JANUARY, 2020

TO36 Hypersonic Study

INDUSTRY PRESENTATION – FEBRUARY 2021

NASA Data and Technical Support Services TORFQ 36

Hypersonic Market Study Summary Findings

Customers of Commercial and private jet services, as well as cargo shippers are willing to pay for more expensive tickets to arrive sooner

The total projected passenger volume for each Mach number were found to be sufficient to support high speed air service for transoceanic routes without including overland routes

Viable business cases are possible from Mach 2 to Mach 5+ however, high speed aircraft cases are less robust than the Mach 2-4 range

In all cases, business viability [IRR] is most sensitive to passenger volume variances and to a lesser degree fuel price fluctuations and government subsidies

Regulatory, certification, societal and infrastructure barriers and challenges pose varying levels of business risk to aspiring service providers

The most challenging barriers are driven by lack of specific regulations and certification requirements to “design to” for this flight regime

TASK 1: MARKET ASSESSMENT

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OVERVIEW OF OUR APPROACH

In analyzing the high-speed air transportation market, we followed a structured approach involving several phases of analysis.

MARKET SEGMENTATION

What are the current trends in the market?

I. Catalogued government, corporate, and academic entities actively engaged in the high-speed air technology ecosystem.

II. Mapped industry supply chain and identified downstream sectors, including passenger, cargo, and private.

III. Analyzed US market trends to identify investment across the public and private sector.

CITY PAIRING

What are the most viable routes in the market?

I. Analyzed industry data to prioritize a list of potential high-speed air routes that align to passenger, cargo, and private transportation subsectors.

II. Down-selected routes based on a route-by-route analysis of economic and technical viability, assigning scored for each route.

III. Benchmarked routes into quadrants to identify select top-candidates.

MARKET DEMAND

How large is the potential market?

I. Surveyed consumers to measure willingness to pay for future high-speed air passenger, cargo, and private transport services.

II. Developed elasticity curves and sized the potential market across all future services including passenger, cargo, and private transport.

III. Catalogued major potential use cases and customers.

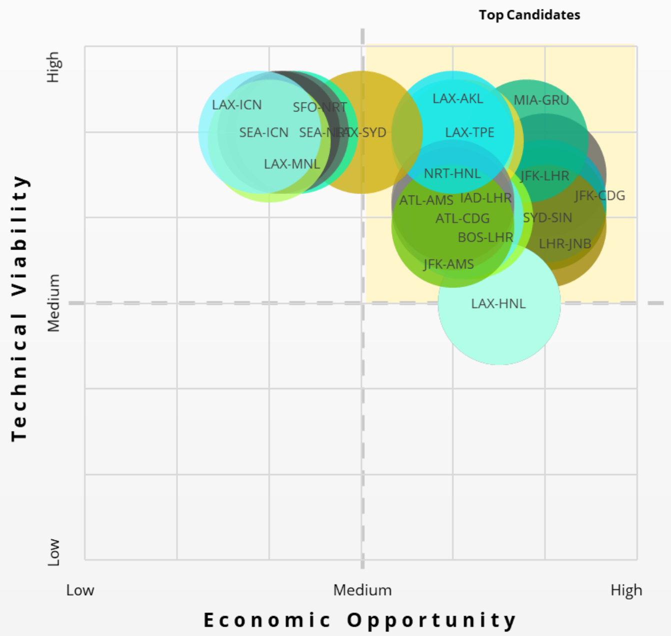
Market Segmentation Key Takeaways

- We observe a strong industrial base for defense applications and a nascent but growing interest in commercial applications from private investors seeking ROI.
- The private sector is developing technologies across the high-speed air supply chain, but these efforts are predominantly aimed at defense applications and technological barriers currently constrain commercial market growth.
- To achieve optimal ROI, industry and government stakeholders will need to leverage existing resources in the defense industrial base while building out the civil side of the market.

To enable commercial market segment, there will likely need to be a concerted government effort to remove market barriers and incentivize commercial development programs inclusive of direct government purchases of airframes and government intervention

Top Routes by Market Segment

PASSENGER

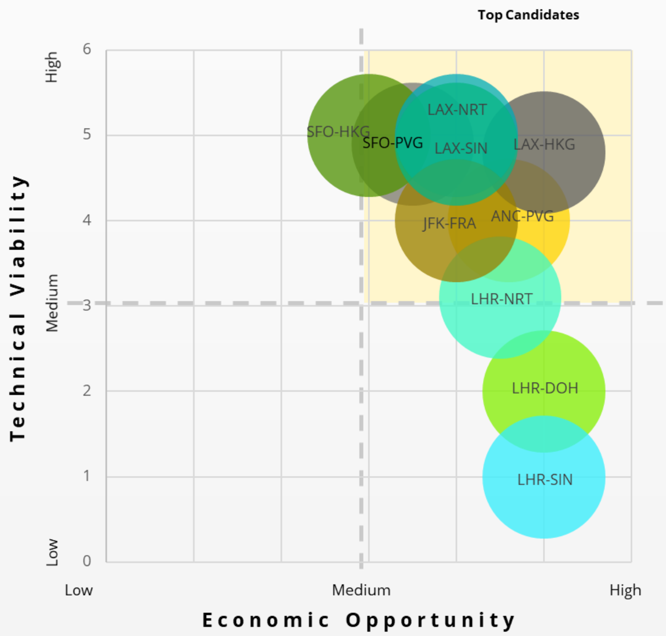


Top Routes for Consideration

JFK-LHR MIA-GRU JFK-CDG

LAX-AKL SYD-SIN

CARGO

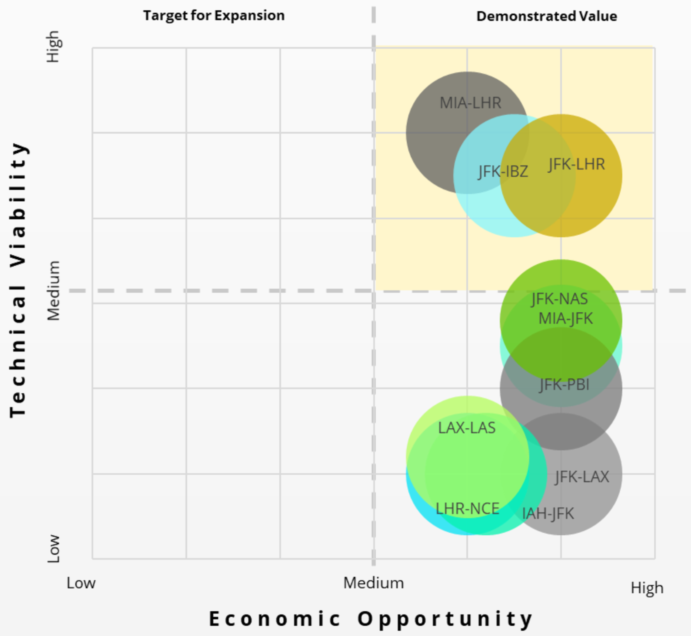


Top Routes for Consideration

LAX-HKG ANC-PVG LAX-NRT

LAX-SIN JFK-FRA

PRIVATE



Top Routes for Consideration

JFK-LHR MIA-LHR

JFK-IBZ JFK-NAS

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City Pairing Key Takeaways

- The top-scoring passenger routes included JFK-LHR, MIA-GRU, and JFK-CDG. Notably, two of these routes historically hosted the Concorde.
- The top-scoring cargo routes included LAX-HKG, ANC-PVG, and LAX-NRT. These were primarily trans-pacific, Asia-based routes, which are the longest haul and have the highest freight volume globally.
- The top-scoring private routes included JFK-LHR, MIA-LHR, and JFK-IBZ. These routes had the highest wealth statistics globally as well as the highest charter flight volume annually.
- Across our analysis of passenger, cargo, and private transportation routes, JFK-LHR remains the dominant market from a technical and economic perspective.

The selection of strategic city pairs for market entry in the three consumer segments will be critical for market success. The litmus test is the Global Crown Jewel JFK-LHR market.

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Market Demand Methodology

In assessing demand for high-speed air transportation, we conducted consumer surveys and open-source research to identify key users and their willingness to pay.

Passenger

- We conducted a direct consumer survey to gauge demand for a high-speed air service.
- We estimated a market size, leveraging historical and forward-looking data to use as benchmarks.
- We assessed the three benchmark routes to determine economic viability of the routes.
- We applied our elasticity curves to identified potential routes to identify a total market size.

Cargo

- We identified potential business-to-business user-stories for a high-speed air shipping service.
- We conducted a direct consumer survey for to gauge consumer demand for high-speed shipping services that the market currently does not offer.
- We estimated a market size, leveraging historical and forward-looking data to use as benchmarks.

