MIT
International Center for
Air Transportation

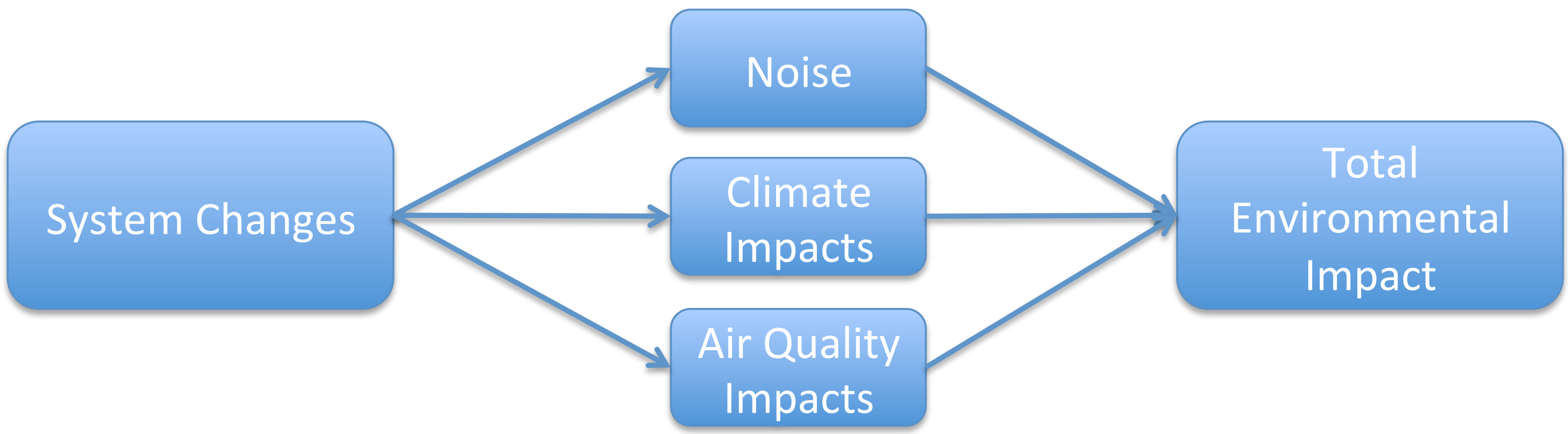
Tools for Rapid Aviation Environmental Assessment

Morrisa Brenner
Collaborators: Cal Brooks, Jacqueline Thomas, Luke Jensen, Sandro Salgueiro
PI: Prof. R. John Hansman

August 1, 2016

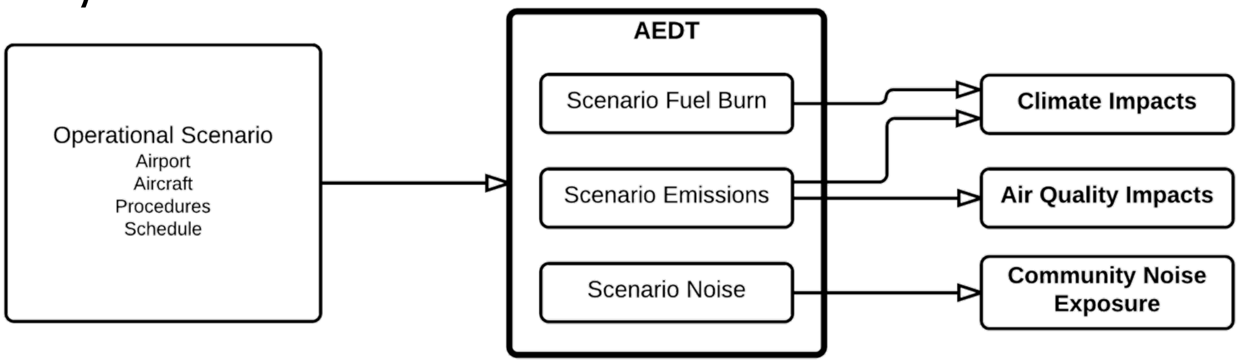
Project Motivation

- Expected growth in demand for air transportation requires novel changes to improve system capacity
  - Aircraft technology improvements
  - Air transportation procedural changes
  - New policy implementation
- Understanding tradeoffs between key environmental issues is critical to effectively selecting changes
  - Noise: community complaints have caused rollback of new procedures at some airports
  - Climate impacts: recently gained importance with the establishment of the first ever global CO_2 emissions standard in early 2016
  - Local air quality impacts: of aviation have been less prominent but continue to be concerns to community
- Effectively evaluating these tradeoffs for a large number of potential solutions requires rapid and flexible methods for approximating these impacts



Aviation Environmental Analysis Tools

- **Current state-of-the-art:** FAA Aviation Environmental Design Tool (AEDT)



  - Only supports analysis using the existing aircraft fleet
  - Each detailed scenario is set up and evaluated independently
    - Scenarios include a schedule of specific aircraft flying specific trajectories on a specific runways at specific airports

