



Using Global Market Demand Analysis to Guide Conceptual Design of Low-Boom Supersonic Transports

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SYSTEMS ANALYSIS AND CONCEPTS DIRECTORATE

Motivation

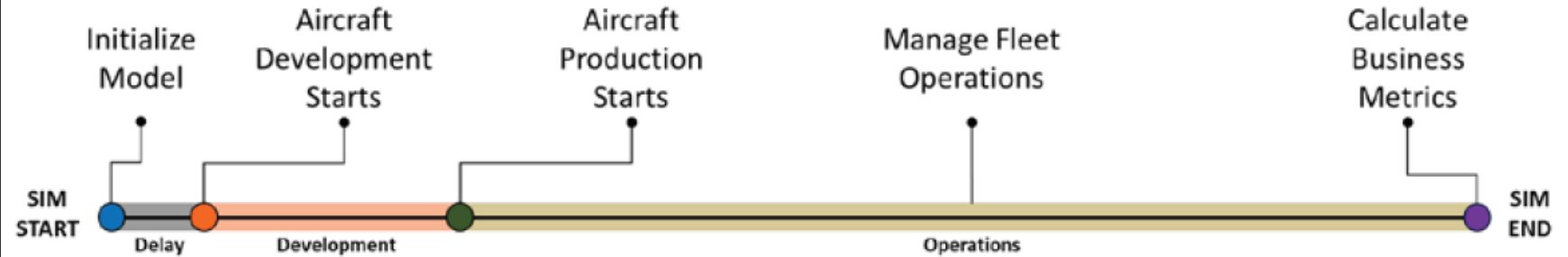


- Need a tool, the supersonic market demand analysis tool (LBSAM2), to compare supersonic concepts for down-selection of an economically viable supersonic transport aircraft.
- Our goal is to use the LBSAM2 analysis to
 - guide conceptual low-boom design.
 - provide system-level requirements for an economically viable supersonic transport aircraft.
 - support future investment decisions on development of commercial supersonic technologies.

Supersonic Market Demand Analysis Methods

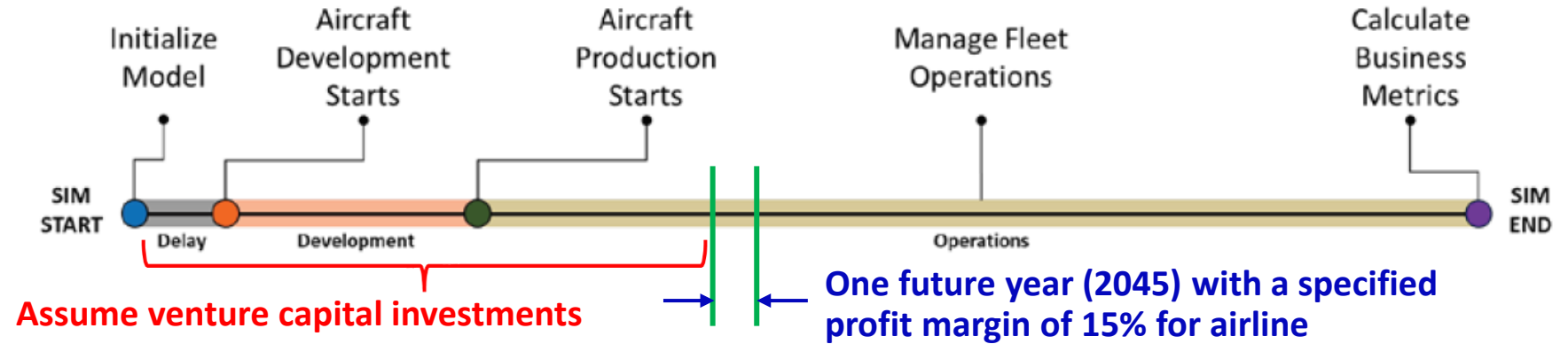


Dynamic analysis of
supersonic market
demand for a 35-year
period (SpaceWorks*)



*H. Magill, *et al.*, “Life Cycle Cost Modeling of High-Speed Commercial Aircraft–Final Report,” NASA/CR-20230012245, Aug. 2023.

