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Commercial Hypersonic Transportation Market Study

National Aeronautics and Space Administration Aeronautics Research Mission Directorate

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Executive Summary

To determine the viability of business cases for high-speed air service, we needed to determine the buying patterns of today's flying public and their willingness to pay premiums to arrive at far away destinations quicker and then compare this to the performance and economic parameters of various aircraft configurations. This analysis enabled us to estimate business cases to understand how attractive a business proposition would be for investors, manufacturers and operators and compare the relative strengths and weaknesses of each point in the trade space. We accomplished this through a combination market research and digital simulation. In addition, we assessed other challenges that aspiring market entrants would have to overcome to offer a 360-degree view of market viability.

We developed a route tree for potential high-speed service to serve as a basis for modelling different business cases for future market entrants. We analyzed 2019 airline passenger data to identify only the routes that met all the following criteria: high annual passenger volumes; significant percentages of premium ticket purchases; and, limited flight time over land. Routes that met all three criteria we deemed to be best suited for high speed air service. This resulted in a set of 90 city pairs which created the baseline for the business case analysis. If the overland routes that met the first two criteria were added to the route tree, we would expect an annual increase of 30% in passenger volumes.

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

We were able to quantify these buying behaviors into price elasticity curves that show the relationship between the willingness to pay ticket premiums versus the speed of service for each of our three proxy routes. With this data, we were able to estimate total passengers per year at a given ticket price for every route/Mach number combination. As expected, annual passenger volumes dropped sharply as prices began to exceed 4x-6x the cost of a first-class ticket today. Appetite for high speed cargo service existed at 2x-8x today's 2-day shipping rates and drops off to near zero after 8x, independent of speed.

By analyzing these two data sets, we determined that the total projected passenger volume for each Mach number were found to be adequate to support high speed air service for transoceanic routes without having to overcome sonic boom restrictions on overland routes.

Transatlantic routes had higher passenger volumes and were more lucrative markets for operator than transpacific routes.

We modeled the business cases for all combinations of three primary variables: cruise Mach number [2.0-5.5]; passenger capacity [20, 50 & 100] and design range [2500-9000 nmi].

Viable business cases, defined as Internal Rates of Return (IRR) modeled to be higher than 25%, are possible from Mach 2 to Mach 5+ however, high speed aircraft cases are less robust than the Mach 2-4 range.

In the Mach 2-4 cases, annual passenger volumes are higher than hypersonic cases due to lower ticket prices that could be charged for those flights while the hypersonic cases relied on a small annual volume of passengers that would be willing to pay higher ticket prices. We concluded this situation was analogous to the different business cases for selling automobiles today. The Mach 2-4 cases we more aligned to the business models of the "Big Three" automakers who rely on high sales volume and thinner margins while the hypersonic air service cases were like that of a low volume, high margin builder such as Ferrari.

We assessed the sensitivity of these business cases to three primary variables in our calculations.

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

Fluctuation in estimated passenger volume, +50%/-50% has a strong effect on estimated IRR with increases/decreases in volume causing +5%/-12% changes in estimate IRR while government upfront investment and fuel price fluctuations off the baseline cases affected IRR by +/- 5%.

Lastly, we researched other obstacles that high-speed air service market entrants would have to overcome beyond fielding a system that is projected to deliver favorable business returns. Through literature research and interviews with subject matter experts from government, industry and academia, we identified 15 "challenges" that spanned the spectrum from regulatory, to infrastructure to societal challenges. Regulatory, certification, societal and infrastructure barriers and challenges pose varying levels of business risk to aspiring service providers. We were able to rank order the severity of the challenges

The "riskiest" challenges to market entrants are driven by lack of specific regulations and certification requirements to "design to" for this flight regime.

This report presents the primary findings in the main body of the text with additional supporting data included in Appendices.

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Study Objectives and Approach

At the request of NASA, Deloitte conducted an independent market study to provide an independent assessment on the economic viability of hypersonic and supersonic air transportation to inform ongoing strategic planning of research areas within the government and industry and to focus on the areas for technology development and vehicle design requirements.

The Study was organized into three primary areas of investigation: Defining the Market appetite for high speed air transport, Defining the business cases; and Assessing Barriers in the environment. The market demand was assessed across a range of Mach numbers from Mach 2 to Mach 6 and ticket price elasticity was determined by surveying potential customers, literature reviews and stakeholder and expert interviews for passenger aircraft, private aircraft and cargo markets. The business case analyses assessed potential business cases across a three-dimensional trade space: flight speed (Mach 2-6), passenger capacity (20-200 passengers) and design range (2500-7500 nmi.). By using the SpaceWorks Rosetta model, we were able to assess each combination in the trade space and to determine the steady state Internal Rate of Return (IRR or profit) was our primary figure of merit and allowed us to rank order the business cases to understand the trends and draw conclusions from the complex trade space. Lastly, we assessed other potential barriers to high speed flight. These were determined through literature review and stakeholder/expert interviews. Once these were compiled, we developed an objective scoring system to allow us to determine overall significance and challenge to aspiring market entrants.

The majority of the research was conducted between July and December of 2020 and the results compiled and communicated to NASA in the first quarter of calendar year 2021. This report, along with the companion briefing deck, document the summation of our research and serve as a data repository for use by future researchers in government and industry.

Section 1

Defining the Market

Market Segmentation

What are the current trends in the market?

Introduction

To begin, we sought to define and map the current and emerging state of high-speed air transportation technologies across the aerospace and defense industry to understand the technological baseline and investment opportunities that could be leveraged by high speed aircraft developers. We conducted a top-down approach by first mapping the landscape and then analyzing key industry trends in successively more depth.

Defining the Landscape

We collected open-source data to identify government agencies, corporations, and universities that are stakeholders within the high-speed air transportation ecosystem.

Identifying Industry Macro-Trends

We researched government contract budget allocations and venture capital transactions to identify the magnitude of investment gravitating toward the high-speed air transportation industry.

Sector-by-Sector Assessment

We created a taxonomy of existing industry sectors and corporations within each sector that are actively developing services and solutions for high-speed air transportation technology.

The Current Hypersonics Technology Landscape

Hypersonics are a category of vehicle capable of traveling above Mach 5. These vehicles encompass both military and civil technologies including missiles, spacecraft (reaching hypersonic speed during orbit or re-entry), and airplanes. In the previous three decades, hypersonic vehicle development efforts faced steep technical challenges that prevented government, academia, and industry from creating new technologies in the field. However, in recent years, advances in the field have cleared a path for hypersonic technologies to enable new mission areas. Developers are now overcoming the key technological barriers to create new systems that realize the full potential of hypersonic flight.

Hypersonic technologies are defined as systems capable of achieving flight speeds of Mach 5 or above.

Hypersonic Engine Technology Overcomes Key Barriers

To-date, engine technology has proven to be the most limiting factor for hypersonic vehicles. Historically, as a vehicle reaches Mach 5 and above, the components of its turbo jet engine begin to melt as a result of intense air friction. Today, two engine variants enable hypersonic vehicles to sustain flight at Mach 5 or above: the ramjet and the scramjet.

Unlike conventional turbo engines, ramjets and scramjets lack moving parts, which reduces friction and enables engine functionality during sustained high-speed flight. Both engines only operate at hypersonic speeds, requiring an assistive propulsion device (typically a jet engine or rocket engine) to accelerate the vehicle to Mach 4-5 before oxygen and fuel can ignite in the hypersonic engine chamber.

These engines were once conceptual but have matured to functioning or semi-functioning prototypes in recent years. This development has generated significant interest from governments and private entities seeking to apply hypersonic systems to the military and civil sectors. Below provides an overview of the key applications and trends in each sector.

Development Efforts

Development efforts to-date can be segmented into military hypersonic vehicles, civilian hypersonic vehicles, and associated dual use technology. It is important to note that these use case segments have matured at different rates driven due to varying government and commercial market priorities. The following sections provide a high-level overview of development efforts to-date.

Military Hypersonic Vehicles

Military applications of hypersonic technology currently center around Hypersonic Missiles, including Hypersonic Glide Vehicles (HGVs) and Hypersonic Cruise Vehicles (HCVs). While HGVs are launched into the upper atmosphere 50-100km), HCVs remain in the lower atmosphere (20-30km). Both variants capable of performing dynamic aeronautical maneuvers while at hypersonic speed, and therefore present major challenges to existing missile defense systems. These systems are uncrewed and their core technological components are unlikely to easily scale to meet crewed vehicle system needs.

Currently, military systems are the most advanced hypersonic technologies to-date due to significant technology developments by Great Power Nations such as Russia, China, and the United States. Even then, the maturation of military hypersonics systems are maturing at varying rates across the Great Power Nations.

For military hypersonic vehicles, private sector activity in the United State and allied countries is dominated by prime defense contractors. The primes are currently engaged in federal contracting opportunities focused on R&D of hypersonic weapons systems. Full-scale production of any hypersonic systems is either state-guarded information or not yet in progress. Further discussion of Military Hypersonic Vehicles can be found in Appendix 1.

Civilian Hypersonic Vehicles

Civilian applications of hypersonic technology largely focus on the transportation of humans or cargo at hypersonic speeds. Civilian hypersonics projects are significantly more nascent than military hypersonics, and most applications are either in development or still conceptual. Civilian hypersonics therefore must be considered under a broader scope of high-speed air transportation, for which several startups are developing aircraft technologies ranging from low-boom supersonic passenger jets to hypersonic passenger vehicles.

Civilian Hypersonic Government Sector Activity

Aside from private sector projects, NASA has been a driver of civil hypersonics R&D, investing $230.6 million and $248.5 million, respectively, in 2018 and 2019 in the Advanced Air Vehicle Program (AAVP) which includes all subsonic, supersonic, and hypersonic efforts. In 2019, NASA received $35M in dedicated funding for the Hypersonic Technology Program (HTP) under AAVP. The AAVP HTP funding will allow NASA to develop hypersonic technologies and form an accompanying

FIGURE 1.1

Commercial Trends in High-Speed Air Transportation Technologies

High-Speed Air Transportation Returns

In the last decade the supersonic flight market has attracted a handful of startups looking to develop new high-speed airframes. Example players are listed below:

Reaction Engines	Reaction Engines is developing a hypersonic engine, and recently successfully completed a test of its air-breathing engine.
HERMEUS	Hermeus is developing a hypersonic aircraft and aims to provide high-speed air travel services to passengers.
BOOM	Boom Supersonic is developing a supersonic aircraft for passengers, and has raised significant funding to-date.

Segments of the Market

Once these manufacturers have perfected and supplied high-speed aircraft, we expect the market to mature into the following three categories:

Passenger Market:	Similar to the Concorde, passenger aircraft are in the works with flight paths planned from New York's JFK airport to London Heathrow.
Cargo Market:	There is potential for expedited shipping services along certain routes, whether that be on already existing passenger aircraft or on cargo-specific aircraft.
Private Market:	Private owners and jet-sharing platforms will likely take advantage of the opportunity to purchase faster aircraft.

technical cadre. The program aims to develop new air frames that fly faster, cleaner, quieter, and use fuel more efficiently than in the past. Further, in 2009, NASA and the United States Air Force designated several national laboratories for hypersonic technology research, hosted by University of Virginia, Texas A&M University, and Teledyne Scientific & Imaging Inc. Each of these organizations lead a consortium of universities to tackle key technological challenges to hypersonic vehicles.

Dual-Use Technologies

While the hypersonics community can be bifurcated into military and civil applications, both markets are highly nascent and inextricably linked through the development horizons of various hypersonic vehicle sub-systems and components. Air-breathing engines, software & guidance systems, heat-resistant materials, manufacturing methods, and other upstream technologies that cumulatively assemble into hypersonic vehicles have highly synergistic effects across the military and civil hypersonic markets.

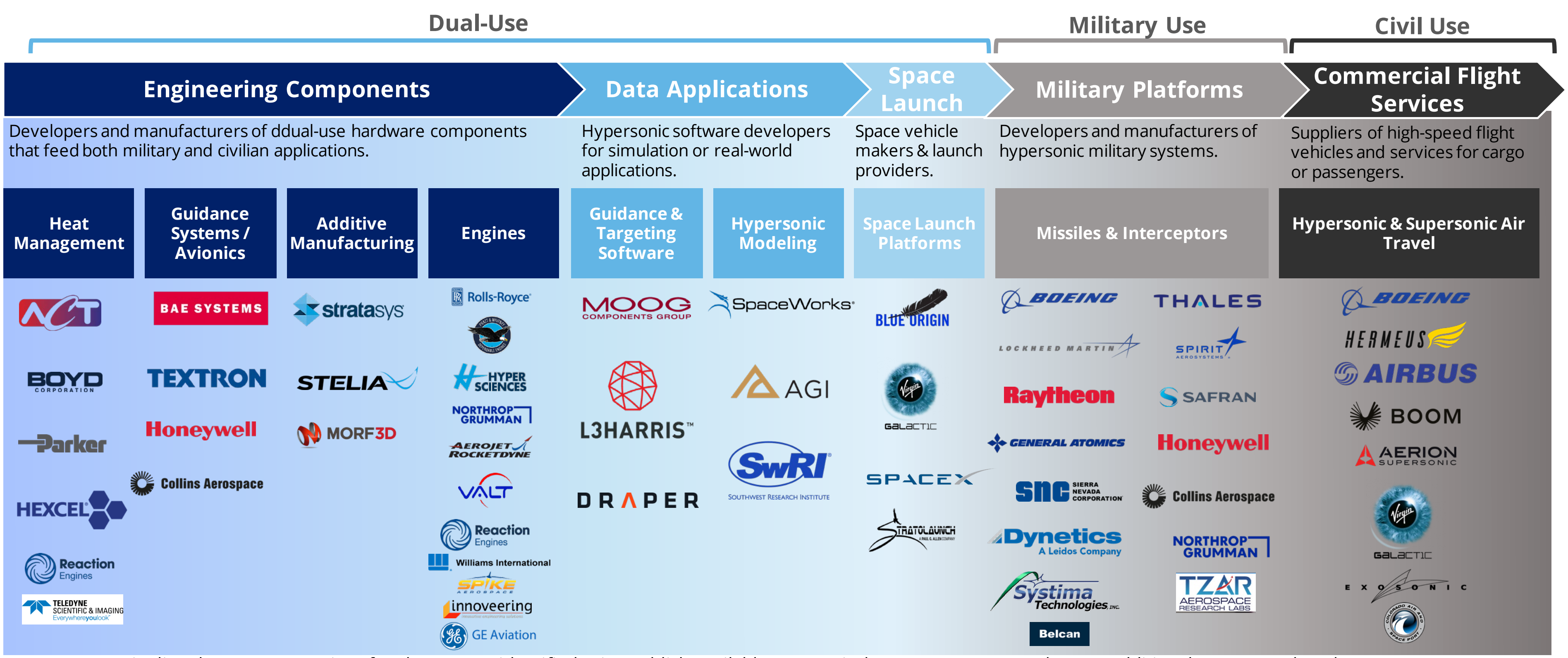
For example, SABRE, the air-breathing engine that Reaction Engines develops, is a versatile system that could potentially operate across a multitude of environments and applications. The company's heat-resistant hypersonic engine concept, if matured successfully, can be applied to multiple hypersonic air frames and in both air and space domains. This is one example of how upstream components and sub-systems can feed into different types of hypersonic vehicles. Therefore, technological advancements in the military market have potential to materially impact the civil market, and vice versa.

Further, as companies and defense programs achieve technological milestones, the USG will need to increasingly weigh the costs and benefits to the availability of this information. A major advancement in any given area of hypersonics could present a national security risk, through a foreign entity seeking to obtain such information either via commercial acquisition or espionage. Therefore, it is paramount that communication exists between civil hypersonic application developers and USG.

Hypersonic technology represents a small but growing set of ecosystem players that fall into respective communities including government entities, academic institutions, corporations, and startups. Industry players such as corporations and startups can be further distinguished by the products they bring to the hypersonics marketplace. This is best reflected via an industry value chain, which captures all immediate segments of the hypersonic technology market, including Commercial Flight Services, Military Platforms, Satellite Launch, Data Applications, and Components & Manufacturing. The diagram below in Figure 1.2 outlines this value chain and classifies industry players by the segment representing each entity's strongest focus on the value chain

FIGURE 1.2

Supply-Side Ecosystem Map



Note: companies listed are representative of each category, identified using publicly available sources (industry reports, press releases); additional names may be relevant.

(entity may operate in multiple segments, so a primary segment was assigned based on their core business).

Competition & Substitutes for High-Speed Air Travel

Hypersonic air travel is a highly nascent category of transportation. While no products exist on the market to gauge pricing, it is reasonable to expect that hypersonic travel services would command high fees relative to conventional transportation methods and would therefore fall within the broader sector of premium air travel. When assessing hypothetical competitor products to hypersonic air travel, it is critical to first understand the core value propositions of hypersonics. We have identified the following key value propositions for hypersonic air travel:

- Efficiency Over Long-Distance: The strongest case for hypersonic transportation is the potential to achieve significant time savings over long distances that otherwise cannot be obtained via other means of transportation. Companies developing hypersonic vehicles have noted the potential for trans-Atlantic flights to achieve flight times as short as 90 minutes via hypersonic speeds.

- Experiential Value: The novelty of using a new method of transportation could provide significant utility to consumers. Experiential value exists across both markets within commercial hypersonics (air travel, and space tourism). For air travel, experiential value may be derived from the comfort of an ultra-premium service (exclusive hangars, luxury vehicle interior, fine dining, etc.), and from the perceived exclusivity in traveling at supersonic or hypersonic speed.

Multiple existing modes of transportation exist that can capture these value propositions, and therefore could serve as competitors to a hypersonic travel service. Some of these services fall within the category of premium air travel, but a handful of alternative transportation methods are emerging that may present competitor services. Each potential substitute service is described below:

Existing Methods

Private Jet Charter Services

Private jet charters present certain advantages to travelers that might rival hypersonic alternatives. Flexibility in take-off time is one advantage, which allows customers the opportunity to book a flight based on their schedule rather than a given airline departure schedule. Exclusivity is also a major driver, as private jets offer an ultra-luxury experience to passengers that might compete with initial hypersonic services.

Ultra-Premium Airline Suites

A handful of international airlines offer ultra-premium enclosed suites that price at $10,000 and higher. Examples include Singapore Airlines’ Suites Class, and Emirates First Class Cabins. While consumers of these services may sacrifice the autonomy afforded by a chart jet service, or the time savings afforded by a hypothetical hypersonic air travel service, they receive significant value through experience and exclusivity.

High-Speed Rail

High-speed rail offers potential advantages to hypersonic air travel due to its efficiency over land. Many countries have regulations against supersonic air travel over populated areas due to the sonic boom created by achieving supersonic speed. Hypersonic or supersonic aircraft therefore would need to slow to subsonic speeds when over land, making alternative forms of high-speed transit, such as bullets trains, a potential competitor service for mid-range distances. This service would not be able to compete at longer distances, however, as with trans-oceanic flight paths.

Long term impacts in flying habits due to COVID-19

Further complicating the relationships between these potential substitute goods are the increasingly apparent changes to long-term consumer trends for public air transportation due to the global COVID-19 epidemic.

Foremost among these trends is increasing consumer reliance on virtual communication & collaboration tools. Since the COVID-19 epidemic began in early 2020, over 90% of the global population has faced partial or complete lockdown, barring residents from international and sometimes local travel. These restrictions have disrupted the professional world, requiring corporations to adopt partially or completely virtual operations. As part of this new operating model, demand has accelerated for virtual collaboration tools in the workplace that enable teams to stay connected. For example, Microsoft Teams, a virtual communication and file sharing platform, experience a 500% increase in usage in China between December 2019 and March 2020. Zoom, a video conference platform, experienced a 378% increase in its daily active user count between March 2019 and March 2020, a trend that industry analysts attribute in part to the changes in demand for virtual communication methods caused by COVID-19. Further, virtual corporate operating models are demonstrating long-term viability, as studies have shown considerable advantages to having remote employees, such as corporate cost savings of up to $11,000 on average annually per employee who works remotely at least half of their time. Therefore, it is possible that virtual collaboration tools will retain their value even after the global travel restrictions from COVID-19 end, placing long-term downward pressure on demand for air travel.

COVID-19 travel restrictions are impacting all segments of the market, including premium-class air travel services. Prior to COVID-19, airlines were focused on increasing seat-counts on planes in order to push ticket prices lower for a larger economy-class customer base. In 2019, premium class services accounted for 5% of international air traffic, but 30% of total international air travel revenue, signaling that is a key counterbalance for lower margins on economy seats. Today, market surveys indicate that as much as 60% of airline managers expect business-class travel to decline even after COVID-19 restrictions end, which could have a negative cascading effect for demand at all levels of airline ticket classes.

These trends indicate a sustained global shift toward reduced public transportation by leveraging virtual connectivity, as well as private transportation methods. Future high-speed air travel may be impacted by these trends and tailored services may be required to adapt to new consumer behaviors and a changing global air travel market. Due to the current state of the COVID-19 pandemic at the time of this writing, and working under the assumption that the global travel market will rebound before supersonic or hypersonic commercial services enter the market, the impact of this shift is not modeled in our analysis.

How this Data was Used

The data and analysis compiled in this section establishes the baseline state of the hypersonic and the civil supersonic aviation industry inclusive of the current development efforts and the focused use of private, public, and government capital to mature needed technologies and capabilities. *This confirms that the market remains in a nascent stage with most of the investment focused on military applications with few technologies that could be leveraged for commercial use. These findings confirm the need to address any barriers that would impede a maturation of the market beyond its current nascent state.* The remainder of Section 1 details the market entry points for commercial high-speed transportation services and Section 3 addresses the barriers and other impediments that should be addressed.

City Pairing and Route Selection

What routes are favorable for the introduction of high-speed aircraft?

Introduction

To determine what routes have favorable conditions for high speed transportation, we need to understand which critical locational factors need to be assessed when choosing a region, city, and airport as a route origin or destination. From there, we extrapolated our findings to assess which high-speed routes would potentially be economically viable between those origins and destinations. While aircraft are flexible to fly wherever paying customers can reasonably demand, establishing economically viable routes that have sustainable passenger bases early on will be critical to advancing high-speed transportation beyond the nascent market state that we find it today.

Methodology

In assessing the business cases for supersonic or hypersonic air transportation, we followed a multi-tiered down-selection process, detailed in Figure 1.3 to thoroughly vet routes that represent viable high-speed air travel targets.

- We identified a set of critical location factors used to assess initial potential among existing global air travel routes. We used these factors to develop a long list of potential routes that broadly represented viable pairings.
- We grouped these initial pairings by those that represent strong candidates for air cargo, passenger transportation, and private transportation. This allowed for a wholistic approach to assessing the market for high-speed air travel.
- We conducted a detailed analysis of each city pair, assigning scores based on economic and technical considerations.

FIGURE 1.3; See *appendix table 1.3*

City Paring and Route Selection Process

Initial Findings
Critical Location Factors

We developed an initial long-list of potential city pairs based on analyzing market driven data and Critical Location Factors for global routes.

GLOBAL CROWN JEWELS	HIGH-DEMAND ROUTES
MARKET COMPETITON	CUSTOMER DEMOGRAPHICS

Down-Selection
Route Down Selection

We conducted a second round of down-selection by analyzing the operational and logistic nuances of each route to identify a short list of viable routes.

ECONOMIC FACTORS

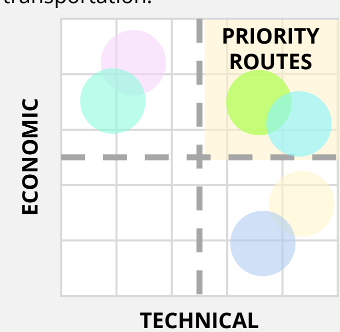
We analyzed annual route revenue, passenger traffic, cargo tons, and wealth indices for each route to identify those with the highest economic viability.

TECHNICAL FACTORS

We considered factors such as nautical distances, sonic boom restrictions, and other logistical filters to identify routes with the highest technical viability.

Scorecards
Scorecard Findings

We ranked each of the city pairings on the short-list to identify the most optimal potential supersonic & hypersonic travel routes across passenger, cargo, and private air transportation.



Global Routes
Demand Analysis

Finally, we used the down-selected routes and scorecards to optimize a global route tree that consists of 90 potential routes that would support high-speed transportation.

Each pair was then plotted according to their respective scores.

- A select group of leading candidates across cargo, passenger, and private route categories were identified as high-viability city pairings.
- The top ranked pairing across each group was selected for a detailed case examination.

Critical Location Factors (CLFs)

To understand which passenger-centric city pairs are viable options for high-speed aircraft, we analyzed existing route composition, air traffic demand, macroeconomic conditions, and location-specific factors.

Route-Driven CLFs

Existing route-driven pairs were evaluated across six categories – distance, route composition model, flight volume, airline service, route history and airline operations, and quality of air service – which allowed us to determine which current and historical routes could support high-speed transportation options. Data was sourced from 2017-2019 route data provided by the U.S. Federal Aviation Administration, OAG, and various airport authorities.

Demand-Driven CLFs

Demand was analyzed across six categories – origin and destination traffic volume, catchment type (i.e. rural or metro), catchment size, catchment density, demand drivers, and alternate transportation options. Data was sourced from 2017-2019 route data provided by the U.S. Federal Aviation Administration, OAG, various airport authorities, and the U.S. Bureau of Economic Analysis.

Market-Driven CLFs

The geographical markets were analyzed across six categories – essential vs. market-driven air service, regional location (i.e. costal or inland), industrial base & technology cluster participation, associated airport classification (i.e. hub vs. spoke), passenger socioeconomic composition, and destination popularity – to understand if a geographic market had the right socioeconomic and locational conditions to support market-entry of high-speed passenger flights. Data was sourced from 2017-2019 airport data provided by the U.S. Federal Aviation Administration, OAG, various airport authorities, the U.S. Bureau of Economic Analysis, Wealth-X, IBISWorld, and the U.S. Cluster Mapping Project.

Determining Factors for City-Paring and Route Development

Combining the various CLFs, we observed that optimal city pairs, and therefore potential routes, often had the following characteristics:

- O&D cities were more likely to be in coastal regions (i.e. JFK or LAX) or only slightly in-land (i.e. CLT or ATL).
- O&D cities were likely to be large catchments – metropolitan areas – with existing hub airports that had a large volume of origin and destination traffic.
- O&D cities were likely to have a high destination popularity that would attract a large volume of annual business and leisure travelers
- O&D cities were likely to have a high percentage of wealthy individuals that are tied to industrial base or technology cluster activities.
- O&D cities had strong passenger transportation markets with multiple highly competitive routes, a competitive airline operation environment, and few alternate transportation options between the pairs.
- In markets with multiple large airports and highly competitive routes, we observed that high-speed transportation services are likely to be centralized at a single airport

Unsurprisingly, the analysis showed that of the 36 CLFs examined, there were four CLFs that became prominent in determining a viable economic pathway towards market entry:

- Crown Jewel Competitiveness (Route CLF): Crown jewel routes are those that have outsized revenue performance at a national, regional, or international level. Currently, the highest performing Global Crown Jewel route is JFK-LHR. Routes that are identified as a crown jewel route should inherently have economic conditions favorable for the introduction of high-speed airline service.
- Route Toughness (Route CLF): Those routes that are served by multiple airlines without a dominant provider, those with low margins, or those with a larger than industry average economy seat cabin density. Routes that are identified as tough may have inherently unfavorable economic conditions for the introduction of high-speed airline service and therefore may represent a location barrier to establishing high-speed air service.
- Demand Drivers (Demand CLF): Those routes that have large passenger volumes as measured by the number of scheduled seats, both in economy and premium cabin densities, or have large cargo volume as measured in available tonnage. High-demand markets with large numbers of premium cabin seats or available tonnage should have inherently favorable conditions for the introduction of high-speed airline service.
- Passenger Socioeconomics (Market CLF): Routes that pair global cities with high concentrations of wealthy individuals. Concentrations of wealthy individuals

above the global averages create favorable conditions for attracting and converting subsonic premium cabin passengers to high-speed aircraft service.

How this Data was Used

The CLF data and the full list of cities and associated routes informs the down selection of routes, detailed in the next section, for scheduled passenger airline service, cargo air transportation service, and private jet routes. The CLF data also informed the analysis performed in Section 2 – Defining the Business Case by establishing favorable locational characteristics to inform the technical and operational analysis.

Route Down Selection

From the initial list of 90 routes compiled during the CLF analysis, we then then performed a down selection of routes based on specific economic and demand factors, mostly driven by the prominent CLFs, and an initial technical viability analysis of the identified routes.

To perform this down selection, we categorized routes as passenger, cargo, or private aircraft routes based on the demand analysis performed as part of the CLF analysis and then looked at the technical viability for serving those routes by passenger, cargo, or private operations. As most routes serve passengers and cargo, many of the routes were analyzed across all three operational types. This resulted in approximately 40 routes which were then fed into scorecards to determine high-potential routes by operational type. Where specific catchments had multiple dominant airports (i.e. the Washington, D.C.-Maryland-Northern Virginia or New York-New Jersey metropolitan areas) or where regions (i.e. Los Angeles-San Diego) were large enough to have multiple O&D airports, single proxies were chosen to simplify the initial analysis.

Three scorecards were created, one for passenger routes, cargo routes, and private routes respectively. The scorecards provided an economic opportunity rating based upon favorable economic characteristics as determined in the CLF analysis and technical fit criteria as determined by technical characteristics from the Rosetta model.

Scheduled Commercial Passenger Transportation Scorecard Findings

From the CLF analysis, we created a passenger scorecard based on economic opportunity ratings and technical fit ratings for those selected routes. Routes that had low technical fit ratings, which included routes operating predominantly over land that would be subject to operational barriers (see Section 3), and those with a low economic opportunity were filtered from the high-performance scatterplot shown in Figure 1.4a. Of the 20 routes that remained, all were transoceanic routes.

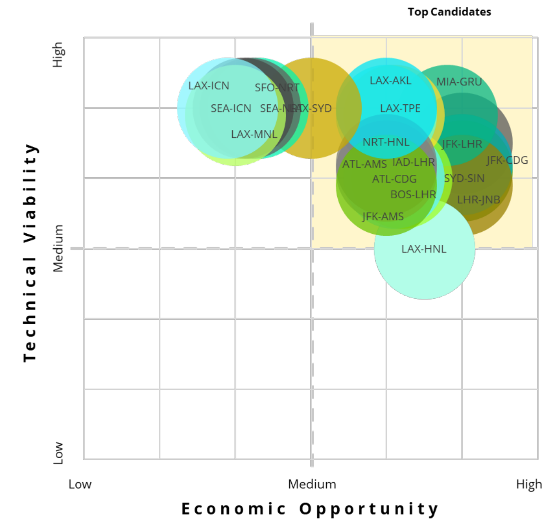
Top Routes for Consideration

Among the 20 routes analyzed, five interesting pairs emerged as potential top performing routes that could be technically possible with specific airframe designs. These routes were:

- **JFK-LHR:** John F. Kennedy Airport and London Heathrow Airport are the two primary airports for New York and London. The trans-Atlantic route consistently ranks among the highest passenger-seats per among global city pairs, demonstrating strong economic and technical viability.
- **MIA-GRU:** Miami International Airport and Sao Paulo International Airport are key hubs for the U.S. and Brazil. MIA is the 13th heaviest-trafficked airport in the US, while GRU is the most heavily trafficked airport in Brazil. The combination of high-volume passenger traffic and high technical feasibility make MIA-GRU a top-ranking potential supersonic route.
- **JFK-CDG:** John F. Kennedy Airport and Paris Charles DeGaulle Airport represents a key international route.

FIGURE 1.4a; *See appendix table A-1.4*

Scorecard Results for High-Potential Passenger Service Routes



While JFK is the heaviest traveled air route in North America, CDG is the heaviest-traveled route in France and second heaviest-traveled route in Europe. The route also has historically offered supersonic service for the Concorde jet.

- **LAX-SYD**: Los Angeles International Airport and Sydney Kingsford Smith Airport are two key hubs for the western United States and Australia, respectively. LAX is the second largest international gateway airport in the U.S. and Sydney is the 38th busiest airport in the world. The route offers strong economic and technical viability.
- **SYD-SIN:** Sydney Airport and Singapore Changi Airport are two key air travel hubs for Australia and Singapore, respectively. Sydney has been consistently ranked among the top passenger airports in the

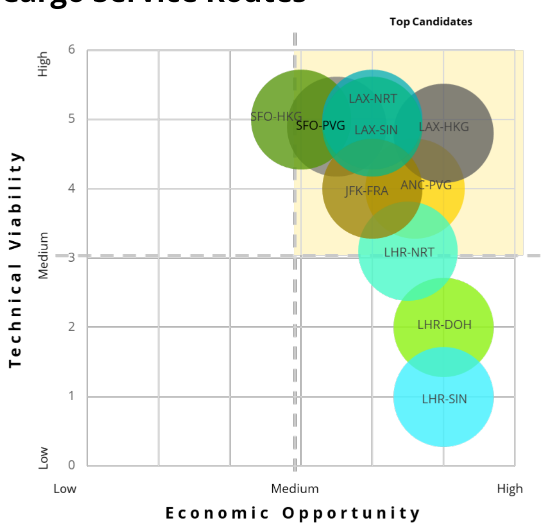
world, and SIN has been ranked as the top passenger airport in 2020. Both airports demonstrate strong economic and technical viability.

Scheduled Cargo Transportation Scorecard Findings

From the CLF analysis, we created a cargo scorecard based on economic opportunity ratings and technical fit ratings for those selected routes. Routes that had low technical fit ratings, which included routes operating predominantly over land that would be subject to operational barriers (see Section 3), and those with a low economic opportunity were filtered from the high-performance scatterplot shown in Figure 1.4b. Of the 10 routes that remained, all were transoceanic with origins or destinations in the North America, Asia, Africa, Australia, and Europe.

FIGURE 1.4b; *See appendix table A-1.4*

Scorecard Results for High-Potential Cargo Service Routes



Top Routes for Consideration

Among the 10 routes analyzed, five interesting pairs emerged as potential top performing routes that could be technically possible with specific airframe designs. These routes were:

- LAX-HKG: Los Angeles International Airport and Hong-Kong International Airport are among the largest global air travel hubs in the world. Both LAX and HKG rank in the top 20 hubs for cargo traffic (by metric tons) as well as passenger traffic. The trans-oceanic international route represents an ideal pairing from both an economic and technical perspective.
- ANC-PVG: Anchorage Airport to Shanghai International Airport represents a major shipping route between North American and East Asia. Both routes rank among the top 20 globally by metric tons, and Anchorage is a key mid-point for trans-pacific shipping.
- LAX-NRT: Los Angeles International Airport and Narita International Airport (60 kilometers east of Tokyo) are among the largest global air travel hubs in the world. Both airports rank among the top 20 global air cargo hubs in the world. The trans-oceanic international route represents an ideal pairing from both an economic and technical perspective.
- LAX-SIN: Los Angeles International Airport and Singapore Changi Airport represent two key global shipping and travel hubs. Their top-tier rankings among trans-oceanic cargo and passenger shipping hubs makes them an ideal pairing both economically and technically
- JFK-FRA: John F. Kennedy International Airport and Frankfurt Main Airport are key international air cargo and passenger hubs, ranking among the top 20 airports globally by both passenger and cargo traffic metrics. They represent a viable potential economic and technical fit.

