CLEEN-EDS Update

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CLEEN Consortium
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PARTNER
Partnership for Air Transportation Noise and Emissions Reduction

Outline

- Overview of the Environmental Design Space (EDS)
- Georgia Tech Support of CLEEN using EDS
  - Past and present
- Georgia Tech CLEEN Phase 2 Fleet Results
  - Fleet Level Analysis Overview and Assumptions
  - CLEEN Phase 2 Fleet Results
- Technology Calculator
- Future Work

Environmental Design Space* (EDS) Overview

- Aircraft modeling and simulation environment developed by Georgia Tech with funding from FAA, NASA, and Transport Canada
- Develops physics-based models using NASA tools: CMPGEN, NPSS, WATE++, FLOPS, and ANOPP
- Allows a more comprehensive assessment of the noise and emissions impacts of aviation to inform national and international decision makers
- Provides a means to understand interdependencies of existing and future classes of vehicles
- Uses generic aircraft classes to emphasize trends and correlations rather than specific aircraft and engine designs
- Capable of passing vehicle characteristics to other elements of FAA tool suite, such as the Aviation Environmental Design Tool (AEDT)

*Referencecs:

-Barros, P., Kirby, R., and Mavris D., "An Approach for Verification and Validation of The Environmental Design Space", 26th International Congress of the Aeronautical Sciences
-Kirby, M., et al., "Development of an Interactive Capability to Trade Off New Technologies and Future Aircraft To Reduce Aviation Environmental Impacts," 27th International Congress of the Aeronautical Sciences

EDS Collaborators

- Georgia Tech team has an ongoing collaboration with the developers and experts responsible for the elements within the EDS framework to ensure the latest capabilities are incorporated
- NASA
  - ANOPP: Casey Burley, Jeff Burton, Charlotte Whitfield
  - NPSS: Bill Haller, Scott Jones, Jon Seidel, Eric Hendricks
  - WATE++: Mike Tong
  - FLOPS: Linwood ("Arnie") McCullers, Phil Arcara, Andy Hahn, Mark Guynn, Craig Nickol
- Volpe
  - AEDT: Dave Senzig, Andrew Hanson, Chris Roof, Sathya Balasurbramanian

Who is EDS supporting domestically?

- CLEEN Program
  - Aircraft and fleet level technology modeling and assessment
- ATO
  - Implications of environmental solutions on the NAS
- ACRP 2-27, Aircraft Taxi Noise Database for INM and AEDT

- Environmentally Responsible Aviation (ERA)
  - Providing system analysis support for the ERA technology portfolio assessment for advanced concepts
- Fixed Wing (FW)
  - Providing system analysis support for the FW technology portfolio assessment for advanced concepts

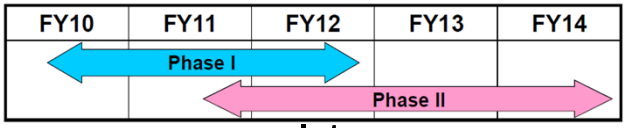
- Interagency Portfolio and Systems Analysis (IPSA)
  - Providing future replacement vehicles
- Technology Standing Committee (TSC)
  - Supporting the technology roadmap definitions through a screening tool analysis

Who is EDS supporting internationally?

- Supporting definition of a CO_2 certification standard
- Supported the definition of long term fuel burn technology goals

- Assessing the implications of imposing CO_2 stringency levels to in production aircraft, not only future aircraft
- Assessing the cost-benefit of imposing a CO_2 standard of total CO_2 production at what cost to the manufacturers

Past EDS Support of CLEEN



- Decided on notional 2 phase approach
  - Phase 1: GT worked with FAA CLEEN Program personnel to define similar, public-domain technologies in order to assess potential benefit
  - Phase 2 (Ongoing)
    - Incorporating proprietary data and models into the assessment
    - Developing parametric spreadsheet based technology calculator
- This year Georgia Tech combined Phase I (public domain) models with Phase II (proprietary) models to update fleet assessment
- Assessment was performed by leveraging the EDS baseline and generic vehicles developed in previous years
- Results included vehicle and fleet level results of fuel burn, emissions, and noise (vehicle only)
  - Vehicle results are proprietary
- Many of the technology models developed last year directly support ongoing assessments

