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On Aircraft Trailing Edge Noise

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Future Aircraft Design and Noise Impact

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Acknowledgments

NEAT Consulting

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Outline

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- Introduction
- Trailing edge noise data
- Prediction methods
- Estimate of HWB trailing edge noise
- Summary

Introduction

- Significant noise reduction opportunities for future aircraft have been investigated for the major airframe noise sources
- Is trailing edge noise the noise floor?
  - Need reliable data and/or prediction tool to assess its relative importance
- Objectives of this presentation
  - Review currently available data and prediction methods
  - Illustrate importance of trailing edge noise for future aircraft by preliminary estimate for the Hybrid-Wing-Body (HWB) aircraft

Airframe Noise Reduction

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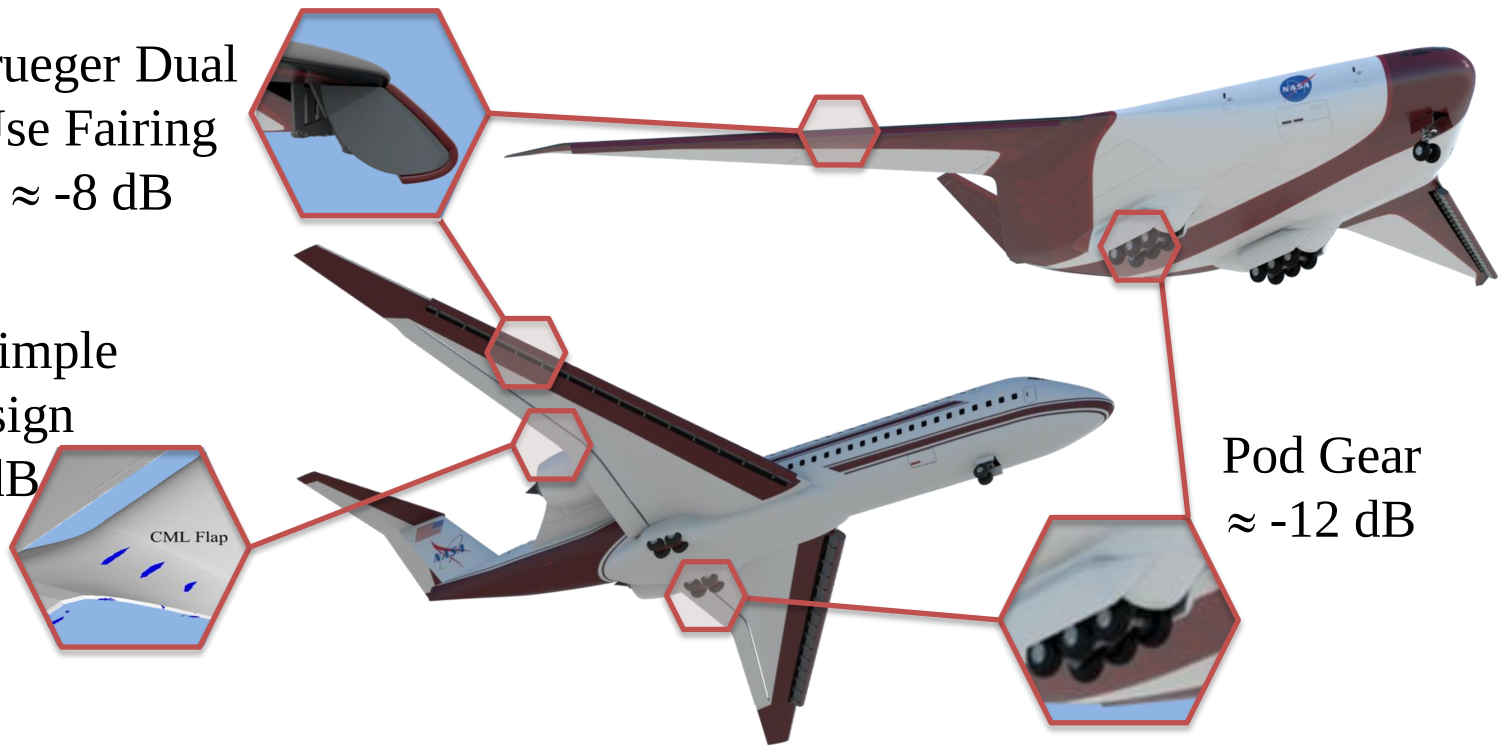
- Thomas R. H., Burley C.L. and Guo Y. P., “Potential for Landing Gear Noise Reduction on Advanced Aircraft Configurations,” AIAA 2016-3039
- Thomas R. H., Guo Y. P., Berton J. J. and Fernandez H., “Aircraft Noise Reduction Technology Roadmap Toward Achieving the NASA 2035 Noise Goal,” AIAA 2017-3193
- Guo Y. P., Thomas R. H., Clark I.A. and June J.C., “Far Term Noise Reduction Roadmap for the Mid-Fuselage Nacelle Subsonic Transport,” AIAA 2018-3126

