EDS Vehicle Technology Trade Space

Presented to: TRB AEDT/APMT Workshop #4

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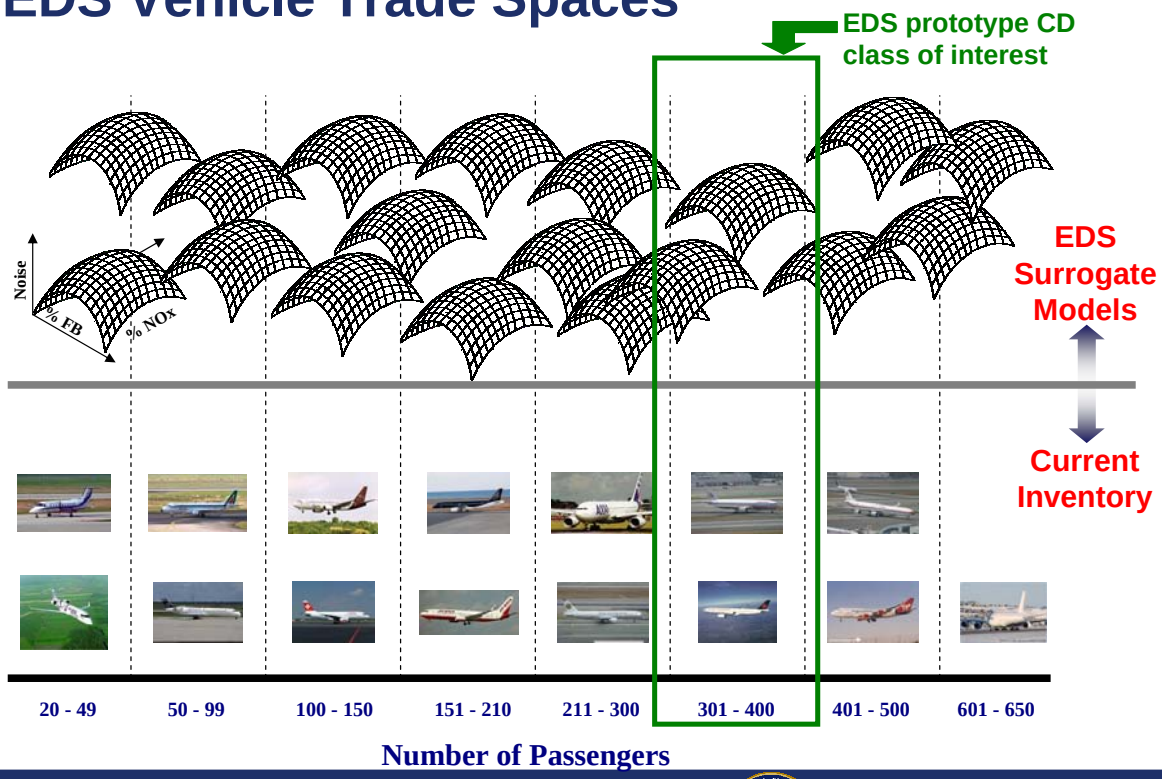
Objectives

- **Demonstrate the process by which EDS supplies new vehicles to APMT and AEDT for CDs**
  - Increase confidence of EDS generated results through industry guidance
  - Define rigorous process for new aircraft types from EDS
- **Exercise capability of the connectivity between EDS-AEDT-APMT**
- **Demonstrate how EDS generated vehicles are incorporated for APMT CDs**

APMT CD with EDS Vehicles

- **EDS supported two CDs for APMT, which included:**
  - Fuel Price Increase (FP)
    - With and without new aircraft technology
  - NOx Emissions Certification Stringency (NX)
    - With and without new aircraft technology
- **Prototype connectivity based on:**
  - Aircraft and engine trade spaces with current technology levels
  - Only one seat class was supplied for the prototype CDs based on a deviation from a benchmark of a Boeing 777-200ER with a GE90-94B
  - Same vehicles used for both CDs as potential replacement vehicles

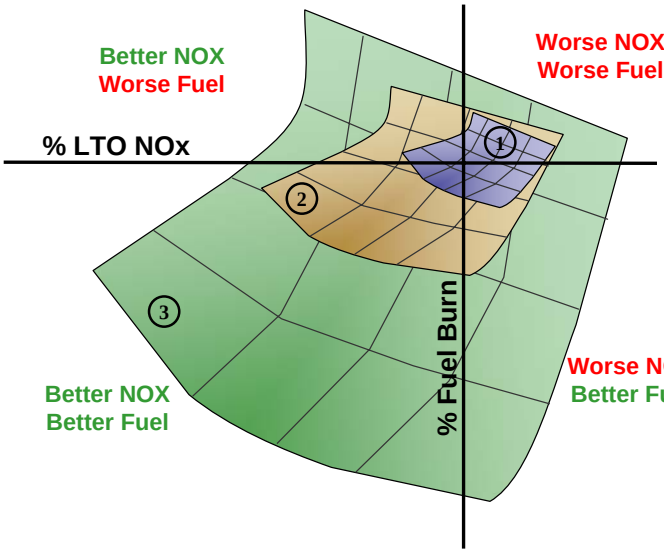
EDS Vehicle Trade Spaces



Creating an EDS Trade Space

- **Trade space creation is complex**
- **Industry participation is critical**
- **Per industry guidance, a detailed process was established:**
  - Establish reference vehicle and calibrate vehicle
  - Create trade space
  - Determine sensitivities of the trade space
  - Hand off EDS vehicles to APMT and AEDT based on the following criteria:
    - Better NOx
    - Better fuel burn

EDS Products: Trade Spaces



Three different trade spaces for a given airframe/engine architecture type within a vehicle class may be investigated:

1. Trade space about current technology
2. Trade space about incremental changes from current technology (e.g., winglets or new combustor)
3. Trade space for future technologies

EDS Vehicle Library Requirements

- **EDS must create an extensive database of the vehicle classes**
  - Input parameters can be defined and the output results validated
  - EDS is executed in three modes for establishing confidence and connectivity
- **EDS must use only non-proprietary and public domain data**
- **The process must also be traceable, transparent, and repeatable**
- **Vehicle entries for APMT CDs are based on:**
  - Existing certified systems within the CAEP vehicle classes

