Life Cycle Cost Modeling of High-Speed Commercial Aircraft

Final Review – Executive Summary

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Agenda

11:00 – 12:15	**Executive Summary**	**John Bradford**
12:15 – 1:00	*Lunch*	
1:00 – 1:45	MIDAS Development & Demonstration	Ami Patel
1:45 – 3:50	Key Findings Detailed	Hayden Magill & Aaron Boysen
3:50 – 4:30	Recommendations & Discussion	Hayden Magill & All

All times Eastern

Introduction

- **For several years, SpaceWorks has been supporting NASA's effort to better understand the future passenger market and potential economic business cases for supersonic and/or hypersonic commercial flight. Key questions…**

Does a reliable passenger demand exist for commercial supersonic / hypersonic flight?

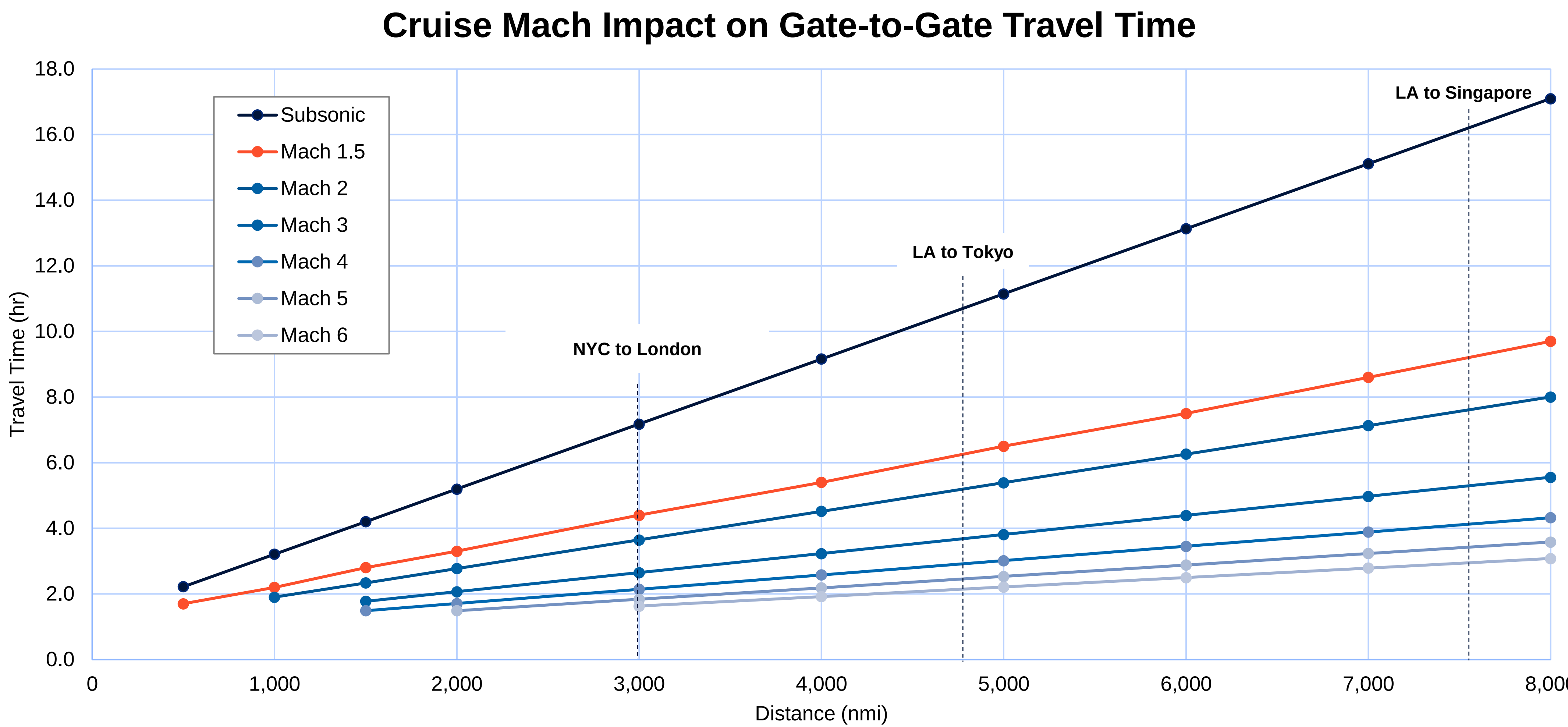
If so, can it result in profitable business cases for companies in the manufacturing and operating sectors?

