

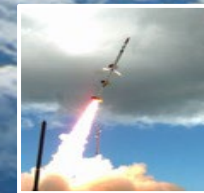
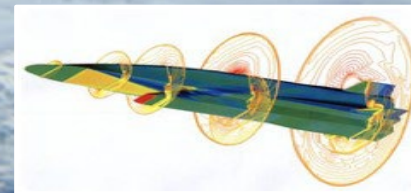


HTTP

Commercial High Speed Market Study(s) Summary

Jeff Robinson
15 Nov 2023

2023 Systems Analysis Symposium



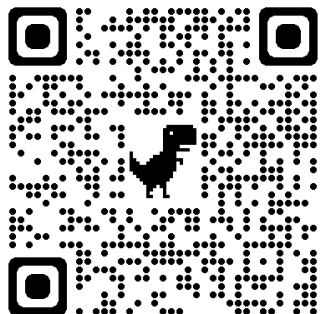
Hypersonic Technology Project



FY20/21 High-Speed Market Studies

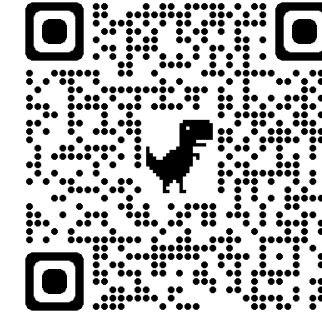


- The overwhelming number one request that industry had for NASA from the Jan 2020 Commercial High-Speed Workshop was to conduct an independent market study to determine the viability of high-speed / hypersonic commercial travel.
- NASA subsequently funded two contracts, one to Deloitte/SpaceWorks and one to SAIC/Bryce, to study the market given three specific tasks:
 - Define the market – how many people would be willing to travel and how much revenue could be generated
 - Define the business case – can an aircraft (Mach 2-5+) be fielded to serve this market and be able to generate enough profit to make it economically viable
 - What are the barriers preventing this market from becoming reality
- Deloitte and SAIC spent six months studying the problem; final reports are public



SAIC/Bryce

- SAIC Report: <https://ntrs.nasa.gov/citations/20210015471>
- SAIC Presentation: <https://ntrs.nasa.gov/citations/20210015472>
- Deloitte Report: <https://ntrs.nasa.gov/citations/20210014711>
- Deloitte Presentation: <https://ntrs.nasa.gov/citations/20210014932>



Deloitte/SpaceWorks



General Approach



Deloitte/SpaceWorks

- Examined commercial, private, cargo
- Evaluated demand / price elasticity by surveying willingness to pay (actual \$) for various flight time savings (correlated to Mach 2, 3, 4, 5, 6) across three proxy routes
- Developed list of 90 city pairs deemed favorable for high-speed travel considering multiple factors
 - City pairs are predominantly over water
 - Five additional over-land routes would add 24% annual revenue (four are over US)
- Developed “Level 0/1” aircraft sizing model to drive costs and environmental factors
 - Sizing model anchored to existing (Concorde, Tu-144) and proposed aircraft
 - Estimates for sonic boom, LTO noise & emissions
 - Costs calculated using Galorath SEER
 - Average IRR primary cost output; required to be equal across manufacturers and operator; minimum 25% IRR to be “viable”
 - Single aircraft type operating model

SAIC/Bryce

- Examined commercial, private, cargo
- Evaluated demand / price elasticity by speed (Mach 2, 3, 4, 5) and willingness to pay (1.5x, 2.5x, 5x, 10x subsonic premium fair price)
- Surveyed 150 high net worth individuals and executive travelers
- 800 long-haul city pairs considered
- Demand & revenue growth forecasted thru 2070
- Interviewed 50+ engineering SMEs, aircraft developers, industry experts and observers
- Business case subtracts costs from available revenue, what remains is available for RDT&E
 - Costs include operating costs, marginal aircraft manufacturing costs, and industry ecosystem profit
 - Operating costs use multipliers over current aircraft operating costs on a per seat mile basis
 - 25% profit for manufacturers and operator
 - Single aircraft type operating model



Initial Market Study Summary



	SAIC (with Bryce Space and Technology)	Deloitte (with SpaceWorks and NIA)
Mach	3	2 to 4 ⁽¹⁾
Range	4,500 nmi	4,000 nmi to 4,500 nmi
Number of routes⁽²⁾	300	90
Aircraft Size (# PAX)	10 GA or 50 Commercial	20 to 50
Aircraft Cost	\$200M to \$300M	\$131M to \$228M ⁽³⁾

Results DO NOT include accommodations to meet environmental / regulatory constraints

(1) Analysis showed profitable routes up to M5.25

(2) Deloitte only considers over-water routes

(3) Mach 3 at 4,500 nmi



Deloitte/SpaceWorks – Barriers / Challenges Heat Map



Challenge	Compliance	Solution	Investment	Ease of Use	Community	Total	Rank Categorization ¹
1. Sonic Boom Restrictions	3	2	3	2	3	13	Barrier
2. Aircraft Certification	3	3	3	1	2	12	Barrier
3. Landing & Takeoff Noise	2	2	2	1	3	10	Barrier
4. Emissions Standards	2	2	2	1	2	9	Significant Challenge
5. Export Controls	3	1	2	2	1	9	Significant Challenge
6. Depressurization Event	1	1	2	2	2	8	Minor Challenge
7. Alternative Fuels	2	2	2	1	1	8	Minor Challenge
8. International Laws	2	2	2	1	1	8	Minor Challenge
9. Heat Sensitivity	1	2	2	2	1	8	Minor Challenge
10. NAS Integration	2	1	1	2	1	7	Minor Challenge
11. Anomalous Radiation Events	2	1	1	1	2	7	Minor Challenge
12. Flight Shaming	1	1	2	1	2	7	Minor Challenge
13. Runway Length	1	3	1	1	1	7	Minor Challenge
14. Time Zone Gaps	1	1	1	2	1	6	Minor Challenge
15. Pilot Certification	1	1	1	1	1	5	Minor Challenge

Rank Categorization Key Definitions:

- **Barrier:** an issue that could outright prevent the market from starting.
- **Significant Challenge:** an issue that will likely materially impact the business case.
- **Minor Challenge:** an issue will likely impact the business case only minimally.



