Realizing NASA’s Vision for Low Noise Subsonic Transport Aircraft

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Acknowledgments

• Aircraft Noise Reduction (ANR) Subproject of the Advanced Air Transport Technology (AATT) Project for funding this research

• John Rawls and Stuart Pope for contributions to the Aircraft System Noise and PAA Team

• ANOPP2 Team, NASA Langley Aeroacoustics Branch, Dr. Leonard Lopes, Lead

• NASA Glenn Propulsion Systems Analysis Branch and the NASA Langley Aeronautics Systems Analysis Branch
Outline

• Background and Motivation
• Critical Role of Favorable Propulsion Airframe Aeroacoustic Effects
• Hybrid Wing Body (HWB) Noise Reduction Potential
• Mid-Fuselage Nacelle (MFN) Noise Reduction Potential
• X-Plane Demonstrators for Acoustic Objectives
• Remarks on Future Low Noise Aircraft Prediction
• Summary
In 1999, NASA’s Aircraft Noise Prediction Program (ANOPP) was inadequate for some key challenges of unconventional aircraft:

- Low pressure ratio and geared fan
- High pressure ratio core
- High lift systems (Krueger flap)
- Propulsion Airframe Aeroacoustic (PAA) Interactions: the aeroacoustic effects associated with integration including:
  - Integration effects on inlet and exhaust systems
  - Flow interaction and acoustic scattering effects
  - Configurations from conventional to revolutionary
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Development in Major Areas:

**ANOPP2**

**ANOPP**
Sources and PAA Interaction Prediction, System Noise Process

**Component and Integrated Technology and Experiments**

**MDAO of Aircraft Concepts**
## NASA Aeronautics Goals

### NASA Subsonic Transport Metrics

<table>
<thead>
<tr>
<th>TECHNOLOGY BENEFITS</th>
<th>TECHNOLOGY GENERATIONS</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Near Term 2015-2025</td>
<td>Mid Term 2025-2035</td>
<td>Far Term beyond 2035</td>
</tr>
<tr>
<td><strong>Noise</strong> (cum below Stage 4)</td>
<td>22 - 32 dB</td>
<td>32 - 42 dB</td>
<td><strong>42 - 52 dB</strong></td>
</tr>
<tr>
<td><strong>LTO NOx Emissions</strong> (below CAEP 6)</td>
<td>70 - 75%</td>
<td>80%</td>
<td>&gt; 80%</td>
</tr>
<tr>
<td><strong>Cruise NOx Emissions</strong> (rel. to 2005 best in class)</td>
<td>65 - 70%</td>
<td>80%</td>
<td>&gt; 80%</td>
</tr>
<tr>
<td><strong>Aircraft Fuel/Energy Consumption</strong> (rel. to 2005 best in class)</td>
<td>40 - 50%</td>
<td>50 - 60%</td>
<td>60 - 80%</td>
</tr>
</tbody>
</table>

**Evolutionary**  **Revolutionary**  **Transformational**
Certification Conditions for Aircraft System Noise

1) Flight Operation/ Trajectory Simulation
2) Source Noise Modeling
3) Noise Propagation to Observers

Approach Reference

2000 m (6562 ft)

450 m (1476 ft)

6500 m (21 325 ft)

Lateral (Sideline) Reference

Flyover (Cutback) Reference

50 Hz to 10 kHz

4) Ground observer noise time history

5) Time Integration to EPNL

PNLT

$\theta_0$

$\theta_1$

$\theta_2$

$t_0$

$t_1$

$t_2$
Continuing Development of the NASA Research Level Aircraft System Noise Prediction Process

ANOPP2

Aircraft Flight Definition

ANOPP:
- Jet
- Core
- Fan
- Duct Treatment
- Landing gear
- Flap-side-edge
- Leading edge (Krueger or Slat)
- Trailing edge

PAA Effects: engine noise installation effects (shielding, diffraction, reflection)

Noise Reduction Technology: predicted suppressions based on methods or best available information

