ASCENT Project 10

Aircraft Technology Modeling & Assessment

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Objective: Model and assess potential evolution of commercial airline fleet due to the introduction of future supersonic aircraft and how technology development could affect the environmental impacts of aviation (e.g., fleet-level fuel burn, emissions and noise). The effort will examine ***SST vehicle modeling (in support of CAEP Exploratory Study); fleet route simulation; fleet simulation, and AEDT supersonic modeling.***

Project Benefits: Provide an understanding of how introduction of new supersonic transports that could enter into commercial airline service and private use will affect fleet-wide fuel burn, noise and emissions.

Research Approach:

SST Vehicle Modeling:
- CFD based aero shaping; installed propulsion modeling; mission analysis; emissions and LTO noise analysis
- Perform design Mach trade study for three SST classes
- Model facsimile of OEM SST for CAEP E-Study

Fleet Route Simulation:
- Computing potential time savings per OD pair
- Computing value of travel time savings per OD pair
- Detailed SST aircraft performance on complex mixed missions

AEDT SST Modeling:
- Generate SST perf. data; aero and propulsion truth models
- Construct appropriate physics-rooted regressions to model drag, thrust, and fuel-burn, fit, and validate
- Develop implementation plan to incorporate into AEDT

Major Accomplishments (to date):

SST Vehicle Modeling: Completed 11 SSTs for design Mach trade study; completed 3 OEM vehicles; completed study on VRNS impact on climb out NOx; completed nvPM study

Fleet Route Simulation: Developed flexible route optimization tool; Completed future SST demand study where demand depends on vehicle; Support for CAEP E-Study

AEDT SST Modeling: Completed data generation and initial model development for ~7 SSTs; developed and implemented Python-based validation tool; setup engagement b/w OEMs & FAA

Future Work / Schedule: Revisit noise modeling assumptions for all vehicles based on feedback (11/2021), Investigate subspace optimization approach for aero shaping (12/2021); complete fleet simulations (12/2021); Refine SST regressions on all SSTs (12/2021); Validate regression approach for all SSTs (12/2021); Supersonic interdependency study (9/2022)

This research was funded by the U.S. Federal Aviation Administration Office of Environment and Energy through ASCENT, the FAA Center of Excellence for Alternative Jet Fuels and the Environment, project 10 through FAA Award Number 13-C-AJFE-GIT-006 under the supervision of Rangasayi Halthore, Maryalice Locke, and Laszlo Windhoffer. Any opinions, findings, conclusions or recommendations expressed in this this material are those of the authors and do not necessarily reflect the views of the FAA.

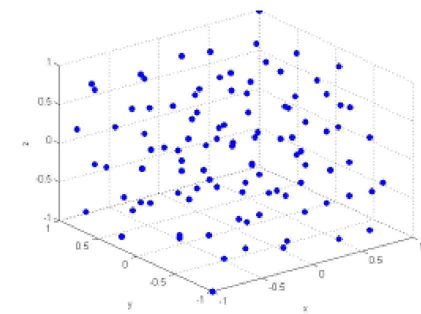
SST Vehicle Modeling: Research Approach

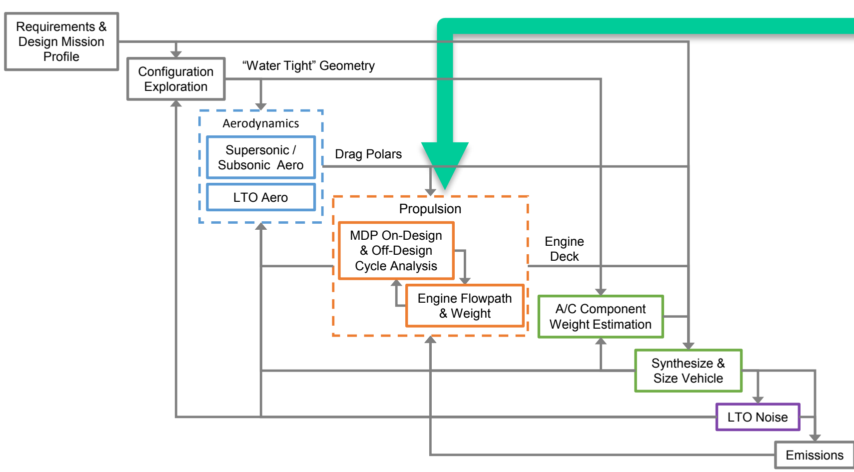
For each vehicle class / Mach number combination, explored a design space of 100,000+ designs by varying the following parameters:

1. Establish design variable and ranges

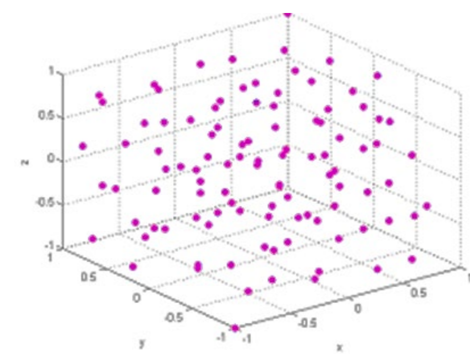
Trajectory Parameters	Engine Cycle Parameters	Vehicle Design Parameters	Airframe Geometry
Takeoff De-rate % Thrust	Fan Pressure Ratio	Takeoff Thrust to Weight Ratio	Trailing edge sweep (inboard and outboard)
% Programmed Lapse Rate	HPC Pressure Ratio	Takeoff Wing Loading (weight to wing area ratio)	Twist (root, mid and tip)
Acceleration During for 2nd Segment	Throttle Ratio (i.e., turbine rotor inlet temperature)		Taper ratio (inboard and outboard)
2nd Segment End Altitude			Aspect Ratio
Cutback Altitude			Dihedral (inboard and outboard)
			Wing break location