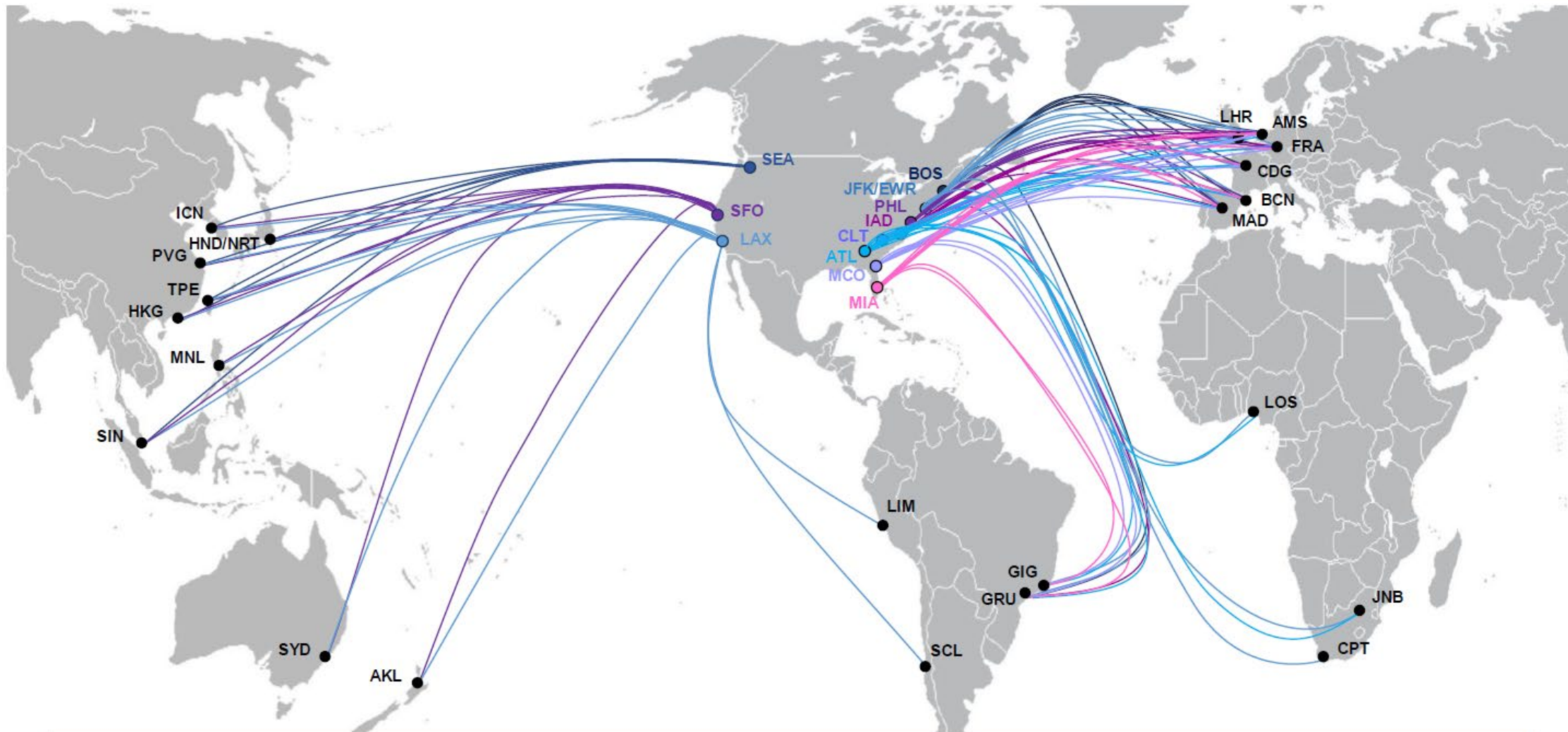
SpaceWorks Initial Follow-on Tasks (Sep21)



1. Initial Deloitte and SAIC efforts use single “aircraft type” model; first task here was to explore whether a “two type” model was better or worse economically (e.g. only a 737 vs both 737 & 777) with A/C split by range
2. Evaluate economic cases for specific matrix of aircraft requirements
 - 20 and 50 PAX, Mach 2, 3, 4, & 5, for “short-range” and “long-range” versions
 - All on Jet-A, and include an “optimized” short- and long-range A/C
3. Develop “baseball card” format for ease of data comparison
4. Evaluate “alternate fuels” (SAF, LNG, LH2) across same matrix
5. What impact does inclusion of overland flights have?
6. What impact does delay of IOC have (does optimal PAX or Mach change)?
7. Develop Discrete Event Simulation (DES) to provide additional fidelity / insight into “two type” operational model



Baseline US-Based Transoceanic Flight Routes (90 routes)



