



Summary of ERA Final 2015 Noise Assessment Results

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Acoustic Technical Working Group Meeting
NASA Glenn Research Center
Cleveland, Ohio

October 21, 2015

**Work funded by
NASA Environmentally Responsible Aviation (ERA) Project**

Objective



- “Demonstration through analysis” will be utilized to document ERA’s progress towards achieving the N+2 system level fuel burn, emissions, and noise goals
 - The ERA Portfolio Assessment Team will analyze the impact of the technologies that comprise the 8 Integrated Technology Demonstrations (ITDs)
 - Three main deliverables, due at the end of FY13, FY14 and FY15
- INITIAL UPDATED FINAL
-
- The diagram shows three labels: INITIAL, UPDATED, and FINAL, arranged horizontally. Above INITIAL is an arrow pointing up and to the right. Above UPDATED is an arrow pointing up. Above FINAL is an arrow pointing up and to the left. These arrows suggest a sequential flow from INITIAL to UPDATED to FINAL.

ERA Systems Analysis Team – FY15



Airframe & Propulsion

- Craig Nickol (Lead)
- Andy Hahn
- Frank Gern
- Doug Wells
- Jesse Quinlin
- Bill Haller
- Mike Tong
- Scott Jones
- Jeff Berton
- Tom Ozoroski

Acoustics

- Russ Thomas (Lead)
- Casey Burley
- Len Lopes
- Doug Nark
- John Rawls, Jr.
- Stuart Pope
- Yueping Guo
- Florence Hutcheson
- Chris Bahr
- Dan Stead
- Taylor Spalt
- Mike Jones
- Steve Rizzi
- Aric Aumann

NASA's N+2 Subsonic Transport System Level Metrics



ERA Approach

- Conduct Integrated System Level Research
- Develop advanced vehicle concepts envisioned for integration into the fleet by 2025
- Develop multi-discipline technologies envisioned for advanced vehicle concepts
- Advance TRL for high-payoff key technologies to 5 or 6 by 2015

	TECHNOLOGY GENERATIONS (Technology Readiness Level = 4-6)		
TECHNOLOGY BENEFITS*	N+1 (2015)	N+2 (2020**)	N+3 (2025)
Noise (cum below Stage 4)	- 32 dB	- 42 dB	- 71 dB
LTO NOx Emissions (below CAEP 6)	-60%	-75%	-80%
Cruise NOx Emissions (rel. to 2005 best in class)	-55%	-70%	-80%
Aircraft Fuel/Energy Consumption [‡] (rel. to 2005 best in class)	-33%	-50%	-60%

* Projected benefits once technologies are matured and implemented by industry. Benefits vary by vehicle size and mission; N+1 and N+3 values are referenced to a 737-800 with CFM56-7B engines, N+2 values are referenced to a 777-200 with GE90 engines

** ERA's time phased approach includes advancing "long-pole" technologies to TRL 6 by 2015

‡ CO₂ emission benefits dependent on life-cycle CO_{2e} per MJ for fuel and/or energy source used

Outline

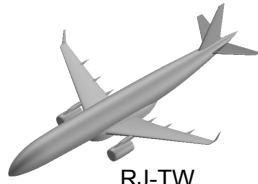


- **ERA Vehicle Concepts**
- **LTO NOx Emissions and Fuel Burn Assessment Summary**
- **Systems Noise Assessment**
 - **Vehicle and flight definitions**
 - **Prediction Process and Modeling Details**
 - **Noise Results**
- **Remarks**

ERA Advanced (2025) Vehicle Concepts



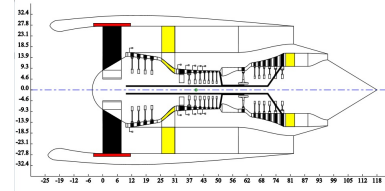
RJ



RJ-TW
(2) Small DD



OWN98
(2) Small DD



Small DD

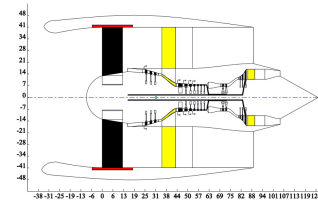
SA



SA-TW
(2) Small GTF

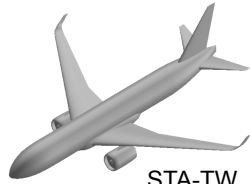


OWN160
(2) Small GTF



Small GTF

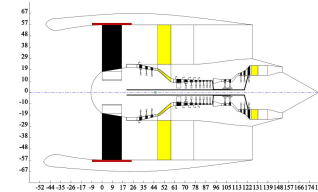
STA



STA-TW
(2) Medium GTF

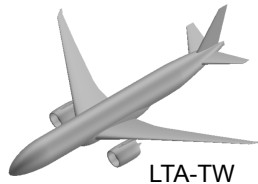


HWB216
(2) Medium GTF

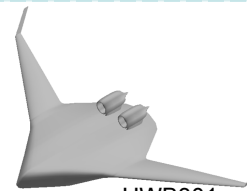


Medium GTF

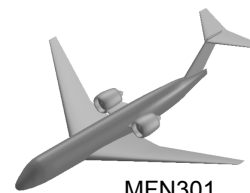
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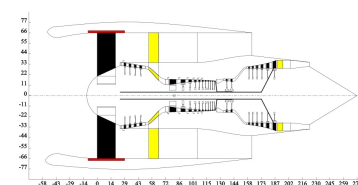
LTA-TW
(2) Large DD
(2) Large GTF



