FAA CENTER OF EXCELLENCE FOR ALTERNATIVE JET FUELS & ENVIRONMENT

Aircraft Technology Modeling and Assessment

Project 10
Purdue University

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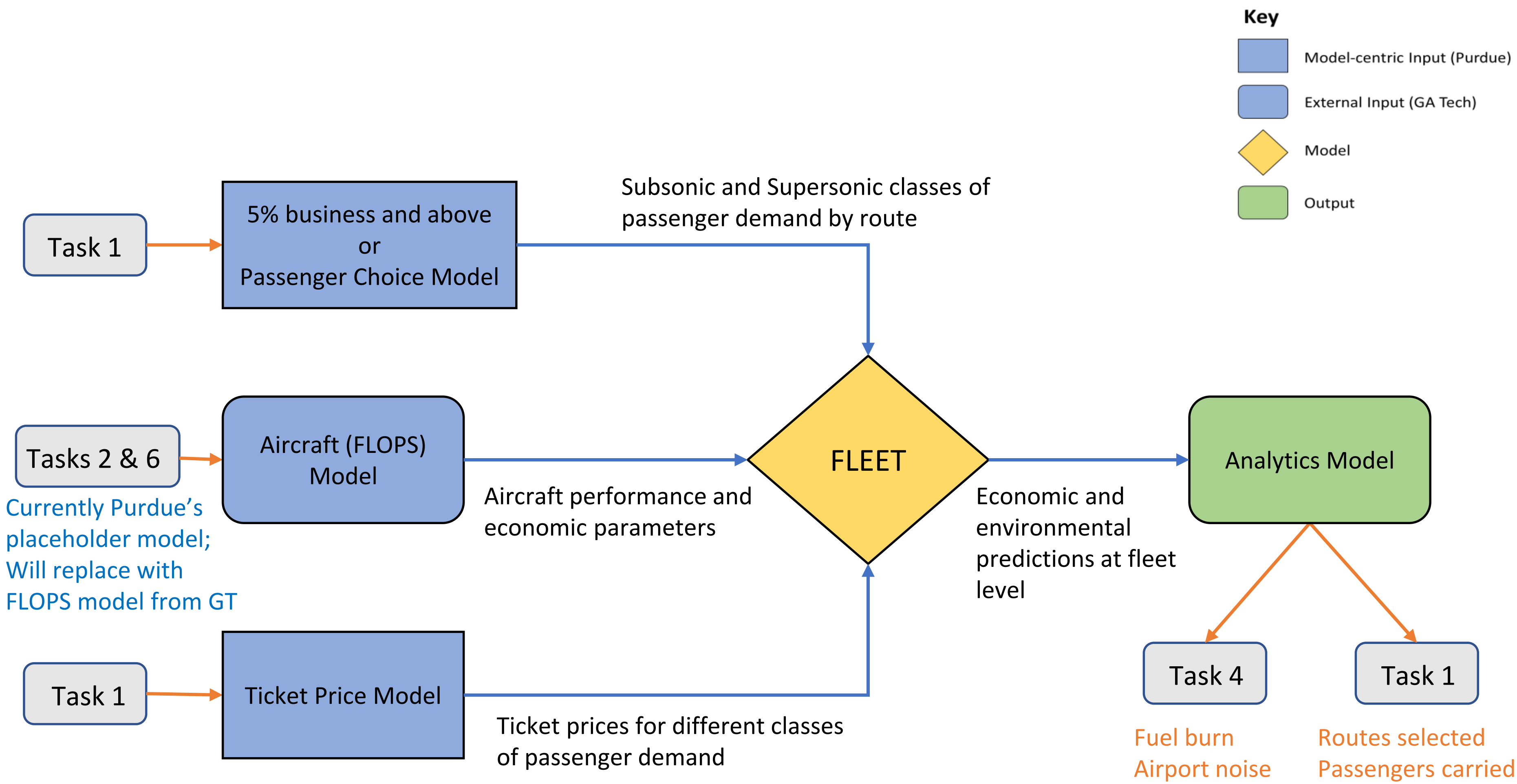
ASCENT
AVIATION SUSTAINABILITY CENTER

Team Approach to Tasks

Overall Objective: Investigating fleet impact of introducing supersonic transport (SST) in terms for fuel burn, emissions and noise, including sonic boom for various scenarios

Objective		Georgia Tech	Purdue
1	Fleet Assumptions & Demand Assessment	Expand Airline cost model: Capture vehicle performance sensitivities (passenger capacity, cruise Mach number); Evaluate which size vehicle the most likely to be able to close the business case	Airline fleet composition and network; Passenger choice for supersonic / subsonic demand; Effect of supersonic aircraft on subsonic aircraft operations and pricing
2	Fleet Analysis	Develop assumptions for supersonic scenarios relative to 12 previously developed subsonic focused fleet scenarios. Perform fleet analysis with the gradual introduction of SST vehicles into the fleet.	Develop assumptions for supersonic scenarios relative to 12 previously developed subsonic focused fleet scenarios; Perform fleet-level assessments, including additional SST vehicle types; Develop FLEET-like tool for supersonic business jet operations; Simple SST sizing to support FLEET development and studies
3	AEDT Vehicle Definition	Develop Methods to Model Supersonic Flights in AEDT	n/a
4	Support CAEP Efforts	FASST Vehicle Modeling: Develop additional SST class for 100 passengers; Develop AEDT coefficient generation algorithm for BADA3 supersonic coefficient; Perform trade studies to support CAEP Exploratory Study	Provide representative supersonic demand scenarios; Develop and assess airport noise model to account for supersonic aircraft
5	BADA4 Coefficient Generation	Develop, implement, and test BADA4 coefficient generation algorithms; Identify gaps and needs for BADA4 coefficient generation for SST	n/a
6	Coordination	Coordinate with entities involved in CAEP Supersonic Exploratory Study; Coordinate with clean-sheet supersonic engine design project	Coordinate with entities involved in CAEP MDG/FESG, particularly the SST demand task group; Maintain ability to incorporate SST vehicle models that use the engine design from ASCENT project 47 and / or NASA-developed SST models

