Booz | Allen | Hamilton

UAM MARKET STUDY - TECHNICAL OUT BRIEF

Presented to: National Aeronautics and Space Administration – Aeronautics Research Mission Directorate

OCTOBER 19, 2018

CONSULTING | ANALYTICS | DIGITAL SOLUTIONS | ENGINEERING | CYBER

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EXECUTIVE SUMMARY

Our analysis focused on three potential UAM markets: **Airport Shuttle, Air Taxi, and Air Ambulance** using **ten target urban areas**[1] to explore market size and barriers to a UAM market. Our results suggest the following:

- Airport Shuttle and Air Taxi markets are **viable markets** with a significant total available market value of **$500B**[2] at the market entry price points in the best-case unconstrained scenario
- Air Ambulance market served by eVTOLs is **not a viable market** due to technology constraints, but utilization of hybrid VTOL aircraft would make the market potentially viable
- Significant legal/regulatory, certification, public perception, infrastructure, and weather constraints exist which reduce market potential in near term for UAM
- After applying operational constraints/barriers, **0.5% of the total** available market worth **$2.5B** can be captured in the near term
- Constraints can potentially be addressed through ongoing intragovernmental partnerships (i.e., NASA-FAA), government and industry collaboration, strong industry commitment, and existing legal and regulatory enablers

[1] New York, Washington DC, Miami, Houston, Dallas, Denver, Phoenix, Los Angeles, San Francisco, Honolulu
[2] US Domestic Airline industry has an annual market value of ~150B (Ibis, 2018)

EXECUTIVE SUMMARY - CONSTRAINTS

UAM MARKETS FACE SIGNIFICANT CHALLENGES AND CONSTRAINTS

	Near Term- Immature Market	*Longer Term- Mature Market*
Technology Challenges	**Economics:** High cost of service (partially driven by capital and battery costs) **Weather:** Adverse Weather can significantly affect aircraft operations and performance **Air Traffic Management:** High density operations will stress the current ATM system **Battery Technology:** Battery weight and recharging times detrimental to the use of eVTOLs for Air Ambulance market **Impacts:** Adverse energy and environmental impacts (particularly, noise) could affect community acceptance	**Impacts:** Energy and Environmental Impacts of large-scale operations **Cybersecurity** of Autonomous systems including vehicles and UTM **Weather**: Disruptions to operations during significant adverse conditions **New Entrants:** Large scale operations of new entrants like UAS, Commercial Space operations, private ownership of UAM vehicles could increase the complexity of airspace management and safety
Non-Technological Challenges	**Infrastructure:** Lack of existing infrastructure and low throughput **Competition:** Existing modes of transportation **Weather:** Conditions could influence non-technological aspects of operation **Public Perception:** Passengers concerned about safety and prefer security screening and preference UAM only for longer trips **Laws and regulations** for flying over people, BVLOS, and carrying passengers (among others) are needed **Certifications:** Gaps in the existing certification framework where UAM will experience challenges, particularly system redundancy and failure management	**Competition: E**merging technologies and concepts like shared Electric and Autonomous Cars, and fast trains **Weather:** Increase in some adverse conditions due to climate change may limit operations **Social Mobility:** New importance of travel time, increase in telecommuting, urbanization and de-congestion scenarios could reduce the viability of markets **Public Perception:** Passengers trust and apprehension with automation and pilot-less UAM and prefer to fly with others they know in an autonomous UAM

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FOUR PHASE APPROACH TO MARKET STUDY

OUR FOUR-PHASED APPROACH FRAMES THE UAM ECOSYSTEM IN THREE DISTINCT MARKETS

Over the 13 months of the project, our team's goal is to understand the Urban Air Mobility Ecosystem, and perform a targeted deep dive on three specific markets that highlight potentially significant barriers to realization.

	SCOPING	INITIAL ASSESSMENT	INTERIM ASSESSMENT	FINAL ASSESSMENT
TIMING	1.5 months	2.5 months	5 months	3 months
OBJECTIVES	• Identify five markets for potential study • Select one market for initial assessment	• Evaluation of barriers (e.g., legal, societal, and economic) related to initial market • Feedback on methodology	• Comprehensive evaluation of barriers (e.g., legal, societal, and economic) for all three markets • Highlight areas for potential research	• Final report of market analysis and regulatory/ societal barriers • Defined lessons learned
TASKS	• Market characterization • Focus market selection and evaluation	• Initial market and barrier analysis	• Detailed analysis • SAG workshop	• Final market analysis • Results presentation **DETAILED OUT BRIEF**

URBAN AIR MOBILITY ECOSYSTEM INCLUDES CITY CENTER, SUBURBAN AND EDGE CITY

AN EMERGING MODE OF TRANSPORTATION, THE SPECIFICS OF UAM ARE YET TO BE DEFINED

NASA defines UAM as a safe and efficient system for air passenger and cargo transportation within an urban area, inclusive of small package delivery and other urban Unmanned Aerial Systems (UAS) services, that supports a mix of onboard/ground-piloted and increasingly autonomous operations.

CITY CENTER

High-density downtown employment centers and surrounding neighborhoods

SUBURBAN

Predominantly lower density residential neighborhood with some mixed use facilities

EDGE CITY

Medium-density employment centers outside of the urban core

THE PROMISE OF URBAN AIR MOBILITY

- *Decongest Road Traffic*
- *Improve Mobility*
- *Reduce Transport Time*
- *Decrease Pollution*
- *Reduced Strain on Existing Public Transport Networks*
- *Reduce Traffic Accidents*

UAM CONCEPT IS ENABLED BY KEY TRENDS

Improvement in Communications Technology

Improvements in GPS Accuracy

Smaller, Lighter and Cheaper Sensors

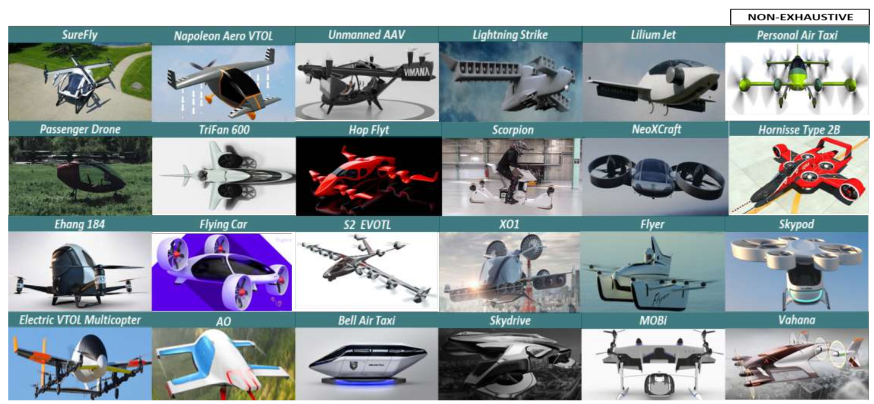
Smaller Microprocessors with Fewer Power Requirements

Energy Storage Optimization

Analytics and Artificial Intelligence Improvements (Autonomy)

Noise Reduction Mechanism Improvements

- **70+ manufacturers** worldwide including Boeing, Airbus and Bell Helicopters
- Over **$1 billion investment** made as of September 2018
- **High profile events** organized around the world in 2018 e.g. Uber Elevate (1200+ attendance, 10k+ online participants), LA City's mayor gathering, etc.



THREE FOCUS MARKETS

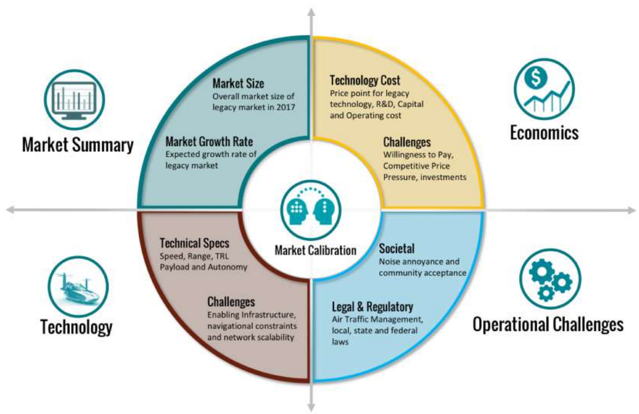
OUR METHODOLOGY CENTERS ON EVALUATING MARKETS WITH INTERESTING BARRIERS

As we walk through our process, the team screened and prioritized markets that will be most relevant for further study as part of the initial and final assessments.

STEP 1 IDENTIFY MARKETS

Market Category	Market Type
First Response (Public Services)	Ambulance Police Firefighter Natural Disaster and Armed Conflict Response
Air Commute	Privately Owned Train Taxi
Air Shuttle	Airport Shuttle Company Shuttle
Entertainment and Media	Film/TV/Radio Stations Tourism
Real Estate and Construction	Aerial Showcasing, Inspections And Survey
Asset/Building Maintenance	Utilities asset maintenance

STEP 2 MARKET CALIBRATION CRITERIA



STEP 3 SCREENED MARKETS

Screened and Prioritized markets

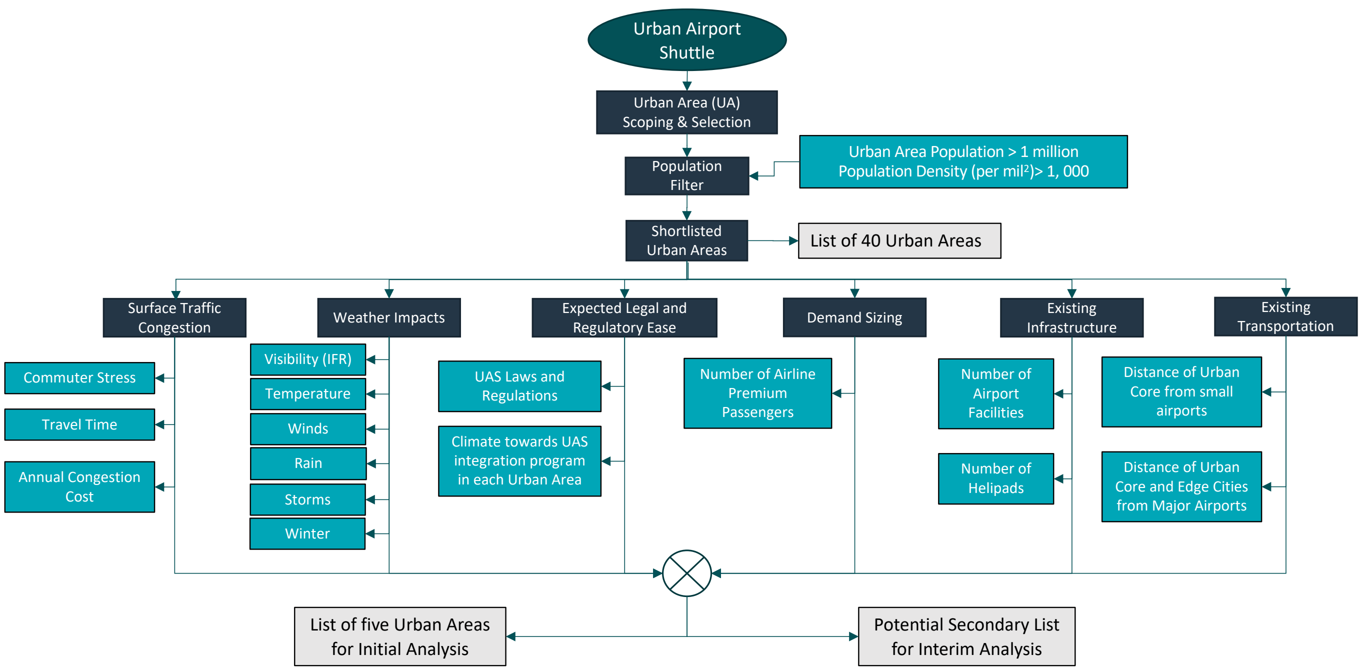
Airport Shuttle (Early Market)

Air Taxi (Mass Market)

Air Ambulance (Complex Market)

Note: *Detailed Methodology available in Market Selection Deliverable*

FOCUS URBAN AREA SELECTION PROCESS



PRIMARY URBAN AREAS TO BE STUDIED FOR INITIAL ANALYSIS

After applying our methodology, we selected the following five urban areas from a shortlisted pool of 40 Urban Areas for initial analysis and five secondary urban areas for interim analysis. We selected urban areas that are representative of the US and will illuminate wide set of barriers for the airport shuttle market that could be operated with human pilots or autonomously.

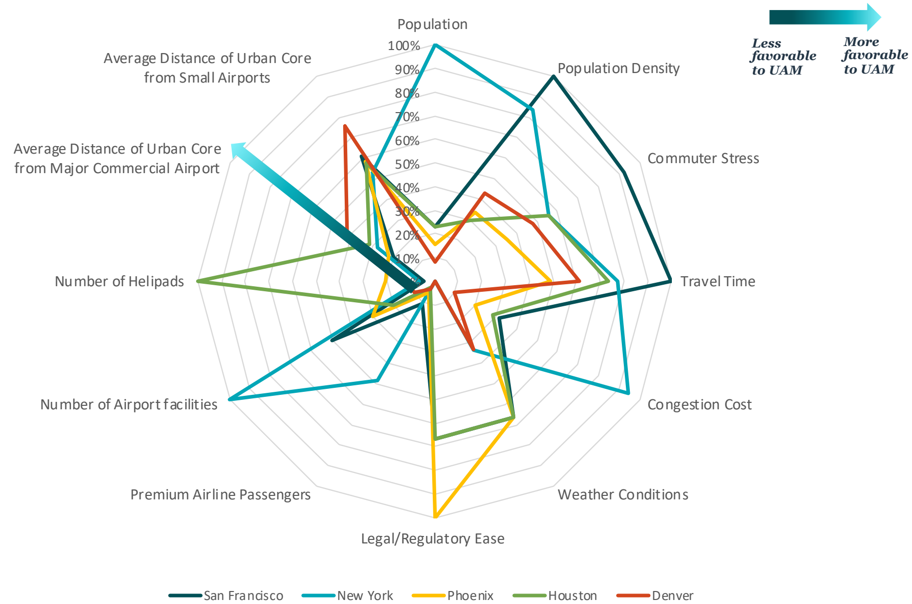
San Francisco--Oakland--San Jose, CA: Multi airport model, high willingness to pay, large market, high traffic congestion, technology forward

New York--Newark, NY--NJ--CT: Multi airport model, Large market, tough local and state regulations, unfavorable weather conditions, high traffic congestion

Phoenix--Mesa, AZ: Favorable regulatory and weather conditions, early adopter

Houston, TX: Two airport model, Large market, favorable weather conditions, good existing infrastructure

Denver--Aurora, CO: One airport model, Luxury market, changing weather conditions, difficult airport accessibility, especially if flying into the mountains



POTENTIAL SECONDARY URBAN AREAS TO BE STUDIED FOR INTERIM ANALYSIS

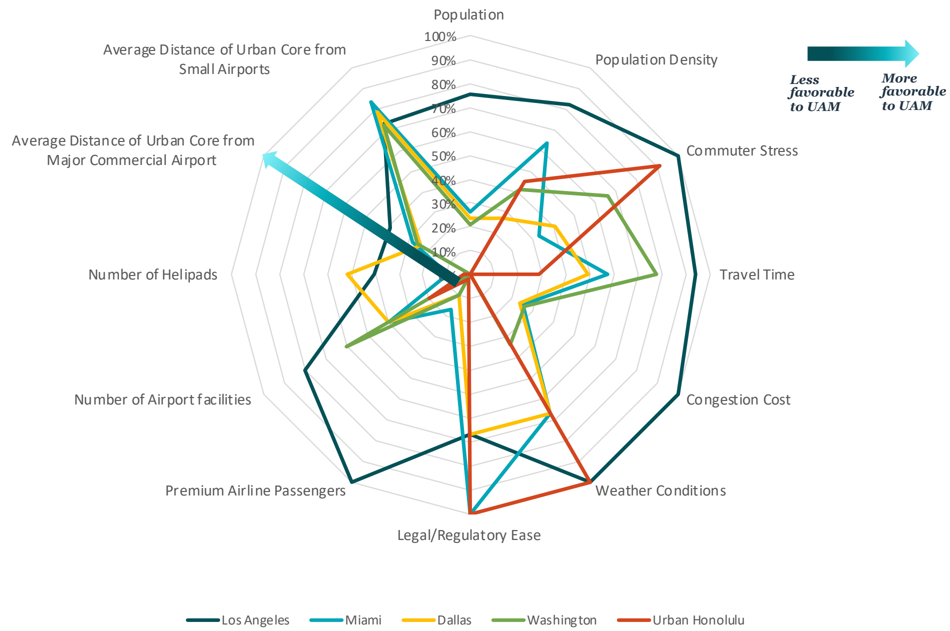
Los Angeles--Long Beach--Anaheim--Riverside--San Bernardino, CA: Multi airport model, high willingness to pay, large market, high traffic congestion, good available infrastructure

Miami, FL: Luxury market, favorable weather conditions, Medium to high traffic congestion, favorable regulatory environment

Dallas--Fort Worth--Arlington, TX: Large market, good weather conditions, high willingness to pay, large number of edge cities and good available infrastructure

Urban Honolulu-- Kailua (Honolulu County), Kaneohe--Kahului, HI: Luxury market, good weather conditions, island to island travel

Washington, DC--VA—MD: Most regulated urban area, unfavorable weather conditions



STRATEGIC ADVISORY GROUP (SAG)

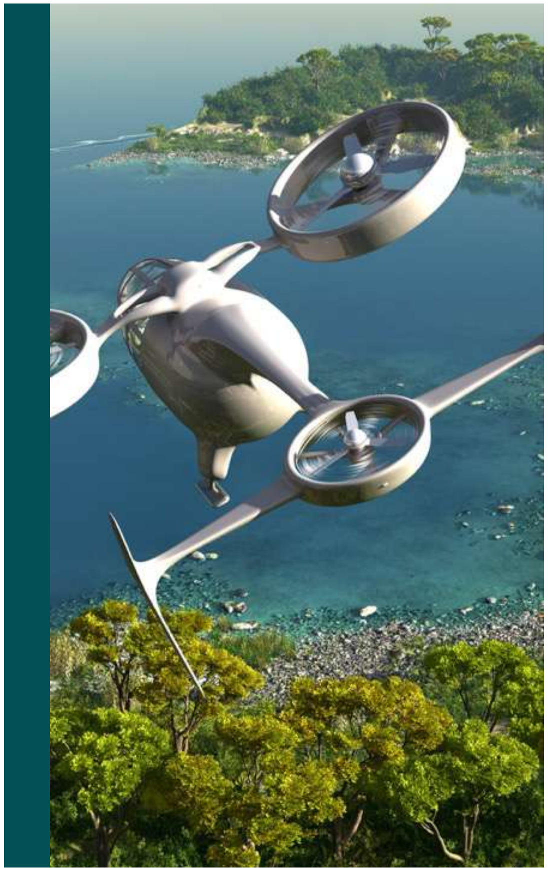
SAG

- The SAG is a diverse and independent group of Urban Air Mobility and/or related market experts and stakeholders that will inform key decision points in the project and help refine the market assessment methodology based on their expertise in the UAM space

OBJECTIVES

- Create a community of UAM experts to inform strategic discussion
- Review project analysis and conclusions
- Validate the market assessment methodology
- Inform key decision points

Note: *Details about members available in Appendix 1*



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DISRUPTING MOBILITY

Easter Morning 1900: 5^{th} Ave, New York City

SPOT THE AUTOMOBILE

Easter Morning 1913: 5^{th} Ave, New York City

SPOT THE HORSE

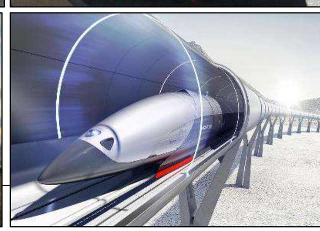
DISRUPTING MOBILITY











ABOUT SOCIETAL BARRIER RESEARCH

Why Do We Conduct Research On Societal Barriers?

- Employed to **understand the potential viability** of use cases, business model, partnerships, and impacts (societal and environmental)
- **Problems to address?** (e.g., airport access, reducing commute barriers (time, distance, congestion), etc.) Hypotheses? Key metrics, etc.?
- **Predictive understanding** of supply-demand patterns
- **Understand the potential business models, partnerships, and impacts**
- **Inform proactive policy development** to maximize the potential benefits and minimize the potential adverse impacts

ABOUT SOCIETAL BARRIER RESEARCH

How Do We Conduct Research On Societal Barriers?

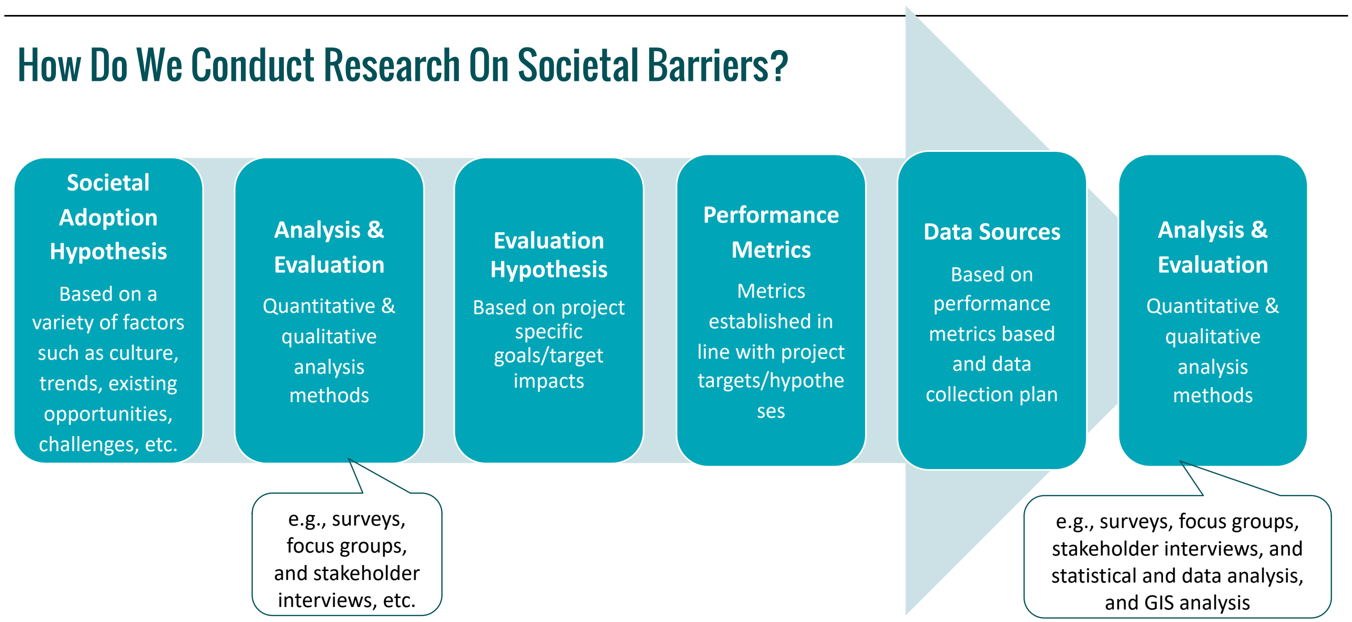
- Regional/national travel surveys exclude predictive questions to forecast modal shift due to changes in transportation technologies.
- Self-report surveys can inform how the public could respond to the advent of a new transportation technology, such as Urban Air Mobility.

Limitations

- Self-report surveys may contain response bias.

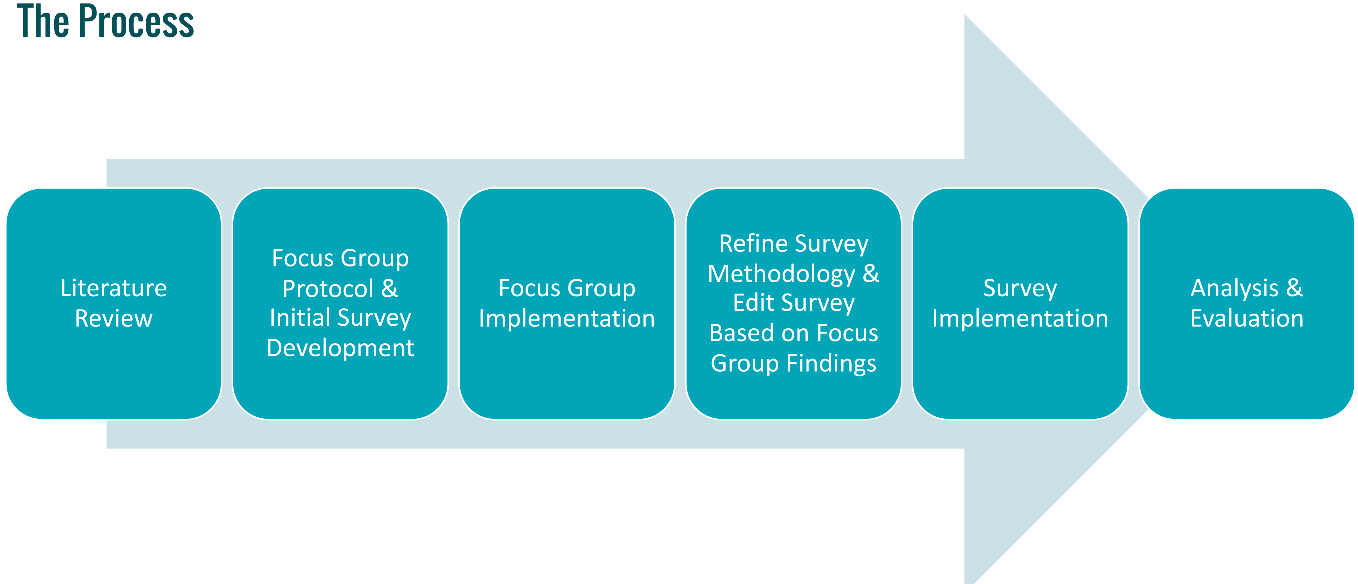
ABOUT SOCIETAL BARRIER RESEARCH

How Do We Conduct Research On Societal Barriers?



SOCIETAL BARRIERS ASSESSMENT METHODOLOGY

The Process



SOCIETAL BARRIERS ANALYSIS FRAMEWORK

OVERVIEW OF THE STEPS FRAMEWORK

STEPS Framework was developed by Booz Allen Hamilton and UC Berkeley for the USDOT to guide assessments on societal barriers for innovative and emerging transportation technologies.

- **Spatial:** Factors that compromise daily travel needs
- **Temporal:** Travel time barriers that inhibit a user from completing time-sensitive trips, such as arriving to work
- **Economic:** Direct costs and indirect costs that create economic hardship or preclude users from completing basic travel
- **Physiological:** Physical and cognitive limitations that make using standard transportation modes difficult or impossible
- **Social:** Cultural, perceptions, safety, security and language barriers that inhibit a user's comfort with using transportation

Note: With UAM, trip length/range is both spatial and temporal factor (distance and flight time)

(Shaheen et al. 2017)

SOCIETAL BARRIERS
USDOT STEPS FRAMEWORK

Societal Barriers

Examples of Potential Barriers/Challenges:

URBAN AIR MOBILITY

Spatial	Temporal	Economic	Physiological	Social
Infrastructure Needs at Origins and Destinations	Are travel times competitive and reliable compared to ground modes?	How much does it cost? Could it substitute for existing modes or create induced demand?	Health/Comfort Sufficient Payload for Passengers and Cargo	Safety
Ability to Pick-up Passengers at Use Case Locations	Sufficient Range / Travel Times for Use Cases	Cost Comparison vs. Existing Modes	Health / Comfort	Security

KEY QUESTIONS ABOUT SOCIETAL ADOPTION

Society and Automation

- Will the public prefer piloted UAM, remote piloted UAM, or automated UAM?
- Will the public accept remote piloted or automated UAM if a “flight attendant” is on board?

Societal Acceptance of UAM

- Will society prefer non-VTOL because of greater familiarity and exposure to fixed-wing take-off and landing?
- Will society prefer electric/gasoline/alternative fuel vehicles? (e.g., safety and environmental perceptions etc.)
- What role will noise and aesthetics have on societal acceptance? (e.g., will “no-fly zones” need to be established to protect views or restrict UAM over certain land uses, such as residential neighborhoods)

Societal Perceptions of Ownership & Sharing

- Will the public prefer privately owned UAM or for-hire (e.g., air taxi) service model?
- Will the public be willing to share a flight with someone they don’t know for a discount?

SURVEY DESIGN

Methodology

- Research team obtained CPHS/IRB approval in Spring 2018
- Exploratory survey targeted approximately ~1,700 respondents in five U.S. cities (~350 respondents per a city)

Survey Market Selection

- Cities selected based a variety of demography, geography, weather, availability of past or present air taxi services, built environments/densities, traffic, etc.

Houston *– Infrastructure ready with a large number of helipads; long history of helicopter services serving offshore drilling operations*

Los Angeles *– High-traffic/long distance/commute time market; existing early UAM services using fixed-wing aircraft (SkyRyde); high-level of public knowledge about UAM due to UberElevate (based on focus group outreach and participation)*

New York *- Long history of helicopter services and societal barriers (safety and noise); a number of high-profile aviation incidents since 2001 including 9/11 (AA #11 & UA #175), AA #587, US #1549, and 2018 Eurocopter AS350 crash; existing app-based on-demand helicopter service (BLADE)*

San Francisco *– Perceived as a tech/early adopter market; potential for notable societal barriers from local environmentalists including noise, aesthetics, etc.*

Washington D.C. *– Perhaps different perceptions on security; N. VA (as an edge city) has a lot of built environment similarities to other edge cities*

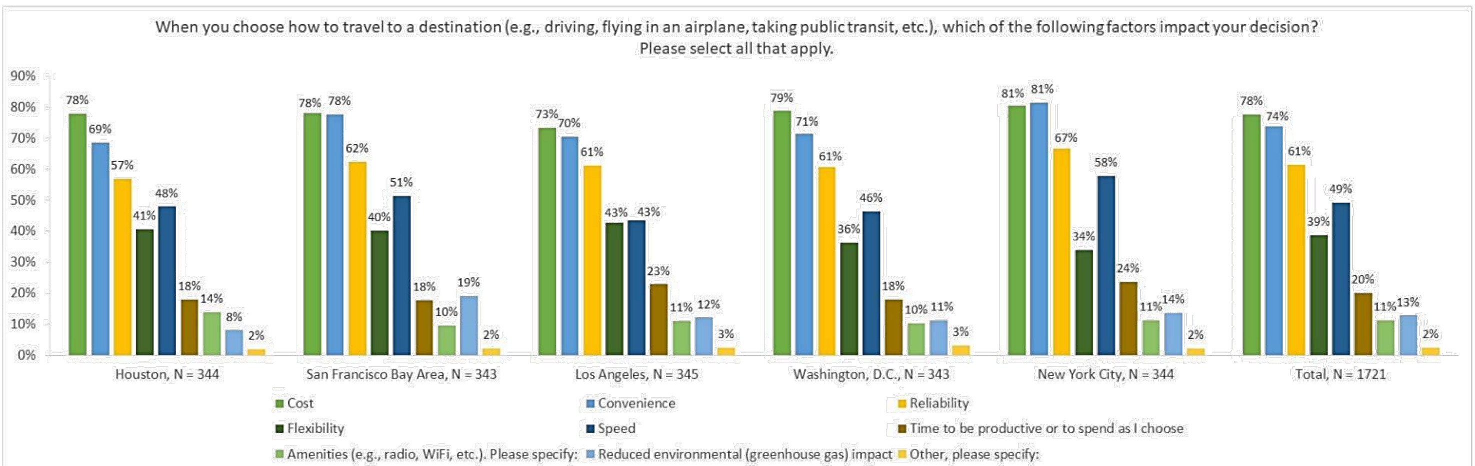
SURVEY DESIGN

Organization & Sections

- Respondent demographics
- Recent travel behavior
- Typical commute behavior
- Familiarity with aviation
- Existing aviation experience & preferences
- Familiarity with UAM
- Perceptions about UAM
- Perceptions towards technology and UAM
- Weather
- Market Preferences
- Perceptions from the non-user perspective

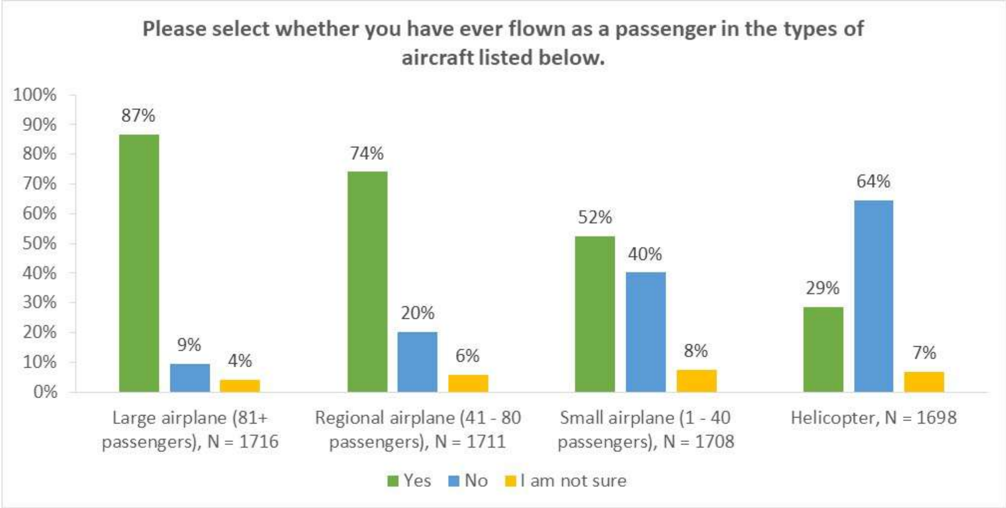
CONSIDERATIONS IMPACTING MODE CHOICE

- **Cost** and **convenience** are the most important motivators impacting mode choice



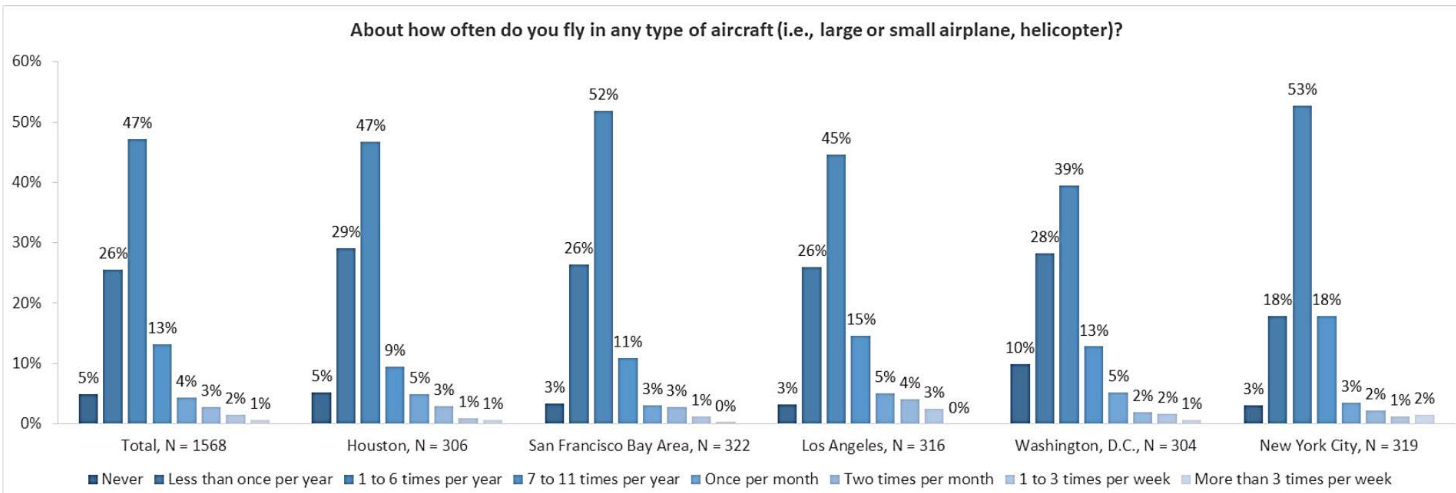
FAMILIARITY WITH AVIATION

- Most respondents had flown in large and regional aircraft
- A higher than expected percentage had also flown in a helicopter



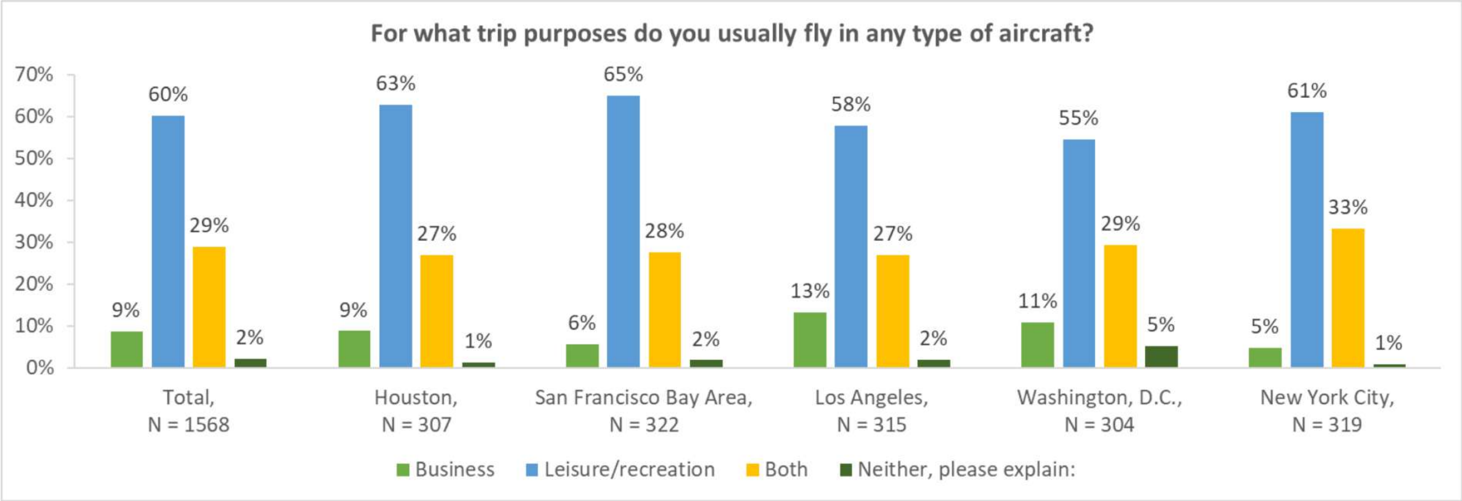
FAMILIARITY WITH AVIATION

- Most respondents fly an average of 1 to 6 times per a year across all cities



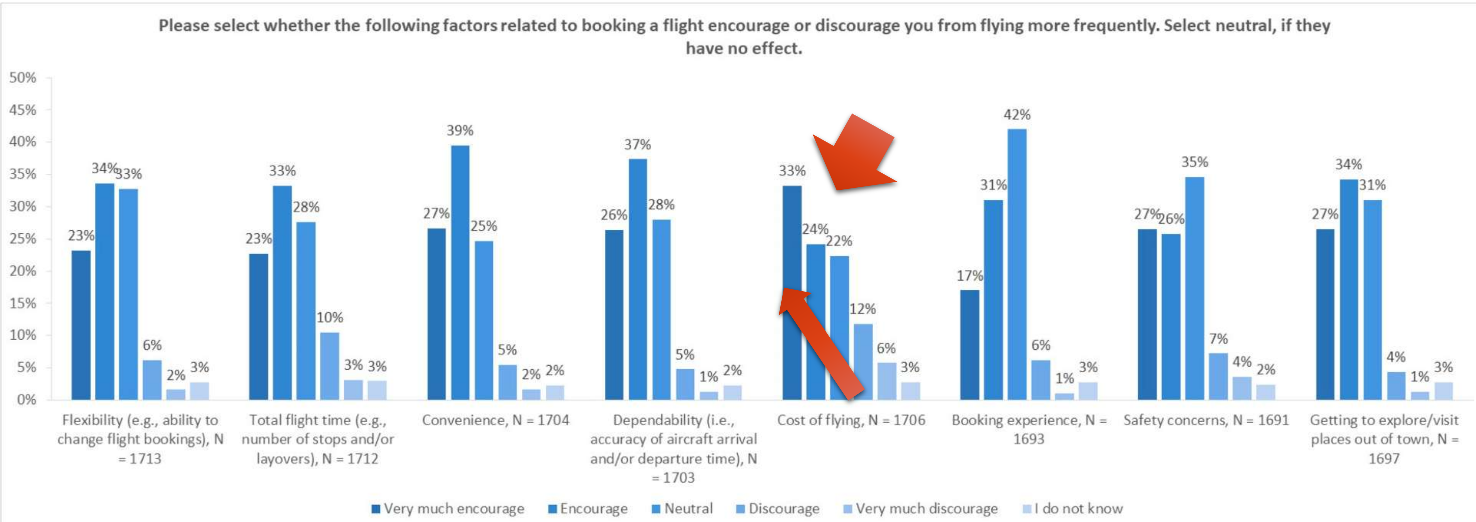
FAMILIARITY WITH AVIATION

- Respondents fly mostly for leisure purposes



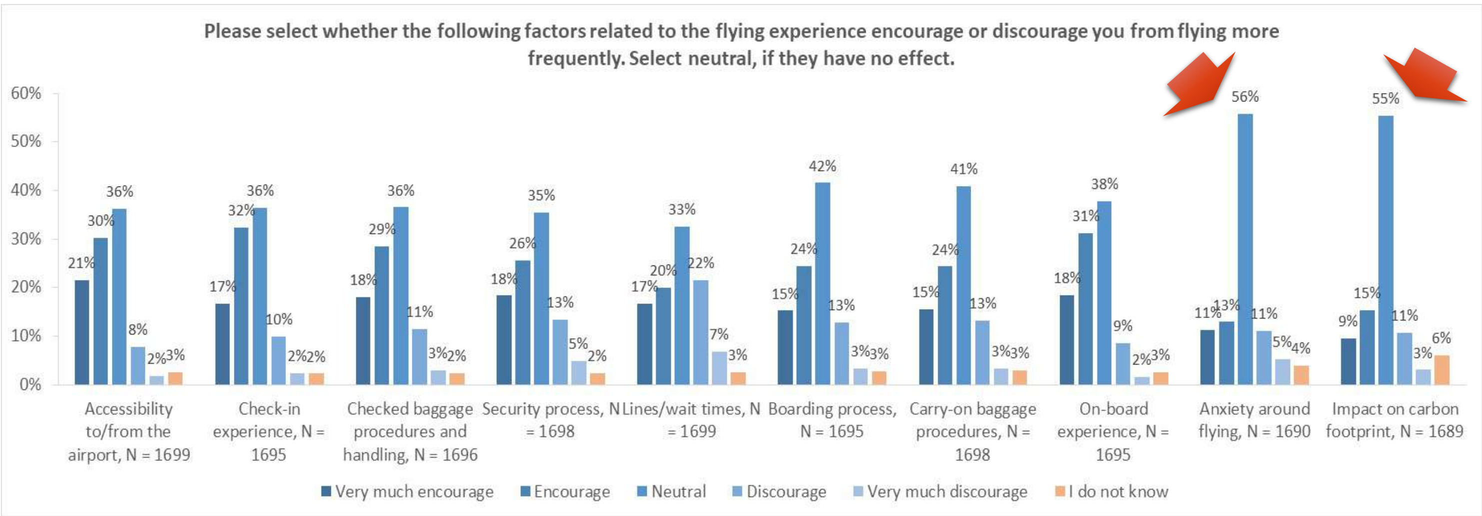
EXISTING AVIATION EXPERIENCE & PREFERENCES

- Cost is the most important factor encouraging or discouraging respondents from flying more frequently.



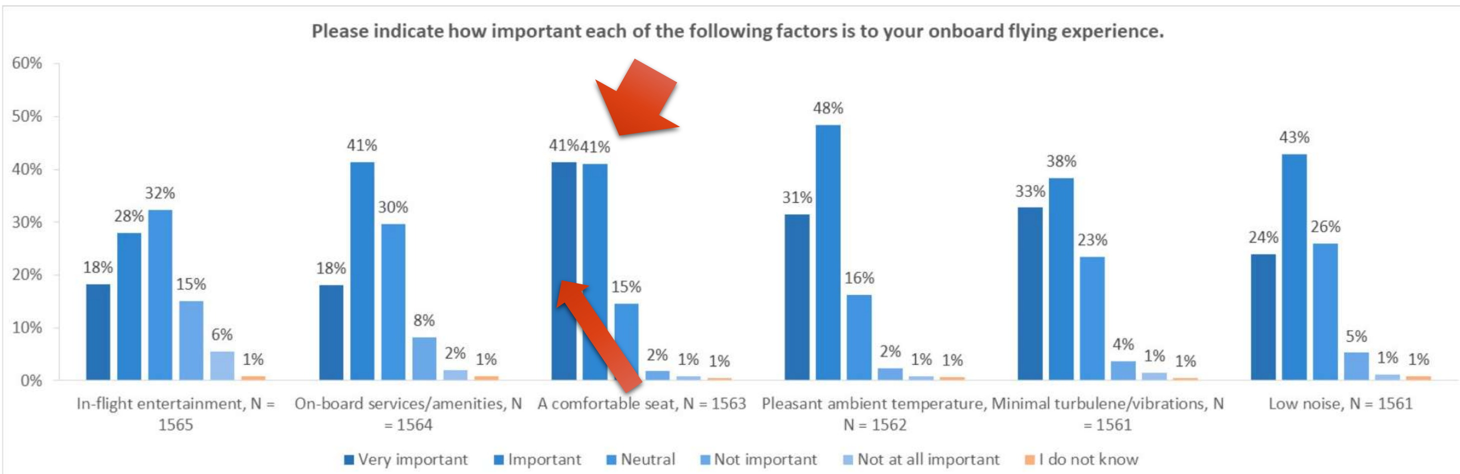
EXISTING AVIATION EXPERIENCE PREFERENCES

- People either do not have anxiety about flying (or it doesn't impact their decision to fly).
- The environmental impacts of aviation also doesn't impact their decision to fly.



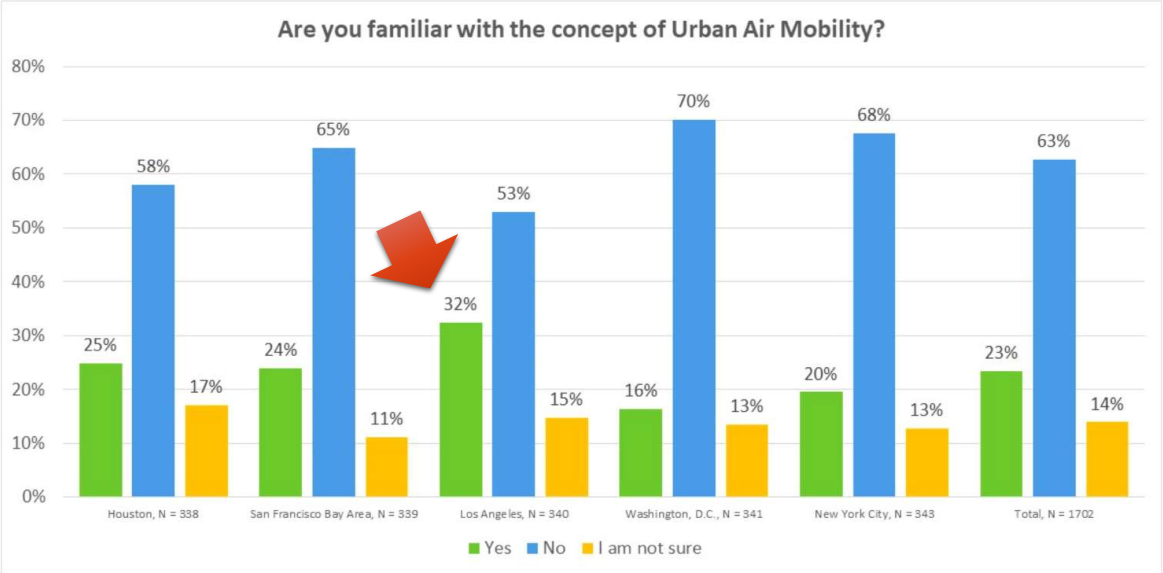
EXISTING AVIATION EXPERIENCE PREFERENCES

- A comfortable seat is key …
- On-board amenities and in-flight entertainment is nice to have but not the most important.



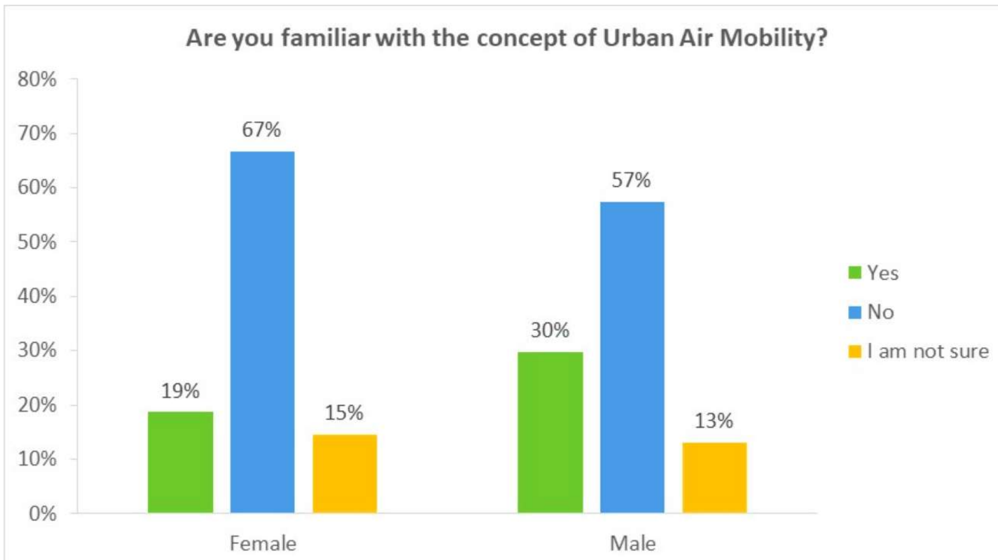
FAMILIARITY WITH URBAN AIR MOBILITY

- Greater familiarity in the Los Angeles market



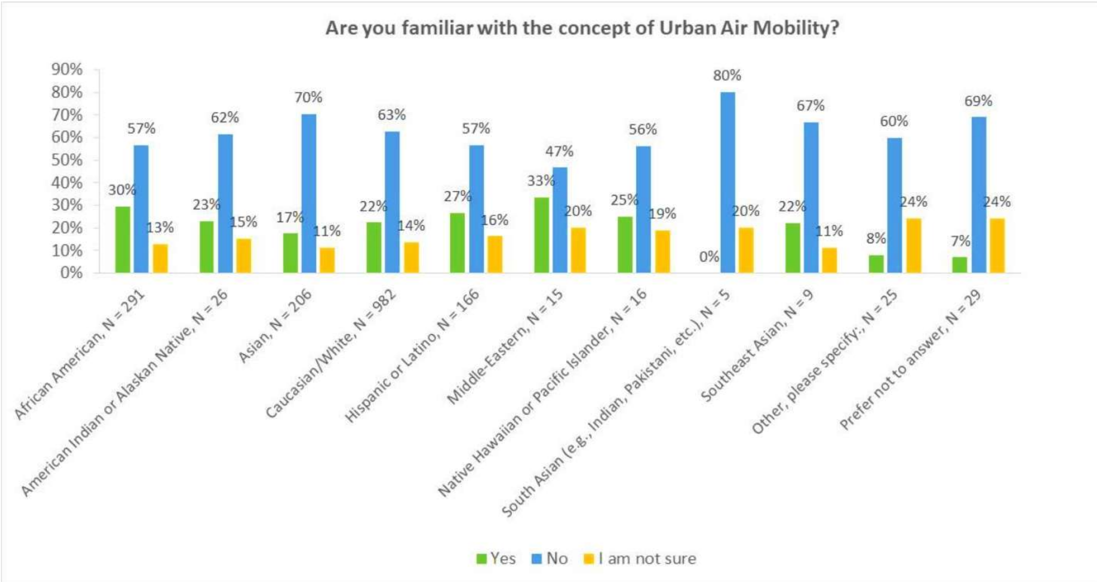
FAMILIARITY WITH URBAN AIR MOBILITY

- Greater familiarity among men



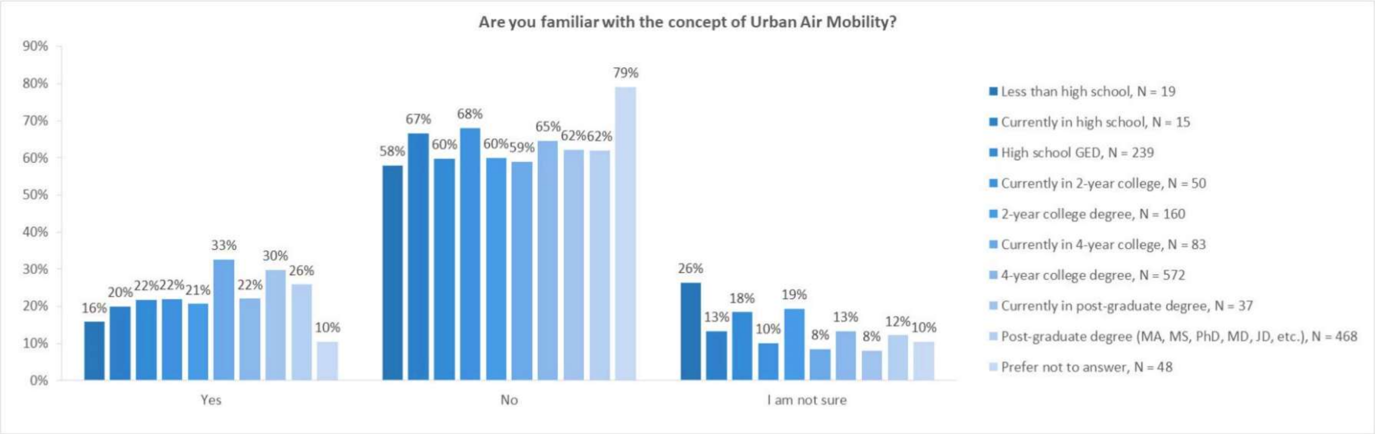
FAMILIARITY WITH URBAN AIR MOBILITY

- Greater familiarity among African Americans



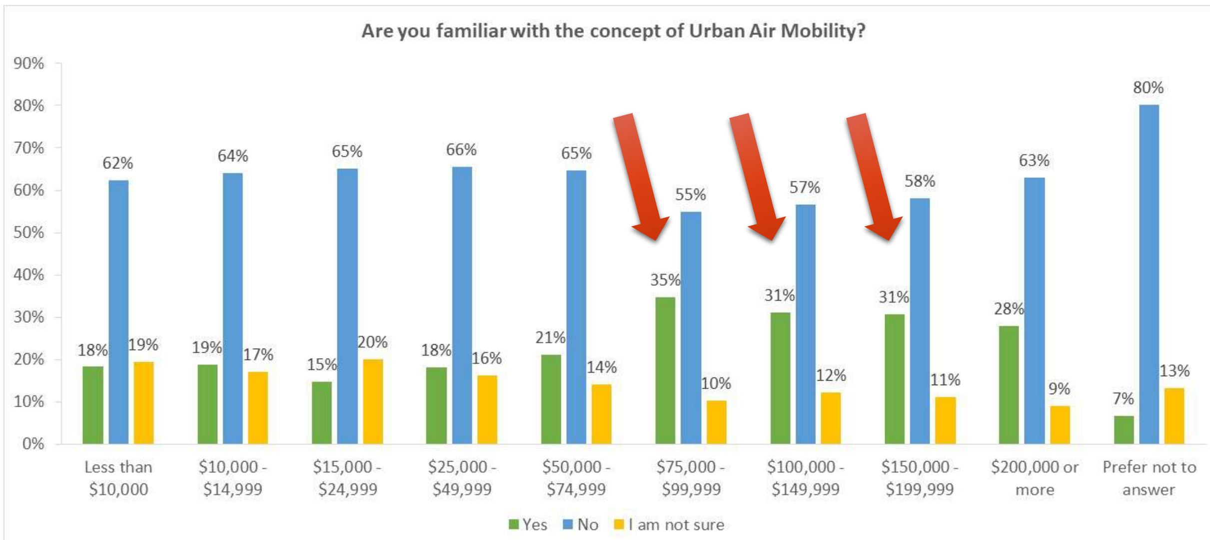
FAMILIARITY WITH URBAN AIR MOBILITY

- Level of educational attainment does not notably impact familiarity



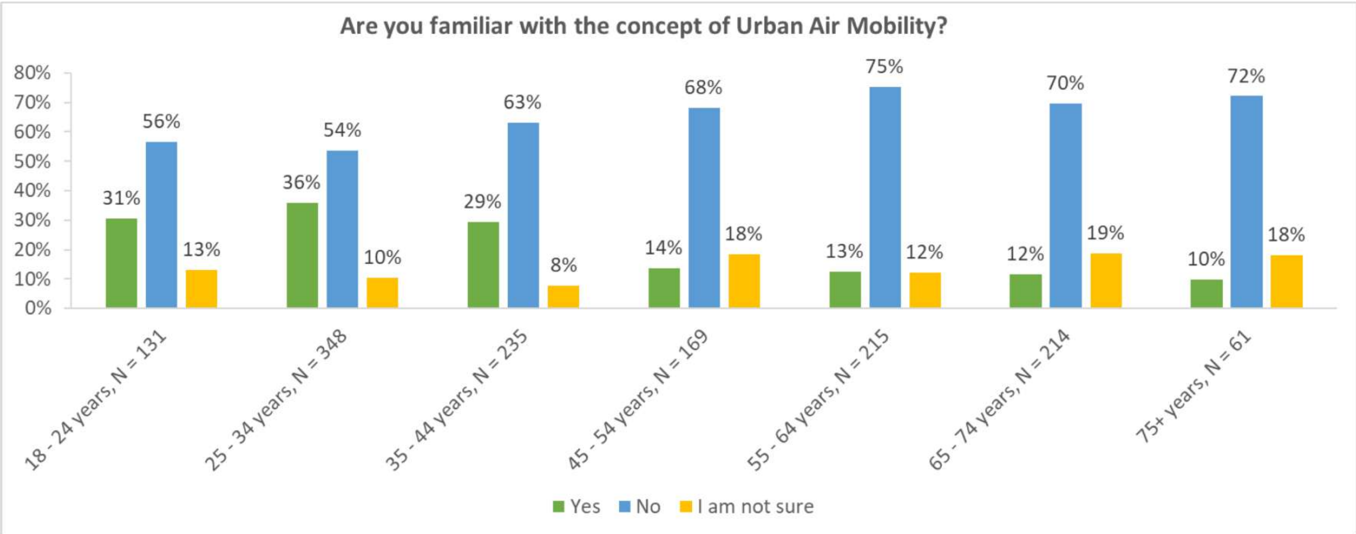
FAMILIARITY WITH URBAN AIR MOBILITY

- Greater familiarity among the upper middle class households.



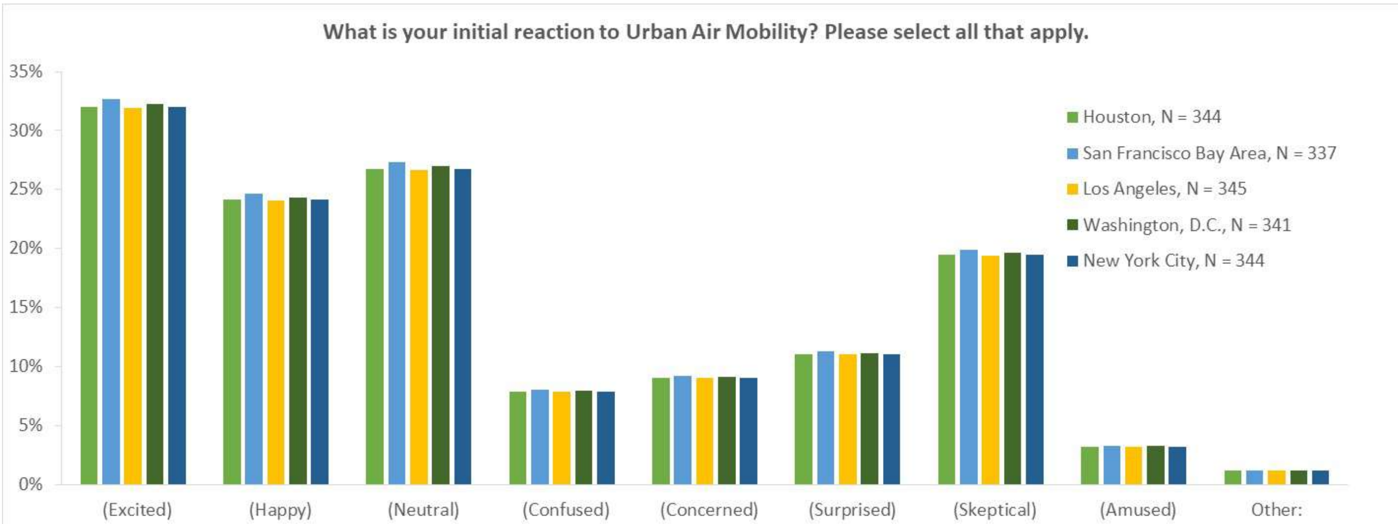
FAMILIARITY WITH URBAN AIR MOBILITY

- Greater familiarity among Millennials and Generation X.



INITIAL FEELINGS ABOUT URBAN AIR MOBILITY

- High-level of consistency in reactions to the UAM concept across all cities
- A positive emotional response with some skepticism



INITIAL FEELINGS ABOUT URBAN AIR MOBILITY

	Excited	Happy	Neutral	Confused	Concerned	Surprised	Skeptical	Amused
GEOGRAPHIC LOCATION	**Survey Results**							
Houston, N = 344	32%	24%	27%	8%	9%	11%	19%	3%
San Francisco Bay Area, N = 337	33%	25%	27%	8%	9%	11%	20%	3%
Los Angeles, N = 345	32%	24%	27%	8%	9%	11%	19%	3%
Washington, D.C., N = 341	32%	24%	27%	8%	9%	11%	20%	3%
New York City, N = 344	32%	24%	27%	8%	9%	11%	19%	3%
GENDER	**Survey Results**							
Female, N = 976	26%	22%	26%	10%	11%	11%	20%	4%
Male, N = 734	37%	23%	23%	6%	10%	8%	18%	4%
RACE/ETHNICITY	**Survey Results**							
African American, N = 291	22%	17%	26%	4%	2%	3%	7%	2%
American Indian or Alaskan Native, N = 26	12%	19%	42%	8%	8%	0%	0%	0%
Asian, N = 206	25%	13%	23%	5%	4%	3%	8%	1%
Caucasian/White, N = 982	20%	14%	17%	6%	5%	2%	10%	1%
Hispanic or Latino, N = 166	26%	19%	19%	2%	2%	5%	2%	2%
Middle-Eastern, N = 15	33%	13%	13%	0%	7%	7%	7%	0%
Native Hawaiian or Pacific Islander, N = 16	0%	13%	19%	6%	0%	13%	0%	0%
South Asian (e.g., Indian, Pakistani, etc.), N = 5	0%	20%	20%	20%	0%	0%	0%	0%
Southeast Asian, N = 9	33%	11%	22%	11%	0%	0%	0%	0%
Other, N = 25	32%	4%	16%	16%	0%	0%	4%	0%

INITIAL FEELINGS ABOUT URBAN AIR MOBILITY

- Greater excitement among middle and upper income households and younger and middle aged respondents

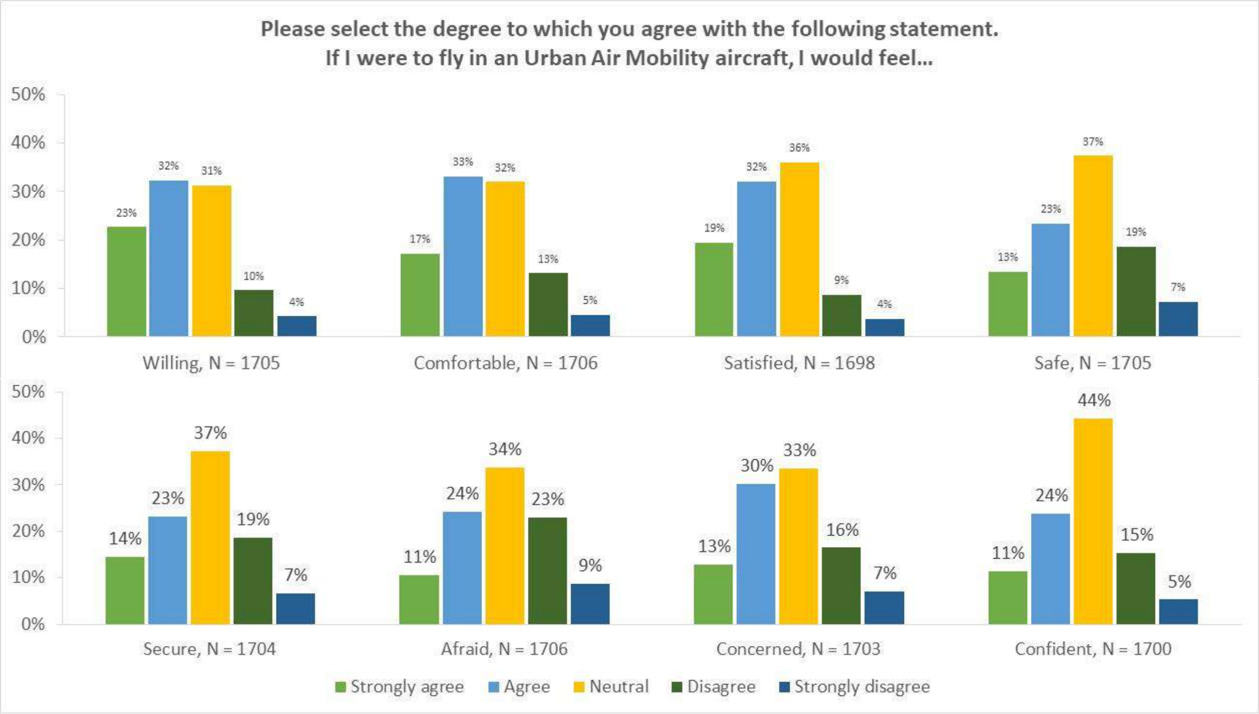
	Excited	Happy	Neutral	Confused	Concerned	Surprised	Skeptical	Amused
INCOME				**Survey Results**				
Less than $10,000, N = 78	14%	17%	40%	8%	3%	4%	10%	3%
$10,000 - $14,999, N = 53	19%	23%	30%	6%	6%	6%	6%	6%
$15,000 - $24,999, N = 101	25%	12%	36%	7%	3%	6%	7%	3%
$25,000 - $49,999, N = 212	28%	15%	27%	8%	5%	3%	11%	2%
$50,000 - $74,999, N = 210	28%	22%	25%	7%	4%	5%	8%	0%
$75,000 - $99,999, N = 192	30%	30%	14%	7%	5%	2%	9%	1%
$100,000 - $149,999, N = 182	36%	14%	25%	4%	6%	1%	12%	2%
$150,000 - $199,999, N = 101	27%	21%	20%	8%	6%	6%	9%	2%
$200,000 or more, N = 112	35%	12%	21%	7%	11%	4%	11%	0%
AGE				**Survey Results**				
18 - 24 years, N = 110	22%	25%	34%	5%	2%	4%	5%	2%
25 - 34 years, N = 271	32%	28%	19%	4%	4%	3%	8%	1%
35 - 44 years, N = 191	43%	16%	17%	6%	5%	2%	8%	3%
45 - 54 years, N = 132	30%	16%	21%	8%	9%	3%	9%	2%
55 - 64 years, N = 178	26%	15%	29%	9%	7%	4%	8%	1%
65 - 74 years, N = 169	14%	12%	33%	9%	6%	4%	18%	1%
75+ years, N = 42	10%	14%	31%	10%	7%	2%	24%	0%

INITIAL FEELINGS ABOUT URBAN AIR MOBILITY

- Greater excitement among respondents with higher levels of educational attainment.

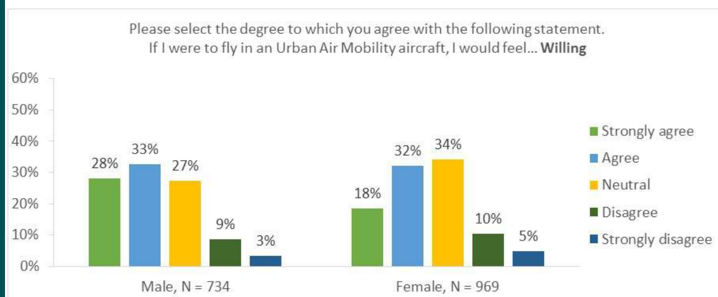
	Excited	Happy	Neutral	Confused	Concerned	Surprised	Skeptical	Amused
EDUCATION	**Survey Results**							
Less than high school, N = 15	27%	20%	33%	7%	7%	7%	0%	0%
Currently in high school, N = 11	18%	0%	64%	0%	0%	0%	0%	9%
High school GED, N = 196	23%	17%	34%	7%	3%	2%	10%	3%
Currently in 2-year college, N = 45	20%	31%	29%	4%	0%	4%	4%	4%
2-year college degree, N = 128	27%	20%	26%	5%	6%	5%	10%	1%
Currently in 4-year college, N = 72	22%	31%	25%	3%	1%	4%	13%	0%
4-year college degree, N = 445	30%	18%	24%	7%	6%	4%	9%	1%
Currently in post-graduate degree, N = 30	23%	23%	20%	17%	3%	0%	7%	3%
Post-graduate degree (MA, MS, PhD, MD, JD, etc.), N = 363	29%	15%	22%	7%	7%	4%	13%	1%

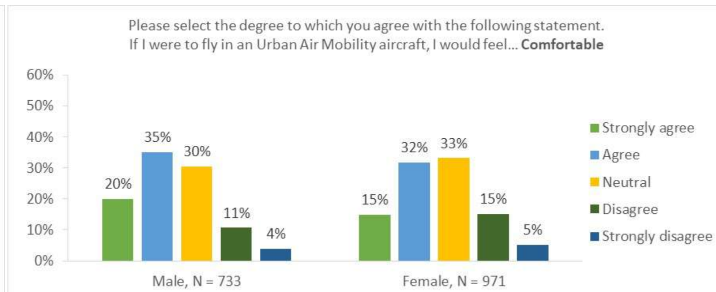
RESPONDENTS CAUTIOUSLY OPTIMISTIC

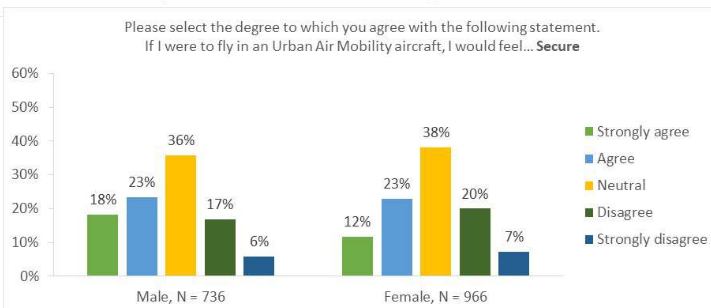


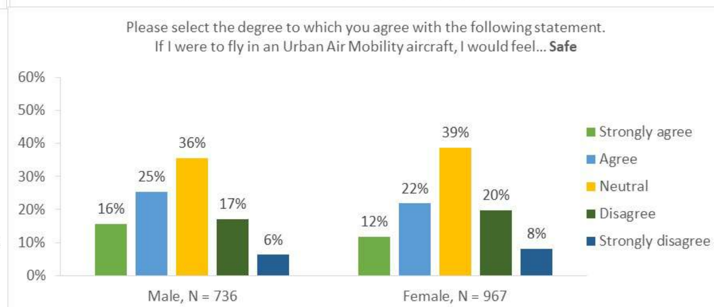
PERCEPTIONS ABOUT URBAN AIR MOBILITY

- Men are more comfortable and willing than women.



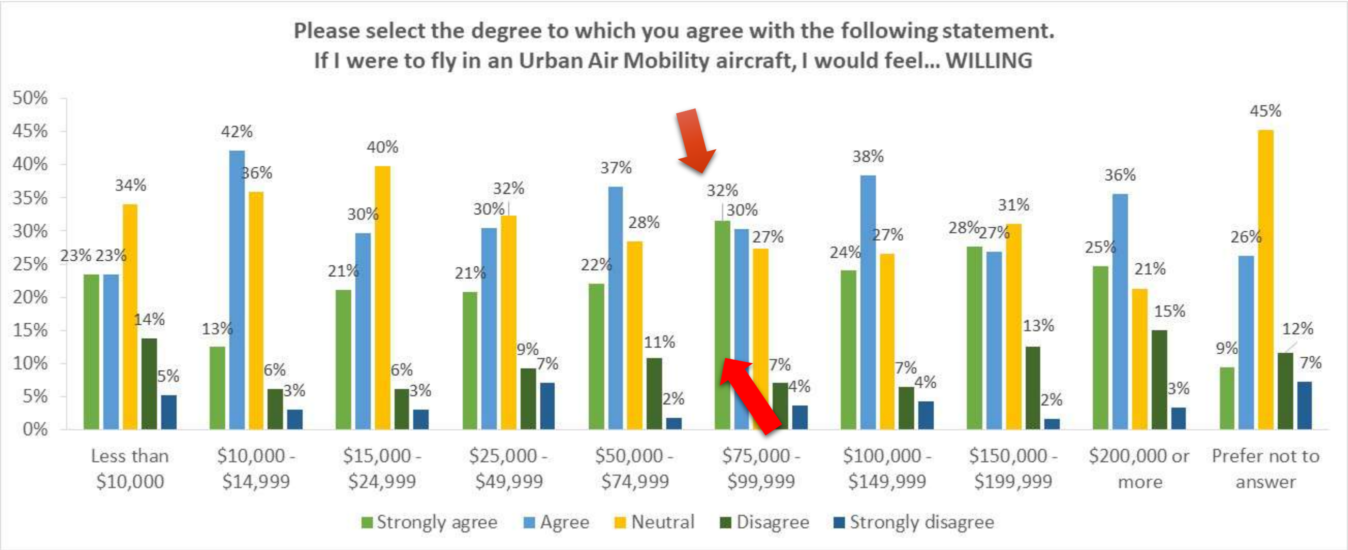






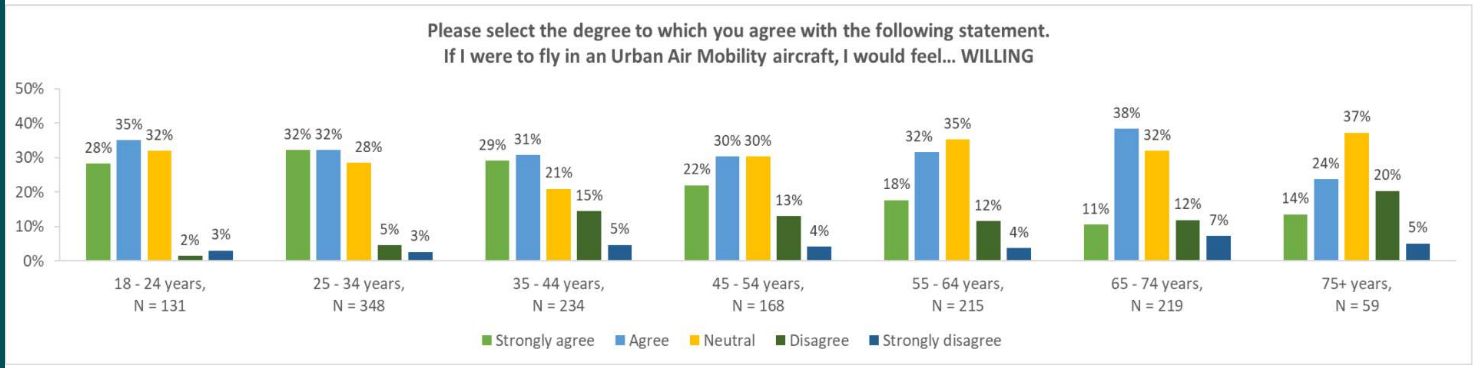
INITIAL FEELINGS ABOUT URBAN AIR MOBILITY

- Willingness peaks among middle income households.



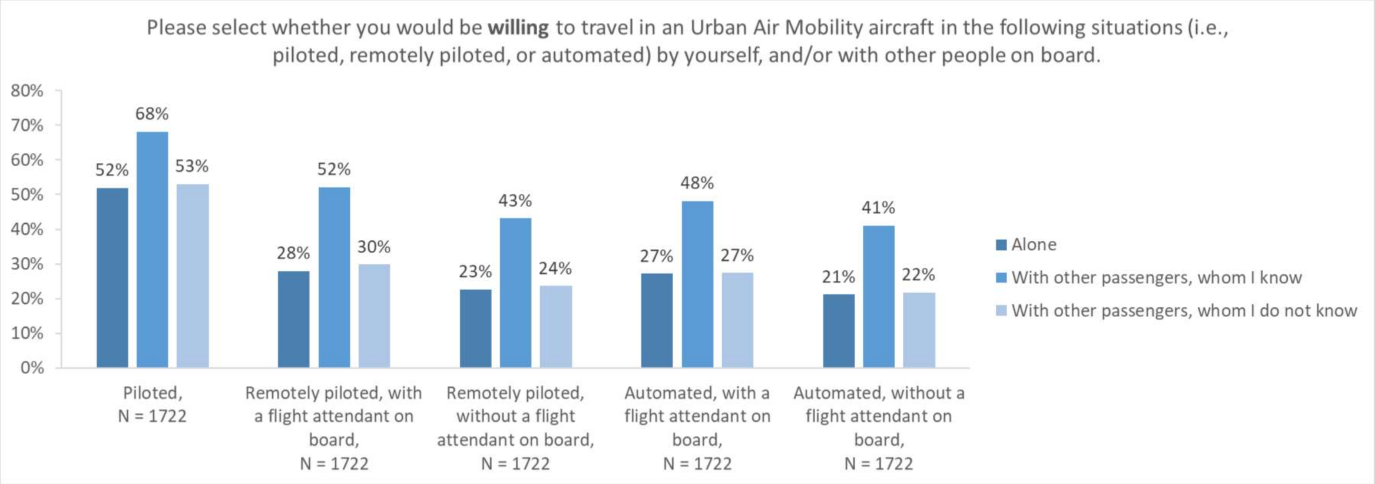
INITIAL FEELINGS ABOUT URBAN AIR MOBILITY

- Willingness highest among Millennials.

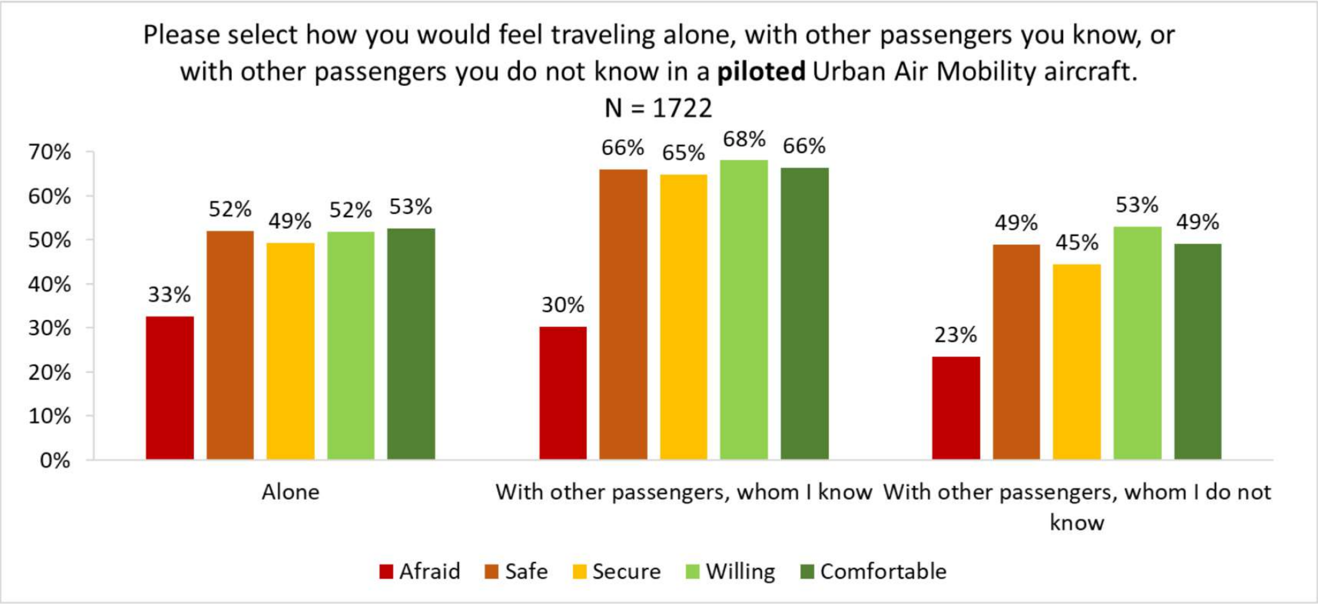


PERCEPTIONS TOWARDS TECHNOLOGY & UAM

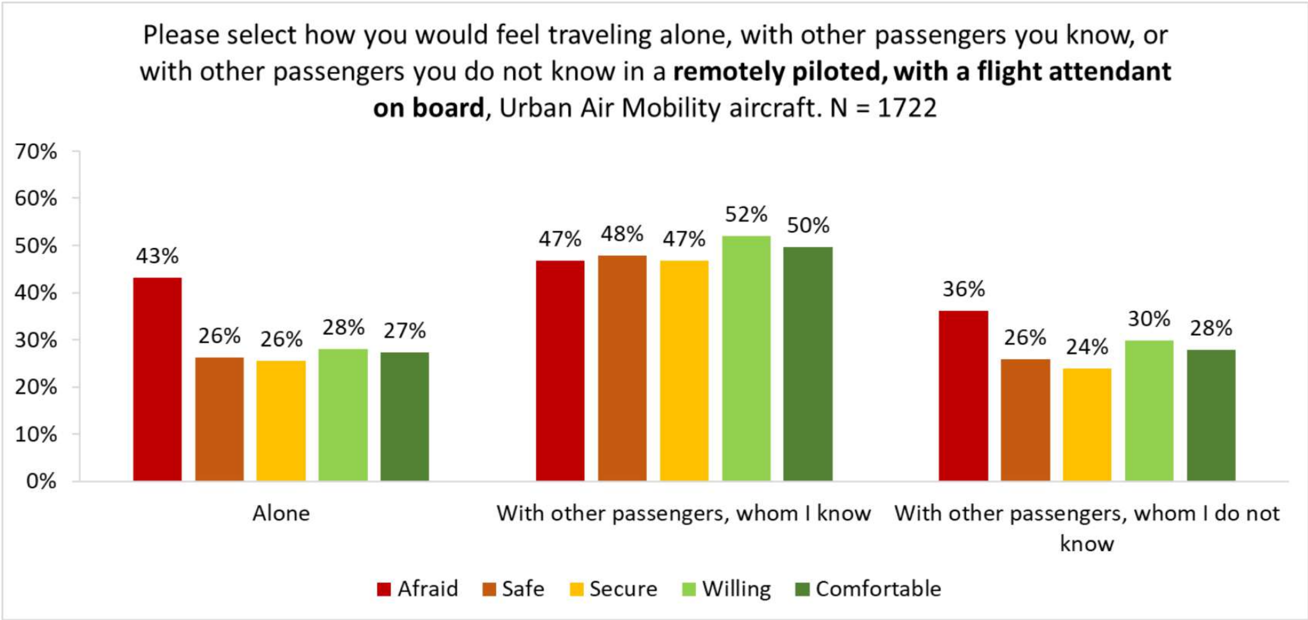
- Respondents prefer flying with other passengers they know; more willing flying alone on a piloted aircraft versus remotely piloted or automated aircraft.



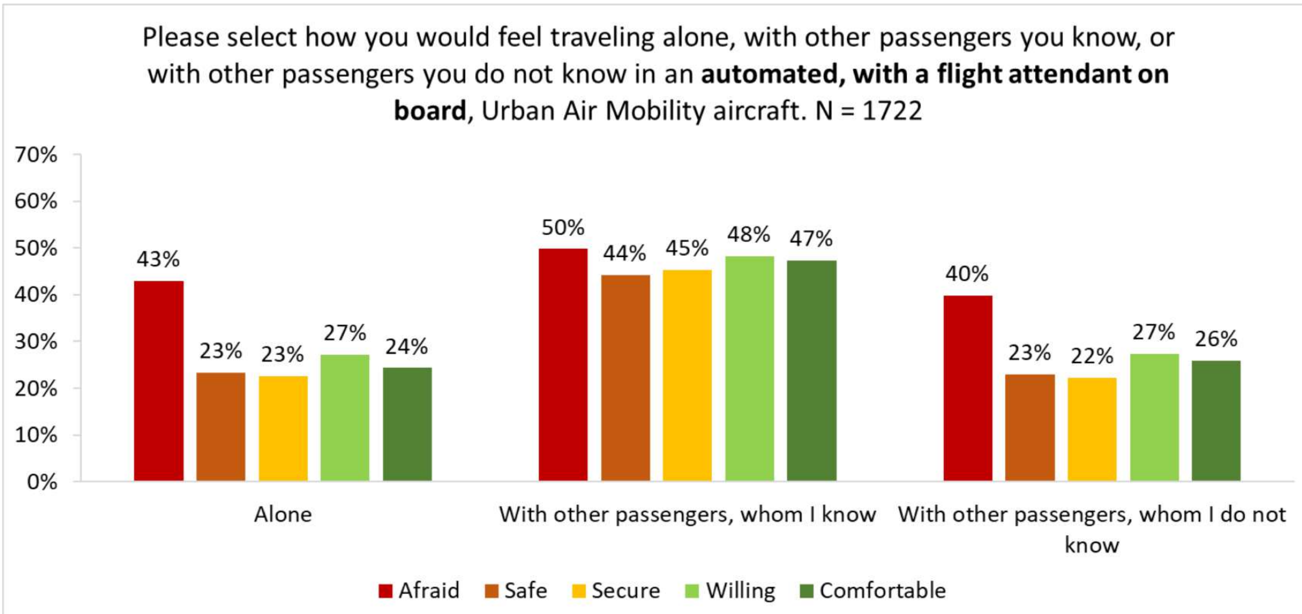
PERCEPTIONS TOWARDS TECHNOLOGY & UAM



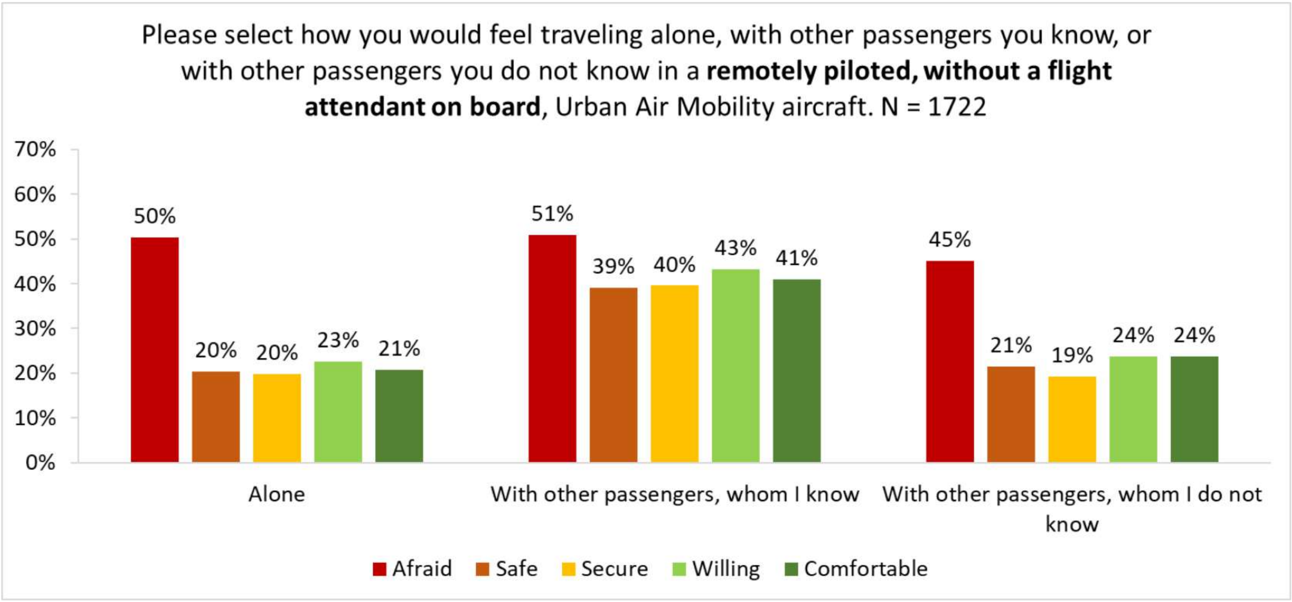
PERCEPTIONS TOWARDS TECHNOLOGY & UAM



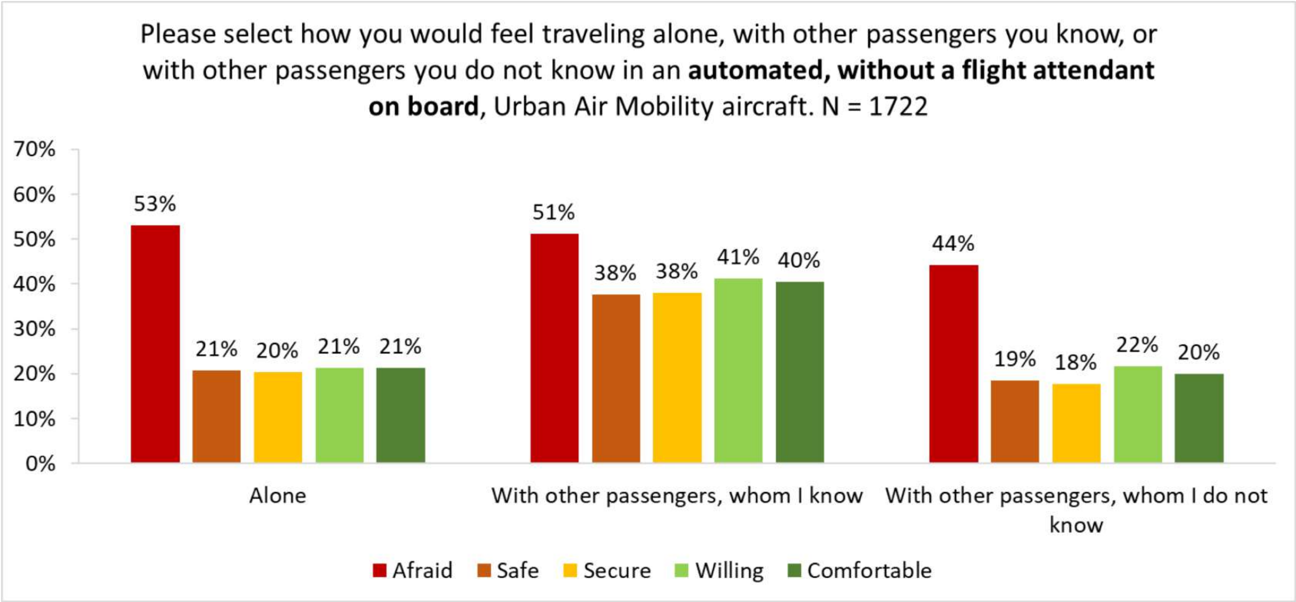
PERCEPTIONS TOWARDS TECHNOLOGY & UAM



PERCEPTIONS TOWARDS TECHNOLOGY & UAM



PERCEPTIONS TOWARDS TECHNOLOGY & UAM



SOCIETAL PERCEPTIONS OF WEATHER

Respondents are somewhat apprehensive flying in turbulence, rain, snow, and low visibility conditions; more indifferent to hot and cold weather conditions.