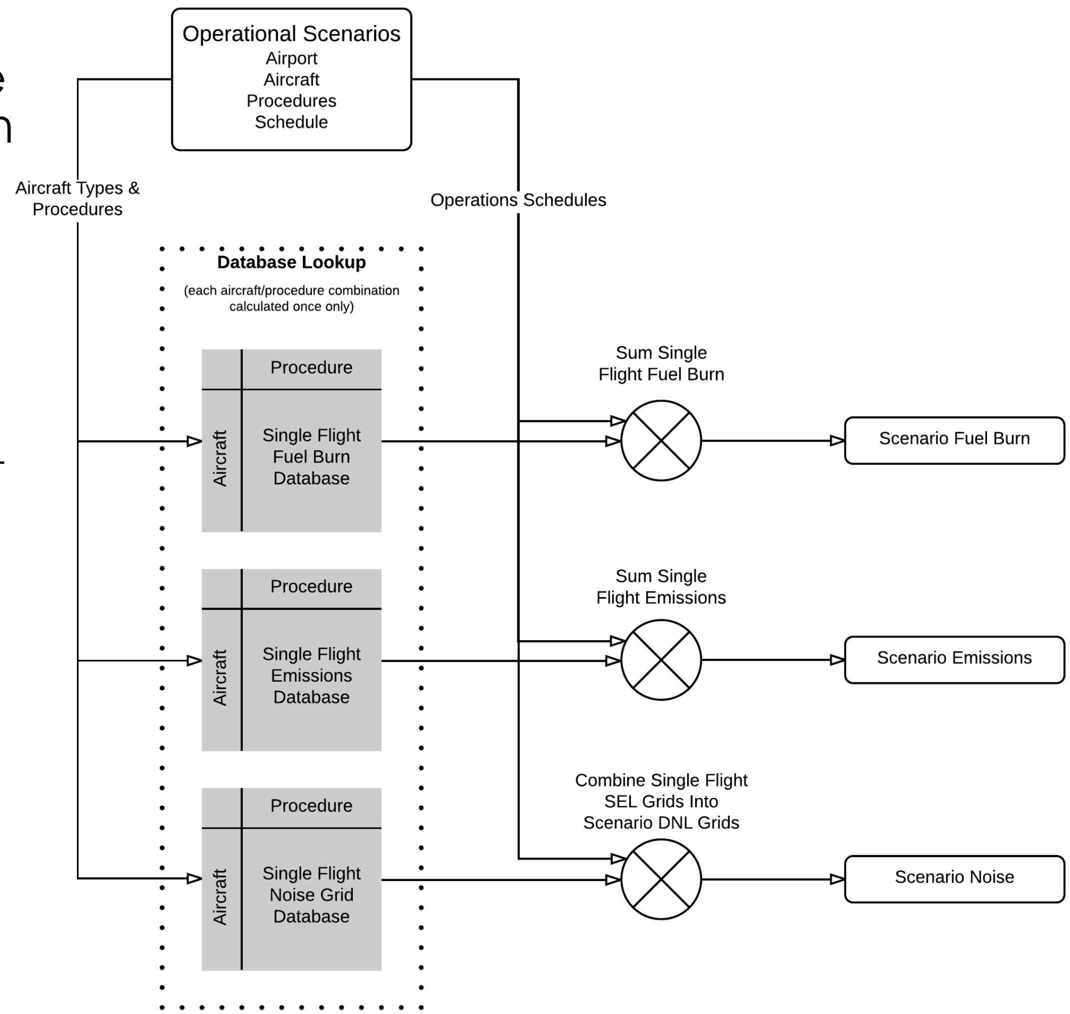
- **Our objective:** develop tools to…
  - Analyze scenarios that include new aircraft types
  - Rapidly conduct preliminary analysis of the environmental footprints for many scenarios

Analysis Approach

- Leverage databases of single-flight fuel burn, emissions, and noise to rapidly combine system-level impacts for multiple operational scenarios using both new and existing aircraft types

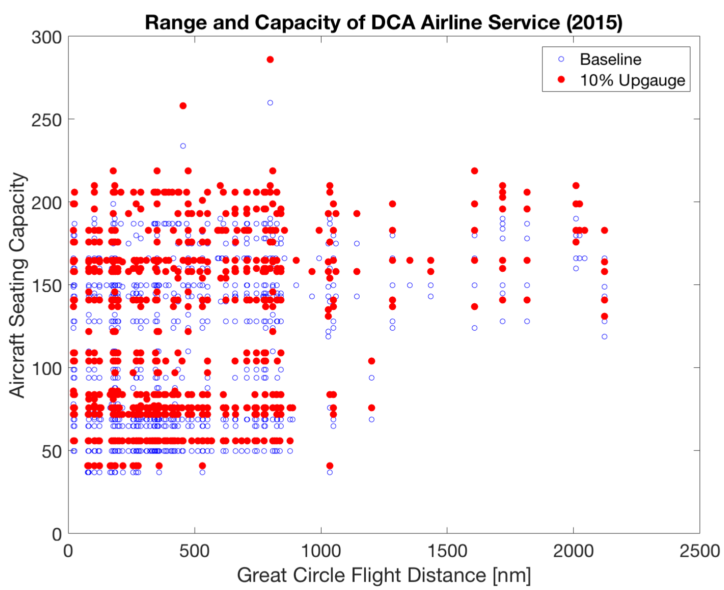
- Database information is stored by aircraft type and procedure flown
  - Procedures: guidelines for approach and departure paths at airports

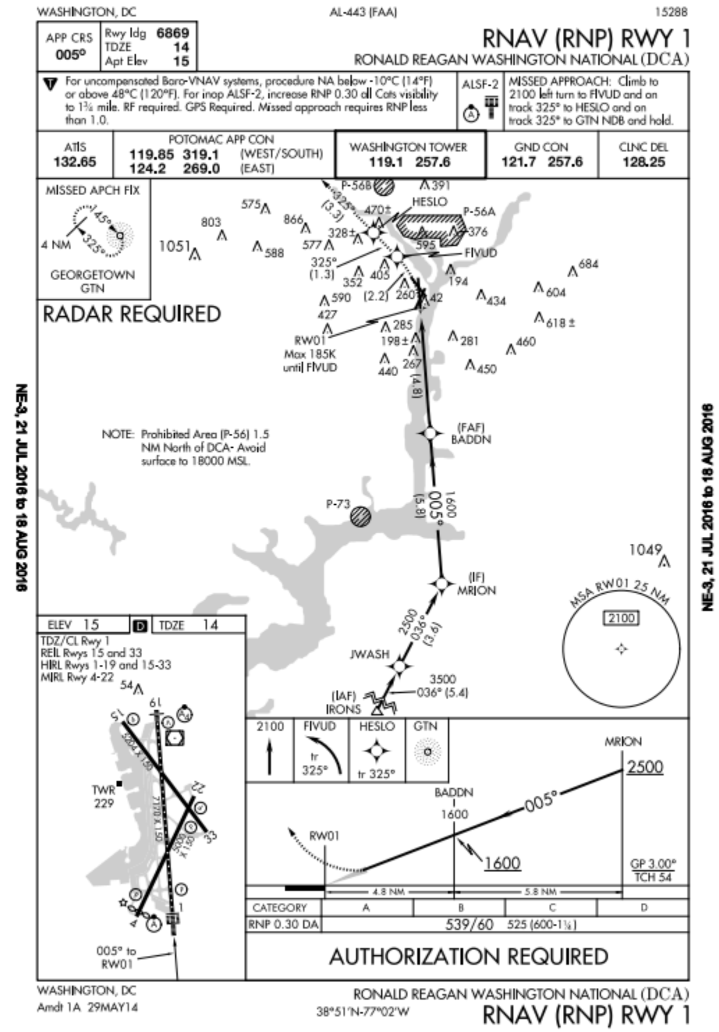
- Schedules used to combine single flight impacts to get full scenario impacts
  - Schedules include the number of aircraft of each type flying each procedure at a given airport during a given time of day



Test Case: DCA

- Defined a sample problem to test the effectiveness and validity of the new approach
  - Examining the impact of increasing DCA passenger throughput by increasing the capacity of all aircraft by 10%
  - Baseline fleet of seven representative aircraft types
  - Future fleet of seven aircraft, each 10% larger than baseline counterpart
  - Analyzing both fleets with on the same procedures with analogous schedules for comparison
- In progress, but preliminary results included in this presentation

