ASCENT Project 10

Aircraft Technology Modeling & Assessment

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Cost Share Partner: Boom Supersonics,
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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; 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:

- RANS CFD based aero shaping
- Multi-fidelity and parametric drag polar generation
- RANS CFD for LTO drag estimation
- Engine cycle modeled using NPSS multi-design point sizing
- Engine power management utilizes variable nozzle throat and fuel flow to optimize fuel efficiency or noise
- Engine flowpath and weight modeled with WATE++
- Mission analysis using FLOPS sizes vehicle for 65pax, M2.0, M1.7, and M1.4, all for 4250 nmi design range
- LTO trajectory modeled using FLOPS detailed takeoff and noise modeled using ANOPP
- Vehicle design space is parametrically explored to determine impact on noise and fuel burn
- Developing modeling methods for supersonic full-flight capabilities in AEDT

Major Accomplishments (to date):

SST Vehicle Modeling: Successfully implemented new RANS CFD based active subspace aero optimization; Implemented parametric drag polar into mission analysis; implemented VRNS optimization; used generic GT 65pax M1.7 SST for Greensboro Airport; implemented additional regulatory constraints for takeoff procedures;

Fleet Route Simulation: Developed flexible route optimization tool; Completed future SST demand study where demand depends on vehicle capabilities; Supported CAEP E-Study; Developed inventory of estimated future global SST emissions

AEDT SST Full-Flight Modeling: Developing implementation plan for SST models in AEDT; Decided on OD pairs for initial SST mission type implementations in AEDT

Future Work/Schedule remainder of PoP: Complete design Mach trade study (finish designs for 65-passenger M2.0 and M1.4 SSTs); Repeat V2 study for remaining vehicles;

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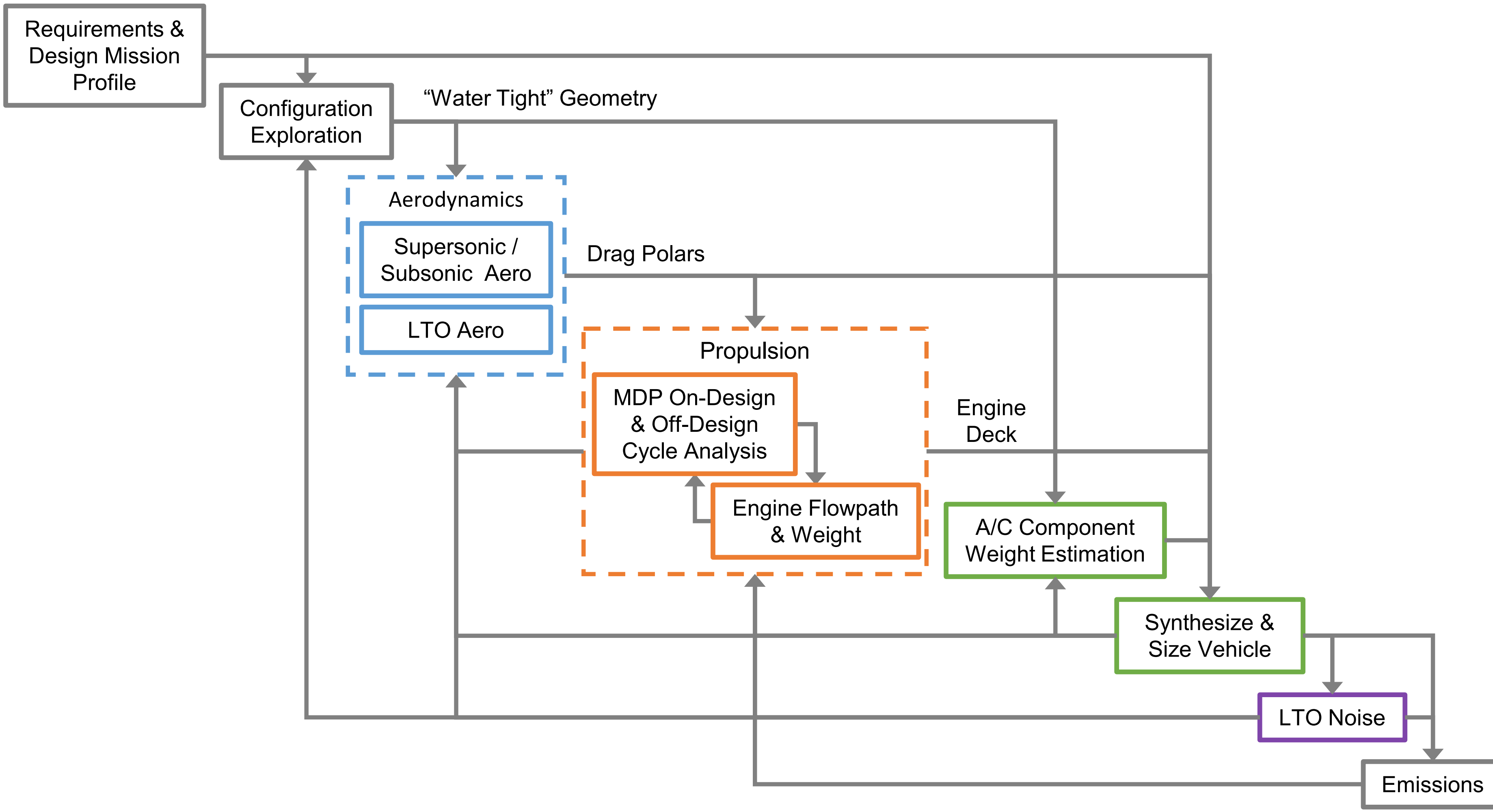
Framework for Advanced Supersonic Transport (FASST)