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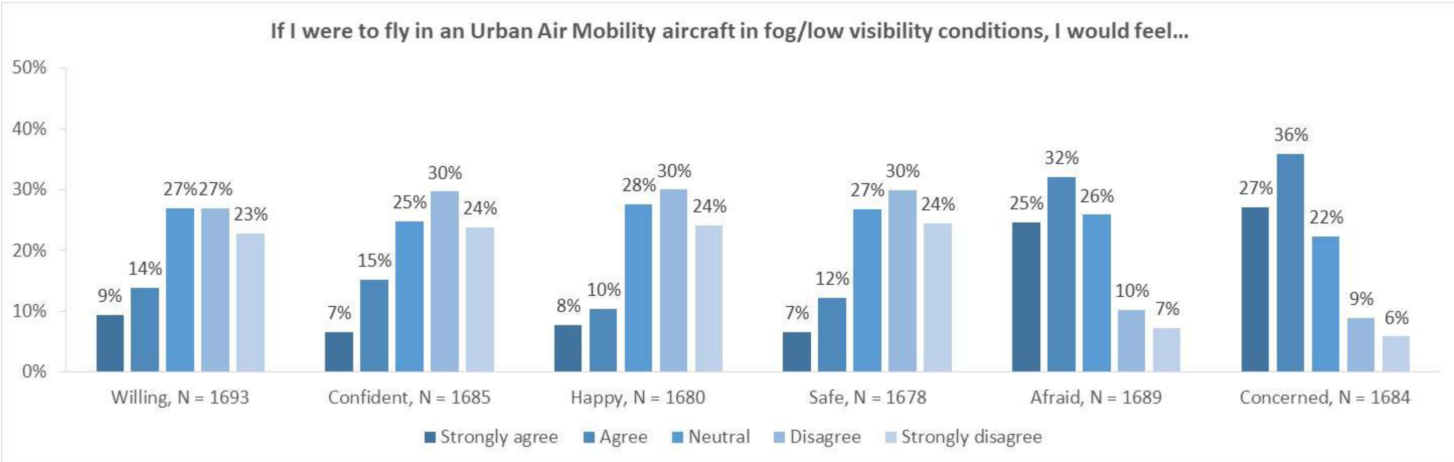
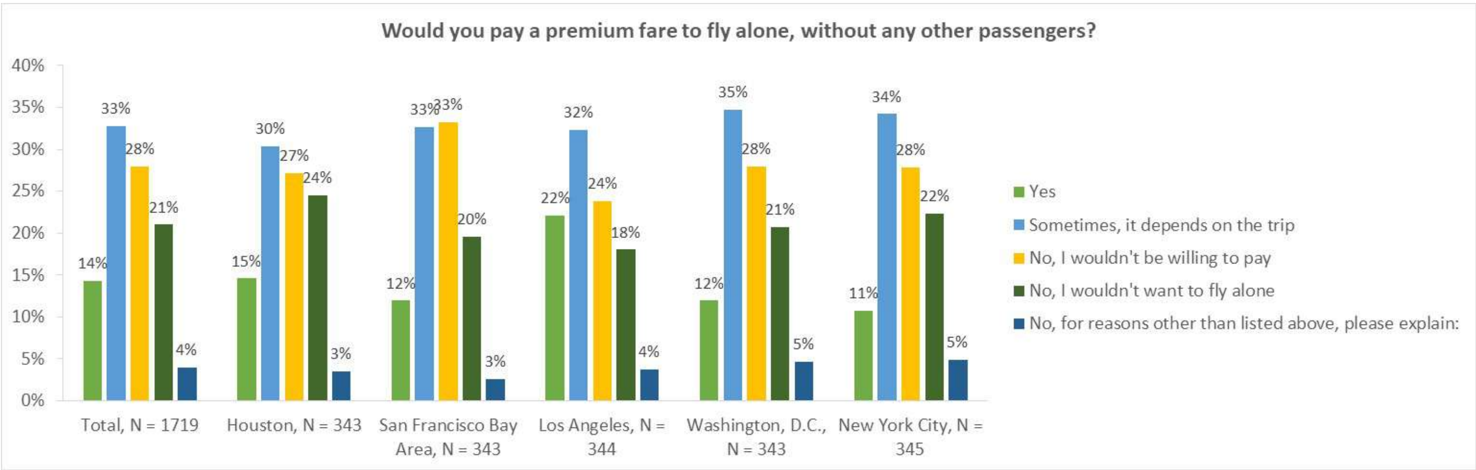
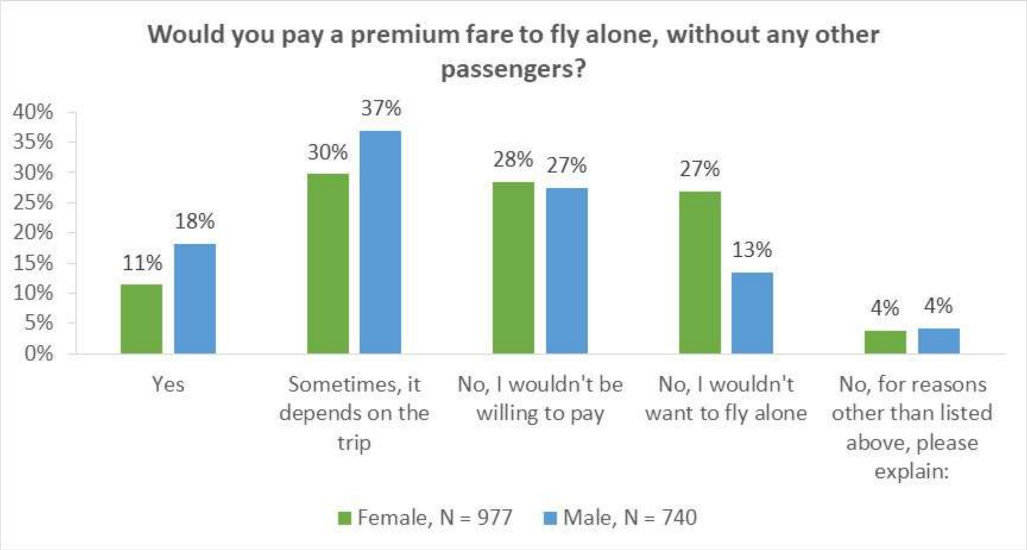


MARKET PREFERENCES: PRICING VS. PRIVACY



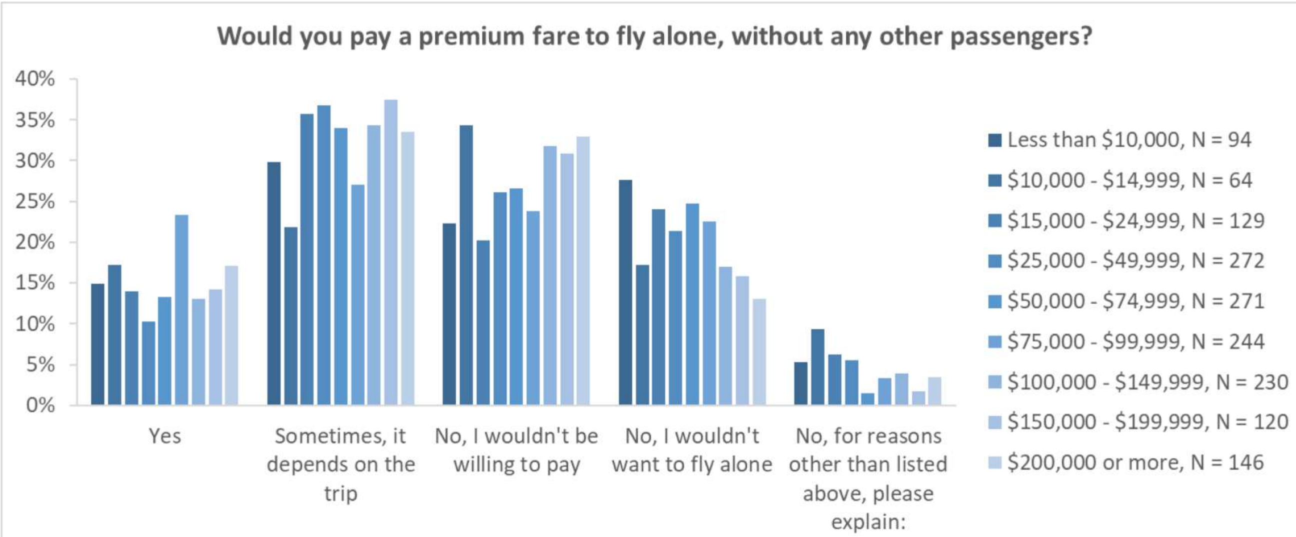
MARKET PREFERENCES: PRICING VS. PRIVACY

- Men are more willing to pay a premium to fly alone without any other passengers.



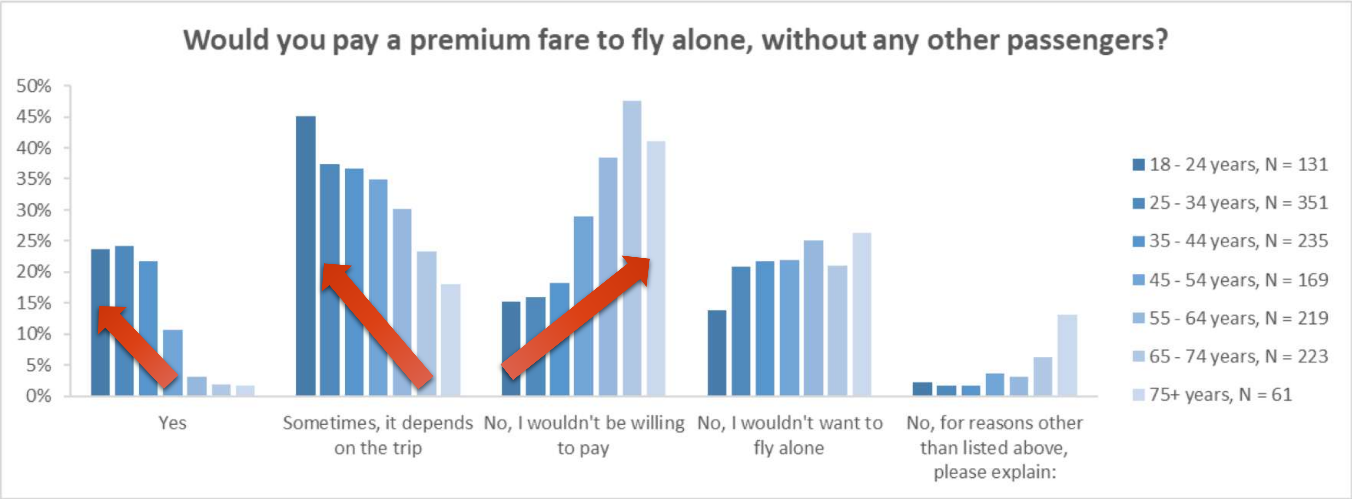
MARKET PREFERENCES: PRICING VS. PRIVACY

- Household income doesn't really impact a person's willingness to pay a premium to fly alone.



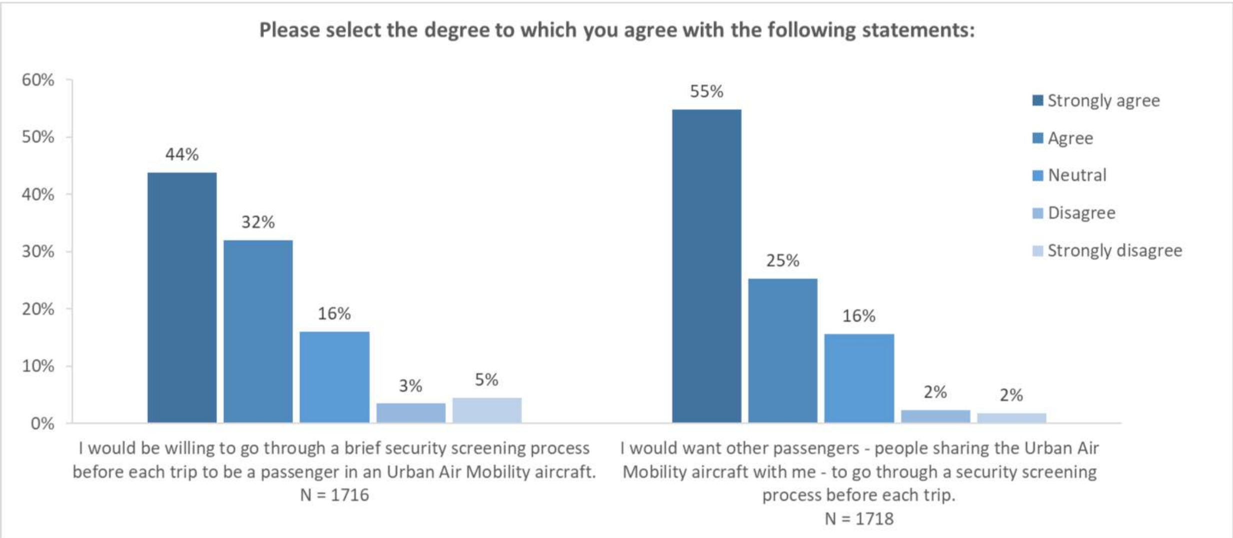
MARKET PREFERENCES: PRICING VS. PRIVACY

- Younger adults are much more willing to pay a premium to fly alone (perhaps the Lyft/Uber effect)



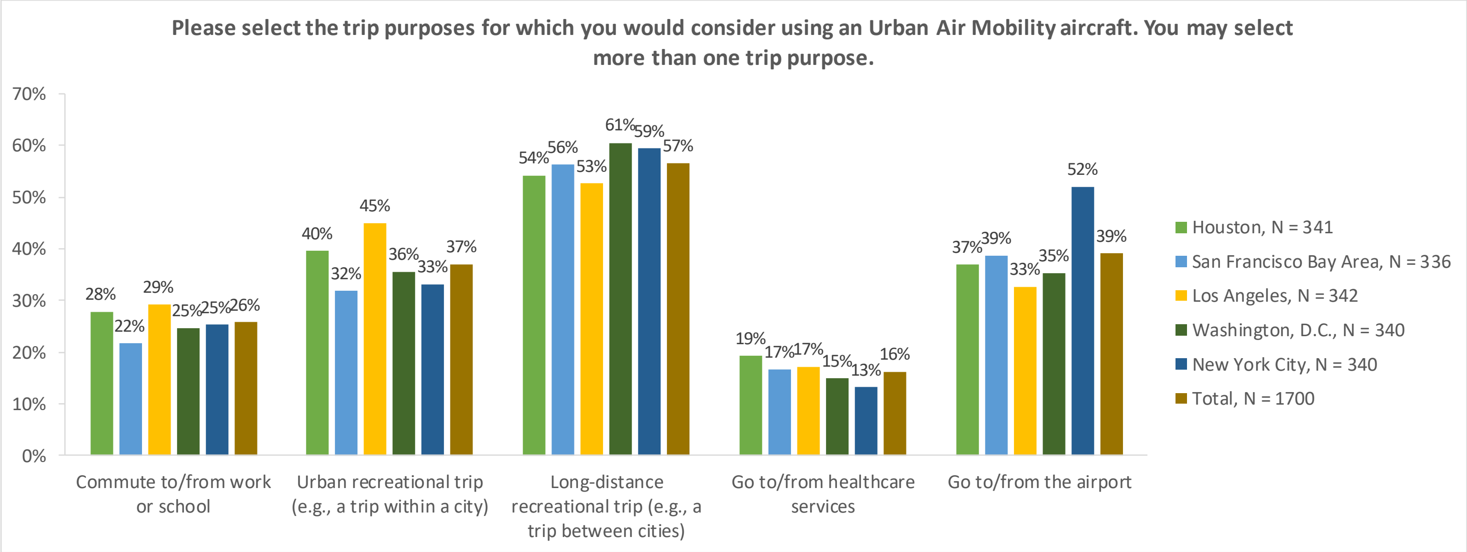
MARKET PREFERENCES: SECURITY SCREENING

- People are willing and want other passengers to go through some type of security screening process



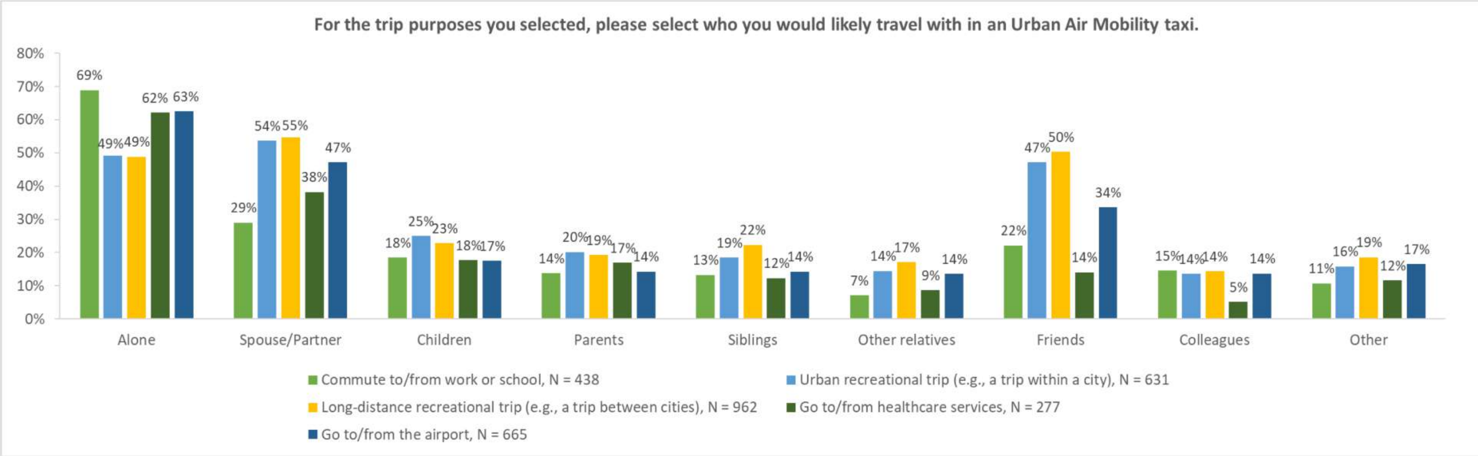
MARKET PREFERENCES: TRIP TYPE

- Respondents were most interested using UAM for long-distance recreational trips.



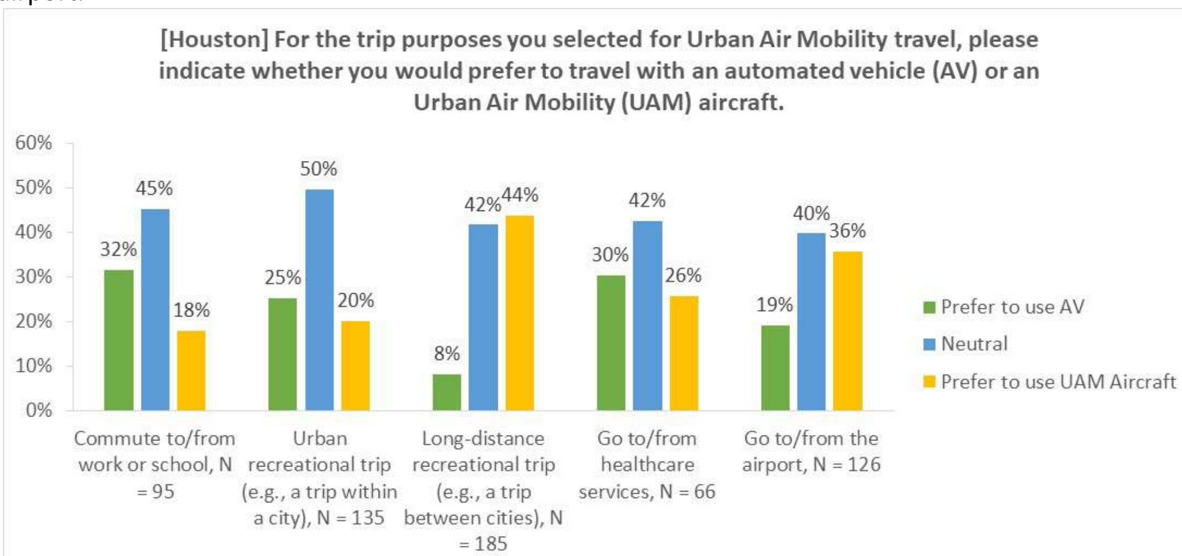
MARKET PREFERENCES: TRIP TYPE

- Most people would fly with friends, intimate partners, or alone.



MARKET PREFERENCES: AV VS. UAM

- Respondents were most interested using UAM for long-distance recreational trips and to go to/from the airport.



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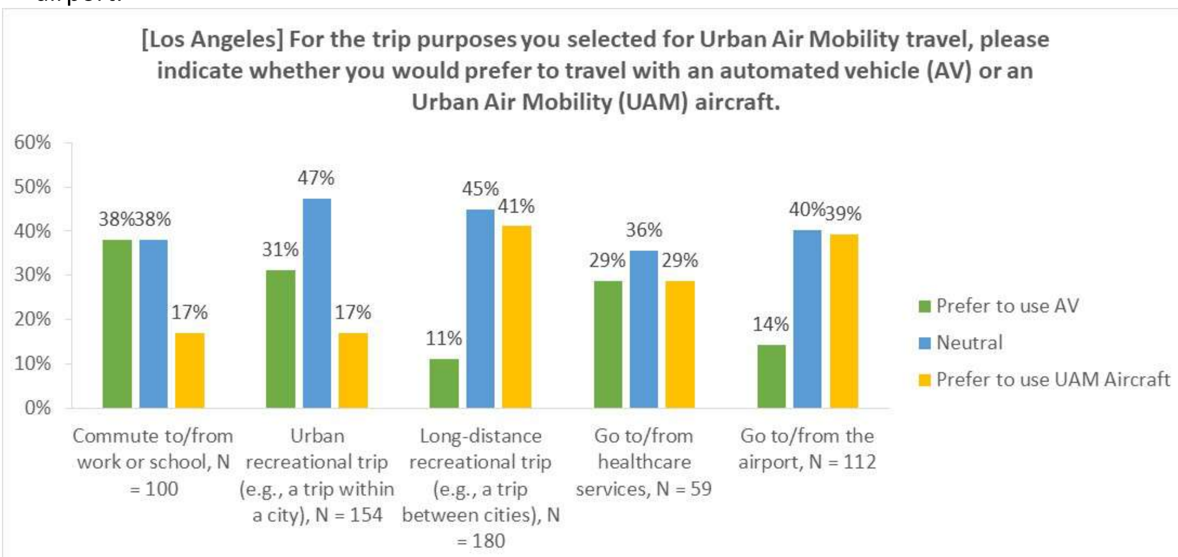
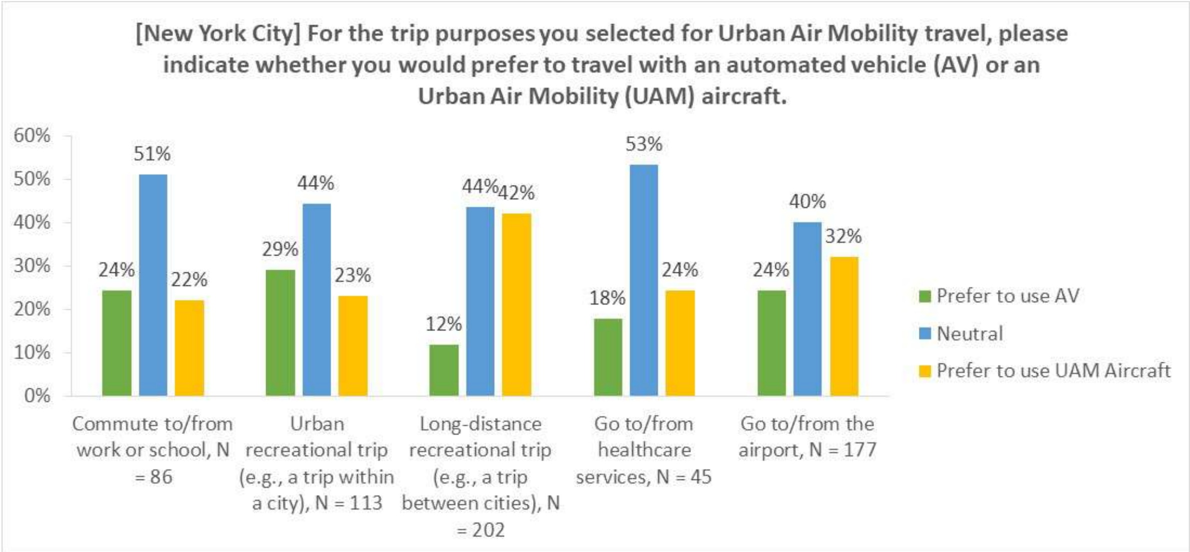


MARKET PREFERENCES: AV VS. UAM

- Respondents were most interested using UAM for long-distance recreational trips and to go to/from the airport; slight preference for UAM for healthcare trips in NYC



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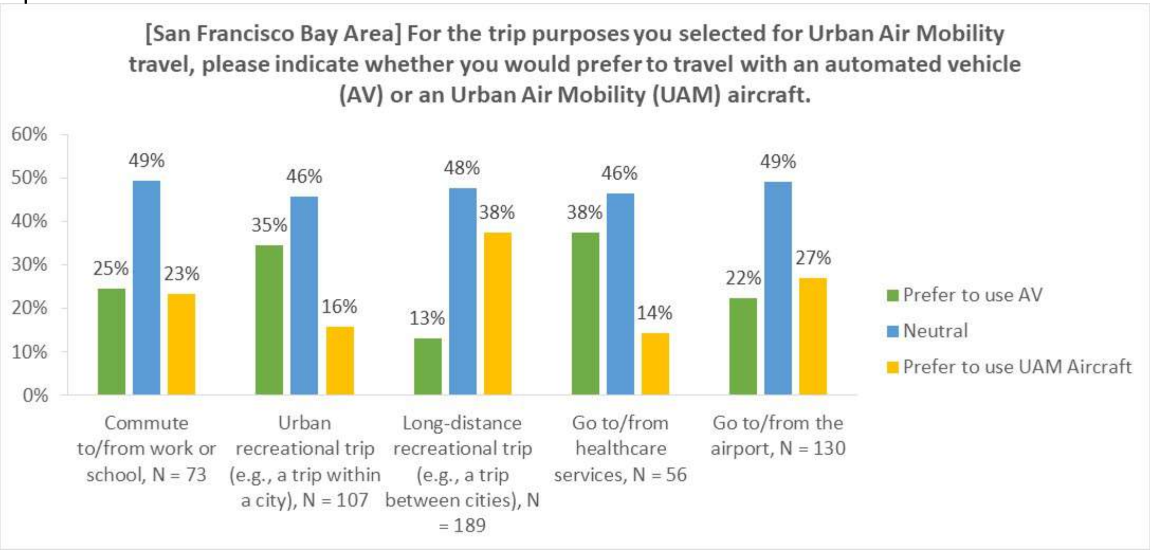

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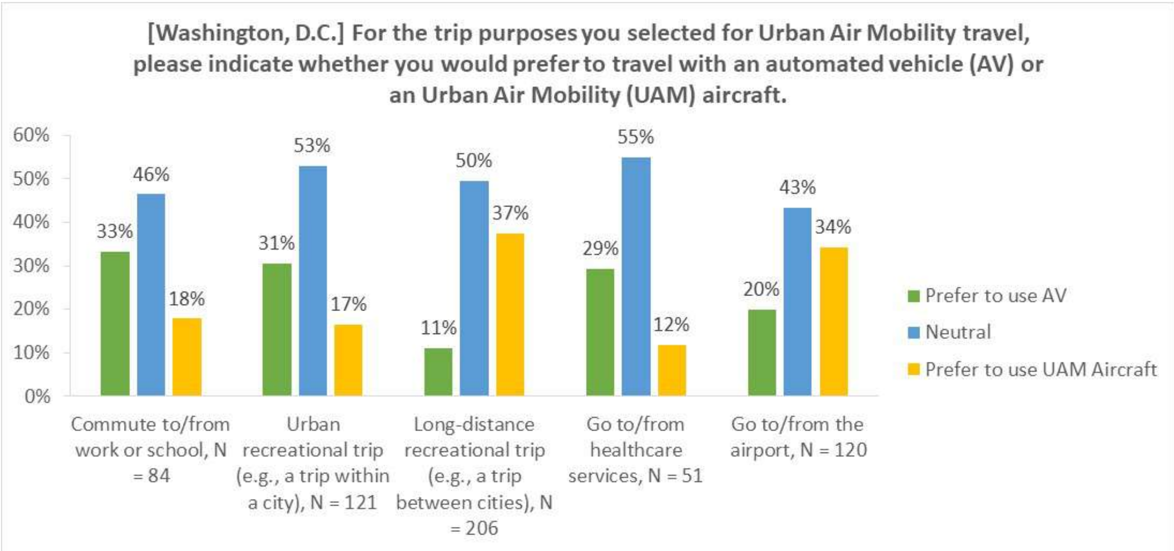
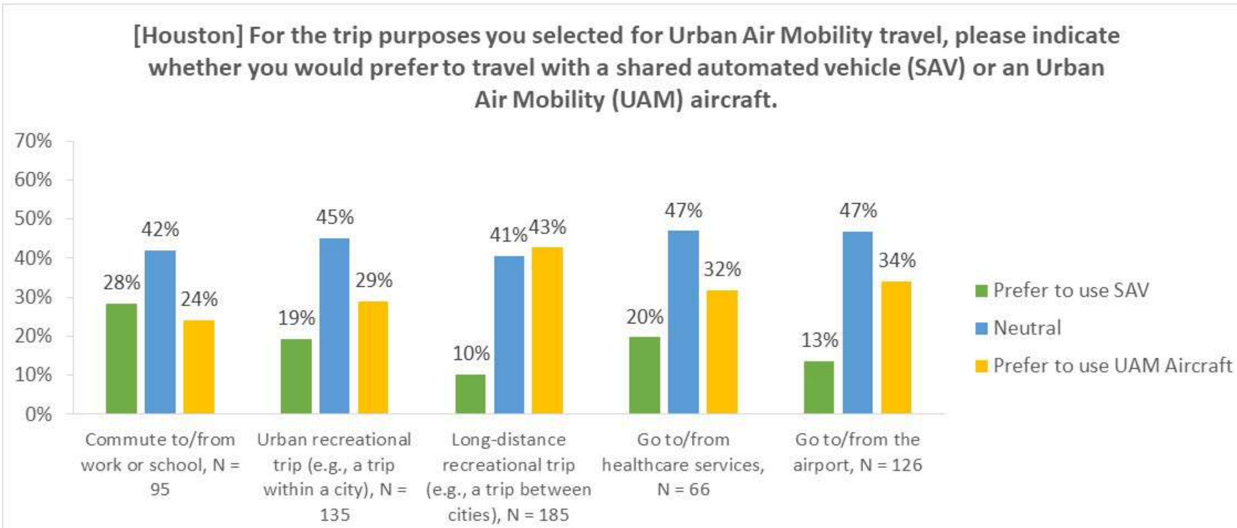


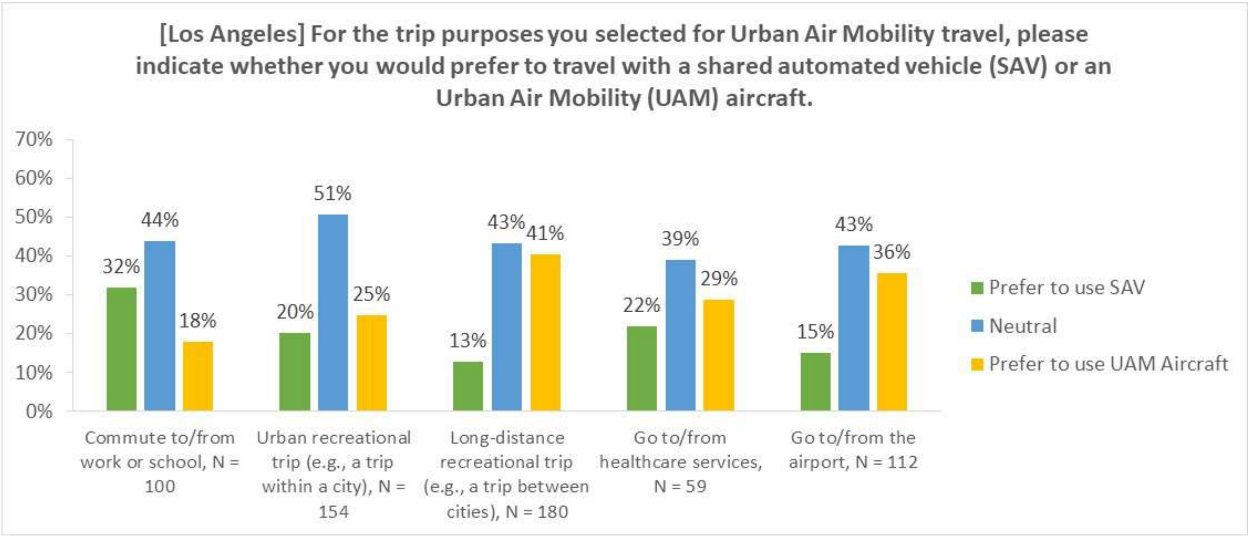
MARKET PREFERENCES: SAV VS. UAM

- Respondents were most interested using UAM for long-distance recreational trips and to go to/from the airport; some preference for healthcare trips in Houston.



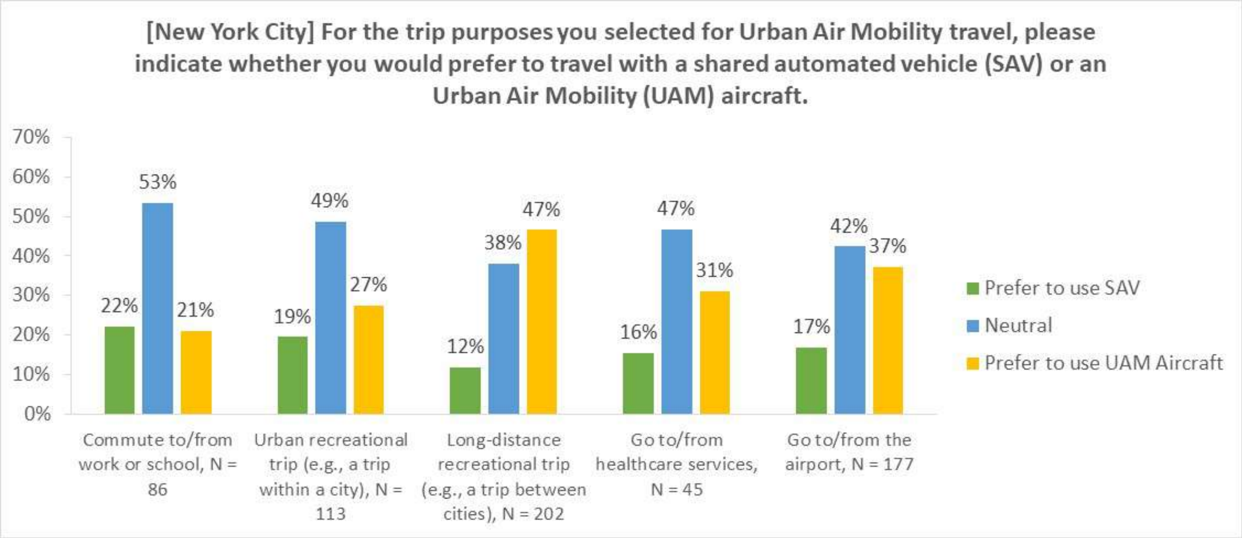
MARKET PREFERENCES: SAV VS. UAM

- Respondents were most interested using UAM for long-distance recreational trips and to go to/from the airport; some preference for healthcare trips in LA.



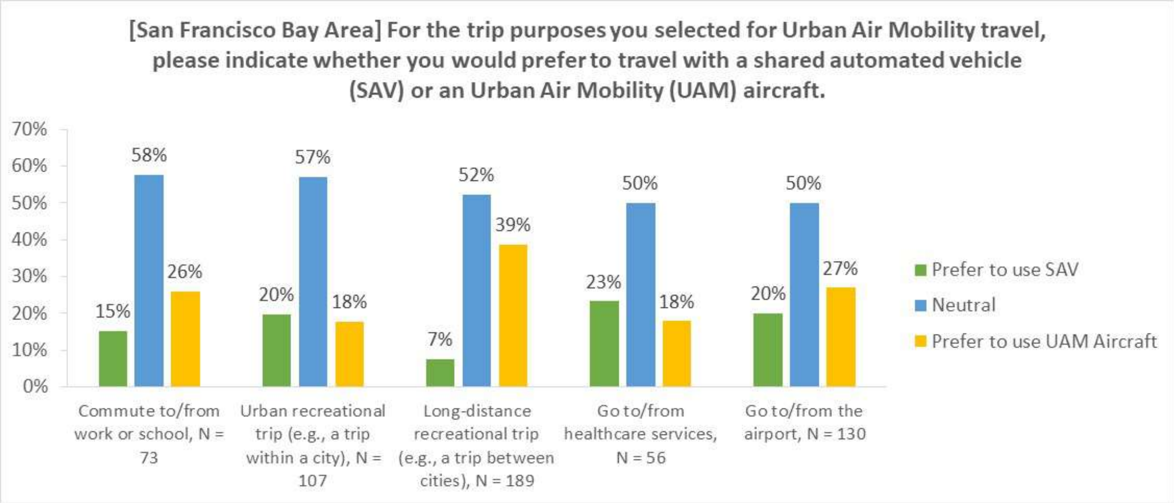
MARKET PREFERENCES: SAV VS. UAM

- Respondents were most interested using UAM for long-distance recreational trips and to go to/from the airport; slight preference for UAM for healthcare trips in NYC



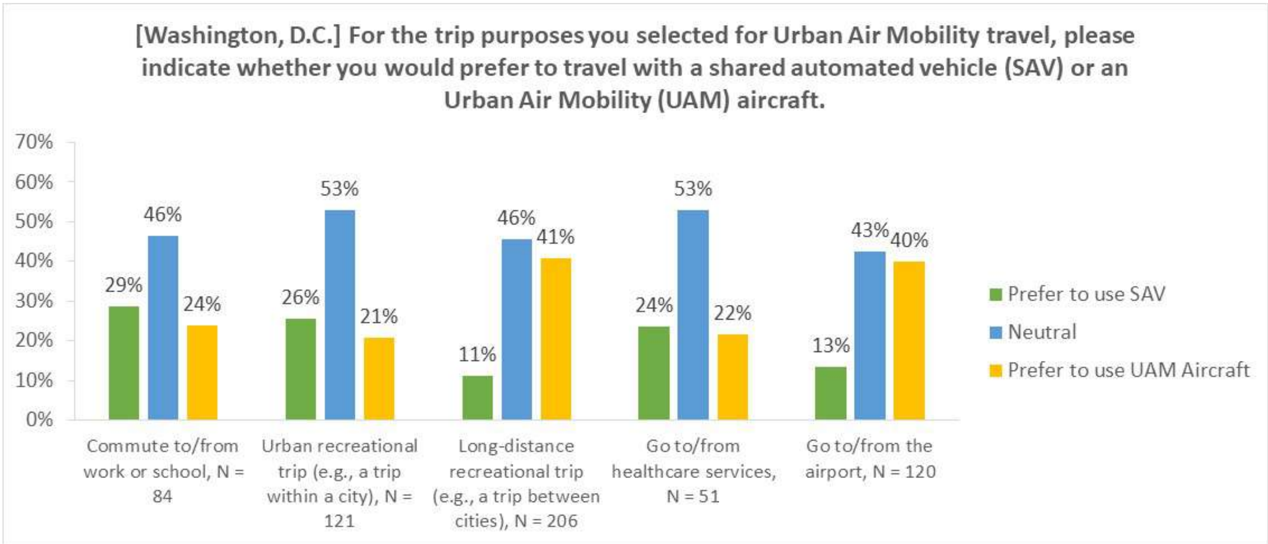
MARKET PREFERENCES: SAV VS. UAM

- Respondents were most interested using UAM for long-distance recreational trips and to go to/from the airport; some preference for commute trips in the SF Bay Area



MARKET PREFERENCES: SAV VS. UAM

- Respondents were most interested using UAM for long-distance recreational trips and to go to/from the airport.



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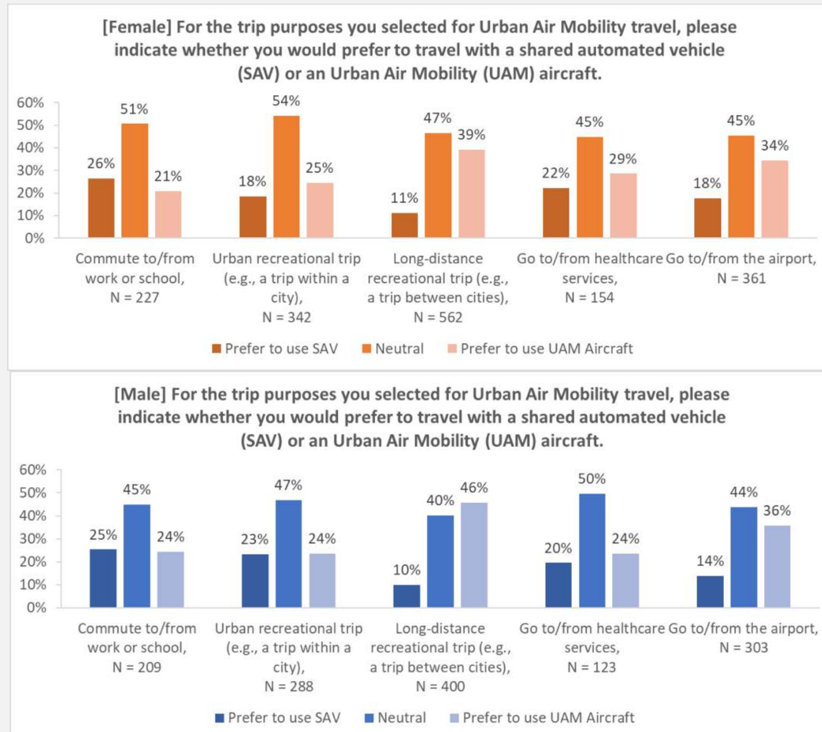
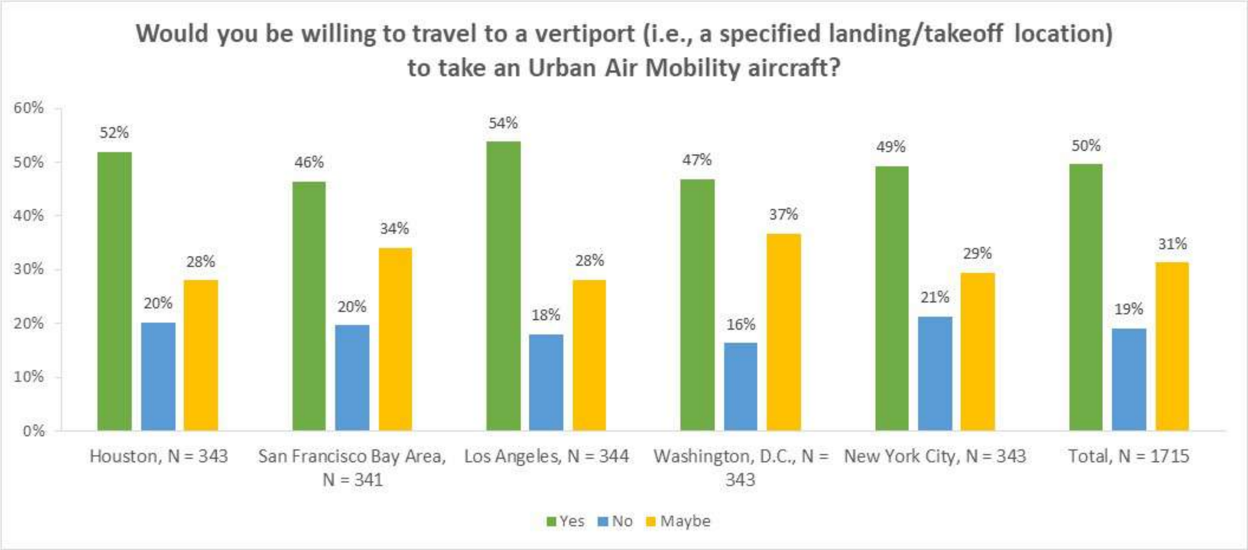


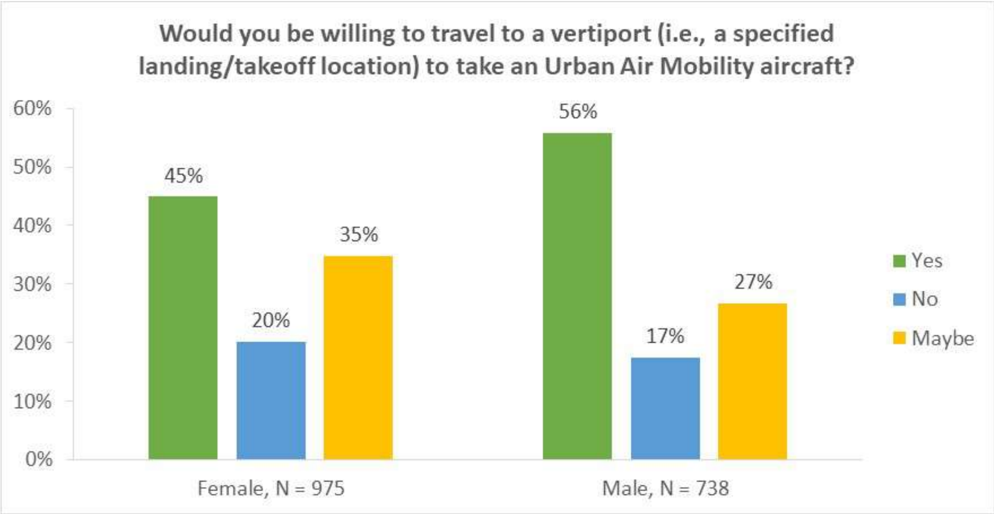
MARKET PREFERENCES:
FIRST/LAST MILE CONNECTIONS TO A VERTIPORT

- An overall expectation to use another travel mode (known as a first or last mile connection) to get to or from the vertiport.



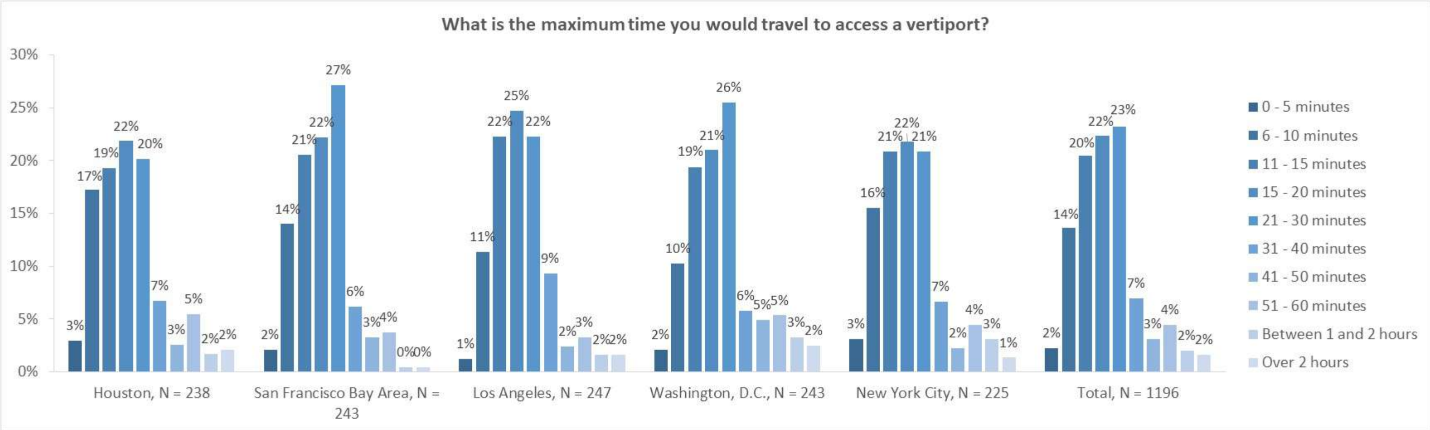
MARKET PREFERENCES:
FIRST/LAST MILE CONNECTIONS TO A VERTIPORT

- Men are more willing to take another mode of transportation to access a vertiport than women.



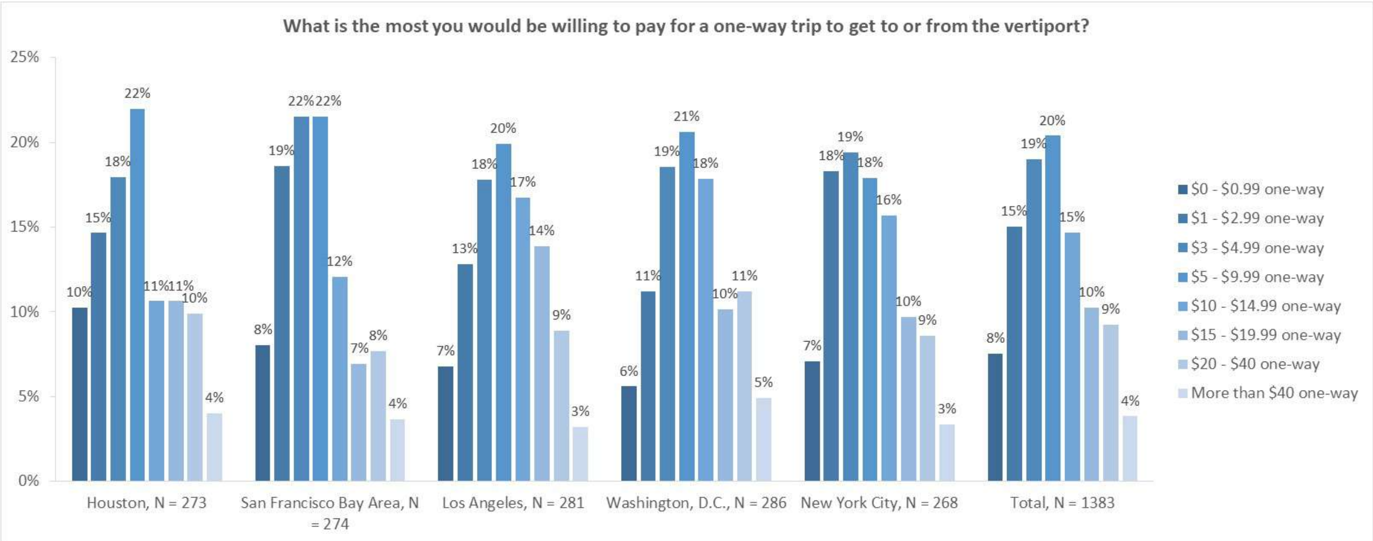
MARKET PREFERENCES:
FIRST/LAST MILE CONNECTIONS TO A VERTIPORT

- Most people are unwilling to take more than 20-30 minutes to access a vertiport.



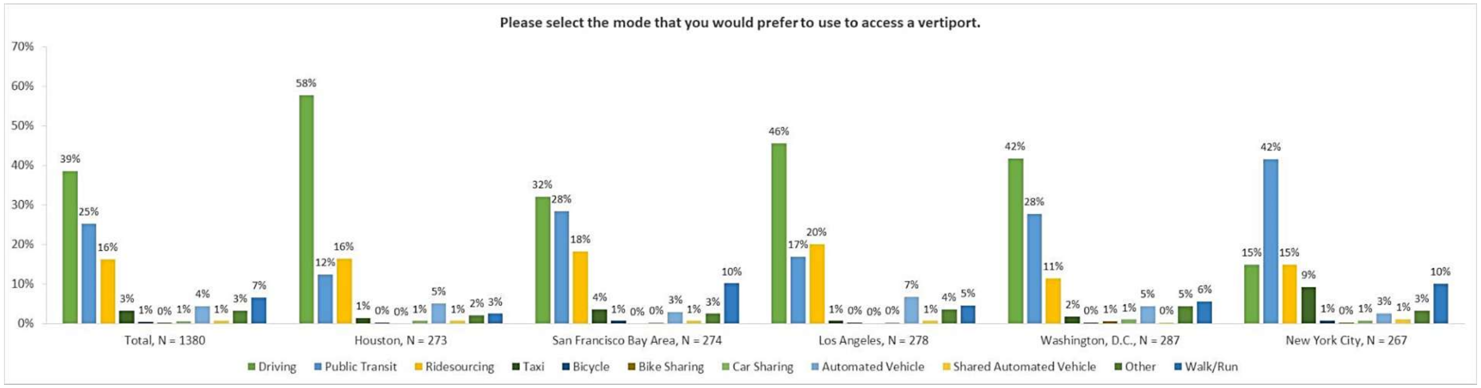
MARKET PREFERENCES:
FIRST/LAST MILE CONNECTIONS TO A VERTIPORT

- Most people are unwilling to pay more than $10 to take another mode to access a vertiport.



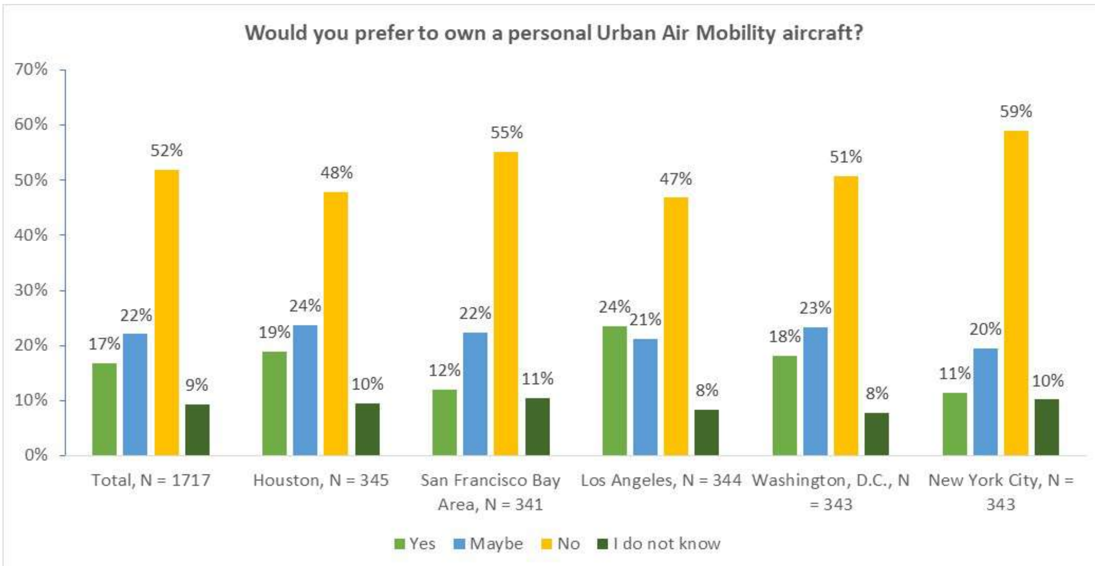
MARKET PREFERENCES:
FIRST/LAST MILE CONNECTIONS TO A VERTIPORT

- Driving, riding public transit, or hiring a for-hire vehicle are the mot common ways respondents would access a vertiport.



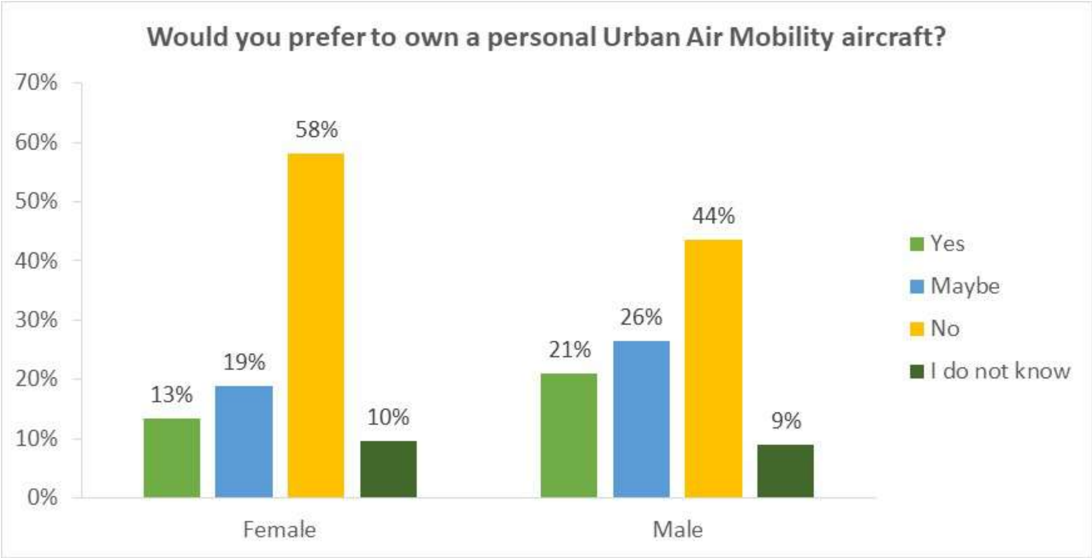
MARKET PREFERENCES: USE VS. OWNERSHIP

- Most people do not want to own their own UAM aircraft, however some do …



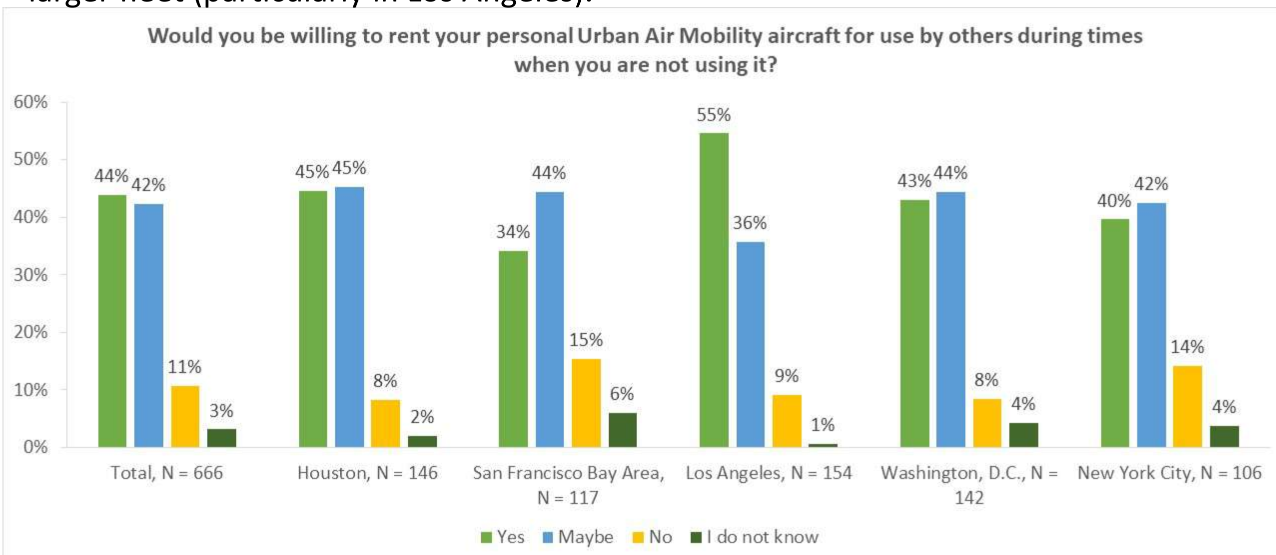
MARKET PREFERENCES: USE VS. OWNERSHIP

- Men are more interested in owning a UAM aircraft than women.



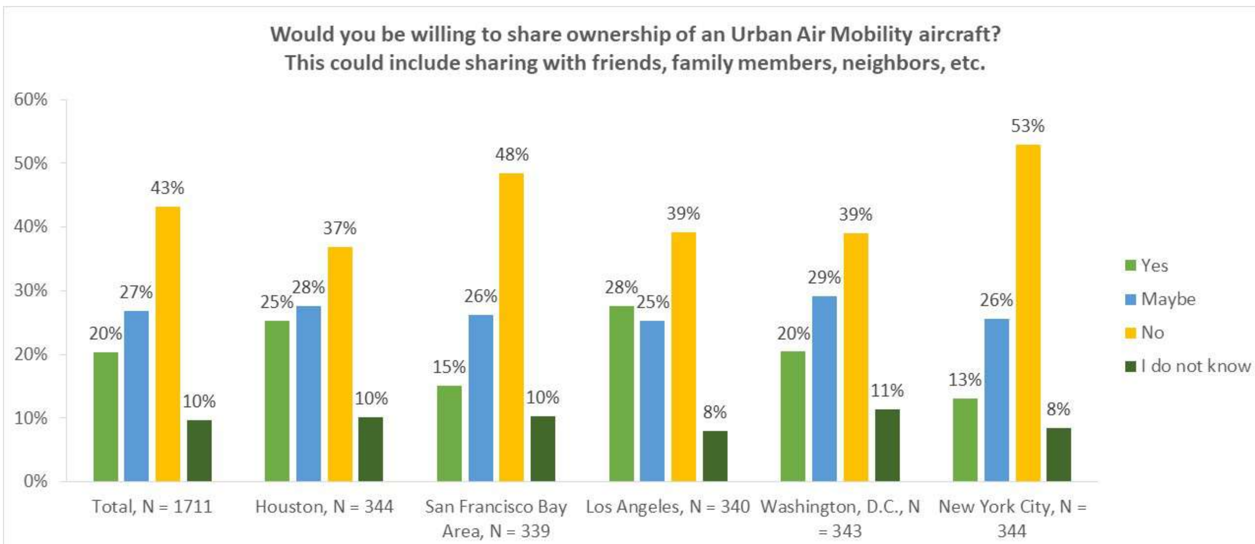
MARKET PREFERENCES: P2P OPERATIONS

- There is a lot of willingness to own a UAM aircraft and place it into service as part of a larger fleet (particularly in Los Angeles).

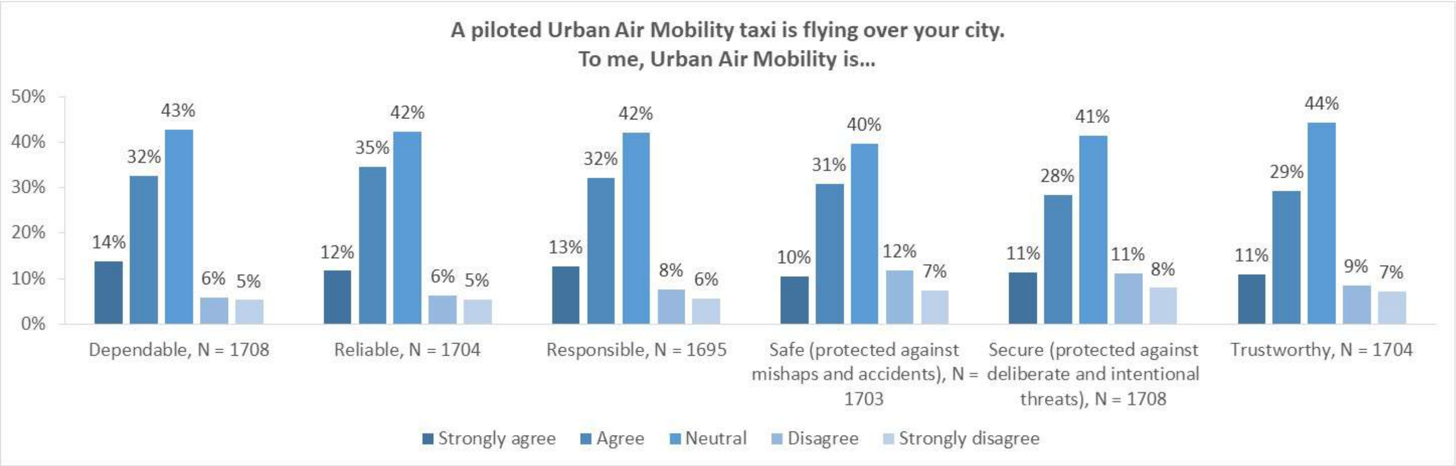


MARKET PREFERENCES: SHARED OWNERSHIP

- Respondents are less interested in fractional ownership.



PERCEPTIONS FROM A NON-USER PERSPECTIVE



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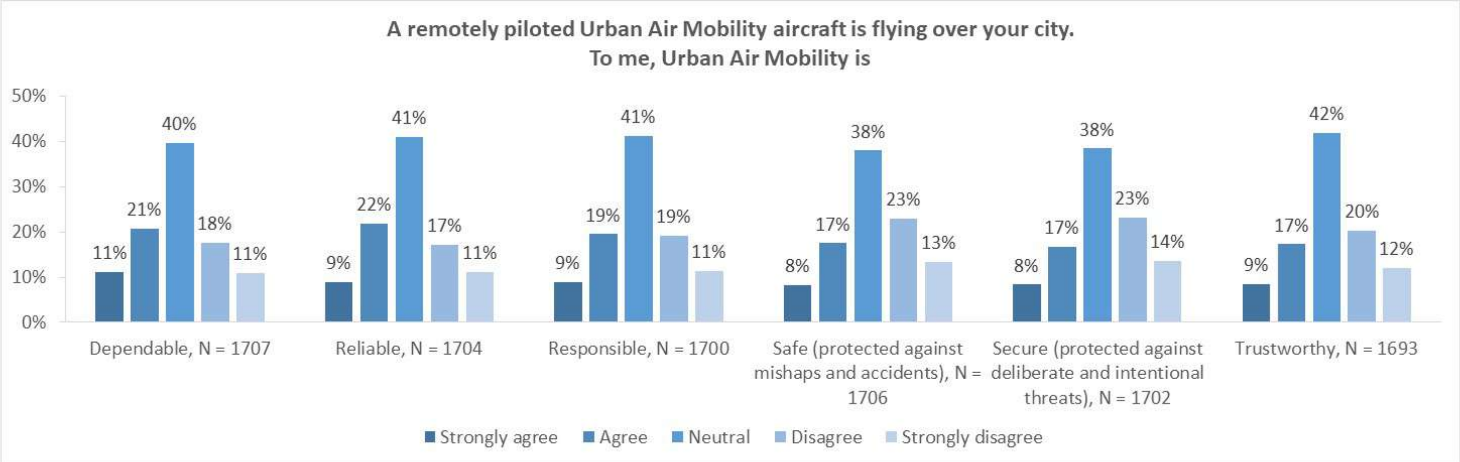

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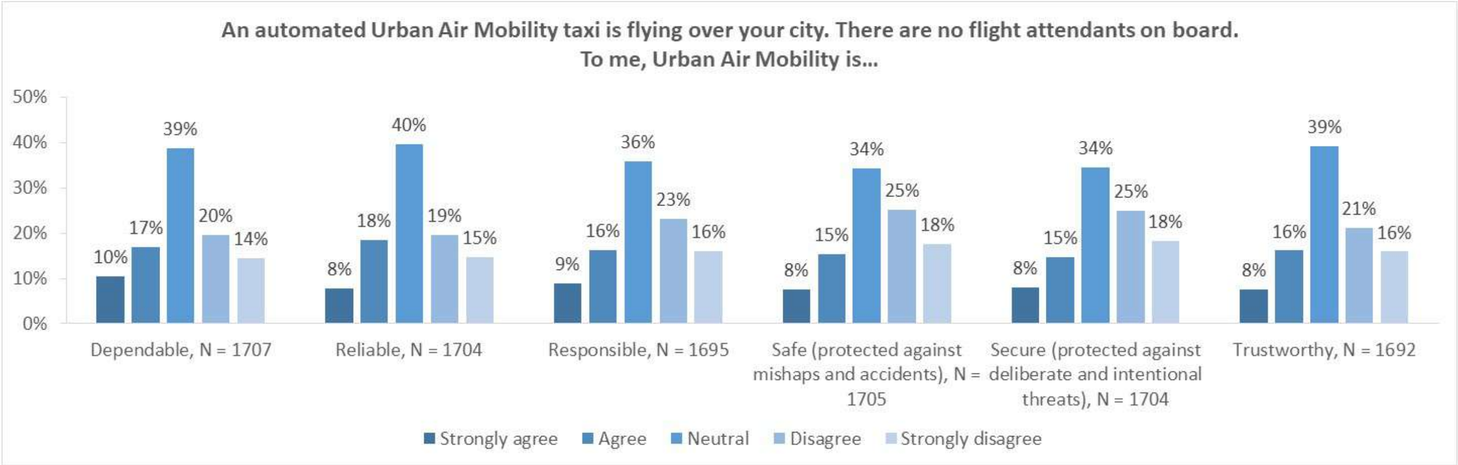

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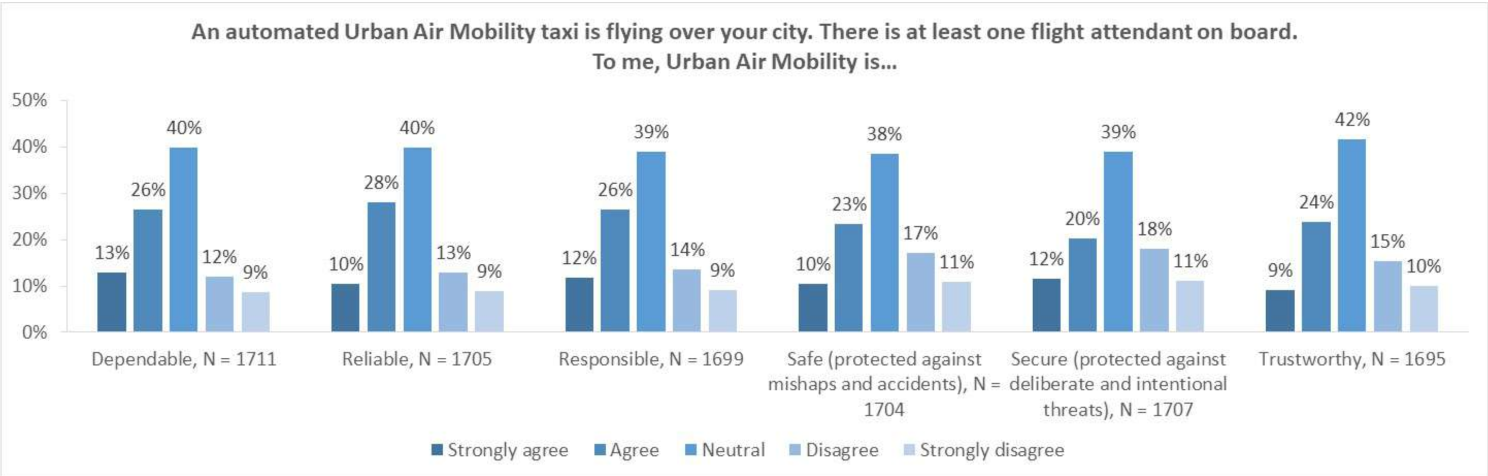
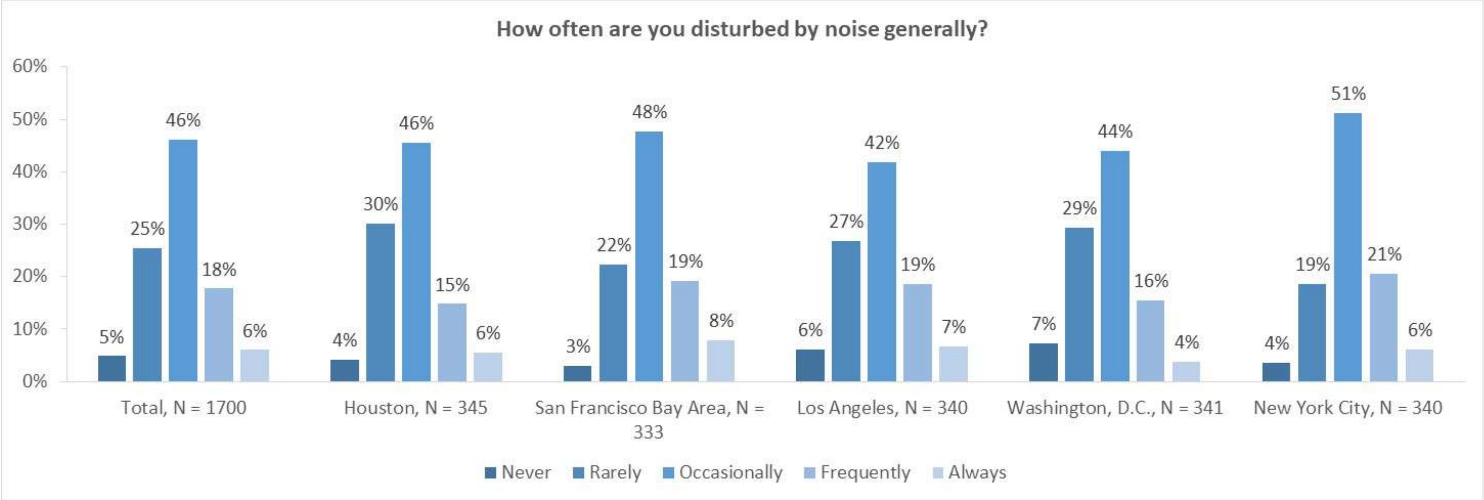
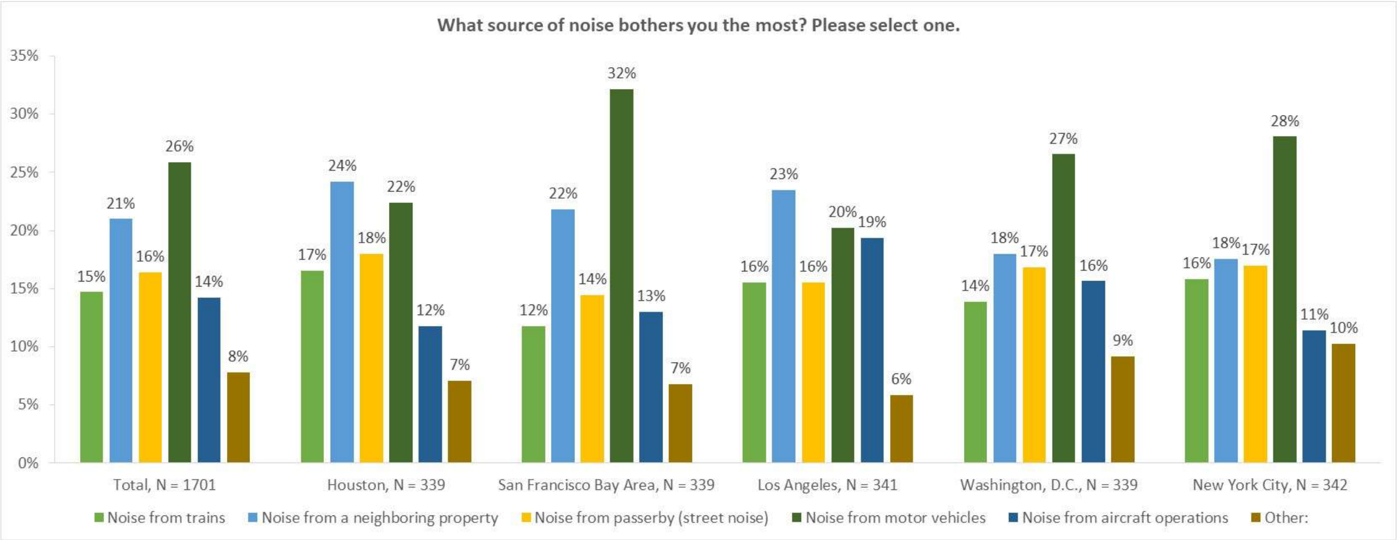


PERCEPTIONS FROM A NON-USER PERSPECTIVE: NOISE



PERCEPTIONS FROM A NON-USER PERSPECTIVE: NOISE

- Respondents are most bothered by motor vehicle noise at home during the night and early morning.



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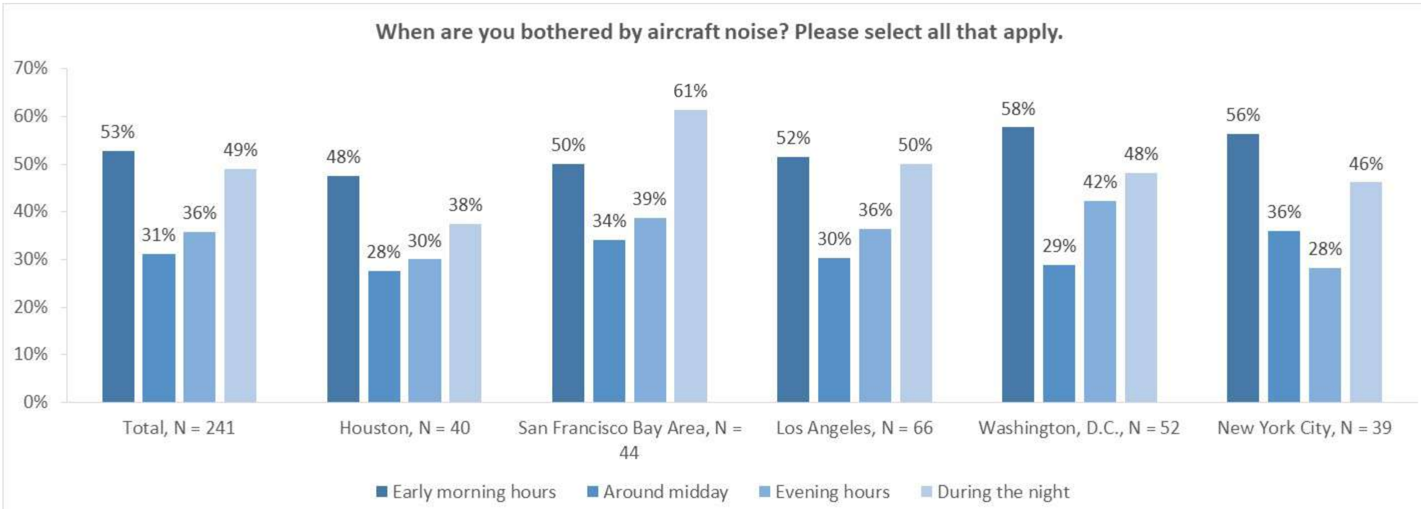

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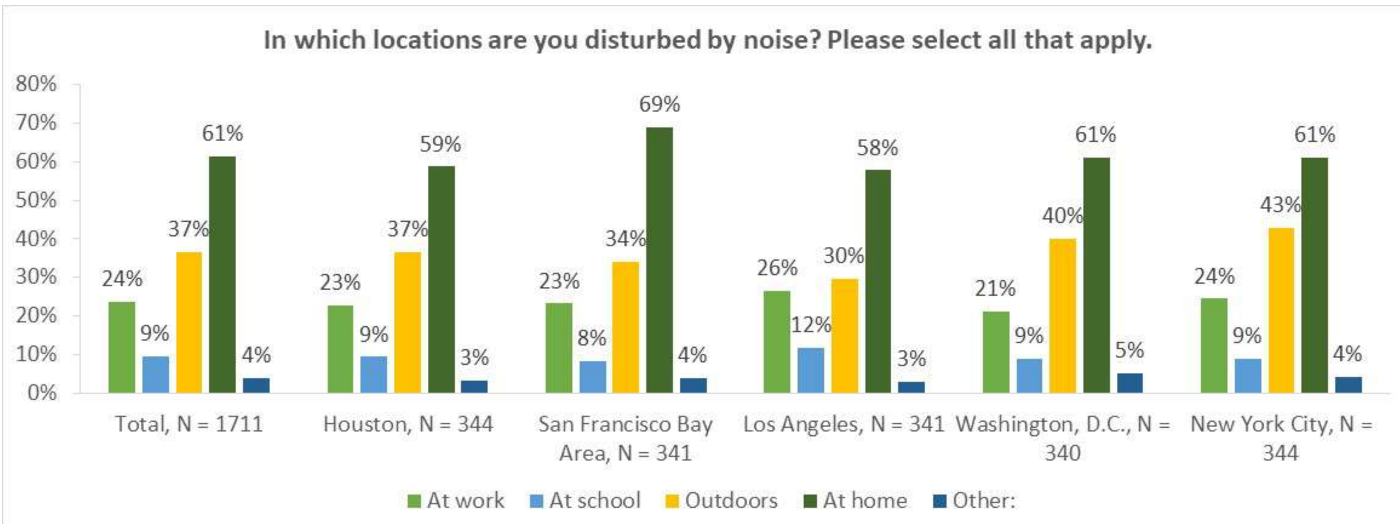
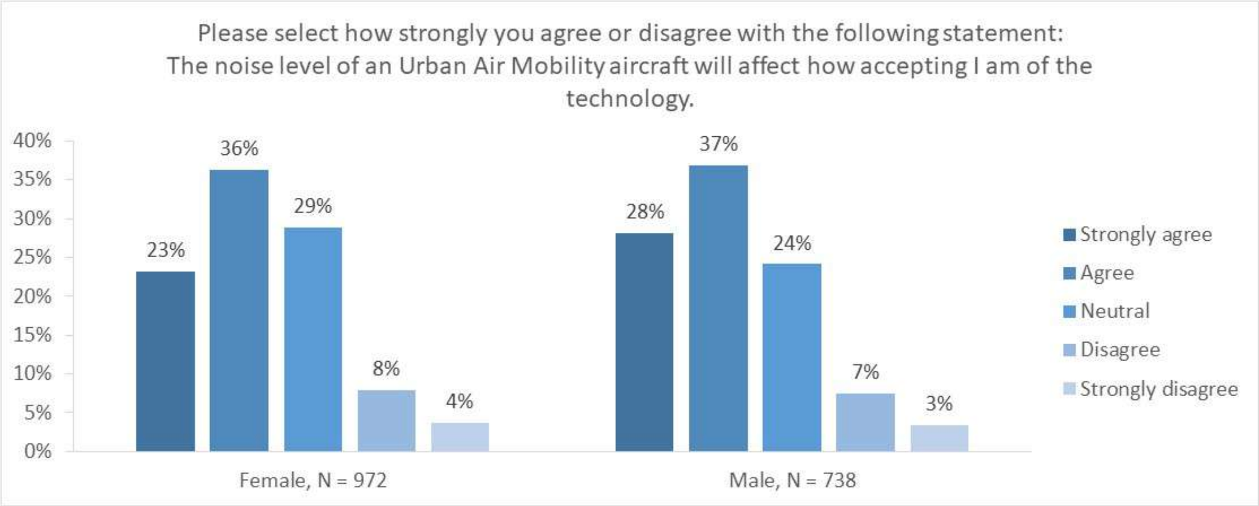


PERCEPTIONS FROM A NON-USER PERSPECTIVE: NOISE

PERCEPTIONS FROM A NON-USER PERSPECTIVE: NOISE

- Noise levels could have some affect on the support for UAM.



PERCEPTIONS FROM A NON-USER PERSPECTIVE: NOISE

- Respondents want the noise to be unnoticeable, if possible.

KEY TAKEAWAYS

- Generally, neutral to positive reactions to the UAM concept
- Respondents most comfortable flying with passengers they know; least comfortable flying with passengers they don’t know
- Some willingness and apprehension about flying alone (particularly in an automated/remote piloted context)
- Strong preference for piloted operations; may need to offer mixed fleets and/or a discount for remote piloted/automated operations to gain mainstream societal acceptance

KEY TAKEAWAYS

- Preference for longer inter-city flights (e.g., DC to Baltimore; LA to San Diego
- Survey and focus groups suggest some resistance to very short trips due to cost, convenience (e.g., required connections to/from vertiport; security screening; etc.)
- Some desire among younger and male respondents to pay a premium to fly alone
- Some willingness to own and pilot UAM aircraft
- There could be a market for peer-to-peer operations that could help provide additional supply to scale the market (similar to Lyft and Uber)
- Existing noise concerns focus on traffic noise during the night and early morning; noise from UAM could pose a more notable obstacle in the future as electric vehicles become more mainstream (potentially causing a reduction in overall ambient noise making UAM more noticeable)

CONTENTS

LEGAL AND REGULATORY BARRIERS/OPPORTUNITIES - SUMMARY

- **Surveyed and analyzed** the Federal Acts, Federal regulations, State laws, local ordinances, and international and foreign law for each of the three UAM urban markets, **identified legal barriers**, along with the **gaps and path to certification**.
- Air Taxi, Ambulance, and Airport Shuttle UAM markets **share common regulatory barriers**.
- **State** and **local** laws range from **no drones** to **protecting UAS operations**.
- **Other nations** integrate UAS into their airspace in **varying degrees**.
- There will be **challenges in determining which of the existing FAA certification standards apply** to the types of vehicles being considered for the Air Taxi or Air Ambulance UAMs, and/or **how existing certification standards can be met or should be amended**.
  - **Air Ambulances** will require **further evaluation** due to the requirements of an operator's air ambulance procedures and air-ambulance-specific sections of their General Operations Manual (GOM).
- **Gaps in current certifications** mean that new standards will need to be developed, especially in areas related to **system redundancy** and **failure management**.

Results

LEGAL AND REGULATORY BARRIERS AND OPPORTUNITIES

Air Taxi, Ambulance, and Airport Shuttle UAM Markets share common Regulatory Barriers

Remotely piloted and autonomous UAM markets ***require the following aviation regulations (either modification of existing regulations, or new regulations):***

- Regulations for **beyond visual line of sight** (currently only with lengthy waiver process to 14 CFR Part 107.31)
- Regulations for **operations over people, streets, etc**. (currently only with lengthy waiver process to 14 CFR 107.39)
- Regulations for when **air cargo** is being carried commercially and across state lines (this is addressed in the FAA Reauthorization Act of 2018 Section 348 whereby Congress tasks the FAA within the year with making regulations for the carriage of property for compensation or hire)
- Regulations for when a **passenger or patient** is being transported in a UAM either within visual line of sight or beyond (airworthiness potentially addressed in 14 CFR Part 23)
- Regulations for flight in **instrument conditions** (not addressed in the FAA Reauthorization Act of 2018)
- Regulations for **airworthiness certification** of remotely piloted and autonomous aircraft
- **Training and knowledge** requirements for pilots and operators (FAA Reauthorization Act of 2018 Section 349 whereby Congress tasks the FAA with creating an aeronautical knowledge test for certain recreational UAS operators

A **legal framework for addressing privacy concerns** should be developed outside of the aviation regulatory framework although FAA Reauthorization Act of 2018 Section 357 and 358 addresses the need for DOT and National Telecommunications and Information Administration (NTIA) to work on this.

STATE AND LOCAL LAWS - RANGING FROM NO DRONES TO PROTECTING UAS OPERATIONS

California has a law favoring first responders.

- In 2016, SB 807 was chaptered - Provides immunity for first responders who damage a UAS that was interfering with the first responder while he or she was providing emergency services.
- AB 1680 – Makes it a misdemeanor to interfere with the activities of first responders during an emergency.

Hawaii has a law that prohibits UAS except for law enforcement.

- SB 2608 – Prohibits the use of unmanned aircraft, except by law enforcement agencies, to conduct surveillance and establishes certain conditions for law enforcement agencies to use an unmanned aircraft to obtain information.

Arizona has a law favoring first responders.

- In 2016, SB 1449 – Prohibits certain operation of UAS, including operation in violation of FAA regulations and operation that interferes with first responders. The law prohibits operating near, or using UAS to take images of, a critical facility. It also preempts any locality from regulating UAS.

Colorado – None.

Texas

- HB 1424 – Prohibits UAS operation over correctional and detention facilities. It also prohibits operation over a sports venue except in certain instances.
- HB 1481 makes it a Class B misdemeanor to operate UAS over a critical infrastructure facility if the UAS is not more than 400 feet off the ground.

Florida

- SB 92 – Prohibiting a law enforcement agency from using a drone to gather evidence or other information.

Washington, DC has a no drone zone.

New York, NY – Drones are more formally known as unmanned aerial vehicles (UAV) and are illegal to fly in New York City.

Note: *Sources for all these laws are provided under the Legal and Regulatory Appendix*

FEDERAL AND STATE / LOCAL LAW TUG OF WAR

Federal Preemption

Where the Federal government occupies a field, **federal laws preempt** state laws and local ordinances

- The 1958 Federal Aviation Act delegated the safe and efficient **use of the airspace to the FAA** requiring it to create and enforce federal regulations (under Title 14 of the Code of Federal Regulations (CFR))
- This is quite the **gray area of law** given the fact that UAS operate from just about anywhere and are not confined to the navigable airspace like manned aircraft (around 500 feet) and helicopters (even lower than that) nor are they confined to runways and heliports for takeoffs and landings.

State / Local Police Power

The 10th Amendment to the Constitution gives **states/local government** the rights and powers "not delegated to the United **States**." **States** are granted the **power** to establish and enforce laws protecting the **welfare**, **safety**, and **health** of the public (police powers).

- Prevents trespass, nuisance, invasion of privacy, and a slew of other issues that UAS cause

The Tug of War

Federal Preemption and State/Local Police Power as each government entity are vying for the power to regulate. Not many courts across the country have settled this power struggle. In aviation tort law there is some clarity but in UAS operations there is only one case of first impression.

Singer vs. City of Newton, MA (Sept. 2017)

(Example of tug of war between federal law and state/local law)

- In December 2016, the City of Newton, MA passed a **local ordinance banning UAS below 400 feet** and requiring operators to register their UAS and receive permission from public and private residence owners in order to fly their UAS over their homes.
- This local ordinance was drafted "for the principal purpose of **protecting the privacy interests** of Newton's residents," according to a court document.
- In September 2017, a **federal judge ruled against this local ordinance**, allowing operators to use UAS that fly below 400 feet and without permission of city residence owners, pretty much in accordance with 14 CFR 107 regulations.
- The ruling in this case was the **first of its kind** setting a precedent that says when it comes to certain UAS operations disputed in this case, federal law preempts local regulations.

Results

INTERNATIONAL REGULATIONS - HOW ARE OTHER NATIONS INTEGRATING UAS INTO THEIR AIRSPACE?

European Aviation Safety Agency (EASA) –

1. after a four month consultation period on the Notice of Proposed Amendment, NPA 2017-05, EASA published Opinion 01/2018, including a proposal for a new Regulation for UAS operations in 'open' and 'specific' category.

   - 'open' category is a category of UAS operation that, considering the risks involved, does not require a prior authorization by the competent authority nor a declaration by the UAS operator before the operation takes place;
   - 'specific' category is a category of UAS operation that, considering the risks involved, requires an authorization by the competent authority before the operation takes place, taking into account the mitigation measures identified in an operational risk assessment, except for certain standard scenarios where a declaration by the operator is sufficient or when the operator holds a light UAS operator certificate (LUC) with the appropriate privileges; and
   - 'certified' category is a category of UA operation that, considering the risks involved, requires the certification of the UAS, a licensed remote pilot and an operator approved by the competent authority, in order to ensure an appropriate level of safety.

2. Proposed Special Condition for VTOL: On October 15th, 2018, EASA proposed a rule to cover VTOL aircraft. VTOL aircraft have unique features that "significantly differentiate them from traditional rotorcraft or aeroplanes and therefore necessitate this dedicated special condition." This proposed rule for the certification small-category VTOL applies to an aircraft with a passenger seating configuration of 5 or less and a maximum certified take-off mass of 2,000kg or less. (Deadline for comments: 11/15/18; https://www.easa.europa.eu/document-library/product-certification-consultations/proposed-special-condition-vtol)

UK – Civil Aviation Authority - National Qualified Entities (NQEs) are established to assess the competence of people operating small unmanned aircraft as part of the CAA's process in granting operating permissions. Assessment by an NQE is necessary for those with no previous aviation training or qualifications. To achieve this, NQEs may offer a short educational course/program prior to the competency assessment aimed at bringing an individual's knowledge up to the required level (but please note that these are not CAA approved training courses). A typical NQE full-course involves:

- pre-entry/online study
- 1-3 days of classroom lessons and exercises
- a written theory test
- a flight assessment

(https://www.caa.co.uk/Commercial-industry/Aircraft/Unmanned-aircraft/Small-drones/Guidance-on-using-small-drones-for-commercial-work/)

Results

INTERNATIONAL REGULATIONS - HOW ARE OTHER NATIONS INTEGRATING UAS INTO THEIR AIRSPACE? *(CONT.)*

Ireland – Visual line of sight is quantified as 300m and UAS must stay 30m away from any person, vessel, vehicle or structure not under the direct control of the operator. (https://www.iaa.ie/general-aviation/drones)

New Zealand – Civil Aviation Authority - A shielded operation is a flight where your aircraft remains within 100m of, and below the top of, a natural or man-made object. For example, a building, tower, or trees. When flying as a shielded operation you are allowed to fly at night, or within controlled airspace without ATC clearance, as other aircraft are unlikely to be flying so low and close to structures.

- **Shielded operations within 4 km of aerodromes -** If you are relying on the shielded operation provision to fly your unmanned aircraft within 4 km of an aerodrome, then in addition to remaining within 100m of, and below the height of the object providing the shield, e.g. a building or tree, there must also be a physical barrier like a building or stand of trees between your unmanned aircraft and the aerodrome. This barrier must be capable of stopping your aircraft in the event of a fly-away. (https://www.caa.govt.nz/unmanned-aircraft/intro-to-part-101/#Shielded_Operations)

Canada - if the drone weighs over 250 g and under 35 kg and flying for fun, fly:
- below 90 m above the ground
- at least 30 m away from vehicles, vessels and the public (if your drone weighs over 250 g and up to 1 kg)
- at least 76 m away from vehicles, vessels and the public (if your drone weighs over 1 kg and up to 35 kg)
- at least 5.6 km away from aerodromes (any airport, seaplane base or area where aircraft take off and land)
- at least 1.9 km away from heliports or aerodromes used by helicopters only
- outside of controlled or restricted airspace
- at least 9 km away from a natural hazard or disaster area
- away from areas where its use could interfere with police or first responders
- during the day and not in clouds
- within your sight at all times
- within 500 m of yourself
- only if clearly marked with your name, address and telephone number

(http://www.tc.gc.ca/en/services/aviation/drone-safety/flying-drone-safely-legally.html)

INTERNATIONAL REGULATIONS - HOW ARE OTHER NATIONS INTEGRATING UAS INTO THEIR AIRSPACE? *(CONT.)*

UAE – Key authorities include General Civil Aviation Authority (the GCAA), Dubai Civil Aviation Authority (DCAA), and Roads and Transport Authority (RTA)

- Contracted Volocopter for a 5 minute public test flight, announced plans for a 5 year path to UAM certification
- UAS
  - Registration
  - Tracking and ID (Exponent Skytrax)
  - Insurance requirements
  - Zones: 5 km from aerodromes, <400 ft
  - No video or image capturing
  - No BVLOS
  - Certification
  - Operator exam for commercial operations
  - COA for each commercial flight

Germany – Volocopter VC200 granted provisional certification from **German Ultralight Flight Association** as an ultralight aircraft

Results

HOW CERTIFICATION APPLIES TO UAM: DEEP DIVE ON AIRWORTHINESS

Regulations govern **certification of aircraft, operators, and operations**. This analysis **focuses on aircraft certification**, which addresses safety risks by setting requirements for aircraft **airworthiness** through **design, manufacturing, performance, failure response, and maintenance**. In some cases, certification requirements may be met through **industry consensus standards** developed by ASTM, SAE, RTCA, and others.

