Independent Market Study: Commercial Hypersonic Transportation

Executive Summary

DATSS TO 36 Delivery Order 80HQTR20F0177

Ms. Carie Mullins, Technical Lead, Bryce Space and Technology

Dr. Ronald Lehmer, Task Order Manager, SAIC

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Study Overview

Market Characterization

Task 1: Define the Market

Task 2: Define the Business Case

Task 3: Identify the Barriers

Study Overview

Methodology

Determine the economic viability of commercial hypersonic point-to-point transportation, identifying business models, markets, and regulatory dynamics, and barriers that will affect technology investment and trades

Define the Market for Commercial Hypersonics

- Segments: commercial, private jet, cargo
- Passenger demand for HNWI ($5M+) and highly compensated execs ($1M+)
- Over 800 long haul (over 5 hours) city pairs considered, viable routes included
- Demand reaches 2019 (pre-COVID) rates in 2024
- Limited cargo market

Define the Business Case and Operations Requirements

- Compare increased revenue associated with value of time saved to increased cost associated with high-speed aircraft
- Consider manufacturer/ airline dynamics
- Estimate supportable RDT&E

SOW specifies Mach 2 to Mach 7 range

Barrier Analysis

- Airport infrastructure
- Air traffic management
- Certification (U.S.)
- Environmental impacts
- Export control
- Insurance
- International legal and regulatory
- Societal
- Supply chain
- Weather
- Workforce

Study Overview

Sources of Data

Desk Research

70+ *Documents reviewed*

Corporate IP

Forecast Model


Task 1: Define the Market
2050 Passenger and Revenue Demand for Commercial and General Aviation Services

Market Survey

150 *Individual results*

UHNWIs

HNWIs

Subject Matter Experts

Pam Melroy*
- *NASA Shuttle commander, USAF test pilot*
- *DARPA TTO Deputy Director*
- *Space Council Users Advisory Group*
- *Board of Directors, Aerospace Corp*

Oscar Garcia
- *Advisor, airlines, aircraft operators, gov't*
- *FAA/AST, Commercial Space Transportation Advisory Committee*
- *Expert in supersonic and hypersonic economics, certification*
- *Former airline captain*

Jim Free
- *Director Glenn Research Center, Deputy AA NASA HEOMD*
- *11+ years as NASA executive PM, space systems engineer*
- *Hypersonics expertise*

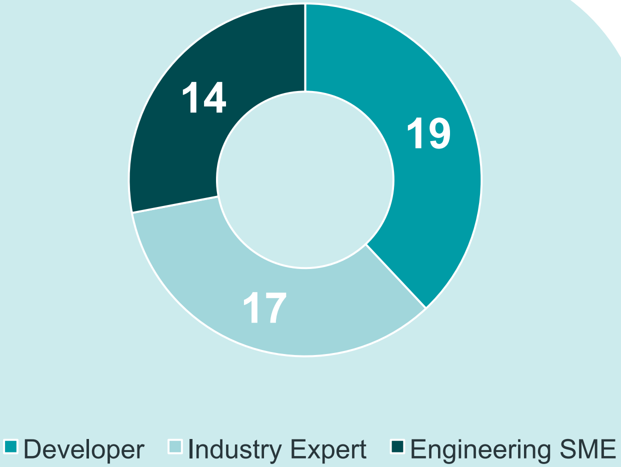
Stu Witt
- *Mojave Air and Space Port Director*
- *Sought FAA approval for disruptive flight technology*
- *42-year veteran of the aerospace industry*
- *Military pilot*

Natasha Heidenrich
- *Senior market and competitive intelligence analyst*
- *Expertise in airport business models*

SAIC SMEs

Interviews

50 *Completed*



Vehicle Developers
- *Aerion*
- *Boeing*
- *Boom Technology*
- *Exosonic*
- *Hermeus*
- *Lockheed Martin*
- *Northrop Grumman*
- *The Spaceship Company*
- *Reaction Engines*
- *SpaceX*

Engine Manufacturers
- *GE*
- *Momentus*
- *Reaction Engines*
- *Rolls-Royce*

Federal Agencies
- *DoD, DDR&T*
- *FAA*

Others
- *AIAA*
- *Apollo Global Management*
- *Aviation Week*
- *AXA XL*
- *Bank of America*
- *Embry-Riddle Aeronautical University*
- *International Airlines Group*
- *JSX*
- *LTA Research*
- *Mojave Air and Space Port*
- *Smithsonian Institution*
- *University of Colorado*
- *Aerospace management consultant*
- *ITAR attorney*
- *Southern Sky*

**Involvement ended on November 11, 2020.*

Study Overview

Results

Define the Market for Commercial Hypersonics

- Pax willingness to pay + route viability (revenue > op costs) define demand for each case
- Willingness to pay ↑ w/ speed, rate of increase ↓ above Mach 3
- Drops off significantly for commercial aviation above 1.5x subsonic fare, for general aviation above 2.5x
- Viable routes ↓ w/ speed due to higher operating costs
- No appreciable cargo demand
- Addressable market of 800 city pairs considered

Define the Business Case and Operations Requirements

- **Strongest case: Mach 3 aircraft, commercial aviation fare 1.5x subsonic, general aviation 2.5x**
  - **200M pax**
  - **$244B revenue (25 yrs, NPV 2020)**
  - **$24B available RDT&E**
- Mach 4+ cases
  - Costs > revenue at lower fares
  - Market driven by price insensitive pax, private jet sales
- Mach 5 cases constrained by few viable routes due to increased cost
- Lower fares result in largest fleet size (300 - 700) over 25 yrs
- Biz cases highly sensitive to fuel costs

Barrier Analysis

- 28 barriers characterized through analysis, SME input, vehicle developer interviews
- Identified 6 priority barriers based on consequence and impact
  - Type certification in increasingly strict safety and environmental conditions
  - Stability and control across all speed regimes
  - Overflight prohibition
  - Emissions
  - Current avionics performance assumptions (e.g., GNSS receivers)
  - Impact on special materials

Study Overview

Market Characterization

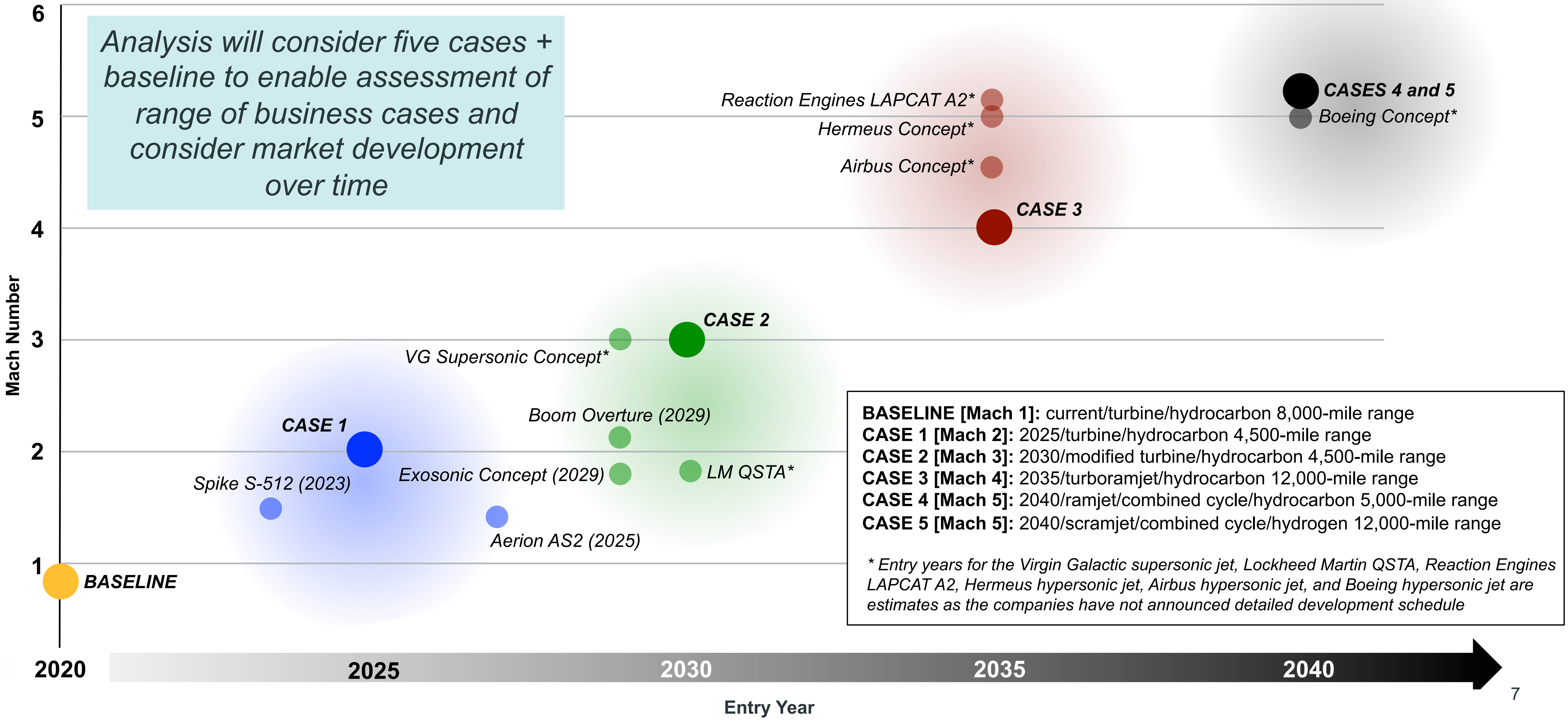
Task 1: Define the Market

Task 2: Define the Business Case

Task 3: Identify the Barriers

Market Characterization

Market Cases: Demand and Business Case



Analysis will consider five cases + baseline to enable assessment of range of business cases and consider market development over time