Private Aircraft Travel Scorecard Findings

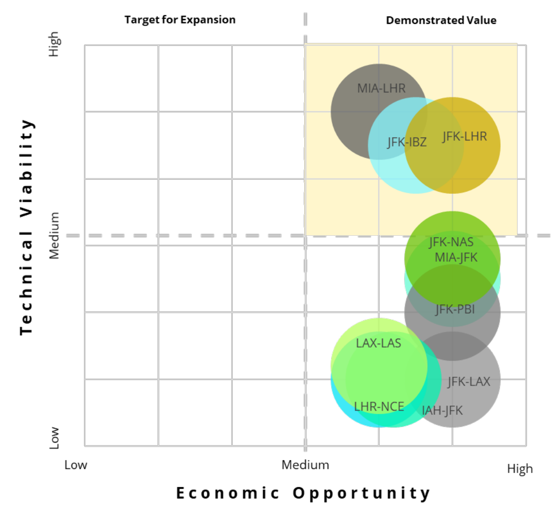
From the CLF analysis, we created a private aircraft scorecard based on economic opportunity ratings and technical fit ratings for those selected routes. Given that private aircraft utilization is entirely dependent upon those individuals that own or charter them, the list of high-performing routes can rapidly change, is unpredictable, and is generally irrational. However, 2017-2019 flight statistics allowed us to create a list of 10 routes for further examination for economic performance and technical fit. Those routes are shown in Figure 1.4c.

Top Routes for Consideration

Among the 10 routes analyzed, five interesting pairs emerged as potential top performing routes that could be technically possible with specific airframe designs. These routes were:

FIGURE 1.4c; *See appendix table A-1.4*

Scorecard Results for High-Potential Private Jet Service Routes



- **JFK-LHR:** In addition to being ranked as a Global Crown Jewel passenger route, JFK-LHR is also a world-leading route for private air travel, and therefore must be noted as a leading option for both markets.
- **MIA-LHR:** Miami International Airport and Heathrow Airport demonstrate strong private air traffic with one of the top high net-worth customer bases globally. LHR previously hosted the supersonic Concord service. As a trans-oceanic route, it represents a viable market for high-speed private air travel.
- **JFK-IBZ:** John F. Kennedy International Airport and Ibiza International airport represent a top pairing for private luxury air travel. Both locations have high wealth index rankings, as well as private aircraft traffic. JFK has also historically hosted the supersonic Concord service. The trans-oceanic route offers a strong value proposition for premium, high-speed air service.
- **New York City Area-NAS:** The New York City area, often using Teterboro Airport, and Lynden Pindling International Airport (formerly Nassau International airport) rank among the highest routes for private air travel. The New York City area has one of the highest wealth demographics in the world. The overseas route represents a strong market with potential for high-speed private air travel.

How this Data was Used

The route scorecards were used to look for optimized city parings, and therefore routes, that were economically viable and technically feasible. These routes and attractive origin and destinations informed our analysis in the demand findings, detailed in the next section, where they anchored our elasticity analysis by informing the various elasticity proxies created. In conjunction with the elasticity findings, the route selections and scorecards ultimately informed the final global passenger route list which underpins the market inputs to the Rosetta model detailed in Section 2.

Demand Analysis

What does demand for high speed transportation look like?

Introduction

To assess market demand for hypothetical high-speed transportation services, we analyzed several markets for air transportation services, including commercial passengers, air freight, and private jet ownership. These markets and our assumed associated characteristics were based upon the route selection analysis. Whether an aircraft was moving a passenger or cargo, demand for that flight was being driven from geographical markets capable of supporting high-speed transportation services on a regular basis.

Commercial Passenger Demand Assessment Method

We engaged consumers directly to understand willingness to pay for high speed air travel services in the current marketplace. From the survey, we captured the quantity of services demanded (in annual passengers) at various ticket price points. We then derived elasticity curves to highlight consumer demand at various price points for high-speed air services. Last, we assessed the demand for various time savings on routes of different lengths at a fixed set of price points. This holistic approach allowed us to identify how the length of the original flight impacts both willingness to pay, as well as tradeoffs consumers are willing to make for time savings.

Air Cargo Shipping Demand Assessment Method

To assess demand for high-speed air travel in the air cargo shipping market, we first identified a series of critical logistical factors that are key considerations when assessing the potential market for a high-speed air cargo service. Second, we identified a set of potential use cases (or products) that might require a supersonic cargo transport service. These use cases were based on a set of assumptions including high-urgency and high willingness to pay. Last, we engaged consumers directly to gauge their willingness to pay for shipping services beyond current shipping times that are widely accessible to consumers.

Private Jet Ownership Demand Assessment Method

To assess demand for private jet ownership, we first collected a dataset of pricing for 15 private aircraft with seating for 19 or fewer passengers, falling within the guidelines of Part 91 aircraft for private operations (Part 125 involves aircraft in commercial use with 20 or more passenger seats). We identified the price, the size category, and the maximum speed for each aircraft, and compared these to the desired prices for supersonic and hypersonic jets. We then analyzed wealth data to understand what individuals could afford a private jet of this caliber.

Commercial Air Passenger Transportation

Based upon the critical location factors and the route selection analysis, we created proxies for mid-haul (JFK-LHR), long-haul (LAX-NRT), and ultra-long-haul (LAX-SIN) routes. These proxy routes all have a high economic potential and technical fit in addition to having at least an industry average, if not a higher than average, premium passenger cabin density (includes premium, business, first, suite, or airline equivalent classes of service).

Types of Commercial Fliers

The demographics of survey respondents broke down as follows:

Most respondents fell within the age categories of 30-44 and 45-60, signaling that most respondents are in their peak earning years.

Respondents surveyed made at least six-figure annual salaries. Most were above $150,000 annually, signaling propensity to purchase luxury goods such as high-speed air travel.

The flying habits of the survey respondents were as follows:

Most respondents flew a few times per year, 30% flew on a monthly basis or more.

Most respondents typically flew 2,500 nautical miles or more, indicating a strong sample size of individuals with recurring trans-oceanic flight experience.

49% of respondents fly in premium economy, business, first, suite, or other premium cabin configurations

18% of respondents fly in business, first, or suite cabins

Estimating the Price Premium for High-Speed Travel

Our objective was to determine how much a passenger would be willing to pay for high-speed air travel by determining the premium that passengers would place on timed save and their sensitivity to ticket price. To estimate this demand, and therefore the market for high-speed passenger air travel, we started by surveying approximately 500 global consumers who identified as frequent travelers to determine consumer willingness to pay at different time savings for various routes represented by the proxies. We targeted consumers most likely to have the financial means to afford long-distance air travel, as well as those who demonstrated a history of air travel for work and leisure purposes. Based on our findings from the critical location factors and route analysis, we specifically asked respondents about international transoceanic flights and conducted our surveys in the United States, the United Kingdom, and Japan – countries represented in the proxies.

Based on the class chosen, we applied the price multiples from the survey responses to the prices listed below. With four classes and 8 price multiples to choose from, data was therefore collected at up to 32 price points, which are shown on the x-axis of the elasticity curves. Note that fewer data points may have been taken depending on survey responses (for example, if no respondents answered Ultra-Premium, and 5x multiple).

FIGURE 1.5; See appendix table A-1.5

A Proxy for Estimating Demand Elasticity on Mid-Haul Flights: JFK-LHR

What does this tell us about mid-haul demand?

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

Noted Assumptions

All prices represent one-way, non-stop tickets.

The average economy ticket for JFK-LHR costs $650 and takes approximately 7 hours.

COVID excluded, JFK-LHR has approximately 2.9 million annual passengers.

Note: annual passenger data from JFK-LHR is derived from 2018 figures.

Estimating the Elasticity for the Proxy Routes

Using estimated average one-way ticket prices for economy, premium economy, business, first, and suite for the three proxy routes, elasticities were estimated by multiplying average ticket prices by the the passenger premiums collected across the 32 price points. This information provided us with the range of prices that a consumer was willing to pay for a one-way ticket on the proxy routes based on their average class of service. Data was collected across desired mach level, in the form of time savings on the route. From there, we transformed the willingness to pay the premiums into elasticity curves by multiplying the percent of responses by the one-way annual demmand, which translates to the y-axis. This method allowed us to create multiple elasticity curves for each proxy at each Mach number. The elasticity curves are shown in Figures 1.5, 1.6, and 1.7.

FIGURE 1.6; See appendix table A-1.6

A Proxy for Estimating Demand Elasticity on Long-Haul Flights: LAX - NRT

What does this tell us about long-haul demand?

We observe the highest price sensitivity and strongest demand between $1,500 and $6,000 per ticket (~2X-8X economy).

Between $1,500 and $18,000 per ticket (~2X-24X economy) we observe higher demand for more hours saved, and relatively lower demand for fewer hours saved. This aligns with rational consumer behavior.

At price points above 24X economy, we observe that the time savings curves converge demonstrating low willingness to pay regardless of time savings.

Noted Assumptions

All prices represent one-way, non-stop tickets.

The average economy ticket for LAX-NRT costs $750 and takes approximately 12 hours.

COVID excluded, LAX-NRT has approximately 860,000 total annual passengers in all classes of service.

We then overlaid the results for all three survey questions to show percentage of respondents who were willing to pay at least two times the price of their regular ticket for different time savings. This allowed us to determine if a greater percentage of consumers would be more willing to pay a premium for time savings on longer flights than shorter flights.

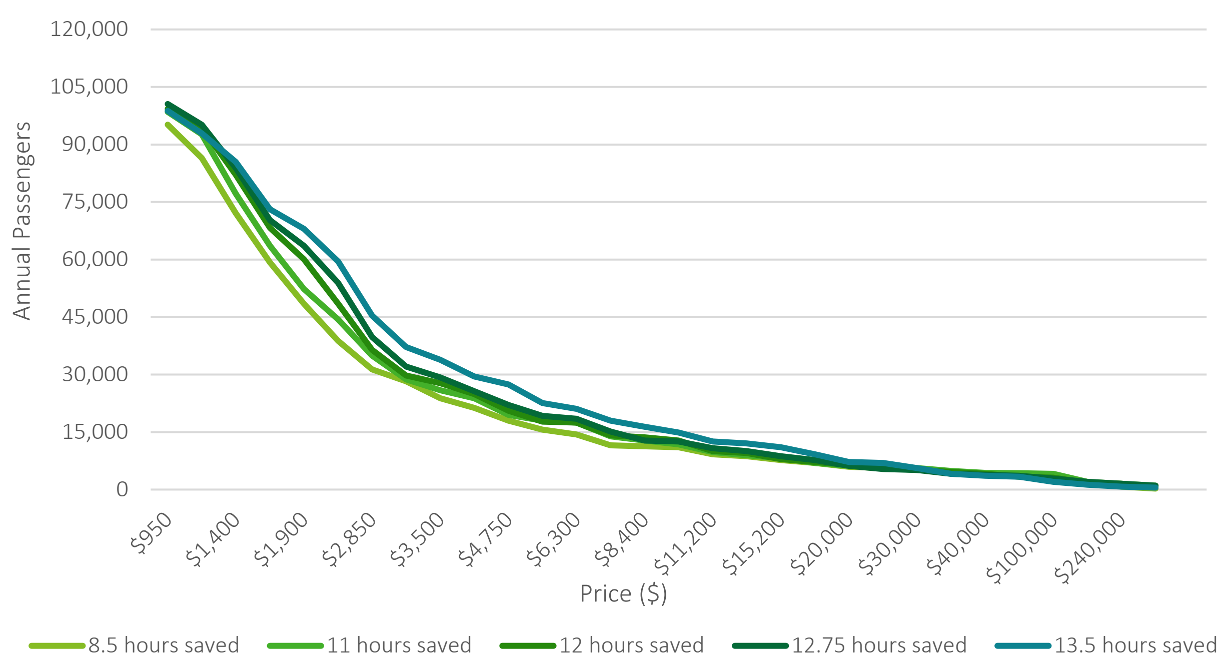
The results of respondents who said they would pay 2x as much as the ticket costs today are shown in Figure 1.8.

According to this figure, the amount of people willing to pay 2x their regular ticket price for a Mach 2 flight increases with the present-day length of the flight. However, at higher speeds, this discrepancy becomes less apparent. This is to be expected as the incremental time saving is less significant at higher Mach numbers, as illustrated on the graph.

However, when applied to the global passenger market, we observe that a willingness by customers to pay a higher premium on longer flights does not necessarily mean that long-haul or ultra-long-haul flights are the most optimal routes due to lower overall passenger volumes. Even with a lower willingness to pay a premium on shorter flights, many mid-haul

FIGURE 1.7; See appendix table A-1.7

A Proxy for Estimating Demand Elasticity on Ultra-Long-Haul Flights: LAX - SIN



What does this tell us about ultra-long-haul demand?

We observe the highest price sensitivity and strongest demand between $1,400 and $4,750 per ticket (~2X-5X economy).

Between $1,400 and $15,000 per ticket (~2X-21X economy) we observe higher demand for more hours saved, and relatively lower demand for fewer hours saved. This aligns with rational consumer behavior.

At price points above 21X economy, we observe that the time savings curves converge demonstrating low willingness to pay regardless of time savings.

Noted Assumptions

All prices represent one-way, non-stop tickets.

The average economy ticket for LAX-SIN costs $700 and takes approximately 17 hours.

COVID excluded, LAX-SIN has approximately 125,000 total annual passengers in all classes of service.

routes have high enough passenger volumes to create strong businesses cases for high-speed transportation.

To create a baseline of how we would observe this demand play out in the market, based on this observation, we then projected the market size for a Mach 2 flight on the JFK-LHR route. Adjusting a one-way ticket price for today's dollars, we observe that a ticket from JFK-LHR would cost approximately $6,500. Leveraging the elasticity projection for JFK-LHR, we estimate an annual demand of approximately 279,000 passengers that would generate $1.814B in total revenue on that route if it were available in 2019 (pre-COVID-19).

From this ticket price and passenger volume, a 5.80% CAGR and a 1.88% inflation rate were applied until the year 2035. Finally, assuming that this estimate could be off by 25% in either direction, the market size was estimated at between $1.6B and $2.6B in 2029, the likely earliest date for new scheduled supersonic passenger services.

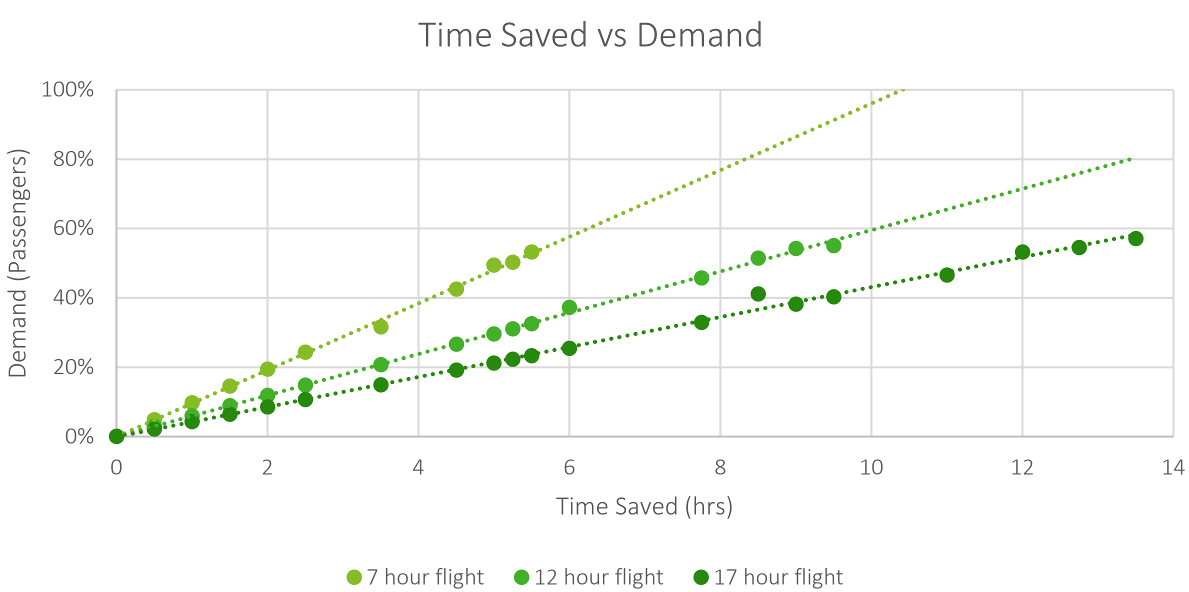
With a market estimate of approximately $2B in its first year of operations, Mach 2 supersonic scheduled passenger services would generate more revenue on the world's most valuable route by capturing around 10% of today's JFK-LHR annual passenger volume.

How this Data was Used

The elasticity data informs the final route listing and the Rosetta model calculations, which ultimately allow us to calculate the global market size.

FIGURE 1.8

Estimating Desired Demand for Time Saved



Key Takeaways: Commercial Passenger Market

Lower priced tickets have higher price sensitivity. According to consumers surveyed, they would expect a supersonic private jet that can reach speeds of Mach 2 to cost around $79M, which is significantly lower than the projected price for current in-development supersonic airframes entering the market in the future.

Speed matters more to consumers at prices closer to that of a current economy ticket. Between 2x and 6x the original economy price, more consumers are willing to pay for faster service. At higher price points, the curves converge, indicating that consumers who can afford a ticket at this price would pay regardless of the time savings.

Demand for certain time savings depends on the length of the subsonic flight. Consumers are more likely to pay high premiums to save a significant amount of time on ultra-long-haul flights than they are to save the same percent of time on a mid-haul flight, but the demand of mid-haul flights still outweighs that of long-haul and ultra-long-haul.

Commercial Air Freight Transportation

Relative to passenger air travel, air freight involves a higher degree of complexity across the value stream. To envision the circumstances that would demand a high-speed air freight service, we first outline the logistical considerations of air freight transportation.

Understanding Air Freight within the Shipping and Logistics Market

First, while passenger air transportation service is denominated by a singular product, or 'airfare', on the other hand, air freight services are typically part of a larger 'shipping & handling' fee. Shipping & handling broadly encompasses all means of delivery services involved in transporting a good from its location of origin to a consumer's destination. Delivery can leverage multiple modes of transportation, including automobiles, aircraft, unmanned systems and couriers. Further, because shipping rates are standardized, the transportation modes involved in any given delivery are not itemized in the fee. This structure complicates pricing for a supersonic air freight service, as suppliers would primarily bear the cost of such a service, and the need for supersonic freight service would depend highly on any given order.

Second, the value-proposition of a supersonic air freight service is further complicated by the unique last-mile logistics of each consumer. A consumer's proximity to the nearest fulfillment center can significantly impact ground-based shipping time. While reducing flight-time can improve shipping speeds, last-mile logistics would remain a limiting factor for delivery speeds, and a supersonic air freight service could yet be insufficient to achieve a faster delivery threshold.

To address this problem, the shipping industry has evolved toward a decentralized, predictive model which poses further challenges to the value-proposition of a high-speed air freight service. Some shipping and logistics companies have evolved to operate many global package warehouses by using artificial intelligence algorithms to forecast demand and determine which products to store.

While suppliers have historically built stockpiles of highly demanded products, the scale and technological resources of modern-day suppliers allow supply managers to anticipate regional consumer behavior patterns with an unprecedented degree of precision. Air freight is therefore typically proactively scheduled, and shipping goods has become significantly more localized. Achieving shipping timelines faster than same-day shipping (which is currently available to the public) is more about managing 'last-mile logistics' involving various forms of localized, ground-based delivery methods, rather than expediting a long-distance flight.

Determining Demand for Faster Shipping Enabled by High-Speed Aircraft

Minding these complexities, we can still gauge consumers' willingness to pay for expedited shipping services beyond what the market currently offers consumers, while assuming Ceteris Paribus, or that a high-speed air freight service would contribute to a faster delivery timeline.

Determining What Goods or Items would Spur Demand for Faster Shipping Enabled by High-Speed Aircraft.

There are several applications, activities, or needs that might demand the faster shipping speeds achieved made capable by high-speed aircraft. These applications include high-value business applications, mission critical parts or supplies, reactionary capabilities to unexpected events, and certain e-commerce transactions. A snapshot of select applications is shown in Figure 1.9. Additionally, goods or supplies that require special handling, such as the current super-chilled COVID-19 vaccines, may benefit from faster air freight transportation simply because it reduces the time the item spends outside of a highly controlled environment.

In many cases, government and private applications that will drive demand for faster shipping provided by high-speed transportation are likely the result of business-to-business (B2B) transactions or the result of companies or governments moving goods on their own behalf or through their own transportation and logistics networks.

Types of Consumers that Demand Faster Shipping

The demographics of survey respondents broke down as follows:

Respondents income ranged from $25,000 to $200,000.

Emphasis was placed on individuals making $75,000 per year or more.

The purchasing and associated shipping habits of the survey respondents were as follows:

Most respondents (66%) make purchases via e-commerce on a monthly basis or more.

Almost half of respondents used expedited shipping services on a recurring basis each year.

The products or goods that they would purchase with faster shipping were as follows:

Respondents were most likely to use expedited shipping for medical supplies, perishable and imported foods, or high-priority documents.

FIGURE 1.9

Examples of Demand Applications for Faster Shipping Service

Private

Supply Chain

Industries need quick and efficient methods of transporting critical parts & materials to maintain operations. For example, power outages are reported to cost businesses over $100,000 per hour; power companies therefore need fast access to the parts and skills required restore grid networks

Pharma & Healthcare

Hospitals and care providers often need time-sensitive medical supplies such as organs and medical equipment. Data indicate that 75% of organs are transported to a patient as soon as they are donated. Using high-speed air transport can increase accessibility over longer-distances.

Consumer Products

E-commerce companies are driving consistently faster shipping options, which consumers are increasingly demanding. In recent years, multiple large retailers have expanded their shipping options to include 1-day shipping, driving the market for this service to grow at a 20% compound annual growth rate.

Government

Supply Chain

Critical government supply chains for items such as military hardware can demand high urgency. For example, part shortages can delay military operations, such as missions carries out by the F-35 Lightning II. As of early 2021, the U.S. Government Accountability Office determined that F-35 supply chain does not have enough parts to maintain desired aircraft mission readiness objectives.

Pharma & Healthcare

Civil and military entities often need time-sensitive medical supplies such as vaccines and blood transfusions. For example, the United States plans to execute Operation Warp Speed to combat COVID-19, during which it will aim to rapidly ship over 300 million vaccines around the U.S. once a vaccine is approved.

Consumer Products

The U.S. government is a critical stakeholder for package shipping demand, as USPS was responsible for 6.2 billion total package deliveries in 2019. As commercial players increasingly evolve to meet the growing market demand for highly expedited options, the federal government may need to respond with comparable services.

Consumer-Driven Demand

Despite the likelihood that faster shipping demand will be driven by B2B transactions or internal organizational needs, there is still an opportunity to service consumer-driven or business-to-consumer demand. Historically, as shown in Figure 1.10, consumers generally tolerate between a 3 and 3.5X premium over 2-day shipping for same-day delivery services. However, changing consumer preferences in general, accelerated by COVID-19-induced consumer behavior changes, are likely to increase demand for faster shipping services inclusive of options that provide same-day and less than same-day delivery for a wide variety of products that would command larger premiums on same-day shipping.

To understand how consumers would react to the option for faster shipping times enabled by high-speed air transportation, we surveyed over 200 consumers to identify preferences, understand price sensitivity, and estimate high-speed air shipping price elasticity. We targeted consumers who would have the means to purchase high-premium expedited shipping services, as well as those who currently use existing expedited shipping services on a frequent basis.

After establishing consumer preferences for faster shipping on specific types of goods, we then asked consumers how much more over two-day shipping prices they would be willing to pay for one-day shipping, same-day shipping, 8-hour shipping, 5-hour shipping, and less than 5-hour shipping. The results can be seen in the Figure 1.11. While these shipping times do not correspond directly to time savings realized by flying at a specific Mach number, the findings do demonstrate current price sensitivity to increased premiums that result by using higher-cost, high-speed aircraft.

We observe higher price sensitivity for lower prices, indicating that consumers with lower purchasing power will be less inclined to spend the premiums. In contrast, the curves flatten around 10x the 2-day shipping cost. This indicates that, while the demand at these prices would be extremely low, consumers who do pay at this price would not be as sensitive to higher premiums.

In this chart, we see a very large spread between the curves and the curves do not converge at high prices. This tells us that the demand for one-day shipping would not be extremely significant past 2x the 2-day shipping price, but the demand is significant for the less than 5-hour shipping option up to 5x the price of 2-day shipping. Even consumers with high purchasing power are much more interested in the latter option over all the other options.

FIGURE 1.10

Historical Consumer Tolerance for Faster Shipping Premiums

For same-day shipping, we found that the historical premium over two-day shipping is 2.2x. We then used the linear trend to find the premiums for the other time savings from the survey.

Applying the Demand Projections to a defined Market

To investigate the JFK-LHR market size for 12-hour, 8-hour, and 5-hour shipping, we used the best-fit curve for the survey results to find the percentage of consumers who would be willing to pay the given premiums.

Knowing that the average the per-pound price for expedited transatlantic shipping is $65 USD, and that the 2019 annual shipping weight for this flight path was 342,214,751 pounds, we applied the percentages and premiums associated with each shipping time to estimate the market size. A CAGR of 20.30% and inflation rate of 1.88% were applied to estimate year-over-year growth.

The market size for a 5-hour shipping service is therefore the largest, at $14 million USD in the first year and growing to $46 million USD by 2035. However, there is still a sizeable market for expedited 12-hour shipping, which may be more feasible given constraints of last mile logistics.

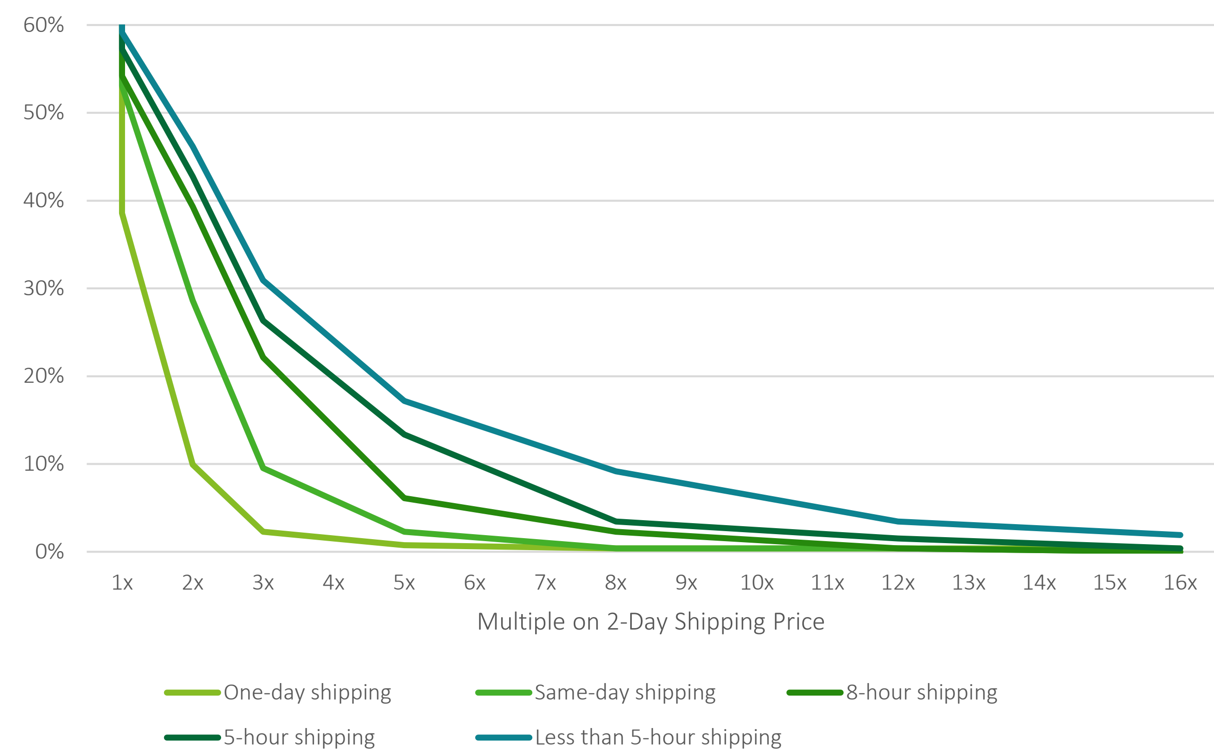
Finally, we can envision a set of extreme scenarios that could stand to benefit significantly from a high-speed air freight service. We assume these scenarios would involve a highly specialized good that requires all possible time-savings regardless of expense and is therefore a perfectly inelastic good. Further, we assume such a transaction would be enterprise-level, and either indirectly or directly benefit individual consumers.

How this Data was Used

The elasticity data informs the final route listings and the Rosetta model calculations, which ultimately allow us to calculate the global market size.

FIGURE 1.11; See appendix table A-1.8

Consumer Elasticity for Expedited Shipping



What does this tell us about mid-haul demand?

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.

Noted 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).

Private Jet Ownership

The final market we investigated was the private jet market which encompasses aircraft that often thought of as private jets, business jets, and corporate jets. These jets are those that are often twin-engine, turbine powered aircraft with pressurized cabins that are capable of transporting between 4 and 20 people.

This market is unique as there are several different models for purchasing and using private jets by the two primary demand segments – private individuals and companies. Generally, we observe specific archetypes emerging that categorize consumer purchasing for private jets across three main methods – ownership, jet card/membership, or charter service – that are defined as follows:

- Ownership: Private jet ownership includes sole or fractional ownership of a specific aircraft.
- Jet Card/Membership: A jet card is a prepaid card that comes loaded with a set number of hours or dollars and is often tied to a specific hourly rate for a desired class of aircraft. A membership provides similar benefits but operates in monthly or annual increments and is often based on a desired class of aircraft or volume of flying.
- Charter Service: Charter service providers offer on-demand aircraft to meet an individual's or organization's needs. In addition to private jet charter services, commercial airlines also offer a variety of charter services.

Many operators can provide services across the jet card/membership, charter services, and even fractional ownership offering models.

Who is flying privately?

The demand for private aircraft comes primarily in the form of corporations and a specific subset of global aviation consumers. For corporations, demand is often driven by the need to move executives, senior leadership, or other important employees such as technical specialists in a more flexible and potentially less risky manner. The class of consumers that fly private jets are those that we generally consider to be "wealthy" individuals. For our purposes, we are adopting a standard definition that a wealthy individual is a person that has a net worth of $1M in combined assets. Globally, there are approximately 22.1 million wealthy individuals. The demand for private flying has resulted in 21,000+ registered private aircraft globally, 700+ annual new aircraft sales, and a projected demand for 7,600 private aircraft over the next decade. In 2019, the business/private jet market was worth approximately $21B.

Global Wealthy Individuals by the Numbers

Global wealthy individuals can be segmented into the following categories:

- Wealthy Individuals: Individuals that are worth between $1M and $5M; approximately 19.2M globally
- Very High Net Worth Individuals (VHNWI): Individuals that are worth between $5M and $30M; approximately 2.6M individuals globally
- Ultra-High Net Worth Individuals (UHNWI): Individuals that are worth more than $30M; approximately 290,000 individuals globally

Aircraft Demand by Types

Private jets refer to non-turboprop and non-piston planes those that fall into the following categories:

- Light Jets: Turbofan aircraft that seat between 4 and 7 people, with a range of about 1,700 nmi, that often retail between $2.6M and $23M
- Midsized Jets: Turbofan aircraft that seat between 7 and 9 people, with an average range of 2,200 nmi, that often retail between $13M and $43M
- Midsized-Large Jets: Turbofan aircraft that seat between 8 and 12 people, with an average range of 3,500 nmi, that often retail between $24M and $62M
- Large Jets: Turbofan aircraft that seat between 9 and 19 people, with a range of 4,000-6,500 nmi, that often retail between $27M and $67M
- Commercial Class Narrowbodies: Turbofan aircraft that seat between 19 and 48 people, with a range of 6,000+ nmi, that often retail between $53M and $108M
- Commercial Class Widebodies: Turbofan aircraft that seat between 19 and 75 people, with a range of 9,000+ nmi, that often retail between $224M and $425M

Types of private flyers

We can categorize wealthy fliers by a series of archetypes that outline what they are looking for when flying. "When I fly, I want…"

Conventional frequency - Likely flying for business, often on long-haul flights between hubs. Frequency of flights and flexibility is the dominant product choice driver. Look for them to purchase commercial first class with some on-demand charter flights.

Adventure - Likely flying for pleasure on long-haul or intercontinental leisure flights. A high-class experience is the dominant product choice driver. Look for them to purchase on-demand charter flights.

Flexibility - Likely a road warrior where flying is the backbone of their life with trips between a wide variety of destinations. A seamless experience is the dominant product choice driver. Look for them to purchase jet card memberships.

Status - Likely a person that has a high affinity for luxury goods and experiences that owns one or more luxury items such as private jets, yachts, or art. Owning a status symbol is the dominant product choice driver. Look for them to purchase light to medium jets and jet cards to augment their aircraft's capabilities.

Time Back - Likely a high-frequency business traveler that has significant time demands because of their high-profile nature. Control over their time is the dominant product choice driver. Look for them to purchase medium-large to large jets and jet cards to augment their aircraft's capabilities.

Demand for Various Classes of Private Jets

Demand for private jets is driven mostly be utility and operating characteristics versus price. As such, unlike other goods that exhibit a normalized elasticity of demand, there is more demand in the private jet market for larger, higher-priced aircraft due to the utility provided, the types of purchasers (i.e. ultra-high-net-worth individuals), and the perceived luxury or affinity that comes with private ownership. We observed that larger jets that can go faster, carry more people, travel farther, and provide additional levels of comfort. As such, demand for midsized-large and large aircraft is significantly higher than that for light jet and small aircraft. However, this consumer behavior and willingness to pay for more expensive jets only extends so far. In today's subsonic market, we observe a significant ceiling between $70M and $90M wherein demand plateaus, likely as a result of a combined loss of utility and acquisition and O&M costs of larger, commercial-class airframes. Aircraft priced above this ceiling, often those that are derivatives of commercial narrow-body aircraft, are not as attractive to buyers as they are likely priced outside of the price range for most HNWI's.

Based on a survey of 1,854 people conducted by Business Jet Traveler, the speed of an aircraft was the seventh most important aircraft feature behind Range, Economical Operations, Cabin Amenities, Manufacturer, Cabin Size, and Age of Aircraft[1].