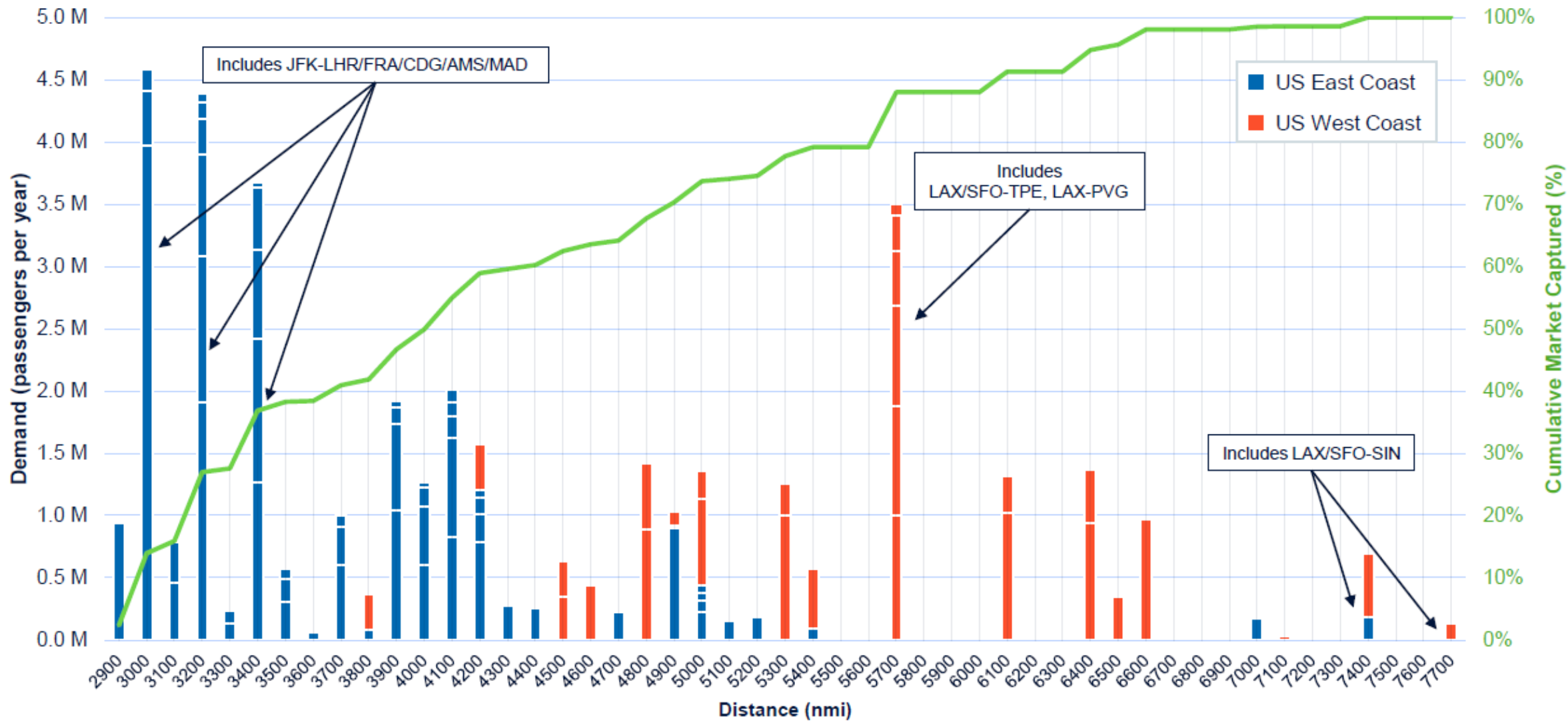
90 Key Transoceanic Routes with 39.6M total annual passengers in 2019



Annual Passenger Market by Route Distance



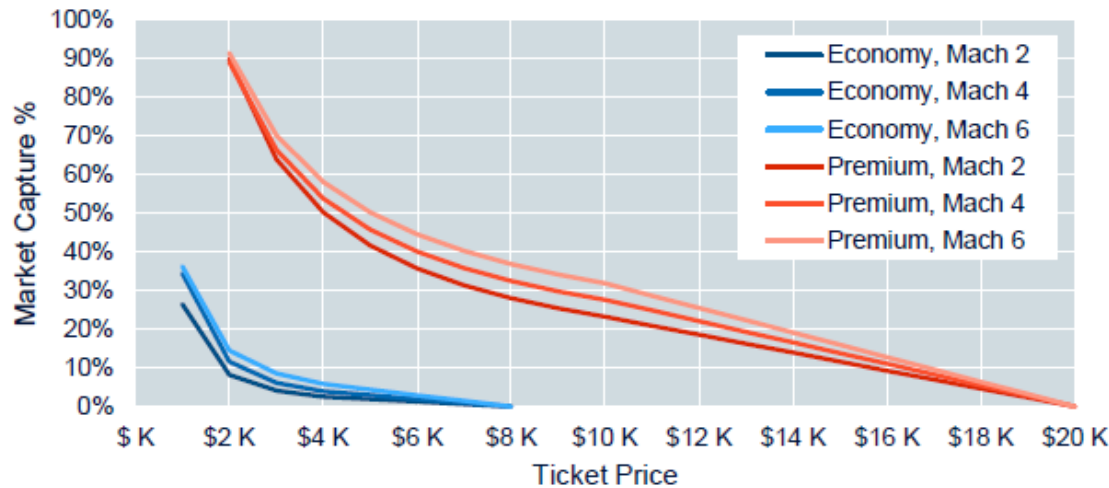
Route Demand for Every 100 nmi (Cumulative Total Market Captured on Secondary Axis)