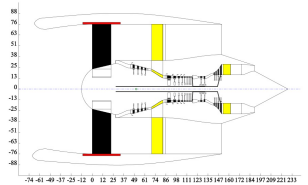
HWB301
(2) Large DD
(2) Large GTF



MFN301
(2) Large GTF



Large DD

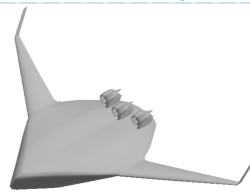


Large GTF

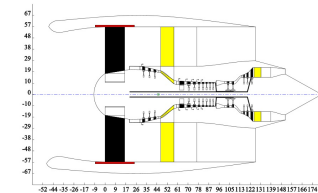
VLTA



VLTA-TW
(4) Medium GTF

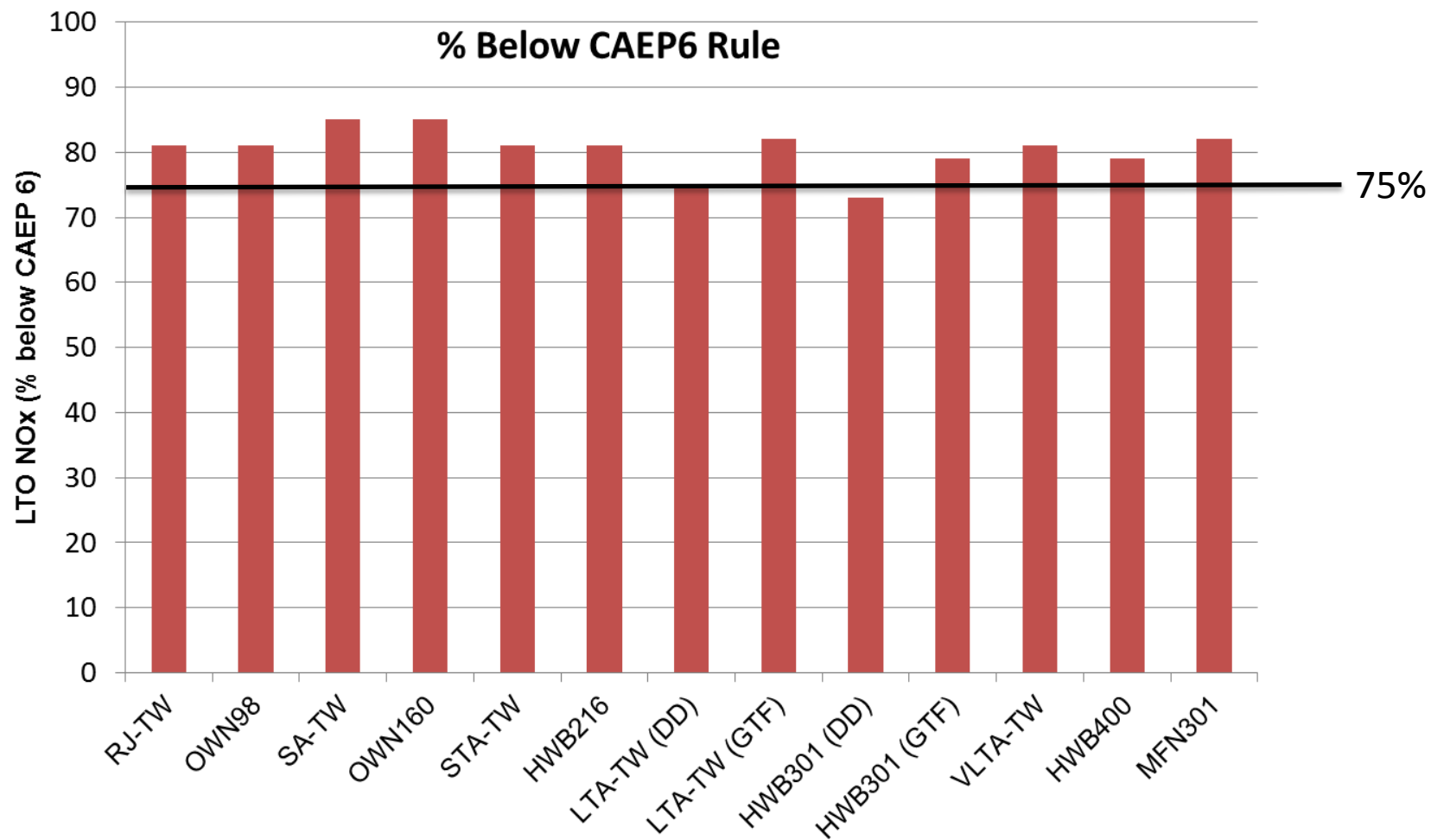
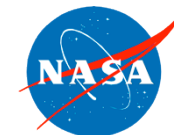


HWB400
(3) Medium GTF

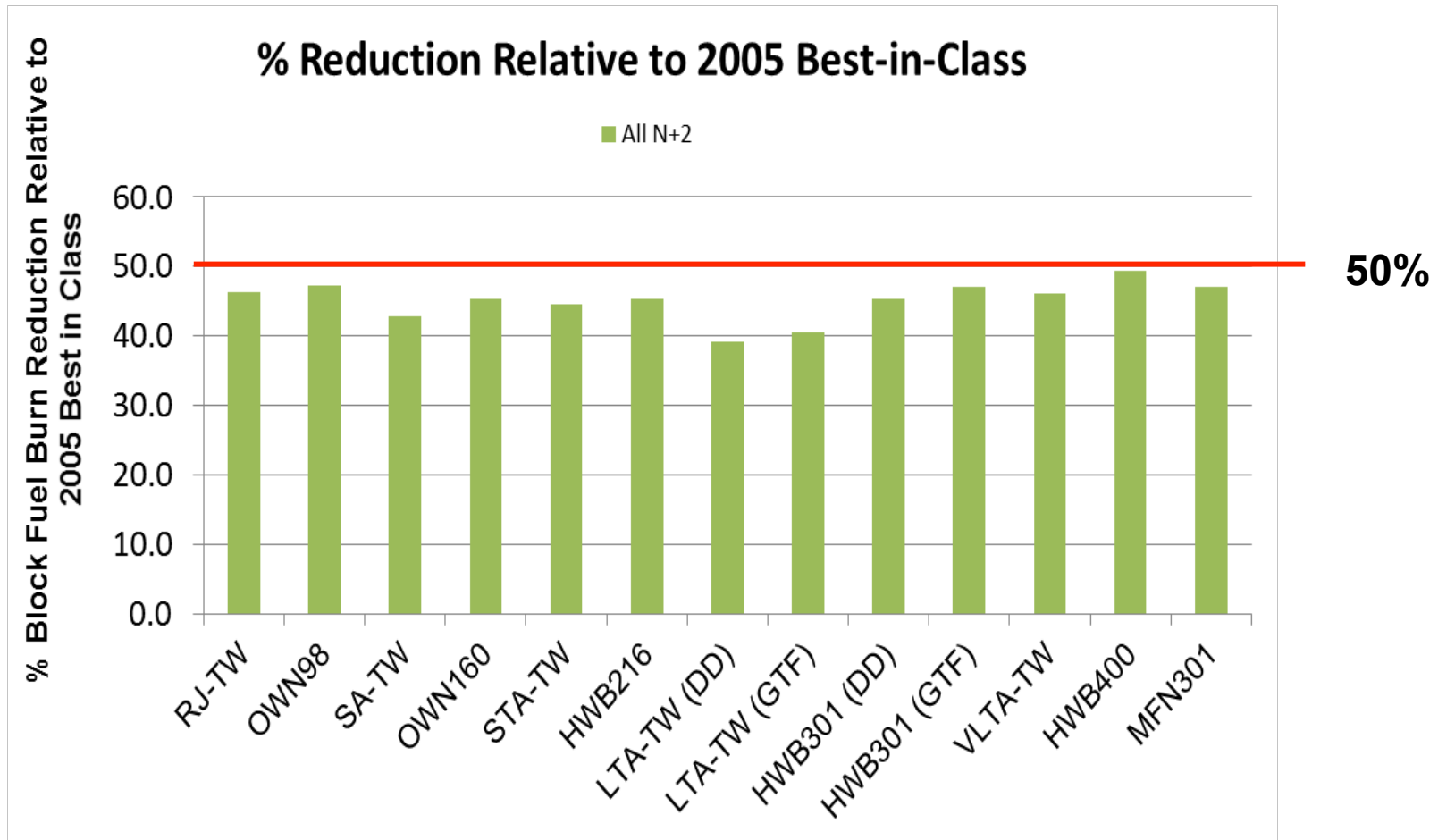


Medium GTF

LTO NOx Emissions Estimates



Fuel Burn Assessment Results



Fuel burn reductions relative to 2005 best in class (ERJ190, 737-800, 767-200ER, 777-200LR, 747-400)

(varying levels of technology)



Noise Assessment



System Noise of 13 ERA Phase II Vehicles

Vehicle / Engine	short name	# of Engines	Landing gear	TOGW (Klbs)
T&W: Regional Jet	RJ-DD	2 small DD	G550	91
T&W: Single Aisle	SA-GTF	2 small GTF	737	146
T&W: Twin Aisle	STA-GTF	2 med GTF	767	287
T&W: Large Twin Aisle	LTA-DD	2 large DD	777	570
T&W: Large Twin Aisle	LTA-GTF	2 large GTF	777	571
T&W: Very Large Twin Aisle	VLTA-GTF	4 med GTF	777	686
HWB: Small Twin Aisle	HWB216-GTF	2 med GTF	767	314
HWB: Large Twin Aisle	HWB301-DD	2 large DD	777	538
HWB: Large Twin Aisle	HWB301-GTF	2 large GTF	777	535
HWB: Very Large Twin Aisle	HWB400-GTF	3 med GTF	777	703
T&W: Over Wing Nacelle 98	OWN98-DD	2 small DD	G550	90
T&W: Over Wing Nacelle 160	OWN160-GTF	2 small GTF	737	142
T&W: Mid-Fuselage Nacelle	MFN301-GTF	2 large GTF	777	541

- **“Vision” vehicle** = includes ERA technology inherent in airframe and engine design.
 - Light weight structures
 - Modernized flap system (single-element design) and Krueger flap for leading edge
 - Advanced Geared TurboFan Engine (GTF) and Advanced Direct Drive Engine (DD)
 - PAA shielding appropriate to each configuration
 - Specialized technologies: interstage and MDOF liner, scarf exhaust nozzle
- **“Vision + ITD”** = ITD noise reduction technology: soft vane (fan noise), partial main landing gear fairing and flap-side edge treatment.

