



# Examining the Business Cases for Supersonic and/or Hypersonic Commercial Passenger Flight

Panel: Supersonic and Hypersonic Flight Tech & Airspace Considerations  
National Academies Meeting of the Aeronautics and Space Board  
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Technical Fellow

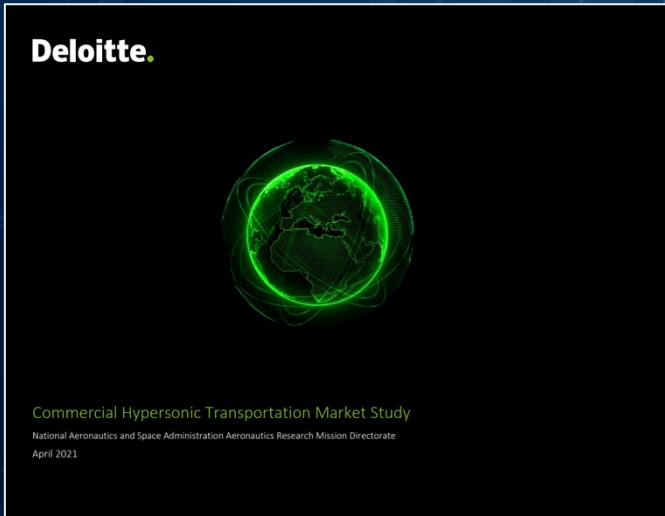
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# Full Study Reports are on NASA Tech Reports Server (NTRS)

## Commercial Hypersonic Transportation Market Study



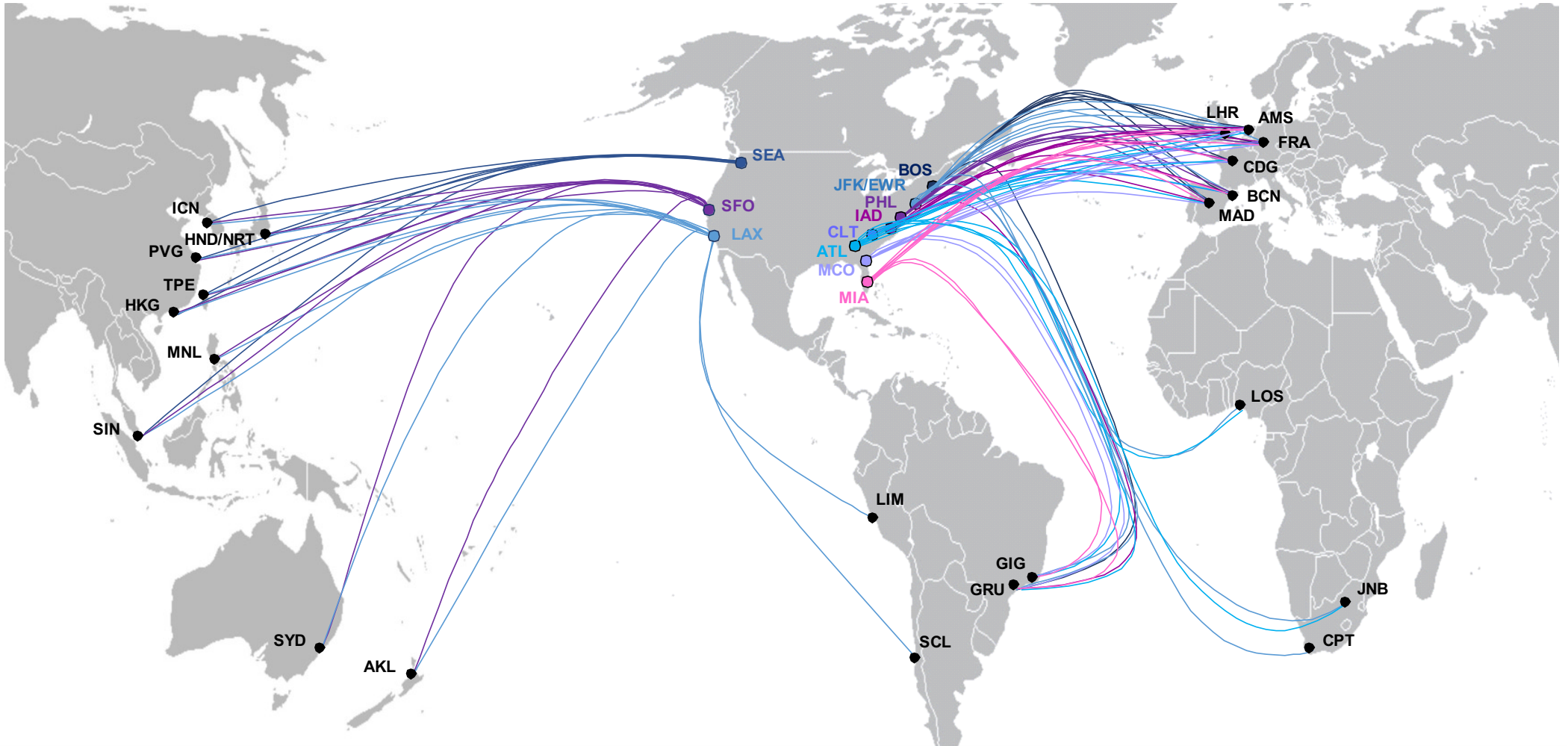
## Life Cycle Cost Modeling of High-Speed Commercial Aircraft