Future Support of CLEEN

- Current work focuses on including additional industry data in EDS vehicle models
- EDS used for *independent assessment* of CLEEN technologies and their environmental benefit (i.e., fleet results) using detailed industry data
- Currently constructing technology tradeoff calculator
  - Spreadsheet based tool that encompasses EDS analysis
  - End goal is to provide integrated platform for FAA to perform internal assessments
  - Leverages CLEEN Phase I and Phase II and NASA technology programs
- Focuses on refining *public-domain* EDS with proprietary data → resulting modeling environment is CLEEN-EDS
  - This allows the fundamental modeling enhancements funded by CLEEN to be leveraged for other technology modeling work
  - If necessary modeling enhancements will be proprietary
- Assessment process will be ongoing and updated on an annual basis

CLEEN Assessment Goals

- **<u>PROPRIETARY:</u>** Show vehicle level benefits and trades including:
  - Technology level benefits
  - "In service" technology benefits
  - Benefits of CLEEN technologies when combined with other potential N+1 technologies
  - Benefits of CLEEN technologies when combined across contractors
- **<u>PUBLIC DOMAIN:</u>** Show benefits of CLEEN program at the national airspace system
  - Show impact on U.S. fleet for fuel burn, emissions, and noise
  - *Benefit based on assumed technology level and insertion rate*
- Provide FAA with in-house analysis capability

Expected Outcomes and Practical Applications

- Outcomes
  - Evaluate specific technology packages based on top level objectives and scenarios
  - Show benefit of CLEEN funded (and potentially other N+1) technologies at vehicle and fleet level
  - Provide information on interactions between various U.S. government technology development programs
- Practical applications
  - Provides CLEEN program capability to evaluate and quantify benefits to relevant stake holders without disclosing proprietary data
  - Allows system level trades
    - Provides a transfer function from industry level analysis and results to higher level environmental impact
    - Calculates system-wide environmental metrics
  - Further validates EDS
  - Can provide new AEDT vehicles for detailed fleet runs

Major Challenges Overcome

- **Phase II Goal**
  - Assess industry technology impacts on a proprietary basis
- **Challenges**
  - Proprietary validation of technology models
- **Approach**
  - Work with each industry member to define validation approach
  - Validate technology modeling at appropriate system level and level of fidelity
  - Have to balance modeling requirements against available data and level of fidelity
  - Apply technologies to EDS vehicles and assess fleet level implications

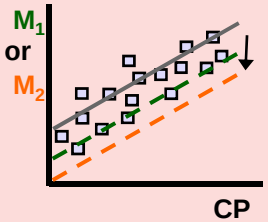
2012 Schedule and Status

- Have updated fleet level fuel burn and noise impacts including proprietary data
  - Incorporated public domain info and Rolls Royce and Honeywell technology data
- Updated annual report to FAA to include proprietary technology assumptions
- Currently working with P&W, Boeing, and GE to incorporate additional proprietary data
- Also creating surrogate models for FAA use to provide in-house analysis capability

Task	Status
Gather and Translate Industry Technology Data	✓
Develop a Set of Ground Rules for Engine Cycle Studies	✓
Develop Technology Models within EDS	✓
Conduct Verification of Technologies	✓
Apply and Assess CLEEN Phase II Technologies	✓
Assess Technology Impacts at the Fleet Level	✓
Incorporate P&W, Boeing, and GE Feedback	Ongoing
Create Surrogate Models / Technology Dashboard	Ongoing

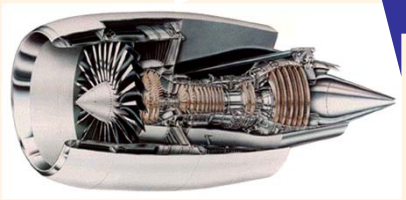
Approach

Standards
(CO_2, NO_x, or noise)



- Metric
- Correlation Parameter
- Evaluation Option
- Applicability
- Implementation Date

