Project 061 Noise Certification Streamlining

Georgia Institute of Technology

Project Lead Investigator

Professor Dimitri N. Mavris (PI)
Director, Aerospace Systems Design Laboratory
School of Aerospace Engineering
Georgia Institute of Technology
(404) 894-1557
dimitri.mavris@ae.gatech.edu

Dr. Jimmy Tai (co-PI)
Division Chief, Advanced Configuration Division
Aerospace Systems Design Laboratory
School of Aerospace Engineering
Georgia Institute of Technology
(404) 894-0197
jimmy.tai@ae.gatech.edu

University Participants

Georgia Institute of Technology

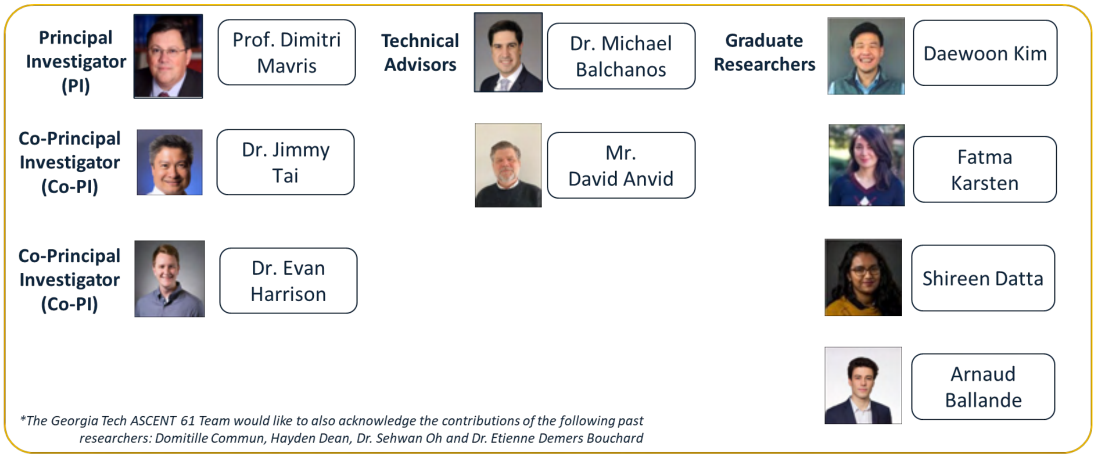
- PI(s): Dr. Dimitri Mavris, Dr. Jimmy Tai
- FAA Award Number: 13-C-AJFE-GIT-066
- Period of Performance: June 5, 2020 to June 4, 2021
- Tasks (for year 1):
    1. Task 1: Interview industrial partners on current noise certification process
        - Task 1.1: FAA noise certification regulation review
        - Task 1.2: Industrial partner interviews via workshops
    2. Task 2: Develop and recommend a streamlined noise certification procedure for existing aircraft
        - Task 2.1: Current process assessment
        - Task 2.2: Streamlined process definition
    3. Task 3: Develop a flexible noise certification procedure for new aircraft
        - Task 3.1: Flexibility assessment of streamlined process
    4. Task 4: Simulate streamlined and flexible noise certification procedure
        - Task 4.1: Identify modeling approach
        - Task 4.2: Noise certification process metric definition

Project Funding Level

The total amount of current funding from the FAA for ASCENT Project 61 is $250,000 for a 12-month period of performance.

Investigation Team

The ASCENT Project 61 Georgia Institute of Technology (Georgia Tech) Aerospace Systems Design Laboratory (ASDL) investigation team is shown in the organization chart below. Professor Dimitri Mavris is the PI of this project, together with co-PIs Dr. Jimmy Tai, Senior Research Engineer, and Dr. Evan Harrison, Research Engineer II. In support of the co-PIs, a team of two research faculty is leading efforts in both planning and technical development for the planned tasks. They are being joined by four graduate student assistants, who are supporting Project 61 as they work toward their M.Sc and PhD degrees. All team members are affiliated with the ASDL at the School of Aerospace Engineering, Georgia Tech.



ASCENT Project 061 Georgia Tech ASDL team.

From the team of technical advisors, the following roles and responsibilities have been defined:

- **Dr. Michael Balchanos**, Research Engineer II, is serving as the technical lead for Project 61. Aside from day-to-day coordination roles, he is responsible for planning a series of workshops with the industry partners and subject-matter experts (SMEs) on benchmarking efforts under Task 1 for current noise certification procedures. Moreover, he is investigating techniques for process simulation, under the process improvement modeling task (Task 4).
- **Mr. David Anvid**, Senior Research Engineer, is supporting Task 1 efforts in understanding Parts 21 (on certification procedures) and 36 (on noise regulations) of Title 14 Part C. He joined ASDL on October 1, 2020, and his multi-year industry experience in noise certification has been invaluable in the team's efforts to benchmark current certification procedures.

The following past technical advisors contributed to the tasks:

- **Dr. Sehwan Oh**, Postdoctoral Researcher, focused on exploring current certification regulations and understanding their structure (e.g., hierarchy and associations) linked to Task 1, and provided input regarding the application of discrete event and agent-based methods as part of the efforts planned for Task 4.
- **Dr. Etienne Demers Bouchard**, Postdoctoral Researcher, explored process modeling methods from the literature, as well as formulating a canonical problem to assess the feasibility and applicability of methods.

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

- **Mr. Daewoon Kim**, first-year M.Sc. student, is leading the team's model-based systems engineering (MBSE) efforts in representing the baseline certification process in Systems Modeling Language (SysML).
- **Ms. Shireen Datta**, second-year M.Sc. student, has been supporting the efforts in documenting current procedures and exploring regulation-driven requirements, which are now included in the verification model.
- **Ms. Fatma Karsten**, PhD student, worked on flight testing plan implementation and the effective perceived noise level (EPNL) calculation module within the MBSE verification model.
- **Mr. Arnaud Ballande**, first year M.Sc. student, has been working on a process simulation capability as part of evaluating equivalent procedures under the process improvement modeling task (Task 4).

The following former students contributed to the tasks:

- **Ms. Hayden Dean**, first year M.Sc. student, was instrumental in capturing and understanding current regulations and certification procedures, as dictated by the Title 14 Subchapter C, Parts 21 and 36, as well as the Part 36 Advisory Circular (AC), with particular focus on AC 36-4D, and emphasis on the guidance instructions regarding flight testing for noise certification.
- **Ms. Domitille Commun**, PhD student, worked on implementing a DES model-based process simulation capability for the certification baseline.

Project Overview

Noise certification procedures (with the inclusion of equivalent procedures) have served aviation stakeholders (including original equipment manufacturers [OEMs], regulators, operators, and airports) well since the 1960s [1–3]. However, with new vehicle types and new technologies (including new entrants, digital technologies for airframes, propulsion, and measurements), the existing certification processes must be critically examined. A key aspect of current certification practices is the equivalent procedures and supporting technology, which many OEMs utilize [4]. Equivalent procedures are anticipated both for existing and new standards to further accommodate future innovation.

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 needed flexibility to accommodate all air vehicle types. Project 61 seeks to propose quantifiable process improvements and facilitate the application of traditional systems engineering (SE) for complex systems with, model-based systems engineering (MBSE), while leveraging these methods for the management of regulatory requirements. To perform the proposed research under this 3-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.

The ASCENT Project 61 team seeks to accomplish the following goals:

- Identify opportunities for increased efficiency (through expediting steps and simplification of the process) and flexibility in the current noise certification process, 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.)
- Develop process modeling methods to enable quantitative assessment of noise certification
- Facilitate the application of traditional SE processes for complex systems and MBSE, leveraging these methods for the management of regulatory requirements

An overview of the ASCENT 61 roadmap toward goals and milestones is shown in Figure 1.

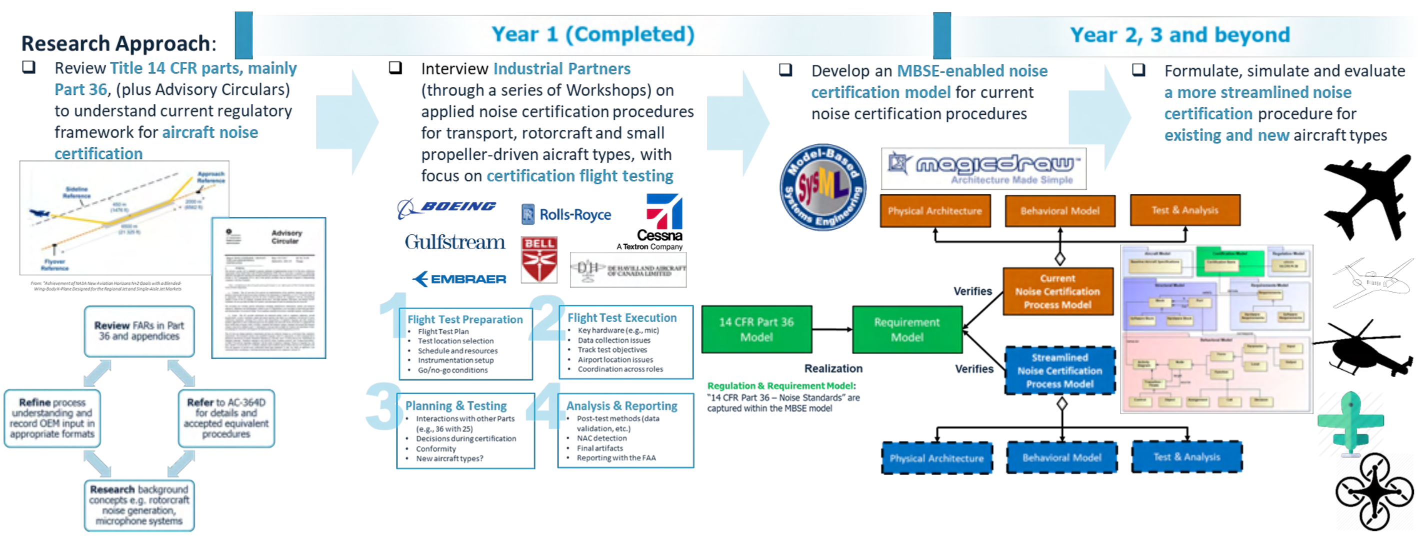


Figure 1. Roadmap toward a model-based framework for exploring current and streamlined noise certification.

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 analytic techniques to support the certification of future air vehicle types. These recommendations should be accompanied by evidence that the suggested equivalent procedures are fully compliant with Part 36, and should use case examples for future air vehicles, e.g., small propeller-driven aircraft and unmanned aircraft systems (UAS).

To implement this roadmap and achieve the targeted outcomes, four main tasks have been delineated, which are shown in Figure 2, along with the subtasks that have been prioritized for year 1 of ASCENT 61. In that figure, a status indication is shown, with completed subtasks highlighted in green, and subtasks that are currently undergoing through iterations and refinements indicated in gold.

Figure 2. Year 1 project task breakdown.

For the full 3-year period of performance, the complete timeline for finalizing all Project 61 tasks is shown in Table 1.

Table 1. ASCENT Project 61 task planning timeline.

		Year 1												Year 2												Year 3											
	Task	M1	M2	M3	M4	M5	M6	M7	M8	M9	M10	M11	M12	M13	M14	M15	M16	M17	M18	M19	M20	M21	M22	M23	M24	M25	M26	M27	M28	M29	M30	M31	M32	M33	M34	M35	M36
1	Interview Industrial Partners on Current Noise Certification Process	■	■	■	■	■	■	■	■	■																											
	1.1 FAA Noise Certification Regulation Review	■	■	■																																	
	1.2 Industry Partner Interviews via Workshops				■	■	■	■	■	■																											
2	Develop a Streamlined Noise Cert. 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	Simulation Streamlined and Flexible Noise Certification Procedure				■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
	4.1 Identify Modeling Approach				■	■	■	■	■	■	■	■																									
	4.2 Noise Certification Process Metric Definition												■	■	■	■	■																				
	4.3 Model Calibration																	■	■	■	■	■	■	■	■												
	4.4 Certification Process Simulation																									■	■	■	■	■	■	■	■	■	■	■	■

On the basis of the actual and recorded Year 1 activities and efforts, these tasks have been focused around communication with our partners, and have resulted in gathering of information and knowledge that have been key for the team's clear understanding of current certification procedures (Task 1, Subtasks 1.1 and 1.2) and the formulation of the respective certification model in SysML (Task 2, Subtasks 2.1. and 2.2; Task 4, Subtasks 4.1 and 4.2). A chronological overview of key activities and milestones during Year 1 is shown in Figure 3.

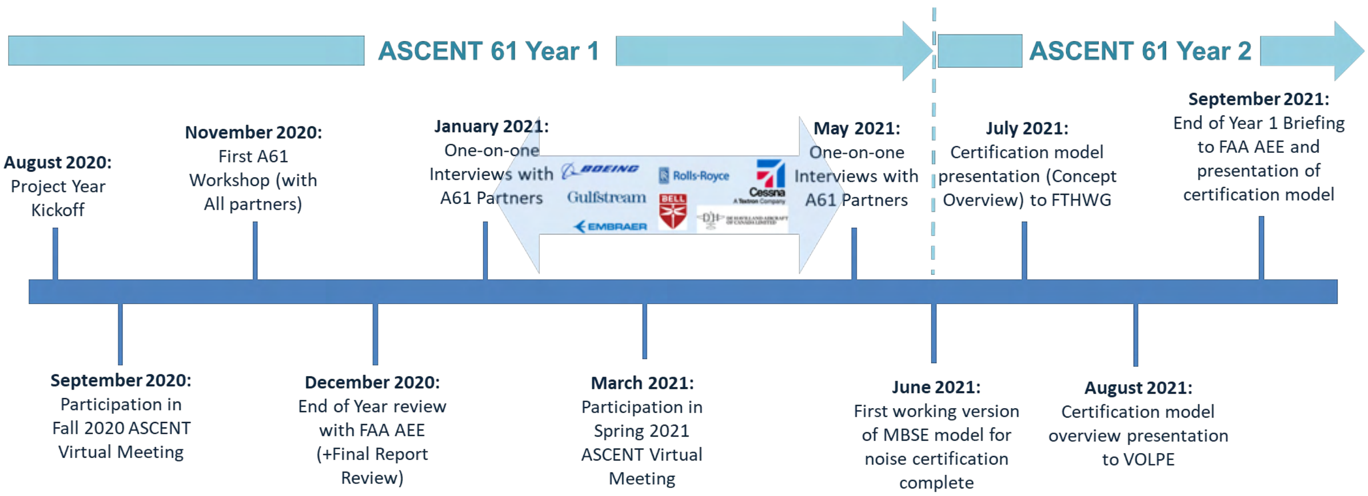


Figure 3. Chronology of A61 team activities and milestones.

The following sections provide detailed descriptions of technical progress, the research approach, key milestones, and accomplishments under each task, for all tasks and subtasks listed in Figure 2.

Task 1 - Interview Industrial Partners on Current Noise Certification Process

Georgia Institute of Technology

Objectives

In support of the main research objective of Project 61, Task 1 is examining current noise certification procedures (Task 1.1) and benchmarking against current industry practices regarding how these procedures are adopted and implemented (Task 1.2). 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, further explore an additional type: 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 follow-up events to iterate on the feedback obtained, and to share lessons learned and the derived recommendations
- Hold a focus workshop on identifying areas of opportunity to streamline the certification process for each type of vehicle and allow for Subject Matter Experts (SMEs) to suggest potential solutions.

Research Approach

Task 1.1
Starting with Task 1.1, the team's main activity 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 parts of 14 CFR (mainly Part 36) and associated relevant documents (e.g., ACs, for instance AC 36-4D). With recommendations from the team's OEM partners, additional documentation from the European Union Aviation Safety Agency (EASA), the International Civil Aviation Organization (ICAO) Environmental Technical Manual, and the Volpe Center website was considered.

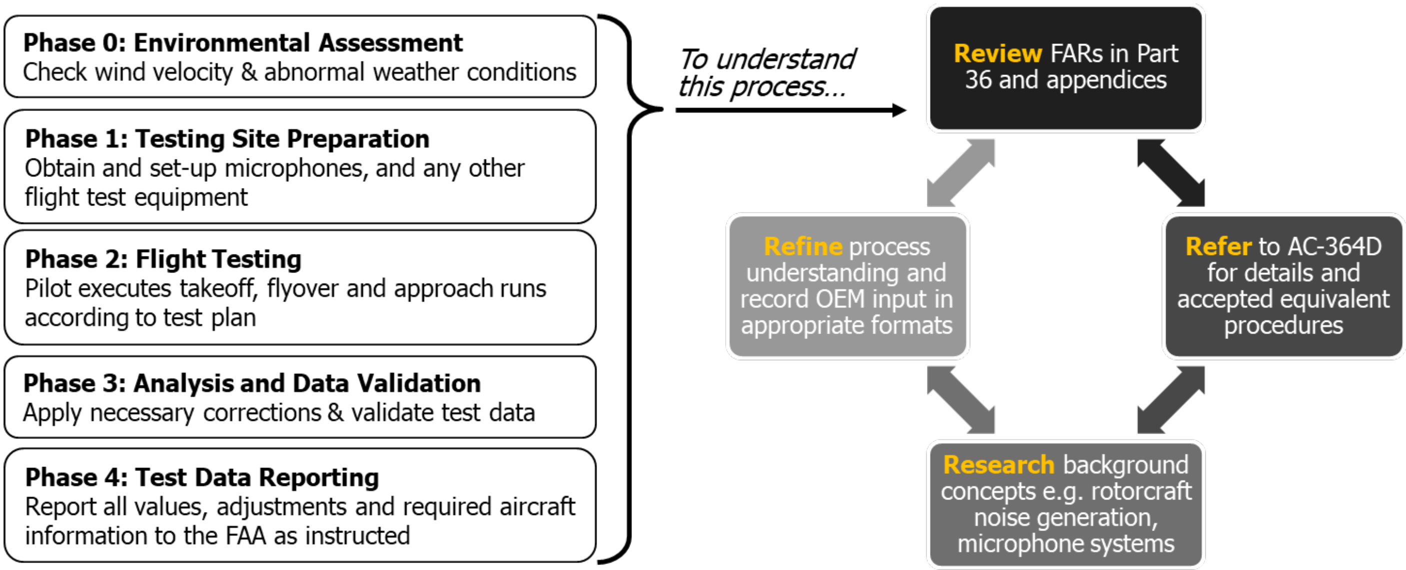


Figure 4. Noise certification regulation review (Task 1.1).

