ASCENT Project 10

Aircraft Technology Modeling & Assessment

Georgia Institute of Technology & Purdue University

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Cost Share Partner: Boom Supersonics, Georgia Institute of Technology

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
- Propulsion cycle modeled with NPSS using parametric loss models and multi-design point sizing
- Propulsion power management utilizes variable nozzle throat and fuel flow to optimize fuel efficiency or noise
- Propulsion flowpath and weight modeled with WATE++
- Mission analysis using FLOPS sizes vehicle for 65pax, Mach 1.7, 4250 nmi
- 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

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 new 65-passenger M2.0 SST; Perform validation on off-design missions for all SSTs for AEDT; Develop and validate models using newly obtained OEM data for AEDT; Develop and support AEDT implementation activity for one SST concept

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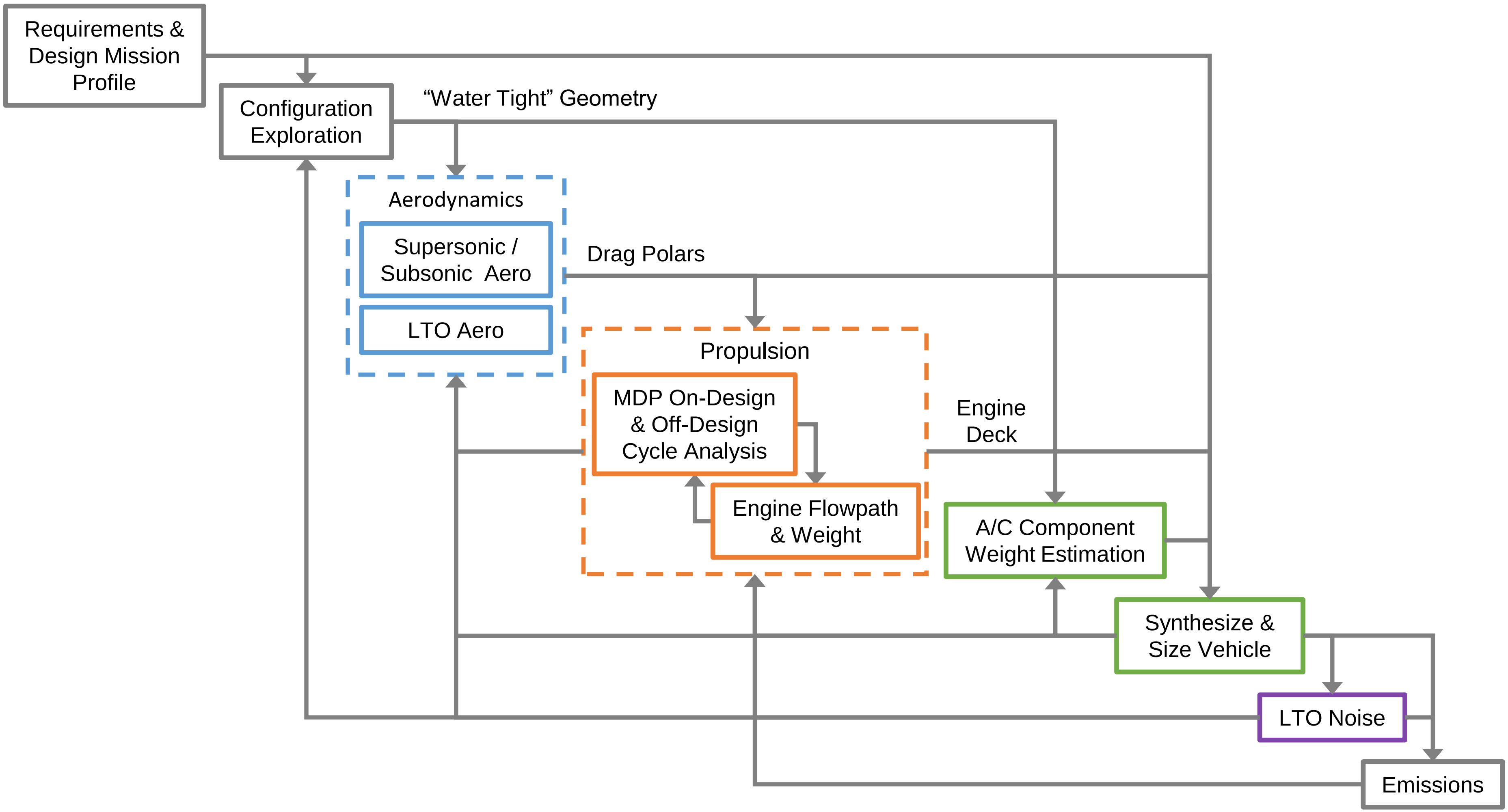
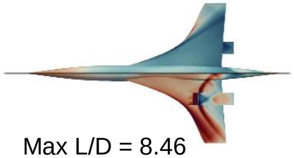
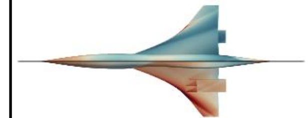
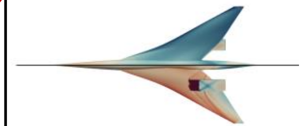
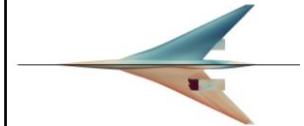
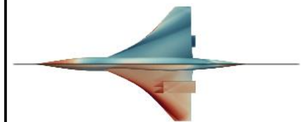
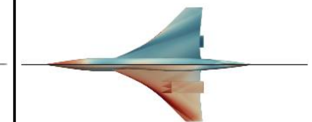
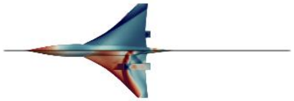
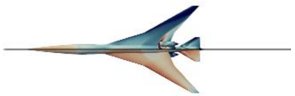
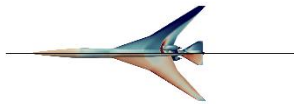
Framework for Advanced Supersonic Transport (FASST)