Estimating Private Ownership Affordability

As previously established, the market for private jet ownership is driven by wealthy individuals and more specifically, comes from the very high and ultra-high net worth individuals. Yet, despite the overall net worth of VHNWIs and UHNWIs, there is a maximum limit that any individual is going to be willing to pay to purchase a private jet outright. While each individual will have a different level of tolerance for affinity or utility goods and a different view on whether private aircraft are affinity or utility goods to them, we can estimate the maximum willingness of the average consumer to pay based on their total net worth and the average asset class allocations of wealthy individuals. We estimate, based on Wealth-X and Capgemini global wealth demographic and asset class holding data, that the average VHWI and UHNWI is likely has around 14.6% of their assets allocated to real estate and other high-value assets. Within this asset allocation, it is likely that real estate holdings comprise a large portion of this asset pool but access to other liquid assets will give an individual some flexibility in purchasing a jet. This means that most VHNWIs and UHNWIs will likely not spend more than 14.6% of their net worth on an affinity or utility good even if they tap into other asset classes to afford the initial aircraft purchase. As such, we can use this 14.6% asset allocation as a notional ceiling for affordability. Based on these calculated ceilings, we can assign behaviors to classes of wealthy individuals to predict how they will travel by air. We have observed that this method of determining the maximum affordability and resulting consumer behavior is closely aligned to real-world conditions.

Speed as an Extension of Utility

The consumer behavior that we observe for subsonic jets and the willingness to pay for is mostly driven by factors such as convenience, range, utility, affinity, and flexibility. Most notably, private jet owners have frequently cited in-flight connectivity as

[1] In this study, speed was based on existing subsonic airframes thereby accounting for the lower preference for speed. However, when questioned about supersonic jets, only 30% were interested in supersonic airframes.

a more important factor than aircraft speed. This is not surprising since the speed difference between many current subsonic business jets is not substantial. However, private jet owners have expressed an interest in supersonic business jets.

The introduction of new high-speed aircraft operating at supersonic or hypersonic speeds can extend the utility of the aircraft and potentially the premium that a consumer would be willing to pay for such an aircraft. During our research, we observed that wealthy individuals would pay a premium, ranging from 1.7x to 3x the purchase price of an aircraft, for speed as an extension of the utility of an aircraft. When speed is factored in as an extension of utility, the demand for more expensive aircraft is expected to increase thereby increasing the demand pricing ceiling for private jets. We used this method to create new price ceilings and affordability estimates for VHNWIs and UHNWIs.

Sizing the Market for High-Speed Aircraft

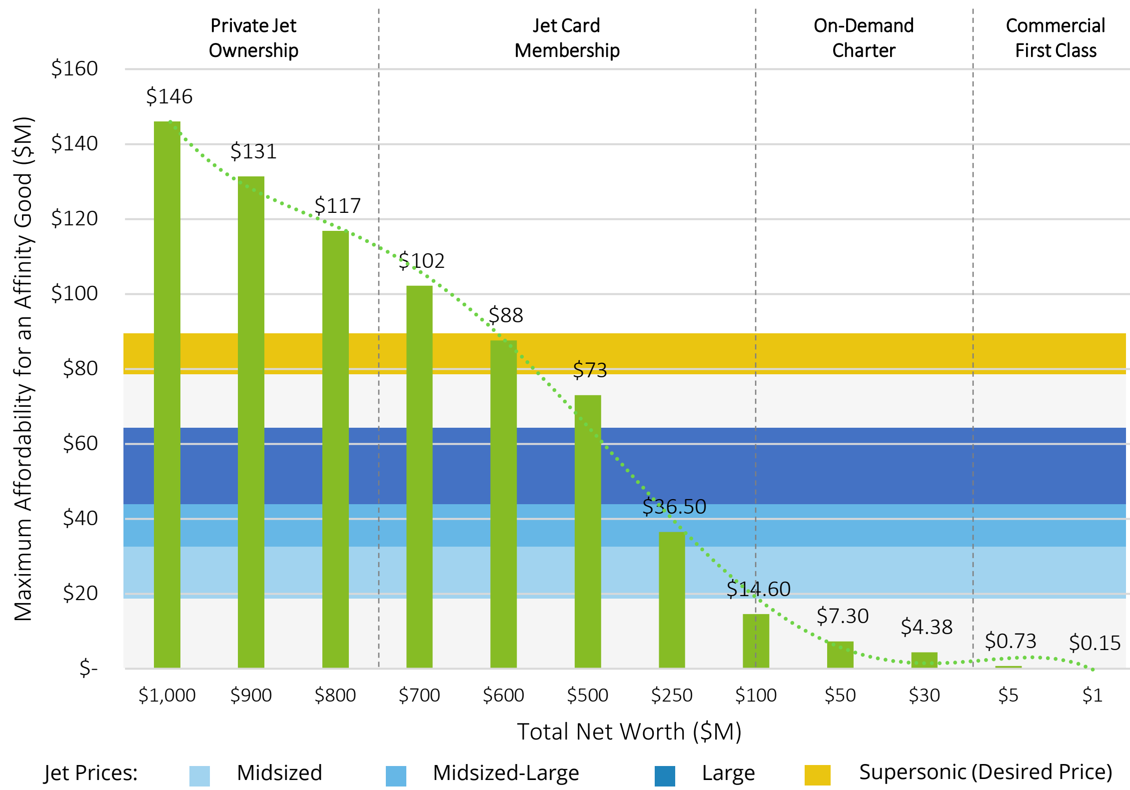
To assess the present-day market for private jets, we leveraged existing industry data from subsonic private jets currently available in the aircraft market.

Our initial market findings observations included:

- Private jet demand is the largest for the midsized large and large jets at 292 (36%) of the 809 new jets sold in 2019.
- The remaining demand was split between 90 (12%) midsized 284 (35%) light, and 121 (15%) very light jets in 2019.
- Demand is usually split between UHNWI ($500M+ net worth) at 50% of the market and Corporations including jet sharing platforms at 49%. Global government usually account for 0-1%.
- There are approximately 300 jets sold each year (2017-2019) in the midsized and large categories but there are 8-10K fractional owners in any given year and 25-30K jet card members.
- As prices increase and potentially exceed the existing and revised cost ceilings, it will likely push UHNWI individuals into the other purchasing categories such as jet card memberships, on-demand charters, or commercial first class.
- Cost per hour of a high-speed airframe then becomes the determining demand factor when demand shifts to jet card memberships and on-demand charter.
- All jets subject to conversation to high-speed airframes in these methods seat between 9 and 16 in executive/luxury seating configurations and no jet in this segment has an FAA certification for more than 19 total passengers.

FIGURE 1.12

Estimating Private Ownership Affordability



- We expect a traditional CAGR, similar to other category growth rates of 3%.
- Non-jet sharing platform corporations, (i.e. Fortune 500 companies) are much harder to characterize given that they often purchase multiple planes both new and used. Early adopters may be more likely to leverage jet cards and membership models versus outright purchases.

Through discussions with private industry and high net-worth individuals, we gauged desired prices for supersonic and hypersonic jets as a multiple of prices for today's subsonic jets. Since supersonic and hypersonic jets will be comparable to jets in the midsized, midsized-large, and large categories, the desired price multiples were applied to the average price of these three categories. We observed that consumers desire supersonic aircraft that are priced between $79M and 91M, a finding that aligns with the currently observed price ceiling but does not align with proposed aircraft cost from next generation supersonic providers. For comparison, current estimates place next-generation supersonic aircraft to be priced between $120M and $210M per airframe. Adjusted for inflation, the Concorde would cost approximately $200M in today's dollars.

Figure 1.12 visualizes jet prices and wealth data for the consumers who would likely participate in this market. Several key variables drive this chart:

- First, the vertical bars represent the average value that wealthy and high-net worth individuals own in luxury goods (such as jets, yachts, art collections, etc.). For example, an individual worth $1B USD is likely to own a maximum of $146M USD worth of luxury goods.
- The horizontal bars represent the same jet price ranges shown on the previous chart. This highlights the net worth required to own a given class of jet.
- Finally, the vertical categories displayed on the top of the chart show the type of customer an individual is likely to be based on their net worth. The wealthiest individuals may own a jet, while those individuals with $1-5M USD in net-worth are likely to fly first-class on regularly scheduled passenger flights.

Lastly, by analyzing data for present-day jet sales in the midsized to large categories, we determined that sales total approximately 300 jets per year. As stated previously, these categories would be the most comparable to future supersonic and hypersonic private jets. Therefore, we assume that with the advent of supersonic and hypersonic private jets, some sales for midsized to large private jets would be lost to these new types of jets. Thus, we estimated three different possible markets for a Mach 2 jet: assuming that supersonic jets would cannibalize 10%, 30%, and 50% of today's jet sales.

With the 10% assumption, the expected market would be about $2B and jet sales would average 30 per year. This volume of jets is very close to predictions in the market for average annual sales of supersonic business jets. However, as stated above, the desired price for these jets is not entirely in line with today's market predictions. Figure 1.13 outlines the potential for a Mach 2 aircraft market.

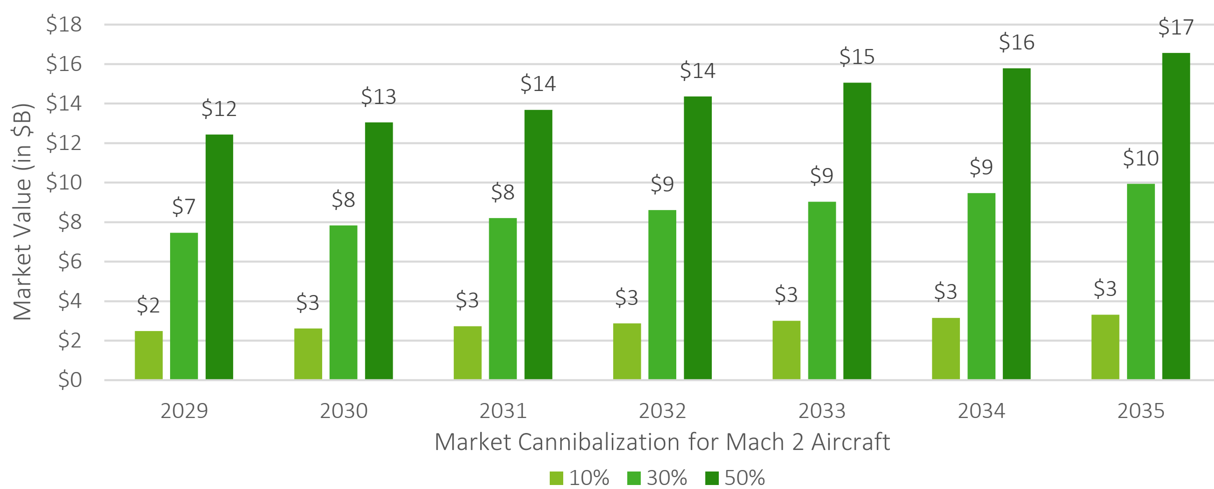
Reconciling a Mismatched Market Picture

This view of the market illustrates a significant mismatch between demand, affordability, and potential future aircraft prices as consumers demand a maximum price of $91M per airframe and manufacturers supply an aircraft with a minimum price per airframe of $120M. However, when factoring in speed as an extension of utility, we believe that the existing price ceiling will raise enough to close to market for specific high-speed aircraft.

To determine the revised price ceiling, we used the premium multiples by Mach number and extended the maximum price a

FIGURE 1.13; See appendix table A-1.9

Potential Market Values for a Mach 2 Private Aircraft



consumer of specific classes of jets would be willing to pay. Based on the Challenger 300, Gulfstream G650ER, and a blended average for large jets, we can extend the ceilings across Mach number.

Using the premium of speed as an extension of utility, we observe that the following revised demand price ceilings:

- Mach 2: the market would assume prices up to $118M
- Mach 3: the market would assume prices up to $146M
- Mach 4: the market would assume prices up to $166M
- Mach 5: the market would assume prices up to $208M
- Mach 6: the market would assume prices up to $208M

However, despite the market assuming higher prices for supersonic and hypersonic aircraft, the tolerance for those increased prices is still limited. While speed as an extension of utility addresses the demand price ceiling that we currently observe between $70M and $90M, the ability of VHNWIs and UHNWIs to afford those jets does not change. As such, we believe that new high-speed jets must be affordable to those worth less than $1B and not solely targeted at multi-billionaires which comprise the smallest portion of the UHNWI wealth segment. Previously, we estimated that a person worth $1B would be able to afford up to $146M which aligns well to the revised demand price ceilings. In short, the desired price ceilings for Mach 2 and Mach 3 aircraft align well to the ability of UHNWIs to afford them creating a sustainable market.

Conversion of the Existing Market Demand to High-Speed Airframes

Our method for assessing the cannibalization potential is based around the desire of UHNWIs and private aircraft owners to purchase and utilize supersonic business jets. At Mach 2, we created a base case that estimated that approximately 30% of UHWNI and corporate jet purchasers would convert to supersonic airframes provided the prices were affordable. The 30% cannibalization rate was based on a survey of consumer sentiment for supersonic transportation that observed around 29-30% of jet owners were interested in supersonic airframes. In the baseline case, which we assume has the maximum potential for cannibalization, this results in demand of 40 jets per year. As Mach number and the associated airframe prices increases, we expect demand to significantly decrease with a 50% reduction (i.e. 20 jets per year) in demand at Mach 3, a collapse of demand for Mach 4, and extremely finite markets at Mach 5 and beyond. Simply put, the world is not big enough and there are not enough wealthy individuals for high-priced hypersonic jets. If prices came down substantially, especially below the demand price and affordability ceilings, then demand for hypersonic jets would substantially increase.

Impact on the Business Case for High-Speed Transportation

These findings directly influenced the business case analysis (Section 2 of this report) were used as annual airframe sale inputs to the Rosetta Model, which informed and further refined the number of potential aircraft sales by size and speed when combined with the other market demand factors and data.

Understanding the Complete Demand Picture

Our findings across the three operational segments, scheduled passenger air transportation, air cargo transportation, and private jet aircraft sales demonstrate that there is addressable demand for high-speed air transportation services.

Most Viable Demand Segments

The dominant driving segment will be scheduled passenger air transportation services when examining the market through the lens of annualized numbers of passengers moved. We also see encouraging demand from private air service providers that include charter, on-demand, and jet card or membership service models. Furthermore, there appears to be a substantial opportunity for private jet sales in full and fractional ownership models provided prices are below certain price ceilings to ensure that more than just the billionaire crowd can afford them. Regardless of market segment, our analysis confirms a significant price sensitivity for most consumers.

Key Takeaways: Private Jet Market

Consumer willingness to spend falls below expected price projections. According to consumers surveyed, they would expect a supersonic private jet that can reach speeds of Mach 2 to cost around $79M, which is significantly lower than the projected price for current in-development supersonic airframes entering the market in the future.

Price estimates indicate a relatively narrow customer base for private supersonic aircraft. Data indicate that individuals worth more than $1B would be most likely to buy a jet at this price point. High net worth consumers below $1B are less likely to afford such a purchase.

Market projections show relatively low volume, but a notable market value for private supersonic aircraft. Assuming high-speed jets would cannibalize 10% of the market, there would be about 30 jets sold per year (approximately $2.5 billion in value) and the market would grow approximately 5% per year due to inflation and compound annual growth.

Speed as an extension of utility will only increase demand in supersonic segments. Demonstrating the value of speed as a utility will likely drive greater market adoption and overall demand but prices for Mach 4+ jets are likely still too expensive leaving a very small global addressable population.

Purchasers of High-Speed Air Transportation

The largest addressable pool of passengers are wealthy individuals that are likely to purchase supersonic transportation in the form of premium scheduled passenger services from airline operators, charter flights, jet cards or memberships, and outright plane purchases. The largest addressable segment is likely scheduled commercial air service for premium and ultra-premium travelers.

Preferred Speed

Demand appears much stronger for supersonic service due to lower comparative costs (i.e. ticket, shipping, or airframe costs) and a diminishing level of returns for hypersonic services.

We have observed strong demand for Mach 2-3 aircraft provided they are supplied in configurations (i.e. sizes) that are attractive to the demand segments. Our observations suggest that there are options to size a single airframe offering that is attractive to the scheduled passenger air service and private jet market segments. Section 2 provides in-depth analysis of the impact of various sized airframes on business case economics.

Where to Start in the Market

Despite our optimism for the future of high-speed transportation, we recognize the market is currently nascent and will need targeted market entry points that are have sustainable customer bases, likely in the form of air service passengers, both scheduled and on-demand.

Leveraging our global passenger demand analysis, critical location factors analysis, route scorecards, route proxies, and our price sensitivity findings detailed previously in this section, we observe the following factors:

- The most technically viable routes are transoceanic and longer than 2,500 nautical miles; regulatory and operational barriers will continue to limit the market (see Section 3)
- 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 route, while additional trans-pacific routes now offer noteworthy potential

With these observations in mind, we returned to the initial city paring and route analysis findings and formulated a list of 90 potential route pairs, detailed in Figure 1.15 and figure 1.16. The 90 city pairs are economically viable and technically feasible in a non-COVID-19 impacted global travel market although the list does contain routes that would be lower priority compared to highly attractive routes like the JFK-LHR Global Crown Jewel.

These routes collectively see an annual total demand of approximately 39.68M passengers and an annual demand of approximately 6.05M premium passengers. In our best-case scenario, we estimate that up to 2.25M passengers, or 6% of the total annual passengers on these routes are likely to purchase tickets on Mach 2 aircraft thereby generating up to $16.5B in annual revenue. This list of routes was used in activities outlined in Section 2 to determine total market demand for each case studied.

In some cases, routes are clearly defined between origin and destination airport (i.e. LAX and NRT) and in other cases, we have defined them as pairs between a catchment area and an origin and destination airport (i.e. New York City Area and London Heathrow Airport). For most pairs, we will observe a single origin or destination airport but for large markets such as the New York City Area which includes New York and New Jersey, we observe passenger loads and market dynamics that could be favorable for Newark Airport (EWR) and John F. Kennedy Airport (JFK). As such, we recognize that factors such as commercial airline first adopters and operational synergies such a maintenance and repair operations may influence airport selection for such markets. Other factors such as airport noise regulations and airport operational constraints may also affect locational decisions (see Section 3).

In addition to an annual global passenger market of 2.25M, we also observe an annual demand for up to 40 additional aircraft to service the private jet market segment demand. These 40 aircraft are projected to be purchased by a mix of individual wealthy individuals, jet sharing and charter air services providers, and corporations.

For a complete breakdown of the business case and market potential, please see Section 4.

Key Takeaways: Demand

A passenger market appears strong with several stand-out routes to start. 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.

The right kind of goods could drive high-speed air services demand for e-commerce. 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.

The private jet market appears to be attractive provided aircraft are priced right. 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. This indicates that private jet sales will be more corporation or jet sharing provider driven.

FIGURE 1.14

Global Market Routes (Transatlantic)

U.S. Region	United Kingdom	Central Europe		Africa	South America
	London Heathrow (LHR)	Paris Charles de Gaulle Airport (CDG) Amsterdam Airport Schiphol (AMS) Frankfurt am Main Airport (FRA) Madrid–Barajas Airport (MAD) Josep Tarradellas Barcelona–El Prat Airport (BCN)		London Heathrow (LHR) Murtala Muhammed International Airport Lagos (LOS) Cape Town International Airport (CPT) O. R. Tambo International Airport (JNB)	São Paulo/Guarulhos (GRU) Rio de Janeiro/Galeão (GIG)
New York City Area John F. Kennedy International (JFK) Newark Liberty International (EWR)	JFK-LHR EWR-LHR	JFK-CDG JFK-AMS JFK-FRA JFK-MAD JFK-BCN	EWR-CDG EWR-AMS EWR-FRA EWR-MAD EWR-BCN	JFK-LOS JFK-CPT JFK-JNB EWR-LOS EWR-CPT EWR-JNB	JFK-GRU JFK-GIG EWR-GRU EWR-GIG
Mid-Atlantic Washington Dulles International (IAD) Boston Logan International Airport (BOS) Philadelphia International Airport (PHL)	IAD-LHR BOS-LHR PHL-LHR	IAD-CDG IAD-AMS IAD-FRA IAD-MAD IAD-BCN BOS-CDG BOS-AMS BOS-FRA BOS-MAD	BOS-BCN PHL-CDG PHL-AMS PHL-FRA PHL-MAD PHL-BCN	IAD-LOS IAD-CPT IAD-JNB BOS-LOS BOS-CPT BOS-JNB PHL-LOS PHL-CPT PHL-JNB	IAD-GRU IAD-GIG BOS-GRU BOS-GIG PHL-GRU PHL-GIG
Southeast Orlando International Airport (MCO) Hartsfield-Jackson Atlanta International Airport (ATL) Charlotte Douglas International Airport (CLT) Miami International Airport (MIA)	MCO-LHR ATL-LHR CLT-LHR MIA-LHR	ATL-CDG ATL-AMS ATL-FRA ATL-MAD ATL-BCN CLT-CDG CLT-AMS CLT-FRA CLT-MAD CLT-BCN	MIA-CDG MIA-AMS MIA-FRA MIA-MAD MIA-BCN MCO-CDG MCO-AMS MCO-FRA MCO-MAD MCO-BCN	ATL-LOS ATL-CPT ATL-JNB CLT-LOS CLT-CPT CLT-JNB MIA-LOS MIA-CPT MIA-JNB MCO-LOS MCO-CPT MCO-JNB	ATL-GRU ATL-GIG CLT-GRU CLT-GIG MIA-GRU MIA-GIG MCO-GRU MCO-GIG

FIGURE 1.15

Global Market Routes (Transpacific)

U.S. Region	Asia Narita International Airport (NRT) Tokyo Haneda Airport (HND) Shanghai Pudong International Airport (PVG) Incheon International Airport (ICN) Hong Kong International Airport (HKG) Singapore Changi Airport (SIN) Taiwan Taoyuan International Airport (TPE)	Southern Pacific Ninoy Aquino Manilla International Airport (MNL) Sydney Kingsford Smith Airport (SYD) Auckland Airport (AKL)	South America Jorge Chávez International Airport (LIM)
Pacific Northwest Seattle–Tacoma International Airport (SEA)	SEA-NRT SEA-HND SEA-PVG SEA-ICN SEA-HKG SEA-SIN SEA-TPE	SEA-MNL SEA-SYD SEA-AKL	SEA-LIM
Northern California San Francisco International Airport (SFO)	SFO-NRT SFO-HND SFO-PVG SFO-ICN SFO-HKG SFO-SIN SFO-TPE	SFO-MNL SFO-SYD SFO-AKL	SFO-LIM
Southern California Los Angeles International Airport (LAX)	LAX-NRT LAX-HND LAX-PVG LAX-ICN LAX-HKG LAX-SIN LAX-TPE	LAX-MNL LAX-SYD LAX-AKL	LAX-LIM

Note on global market routes: The 90 routes detailed in Figures 1.14 and 1.15 were selected based on available global route data. All routes are non-stop, one-way pairings. To size the initial market, a global set of route pairs was created based on the critical location factors analysis that included international pairs. However, due to factors such as overland flight restrictions, route length, and competitiveness, most economically and technically viable routes tended to be transoceanic routes and those with a U.S. origin or destination tended to be more favorable due to regional demographics and origin and destination traffic volume. Future established operators of high-speed transportation services may find additional favorable transoceanic routes, such as those from Europe to South America, as part of a service market growth effort following initial market entry on routes identified in both figures.

Key Takeaways

Is there enough demand to create a market for high-speed transportation services?

Yes. There is enough sustainable demand for high-speed transportation. Demand will likely come from schedule air passenger transportation (i.e. airline service) and private jet operations inclusive of charter services, jet card or membership models, and direct aircraft sales. Specific types of cargo could also drive airframe and belly cargo demand although this segment is likely not enough as a single market entry point.

Who wants to fly at high speeds?

Wealthy individuals travelling for business and leisure and business travelers and executives are likely to drive the majority of passenger transportation demand across commercial and private services.

How fast do people really want to go?

Mach 2 – 3. This is mostly based on the large price premiums that are likely to commanded by aircraft beyond the Mach 3 range. With time savings diminishing despite Mach number increasing, the price sensitivity of most customers, regardless of how they purchase high-speed transportation services (tickets or aircraft), is significant enough to make hypersonic speeds less attractive than supersonic speeds.

Where do we start?

Transoceanic, global crown jewel routes are the likely market entry points for scheduled air transportation services with an additional subset of the market also appearing attractive. We identified a total addressable market of 90 transoceanic routes that includes 2.25M annual passengers and a potential for $16.5B in revenue. For private jet sales, focus on making jets that are affordable for both operators and individuals to ensure that more than just the billionaires can afford them. High-speed aircraft that are priced below $146M remain attractive to operators and individuals alike.

Section 2

Defining the Business Case

Photo credit: NASA

Introduction to the Model

Approach

Upon completing the assessment of route pairings and the potential size of major high-speed air transportation markets, the next portion of our analysis focused on determining cost structures, return on investment (IRR), and the major variables driving IRR sensitivity.

To conduct this analysis, our team developed a comprehensive, multidisciplinary modeling tool customized for this high-speed aircraft market simulation.

To produce the business case models, our team leveraged a customized version of the SpaceWorks Type II Reduced-order Simulation for Evaluating Technologies and Transportation Architectures (ROSETTA) Model[2]. The SpaceWorks P2P ROSETTA model, or simply the ROSETTA model, is a Microsoft-Excel based model that was built from SpaceWorks' extensive past research in cost modelling for complex technical systems.

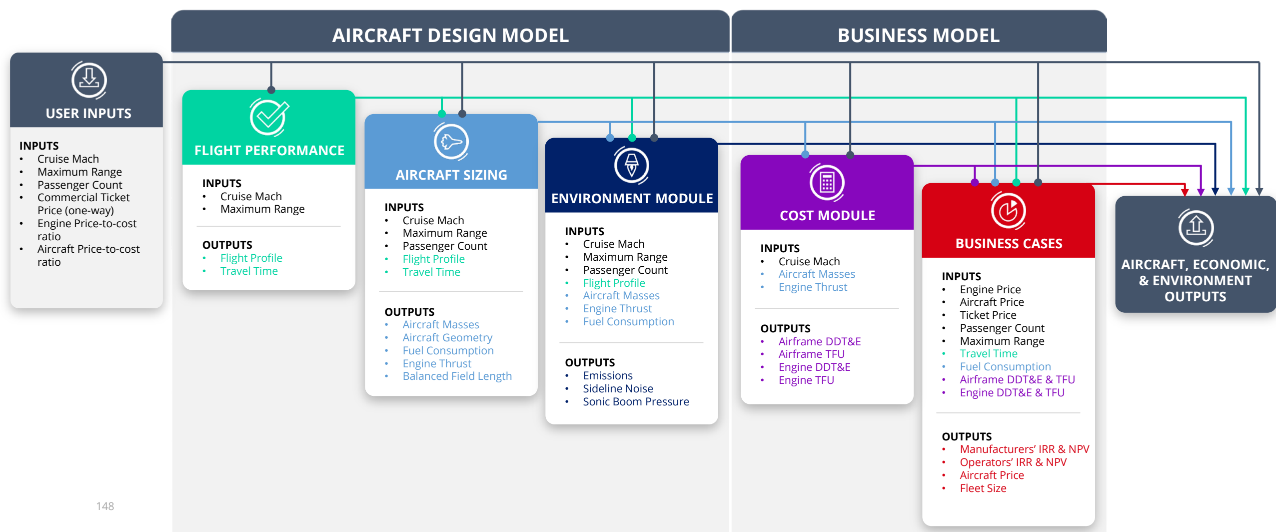
Simulating the Business Case for High-Speed Transportation

The model for this simulation has thousands of active cells and coupling variables, 11 separate and interrelated worksheets, and a custom Genetic Algorithm optimizer used for each candidate aircraft in the trade space. Iterative calculations are used in Excel to converge interdependent equations.

For this simulation, we leveraged our findings outlined in Section 1, inclusive of the addressable passenger demand from the 90 identified transoceanic routes, passenger price sensitivity, critical local factors, and private jet sales. This data provided input to the model as detailed in Figure 2.1. The model formulates aircraft, economic, and environmental outputs based on a concept of operations for high-speed transportation. Figure 2.2 shows how the mission duration for each case was calculated. Times for taxi, take-off, approach & landing and taxi at destination were treated as constants in the model, while the duration of the climb, acceleration, cruise, deceleration, and decent were calculated by the model for case assessed. Furthermore, anchor inputs from previous (Figure 2.3a) and in-development (Figure 2.3b) high-speed aircraft are input to ground and guide the model.

FIGURE 2.1

Interactive Modules in the P2P ROSETTA Model.

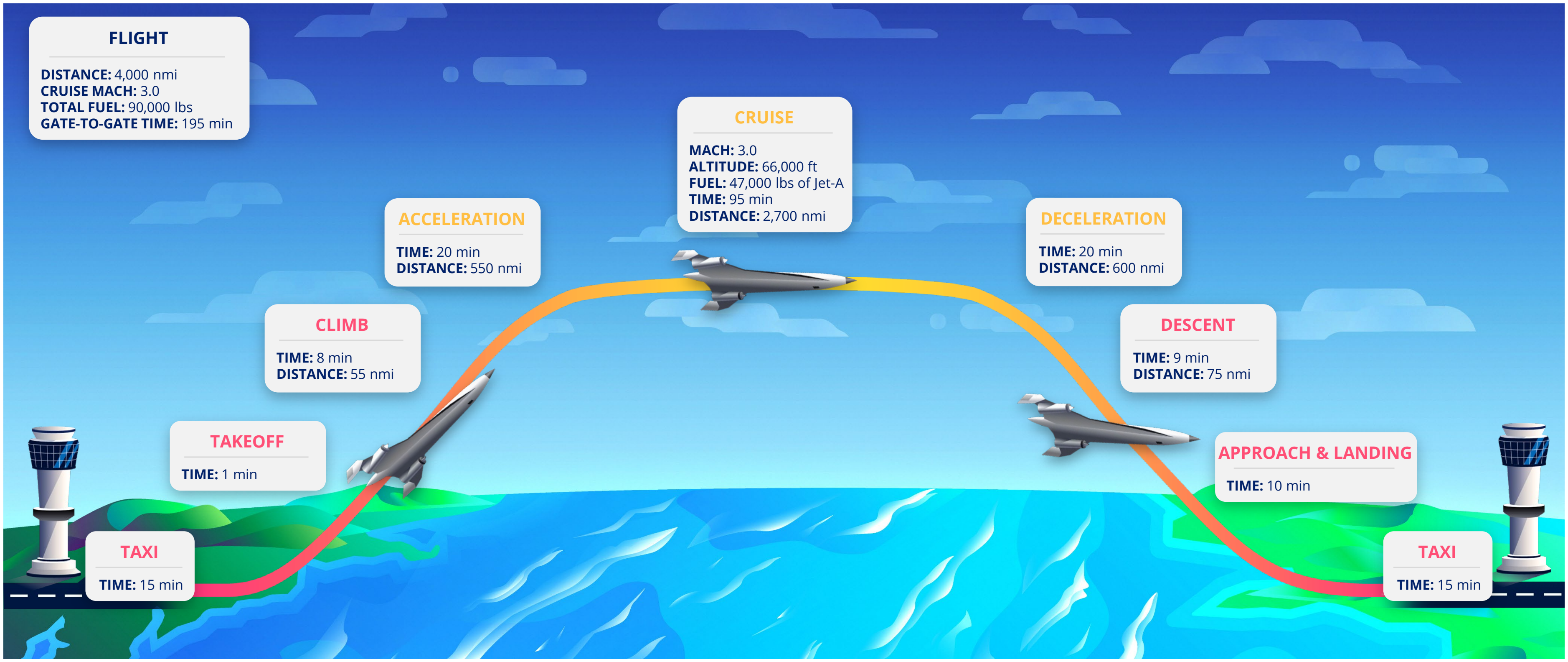


[2] Marcus, L.; Way, D.; Medlin, M.; Sakai, T.; McIntire, J.; and Olds, J.; "Technology Assessment for Manned Mars Exploration Using a ROSETTA Model of a Bimodal Nuclear Thermal Rocket (BNTR)," AIAA 2001-4623, AIAA Space 2001 Conference and Exposition, Albuquerque, NM, August 2001.

FIGURE 2.2

ROSETTA Model Nine-Segment Concept of Operations Model Overview

The nine-segment model is used to estimate flight times and required propellant fractions to service identified routes and operational models.



Note: The graphic above is representative of the model. Factors such as Mach number, range, and distance were unique to each scenario and operational use case run through the model.

FIGURE 2.3a

Historical Supersonic Aircraft Data

Historical production and operational data for supersonic aircraft was used to anchor the ROSETTA model

Concorde

Range	3,900 nmi
Max Speed	Mach 2.04
Capacity	92 - 120
Unit Price*	$170M
First Flight	1969
Operating Empty Weight (OEW)	173,500 lb
Max Takeoff Weight (MTOW)	408,000 lb

Tu 144 "Concordski"

Range	3,500 nmi
Max Speed	Mach 2.15
Capacity	140
Unit Price	Unknown
First Flight	1968
Operating Empty Weight (OEW)	218,700 lb
Max Takeoff Weight (MTOW)	456,400 lb

High Speed Civil Transport (HSCT)

Range	5,000 nmi
Max Speed	Mach 2.4
Capacity	300
Unit Price	-
First Flight	-
Operating Empty Weight (OEW)	302,000 lb
Max Takeoff Weight (MTOW)	753,000 lb

Boeing 2707

Range	3,500 nmi
Max Speed	Mach 2.7
Capacity	277 - 300
Unit Price*	$340M
First Flight	-
Operating Empty Weight (OEW)	287,500 lb
Max Takeoff Weight (MTOW)	675,000 lb

Lockheed L-2000

Range	4,000 nmi
Max Speed	Mach 3.0
Capacity	273
Unit Price	-
First Flight	-
Operating Empty Weight (OEW)	238,000 lb
Max Takeoff Weight (MTOW)	590,000 lb

SR-71

Range	2,800 nmi
Max Speed	Mach 3.32
Capacity	2
Unit Price*	$280M
First Flight	1964
Operating Empty Weight (OEW)	67,500 lb
Max Takeoff Weight (MTOW)	172,000 lb

*Adjusted to FY21 dollars

FIGURE 2.3b

Proposed Supersonic and Hypersonic Aircraft Data

Assumed production and operational data for proposed supersonic and hypersonic aircraft was used to anchor the ROSETTA model

Aerion Supersonic AS2

Range	5,000 nmi
Max Speed	Mach 1.4
Capacity	8 - 12
Unit Price	$120M
First Flight	2023
Operating Empty Weight (OEW)	50,000 lb
Max Takeoff Weight (MTOW)	115,000 lb

Spike Aerospace S-512

Range	6,000 nmi
Max Speed	Mach 1.6
Capacity	12 - 18
Unit Price	$100M
First Flight	2021
Operating Empty Weight (OEW)	47,300 lb
Max Takeoff Weight (MTOW)	115,000 lb

Boom Technology Overture

Range	4,500 nmi
Max Speed	Mach 2.2
Capacity	55 - 75
Unit Price	$200M
Demo Flight	2025
Operating Empty Weight (OEW)	Unknown
Max Takeoff Weight (MTOW)	170,000 lb

Virgin Galactic N2000VG

Range	4,000+ nmi
Max Speed	Mach 3.0
Capacity	9 - 19
Unit Price	Unknown
First Flight	Unknown
Operating Empty Weight (OEW)	Unknown
Max Takeoff Weight (MTOW)	Unknown

HyperMach SonicStar

Range	6,500 nmi
Max Speed	Mach 4.5
Capacity	32
Unit Price	$180M
First Flight	2022
Operating Empty Weight (OEW)	Unknown
Max Takeoff Weight (MTOW)	Unknown

Hermeus

Range	4,000 nmi
Max Speed	Mach 5.0
Capacity	20
Unit Price	Unknown
Demo Flight	2023
Operating Empty Weight (OEW)	Unknown
Max Takeoff Weight (MTOW)	Unknown

The Type II ROSETTA models include both technical convergence modules as well as cost and economics modules. The SpaceWorks P2P ROSETTA first “sizes” a candidate aircraft to meet mission requirements using preliminary mass estimating relationships, Mach-dependent estimates of aircraft aerodynamic and propulsion performance, and mission requirements such as range and altitude (Figure 2.1).

