Project 061 Noise Certification Streamlining

Georgia Institute of Technology

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University Participants

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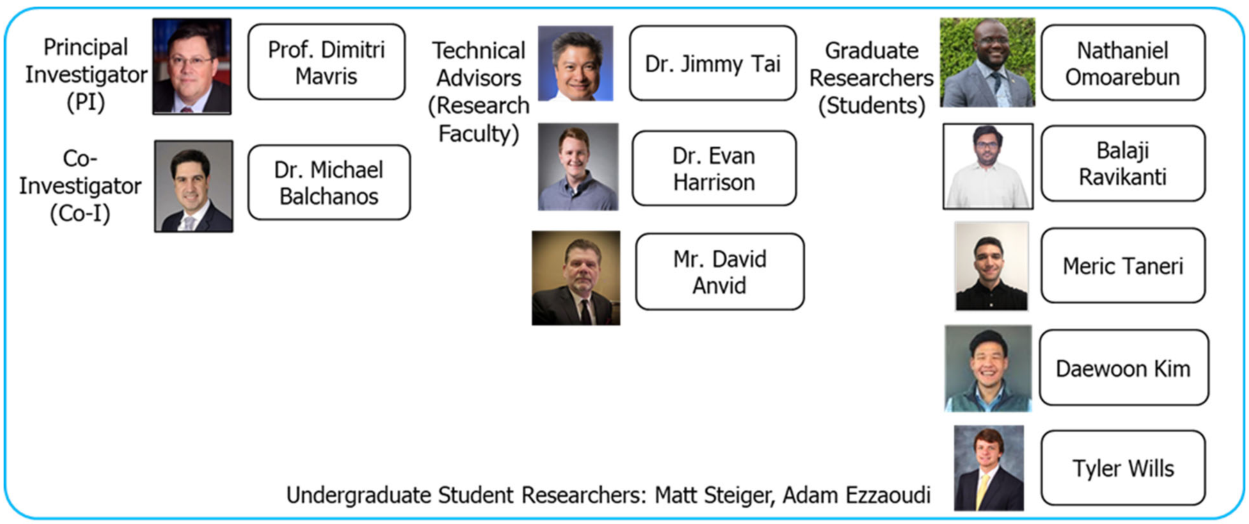
- P.I.s: Dr. Dimitri Mavris, Dr. Michael Balchanos
- FAA Award Number: 13-C-AJFE-GIT-066
- Period of Performance: October 1, 2021 to September 30, 2022
- Tasks:
    1. Interview Industrial Partners on Current Noise Certification Processes
        - 1.1 FAA Noise Certification Regulation Review
        - 1.2 Industry Partner Interviews via Workshops
    2. Develop a Streamlined Noise Certification Procedure for Existing Aircraft
        - 2.1 Current Process Assessment
        - 2.2 Streamlined Process Definition
        - 2.3 Streamlined Process Assessment and Revision
    3. Develop a Flexible Noise Certification Procedure for New Aircraft
        - 3.1 Flexibility Assessment of Streamlined Process
        - 3.2 Flexible Process Definition
        - 3.3 Flexible Process Assessment and Revision
    4. Simulate Streamlined and Flexible Noise Certification Procedures
        - 4.1 Identification of a Modeling Approach
        - 4.2 Noise Certification Process Metric Definition
        - 4.3 Model Calibration
        - 4.4 Certification Process Simulation

Project Funding Level

The total amount of current funding from the 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

The ASCENT Project 061 Georgia Institute of Technology (Georgia Tech) Aerospace Systems Design Laboratory (ASDL) investigation team is shown in Figure 1. Professor Dimitri Mavris is the P.I. of this project, joined by Dr. Michael Balchanos, Research Engineer II as the Co-P.I. and Project Manager. In support of the co-P.I.s, a team of three research faculty, Dr. Jimmy Tai, Senior Research Engineer, Mr. David Anvid, Senior Research Engineer, and Dr. Evan Harrison, Research Engineer II are acting as Technical Advisors on both the planning and technical development for the allocated tasks. The team is joined by five graduate student assistants, who are supporting Project 061 as they work toward their MSc and PhD degrees. All team members are affiliated with the ASDL, under the School of Aerospace Engineering at Georgia Tech.



**The Georgia Tech ASCENT 61 Team would like to also acknowledge the contributions of the following past researchers: Fatma Karsten, Shireen Datta, Arnaud Ballande, Domitille Commun, Hayden Dean, Dr. Sehwan Oh and Dr. Etienne Demers Bouchard*

Figure 1. ASCENT Project 061 Georgia Tech ASDL team.

From the team of graduate student researchers, the following roles and responsibilities have been defined:

- **Mr. Daewoon Kim,** a second-year MSc student, is leading the team's model-based systems engineering (MBSE) efforts for representing the baseline certification process in Systems Modeling Language (SysML).
- **Mr. Nathaniel Omoarebun,** a fifth-year PhD student, is supporting the team's MBSE efforts and SysML modeling activities.
- **Mr. Balaji Ravikanti,** a second-year MSc student, is leading the team's efforts in understanding and documenting current certification procedures in SysML, as well as formulating candidate procedures for unmanned aerial system (UAS) noise certification, tied to Part 36, Appendices H and J, and recent FAA notices of proposed rulemaking (NPRMs).
- **Mr. Tyler Wills,** a second-year MSc student, is supporting the team's efforts in process improvement modeling (PIM) methods and process simulation.
- **Mr. Merc Taneri,** a second-year MSc student, is leading the team's efforts in PIM methods, stochastic process simulation (Markov chain Monte Carlo [MCMC]), and interactive visualization.

Past technical advisors who contributed to the tasks:

- **Dr. Sehwan Oh**, Postdoctoral Researcher, focused on exploring current certification regulations, understanding their structure (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 the literature and formulating a canonical problem to assess the feasibility and applicability of various methods.

Former students who have contributed to the tasks:

- **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 Title 14 Subchapter C, Part 21, and Part 36, as well as Part 36 Advisory Circulars (ACs), with a particular focus on AC 36-4D 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 (original equipment manufacturers [OEMs], regulators, operators, airports, etc.) well since the 1960s (Metzger, 1970; Ollerhead, 1968; Senzig, 2018). 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 (FAA, 2023). 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 for building the flexibility needed to accommodate all air vehicle types.* Project 061 seeks to propose quantifiable process improvements and facilitate the application of traditional systems engineering for complex systems and Model-Based Systems Engineering (MBSE), while leveraging these methods for the management of regulatory requirements. To perform the proposed research under this three-year effort, Georgia Tech has teamed with several industrial partners with extensive experience in noise certification. Each industrial partner represents different types of vehicles, such as large subsonic transports, propeller-driven small aircraft, and rotorcraft.

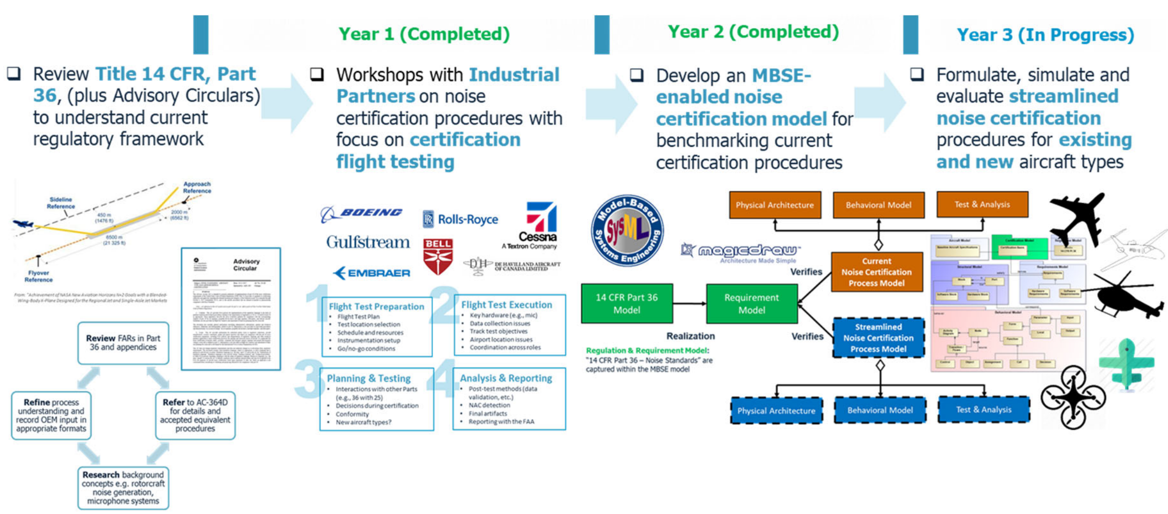


Figure 2. Roadmap toward a model-based framework for exploring current and streamlined noise certification. AC: advisory circular; CFR: Code of Federal Regulations; FAR: Federal Acquisition Regulation; MBSE: model-based systems engineering; NAC: non-acoustical change; OEM: original equipment manufacturer.

The ASCENT Project 061 team is seeking to accomplish the following 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 (Part 36, AC 36-4D, etc.) (FAA, 2017).
- 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 061 Roadmap and Statement of Work

An overview of the ASCENT 061 roadmap toward goals and milestones is shown in Figure 2.

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 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 2 of ASCENT 061. These tasks are summarized below.

Task 1: Interview Industrial Partners on Current Noise Certification Processes

1.1 FAA Noise Certification Regulation Review [Year 1]
1.2 Industry Partner Interviews via Workshops [Year 1]

Task 2: Develop a Streamlined Noise Certification Procedure for Existing Aircraft

2.1 Current Process Assessment [Year 1]
2.2 Streamlined Process Definition [Year 2]
2.3 Streamlined Process Assessment and Revision [Year 2]

Task 3: Develop a Flexible Noise Certification Procedure for New Aircraft

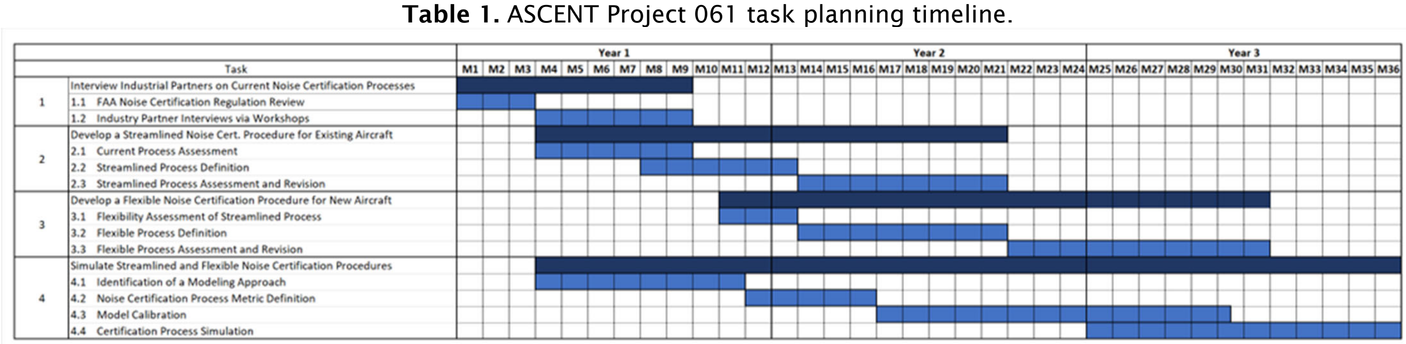
3.1 Flexibility Assessment of Streamlined Process [Year 2]
3.2 Flexible Process Definition [Year 2]
3.3 Flexible Process Assessment and Revision [Year 2]

Task 4: Simulate Streamlined and Flexible Noise Certification Procedures

4.1 Identification of a Modeling Approach [Year 1]
4.2 Noise Certification Process Metric Definition [Year 2]
4.3 Model Calibration [Year 2]
4.4 Certification Process Simulation [Year 2]

For the full three-year period of performance, the complete timeline for finalizing all Project 061 tasks is shown in Table 1.

Table 1. ASCENT Project 061 task planning timeline.



Pivoting to UAS Category (effective June 2022)
The FAA's Office of Environment and Energy (AEE) has suggested a timeframe for pivoting to UAS category certification model exploration, using the transport category certification model as a basis. The main task for the Georgia Tech team is to investigate the feasibility and applicability of current ASCENT 061 models and analysis tools for exploring procedures and flight test planning to support noise certification of small propeller-driven UASs. The primary issue with UAS certification is that the spectrum of possible and available configurations covers a large class of aerial systems with completely different characteristics, as shown in Figure 3.

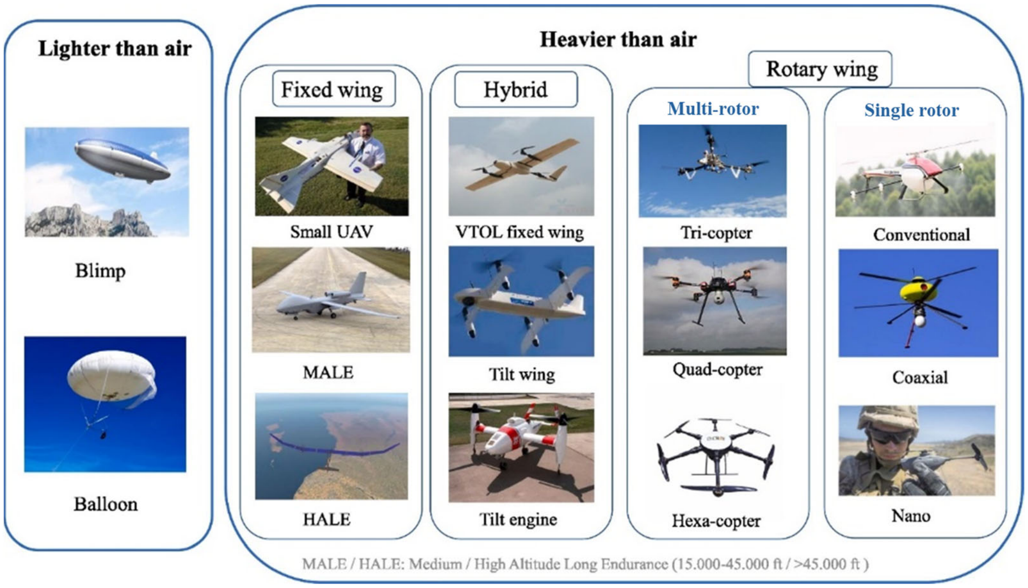


Figure 3. Overview of unmanned aerial system concepts. UAV: unmanned aerial vehicle; VTOL: vertical takeoff and landing.

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. Although rulemaking by the ICAO may lag behind the efforts of individual countries, ultimately, the harmonization of certification requirements among national airworthiness authorities (NAAs) is desirable. Several iterations of the regulatory framework may be required before this target is achieved.

The ASCENT 061 team has agreed with the FAA AEE to adjust the statement of work (SoW) in order to lay the groundwork for noise certification for the UAS category, as this initiative has been given a higher priority. Key challenges that have been identified and will be addressed by the Georgia Tech 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 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.
- We must determine how the ASCENT 061 team can use the established framework to demonstrate its effectiveness in assisting the FAA through the assessment of NPRM plans, as these are being iterated before they become approved as part of the UAS noise certification standards.

Putting this plan forward, the suggested starting point is to perform an inventory of existing certification practices for low MTOW general aviation and propeller/rotor-driven aircraft (i.e., fixed wing and rotorcraft). Currently, the priority is to focus on UASs before urban air mobility (UAM), as the anticipated risks are expected to be higher for the latter. In response to this pivot, the following guiding actions have been set:

- Study current certification practices for noise for small propeller-driven airplanes (Code of Federal Regulations (CFR) Title 14, Part 36, Appendix G) and light helicopters (Code of Federal Regulations (CFR) Title 14, Part 36, Appendix J).
- Perform a literature/technical review of noise source characteristics associated with propeller/rotor propulsion systems.
- Explore current practices for UAS flight testing for noise. The ASCENT 061 team has been encouraged to explore collaboration with ASCENT 077 researchers at Penn State regarding their research on "Measurements to Support Noise Certification For UAS/UAM Vehicles and Identify Noise Reduction Opportunities."
- Utilize the team's current MBSE-enabled certification framework to test current procedures for UASs and its overall flexibility to accommodate multiple aircraft categories.

As a starting point for the literature search, 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, 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, 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.

SoW/Task Definitions for UAS Noise Certification Research

Following the reassigned focus on UAS certification, the original task definitions that had guided the work on transport category aircraft noise certification required a review. An updated SoW has been formulated to guide the pivot toward the development of use cases that address the FAA's needs for UAS noise certification. This SoW is based on the concept that the original tasking is substantially complete; thus, a significantly revised SoW is necessary to reflect the integration of UAS certification goals with the previously developed MBSE and PIM modeling. 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 under the revised SoW are defined as follows:
(Please note: This is a notional construct for this annual reporting period and will be described in more detail during future reporting. Modifications or revisions to this SoW may occur based on the research sponsor's input.)

Task 1: Develop a Traceable Structure for UAS Noise Certification Requirements (Year 2)

1.1 Document related regulations and current standards.
1.2 Generate noise certification requirements from currently known and established regulations.
1.3 Define a validation process for noise requirements.

Task 2: Develop a Library of UASs and Testing Procedures (Year 3)

2.1 Perform a technical documentation of UASs.
2.2 Conduct a 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 (Years 2, 3)

3.1 Transfer noise testing plans to the MBSE model (Year 2).
3.2 Transfer noise testing data to the MBSE model (Year 3).
3.3 Develop a full noise test plan (Year 3).
3.4 Implement a validation process (Year 3).

Task 4: Develop Alternative Procedures and Assess Their Performance with Existing Tools (Year 3)

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.

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:

- ASCENT 77: Measurements to Support Noise Certification for UAS/UAM Vehicles and Identify Noise Reduction (Penn State University)
- ASCENT 9/94: Geospatially Driven Noise Estimation Module (Georgia Tech ASDL)
- ASCENT 061: Noise Certification Streamlining (Georgia Tech ASDL)

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

- ASCENT 77: Data sharing. Experimental test data provide real-world input for noise certification modeling. The results of the ASCENT 77 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 09/91: Evaluation of possible vehicle operational environments and the practical impacts of noise profiles on the public. While the ASCENT 09/91 efforts do not provide direct technical data for MBSE modeling, these efforts do provide context for how noise level outputs from the certification process may be applied to an operational environment.

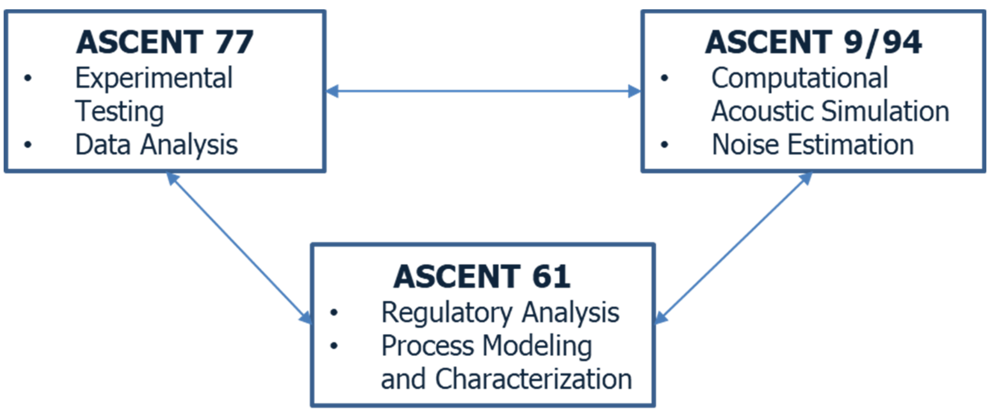


Figure 4. Coordination with parallel ASCENT work related to unmanned aerial system certification.

Summary of Major Accomplishments (to date)

Transport Category Tasks

- Completed **architecting of a noise certification modeling and assessment framework** for transport category aircraft
- 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 or removal, if trusted analysis is used)
- Achieved key improvements in a SysML-based verification model based on training materials provided by VOLPE (acoustical designated engineering representatives regarding the processes of determining EPNLs used in FAA Recurrent Seminars)
- Conducted PIM for process assessment, evaluation, and testing of equivalent procedures using Markov chains
- Provided a demonstration by assessing a simplified noise collection/analysis process, with the Waco YMF-5 propeller aircraft as an example
- Documented options for equivalent procedures in a database/library compilation
- Conceptualized and developed a visualization environment to aid as a use case demonstrator and decision support environment

UAS Category Pivot

- Completed initial steps and updated the SoW to explore the applicability of the current ASCENT 061 framework for noise certification of rotor or small propeller-driven UASs
- Performed a literature search on current noise certification practices for UASs
  - CFR Title 14 Part 36 Appendix G, J, and H **Error! Reference source not found.**
- Produced a plan to modify the ASCENT 061 MBSE noise certification framework to accommodate UAS category vehicles in order to provide oversight on Equivalent Procedures (EP) and regulatory compliance

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

Task 1 - Interview Industrial Partners on Current Noise Certification Processes

Georgia Institute of Technology

Objectives

In support of the main research objective of Project 061, Task 1 focuses on examining current noise certification procedures (Task 1.1) and benchmarking against current industry practices in how these procedures are adopted and implemented (Task 1.2). In particular, the subtasks are organized as follows:

Task 1.1: FAA Noise Certification Regulation Review

- Perform a thorough review of FAA noise certification regulations for large subsonic jet and transport category airplanes, as well as rotorcraft types of vehicles (14 CFR, Chapter 1, Subchapter C, Part 36, Subparts B and H). With input from the FAA, the Georgia Tech team will also explore propeller-driven small airplanes and propeller-driven commuter category airplanes.
- Include recent certification regulations for new types of aircraft (e.g., advanced air mobility), in addition to conventional configurations.
- Document existing regulatory framework for aircraft noise certification, including both specified regulatory standards and accepted means of compliance.

Task 1.2: Industrial Partner Interviews via Workshops

- Gather information through interviews and workshops on industry-applied noise certification procedures, including equivalent procedures.
- Propose workshops and invite industry partners with subject matter expertise on airframe noise certification (large transport, small propeller aircraft, and rotorcraft).
- Facilitate a dedicated workshop for each vehicle type and plan for follow-up events to iterate on feedback obtained, as well as to share lessons learned and the derived recommendations.
  - The focus of the workshop is to identify areas of opportunity to streamline the certification process for each type of vehicle and to allow subject matter experts to suggest potential solutions.

[UAS Pivot] Task 1: Develop a Traceable Structure for UAS Noise Certification Requirements (Year 2)

- Document related regulations and current standards.
- Generate noise certification requirements from currently known and established regulations.
- Define a validation process for noise requirements.

Research Approach

Task 1.1

For Task 1.1, the main goal was to review and document current noise certification procedures. The task objective was to gain an understanding of the current regulatory framework for aircraft noise certification, as required by FAA regulations and followed by OEMs to demonstrate compliance. In particular, the team conducted a thorough literature review of relevant 14 CFR parts (mainly Part 36) and associated documents where relevant (e.g., ACs such as AC 36-4D (Federal Register, 2022). With recommendations from the team's partners, this task also considered other documentation from the European Union Aviation Safety Agency (EASA), the ICAO Environmental Technical Manual, and the VOLPE website.

Along with the extensive review of Federal Acquisition Regulations (FAR) and literature on the regulatory framework, the team produced a series of views to demonstrate the flow of procedures, associations, and dependencies across regulatory items. Finally, the team obtained background information on noise generation for various aircraft categories, as well as technologies used during testing, to better understand current recommended practices and the potential for alternative equivalent procedures with the use of modern technologies and equipment. One of the benefits of this task's outcome is that team members quickly became more knowledgeable of the certification basics in preparation for Task 1.2 (industry interviews) and were able to build a comprehensive MBSE representation (in SysML) of the current framework (see Task 2.1). An overview of the methodology behind the review of FARs and literature is provided in Figure 5. Please see Appendix A of this document for a full overview and documentation produced under this exercise.

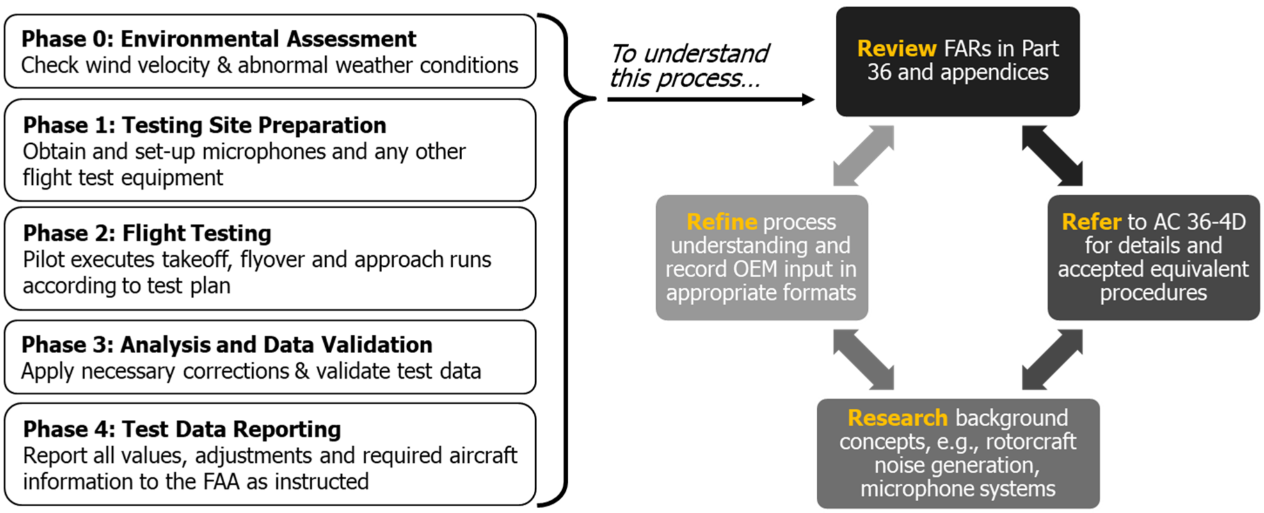


Figure 5. Noise certification regulation review (Task 1.1). AC: advisory circular; FAR: federal acquisition regulations; OEM: original equipment manufacturer.

The approach that was formulated under Task 1.1 has been applied to the [UAS Pivot] Task 1, in order for a similar database and series of views to be produced for current certification regulations.