ERA System Noise Prediction Process



ANOPP2

Aircraft Flight Definition

Source Noise (ANOPP)

Jet: ST2JET + AOA correction

Core: GECOR (SAE)

Fan: Krejsa* model, ACD**(GTF)

Landing gear (nose & main): BoeingLG

Flap-side-edge: BoeingFlap

Leading edge (Krueger): estimated using BoeingSlat

Trailing edge: Fink

Liner: modified TREAT-GE method for MDOF liner design

PAA Effects: engine noise installation effects (shielding, reflections)

ITD noise technology reduction through suppression of specific source noise (fan, gear, flap, slat)

Propagation & Noise Metrics

Flight profiles that meet CFR 36
Aircraft geometries

FLOPS
MVL-aero

- Low speed aero
- Engine operating limits
- Airframe geometric definition
- Aircraft weights

Engine states and geometric parameters

NPSS

Processed 9x15 Fan Noise

ITD 35A: Soft Vane fan noise reduction
GTF source fan noise and 'effects' data for cut-off, bifurcation, sweep & lean, rotor-stator-spacing, directivity)
ITD 50A: LG & Flap data for RJ prediction
LG & Flap noise reduction data/prediction for all vehicles

PAA effects: LSAF data (HWB and TW)
14x22 HWB data

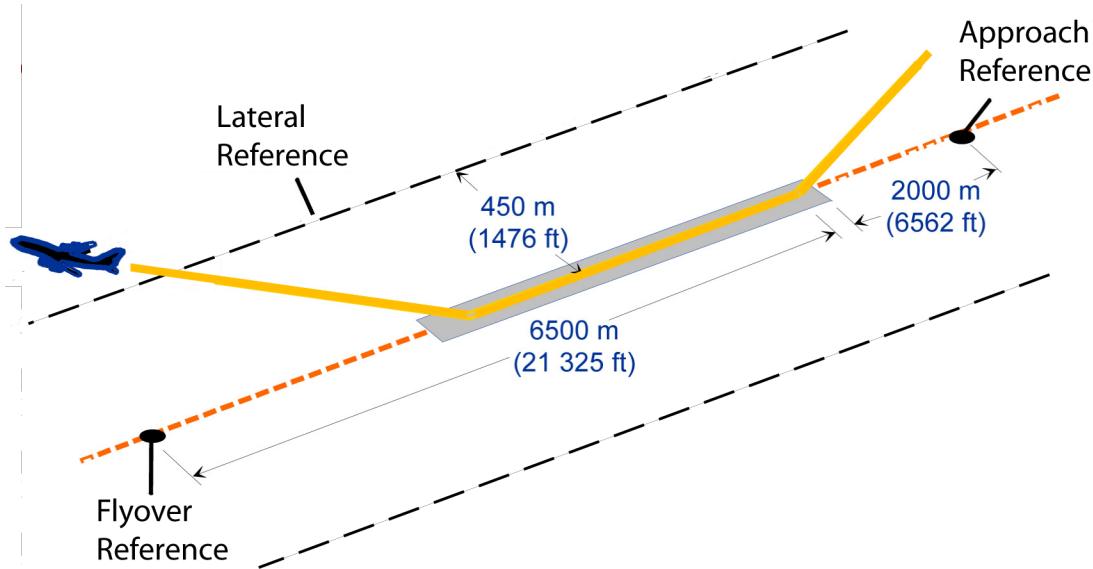


EPNL predicted at CFR 36 locations

- Heidmann Krejsa model updated with new rotor/stator spacing effect function for broadband and tone components
- Calibrated for full scale fan prediction

**ACD= Acoustic Data Module within ANOPP to allow for external noise input

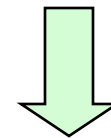
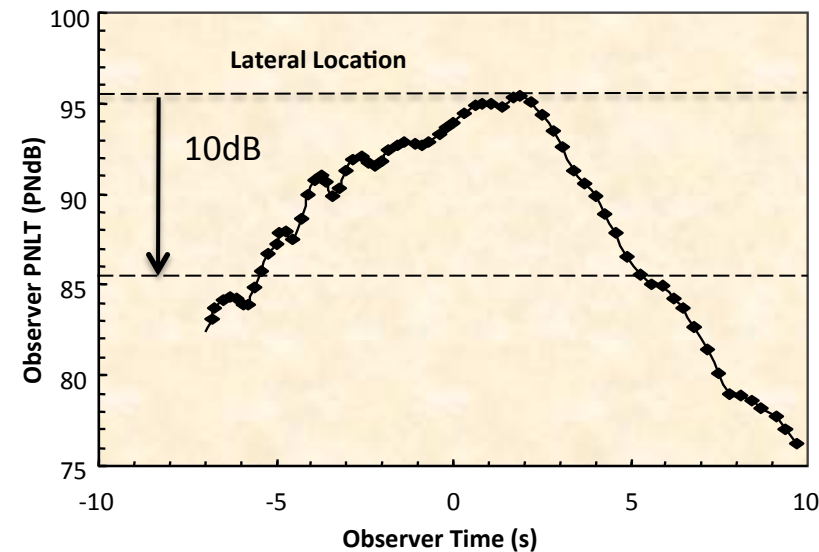
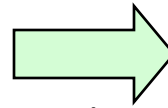
CFR* Title 14 Part 36 Noise Measurement and Metrics



Noise certification points

- Lateral (sideline)
- Flyover with cutback
- Approach

- Source noise modeling
- Trajectory simulation
- Spectra propagation (spreading, atmospheric and lateral attenuation, ground effects, reflections)
- Frequency integration for each obs. time
- Tonal content and amplitude penalties
- Ground observer noise-time history: (PNLT)
 - Lateral observer set when vehicle altitude=1000ft.
- Separate computations performed to obtain approach, lateral and flyover EPNL noise levels, consistent with previous assessments performed by NASA and Boeing.



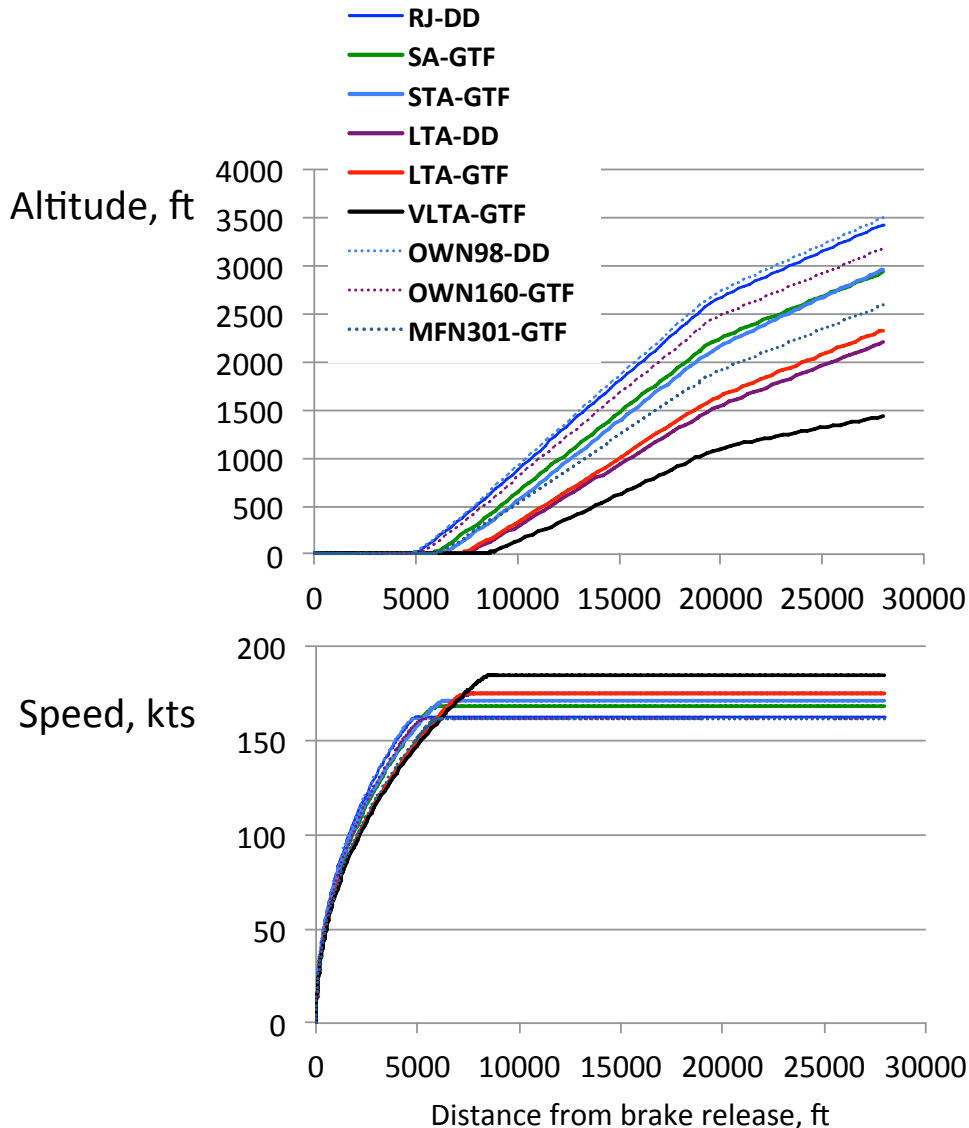
Time integration to Effective Perceived Noise Level: EPNL