Leveraging Historical Data

For aircraft closure, the model used a set of preliminary mass-estimating relationships for major aircraft dry weight components including fuselage, wings, tails, landing, gear, crew systems, power, avionics, passenger cabin, thermal protection systems, engines, propellant tankage, pressurization, and propellant reserves and residuals. The model was anchored to a set of historical reference vehicles for which propellant, empty mass, and max takeoff mass data was available or could be easily estimated (Figure 2.4).

The ROSETTA Model is used as a broad parametric tool for estimating supersonic and hypersonic aircraft size, non-recurring development costs, and production costs within a range of cruise target Mach numbers (Mach 2 to 6), unrefueled one-way mission range (3000 nmi – 7500 nmi) and standard configuration passenger loads (20 – 250). It is meant to produce approximate data points across the design space, but it cannot represent all the technology decisions that a full program development team might make to optimize the performance of a particular aircraft. The model was typically within +/- 20% of the empty and max takeoff weight targets from the validation dataset (Figure 2.4).

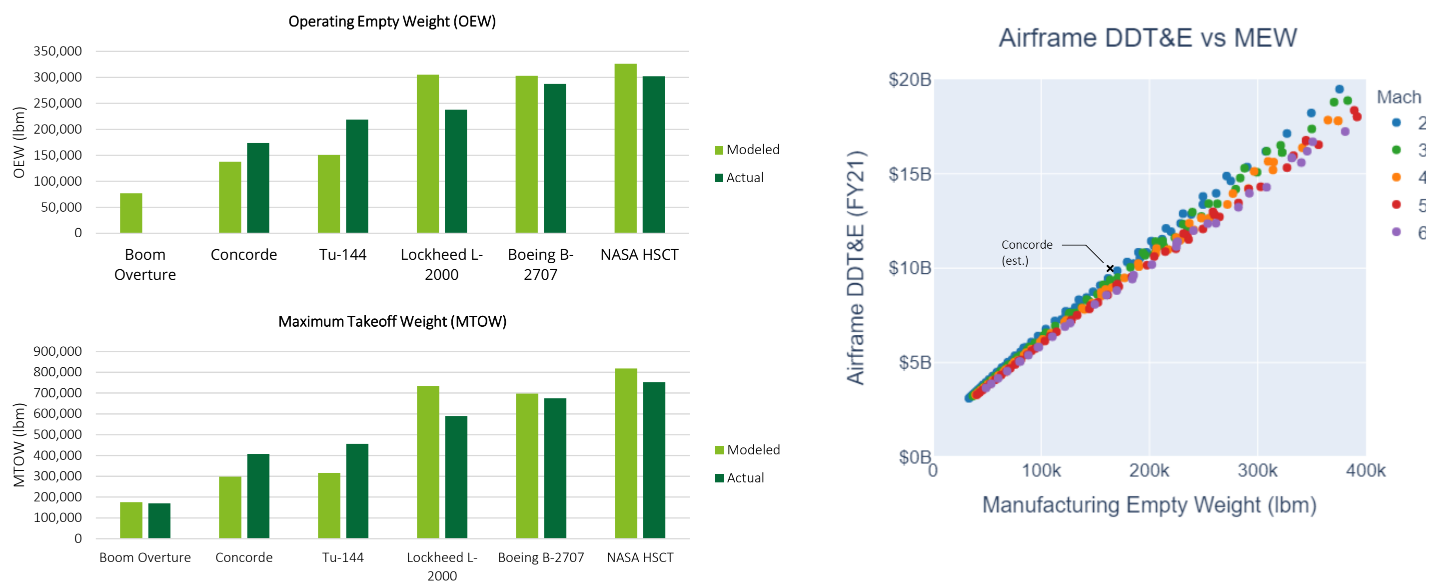
Galorath SEER software was used to estimate the non-recurring costs (development costs, including prototyping and certification aircraft) as well as the Theoretical First Unit (TFU) costs for the airframe (without engines) for a series of aircraft across the trade space. These datapoints were then fit with polynomial response surface equations and added to the cost module of the P2P ROSETTA Model. All cost numbers are reported in FY21 USD.

For aircraft propulsion, we assume that future aircraft up to Mach 3 will use standard non-afterburning turbojet/turbofan engines operating on Jet-A fuel. Aircraft with a cruise capability between Mach 3 and Mach 5 are assumed to use co-annular turbo-ramjets with Jet-A or similar hydrocarbon fuel. Aircraft with a cruise capability above Mach 5 are assumed to use an over/under turbine-based combined cycle (TBCC) engine. The turbojets on these TBCC configurations use Jet-A or a similar hydrocarbon. The dual-mode ramjet/scramjet modules are assumed to consume liquified natural gas (LNG).

Higher Mach aircraft have higher empty weights for the same design range and passenger count.

FIGURE 2.4; See appendix table A-2.1

Sample of our ROSETTA Model Predictions vs. Validation Data.



Sizing model is typically within ±20% of anchor points.

Higher Mach aircraft have higher empty weights for the same design range and passenger count.

Assumptions & Processes Driving the ROSETTA Model Analysis

The SpaceWorks P2P ROSETTA Model intakes several variables to produce estimates of key aspects of high-speed aircraft. The assumptions outlined in this section drive outputs such as sideline takeoff (airport) noise produced, sonic boom overpressure at cruise altitudes, emissions (pollutants and greenhouse gasses), and balanced field lengths at sea-level and altitude (runway requirements). Figure 2.5 displays an example of the outputs from the model as they relate to landing & takeoff noise.

The P2P ROSETTA Model uses aircraft propellant utilization, and data from the market elasticity analysis. Our parametric estimates of aircraft non-recurring development costs, and our parametric estimates of aircraft manufacturing costs to create three different cash flow business models. Year-by-year cash flow business models are created for the elite airline, the airframe manufacturer, and the engine manufacturer. Annual cash flow data for each of these three players in the high-speed P2P economy can be used to estimate that business's life-cycle cost, total revenue, discounted cash flow, net present value (NPV, at a user-specified discount rate), and the overall internal rate of return (IRR) of the business. We use IRR as a mathematical metric related to annualized return on investment. We consider IRR > 25% to be a threshold for program success in this industry. Our model considers a 30-year timeframe starting from 2024. The overall model always starts with the engine manufacturer, then the airframe manufacturer, and finally the elite airline operator.

Each one of the three players in the economy is given an independent variable that is key to their economic performance. The engine manufacturer has a unit sales price for their engines. The airframer is assumed to buy engines from the engine manufacturer. The engine manufacturer also supplies spares and replacement engines to the industry.

The airframe manufacture establishes a sales price for the integrated aircraft. This establishes the purchasing costs for the elite airline operator as well as private owners, the US Government, and charter/fractional-owner operators who may also wish to buy airplanes according to an equation based on its sales price.

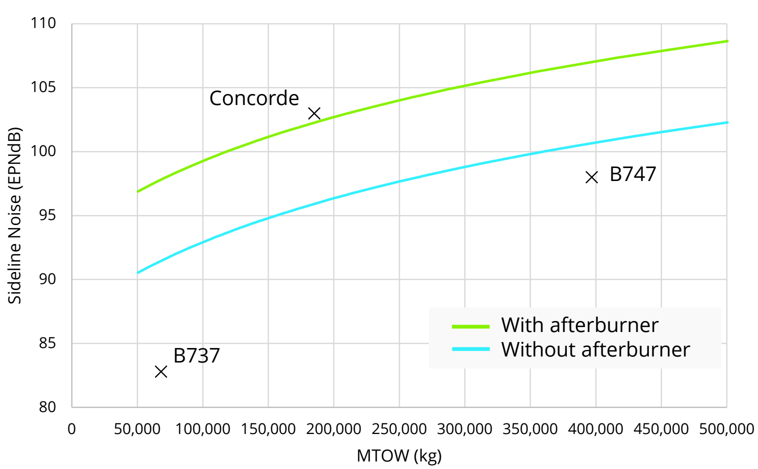
Lastly, the elite airline operator can establish ticket prices for each route (scaled from a single "reference ticket" price for a one-way trip between JFK and LHR). Longer distance routes are scaled upward from this reference price.

The ticket price and market data establish demand and therefore potential revenue for the elite airline operator. As a baseline, we assumed that the addressable passenger market sizes along each of our candidate routes increases annually according to a historically derived FAA projection of 0.94% per year. To account for the effect of the COVID-19 pandemic, we have assumed that airline traffic models will return to 2019 level by 2024. Initial operations depend on engine and airframe development and certification times, which are Mach number

FIGURE 2.5; See appendix Figures A-2.1 and A-2.2

Estimates of Sideline Takeoff Noise vs. Supersonic/Hypersonic Aircraft Size.

Takeoff Lateral Noise vs Maximum Takeoff Weight (MTOW); Sideline at 450 m distance



SpaceWorks ROSETTA model assumes no afterburner

Common Noise Levels (dB)	
Normal breathing	10
Ticking watch	20
Soft whisper	30
Normal conversation	60
City traffic (inside a car)	85
Motorcycle	95
Car horn from 16 ft	100
Maximum personal device volume	110
Standing beside/near sirens	120
Firecrackers	140

dependent. Depending on the case, the major airlines might enter commercial service somewhere between 2030 and 2035.

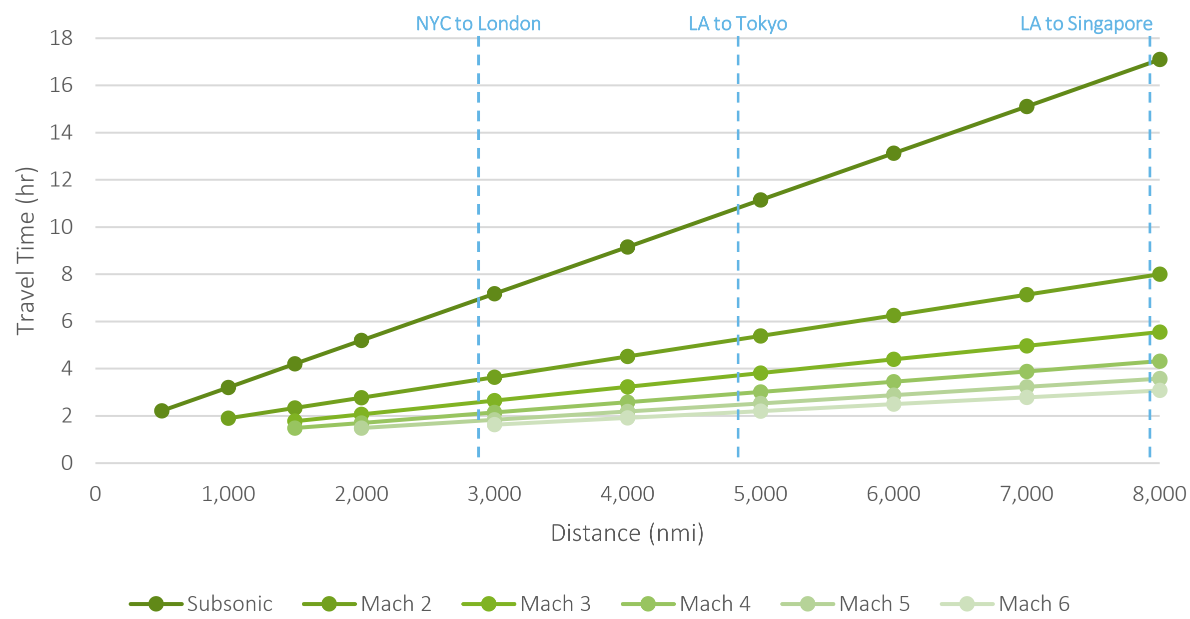
We start our process in the P2P ROSETTA Model by defining a candidate aircraft to model. For a given aircraft characterized by 1) cruise Mach, 2) standard-layout cabin passenger count, and 3) one-way unrefueled range, the three revenue variables in the ROSETTA are used to optimize financial performance for the three businesses in the high-speed flight economy. As a basic assumption, we determine that each of the three players must have a favorable IRR in their own businesses for this economy to be successful. The engine manufacturer cannot simply raise the price of its engines because of the increased cost burden on the airframer and thus the elite airline operator. Similarly, the elite airline operator cannot simply raise ticket prices to increase its revenue since the market capture is inversely proportional to ticket prices.

Since the ROSETTA model itself contains many non-linear and discontinuous equations (e.g. minimum passenger load factors for each route, active routes vs design range, step changes in propulsion and thermal technologies, and the number of engines per airframe), we used a Genetic Algorithm (GA) optimizer for each candidate aircraft to optimize the three price variables, subject to the constraint that all three business cases must produce a similar IRR for their investors. The objective of the optimizer is to select those prices that maximize the major airline IRR while keeping the engine and airframe manufactures near that same IRR. If all three IRRS are above 25%, we consider that to be a successful case for that aircraft configuration.

We use sufficient bit resolution and population settings in our internal GA optimization process to capture effects down to the $10’s of dollars in the internal ticket price variable and $1000’s of dollars in the engine and airframe prices. Our research team member employed clusters of multiple PCs simultaneously to

FIGURE 2.6; See appendix table A-2.2

Estimates of Gate-to-Gate Travel Times for High-speed Aircraft as a Function of Range and Maximum Cruise Mach Number.



conduct sweeps of the aircraft configuration trade space to understand the impacts of cruise Mach, passenger count, and aircraft range on the business cases. Over the course of the study, we examined over 500 specific points in the aircraft trade space. We also used the P2P ROSETTA Model to conduct several sensitivity analyses to our assumptions. These sensitivity analyses or trade studies helped yield additional insight from this study.

Above Mach 3, we observe a rapid decline in marginal time savings at each level of Mach speed, which supports the relatively greater time savings of high-speed aircraft in the range of Mach 1-3, as compared with speeds above Mach 3.

Analyzing the Business Case

What are the optimal airframe configurations and variables that will create an economically viable business case?

Flight Time Savings

The results of the gate-to-gate travel time analysis are summarized in Figure 2.6. The chart indicates a significant reduction of travel time when moving from subsonic travel (Mach 0.85) to Mach 2. While faster travel speeds continue to have decreasing effects on gate-to-gate travel times, the impacts above Mach 4 produce ever smaller gate-to-gate advantages due to fixed taxi times, takeoff and departure models with limited allowable accelerations, and shorter times at maximum cruise velocity.

We often observe that the Earth is simply not big enough to realize significant advantages from hypersonic commercial flight. Longer ranges would be necessary to truly realize measurable time savings at the highest Mach numbers in our study.

IRR Projections

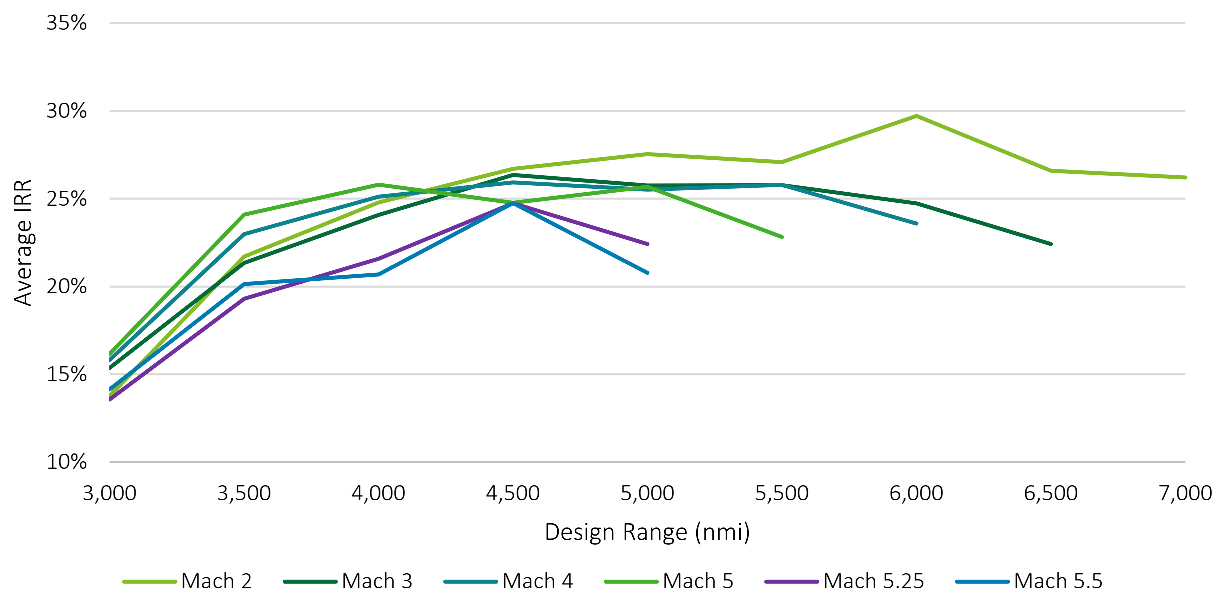
The data from the market analysis was originally collected as price elasticity curves as a function of travel time savings (traffic volume vs. ticket price for different time savings on three representative routes). For the P2P ROSETTA Model, we translated the time savings curves into cruise Mach number curves. The spread in the price elasticity curves was therefore minimal between Mach 4 and Mach 5, for example, because of the marginal gate-to-gate time savings for most routes.

For this section of our report, we present a few selected samples of the overall dataset for the purposes of discussing major findings.

FIGURE 2.7; See appendix table A-2.3

Typical ROSETTA Model Result for Business Case IRR Analysis

Typical ROSETTA Model Result for Business Case IRR vs. Aircraft Range showing Isolines of Maximum Cruise Mach Number (50 Passenger Aircraft Case).



Our most general finding is represented in Figure 2.7 (a 50-passenger aircraft example). Recall Internal Rate of Return (IRR) is the overall objective function in our analyses. Our model reveals that there are multiple aircraft configurations and market approaches that result in positive business cases for their manufacturers and operators (assumed as IRR > 25% across all three business models). In Figure 2.7, we see a "sweet spot" for ranges above 4,000 nmi and below 6,000 nmi for several different design speeds. Aircraft designed below 3,500 nmi range do not typically capture a large enough market. Other than the Mach 2 case shown, high speed aircraft tended to grow exponentially large in our sizing module until they were technically infeasible at some range in our trade space. For example, the 50 passenger Mach 3 aircraft was not technically feasible with our assumptions at or above the 7,000 nmi range point.

Regarding maximum design Mach number, this was ultimately a technology-related variable that determined fuel consumption, structural and thermal protection system masses, development costs, and production costs. The basic tradeoff is one of larger market demand with higher speed, but with more fuel costs and acquisition costs at higher speed. There is a clear tradeoff between these two impacts. Our model reveals that the Mach 4 and Mach 5 turboramjet cases do well economically until the range increases above 4,000 nmi and the aircraft becomes too large and expensive. The Mach 2 and Mach 3 aircraft lose early, but they tend to perform better at longer ranges. For the 50-passenger case shown in Figure 2.7, the Mach 2 turbojet/turbofan aircraft has the highest overall IRR in the trade space at nearly 30% for the 6,000 nmi range. The Mach 5+ TBCC-powered aircraft were consistently dominated by slower speed aircraft due to their higher development and production costs, and the marginal market advantage in speed above Mach 4 or 5.

Two notes on these results are worth additional discussion. First, the P2P ROSETTA model contains a number of discontinuities, "if-statements", technology step functions, discrete engine counts between 2 and 4 engines, number of addressable city-pairs as a function of range, and daily flights along various routes as a step function of minimum passenger load factors and passenger ticket price. The results of our localized IRR optimizations are therefore not smooth lines when plotted on isolines of maximum Mach at each of the discrete points we chose for aircraft range in this sweep. The connecting line segments we have provided appear choppy. The trends presented are generally correct along each connecting line segment in the plot, but the resolution of our sweeps may not capture a particularly advantageous point in the multi-variable space. Expert designers will likely refine their technical concepts and business models to optimize economic performance in their chosen area of the design space.

Second, our current P2P ROSETTA Model allows for only a single aircraft configuration to be simulated in the model at a time. The P2P ROSETTA Model does not allow for mixed fleet operations. For example, an aircraft designed to fly a range of 7,000 nmi will also be used to capture all the shorter routes in the network model. While fuel can be offloaded on the shorter routes, that aircraft is typically oversized for shorter routes compared to an aircraft designed precisely for that range. The one-size-fits-all assumption benefits the engine and airframe manufacturers in the model through larger production runs and enables them to realize lower average production costs due to learning curve effects. However, the major airline operator usually suffers a cost penalty for flying a large jet designed for trans-Pacific range along its north Atlantic routes. Operating two aircraft types in an airline fleet might produce higher overall IRRs if the second is a simple derivative of the first, but we did not explore that option in this study.

Range and Design Range implications

Figure 2.8 shows three supporting plots that highlight a few of the internal variables that the P2P ROSETTA Model produces as a result of its internal three-variable price optimization at each point in the trade space (50 passenger case shown). Recall that Reference Ticket Price (JFK to LHR in FY$21) is the price that a passenger would pay to a one-way trip from JFK to LHR on a plane that was designed for the indicated design range in the topmost plot and flying all routes addressable with that design range. We observe that the JFK-LHR passenger must pay more to fly that route on a longer-range, overdesigned aircraft. A passenger's true ticket price when using that aircraft to fly longer ranges is a scaled price according to the scale factor plotted in Figure 2.9.

In Figure 2.8, we observe a peak in the captured passenger market for all aircraft, regardless of Mach number, near the 3,500 nmi design range. While the number of addressable passengers and overwater routes in our model increases with increasing aircraft design range (Figure 2.10), the competing effect of increasing ticket prices diminishes market capture to the point that the average number of yearly passengers who choose to fly on a high-speed airliner peaks at a design range of 3,500 nmi and decreases beyond that.

As annual revenue for an elite airline operator is proportional to the product of scaled ticket price and annual passengers, plus an assumed value for high-priority belly cargo revenue (baseline of 500 kg per flight at $100/kg), the peak IRR for all players is therefore does not necessarily occur at peak passenger capture. In most cases, peak IRR is attained between 5,000 – 6,000 nmi of design range. Lastly, from the view of the airframe manufacturer, total aircraft sold to the airline and private/charter/DoD markets is also shown in the lower plot.

FIGURE 2.8; See appendix table A-2.3

Key Factors Contribution to the Average Internal Rate of Return

Typical ROSETTA Model Internal Variable Results as a Function of Design Range and Maximum Cruise Mach Number (50 Passenger Aircraft Case).

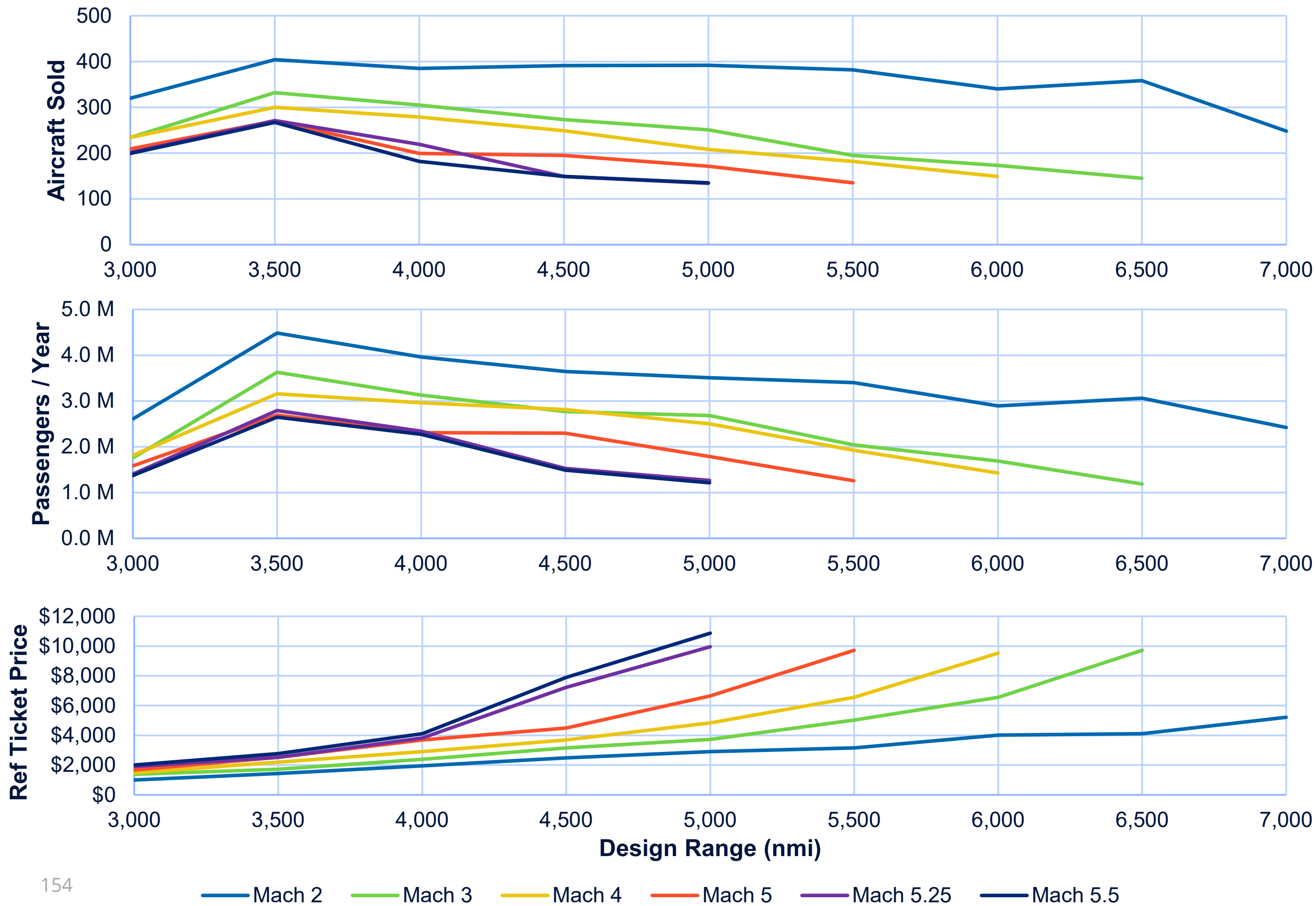


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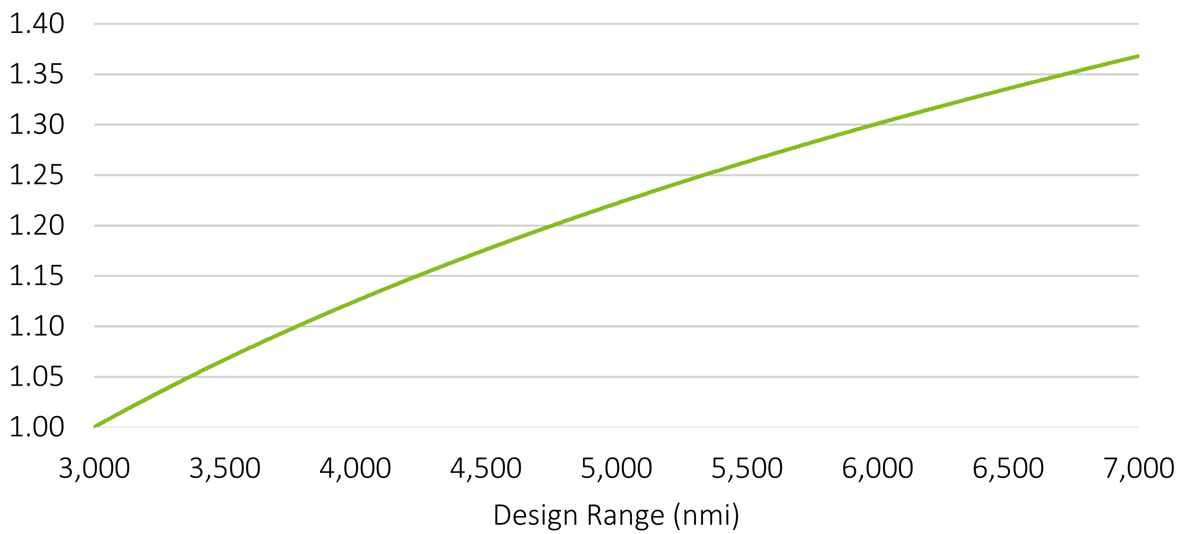
FIGURE 2.9

Ticket Price Scale Factor

Ticket Scale Factor as a Function of Actual Flight Range (True Ticket Price = Scale Factor * JFK-LHR Reference Ticket Price).



In general, longer-range aircraft strike a balance between capturing a larger market segment along the most prized north Atlantic routes, while keeping development and acquisition costs low enough to be economically competitive.

We observed one outlier case at 20 passengers, Mach 2, and 7,000 nmi range that resulted in the highest IRR in our entire grid search. It captures all but the longest range trans-Pacific markets and sells enough airframes (over 400) to keep aircraft prices just attractive enough for the private market (under $200M). This case does not deliver the most annual passengers in the market, but it strikes a balance between all the competing effects in the model to result in an IRR for all players above 32%. Still, a “safer” choice might be the 20 passenger, Mach 2, and 5,250 nmi range jet that results in a 30% IRR with more passengers and a lower ticket price.

Key Takeaways: Variables Influencing Business Cases

Ticket Price: Figure 2.10 leads us to make a broad conclusion that the Mach 2 aircraft produces business cases with lower ticket prices, larger market captures (annual passengers), and larger production runs for the manufactures. We consider this to be a more robust market compared to other alternatives. While higher Mach aircraft (up to Mach 5) also produce attractive business cases (Figure 2.8), they tend to cater to a smaller market segment of travelers willing to pay higher prices. They also sell fewer overall aircraft to the airline and private/charter/Government markets.

Aircraft Size: As part of the overall trade space exploration, our team investigated aircraft passenger sizes of 20, 50, 100, and 200 passengers. We conclude that smaller aircraft, in the range of 20 to 50 passengers, tended to perform economically better in our models (see Figure 2.11). Smaller aircraft tended to have higher passenger load factors, could support less populous routes, showed synergies with sales to the private/charter market, and resulted in higher airframe and engine production quantities. Individual passenger ticket prices are lower on larger aircraft (for the same range) and fewer daily flights were required from NYC to London on larger aircraft, but smaller aircraft remain our preferred option for a robust economic solution in this Mach range.

Route Distance: We consistently observe that an aircraft range of greater than 3,500 nmi is necessary to produce more attractive IRR results, but increasing that range to 4,000 nmi – 6,000 nmi results in the best cases.

FIGURE 2.10

P2P ROSETTA Model Addressable Market Capture Analysis

Addressable Market in both Routes (left) and Passengers (right) in the Current P2P ROSETTA Model as a Function of Aircraft Unrefueled Design Range (nmi).

