CLEEN II/III System Level Assessment

Project 37

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CLEEN Overview

Purpose:

- Mature previously conceived noise, emissions and fuel burn reduction technologies for civil subsonic airplanes from Technology Readiness Levels (TRL) of 3-5 to TRLs of 6-7 to enable industry to expedite introduction of these technologies into current and future aircraft and engines.
- Assess the benefits and advance the development and introduction of "drop-in" alternative jet fuels, including blends.

CLEEN III technologies on a path for introduction into commercial aircraft by 2031.

	CLEEN I	CLEEN II	CLEEN III	
Noise	-25 dB (cumulative to Stage 5)			*and/or reduces the noise contour area in absolute terms*
LTO NOx Emissions	-60% *(margin to CAEP/6)*	*-70% (margin to CAEP/8)*		*and/or reduces absolute NOx production over the aircraft's mission*
Aircraft Fuel Burn	-33% (relative 2000 best in class)	-40% (relative 2000 best in class)	-20% (below CAEP/10)	*and/or supports the FAA's goal to achieve a net reduction in climate impact from aviation*

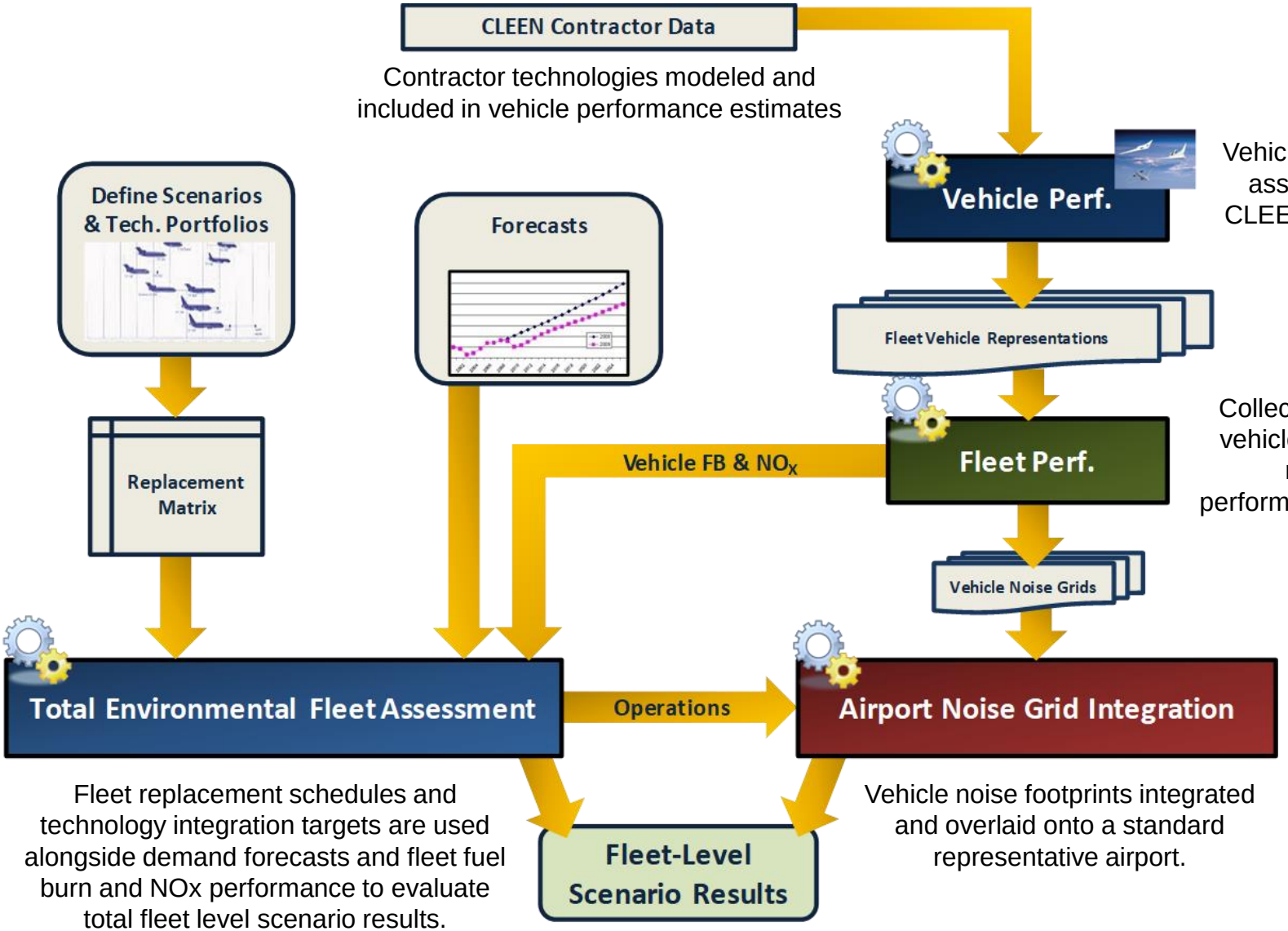
CLEEN II Technologies

Contractor	Technology	Fuel Burn	NOx	Noise	Status
Aurora	D8 Fuselage	X		X	Complete
Boeing	Structurally Efficient Wing	X			Complete
	Compact Nacelle	X			Complete
	Compact Nacelle (Noise liner)			X	Complete
Delta/MDS/America's Phenix	Leading Edge Protective Coating for Turbine Blades	X	X		Complete
GE	TAPS III Combustor		X		Complete
	MESTANG	X			Complete
	Flight Management System	X			Complete

CLEEN II Technologies