Task 1.2

Task 1.2 aims to enhance the team's understanding of the current noise certification process through interactions with subject matter experts from various OEMs, with the objective of leveraging industry insight into practical aspects of noise certification requirements. This goal was achieved via virtual workshops, guided by questionnaires compiled by the team based on the reviews completed under Task 1.1. Based on insights and findings from documented work under Task 1.1, the team has identified topics for which more context and additional insight into ancillary/non-regulatory processes is needed, with regards to how the certification procedure is facilitated by each OEM partner. These topics are shown in Figure 6.

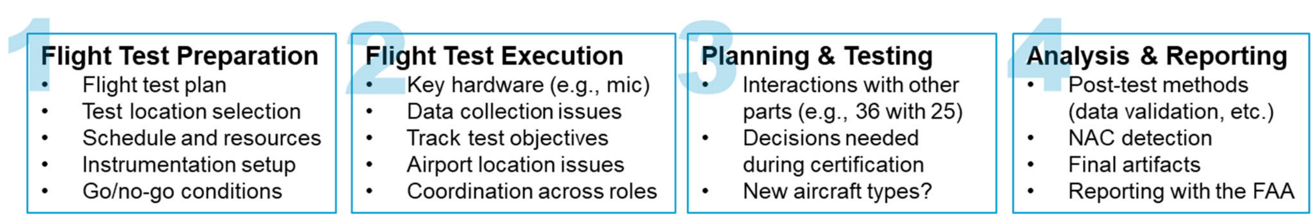


Figure 6. Workshop interview topics for transport category aircraft. NAC: non-acoustical change.

The overarching goal of these workshops was to identify common practices, checkpoints, and milestones across industry partners, while soliciting feedback on key challenges they have identified on their end, as well as what recommendation each partner would provide and why. Such suggestions could convert to opportunities for potential process streamlining if recommended practices are out of sync with current technology. The limitation in this exercise is that no recommendations should suggest or presume any change in the regulatory side; hence, the suggestions should be concentrated on equivalent procedures, with either simplified processes or connections to modern technologies that are expected to meet the same regulations.

To facilitate a directed discussion within the workshops/interviews, the Georgia Tech team formulated questions on the discussion topics listed in Figure 6 and produced questionnaires that were then distributed to the participants prior to the respective meetings. A high-level summary of the questions is as follows:

- What is the current guidance provided by the FAA for noise certification?
- How does a company interact with the FAA to ensure that requirements and constraints related to noise regulations are satisfied and that the vehicle is compliant?

The initial workshop along with the subsequent interviews with the participants generated a wealth of information. Planning and a methodological approach are required to post-process and direct this information toward usable conclusions and insightful findings.

While the level of detail in the answers and feedback obtained varied significantly across the participants, the team was able to summarize the overall themes of the feedback provided under the defined categories. The main takeaways from the OEM feedback are the following:

- Acoustical changes/non-acoustical changes (ACs/NACs) are challenging to navigate without standardized approval procedures. More detailed feedback would be useful for OEMs to propose suitable solutions.
- Test site selection is normally restricted by sound measurement technology and requirements (e.g., the lateral microphone component) and by weather window options.
- Delays in flight testing are primarily weather-induced, but are occasionally due to communication disruptions.
- Conformity discussions can be significantly time/effort-consuming, especially for cases in which there is a need to justify changes that are unrelated to acoustics.
- Regarding interactions between Part 36 and Part 25/23, there seems to be a discontinuity between environmental and design standards, often leaving little space to apply acoustic improvements.
- There is no single standardized software for calculating EPNL values from noise data collected during flight testing; rather, each OEM's methodology and code are different.

This lack of standardization appears to be a common area of opportunity for improvements across current noise certification procedures. This observation is even more relevant for the UAS category, where regulations will be expected to cover a broader range of configurations.

[UAS Pivot] Task 1

The purpose of this task is to establish a work thread that repeats the work completed for the transport category, with the intent to document and understand the current regulatory framework for UAS noise certification. With the completion of the first phase of the literature search, the following observations have been documented:

- No clear regulatory framework
  - Study will rely on NPRMs and Appendices G, J, and H of CFR Title 14 Part 36 (FAA, 2017).
- No clear categorization of UAS configurations
  - Study will propose criteria, e.g., weight, propeller number/type/orientation, flight envelope, maximum speed, and operational altitude.
- No test data immediately available
  - Study will rely on test plan information, test-day logs, and available/sharable noise data from ASCENT 77.
- No established validation process against regulation-driven requirements
  - Study will track/ensure traceability among regulations, testing requirements, and certification procedures.

Aside from published regulatory guidance, several previous studies were available and provided a baseline for the testing procedures. These studies were the following:

- The document entitled "Noise Measurement Report: Unconventional Aircraft - Choctaw Nation of Oklahoma: July 2019," which provides an explanatory overview of the noise certification approach for UASs.
- The document entitled "Sound Exposure Level Duration Adjustments in UAS Rotorcraft Noise Certification Tests," which provides an overview of the applicability of the "duration correction" for manned helicopters on small UASs.

As a pilot exercise and with the recommendation of the FAA, the ASCENT 061 team has selected the NPRM 86 FR 48281 (FAA, 2022) to evaluate the procedure for type certification for the Matternet M2 UAS, as highlighted in Figure 7. Please note that the Matternet noise standard final rule was eventually published in September 2022.

Figure 7. NPRM 86 FR 48281* for evaluating the procedure for type certification for the Matternet M2 unmanned aerial system (FAA, 2022).

The process that the ASCENT 061 team has followed is shown in Figure 8. The first step involves exploring and gathering requirements. This information was organized under the following criteria: noise level classification, vehicle/operational classification, and noise metrics. For the testing framework, the search included flight profiles, system under test (SUT) configurations, and available measurements.

Figure 8. Process for reviewing noise certification for unmanned aerial system regulations.

In the second step, the search included the gathering of supporting data for noise measurements. A dataset was obtained from the test data and insights of the ASCENT 77 group for the Octocopter (Tarot X8) **Error! Reference source not found.**, which included data for hovering, vertical takeoff and landing, flyover, maneuvering, and approach/climb, as shown in Figure 9. The tests were conducted for varying payload weights, speeds, and weather conditions. Alternatively, data and measurements could be obtained from academic or industrial research literature (e.g., FAA UAS BEYOND program) or from trusted noise prediction models.

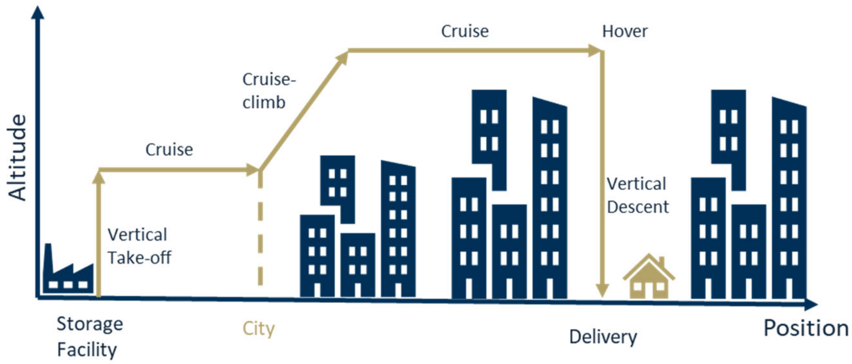


Figure 9. Typical mission profile for a delivery unmanned aerial system.

With the available data, the third step is to perform a requirement analysis, which is the basis for the regulation assessment proposed in the NPRM (FAA, 2022). This analysis will make use of the ASCENT 061 MBSE-enabled certification framework, for which regulations must be mapped to requirements, which will be subsequently implemented in SysML and tested in MagicDraw.

The U.S. Department of Defense Systems Engineering Guidebook, under section 4.2.7, defines the attributes of "Good Requirements," which are further categorized to help characterize the effectiveness of the requirements, as shown in Figure 10. The attributes pertaining to the quality and standard of writing (listed in green) are met, given that the NPRM is largely based on the existing enforced regulation.

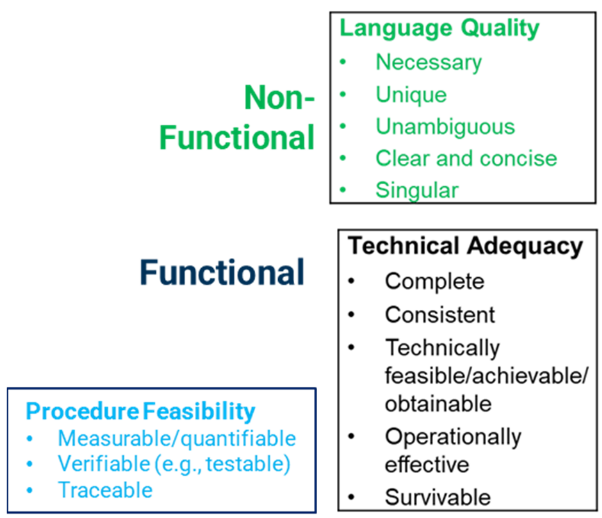


Figure 10. Criteria for analyzing certification testing requirements.

A typical mission profile is shown in Figure 9. The NPRM (86 FR 48281) presents only the noise certification basis for one new model of UAS seeking type certification, the Matternet M2 (FAA, 2022). The NPRM is traced to and draws from the best practices and proven methods of the existing enforced regulations and incorporates requirements that are verifiable in principle. Part 36 Appendix J, however, covers an alternative noise certification procedure for helicopters under Subpart H, having a maximum certified takeoff weight of not more than 7,000 lbs. V_H is defined as the airspeed in level flight obtained using the minimum specification engine power corresponding to the maximum continuous power available. V_{NE} is the never-exceed speed. A comparison table of testing requirements between the NPRM and the Part 36 Appendix J is shown in Table 2.

Table 2. Matternet M2 noise certification requirements (FAA, 2017; FAA, 2022). MTOW: maximum takeoff weight; NPRM: notice of proposed rulemaking.

Measurement Parameter	NPRM	Part 36 Appendix J	More NPRM Details
Reference Altitude	250 feet	492 feet	Test altitude may be lowered to attain acceptable signal-noise ratio and the noise data will then be mathematically adjusted to reference altitude
Reference Flight Speed (Empty Weight)	$0.9V_{NE}^{\dagger}$	N/A	Two test speeds are employed because the sensitivity of noise level to weight and flight speed are unclear for MM2
Reference Flight Speed (Maximum Takeoff weight)	Maximum Performance Speed	Minimum of $0.9V_H^*$; $0.9V_{NE}$; $0.45V_H$ + 65 kts; $0.45V_{NE}$ + 65 kts;	
Noise Level	78 dB	$^{\ddagger}82+3.0[\log_{10}(MTOW/3125)/\log_{10}(2)]$ dB	78 = 82 + 3.7 (accounts for reduced ref altitude) − 7.7 (noise curve reduction for MM2)

Modeling the requirements relies on ontological descriptions and element stereotypes of the system under consideration and its constituent parts, along with key relationships between elements of the system. To build the model, descriptive and prescriptive versions of potential FAA certification regulations are introduced. Element relationships are used to enable a representation of model relationships, where containment is used to represent the hierarchical arrangement. Further refinement of the model was enabled by access to training material and process information provided by VOLPE. Finally, resources tied to the certification process could be traced throughout the entire model and for all exchanges that have been documented. In Figure 11, an excerpt view is shown from the full requirement model developed by the A61 team, sourced by the regulations within the NPRM (FAA, 2022) model, as well as Part 36.

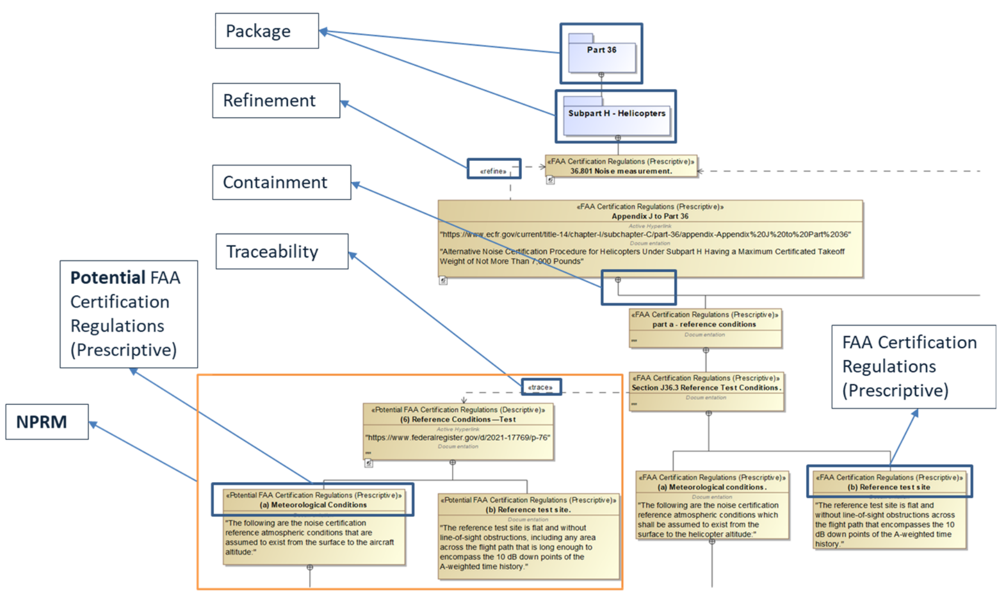


Figure 11. Regulations model for unmanned aerial systems (partial view, excerpt).

The next action in the requirement analysis phase is to assess the technical adequacy of the proposed requirements. The following criteria have been set for ensuring a consistent set of regulatory statements that are generally applicable to the noise certification of UAS category vehicles:

- Regulatory statements shall not directly contradict each other.
- No regulatory statement may entirely prevent compliance to one or more other statements.
- A technically feasible/achievable/obtainable set of regulatory statements that are generally applicable to the noise certification of UAS category vehicles shall adequately account for aspects of noise generation mechanisms that give rise to uncontrollable variations in noise radiation.

- Regulatory statements that are generally applicable to the noise certification of UAS category vehicles shall specify noise metrics and test profiles that enable applicants to determine the noisiest vehicle configurations.
- Regulatory statements shall be measurable/quantifiable, verifiable (e.g., testable), and traceable.

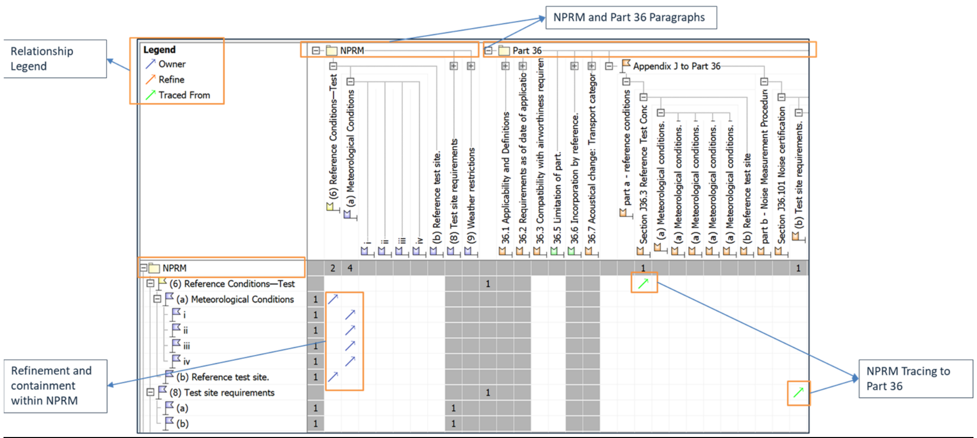
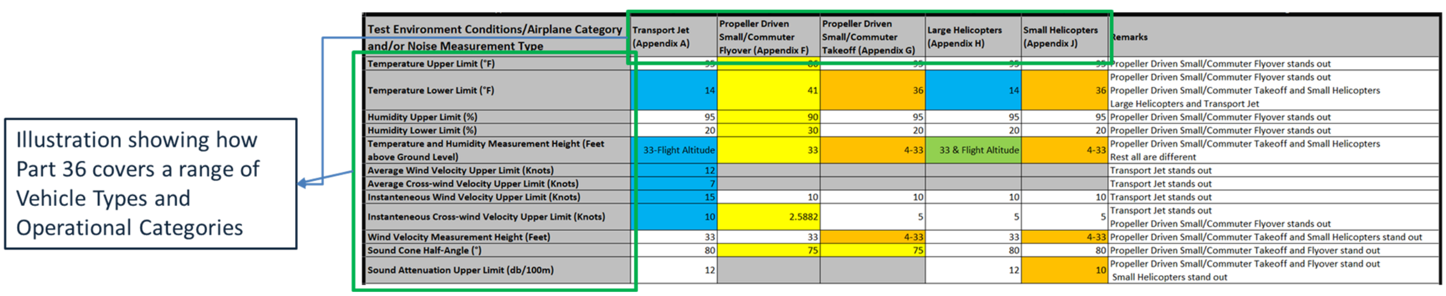


Figure 12. Dependency matrix (excerpt).

Scalability is an important factor, as regulatory statements that are generally applicable to UAS category vehicles shall encompass a broad range of operating conditions and vehicle types, which is evident from the organization of Part 36. "Weather Restrictions" pertain to testing environments imposed on different aircraft categories. For instance, multi-rotor vertical takeoff/landing aircraft conducting package deliveries in urban city centers present a particular combination of vehicle type and operational scenario that shall be analyzed, and then the approach shall be extended to other combinations. Hence, in Figure 13, the level of "completeness" for regulations refers to the coverage footprint of the unique combinations of vehicles and operations that pertain to noise generation for a particular use case.



Test Environment Conditions/Airplane Category and/or Noise Measurement Type	Transport Jet (Appendix A)	Propeller Driven Small/Commuter Flyover (Appendix F)	Propeller Driven Small/Commuter Takeoff (Appendix G)	Large Helicopters (Appendix H)	Small Helicopters (Appendix J)	Remarks
Temperature Upper Limit (°F)	95	86	95	95	95	Propeller Driven Small/Commuter Flyover stands out
Temperature Lower Limit (°F)	14	41	36	14	36	Propeller Driven Small/Commuter Flyover stands out Propeller Driven Small/Commuter Takeoff and Small Helicopters Large Helicopters and Transport Jet
Humidity Upper Limit (%)	95	90	95	95	95	Propeller Driven Small/Commuter Flyover stands out
Humidity Lower Limit (%)	20	30	20	20	20	Propeller Driven Small/Commuter Flyover stands out
Temperature and Humidity Measurement Height (Feet above Ground Level)	33-Flight Altitude	33	4-33	33 & Flight Altitude	4-33	Propeller Driven Small/Commuter Takeoff and Small Helicopters Rest all are different
Average Wind Velocity Upper Limit (Knots)	12					Transport Jet stands out
Average Cross-wind Velocity Upper Limit (Knots)	7					Transport Jet stands out
Instantaneous Wind Velocity Upper Limit (Knots)	15	10	10	10	10	Transport Jet stands out
Instantaneous Cross-wind Velocity Upper Limit (Knots)	10	2.5882	5	5	5	Transport Jet stands out Propeller Driven Small/Commuter Flyover stands out
Wind Velocity Measurement Height (Feet)	33	33	4-33	33	4-33	Propeller Driven Small/Commuter Takeoff and Small Helicopters stand out
Sound Cone Half-Angle (°)	80	75	75	80	80	Propeller Driven Small/Commuter Takeoff and Flyover stand out
Sound Attenuation Upper Limit (db/100m)	12			12	10	Propeller Driven Small/Commuter Takeoff and Flyover stand out Small Helicopters stand out

Figure 13. Vehicle types and operational categories covered by Part 36.

The certification analysis framework proposed in Figure 8 has been demonstrated end-to-end, for instance, in assessing the technical feasibility of NPRM paragraph 26(b) by leveraging the experimental test data provided by ASCENT 077. Paragraph 26(b) states that "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)." Experimental test data (More, 2011) at flight speeds of 10 and 20 mph conducted over two days with varying weather conditions were considered to cover a range of natural variability. Figure 14 shows that within a wide range of sample standard deviation, as is evident from the experimental data considered, increasing the number of runs reduces the length of the confidence interval that is expected from a controlled process. It is also observed that decreasing the number of runs beyond the prescribed six runs can also result in meeting the requirement for a considerable range of sample standard deviations. Hence, the experimental data suggest that the requirement is technically feasible.

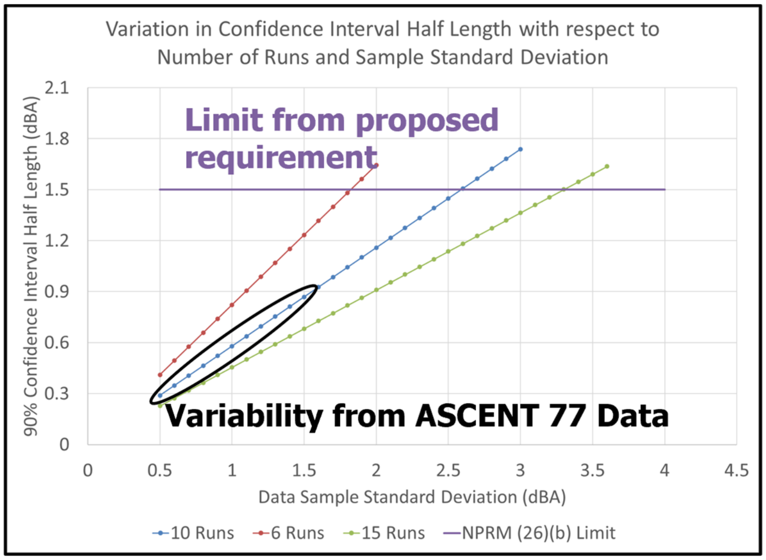


Figure 14. Technical feasibility analysis of NPRM paragraph 26(b). NPRM: notice of proposed rulemaking.

When repeated with the traceability afforded by the MBSE framework shown in Figure 11 and Figure 12, this process results in a holistic assessment of a body of regulatory statements for the attributes outlined in Figure 10.

Milestones

Between October 2021 and September 2022, the following milestones were achieved:

- Participation in Fall 2021, Spring 2022, and Fall 2022 ASCENT Advisory Committee Meetings
- Completion of Tasks 1.1 and 1.2. for the transport category
- Extension of Tasks 1.1 and 1.2 for the exploration of UAS regulations for noise
    - The findings and documentation were utilized to define a requirement model in SysML as a first step to reconfigure the MBSE framework for UAS category certification modeling.
- Completion of 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

Major Accomplishments

For Task 1.1, the following accomplishments are reported:

- Completion of a literature review on current noise certification practices, as dictated by Title 14 Part C, Part 21 on certification procedures and Part 36 on noise regulations (including Part 36 ACs), with a particular focus on AC 36-4D **Error! Reference source not found.** and an emphasis on the instruction regarding flight testing for certification
- Summary and visual representation of the regulations and their associations (both in flow chart and SysML views)
- Identification of certain gaps in understanding the certification process, which have been documented and have enabled the production of a topic questionnaire to further support the facilitation of workshops with industry partners, as planned for Task 1.2

Task 1.1 is now completed.

For Task 1.2, the following accomplishments are reported:

- Workshops were completed for the large transport category, and feedback and input from industry partners were collected during the workshop. Additional responses and guidance were obtained through follow-up meetings during Years 1 and 2.
- Key takeaways became available, which have been shaping the research direction and clarified priorities within the problem (e.g., streamlining to be targeted not only in terms of time and cost, but also for complexity reduction and exploration of technologies to support process simplification).

Task 1.2 is now completed for transport category aircraft, and tasks will be repeated for rotorcraft and small propeller-driven air vehicles.

For the UAS-specific version of Task 1, the following accomplishments are reported:

- Performed a literature search and documented regulations and current testing standards for rotor and small propeller-driven UASs.
- Defined a traceable structure for UAS noise certification requirements, using the MBSE verification model developed for the transport category.
- Published articles with the International Council of the Aeronautical Sciences (ICAS) 2022 and the American Institute of Aeronautics and Astronautics (AIAA) SciTech 2023.

Publications

Peer-reviewed journal publications

None.

Published conference proceedings

Kim, D., Karagoz, F., Datta, S., Balchanos, M., Anvid, D., Harrison, E., & D.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.

Kim, D., Taneri, M., Omoarebun, E.N, Wills, T., Balchanos, M., & Mavris, D. (2023). *MBSE-Enabled System Verification and Process Improvement of Transport Aircraft Certification.* Accepted and to be presented In AIAA SciTech 2023 Forum, National Harbor, MD, January 23-27, 2023.

Written reports

December 2021 ASCENT Quarterly Report, ASCENT Project 61. (2022, January 30). *Noise Certification Streamlining*. Award number 13-C-AJFE-GIT-066.

March 2022 ASCENT Quarterly Report, ASCENT Project 61. (2022, April 30) "*Noise Certification Streamlining*. Award number 13-C-AJFE-GIT-066.

June 2022 ASCENT Quarterly Report, ASCENT Project 61. (2022, July 30). "*Noise Certification Streamlining*. Award number 13-C-AJFE-GIT-066.

September 2022 ASCENT Quarterly Report, ASCENT Project 61. (2022, October 30). *Noise Certification Streamlinin*g. Award number 13-C-AJFE-GIT-066.

Annual Report (period ending September 2021), ASCENT Project 61. (2021, December 12). *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 through Spring 2022.
- Completed a project overview and a capability demonstration to VOLPE and requested information for model finetuning.
- Participated in conferences (ICAS and AIAA SciTech).

Awards

None.

Student Involvement

- All participating graduate students have supported Task 1 activities by contributing to the literature and background search 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

- Plan a series of workshops with partners and subject matter experts on rotorcraft and small propeller-driven air vehicles.
- Demonstrate noise certification based on NPRM 86 FR 48281.
- Demonstrate an EP assessment through certification modeling across different UAS configurations.
- Publish articles with AIAA Journal and AIAA SciTech.

Task 2 - Develop a Streamlined Noise Certification Procedure for Existing Aircraft

Georgia Institute of Technology

Objectives

Task 2.1: Current Process Assessment

- Identify which aspects of the present process would benefit from the proposed concept. As current procedures are captured and mapped against the regulatory requirements, this task seeks to enable an assessment capability for testing equivalent procedures within the overall certification model.