Supersonic Market Demand Analysis Methods



Our market demand analysis approach for one future year (LBSAM2[#]):

Analyze the equilibrium state for the specified future year with consistent coupling of involved disciplinary analyses.

Equilibrium state means that the number of acquired aircraft by the airline meets the predicted supersonic passenger demand.

[#] Z. Wang, *et al.*, "Integrated Model for Predicting Demand of Supersonic Transports Under Low-Boom Constraint," J. Air Transportation, 2024.

Coupling of Mission Analysis and Low-Boom Constraint

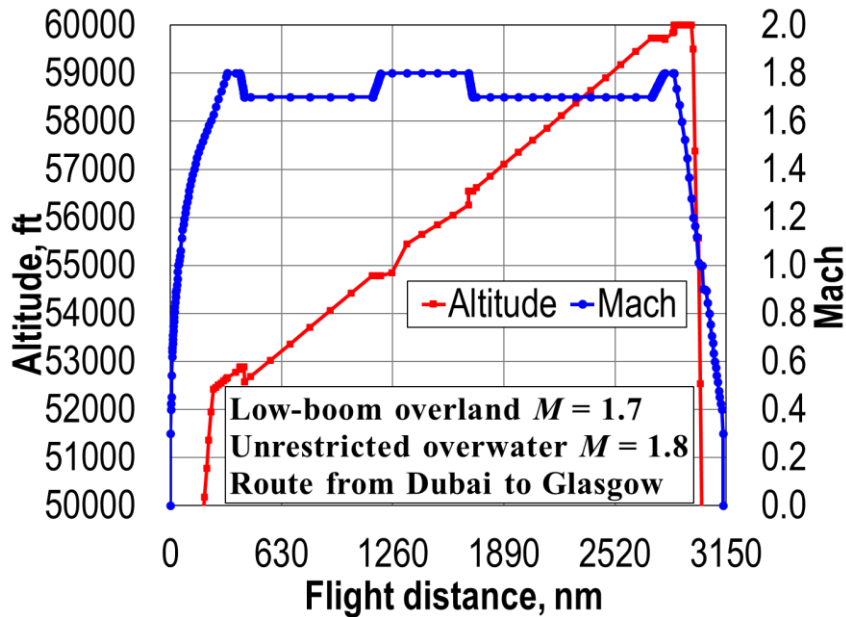


Unrestricted supersonic overwater flight
(using the optimal altitude for min fuel burn)

Low-boom overland flight with target
ground noise level below 70 PLdB
(using a fixed angle of attack for cruise)



Different altitudes and
Mach numbers of the
trajectory for a route
with mixed overland and
overwater segments



Coupling of Mission Analysis and Market Demand Analysis



$$C_{\text{sup}} = [1 + (\text{airline profit margin})] \cdot [1 + (\text{US excise tax rate})] \cdot [C_{\text{flight}} + C_{\text{hour}} \cdot T_{\text{sup}} + FW_{\text{sup}} \cdot (\text{jet fuel price in \$/lb})] / [(\text{load factor for the future year}) \cdot (\text{seating capacity of aircraft})]$$

- LBSAM2 uses approximations of travel time (T_{sup}) and fuel burn (FW_{sup}) for a route of mixed overland and overwater segments to compute the supersonic ticket price (C_{sup}) for an OD pair.
- C_{hour} = airline operating cost per revenue flight hour excluding jet fuel cost and C_{flight} , \$/hr
- C_{flight} = various fees per flight such as ground handling, navigation, landing, emission, and noise fees, \$

The passenger preference model:

$$\text{VOT} \cdot (T_{\text{sub}} - T_{\text{sup}}) - (\text{Value of Passenger Comfort Loss}) \geq C_{\text{sup}} - C_{\text{sub}}$$

(Value of saved travel time) (Due to a smaller seat pitch) (Increase in ticket cost)

