CLEEN-EDS Update

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CLEEN Consortium
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Atlanta, GA

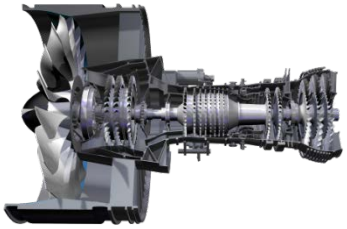
PARTNER
Partnership for Air Transportation Noise and Emissions Reduction

Motivation

- Develop the capability of independently assessing technologies proposed under the Continuous Lower Energy, Emissions and Noise (CLEEN) program
  - CLEEN objectives include reducing:
    - Fuel burn by 33% compared to current technology;
    - LTO NOx emissions by 60 percent relative to CAEP 6;
    - Noise levels by 32 EPNdB cumulative, relative to Stage 4
- Use the Environmental Design Space (EDS) to assess a set of sample technologies
  - Model CLEEN contractor technologies
  - Assess impacts on CLEEN metrics at vehicle and fleet level
  - Provide the FAA with independent technology assessment capability
- Show fleet level environmental impact of CLEEN technologies for five aircraft classes

Objectives

- **GA Tech integrates NASA design & analysis tools**
- **Assess technology combinations**
- **Identify synergistic technologies**
- **Compare to company estimate**



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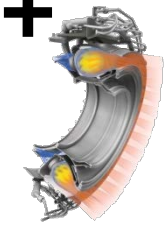

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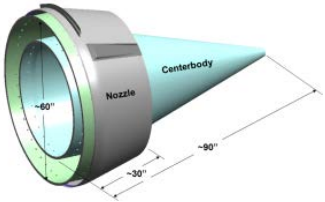


Regional Jet

Single-Aisle

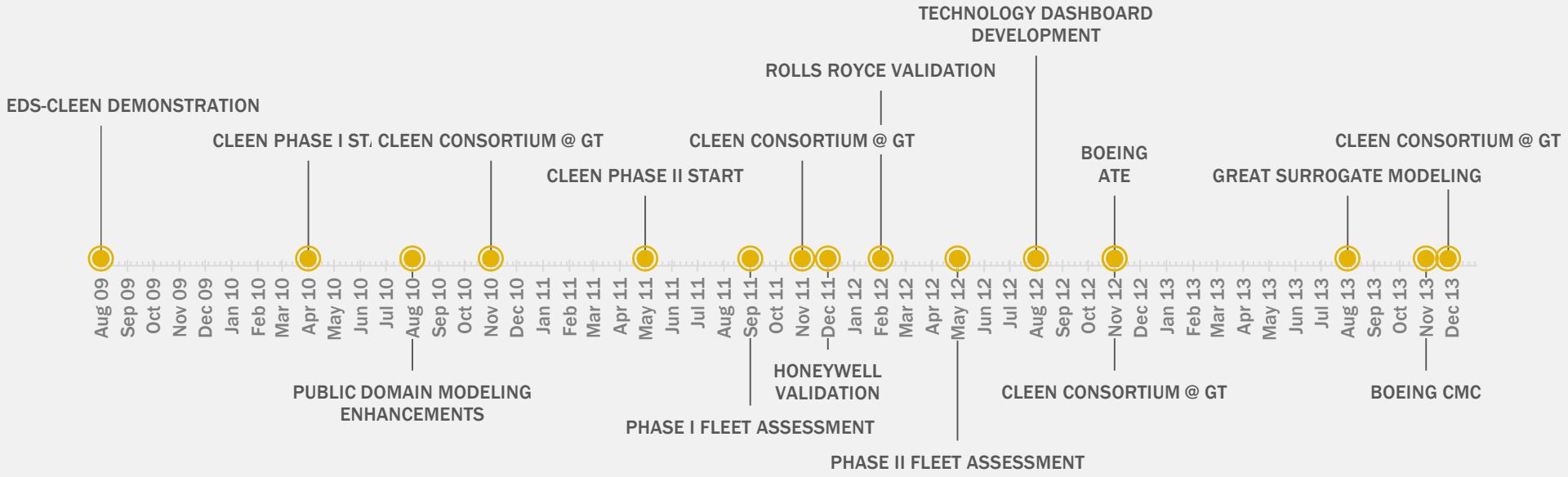
Large Twin-Aisle

Subsystem Technology Impacts → **Technology Effects on Vehicle** → **Fleet Level Implications**

