Propulsion Airframe Aeroacoustic Integration Effects and Enhancement Strategies Using Acoustic Liners

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Continual Need for Noise Reduction

737-300
EIS 1984

13 EPNdB
in 32 years

737 MAX8
EIS 2016

- Challenges for continued use of incremental noise reduction strategies
- Propulsion airframe integration (PAI) and aeroacoustics (PAA) demand increasing consideration in aircraft design
- Configuration change provides an opportunity for substantial noise reduction benefit

Prediction of 2025-2035 Vision Aircraft Configurations (301 pax)

Configuration	Tube and Wing (T+W)
Ref. Vehicle Margin*	14.5 EPNdB
PAA Effects	Aft engine reflection by wing
Configuration	Mid-Fuselage Nacelle (MFN)
Ref. Vehicle Margin*	26.3 EPNdB
PAA Effects	Inlet engine shielding by wing and fuselage Aft engine reflection by T-tail
Configuration	Hybrid Wing Body (HWB)
Ref. Vehicle Margin*	32.7 EPNdB
PAA Effects	Inlet and aft engine shielding by body

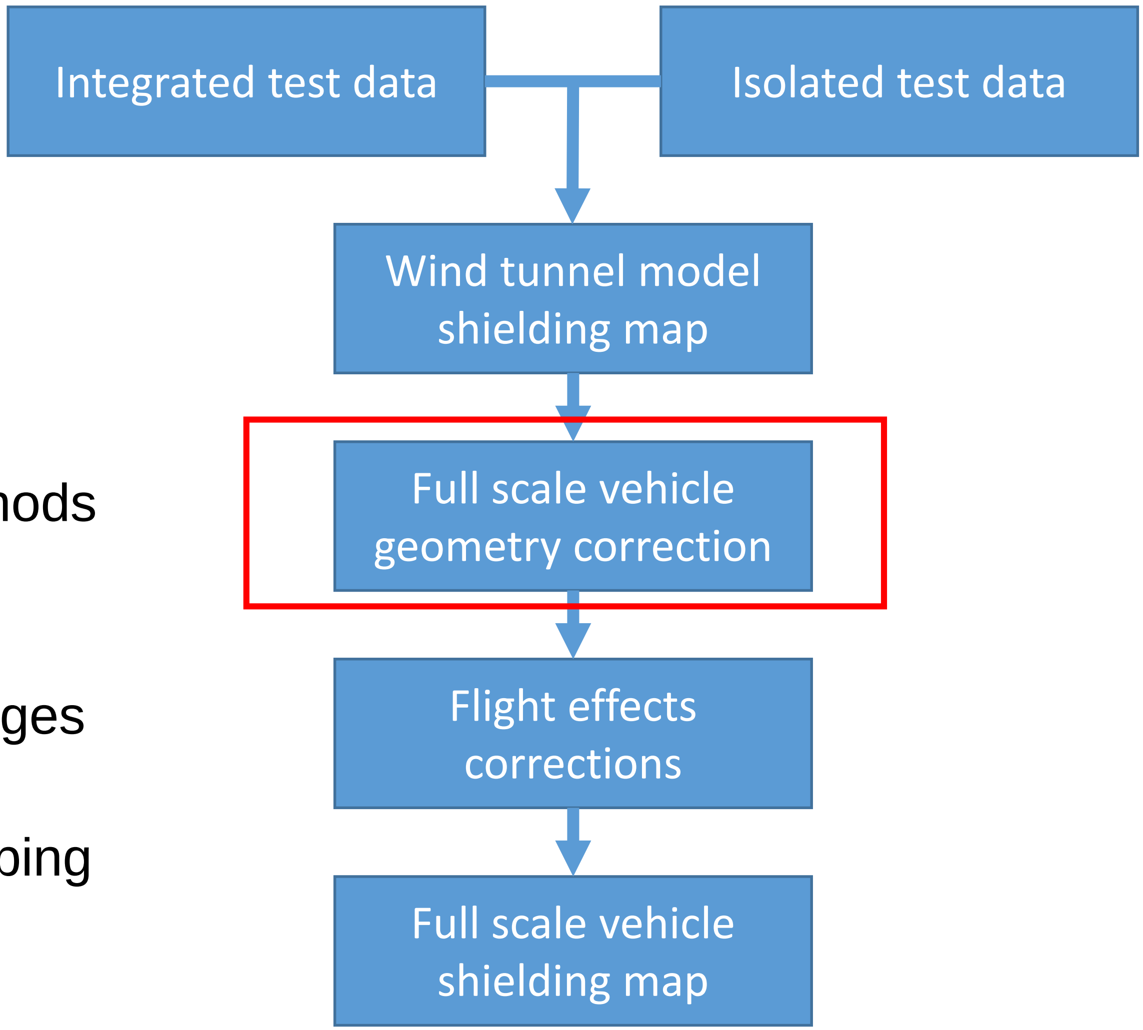
*Cumulative margin referenced to 777-200LR

