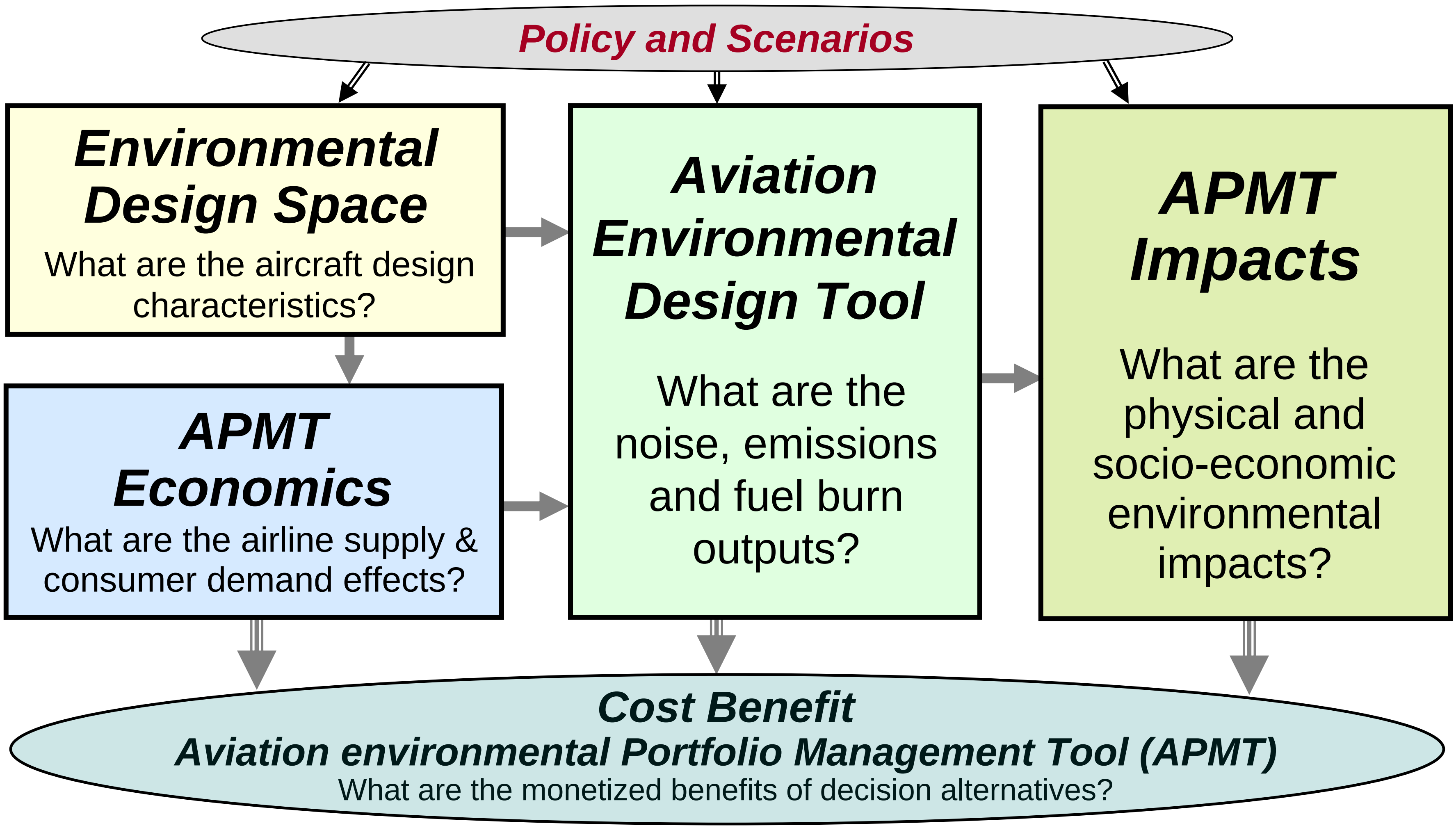
Assessment of the Aviation Environmental Design Tool (AEDT)