Expected Outcomes and Practical Applications

- Outcomes
  - Evaluate specific technology packages based on top level metrics and scenarios
  - Show benefit of CLEEN funded (and potentially other N+1 or N+2) technologies at vehicle and fleet level
  - Provide FAA with independent technology assessment and tradeoff capability
- 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 between industry and higher level environmental analyses
    - Calculates system-wide environmental metrics
  - Can provide new AEDT vehicles for detailed fleet runs

Schedule and Status



- CLEEN-EDS has evolved throughout it's lifetime
- Continuous improvement in modeling assumptions and capability

Schedule and Status

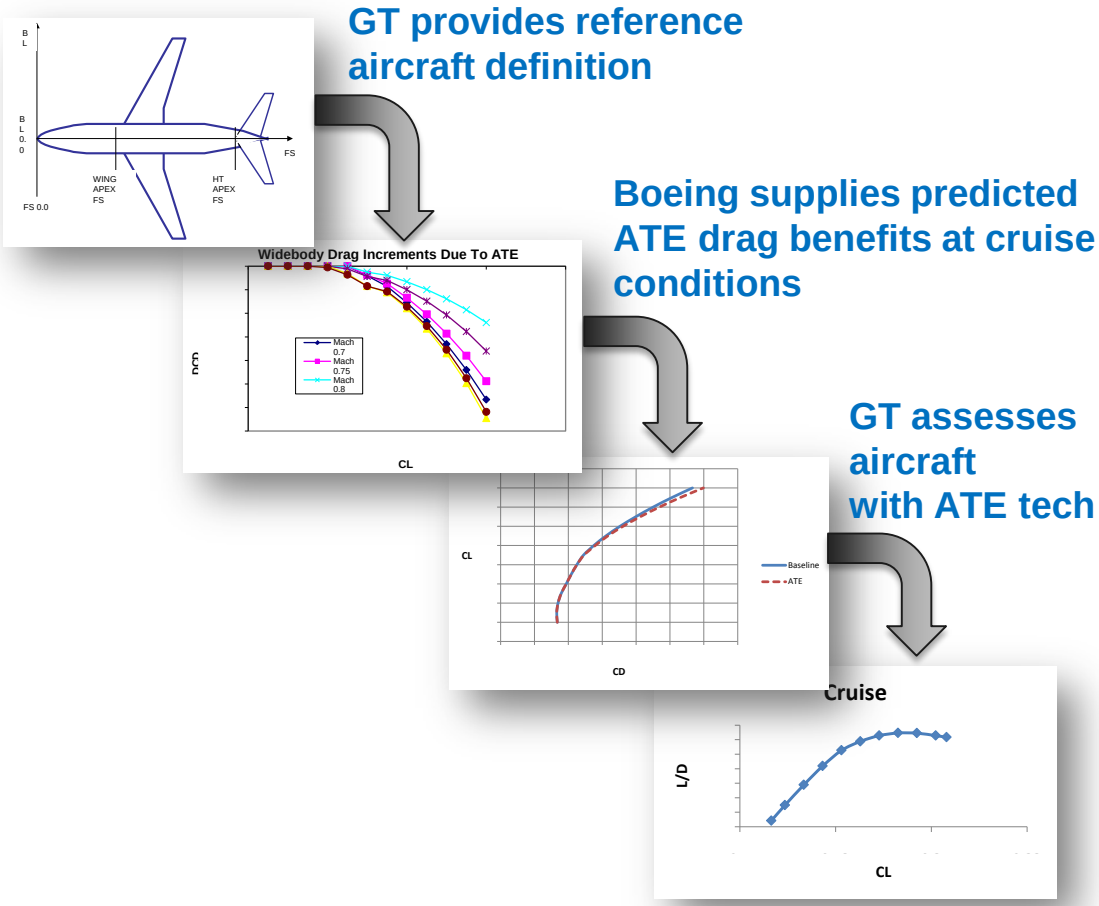
- Complete
  - Boeing adaptive trailing edge assessment
  - Cross validation of EDS geared fan model to recent NASA studies
  - Historical trend analysis
  - Validate process for creating surrogates of fleet analysis inputs
- Ongoing
  - Industry Technology Modeling - Ongoing
    - Verified EDS geared fan against NASA studies – Currently working with P&W to review results
    - Have begun Boeing CMC Nozzle assessment
  - Define common set of fleet level insertion and technology availability assumptions
  - General EDS analysis support
    - This include more detailed analysis of certain technology packages
    - Optimization of engine and airframe design parameters to meet goals
- Remaining
  - Update technology dashboard surrogate models
  - Support fall CLEEN consortium meeting
  - New technology modeling to support CLEEN II
  - Update fleet analysis based on proprietary models
  - Technology dashboard enhancements