Propagation & Noise Metrics

EPNL predicted at locations defined by Code of Federal Regulations (CFR) Title 14 Part 36

Aircraft, Engine and Flight Path from NASA System Analysis Team

Best Available Methods, Modified Methods or Use of Extensive Databases for Fan Source, Engine and Airframe Noise Reduction Technologies

New Generation of System Level Physics Based Airframe Noise Models for:
- Landing Gear, Flap, Slat, and Krueger

Propulsion Airframe Aeroacoustic (PAA) Effects from:
- Extensive Databases for Acoustic and Flow Interactions
- Prediction Methods in Development
- Boundary Layer Ingestion Noise Impact Model
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**ANOPP2**

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- Extensive Databases for Acoustic and Flow Interactions
- Prediction Methods in Development
- Boundary Layer Ingestion Noise Impact Model

**Only noise prediction method used unmodified from the Released version of ANOPP**
PAA Chevron with Partner Boeing on QTD2: Concept to Flight in Two Years 2003-2005

Exploration of Possible PAA Concepts with QTD2 Partners (5/03 – 4/04)

Extensive PAA CFD/Prediction Work (10/03 – 8/05)

(AIAA 05-3083, 06-2436)

PAA Experiment at Boeing LSAF 9/04

PAA Effects and Noise Reduction Technologies Studied

AIAA 06-2467, 06-2434, 06-2435

PAA on QTD2 – 8/05

• PAA T-Fan Chevron Nozzle

• PAA Effects Instrumentation

AIAA 06-2438, 06-2439
2004-2013: PAA on Hybrid Wing Body (HWB) Concept

Series of NASA/Boeing PAA experiments developed PAA database, technologies, and first Low Noise HWB Technical Roadmap and Noise Assessment, 42.4 EPNLdB below Stage 4 (International Journal of Aeroacoustics, Vol 11 (3+4), 2012)

Boeing Designed N2A Concept

Noise Assessment of 38.7 dB Cumulative Below Stage 4 Added Validation to Low Noise HWB Technical Approach (from AIAA 2014-2626)

Shielding Effectiveness for Jet Component
Mid Term Technology: Large Twin Aisle
301 Pax Class Results


- **Tube and Wing**
  - T+W301-GTF
  - 22.1 EPNLdB cumulative below Stage 4

- **Mid-Fuselage Nacelle**
  - MFN301-GTF
  - 33.9 EPNLdB cumulative below Stage 4

- **Hybrid Wing Body**
  - HWB301-GTF
  - 40.3 EPNLdB cumulative below Stage 4

- Aircraft with the most favorable PAA effects are the ones able to achieve the Mid Term goal
- Configuration change is required to achieve low noise levels
Aircraft Configuration Impact on Ground Contour Area

**Approach**

- **Stage 4 A/C**
  - 41% reduction

- **B777-like**
  - 61.7% reduction

- **T+W301**
  - 65.9% reduction

**Takeoff**

From AIAA-2017-3194
Aircraft Configuration Impact on Ground Contour Area

- T+W301 and HWB-2016 are of equal technology levels except for aircraft configuration.
- About 12 of the 17.7 EPNL dB total difference is due to PAA effects.

From AIAA-2017-3194
HWB Far Term Technology Roadmap

Pod Gear

Shielding Effectiveness

Krueger Flap Design and Technologies

Nacelle and Core Acoustic Liner Technologies

From AIAA-2017-3193
One technology at a time from the final configuration is the most effective way of measuring impact at the system level on equivalent basis