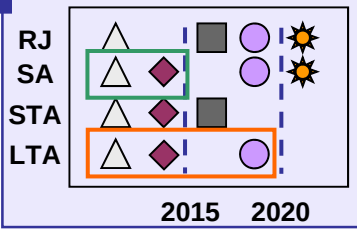
EDS
Generic Vehicles



Technologies

- Benefit
- Cost
- Applicability
- Availability

Technology Roadmaps



Scenarios

Scenario 1
Scenario 2
⋮

Vehicle Performance Characteristics

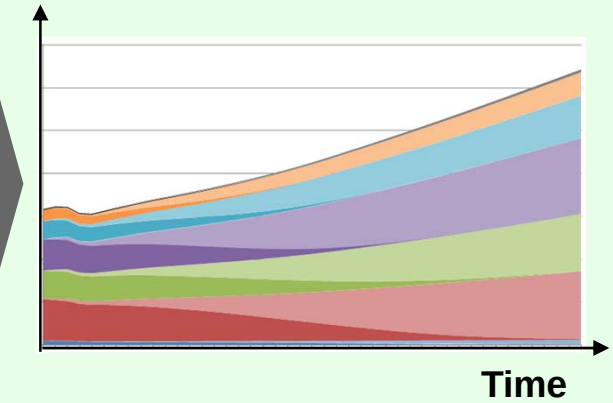
Operations

- Demand Forecast
- Aircraft Retirements
- Replacements Schedule

AEDT or GREAT
Fleet Analysis

- FB/Operation
- Total Ops
- Total FB

Fleet Impact



Considerations for Fleet Level Scenarios

- Wanted to capture best guess at when techs are available
  - Based on public market information on new products
  - Considered technology funded under CLEEN while recognizing other technologies that could be on CLEEN aircraft

- Defined 3 fleet scenarios
  - **RE1 (Re-engine N+1):** Determined that the entrance of the A320neo and 737MAX later in this decade (~2015) would push back the entrance of single aisle CLEEN vehicles (~2023)
    - Only affects single aisle class (*uses representative EDS vehicles, not actual A320neo or 737MAX models)*
    - Included as part of the RC1 scenario for fleet insertion assumptions
    - Primarily engine cycle change without any other technologies

  - **RC1 (Realistic CLEEN N+1):** Takes into account CLEEN funded and other potential N+1 technologies across all five vehicle classes
    - RC1 vehicles begin to enter the fleet between 2016 and 2018 (except SA)
    - Representative of introduction of 777X and potential widebody upgrades later in this decade
    - CLEEN funded + potential N+1 + engine cycle change + aircraft resizing

  - **PC2 (Potential CLEEN N+2):** Adds NASA ERA work plan technologies to the **RC1** scenario in order to put perspective on the benefit of continuing technology programs
    - Adds compatible ERA work plan technologies
    - Vehicles enter fleet from 2025 – 2030

Technology Scenarios

- Chart shows mapping of specific technologies to fleet insertion scenarios
- RC1 scenario carries over engine changes from RE1
- Different scenarios defined for narrow body and wide body aircraft
- “ERA Workplan” includes technologies detailed on previous slide

		RC1-NB	RC1-WB	PC2-NB	PC2-WB
Fuel Burn	60 deg. Winglets	●	●	●	●
	Composite Structures			●	●
	Hybrid Laminar Flow Control				●
	Natural Laminar Flow Control			●	
	Cooled Cooling Air			●	●
	Adaptive Trailing Edge	●	●	●	●
	Rolls Royce Cooling	●	●	●	●
	Honeywell Cooling	●	●	●	●
	CMC Nozzle	●	●	●	●
	Highly Loaded Compressor	●	●	●	●
	Highly Loaded Turbine	●	●	●	●
	ERA Workplan			●	●
Noise	Landing Gear Fairings	●	●	●	●
	Flap Fences / Flaplets			●	●
	Fixed Chevrons	●	●	●	●
	Combustor Noise Liner	●	●	●	●
	Variable Area Nozzle	●		●	●
	Stator Sweep and Lean	●	●	●	●
	Acoustically Soft Vane	●	●	●	●
	Aft Cowl Liners			●	●
	Zero Splice Inlet			●	●
	Nose Lip Liner	●		●	●
Emissions	Advanced Low-Nox Combustor	●	●	●	●