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



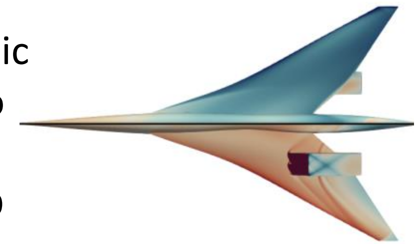
Matrix of SST Airframe Designs

	$M_\infty = 1.4$	$M_\infty = 1.6$	$M_\infty = 1.7$	$M_\infty = 1.8$	$M_\infty = 2.0$	$M_\infty = 2.2$
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

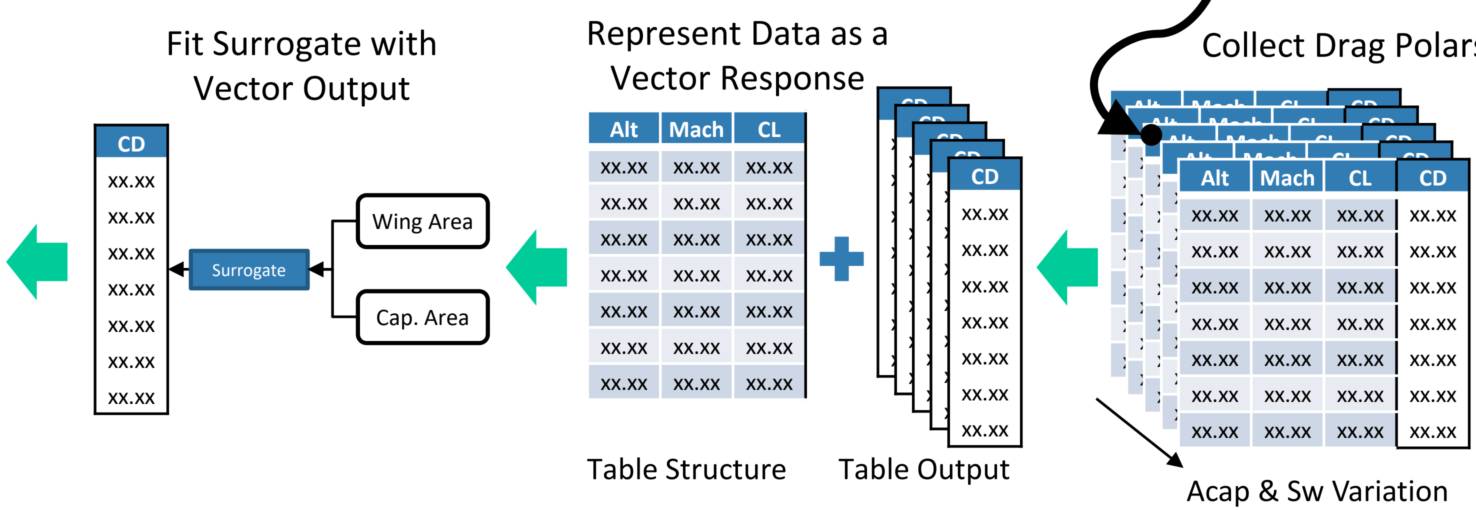
Aerodynamic shaping to **maximize cruise L/D**