- Similar reduction over 30 years from 777-200LR (EIS 2006) to T+W
- Additional difference of 18.2 dB from T+W to HWB
  - 11.2 dB attributed to PAA effects
- Roughly equivalent to an additional 30 years of progress

Thomas, R.H., Burley, C.L., and Nickol, C.L., "Assessment of the Noise Reduction Potential of Advanced Subsonic Transport Concepts for the NASA Environmentally Responsible Aviation Project," AIAA-2016-0863.

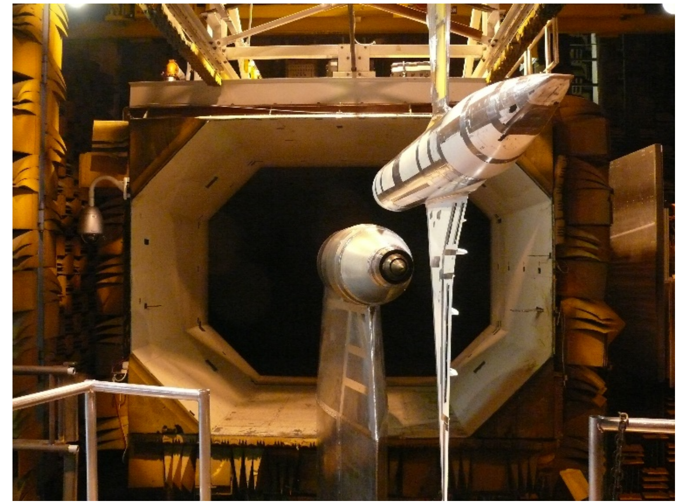
Update to Previous Results

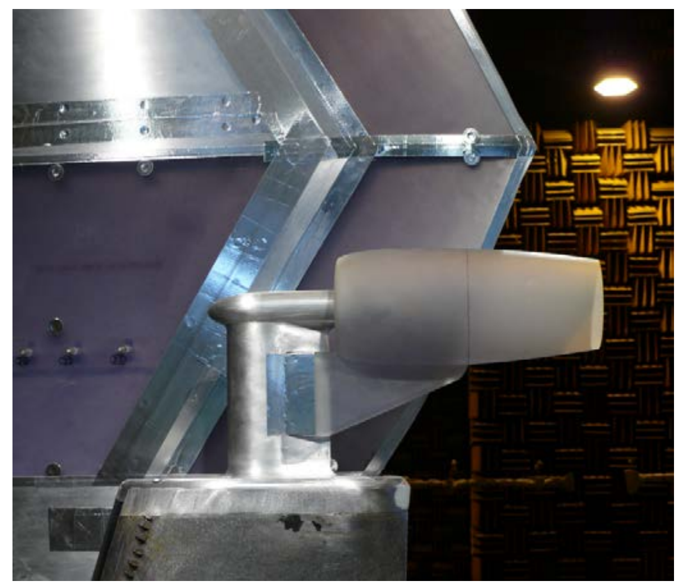
- Potential benefit merits additional analysis
- Continued Modeling Advancements
  - Airframe Prediction methods
    - High lift devices
    - Landing gear
  - Jet noise modeling changes
  - PAA maps
    - Upgraded data mapping procedure