Flowchart relating FLEET simulations and ASCENT 10 project tasks



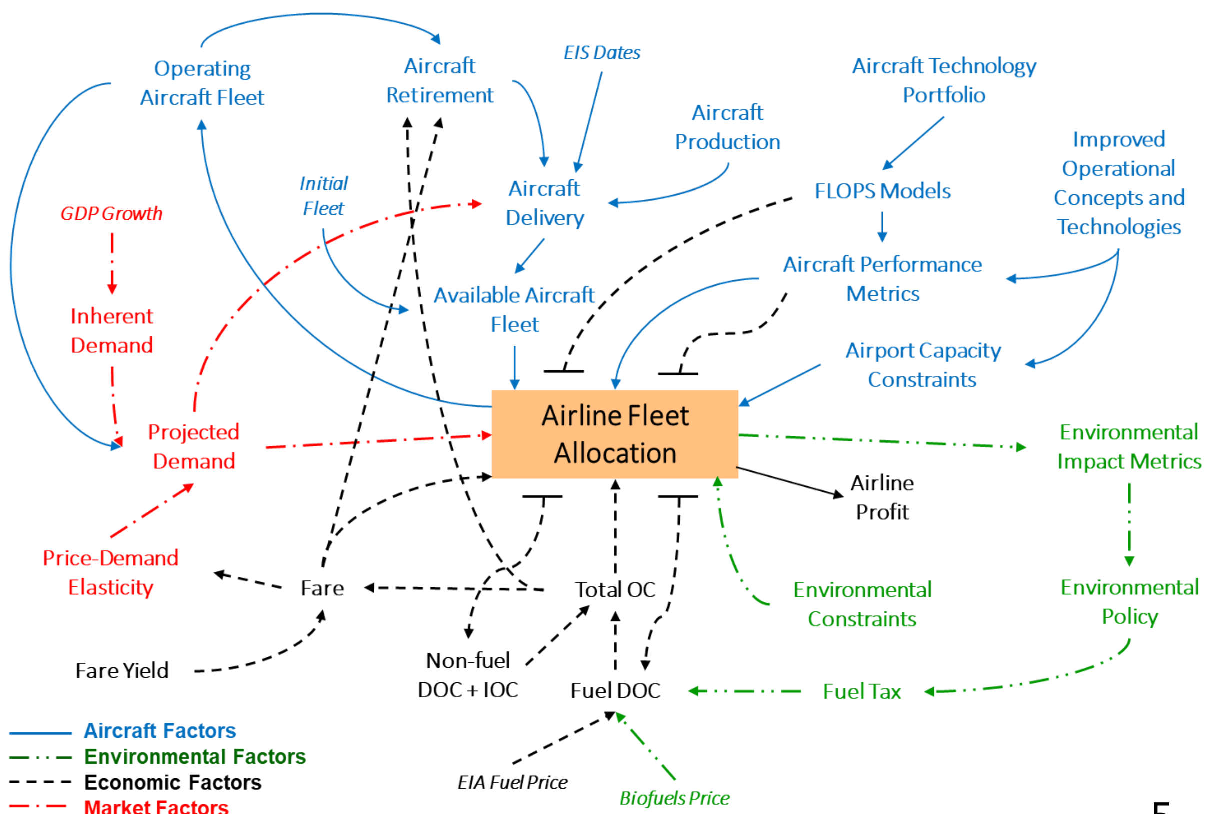
Fleet-Level Environmental Evaluation Tool (FLEET) and Supersonic Demand Prediction

- FLEET originally developed to predict fleet-level environmental impacts of "US-touching" commercial aviation
  - New aircraft technology and new aircraft concepts predicted to consume less fuel, generate less noise than current aircraft
  - How airlines use the new aircraft will drive the fleet-level impacts
- FLEET includes a model of a profit-seeking airline
  - Output includes information about the type(s) of and number of aircraft allocated to routes to meet passenger demand
  - FLEET predictions build upon reported data from Bureau of Transportation Statistics for routes and passenger demand
- Introducing supersonic aircraft to FLEET in ASCENT Project 10
  - Challenge of little relevant historical data in BTS for supersonic passenger demand
  - Allocation would indicate routes where supersonic aircraft might be used and number of operations
    - Supersonic-eligible route network has 205 potential routes including those with fuel stops
    - Allocation results show supersonic aircraft allocation on 51 routes for year 2038
  - Work in still in progress

Supersonic demand includes both passenger demand and routes

Fleet-Level Environmental Evaluation Tool (FLEET) Overview

- A system dynamics-inspired simulation to evolve airline fleet, passenger demand, environmental impact over time
- At core, an allocation problem simulates a profit-seeking airline
  - 1,940 routes connects a subset of WWLMINET 257 airports
  - **US-domestic routes**
  - **Int'l routes with direct flight originating or ending at US airport**
- FLEET represents aircraft by class (number of seats) and by technology age



Airline Fleet Allocation

Maximize $$\sum_{k=1}^{K}\sum_{j=1}^{J} pax_{k,j}P_{k,j} - \sum_{k=1}^{K}\sum_{j=1}^{J} x_{k,j}C_{k,j}$$

Profit = (Revenue – Cost)

Subject to:

$$\sum_{k=1}^{K} pax_{k,j} \leq dem_j$$

Maximum passenger demand constraint

$$\sum_{k=1}^{K} 2x_{k,j}\left(BH_{k,j} + MH_{k,j} + t\right) \leq 24fleet_k$$

A/C count constraint

$$pax_{k,j} \leq x_{k,j}cap_k$$

A/C capacity constraint

$$\sum_{a=1}^{A} NArea_a(x) \leq NArea$$

Airport noise constraint

Parameters:

$P_{k,j}$ = roundtrip ticket price per passenger on aircraft k and route j

$C_{k,j}$ = roundtrip cost to fly aircraft type k on route j

dem_j = one way passenger demand on route j

$BH_{k,j}$ = one way block hours for aircraft type k on route j

$MH_{k,j}$ = one way maintenance hour for aircraft type k on route j

t = aircraft turnaround time

$fleet_k$ = fleet size (number of aircraft) of type k

cap_k = capacity of aircraft type k

Parameters (con't):

$NArea$ = total allowable noise area

Variables:

$x_{k,j}$ = number of round trips of aircraft type k on route j

$pax_{k,j}$ = passengers flown one way on aircraft type k on route j

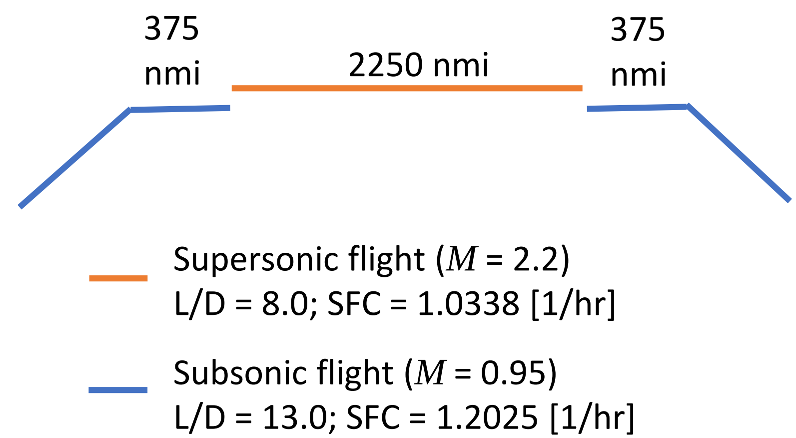
Intermediate function:

$NArea_a(x)$ = noise area at airport a based on linear equation of number of operations at airport a

Supersonic Aircraft Model for Block Time and Fuel Burn Estimates

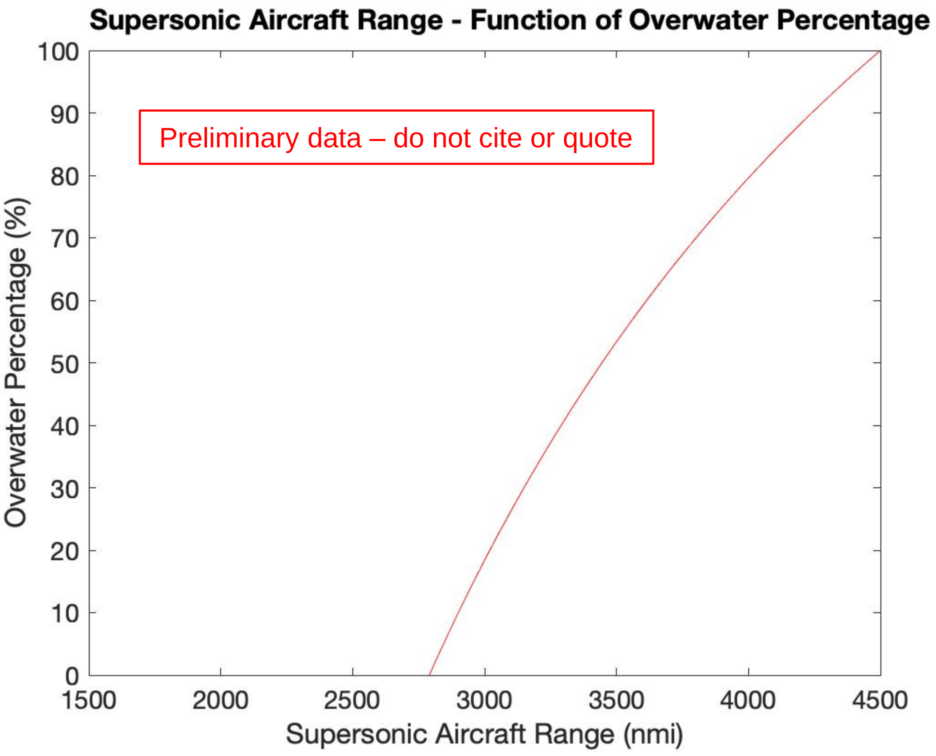
- Supersonic Aircraft Sizing ("back of the envelope" representation of A10 notional medium SST)
  - 55-seat supersonic aircraft with 4500 nmi range
  - Noisy sonic boom; flies supersonic over water at M = 2.2 and subsonic over land at M = 0.95
  - Breguet range equation for fuel burn, and block time for different overwater percentages
    - Overland flight segment assumed equally split at each end of overwater segment; in reality, overland segment is route dependent and may lead to different fuel burn characteristics for each direction on each route
    - L/D ratio changes for M = 2.2 and M = 0.95; as per our engineering judgement
      - L/D_{sup} = 8.0 @ M = 2.2; L/D_{sub} = 13.0 @ M = 0.95
    - Fuel burn estimates based on multipliers for fuel per seat nautical mile [lb.fuel / seat-nmi] provided by GT for consistency in A10 team
      - SFC_{Sup} = 1.0338 [1/hr]@ M = 2.2 and SFC_{Sub} = 1.2025 [1/hr] @ M = 0.95