BASELINE [Mach 1]: current/turbine/hydrocarbon 8,000-mile range
CASE 1 [Mach 2]: 2025/turbine/hydrocarbon 4,500-mile range
CASE 2 [Mach 3]: 2030/modified turbine/hydrocarbon 4,500-mile range
CASE 3 [Mach 4]: 2035/turboramjet/hydrocarbon 12,000-mile range
CASE 4 [Mach 5]: 2040/ramjet/combined cycle/hydrocarbon 5,000-mile range
CASE 5 [Mach 5]: 2040/scramjet/combined cycle/hydrogen 12,000-mile range

** Entry years for the Virgin Galactic supersonic jet, Lockheed Martin QSTA, Reaction Engines LAPCAT A2, Hermeus hypersonic jet, Airbus hypersonic jet, and Boeing hypersonic jet are estimates as the companies have not announced detailed development schedule*

Study Overview

Market Characterization

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Task 1: Define the Market

Air Transportation Market Segments Mapped to Demand Model Elements

General Aviation

- On-demand commercially-operated flights, including charters, fractional flights for passengers (priced by itinerary) and cargo
- At-will flights of privately-owned aircraft (including individually-owned, corporate-owned)
- Addressable passenger market consists of charters, fractional flights and sales of aircraft purchased by individuals or corporations for their own use. A proportion of those privately-owned aircraft are made available to commercial operators for charters, so model will excise overlap

Demand Model Elements

- General Aviation Services
- Private Aircraft Sales
- General Aviation Cargo

Commercial Aviation

- Scheduled commercial flights for passengers (priced by seat) and cargo
- Addressable passenger market consists of existing passengers flying subsonic business and first class (not upgraded)

Demand Model Elements

- Commercial Aviation Passengers
- Commercial Cargo

Task 1: Define the Market

Commercial and GA Passenger Services Demand: Passenger Model Architecture

Premium Passenger Demand per Route and Demographics

- *Passenger forecast, by city pair (seats)*
- *Based on widely-used industry projections, real world*
- *# 1st, business, private jet passenger (seats)*
- *By wealth/income category*

Value of Time Saved

Calculate current fare +
value of travel time saved (VTTS)

- *Fare per route by class, by business/leisure travel (USD)*
- *Current fare drawn from regional estimates based on current fares*
- *Willingness to pay by passenger type, route, type of travel, fare class (USD)*

Assume business class level comfort, equivalent level of safety. Sensitivity to be tested with additional data

Ticket Price Comparison

If $$HIGH SPEED < FARE +VTTS,
then purchase high-speed ticket

- *Time saved per route (at Mach x) (Hrs.)*
- *Ticket price (from business case) (USD)*

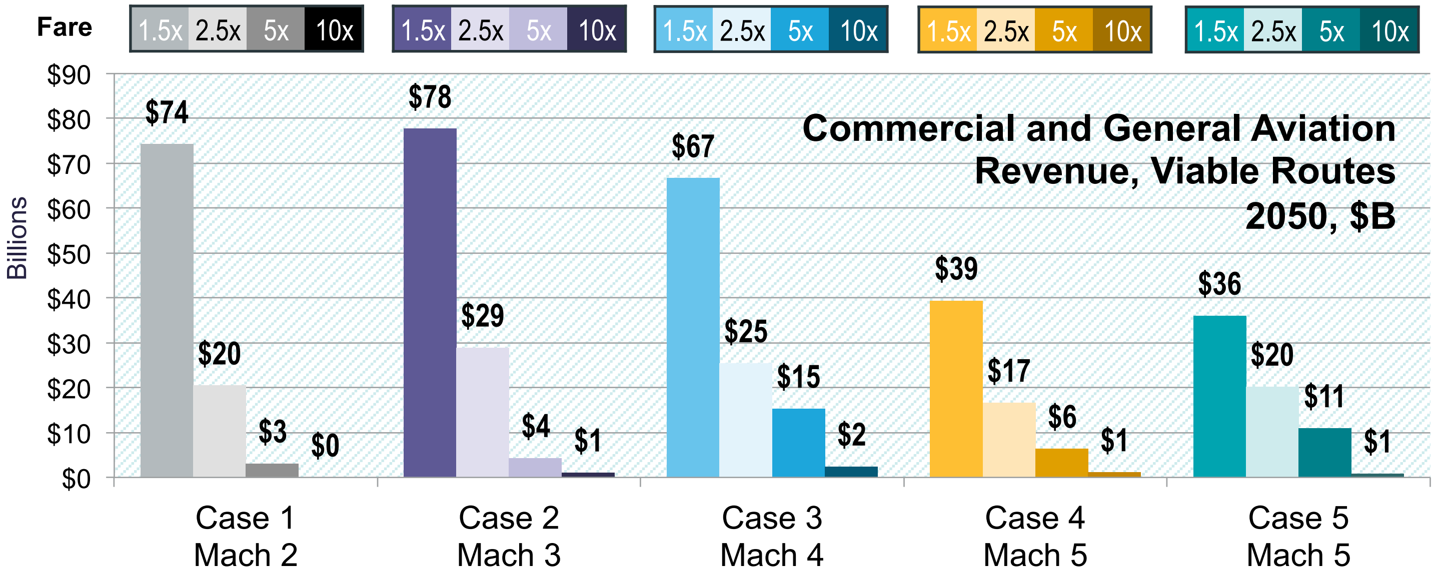
Traffic Analysis

Cost per route estimated in business model, informs route selection based on profitability in demand model

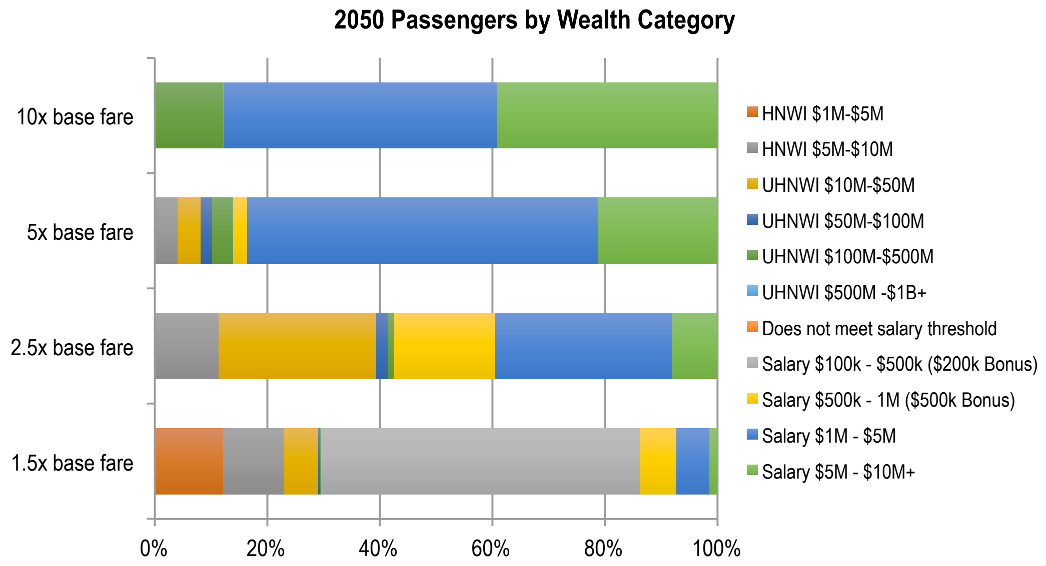
Passenger demand (#,$)
Viable routes (#,$)

Task 1: Define the Market

2050 Passenger and Revenue Demand for Commercial and General Aviation Services



Fare	1.5x	2.5x	5x	10x	1.5x	2.5x	5x	10x	1.5x	2.5x	5x	10x	1.5x	2.5x	5x	10x	1.5x	2.5x	5x	10x
# of profitable routes	296	64	29	0	249	49	30	9	177	50	29	19	85	24	21	8	69	22	22	5
# pax on viable routes	11M	1.3M	0.2M	0M	10M	1.4M	0.2M	0.06M	8.2M	1.3M	0.5M	0.1M	4.6M	0.8M	0.3M	0.05M	4.1M	0.8M	0.3M	0.03M