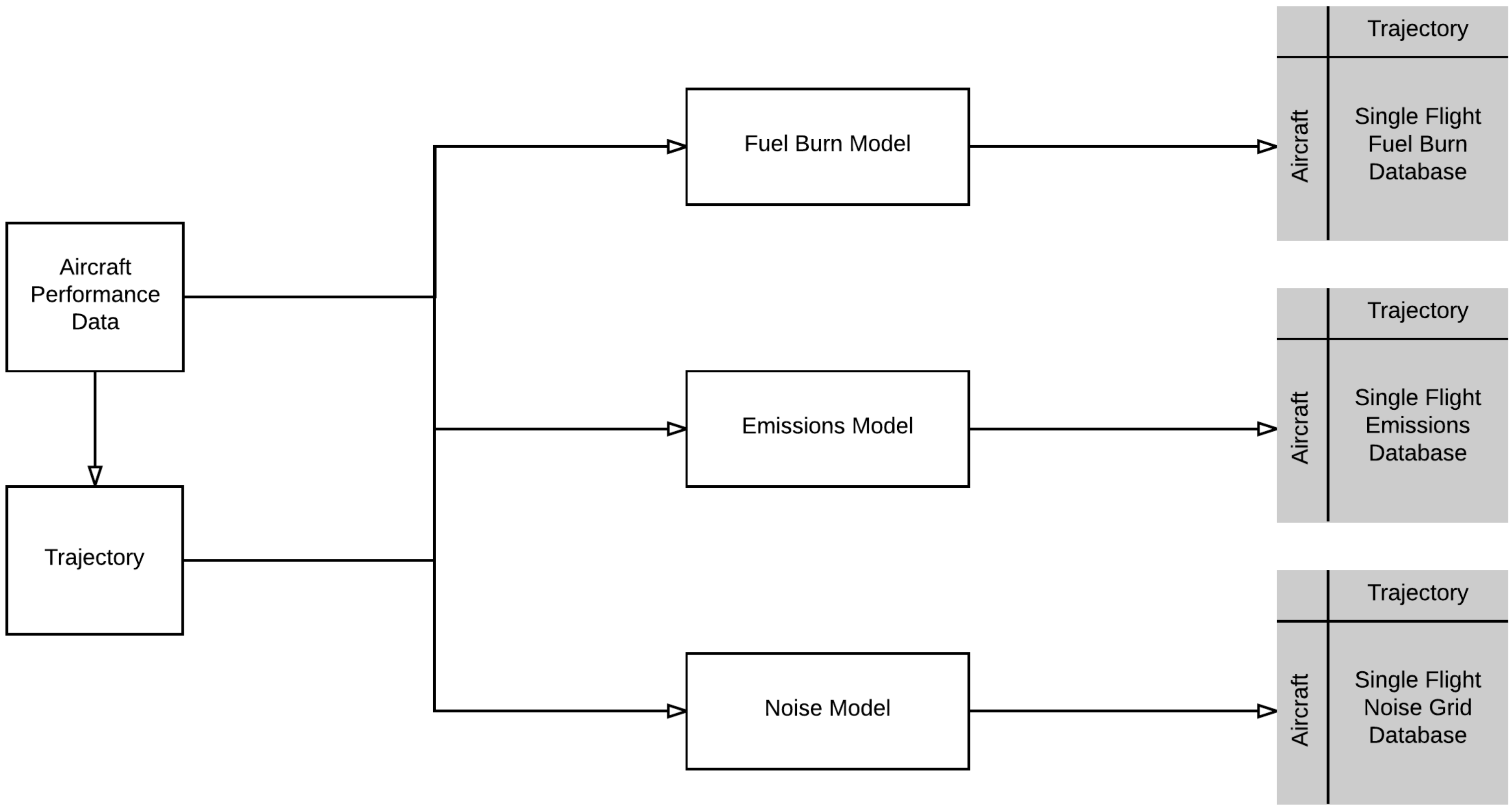




Example: DCA Runway 1 RNAV Approach

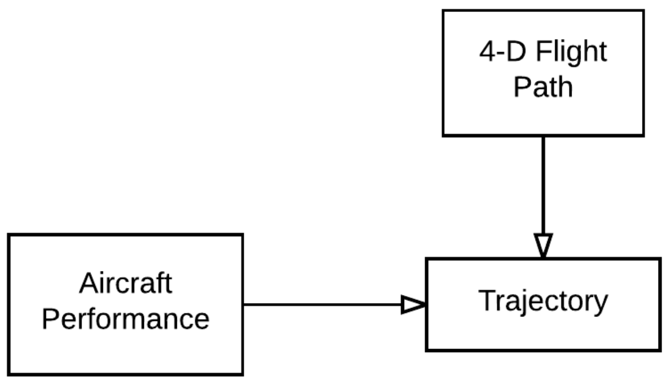
Building Single Flight Databases

- Each fuel burn, emissions, or noise data set is specific to an aircraft type and trajectory
- Fuel burn, emissions, and noise calculation methods require aircraft performance data and trajectory



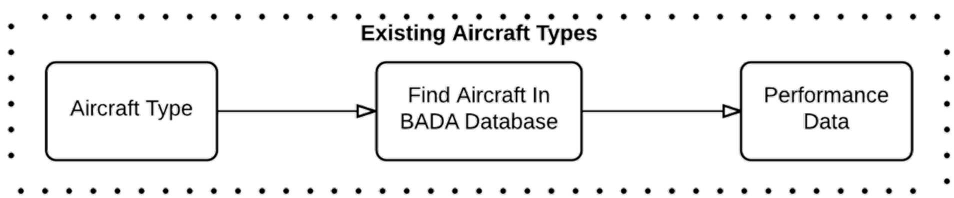
Aircraft Performance and Trajectories

- Aircraft performance data needed to calculate trajectories
- Trajectory calculation also require 4-D aircraft flight path, including lateral position, altitude, and time

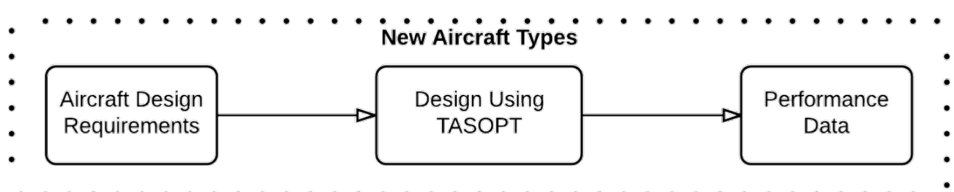


Aircraft Performance

- Detailed aircraft performance data is needed for both trajectory definition and environmental calculations
- We use two data sources
  - For existing aircraft types: data exists in BADA
    - Industry-standard Base of Aircraft Data, developed by Eurocontrol
    - Aircraft performance calculated from manufacturer-supplied performance coefficients using physics principles