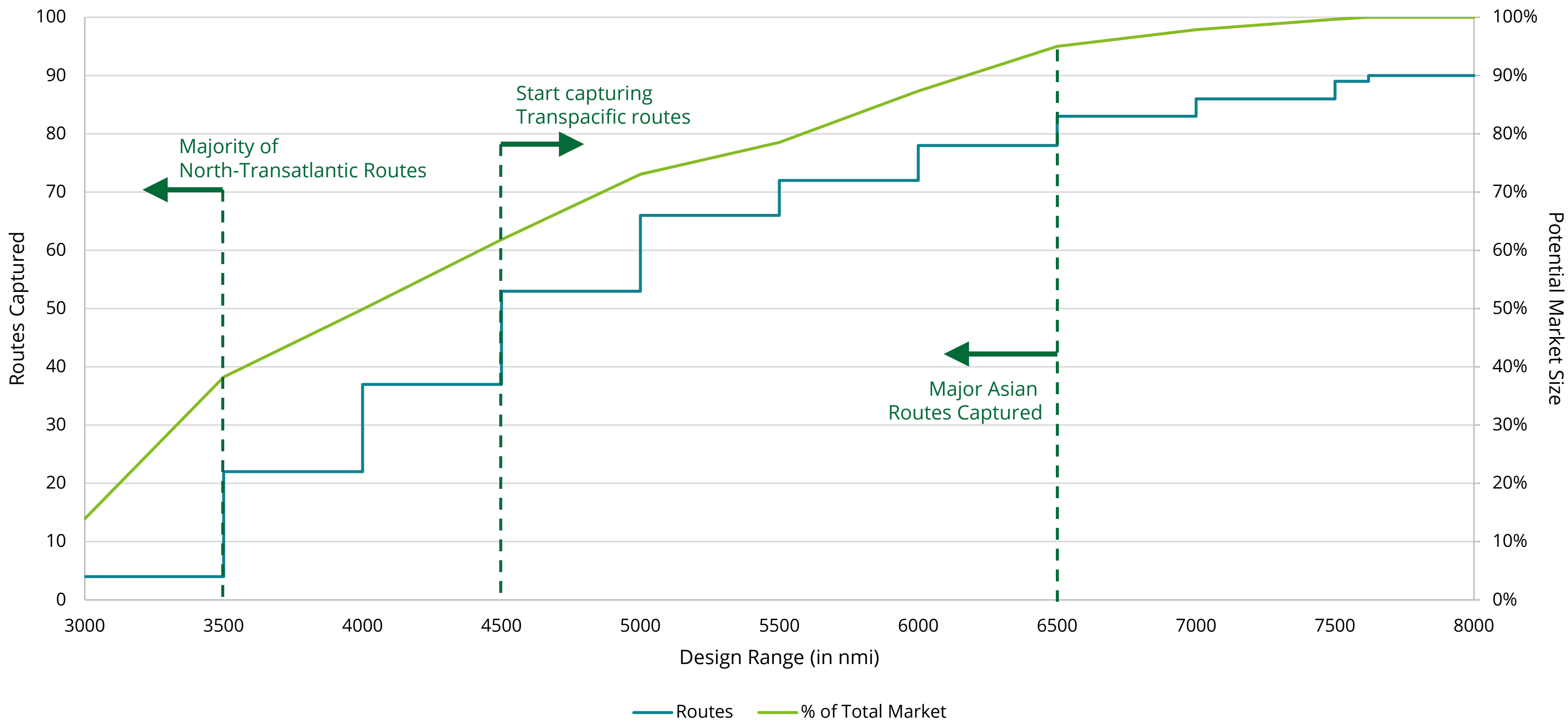
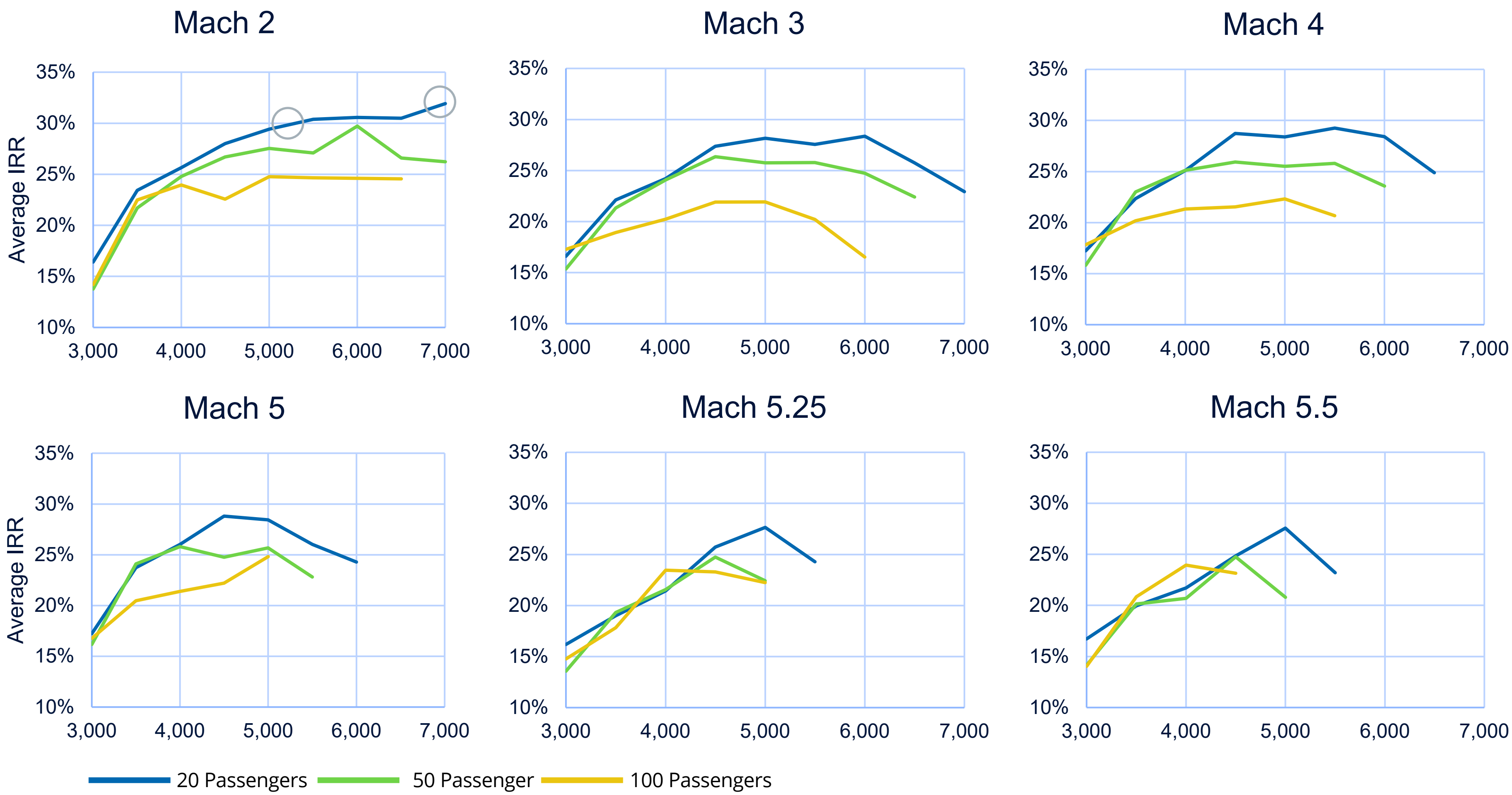


FIGURE 2.11

Aircraft Size (Passenger Count) as a Primary Driver for Internal Rate of Return

Summary Plots of IRR vs. Aircraft Range (in nmi) for Various Passenger Counts and Maximum Cruise Mach Numbers



Cash Flow Projections

While IRR was our primary economic objective function, IRR alone does not tell the whole story of the business case. Depending on cash/finances available, business operators may prefer one choice or another. Figure 2.12 shows the cash flow diagram from our P2P ROSETTA Model for an airframe manufacturer producing a Mach 2, 20 passenger, range 5,000 nmi jet. This business results in an IRR of 29.37% with a net undiscounted revenue of $74B (FY21$). The business' maximum exposure (worst cumulative cash flow) is -$0.93B.

By comparison, Figure 2.13 shows the cash flow of an airframe manufacturer producing a Mach 5, 100 passenger, range 4,500 nmi jet. This business model results in an IRR of 21.49%. However, its undiscounted revenue is $132.4B – nearly 80% more than the prior case. For a large-scale airframe manufacturer, this might be a preferred business despite the requirement of a maximum exposure of -$8.3B. The caution here is that IRR is an important indicator of annualized return, but in some cases gross revenue or even net present value (NPV) might be a more important metric to certain businesses.

FIGURE 2.12

ROSETTA Model Airline Manufacturer Business Model Cash Flow Analysis

Sample cash flow result for a 20 passenger, Mach 2, 5,000 nmi range airframe manufacturer

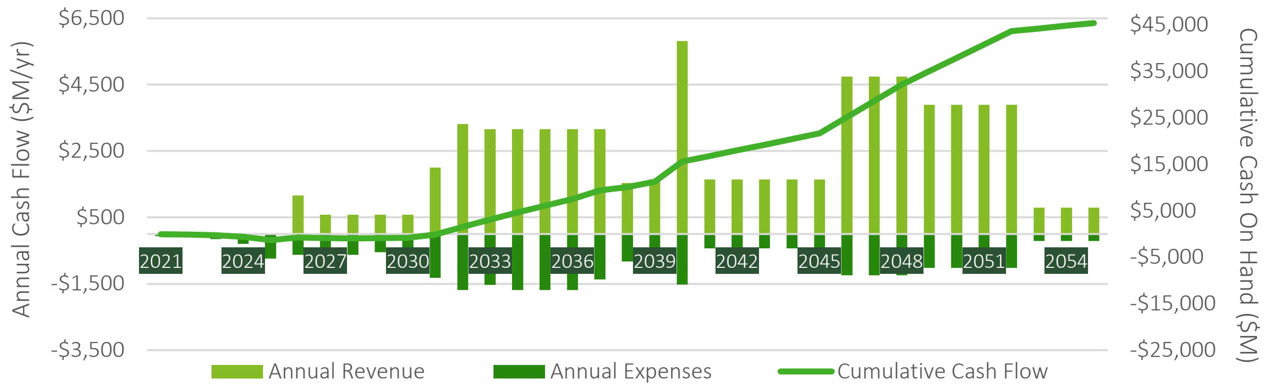
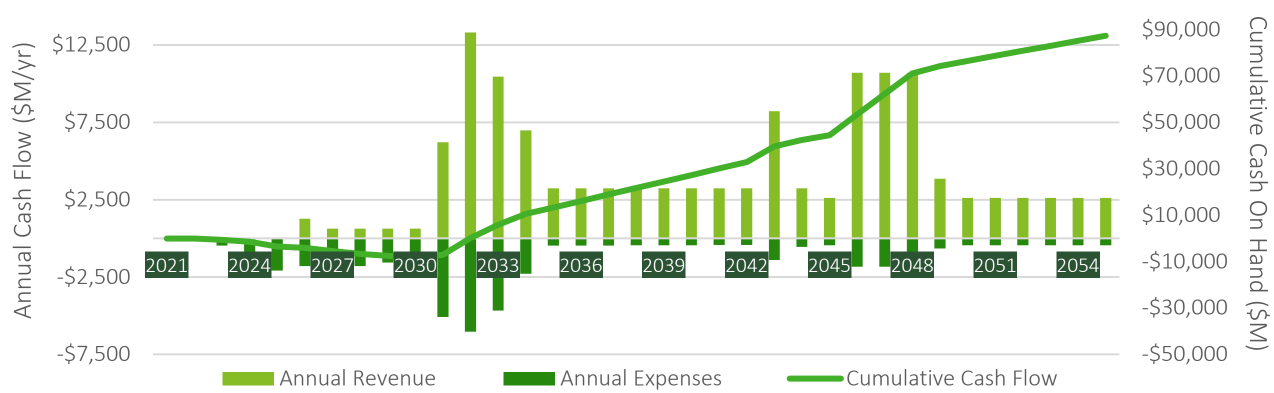


FIGURE 2.13

ROSETTA Model Airline Manufacturer Business Model Cash Flow Analysis

Sample cash flow result for a 50 Passenger, Mach 5, 5,000 nmi range airframe manufacturer



Business Case Factors Sensitivity

If specific factors change, how will that affect the viability of high-speed airframe production business cases?

Key Variables Impacting IRR

Our team conducted six trade studies to explore the sensitivities to some of our key assumptions. Those results are summarized in Figure 2.14 for a 50 passenger, Mach 3, range 5,000 nmi jet. Results are similar for other aircraft in the preferred parts of the trade space except as noted below.

In Figure 2.14, the baseline assumptions in the model is shown in the leftmost column. Each sensitivity study was performed by perturbing one variable at a time and are shown in the Figure as "bundles" of bars for each sensitivity scenario. For example, the size of government investment/subsidy early in the development of high-speed systems does not drive successful outcomes. In all cases, expected IRR (profit) to be greater than 25% and less than 30% for ranges of government investment ranging from $0 (baseline) -$1B.

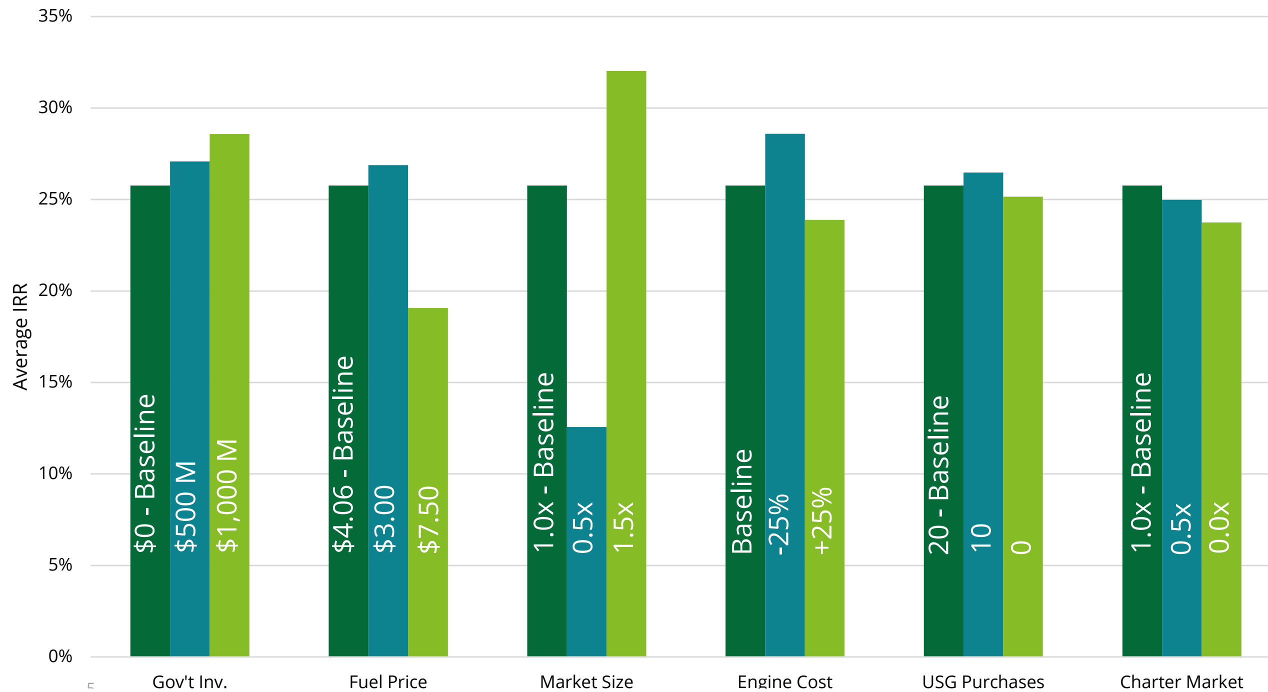
The business cases are most sensitive to changes in market size. If the number of passengers willing to pay the needed ticket prices flying is only half of what our price elasticity research indicated, expected IRR would be reduced by approximately 50% into a range that would significantly less attractive to the investment community which would be vital to the development of new systems.

Fuel costs ($/gal of Jet-A or similar hydrocarbon fuel) is also a key impact on the market economics. Our underlying

FIGURE 2.14; See appendix table A-2.4

Overview of ROSETTA Model Sensitivities for Key Assumptions

Trade study outputs for a 50 passenger Mach 3 aircraft with a range of 5000 nmi.



assumption was based on recent national averages for Jet-A in the United States ($4.06/gal). Should Jet-A prices return to a higher historical number like $7.50/gal, an economically unattractive business model would result. Figure 2.15 shows the squeezing effect on annualized profit as fuel costs increase for this business model.

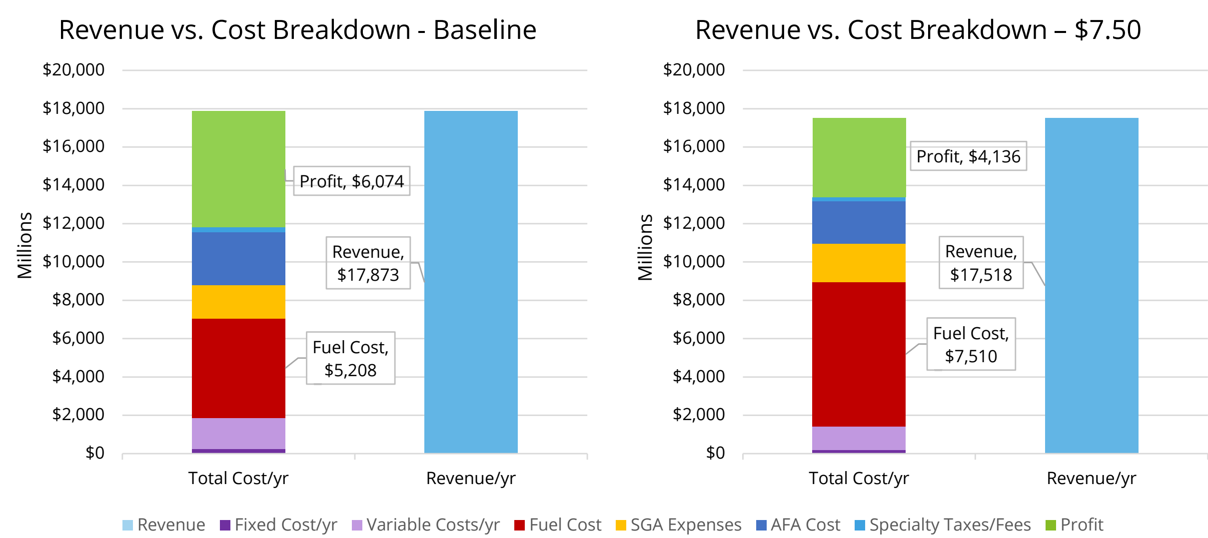
On Figure 2.14, our team considered the impact on U.S. government support of this market. Our baseline assumes no government contributions in the form of government grants, use of facilities, use of civil servant engineering services, computing facilities, technology sharing, etc.). However, if $500M or $1B of upfront government contribution were provided to the two manufacturers, split evenly between the engine and airframe manufacturers, the overall business case IRR for all three players in the market will improve accordingly.

Alternately, we examine the sensitivity to our baseline assumption that the U.S. Government will provide an anchor buy of the first 20 jets off the assembly line. We have assumed these jets might be used for DoD or U.S. State Department or Executive transport needs while also providing a minimum market demand for high-speed aircraft manufacturers. Figure 2.14 shows the impact of the effect of reducing this anchor buy assumption to 10 or even zero aircraft. For the reference aircraft with a large production run shown, the effect is rather minimal as those aircraft could otherwise be used to improve the market entry date for commercial operators. At other points in the trade space, however, we observed a more detrimental impact of this sensitivity on Mach 4 or 5 aircraft since the anchor buy aircraft provide a more significant portion of their overall production runs. In the “sweet spot” of our recommended aircraft size, speed, and range, we conclude that U.S. Government is helpful to the business models of all three players, but it is not a requirement for success.

FIGURE 2.15; See appendix table A-2.5

Impact of Fuel Costs on the Business Case for Airline Operators

Fuel Costs as a Percentage of Annualized Elite Airline Operator Costs at $4.06/gal (left) and $7.50/gal (right).



The sensitivity of fuel price on Profit was explored and the results shown in Figure 2.15. The figure assumes ticket prices stay the same and the increase in fuels costs decrease total profit realized by the operator. For clarity, Revenue is the total sales received through the sale of tickets to passengers which must cover all costs and profits. Fixed costs account for costs that are not scalable with sales such as leases at airport locations, while variable costs account for cost elements that scale with sales and service (exclusive of fuel costs) such as labor costs. Sales, general, and administration (SGA) expenses accounts for the actual costs associated with sales and collection of tickets and the necessary marketing costs. Amortization of fixed assets (AFA) accounts to services loans and other obligations taken to acquire assets. As shown in the analysis, a 1.84x, or essentially a doubling of fuel price, decreases profit by 10.5%.

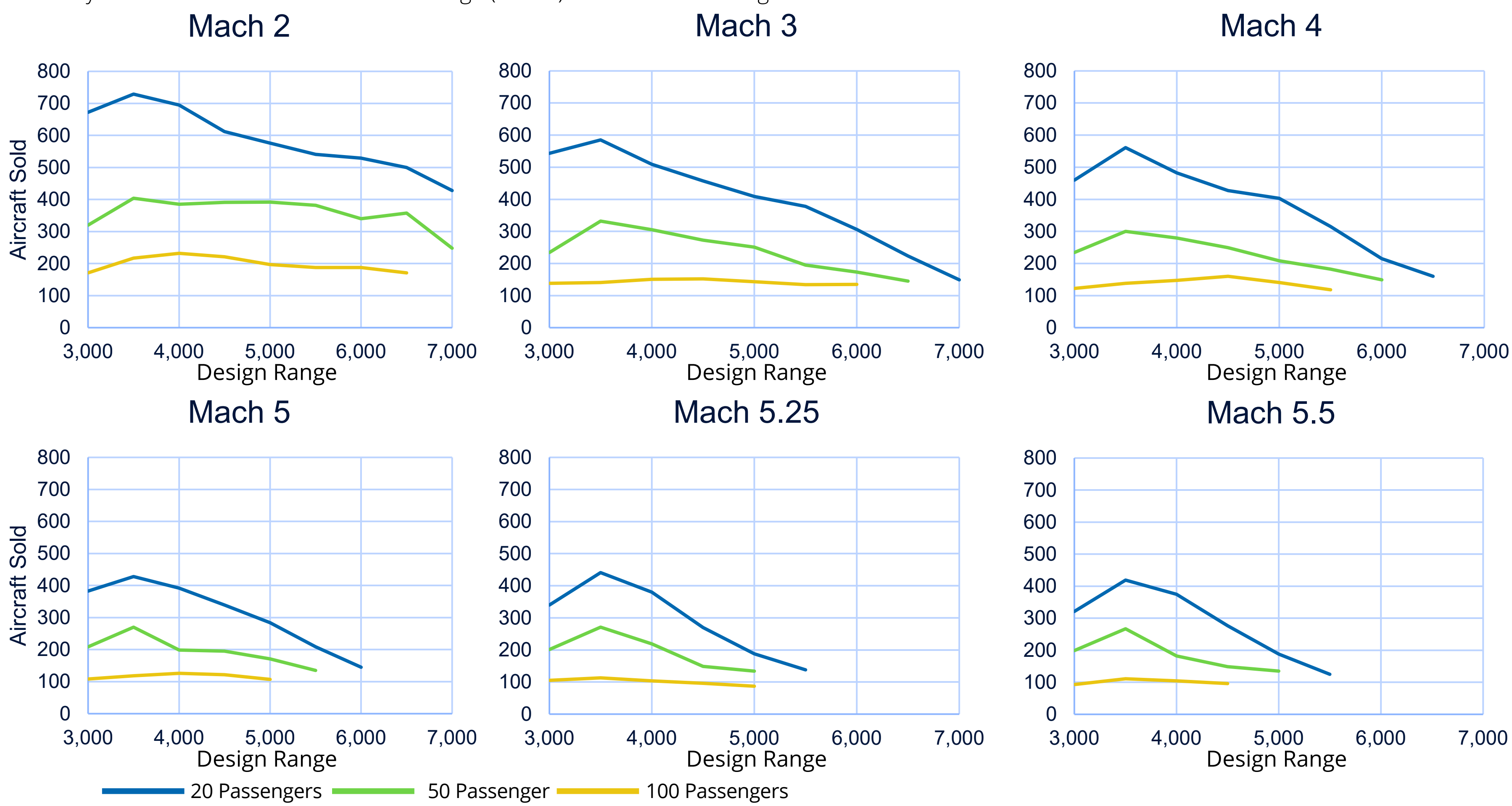
Trade studies on the private owner/charter market size and engine development costs were also conducted and presented in Figure 2.16 for this reference aircraft. We separately observed that the impact of private/charter market size is more pronounced for smaller and less expensive jets where the private/charter market can contribute more to total airframe and engine sales.

Our investigation of the engine development cost sensitivity highlighted the importance of this variable. It is among the first cash outlays in the entire high-speed aircraft economy and thus more significantly impacts IRR compared to outyear expenses. Separately, we observed a more significant sensitivity from this variable on more expensive TBCC engine cases relative to the straight turbojet/turbofan cases.

FIGURE 2.16

Cumulative Aircraft Sold as a Primary Driver for Internal Rate of Return

Summary Plots of Aircraft Sold vs. Aircraft Range (in nmi) for Various Passenger Counts and Maximum Cruise Mach Numbers



Key Takeaways

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 economic sense (producing IRR > 25%) although the benefit of additional speed is still marginal on most routes.

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

Aircraft sized for 20 – 50 passengers appear to strike the best balance between high passenger load factor, synergies with private/charter sales, and elite aircraft sales and still maintain reasonable passenger ticket prices.

What about ticket prices? Are they too expensive?

Many viable business cases result from ticket prices less than $3500 per direction (NYC to LHR reference ticket price). These are certainly more expensive than today's ticket prices (<2x first class service), but not unreasonable for the value expressed in time saved of high-speed passenger service.

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

Our analysis considered only 90 potential over-water routes for the elite airline operator. We found 4,000 nmi – 6,000 nmi design range to be a sweet spot in the trade space. This range captures about 50 valuable city-pairs in our network and 75% of the addressable passengers in our simulation. Aircraft designed for longer trans-pacific ranges could also do well in unique cases, but they tended to be oversized for the very high volume north Atlantic routes on average. Our analysis did not consider derivative or stretch airframes for more than one simultaneous aircraft configuration in the fleet. This might produce slightly better economic results across the network.

What are the key sensitivities to our assumptions?

Our results are very sensitive to passenger volume assumptions, but we have confidence in our research approach to characterize the future high-speed passenger travel market demand. Increases in future fuel costs and engine development costs remain concerns as well. Government contributions can help improve business case results, but they are not required for economic success.

Section 3

Identifying and Understanding Barriers to High-Speed Transportation

Barriers to High-Speed Air Transportation

What would prevent a viable market from emerging?

The third part of this study focuses on the barriers to high-speed air travel—that which could limit or prevent the development of this market. Using a structured methodology, this section starts with a considerations framework as a guide to enable the team to identify a set of challenges to the market. From those challenges, the team used a rubric to determine the relative strength of each in order to determine which of the 15 identified challenges rose to the level of market barrier and which challenges did not. In the end, the study determined the key barriers to high-speed air transportation are sonic boom regulations, aircraft certification requirements, and landing and takeoff noise requirements. What is common about these three barriers is that that all three of these barriers are rooted in regulatory compliance. Secondary to these barriers, the study also found two challenges that were significant: emissions standards and export controls. In general, the team found that challenges that had key regulatory compliance elements ranked higher as barriers that challenges rooted in engineering or socialization.

Our Approach

We developed a methodology to enable us to rank order barriers and impediments to the introduction and market adoption of high-speed aircraft. To accomplish this, we performed a detailed literature review and conducted primary interviews with experts from industry and academia, potential early adopters, government officials and regulatory experts. Finally, we developed a series of recommendations on how best to address challenges, impediments, and absolute barriers facing the high-speed transportation market.

Literature Review

To perform this analysis, the study started with a research and identification phase that began with a literature review to assess what existing documents tell us about the current market barriers. This began with researching publicly available industry literature including publications, corporate press releases and industry and think tank reports. This also included a deep dive into the existing and evolving regulations that apply to high-speed air travel. The study team looked at over 80 sources spanning seven key considerations in order to ensure comprehensiveness. This included regulatory/treaty, certification, weather, environment, export controls, infrastructure, and societal considerations. Sources reviewed were catalogued by the considerations that they were the most aligned to.

Stakeholder Interviews

The study continued with a series of first-hand interviews. Interviewees included representatives from emerging market entrants, federal government, legacy U.S. carrier airlines, logistics companies, legacy aerospace companies, trade associations, engine manufacturers, and environmental and regulatory policy experts. Underlying these interviews was the objective to understand industry experts and first-movers perception of the barriers to the high-speed air transportation market. The focus of these interviews evolved as the research developed: early interviews were of a more general nature whereas later interviews were about refining our findings and digging deeper into certain topics. Overall, these interviews were extremely successful lending a level of fidelity to our study that could never be obtained through desktop research alone. In total, we conducted 23 interviews across the various stakeholder categories.

The findings of the interviews and research were synthesized to understand that, based on the current market trends, what are the paths forward? This process involved synthesizing the challenges identified from the research and interviews and assessing each challenge in order to identify the barriers using a down-selection process.

Key Takeaways: Literature Review

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

Green solutions are top of mind. Environmental issues have recently risen to the forefront of public policy focus; the prospect of high-speed aircraft, as well as the emissions and noise implications of these vehicles, are major concerns for the public.

Regulatory challenges are beginning to be addressed. 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).

Barrier Identification Methodology

Identifying and assessing barriers began as a three-step down-selection process. As shown in Figure 3.1, the research team utilized a framework of broad considerations to guide conversations, interview questions, research, and analysis. This framework included 7 broad consideration areas: regulatory and treaty, certification, weather, environment, export, infrastructure, and societal considerations.

These considerations represent broad areas of concern to the high-speed air transportation market.

The interviews and research supported by the consideration's framework were used to identify challenges to the high-speed air transportation market. Ultimately, fifteen challenges were identified, including sonic boom restrictions, aircraft certification, landing and takeoff noise, emissions standards, export controls, depressurization events, alternative fuels, international laws, heat sensitivity, National Airspace System (NAS) integration, anomalous radiation, flight shaming, runway length, time zone gaps, and pilot certification. These challenges are described as follows:

FIGURE 3.1

Barrier Analysis Process

CONSIDERATIONS

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

*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.

*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 significantly inhibit market entry and prevent companies from operating.

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

Broad Consideration Definitions

Regulatory & Treaty: Regulations and treaties, or lack thereof, that create obstacles for international high-speed aircraft industry stakeholders.
Certification: Obscure, outdated, or missing industry guidelines on various aircraft certification standards and general training.
Weather: Impact of weather on high-speed air vehicles while taking off, en route, and/or landing such as atmospheric pressure, temperature, and inclement weather.
Environment: Impacts to the climate and communities from commercial high-speed air travel, such as noise and emissions, from supersonic flight over both land and sea
Export: Regulations and controls that would require compliance to enable both a domestic and international hypersonic market
Infrastructure: Major upgrades and overhauls to existing equipment and facilities that airports will need to support high-speed commercial flight.
Societal: Current events that pose challenges to high-speed air travel, as well as issues with international markets

1. Sonic Boom Restrictions

Flying Mach 1 or above creates a sonic boom that can be highly disruptive to communities within proximity to it. National governments including the United States have passed restrictions on the noise level that planes can omit, as well as their speed. For example, in the Unites States, law prohibits flight in excess of Mach 1 unless specifically authorized by the FAA.

2. Aircraft Certification

Existing FAA certification guidelines will apply to the engines and airframes of high-speed aircraft. Depending on how much these aircraft vary in technology from existing subsonic counterparts, the process could significantly impact the timeline for achieving commercial flight operations. Further, FAA and ICAO are reviewing current regulation to modernize standards for high-speed aircraft.

3. Landing and Takeoff Noise

High-speed aircraft historically produce significantly higher levels of engine noise as compared to subsonic aircraft. Further, high-speed aircraft have distinct sound signatures. Airports currently have noise limits in place to protect nearby communities. If high-speed aircraft are too loud, they may face fines or operational restrictions.

4. Emissions Standards

Aircraft contribute approximately 2% of total annual global carbon emissions and emit NOx, a key contributor to ozone depletion. These issues have pushed FAA and the EPA to pass industry-wide restrictions for aircraft fuel efficiency. Reports indicate that high-speed aircraft could be as much as 5X more pollutive than subsonic vehicles, which presents a challenge from a regulatory perspective.

5. Export Controls

High-speed aircraft technology has national security implications for supersonic and hypersonic capabilities. Companies will need to satisfy a broad range of applicable regulations, such as ITAR, EAR, and CFIUS. Navigating this environment will require effort on behalf of private stakeholders to ensure compliance, as well as public stakeholders to provide clear and actionable direction.

6. Depressurization Event

High-speed aircraft will cruise at ultra-high altitudes at 50,000-70,000 feet. The atmospheric pressure at high altitude offers insufficient oxygen for humans, which poses the risk of hypoxia. Further, at 62,000 feet, aircraft passengers and crew reach the Armstrong Limit, at which the boiling temperature for water is the same as the natural human body temperature. These issues may require more advanced cabin pressurization safety technology.

7. Alternative Fuels

Aircraft capable of traveling in the Mach 1-6 range may require different fuels from those that exist for current subsonic aircraft. Further, at higher Mach numbers, more exotic fuels are required, which could create additional unique infrastructure requirements on the ground to support fuel storage and refueling. This impacts the cost and availability of such fuels.

8. International Laws

Operating civil aircraft internationally involves accommodating a regulatory ecosystem beyond FAA's guidelines. As the primary international authority for civil aviation, ICAO sets standards across the civil aviation authorities of various nations. Understanding international operating standards and ensuring compliance will be critical to successfully opening the market.

9. Heat Sensitivity

High-speed aircraft typically fly in a unique operating environment of approximately 60,000 feet in altitude. While the aircraft are less subject to weather patterns at this altitude, cold atmospheric temperature combined with air friction at supersonic speed expands the airframe. high-speed aircraft will need to be capable of withstanding this environment.

10. NAS Integration

High-speed aircraft will operate at significantly higher speeds during their flight trajectory as compared to subsonic aircraft. Further, these aircraft, or the airports that host these aircraft, may require unique air traffic operations during landing and takeoff procedures that could disrupt sub-sonic airline operations. Both issues imply increased complexity to integration high-speed aircraft into the NAS.

11. Anomalous Radiation Events

High-speed aircraft will operate at significantly higher altitudes during their flight trajectory as compared to subsonic aircraft. As such, aircraft will be exposed to additional radiation in normal operations and may be subject to anomalous radiation due to solar flares or other unplanned events, which must be addressed for safe and continuous operations.

12. Flight Shaming

Recent public outcries over the accelerating impacts from climate change have prompted the public to re-evaluate preconceived social norms of leisure and business air travel. After a series of high-profile climate change action campaigns, public sentiment toward air travel is shifting toward a preference to minimize carbon footprints, leading to 'shaming' individuals flying on commercial or charter planes.

13. Runway Length

High-speed aircraft will adopt new airframes and technologies that could have unique runway length requirements. For example, the Concorde officially required a minimum runway length of approximately 11,800 feet. While most large airports have robust runways, local & private airports with shorter runways will likely face challenges hosting high-speed aircraft.

14. Time Zone Gaps

High-speed passenger transportation will likely have limited flight volume in its early stages. For long distance and trans-Atlantic routes, flight times between time zones could force consumers to depart and land at unusual times, such as in the early AM, or late PM, which could detract from ticket demand.

15. Pilot Certification

Current pilot education programs do not incorporate training for civil high-speed aircraft, yet these aircraft operate at significantly higher altitudes and involve different technologies from current jets. Airlines may need specialized pilots with training in high-speed commercial aircraft. This may require adjustments or additions to current pilot training curriculums.

Recognizing that not all challenges are equal in terms of negative impact on the market, the next step was to determine which of the challenges were potential barriers to the market. Each challenge was scored on a rubric from one to three on five parameters based on how constraining that parameter was to the business case: compliance, technology, investment, ease of use, and community. These scores were vetted by interviewees and senior advisors with substantial aerospace and aviation expertise.

Using the ranking system, the research team rated each challenge on each of the five parameters and then added the ratings together to estimate the magnitude of the challenge relative to one another. The team ranked the challenges and developed a heat map using the selection methodology (Figure 3.2), guided by the criteria set forth in the rubric (Figure 3.3). The outcomes of our scoring are shown in the Barriers Heat Map (Figure 3.4), for which the in-depth rationales can be found in appendix tables A-3.1-3.15.

FIGURE 3.2

Barrier Selection Methodology

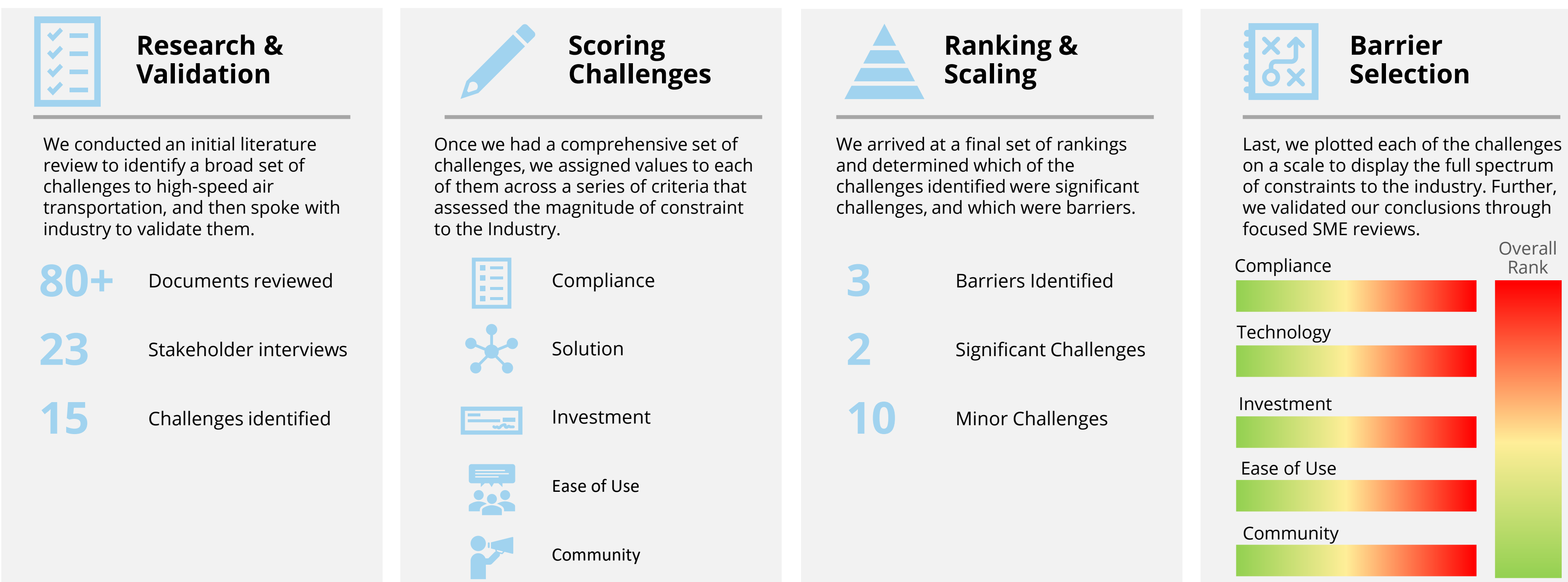


FIGURE 3.3

Scoring Criteria Rubric

To clearly define a challenge versus a barrier, we identified a set of criteria that allows us to appropriately categorize each issue.