Presented to: ATM2009

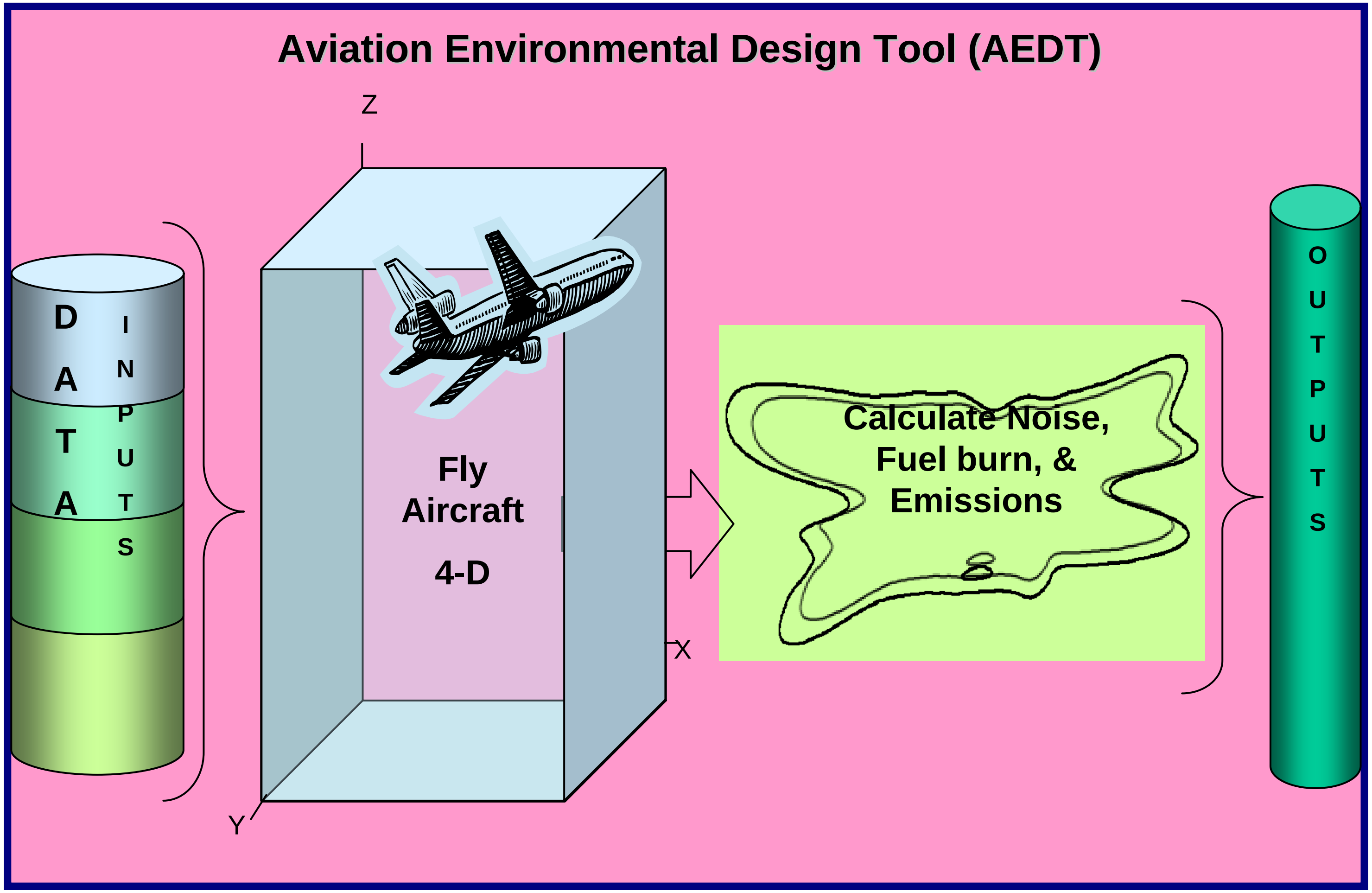
By: Rebecca Cointin

Date: June 29, 2009

Aviation Environmental Tool Suite



AEDT Overview



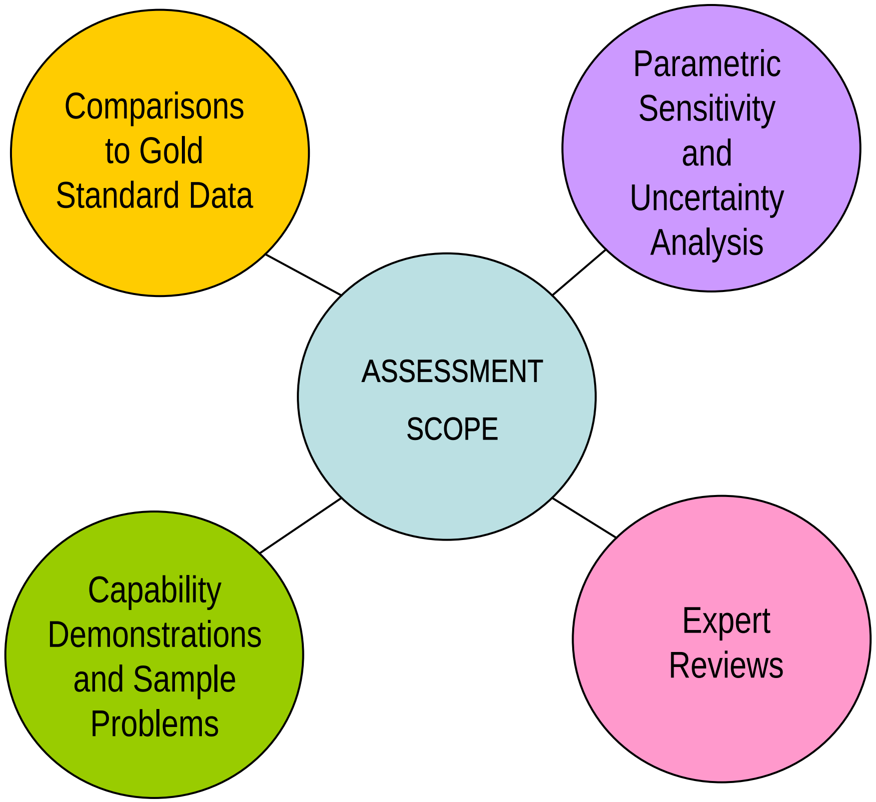
Outline

- Building Confidence in the Tool
- Expert Review
- Capability Demonstrations and Sample Problems
- Comparison to Gold Standard Data
- Formal Parametric Sensitivity and Uncertainty Analyses

Building Confidence in the Tool

Why Assess AEDT?