<table>
<thead>
<tr>
<th>Description</th>
<th>Cumulative below Stage 4 with one technology “off”</th>
<th>One-off cumulative noise reduction due to technology</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lip Liner</td>
<td>50.9</td>
<td>0.0</td>
</tr>
<tr>
<td>Center Plug Liner</td>
<td>49.7</td>
<td>1.3</td>
</tr>
<tr>
<td>Over-the-Rotor Treatment</td>
<td>50.6</td>
<td>0.4</td>
</tr>
<tr>
<td>Center Elevon PAA Liner</td>
<td>50.4</td>
<td>0.5</td>
</tr>
<tr>
<td>Increase Upper Bifurcation Liner</td>
<td>50.9</td>
<td>0.0</td>
</tr>
<tr>
<td>PAA Chevrons</td>
<td>50.0</td>
<td>0.9</td>
</tr>
<tr>
<td>Fan Noise Shielding Effectiveness via Duct Liner</td>
<td>50.5</td>
<td>0.4</td>
</tr>
<tr>
<td>Fan Noise Shielding Effectiveness via PAA Design</td>
<td>50.6</td>
<td>0.3</td>
</tr>
<tr>
<td>Trailing Edge Treatment</td>
<td>50.5</td>
<td>0.4</td>
</tr>
<tr>
<td>Krueger Flap Bracket Alignment</td>
<td>48.4</td>
<td>2.6</td>
</tr>
<tr>
<td>Krueger Flap Cove Filler</td>
<td>49.8</td>
<td>1.1</td>
</tr>
<tr>
<td>Pod Gear</td>
<td>47.7</td>
<td>3.3</td>
</tr>
<tr>
<td>Aircraft cumulative margin to Stage 4, with all technologies</td>
<td>50.9</td>
<td></td>
</tr>
</tbody>
</table>

Nacelle and Core Liner Technologies: 1.7 dB

Shielding Effectiveness Technologies and Design: 2.5 dB

Krueger and Main Gear Technologies and Design: 7.0 dB
Uncertainty Quantification for the System Noise Prediction of the HWB

- Considerable progress over time in 95% coverage interval (CI)
- One-sided distributions increasingly important over time

<table>
<thead>
<tr>
<th>Case</th>
<th>Standard Uncertainty</th>
<th>95% CI Span</th>
<th>Reduction</th>
</tr>
</thead>
<tbody>
<tr>
<td>2013</td>
<td>3.1</td>
<td>12.2</td>
<td>–</td>
</tr>
<tr>
<td>2016</td>
<td>2.4</td>
<td>9.6</td>
<td>2.6</td>
</tr>
<tr>
<td>Current</td>
<td>2.2</td>
<td>8.5</td>
<td>1.1</td>
</tr>
</tbody>
</table>

Boeing Advanced Tube-and-Wing from 2013

Bonet et al., NASA CR 2013-216519

ERA-0027 Configuration assessed at 28.0 EPNL dB below St 4 with a Direct Drive BPR 13.5 Turbofan at Fan Pressure Ratio 1.6
Boeing Advanced Tube-and-Wing from 2013

Bonet et al., NASA CR 2013-216519

ERA-0027 Configuration assessed at 28.0 EPNL dB below St 4 with a Direct Drive BPR 13.5 Turbofan at Fan Pressure Ratio 1.6

AIAA 2014-0257 an additional detailed noise prediction was performed with an early far term suite of technologies, 36 EPNL dB below St 4

With advanced GTF, FPR 1.375, estimated the system noise could reach 40-42 EPNL dB below St 4
### NASA MFN Aircraft in 2016

- AIAA Paper 2016-1030, Nickol and Haller
- Mid Term Technology Level

<table>
<thead>
<tr>
<th>Feature</th>
<th>Specification</th>
</tr>
</thead>
<tbody>
<tr>
<td>Airframe</td>
<td>T+W</td>
</tr>
<tr>
<td>Fuselage</td>
<td>Double Deck</td>
</tr>
<tr>
<td>Engine</td>
<td>GTF</td>
</tr>
<tr>
<td>Engine Mounting</td>
<td>Fuselage</td>
</tr>
<tr>
<td>Leading Edge Device</td>
<td>Krueger</td>
</tr>
<tr>
<td>Trailing Edge Device</td>
<td>Simple Flap</td>
</tr>
<tr>
<td>Main Gear Type</td>
<td>6 Wheels</td>
</tr>
<tr>
<td>Takeoff Gross Weight</td>
<td>544,748 lb</td>
</tr>
<tr>
<td>Lift/Drag Ratio (Sideline/Cutback/Approach)</td>
<td>13.92/13.5/8.9</td>
</tr>
<tr>
<td>Bypass Ratio (Sideline/Cutback/Approach)</td>
<td>23.34/25.38/31.91</td>
</tr>
<tr>
<td>Fan Pressure Ratio (Sideline/Cutback/Approach)</td>
<td>1.25/1.2/1.06</td>
</tr>
</tbody>
</table>