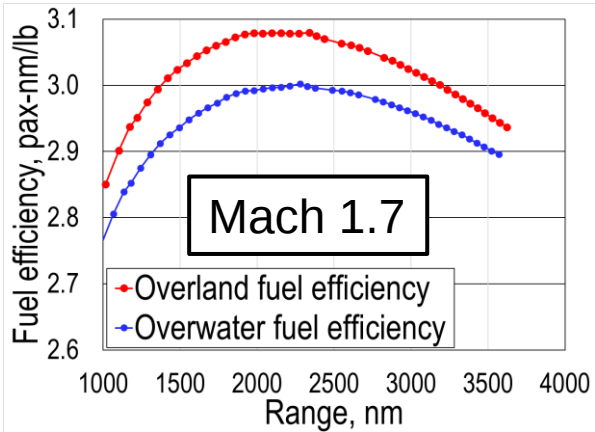
- C_{sub} = subsonic premium ticket price for an OD pair, \$

LBSAM2 achieves the coupling consistency between the market demand analysis, detailed mission analysis, and conceptual-level low-boom constraint.

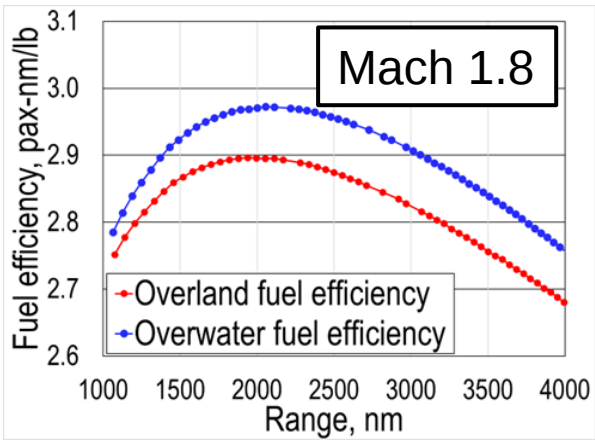
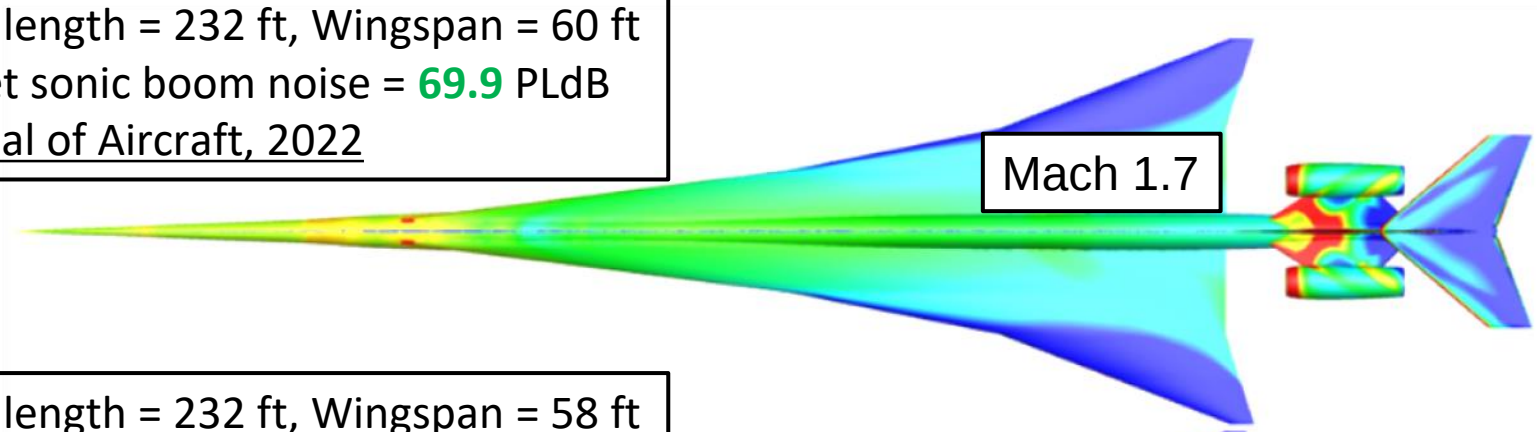