Execution Modes

- **EDS is executed in 3 modes for an APMT CD:**
  - Calibration (~5 minutes per run)
    - Single pass through modules and calibration values are post processed with Monte Carlo filtering
  - Parametric mode without AEDT for APMT (~7 minutes per run)
    - Useful for exploration of a trade space for a given airframe/engine architecture and validating trends (key for gaining industry confidence)
    - APMT data generated
  - Parametric mode with AEDT (~10 minutes per run)
    - Various payloads, ranges and trajectories
    - Useful for exploration of trades in a future policy scenario
    - AEDT data generated

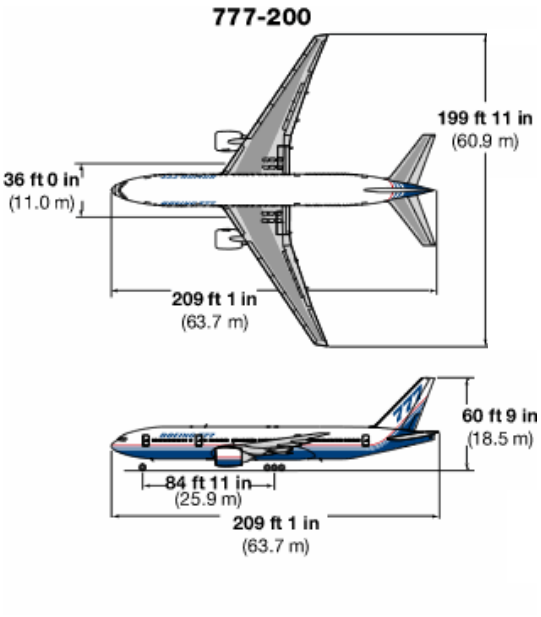
300 Passenger Class Reference Vehicle

- **Airframe: Boeing 777-200ER**
- **Engine: GE 90-94B**

http://www.snecma.com

http://www.geae.com/

http://www.boeing.com/



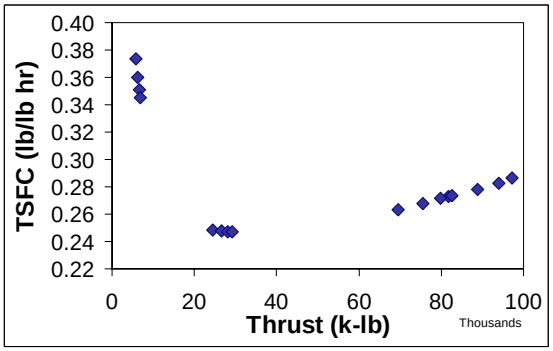
http://www.boeing.com/

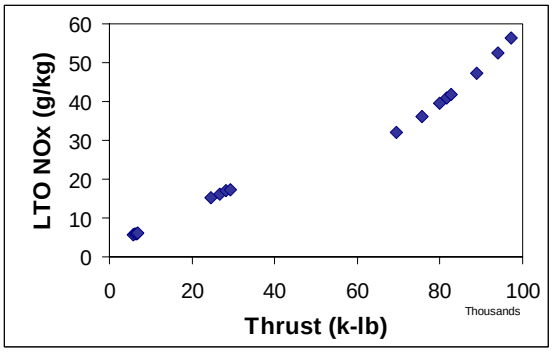
EDS Engine Calibration

- **Engine related validation data:**
  - ICAO Engine Emissions Databank:
    - Fuel flows at LTO power settings
    - NC, CO, and NOx emissions indices for each power setting
    - Multiple points for a de-rated engine (depends on company and engine type)
  - FAA Type Certification Data Sheet:
    - Number of stages
    - Maximum SLS thrust
    - Outer envelope dimensions
    - Dry weight
    - Turbine exhaust gas temperature limits
    - Maximum permissible air bleed extraction
  - Jane's Aero-Engine or Engine Manufacturer's web site:
    - Component dimensions and locations
    - Component hub-to-tip ratios
    - Specific fuel consumption at various flight conditions
  - Typically between **35 and 40 validation points** are used depending on the number of engines in a family

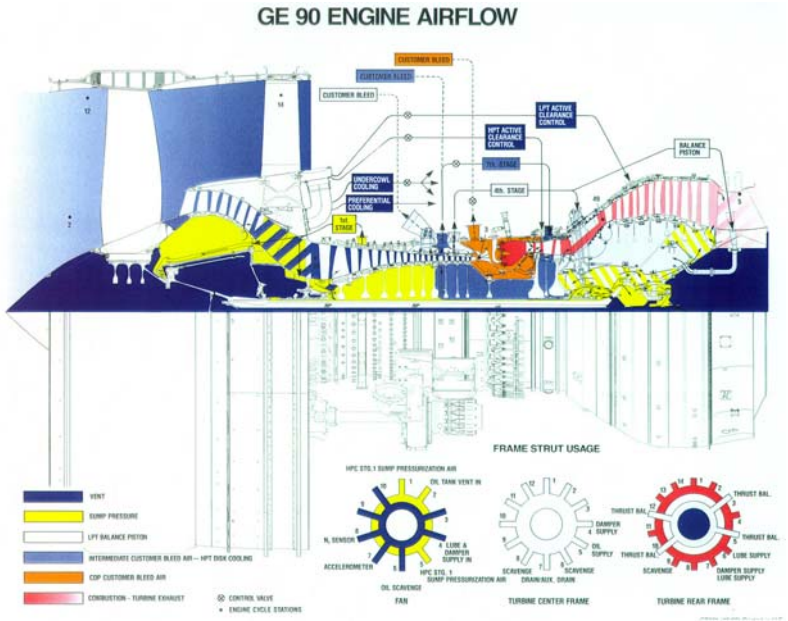
GE90-94B Parameters to Match

Parameters	Source	Value	Units
Rated Thrust	ICAO Databank	97300	lb
OPR	ICAO Databank	40.53	
BPR	ICAO Databank	8.33	
Horsepower Extraction	TCDS	386	HP
100% N1 @ TO	TCDS	2261	rpm
100% N2 @ TO	TCDS	9331	rpm
Fan Diameter	Jane's Aircraft Engine	123	in
Fan Stages	TCDS	1	
LPC Stages	TCDS	3	
HPC Stages	TCDS	10	
HPT Stages	TCDS	2	
LPT Stages	TCDS	6	
Fan Length	Engine Flowpath	20.7	in
LPC Length	Engine Flowpath	19.8	in
HPC Length	Engine Flowpath	43.2	in
HPT Length	Engine Flowpath	11.8	in
LPT Length	Engine Flowpath	40.4	in
Dry Weight	GEAE Website	16644	lb
Dry Weight (with acc.)	TCDS	17400	lb
Max Width	TCDS	152.4	in
Rated Mass Flow	Jane's Aircraft Engine	3221	lb/s