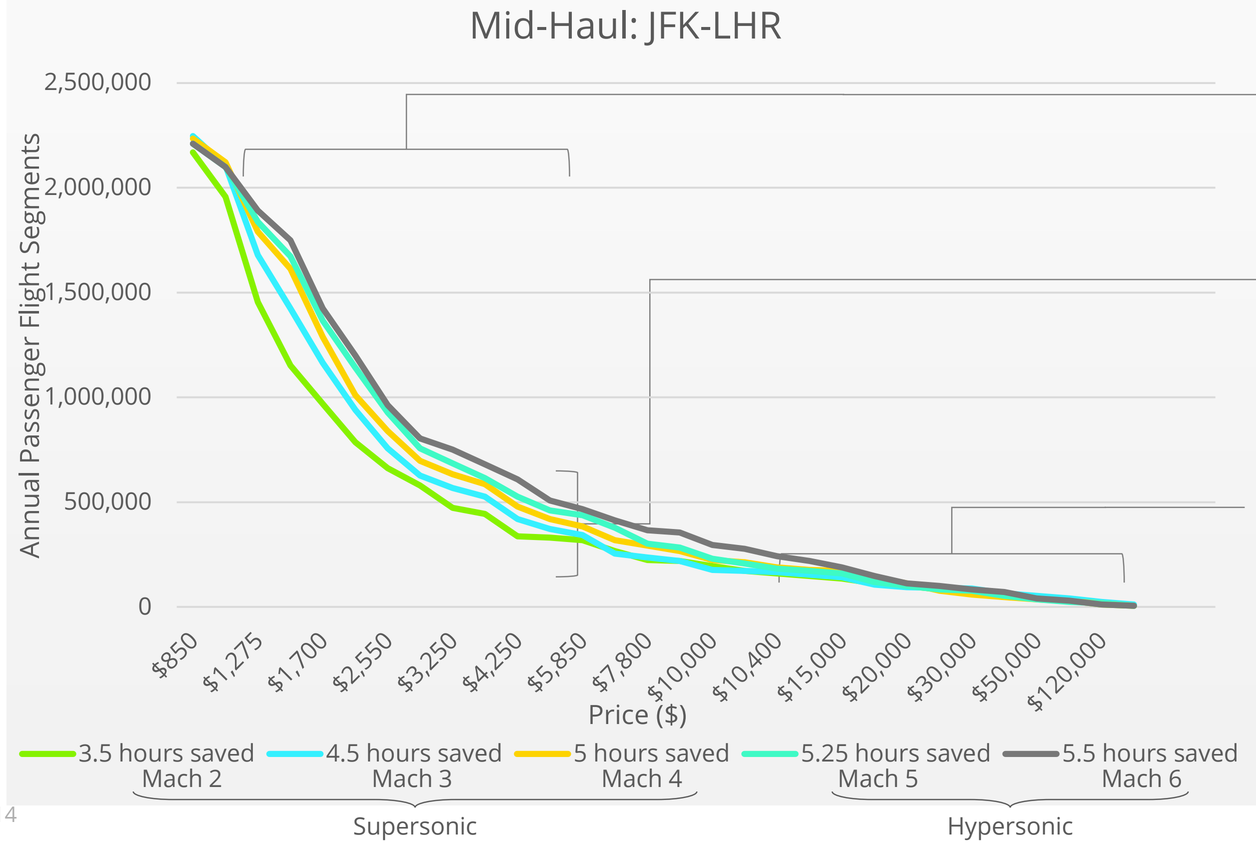
Private

- We collected historical data on subsonic aircraft to project out potential costs.
- We benchmarked this against historic and future supersonic aircraft pricing.
- We analyzed global wealth data to determine net-worth brackets required to purchase high-speed air vehicles.

Survey Results: Consumer Price Elasticity

We presented a series of questions that asked for consumers' maximum willingness to pay at various time savings (as determined by Mach ranges). We asked these questions for several route lengths, including mid-haul, long-haul, and ultra long-haul flights.

Mid-Haul



What it Tells Us

We observe the highest price sensitivity and strongest demand between $1,275 and $4,250 (2X-6X economy).

Between $1,275 and $15,000 (2X-23X economy), we observe higher demand for more hours saved, and relatively lower demand for fewer hours saved. This aligns with rational consumer behavior.

However, after ~$15,000 per ticket (23X economy), the time savings curves converge, demonstrating low willingness to pay regardless of time savings.

Assumptions:

- All prices represent one-way tickets.
- The average economy ticket for JFK-LHR costs $650.
- COVID excluded, JFK-LHR has approximately 2.9 million annual passengers.[1]

1. Figure based on Routes Online passenger data

Survey Results: Cargo Elasticity

To assess willingness to pay for faster shipping services enabled by high-speed air transportation, we asked consumers about their willingness to pay for various shipping options beyond what is currently widely available to the public.

Consumer willingness to pay for expedited shipping

What it Tells Us

We observe the highest price sensitivity and strongest demand between 2X and 7X the typical cost of standard 2-day shipping rates.

Between 2X and 8X standard 2-day shipping rates, we observe higher demand for more hours saved, and relatively lower demand for fewer hours saved. This aligns with rational consumer behavior.

However, after 8X the standard 2-day rate, the time savings curves converge, demonstrating low willingness to pay regardless of time savings.

Assumptions:

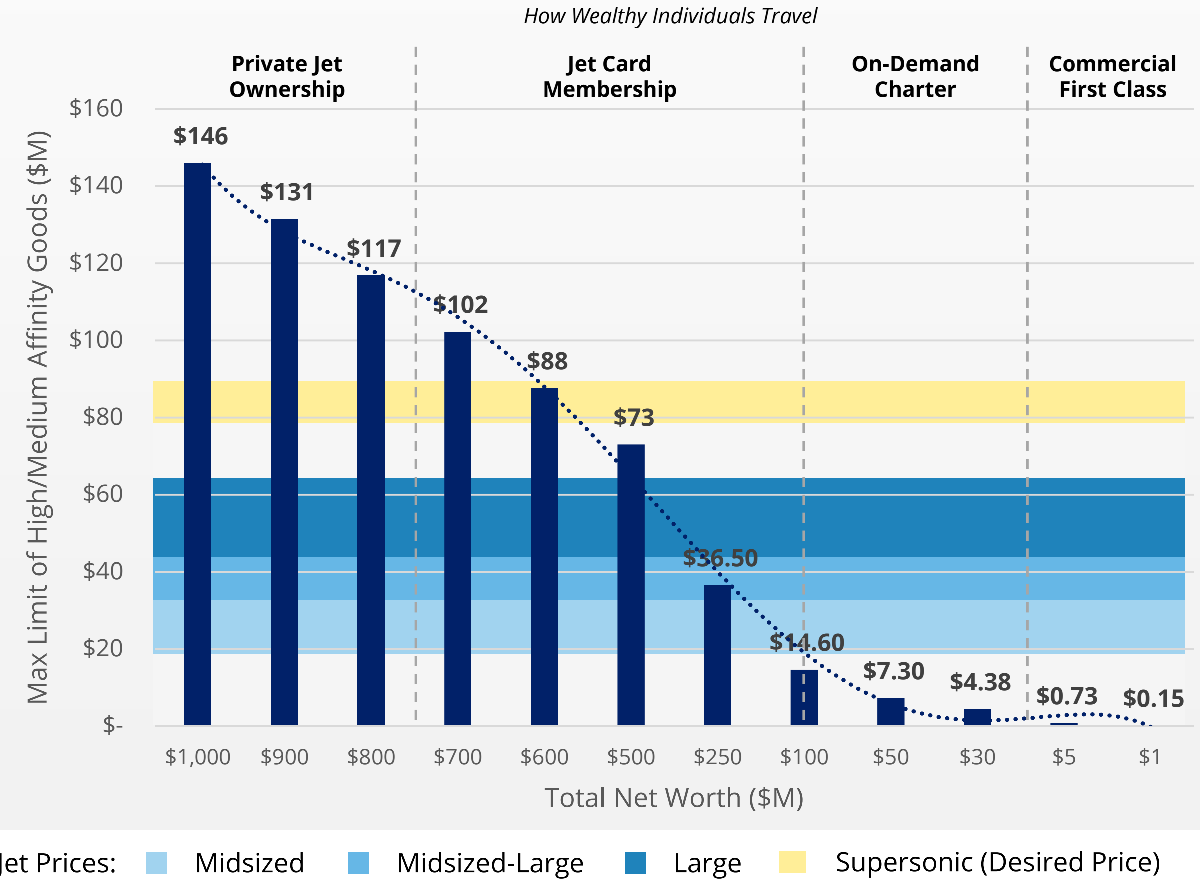
- High-speed air transport is specifically used to expedite the shipping process.
- Last mile logistics are not a limiting factor for delivery.
- Downstream retailers do not have the item in stock locally (which would eliminate the need for air freight).

1. Figure based on Bureau of Transportation Statistics air cargo data

Private Ownership Elasticity

The graph below breaks down the maximum amount that high net worth individuals pay for luxury goods on average (i.e. jets, yachts, art collections). The horizontal price bands illustrate the jet prices outlined on the previous slide.

Consumer willingness to pay for private jets



What it Tells Us

An individual's level of wealth dictates how they would be a customer for supersonic travel, i.e. jet card membership, on-demand charter, or ownership.

According to this data, approximately 60,000 people are wealthy enough to afford midsized private jets or larger jets.

Each consumer will have a price ceiling based on their net worth and the premium for speed as a utility. Jets priced above $146M will likely be unattainable for all but the multi-billionaires.

Net Worth	Global Population
$1M-$5M	19,220,830
$5M-$30M	2,659,980
$30M-$50M	139,060
$50M-$100M	88,680
$100M-$250M	43,280
$250M-$500M	11,660
$500M-$1Bn	5,215
>$1B	2,825

1. Figure based on WealthX 2020 Global Wealth Report

Demand Analysis Key Takeaways

- Passenger willingness to pay indicated that the JFK-LHR route would create a market of about $2.1B in the first year; the potential to add several other city pairs increases this market size as well.
- Consumers who were willing to pay for faster shipping services (40% of surveyed) would create between a $7B market for 12-hour shipping to a $14B market for 5-hour shipping in the first year.
- Historical private aircraft at comparable sizes and prices indicates that the market would tolerate a Mach 2 jet at $79M, a price much lower than current manufacturers are projecting.