	1 (least constraining)	2	3 (most constraining)
Compliance	The business is not constrained materially by existing compliance standards.	The business can still move forward if the compliance standards are partially satisfied.	The business can only move forward if the compliance standards are 100% satisfied.
Solution	The solution to the issue exists and is readily available to the market; no advancement (technological, regulatory, etc.) is necessary.	The solution to the issue is in development but still not yet resolved.	The solution to the issue is not in development yet.
Investment	The solution to the problem at hand will not require significant capital outlay.	The solution to the problem at hand will require moderate capital outlay.	The solution to the problem at hand will require significant capital outlay.
Ease of Use	Existing solutions that mitigate the problem can be integrated into a customer experience that is comparable to that of a subsonic commercial airline service.	Existing solutions are plug-and-play, with additional inconveniences to consumers that would not be overly burdensome compared to subsonic commercial airline services.	Existing solutions that mitigate the problem are not plug-and-play; would require significant additional effort or inconvenience relative to that of a subsonic commercial airline service.
Community	Minimal impact on local communities and/or of little concern to them.	Moderate impact on local communities or a subset of the community is significantly concerned.	Significant impact on communities; major concern for them.

FIGURE 3.4; *See appendix table A-3.1-3.15*

Barriers Heat Map

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

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.

Barriers Analysis

What are the most impactful barriers and how should we deal with them?

Using the methodology described above and associated heat map, the research team identified three challenges that were potential barriers to the high-speed air transportation market. The following three barriers; sonic boom restrictions, aircraft certification, and landing and takeoff noise limitations; are the challenges that the research team determined could drastically inhibit the high-speed air transportation market.

The following sections look at each of the three barriers in depth. These sections give an overview of each barrier, describe the key problem or issue at hand, and rationale for why this challenge is a barrier. These sections also take a deeper dive look at the policies and practices that contribute to the barrier as well as a path forward to potentially overcome the barrier.

Sonic Boom Restrictions

Sonic booms from high-speed aircraft can significantly disrupt fly-over communities. In response, leading regulatory bodies including FAA and ICAO have passed regulation restricting supersonic flight over land. This creates a significant constraint on potential routes where a high-speed aircraft service could operate.

Understanding the Problem

Current international regulatory bodies are either restrictive of high-speed flight or lack specificity:

Under 14 C.F.R. 91.87, the FAA restricts civil aircraft flight speeds above Mach 1 unless authorized by FAA. Likewise, ICAO Annex 16, Chapter 4 classification includes supersonic aircraft. ICAO states that these aircraft must adhere to Chapter 3 (subsonic) noise standards. ICAO standards and recommended practices (SARPS) are developed and widely adopted by most civil aviation authorities around the world. Realistically, all potentially viable high-speed air transportation routes are international, so it is critical to assess these barriers at both the federal and international levels.

ICAO and FAA are researching supersonic speed guidelines, but no final rules have yet emerged from these efforts.

Why Sonic Boom Restrictions are a Barrier

Sonic boom restrictions present the most significant barrier to the high-speed air transportation industry because they restrict supersonic flight. Further, FAA's guidelines restrict flight above Mach 1, implying that even if modern supersonic aircraft can operate above Mach 1 without producing a sonic boom, they are still restricted from such speeds. Therefore, until new or amended regulations are developed and finalized (which is a multi-year process), high-speed air service providers will be restricted in their operations.

Sonic Boom Restrictions: A Deeper Dive

Sonic boom restrictions for high-speed aircraft are vaguely defined at the international level, while domestic U.S. policy outright restricts supersonic flight. The lack of clear guidelines presents a major constraint for economically viable routes that involve significant over-land flight.

Regulation for civil aircraft traveling above Mach 1 is currently undefined at the international level, and both ICAO and FAA are revisiting this issue to develop specific standards for these types of aircraft.

ICAO currently does not have SARPs or other guidelines in place that address standards for high-speed civil aircraft; however, in recent years ICAO has directed its attention to establishing standards for the market as part of its cyclical reviews, which typically span several years at a time. ICAO's Committee of Aviation Environmental Protection is currently studying potential sonic boom standards and is expected to complete its study by 2022 (CAEP Cycle 12). ICAO is expected to establish some form of standard during CAEP Cycle 13 (2022-2025).

At the U.S. federal level, the FAA released a Notice of Proposed Rule Making in 2019 to clarify its procedure for companies to request an exception to the current law restricting above Mach 1 flight in the US; however, industry expects that FAA will not pass regulation addressing high-speed flight standards until ICAO releases its guidelines by 2025, which could significantly delay the industry.

These sonic boom restrictions inhibit the market by preventing supersonic or hypersonic travel overland. This impacts both coastal and overland routes. For coastal routes, such as transatlantic, these prohibitions mean that aircraft cannot achieve Mach speed until they are sufficiently away from the coast so that the sound carpet does not impact communities, resulting in unique traffic patterns for these aircraft and reducing the amount of flight distance that can be optimized by operating at high speeds, thus reducing the core value proposition of high-speed air travel: less flying time.

While sonic boom restrictions are a nuisance for overwater flight, their greatest impact as a barrier concerns overland flight. Restrictions on sonic booms effectively prohibit all overland high-speed air travel. The inability to serve select overland routes due to these restrictions significantly reduces the size of high-speed air transportation market.

Our research determined that viable business cases are possible without having to fly at speeds greater than Mach 1. The 90 route (city pairs) model that was discussed in the Defining the Market section was entirely composed of "overwater" routes and all findings in the Defining the Business Case section are based on the "overwater" routes as well. The sonic boom restrictions do not need to be modified to enable successful business cases. However, to address the question of how much potential market could be added to the current analysis baseline, the team analyzed how much larger the high-speed air transportation market could be if high density overland routes were added to the analysis baseline. To do this, the team analyzed five routes that would add considerable revenue to the market if they could be permitted under law.

FIGURE 3.5

Estimated Passengers and Revenue for Overland High-Speed Routes

Crown Jewel Route	Annual Passengers	Annual Revenue
LAX-JFK	345K	$1.06B
SFO-EWR	196K	$0.54B
LAX-EWR	168K	$0.35B
LHR-SIN	149K	$0.94B
LAX-LHR	140K	$1.05B

Source: *FAA T-100 2019 flight volume data & Deloitte price elasticity analysis. Volume and revenue were calculated using T-100 data for each route as source data, with Deloitte analysis of global ticket price averages and price elasticity.*

The research team analyzed the addition of LAX-JFK, SFO-EWR, LAX-EWR, LHR-SIN, and LAX-LHR. Using the same analysis methodology as Task 1, the addition of these crown jewel routes is estimated to serve about one million annual passengers and bring in roughly $3.94 bn in additional annual revenue. This increase represents a 24% gain in annual revenue.

Key Takeaways: Sonic Boom

Standards are vague. 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. If overland restrictions were removed or made not needed due to technological advancement, we expect an increase of at least 24% in addressable market size.

The regulatory environment is prohibitive. 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.

Developing standards will take time. 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.

Of these five added routes, four traverse the United States. Even if the route between London and Singapore were excluded, the four U.S. transcontinental routes alone would add approximately 850,000 passengers and $3 billion in annual revenue – a 38% increase in the global addressable market when served by a Mach 2 aircraft with a 5500 nmi design range. This demonstrates that even a change in U.S. policy alone could enable high-speed transportation on four crown jewel routes and have a significant impact on the size of the overall addressable market. It is worth noting that the LAX-JFK passenger volume surpasses even that of the JFK-LHR global crown jewel route and could easily be served by the same aircraft design.

Sonic Boom – The Path Forward

In analyzing the sonic boom restrictions that high-speed air transportation market faces, the research team identified a few themes 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.

Aircraft Certification

The second barrier identified was aircraft certification. Modern high-speed aircraft under development include new airframe and engine technologies that will require a full aircraft certification from FAA in order to operate commercially. Certifying a new aircraft is a process that involves close collaboration with the FAA and funding of research teams over multiple years to complete.

Understanding the Problem

New aircraft will need to complete the certification process which requires a significant outlay of capital and long certification cycles. New aircraft must successfully complete certification under 14 C.F.R Part 21 Aircraft Certification. This involves a comprehensive review of all systems, components, and parts as well as their supply chains. Long certification cycles pose significant threats to business models for new entrants, as such entrants are unable to operate and collect revenue until this process is complete.

Why Aircraft Certification is a Barrier

The high-speed commercial aircraft manufacturing ecosystem is currently largely comprised of nascent companies developing their aircraft from venture capital funding. The anticipated market entrants have highly constrained resources and are operating to serve investor time-horizons of 5-10 years. The FAA aircraft certification process will require major capital outlays from these startups and will also take multiple years – potentially pushing these companies' ROI horizons past a 5-10 year range. This represents a major risk to the market progressing because it could prevent aircraft from operationalizing.

Aircraft Certification: A Deeper Dive

Currently, there are no certification standards for supersonic aircraft. However, in 2018, congress gave the FAA a mandate to create policies and standards relating to the certification of supersonic aircraft. Below are the relevant parts of CFR that relate to key supersonic aircraft certification issues.

- 14 C.F.R. part 21: Aircraft Certification: Sets forth type certification guidelines for aircraft and components.
- 14 C.F.R. part 36: Noise Standards: Sets forth noise certification standards, a necessary element for aircraft certification.
- 14 C.F.R. part 91: General Operating and Flight Rules: Includes the prohibition of flight over Mach 1 and overland sonic booms.

The issue with current regulations is that the prohibition on flight over Mach 1 and overland sonic booms prevents manufacturers from being able to test and evaluate their aircraft for noise. If aircraft can't meet noise standards, then manufacturers cannot obtain a type certificate for the aircraft.

FAA both recognizes this emerging market and has a mandate to address certification of supersonic aircraft and has therefore issued the following Final Rule and NPRMs.

Special Flight Authorization for Supersonic Aircraft (Final Rule issued January 2021)

Current regulations (14 C.F.R. part 91.817) prohibit overland supersonic civil flight in the U.S. but include a procedure to request authorization for the purposes of test and development of new aircraft. In the current regulations, the requirements to get the authorization to exceed Mach 1 are found in Appendix B to Part 91. Applicants have found Appendix B to be confusing and disorganized. This 2019 NPRM streamlines the application procedure for authorization by setting forth the criteria in a user-friendly format that will be codified in 14 C.F.R. part 91.818.

What People are Saying: Aircraft Certification

High-speed air transportation will exist only within the framework of safety and reliability that the industry displays today.
– Stakeholder Interview, Aircraft Certification Subject Matter Expert, October 2020

Engineered Propulsion Systems (EPS) has declared bankruptcy amid mounting debt to get its… engine to the finish line of FAA certification.
– Plane and Pilot Magazine, August 2020

"We have a design… that will be no louder than aircraft flying today"
– Blake Scholl, Boom Supersonic, July 2020

Noise Certification of Supersonic Airplanes (NPRM published April 2020)

Current noise certification regulations do not include standards for supersonic airplanes other than the Concorde. This 2020 NPRM proposes amending the noise certification regulations in Parts 21 and 36 to provide for new supersonic airplanes, and to add subsonic landing and takeoff (LTO) cycle standards for supersonic airplanes that have a maximum takeoff weight no greater than 150,000 pounds and a maximum operating cruise speed up to Mach 1.8.

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

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.

Key Takeaways: Aircraft Certification

Certification timelines are long. 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.

Noise standards are not clear. 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.

Flight testing is challenging. Flight that exceeds Mach 1 is currently prohibited without an FAA exemption, preventing manufacturers from efficiently completing the flight tests necessary for certification. FAA recently released a final rule that addresses this issue and seeks to establish a more streamlined exemption process.

What People are Saying: Landing and Takeoff Noise

We have seen lawsuits and settlements over airport noise in the past, and the Concorde paid a heavy noise fee for each flight"
– Interview with Large Aerospace Manufacturer, December 2020

Three Colorado residents filed 76% of all DIA noise complaints last year. Two of them live 30 miles away from the runways.
– The Denver Post, February 2018

Landing and Takeoff Noise Limitations

The third barrier identified by the research team was landing and takeoff noise restrictions. Engine noise at landing and takeoff can be highly disruptive to local communities. No clear regulation exists at international and national levels, and noise limits are typically established on an airport-by-airport basis. This creates a complex patchwork of regulations that market entrants must navigate to establish routes.

Understanding the Issue: Landing and Takeoff Noise

In the U.S., aircraft noise presents a twofold problem of certification requirements and operational requirements. The first problem is that there is a lack of landing and takeoff noise standards for high-speed aircraft. After the 2018 FAA reauthorization, FAA released an NPRM to add landing and takeoff noise standards for supersonic aircraft; no national level guidance currently exists.

The second part of the problem is the lack of unified standards for landing and takeoff noise restrictions between various airports. Individual airport authorities have non-standardized noise restrictions, such as decibel-based bans, noise fees, and operational curfews. The lack of unified standards can lead to problems as early as the aircraft design stage.

Similarly, in addition to the lack of unified standards in the U.S., there is also a lack of unified standards globally. Different airports around the world have different landing and takeoff noise restrictions, and as all viable high-speed air travel will effectively occur on international routes, the lack of global standards has a significant impact as well.

Why Landing and Takeoff Noise Limitations are a Barrier

Because a regulatory framework is currently not clearly defined at the national level, companies seeking to offer high-speed air transportation services will need to engage individual airports and negotiate operating models that satisfy the needs of local communities and regional airport authorities. This presents multiple risks such as added costs associated with potential investments/fees the airports may require, as well as delays in establishing operations at each airport as stakeholders negotiate an agreeable set of operating terms.

A Deeper Dive: Landing and Takeoff Noise

Like the issue of sonic booms, current international and national guidelines do not define landing & takeoff noise standards for civil high-speed aircraft; in the US, operators will need to meet existing standards at the local level.

As part of CAEP's Cycle 12 study, ICAO will review the issue of landing and takeoff noise produced by high-speed aircraft and is targeting a 2025 timeline for releasing standards that address the new market category. Following the release of its NPRM addressing domestic sonic-boom authorizations, FAA released another NPRM in 2020 that, amongst other objectives, seeks to establish landing and takeoff noise standards for high-speed civil aircraft.

While international and national aviation bodies are working to develop a clear set of guidelines for airport noise, in the United States, airports currently have individual noise standards that limit noise levels based on the maximum allowable decibel levels (typically approximately 90-100 dB) detectable in communities surrounding the given airport. High-speed aircraft, when introduced, may not be able to remain below the thresholds set by each airport.

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 and Takeoff Noise Limitations: The Path Forward

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.

Key Takeaways: Landing and Takeoff Noise Limitations

Standards are vague. 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 in advance of market entry. This could create delays in go-to-market timelines and even prohibit some routes.

Noise may limit airport operations. 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.

Negating noise impacts could be prohibitive. Modern high-speed aircraft developers 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.

Are supersonic or hypersonic aircraft simply "too loud" to fly?

A look at how prospective high-speed aircraft measure up to existing noise limitations

Airport-by-airport noise limitations present unique challenges for operators as they not only navigate federal regulations, but also compliance with rules at their core airports as well. To better understand the possible practical impact of airport-by-airport noise limitations, the research team analyzed the existing restrictions at the crown jewel airports and compared to findings from the P2P ROSETTA model used in the business case analysis portion of this report and how those findings relate back to current federal regulations and local noise restrictions at our crown jewel airports.

Limits for airport noise in the United States are controlled by a complex assessment that accounts for all aircraft traffic generated noise at the airport over a 24 hours period [as defined in 14 CFR § 150.9 - Designation of noise systems/Appendix A]. The FAA rules place the burden of compliance on the airport operator and charges them with the responsibility to meet the threshold noise limitations set forth at the federal level.

If exceedances occur, there are a predetermined series of fines that are levied on the airport. In turn, some airports have developed a fine structure that is passed along to the operators to recoup the expense. International airports regulate allowable noise with similar algorithms.

Because of this, there is not a simple way to determine if a single aircraft is "too loud" or if it alone breaks the "sound budget" for that airport. In general, the smaller aircraft have lower MTOW, lower takeoff thrust, and are thus quieter and less of a problem to accommodate at an airport. We assumed no afterburner use on takeoff in our mission models. For example, a Mach 2/20 passenger aircraft [92 – 96 dB] is predicted to be quieter than today's 747 aircraft [~98 dB] which should not pose significant challenges. Concorde [108 dB] was a particularly loud aircraft at takeoff. We did not predict any aircraft louder than Concorde in our model, although the largest aircraft configurations we considered approached 103 dB. These large aircraft were not our preferred economic recommendation. The P2P ROSETTA model predicted sideline noise for various airframe configurations as part of its standard calculations.

Mitigations to limit aircraft noise fields include:

• Operational limitations such as take-off/landing patterns on over water for coast airports [i.e. – LAX, SFO etc.]

• Investing in soundproofing of nearby structures to reduce sound impacts

The challenges this will present to operators of high-speed aircraft systems include:

• Having to negotiate with each individual airport to secure a "sound allocation" in addition to gate allocations which will increase overhead costs before service can be established

•May face local airport fines to address sound exceedances which will need to be recovered through higher ticket prices for customers which could lower annual passenger volumes

Significant Challenges

In addition to the three barriers identified, the research team identified two significant challenges: emissions and export controls. Based on the rubric, these challenges did not rise to the level of barrier, however, they both notably stood out from lesser challenges, warranting further discussion.

The following sections look at each of these significant challenges in depth. These sections give an overview of each challenge, describe the key problem or issue at hand, and rationale for why this challenge is significant. These sections also take a deeper dive look at the policies and practices that contribute to the significant challenge as well as a path forward to potentially overcome it.

Emissions Standards

The first significant challenge identified was emission standards. In response to mounting public pressure on corporations to mitigate emissions, ICAO and FAA have established regulation that defines and mandates standards for aircraft emissions, specifically for CO_2 and NOx. high-speed aircraft manufacturers will need to address this trend and meet aircraft emissions standards as they go to market. Legacy emissions standards for supersonic and hypersonic flight still exist, but the community widely acknowledges that these will need to be updated for next generation vehicles. In today's world that is much more sensitive to environmental implications, this could take many years to reach consensus and implement which represents design risk to developers working parallel with regulation updates.

Understanding the Issue: Emissions Standards

Studies have cited that high-speed aircraft will produce higher emissions output, which would fail current regulations. Under 40 C.F.R., EPA and FAA outline efficiency requirements for all aircraft, and high-speed aircraft are unlikely to meet them, given current estimates. The International Council on Clean Transportation projected that high-speed aircraft will emit 5-7 times more emissions per passenger as subsonic aircraft.

Why Emissions Standards are a Significant Challenge

Corporate, public, and regulatory standpoints on emissions have significantly tightened since the Concorde flew. New restrictions have been placed on manufacturers to improve engine fuel efficiency, and airports within the United States are subject to meeting state-by-state annual emissions caps. The tighter regulatory environment and growing focus on emissions targets poses a significant technology challenge for high-speed aircraft manufacturers to meet these standards. High-speed aircraft may not be able to meet these standards, thereby preventing operationalization.

What People are Saying: Emissions Standards

[Manufacturers] need to convince a climate-change-rattled world that their comfort won't make the greenhouse gas problem worse.
–Adam Hadhazy, Aerospace America, October 2019

There's a lot of excitement over… supersonic planes, but… we're finding that [they] will have a significant environmental impact.
– Dan Rutherford, ICCT, July 2018

Deeper Dive: Emissions Standards

Regulation exists internationally and domestically that reduce and mitigate the negative externalities produced by aircraft engines over time. Aircraft manufacturers will need to adopt these new standards to get new engines certified. There are two key categories of emissions standards analyzed by this research team. The first are those that apply to the emission of greenhouse gasses (GHGs), including carbon dioxide (CO_2). The second category is nitrous oxide (NOx) emissions standards. Below is a look at the current state of GHG/CO_2 and NOx emissions standards.

Direct GHG and CO2 Standards

International Regulation: In 2016, ICAO developed GHG emissions standards for new commercial aircraft that call for lower levels of CO_2 output as compared to past aircraft. Under the standard, the fuel efficiency targets are set as a function of an aircraft's Maximum Take-Off Mass (MTOM). For example, an aircraft of 225 MTOM tonnes would be required to emit no more than approximately 1.5 kilograms of CO_2 per Kilometer. These regulations will become official in 2028, mandating that sovereign aviation authorities require aircraft to meet ICAO's standards for type certification.

Domestic Regulation: In 2016, the Environmental Protective Agency (EPA), under Section 231(a) of the Clean Air Act (CAA), found that "certain classes of engines used in aircraft contribute to the air pollution that causes climate change endangering public health and welfare." EPA states that this finding is in preparation for a "future domestic rulemaking process to adopt GHG standards." In July 2020, EPA issued a Notice of Proposed Rulemaking stating that it will move to align U.S. aircraft emissions standards to those set forth by ICAO, covering all large passenger jets. If the regulation becomes a final rule, all future aircraft will likely need to conform to GHG emissions standards, including high-speed aircraft.

Cap and Trade Policy: In the last decade, the European Union has set forth various Cap and Trade policies that mandate maximum allowances of emissions from European states that large emitters such as airports, powerplants, and other entities can purchase and sell. The U.S. Federal government has opposed this effort, stating that it will not sufficiently address the problem of GHG emissions, and instead, USG has focused on addressing emissions through the Clean Air Act. However, U.S. state governments such as California have launched state-level cap and trade systems that obligate airports to curb emissions. Further, some large U.S. airports have proactive efforts to reduce emissions, including SFO, SEA, DFW, DEN, and AUS.

NOx Standards

International Regulation: Over the last four decades, certified aircraft have incrementally lowered their NOx emissions, but future aircraft will need to further reduce NOx emissions to meet ICAO's mid-term and long-term guidelines. As part of its 2016 emissions standards, ICAO established requirements for NOx emissions for commercial aircraft. Under the standard, emissions targets are set as a function of the mass of NOx particles emitted during landing and take-off test cycles relative to the thrust of the engine. ICAO developed a white paper in 2018 to further its efforts in developing new SARPs for high-speed aircraft focused on environmental issues including emissions.

Domestic Regulation: In 2012, EPA updated standards for nitrogen oxide limits in aircraft engines producing a thrust greater than 26.7 kilonewtons. The requirements are based on ICAO's standards and are organized by an incremental reduction in NOx allowances, outlined by Tier 6 and Tier 8 standards. Tier 6 had set lower NOx limits on aircraft engines manufactured before 2014, while Tier 8 reduced NOx emissions by 15% from Tier 6 standards for all engines manufactured in 2014 onward. High-speed aircraft will need to meet the criteria outlined in Tier 8 standards, which poses a significant challenge to existing engine technology.

State-level Policy: In the US, some states choose to set their own NOx emissions standards. The states that form New England – largely northeast industrial states – are identified under the Clean Air Act as the Ozone Transport Region. These states are uniquely classified because they are down-wind from other regions in the U.S. that produce high amounts of NOx, which contributes to Ozone depletion. These states are subject to 'model rules', which are state-level NOx emissions standards that the implementation of NOx capture technology to reduce downstream Nitrogen Oxide emissions. These states are also home some of the wealthiest demographics and most highly trafficked airports globally presenting an operational challenge to high-speed aircraft that are potential heavy emitters of NOx.

High-speed Aircraft Emission Estimations

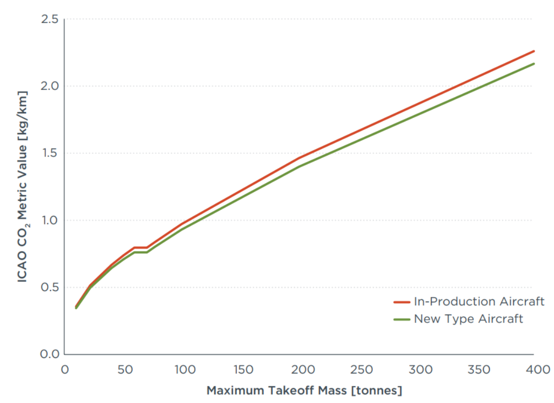
Emissions and fuel efficiency are an ongoing concern with the current subsonic aviation industry and is a concern with supersonic aircraft. Below we discuss current trends in this area, including ICAO's current fuel efficiency guidelines.

The International Council on Clean Transportation estimated in 2019 that supersonic aircraft could consume 5-7x more fuel per passenger than subsonic aircraft. While interviews with industry stakeholders have indicated that this report is biased toward constraining the supersonic aircraft industry, stakeholder recognize that emissions is a major issue. In Figure 3.6, we observe current CO2 emissions levels for subsonic aircraft and future guidelines, as set by ICAO.

Based on these trends, emissions regulations are unclear for high-speed aircraft and current estimates indicate that these aircraft cannot meet current subsonic standards. This could inhibit market entry if regulations appropriate for this type of service are not established in the next few years, as companies need to invest to finalize system designs.

FIGURE 3.6

ICAO Guidelines for New and In-Production Aircraft



Source: *International Council on Clean Transportation*

Emissions: The Path Forward

Establish Standards as Soon as Possible

Unless clear standards for high-speed aircraft are established at least 5 years before planned market entry, high-speed aircraft manufacturers may not be able to account for new emissions requirements in their R&D process. Therefore, establishing emissions standards in the mid-2020s will be paramount to enabling the industry to prepare accordingly, and meet these standards while remaining on-track with their current go-to-market timelines.

Cap and Trade Programs

While cap and trade programs have met broad resistance from the private sector and federal government, they represent a viable alternative to investing in technological development.

Key Takeaways: Emissions Standards

International emissions guidelines flow from ICAO down to various national aviation regulators; countries ultimately determine what defines a 'certifiable' emissions level, which can complicate the regulatory landscape for companies entering the market.

Greenhouse Gas Emissions standards have tightened in recent years and are continuing to tighten, both at national and regional levels of governments. Particularly in the Coastal US and the EU, market entrants may encounter significant resistance to standing-up new routes or expanding flight volume.

ICAO and FAA are in the process of reviewing the regulatory implications of a future high-speed air transportation market; this could result in additional regulation for high-speed aircraft that further constrains the market and represents risk to developers.

Programs applied to high-speed air transportation as an industry could help mitigate risk early in the development of the market, giving regulators power to adjust standards as the market and technology matures.

New Technology

Longer-term solutions will come from adoption of synthetic fuels and improved engine technology. Currently, the synthetic fuel creation process can produce 100% synthetic Jet A, which many of the high-speed aircraft developers are building their aircraft to use. High-speed aircraft developers are also researching engine technology that is more emissions-efficient and can better position the aircraft to meet future CO2 and NOx standards.

Export Controls

The first significant challenge identified was export controls. High-speed aircraft use sensitive technologies ranging from airframes to powerplants, which have military applications. These aircraft are therefore subject to U.S. export regulation. Companies will need to allocate resources to compliance professionals to ensure adequate protection of U.S. intellectual property from rival powers or hostile nations.

Understanding the Issue: Export Controls

Manufacturers developing high-speed airframes and engines will need to allocate valuable resources to protect export-sensitive technology.

The International Traffic in Arms Regulations (ITAR) cover technology with military applications. High-speed aircraft will be subject to this regulation. The Export Administration Regulations (EAR) concerns dual-use technology: technology that has both civil and military applications. It is anticipated that numerous components in high-speed aircraft will be adopted from military technology, thereby trigging application of these regulations. EAR also outlines a Commerce Control List that limits product sales to certain foreign countries.

In addition to these two key regulations, the Committee on Foreign Investment in the United States (CFIUS) is an interagency committee tasked with reviewing certain transactions involving foreign investment. This review can constrain U.S. companies from receiving investment from certain foreign entities.

What People are Saying: Export Controls

Manufacturers currently address ITAR & EAR regulation, requiring that all employees and processes comply with export regulatory standards.

High-speed aircraft developers are currently hiring subject matter experts in ITAR & EAR regulation.

Why Export Controls are a Significant Challenge

Export controls demonstrate a two-fold problem for civilian high-speed aircraft. First, complying with ITAR, EAR, and CFIUS regulations involves navigating a complex legal landscape that demands specialized expertise, and this places a financial burden on startups. Second, today, US-based airlines are restricted from offering routes involving hostile nations or geopolitically risky countries; high-speed aircraft routes will face these restrictions as well, particularly if they have sensitive technologies on-board which could limit global route tree possibilities.

Deeper Dive: Export Controls

In navigating ITAR, EAR, and CFIUS restrictions, manufacturers will need to ensure compliance with rules and guidelines within each area. Below outlines the key processes and guidelines that high-speed aircraft developers will need to consider before the enter the market. This section provides a primer on each of the three key regulations and committees that will impact the high-speed air transportation market.

International Traffic in Arms Regulation (ITAR)

ITAR (22 C.F.R. part 121) outlines the United States Munitions List (USML) including services and technologies designated as defense or space related. Any items that fall within USML descriptions are under the jurisdiction of the Department of State. Hypersonic aircraft will most be likely a consideration for USML. Supersonic aircraft are also relevant but have precedent for international use given the Concorde. Companies developing technologies that align to USML must register with the Directorate of Defense Trade Controls, which determines compliance and issues certificates for U.S. exporters. high-speed aircraft, particularly hypersonic aircraft, will likely be applicable.

Export Arms Regulation (EAR)

EAR outlines various technology categories that constitute dual-use technologies that are subject to export restrictions under the Department of Commerce (DoC). The Commerce Control List (CCL) is a list within EAR of items that have military application and require an export license. Many items, however, are designated as EAR99, which are low-technology and do not always require an export license. High-speed aircraft will likely have parts that fall under both CCL and EAR99.

Companies developing technologies that fall under EAR (CCL and EAR99) must obtain an ECCN by submitting a license application (via SNAP-R) to DoC. High-speed aircraft may have components and subsystems (engines, airframe parts, etc.) that fall under CCL and EAR99.

Committee on Foreign Investment in the U.S. (CFIUS)

CFIUS is a review committee that approves foreign investment transactions in U.S. companies. CFIUS is comprised of leaders across U.S. federal agencies. Together the agencies form a board that reviews a given investment transaction and determines the risks posed to U.S. national security.

Historically, the CFIUS review process involves multiple tiers of review, including a 45-day general review, followed by an optional 45-day investigation period, and concluding with a 15-day presidential review. Given that high-speed aircraft will serve international routes, the startups and larger companies operating them will need to comply with CFIUS when receiving investment, or when engaging foreign companies for acquisitions.

While companies must ultimately ensure compliance with export regulations, the public sector can help industry meet these requirements via programs that streamline information, guide companies through the process, and educate founders. If companies are left to manage the landscape by themselves, startups risk missing critical compliance requirements, which could inhibit their ability to operate in the U.S. market.

Export Controls: The Path Forward

In analyzing the export control issues that high-speed aircraft face, there are a few activities that could help mitigate this significant challenge.

Streamline Information

Allowing early-stage founders to access the basic, critical information they need can allow startups to maximize efforts allocated to developing their technical solution, rather than hiring specialized expertise to help them navigate compliance.

Assist Founders Early

Regulations such as those outlined by CFIUS often bar companies from entering markets after they have begun the development process, due to outside investors from rival power nations. The more the public sector can work with startups to help them navigate regulations early on, the better the outcome will be for all parties involved.

Training Programs

Incorporating export control training into various government programs such as publicly funded innovation incubators and accelerators can help early-stage companies understand the requirements that they must meet and the resources available to them.

Key Takeaways: Export Controls

Export restrictions are greater than subsonic aircraft. Supersonic and hypersonic aircraft are more likely to be subject to export restrictions than their civil sub-sonic counterparts. This implies additional challenges with compliance and international operations.

High-speed aircraft will be covered by multiple export control types. Supersonic aircraft technologies are likely to have some overlap with ITAR and significant overlap with EAR; hypersonic technologies will likely have a significant degree of overlap with both regulations. All high-speed aircraft will likely be relevant for CFIUS review.

Export controls may make some global routes less attractive. Some city pairs that scored highly in our study involve countries that are on EAR control lists. This could pose significant challenges to companies that wish to operate high-speed aircraft travel routes in those countries.

Key Takeaways

What are the commonalities among the greatest barriers to high-speed air transportation?

Many of the most pressing challenges to the industry, including aircraft noise, emissions, regulation, and certification, are highly inter-connected. Notably, what's common among these is that regulatory compliance is a substantial element to all the barriers and significant challenges.

What are the greatest near-term concerns in terms of barriers?

In the near-term, significant regulatory and certification barriers exist that could prevent high-speed aircraft from entering service. The FAA is actively laying the groundwork to regulate this market, as evidenced by recent NPRMs, but the regulatory process is still lengthy.

What about regulatory modernization? Will that solve the problem?

While government regulators 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.

What is the most significant barrier for future high-speed aircraft?

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

Section 4

Study Conclusions

Summary Findings

Through our study, we were able to determine where and how viable business cases for high-speed air transportation materialize.

In our market analysis, we found that commercial and private jet services, as well as cargo shippers are willing to pay for more expensive tickets to arrive sooner. When considering speed and distance in the market picture, 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.

In our business case analysis, we generally found that the most viable business cases are possible from Mach 2 to Mach 5+ however, hypersonic 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 during development.

In our barrier assessment, we found that regulatory, certification, societal and infrastructure barriers and challenges pose varying levels of business risk to aspiring service providers, and many of these barriers are inter-related. The most constraining issues are driven by lack of specific regulations and certification requirements to "design to" for this flight regime. The three challenges that were determined to be barriers, aircraft certification, sonic boom restrictions, and landing and takeoff noise limits, all tie back to international aircraft operating standards and FAA federal regulations which in most cases are not clearly defined for these flight regimes. Likewise, the two significant challenges, emissions limits and export control regulations, both also rely heavily on unclear federal and international regulations.