Purpose: Modeling and simulation (M&S) environment to design commercial supersonic transports with capability to examine fuel burn and LTO noise interdependencies and with direct linkage to fleet analysis



Matrix of SST Airframe Designs

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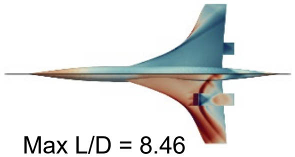
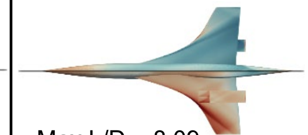
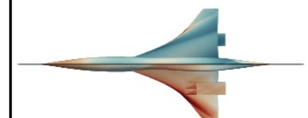
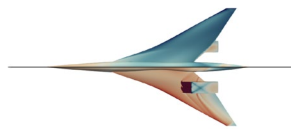
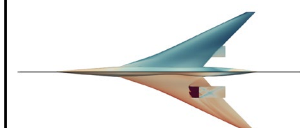
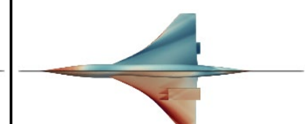
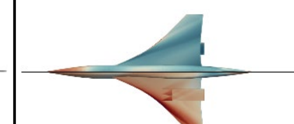
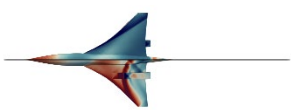
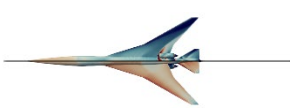
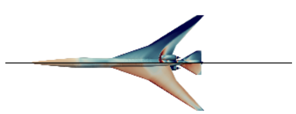
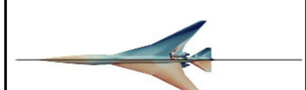
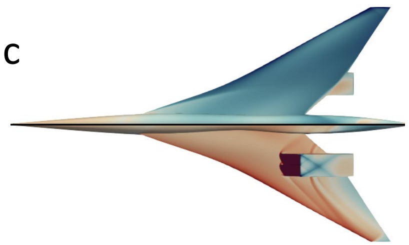
	$M_\infty = 1.4$	$M_\infty = 1.6$	$M_\infty = 1.7$	$M_\infty = 1.8$	$M_\infty = 2.0$	$M_\infty = 2.2$
100 PAX	"Large SST"	 Max L/D = 8.46		 Max L/D = 8.39	 Max L/D = 8.09	
75 PAX						 Max L/D = 7.13
65 PAX			 Max L/D = 10.34		 Max L/D = 9.68	
55 PAX	"Medium SST"			 Max L/D = 7.51	 Max L/D = 7.26	 Max 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"

Aerodynamics: Optimized Wing Geometry

AERO DESIGN VARIABLES
Sweep (inboard and outboard)
Twist at 5 wing stations
Taper ratio (inboard and outboard)
Aspect Ratio
Dihedral (inboard and outboard)
Wing break location
Airfoil camber at 5 wing stations