There is addressable demand in the scheduled passenger service, cargo transportation, and private air service market segments with schedule passenger and charter air service acting as the primary demand drivers.

Task 1 Findings – An Emerging Market Picture

From a demand-side view, an emerging market picture for the nascent high-speed transportation market begins to take shape as follows:

MARKET OBSERVATIONS

Barriers remain | Supersonic speeds are preferred | Predominantly Defense Focused Investments

- An addressable market is emerging, but it **will require technical serviceability and removal of barriers**
- For all demand segments, **supersonic flight is more likely to drive market adoption** and sustainable prices versus hypersonic.
- As expected, **consumers would be more willing to pay premiums for longer flights**. However, high-demand, shorter routes can still produce more customers than lower-demand, longer routes, despite this consumer behavior

COMMERCIAL MARKET SEGMENTATION

Premium Passengers | Private Aircraft | Cargo

- Elasticity analysis for each segment reveals **significant price sensitivity for most consumers**
- **Ideal routes vary for each application** (passenger, cargo, and private travel). In general, trans-Atlantic routes are most preferable for the passenger and private markets, while trans-Pacific routes close the business case for cargo
- Unlike passenger airlines, jet sharing companies have gained new customers; industry experts expect private jet demand to continue to be higher than pre-pandemic

OUR FINDINGS

SUPERSONIC SERVICE
PREFERRED SPEED

PASSENGER & PRIVATE
MOST VIABLE SEGMENTS

22.1M
GLOBAL WEALTHY INDIVIDUALS

NASCENT
MARKET STAGE

~300
TOTAL ANNUAL DEMAND FOR PRIVATE AIRCRAFT

90
IDENTIFIED ROUTES FOR ANALYSIS

DEMAND

Wealthy Individuals | Business Travelers & Executives | Time or Shipping Sensitive Cargo

- The largest addressable pool of passengers are **wealthy individuals that are likely to purchase supersonic transportation** in the form of premium scheduled service, charter flights, jet cards/memberships, and outright plane purchases.
- The largest addressable segment is likely **scheduled commercial air service for premium and ultra-premium travelers**.
- Charter and on-demand services are likely to drive more demand for supersonic airframes than individual private owners.

WHERE TO START

Global Crown Jewel Routes | Transatlantic & Transpacific Routes

- The **most technically viable routes are transoceanic** and longer than 2,500 nautical miles
- The **most economically viable routes were 'crown jewel'** routes/city pairs with high volume and considerable wealth demographics
- The industry incumbent route JFK-LHR remains the most viable market, while additional trans-pacific routes now offer noteworthy potential

TASK 2: DEFINING THE BUSINESS CASES

Top-Level Economic Findings (BLUF)

The analyses resulting in several interesting findings across the entire trade space, including the following

1. **There are multiple aircraft configurations and market approaches that result in positive business cases for their manufacturers and operators (assumed as 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 nmi – 4,500 nmi class are also slightly favored and result in lower ticket prices and therefore larger market sizes. This seems 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+
2. **Results are most sensitive to potential reductions in estimated passenger market size**
   - Fuel cost increases, engine development cost increases, and lost of private/charter sales are also important
3. **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

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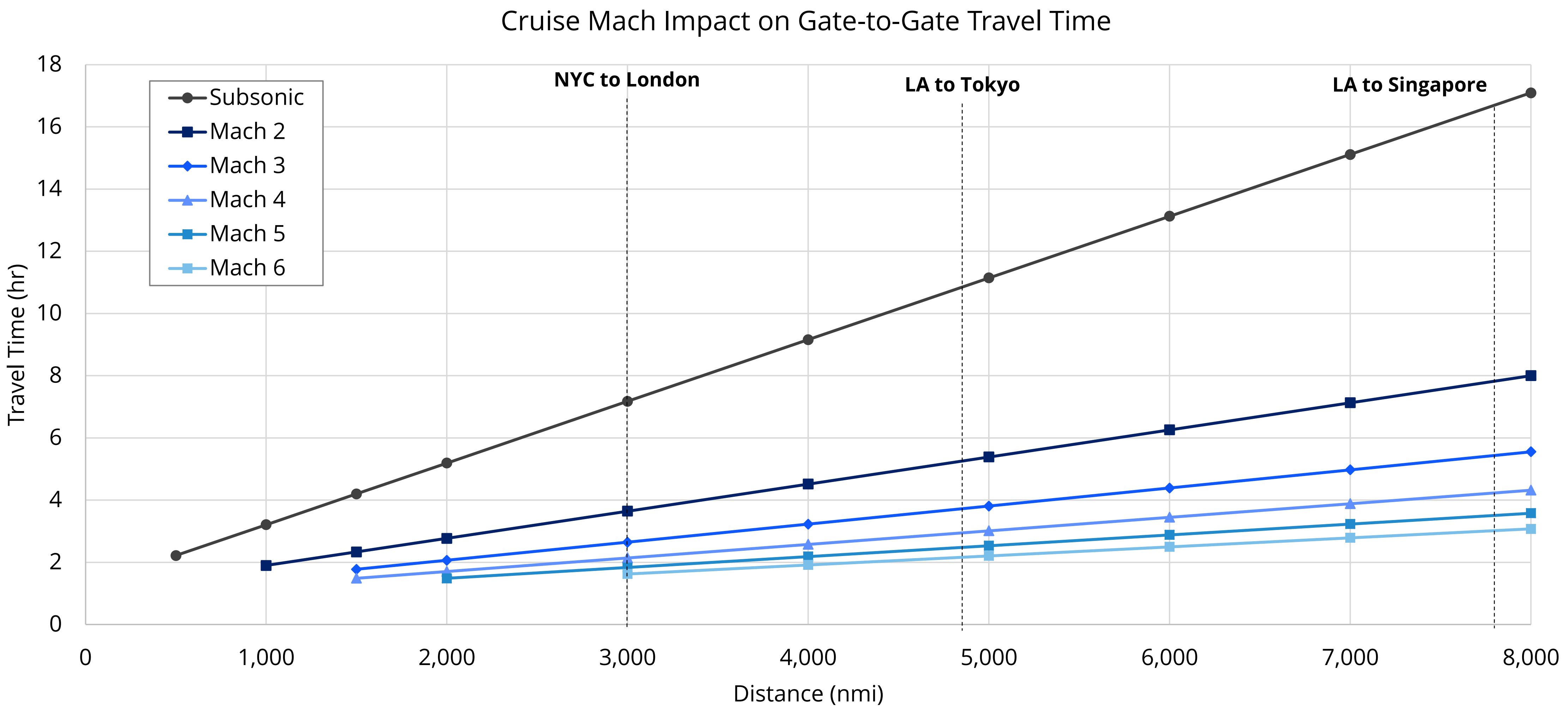
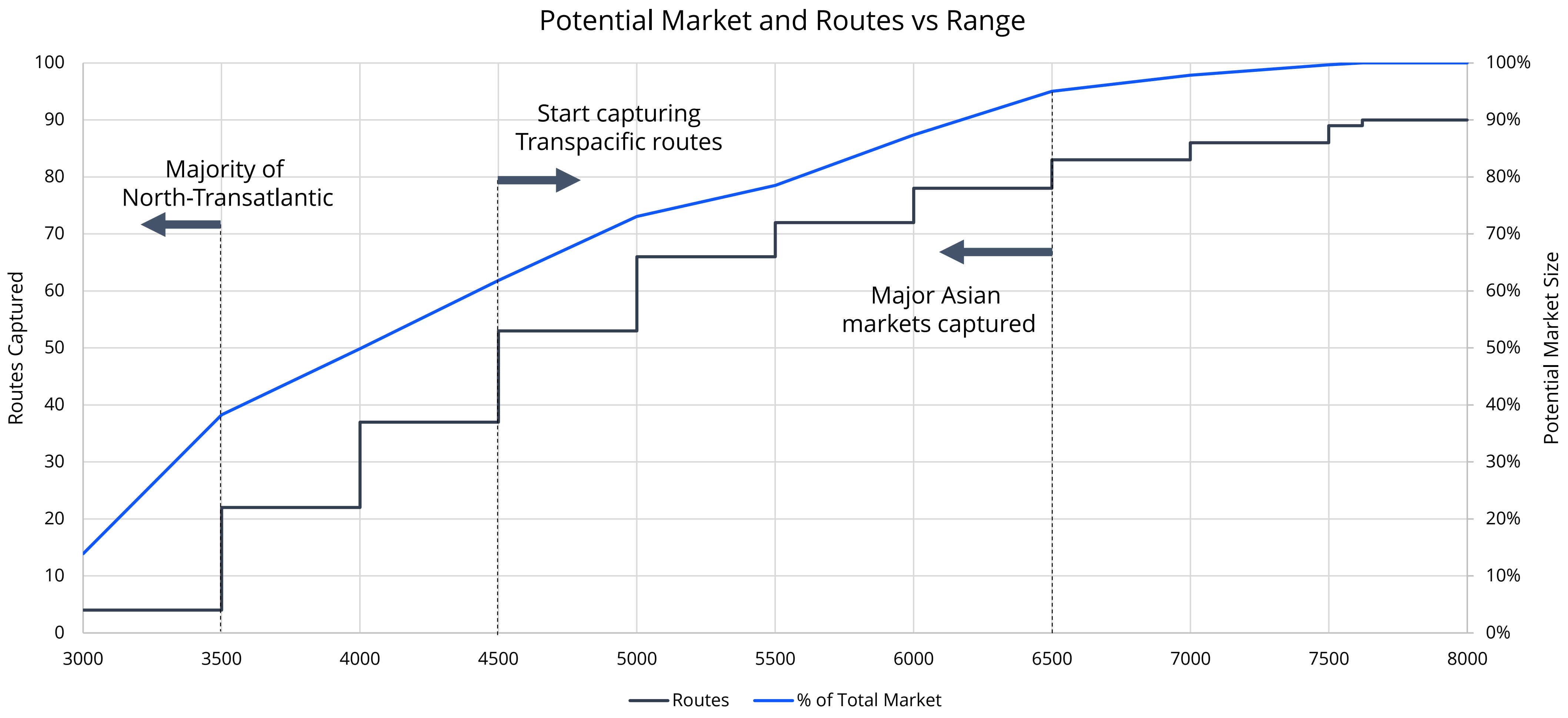
The Case For Speed

From our flight performance module, we compared the total travel time for a flight at various speeds and for various one-way route distances.