Because the full certification process is comprised of multiple processes and standard procedures, which are highly coupled, with recommendations by the FAA and the OEM partners, the team focused this exercise on the certification flight testing phases. Specific to flight testing phases, federal aviation regulations (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 the extensive review of FARs and literature regarding 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 the 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. Benefits of this task's outcome is that team members quickly became more knowledgeable in the certification basics in preparation for Task 1.2 (industry interviews) and able to build a comprehensive MBSE representation (in SysML) of the current framework from zero (Task 2.1). An overview of the methodology for the review of FARs and literature is provided in Figure 4. Appendix A of this document provides a full overview and 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 in practical aspects of noise certification requirements. This interaction occurred via virtual workshops, guided using questionnaires compiled by the team based on the reviews completed under Task 1.1. Through insights and findings from the work documented under Task 1.1, the team has identified topics in which more context and additional insight into ancillary/non-regulatory processes is needed regarding how the certification procedure is facilitated by each OEM partner. These topics are shown in Figure 5.

1 Flight Test Preparation	2 Flight Test Execution	3 Planning & Testing	4 Analysis & Reporting
• Flight Test Plan • Test location selection • Schedule and resources • Instrumentation setup • Go/no-go conditions	• Key hardware (e.g., mic) • Data collection issues • Track test objectives • Airport location issues • Coordination across roles	• Interactions with other Parts (e.g., 36 with 25) • Decisions needed during certification • New aircraft types?	• Post-test methods (data validation, etc.) • NAC detection • Final artifacts • Reporting with the FAA

Figure 5. Workshop interview topics for transport category aircraft.

The overarching goal of these workshops was to identify common practices, checkpoints, and milestones across industry partners, while soliciting feedback on key challenges identified by the partners, as well as what recommendations each partner would provide and why. Such suggestions could provide opportunities for potential process streamlining, such as recommended practices that might 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, and hence they should be focused on equivalent procedures with simplified processes, or tied to modern technologies, which are still expected to meet the same regulations.

The first workshop was planned by the Georgia Tech team and held virtually on November 5, 2020. The 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 to May of 2021 (detailed timeline in Figure 3). In this expanded outreach, most interviews were planned with one OEM partner at a time, to ensure that the participants would be comfortable sharing their thoughts and expertise, without the time constraints of a high-participation event and with more flexibility in scheduling and necessary follow-up. The list of participating partners was expanded to include more OEMs (Embraer, Cessna, and De Havilland Canada) than those supporting the original workshop in November 2020. The Volpe Center has also participated in shaping the team's knowledge and understanding of the recommended procedures through providing technical feedback, especially regarding 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 6.

Organization	Participants	Organization	Participants
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 6. Participating partners (airframe OEMs and the Volpe Center) in workshops/interviews under Task 1.2.

To facilitate directed discussion in the workshops/interviews, the Georgia Tech team formulated questions on the discussion topics listed in Figure 5 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?
- 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 first round of certification?

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

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 7. Post-processing of collected information and categorization.

The initial workshop, along with the follow-on interviews, generated a wealth of information. Planning and following a methodological approach are necessary to post-process and direct this information to gain usable conclusions and insightful findings. One idea was to generate categories for sorting and organizing the material collected from the questionnaire responses. As part of the categorization of the responses to the questions, several categories have been defined, as shown in Figure 7.

Although there was substantial variability in the level of detail provided in the answers and feedback obtained from participants, the team was able to summarize the gist of the feedback provided under the defined categories, as illustrated in Table 2. To summarize those findings, the main takeaway messages from all OEM feedback are as follows:

- Acoustical changes (AC's/NAC's) 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 and are occasionally due to communication disruptions.
- Conformity discussions can be consume substantial time and effort, especially in cases that must justify changes that are unrelated to acoustics.
- Interactions between Part 36 and Part 25/23 are of concern, because a discontinuity appears to exist between environmental and design standards, thus often leaving little space to apply acoustic improvements.
- For calculating EPNL values from noise data collected during flight testing, there is no single standardized software: each OEM's methodology and code is different.

The lack of standardization appears to be a common area of opportunity for improvements across current noise certification procedures. Within the same context, participant-recommended value-added outcomes that could be explored and evaluated through use of the MBSE-enabled platform for streamlined certification are: (note that all need not be examined within the current Project 61 statement of work, but some could serve as appropriate use-case opportunities for years 2 and 3, or beyond):

- Along with exploring improvements in time and cost, the Project 61 team could explore options to simplify testing and instrumentation setup requirements to facilitate more test locations/weather-window options (i.e., which could allow removal of 4-ft microphones for ground planes and removal of lateral location altogether).
- Testing uncertainty could be managed through evaluation of no-acoustical-change limits.
- Conformity issues could be addressed through the formulation of a concept that could be tested and demonstrated within the MBSE-based verification framework.
- Criteria for approval for acoustical analyses could define new certification noise levels (acoustical change by analysis)
- As a longer-term goal, a framework could be defined for oversight that gives FAA confidence in manufacturers' tools/methods used in noise certification (e.g., with predefined audit guidelines/procedures).

Table 2. Summary of findings from transport category workshop/interview feedback.

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

Finally, this exercise under Task 1.2, with the identified findings and participant-provided recommendations, has successfully established the need for a solution that enables exploration and formulation of a standardized, simplified certification procedure that can be flexible to accommodate different types of air vehicles and new technologies. The use of a comprehensive systems engineering process would enable connectivity throughout the certification steps and traceability of regulatory compliance. Because model reusability and scalability across different categories are very important, the team has been utilizing MBSE methods to effectively "re-architect" the certification procedures to achieve the goals and desired outcomes identified through the feedback obtained by Task 1.2 activities.

Milestones

Since October 2020, the following milestones have been achieved (also shown in Table 2):

- Participation in the Fall 2020 ASCENT Advisory Committee Meeting (September 30, 2020)
- Workshop 1 on transport category aircraft (November 5, 2020)
- End-of-Year review with the FAA Office of Environment and Energy plus annual report review (December 2020)
- One-on-one Interviews with A61 partners (January 2021)
- Participation in the Spring 2021 ASCENT Virtual Meeting (March 2021)
- Final round of planned one-on-one Interviews with A61 partners (May 2021)
- Participation in the Fall 2021 ASCENT Virtual Meeting (October 2021)
- Completion of Tasks 1.1 and 1.2. for the transport category (June 2021)

Table 3 ASCENT Project 61 year 1 milestone status.

Milestone	Due Date	Estimated Date of Completion	Actual Completion Date	Status
Workplan	7/5/20	7/5/20	7/5/20	Completed
Kick-off Meeting	8/30/20	8/30/20	8/24/20	Completed
Center of Excellence Meeting 1 (Fall 2020 ASCENT Meeting)	10/1/20	10/1/20	9/29/20 to 9/30/20	Completed
Center of Excellence Meeting 2 (Spring 2021 ASCENT Meeting)	4/1/21	4/1/21	4/27/21 to 4/29/21	Completed
Annual Report	6/5/21	6/5/21	9/30/21	Completed
Project Closeout	6/5/21	6/5/21	Continue for year 2	Completed

Major Accomplishments

The primary focus of the team's effort for Project 61 year 1 was the completion of Task 1.1 and planning a series of workshops with industry partners to support efforts under Task 1.2 for the identification of currently applied noise certification practices and opportunities for streamlining the certification process.

Task 1.1 is now complete. The following accomplishments are reported:

- The literature review was completed on current noise certification practices, as dictated by Title 14 Part C, Part 21 regarding certification procedures and Part 36 regarding noise regulations. The review of AC Part 36 was incorporated, with a particular focus on AC 36-4D. Emphasis was placed on the instruction regarding the flight testing for certification.
- A summary and visual representation of the regulations and their respective relationships/associations, in both flowchart and SySML views, has been provided.
- Certain gaps in understanding of the certification process have been identified and documented. These findings have enabled the production of a topic questionnaire to further support the facilitation of workshops with industry partners, as planned for Task 1.2.

For Task 1.2, the following accomplishments are reported:

- Workshop 1 for the large transport category was held virtually and completed on November 5
- Feedback and input were collected from industry partners during the workshop.
- Key takeaways became available, which are shaping the project's direction and aiding in the understanding of priorities within the problem. For instance, certification procedures must be not only more efficient in terms of time and cost, but also less complex and better aligned with use of current technology (which is an enabler of process simplification).
- The questionnaire for the workshop has been compiled with input from Task 1.1's literature review and benchmarking activities. Consideration of additional responses from our industry partners is underway and will inform our modeling efforts under Tasks 2, 3, and 4.

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

Publications

Peer-reviewed journal publications

None

Published conference proceedings

Mavris, D. N., Tai, J., Harrison, E., & Balchanos, M. (2020, September 29-30). ASCENT Project 61 – Noise certification streamlining [Presentation]. Fall 2020 ASCENT Advisory Committee Meeting.

Mavris, D. N., Tai, J., Harrison, E., & Balchanos, M. (2021, March 27-29). ASCENT Project 61 – Noise certification streamlining [Presentation]. Spring 2021 ASCENT Advisory Committee Meeting.

Mavris, D. N., Tai, J., Harrison, E., and Balchanos, M. (2021). ASCENT Project 61 – Noise certification streamlining [Presentation]. Fall 2021 ASCENT Advisory Committee Meeting.

Written reports

December 2020 ASCENT Quarterly Report, ASCENT Project 61, "Noise Certification Streamlining," Award number 13-C-AJFE-GIT-066, submitted January 30th, 2021.

2020 ASCENT Annual Report (period ending September 2020), ASCENT Project 61, "Noise Certification Streamlining," Award number 13-C-AJFE-GIT-066, submitted December 12th, 2020.

March 2021 ASCENT Quarterly Report, ASCENT Project 61, "Noise Certification Streamlining," Award number 13-C-AJFE-GIT-066, submitted April 30th, 2021.

June 2020 ASCENT Quarterly Report, ASCENT Project 61, "Noise Certification Streamlining," Award number 13-C-AJFE-GIT-066, submitted July 30th, 2021.

September 2020 ASCENT Quarterly Report, ASCENT Project 61, "Noise Certification Streamlining," Award number 13-C-AJFE-GIT-066, submitted October 30th, 2020.

Outreach Efforts

- Planned and held Workshop 1 with industry partners (Boeing, Gulfstream, Rolls-Royce, and the FAA) on transport category aircraft
- Completed follow-up meetings with OEM partners in Workshop 1 and through the spring of 2021
- Performed capability demonstration to the Flight Test Harmonization Working Group (FTHWG)
- Project overview and request for information and technical feedback to be provided by the Volpe Center (Department of Transportation)

Awards

None

Student Involvement

- All three participating graduate students have supported Task 1 activities by performing the literature and background search and reviewing current regulations and FAA-instructed certification procedures (Parts 21 and 36, and AC 36-4D).
- All students contributed to producing the certification process views and compiling the questionnaire for supporting discussions and feedback solicitation as part of hosting Workshop 1 and follow-on interviews.

Plans for Next Period

- Coordinate a follow-up meeting for Workshop 1 on large transport category aircraft with industry partners, to showcase our verification model capabilities and present a number of relevant use cases
- Complete planned workshops on rotorcraft category aircraft and small propeller-driven air vehicles
- Plan for submission of two articles to ICAS 2022, for further dissemination of the A61 team's developed capabilities, demonstrating the requirement generation techniques, the MBSE certification model, and the certification process evaluation and assessment model using discrete event techniques
- 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 is focusing on the development of a more streamlined noise certification procedure, leveraging MBSE for the formulation and implementation of a certification process model. For Task 2.1, the goal is to fine-tune and adjust the MBSE certification model to represent current certification steps (ranging from regulatory-derived requirements to certification flight testing) for transport category aircraft, as identified and benchmarked in Task 1.

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.
- Of primary interest should be the use of technology that seek to simplify the certification process while demonstrating 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 technical feedback on the proposed process alternatives from the FAA, Volpe Center, and industry partners.
- Perform revision of suggested process, which incorporating key aspects of the collected feedback to build a consensus among the research partners.

Research Approach

Task 2.1

A key takeaway message from Task 1.2 is the need for formulating a flexible noise certification process. The process should allow for process reusability for the certification of various air vehicles and should be usable as a tool to assess current procedures and identify improvements that increase efficiency and decrease complexity. To assess current noise certification practices, a MBSE approach has been proposed. Work completed under Task 1—both benchmarking of current practices and input from the workshops—will be compiled and used to inform a certification process model formulated in SysML language (implemented in MagicDraw and Cameo Toolkit software tools).

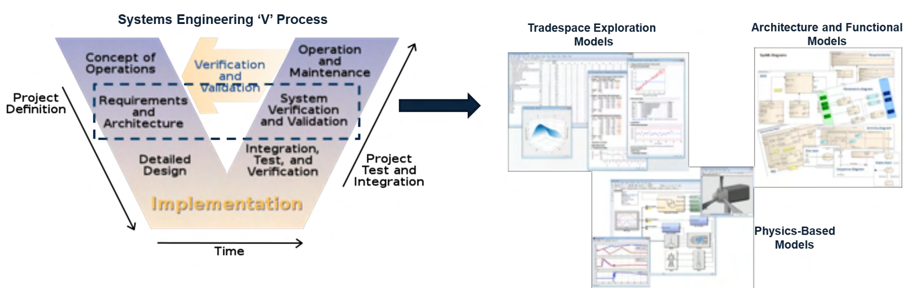


Figure 8. Systems engineering "V" and MBSE-enabled systems architecting.

MBSE is the formalized application of modeling to support system requirements, design, analysis, verification, and validation activities beginning in the conceptual design phase and continuing throughout development and later lifecycle phases. [INCOSE SE Vision 2020, Sept 2007]. MBSE supports traditional Systems Engineering (SE) activities by applying modeling techniques to create a modular structure of system representation, as shown in Figure 8. With this approach, the models are more rigorous because of their mathematical or logical formulation, with minimum reliance on static documents and sources.

To enable reusability and effectively expedite steps through digital modeling and process execution, MBSE shifts the representation of systems from documents to explicit representation of systems via models; hence, it merges product information and engineering models. In addition, MBSE 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 common understanding for people with different roles and responsibilities. MBSE allows for linking of regulations and requirements to certification steps, and representing links and associations between regulations. It improves communication among stakeholders, management of complexity, and precision of operational use cases; as a result, it addresses common issues that arise during certification audits, e.g., requirement traceability, configuration management, document control, and change impact analysis.

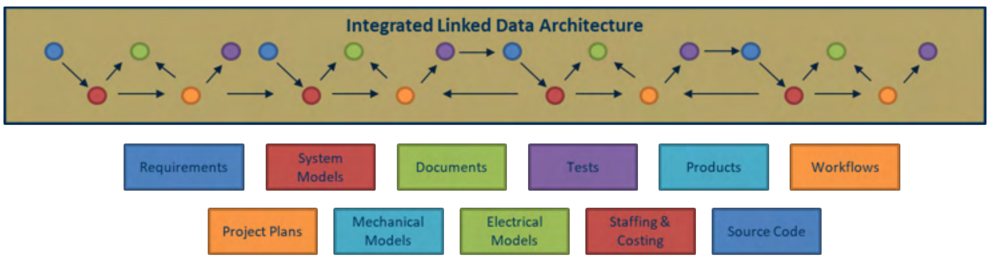


Figure 9. Integrating data and models through a digital thread.

Because MBSE provides a platform for knowledge transfer between projects, system models can evolve across the lifecycle, while preventing loss of knowledge and investment despite any project discontinuities. This capability can enable a digital thread, which is a framework that connects information, information flows, and relationships through the lifecycle of the system, as shown in Figure 9. Thus, information previously captured in individual silos is integrated to enable greater transparency (including technical baseline, resources, and workflow). An example is shown in Figure 10.

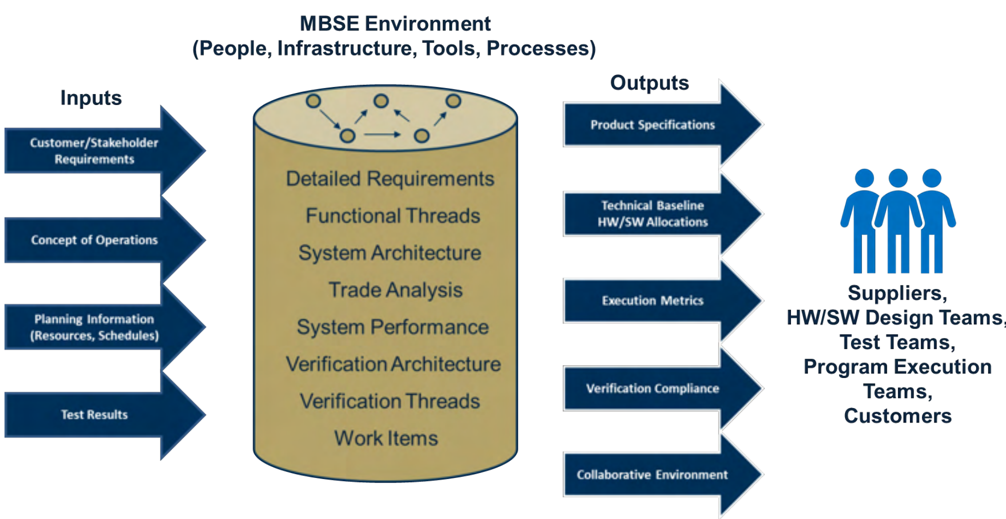


Figure 10. Digital thread for certification: inputs and outputs.