Low-Boom Supersonic Transport Concepts

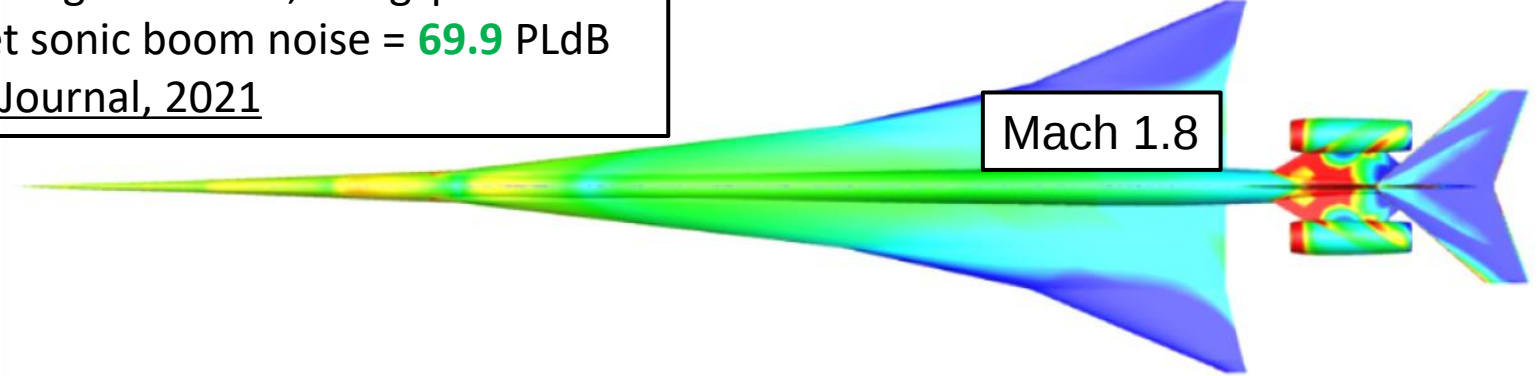
Concept	PAX	MTOGW, lb	OL Mach	OL Range, nm	OW Mach	OW Range, nm
Mach 1.7 concept	50	147,600	1.7	3622	1.8	3572
Mach 1.8 concept	50	167,250	1.8	4163	1.8	4328



Body length = 232 ft, Wingspan = 60 ft
Target sonic boom noise = **69.9** PLdB
Journal of Aircraft, 2022



Body length = 232 ft, Wingspan = 58 ft
Target sonic boom noise = **69.9** PLdB
AIAA Journal, 2021





Market Demand Prediction for 2045

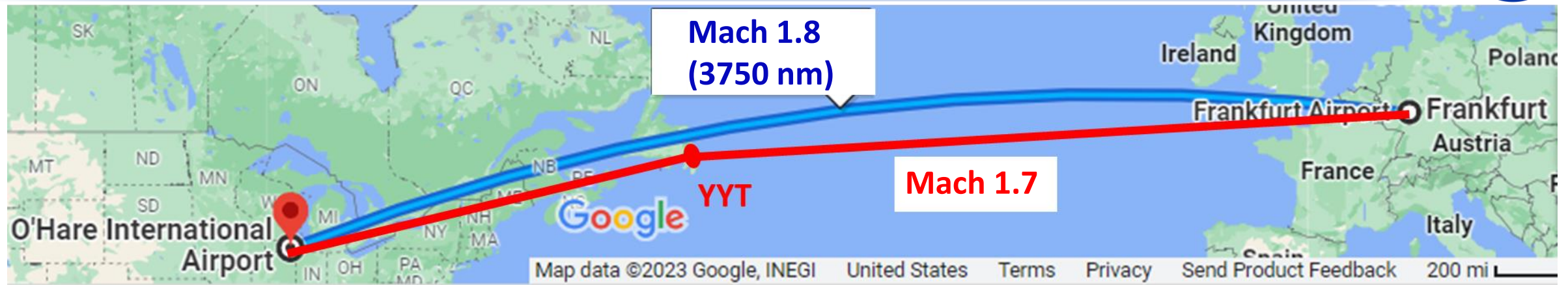
Assumptions:

- Fuel cost = \$3.50 per gallon
- Value of time = \$200 per hour
- Fixed 15% percent of manufacturing/operating profit
- The number of aircraft includes 10% margin for maintenance

Concept	Aircraft required	OD pairs served	Passengers served
Mach 1.7 concept	376	402	11,000,000
Mach 1.8 concept	560 (+48.9%)	646 (+60.7%)	18,600,000 (+69.1%)

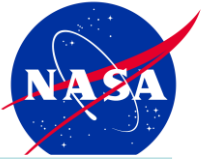
Concept	PAX	MTOGW, lb	OL Mach	OL Range, nm	OW Mach	OW Range, nm
Mach 1.7 concept	50	147,600	1.7	3622	1.8	3572
Mach 1.8 concept	50	167,250	1.8	4163	1.8	4328

Insight from Market Demand Analysis: Range Matters?

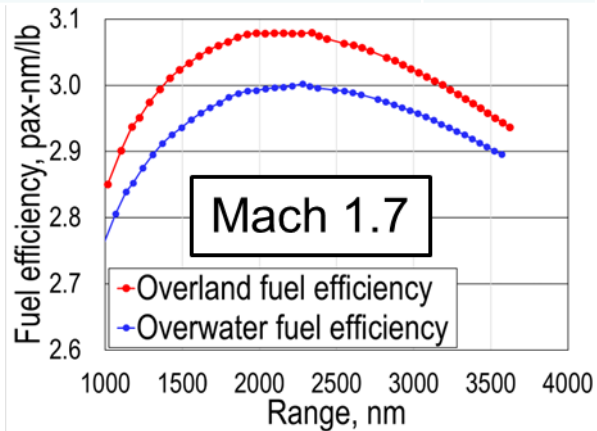


- A refueling stop reduces the time benefit for the Mach 1.7 concept.
 - A refueling stop makes a low-demand OD pair unprofitable.
 - A refueling stop reduces the demand at a high-demand OD pair.
 - The demand reduction leads to a reduced number of aircraft needed, which increases the unit purchase cost of the aircraft and the ticket price.
 - The increased ticket price and reduced time benefit cascade into a significant reduction of the demand.
- The longest nonstop route of the Mach 1.8 concept has **4195** nm (from LHR to IAH).
 - A maximum range of 4200 nm is a good requirement based on the given analysis!

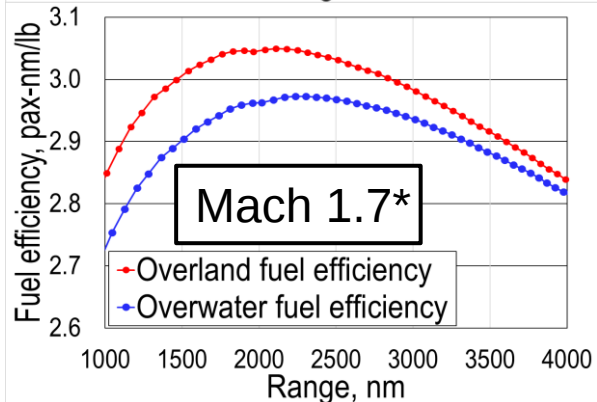
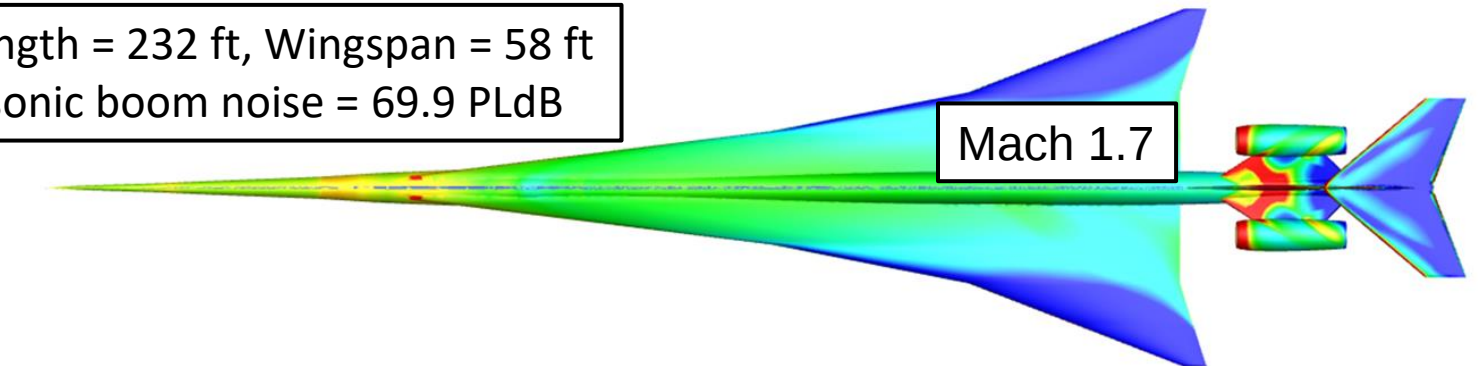
Physics-Based System-Level Trade: PLdB & Weight vs Range