Distribution of Potential Passengers vs. Range

What is the best one-way aircraft range? At a design range of 5,000 nmi, 73% of the addressable transoceanic US passenger traffic and routes are captured from the 90 potential city-pairs in our model. Longer routes can be captured for diminishing returns



SEI's INTEGRATED P2P ROSETTA MODEL

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Integrated P2P ROSETTA Model Overview

A ROSETTA model is a highly coupled multidisciplinary aircraft sizing, performance, and economic simulation. Key user inputs (i.e. Mach, Range, and Passengers) generate an estimated aircraft size, cost, and a set of all-encompassing business case outputs for manufacturers and operators

AIRCRAFT DESIGN MODEL

BUSINESS MODEL

USER INPUTS

INPUTS
- Cruise Mach
- Maximum Range
- Passenger Count
- Commercial Ticket Price (one-way)
- Engine Price-to-cost ratio
- Aircraft Price-to-cost ratio

FLIGHT PERFORMANCE

INPUTS
- Cruise Mach
- Maximum Range

OUTPUTS
- Flight Profile
- Travel Time

AIRCRAFT SIZING

INPUTS
- Cruise Mach
- Maximum Range
- Passenger Count
- Flight Profile
- Travel Time

OUTPUTS
- Aircraft Masses
- Aircraft Geometry
- Fuel Consumption
- Engine Thrust
- Balanced Field Length

ENVIRONMENT MODULE

INPUTS
- Cruise Mach
- Maximum Range
- Passenger Count
- Flight Profile
- Aircraft Masses
- Engine Thrust
- Fuel Consumption

OUTPUTS
- Emissions
- Sideline Noise
- Sonic Boom Pressure

COST MODULE

INPUTS
- Cruise Mach
- Aircraft Masses
- Engine Thrust

OUTPUTS
- Airframe DDT&E
- Airframe TFU
- Engine DDT&E
- Engine TFU

BUSINESS CASES

INPUTS
- Engine Price
- Aircraft Price
- Ticket Price
- Passenger Count
- Maximum Range
- Travel Time
- Fuel Consumption
- Airframe DDT&E & TFU
- Engine DDT&E & TFU

OUTPUTS
- Manufacturers' IRR & NPV
- Operators' IRR & NPV
- Aircraft Price
- Fleet Size

AIRCRAFT, ECONOMIC, & ENVIRONMENT OUTPUTS

P2P ROSETTA Model Notes

Things to know about our model

1. **Anchored and validated against a set of 8 historical or proposed Mach 2+ aircraft**
    - Model is an approximate tool designed to rapidly and parametrically explore are large trade space from Mach 2 to 6, Passengers from 20 to 250, and design ranges from 3,000 nmi to 8,000 nmi
    - Estimate aircraft size and mass, development costs, production costs, and profit/loss business case
    - Accuracies in the range of +/-20% for any particular reference concept
2. **Built-in Genetic Algorithm optimizer is used to optimize airframe, engine, and passenger ticket prices to improve business case**
    - The model contains “if” statements and technology step changes. Its results are not smooth!
    - Each data point is a locally optimized business case that maximizes the annualized return on investment for manufactures and operators (assumes all three players must succeed equally)
3. **Runtimes vary with the number of independent variables and complexity**
    - 60 minutes for each point for smaller problems (typical desktop PC)
    - 60 hours for large, complex problems

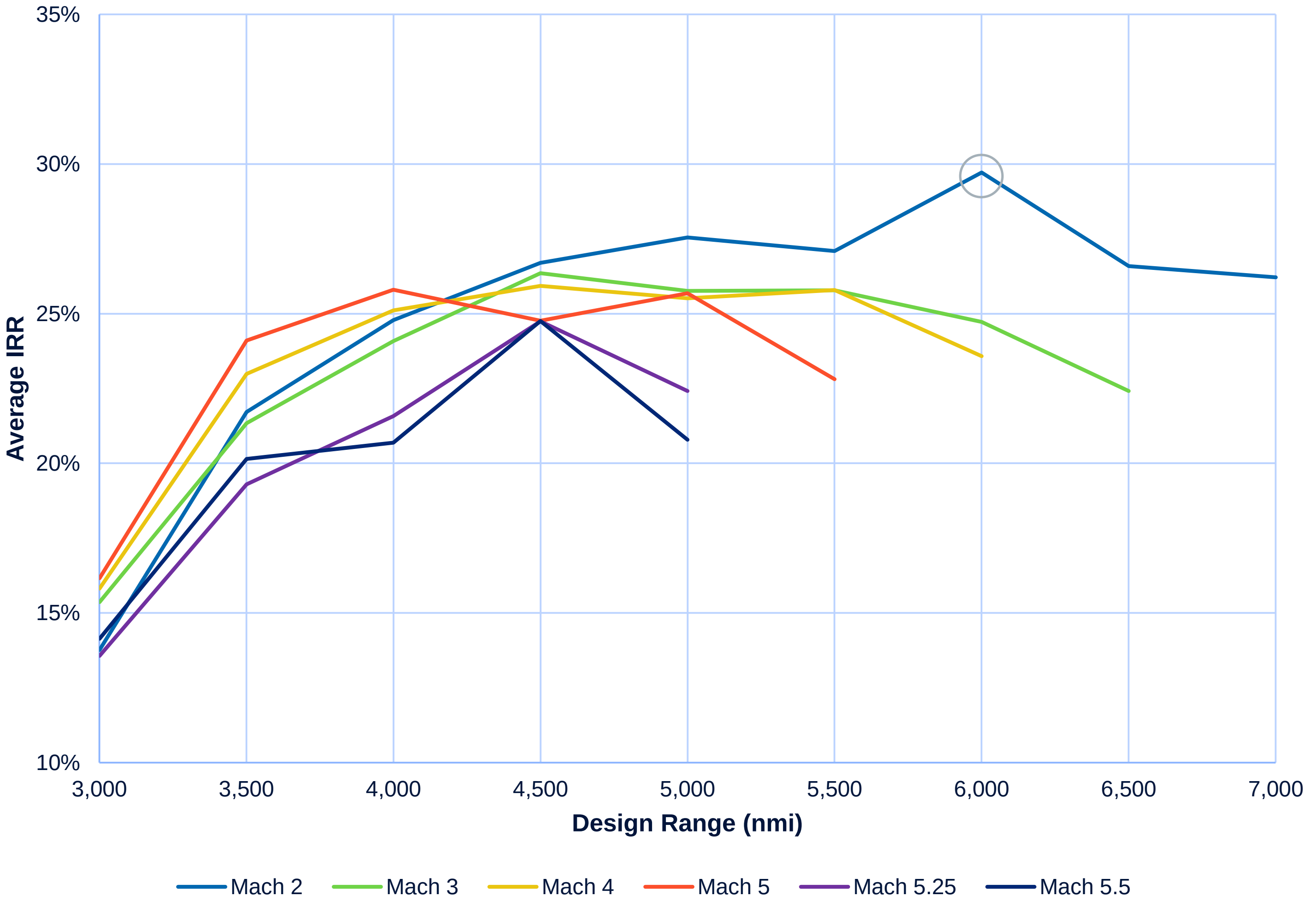
Key Assumptions

1. **The high speed aircraft is sized for its design range and offers a single passenger-class service**
   - That is, aircraft designed for ultra-long haul routes are <u>also</u> used for medium and long haul routes (one size fits all approach). There is economic incentive therefore to “right size” the aircraft for the preferred business case
2. **Business model captures operations from 2021-2055**
   - Manufacturers develop products for first 10 years then transition to production. Airliner begins operating once aircraft are delivered.
3. **United States Government purchases first 20 aircraft produced regardless of size or speed**
   - “Anchor buy” concept establishes a minimum number of aircraft to be produced
4. **All cost numbers are in FY21 dollars**
5. **A turbojet is used to power aircraft from Mach 2 to Mach 3. A turboramjet is used for aircraft operating from Mach 3 to Mach 5. Above Mach 5, a dual mode scramjet is used with a turbojet**
6. **Jet A fuel is priced at the national average of $4.06 per gallon. LNG is priced at $3.00 per gallon.**
7. **“Captured” routes from the list of 90+ candidate transoceanic city pairs must be within range and have the demand for at least one flight per day**
8. **Routes mostly over land are not included in our current model**
9. **Belly cargo is included as additional revenue on all flights at $100/kg and 500 kg**
10. **To approximate COVID recovery, we expect market numbers to return to 2019 levels by 2024**
    - A market growth rate of 0.94% is applied annually to all addressable markets after 2024

A SAMPLE OF ECONOMIC RESULTS FROM THE CURRENT MARKET STUDY

50 Passenger IRR

50 passenger count aircraft all perform relatively well between 4,000-5,000 nmi. This design size provides a good balance between ticket price and demand for the airliner and manufacturers.