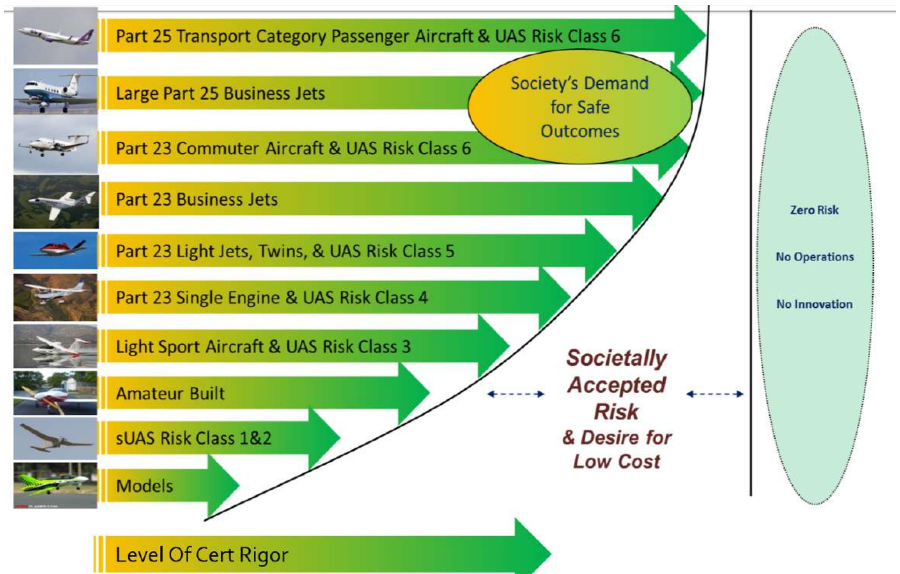
Aircraft certification can act as an **barrier** for promoting rapid integration of emerging technologies for UAM. UAM aircraft challenge the existing certification process due to novel features and combinations of features, such as **distributed electric propulsion/ tilt-wing propulsion, VTOL, autonomy software, optionally piloted, energy storage, and ratio of aircraft to pilots is < 1.**

Questions considered in this analysis:

- How are new aircraft certified?
- What is the preferred path to certification for UAM aircraft, e.g., Part 23, 27, 21.17(b)?
- What are the gaps in requirements and means of compliance, e.g., RTCA DO-178C, ASTM F39?
- What is being done to address these gaps?

FAA TYPE CERTIFICATION CATEGORIES AND CLASSES

- Aircraft are organized by category and class, which **determines the risk regime** that they reside in
- **Certification requirements differ by class**, and influence design of aircraft and heliports, for example, after critical loss of thrust[1]:
  - Transport category, airplane class: Certified to <u>2.4 – 3 percent climb gradient</u>
  - Transport category A, rotorcraft class: Certified to <u>100 ft/min climb rate</u>
  - Normal category, rotorcraft class: <u>no min climb rate</u>



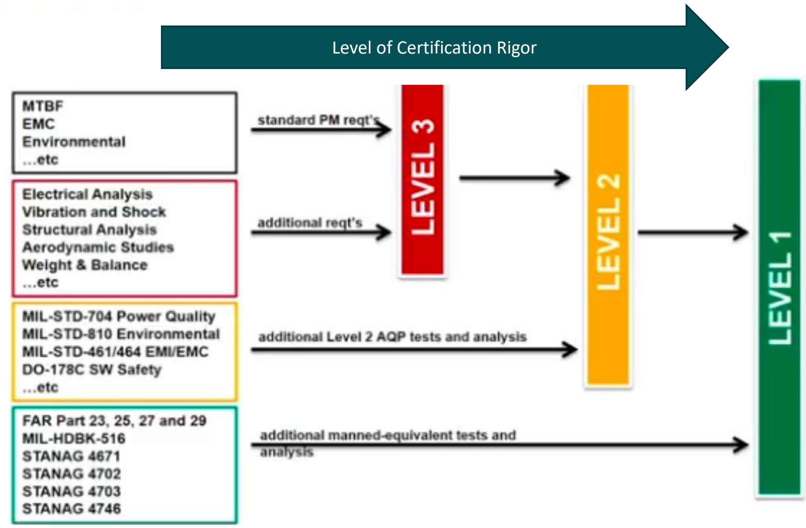
Gunnarson, Tom, "Aircraft Type Certification Considerations." AHS TVF Workshop, Jan 2018, https://vtol.org/files/dmfile/13-TVF5-2018-Gunnarson-ASTM-Jan191.pdf

[1]Webber, David of FAA, "Flight Qualification and Certificaiton of Advanced VTOL Aircraft" Vertical Flight Society 74th Annual Forum, May 2018. Time 1:28:20, https://www.youtube.com/watch?v=JJf4u4MTiFs&feature=youtu.be

TYPE CERTIFICATION AND RISK ACCEPTANCE FOR NATO STANAG

Risk acceptance and airworthiness certification standards

- **Level 1: Low Safety Threshold** Certifies to standards equivalent to manned systems tailored for UAS
  - STANAGs 4671, 4702, 4703, and 4746
  - Follows part 23 (fixed) and part 27 (rotorcraft)
- **Level 2 Moderate Safety Threshold:** Authorizes to standards less stringent than those for manned systems:
- **Level 3 High Safety Threshold:** Poses the highest level of uncertainty and risk according to a casualty model, typically for expendable platforms or experimental aircraft enduring testing



Webber, David of FAA, "Flight Qualification and Certification of Advanced VTOL Aircraft" Vertical Flight Society 74th Annual Forum, May 2018. Time 38:17, https://www.youtube.com/watch?v=JJf4u4MTiFs&feature=youtu.be

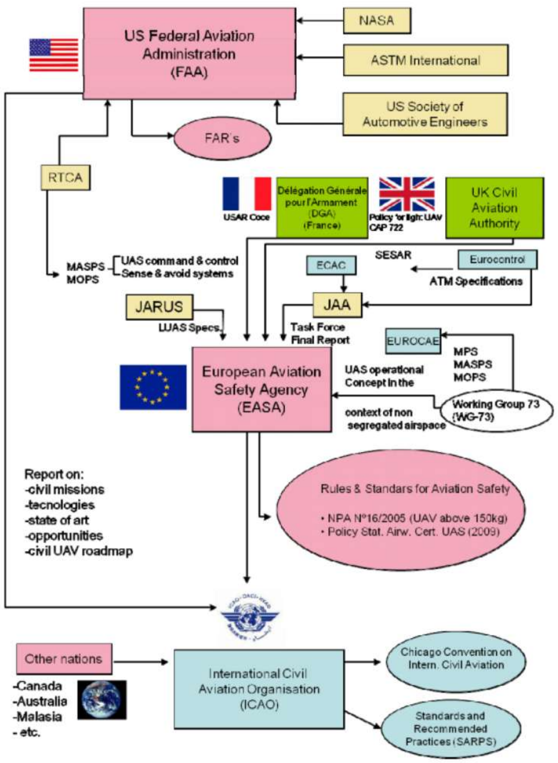
Results

INTERNATIONAL UAS REGULATORY FIELD

Example International Regulations for Certification

- This figure summarizes the actual UAS regulatory scene, and the relationship among all actors in the international playfield.
- This figure provides an indication of the standards to be applied to any feature of the design whose failure would affect the ability to maintain safe altitude above the ground

UAS Regulatory field, 25th Bristol Int'l UAV systems conference.
http://oa.upm.es/9504/1/INVE_MEM_2010_88111.pdf

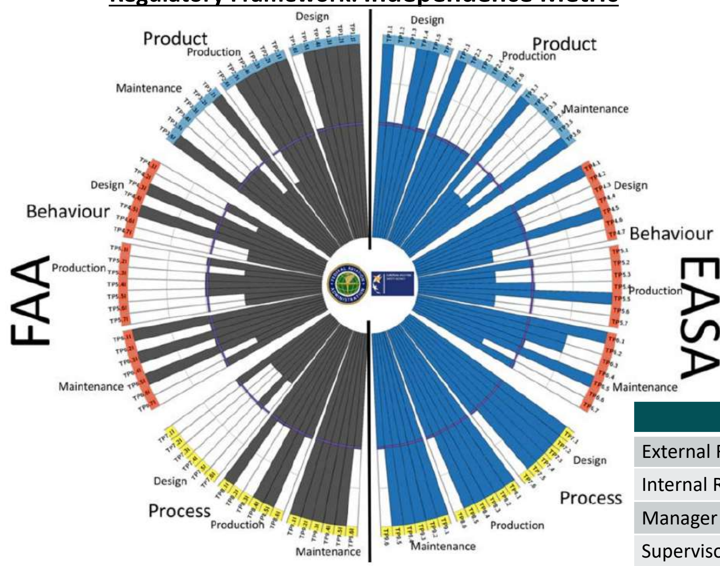


INTERNATIONAL TYPE CERTIFICATION COMPARISON TABLE

	Fixed Wing	Rotary	Hybrid Or Special	Engines	Propellers
FAA	**Part 21** – Certification Procedures for Products and Parts **Part 23** – Small Fixed Wing **Part 25** –Transport Category Airplanes	**Part 27** – Small Rotorwing **Part 29** –Transport Category Rotorcraft	**Part 21.17(b)** – Designation of applicable regulations	**Part 33** – Aircraft Engines	**Part 35** – Aircraft Propellers
EASA	**CS-22**-Sailplanes and Powered Sailplanes **CS-23**- Normal, utility, aerobatic, and commuter aeroplanes **CS-25** – Large Aeroplanes	**CS-27** – Small Rotorcraft **CS-29** – Large Rotorcraft	**CS-VLA**- Very light aircraft **CS-VLR**- Very Light Rotorcraft	**CS-E** - Engines	**CS-P** -Propellers
NATO	**STANAG 4671** – UAV System Airworthiness Requirements (USAR), Fixed wing aircraft weighing 150kg to 20,000 kg **STANAG 4703** – Light unmanned aircraft systems	**STANAG 4702** – Rotary wing unmanned aircraft systems	**Draft STANAG 4746-** Vertical Take-off and landing (VTOL)	Referenced in **STANAG 4703** **STANAG 3372**	Referenced in **STANAG 4703**
Comparison	Terminology such as: proof of structure FAA Fixed and rotary aircraft factor in additional engine part certification (Part 33) **EASA CS -25** vs **FAA Part 25** Large aeroplanes vs Transportation category airplanes Comparison: i.e. Proof of Structure terminology - The wording of Part 25 is different from CS-25 and this has resulted in different interpretations on the need for and the extent of static strength testing, including the load level to be achieved.	**STANAG 4702** is based on Parts 23, 27, and CS-23	**CS-VLA** has similarities to PART 21.17B **Draft STANAG 4746** is based on EASA Essential Airworthiness and is Harmonized with STANAG 4703. 4746 and 4703 Use **EASA CS-VLR** as a basis; Includes Electric Propulsion Certification Requirements	**CS-E** shares similar standards to **Part 33**- Testing covers all thrust ratings Development assurance for software & airborne Electronic Hardware under policy draft review	**CS-P** shares similar standards to **Part 35**: Bird Impact-Both require demonstration that the propeller can withstand the impact of a 4-pound bird for all airplanes.

VISUAL COMPARISON FOR FAA AND EASA REGULATORY FRAMEWORK

Regulatory Framework: Independence Metric



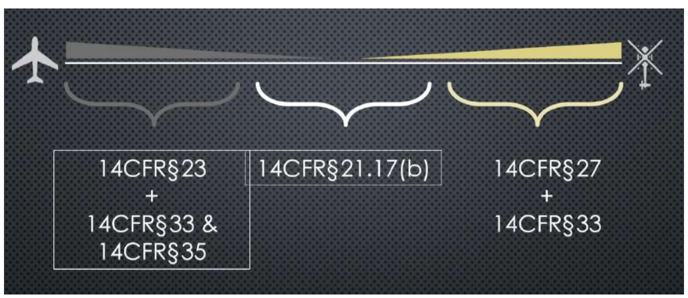
Source: https://researchbank.rmit.edu.au/eserv/rmit:161035/Purton.pdf

Independence Metric	
External Regulator / Legislation	5
Internal Regulator	4
Manager	3
Supervisor	2
Practitioner	1

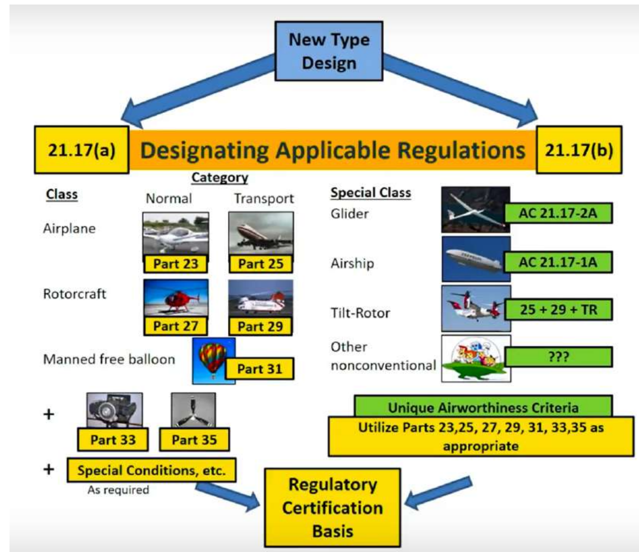
- This Figure shows similarity in structure of **EASA and FAA regulatory frameworks**
- FAA has more independent Product Certification
- Airworthiness relates to multi dimensions of framework including:
  - Process
  - Product
  - Behavior

FAA TYPE CERTIFICATION PATHS FOR NEW TYPE DESIGNS

- New type designs for UAM may have **multiple paths to certification with FAA**
- **UAM aircraft vary** in weight, type of service, propulsion, number of passengers, and speed
- **Additional requirements and special conditions may apply**, for example, Part 23 and 25 must comply with Part 33 Engine and Part 35 Propeller



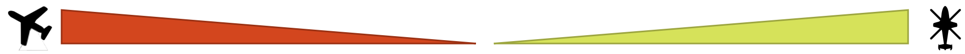
GAMA "Path to Certification." AHS TVF Workshop, Jan 2018, https://vtol.org/files/dmfile/13-TVF5-2018-Gunnarson-ASTM-Jan191.pdf



[1]Webber, David of FAA, "Flight Qualification and Certification of Advanced VTOL Aircraft" Vertical Flight Society 74th Annual Forum, May 2018. Time 1:28:20, https://www.youtube.com/watch?v=JJf4u4MTiFs&feature=youtu.be

Results

WHAT ARE POTENTIAL CERTIFICATION APPROACHES FOR AIR TAXI AND AIR AMBULANCE?



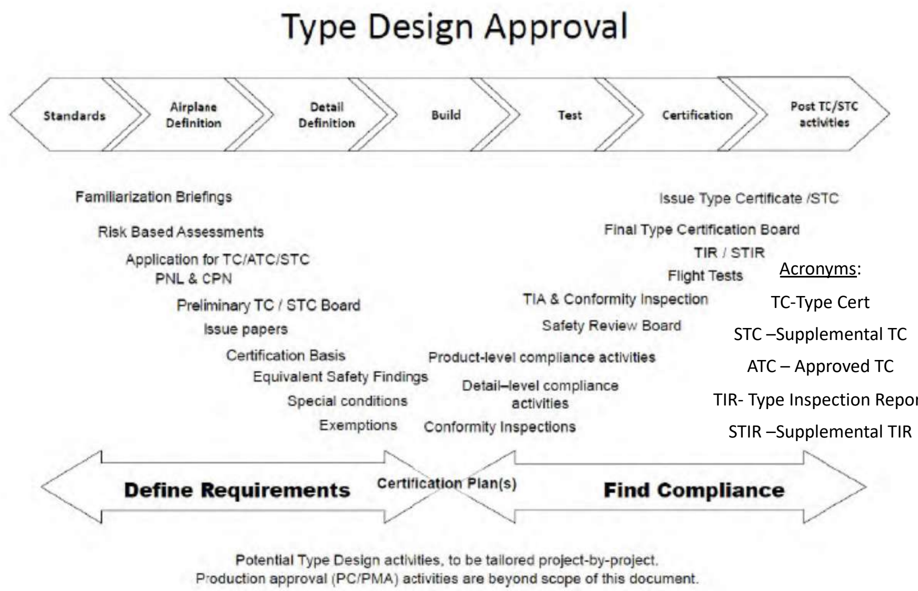
Part 23
+ Part 33, 35

Part 21.17(b)

Part 27
+ Part 33

FAA PART CERTIFICATION PROCESS

- **Duration and process differs** by Part Regulation, for example Part 23 generally has a 3 year limit, while Part 25 has a 5 year limit[1]
- **ODA and DER** serve as representatives to oversee the certification process (8100.8D)
- **Technical standards** (RTCA, SAE, ASTM, etc.) can provide means of compliance
- FAA continuously improving process, for example, **Part 23 Amendment 64** was updated Aug 2017
  - Reduced from 377 regulations to 71, heavy **reliance on consensus standards**
  - This took ~ 10 years



The FAA and Industry Guide to Product Certification, May 2017, pg. 15: https://www.faa.gov/aircraft/air_cert/design_approvals/media/CPI_guide.pdf

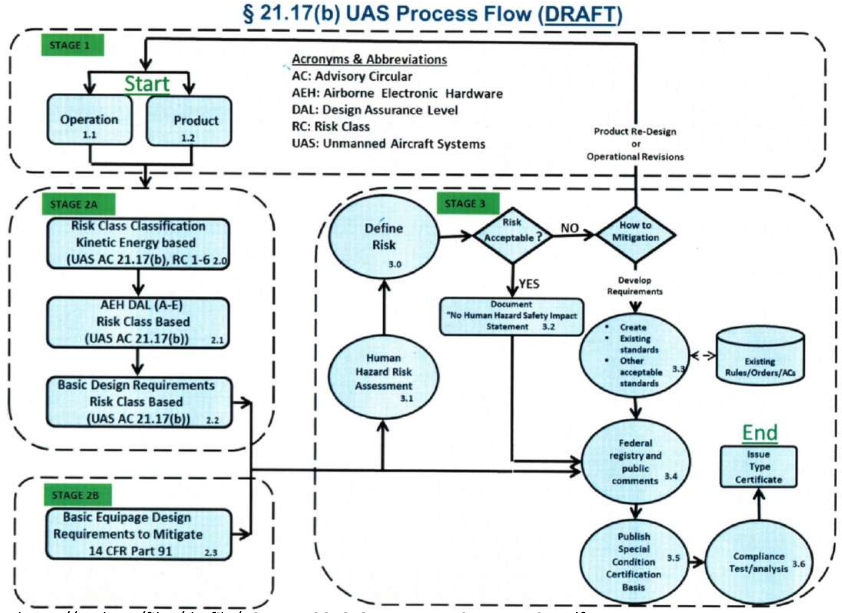
[1]Thurber, Matt, "The Aircraft Certification Process." Dec 2006. https://www.ainonline.com/aviation-news/aviation-international-news/2006-12-18/aircraft-certification-process#

Results

EXAMPLE PROCESS FOR 21.17(B)

- **The Safety Risk Management (SRM)** is applied by the regulator in developing regulations
- A design transforms safety requirements into risk controls for a product or article. **A safety requirement** in the form of an airworthiness regulation is a safety risk control that, when complied, **constitutes acceptable risk**
- **Airworthiness Regulations** are developed when systematic hazards are discovered and the related outcome(s) have **unacceptable risk**. Acceptable level of risk is determined as part of the rulemaking process and summarized in **25.561** per **amendment 25-64.**
- The FAA uses the information and data supplied by the approval holders and other sources to develop airworthiness regulations as displayed in the figure.

§ 21.17(b) UAS Process Flow (DRAFT)



https://vtol.org/files/dmfile/13-TVF5-2018-Gunnarson-ASTM-Jan191.pdf

Results

HOW STANDARDS SUPPORT CERTIFICATION: MEANS OF COMPLIANCE

Part 23 Accepted Means of Compliance Based on ASTM Consensus Standards
Updated May 11, 2018

Part 23 Rule		Accepted MOC[1]			Potential Supplemental MOC[2]
Section	**Title**	**ASTM Standard**	**FAA Changes**		and additional notes
			Replace:	With:	
23.2135	Controllability	F3264-17, Section 5.8	ASTM F3173/F3173M-17, Sections 4.9.1.1 and 4.9.1.2	FAA 4.9.1.1 and 4.9.1.2: 4.9.1.1: "For a level 1 or 2 airplane, or level 3 or 4 airplane of 6,000 pounds or less maximum weight, 5 seconds from initiation of roll and" 4.9.1.2: "For a level 3 or 4 airplane of over 6,000 pounds maximum weight, (W+500) / 1300 seconds, but not more than 10 seconds, where W is the weight in pounds."	
			ASTM F3173/F3173M-17, Sections 4.9.3.1 and 4.9.3.2	FAA 4.9.3.1 and 4.9.3.2: 4.9.3.1: "For a level 1 or 2 airplane, or level 3 or 4 airplane of 6,000 pounds or less maximum weight, 4 seconds from initiation of roll and" 4.9.3.2: "For a level 3 or 4 airplane of over 6,000 pounds maximum weight, (W+2,800) / 2,200 seconds, but not more than 7 seconds, where W is the weight in pounds."	
23.2140	Trim	F3264-17, Section 5.9	None		
23.2145	Stability	F3264-17, Section 5.10	None		
23.2150	Stall characteristics, stall warning, and spins	F3264-17, Section 5.11	None		

https://www.faa.gov/aircraft/air_cert/design_approvals/small_airplanes/small_airplanes_regs/media/part_23_moc.pdf

Results

CURRENT STANDARDS PROVIDE MEANS OF COMPLIANCE

RTCA:

- Example RTCA standards that relate to UAM:
  - DO-160 - Environmental Conditions and Test Procedures for Airborne Electronic/Electrical Equipment and Instruments
  - DO-178C - Software Considerations in Airborne Systems and Equipment Certification
  - DO-254 - Design Assurance Guidance for Airborne Electronic Hardware
  - DO-362 - Command and Control (C2) Data Link Minimum Operational Performance Standards (MOPS)(Terrestrial)
  - DO-365 - Minimum Operational Performance Standards (MOPS) for Detect and Avoid (DAA) Systems
  - DO-366 - Minimum Operational Performance Standards (MOPS) for Air-to-Air Radar for Traffic Surveillance
  - DO-278 – Software Integrity Assurance Considerations for Communication, Navigation, Surveillance, and Air Traffic Management (CNS?ATM) Systems
  - Supplement DOs (used as applicable):
  - DO-248C - Supporting Information for DO-178C and DO-278A
  - DO-330 - Software Tool Qualification Considerations
  - DO-331 - Model-Based Development and Verification Supplement to DO-178C and DO-278A
  - DO-332 - Object-Oriented Technology and Related Techniques Supplement to DO-178C and DO-278A
  - DO-333 - Formal Methods Supplement to DO-178C and DO-278A

- Examples of ongoing activities:
  - SC-228 - Minimum Ops Performance Standards for UAS
  - SC-214 - Air Traffic Data Communications
  - SC-186 - ADS-B

SAE:

- Example SAE standards that relate to UAM:
  - ARP-4761 - Guidelines and Methods for Conducting the Safety Assessment Process on Civil Airborne Systems and Equipment; In conjunction with ARP4754, ARP4761
  - ARP-4754A - Certification Considerations for Highly-Integrated Or Complex Aircraft Systems
  - ARP94910 Aerospace - Vehicle Management Systems - Flight Control Design, Installation and Test of, Military Unmanned Aircraft, Specification Guide For
  - ARP6461 - Guidelines for Implementation of Structural Health Monitoring on Fixed Wing Aircraft
  - AS-1212 – Electric Power, Aircraft, Characteristics, and Utilization

Leveraging of standards efforts in other domains may be beneficial, such as:
  - SAE J3016: Taxonomy and Definitions for Terms Related to On-Road Motor Vehicle Automated Driving Systems – known for the "5 Levels of Automation."
  - SAE J3092: Dynamic Test Procedures for Verification & Validation of Automated Driving Systems (ADS)

ASTM:

- Example ASTM standards that relate to UAM:
- F3264-17 - Standard Specification for Normal Category Aeroplanes Certification
- F3201 – 16 - Standard Practice for Ensuring Dependability of Software Used in Unmanned Aircraft Systems (UAS)
- F3269 – 17 - Standard Practice for Methods to Safely Bound Flight Behavior of Unmanned Aircraft Systems Containing Complex Functions
- F3298 – 18 - Standard Specification for Design, Construction, and Verification of Fixed-Wing Unmanned Aircraft Systems (UAS)
- F2295-10 – Standard Practices for Continued Operational Safety Monitoring of a Light Sport Aircraft
- F39.05 Standard Practice for Design and Manufacture of Electric Propulsion Units
- F44.40 Powerplant
- Examples of ongoing activities:
  - Committee F38, F39, F44

Results

SOME CURRENT STANDARDS ARE INSUFFICIENT OR TOO COSTLY FOR UAM AIRCRAFT

RTCA:

- Example RTCA standards that relate to UAM:
  - DO-160 - Environmental Conditions and Test Procedures for Airborne Electronic/Electrical Equipment and Instruments
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  - DO-331 - Model-Based Development and Verification Supplement to DO-178C and DO-278A
  - DO-332 - Object-Oriented Technology and Related Techniques Supplement to DO-178C and DO-278A
  - DO-333 - Formal Methods Supplement to DO-178C and DO-278A
- Examples of ongoing activities:
  - **SC-228 - Minimum Ops Performance Standards for UAS**
  - SC-214 - Air Traffic Data Communications
  - SC-186 - ADS-B

SAE:

- Example SAE standards that relate to UAM:
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- F3298 – 18 - Standard Specification for Design, Construction, and Verification of Fixed-Wing Unmanned Aircraft Systems (UAS)
- F2295-10 – Standard Practices for Continued Operational Safety Monitoring of a Light Sport Aircraft
- **F39.05 Standard Practice for Design and Manufacture of Electric Propulsion Units**
- **F44.40 Powerplant**
- Examples of ongoing activities:
  - Committee F38, F39, F44

Results

GAPS IN CERTIFICATIONS WHERE NEW APPROACHES MAY BE NEEDED FOR AIR TAXI AND AIR AMBULANCE UAM VEHICLES

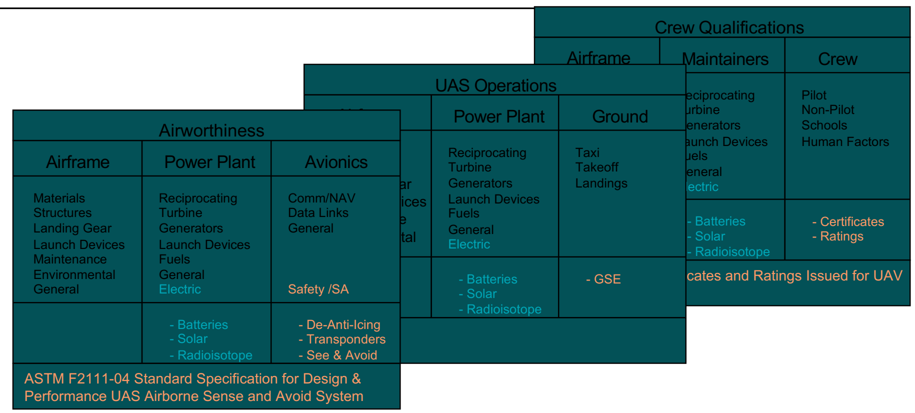
There may be **some gaps in the certification process** where specific approaches and tools need to be developed, particularly along system redundancy and failure management:

- **Autonomous and highly complex software** with many potential states challenges existing requirements for design considerations and fault tolerance.
- Requirements for **distributed electric propulsion and electric powerplant** design, integration, and maintenance are perceived gaps (e.g., Helicopters have redundant engines and can autorotate to handle certain failures)
- **Optionally piloted** aircraft must address safety mitigations through Operational Risk Assessment on BVLOS, see and avoid, communications failure, and lost link, such as when to "land immediately," vs. "when practical," vs. "closest available airport" in the context of the operating environment
- Operations with **ratio of aircraft to pilots > 1** must consider roles and responsibility of the aircraft vs human and dependence on network link

Results

GAPS IN STANDARDS

- ASTM F38 on Unmanned Aircraft Systems conducted a **gap analysis for UAS**
- **Gaps were identified in Power Plant and Avionics** for Airworthiness, Operations, and Crew Qualifications



Roadmap Key: ASTM F38 standards in progress - in orange
ASTM approved standards – in yellow
Outstanding needs – in red

ASTM, "UAS Standards Gap Analysis," Committee F38

POTENTIAL GAPS IN MEANS OF COMPLIANCE FOR UAM: GENERAL AND PROPULSION/ ENERGY STORAGE

Requirement	Relevant Documents	Gap	Efforts to Address
All Aircraft: Functional Hazards	FAA 23.1309-1E, AR 70-62, MIL-HDBK-516C	Identification of hazards, design methods to address hazards, and testing methods	ISO-26262 SOTIF
All Aircraft: Risk Assessment and Management	FAA Order 8040.4A, SAE ARP 4761, MIL-STD-882E	New flight modes and characteristics, unclear risk profiles	
Part 33/ CS-E: Electric Propulsion	ASTM F39.05 *Electric Propulsion Units*	Design and manufacture issues	Proposed Revision (WK47374)
Part 33/ CS-E: Electric Propulsion	ASTM F44.40 *Powerplant*	Integration issues for hybrid-electric propulsion	Proposed Revision (WK41136)
Part 33/ CS-E: Electric Propulsion	ASTM F39.05 *Electric Propulsion Units*	Energy storage systems	Proposed Revision (WK56255)

https://www.faa.gov/aircraft/air_cert/design_approvals/small_airplanes/small_airplanes_regs/media/part_23_moc.pdf

Results

POTENTIAL GAPS IN MEANS OF COMPLIANCE FOR UAM: AUTONOMOUS AND OPTIONALLY PILOTED

Requirement	Relevant Documents	Gap	Efforts to Address
All Aircraft: Software Design Assurance	RTCA DO-178C	The methods are unable to handle the large number of states and decisions that autonomy algorithms can take	
Optionally Piloted Aircraft: Operational Risk Assessment		BVLOS, see and avoid, communications failure, and lost link, such as when to “land immediately,” vs. “when practical,” vs. “closest available airport” in the context of the operating environment	DAA/C2 MOPS: RTCA SC-228 ORA Update: F38 WK49619 C2 Design: F3002-14a Ops over people: F38 WK37164 BVLOS/EVLOS: F38 WK49620

https://www.faa.gov/aircraft/air_cert/design_approvals/small_airplanes/small_airplanes_regs/media/part_23_moc.pdf

Results

SUMMARY: AIR TAXI AND AIR AMBULANCE POTENTIAL CERTIFICATION APPROACHES

There will be challenges in determining **which of the existing FAA certification standards** apply to the types of vehicles being considered for the Air Taxi or Air Ambulance UAMs, and/or how existing certification standards can be met or should be amended.

Air Taxi UAMs: Given their sizes, they could be compared to "light civil", which would be FAA Part 23 (normal airplanes) or a Part 27 (normal rotorcraft).

However, given the mission of passenger transport, it could be argued that Part 25 (airplane) or Part 29 (rotorcraft) could apply.

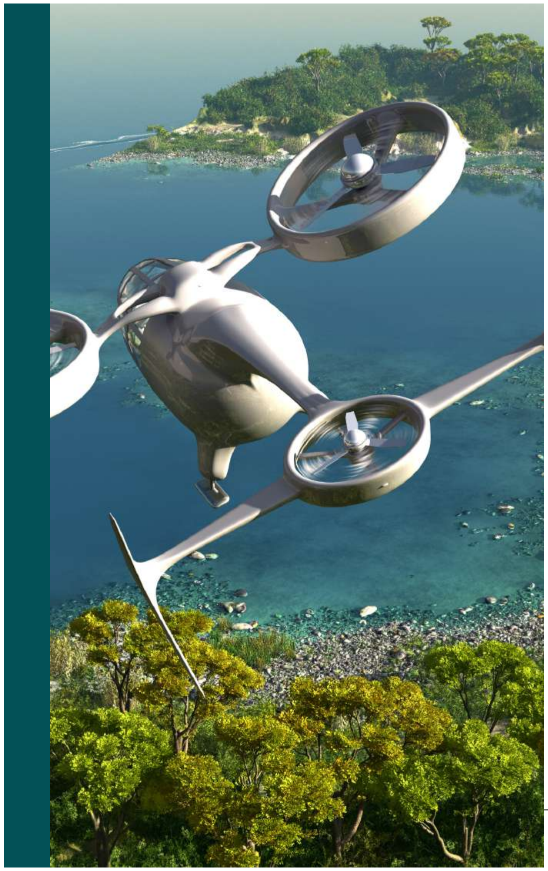
Air Ambulances UAMs: In addition to the certification standards listed above for Air Taxis, Air Ambulance UAMs will require detailed guidance for the evaluation of an operator's air ambulance procedures, air-ambulance-specific sections of their General Operations Manual (GOM), and the unique requirements an operator must meet prior to being issued Operations Specification (OpSpec) for Helicopter, Airplane, or a new category depending on how the UAM is classified.

LEGAL AND REGULATORY SUMMARY

Legal, regulatory, and certification challenges **and** opportunities exist in order to bring UAM to the market.

- **Legal Environment:** Dynamic legal environment with many unresolved challenges, especially establishing where federal, state, and local authorities take lead.
- **Breadth of Challenges:** UAM pose legal challenges that touch on most aspects of aviation, especially in the areas of air traffic control and management and flight standards, but also environmental policy, public use, land use, and local restrictions.
- **Legal Barriers/Opportunities for Remotely Operated and Automated Piloting System:** Current legal framework is starting to evolve to match the technology. Assured autonomy remains a challenging technical and legal problem.
- **Diversity in Approaches:** States and locales are undertaking legal experiments through a mix of approaches, ranging from designating UAS launch sites to hyperlocal restrictions. **State and local laws** range from laws prohibiting drones to laws protecting UAS operations.
- **Certification:** Many efforts are underway at FAA, ASTM, RTCA, SAE, and elsewhere to provide **methods of aircraft certification for UAM**, but there is still no clear certification path and several gaps in means of compliance. Opportunities may exist to:
  - Develop a roadmap to airworthiness that considers the range of potential UAM aircraft and paths to certification
  - Study and leverage international efforts (e.g., ICAO, EASA, NATO)
  - Study and leverage efforts from similar domains, such as autonomous cars (e.g., SAE Validation and Verification Task Force)
  - Explore other certification challenges for operator and operations certification
- **Strategies moving forward:** Enabling strategies can be employed to **accelerate the development** of a UAM legal framework:
  - NASA – FAA cooperation, such as the Research Transition Teams
  - FAA Aviation Rulemaking Committee
  - FAA UAS Integration Pilot Program
  - Leveraging strategies from automobile automation, such as voluntary standards may help UAM deployment
  - FAA Reauthorization act of 2018 provides much needed support for industry and ensuing economy

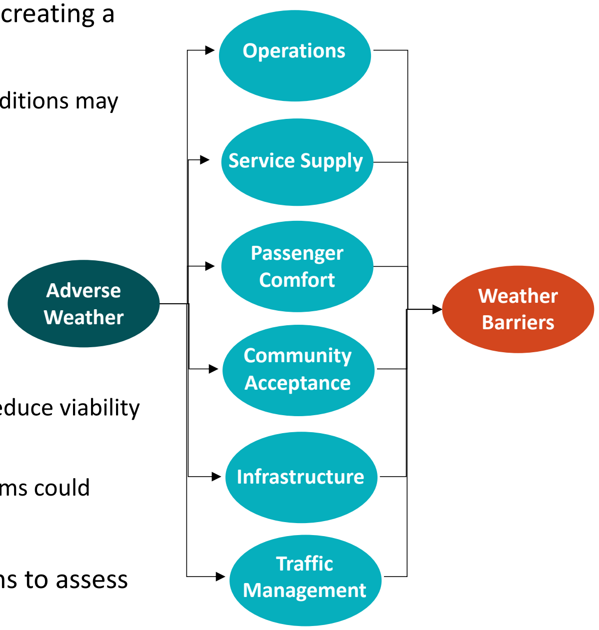
CONTENTS



WEATHER BARRIERS CONTENTS

WEATHER ANALYSIS - MOTIVATION

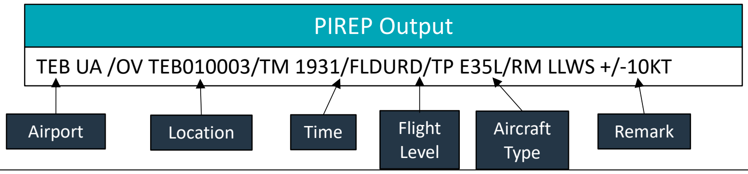
- Weather can influence many components of Urban Air Mobility, creating a variety of potential barriers
  - **Operations**: Reduction or cessation of operations during adverse conditions may occur due to safety concerns
  - **Service Supply**: Conditions may extend trip distance or reduce battery life
  - **Passenger Comfort**: May be impacted due to conditions such as extreme temperatures and turbulence
  - **Community Acceptance**: Could lead to passenger apprehension toward flying in certain conditions
  - **Infrastructure**: Consistent adverse weather may increase wear and reduce viability of vertiports
  - **Traffic Management**: Conditions such as wind shear and thunderstorms could disrupt flow patterns and structure
- Need to evaluate underlying frequent adverse weather conditions to assess range of potential barriers

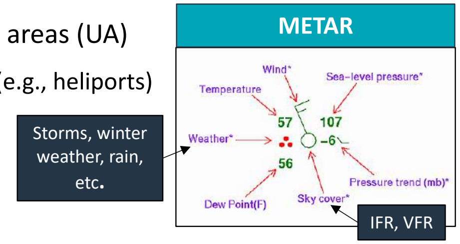


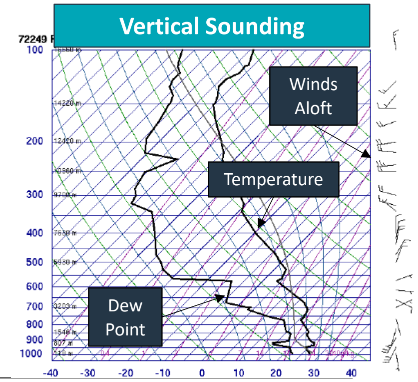
WEATHER BARRIERS CONTENTS

CLIMATOLOGY DATA SOURCES

- Surveyed available weather observation data sources in and near focus urban areas (UA)
  - Limited availability of reliable observations collected directly in urban environment (e.g., heliports)
- Identified several standard data sources which contain routinely collected weather observations
  - **Meteorological Aerodrome Report (METAR)** point surface observations which are taken hourly and provide conditions at takeoff/landing
  - **Vertical soundings** generated from weather balloons launched at 12Z and 00Z which provide conditions aloft that would be experienced during flight or at elevated vertiports
  - **Pilot Reports (PIREP)** of weather conditions encountered during flight which provide supplemental information on weather deemed impactful by pilots



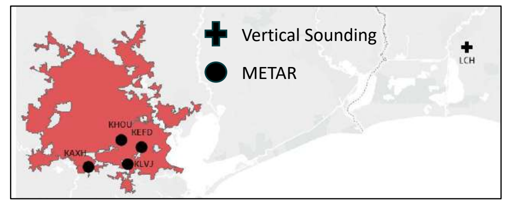




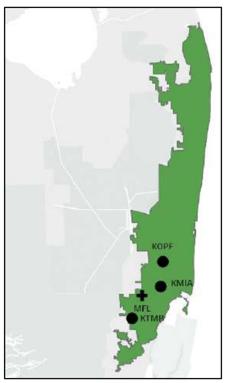
DATA SPATIAL COVERAGE - EASTERN AND CENTRAL UA

- Extensive overlap between standard observation locations and Eastern and Central urban areas
  - Many located in close proximity to each other, so observations may not represent full urban area (e.g., northern Miami)

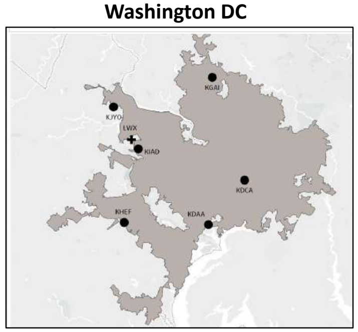
Houston



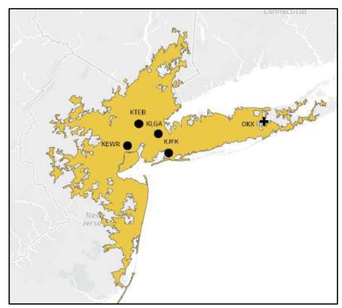
Miami



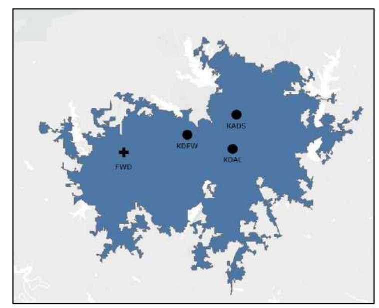
Washington DC



New York



Dallas

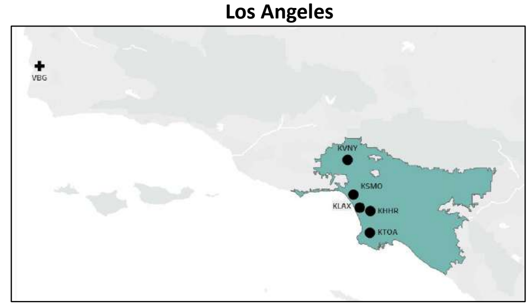


**Urban area maps based on U.S. Census definition*

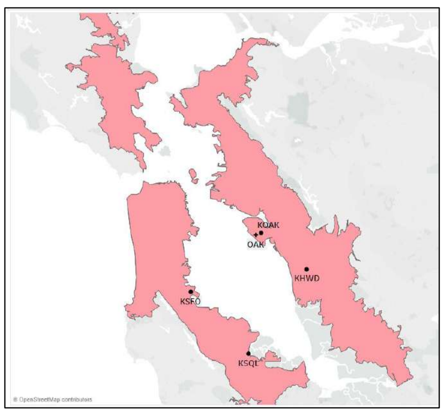
DATA SPATIAL COVERAGE - WESTERN UA

- Less coverage of standard observation locations in Western focus urban areas
  - Vertical soundings collected outside urban area at several locations, so may not be fully representative

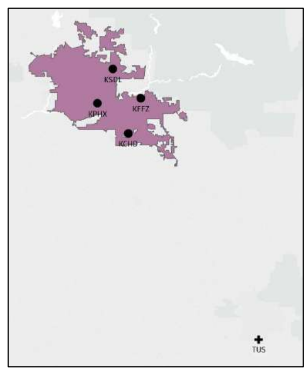
Los Angeles



San Francisco

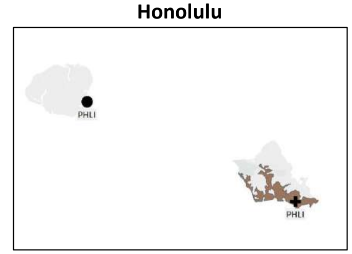


Phoenix



Denver

Honolulu



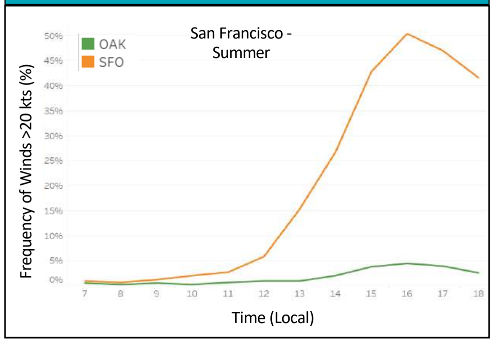
**Urban area maps based on U.S. Census definition*

SURFACE OBSERVATIONS - METHODOLOGY

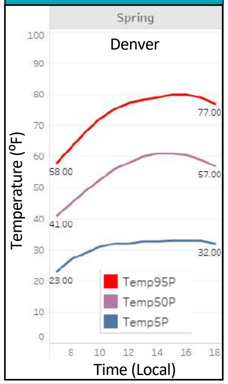
- Surface observations were collected over 7 year period (2010-2017) at METAR locations in 10 focus urban areas
  - Conditions and potential impacts to UAM operations likely to vary seasonally and diurnally
  - Observations binned by meteorological season and hour (7AM – 6PM Local)
- Computed statistics for operational window to evaluate frequencies of potentially adverse conditions in each urban area
  - First assessed differences between local observations in same urban area
  - Generated statistics capturing observations from all stations to provide aggregate of conditions in urban area

Meteorological Seasons
Winter: DJF
Spring: MAM
Summer: JJA
Fall: SON

Frequency of IFR, Winter Weather, Rain, Winds > 20 kts, and Thunderstorms



5th, 50th, 95th Percentile Temperature



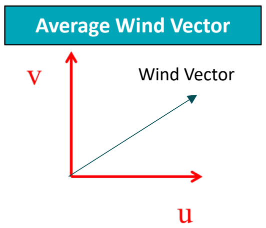
VERTICAL SOUNDING OBSERVATIONS - METHODOLOGY

- Average conditions computed from historical soundings over 5 year historical period (2013-2018) at 10 focus urban areas
  - Balloons only launched twice a day, so averages computed for <u>morning</u> (12Z) and <u>evening</u> (00Z) stratified by <u>season</u>
  - Observations taken at irregular altitude intervals during balloon ascent (nature of the instrument), so averages computed in 500 ft bins to ensure sufficient sample size
- Density altitude computed from sounding data to better understand lift conditions at vertiports / landing sites

$$\mathrm{DA} = \frac{T_{\mathrm{SL}}}{\Gamma}\left[1 - \left(\frac{P/P_{\mathrm{SL}}}{T/T_{\mathrm{SL}}}\right)^{\frac{\Gamma R}{gM - \Gamma R}}\right]$$

DA = Density altitude in meters (m);
P = (Static) atmospheric pressure;
P_{SL} = Standard sea-level atmospheric pressure (1013.25 hectopascals (hPa) in the International Standard Atmosphere (ISA), or 29.92 inches of mercury (inHg) in the U.S. Standard Atmosphere);
T = Outside air temperature in kelvins (K) (add 273.15 to the temperature in degrees Celsius ($^\circ\mathrm{C}$));
T_{SL} = ISA sea-level air temperature $= 288.15\ \mathrm{K}$;
Γ = ISA temperature lapse rate $= 0.0065\ \mathrm{K/m}$;
R = Ideal gas constant $= 8.3144598\ \mathrm{J/(mol\ K)}$;
g = Gravitational acceleration $= 9.80665\ \mathrm{m/s^2}$;
M = Molar mass of dry air $= 0.028964\ \mathrm{kg/mol}$.

- Average wind speed and direction calculated in each altitude bin by processing average *u* (East-West) and *v* (North-South) wind vector components



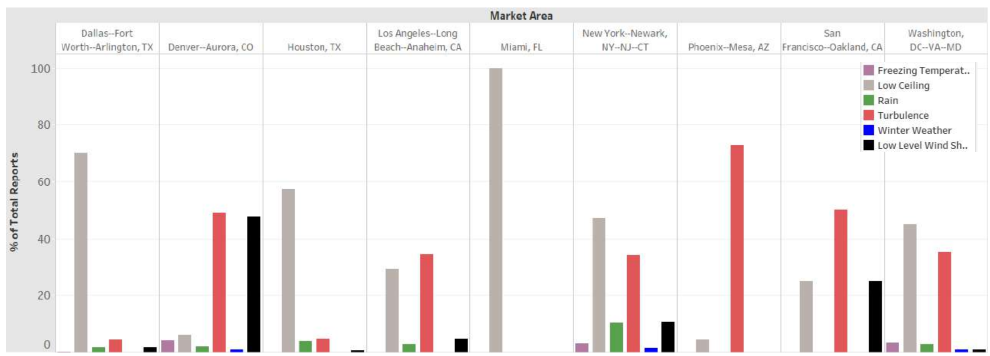
PILOT REPORTS - METHODOLOGY

- Evaluated 3 years (2015-2018) of historical Pilot Reports (PIREPS) to provide supplemental observations of certain conditions when they occur
  - Provide ad hoc observations to augment climatology and increase spatial distribution of data
  - Due to the highly subjective nature of PIREPs, data was scrutinized to ensure only appropriate reports were included
  - Isolated PIREPs over/near airports within UA's by searching the airport code in the PIREP
  - Computed percentage of PIREPs with each type of reported weather for each UA to identify which phenomenon was most prevalent at that location
  - Reports may contain more than one weather condition, so percentages may not always add to 100% (i.e., low visibility with turbulence)

PIREP Condition Categories*

- **Freezing Temperature:** Reported temperature <= 0 Celsius
- **Low Ceiling:** Overcast or broken layer is reported at under 5,000 ft AGL (within operational window)
- **Rain:** Rain reported
- **Turbulence:** Turbulence reported
- **Winter Weather:** Snow or other frozen precipitation reported

*Icing reports excluded due to complexity



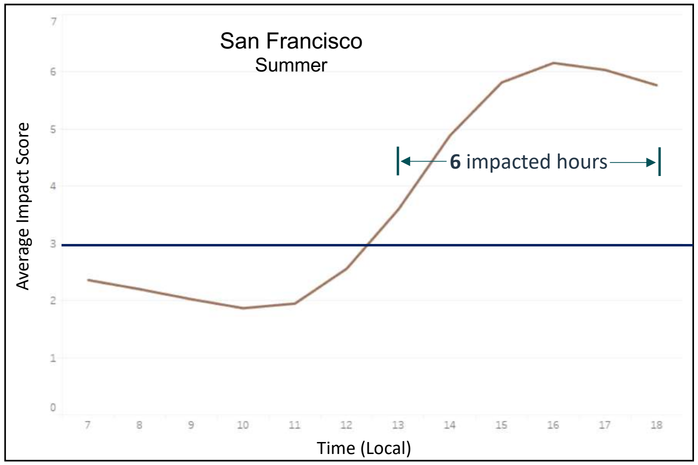
SIGNIFICANTLY IMPACTED HOUR - METHODOLOGY

- Goal to consolidate individual conditions into **comprehensive expression** of overall potential weather impacts at each hour and urban area

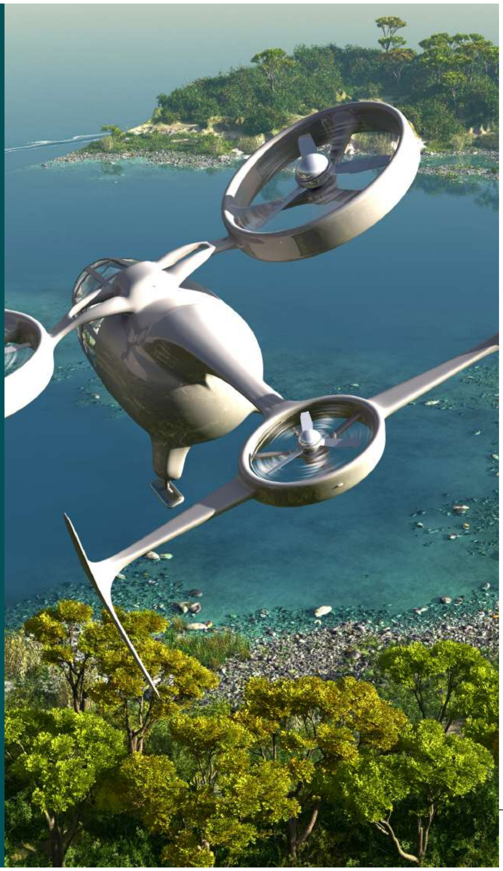
- First developed "impact scores" to capture potential impacts of individual conditions
  - Range from 1-10 based on impacts to current operations and potential disruption to UAM

Weather Condition	Score		Weather Condition	Score
Drizzle	1		Wind 20 - 25 kts	7
Rain	1		Smoke (<3 sm)	7
MVFR Ceiling	1		LIFR Ceiling	7
Haze	1		IFR Visibility	7
Ice Crystals	1		Wind ≥ 25 kts	8
Sand Whirls	1		Sleet	8
Sand	2		Squalls	8
Snow Grains	2		Fog	8.5
Temp ≤ 32°F	3		Freezing Fog	8.5
Temp ≥ 100°F	3		Freezing Drizzle	9
IFR Ceiling	4		Thunderstorms	9
Dust	5		Dust Storm	10
Snow	5		Funnel Cloud/Tornado	10
Sandstorm	5		Freezing Rain	10
Wind 15 - 20 kts	5		Hail	10
Mist (vis >= 5/8 sm)	6		Volcanic Ash	10
Snow Pellets	6			

- Computed average overall "impact score" at each hour and season for all urban areas



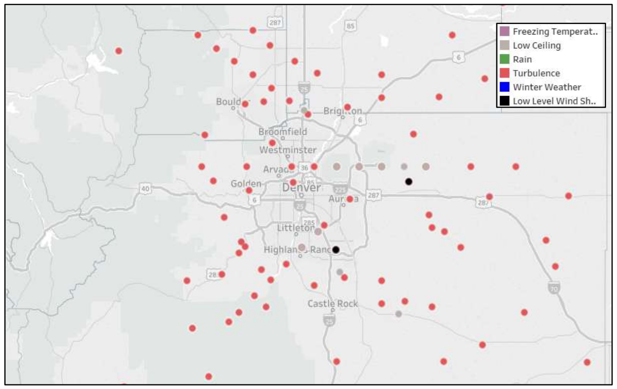
- Defined an **"impacted hour"** as having average impact score greater than 3



WEATHER BARRIERS CONTENTS

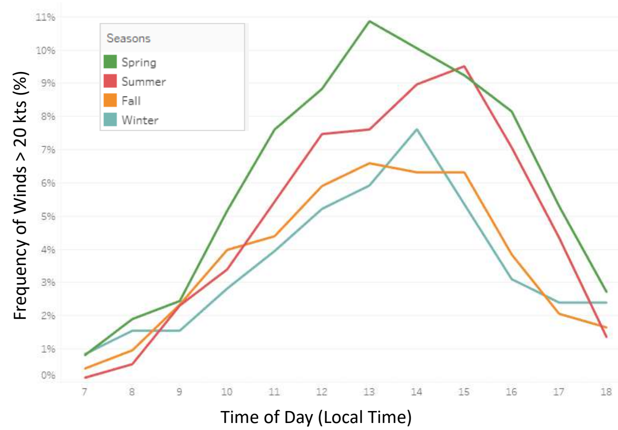
RESULTS

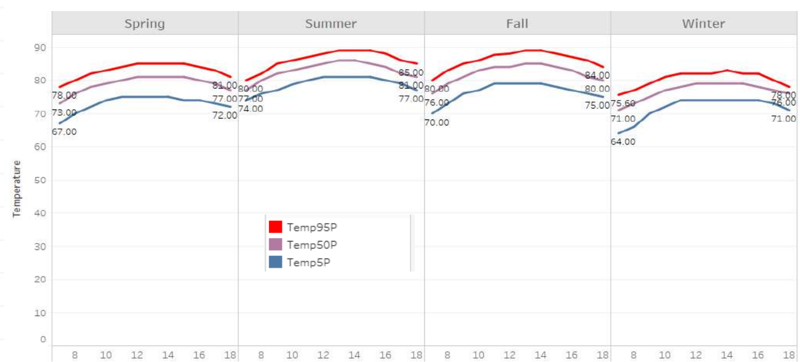
- Evaluated statistics at all urban areas, focused on key findings relevant to UAM operational impacts
  - Significant differences in observed conditions within urban area
  - Frequent adverse and occasional extreme conditions at surface and aloft
  - Results presented as regional groupings of urban areas
  - Computed number of average impacted hours at each urban area
- Number of PIREPS assessed and sample size not sufficient to highlight unique signals
  - Analyzed spatial distribution in each UA to identify corridors or regions of greater PIREP activity
  - Inconsistencies in temporal availability of data precluded identification of any seasonal patterns



RESULTS - HONOLULU UA

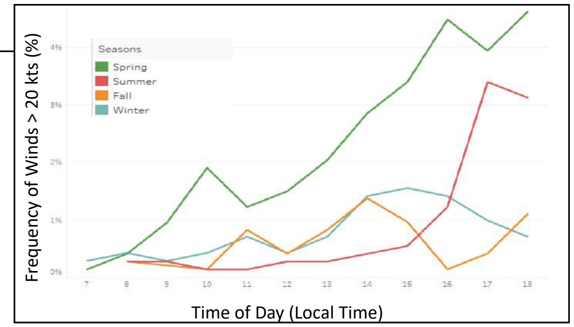
- Favorable conditions for UAM operations for most hours, especially during winter and fall
  - Mild temperatures throughout day for all seasons
  - Strong winds possible in afternoon (1PM – 3PM) during all seasons; more frequent during spring and summer
  - No PIREPs during historical analysis period

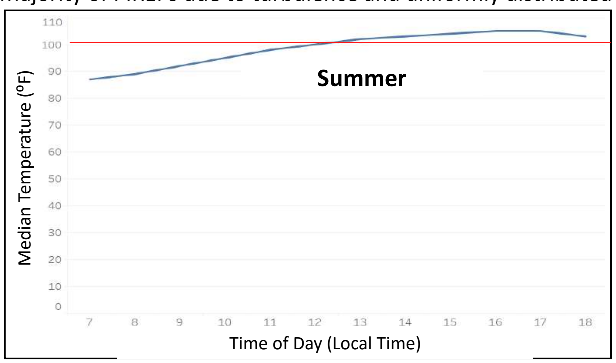


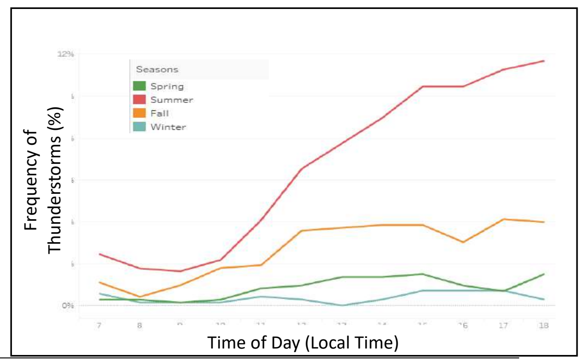


RESULTS - PHOENIX UA

- Overall favorable conditions, with most adverse conditions occurring in summer due to high temperatures, strong winds, and thunderstorms
  - High frequency of thunderstorms during afternoons hours in summer
  - Median temperature exceeds 100º F in afternoon (12PM – 6PM) in summer
  - Strong winds may occur in late afternoon during spring and summer
  - Majority of PIREPs due to turbulence and uniformly distributed spatially



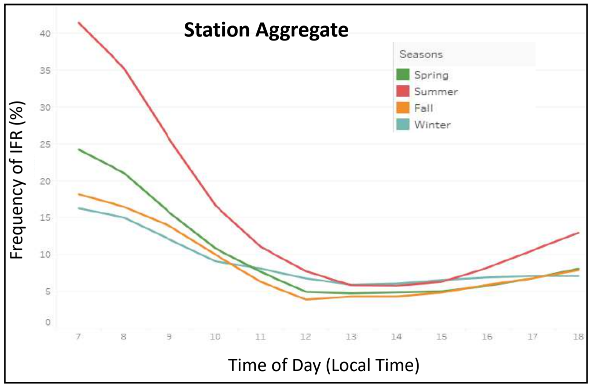


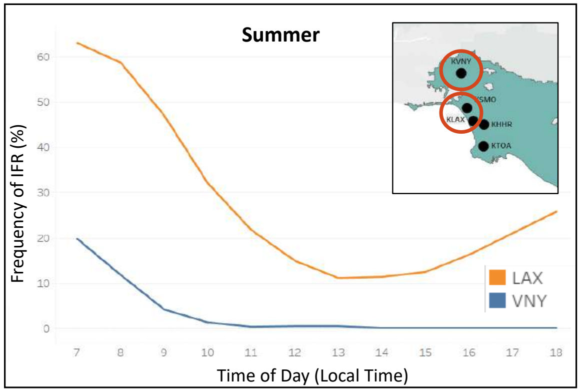


RESULTS - LOS ANGELES UA

- Instrument Flight Rules (IFR) conditions primary impactful weather
  - IFR conditions most frequent in morning in summer across all observation sites
  - More frequent IFR observations at LAX than VNY, most often in morning in summer
  - Warmer temperatures possible in summer and fall
  - Most PIREPs due to turbulence (primarily over ocean) and low ceilings (western UA)

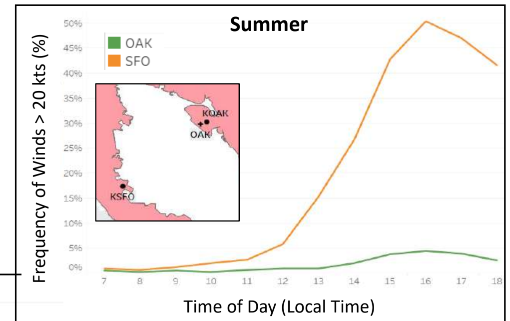
	Fall	Spring	Summer	Winter
TMax	109.00	103.00	112.00	91.00
TMin	35.00	38.00	32.00	31.00
Temp Range	74.00	65.00	80.00	60.00
Temp50P	66.00	61.00	69.00	57.00
Temp5P	53.00	51.00	60.00	45.00
Temp95P	87.00	79.00	90.00	73.00

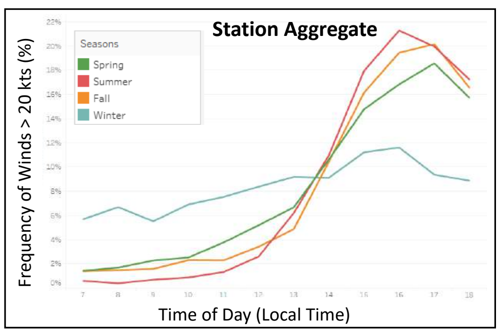


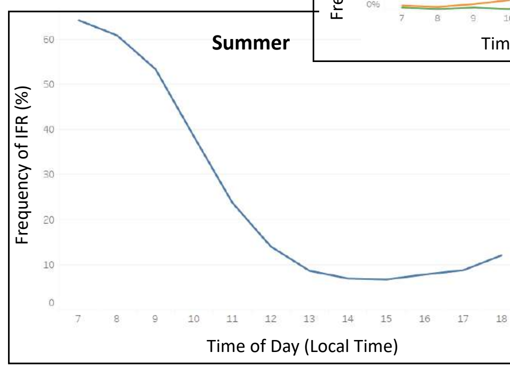


RESULTS - SAN FRANCISCO UA

- IFR conditions and strong winds most frequent adverse weather across all stations
  - Frequency of strong winds (>20 kts) significantly greater at SFO than OAK in afternoon for all seasons except Winter.
  - Strong winds possible in afternoon for most seasons across all stations
  - IFR conditions frequent during morning hours in summer
  - Only 3 PIREPs during historical analysis period

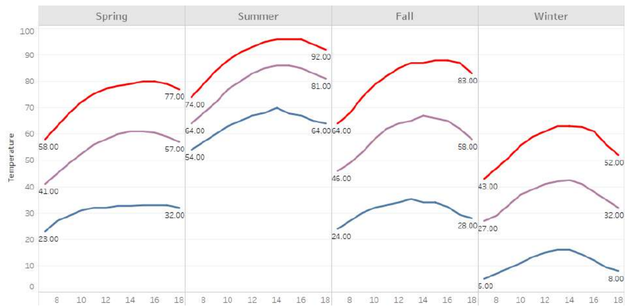


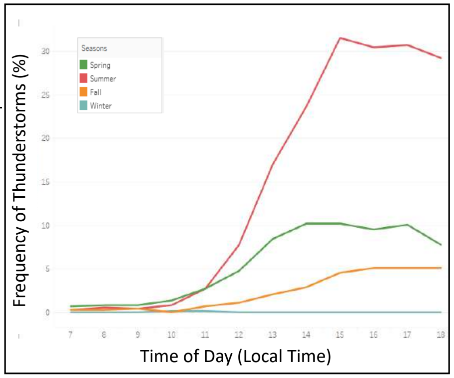


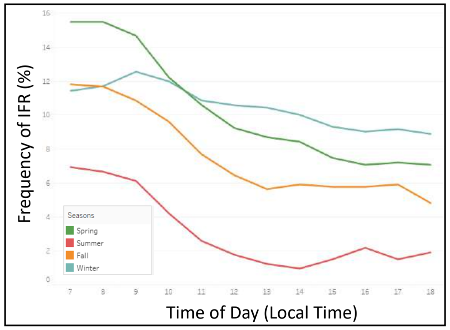


RESULTS - DENVER UA

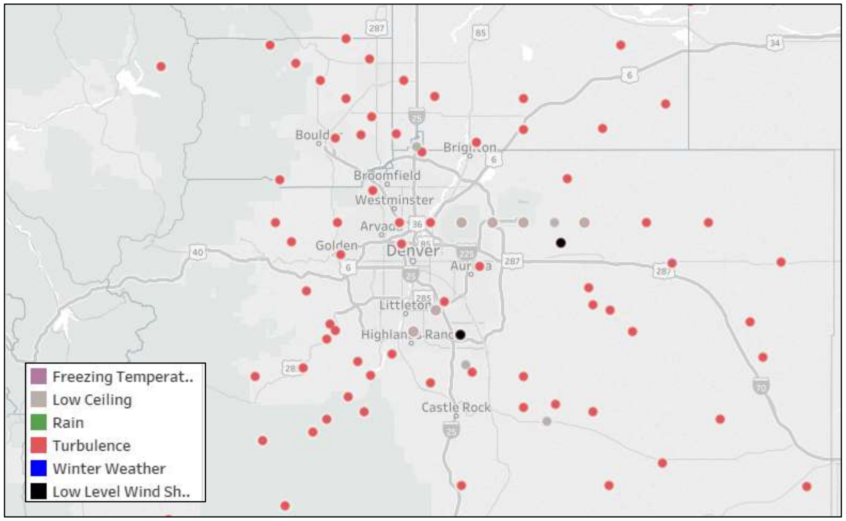
- Unfavorable weather for UAM operations during most hours and seasons
  - Cold temperatures possible during Spring, Fall, and Winter, especially morning and evening
  - Thunderstorms and strong winds common in summer during afternoon
  - IFR conditions frequent through all seasons in the morning
  - Strong winds (> 20 kts) at 5,000 ft AGL during all seasons
  - Frozen precipitation most prevalent in winter, also possible in spring and fall



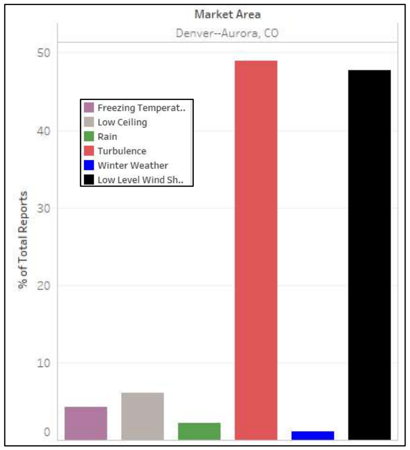




RESULTS - DENVER UA PIREP DISTRIBUTION



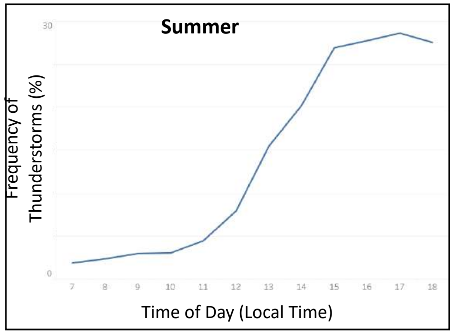
- Denver one of the few UAs to have PIREPs for all conditions
  - Turbulence and wind shear most frequent conditions
  - Most conditions reported uniformly across UA

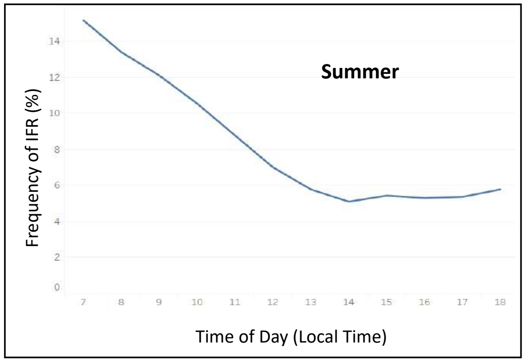


RESULTS - WASHINGTON DC UA

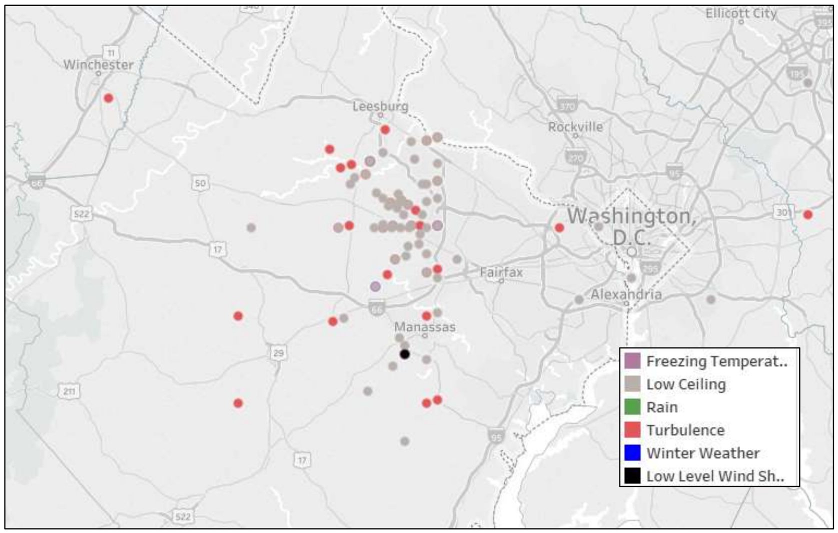
- Thunderstorms and IFR conditions primary adverse conditions
  - IFR conditions most frequent in morning (7AM – 12PM) across all seasons
  - Thunderstorms occur most often in afternoon (1PM – 6PM) in summer months
- No significant differences in surface observations between different locations
  - DCA records slightly greater median temperatures than IAD
  - Greater range in temperatures observed at IAD

	DCA	IAD
TMax	105.0	105.0
TMin	6.0	-2.0
Temp Range	99.0	107.0
Temp50P	61.0	58.0
Temp5P	31.0	27.0
Temp95P	86.0	84.0

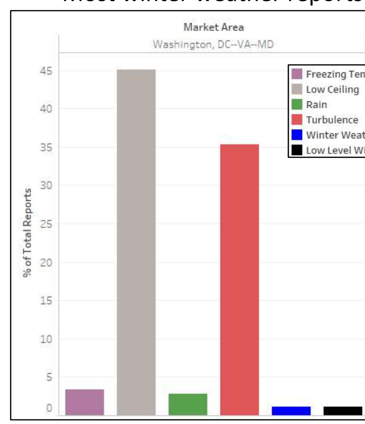




RESULTS - WASHINGTON DC UA PIREP DISTRIBUTION

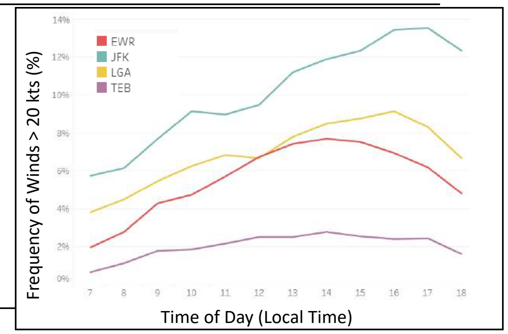


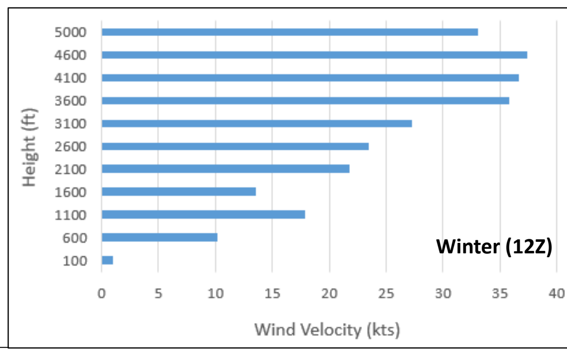
- Most PIREPs due to turbulence and low ceilings
  - Majority of reports while departing out of IAD
  - Most winter weather reports in western UA

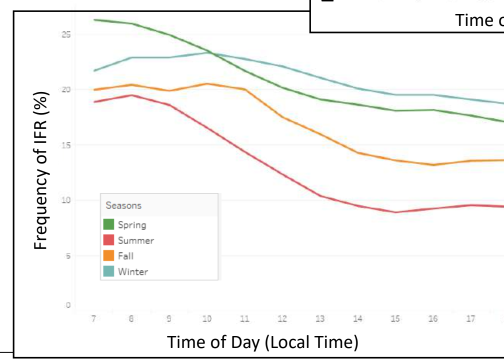


RESULTS - NEW YORK UA

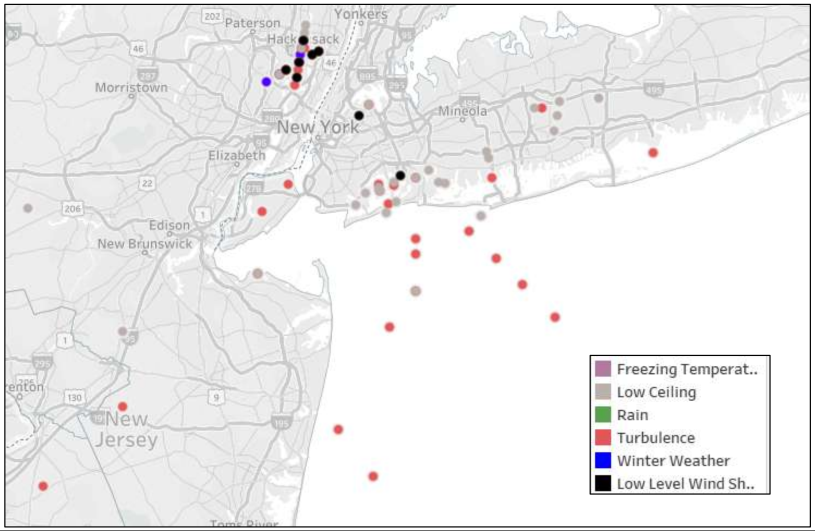
- Several adverse weather conditions frequent for most hours and seasons which could impact UAM operations
  - Strong winds common in afternoon across most of UA in winter and spring, most frequent at JFK across all seasons
  - IFR conditions occur often during morning hours through the year
  - Strong winds and wind shear (change in wind speed and/or direction with height) aloft observed above 500 ft during morning in winter



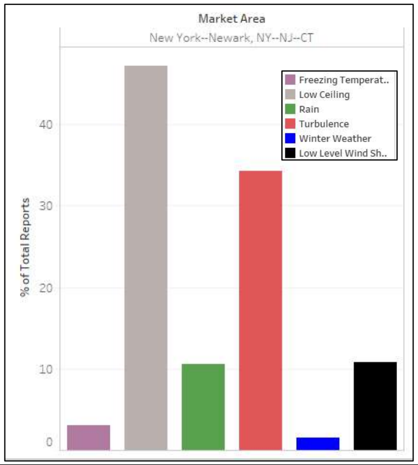




RESULTS - NEW YORK UA PIREP DISTRIBUTION

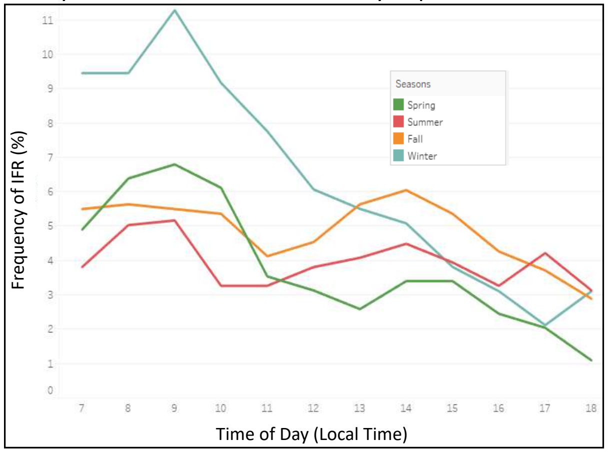


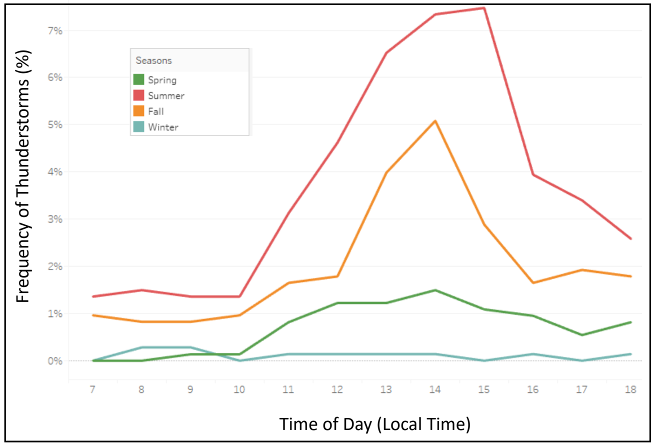
- Turbulence and low ceilings most frequent reported conditions
  - Similar to Washington D.C. UA
  - Most reports near EWR and in eastern UA



RESULTS - MIAMI UA

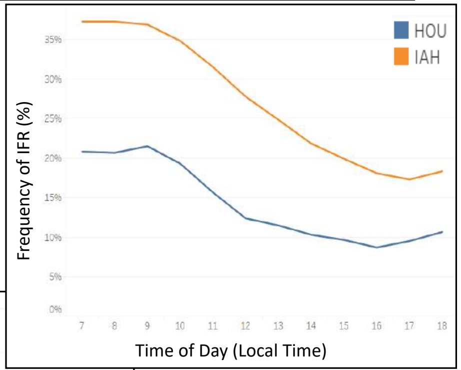
- Thunderstorms and IFR conditions most common weather that could impact UAM operations
  - Thunderstorms most frequent in afternoon during summer and fall at all locations within UA
  - IFR conditions most common during morning of winter
  - Only 1 PIREP across historical analysis period

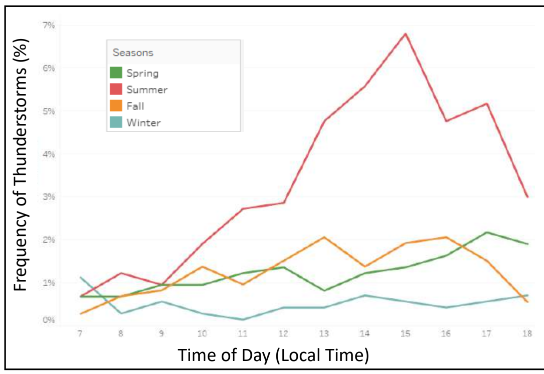


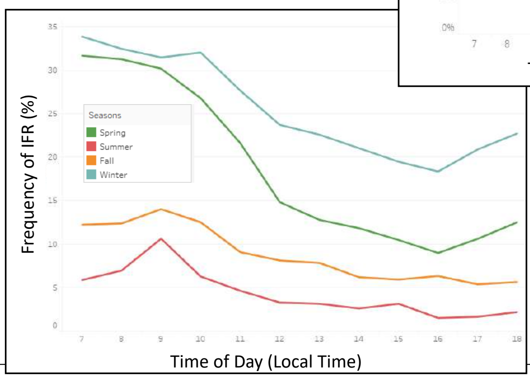


RESULTS - HOUSTON UA

- Several potentially impactful conditions possible in all seasons
  - IFR conditions in morning of winter and spring, more frequent at IAH
  - Thunderstorms most frequent in afternoon during summer
  - Hot temperatures possible in summer and early fall
  - Strong low level jet at 2500 ft in morning during winter and strong winds (>20 kts) near 5000 ft

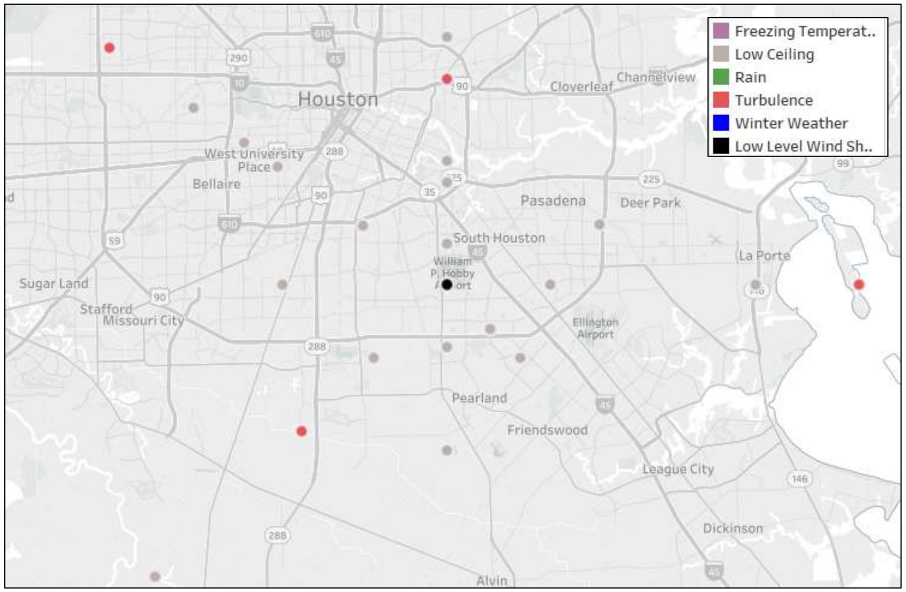




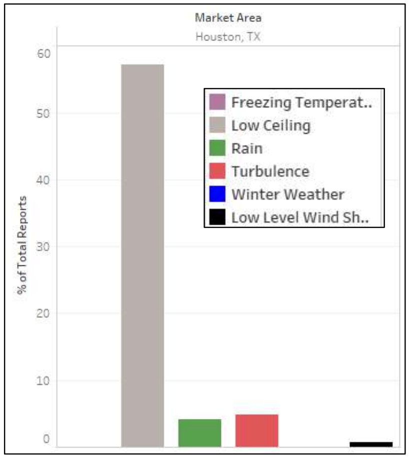


	Fall	Spring	Summer	Winter
TMax	99.00	97.00	105.00	86.00
TMin	32.00	28.00	70.00	23.00
Temp Range	67.00	69.00	35.00	63.00
Temp95P	90.00	86.00	96.00	77.00
Temp50P	78.00	75.00	88.00	60.00
Temp5P	54.00	56.00	77.00	39.00

RESULTS - HOUSTON UA PIREP DISTRIBUTION

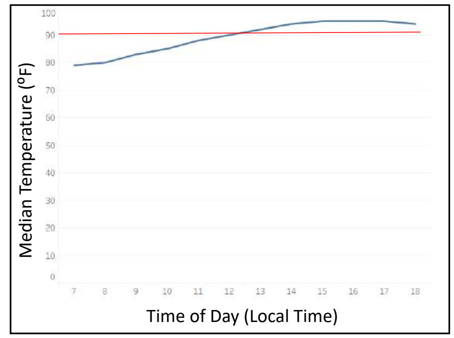


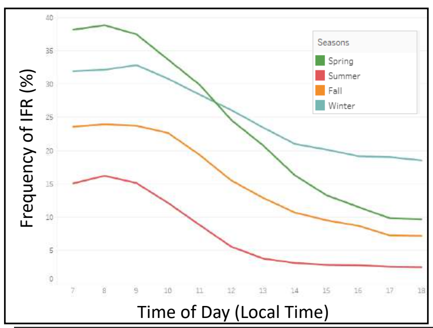
- Low ceilings most commonly reported condition
  - Most reports located in southeastern portion of UA

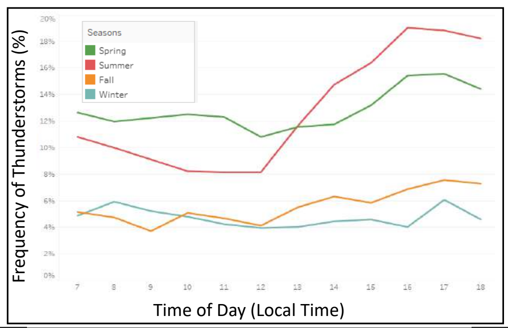


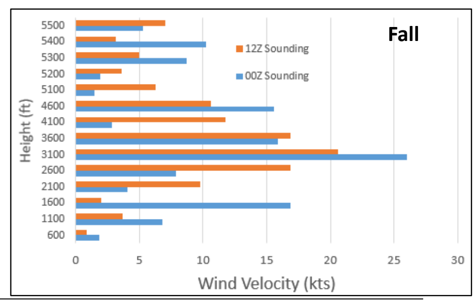
RESULTS - DALLAS UA

- Several adverse conditions possible in all seasons
  - Median temperature exceeds 90^{o} F for all hours after 12PM in summer
  - Thunderstorms frequent during afternoon of spring and summer
  - IFR conditions frequent all year in morning, most common in winter and spring
  - Strong low level jet (>20 knots) near 3,100 ft in afternoon during fall may impact UAM in flight
  - Majority of PIREPs for low ceilings reported on approach/departure (DFW, DAL









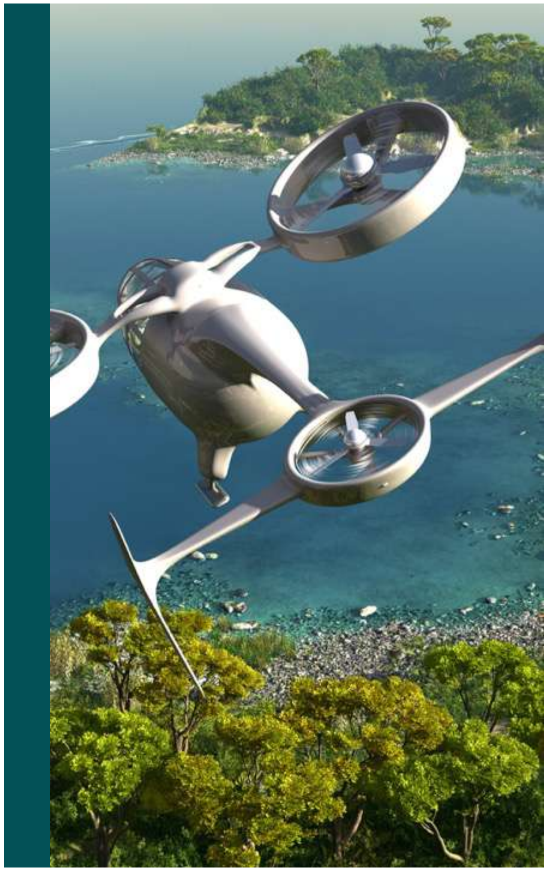
RESULTS - SIGNIFICANTLY IMPACTED HOURS

- Approximately half the UAM operational day potentially impacted by weather in several urban areas on average across all seasons
- High number of impacted hours in winter and spring in the Northeast, Texas, and Denver urban areas
- Fewest impacted hours during summer and fall at most focus urban areas
  - Most impacted hours during summer in Phoenix and Honolulu
- Adverse weather does occur in Miami, but low frequency of localized thunderstorms results in no average significantly impacted hours

	Average Number of Impacted Hours (7am – 6pm Local)				
Urban Areas	**Winter**	**Spring**	**Summer**	**Fall**	**Average**
New York	12	12	0	8	8
Washington DC	12	12	0	0	6
Miami	0	0	0	0	0
Dallas	11	12	3	0	6.5
Houston	9	11	0	0	5
Denver	12	12	4	3	7.75
Phoenix	0	0	5	0	1.25
Los Angeles	2	1	2	1	1.5
San Francisco	3	6	6	4	4.75
Honolulu	0	7	9	6	5.5
Average	6.1	7.3	2.9	2.2	

RESULTS - SUMMARY

- Weather mostly favorable for UAM operations in Western urban areas
  - Western urban areas experience significantly impacted hours less than half the operational window
  - IFR conditions during morning hours in summer may reduce visual operations or warrant different navigation equipment
  - Median temperature exceeds 90°F most of the day in Phoenix during summer
  - Strong surface winds may disrupt takeoff/landing during afternoon in Honolulu, San Francisco, and Phoenix
  - Conditions **highly unfavorable** for UAM operations in Denver due to frequent adverse weather in every season
- Weather conditions less favorable in Eastern urban areas as potential for most of operational day to be impacted by weather
  - New York is impacted on average 8 hours of the operations window while DC is impacted 6 hours of that window
  - IFR conditions and strong surface winds are also common during winter and spring in both DC and New York
  - Conditions are favorable on average in Miami for UAM operations, though thunderstorms could cause short term disruptions
- Approximately half the UAM operational day potentially impacted by weather in Texas urban areas due to thunderstorms, IFR conditions, and wind shear (low level jet)
  - IFR conditions occur most frequently during morning of winter and spring
  - Wind shear in the afternoon leads to turbulence and safety concerns

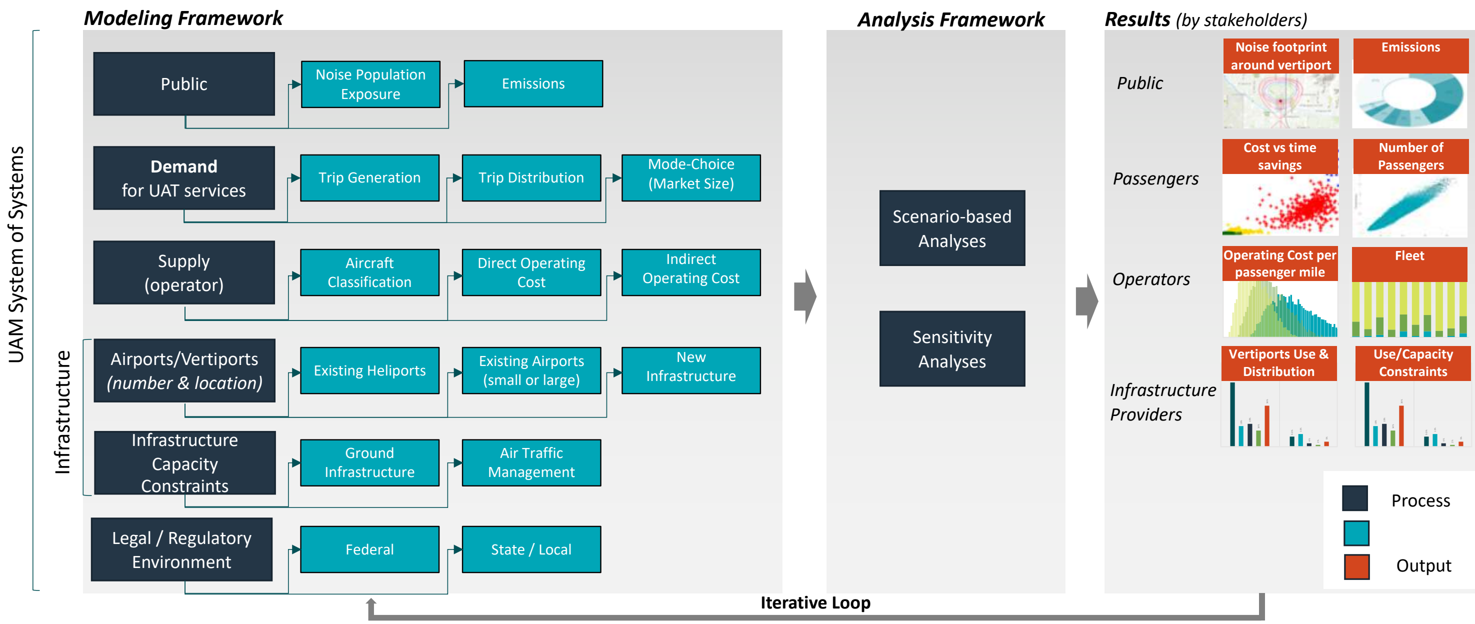


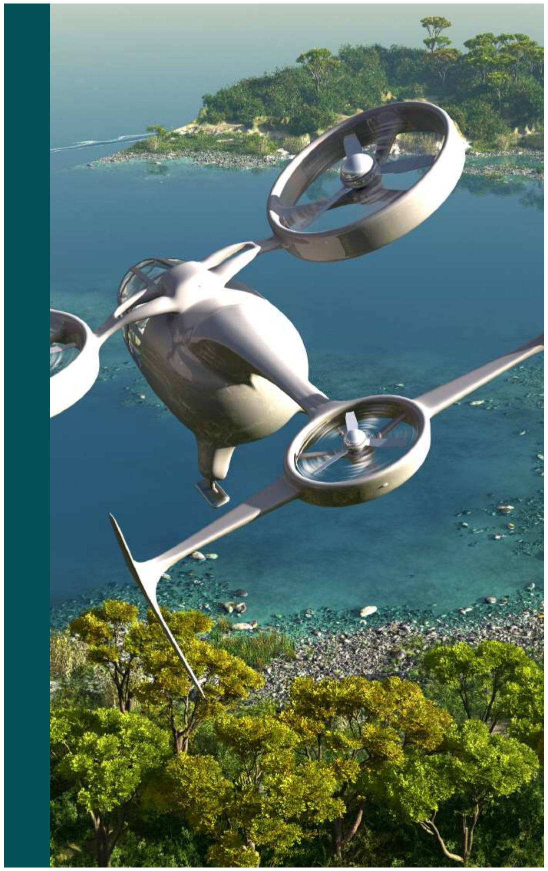
CONTENTS

AIRPORT SHUTTLE AND AIR TAXI ANALYSIS CONTENTS

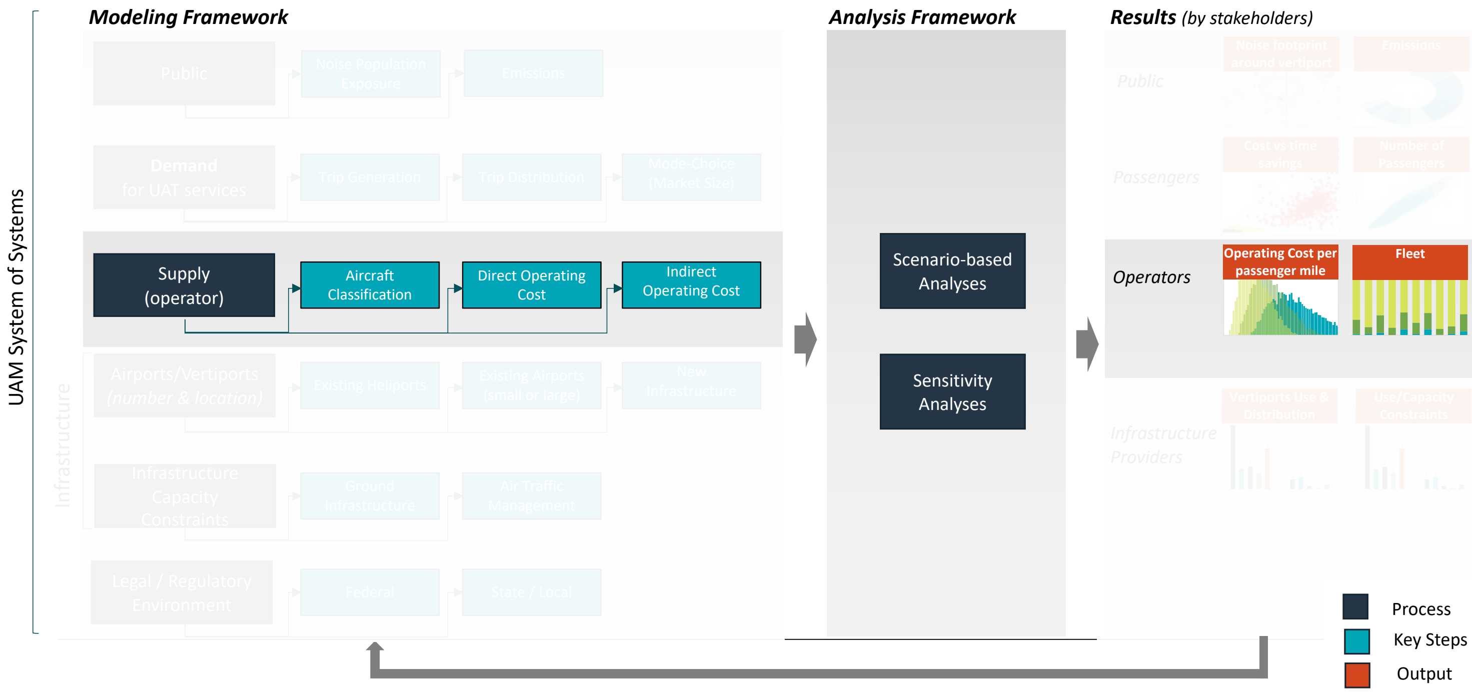
SYSTEM LEVEL FRAMEWORK IS REQUIRED

Analysis of urban Airport Shuttle and Air Taxi markets requires a system-level approach that comprise of various system level layers like supply, demand, infrastructure, legal/regulatory environment, public acceptance, safety and security. Each layer is investigated in a scenario and sensitivity based analysis framework. More about the markets is available in Appendix 4.1.