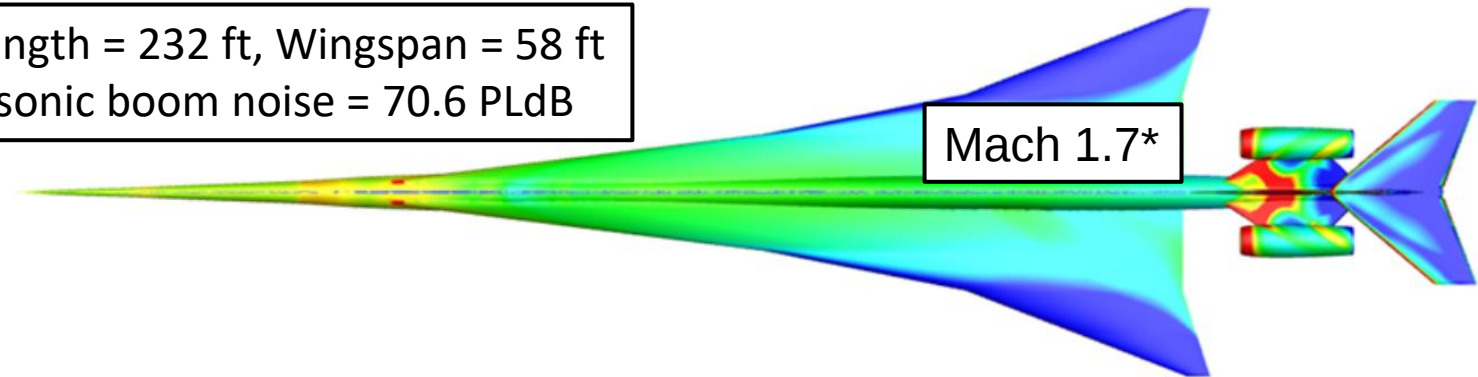
Concept	PAX	MTOGW, lb	OL Mach	OL Range, nm	OW Mach	OW Range, nm
Mach 1.7 concept	50	147,600	1.7	3622	1.8	3572
Mach 1.7* concept	50	163,413	1.7	4234	1.8	4200
Mach 1.8 concept	50	167,250	1.8	4163	1.8	4328