Wind Tunnel PAA Database

- Testing in Boeing Low Speed Aeroacoustic Facility[1]
- Traversable scale models
  - 777
  - HWB
- Fixed broadband noise source in nacelle
- Fixed jet engine simulator
- Varied:
  - Flap settings
  - Mach number
- Microphone Arrays
  - Far field
  - In flow

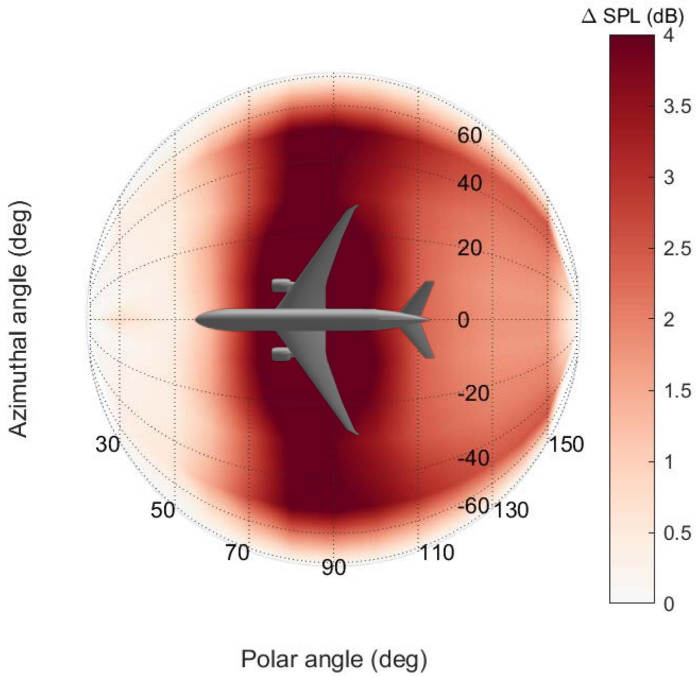




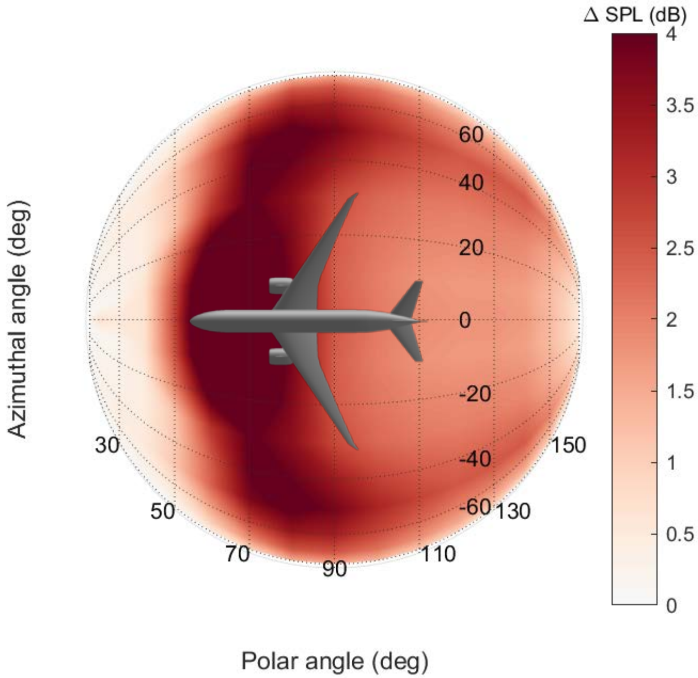
[1]Thomas, R.H., Czech, M.J., and Doty, M.J., "High Bypass Ratio Jet Noise Reduction and Installation Effects Including Shielding Effectiveness," AIAA Paper 2013-0541.