GE90 Flowpath

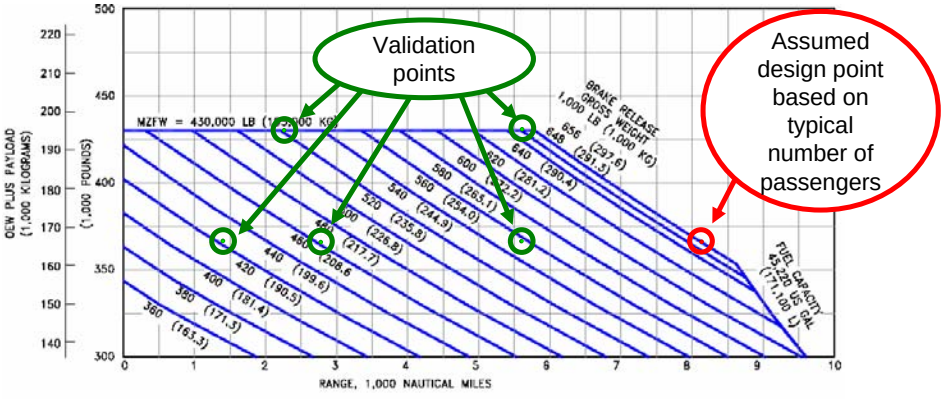


- A cross-section of a particular engine can be used to calibrate locations and dimensions
- GE90 Engine Airflow obtained from http://ctr-sgi1.stanford.edu/CITS/

EDS Airframe Calibration

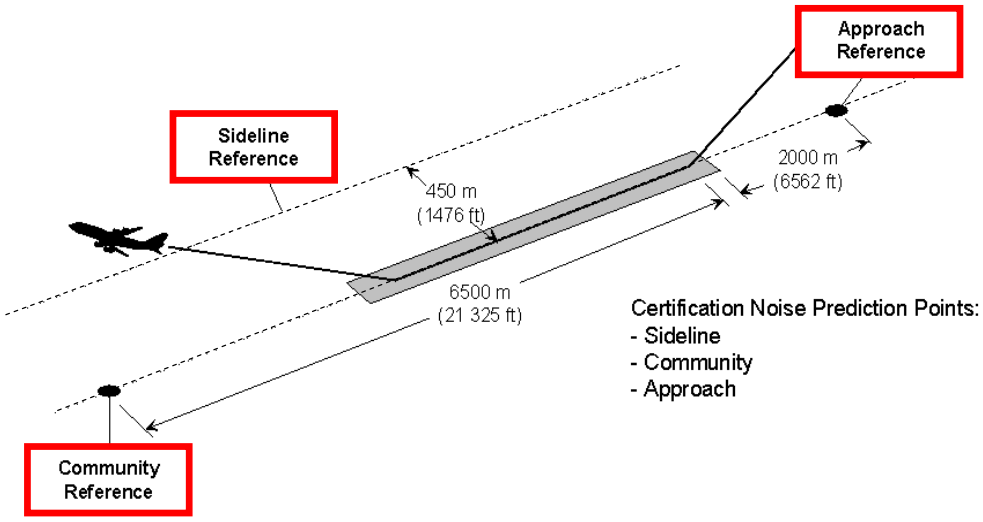
- **Airframe related validation data:**
  - FAA AC 36-H1
    - Noise certification data points
  - FAA/EASA Aircraft Type Certification Data Sheet
    - Applicable engines
    - Aircraft operating limits
    - Aircraft weight variant specifics
  - Manufacturer's web site
    - Aircraft weight breakdown (OEW, MZFW, MTOGW, Payload, Max Fuel)
    - Payload/range charts
    - Mission fuel vs. range
    - FAR field lengths for various takeoff weights and pressure altitudes
    - 3-view drawings
  - Jane's All the World's Aircraft
    - Component geometries and control surface areas
    - Airframe materials
    - Approach speed

B777-200ER Matching Points



- The published typical number of passengers is used to establish the design range and provide the MTOW, OEW, and payload
- From historical data of maximum structural payload as a function of the number of typical passengers, thus MZFW can be determined
- For a sweep of gross weights, the vehicle can be calibrated to approximate the published payload v. range

B777-200ER Noise Matching Points



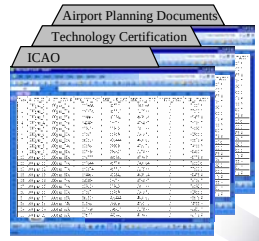
Noise spectra are analytically "flown" over the three-point listening references on the ground. Propagation effects are calculated.

•Ref: http://www-psao.grc.nasa.gov/Reengine/Images/cert_obs.gif

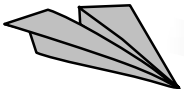
Calibration Factors

- **Calibration factors were determined by a sensitivity study in addition to input and expert judgment from industry**
  - Engine (31)
    - Component pressure ratios, speeds, efficiencies, and weights
    - Combustor temperature, residence time, bleed and cooling schemes
  - Aircraft (80)
    - Basic geometry, materials, and weights
    - Drag and lift coefficients and low speed aerodynamics
  - Emissions (1)
    - NOx correlation coefficients
  - Noise (27)
    - Component suppression factors

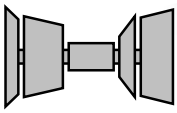
EDS Calibration



Publicly Available Data



Aircraft Characteristics

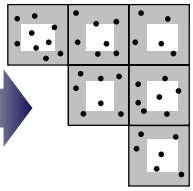


Engine Parameters

Payload

EDS

Monte Carlo Filter



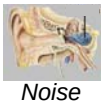
Final calibration model is based on the variable settings that minimize the error for all validation points