Body length = 232 ft, Wingspan = 58 ft
Target sonic boom noise = 69.9 PLdB



Body length = 232 ft, Wingspan = 58 ft
Target sonic boom noise = 70.6 PLdB

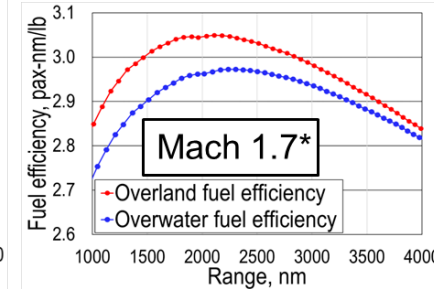
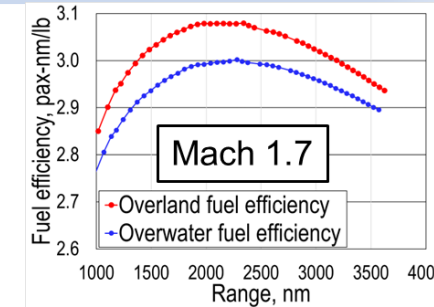


Confirmation of Demand Analysis Insight: Range Matters!



Assumptions:

- Fuel cost = \$3.50 per gallon
- Value of time = \$200 per hour
- Fixed 15% percent of manufacturing/operating profit
- The number of aircraft includes 10% margin for maintenance



Concept	Aircraft required	OD pairs served	Passengers served
Mach 1.7 concept	376 (-12.9%)	402 (-12.2%)	11,000,000 (-11.2%)
Mach 1.7* concept	432	458	12,400,000

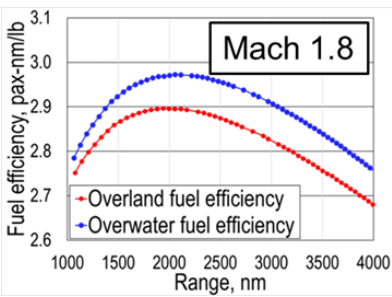
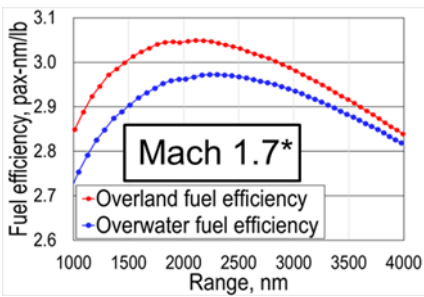
Range matters: The Mach 1.7* concept is heavier and less fuel efficient but has longer ranges when compared to the Mach 1.7 concept. (Demand increase with 0.7 target PLdB increase)



Unexpected Discovery from System-Level Trade

Assumptions:

- Fuel cost = \$3.50 per gallon
- Value of time = \$200 per hour
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Mach 1.7 concept	376 (−12.9%)	402 (−12.2%)	11,000,000 (−11.2%)
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Mach 1.8 concept	560 (+29.6%)	646 (+41.0%)	18,600,000 (+50.0%)

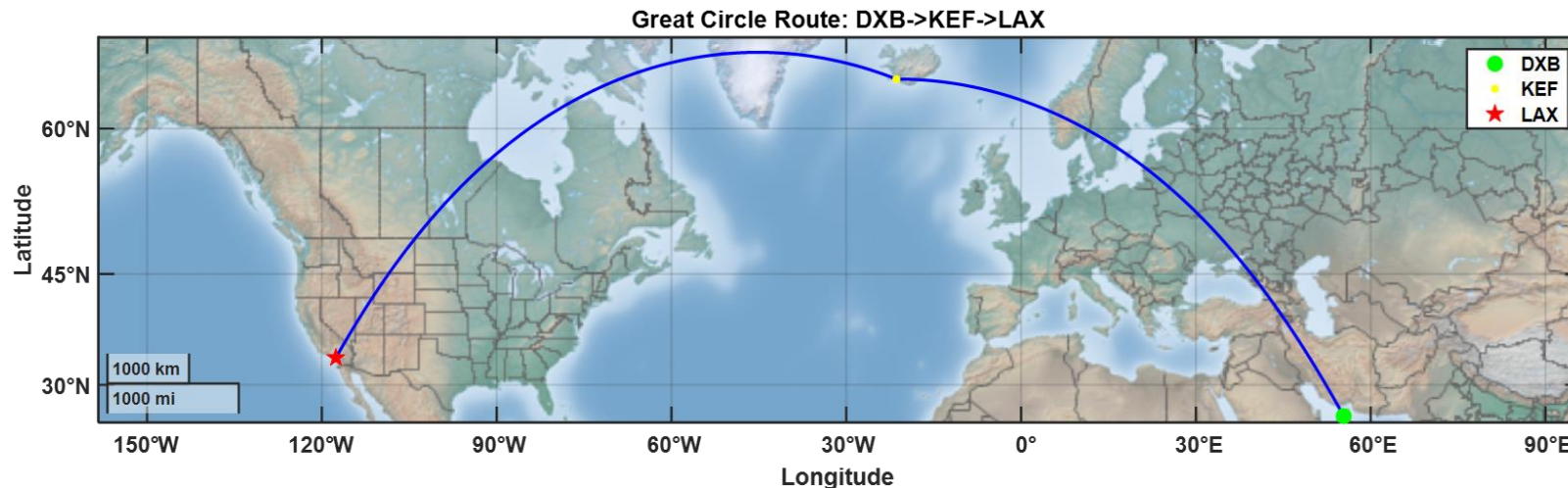
Range matters: The Mach 1.7* concept is heavier and less fuel efficient but has longer ranges when compared to the Mach 1.7 concept. (Demand increase with 0.7 target PLdB increase)

