Propulsion Airframe Aeroacoustics and Aircraft System Noise Flight Test on the Boeing 787 ecoDemonstrator 2020

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Background and Overview

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Acoustics Personnel and Project Contacts

This NASA task is funded by the Advanced Air Transport Technology Project.

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In addition to supplying key pretest predictions on Charts 20-21 (and other images from this presentation as needed), we expect to provide photos from the flight test as soon as they are available.
Outline

• Summary
• Uniqueness and Impacts
• Timeline
• Key Definitions
• NASA’s Aircraft Noise Prediction Program (ANOPP) and Improvements In Development
• Importance of Flight Research
• Key Ideas in the Design of this Test
• Description of this Flight Research Test
• Future Impacts/Directions
Summary

- Boeing will perform the NASA Propulsion Airframe Aeroacoustics and Aircraft System Noise Flight Test on the 2020 ecoDemonstrator Program with an Etihad Airways Boeing 787-10
- The NASA test is scheduled for four days of testing during the window of August 25th through 31st.
- This is a dedicated NASA task, developed and planned for the past several years in close collaboration between NASA and Boeing combining the unique capabilities and expertise of each organization:
  - NASA’s test objectives, prediction methods, and test design ideas
  - Boeing’s flight test experience, acoustics engineering capabilities and instrumentation
  - A state-of-the-art 787-10 aircraft
- The ambitious objectives require high-resolution near- and far-field acoustic data from over 1200 microphones both on the ground and on the aircraft and for a range of flight conditions and maneuvers.
- Following the test, the data will be used for many purposes and for many years.
Uniqueness

Uniqueness (Why is NASA interested?):

- **First ever** NASA flight test for vehicle-system level acoustic objectives.

- First ever NASA flight test that studies the individual noise sources, their interaction with the airframe also known as propulsion airframe aeroacoustics (PAA), and how they combine to the total aircraft system noise.

- **First ever** NASA flight test to measure shielding and reflection PAA effects, applicable to both conventional and unconventional aircraft using an innovative NASA approach.

- Most highly instrumented NASA acoustic flight test to date (991 mics on-ground, 214 on-aircraft) to yield high resolution data.

- **First NASA acoustics flight test on a 787** subsonic transport with its advanced design features representative of future aircraft.
Impacts

Impacts (How will this benefit NASA and the Community?):

• ANOPP (Aircraft Noise Prediction Program) is NASA Aeronautics’ sole source of aircraft system level noise prediction and design
  o FAA relies on ANOPP to be accurate and validated,
  o Widely used in industry and academia,
  o ANOPP improvements benefit all US users as future updates are released.

• First ever vehicle-system level validation of ANOPP with high resolution data:
  o at full scale, full fidelity (not possible in wind tunnel),
  o enables thorough validation, uncertainty quantification, and future improvements,
  o applicable to conventional and unconventional configurations,
  o will have enduring impact as a unique benchmark dataset.

• Stimulate and enable the development of noise reduction technologies and approaches involving propulsion airframe aeroacoustic integration effects and for airframe noise sources

• Boeing is a valued partner seeing value in this unique dataset and in future improvements to ANOPP.

• NASA gains valuable experience for future experimental acoustics flight testing.
Timeline for this flight test

• NASA conceived key technical ideas and objectives in 2015
• Technical discussions between NASA and Boeing teams began in early 2016
• Extensive technical discussions between NASA and Boeing teams continued through 2016-2018 to develop the approaches
• Discussions and presentation to the AATT Project in January 2018, led to the award of a sole source feasibility study task to Boeing from April to June of 2018.
• AATT authorizes sole source RFP, September 2018, Boeing proposal received November 26, 2018
• Task award in May 22, 2019 based on a 787 aircraft with testing at Moses Lake, WA site.
• Since task award, Boeing began seeking to secure agreement with an airline for the use of an aircraft during the weather window in 2020 (April – October).
• In January 2020, NASA AATT seeks to proactively move the test to the Glasgow site to increase the number of test points possible during the test window.
• Since task award, extensive collaborative work between the Boeing and NASA teams to develop detailed designs and plans.
• July 20, 2020 the ecoDemonstrator Program announces the partnership with Etihad Airways for the 787-10 aircraft with GEnx1B engines.
Background Definitions