Contractor	Technology	Fuel Burn	NOx	Noise	Status
Honeywell	Compact Low Emissions Combustor	X	X		Complete
	Advanced Turbine Blade Outer Air Seal	X			Complete
	Advanced High-Pressure Compressor (CII+)	X			Complete
	Advanced Acoustic Fan Rotor/Liner (CII+)			X	In Progress
Pratt and Whitney	Enhanced Efficiency Compressor	X			Complete
	Enhanced Efficiency High Pressure Turbine	X			Complete
Rolls-Royce	Advanced RQL Low NOx Combustor		X		Complete
Collins Aerospace	Short Inlet and Clean Fan Duct for HBR Engines	X		X	Complete
	Advanced Acoustics			X	Complete

System Level Assessment



Fuel Consumption: CLEEN I and II

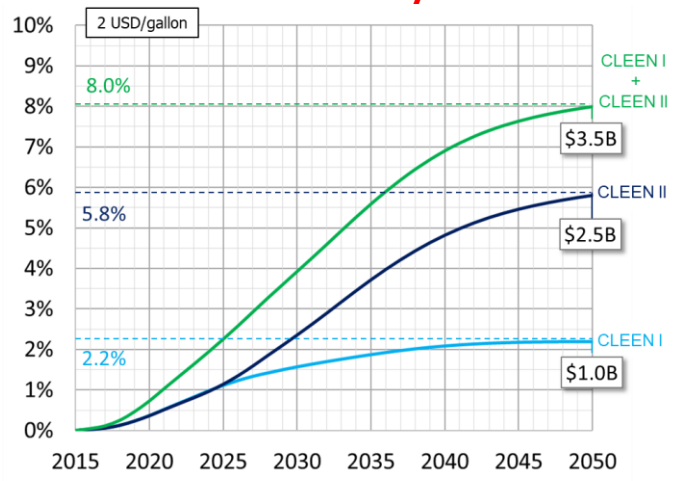
Assumptions

- Five generic vehicles assembled for analysis in EDS environment:
  - Regional Jet
  - Single Aisle
  - Small Twin Aisle
  - Large Twin Aisle
  - Very Large Aircraft
- Each vehicle has technology package varied for analysis across 5 technology integration scenarios:
  1. Frozen technology introduction (FTI)
  2. Evolutionary: Conservative performance and concrete entry into service plan
  3. CLEEN I Aggressive: Aggressive performance, including CLEEN I technologies and no entry into service plan
  4. CLEEN II Aggressive: Aggressive performance, including CLEEN I and II technologies and no entry into service plan
  5. Aggressive minus CLEEN: Scenario 3 or 4 without CLEEN technologies
- Difference between Scenario 5 and Scenarios 3 and 4 estimate the contributions of CLEEN I and II technology sets, respectively

CLEEN I and II technologies lead to 8.0% fuel burn savings compared to the evolutionary scenario in 2050