Introduction

- **This presentation is the culmination of a 9-month research and development effort**
  - Follow-on to a 9-month Base effort from SpaceWorks ("Life Cycle Cost Modeling of High-Speed Commercial Aircraft"), which followed the 2021 "Commercial Hypersonic Transportation Market Study" effort led by Deloitte, the NIA, and SpaceWorks

- **Based in part on the recommendations of the prior studies, the objectives of this current effort were to:**
  1) Expand the trade space to include Mach 1.5 aircraft
  2) Evaluate various operating scenarios such as tech stop utilization and demand-based mixed fleets
  3) Update the market research data driving the model to produce new elasticity curves, market growth rates, & development costs
     - Use the new data to reevaluate alternative fuel business cases
  4) Continue to improve and develop the modeling & simulation tool to evaluate behaviors like flight scheduling & multiple operator scenarios

Value Proposition of High-Speed Travel



High-Speed Aircraft Landscape – Then (2020)

Aerion
[Mach 1.6]

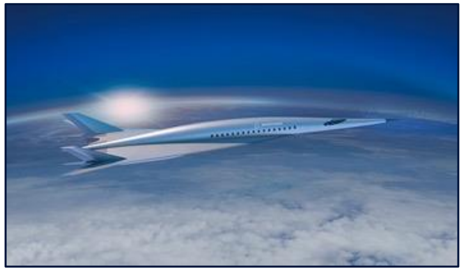
Boom
[Mach 1.7]

Hermeus
[Mach 5]

Spike
[Mach 1.7]

HyperMach
[Mach 3.6]

Virgin Galactic
[Mach 3]



Boeing
[Mach 5]

Reaction Engines
[Mach 5+?]

Exosonic
[Mach 1.8]

High-Speed Aircraft Landscape – Then (2020) vs. Now

Aerion
[Mach 1.6]

Boom
[Mach 1.7]

Hermeus
[Mach 5]

Destinus
[Mach 5]

Spike
[Mach 1.7]

HyperMach
[Mach 3.6]

Virgin Galactic
[Mach 3]

Venus Aerospace
[Mach 9]

Boeing
[Mach 5]

Reaction Engines
[Mach 5+?]

Exosonic
[Mach 1.8]

EON Aerospace
[Mach ~2]

FLASHBACK: 2020 Commercial Hypersonic Transportation Study

Deloitte.

- Market Segmentation – analyzed current trends in the aviation market for scheduled service, private-owner operations, and air cargo
- City Pairing - determined the most viable routes for high-speed passenger travel by analyzing industry data and selected routes based on route-by-route economic and technical viability. Emphasis was placed on transoceanic routes die to sonic boom challenges for overland flight
- Market Demand – developed ticket price elasticity curves based on direct customer surveys to quantify passenger willingness to pay for high-speed travel
- Barriers Assessment – characterize key policy, regulatory, and technical barriers to future high-speed flight operations