Subsonic premium base fares

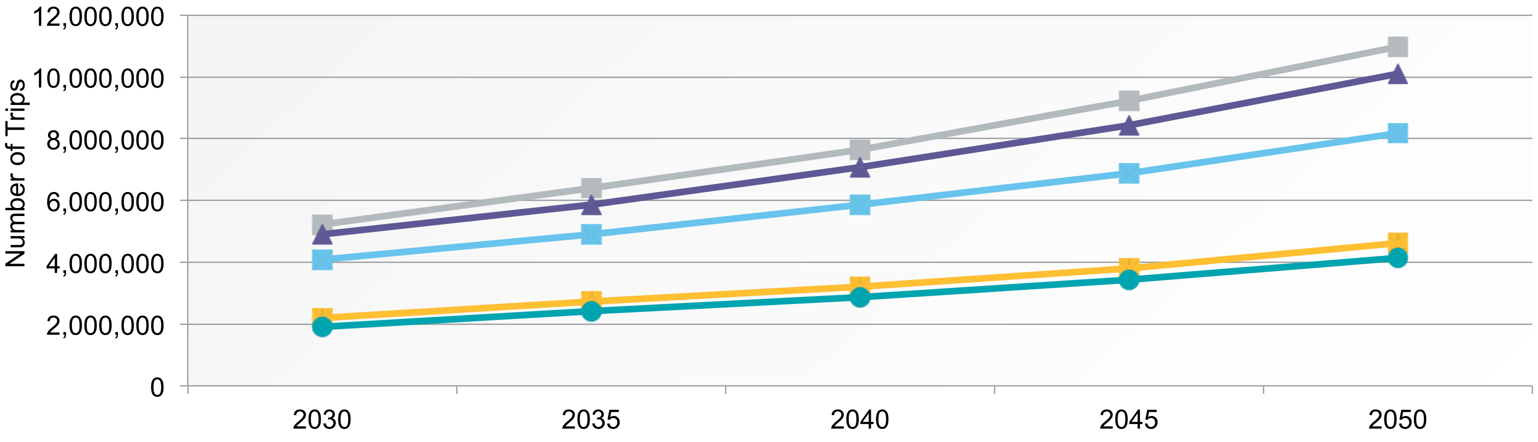
- Average across all routes: ~$3,500
- Top 249 viable routes (Case 2): ~$4,000

- Passenger demand (for viable routes) is greatest for Case 1 (Mach 2)
- Revenue greatest for Case 2 (Mach 3); while there are slightly fewer viable routes for Case 2, they generate higher average revenue per route
- At 2.5x fares lose demand for lowest demographic business and leisure travelers, the largest demographic group
- Across addressable market of 800 city pairs, max # viable city pairs = 327 (Case 1 commercial), 382 (Case 2 general)

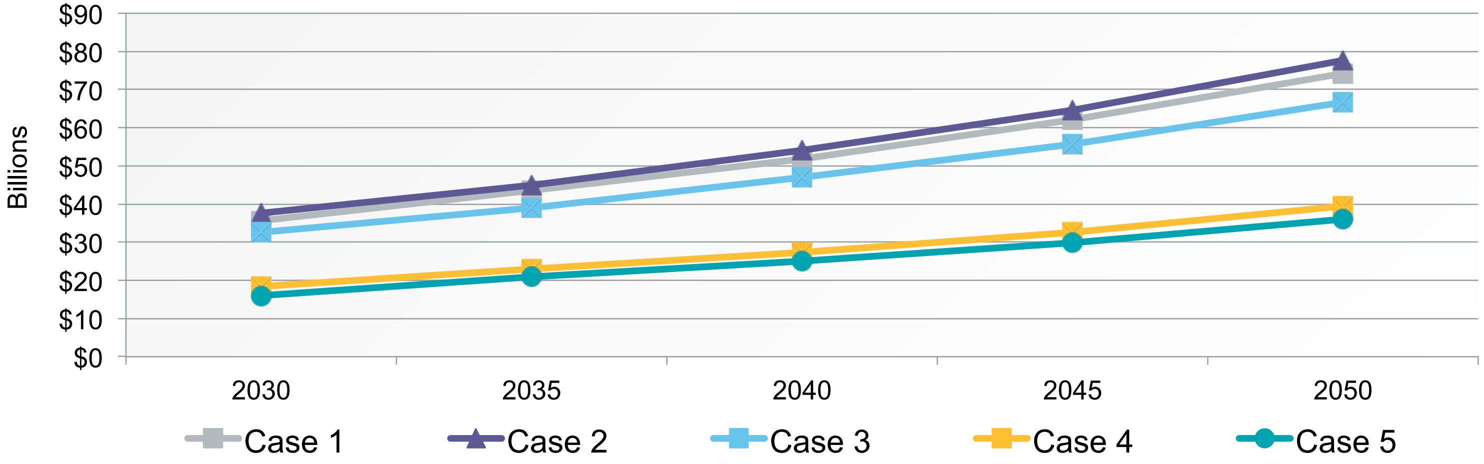
Task 1: Define the Market

Commercial and General Aviation Services Demand at 1.5x Fare, All Cases

Total Passenger Trips per Year on Viable Routes at 1.5x Subsonic Fare



Total Revenue per Year on Viable Routes at 1.5x Subsonic Fare

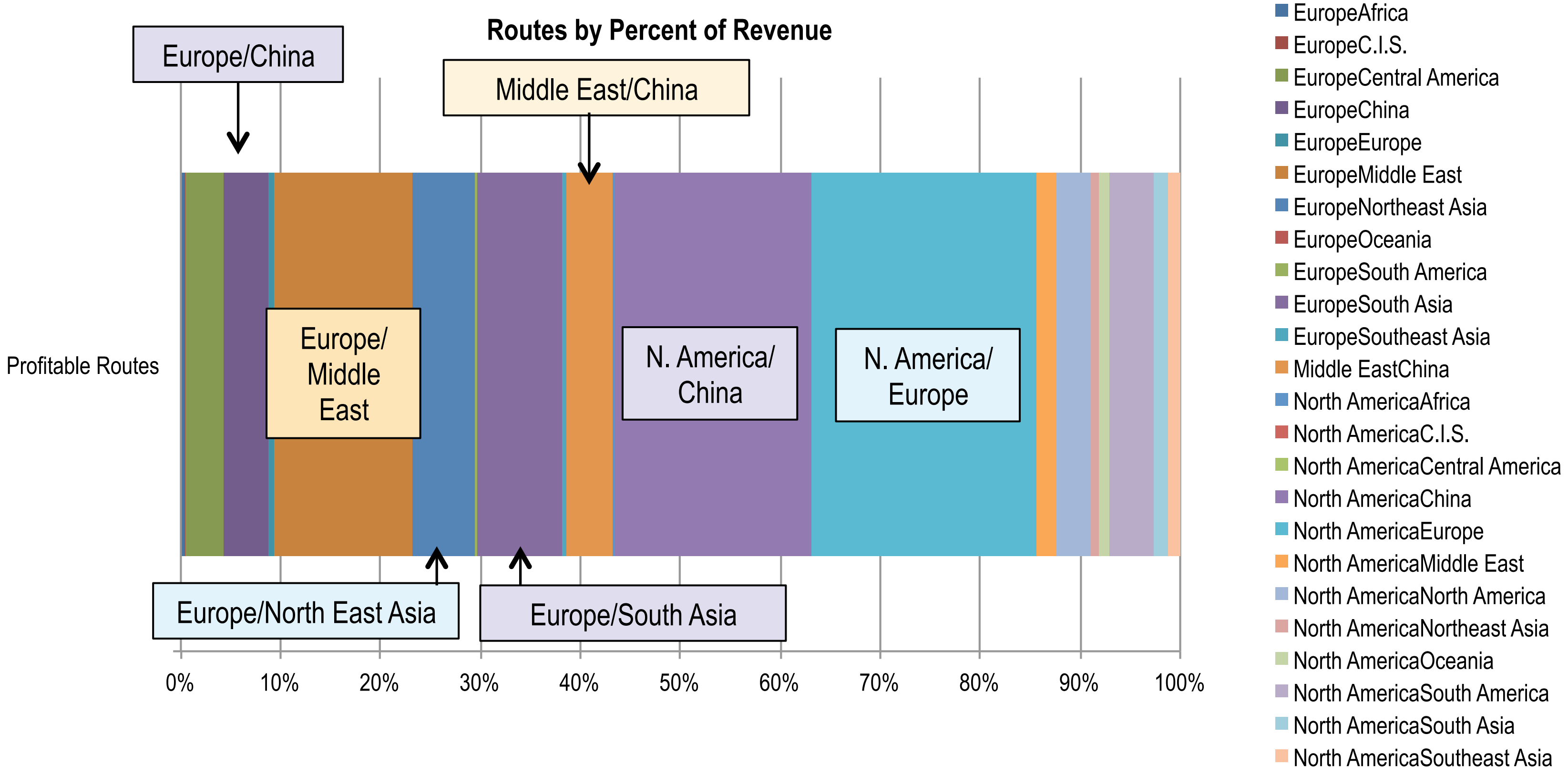


- Case 1 yields most pax trips; ~15% of 2050 addressable market (i.e., premium pax on long-haul routes)
- Case 2 yields highest revenue; ~25% of 2050 addressable market
- Context, current subsonic industry
  - 2019 total airline industry revenue $870B; representing 4B passengers
  - 15% of industry revenue is from premium pax on long haul routes, ~$130B