T+W PAA Fan Map Comparison

Model Geometry



Full Scale T+W Geometry



- Shows the increase in radiated fan noise due to airframe reflection at 1 kHz
- Approach conditions
- Maps reflect differences in:
  - Chord length
  - Trailing edge sweep
  - Distance from nozzle to leading edge

Study Design

- Utilize ANOPP-Research to predict each of the three aircraft
- Compare cases with and without PAA effects
  - Currently including fan and core PAA
  - Jet noise shielding included on HWB and MFN
  - Jet-flap interaction not currently included on T+W
  - Jet-pylon interaction not included on any vehicles
- Identify impact of changes from previous results
  - Jet noise modeling
  - Airframe noise methods
  - PAA mapping process

Updated Results

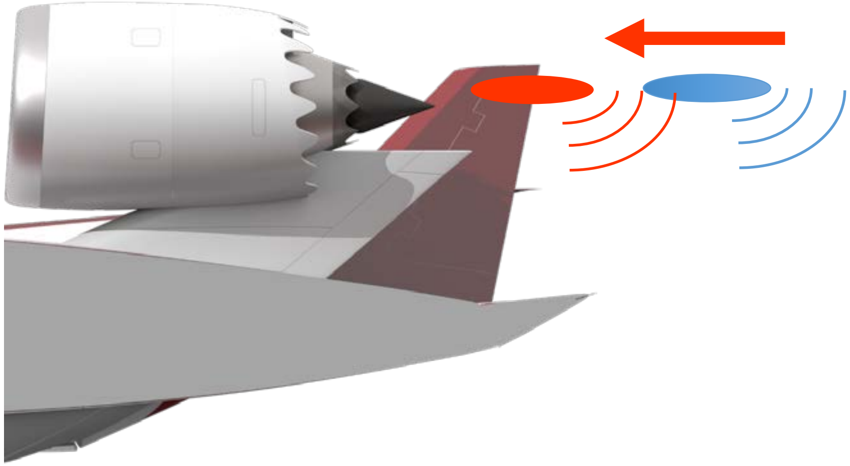
Configuration	Margin With PAA	Margin Without PAA	PAA Benefit	2016 Value[1]
T+W	22.4	26.0	-3.6	-4.8
MFN	34.4	30.2	4.2	–
HWB	40.4	34.0	6.4	7.1

- Estimate a 8-10 EPN dB PAA benefit from configuration change
  - MFN presents a lower risk option that still gets most of the benefit
  - Existing Data Point: 5.6 EPNdB difference between MD-90 and A319
- Assumptions with impact on PAA benefit
  - Fan pressure ratio (FPR) – balance in inlet and aft radiated fan noise
    - Low FPR enhances T+W reflection and weakens effectiveness of MFN, HWB inlet shielding
  - Bypass ratio (BPR) – changes in rank ordering of fan and core, and jet noise
    - High BPR increases effectiveness of fan and core noise shielding
    - Reduces jet-flap interaction noise penalty
  - Airframe noise – provides ceiling for PAA benefit (as for HWB)

[1]Thomas, R.H., Burley, C.L., and Nickol, C.L., "Assessment of the Noise Reduction Potential of Advanced Subsonic Transport Concepts for the NASA Environmentally Responsible Aviation Project," AIAA-2016-0863.

Further Increasing Shielding Effectiveness

- Chevrons
  - Aft jet shielding[1]
  - Jet-flap interaction[2] (T+W)
- Engine scarfing
- Elliptical nozzle
- Vertical tail extension



[1]Thomas, R.H., Guo, Y., Berton, J.J., and Fernandez H., "Aircraft Noise Reduction Technology Roadmap Toward Achieving the NASA 2035 Noise Goal," AIAA Paper 2017-3193.
[2]Mengle, V.G., Brusniak, L., Elkoby, R., and Thomas, R.H., "Reducing Propulsion Airframe Aeroacoustic Interactions with Uniquely Tailored Chevrons: 3. Jet-Flap Interaction," AIAA 2006-2435.