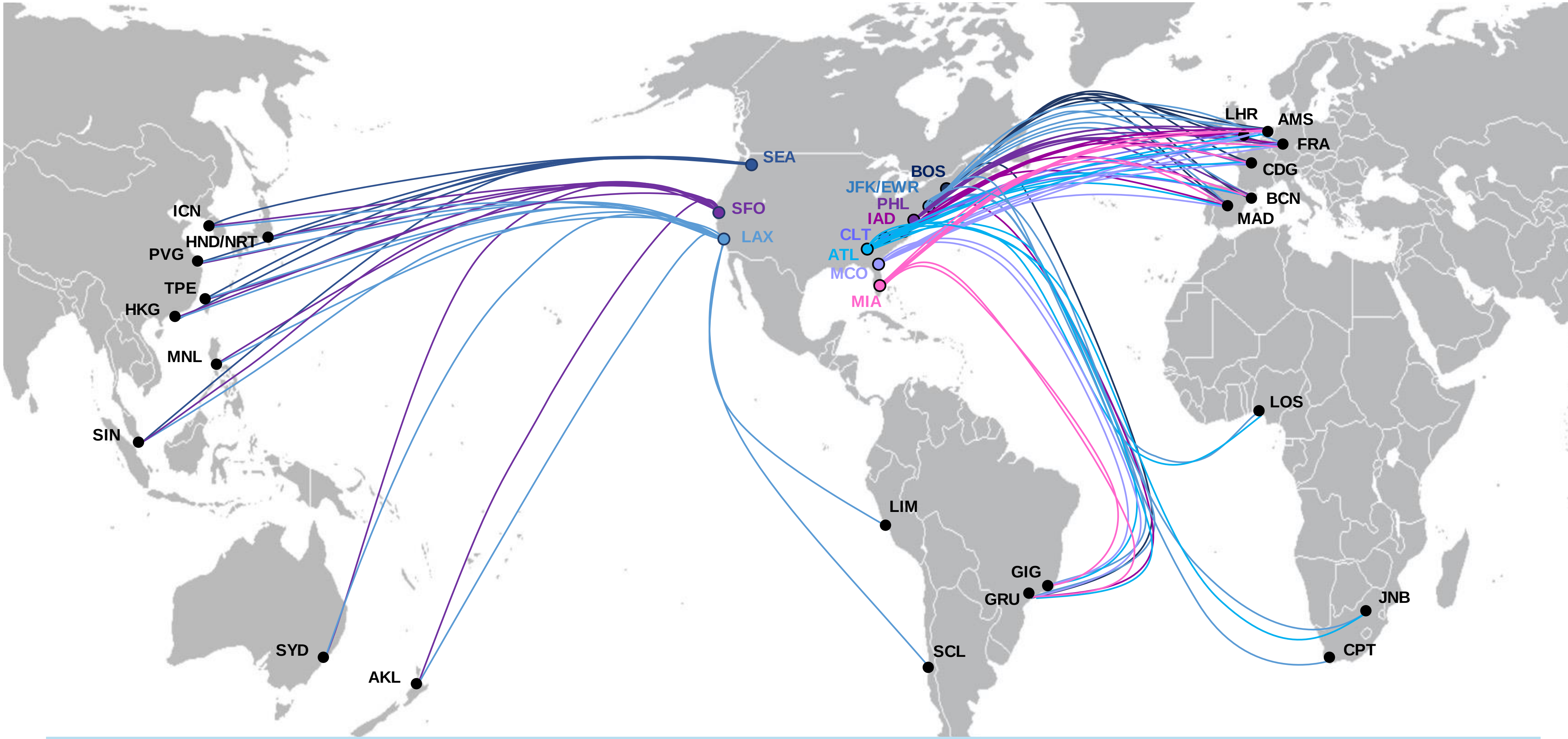
SpaceWorks®

- ROSETTA Model Development – built on existing ROSETTA model to integrate flight performance, aircraft sizing environment impact, airframe costing, engine costing, manufacturer and operator economic modules
- Optimize Business Cases – implemented ticket price elasticity curves from Deloitte and optimize model inputs to determine best business cases across *Mach, range, and passenger count*
- Investigate Sensitivities – characterized sensitivity of aircraft design parameters and business case assumptions

National Institute of Aerospace

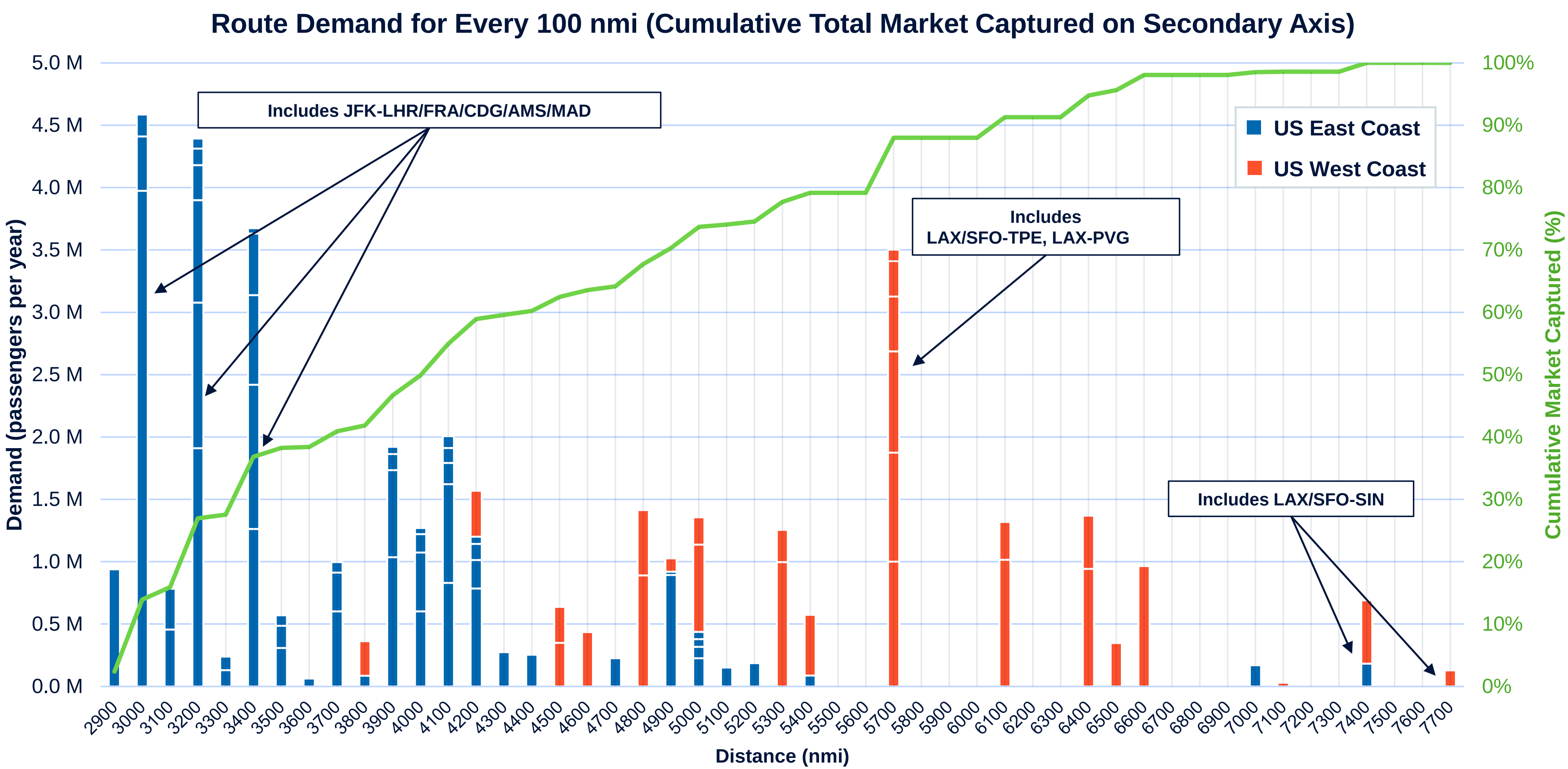
- Project Review and Guidance– provided expert review and study guidance throughout the study