Vehicle

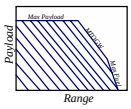
Flight Profile

Engine

Field Lengths



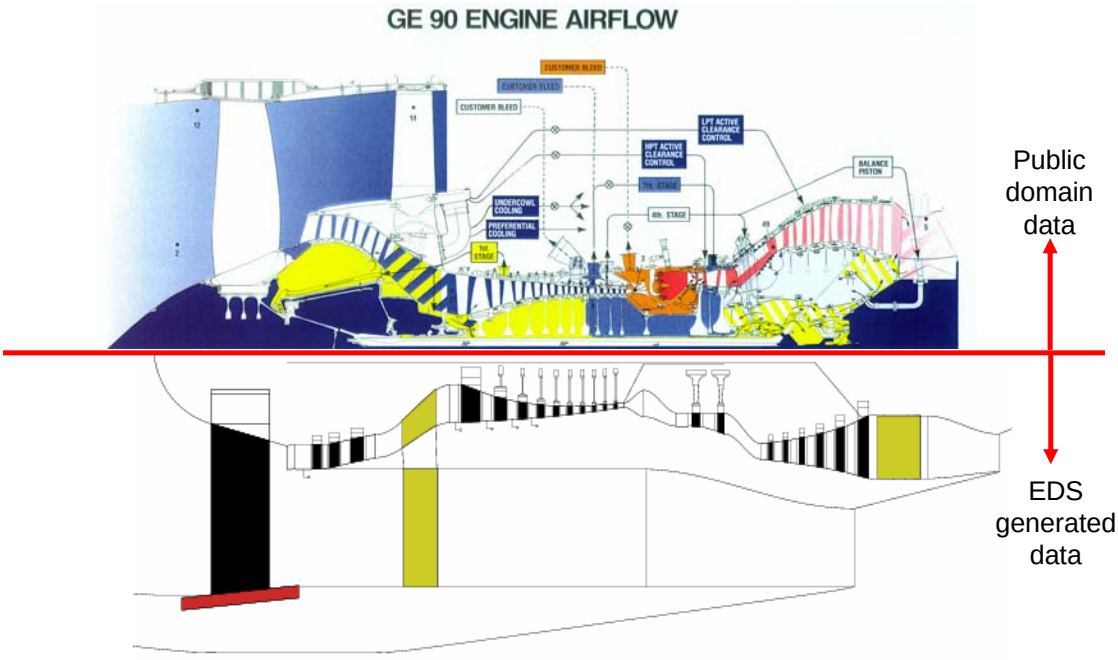
Noise



Payload vs. Range

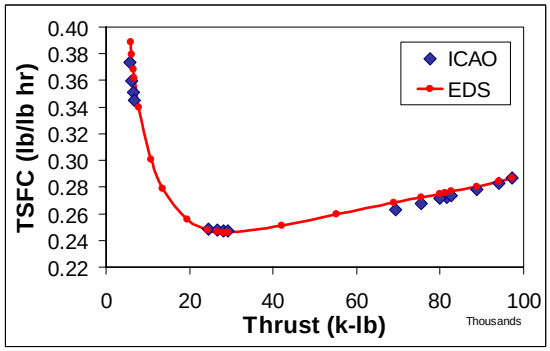
Emissions

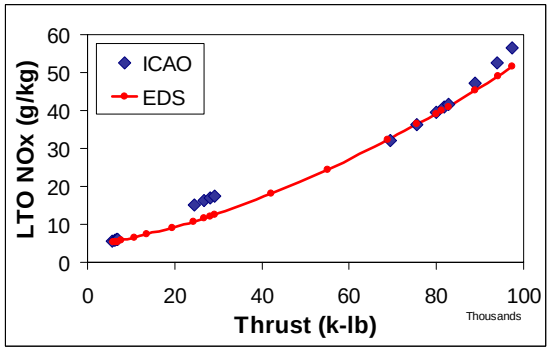
Matching Engine Flowpath



GE90-94B: Parameters to Match

Parameters	Target	Actual	% Diff	Units
Rated Thrust	97300	97300	0.00%	lb
OPR	40.53	40.534	0.01%	
BPR	8.33	8.335	0.06%	
Horsepower Extraction	386	386	0.00%	HP
100% N1 @ TO	2261	2262	0.03%	rpm
100% N2 @ TO	9331	9325	-0.07%	rpm
Fan Diameter	123	124.3	1.05%	in
Fan Stages	1	1		
LPC Stages	3	3		
HPC Stages	10	10		
HPT Stages	2	2		
LPT Stages	6	6		
Fan Length	20.7	20.9	1.21%	in
LPC Length	19.8	20.2	1.81%	in
HPC Length	43.2	43.8	1.34%	in
HPT Length	11.8	12	1.87%	in
LPT Length	40.4	40.8	1.12%	in
Dry Weight	16644	17322	4.1%	lb
Dry Weight (with acc.)	17400	18072	3.9%	lb
Max Width	152.4	152.4	0.00%	in
Rated Mass Flow	3221	3160	-1.90%	lb/s