Block Fuel Reduction of 46.8% relative to 777-200LR-like on a 7500 nm mission
MFN System Noise in 2016

Reported in AIAA 2016-0863, Thomas, Burley and Nickol
(with calculations updated)

<table>
<thead>
<tr>
<th></th>
<th>Approach</th>
<th>Cutback</th>
<th>Sideline</th>
<th>Cumulative</th>
</tr>
</thead>
<tbody>
<tr>
<td>MFN (C0)</td>
<td>91.0</td>
<td>84.8</td>
<td>85.0</td>
<td>260.8</td>
</tr>
<tr>
<td>Stage 4 Limit</td>
<td>104.6</td>
<td>98.4</td>
<td>101.2</td>
<td>294.2</td>
</tr>
<tr>
<td>Margin to Stage 4</td>
<td>13.6</td>
<td>13.6</td>
<td>16.2</td>
<td>33.4</td>
</tr>
<tr>
<td>NASA Mid Term Goal</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>32 - 42</td>
</tr>
</tbody>
</table>

MFN aircraft with mid term technology

- PAA: propulsion airframe aeroacoustics
- MDOF: multidegree-of-freedom duct acoustic liner
- MG: main gear partial fairing
- Fan: soft stator vane treatment
- Flap: side edge treatment

Establishes the starting point for the far term roadmap
MFN Engine Far Term Noise Technologies

No chevrons and scarf on MFN engine

Example references
- Inlet lip liner: AIAA 2006-2720, Herkes, Olsen and Uellenberg
- Over-the-rotor treatment: AIAA 2006-2681, Sutliff, Jones and Hartley
- Center plug liner: AIAA 2009-3141, Yu and Chien
- Maximized Bifurcation liner: AIAA 2017-3193, Thomas et al.
Krueger Dual Use Fairing

From AIAA-2018-3126

EPNL
- Baseline Krueger: 78.99 dB
- Cove Filler: 77.80 dB
- Aligned Bracket: 77.44 dB
- Dual Use Fairing: 75.69 dB

PNLT (dB)

Flow Simulation
(Kreitzman et al.
AIAA 2017-3365)
Pod gear concept has the potential of a breakthrough in reducing main landing gear component noise.

MFN Pod Gear in 2018

Noise calculation:
• Reflection from airframe with pod geometry
• Reduced flow velocity inside the pod

From AIAA-2018-3126
MFN Far Term Technology Roadmap

MFN 40.2 EPNL dB cumulative margin to Stage 4 predicted in AIAA-2018-3126

Krueger Dual Use Fairing

Aligned Krueger Bracket

Flow

CML Flap

Center Plug Liner, Over the Rotor Treatment, MDOF Duct Liner, Soft Vane

Pod Gear

4-Wheel Main Gear

Partial Nose Gear Fairing
## MFN Far Term Predicted at 40.2 EPNL dB below Stage 4