- Understand sensitivities of output response to uncertainties in input parameters/assumptions
- Identify gaps in functionality
  - Identify high-priority areas for further research & development
- Contribute to the development of external understanding of AEDT
- Inform decision makers



Expert Review

- **Development initiated by series of stakeholder reviews conducted by National Academy of Science's Transportation Research Board**

- **Design Review Group – set of expert users of the FAA legacy regulatory tools**
  - Review model capabilities
  - Provide input and advice on development

- **International Civil Aviation Organization's Committee on Aviation Environmental Protection**
  - Review and documentation of model capabilities, including an initial assessment of model readiness relative to anticipated CAEP analyses;
  - Rigorous, aircraft performance segment-by-segment comparison of AEDT with the European Commission's Standard Doc 29 3rd Edition to ensure compliance

Capability Demonstrations and Sample Problems

- NOx Stringency Analyses (Environmental Effects of NOx output restrictions on aircraft)
- Analyses to show Environmental Benefits of Reduced Vertical Separation Minimums
- Optimized Profile Descents/Continuous Descent Arrival Analyses
- Yearly Emission Inventories
- Future aircraft technology Analyses
- Global Fuel Burn Analyses

Comparison to Gold Standard Data

- **Computer Flight Data Recorder Information and Airline reported fuel burn data**
  - Airline reported fuel burn has been used to assess the performance module

- **Boeing's Climb out Program**
  - the performance tool (used for low speed terminal area) has been used to compare to the modeled performance
  - has led to a change in fuel burn computation methodology, for the Boeing fleet, within AEDT

- **Leveraging legacy tool validation through Society of Automotive Engineers A-21 Committee**
  - Compare legacy computations to those performed by AEDT modules

Formal Parametric Sensitivity and Uncertainty Analysis - Process

- **Used to understand sensitivities of output response to uncertainties in input parameters/assumptions and identify gaps in functionality.**

- **Allows the decision maker to understand where the uncertainty in the answer lies.**

- **Five Step Process**

  Step 1: document assumptions and limitations of the model

  Step 2: create an assessment plan stating factor distributions and type of analyses to be performed,

  Step 3: conduct uncertainty analysis,

  Step 4: conduct sensitivity analysis,

  Step 5: present results

Document Assumptions and Limitations

- **Describes the assumption**
  - what it means, where it enters the module/database, and what modules/algorithms/databases it affects.

- **Describes the impacts of the assumption in terms of module validity**
  - references to previous validation work,
  - description of what it will take to assess the validity of an assumption in cases where validation efforts have not taken place

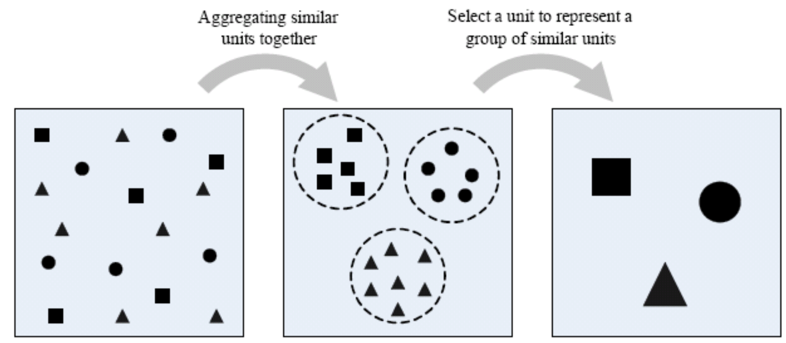
- **Determines implications for applicability of the module in terms of known policies and other uses for AEDT**

Conduct Uncertainty and Sensitivity Analysis

- **"How do uncertainties in model factors propagate to uncertainties in model outputs?"**
- Answer determined by using:
  - Monte Carlo Simulation:
    - Used to propagate uncertainty from inputs and assumptions to outputs in support of decision-making
    - Primary method used in both distributional and global sensitivity analysis
  - Global Sensitivity Analysis (GSA):
    - Used to quantify input contributions to output variability
    - Allows us to identify biggest hitter inputs and direct future research efforts (ranking of factors)
  - Distributional Sensitivity Analysis (DSA):
    - Used to quantify the effects of shifting distribution mean values, changing distribution variance, and using different distributions
    - Determines if the distribution used for the factor is contributing to its ranking

Surrogate Modeling

- **Less expensive, (often) lower-fidelity model that represents the system input/output behavior**
- **For AEDT, the surrogates are Hierarchical models e.g. coarser grid, aggregation**
- **Why surrogates?**
  - If one analysis takes 1 minute, then a Monte Carlo simulation with 10,000 samples takes 10,000 minutes = 7 days
  - AEDT modules take much longer than one minute
- **How do we assess the surrogate quality?**
  - We have employed rigorous mathematical analysis tools to construct and assess the quality of the emissions module surrogate, so that surrogate modeling estimates have quantified confidence intervals