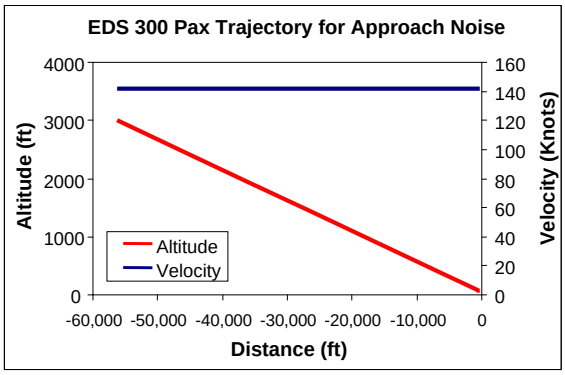
B777-200ER Parameters to Match

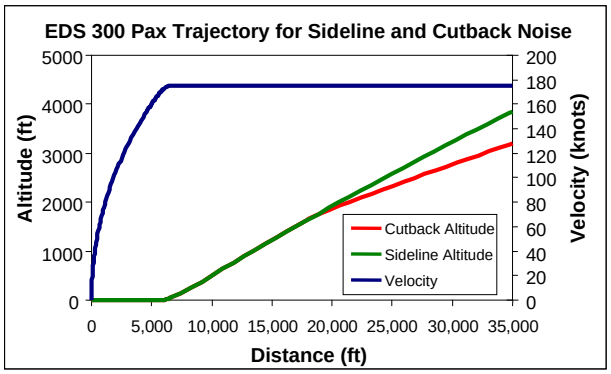
	EDS Pax300	777-200ER	% Diff	Units
Maximum Takeoff Gross Weight	655,281	656,000	-0.11%	lb
Operating Empty Weight	298,102	300,000	-0.61%	lb
Maximum Payload	129,913	130,000	-0.07%	lb
Maximum Landing Weight	467,562	470,000	-0.53%	lb
FAR Takeoff Field Length*	8584			ft
FAR Landing Field Length*	5796			ft
Approach Velocity*	130.0			knots

Payload (lb)	Range (nmi)	EDS Pax300 Fuel Weight (lb)	777-200ER Fuel Weight (lb)	% Diff
66,220	8100	290,959	289,780	0.41%
129,913	5600	217,681	218,000	-0.15%
66,220	5600	190,348	188,780	0.83%
66,220	2750	93,774	93,780	-0.01%
129,913	2250	89,226	90,000	-0.86%
66,220	1400	53,913	53,780	0.25%

* Note: the unspecified B777-200ER parameters in the Airport Planning documents do not clarify an engine type

Noise Parameters to Match





Per certification procedures, Approach noise is calculated at approach speed + 10 kts

Cutback at 80.9% of max thrust

Velocity profile for Sideline and Cutback trajectories

	MTOW (lb)	MLW (lb)	Noise Level (EPNL dB)		
			Takeoff	Sideline	Approach
777-200ER	656,000	470,000	91.1	96.4	98.3
EDS 300 Pax	655,281	467,562	91.06	96.4	98.4

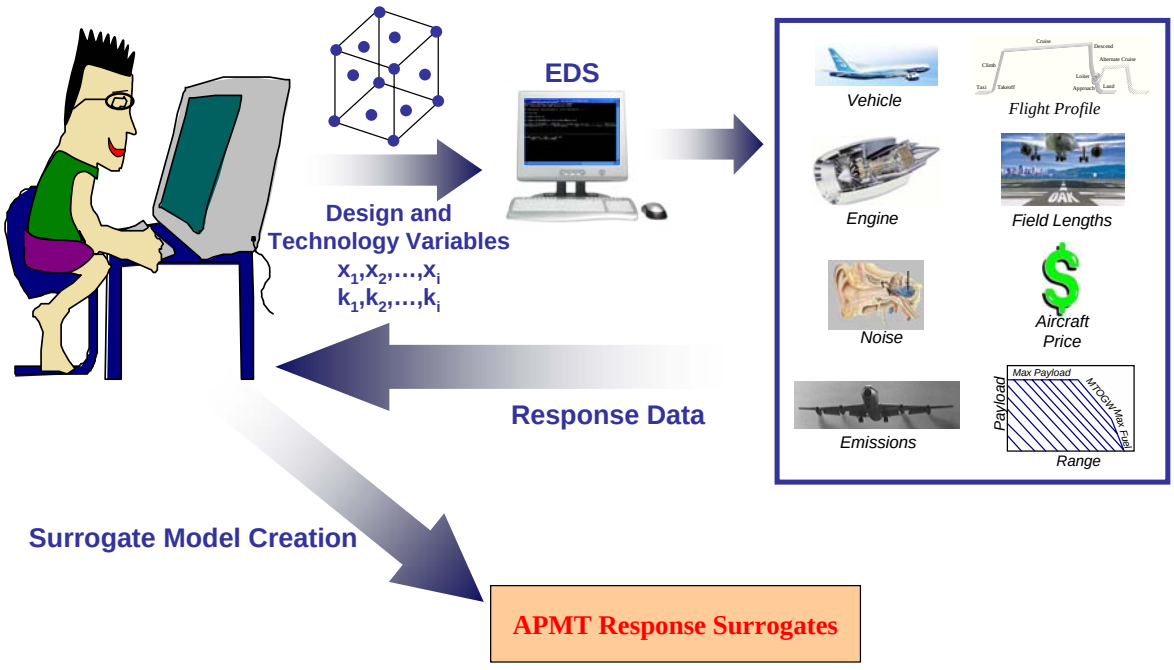
Initial Trade Space Definition

- **300 passenger class system encompassing Boeing and Airbus aircraft and GE engine architectures**
- **Trade space bounds defined for both current and future technologies**
  - Original space was defined prior to the definition of the CDs
  - Trade space exploration subsequently limited to current technology levels (small deviations about departure point)
  - Expansion of trade space can occur once industry provides guidance as to the bounds and trends for future technology