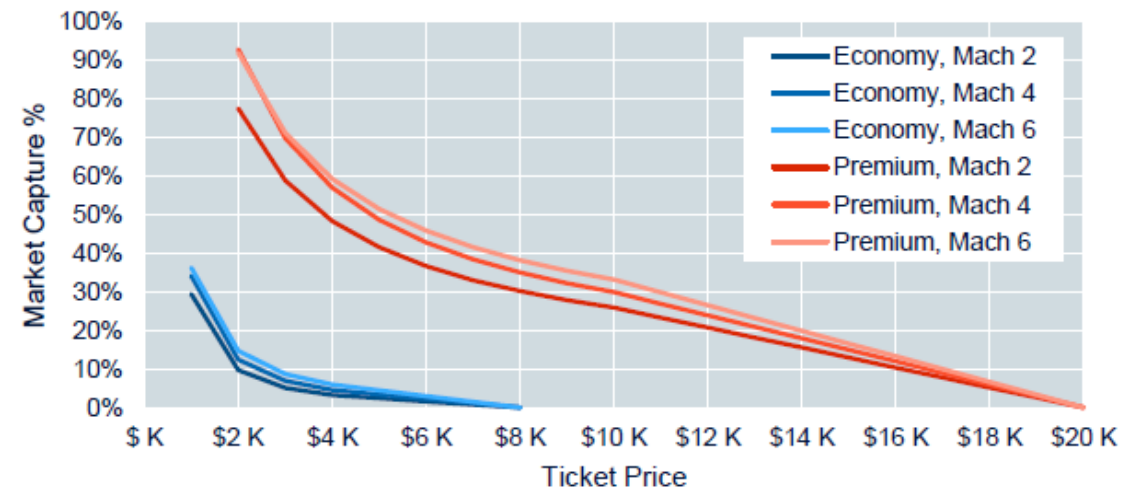
- ▶ **Deloitte surveyed passengers' willingness to pay for speed for for three representative routes: JFK-LHR, LAX-NRT, & LAX-SIN**
 - Data for economy and premium passengers was collected

- ▶ **SpaceWorks generated smooth price elasticity curves from the survey data for implementation into the ROSETTA model**
 - Separate curves for market capture versus ticket price are used for economy and premium passengers, with the total passenger capture determined from percent of market capture for each class
 - Market capture is ground ruled to be 0% for economy ticket prices above \$8K and premium ticket prices above \$20K

JFK-LHR Elasticity Curves



LAX-NRT Elasticity Curves



Jet-A Mach 2 Long Range



ID: JTA.M2.00.P38.R5700.20220810



Mach 2
Cruise Speed



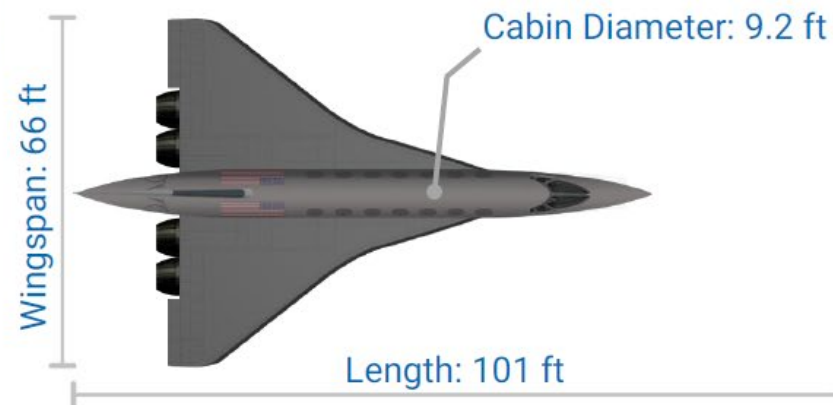
5,700 nmi
Max Range



38
Passenger Count



JetA
Fuel Type



COST METRICS (FY21 USD)

DDT&E

\$4.1B
Airframe

\$2.3B
Engine

TFU

\$109M
Airframe

\$15M
Engine

ENVIRONMENTAL METRICS

92 EPNdB
Lateral Takeoff Noise

105 PNLdB
Sonic Boom

0.49 kg/km/pax
Emissions (CO₂e)

0.15 kg/km/pax
Fuel Consumption Rate

222,000 lbm
MTOW

5.8 hours
Gate-to-Gate Time
at Max Range

77,000 lbm
MEW

56,400 ft
Cruise Altitude

4 x 20,900 lbf
Engine Thrust SLS

6,600 ft
Bal. Field Length SL

AIRCRAFT NOTES

- Supersonic cruise condition L/D = 8
- Supersonic cruise condition Isp = 3000 s
- Vehicle propellant mass fraction (PMF) = 0.47
- Takeoff T/W = 0.375

No accommodations to try to achieve regs; output engineering estimates based on SOA tech



Example Baseball Card (back)



Jet-A Mach 2 Long Range

ID: JTA.M2.00.P38.R5700.20220810

Key Inputs

- Mach 2**
Cruise Speed
- 5,700 nmi**
Range
- 38**
Passenger Count
- JetA**
Fuel Type

OPERATOR METRICS

\$5,200-\$6,700
Ticket Price

2.3M Pax/Year

49 Routes Captured

MANUFACTURER METRICS

\$251M
Aircraft Price

\$172M Airframe Price

\$20M x4 Engine Price

300 Aircraft Sold

KEY EVENTS & DATES

● OPERATOR ● ENGINE MANUFACTURER ● AIRFRAME MANUFACTURER

Timeline events: Start DDT&E (2020), Aircraft Ordered (2026), IOC Breakeven (2030), Breakeven (2032), Breakeven (2034).

Business Results

OPERATOR		
25%	\$3.5B	\$7.2B
IRR	NPV	Max Exposure
ENGINE MANUFACTURER		
25%	\$1.0B	\$1.2B
IRR	NPV	Max Exposure
AIRFRAME MANUFACTURER		
25%	\$2.1B	\$2.9B
IRR	NPV	Max Exposure

BUSINESS CASE ANALYSIS

This aircraft is capturing 49 of 78 addressable routes that are within its design range which are exclusively Atlantic Ocean routes. Since the aircraft is more passenger efficient, ticket prices don't become overly expensive, enabling higher demand capture overall.