2. Create set of configurations (design space) to be explored



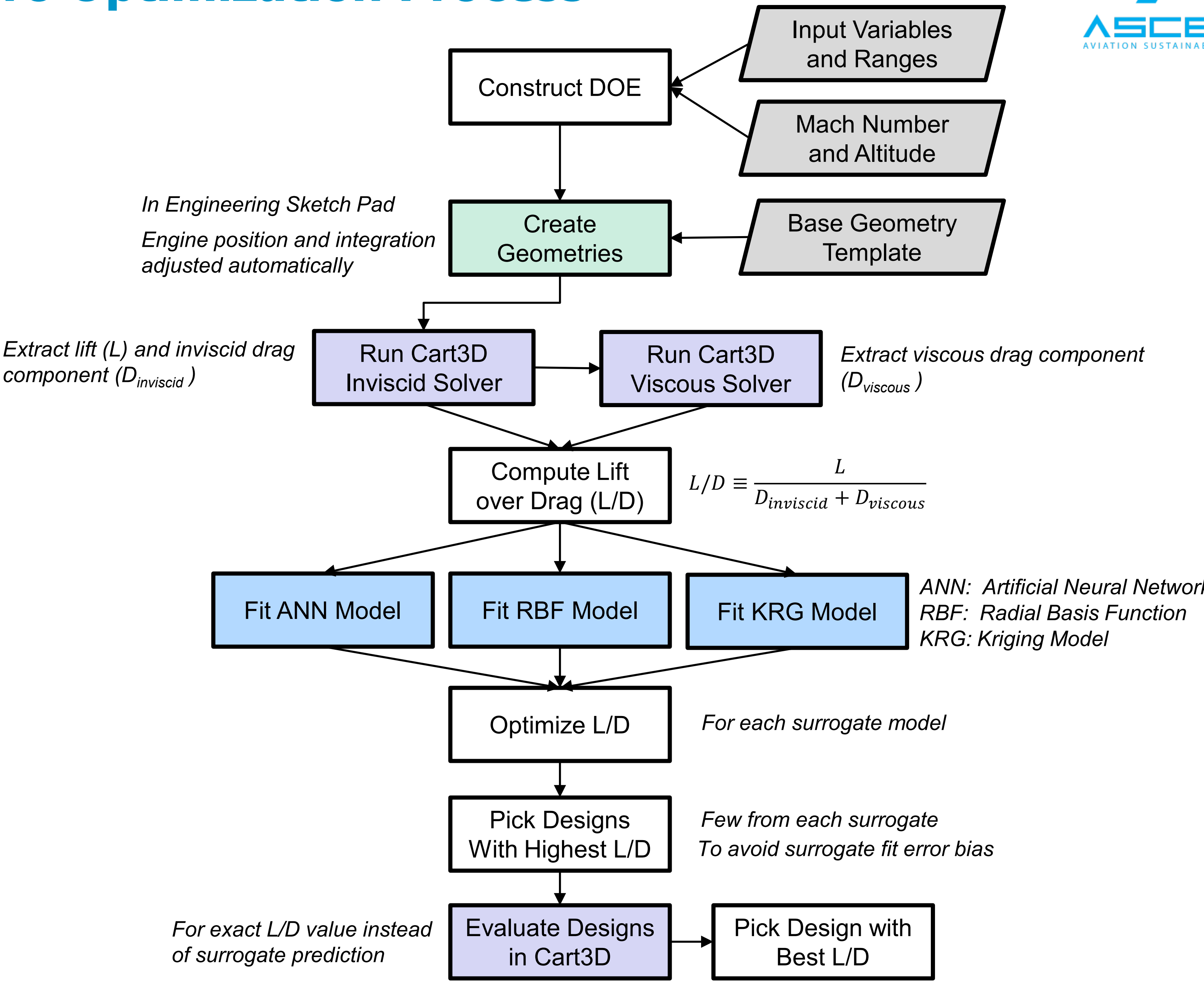


3. Simulate Vehicle with FASST M&S Environment



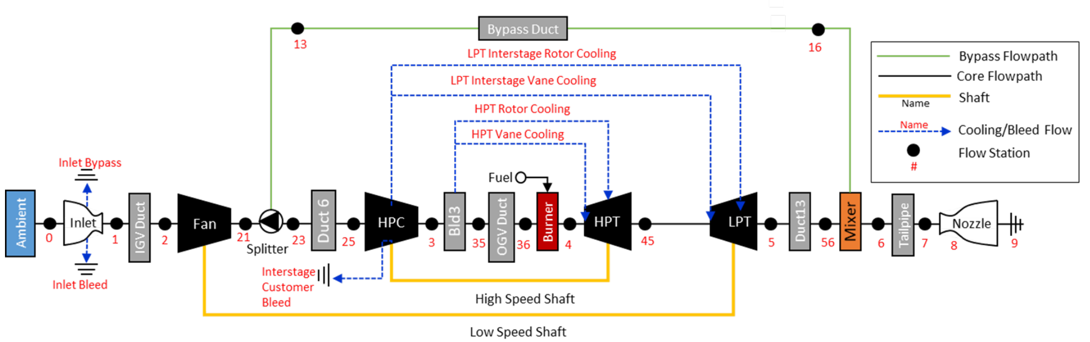
4. Record metrics of interest (fuel burn, noise, emissions, etc.)