- Propulsion Airframe Aeroacoustic (PAA) effects include the acoustic and flow interactions from integration of propulsion and airframe. Shielding, reflection, and diffraction are a function of the aircraft configuration and are influenced by the flowfield. Flow interactions can modify noise sources. Engine type, airframe edge geometry details, control surfaces, flow properties, and flight parameters can all impact PAA effects among others.

- Aircraft System Noise (ASN) is the total noise of the aircraft and is the combination of many noise components and PAA interaction effects. (see next slide for examples)

- The NASA PAA and ASN Team is also a part of the Aeroacoustics Branch, NASA Langley. This Branch is also responsible for NASA’s ANOPP and ANOPP2 codes.
Examples of Aircraft Noise Sources and PAA Effects

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What is ANOPP?

- Aircraft NOise Prediction Program (ANOPP) is a NASA code that is used to predict the total aircraft noise.
- The entire code and prediction models for each noise source on an aircraft have been continuously developed over the last 50 years as deeper physical understanding of noise generation has improved.
- They have been updated as new noise reduction technology is standardized, or aircraft design philosophy changes (e.g., higher BPR, simplified high lift systems).
- This flight test and subsequent joint NASA/Boeing predictions using the latest ANOPP version will allow better understanding of the performance of the models and strategies for how to make improvements.
- It is expected that this dataset will have a lasting value and be used for many years.

ANOPP is undergoing major, multiyear improvements for prediction of newer technologies and to add new capabilities important for current aircraft and future aircraft.

See next 4 charts
Overview of the 3rd Generation Methods:
- Similar first principles based modeling approach as in Boeing Airframe methods
- More in-depth formulation enables unconventional aircraft prediction
- Scales well across wide range
- Frequency-dependent power law
- Airframe geometry-dependent reflection model
- Absolute amplitude without need for calibration
- Expanded, higher fidelity validation database
### ANOPP Engine and Liner Noise Prediction Methods

#### ANOPP-Planned Development

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<tr>
<th>1970s</th>
<th>ANOPP</th>
<th>1990s</th>
<th>ANOPP</th>
<th>2000s</th>
<th>ANOPP</th>
<th>Early 2020s (Planned)</th>
<th>ANOPP</th>
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<tbody>
<tr>
<td>Fan (Heidmann)</td>
<td>Acoustic Liner (Magliozzi)</td>
<td>Core (Emmerling)</td>
<td>Jet (Stone)</td>
<td>Fan (Allied Signal)</td>
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### Overview of proposed Fan and Core Methods (Developed at NASA Glenn Research Center):
- Fan – Expanded parametric range from larger, more diverse validation database
- Core – Account for leaner combustion cycles

### Overview of proposed Acoustic Liner Method (Developed at NASA Langley Research Center):
- Account for technology changes since 1990s
  - Removal of inlet liner splice
  - Expanded use of higher performance multiple-degree-of-freedom liners
- Support predictions for the full range of thrust classes (regional to very large twin aisle)
- Improved modeling of physical sound attenuation process
ANOPP PAA Prediction Methods

- ANOPP contains an expanding collection of PAA prediction methods.
- One recent focus has been shielding of engine noise by the wing or fuselage.
  - Typically important for accurate predictions of unconventional low noise aircraft concepts.
  - This has been previously accounted for by either:
    - Maekawa barrier theory – limited accounting of geometry, physics
    - Prediction from extensive wind tunnel data – extensive physics, but geometry limited
  - This test will provide an opportunity to measure this effect at full scale and with flight effects.
    - Flights are planned for noise shielding measurements, both in the far field and in the near field.
    - The test data will also reveal physical features of noise scattering associated with real aircraft in flight, such as the effects of component configurations and their interactions, as well as the flow effects.
    - This will not only improve and mature the prediction tool, but also potentially lead to optimal configurations for noise minimization.
  - It also aids in validation of a new prediction method through carefully planned flight procedures, such as aircraft banking and engine power, and extensive noise measurements, both on the ground and on the aircraft.
  - This method:
    - Includes sound propagation, reflection, diffraction, and refraction.
    - Has no restrictions on practical parameters such as frequency, geometry, and source description.
ANOPP PAA Prediction Methods