Task 2.2: Streamlined Process Definition

- Incorporate feedback from industry partners with identified areas of improvement over the present process to formulate a new certification process.
- Focus on the use of technology that seeks to transform the certification to a simpler process that can still demonstrate that regulatory requirements are being met.
    - Process modeling within Task 4 should also yield improvements in the cost and efficiency of the noise certification process.

Task 2.3: Streamlined Process Assessment and Revision

- Solicit feedback on the proposed process alternatives from the FAA, VOLPE, and industry partners.
- Revise the suggested process, which incorporates key aspects of the collected feedback in order to build a consensus among the research partners.

[UAS Pivot] Task 2: Develop a Library of UASs and Testing Procedures (Year 3)

2.1 Perform a technical documentation of UASs.
2.2 Conduct a 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 Current Process Assessment

Work that has been completed under Task 1 with benchmarking of current practices, as well as input from the workshops, will be compiled and used to inform a certification process model formulated in SySML (implemented in MagicDraw and Cameo Toolkit software tools). To enable reusability and flexibility for testing equivalent procedures, the MBSE-enabled platform allows the representation of systems from documents to explicit representation of systems via models; hence, it merges product information and engineering models. The platform provides a consistent system model that everyone can "view," maintaining a shared system model as the authoritative source of information, a feature that is helpful in preserving a common understanding among people with different roles and responsibilities. MBSE allows regulations and requirements to be linked to certification steps and can represent links and associations between regulations. This approach improves communication among stakeholders, complexity management, and precision of operational use cases; thus, it addresses common issues that arise during certification audits, e.g., requirement traceability, configuration management, document control, and change impact analysis. In sum, information previously captured in individual silos is now integrated together to enable greater transparency (including technical baselines, resources, workflow, etc.).

For Task 2 and particularly subtask 2.1, the goal is to assess current noise certification procedures by implementing an MBSE-enabled model. 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 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 overall progression from the building blocks and subject matter expert input provided by Task 1 to the full MBSE model formulation for certification and implementation is showcased in Figure 15.

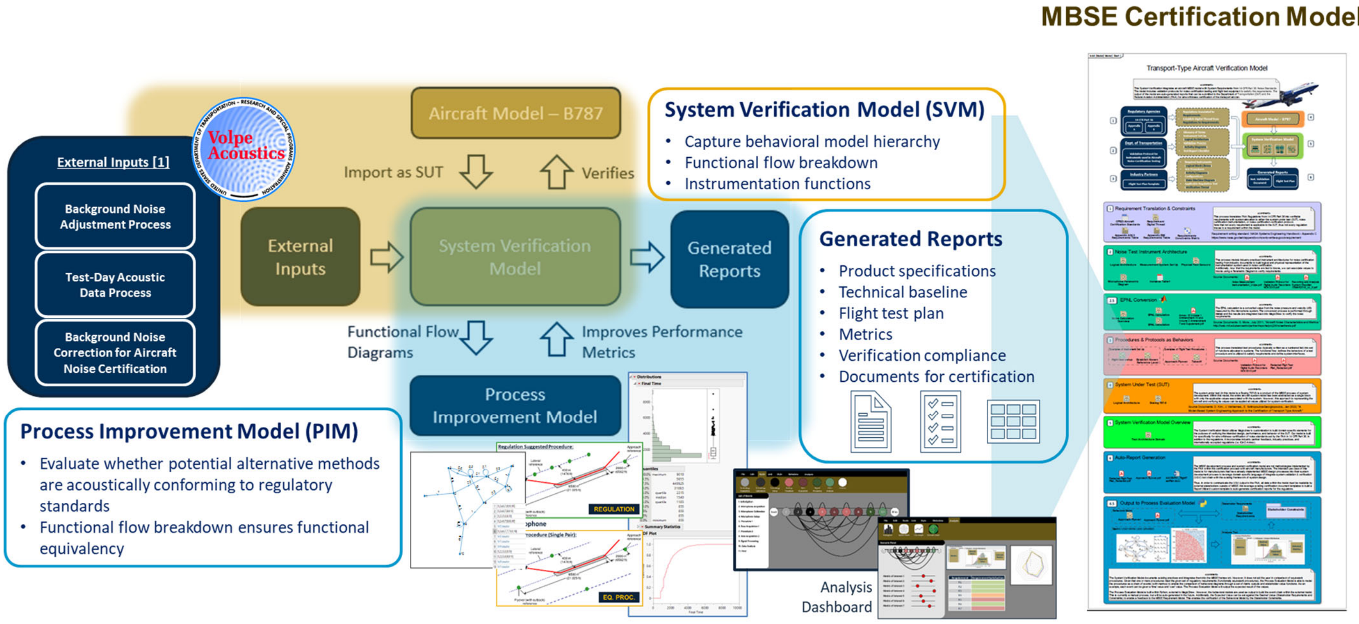


Figure 15. Model-based systems engineering (MBSE) approach for the noise certification modeling platform. SUT: system under test.

The roadmap for creating an MBSE system architecture is not unique. Several approaches have been introduced in the literature, but a commonly preferred option is the requirements-functional-logical-parametric approach (More, 2011) which maps to the traditional systems engineering "Vee" approach. A custom model development process was created to capture the functional architecture of the noise certification process, as shown in Figure 16. Marked in blue are inputs to the process that are provided by activities outside of the MBSE environment, which include an operation concept of the certification (as documented in Tasks 1.1 and 1.2), as well as requirements that represent Part 36, Appendix A and Appendix B regulations for noise. Moreover, these inputs are a placeholder for importing the validation protocol for instruments used in aircraft noise certification testing, as well as a representation for flight test plans, as adopted by airframe OEMs.

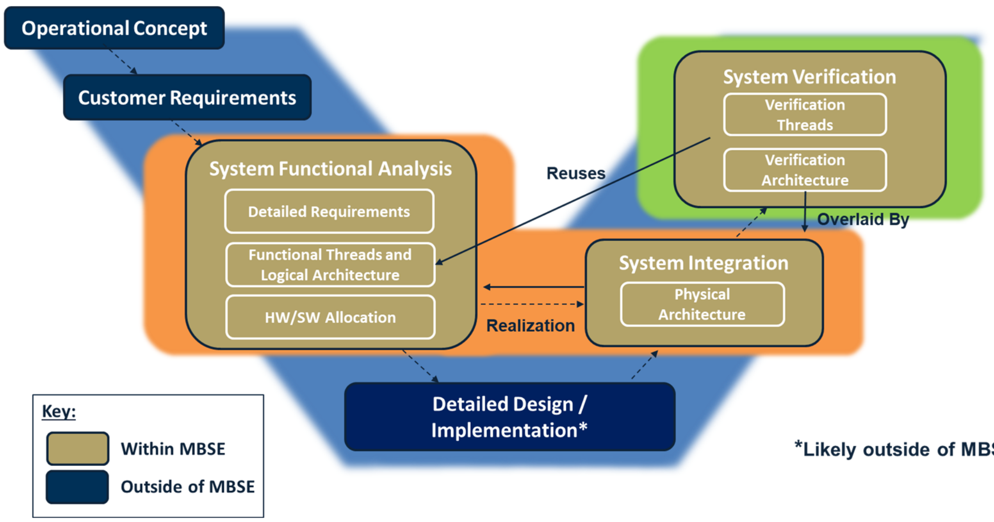


Figure 16. Model-based systems engineering (MBSE) architecture and functional model development workflow, leveraging the requirements-functional-logical-parametric approach. SW: Software; HW: Hardware.

The activities shown in gold within the process are the aspects of system modeling that are captured within the MBSE environment. As shown in the development flow, regulations and information about the certification process are captured as requirements and functional blocks within the model. A digital thread is created between the regulation, requirement, and function to build a verification thread. The form in the certification process that displays a function is also threaded by an <<allocation>> relationship to build a full digital thread from the certification standard to the form that verifies the standard.

Following the requirements-functional-logical-parametric approach, a more detailed workflow has been formulated toward implementing the verification model. This version is shown in Figure 17, where the steps for converting input information (artifacts shown in blue) toward a completed model in SysML are further explained. In the middle part of the figure, artifacts and templates provided by the OEMs used during the certification are converted into model representations in SysML. For instance, a requirement model in SysML is populated by requirements extracted from Title 14 CFR Part 36, Appendices A and B (FAA, 2017), through a process developed in-house (as discussed later in this document).

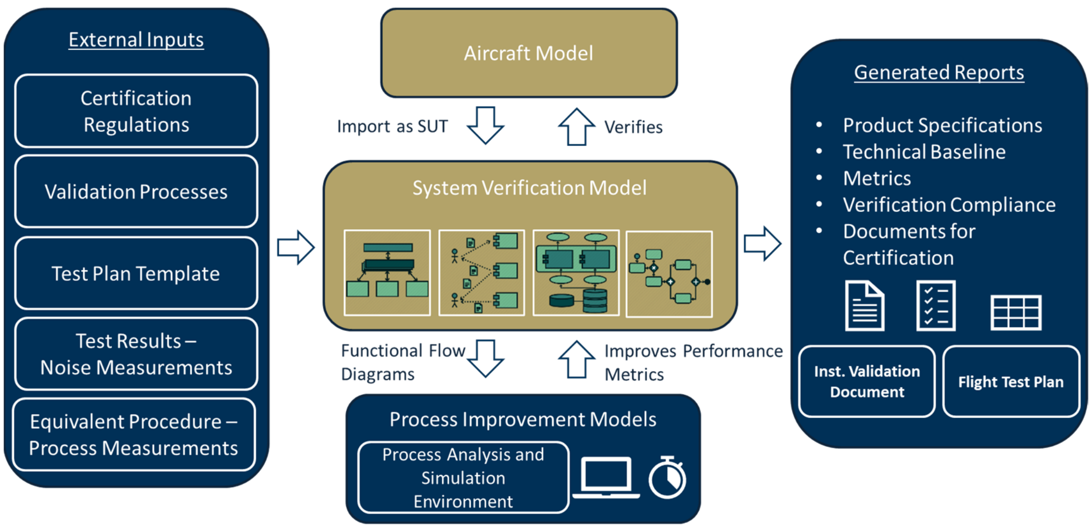


Figure 17. Model-based systems engineering (MBSE) verification model structure. SUT: system under test.

The validation process contains the steps needed to showcase that vehicle noise levels calculated from flight testing results are meeting the 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 alternative instrumentation lineups can be modeled. The latter feature is key, as this framework should allow for the evaluation of equivalent procedures, e.g., lateral 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 aircraft 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 in order to obtain the needed flexibility for testing equivalent procedure alternatives and for accommodating a broader range of air vehicle designs and configurations. Following the structure of the verification model shown in Figure 17, the SysML implementation is currently comprised of the following modules:

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

Model Refinement with VOLPE Assistance

Modules 1–3 from the list above have been further refined with regard to definitions and representations. This refinement was enabled by documents and training modules that were received from VOLPE, including the following documents (VOLPE, 2018; VOLPE, 2003; VOLPE, 2003; FAA, n.d.; Aleksandraviciene, 2018):

- Implementation of background noise adjustment
- Background noise correction for aircraft noise certification
- Test-day processes (acoustic data, adjustments, instrumentation, etc.) in diagram format

After a thorough review of the material, the ASCENT 061 team was able to extract the needed information and apply it on certain views within the MBSE certification model. A key outcome was the generation of process flow diagrams, as shown in Figure 18, which provide the basis of the event process models needed to improve the accuracy of the PIM within the certification framework.

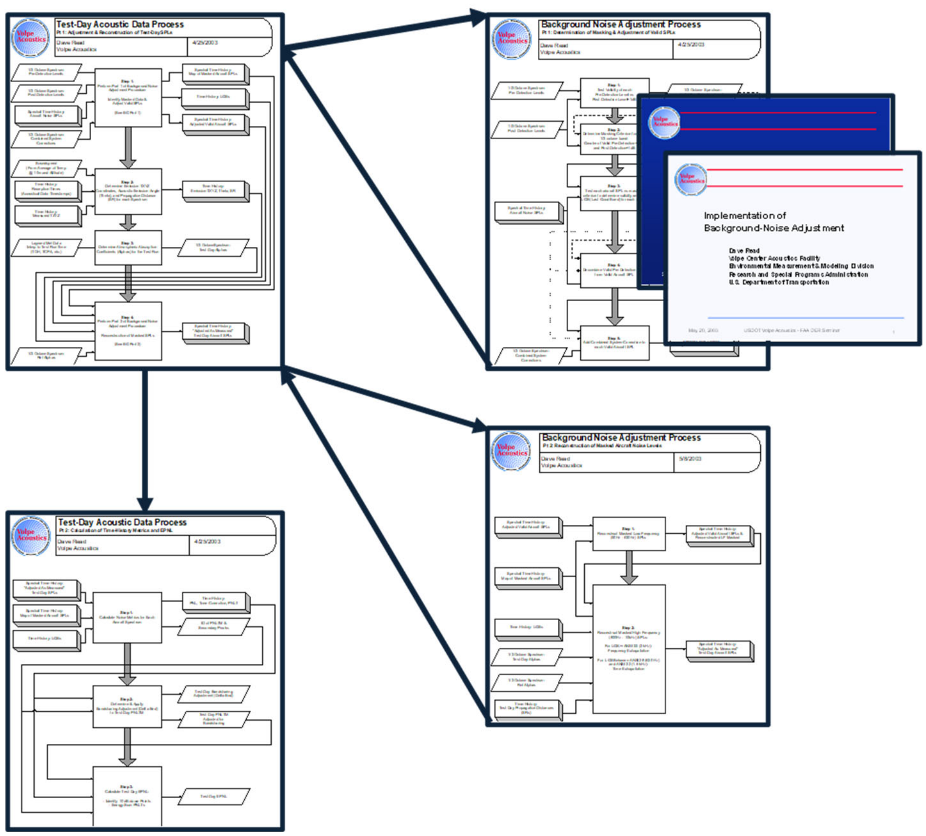


Figure 18. Use and association of content provided through documents shared by VOLPE.

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 (takeoff, approach, flyover). A thread that shows the various hierarchy levels of activity diagrams was established, as shown in Figure 19.

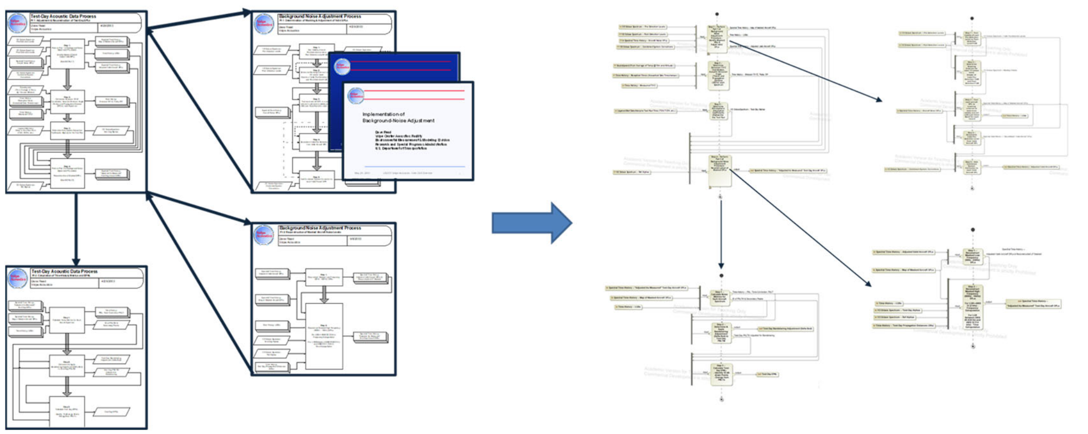


Figure 19. Definition of event processes for certification testing and conversion to SysML views.

Library Creation

A new task was identified to command the creation of libraries within the certification model, in order to allow for added flexibility and modularity, in response to Task 3 requirements. Current libraries include the aircraft library, engine library, microphone library, and data amplifier library. The SUT representation has been modified to allow for adaptability to various aircraft/engine types and configurations, including UASs.

Aircraft Testing Environment

Another finalized improvement on the certification model is the modeling of the transport aircraft test environment, including the flight test setup configuration. With input from the documents shared by VOLPE, the model was updated and refined to include the addition of various instrumentation system architectures.

Noise Calculation

Aircraft noise certification typically requires noise measurements at three reference points: flyover, lateral, and approach. Therefore, EPNL calculation was established by considering three different maximum permitted noise levels. The process was tested against a known flight dataset from an industry partner for a transport category aircraft that has been certified. The test data contain a spectral noise history of the aircraft at an unknown reference point, without the inclusion of background noise adjustment or reference condition corrections. The metrics of interest include the following:

- *Annoyance-based measure or EPNL* (in units of EPNdB). This metric accounts for subjective effects of aircraft noise on humans over the duration of the perceived noise level (PNL). Because certification-quality EPNdB cannot be directly measured, it is calculated as described in the Annex 16 standard.
- *Loudness-based measure*. For this metric, the maximum sound exposure level is calculated (in dBA units).

The available data for sound pressure levels, frequency distributions, and time variation measurements are used to evaluate levels in EPNdB units and to validate the EPNL tool in the verification model. EPNL is widely used in aircraft noise projections and is based on prior loudness models. While loudness is considered the most effective contributor to annoyance, other attributes such as sharpness, tonelessness, roughness, and fluctuation strength may also affect the annoyance perceived. FAA's EPNL metric considers intensity, tonelessness, and duration of the aircraft noise.

Before the EPNL is 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. A conversion process of the flight test data is required to obtain certification-quality EPNdB, as it cannot be directly measured from raw test data. The standardized conversion process is described in ICAO Annex 16, which contains the aircraft noise standards. The EPNL calculation is performed utilizing the programs written by More (2011) as per ICAO Annex 16. The steps for EPNL calculation, per the ICAO-recommended practice, are as follows:

1. Convert the sound pressure level (SPL) to the instantaneous PNL for each 0.5-s sample, by means of a noy table.

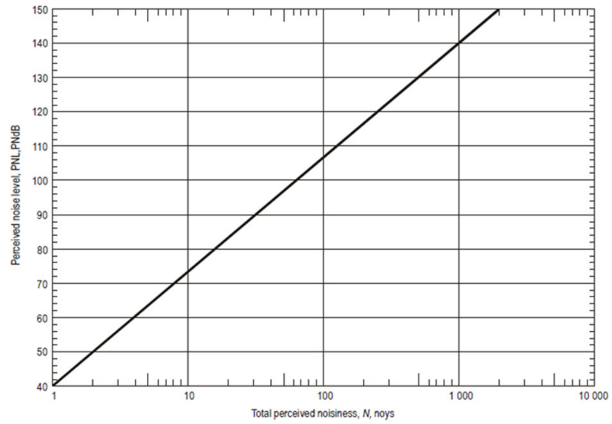


Figure 20. PNL as a function of total perceived noisiness.

2. Calculate the tone correction factor C to account for the subjective response to the presence of spectral irregularities.
3. Calculate PNLT = PNL + C, for each 0.5-s increment of time.
4. Calculate the duration correction D for the entire flight (where T = 10 s and $\Delta t = 0.5\ s$).

$$D = 10 \log \left[\left(\frac{1}{T} \right) \sum_{k=0}^{d/\Delta t} \Delta t \cdot \text{antilog} \frac{\text{PNLT}(k)}{10} \right] - \text{PNLTM}$$

5. Calculate EPNL = PNLTM + D, where PNLTM = max(PNLT).

The validation results are depicted in Figure 21, where the available flight test data are compared with the calculated PNL values. The results show that the PNLs calculated from the sound pressure levels align with the validation data, except for a small peak between 20 and 25 s with a difference of less than 1%. The corrected PNLs are also depicted in the figure as a reference; however, these values could not be compared against known data, as the given dataset was limited to the uncorrected values. Therefore, EPNL is calculated with both corrected and uncorrected PNL values. As the results show, the EPNL tool used in the verification model can match the validation data. For comparison, the maximum noise levels from the requirements are also provided at flyover, lateral, and approach reference points. The data used to validate our EPNL conversion tool were provided by one of our industry partners and include raw noise measurements from a previously certified transport aircraft.

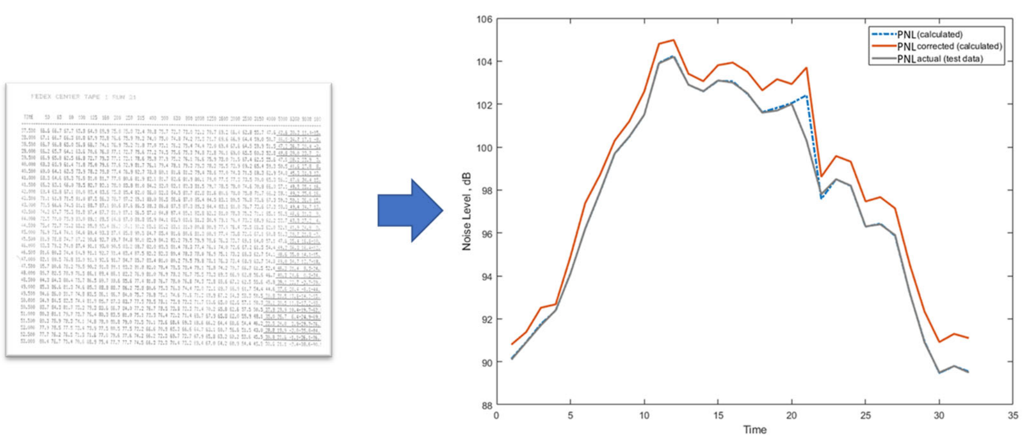


Figure 21. Validation results for the effective perceived noise level (PNL) analysis module.

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. For this purpose, a version of a software tool written in MATLAB for calculating the EPNL, based on 14 CFR Parts 36 and 91 (Konzel, 2022), was identified in the literature. Expanding on the logical architecture library, the EPNL calculation has been implemented through a block representation in the MBSE framework, as shown in Figure 22. The team completed the integration by effectively linking the EPNL calculation to the MATLAB source code of this analysis through use of the Cameo Simulation Toolkit (More, 2011).

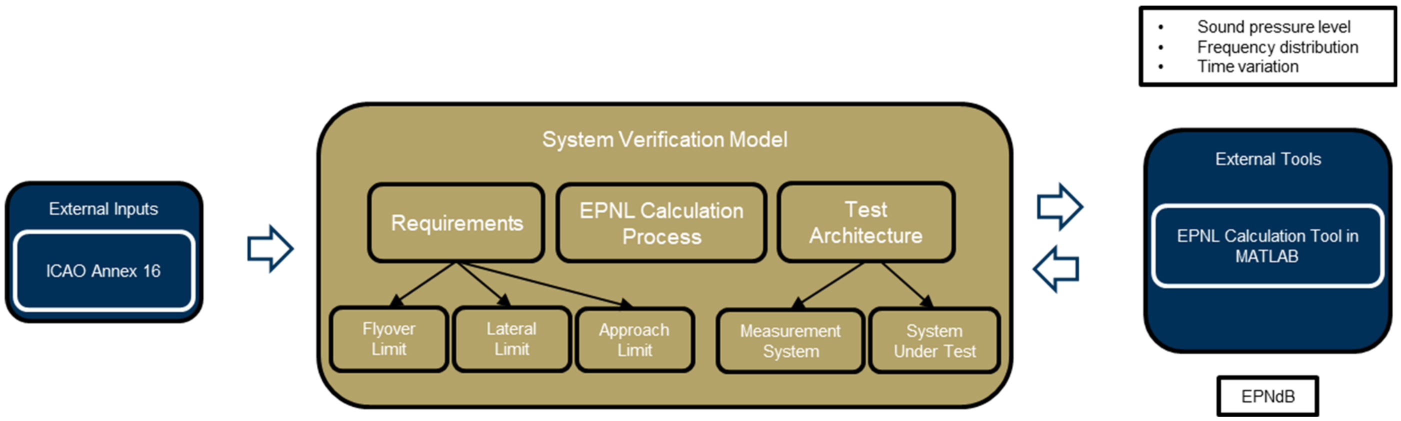


Figure 22. Integration of effective perceived noise level (EPNL) analysis in the verification thread. ICAO: International Civil Aviation Organization.

In conclusion, Task 2.1 is complete, resulting in a verification model that allows for a basic certification assessment (for the transport category). However, several improvements and additions are required before the fully planned capability is in place. Planned improvements include targeting the expansion to the UAS category, as follows:

- Repurpose the verification model for other categories, particularly for UASs.
  - This step will be further addressed by Task 3.
- Build test constraints for the SUT for UASs.
  - Import regulations from CFR Title 14 Part 36 Appendix G, J, and H and translate to verifiable requirements.
  - Define constraints with numerical/logical limits and apply to systems.
- Document the EPNL calculation process to verify noise constraints on the SUT.
  - Import raw noise testing data into the verification model (data possibly available through ASCENT 077).
  - Verify noise requirements using EPNL-converted noise data.

Task 2.2 Streamlined Process Definition

The objective for this task is to explore options for formulating streamlined certification process alternatives, driven by feedback from the OEM partners. The following target objectives for streamlining the certification process are currently being considered:

- Reduce the number of steps in the process, with an anticipated savings in time and cost. Replace steps, mostly in analysis, data preparation, and post-processing, with digital tools.
- Enhance automation on procedural tasks (e.g., data retrieval, queries, processing, and report generation).
- Implement affordable technology solutions, e.g., virtual sensing. The goal is to utilize digital tools that will allow the omission of physical instrumentation, such as lateral microphones.

A comprehensive literature search led to the identification of options for equivalent procedures, and the findings are summarized in Table 3. However, in follow-up discussions with OEM partners, it was concluded that potential improvements in noise certification procedures and testing extend beyond time and cost savings. Possible higher value-added improvements to streamline noise certification (with input kindly provided by Boeing) are as follows:

- Simplify setup requirements to facilitate more test locations/weather windows (i.e., remove 4-ft microphones for the ground plane and remove lateral locations all together).
- Evaluate NAC limits in the context of testing uncertainty.

- Address conformity issues by formulating an acoustical conformity concept.
- Expand the use of certification by analyses to expedite approval procedures within the FAA. This step would involve criteria developed for approval for acoustical analyses that define new certification noise levels (acoustical change by analysis), leading to a framework for oversight that gives FAA confidence in the manufacturer tools/methods used.