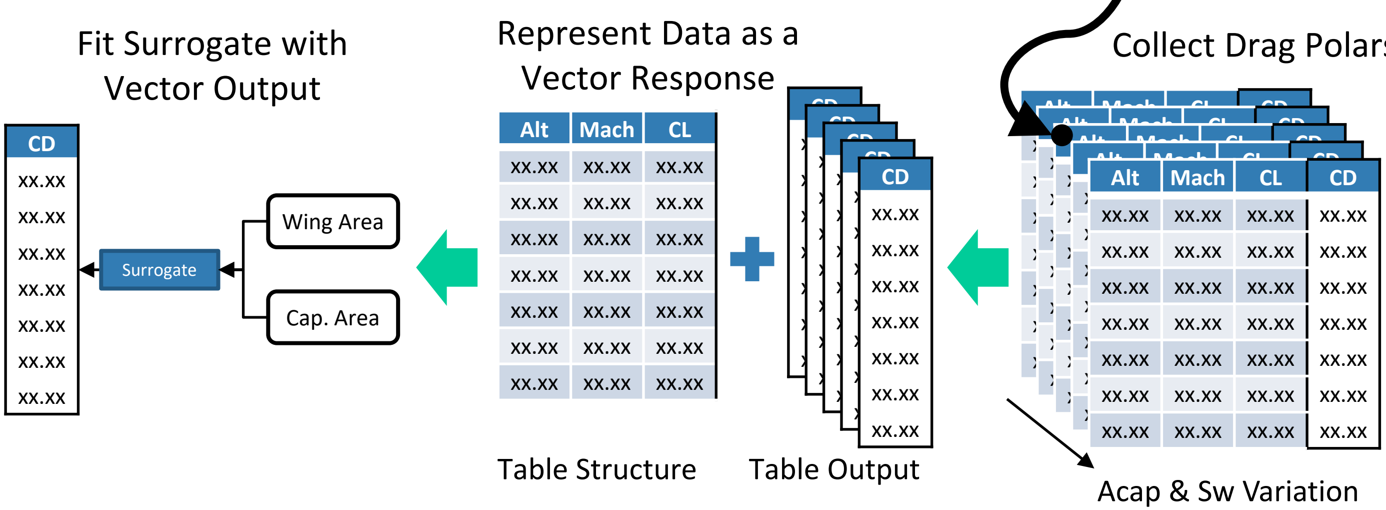
Aerodynamic shaping to **maximize cruise L/D**



Freeze Configuration Except Engine Capture Area (Acap) and Wing Area (Sw)

Active subspaces for dimensionality reduction
Adaptive sampling for RANS based design optimization