Aero Optimization Process

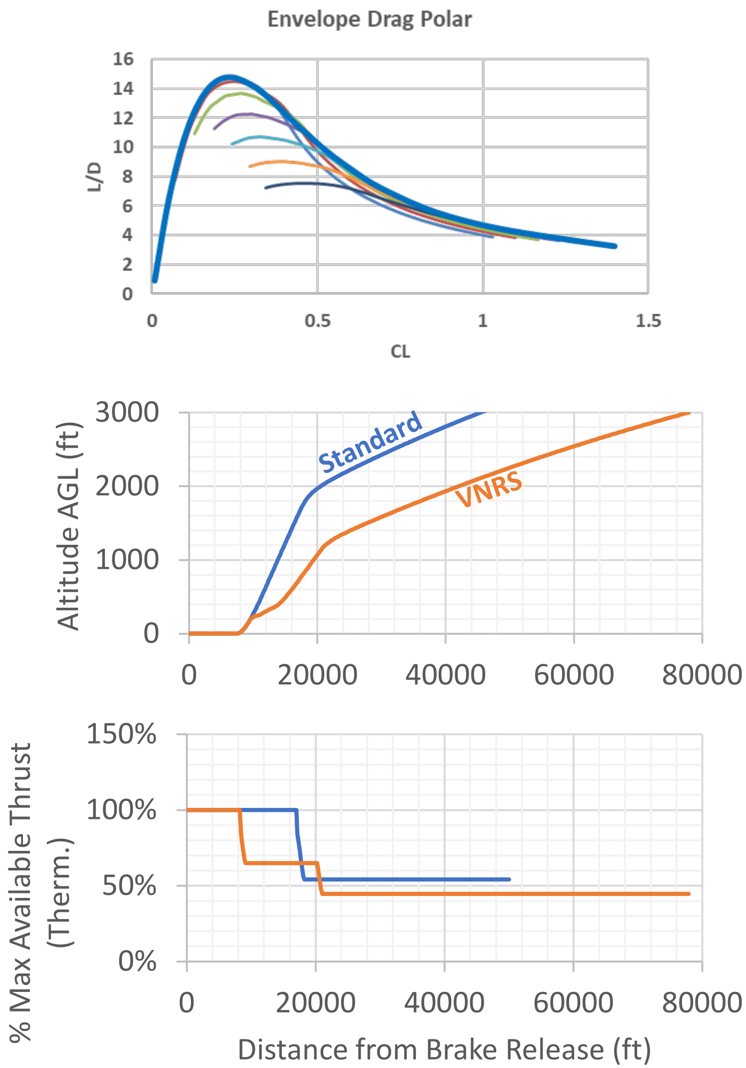


Propulsion Modeling

- Non-afterburning, two-spool, mixed-flow turbofan
- Cycle/performance modeled with NPSS and weight modeled with WATE++
  - Parametric maps for inlet and nozzle from PIPSI/INSTAL
  - Parametric maps for fan and HPC from CMPGEN with design point computed with simple meanline code
  - Parametric maps for HPT and LPT scaled for design point computed with simple meanline code
  - Cooling flows modeled using updated CoolIt algorithm for advanced cooling tech
  - Nominal losses assumed for ducts, burner and mixer
- Multi-design point (MDP) approach was used to simultaneously meet requirements at multiple flight conditions
- Off-design power management uses both fuel flow and nozzle throat
  - Typically hold fan op-line as thrust changes
  - For LTO: reduce thrust initially along fan constant speed line to reduce noise



VNRS Takeoff Assumptions

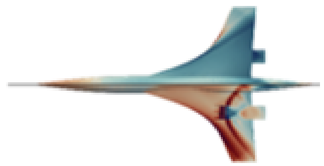
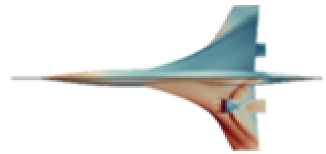
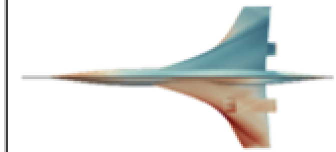
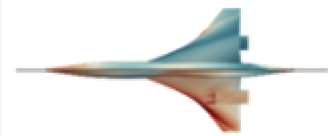
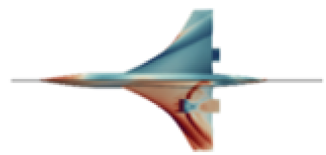
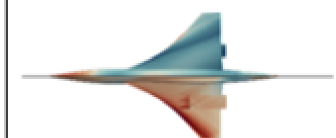
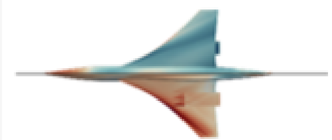
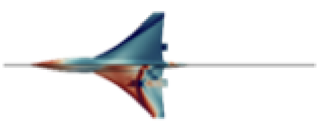
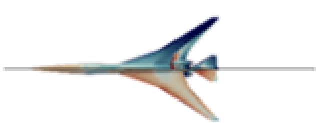
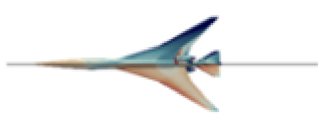
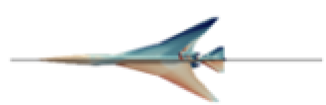


The variable noise reduction system (VNRS) includes:

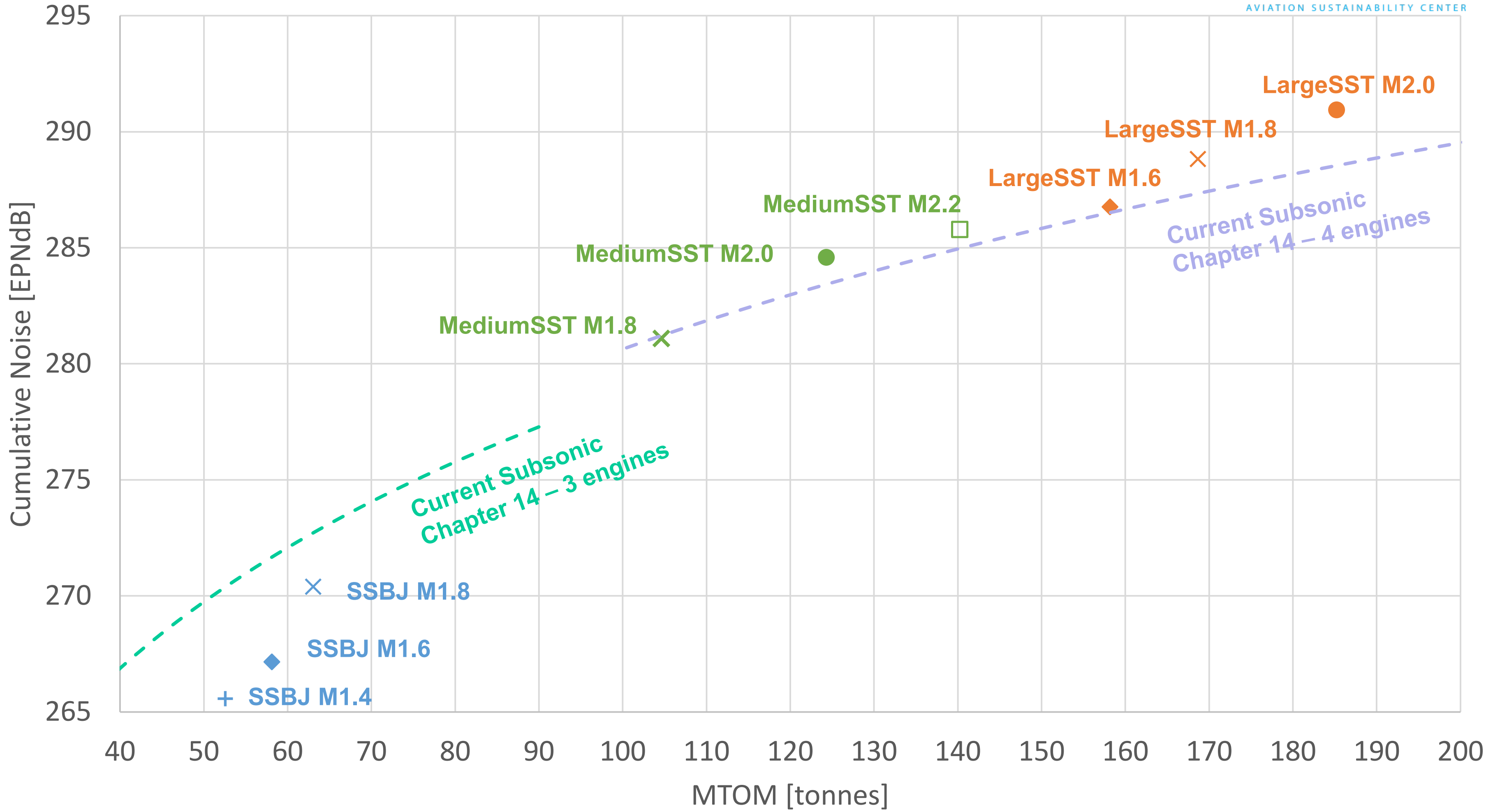
- Programmed high lift devices (PHLD) schedule optimized for L/D
- Programmed thrust lapse rate (PLR) implemented right after the obstacle
- Second segment acceleration (2SA) which is broken down into
  - Initial climb angle
  - Constant speed transition altitude
  - Cutback altitude

Summary Matrix of Airframe Designs

*Vehicles notionally scaled by passenger class. L/D shown at 55,000 ft.