- Example mission: 3000 nmi with 75% flight overwater
  - Segment overwater: 2250 nmi
  - Segment overland: 750 nmi



Supersonic Aircraft Model for Block Time and Fuel Burn Estimates

- The simple sizing and performance assessment allows estimation of supersonic aircraft maximum range as a function of route % overwater
- In simulations out to 2050, two generations of supersonic aircraft considered with EIS dates of 2025 and 2038
  - Generation 2 supersonic aircraft shows improved fuel burn only; no change in noise characteristics
- Will replace with refined vehicle model(s) when available



Supersonic Aircraft Cost Models in FLEET Allocation

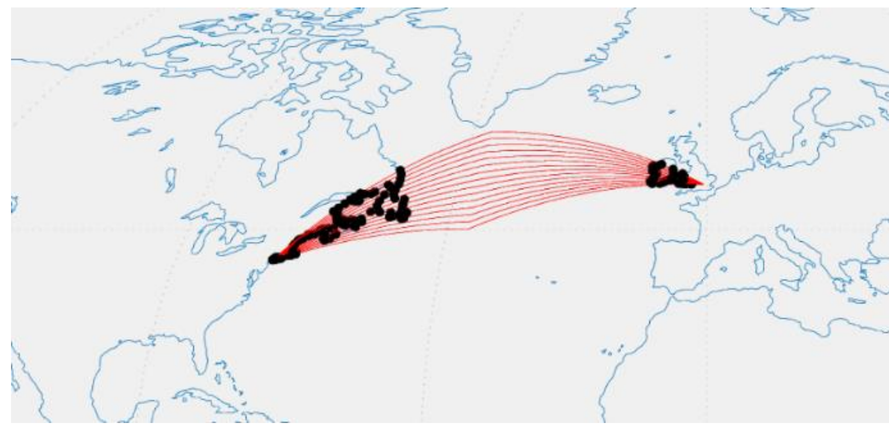
- Assume that notional medium SST acquisition cost equals that of a very large commercial subsonic aircraft (Class 6: 400+ passengers)
- Assume 100% of SST acquisition cost amortized over a 15-year period, and this is reflected in financing cost.
- Total operating costs of SST includes:
  - **Crew cost**: Based on time, but crew pay rate equal to very large subsonic aircraft (class 6)
  - **Maintenance cost**: Equal to very large subsonic aircraft (class 6)
  - **Financing cost**: Includes acquisition cost and interest cost
  - **Indirect operating cost**: Includes financing cost, servicing cost, insurance cost, etc.
  - **Fuel cost**: Based on fuel consumption of each flight and average fuel price every year

Characterizing Supersonic Passenger Demand

- To estimate supersonic passenger demand, start from BOOM statement about passengers paying same fares as today's business class
- Assume 5% of passengers on a given flight pay business class or above fares
  - Correlates with data for *domestic flights* (DB1B 2016, 10% sample of O-D fares)
    - All domestic flights, 4.3% of reported tickets were business or above
    - Domestic flights between 2350 and 4500 nmi, 6.89% business or above
- For FLEET currently, 5% of passengers on a route are the only potential supersonic passengers
  - This is just a starting point
  - Some form of a passenger choice model likely preferable
- FLEET uses BTS reported enplanements as the basis for passenger demand in the allocation problem
  - Reflects passengers carried on US-touching routes by US flag carriers

Identifying Potential Supersonic Routes

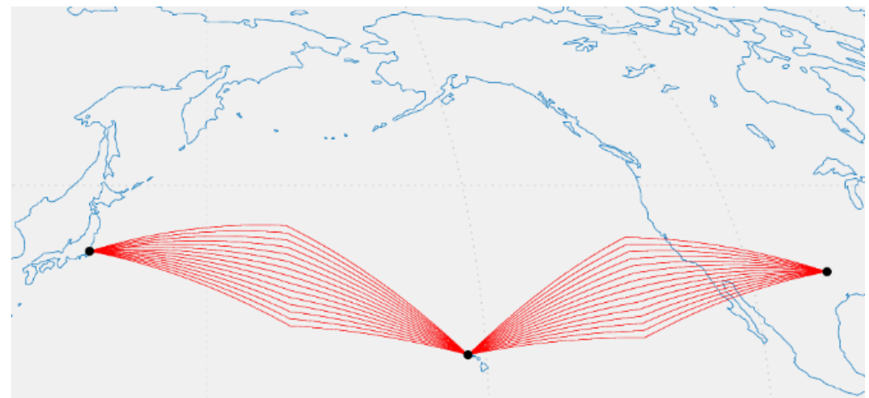
- To identify *nonstop* potential supersonic routes
  - Distance flown adjustment to minimize block time
  - Minimum time distance less than or equal to 4,500 nmi
  - Routes satisfying supersonic aircraft's range capability as a function of overwater flight percentage
  - Routes with block time savings of 1 hour or more when flying supersonic aircraft
    - Time savings reflect willingness to pay
    - Will be better represented by a passenger choice model in future
- 193 nonstop potential supersonic routes in FLEET network



Simple overwater route adjustment strategy using JFK-LHR

Identifying Potential Supersonic Routes

- To identify potential supersonic routes *with fuel stops*
  - Minimum time distance less than or equal to 9,000 nmi
  - Only airports in FLEET network eligible fuel stops
    - Two trans-Pacific fuel stops flights: HNL and ANC
    - Four trans-Atlantic fuel stops : SNN, KEF, OSL and SJU
  - Considers range vs. percent overwater per "hop"
  - Allows heading deviation for each hop; i.e., from airport A – fuel stop and fuel stop – airport B
  - Currently, fuel stop adds 60 minutes
  - Routes with block time savings of 1 hour or more when flying supersonic aircraft
- 12 additional routes with fuel stop in FLEET network (total of 205 supersonic routes)