## Life Cycle Cost Modeling of High-Speed Commercial Aircraft: Expanded Trade Studies

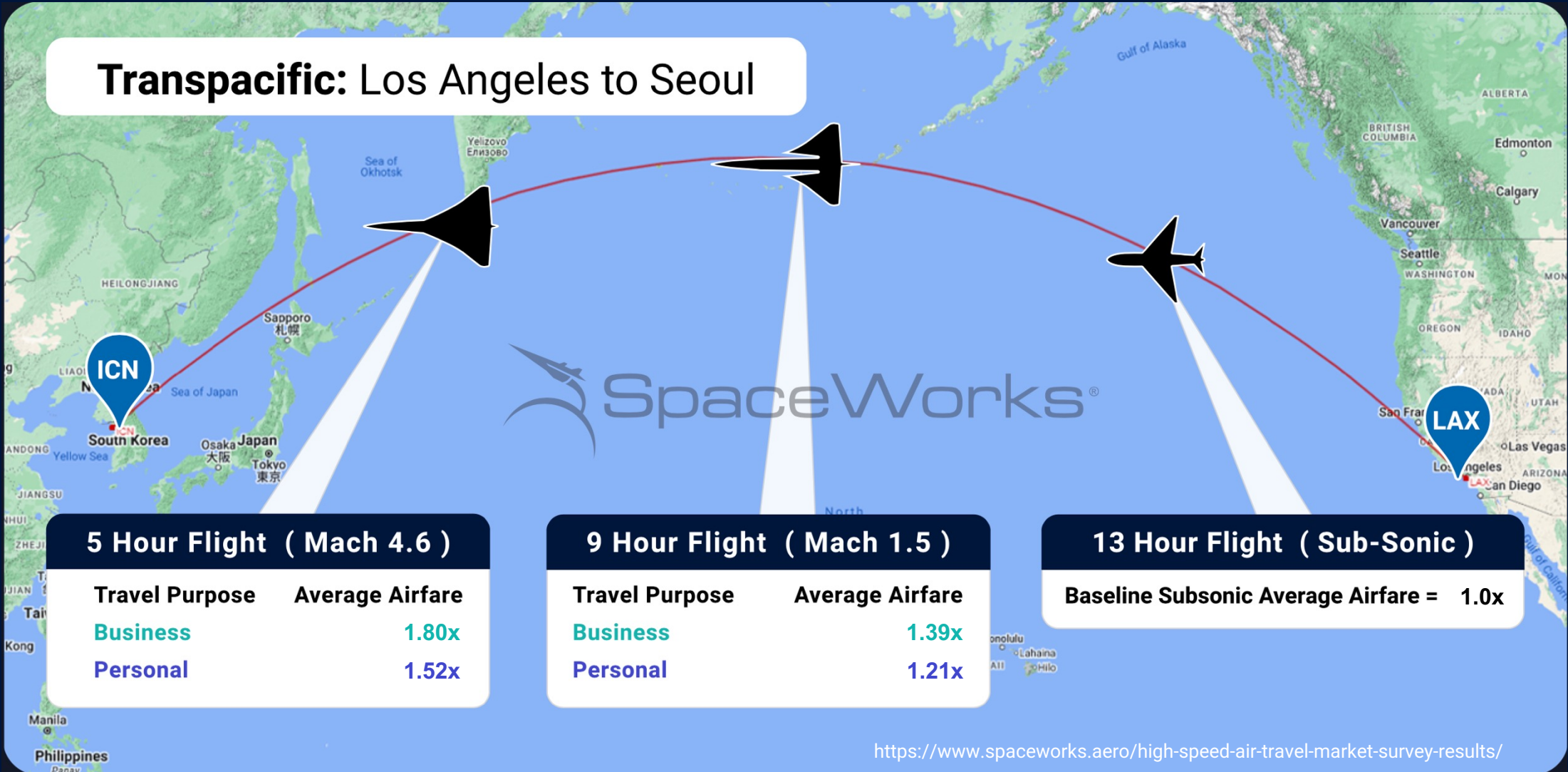


# Our Preferred US-Based Transoceanic Flight Route Map



The top 90 U.S. transoceanic routes served 40M total annual passengers in 2019

# Average Willingness-to-Pay for Transpacific Route by Mach



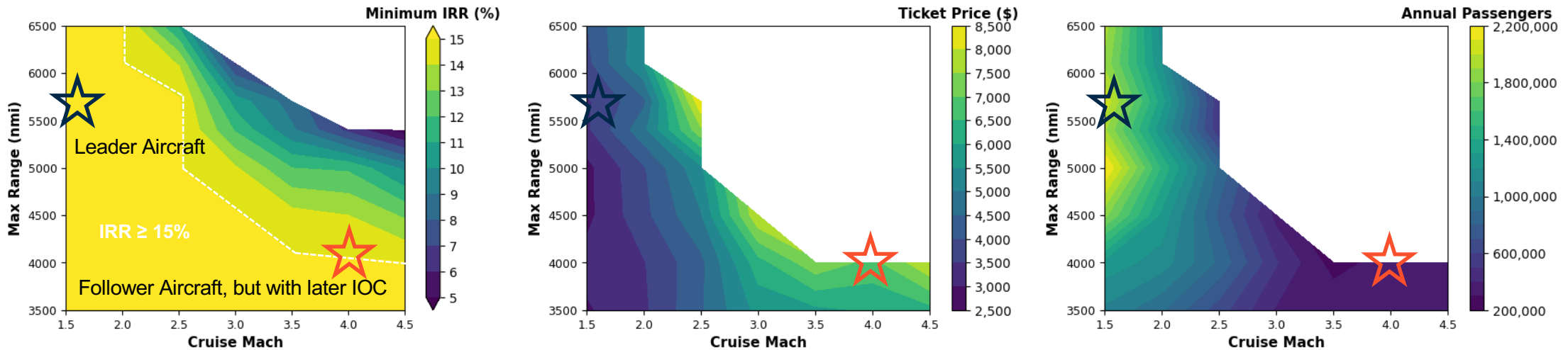
# Market Performance

SpaceWorks closed over 500 aircraft designs and business cases to create a contour of the trade space from Mach 1.5 – 5.0 , 20 – 80 passengers, and 3500 – 6500 nmi unrefueled ranges

- Utilized SpaceWorks' MIDAS simulation to model vehicle closure and optimize market prices at each point to achieve 15% IRR
- Model predicts several marginally feasible business cases in the trade space, even up to Mach 4.5

Aircraft designs with the largest market capture (our objective) were at the lower Mach numbers

- An attractive solution lies in the Mach 1.6, 5700 nmi, 60 passenger class. We like this regime as a “Leader” solution in the near term
- With additional time to grow the market and mature technologies, a faster 32 pax “Follower” aircraft in the Mach 4 regime emerges