*CFR = Code of Federal Regulation

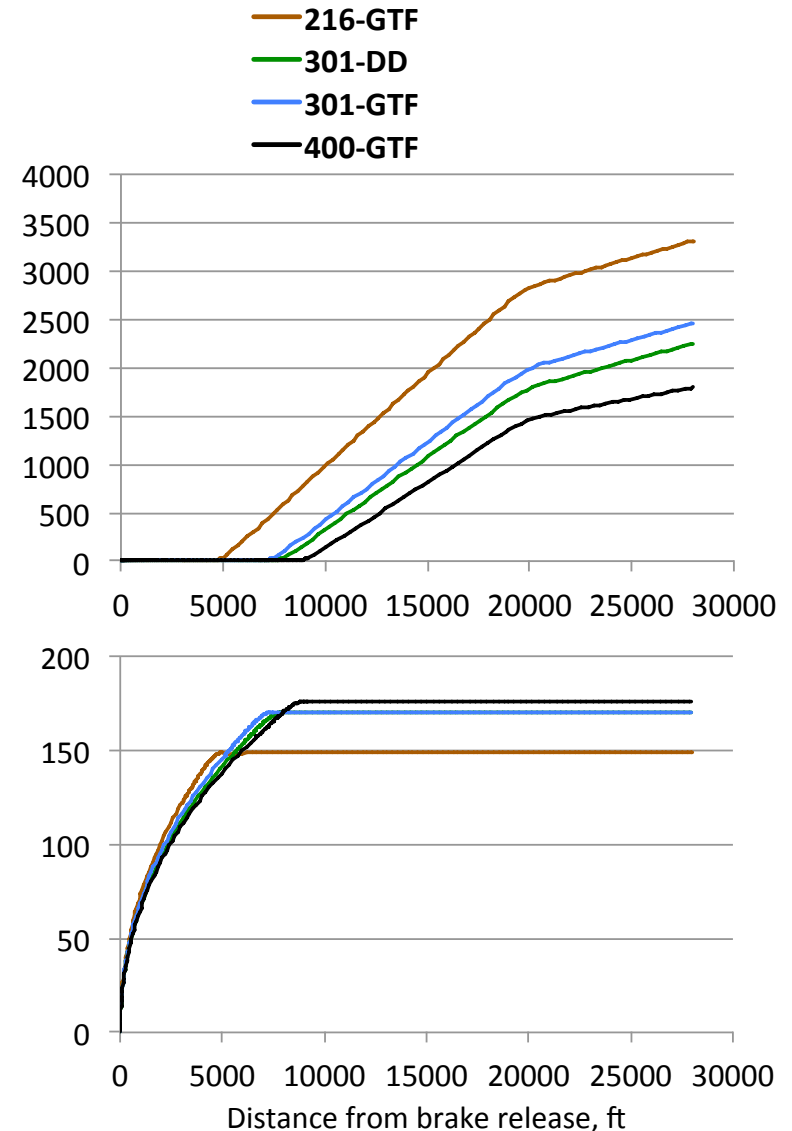
Flight Profiles: Take-Off