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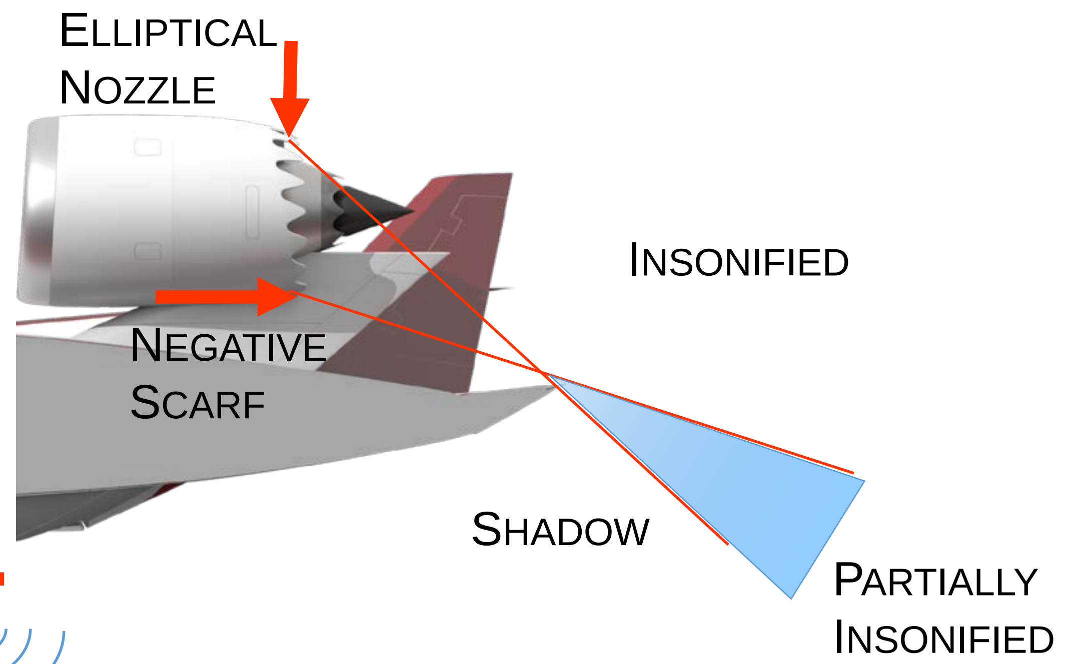