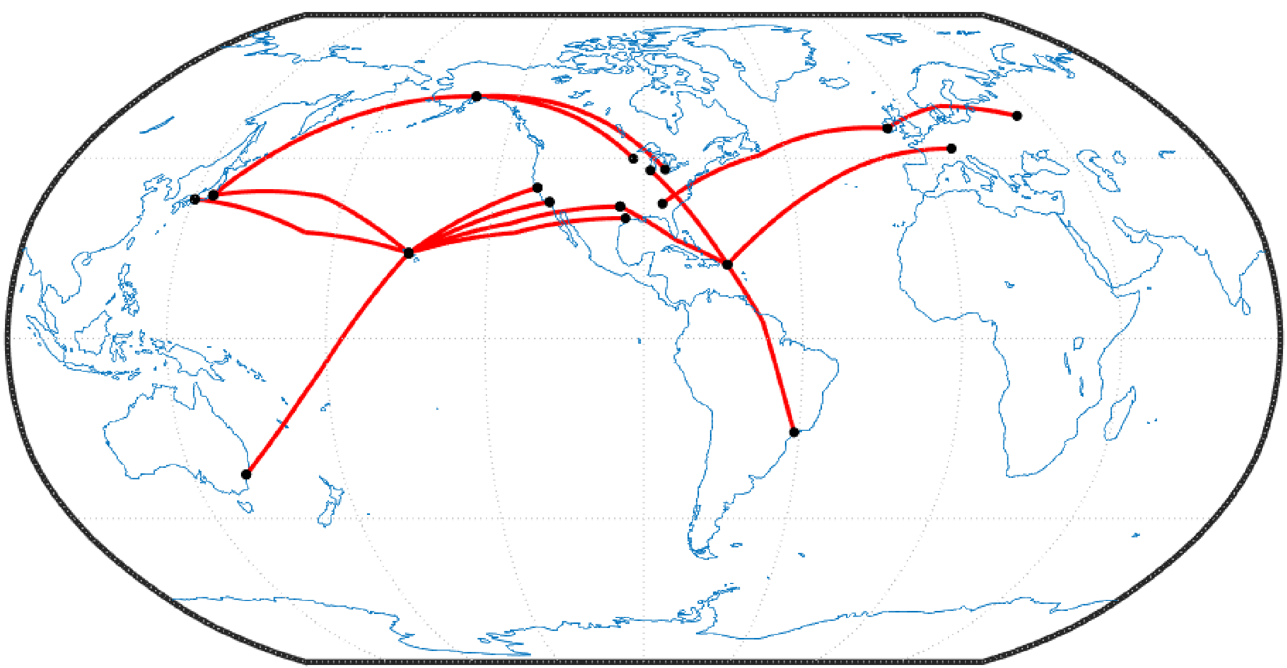


Simple overwater route adjustment strategy for supersonic routes with fuel stop using DFW – NRT with fuel stop at HNL

FLEET Potential Supersonic Routes with Fuel Stops

Preliminary data – do not cite or quote

Airport A	Fuel Stop	Airport B	Min Time Route Length [nmi]	Time Savings [hr]	Cumulative % Overwater	Segment 1 % Overwater	Segment 2 % Overwater
ATL	SNN	SVO	4976.93	2.98	65.15	82.74	28.69
DFW	HNL	KIX	6910.03	4.41	83.63	69.48	96.50
DFW	HNL	NRT	6620.84	4.23	83.99	69.48	98.32
DFW	SJU	ZRH	5866.45	2.88	84.98	76.23	89.15
DTW	ANC	NRT	5564.78	3.04	45.28	0	84.64
GRU	SJU	ORD	4586.12	2.19	43.11	30.08	63.26
IAH	HNL	NRT	6733.72	4.52	84.02	70.03	98.32
KIX	HNL	SFO	5701.47	4.05	97.50	96.5	99.24
LAX	HNL	NRT	5557.11	4.30	98.65	99.13	98.32
LAX	HNL	SYD	6639.63	7.17	99.22	99.13	99.27
MSP	ANC	NRT	5159.83	2.96	48.84	0	84.64
SFO	HNL	SYD	6494.80	7.16	99.26	99.24	99.27



Summary and a Few "Interesting" Routes

- 193 nonstop routes in FLEET network
  - 137 routes with ≥ 75% of overwater flight
  - 33 routes with overwater flight between 50% and 75%
  - 23 routes with overwater flight < 50%
- 12 routes with fuel stop in FLEET network

	Parameter	Airport A	Airport B	Great Circle Distance [nmi]	% Over-water	Min Time Distance [nmi]	Block Time (in hours)		Time Savings (in hours)
							Subsonic	SST	
Nonstop routes	Max % overwater	EWR	SJU	1400.98	**99.63**	1400.98	2.90	1.17	1.73
	Min % overwater	MIA	SEA	2364.89	**18.37**	2414.53	4.90	3.87	1.03
	Max time savings	NRT	SJC	4468.74	98.92	4468.80	9.26	3.60	**5.66**
	Min time savings	EWR	FLL	927.18	85.71	980.67	1.92	0.92	**1.00**
Fuel stop routes	Max % overwater	SFO	SYD	6452.35	**99.26**	6494.80	13.35	6.19	7.16
	Max time savings	LAX	SYD	6512.48	99.22	6639.63	13.48	6.31	**7.17**

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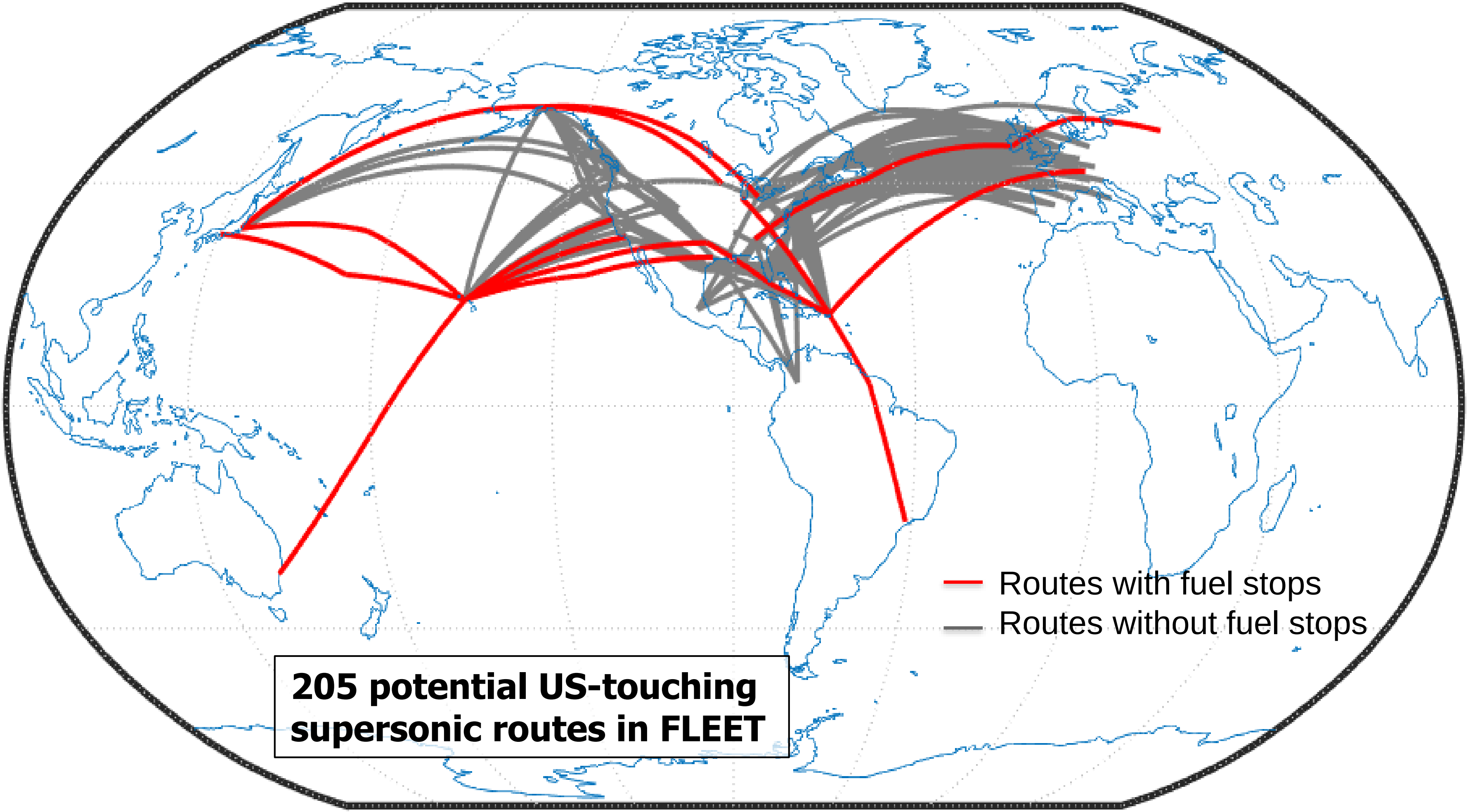
Potential Supersonic Routes for FLEET