FIGURE 4.1

Aircraft Characteristics

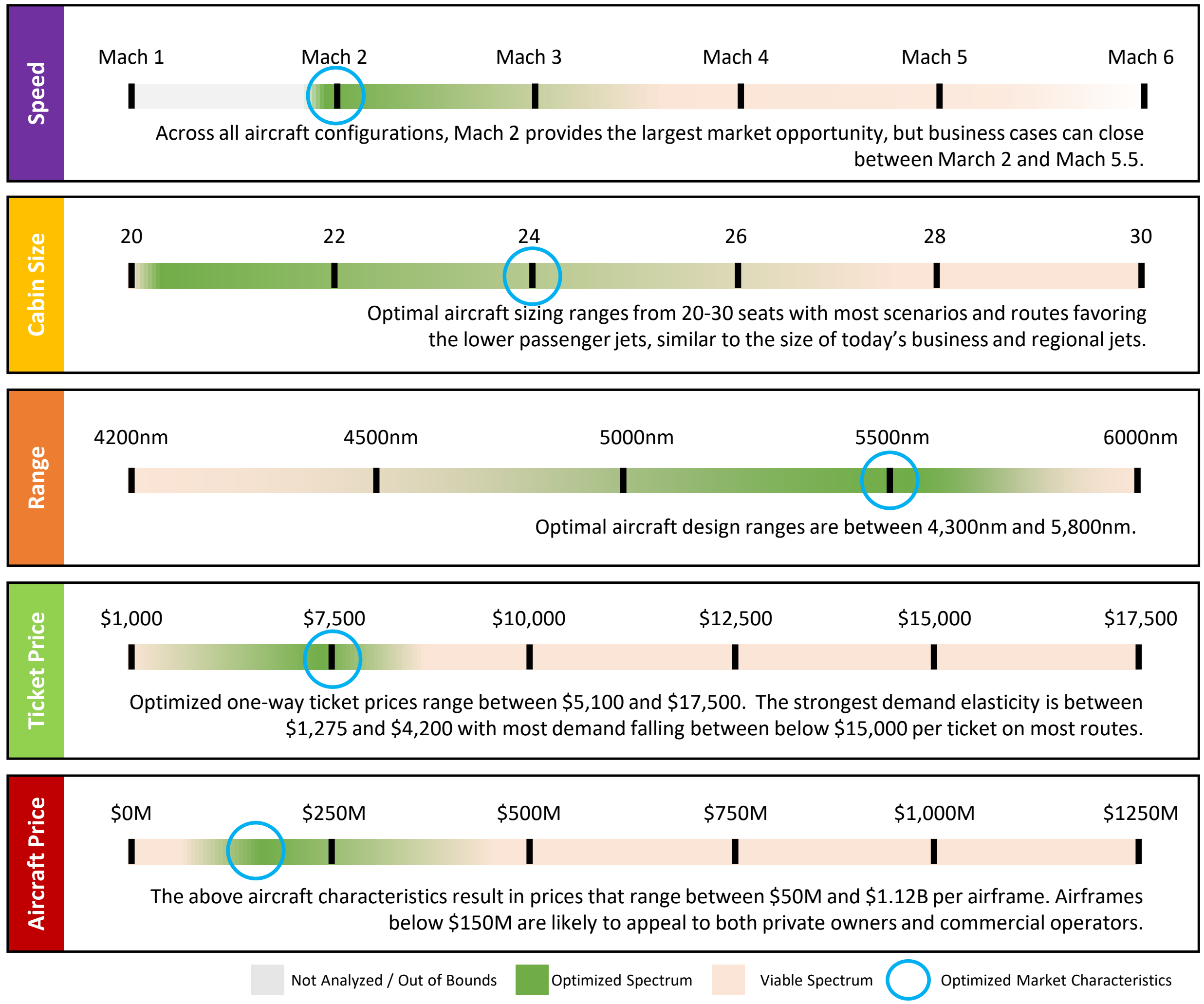
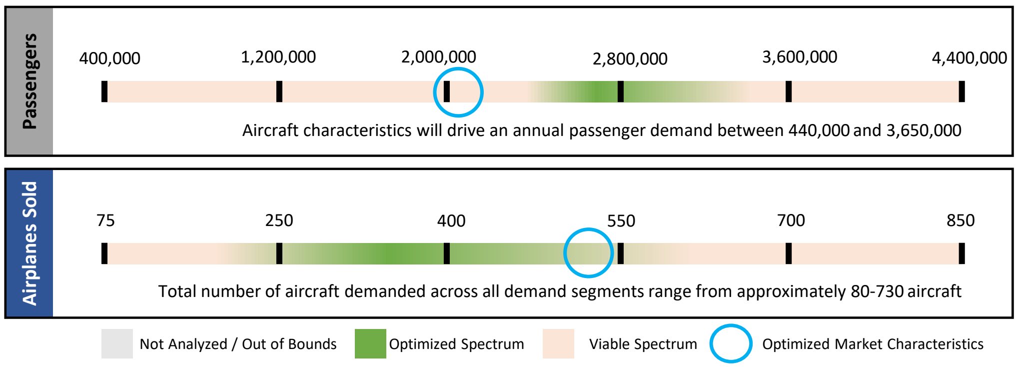


FIGURE 4.2

Market Characteristics



Our assessment leads us to conclude – with measure – that viable business cases are possible for civil high-speed aircraft, and that stakeholders seeking to invest in this nascent industry are best-served to focus on technologies and markets that have demonstrated historical precedent for business cases. Ultimately, investing the time and resources in the issues that constrained historic market efforts is more likely to yield results than to focus on edge-technologies that will face significant barriers including R&D timelines, program costs, and regulatory/certification constraints.

A Global Market Picture

Our analysis demonstrated that there are business case scenarios tied to technically achievable solutions between Mach 2 and Mach 5.5 with economic characteristics capable of creating a sustainable market for high speed transportation. Unsurprisingly, we observe favorable market conditions that 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

The Rosetta model produced a series of optimized scenarios across the Mach 2 to Mach 6 spectrum that have viable business cases. We observe that the optimized scenarios, and therefore the business cases, tend of prefer smaller sized jets that can serve both the commercial airline and private jet markets.

Based on the various aircraft design configurations and optimized characteristics analyzed in the Rosetta Model and through the lens of the demand elasticity data, we see a market that can sustain prices for high-speed travel up to $17,500 per ticket and aircraft that cost up to $1.12B per airframe. However, the higher costs on a per ticket and per airframe basis will create a niche market with slow customer adoption due to the small fraction of the subsonic passenger addressable market that can be converted to paying customers. Unsurprisingly, the strongest market demand is observed when ticket prices are less than 10x more expensive than an economy ticket and when aircraft costs are below $150M. The full range of aircraft characteristics is shown in Figure 4.1.

Market Characteristics

Across the spectrum of optimized business cases, we observed market conditions that could generate a global demand of between 440,000 and 3.65M annual passengers and a total aircraft market between 80 and 730 aircraft. The full range of market conditions is shown in Figure 4.2 and the market by Mach number is detailed in Figure 4.4.

An Optimized Market Scenario

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

FIGURE 4.3

Optimized Market Scenario

Aircraft and Market Characteristics	Optimized Market
Aircraft Speed	Mach 2
Passenger Capacity	20
Range	5,500 NM
Approximate Aircraft Cost	$120M
Total Aircraft Demand	541
Reference Ticket Price	$5,350
Estimated Approximate Market Size	2.1M
Estimated Maximum Market Value	$11,235M

FIGURE 4.4

"Optimized" Market Opportunity by Mach Number

Aircraft and Market Characteristics	Mach 2	Mach 3	Mach 4	Mach 5	Mach 5.25	Mach 5.5
Passengers Capacity	20	20	23	29	26	20
Design Range	5,800 nmi	5,500 nmi	5,100 nmi	4,300 nmi	4,900 nmi	4,800 nmi
Average Ticket Price	$5,980	$7,230	$7,610	$5,260	$13,310	$17,700
Estimated Approximate Market Size	1.96M	1.56M	1.84M	1.53M	0.84M	0.78M
Estimated Maximum Market Value	$11,732M	$11,286M	$13,979M	$8,063M	$11,170M	$13,192M

Appendix

Glossary & Acronyms

Term	Definition
Afterburner	An afterburner is an additional combustion component used on some jet engines, mostly those on military supersonic aircraft. Its purpose is to increase thrust, usually for supersonic flight, takeoff, and combat.
CAGR	CAGR is the rate of return that would be required for an amount to grow from its beginning balance to its ending balance
Critical Location Factors	Key factors influencing ideal city / route pairings for high-speed aircraft routes in our study.
dB	Decibel: Unit of measurement for noise in the context of this study. Decibels are measured on a logarithmic scale.
DDT&E	Design, Development, Test & Evaluation: factors influencing the resources required to bring aircraft programs to fruition.
Genetic Algorithm Optimizer	A method for solving both constrained and unconstrained optimization problems, and a key driver of the sensitivity analysis of this study.
Global Crown Jewels	Major global air routes, domestic and international, that are the highest ranked in the world for total revenue or profitability.
High-Speed Aircraft	As defined in this study, aircraft capable of achieving greater-than Mach 1 speeds.
Hypersonic Aircraft	Aircraft capable of achieving speeds of Mach 5 or greater.
Internal Rate of Return (IRR)	Return generated by the business in question for investing in development of high-speed aircraft.
Mach	A unit of speed measurement as a multiple of the speed of sound.
MTOW	Maximum Takeoff Weight: the maximum weight at which pilots is allowed to take off in a given aircraft, due to structural limits, among others.
NAS	National Airspace System: The National Airspace System is the airspace, navigation facilities and airports of the United States along with their associated information, services, rules, regulations, policies, procedures, personnel and equipment.
NMI (nmi)	Nautical Mile: a unit of distance used in navigation and based on the length of one minute of arc taken along a great circle.
OEW	Operating Empty Weight: Empty weight is the sum of the 'as built' manufacturer's empty weight, plus any standard items plus any operator items.
Pax	Airline Passengers: Abbreviation for number of passengers on a given aircraft.
ROSETTA Model	Modeling tool used to estimate IRR for various business cases and the key variables influencing them.
Supersonic Aircraft	Aircraft Capable of achieving speeds of Mach 1-5; Mach 5 or greater is considered hypersonic.
USG	United States Government.

Airport Codes

IATA Airport Code	Airport Name
AKL	Auckland Airport
ANC	Ted Stevens Anchorage International Airport
CDG	Paris-Charles de Gaulle International Airport
FRA	Frankfurt am Main Airport
GRU	São Paulo/Guarulhos – Governador André Franco Montoro International Airport
HKG	Hong Kong International Airport
JFK	John F. Kennedy International Airport
LAX	Los Angeles International Airport
LHR	Heathrow Airport
MIA	Miami International Airport
NRT	Narita International Airport
PVG	Shanghai Pudong International Airport
SIN	Singapore Changi Airport
SYD	Sydney Kingsford Smith Airport

Appendix 1 – Defining the Market Supporting Data

Development Efforts: Military Hypersonic Vehicles In-Depth

Military applications of hypersonic technology currently center around Hypersonic Missiles, including Hypersonic Glide Vehicles (HGVs) and Hypersonic Cruise Vehicles (HCVs). While HGVs are launched into the upper atmosphere 50-100km), HCVs remain in the lower atmosphere (20-30km). Both variants capable of performing dynamic aeronautical maneuvers while at hypersonic speed, and therefore present major challenges to existing missile defense systems. The strategic significance of this technology has motivated Great Power Nations such as Russia, China, and the United States to concentrate significant R&D efforts aimed at developing prototypes.

The advent of hypersonic missiles has also called for the development of hypersonic missile defense systems. Specifically, many modern ballistic missile defense platforms can detect within a 4,000 km altitude range. At 50-100km and 20-30km, respectively, HGVs and HCVs can fly beyond the range of many existing threat detection systems. This is further complicated by the fact that HCV are capable of a dynamic flight-path, compared to conventional Intercontinental Ballistic Missiles which have a predictable flight path.[1] Government development programs now focus not only on offensive capabilities (the hypersonic missiles themselves) but also defensive capabilities (the sensors and kinetic systems capable of destroying active hypersonic threats).

Military systems are the most advanced hypersonic technologies to-date. In the 2010's, Great Power Nations including Russia and China reportedly developed boost-glide hypersonic weapons (HGVs and HCVs) that could outmatch existing Western missile defense technologies. Russia and China's efforts culminated in reportedly significant technological achievements during the latter half of the decade, including:

- December 2017: Russia announced that Kh-47M2 Kinzhal, a hypersonic boost-glide missile, had successfully been developed and was in its testing phase. Kinzhal is reportedly capable of reaching Mach 10 on its own power.
- August 2018: China unveils XingKong-2, a hypersonic boost-cruise missile that is currently in development and testing.
- October 2019: China displays Dong-Feng 17, a hypersonic boost-glide missile, on top of a military transport vehicle during a national military parade. The DF-17 was China's first hypersonic weapon system of its kind to enter service and had been in testing since 2014.
- December 2019: Russia announces that Avangard, a hypersonic boost-glide missile reportedly capable of carrying nuclear payloads, has entered service after successful testing.

Each announcement reinforced global concern of a capability gap in Western Great Power Nations, including the United States, to address the new weapon class. The new missiles are thought pose a material threat to global security if left unchecked, particularly in geopolitically sensitive areas such as the Middle East and the South China Sea.

The United States and Europe are also leading efforts to develop hypersonic technologies, and the United States has accelerated federal funding allocations to these development programs in response to the concerns that Russian and Chinese advancements have raised with the international community.

The Department of Defense has made hypersonic technology a priority for their strategic plan and their increases in funding toward hypersonics reflect this.

The DoD's investment in hypersonic launch research has seen a 44% compound annual growth rate (CAGR) since 2017. DARPA has led this research through a variety of offensive and defensive research programs. One significant campaign is the Tactical Boost Glide (TBG) program and the Hypersonic Air-breathing Weapon Concept (HAWC). This R&D program is a joint venture between DARPA and the U.S. Air Force effort that will develop and demonstrate technologies to enable air-launched tactical range hypersonic boost glide systems. In DARPA's FY2020 budget the TBG program was allocated $162 million in funding, an almost $100 million increase from 2018. Like the TBG, the Hypersonic Air-breathing Weapon Concept (HAWC) program is also a joint effort between DARPA and the U.S. Air Force. This effort will develop and demonstrate technologies for an effective and affordable air-launched cruise missile.

Table 1.1: Military Trends in High-Speed Air Transportation Technology – Global Competition

Country	**Type**
United States	Hypersonic Weapons & Hypersonic Anti-Ballistic Missile Capabilities
United Kingdom	Active Hypersonic R&D Pursuits
France	Active Hypersonic R&D Pursuits
Germany	Active Hypersonic R&D Pursuits
Israel	Active Hypersonic R&D Pursuits
Australia	Active Hypersonic R&D Pursuits
Japan	Active Hypersonic R&D Pursuits
Russia	Hypersonic Weapons & Hypersonic Anti-Ballistic Missile Capabilities
China	Hypersonic Weapons & Hypersonic Anti-Ballistic Missile Capabilities
India	Active Hypersonic R&D Pursuits

Source: https://breakingdefense.com/2020/04/exclusive-dod-asks-2-9b-for-hypersonics-in-2021/#:~:text=WASHINGTON%3A%20The%20Pentagon%20is%20asking,Each%20increases%20by%2095%20percent

Table 1.2: Military Trends in High-Speed Air Transportation Technology – U.S. Government Investment

Hypersonic Program Funding by Agency	**Air Force**	**Army**	**Navy**	**DoD Agencies**
2020	$848	$441	$526	$693
2021	$554	$859	$1,026	$417

Source: https://breakingdefense.com/2020/04/exclusive-dod-asks-2-9b-for-hypersonics-in-2021/#:~:text=WASHINGTON%3A%20The%20Pentagon%20is%20asking,Each%20increases%20by%2095%20percent

Private Sector Activity for Military Hypersonics

For military hypersonic vehicles, private sector activity in the United State and allied countries is dominated by prime defense contractors. The primes are currently engaged in federal contracting opportunities focused on R&D of hypersonic weapons systems. Full-scale production of any hypersonic systems is either state-guarded information or not yet in progress. Below are examples of prime contractors invested in military hypersonics projects:

Raytheon

- DARPA awarded Raytheon the $174.7 million for phase two of the Hypersonic Air-breathing Weapon Concept, accounting for one of the two hypersonic joint-development programs between DARPA and the Air Force.

Lockheed Martin

- Lockheed Martin Space is the successful offeror of a $928,000,000 ceiling indefinite-delivery/indefinite-quantity contract for the hypersonic conventional strike weapon.
- DARPA awarded a $171.2 million contract to Lockheed Martin for the first phase of the Hypersonic Air-breathing Weapon Concept program.
- DARPA also awarded Lockheed Martin a $147.3 million contract as part of its Tactical Boost Glide program.

Boeing

- Boeing competed for a $1 billion counter-hypersonic contract that would utilize Raytheon interceptor missiles. Boeing has also proposed directed energy weapons for use against hypersonic weapons.

Northrop Grumman

- Northrop Grumman, in partnership with Raytheon, has a $200 million contract for the Hypersonic Air-breathing Weapon Concept, or HAWC, with the Defense Advanced Research Projects Agency and U.S. Air Force. Northrop Grumman will be using 3D printing technology to produce parts for the SCRAMJET engine.

A handful of nascent companies (startups) are also developing hypersonic applications for military uses. These companies are largely focused on tackling individual technology barriers for hypersonics, rather than engaging in large-scale R&D. Examples of startup players are listed below:

SpinLaunch

- SpinLaunch designed a hypersonic launch platform that will propel small satellites into the Low Earth Orbit (LEO). By leveraging technology concepts from the wind turbine and oil & gas industries, SpinLaunch uses a centrifuge style system to launch the satellites into a flight path, after which a rocket booster finishes the payload's delivery into LEO.
- In April 2018, SpinLaunch announced that it had raised $40 million in initial seed funding from venture capital funds and corporate venture capital funds.
- Since the completion of the funding round, SpinLaunch has secured a contract with the DoD's Defense Innovation Unit (DIU), to test a responsive launch prototype.

HyperSciences

- HyperSciences has developed a hypersonic projectile that has dual-use applications to a variety of fields to include mining and aerospace.
- The platform uses a projectile loaded into a launch chamber filled with natural gas and compressed air to create the necessary velocity.
- Through a NASA grant, HyperSciences has created various test "hyper drones" to mimic launching satellite payloads.

Additional Supporting Information

The following tables support the charts and analysis detailed in Section 1 of this report.

Table A-1.3: City Pair and Route Identification Down Selection

Method 1 (Global Crown Jewel Routes)	**Method 2 (High Demand Routes)**		**Method 3 (Toughest Routes for Competition)**		**Method 4 (Centers of High-Net-Worth Individuals)**	
Global Top Performers	*Domestic*	*International*	*Domestic*	*International*	*Domestic*	*International*
JFK-LHR	CJU-GMP	HKG-TPE	JHG-KMG	KUL-SIN	LAX-JFK	NRT-JFK
MEL-SYD	CTS-HND	KUL-SIN	CKG-SZX	HKG-ICN	ORD-JFK	JFK-HKG
LHR-DXB	FUK-HND	CGK-SIN	CGO-URC	KIX-PVG	SFO-JFK	CDG-JFK
LHR-SIN	HAN-SGN	BKK-HKG	CAN-HGH	DAD-ICN	IAD-JFK	HKG-NRT
SFO-EWR	MEL-SYD	HKG-PVG	HGH-PEK	NRT-TPE	DFW-JFK	LAX-NRT
LAX-JFK	BOM-DEL	HKG-ICN	MHD-THR	ICN-TPE	ORD-LAX	CDG-NRT
LHR-DOH	PEK-SHA	HKG-MNL	LHW-URC	CGK-KUL	LAX-SFO	ORD-NRT
HKG-LHR	JED-RUH	JFK-LHR	AWZ-THR	ICN-KIX	IAD-LAX	SFO-NRT
SYD-SIN	HND-OKA	BKK-SIN	HRB-NKG	ICN-NRT	DFW-LAX	IAD-NRT
YVR-YYZ	HND-ITM	CGK-KUL	CJU-GMP	KIX-TPE	IAD-SFO	JFK-LHR
					DFW-SFO	LHR-NRT
					DFW-IAD	LHR-HKG
						LAX-LHR
						LHR-CDG
						ORD-LHR
						SFO-LHR
						IAD-LHR
						DFW-LHR

Table A-1.4: City Pair / Route Scoring

Type (Passenger, Cargo, Private)	Initial Pairings	Economic Opportunity Rating (1-5)	Technical Fit Rating (1-5)
Cargo	LHR-DOH	5	2
Cargo	LHR-SIN	5	1
Cargo	ANC-PVG	4.6	4
Cargo	LHR-NRT	4.5	3.1
Cargo	SFO-PVG	3.5	4.9
Cargo	LAX-HKG	5	4.8
Cargo	SFO-HKG	3	5
Cargo	LAX-NRT	4	5
Cargo	JFK-FRA	4	4
Cargo	LAX-SIN	4	4.9
Passenger	JFK-LHR	5	4.5
Passenger	SYD-SIN	5	4.1
Passenger	JFK-CDG	5	4.2
Passenger	LHR-JNB	5	3.9
Passenger	MIA-GRU	4.8	4.9
Passenger	LAX-HNL	4.5	3
Passenger	BOS-LHR	4.2	4
Passenger	ATL-CDG	4.1	4
Passenger	LAX-AKL	4.1	4.9
Passenger	NRT-HNL	4	4.9
Passenger	ATL-AMS	4	4.1
Passenger	IAD-LHR	4	4.2

Passenger	JFK-AMS	4	3.9
Passenger	LAX-TPE	4	5
Passenger	LAX-SYD	3	5
Passenger	SFO-NRT	2.3	5
Passenger	SEA-NRT	2.2	5
Passenger	SEA-ICN	2.1	5
Passenger	LAX-MNL	2	4.9
Passenger	LAX-ICN	1.9	5
Private	MIA-JFK	5	2.5
Private	JFK-LAX	5	1
Private	JFK-PBI	5	2
Private	LHR-NCE	4	1
Private	IAH-JFK	4.2	1
Private	MIA-LHR	4	5
Private	LAX-LAS	4	1.2
Private	JFK-NAS	5	2.8
Private	JFK-IBZ	4.5	4.5
Private	JFK-LHR	5	4.5

Table A-1.5: Demand Elasticity for Mid-Haul (JFK-LHR)

	Passenger Demand				
	Mach 2	**Mach 3**	**Mach 4**	**Mach 5**	**Mach 6**
Ticket Price	**3.5 hours saved**	**4.5 hours saved**	**5 hours saved**	**5.25 hours saved**	**5.5 hours saved**
$850	2,169,211	2,246,049	2,234,228	2,210,585	2,210,585
$975	1,956,427	2,104,193	2,121,925	2,098,283	2,098,283
$1,275	1,454,021	1,678,626	1,790,929	1,838,214	1,891,410
$1,300	1,152,578	1,424,468	1,613,609	1,672,716	1,749,554
$1,700	969,348	1,164,399	1,288,523	1,365,362	1,424,468
$1,950	786,117	939,794	1,010,722	1,140,757	1,199,863
$2,550	661,993	756,564	839,313	927,973	963,437
$2,925	579,244	626,530	697,457	756,564	803,849
$3,250	472,852	567,423	632,440	685,636	750,653
$3,900	443,299	526,048	585,155	614,708	679,725
$4,250	336,907	419,657	478,763	526,048	608,798
$5,200	330,997	372,371	419,657	461,031	508,316
$5,850	319,175	342,818	384,193	437,389	466,942
$6,800	265,980	254,158	319,175	378,282	413,746
$7,800	224,605	236,426	292,577	301,443	366,461
$9,750	218,694	218,694	265,980	283,711	354,639
$10,000	195,052	177,320	224,605	230,516	295,533
$10,200	171,409	171,409	212,784	206,873	277,801
$10,400	159,588	165,498	189,141	183,230	242,337
$13,600	147,766	153,677	177,320	171,409	218,694

$15,000	135,945	141,856	171,409	159,588	189,141
$15,600	112,302	106,392	141,856	118,213	147,766
$20,000	100,481	94,570	112,302	100,481	112,302
$23,400	82,749	91,615	76,839	82,749	100,481
$30,000	70,928	88,660	59,107	76,839	82,749
$31,200	59,107	65,017	47,285	53,196	70,928
$50,000	47,285	53,196	35,464	35,464	41,375
$80,000	29,553	41,375	26,598	23,643	29,553
$120,000	11,821	23,643	17,732	17,732	11,821
$160,000	5,911	11,821	5,911	5,911	5,911

Table A-1.6: Demand Elasticity for Long-Haul (LAX-NRT)

	Passenger Demand				
	Mach 2	**Mach 3**	**Mach 4**	**Mach 5**	**Mach 6**
Ticket Price	***6 hours saved***	***7.75 hours saved***	***8.5 hours saved***	***9 hours saved***	***9.5 hours saved***
$1,000	663,127	671,922	670,163	675,440	670,163
$1,125	608,599	631,466	627,948	638,502	631,466
$1,500	473,160	513,616	547,036	562,866	564,625
$2,000	320,130	360,586	390,489	413,355	429,186
$2,250	262,085	295,505	316,612	346,515	374,658
$3,000	209,316	240,977	255,049	281,433	306,059
$3,375	177,655	211,075	209,316	218,111	240,977
$3,750	151,270	191,726	189,967	198,762	225,147
$4,500	142,476	175,896	174,137	172,378	198,762
$5,000	112,573	144,235	147,752	149,511	172,378
$6,000	107,296	119,609	126,645	131,922	140,717
$6,750	98,502	116,091	119,609	126,645	128,404
$8,000	82,671	84,430	96,743	107,296	116,091
$9,000	73,876	72,117	89,707	94,984	110,814
$11,250	72,117	68,599	86,189	93,225	105,537
$12,000	61,564	54,528	70,358	68,599	89,707
$15,000	52,769	47,492	52,769	58,046	75,635
$16,000	43,974	42,215	51,010	56,287	72,117
$18,000	36,938	39,577	47,492	49,251	58,046
$22,500	35,179	36,938	43,974	38,697	45,733

$27,000	33,420	36,059	35,179	34,300	38,697
$30,000	31,661	35,179	31,661	29,902	31,661
$36,000	28,143	31,661	24,625	24,625	24,625
$45,000	22,866	26,384	19,349	21,107	19,349
$75,000	19,349	17,590	12,313	15,831	17,590
$120,000	12,313	12,313	8,795	10,554	10,554
$180,000	7,036	7,036	5,277	5,277	7,036
$240,000	3,518	3,518	3,518	1,759	3,518

Table A-1.7: Demand Elasticity for Long-Haul (LAX-SIN)

	Passenger Demand				
	Mach 2	**Mach 3**	**Mach 4**	**Mach 5**	**Mach 6**
Ticket Price	***8.5 hours saved***	***11 hours saved***	***12 hours saved***	***12.75 hours saved***	***13.5 hours saved***
$850	95,171	98,506	99,276	100,558	98,763
$975	86,449	92,606	94,402	95,171	92,863
$1,275	72,084	77,214	82,088	83,884	85,423
$1,300	59,258	63,619	68,236	70,288	73,110
$1,700	48,483	52,331	60,027	63,619	67,979
$1,950	38,735	44,379	48,483	53,871	59,514
$2,550	31,296	34,888	36,427	39,762	45,405
$2,925	28,218	28,731	29,757	32,066	37,196
$3,250	23,857	25,909	27,705	29,244	33,861
$3,900	21,292	23,857	24,883	25,653	29,501
$4,250	17,957	19,496	20,522	22,061	27,448
$5,200	15,648	17,957	17,700	19,239	22,574
$5,850	14,365	17,444	17,444	18,470	21,035
$6,800	11,544	13,852	14,109	15,135	17,957
$7,800	11,287	12,826	13,596	12,826	16,418
$9,750	11,031	11,800	12,826	12,570	14,879
$10,000	9,235	9,748	10,005	10,774	12,570
$10,200	8,722	8,978	9,491	10,005	12,057
$10,400	7,696	8,209	7,952	8,722	11,031
$13,600	6,926	6,926	7,183	7,696	9,235

$15,000	5,900	6,157	6,413	6,157	7,183
$15,600	5,644	5,900	5,644	5,387	6,926
$20,000	5,387	5,644	5,131	5,131	5,644
$23,400	4,617	4,874	4,617	4,104	4,104
$30,000	4,104	4,361	4,104	3,848	3,591
$31,200	3,591	4,233	3,335	3,591	3,335
$50,000	3,078	4,104	3,078	2,822	2,052
$80,000	2,052	2,052	1,796	2,052	1,283
$120,000	770	1,539	1,539	1,539	770
$160,000	257	1,026	770	1,026	513

Table A-1.8: Consumer Elasticity for Expedited Shipping

Premium over 2-day shipping (Multiples)	One-day shipping	Same-day shipping	8-hour shipping	5-hour shipping	Less than 5-hour shipping
1x	100.00%	100.00%	100.00%	100.00%	100.00%
1.5x	38.55%	53.05%	54.20%	57.25%	59.16%
2x	9.92%	28.63%	39.31%	42.75%	46.18%
3x	2.29%	9.54%	22.14%	26.34%	30.92%
5x	0.76%	2.29%	6.11%	13.36%	17.18%
8x	0.38%	0.38%	2.29%	3.44%	9.16%
12x	0.38%	0.38%	0.38%	1.53%	3.44%
16x	0.38%	0.00%	0.00%	0.38%	1.91%

Table A-1.9: Estimating a Market for Mach 2 Private Aircraft

Market Size by Year	10% Market Cannibalization	30% Market Cannibalization	50% Market Cannibalization
2029	$2,488,500,000	$7,465,500,000	$12,442,500,000
2030	$2,609,938,800	$7,829,816,400	$13,049,694,000
2031	$2,737,303,813	$8,211,911,440	$13,686,519,067
2032	$2,870,884,240	$8,612,652,719	$14,354,421,198
2033	$3,010,983,390	$9,032,950,171	$15,054,916,952
2034	$3,157,919,380	$9,473,758,140	$15,789,596,899
2035	$3,312,025,846	$9,936,077,537	$16,560,129,228

Appendix 2 - Defining the Business Case Supporting Data

The following tables support the charts and analysis detailed in Section 2 of this report.