<table>
<thead>
<tr>
<th>Reduction</th>
<th>Technology</th>
<th>EPNL Impact (dB)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Significant</td>
<td>• PAA Effects</td>
<td>4.7</td>
</tr>
<tr>
<td></td>
<td>• MDOF Liner (mid term)</td>
<td>2.4</td>
</tr>
<tr>
<td></td>
<td>• 4-Wheel Pod Gear</td>
<td>2.2</td>
</tr>
<tr>
<td>Substantial</td>
<td>• Soft Vane Liner (mid term)</td>
<td>1.0</td>
</tr>
<tr>
<td></td>
<td>• Center Plug Liner</td>
<td>0.8</td>
</tr>
<tr>
<td></td>
<td>• Over-the-Rotor Liner</td>
<td>1.6</td>
</tr>
<tr>
<td></td>
<td>• Dual Use Krueger Fairing</td>
<td>0.6</td>
</tr>
<tr>
<td></td>
<td>• Continuous Mold Line Flap</td>
<td>0.6</td>
</tr>
<tr>
<td>Small</td>
<td>• Inlet Lip Liner</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Increased Outer Bifurcation Liner</td>
<td>~0.0</td>
</tr>
<tr>
<td></td>
<td>• Sealed Krueger Gap</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Partial Nose Gear Fairing</td>
<td></td>
</tr>
<tr>
<td>Not Used</td>
<td>• 6-Wheel Pod Gear</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Krueger Bracket Alignment</td>
<td></td>
</tr>
</tbody>
</table>
Precedence for MFN Configuration

Design Heritage Examples:
- Engine Above Wing
- Short Gear
- Double Deck
- Pod Gear Similar

Accessed [www.lockheedmartin.com](http://www.lockheedmartin.com) August 19, 2018
Precedence for MFN Configuration

Design Heritage Examples:
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MFN Advantages:
- Improved Weight/Balance from Mid-Fuselage
- Engine Mounting Structure through the Deck
- Favorable PAA Effects
- Faster Passenger Loading
- Integration of Pod with Wing/Body Joint
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40.2 EPNL dB below Stage 4 represents a community noise breakthrough with what is still a “Tube-and-Wing” aircraft
Beginning in mid-2022, NASA will fly the X-59 over select cities to collect data on community responses.

April 3, 2018 Lockheed Martin Aeronautics Company awarded the Low-Boom Flight Demonstration contract for $247.5 million to design, build and test an experimental aircraft that reduces the sonic boom to a gentle thump.
Scenarios for a Subsonic X-Plane Demonstrator for Acoustic Research

X-48B 8.5% Dynamically Scaled
Built and Flight Tested for Low Speed Flight Dynamics Characteristics
Scenarios for a Subsonic X-Plane Demonstrator for Acoustic Research

X-48B 8.5% Dynamically Scaled
Built and Flight Tested for Low Speed Flight Dynamics Characteristics

One-of-a-kind HWB X-Plane

- At what scale?
- What type of scaling?
  - Perfect scaling
  - Realistic scaling
- Engine Selection?
- Technologies?
A key development step toward maturing an unconventional advanced aircraft configuration with favorable PAA effects and noise reduction technologies.

Aircraft configuration, engine selection, technology selection, integration, and scale factor will all drive the cost AND be critical to the value. Therefore, expect:

- X-Plane not an exact copy of the vision vehicle
- Focus on selected technologies including the configuration
- Use a commercial-off-the-shelf engine

Reference develops a process for formulating the acoustic aspects of an X-Plane Demonstrator scale, design, and flight research.

General objectives:
- Acoustic flight validation of configuration PAA effects and selected technologies
- Improving the prediction of the vision vehicle

Flight Test Distances and Absorption

Propagation distances for wind tunnel tests

Propagation distances for flight testing

Spherical Spreading
- Only, No Absorption
- Absorption at 1000 Hz
- Absorption at 5000 Hz
- Absorption at 10000 Hz
- Absorption at 20000 Hz

~25 dB is the additional signal loss if measuring to 20 kHz instead of 10 kHz
Scaled MFN at Approach

Representative background noise obtained from measurements at NASA Armstrong and Wallops

If No Absorption
- Loss of Signal
- Background Noise Cutoff

With Absorption

Acknowledgments to Dr. Christopher Bahr and Dr. Patricio Ravetta for supplying background noise data

From AIAA-2018-3127
Realistically scaled MFN

Realistically scaled (reduced geometric fidelity) as measured, propagation length of 396 ft.