Replacement Schedule

- Replacement schedules developed for each specific scenario
- Percentages indicate % of new aircraft entering fleet
- Working with NASA to come up with consistent set of insertion assumptions across CLEEN, ERA, and FW projects

Vehicle	Scenario	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034
RJ	RC1-D	0	0	0	0	0	0	0	0	0	0	13	13	25	25	38	50	50	50	50	38	25	13	0	0	0	0	0	0	0
RJ	RC1-G	0	0	0	0	0	0	0	0	0	0	13	13	25	25	38	50	50	50	50	38	25	13	0	0	0	0	0	0	0
RJ	PC2-D	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	25	50	75	100	100	100	100	100	100	100
SA	EC1-D	0	0	0	0	0	0	0	0	0	13	25	25	38	38	50	50	50	25	0	0	0	0	0	0	0	0	0	0	0
SA	EC1-G	0	0	0	0	0	0	0	0	0	13	25	25	38	38	50	50	50	25	0	0	0	0	0	0	0	0	0	0	0
SA	RC1-D	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	25	50	50	50	38	13	0	0	0	0	0	0
SA	RC1-G	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	25	50	50	50	38	13	0	0	0	0	0	0
SA	PC2-D	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	25	75	100	100	100	100	100	100
STA	RC1-D	0	0	0	0	0	0	0	0	0	0	0	0	25	25	25	50	50	50	50	75	75	75	75	75	75	75	50	25	0
STA	PC2-D/G	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	25	50	75	100
LTA	RC1-D	0	0	0	0	0	0	0	0	0	0	0	0	25	25	25	25	25	50	75	100	100	100	100	100	100	75	50	25	0
LTA	PC2-D/G	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	25	50	75	100
LQ	RC1-D	0	0	0	0	0	0	0	0	0	0	0	0	25	25	50	50	50	50	50	75	100	100	100	100	100	75	50	25	0
LQ	PC2-D/G	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	25	50	75	100