205 potential US-touching supersonic routes in FLEET

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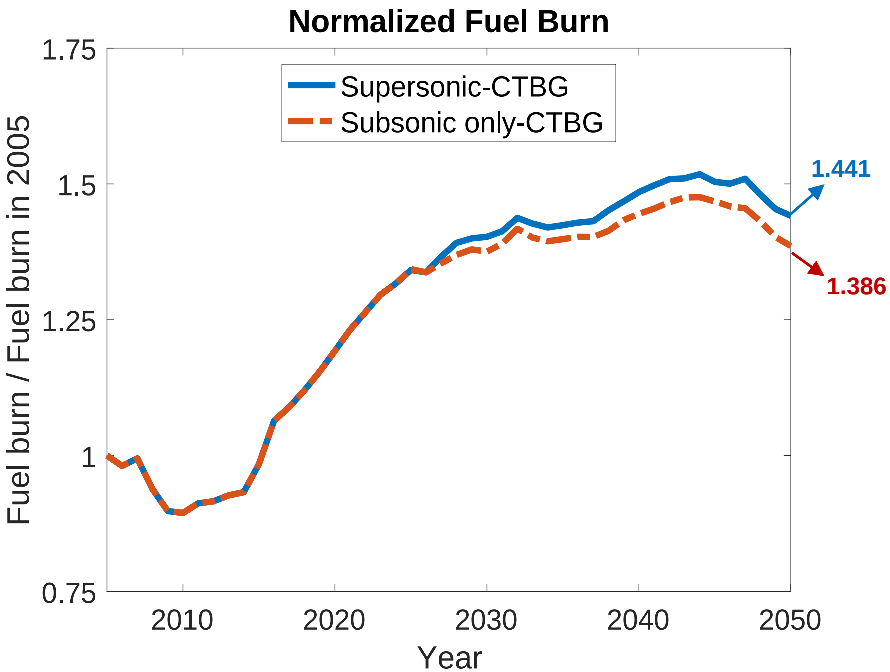
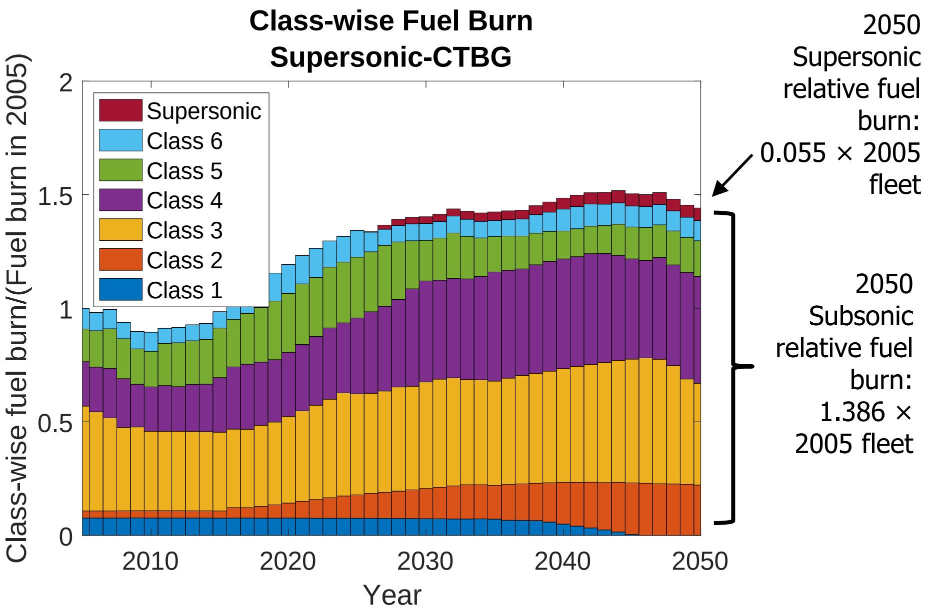
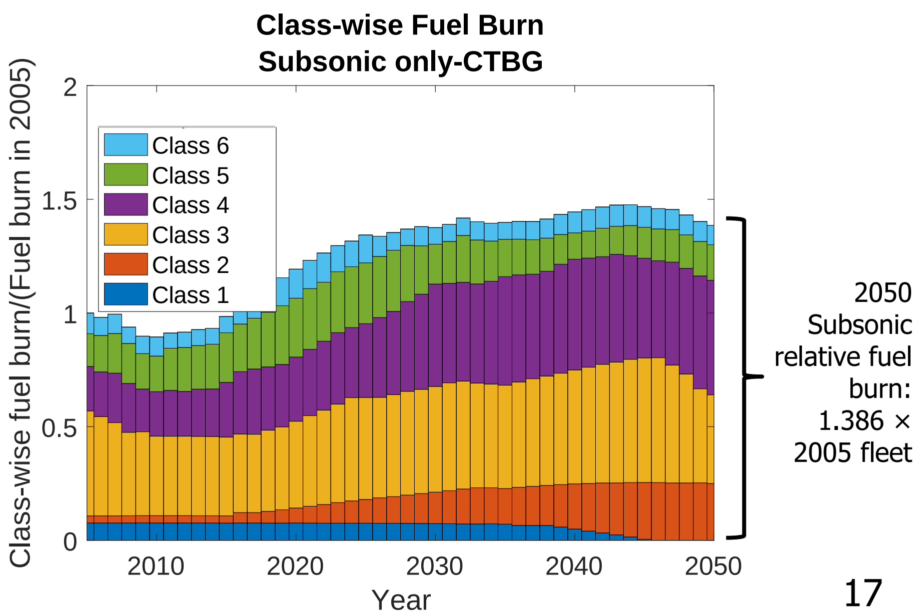
Classification of Aircraft in FLEET

- FLEET represents aircraft by class (number of seats) and by technology age
- Classification with respect to number of seats (class)
  - Class 1: Small Regional Jet [SRJ]
  - Class 2: Regional Jet [RJ]
  - Class 3: Small Single Aisle [SSA]
  - Class 4: Large Single Aisle [LSA]
  - Class 5: Small Twin Aisle [STA]
  - Class 6: Large Twin Aisle [LTA]
  - A10 Notional Medium Supersonic Transport [SST]
- Classification with respect to technology age
  - Representative-in-class (most flown aircraft in 2005)
  - Best-in-class (aircraft with most recent entry into service dates in 2005)
  - New-in-class (aircraft currently under development that will enter service in near future)
  - Future-in-class aircraft (aircraft that will enter into service after new-in-class aircraft)

Example Fleet Impact Assessment







- Current Trends Best Guess scenario from previous subsonic-only ASCENT 10 work
  - Supersonic aircraft introduced in 2025 and 2038
  - Supersonic allocation before subsonic; accommodating premium passengers first
- With current modeling:
  - 2050 fleet fuel burn higher with supersonic aircraft than subsonic only
  - Allocating supersonic aircraft changes the use, retirement and acquisition of subsonic aircraft

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Example 2038 FLEET Aircraft Allocations on Potential Supersonic Routes

- 2038 selected as a year of interest; chose in part because airline has only one “type” of medium SST available in 2038
- SST aircraft allocated on 51 routes in year 2038 (26 shown on this slide)