Along with the selection of the equivalent procedures of interest, based on the above feedback, the outcome of Task 2.2 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 certification model against the SUT configuration and for showcasing quantifiable improvements against the process criteria listed above, while meeting the same regulatory constraints and requirements as the benchmarked certification procedure.

Table 3. Summary of options for equivalent procedures (EPs) provided by workshop/interview feedback.
(Note: This is an inclusive list of findings collected through the partners' responses and does not determine the final outcome nor any chosen direction, as these options are still under discussion between the team and project partners.)

Title/summary of EP or a grouping of EPs	Time savings	Cost savings	Providing compliance flexibility to the applicant
Flight path intercept in lieu of full takeoff/ landing profiles	Yes (by factors of 5-10)	Yes (less wear, less maintenance)	
Lateral mic placement (single or multi pair)	Possibly (multiple = better data)	Yes (single pair)	
Derivation of noise-power-distance (NPD) data (data reduction/expansion by analysis, based on few points)	Yes (several weeks)	Yes	
Approved measurements at non-reference points (adjusted data)		Possibly	Yes (in test conditions/ site selection)
Exceeding sound attenuation limits allowed in some cases			Yes (in test conditions)
Static-to-flight projections (not making a new noise-power-distance (NPD) database)	Yes (no flight test for derivations)	Yes (no flight test for derivations)	Possibly (gives a noise change range for derived versions)
Inflow control device & calibration options (for change of engine)			? (provides an option to certify engine change)
Cert by analysis noise-power-distance (NDP) data extrapolation for design changes with predictable noise effects)	Yes (no flight test for derivations)	Yes (no flight test for derivations)	

A potential use case (also endorsed by OEM partner feedback) is an alternative setup and placement of the lateral microphone. The microphone setup must abide by Regulatory Requirement B36.3, B36.4, which relates to "Measurement point(s) defined as point(s) on the line parallel to and 1476 ft (450 m) from the runway centerline, where noise level is a maximum during takeoff." The main benefit of this alternative layout is the reduction in complexity that is present due to the use of multiple microphone arrays along the lateral line, aside from direct savings in acquisition and maintenance costs and the time needed for setting up. As a drawback, however, this solution covers a smaller sound field than multiple arrays, and more test points may be needed to obtain sufficient data for compliance (accuracy, data quality). The top panel in Figure 23 displays the current microphone setup and how their locations are chosen.

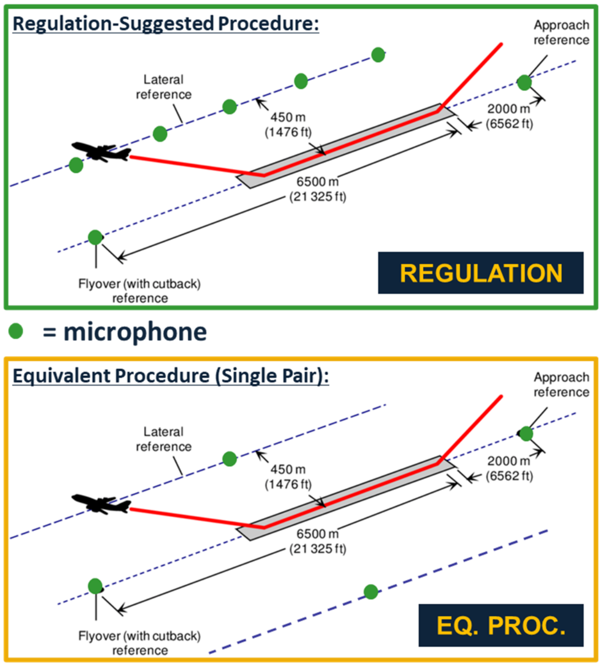


Figure 23. Equivalent procedure example: a lateral microphone setup **Error! Reference source not found.**.

For the proposed equivalent procedure, a single pair of symmetric microphone stations is considered, with a placement as shown in Figure 23. With the use of the verification thread and for a given aircraft model as the SUT, the following constraints and requirements must be met:

- Full takeoff power, configuration, and airspeed as in Regulation B36.7(b)(3-4)
- At several specified heights above a track (covering a range of 200–2000 ft)
- At right angles to and midway along the line joining the two microphone stations
- Lateral noise determination based on matching data from both lateral microphones for each fly-past
- Adjusted noise levels: symmetric OR asymmetric (one or two regression curves)
    - Usually second order; justification needed for exceptional use of third order
- Confidence interval of reported EPNL within +/- 1.5 dB (Regulation A36.5.4)
- Minimum of six runs to obtain sufficient data for compliance

Task 2.3 Streamlined Process Assessment and Revision

For this task, the objective is to further assess the feasibility of the proposed equivalent procedures and apply any revisions, per feedback from the FAA, VOLPE, and industry partners. 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.

This task is currently underway. As additional meetings with OEMs have been held, it has become evident that obtaining past test data from OEMs and/or gaining additional insight into a test baseline and testing plan would be difficult. In the interest of time and with the lack of testing data and lack of direct access to information for providing a SUT baseline, a decision has been made, with support by the FAA AEE, to immediately pivot to a UAS category SUT for the framework demonstration. 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. An expanded breakdown of Task 2.3, specific to UASs, is provided in the next section.

[UAS Pivot] Task 2: Develop a Library of UASs and Testing Procedures

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 061 team has started to document and that has been valuable in identifying the most important technical challenges for UAS noise testing is the document entitled "Noise

Measurement Report: Unconventional Aircraft" by the Choctaw Nation of Oklahoma (July 2019). The described practice 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.

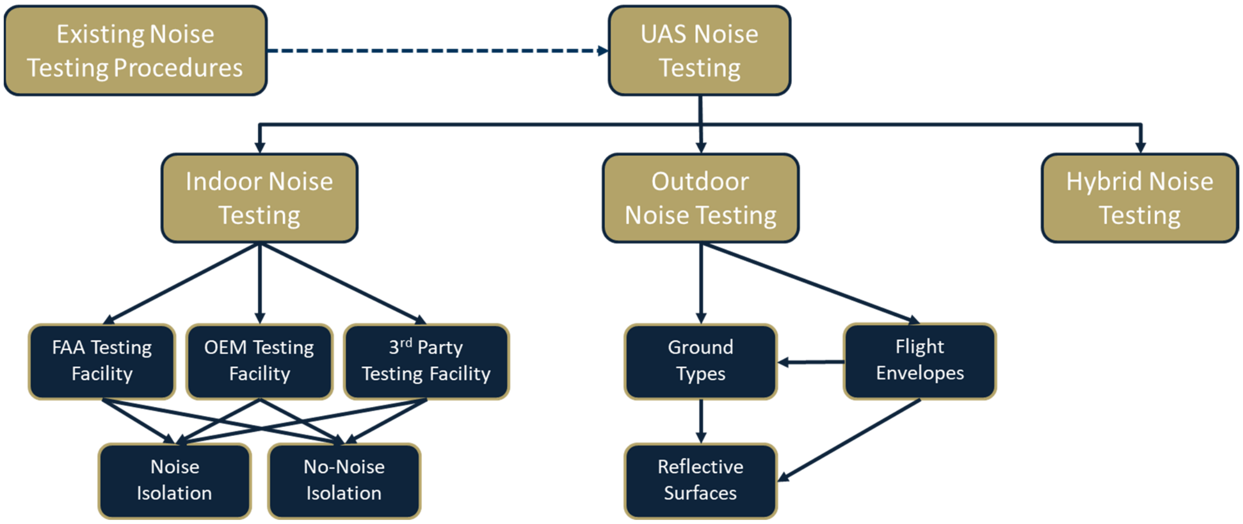


Figure 24. Alternative noise testing procedures for an unmanned aerial system (UAS). OEM: original equipment manufacturer.

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, and examples are shown in Figure 24. 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.

Milestones

- A first complete version of the noise certification process model has been implemented in SysML.
- Through the verification model, the applicability of MBSE methods for this problem has been demonstrated.

Major Accomplishments

- A noise certification process model represented in SysML has been completed, where equivalent procedures can be tested through a requirement verification model.
- UAS noise testing practices and processes have been documented.

Publications

None.

Outreach Efforts

- Provided a full Year 2 performance review to the FAA AEE
- Technical discussions and feedback provided by VOLPE
- Collaboration with ASCENT 077 and Dr. Eric Greenwood's research group

Awards

None.

Student Involvement

- The implementation of the verification model required significant skillset development in the use of SysML and software, which all students were successfully able to acquire.
- All students participated in the integration of all main enablers into a first complete version of the verification model.

Plans for Next Period

- Finalize the baseline model for current certification practices for UASs.
- Proceed to the next steps for MBSE framework development:
  - Model finetuning, consistent format, reusability, easy navigation setup
  - UAS configuration definitions
  - Noise testing procedures
  - Process alternatives and evaluation
- Identify use case examples to plan for demonstration, based on selected areas of improvement.
- Implement an interactive decision support tool to aid in further showcasing the capabilities of the MBSE framework through the selected use case examples.

Task 3 - Develop a Flexible Noise Certification Procedure for New Aircraft

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 subtasks will be conducted under Task 3:

Task 3.1: Flexibility Assessment of Streamlined Process

- Evaluate the flexibility of the streamlined noise certification process for new category air vehicles.

Task 3.2: Flexible Process Definition

- Define and recommend improvements for the streamlined noise certification process to accommodate a flexible noise certification process with respect to vehicle type.

Task 3.3: Flexible Process Assessment and Revision

- Solicit feedback on the new process from the FAA and industry partners.
- Perform a revision of the suggested process by incorporating key aspects of the collected feedback in order to build a consensus among research partners.

Research Approach

Task 3.1

Task 3.1 seeks to define what is meant by a "flexible" process. One way to develop this definition to determine whether the introduction of a different vehicle configuration leads to a large number of incompatibilities with the streamlined process under evaluation. For instance, it is important to assess how the rotorcraft configuration affects the microphone technology and quantity needed and the microphone placement in the testing facility. This subtask will involve testing procedures, and a mapping of compatibilities between vehicle configurations and testing procedures will be produced. A set of criteria and evaluation metrics is needed in order 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:

- Compatibility and applicability of equivalent procedures
- 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 NACs different than other categories
- Sensitivity to weather, etc.

The defined criteria will be tested and applied in the following tasks; hence this task is considered as completed.

Task 3.2

Based on the verification model available for the transport category, a first iteration of the proposed concept for evaluating a flexible certification process has been formulated, as presented in Figure 25. The original model is sufficiently flexible to accommodate a different set of regulations as one of the inputs, which, like in the transport category example, will undergo a conversion to requirements based on a digital thread and a requirement model in SysML. The fields that are currently undergoing adjustments are highlighted in orange, and the algorithm modifications for the logical conversion are in progress. Similarly, a conversion of the noise instrument validation protocol to SysML views is underway. However, the vehicle representation model (top right in Figure 25) is not process-dependent, and the interface definitions require modifications for this module to interface with the verification model.

After considering the above modifications, a UAS-specific version for the MBSE certification framework has been formulated, as showcased in Figure 26. The ASCENT 061 team has been working to convert the following information items into SysML views:

- Certification regulations: An updated requirement model has been finalized, based on guidance from Appendices H and J and with the use of the NPRM (FAA, 2022) as a template.

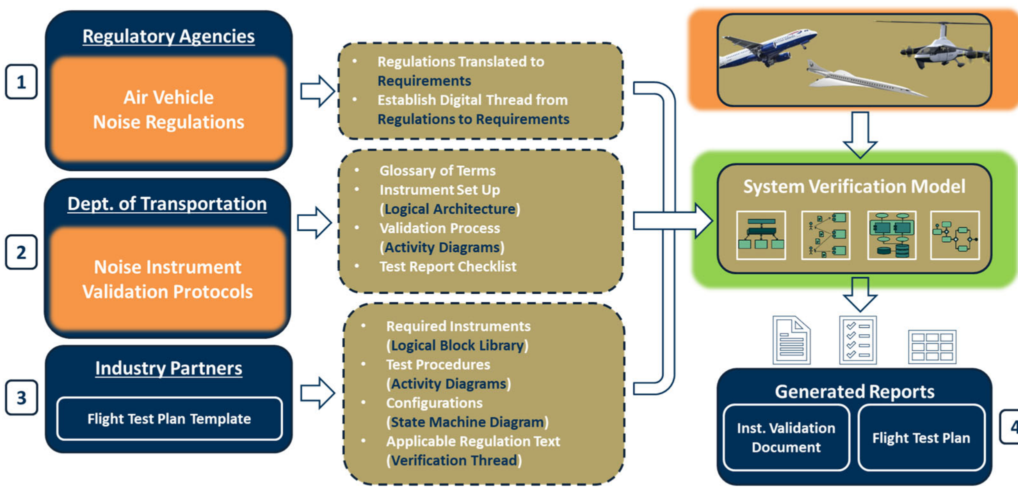


Figure 25. Verification model for multiple vehicle configurations.

- Validation processes: Validation processes are driven by current guidance from the NPRM-derived instruction for UAS certification testing.
- Test plan template: The Matternet (USDOD, 2022) example for certification testing has been used to generate a testing plan template.
- Test results and noise measurements: The ASCENT 061 team is collaborating with the ASCENT 077 team and has obtained samples of noise measurements in order to further define the analysis functions that will produce the validation metrics. These metrics will be used for validation and for assessments of the proposed streamlining improvements and equivalent procedures.
- Equivalent procedures: Utilizing the format of a database with equivalent procedures built for transport category configurations, the ASCENT 061 team will build a similar database and incorporate a modeling approach for assessing the impact of an alternative against the baseline.

Based on the workflow proposed in Figure 25, the integrated framework for flexibility assessment of the certification process is expected to be reusable for a broader set of UAS configurations, as highlighted in Figure 26.

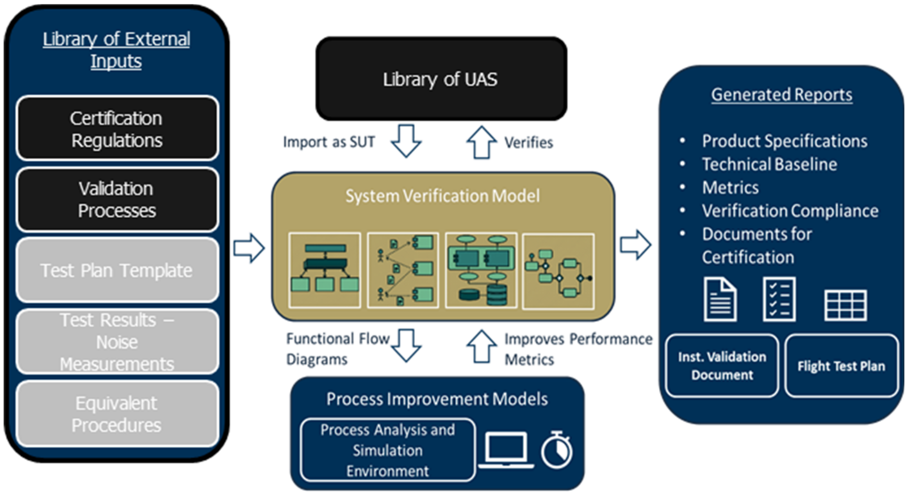


Figure 26. Model-based systems engineering certification framework version for unmanned aerial systems (UASs) to test category flexibility in equivalent certification procedures. SUT: system under test.

Task 3.3

The certification framework for UASs developed under Task 3, as well as the use of the PIM completed under Task 4, will allow for measuring 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.

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 through the use of 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 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.

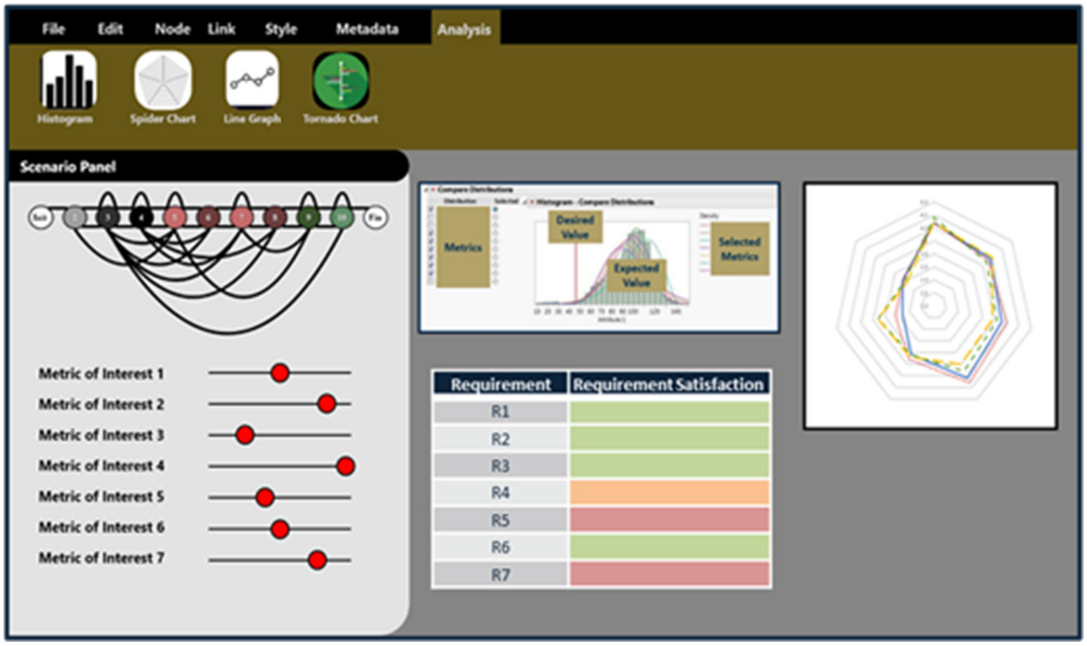


Figure 27. Graphical user interface for process specification.

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

- Left side: Here, a process alternative is represented (one at a time), including all steps of the test plan execution and the preparation and post-processing of noise data. At the lower portion of the left side of the tool, a set of slide bars allows the user to select the priorities/desirability of the evaluation criteria and metrics used (e.g., time, resources, budget, complexity, redundancy, etc.).
- Center: In this part, the focus is on data analytics supported by 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 (CDFs) to assess whether constraints and requirements are being met. The table in the lower center portion presents an assessment check on whether requirements are being met, which is included to provide guidance toward the exploration of procedures and technologies that would help close any gaps and meet all requirements.
- Right side: For multi-variate and multi-criteria problems, a spider chart 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.

An early version of the interactive certification process exploration and selection capability, built as a minimum viable product, is presented in Figure 28. In this version, the user can prioritize the process evaluation metrics, represent the certification process alternative of interest as a graph, and then view all distributions obtained by Monte Carlo experiments, with statistical analysis results given in a radar plot for all alternative processes. The highest ranked process from the selection portion is displayed in its process diagram version and can then be compared with the baseline. If requirements are not met and certain capability gaps exist, the user can expand the space of process alternatives and repeat the analysis.

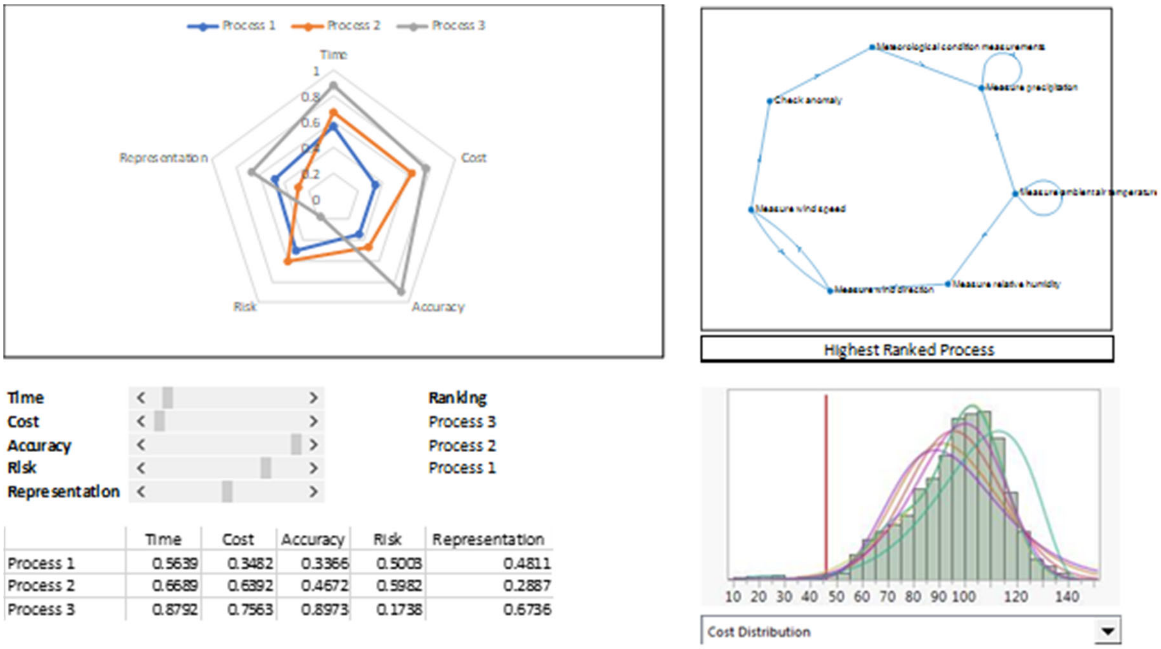


Figure 28. Early implementation of a minimum viable product for the visualization environment.

To enable the multi-criteria, parametric, and interactive capability for rapid exploration of certification alternatives, the PIM, which executes a process simulation through Markov chains 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 of this report.

Milestones
Please see the milestones under Task 1.

Major Accomplishments
- An initial concept formulation and implementation roadmap have been completed for the MBSE framework to accommodate multiple UAS types and to allow for process effectiveness and flexibility evaluation.
- Metrics have been developed and the PIM has been integrated under a parametric interactive decision support environment. The concept has been demonstrated through a minimum viable project exercise.

Publications
None.

Awards
None.

Student Involvement
The full student team has participated in brainstorming sessions toward formulating the integrated certification process assessment framework for UASs.

Plans for Next Period
- Perform a morphological matrix exercise to explore and identify feasible certification process alternatives, based on permutations of UAS type, testing plan, testing and sensing technologies, data analysis methods, and map options for evaluation criteria.
- Finalize process evaluation metrics and incorporate them in the next iteration of the decision support tool.

- Demonstrate a simple use case, where a number of feasible alternatives lead to comparisons with the process baseline. The use case and the improvement propositions within the alternative options will be formulated with input from subject matter experts and current gaps in meeting certification targets.

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Task 4 - Simulate Streamlined and Flexible Noise Certification Procedures

Georgia Institute of Technology

Objectives

Task 4 seeks to explore options for evaluating noise certification within the MBSE certification framework. The purpose for 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 4.1: Identification of a Modeling Approach

- Explore options for modeling approaches in order to simulate and evaluate the certification process within the MBSE framework.

Task 4.2: Noise Certification Process Metric Definition

- Identify a set of metrics to allow for a quantitative comparison of the current and proposed noise certification processes.

Task 4.3: Model Calibration

- Identify a benchmark for noise certification procedure simulations.
- Perform calibration of noise certification procedure simulations.

Task 4.4: Certification Process Simulation

- Execute simulations of current and proposed noise certification procedures.

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, which, in a broader sense, is referred to as the PIM. Tasks 4.1–4.3. 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 29.

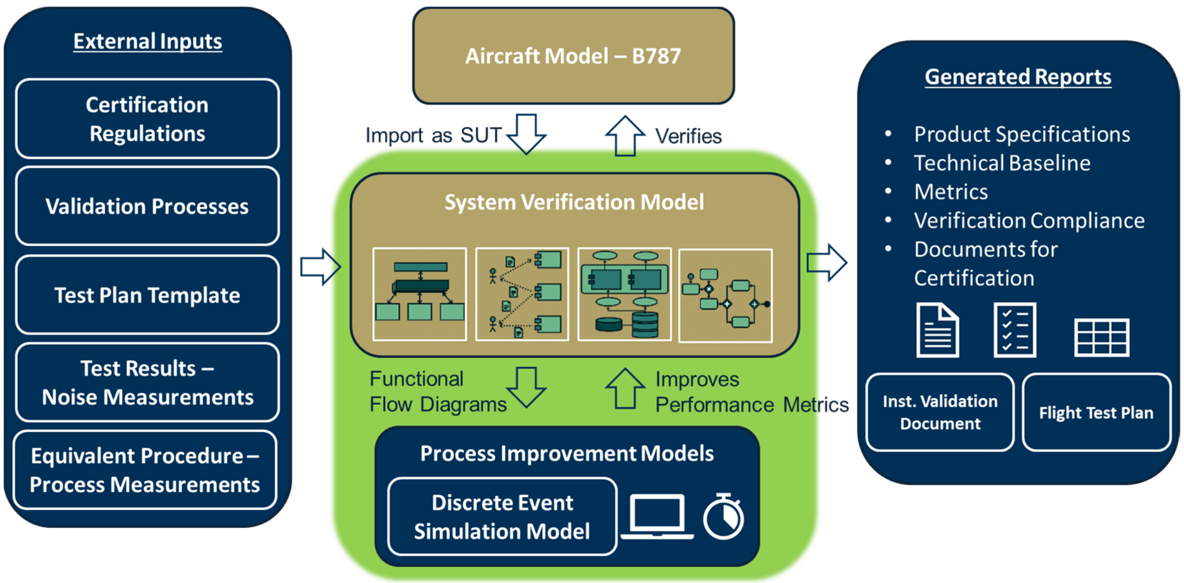

Figure 29. Integration of the process improvement model within the model-based systems engineering certification framework. SUT: system under test.

Task 4.1

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 how well they can capture and simulate actual industry-applied procedures and their ability 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 30. The objective was to demonstrate that a process model, as defined in the MBSE framework, can be simulated using DES. With the model states imported, DES can track the clock and return the time points at which each event is concluded. The DES results are then fed back as an input and update the process diagram in the verification model, which then checks the process model against requirements and compliance.