Multi-fidelity (inviscid + RANS CFD) Drag Polar Generation



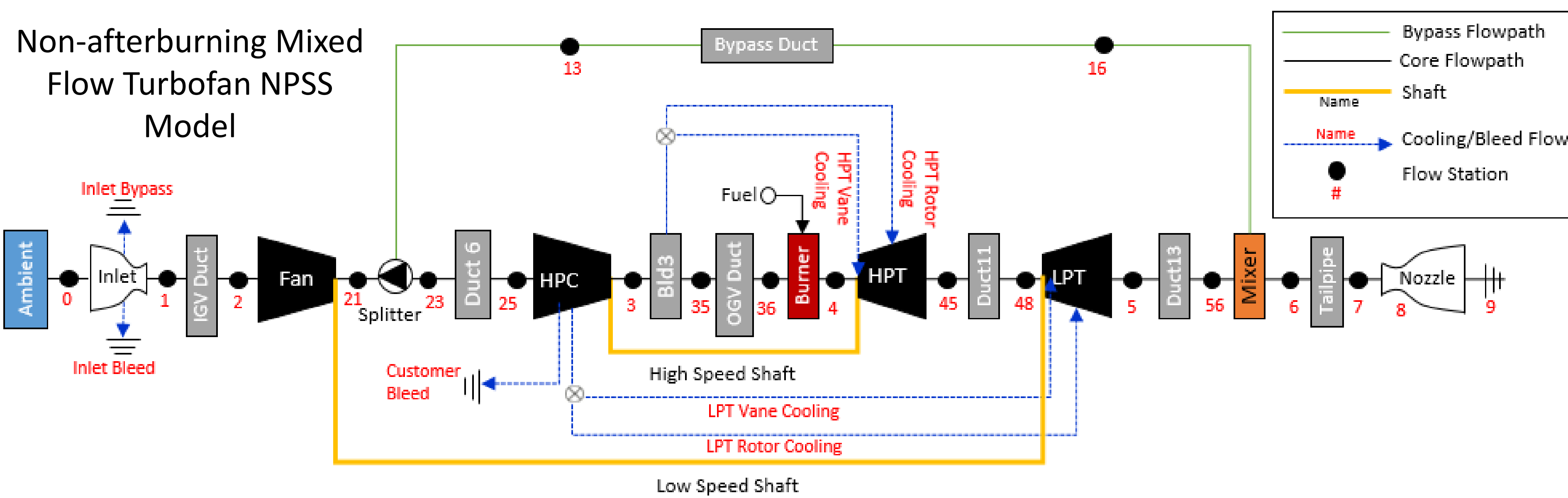
SST Sizing via FASST

Supersonic Engine Modeling

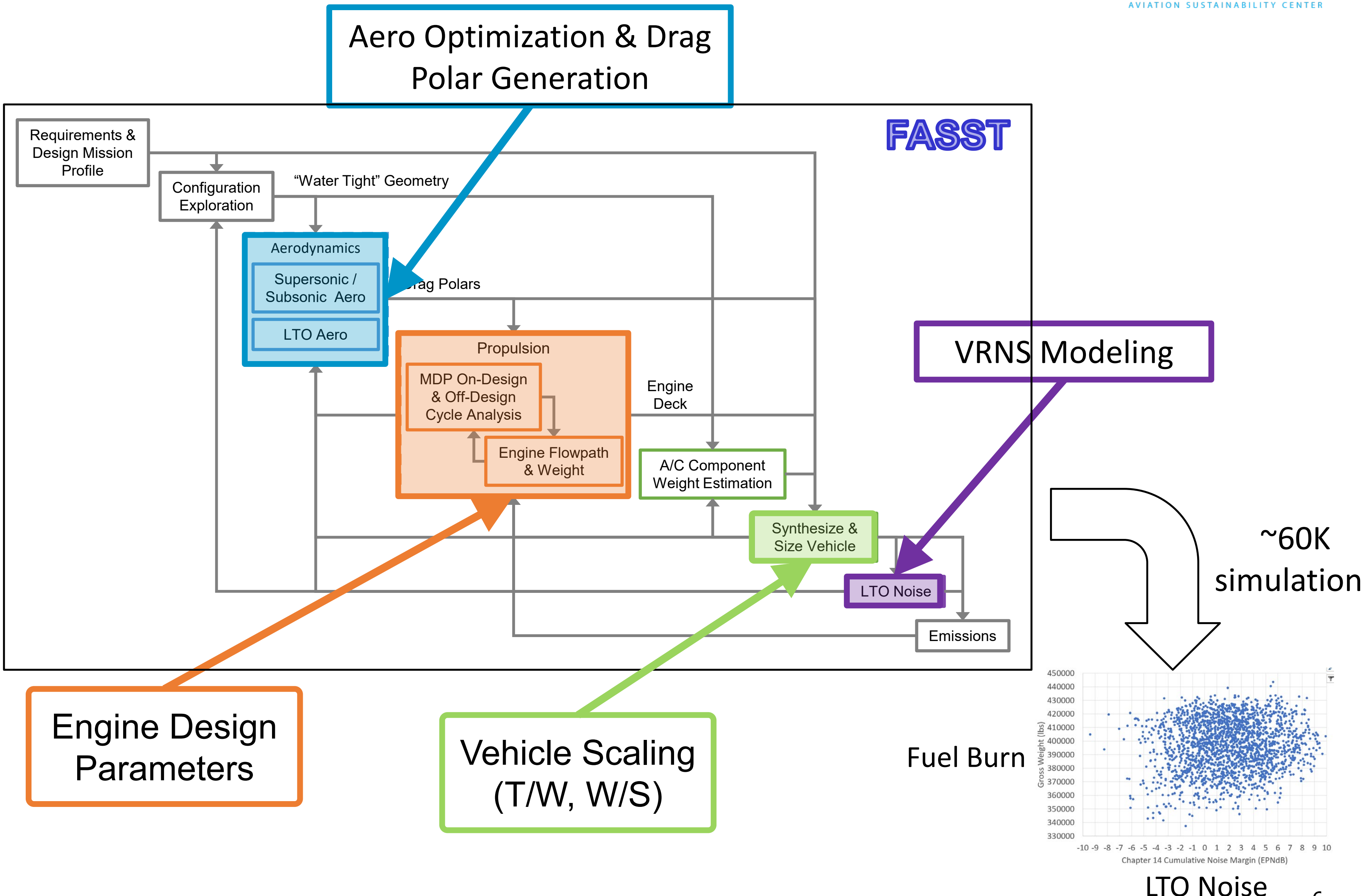
- On-Design
  - Simultaneous multi-design point sizing
- Off-Design
  - Engine has 2 controls:
    1. fuel flow
    2. nozzle throat
  - For mission analysis:
    1. fuel flow controls thrust
    2. nozzle throat targets peak fan efficiency
  - For LTO noise analysis:
    1. Fuel flow still controls thrust
    2. At high power: nozzle throat used to keep airflow high and reduce jet speed and noise
    3. At low power: nozzle throat is used to reduce fan speed and fan noise

Engine Design Parameters
Fan Pressure Ratio
Overall Pressure Ratio
Design Turbine Rotor Inlet Temperature
Bypass Ratio
Max Turbine Rotor Inlet Temperature