Table A-2.1: ROSETTA Model Sample Predictions & Validation Data

	Boom	Concorde	TU-144	L-2000	B-2707	HSCT
OEW (lbm)	-	173,500	218,699	238,000	287,500	302,000
MTOW (lbm)	170,000	408,000	456,357	590,000	675,000	753,000
Model OEW	76,734	137,630	150,671	305,310	303,048	326,320
Model MTOW	175,428	298,368	316,368	734,849	697,302	817,919

Table A-2.2: Estimates of Gate-to-Gate Travel Times for High-Speed Aircraft

	Time (hour)	Mach 0.85	Mach 2	Mach 3	Mach 4	Mach 5	Mach 6
Distance (nmi)	**500**	2.2					
	1000	3.2	1.9				
	1500	4.2	2.3	1.8	1.5		
	2000	5.2	2.8	2.1	1.7	1.5	
	3000	7.2	3.6	2.6	2.1	1.8	1.6
	4000	9.2	4.5	3.2	2.6	2.2	1.9
	5000	11.1	5.4	3.8	3.0	2.5	2.2
	6000	13.1	6.3	4.4	3.4	2.9	2.5
	7000	15.1	7.1	5.0	3.9	3.2	2.8
	8000	17.1	8.0	5.6	4.3	3.6	3.1

Table A-2.3: Sample IRR Data from ROSETTA Model

Range	Mach	Airframe IRR	Engine IRR	Major Airline IRR	Average IRR	Ticket Price	Total Aircraft Sold	Fleet Size	Total Pax/Year	MTOW	Aircraft Price	Engine Count
3,000	2	13.86%	13.79%	13.64%	13.76%	$1,000	320	66	2,609,885	111,000	$78.06	2
3,500	2	21.71%	21.77%	21.65%	21.71%	$1,431	404	130	4,484,077	124,000	$114.00	2
4,000	2	24.92%	24.49%	24.94%	24.78%	$1,958	385	128	3,958,603	140,000	$137.92	2
4,500	2	26.69%	26.78%	26.64%	26.70%	$2,485	391	131	3,644,258	159,000	$156.97	2
5,000	2	27.43%	27.60%	27.61%	27.55%	$2,916	392	132	3,505,110	182,000	$171.32	2
5,500	2	26.93%	27.20%	27.14%	27.09%	$3,155	382	128	3,401,042	211,000	$187.00	2
6,000	2	29.60%	29.79%	29.76%	29.72%	$4,018	340	115	2,894,625	249,000	$219.77	3
6,500	2	26.58%	26.62%	26.59%	26.59%	$4,113	358	123	3,062,101	300,000	$228.13	3
7,000	2	26.20%	26.24%	26.22%	26.22%	$5,215	248	98	2,421,304	372,000	$308.74	4
3,000	3	16.26%	13.86%	15.97%	15.36%	$1,383	234	46	1,757,943	131,000	$114.03	2
3,500	3	21.27%	21.34%	21.40%	21.34%	$1,718	332	98	3,627,189	152,000	$141.19	2
4,000	3	24.61%	23.45%	24.19%	24.09%	$2,389	305	92	3,130,459	179,000	$184.18	2
4,500	3	26.22%	26.44%	26.41%	26.36%	$3,155	273	84	2,767,864	216,000	$228.04	3
5,000	3	25.61%	26.21%	25.47%	25.76%	$3,730	251	86	2,680,938	267,000	$265.77	3
5,500	3	25.75%	25.82%	25.76%	25.78%	$5,023	195	74	2,040,318	342,000	$336.05	4
6,000	3	24.66%	24.77%	24.75%	24.73%	$6,556	173	64	1,685,275	467,000	$432.46	4
6,500	3	22.28%	22.52%	22.43%	22.41%	$9,717	145	51	1,186,566	715,000	$616.42	4
3,000	4	16.18%	15.85%	15.42%	15.82%	$1,479	234	47	1,815,583	140,000	$127.49	2
3,500	4	23.07%	22.96%	22.96%	22.99%	$2,197	300	89	3,156,969	166,000	$181.22	2
4,000	4	25.18%	24.95%	25.20%	25.11%	$2,916	279	86	2,962,737	200,000	$229.06	2
4,500	4	26.03%	25.87%	25.89%	25.93%	$3,682	249	85	2,813,835	249,000	$275.91	3

5,000	4	25.04%	25.78%	25.71%	25.51%	$4,832	208	80	2,500,716	321,000	$346.89	4
5,500	4	25.85%	25.66%	25.85%	25.79%	$6,556	182	68	1,925,641	442,000	$448.19	4
6,000	4	23.57%	23.57%	23.59%	23.58%	$9,526	149	53	1,427,428	689,000	$654.98	4
3,000	5	16.19%	16.12%	16.18%	16.16%	$1,671	209	41	1,583,085	150,000	$149.74	2
3,500	5	24.15%	24.15%	24.01%	24.10%	$2,533	270	76	2,692,253	182,000	$211.65	2
4,000	5	25.88%	25.85%	25.67%	25.80%	$3,682	199	69	2,308,355	227,000	$299.23	3
4,500	5	24.75%	24.87%	24.68%	24.77%	$4,497	195	74	2,299,325	295,000	$346.53	3
5,000	5	25.83%	25.77%	25.46%	25.69%	$6,652	171	63	1,787,152	410,000	$473.02	4
5,500	5	22.82%	22.76%	22.86%	22.81%	$9,717	135	47	1,257,810	646,000	$693.50	4
3,000	5.25	14.69%	12.92%	13.09%	13.57%	$1,910	201	38	1,405,140	162,000	$153.71	2
3,500	5.25	19.23%	19.28%	19.40%	19.30%	$2,533	271	76	2,791,489	202,000	$198.27	2
4,000	5.25	21.62%	21.49%	21.61%	21.57%	$3,826	219	71	2,342,751	261,000	$285.26	3
4,500	5.25	24.74%	24.75%	24.74%	24.74%	$7,227	149	53	1,527,238	362,000	$516.62	4
5,000	5.25	22.68%	22.11%	22.46%	22.42%	$9,957	134	46	1,265,273	571,000	$691.35	4
3,000	5.5	14.73%	13.28%	14.41%	14.14%	$2,006	199	37	1,373,889	166,000	$158.20	2
3,500	5.5	20.12%	20.27%	20.06%	20.15%	$2,772	267	75	2,646,671	209,000	$213.89	2
4,000	5.5	20.65%	20.73%	20.68%	20.69%	$4,113	182	68	2,272,487	276,000	$324.45	3
4,500	5.5	24.79%	24.70%	24.78%	24.75%	$7,897	149	53	1,492,653	394,000	$546.77	4
5,000	5.5	20.82%	20.76%	20.78%	20.79%	$10,867	135	47	1,213,583	659,000	$712.29	4

Table A-2.4: ROSETTA Model Sensitivity Data

		Pax	Range	Mach	Airframe IRR	Engine IRR	Major Airline IRR	Average IRR	Min IRR	Difference
GOVERNMENT INVESTMENT	BASELINE - $0	50	5,000	2	27.43%	27.60%	27.61%	**27.55%**	27.43%	0.18%
		50	5,000	3	25.61%	26.21%	25.47%	**25.76%**	25.47%	0.74%
		50	5,000	4	25.04%	25.78%	25.71%	**25.51%**	25.04%	0.75%
		50	5,000	5	25.83%	25.77%	25.46%	**25.69%**	25.46%	0.38%
		50	5,000	5.25	22.68%	22.11%	22.46%	**22.42%**	22.11%	0.57%
		50	5,000	5.5	20.82%	20.76%	20.78%	**20.79%**	20.76%	0.07%
	$500M	50	5,000	2	28.71%	31.37%	27.62%	**29.24%**	27.62%	3.75%
		50	5,000	3	26.54%	29.27%	25.45%	**27.09%**	25.45%	3.82%
		50	5,000	4	25.83%	28.71%	25.68%	**26.74%**	25.68%	3.03%
		50	5,000	5	26.46%	27.75%	25.48%	**26.56%**	25.48%	2.27%
		50	5,000	5.25	23.06%	23.16%	22.50%	**22.90%**	22.50%	0.66%
		50	5,000	5.5	21.16%	21.89%	20.76%	**21.27%**	20.76%	1.13%
	$1,000M	50	5,000	2	30.14%	35.91%	27.62%	**31.22%**	27.62%	8.29%
		50	5,000	3	27.54%	32.76%	25.45%	**28.58%**	25.45%	7.32%
		50	5,000	4	26.66%	31.96%	25.68%	**28.10%**	25.68%	6.28%
		50	5,000	5	27.12%	30.11%	25.48%	**27.57%**	25.48%	4.63%
		50	5,000	5.25	23.48%	24.35%	22.50%	**23.44%**	22.50%	1.86%
		50	5,000	5.5	21.51%	23.00%	20.76%	**21.76%**	20.76%	2.24%

Table A-2.4: ROSETTA Model Sensitivity Data (Continued)

		Pax	Range	Mach	Airframe IRR	Engine IRR	Major Airline IRR	Average IRR	Min IRR	Difference
FUEL PRICE	BASELINE - $4.06	50	5,000	2	27.43%	27.60%	27.61%	**27.55%**	27.43%	0.18%
		50	5,000	3	25.61%	26.21%	25.47%	**25.76%**	25.47%	0.74%
		50	5,000	4	25.04%	25.78%	25.71%	**25.51%**	25.04%	0.75%
		50	5,000	5	25.83%	25.77%	25.46%	**25.69%**	25.46%	0.38%
		50	5,000	5.25	22.68%	22.11%	22.46%	**22.42%**	22.11%	0.57%
		50	5,000	5.5	20.82%	20.76%	20.78%	**20.79%**	20.76%	0.07%
	$3.00	50	5,000	2	27.43%	27.53%	29.76%	**28.24%**	27.43%	2.33%
		50	5,000	3	25.62%	26.29%	28.72%	**26.88%**	25.62%	3.09%
		50	5,000	4	25.05%	25.91%	28.71%	**26.55%**	25.05%	3.66%
		50	5,000	5	25.83%	25.67%	28.51%	**26.67%**	25.67%	2.83%
		50	5,000	5.25	22.65%	22.06%	23.85%	**22.85%**	22.06%	1.79%
		50	5,000	5.5	20.81%	20.87%	22.34%	**21.34%**	20.81%	1.53%
	$7.50	50	5,000	2	27.43%	27.53%	17.55%	**24.17%**	17.55%	9.98%
		50	5,000	3	25.62%	26.29%	5.29%	**19.07%**	5.29%	21.01%
		50	5,000	4	25.05%	25.91%	8.38%	**19.78%**	8.38%	17.52%
		50	5,000	5	25.83%	25.67%	9.40%	**20.30%**	9.40%	16.43%
		50	5,000	5.25	22.65%	22.06%	17.22%	**20.64%**	17.22%	5.43%
		50	5,000	5.5	20.81%	20.87%	14.33%	**18.67%**	14.33%	6.54%

Table A-2.4: ROSETTA Model Sensitivity Data (Continued)

		Pax	Range	Mach	Airframe IRR	Engine IRR	Major Airline IRR	Average IRR	Min IRR	Difference
MARKET SIZE	**BASELINE - 1x**	50	5,000	2	27.43%	27.60%	27.61%	**27.55%**	27.43%	0.18%
		50	5,000	3	25.61%	26.21%	25.47%	**25.76%**	25.47%	0.74%
		50	5,000	4	25.04%	25.78%	25.71%	**25.51%**	25.04%	0.75%
		50	5,000	5	25.83%	25.77%	25.46%	**25.69%**	25.46%	0.38%
		50	5,000	5.25	22.68%	22.11%	22.46%	**22.42%**	22.11%	0.57%
		50	5,000	5.5	20.82%	20.76%	20.78%	**20.79%**	20.76%	0.07%
	0.5x	50	5,000	2	23.78%	17.08%	4.06%	**14.97%**	4.06%	19.72%
		50	5,000	3	21.14%	16.55%	0.00%	**12.56%**	0.00%	21.14%
		50	5,000	4	19.12%	13.74%	0.00%	**10.95%**	0.00%	19.12%
		50	5,000	5	21.38%	15.91%	0.37%	**12.55%**	0.37%	21.01%
		50	5,000	5.25	20.24%	16.00%	0.00%	**12.08%**	0.00%	20.24%
		50	5,000	5.5	18.77%	14.91%	0.00%	**11.23%**	0.00%	18.77%
	1.5x	50	5,000	2	32.05%	39.39%	31.00%	**34.15%**	31.00%	8.39%
		50	5,000	3	29.17%	37.19%	29.71%	**32.02%**	29.17%	8.01%
		50	5,000	4	28.54%	38.03%	29.78%	**32.12%**	28.54%	9.49%
		50	5,000	5	27.64%	34.02%	30.73%	**30.80%**	27.64%	6.37%
		50	5,000	5.25	27.27%	31.59%	29.28%	**29.38%**	27.27%	4.32%
		50	5,000	5.5	25.85%	30.72%	29.03%	**28.53%**	25.85%	4.87%

Table A-2.4: ROSETTA Model Sensitivity Data (Continued)

		Pax	Range	Mach	Airframe IRR	Engine IRR	Major Airline IRR	Average IRR	Min IRR	Difference
ENGINE DDT&E COST	BASELINE	50	5,000	2	27.43%	27.60%	27.61%	**27.55%**	27.43%	0.18%
		50	5,000	3	25.61%	26.21%	25.47%	**25.76%**	25.47%	0.74%
		50	5,000	4	25.04%	25.78%	25.71%	**25.51%**	25.04%	0.75%
		50	5,000	5	25.83%	25.77%	25.46%	**25.69%**	25.46%	0.38%
		50	5,000	5.25	22.68%	22.11%	22.46%	**22.42%**	22.11%	0.57%
		50	5,000	5.5	20.82%	20.76%	20.78%	**20.79%**	20.76%	0.07%
	-25%	50	5,000	2	27.43%	36.70%	27.62%	**30.58%**	27.43%	9.27%
		50	5,000	3	25.62%	34.71%	25.45%	**28.59%**	25.45%	9.27%
		50	5,000	4	25.05%	34.71%	25.68%	**28.48%**	25.05%	9.66%
		50	5,000	5	25.83%	33.94%	25.48%	**28.42%**	25.48%	8.46%
		50	5,000	5.25	22.65%	28.94%	22.50%	**24.70%**	22.50%	6.44%
		50	5,000	5.5	20.81%	27.72%	20.76%	**23.09%**	20.76%	6.96%
	+25%	50	5,000	2	27.43%	21.21%	27.62%	**25.42%**	21.21%	6.41%
		50	5,000	3	25.62%	20.62%	25.45%	**23.89%**	20.62%	5.01%
		50	5,000	4	25.05%	20.06%	25.68%	**23.60%**	20.06%	5.62%
		50	5,000	5	25.83%	20.24%	25.48%	**23.85%**	20.24%	5.59%
		50	5,000	5.25	22.65%	17.62%	22.50%	**20.92%**	17.62%	5.03%
		50	5,000	5.5	20.81%	16.53%	20.76%	**19.37%**	16.53%	4.28%

Table A-2.4: ROSETTA Model Sensitivity Data (Continued)

		Pax	Range	Mach	Airframe IRR	Engine IRR	Major Airline IRR	Average IRR	Min IRR	Difference
AIRCRAFT PURCHASED BY U.S. GOVERNMENT	**BASELINE - 20**	50	5,000	2	27.43%	27.60%	27.61%	**27.55%**	27.43%	0.18%
		50	5,000	3	25.61%	26.21%	25.47%	**25.76%**	25.47%	0.74%
		50	5,000	4	25.04%	25.78%	25.71%	**25.51%**	25.04%	0.75%
		50	5,000	5	25.83%	25.77%	25.46%	**25.69%**	25.46%	0.38%
		50	5,000	5.25	22.68%	22.11%	22.46%	**22.42%**	22.11%	0.57%
		50	5,000	5.5	20.82%	20.76%	20.78%	**20.79%**	20.76%	0.07%
	10	50	5,000	2	26.64%	26.84%	27.35%	**26.94%**	26.64%	0.70%
		50	5,000	3	26.80%	27.00%	25.63%	**26.48%**	25.63%	1.38%
		50	5,000	4	25.89%	25.81%	26.97%	**26.22%**	25.81%	1.17%
		50	5,000	5	23.95%	23.14%	25.71%	**24.27%**	23.14%	2.56%
		50	5,000	5.25	24.06%	22.16%	23.46%	**23.23%**	22.16%	1.91%
		50	5,000	5.5	19.31%	18.16%	21.29%	**19.58%**	18.16%	3.13%
	0	50	5,000	2	28.04%	27.31%	26.98%	**27.44%**	26.98%	1.06%
		50	5,000	3	26.03%	25.76%	23.68%	**25.16%**	23.68%	2.35%
		50	5,000	4	25.22%	24.56%	24.37%	**24.72%**	24.37%	0.85%
		50	5,000	5	23.13%	21.59%	22.93%	**22.55%**	21.59%	1.54%
		50	5,000	5.25	23.01%	19.80%	19.32%	**20.71%**	19.32%	3.69%
		50	5,000	5.5	21.45%	18.86%	17.70%	**19.34%**	17.70%	3.75%

Table A-2.4: ROSETTA Model Sensitivity Data (Continued)

		Pax	Range	Mach	Airframe IRR	Engine IRR	Major Airline IRR	Average IRR	Min IRR	Difference
CHARTER MARKET SIZE	BASELINE - 1x	50	5,000	2	27.43%	27.60%	27.61%	**27.55%**	27.43%	0.18%
		50	5,000	3	25.61%	26.21%	25.47%	**25.76%**	25.47%	0.74%
		50	5,000	4	25.04%	25.78%	25.71%	**25.51%**	25.04%	0.75%
		50	5,000	5	25.83%	25.77%	25.46%	**25.69%**	25.46%	0.38%
		50	5,000	5.25	22.68%	22.11%	22.46%	**22.42%**	22.11%	0.57%
		50	5,000	5.5	20.82%	20.76%	20.78%	**20.79%**	20.76%	0.07%
	0.5x	50	5,000	2	25.85%	25.44%	27.61%	**26.30%**	25.44%	2.16%
		50	5,000	3	24.55%	24.92%	25.47%	**24.98%**	24.55%	0.92%
		50	5,000	4	24.51%	25.56%	25.71%	**25.26%**	24.51%	1.20%
		50	5,000	5	24.79%	25.31%	25.23%	**25.11%**	24.79%	0.52%
		50	5,000	5.25	21.80%	21.65%	22.46%	**21.97%**	21.65%	0.80%
		50	5,000	5.5	20.10%	20.29%	20.78%	**20.39%**	20.10%	0.67%
	0.0x	50	5,000	2	24.13%	23.06%	27.61%	**24.93%**	23.06%	4.55%
		50	5,000	3	22.99%	22.83%	25.43%	**23.75%**	22.83%	2.60%
		50	5,000	4	24.54%	25.23%	25.71%	**25.16%**	24.54%	1.18%
		50	5,000	5	24.91%	25.15%	25.36%	**25.14%**	24.91%	0.45%
		50	5,000	5.25	21.75%	21.24%	22.46%	**21.81%**	21.24%	1.22%
		50	5,000	5.5	20.24%	20.09%	20.93%	**20.42%**	20.09%	0.84%

Table A-2.5: Estimated Annualized Major Airliner Operator Costs Based on Fuel Prices per Gallon

Cost Breakdown - $4.06/Gallon		**Cost Breakdown - $3.00/Gallon**		**Cost Breakdown - $7.50/Gallon**	
Fixed Costs	$252,570,000	Fixed Costs	$270,470,000	Fixed Costs	$198,880,000
Variable Costs	$1,594,300,000	Variable Costs	$1,703,320,000	Variable Costs	$1,229,000,000
Fuel Costs	$5,208,300,000	Fuel Costs	$4,120,200,000	Fuel Costs	$7,510,100,000
AFA Costs	$2,733,300,000	AFA Costs	$2,894,100,000	AFA Costs	$2,234,200,000
SGA Costs	$1,761,900,000	SGA Costs	$1,617,900,000	SGA Costs	$2,011,000,000
Specialty Taxes/Fees	$249,000,000	Specialty Taxes/Fees	$265,400,000	Specialty Taxes/Fees	$198,500,000
Total Cost	**$11,799,370,000**	**Total Cost**	**$10,871,390,000**	**Total Cost**	**$13,381,680,000**
Total Revenue	**$17,873,000,000**	**Total Revenue**	**$18,023,000,000**	**Total Revenue**	**$17,518,000,000**
Profit	**$6,073,630,000**	**Profit**	**$7,151,610,000**	**Profit**	**$4,136,320,000**

FIGURE A-2.1

Aircraft Sideline Noise at Takeoff Conditions

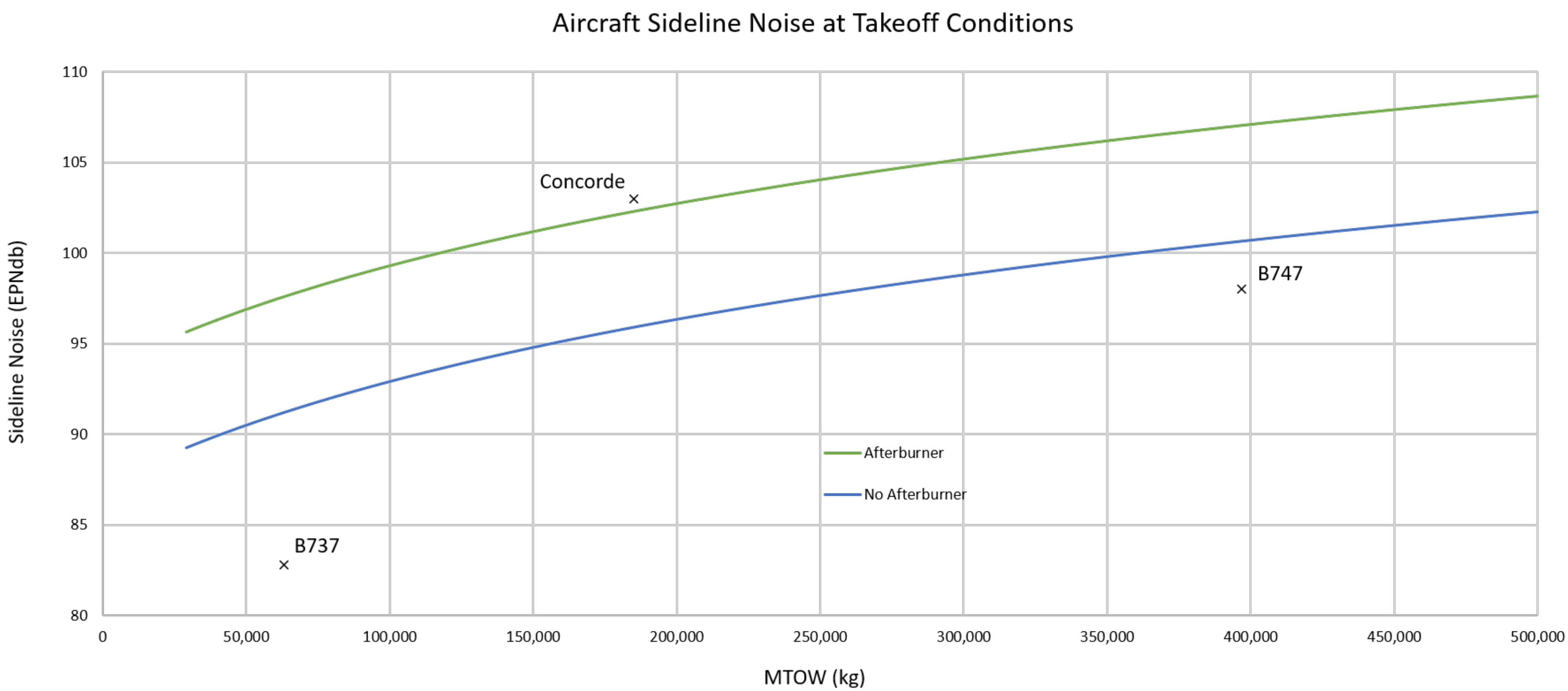
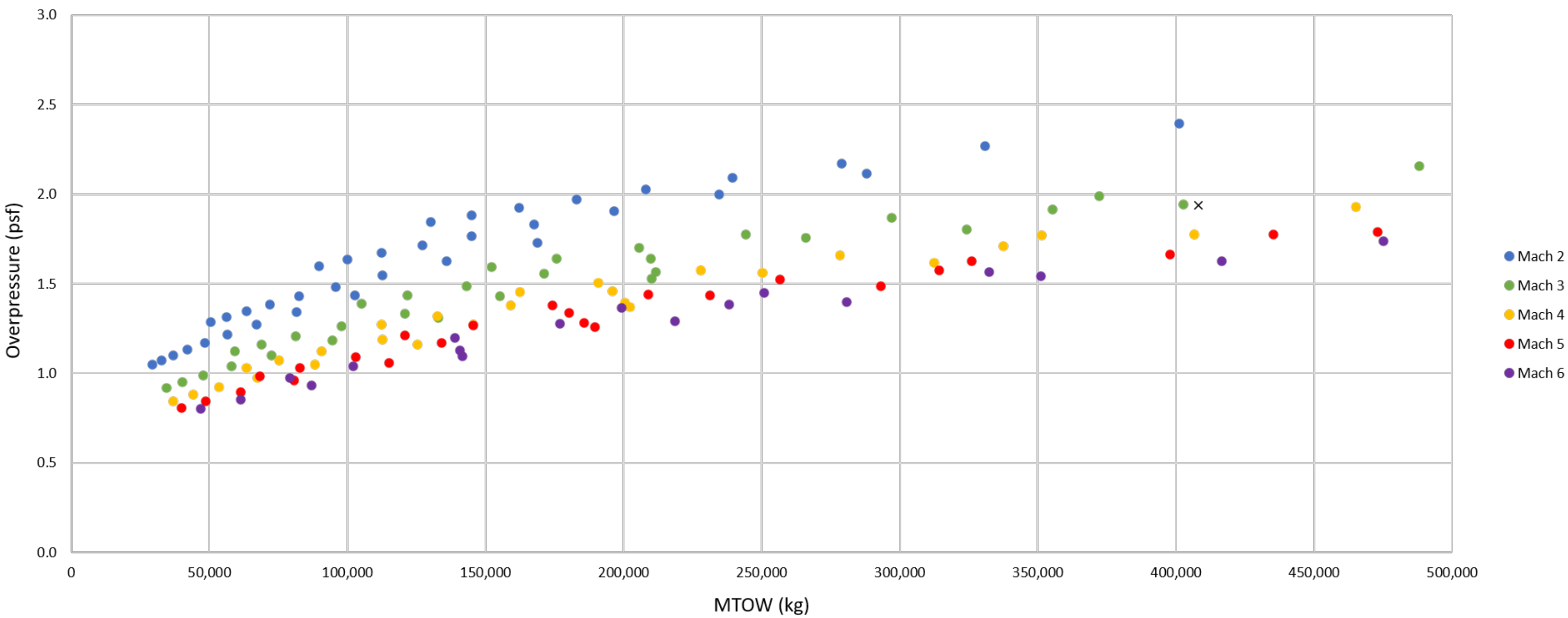


FIGURE A-2.2

Overpressure on the Ground from Aircraft at its Cruise Conditions



Appendix 3 – Barriers Analysis Supporting Data

The following tables support the charts and analysis detailed in Section 1 of this report.

Table A-3.1: Sonic Boom Restrictions Scoring

Sonic Boom Restrictions	Assigned Score	Rationale
Regulation	3	Among the most rigid of all aircraft regulation, the U.S. and international community largely prohibit supersonic flight over land unless by exception.
Technology	2	Companies are developing low-boom airframes and operating models that could mitigate or eliminate this issue.
Investment	3	This is a core engineering problem for current high-speed aircraft developers and developing this technology impacts both the airframe and engine development and certification costs. For this study, we have eliminated routes with overland super/hyper sonic flight from the market analysis. It will be a technical and business decision for operators to invest in low boom technologies to capture additional routes and passenger volumes.
Ease of Use	2	The body / shape of the aircraft will be different from current subsonic aircraft, which will moderately impact the customer experience.
Community	3	Sonic boom is a major concern for communities, and they are highly impacted by and sensitive to sonic booms.
Total Score	**13**	

Table A-3.2: Aircraft Certification Scoring

Aircraft Certification	Assigned Score	Rationale
Regulation	3	Today's regulations are written primarily for subsonic aircraft. The extension of use may or may not be deemed allowable by domestic and international regulatory entities. If regulations need to be developed for super/hypersonic flight systems, this could cause delay in certification programs and ultimately delay high-speed flight service starting in the market.
Technology	3	Clear regulatory requirements for this flight regime do not exist today and system developers cannot control the speed of development of such by domestic and international authorities. The Concorde flew because it received an exception. This represents a high risk to aspiring operators.
Investment	3	Historically, aircraft certification in the U.S. has been very slow and expensive for developers to prove air worthiness. Both create conditions that work against business cases that close.
Ease of Use	1	The certification process could require that adjustments are made to the airframe or interior, which could impact the customer experience, but it is unlikely that this impact will result in significant degradation.
Community	2	The community is likely to be materially concerned with the safety of new aircraft on the market, particularly given recent events with the Boeing 737 MAX. Initial trepidation would be expected to decline within the first few years of operation.
Total Score	**12**	

Table A-3.3: Landing & Takeoff Noise Scoring

Landing & Takeoff Noise	Assigned Score	Rationale
Regulation	3	Airports have tight noise rules and will simply restrict operation of aircraft that would violate these rules unless regulations are modified to allow higher levels for high-speed aircraft.
Technology	2	High-speed aircraft companies are currently considering engine noise with the goal of minimizing it as they develop the aircraft and engines.
Investment	2	The solution will require investment in developing quieter engine technology, which will have notable impact on development costs.
Ease of Use	2	Aircraft noise at airports could impact the customer experience if there are unique operating restrictions set in place for takeoff / landing [operational windows, etc.].
Community	3	Noise is one of the most significant concerns for communities around airports, and high-speed aircraft will likely have a distinct noise signature, which may generate negative public sentiment.
Total Score	**12**	

Table A-3.4: Emissions Standards Scoring

Emissions Standards	Assigned Score	Rationale
Regulation	2	International agreements have currently set efficiency standards that aircraft will need to meet in the future. Most modern subsonic aircraft have been designed proactively to meet these measures but meeting them is not currently necessary.
Technology	2	high-speed aircraft manufacturers are incorporating fuel efficiency into their development process. This is an ongoing effort. It is unclear of existing efficiency standards designed for subsonic aircraft will apply to this class of service.
Investment	2	Addressing this issue will require engineering resources to design more fuel-efficient high-speed engine technology; this increases engine development costs.
Ease of Use	1	No material impact on customer experience; only thing that is changing is the technology behind the product, not the product itself.
Community	2	Communities are significantly concerned with emissions such as NOx and CO2, and this trend is growing.
Total Score	**9**	

Table A-3.5: Export Controls Scoring

Export Controls	Assigned Score	Rationale
Regulation	3	All regulation must be satisfied, no exceptions.
Technology	1	This does not require a complex solution; companies must simply comply and existing resources/professionals are available to ensure this.
Investment	2	Acquiring staff that can develop and enforce export control compliance efforts will be an overhead cost that must be carried by U.S.-based companies. This cost will be low compared to DDT&E costs to field systems and annual operational costs.
Ease of Use	2	Export controls could limit how and where the aircraft operates, having a moderate impact on the customer experience.
Community	1	The exportation and sharing of new industrial technologies are an ongoing concern and current political issue.
Total Score	**9**	

Table A-3.6: Depressurization Event Scoring

Depressurization Event	Assigned Score	Rationale
Regulation	1	Flight safety solutions such as cabin pressurization are authorized through the aircraft certification program. This would not pose additional regulatory burden to high-speed aircraft if they pass through the certification program.
Technology	1	Commercial subsonic aircraft have largely resolved the issue of pressurization; the Concorde also had no issues with this, indicating precedent that solutions exist on the market. Further, the severity of the impact of this risk is entirely driven by planned operating altitude which is aircraft specific. Part of the mitigation approach can be addressed by operational workarounds [descend altitude if cabin pressure loss is sensed].
Investment	2	Given these aircraft will likely operate above 50,000 feet, the atmospheric pressure conditions are likely to be significantly more demanding than subsonic aircraft, which could demand advancements in technology, or improvements / redundancies for existing pressurization systems. This will increase R&D costs for these aircraft.
Ease of Use	2	At ultra-high altitudes, additional equipment for pressurization may be required, which could impact the customer experience.
Community	2	Concerns over the impacts of high-altitude flight on human health could generate public concern, particularly given existing media coverage of historical issues with U-2 pilots and the Armstrong Limit (at 62,000 feet the boiling temperature for water becomes the same as the natural human body temperature which causes mild to severe health issues).
Total Score	**8**	

Table A-3.7: Alternative Fuels Scoring

Alternative Fuels	Assigned Score	Rationale
Regulation	2	Interviews reflect that supersonic aircraft developers are working to utilize fuels to avoid regulatory, technology and investment impacts. Hypersonic systems may require exotic fuels which could be use constrained due to federal, state and local regulations in the U.S. as well as international regulations at destination airports.
Technology	2	Based on stakeholder interviews, existing fuels on the market can meet the needs of most high-speed aircraft in development; only hypersonic aircraft will require exotic fuels.
Investment	2	Since the solution exists on the market today, investment in development, certification, storage and operational use of new fuels is not needed for supersonic aircraft in development. Exotic fuels potentially needed for hypersonic systems could require significant investment to operationalize at each airport in the route tree.
Ease of Use	1	Fuel input is unlikely to directly impact the customer experience.
Community	1	The public is broadly concerned with the issue of emissions and pollution, and how this is being addressed via the fuels powering aircraft and the transportation and storage of new fuels through their communities.
Total Score	**8**	

Table A-3.8: International Laws Scoring

International Laws	Assigned Score	Rationale
Regulation	2	Businesses do not have to comply with all international laws and standards; for example, some countries banned the Concorde, but it still successfully operated on routes for which it was allowed.
Technology	2	ICAO is currently reviewing potential new standards for high-speed aircraft, which could establish a standard set of guidelines for the international community to follow.
Investment	2	Companies will need to invest in personnel with expertise in international aerospace regulation in order to ensure compliance in the markets of focus.
Ease of Use	1	It is unlikely that new international standards would pose a significant disruption to the customer experience at today's airports; interviews with SMEs have indicated that this type of service would largely need to be plug-and-play from a regulatory standpoint and seamlessly integrate into airports to succeed.
Community	1	If aircraft meet standards of the respective region, communities are unlikely to be highly concerned.
Total Score	**8**	

Table A-3.9: Heat Sensitivity Scoring

Heat Sensitivity	Assigned Score	Rationale
Regulation	1	All flight safety componentry will be inspected intervals per regulations and operators' internal requirements. New materials will drive higher certification costs but may not drive inspection costs unless they prove to be problematic.
Technology	2	Multiple companies exist that are developing heat resistant materials for high-speed aircraft.
Investment	2	As part of the broader R&D effort for high-speed aircraft, materials that address heat sensitivity will require capital outlay to develop.
Ease of Use	2	Materials could impact the make of the plane, such as the size and number of windows. This could have an impact on the customer experience while flying in the aircraft.
Community	1	Society is less likely to be concerned about the materials in the aircraft, if it meets regulatory / safety standards.
Total Score	**8**	

Table A-3.10: NAS Integration Scoring

NAS Integration	Assigned Score	Rationale
Regulation	2	While the Concorde established precedent that a supersonic aircraft service can integrate with the NAS, modern high-speed air service providers will need to navigate a more complex and higher-volume NAS landscape, and more complex oceanic airspace, thereby presenting potential complications as these aircraft seek to establish regular routes.
Technology	1	Integrating into the NAS is not as much a technology or policy issue; rather, it is a logistical issue that air navigation service providers must coordinate with airlines and airports. The NAS infrastructure exists to support a wide variety of vehicles. High-speed vehicles will require new separation standards, but the Concorde provides precedence on how to approach this.
Investment	1	Since the issue is primarily logistics-oriented, it is unlikely to demand a major investment in human capital or physical infrastructure.
Ease of Use	2	Logistical considerations could impact departure / arrival times, which may have a moderate effect on the customer experience, especially during busy air traffic times.
Community	1	Communities are unlikely to be concerned with air traffic logistics.
Total Score	**7**	

Table A-3.11: Anomalous Radiation Scoring

Anomalous Radiation	Assigned Score	Rationale
Regulation	2	Aircraft such as the Concorde have historically partially satisfied regulation by equipping sensors on the aircraft do detect and monitor radiation levels.
Technology	1	Solutions exist to monitor and protect passengers and aircraft instruments from space weather.
Investment	1	Aircraft may need to be outfitted with additional equipment that can monitor and protect against space weather; however, this is less likely to be a major cost as compared to other items such as fuel expenses, or aircraft certification.
Ease of Use	1	Crewmembers and frequent flyers would be most susceptible to health risks posed by sustained exposure to relatively higher levels of radiation as compared with those flying on subsonic aircraft. However, this will likely be addressed through limitations on frequency and total number of flights and won't directly impact the in-flight customer experience.
Community	2	Health risks from space weather, even if mitigated via technology, could generate negative public perception and impact willingness to use the service.
Total Score	**7**	

Table A-3.12: Flight Shaming Scoring

Flight Shaming	Assigned Score	Rationale
Regulation	1	This is primarily a social issue; regulations do not restrict people from traveling based on their carbon footprint.
Technology	1	This issue does create hard constraints for businesses for entering the market.
Investment	2	Higher fuel consumption for supersonic and hypersonic flight cannot be eliminated technically in the foreseeable future. Companies can address negative public perceptions, and a likely course of action will be to engage in marketing campaigns. This will carry additional expense.
Ease of Use	1	Addressing public perception / negative sentiment is unlikely to alter the customer experience; it is a business function rather than a product function.
Community	2	Communities are broadly concerned with this issue and political activist campaigns are particularly focused on emissions from airlines. It is expected that carbon footprint concerns may eliminate certain classes of potential customers but will not significantly affect expected passenger volumes as is seen with air travel today.
Total Score	**7**	

Table A-3.13: Runway Length Scoring

Runway Length	Assigned Score	Rationale
Regulation	1	This is not a regulatory issue, but a technology issue.
Technology	3	Airports may have the option to upgrade infrastructure, should they choose to do so.
Investment	1	The logical routes that would host initial high-speed aircraft transport services are typically crown jewels with robust existing infrastructure that would meet the runway length standards required by these aircraft.
Ease of Use	1	Not a significant factor impacting the customer experience.
Community	1	Passengers are unlikely to consider / be worried about this, as it is an airport infrastructure matter, and if rules are followed, there is not safety risk.
Total Score	**7**	

Table A-3.14: Time Zone Gaps Scoring

Time Zone Gaps	Assigned Score	Rationale
Regulation	1	Not a regulatory issue.
Technology	1	The solution largely rests on scheduling & logistics; it does not require a new technology or process to address.
Investment	1	The solution is unlikely to demand any major investment in new technology or processes.
Ease of Use	2	The issue moderately impacts consumers; some flights could encounter this problem, while others would be a seamless experience.
Community	1	This is not a contentious issue; it is a potential inconvenience to passengers for which they have the option to accept or choose another service.
Total Score	**6**	

Table A-3.15: Pilot Certification Scoring

Pilot Certification	Assigned Score	Rationale
Regulation	1	Currently, no regulation exists that specified unique criteria for civil high-speed aircraft pilots. Therefore, existing pilots could be selected to fly such an aircraft with specific aircraft type training as is done today.
Technology	1	Not currently a regulatory issue per assignment in compliance category, and further, pilots exist today with supersonic training and capability to transfer skills into commercial high-speed air services.
Investment	1	Pilots of high-speed civilian aircraft may require a premium salary for flying a unique class of jet; however, this is unlikely to significantly impact cost dynamics when compared to other major expenses, such as fuel costs or R&D, and amortization costs.
Ease of Use	1	Pilot certification is unlikely to directly impact the customer experience.
Community	1	Society is unlikely to focus on the logistics of pilot training, assuming pilots satisfy current and future regulation.
Total Score	**6**	

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