Select US-Based Transoceanic Flight Routes



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

Annual Passenger Market by Route Distance



2020 Commercial Hypersonic Transportation Study Findings

- **Multiple aircraft configurations and market approaches resulted in positive business cases for their manufacturers (engine & airframe), as well as operators** *(assuming IRR > 25%)*
  - Smaller aircraft (20-50 pax) tend to be favored over larger aircraft for several factors, including sales synergies with the private/charter market and higher average passenger load factors on thin routes
  - Slower cruise speed aircraft (Mach 2-3) in the 4,000-4,500 nmi class are also slightly favored and result in lower ticket prices and therefore larger market sizes. This appeared to be a more robust part of the market
  - North-Atlantic markets remain the largest economic prize, but longer trans-Pacific ranges remain interesting for smaller Mach 2-3 vehicles that can reach to 6,000 nmi+

- **Results are most sensitive to potential reductions in estimated passenger market size**
  - Fuel cost increases, engine development cost increases, and loss of private/charter sales are also important

- **Government contributions via non-recurring offsets or "anchor buys" are helpful**
  - More beneficial for 1) smaller overall aircraft development program (gov't contributes a larger percentage of the total cost) or 2) higher speed aircraft where predicted annual airframe sales are not as large. However, government contributions are not required for success

- **Ultimately, this study determined that there are viable business cases for high-speed aircraft but left us with the question of what those business cases may look like**

2021-'23 *Life Cycle Cost Modeling of High-Speed Commercial Aircraft* Study

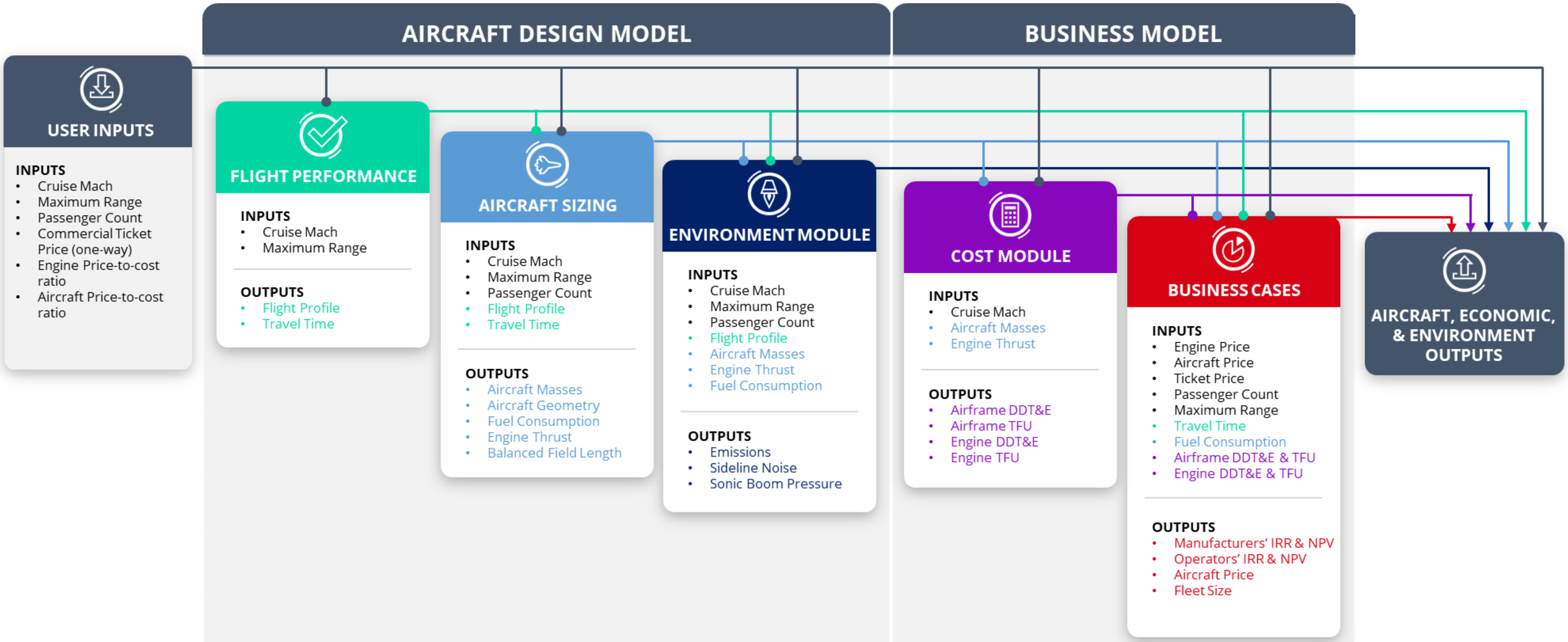
- **Based on the 2021 study findings, several areas were identified for further analysis and subsequently have been conducted under a new effort**

- **This included improving the HCSA ROSETTA Model & development of MIDAS for advanced Modeling & Simulation (M&S) of the market dynamics. Specific activities included:**