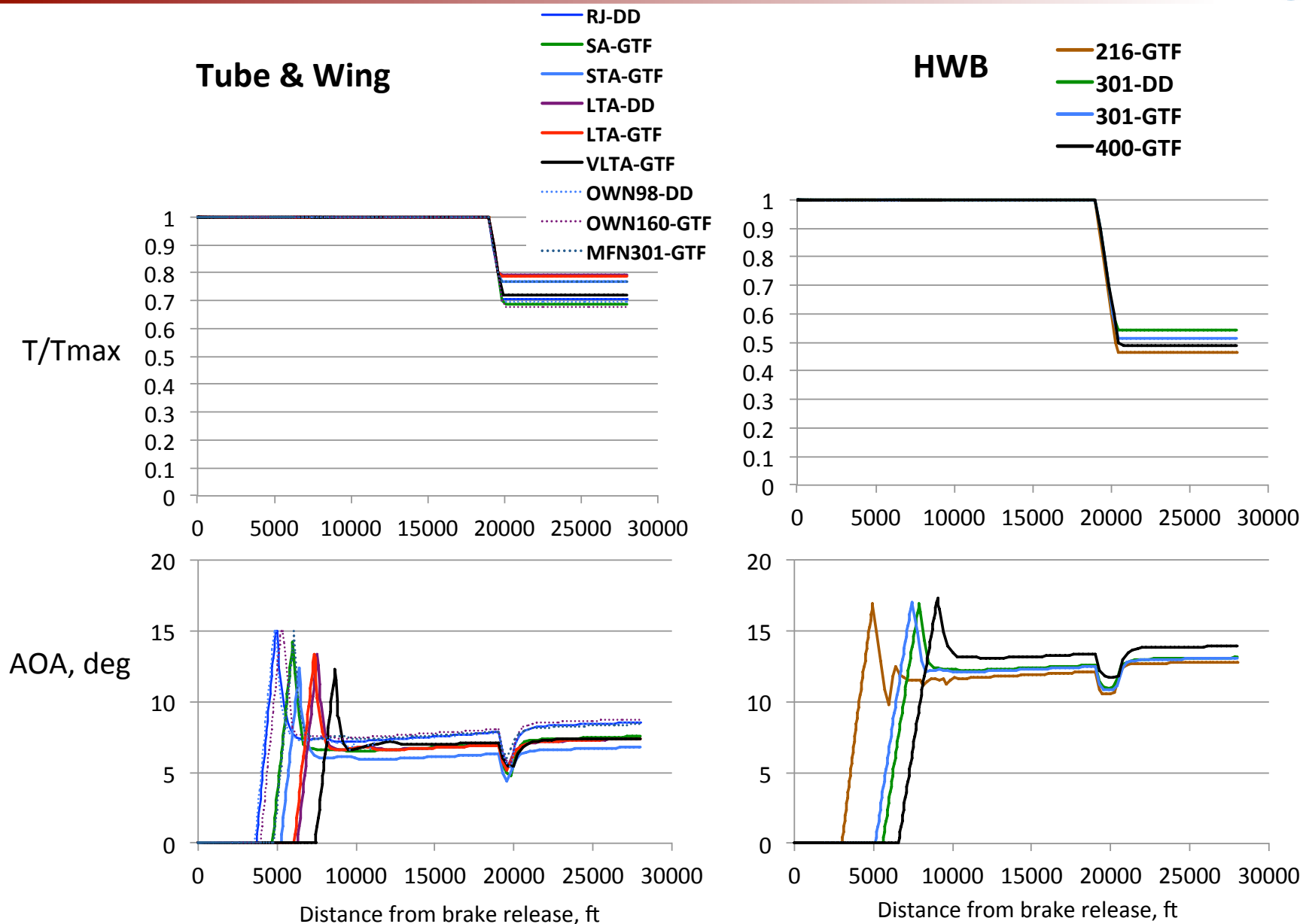
Tube & Wing



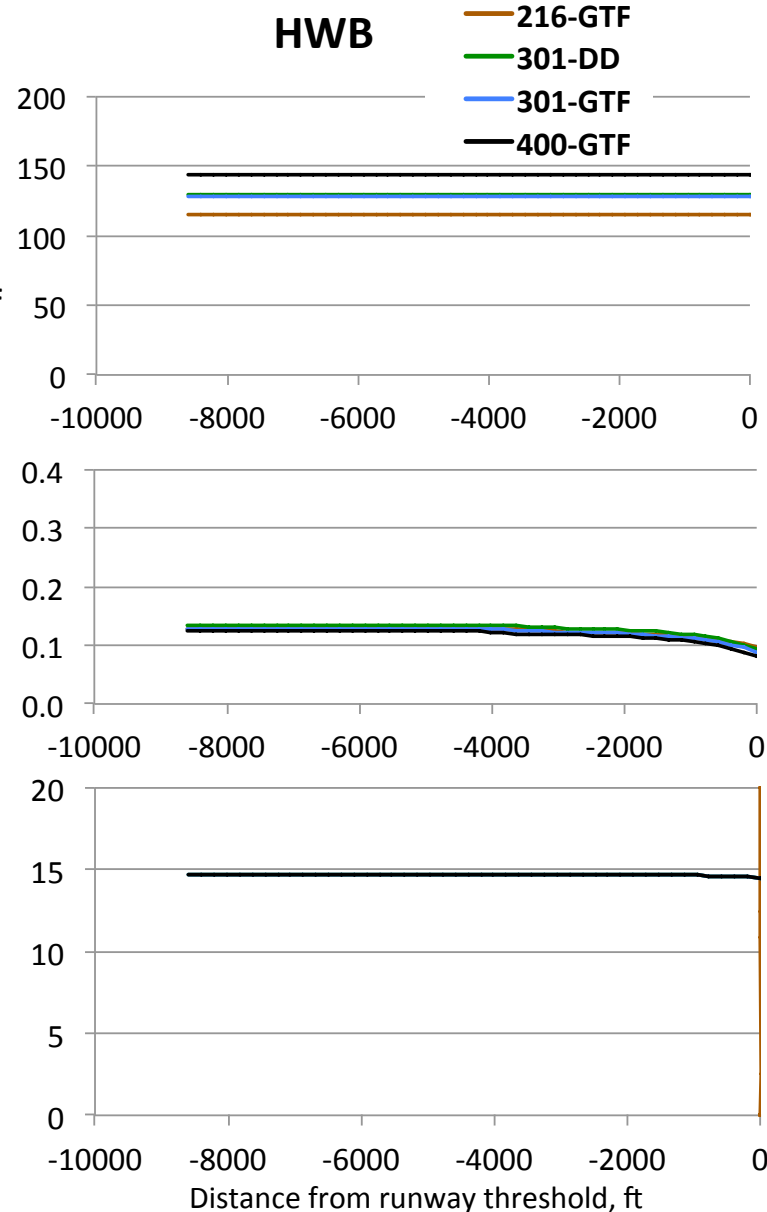
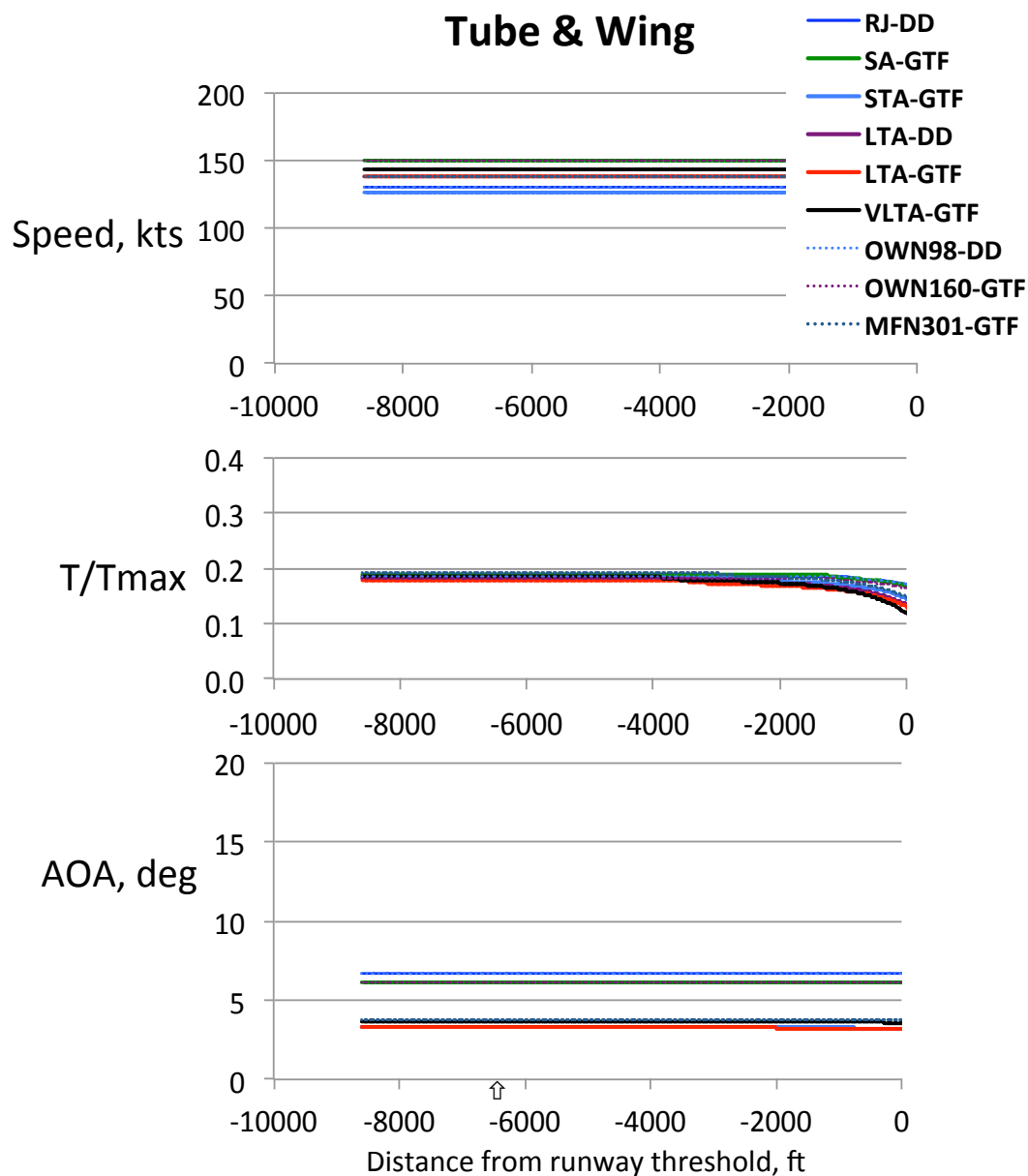
HWB