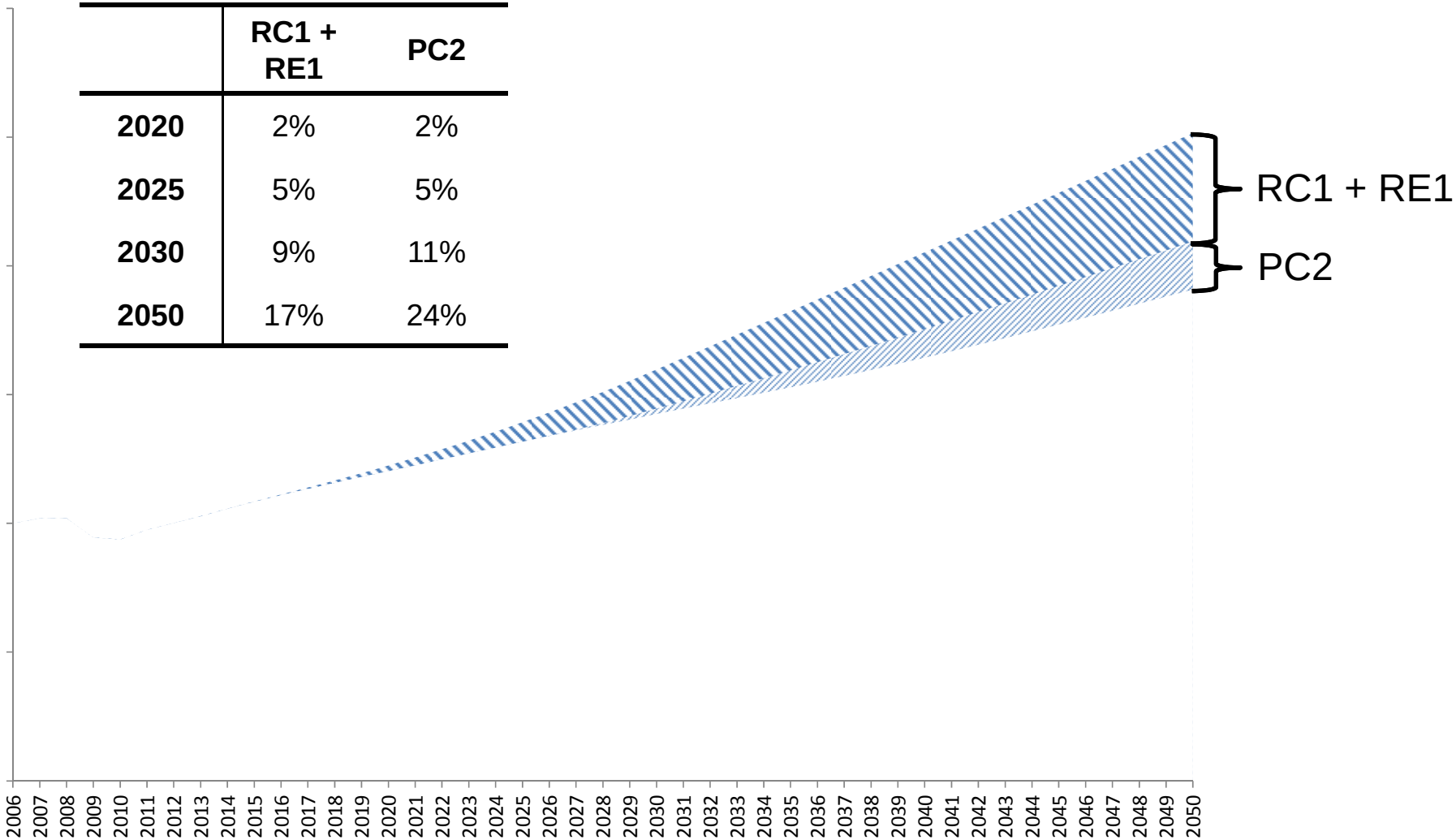
Updated Fleet Assessment Results

- Following results assume benefits only due to technology improvements
- Results do not include
  - Operational improvements
  - Alternative fuel benefits
- Forecast is the Terminal Area Forecast (TAF)
  - TAF goes out to 2030
  - Linear extrapolation assumed beyond 2030
  - Assumes unconstrained growth
- CLEEN-EDS work next year will focus on how to incorporate operational enhancements into vehicle and fleet level assessments

Fuel Burn Fleet Results – D only

Fuel Burn Normalized to 2006 (Int'l Departures)