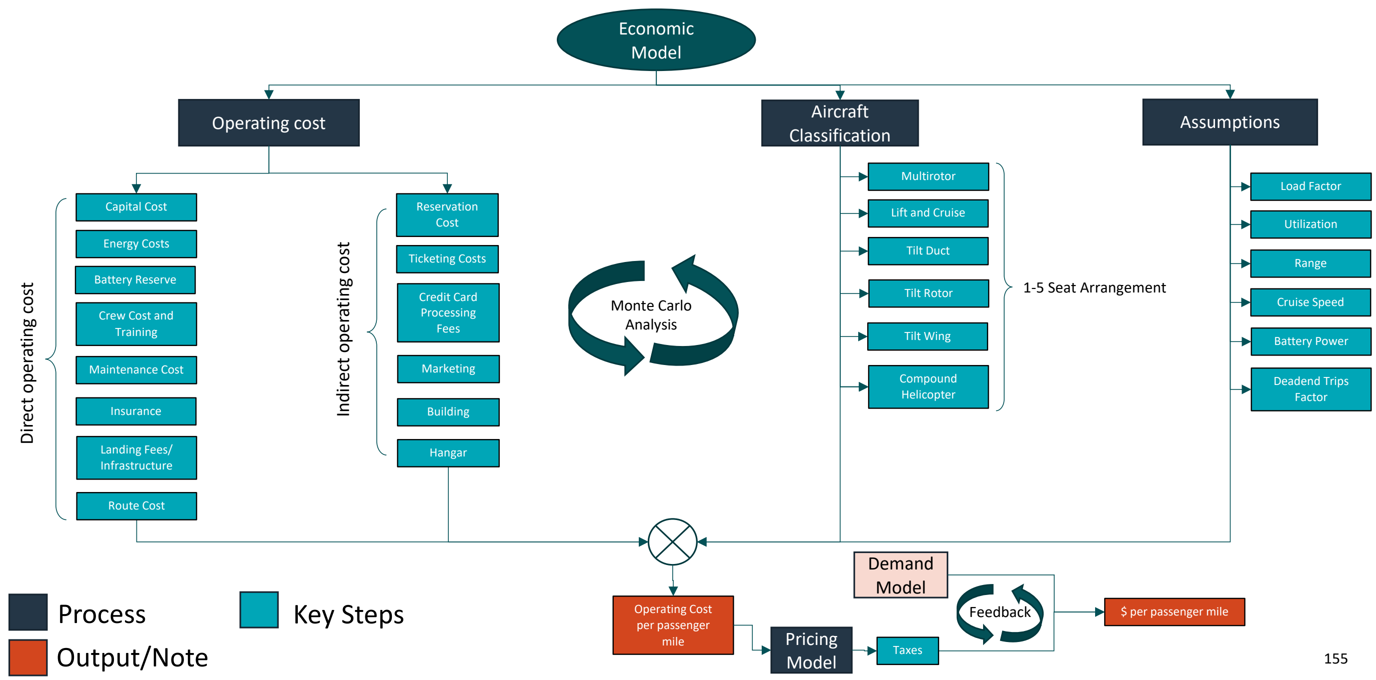




SYSTEM LEVEL FRAMEWORK



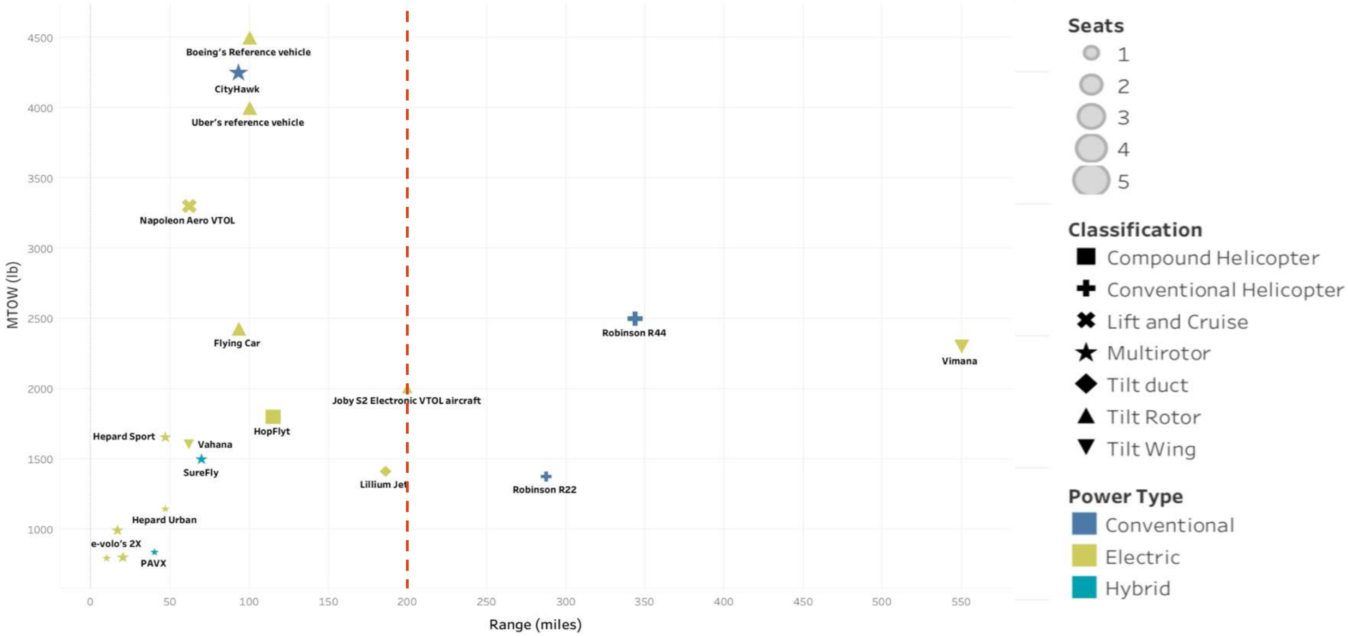
STRUCTURE OF SUPPLY ECONOMIC MODEL FOR AN eVTOL



Aircraft Classification

MULTIPLE CLASSES OF AIRCRAFT ARE PROPOSED

Vehicles with electric and hybrid power types in 1-5 seat configuration and less than 200 mile range are proposed for the urban Air Taxi and Airport Shuttle market.



MANY DESIGNS IN MULTIROTOR AND TILT ROTOR MARKET AROUND THE WORLD

NON-EXHAUSTIVE

MULTIROTOR MARKET OVERVIEW

Manufacturer	Product	Technical Specifications
Workhorse Photo Source: http://workhorse.com/surefly	SureFly 	Passengers 2 Range 70 mi MTOW 1500 lbs. Cruise Speed 50 mph Cost $200,000 Timeline First flight in April 2018
Astro Photo Source: https://flyastro.com/	Passenger Drone 	Passengers 2 Range 20 mi MTOW 800 lbs. Cruise Speed 50 mph Cost $150,000 Timeline First flight in August 2017
Ehang Photo Source: http://www.ehang.com/ehang184/gallery/	Ehang 184 	Passengers 1 Range 10 mi MTOW 795 lbs. Cruise Speed 50 mph Cost $250,000 Timeline Flight testing in 2016-2017
VRCO Photo Source: http://www.vrco.co.uk/	NeoXCraft 	Passengers 2 Range 210 mi MTOW 1600 lbs. Cruise Speed 50 mph Cost $2M Timeline NA

TILT ROTOR MARKET OVERVIEW

Manufacturer	Product	Technical Specifications
Bartini Photo Source: https://bartini.aero/	Flying Car 	Passengers 4 Range 93 mi MTOW 2425 lbs. Cruise Speed 150 mph Cost $120,000 Timeline Fully functioning by 2020
Joby Aviation Photo Source: http://www.jobyaviation.com/S2ConceptualDesign(AIAA).pdf	S2 EVOTL 	Passengers 2 Range 200 mi MTOW 2000 lbs. Cruise Speed 150 mph Cost $200,000 Timeline First flight in 2018
EVA Photo Source: http://evtol.news/aircraft/eva-x01/	XO1 	Passengers 2 Range 156.25 mi MTOW 2000lbs Cruise Speed 150 mph Cost $297,619 Timeline Testing in 2019
XTI Photo Source: http://www.xtiaircraft.com/the-a-team/	TriFan 600 	Passengers 6 Range 1377 mi MTOW 5300 lbs. Cruise Speed 150 mph Cost $6.5M Timeline First flight 2019

Technical Specification Sources: eVTOL News from the American Helicopter Society

Aircraft Classification

LIFT/CRUISE AND TILT DUCT VEHICLES ARE MORE POPULAR WITH US MANUFACTURERS SIMILAR TO ....

NON-EXHAUSTIVE

LIFT AND CRUISE MARKET OVERVIEW

Manufacturer	Product	Technical Specifications
Napoleon Aero Photo Source: http://evtol.news/aircraft/napoleon-aero-vtol/	*Napoleon Aero VTOL* 	*Passengers* 4 *Range* 62 mi *MTOW* 3300 lbs. *Cruise Speed* 150 mph *Cost* NA *Timeline* NA
Aurora Photo Source: http://www.aurora.aero/evtol/	*Electric VTOL Multicopter* 	*Passengers* 2 *Range* NA *MTOW* 1760 lbs. *Cruise Speed* 150 mph *Cost* NA *Timeline* Expected 2020
Cartivator Photo Source: http://cartivator.com/skydrive	*Skydrive* 	*Passengers* 2 *Range* NA mi *MTOW* 880 lbs. *Cruise Speed* 150 mph *Cost* NA *Timeline* NA
Skypod Photo Source: http://evtol.news/aircraft/skypod/	*Skypod* 	*Passengers* 2 *Range* NA *MTOW* 1600 lbs. *Cruise Speed* 150 mph *Cost* NA *Timeline* NA

TILT DUCT MARKET OVERVIEW

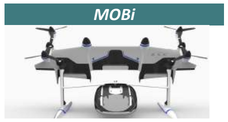
Manufacturer	Product	Technical Specifications
Lilium Photo Source: https://lilium.com/	*Lilium Jet* 	*Passengers* 2 *Range* 186 mi *MTOW* 1410 lbs. *Cruise Speed* 150 mph *Cost* NA *Timeline* Expected 2019
Skylys Photo Source: http://evtol.news/aircraft/skylys-ao/	*AO* 	*Passengers* 2 *Range* 93 mi *MTOW* 2400 lbs. *Cruise Speed* 150 mph *Cost* NA *Timeline* Expected 2018
Bell Helicopter Photo Source: http://www.bellflight.com/company/innovation/air-taxi	*Bell Air Taxi* 	*Passengers* 4 *Range* NA *MTOW* 3200 lbs. *Cruise Speed* 150 mph *Cost* NA *Timeline* Expected 2020
Aurora Photo Source: http://www.aurora.aero/lightningstrike/	*Lightning Strike* 	*Passengers* 0 *Range* NA *MTOW* NA *Cruise Speed* 150 mph *Cost* NA *Timeline* NA

Technical Specification Sources: eVTOL News from the American Helicopter Society

.... TILT WING AND COMPOUND HELICOPTER VEHICLES

NON-EXHAUSTIVE

TILT WING MARKET OVERVIEW

Manufacturer	Product	Technical Specifications
Vimana VIMANA Photo Source: http://evtol.news/aircraft/vimana/	Unmanned AAV 	Passengers 4 Range 550 mi MTOW per seat 2300 lbs. Cruise Speed 150 mph Cost per seat NA Timeline NA
Air Bus A3 Photo Source: https://vahana.aero/welcome-to-vahana-edfa689f2b75	Vahana 	Passengers 2 Range 62 mi MTOW per seat 1600 lbs. Cruise Speed 150 mph Cost per seat NA Timeline Expected 2020
ASX ASX Photo Source: http://airspacex.com/mobi-2025/	MOBi 	Passengers 4 Range 65 mi MTOW 2800 lbs. Cruise Speed 150 mph Cost NA Timeline Expected 2025
VerdeGo Aero VERDEGO AERO Photo Source: https://www.verdegoaero.com/	Personal Air Taxi 	Passengers 2 Range 40 mi MTOW NA Cruise Speed 150 mph Cost NA Timeline Expected 2020

COMPOUND HELICOPTER MARKET OVERVIEW

Manufacturer	Product	Technical Specifications
Hop Flyt hop Flyt Photo Source: https://hopflyt.com	Hop Flyt 	Passengers 4 Range 115 mi MTOW per seat 1800 lbs. Cruise Speed 150 mph Cost NA Timeline Scale model flight in 2017

CONVENTIONAL HELICOPTER MARKET OVERVIEW

Manufacturer	Product	Technical Specifications
Robinson ROBINSON HELICOPTER COMPANY Photo Source: https://robinsonheli.com/	R22 	Passengers 2 Range 287.5 mi MTOW per seat 1370 lbs. Cruise Speed 100 mph Cost $300,000 Timeline Widely Available
Robinson ROBINSON HELICOPTER COMPANY Photo Source: https://robinsonheli.com/	R44 	Passengers 4 Range 343.75 mi MTOW per seat 2500 lbs. Cruise Speed 100 mph Cost $450,000 Timeline Widely Available
Carter CARTER Photo Source: http://www.cartercopters.com/	Cartercopter 	Passengers 6 Range 690 mi MTOW 2500 lbs. Cruise Speed 100 mph Cost NA Timeline NA

Technical Specification Sources: eVTOL News from the American Helicopter Society

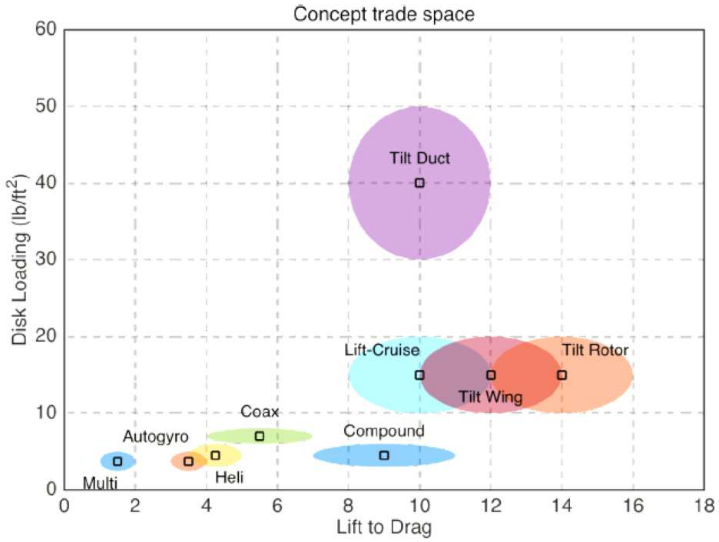
ALL NINE VEHICLE TYPES HAVE DISTINCT PERFORMANCE CHARACTERISTICS

- **Tilt Ducts** have significantly higher disk loading i.e., **higher engine power** will be required to hover while **Multirotor** has significantly low lift to drag ratio indicating **lower performance**
- **Tilt Wing/Rotor, Lift-Cruise and Compound helicopters** are in the **optimum** trade space and may be more favorable for urban Air Taxi market

Vehicle Class	Average Cruise Speed (mph)	Lift-to-Drag Ratio	Disk Loading (lb./ft^2)
Multirotor	50	1-2	2.5-5
Autogyro*	100	3-4	2.5-5
Conventional Helicopter	100	3.5-5	3-6
Tilt Duct	150	8-12	30-50
Coaxial Rotor*	150	4-7	6-8
Lift + Cruise	150	8-12	10-20
Tilt Wing	150	10-14	10-20
Compound Helicopter	150	7-11	3-6
Tilt Rotor	150	12-16	10-20

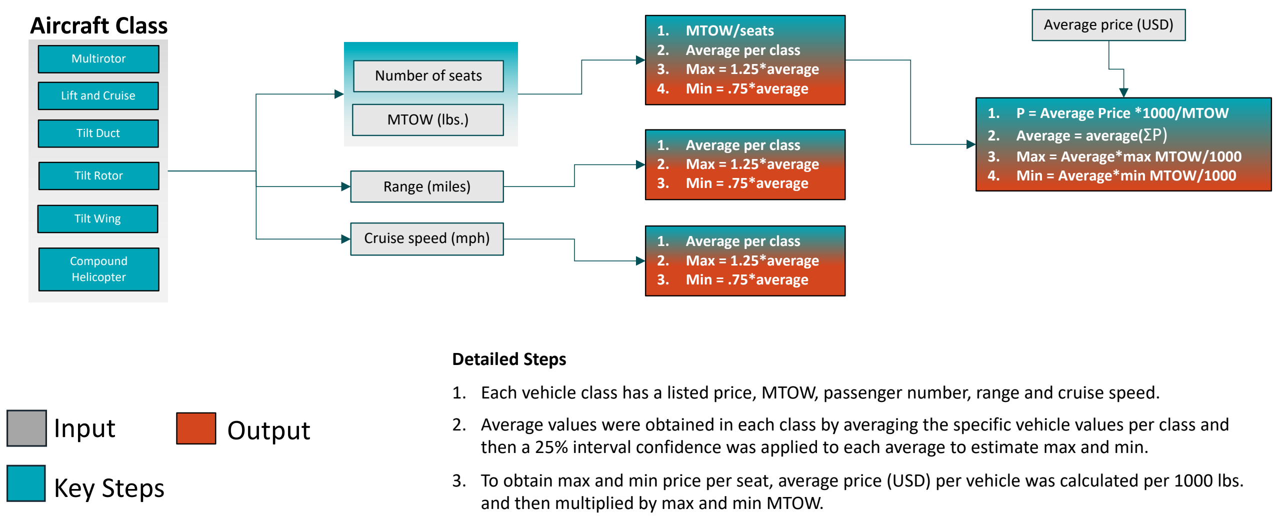
* Not considered for further analysis due to little information available

Source: Slide adapted from McDonald and German (eVTOL Stored Energy Overview)



TECHNICAL SPECIFICATIONS OF REFERENCE VEHICLE FOR EACH CLASS ARE DEVELOPED BASED ON LITERATURE REVIEW

Using available literature, we developed a reference aircraft for each class type in 1-5 seat configuration. Our approach was to calculate average values for MTOW, range, price and speed within a 25% confidence interval.



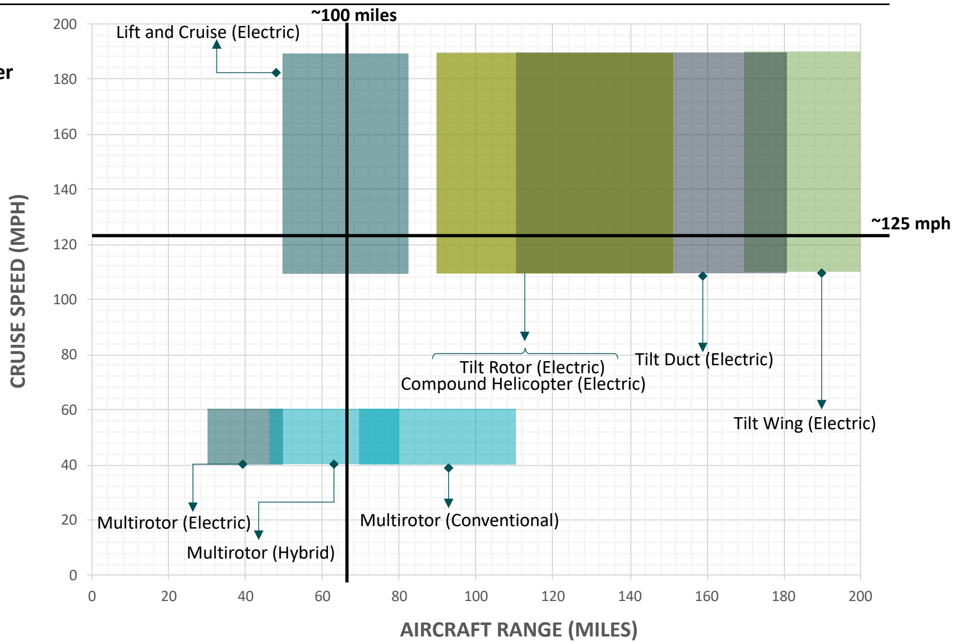
Detailed Steps

1. Each vehicle class has a listed price, MTOW, passenger number, range and cruise speed.
2. Average values were obtained in each class by averaging the specific vehicle values per class and then a 25% interval confidence was applied to each average to estimate max and min.
3. To obtain max and min price per seat, average price (USD) per vehicle was calculated per 1000 lbs. and then multiplied by max and min MTOW.

MOST PROPOSED AIRCRAFT DESIGNS ARE FASTER THAN CONVENTIONAL HELICOPTERS

- Hybrid and conventional powered vehicles usually have **higher range**
- All electric aircraft except Multirotor have **higher speed** than conventional helicopters of similar category

	Classification	MIN CRUISE SPEED (mph)	MAX CRUISE SPEED (mph)	MIN RANGE (miles)	MAX RANGE (miles)
Electric	Multirotor	40	60	30	50
Electric	Tilt Rotor	110	190	90	150
Electric	Lift and Cruise	110	190	50	80
Electric	Tilt Wing	110	190	170	290
Electric	Tilt duct	110	190	110	180
Electric	Compound Helicopter	110	190	90	150
Hybrid	Multirotor	40	60	50	80
Hybrid	Tilt Rotor	110	190	1040	1730
Conv.	Multirotor	40	60	70	110
Conv.	Helicopter	80	130	330	550



High range Tilt Rotor (Hybrid) and Conventional Helicopter not pictured

URBAN AIR TAXI MARKET IS LIKELY TO BE SERVED BY ELECTRIC AIRCRAFT

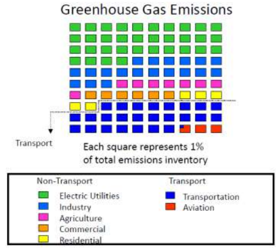
*Interest in electric aviation for Urban Air Taxi and Airport Shuttle market is partly driven by it's expected lower environmental footprint (essential for public acceptance) and lower overall costs. Therefore, this **analysis focuses on electric variants** (refer to as eVTOL in analysis) of various aircraft type discussed in previous slides.*

Environmental Impact

Noise pollution

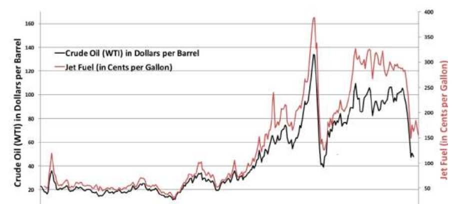
Image: www.getreading.co.uk

Greenhouse Gas Emissions



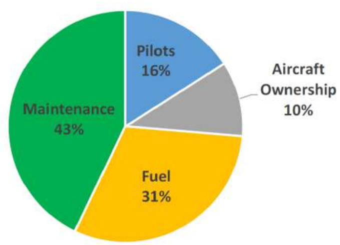
Source: US EPA data, 2005

Rising and Fluctuating Fuel Prices



Data sources: ATA Fuel Cost and Consumption

High Maintenance Cost of Fleet



Source: Cape Air 2015 Essential Air Services Proposal

Operator's / Market Interest

UBER Elevate

A3 BY AIRBUS

Aurora FLIGHT SCIENCES A BOEING COMPANY

KEY OPERATION RELATED ASSUMPTIONS

For the first few years of operations, analysis assumes a ***pilot on-board*** *that controls the aircraft i.e. no autonomy (although aircraft are expected to be fully autonomous from the beginning)*

We assume a ***longest mission of 50 miles*** *in single charge. All other assumptions for Monte Carlo analysis are available in later sections.*

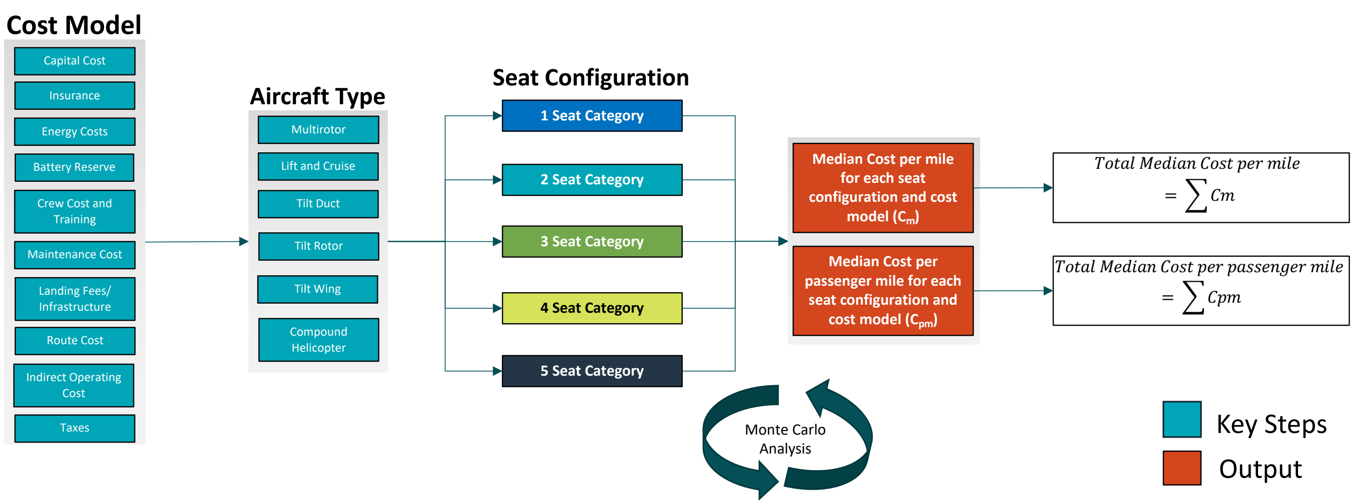
Parameter	Definition	Minimum	Maximum	Source
Seats	Number of seats in aircraft. First few years of operation assumes a pilot on-board, hence there is one seat less available to be occupied by a passenger	1	5	SAG Interviews[1] BAH Assumption[2]
Load Factor (%)	Refers to passenger load factor and measures the capacity utilization of eVTOL	50%	80%	
Utilization for 2+ seat aircraft (number of flight hours per year)	Average numbers of hours in a year that an aircraft is actually in flight. Conservative utilization numbers are used to take into account battery recharging/swapping times	1000	2000	
Utilization for 2-seat aircraft (number of flight hours per year)	For 2-seat aircraft (only one passenger seat), aircraft is only flown when the passenger seat is filled. Therefore, utilization range is adjusted by multiplying with load factor of 2+ seat aircraft i.e. 1000*50%, 2000*80%	500	1600	
Max Reserve (mins)	Minimum energy required to fly for a certain time (outside of mission time) at a specified altitude	20	30	Part 91 requirements[3]
Deadend Trips (%)	Ratio of non-revenue trips and total trips	25%	50%	BAH Assumption
Detour Factor (%)	Factor to represent actual flight distance above great circle distance	5%	15%	
Cruise Altitude (ft)	Cruise altitude for eVTOL	500	5000	NASA Study[4]

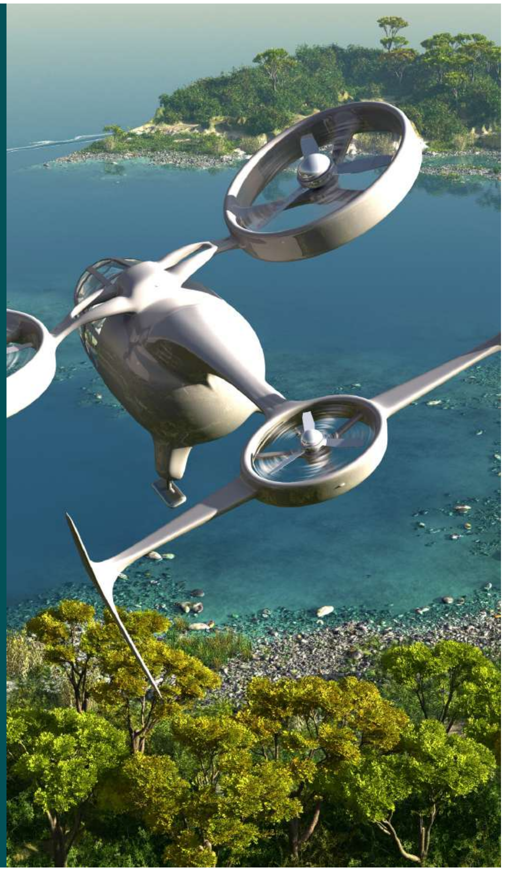
[1]BAH conducted interviews with SAG members in February/April 2018. Their feedback is documented in deliverable 'SAG Interview and Workshop summary'
[2]BAH assumption based on the literature review
[3]FAA. Details available at https://www.law.cornell.edu/cfr/text/14/91.167
[4]Patterson, M. A Proposed Approach to Studying Urban Air Mobility Missions Including an Initial Exploration of Mission Requirements, 2018

STRUCTURE OF COST MODELING

*Cost models are applied to six types of eVTOLs in **1-5 seat** configuration. In the first few years of operation, there is an on-board pilot to operate the aircraft. Pilot occupies one seat, therefore, each eVTOL has one less seat available for passengers. Hence, **1-seat aircraft** are assumed to be **unavailable**.*

*For a certain seat category, cost per passenger mile (or vehicle mile) is calculated for each aircraft type separately. A **median value** is then calculated from the cost numbers of all six aircraft type that represents cost per passenger mile (or vehicle mile) for that seat category.*

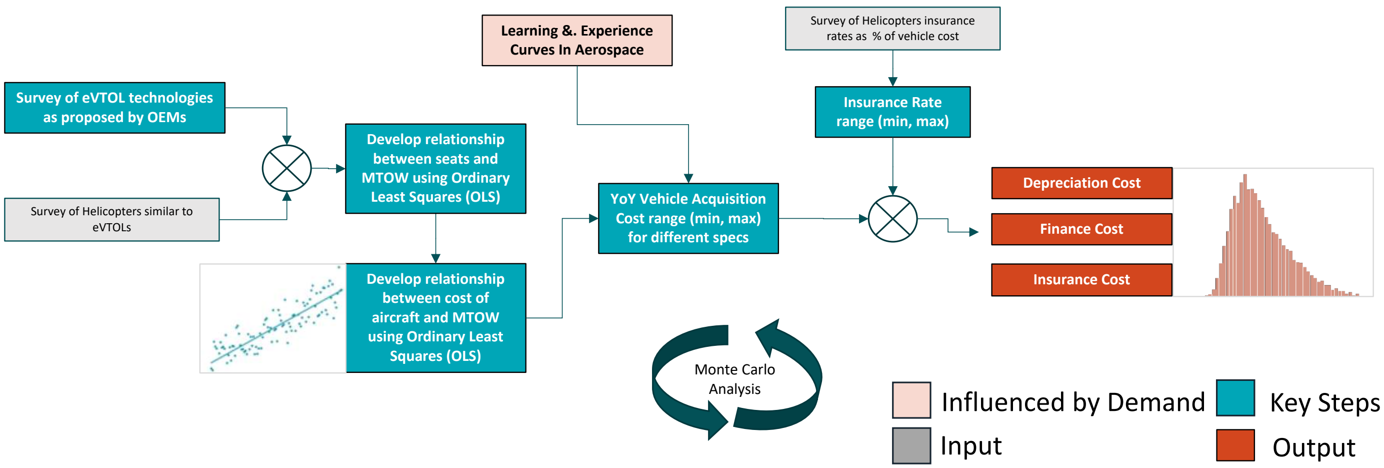




CAPITAL AND INSURANCE COST MODEL

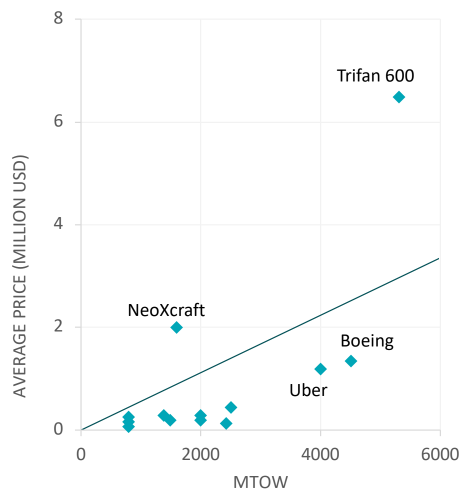
*There are 100+ aircraft designs proposed around the world to serve urban Air Taxi and Airport Shuttle market. Our analysis assumes that each of the aircraft type may need to be **priced similarly** to serve the same market.*

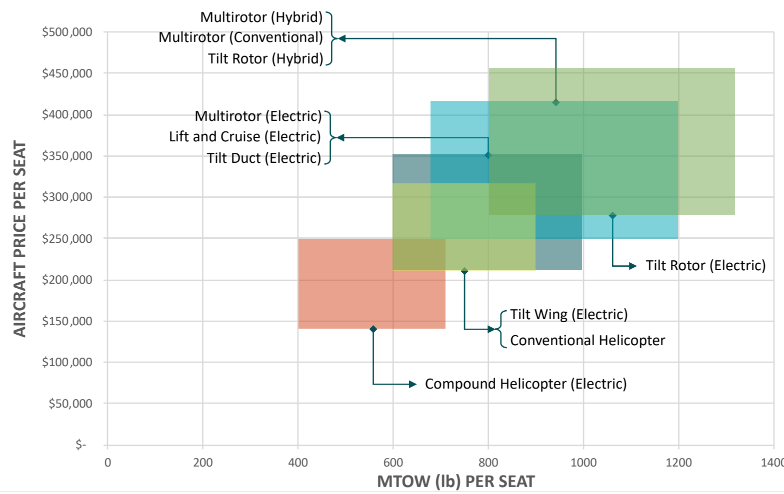
*We developed a relationship between aircraft price per seat and MTOW per seat through regression analysis of the available price data as shown in the previous slides. Our analysis assumes that **MTOW and aircraft price varies linearly** with the number of seats (as typically observed in commercial aviation)*



AIRCRAFT PRICE VARIES LINEARLY WITH WEIGHT OF THE AIRCRAFT

- Aircraft price per seat and MTOW per seat developed through **regression analysis** of the available data. Our analysis assumes that MTOW and Aircraft Price **varies linearly** with the number of seats (as typically observed in commercial aviation)
- Payload is expected to be 15-25% of aircraft weight which translates to 1000 lb per seat (assuming an average of 200 lb per passenger). However, we calculate MTOW for each aircraft class **using publicly available data sources** (Slide 172 describes our approach). Figure on the right shows MTOW range for each aircraft class used in this study.





Detailed price information can be found in literature review

Only electric aviation considered for further analysis

ASSUMPTIONS

Parameter	Min	Max	Source
Vehicle Life (flight hours)	12000	25000	SAG Interviews[1] Cirrus SR20 Cessna 350
Depreciation Rate (%)	5%	10%	BAH Assumption
Finance Rate (%)	5%	10%	BAH Assumption

[1]BAH conducted interviews with SAG members in February. Their feedback is documented in SAG document shared with the deliverable package

Results

CAPITAL COST PER PASSENGER MILE

- Capital Cost is the sum of depreciation cost (given by 1) and finance cost (given by 2). Certification costs are included in aircraft price
- **Life time** of the aircraft in years is calculated as the ratio of Vehicle Life (flight hours) and Utilization (hours per year)
- **Residual value** of the aircraft is assumed to be **negligible** since aircraft's value depreciates at rate of ~5-10% in its life time

$$Depreciation\ Cost = Aircraft\ price \times \left(1 - e^{-depreciation\ rate}\right) ---(1)$$

$$Finance\ Cost = Aircraft\ price \times finance\ rate \times \frac{(1 + monthly\ finance\ rate)^{12 \times Loan\ Term}}{(1 + monthly\ finance\ rate)^{12 \times Loan\ Term - 1}} ---(2)$$

where,

$$monthly\ finance\ rate = \frac{finance\ rate}{12}$$

Aircraft Type	Median Capital Cost per passenger mile	Median Capital Cost per vehicle mile
2 Seat Aircraft	**$ 1.87**	**$ 1.87**
3 Seat Aircraft	**$ 1.65**	**$ 2.10**
4 Seat Aircraft	**$ 1.47**	**$ 2.80**
5 Seat Aircraft	**$ 1.38**	**$ 3.50**

Results

INSURANCE COST PER PASSENGER MILE

- Analysis assumes that the **operator** would be **required to have full insurance** as typically observed in commercial aviation industry.
- Calculation of insurance cost of an aircraft is **subjective in nature** as it depends on 6-12 months of recent aviation history. Therefore, this analysis relies on **historical insurance cost of helicopters** as a percent of vehicle price.
- Aircraft insurance is a sum of liability[1] and hull[2] insurance for the base year. Age adjustment will be added for future year projections.
- Liability insurance covers both public and private liabilities while hull insurance covers both in-motion and not-in-motion cases. Insurance cost does not include infrastructure/facilities insurance (bundled under indirect operating cost).

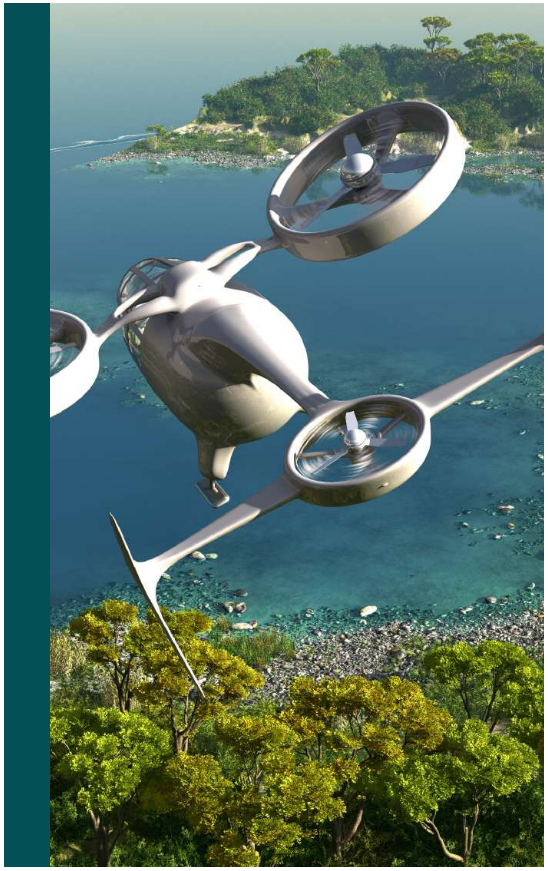
Helicopter	Insurance as a % of aircraft price	
Robinson R22	2.60%	
Robinson R44_1	2.67%	
Robinson R44_2	2.47%	
Robinson R66	2.30%	MIN
Bell 427	3.28%	
Bell 206L3	2.36%	
Agusta Westland 109 Grand New	2.39%	
Agusta Westland 119 Koala	2.78%	
Airbus H120/Eurocopter EC 120B	3.93%	MAX

Source: Aircraft Cost Calculator (2015), Robinson Helicopter Company (2018)

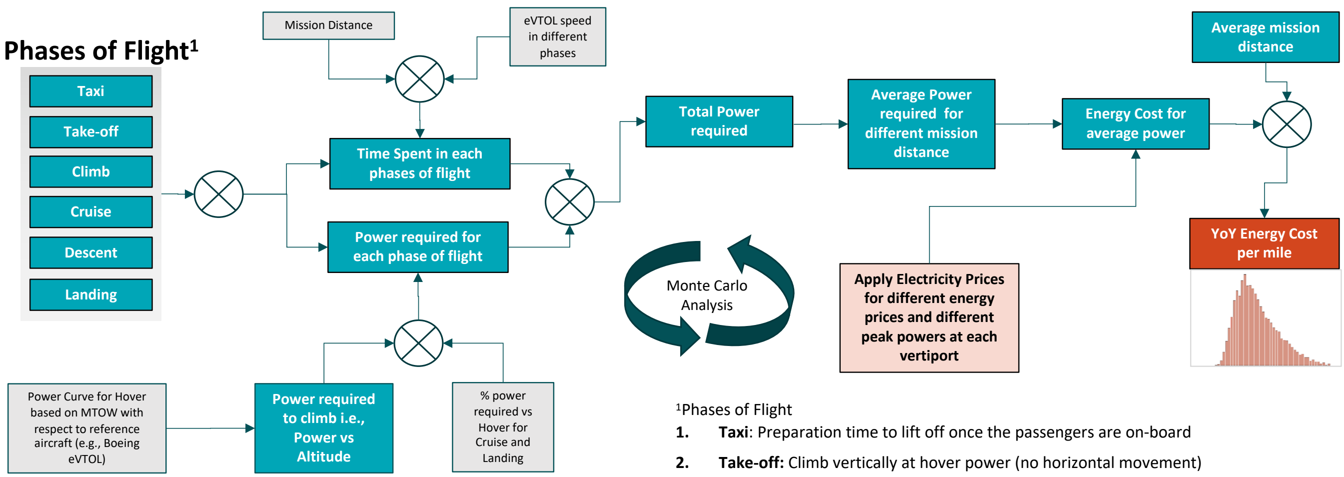
Aircraft Type	Median Insurance Cost per passenger mile	Median Insurance Cost per vehicle mile
2 Seat Aircraft	**$ 0.32**	**$ 0.32**
3 Seat Aircraft	**$ 0.26**	**$ 0.30**
4 Seat Aircraft	**$ 0.22**	**$ 0.39**
5 Seat Aircraft	**$ 0.21**	**$ 0.47**

[1] Liability Insurance
- **Passenger:** Protects passengers riding in the accident aircraft who are injured or killed
- **Public Related:** Protects aircraft owners for damage that their aircraft does to third party property, such as houses, cars, crops, airport facilities and other aircraft struck in a collision

[2] Hull Insurance
- **Not-in-motion:** Provides coverage for the insured aircraft against damage when it is on the ground and not in motion
- **In-motion:** Protects an insured aircraft against damage during all phases of flight and ground operation



ENERGY COSTS FOR ELECTRIC VTOLs



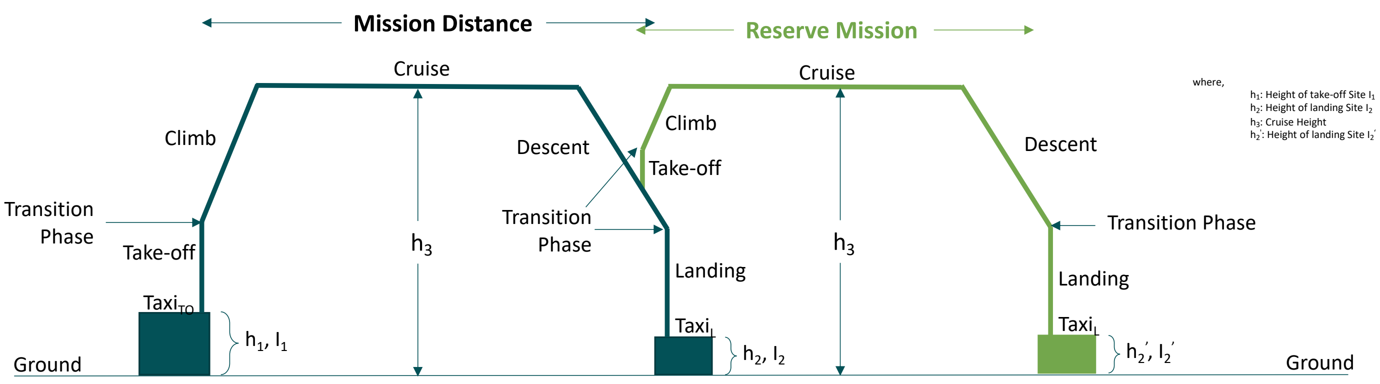
[1]Phases of Flight

1. **Taxi**: Preparation time to lift off once the passengers are on-board
2. **Take-off:** Climb vertically at hover power (no horizontal movement)
3. **Climb:** Climb to cruise height
4. **Cruise:** Flight phase that occurs when the aircraft levels after a climb to a cruise altitude and before it begins to descend
5. **Descent:** Aircraft begins approach to final landing. Has both horizontal and vertical component
6. **Landing:** Vertical landing at hover power (no horizontal movement)

Influenced by Demand | Key Steps
Input | Output

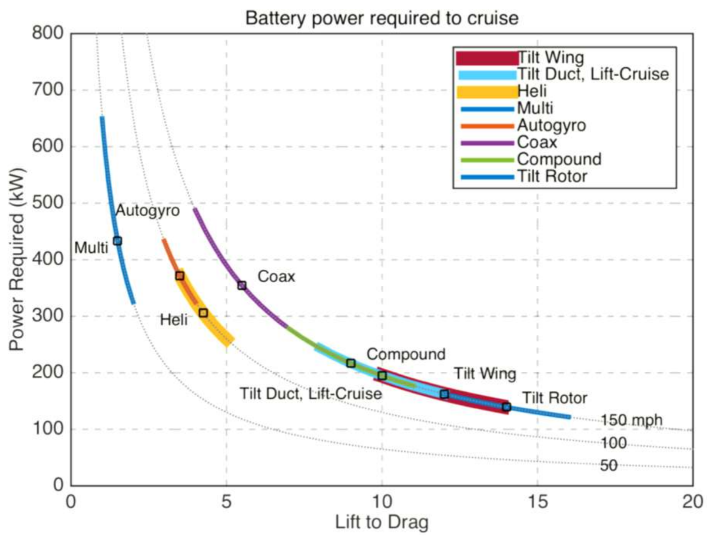
FULL DESIGN MISSION INCLUDING RESERVE PROFILE

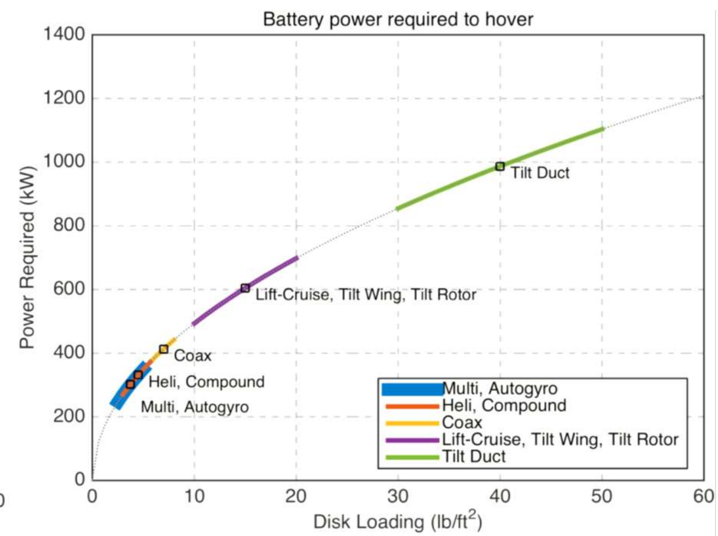
- Each eVTOL mission has **six main phases of flight:** taxi, take-off, climb, cruise, descent and landing.
- Reserve mission kicks off during the **descent phase** and follows a similar profile as original mission i.e. take-off (or hover climb), climb, cruise (at cruise altitude and cruise speed), descent, landing and taxi (landing).
- An additional **transition phase** (vertical to horizontal flight) is added between take-off and climb phase for tilt rotor, tilt wing and tilt duct type of aircraft. There is **no horizontal movement** considered during transition phase
- Aircraft can **loiter** and land at original destination (l_2) or **travel to another landing area** (l_2’). However, **in demand analysis** conops, we assume that the aircraft **lands at it’s original destination** (captured under delay time at vertiport)



HOVER AND CRUISE POWER REQUIREMENT FOR DIFFERENT AIRCRAFT TYPE

- Different aircraft have different battery power requirements. This analysis utilizes research performed by McDonald and German for aircraft with maximum take-off weight of **5000 lb** at mean sea level and standard temperature/pressure conditions. Power requirements specific to different MTOW is calculated in the next slide.





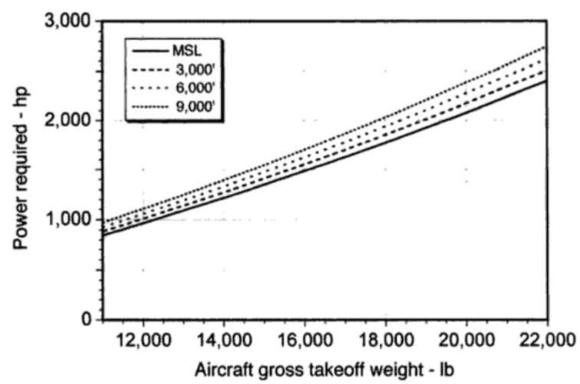
Source: McDonald, R et al. eVTOL Stored Energy Overview

POWER REQUIREMENT VARIES FOR DIFFERENT AIRCRAFT TYPES IN CERTAIN WEATHER CONDITIONS

Power required vs MTOW

- Hover and cruise power required is a **function of aircraft maximum take-off weight (W) and ambient density (ρ)** as shown in equation (1). Power values for aircraft at 5000 lb from previous slide is considered as reference aircraft.

$$P_{hover} \propto \frac{W^1}{\rho^{\frac{1}{2}}} \qquad (1)$$

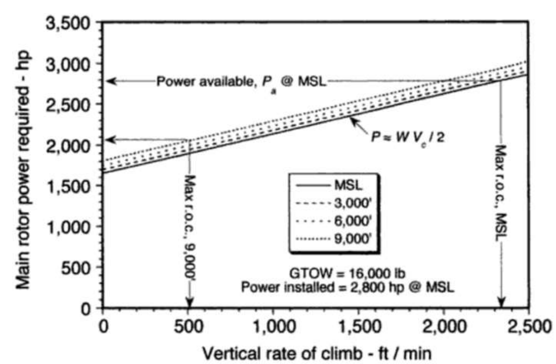


Source: Lieshman, G. Aerodynamics of Helicopters, 2002

Power required to climb vs Speed

- At low or moderate vertical rate of climb, power required to climb at the **cruise altitude is proportional to take-off speed (climb speed, V_c)** and MTOW as shown in equation (2). This analysis assume a standard rate of climb of **500 ft/min**

$$P_{climb} \propto WV \qquad (2)$$

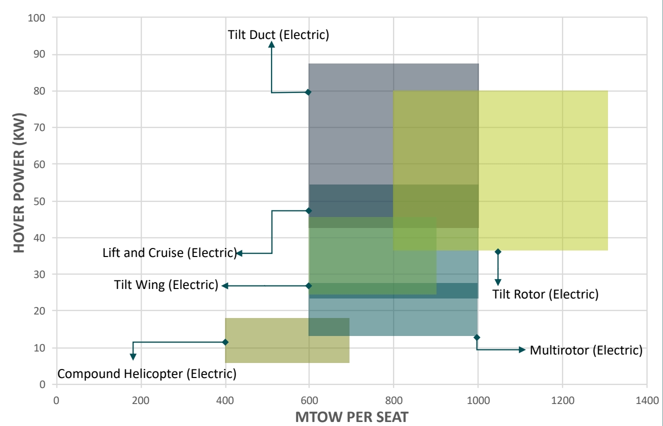


Source: Lieshman, G. Aerodynamics of Helicopters, 2002

ADJUSTED HOVER AND CRUISE POWER REQUIREMENT FOR DIFFERENT AIRCRAFT TYPE

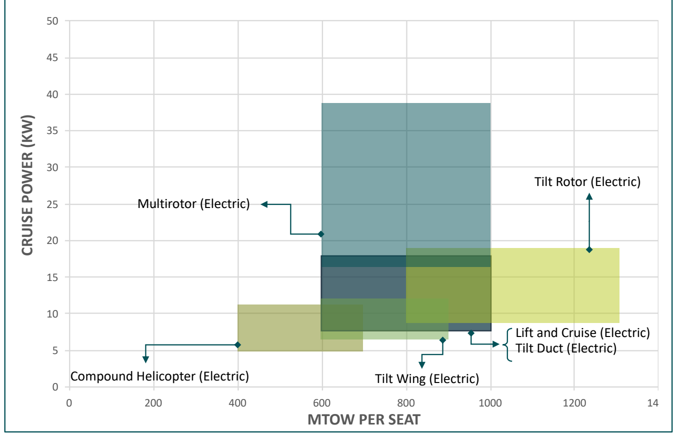
Hover Power required vs MTOW

- **Tilt Duct aircraft** have a **higher hover power requirement** due to high disk loading as compared to aircraft with MTOW.



Cruise Power required vs MTOW

- **Multirotor** aircraft have a **significantly higher cruise power range requirement** due to low lift-drag ratio as compared to aircraft with similar MTOW.



ASSUMPTIONS

Parameter	Min	Max	Source
Height of landing and take-off sites (ft)	0	200	BAH Assumption
Climb/Descent Distance (miles)	1	2	MIT Study, BAH Assumption
LTO Height (ft)	100	200	
LTO Time (sec)	10	20	
Embarkation time (mins)	3	5	
Disembarkation time (mins)	2	3	
Transition Time (sec)	15	30	BAH Assumption
Power required in descent (as % of P_{hover})	10%	15%	Boeing Study[1] Uber Elevate[2] Lieshman, 2002[3]
Power required in Taxi (as % of P_{hover})	5%	10%	BAH Assumption
Power required in Climb (% of cruise)	130%	150%	BAH Assumption
Energy Conversion efficiency (%)	90%	98%	Georgia Tech Study[4]
Electricity Price ($/kwh)	0.1	0.3	BAH Assumption

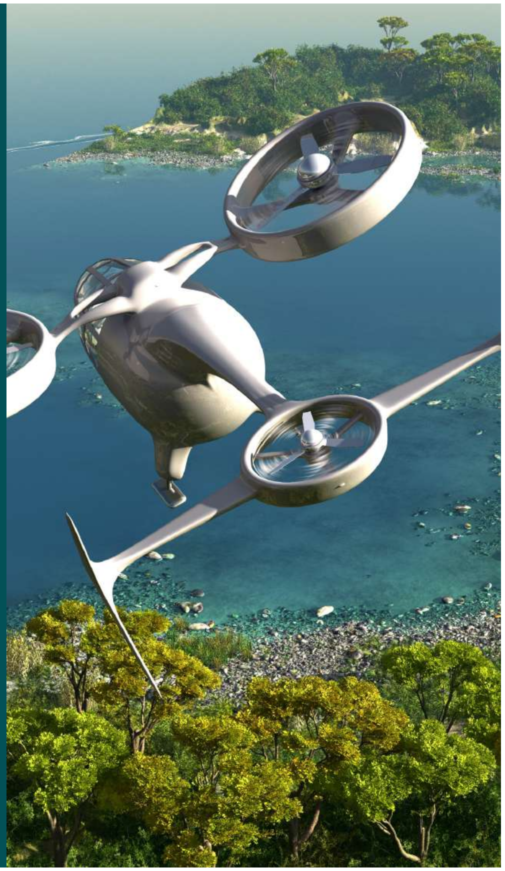
[1]*Fast-Forwarding to a Future of On-Demand Urban Air Transportation, Uber Elevate, October 2017*
[2]*Duffy, M. A Study in Reducing the Cost of Vertical Flight with Electric Propulsion. AHS, 2017*
[3]*Lieshman, G. Aerodynamics of Helicopters, 2002*
[4]*Harish, A. Economics of Advanced Thin-Haul Concepts and Operations. AIAA, 2016*

Results

ENERGY COST PER PASSENGER MILE

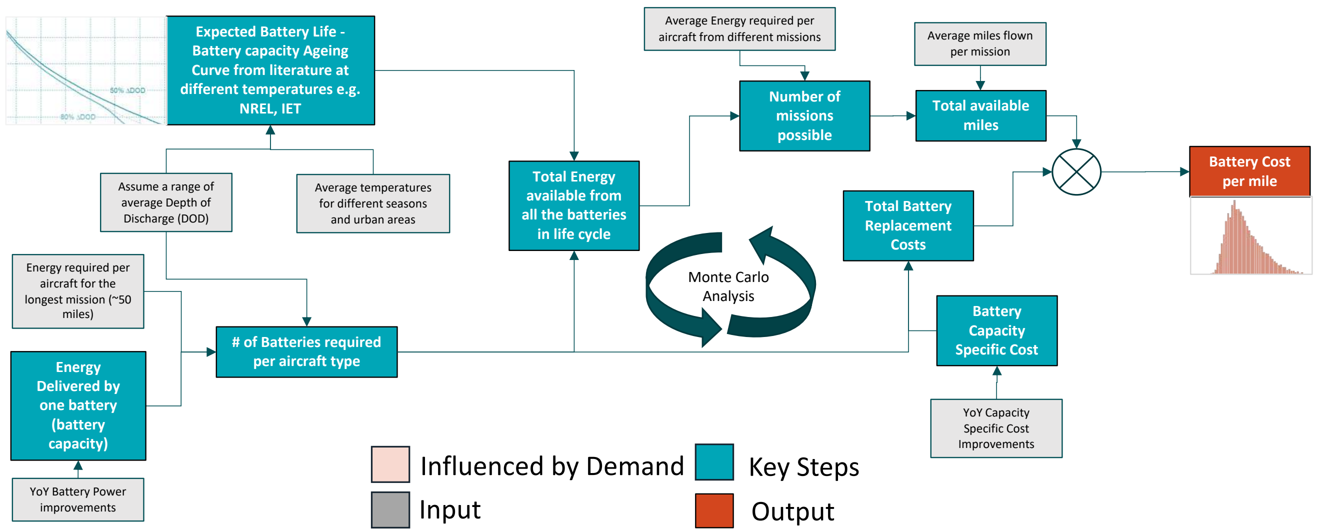
- **Power required for larger aircraft** (i.e. more seats) is **higher**[1], and therefore an increase in cost per vehicle mile.
- Energy cost **per passenger mile** for more than 2-seat aircraft is **similar** since power requirement is directly proportional to MTOW (which is based on number of seats).
- Power requirement is **inversely proportional to square root of ambient air density**. Therefore, lighter air (due to warm temperature conditions or higher altitude) requires more power to complete a mission (hence extra cost).
- Current calculations are **based on standard day at mean sea level**. Effect of weather is explored later in the analysis.

Aircraft Type	Median Energy Cost per passenger mile	Median Energy Cost per vehicle mile
2 Seat Aircraft	**$ 0.24**	**$ 0.24**
3 Seat Aircraft	**$ 0.24**	**$ 0.35**
4 Seat Aircraft	**$ 0.21**	**$ 0.47**
5 Seat Aircraft	**$ 0.20**	**$ 0.59**



BATTERY RESERVE COSTS FOR ELECTRIC VTOLs

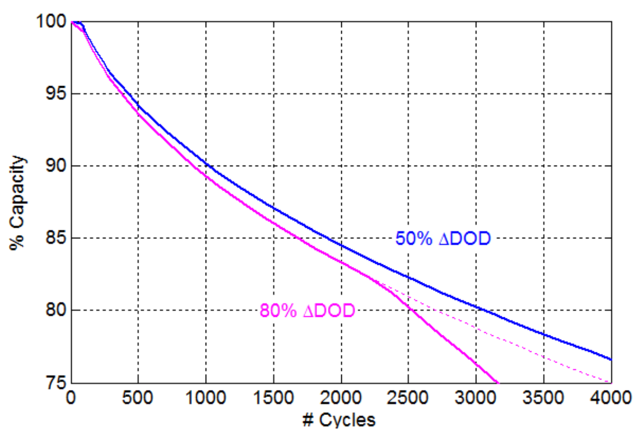
Our analysis sizes the battery pack ***based on the longest mission*** *assumption for the urban air taxi market. For supply side model only, we assume a standard day operating conditions. However, we integrate effects of wind speed, direction and temperature conditions later in the analysis. We also assume that batteries have negligible residual value*



BATTERY LIFE CYCLE AND CAPACITY DEPENDENCIES

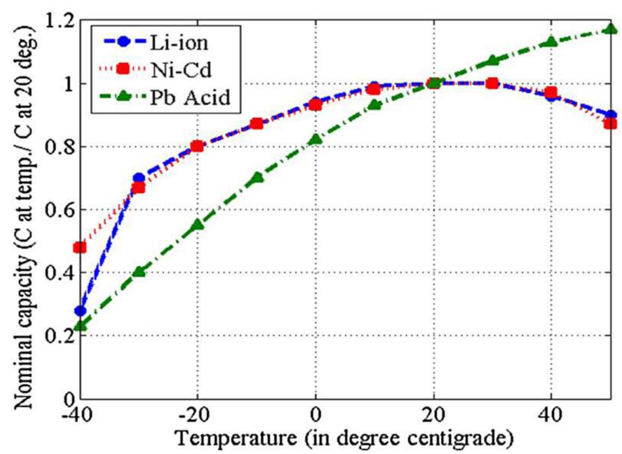
- *Battery life cycle of a Li ion battery directly depends on the depth of discharge (DOD). Increasing DOD decreases battery life. Generalized relationship is shown below:*

$$Life\ Cycle = -1666.7 * Depth\_of\_Discharge + 3833.3$$



Source: National Renewable Energy Laboratory, 2014

- *Capacity of Li-ion battery decreases at low temperatures since the total resistance (sum of bulk, surface layer and charge-transfer resistance layer) increases*
- *Resistance becomes the most dominant as the temperature goes to below −10°C*



Source: The Institution of Engineering and Technology, 2016

Results

ASSUMPTIONS

Parameter	Min	Max	Source
Battery Specific Energy in Wh/kg	300	400	Boeing Study[1]
Battery Capacity Specific Cost ($/kwh)	200	250	Nykvist et al[2]
Depth of Discharge (%)	50%	80%	Georgia Tech Study[3]

[1]*Duffy, M. A Study in Reducing the Cost of Vertical Flight with Electric Propulsion. AHS, 2017*

[2]*Nykvist, B. and Nilsson, M., "Rapidly falling costs of battery packs for electric vehicles," Nature Climate Change, Vol. 5, No. 4, 2015*

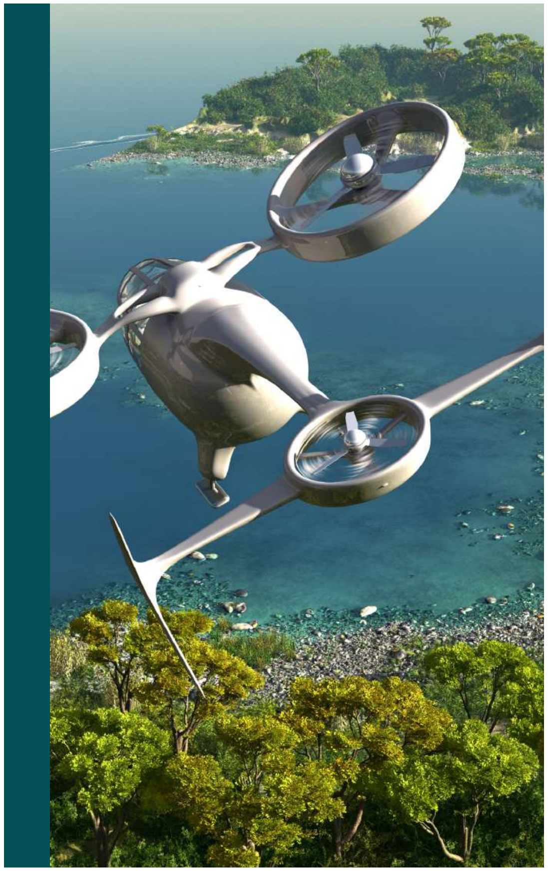
[3]*Harish, A. Economics of Advanced Thin-Haul Concepts and Operations. AIAA, 2016*

BATTERY RESERVE COST PER PASSENGER MILE

- Battery[1] cost **increases** as the **size of the vehicle increase** (due to increase in energy requirement). However, battery reserve cost per passenger mile is **similar** for different types of aircraft.
- **Battery specific energy reduces at extreme temperature** conditions, and therefore larger battery size is required which increases the cost.
- Low temperatures have a higher effect on cost in comparison to high temperatures.
- We use Li-ion batteries in this study. Our analysis assumes **negligible battery recycling** since only 3-5% of a lithium battery can be recycled i.e. original amount of lithium by weight in the batteries

	Median Battery Reserve Cost per passenger mile			Median Battery Reserve Cost per vehicle mile at 20° C
Aircraft Type	20° C	-10° C	50° C	
2 Seat Aircraft	**$ 0.12**	**$ 0.14**	**$ 0.13**	**$ 0.12**
3 Seat Aircraft	**$ 0.17**	**$ 0.19**	**$ 0.18**	**$ 0.23**
4 Seat Aircraft	**$ 0.18**	**$ 0.20**	**$ 0.19**	**$ 0.36**
5 Seat Aircraft	**$ 0.19**	**$ 0.21**	**$ 0.20**	**$ 0.49**

[1]This analysis assumes batteries are recharged by fast chargers as soon as aircraft reach the vertiport with no consideration given to the number of chargers needed or the price of electricity. Various optimization and battery swapping capabilities have been proposed in literature (like Justin et al Georgia Tech), which may reduce the battery requirements.



Overall Analysis Framework

Supply Side Modeling

- Overall Methodology
- Capital and Insurance Cost Model
- Energy Cost Model
- Battery Cost Model
- Crew Cost Model
- Infrastructure Cost Model
- Other Cost Models
- Results and Discussions

Weather Related Adjustments

Demand Side Modeling

Airspace Constraints

Environmental Impact

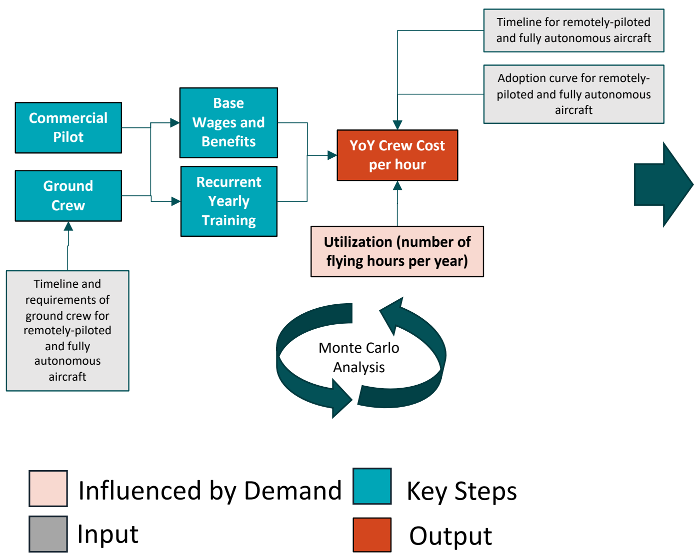
Total Demand Projection for US

Scenario Analysis

Next Steps

CREW COSTS PER PASSENGER MILE

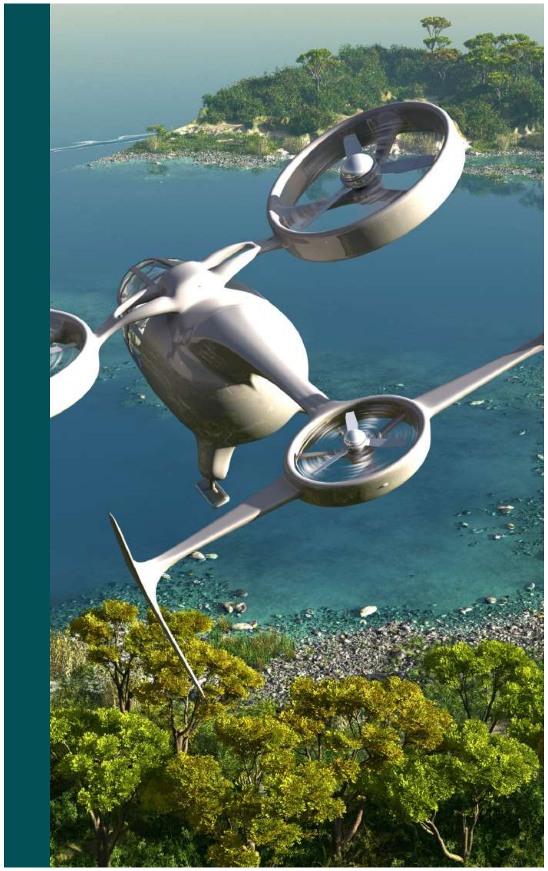
We assume one full time equivalent pilot per aircraft and one full time equivalent ground crew member in the first few years of the analysis. We assume that the ground crew is expected to serve multiple roles including passenger check-in, security check and any other customer related service.



Monte Carlo Assumptions	Min	Max	Source
Pilot Salary per year (US $)	50, 000	90, 000	Uber Elevate[1], US BLS Helicopter Pilot Salary[2]
Ground Crew Salary per year (US $)	20, 000	30, 000	
Pilot training cost per year (US $)	10, 000	20, 000	
Ground Crew training cost per year (US $)	5, 000	10, 000	

Aircraft Type	Median Crew Cost per passenger mile	Median Crew Cost per vehicle mile
2 Seat Aircraft	**$ 2.03**	**$ 2.03**
3 Seat Aircraft	**$ 1.13**	**$ 1.50**
4 Seat Aircraft	**$ 0.75**	**$ 1.50**
5 Seat Aircraft	**$ 0.56**	**$ 1.50**

[1]Uber Elevate white paper available at https://www.uber.com/elevate.pdf
[2]US Department Bureau of Labor Statistics, https://www.bls.gov/



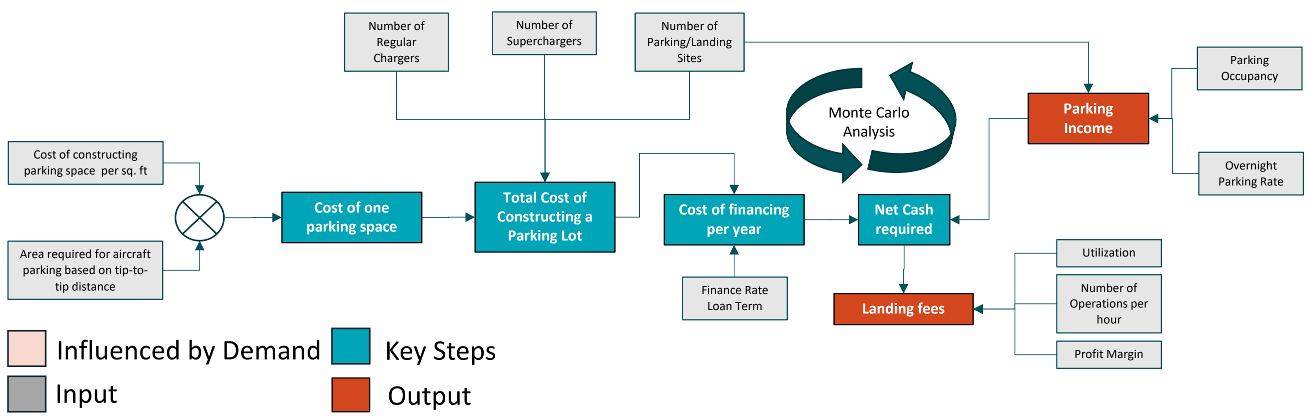
INFRASTRUCTURE COST MODEL

*Our first order infrastructure model assumes **car parking garage style architecture** and construction with a certain number of parking sites. Our assumption is based on the market's interest to use a **multi-purpose garage** (like top of garage roof) for operating air taxis in the near term. However, there are number of terminal type designs proposed by OEMs, which are expected to have higher cost.*

***Step 1:** We retrieve cost of constructing a parking space from literature, adjusted by area required for aircraft size. Depending on the number of chargers and parking sites, **total cost** of building is calculated (financed over a certain amortization period).*

***Step 2:** Each parking garage is expected to have **yearly parking income** from overnight parking of Air Taxis.*

***Step 3:** The net cash required (yearly cost of building – yearly parking income) is divided by utilization and number of operations per hour to calculate landing fees per hour (which is further divided by trip speed to calculate landing fees per mile)*



Results

ASSUMPTIONS

Parameter	Min	Max	Source
Tip-to-Tip length of aircraft (m)	5	15	BAH Assumption
Number of Parking/Landing Spots	1	12	BAH Assumption
Number of Superchargers (% of landing spots)	0%	30%	BAH Assumption
Number of regular chargers (% of landing spots)	0%	50%	BAH Assumption
Cost of one supercharger (US $)	200, 000	300, 000	Uber Elevate[1]
Cost of regular charger (US $)	10, 000	15, 000	Uber Elevate
Indirect Costs (% of total cost)	15%	25%	BAH Assumption
Overnight parking costs (US $)	50	75	BAH Assumption
Parking Occupancy Rate (%)	50%	100%	BAH Assumption

[1]*Fast-Forwarding to a Future of On-Demand Urban Air Transportation, Uber Elevate, October 2017*

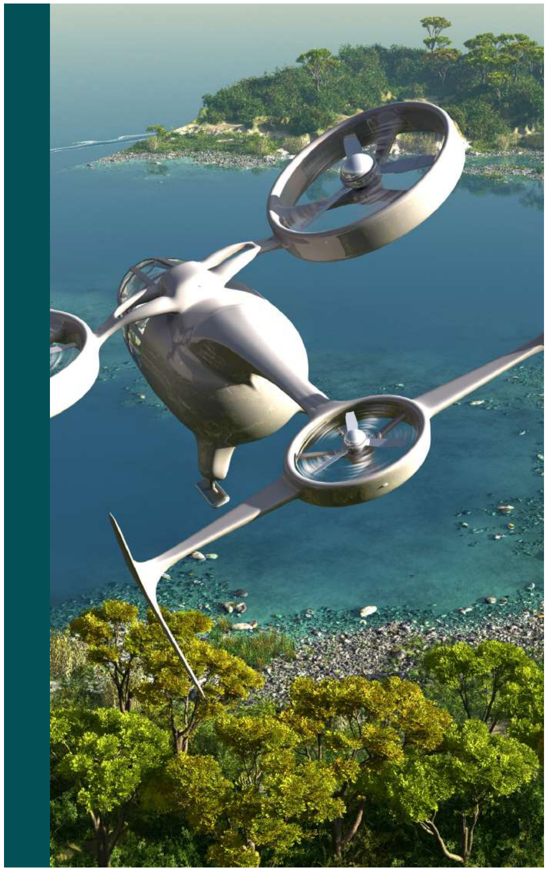
INFRASTRUCTURE COST PER PASSENGER MILE

- On average, the **cost to build one parking spot** (in a car parking garage style) will cost approximately **~ $15,000** without including any type of charger. This cost varies by real estate prices of an urban area. Our analysis assumes an average of ~$60/ft² across urban area.

- In comparison, **other studies have reported higher infrastructure cost per passenger mile** (e.g. Uber Elevate reported over $1.5 per passenger mile during the 2018 Uber Elevate Summit). Higher cost is likely due to the power line installation costs and terminal design of the infrastructure that includes extra amenities like lounge areas, shopping, cafés etc.

Aircraft Type	Median infrastructure Cost per passenger mile	Median infrastructure Cost per vehicle mile
2 Seat Aircraft	**$ 0.53**	**$ 0.53**
3 Seat Aircraft	**$ 0.38**	**$ 0.53**
4 Seat Aircraft	**$ 0.25**	**$ 0.53**
5 Seat Aircraft	**$ 0.19**	**$ 0.53**

- Infrastructure designs may be influenced by community noise signatures, public acceptance, capacity requirements (influenced by demand), airspace constraints, routing, power grid capacity etc.



Results

ASSUMPTIONS

Parameter	Min	Max	Source
Mechanic Wrap Rate ($ per hour)	$60	$100	MIT Study[1]
Maintenance man-hours per flight hour (MMH/FH)	0.25	1	
Mechanic Wrap Rate ($ per hour)	$60	$100	

[1]Brown, A. A Vehicle Design and Optimization Model for On-Demand Aviation, 2018

MAINTENANCE COST MODEL

- Maintenance cost per mission is calculated using the following equation

$$Maintenance\ Cost = Mechanic\ Wrap\ Rate \times \frac{MMH}{FH} \times t_{mission}$$

where,

Mechanic Wrap rate is the hourly rate of mechanic

MMH/FH : Ratio of maintenance man hours to flight hours

$t_{mission}$ is the average mission time for range of mission distances (including time spent on the ground)

- Our analysis assumes **similar maintenance cost** for different size of aircraft (usually, maintenance cost is higher for larger aircraft)

Aircraft Type	Median Maintenance Cost per passenger mile	Median Maintenance Cost per vehicle mile
2 Seat Aircraft	**$ 1.88**	**$ 1.88**
3 Seat Aircraft	**$ 1.45**	**$ 1.88**
4 Seat Aircraft	**$ 0.97**	**$ 1.88**
5 Seat Aircraft	**$ 0.72**	**$ 1.88**

Results

ROUTE COST

- Route cost in commercial aviation refers to **fees paid to air traffic control** while crossing their managed airspace. In urban air mobility, this fees may be collected at administrative zone level.
- The route charge is usually calculated using three basic elements:
  - **Distance factor** (for each charging zone) i.e., distance flown in a particular zone
  - **Aircraft weight**
  - **Unit rate of charge** (for each charging zone)
- For this analysis , we obtained historical route cost per seat per mile for commercial business jets flown in United States to develop the minimum and maximum range as shown in table below.

Business jet Type	Route cost per seat per mile	
Very Light Business Jet	0.0079	MIN
Light Business Jet	0.0081	
Corporate Business Jet	0.0162	MAX

Source: Bureau of Transportation Statistics, 2018 ; OAG, 2018

Aircraft Type	Median Route Cost per passenger mile	Median Route Cost per vehicle mile
2 Seat Aircraft	**$ 0.04**	**$ 0.04**
3 Seat Aircraft	**$ 0.05**	**$ 0.06**
4 Seat Aircraft	**$ 0.04**	**$ 0.08**
5 Seat Aircraft	**$ 0.04**	**$ 0.10**

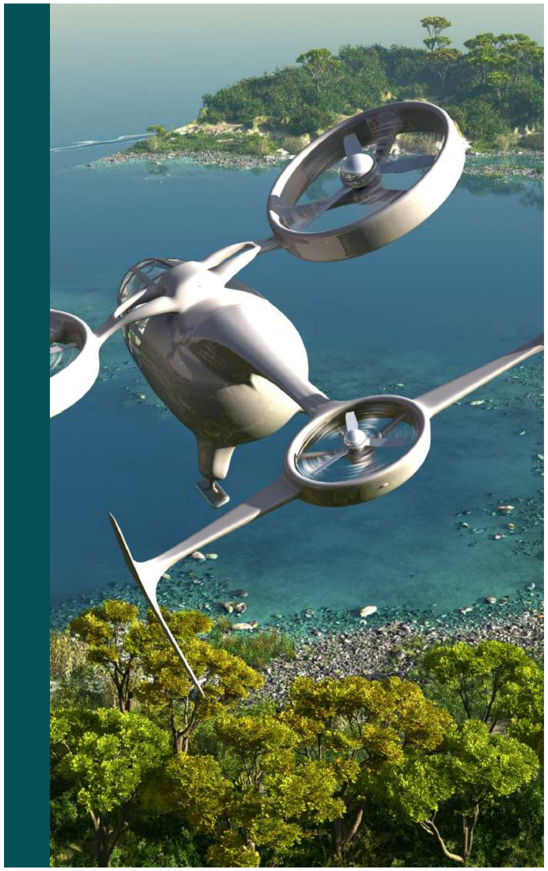
Results

INDIRECT OPERATING COST

- Commercial aviation industry reports approximately **10-30%** in indirect costs associated with operations. (Source: ICAO, Form 41, Boeing Forecasts, MIT Airline Project)
- Since operations of urban Air Taxis and Airport Shuttles are expected to be similar to commercial aviation, our analysis adopts similar percentages for indirect cost calculations. Part of these costs (like reservation, ticketing cost etc.) may be irrelevant for UATs.

NON-EXHAUSTIVE

			Passenger price per mile / Per vehicle mile			
Indirect Cost Component	Min	Max	2 Seat Aircraft	3 Seat Aircraft	4 Seat Aircraft	5 Seat Aircraft
1. **Reservation Cost** – Need to arrange booking and connect passengers with vehicles 2. **Ticketing Costs** – Administrative costs to ensure that passengers can fly 3. **Credit Card Processing Fees** – Recently upheld by the Supreme Court, credit card companies charge merchants for using their cards 4. **Marketing –** "If you don't keep giving customers reasons to buy from you, they won't." – Sergio Zyman, former head of marketing at Coca Cola 5. **Building –** Need a place for vehicles to land and take off 6. **Hangar –** Need a place to store and repair/maintain vehicles	10%	30%	$1.74 / $1.74	$1.29 / $1.40	$1.02 / $1.68	$0.88 / $2.00



Overall Analysis Framework

Supply Side Modeling

- Overall Methodology
- Capital and Insurance Cost Model
- Energy Cost Model
- Battery Cost Model
- Crew Cost Model
- Infrastructure Cost Model
- Other Cost Models
- Results and Discussions

Weather Related Adjustments

Demand Side Modeling

Airspace Constraints

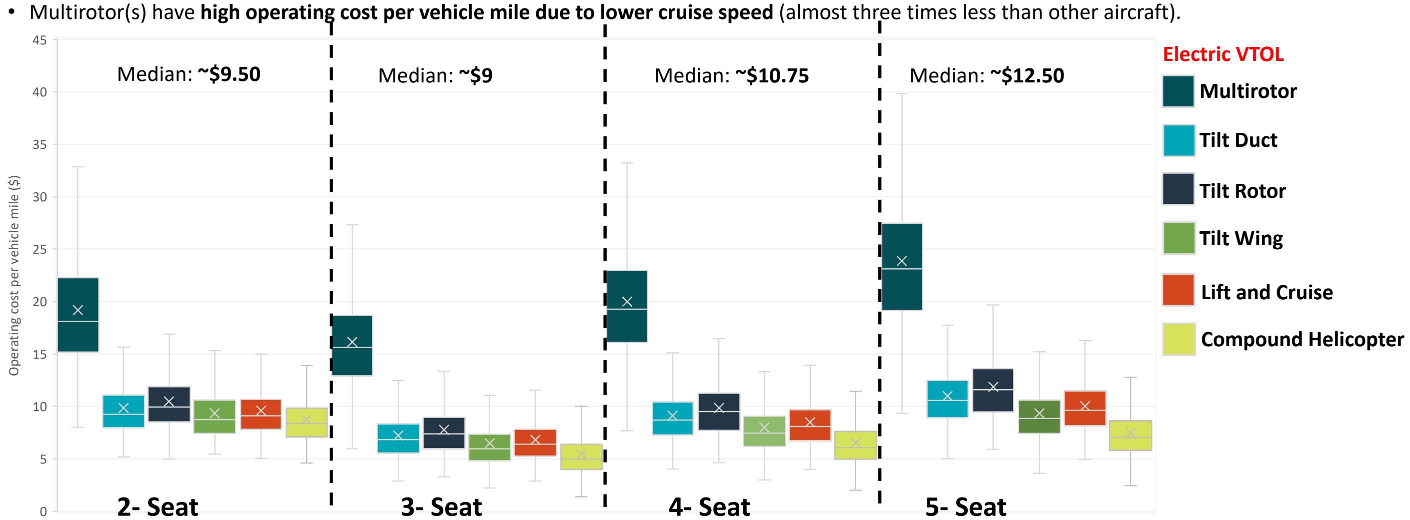
Environmental Impact

Total Demand Projection for US

Scenario Analysis

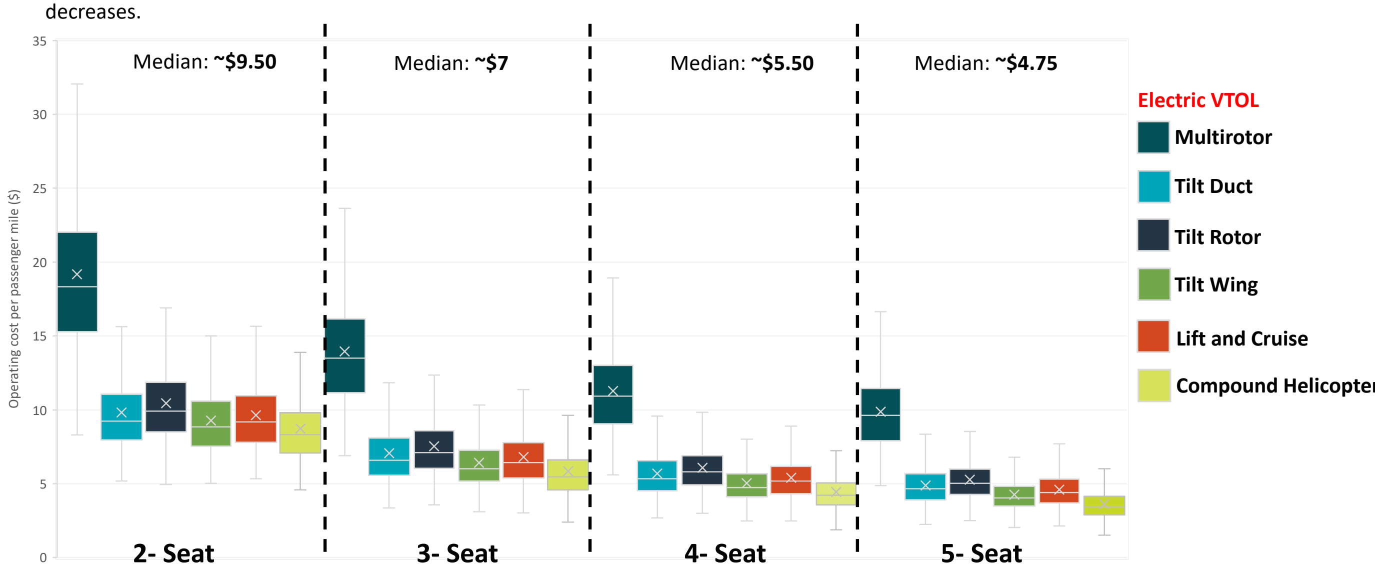
OPERATING COST PER VEHICLE MILE FOR eVTOL

- Monte Carlo Analysis was conducted on each of the items shown in the previous sections to understand the impact and uncertainty associated with the assumptions made in the supply model. 10,000 iterations were conducted.
- The median **operating cost per vehicle mile increases as the size of vehicle increases** (i.e. number of seats increases).
- Multirotor(s) have **high operating cost per vehicle mile due to lower cruise speed** (almost three times less than other aircraft).



OPERATING COST PER PASSENGER MILE FOR eVTOL

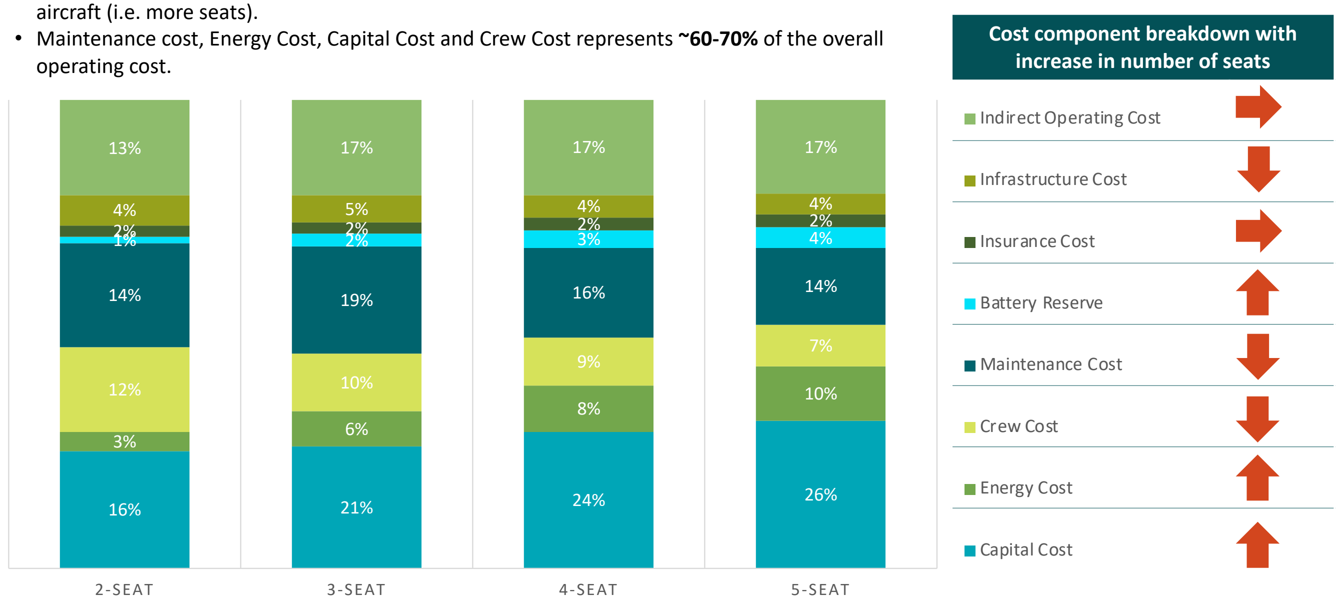
- The median **operating cost per passenger mile decreases as the number of seats increases** because of economies of scale for maintenance costs, indirect operating costs, and capital costs. Therefore, while the total cost per vehicle mile increases, the cost per passenger mile decreases.