Realistically scaled (reduced geometric fidelity) processed to full scale. Vertical lines indicate the frequency cutoff.

Lower levels at full scale due to reduced complexity of scaled vehicles

From AIAA-2018-3127
Subsonic X-Plane Study Summary

• An X-Plane focused system noise analysis process is essential to engage in:
  • X-Plane design requirements,
  • acoustic technical objectives,
  • flight research planning, and
  • analysis for application to prediction of the vision aircraft

• Highlights the interrelated issues of
  • scale
  • atmospheric absorption and background noise levels
  • geometric fidelity
  • source ranking
  • engine selection
  • instrumentation requirements

• X-Plane scale of 75% or more is most directly useful. Limitations become more severe as the scale factor approaches 50%.

• Selection of a UHB representative engine is valuable for prediction of engine system, PAA effects, and vision aircraft
Consider a Single Aisle Replacement, 160-230 pax, MFN Vision Vehicle

X-Plane Demonstrator B717 Hybrid Example


Today’s B717

Ultra Quiet B717 Notional Concept

20+ bypass ratio geared turbofan engine

Variable area fan nozzle cycle

Low noise landing gear

~45% for MFN301
~80% for a 160-230 pax
Consider a Single Aisle Replacement, 160-230 pax, MFN Vision Vehicle

X-Plane Demonstrator B717 Hybrid Example


Today’s B717

Ultra Quiet B717 Notional Concept

- High Aspect Ratio Wing w/ Krueger and Dual Use Fairing
- Engine Inlet Over Wing TE
- Best COTS UHB Engine
- Pod Gear
- CML Flap
- Variable area fan nozzle cycle
- Soft vane, MDOF, Over-the-Rotor, Center Plug Liner
- Low noise landing gear

~45% for MFN301
~80% for a 160-230 pax
Remarks on Future Low Noise Aircraft Prediction

Starts with excellent modeling teams for the engine and airframe

Combining experience in one team from:
• Acoustics Experimentation
• Noise Reduction Technology Development
• Prediction Method Development
• Aircraft System Noise

Experience from wide variety of technologies and concepts provides valuable perspective and insight

Advanced concepts require advanced methods
- PAA effects from scattering, flow interaction, BLI
- Noise reduction concepts such as Pod Gear, MDOF Liner, etc.
HWB acoustics has matured considerably, 40 EPNL dB below St 4 is clearly achievable in the mid term.

Credible far term technology roadmap developed to enable the HWB to reach 50.9 EPNL dB below St 4.

MFN concept is a revolutionary and yet still tube-and-wing type vehicle capable of reaching 40.2 EPNL dB below St 4 enabling:
- shift from under to over-wing
- fundamentally quieter landing gear installation

Flight testing of advanced configurations and technologies will be valuable step.

An X-plane subsonic demonstrator should be large scale (~75%) to produce the most directly useable community noise measurements.

Portfolio of advanced concepts, missions, and technologies continues to expand and will require advanced methods, experiments and rigorous analysis.
Grand Opportunity to Realize a Step Change in Aircraft Noise

Contour area for an aircraft meeting the Stage 4 limit = 100% area

B777-like: Stage 4 – 7.8 EPNL dB, Area = 59.0%

HWB ERA (C6): Stage 4 – 41.7 EPNL dB, Area = 6.9%

HWB-Far Term: Stage 4 – 50.9 EPNL dB, Area = 3.3%

88.3% area reduction

94.4% area reduction

From AIAA-2017-3193

SEL contour levels, dB
Grand Opportunity to Realize a Step Change in Aircraft Noise

- B777-like: Stage 4 – 7.8 EPNL dB, Area = 59.0%
- HWB ERA (C6): Stage 4 – 41.7 EPNL dB, Area = 6.9%
- HWB-Far Term: Stage 4 – 50.9 EPNL dB, Area = 3.3%