Krueger Dual Use Fairing ≈ -8 dB

CML on Simple Flap Design ≈ -10 dB

Pod Gear ≈ -12 dB



Trailing Edge Noise Measurement

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- Challenges
  - Wind tunnel background noise
  - Other noise components
  - Flight test at engine idle for cruise configuration
  - Noise floor may also contain other components such as wing tip, fuselage boundary layer, aileron, and residual engine noise
- Useful techniques
  - Phased array: subdomain integration to extract trailing edge noise when it is not significantly lower than other sources

Trailing Edge vs Slat

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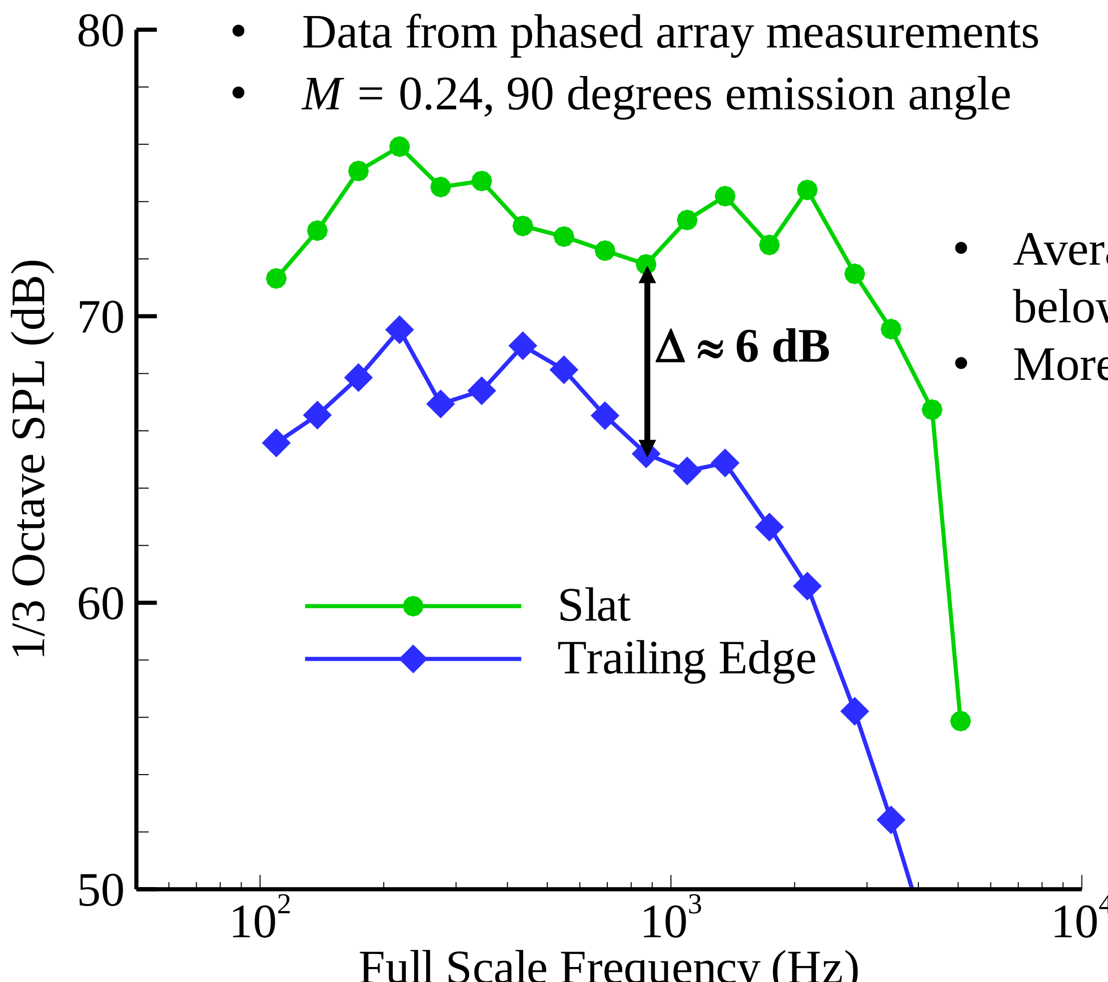
- Guo Y. P., Yamamoto K. J. and Stoker R. W., "A Component Based Empirical Model for High Lift System Noise Prediction," *J. Aircraft* **40**(5), 914-922, 2003
- Conventional Aircraft: 4.7% MD-11 Model
- Data from phased array measurements
- M = 0.24, 90 degrees emission angle