Assessment First Round Caveats

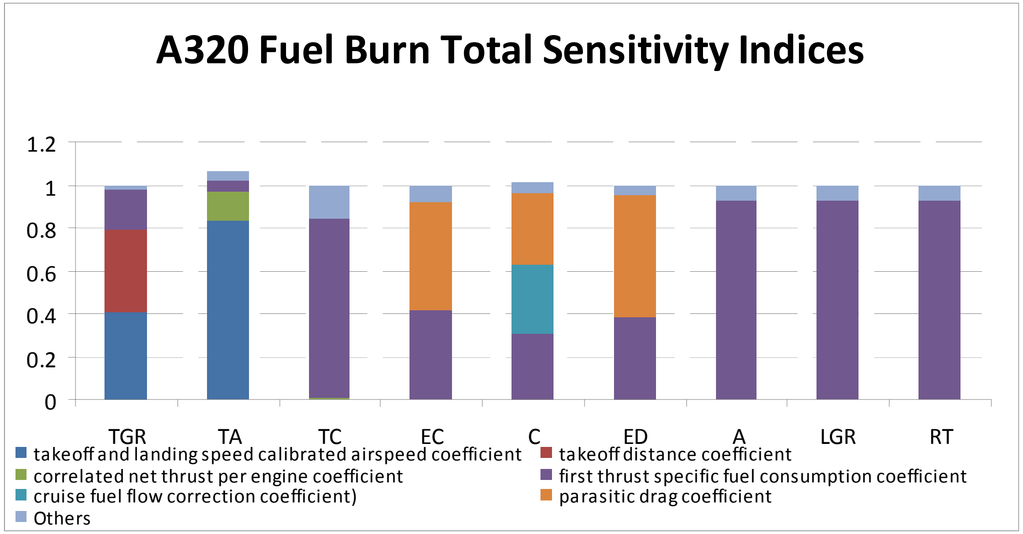
- **Was a mathematical process**
- **Looking to create repeatable process**
- **Results are from individual module assessments and may not reflect what is found when modules are assessed together**
- **Results presented are first step in a longer program and are a small picture of the total assessment answer**

Present Results – Performance Module – Global Sensitivity Analysis

- Certain flight modes have little variability associated with the fuel burn output (A & LGR), while other modes have substantial variability associated with the output (TC & TGR)
- Confirms need to assess the APM by looking at several different aircraft types rather than a single representative type

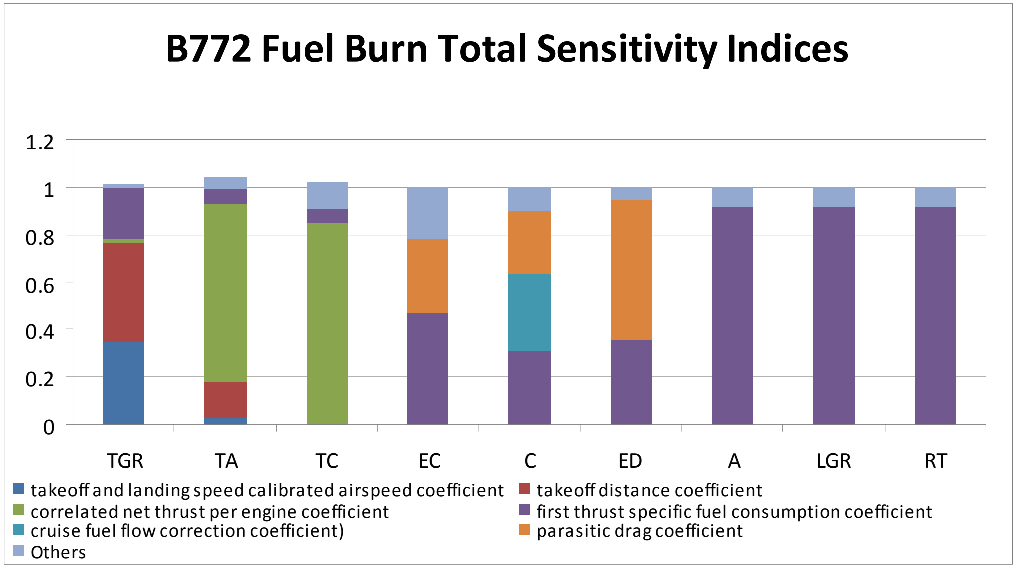
	A320		B777-200	
	Fuel Burn mean (kg)	Fuel Burn Variance (kg^2)	Fuel Burn mean (kg)	Fuel Burn Variance (kg^2)
Takeoff Ground Roll (TGR)	110.94	105.36	320.09	3798.07
Takeoff (TA)	42.51	90.25	130.60	530.08
Climb Out (TC)	62.74	155.42	120.34	1014.02
En-route Climb (EC)	36.30	5.26	139.24	68.91
Cruise (C)	294.01	407.81	105.56	49.09
En-route Descent (ED)	38.73	6.29	165.67	118.81
Approach (A)	1.24	0.00	2.94	0.02
Landing Ground Roll (LGR)	1.47	0.00	1.11	0.00
Reverse Thrust (RT)	19.36	0.67	21.17	0.83

Present Results – Performance Module – Total Sensitivity Indices



- Few inputs contribute to variability in the fuel burn output
- Research should be focused on the first thrust specific fuel consumption coefficient if decisions will be made for the approach (A) mode, because it contributes the most to fuel burn variability

- For climb out (TC) The first thrust specific fuel consumption coefficient contributes the most to the fuel burn variability for the A320, but for the B772, it’s the correlated net thrust for each engine coefficient



Present Results – Acoustic Module – Global Sensitivity Analysis

- Noise-Power-Distance curves and atmospheric temperature inputs contributed the most to aggregated SEL variation.