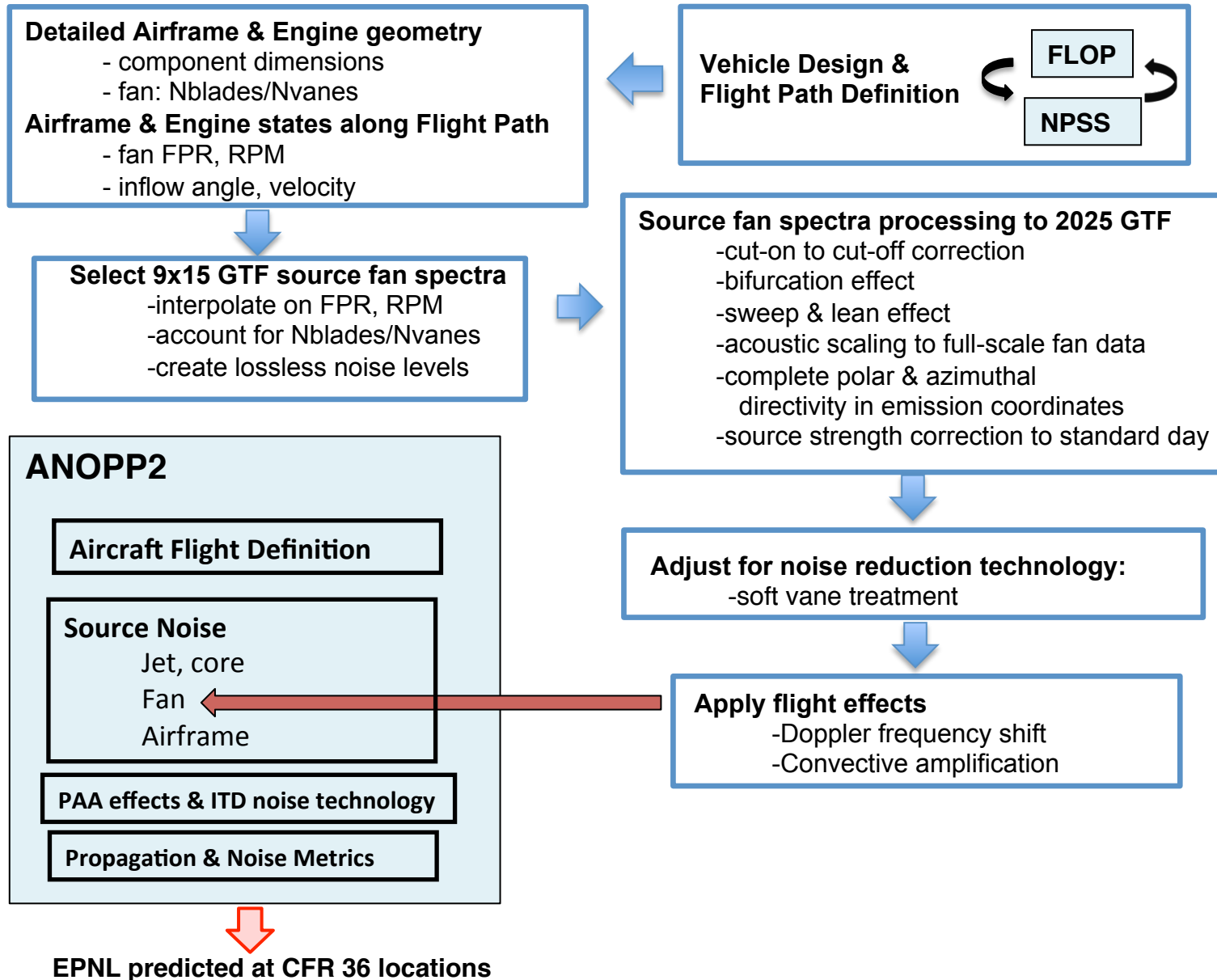
Flight Profiles: Take-Off



Flight Profiles: Approach



GTF Engine Fan Noise Prediction Process





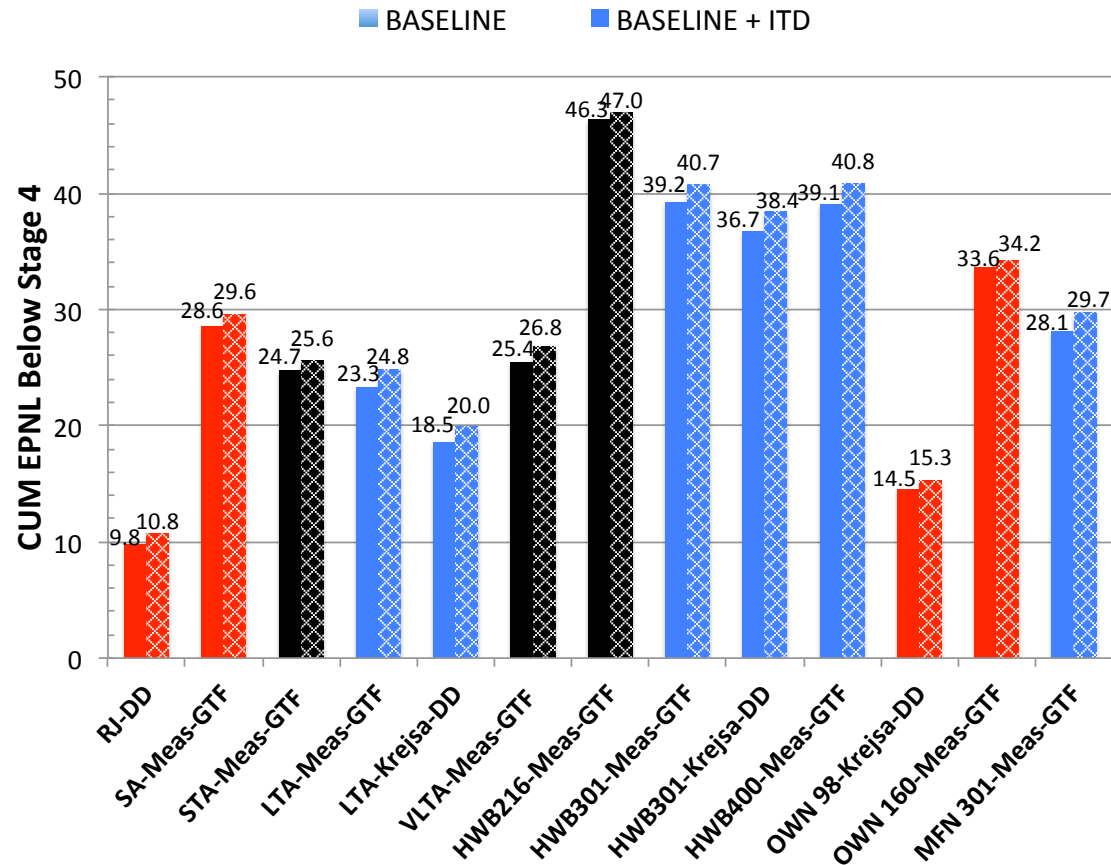
Acoustic Modeling Updates 2015 (p. 1)

- 2015 Aircraft and Engines (with iteration 3 throttles and flight profiles)
- Direct Drive engine fan noise predicted from Krejsa model:
 - 2 dB correction at spectral level (louder) implemented due to comparison with prior SDT & ADP data at frequencies more relevant to the ERA DD engines
 - New model developed/implemented for improved rotor-stator spacing effect
 - Effect of bifurcation included similarly as on GTF engines
- GTF fan noise predicted from processed ITD35A 9x15 wind tunnel data:
 - Accounts for model to full-scale, number of blades, and cut-on/cut-off effect
 - Semi-empirical model developed for effects of stator sweep and lean
 - Semi-empirical model developed for effect of bifurcation based on data as a function of FPR, RPM, and thrust
 - Polar angle for peak directivity and aft angle directivity corrected consistent with 1) Krejsa model experience and 2) P&W/Boeing experience through ITD51A
- More detailed shielding effect implementation from LSAF and 14x22 databases, more realistic source locations:
 - HWB engines positioned with core exit plane at $1D_{\text{fan}}$ upstream of trailing edge (core and jet noise) and fan exit plane at $1.5D_{\text{fan}}$ upstream (fan exhaust noise)
 - TW and OWN installation effects from LSAF database