- Average difference about 6 dB below 1000 Hz
- More above 1000 Hz

Trailing Edge vs Flap

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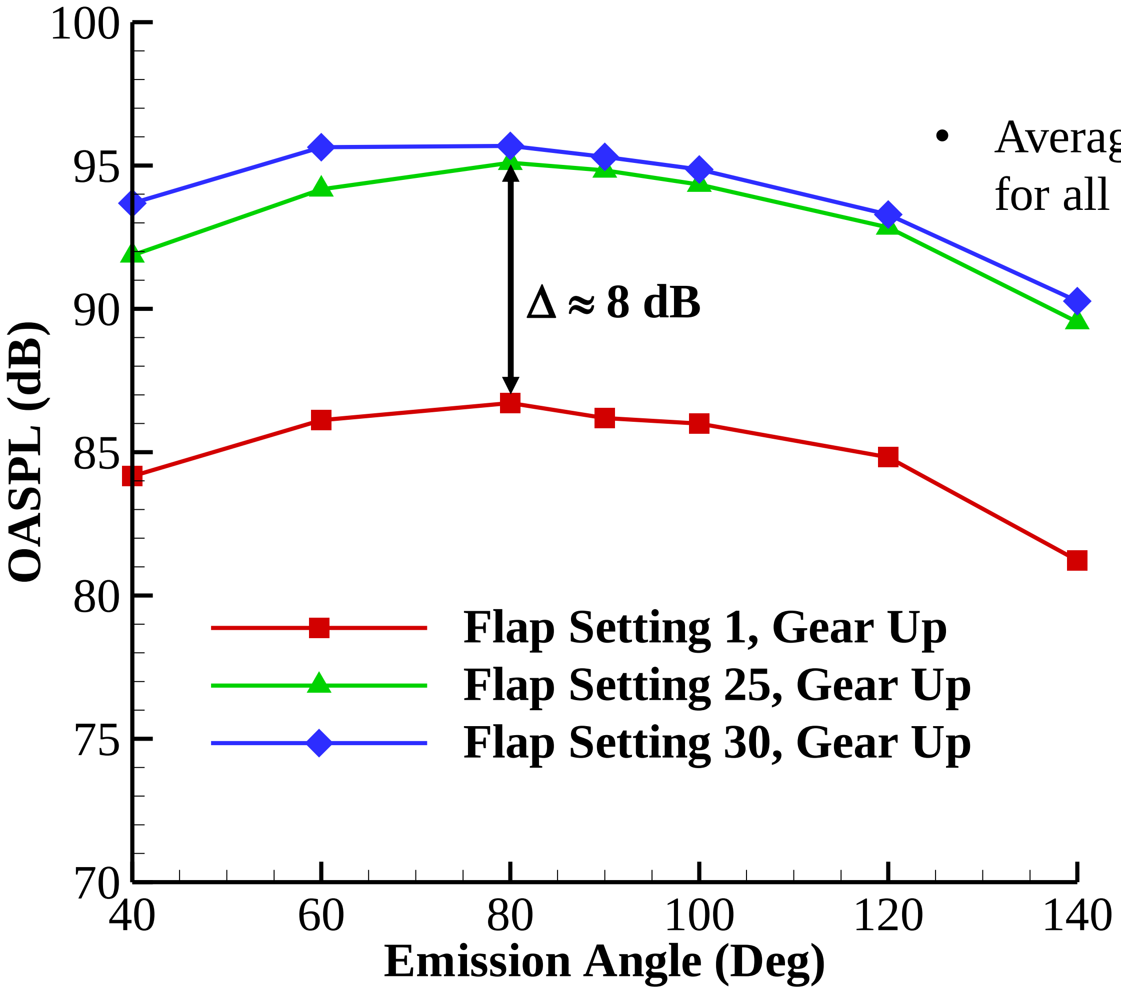
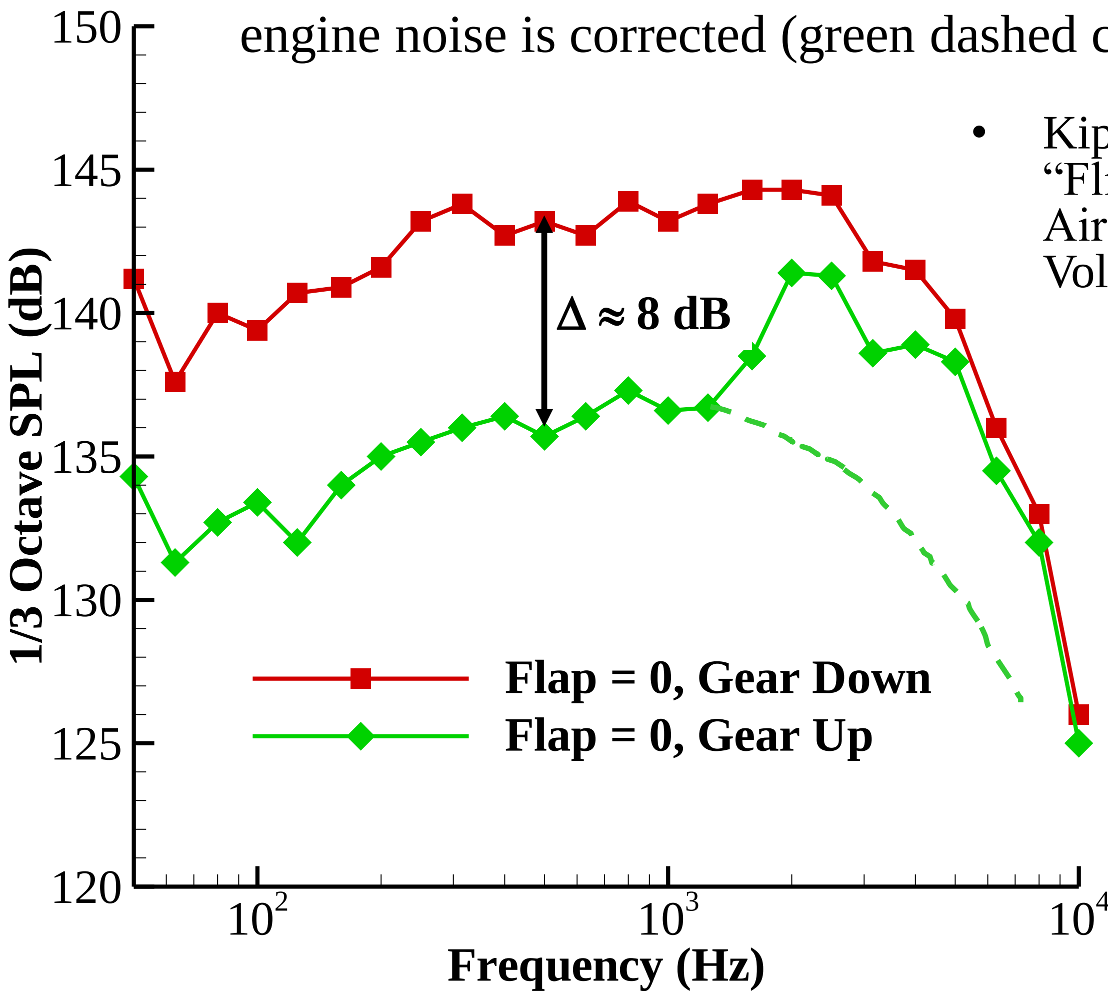
- Stoker R. and Guo Y. P., "Airframe Noise of a Full-Scale 777 and Comparison with Past Model-Scale Tests," *NASA Contract Report*, *Contract NAS1-97040*, February 2002