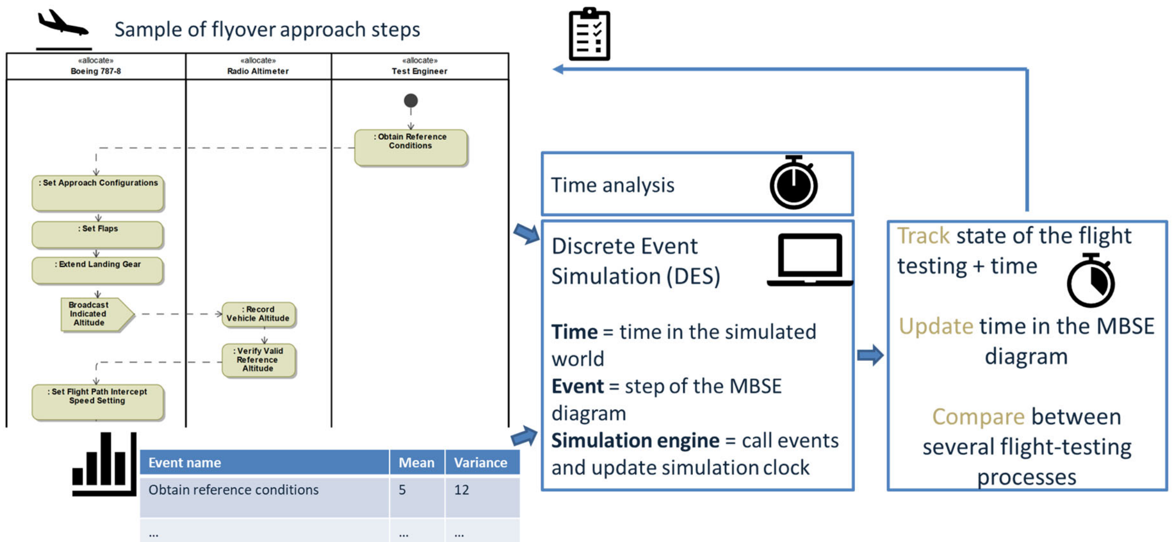

Figure 30. Discrete event simulation for a flyover approach. MBSE: model-based systems engineering.

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 possibly utilizing 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 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, and 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 31, which illustrates the interface with the verification model. Using a similar flyover approach plan example, as in Figure 30, 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 (time, cost, resources, disruption risks, accuracy penalty, etc.), and distributions for Monte Carlo simulations are chosen. The Monte Carlo (MC) simulation then generates the PIM metrics and prepares the dataset for verification.

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

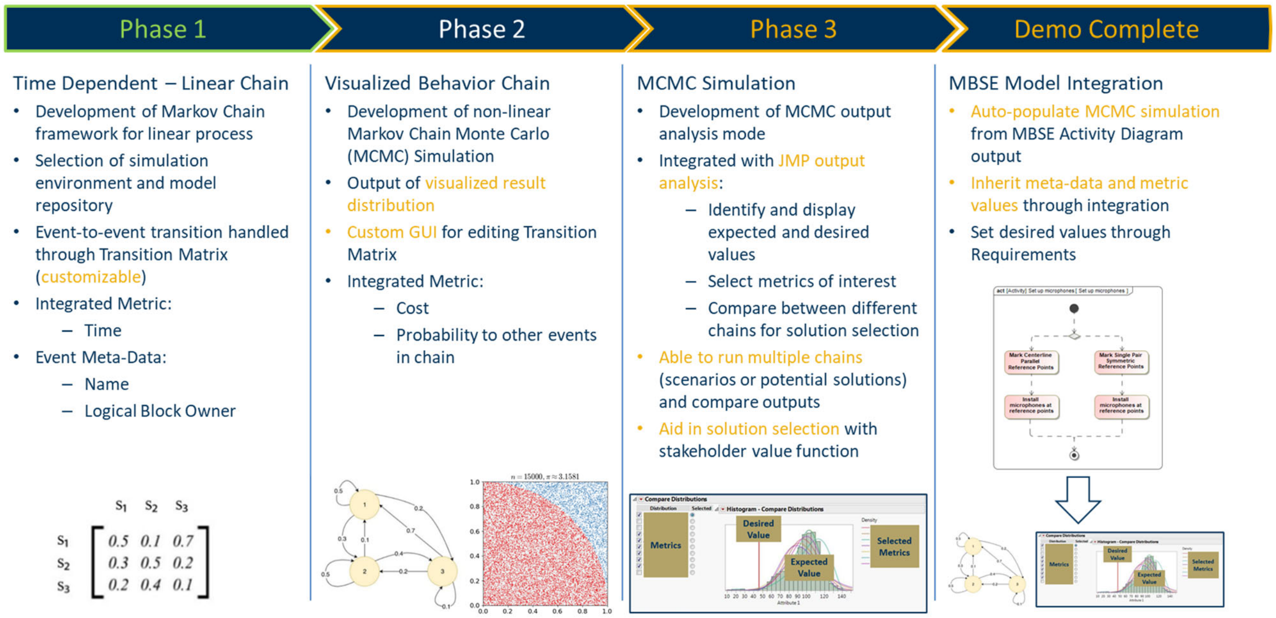

Figure 31. Functional development plan based on a process improvement model. GUI: graphical user interface; MBSE: model-based systems engineering; JMP: John's Macintosh Program.

Task 4.2

With the PIM model now available in a flexible and customizable format, Task 4.2 seeks to expand the process simulation and analysis towards 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 current list of identified metrics is as follows:

- Time: schedule cost incurred to complete event
- Cost: budget cost incurred to complete event
- P(Failure): probability of repeating an event or reverting to a previous event (does incur time and cost [full or partial] in each occurrence)
- P(Success): probability of moving out of the current event
- Accuracy penalty: impact on overall accuracy value for executing the event (does not incur an additional cost in each occurrence)

Depending on the requirements and acceptance–rejection distributions, changes will be proposed for the process model, (e.g., by incorporating equivalent procedures, modifying recording lineups, considering conformity models, etc.), and then, another iteration cycle will be ready for execution. The long-term benefit is that the process will evolve as a key function for testing the feasibility of equivalent procedures, all within the automation of workflows and functions enabled by the MBSE framework.

At present, currently identified metrics have been applied in a use case demonstration under Task 4.4 for the transport category. With the pivot to UAS configurations, the team is expanding on this task to identify metrics that extend beyond the efficiency-oriented focus of the original process streamlining concept, with an added focus on flexibility for a metric to accommodate alternative UAS concepts.

Task 4.3

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 061 partners. The analysis workflow for the PIM module is shown in Figure 32. 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:

- *Definition of test data*: This step includes a test plan, setup, instrumentation and recording information, and sound pressure level measurement data.
- *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.
- *Execution of the MCMC algorithm*: The simulation starts from a node, and a “roll the dice” (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).

Regarding the simulation outcomes, the PIM in its current form tracks time and cost metrics for each completed certification process, as well as the complexity/uncertainty-driven error propagation.

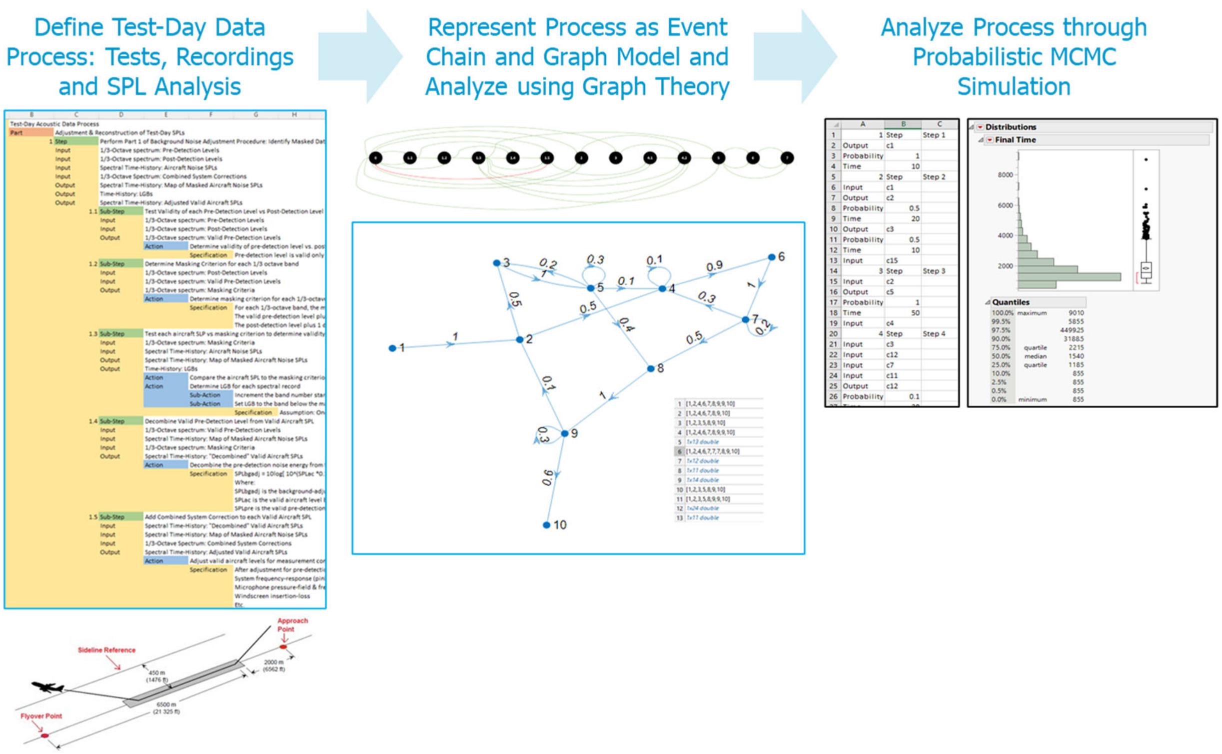

Figure 32. Analysis workflow based on the process improvement model. MCMC: Markov chain Monte Carlo; SPL: sound pressure level.

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 project’s 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 061 partners could provide for further calibrating the model, according to the use cases of preference.

Task 4.4

In a proof-of-concept demonstration of the complete certification process simulation capability within the PIM, the 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 Waco YMF-5 propeller aircraft.

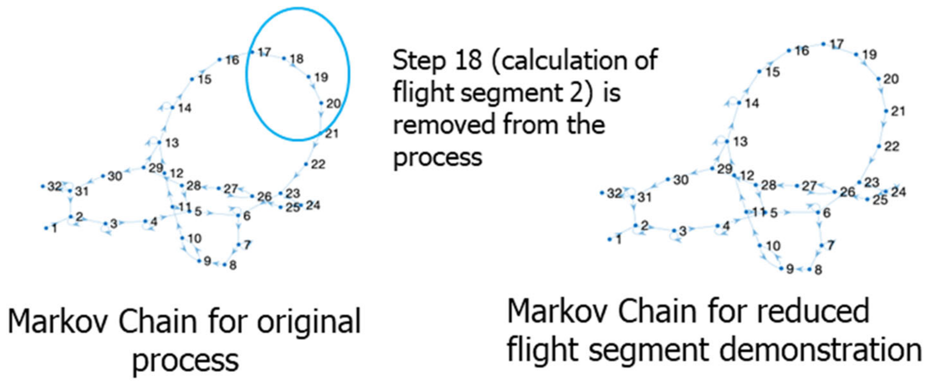

Figure 33. Process modification: Step 18 (calculation of the second flight segment) is removed from the flight-testing process.

The baseline (original) process was formulated within the PIM and executed using best estimates for times and cost. The term “best” implies that the 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, the guidance was provided at a higher level, without any limitations on how this 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 33, the simplified process removes step 18 (calculation of the second flight segment) while other steps were updated with new values to capture the updated process.

Table 4. Summary of cost ($) and time (hr) improvements.

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

A comparison of the two process alternatives is presented in Table 4. 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 34, where the Monte Carlo simulation data are plotted as distributions for the cost and time required for the process.

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 team’s priorities are to investigate current noise testing plans and procedures and to be in a position to propose promising equivalent procedures.

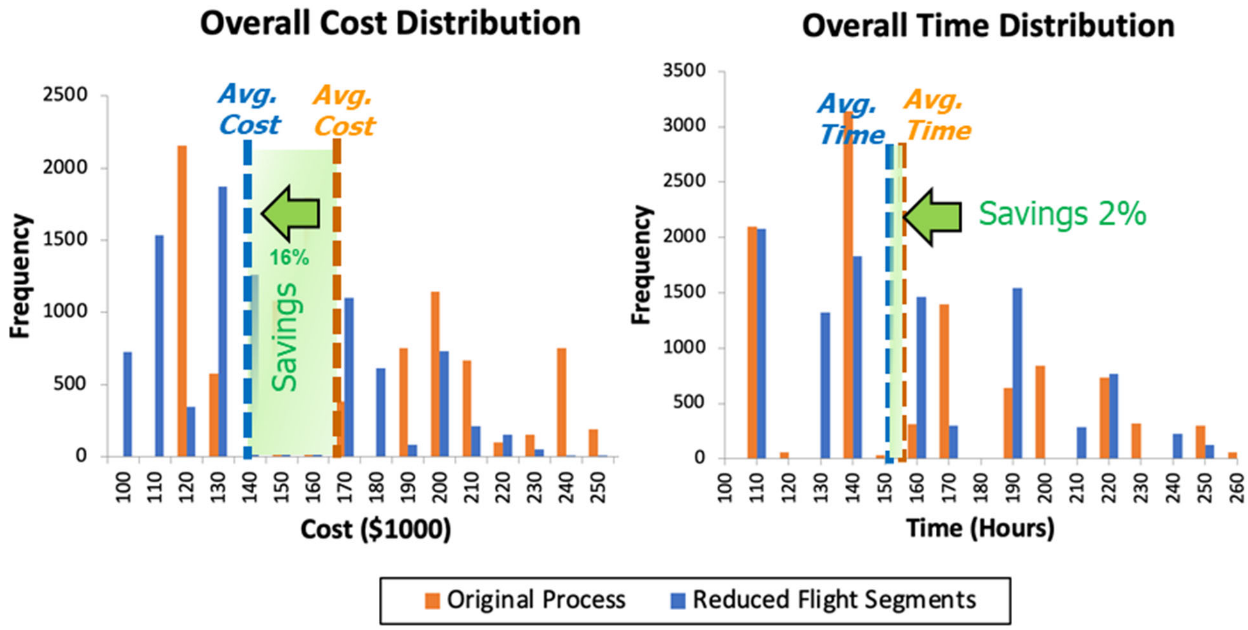

Figure 34. Execution of Markov chain-based Monte Carlo analysis and comparison between the baseline and simplified process.

Milestones

Please refer to the milestones listed under Task 1.

Major Accomplishments

- Development of a small-scale PIM using DES, as a deterministic modeling exercise
- Development of 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
- Definition of a starting set of metrics, as a working solution with a focus on process efficiency improvements
- 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
- Workflow integrated with the MBSE verification model
- 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

Publications

None.

Outreach Efforts

- Presentation of concepts to VOLPE partners, who provided feedback on the tools and analysis methods
- Collaboration with ASCENT 077 and 094 research groups
- Discussions with experts in the field with similar applications, e.g., process simulations for industrial systems, manufacturing, supply chains, etc.

Awards

None.

Student Involvement

While a small portion of the team has been leading the technical approach of PIM development, this task has involved the full team, as PIM integration with the MBSE model is a key enabler to be addressed early in the process.

Plans for Next Period

- Continue with the PIM development steps, toward a full verification model scale capability for the UAS category.
  - Finalize the interface with the MBSE verification model.
  - Ensure flexibility with other UAS configurations (the Matternet M2 example is the current working baseline).
  - Iterate on noise measurement data to be used for PIM improvements.
  - Integrate sound pressure level conversion to EPNL for UASs.
  - Expand on metrics that can better track process complexity and vulnerability and test against varying contingency scenarios, with the goal of ensuring that the analysis is capable of driving robust decisions.
  - Calibrate the model with input from ASCENT 077 work.
- Expand on metric definitions at a level beyond process inefficiencies (e.g., directly addressing time and costs) and consider complexities that could affect the process with bottlenecks and unnecessary use of resources (e.g., duplicate testing, time-intensive procedures, etc.). The flight-testing part of the process will be the primary focus.
- Formulate a simple certification problem for each vehicle type and use it as a pilot for comparing and selecting the appropriate method.
- Integrate results and PIM analysis in the interactive decision support tool.

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Conclusion - ASCENT 061 Year 2 Recap

The following key tasks and activities have been completed within the ASCENT 061, Year 2 performance period:

- Built a noise certification modeling and assessment framework for transport category aircraft:
  - Informed by training materials and data provided by VOLPE and OEMs
  - Completed verification model implementation using the ASCENT 061 MBSE framework

  - Completed PIM for process assessment, evaluation, and testing of equivalent procedures; expanded the current version from a deterministic DES approach to a probabilistic MCMC approach
  - Demonstrated the framework by assessing a simplified noise collection/analysis process for the Waco YMF-5 propeller aircraft
- Established a connection with VOLPE and developed a plan for regular status checks, model reviews, and auditing of findings
- Developed the first proof of concept of an interactive decision support capability for exploring and assessing equivalent procedures
- UAS pivot: Explored the applicability of the current ASCENT 061 framework for noise certification of rotor or small propeller-driven UASs
  - Performed a literature search on current noise certification practices for UASs; identified gaps and opportunities
  - Analyzed proposed noise certification guidance based on NPRM 86 FR 48281 and used this guidance as a benchmark
  - Formulated a requirement model based on current regulations and incorporated this model in the MBSE certification framework
  - Modified the ASCENT 061 MBSE noise certification framework for the UAS category to provide oversight on equivalent procedures and regulatory compliance
- Engaged in a broader outreach of ASCENT 061 to the aviation community on noise certification
  - ASCENT fall/spring meetings
  - Other groups within VOLPE
  - Boeing Commercial Aircraft Acoustics Division
- Exchanged noise measurements and knowledge with the ASCENT 77 team
- Provided annual and quarterly reports, which are available on the ASCENT Knowledge Services Network (KSN) database
- Prepared contributions and new technical capabilities that will be published in conferences and peer-reviewed journal articles:
  - Kim, D., Karagoz, F., Datta, S., Balchanos, M., Anvid, D., Harrison, E., & D.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.
  - Kim, D., Taneri, M., Omoarebun, E.N, Wills, T., Balchanos, M., & Mavris, D. (2023). *MBSE-Enabled System Verification and Process Improvement of Transport Aircraft Certification.* Accepted and to be presented In AIAA SciTech 2023 Forum, National Harbor, MD, January 23-27, 2023.

Appendix A - Survey of Title 14, Part 21 and Part 36

FAA rules are described in the U.S. Code of Federal Regulations, Title 14 (14 CFR), Chapter 1. Aircraft certification procedures and noise standards are found in Subchapter C, Parts 21 and 36, respectively. Additional relevant sections of Subchapter C include the following:

- **Part 21 – Certification Procedures**
- Parts 23–31 – Airworthiness Standards for Aircraft
- Parts 33–35 – Airworthiness Standards for Aircraft Engines
- **Part 36 – Noise Standards**
- Part 39 – Airworthiness Directives
- Part 43 – Maintenance
- Part 45 – ID and Registration Marking
- Part 47 – Aircraft Registration
- Part 48 – Registration and Marking for Small Unmanned Aircraft
- Part 49 – Recording of Aircraft Titles and Security Documents

Benchmarking of current certification practices will be driven by Part 21, Part 36 (FAA, 2017), and AC 36-4D (procedures and steps for noise certification (Federal Register, 2022). Please note that this list of requirements is derived from the FAA standards, guidance, and practices alone. The FAA works closely with the international community to ensure that their standards align with ICAO noise regulations and can adapt to changing noise mitigation technologies (FAA, 2022). ICAO noise regulations (Chapter 3) use FAA's FAR36 Stage 3 as a starting point. It is acknowledged that other NAAs, such as the EASA, have practices that may vary from FAA requirements.

The intent is to identify any potential gaps in the team's understanding of noise certification procedures and to detect any equivalent procedures and accepted means of compliance that should be noted. Figure A1 presents an overview of the process, which is broken down into five phases. This review covered the mapping of all detailed procedures contained in AC 36-4D on the testing practices (the "how"), whereas Part 36 focuses on the regulatory side (the "what") for compliance.

The following subsections present the team's findings and high-level process views.

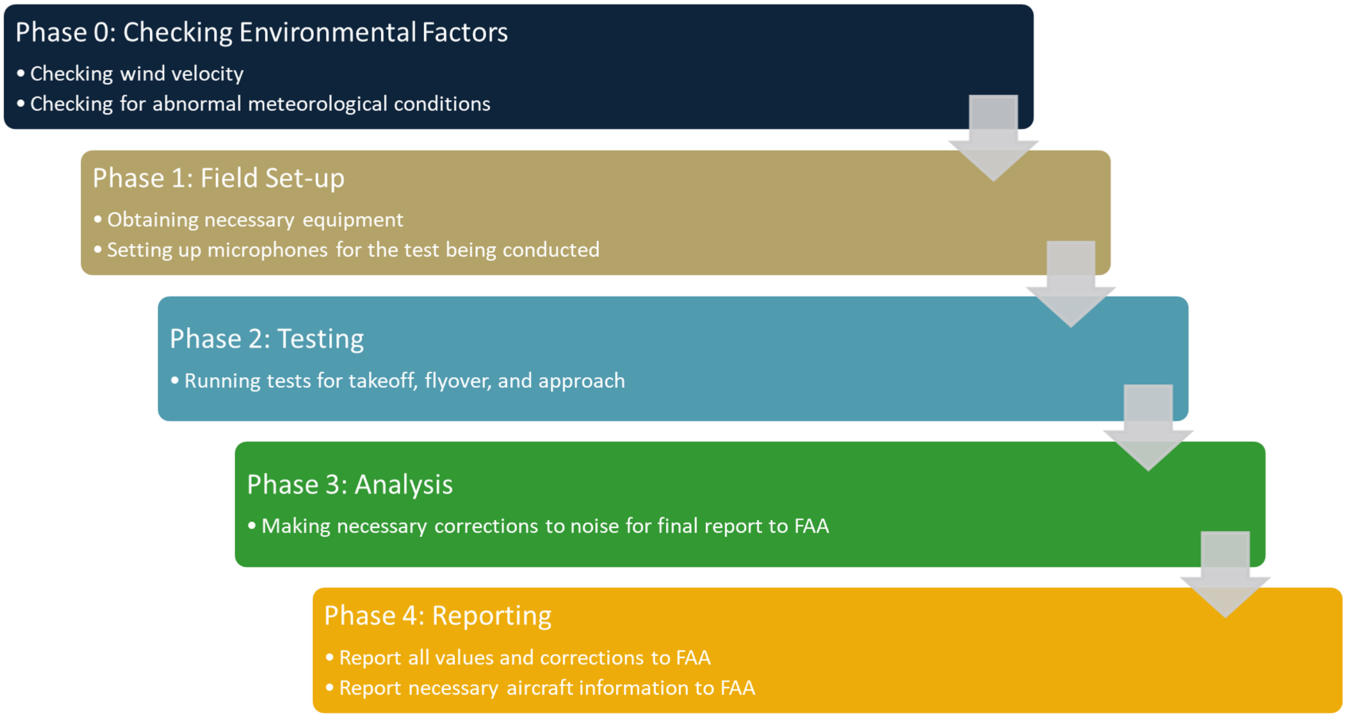

Figure A1. Overview of the noise certification process as described in Parts 21 and 36 and Advisory Circular 36-4D.

Phase 0: Checking Environmental Factors
In this phase, the goal is to measure and verify that weather and testing conditions are appropriate. This step includes checking the wind velocity and assessing for abnormal meteorological conditions. One must also verify that the terrain meets the appropriate FAA specifications. In the case that a non-airport test site is sought, the test site criteria must be followed. Figure A2 provides a visual summary of the steps that must be performed before field setup occurs.

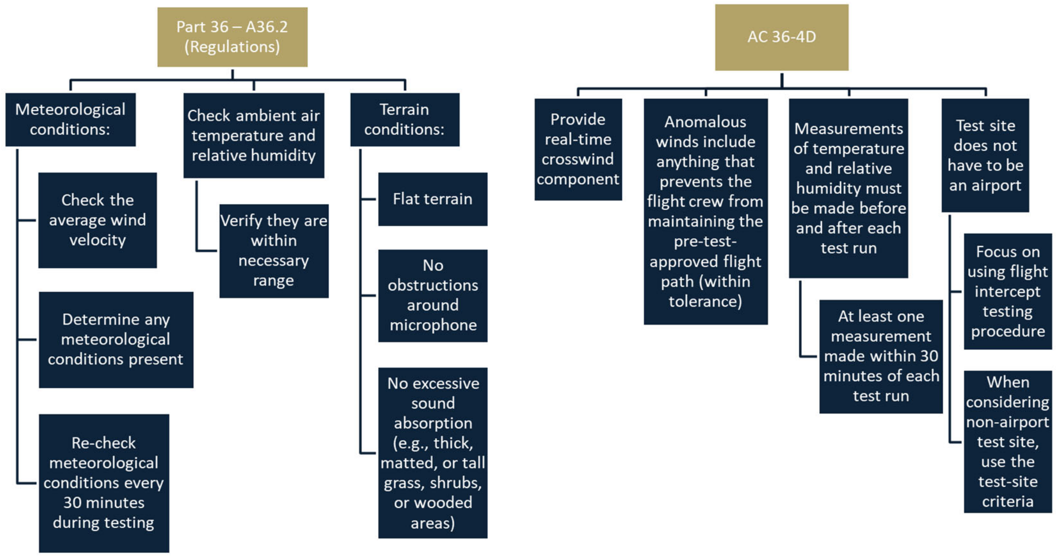

Figure A2. Phase 0: Checking environmental factors. AC: advisory circular.

Based on Phase 0 benchmarking, the team prioritized the following inquiries to the industry partners, in support of Task 1.2:

- Is an airport used for testing, or is another location typically used? If elsewhere, where are the certification procedures completed?
- How difficult is it to obtain FAA approval to conduct the test at another location besides an airport?
- If an organization has multiple certification sites, how does testing differ amongst the sites (e.g., in the number of trials needed to successfully certify)?