  - For new aircraft types: aircraft generated using TASOPT
    - Transport Aircraft System OPTimization, developed by Prof. Mark Drela at MIT
    - Physics-based model that calculates engine, airframe, and aerodynamic performance parameters for new aircraft from basic mission requirements (i.e. payload and range)

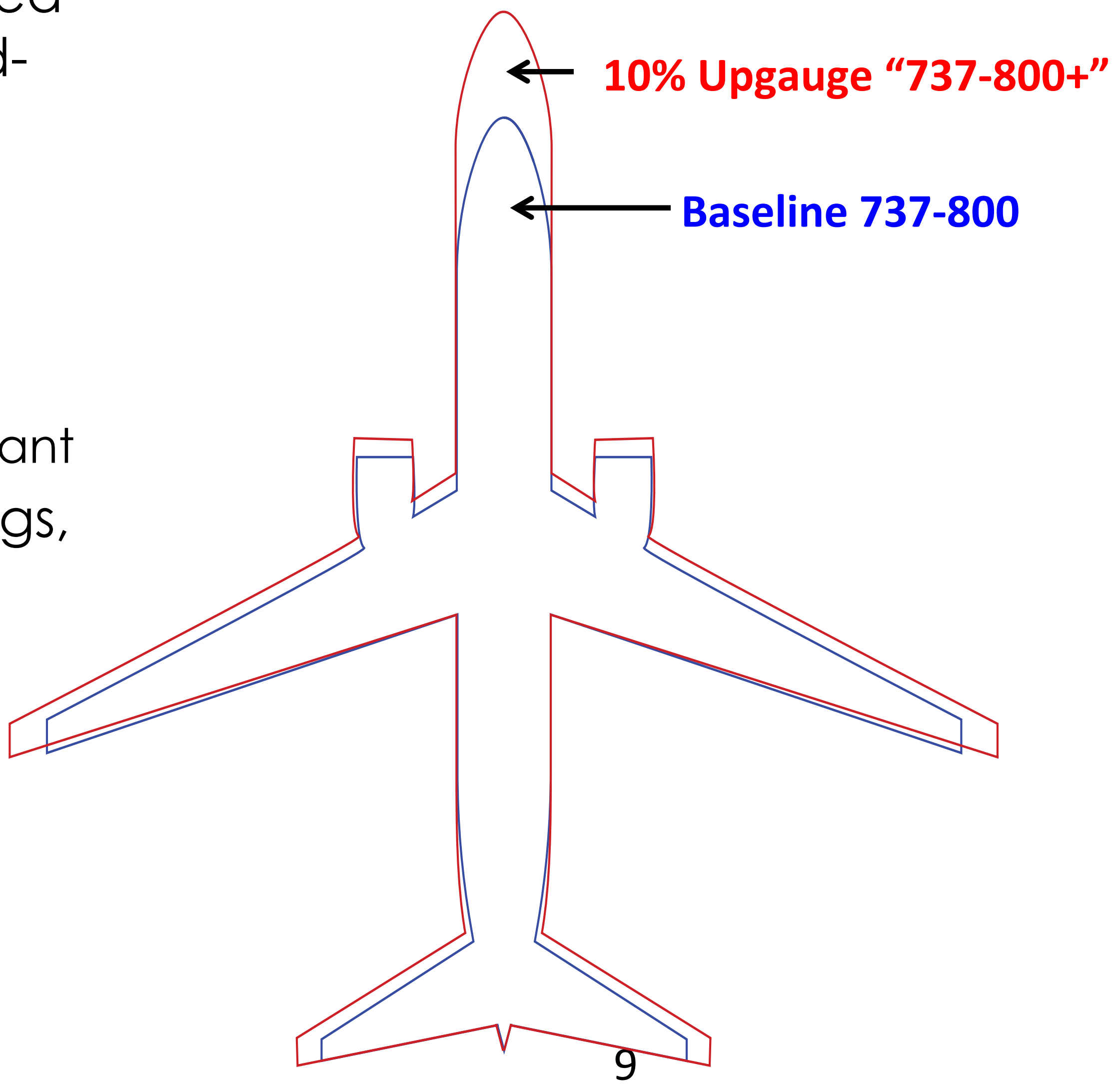


Example TASOPT Aircraft

- Upgauged fleet generated using TASOPT constrained-optimization approach
  - Floor area and payload increased by 10%
  - Range held constant
  - Structural and engine technologies held constant
- TASOPT sizes engines, wings, and tail for new aircraft

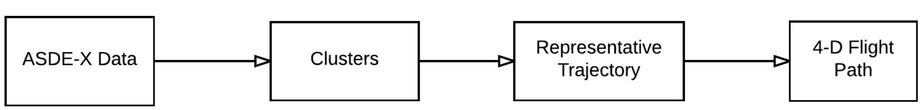
- Baseline 737-800 performance data also available in BADA