- Average difference about 8 dB for all angles

Trailing Edge vs Landing Gear

- Average difference about 8 dB below 1000 Hz
- Engine noise contamination above 1000 Hz
- Difference expected to be more than 8 dB above 1000 Hz when engine noise is corrected (green dashed curve)



- Kipersztok O. and Sengupta, G., "Flight Test of the 747-JT9D for Airframe Noise," *Journal of Aircraft*, Vol. 19, No. 12, December, 1982

Component Noise

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	Landing Gear	Flap	Slat
Current Level above TE Noise (dB)	8	8	6
Potential Noise Reduction (dB)	-12	-10	-8
∗Potential Level above TE Noise (dB)	-4	-2	-2

∗Worst case because of other noise components in the noise floor and the potential of trailing edge noise reduction for advanced aircraft

- With advanced noise reduction, trailing edge noise can potentially hold up the noise floor
- Order of estimate only and need more accurate quantitative study
  - Detailed study for existing database in aircraft type, directivity, etc.
  - Extract other components and engine residual noise
- Even without noise reduction, trailing edge noise may increase for particular aircraft configurations (see HWB example later)

Prediction Method

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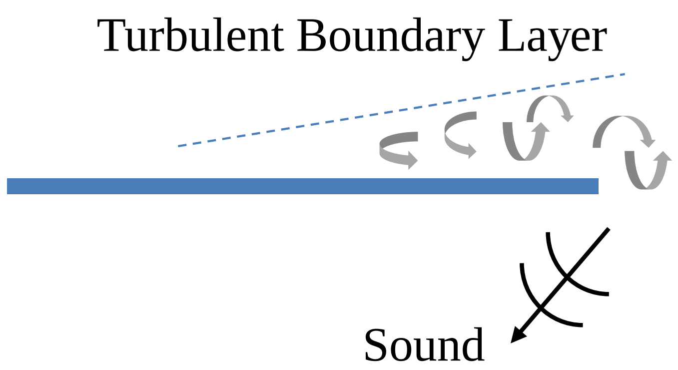
- Source mechanisms well studied
- Prediction formulation for noise spectrum Π

$$\Pi(\omega, \mathbf{x}) = A\rho_0^2 u^2 V^2 M \frac{L\delta}{r^2} \cos^3 \beta D(\varphi, \theta) F(\omega, M)$$