52.2% reduction in area from HWB Mid Term to HWB Far Term

88.3% area reduction

94.4% area reduction

From AIAA-2017-3193

10K ft

SEL contour levels, dB

85
90
95
100
105
110
N+2 includes:
- UHB GTF or DD engines
- Light weight structures
- Single element trailing edge flap
- Leading edge Krueger flap
- Configuration dependent PAA effects
- MDOF duct liners

ITD Noise Reduction adds:
- Soft vane
- Flap side edge treatment
- Partial main gear fairing

Combined 0.9 to 2.5 dB more noise reduction

**42 dB Goal**

Relative to T+W160
OWN160: 9.7 dB quieter

Relative to T+W301,
HWP301: 18.2 dB quieter
MFN301: 11.8 dB quieter

PAA effects are the single largest differentiator:
11.9 out of the 18.2 EPNLdB
# NASA-developed Concept Vehicles for UAM

**NOT “BEST” DESIGNS; NO INTENT TO BUILD AND FLY**

<table>
<thead>
<tr>
<th>Passengers</th>
<th>50 nm trips per full charge/refuel</th>
<th>Market</th>
<th>Type</th>
<th>Propulsion</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1 x 50 nm</td>
<td>Air Taxi</td>
<td>Multicopter</td>
<td>Battery</td>
</tr>
<tr>
<td>2</td>
<td>2 x 50 nm</td>
<td>Commuter Scheduled</td>
<td>Side by Side (no tilt)</td>
<td>Parallel hybrid</td>
</tr>
<tr>
<td>4</td>
<td>4 x 50 nm</td>
<td>Mass Transit</td>
<td>(multi-) Tilt wing</td>
<td>Turboelectric</td>
</tr>
<tr>
<td>6</td>
<td>8 x 50 nm</td>
<td>Air Line</td>
<td>(multi-) Tilt rotor</td>
<td>Turboshift</td>
</tr>
<tr>
<td>15</td>
<td></td>
<td></td>
<td>Lift + cruise</td>
<td>Hydrogen fuel cell</td>
</tr>
<tr>
<td>30</td>
<td></td>
<td></td>
<td>Vectored thrust</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Compound</td>
<td></td>
</tr>
</tbody>
</table>

- Aircraft designed through use of NASA conceptual design and sizing tool for vertical lift, NDARC.

06 Feb 2018
Configuration and Parameter Changes for the OREIO Noise Assessment

- Vertical control surface cant angle
- Projected landing gear noise reduction (NASA)
- Rotor installation distance $x/D$ upstream of the trailing edge
- NASA designed proof-of-concept airframe surface acoustic liner
- Center elevon deflection angle

AIAA 2014-0258, “System Noise Assessment and the Potential for Low Noise Hybrid Wing Aircraft with Open Rotor Propulsion”
Shielding in the flyover plane for interaction tones at takeoff power

Methods for application of PAA experimental effects to a future rotor of arbitrary design:


Open Rotor HWB Aircraft System Level Results

Cumulative EPNLdB rel Stage 4

<table>
<thead>
<tr>
<th>Configuration</th>
<th>EPNLdB</th>
</tr>
</thead>
<tbody>
<tr>
<td>Isolated AQR, Baseline Airframe, No Shielding</td>
<td>-10.3</td>
</tr>
<tr>
<td>OREIO, AQR at 1D, Airframe w/ Noise Reduction (NR) Techs</td>
<td>-26.0</td>
</tr>
<tr>
<td>OREIO, AQR at 1.5D, Airframe w/ NR</td>
<td>-30.8</td>
</tr>
<tr>
<td>OREIO, AQR at 1.5D, Airframe w/ NR + Additional Possible Approaches</td>
<td>-38.0</td>
</tr>
</tbody>
</table>

AQR = Advanced Quiet Rotor, 2025 Projection

AIAA 2014-0258, “System Noise Assessment and the Potential for Low Noise Hybrid Wing Aircraft with Open Rotor Propulsion”
Processing of Predicted “Flight Test” Data