	$M_\infty = 1.4$	$M_\infty = 1.6$	$M_\infty = 1.8$	$M_\infty = 2.0$	$M_\infty = 2.2$
100 PAX	"Large SST"	 Max L/D = 8.46	 Max L/D = 8.39	 Max L/D = 8.09	
75 PAX					 Max L/D = 7.13
55 PAX	"Medium SST"		 Max L/D = 7.51	 Max L/D = 7.26	 Max L/D = 7.07
25 PAX	 Max L/D = 7.73				
SSBJ	 Max L/D = 9.41	 Max L/D = 8.72	 Max L/D = 8.29		"SSBJ"

Chosen Designs: Noise vs MTOM



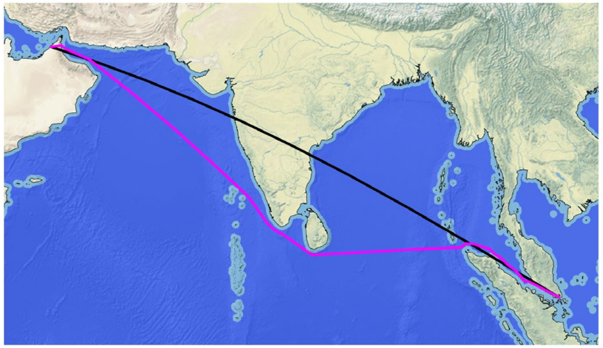
- Initial optimum chosen for min noise from raw data (>5000 designs per vehicle).
- Subsequent optimization utilized surrogate models (trained on the raw data) to minimize fuel constrained to less than 1dB above the raw data min noise.
- Final noise optimization for trajectory to further minimize noise.

Fleet Demand Route

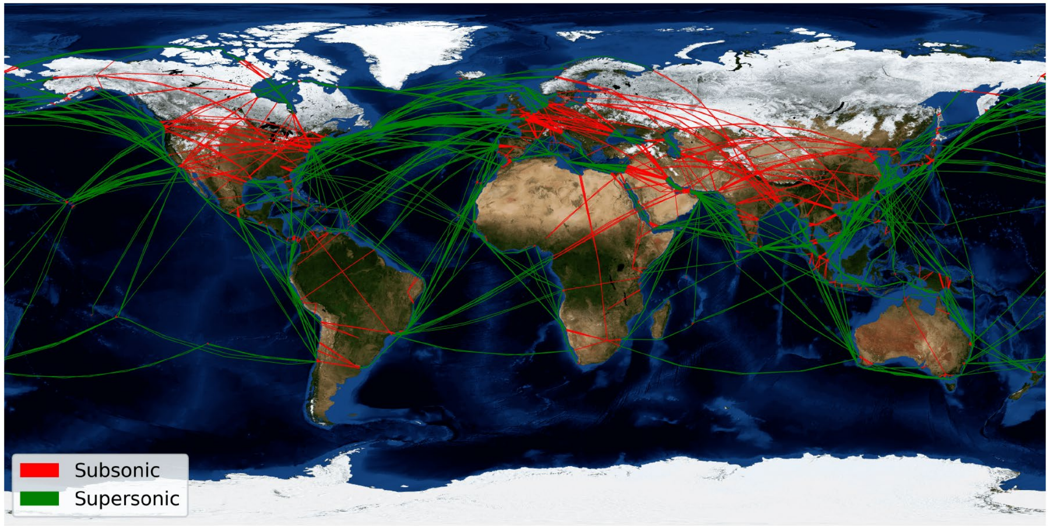
Goal: Determine potential SST demand globally in the future and estimate fuel burn and emissions

Approach: Vehicle capability based time savings and cost per route to estimate demand and aircraft performance

- Developed SST route optimization tool that takes aircraft specific performance into account and allows trading off time savings and fuel efficiency
- Support for CAEP E-Study
  - Supplied demand input to scenarios
  - Performed full flight runs for BJ and commercial vehicles
- Developed detailed global emissions dataset for Projects 22 and 58
- Use Mach Design Trade Study vehicles to define most favorable market for vehicle size and design Mach number
- Mach 2.2, 55 seat aircraft yields a maximum of 970 feasible unidirectional routes for 2035