Under Task 2, particularly Subtask 2.1, the goal is the assessment of current noise certification procedures with 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. Because the product is usually an executable vehicle architecture, in the case of Project 61, the product is a process architecture within which current procedures will be assessed; equivalent procedures will also be proposed, defined, implemented, and tested within this environment. The overall progression from the building blocks and subject matter expert input, made possible through Task 1, to the full MBSE model formulation for certification and implementation is shown in Figure 11.

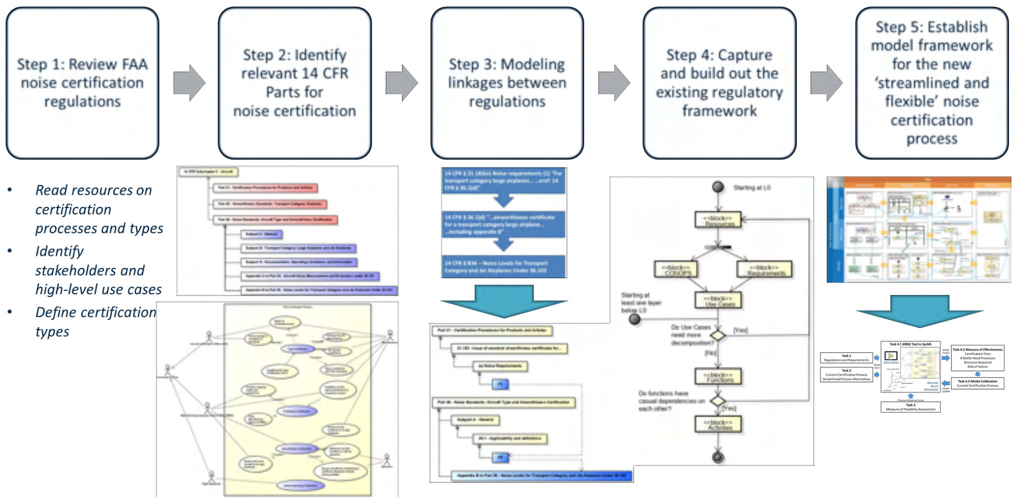


Figure 11. General roadmap toward a model-based framework for exploring current and streamlined noise certification.

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 (RFLP) approach, which maps to the traditional systems engineering "V" approach (Figure 8). A custom model development process was created to capture the functional architecture of the noise certification process, as shown in Figure 12. Inputs to the process that are provided by activities outside of the MBSE environment are marked in blue. This would 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, this is the placeholder for importing the validation protocol for instruments used in aircraft noise certification testing, as well as a representation for the flight test plans, as adopted by the airframe OEMs.

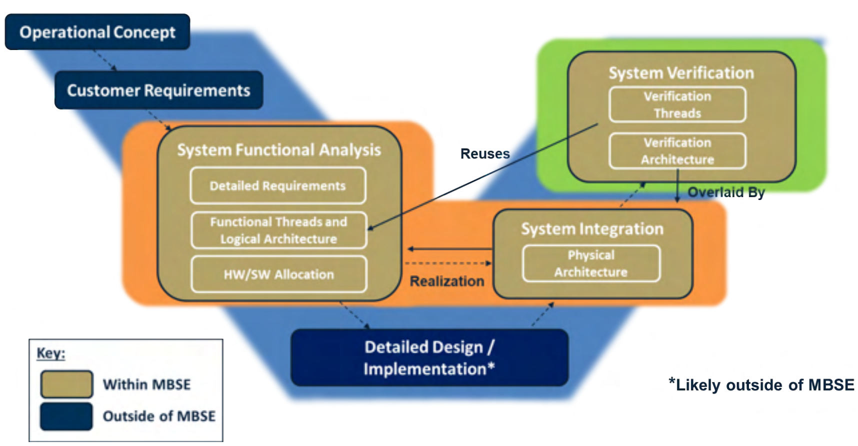


Figure 12. MBSE architecture and functional model development workflow, leveraging the RFLP approach.

The activities within the process indicated in gold are the aspects of the system modeling 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 certification standard to the form that verifies the standard.

Following the RFLP approach, as explained in Figure 12, a more detailed workflow is formulated for the verification model implementation. This version is shown in Figure 13, in which the steps for the conversion of the input information (the artifacts in blue) into a completed model, applied in SySML is 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, through a process developed in-house (and explained later in this document).

The validation process essentially contains the steps needed to demonstrate that the vehicle noise levels calculated from flight testing results meet the requirements. Part of meeting the requirements also involves the right instrumentation setup, which is implemented as a logical architecture within the model. A library of instrument model representations is constructed, from which alternative instrumentation lineups can be modeled. This latter feature is key, because this framework should be able to allow for the evaluation of equivalent procedures, such as lateral microphone placement. Other components of the verification model include 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 an applied SySML verification thread.

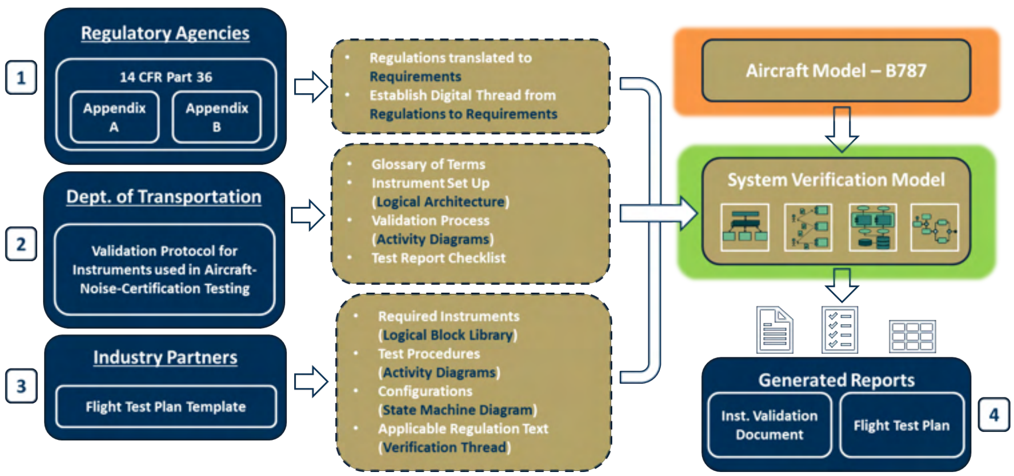


Figure 13**.** Detailed workflow for verification model development toward a digital thread.

With the verification model in place, users will then be able to import any aircraft model, perform the certification equivalent process through execution of the verification model, and generate a final report containing the instrument validation document and flight test plan. It is crucial that the overall framework is implemented in a highly modular fashion to obtain the flexibility necessary for testing equivalent procedure alternatives as well as a broader range of air vehicle designs and configurations. The complete applied SySML implementation of the verification thread in SySML is shown in Figure 14. Following the structure of the verification model as explained in Figure 13, the applied SySML implementation is currently comprised of the following modules:

1. Requirements translation & constraints
2. Noise testing instrument architecture
    a. EPNL conversion
3. Procedures, protocols, and behaviors
4. System under test (SUT)
5. System verification model overview
6. Auto-report generation
    a. Output to process evaluation model

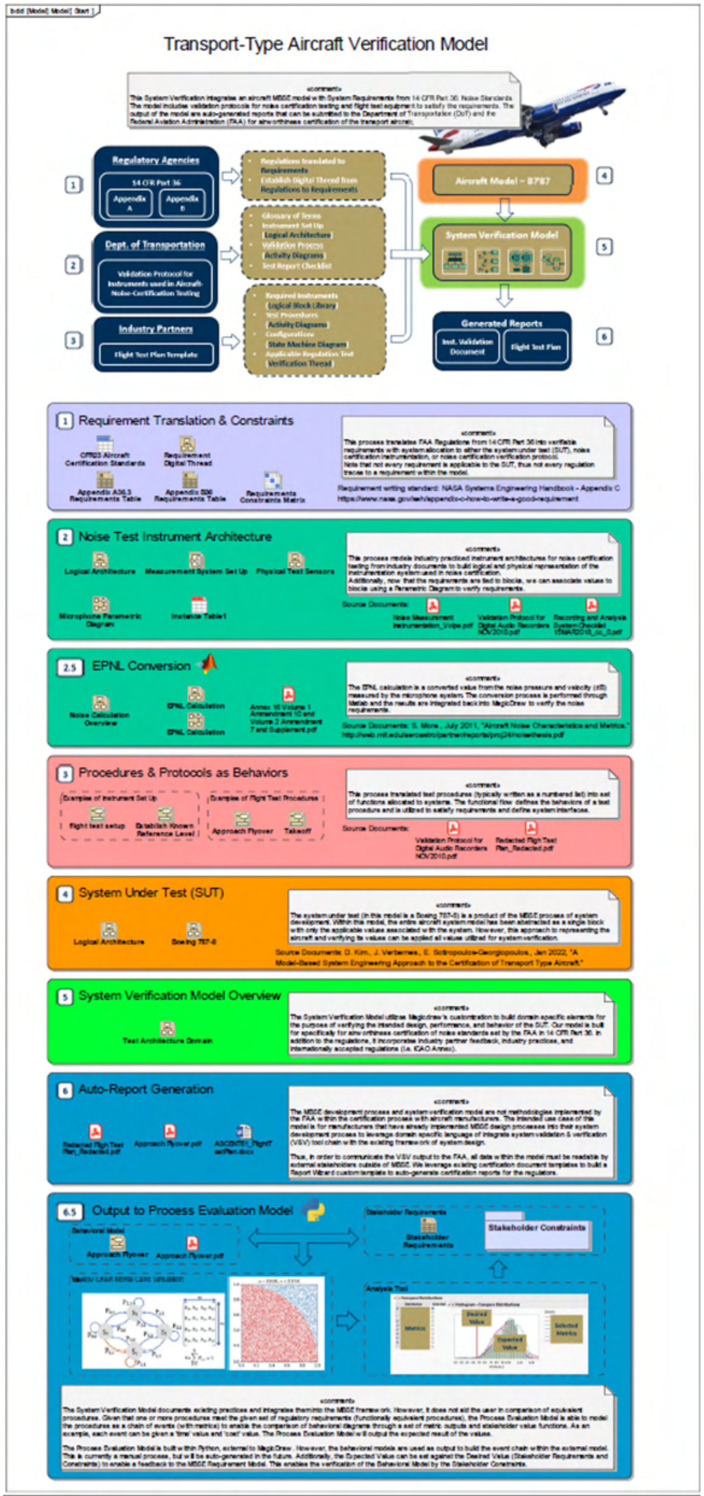


Figure 14. Complete aircraft type verification model for noise certification.

The following provides 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 15.

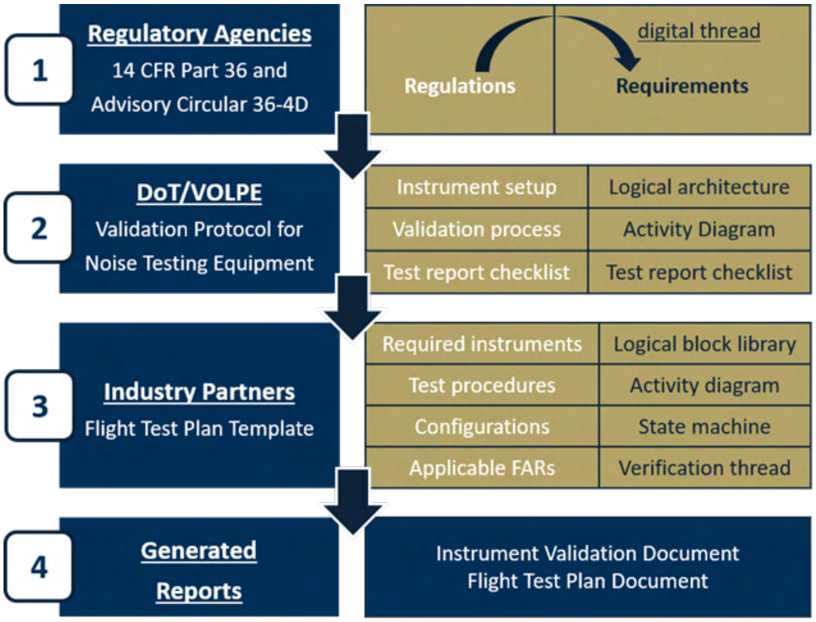


Figure 15. Verification model integration steps.

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 for this design constraint to be satisfied by the system under test. To provide this verification step, a constraint block is introduced as a verification mechanism by integrating engineering analysis into the model. In particular, with the use of a constraint block, the textual requirement can be quantified by using only mathematical and logical expressions. Verification simulations, which can determine whether a certain metric passes or fails a requirement, can be enabled. Overall, the constraint block acts as the interface linking a requirement model and the logical/physical model of a System under Test. An example of how a regulatory article can be imported as a requirement, linked to the verification model, and tested is shown in Figure 16.

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 16. Regulation to requirement: example of design constraint formulation.

Step 2 seeks to implement the validation protocol for noise testing (as dictated by the Volpe Center's guidance) in a logical model. This step returns the representation of the physical noise instrument architecture as an applied SySML logical model. The architecture description is achieved by using "blocks," which essentially describe a system with 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 17. 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).

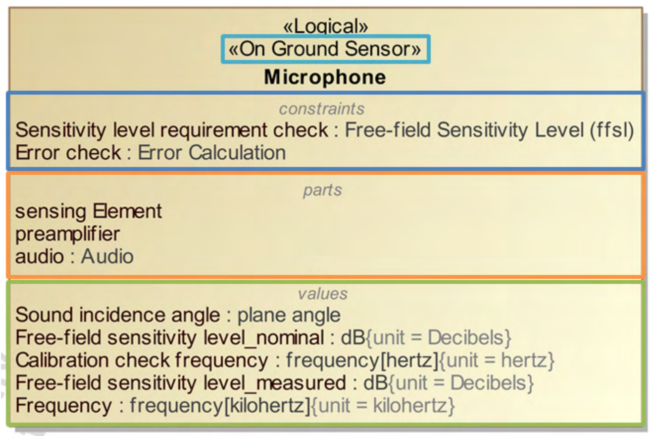


Figure 17**.** Example of a logical block representing physical microphone technology.

The instrumentation architecture is further characterized by the types of sensors used, e.g., the two types of sensors: <<on ground sensor>> (namely the microphone, as represented by the logical block in Figure 17), and <<on A/C sensor>>. An example of an applied SySML logical representation of a microphone and hardware setup as part of the Volpe Center's validation protocol is shown in Figure 18.

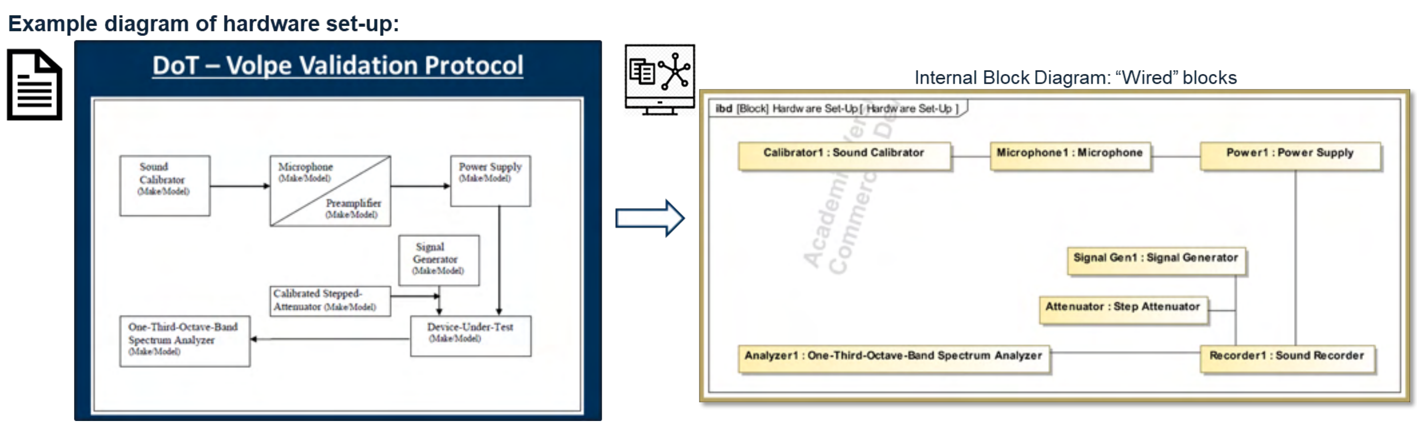


Figure 18**.** Example diagram of hardware setup.

The complete logical architecture representation in an applied SySML environment provides a unified model for all system elements (single source of truth), full transparency, and shared understanding of the system. It is an extensible representation of system, and its components and their properties, with clear definitions of interfaces between architectural elements. This architecture is described hierarchically, with the systems decomposition level being dictated by the requirements. As more architectural elements are progressively accounted for, the model can be easily updated accordingly. An example of a complete logical, hierarchical architecture is shown in Figure 19.