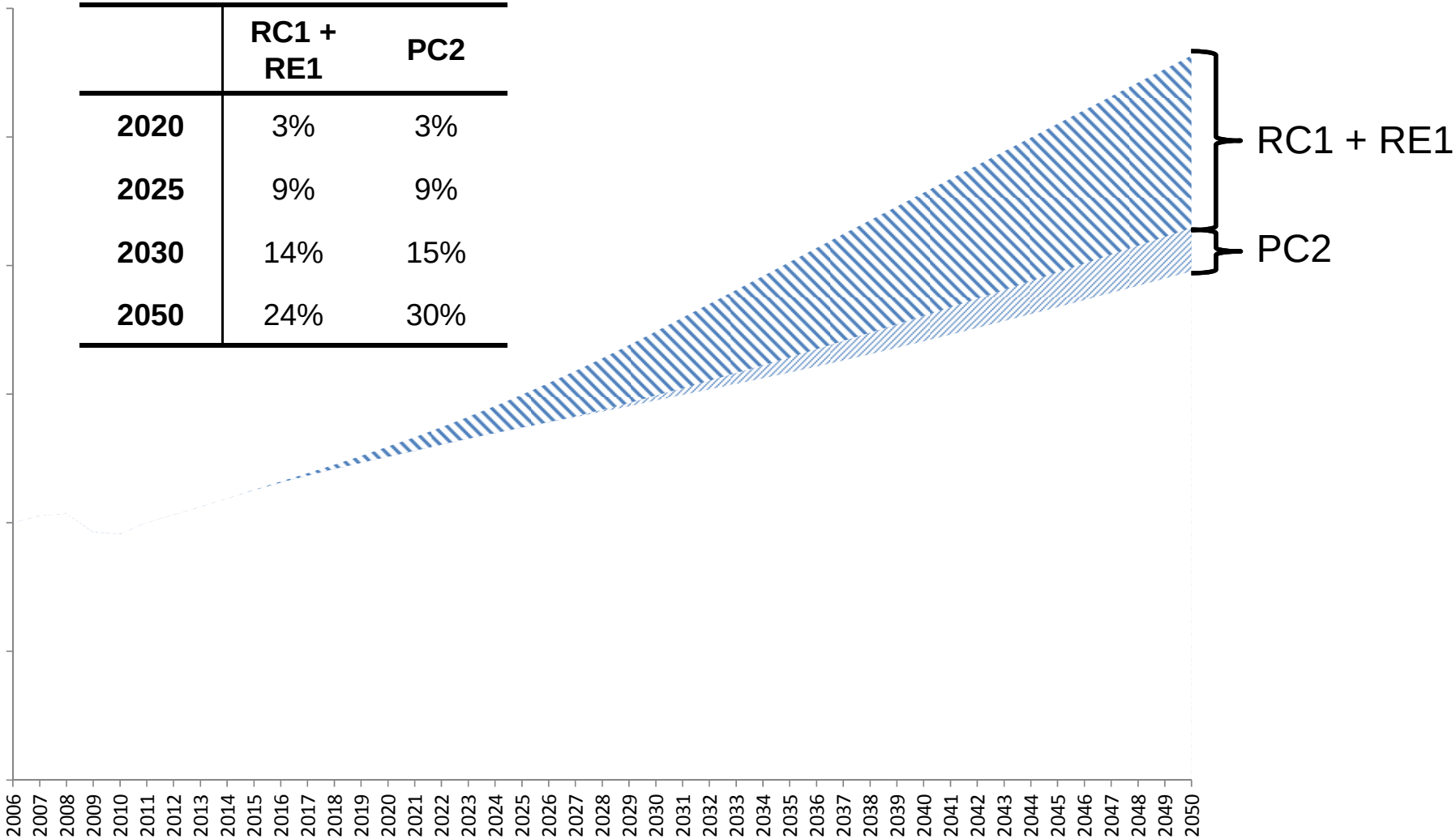
	RC1 + RE1	PC2
2020	2%	2%
2025	5%	5%
2030	9%	11%
2050	17%	24%