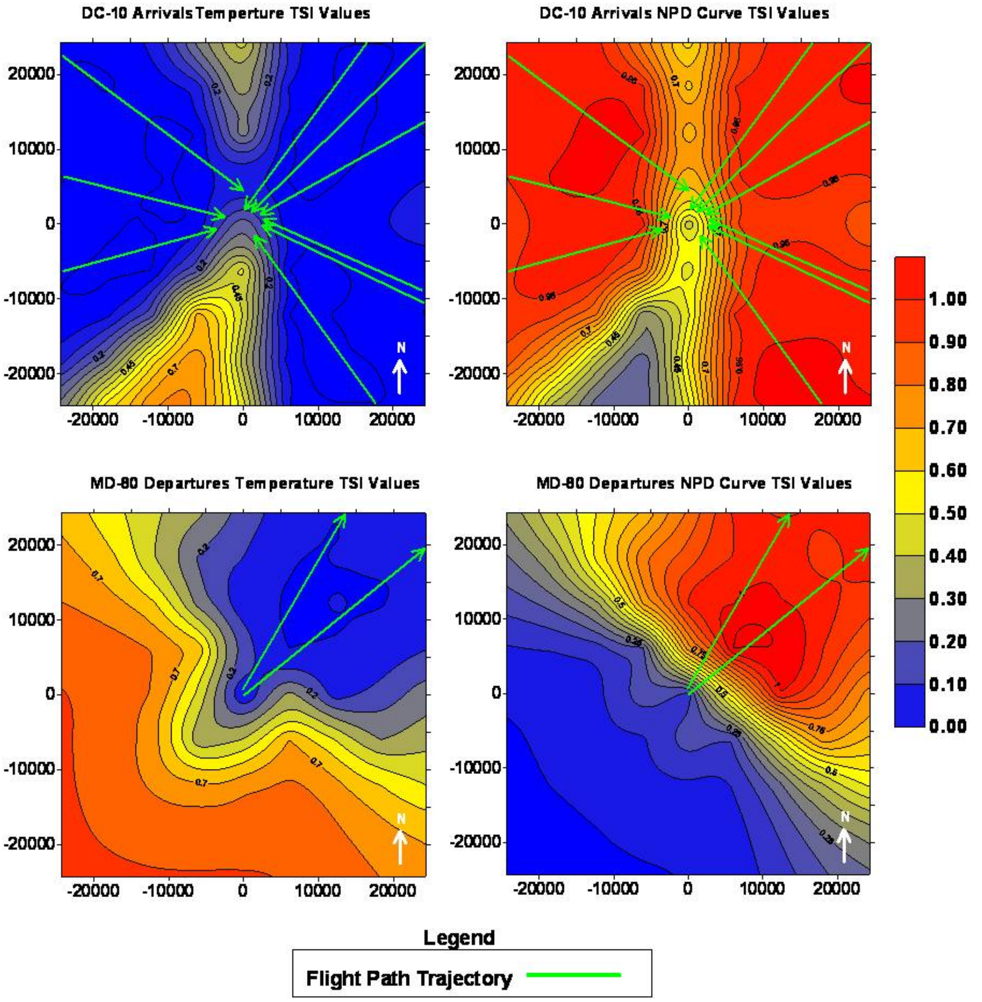
- Pressure and humidity had minor contributions to aggregated SEL variation

- Speed, thrust, duration, and bank angle all had effectively zero contribution to the variability of the output.
  - Thus inputs from the performance module that affect these acoustic module inputs would not need to be considered in the acoustic module development efforts aimed at reducing the variation in aggregated SEL estimates.

Present Results – Acoustic Module – Total Sensitivity Indices

- Noise-Power-Distance curves have a substantial impact on output variation for grid points in close proximity to the flight path trajectory

- Temperature has a substantial impact on output variation for grid points in areas further away from the flight path trajectory