1. **Further characterize the business case viability in the Mach 1.5 to 5.0 speed regime, for 20-50 passenger configurations, and maximum aircraft ranges of 3,500-7,000 nmi.**
   - Evaluating short-range aircraft in this trade space that could utilize tech stops to reach long-range routes
   - Conducting market research to update existing model assumptions with current passenger survey data post-COVID
   - Developing baseball cards with details on individual point designs in this space
2. **Explored alternative business case and economic scenarios**
   - Analyzing mixed fleet solutions with short- and long-range aircraft that split demand based on distance
     - Additional analysis was conducted for demand-based mixed fleet solutions that split demand based on route size
   - Analyzing competitive operator scenarios to determine if splitting the market was beneficial
   - Evaluating alternative fuels to Jet-A: sustainable aviation fuel (SAF), liquified natural gas (LNG), and liquified hydrogen (LH2)
   - Evaluating the impact of allowing overland routes over the continental United States
   - Assessing the impact of delaying initial operating capability (IOC) date
   - Implementing flight scheduling to improve the fidelity of aircraft utilization within the constraints of fixed flight times and time zones

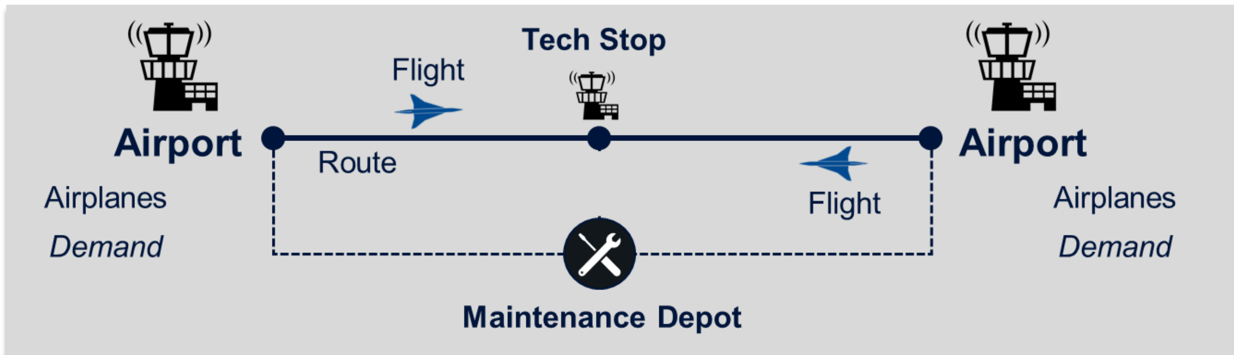
Modeling & Simulation Data Flow

SpaceWorks developed aircraft sizing and business modules for high-speed simulations



Multi-Market Integrated Dynamic Aerospace Simulation

Generic Model "Node"