1. X-Plane Measured Data at Small Scale
2. Background Noise Cutoff
3. Correct to Standard Acoustic Day Condition
4. Remove Atmospheric Absorption at Small Scale Frequency
5. Strouhal Number Scaling
6. Amplitude Scaling by Size
7. Mach Number Scaling
8. Flight Altitude Scaling
9. Add Atmospheric Absorption at Full Scale Frequency
10. Processed Full Scale Data
11. High resolution data and analysis required

General Note:
- Scale
- Frequency
- Amplitude

Atmospheric Absorption Applied in Multiple Steps

Application to method development and vision aircraft prediction

From AIAA-2018-3127
## Limitations on Measuring High Frequencies

### Perfectly Scalable Aircraft

**From AIAA-2018-3127**

<table>
<thead>
<tr>
<th>Frequency (Hz)</th>
<th>One-Third Octave SPL (dB)</th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
<td>2</td>
</tr>
<tr>
<td>30</td>
<td>4</td>
</tr>
<tr>
<td>50</td>
<td>6</td>
</tr>
<tr>
<td>70</td>
<td>8</td>
</tr>
<tr>
<td>90</td>
<td>10</td>
</tr>
<tr>
<td>100</td>
<td>12</td>
</tr>
<tr>
<td>500</td>
<td>90</td>
</tr>
<tr>
<td>1000</td>
<td>70</td>
</tr>
<tr>
<td>10,000</td>
<td>50</td>
</tr>
</tbody>
</table>

- **Atmospheric absorption** establishes an upper limit on frequency just above 20 kHz.
- **Variability in background noise** makes cutoff uncertain.
- **Background noise** establishes a cutoff at less than 20 kHz.

- **Full Scale at θ=90°**
- **50% Scale at θ=90°**
- **25% Scale at θ=90°**
- **12.5% Scale at θ=90°**
- **Background**

---

*Note: The data and graphical representation are based on the information provided.*
Loss of Signal Impacts Full Scale Result

Perfectly Scalable Results Processed to Full Scale

Note, this is at a minimum distance

Range of full scale spectrum of most impact on metric

For 25% scale, useable range stops at 4 kHz due to absorption and background

For 50% scale, useable range stops at 8 kHz due to absorption and background

Background Range of full scale spectrum of most impact on metric
MFN Vision Vehicle and Airframe Noise Reduction Technologies

Mid Term MFN Aircraft Concept

Continuous Mold Line (CML) Flap

Far Term MFN Aircraft Concept

Dual Use Krueger Fairing (fills cove and fairs the brackets)

MFN Concept Redesigned with Pod Gear Concept

Figure 7 Illustration of continuous mold line technology
Realistically Scaled MFN with Technologies

**Without Noise Reduction Technologies**

- **EPNL (dB)**
  - Total
  - Nose Gear
  - Main Gear
  - Krueger
  - Flap Side Edge
  - Trailing Edge

**With Noise Reduction Technologies Applied to Main Gear, Krueger, and Flap Side Edge**

- **EPNL (dB)**
  - Total
  - Nose Gear
  - Main Gear
  - Krueger
  - Flap Side Edge
  - Trailing Edge

- **Main Gear (MG) drops from highest to third rank due to six to two wheel change**

- **Pod Gear reduced MG more than other technologies, MG now equal NG**
Impact of Engine Selection on PAA Effects

<table>
<thead>
<tr>
<th>Engine Class</th>
<th>BPR</th>
<th>Dominant Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>Legacy</td>
<td>6-9</td>
<td>Jet</td>
</tr>
<tr>
<td>Current EIS HBP</td>
<td>9-12</td>
<td>Fan and Jet</td>
</tr>
<tr>
<td>UHBP Vision Engine</td>
<td>15+</td>
<td>Fan</td>
</tr>
</tbody>
</table>

Isolated engine characterization, engine source ranking, and analysis required to apply X-Plane Engine and PAA results to Vision Vehicle.