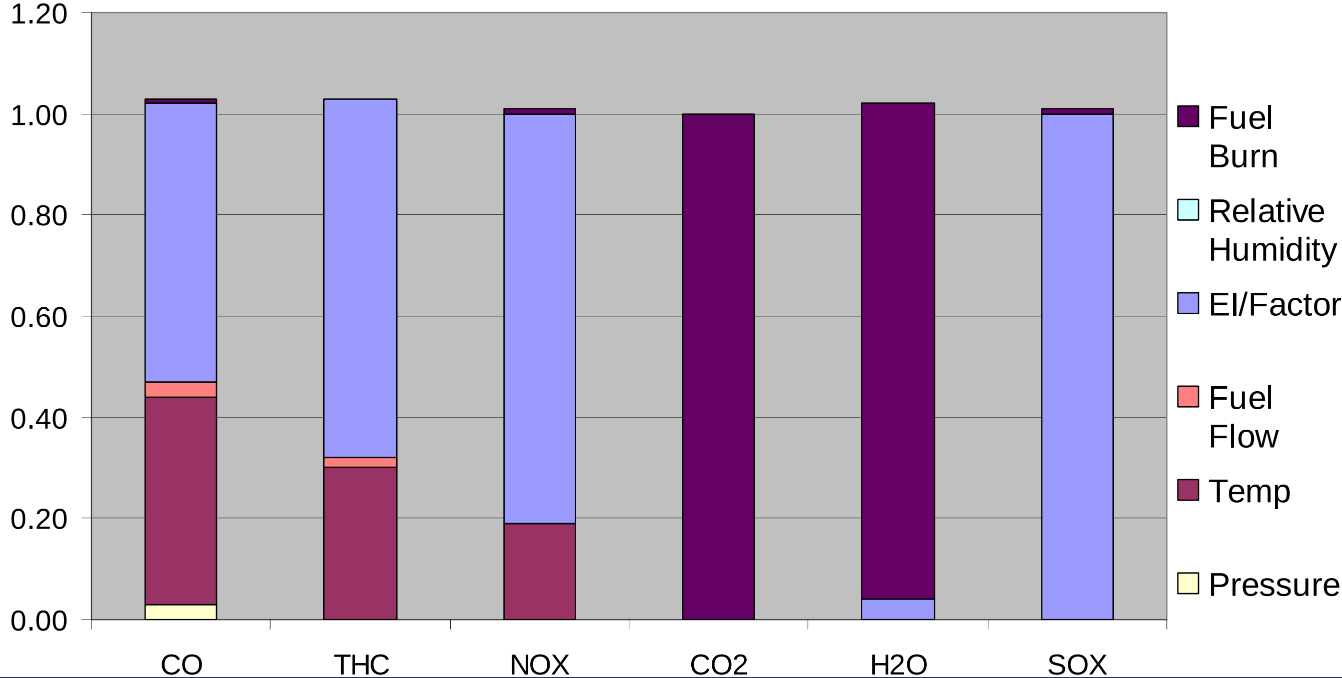


Present Results – Emissions Module – Total Sensitivity Indices

- For policy decisions for SOx, NOX, THC, and CO, it is important to understand that the Emission Indices and Factors contribute to the uncertainty of the results. If a decision is being made based on one of these numbers, it is important to understand that there is a level of uncertainty in the answer.

	Mean (kg)	Variance (kg2)
CO	6,612	213,680
CO2	6,277,601	468,905,000
H2O	2,455,553	74,464,806
HC	951	66,217
NOx	34,183	3,668,808
SOx	2,120	12,219

- To get more accurate results for CO_2 and H_2O, research on better ways to compute fuel burn is needed.