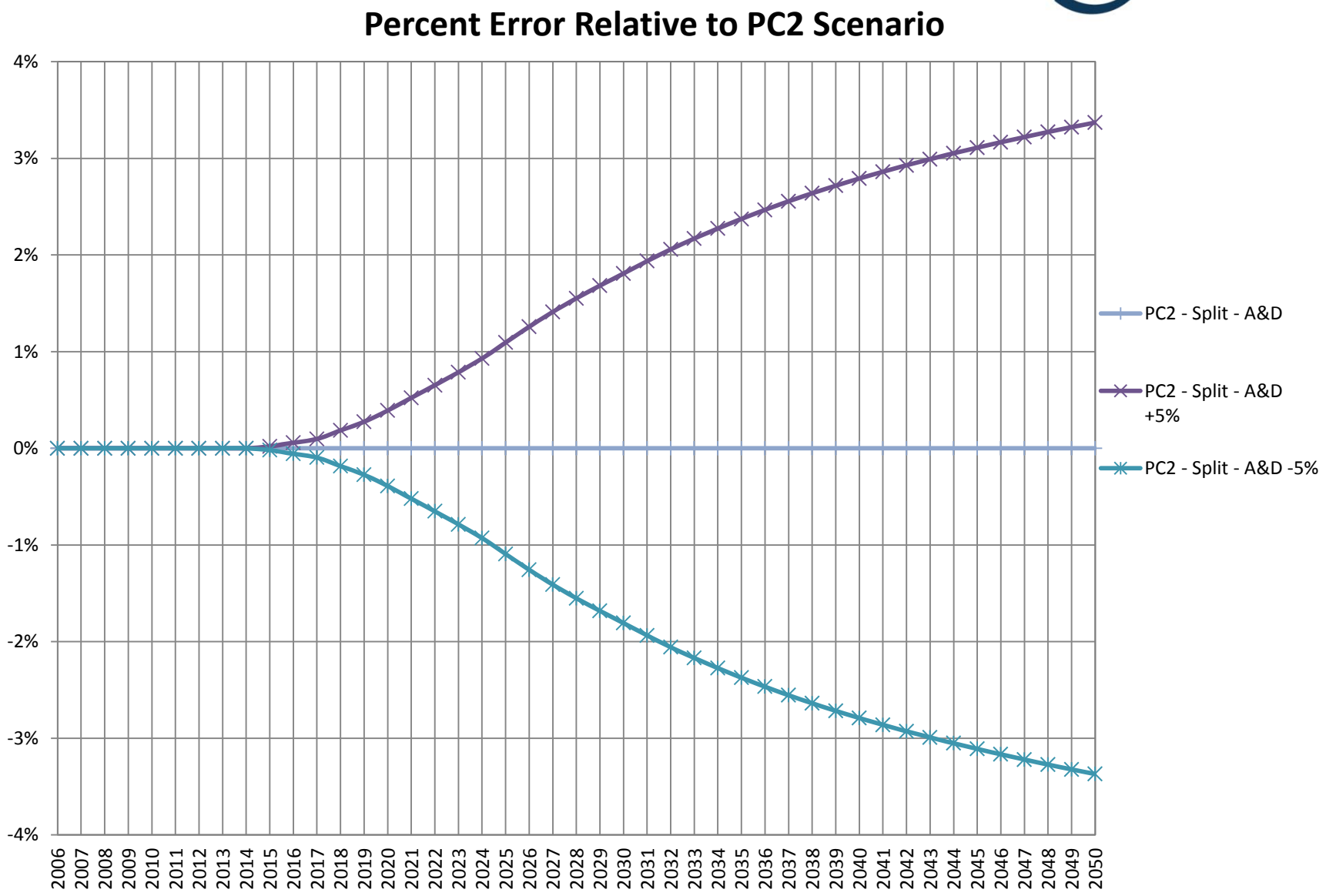
NOx Results – D only

NOx Normalized to 2006 (Int'l Departures)