Results

OPERATING COST BREAKDOWN (PER PASSENGER MILE)

- Energy and Battery Cost breakdown increases while other cost component decreases for larger aircraft (i.e. more seats).
- Maintenance cost, Energy Cost, Capital Cost and Crew Cost represents **~60-70%** of the overall operating cost.



PRICING MODEL

Air taxi and Airport Shuttle operators can use a variety of pricing strategies when selling taxi services. However, the team expects taxi operators to first ***price their services based on buyer's perceived value*** *of the service followed by bundle pricing and other cost based methods. We expect operators to pursue competition based pricing in the longer term to compete with the strong competition within the industry and from other modes of transportation.*

Near-term

1. **Cost Based Pricing Strategy:** This analysis is based on Cost Based pricing strategy. Under this approach, the direct material cost, direct labor cost, and overhead costs for the taxi are added up and a profit margin is assumed in order to derive the price of the product.
2. **Premium pricing (Perceived high value):** Air Taxi service may be viewed as a service of high value and its likely that taxi operators will sell their services at a premium price to encourage favorable perceptions among buyers and also to generate extra revenue to recover R&D costs

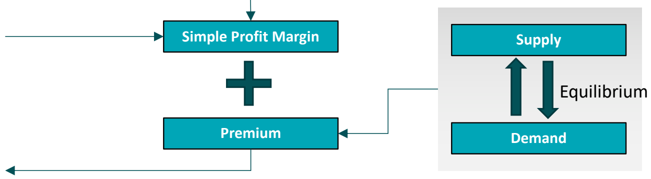
Mid-term

3. **Bundle/Subsidized Premium Pricing:** Travel (i.e., airlines) and hospitality industry (market enablers) may combine the price of taxi trip with their tickets to enhance experience of their most premium passengers. It is also likely that the market enablers may subsidize price of the taxi service to as an offer to their premium customers

Long-term

4. **Competition Based:** The team expects operators to follow competition based pricing in the long term due to price pressures from other service providers and substitute modes of transportation

Assumption	Min	Max
Profit Margin (%)	10%	30%



Aircraft Type	Median profit per passenger mile	Median profit per vehicle mile
2 Seat Aircraft	**$ 1.70**	**$ 1.60**
3 Seat Aircraft	**$ 1.28**	**$ 1.80**
4 Seat Aircraft	**$ 0.99**	**$ 2.15**
5 Seat Aircraft	**$ 0.85**	**$ 2.53**

TAXES AND FEES

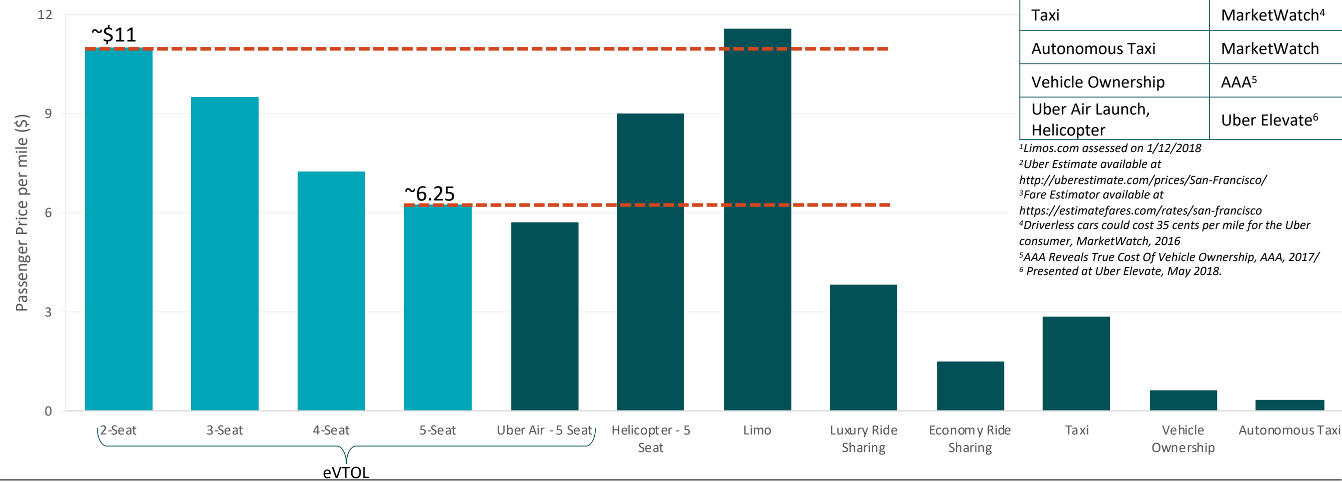
Urban Air taxis may be charged similar taxes and fees like on demand taxis or ride sharing services. The list below shows possible tax codes (not exhaustive) that may be levied on UATs.

			Passenger price per mile / Per vehicle mile			
Type of Tax	Min	Max	2 Seat Aircraft	3 Seat Aircraft	4 Seat Aircraft	5 Seat Aircraft
1. **Sales tax** – Charged by state at the point of purchase 2. **Commercial Motor Tax** – Charged by municipalities on vehicles for business use 3. **Workers Compensation Fund** – May be for pilots' union or manufacturers 4. **Surcharge for Public Transportation** – Municipalities are beginning to charge rideshare taxes to pay for public transit (Following Chicago's example, DC is trying to increase tax from 1% from 4.5%) 5. **Surcharge for Accessibility** – Introduced in New York, charges all riders to provide funds to make vehicles accessible to the disabled 6. **Licensing Fees** – For technology (i.e. batteries or engines) or trademarks (i.e. brand names) 7. **Recall Charges** – As needed in case of flawed equipment 8. **Inspection Fees** - Needed to pay for certification 9. **Environment Tax** - Depends on location, may include carbon offset fees 10. **Local/State property tax –** Depends on location, may be charged to vertiport owners	5%	15%	\$1.24 / \$1.24	\$0.93 / \$1.16	\$0.73 / \$1.32	\$0.63 / \$1.58

Results

PRICE COMPARISON WITH OTHER MODES OF TRANSPORTATION

- 5-Seat eVTOL passenger price per mile is expected to be **more expensive than luxury ride sharing on the ground**
- 2-seat eVTOL aircraft is **comparable** to current limo type services. Operators like **Blade and Skyride charges ~$30** per passenger mile while **Voom charges ~$10** per passenger mile



Mode of Transportation	Source
Limo	Limos[1]
Luxury Ride Sharing	Uber[2], Fare Estimator[3]
Economy Ride Sharing	Uber, Fare Estimator
Taxi	MarketWatch[4]
Autonomous Taxi	MarketWatch
Vehicle Ownership	AAA[5]
Uber Air Launch, Helicopter	Uber Elevate[6]

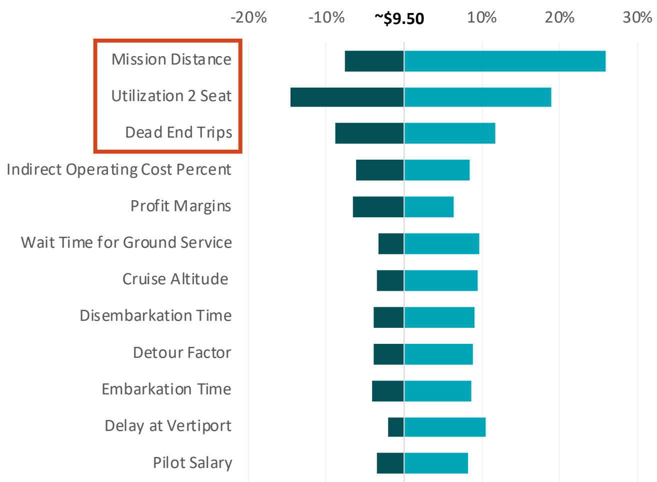
[1]Limos.com assessed on 1/12/2018
[2]Uber Estimate available at http://uberestimate.com/prices/San-Francisco/
[3]Fare Estimator available at https://estimatefares.com/rates/san-francisco
[4]Driverless cars could cost 35 cents per mile for the Uber consumer, MarketWatch, 2016
[5]AAA Reveals True Cost Of Vehicle Ownership, AAA, 2017/
[6] Presented at Uber Elevate, May 2018.

Results

LOW OPERATING COST PER MILE MAY DEPEND UPON HIGH NETWORK EFFICIENCY AND ….

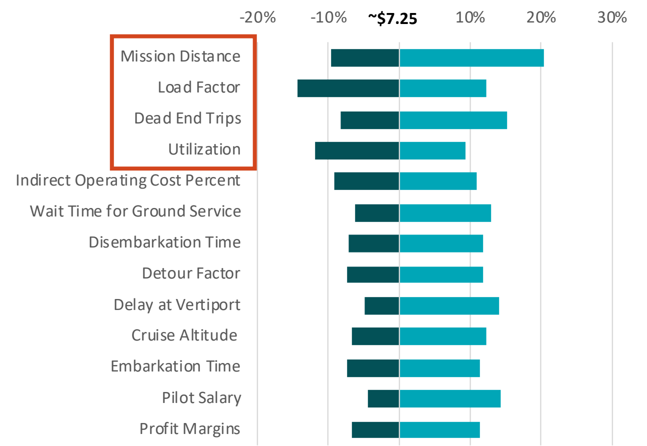
2-Seat Aircraft

- ***Mission Distance** and network efficiency parameters like **Utilization and Deadend Trips** are most important operation related parameters in cost calculations*



4-Seat Aircraft[1]

- *Operating cost for all types of aircraft with more than 2 seats is most sensitive to **mission distance, load factor, utilization and dead-end trips***



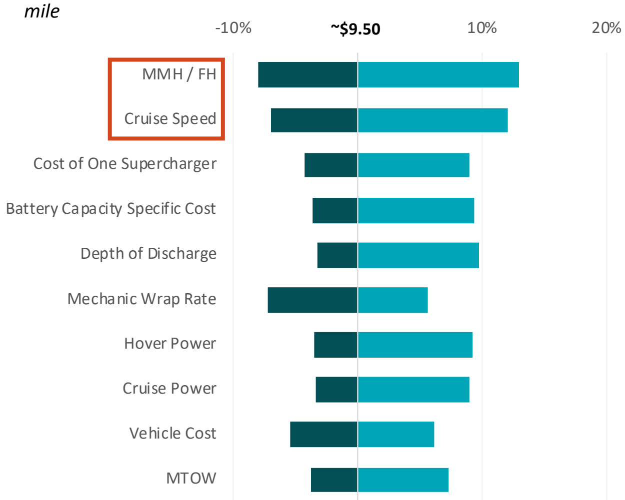
[1] 3-Seat and 5-Seat aircraft follow similar trend (available in Appendix 4.3)

Results

…. AIRCRAFT SPEED, BATTERY COST AND MAINTENANCE REQUIREMENT

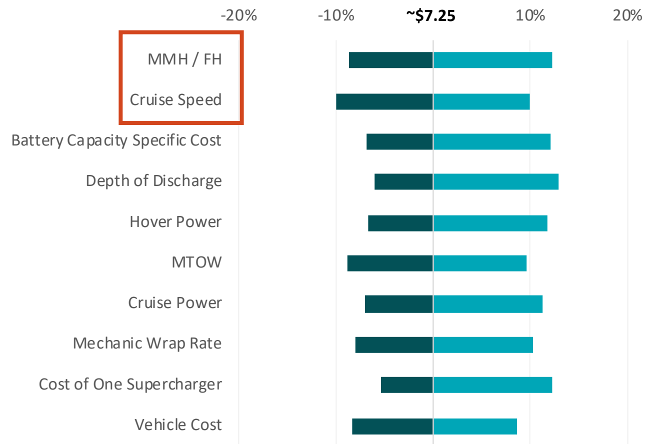
2-Seat Aircraft

- ***Maintenance requirement , aircraft speed, and battery*** *are among the most important technical assumptions that affect passenger price per mile*



4-Seat Aircraft[1]

- *Similar trend to 2-seat aircraft is observed in all 2+ seat aircraft in relation to sensitivities of technical assumptions*

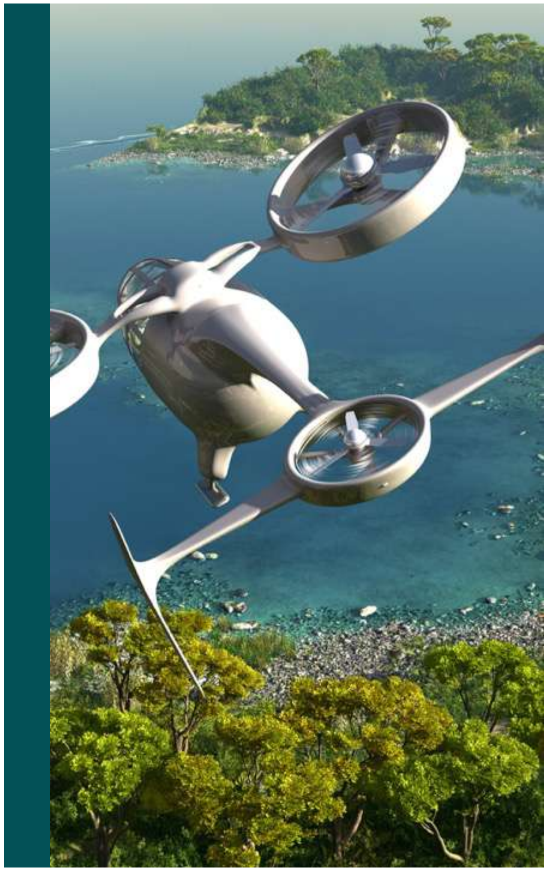


[1] 3-Seat and 5-Seat aircraft follow similar trend (available in Appendix 4.3)

SUMMARY AND CONCLUSIONS

$ per passenger mile depends upon number of seats, range of technology, operational and cost assumptions.

- Median cost of operating a 2-seat vehicle is **~$11** while a 5-seat vehicle (with pooling) is **~$6.25** per passenger mile (based on market entry/near term assumptions).
- Maintenance cost, energy cost, capital cost and crew cost represents **~60-70%** of the overall operating cost.
- **High operational efficiency** (i.e. increased utilization, high load factor and lower dead-end trips), technology improvements and autonomy can decrease the cost of operating an eVTOL by **~60%**
- Aircraft with **higher speed and lower maintenance requirements** may further decrease cost of operating an eVTOL.
- Multirotor(s) have high operating cost per vehicle mile due to lower cruise speed (almost three times less than other aircraft).

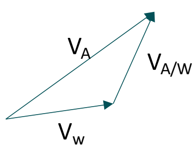


CONTENTS

WEATHER ADJUSTMENTS IN A MISSION

True Airspeed

- To determine the true airspeed of eVTOL (A) with respect to wind direction (w) at a **certain altitude**, the time derivative of the relative position equation is taken i.e.



$$\boldsymbol{V_{A/w}} = \boldsymbol{V_A} + \boldsymbol{V_w}$$

where,

V_A is aircraft velocity in the direction of motion (i.e. mission direction)

V_W is wind speed at different altitudes for a particular urban area

$V_{A/W}$ is the relative velocity. Our analysis adjusts the eVTOL speed to the magnitude of relative velocity at a certain altitude

Temperature

- **Battery specific energy reduces at extreme temperature conditions**, and therefore larger battery size is required which increases the cost
- Since temperature changes with altitude, battery sizing is done **by integral (or summation) of battery requirements at different phases of flight** for the longest mission

$$Battery\ requirement = \int_{h=h_t}^{h=h_l} dB_t$$

where,

h_t refers to take-off sight altitude

h_l : landing sight altitude

dB_t : Battery requirement for each phase at different altitude (100 ft interval) i.e. different temperature

Ambient Density

- **Performance** of an eVTOL varies with air **density**. Higher density means less power while lighter air (lower density) requires more power to lift and take-off.
- Air density **varies with temperature and altitude** as shown in the formula below

$$\frac{\rho}{\rho_0} = \int_{h=h_t}^{h=h_l} \frac{288.16}{T + 273.16} \times \left(1 - \frac{h}{k}\right)^{5.256}$$

where,

h refers to flying altitude (msl)

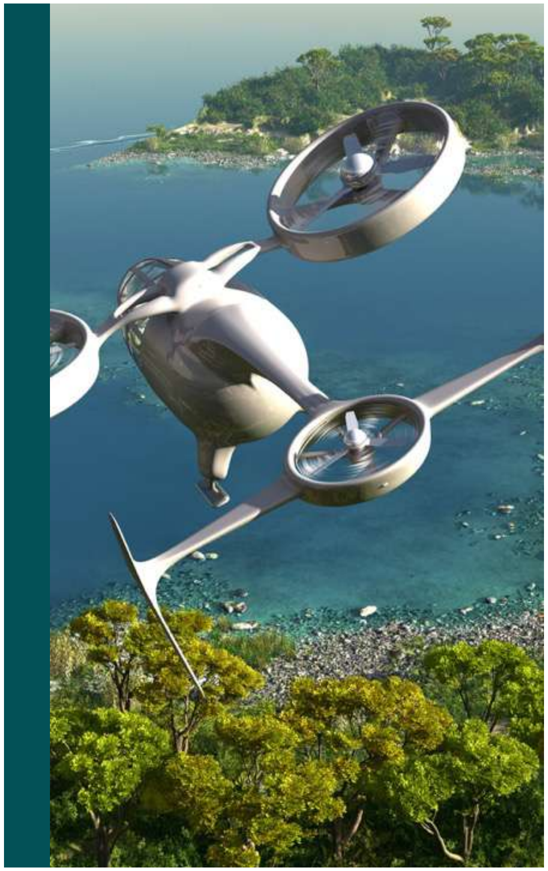
T: Temperature in ^{o}C

k : constant (2.255 x 10^{-5})

$\rho_{o:}$ 1.225kg/m^3 (air density at standard temperature pressure)

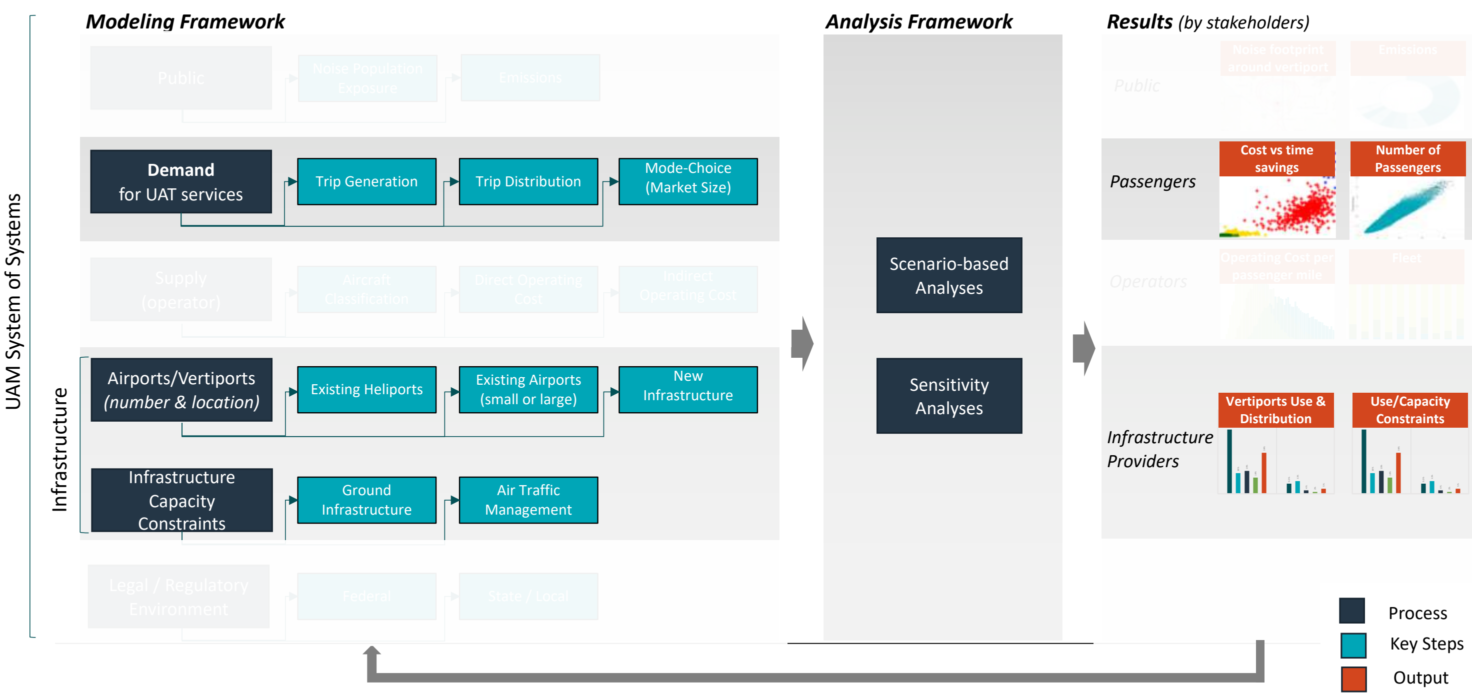
Source: Lieshman, G. Aerodynamics of Helicopters, 2002

*Weather adjustment is done specific to an urban area and applied during demand analysis



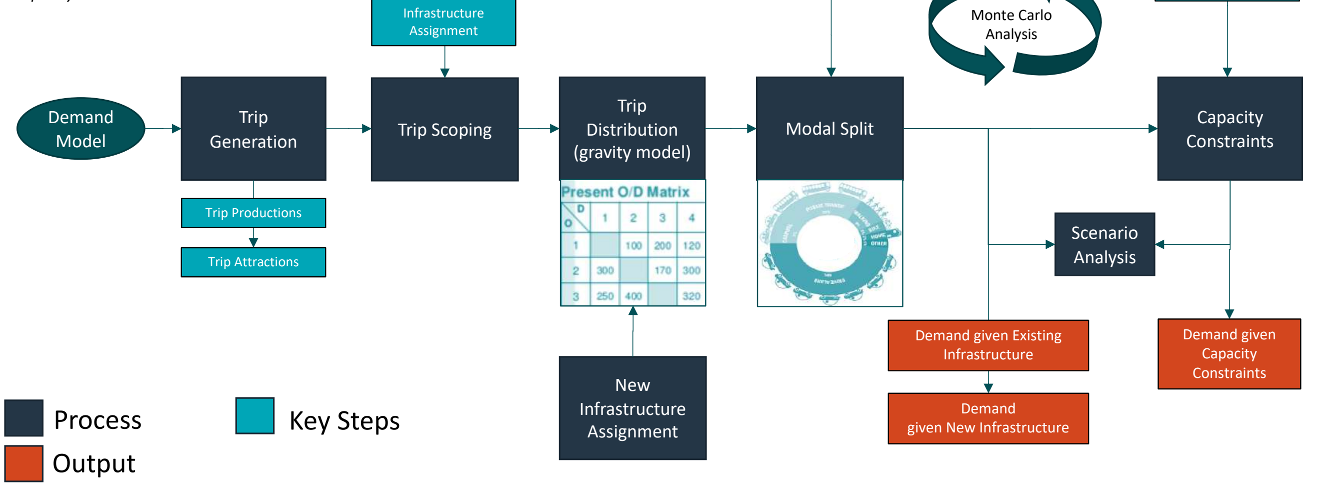
CONTENTS

OVERALL FRAMEWORK OF URBAN AIR TAXI ANALYSIS



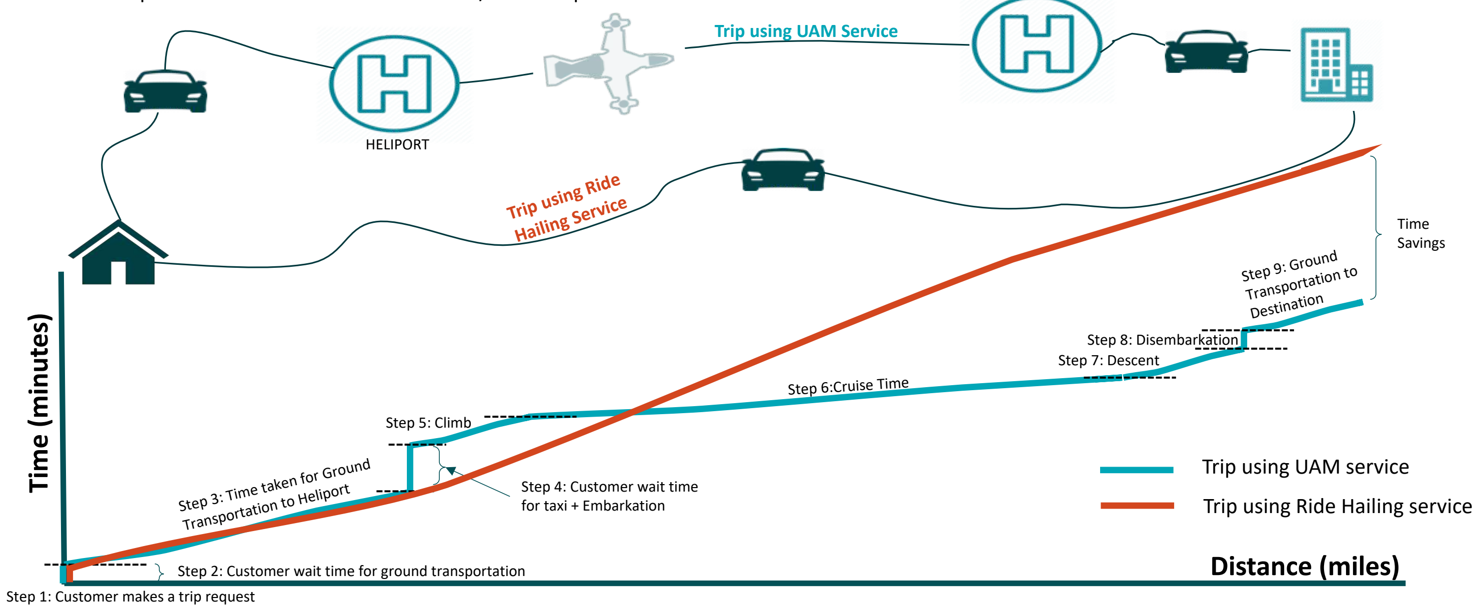
STRUCTURE OF DEMAND SIDE MODEL

Urban Air Taxi and Airport Shuttle Demand modeling is a five step model; Trip Generation, Scoping, Trip Distribution, Mode Choice and Capacity Constraints



DEFINING ConOps FOR URBAN AIR TAXI AND AIRPORT SHUTTLE

- Notional ConOps for a trip is shown below highlighting the **9 steps** considered in this analysis.
- Customer using UAM does not cover any distance at Step 2, Step 4 and Step 8. Steps 5 and 7 show more time to cover a unit distance as compared to cruise time due to low climb/descent speed.



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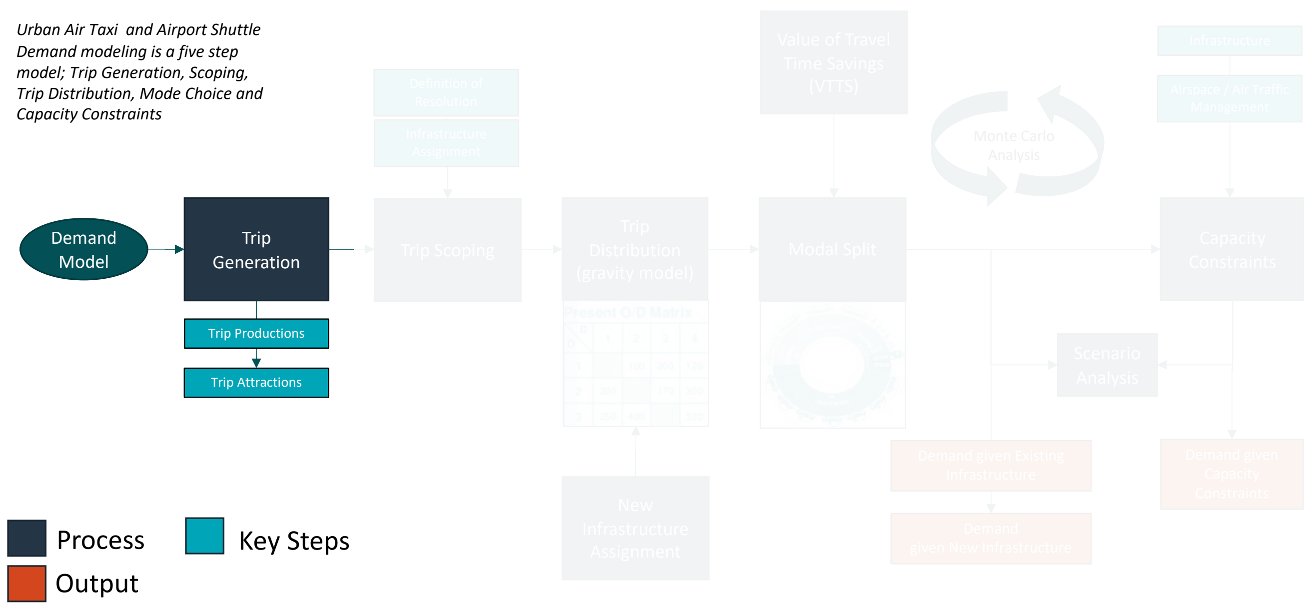


TOTAL DAILY TRIPS IN EACH URBAN AREA

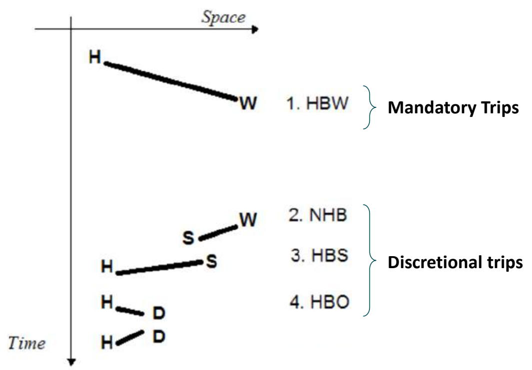
The figure shows 5-year average estimates of total daily trips and average annual household income of each urban area. Hawaii includes all Urbanized Areas in the State of Hawaii.

Source: American Community Survey, 2016

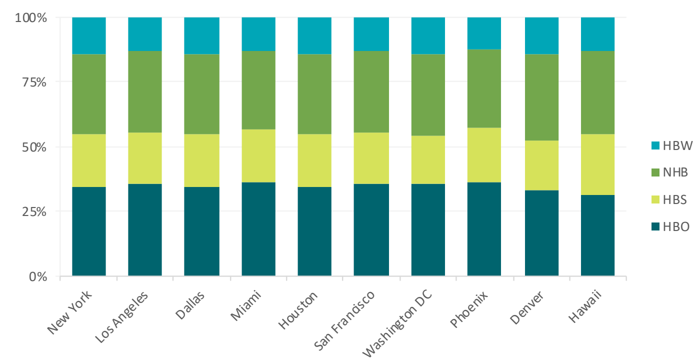
TRIP CLASSIFICATION

Usually, there are four types of trip purpose within an urban area:

1. **Home-based work (HBW)** - One trip end is home and other is work
2. **Home-based shop (HBS)** - One trip end is home and other is shopping
3. **Home-based other (HBO)** - One trip end is home and other is miscellaneous (like entertainment, theatre, dinner (D) etc.)
4. **Non-home-based (NHB)** – Neither trip end is home



Source: Moshe Ben Akiva, 2008



Source: Federal Highway Administration, 2017 National Household Travel Survey (NHTS)

TRIP PRODUCTION AND ATTRACTION

Airport Shuttle

- We first set up our model based using Bureau of Transportation Statistics, T-100 Market (All Carriers) data to focus on passengers traveling to and from US airports after scoping as shown in previous slide
- Scoped daily demand from each airport in an urban area is distributed proportionally to the population of census tract.

Trip Production (Origin, O)	**BTS T-100 Market (All Carriers)** **Scope**: Passenger traveling to and from US airports after scoping as shown in previous slide
Trip Attraction (Destination, D)	**ACS Table B01003** *Total Population* **Scope**: All members of household greater than 2 years of age

Source: American Community Survey (ACS) , 2016 (5 year estimates)

Air Taxi

US Department of Transportation provides guidance on value of travel time savings (VTTS) for passengers on mandatory (i.e., work related) and discretional (i.e. personal) trips.

- In general, **VTTS is estimated to be half for personal travel** when compared to work related travels i.e. a passenger on a personal trip would be willing to pay half as compared to work trip for same amount of travel time savings
- We first set up our model based on **mandatory work related trips** to calculate work-related demand. Our next iteration of analysis would apply similar trip distribution for discretional trips to calculate final demand

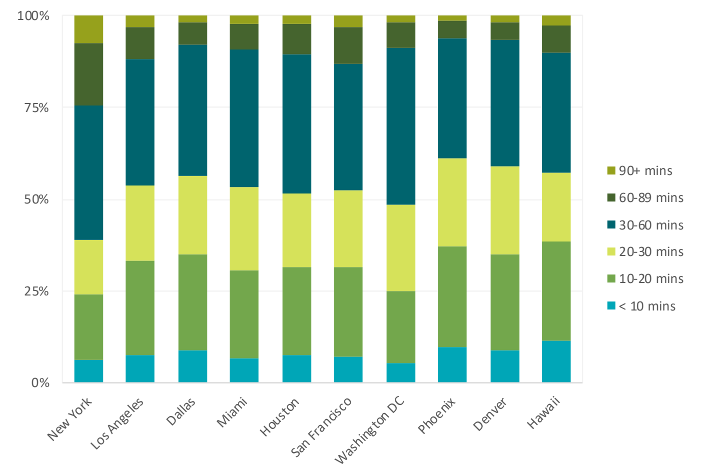
Trip Production (Origin, O)	**ACS Table B08134** *Means Of Transportation To Work By Travel Time To Work* **Scope**: Workers 16 years and over who did not work at home (tract Level)
Trip Attraction (Destination, D)	**ACS Table B99081** *Imputation of Place of work* **Scope:** Workers 16 years and over who did not work at home (tract Level)

Source: American Community Survey (ACS) , 2016 (5 year estimates)

TRIP SHARE BY TRAVEL TIME AND MODE

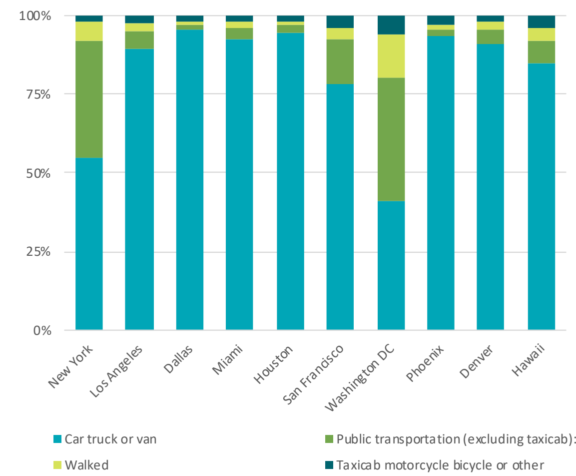
Trip Share by Travel Time

***25% work trips in the New York** urban area require more than 60 mins total travel time on a daily basis. These trips can be potentially served by UAM.*



Trip Share by Mode Type

***Driving is the most preferred choice for work** related trips in most urban areas except New York and Washington D.C. (both have good public transportation systems).*



Source: American Community Survey, 2016

STRUCTURE OF DEMAND SIDE MODEL

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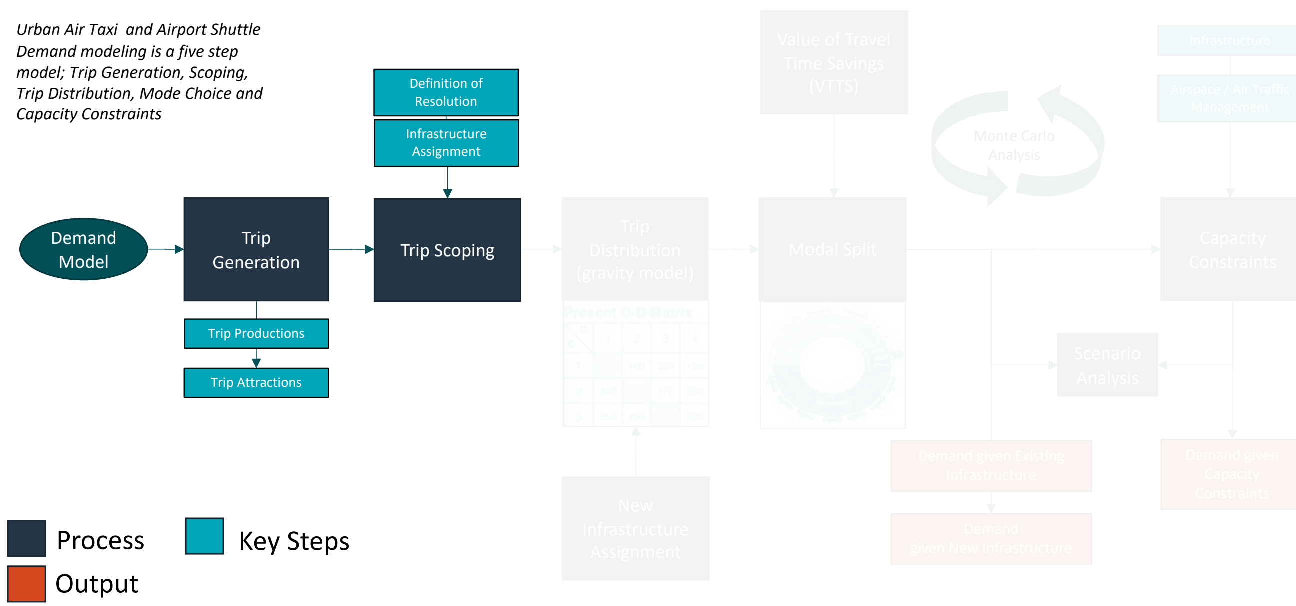


STEP 1: DEFINE ANALYSIS RESOLUTION

*To achieve optimum computational speed and high-fidelity, this analysis is done at a **Census Tract level** for an average day of the year as shown in the figure below (by red boxes).*

Dimension	Lowest Resolution					Highest Resolution
Geography	Urban Area	County	Place	Census Tract	Block Group	
Mode Type	All modes are considered same	Classified as Driving, Ride-sharing, Taxi, Public Transportation and Walking	Driving – Drove alone (Car/Truck), carpooled with 2, 3 or 4 passengers) Public Transportation – Bus, Train, Boat etc. Others - Motor Bike, Bicycle etc. Ride-Sharing Taxi Walking			
Temporal	Average Day of Year (i.e. each weekday in a year is same)	Seasonal Average day (i.e. define seasons, each weekday in a season is same)	Monthly Average day (i.e. each weekday in a month is same)	Weekly Average day (i.e. each weekday in a week is same)	Daily (i.e. treat each weekday as unique)	Hourly (i.e. treat each hour of weekday as unique)

Fastest computational speed — **Slowest computational speed**

Trip Scoping

STEP 2: SCENARIO DEFINITIONS

- **Unconstrained Scenario** – Refers to the case where:
  - **Infrastructure** to take-off and land is **available at every tract** and is not constrained by capacity;
  - **Cost is also not a constraint** i.e., demand is not constrained by willingness to pay;
  - Demand calculated in this scenario refers to the total available market at the market entry price points.
- **WTP Constraint** – Constrained by user's willingness to pay
- **Infrastructure Constraint**– This scenario utilizes **existing infrastructure** in the form of heliports and airports (assuming only one landing take-off pad)
- **Capacity Constraint**– Refers to the demand reduction due to existing **infrastructure's operational capacity** on per hour basis.
- **Time of Day Constraint** – Demand reduction due to operations in specific time of day.
- **Weather Constraint** - Initial operations are expected to be under Visual Flight Rules (VFR) conditions

AVAILABLE INFRASTRUCTURE[1]

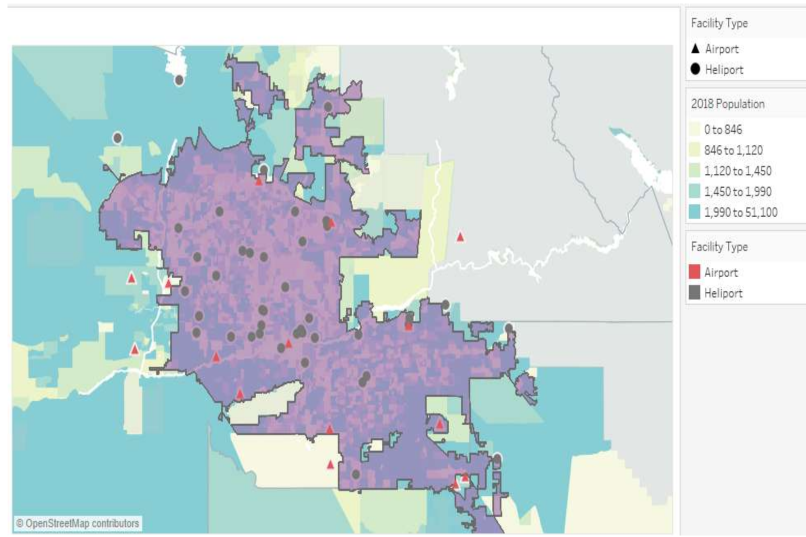
Urban Area	Heliports	Airports	Source
New York	157	31	
Los Angeles	128	24	
Dallas	56	45	
Miami	28	14	
Houston	69	19	AEDT Airports Database[2]
San Francisco	12	10	
Washington DC	10	2	
Phoenix	41	15	
Denver	26	10	
Hawaii	4	3	

[1]Includes active commercial heliports and airports only
[2]www.AEDT.faa.gov

Trip Scoping

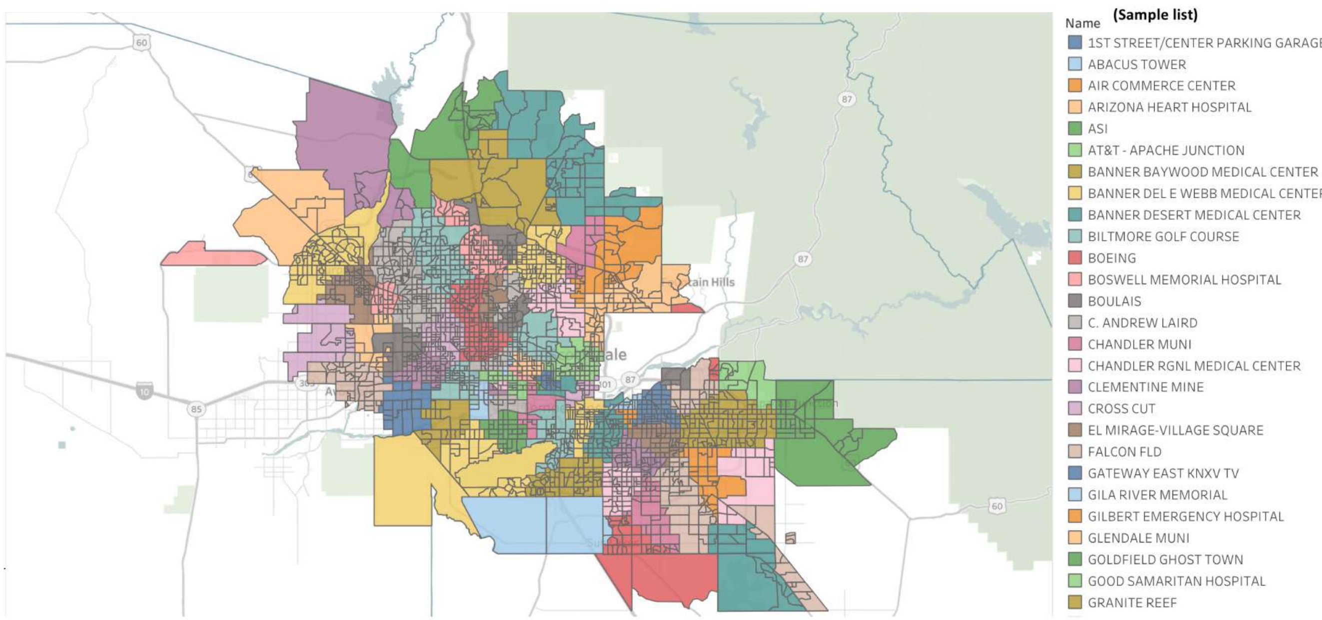
STEP 3: MAPPING AVAILABLE INFRASTRUCTURE - PHOENIX EXAMPLE

*Given that the ground infrastructure requirements are critical for the success of UAM, an urban area (Phoenix in this example) could leverage **its existing helipad and airport infrastructure** for early stages of commercial air taxi operations. (See Appendix 4.4 for more details).*



STEP 4: INFRASTRUCTURE ASSIGNMENT - PHOENIX EXAMPLE

Infrastructure is assigned to each tract *by measuring the* ***minimum great circle distance*** *between the tract center and each infrastructure in the Phoenix urban area. The analysis assumes that a portion of the population of a certain* ***tract will use a particular infrastructure in a given time****.*



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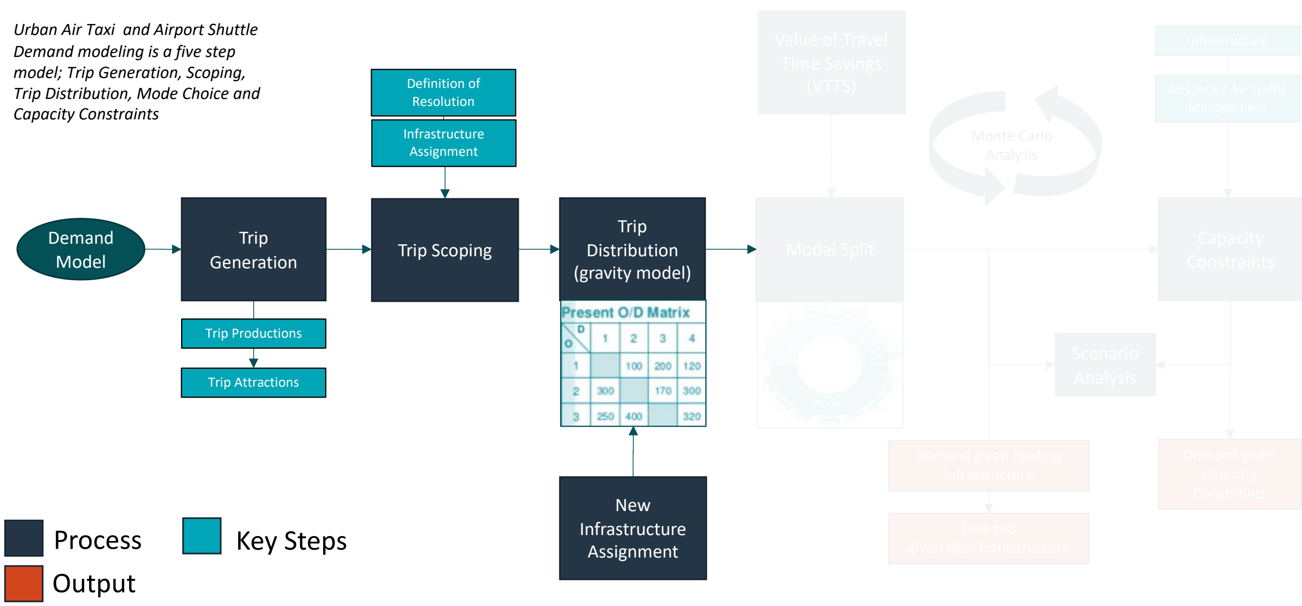


STEP 1: UAM TRIP DISTRIBUTION

*Equation (1) shows a simplified **gravity model**, which assumes that the trips produced at an origin and attracted to a destination are directly proportional to the total trip productions at the origin and the total attractions at the destination. Due to the availability of trips data for different travel times, **calibration factor (or friction factor) is not required**. This study assumes **equal likelihood of individual trip interchanges** between the tracts.*

Trip Matrix

Generations	Attractions							
	1	2	3	…	j	…	J	$\sum_j T_{ij}$
1	T_{11}	T_{12}	T_{13}	…	T_{1j}	…	T_{1J}	O_1
2	T_{21}	T_{22}	T_{23}	…	T_{2j}	…	T_{2J}	O_2
3	T_{31}	T_{32}	T_{33}	…	T_{3j}	…	T_{3J}	O_3
:	:	:	:		:		:	:
i	T_{i1}	T_{i2}	T_{i3}	…	T_{ij}	…	T_{iJ}	O_i
:	:	:	:		:		:	:
I	T_{I1}	T_{I2}	T_{I3}	…	T_{Ij}	…	T_{IJ}	O_I
$\sum_i T_{ij}$	D_1	D_2	D_3	…	D_j	…	D_J	$\sum_i \sum_j T_{ij} = T$

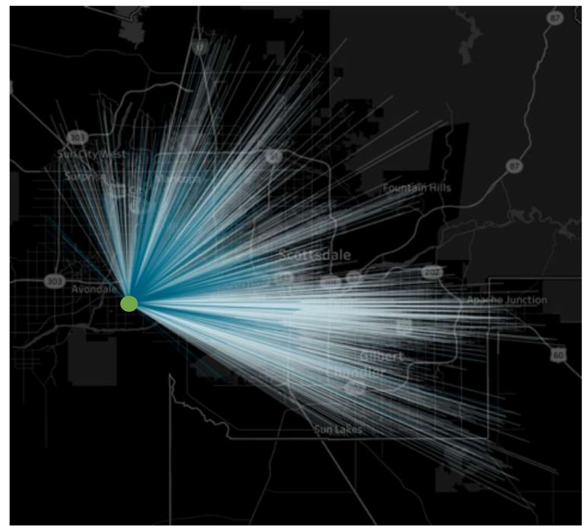
where,

$$T_{ij} = Oit \frac{D_{jt}}{\sum D_{jt}} \quad \text{------------} \quad (1)$$

subject to $\sum O_i = \sum D_j$

O_{it} = *Workers at the origin (tract) i for a certain trip duration t*

D_{jt} = *Workers attracted to a destination (tract) j for a trip duration t*



Sample Trips from different part of Phoenix to one destination tract (green dot). Trips shown in blue indicate at least one trip from the originating tract to destination tract.)

STEP 2A: SCOPING OF AIRPORT PASSENGER DEMAND TOWARDS UAM TRAFFIC

Due to technical feasibility and travel characteristics limitations, not all passenger arriving or departing at a major airport within the UAs are expected to be potential customers of Airport Shuttle service. Therefore, demand is scoped by following:

- **Technical feasibility:** The eVTOL aircraft contemplated for the provision of early market entry for the Airport Shuttle Market may **likely be 2 to 5 seat aircraft**.
  - The seating capacity (assuming that one seat would be occupied by a pilot) does limit the size of the group of passengers taking the trip between the heliport/vertiport and the airport.
  - For example, it seems unrealistic for a family of 4 traveling long distance with approx. 220 lbs.. of baggage to be taking a UAM.
  - A filter was therefore developed to **focus the analysis on 1 to 3 passengers per ticket.**
- **Travel characteristics:** Passengers on **long journeys** (e.g., long distance flights with several connections) **are less time sensitive** (especially for departing flights) than on short trips.
  - The passengers taking an airplane trip with 2, 3 or more connections (for e.g., 10, 15 hour journeys), are less likely to be time sensitive at the airport to justify/prefer a UAM.
  - In addition, these passengers are likely to carry more baggage weight than passengers making day trip flights or short distance flights.
  - It is expected that **Airport Shuttle UAM would focus on passenger making less than 2 connections.**

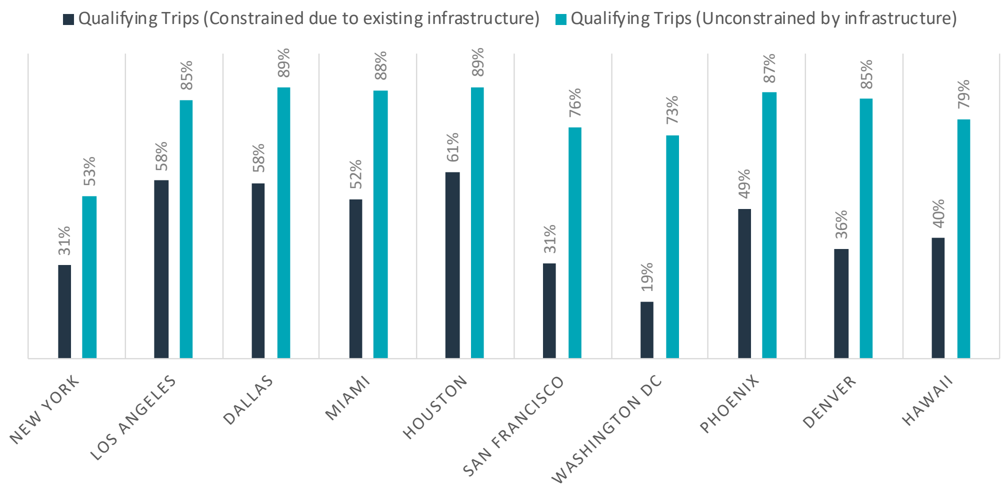
Airport Name (Sample Set)	Percent total outbound passengers with 1 to 3 pax per TicketID and less than two connections
DEN	43%
IAH	58%
HOU	40%
JFK	40%
LGA	47%
SFO	45%
OAK	35%

Source: BTS DB1B - Ticket Database Q2 2016

STEP 2B: QUALIFYING UAM TRIPS

Utility of Urban Air Mobility is to ***reduce travel time*** *as compared to major competing modes of transportation (like driving, ride-sharing, public transportation etc.). Therefore, this analysis applies* ***a rule where UAM total travel time (on ground time and air time) is less than travel time*** *for ground transportation to calculate total available market.*

Cases of Los Angeles, Miami, Houston, Dallas and Phoenix shows that the existing infrastructure captures large part of the available market.

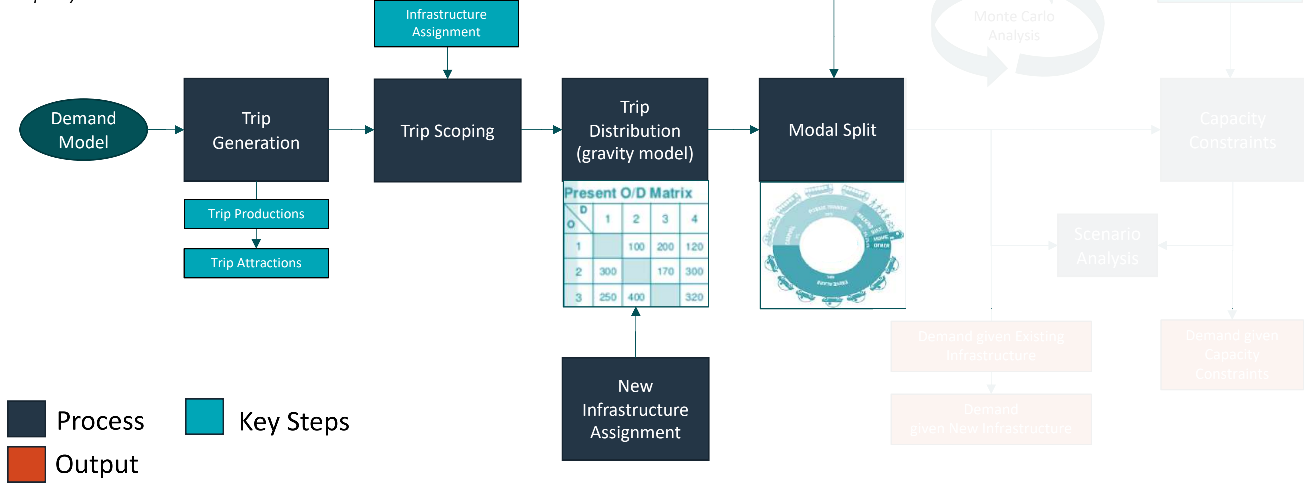


Urban Area	Total Daily Work Trips (mn)
Dallas	2.7
Denver	1.2
Hawaii	0.6
Houston	2.4
Los Angeles	5.9
Miami	2.4
New York	8.2
Phoenix	1.6
San Francisco	2.4
Washington DC	2.3

Source: American Community Survey, 2016

STRUCTURE OF DEMAND SIDE MODEL

Urban Air Taxi and Airport Shuttle Demand modeling is a five step model; Trip Generation, Scoping, Trip Distribution, Mode Choice and Capacity Constraints



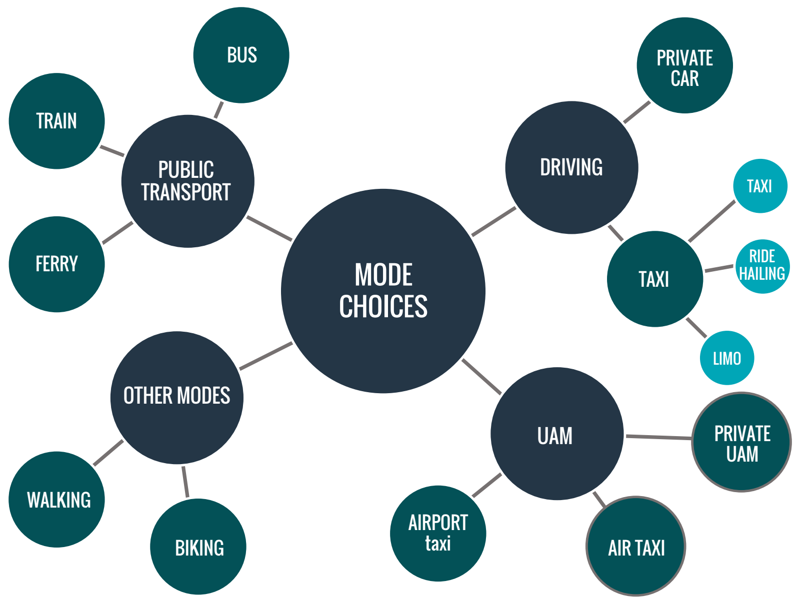
MODE CHOICE MODELING - EVALUATING TRAVELER MODE CHOICES

Mode Choice Modeling is used to predict traveler mode choice and is the third step in the conventional four-step transportation forecasting model. Factors that affects a traveler mode choice are:

- **Person/household characteristics:** Car availability, income, household size
- **Trip characteristics:** Travel time, travel cost, purpose
- **Land use characteristics:** Pedestrian facilities, mix of uses at both ends, parking, density at both ends
- **Service characteristics:** Facility design (HOV, bikes), frequency, congestion, cost (parking, tolls, fares, out-of-pocket costs), stop spacing

Factors considered in this analysis:

- Household income
- Travel time
- Travel cost



STEP 1: CALCULATION OF UTILITY FUNCTION (MODE CHOICE)

Utility Function

- Utility of a mode is an indicator of value a mode provides to an individual. **Higher the utility** of a particular mode, a **user is likely to choose that mode**.
- Number of attributes influence the utility of each alternative for all people in the population of interest. These include measures of travel time, travel cost, walk access distance, transfers required, crowding, seat availability, and others.
- Two **key attributes that influence choice of mode are travel time and travel cost per median household Income per hour**. The utility function (V) of any mode (m_i) is defined as:

$$V(m_i) = \beta_t * Travel\ Time_i + \beta_{costinc} * \frac{Travel\ Cost_i}{Income\ per\ hour}$$

where,

m_i = Represents different modes like Driving, Public Transportation, Taxi etc.

β_t = Constant parameter for travel time

β_{cost_inc} = Constant parameter for travel cost and Income per hour

Deterministic Components

- β_t and $\beta_{costinc}$ are calibrated for each urban area by **fitting a logit model** to the training data as shown below
- Training data is generated using the **2016 American Community Survey** and **General Population Survey** described in societal barriers section

Trip Number	Mode	Travel Time (mins)	Travel Cost ($)	Income ($ per year	Mode Selection
1	Driving	20	5	90000	1
1	Public Transportation	60	2	90000	0
1	Ride Sharing / Taxi	20	24	90000	0
1	Walking	120	0	90000	0
2	Driving	25	10	90000	0
2	Public Transportation	70	2	90000	0
2	Ride Sharing / Taxi	25	30	90000	1
2	Walking	200	0	90000	0
…….	…….	…..	….	……	….
n	Driving	4	5	190000	0
n	Public Transportation	30	2	190000	0
n	Ride Sharing / Taxi	4	10	190000	0
n	Walking	20	0	190000	1

Source: Mode Choice Modeling: Multinomial and Nested Logit Models, U.S. Department of Transportation Federal Transit Administration, 2006

ASSUMPTIONS[1]

Urban area	Average Driving Speed	Source
New York	17	Inrix, 2018[2]
Los Angeles	27	
Dallas	27	
Miami	32	
Houston	28	
San Francisco	18	
Washington DC	19	
Phoenix	28	
Denver	22	
Hawaii	28	

[1]Study assumes average public transportation speed to be 1/3rd of average driving speed in an urban area
[2]INRIX Global Traffic Scorecard, 2018

STEP 2: MULTINOMIAL CHOICE MODEL

- We choose **Probabilistic Choice models** over **Deterministic utility models** since it's difficult to understand the decision process of each individual or their perceptions while choosing a certain mode.
- **Multinomial Logit Model** allows us to describe **preferences and choice of a user in terms of probabilities** of choosing each alternative rather than predicting that an individual will choose a particular mode with certainty.
- The general expression for the probability of choosing an alternative 'i' (i = 1,2,.., J) from a set of J alternatives is

$$\Pr(i) = \frac{\exp(Vi)}{\sum_{i=1}^{j} \exp(Vi)}$$

where,

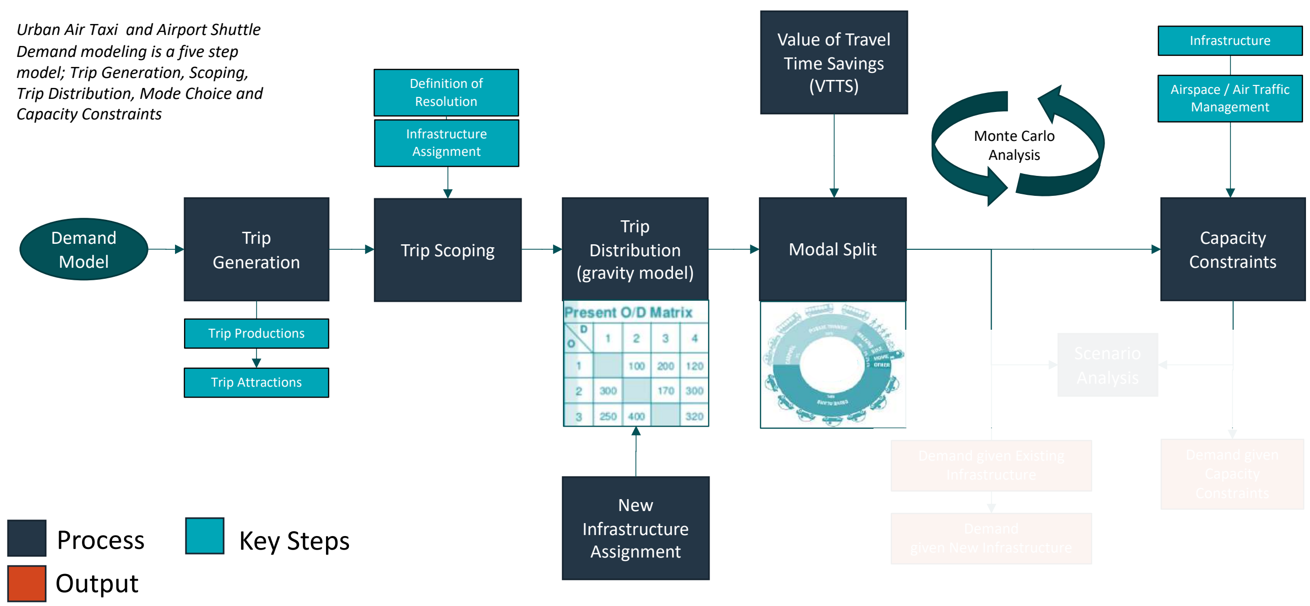
Pr(i) is the probability of the decision-maker choosing alternative i

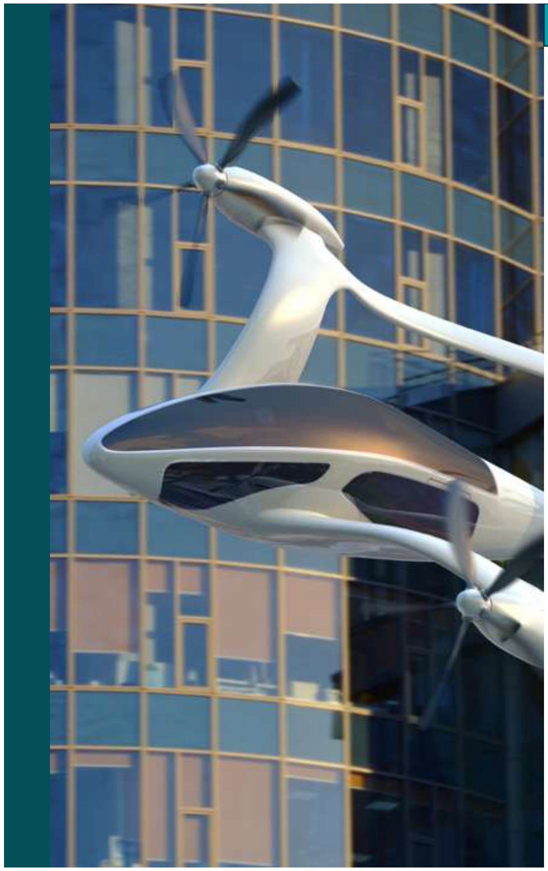
V_i is the systematic component of the utility of alternative i. Alternatives includes all forms of transportation system

Source: US Department of Transportation Guidance on Valuation of Travel Time in Economic Analysis, 2015

STRUCTURE OF DEMAND SIDE MODEL

Urban Air Taxi and Airport Shuttle Demand modeling is a five step model; Trip Generation, Scoping, Trip Distribution, Mode Choice and Capacity Constraints





Constraints

WILLINGNESS TO PAY CONSTRAINT

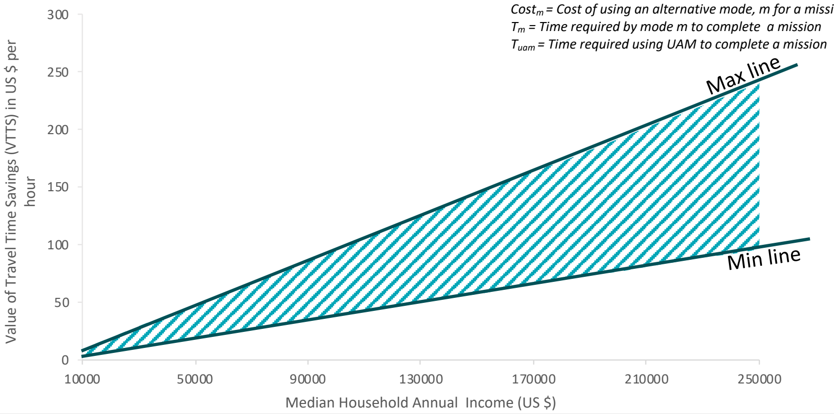
- US Department of Transportation provides guidance on valuation of travel time in economic analysis. For business travelers doing local travel, VTTS is assumed to **be 80%-120% per person hour as a percentage of total earnings**. The figure below shows change in VTTS as a function of median household income

- **Willingness-to-pay for UAM** is calculated as a function of travel-time savings when compared to ground transport and can be generalized using the formula below:

$$WTP_{uam} = Cost_m + (T_m - T_{UAM}) * VTTS$$

where,

$Cost_m$ = Cost of using an alternative mode, m for a mission
T_m = Time required by mode m to complete a mission
T_{uam} = Time required using UAM to complete a mission



Source: US Department of Transportation Guidance on Valuation of Travel Time in Economic Analysis, 2015

Constraints

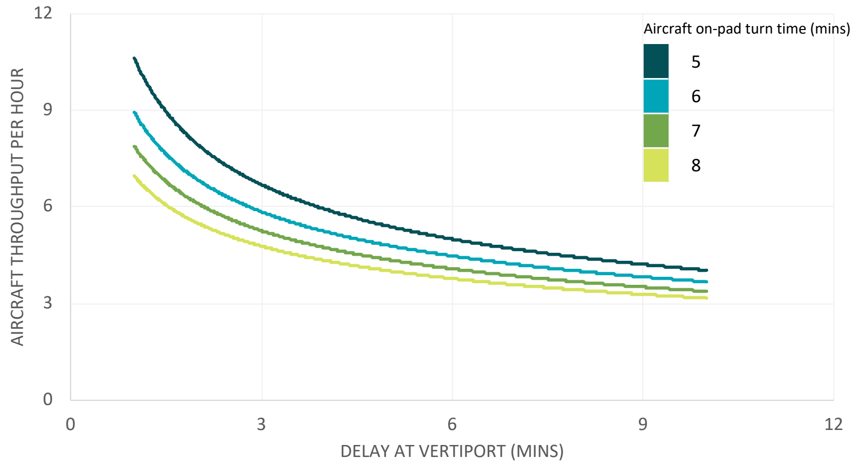
ASSUMPTIONS

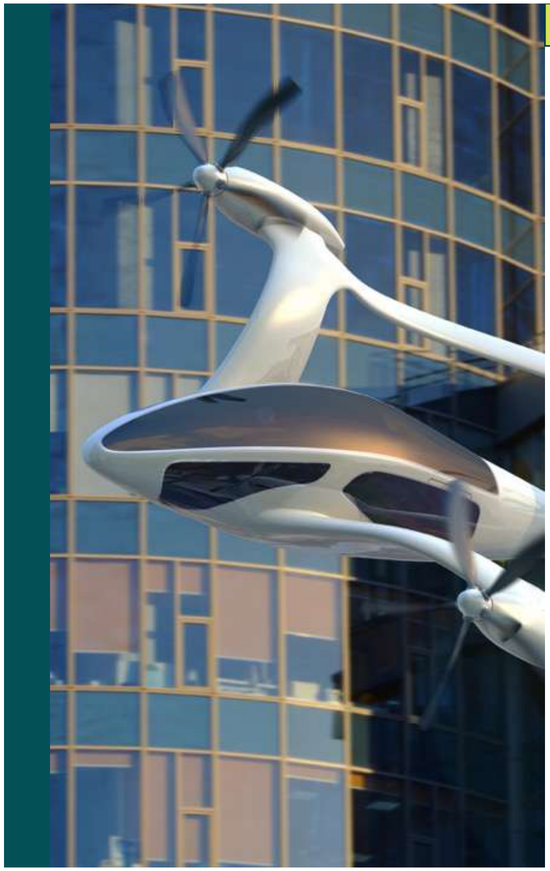
Parameter	Min	Max	Source
Embarkation Time (mins)	3	5	MIT Study[1]
Disembarkation Time (mins)	2	3	
Airspace Clearance (sec)	30	60	
Delay at Vertiport (mins)	1	10	BAH Assumption

[1]*Vascik, P. Systems-level Analysis Of On Demand Mobility For Aviation. MIT, 2017*

INFRASTRUCTURE CAPACITY CONSTRAINTS

- Heliports/Vertiport operational capacity in the form of flights per hour depends upon **aircraft total turn-time** during loading (**embarkation**) and unloading (**disembarkation**), time required for the departing aircraft to lift off and **clear the airspace** in proximity, and **delay** caused by the security time and late arrival of the taxi (may be due to hovering or delay in arrival from its parked/charging location).
- Aircraft **on-pad turn time** is defined as sum of embarkation and disembarkation time

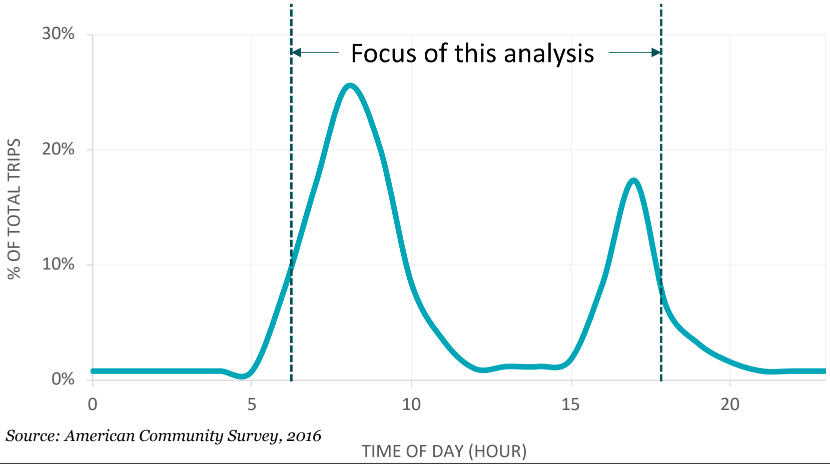




Constraints

TIME OF DAY RESTRICTIONS

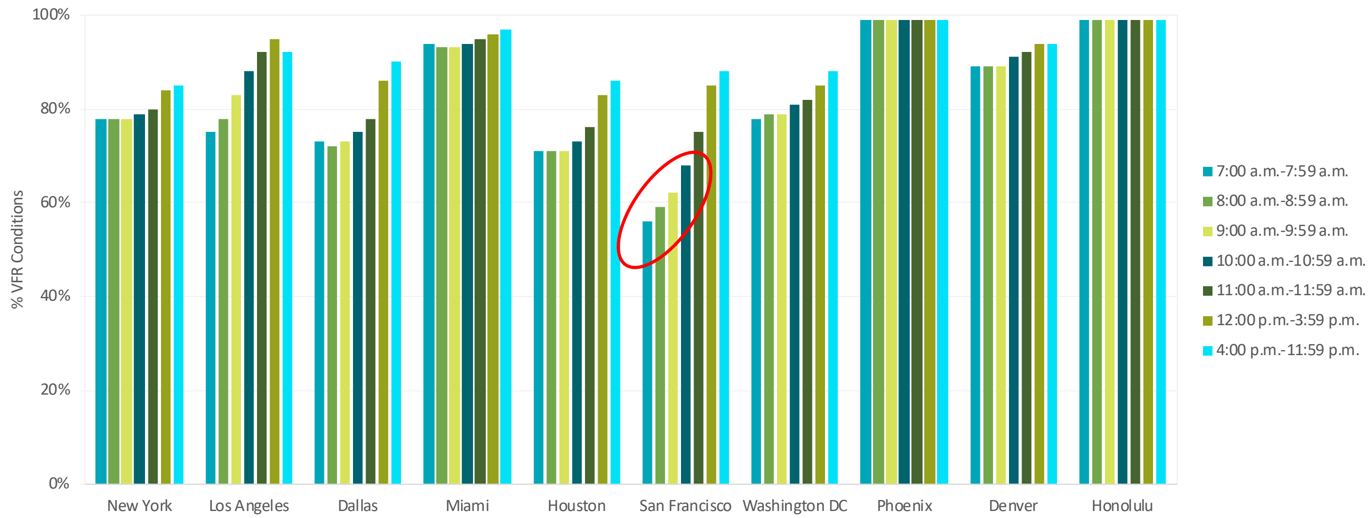
- Heliports/Vertiports and UAM service providers are expected to operate for specific time of day that is determined by various factors like demand, legal/regulatory restrictions, weather etc.
- **Demand in usually high between 7-10 am and 3-6 pm** as evident from the graph below. Therefore, for the purpose of this analysis we assume heliports/vertiports operating schedule to be **7 am to 6 pm.**



Source: American Community Survey, 2016

WEATHER CONSTRAINTS

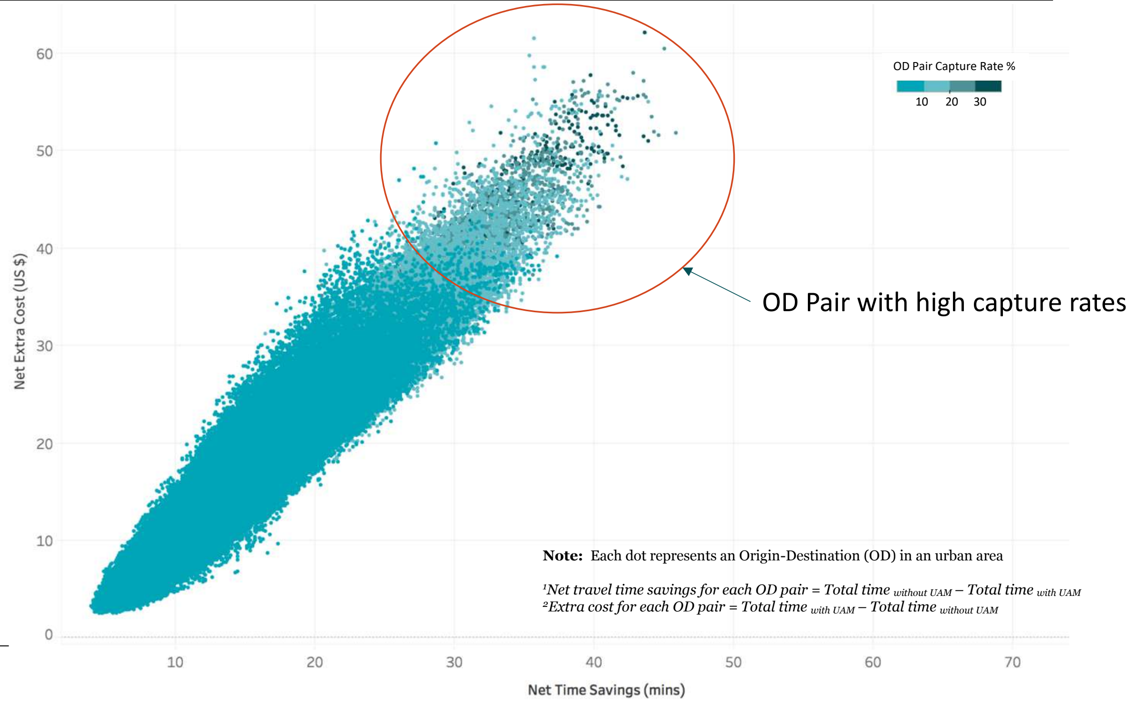
- Near term operations in the US are expected to be under Visual Flight Rules (VFR) conditions
- IFR conditions are usually prevalent in the morning rush hour as evident from the graph below. Urban Areas like San Francisco have **low VFR conditions between 7am-11am** that can limit the number of operations and reduce the reliability of Air Taxi operations



Results

INCREMENTAL TRIP COST VS TIME SAVINGS - UNCONSTRAINED SCENARIO (PHOENIX EXAMPLE)

- **High volume trips** refers to Air Taxi trips which capture a significant amount of daily work trips.
- In an unconstrained scenario, in some cases, Air Taxi service could potentially capture more than **20-30% of total daily work trips** originating from a particular origin and destination (i.e. census tracts).
- Trips with a **net time savings[1] of more than 30 minutes** capture most trips and it costs an extra[2] $30 or more per trip for each OD pair.



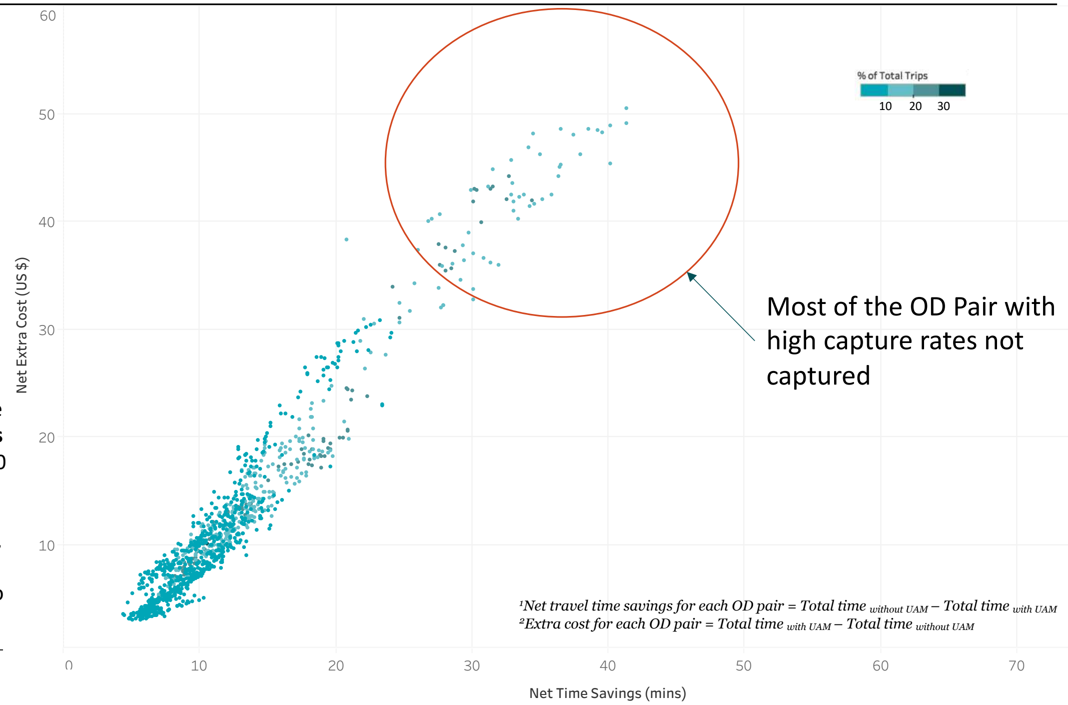
Note: Each dot represents an Origin-Destination (OD) in an urban area

[1]*Net travel time savings for each OD pair = Total time $_{without\ UAM}$ – Total time $_{with\ UAM}$*
[2]*Extra cost for each OD pair = Total time $_{with\ UAM}$ – Total time $_{without\ UAM}$*

Results

INCREMENTAL TRIP COST VS TIME SAVINGS - CONSTRAINED SCENARIO (PHOENIX EXAMPLE)

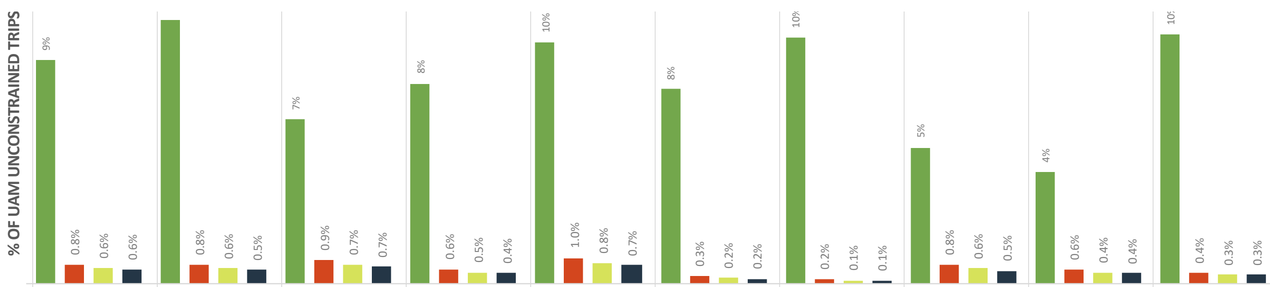
- Five levels of constraints are applied
  - WTP Constraint
  - Infrastructure Constraints
  - Capacity Constraints
  - Time of Day Constraints
  - Weather Constraint
- Most of the high volume trips **were not captured due to infrastructure constraints**. Trips with higher time savings and extra cost are retained.
- Most of the serviceable Air Taxi trips, for Phoenix, provide a **net time savings[1] of 20 mins or less** that costs an extra[2] $20 or less per trip.
- After applying the constraints, **~ 0.5% of the Air Taxi trips were captured** with respect to unconstrained scenario.



[1]Net travel time savings for each OD pair = Total time $_{without\ UAM}$ – Total time $_{with\ UAM}$
[2]Extra cost for each OD pair = Total time $_{with\ UAM}$ – Total time $_{without\ UAM}$

BASE YEAR DEMAND COMPARISON FOR ALL URBAN AREAS

- On average **~0.5% of unconstrained trips are captured** after applying constraints[1]. **New York**, **Los Angeles, Houston and Dallas** are potential urban areas of high daily demand (see appendix 4.45 for Airport Shuttle numbers only)



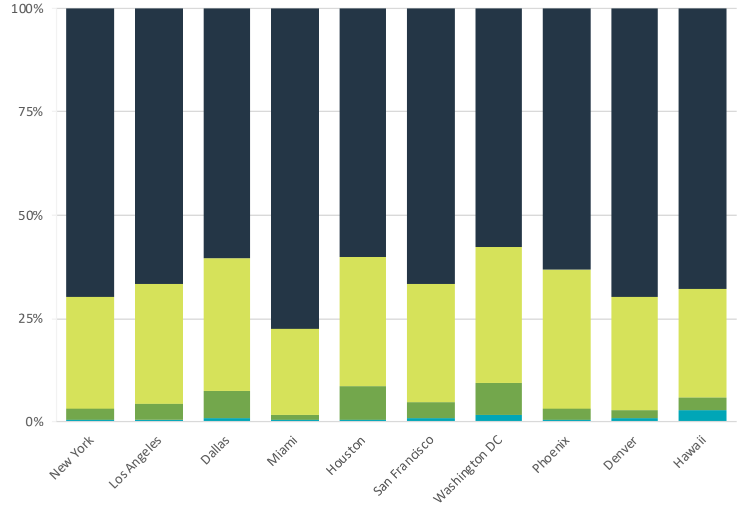
	NEW YORK	LOS ANGELES	DALLAS	MIAMI	HOUSTON	SAN FRANCISCO	WASHINGTON DC	PHOENIX	DENVER	HONOLULU
Un-constrained	1, 421, 000	1, 380, 000	717, 000	587, 000	673, 000	606, 000	600, 000	422, 000	358, 000	161, 000
Infrastructure Constrained	127, 000	145, 000	47, 000	47, 000	65, 000	47, 000	59, 000	23, 000	16, 000	16, 000
Capacity Constraint	11, 000	10, 500	6, 700	3, 400	7, 000	1, 800	1, 100	3, 200	2, 000	700
Time of Day Constraint	8, 800	8, 400	5, 360	2, 720	5, 600	1, 440	880	2, 560	1, 600	560
Weather Constraint	8, 000	7, 500	4, 750	2, 470	4, 890	1, 250	780	2, 230	1, 460	550

[1] WTP constraint not shown here but is applied

Results

MARKET SHARE FOR DIFFERENT TYPES OF AIRCRAFT ACROSS FOCUS URBAN AREAS

*The figure shows first-order market share[1] for different types of aircraft (categorized based on number of seats). **Aircraft with larger number of seats** have fewer passengers per mile, hence **larger market share**.*



	Number of Aircraft Required				
	2-Seat	3-Seat	4-Seat	5-Seat	Total
New York	2	11	113	294	420
Los Angeles	1	14	103	236	354
Dallas	2	16	77	145	240
Miami	1	2	29	109	141
Houston	2	17	68	130	217
San Francisco	1	3	19	43	66
Washington DC	1	3	12	22	38
Phoenix	1	3	34	65	103
Denver	1	1	17	42	61
Hawaii	1	1	6	15	23
Total	13	71	478	1101	**1663**

[1] Market share of a UAM aircraft will also depends upon availability of each type of aircraft (i.e., delivery year), environmental impact, flexibility, user preference, size, infrastructure requirements etc. This analysis calculates market share based on operating cost of an aircraft

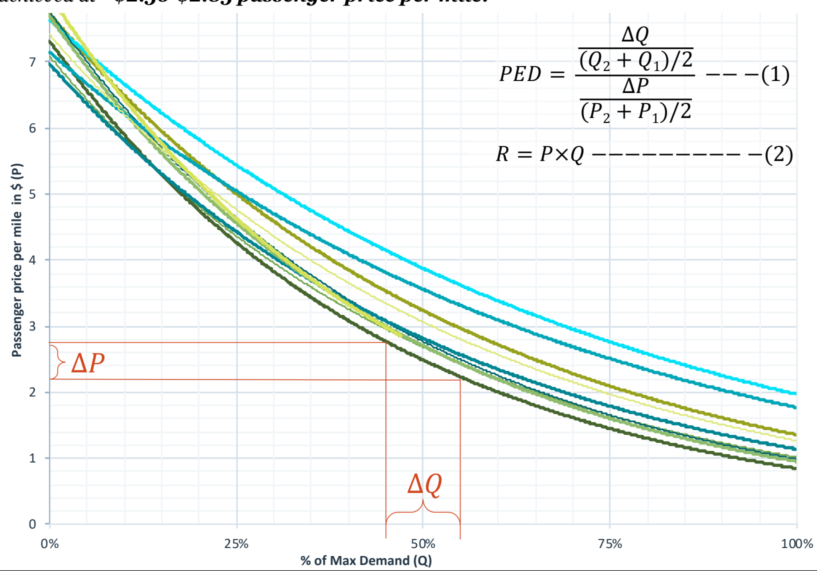
Results

PRICE ELASTICITY DEMAND CURVE AND REVENUE MAXIMIZATION

The price elasticity of demand (PED) as given by (1) measures the sensitivity of the quantity demanded to changes in the price. Absolute value of PED is greater than 1 for all urban areas i.e. ***demand is elastic****. Revenue is calculated using equation 2.* ***Maximum revenue*** *for each of the urban area is achieved at* ***~$2.50-$2.85 passenger price per mile.***

$$PED = \frac{\frac{\Delta Q}{(Q_2 + Q_1)/2}}{\frac{\Delta P}{(P_2 + P_1)/2}} \quad ---(1)$$

$$R = P \times Q \quad ----------(2)$$



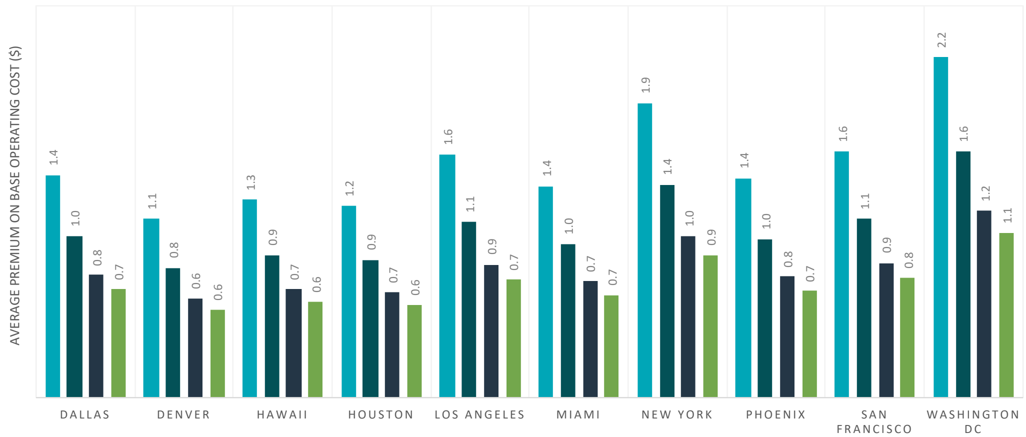
		PED	Passenger price per mile for Max. Revenue (R)
	Dallas	-3.48	$2.84
	Denver	-4.29	$2.69
	Hawaii	-4.17	$2.82
	Houston	-4.05	$2.83
	Los Angeles	-3.36	$2.60
	Miami	-3.85	$2.60
	New York	-2.80	$2.63
	Phoenix	-3.56	$2.50
	San Francisco	-3.52	$2.70
	Washington DC	-2.68	$2.78

Results

BASE YEAR MARKET EQUILIBRIUM

This analysis attains supply demand equilibrium by applying price elasticity demand curves (shown by equation 1) on the final demand obtained after apply applying infrastructure capacity constraints.

$$PED_{avg} = \frac{1}{b-a}\int_{a=0\%}^{b=100\%} PED \quad ------(1)$$



	Base passenger price per mile ($)	Average Premium ($)
2-Seat	$11.25	$1.50
3-Seat	$9.50	$1.10
4-Seat	$7.25	$0.80
5-Seat	$6.25	$0.75

CONTENTS

AIR TAXI OPERATIONS MAY FALL UNDER AIRSPACE CLASS B-E AND TFRS MAY APPLY

Controlled airspace (i.e. air traffic control interaction may be required) can potentially limit the number of operations per hour, thereby further restricting the demand. Each class of airspace has certain operation protocols as described in Appendix 4.5

Class A: airspace from 18,000 feet Mean Sea Level (MSL) up to and including Flight Level (FL) 600, including the airspace overlying the waters within 12 nautical miles off the coast of the 48 contiguous States and Alaska;

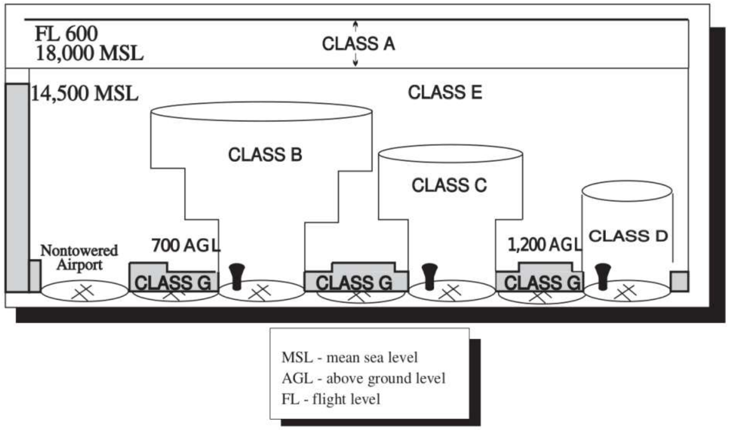
Class B: airspace from the surface to 10,000 feet MSL surrounding the nation's busiest airports in terms of IFR operations or passenger enplanements

Class C: airspace from the surface to 4,000 feet above the airport elevation (charted in MSL) surrounding those airports that have an operational control tower, are serviced by a radar approach control, and that have a certain number of IFR operations or passenger enplanements

Class D: airspace extends upward from the surface to 2,500 feet above the airport elevation (charted in MSL) surrounding those airports that have an operational control tower (Manassas Rgnl/Harry P Davis Fld);

Class E: Class E airspace is controlled airspace that is designated to serve a variety of terminal or en route purposes

Temporary Flight Restrictions: Temporary flight restrictions often encompass major sporting events, natural disaster areas, air shows, space launches, and Presidential movements. Since 9/11, TFRs have been routinely used to restrict airspace for 30 nautical miles around the President, with a 10-nautical-mile (18.5 km) radius no-fly zone for non-scheduled flights. See Appendix 4.6 for details



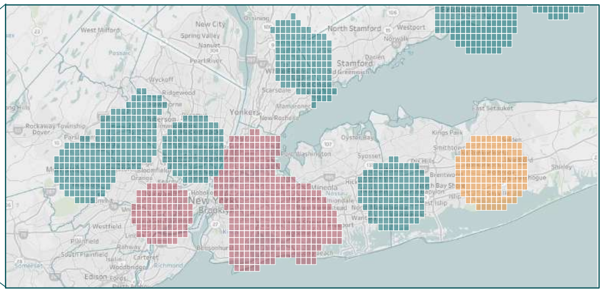
Source: FAA Aeronautical Information Manual (FAA website). Accessed on 07/01/2018

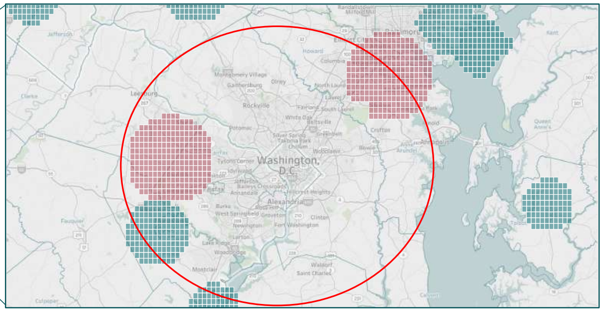
MORE THAN 50% POPULATION IN URBAN AREAS MAY BE UNDER CONTROLLED AIRSPACE AND ....