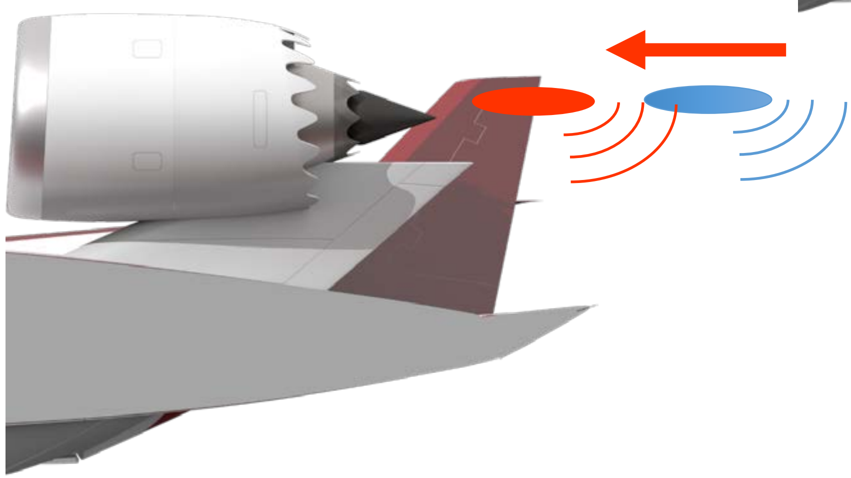

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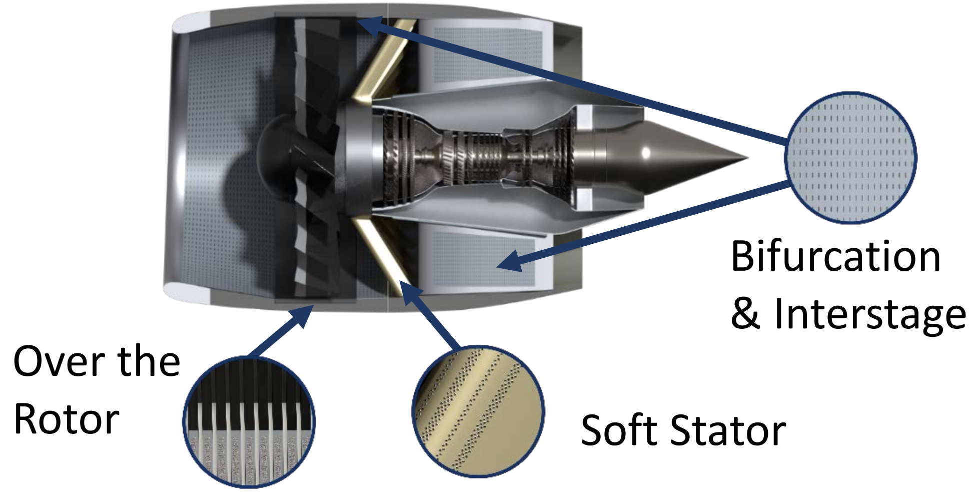
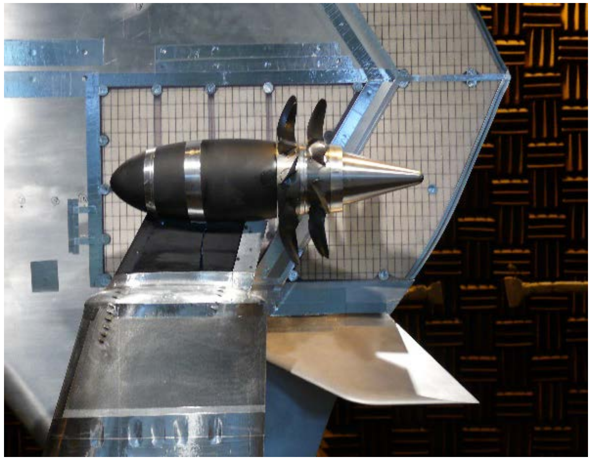
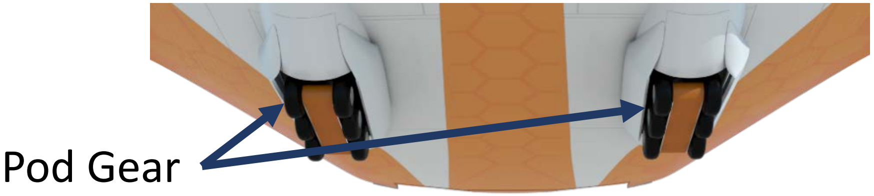
Future Acoustic Liner Utilization

Driver	Opportunity
Short Nacelles	Efficient Engine Liners
Open Rotor	External Acoustic Liners
Engine Noise Reduction	
Fuselage Reflection	
Fan-Wing Reflection	
Landing Gear Reflection	Pod Gear Door Liner







Future Acoustic Liner Utilization

Opportunity

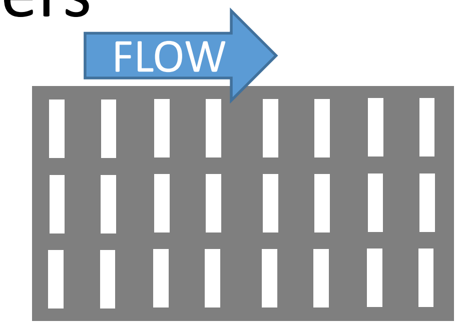
- Efficient Engine Liners
- External Acoustic Liners
- Pod Gear Door Liner