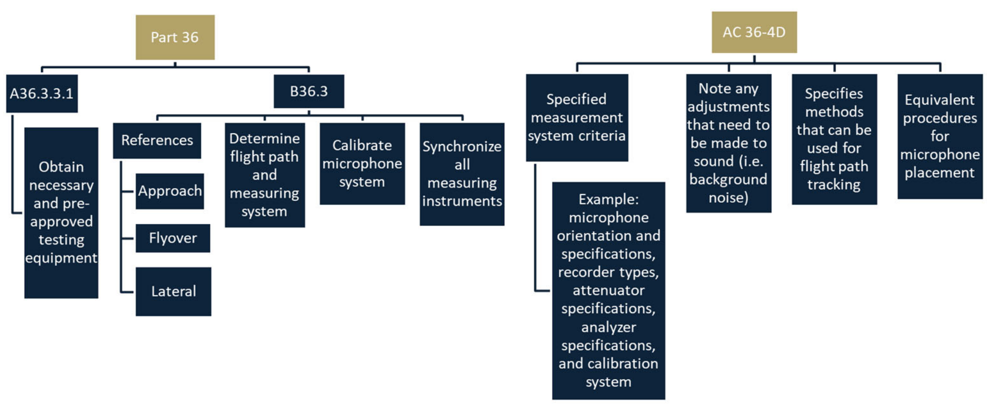

Figure A3. Phase 1: Field setup. AC: advisory circular.

Phase 1: Field Setup

For Phase 1, the field setup procedures prioritize the selection and setup of equipment, calibration, and ensuring that equivalent procedures are fully defined. Figure A3 shows the complete steps of the setup procedure. Testing equipment must be preapproved. Much of the hardware setup involves setting up approach, takeoff, and lateral microphones, which must be calibrated. There are two equivalent procedures that can be used for lateral microphone placement. Flyover and approach reference points remain the same. A flight tracking system must be determined, and all measuring instruments must be synchronized.

Based on Phase 1 benchmarking, the team has identified the following inquiries for industry partners:

- What equipment is used for certification?
- What equipment (if any) could be seen as an opportunity for upgrading or could potentially be replaced by newer technology, but is required for use by the FAA?

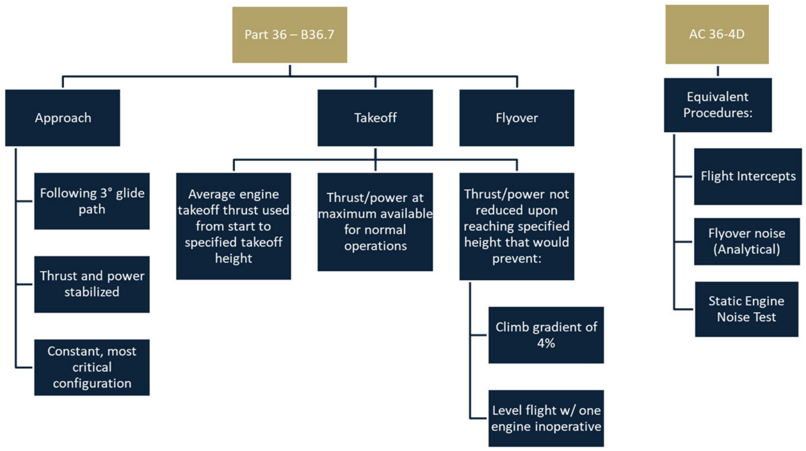

Figure A4. Phase 2: Testing. AC: advisory circular.

Phase 2: Testing

The testing procedures listed in Part 36 and AC 36-4D are outlined in Figure A4. The benchmarking exercise has also identified three equivalent testing procedures: flight intercepts, flyover noise, and static engine noise testing.

In lieu of the full takeoff and/or landing profiles described in A36.9.2.1 and A36.9.2.2 of Part 36, *flight path intercepts* can be used. This procedure eliminates the need for actual takeoffs and landings. Moreover, it leads to significant cost and operational advantages at high gross weight, while substantially reducing the test time required and site selection issues. The shorter test time also provides a high probability of stable meteorological conditions, reduced wear, reduced fuel consumption, and greater consistency in generated data.

Flyover noise levels with thrust (power) reduction may also be established without making measurements during takeoff with full thrust (power) followed by thrust (power) reduction. This can be accomplished by merging tone-corrected perceived noise level (PNLT) versus time measurements obtained during constant power operations.

Last, *static engine noise tests and projections to flight noise levels* (403.a.3) are performed when changes are made to the powerplant or when a similar powerplant is installed. This process is also performed after the initial noise certification of a "datum" airplane. This process provides sufficient additional data or source noise characteristics to allow for predictions regarding the effect of changes on airplane certification noise levels.

In summary of Phase 2, takeoff, flyover, and approach flight tests for noise certification must still be completed. Three types of equivalent procedures are recommended. When applicable, static engine noise tests are used, and flyover noise certification can be completed analytically.

As part of the team's assessment for this phase, the following inquiries were addressed to our industry partners:

- How often are equivalent procedures used instead of procedures specified in appendix A/B?
- How many tests (e.g., approach, takeoff, and flyover) are usually conducted for noise certification?

Phase 3: Analysis

Phase 3 involves the analysis for determining the EPNL. This phase involves the following steps, which are also outlined in detail in Figure A5:

- Find the perceived noise level (PNL(k)).
- Correct for spectral irregularities.

- Determine the duration correction.
- Determine the EPNL.

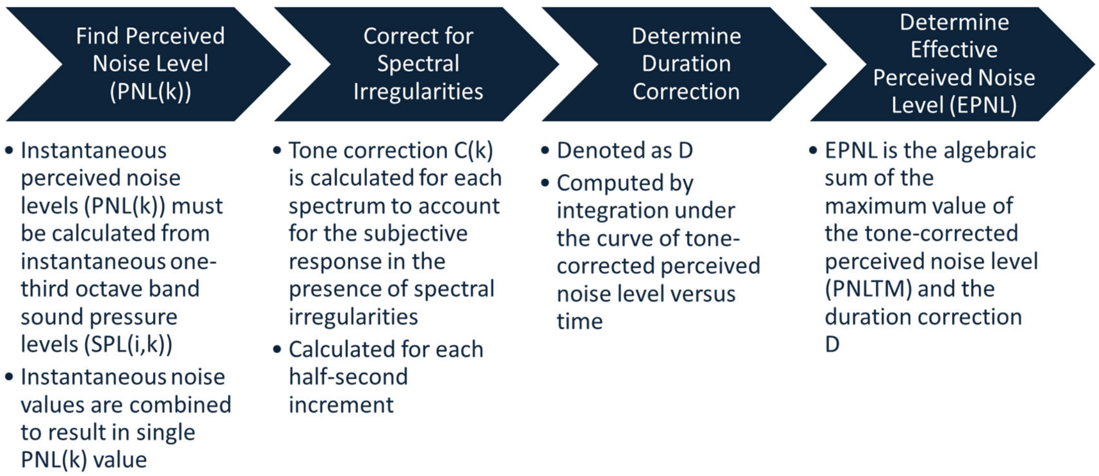

Figure A5. Phase 3: Analysis steps for calculating EPNL.

EPNdB (effective perceived noise in decibels) is a measure of human annoyance to aircraft noise, which has unique spectral characteristics and sound persistence. The EPNL (measured in EPNdB) consists of the instantaneous PNL corrected for spectral irregularities (tone correction factor) and for duration.

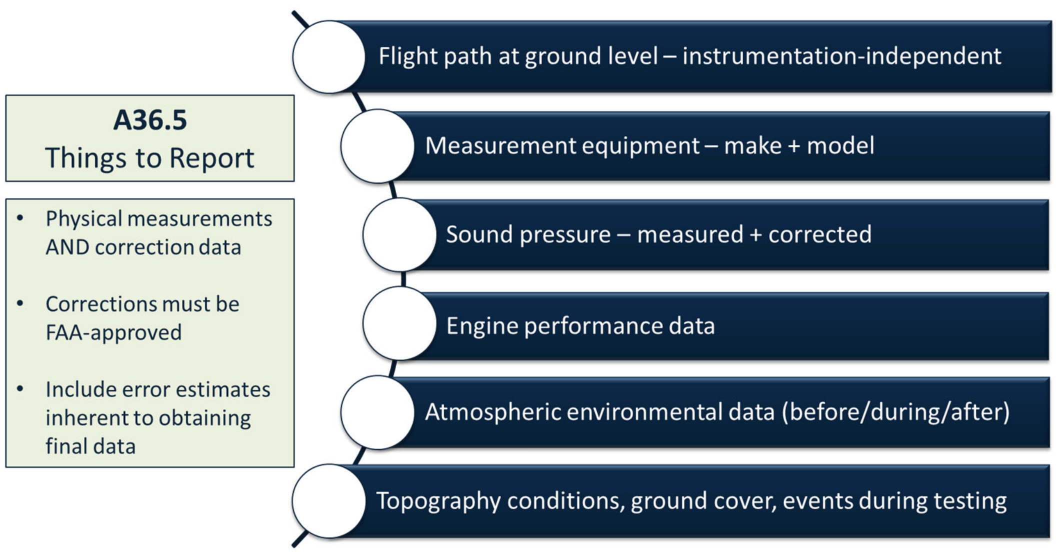

Figure A6. Phase 4: Reporting.

Phase 4: Reporting

In this phase, the goal is to ensure that the correct types of data to be recorded during analysis are selected and meet the given FAA requirements, e.g., inclusion of error estimates. This step also determines what materials must be reported for FAA inspection and approval, ranging from test data and adjustments to noise recordings and instrument calibrations. The reporting requirements based on current regulations are summarized in Figure A6.

Appendix B - Workshop Planning and Findings for the Transport Category

Task 1.1
Starting with Task 1.1, the main action pursued by the team was to review and document current noise certification procedures. The task objective is to gain an understanding of the current regulatory framework for aircraft noise certification, as required by FAA regulations and followed by OEMs to demonstrate compliance. In particular, the team conducted a thorough literature review of relevant 14 CFR parts (mainly Part 36) and associated documents where relevant (e.g., ACs such as AC 36-4D). With recommendations from the team's partners, other documentation from the EASA, the ICAO Environmental Technical Manual, and the VOLPE website were also considered.

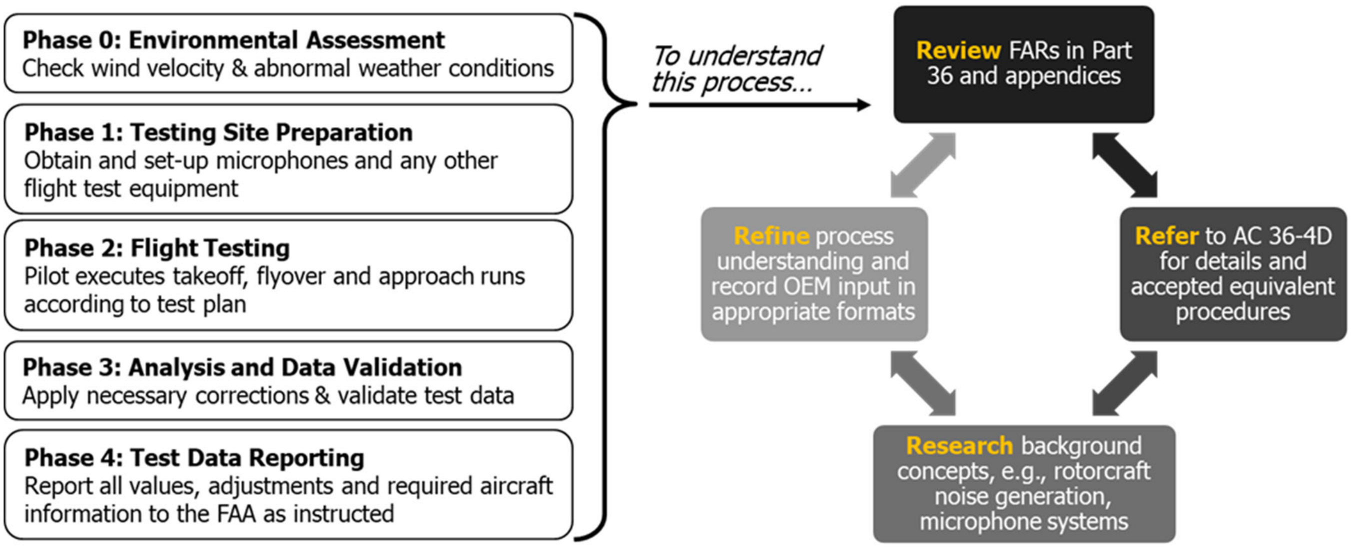

Figure B1. Noise certification regulation review (Task 1.1). AC: advisory circular; FAR: Federal Aviation Regulations; OEM: original equipment manufacturer.

As the full certification process is comprised of multiple processes and standard procedures, which are highly coupled, with recommendations by the FAA and OEM partners, the team focused on the certification flight testing phases in this exercise. Specific to flight testing phases, FARs in Part 36 and Appendix A and B have been reviewed and documented. This review included AC 36-4D for providing details on currently accepted equivalent procedures for the large transport aircraft category.

Along with an extensive review of FARs and literature on the regulatory framework, the team produced a series of views to demonstrate the flow of procedures, associations, and dependencies across regulatory items. Finally, the team obtained background information on noise generation for various aircraft categories, as well as technologies used during testing, to better understand current recommended practices and the potential for alternative equivalent procedures with the use of modern technologies and equipment. One of the benefits of this task is that team members quickly became more knowledgeable of the certification basics in preparation for Task 1.2 (industry interviews) and for building a comprehensive MBSE representation of the current framework in SysML (see Task 2.1). An overview of the methodology behind the review of FARs and literature is provided in Figure B1. Please see Appendix A of this document for a full overview and for the documentation produced under this exercise.

Task 1.2
Task 1.2 aims to enhance the team's understanding of the current noise certification process through interaction with subject matter experts from various OEMs, with the objective of leveraging industry insight into practical aspects of noise certification requirements. This step was performed via virtual workshops, guided by questionnaires compiled by the team based on the reviews completed under Task 1.1. Through insights and findings from documented work under Task 1.1, the team identified topics for which more context and additional insight into ancillary/non-regulatory processes are needed, with regard to how the certification procedure is facilitated by each OEM partner. These topics are shown in Figure B2.

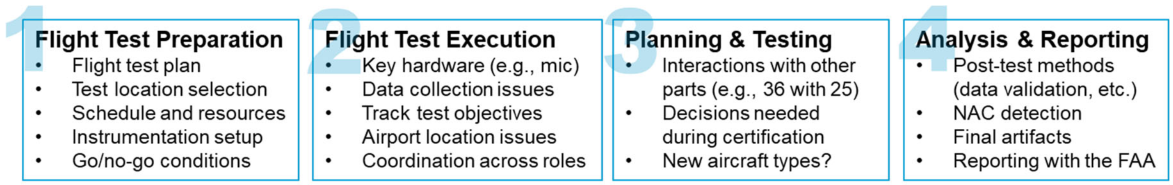

Figure B2. Workshop interview topics for transport category aircraft. NAC: non-acoustical change.

The overarching goal of these workshops is to identify common practices, checkpoints, and milestones across industry partners, while soliciting feedback on key challenges they have identified on their end, as well as what recommendation each partner would provide and why. Such suggestions could convert to opportunities for potential process streamlining, whereas other recommended practices could be out of sync with current technology. The limitation in this exercise is that no recommendations should suggest or presume any change in the regulatory side; hence, the suggestions should be concentrated on equivalent procedures, with either simplified processes or connections to modern technologies, which are still expected to meet the same regulations.

The first workshop was planned by the Georgia Tech team and was held virtually on November 5, 2020. Discussion centered on certification practices for large transport and business jet categories for aircraft, as applied by the team's industry partners (representing airframers such as Boeing, Gulfstream, and Rolls-Royce). With the forum in place and the key connection established, a series of follow-up workshops and interviews was planned, which extended from January 2021 to May 2021. In this expanded outreach, most interviews were planned with one OEM partner at a time, in order to ensure that participants would be more comfortable sharing their thoughts and expertise, without the time constraints of a high-participation event and with more flexibility in scheduling and needed follow-ups. Moreover, the list of participating partners had been expanded to include more OEMs (Embraer, Cessna, De Havilland Canada) beyond those supporting the original workshop of November 2020. VOLPE Center has also participated in shaping the team's knowledge and understanding of the recommended procedures, especially for the flight-testing portion of the process. The final set of participating OEMs who have contributed to the completion of this task is shown in Figure B3.

BOEING	Melvin Kosanchick Jon Larssen Rob Stoker Scott Piercy
BELL	Royce Snider
Rolls-Royce	Jeff Peters
Cessna, A Textron Company	Scott Sanborn William Dolesji
Gulfstream	Brian Cook Troy Downen Matt Nickerson
De Havilland Aircraft of Canada Limited	Eric Herrmann Thineshan Kathirchelvan
EMBRAER	Murilo Pinto Ribeiro Micael Gianini Valle Do Carmo Mario Triches Junior Alysson Kennerly Colaciti Vinicius Losada Gouveia Leandro Guilherme Crenite Simoes
U.S. Department of Transportation Volpe Center	David Read Chris Cutler-Wood

Figure B3. Participating partners (airframe manufacturers, VOLPE) in workshops/interviews under Task 1.2.

To facilitate a directed discussion within the workshops/interviews, the Georgia Tech team formulated questions on the discussion topics listed in Figure B4 and produced questionnaires that were distributed to the participants prior to the respective meetings. A high-level summary of the questions is as follows:

- What is the current guidance provided by the FAA for noise certification?
- How does a company interact with the FAA to ensure that requirements and constraints related to noise regulations are satisfied and that the vehicle is compliant?
- How does the company perform the testing, internal processes, etc.?

- Can you identify procedures within flight testing that should be revised or updated to reflect the capabilities of modern configurations? Are there any opportunities for improvement?
- Are existing certification procedures and methods sufficient to meet future configurations?
- Regarding certification amendments due to type design changes, if a vehicle needs to be recertified after design changes have been made, does your organization's approach change from the first round of certification?

The actual questionnaires are included in Appendix B, in the format in which they were distributed to the workshop participants.

Questionnaire Discussion Topics

- Testing locations, duration and number of tests
- Usage of equivalent procedures
- Certification cost – breakdown, fluctuations, etc.
- Certification time – delays and their impact on various metrics, end to end time taken, etc.
- Certification equipment – weather, microphone, calibration, recording and other systems
- Internal/external communication & collaboration
- Ancillary practices, procedures, contingencies

Categories of Responses	
Cert Plan Coordination w/ NAA	Responses in various levels of detail organized by industry partner: **Boeing, Cessna/Textron, Embraer, Gulfstream, De Havilland**
Flight Test location	
Duration of Flight Test	
Ground Instrumentation/ Provider	
Aircraft Instrumentation /Provider	
Go/No-go conditions (Test limits)	
Go/No-go Conditions (Safety)	
General testing challenges	
Method for QA of test points	
Post test data anlaysis	
Method to Cert Incremental Acoustical Change: ACs or NACs	

Figure B4. Post-processing of collected information and categorization. AC: acoustical change; NAA: national airworthiness authorities; NAC: non-acoustical change; QA: quality assurance.

The initial workshop and follow-up interviews with the participants generated a wealth of information. Planning and a methodological approach are required to post-process this information and to direct it to usable conclusions and insightful findings. One idea was to generate categories, under which the collected material from the questionnaire responses will be sorted and organized. For this purpose, a number of categories have been defined, as shown in Figure B4.

While the level of detail in the answers and feedback obtained varied significantly across the participants, the team was able to summarize the primary themes of the feedback under the defined categories, as shown in **Table** B1. To summarize these findings, the main takeaways from all OEM feedback are the following:

- ACs and NACs are challenging to navigate without standardized approval procedures. More detailed feedback would be useful for OEMs to propose suitable solutions.
- Test site selection is normally restricted by sound measurement technology and requirements (e.g., lateral microphone component) and by weather window options.
- Delays in flight testing are primarily weather-induced and are occasionally due to communication disruptions.
- Conformity discussions can be significantly time/effort-consuming, especially for cases in which there is a need to justify changes that are unrelated to acoustics.
- Interactions between Part 36 and Part 25/23 can be challenging, as there seems to be a discontinuity between environmental and design standards, often leaving little space to apply acoustic improvements.
- There is no single standardized software for calculating EPNL values from noise data collected during flight testing. Each OEM's methodology and code are different.

This lack of standardization appears to be a common area of opportunity for improvements across current noise certification procedures. Within the same context, some participant-recommended value-added outcomes could be explored; not all of these outcomes can necessarily be explored within the current Project 061 SoW, but some could be appropriate use case opportunities for Years 2 and 3 or beyond. Participant-recommended outcomes that could be evaluated through the use of the MBSE-enabled platform for streamlined certification are the following:

- Along with exploring improvements in time and cost, the Project 061 team could explore options to simplify testing and instrumentation setup requirements to facilitate more test locations/weather window options (i.e., which could allow 4-ft microphones to be removed for ground planes and lateral microphones to be removed all together).
- Testing uncertainty could be managed through the evaluation of NAC limits.
- Conformity issues could be addressed through the formulation of a concept that could tested and demonstrated within the MBSE-based verification framework.
- Criteria for approval for acoustical analyses could be defined to establish new certification noise levels (AC by analysis).
- As a longer-term goal, a framework for oversight could be defined to give the FAA confidence in manufacturers' tools/methods used in noise certification (e.g., with pre-defined audit guidelines/procedures).

Table B1. Summary of findings from the transport category workshop and interview feedback. AC: acoustical change; NAC: non-acoustical change.

Subject	Boeing	Cessna/Textron	Embraer	Gulfstream
Test deliverable setting	Not much deliberation	Some deliberation, approved easily	Follow exact regulation protocol	Early FAA involvement for flight planning
Test location	Airport for safety, restricted by lateral mic requirement	Low traffic, stable weather (current site in CA)	Remote location, restricted by season/weather and traffic	Based on acoustic & atmospheric environment (current sites in CA, GA)
Time spent on site	Final checks 1 month out (if new site, 2-year prep)	5-6 hours/day if stable weather	2-hour set up, 5/7-hour testing (10-day window)	1 series in 2 days, 1-hour sunrise setup, 6-day approach
Instrumentation	Highly optimized lab procedures	Consultant: 6 mics (1 central, 2 lateral + backups)	Consultant: approved Volpe list equipment (old	Pole & ground plane mics, daily setup/take-down
Go/ no-go conditions	Borderline test points discussed with Eng. Unit	Mainly weather related	Mainly weather related, occasional aircraft issue	Upper atmosphere weather/ wind issues
General testing challenges	Mainly weather, rarely from equipment or communications	Mainly weather, equipment old but reliable, crucial to maintain comms	Cell phone reliance, can lose comms airport-test site (must stop testing)	Mainly weather
Confirmation of meeting test objectives	Parameters printed to support decision, borderline points	Check raw noise level (test engineer/mic teams), verify GPS, monitor NPD trends	Consultant responsible: get approx. 60-80 test points	Get approx 40 points, sound pressure/exposure for NPD, monitor tolerances on PFD
Post test data anlaysis	3-4 months, flight & engine test combined in NPD to find uncertainties	Data check after test, 1-2 months for report & revisions before FAA (2-3 mth total)	Time consuming in-house analysis, matching results to predictions	
Acoustical Change - ACs or NACs	Game-changer = AC by analysis ; difficult to get FAA approved tools ; high scrutiny on small ACs ; have killed modifications that cause AC>0.3 dB	Game-changer = AC by analysis ; can be 3-6 month response time from FAA with no constructive feedback even with past accepted methods ; Textron proposed FAA procedure library to reduce guesswork	Nightmare to submit AC ; approval discussed with ANEC especially for newer ACs ; lack of common ground & standardisation between NAC reviewers	Tedious ; if performance changes, rely on NPD equivalence to provide basis for compliance plan/report ; if no performance change, do method analysis of noise increment

The exercise under Task 1.2 with identified findings and participant-provided recommendations has successfully established the need for a solution that allows one to explore and formulate a standardized, simplified certification procedure that is flexible to accommodate different types of air vehicles and new technologies. This procedure would require a comprehensive systems engineering process that enables connectivity throughout the certification steps and traceability of regulatory compliance. As model reusability and scalability across different categories are very important, the team has been utilizing MBSE methods to effectively "re-architect" the certification procedures in order to achieve the goals and the desired outcomes that have been identified through the feedback obtained by Task 1.2 activities.

Appendix C - Workshop Interview Questionnaires

Comprehensive Questionnaire (original version for November 2020 workshop)

SUBJECT MATTER EXPERT FEEDBACK REQUEST SHEET
Project 61: Noise Certification Streamlining – FAA ASCENT
Workshop 1 – Transport Category Aircraft
Conducted by the Georgia Institute of Technology

What is the purpose of this study and workshop?
"Noise Certification Streamlining" is Project 61 within the Center of Excellence for Alternative Jet Fuels and Environment (ASCENT), the Federal Aviation Administration Aviation Sustainability Center. The purpose of the project is to examine, and document current noise certification processes as applied by the industry and develop a more streamlined and flexible noise certification process for all applicable air vehicles. As part of this approach, the Project 61 team will seek to identify opportunities for increased efficiency and flexibility in the existing noise certification process, develop revised noise certification processes, and perform quantitative assessments. Lastly, the team will extensively apply Systems Engineering (SE) processes for complex systems, enabled by Model-Based Systems Engineering (MBSE) techniques, to facilitate certification process benchmarking and management of regulatory requirements.

The purpose of this questionnaire Is to acquire Subject Matter Experts' (SME) opinions about the future of noise certification and the related research areas that should be addressed. The Project 61 team is expected to have 5-8 participants.

Who can I contact if I have questions about the study?
If you have questions, comments, or concerns about this study, you can talk to one of the researchers. Please contact
Dr. Jimmy Tai (Email: jimmy.tai@ae.gatech.edu, Phone: (404) 894-0197),
Dr. Evan Harrison (Email: evan.harrison@asdl.gatech.edu, Phone: (706) 401-0976)
Dr. Michael Balchanos (Email: michael.balchanos@asdl.gatech.edu, Phone: (404) 894-9799).