Example: Dubai – Singapore



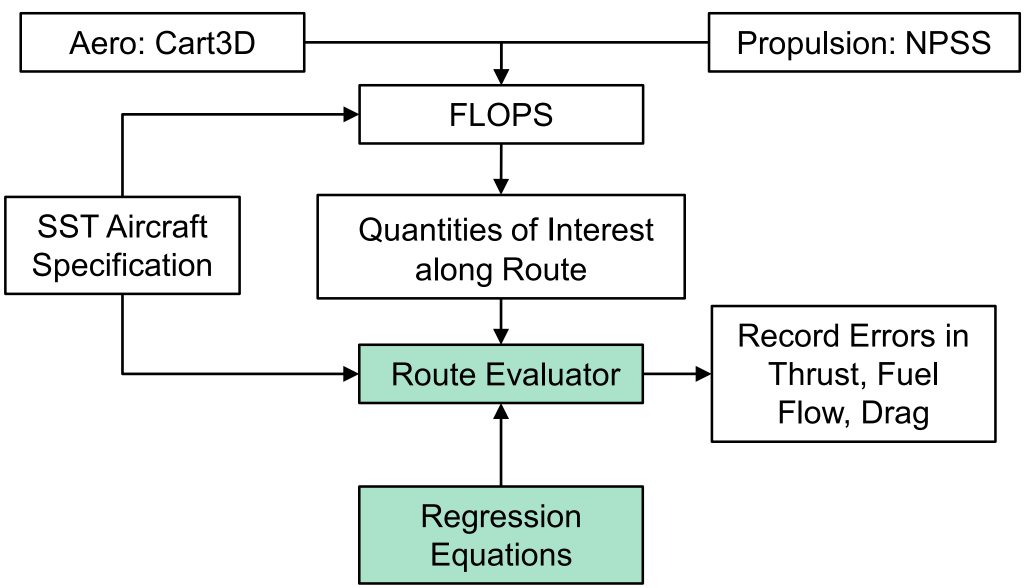
AEDT SST Modeling

Goal: Develop & validate approach for modeling Supersonic Transport (SST) aerodynamics & propulsion performance within AEDT

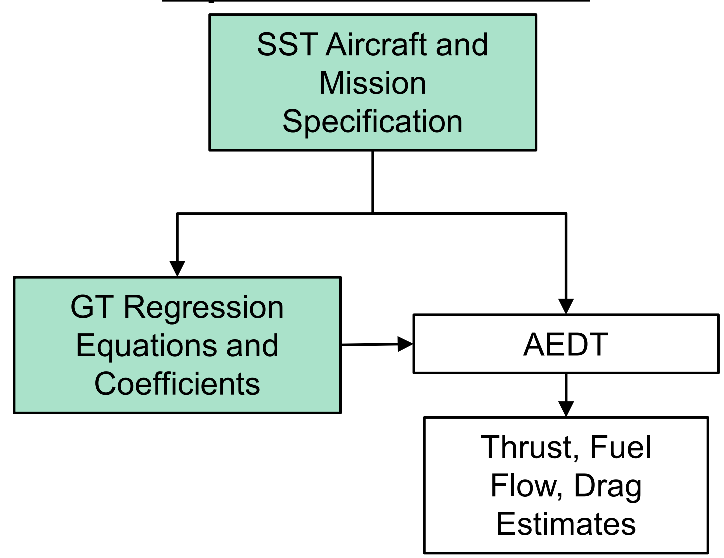
Approach:

- Generate performance "*truth*" data for SST aircraft concepts using:
  - Aerodynamic Analysis: CART3D inviscid Computational Fluid Dynamics (CFD) with viscous correction
  - Propulsion Analysis: NPSS
- Develop new regression equations to model both supersonic and subsonic regimes
  - Physics-rooted functional forms
  - Focus on maximizing parsimony (minimal number of coefficients) while minimizing prediction errors
- Fit truth data to physics-rooted functional forms, quantify errors and propagate through aircraft mission
  - Region of validity for regressions extracted from notional SST missions
  - Fit several regressions using identical functional forms; applicable within specified envelope, i.e., region of validity
  - Assess prediction errors and propagate through simulated mission(s)
- **Validate approach on notional missions flown by SSTs**
- Provide implementation plan to incorporate models within AEDT