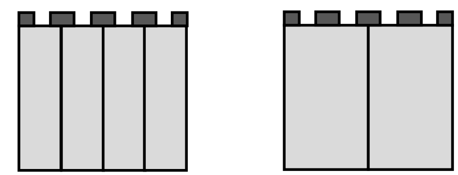
Challenges

- Fuel Burn
- Mass
- Broadband Attenuation
- Volume

Potential Enablers

- Perpendicular Slot[1]
- Large Cavity[2]
- Variable Depth[3]
- Bent Chamber[3]





[1]Howerton, B.M. and Jones, M.G., "Acoustic Liner Drag: Measurements on Novel Facesheet Perforate Geometries," AIAA Paper 2016-2979.
[2]Brown, M.C. and Jones, M.G., "Effects of Cavity Diameter on Acoustic Impedance in a Complex Acoustic Environment," AIAA Paper 2018-3443.
[3]Jones, M.G., Watson, W.R., Nark, D.M., Schiller, N.H., and Born, J.C., "Optimization of Variable-Depth Liner Configurations for Increased Broadband Noise Reduction," AIAA Paper 2016-2783.

Conceptual System Design with Acoustic Liners

- Experimental data
  - Minimal conventional acoustic liner data outside of engine
  - Difficult to explore a wide design space or unique concepts
- Analytical tools
  - Ray tracers
    - Requires only geometry and estimate of liner absorption coefficient
    - Run time suitable for optimization loops
    - Neglects diffraction effects
  - Boundary Integral Equation (TD-FAST[1])
    - Higher fidelity
    - Requires geometry and acoustic liner impedance
    - Less suitable for optimization

[1]Hu, F.Q., Pizzo, M.E., and Nark, D.M., "On the Assessment of Acoustic Scattering and Shielding by Time Domain Boundary Integral Equation Solutions," AIAA Paper 2016-2779.

Outlook

- Current T+W design has a 3.6 dB penalty from reflection
- HWB has the largest benefit of 10 dB relative to the T+W
- Lower risk MFN concept still provides 7.8 dB benefit
- Acoustic Liner Usage
  - Tools available to incorporate novel liner concepts into system design process
  - Technologies developing to meet challenges and enable external liners
- Opportunities to alter PAA effects for a noise benefit
  - Increase incentive for unconventional configurations
  - Potential retrofit to noisier existing aircraft

Backup

T+W Results

Case	Approach	Cutback	Sideline	CUM	Margin
Stage 4	104.64	98.54	101.29	294.47	
PAA	93.35	86.74	91.99	272.08	22.39
No PAA	92.46	85.40	90.57	268.43	26.04
Δ PAA	-0.89	-1.34	-1.42	-3.65	

Takeoff weight: 555000

MFN Results

Case	Approach	Cutback	Sideline	CUM	Margin
Stage 4	104.58	98.43	101.22	294.23	
PAA	90.42	84.63	84.74	259.79	34.44
No PAA	91.58	84.61	87.83	264.02	30.21
ΔPAA	1.16	-0.02	3.09	4.23	

Takeoff weight: 544748

HWB Results

Case	Approach	Cutback	Sideline	CUM	Margin
Stage 4	104.52	98.33	101.15	294.00	
PAA	90.89	79.83	82.88	253.6	40.4
No PAA	92.21	82.92	84.9	260.03	33.97
ΔPAA	1.32	3.09	2.02	6.43	