Task 1: Define the Market

Commercial Services Routes for Case 2: Mach 3 with 4,500 mi Range

- Best case: Case 2 (Mach 3) at 1.5x base fare
- 249 viable city pairs in 2050



Top 25 City Pairs (2050)
London/Dubai
New York/London
Middle East China
San Francisco/Hong Kong
London/Mumbai
New York/Shanghai
London/Doha
London/Delhi
Paris/Dubai
Los Angeles/London
Anchorage/Hong Kong
New York/Beijing
Dubai/Beijing
Los Angeles/Hong Kong
Manchester/Dubai
New York/Paris
Los Angeles/Shanghai
New York/Hong Kong
London/Abu Dhabi
New York/Frankfurt
Frankfurt/Delhi
Birmingham/Dubai
New York/Tel Aviv
Chicago/London
New York/Delhi

Task 1: Define the Market

Hypersonic Cargo Market

- Very few commercial markets for urgent cargo delivery are sensitive to changes of hours
  - Organ transplants
  - Urgent documents
  - Disaster aid
  - Perishable luxury goods
  - Emergency repair parts
- Little new commercial demand expected for high-speed cargo transport; small marginal gains
  - Currently, air freight is dwarfed by maritime freight
    - Of the 108 trillion tonne-km of freight transported in 2015, 70% went by sea and less than 0.25% by air
    - 50% of air freight travels aboard passenger aircraft
  - Currently, next-day shipping is available between every inhabited continent for small delivery fees
  - Hypersonic cargo transportation would continue to face “last-mile” challenges
- A military hypersonic cargo market may emerge, separate from commercial demand
  - The U.S. Transportation Command signed a non-funded cooperative research and development agreement with SpaceX and XArc to study the use of space launch vehicles to transport supplies in emergencies
  - U.S. Army and Air Force officials have previously entered discussions with SpaceX regarding the possibility of using the Starship for point-to-point transportation around Earth and to deliver intercontinentally

Some niche cargo revenue likely; not a driver of business case

Task 2: Define the Business Case

Business Case Model Architecture

Demand-Driven Annual Revenue, Pax for Viable Routes
(from Task 1)

General Aviation (services + private jet sales)

Commercial Aviation

Set Market Timing (Operations)

- Private aircraft sales phase
- General aviation phase
- Commercial aviation phase

- *Market timing for operations by industry segment (intro year + n years)*
- *Private aircraft phase start year 5 yrs prior to general aviation*
- *General aviation phase start year 5 yrs prior to commercial start*
- *Commercial aviation phase start*

Operator Business Model

- NPV (phase-adjusted revenue) – NPV (all-up operating costs) = budget for aircraft acquisition
- NPV = 2020 dollars

- *Operating costs: fuel, non-fuel, target profitability as % revenue*
- *Depreciation, interest excluded from operating costs*
- *Costs estimated based on equivalent subsonic costs * high-speed multipliers*
- *Multipliers applied to fuel and non-fuel costs*

Manufacturer Business Model

- Set development phase timing
- Add private jet sales revenue, fleet
- Estimate marginal production cost, target profit, profit from services, fleet size, cost/vehicle
- NPV (phase-adjusted revenue) – NPV (fleet marginal production cost) = funds available for RDT&E (developmental, vehicle, manufacturing)

- *Set timing (intro year – n years)*
  - *- Developmental phase start*
  - *- Vehicle integration, cert phase start*
  - *- Manufacturing level phase start*
- *Fleet size, turnaround estimate based on pax demand,* pax/vehicle, flight frequency

Traffic Analysis

Cost per route estimated in business model, informs route selection based on profitability in demand model

Available RDT&E

- NPV (2020)

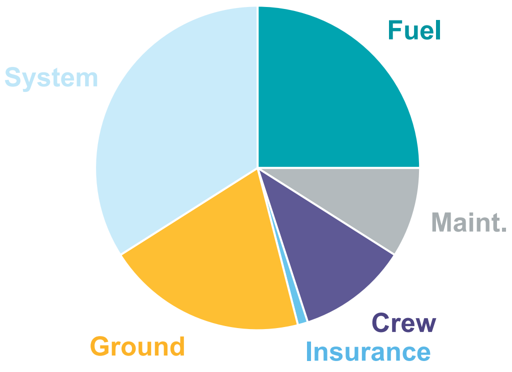
Task 2: Define the Business Case

Overview of Operating Cost Inputs

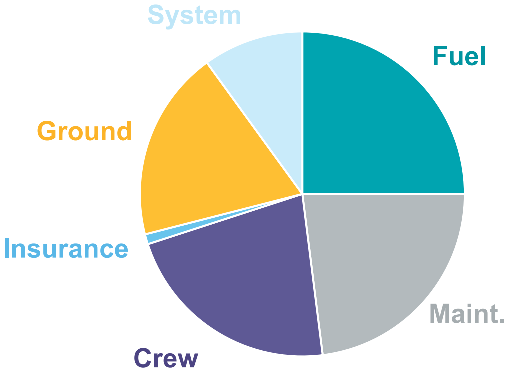
- Operating costs estimated relative to subsonic
  - Multipliers calculated and applied per seat-mile
  - Applied to fuel and non-fuel costs
  - Informed by insight from SMEs/aircraft developers, recent conceptual design studies, historical data comparing Concorde with Boeing 747
- Operating costs considered
  - Fuel is largest single operating cost for airlines with significant increases anticipated for high-speed aircraft
  - Non-fuel costs being escalated: maintenance, insurance, and ground (aircraft handling, airport fees, and passenger/cargo processing)
  - Non-fuel costs held constant: air crew, and system (transport related, G&A, pax service, marketing)

	Propulsion	Speed	Fuel Multiplier	Non-Fuel CA	Non-Fuel GA
CASE 1	Turbine	Mach 2.0	4.5x	1.5x	1.9x
CASE 2	Modified Turbine	Mach 3.0	5.5x	1.7x	2.3x
CASE 3	Turboramjet	Mach 4.0	7x	1.9x	2.7x
CASE 4	Ramjet	Mach 5.0	10x	2.1x	3.2x
CASE 5	Scramjet	Mach 5.0	11x	2.5x	3.7x

Commercial Aviation Costs (2020)



General Aviation Costs (2020)



Sources:

Kharina, Anastasia, et al. "Environmental Performance of Emerging Supersonic Transport Aircraft." The International Council on Clean Transportation, July 2018

Pincini, Margherita. "Analysis of Cost Drivers Impact on Direct Operating Costs Estimation of a Hypersonic Point-to-Point Vehicle." Polytechnic University of Turin, March 2018

Task 2: Define the Business Case

Overview of Manufacturing Cost Inputs

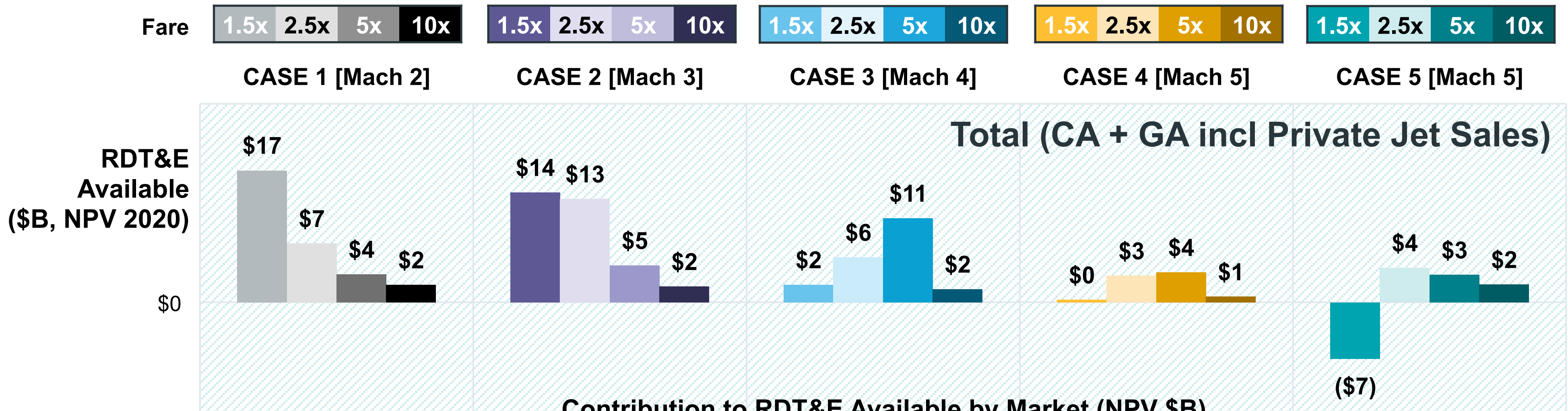
- Marginal manufacturing cost, excluding RDT&E, profit
  - RDT&E excluded to calculate available RDT&E as model output
  - Aircraft sale prices are typically quoted including RDT&E, profit
  - Marginal cost typically ~75% of aircraft sale price [AIAA]
- Includes cost of production, tooling for building single aircraft
- Estimated as an input value denominated in $, considered in business case model to determine available RDT&E
- Assumed to increase with speed regime, vehicle complexity
  - Powerplant cost driven by required enhancements such as pre-cooling technology, variable inlets, augmented thrust, more robust components, etc.
  - Airframe cost driven by use of titanium, Inconel, and other expensive materials, combined with optimized structures
  - Wide range of expert views regarding costs for higher Mach cases

	Speed
CASE 1	Mach 2.0
CASE 2	Mach 3.0
CASE 3	Mach 4.0
CASE 4	Mach 5.0
CASE 5	Mach 5.0