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



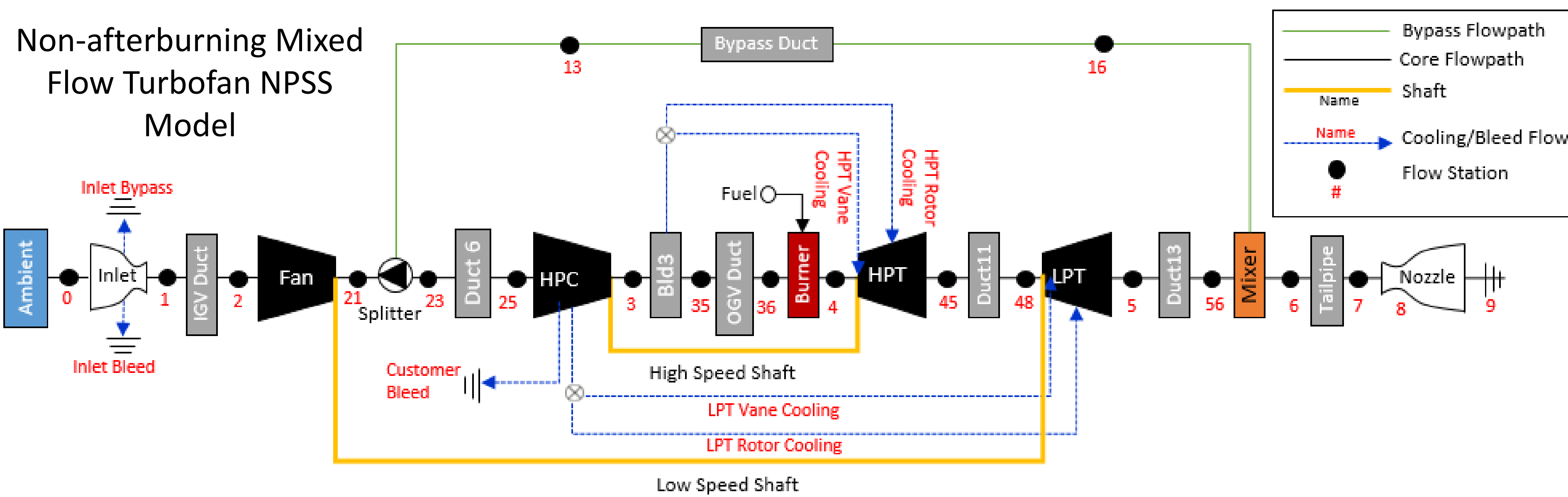
SST Sizing via FASST

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

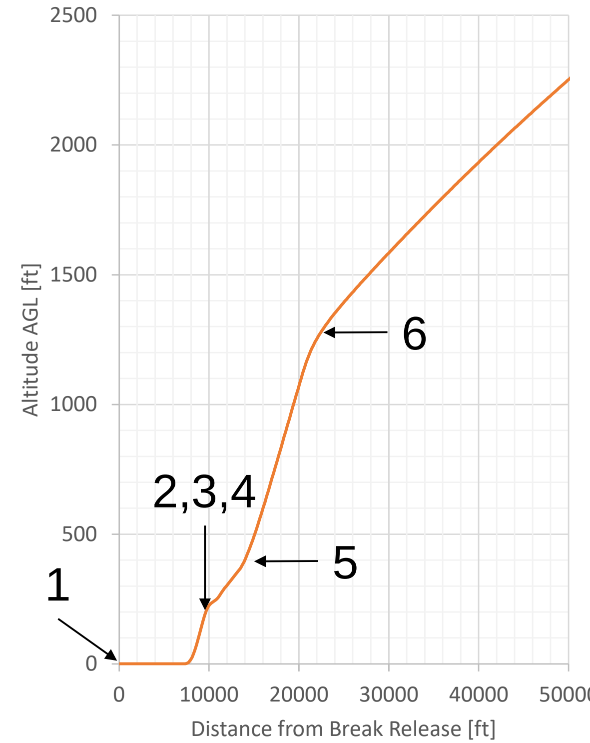
Non-afterburning Mixed Flow Turbofan NPSS Model



Variable Noise Reduction System (VRNS) Modeling

Trajectory Variables

1. Takeoff De-rate – initial reduction in thrust for takeoff
2. Programmed Lapse Rate – automatic reduction in thrust engaged after the obstacle
3. Programmed High Lift Devices – automatic schedule of high lift devices settings optimized for L/D
4. Target Flight Path Angle – reduced flight path to gain speed
5. Transition to Constant Thrust and Speed – maintain speed and gain altitude
6. Pilot Initiated Cutback



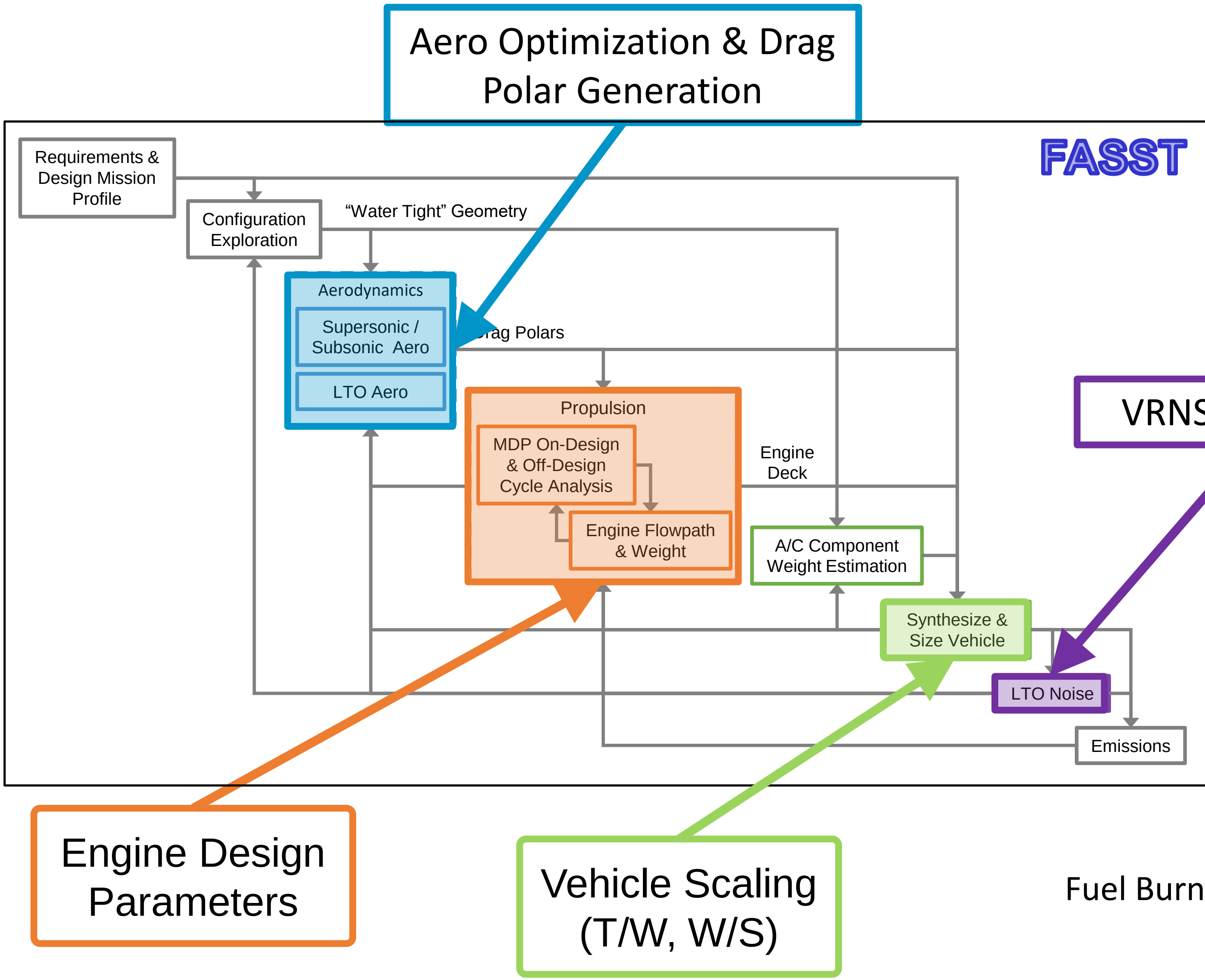
Take-off & Landing Drag Polar with Multiple High Lift Device Settings