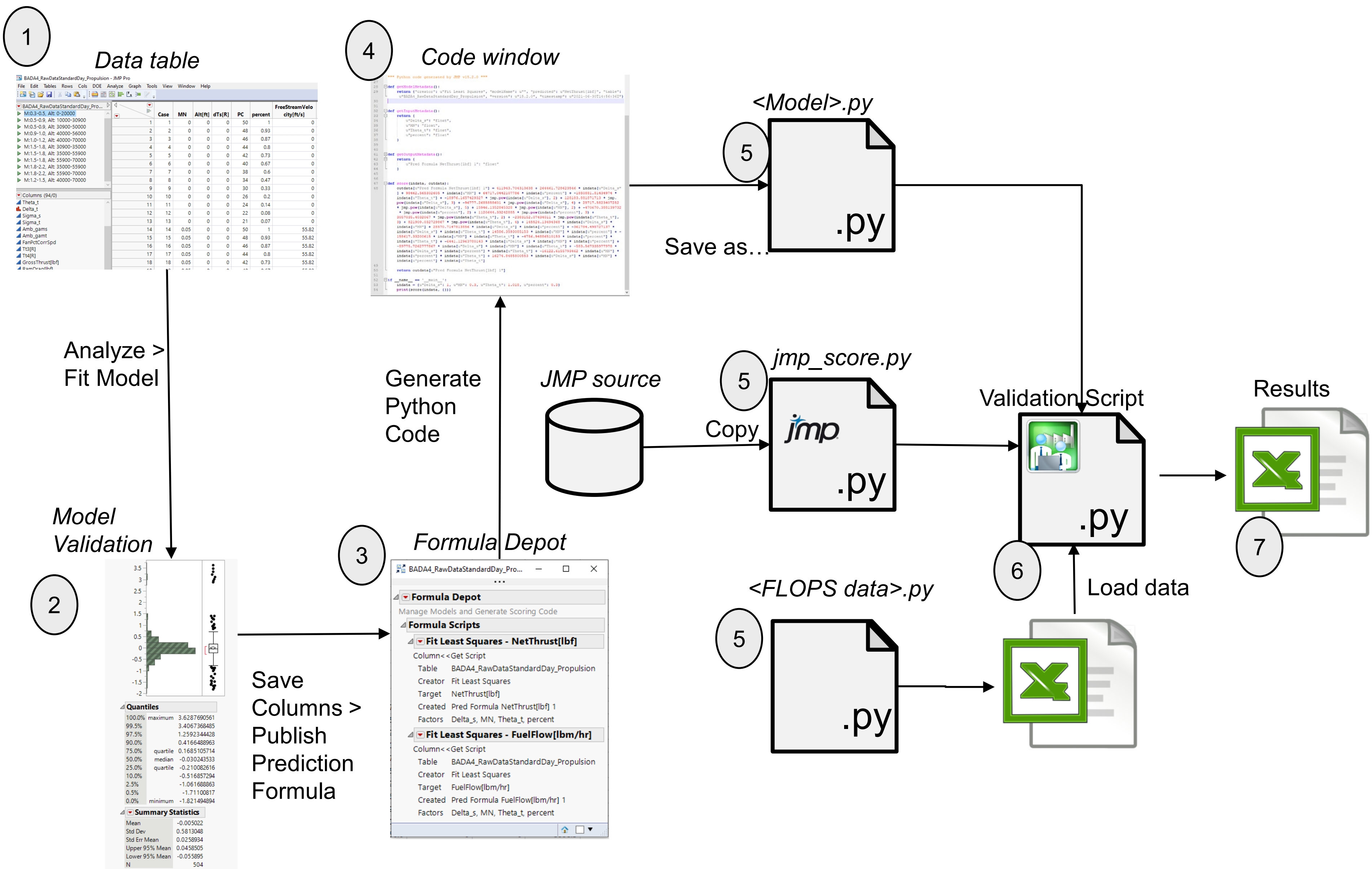
Validation Process



Implementation in AEDT



Validation Process Implementation Details



Supersonic Engine Emissions Research