Engine guy goes first

But Operator's outlay is the biggest



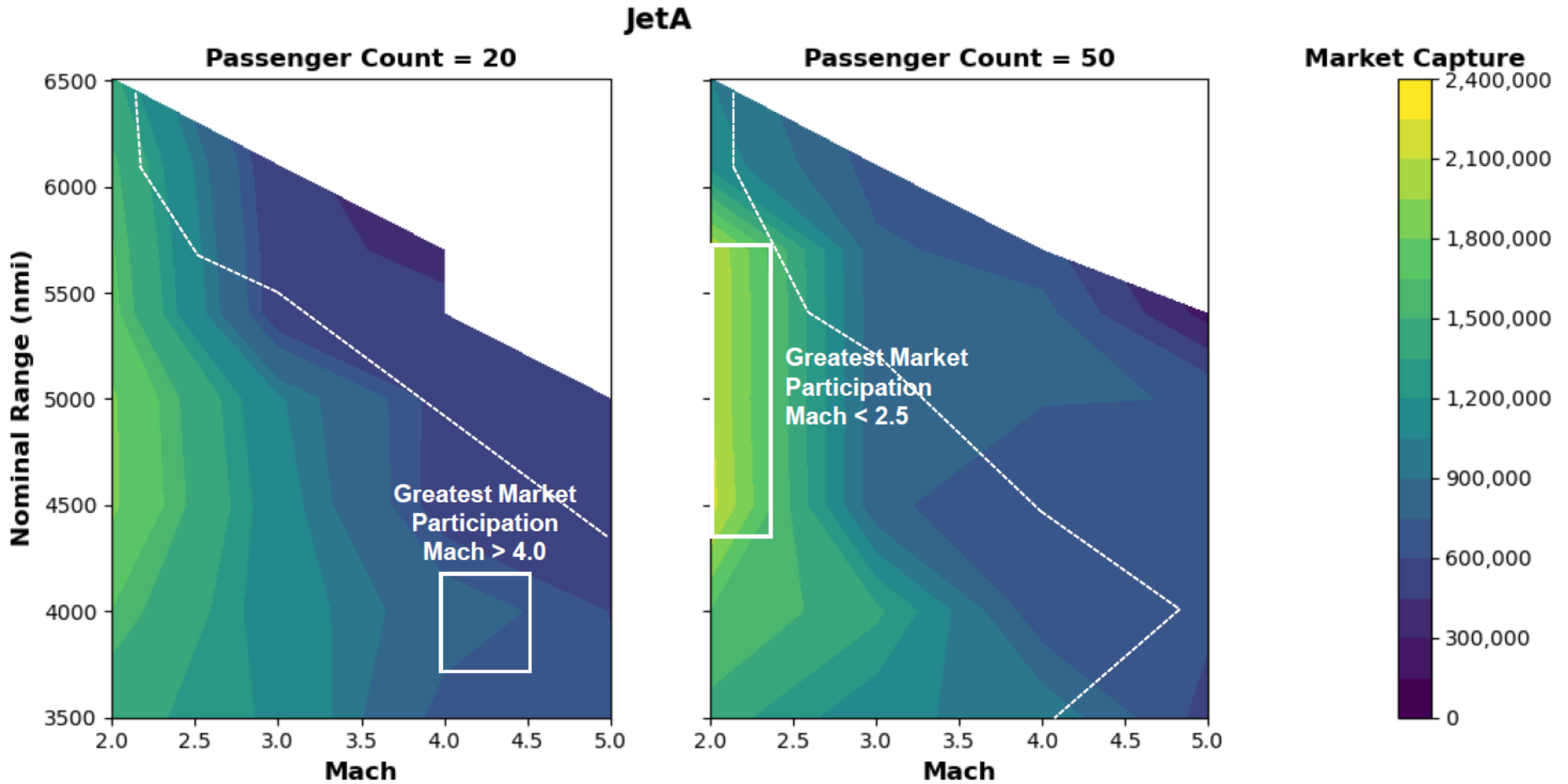
Key Findings from Follow-on (Phase 1)



- Overall, when modeling a single Jet-A fueled aircraft type that serves a subset of our 90 candidate transoceanic passenger routes that lie within its unrefueled range, the Mach 2-2.5, 4,500-5,500 nmi, and 40-50 passenger aircraft had the best business cases
- Safety, noise compliance, emission, compliance, and sonic boom remain significant challenges to this industry
- Trade results:
 - A two-type model with A/C split by range offered minimal improvement over single type A/C operating model
 - Jet-A had the best economics initially, transitioning to SAF over time (assumed lower future cost of SAF and adequate producibility); jury still out on LNG, LH2 largely infeasible due to A/C physical size (size=cost)
 - Adding overland routes (still U.S. based) increases market > 5X; capital outlay for single operator becomes restrictive; optimal PAX increases, ticket prices lower
 - Delayed IOC improves economics (market grows, tech advances), but environmental impacts (impacts not modeled here) also likely to get more stringent