More than 50% of the population in most urban areas are under controlled airspace which could limit the number of operations in an urban area.

Urban Area	% population under Controlled Airspace				
	Class B	**Class C**	**Class D**	**Class E**	**Total**
New York	41%	15%	3%	0%	60%
Los Angeles	3%	42%	17%	0%	62%
Dallas	23%	35%	0%	0%	58%
Miami	17%	39%	14%	0%	70%
Houston	30%	15%	0%	0%	45%
San Francisco	13%	24%	24%	0%	61%
Washington DC[1]	11%	4%	0%	0%	15%
Phoenix	19%	42%	0%	0%	61%
Denver	3%	36%	0%	0%	40%
Hawaii	22%	18%	5%	2%	47%

[1] Washington DC is usually under security related TFR as shown by red circle





Source: FAA

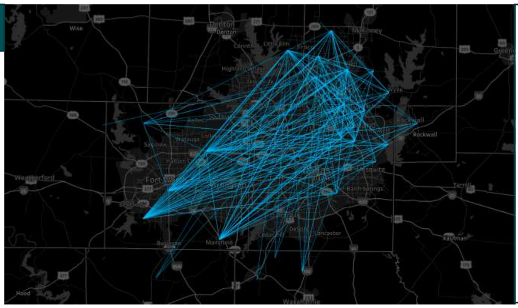
…. OVER AT LEAST 85% OPERATIONS MAY BE FLOWN IN CONTROLLED AIRSPACE

Our first order assessment shows that more than 85% of the operations in most urban areas may be flown[1] *under controlled airspace. Existing air traffic control may not have sufficient capacity to administer the large amount of operations.* ***New technologies like UTM*** *will be needed to serve the Air Taxi market.*

Urban Area	Not Controlled Airspace (A)	Controlled Airspace (B)
New York	10%	90%
Los Angeles	10%	90%
Dallas	15%	85%
Miami	5%	95%
Houston	16%	84%
San Francisco	12%	88%
Washington DC	22%	78%
Phoenix	13%	87%
Denver	36%	64%
Hawaii	11%	89%

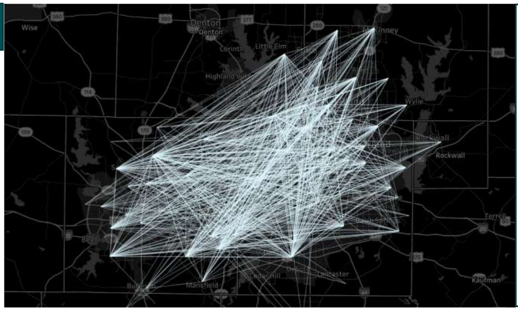
[1] Our analysis assumes that a mission is completed on a great circle track. We simply add detour factor to take into account deviation in flight tracks based on airspace, noise, weather constraints etc. However, airspace design is a complicated process as shown by active researches done at MIT, NASA etc.

A



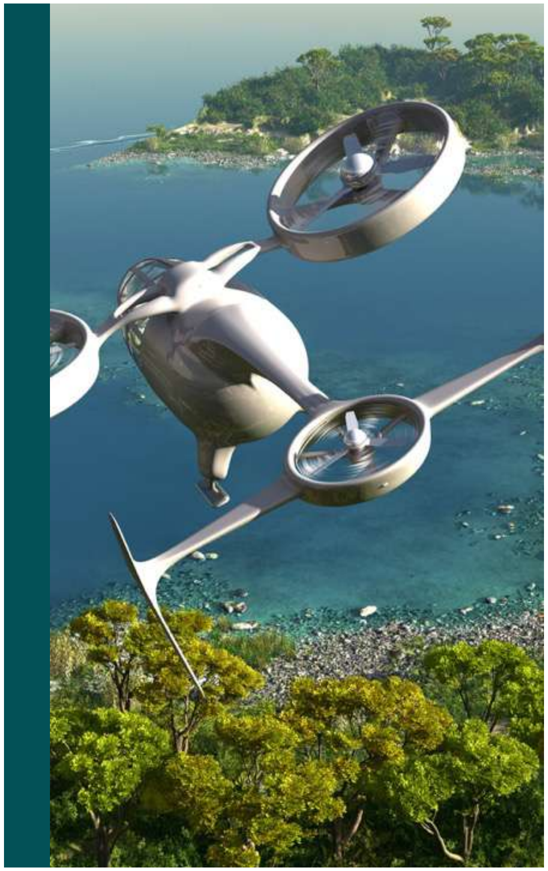
In this case, O-D infrastructure are outside the controlled (B-E) airspace (CA). Since flight path may still intersect CA, operators can make a detour (captured under detour factor) and not fly great circle track to avoid CA.

B



In this case, either origin or destination infrastructure are in the controlled (B-E) airspace (CA). Therefore, CA cannot be avoided using detours or other track efficiency metrics.

Note: Subset of the trips (>~1 trip/hr. per infrastructure) shown for Dallas in the above figures



CONTENTS

ENVIRONMENTAL IMPACTS OF AIR TAXIS MAY BE CRITICAL FOR PUBLIC ACCEPTANCE AND REGULATIONS

- **Environmental factors** will play large role in governing the role of air taxis in an urban environment, and have been **contributing factors in the failure of other technological advances in aviation** (like Concorde).
- Societal Barriers focus groups indicated **low public acceptance of large number of high-noise Air Taxi operations**. Therefore, we focus our analysis on noise and map number of potential operations in quite (<50 dB) and non-quite (>50 dB) areas

Emissions

Emissions and CO_2 will depend on sources of electricity – usually less but some sources may have equivalent carbon footprint to conventional fuel use.

Noise

Noisy operations could severely constraint Air Taxi market as historically observed with helicopters.

Ecological Impacts

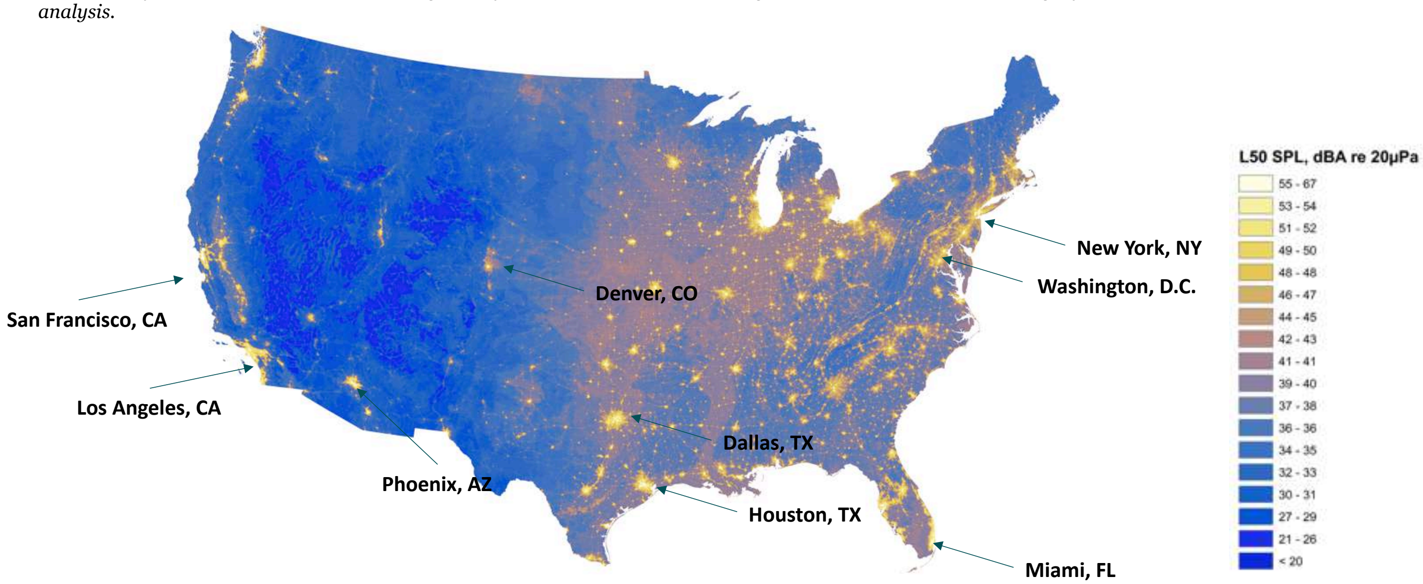
Air taxis have potential to cause ecological impacts to avian populations in cities, increase risk of bird collisions and other impacts on animals.

Visual Pollution

Growth in scale of operations will cause visual pollution in cities, increases in DNL.

BACKGROUND NOISE MAP FROM NATIONAL PARK SERVICE

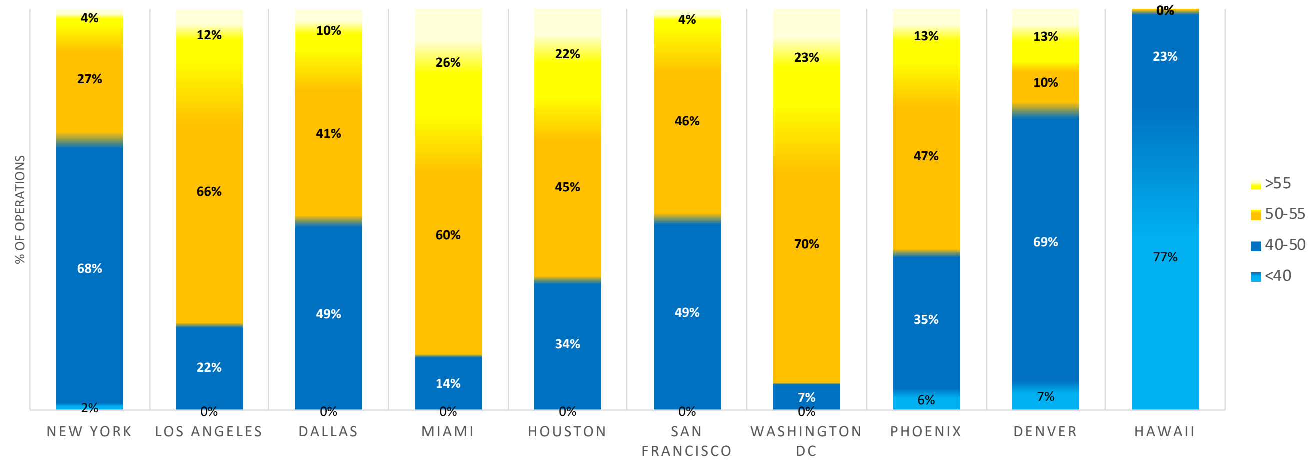
National Park Service made long term measurements of sound in parks as well as urban and rural areas across the country which helped predict current sound levels for the entire United States. Using this information, we calculate average noise level around each existing infrastructure considered in this analysis.



Source: National Park Service, 2017

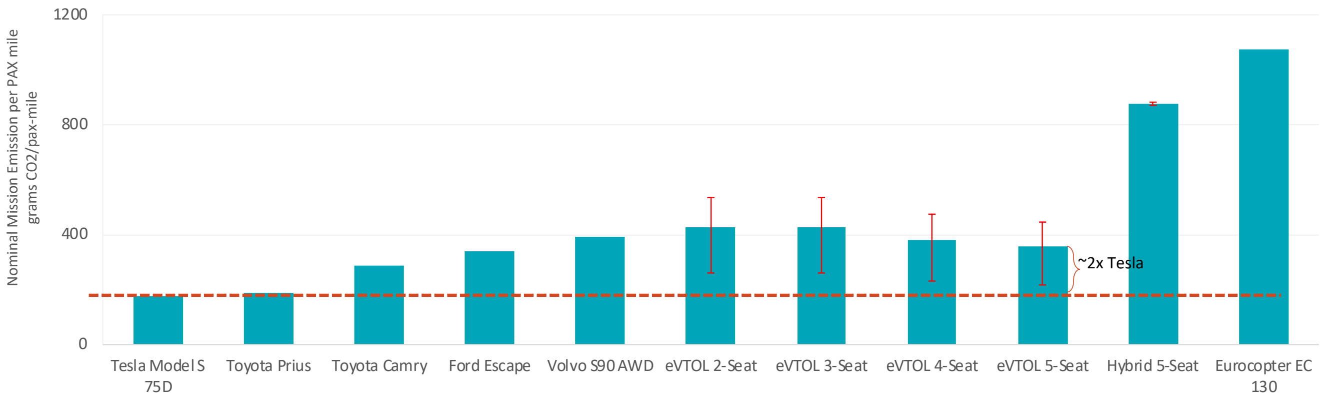
LARGE PERCENTAGE OF OPERATIONS ARE IN THE AREAS OF LOW BACKGROUND NOISE

- Our preliminary first order noise analysis (available in Appendix 4.7) showed that **noise exposure is expected to be more severe near the take-off and landing areas**. Also, there are may be ways to mitigate noise impacts while in flight by choosing routes and flying altitude of minimum impact.
- Urban areas like **Washington DC, Los Angeles and Miami** have most of their **operations in areas of high background noise** (greater than 50 dB as defined by Federal Highway Administration). **Public acceptance** to Air Taxi operations in these urban areas **may be higher** in comparison to New York, Hawaii or Denver



WELL-TO-WAKE GREENHOUSE GAS (GHG) EMISSIONS

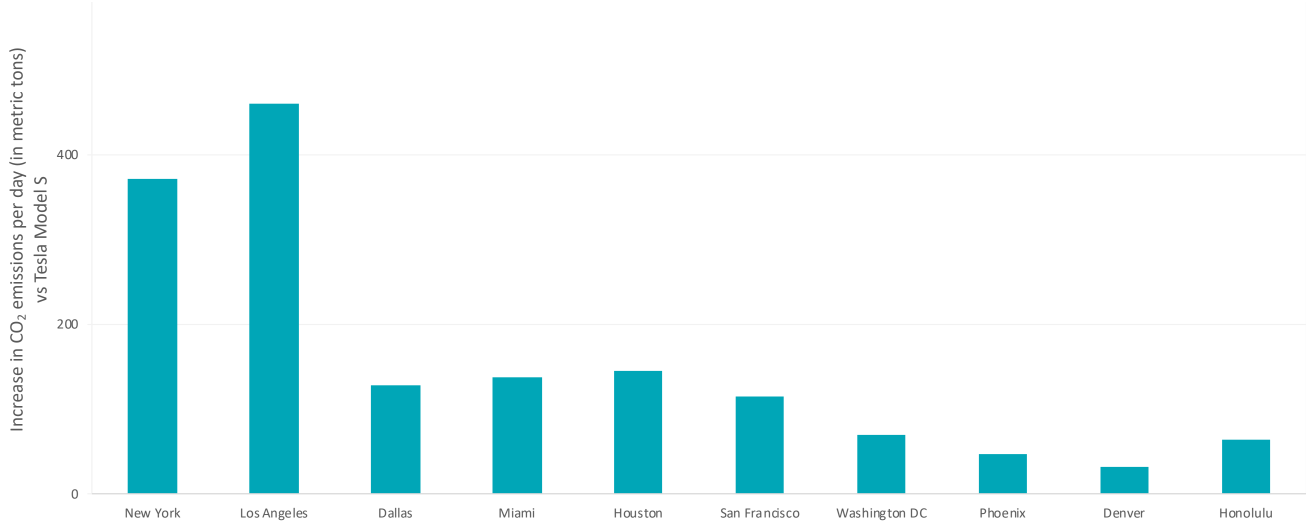
- US Department of Energy and Environment Protection Agency (EPA) estimates a vehicle's impact on climate change in terms of the amount of greenhouse gases, mostly carbon dioxide (CO_2). Tailpipe emissions and upstream emissions include CO_2, methane, and nitrous oxide emitted from all steps in the use of a fuel, from production and refining to distribution and final use—vehicle manufacture is excluded.
- Our first order analysis shows that a 5 seat eVTOL (at 75% load factor) is expected to generate **~2 times more CO_2 emissions per passenger mile[1]** when compared with Tesla Model S 75D (1.54 persons per vehicle), but 35% less than Eurocopter EC 130 in the worst case scenario.

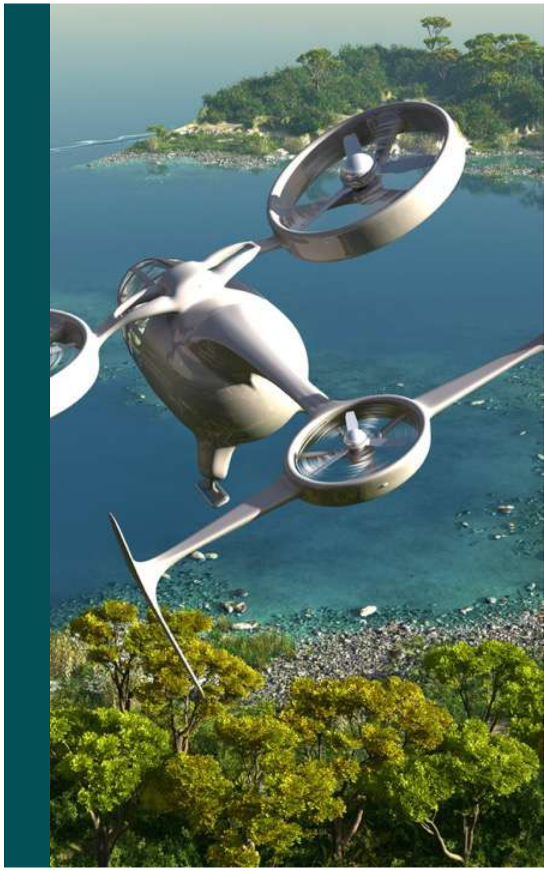


[1]Takes into account the extra distance required on road vs air. A factor of 1.42 is used. To calculate CO_2 emissions, we use energy requirement per vehicle mile calculated earlier in supply side modeling and extrapolated Tesla GHG emissions per mile to obtain grams CO_2 per vehicle mile. Load factor of 75% (including pilot) was then applied to obtain grams CO_2 per passenger trip mile. It is to be noted that energy required to perform reserve mission and deadend trips was not included. Uncertainty bars represent energy usage of different vehicle types explored in this study

AIR TAXI WILL LIKELY ADD SIGNIFICANT AMOUNT OF WELL TO WAKE GHG EMISSIONS AS COMPARED TO ELECTRIC CARS

- On average, Air Taxi market at the system level is likely to contribute **significant well-to-wake (WTW) GHG emissions** as compared to Tesla Model S 75D when the same Air Taxi mission is performed by Tesla on the ground.
- To serve the near term Air taxi demand in Urban areas like New York and Los Angeles combined can add more than **800 metric tonne of WTW CO_2 emissions** might be added to the atmosphere based on current sources of electricity generation (averaged across US)





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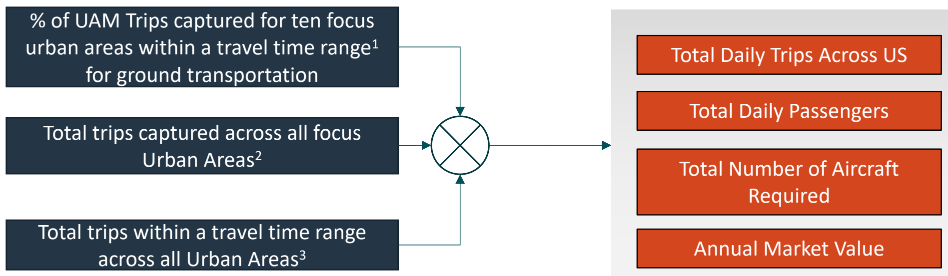
METHOD TO ESTIMATE TOTAL DEMAND FOR US



$$Total\ Daily\ UAM\ trips = \sum UAM\ Trips_{10} \times C_i \times \frac{\sum T_{tot}\ (i)}{\sum T_{10}\ (i)}$$

where,

UAM Trips$_{10}$: Total Daily trips for ten focus urban areas

i : Travel time ranges in minutes i.e. 0-10, 10-20, 20-30, 30-60 and 60+

C_i:% of UAM Trips captured for ten focus urban areas within a travel time range, i, for ground transportation

$T_{tot}(i)$: Total daily trips across all urban areas in US within a travel time range, i,

$T_{10}(i)$: Total daily trips for ten focus urban areas within a travel time range, i

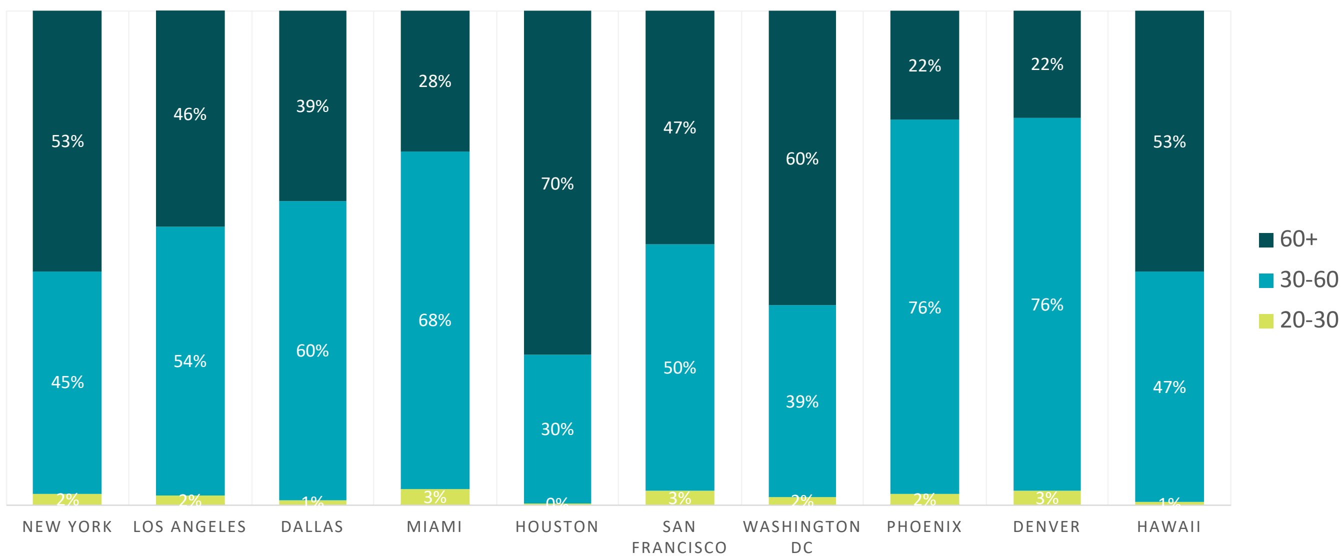
[1]*Travel time ranges as defined by American Community Survey, 2016.Travel time ranges in minutes i.e. 0-10, 10-20, 20-30, 30-60 and 60+*

[2]*Focus urban areas include New York, San Francisco, Denver, Dallas, Miami, Honolulu, Los Angeles, Phoenix, Washington DC and Houston*

[3]*There are in total 484 urbanized areas in US as defined by US Census Bureau*

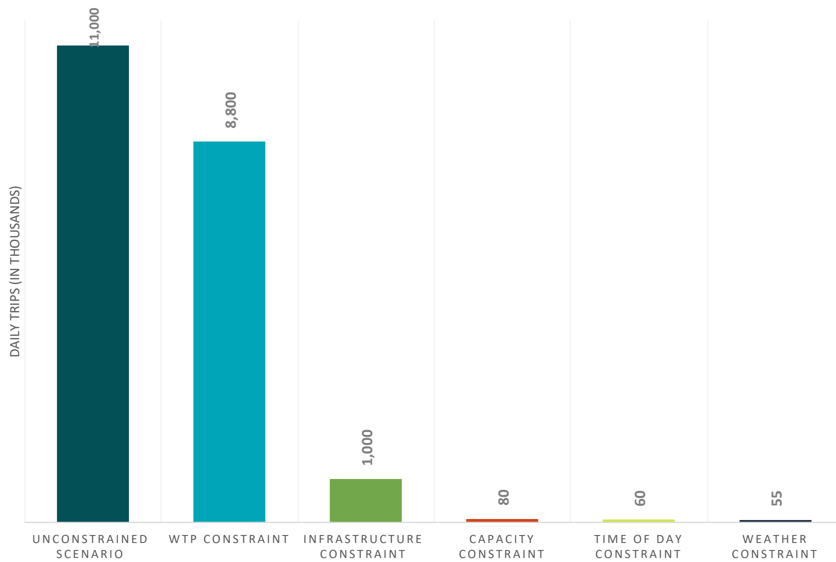
PERCENT OF UAM TRIPS CAPTURED FOR TEN FOCUS URBAN AREAS

*Air Taxi market generates **~98%** of it's demand by capturing part of the **long trips (i.e. 30 mins and more)** served by ground transportation.*

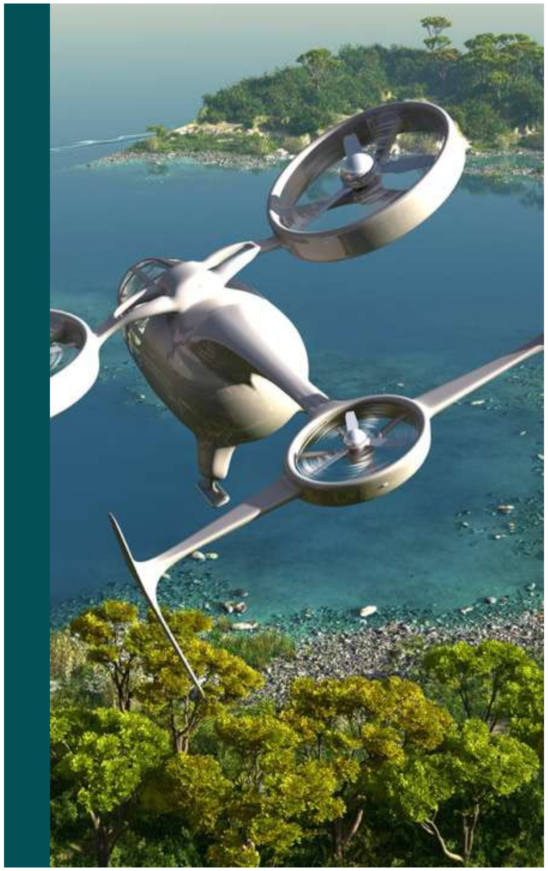


OVERALL MARKET SIZE AND VALUE

*Air Taxi market has a potential demand of ~**55k daily trips** (or ~ **80k daily passengers**) across the US that can be served by ~**4k aircraft.** Based on near term market entry assumptions, annual market value is projected to be ~**$2.5 bn** for the first few years of operation.*



	Daily Trips	Daily Passengers	Total Number of Aircraft	Annual Market Value (in bn $)
Un-constrained	11,000,000	16, 000, 000	850, 000	500
WTP Constraint	8, 800, 000	13, 000, 000	680, 000	400
Infrastructure Constrained	1, 000, 000	1, 500, 000	80, 000	45
Capacity Constraint	80, 000	120, 000	6, 000	3.6
Time of Day Constraint	60, 000	90, 000	4, 500	2.75
Weather Constraint	55, 000	82, 000	4, 100	2.5



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FRAMEWORK FOR DEVELOPING SCENARIOS FOR ANALYSIS OF URBAN AIR TAXI (UAT)

THE EMERGENCE AND GROWTH OF THE UAT MARKET IS EXPECTED TO BE DRIVEN BY SEVERAL FACTORS[1]

- ATM infrastructure capabilities and development
- Ground infrastructure capabilities and development
- Aircraft noise/community noise tolerance
- Regulatory environment for certification
- Continued investment
- Demand for Urban Air Taxi (UAT) services,

SCENARIOS WILL ALSO BE DEPENDENT ON:

- Current state of the UAT System of System (SoS) (e.g., in the analysis reference base year)
- Decisions and actions by key stakeholders in the UAT market
- Future states (evolution) of the UAT System of System

[1]UAM SoS also includes layers of reliability/security, weather, training/workforce, cybersecurity and public perception about technology. BAH team plans to include these in future scenarios.

FRAMEWORK FOR DEVELOPING SCENARIOS FOR ANALYSIS OF URBAN AIR TAXI (UAT)

FRAMEWORK FOR DEVELOPING SCENARIOS FOR EMERGENCE AND GROWTH OF THE UAT MARKET

System of System Layer	Current **System State**	**Decisions & Actions by Stakeholders**	**Future States** (evolution of the UAT SoS)
Supply Side (for UAT)	N/A	- Technology scenarios - Operating model - Pricing strategy	- Technology (eVTOL) characteristics - Operating characteristics - Pricing/Premiums
Demand (for UAT)	- Population, - B2B Trip Characteristics, - Realized Demand	- General population/demand trends - Actions from other modes of transport (i.e., competition)	- Demand for UAT
ATM Infrastructure	- ATM Procedures - Airspace capacity (given current system)	- Enhancement to current system - Development of UTM	- Airspace capacity - Heliport/Vertiport capacity
Ground Infrastructure	- Set of existing Heliports and Airports	- Capacity increase of Heliports/Airports - Creation and development of new "Vertiports"	- Number, location and capacity of Vertiports

TECHNOLOGY AND INFRASTRUCTURE SCENARIOS

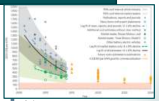
We outline a set of illustrative technology and infrastructure scenarios to measure the order-of-magnitude implications of improvements and investments in technology and infrastructure proposed to be used for Urban Air Mobility. Each of these scenarios are evaluated independently first and then in an integrated form.

Technology and Infrastructure Scenarios

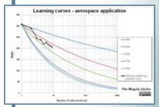
A Technology Improvements

This scenario includes improvements in battery technology and reduction of vehicle cost due to manufacturing learning and experience.

- Li-ion battery capacity specific cost is expected to fall to the **$100/kWh to $150/kWh** price range by 2025 at a $10/kWh annual reduction (Nykvist)
- On average, **vehicle cost reduces by ~15%** on doubling the production (source: NASA). We **double the production every five years.**



Nykvist



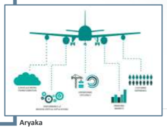
The blog by Javier

B High Network Efficiency

Network efficiency parameters like load factor, utilization and dead-end trips are among the most significant parameters that influences the operating cost (slide 56). We consider following improvements in these factors:

Utilization: ~7 hours/day (from ~4 hours/day) may be possible due to supercharging, higher system capacity, demand etc.
Load Factor: ~80% (from ~65%) similar to commercial aviation
Deadend trips: ~20% (from ~37.5%)

JDA Aviation Technology solutions



Aryaka

D Infrastructure Improvements

This scenario assumes enhancement to the current air traffic system (or a developed UTM system), which allows in-part an increase of vertiport's operations capacity

Increase in number of vertiports is coupled with increase in capacity. We **double the number of vertiports and operational capacity every five years** to measure new demand.

NASA

Gannett Fleming Image

C Autonomous eVTOL

Most of the vehicles being developed are expected to have the capability to be fully autonomous. Given the pilot shortages facing the aviation industry and the scale of UAM operations anticipated, autonomy may play a key role to fully capture the realized demand. For this scenario we assume the following:

- **Pilot not required**, and therefore **all the seats are available to passengers**
- An **extra ground staff** required to do safety briefings, loading and unloading of passengers.

Bell Helicopters

Uber

DEMAND SCENARIOS

We outline a set of illustrative scenarios to measure the order-of-magnitude implications of new technologies / concepts like autonomous cars, telecommuting trends and new importance to travel time due to other enabling teleconferencing technologies. Each of these scenarios are evaluated independently first and then in an integrated form.

Demand related Scenarios

E New importance of travel time

Continuous advancement in Virtual Reality / Augmented Reality, large screens, new interiors in ground vehicles and other teleconferencing technologies may **enhance the productivity** of the human driver/passenger while in transit. Increased productivity may result in **decrease in value of travel time**, thereby affecting demand of Urban Air Taxis

We evaluate the importance of travel time/cost by introducing a **significance factor in the utility function** (slide 83) and vary it between 0 and 1. '0' represents no importance to travel time and the user is expected to chose the mode entirely based on price, comfort etc.

The Zebra

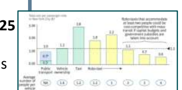
Shutterstock

F Competition from other modes

Autonomous cars, high speed rails and many new or improved existing modes of transportation may pose a potential challenge to the adoption / demand of urban air taxis. Under this scenario, we examine the emergence of fully autonomous vehicles (AVs) only.

BCG U.S. Self-Driving Cars survey 2014 showed **strong willingness** among the American consumers to buy **autonomous cars**. The analysis further shows a **penetration rate of 0.5% and 10% in 2025 and 2035** for full AVs. At an average occupancy rate of ~65% (similar to eVTOL), we use ~$0.9 cost per passenger mile, which is **~35% less than current car ownership / operating costs** in our mode choice model

Strategic Finance



BCG

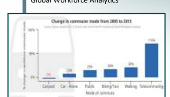
G Telecommuting

Regular telecommuting grew 115% in the past decade (i.e. ~10% annual), nearly 10 times faster than the rest of the workforce. Current telecommuting population of 3.9 million (3% of total workforce) avoided 530 million trips or 7.8 vehicle miles annually (source: Global Workforce Analytics)

We consider a scenario where **telecommuting continues to increase[1] at a rate of ~10% every year** to scope the available demand.

[1]Several researches have shown a possible reverse trend in telecommuting where companies (like IBM) are restricting telework (source: Comcast, Blank Rome LLP, IBM)

Global Workforce Analytics



Global Workforce Analytics

H Congestion & Latent Demand

eVTOLs can induce new mobility patterns including **de-urbanization** i.e. people moving out of the city due to faster transportation options available. We explore such a scenario using parametric analysis by varying average distances for each trip by -25% to +25% at an interval of 10%. Negative percentage indicates increased urbanization.

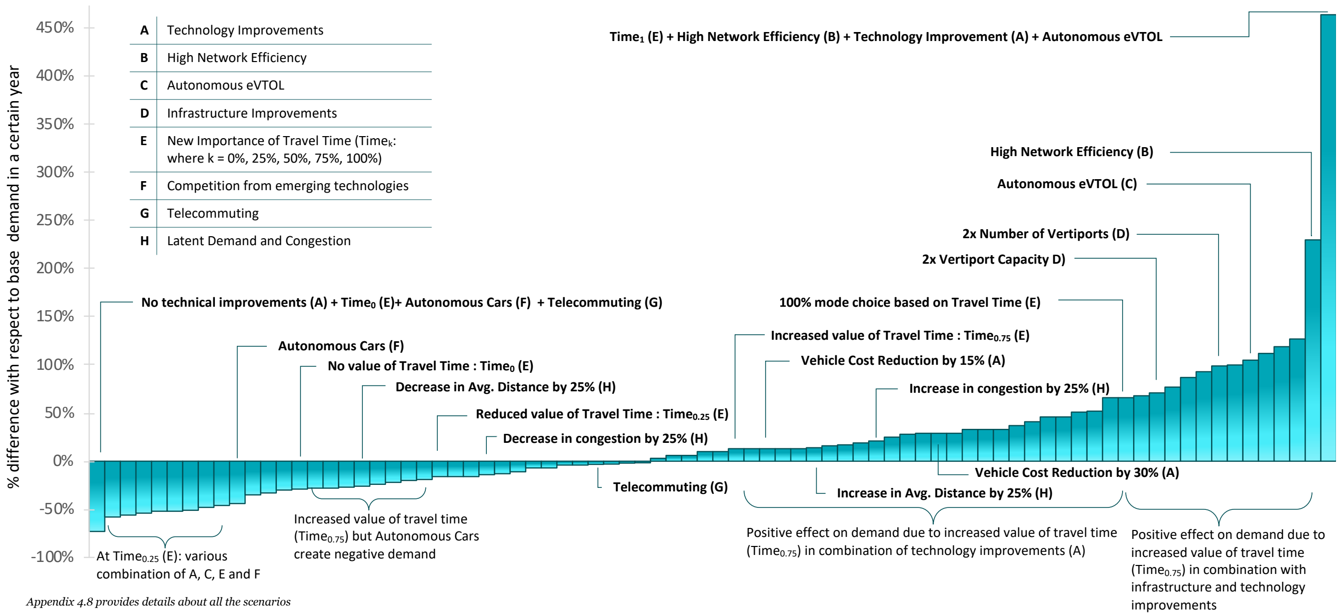
Finally, mega cities can get **more congested over time**. However, in some scenarios (more pooling, better public transportation etc.), cities can also de-congest. We explore such possibilities by varying average driving speed by -25% to 25% at an interval of 10%. Negative percent indicates increased congestion.

CNBC

V2Gov

LARGE DEMAND MAY BE ACHIEVED BY HIGH NETWORK EFFICIENCY BUT AUTONOMOUS CARS ARE EXPECTED TO PROVIDE STRONG COMPETITION

- **Autonomous vehicle** and **reduced importance of travel time** may severely **constrain the demand for Air Taxis**. Telecommuting further reduces the demand marginally.
- **High network efficiency**, increased importance of travel time, **autonomous eVTOL**, **technology improvements,** and increased available infrastructure/capacity may all **increase demand.**



Appendix 4.8 provides details about all the scenarios

SUMMARY AND CONCLUSIONS

- High variability in demand is observed for all ten selected urban areas. Monte Carlo simulations provided a combined daily potential demand of **~55k daily trips** (or **~ 80k daily passengers**) across the US that can be served by **~4k aircraft.**
- For the first few years of operation, **market value** of total available demand is projected to be **~$500 bn** while only **~$2.5 bn can be potentially captured** due to operation constraints
- In order to scale up demand, **new ground infrastructure** with larger operational capacity would need to be built, and **operating costs lowered**. Increased demand would risk posing greater noise concern for impacted communities.
- Air Taxi market generates ~98% of it's demand by capturing part of the long trips (i.e. 30 mins and more) served by ground transportation.
- Over **85% operations** may be **flown in controlled airspace** (B-E) where existing air traffic control may not have sufficient capacity to administer the large amount of operations. New technologies like **UTM** may be needed to serve the Air Taxi market.
- **Large percentage of air taxi operations** are in the **areas of low background noise**. Community acceptance of operations in areas of low background is usually low.
- On average, Air Taxi market is likely to **add significant upstream GHG emissions** as compared to high-end electric car when the same Air Taxi mission is performed by the electric car on the ground.
- **High operational efficiency** (i.e. increased utilization, high load factor and lower dead-end trips), increased importance of travel time, higher congestion, **autonomous eVTOL**, **technology improvements** and increased available infrastructure/capacity may all **increase demand.**
- **Autonomous vehicle** and **reduced importance of travel time** may severely **constrain the demand for Air Taxis**. Telecommuting further reduces the demand marginally.

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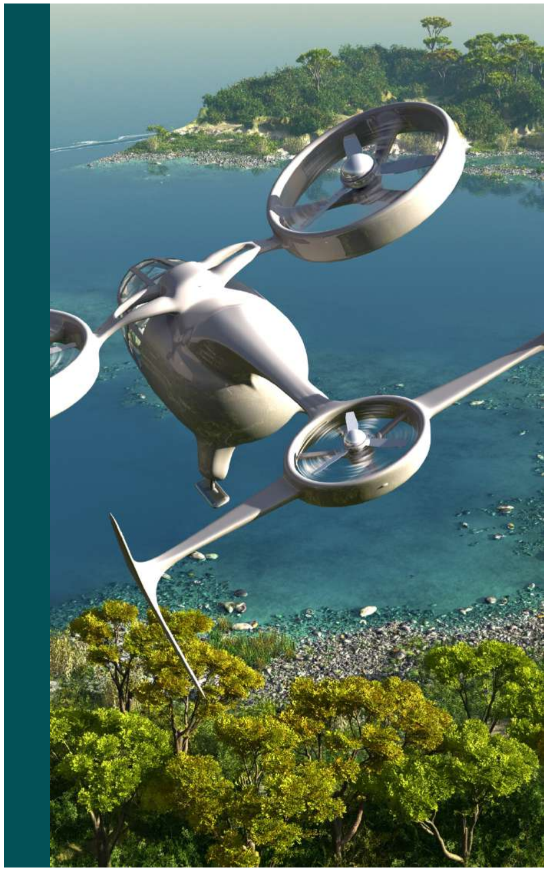


AGENDA

AIR AMBULANCE IS A COMPLEX POTENTIAL MARKET

AIR AMBULANCE OVERVIEW

Definition: The Air Ambulance market includes travel to/from the hospital for emergencies and potentially hospital visits. Both public and private operations are considered.

Selection Criteria: A complex market and likely to highlight technology barriers in terms of technical capabilities needed on board the aircraft, in addition to other legal and regulatory barriers. Air Ambulances have high public acceptability.

Value Proposition: Lifeline; public safety; reduction of travel time by 1.5-2 times, hence reducing fatalities

Market Dynamics:

- **Market Size:** Relatively limited market; however, the services are of high value
- **Market Drivers:**
  - Events i.e. Accidents, health related events etc.
  - Demographic trends
  - Healthcare legislation
  - Changes in insurance policies
- **Potential Business Models at Play:** Insurance subscription, hospital ownership, fleet operators, pay per ride

Connected Markets: Emergency Response markets such as law enforcement, natural disaster response, and firefighting

Source: BAH Analysis; Ibis, 2016

AGENDA

THERE ARE MULTIPLE VEHICLE TYPES USED IN AMBULANCE INDUSTRY AND….

Ambulance Industry provides transportation of patients by ground or air, along with medical care. These services are often provided during a medical emergency, but they are not restricted to such instances. The vehicles are equipped with lifesaving equipment operated by medically trained personnel. See Appendix 5.1 for more details.

Ground Transportation

- Typically used for short-distance patient transport from scene to hospital or inter-facility transfer
- Includes both ALS (advanced life support) and BLS (basic life support) emergency and non-emergency care

Current Service Data

- **Number of Vehicles:** ~50, 000
- **Total Businesses:** ~3400
- **Total Revenue:** ~$11bn per year

Source: Ibis 2016

Helicopter

- Helicopter or Rotary Wing (RW) services are typically used for short- distance transport between the accident or patient site, and a hospital
- Mainly used for emergency transport by air and critical care services performed on site

Current Service Data

- **Number of Vehicles:** 1049
- **Number of RW Bases:** 908
- **Total Revenue:** ~$4bn per year

Source: Atlas, 2017; Ibis 2016

Fixed Wing

- Fixed-wing (FW) ambulances look similar to traditional airplanes and are typically larger than rotary-wing
- Typically used for long distance emergency care
- Often utilized by patients that require transport across countries and oceans

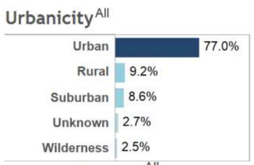
Current Service Data

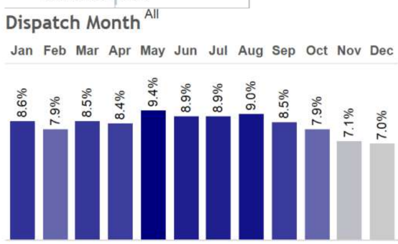
- **Number of Vehicles:** 362
- **Number of FW Bases:** 209
- **Total Revenue:** ~$1bn per year

Source: Atlas, 2017; Ibis, 2016

…. USUALLY HAS A RESPONSE TIME OF LESS THAN 15 MINUTES IN AN URBAN ENVIRONMENT

Ground ambulances mostly operate in an urban environment for short distances to maintain response time of less than 15 minutes. On the other hand, air ambulances, like rotary wing, usually operate between rural and urban environments.

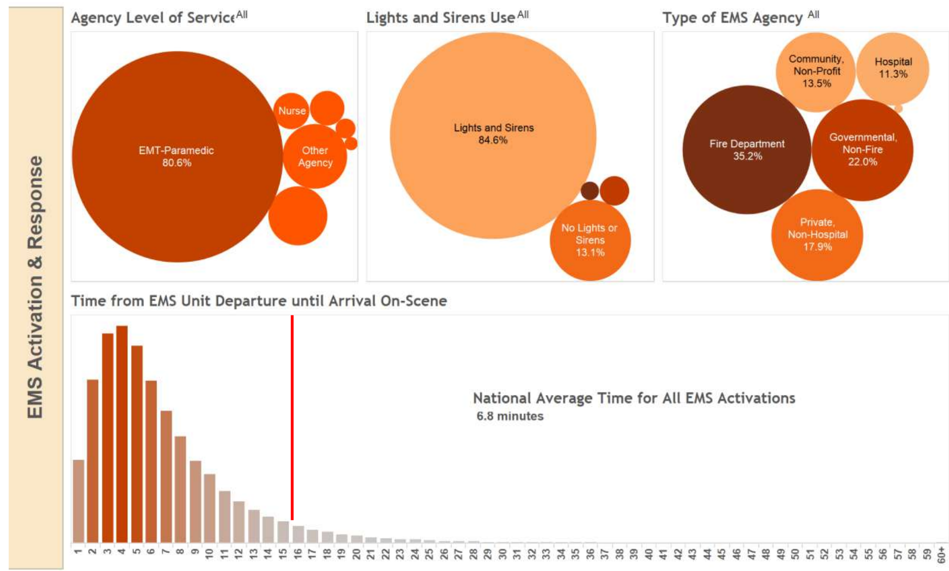




Dispatch Time All

All

	Sun	Mon	Tue	Wed	Thu	Fri	Sat
12 AM - 6 AM	2.3%	1.4%	1.4%	1.4%	1.4%	1.6%	2.3%
6 AM - 12 PM	2.2%	3.2%	3.3%	3.3%	3.2%	3.3%	2.8%
12 PM - 6 PM	4.3%	5.6%	5.7%	5.6%	5.7%	6.6%	5.2%
6 PM - 12 AM	3.4%	3.8%	3.8%	3.9%	4.1%	5.0%	4.4%



Source: NEMSIS, 2018

THERE ARE NINE SERVICE LEVELS AS DEFINED BY CENTERS FOR MEDICARE & MEDICAID SERVICES (CMS) AND ....

Centers for Medicare & Medicaid Services (CMS)

- Administers the Medicare program
- Works in partnership with state governments to administer Medicaid, the Children's Health Insurance Program (CHIP), and health insurance portability standards (Wikipedia, 2018)

CMS Service Level

- Different medical equipment, crew and vehicle requirements for each service level
- Nine levels of service differentiated by the following means of transport:
  - Ground Ambulance
  - Air Ambulance

Emergency Response

- The determination to respond emergently with an ambulance must be in accord with the local 911 or equivalent service dispatch protocol

	Service Level	Definition
Ground Ambulance	BLS (Basic Life Support) non-emergent	Provision of medically necessary supplies and services
	BLS Emergency	Provision of BLS services, as specified above, in the context of an emergency response
	ALS (Advanced Life Support) non-emergent	Provision of medically necessary supplies and services including the provision of an ALS assessment or at least one ALS intervention
	ALS1 (Advanced Life Support) emergent	Provision of ALS services in the context of an emergency response
	ALS2 (3 separate medications by IV)	Provision of ALS services in the context of an emergency response plus 3 separate medications by IV
	SCT (Specialty Care Transport)	Interfacility transportation of a critically injured or ill beneficiary including the provision of medically necessary supplies and services
	PI (Paramedic Intercept)	ALS services provided by an entity that does not provide the ambulance transport
Air Ambulance	Rotary Wing (Helicopters)	BLS or ALS type service for short distances that require rapid air transport
	Fixed Wing	BLS or ALS type service for long distances that require rapid inter-city air transport

…. CREW REQUIREMENT VARIES WITH SERVICE LEVELS

Each service level has different crew, experience and training requirements.

According to FAA duty hour requirements, a single emergency eVTOL will require 4 full time pilots, 4 full time flight nurses, and 4 full time paramedics with CAMTS Accreditation. Each crew goes through annual training requirements.

Service Level	Driver[1]/Pilot[2]	Emergency Medical Technician (EMT)[3]	Paramedic[4]	Health Professional[5]	Total
BLS (Basic Life Support) non-emergent	1	2	-	-	3
BLS Emergency	1	2	-	-	3
ALS (Advanced Life Support) non-emergent	1	1	1	-	3
ALS1 (Advanced Life Support) emergent	1	1	1	-	3
ALS2 (3 separate medications by IV)	1	1	1	-	3
SCT (Specialty Care Transport)	1	1	-	1+	3+
PI (Paramedic Intercept)	1	1	-	1+	3+
Rotary Wing (Helicopters)	1	1	1	-	3
Fixed Wing	1+	1+	-	1+	3+

[1]**Driver**: Drives the patients from place to place. This analysis does not require driver to perform any medical duties.

[2]**Pilot**: Required to conduct flight planning, preflight risk analyses, safety briefings for medical personnel, and the establishment of operations control centers (OCC) for certain operators to help with risk management and flight monitoring.

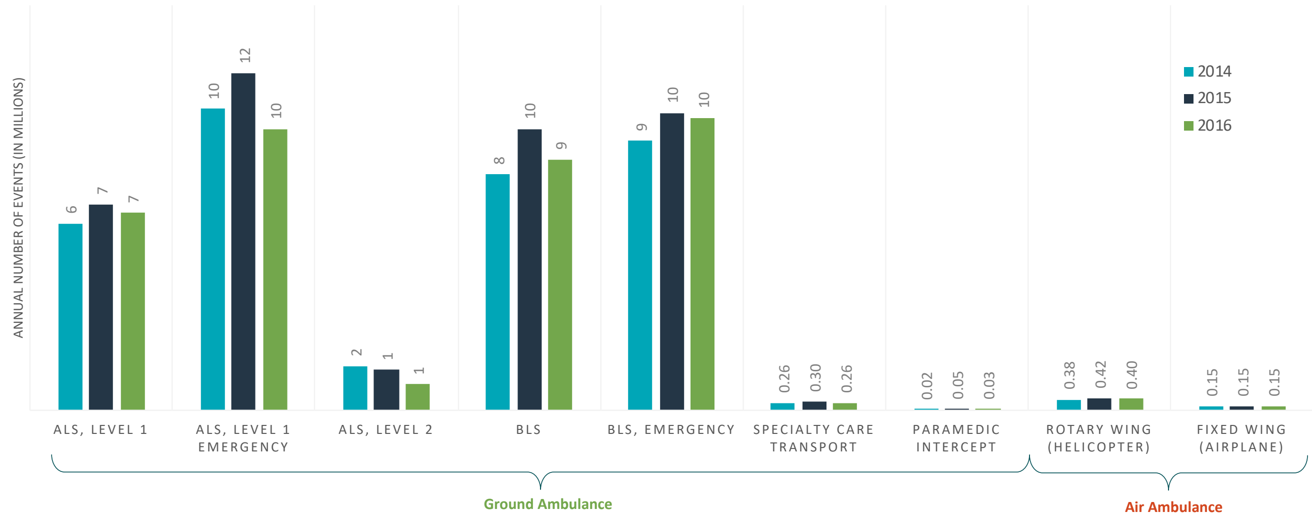
[3]**EMT**: Entry-level EMS healthcare professional trained in BLS, anatomy/physiology, pathophysiology, pharmacology, ECG monitoring, advanced airway management (supraglottic airways) and spinal immobilization.

[1]**Paramedic**: Emergency Ambulance Practitioner. Trained in advanced Pharmacology, advanced Airway management etc., Advanced Life support.

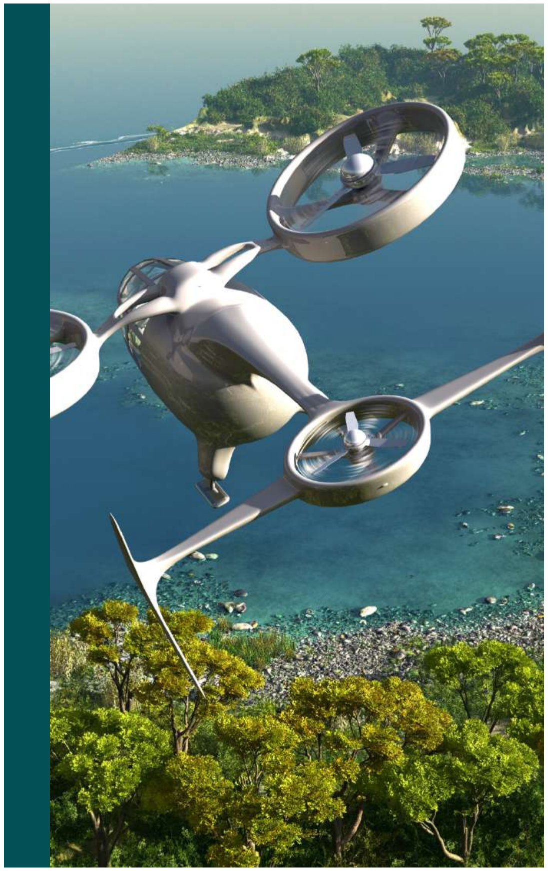
[5]**Health Professional**: Trained to Paramedic level plus IV & IO access, a wide range of medications, tracheal intubation, manual defibulator, etc.

AROUND 1.5% OF TOTAL EVENTS ARE SERVED BY AIR AMBULANCES

- Air Ambulances comprise a relatively small proportion of all ambulance service level events of which 2/3rd are life guard operations
- Air Ambulance events follow the same general trends as the rest of the ambulance market, demonstrating no clear growth or decline relative to other service levels.



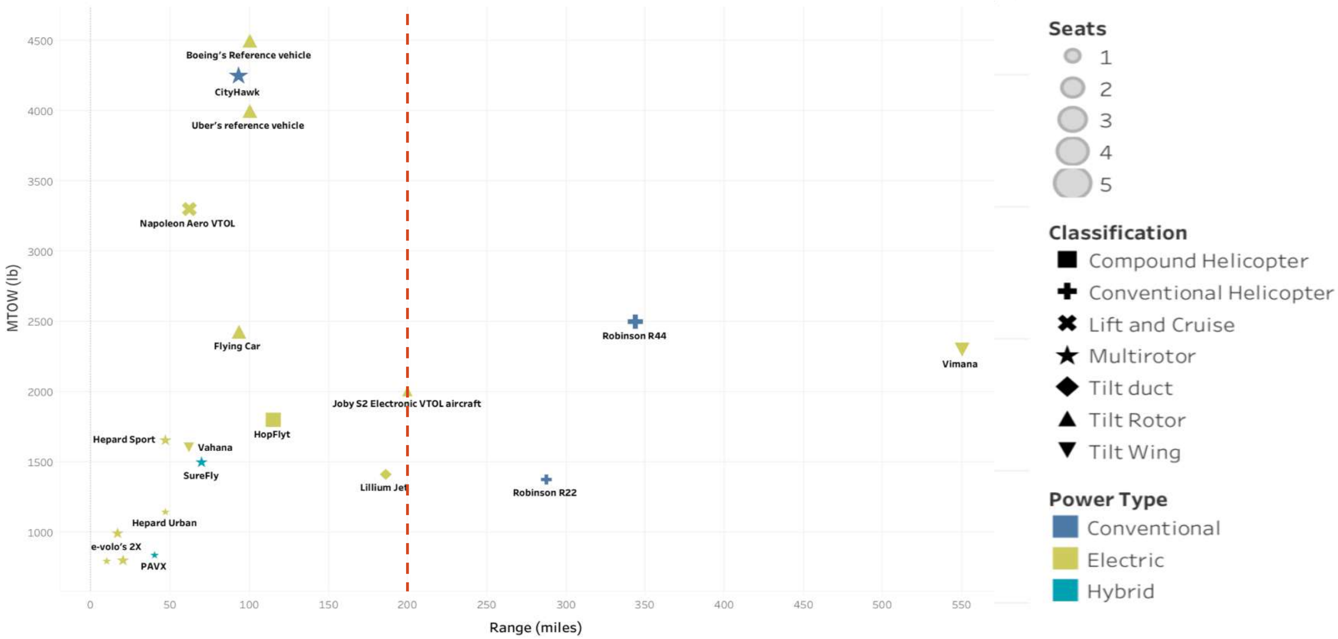
Data Source: NEMSIS, 2018; NASEMSO, 2011. See Appendix 5 for more details



AGENDA

MULTIPLE CLASSES OF AIRCRAFT ARE PROPOSED FOR AIR AMBULANCE MARKET

*Vehicles with **electric and hybrid power type** are proposed for the air ambulance market. Vehicle sizing, speed and range requirements are described later in the study.*



MANY DESIGNS IN MULTIROTOR AND TILT ROTOR MARKET AROUND THE WORLD

NON-EXHAUSTIVE

MULTIROTOR MARKET OVERVIEW

Manufacturer	Product	Technical Specifications
Workhorse Photo Source: http://workhorse.com/surefly	*SureFly* 	*Passengers* 2 *Range* 70 mi *MTOW* 1500 lbs. *Cruise Speed* 50 mph *Cost* $200,000 *Timeline* First flight in April 2018.
Astro Photo Source: https://flyastro.com/	*Passenger Drone* 	*Passengers* 2 *Range* 20 mi *MTOW* 800 lbs. *Cruise Speed* 50 mph *Cost* $150,000 *Timeline* First flight in August 2017
Ehang Photo Source: http://www.ehang.com/ehang184/gallery/	*Ehang 184* 	*Passengers* 1 *Range* 10 mi *MTOW* 795 lbs. *Cruise Speed* 50 mph *Cost* $250,000 *Timeline* Flight testing in 2016-2017
VRCO Photo Source: http://www.vrco.co.uk/	*NeoXCraft* 	*Passengers* 2 *Range* 210 mi *MTOW* 1600 lbs. *Cruise Speed* 50 mph *Cost* $2M *Timeline* NA

TILT ROTOR MARKET OVERVIEW

Manufacturer	Product	Technical Specifications
Bartini Photo Source: https://bartini.aero/	*Flying Car* 	*Passengers* 4 *Range* 93 mi *MTOW* 2425 lbs. *Cruise Speed* 150 mph *Cost* $120,000 *Timeline* Fully functioning by 2020
Joby Aviation Photo Source: http://www.jobyaviation.com/S2ConceptualDesign(AIAA).pdf	*S2 EVOTL* 	*Passengers* 2 *Range* 200 mi *MTOW* 2000 lbs. *Cruise Speed* 150 mph *Cost* $200,000 *Timeline* First flight in 2018
EVA Photo Source: http://evtol.news/aircraft/eva-x01/	*XO1* 	*Passengers* 2 *Range* 156.25 mi *MTOW* 2000lbs *Cruise Speed* 150 mph *Cost* $297,619 *Timeline* Testing in 2019
XTI Photo Source: http://www.xtiaircraft.com/the-a-team/	*TriFan 600* 	*Passengers* 6 *Range* 1377 mi *MTOW* 5300 lbs. *Cruise Speed* 150 mph *Cost* $6.5M *Timeline* First flight 2019

Technical Specification Sources: eVTOL News from the American Helicopter Society

LIFT/CRUISE AND TILT DUCT VEHICLES ARE MORE POPULAR WITH US MANUFACTURERS SIMILAR TO ▯.

NON-EXHAUSTIVE

LIFT AND CRUISE MARKET OVERVIEW

Manufacturer	Product	Technical Specifications
Napoleon Aero Photo Source: http://evtol.news/aircraft/napoleon-aero-vtol/	*Napoleon Aero VTOL* 	*Passengers* 4 *Range* 62 mi *MTOW* 3300 lbs. *Cruise Speed* 150 mph *Cost* NA *Timeline* NA
Aurora Photo Source: http://www.aurora.aero/evtol/	*Electric VTOL Multicopter* 	*Passengers* 2 *Range* NA *MTOW* 1760 lbs. *Cruise Speed* 150 mph *Cost* NA *Timeline* Expected 2020
Cartivator Photo Source: http://cartivator.com/skydrive	*Skydrive* 	*Passengers* 2 *Range* NA mi *MTOW* 880 lbs. *Cruise Speed* 150 mph *Cost* NA *Timeline* NA
Skypod Photo Source: http://evtol.news/aircraft/skypod/	*Skypod* 	*Passengers* 2 *Range* NA *MTOW* 1600 lbs. *Cruise Speed* 150 mph *Cost* NA *Timeline* NA

TILT DUCT MARKET OVERVIEW

Manufacturer	Product	Technical Specifications
Lilium Photo Source: https://lilium.com/	*Lilium Jet* 	*Passengers* 2 *Range* 186 mi *MTOW* 1410 lbs. *Cruise Speed* 150 mph *Cost* NA *Timeline* Expected 2019
Skylys Photo Source: http://evtol.news/aircraft/skylys-ao/	*AO* 	*Passengers* 2 *Range* 93 mi *MTOW* 2400 lbs. *Cruise Speed* 150 mph *Cost* NA *Timeline* Expected 2018
Bell Helicopter Photo Source: http://www.bellflight.com/company/innovation/air-tax	*Bell Air Ambulance* 	*Passengers* 4 *Range* NA *MTOW* 3200 lbs. *Cruise Speed* 150 mph *Cost* NA *Timeline* Expected 2020
Aurora Photo Source: http://www.aurora.aero/lightningstrike/	*Lightning Strike* 	*Passengers* 0 *Range* NA *MTOW* NA *Cruise Speed* 150 mph *Cost* NA *Timeline* NA

Technical Specification Sources: eVTOL News from the American Helicopter Society

.... TILT WING AND COMPOUND HELICOPTER VEHICLES

NON-EXHAUSTIVE

TILT WING MARKET OVERVIEW

Manufacturer	Product	Technical Specifications
Vimana Photo Source: http://evtol.news/aircraft/vimana/	Unmanned AAV 	Passengers: 4 Range: 550 mi MTOW per seat: 2300 lbs. Cruise Speed: 150 mph Cost per seat: NA Timeline: NA
Air Bus A3 Photo Source: https://vahana.aero/welcome-to-vahana-edfa689f2b75	Vahana 	Passengers: 2 Range: 62 mi MTOW per seat: 1600 lbs. Cruise Speed: 150 mph Cost per seat: NA Timeline: Expected 2020
ASX Photo Source: http://airspacex.com/mobi-2025/	MOBi 	Passengers: 4 Range: 65 mi MTOW: 2800 lbs. Cruise Speed: 150 mph Cost: NA Timeline: Expected 2025
VerdeGo Aero Photo Source: https://www.verdegoaero.com/	Personal Air Ambulance 	Passengers: 2 Range: 40 mi MTOW: NA Cruise Speed: 150 mph Cost: NA Timeline: Expected 2020

COMPOUND HELICOPTER MARKET OVERVIEW

Manufacturer	Product	Technical Specifications
Hop Flyt Photo Source: https://hopflyt.com	Hop Flyt 	Passengers: 4 Range: 115 mi MTOW per seat: 1800 lbs. Cruise Speed: 150 mph Cost: NA Timeline: Scale model flight in 2017

CONVENTIONAL HELICOPTER MARKET OVERVIEW

Manufacturer	Product	Technical Specifications
Robinson Photo Source: https://robinsonheli.com/	R22 	Passengers: 2 Range: 287.5 mi MTOW per seat: 1370 lbs. Cruise Speed: 100 mph Cost: $300,000 Timeline: Widely Available
Robinson Photo Source: https://robinsonheli.com/	R44 	Passengers: 4 Range: 343.75 mi MTOW per seat: 2500 lbs. Cruise Speed: 100 mph Cost: $450,000 Timeline: Widely Available
Carter Photo Source: http://www.cartercopters.com/	Cartercopter 	Passengers: 6 Range: 690 mi MTOW: 2500 lbs. Cruise Speed: 100 mph Cost: NA Timeline: NA

Technical Specification Sources: eVTOL News from the American Helicopter Society

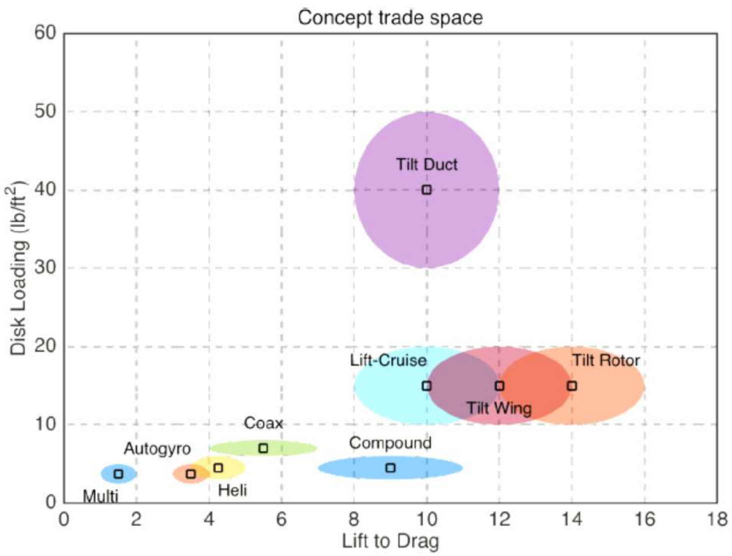
ALL NINE VEHICLE TYPES HAVE DISTINCT PERFORMANCE CHARACTERISTICS

- **Multirotor** have **low cruise** speed and lift-to-drag ratio that makes them **less desirable** for Air Ambulance market
- Tilt wing/Rotor, Lift-Cruise and Compound helicopters are in the optimum trade space and may be more favorable if they meet the range requirements

Vehicle Class	Average Cruise Speed (mph)	Lift-to-Drag Ratio	Disk Loading (lb/ft²)
Multirotor	50	1-2	2.5-5
Autogyro*	100	3-4	2.5-5
Conventional Helicopter	100	3.5-5	3-6
Tilt Duct	150	8-12	30-50
Coaxial Rotor*	150	4-7	6-8
Lift + Cruise	150	8-12	10-20
Tilt Wing	150	10-14	10-20
Compound Helicopter	150	7-11	3-6
Tilt Rotor	150	12-16	10-20

* Not considered for further analysis due to little information available

Source: Slide adapted from McDonald and German



Hybrid Aircraft

MULTIPLE VERSIONS OF HYBRID VTOL AIRCRAFT ARE PROPOSED FOR AIR AMBULANCE MARKET

- Literature suggests that hybrid aircraft have **high range capabilities** and are proposed to be **faster** than eVTOLs and conventional helicopters. Both these characteristics are beneficial for Air Ambulance market where time is of significance
- We assume **average cruise speed of 250 mph for hybrids** in comparison to 150 mph for eVTOLs and 100 mph for conventional Helicopters. Due to a lack to data, we assume **range of hybrid aircraft** to be **similar to conventional helicopters**.

Manufacturer: Workhorse

Photo Source: http://workhorse.com/surefly

Product: SureFly

Technical Specifications

Passengers	*2*
Range	*70 mi*
MTOW	*1500 lbs.*
Cruise Speed	*70 mph*
Cost	*$200,000*
Timeline	*First flight in April 2018.*

Manufacturer: PAV-X

Photo Source: https://transportup.com/pav-x/

Product: PAVX

Technical Specifications

Passengers	*1*
Range	*40 mi*
MTOW	*838 lbs.*
Cruise Speed	*NA mph*
Cost	*NA*
Timeline	*NA*

Manufacturer: VerdeGo Aero

Photo Source: https://www.verdegoaero.com/

Product: Personal Air Ambulance

Technical Specifications

Passengers	*2*
Range	*40 mi*
MTOW	*NA*
Cruise Speed	*150 mph*
Cost	*NA*
Timeline	*Expected 2020*

Manufacturer: XTI

Photo Source: http://www.xtiaircraft.com/the-a-team/

Product: TriFan 600

Technical Specifications

Passengers	*6*
Range	*1377 mi*
MTOW	*5300 lbs.*
Cruise Speed	*310 mph*
Cost	*$6.5M*
Timeline	*First flight 2019*

Manufacturer: Aurora

Photo Source: http://www.aurora.aero/lightningstrike/

Product: Lightning Strike

Technical Specifications

Passengers	*0*
Range	*NA*
MTOW	*NA*
Cruise Speed	*344 mph*
Cost	*NA*
Timeline	*First flight 2018*

Manufacturer: Hoversurf

Photo Source: http://evtol.news/aircraft/hoversurf/

Product: Drone Taxi R-1

Technical Specifications

Passengers	*1*
Range	*248*
MTOW	*NA*
Cruise Speed	*186 mph*
Cost	*NA*
Timeline	*Expected 2018*

Technical Specification Sources: eVTOL News from the American Helicopter Society

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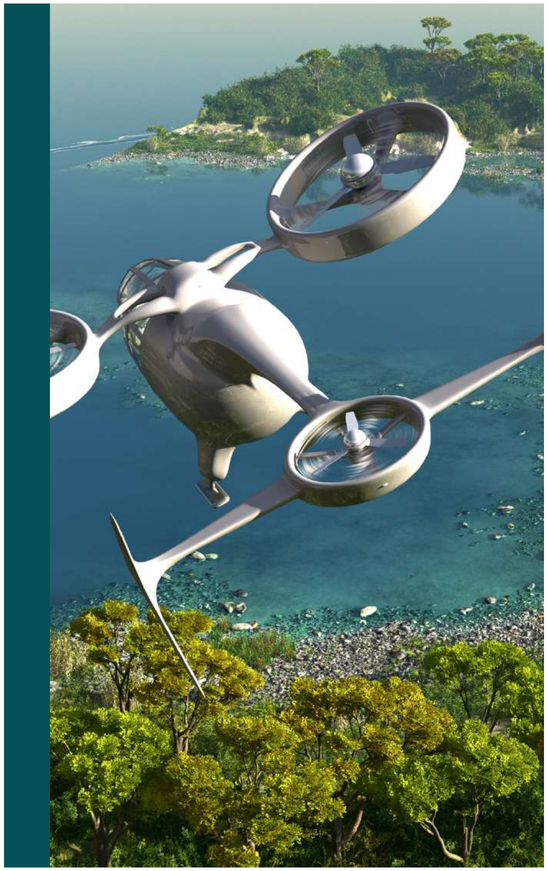
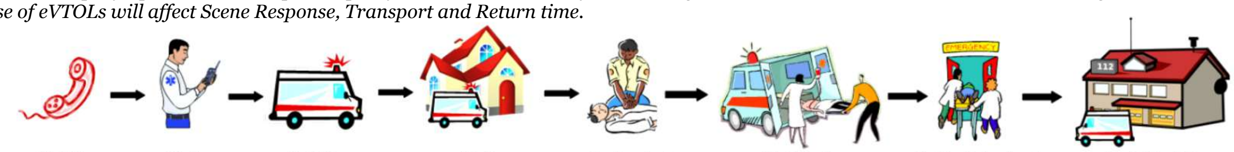


AGENDA

AMBULANCE CONOPS INCLUDE NINE MAJOR STEPS

Ambulance Concept of Operations (ConOps) adapted from National EMS Information System (NEMSIS). All times are in minutes averaged over 2014-2016. Use of eVTOLs will affect Scene Response, Transport and Return time.

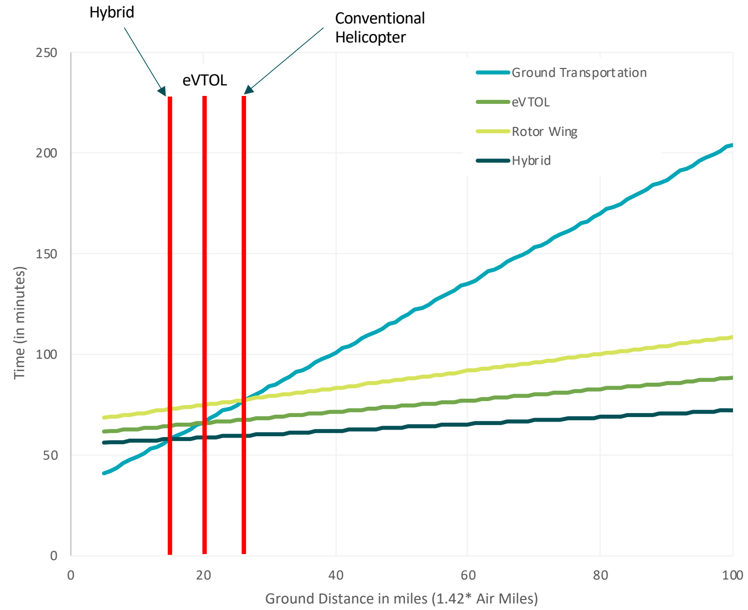


	← Dispatch → (Time interval from Call Received to the Unit Notified by Dispatch)	← Chute → (Time interval from Unit Notified by Dispatch to Unit en route)	←Scene Response→ (Time interval from Unit en route to Unit Arrived on Scene)	← Total Scene → (Time interval from Unit Arrived on Scene to Unit Left Scene)	← Transport → (Time interval from Unit Left Scene to Patient Arrived at Destination)	← Return → (Time interval from Unit left the Destination to Unit Back in Service)	Total Call time (in mins) (Time interval from Unit Notified by Dispatch to Unit Back in Service)
BLS	10	5	19	23	23	16	80
BLS Emergency	3	2	8	17	15	10	50
ALS	3	2	9	18	20	16	70
ALS1	2	2	8	17	17	18	60
ALS2	3	2	9	21	19	19	70
SCT	10	8	28	37	40	28	140
PI	3	3	10	13	18	27	70
Rotary Wing	5	11	18	32	28	37	130
Fixed Wing	9	17	32	53	61	54	220

Source: NEMSIS, 2018

EVTOLS AND HYBRID AIRCRAFT MAY ONLY COMPETE WITH ROTARY WING MARKET BECAUSE ....

- First order analysis shows that the total transport time for **ground transportation** (i.e. time to transfer the patient to the nearest hospital) **is faster for distances less than 20-25 miles** (next slide, maximum distance served by ground transportation is around 20 miles).
- Our first order cost analysis and literature review suggests that air transportation is expected to be more expensive than ground transportation. Therefore, we expect that **eVTOLs may not compete with ground ambulances at all in the first year of entry into market.**
- Hybrids may **compete for market share for distances between 15-20 miles**. However, as shown in slide 6, less than 1% of events served by ground ambulances are greater than 15 miles.



[1]Transport Time = Dispatch Time + Chute Time+ Response Time + Scene Time + Transport Time

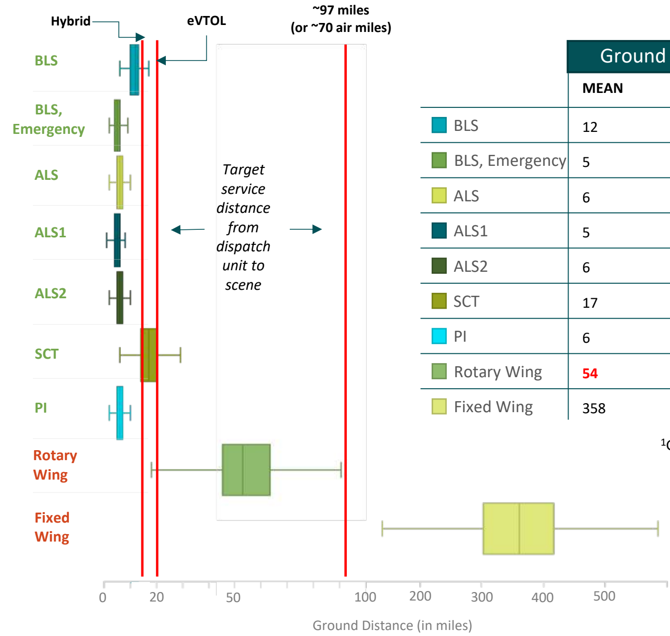
.... OF LOW RANGE REQUIREMENTS AND COMPETITION FROM GROUND AMBULANCES

The eVTOL and Hybrid air ambulance market constraints:

- **Range:** eVTOLs and hybrid aircraft are not expected to serve fixed wing market in the near term due to high range requirements
- **Competition:**
    - eVTOL air ambulances are not expected to compete with ground ambulances (since transport time is less).
    - Hybrid aircraft can potentially serve Specialty Care Transport (SCT) service levels. However, SCT is <1% of ambulance market and requires much larger vehicle size (higher number of crew)

Therefore, eVTOL air ambulances in the near term **may only compete with rotary wing market.**

See Appendix 5.2-5.6 for more details on Air Ambulance market



Ground Distance[1] (in miles)	MEAN	MIN	MAX
BLS	12	4	21
BLS, Emergency	5	2	9
ALS	6	2	11
ALS1	5	1	8
ALS2	6	2	10
SCT	17	6	31
PI	6	2	12
Rotary Wing	54	17	97
Fixed Wing	358	97	616

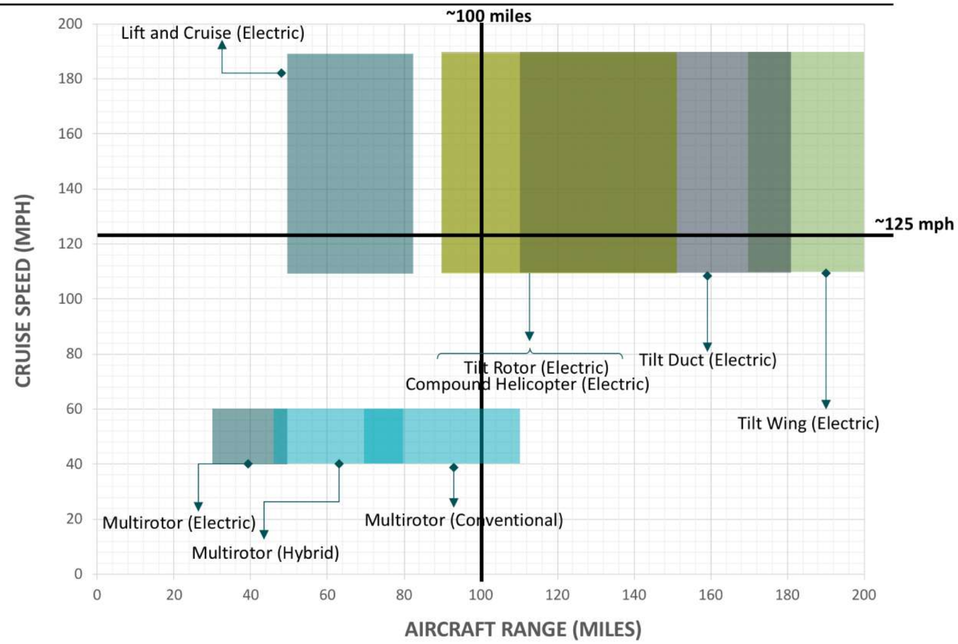
[1]Ground Miles = 1.42* Air Miles

Source: NEMSIS, 2018

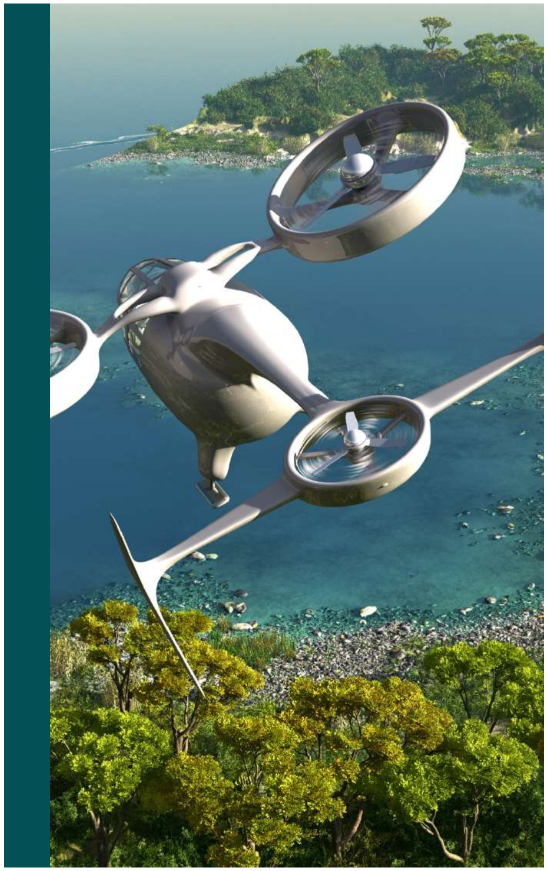
MANY OF THE PROPOSED EVTOL AIRCRAFT TYPE DO NOT MEET MINIMUM RANGE REQUIREMENTS TO SERVE ROTARY WING (RW) MARKET

- To be able to serve the existing rotary wing market, eVTOLs and Hybrid Aircraft type should have ~100 mile one-way range (including reserve) i.e., **~200 mile range** in one charge or re-fuel.

	Classification	MIN CRUISE SPEED (mph)	MAX CRUISE SPEED (mph)	MIN RANGE (miles)	MAX RANGE (miles)
Electric	Multirotor	40	60	30	50
Electric	Tilt Rotor	110	190	90	150
Electric	Lift and Cruise	110	190	50	80
Electric	Tilt Wing	110	190	170	290
Electric	Tilt duct	110	190	110	180
Electric	Compound Helicopter	110	190	90	150
Hybrid	Multirotor	40	60	50	80
Hybrid	Tilt Rotor	200	300	Same as Helicopter	
Conv.	Multirotor	40	60	70	110
Conv.	Helicopter	80	130	330	550



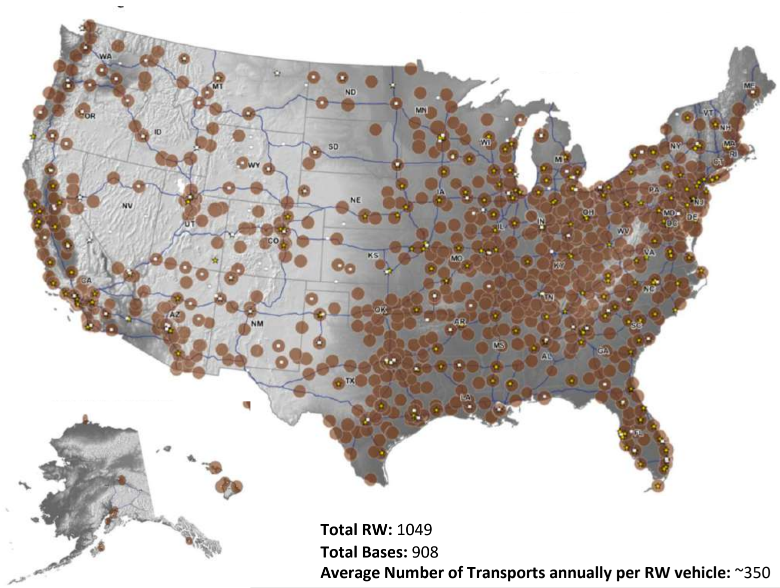
High range Tilt Rotor (Hybrid) and Conventional Helicopter not pictured



AGENDA

MORE THAN 80% OF THE US POPULATION IS COVERED BY ROTARY WINGS WITHIN 20 MIN RESPONSE

Brown circles indicate 10 minute fly circles around each base where a RW is stationed. 84.3% of the population is covered within a 20 min response time (RW launch time + 10 min flight time).



Total RW: 1049
Total Bases: 908
Average Number of Transports annually per RW vehicle: ~350

State	Number of RW
Alabama	15
Alaska	22
Arizona	46
Arkansas	23
California	99
Colorado	21
Connecticut	2
D.C.	4
Delaware	6
Florida	44
Georgia	31
Hawaii	5
Idaho	11
Illinois	27
Indiana	23
Iowa	13
Kansas	8
Kentucky	31
Louisiana	15
Maine	4
Maryland	17
Massachusetts	5
Michigan	11
Minnesota	18
Mississippi	21
Missouri	34
Montana	8
Nebraska	11

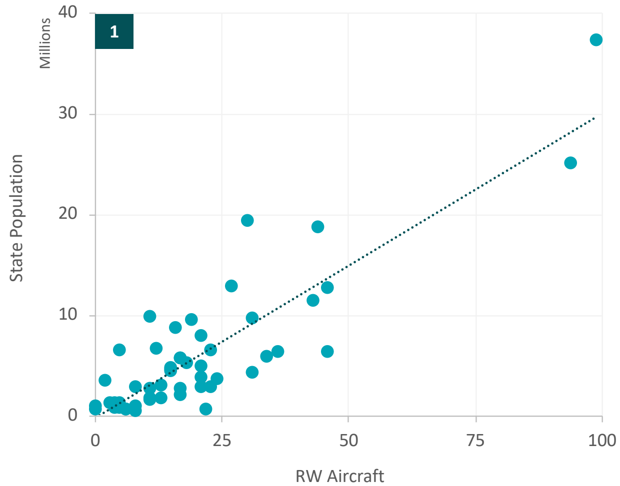
State	Number of RW
Nevada	11
New Hampshire	3
New Jersey	16
New Mexico	17
New York	30
North Carolina	19
North Dakota	6
Ohio	43
Oklahoma	24
Oregon	21
Pennsylvania	46
Rhode Island	0
South Carolina	15
South Dakota	5
Tennessee	36
Texas	94
Utah	17
Vermont	0
Virginia	21
Washington	12
West Virginia	13
Wisconsin	17
Wyoming	8

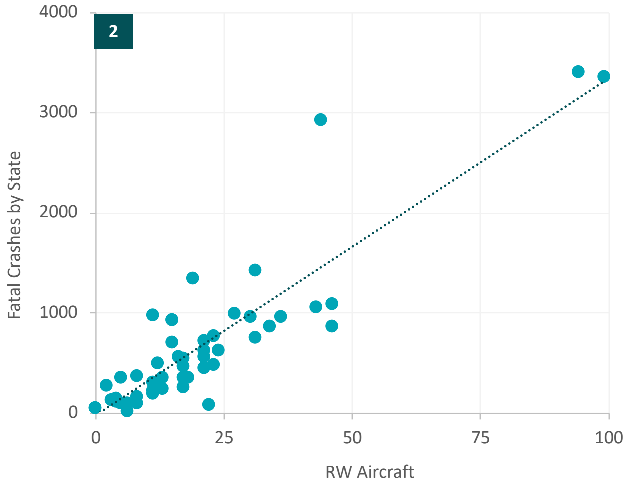
Source: ADAMS, 2017

INDUSTRY ACTIVITY IS CONCENTRATED TO FEW REGIONS

Industry activity is concentrated in

1. Regions with high population levels, and subsequently, a large number of hospitals
2. Areas with major interstate highways and high-volume roads, as air ambulance services respond to serious motor vehicle accidents





Source:

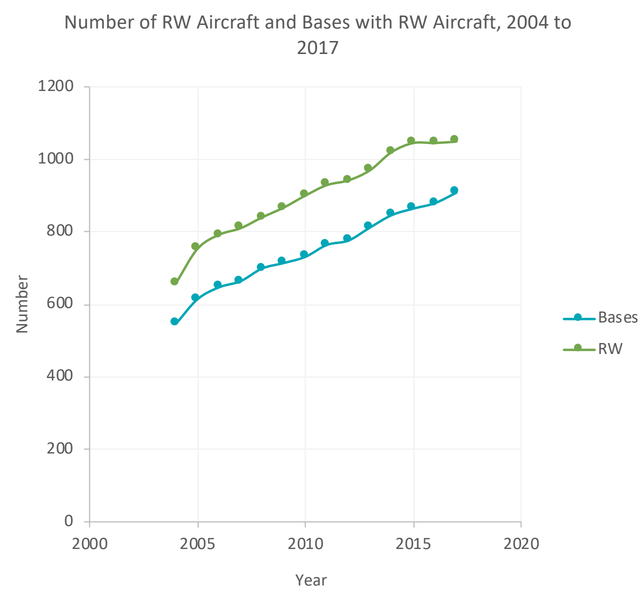
Source:

AFTER STEADY GROWTH, THE NUMBER OF RW AIRCRAFT SEEMS TO PLATEAU LATELY

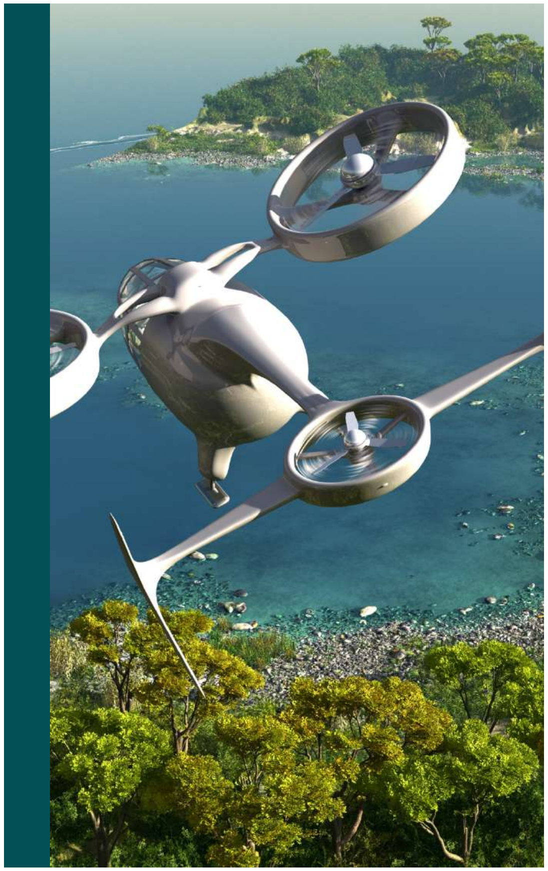
Both aircraft and bases steadily increased from 2005 to 2015. While bases continue to show a roughly linear increase, the number of RW aircraft for the year **2015-2017 seems to plateau** due to following reasons:

- **Industry has reached maturity:** Number of industry operators declined by average annual rate of .3% between 2011 to 2016
- **Consolidation of providers:**
  - 2011: Air Methods acquired Omniflight Helicopters, a provider of air medical transportation services in 18 states
  - 2016: Air Methods acquired Tri-State Care Flight, a provider of air medical transportation services in Arizona, New Mexico, Nevada, and Colorado
- **Legislative Changes create uncertainty in revenue:**
  - Patient Care Protection and Affordable Care Act (PPACA) relies heavily on young people, who may not need air medical transport as often. Since Medicare and Medicaid are large revenue streams, the PPACA highly impacts the industry.
  - 2015: Legislation introduced in House and Senate to increase Medicare payments for air ambulance providers and create a data-reporting program (supported by Association of Air Medical Services)
  - 2014: FAA amended regulation of air ambulances to have stricter flight rules and procedures and additional on-board safety and communication equipment, such as Helicopter Terrain Awareness and Warning Systems (HTAWS) and flight data monitoring systems within for years.
  - April 2015: Air ambulance pilots given more discretion when flying in bad weather conditions

Source: Ibis, 2016

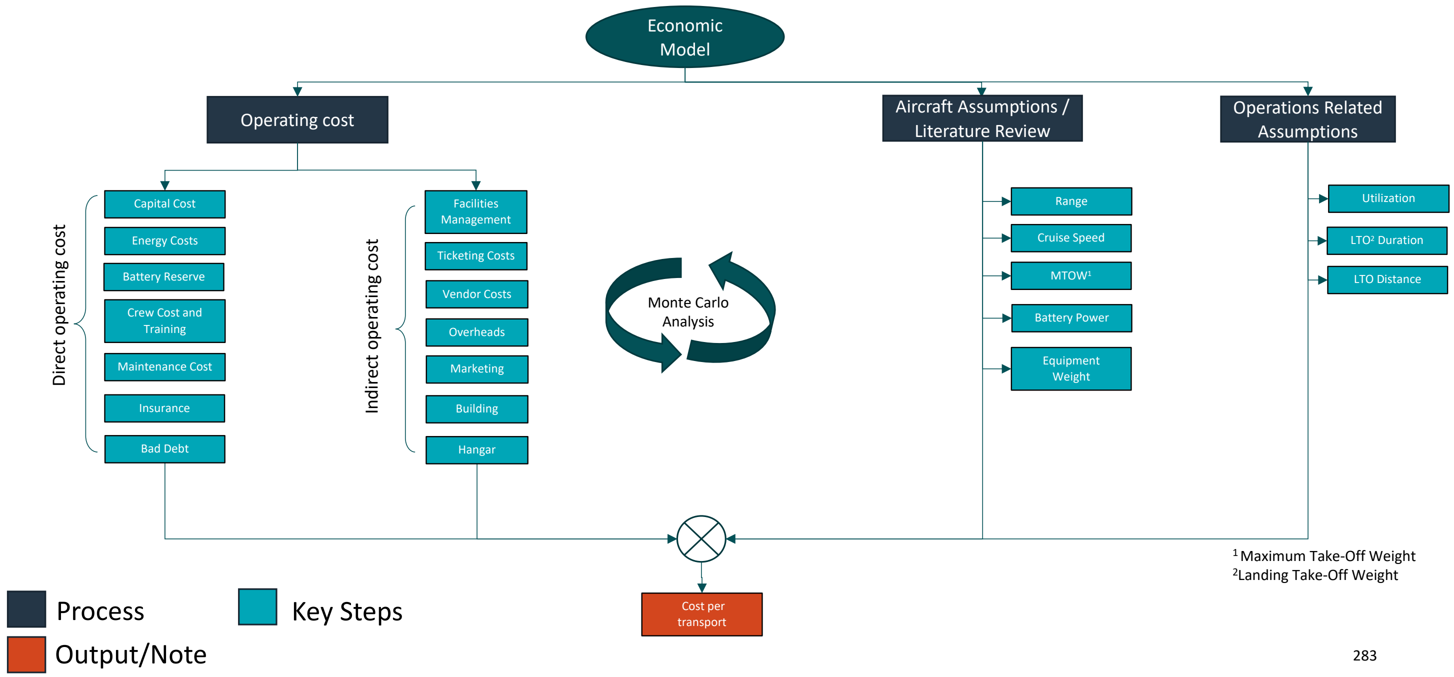


Source: Atlas, 2017



AGENDA

SUPPLY ECONOMIC MODEL FOR AN AIR AMBULANCE



[1] Maximum Take-Off Weight
[2] Landing Take-Off Weight

LITERATURE REVIEW OF CURRENT ROTARY WING AIR AMBULANCES

NON-EXHAUSTIVE

ROTARY WING MARKET OVERVIEW

OEM	Product	Technical Specifications
Airbus	H135 	Passengers 6-7; Range 377 mi; MTOW 6570 lbs.; Cruise Speed 157 mph; Cost $5.7M
Airbus	H145 	Passengers 10-11; Range 405 mi; MTOW 8157 lbs.; Cruise Speed 148 mph; Cost $9.7M
Airbus	EC130 	Passengers 7; Range 383 mi; MTOW 5512 lbs.; Cruise Speed 147 mph; Cost $3.3M
Sikorsky	76-D 	Passengers 6; Range 543 mi; MTOW 11,875 lbs.; Cruise Speed 175 mph; Cost $15M

OEM	Product	Technical Specifications
Bell	407 	Passengers 7; Range 387 mi; MTOW 5000 lbs.; Cruise Speed 153 mph; Cost $3.1M
Bell	429 	Passengers 8; Range 472 mi; MTOW 7000 lbs.; Cruise Speed 172 mph; Cost $6.4M
Bell	206 	Passengers 7; Range 374 mi; MTOW 4450 lbs.; Cruise Speed 125 mph; Cost $2.5M

- Literature review of current rotary wing ambulances shows that an eVTOL of size **5-8 seat equivalent** is required for carrying capacity of one patient at a time
- **High range (inclusive of reserve)** is required
- Sources are available in Appendix 5.7

REFERENCE AIRCRAFT ASSUMPTIONS

- eVTOL and Hybrid aircraft, like the current rotor wing market, may be used mainly for 1-patient emergency medical transports, both from accident scenes and between hospitals. Therefore, we consider a 5-8 seat size equivalent eVTOL that can fly a **cruise altitude of 500-5000 ft.**
- According to FAA duty hour requirements, a single emergency eVTOL will require **4 full time pilots, 4 full time flight nurses, and 4 full time paramedics** with CAMTS Accreditation. Each crew goes through annual training requirements.