Route Information				Number of Daily Roundtrips for different A/C Size and Generation							
Airport A	Airport B	Fuel Stop	Min Time Distance (nmi)	New-in-Class 3	Future-in-Class 3	Best-in-Class 4	New-in-Class 4	New-in-Class 5	Future-in-Class 5	New-in-Class 6	Best-in-Class Supersonic
AMS	DTW	0	3443.63	0	0	0	6	2	0	1	2
ANC	SEA	0	1284.51	0	0	0	17	0	1	0	3
ATL	CDG	0	3864.97	0	0	0	4	0	0	0	1
ATL	LGW	0	3742.39	0	0	0	5	0	0	0	1
ATL	SJU	0	1345.09	2	0	0	5	0	0	0	1
BOG	MIA	0	1387.67	1	0	0	5	0	0	0	1
BOS	FLL	0	1077.99	9	0	0	5	0	0	0	2
BOS	MCO	0	983.33	18	0	0	2	0	0	0	2
BOS	MIA	0	1096.31	5	0	0	5	0	0	0	1
BOS	RSW	0	1093.41	6	0	0	2	0	0	0	1
BOS	SJU	0	1458.95	2	0	0	3	1	0	0	1
BOS	TPA	0	1050.29	3	0	0	5	0	0	0	1
CDG	JFK	0	3182.62	0	0	0	4	2	0	0	1
DFW	NRT	HNL	6620.84	0	0	0	6	0	0	0	1
DFW	SJU	0	1891.91	0	1	0	4	0	0	0	1
DTW	NRT	ANC	5564.78	0	0	0	1	0	0	6	2
EWR	FLL	0	980.63	17	0	0	0	0	0	0	2
EWR	LGW	0	3093.84	0	0	0	4	0	0	0	1
EWR	SJU	0	1400.89	0	0	0	8	0	1	0	1
FLL	JFK	0	934.26	29	0	0	0	0	1	0	4
FLL	LAX	0	2075.74	0	0	0	5	0	0	0	1
FLL	LGA	0	953.83	40	0	0	0	0	0	0	5
FRA	IAD	0	3622.24	0	0	0	1	0	2	1	1
HNL	IAH	0	3404.05	0	0	0	2	0	0	1	1
HNL	KIX	0	3618.86	0	0	0	3	0	3	0	1
HNL	LAS	0	2397.7	0	1	0	4	0	0	0	1

Preliminary data – do not cite or quote

Example 2038 FLEET Aircraft Allocations on Potential Supersonic Routes

- 2038 selected as a year of interest; chose in part because airline has only one "type" of medium SST available in 2038
- SST aircraft allocated on 51 routes in year 2038 (remaining 25 shown on this slide)

Route Information				Number of Daily Roundtrips for different A/C Size and Generation							
Airport A	Airport B	Fuel Stop	Min Time Distance (nmi)	New-in-Class 3	Future-in-Class 3	Best-in-Class 4	New-in-Class 4	New-in-Class 5	Future-in-Class 5	New-in-Class 6	Best-in-Class Supersonic
HNL	LAX	0	2227.44	0	0	1	26	2	0	0	5
HNL	NRT	0	3329.67	0	0	0	10	3	0	0	2
HNL	SEA	0	2326.19	0	0	0	2	2	1	0	1
HNL	SFO	0	2082.62	0	1	0	15	1	0	0	3
IAD	LHR	0	3255.82	0	1	0	5	1	0	0	1
JFK	LHR	0	3093.34	0	0	0	12	0	0	1	2
JFK	MIA	0	952.46	12	0	0	2	0	0	0	2
JFK	PBI	0	898.93	19	0	0	0	0	0	0	2
JFK	RSW	0	982.9	7	0	0	5	0	0	0	1
JFK	SJU	0	1391.97	0	1	0	20	0	0	0	4
KIX	SFO	HNL	5701.47	0	0	0	1	0	2	0	1
LAX	MCO	0	2001.92	0	2	0	5	1	0	0	1
LAX	MIA	0	2052.94	0	2	0	6	1	0	0	1
LAX	NRT	HNL	5557.11	0	0	0	9	0	3	0	2
LGA	PBI	0	920.09	10	0	0	1	0	0	0	1
LHR	ORD	0	3514.57	0	0	0	11	1	0	1	3
MCO	PVD	0	941.49	2	0	0	4	0	0	0	1
MCO	SJU	0	1051.87	16	0	0	2	0	0	0	2
MIA	SFO	0	2311.44	0	1	0	4	0	0	0	1
MIA	SJU	0	962.57	14	0	0	2	0	0	0	2
MSP	NRT	ANC	5159.83	0	0	0	2	0	0	3	1
NRT	SEA	0	4133.73	0	0	0	1	0	5	0	1
NRT	SFO	0	4442.36	0	0	0	8	0	3	0	2
ORD	SJU	0	1802.24	0	0	0	5	1	0	0	1
PHL	SJU	0	1372.99	2	0	0	6	0	0	0	1

Preliminary data – do not cite or quote

Example 2038 FLEET Aircraft Allocations on Selected Routes

Selected supersonic-eligible routes

Route Information		FLEET Allocation Information			Number of Daily Roundtrips for different A/C Size and Generation						
Airport A	Airport B	Allocation Model	Fuel Stop	Distance Flown (nmi)	Future-in-Class 3	Best-in-Class 4	New-in-Class 4	New-in-Class 5	Future-in-Class 5	New-in-Class 6	Best-in-Class Supersonic
JFK	LHR	*Supersonic*		3093.34	0	0	12	0	0	1	2
		Subsonic-only		2991.45	0	0	12	0	0	1	
LAX	HNL	*Supersonic*		2227.44	0	1	26	2	0	0	5
		Subsonic-only		2217.99	0	0	28	2	0	0	
DFW	NRT	*Supersonic*	HNL	6620.84	0	0	6	0	0	0	1
		Subsonic-only		5573.4	0	0	0	1	3	1	

Selected subsonic route (supersonic-ineligible route)

Route Information		FLEET Allocation Information		Number of Daily Roundtrips for different A/C Size and Generation				
Airport A	Airport B	Allocation Model	Distance Flown (nmi)	New-in-Class 3	Future-in-Class 3	Best-in-Class 4	New-in-Class 4	Best-in-Class Supersonic
EWR	LAS	*Supersonic*	1930.89	0	1	0	11	N/A
		Subsonic-only	1930.89	2	0	2	9	N/A

- Introduction of supersonic aircraft influences subsonic aircraft allocation
- This FLEET run has no constraints on number of airport operations
- FLEET represents demand carried by US flag carriers, so LAX-HNL has more demand in FLEET than JFK-LHR