# SpaceWorks' Near-Term Mach 1.6 Vision Vehicle (Leader)



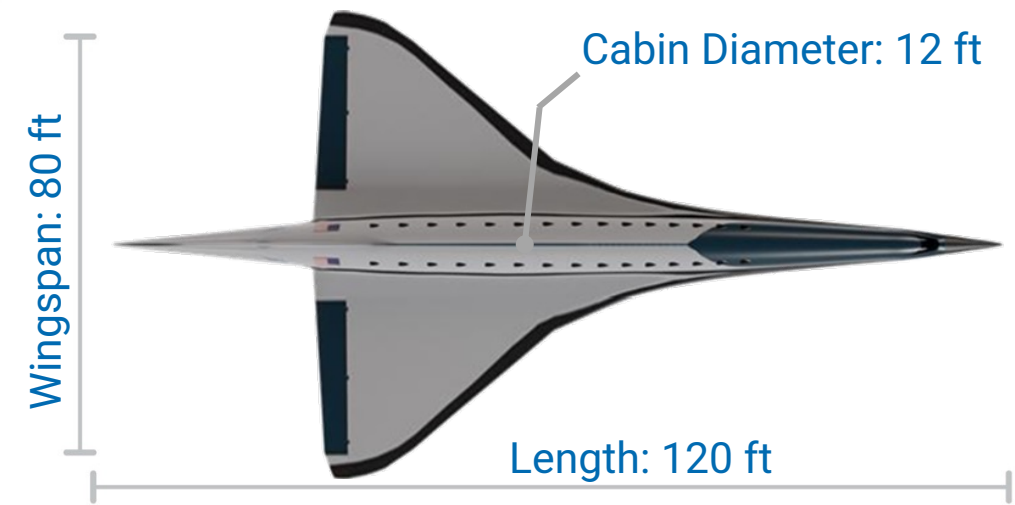
# Leader Aircraft Solution

**Mach 1.6**  
Cruise Speed

**5,700 nmi**  
Max Range

**60**  
Passenger Count

**SAF**  
Fuel Type



## COST METRICS (FY21 USD)

### DDT&E

**\$8.4B**   **\$2.7B**  
Airframe   Engine

### TFU

**\$118M**   **\$14M**  
Airframe   Engine

## ENVIRONMENTAL METRICS

**93 EPNdB**  
Lateral Takeoff Noise

**0.29 kg/km/pax**  
Emissions (CO<sub>2</sub>e)

**107 PNLdB**  
Sonic Boom

**0.1 kg/km/pax**  
Fuel Consumption Rate

<b>231,000 lbm</b> MTOW	<b>88,000 lbm</b> MEW	<b>4 x 22,000 lbf</b> Engine Thrust SLS
<b>7.1 hours</b> Gate-to-Gate Time at Max Range	<b>50,000 ft</b> Cruise Altitude	<b>6,000 ft</b> Bal. Field Length SL

## AIRCRAFT NOTES

- Supersonic cruise condition L/D = 9.2
- Supersonic cruise condition Isp = 3800 s
- Vehicle propellant mass fraction (PMF) = 0.55
- Takeoff T/W = 0.375
- Effective Dose Rate (51° Lat.) = 7.0 μSv/hr

# Leader Aircraft Solution



## Key Inputs

- Mach 1.6**  
Cruise Speed
- 5,700 nmi**  
Range
- 60**  
Passenger Count
- SAF**  
Fuel Type