	Model Input: Unit Cost	
Propulsion	**10 Pax**	**50 Pax**
Turbine	$150M	$200M
Modified Turbine	$200M	$300M
Turboramjet	$250M	$400M
Ramjet	$400M	$500M
Scramjet	$450M	$500M

Task 2: Define the Business Case

Analysis of Market-Supported Available RDT&E: Total



Contribution to RDT&E Available by Market (NPV $B)

	CASE 1 [Mach 2]				CASE 2 [Mach 3]				CASE 3 [Mach 4]				CASE 4 [Mach 5]				CASE 5 [Mach 5]			
Fare	1.5x	2.5x	5x	10x	1.5x	2.5x	5x	10x	1.5x	2.5x	5x	10x	1.5x	2.5x	5x	10x	1.5x	2.5x	5x	10x
CA	**$13**	$3	$1	$0	**$15**	$4	$3	$0	**$5**	$3	$3	$0	($2)	**$2**	$2	$0	($9)	**$1**	$1	$0
GA: Services	$2	**$3**	$0	$0	($3)	**$7**	$0	$0	($5)	$1	**$6**	$0	$0	($1)	$0	**$0**	$0	**$1**	$0	$0
GA: Jet Sales	$2	**$2**	$2	$2	$2	**$2**	$2	$2	$2	$2	**$2**	$2	$2	$2	$2	**$2**	$2	**$2**	$2	$2

Time Horizon

	CASE 1 [Mach 2]	CASE 2 [Mach 3]	CASE 3 [Mach 4]	CASE 4 [Mach 5]	CASE 5 [Mach 5]
CA	2035 – 2055	2040 – 2060	2045 – 2065	2050 – 2070	2050 – 2070
GA: Services	2030 – 2055	2035 – 2060	2040 – 2065	2045 – 2070	2045 – 2070
GA: Jet Sales	2025 – 2055	2030 – 2060	2035 – 2065	2040 – 2070	2040 – 2070

	CASE 1 [Mach 2]				CASE 2 [Mach 3]				CASE 3 [Mach 4]				CASE 4 [Mach 5]				CASE 5 [Mach 5]			
Fare	1.5x	2.5x	5x	10x	1.5x	2.5x	5x	10x	1.5x	2.5x	5x	10x	1.5x	2.5x	5x	10x	1.5x	2.5x	5x	10x
Viable Routes	502	392	45	0	419	454	51	33	303	340	200	86	151	146	79	29	118	142	120	21
Fleet Required	618	320	166	150	512	329	166	160	441	290	224	171	285	229	184	174	277	235	213	156

	CASE 1 [Mach 2]	CASE 2 [Mach 3]	CASE 3 [Mach 4]	CASE 4 [Mach 5]	CASE 5 [Mach 5]
Max RDT&E Available ($B, NPV 2020)	**$18B** CA 1.5x fare GA 2.5x fare	**$24B** CA 1.5x fare GA 2.5x fare	**$13B** CA 1.5x fare GA 5x fare	**$4B** CA 2.5x fare, GA 10x fare	**$4B** CA 2.5x fare GA 2.5x fare

All cases at all fares, with one exception, achieve RDT&E > $0

Case 1 achieves highest available RDT&E for a given fare multiplier

Case 2 achieves highest available RDT&E varying fares by market segment

Cases 4/5 constrained by few viable routes

Task 2: Define the Business Case

Analysis of Market-Supported Available RDT&E: Best Case

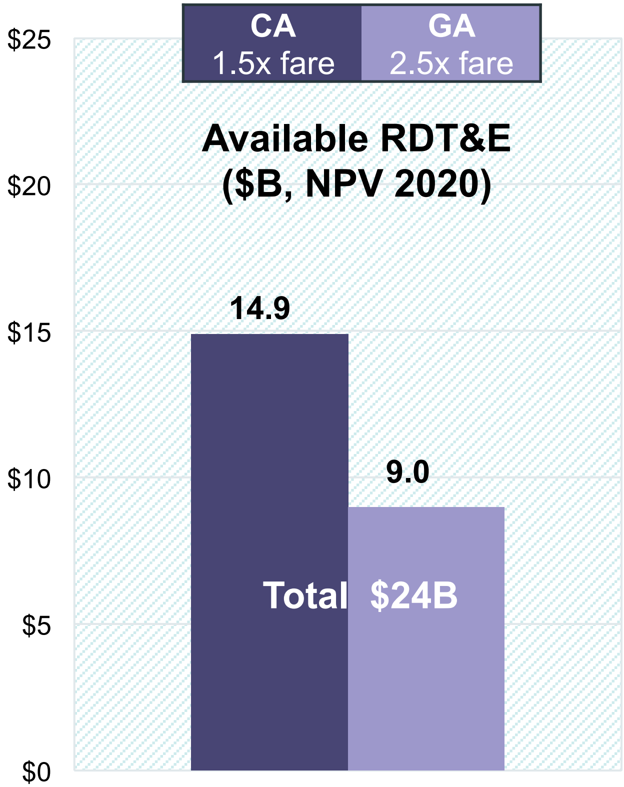
Best case: Mach 3 aircraft, 4,500 mi range, commercial and general aviation

Inputs

	CA 1.5x fare	**GA** 2.5x fare
Pax Capacity	50	10
Discount Rate	7%	7%
Aircraft Unit Cost	$300M	$200M
Fuel Multiplier	5.5x	5.5x
Non-Fuel Multiplier	1.8x	2.3x

Findings

	CA 1.5x fare	**GA** 2.5x fare
Total Viable Routes	302	382
Avg Route Length (hrs)	2.6	2.3
Routes/Day	2.9	3.2
Flight hrs/Year	2,780	2,650
Implied Load Factor	94%	50%
Fleet	252	299

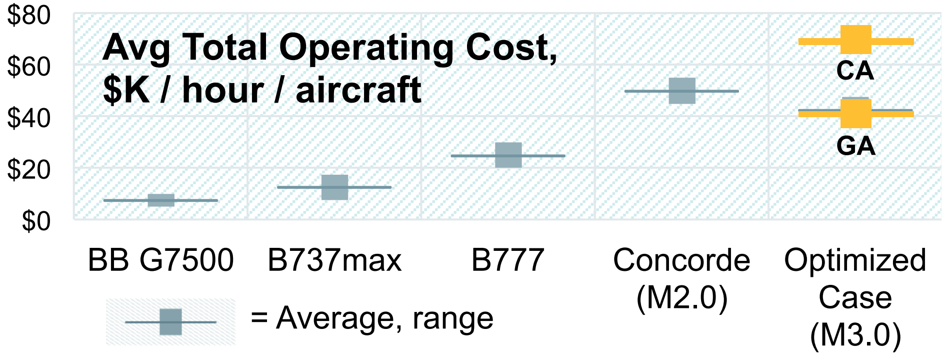


- Time horizon = CA: 2040 – 2060, GA: 2035 – 2060, Jet: 2030 – 2060
- Cost multipliers applied to approx. total cost per available premium-seat-mile for subsonic operator
- 25% profit

Cost Breakdown ($B, CA 20 years, GA 25 years)

	CA	*% total*	GA	*% total*
Fuel	$385	*51%*	$126	*44%*
Maintenance	$112	*15%*	$84	*30%*
Crew	$34	*4%*	$20	*7%*
Insurance	$28	*4%*	$9	*3%*
Ground	$106	*14%*	$35	*12%*
System	$92	*12%*	$9	*3%*

Cost / available premium-seat-mile	$0.81	$2.32



Task 2: Define the Business Case

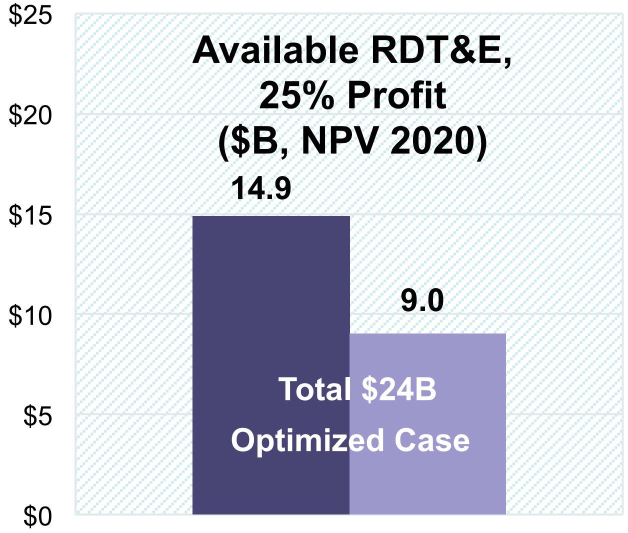
Sensitivity Analysis Based on Optimized Case