Preliminary

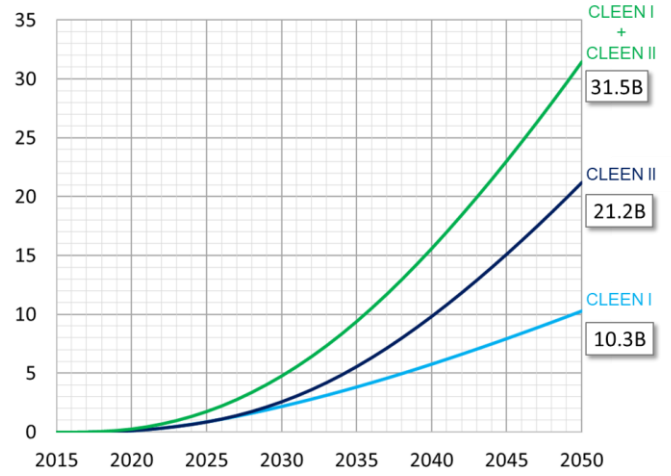
CLEEN Cost Savings relative to Evolutionary Scenario



Not all technologies are modeled/included at this time.

Preliminary

Cumulative CLEEN Fuel Savings relative to Evolutionary Scenario (Billion Gallons)



NOx Emissions: CLEEN I and II

Assumptions

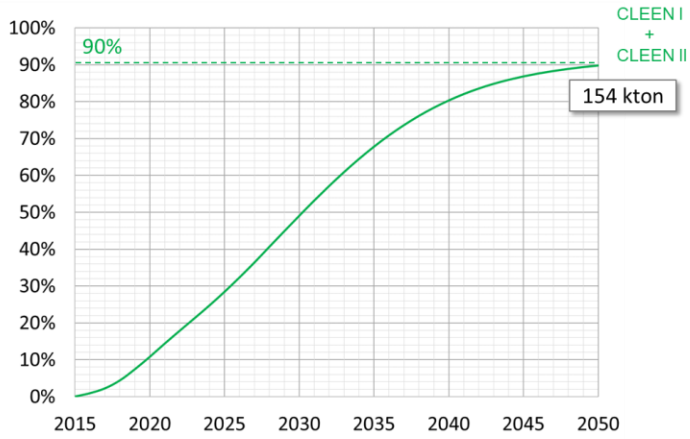
- Identical to fuel burn regarding:
  - Fleet replacement matrices
  - Demand forecast
  - Technology integration scenarios
  - Scope: Domestic + International departures
- Technologies included:
  - Traditional Combustors (GT Model)
  - CLEEN Combustors
    - GE TAPS II (GT Model) *[RJ, SA classes]*
    - GE TAPS III *[STA, LTA, VLA classes]*
    - Honeywell Compact Combustor *[RJ, SA classes]*
    - Rolls-Royce Combustor *[RJ, SA classes]*
- Dp/Foo and SLS thrust to calculate NOx emissions throughout "LTO cycle"
  - Taxi
  - Takeoff
  - Climbout
  - Approach

$$LTO\ NOx\ (g) = Dp/Foo\ (g/kN) * F_{SLS}(kN)$$

(per engine)

Preliminary

Annual LTO NOx Emissions Savings relative to Evolutionary Scenario



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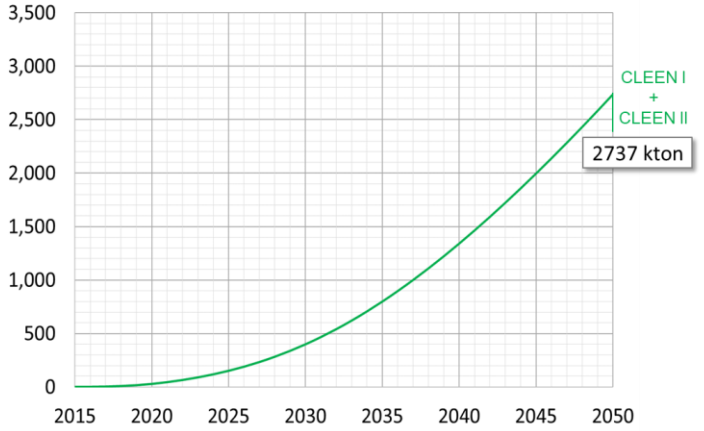
Preliminary