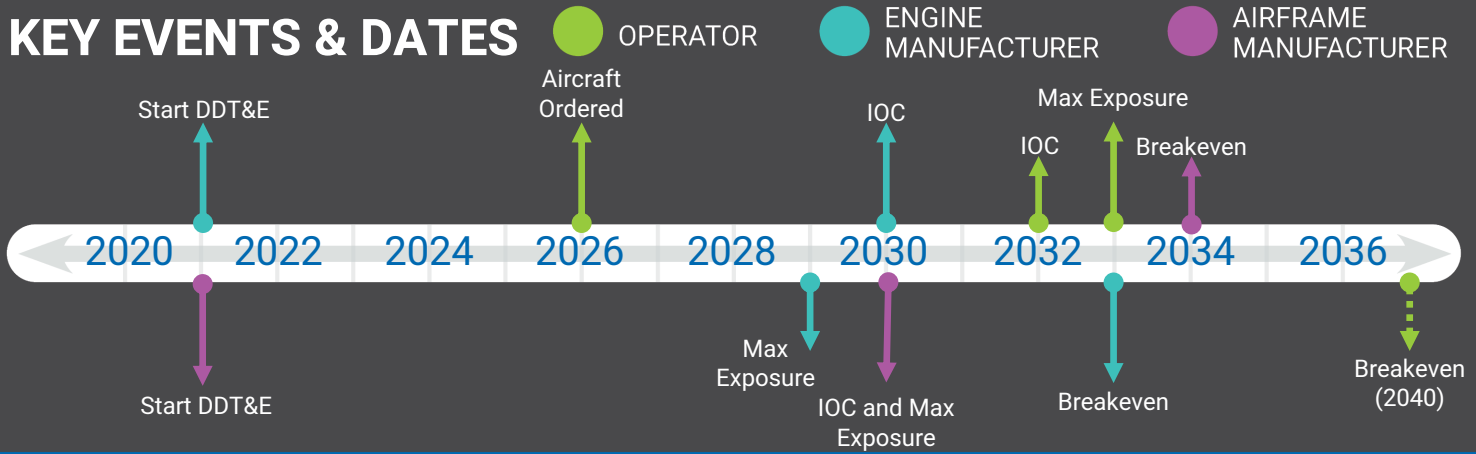
### OPERATOR METRICS

- \$3,500-\$4,500**  
Ticket Price
- 2.4M**  
Pax @ IOC Year
- 46**  
Routes Captured

### MANUFACTURER METRICS

- \$240M**  
Aircraft Price
- \$184M**  
Airframe Price
- \$14M x4**  
Engine Price
- 431**  
Aircraft Sold

## KEY EVENTS & DATES



## Business Results

### OPERATOR

- 15%**  
IRR
- \$2.5B**  
NPV
- \$5.5B**  
Max Exposure

### ENGINE MANUFACTURER

- 15%**  
IRR
- \$1.2B**  
NPV
- \$2.3B**  
Max Exposure

### AIRFRAME MANUFACTURER

- 15%**  
IRR
- \$4.3B**  
NPV
- \$9.4B**  
Max Exposure

## BUSINESS CASE ANALYSIS

This aircraft is capturing 46 of 78 addressable routes that are within its design range which are a mix of Atlantic & Pacific Ocean routes.

# SpaceWorks' Far-term Mach 4 Vision Vehicle (Follower)



# Follower Aircraft Solution



**Mach 4.0**  
Cruise Speed



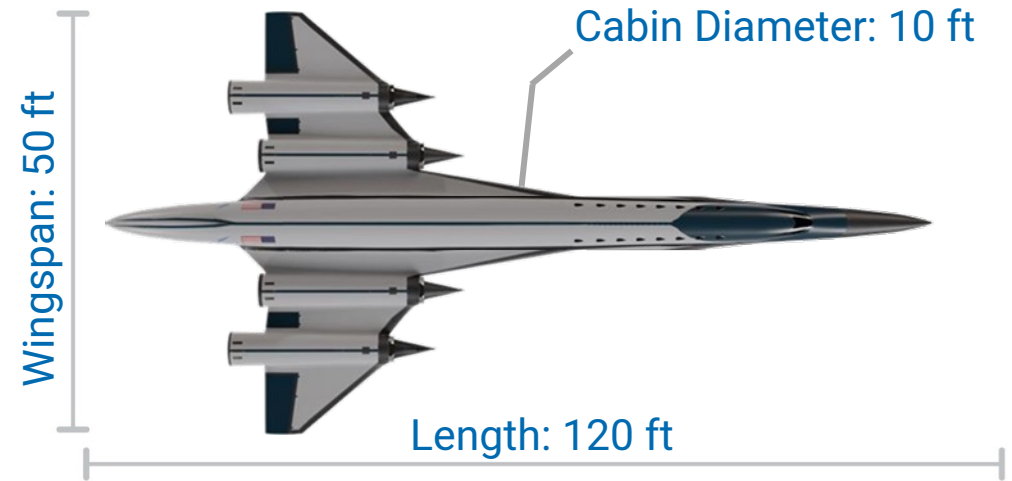
**4,500 nmi**  
Max Range



**32**  
Passenger Count



**SAF**  
Fuel Type



## COST METRICS (FY21 USD)

### DDT&E

**\$8.8B**  
Airframe

**\$4.6B**  
Engine

### TFU

**\$128M**  
Airframe

**\$33M**  
Engine

## ENVIRONMENTAL METRICS

**89 EPNdB**

Lateral Takeoff Noise

**0.84 kg/km/pax**

Emissions (CO<sub>2</sub>e)

**103 PNLdB**

Sonic Boom

**0.26 kg/km/pax**

Fuel Consumption Rate

**262,000 lbm**  
MTOW

**92,000 lbm**  
MEW

**4 x 28,000 lbf**  
Engine Thrust SLS

**2.7 hours**  
Gate-to-Gate Time  
at Max Range

**85,500 ft**  
Cruise Altitude

**9,000 ft**  
Bal. Field Length SL

## AIRCRAFT NOTES

- Supersonic cruise condition L/D = 5.8
- Supersonic cruise condition Isp = 1500 s
- Vehicle propellant mass fraction (PMF) = 0.62
- Takeoff T/W = 0.425
- Effective Dose Rate (51° Lat.) = 8.5 μSv/hr