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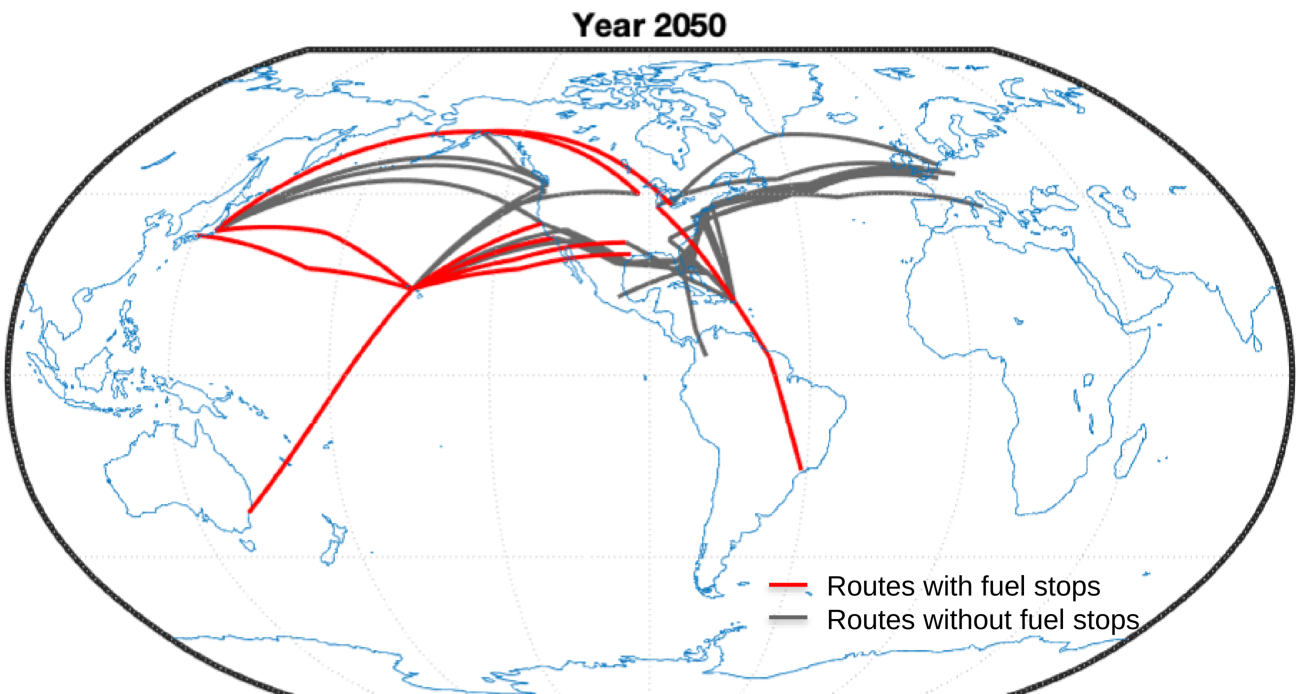
Example Supersonic Route Allocation in FLEET (2026 - 2050)

- First new supersonic aircraft available for allocation in 2026 (EIS 2025); next generation of supersonic aircraft available in 2039 (EIS 2038)
- Airline serves 51 routes with supersonic aircraft in year 2038; 73 routes served with supersonic aircraft in year 2050
- Potential approach to capture total supersonic operations on US-touching international routes



For example, JFK-LHR route (data from flightaware.com)

- Carriers operating flights: 2 US flag carriers (AA, DL), 2 Int'l (VS, BA)
- Number of flights: 6 US, 14 Int'l
- In 2038, FLEET allocates 4 flights on JFK-LHR route; total flights could be 8 (= 4 × 4/2) or 14 (= 4 × 20/6, rounded up)

Summary

- For FLEET currently, 5% of passengers on a route are the only potential supersonic passengers
  – Will replace with a passenger choice model
- Supersonic-eligible route network has 205 potential routes selected based on SST aircraft range and block time savings
  – FLEET route network includes “US-touching” routes only
  – Aircraft range calculations based on “back of the envelope” representation of A10 notional medium SST aircraft
  – Routing utilizes simple overwater route path adjustment strategy
  – 193 nonstop routes
  – 12 routes with fuel stop
- FLEET allocation results indicate routes where supersonic aircraft might be used and number of operations
  – Allocation results show supersonic aircraft allocation on 51 routes for year 2038; 73 routes served with supersonic aircraft in year 2050

Future Work

- Incorporate GT's A10 notional medium SST aircraft models in FLEET simulations along with detailed route path adjustments
- Develop a passenger choice model for supersonic / subsonic demand
- Study the effect of supersonic aircraft on subsonic operations and pricing (includes "higher-density" subsonic work)
- Perform fleet-level assessments, including additional SST vehicle types ("Types 2 and 3" supersonic aircraft)
  - Incorporate SST vehicle models that use the engine design from ASCENT project 47 and / or NASA-developed SST models
- Develop FLEET-like tool for supersonic business jet operations

BACKUP SLIDES

Proposed Work for ASCENT 10 Year 3

- Fleet Assumptions and Demand Assessment
  - Provide representative supersonic demand scenarios (includes pseudo-schedule, acquisition cost sensitivity study)
  - Develop and assess supersonic noise model for FLEET airport noise area constraints

- Coordination
  - Develop assumptions for supersonic scenarios relative to 12 previously developed subsonic focused fleet scenarios
  - Perform fleet-level assessments, including additional SST vehicle types ("Types 2 and 3" supersonic aircraft)
  - Develop FLEET-like tool for supersonic business jet operations
  - Simple SST sizing to support FLEET development and studies

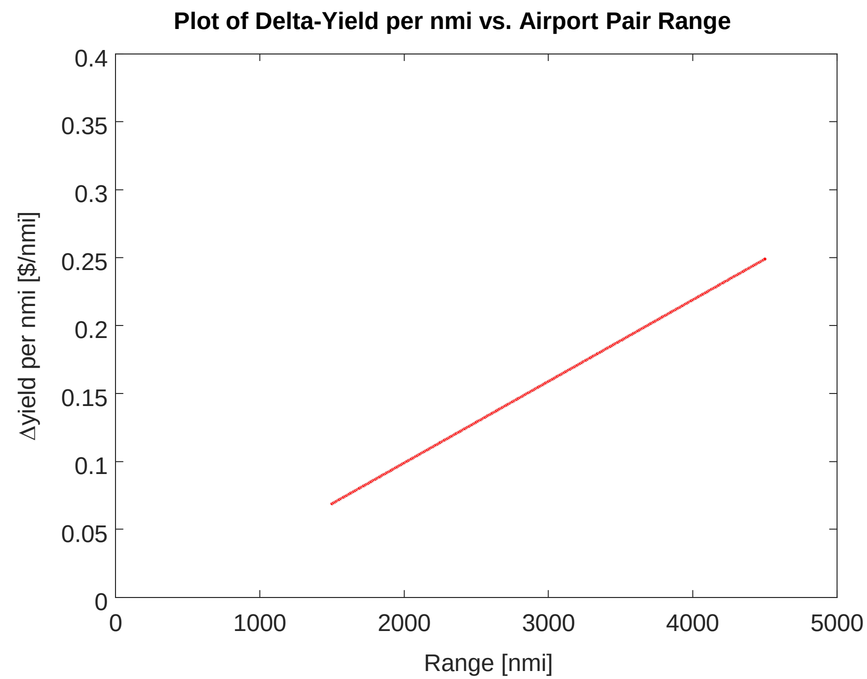
Proposed Work for ASCENT 10 Year 3

- Support CAEP Efforts
  - Update the initial fleet composition and the airline network
  - Develop a passenger choice model for supersonic / subsonic demand
  - Study the effect of supersonic aircraft on subsonic operations and pricing (includes the aforementioned "higher-density" subsonic work)
  - Update the aircraft retirement and acquisition models in FLEET
- Fleet Analysis
  - Coordinate with entities involved in CAEP MDG/FESG, particularly the SST demand task group
  - Maintain ability to incorporate SST vehicle models that use the engine design from ASCENT project 47 and / or NASA-developed SST models