	RC1 + RE1	PC2
2020	3%	3%
2025	9%	9%
2030	14%	15%
2050	24%	30%



Fleet Sensitivity to Vehicle Performance

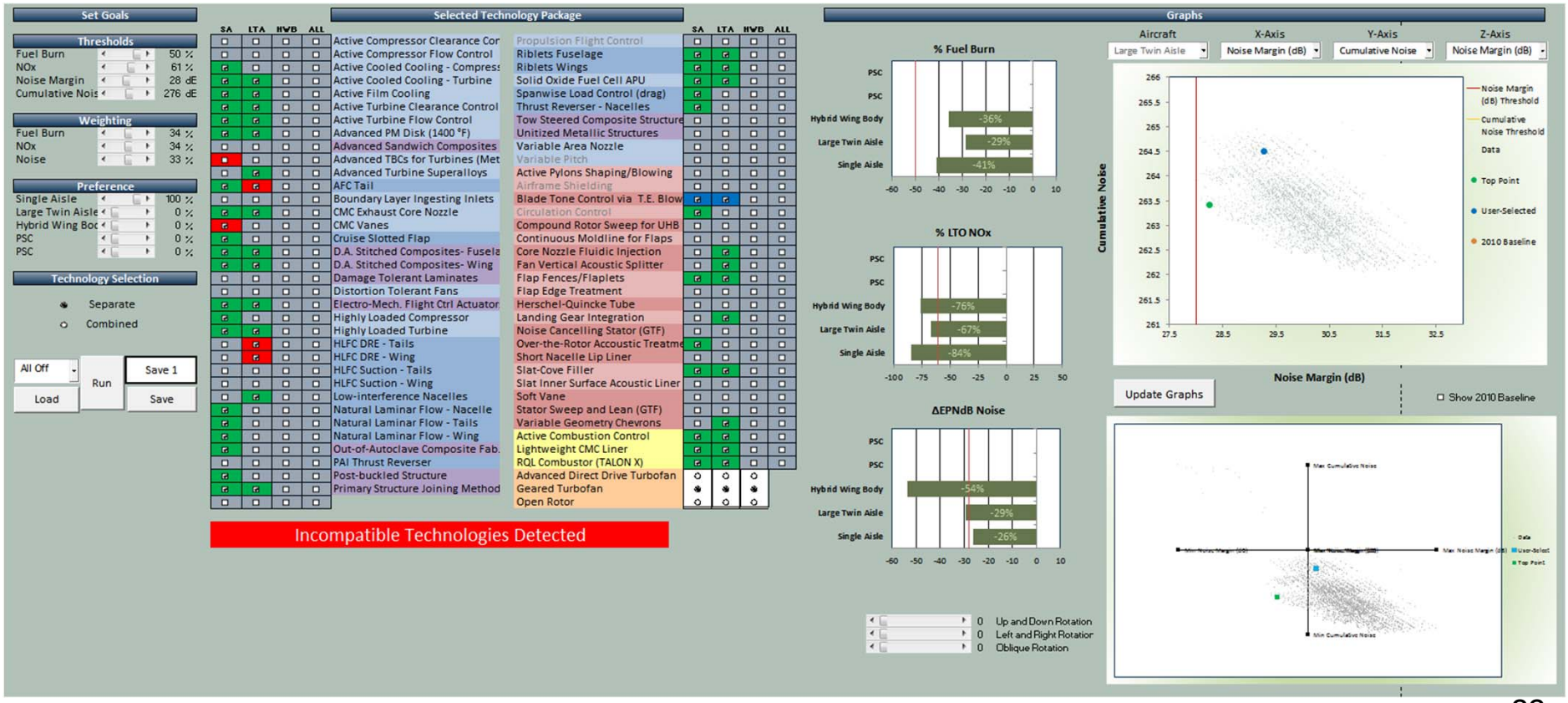


Where are we now?

- Finished up fleet level analysis of phase 1 and some phase 2 technologies
  - Generic Ops
  - Generic Noise
- Currently interfacing with P&W, Boeing, and GE
- EDS open rotor model ready for GE input and feedback
- EDS GTF model ready for P&W input and feedback
- Currently using models developed during current and previous years to create technology dashboard for the FAA CLEEN office...

Technology Dashboard Development

- Goal is to embed EDS capabilities within excel-based analysis
- Planned capabilities
  - Bottoms-up or top-down (gap) analysis
  - Provide inputs necessary for GREAT (rapid fleet level analysis)
- Spiral development process
  - Delivering intermediate versions to FAA as vehicles are populated into the environment



TECHNOLOGY CALCULATOR DEMO

Upcoming Work

- Have updated assessment of fleet level impacts of CLEEN using first round of proprietary data
- Will be repeating this process again as interactions with the CLEEN companies proceeds and better data becomes available
- Must remember assessment is an ongoing process that is continually improving
- As more proprietary information becomes available assessments will become more precise

Summary

- We are attempting to create a physics based, results driven tool that allows for informed real-time decision making which allows the selection of technology packages for future funding and research
- Key challenges/barriers
  - **How will proprietary technologies be assessed within EDS?**
    - **Current collaboration with industry is going well**
  - Defining realistic assumptions that show CLEEN's value added to future vehicles
  - How good is good enough, in terms of modeling?
    - **Have achieved a good balance between fidelity vs. resources available**
  - Stakeholder buy-in
  - Agreement on baseline modeling assumptions
  - Issues regarding any merging of proprietary data need to be addressed
  - **Fleet wide assessments and V&V**
    - **GREAT V&V recently completed**

Contributors

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