Acoustic Modeling and Technology Updates 2015 (p.2)

- Additional noise reduction technologies implemented and/or changed on “baseline” vehicle:
 - PAA Chevrons removed from the HWB due to large BPR (may reconsider for delta assessment)
 - Low noise spoiler was removed from the HWB (not needed for 2015 vehicle)
 - Krueger gap on approach is sealed based on ITD51A final results
 - Interstage acoustic liner added as an effective $L/H=0.5$ area
 - Multi-Degree of Freedom (MDOF) acoustic duct liner replaces the conventional technology liners (modeled as Double Degree of Freedom (DDOF), spliceless). MDOF increases the frequency band of suppression
 - Noise constraint added to take off and cutback flight conditions
- Specific Phase 2 ITD noise reduction technologies implemented:
 - Soft vane implemented at narrowband, same as in prior assessments
 - Main landing gear partial fairing: 2015 ITD50A spectral reduction at the source applied on all aircraft
 - Flap side-edge noise reduction: use 2015 ITD50A spectral reduction applied to the RJ, uniform 3 dB reduction at the source for all other vehicles with flaps

2015 Final Cumulative EPNL Results



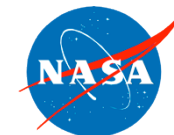
Solid bar = “baseline” vehicle includes ERA technology inherent in airframe and engine design:

- Light weight structures
- Modernized flap system (single-element design) and Krueger flap for leading edge (sealed on approach)
- Advanced Geared TurboFan Engine (GTF) or Advanced Direct Drive Engine (DD)
- MDOF acoustic duct liner and an interstage liner
- PAA shielding appropriate to each configuration

Hash bar = “baseline + ITD” adds ITD noise reduction technology: soft vane (fan noise), partial main landing gear fairing and flap-side edge treatment.

Diagnosis of the 2015 HWB GTF vs DD

Effects of Design Choices

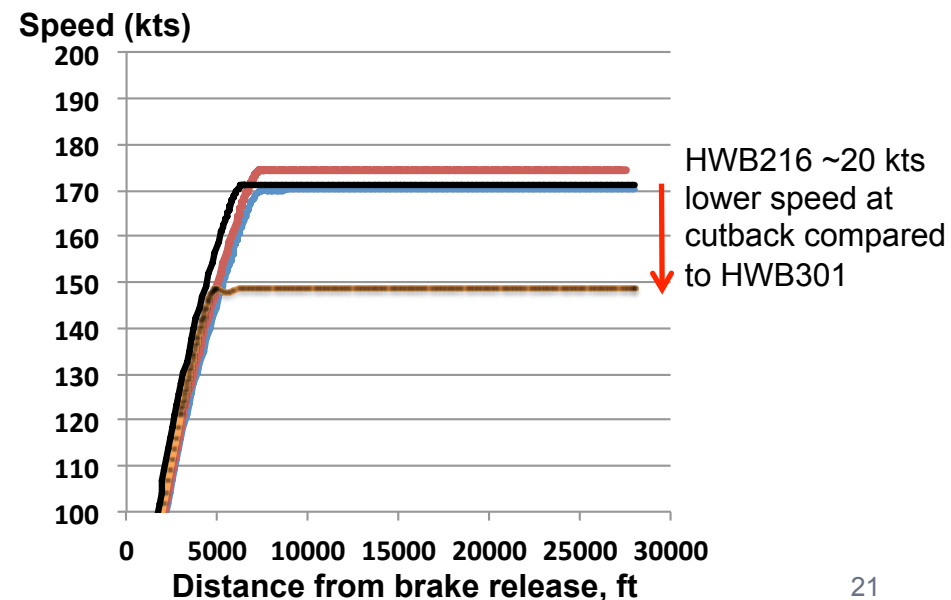
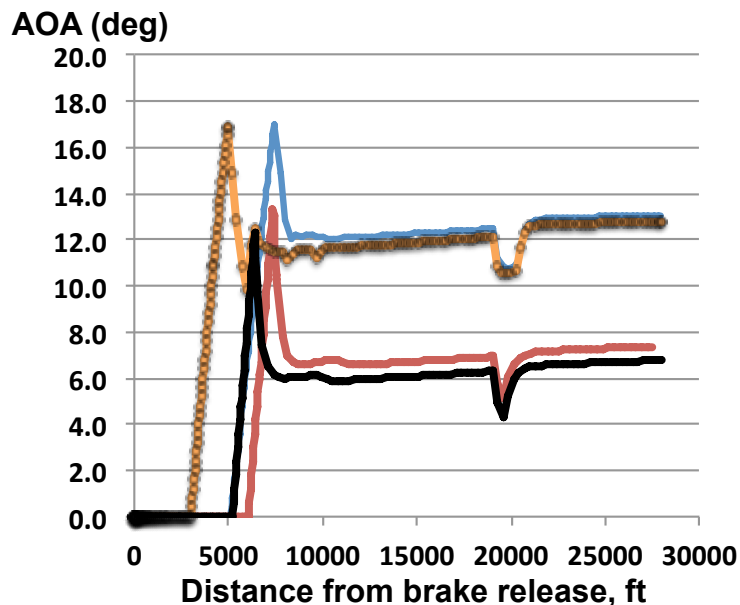
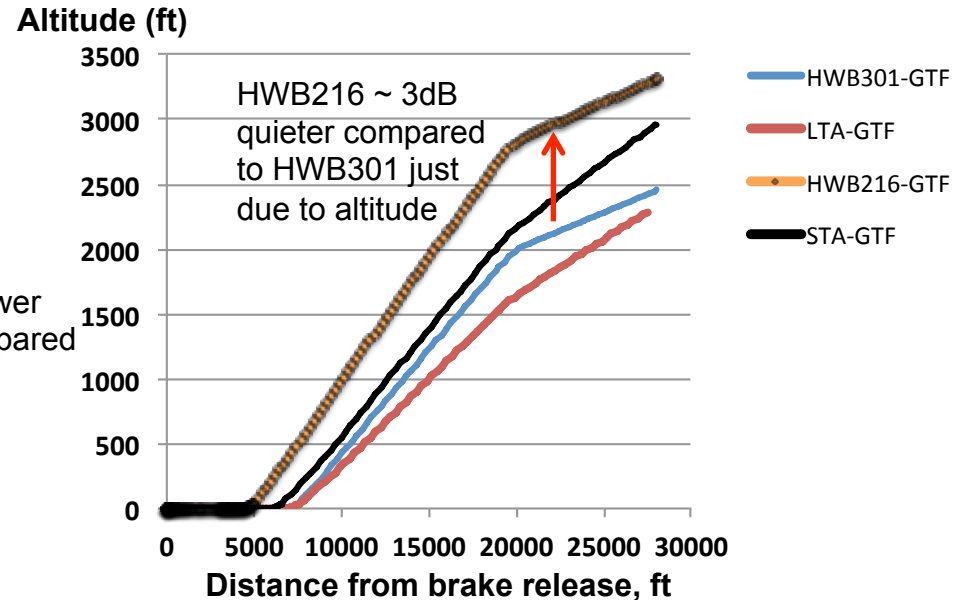
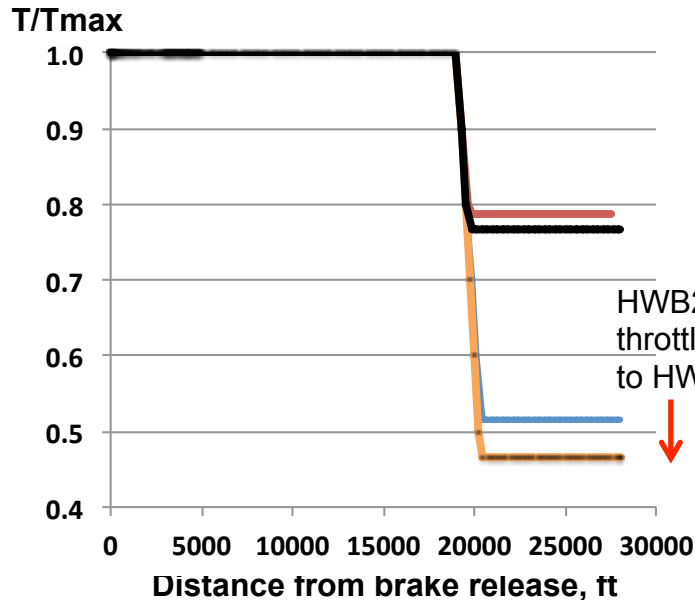