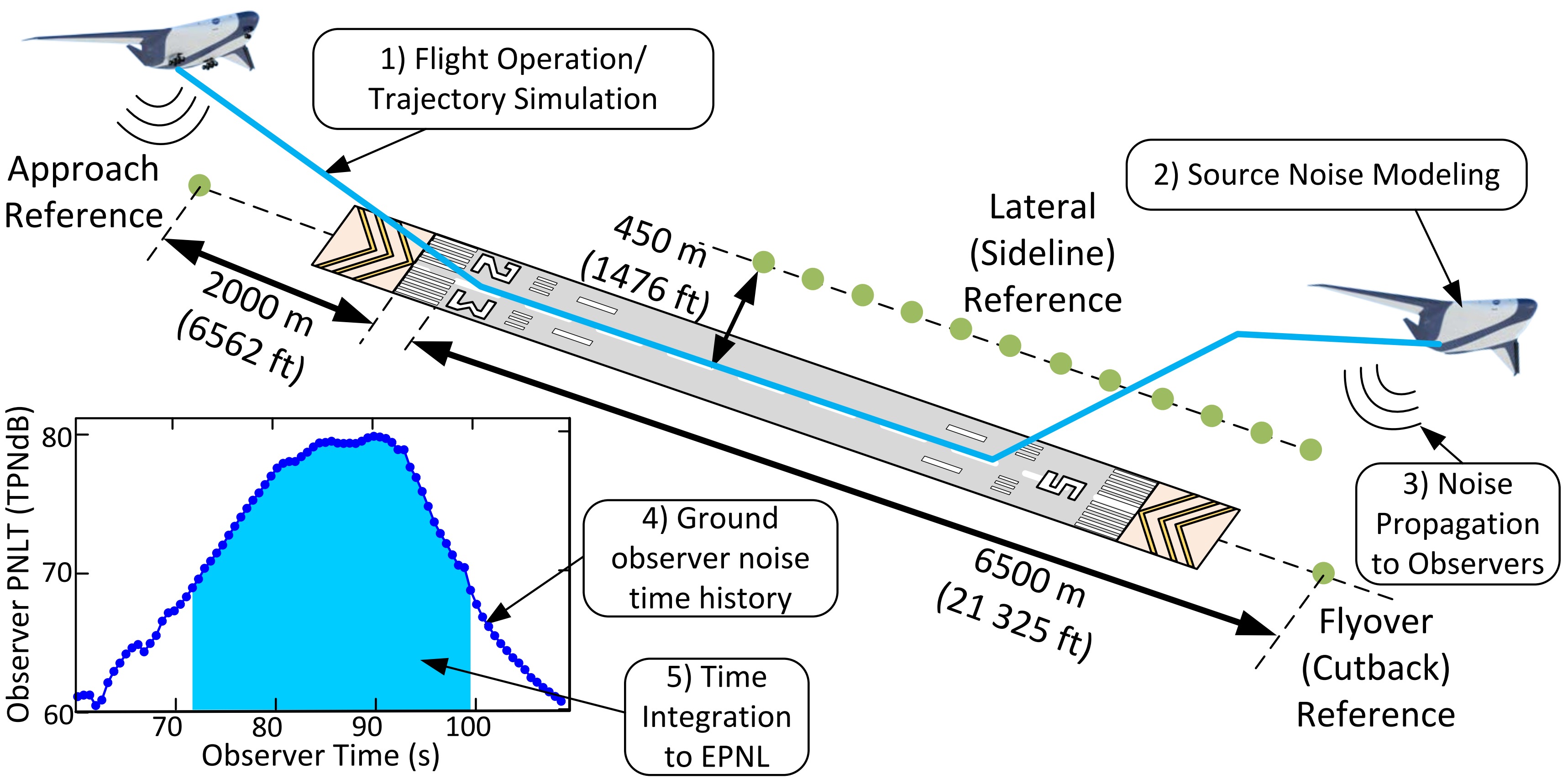
Takeoff weight: 535164 lbs

NASA Subsonic Transport Target Metrics

Technology Benefits	Technology Generations (Technology Readiness Level = 5 – 6)		
	Near Term 2015 – 2025	Mid Term 2025 – 2035	Far Term Beyond 2035
Noise (cumulative below Stage 4)	22 – 32 dB	**32 – 42 dB**	42 – 52 dB
LTO NO_x Emissions (below CAEP 6)	70 – 75%	80%	> 80%
Cruise NO_x Emissions (relative to 2005 best in class)	65 – 70%	80%	> 80%
Aircraft Fuel Consumption (relative to 2005 best in class)	40 – 50%	50 – 60%	60 – 80%

Evolutionary Revolutionary Transformational

Certification Procedure



ANOPP-Research Noise Prediction Process