1. **Mach 2 - 3 aircraft perform best overall, especially at longer ranges**
    - Ticket and aircraft prices stay lower for the slower aircraft allowing them to capture a large market
2. **At shorter ranges, higher available ticket prices help benefit Mach 4 to 5 aircraft despite smaller markets**
3. **For the Mach 2 aircraft, engine count jumps from 2 to 3 at 6,000 nmi**
    - This results in a production increase for the engine manufacturer that allows airliners to increase ticket prices and sacrifice demand.

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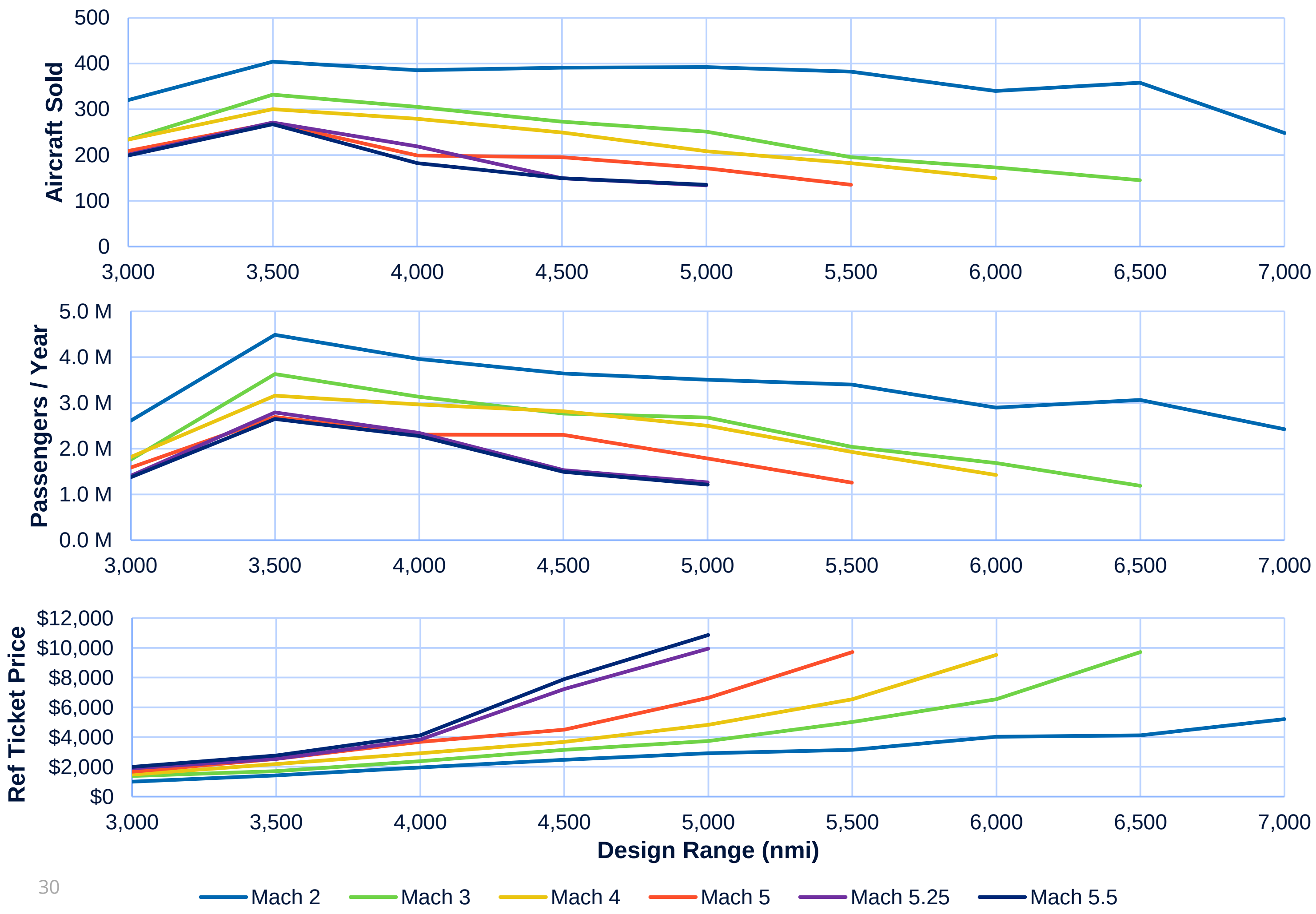
50 Passenger Secondary Factors

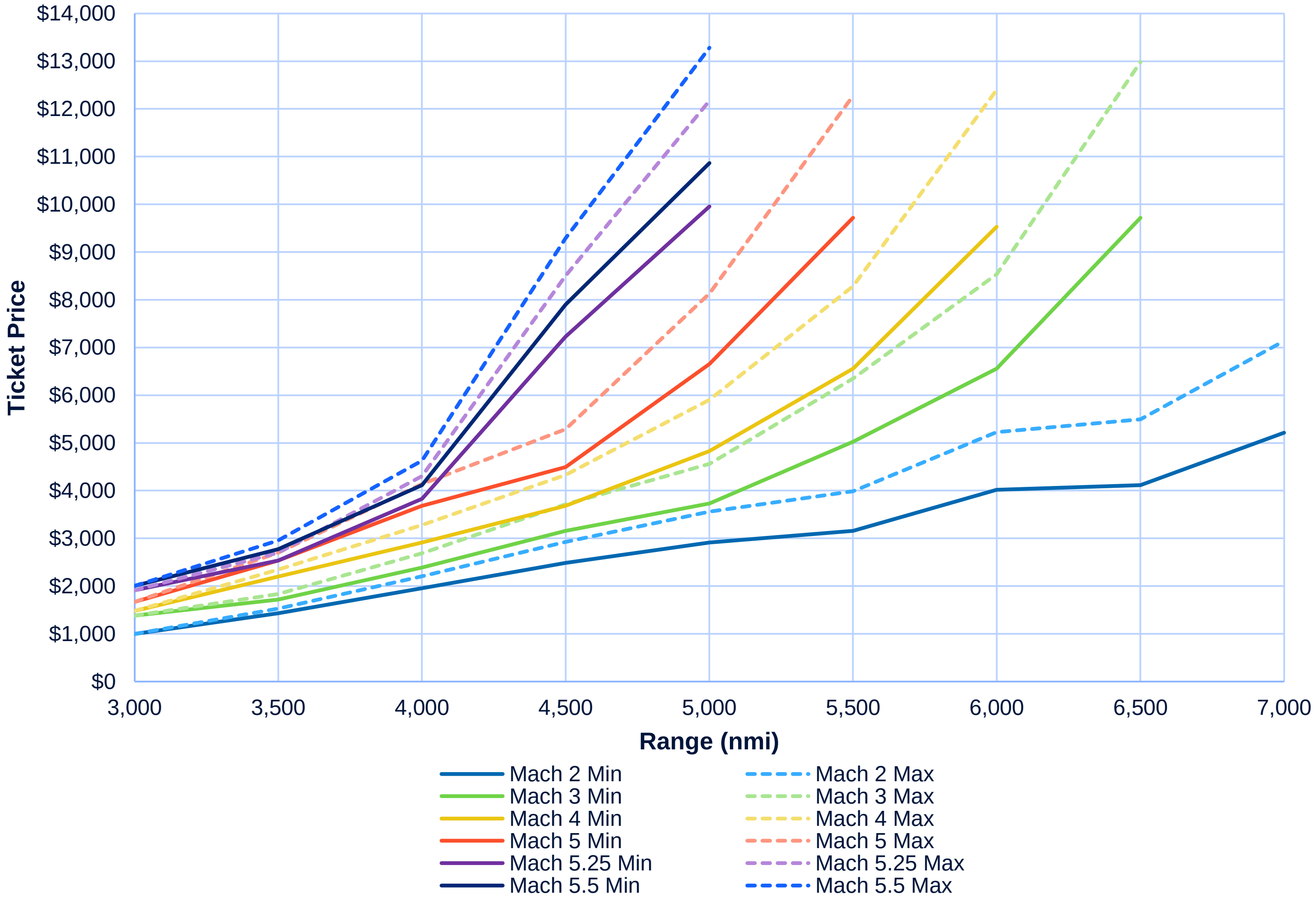
Key factors contributing to the average IRR are below:



1. **More passengers means more aircraft sold**
   - This almost always benefits the manufacturers
2. **Ticket price determines captured passenger demand**
   - Ticket price needs to be high enough for the airline to profit but not too high as to overly reduce demand.
3. **Mach 2 aircraft stay cheaper at higher ranges, capturing more of the addressable market**
   - Higher Mach aircraft get very expensive at higher ranges, so ticket price increases but demand suffers

50 Passenger Ticket Price

Ticket Price is the main input that seeks a balance between revenues and demand.