Flexible and Interactive Simulation

MIDAS | Scenario Based Analysis

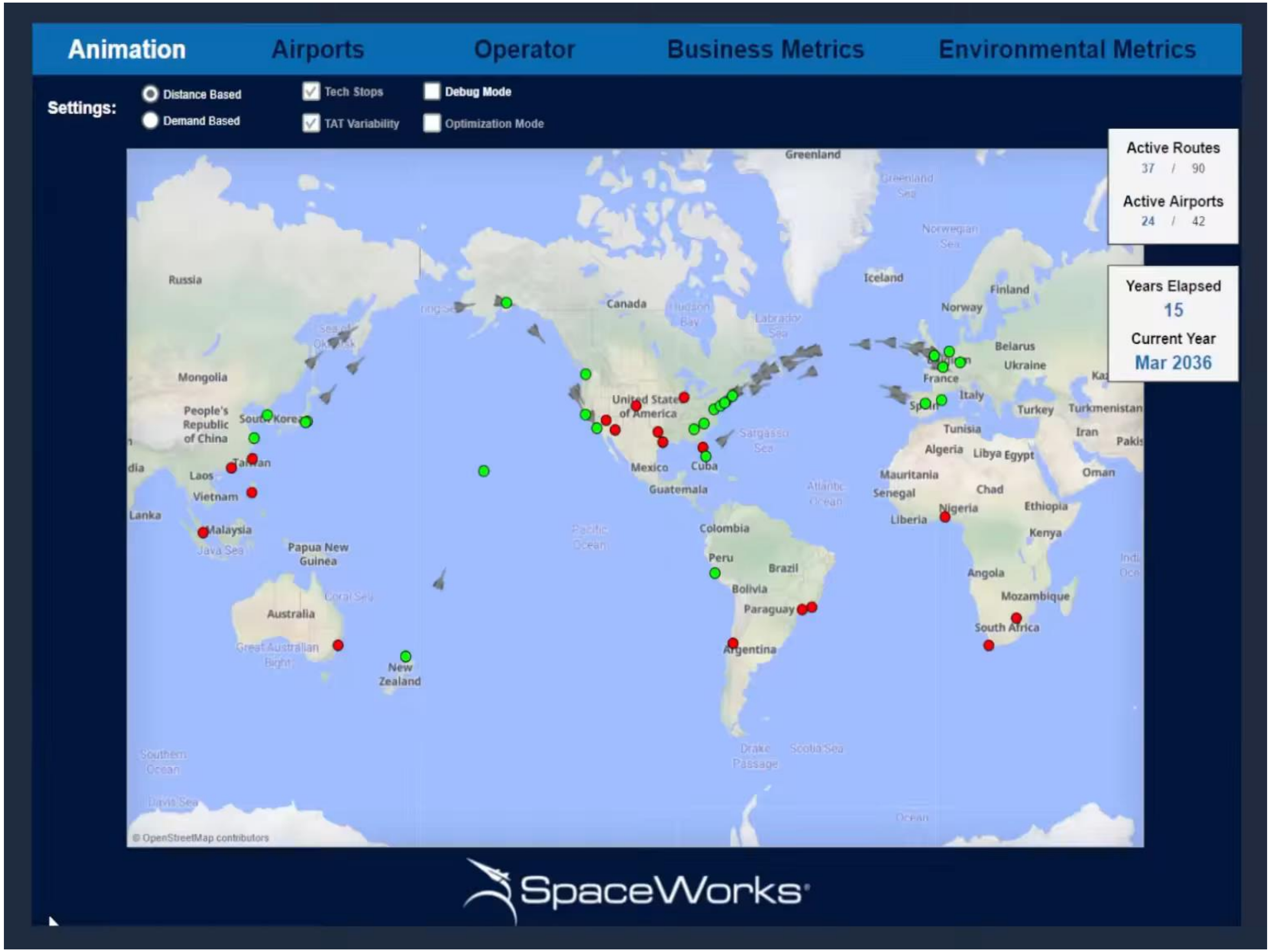
Market/Route Scenarios for Optimization

NUMBER OPERATORS

NUMBER AIRCRAFT TYPES

	1 (*Monopoly*)	**2** (*Competitive*)
1	***Route Length (baseline)*** ***Tech Stops*** ***Flight Scheduling***	***Split-Even (50/50 share)*** ***Crown Jewels***
2	***Route Length*** ***Demand***	***Split-Weighted***

MIDAS Simulation | Preview



MIDAS | Comparison of Capabilities

- **Core capability is captured by both the ROSETTA and MIDAS models**
- **MIDAS offers greater resolution into fleet operations and annual metrics**

	Feature	ROSETTA	MIDAS
Scenarios	Ability to model multiple aircraft (e.g., short-range, long-range)	✓	✓
	Ability to model multiple operators	✓	✓
	Incorporate tech stops in routes	✓	✓
	Model alternative fuels (e.g., SAF, LNG, LH2)	✓	✓
	Vary IOC year for aircraft	✓	✓
	Flight scheduling scenario		✓
	Extensibility to new modules and scenarios		✓
Metrics	Detailed annual tracking metrics for operators and manufacturers	✓	✓
	Determine environmental (emissions) metrics	✓	✓
	Provide metrics for individual airplanes (maintenance checks, TOLs)		✓