Approach

	Boeing ATE Assessment	EDS Geared Fan Model Verification	Historical Trend Analysis	Fleet Level Surrogate Modeling
Goal	• Quantitatively Evaluate Boeing ATE on SA and LTA platforms	• Show EDS can replicate recent NASA geared fan studies	• Provide FAA with high level and low level technology trends	• Provide FAA with ability to perform vehicle and fleet level technology trades
Challenges	• High & low speed modeling effects • Simplification of detailed test data	• Gathering of NASA data • Matching of assumptions	• None	• Encapsulating EDS vehicle and fleet capabilities within surrogate models
Approach	• Work with Boeing to define aerodynamic input to EDS • Isolate high speed (fuel burn) and low speed (noise) analysis for simplification of analysis • Assess ATE in EDS from noise and fuel burn perspective	• Gather NASA assumptions • Review assumptions with NASA • Send results to P&W for review	• Literature Review	• Construct surrogate models of EDS outputs needed for GREAT fleet level modeling tool • Validate surrogate models against previous EDS-GREAT fleet results

Analysis of Boeing ATE Technology in EDS

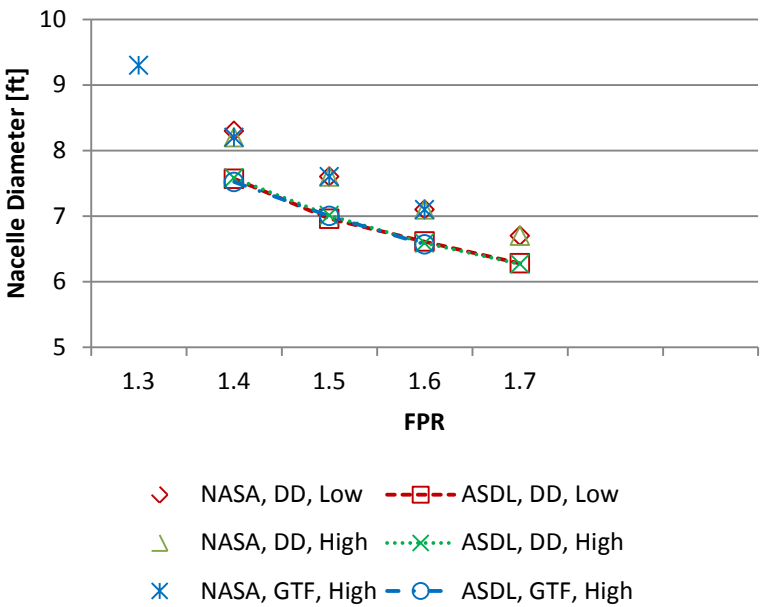
- Analyzed ATE technology to assess integrated mission performance in two stages
  - High speed (Fuel burn)
  - Low speed (Noise)
- Iterated with Boeing to obtain necessary data and refine model
- ATE model demonstrates both fuel burn and noise improvements from baseline case