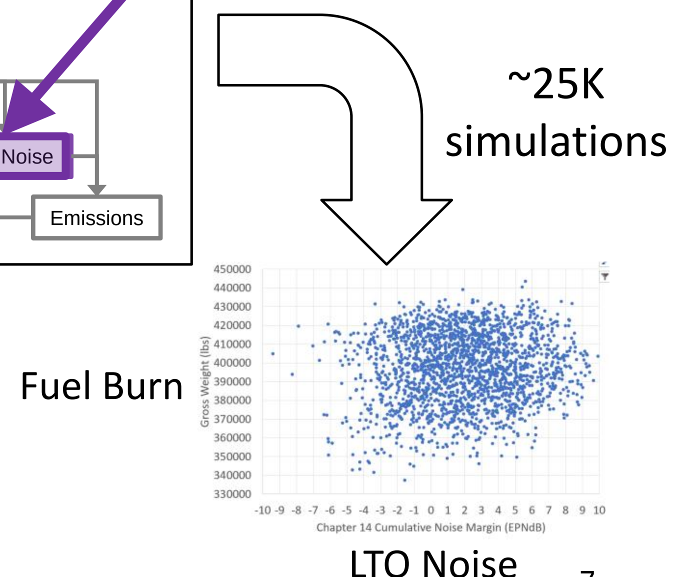
NASA FLOPS Detailed Take-off & Landing Analysis