	Variable airplane retirement rates based on Mach number		✓
	Track airplane deliveries based on priority status		✓
	Track unsatisfied demand		✓
Market	Allow markets to grow annually	✓	✓
	Add routes as markets become viable due to growth		✓
Simulation	Incorporates aircraft sizing in the loop	✓	
	Graphical User Interface (GUI)		✓
	Allow variability and randomness in simulation		✓

Key Findings | Overall

- **Economic metrics resulted in ticket price premiums of 2 to 2.5 times over business class tickets in order to capture ~10% of the market currently serviced by hundreds of subsonic aircraft.**

- **Given our key findings with respect to market demand, aircraft technical specifications/capabilities, financial considerations, and various environment factors:**

  - ***We believe there is a high-speed PTP market, but it is <u>relatively small</u> for the foreseeable future due to a combination of challenging factors***

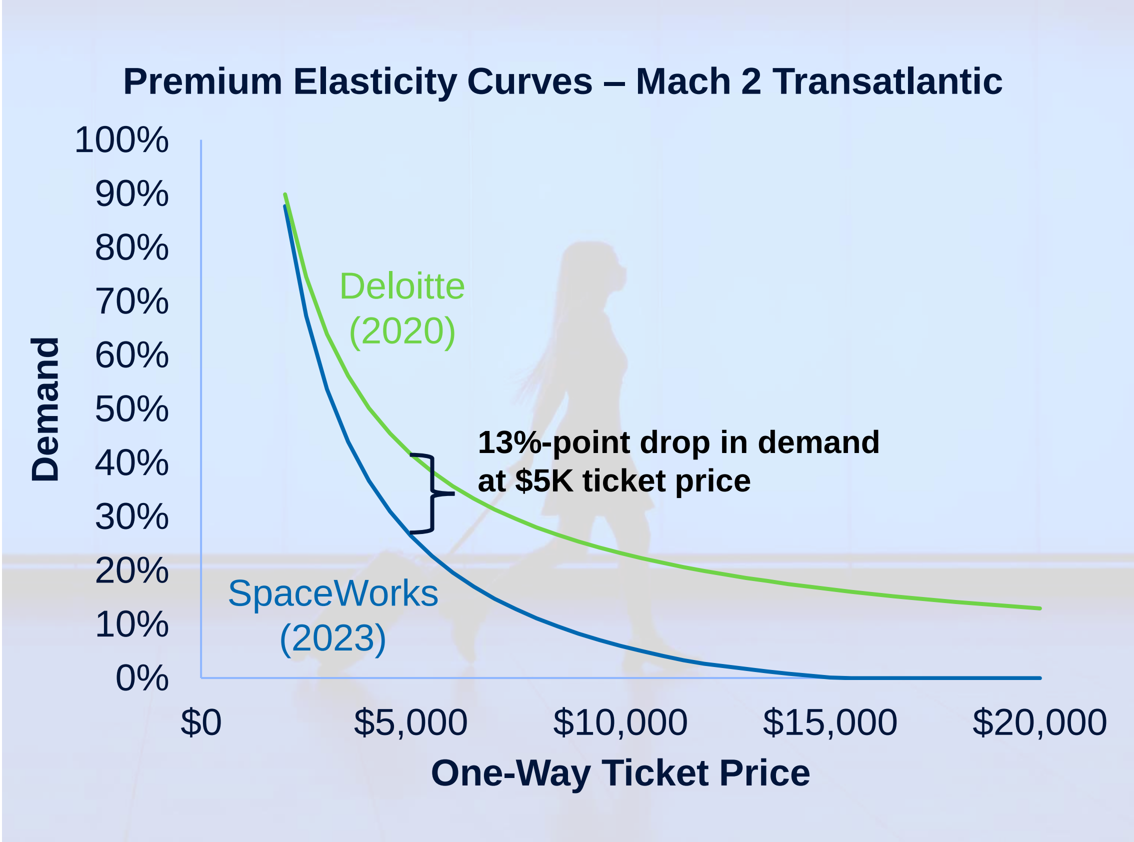
  - ***The <u>environmental issues must be solved</u> without significantly impacting the design and capabilities of the aircraft in order for this market to be realized***