Best Solutions Are on Edge of Trade Space



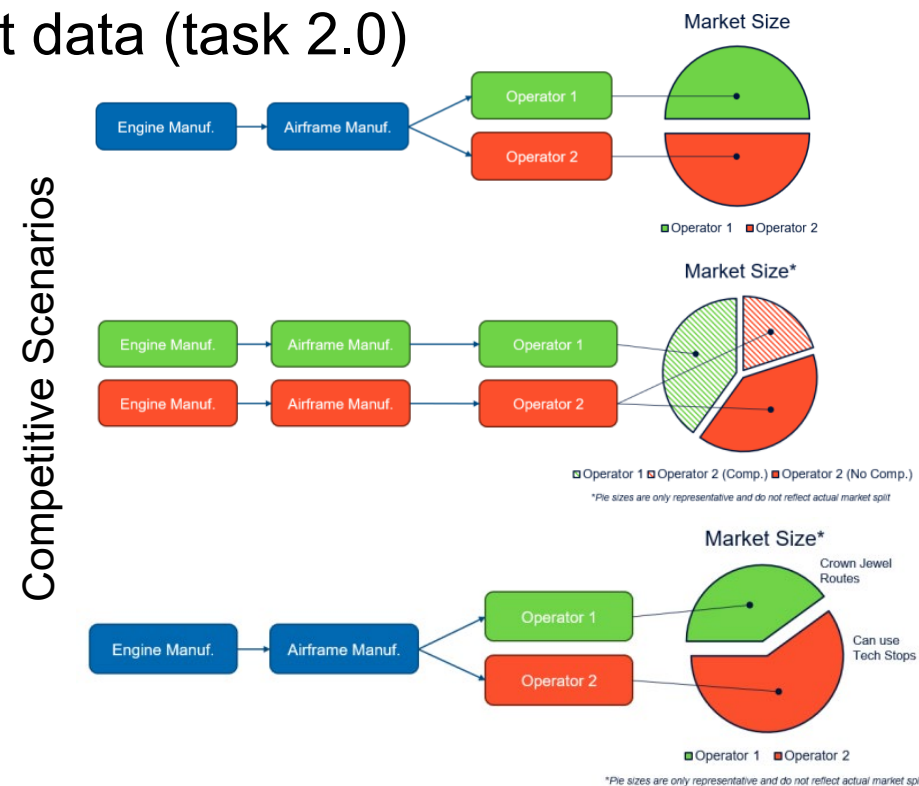
1. Additional analysis with ROSETTA model

1. Add Mach 1.5 to trade space
2. Evaluate impact of performing tech stops
3. Change “two type” model from range-based to demand-based
4. Rerun design space for all fuels given new market data (task 2.0)
5. Evaluate same-day round-trip case
6. Evaluate various competitive scenarios to understand economic impact

2. Updated market research data

3. Enhance DES capability to:

1. Analyze round-trip “business traveler” case
2. Analyze competitive market cases
3. Analyze tech stops





New MIDAS DES Tool



Animation

Settings:

- Distance Based
- Demand Based
- Competitive Market
- Tech Stops
- Debug Mode
- Flight Scheduling
- Split - Even
- Split - Weighted
- Crown Jewels
- TAT Variability
- Optimization Mode
- New Elasticity Curves

Animation

Operator: Milky Airways

58 Total Fleet Size, 6 Num. Retired Planes

Break Even Year: 2034

End Of Year Accounting

Year	Ass. Cost	Comp. Cost	Rev. Exp.	Crash Rev.
1	\$8.00	\$6.90	\$9.00	\$9.00
2	\$8.00	\$6.90	\$9.00	\$9.00
3	\$8.00	\$6.90	\$9.00	\$9.00
4	\$8.00	\$6.90	\$9.00	\$9.00
5	\$1.528	\$1.528	\$9.00	\$9.00
6	\$517.66M	\$1.965	\$9.00	\$9.00
7	\$517.66M	\$2.769	\$9.00	\$9.00
8	\$517.66M	\$3.535	\$9.00	\$9.00
9	\$1.728	\$5.300	\$9.00	\$9.00

Airplanes

Plane ID	Status	Loc
1	IN SERVICE	LHR
2	IN SERVICE	LHR
3	IN SERVICE	JFK
4	IN SERVICE	JFK
5	IN SERVICE	LHR
6	IN SERVICE	LHR
7	IN SERVICE	JFK
8	IN SERVICE	LHR
9	IN SERVICE	LHR
10	IN SERVICE	JFK
11	IN SERVICE	JFK
12	IN SERVICE	JFK

JFK - LHR

11 JFK, 9 LHR, 32 Actual Flights/Day, 27 Daily Flights, 2 Mech, 3.7 Flight Hours, 5 Time Change

Airplanes

Plane ID	Status	Loc	Dep. Local	Dep. GMT	Status
1	IN SERVICE	LHR	06:00	11:09	Green
2	IN SERVICE	LHR	06:35	11:35	Green
3	IN SERVICE	JFK	07:19	12:11	Green
4	IN SERVICE	JFK	07:46	12:46	Green
5	IN SERVICE	LHR	08:22	13:22	Green
6	IN SERVICE	LHR	08:55	13:58	Green
7	IN SERVICE	JFK	09:33	14:33	Green
8	IN SERVICE	LHR	10:09	15:09	Green
9	IN SERVICE	LHR	10:45	15:45	Green
10	IN SERVICE	JFK	11:20	16:20	Green
11	IN SERVICE	JFK	11:59	16:59	Green
12	IN SERVICE	JFK	12:44	17:44	Green

17 Active Aircraft, 20 Current Fleet

GMT: Thu Nov 22:36

Delta to GMT: JFK -5 Hours, LHR 0 Hours

Tech stops enabled for Operator 2

Operator 2

51 IN SERVICE

2 Mach, 4,000 nmi Range, 50 Fuel Type, 5.7 Flight Hours

Airdromeda Operator

\$2293.1M Total Pax Revenue, \$340.3M Total Cargo Revenue

\$2633.3M Total Revenue, \$647.7M Total Cost

Anchorage Tech Stop Airport, 1,754 nmi SFO - ANC, 5,855 Flight Hours, 3,744 nmi ANC - PVG

Maintenance

Check	Hours to Check	Num Checks
A	116.45	168
B	139.646	77
C	526.583	25
D	4,124.601	3
Eng Rest	6,116.009	1