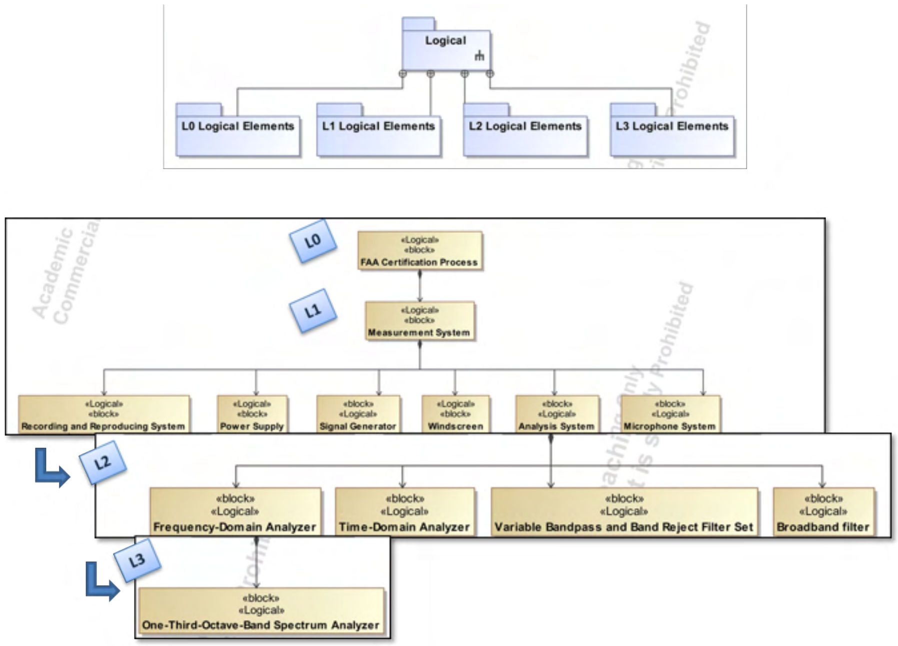


Figure 19**.** Logical architecture for the verification model.

In addition, the parametric construct allows for the logical architecture to be executable through simulations, a key aspect for performing requirement verification. This includes improved traceability between requirements, architecture, and verification information. The stored information in relevant blocks is used for requirements verification, with the quantitative characteristics defined as value properties for each block. This step does require obtaining validation/measurement data for a system under test, to create instances within the model for data representation. The requirement verification is performed by executing the logical architecture with Cameo Simulation Toolkit. An example of requirement verification for the microphone setup within the logical architecture in SysML is shown in Figure 20.

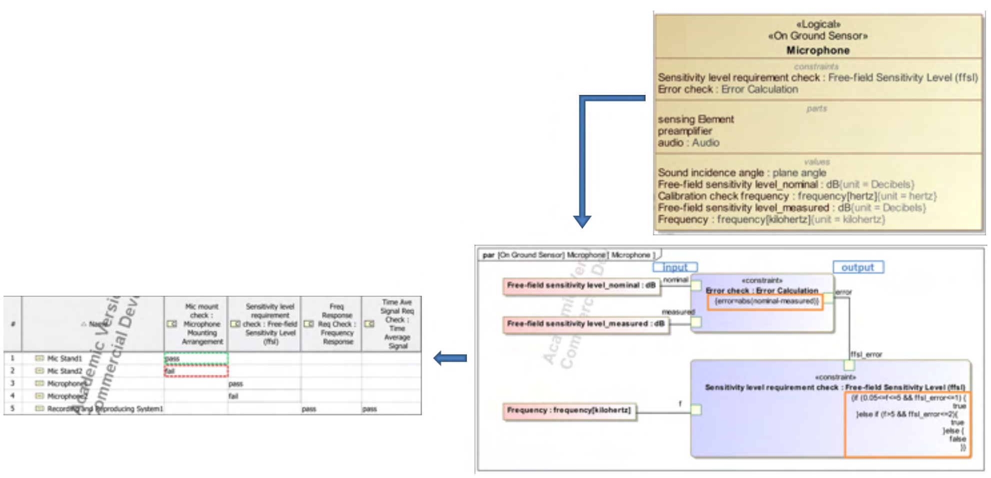


Figure 20**.** Example requirement verification of the logical architecture.

In the current state, the logical architecture model can accommodate the full aircraft noise certification test system; an example physical view is shown in Figure 23, and the corresponding logical architecture implementation is shown in Figure

21. The system under test used for the verification model development was based on a Boeing 787-8 configuration, and its logical representation applied in SysML is shown in Figure 22.

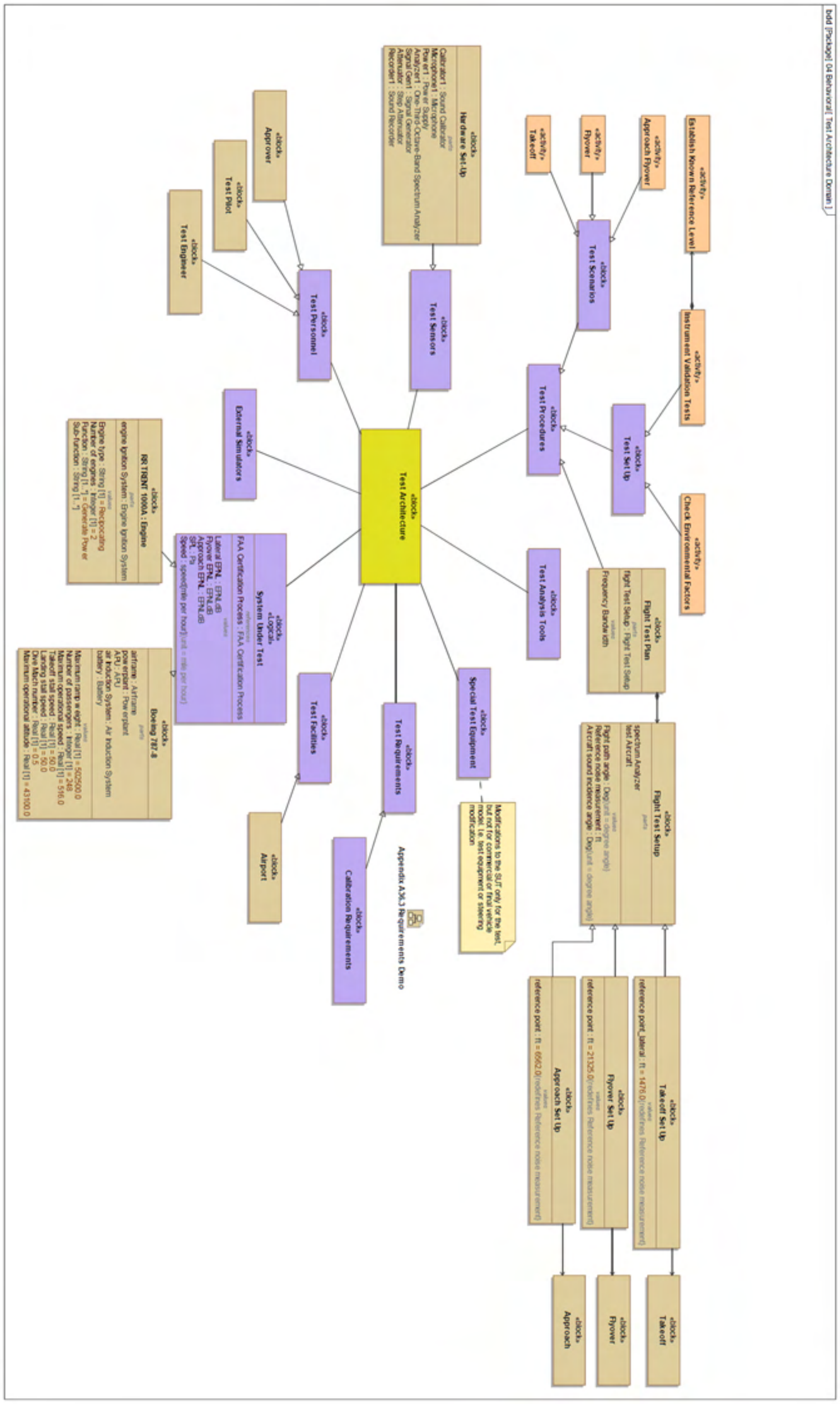


Figure 21. Flight testing architecture domain.

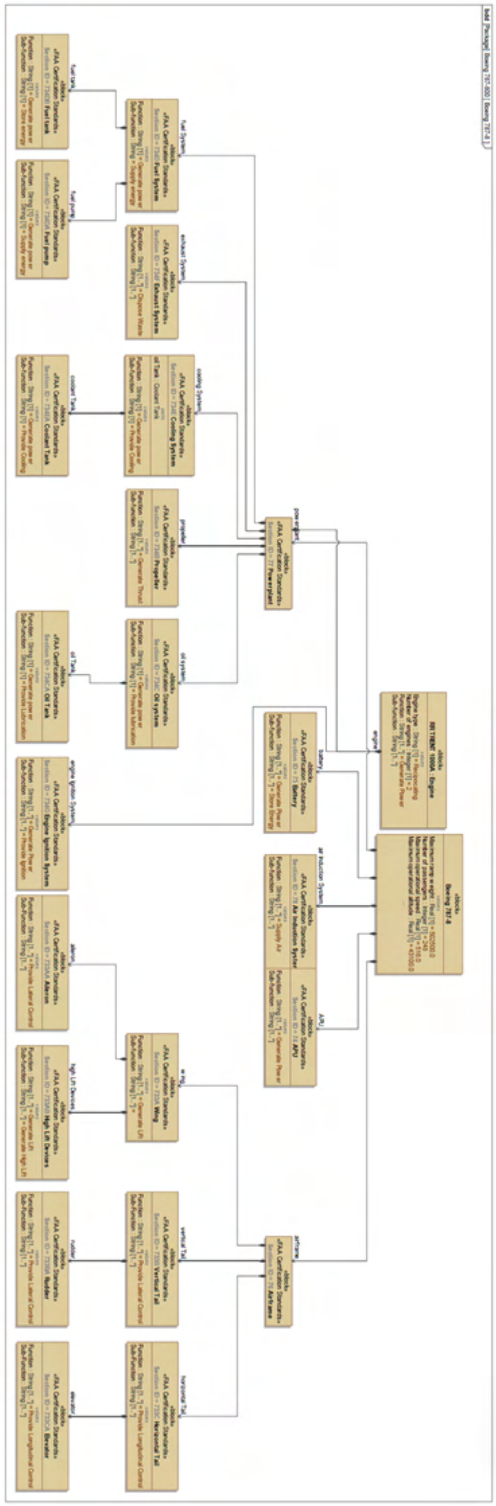


Figure 22**.** Aircraft model (Boeing 787-8) used as the System under Test (SUT).

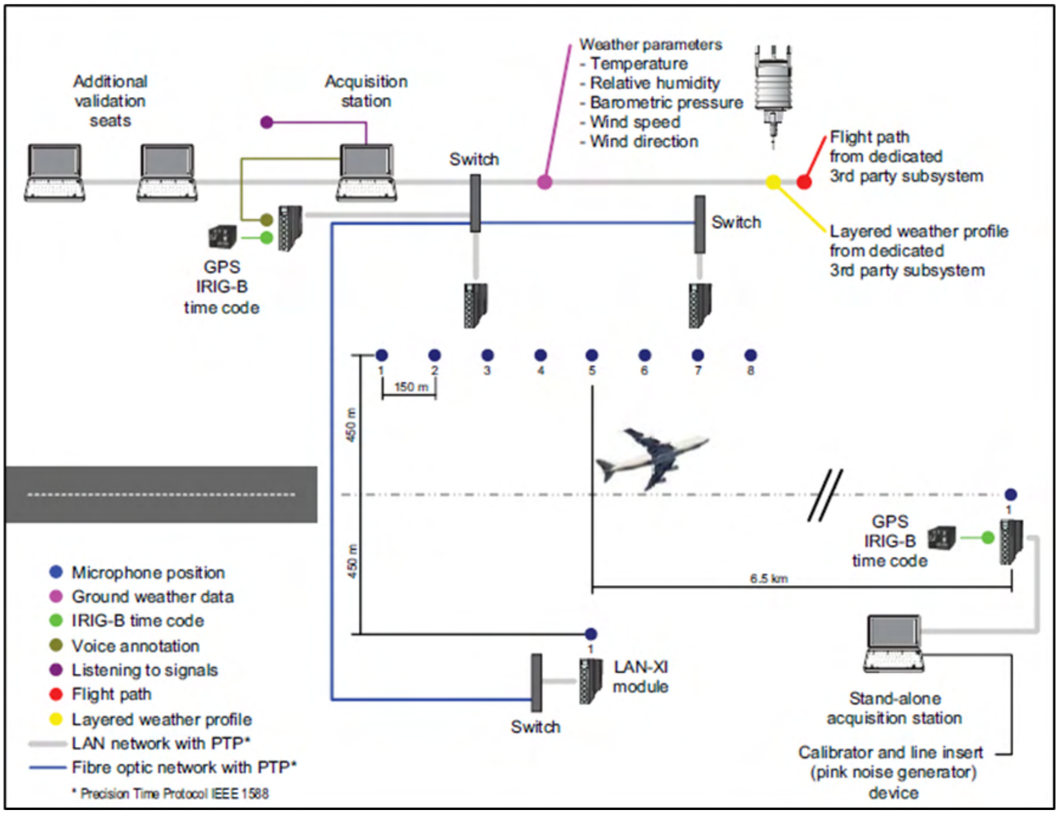


Figure 23. Schematic overview of aircraft noise certification test system by Brüel & Kjær.

Step 3 of the verification model implementation process involves the representation of the flight test procedures to behavioral models. Because test procedures are written in text (bullet points, numbered lists, etc.), the functions performed by the system are not clearly defined, nor are the external system interfaces. To model the process as behavioral diagrams, functions allocated to systems must be defined, and functional flows with defined interfaces must be established, as explained in Figure 24.

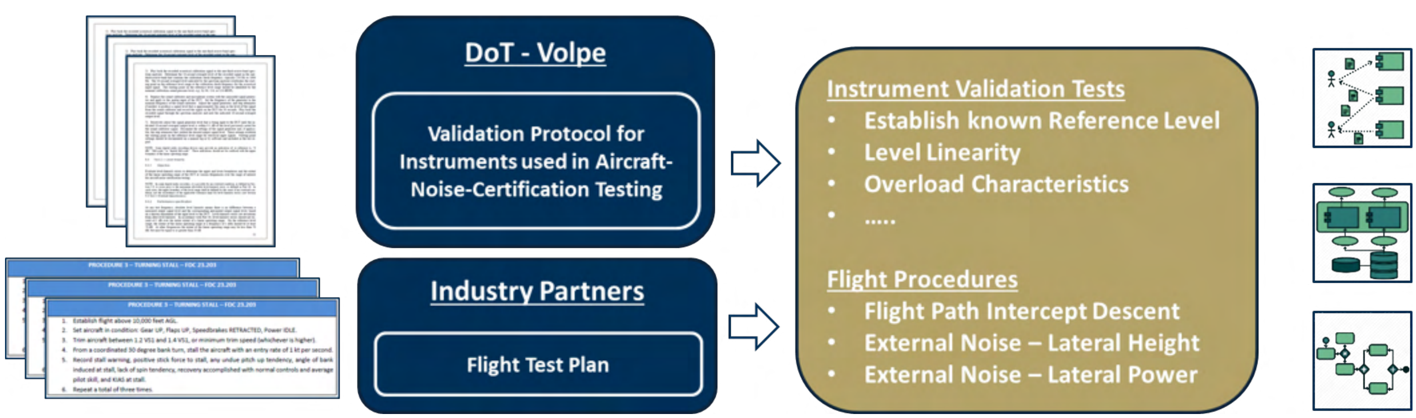


Figure 24. Process for representation of flight test procedures to behavioral models.

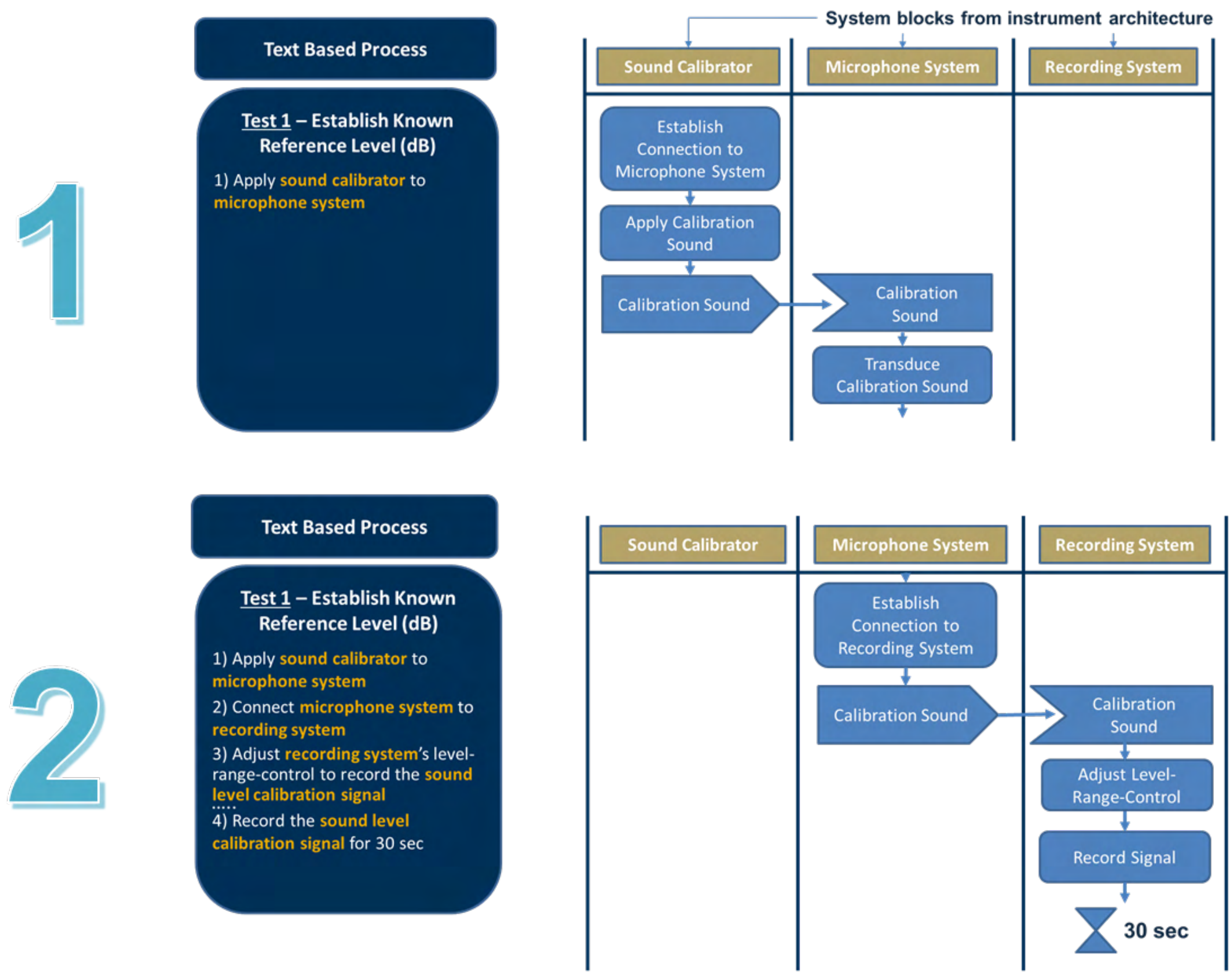


Figure 25. Text-based method for behavioral process model implementation.