  - ***Small improvements in the aircraft (i.e., engine TSFC, structural mass reductions, etc.) can have a <u>significant positive impact on financial viability</u> due to impacts on $/RPM***

Key Finding | Market

The average airline passenger remains too price sensitive for high-speed flight, but premium passengers are still willing to pay for speed/time

- **Worsening macro-economic factors have caused increased price sensitivity, however long-term market growth has improved**
- **High-speed flight will marginally grow the overall commercial air passenger market (by accessing a small, untapped market for unrealized travel due to current time constraints)**
- **Surveys confirmed that additional factors such as degree of cabin outfitting/amenities (i.e., the experience) and the environmental impact of the travel are considerations/concerns in willingness to travel**

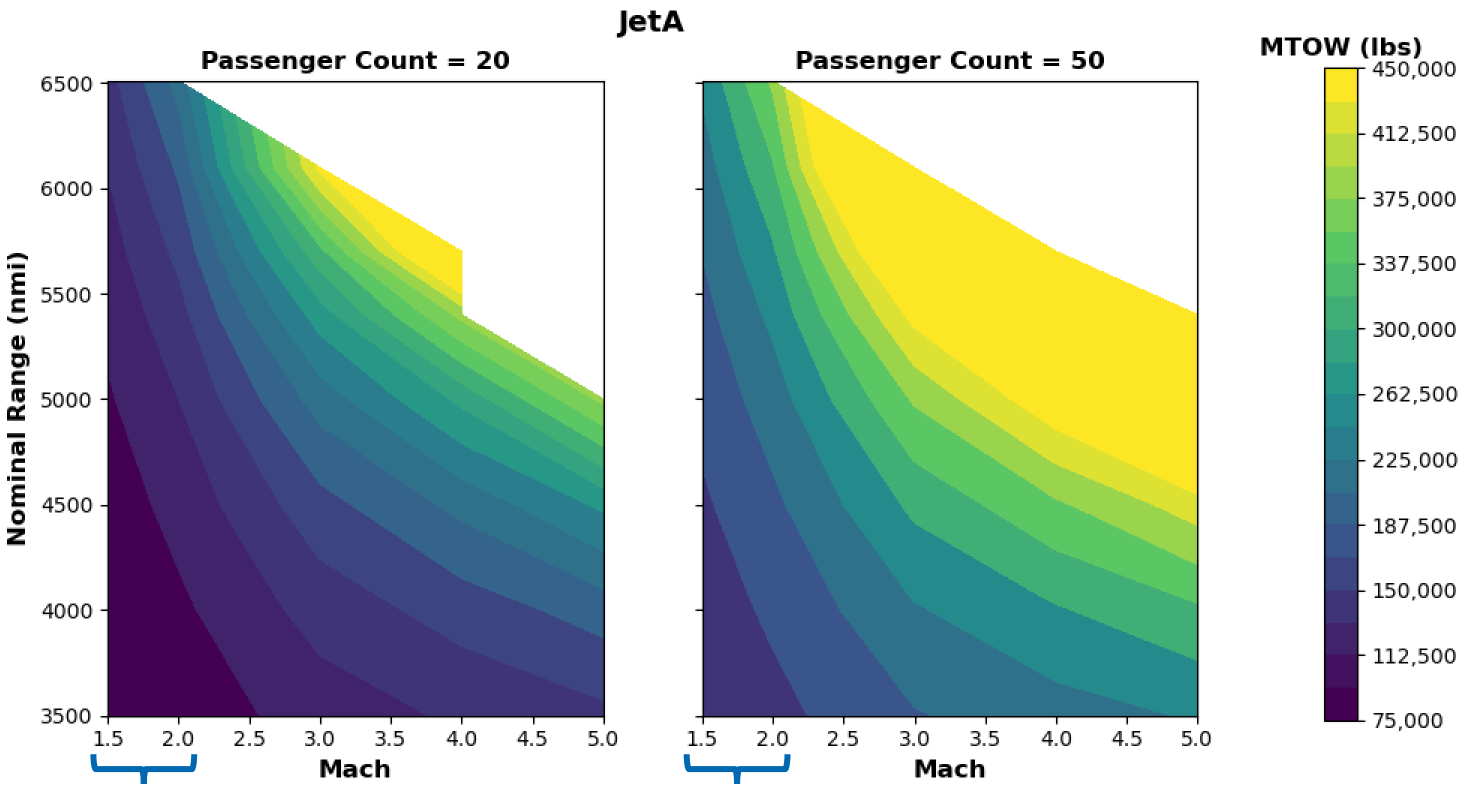


Key Finding | Aircraft

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 Jet-A 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 CO_2e kg/km/pax (still ~5x higher than subsonic A/C)
- **Lowest noise level for takeoff**
  - < 92 EPNdB

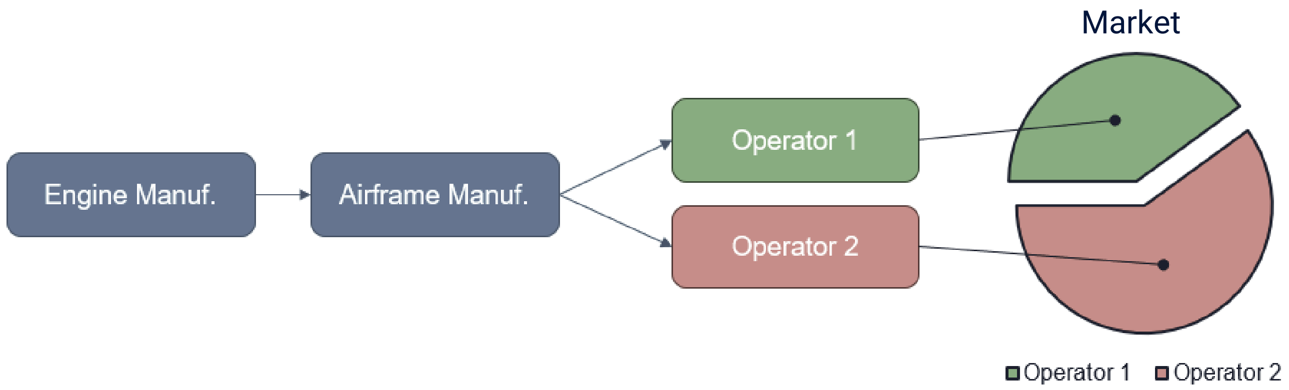


Key Finding | Financials

For the optimal aircraft configuration, spreading the financial risk between multiple operators enables improved business cases for all stakeholders

- **Splitting demand tempers initial investments by the operators while still enabling a high production rates by the manufacturer**
  - Reduces maximum exposures for both operators and is therefore a less risky venture overall

- **This enables the engine and airframe manufacturer to reduce their list prices, resulting in operators breaking even sooner**
  - Faster break-even points are driven by lower ticket prices that generate higher market capture and revenue



Key Finding | Environment

Takeoff noise, sonic booms, and emissions continue to pose a major challenge to high-speed flight and will need to be addressed before a high-speed market can be realized

- **High-speed aircraft are chasing regulations that continue to become more stringent as climate concerns become more prevalent**
- **Advanced technology will help address these issues - but requires time and money**
- **Alternative fuels can mitigate the emissions challenge, but production scale of these fuels need to be significantly higher**
- **Shorter flight times appear to offer benefits with regard to radiation exposure compared to longer duration subsonic travel**

Recommendations

1. **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

2. **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+)

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

4. **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

Future Work

- **Economic Model Improvements (for MIDAS)**
  - Enable more refined route-based ticket pricing
  - Permit dynamic ticket pricing in competitive environments
  - Incorporate more ground operations details for pre-flight/post-flight maintenance and/or overhaul
- **Environmental Impact Factors**
  - Enable technology modeling for noise reduction, sonic boom mitigation, and improved emissions to be implemented into the aircraft design & sizing process/model
  - Evaluate high-fidelity HSCEV reference vehicles that are more explicitly addressing these challenges and benchmark against vehicle sizing models used to date
- **Additional Scenario Studies**
  - Evaluate PTP scenarios with staggered aircraft retirement rates that would more easily enable block upgrades
  - Perform more refined analysis of the "leader-follower" scenarios
    - Consider more synergies between manufacturers
    - Combine trade/sensitivity studies to evaluate multiple scenarios
  - Reduce trade space to focus on specific aircraft
    - Target more company-specific economic metrics and include more risk factors for each operator and manufacturer
  - Conduct further analysis into the airport operations that would make the most sense for high-speed aircraft and the expected passenger class that would be served
- **Market Ideation**
  - Evaluate integration with Regional Air Mobility (RAM) transportation through hub-spoke architecture
  - Continue to investigate and characterize the market and public interest

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