Research Area: Noise Certification Process

Goal: Examine and understand current noise certification procedures and recommend guidelines to the FAA for a more streamlined and flexible noise certification process for all applicable air vehicles

Overview
Noise certification procedures were developed in the 1960s and many parts of the regulations may reference processes and equipment that are obsolete. Consequently, many Original Equipment Manufacturers (OEMs) utilize equivalent procedures and technology not explicitly addressed in the regulations. The objective of this research is to properly document the current noise certification procedures, examine the current process and identify areas of improvement, and develop a streamlined noise certification process for all applicable air vehicles. To perform the proposed research, Georgia Tech has teamed with several industrial partners with extensive experience in noise certification, across different classes of vehicles, ranging from large subsonic transports to business jets to rotorcraft.

The main focus for Workshop 1 will be transport category aircraft.

At present, the research team at Georgia Tech are members of two FAA Centers of Excellence: The Partnership to Enhance General Aviation Safety, Accessibility and Sustainability (PEGASAS) and the Aviation Sustainability Center (ASCENT). Through its participation in these centers, Georgia Tech has demonstrated its ability to collaborate with industry and the FAA to study various safety and certification problems and provide key understanding and insight.

Disruptors

Disruptors are defined as novel technologies or concepts of operation that are likely to disrupt the current paradigm. Based on previous benchmarking exercises and SME feedback, we have identified the following potential disruptors relevant to the current research area:

- Application of traditional Systems Engineering (SE) processes for complex systems, Model-based Systems Engineering (MBSE), and utilization these methods for the management of regulatory requirements
- Digital documentation of the noise certification process
- Modeling methods for simulating current certification process and simulation-based experimentation for testing improved and streamlined process alternatives

Are there any other disruptors or scenarios that you would include in this list?

Description of current certification practices

Noise Certification regulations contained in Title 14 of the Code of Federal Regulations Part 36 (14 CFR Part 36). Title 14 includes most of the regulations specifying the FAA's charter and regulations. Part C of Title 14 contains aircraft regulations, divided into Parts numbered 21-49 (Parts 50-59 reserved). These are the following:

- Part 21 – Certification Procedures
- Part 23-31 – Airworthiness standards for aircraft
- Part 33-35 – Airworthiness standards for aircraft engines
- Part 36–- Noise Standards
- Part 39 – Airworthiness Directives
- Part 43 – Maintenance
- Part 45 – ID and Registration Marking
- Part 47 – Aircraft Registration
- Part 48 – Registration and Marking for Small Unmanned Aircraft
- Part 49 – Recording of Aircraft Titles and Security Documents

Benchmarking of current certification practices will be driven by Part 21 (Certification Procedures) and Part 36 (Noise Standards). Please note that this list of regulatory practices is derived from the FAA methods and standards alone. They are a sub-set of the original ICAO standards. It is acknowledged that other NAAs such as EASA may have practices that may vary from FAA requirements.

What questions must be answered to describe the overall process for current noise certification practices adopted by the industry?

Q1. What is the current guidance provided by the FAA for noise certification?
  - **a.** Who is currently responsible for overseeing existing noise certification procedures?

Q2. How does a company interact with the FAA to ensure that requirements for noise are satisfied and that the vehicle is compliant?
  - **a.** How will these requirements change for different vehicles?
  - **b.** What does a nominal testing timeline look like?
  - **c.** What type of certification phases are taking place?
  - **d.** What kinds of delay factors exist? How do they affect the timeline?
  - **e.** What happens if you fail a noise certification demonstration?
  - **f.** Does your company factor in potential noise certification failures?

Q3. How does the company perform the testing, internal processes, etc.?
  - **a.** What technologies and methods are standard in support of the certification process?
  - **b.** How is data being collected, managed, and facilitated?
  - **c.** How is storage of the data handled?
  - **d.** How are the instruments calibrated? Under what schedule?

- **e.** What is the process for acquiring and operating the right hardware?
- **f.** How do companies decide upon the testing conditions (e.g., weather, seasonality effects, location, etc.)?

Q4. Can you identify regulations that are obsolete and should be eliminated, as well as any opportunities for improvement?
- **a.** Can you provide an example?

Q5. Are existing certification procedures and methods sufficient to meet future configurations?
- **a.** Can you provide an example as it relates to transport category aircraft?
- **b.** If not, what improvements must be made and how soon should these changes be implemented?
- **c.** Has your organization already faced any challenges to certify newer designs with the existing certification framework? If so, what aspect of the regulations were the challenges faced in?

Q6. Certification Amendments Due to Type Design Changes – If a vehicle needs to be recertified after making design changes, does your organization's approach change from the 1st round of certification?
- **a.** Does it take almost as much time/effort as the first time, or significantly less? If the former, why do you think there is no gain in time efficiency?
- **b.** If your organization created any models/interpretations of the original regulations (to understand them better), are these used for certification amendments due to type design changes or do you return to the full collection of original documents?
- **c.** Are there any instances where a type design change may require a full noise certification test?

Topic 1: Benchmarking of current practices: Transport Category Aircraft

Goal: Benchmark, evaluate and identify inefficiencies in current noise certification procedures for Transport Category Aircraft noise and provide recommendations to the FAA on streamlining certification practices.

General

Q1.1 How many tests (e.g. Approach, Takeoff, and Flyover) do you usually conduct for noise certification?
- **a.** Are tests completed in a single day or must they be completed over multiple days?

Q1.2 Do you use an airport for testing or elsewhere?
- **a.** If elsewhere, where do you complete the certification procedures?
- **b.** How hard is it to get FAA approval to conduct the test at another location besides an airport?
- **c.** If your organization has multiple certification sites, do you see a difference between them (e.g. in number of trials needed to successfully certify)?

Q1.3 How often are equivalent procedures used instead of the procedures specified in appendix A/B?
- **a.** If you used an equivalent procedure, which procedure are you using?
- **b.** What is the main reason for using the specified equivalent procedure?
- **c.** Do you see a need to use more equivalent procedures for newly developed vehicles rather than the established versions that may need re-certification?
- **d.** Are there particular sections where equivalent procedures make more sense to use rather than the originally specified procedures?

Impact Area 1: Certification Cost

Q1.4 What is the relative breakdown of cost associated with noise certification of an aircraft?
- **a.** What percentage of the certification budget is devoted to the relative phases outlined in question 2 in the previous section?

Q1.5 What are areas in noise certification that have fluctuating costs (e.g. fuel)?

- **a.** How often do these cost fluctuations affect noise certification?
- **b.** Can you provide an example where fluctuating costs prevented the noise certification of an aircraft?
- **c.** Is there a specific configuration of aircraft that are more impacted by fluctuating costs? Why is this type of aircraft more impacted?

Impact Area 2: Certification Time

Q1.6 What sort of delays frequently occur in the certification process?

- **a.** What metrics do these delays eventually affect (e.g. revenue loss from delivery delays, unsatisfactory reports from inspectors, post-delivery issues or need to recall)?
- **b.** What role does weather/location of your facilities play in delays (if any)?

Q1.7 How much time is spent completing the certification procedure for large transport category aircraft? (e.g. hours, days, weeks, etc.)

- **a.** Are there particular sections of certification that take longer than others?

Q1.8 Where do you see an area to minimize the time taken to complete the certification process?

Q1.9 How many times a year are you conducting noise certifications?

Impact Area 3: Certification Equipment

Q1.10 What equipment does your team use for certification?

- **a.** What meteorological system is used?
- **b.** What microphones are used?
- **c.** What recording and reproducing equipment is used?
- **d.** What calibration systems are used?

Q1.11 What equipment (if any) do you see as "out of date" but are required to use by the FAA?

Q1.12 Is there a piece of equipment that you prefer to use over the specified equipment in appendix A/B?

- **a.** How long does it take for an equipment approval by the FAA?

Critical Milestones & Task Outputs

Q1.13 What process (if any) do you use to "translate" the appendix materials into requirements that are easy to check off?

Q1.14 How often is there confusion between various departments conducting noise certification?

- **a.** Do you get reports of confusion/misunderstanding from technicians or engineers who are responsible for reading the requirements from the FAA?
- **b.** Is there any confusion with the pilots who are responsible for flying the aircraft during testing?

Summary & Outcomes

Q1.15 Is there anything that is not directly specified in advisory circulations or in the FAA regulations, that is important to know when conducting transport category certification?

Topic 2: Ancillary Practices, Procedures, and Contingencies

Goal: Please describe ancillary practice or procedures that may be required to support the certification effort but do not directly demonstrate compliance to the regulations. Do these practices shorten, lengthen, or provide economic benefit to the applicant? Also, do these practices support contingency efforts if initial efforts to demonstrate compliance are not achieved?

Description

Q2.1 Has there ever been a project that was canceled because there was not a way to noise certify it with the FAA?

- **a.** If so, why couldn't it be noise certified?
- **b.** Did you seek FAA approval to certify the aircraft?

Q2.2 Are there any non-regulatory procedures (e.g., anything recorded and procedural that is not required by the FAA regulations) that your team uses to certify your aircraft?

- **a.** If so, please explain the procedure(s) in as much detail as possible.
- **b.** Do you believe your procedures are more efficient?
    - i. If so, please explain why.
    - ii. If not, please explain the motivation for using the prescribed procedures.

Deviations from Certification Requirements of Part 36:

Q2.3 What, if any, are common alternative procedures for Part 36 noise certification? For each alternative procedure, please answer each of the parts separately.

- **a.** What is the reason for the change?
- **b.** What are the potential benefits of this change from the as written standard?
- **c.** What is the process of documentation for the change?

Summary & Outcomes

Q2.4 Summary of the required outcomes for this topic area. How do the tasks from the research fill the gap described before?

<u>Simplified Questionnaire (Used on January 2021 and after)</u>

<u>Topics of discussion</u>:

- Flight Test Preparation
    - Negotiation process of Flight Test objectives (with FAA)
    - Is access to a Flight Test Plan document and/or Sample Test Card for a noise measurement test possible?
    - Selection of testing location (e.g., airport, and why?)
    - Up-front preparation steps
    - Detail of typical schedule (typical number of allotted days/hours & FTEs)
    - Set up of DAS/DAU and key instruments.
    - Go/No-go conditions
- Test Execution
    - Details of key hardware set up.
        - Microphone type selection, location.
        - Specifically, about how information is relayed.
    - General challenges during data collection
        - Physical barrier (weather, environment, etc.)
        - Common instrument issues
        - Key points of difficulty (specific data type, communication amongst teams, etc.)
    - How do the test engineers confirm test objectives were met during test?
    - Challenges of airport testing
    - Sensitivities of airport/testing site location? (e.g., data quality issues… trees, snow, freezing temperatures, moisture from humidity/rain/etc.?)
    - Coordination between roles (test pilot, ATC, ground crew, test engineers, etc.)

- Miscellaneous in planning and testing
  - [Comment from Workshop 1]: "The 'decision process for Part 36 is not as 'easy to set up' as some of the other parts. Also, Part 36 does not 'interact very well' with the other parts, e.g., 25."
    - What decisions need to be made at different points in the certification process?
    - What does your decision process look like, is it more difficult for new aircraft?
- Analysis & Reporting
  - Discuss general post-test analysis method(s).
    - How to match predicted versus actual for verification.
    - Effort length and duration
  - Discussion of final artifact from flight test
  - How is the data stored with the FAA (report/database/etc.)?
  - Analysis Methods for small items: Determination of NAC
    - Is AC 36-4D the sole source of guidance and methods for small changes?
    - What tools / methods might make NAC determinations simpler?
    - Would analysis methods that allowed cumulative changes greater than 0.30 db be beneficial? (i.e., reduced flight demonstrations)

Appendix D - Implementation of the Verification Model

In the following, we present a brief overview of how each module has been implemented and how the integration development spiral was pursued. The integration process followed the steps shown in Figure D1.

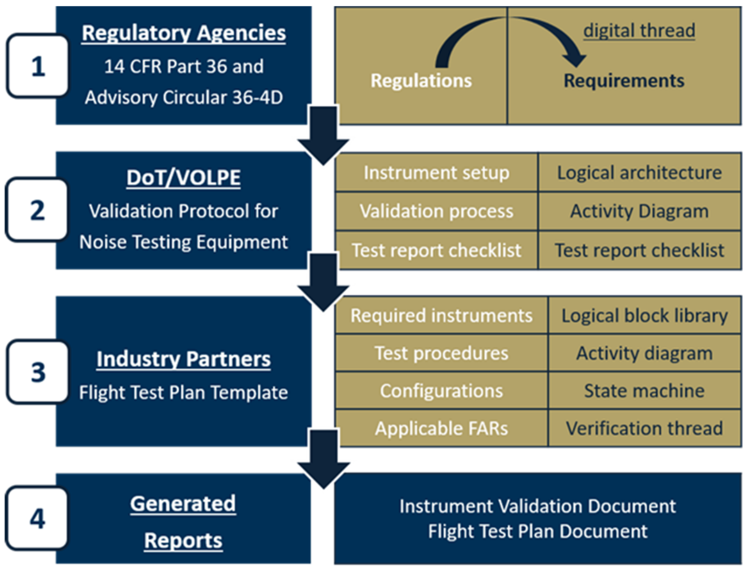

Figure D1. Verification model integration steps. CFR: Code of Federal Regulations; DoT: Department of Transportation; FAR: Federal Aviation Regulations.

Step 1 includes the conversion of regulations to requirements. In this context, a requirement normally represents a single design constraint, extracted from one or more regulations. A method of verification is required in order for this design constraint to be satisfied by the SUT. To provide this verification step, a constraint block is introduced as a verification mechanism by integrating engineering analysis into a model. In particular, with the use of a constraint block, it is possible to quantify the textual requirement using mathematical and logical expressions only, while verification simulations, which can determine whether a certain metric meets a requirement, can be enabled. Overall, the constraint block acts as an interface that links a requirement model and the logical/physical model of an SUT. Figure D2 presents an example of how a regulatory article can be imported as a requirement, linked to the verification model, and tested.

A36.3.7.4 When slow time averaging is performed in the analyzer, the response of the one-third octave band analysis system to a sudden onset or interruption of a constant sinusoidal signal at the respective one-third octave nominal mid-band frequency, must be measured at sampling instants 0.5, 1, 1.5 and 2 seconds(s) after the onset and 0.5 and 1s after interruption. The rising response must be −4 ±1 dB at 0.5s, −1.75 ±0.75 dB at 1s, −1 ±0.5 dB at 1.5s and −0.5 ±0.5 dB at 2s relative to the steady-state level. The falling response must be such that the sum of the output signal levels, relative to the initial steady-state level, and the corresponding rising response reading is −6.5 ±1 dB, at both 0.5 and 1s. At subsequent times the sum of the rising and falling responses must be −7.5 dB or less. This equates to an exponential averaging process (slow time-weighting) with a nominal 1s time constant (*i.e.,* 2s averaging time).

ID: Name	Requirement Text	Owned By	Traced To	Satisfied By
40: Sudden Onset Response Sampling Instants	The analysis system shall have a response (to the sudden onset of a constant sinusoidal signal) that is measured at sampling instants 0.5, 1, 1.5 and 2 seconds after the onset.	Measurement System Requirements	A36.3.3.1, 1D A36.3.7.1 A36.3.7.4	Sound pressure level response (Analysis System: Value Property)
41: Interruption Response Sampling Instants	The analysis system shall have a response (to the sudden interruption of a constant sinusoidal signal) that is measured at sampling instants 0.5 and 1 second after the onset	Same as ID 40	Same as ID 40	Same as ID 40
42: Rising Response Limits	The analysis system shall have a rising response that conforms to these dB values at each sampling instant (relative to the steady-state level): −4 ±1 dB at 0.5s, −1.75 ±0.75 dB at 1s, −1 ±0.5 dB at 1.5s and −0.5 ±0.5 dB at 2s.	Same as ID 40	Same as ID 40	Same as ID 40
43: Falling Response Limits	The analysis system shall have a falling response such that the sum of the output signal levels is −6.5 ±1 dB, at both 0.5 and 1s (relative to the initial steady-state level, and to the corresponding rising response)	Same as ID 40	Same as ID 40	Same as ID 40
44: Sum of Rising and Falling Response	The analysis system shall have a sum of rising and falling responses less than or equal to -7.5dB (at subsequent times).	Same as ID 40	Same as ID 40	Same as ID 40

Figure D2. Regulation to requirement: example for design constraint formulation.

Step 2 seeks to implement the validation protocol for noise testing (as dictated by VOLPE's guidance) in a logical model. This step returns the representation of the physical noise instrument architecture as a SysML logical model. The architecture description is achieved by using "blocks," essentially describing a system by reusable, modular units. These blocks contain structural and behavioral features that define relationships between parts via connectors. An example of a block, representing the microphone type used during flight testing, is shown in Figure D3. Each block is functionally verified by constraints (highlighted in blue), contains a hierarchy to define parts (highlighted in orange), and holds defined values as value properties (highlighted in green).

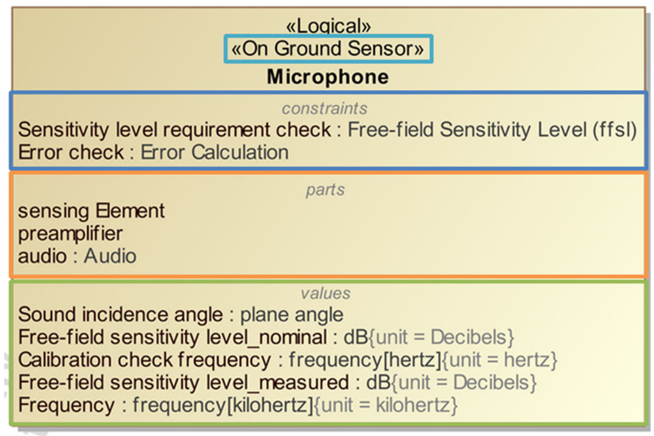

Figure D3. Example of a logical block, representing physical microphone technology.

The instrumentation architecture is further characterized by the types of sensors used, e.g., two types of sensors: <<On Ground Sensor>> (namely the microphone, as represented by the logical block in Figure D3) and <<On A/C Sensor>>. An example of a SysML logical representation of a microphone and hardware setup as part of the VOLPE validation protocol is shown in Figure D4.

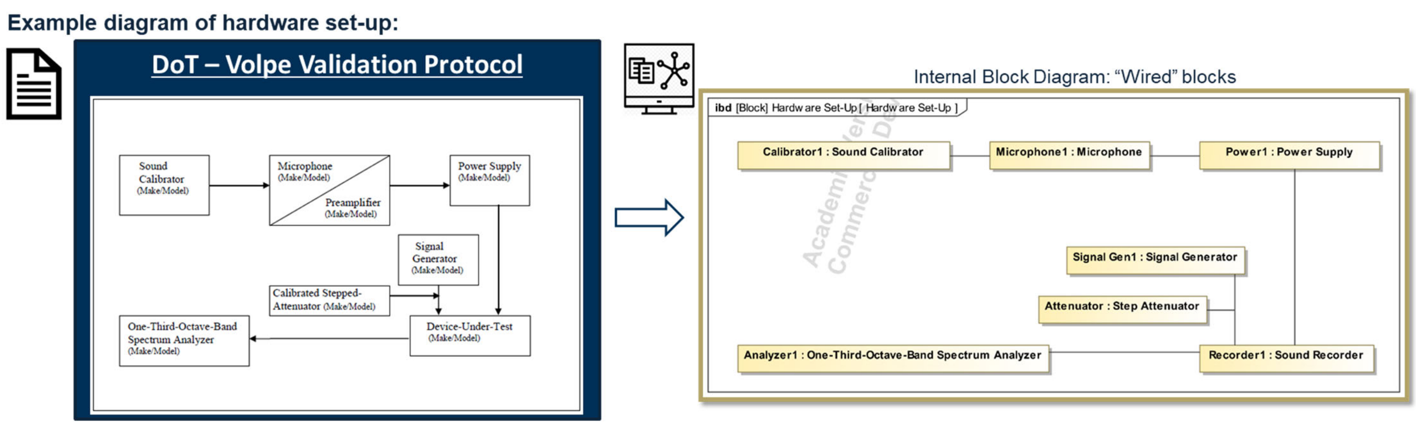

Figure C4. Example diagram of hardware setup. DoT: Department of Transportation.

The complete logical architecture representation in a SysML environment provides a unified model for all system elements (single source of truth), full transparency, and shared understanding of the system. This model is an extensible representation of the system and its components with their properties, with a clear definition of interfaces between architectural elements. This architecture is described hierarchically, with the system decomposition level being dictated by the requirements. As more architectural elements are progressively included, the model can be easily updated accordingly. An example of a complete logical hierarchical architecture is shown in Figure D5.

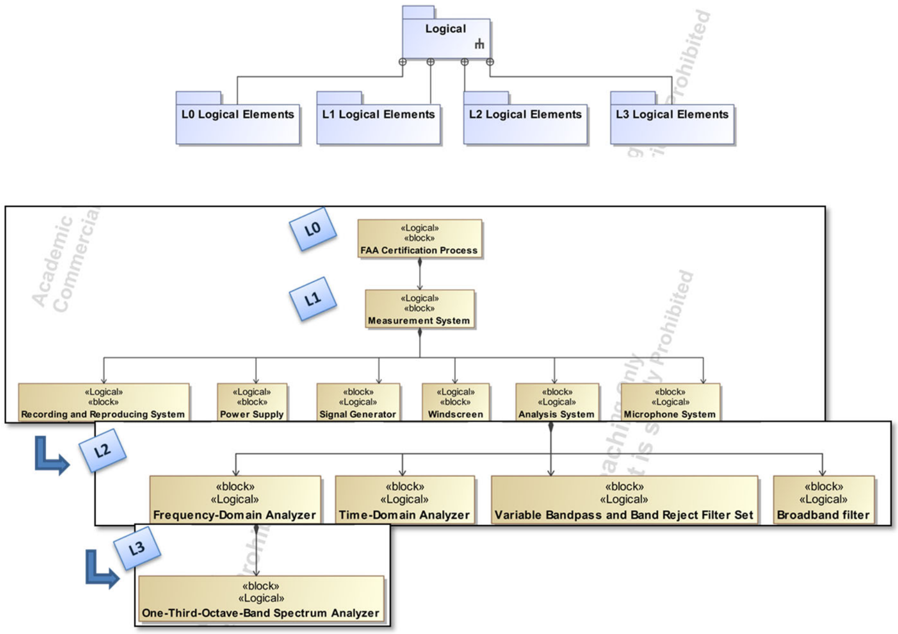

Figure D5. Logical architecture for the verification model.

The parametric construct allows for the logical architecture to be executable through simulations, which is key for performing requirement verification. This construct includes improved traceability among requirements, architecture, and verification information. The stored information in relevant blocks is used for requirement verification, with the quantitative characteristics defined as value properties for each block. This step requires validation/measurement data for an SUT, in order to create instances within the model for data representation. The requirement verification is performed by executing the logical architecture, using the Cameo Simulation Toolkit. An example of requirement verification for the microphone setup within the logical architecture in SysML is shown in Figure D6.

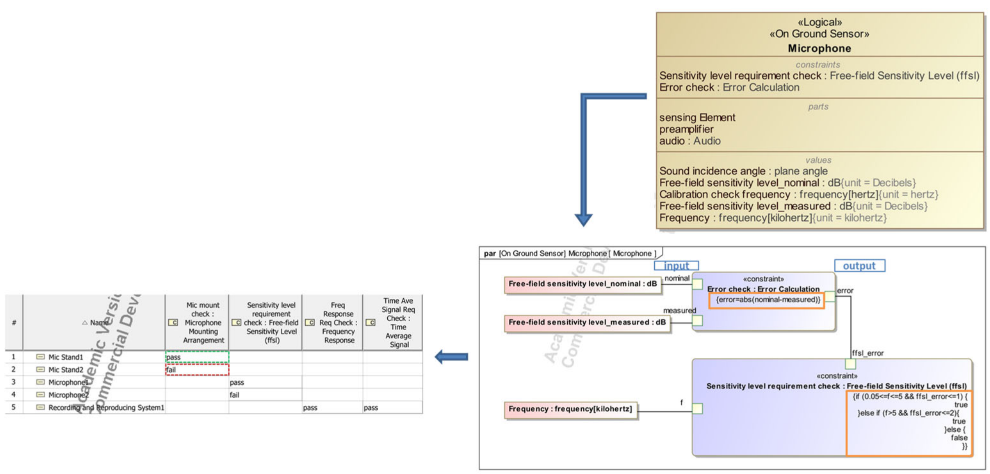

Figure D6. Requirement verification of the logical architecture: an example.

At the current state, the logical architecture model can accommodate the full aircraft noise certification test system, an example physical view, and the corresponding logical architecture implementation shown in Figure D7. The SUT that has been used for verification model development is based on a Boeing 787-8 configuration, and its logical representation in SysML is shown in Figure D8.