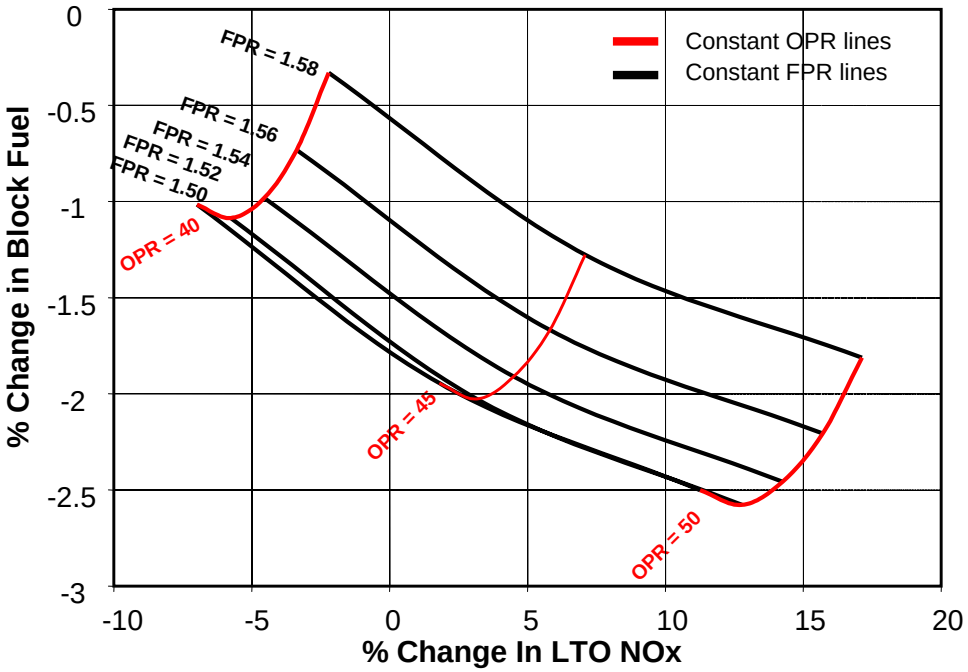
Trade Space Independent Variables

- **Independent variables were determined by sensitivity studies in addition to input and expert judgment from industry**
  - Engine (39 total)
    - Pressure ratios, component weight factors, cooling percentages, maximum combustion discharge temperature, component efficiencies, extracted work, velocity ratio, material temperature limit deltas, and component load factors
  - Noise (15 total)
    - Noise suppression factors used for approach, cutback, and sideline
  - Airframe (37 total)
    - Wing geometry, passenger number, mission parameters, weight correction factors, aerodynamic suppression factors, approach noise factors for vehicle devices, operations adjustment factors, maximum takeoff and landing lift coefficients, and aircraft scaling factors

EDS Trade Space Creation



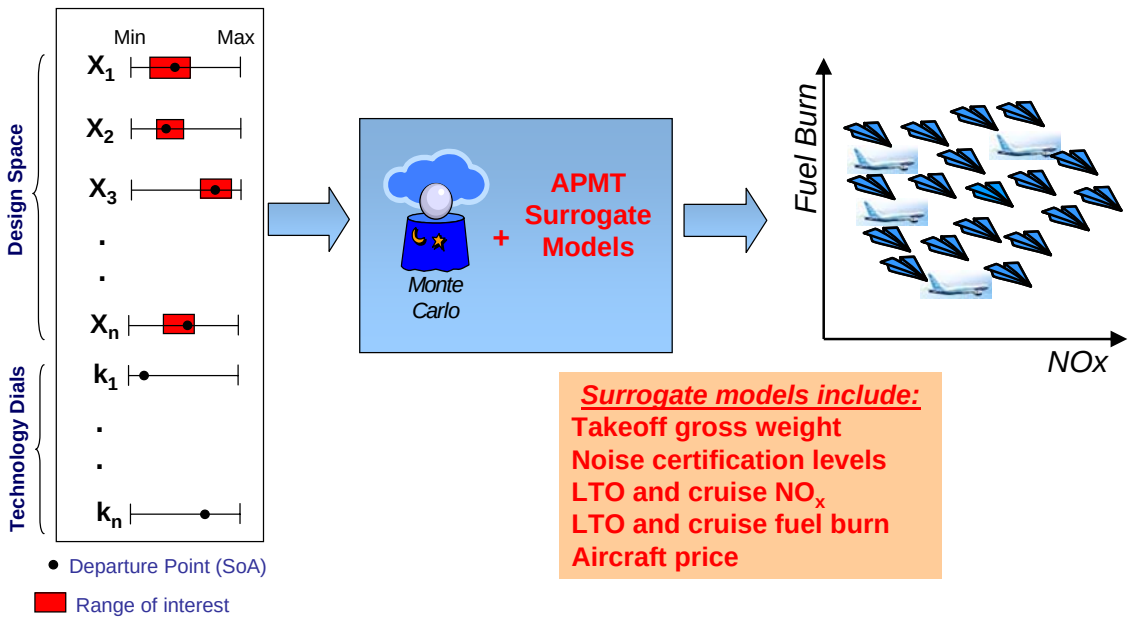
NOX/Fuel Burn Trends*



* Numbers quoted for an optimized system at SLS ambient conditions from reference vehicle, prior to incorporation of industry guidance

Trade Space Exploration

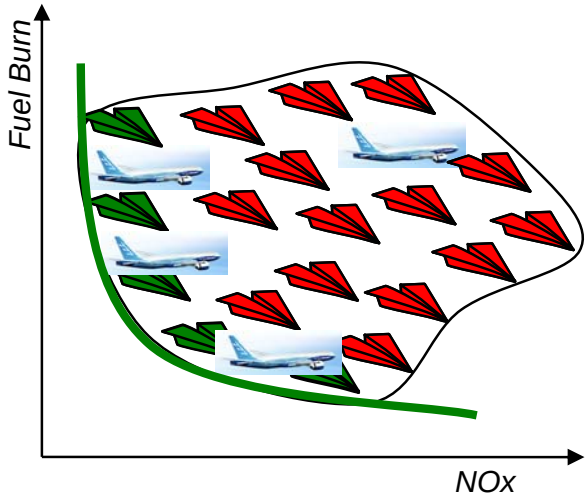
Independent variables



Surrogate models include:

Takeoff gross weight
Noise certification levels
LTO and cruise NO_x
LTO and cruise fuel burn
Aircraft price