TASOPT-Generated Planforms



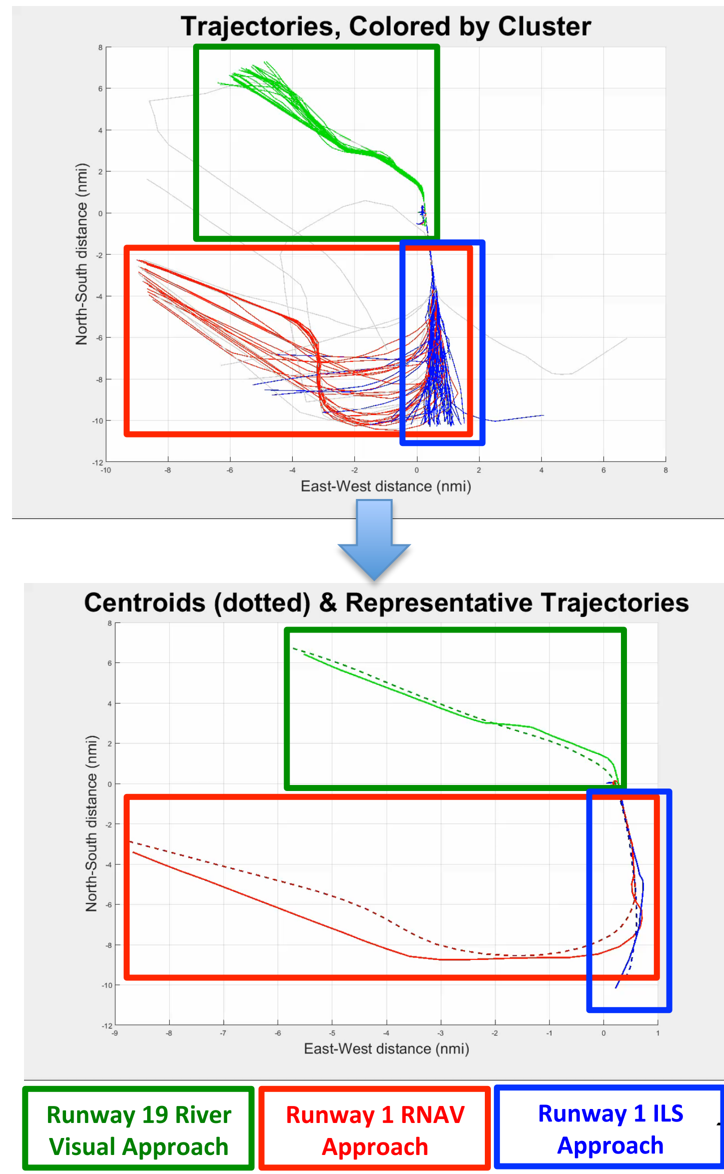
4-D Flight Paths

- Representative 3-D position and time data is needed to define to what points the what points the flight trajectory needs to be fit
- Flight paths for existing procedures can be created from historical ASDE-X data
  - High-rate, high-resolution flight position data near major airports
  - Use data clustering techniques to define centroid trajectories
  - Select representative trajectory close to centroid to ensure selected flight path is realistic



- Notional flight paths can also be developed for future procedures

Example ASDE-X Data Set: DCA Approaches

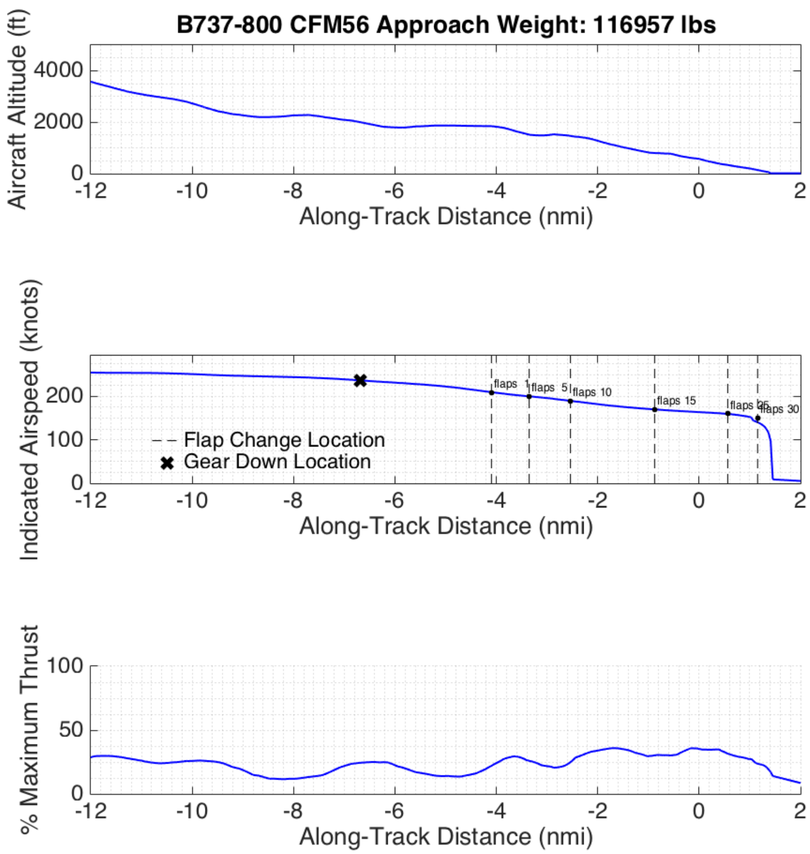


Defining Trajectories

- Trajectory includes
  - 4-D Flight path
  - Speed
  - Thrust
  - Flap/Gear configurations

- Trajectory calculation needs to match aircraft performance capabilities to the required flight path
  - Thrust, glideslope, or speed for each flight segment

- Calculating the trajectory therefore requires:
  - Aircraft performance data
  - 4-D flight path



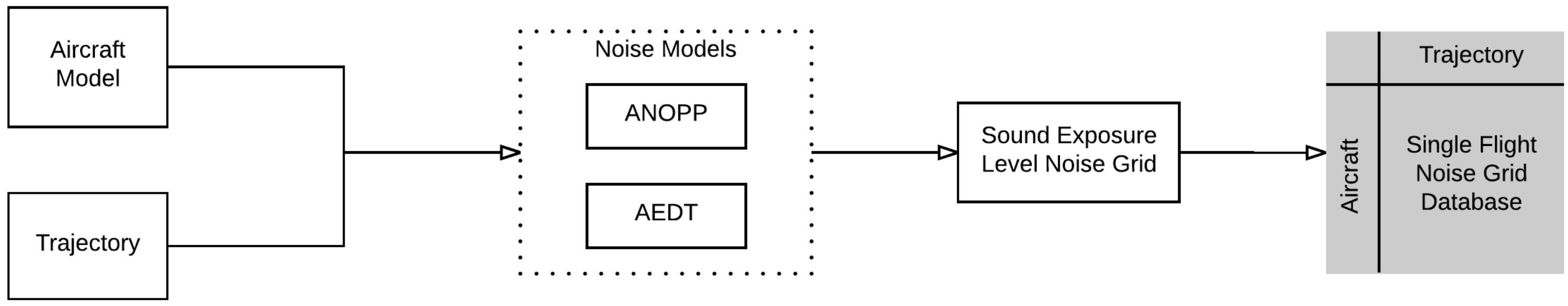
Example Trajectory
737-800, DCA Runway 1 RNAV Approach

Calculating Single Flight Noise

- Calculating noise requires:
  - Flight Trajectory
  - Detailed aircraft sizing and performance data

- Two available noise models
  - AEDT: current FAA standard for existing aircraft, but does not account well for high-lift device noise
  - ANOPP: physics-based noise model that accounts for a greater number of noise sources (including airframe noise) developed by NASA