Cumulative LTO NOx Emissions Savings relative to Evolutionary Scenario (kton LTO NOx)



CLEEN I and II combustors lead to 90% LTO NOx savings compared to FTI in 2050

Noise: CLEEN I and II

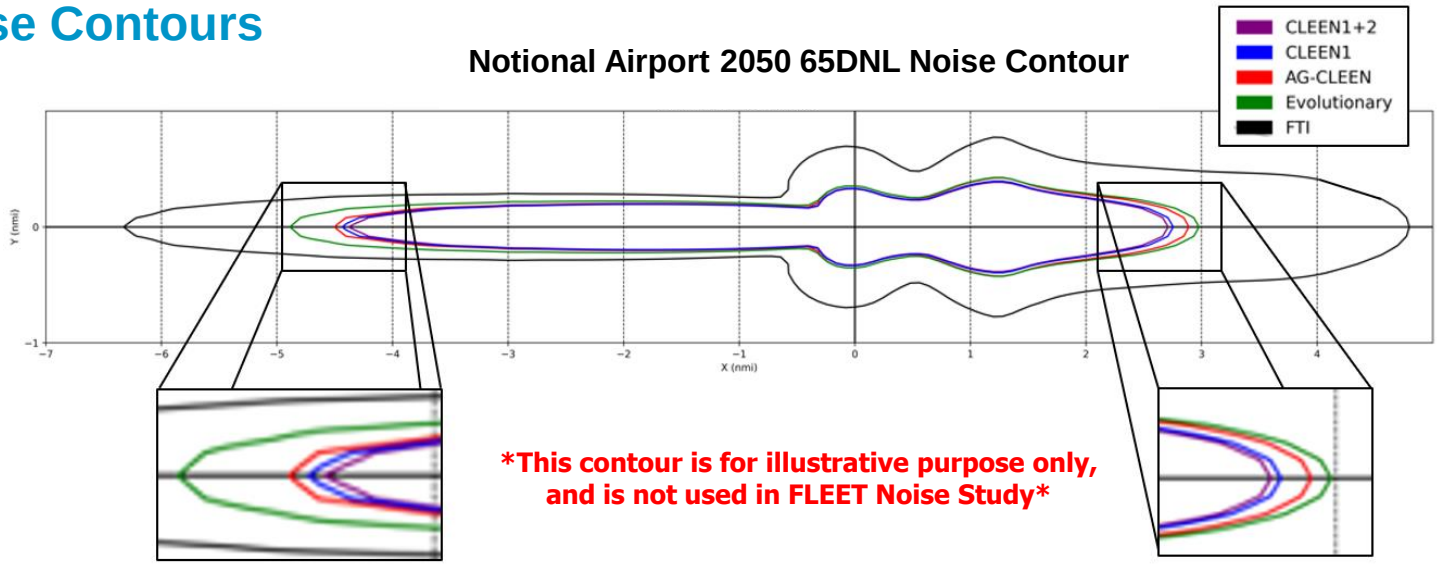
Assumptions

- Identical to fuel burn regarding:
  - Fleet replacement matrices
  - Demand forecast
  - Technology integration scenarios
  - Scope: Domestic + International departures
- Technologies included:
  - GT Public Set
  - All Fuel Burn/NOx Techs
  - CLEEN Acoustic Technologies
    - Boeing Compact Nacelle (Noise liner) [SA, STA, LTA, VLA]
    - Collins Aerospace Advanced Acoustics [RJ - GTF]
    - Honeywell Advanced Fan Rotor/Liner [RJ - ADD]

GT Fleet Noise Modeling Process

- Generic noise contours are generated for each vehicle class and technology integration scenario
- For each scenario, average 65 DNL exposure area is computed for each year
  - Output noise data for every 5 years, 2020-2050
  - Exposure area calculations accounts for demand forecast, scope, and fleet replacement matrix
- Result:
  - Predicted contour area for each scenario can be traced over 3 decades
  - Noise contours display impacts between scenarios and/or years