To better understand and demonstrate how this process functions in practice, an example is provided in Figure 25. 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 to 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 a sound calibrator is applied to the microphone system. In the behavioral process model, this means that three system blocks from the instrument architecture library are used: the sound calibrator, the microphone system, and the recording system. In terms of process steps, connection of the sound calibrator to the microphone system must be established, and the calibrator then applies the calibration sound to the microphone. In the next phase of steps (phase 2 at the bottom of the figure), the instructions are to connect the microphone system to the recording system, adjust the recording system's level-range-control to record the sound level calibration signal, and record the sound level calibration signal for 30 sec. All these process steps are then populated in the process model on the right side of the figure and mapped accordingly to the system blocks.

Continuing along that same implementation path, the completed process mode for establishing a known reference noise level is shown in Figure 26. Following similar steps, behavioral process models applied in SySML were formulated for the flight testing phases of interest, which are the approach flyover (Figure 27) and takeoff (Figure 28).

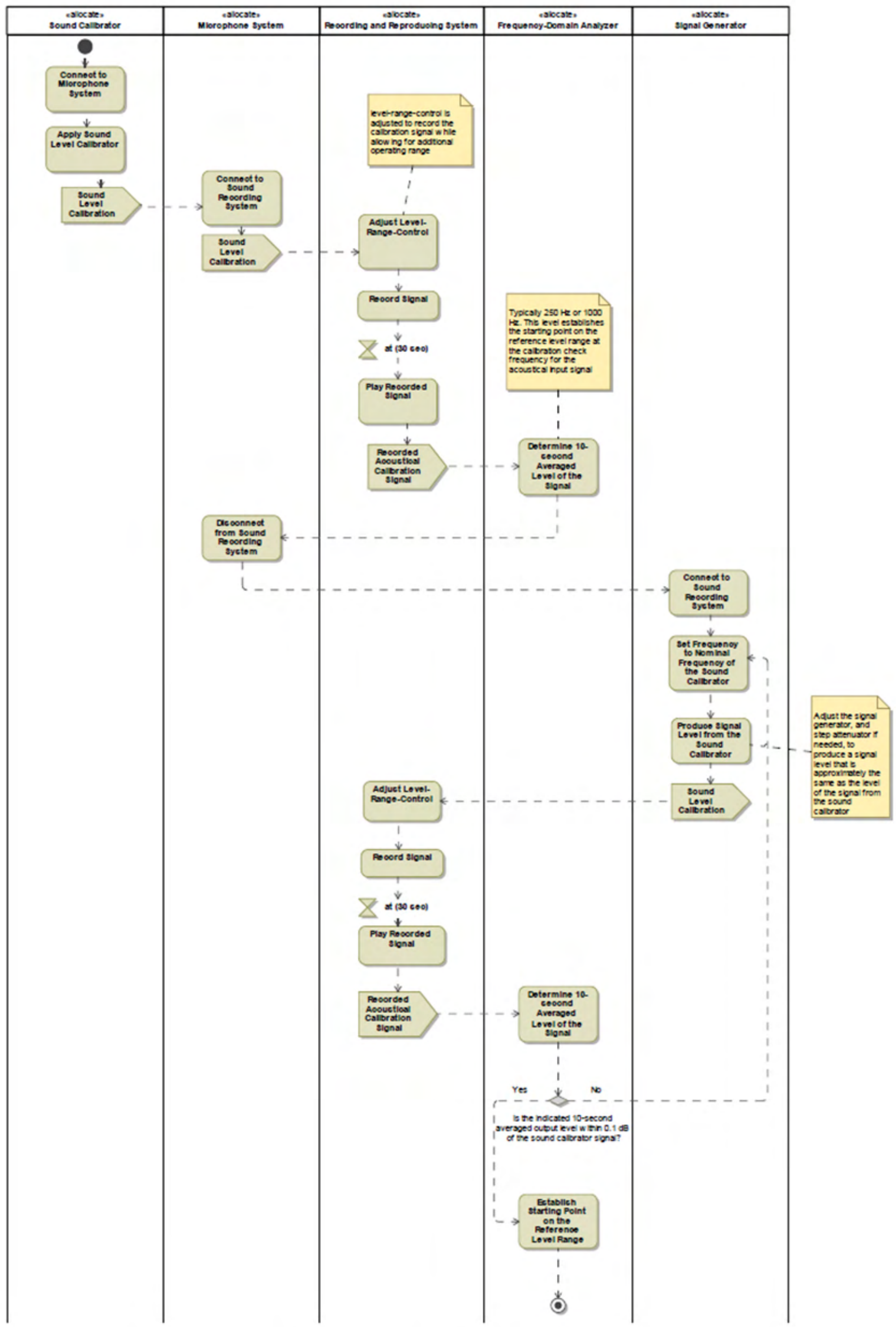


Figure 26. Process model for establishing a known reference noise level (baseline noise definition process).

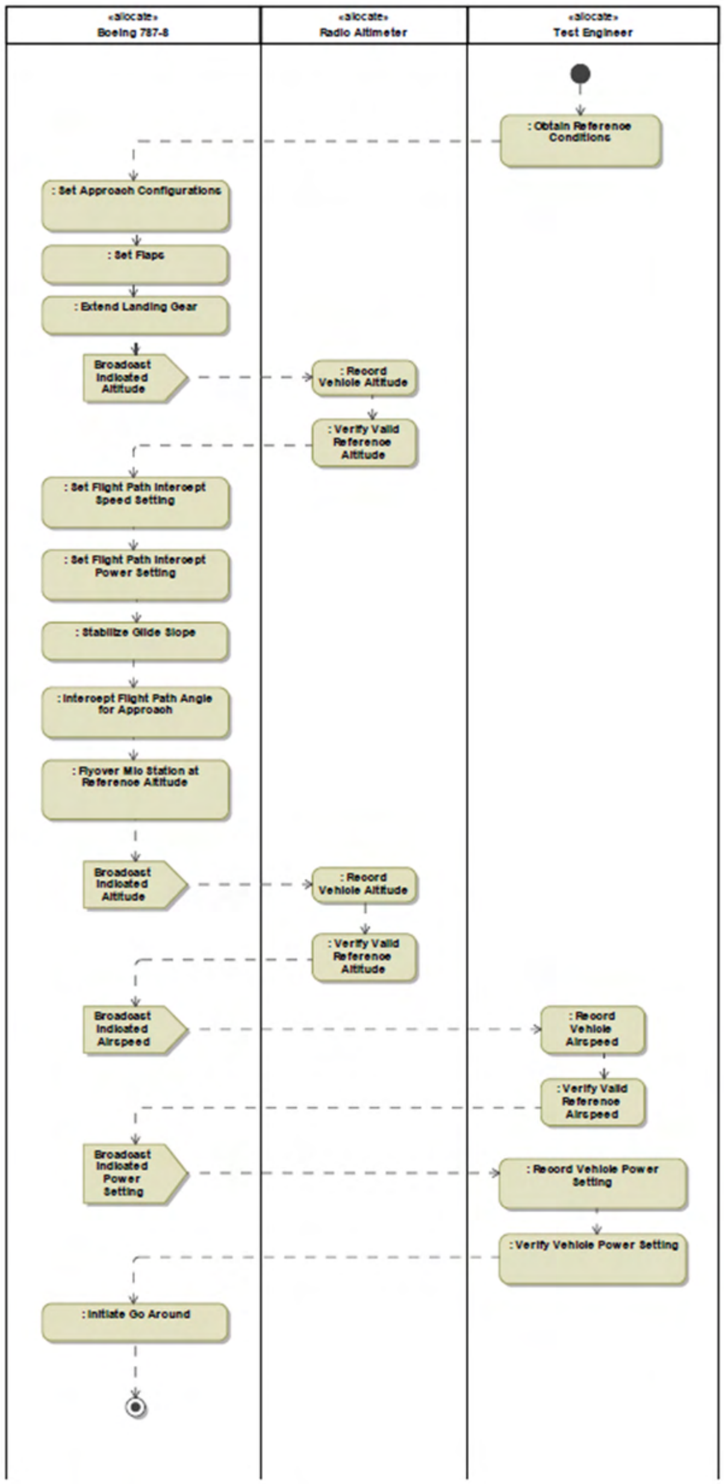


Figure 27. Behavioral process model for approach flyover.

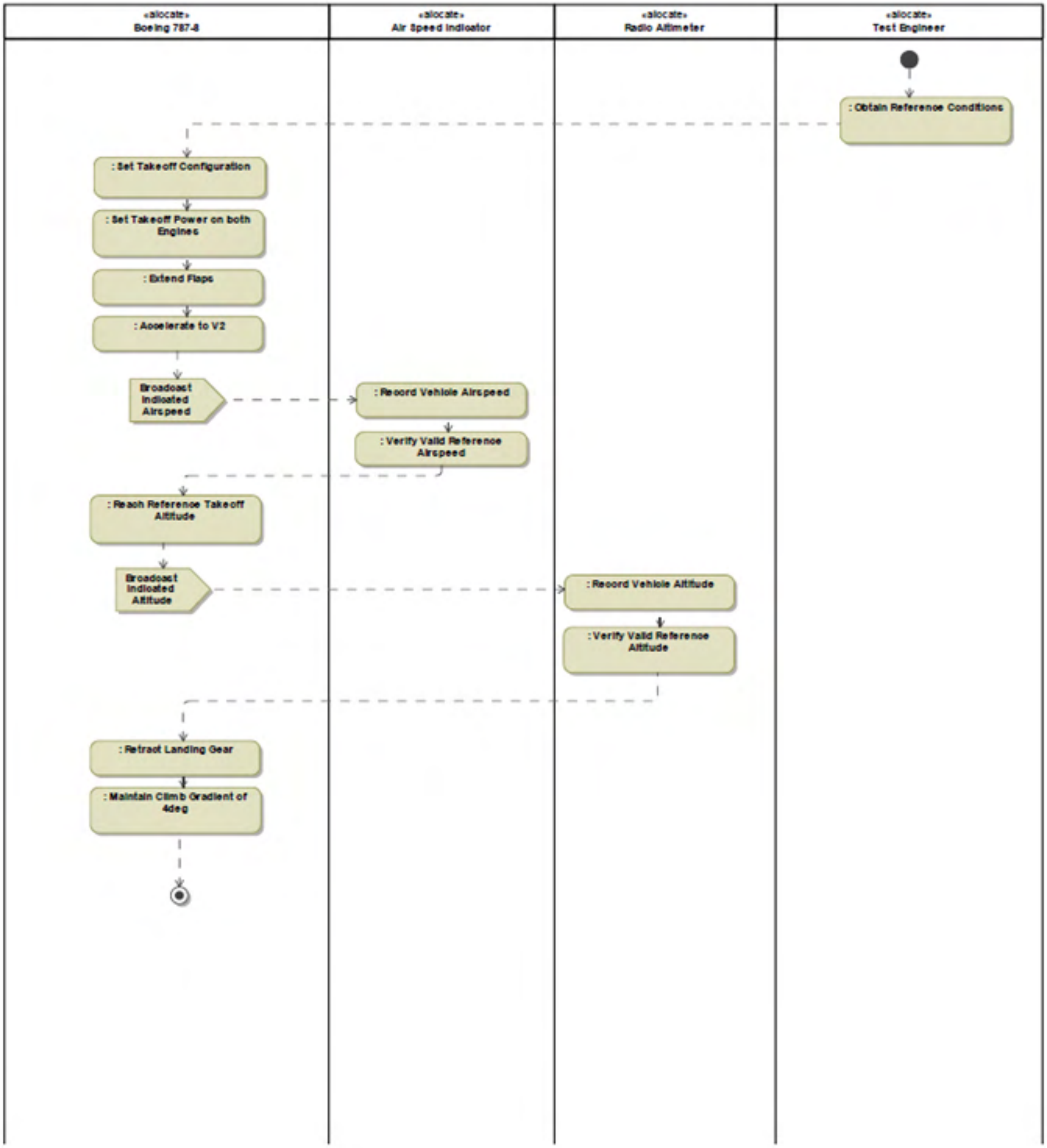


Figure 28. Behavioral process model for takeoff.

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

1. Product specifications
2. Technical baseline
3. Metrics
4. Verification compliance

The produced reports also include documents for certification, which include:

- Instrumentation validation document
- Flight test plan

Noise calculation is a key enabler under the noise testing instrument architecture module of the verification model. The goal of this module's function is to represent and capture the noise calculation process on the basis of flight test data within the model-based framework. The metrics of interest are as follows:

- Annoyance-based measure, or EPNL, as the effective perceived noise level (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 in a standard manner, as described in Annex 16.
- Loudness-based measure: The maximum sound exposure level is calculated in dBA units.

Before calculation of EPNL, corrections must be applied to measured data, which account for uncertainties related to the measurement system, the microphone and recording system used, background noise, the actual flight path, and the meteorological conditions when the measurements were taken.

The steps for EPNL calculation, per ICAO recommended practice, are as follows:

1. Perform conversion of sound pressure level to PNL (instantaneous perceived noise level) for each 0.5-s sample, by means of a Noy table (Figure 29)

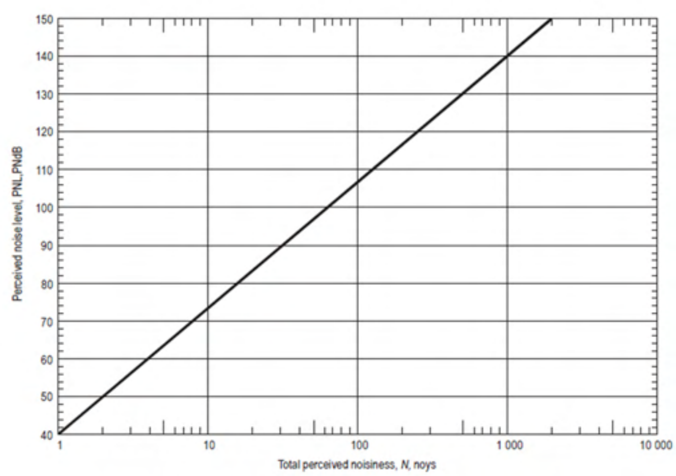


Figure 29. Perceived noise level as a function of total perceived noisiness.

2. Calculate tone-correction factor C to account for the subjective response to the presence of spectral irregularities
3. Calculate tone-corrected perceived noise level (PNLT) = PNL + C, at 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)

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

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

For the calculation of EPNL from measured noise data, three basic properties of sound pressure must be measured: sound pressure level, frequency distribution, and time variation. The PNL(*k*) measurement requires Noy table values (perceived noisiness as a function of sound pressure level) and a mathematical formulation, which requires constants for mathematically formulated Noy values (Figure 30).

BAND (*i*)	*f* HZ	SPL (*a*)	SPL (*b*)	SPL (*c*)	SPL (*d*)	SPL (*e*)	*M*(*b*)	*M*(*c*)	*M*(*d*)	*M*(*e*)
1	50	91.0	64	52	49	55	0.043478	0.030103	0.079520	0.058098
2	63	85.9	60	51	44	51	0.040570		0.068160	"
3	80	87.3	56	49	39	46	0.036831		"	0.052288
4	100	79.9	53	47	34	42	"		0.059640	0.047534
5	125	79.8	51	46	30	39	0.035336		0.053013	0.043573
6	160	76.0	48	45	27	36	0.033333			"
7	200	74.0	46	43	24	33	"			0.040221
8	250	74.9	44	42	21	30	0.032051			0.037349
9	315	94.6	42	41	18	27	0.030675	0.030103		0.034859
10	400	∞	40	40	16	25	0.030103			
11	500		40	40	16	25				
12	630		40	40	16	25				
13	800		40	40	16	25				
14	1 000		40	40	16	25			0.053013	
15	1 250		38	38	15	23	0.030103		0.059640	0.034859
16	1 600		34	34	12	21	0.029960	NOT APPLICABLE	0.053013	0.040221
17	2 000		32	32	9	18			"	0.037349
18	2 500		30	30	5	15			0.047712	0.034859
19	3 150		29	29	4	14			"	
20	4 000		29	29	5	14			0.053013	
21	5 000		30	30	6	15			"	0.034859
22	6 300	∞	31	31	10	17	0.029960		0.068160	0.037349
23	8 000	44.3	37	34	17	23	0.042285	0.029960	0.079520	"
24	10 000	50.7	41	37	21	29	"	"	0.059640	0.043573

Figure 30**.** Constants for mathematically formulated Noy values.

No option for directly performing noise metric calculations within SySML is available. 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 calculation of the effective perceived noise level, based on 14 CFR Parts 36 and 91 (More, 2011) was discovered in the literature. Expanding on the logical architecture library, the EPNL calculation has been implemented through block representation in the MBSE framework, which is shown in Figure 31. The integration was completed by effectively linking it to the MATLAB source code of this analysis through use of the Cameo Simulation Toolkit.