ROM Change in RDT&E Available | **ROM Change in RDT&E Available**

Total	GA	CA	Sensitivity Analysis (~10% change in magnitude)			CA	GA	Total
+$9B	*+$3B*	*+$6B*	**6%**	**Discount rate**	**8%**	*-$4B*	*-$2B*	**-$6B**
+$2B	*+$1B*	*+$1B*	**-$25M**	**Aircraft unit cost**	**+$25M**	*-$1B*	*-$1B*	**-$2B**
+$6B	*+$2B*	*+$3B*	**-0.5x**	**Fuel multiplier**	**+0.5x**	*-$3B*	*-$2B*	**-$5B**
+$3B	*+$2B*	*+$1B*	**-0.4x**	**Maintenance multiplier**	**+0.4x**	*-$1B*	*-$1B*	**-$3B**
+$2B	*+$1B*	*$1B*	**-0.2x**	**Ground multiplier**	**+0.2x**	*-$1B*	*-$1B*	**-$2B**
+$5B	*+$1B*	*+$4B*	**-0.2x**	**Non-fuel multiplier**	**+0.2x**	*-$3B*	*-$1B*	**-$4B**

Totals may reflect rounding

- Results most sensitive to discount rate, due to long time periods assessed. Highest for Cases 4 and 5
- Other than discount rate, available RDT&E is most sensitive to fuel across cases, followed by maintenance
- Sensitivity to marginal manufacturing cost varies by fleet required, highest for low Mach regimes



Optimized Case Inputs

	CA 1.5x fare	GA 2.5x fare
Pax Capacity	50	10
Discount Rate	7%	7%
Aircraft Unit Cost	$300M	$200M
Fuel Multiplier	5.5x	5.5x
Maintenance Multiplier	4x	4x
Ground Multiplier	2x	2x
Non-Fuel Multiplier	1.8x	2.3x

Task 2: Define the Business Case

Practical Business Case Considerations

- Future cost and performance
  - SME/developer uncertainty around (operating, manufacturing) costs at higher Mach regimes
  - High-speed aircraft assumed to achieve annual flight hours comparable to subsonic aircraft; performance variations could require more aircraft
- Alignment of fleet size with manufacturer incentives
  - Accepted subsonic industry norm is 500+ aircraft to achieve manufacturing viability
  - At least one high-speed aircraft developer anticipates viability at ~100 units
- Whether available RDT&E is adequate
  - Media, anecdotal reports of high-speed aircraft developers (Mach 2) predicting < $10B; unvalidated estimates
  - RDT&E cost for advanced subsonic aircraft, requiring less innovation than high-speed aircraft, have reportedly exceeded $10B (Airbus A350 and A380), up to $30+B (Boeing 787)

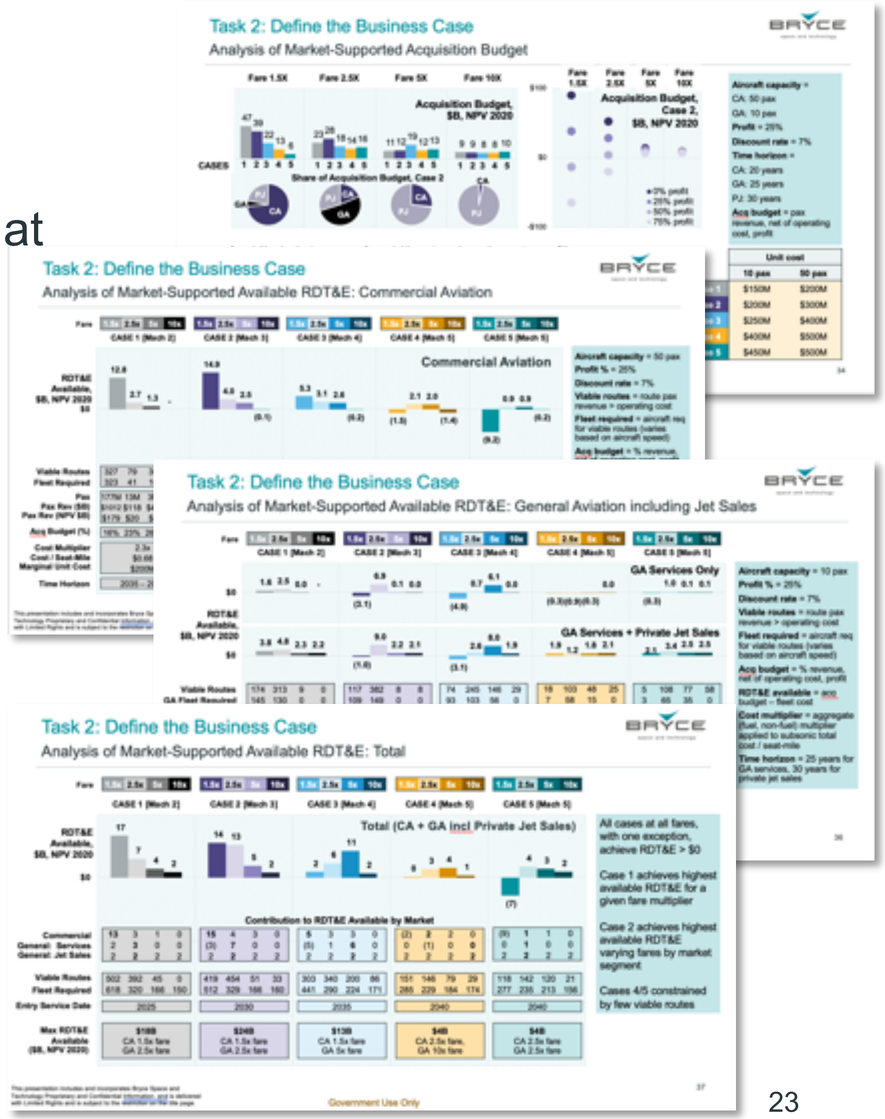
	Year Entered Service	RDT&E ($B 2020)	Orders (as of 2020)
Boeing 777	1995	$9	2,012
Boeing 787	2011	$36	1,507
Airbus A350	2015	$17	930
Airbus A380	2007	$18	251
Concorde	1976	$15 – 22	70

Source: Nolte, Peter, et al. "Quantitative Assessment of Technology Impact on Aviation Fuel Efficiency." International Air Transportation Association, June 2012.

Task 2: Define the Business Case

Takeaways

- Available RDT&E >$0 for most cases, max $24B (2020 $)
  - Available RDT&E lower for higher Mach cases
  - Fewer viable routes as operating and aircraft costs increase
- Acquisition budget (e.g., revenue – [operating cost + profit]) shrinks at higher Mach speeds due to increased operating costs
- Required fleet size ranges from ~150 to 600+ across cases
  - 50-pax commercial aircraft 100 - 300 at 1.5x fare, <50 at higher fares
  - 10-pax general aviation aircraft (other than private jet sales) 0 - 150
  - 10-pax private jet sales estimated at 5/yr across cases, total 150
  - Manufacturers typically seek production volume of several hundred, potentially as high as 500 - 1,000 for a single aircraft
- Best case: Mach 3 vehicle, $24B available RDT&E 1.5x fare commercial, 2.5x general
  - 302 viable routes for commercial aviation, 382 for general
  - Fleet size: 252 commercial, 299 general (including private jets)
  - Aircraft marginal manufacturing cost (excluding RDT&E) $300M for commercial, $200M for general
  - Available RDT&E $24B ($15B commercial, $9B general)



Task 2: Define the Business Case
Analysis of Market-Supported Acquisition Budget

Task 2: Define the Business Case
Analysis of Market-Supported Available RDT&E: Commercial Aviation

Task 2: Define the Business Case
Analysis of Market-Supported Available RDT&E: General Aviation including Jet Sales

Task 2: Define the Business Case
Analysis of Market-Supported Available RDT&E: Total

Task 3: Identify the Barriers

Methodology

Catalog real and perceived <u>non-technical</u> barriers, conduct a preliminary assessment of ways to address those barriers, and forecast the likely consequences of different approaches

Identify and Catalog Barriers

- Reviewed articles, papers, studies, and reports
- Interviews with industry professionals
- Reviews with Bryce and SAIC SMEs

Task 3: Identify the Barriers

Identify and Catalog Non-Technical Barriers

Characterize Consequences

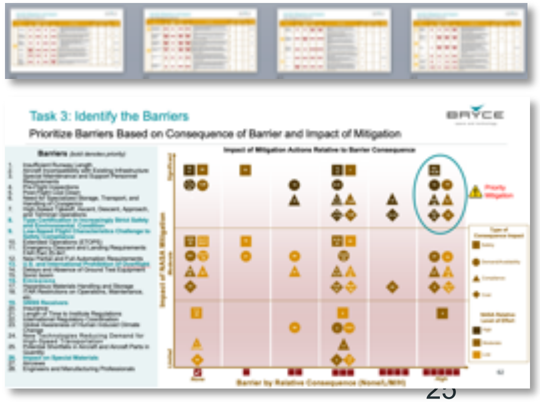
- Identify potential consequences of barriers
- Categorize consequences
- Estimate magnitude of consequences
- Identify relevance by vehicle configuration and fuel type
- Quantify consequences

Identify Mitigations and Impacts

- Map interdependencies among barriers
- Identify actions to mitigate barriers
- Map mitigations to barriers
- Use categorization to elicit further actions from interviews
- Categorize mitigations by type and actor

Assess and Prioritize

- Assess impact of mitigations
- Model mitigated barrier to determine impact on demand and business case
- Rank mitigations based on efficacy and cost