• Other PAA effects are calculated separately and applied to the noise sources.
  • Wing reflection of engine noise
    • Predictions can come from wind tunnel data
    • A sophisticated ray tracing method is also in validation stage
  • Wing reflection of the landing gear noise
  • Jet-pylon effect – variability of jet noise due to the presence of the pylon breaking the symmetry of the jet exhaust
  • Jet angle of attack – this accounts for the variability of the jet noise due to the misalignment of the jet exhaust and the flight vector
Wind tunnel research and high fidelity computational research are very useful research tools; however, flight research offers unique characteristics otherwise unavailable, and flight testing is also an essential step to effective technology insertion.

The following 2 charts highlight the value of flight research to the progress of acoustics research.
Flight vs Wind Tunnel Testing

• A flight test, as the one described here, has many advantages over wind tunnel testing.
• The full aircraft is tested, as opposed to individual noise components tested in wind tunnels. The largest wind tunnel in the world at NASA Ames Research Center has a test section with an 80 by 120 ft cross-section. The 787 has a wingspan of nearly 200 ft. For many reasons it is simply not possible to study key aspects of aircraft acoustics without flight research.
• The test is performed at full scale, with all relevant geometry included. Because of the smaller size of most wind tunnels, models need to be scaled down relative to their real-world versions, many times leading to a loss in geometric details. This also requires additional post-processing of data to account for the reduced size – assumptions must be made for how the noise changes with scale.
• In contrast, testing the full scale aircraft ensures 1) complete realism of all noise sources, 2) all relevant interactions between components and 3) all acoustic flight effects are present. In addition, it is possible to include operational aspects.

Whether it is noise reduction approaches or technologies or prediction methods, it is essential that they ultimately perform at flight conditions.
Current Test is Part of a Multiyear Collaboration Between NASA and Boeing

NASA wind-tunnel tests
Advanced propulsion systems and airplane configuration studies

NASA Flight Tests (QTD2, ecoD 2020)
Full scale propulsion airframe aeroacoustics and aircraft system noise

Learnings

Technology experiments, data bases & models

Unique experiments and validation data

NASA/Boeing
Future designs

NASA Design tools
Key Test Design Ideas to Accomplish Innovative Test Objectives Related to PAA

To measure the PAA effects of shielding and reflection of full scale fan noise by an aircraft:

- Fan noise shielded by the wing to microphones placed above the wing (see next chart)
- Flying the aircraft at a bank angle to shield fan noise by the fuselage to microphones on the ground (see second chart following)

Measure the azimuthal directivity of the aircraft’s sound field by

- Flying the aircraft at a bank angle
- Flying the aircraft on lines offset from the centerline of the microphone arrays

Taping over the acoustic lining in the aft duct of the engine. This has the effect of increasing aft fan noise for the purposes of:

- Quantifying the aft liner effectiveness
- Changing the rank order of aft fan and jet to simulate higher bypass ratio engines of the future
NASA predicted surface acoustic attenuation contours for an engine noise source radiating from the inlet.
Banking Maneuver for Shielding

NASA pretest prediction of inlet-radiated fan noise shielded by the fuselage with the aircraft flying at a bank angle (one of the test conditions).
Offset Flying for Additional Azimuthal Directivity

Multiple passes at different offsets yields a range of azimuthal angles to the far field community microphones and phased array.
Description of this Flight Research Test