Unexpected: The Mach 1.8 concept is heavier and less fuel efficient, and has no range advantage when compared to the Mach 1.7* concept. (50% passenger demand increase)

Plausible Root Cause for Demand Increase: Speed Matters?



Max increase of value of saved travel time by the Mach 1.8 concept, when compared to the Mach 1.7* concept, is from DXB to LAX: **\$46 for time saving of 14.5 min**



Mach 1.7* concept: time = 10.21 hr
Mach 1.8 concept: time = 9.97 hr
with one refueling stop at KEF

- The increased value of saved travel time is less than **1.5%** of the supersonic ticket price for every OD pair.
- Value of saved travel time alone is **inadequate** to explain the 50% demand increase for the Mach 1.8 concept.

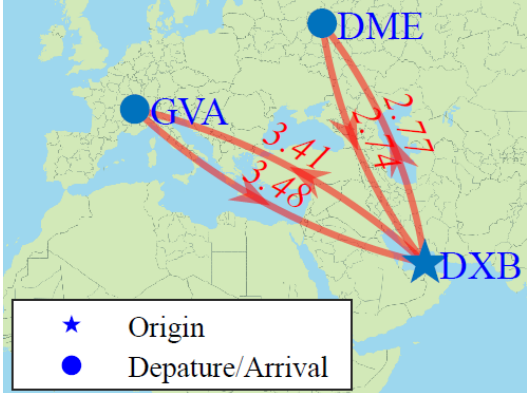


Insight from Market Demand Analysis: Speed Matters!

Overland cruise Mach increase of just 0.1 allows the Mach 1.8 concept to serve more overland OD pairs per day. (Fleet productivity increase)

- The Mach 1.8 fleet has **revenue passenger miles per aircraft** of 12% higher than the Mach 1.7* fleet in 2045.
- Cruise-speed-induced fleet productivity increase of 12% is the root cause for the 50% passenger demand increase.

Departure Airport	Arrival Airport	Distance (nm)	Travel Time	Connection Time	Departure Local Time	Departure UTC	Arrival Local Time	Arrival UTC
DXB	DME	1925	2.77 hr	0 hr	06:00	4	07:46	3
DME	DXB	1925	2.74 hr	1 hr	08:46	3	12:30	4
DXB	GVA	2617	3.41 hr	1 hr	15:06	4	15:31	1
GVA	DXB	2622	3.48 hr	1 hr	16:31	1	23:00	4





Conclusions

- Consistent coupling of the market demand analysis, detailed mission analysis, and conceptual-level low-boom constraint enables a model-based analysis of the economic impact of a future regulation on acceptable sonic boom ground noise level for supersonic overland flight.
- It might be beneficial to use the overland range as the primary performance objective in MDO for achieving both low-boom and mission performance goals.
- The overland cruise speed of a low-boom supersonic transport aircraft may have significant impacts on the fleet productivity and the resulting passenger demand.





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