Task 3: Identify the Barriers

Prioritize Barriers Based on Consequence of Barrier and Impact of Mitigation

Task 3: Identify the Barriers

Identify and Catalog Non-Technical Barriers

Number of Non-Technical Barriers by Group

Barrier Category	Barrier Description
Airport Infrastructure	1. Required runway lengths to support SST and HST likely to limit airport operation planning
	2. Existing terminal layouts, vehicle clearances (especially length), and other facilities may be incompatible with SST and HST aircraft designs
	3. Special maintenance and support personnel requirements (especially propulsion and materials)
	4. Potential need for non-destructive inspection and other quality control and safety processes may slow turn around or increase costs
	5. Need for post-flight cool down aircraft holding areas for some SST and all HST may increase flight time, slow turn around, increase costs, and increase fleet size
	6. Need for specialized storage, transport, and handling of cryogenics (liquid hydrogen) safely may increase costs
Air Traffic Management	7. High-speed aircraft exiting and reentering terminal air traffic systems as well as traffic lane management may create handoff challenges, and potentially safety issues
Certification (U.S.)	8. Type certification during time when safety standards and environmental compliance trends are tightening
	9. Stability and control challenges to include inadequate certification regulations, across the operational flight envelope may increase difficulty to certify as safe, increase test program duration, and/or require more highly skilled pilots
	10. Extended operations (ETOPS) for twin-engine aircraft, polar operations
	11. Emergency descent and landing requirements under FAR Part 25
	12. Current avionic Minimum Operational Performance Standards (MOPS) will require reevaluation to determine if assumptions and algorithms are still valid for SST and HST operations (e.g., TCAS/ACAS traffic alerting, frequency shift due to Doppler effect, environmental testing (temperature and vibration), etc.
	13. Prohibition of supersonic flight over the continental U.S. and certain areas outside the U.S. may prevent operations
	14. Potential shortage or schedule availability of ground testing facilities (e.g., wind tunnels)

Task 3: Identify the Barriers

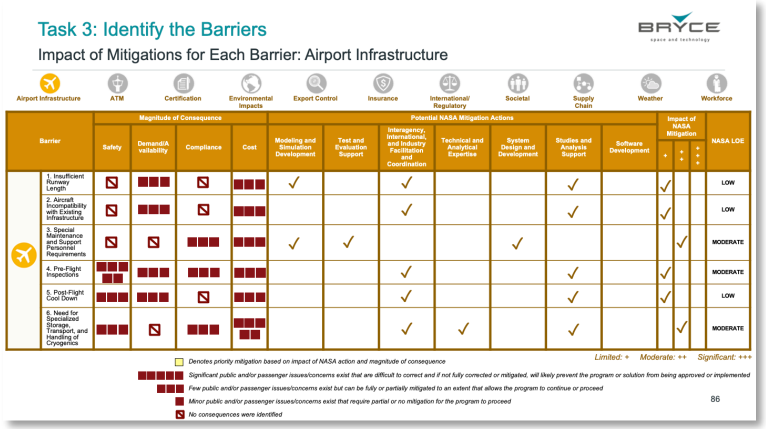
Identify and Catalog Non-Technical Barriers

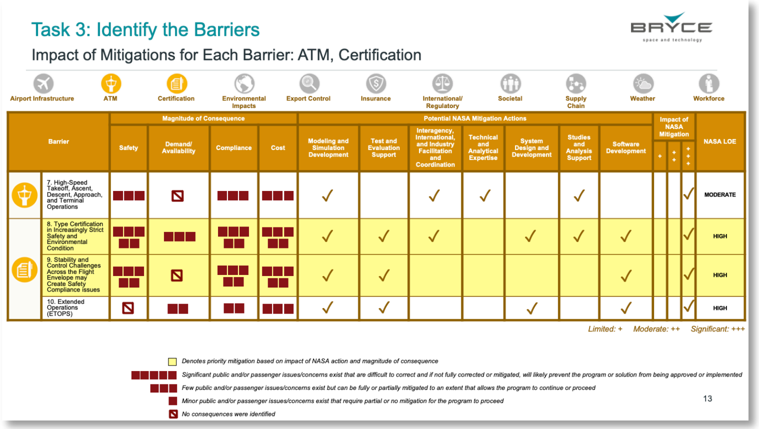
Barrier Category	Barrier Description
Environmental Impacts	15. Sonic boom and takeoff and landing noise may make it difficult for SST and HST aircraft to meet current Stage 4/5 international noise certification standards
	16. Emissions (CO_2, NO_x, UHC, and particulates) may prevent chemical emission compliance
	17. Need for special handling of certain hazardous materials may increase costs
Export Control	18. ITAR restrictions may prevent or hinder operations at non-U.S. facilities, especially in terms of maintenance, software and cyber security, and servicing
	19. GNSS operations above 600 m/s (Mach 1.8) restricted by U.S. Munitions List (22 CFR Part 121 Category XII (d)(2))
Insurance	20. Non-existing or unclear insurance approach for SST and HST
International Legal and Regulatory	21. Length of time to develop and institute regulations will take several years
	22. Coordination with international partners to ensure integrated regulatory approach (e.g., lack of International agreement for flight operations above 60,000 feet may impede safe operations)
Societal	23. Increased emissions may create resistance to high-speed aircraft in light of climate change
	24. Virtual communication technologies replacing certain travel may reduce demand for high-speed flight
Supply Chain	25. Potential shortfalls in producing SST and HST aircraft and components in quantity; higher costs for lower volume
Weather	26. Weather can impact special materials needed at greater than Mach 4 cruise such as tiles, potentially degrading performance; de-icing systems and/or ground support
Workforce	27. Potential shortage of pilots with sufficient experience yet not about to retire
	28. Potential shortage of engineers and skilled manufacturers to design, build, and maintain SST and HST aircraft and components, also regulators

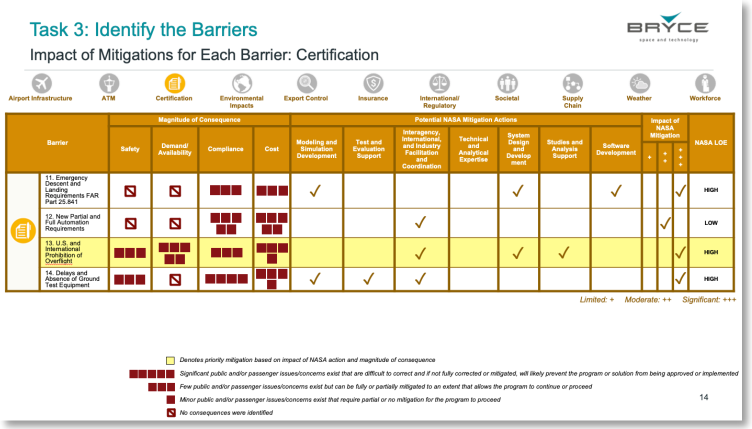
Task 3: Identify the Barriers

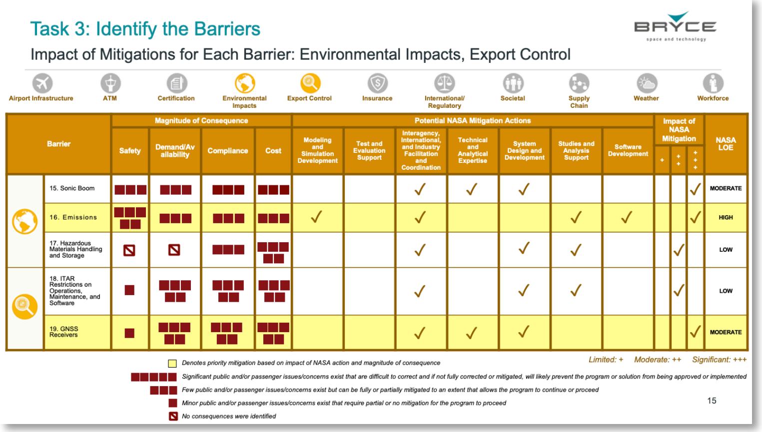
Impact of Mitigations for Each Barrier

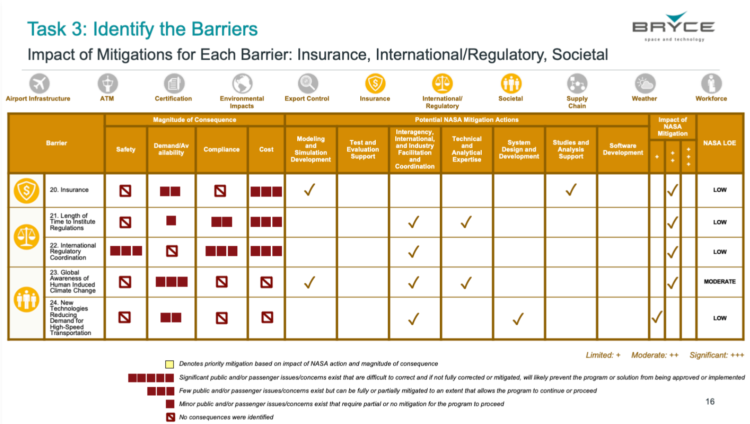
NASA proposed mitigations were determined to fall within 7 common categories. The potential impact of these proposed mitigations and relative level of effort to implement were assessed and mapped to barriers