Take-off & Landing Trajectories

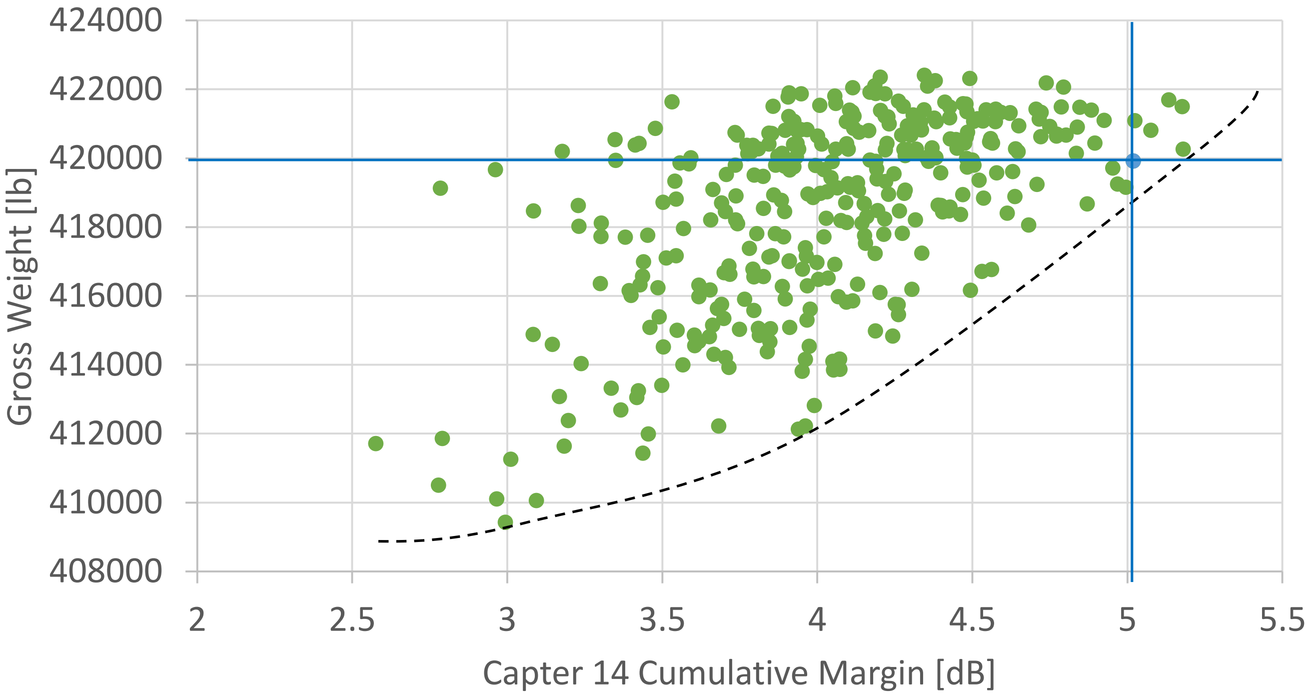
NASA ANOPP

Pareto Front Generation





65pax Mach 1.7 Pareto Front



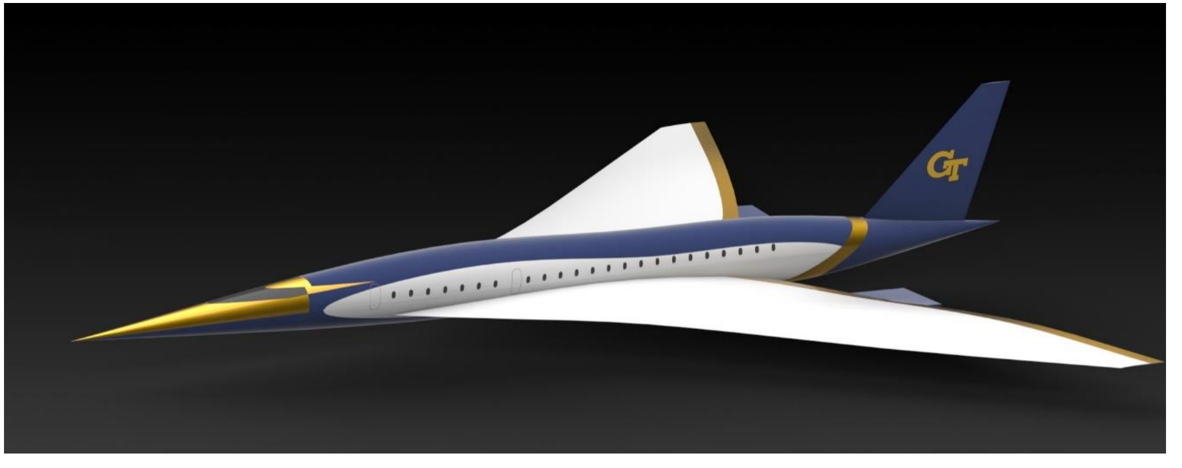
Highlighted Point Design Variables

FPR = 2.16
OPR = 26.82
PNT2Nc = 0.94
TOC_EXTR = 1.04
TWR = 0.29
WSR = 82.20
VARTH = 1.00
PLR = 0.77
GFIX = 5.84
HSTOP1 = 385.24
HSTOP2 = 941.71
HPT_desBladeTemp = 2050
LPT_desBladeTemp = 2100
Fan_RSspacing = 1.57

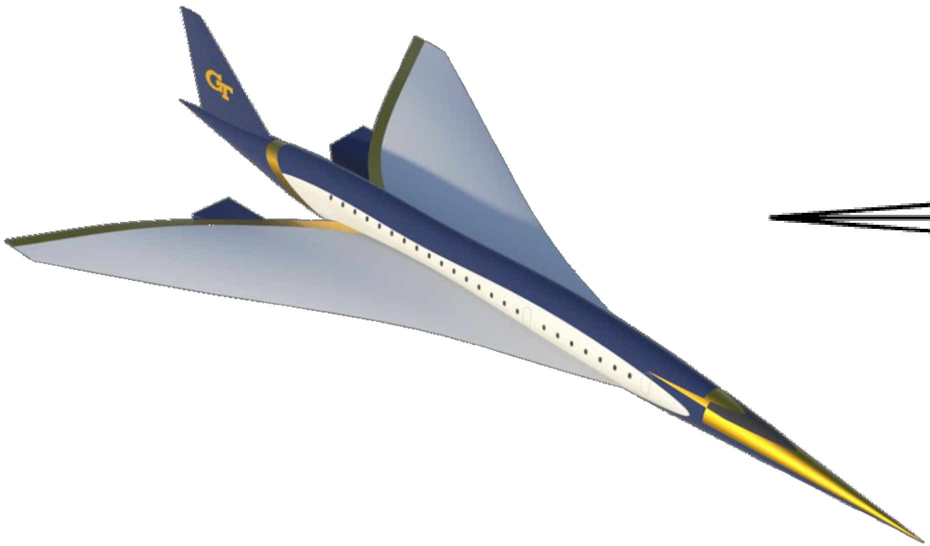
Highlighted design point predicts just over 5db of margin
The gross weight penalty needed to gain 1db of margin increases with margin

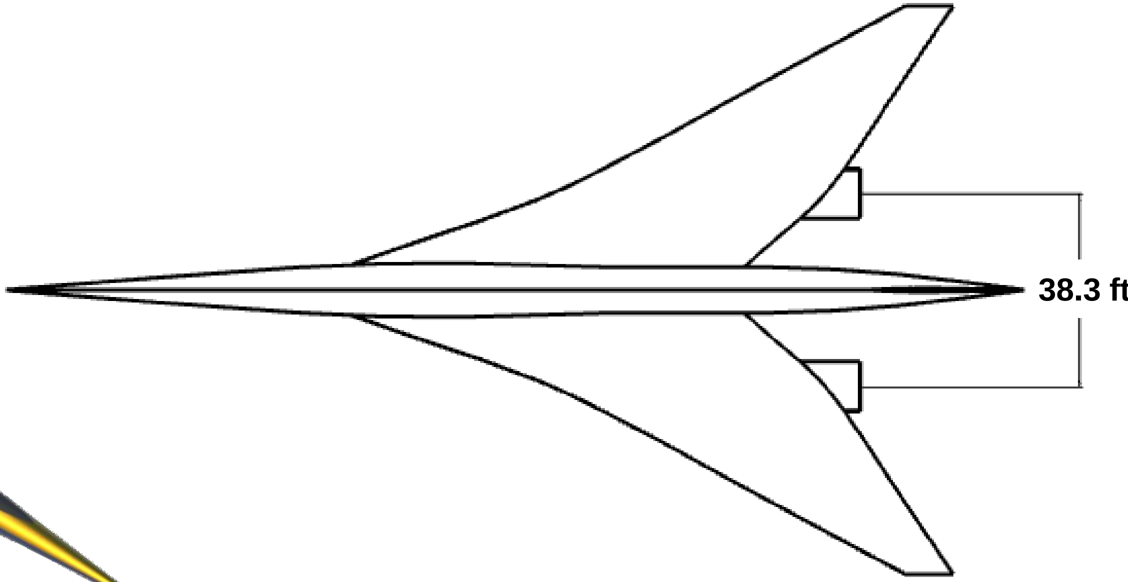
Requirements and Configuration Assumptions

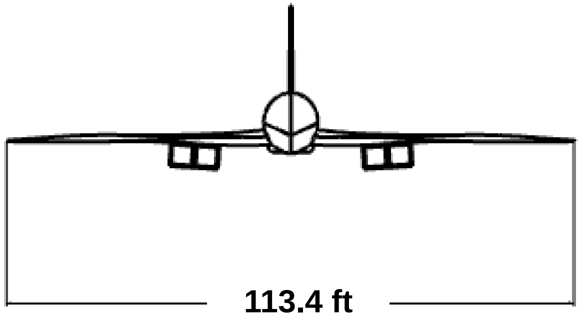
- The vehicle described in this presentation was designed to several requirements
  - Passengers: 65
  - Range: 4,250 nmi
  - Cruise Mach: 1.7
  - Max Takeoff and landing field length: 11,000 ft
  - Approach speed: 165 kts
  - Chapter 14 Noise Margin: 5 EPNdB
- Additional configuration assumptions
 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