	HWB301-GTF (40.7 dB Cum) with measured GTF data	HWB301-DD (38.4 dB Cum) with modified Kresja	Approximate Difference (Cum) with all else equal – means GTF quieter, + means GTF louder
Fan Dia (inches)	132.4	118.7	
RSS (rotor stator spacing) rel DD	0.78 (tip)	1 (tip)	+ 2.5 dB
FPR	SLS 1.25	SLS 1.38	– 5 dB (from using Kresja prediction) (NASA TM-2011-216883)
Throttle (3 rd API Iteration)	AP 0.128 SL 1.0 CB 0.514	AP 0.135 SL 1.0 CB 0.543	~
Core exit Xc/Df	1	1	~
Fan exit Xf/Df	1.5	1.5	~
Inlet Liner L/H (H=D/2)	0.66	0.66	~
Aft liner L/H	1.99	3.33	+ 5 dB (direct to aft fan noise, more impact due to limited shielding)
Approach speed (knots)	~130	~130	~

GTF quieter compared to DD, however, GTF could be even quieter IF the aft duct length (and liner treatment) and RSS were equivalent

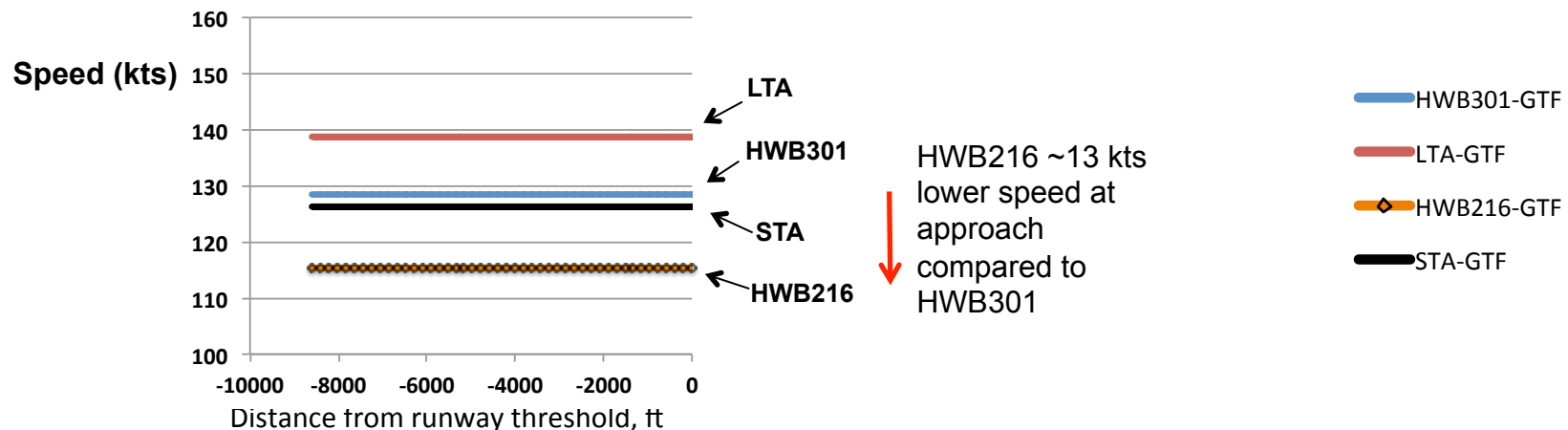
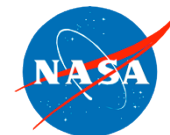
2015 Flight Profiles: Take Off

HWB and T&W for 2 Vehicle Classes (LTA and STA)

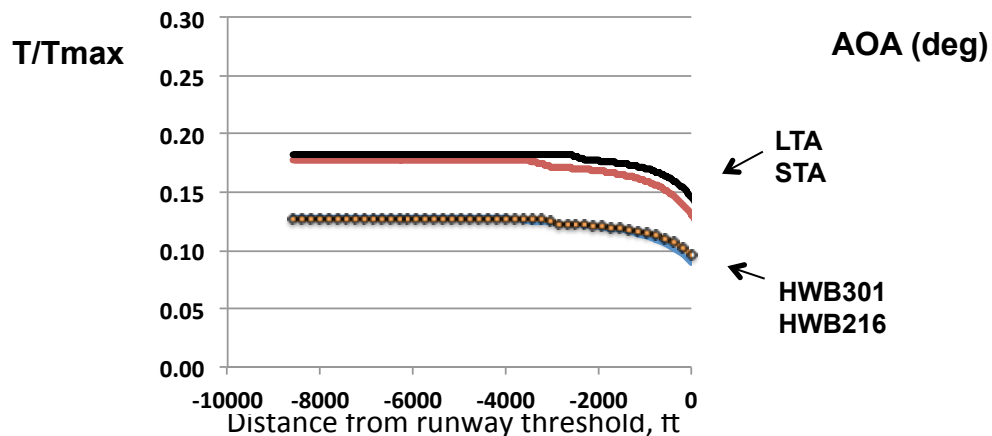


2015 Flight Profiles: Approach

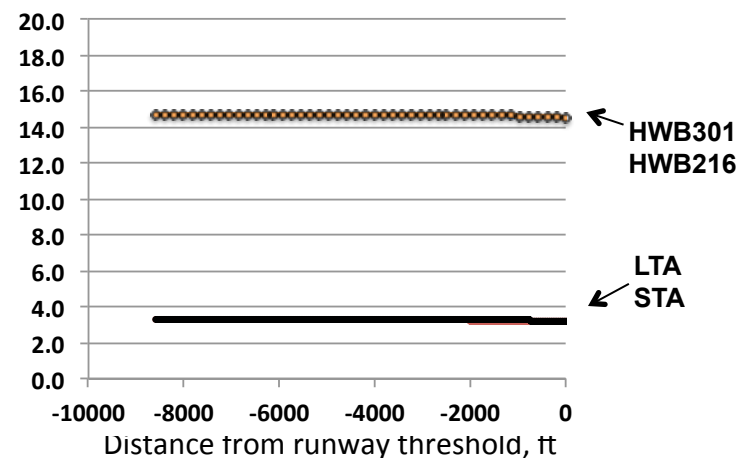
HWB and T&W for 2 Vehicle Classes (LTA and STA)



Lower speed → ~lower airframe noise*



lower throttle → ~ lower noise



Higher AOA → ~ higher noise

*Assuming duration is similar



Remarks on Noise Assessment

- **The NASA noise assessment team continues to pursue:**
 - the highest fidelity assessment of the ERA portfolio of conceptual vehicles while
 - simultaneously improving the assessment methods and
 - understanding of the assessment process and noise reduction technology paths
 - identifying remaining challenges
- **Assessment process improved with tighter communication between ITD leads, system analysis and engine design processes.**
 - Acoustic constraints
- **Gaps in capabilities/understanding required to advance aircraft noise science identified:**
 - Conceptual design level detail for flaps, slats, and landing gear continues to be improved
 - Airframe source ranking
 - Source prediction for landing gear, flap, and Krueger. Isolated and installed
 - Propulsion/airframe integration constraints for viable conceptual aircraft
 - GTF fan source prediction from data (and need for new UHB fan noise method)
 - Engine source ranking for UHB engines
 - Predicting turbomachinery noise shielding (versus existing databases)
 - Improved system level liner effectiveness (design and application)
 - Establish uncertainty of conceptual level aircraft system noise predictions



Thank you