Route: SFO - PVG

Total Flight Hours: 43,885

Hours to Retirement: 1,114

Entry into Service Year: 2033

Years of Ops: -

TAT (min) = 36.30

TAT (min) = 123.75

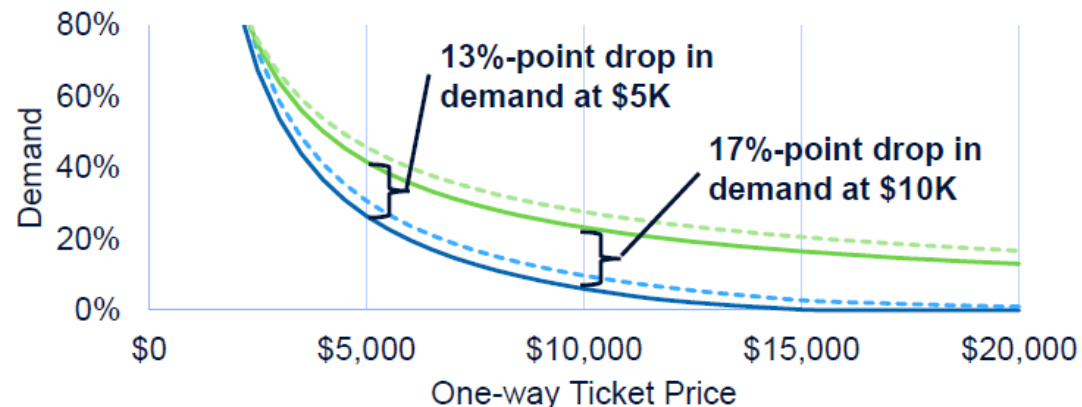
- ▶ **New results indicate an overall reduction in willingness to pay**
 - Most passengers were only willing to pay 1.5x to 2.5x the normal ticket price
 - Reduction was more pronounced in the transatlantic market

- ▶ **Price is more elastic compared to previous data**
 - Premium class less elastic at lower prices and much more elastic at higher prices
 - Economy class maintained similar behavior both at low and high prices

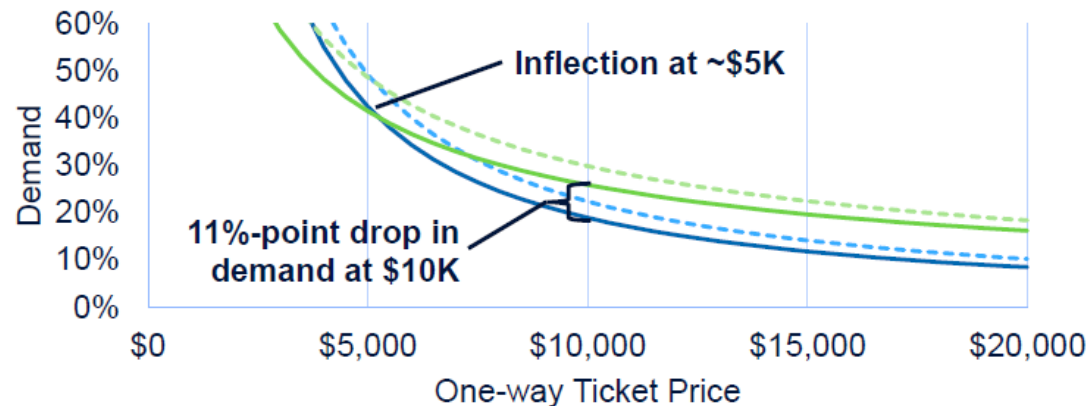
- ▶ **Corporate travel manager curve is more elastic than individual business travelers**
 - Likely due to corporate travel managers being more aware of travel budget limitations

- ▶ **These curves offer more insight into willingness to pay but still include some uncertainty and bias**

Premium Class Elasticity Curves - Transatlantic



Premium Class Elasticity Curves - Transpacific



- Demand-based two-type aircraft model still showed only modest improvement over single type aircraft model
- No premium found in new market data for “same day businessman” scenario; DES model incorporated flight scheduling / manifest
- Tech stops modestly improve addressable market for shorter range aircraft (helps highspeed aircraft more)
 - Potential to open up Asian routes to east coast cities
- Competitive analyses:
 - Even split of demand lowered operator outlay; all else similar to single type / single operator
 - Similar to mixed fleet; splitting demand between manufacturers has adverse effect on entire business case
 - Most promising results; advantage of splitting risk between operators and maximizing route/demand capture via tech stops; supports “leader/follower” scenario