# Follower Aircraft Solution



## Key Inputs



**Mach 4.0**  
Cruise Speed



**4,500 nmi**  
Range



**32**  
Passenger Count



**SAF**  
Fuel Type

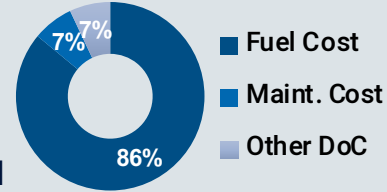


## OPERATOR METRICS

**\$6,400-\$7,600**  
Ticket Price

**1.1M**  
Pax @  
IOC Year

**30**  
Routes Captured



## MANUFACTURER METRICS

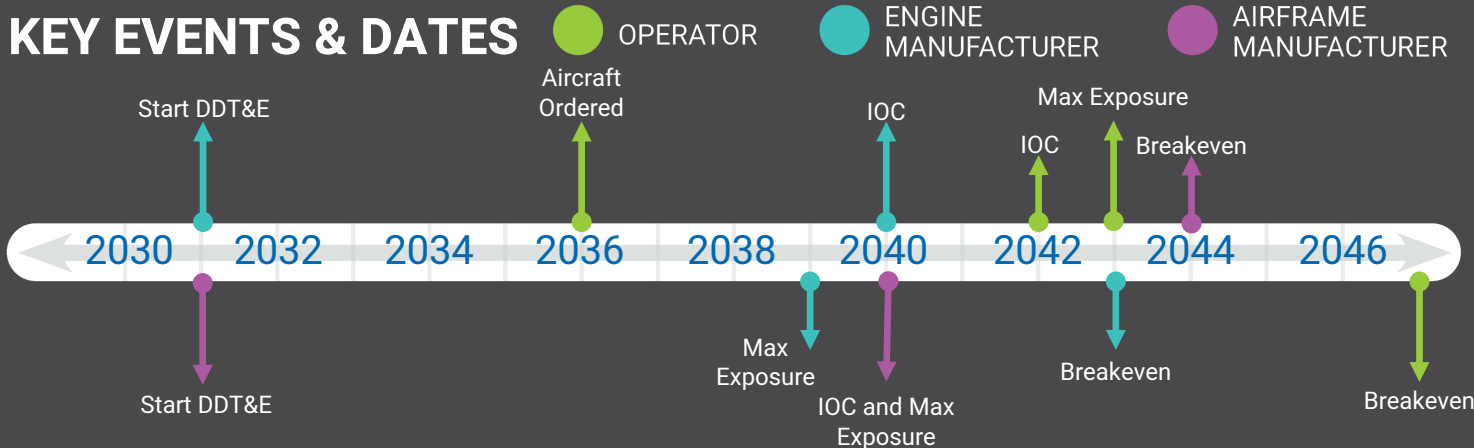
**\$426M**  
Aircraft Price

**\$278M**  
Airframe Price

**\$37M x4**  
Engine Price

**151**  
Aircraft Sold

## KEY EVENTS & DATES



## Business Results

### OPERATOR

**15%** IRR  
**\$1.2B** NPV  
**\$5.8B** Max Exposure

### ENGINE MANUFACTURER

**15%** IRR  
**\$1.4B** NPV  
**\$4.2B** Max Exposure

### AIRFRAME MANUFACTURER

**15%** IRR  
**\$3.2B** NPV  
**\$11B** Max Exposure

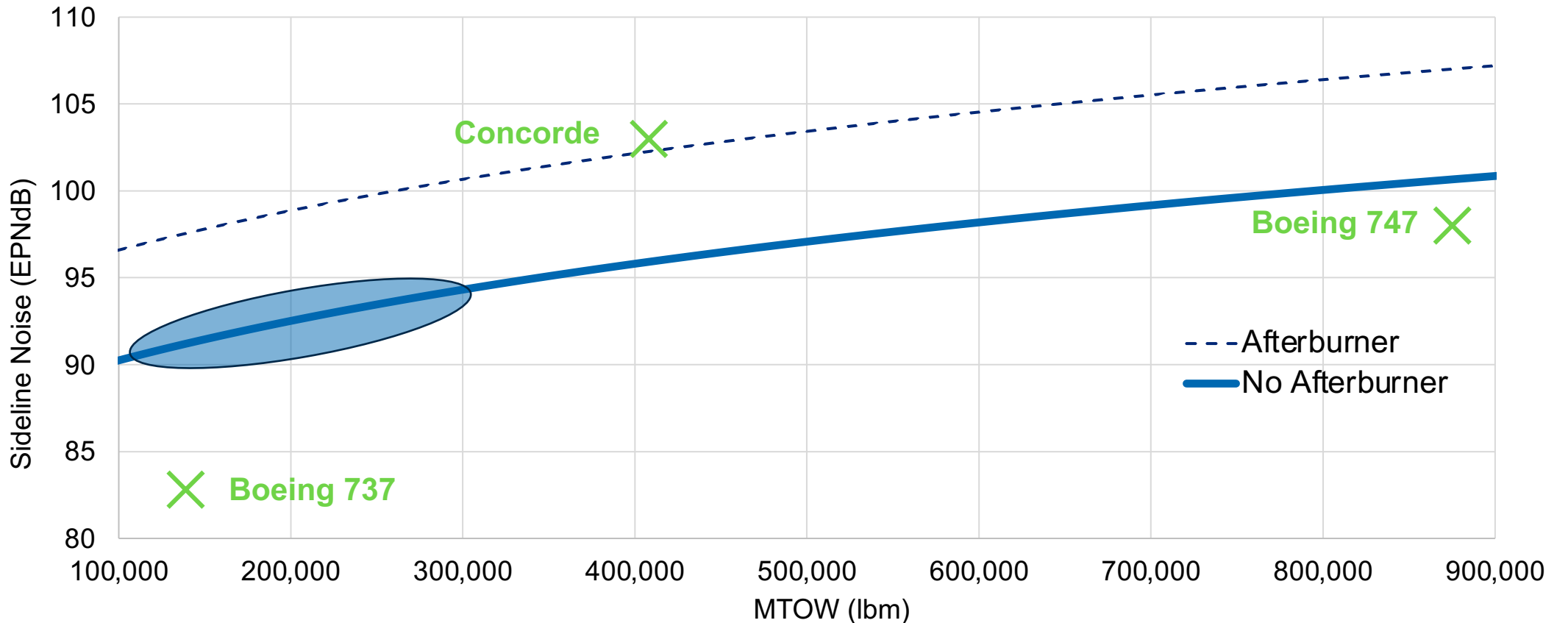