Parameter	Sub Parameter	Minimum	Maximum	Source
Aircraft Assumptions	Cruise Speed (for eVTOL) [1]	125 mph	175 mph	MIT Study
	Cruise Speed (for Hybrid) [2]	200 mph	300 mph	BAH Literature review, XTI Aircraft
	Equivalent Number of Seats[2]	5	8	Helicopter Market Literature Review
	Reserve (mins)	20	30	Part 91 requirements
	Range (miles)	50 + Reserve	200 + Reserve	BAH Assumption
	Battery Capacity (kWh)	100 kWh	150 kWh	Nykvist et al, 2015
	Annual number of Transports[3]	300	400	AAMS, 2017
Crew/Payroll Assumptions	Pilot Salary ($ per year)	$ 60, 000	$ 100, 000	US Bureau of Labor Statistics
	Paramedic ($ per year)	$ 50, 000	$ 75, 000	
	EMT ($ per year)	$ 60, 000	$ 90, 000	
	Mechanic Salary ($ per year)[4]	$ 50, 000	$ 90, 000	

[1] Cruise Speed is use to calculate Trip Speed, which is a parametric function of average distance, LTO speed and Cruise Speed
[2] Based on helicopter market to accommodate one patient
[3] Standard unit for Air Ambulance utilization
[4] Air ambulances generally have one full time mechanic onsite

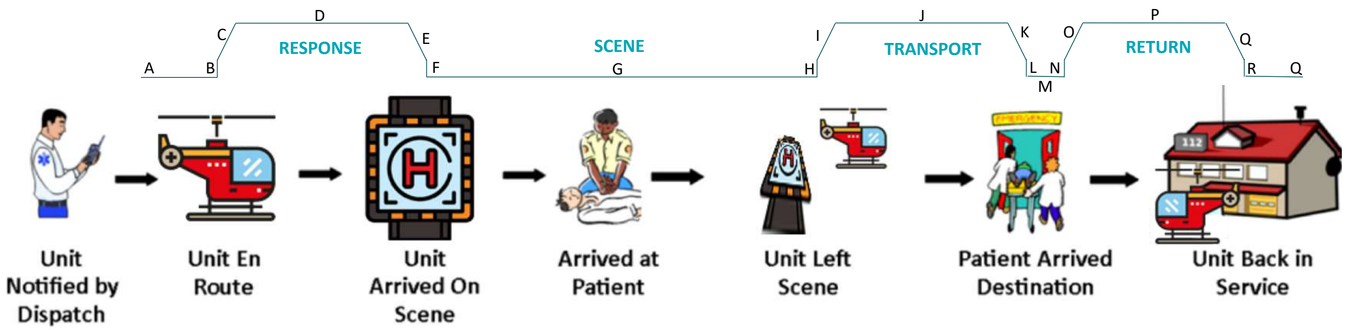
TYPICAL AIR AMBULANCE MISSION

A typical air ambulance mission consists of three sub-missions; Response (A-F), Transport (H-M) and Return to Service (N-R). We assume that each of these sub-missions are flown at similar speeds[1] and follow similar profiles i.e., Taxi, Hover Climb, Climb, Cruise, Descend, Hover Descend and Taxi. For the fourth mission (Scene) we assume an air ambulance in Taxi mode. Total Flight time is given by (1).

After completing the transport, the air ambulance returns to its base (N-R) and is prepared for service (R-Q). For this analysis, time required to complete mission N-R is assumed to be 5-15 mins while eVTOL preparation time (R-Q) refers to time required to recharge batteries completely (assuming battery swapping is not possible).

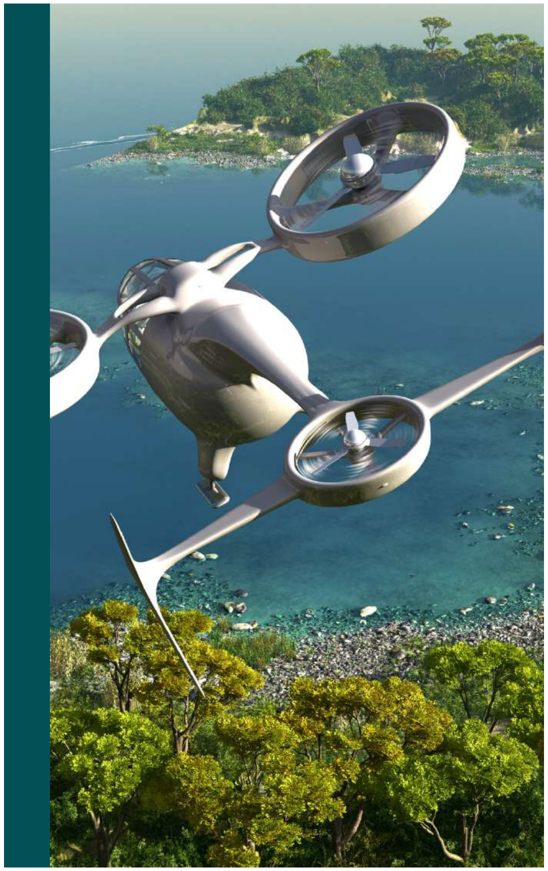
Air Ambulance mission for scene and interfacility are detailed in Appendix 5.8

$$\text{Total Flight Time} = \text{Response }(B-F) + \text{Transport}(H-M) + \text{ Return Time }(N - R). \qquad ----(1)$$



[1]Literature suggests that ground ambulances are operated at different speeds for all three sub-missions (i.e., Response speed > Transport Speed > Return to Service speed. However, there is little literature to support a similar trend for Air Ambulances).

Source: NEMSIS, 2018



AGENDA

Third Focus Market Overview

Current Ambulance Industry Overview

New Vehicle Types

Ambulance ConOps and Scoping

Rotary Wing Market Overview

Supply Side Modeling

- Detailed Methodology
- Capital and Insurance Cost Model
- Energy Cost Model
- Battery Cost Model
- Results and Discussion

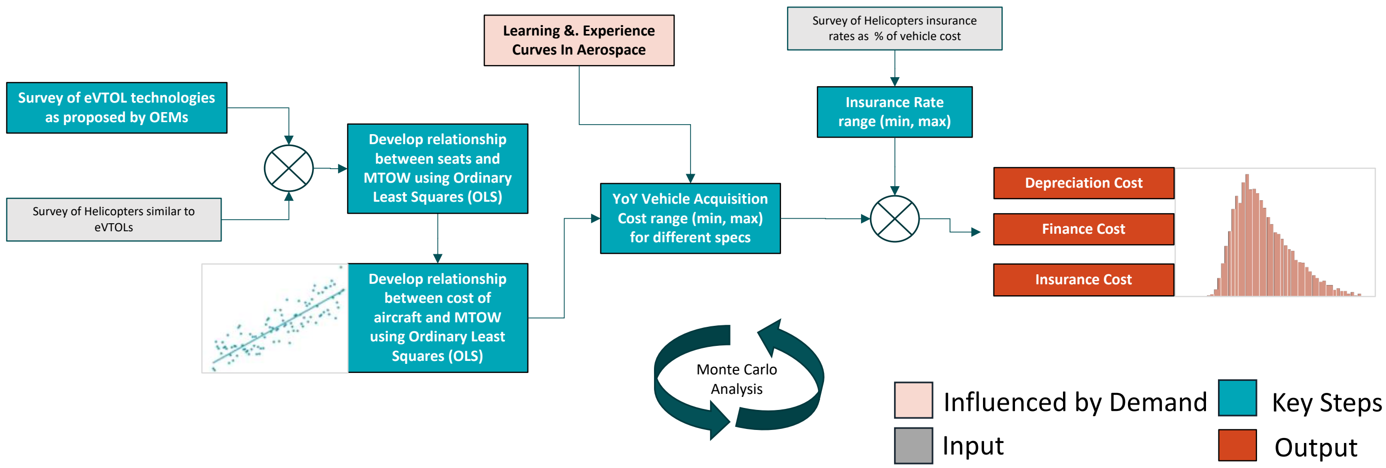
Effective Number of Transports

Demand Side Modeling

CAPITAL AND INSURANCE COST MODEL

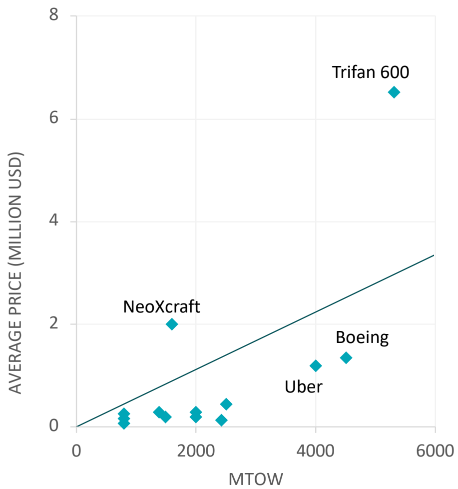
There are 70+ aircraft designs proposed around the world to serve electric and hybrid aircraft market for air ambulance. Our analysis assumes that each of the aircraft type may need to be ***priced similarly*** *to serve the same market.*

We developed a relationship between Aircraft price per seat and MTOW per seat through regression analysis of the available price data as shown in the previous slides. Our analysis assumes that ***MTOW and Aircraft Price varies linearly*** *with the number of seats (as typically observed in commercial aviation)*

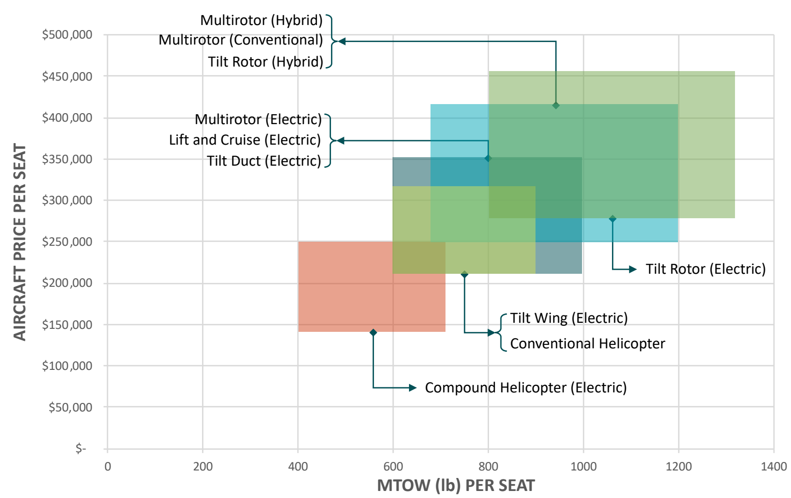


AIRCRAFT PRICE VARIES LINEARLY WITH WEIGHT OF THE AIRCRAFT

- Aircraft price per seat and MTOW per seat developed through **regression analysis** of the available data
- Our analysis assumes that MTOW and Aircraft Price **varies linearly** with the number of seats (as typically observed in commercial aviation)



Detailed price information can be found in literature review



Only electric and hybrid aviation considered for further analysis

Results

ASSUMPTIONS

Parameter	Min	Max	Source
Vehicle Life (years)	12000	25000	SAG Interviews[1] Cirrus SR20 Cessna 350
Depreciation Rate (%)	5%	10%	BAH Assumption
Finance Rate (%)	5%	10%	BAH Assumption
Loan Term (years)	10	15	BAH Assumption

[1]BAH conducted interviews with SAG members in February. Their feedback is documented in SAG document shared with the deliverable package

CAPITAL COST PER TRANSPORT

- Capital Cost is the sum of depreciation cost (given by 1) and finance cost (given by 2). Certification costs are included in aircraft price
- **Residual value** of the aircraft is assumed to be **negligible** since aircraft's value depreciates at rate of ~5-10% over a period of 10-15 years

$$Depreciation\ Cost = Aircraft\ price \times \left(1 - e^{-depreciation\ rate)}\right) --- (1)$$

$$Finance\ Cost = Aircraft\ price \times finance\ rate \times \frac{(1 + monthly\ finance\ rate)^{12 \times Loan\ Term}}{(1 + monthly\ finance\ rate)^{12 \times Loan\ Term - 1}} --- (2)$$

where,

$$monthly\ finance\ rate = \frac{finance\ rate}{12}$$

Aircraft Type	Median Capital Cost per transport[1]	Median Finance Cost per transport	Median Depreciation Cost per transport
eVTOL	**$ 1, 000**	**$ 600**	**$ 400**
Hybrid	**$ 1, 400**	**$ 900**	**$ 500**

[1] Median cost is same as analysis assumes that each aircraft may need to be priced similarly for the same air ambulance market

Results

INSURANCE COST PER TRANSPORT

- Analysis assumes that the **operator** would be **required to have full insurance** as typically observed in air ambulance RW industry.
- Calculation of insurance cost of an aircraft is **subjective in nature** as it depends on 6-12 months of recent operating history (see Appendix 5 for air ambulance accident history). Therefore, this analysis relies on **historical insurance cost of helicopters** as a percent of vehicle price.
- Aircraft insurance is a sum of Liability[1] and Hull[2] insurance for the base year. Age adjustment will be added for future year projections.
- Liability insurance covers both public and private liabilities while Hull insurance covers both in-motion and not-in-motion cases. Insurance cost does not include infrastructure/facilities insurance (bundled under Indirect Operating Cost).

Helicopter	Insurance as a % of aircraft price	
Robinson R22	2.60%	
Robinson R44_1	2.67%	
Robinson R44_2	2.47%	
Robinson R66	2.30%	MIN
Bell 427	3.28%	
Bell 206L3	2.36%	
Agusta Westland 109 Grand New	2.39%	
Agusta Westland 119 Koala	2.78%	
Airbus H120/Eurocopter EC 120B	3.93%	MAX

Source: Aircraft Cost Calculator (2015), Robinson Helicopter Company (2018)

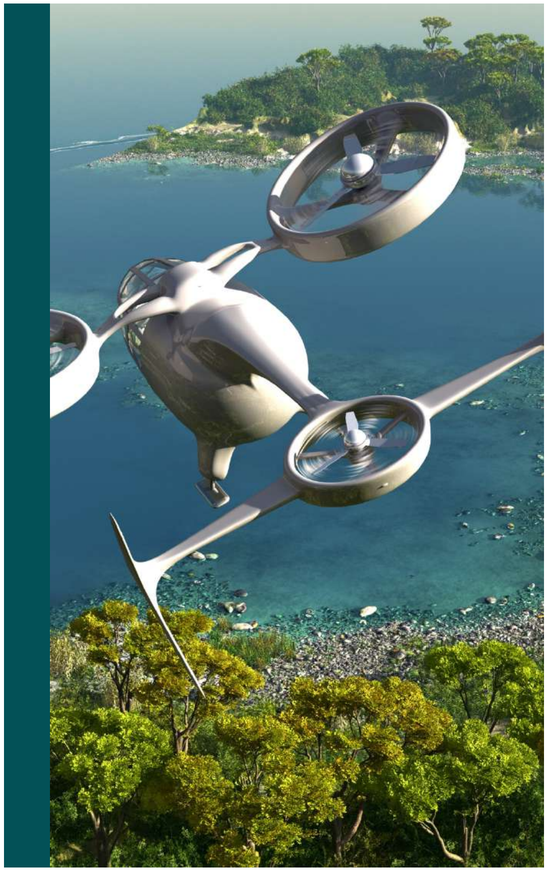
Aircraft Type	Median Insurance Cost per transport
eVTOL	**$ 150**
Hybrid	**$ 200**

[1] Liability Insurance

- **Passenger:** Protects passengers riding in the accident aircraft who are injured or killed
- **Public Related:** Protects aircraft owners for damage that their aircraft does to third party property, such as houses, cars, crops, airport facilities and other aircraft struck in a collision

[2] Hull Insurance

- **Not-in-motion:** Provides coverage for the insured aircraft against damage when it is on the ground and not in motion
- **In-motion:** Protects an insured aircraft against damage during all phases of flight and ground operation



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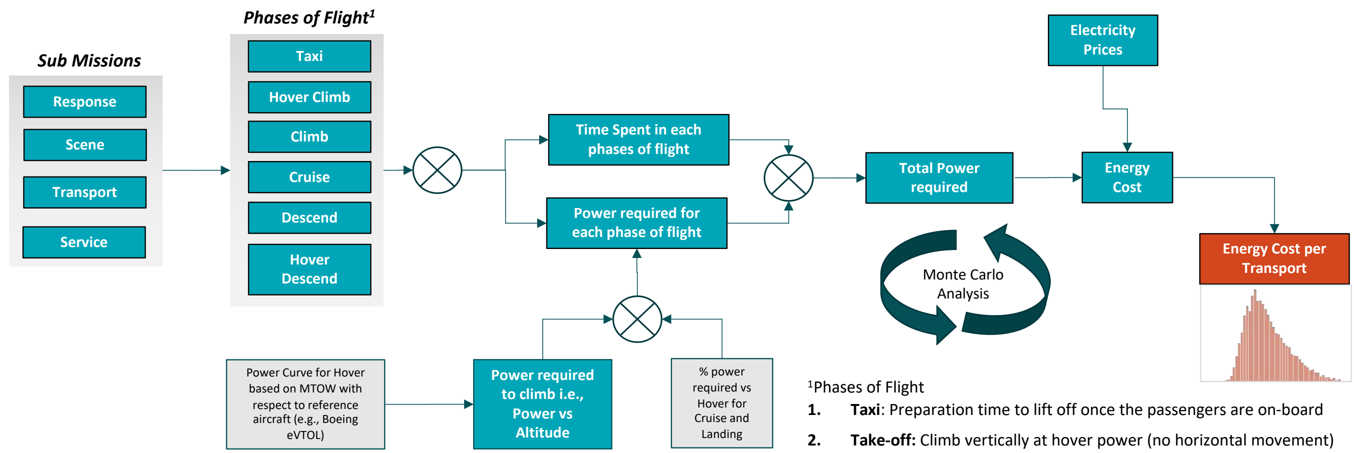
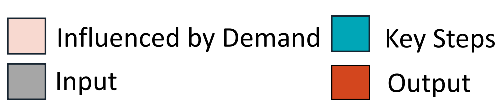
Demand Side Modeling

ENERGY COST MODELING FOR AIR AMBULANCES



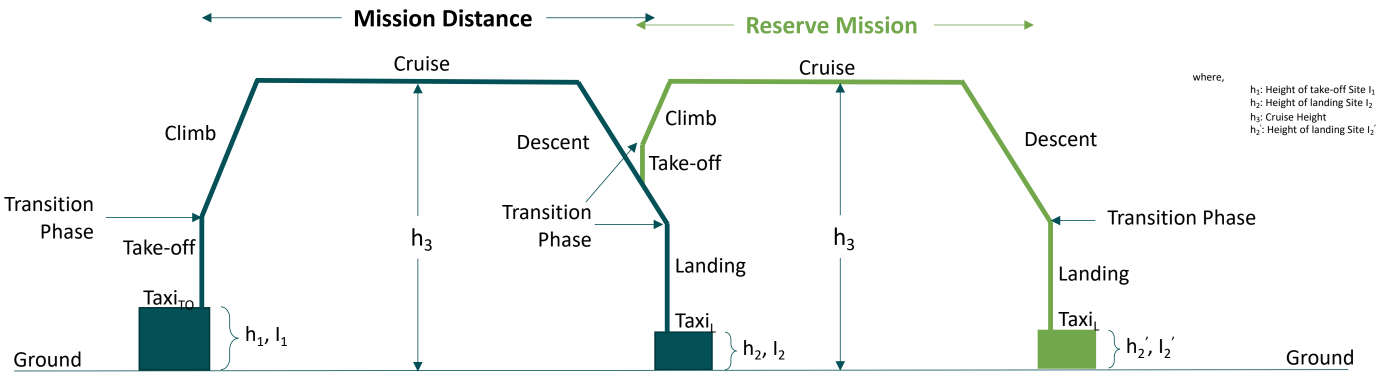


[1]Phases of Flight

1. **Taxi**: Preparation time to lift off once the passengers are on-board
2. **Take-off:** Climb vertically at hover power (no horizontal movement)
3. **Climb:** Climb to cruise height
4. **Cruise:** Flight phase that occurs when the aircraft levels after a climb to a cruise altitude and before it begins to descend
5. **Descent:** Aircraft begins approach to final landing. Has both horizontal and vertical component
6. **Landing:** Vertical landing at hover power (no horizontal movement)

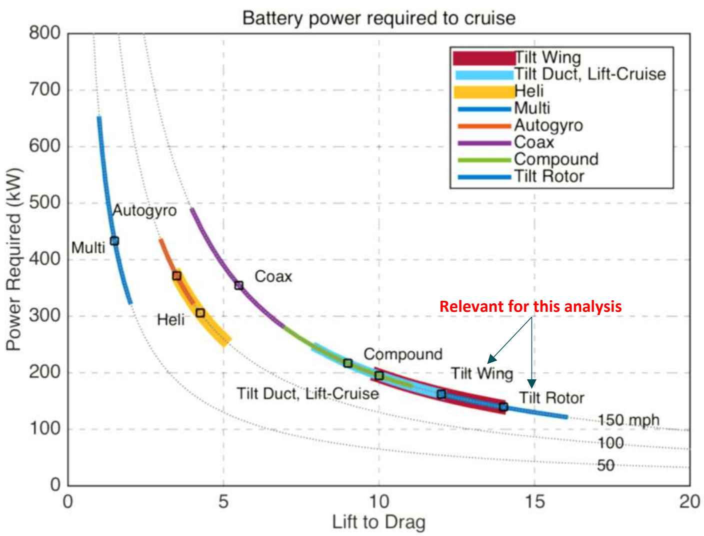
MISSION PROFILE FOR eVTOL AND HYBRID AIRCRAFT

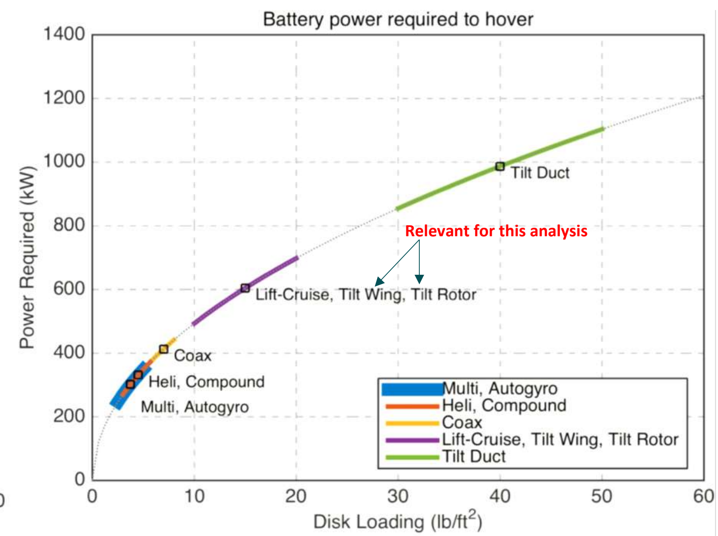
- Each mission has six main phases of flight; Taxi, Take-off, Climb, Cruise, Descent and Landing.
  - **eVTOL:** All **six phases are flown on electric (battery) power**
  - **Hybrid:** **Take-off landing** is flown on **electric (battery) power** while **rest of the phases are flown on turboshaft** (source: XTI Aircraft)
- Reserve mission kicks off during the descent phase and follows a similar profile as original mission
- An additional Transition phase (vertical to horizontal flight) is added between Take-off and Climb phase for tilt rotor, tilt wing and tilt duct type of aircraft. There is no horizontal movement considered during transition phase
- Aircraft can loiter and land at original destination (l_2) or travel to another landing area (l_2‘)



HOVER AND CRUISE POWER REQUIREMENT FOR DIFFERENT AIRCRAFT TYPE

- Different aircraft have different battery power requirements. This analysis utilizes research performed by McDonald and German for aircraft with Maximum take-off weight **5000 lb** at mean sea level and standard temperature/pressure conditions. Power requirements specific to different MTOW are calculated in the next slide.





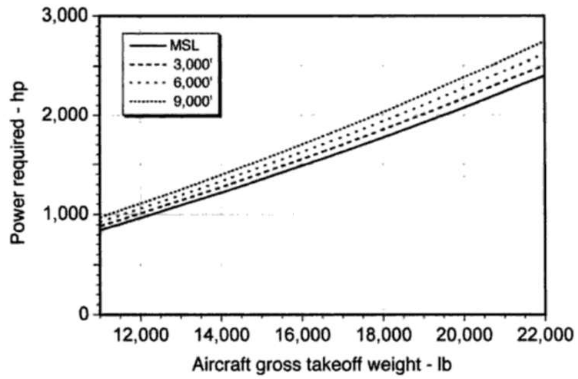
Source: McDonald, R et al.

POWER REQUIREMENT VARIES FOR DIFFERENT AIRCRAFT TYPE IN CERTAIN WEATHER CONDITIONS

Power required vs MTOW

- Hover and cruise power required is a **function of aircraft maximum take-off weight (W) and ambient density (ρ)** as shown in equation (1). Power values for aircraft at 5000 lb from previous slide is considered as reference aircraft.

$$P_{hover} \propto \frac{W^{\frac{3}{2}}}{\rho^{\frac{1}{2}}} \quad \text{- - - - - - - - -} \quad (1)$$

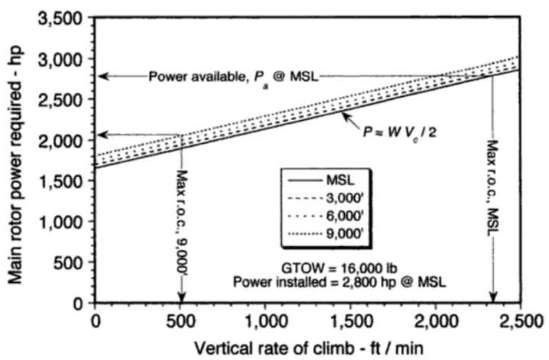


Source: Lieshman, G. Aerodynamics of Helicopters, 2002

Power required to Climb vs Speed

- At low or moderate vertical rate of climb, power required to climb at the **cruise altitude is proportional to take-off speed (climb speed, V_c)** and MTOW as shown in equation (2). This analysis assume a standard rate of climb of **500 ft/min.**

$$P_{climb} \propto WV \quad \text{- - - - - - - - -} \quad (2)$$

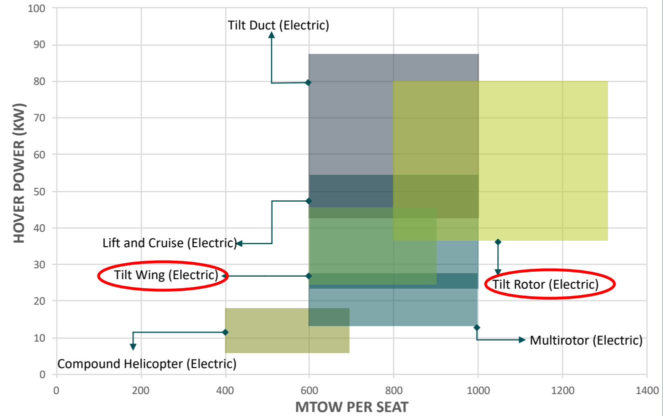


Source: Lieshman, G. Aerodynamics of Helicopters, 2002

ADJUSTED HOVER AND CRUISE POWER REQUIREMENT FOR DIFFERENT AIRCRAFT TYPE

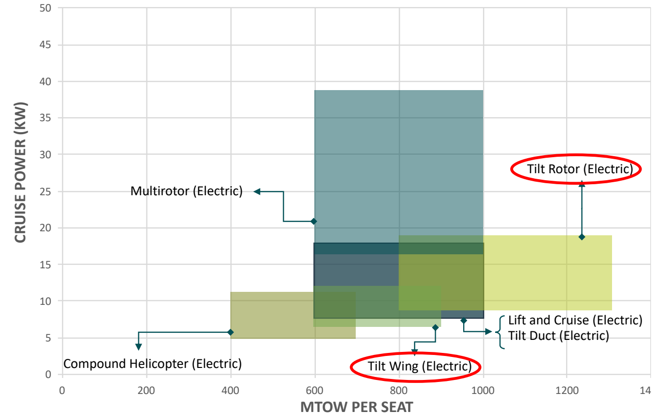
Hover Power required vs MTOW

- **Tilt duct aircraft** type due to high disk-loading has **higher hover power requirement** as compared to aircraft with similar maximum take off weight (MTOW)



Cruise Power required vs MTOW

- **Multirotor** aircraft due to low lift-drag ratio has **significantly higher cruise power range requirement** as compared to aircraft with similar MTOW



Relevant for this analysis

FUEL COSTS FOR HYBRID AIRCRAFT

- In our analysis, hybrid aircraft **uses fuel in all the phases except landing take-off.**
- **FAA's Aviation Environment Design Tool (AEDT)** defines fuel use (in kg) per kilometer during cruise for each aircraft in commercial aviation category (i.e. Passengers, Business and Freight).
- Fuel use **varies by stage length** (the distance traveled by an aircraft from takeoff to landing). We limit the stage length values to less than 200 miles (design range of air ambulance)
- We use business aviation as a proxy and calculate fuel requirement per seat. Finally, we use **~$0.97 per kg as fuel price** for Jet A fuel

Aircraft Type[1]	Fuel use (in kg) per km per seat
BJ 2.0 Light Jet	0.10 MIN
BJ 3.0 Light Jet	0.12
BJ 1.5 Very Light Jet	0.13
BJ 3.5 Light Jet	0.13
BJ 5.0 Medium	0.15
BJ 4.0 Medium	0.15
BJ 6.0 Large	0.18
BJ 7.0 Large	0.21
BJ 7.5 Large	0.21
BJ 8.0 Corporate	0.46 MAX

[1] Definitions of each aircraft type can be found in AEDT database document available at www.aedt.faa.gov

$$fuel\ cost = fuel\ use \times seats \times cruise\ distance \times fuel\ price$$

Aircraft Type	Median Fuel Cost per transport
Hybrid Aircraft	**$ 350**

Source: AEDT

Results

ASSUMPTIONS

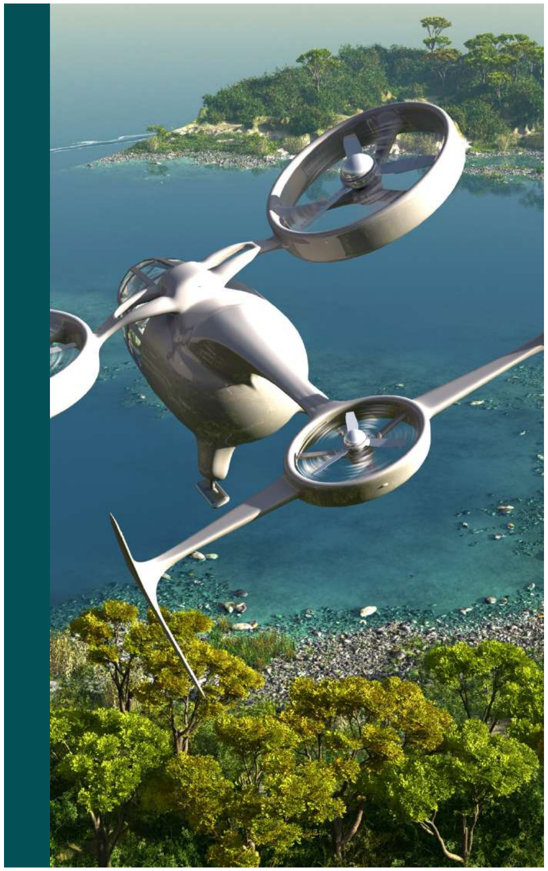
Parameter	Min	Max	Source
Height of landing and take-off sites (ft)	0	200	BAH Assumption
Climb/Descent Distance (miles)	1	2	MIT Study, BAH Assumption
LTO Height (ft)	100	200	
LTO Time (sec)	10	20	
Disembarkation time (mins)	3	5	
Transition Time (sec)	15	30	BAH Assumption
Power required in descent (as % of P_{hover})	10%	15%	Lieshman, 2002[3] Boeing Study Uber Elevate
Power required in Taxi (as % of P_{hover})	5%	10%	BAH Assumption
Energy Conversion efficiency (%)	90%	98%	Georgia Tech Study[4]
Electricity Price ($/kwh)	0.1	0.3	BAH Assumption

[1]Fast-Forwarding to a Future of On-Demand Urban Air Transportation, Uber Elevate, October 2017
[2]Duffy, M. A Study in Reducing the Cost of Vertical Flight with Electric Propulsion. AHS, 2017
[3]Lieshman, G. Aerodynamics of Helicopters, 2002
[4]Harish, A. Economics of Advanced Thin-Haul Concepts and Operations. AIAA, 2016

ENERGY COST PER TRANSPORT

- **Power required for hybrid aircraft** (i.e. more seats) is **higher**, since hybrid aircraft is tilt rotor type vs tilt wing for electric aircraft
- **Energy cost** per transport **for hybrid is higher** due to high fuel cost for cruise phase of flight in comparison to electric aircraft
- Since we use business aviation as a proxy to calculate fuel requirement per seat, we do not take into account any advanced fuel usage/efficient technology that might be introduced into hybrids. Therefore, our **fuel costs might be overestimated**. On availability of fuel usage data of hybrids, models can be further revised
- Power requirement is **inversely proportional to square root of ambient air density**,. Therefore, lighter air (due to warm temperature conditions or higher altitude) requires more power to complete a mission (hence extra cost)
- Current calculations are **based on standard day at mean sea level**. Effect of weather is not explored in the analysis

Aircraft Type	Median Energy Cost per transport
eVTOL	**$ 100**
Hybrid	**$ 400**



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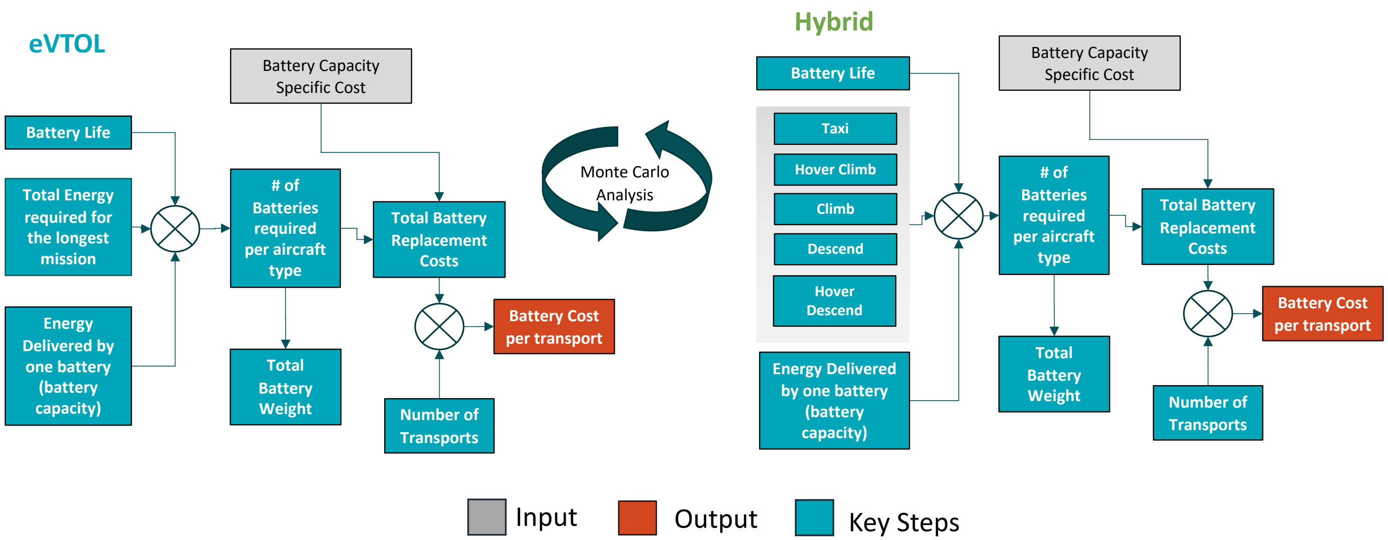
BATTERY RESERVE COSTS

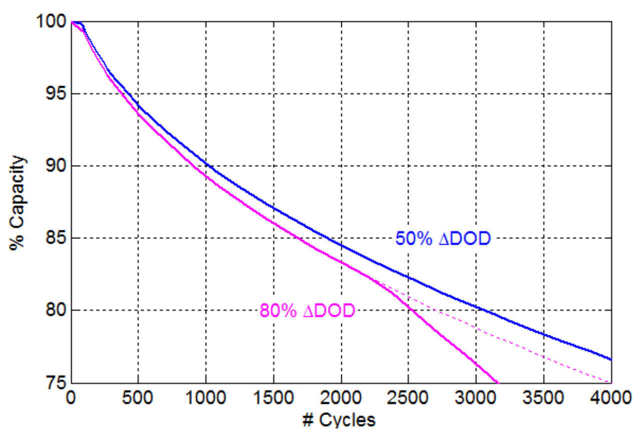
*Our analysis sizes the battery pack for eVTOLs **based on the longest mission** assumption for the air ambulance market, while for hybrid aircraft battery sizing is done for the electric powered phases only (including reserve). For supply side model only, we assume a standard day operating conditions. We assume that batteries have negligible residual value*



BATTERY LIFE CYCLE AND CAPACITY DEPENDENCIES

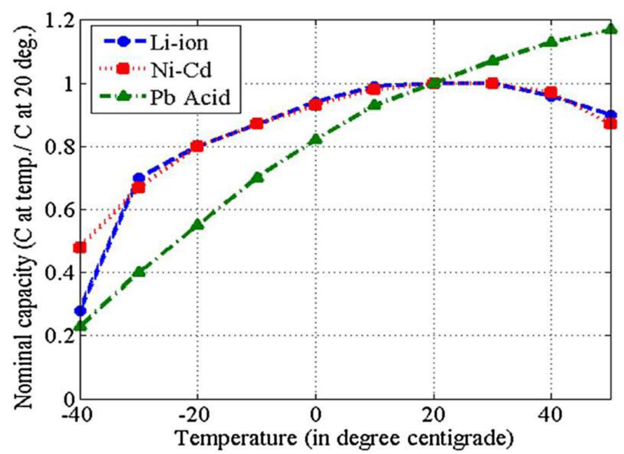
- *Battery life cycle of a Li ion battery directly depends on the depth of discharge (DOD). Increasing DOD decreases battery life. Generalized relationship is shown below:*

$$\boldsymbol{Life\ Cycle = -1666.7 * Depth\_of\_Discharge + 3833.3}$$



Source: National Renewable Energy Laboratory, 2014

- *Capacity of Li-ion battery decreases at low temperatures since the total resistance (sum of bulk, surface layer and charge-transfer resistance layer) increases*
- *Resistance becomes the most dominant as the temperature goes to below −10°C*



Source: The Institution of Engineering and Technology, 2016

ASSUMPTIONS

Parameter	Min	Max	Source
Battery Specific Energy in Wh/kg	300	400	Boeing Study[1]
Battery Capacity Specific Cost ($/kwh)	200	250	Nykvist et al[2]
Depth of Discharge (%)	50%	80%	Georgia Tech Study

[1]Duffy, M. A Study in Reducing the Cost of Vertical Flight with Electric Propulsion. AHS, 2017

[1]Nykvist, B. and Nilsson, M., "Rapidly falling costs of battery packs for electric vehicles," Nature Climate Change, Vol. 5, No. 4, 2015

Results

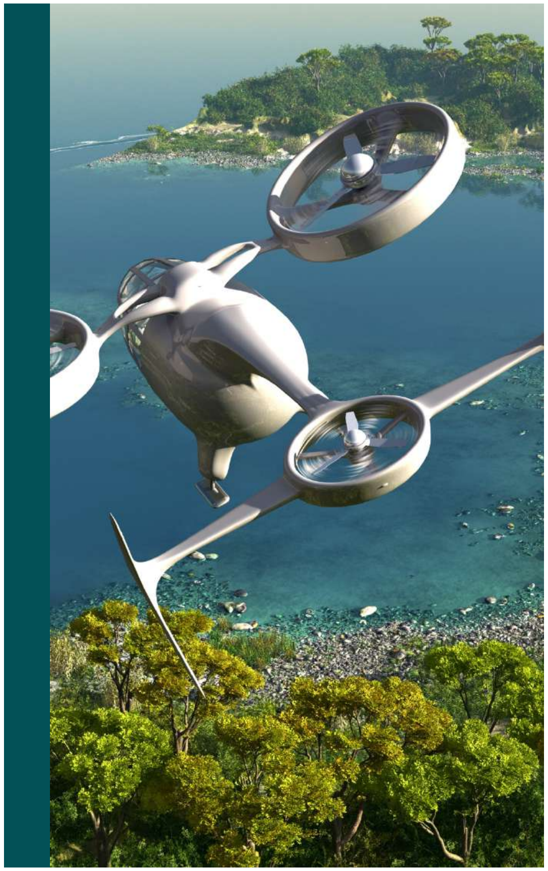
BATTERY RESERVE COST PER TRANSPORT

- Hybrid aircraft in it's current mission profile[1] needs half the battery size of an eVTOL.
- Battery[2] cost **increases** as the **size of the vehicle increase** (due to increase in energy requirement)
- However, battery reserve cost per transport is **similar** for different types of aircraft
- **Battery Specific Energy reduces at extreme temperature** conditions, and therefore larger battery size is required which increases the cost
- Low temperatures has higher effect on cost in comparison to high temperatures. This analysis is based on standard day conditions

	Median Battery Reserve Cost per transport
Aircraft Type	20º C
eVTOL	**$ 500**
Hybrid	**$ 250**

[1] Various sensitivity analysis can be done on hybrid aircraft's mission profile to model reduction in battery costs vs increase in environmental impacts. For this analysis, we adopted the proposed profile by XTI Aircraft in which LTO phase is done by battery power while all other phases are completed by conventional turboshaft

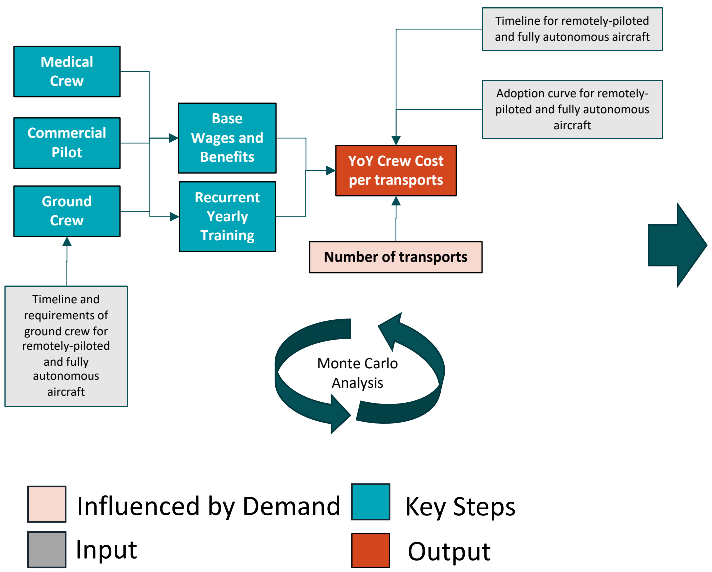
[2]This analysis assumes batteries are recharged by fast chargers as soon as aircraft reach the vertiport with no consideration given to the number of chargers needed or the price of electricity. Various optimization and battery swapping capabilities have been proposed in literature (like Justin et al Georgia Tech), which may reduce the battery requirements.



AGENDA

CREW COSTS PER TRANSPORT

According to FAA duty hour requirements, a single emergency eVTOL will require 4 full time pilots, 4 full time flight nurses, and 4 full time paramedics with CAMTS Accreditation. Each crew goes through annual training requirements.



Monte Carlo Assumptions	Min	Max	Source
Pilot Salary ($ per year)	$ 60, 000	$ 100, 000	US Bureau of Labor Statistics[1]
Paramedic ($ per year)	$ 50, 000	$ 90, 000	
EMT ($ per year)	$ 60, 000	$ 90, 000	
Mechanic Salary ($ per year)	$ 50, 000	$ 90, 000	

[1]US Department Bureau of Labor Statistics, https://www.bls.gov/

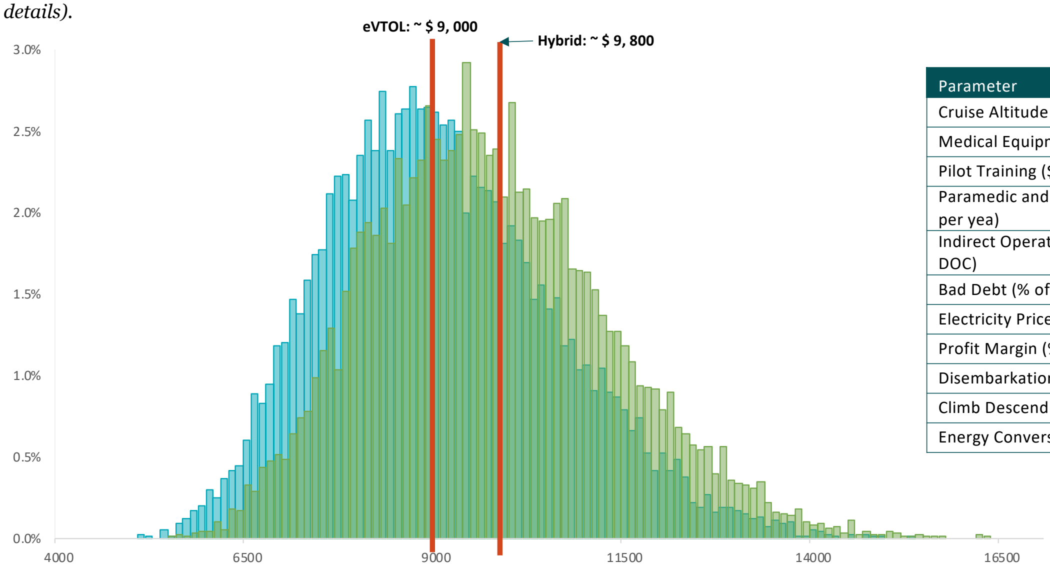
Aircraft Type	Median Crew Cost per transport
eVTOL	**$ 3, 200**
Hybrid	**$ 3, 200**

AGENDA

Results

TOTAL COST PER TRANSPORT

After performing 10,000 iterations of Monte Carlo, the median cost of operating an eVTOL air ambulance is ~ ***$9, 000*** *per transport and hybrid air ambulance is ~****$9, 800*** *as compared to ~10, 000 for rotary wing helicopter (source: AAMS) and ~$500 for ground ambulance (see Appendix 5.15 for details).*

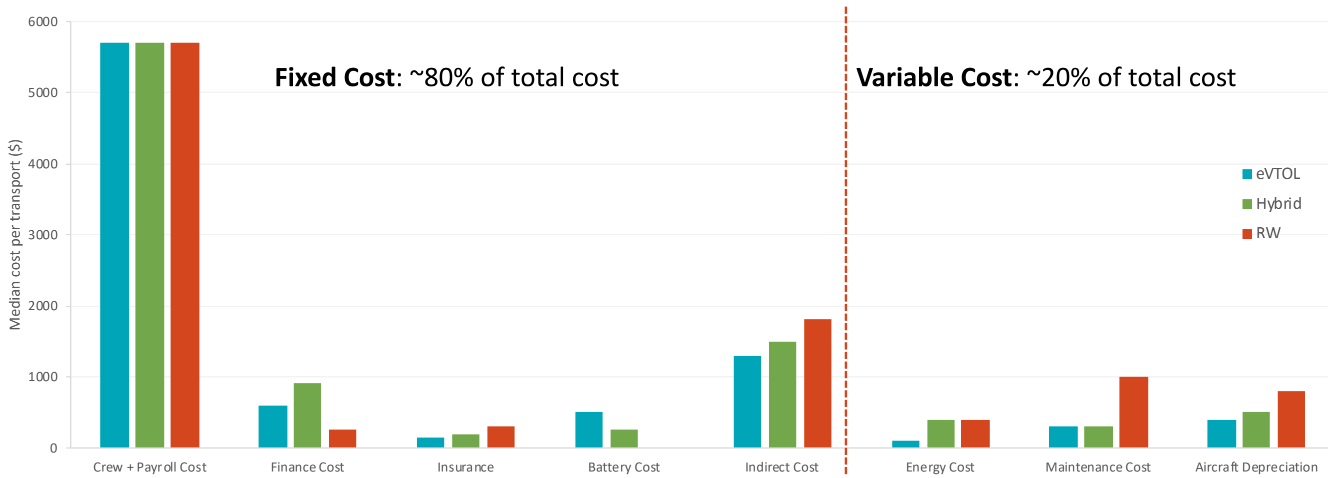


Parameter	Min	Max
Cruise Altitude (ft)	500	5,000
Medical Equipment Weight (lb)	200	400
Pilot Training ($ per year)	10,000	30,000
Paramedic and EMT Training ($ per yea)	10,000	20,000
Indirect Operating Cost (% of DOC)	5%	50%
Bad Debt (% of Operating Cost)	10%	20%
Electricity Price ($/kwh)	0.1	0.3
Profit Margin (% of Cost)	10%	30%
Disembarkation Time (in mins)	3	5
Climb Descend Distance (miles)	1	2
Energy Conversion Efficiency (%)	90%	98%

Results

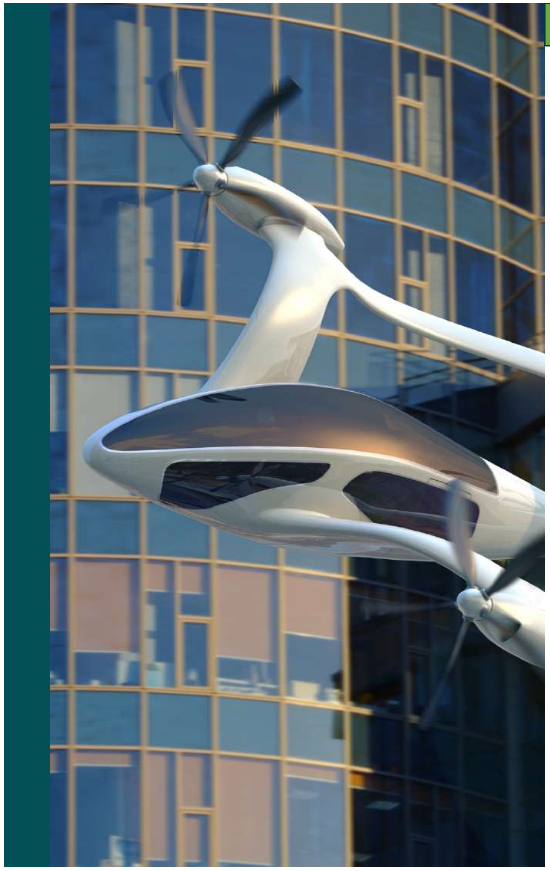
eVTOL AND RW COST COMPARISON

*Association of Air Medical Services reports cost for RW in the form of Fixed[1] and Variable[2] cost. It is observed that fixed cost for RW, eVTOL and Hybrid account for approximately ~**80% of the overall cost per transport.** Fixed cost can potentially be reduced if it is spread over a larger number of transports. Appendix 5.13 shows cost breakdown in %.*



[1]Fixed Cost for RW includes payroll (crew cost), aircraft ownership (finance cost), insurance and indirect cost (Vendor costs, supplies, overheads, training etc.). Fixed cost for eVTOL includes crew and payroll cost, finance, battery cost, insurance and indirect cost (similar to RW + bad debt).

[2]Variable Cost for RW includes fuel (energy cost), aircraft depreciation and maintenance. Variable costs for eVTOL includes energy cost (i.e., electricity cost), maintenance (full time mechanic) and depreciation.



Results

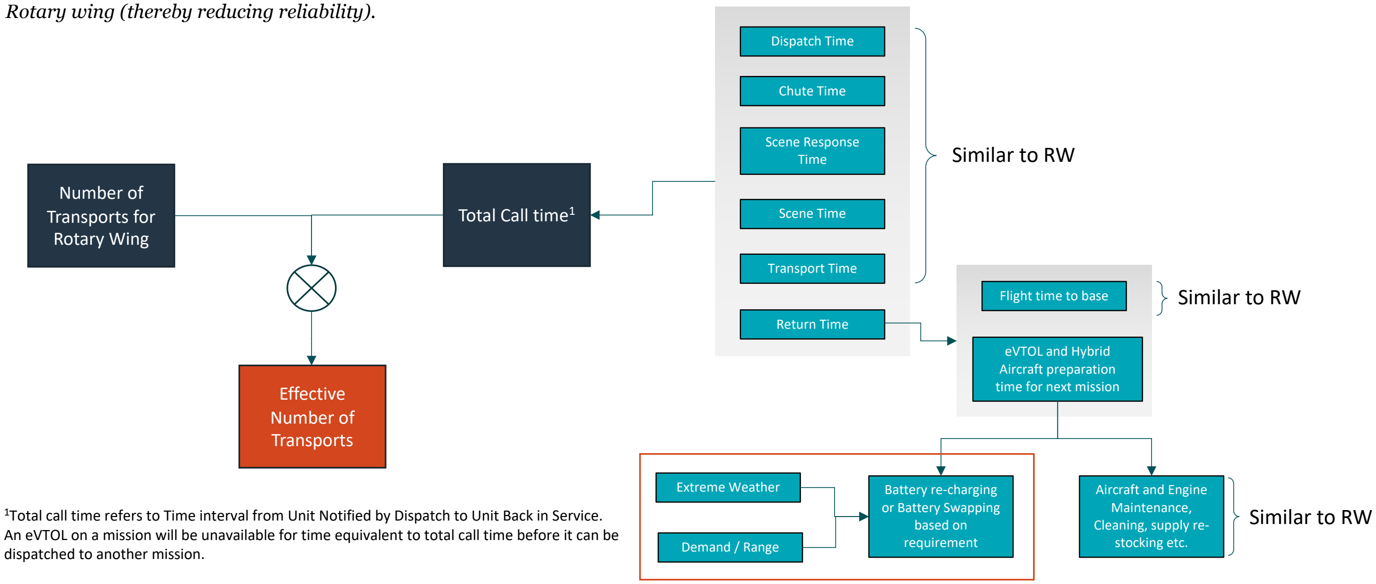
NUMBER OF TRANSPORTS VS COST PER TRANSPORT

Since fixed cost accounts for most of the cost per transport, it can be potentially reduced by increasing the number of transports per year. Preliminary analysis shows that cost per transport ***reduces to approximately half on doubling the number of transports.***

AGENDA

EFFECTIVE NUMBER OF TRANSPORTS FOR eVTOLs

Number of transports for an aircraft will be affected by battery weight, battery charging time (affects preparation time) and adverse weather conditions that affect eVTOLs but not so much RW (like extreme temperature conditions). Increase in total call time reduces availability of eVTOL as compared to Rotary wing (thereby reducing reliability).



[1]Total call time refers to Time interval from Unit Notified by Dispatch to Unit Back in Service. An eVTOL on a mission will be unavailable for time equivalent to total call time before it can be dispatched to another mission.

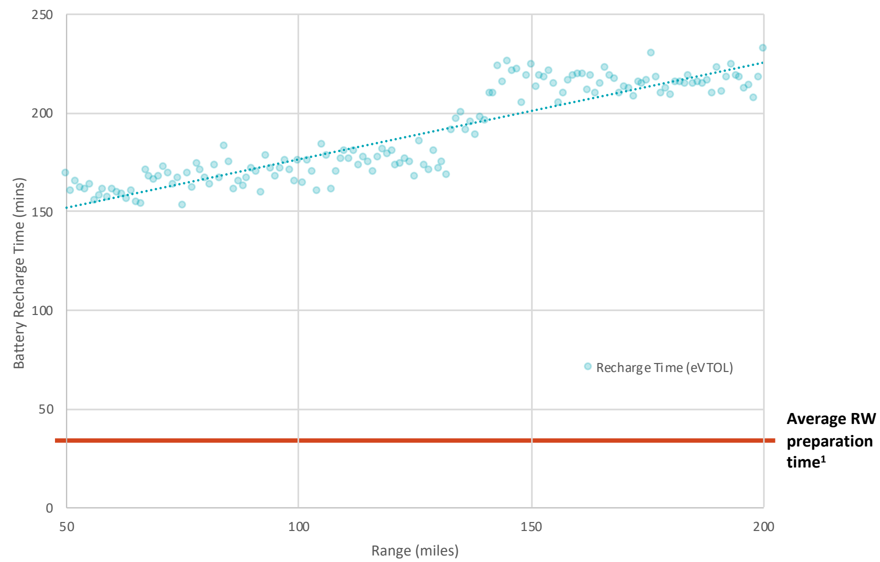
BATTERY RECHARGING TIME AS FUNCTION OF RANGE

Battery Requirements

- Our analysis shows that an eVTOL air ambulance total battery requirements are high (**~3, 500 lb**) which can limit its capability to compete on long missions (See Appendix 5.12b for detailed analysis). Our analysis assumes that an eVTOL will have sufficient available volume to store large batteries.

Battery Re-charging

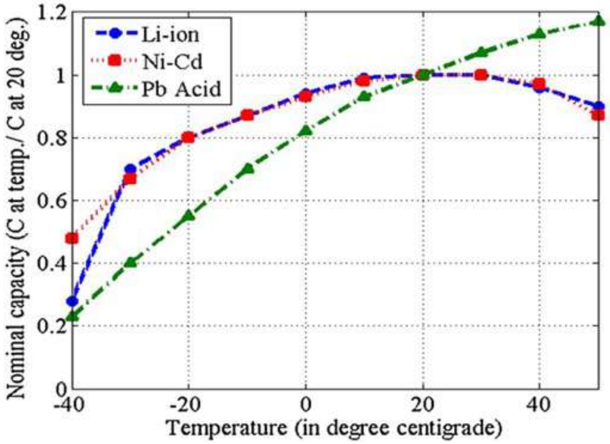
- At battery charger max power setting of 125 KW, we observe that eVTOL preparation time (i.e., time required to bring the vehicle back in service) is **significantly higher** due to high battery charging times. In comparison, current Rotary wings take about approximately 30 minutes

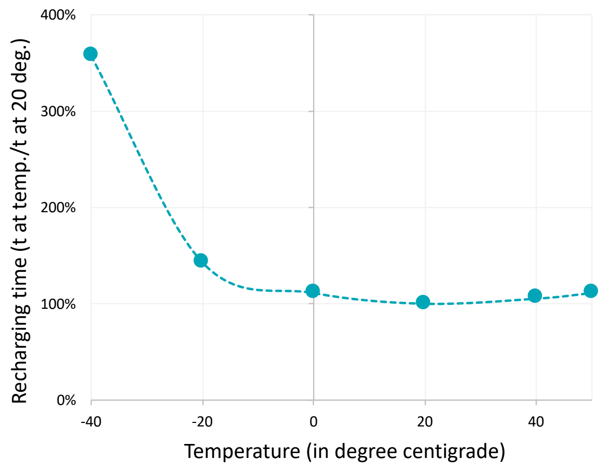


[1]RW preparation time refers to time required to bring the vehicle back in service once it has returned to the base. This time includes re-fueling, maintenance, re-stocking of medical supplies, cleaning etc. Usually, re-fueling takes about ~15 minutes.

EFFECT OF EXTREME WEATHER ON BATTERY CHARGING TIMES

- Our analysis for air ambulance market defines extreme weather as **conditions of low and high temperature**. It is assumed that other weather conditions like rain, storm and high winds conditions equally affect the Rotary Wing market.
- **Capacity** of Li-ion battery **decreases at low temperatures** since the total resistance (sum of bulk, surface layer and charge-transfer resistance layer) increases. Recharging time proportionally increases as capacity decreases.
- Approximately **10% of events** are **performed in 0-10°C conditions** every year (analysis available in Appendix 5.14). Therefore, we calculate eVTOL recharging time as a weighted average of recharging time of ~90% of events performed at 20°C and ~10% events performed in 0-10°C.



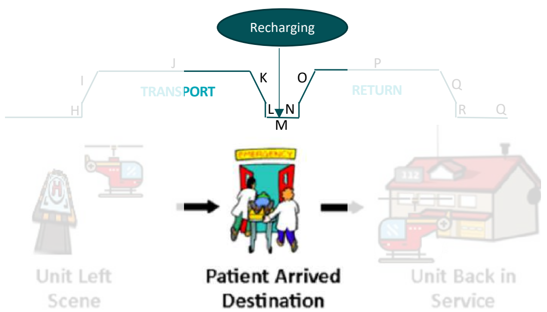


Source: The Institution of Engineering and Technology, 2016

SCENARIOS: REVISED CONOPS AND BATTERY SWAPPING

Scenario 1: Revised ConOps

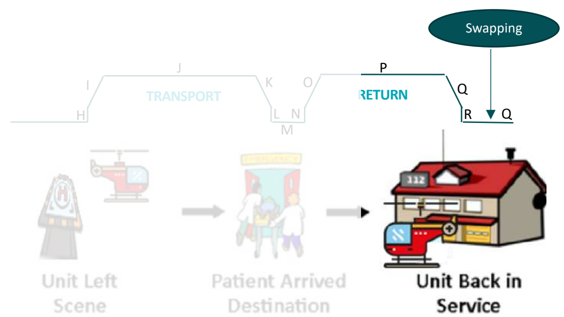
- Under Transport phase, patient is transported from the scene to the medical facilities. Our analysis explores charging during patient disembarkation **(~ 5 mins**) to reduce range requirement (hence, battery requirement) combined with fast recharging from scenario 1. This phase is represented by ‘M’ in the figure below.



- Under this scenario, total range required reduces to 30-180 miles as opposed to 50-200 miles. Average battery weight reduces to ~3, 200 lb (as opposed to ~3, 500 lb).

Scenario 2: Battery Swapping

- Given high re-charging times, air ambulances may rely on swapping batteries when eVTOL returns to the base after each mission to reduce the total call time (increasing dispatch reliability). Battery swapping is expected to take **~5 minutes** (Georgia Tech Study).

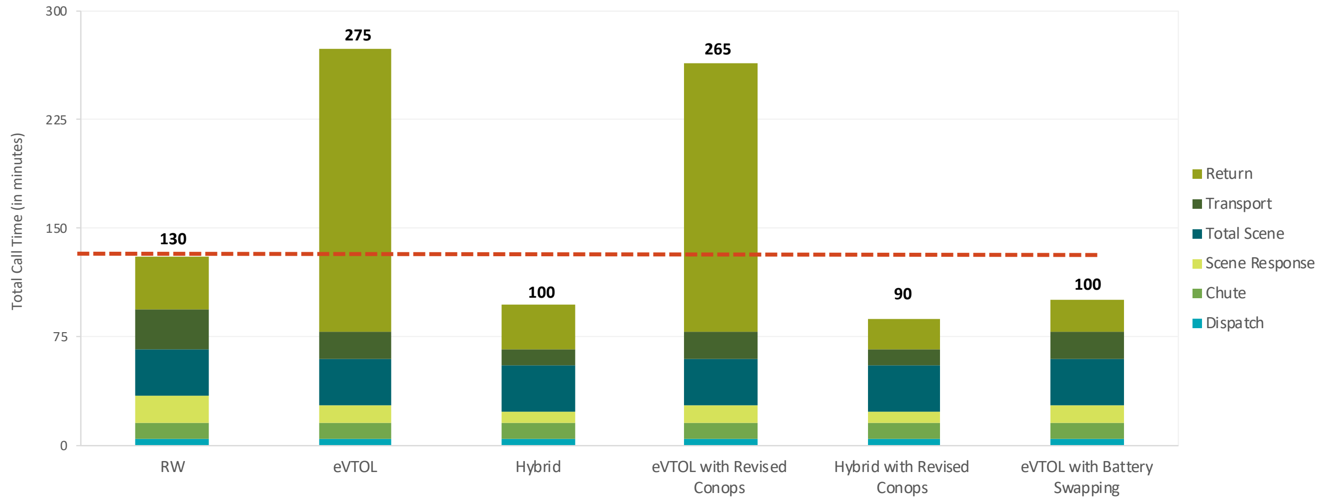


- Median price of battery cost per transport was calculated to be **~$300**, which will be added to the operating cost. Staff and equipment required to swap the batteries can be considered as a part of indirect operating costs.

BOTH EVTOL AND HYBRID AIRCRAFT HAVE HIGH RETURN TIMES DUE TO HIGH BATTERY RE-CHARGING TIME

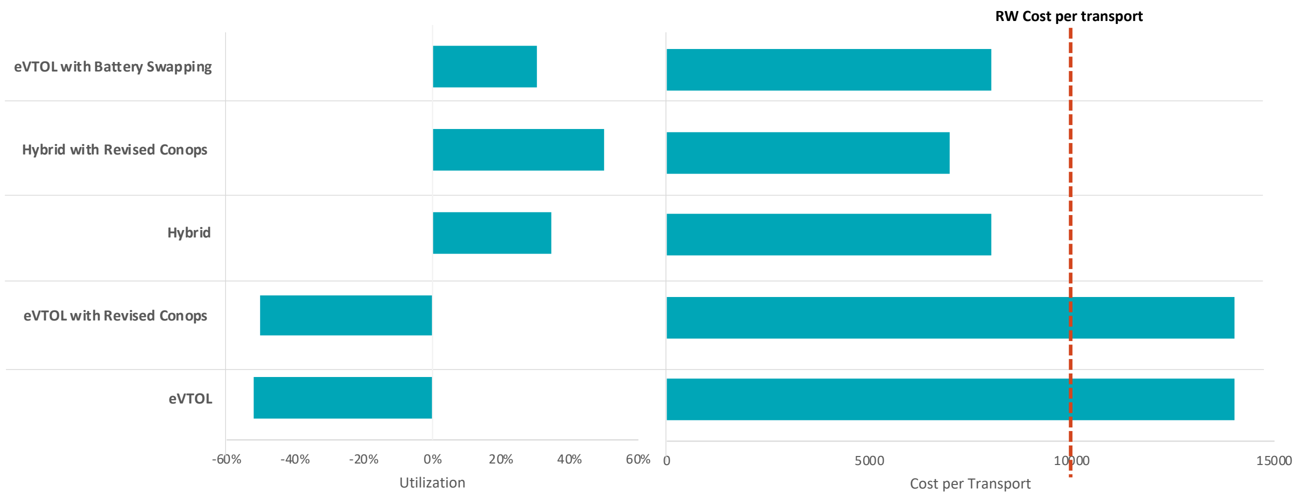
Dispatch, Chute and Scene time remains the same for RW and eVTOL/hybrid while scene response and transport time changes due to differences in speed. Return time increases significantly for eVTOL due to high battery recharging times.

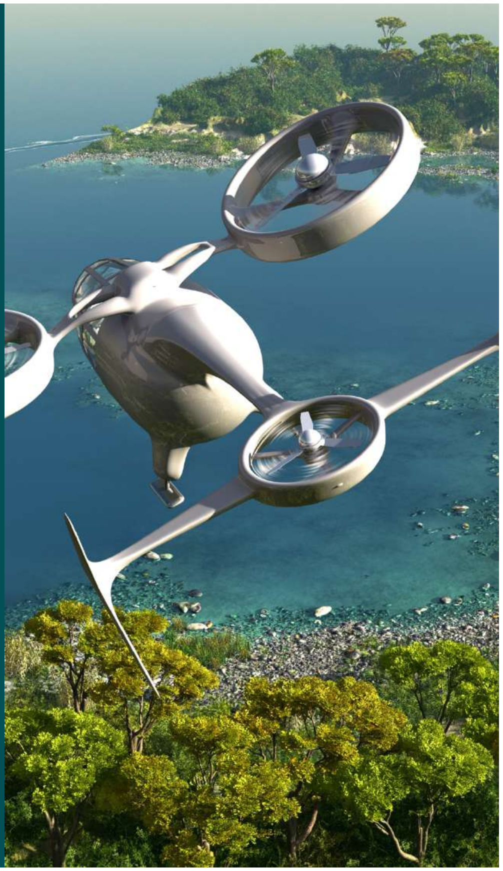
Total call time in Battery swapping scenario is comparable to current Rotary Wing market while total call time for all other scenarios far exceeds to that of RW.



EFFECTIVE NUMBER OF TRANSPORTS VS COST PER TRANSPORT

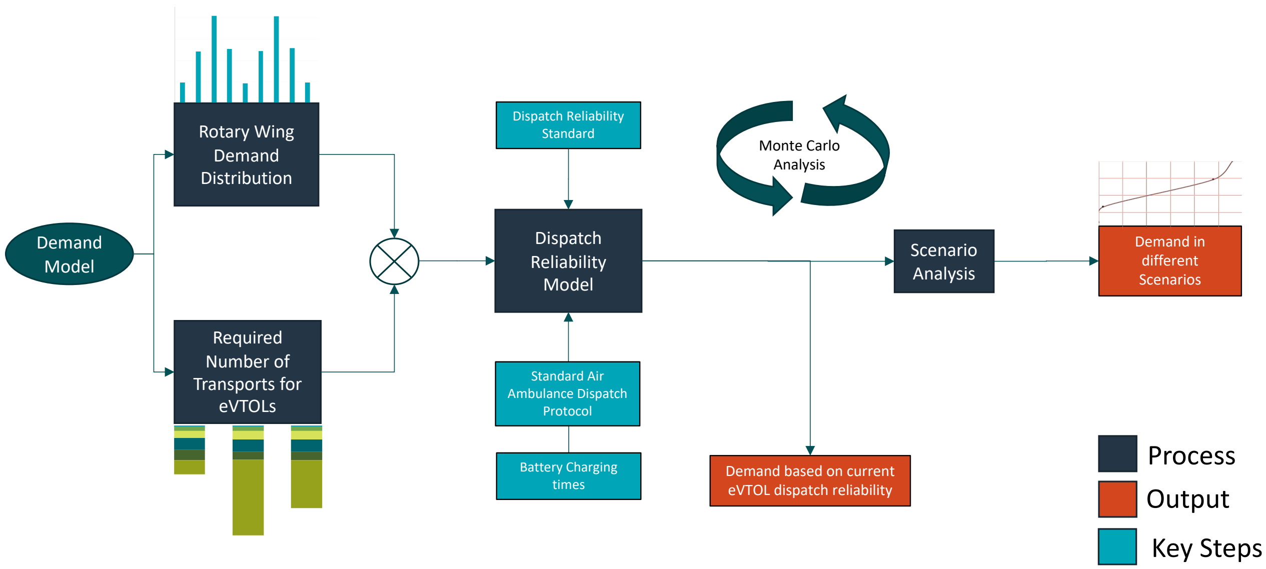
- Effective number of transports for different scenarios significantly decreases as compared to RW annual transports (~350) per vehicle (keeping total usage of vehicles constant in terms of hours).
- Cost per transport for eVTOL increases (due to decreased number of transports) for all scenarios and is more than RW cost per transport (except battery swapping scenario). However, cost per transport for Hybrids decreases due to increased number of transports.





AGENDA

STRUCTURE OF DEMAND SIDE MODEL FOR AIR AMBULANCE



TYPICAL AIR AMBULANCE DISPATCH PROTOCOL

FACTORS INFLUENCING AIR AMBULANCE DISPATCH DECISION

Patient Requirements:

- **Minimized time outside hospital:** Patient must minimize time spent outside a hospital environment
- **Current facility unable to provide services:** Needs time-sensitive evaluation or procedure outside the capacity of the current facility
- **Critical care life support necessary:** Requires critical care support not available in ground transportation

Variables:

- **Passenger Weight:** Must be within allowable range for air transport
- **Helipad Accessibility:** Destination facility must have helipad or close geographic access to one
- **Weather Conditions:** Current and predicted weather conditions must be favorable for air transport

Local Constraints:

- **Area unsuitable for ground transport:** Ground transportation unavailable or unsuitable for transport
- **Lack of EMS coverage:** Deploying ground transportation leaves local area without adequate EMS coverage

Source: Emergency Medical Services, 2015

DISPATCH RELIABILITY VS NUMBER OF TRANSPORTS

- Air Medical Transport follows a certain dispatch protocols that considers the need of minimization of time, weather considerations, availability, safety etc. before deploying a RW aircraft.
- Cost per transport of air ambulances **decrease significantly** as number of transports increases. However, increased use of an air ambulance (i.e., less availability) decreases dispatch reliability.
- **Dispatch reliability** is calculated at an event interval of one hour assuming that an RW Air Ambulance total call time ~2 hours:

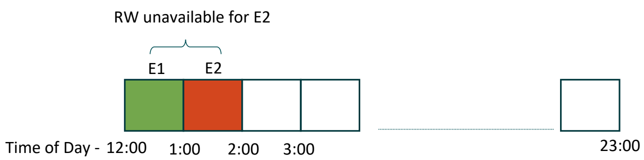
$$\text{Dispatch Reliability} = \frac{\text{Number of events for which ambulance is available (A)}}{\text{Total number of events (T)}}$$

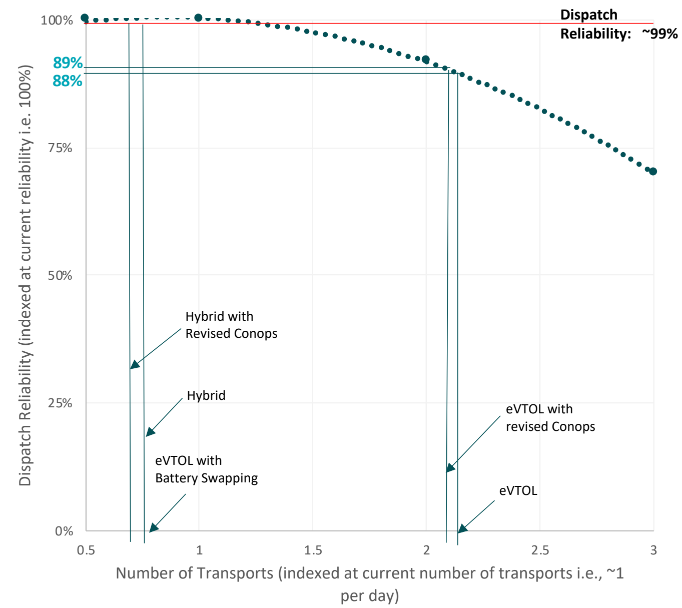
where,

A = T- NA (number of events for which ambulance is unavailable)

e.g. Case of NA

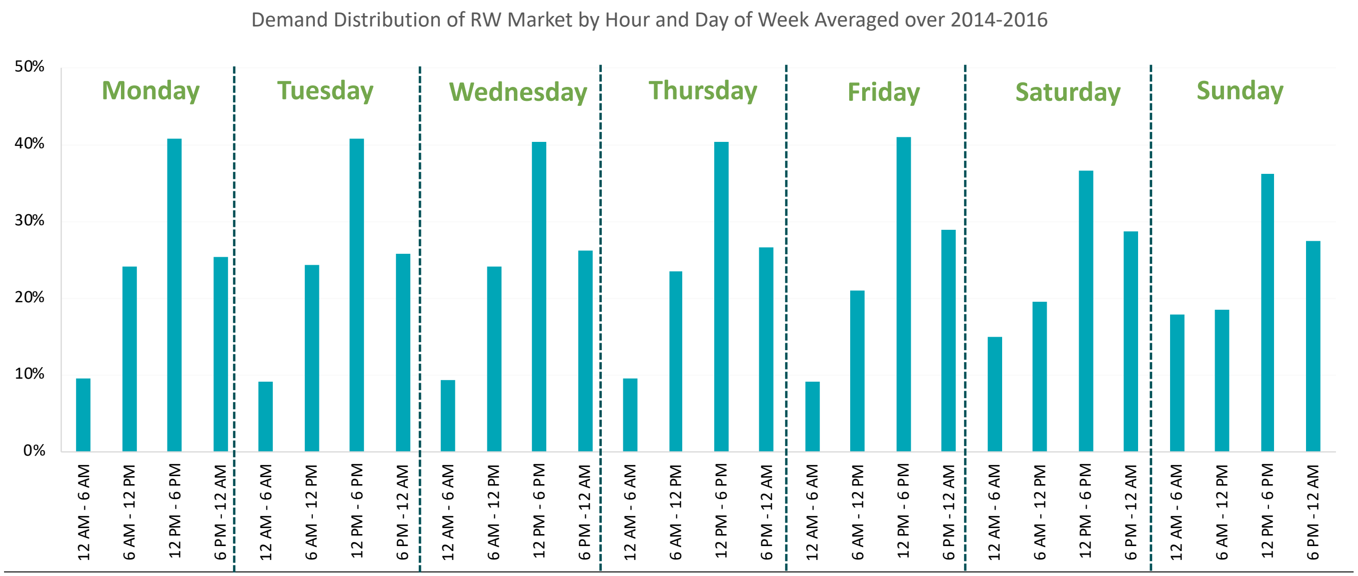
E1 = Emergency event 1 satisfying RW dispatch protocol. RW dispatched
E2 = Emergency event 2 satisfying RW dispatch protocol





DEMAND DISTRIBUTION BY HOUR AND DAY OF WEEK

Each day of the week follows a similar trend where demand peaks between 12 pm – 6 pm while the demand is lowest between 12 am – 6 am.



DISPATCH RELIABILITY BASED ON DEMAND DISTRIBUTION

Dispatch Reliability:

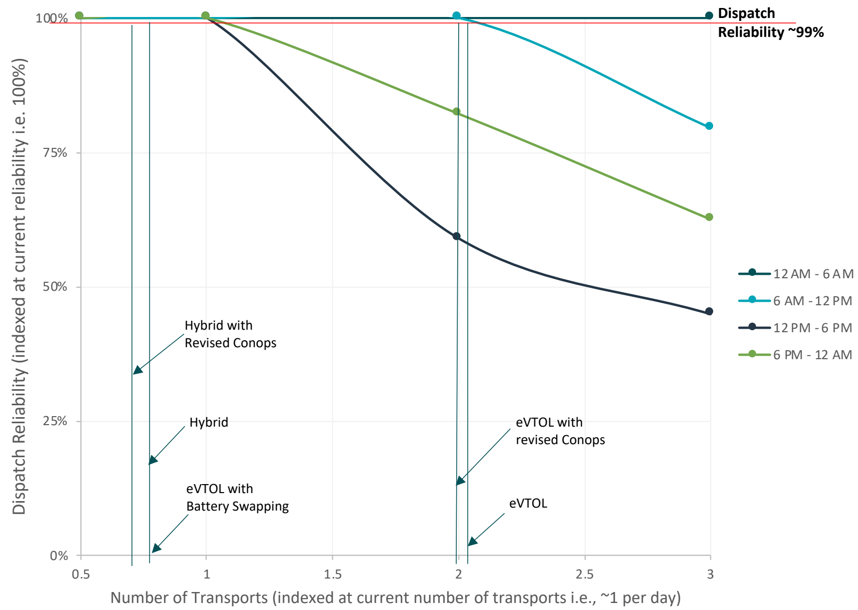
- **Lowest for 12 pm – 6 pm** (since demand is highest with the increase in number of transport)

Available market (based on Battery recharging):

- Demand (~10% of the current total demand) between **12 am – 6 am** can possibly be served by eVTOLs where Dispatch reliability is the highest
- Expected lower noise levels makes eVTOLs an attractive option

Available market (based on Battery Swapping):

- **Full market** can be served by eVTOLs with Battery Swapping capabilities and Hybrid aircraft



Results

MARKET SIZE CAPTURE UNDER DIFFERENT OPERATION SCENARIOS

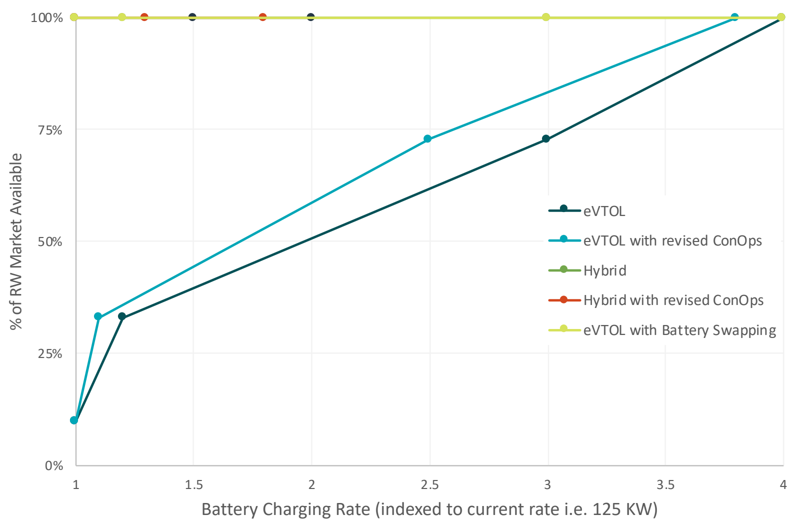
Due to high recharging time, dispatch reliability of eVTOLs for 90% of the market may be below the acceptable standard. Therefore, under current technology, eVTOLs may not be an attractive option for air ambulances. Fast Recharging and Battery Swapping capabilities may propel the capture of available RW market for eVTOLs.

Fast Recharging:

- Assumes a scenario where battery recharging rate increases with respect to current rates
- On increasing Battery recharge rate **approximately 4 times to current rate,** eVTOLs may address the total available RW market because of the following
  - Dispatch reliability similar to current RW market achieved
  - Cost per transport less than current RW market

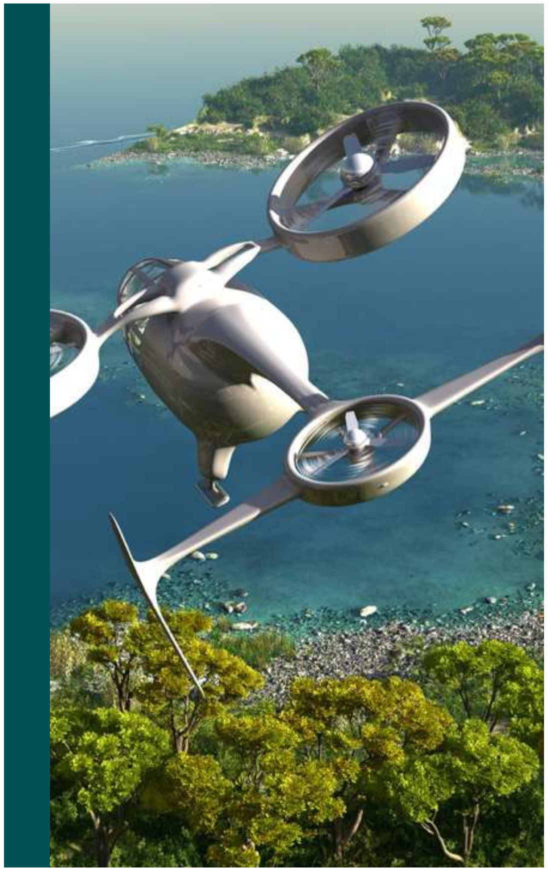
Battery Swapping:

- **~100% of RW market** is available for eVTOLs with Battery Swapping capabilities



SUMMARY

- eVTOLs and hybrid aircraft are expected to **compete with existing Rotary Wing** market for the near term due to competition from ground ambulances and high range requirements for fixed wing market
- Median cost of operating an eVTOL and hybrid air ambulance, at RW utilization rates, is **~ $9, 000 and ~9, 800** per transport respectively of which **~80% is fixed costs** and ~20% variable costs
- Battery **recharging time is high,** thus making the vehicle unavailable for longer times (reducing reliability).
- **Battery recharge rate** will need to be increased approximately **4 times** to current rate for eVTOLs to address the total available RW market
- Hybrid vehicles have **faster return time than eVTOLs** and conventional helicopters
- **Battery swapping** capability is more **preferred** eVTOLs due to similar level of dispatch reliability as current RW market
- **Hybrid vehicles** can be utilized ~35% more than current RW maintaining the desired reliability levels. This could potentially **reduce cost per transport by ~30%.** Therefore, tilt rotor hybrids are an attractive option to replace traditional RWs



CONTENTS

CONCLUSION - SUMMARY OF KEY FINDINGS

UAM markets have strong potential but face significant challenges and constraints that could severely limit the available market. Our results suggests the following:

- Airport Shuttle and Air Taxi markets are viable markets with a significant total available market value of $500 bn at the market entry price points in the best case unconstrained scenario
- In the near term, a 5-seat piloted eVTOL will cost ~$6.25 per passenger mile. However, in the long term, high operational efficiency, autonomy, technology improvements may decrease the cost by ~60%
- Infrastructure availability and capacity combined with high cost is a major barrier to fully capture the available demand
- Air Ambulance market served by eVTOLs is not a viable market due to technology constraints. Hybrid VTOL aircraft is a more attractive option to serve air ambulance markets
- Legal and Regulatory analysis found all markets share the same regulatory barriers
- Public perception is a large obstacle. Safety is the greatest concern with “unruly” passengers, “lasing” of pilots, and aircraft sabotage being main contributors
- Weather poses significant challenges to UAM operations at several focus urban areas with low visibility, strong winds, and storms being the most frequent adverse conditions

APPENDIX

FOCUS MARKETS AND URBAN AREAS APPENDIX

APPENDIX 1: SAG MEMBERS - FEDERAL GOVERNMENT

NAN SHELLABARGER
Executive Director
FAA Aviation Policy & Plans Office

- Responsible for setting direction and overseeing operations for FAA'S Policy organization
- Previously the Manager of the Planning Analysis Division at FAA where she was responsible for facilitating agency-wide strategic planning, developing long range aviation forecasts, and analyzing airline delays

DR. KARLIN TONER
Director of Global Strategy
FAA Office of International Affairs

- Provides executive leadership in the development, implementation and evaluation of program policies, goals, and objectives for US international aviation
- Master's Degree and Ph.D. in Aerospace Engineering along with honorary Ph.D. in Science
- Oversees the development of a data-informed process to enable the FAA to most effectively prioritize future international engagement

EARL LAWRENCE
Director
FAA UAS Integration Office

- Director of the UAS Integration office responsible for the facilitation of all regulations, policies, and procedures required to support FAA's UAS integration efforts
- Previously served as the Manager of the FAA'S Small Airplane Directorate where he managed airworthiness standards, continued operational safety, policy, and guidance for small aircraft, gliders, light sport aircraft, airships, and balloons

DR. JIM HILEMAN
Chief Scientific and Technical Advisor for Environment
FAA

- Ph.D. and Master's Degree in Mechanical Engineering
- Previously the Principal Research Engineer within MIT's Department of Aeronautics and Astronautics and its Associate Director, Partnership for AiR Transportation Noise and Emission Reduction
- Research focused on modeling the impacts of alternative jet fuel and innovative aircraft concepts on efficiency, noise, air quality and global climate change

CHRISTOPHER HART
Former Chairman
NTSB

- Former Deputy Director of Air Traffic Safety Oversight Service at FAA
- Former Assistant Administrator for System Safety at FAA
- Former Deputy Assistant General Counsel to DOT
- Former Attorney with the Air Transport Association
- Master's Degree in Aerospace Engineering

JULIET PAGE
Acoustics & Sonic Boom Expert
Volpe (DOT)

- SME in the field of acoustics / aerospace engineering including sonic boom, atmospheric propagation, aircraft, rotorcraft, tiltrotor, space and launch vehicle noise
- Experience conducting scientific research, regulatory standards and model development and validation for air and ground based transportation systems through analytic development, experimentation and measurements

Bios of the members were last updated in April 2018

APPENDIX 1: SAG MEMBERS - STATE AND LOCAL GOVERNMENT

BASIL YAP
UAS Program Manager
North Carolina DOT

- 9+ years of experience in airport development
- 4+ years experience in UAS Program Management
- UAS SME
- Designs, establishes, and conducts studies and makes recommendations relative to the UAS policies, programs, methods and procedures currently in place

DARHAN DIVAKARAN
UAS Program Engineer and Geospatial Analyst
NCDOT Division of Aviation

- Unmanned aviation expert with expertise in unmanned flight operations, flight safety, remote sensing, geospatial analysis and project management
- Experience developing best practices and procedures for safe and efficient unmanned aviation operations
- Previously Research Associate – Flight Operations with NGAT and AirTAP at the ITRE in NC

MEERA JOSHI
Chair and CEO
NYC'S Taxi & Limousine Commission

- Previously served as the Frist Deputy Executive Director of the NYC Civilian Complaint Review Board, an agency tasked with investigating complaints of police misconduct
- Responsible for initiation of a landmark prosecution program that resulted in the agency's ability to independently prosecute founded complaints against police officers

ALEX PAZUCHANICS
Assistant Director
Department of Mobility and Infrastructure – City of Pittsburgh

- Policy Advisor for Pittsburgh Mayor William Peduto
- Led Pittsburgh's response to the USDOT Smart City Challenge
- Manages the City's designation as an Autonomous Vehicle Proving Ground and is a member of the PennDOT Autonomous Vehicle Policy Task Force

MARK DOWD
Executive Director
Smart Cities Lab

- Previously worked for the White House as the Senior Advisor for the Office of Management and Budget
- Responsible for creating and executing the USDOT'S Smart City Challenge that changed the way cities use technology and innovation to drive change and solve problems related to mobility
- Broad experience in policy development and implementation related to technology, mobility, smart cities, public-private partnerships, energy, and environmental issues

Bios of the members were last updated in April 2018

APPENDIX 1: SAG MEMBERS - STATE AND LOCAL GOVERNMENT

ADRIENNE LINDGREN
Economic Policy & UAS/UAM Integration
LA City

- Oversees the implementation of public-private partnerships for industrial innovation and cluster development, in partnership with the U.S. Departments of Energy and Commerce
- Leads the development of testing and demonstration zones for urban aviation, including the integration of UAV and AV policy strategy, in partnership with the Los Angeles Department of Transportation, LA Fire Department, the Port of LA, Los Angeles World Airports, and the Federal Aviation Administration.