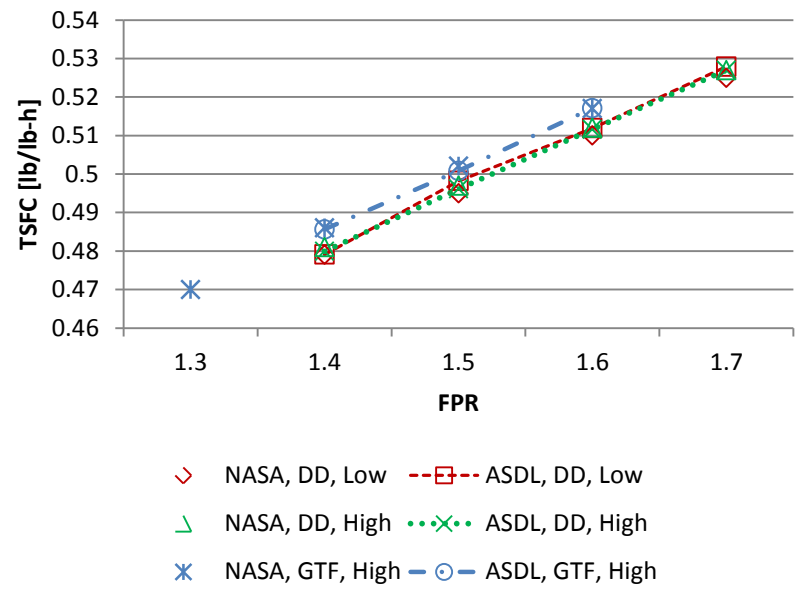


ATE High Speed Modeling Process

Verifying EDS Geared Fan Model

- Verified the EDS geared fan model against most recent NASA geared fan study
- With common assumptions EDS generated common results
- Some minor differences expected due primarily to engine sizing methodologies, bookkeeping, and tool versions

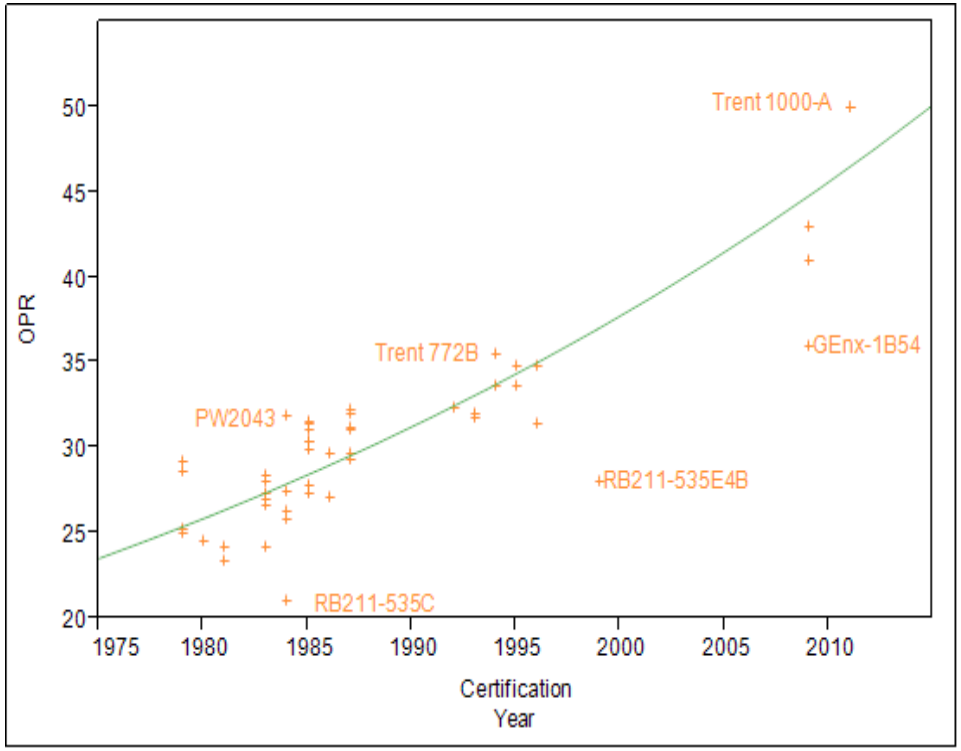




*Berton, J., Guynn, M., "Multi-Objective Optimization of a Turbofan for an Advanced Single-Aisle Transport," Journal of Aircraft, Vol. 48, No. 5, pp. 1795-1805