- Need local turbulent kinetic energy k, convection velocity V, and boundary layer thickness δ

A = empirical constant
ρ_0 = mean density
u = turbulent velocity ($u^2 \propto k$)
V = convection velocity
M = flight Mach number
L = trailing edge length
δ = boundary layer thickness
r = far field distance
β = sweep angle
D = directivity
F = spectral function



Fink Method

- Approximate all local flow quantities by an empirical constant

$$\Pi_{FINK}(\omega,\mathbf{x}) = A_{FINK} M^5 \frac{S}{r^2} D(\varphi,\theta) F(\omega,M)$$

  - S = wing surface area
  - A_{FINK} = empirical constant defined for two classes of aircraft ("aerodynamically clean" or otherwise)

- Database only include old aircraft pre 1977
- Variations in current and future aircraft not likely to fit into an empirical constant
- Empirical approximation no longer necessary because local flow quantities can be derived by CFD

HWB Trailing Edge Noise Estimate

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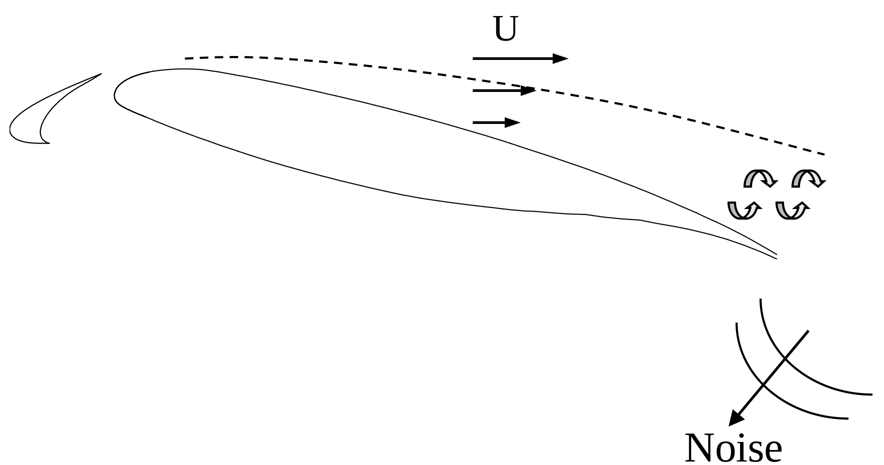
- Estimate source flow quantities in reference to conventional aircraft by using a generic two-element high lift system
  - 4^o angle of attack for tube-and-wing (T+W) aircraft
  - 15^o angle of attack for HWB

- Estimate noise variations due to changes in
  - turbulent kinetic energy k
  - convection velocity V
  - trailing edge length L
  - boundary layer thickness δ

- Effect of flight Mach number not considered because it affects all components



Turbulent Kinetic Energy

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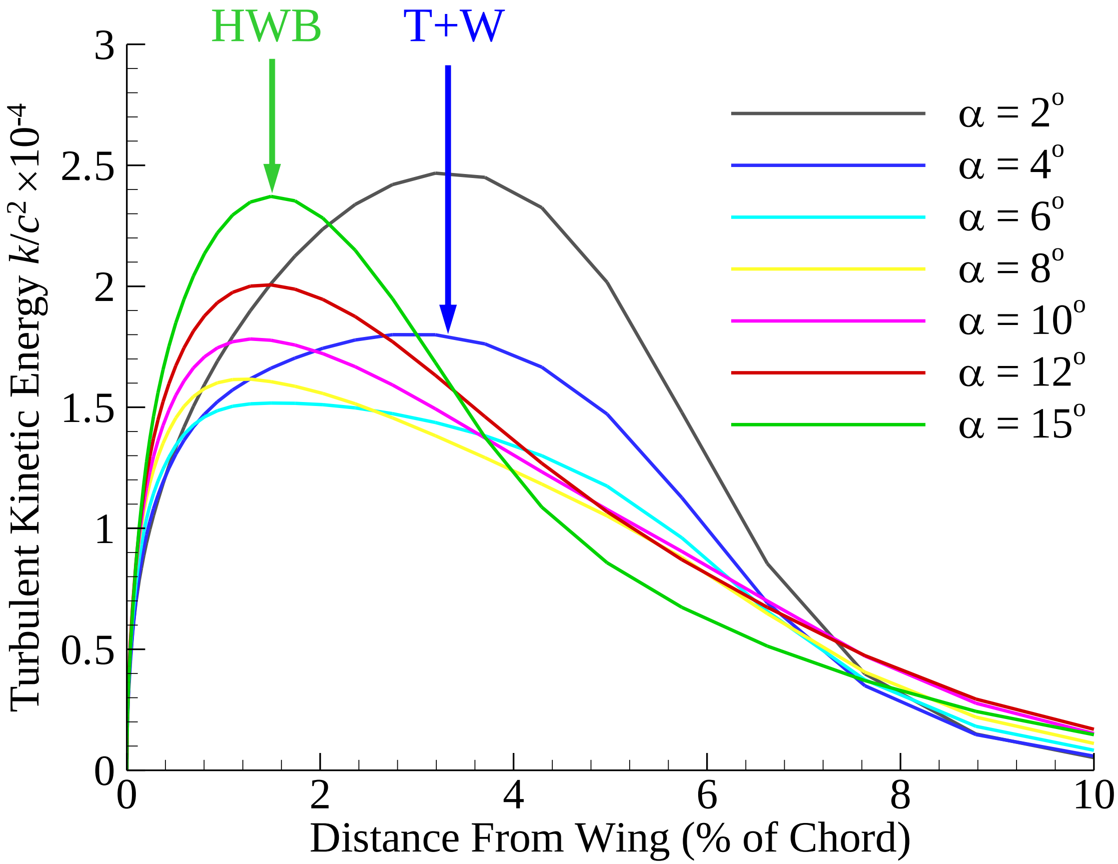
$k_{HWB} / k_{T+W} = 1.33$