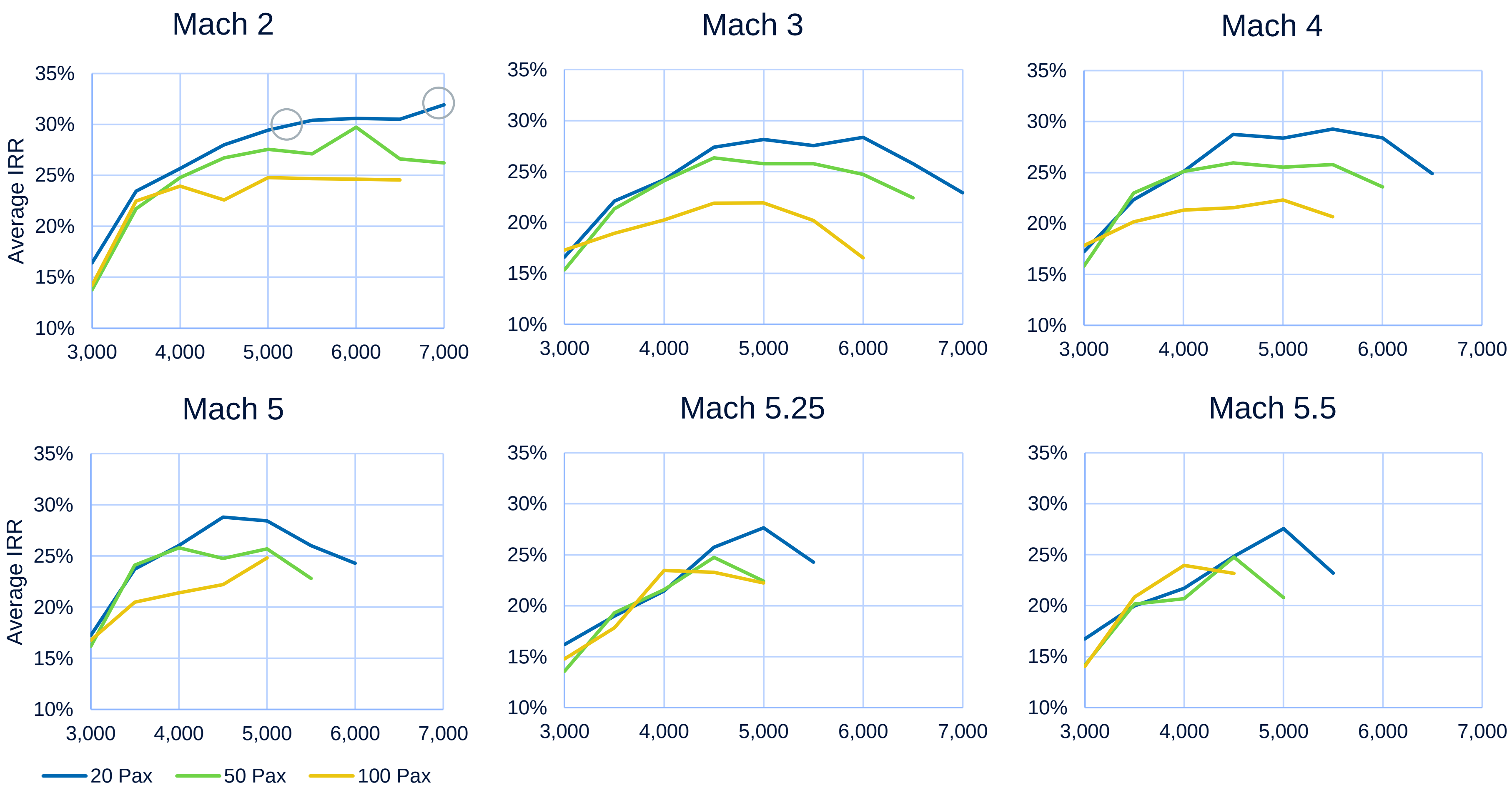


1. **The solid lines represent the reference ticket price (JFK-LHR ticket price)**
   - This is input ticket price for the model/optimizer
2. **The dotted lines show the ticket price scaled for the design range of the aircraft.**
   - Essentially, the max ticket price applicable for a given aircraft.
3. **Ticket price tends to be closer to the reference ticket price.**
   - This is due to the large market size for JFK-LHR and similar routes

COMPARISONS WITH ISO LINES OF PASSENGER COUNT

Internal Rate of Return (IRR)

IRRs relative to passenger count:



1. **Lower passenger count performs better in most scenarios.**
   - 100 passengers does better above Mach 5 briefly due to fuel savings per passenger with LNG
2. **Slower aircraft perform better in general**
   - Less fuel needed to reach and maintain speed
3. **4,000-5,000 nmi seems to be ideal range**
   - Captures enough markets without aircraft growing in size and dev cost

SENSITIVITIES

Sensitivity Assumptions

1. Sensitivities were gathered by taking an optimized case and then varying one variable at a time

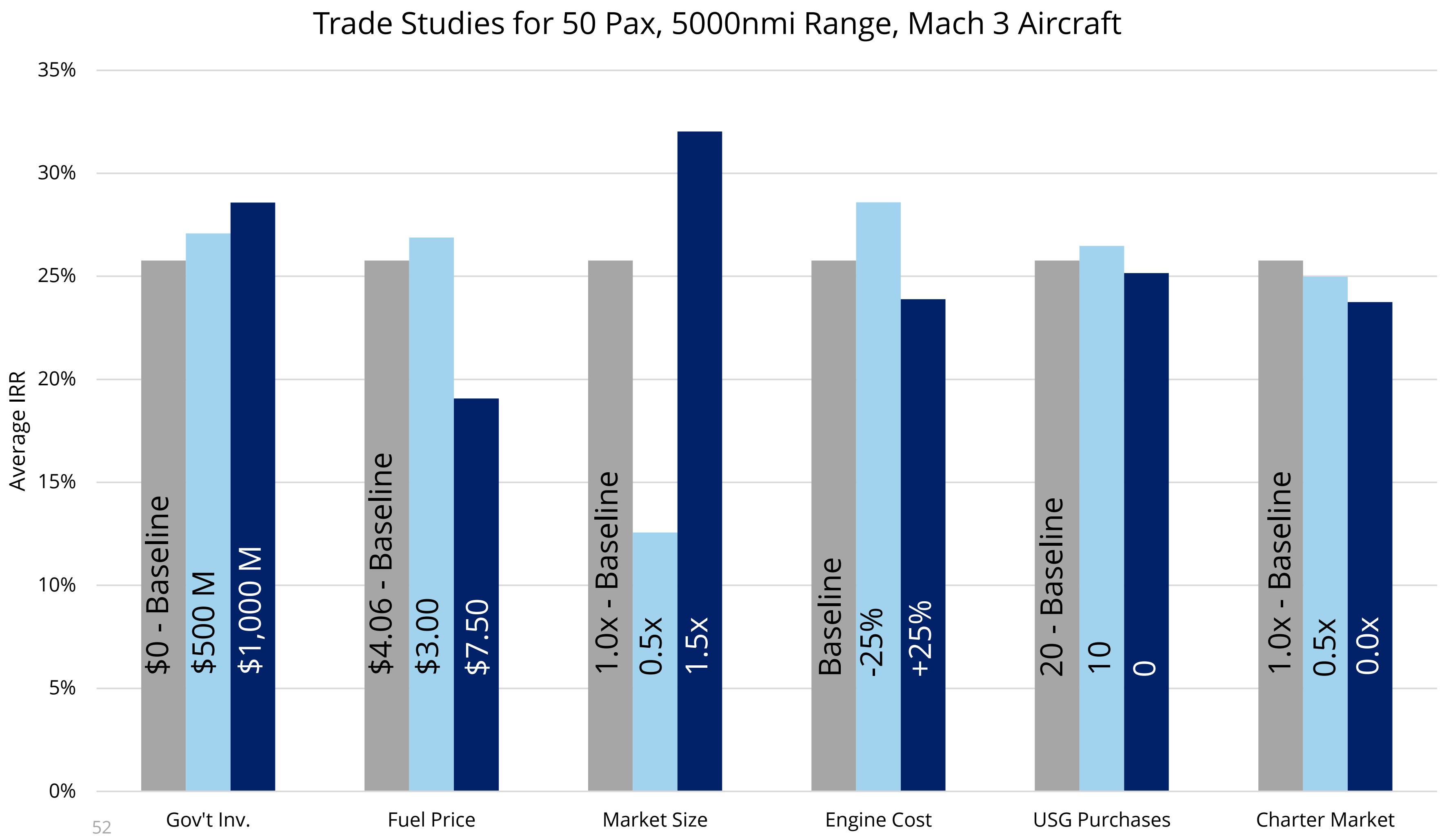
- Sensitivities include:
  - Government Investment to manufacturers, evenly split (None, $500M, $1,000M)
  - Jet A Fuel Price ($4.06/gal – national average, $7.50/gal – expect higher prices in future; $3.00/gal LNG price fixed)
  - Market Size (1x – nominal case for given routes, 0.5x – demand falls short of nominal, 1.5x – certain markets more viable)
  - Engine DDT&E Cost (Nominal Case, 25% decrease in development costs, 25% increase in development costs)
  - U.S. Government Purchases (20 aircraft – nominal case, 10 aircraft, 0 aircraft)
  - Charter/Private Market Size (1x – nominal case, 0.5x, 0.0x)
- Sensitivities were conducted at each Mach number and at passenger counts of 20, 50, & 100
- The average IRR across all models from the immediate change was used as the resultant IRR metric

2. Select cases were re-optimized for each sensitivity to validate partial derivative results above

- For the re-optimized "total derivative" cases we examined for the 20 passenger aircraft:
  - Average IRRs due to increased fuel prices were seen to be a couple percentage points higher in re-optimized cases.
  - Average IRRs due to a decrease in market size were seen to be several percentage points higher in re-optimized cases.
- For the most part, the average IRR from the partial derivative is a good representation of the re-optimized IRR and trends behave similarly. We believe the one-at-a-time sensitivities are representative

50 Passenger Sensitivity Comparison

The trends seen below are relatively consistent for 20 and 100 passenger cases.