Historical Trend Literature Review

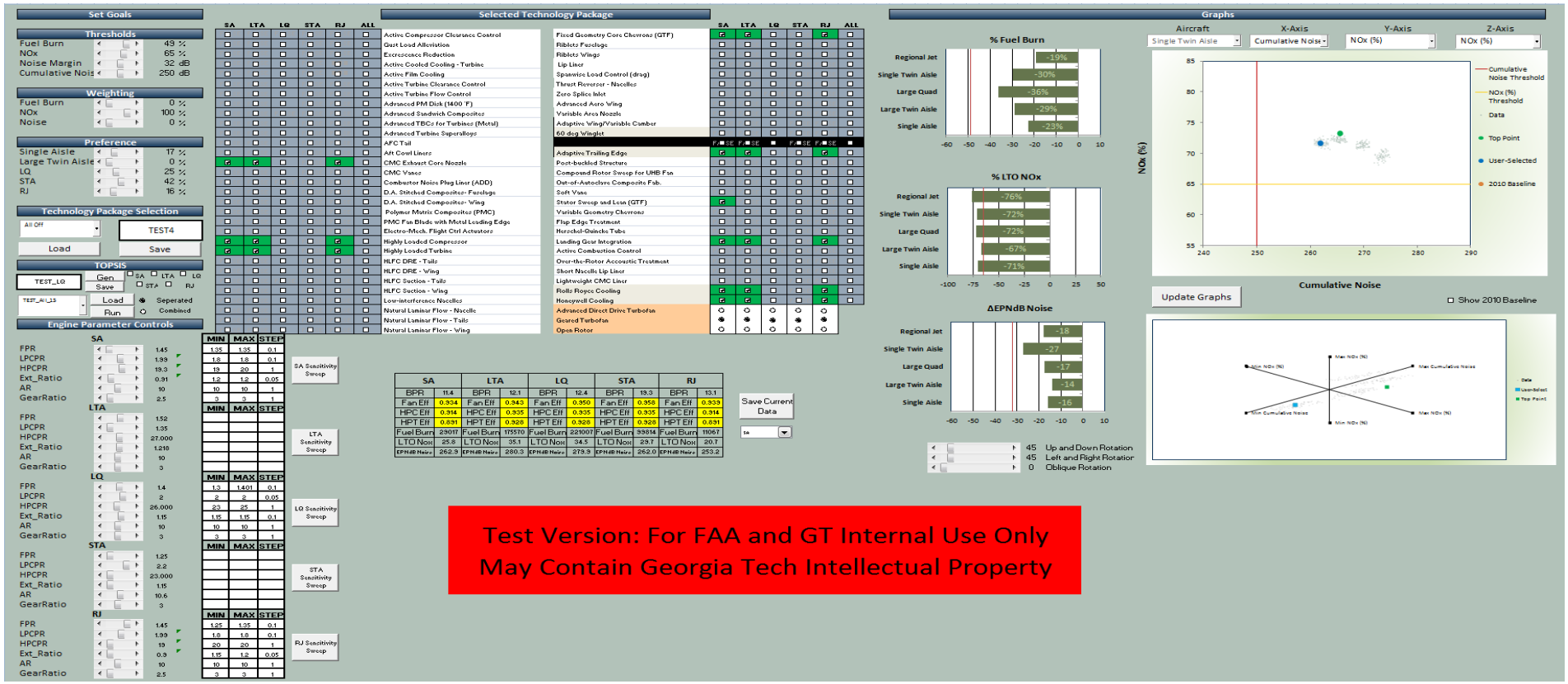
- Conducted so FAA can look at how future technologies may fall compared to historical trends
  - For FAA internal modeling activities
  - Inform FAA about future technologies relative to past trends
- Conducted a literature review and database search of quantified trends
- Goal was to collect and distill high level and low level technology evolution over time



High Level Metrics
Fuel burn/payload*range
TSFC
Empty Weight/payload weight
L/D at cruise
Engine weight/thrust
NOx
Cumulative Noise
TSFC
BPR
OPR

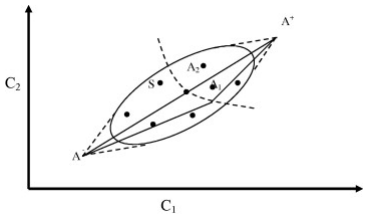
Technology Dashboard Development

- Goal is to embed EDS capabilities within excel-based analysis
- 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