## BUSINESS CASE ANALYSIS

This aircraft is capturing 30 of 53 addressable routes which are primarily Atlantic Ocean routes and Pacific Ocean routes including Seattle/San Fran. - Tokyo & Los Angeles - Lima. Additional routes to Tokyo, Seoul, Shanghai, Taipei, Hong Kong, Sydney, & Auckland can be reached via tech stops.

# Takeoff Noise Trends

- ▶ Many economically viable aircraft in our trade space have MTOWs less than 300,000 lb and result in estimated takeoff noises in the low 90s EPNdB. These smaller MTOW aircraft may have the best chance of meeting future takeoff noise regulations

Aircraft Sideline Noise at Takeoff Conditions



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# Backup Charts

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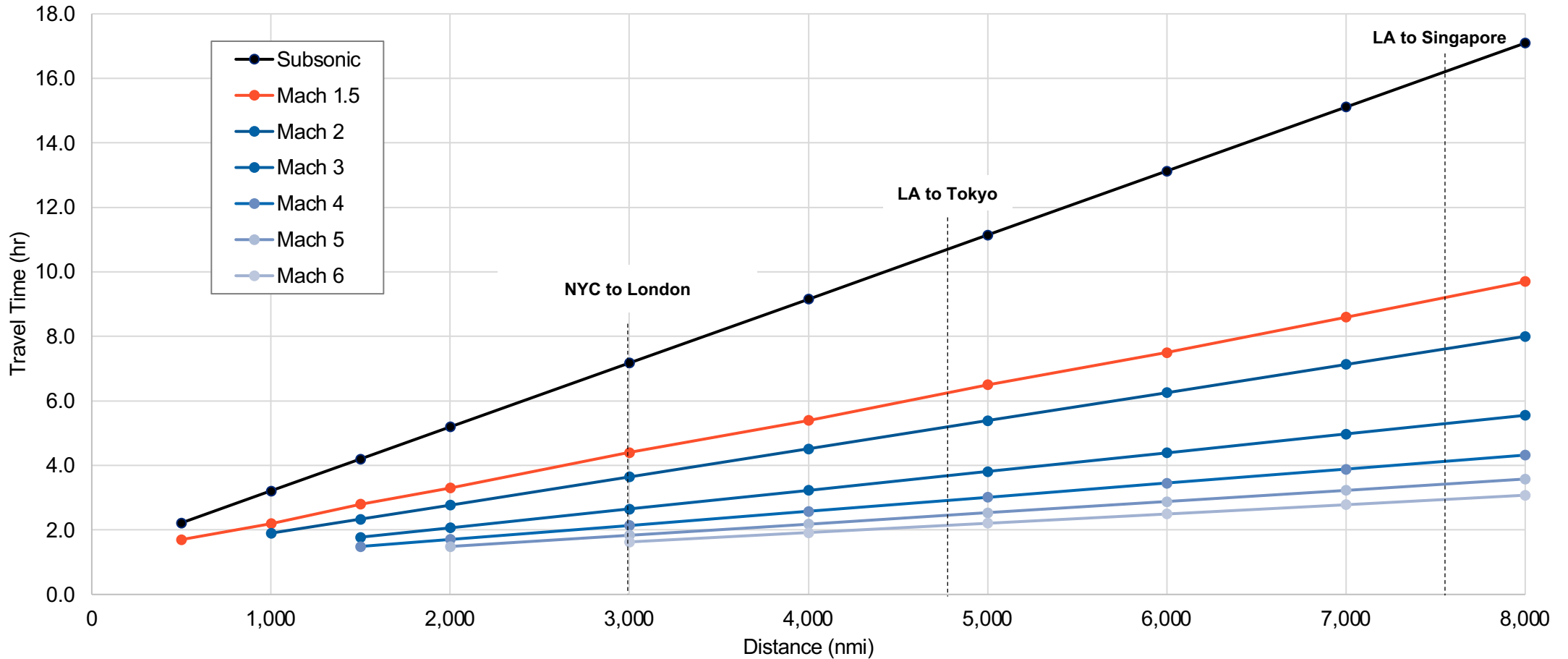
- ▶ **Study Scope & Assumptions**
- ▶ **Travel Time Benefits vs. Cruise Speed and Distance**
- ▶ **Market Price Elasticity Curves (Premium Travelers)**
- ▶ **US Overwater Route Capture by Distance**
- ▶ **CO<sub>2</sub>e Emissions per Pax vs. Aircraft Range and Cruise speed**