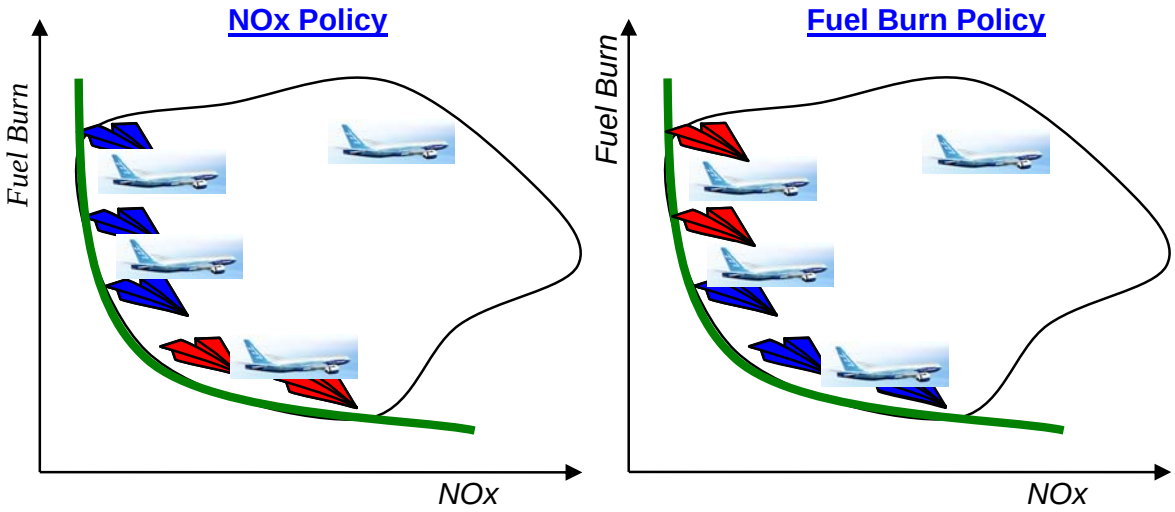
EDS Identification of Vehicles for APMT



- Potential vehicle concepts are generated using current day technology levels
- The best vehicles in multiple dimensions dictate a Pareto front
- From this, “equally as good” Pareto-efficient vehicles are selected and provided to APMT
- The remaining dominated concepts are eliminated

APMT Selection of EDS Vehicles

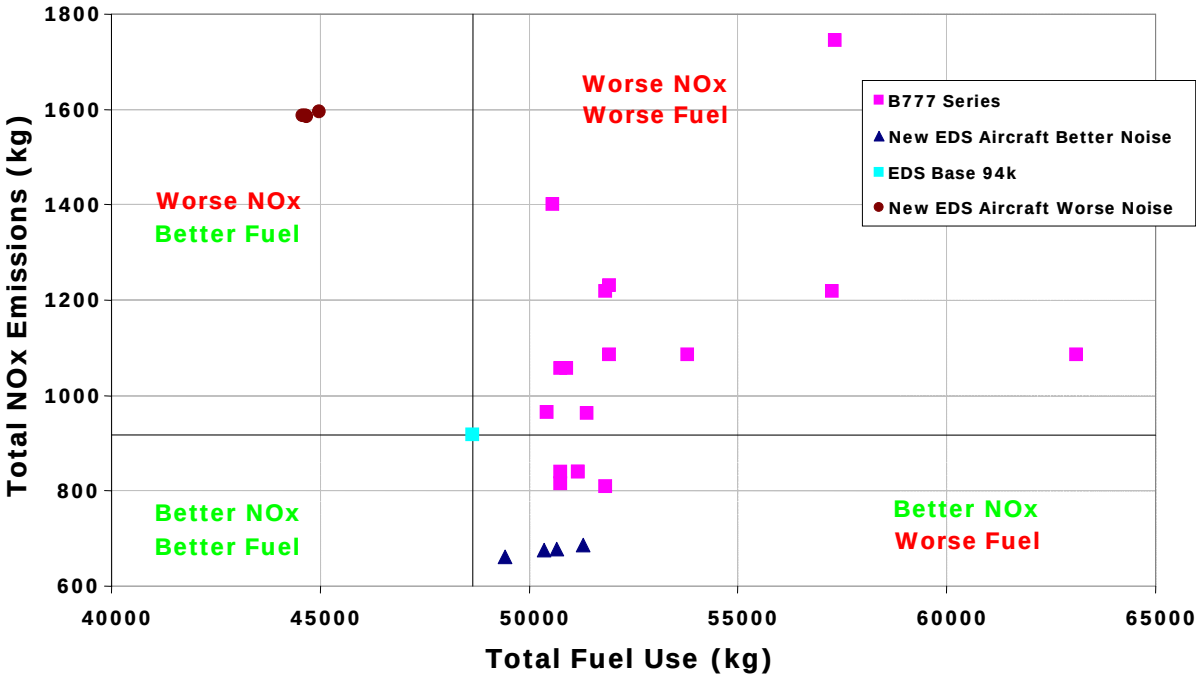
- For a given vehicle class, EDS supplies potential replacement vehicles for the future fleet
- If EDS vehicles are chosen for the policy case, AEDT coefficients are created and the AEDT database is amended



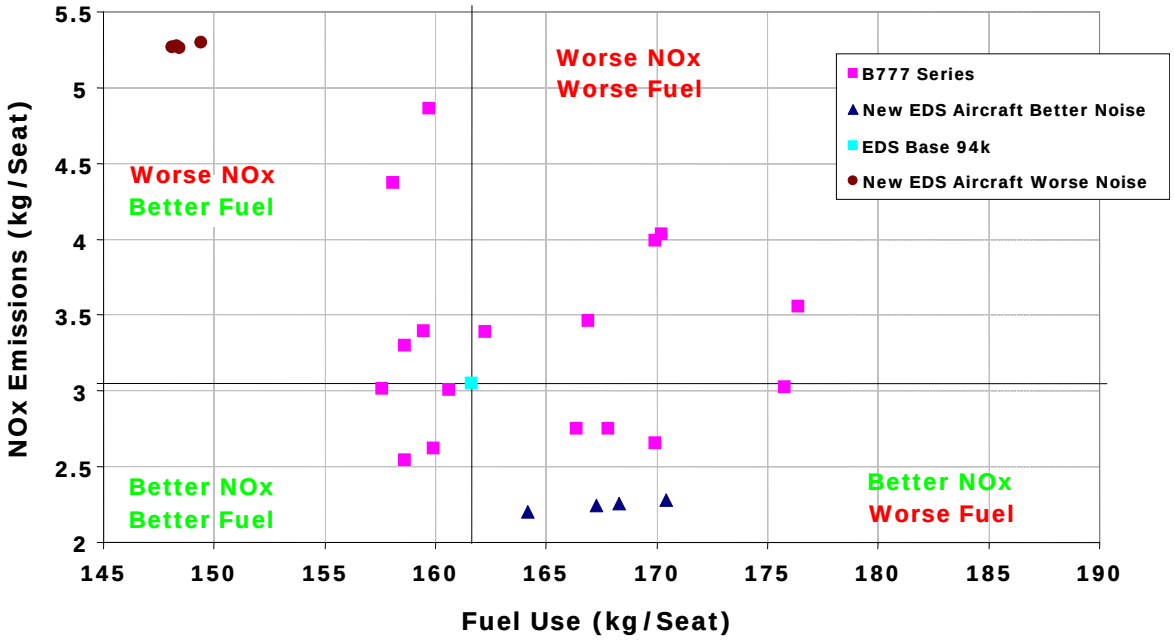
EDS Supplied Vehicles for APMT

- **Due to the parametric representation of the trade space, many more potential EDS replacement vehicles could have been supplied**
- **Focus was to demonstrate capability and connectivity between EDS-APMT-AEDT**
- **8 vehicles were supplied to APMT for the CDs based on 2 criteria:**
  - Improved NOx over current technology
  - Improved fuel burn over current technology
- **Other combinations of potential vehicles may be supplied for future CD applications**