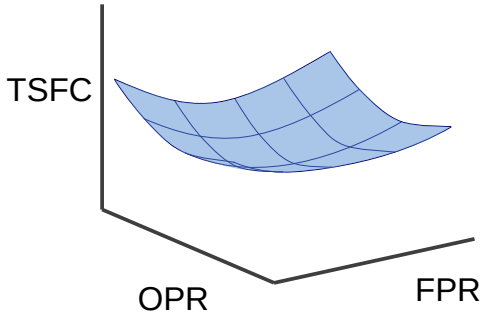


Dashboard Development

- Have developed surrogate models for GTF representations of 5 vehicle classes
  - RJ through LQ
  - Captured both high and intermediate level responses

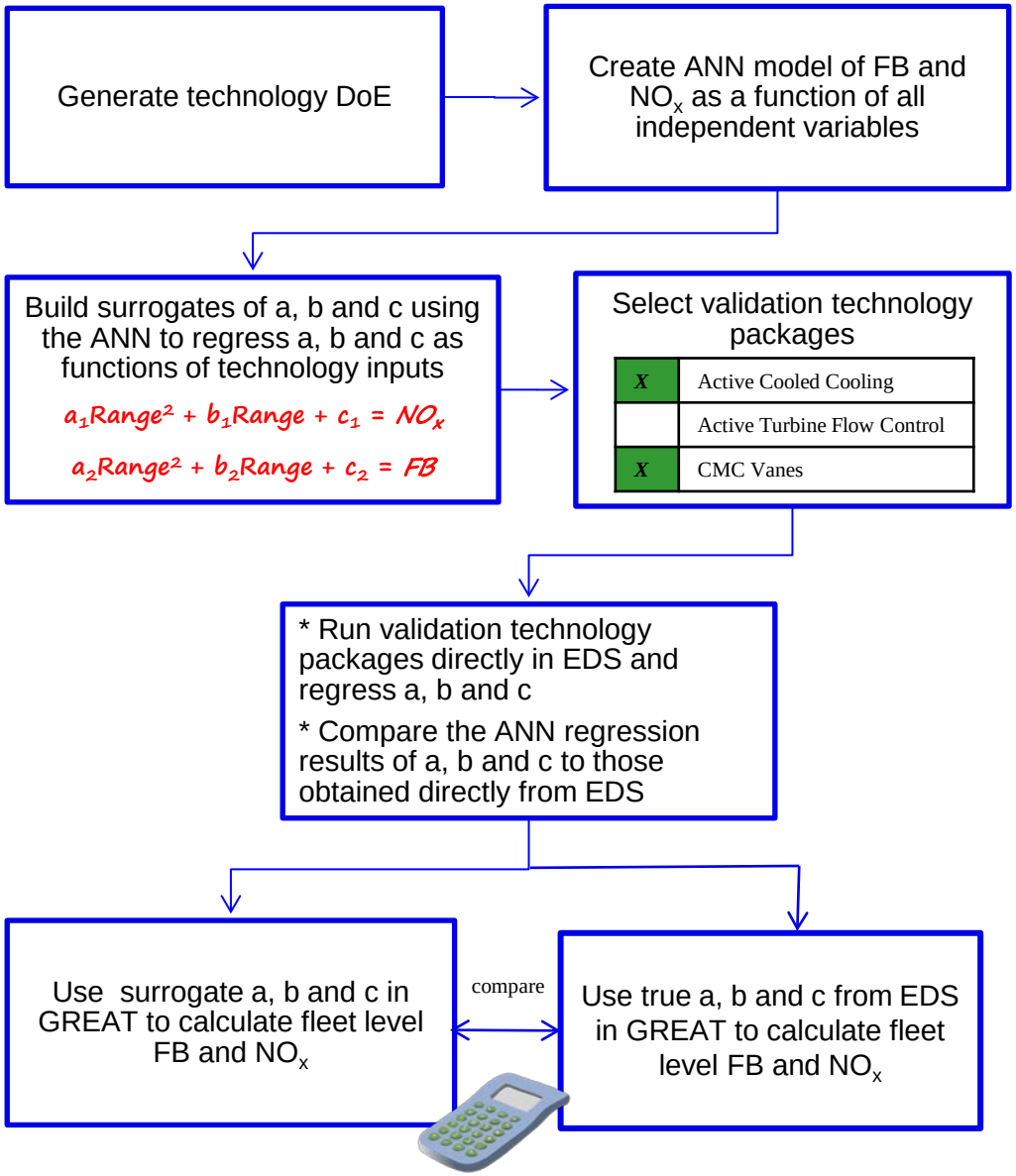


- Implemented multi-attribute decision making methods to assist in technology package selection
  - Includes ability to ‘choose’ from arbitrary subset of technologies
  - Also includes major engine cycle selection