1. **Market size is the most impactful sensitivity**
   - Demand is a major factor for a viable business case so increasing or decreasing it has a big impact
2. **20 passenger sensitivities behave more like the slower sensitivities previously, while 100 is the opposite**

TASK 2 CONCLUSIONS

Task 2 Analysis Conclusions (1 of 2)

Does commercial flight above Mach 2 make any economic sense (barriers aside)?

- Yes. There are several business cases that make economic sense for manufacturers and operators alike. Mach 2 – 3 cases look to be the most robust, but certain turboramjet cases up to Mach 5 also make sense (producing IRRs > 25%), although the incremental benefit for speed remains limited for most routes.

What aircraft sizes (passenger count) make the most sense?

- Aircraft sized for 20 – 50 passengers seem to strike the best balance between passenger load factor, aircraft sales (manufacturers' sales) and still maintain reasonable ticket prices.

What about those ticket prices? They are expensive, right?

- Many viable business cases can result from ticket prices less than $3,500 per direction (NYC to LHR reference). More expensive than today's coach prices to be sure, but not unreasonable.

Task 2 Analysis Conclusions (2 of 2)

What is the best “design range” for a future high-speed aircraft?

- Our analysis considered only over-water routes. We found 4,000 nmi – 4,500 nmi to be a nice sweet spot in the trade space. This range captures about 50 valuable city-pairs in our network. Aircraft designed for longer trans-Pacific ranges could also do well, but they tended to be oversized for the very high demand North Atlantic routes. Our analysis did not consider derivative or stretch airframes for more than one market

Won’t these aircraft be expensive?

- Yes, they will be more expensive than today’s subsonic airliners. However, if manufacturers can exploit the synergies between elite airline operators and private owners with smaller aircraft, high production volumes can reduce aircraft prices below $125M - $150M. Smaller aircraft also require lower development costs and decrease capital needs.

What are the Gotcha’s Here?

- These results are very sensitive to passenger market assumptions, but we have confidence in our research approach to characterize the future high speed passenger travel market. Future fuel costs and engine development costs remain concerns as well. Government contributions can help, but are not required for success

TASK 3: IDENTIFYING BARRIERS

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OVERVIEW OF OUR APPROACH

In discovering and analyzing the barriers to high-speed air transportation, we are following a structured approach involving several phases of analysis.

LITERATURE REVIEW & CATALOGUE

What do existing documents tell us about current market barriers?

I. Research existing publicly available industry literature, including publications, corporate press release, and industry & think-tank reports.
II. Synthesize research into an initial list of clearly defined challenges.
III. Align challenges to applicable categories and catalogue initial data sources.

FIRST-HAND INTERVIEWS

What do industry experts and first-movers have to say about these barriers?

I. Develop a list of relevant subject matter experts from industry and Deloitte's internal firm network.
II. Conduct outreach to candidates for focused discussions based on their expertise related to high-speed air travel.
III. Capture insights from stakeholder interviews and incorporate into Task 3 analysis.

DELOITTE RESEARCH & ANALYSIS

Based on current market trends, what are the potential paths forward?

I. Synthesize challenges identified from research and interviews to identify the key barriers to high-speed air transport.
II. Organize barriers into a workable framework that addresses the significance of each barrier.
III. Leverage all data collected to provide detailed analysis on each barrier, including possible paths-forward for the private & public sectors.

RESEARCH & IDENTIFICATION

Initial study of available documentation & stakeholder interviews.

VALIDATION & DUE-DILIGENCE

Targeted stakeholder discussions & in-depth research on each issue .

Literature Review: By The Numbers

As part of our analysis of industry barriers, we conducted a comprehensive review of existing literature too identify and conduct due-diligence on potential barriers to high-speed air transportation.

BY THE NUMBERS

80+

Total documents reviewed & catalogued spanning across 7 key considerations / categories of barriers.

15

Total challenges identified from our literature review.

KEY TAKEAWAYS

Modern high-speed aircraft manufacturers are developing multiple new technologies, such as new airframes, low-sonic boom technology, and new engine technology.

Environmental issues have recently risen to the forefront of public policy focus; the prospect of high-speed aircraft and the emissions & noise implications of these vehicles are a major concern for the public.

Regulators are aware of the major regulatory & certification challenges for high-speed aircraft, and authorities are acting on them via NPRMs (FAA-level) and SARPs (ICAO-level).

Stakeholder Interviews: By The Numbers

As part of our analysis of industry barriers, we interviewed a broad range of industry experts to identify and validate data we collected on potential barriers for the market.

OUR APPROACH

We engaged experts in the aerospace and logistics industries covering a diverse range of subject matter backgrounds.

We conducted an initial round of interviews in parallel to our literature review to identify a long-list of potential issues facing the market.

Following our analysis and rankings of the identified issues, we conducted a final round of due-diligence interviews to validate our findings.

BY THE NUMBERS

23

Total interviews with industry SMEs across business, technical, and legal/policy professions in the aerospace industry

8

Total types of entities including:

- *Airlines*
- *Jet Sharing Platforms*
- *Aircraft Manufacturers*
- *Airport Authorities*
- *US Regulatory Agencies*
- *Industry Associations*
- *Startups*
- *Universities*

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IDENTIFYING BARRIERS

Barrier Analysis Process

As we developed the study, we determined that the initial 7 considerations outlines in the SoW required further categorization to adequately characterize the magnitude of constraint for each issue. Therefore, we further classified each topic to understand the degree to which is impacts the market.

CONSIDERATIONS

We reviewed 7 broad considerations and identified a granular list of specific challenges that overlap across each of these categories.

Data Sources

- NASA, as outlined in TO36 Statement of Work

*We define considerations as **the 7 overarching topics** to which various barriers relate.*

CHALLENGES

Of the challenges identified, we assessed them based on whether they could constrain the growth of the high-speed air transport market.

- Literature Review
- Stakeholder Interviews

*We define challenges as issues that could **limit the business case, but do not outright prevent market viability.***

BARRIERS

From that assessment, we discovered which challenges were barriers: those that could block the market entirely and prevent companies from operating.

- Deloitte Research & Analysis
- Stakeholder Interviews

*We define barriers as issues that are **constraining enough to prevent the market from starting.***

Down-Selection Methodology

[1]**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.*

To arrive at a final list of barriers to high-speed air transportation, we used a methodical down-selection approach involving multiple tiers of analysis and validation.

Research & Validation

We conducted an initial literature review to identify a broad set of challenges to high-speed air transportation, and then spoke with industry to validate them.

80+ Documents reviewed

23 Stakeholder interviews

15 Challenges identified

Scoring Challenges

Once we had a comprehensive set of challenges, we assigned values to each of them across a series of criteria that assessed the magnitude of constraint to the Industry.

- Compliance
- Technology
- Investment
- Ease of Use
- Community

Ranking & Scaling[1]

We arrived at a final set of rankings and determined which of the challenges identified were significant challenges, and which were barriers.

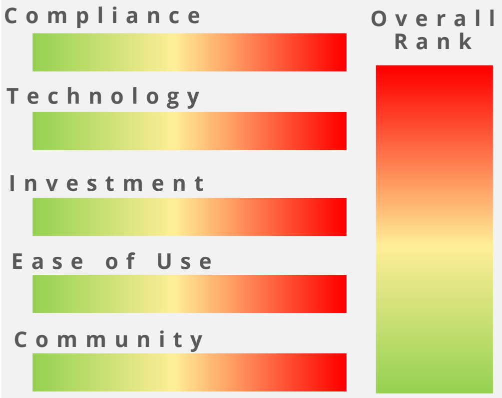
3 Barriers identified

2 Significant challenges

10 Minor challenges

Barrier Selection

Last, we plotted each of the challenges on a scale to display the full spectrum of constraints to the industry. Further, we validated our conclusions through focused SME reviews.



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Barriers Heat-Map

[1]*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.*

Using the rubric, we developed a heat map to down-select the barriers from the challenges, and also use the rankings to distinguish which of the remaining challenges were significant or minor.

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

BARRIERS

Sonic Boom Restrictions – Key Takeaways

From our analysis of sonic boom restrictions, we observed the following underlying themes:

1. **Sonic boom standards for high-speed aircraft are currently vaguely defined** at international and domestic levels due to the nascent status of this market, and therefore the lack of necessity for such regulations until recent years. FAA and ICAO recently announced that they are reviewing new standards, so aircraft developers will need to monitor these ongoing reviews to ensure they are fully compliant with potential future policies.

2. **Regulations and guidelines that do exist in the United States are currently prohibitive to high-speed aircraft,** as sonic booms are outlawed nationally, and any aircraft traveling above Mach 1 require an FAA flight exemption to operate. Unless these restrictions are modernized, commercial players will be barred from over-land operations in the United States above Mach 1, restricting the number of viable routes.

3. **Although ICAO and FAA are considering standards and regulation for these aircraft,** establishing these standards will likely take multiple years, which presents a risk to market entrants seeking to operationalize by 2029.

If a trans-continental service were allowed, the addressable market increases significantly, as major coast-to-coast city pairs become viable. For example, LAX-JFK passenger volume surpasses the highest volume international route, JFK-LHR.

Sonic Boom Restrictions : The Path Forward

In analyzing the sonic boom restrictions that high-speed aircraft face, we identified a few themes that provide a framework for addressing the issue.