See next 11 charts
Overview of flight research

• NASA and Boeing have collaboratively designed a test matrix covering a wide range of ambitious objectives.
• Test parameters include engine power, high lift detent, landing gear deployment, and aircraft speed, bank angle, spoiler deflection, among other variations.
• Over 50 unique test points are planned.
• Boeing provides an extensive set of instrumentation, with the layouts collaboratively designed by NASA and Boeing:
  • Eight ground microphone arrays on the centerline and on offset lines (total of 31 mics)
  • 960 mics in a phased microphone array
  • 214 on-aircraft sensors in four arrays: Under-the-Wing, Over-the-Wing, Linear (along the fuselage), and Circumferential (around the forward fuselage)
• Following the test, NASA and Boeing will verify the predictions with the flight test data.
Location of the Flight Test

- Site used for Boeing noise testing.
- Site of the NASA/Boeing Quiet Technology Demonstrator 2 flight test in August, 2005.
- Requires moving personnel from Boeing Field to support the 787.
- High productivity and data quality.
- Aircraft will be outfitted with instrumentation at Boeing Field in Seattle.

Former SAC Runway, now a Boeing owned site, the Glasgow Industrial Airport, 20 miles north of Glasgow, Montana
Notable Test Elements

- Quantification of engine noise signature as a function of power for validation of new engine noise methods in ANOPP under real flight conditions.
- Separation and quantification of airframe noise sources for validation and improvement of new the Guo airframe noise methods in ANOPP.
- Various combinations of flap and gear setting are planned for measuring the gear-flap interaction PAA effect.
- The jet-flap interaction PAA effect will be measured for various engine settings and flap detents.
- Engine noise will be measured for a production engine with and without the acoustic liner taped over. This modification will create a clearer dominance of fan noise relative to other noise sources, simulating in some ways the acoustic characteristics of a future Ultra High Bypass Ratio engine. The data will also be used for improved modeling of the aft acoustic liner in a state-of-the-art engine by comparing the lined and taped over conditions.
- Some flight paths will feature offset or banking maneuvers, providing the opportunity to measure operationally-relevant noise phenomena such as spoiler deployment and shielding of engine noise by the fuselage. Banking also allows the ground microphones to measure higher effective azimuthal angles – essential for developing a complete understanding of the noise field around the aircraft and how it propagates to the community on the ground.
There are six distinct acoustic measurement systems that all contribute unique, high-resolution data in support of the test’s objectives.

- Ground phased array
- Far Field community microphone array
- Linear array on the aircraft fuselage
- Circumferential array around the aircraft fuselage
- Phased array above the wing
- Phased array under the wing

See following charts for more description
Ground phased array

- This microphone array consists of 960 microphones placed in a spiral pattern across the runway – approximately 300 ft in diameter.
- The array includes a replicant subarray for reduced measurement uncertainty over the most critical frequency range for annoyance.
- This allows for source localization and will provide high-resolution data to show the level and location of each noise source on the aircraft.
- Separation of sources is one of the most important aspects of this test.
  - By isolating the flap noise, for example, the phased array can be used to measure flap noise variation with deployment angle, speed, etc. as well as the PAA effects relevant to the flap such as jet-flap and gear-flap interactions.
- With offset and banked flight paths, the phased array can also be used to measure directivity of individual sources.

Boeing ground mic array as shown in photo in 2005 was ~60% of the new 960 mic array
Far Field community microphone array

• This array consists of 31 microphones spread farther afield beyond the runway.
• The data captured will provide a wide range of directivity measurements of the overall aircraft levels.
• With bank angle flying, the microphones can measure the level of shielding of engine noise by the fuselage.
• Flight test allows for a more accurate measurement of this effect by only spooling up shielded engine to a high power setting
Linear Array

- This array consists of microphones placed along the fuselage.
- Measurements during flight will reveal the variation of engine noise along the fuselage and how the wing shields noise from the engine.
- Flow effects and aircraft configuration will affect the shielding – data gathered at different engine settings, flap detents, and aircraft speed will provide insight into these dependencies.
- The microphones will quantify the transition from the fully “lit” to the fully shielded zones, and how flap/slat setting, engine condition, and flow speed affect this transition.
Circumferential Array