Noise Contours



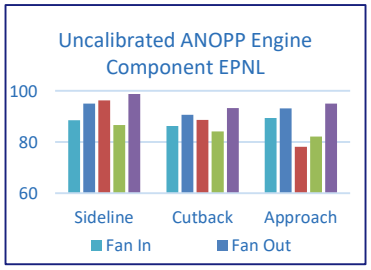
Baseline Source Noise Calibration

EDS Engine State Tables

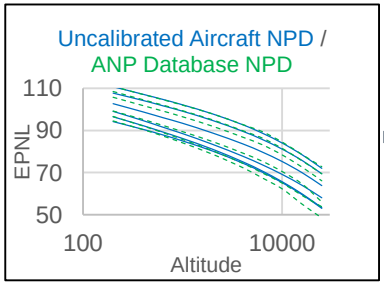
EDS Aircraft Size and Mission

NASA's ANOPP

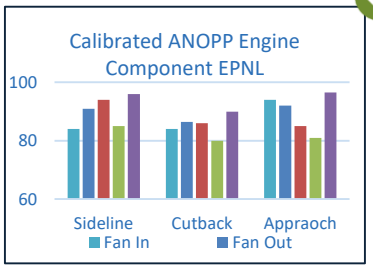
Component EPNL Level Calibration



Calibrated baseline vehicle component EPNLs for each vehicle class using NPDs from the ANP Database



Aircraft EPNL Level Calibration



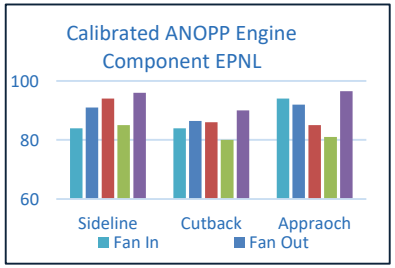
Baseline (Notional B737-800)		
Cutback	Approach	Sideline
86.97	92.84	97.96

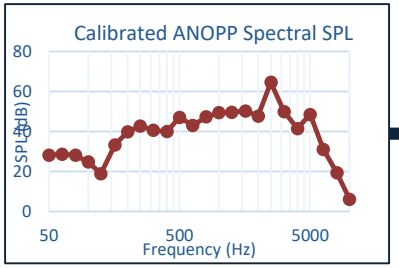
While preserving the component EPNL distribution, adjust aircraft calibration factors to match final certification targets

Certification (B737-800, EASA Certification Noise Levels)		
Cutback	Approach	Sideline
87.00	96.40	94.70

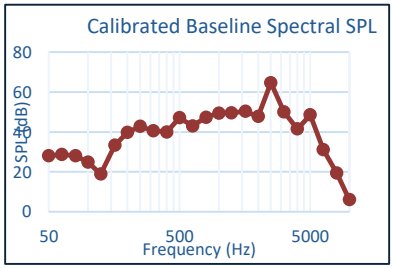
Calibrated Aircraft EPNL Level

Calibrated Baseline (Notional B737-800)		
Cutback	Approach	Sideline
87.00	96.40	94.70