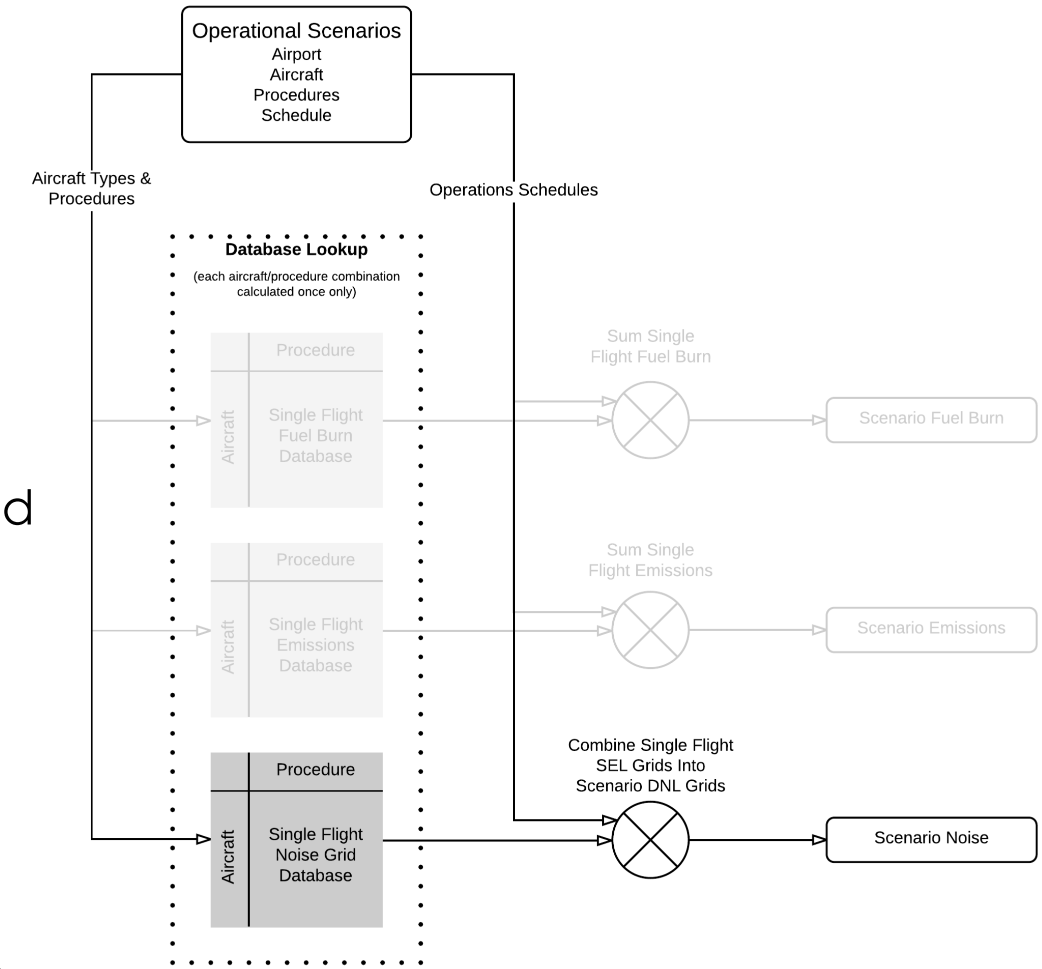
- Output of both models is a grid of sound exposure levels (SEL) at ground level



Calculating System Noise

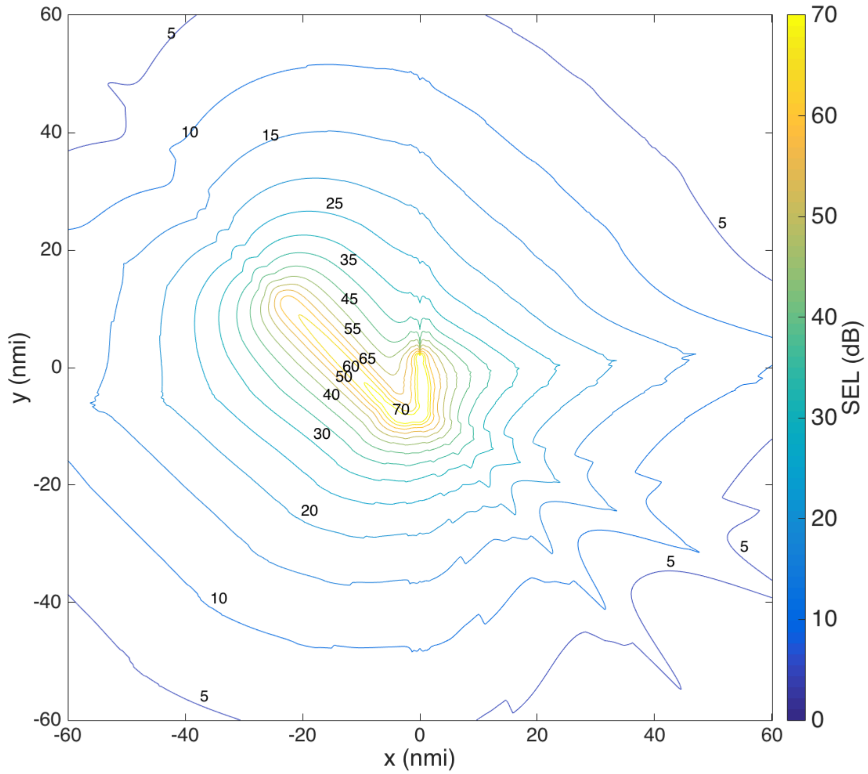
- Traditional approach recalculates each SEL grid every time data is generated for a new scenario
  - Computationally intensive, especially for higher fidelity models like ANOPP

- New approach calculates each SEL grid only once
- SEL grids for the aircraft types and procedures used in the scenarios under analysis pulled from database
- SEL grids combined logarithmically to generate system Day-Night Level (DNL) noise grids
  - Standard metric used for regulatory noise analysis
  - Averages the impact of each flight over the course of a day
  - Penalty applied to all nighttime operations