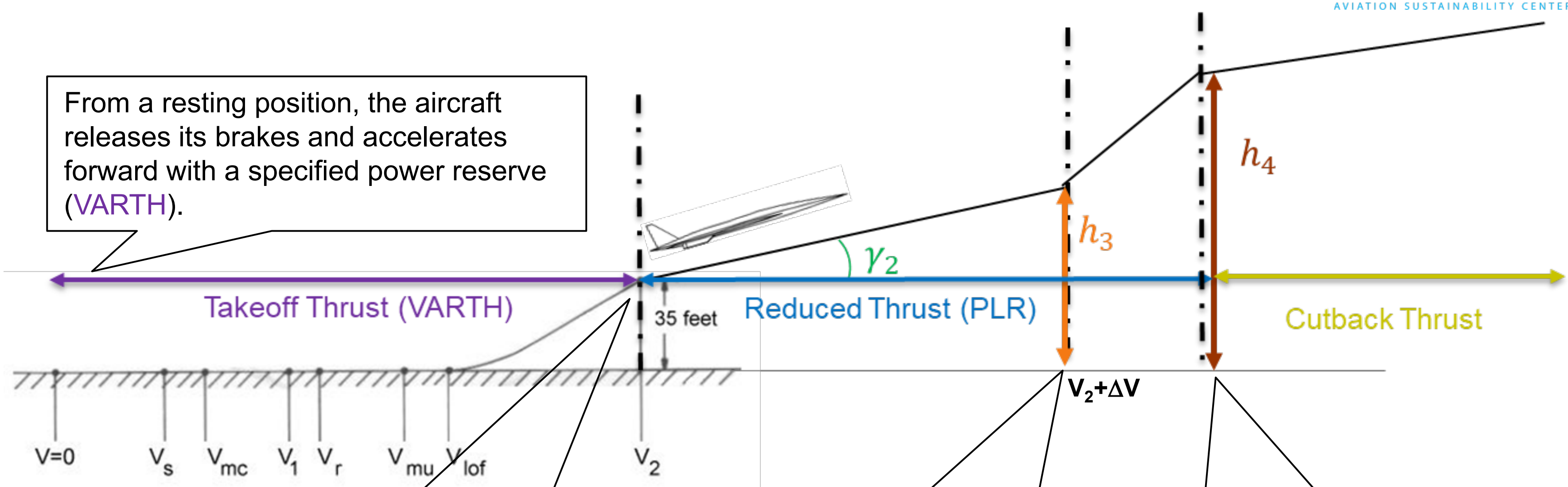
Non-afterburning Mixed Flow Turbofan NPSS Model



Pareto Front Generation



Variable Noise Reduction System (VRNS) Take-off Modeling



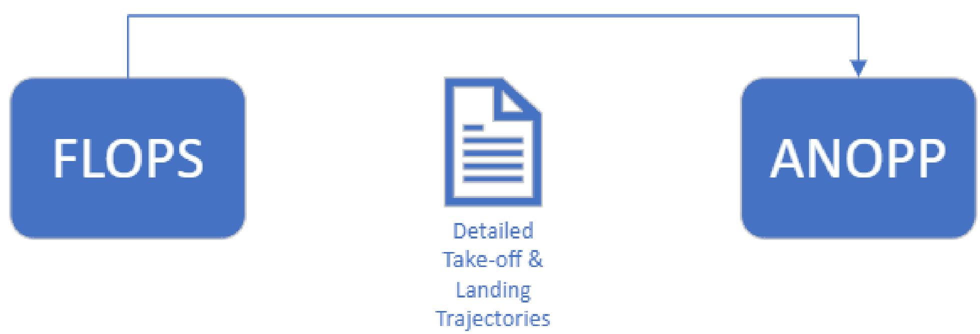
From a resting position, the aircraft releases its brakes and accelerates forward with a specified power reserve (VARTH).

Upon clearing the obstacle, the aircraft engages the PHLD schedule, reduces power to the specified lapse rate (PLR) and switches to a constant thrust flight at a prescribed flight path angle (γ_2).

Upon reaching a prescribed altitude (h_3), the aircraft switches to a constant thrust flight at the speed obtained in the previous segment.