Convection Velocity at Trailing Edge

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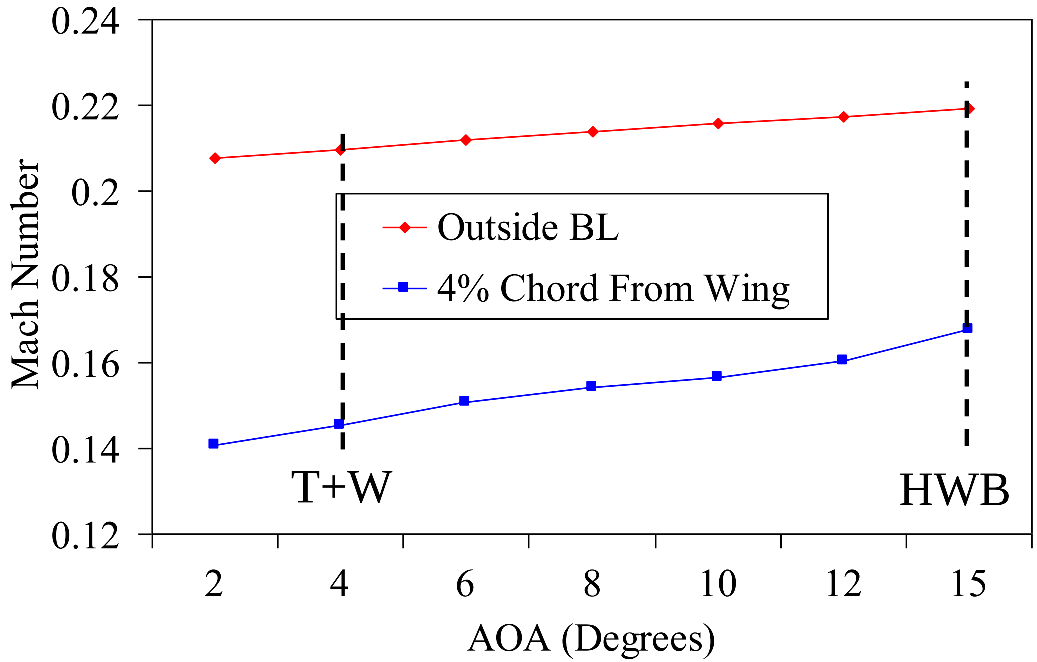
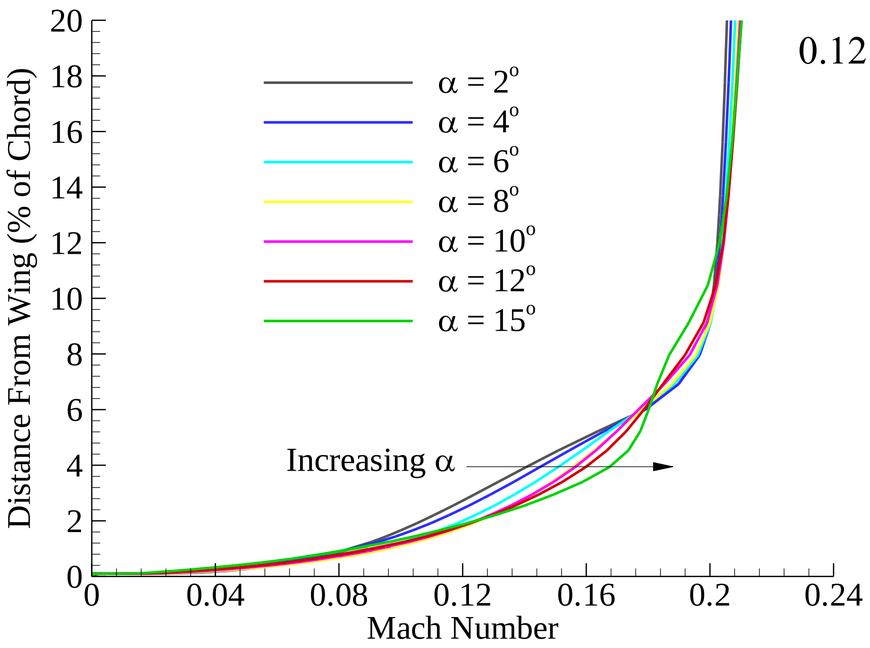