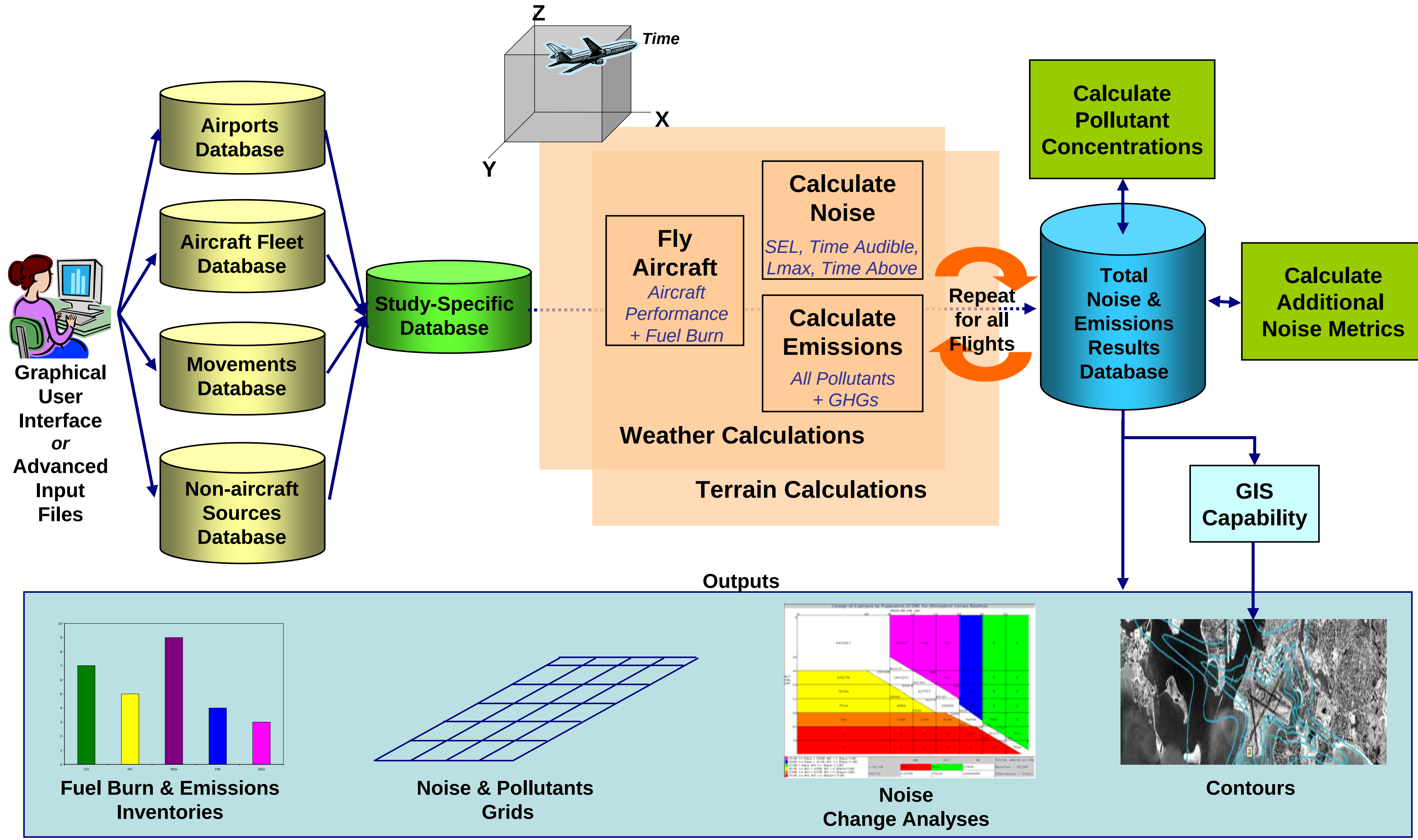


Conclusions

- Assessment is an important part of the development process of a tool
- Surrogate models are needed during the assessment process
- Assessment of the individual components of AEDT will help inform future research, development, and assessment
- Next step is to perform assessment of the system of modules of AEDT

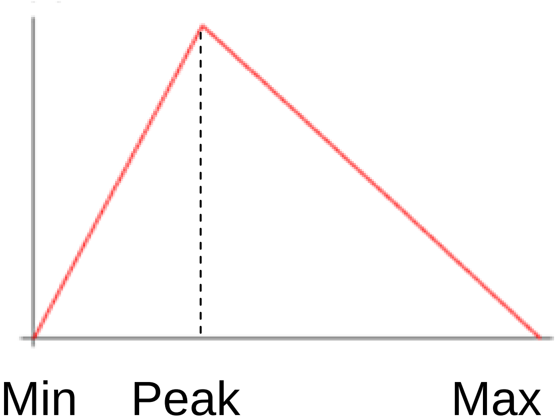
BACK UP SLIDES

AEDT Overview

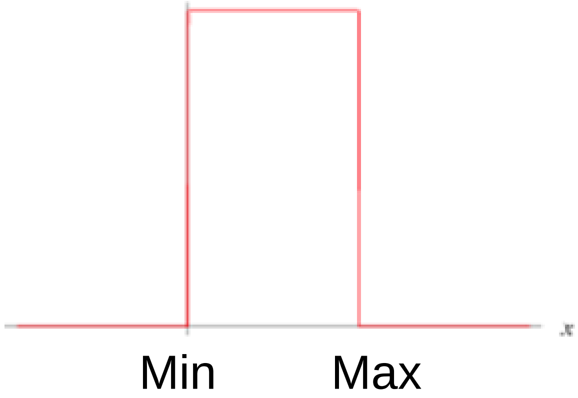


Probability Distributions

- **Triangular**
  - Three points: Minimum, Maximum, and Peak
  - Presented as multipliers to the input variable
    - (minimum multiplier, 1.0, maximum multiplier)



- **Uniform**
  - Two points: Minimum and Maximum
  - Distributes values equally between the minimum and maximum points
  - Presented as offset to the input variable
    - (minimum offset, maximum offset)

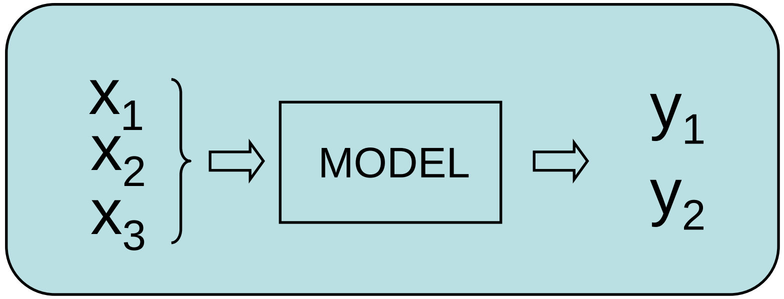


Monte Carlo Simulation (MCS)

Deterministic Simulation

Inputs

One value for each factor (x_1, x_2, x_3)