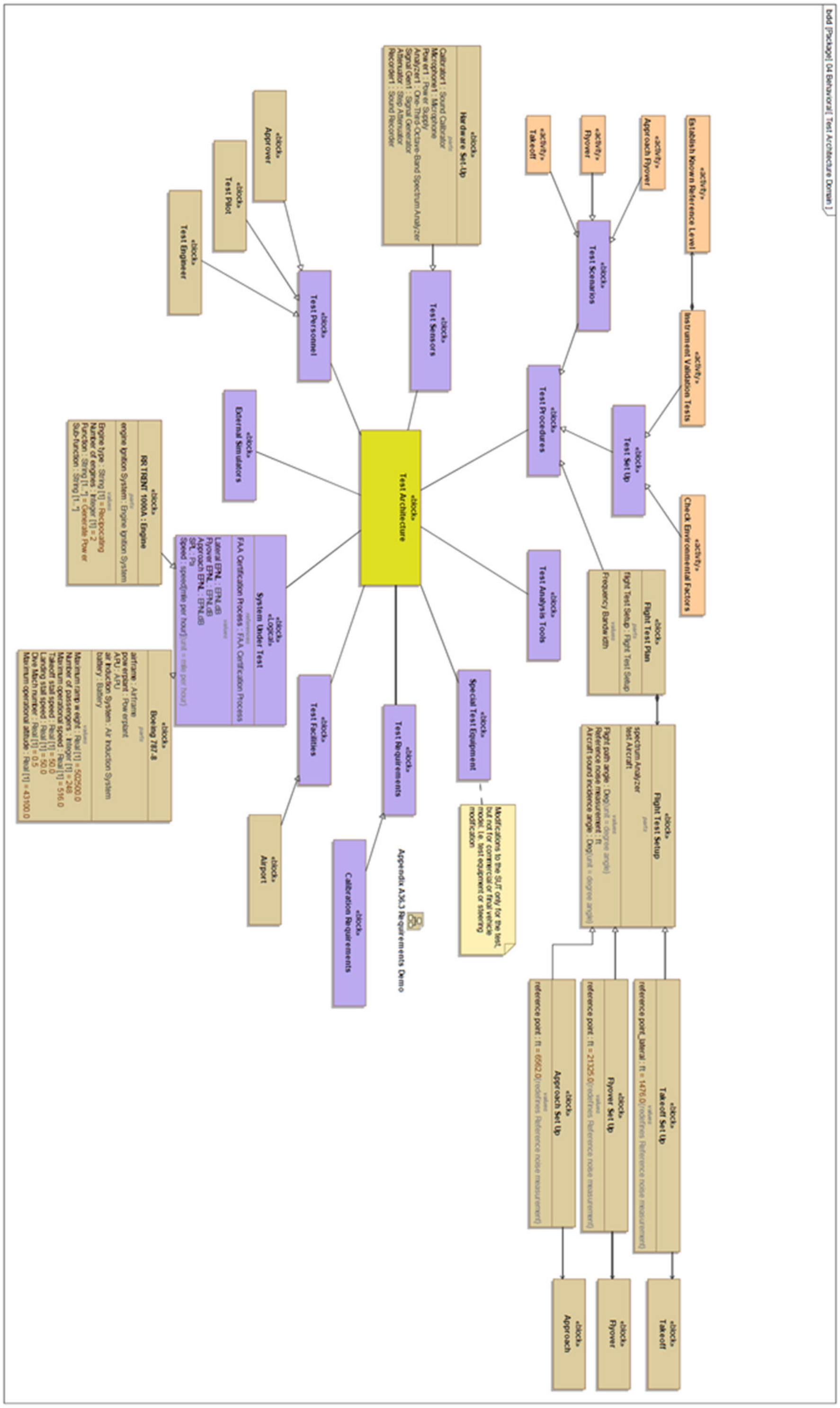

Figure D7. Flight testing architecture domain.

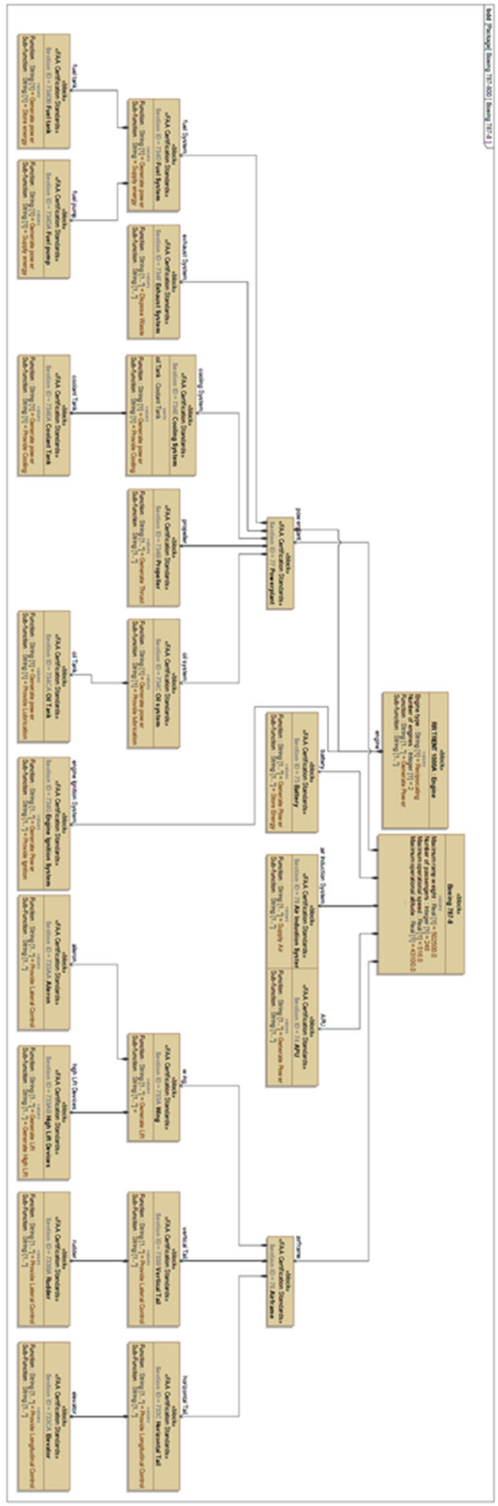

Figure D8. Aircraft model (Boeing 787-8) used as the system under test (SUT).

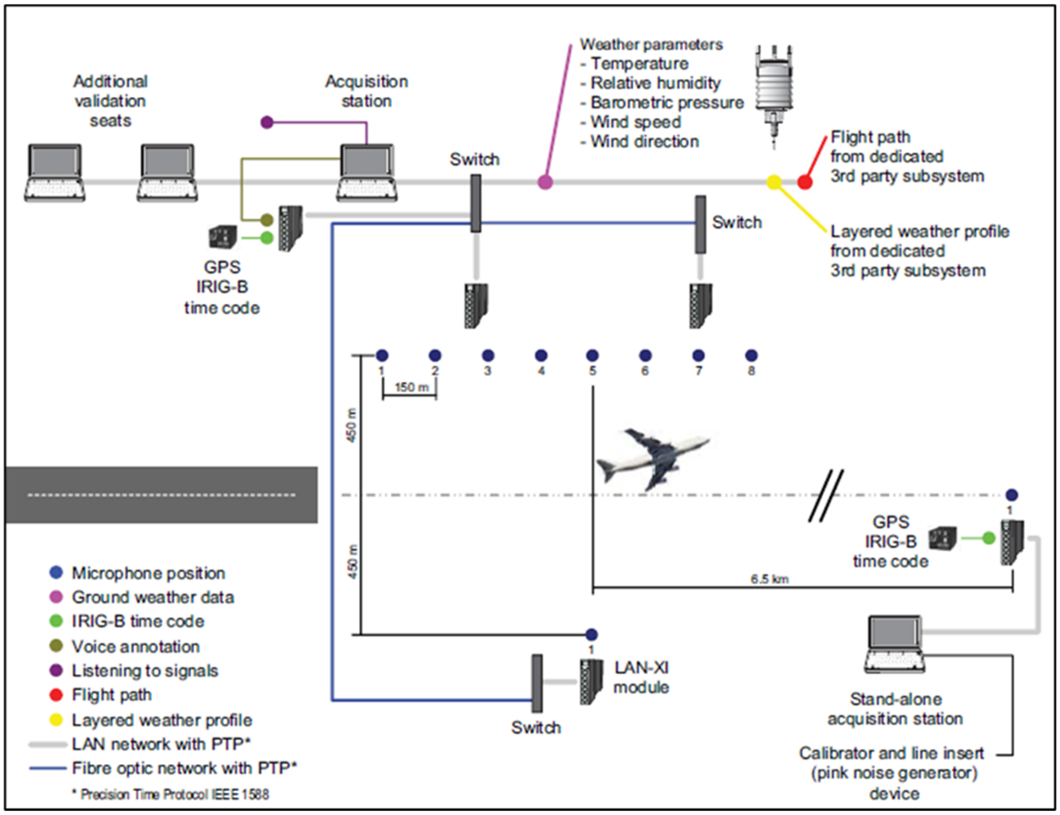

Figure D9. Schematic overview of aircraft noise certification test system by Brüel & Kjær. GPS: Global Positioning System; IRIG: Inter-Range Instrumentation Group; LAN: Local Area Network; PTP: Precision Time Protocol.

Step 3 of the verification model implementation process involves the representation of the flight test procedures as behavioral models. As test procedures are written in text (bullet points, numbered lists, etc.), functions performed by the system and the external system interfaces are not clearly defined. To model the process as behavioral diagrams, it is necessary to define functions allocated to systems and establish functional flows with defined interfaces, as shown in Figure D10.

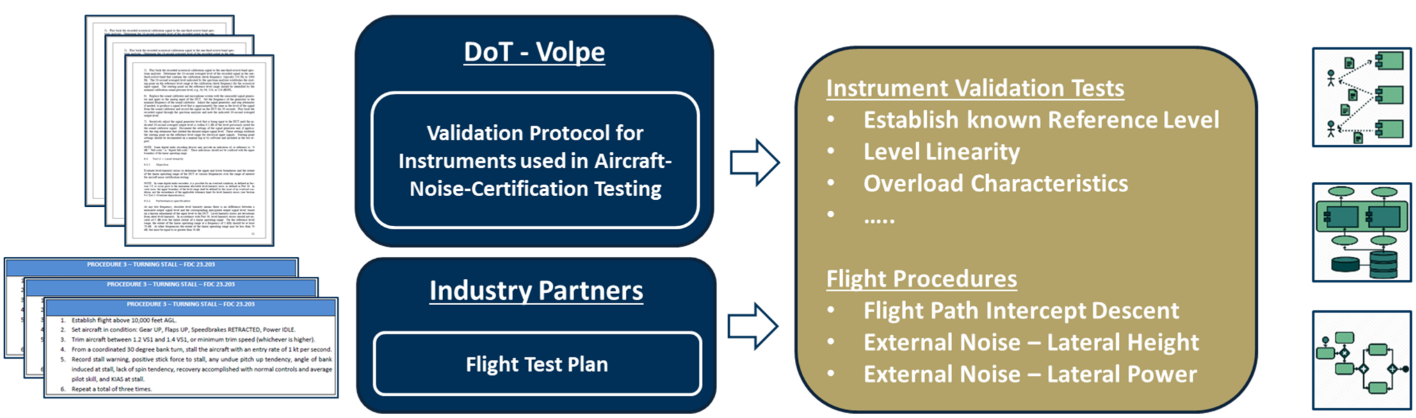

Figure D10. Process for representation of flight test procedures as behavioral models. DoT: Department of Transportation.

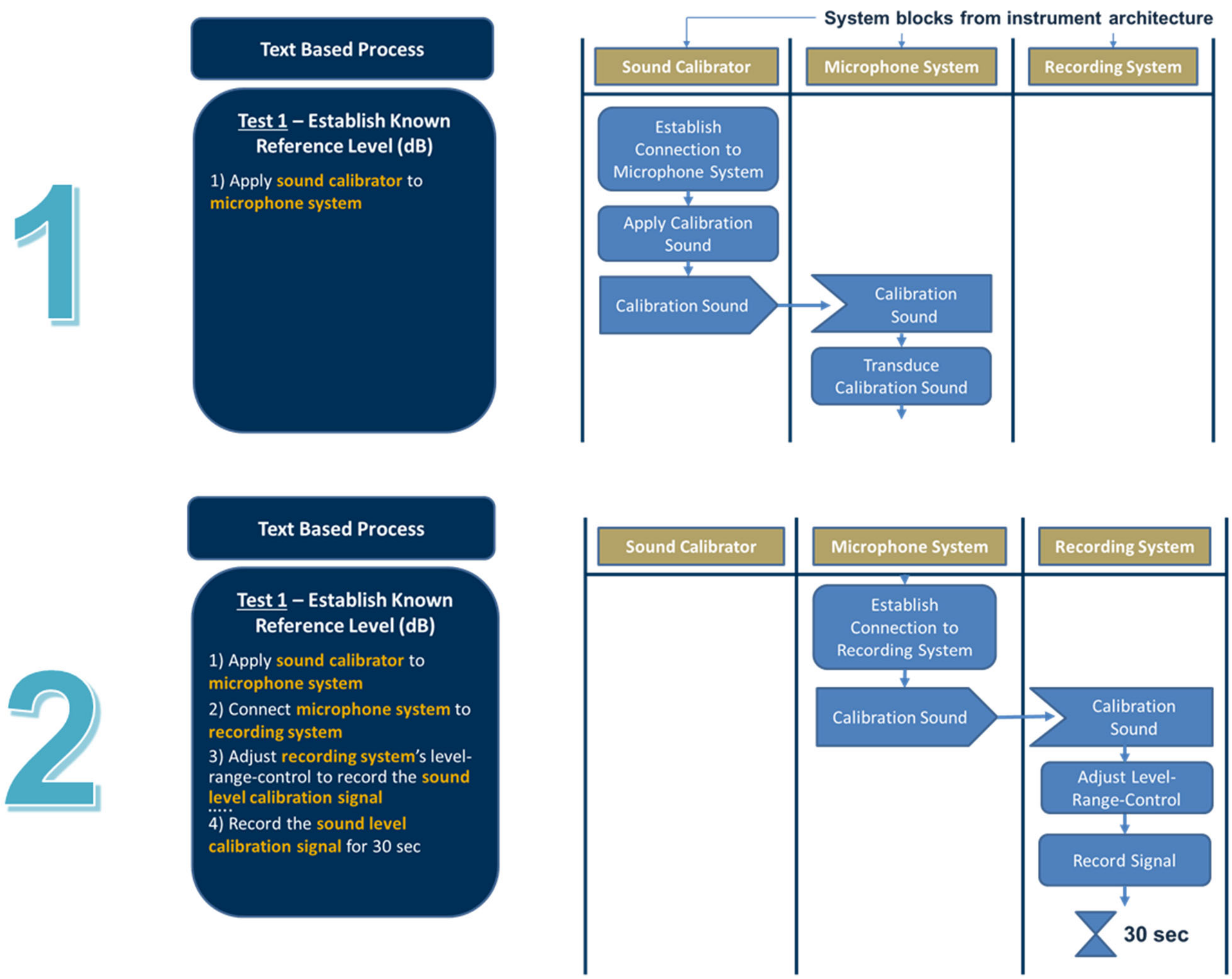

Figure D11. Text-based method for behavioral process model implementation.

To clarify and demonstrate how this process functions in practice, an example is provided in Figure D11. The purpose of the example test function is to establish a known reference noise level (in dB), with steps of the process listed in text format (indicated on the left side of the figure). Starting from phase 1 of the implementation (at the top of the figure), the first process step indicates that 1) a sound calibrator is applied to the microphone system. In the behavioral process model, this step corresponds to the use of three system blocks from the instrument architecture library, namely, the sound calibrator, the microphone system, and the recording system. In terms of process steps, a connection between the sound calibrator and the microphone system must be established, and the calibrator must then supply a calibration sound to the microphone. In the next phase of steps (phase 2 at the bottom part of the figure), there is instruction to 2) connect the microphone system to the recording system, 3) adjust the recording system's level-range control to record the sound level calibration signal, and 4) record the sound level calibration signal for 30 s. These process steps are then populated to the process model on the right side of Figure D11 and mapped accordingly to the system blocks.

Continuing this same implementation path, the completed process mode for establishing a known reference noise level is shown in Figure D12. Following similar steps, behavioral process models in SysML were formulated for the flight-testing phases of interest, which are the 1) approach flyover and 2) takeoff.

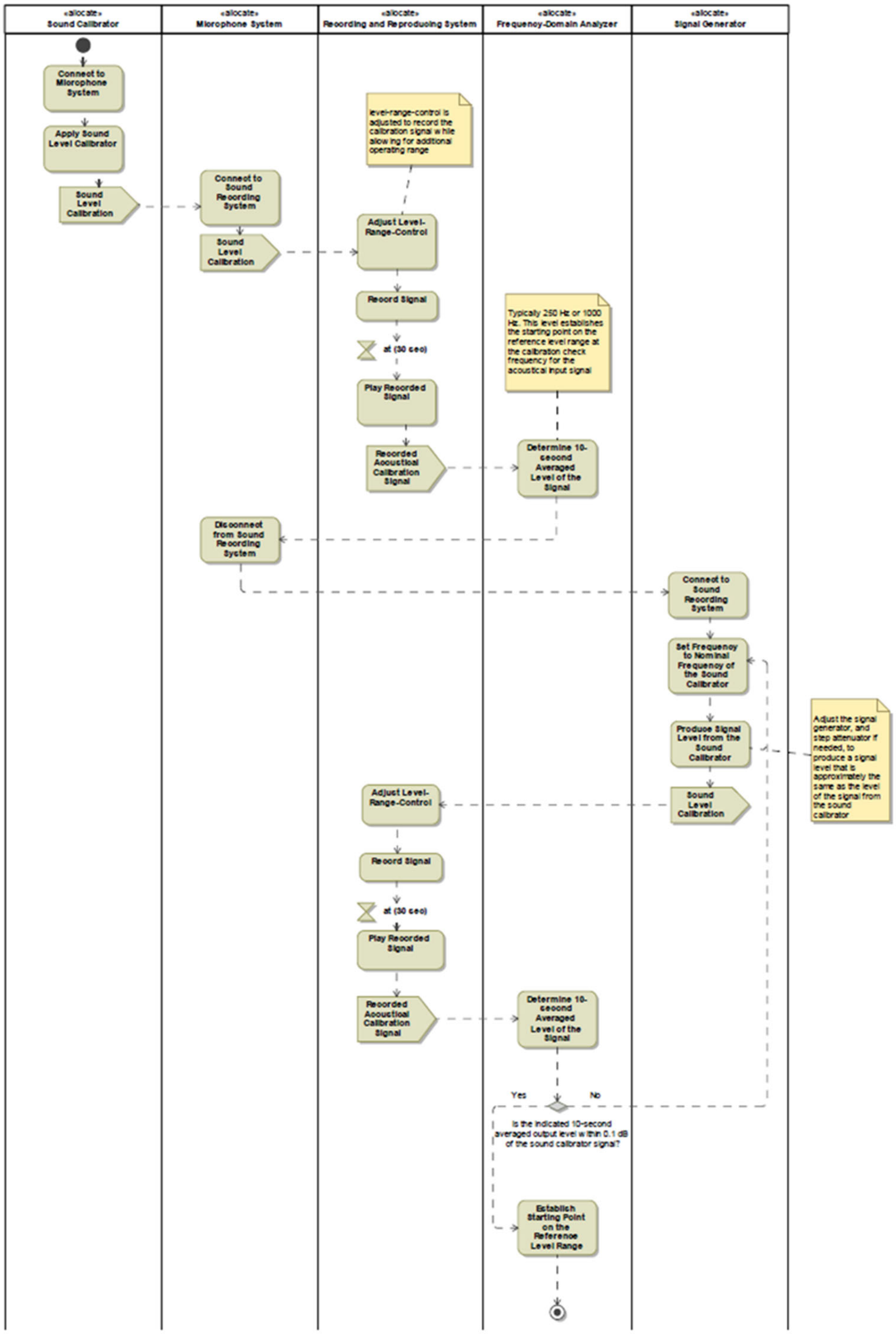

Figure D12. Process model for establishing a known reference noise level (baseline noise definition process).

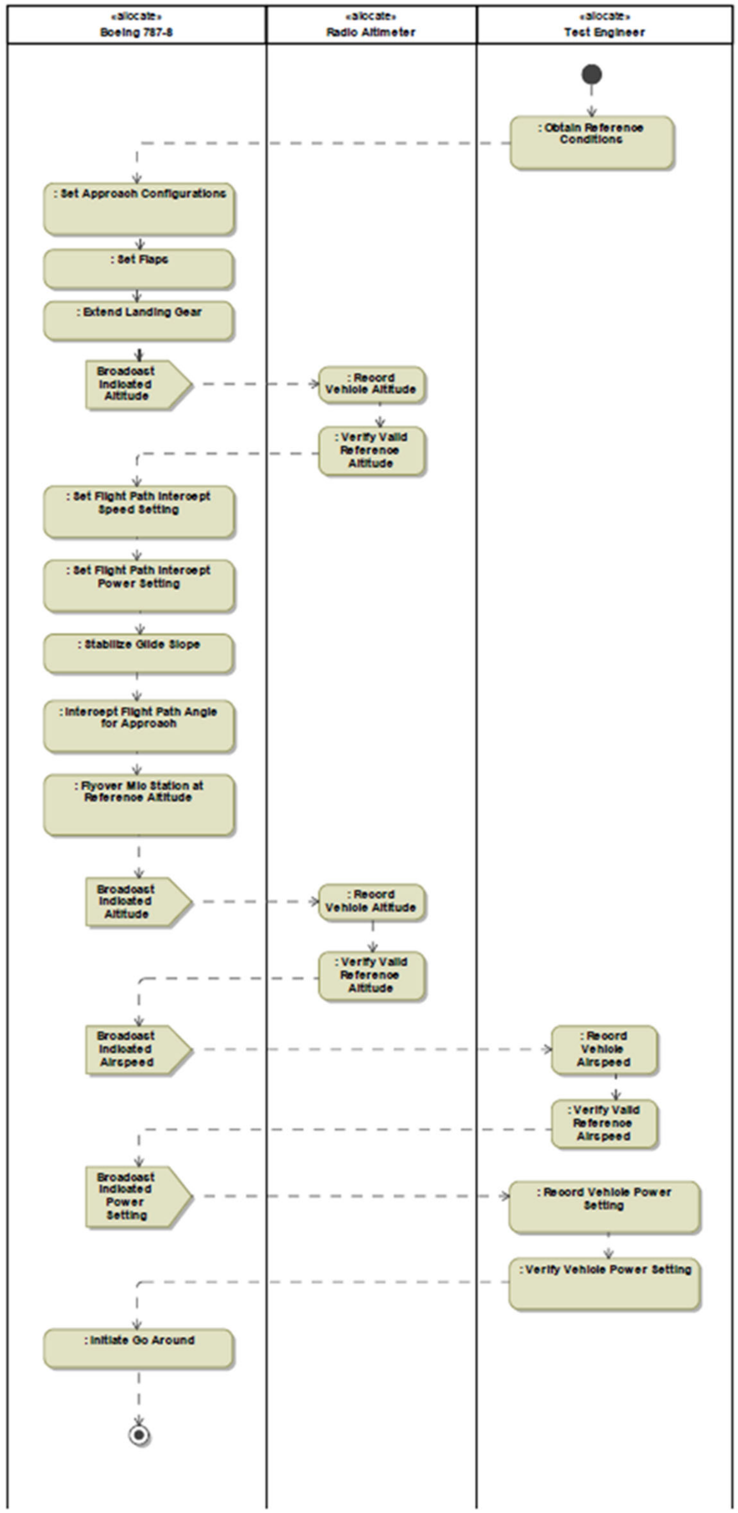

Figure D13. Behavioral process model for approach flyover.

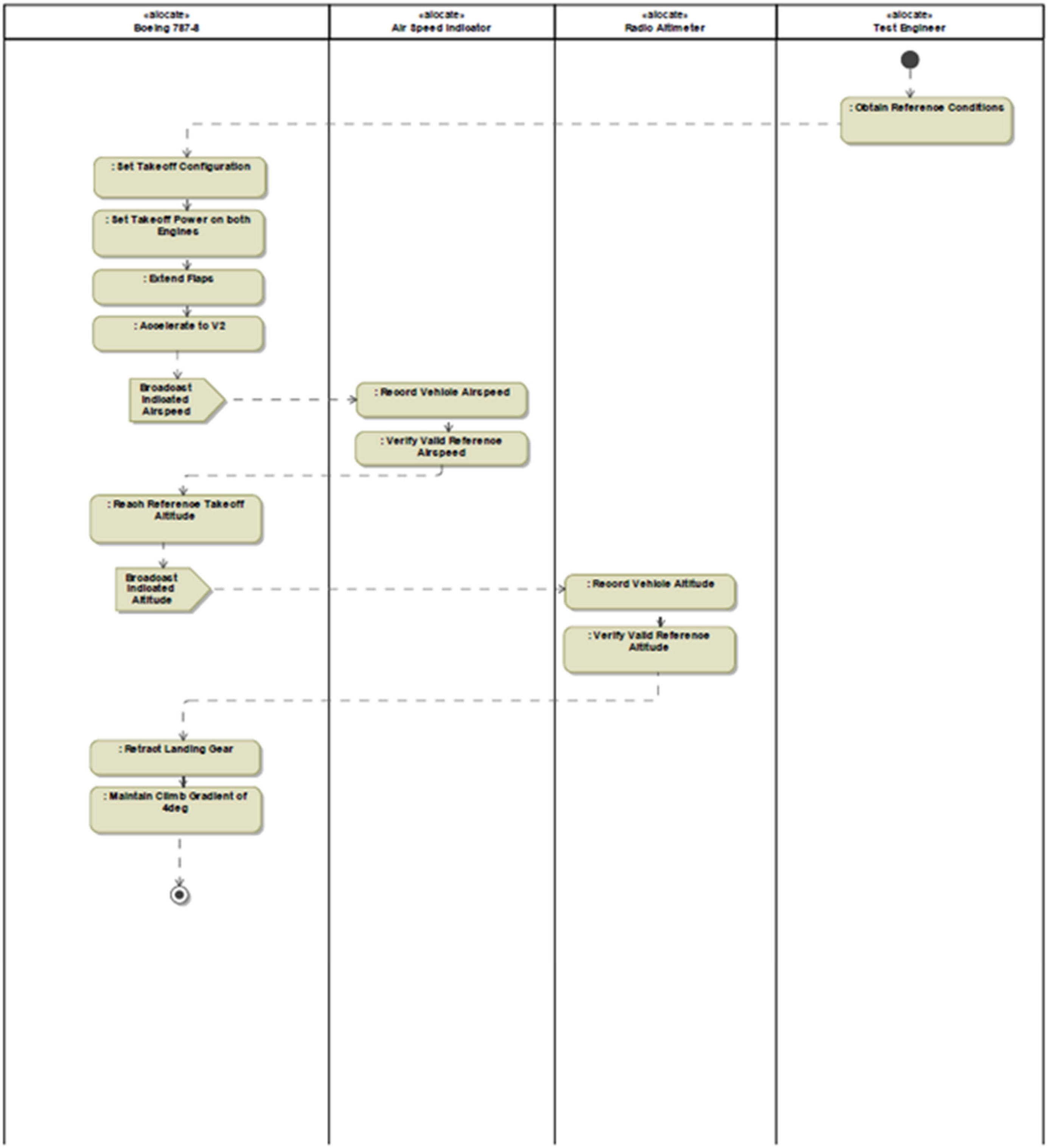

Figure D14. Behavioral process model for takeoff.

Step 4, the final integration step for the verification model, is the automated document generation. A suite of reports is generated through this function, including the following documents:

- Product specifications
- Technical baseline
- Metrics
- Verification compliance

The produced reports also include the following documents for certification:

- Instrumentation validation document
- Flight test plan