# Key Study Assumptions

- ▶ Due to current overland restrictions on supersonic flight, only the top-90 **transoceanic, U.S.-based routes** were considered for this study, unless otherwise noted
- ▶ In most cases, a Technology Availability Date of 2025 was used to close the parametric aircraft. **IOC varied from 2030 to 2040**, depending on predicted aircraft development and certification times
- ▶ Our simulation enforced a **minimum economic performance of 15% - 25% internal rate of return** (IRR) for all manufacturers and operators. One-way passenger ticket price was the primary independent variable with an objective to **maximize annual supersonic / hypersonic passenger demand**
- ▶ Aircraft **above 1 Mlbm MTOW were excluded** from economic analysis due to runway limitations and excessive aircraft prices
- ▶ Aircraft trade space was **not directly constrained to meet expected regulations on emissions, takeoff noise, radiation exposure, or sonic boom mitigation**, but these parameters were estimated in the analysis process for characterizing the magnitude of remaining environmental challenges
- ▶ Assumed the **government/military is an anchor customer** and purchases the first 20 aircraft, or up to \$5B, whichever occurs first

# Travel Time Value Proposition for High-Speed Air Travel

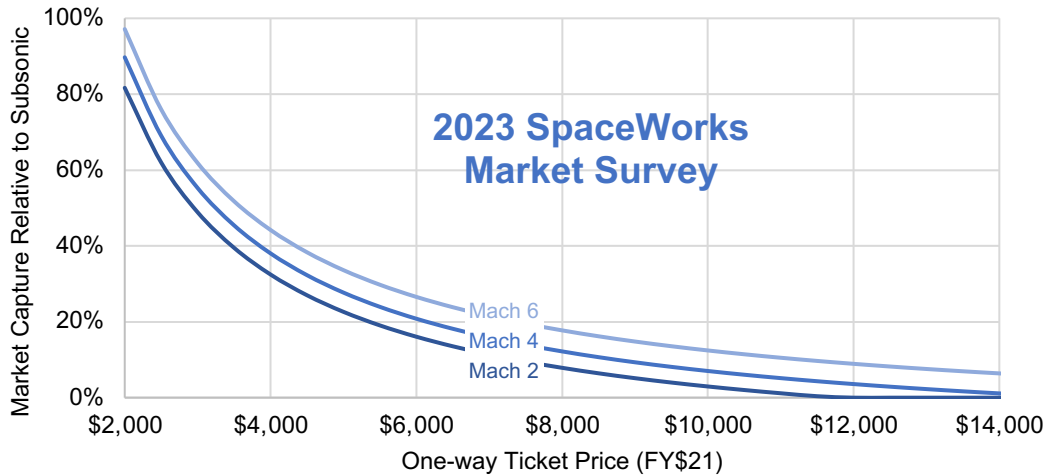
## Cruise Mach Impact on Gate-to-Gate Travel Time



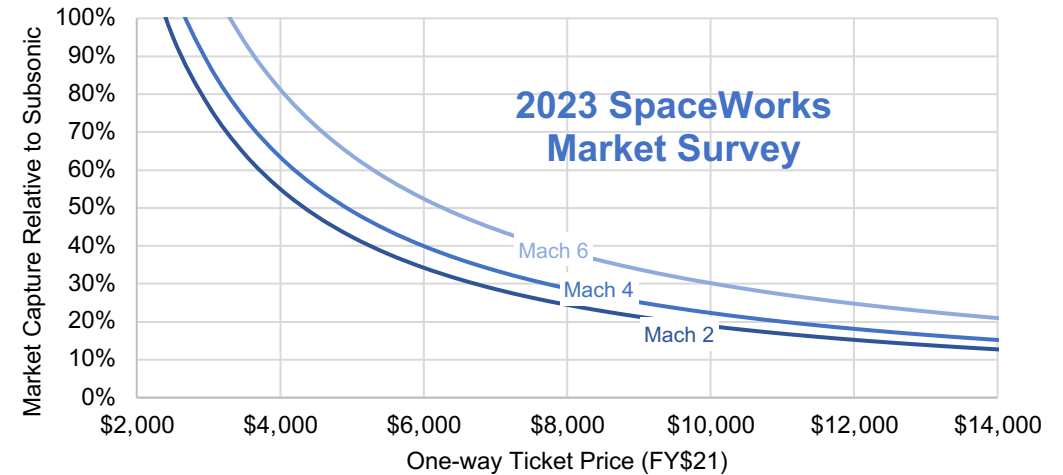
# Price Elasticity Survey Results – Premium Passengers