- Implemented ability to perform basic design parameter sweeps to help understand confluence of technology and design
- Currently integrating direct drive vehicle representations

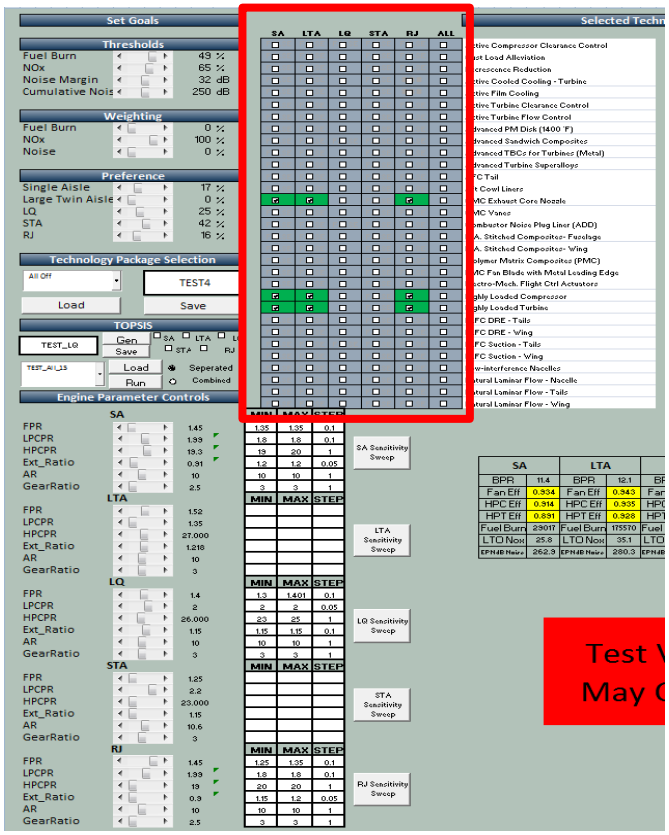
Fleet Level Analysis: GREAT Integration Overview



- Fleet level analysis can be conducted with GREAT using polynomial regression of AEDT generated fuel burn and emissions as a function of stage length
- Previous process required EDS user "in the loop" to generate necessary GREAT input data
- New approach validates use of surrogates to eliminate need for GT to run EDS technology scenarios