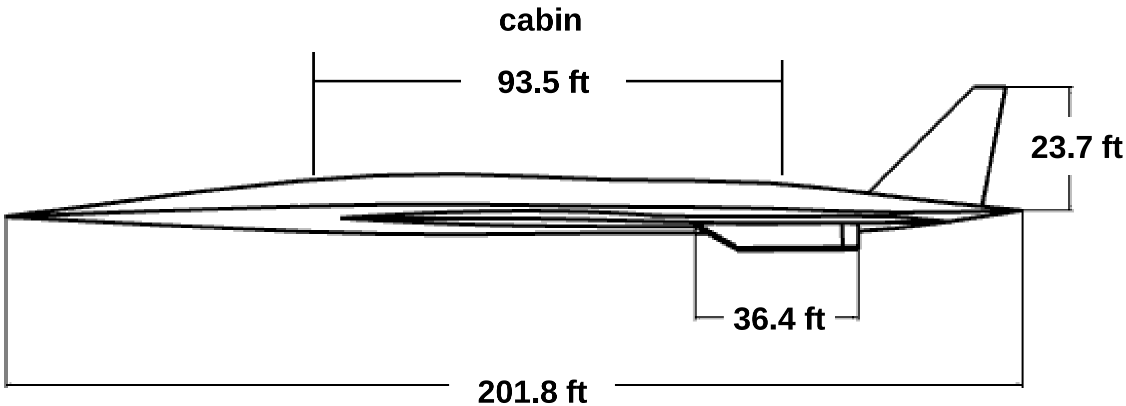


65pax Mach 1.7 SST Optimized Geometry









65pax SST Results

Description	Value
Design Range	4,250 nmi
Design Payload	13,650 lbs
Design Cruise Mach No.	1.7
Block Fuel	156,611 lbs
Total fuel	183,725 lbs
Fuel fraction	0.438
Take-off Field Length	10,832 ft
Landing Field Length	10,442 ft
Approach Speed	164.9 kts
Max L/D (cruise)	10.34
TSFC (cruise)	1.023
CL @ 12deg Take-off	0.704
CL @ 8deg Landing	0.658

Description	Value
Ramp Weight	419,923
Span	113.5 ft
Wing Area	5,109 ft^2
Aspect Ratio	2.52
Taper Ratio	0.109
¼ Chord Sweep	61.6 deg
VT Area	373.4 ft^2
VT Span	23.7 ft
VT Aspect Ratio	1.5
VT ¼ Chord Sweep	38.7 deg
Fuselage Length	201.83 ft
Fuselage Height	12 ft
Fuselage Width	10.75 ft

Weight Breakdown

Empty Weight Item	Weight [lb]
WING	78,114
VERTICAL TAIL	2,061
FUSELAGE	31,115
LANDING GEAR	18,386
STRUCTURE TOTAL	**129,676**
INSTALLED ENGINES*	43,664
FUEL SYSTEMS/ PLUMBING	3,024
PROPULSION TOTAL	**51,705**
SURFACE CONTROLS	6,466
AUXILIARY POWER	888
ELECTRICAL & INSTRUMENTS	4,895
HYDRAULICS	3,104
AVIONICS	1,852
FURNISHINGS & MISC SYSTEMS	15,023
AIR CONDITIONING & ANTI-ICING	3,807
FIXED EQUIPMENT TOTAL	**36,035**

Mass and Balance: Summary	Weight [lbs]
WEIGHT EMPTY	217,416
OPERATOR ITEMS	5,134
OPERATING WEIGHT EMPTY (OWE)	**222,549**
PAYLOAD 65 Passengers + baggage (210 lbs each)	13,650
ZERO FUEL WEIGHT	**236,199**
TOTAL FUEL	183,724
TRIP FUEL (TOTAL w/o RESERVES AND TAXI)	156,611
RAMP GROSS WEIGHT	**419,923**
Taxi Out Fuel Weight	1,215
MAXIMUM TAKE-OFF WEIGHT	**418,708**
OEW/MTOW	0.532

*includes bare engine, accessories, mounts, inlet, nozzle, nacelle

Fleet Analysis Overview

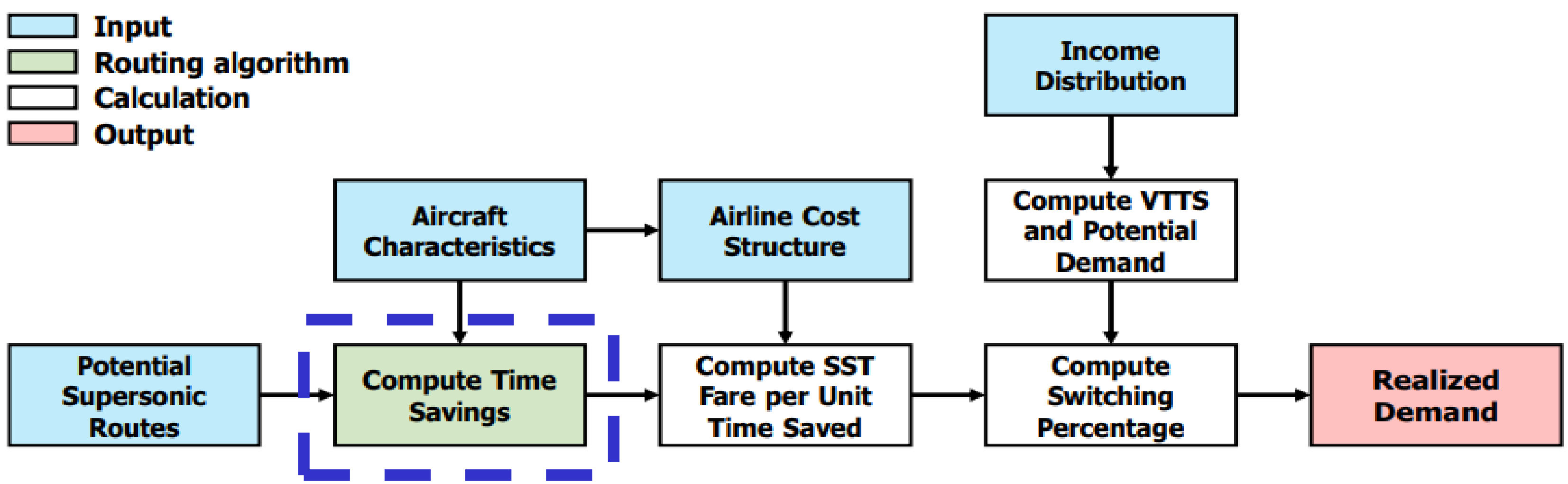
- **Updated** demand forecast from the **latest** Boeing Commercial Market Outlook (2022)
  - COVID recovery is still on-going
  - Boeing calls for a full recovery of global aviation by 2024, along with a return to growth rates comparable to those observed pre-pandemic