$$V_{HWB} / V_{T+W} = 1.154$$



Boundary Layer Thickness

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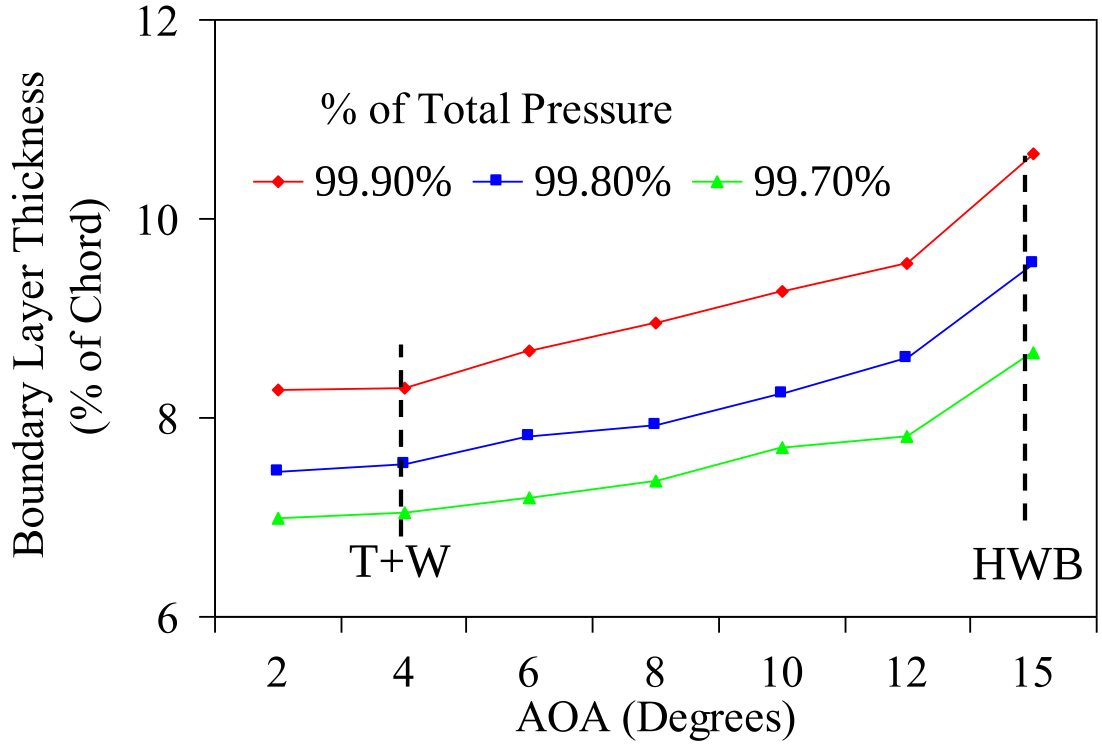

Total Pressure (%)	99.9	99.8	99.7
$\delta_{HWB}/\ \delta_{T+W}$	1.28	1.27	1.23

Average Value of $\delta_{HWB}/\ \delta_{T+W} = 1.26$

HWB Trailing Edge Noise Estimate

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$$\Delta SPL = 10 \times \log(k_{HWB}/\ k_{T+W})$$ ← Turbulent Kinetic Energy

$$+\ 20 \times \log(V_{HWB}/\ V_{T+W})$$ ← Convection Velocity

$$+\ 10 \times \log(\delta_{HWB}/\ \delta_{T+W})$$ ← Boundary Layer Thickness

$$+\ 10 \times \log(L_{HWB}/\ L_{T+W})$$ ← Trailing Edge Length

Estimate:

$k_{HWB}/\ k_{T+W} = 1.33$

$V_{HWB}/\ V_{T+W} = 1.15$

$\delta_{HWB}/\ \delta_{T+W} = 1.26$

$L_{HWB}/\ L_{T+W} = 1.2$

$\Delta SPL = 4.3$ dB

Question: Does this increase make TE noise important?