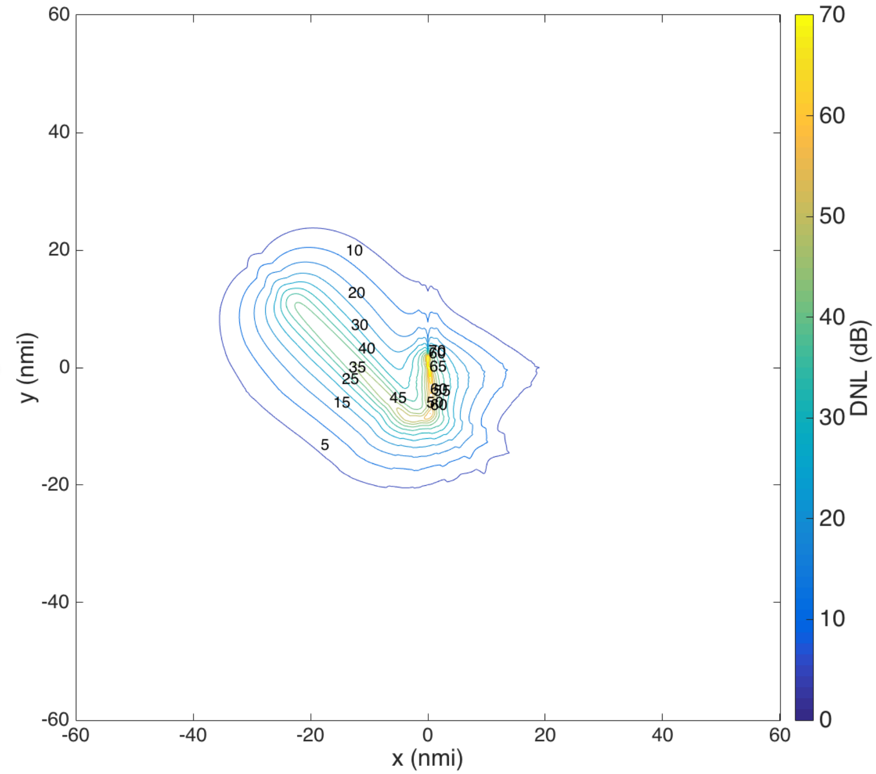


Preliminary Example Noise Buildup

Single Flight SEL Contours



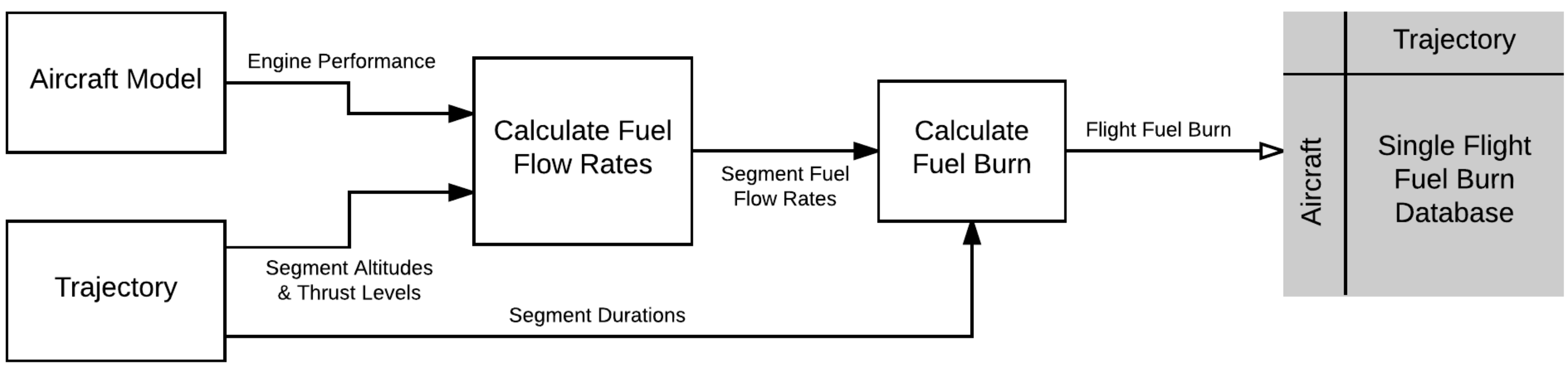
DNL Contours: 400 daytime flights



Preliminary Example Analysis
737-800, DCA Runway 1 RNAV Approach

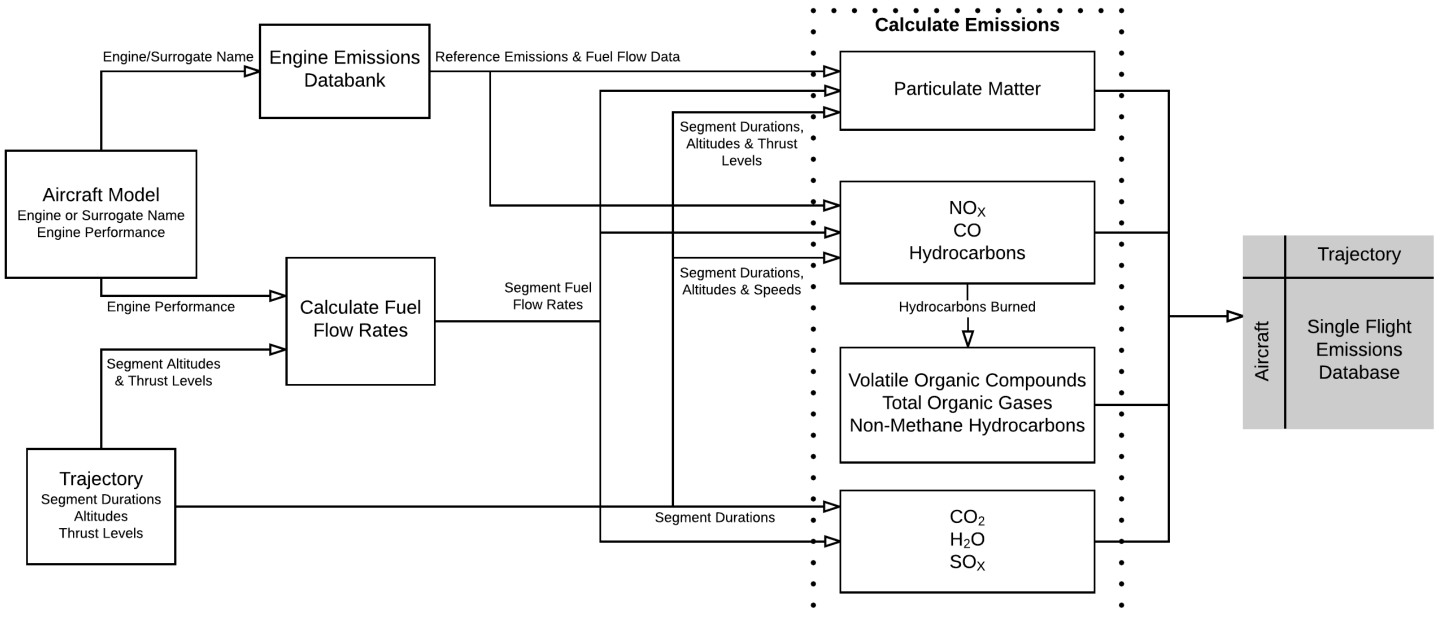
Calculating Single Flight Fuel Burn

- Calculating fuel burn requires:
  - Flight Trajectory
  - Engine performance data