- This array consists of microphones placed around the circumference of the fuselage at two angles relative to the engine inlet.
- Measurements during flight will reveal the azimuthal directivity of the inlet-radiated fan tones.
- The data will show the detailed characteristics of the inlet-radiated engine noise, and how this noise propagates around the cylindrical fuselage.
- Data collected here will also be paired with ground data during banked flight paths to relate the shielded levels on the ground to the source levels measured on the aircraft.
Above-Wing Phased Array

• This array consists of microphones placed above the wing in a circular pattern to form a phased array.
• This system will allow for direct measurement of the diffraction (scattering) of engine noise around the leading edge and trailing edges of the wing.
• The resulting data will be useful for validating the latest generation of PAA prediction software under development by NASA, a key to the design of future low noise aircraft.
Under-Wing Phased Array

- This array consists of microphones placed under the wing in a circular pattern to form a phased array.
- This array will provide high-resolution, detailed acoustic source info to define the aft fan noise and jet noise, including directivity.
- These acoustic source data can be used as input to acoustic scattering software to allow for higher-fidelity predictions for comparison with the shielded data from the other microphone arrays, such as the above-wing phased array.
- The array will also identify reflections of engine noise from the wing to help quantify this important PAA effect for engine-under-wing configurations.

Photo Reference: FAA CLEEN Technologies Boeing Program Overview, Nov. 2014. Photo shows location, but actual 2020 design and layout will differ from this 2014 version.
Future Directions

Applying in future campaigns the novel instrumentation strategy developed on this test for measuring the PAA effects of an aircraft.

Advancing NASA’s noise prediction tools and applying to the design of:
- low noise aircraft configurations
- noise reduction technologies and
- quieter operations.

Applied to all three areas, the outcome from this test and research will be a much greater ability to take advantage of the new approach of PAA effects (two slides following).
Examples of How PAA is a Key To Advancing Aircraft Noise Reduction

PAA effects include the acoustic and flow interactions from integration of propulsion and airframe. Shielding, reflection and diffraction are the most obvious acoustic effects and are also strongly influenced by the flowfield and flow distortions between components. Engine type, airframe edge geometry details, control surfaces, flow profiles and properties, can all impact PAA effects.

PAA Chevron flight tested on Quiet Technology Demonstrator 2 in 2005. This innovation came from new understanding of the flow interaction between the pylon, jet, and chevron.

Advanced set of vehicles modeled with equivalent technology assumptions at the Mid-Term technology level, updated results from 2018-2019 predictions:

- Tube and Wing T+W301-GTF
  - 24.3 EPNLdB cumulative below St 4

- Mid-Fuselage Nacelle MFN301-GTF
  - 34.3 EPNLdB cumulative below St 4

- Hybrid Wing Body HWB301-GTF
  - 40.4 EPNLdB cumulative below St 4

11 dB of the 16 dB difference from T+W to HWB configuration change is from PAA shielding/reflection effects.

Using the far term technology level, the difference grows to more than 20 dB between T+W and HWB.
Applicability to New Concepts – Example TTBW

The TTBW has unique acoustic features that impact aircraft system noise and differentiate the TTBW from an engine-under-wing (737-like):

- **High aspect ratio wings, strut, and junctures** – all impacting trailing edge noise and high lift device noise.
- **High wing PAA** – engine noise is:
  - scattered from strut (also a potential shielding surface),
  - both reflected (near engine in image) and shielded (far engine) by the fuselage depending on observer location and,
  - reflected from wing.
- **Body mounted main gear** – short gear with local flow at the gear impacted by strut and flap on the strut
- **Leading Edge Device** – either a conventional slat or a Krueger flap

This flight test instrumentation, test design, and evaluation of ANOPP with the flight data will all contribute to improving our ability to more realistically predict many aspects of the TTBW system noise, as well as other advanced concepts of AATT.