Private Sector Development

Startups are currently developing low-boom aircraft technology and operating models that limit fly-over disruptions. Examples include the Boom XB-1, a demonstrator aircraft that minimizes sonic boom noise, the Aerion AS2, a passenger jet that operates at a 'Boom-less Cruise' over urban areas, and the Spike S-512, a business jet with 'quiet supersonic flight technology' designed to significantly reduce sonic boom noise.

Public Sector Sponsorship

Government entities have historically funded industry to develop low-boom aircraft, and interest is re-emerging. DARPA QSP funded Northrop Grumman for the 'Quiet Supersonic Aircraft' program, which sought to develop a low-boom supersonic aircraft. Additionally, the NASA Que-SST program funded Lockheed Martin to develop a concept for a low-boom supersonic aircraft, and later funded Lockheed for X-59, an aircraft designed to minimize sonic booms.

Regulatory Modernization

In addition to technology R&D, government regulatory bodies can modernize existing regulation to enable opportunities for high-speed air routes and provide guidelines that allow companies to operate above Mach 1 over-land while minimizing disturbances to fly-over communities. Collaborating with industry players to identify opportunities where regulation can meet technology improvements will be critical to ensuring successful policy.

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Aircraft Certification – Key Takeaways

From our analysis of aircraft certification, we observed the following underlying themes:

1. **The certification process entails a resource intensive process over a long period of time**, which presents a major obstacle to this market given that most of the players are resource-constrained startups.

2. **Lack of clarity around noise standards is standing in the way of overall high-speed aircraft certification.** Noise certification is a necessary element of aircraft certification, so aircraft certification can't occur until the noise standards are clarified.

3. **Flight over Mach 1 is currently prohibited without an FAA exemption, preventing manufacturers from efficiently completing the flight tests necessary for certification.** FAA recently released an NPRM that addresses this exact issue and seeks to establish a more streamlined exemption process.

Due to the significant resource requirements for certifying new aircraft, as well as unclear or conflicting standards in place for high-speed aircraft in the US, **the FAA aircraft certification process represents one of the most significant barriers for aspiring market entrants.** The significant time and resource requirements could prevent manufacturers from bringing high-speed aircraft to the market.

Aircraft Certification: The Path Forward

In analyzing the aircraft certification process that high-speed aircraft will need to complete, we identified key themes in how the industry can move forward to address the barrier.

Modernize Existing Restrictions

Allowing manufacturers easier access to above Mach 1 flight operations will help speed up the development of key technologies such as low-boom airframes, as well as low-boom flight operating models.

Establish Clear Standards

Establishing a clear set of noise standards for aircraft capable of above Mach 1 flight is critical to enabling manufacturers to develop an aircraft that will succeed in the certification process. The sooner that these standards can be established, the more time manufacturers will have to adjust their R&D priorities to meet these standards.

Enable Contract Opportunities

Issuing contracts and partnering with the private sector in ways that synergize with the certification process can help ease the capital burden that companies face during certification. This will be paramount to enabling startups to succeed, as investors may not continue funding startups if the certification process requires excessive amounts of capital and time.

Expand Testing

Establishing locations suitable, or outright designated, for supersonic flight testing is critical for manufacturers to obtain noise certification, which is a crucial part of aircraft certification. Recent FAA rulemaking efforts clarify the process, but the next step is finding real locations for test flight. One state has already designated a high-altitude supersonic flight corridor for testing purposes. Such locations could also be used to determine airworthiness.

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Landing & Takeoff Noise – Key Takeaways

From our analysis of landing & takeoff noise restrictions, we observed the following underlying themes:

1. **Noise standards for high-speed aircraft are currently vaguely defined** at international and national levels, and market entrants will need to navigate a complex ecosystem of airport-specific rules and restrictions if national standards are not adopted in time. This could create delays in go-to-market timelines and even prohibit some routes.

2. **For aircraft in general, faster speed and larger size correlate with higher noise output; therefore, high-speed aircraft in development today are likely to significantly exceed subsonic noise production; therefore, these aircraft may not be able to operate out of desired airports.** Data from the Concorde and stakeholder interviews indicate that this presents a significant risk to service providers.

3. **Modern high-speed aircraft will need to allocate time and resources to meet airport requirements or negotiate operational exceptions**. This could prove prohibitive to market entry for some routes.

The complex, localized regulatory environment for airport noise restrictions is likely to present obstacles to high-speed air transportation service providers. Successfully establishing routes will depend on airport-specific and community-level discussions, presenting a risk to companies seeking to offer flights.

Landing & Takeoff Noise : The Path Forward

In analyzing the landing & takeoff noise restrictions that high-speed aircraft face, we identified key themes in how the industry can move forward to address the barrier.

Regulatory Standardization

A significant hurtle for landing & takeoff noise requirements is the localization of noise policies. Creating national-level guidelines for major airports that can inform individual policies can help minimize the level of time and effort needed for high-speed air transportation providers to comply with regulation.

Streamlined Information

In the absence of national level standards, enabling ease-of-access to airport noise policy information can allow high-speed air transportation providers to navigate the regulatory landscape more effectively and plan for potential compliance risks.

Early Collaboration

Establishing consistent communication between airport authorities, policy makers, and private entities can enable more effective planning throughout the R&D lifecycle to ensure that high-speed aircraft technology and operations meet current and future standards. Further, including communities in this process can help prevent public backlash.

Task 3 Barriers Analysis - Key Takeaways

- Many of the most pressing challenges to the industry, including **aircraft noise, emissions, regulation, and certification, are highly inter-connected.**

- In the **near-term, significant regulatory and certification barriers exist** that will prevent high-speed aircraft from entering service.

- While **airline industry authorities are in the process of modernizing guidelines** and regulation of high-speed aircraft, it will **require multiple years** to put a standard framework in place.

- **The FAA aircraft certification process represents one of the most significant barriers for aspiring market entrants.** The significant time and resource requirements could prevent manufacturers from bringing high-speed aircraft to the market.

SUMMARY CONCLUSIONS

Hypersonic Market Study Summary Findings

Customers of Commercial and private jet services, as well as cargo shippers are willing to pay for more expensive tickets to arrive sooner

The total projected passenger volume for each Mach number were found to be sufficient to support high speed air service for transoceanic routes without including overland routes

Viable business cases are possible from Mach 2 to Mach 5+ however, high speed aircraft cases are less robust than the Mach 2-4 range

In all cases, business viability [IRR] is most sensitive to passenger volume variances and to a lesser degree fuel price fluctuations and government subsidies

Regulatory, certification, societal and infrastructure barriers and challenges pose varying levels of business risk to aspiring service providers

The most challenging barriers are driven by lack of specific regulations and certification requirements to “design to” for this flight regime

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SUMMARY

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High Speed Transportation Market Overview

There are multiple markets scenarios that close economically with technically achievable solutions between Mach 2 and Mach 5.5. The market conditions point towards a March 2 to Mach 3 jet that can serve key transatlantic and transpacific routes at market entry and can be utilized for both passenger and private air service.

Aircraft Characteristics

Speed

Mach 1 | Mach 2 | Mach 3 | Mach 4 | Mach 5 | Mach 6

Across all aircraft configurations, Mach 2 provides the largest market opportunity, but business cases can close between March 2 and Mach 5.5.

Cabin Size

20 | 22 | 24 | 26 | 28 | 30

Optimal aircraft sizing ranges from 20-30 seats with most scenarios and routes favoring the lower passenger jets, similar to the size of today's business and regional jets.

Range

4200nm | 4500nm | 5000nm | 5500nm | 6000nm

Optimal aircraft design ranges are between 4,300nm and 5,800nm.

Ticket Price

$1,000 | $7,500 | $10,000 | $12,500 | $15,000 | $17,500

Optimized one-way ticket prices range between $5,100 and $17,500. The strongest demand elasticity is between $1,275 and $4,200 with most demand falling between below $15,000 per ticket on most routes.

Aircraft Price

$0M | $250M | $500M | $750M | $1,000M | $1250M

The above aircraft characteristics result in prices that range between $50M and $1.12B per airframe. Airframes below $150M are likely to appeal to both private owners and commercial operators.

Not Analyzed / Out of Bounds | Optimized Spectrum | Viable Spectrum | Optimized Market Characteristics

Market Characteristics

Passengers

400,000 | 1,200,000 | 2,000,000 | 2,800,000 | 3,600,000 | 4,400,000

Aircraft characteristics will drive an annual passenger demand between 440,000 and 3,650,000

Airplanes Sold

75 | 250 | 400 | 550 | 700 | 850

Total number of aircraft demanded across all demand segments range from approximately 80-730 aircraft

A Strong Market Picture

Though there are multiple markets scenarios that close economically with technically achievable solutions, our analysis suggests a likely optimized outcome:

Mach 2
Aircraft

$120M
Approximate Aircraft Cost

541
Total Aircraft Demand

20
Passengers Capacity

5,500 NM
Aircraft Range

2.1M
Annualized Passengers

Primary Demand Categories:

1. Scheduled passenger service providers (i.e., airlines) for transoceanic routes
2. Jet Card Memberships and Charter (i.e., on-demand) service providers for transoceanic routes
3. High net worth individuals that travel transoceanic routes, often between global wealth centers

While the likely market scenario is economically sustainable and technically feasible, the current regulatory environment, specifically sonic boom restrictions, significant limits the ability to serve primarily overland routes, such as Los Angeles (LAX) to London (LHR) or London (LHR) to Singapore (SIN) which could attract an additional 1M annual passengers and result in an additional $3.94B in revenue.

Thank you.

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