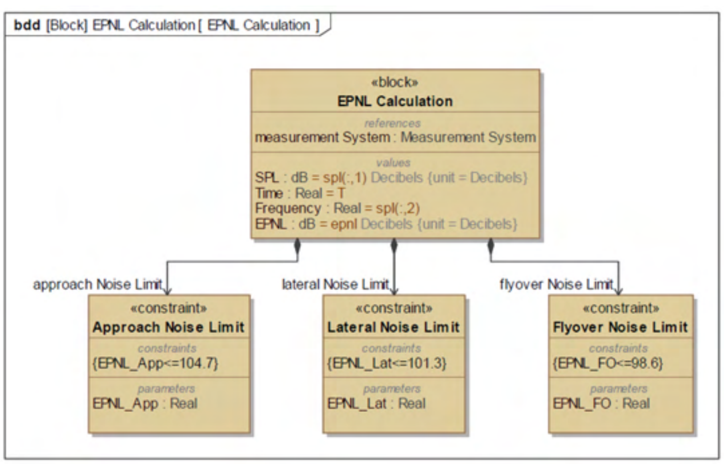


Figure 31**.** EPNL calculation model as a logical block in SySML.

After the progress made under Task 2.1, the current state of the verification model allows basic certification assessment for transport category configurations to be performed. However, the following improvements and additions will be required before the fully planned capability is in place:

- Build test constraints to the System Under Test (SUT) transport aircraft
  - Import Appendix B 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
  - Document the calculation process from raw noise data to EPNL
  - Import raw data into MBSE (if data become available)
  - Verify noise requirements by using EPNL converted noise data

Task 2.2

The objective for this task is to explore options for formulating and evaluating a streamlined certification process alternative. Feedback from the planned workshops and guidance by the OEM partners is used to inform the development of process alternatives in which streamlining is the main improvement criterion. Beyond the recommendations offered by the partners, the team has also been exploring what "streamlining" would mean in this context, to ensure that the chosen direction will provide added value across all partners and stakeholders. The target objectives for streamlining the certification process currently being considered are the following:

- More efficient process steps, with anticipated savings in time and cost: This direction could involve investigating time efficiencies, with the use of digital tools to expedite information exchange and reduce intermediate steps and proxies. Associated cost benefits may also be possible.
- Affordable solutions in the form of cost-effective use of technology: This direction could be operated with reduced maintenance costs and supporting resources (e.g., a technology allowing for omission of lateral microphones).
- Technology use that will facilitate data collection and predictive analysis: This direction could eventually improve planning and facilitation of flight testing campaigns.

Table 4 Summary of options for equivalent procedures, as provided by the workshop/interview feedback

Title/summary of EP or a grouping of EP's	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 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 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)			? (more of providing an option to certify engine change)
Cert by analysis (NPD extrapolation for design changes with predictable noise effects)	Yes (no flight test for derivations)	Yes (no flight test for derivations)	

(Note: This table provides an inclusive list of information collected through the partners' responses but does not indicate the final or any chosen direction; the direction remains under discussion between the team and the project partners.)

An earlier version of options for equivalent procedures (Eps) is presented in Table 4. However, in follow-up discussions with OEM partners, a consensus was reached that the use of MBSE tools provides a unique opportunity to address the technical challenges in noise certification at a level beyond only time and cost savings. Possible outcomes and use cases that would provide higher added value to streamlining noise certification (with input kindly provided by Boeing) are as follows:

- Explore options and possible recommendations for the simplification of setup requirements, to facilitate more test locations/weather windows (i.e., remove 4-ft microphones for ground plane, and remove lateral location altogether)
- Evaluate no-acoustical-change limits in the context of testing uncertainty
- Address conformity issues by formulating an acoustical conformity concept, which could be included in the MBSE-enabled framework

Another category of recommended use cases is associated with the expanded use of certification by analysis and exploration of the possibility of helping expedite the approval procedures within the FAA, as follows:

- Define criteria for approval for acoustical analyses that define new certification noise levels (acoustical change by analysis)
- Define a framework for oversight that gives the FAA confidence in manufacturers' tools/methods used in noise certification (defined audit guidelines/procedures)
- Update instrumentation/measurement recommended procedures to better align with currently available equipment/processes

Of primary interest should be the use of technology that seeks to simplify the certification process, thereby eliminating the added uncertainties and instances in which stakeholders (e.g., OEMs) have minimal or no control over process bottlenecks and unexpected emerging factors (e.g., the impacts of a pandemic, weather, or supply-chain or personnel issues). In addition, the simplification of the noise certification is directly linked to anticipated cost savings, because the same outcome could be achieved with fewer resources and reduced budget levels.

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 in which the MBSE framework can demonstrate, through the verification model, that a streamlined noise certification procedure is possible. That is, the streamlined alternative can result in quantifiable improvements with respect to the criteria listed above while meeting the same regulatory constraints and requirements that the current benchmarked certification procedure can meet.

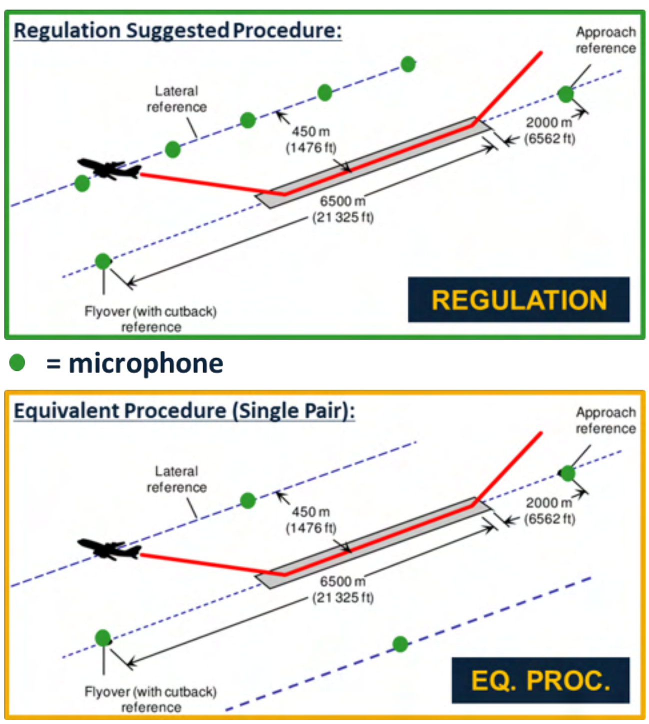


Figure 32. Equivalent procedure example: lateral microphone setup.

A potential use case currently under strong consideration and development by the team is the alternative setup and placement of the lateral microphone. Microphone setup must abide by regulatory requirements (B36.3, B36.4) regarding "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 hypothesis on this solution being effective in terms of time and cost savings, stems from the observation that complexity difficulties encountered when using multiple microphone arrays along the lateral line (multiple interference points, need statistical independence) are avoided. However, this solution covers a smaller sound field than multiple arrays and may require more test points to obtain sufficient data for compliance (accuracy and data quality). The top portion of Figure 35 shows how the microphone setup and their locations are currently chosen.

For the proposed equivalent procedure, a single pair of symmetric microphone stations is considered, with placement as shown in Figure 35. With the use of the verification thread, for a given aircraft model as the system under testing (SUT), the following constraints and requirements must be met:

- Full takeoff power, configuration, airspeed as in Regulation B36.7(b)(3-4).
- At several specified heights above a track (covers range 200-2000 ft).
- At right angles to and midway along the line joining the 2 mic stations.
- Matching data from both lateral mics for each fly-past should be used for the lateral noise determination.
- Adjusted noise levels: symmetric or asymmetric (one or two regression curves)
    - Usually second order; exceptional use of third order needs justification.
- Confidence interval of reported EPNL within ±1.5 dB (Regulation A36.5.4)
- Minimum of six runs necessary to obtain sufficient data for compliance

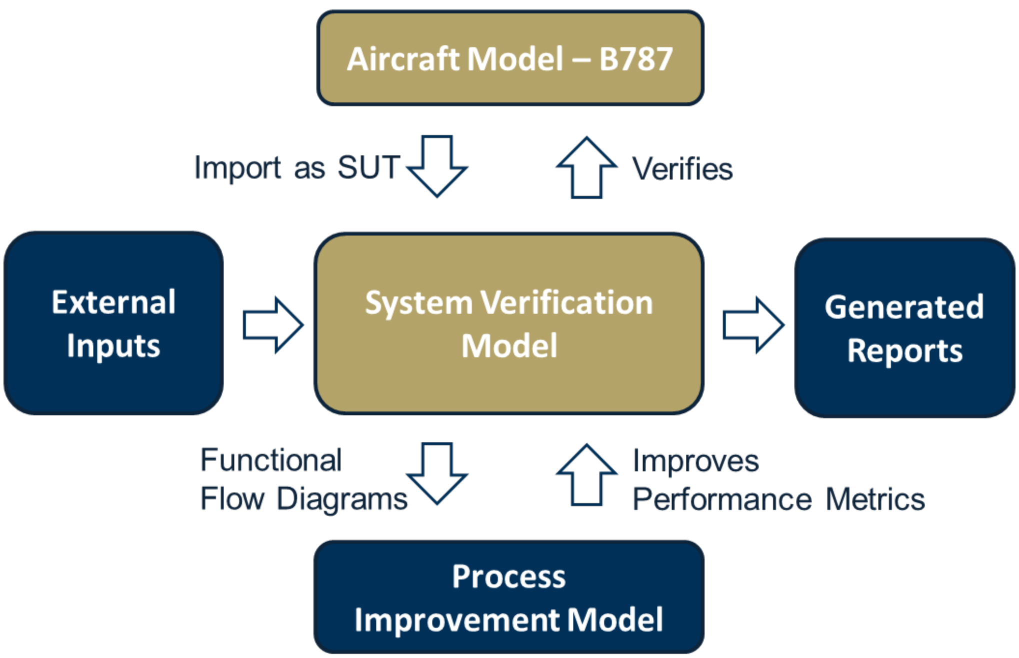


Figure 33. Complete MBSE framework for the evaluation of equivalent procedures, as part of exploring streamlined process alternatives for noise certification.

Because the steps of this task up to this point cover only the portion of demonstrating compliance through use of the MBSE framework, this use case will not be complete until a case is made that process improvements can be quantified regarding the use of fewer microphones. For this purpose, a process improvement model (PIM) is being developed under Task 4 and will be interfacing with the verification model, as shown in Figure 33. More information about the PIM development can be found under the section for Task 4.

Task 2.3
For this task, the objective is to further assess the viability of the proposed streamlined process and apply any revisions, according to feedback from the FAA, Volpe Center, and industry partners. The end goal is to complete a number of revisions to ensure that the streamlined process will meet expectations and provide added value across all project stakeholders. With the efforts toward completing Task 2.2 and a demonstration of a streamlined process, this task is currently underway and is pending additional workshops planned in the future, along with the team's further definition of metrics and evaluation criteria for the streamlined process assessment.

Milestones

- The first complete version of the MBSE noise certification process model has been implemented in SysML and is being updated based on feedback from workshops and interviews with the OEM partners.
- 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 was completed, in which equivalent procedures can be tested through a requirement verification model.
  - Importing of FAA noise certification regulations (Task 1), an aircraft model as the SUT, industry partner interview outputs (Task 1.2), and flight testing instrumentation procedures (e.g., the Volpe Center's recommended instrument validation) (Task 2.1) was completed.
  - The current certification process was modeled into the MBSE framework (Task 2.2), including definitions for requirements, validation architecture, and creation of a digital thread for requirement verification from data input.
  - Model data were output into auto-generated reports.
- Continual community outreach and interaction with OEM partners yielded technical feedback to improve model accuracy and capability (OEMs, Volpe, and FTHWG).
- Options for formulating streamlined process alternatives were narrowed through down-selection of equivalent procedures (e.g., exploration of lateral microphone setup and placement).
- The team became familiar with MBSE methods (e.g., SysML software tutorials, the RFLP approach, etc.).

Publications

Peer-reviewed journal publications
Listed under Task 1

Published conference proceedings
Listed under Task 1

Written reports
Listed under Task 1

Outreach Efforts

- Facilitated follow-up meetings with OEM partners
- Presented a demonstration of the MBSE-enabled certification concept to the Flight Test Harmonization Working Group (FTHWG).
- Presented the project's Year 1 performance review to the FAA Office of Environment and Energy, and Volpe Center
- Planned upcoming calls and expanded communication with the Volpe Center

Awards

None

Student Involvement

- The implementation of the verification model required substantial skillset development in SysML and use of software, which all students were successfully able to acquire.

- Three major roles have been maintained within the student team for implementation of the verification thread: (a) verification model development, (b) instrumentation for flight testing and noise analysis, and (c) requirements and constraint formulation based on Part 38, Appendix A and B.
- All students participated in the integration of all main enablers into the first complete version of the verification model.

Plans for Next Period

- Finalize the baseline model for current certification practices, incorporating feedback obtained through the workshops
  - This model will consist primarily of documented regulations and certification procedures (both regulatory and equivalent procedures), all compiled in SysML views.
- Next steps for MBSE framework development:
  - Perform model fine-tuning, ensuring a consistent format, reusability, and easy navigation setup
  - Obtain data for a specific application of a known test article for verifying a set of requirements for more relatable and realistic results
  - Define interfaces between instruments
  - Update current hardware diagrams with interface definitions
- Identify use-case examples to plan for demonstration, according to selected areas of improvement: The priority is to identify solutions seeking to simplify the certification process, either through use of technology and/or different technology setup configurations, or through use of data and analytics to automate steps and/or address uncertainties.
- 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 define what a more flexible certification process would look like and the evaluation criteria for determining that the procedure is more streamlined than the baseline. Task 3 will build upon the capabilities of the integrated MBSE platform and leverage contributions from all other tasks. The breakdown of tasks is as follows:

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 to the streamlined noise certification process to accommodate for 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 revision of the suggested process, incorporating key aspects of the collected feedback to build consensus the research partners

Research Approach

The main objective for Task 3 is to ensure that the certification process model in MBSE is sufficiently flexible to apply to other air vehicle categories. If this is true, the framework will be capable of testing and evaluating alternative certification process options and identifying those that can successfully accommodate the vehicle types of interest. One premise underlying the use of SysML in implementing an MBSE framework for certification is the feature of modularity, which should allow for rapid formulation of multiple streamlined process alternatives and rapid identification of the preferred option, according to the characteristics of a flexible process.

Task 3.1
For Task 3.1 (flexibility assessment of streamlined process), defining what is meant by a “flexible” process is important. One strategy is to assess whether the introduction of a different vehicle configuration would introduce a large number of incompatibilities with the streamlined process under evaluation. For instance, how does the rotorcraft configuration affect the type of microphone technology, the quantity needed, and the placement in the testing facility? Although switching the noise regulations and the noise instrument validation protocols to the new configuration might be straightforward and faster, if done within the MBSE framework, the compatibility of equivalent procedures might not remain the same as it was when the streamlined process was applicable to a transport category vehicle. The flexibility criteria for a streamlined process could comprise 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, the vehicle is more sensitive to the variation of certain factors during testing.
- Sensitivity to non-acoustical change, different than other categories.
- Sensitivity to weather, etc.

In short, one way to evaluate the flexibility for a streamlined process alternative is to focus on the equivalent procedures that make the process more streamlined than the baseline, and to understand the factors that eliminate their benefits, if a configuration is chosen, other than the one for which it was streamlined.

Task 3.2
The definition of what constitutes a “streamlined” process may depend on the vehicle configuration. Hence, to evaluate the flexibility of a streamlined process, the vehicle type(s) for which the process is streamlined would need to be accounted for, and the assessment comparison would need to be performed on that basis. Therefore, investigation of process efficiency metrics to support characterization and comparative assessment of the current certification process and alternatives is underway, with the requirement that the metrics be agnostic to the vehicle configuration type.

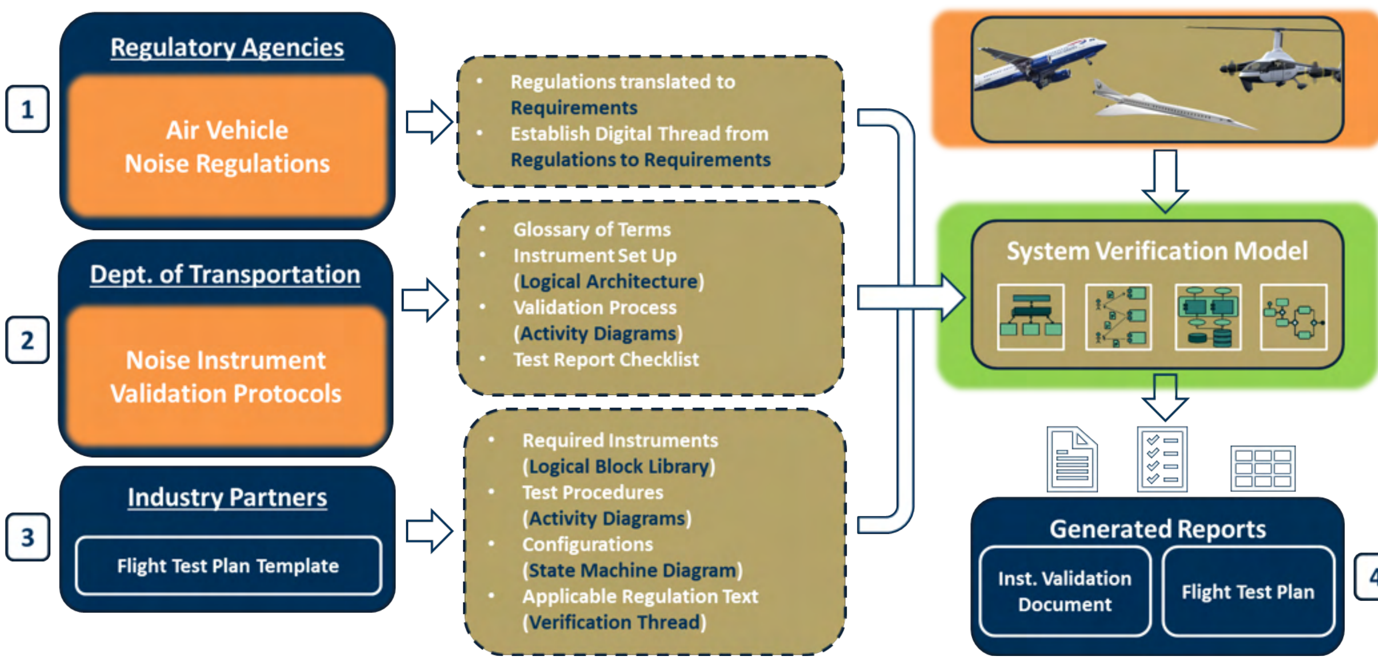


Figure 34. Verification model for multiple vehicle configurations

With the verification model now available for transport category, the first spiral iteration of the proposed concept for evaluating a flexible certification process has been formulated and is presented in Figure 34. The original model is flexible to accommodate a different set of regulations as one of the inputs which, like in the transport category example, will undergo the conversion to requirements by establishing a digital thread and a requirements model applied in SysML. While the function is currently not "plug and play," algorithm modifications for the logical conversion are in progress. Similarly, the noise instrument validation protocol conversion to SysML views is underway. However, the vehicle representation model is more straightforward, because it is not process dependent, and the interface definitions might possibly require modifications for this module to seamlessly integrate with the verification model.