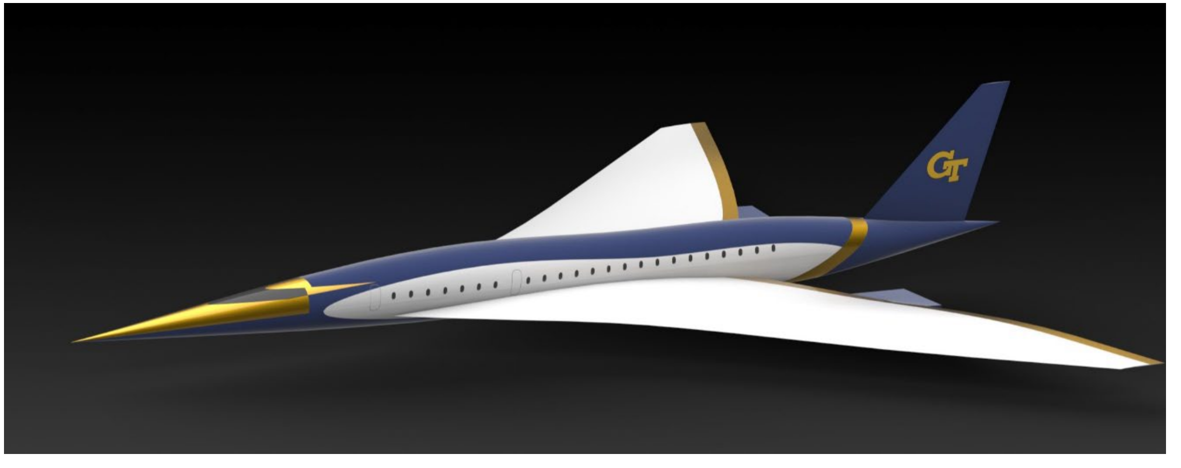
Finally, at a second prescribed altitude (h_4), the aircraft performs the pilot-initiated cutback and then maintains the current settings until it flies off the aerodrome.

PHLD consists of a flap deflection schedule optimized for the aerodynamic efficiency for the required lift at each point in the takeoff trajectory (controlled by FMS)



Requirements and Configuration Assumptions

- The vehicle described in this presentation was designed to several requirements
  - Passengers: 65
  - Range: 4,250 nmi
  - Cruise Mach: 1.7
  - Max Takeoff and landing field length: 11,000 ft
  - Approach speed: 165 kts
  - Chapter 14 Noise Margin: 5 EPNdB
- Additional configuration assumptions
  - No horizontal tail
  - Double-delta wing
  - Number of engines: 4 mixed-flow turbofans, under-wing



65pax Mach 1.7 SST Optimized Geometry

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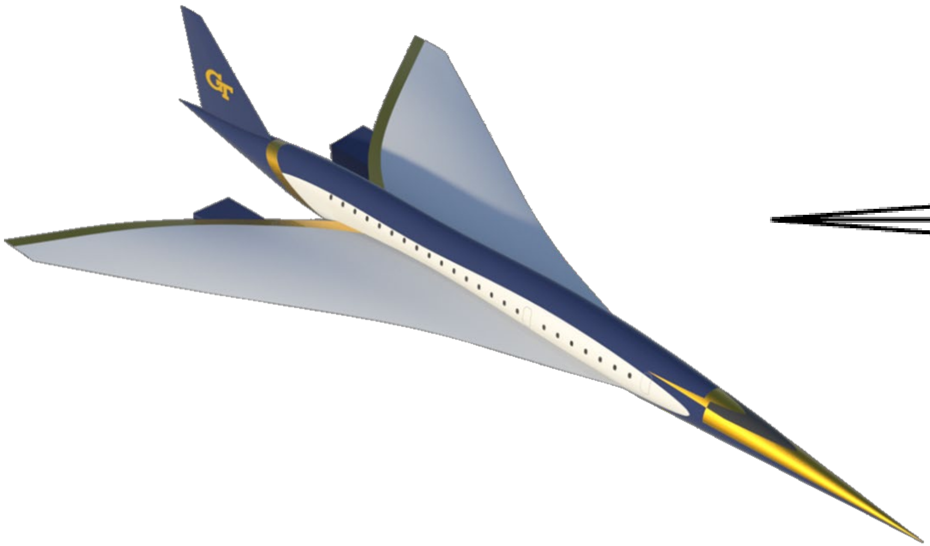