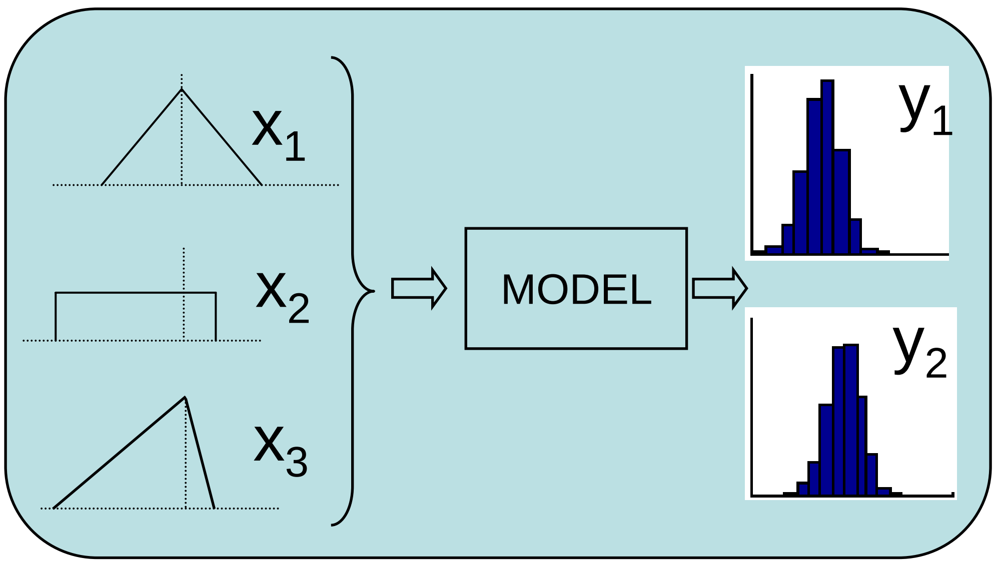
Outputs

Model computes a value for each output (y_1, y_2)

Monte Carlo Simulation

Inputs

1. Define a probability distribution for each factor (x_1, x_2, x_3)
2. Draw a random sample for each factor
3. Goto #2 and repeat

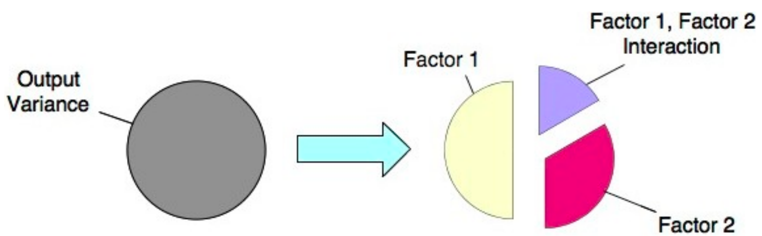


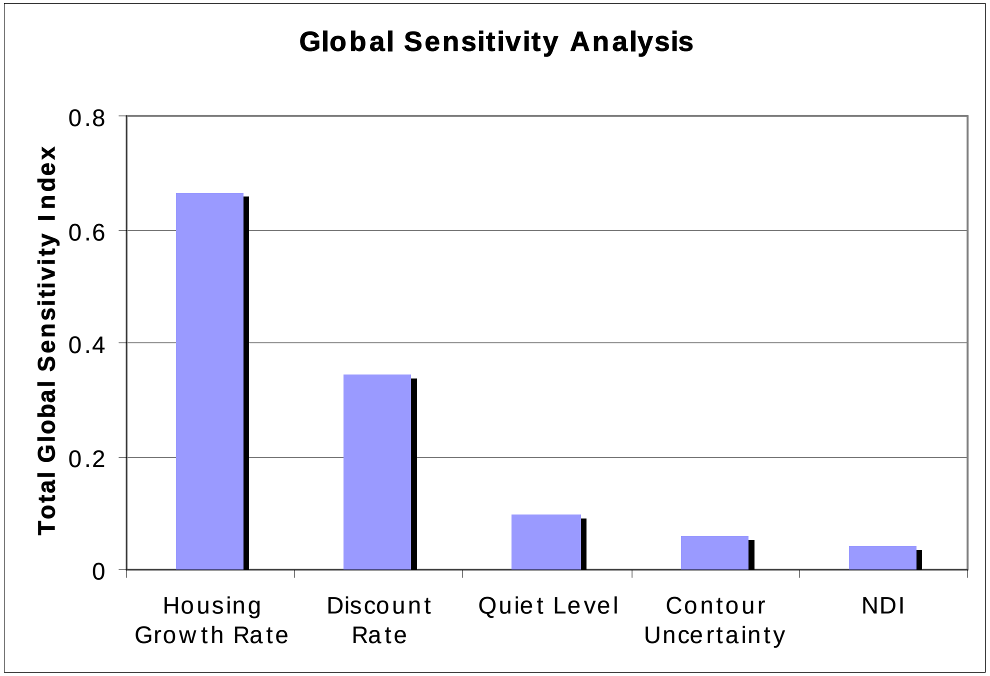
Outputs

1. Model computes the outputs (y_1, y_2) for each random draw of factors
2. Results in probability distributions for each output that may be used to compute means, standard deviations, and confidence intervals

Global Sensitivity Analysis (GSA)

- Determines how factors contribute to output uncertainty
- Calculates an averaged global contribution to output variance for each factor (including interaction between factors)
- Sobol' method used to compute the average global contribution by computing a total sensitivity index (TSI)
- Allows us to identify biggest hitter inputs (larger a factor's TSI, larger the impact on the output variance) and direct future research efforts





Distributional Sensitivity Analysis (DSA)

- Determine sensitivity of the output response to an individual factor
- For a single factor, distribution is altered (shift mean, increase standard deviation, change distribution type, etc) while all other factor distributions are held constant.
- The Analysis results can be shown in a tornado chart that shows the sensitivity of the output response to changes in input distributions.