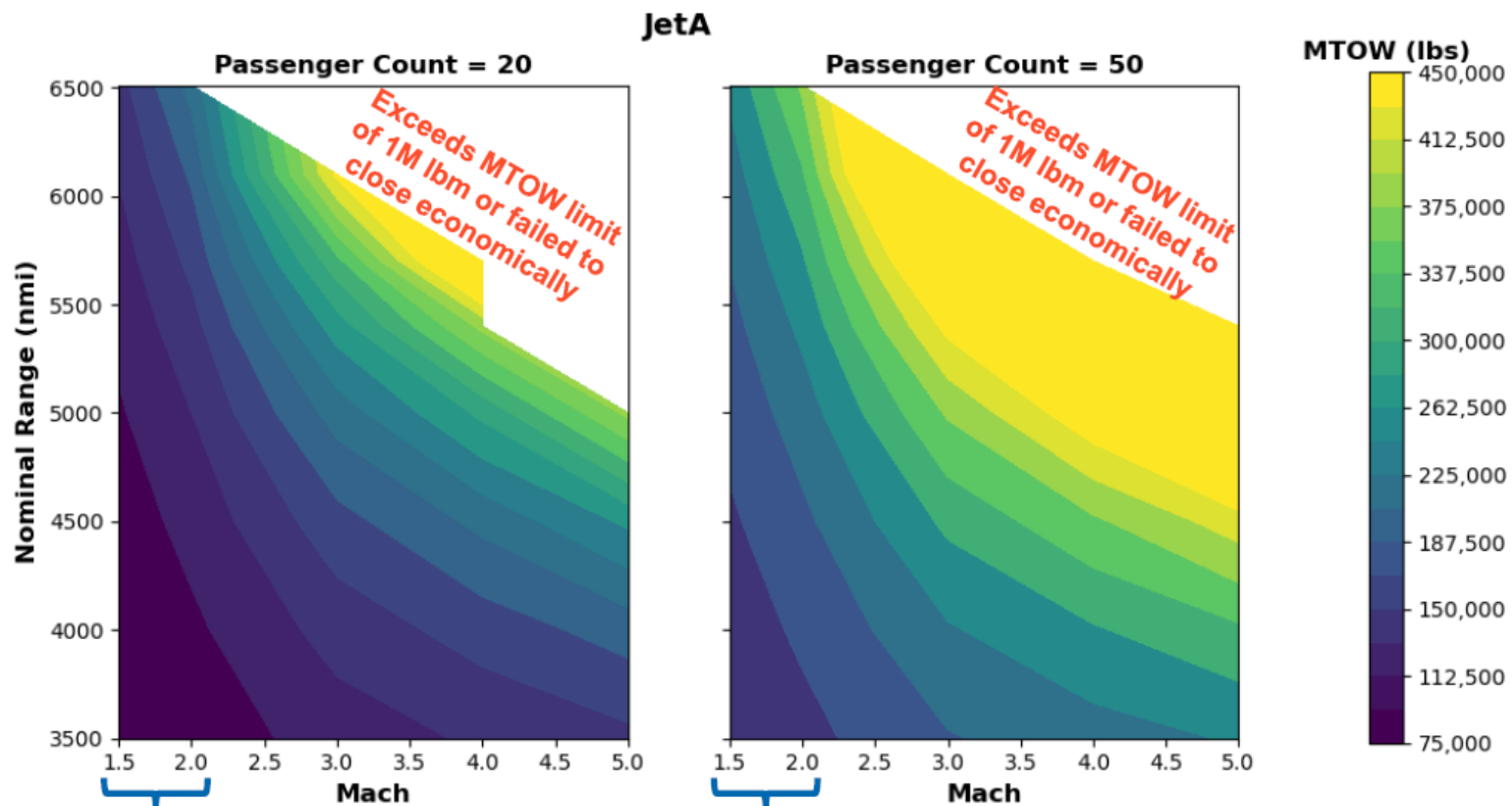




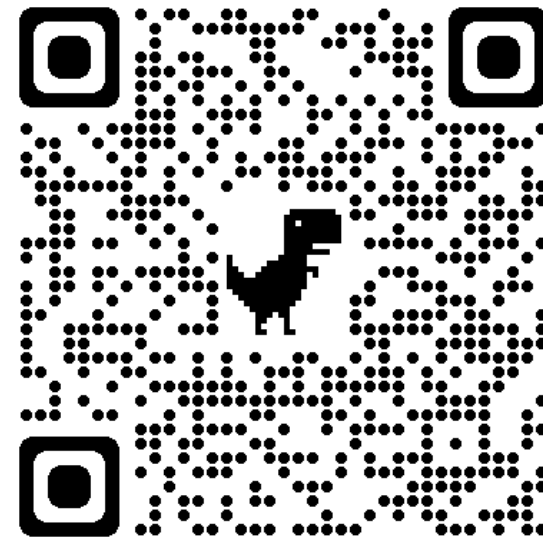
Mach 1.5-2, 40-50 pax, 4,500-5,700 nmi range were the preferred aircraft configuration that kept masses and complexity low, enabling lower development and production costs

Key Features of Mach 1.5-2 Aircraft

- ▶ “Best” fuel option of JetA to SAF or straight to SAF, relative to LNG or hydrogen
- ▶ Least technical hurdles and complexity
- ▶ Lower masses
 - < 200klb MTOW
 - < 90klb MEW
- ▶ Long ranges more feasible from vehicle closure sensitivity
 - Up to 5,700-6,100 nmi
- ▶ Lowest emissions
 - 0.25 - 0.40 CO₂e kg/km/pax (still ~5x higher than subsonic A/C)
- ▶ Lowest noise level for takeoff
 - < 92 EPNdB



- **NASA and FAA should continue their efforts to enable and permit overland supersonic flight**
 - Potential to drastically increase market size by six-fold and increase access to providers
 - Provides more robust business cases for supersonic / hypersonic developers and operators
- **In the meantime, enact a two-phased “leader-follower” strategy to allow markets and technology to mature**
 - First-to-market transoceanic “leader” aircraft in Mach 1.5-2 range aimed at addressing high demand routes
 - “Follower” aircraft designed to address growing and/or newly emerging markets via further technology improvements (longer range, higher speeds, etc.)
 - Allows for initial regulatory requirements and certification processes to be established and matured for lower speed systems (Mach 1.5 to 2) before attempting higher speeds (Mach 3+)
- **Continue investments in supersonic and hypersonic aircraft technologies, particularly in the areas of:**
 - Engine fuel efficiency and emissions
 - Takeoff noise
 - Aircraft and engine structures/materials
- **Continue investment in SAF with further exploration of LNG and LH2 viability**
 - Supply of all alternative fuels needs to be orders of magnitudes greater
 - LNG shows promise while LH2 is economically viable for some simulated solutions



<https://ntrs.nasa.gov/citations/20230012245>