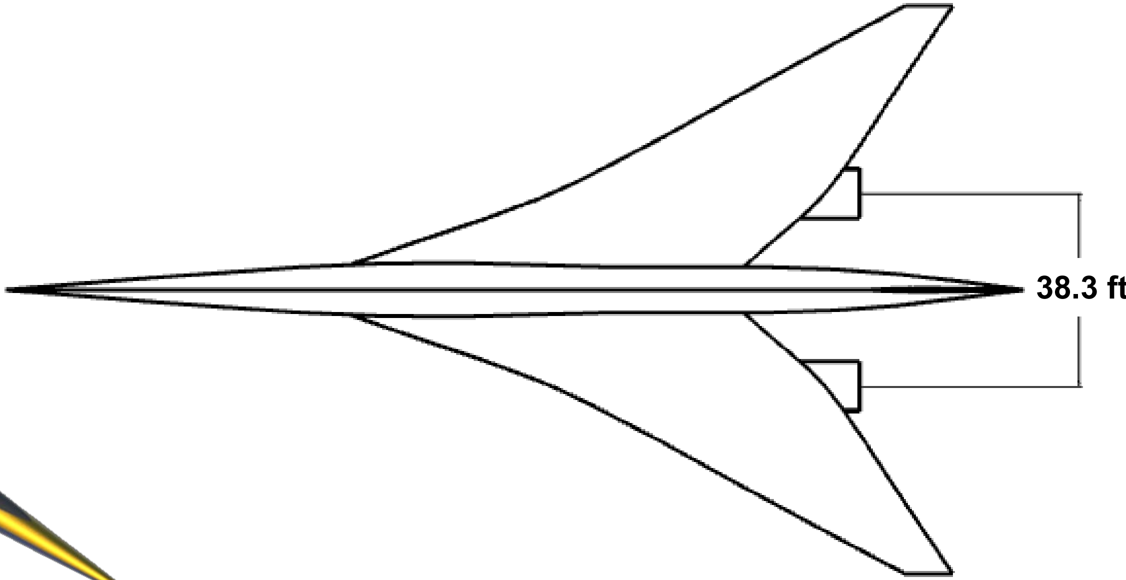

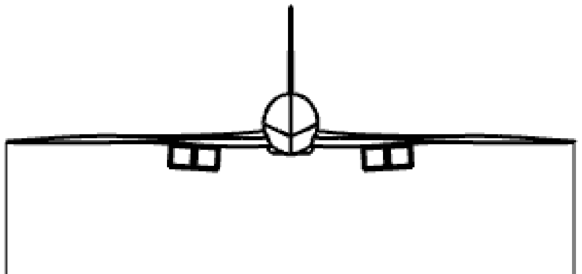

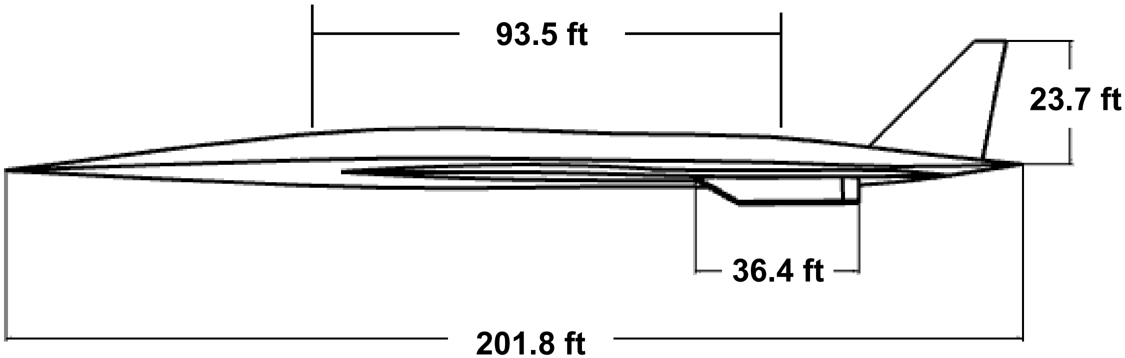

LTO Constraint Discussion

- Additional LTO constraints have been added as part of the optimization process to ensure that all viable design comply with certification standards
  - Minimum Cutback Altitude is enforced to be 689 ft, based proposed amendments to 14 CFR Part 36 for a VNRS trajectory [1]
  - The post-obstacle speed increment (i.e. x in V2+x) is now constrained

Previous Iteration Active Optimization Constraints

Metric	Type	Rule
Design block fuel	Objective	Minimize
Cumulative LTO noise margin	Objective	Maximize
Takeoff field length	Constraint	≤11,000ft
Landing field length	Constraint	≤11,000ft
Cutback Altitude Limit	Free	
Approach Speed	Constraint	≤165kts
Span	Constraint	≤118ft
Second segment net thrust	Constraint	≥0lb
Speed below 10,000ft	Constraint	≤250kts
Cutback Ground Track Dist.	Free	
Post-obstacle speed increment (i.e. x in V2+x)	Free	