Fleet level analysis: 25 validation technology packages used

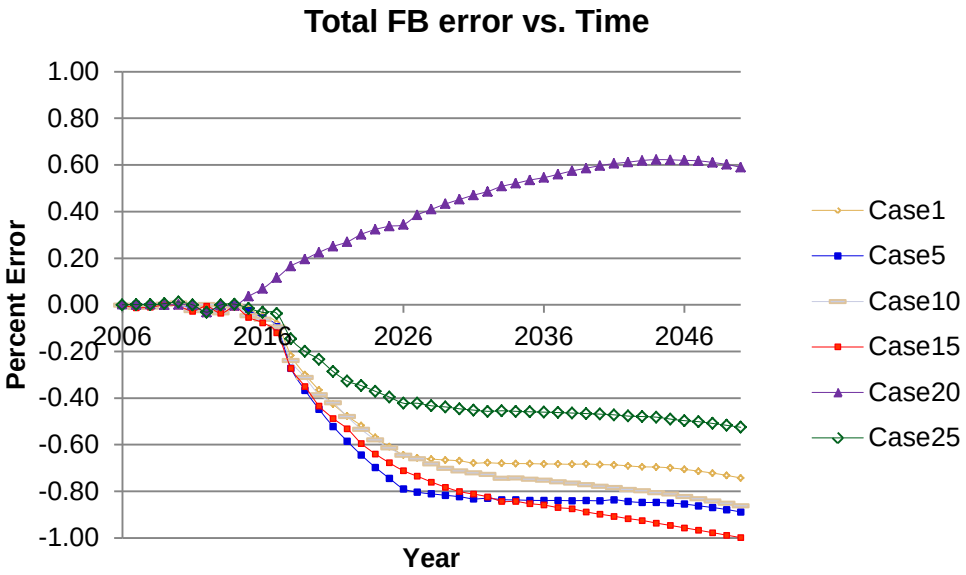
1. None
2. Active film, adv sandwich, CMC vanes, PMC, NLF nacelle
3. Cooling techs
4. Rotating components – minus last 2
5. Weight, combustor, other – minus VAN
6. Stitched comp – fuse and wing, PMC fan blade, riblets – fuse and wing
7. Sandwich, out of autoclave, flap edge treatments
8. Thrust reverser, adv aero wing, ATE, post-buckled structure, landing gear
9. TBC, 2 CMC, PMC
10. Gust load alleviation, excersence red, adv PM disk
11. Variable geom. Chevrons, low-int nacelles, NLF nacelle
12. Highly loaded – comp and turbine
13. Adv turbine superalloy, aft cowl liner, Hershel-quincke tube, rolls Royce cooking
14. All the HLFC
15. All NLF
16. Adv aero wing, adaptive wing, flap edge treatment,
17. Lip liner, spanwise, soft vane, Honeywell cooling
18. Test 5
19. Cooling + rotating
20. Cooling + weight
21. Rotating + weight
22. Combustor plus liner, electro-mech flight control actuator
23. Every other – minus stator sweep
24. Start from top and every other (skip 3)
25. Active cooled cooling, adv turbine superalloys, HLC, LIN, tube, riblets wings

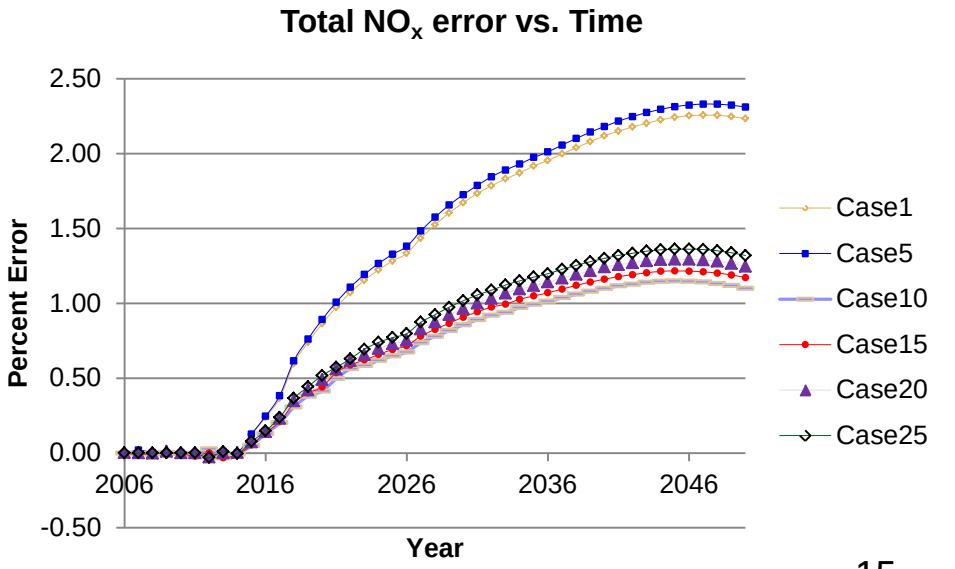


CLEEN technology Dashboard

Fleet level analysis: fleet level error for the validation technology packages

- For each validation package, the EDS and the surrogate values of a, b and c were inputted into GREAT
- A 100% fleet replacement in year 2015 and a same type of vehicle replacement were assumed
- For all validation packages, the error in the total fleet FB and total NO_x from years 2006 to 2050 was computed, taking EDS as the reference





Upcoming Work

- Incorporate recent proprietary modeling efforts into fleet analysis
- Repeat fleet analysis with harmonized N+1/N+2/N+3 assumptions
- Continue to develop dashboard
  - Short term
    - Update vehicle level surrogates
    - Create fleet level input surrogates
  - Longer term
    - Integrate technology dashboard with GT fleet level modeling tools (GREAT)

QUESTIONS?