Fuel vs. NOx vs. Cumulative Noise Margin



Fuel vs. NOx vs. Cumulative Noise Margin



EDS Vehicles Supplied to APMT

- **The information required by APMT for the CDs included:**
  - Vehicle related:
    - Number of passengers, range, MTOW, cruise velocity, number of engines, cruise fuel, aircraft price
  - Emissions related:
    - NOx emission indices for LTO, cruise NOx, LTO rule
  - Noise related:
    - Certification levels
  - Production year (year available for replacement)

AEDT Data Requirements

- **EDS connectivity to AEDT requires a complete entry into the Fleet Database for each EDS vehicle entries for the CD**
- **The Fleet Database is 40 separate data tables and files**
  - Three data table groups
    - Common tables
    - Emissions-specific tables
    - Noise-specific tables
- **For streamlining EDS execution, data tables were organized as follows:**
  - Vehicle classification
  - Airframe classification
  - Engine classification
  - Emissions
  - Noise
  - Procedures
- **Each category requires numerous calculations within EDS**

AEDT Database Population

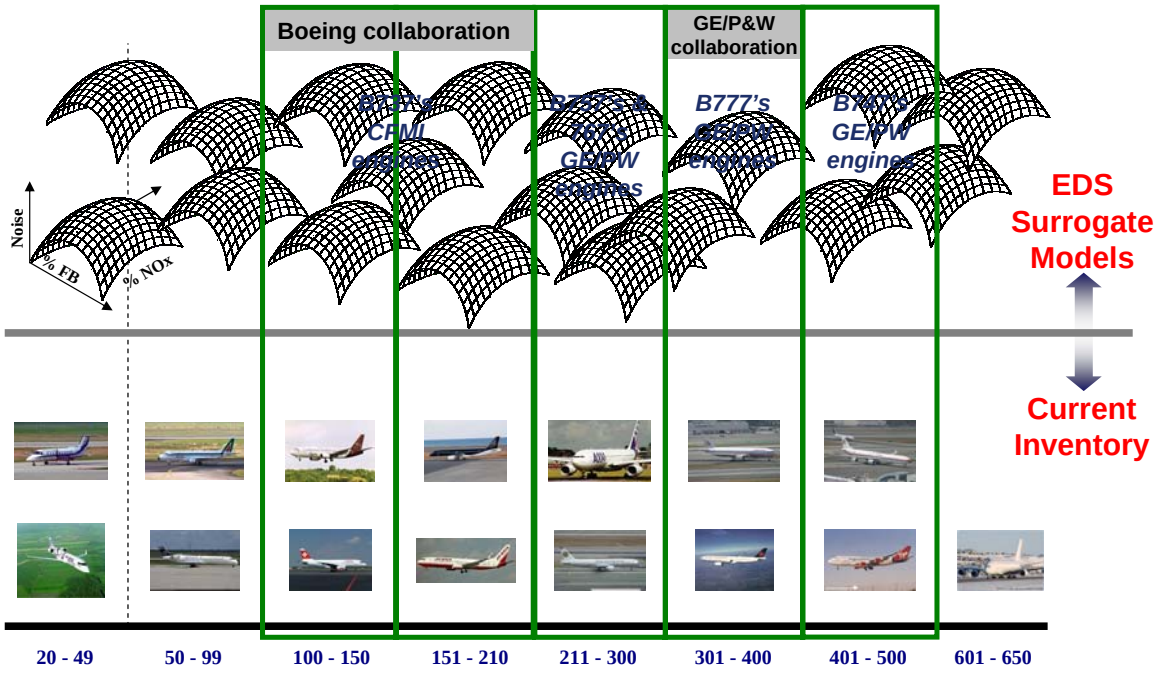
- **The majority of data fields extracted from the design point for (~400 data field entries):**
  - Vehicle, engine, and airframe classifications
  - Emissions
- **Significant modifications to EDS execution and module source codes were required to populate the procedures and noise categories (~3300 data field entries)**
  - Operational payloads and ranges
  - Airport trajectories (Standard, ICAO A, and ICAO B)
  - Flaps and slat deviations
  - Noise-power-distance and spectral curves

"Handshake" between EDS and AEDT is done manually for the CD and will be automated in the future

Summary

- Prototype trade space was established for a 300 passenger vehicle
- Trade space calibrated for current technology applications with industry input
- Prototype EDS aircraft selection process was implemented
- EDS connectivity to APMT established
- EDS "handshake" to AEDT established
- Eight vehicles from the 300 passenger vehicle class trade space were provided for two APMT CDs
- Sample results of EDS within APMT and AEDT will be discussed in the following briefing

EDS Current Vehicle Trade Spaces Status



Future Work

- **Create parametric spaces spanning all FESG vehicle classes**
  - Add Airbus, Bombardier, Embraer, Rolls Royce, and IAE airframe and engine combinations to the current trade spaces
  - "Currency of Communication" to CAEP and JPDO/NextGen
- **Continue to engage industry**
  - Define bounds for the trade spaces
  - Increase confidence in trends and results
  - Incorporate industry "best practices"
- **Automate connectivity to APMT and AEDT**
- **Continue support of future CD's and Sample Problems**
- **Expand EDS capability to support additional policy scenarios, JPDO/NextGen needs, and CAEP/8 needs**

??? Questions ???

FAA Environmental Tools web site:

http://www.faa.gov/about/office_org/headquarters_offices/aep/models/