Current Iteration Active Optimization Constraints

Metric	Type	Rule
Design block fuel	Objective	Minimize
Cumulative LTO noise margin	Objective	Maximize
Takeoff field length	Constraint	≤11,000ft
Landing field length	Constraint	≤11,000ft
Cutback Altitude Limit	Constraint	$\geq 689ft$
Approach Speed	Constraint	≤165kts
Span	Constraint	≤118ft
Second segment net thrust	Constraint	≥0lb
Speed below 10,000ft	Constraint	≤250kts
Cutback Ground Track Dist.	Constraint	≤21,325ft
Post-obstacle speed increment (i.e. x in V2+x)	Constraint	≥10kts

[1] Federal Aviation Administration *A Proposed Rule for Noise Certification of Supersonic Airplanes*. 85 FR 20431. 2020

Comparison of Different Takeoff ΔV Constraints at Constant Fuel Burn = 160,000 lbs

	$\Delta V > 0$	$\Delta V > 10$	$\Delta V > 20$	$\Delta V > 40$
Block Fuel [lb]	160,060	160,100	160,045	159,552
TOGW [lb]	449,578	449,468	449,253	443,340
Cumulative Noise Margin* [EPNdB]	6.12	5.42	4.29	2.35
AP | CB | SL Margin* [EPNdB]	6.8 | 5.4 | 6.5	6.7 | 5.2 | 6.1	6.5 | 5.4 | 5.5	6.8 | 6.5 | 2.4
FPR | OPR	1.88 | 22.6	1.90 | 23.2	1.93 | 23.2	2.04 | 23.1
T41max [R]	3,146	3,120	3,100	3,200
Bypass Ratio	3.28	3.20	3.12	3.08
T/W | W/S [psf]	0.304 | 81.8	0.309 | 82.1	0.316 | 82.1	0.304 | 80.2
Power Reserve	0.90	0.91	0.93	1.0
Programmable Lapse Rate	0.81	0.81	0.83	0.97
Flight Path Angle [°]	2.76	3.14	2.83	3.22
Transition Altitude [ft]	143	296	376	532
$V_2 + \Delta V$ [kts]	205.2 + 4.3	203.4 + 10.2	202.1 + 20.1	202.3 + 40.2
Cutback Altitude [ft]	689	689	689	689

* Relative to Chapter 14

Table data generated through surrogate models. **Preliminary results, do not quote**

Comparison of Different Takeoff ΔV Constraints at Constant Noise Margin = 5 EPNdB

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	ΔV > 0	ΔV > 10	ΔV > 20	ΔV > 40
Block Fuel [lb]	158,541	159, 719	161,428	159,552
TOGW [lb]	446,382	449,468	453,800	443,340
Cumulative Noise Margin* [EPNdB]	5.12	5.14	5.05	2.35
AP | CB | SL Margin* [EPNdB]	6.3 | 5.1 | 6.4	6.3 | 5.1 | 6.2	6.8 | 5.7 | 5.6	6.8 | 6.5 | 2.4
FPR | OPR	1.88 | 22.5	1.90 | 23.0	1.92 | 23.3	2.04 | 23.1
T41max [R]	3129	3125	3116	3,200
Bypass Ratio	3.25	3.26	3.25	3.08
T/W | W/S [psf]	0.304 | 81.1	0.310 | 81.8	0.316 | 83.0	0.304 | 80.2
Power Reserve	0.90	0.90	0.93	1.0
Programmable Lapse Rate	0.81	0.81	0.83	0.97
Flight Path Angle [°]	2.74	3.14	2.87	3.22
Transition Altitude [ft]	141	296	377	532
V_2+ΔV [kts]	204.5 | 4.3	202.9 + 10.8	203.2 + 20.0	202.3 + 40.2
Cutback Altitude [ft]	689	689	689	689

* Relative to Chapter 14

Table Data Generated through surrogate models, **Preliminary results, do not quote**

When the constraint was set $\Delta V > 40$ a 5 EPNdB cumulative margin case could not be found, the highest margin case was included instead

Summary Remarks

- Completed $V_2+\Delta V$ study for a single commercial class SST
- For the GT 65pax, Mach 1.7 design, we have observed…
  - Demonstrated trade between $V_2+\Delta V$ and Fuel Burn/Noise Margin
    - To achieve the same cumulative noise margin with increasing ΔV requirement fuel burn increases
    - To achieve the same fuel burn with increasing ΔV requirement cumulative noise margin decreases
  - With increasing ΔV requirement PLR for VNRS approaches 1 (i.e. no programable lapse rate)
  - With increasing ΔV requirement the constant-speed transition altitude (h_3) increases
  - With increasing ΔV requirement the engine cycle and vehicle sizing (T/W, W/S) variables change in addition to the operational variables
- Next steps:
  - Repeat study for Mach 1.4 and Mach 2.0
  - If time permits, repeat for SSBJ