Extrapolation to HWB

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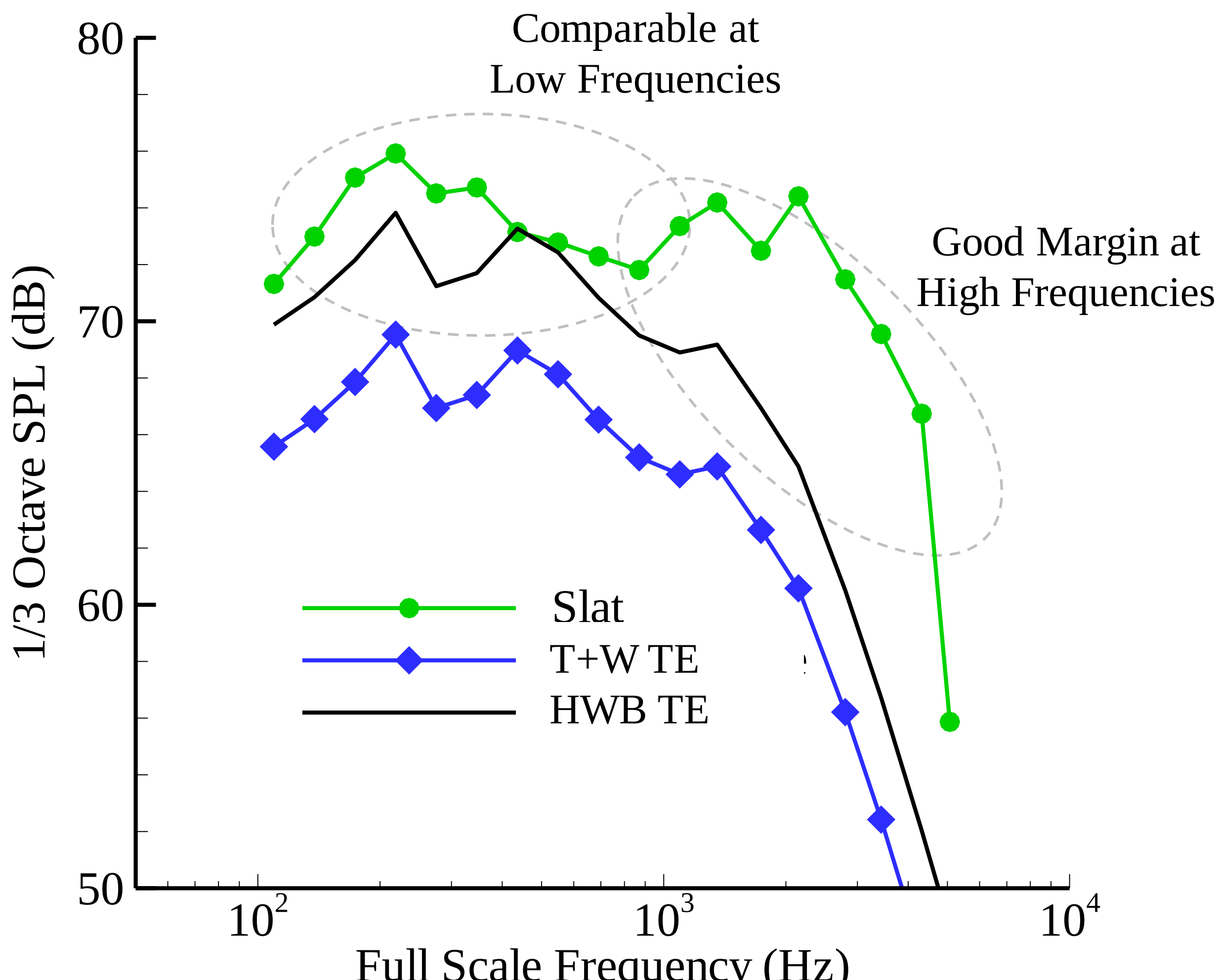
- Assume the same slat noise for HWB and T+W aircraft (green circles)
- Trailing edge noise increases 4 dB from T+W (blue diamonds) to HWB (black curve)



Preliminary Observations

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- Because of the potential reduction of other noise components, trailing edge noise may become the noise floor for future aircraft
- Trailing edge noise itself can increase for some aircraft such as HWB and truss braced wing aircraft, increase the importance of trailing edge noise in reference to other components
- Current prediction method is outdated and has been used only because trailing edge noise is more than 8 dB lower than other components for current aircraft
- More accurate and robust prediction tools are feasible by computing the local flow quantities


Thank you