Supersonic Ticket Price Modeling Strategy

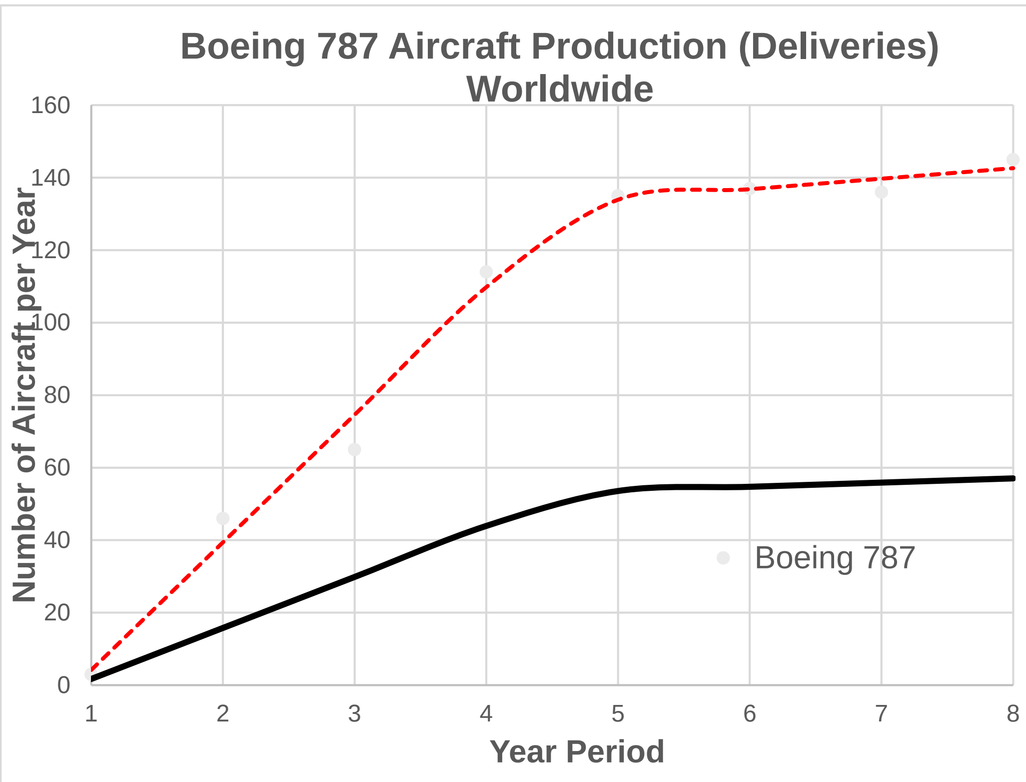
- For subsonic aircraft, FLEET used published ticket prices paid for domestic routes to build power-law model
  - Isolate routes dominated by one class (size) of aircraft from BTS DB1B and T100
  - Power-law curve fit to establish price as a function of aircraft size and route distance
  - Mimics reported preferences of passengers for aircraft size and frequency of service

- For supersonic aircraft, FLEET uses "offered" ticket prices to build a range-dependent delta-yield model
  - International ticket prices paid not available from BTS, "offered" ticket price based upon 2018 "business class and above" offered fares (via matrix.itasoftware.com)
  - Delta-yield here is mark-up (profit) per pax-nmi
    - Linear fit for simplistic ticket delta-yield vs. range elasticity
    - Accounts for willingness to pay more for increased passenger time savings when flying a longer distance using supersonic aircraft
  - Ticket fares equal to operating costs per passenger plus a margin term:



$$Fare_{SST,route\ i} = \left(\Delta yield_{per\ nmi} \times Range_{route\ i}\right) + \frac{Cost\ of\ SST_{route\ i}}{55\ pax}$$

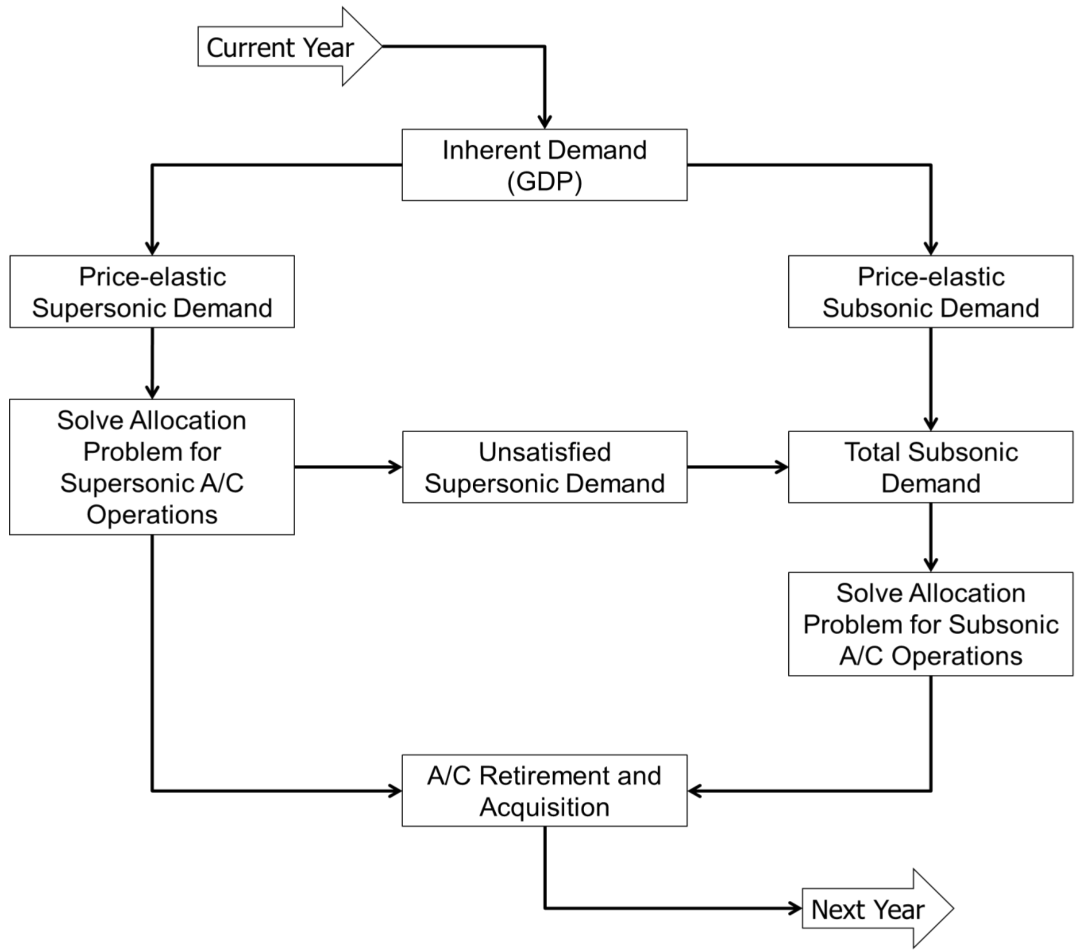
Supersonic Aircraft Production and Aircraft Available in FLEET



- Assume that supersonic aircraft production follows trend for Boeing 787 deliveries over the last decade
  - Recent, high-technology introduction aircraft
  - Provides a historical basis
- 40% of production available to FLEET airline (based on Boeing Market Outlook, North America share of future deliveries)

A Separate Supersonic Aircraft Allocation Problem in FLEET

- Motivation for a separate supersonic allocation
  - Passengers willing to pay for supersonic travel are a subset of all passengers
  - Allocation requires ticket price for aircraft; historical data unavailable for international flights
- Impacts
  - Gives priority to serving supersonic demand
  - Supersonic passenger demand not met with supersonic aircraft combined with subsonic demand
  - "Unsatisfied Supersonic Demand" also drives acquisition of new supersonic aircraft



Levels of Abstraction for FLEET

	Simplification Criterion	Effect on analysis
US-related passenger air traffic (2005 reference for CO_2)		
↓ Passenger air travel on WWLMINET 257 subset	• US airport as at least origin or destination on flights between 257 airports	• Route/city reduction • 190 airports • 80% of passenger traffic (65% of operations)
↓ Aircraft fleet represented by 24 aircraft	• One aircraft represents all aircraft in a class • Reflect technology "age"	• Reduction from 100+ different aircraft types • Resolution in airline fleet reduced
↓ Single airline serves all routes in network	• Single airline provides service on routes currently served by many airlines	• Omits competitive behaviors • Simplifies revenue / profit modeling • Single airline is very large
↓ Aircraft allocation using round-trip assumption	• Avoid time of day scheduling • Assume symmetric demand between cities	• Huge reduction in number of decision variables • Removes "balance constraint" • Omits some time of day issues