According to the workflow proposed in Figure 34, the integrated framework for flexibility assessment of the certification process is shown in Figure 35. The key difference between this view and that used under Task 2 development for the transport category vehicle is the addition of a PIM. Although this module is currently developed under Task 4 activities, it will be integrated in the flexible MBSE framework, in which process alternatives will eventually be formulated, and evaluated through the PIM.

Task 3.3
For this purpose, metrics are developed under Tasks 3 and 4, which will allow for measuring process flexibility and other relevant figures of merit as part of comparing alternatives to the baseline. The first version of the discrete event simulation model has been completed for evaluating process efficiencies. After calibration of the model with inputs and parameter definitions that will be obtained by OEM partner input, the model will return time durations between key events, and allow for statistical analysis and identification of process bottlenecks and show-stoppers. Another set of metrics for characterizing complexities are under development, which will target the need to further simplify the process through the use of technologies allowing process steps to be reduced or eliminated. More information on PIM development is provided under Task 4 reporting, and Task 3 activities will seek to provide several use cases of interest according to the input and technical feedback provided by OEM partners, FAA, and the Volpe Center.

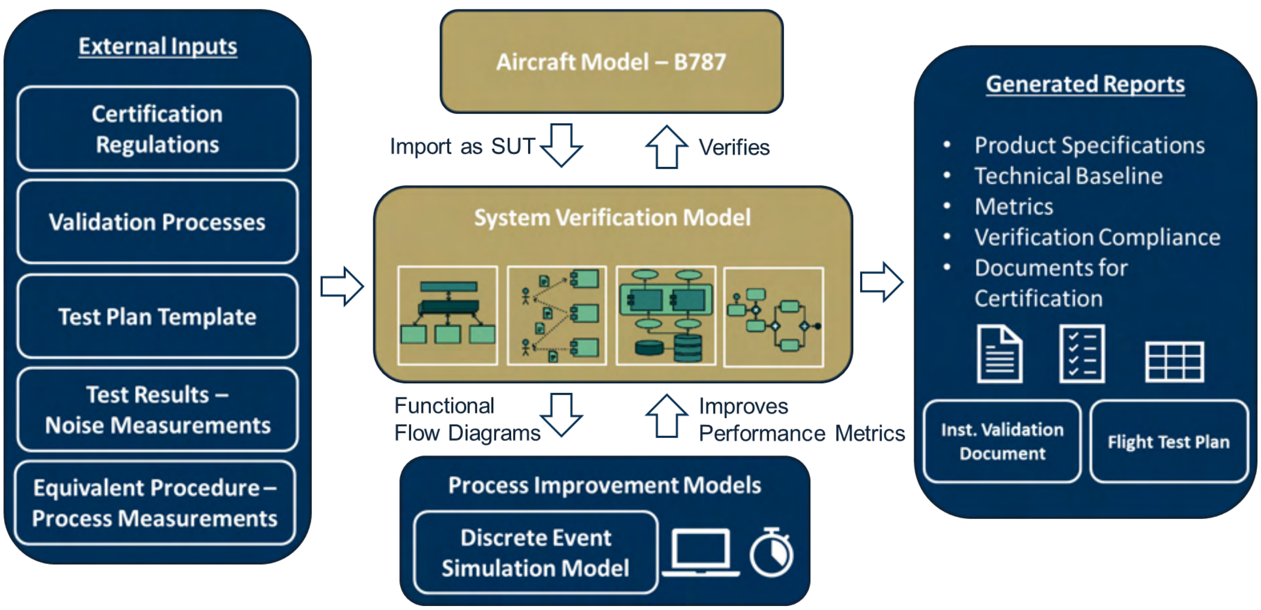


Figure 35. Integrated modeling and assessment framework for flexibility evaluation of certification procedures.

Milestones
Listed under Task 1

Major Accomplishments
- The initial concept for the MBSE framework has been formulated to accommodate multiple vehicle types and allow for process effectiveness and flexibility evaluation.
- Metrics development is underway, with demonstration examples planned to solicit input from OEM partners and stakeholders.

Publications
Peer-reviewed journal publications
Listed under Task 1

Published conference proceedings
Listed under Task 1

Written reports
Listed under Task 1

Outreach Efforts
Listed under Task 1

Awards
None

Student Involvement
The full student team has participated in brainstorming sessions for formulating the integrated certification process assessment framework shown in Figure 35.

Plans for Next Period
- Implement concept and demonstration of a simple use case (with input for streamlined process definition, as decided by Task 2 activities)
- Finalize metrics for assessment of process flexibility
- Formulate a decision support concept for selection of technology or equivalent procedure options, which will leverage the MBSE framework analysis and evaluation features, toward an end goal of an interactive capability allowing planners to evaluate alternatives in equivalent procedure selection and identify simplified, more flexible certification process alternatives

Task 4 - Simulate Streamlined and Flexible Noise Certification Procedure
Georgia Institute of Technology

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

Task 4.1: Identify Modeling Approach
- Explore options for modeling approaches 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 quantitative comparison of the current and proposed noise certification processes

Task 4.3: Model Calibration
- Identify a benchmark for noise certification procedure simulation
- Calibrate the noise certification procedure simulation

Task 4.4: Certification Process Simulation
- Execute simulations of current and proposed noise certification procedures

Task 4 focuses on exploring and identifying suitable process modeling approaches for the simulating the noise certification procedure. On the basis of this objective, this task aims to deliver a solution broadly referred to as a Process Improvement Model (PIM). Tasks 4.1 to 4.3. seek to explore suitable enablers of the PIM implementation, and Task 4.4 aims to integrate the PIM into the current MBSE framework. The chosen modeling approach should accommodate process performance evaluation and provide responses back to the verification model for completing steps regarding meeting requirements and compliance. In addition, the PIM must be flexible and reusable according to the definitions of the certification process, equivalent procedures, etc., as they are formulated within the verification thread. Overall, a closed loop is defined between the verification thread and the PIM(s), which are implemented under Task 4.4. An overview of the integrated verification thread and the PIM(s) is shown in Figure 36.

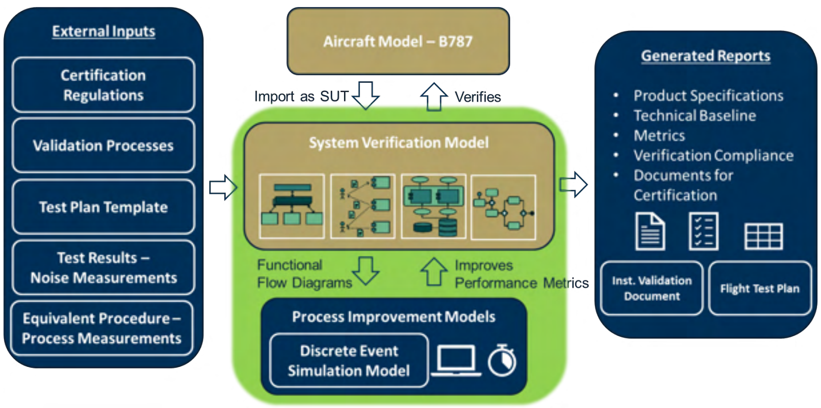


Figure 36. Process Improvement Model (PIM) integration into the verification thread within the MBSE framework for certification.

Task 4.1

The team has completed a literature review on the following process modeling methods to enable process simulation:

- Discrete Event Simulations (DES), wherein a clock tracks the duration of the transition between model states
- Agent-based simulation (ABM) methods.
- System dynamics
- Markov chain–Monte Carlo (MCMC) simulation

These techniques are evaluated according to how well they could capture and simulate actual industry-applied procedures and their ability to interface with the verification thread.

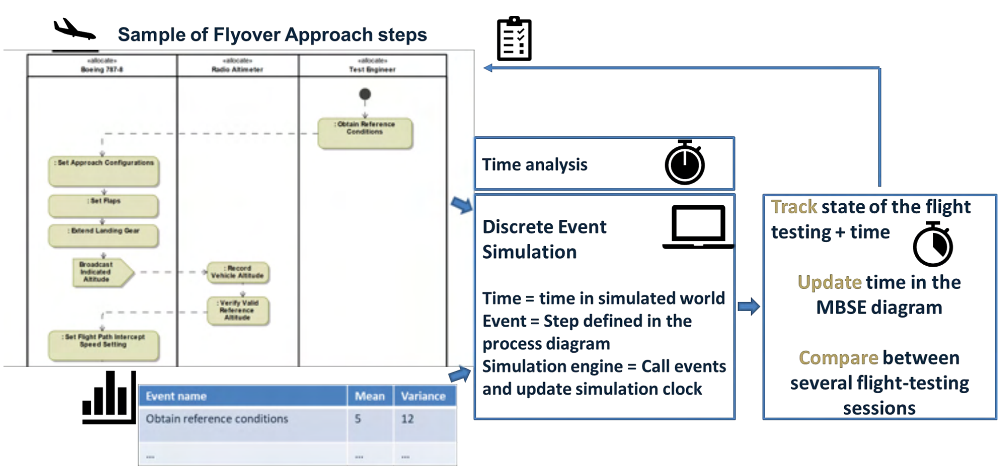


Figure 37. Discrete event simulation for flyover approach.

The first option for the DES model was the approach originally chosen. The first demonstration version of a certification process model, using DES methods in a Python-based environment, is now completed. An example for a flyover approach has been implemented and is shown in Figure 37. In this example, a proof of concept was put in place to show how the process model, as defined in the MBSE framework, can be simulated by 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 the process diagram is updated in the verification model, which then performs checks against requirements and compliance.

However, because flight testing procedures carry uncertainties that must be considered as equivalent procedures are formulated, a more comprehensive modeling approach is needed. To account for the uncertainties surrounding process performance, development of a probabilistic model using Markov chains is underway to improve the process assessment capability. This approach is better suited to support use cases, where the objective is to further simplify the FAA's recommended procedures by eliminating steps, replacing, reducing, or even eliminating the presence of certain technologies. Other recommendations, such as a conformity model, could be better tested with a probabilistic approach, in which a broader range of scenarios could be tested.

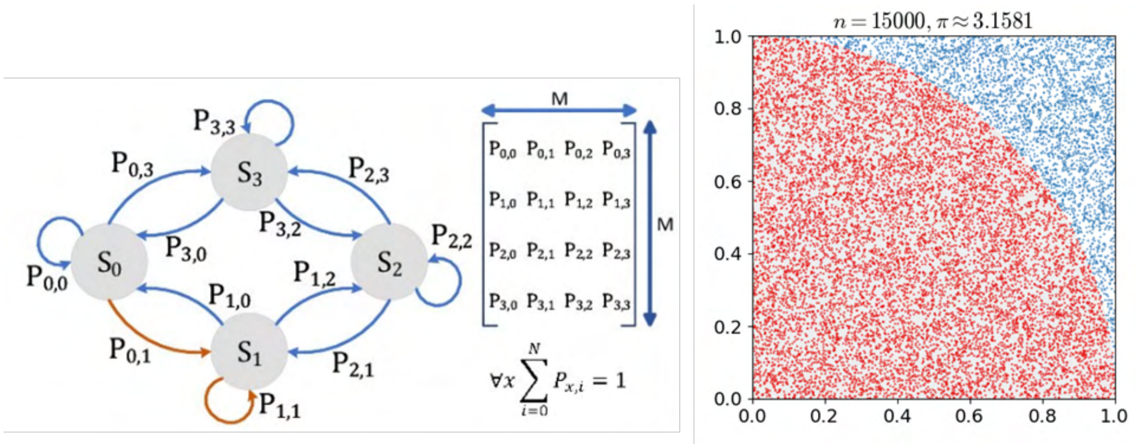


Figure 38. MCMC: Markov Chain Monte Carlo.

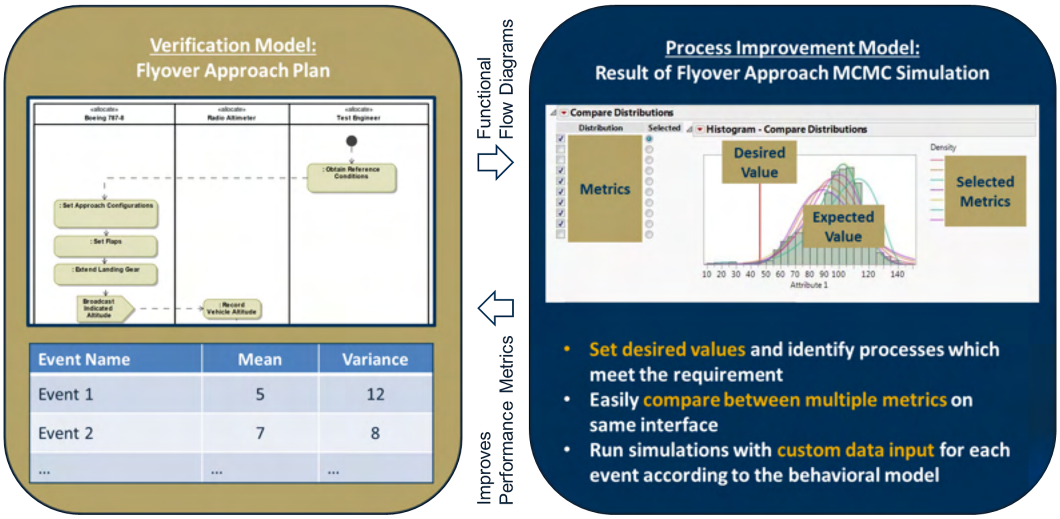
An example of such an approach is the MCMC approach, wherein a discrete event simulation model is used to run a Monte Carlo study to collect sample runs, given an input probability matrix and stakeholder value function. Each run will be associated with incurred time, cost, and an accuracy penalty; the output will be provided in the form of activity diagrams and responses, which are fed back to the verification model within the MBSE framework. An example view of the MCMC is shown in Figure 38.

Table 5 Step-by-step sequence MCMC data format for acceptance-rejection sampling.

Step #	1	2	3	4	...
Event	A	A	B	C	...
Time	+5	+5	+2	+2	...
Cost	+10	+8	+5	+7	...
Accuracy	1.0	1.0	0.99	0.98	...

Within the MBSE framework, the MCMC simulation data are then imported for performing acceptance-rejection sampling, wherein each run (with its associated metric) will be accepted or rejected by requirement constraints within the verification model. The format of the MCMC simulation data follows a step-by-step sequence (similar to a discrete event simulation), as shown in Table 5.

A simple example of the implementation path summarizing the development of the PIM is shown in Figure 39, in which the interfacing with the verification model is further explained. In the example of a flyover approach plan similar to that in Figure 37, the process model informs the PIM, which converts the flyover approach test into an executable simulation model. Given the type of requirement tests in which a user is interested, the appropriate response values are chosen, and parametric settings for the baseline values (e.g., time, cost, resources, disruption risks, and accuracy penalty), as well as MC distributions are chosen. The simulation then generates the PIM metrics and prepares the dataset for the verification.



Event Name	Mean	Variance
Event 1	5	12
Event 2	7	8
...	...	...

Figure 39**.** Example of DES – time analysis for a flyover approach planning scenario.

Depending on the requirement acceptance-rejection distributions, changes to the process model (e.g., by incorporating equivalent procedures, modifying recording lineups, considering conformity models, etc.) will be proposed, and then another iteration cycle will be ready to be executed. The long-term benefit is that the process will evolve as a key function for testing the feasibility of equivalent procedures, then scaling up to characterize the flexibility of the streamlined noise certification process that users actively formulate within the MBSE framework.

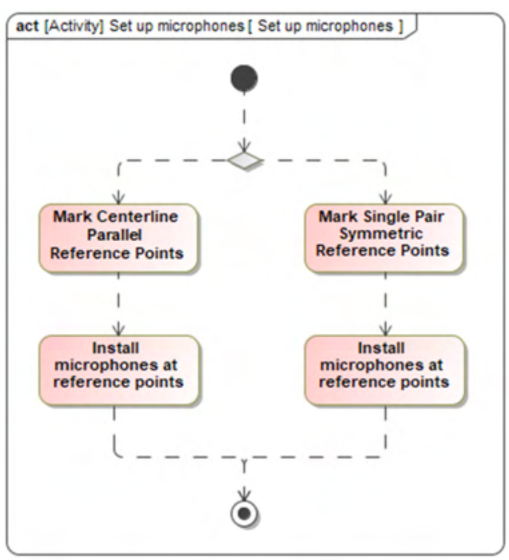


Figure 40**.** Example activity diagram for microphone setup.