- ▶ **In 2023 under NASA sponsorship, SpaceWorks conducted a market survey of ~1000 high net worth international business travelers to forecast the market elasticity for future commercial airline travel at average speeds above Mach 1**
  - Assume premium-class seating (but not lay flat seating), high-end onboard services, high-end concourse experience, but limited cabin size, window size, and headroom
  - Noise and emissions challenges were noted in the survey intro, so those impacts on the market are implied to have been captured
  - Sources included the Global Business Travel Association (GBTA), carefully-selected SurveyMonkey members, and broad LinkedIn responses
- ▶ **Results indicate a strong interest in faster travel, but a drastic decrease in willingness-to-pay as prices increase**
  - Responses plotted below for respondents who most often select first class or “business equivalent” for transoceanic flights (i.e. SpaceWorks’ “Premium” travel market dataset). Relative to this set, willingness-to-pay is even lower from Economy class transoceanic fliers

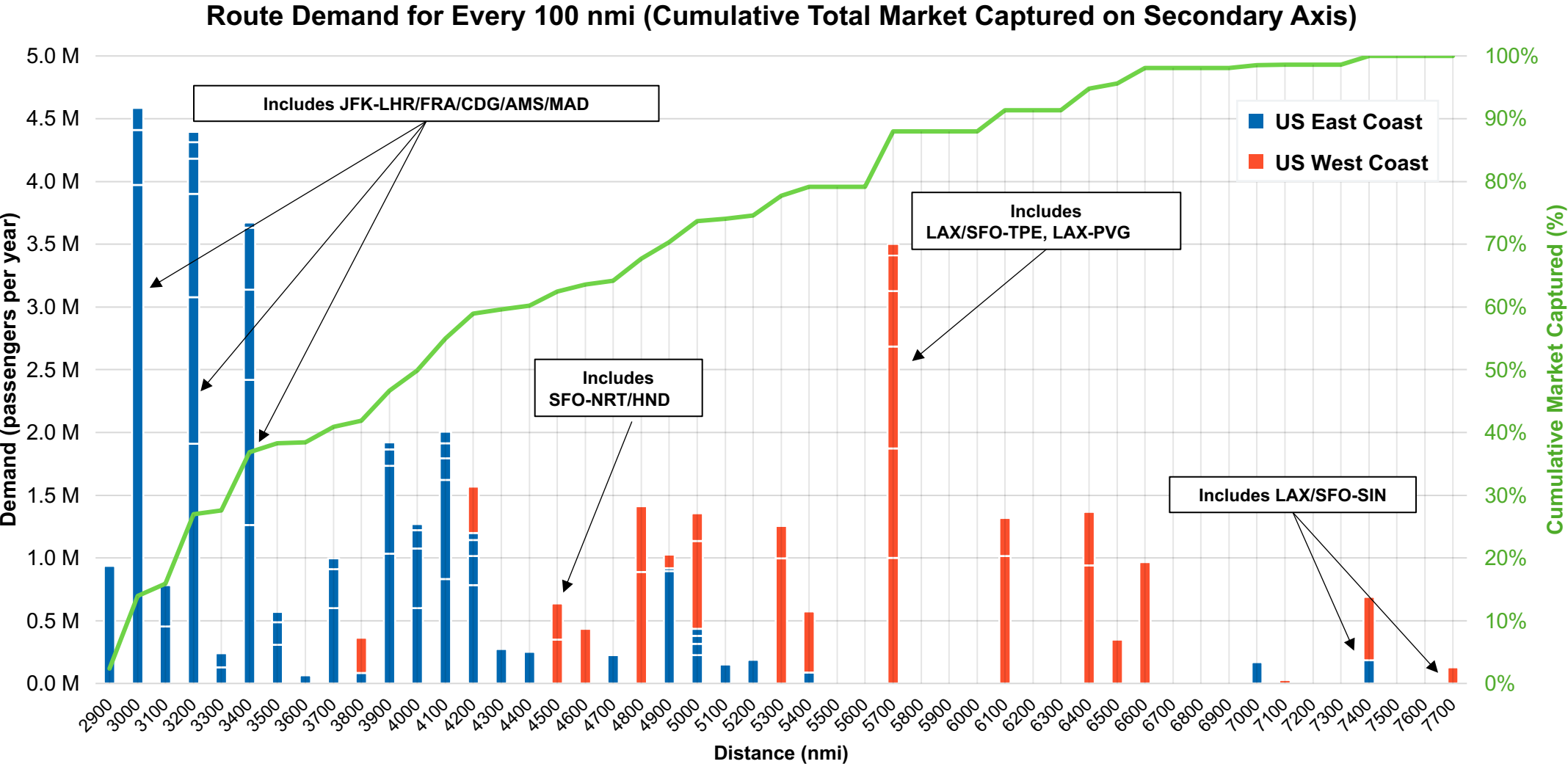
**Premium Travel Market, Transatlantic**



**Premium Traveler Market, Transpacific**



# Annual Passenger Market by Route Distance (2019 data)



# Emissions Remain a Significant Challenge

- At lower supersonic flight speeds and/or larger passenger aircraft, less fuel is needed per km per pax which helps reduce the total emissions metric
  - These values are still **well above current subsonic levels** ( which are  $\sim 0.08$  CO<sub>2</sub>e kg/km/pax)
- SAF and LNG have similar magnitudes for carbon emissions to Jet-A while LH<sub>2</sub> produces nearly zero**
  - However, the benefits for these fuels may only be realized when evaluating the entire life cycle of the fuel, especially for SAF which becomes net-zero carbon only when the manufacturing process is accounted for
  - Supply of alt fuels needs to greatly increase to serve the entire aviation market (from millions to billions of gallons/yr)