Calculating Single Flight Emissions

- Calculating emissions requires:
  - Flight Trajectory
  - Aircraft engine performance data
  - Engine emissions reference data: ICAO Engine Emissions Databank
    - Measured certification data for current engines
    - Using existing engine types as surrogates for new aircraft engines



Preliminary Example Single Flight Fuel Burn and Emissions

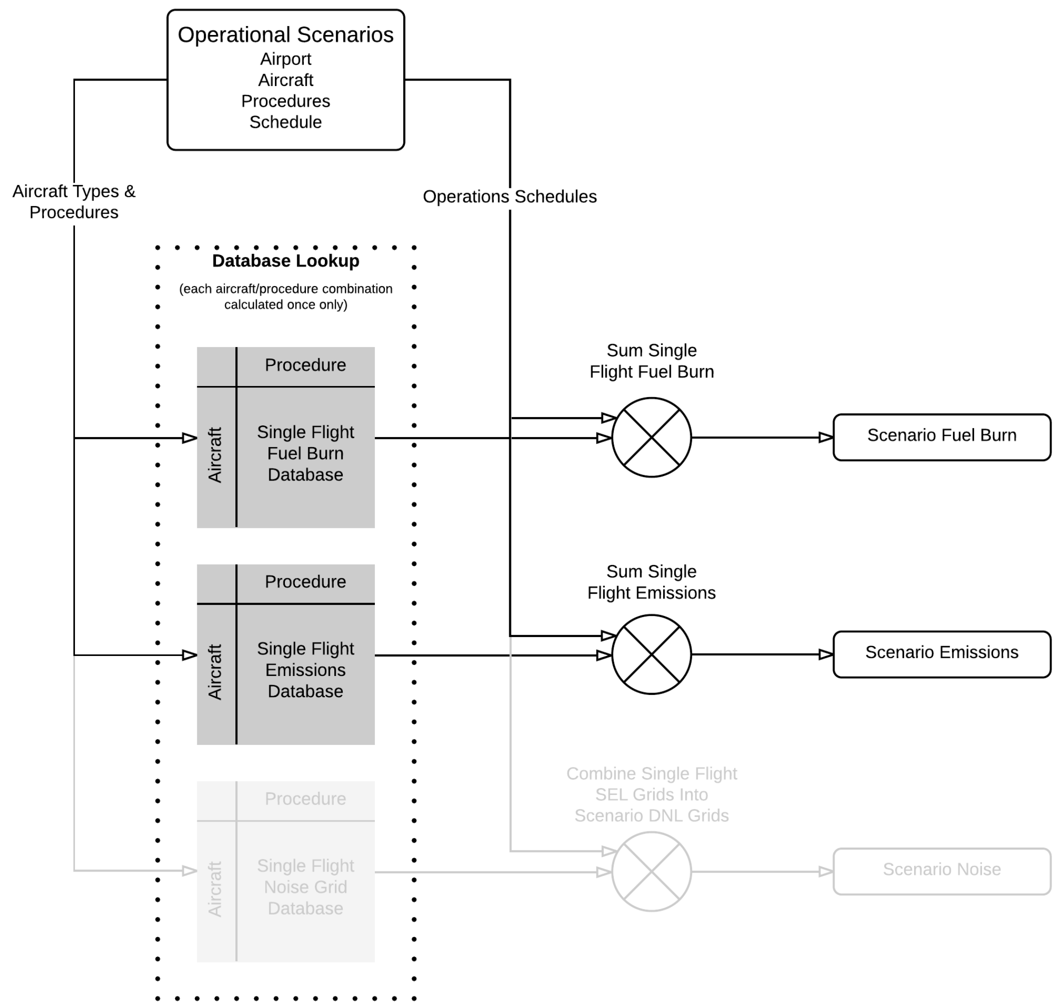
Output Category	Average Fuel Consumption and Emissions per Unit Fuel <= 3,000' AGL	Average Fuel Consumption and Emissions per Unit Fuel 3,000'-10,000' AGL
Fuel Burn	0.87 kg/s	0.92 kg/s
NO_X	4.3 g/kg fuel	4.6 g/kg fuel
Hydrocarbons	0.06 g/kg fuel	0.86 g/kg fuel
CO	2.4 g/kg fuel	3.9 g/kg fuel
Total Particulate Matter	0.02 g/kg fuel	1.07 g/kg fuel
SO_X	1.2 g/kg fuel	1.2 g/kg fuel
CO_2	3.2 kg/kg fuel	3.2 kg/kg fuel
H_2O	1.2 kg/kg fuel	1.2 kg/kg fuel
Total Organic Gases	0.06 g/kg fuel	1.0 g/kg fuel
Non-Methane Hydrocarbons	0.06 g/kg fuel	1.0 g/kg fuel
Volatile Organic Compounds	0.06 g/kg fuel	0.99 g/kg fuel

Preliminary Example Analysis
737-800, DCA Runway 1 RNAV Approach

Calculating System Fuel Burn and Emissions

- Traditional approach recalculates fuel burn and emissions for a trajectory every time data is generated for a new scenario

- New approach calculates data only once
- Data for the aircraft types and procedures used in the scenarios under analysis pulled from database
- Data added directly to generate system total outputs



Preliminary Example Fuel Burn and Emissions Buildup

Output Category	Single Flight Total Consumption and Emissions	System Total Consumption and Emissions
Fuel Burn	915 kg	366,088 kg
NO_X	4,021 g	1,608,238 g
Hydrocarbons	271 g	108,416 g
CO	2,584 g	1,033,707 g
Total Particulate Matter	306 g	122,454 g
SO_X	1,072 g	428,763 g
CO_2	2,888 kg	1,155,009 kg
H_2O	1,132 kg	452,851 kg
Total Organic Gases	313 g	125,354 g
Non-Methane Hydrocarbons	313 g	125,354 g
Volatile Organic Compounds	312 g	124,700 g

Preliminary Example Analysis
400 737-800, DCA Runway 1 RNAV Approach

Future Work

- Complete toolset integration
- Complete fleet development and analysis for DCA sample problem to validate toolset
- Compare results for baseline scenario with AEDT results for method validation
- Further develop noise methodology to allow for more rapid or flexible generation of SEL grids

Acknowledgements

- Other members of the ICAT team included Cal Brooks, Jacqueline Thomas, Luke Jensen, Sandro Salgueiro. They produced many of the results and tools presented here. They could not be at JUP to present their work on the project directly, but it was included to help explain the scope of the project.

Questions?