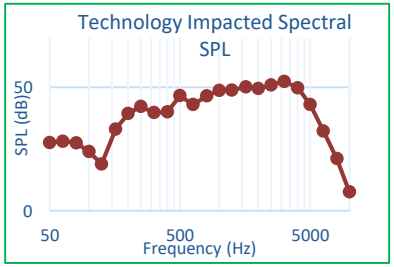




Technology Impacts to EPNL Level



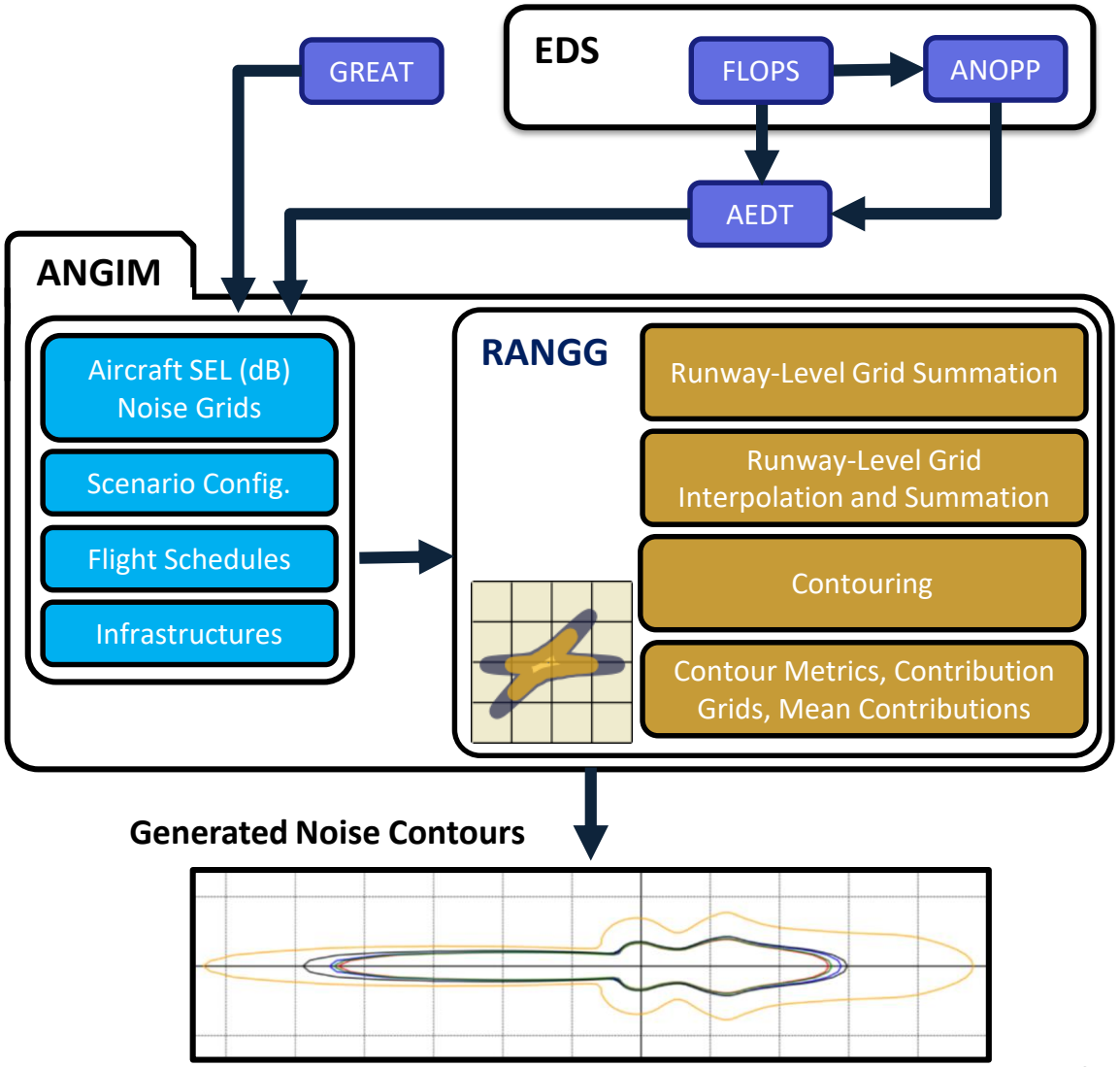
Apply suppression factors strategically inline with technology impacts



Airport Noise Grid Integration Method (ANGIM)

How does this translate to fleet noise contours?

- ANGIM applies individual vehicle noise grids under each scenario to a flight schedule and a runway configuration for a representative set of domestic airports
- ANGIM contains the C++ application Rapid Airport Noise Grid Generator (RANGG) that can perform grid summation, interpolation, contour generation, and metric computation
- Computes runway-level DNL noise, interpolates to airport-level DNL grids, and computes contours, areas, and other desired metrics for each airport
- Enables a rapid yet comprehensive analysis of fleet-level noise
- **Fleet level noise results are computed by taking the average 65 DNL exposure area across 95 U.S. airports for each technology scenario**