Task 4.2
Within this subtask, the team has been exploring options for sets of metrics that will allow for quantitative comparison of current and proposed streamlined noise certification process options. The current list of identified metrics is the following:

- Time: schedule cost incurred to complete event
- Cost: budget cost incurred to complete event
- *P*(failure): probability of repeating the event (does incur time and cost [full or partial] for 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 additional cost for each occurrence)

A stakeholder value function is formulated to represent an overall evaluation of the process, and to help characterize flexibility and the resulting added value for a particular stakeholder. One main observation from the responses recorded in Task 1.2 was that not all OEMs and stakeholders maintain the same needs and improvement recommendations, and the priority varies. A stakeholder value metric would allow the process evaluation method to be tailored to stakeholder preferences.

$$\llbracket Value \rrbracket\_Process = F(Cost\_Schedule,\ Cost\_Budget,\ Risk,\ Stakeholder\ Importance\_(Schedule,\ \mathrm{Budget},\ \mathrm{Risk}))$$

As mentioned previously, the team is expanding on this task to identify metrics that go beyond the efficiency-oriented focus of the original process streamlining concept. Another objective involves identifying ways to accomplish process simplification, which could be reflected in reducing or combining steps, eliminating feedbacks and redundant actions, and possibly removing tasks, if a technology in which data and information are automatically circulated could provide the same expected outcomes. Hence, new sets of metrics will be needed to characterize such alternatives and incorporate them in the MCMC analysis before the verification step.

Task 4.3
This task requires a completed process simulation capability implementation to allow the team to Identify a benchmark for noise certification, against which the PIM model can be calibrated. The current PIM development plan is shown in Figure 41. The team has identified all necessary enablers and is finalizing a demonstration version of the implementation approach. Given that scalability issues are bound to appear as this model is expanded to reflect the full verification thread, the next step is to discuss options for data that ASCENT 61 partners could provide for further calibrating the model, according to the preferred use cases.

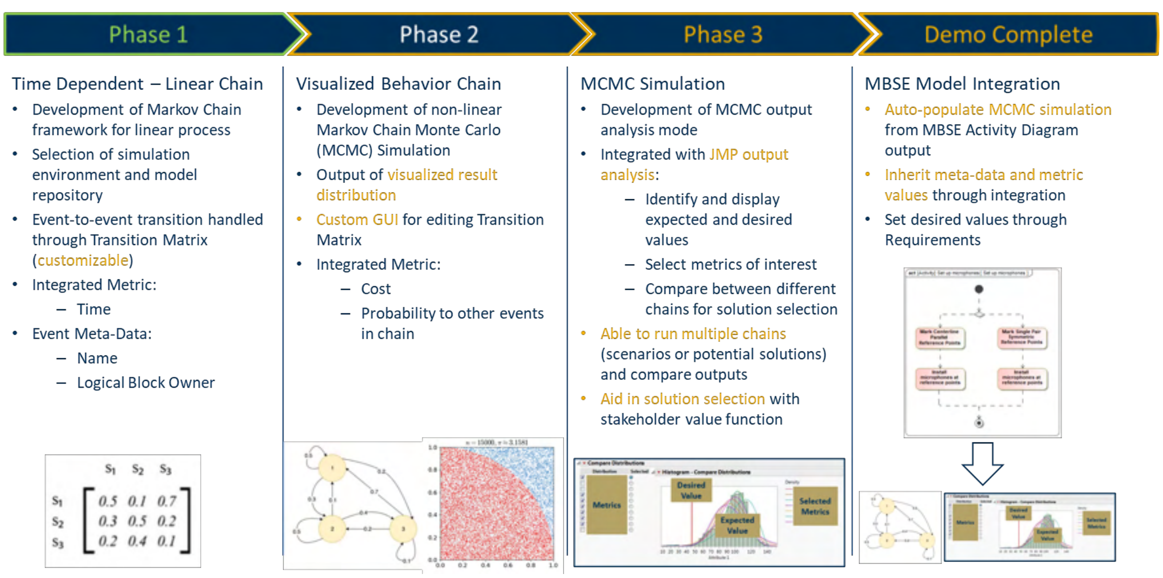


Figure 41. PIM functional development plan.

Task 4.4
Because this task will be performed further in the future, the team has been formulating use-case examples based on scenarios provided by the OEM partners. Under these examples, simulations of current and proposed noise certification procedures will be planned for.

Milestones
Listed under Task 1

Major Accomplishments
- Literature review on process modeling methods (DES, ABM, and SD, and stochastic [MCMC] methods) for enabling simulation and assessment of the noise certification process
- Development of a small-scale PIM by using DES
- Development of a more comprehensive stochastic model by using stochastic MCMC methods, formulated to seamlessly integrate to 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
    - Because the process improvement direction could become more diverse and consider goals for further process simplification and integration with other concepts, additional metrics have been added and mapped to use-case scenarios that the team will be using for a full-capability demonstration in the future (year 2 activities).
- Approach for Integrating the PIM model into the verification model within MBSE

Publications
Peer-reviewed journal publications
Listed under Task 1

Published conference proceedings
Listed under Task 1

Written reports
Listed under Task 1

Outreach Efforts
- Presentation of concepts to the Volpe Center, and collection of their technical feedback on the tools and analytic methods
- Discussions with experts in fields with similar problem applications, e.g., process simulations for industrial systems, manufacturing, supply chains, etc.

Awards
None

Student Involvement
Although a small portion of the team has been leading the technical approach to PIM development, involving the full team in the tasks, e.g., PIM integration with the MBSE model, will be a key enabler to be addressed earlier in the process.

Plans for Next Period
- Complete the PIM implementation steps as described in Figure 41, in which the outcome should be at the full verification model scale
    - Finalize interface with the MBSE verification model
    - Determine equivalent procedures to showcase
    - Fabricate data to show functionality
    - Select metrics for test scenarios
    - Develop value function for multi-factor optimization between equivalent processes
    - Calibrate model according to technical input from industry OEMs and the Volpe Center

- Expand on metrics definition beyond process inefficiencies (e.g., directly addressing time and costs), and consider complexities that could affect the process with bottlenecks and the unnecessary use of resources (e.g., duplicate testing, time-intensive procedures, etc.), with a primary focus on the flight-testing part of the process
- Formulate a simple certification problem per vehicle type and use it in pilot tests for comparing and selecting the appropriate method

Conclusion – ASCENT 61 Year 1 Summary

The following key tasks and activities have been completed under the ASCENT 61, year 1 performance period:

- Completed documentation of current noise certification regulatory framework (14 CFR Part 36, AC 36-4D) with input from the literature and partner interviews/workshops
- Hosted workshops/interviews with industry partners for transport category aircraft (jet and turboprop)
- Benchmarked current practices in certification flight testing, and identified key technical challenges and improvement opportunities
- Developed a working version of the process model on current noise certification procedures in SySML, made possible by input and guidance from OEM participation in interviews
- Established connection with the Volpe Center, and plans for model review and technical feedback
- Performed broader outreach of A61 to the aviation community on noise certification
    - ASCENT Fall/Spring meetings
    - Presentation to Flight Test Harmonization Working Group (FTHWG).
- Annual and quarterly reports made available to the ASCENT KSN database
- Plan for publication of OEM contributions and applied SySML technical capabilities in conferences and peer-reviewed journal articles

References

[1] Metzger, F., & Foley, W. (1970). STOL Aircraft Noise Certification: A Rational Approach. SAE Transactions, 79, 1021-1031.
[2] Federal Aviation Regulation, Part 21, Certification Procedures for Products and Ports; Part 36, Noise Standards: Aircraft Type Certification. December 1969.
[3] J. B. Ollerhead, "Subjective Evaluation of General Aviation Aircraft Noise." FAA Technical Report NO-68-35, April 1968.
[4] Senzig, D.A. and Marsan, M., 2018. UAS Noise Certification.
[5] FAA 14 CFR Part 36 - NOISE STANDARDS: AIRCRAFT TYPE AND AIRWORTHINESS CERTIFICATION.
[6] FAA Advisory Circular 36-4D - Noise Standards: Aircraft Type and Airworthiness CertificationAdvisory Circular 36-4D - , date Issued October 12, 2017.
[7] FAA, *Details on FAA Noise Levels, Stages, and Phaseouts* Available: https://www.faa.gov/about/office_org/headquarters_offices/apl/noise_emissions/airport_aircraft_noise_issues/levels/.
[8] Aleksandraviciene, A. “MagicGrid Book of Knowledge. Kansas, 2018. NoMagic.
[9] More, “Aircraft Noise Characteristics and Metrics”, Ph.D thesis Dissertation, Purdue University, 2011.

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

Federal Aviation Administration rules are 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, and Advisory Circular 36-4D (procedures and steps for noise certification) [6]. 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 their standards align with International Civil Aviation Organization (ICAO) noise regulations and adapt to changing noise mitigation technologies [7]. ICAO noise regulations (Chapter 3) used the FAA's FAR36 Stage 3 as a starting point. Other national aviation authorities, such as the European Union Aviation Safety Agency (EASA), have practices that may differ from FAA requirements.

The intent is to identify any potential gaps in the team's understanding of the noise certification procedures, or detect any equivalent procedures and accepted means of compliance that should be noted. In Figure A1, an overview of the process is summarized and divided 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.

In the following subsections, the team's findings and high-level process views are included.

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

Phase 0: Checking Environmental Factors
The goal of this phase is to measure and verify that the weather and testing conditions are appropriate. The process includes checking the wind velocity and abnormal meteorological conditions. In addition, the terrain must be verified to meet the appropriate FAA specifications. If a non-airport test site is sought, the test-site criteria must be followed. Figure A2 provides a visual summary of the checks that must be put in place before field setup.

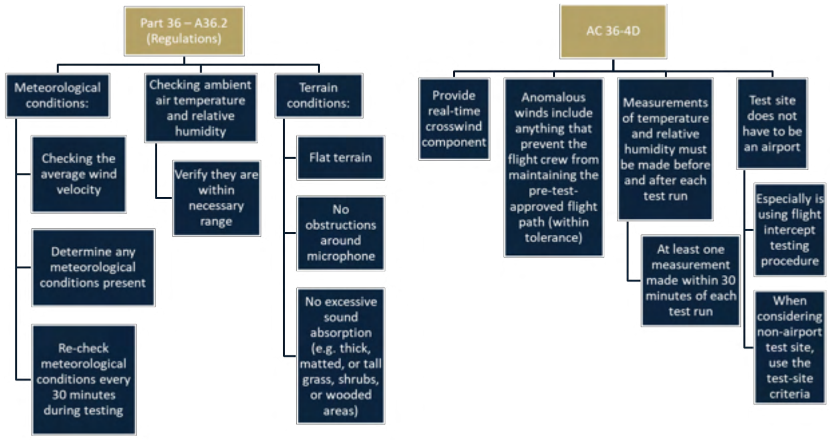


Figure A2. Phase 0: Checking environmental factors.

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 there another location that is typically used? If elsewhere, where are the certification procedures completed?
- How difficult is obtaining FAA approval to conduct the test at another location besides an airport?
- If an organization has multiple certification sites, how does testing differ among them (e.g., in the number of trials needed for successful certification)?

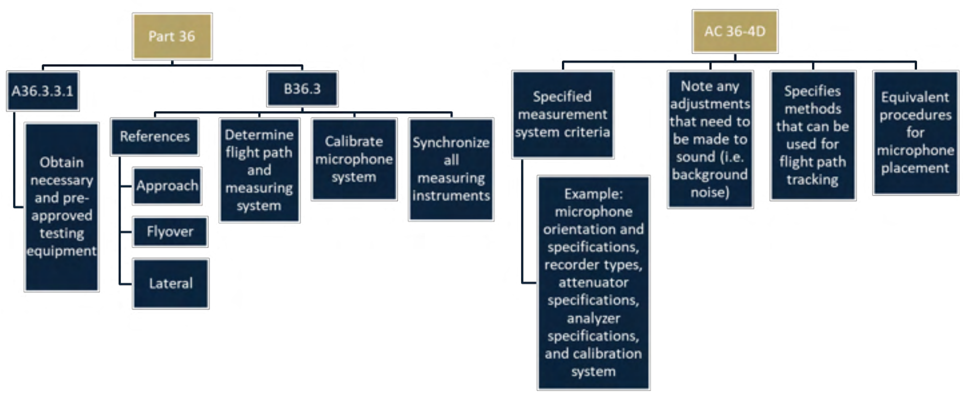


Figure A3. Phase 1: Field Setup.

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 the approach, takeoff, and lateral microphones, which must be calibrated. Two equivalent procedures 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.

According to Phase 1 benchmarking, the team has identified the following inquiries addressed to industry partners:

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

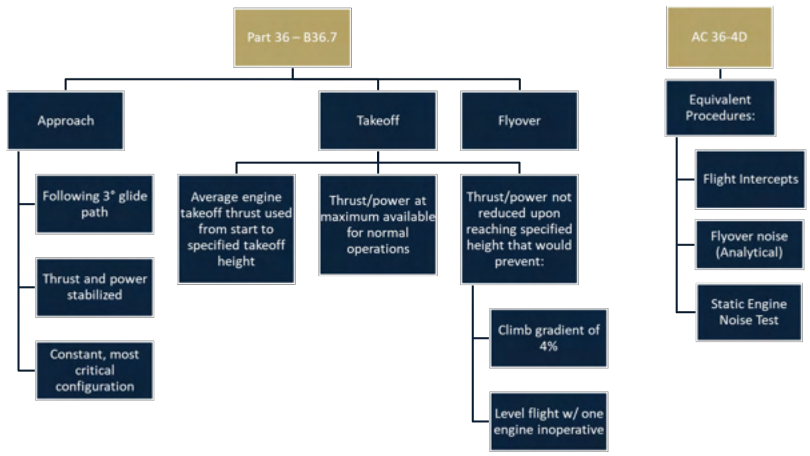


Figure A4. Phase 2: Testing.

Phase 2: Testing

Testing procedures, as 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 operational and cost advantages at high gross weight, while substantially decreasing the test time required and site selection issues. The shorter test time additionally provides a high probability of stable meteorological conditions, reduced wear, and reduced fuel consumption, while increasing the consistency of the data generated.

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, by merging measurements of PNLT versus time measurements obtained during constant power operations.

Finally, static engine noise tests and projections to flight noise levels (403.a.3) are performed when changes are made to powerplants or similar powerplants are installed. This process is also preferred after initial noise certification of a "datum" airplane. This procedure provides sufficient additional data or source noise characteristics to enable predictions regarding the effects of changes on the airplane certification noise levels.

In summary, phase 2 requires takeoff, flyover, and approach flight tests for noise certification to 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 test(s) (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, as also outlined in detail in Figure A5:

- Find perceived noise level PNL(*k*)
- Correct for spectral irregularities
- Determine duration correction
- Determine EPNL

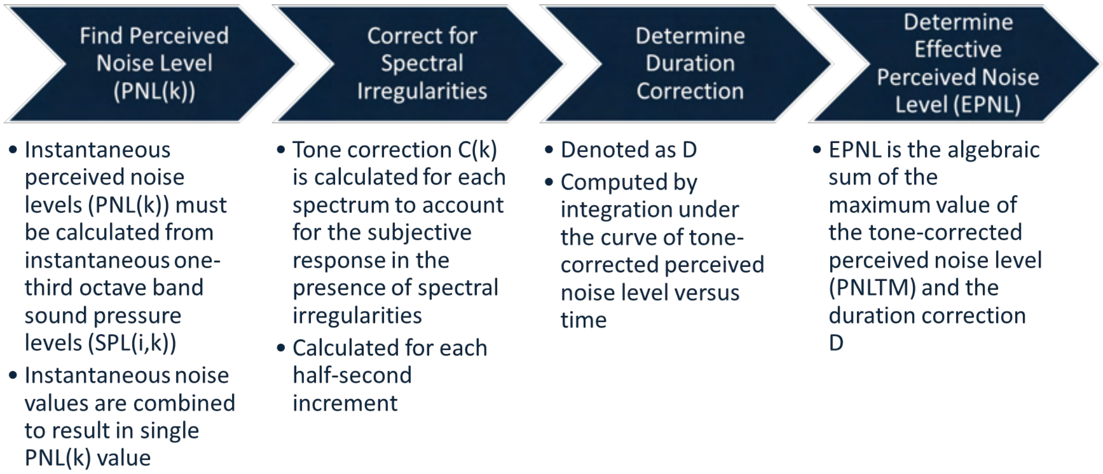


Figure A5. Phase 3: analysis steps for calculating EPNL.

EPNdb is a measure of human annoyance in response to aircraft noise, which has special spectral characteristics and persistence of sounds. The EPNL (measured in EPNdB) consists of instantaneous PNL corrected for spectral irregularities (tone-correction factor) and for duration.

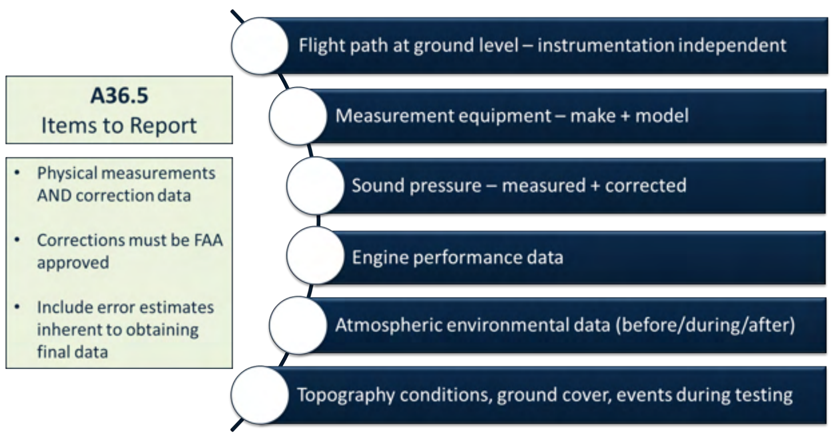


Figure A6. Phase 4: reporting.

Phase 4: Reporting
In this phase, the goal is to ensure that the correct types of data that must be recorded during analysis are selected and meet the given FAA requirements, e.g., inclusion of error estimates. This phase also determines what material 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 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), or 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?

Simplified Questionnaire (Used on January 2021 and after)

Topics of discussion:

- **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)