Decline in world total passengers

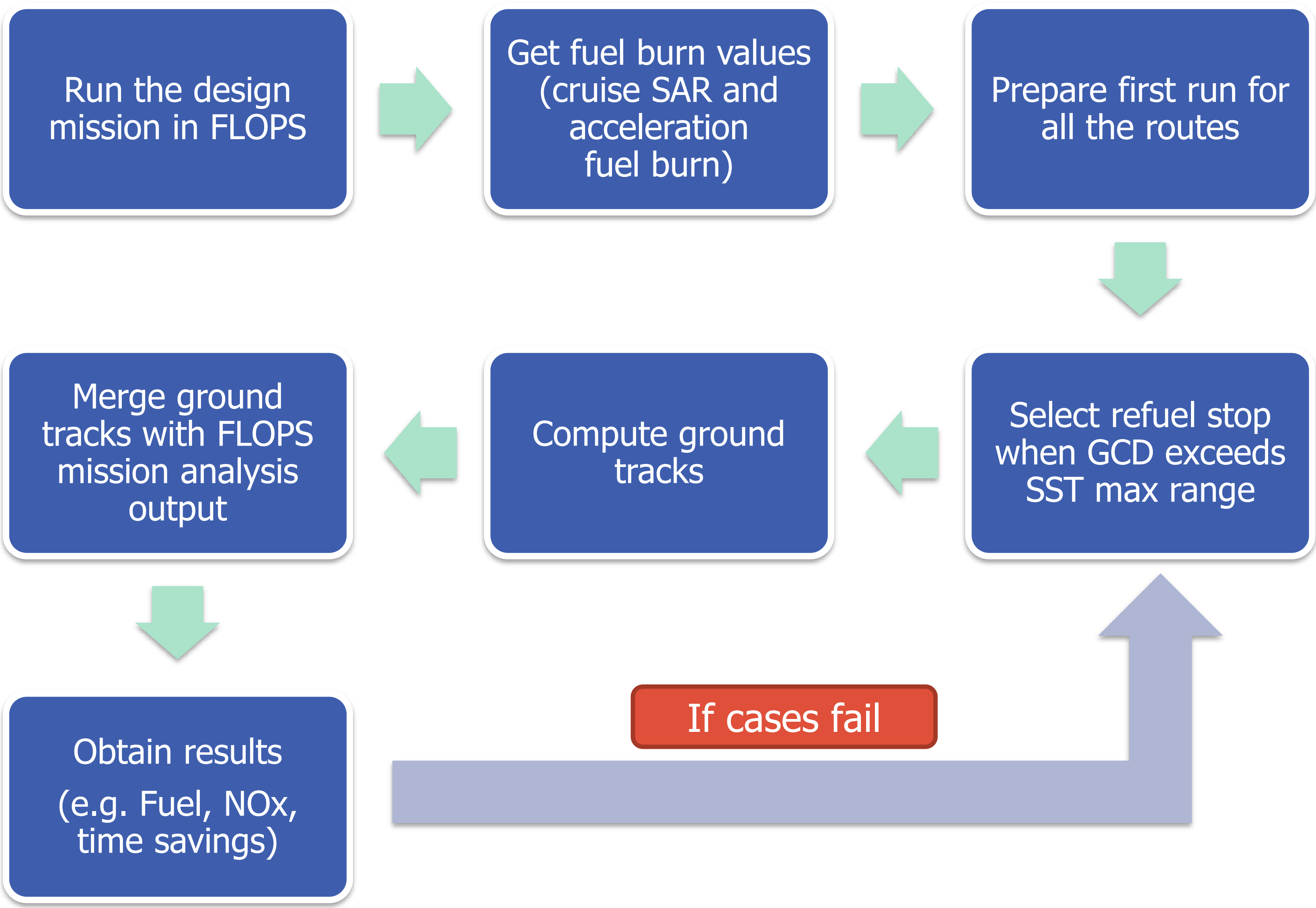
2022 vs. 2019	⬇ -28% to -29%
2021 vs. 2019	⬇ -49%
2020 vs. 2019	⬇ -60%

Source: ICAO

- Value of Travel Time Savings (VTTS) calculated to estimate passengers willing to pay extra for time savings
- Use income distribution and ticket price estimates to infer switching percentage



Refresher: Off-design Mission Analysis Flowchart



Fleet Analysis Results

Passenger load factor assumption: **80%**

Total potential routes in **2050** using the updated forecast: **1222**

- dropped from 2000+ forecasted pre-pandemic, but basically a subset of the previous routes
- routes with high passenger demand for SST service, not necessarily viable