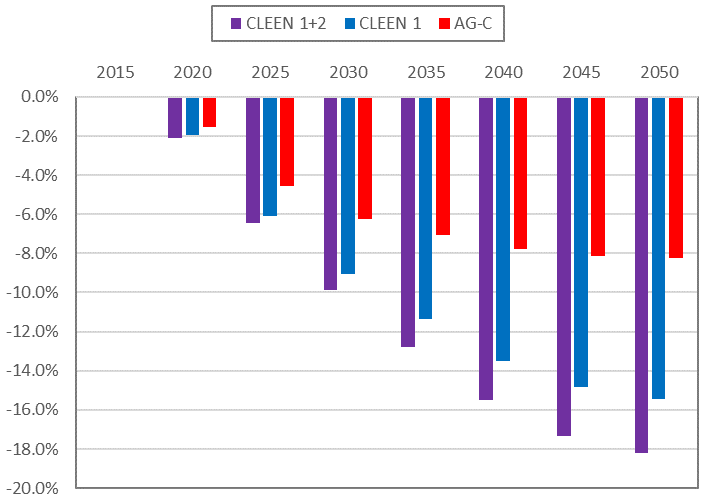
Noise: CLEEN I and II

Assumptions

- Identical to fuel burn regarding:
  - Fleet replacement matrices
  - Demand forecast
  - Technology integration scenarios
  - Scope: Domestic + International departures
- Technologies included:
  - GT Public Set
  - All CLEEN 1 Techs
  - All Fuel Burn/NOx Techs
  - CLEEN Acoustic Technologies
    - Boeing Compact Nacelle (Noise liner) [SA, STA, LTA, VLA]
    - Collins Aerospace Advanced Acoustics [RJ]
    - Honeywell Advanced Fan Rotor/Liner [Not included at this time]
- Results show change in 65 DNL exposure area with respect to the evolutionary scenario
  - In 2050, AG (CLEEN I+II) produces an 18% reduction
  - Compared to 2050 AG-C's 10%, this nets a 10% improvement for CLEEN I+II technologies

Preliminary

CLEEN noise reduction benefit relative to Evolutionary scenario



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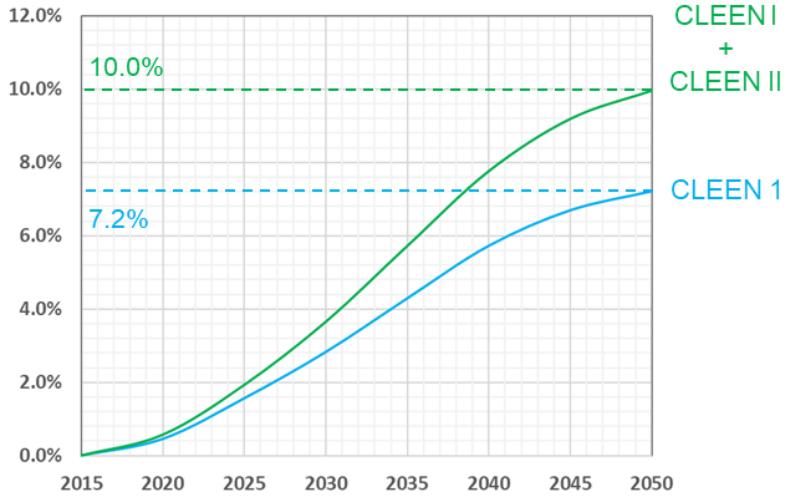
CLEEN noise reduction benefit relative to Evolutionary scenario



CLEEN I and II technologies lead to 10% improvement relative to the evolutionary scenario in 2050.

Summary & Next Steps

CLEEN II Technology Portfolio:

- Modeled
  - Boeing Aurora D8 Fuselage
  - Boeing structurally efficient wing, compact nacelle
  - Delta/MDS/America's Phenix Leading Edge Protective Cooling (FAA)
  - GE MESTANG, FMS, and TAPS III Low NOx combustor
  - Honeywell Turbine Blade Outer Air Seal
  - Pratt & Whitney Compressor and Aero-Efficiency Technologies
  - Collins Aerospace: Slim Nacelle
  - Honeywell Compact Combustor
  - Honeywell Advanced HPC
  - Collins Aerospace: Noise Liner Technologies
  - Boeing compact nacelle acoustics
  - Rolls-Royce: Advanced Rich Quench Lean Low NOx Combustor
- Awaiting Data/Testing
  - Honeywell Acoustic Fan Rotor/Liner Technologies

Next Steps:

- Complete CLEEN II noise benefits assessment
- Complete technology modeling for CLEEN II
- Extend Current Fleet Level Assessments to include all CLEEN II technologies
- Continue CLEEN III technology modeling
- Update Fleet assessment assumptions

Thank you.

GT-ASDL would like to thank Levent Ileri, Arthur Orton, and Roxanna Moores for their continued support in this work.