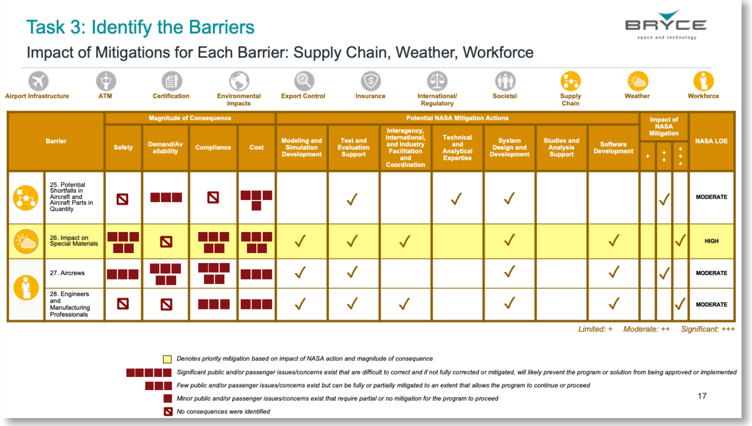

Task 3: Identify the Barriers
Impact of Mitigations for Each Barrier: Airport Infrastructure


Task 3: Identify the Barriers
Impact of Mitigations for Each Barrier: ATM, Certification


Task 3: Identify the Barriers
Impact of Mitigations for Each Barrier: Certification


Task 3: Identify the Barriers
Impact of Mitigations for Each Barrier: Environmental Impacts, Export Control


Task 3: Identify the Barriers
Impact of Mitigations for Each Barrier: Insurance, International/Regulatory, Societal


Task 3: Identify the Barriers
Impact of Mitigations for Each Barrier: Supply Chain, Weather, Workforce

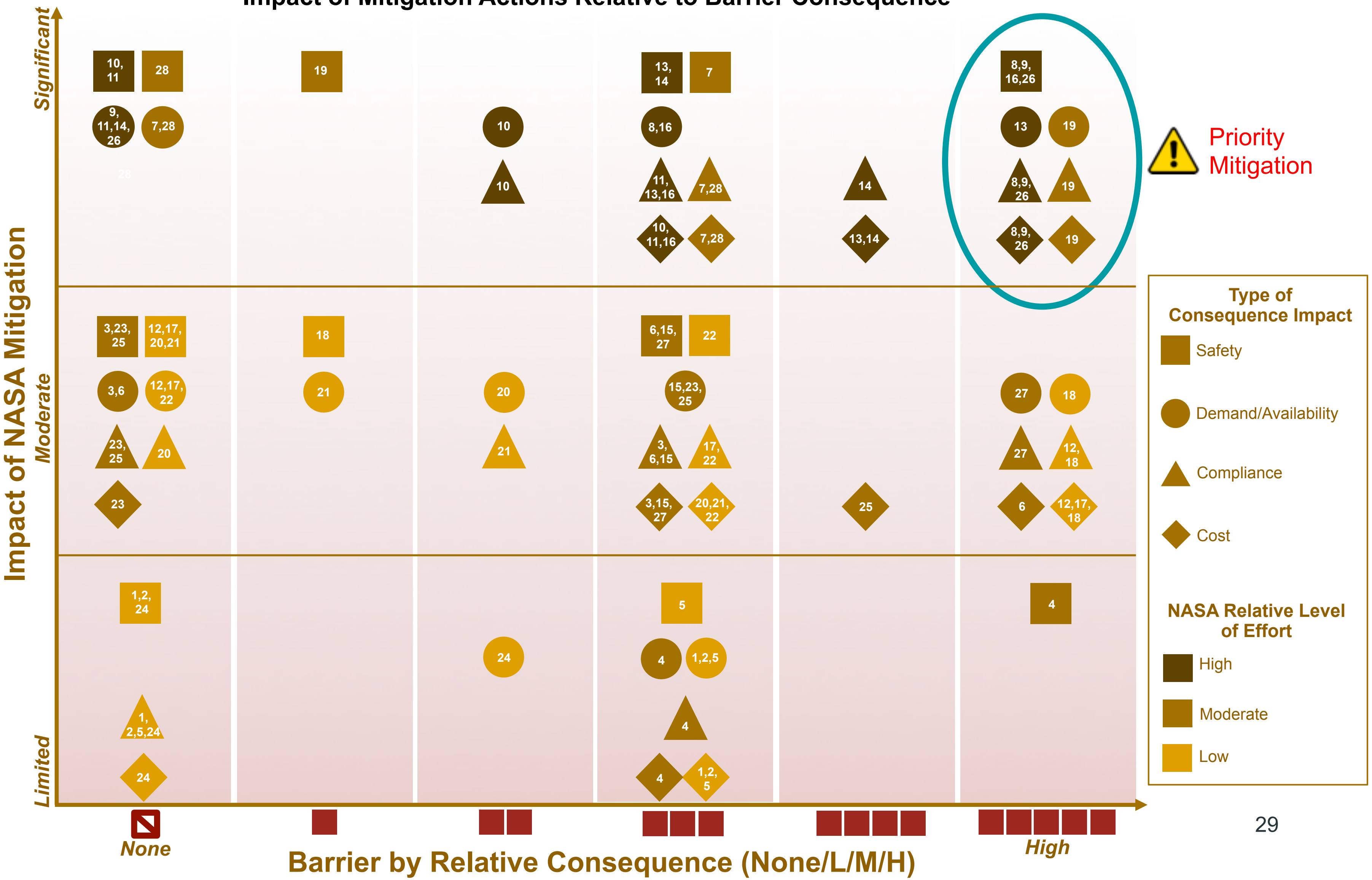
Task 3: Identify the Barriers

Prioritize Barriers Based on Consequence of Barrier and Impact of Mitigation

Barriers *(bold denotes priority)*

1. Insufficient Runway Length
2. Aircraft Incompatibility with Existing Infrastructure
3. Special Maintenance and Support Personnel Requirements
4. Pre-Flight Inspections
5. Post-Flight Cool Down
6. Need for Specialized Storage, Transport, and Handling of Cryogenics
7. High-Speed Takeoff, Ascent, Descent, Approach, and Terminal Operations
8. **Type Certification in Increasingly Strict Safety and Environmental Condition**
9. **Low-Speed Flight Characteristics Challenge to Safety Compliance**
10. Extended Operations (ETOPS)
11. Emergency Descent and Landing Requirements FAR Part 25.841
12. New Partial and Full Automation Requirements
13. **U.S. and International Prohibition of Overflight**
14. Delays and Absence of Ground Test Equipment
15. Sonic boom
16. **Emissions**
17. Hazardous Materials Handling and Storage
18. ITAR Restrictions on Operations, Maintenance, etc.
19. **GNSS Receivers**
20. Insurance
21. Length of Time to Institute Regulations
22. International Regulatory Coordination
23. Global Awareness of Human Induced Climate Change
24. New Technologies Reducing Demand for High-Speed Transportation
25. Potential Shortfalls in Aircraft and Aircraft Parts in Quantity
26. **Impact on Special Materials**
27. Aircrews
28. Engineers and Manufacturing Professionals

Impact of Mitigation Actions Relative to Barrier Consequence



Task 3: Identify the Barriers

High Consequence Barriers with Significant Mitigation Impact

- **Barrier 8.** Type certification during time when safety standards and environmental compliance trends are tightening
- **Barrier 9.** Aircraft designed to fly at high Mach regimes across all weather conditions may be less stable at lower speeds and be more difficult to certify as safe, increase test program duration, and/or require more highly skilled pilots
- **Barrier 13.** Prohibition of supersonic flight over the continental U.S. and certain areas outside the U.S. may prevent operations
- **Barrier 16.** Emissions (CO_2, NO_x, UHC, and particulates) may prevent chemical emission compliance
- **Barrier 19.** 600 m/s (Mach 1.8) velocity limit on GNSS receivers (22 CFR Part 121 U.S. Munitions List)
- **Barrier 26.** Weather can impact special materials needed at greater than Mach 4 cruise such as tiles, potentially degrading performance; de-icing systems and/or ground support

Detailed consequences and mitigations for all barriers are incorporated in Appendix to this briefing

Task 3: Identify the Barriers

Priority Actions to Mitigate Barriers

- NASA
  - Facilitate working groups with FAA, Department of State, Department of Defense, airport authorities, and industry as appropriate to address certification, regulatory, and environmental barriers
  - Provide technical expertise and modeling/simulation to FAA and industry relating to critical technologies (e.g. materials, fuels) across a variety of environmental conditions to help reduce certification delays
  - Work closely with developers to provide technical expertise in RDT&E of cleaner propulsion systems and fuels
  - Continue to pursue sonic boom reduction technologies and social science experiments to determine the acceptable level of takeoff noise and sonic boom
  - Work with industry to leverage government programs to develop innovative alternative capabilities, technologies, and processes to address cleaner propulsion, navigation receivers, and special materials
- Industry – Establish early coordination with Department of State Department's Directorate of Defense Trade Controls (DDTC) and Department of Commerce to determine if GNSS receivers are an export restricted technology

Dr. Ronald Lehmer
Senior Program Manager, Civil Space/National Security and Space Sector
SAIC
925-257-3438
ronald.d.lehmer@saic.com

Ms. Carie Mullins
Analytic Lead, Consulting Team
Bryce Space and Technology
724-766-2796
carie.mullins@brycetech.com

@BryceSpaceTech @SAICInc

www.brycetech.com www.saic.com