Viability Filters

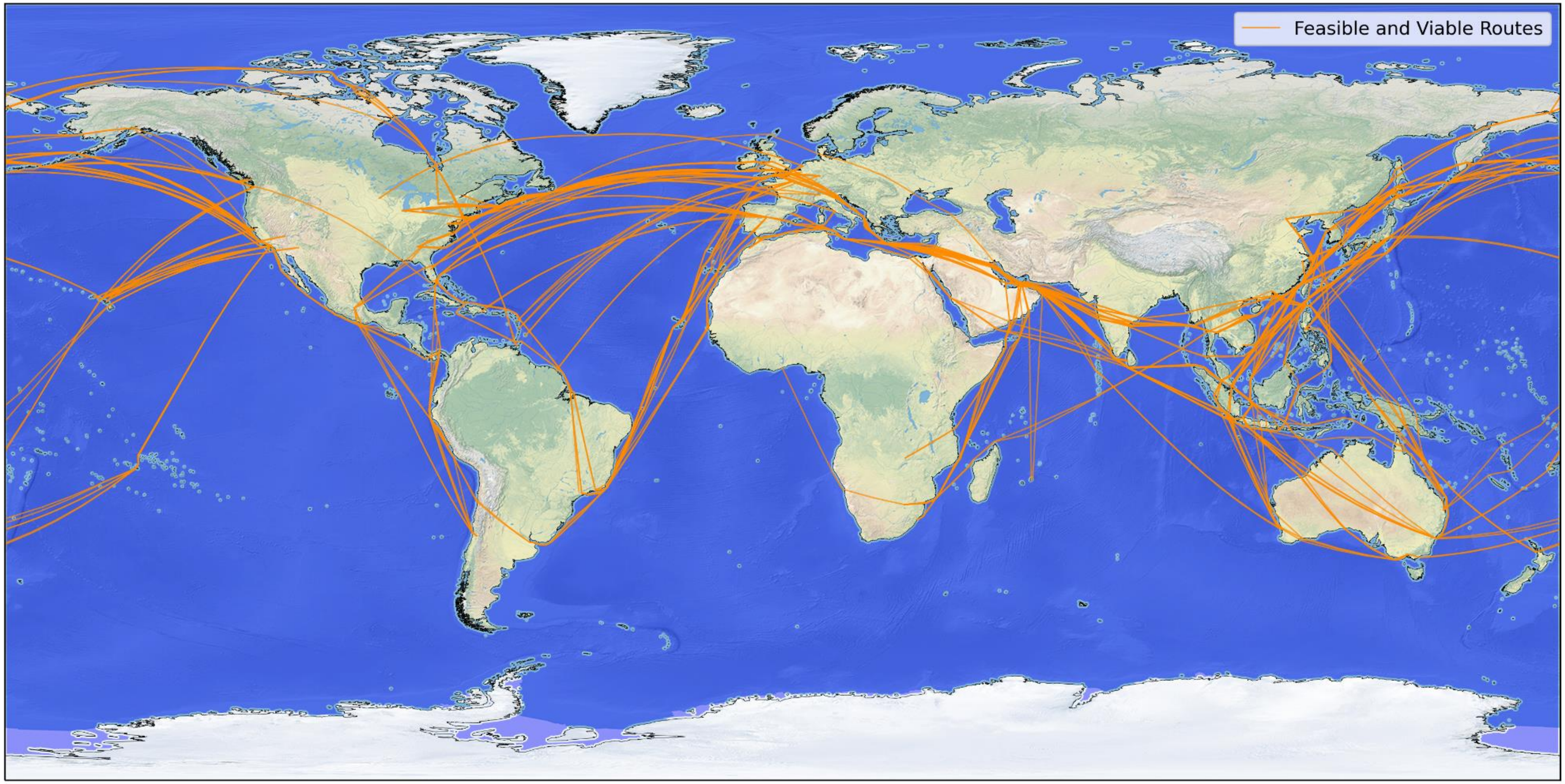
- **>20%** relative time savings compared to the reference subsonic aircraft
- **>2 hrs.** absolute time savings compared to the reference subsonic aircraft
- **>1** flight per day in 2050
- **< $1,000** ΔFare per hour saved

Aircraft Model	Feasible and Viable Routes	% Feasible Routes Also Viable	% Routes with Refuel	Total Daily Flights in 2050	Total Annual Flights (Thousands)	Total Annual Passengers (Millions)	Total Annual Flight Distance (Billion km)
65pax M1.7	391	32.0%	24.3%	1432	523	27.2	3.19

Total Annual Flight Hours (Millions)	Total Annual ASK (Billions)	Total Annual RPK (Billions)	Total Annual Fuel Burn (Megatonne)	Total Annual CO_2 (Megatonne)	Total Annual NO_x (Kilotonne)	Fuel Intensity (kg/ASK)	Fuel Efficiency (RPK/L)
2.54	207.2	165.8	29.8	94.0	450.3	0.144	4.45

Fleet of ~1700 aircraft is required

Trajectories of the Forecasted SST Flight Network



Summary Remarks

- Showcased following capabilities …
  - Aero shaped optimization process
    - Utilizing active subspace technique
  - Supersonic propulsion system modeling
  - Multi-fidelity and parametric drag polar generation process
  - VRNS modeling process
- Interdependencies between fuel burn and LTO noise (Ch.14 margin)
  - Varies along the Pareto Front

- Full flight modeling of SSTs in AEDT
  - Arrived at consensus on AEDT implementation requirements to address specific differences between SSTs and subsonic aircraft
  - Developed a plan for generating data packages for enabling full-flight SST modeling in AEDT
  - Generating data for NASA 55t STCA on a set of 4 high demand OD pairs for enabling first cut implementation of SSTs in AEDT
  - Developing requirements and scoping documents to lay out specifics of implementation plan for SMEs
- Updated fleet analysis
  - Using latest forecast including Covid
  - Latest M 1.7 vehicle