JUSTIN ERBACCI
Chief Innovation and Technology Officer
Los Angeles World Airports

- Responsible for implementing LAWA's overall Information Technology vision and strategy, in addition to leveraging innovative technologies and processes to enhance operations at Los Angeles International (LAX) and Van Nuys general aviation airports.
- Prior to his appointment with LAWA, he served as Vice President of Customer Experience & Technology for Star Alliance, a global airline network comprised of 28 airlines serving 640 million passengers annually

Bios of the members were last updated in April 2018

APPENDIX 1: SAG MEMBERS - LEGAL AND REGULATORY

GRETCHEN WEST
Senior Advisor in the Global Unmanned Aircraft Systems
Hogan Lovells

- Policy advocate for the commercial drone industry over a decade working to reduce barriers to entry
- Works with companies to assist in understanding market trends and develop strategies for market growth
- Co-leads the Commercial Drone Alliance, a non-profit association
- Previously served as AUVSI's Executive VP overseeing AUVSI's global business development initiatives and government relations efforts for the unmanned systems and robotics industry

LISA ELLMAN
Co-Executive Director of Commercial Drone Alliance
Hogan Lovells

- Co-chair of firm's UAS practice
- Counsels businesses and trade groups on UAS issues in industries ranging from newsgathering, aerial photography, energy, precision agriculture and insurance, higher education, drone technology, to construction
- Held variety of positions at top levels of executive branch at the White House and the U.S. Department of Justice (DOJ)

DAVID ESTRADA
Chief Legal Counsel
ZEE Aero

- Previously VP of Government Relations at Lyft and helped establish a legal and regulatory framework for TNCs in the US
- Previously held Legal Director role at Google X, leading the legal efforts behind Google's self-driving cars, Google Glass, and drone delivery program
- While at Google, helped create the first state laws and regulations governing self-driving cars in Nevada, California, and Florida

MATTHEW DAUS
Partner, Chair of Transportation Practice Group
Windels Marx LLP

- Practice focuses on transportation law, counseling clients on a wide range of matters including regulatory compliance, strategic planning, procurement, litigation, regulatory due diligence, expert witness testimony and reports, administrative law and public policy
- Previously served as Commissioner and Chairman of NYC TLC
- Formerly served as General Counsel to the Commission and Deputy Commissioner for Legal Affairs
- Served as Special Counsel to the TLC Chair – supervising over 75 lawyers and Administrate Law Judges

MARK AITKEN II
Senior Policy Advisor
Akin Gump Strauss Hauer & Feld LLP

- Leads advocacy for the inclusion of association priorities in House and Senate versions of FAA reauthorization and associated appropriation measures
- Influences to safely expedite the US framework for integrating UAS into the NAS for commercial opportunities
- ACRP 03-42 Panel Member

Bios of the members were last updated in April 2018

APPENDIX 1: SAG MEMBERS - EDUCATIONAL INSTITUTIONS

JOHN HANSMAN
T. Wilson Professor of Aeronautics & Astronautics
Massachusetts Institute of Technology

- Head of the Humans and Automation Division at MIT
- Director of the MIT International Center for Air Transportation
- Current research interests focus on advanced cockpit information systems, including Flight Management Systems, Air-Ground Datalink, Electronic Charting, Advanced Alerting Systems, and Flight Crew Situational Awareness

PARKER VASCIK
Ph.D. Candidate, Aeronautics and Astronautics
Massachusetts Institute of Technology

- Conducting research in collaboration with the NASA On Demand Mobility and UAS Traffic Management (UTM) programs
- Research areas include Unmanned Aircraft System Traffic Management, On-Demand Mobility Aviation, Design for Ilities under Uncertainty, and Technology Infusion Analysis

JESSIE MOOBERRY
Technologist
Peace and Innovation Lab at Stanford

- Expert in humanitarian UAV design and operations
- Built and served as VP of Uplift Aeronautics, first cargo drone nonprofit
- Founded SwarmX, an enterprise drone company
- Commercial drone pilot
- Mentor for Ariane de Rothschild Social Enterprise Fellowship

BRIAN J. GERMAN
Associate Professor
Georgia Tech

- Ph.D. in Aerospace Engineering
- Senior Member of the American Institute of Aeronautics and Astronautics
- Research areas are multidisciplinary design, multi-objective optimization, and decision methods applied to air vehicle design and systems engineering
- Also conducts research in aerodynamic, propulsion, subsystem, and performance models suitable for aircraft concept studies

DR. JUAN ALONSO
Professor, Department of Aeronautics & Astronautics
Stanford University

- Founder and director of the Aerospace Design Laboratory where he specializes in the development of high-fidelity computational design methodologies to enable the creation of realizable and efficient aerospace systems
- Research involves manned and unmanned applications including transonic, supersonic, and hypersonic aircraft, helicopters, turbomachinery, and launch and re-entry vehicles
- Ph.D. in Mechanical & Aerospace Engineering

Bios of the members were last updated in April 2018

APPENDIX 1: SAG MEMBERS - MANUFACTURERS

DR. BRIAN YUKTO
VP of Research & Development
Aurora Flight Sciences, a Boeing Company

- Responsible for Aurora's R&D business unit which advances Auroras capabilities in the areas of autonomy, next generation, air vehicle design, advanced electric propulsion, and operations of intelligent flight systems in the national airspace

DR. ERIC ALLISON
CEO
Zee Aero

- Previously served as Zee Aero's Director of Engineering
- Thesis covered ultrasonic propulsion
- Ph.D. in Aeronautics and Astronautics from Stanford University

TRAVIS MASON
VP Public Policy
Airbus

- Master's Degree in Public Policy
- Leading Public Policy for our future of flight projects across A^3 by Airbus, Airbus Aerial, the Corporate Technology Office urban air mobility group and with Airbus Defense & Space

DR. CARL C. DIETRICH
Co-founder and CTO
Terrafugia

- Focused on development of future product concepts and establishment of new R&D center for Terrafugia
- BS, MS and Ph.D. from the Department of Aeronautics and Astronautics at MIT

Bios of the members were last updated in April 2018

APPENDIX 1: SAG MEMBERS - MANUFACTURERS

PETER BERGER II
Director of Innovation, Silicon Valley

Embraer Business Innovation Center

- Former CEO of Contact IQ, Alitora Systems and Topicmarks
- Advised numerous startups and Fortune 500 companies such as Orange Telecom and Qualcomm
- Undergraduate degree from California Polytechnic and a law degree from Rutgers University

DAVID ROTTBLATT
Business Development Director

Embraer

- Experience in large multi-national corporations
- Recent projects have focused on business model design and execution, strategic marketing, market development and international project management
- Developed in-depth knowledge of aviation market and customer needs to identify new ventures for Embraer to pursue

BOB LABELLE
CEO

XTI Aircraft Company

- 25+ years experience in top-level aviation management and strategy, aircraft development and operations
- Responsible for development of the TriFan 600 aircraft
- Led the drive to incorporate hybrid-electric propulsion in the TriFan 600 and championed other enhancements in order to better position the aircraft in the future
- Former Chairman and CEO of AgustaWestland North America

JOEBEN BEVIRT
Founder

Joby Aviation

- Master's Degree in Mechanical Engineering Design from Stanford
- Founded Joby Aviation to develop a compact electric personal aircraft designed for efficient high speed flights
- Former Co-Founder of Velocity11 which developed high-performance laboratory equipment
- Former Director of Engineering of Incyte Corporation where he built a team to develop robotics to improve the throughput and efficiency of Incyte's laboratories

Bios of the members were last updated in April 2018

APPENDIX 1: SAG MEMBERS

OPERATORS

MARK MOORE
Engineering Director of Aviation
Uber Elevate

- Mark D. Moore worked for NASA for over 32 years before joining Uber, the entire time focusing on conceptual design studies of advanced aircraft concepts.
- His research focused on understanding how to best integrate the emerging technology area of electric propulsion and automation to achieve breakthrough on-demand aviation capabilities

JUSTIN ERLICH
Head of Policy, Autonomous Vehicles & Urban Aviation
Uber Elevate

- Subject matter expertise includes transportation, sustainability, smart open data, and smart cities, with an academic background in law, government, and behavioral science
- Previously worked on the leadership team of former California Attorney General (currently Senator) Kamala Harris managing technology policy, strategy, and operations

INTERNATIONAL

CHRISTOPHER PETRAS
Legal Officer at the ICAO Legal Bureau
International Civil Aviation Organization (ICAO)

- Provides legal advice to ICAO's Secretary General on international law, air law, commercial law, labor law and related issues
- Former Chief Counsel for International Law for the U.S. Air Force's Air Mobility Command and NORAD
- LL.M. in Air and Space Law (McGill University)

RESEARCH ORG.

MATTHIAS STEINER
Director Aviation Applications Program
NCAR Research Applications Laboratory

- Expertise in mitigating weather impacts on the aviation industry
- Leading efforts to understand weather sensitivities and requirements for the rapidly growing interests in urban air mobility and using unmanned aerial systems for wide-ranging applications and safe integration into the national airspace system.

Bios of the members were last updated in April 2018

APPENDIX 1: SAG MEMBERS - INSURANCE AND REAL ESTATE

BRYANT DUNN
Assistant Vice President
Global Aerospace

- Experience in aviation insurance, underwriting, aircraft and airport operations, market research, marketing, sales, finance, and flight instruction
- Specialized in corporate flight department hull & liability program, aviation manufacturer products liability, airport liability, and unmanned aircraft systems

TOM PLAMBECK
Underwriter
Global Aerospace

- Active Pilot
- Expert in underwriting of drones and light aircraft
- Bachelor's Degree in Aviation Management

ERIC ROTHMAN
President
HR&A Advisors

- 20+ years in transportation planning and transit-oriented development
- Expertise in strategic planning, transportation planning and development, economic development, capital program management, financial management, and program implementation
- Leads the firm's work creating transit-oriented development strategies anchored by station redevelopment across the US

Bios of the members were last updated in April 2018

APPENDIX 1: SAG MEMBERS - VENTURE CAPITAL

FRANCOIS CHOPARD
CEO
Starburst Aerospace Accelerator

- 20+ years of experience in strategy consulting, entrepreneurship, and business development
- Specializes in the Aviation Aerospace and Defense industries featuring high stakes technology and has developed a wide experience of innovation-related issues
- Works on topics like future trends, product strategy, open innovation for companies mainly from the aerospace industry as well as investment funds
- Master's Degree in Electrical Engineering

VAN ESPAHBODI
Aerospace Ventures / International Business Development
Starburst Aerospace Accelerator

- Bringing technology + investment + design together to improve the way aerospace infrastructure operates
- Focus areas include: Corporate and Strategy Development, Corporate Venturing and Open Innovation, Partnerships & Alliances, International Sales, Government Affairs, Competitive Intelligence Analysis

KEN STEWART
Entrepreneur in Residence
GE VENTURES

- 20+ years of business development, strategic planning, sales/marketing, and product development/line-of-business management experience

BARRY MARTIN
Senior Manager - Business Development & Strategy
The Boeing Company

- Coordinates internal functional groups (Legal, Contracts, Intellectual Property, Supplier Management, Communications) to place agreements with customers/partners/suppliers
- Previously Avionics Integration Project Manager at Boeing and responsible for managing cross-functional teams for various F/A-18 avionics system upgrades

Bios of the members were last updated in April 2018

SOCIETAL BARRIERS APPENDIX

ABOUT SOCIETAL BARRIER RESEARCH

Importance of Data and Research

- Need to develop data metrics, models, planning platforms, and methodologies to assess the economic, social, and travel impacts of Urban Air Mobility.
- Longitudinal tracking and forecasting of modal impacts.
- Develop ability for public agencies to forecast the economic and travel behavior impacts of UAM/pilot projects and guide public policy development.
- Developing policies that balance data sharing with privacy (user, private companies, and public agencies).
- Key for providing seamless multi-modal integration.

EXISTING LITERATURE ON PUBLIC PERCEPTION

Public Perception (Based on Existing Literature):

- Trust in Automation/Aviation Systems: Passengers are less willing to fly on-board a solely automated aircraft as compared to the hybrid cockpit or the traditional two-pilot cockpits
- Trust In Automation Based on Branding: Differences in people's trust of the system based upon whether the system was made by a well-known company vs. a "small, startup company"
- Trust in Pilots – Prejudices & Cultural Considerations: Negative gender biases and racial or other stereotypes could have an influence on passengers' willingness to fly based on the composition of a flight crew
- Trust in Air Traffic Controllers: In the U.S., study participants trusted older controllers (55 years old) more than the younger counterparts (25 years old) regardless of gender
- Willingness to Fly: scale consists of seven items using a 5-point Likert scale from ranging from –2 (strongly disagree) to +2 (strongly agree) with a neutral option (0)

FOCUS GROUP FINDINGS

Methodology

- In June 2018, two focus groups were held in Los Angeles and Washington D.C.

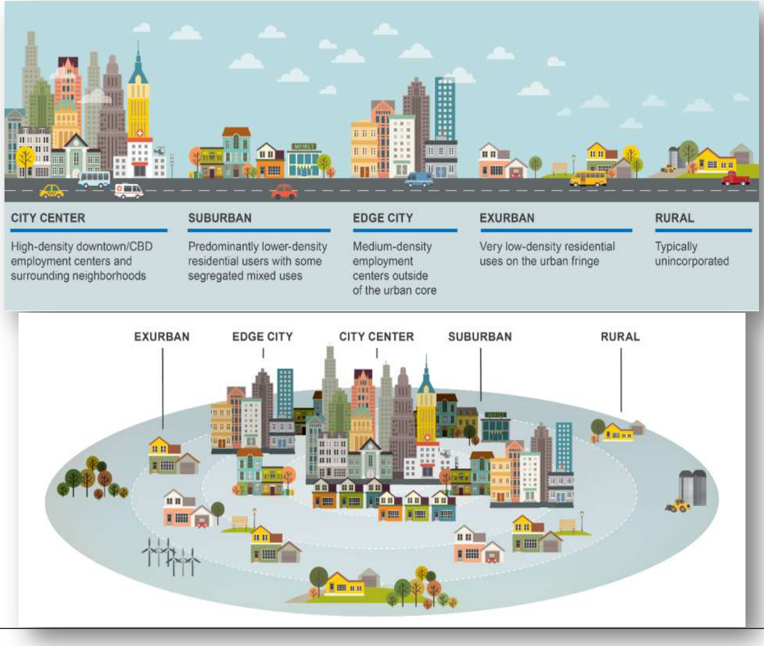
Societal Acceptance of UAM

- Strong emphasis on personal safety, particularly among D.C. respondents
- Travel time savings was a key motivator for willingness to use
- Preference for piloted aircraft (some openness to using automated/pilotless) if the technology were demonstrated to be safe
- Strong preference for short inter-regional travel

Summary of Findings

- A detailed summary of findings will be included in the final report

THE ROLE OF THE BUILT ENVIRONMENT



DEMOGRAPHICS

HOUSEHOLD INCOME	Total (N=1,722)	Houston (N=345)	San Francisco Bay Area (N=343)	Los Angeles (N=345)	Washington, D.C. (N=343)	New York City (N=345)
Less than $10,000	5%	6%	3%	4%	8%	6%
$10,000 - $14,999	4%	5%	3%	5%	4%	2%
$15,000 - $24,999	8%	6%	7%	9%	10%	6%
$25,000 - $49,999	16%	20%	13%	16%	18%	13%
$50,000 - $74,999	16%	22%	14%	14%	13%	17%
$75,000 - $99,999	14%	14%	14%	18%	13%	12%
$100,000 - $149,999	13%	12%	14%	15%	12%	14%
$150,000 - $199,999	7%	4%	9%	8%	6%	8%
$200,000 or more	9%	5%	13%	5%	8%	11%

DEMOGRAPHICS

AGE	Total (N=1,722)	Houston (N=345)	San Francisco Bay Area (N=343)	Los Angeles (N=345)	Washington, D.C. (N=343)	New York City (N=345)
18-24 years	9%	11%	7%	10%	13%	7%
25-34 years	26%	26%	18%	34%	25%	23%
35-44 years	18%	13%	18%	17%	19%	17%
45-54 years	13%	10%	16%	9%	13%	13%
55-64 years	16%	16%	20%	10%	15%	17%
65-74 years	17%	18%	18%	15%	12%	17%
75+ years	5%	5%	4%	4%	3%	6%

DEMOGRAPHICS

RACE/ETHNICITY	Total (N=1,722)	Houston (N=345)	San Francisco Bay Area (N=343)	Los Angeles (N=345)	Washington, D.C. (N=343)	New York City (N=345)
African America	17%	21%	5%	17%	33%	10%
Alaskan Native	2%	1%	1%	1%	2%	2%
Asian	12%	7%	30%	11%	3%	10%
Caucasian/White	58%	56%	54%	55%	57%	68%
Hispanic or Latino	10%	12%	6%	15%	4%	12%
Middle Eastern	1%	1%	1%	1%	1%	0%
Native Hawaiian or Pacific Islander	1%	0%	3%	1%	0%	0%
South Asian	0%	1%	0%	0%	0%	0%
Southeast Asian	1%	1%	1%	0%	1%	0%
Other	1%	2%	1%	2%	1%	1%

DEMOGRAPHICS

- Higher response rate among women
- Mostly 1-2 person households

GENDER	Total (N=1,722)	Houston (N=345)	San Francisco Bay Area (N=343)	Los Angeles (N=345)	Washington, D.C. (N=343)	New York City (N=345)
Female	57%	63%	50%	59%	56%	57%
Male	43%	37%	50%	41%	44%	43%
HOUSEHOLD SIZE						
1	34%	28%	33%	27%	33%	47%
2	32%	38%	33%	30%	33%	28%
3	16%	15%	14%	21%	16%	13%
4	12%	13%	13%	16%	12%	9%
5	4%	3%	4%	4%	4%	2%
6	1%	1%	1%	1%	1%	1%
More than 6	1%	1%	1%	1%	1%	0%

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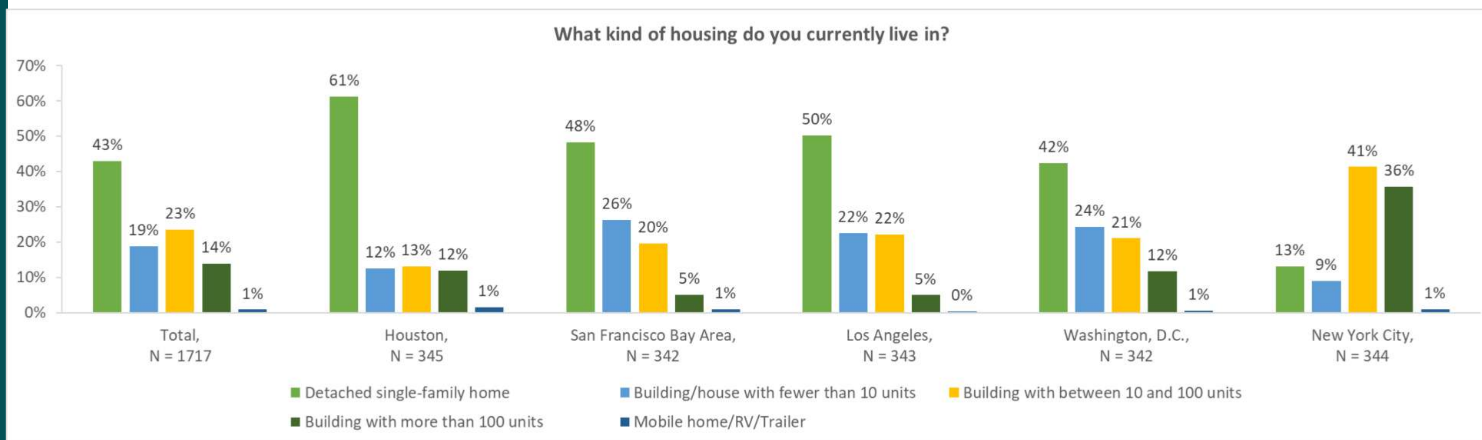
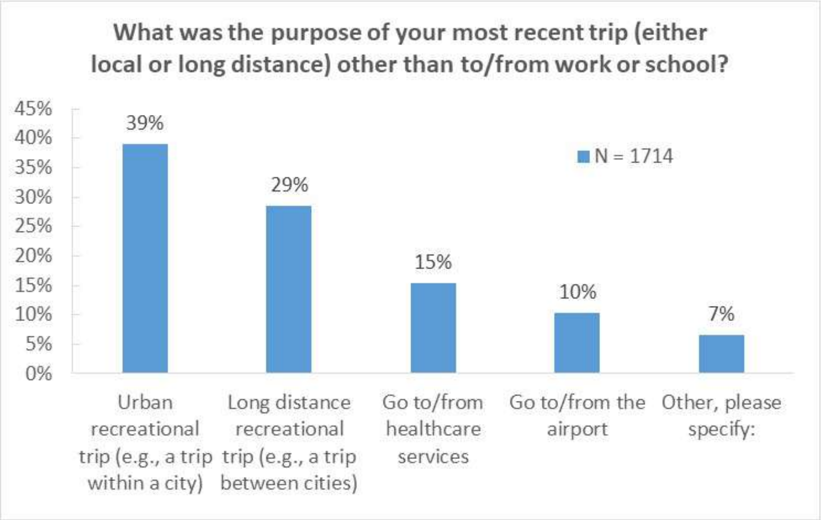
DEMOGRAPHICS



RECENT TRAVEL BEHAVIOR

- Question designed to inform the market analysis (air taxi, airport, and air ambulance markets)



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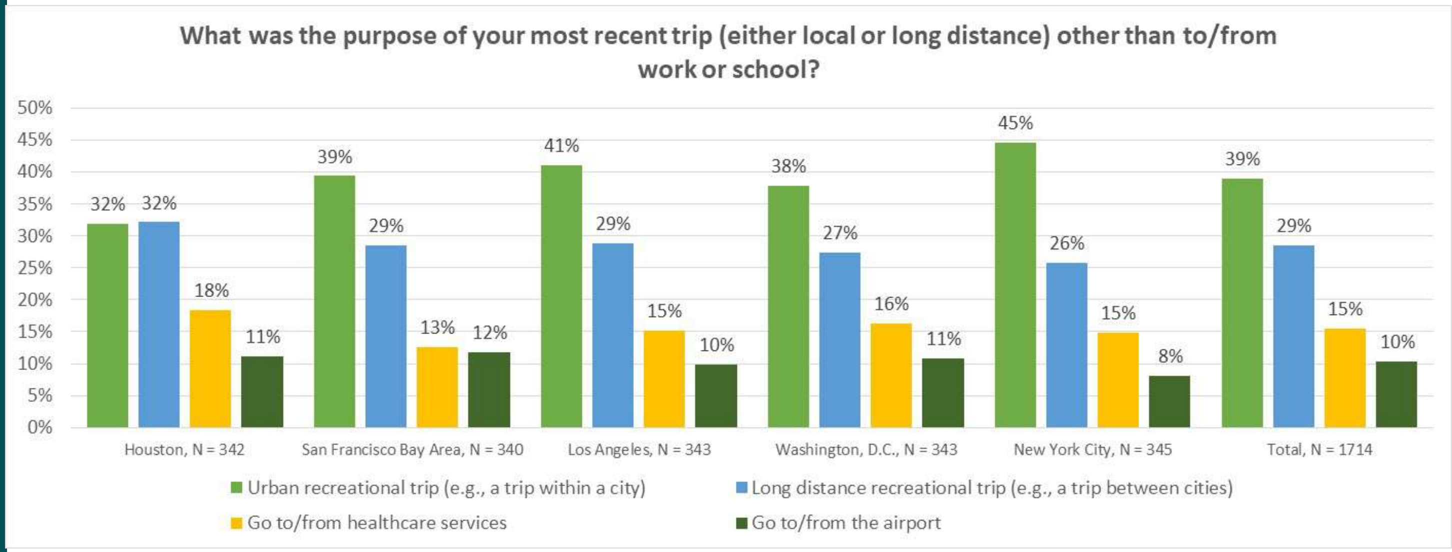
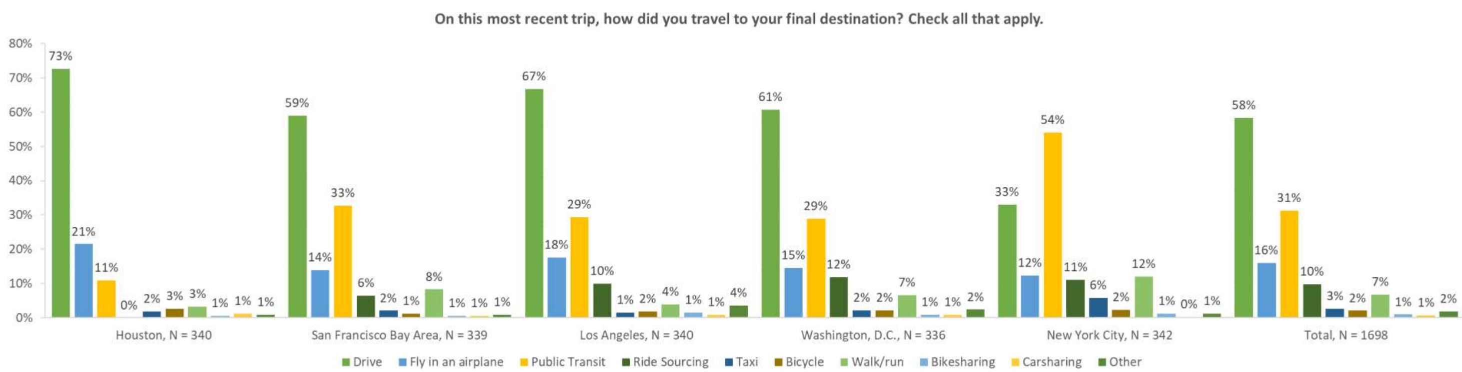


RECENT TRAVEL BEHAVIOR



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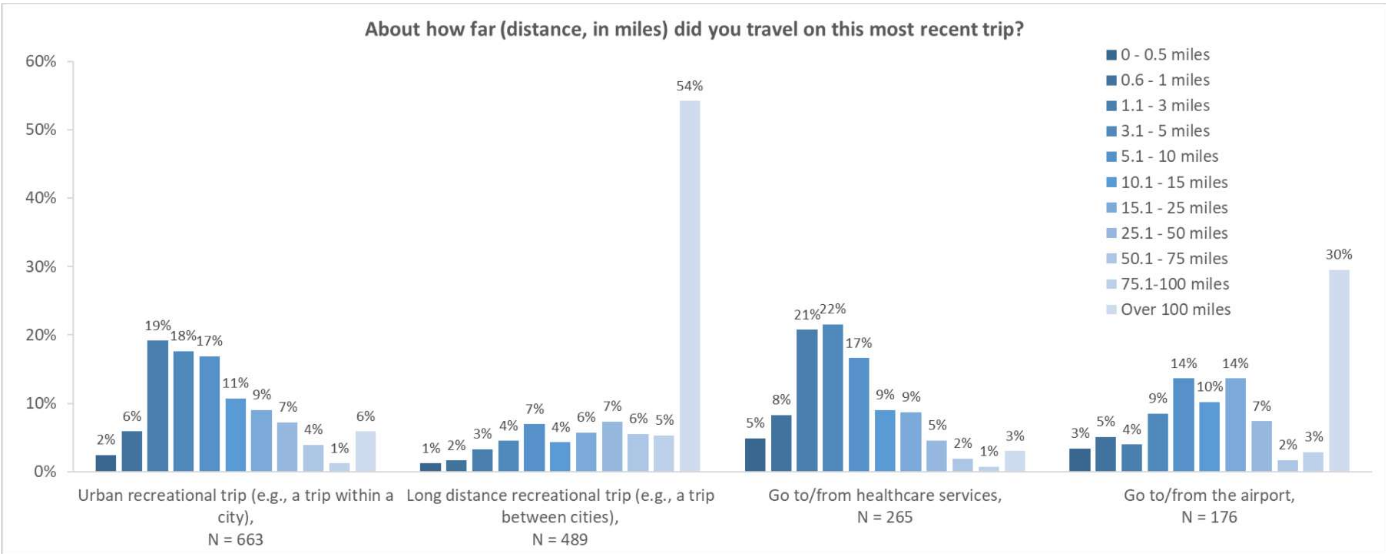
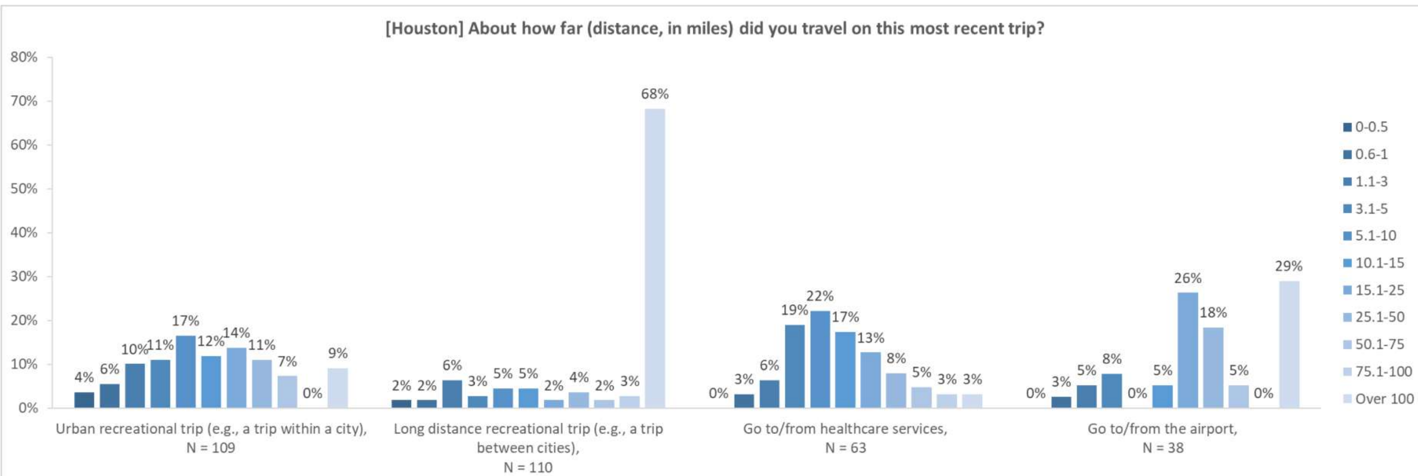
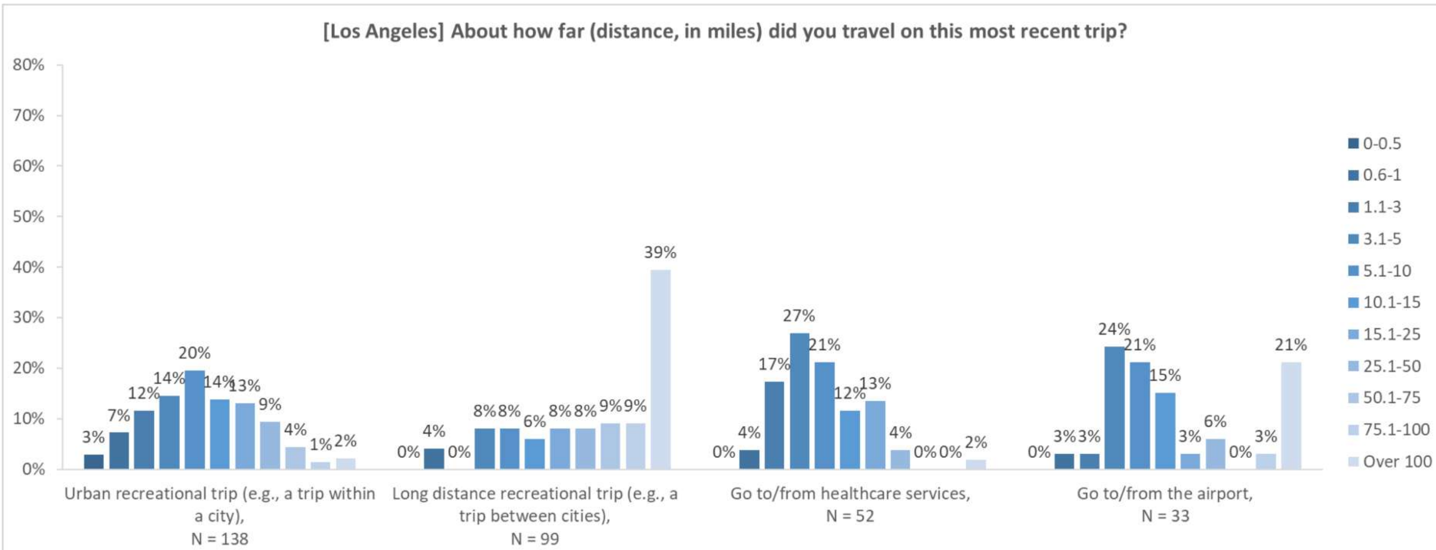


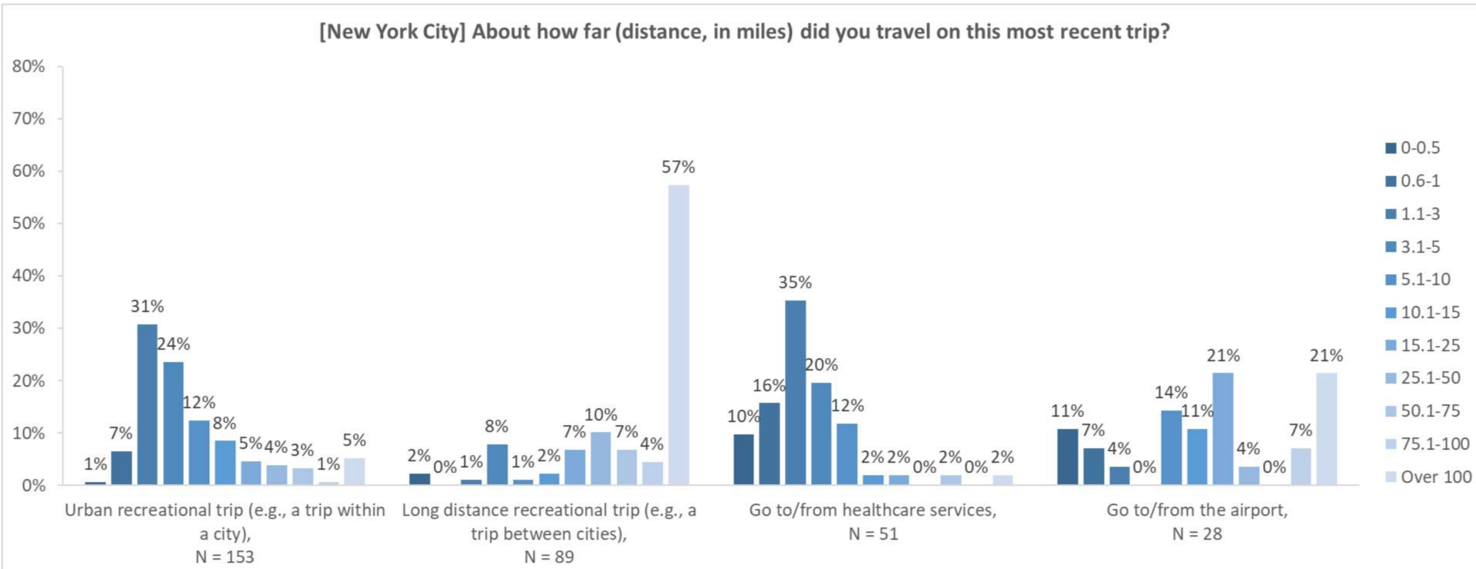
RECENT TRAVEL BEHAVIOR



RECENT TRAVEL BEHAVIOR



RECENT TRAVEL BEHAVIOR



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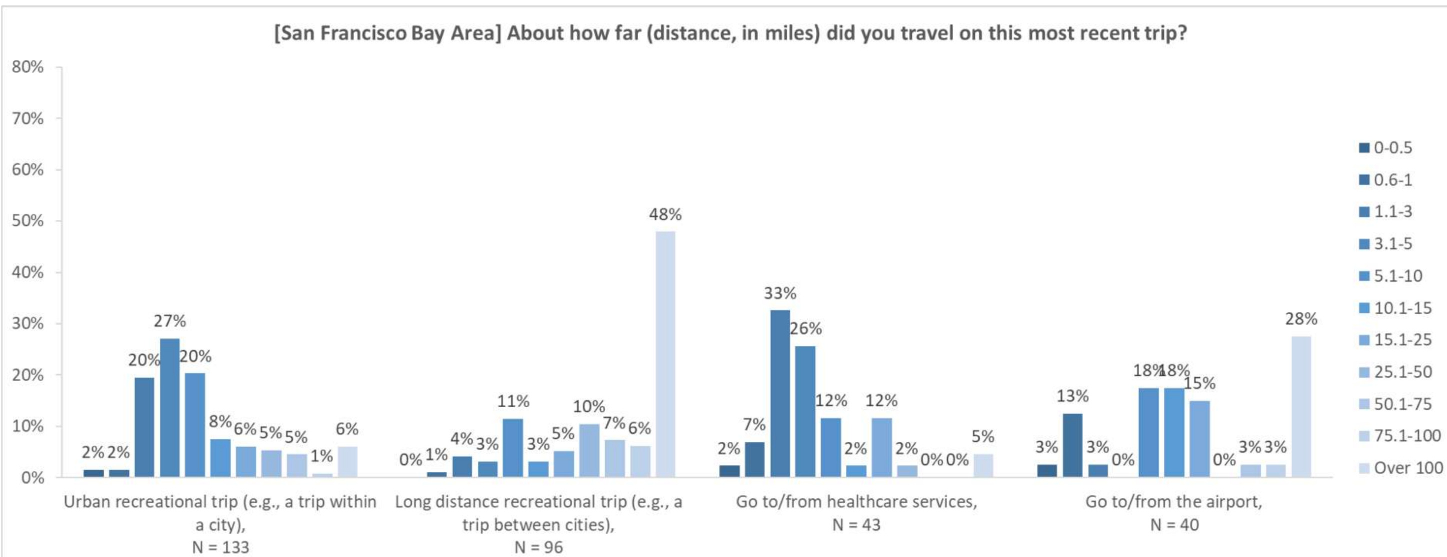
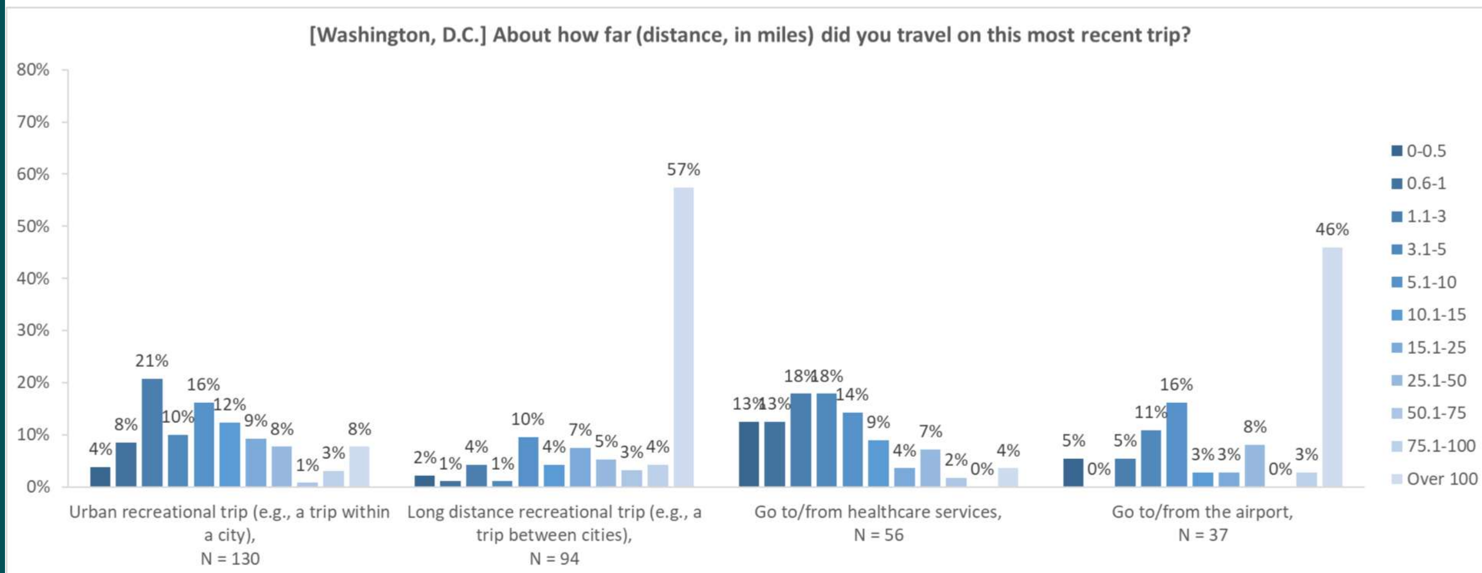
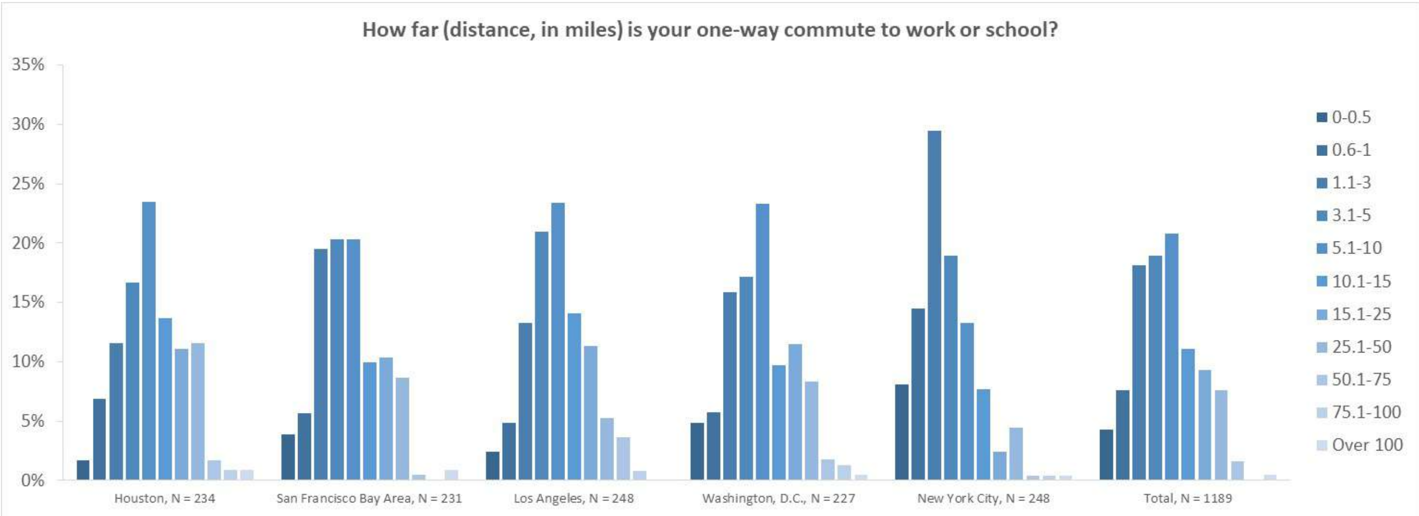


RECENT TRAVEL BEHAVIOR



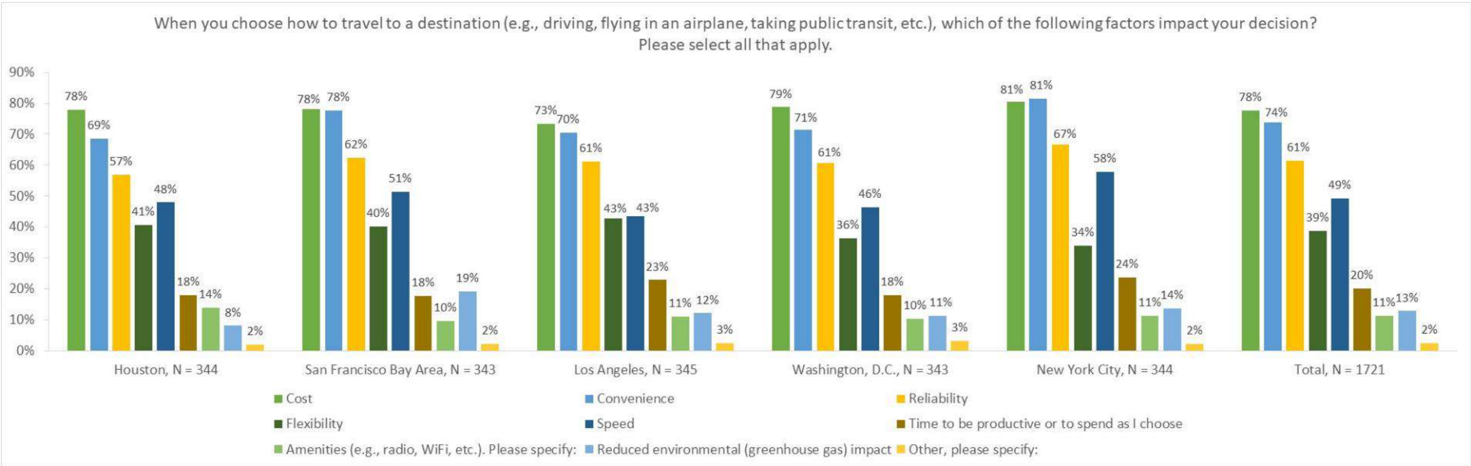
TYPICAL COMMUTE DISTANCE

- The typical commute distance was generally between 1 and 10 miles in all cities

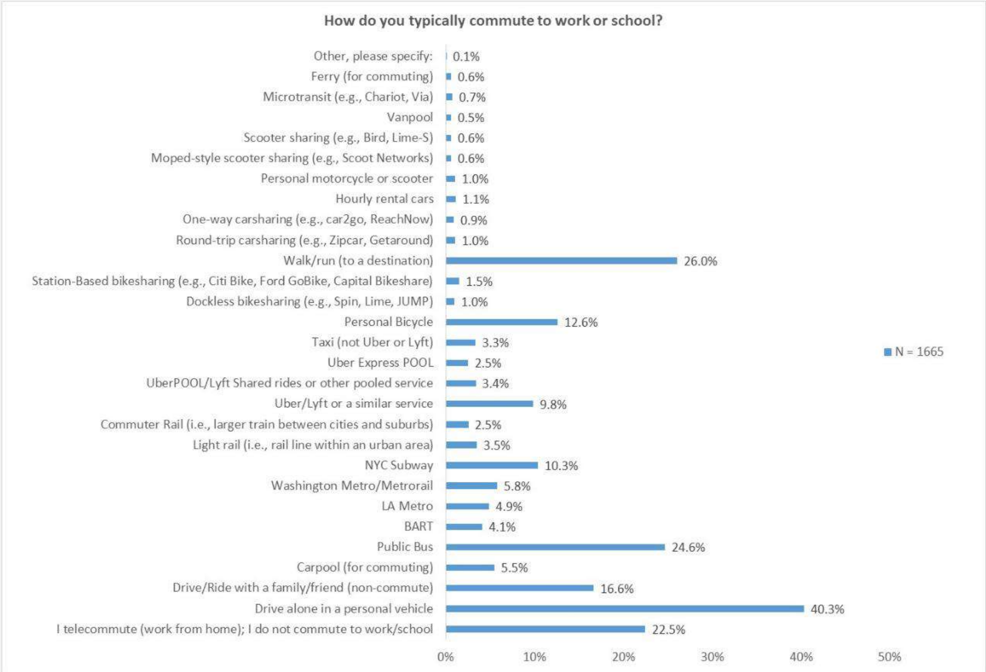


CONSIDERATIONS IMPACTING MODE CHOICE

- **Cost** and **convenience** are the most important motivators impacting mode choice



TYPICAL COMMUTE BEHAVIOR



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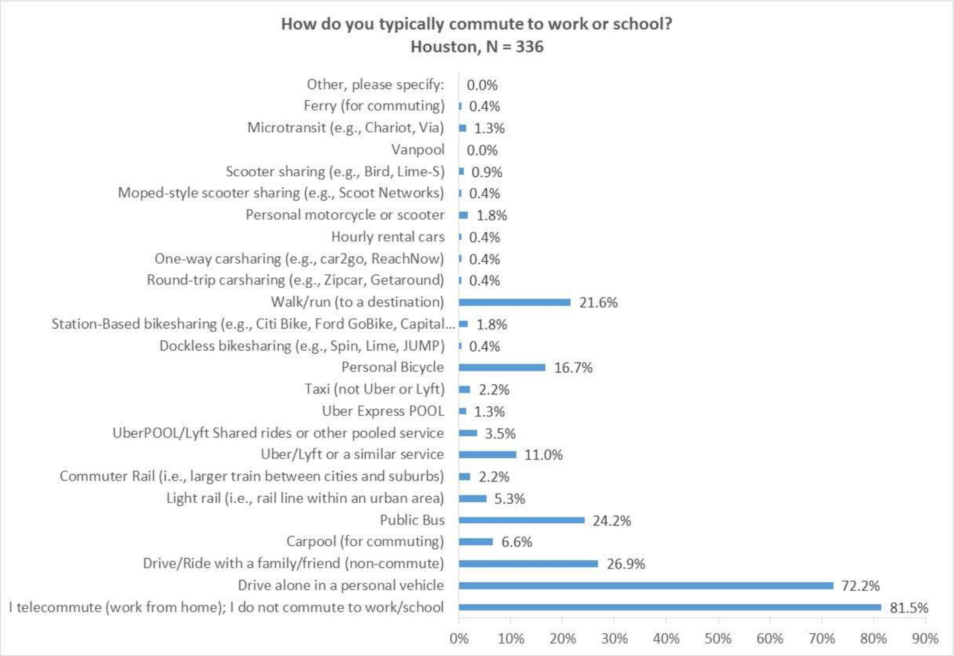

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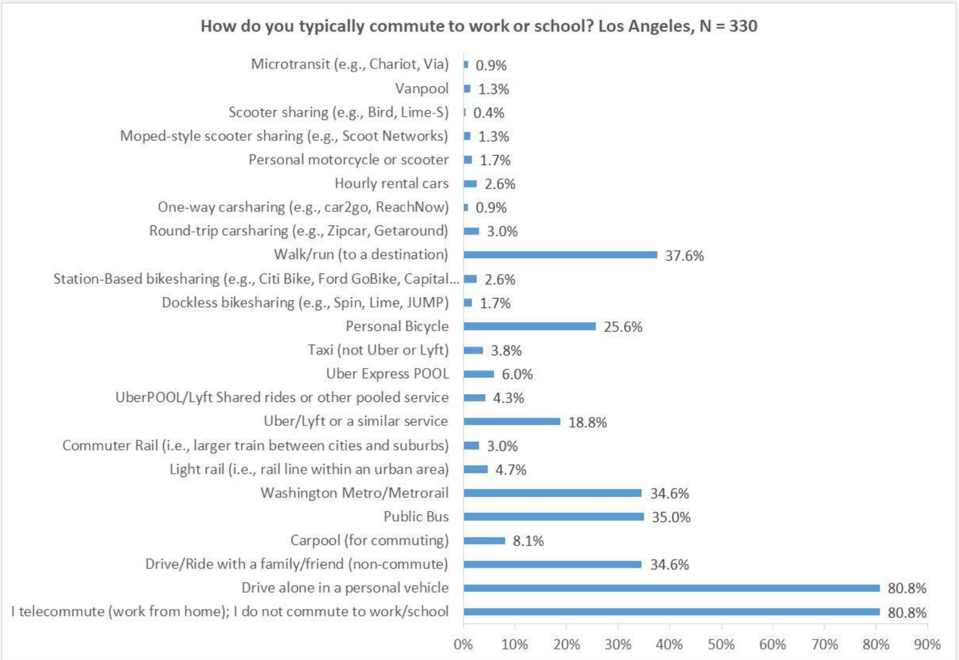

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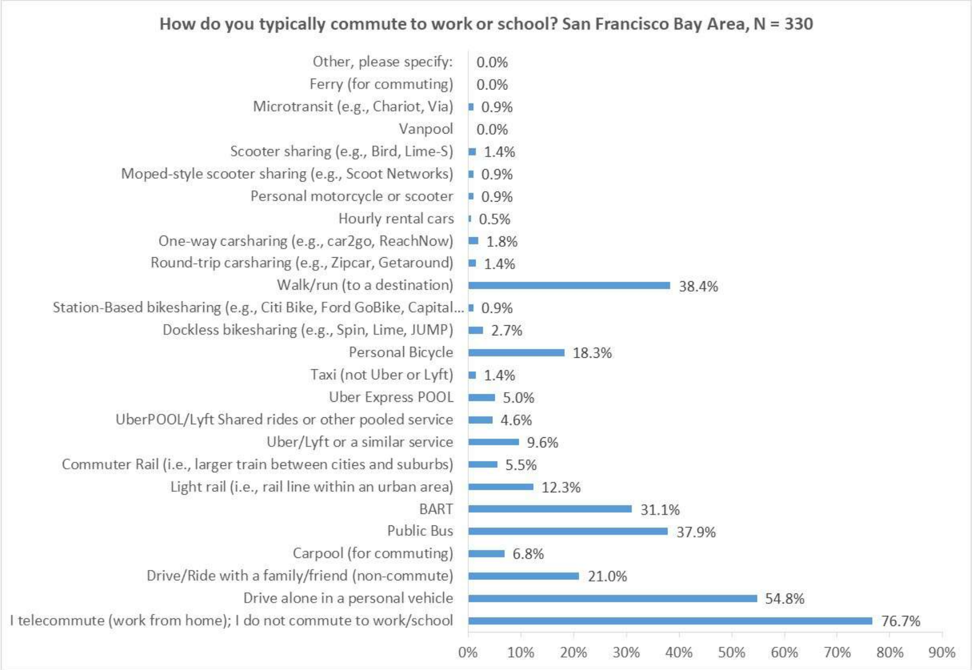

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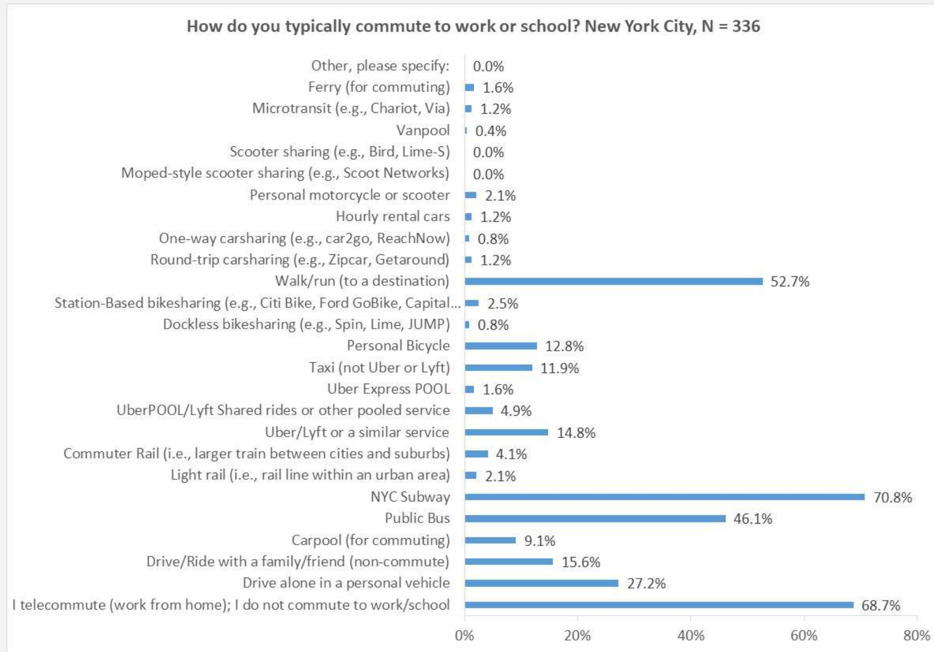

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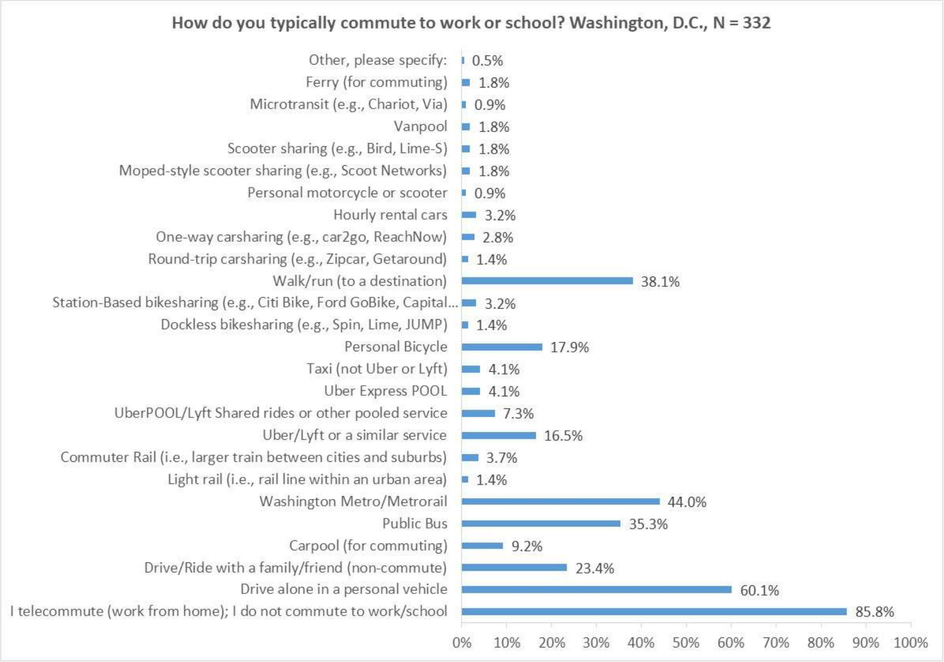
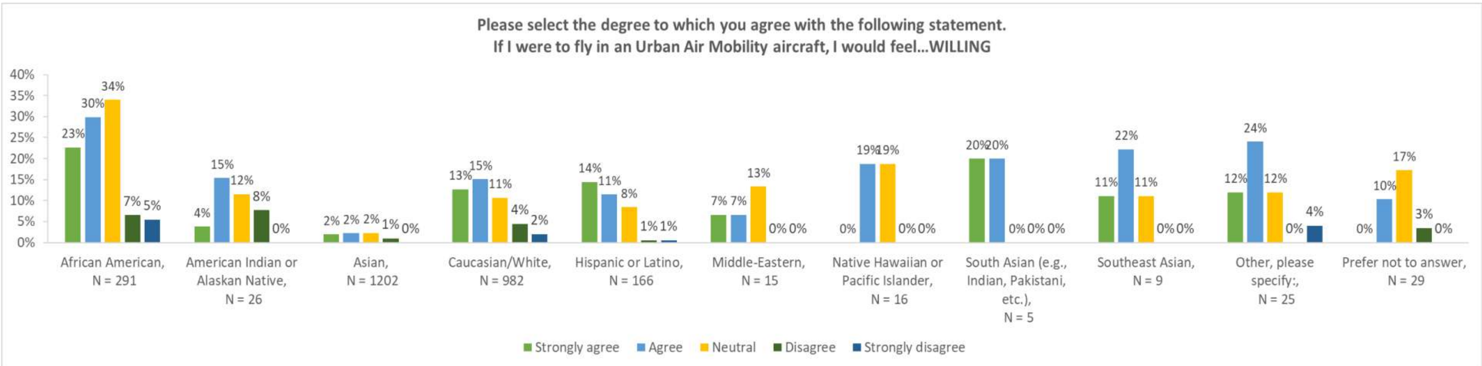
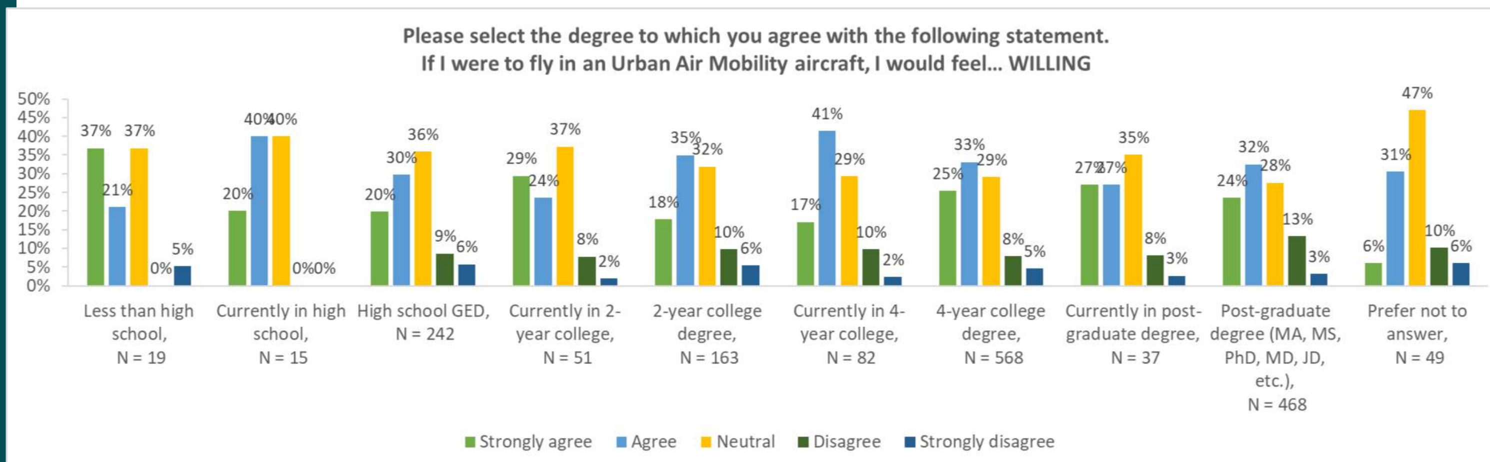


PERCEPTIONS ABOUT URBAN AIR MOBILITY

- A high level of willingness among African Americans

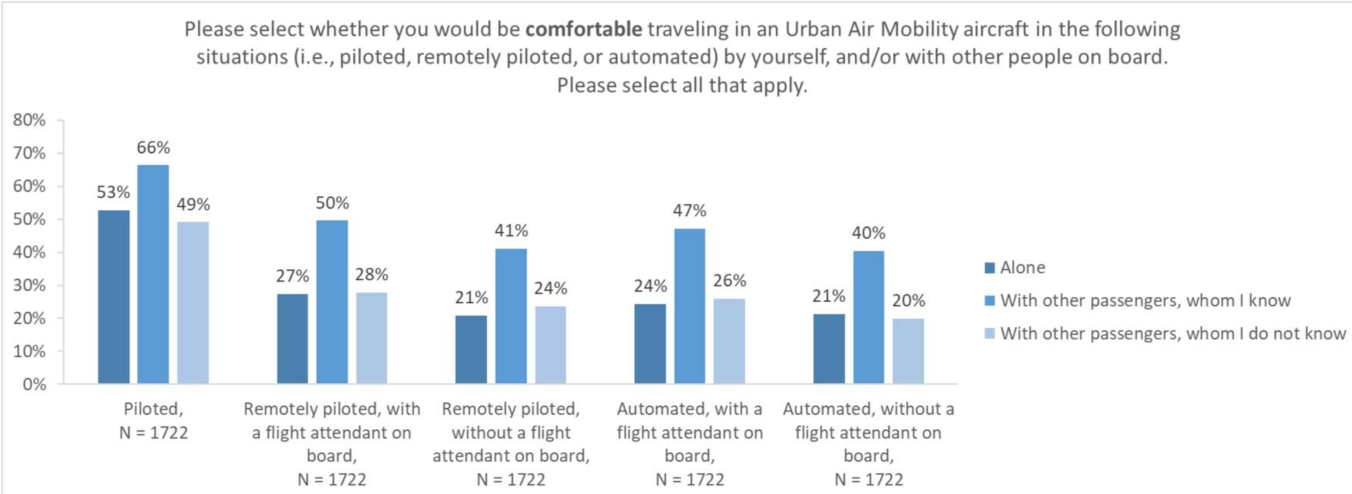


PERCEPTIONS ABOUT URBAN AIR MOBILITY



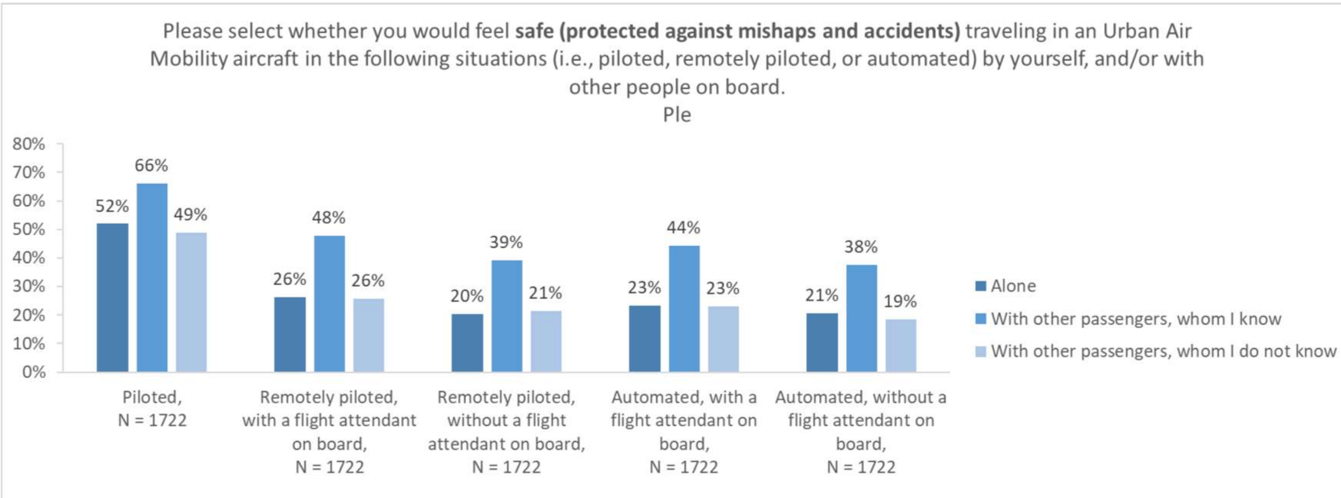
PERCEPTIONS TOWARDS TECHNOLOGY & UAM

- Respondents prefer flying with other passengers they know; more comfortable flying alone on a piloted aircraft versus remotely piloted or automated aircraft.



PERCEPTIONS TOWARDS TECHNOLOGY & UAM

- Respondents prefer flying with other passengers they know; feel safer flying alone on a piloted aircraft versus remotely piloted or automated aircraft.



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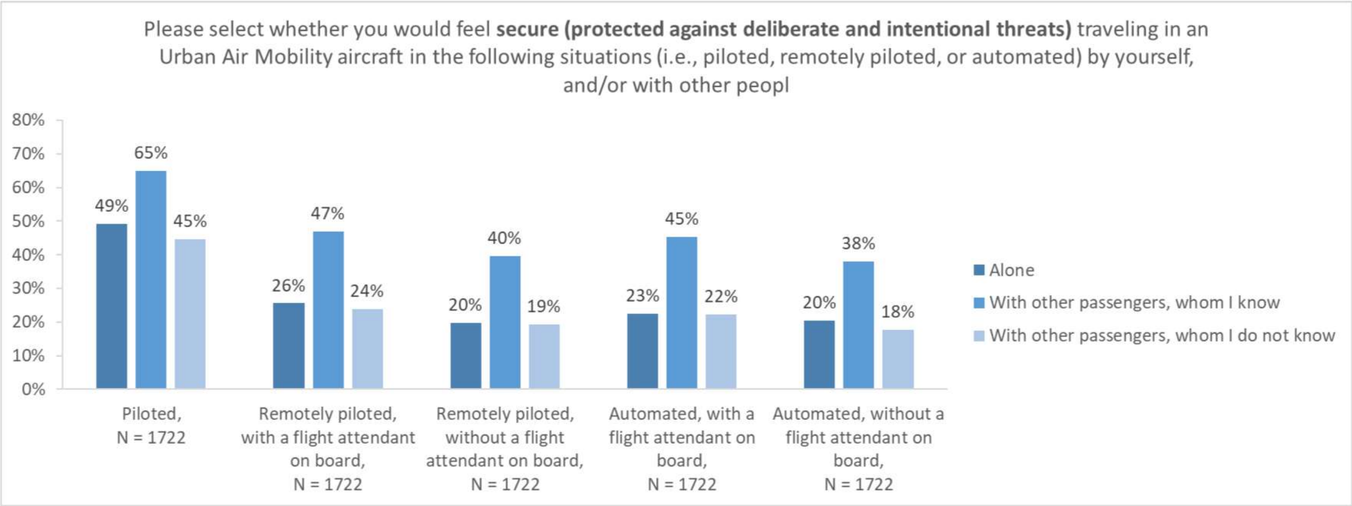
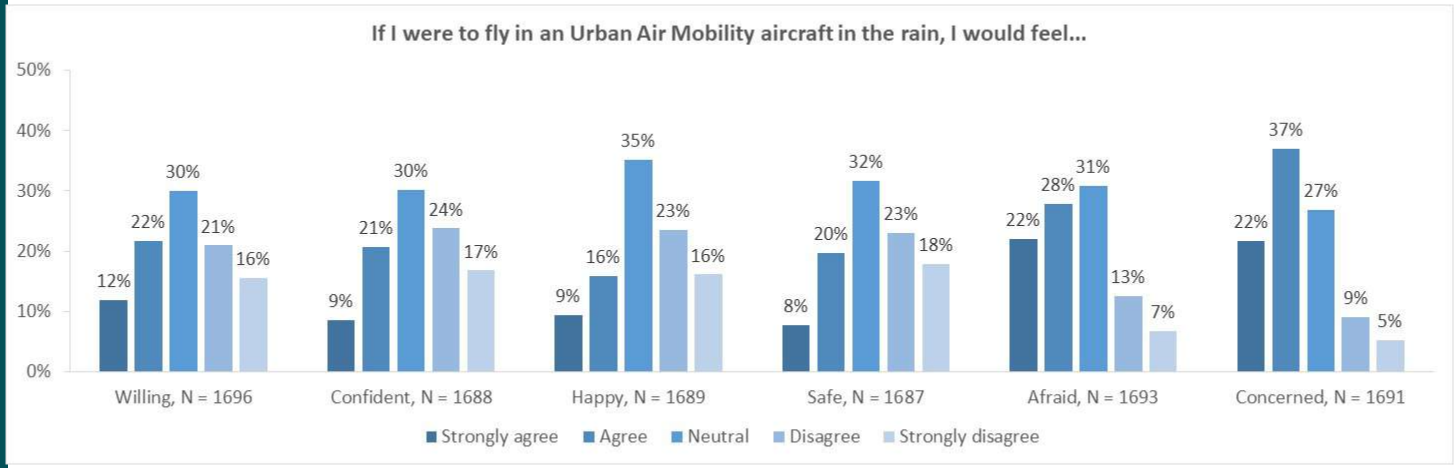


PERCEPTIONS TOWARDS WEATHER

- Respondents are somewhat apprehensive flying in turbulence, rain, snow, and low visibility conditions; more indifferent to hot and cold weather conditions.



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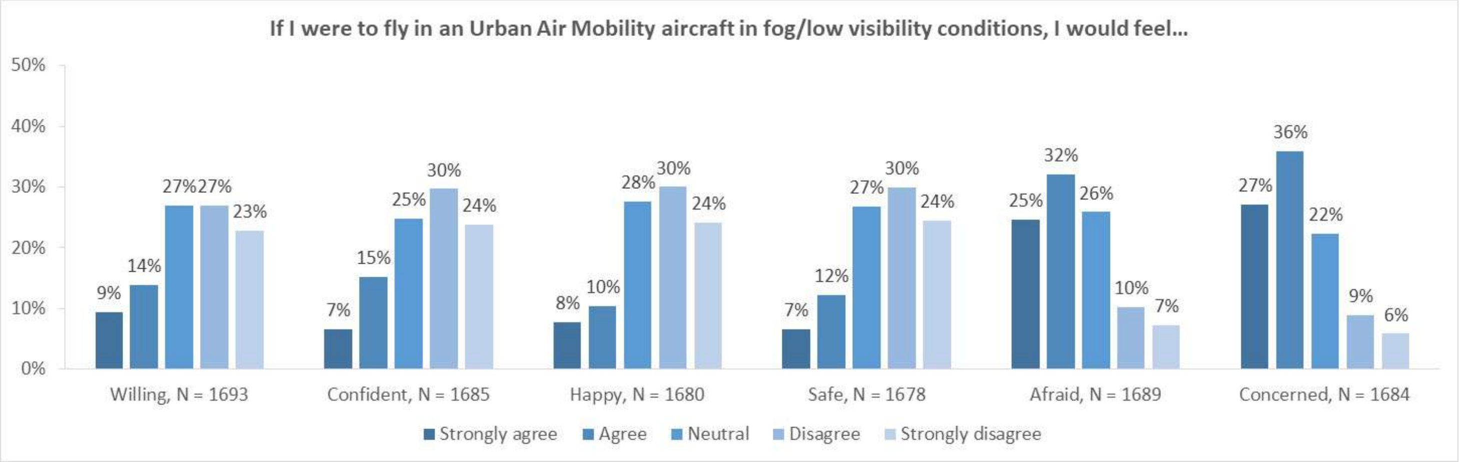

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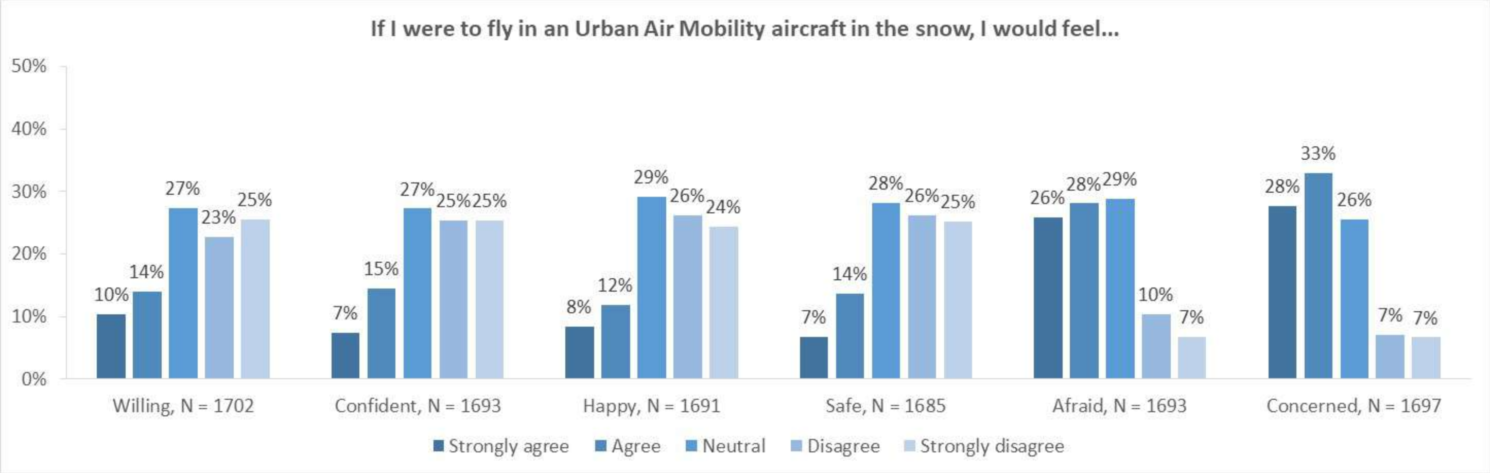

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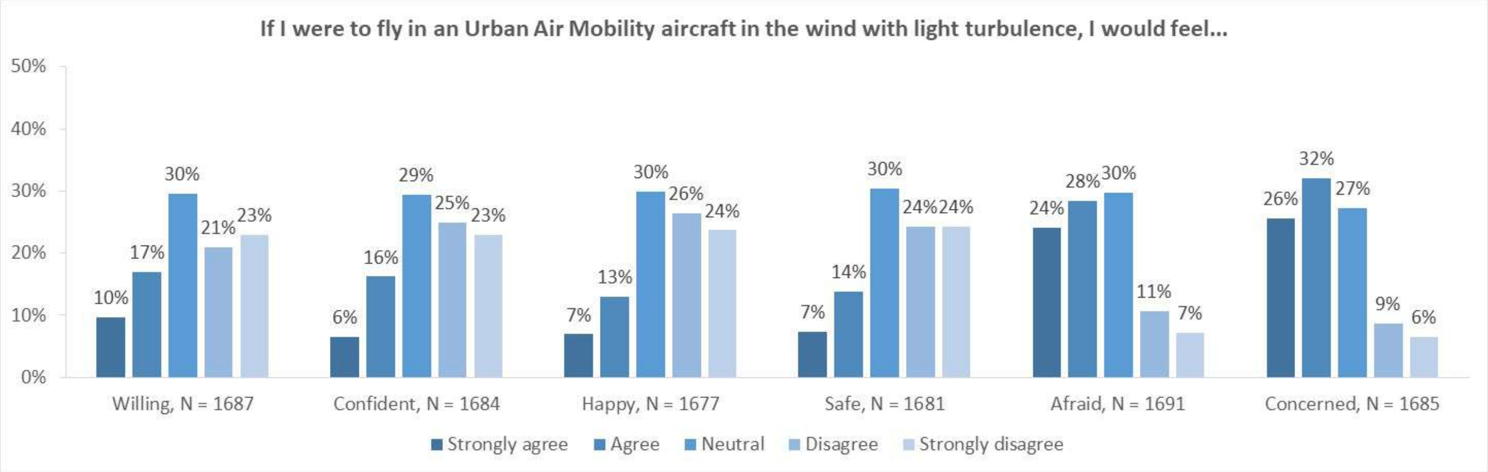

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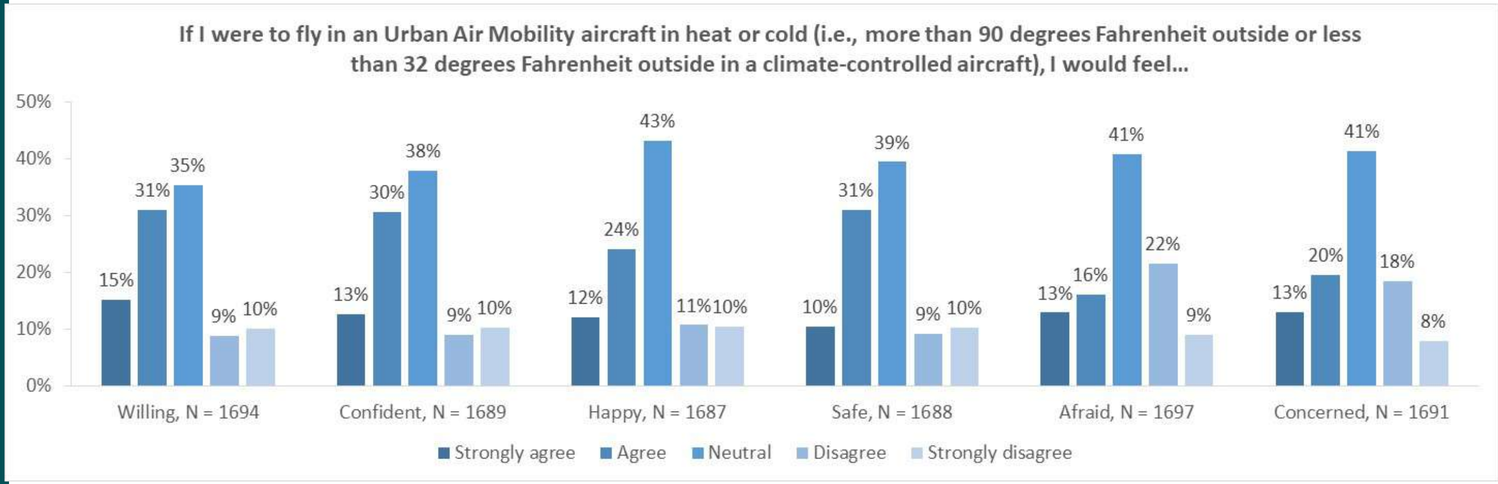
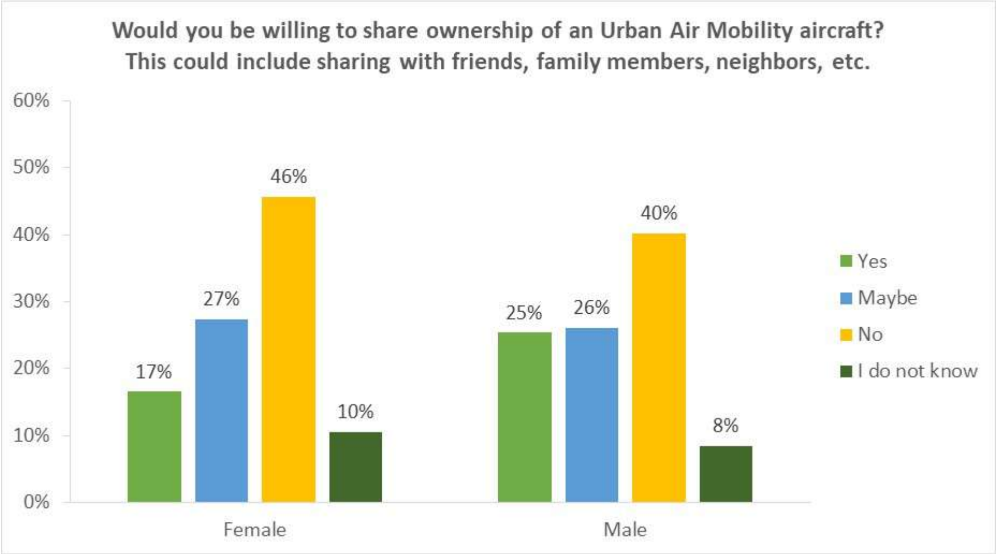


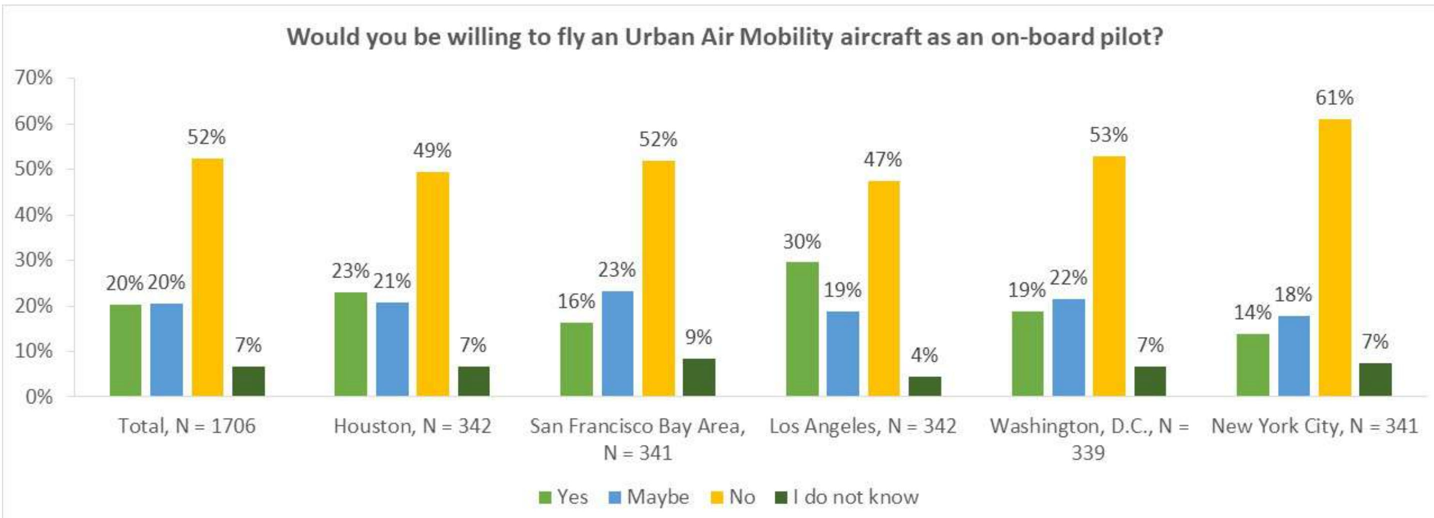
MARKET PREFERENCES: SHARED OWNERSHIP

- Men are more open to fractional ownership than women.



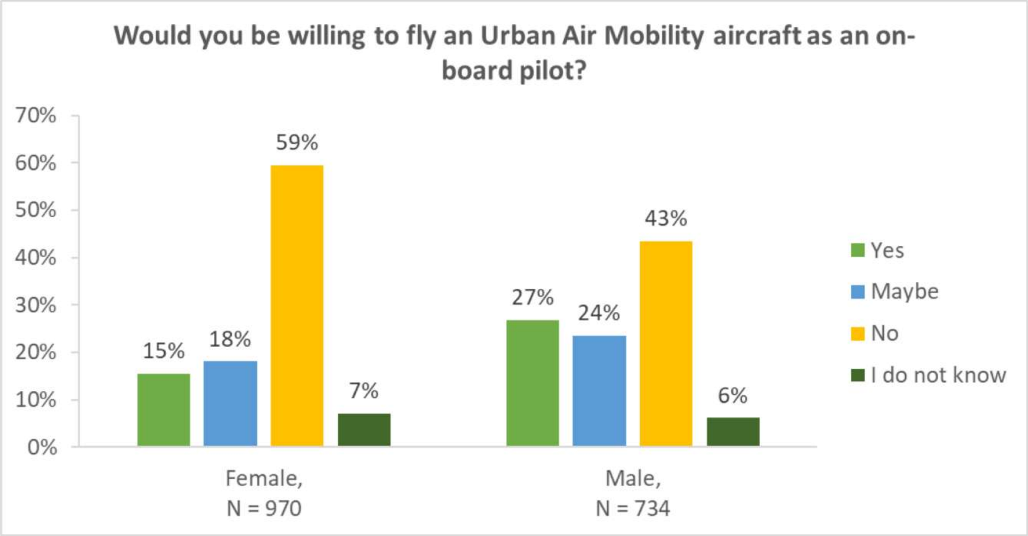
MARKET PREFERENCES: WILLINGNESS TO PILOT

- Approximately 1 in 5 people are willing to fly a UAM aircraft as a pilot (with greater willingness in Los Angeles).

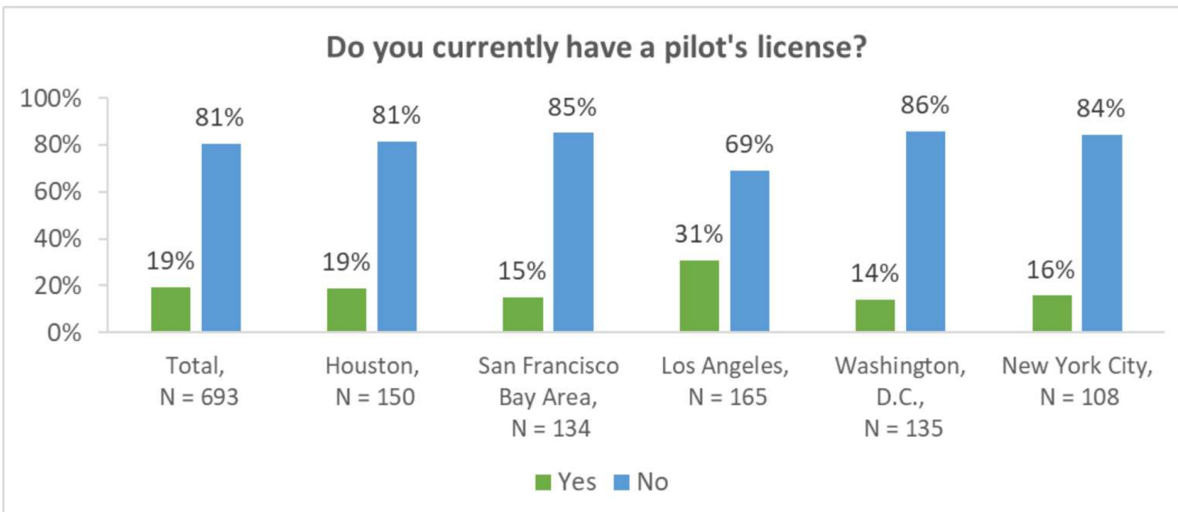


MARKET PREFERENCES: WILLINGNESS TO PILOT

- Men are more interested in piloting than women.



MARKET PREFERENCES: EXISTING PILOT TRAINING



LEGAL AND REGULATORY BARRIERS APPENDIX

APPENDIX 3: LEGAL AND REGULATORY BARRIERS VARIATION IN STATE AND LOCAL LAWS *(1 OF 4)*

State and Local Laws

Virginia

		On-Board Pilot	Remotely Piloted	Autonomous
States do not regulate or govern manned aviation. State policy does guide where, when, and how much air commerce it attracts.	Public Use	14 CFR 21, 23, 25, 27, 36, 61, 91, 119	**HB 412** - Provides that no locality may regulate the use of privately owned, unmanned aircraft systems within its boundaries. **HB 2350** - makes it a Class 1 misdemeanor to use UAS to trespass upon the property of another for the purpose of secretly or furtively peeping, spying, or attempting to peep or spy into a dwelling or occupied building located on such property. **SB 1301** - require that a law enforcement agency obtain a warrant before using a drone for any purpose, except in limited circumstances.	
	Land Use, Environmental and Restrictions	14 CFR 21, 23, 25, 27, 36, 61, 91, 119		
Owners of Airports enter into agreements for service at the local level.	Airports	None yet		

Maryland

	On-Board Pilot	Remotely Piloted	Autonomous
Public Use	14 CFR 21, 23, 25, 27, 36, 61, 91, 119	**SB 370** - specifies that only the state can enact laws to prohibit, restrict, or regulate the testing or operation of unmanned aircraft systems. This preempts county and municipal authority. The bill also requires a study on specified benefits.	
Land Use, Environmental and Restrictions	14 CFR 21, 23, 25, 27, 36, 61, 91, 119		
Airports	None yet		

VARIATION IN STATE AND LOCAL LAWS *(2 OF 4)*

State and Local Laws

States do not regulate or govern manned aviation. State policy does guide where, when, and how much air commerce it attracts.

Owners of Airports enter into agreements for service at the local level.

California / LA

	On-Board Pilot	Remotely Piloted	Autonomous
Public Use	14 CFR 21, 23, 25, 27, 36, 61, 91, 119	**SB 807** - Limits the exposure to civil liability of an emergency responder for damage to a UAS, if the damage was caused while the emergency responder was performing specific emergency services and the UAS was interfering.	
Land Use, Environmental and Restrictions	14 CFR 21, 23, 25, 27, 36, 61, 91, 119	**AB 1680** - UAS going to the scene of an emergency or stopping at the scene of an emergency, for the purpose of viewing the scene or the activities is a misdemeanor. **Los Angeles Municipal Code 183912** - to impose community-based safety requirements on the operation of Model Aircraft	
Airports	None yet		

Florida / Miami

	On-Board Pilot	Remotely Piloted	Autonomous
Public Use / Land Use, Environmental and Restrictions	14 CFR 21, 23, 25, 27, 36, 61, 91, 119	**HB 1027** - preempts local governments from regulating the operation of unmanned aircraft systems, but does allow them to enact or enforce local ordinances relating to illegal acts arising from the use of unmanned aircraft systems if the ordinances are not specifically related to the use of a drone for the commission of the illegal acts. **SB 92** - law enforcement may use a drone if they obtain a warrant, there is a terrorist threat, or swift action is needed to prevent loss of life or to search for a missing person. The law also enables someone harmed by an inappropriate use of drones to pursue civil remedies. **SB 766** - prohibiting a person, a state agency, or a political subdivision from using a drone to capture an image of privately owned real property or of the owner, tenant, occupant, invitee, or licensee of such property with the intent to conduct surveillance without his or her written consent if a reasonable expectation of privacy exists. **Miami Ordinance 37-12** - to regulate the use of UAS within a half-mile radius around stadiums and sport facilities when these devices are in use, and over other large venue special events in public parks, public facilities, streets, plazas, open spaces and the like that will attract large groups of people.	
	None yet		
Airports	None yet		

Hawaii / Honolulu

	On-Board Pilot	Remotely Piloted	Autonomous
Public Use / Land Use, Environmental and Restrictions	14 CFR 21, 23, 25, 27, 36, 61, 91, 119	**SB 2608**: prohibits the use of unmanned aircraft, except by law enforcement agencies, to conduct surveillance and establishes certain conditions for law enforcement agencies to use an unmanned aircraft to obtain information.	
	None yet		
Airports	None yet		

Texas / Dallas

	On-Board Pilot	Remotely Piloted	Autonomous
Public Use	14 CFR 21, 23, 25, 27, 36, 61, 91, 119	**HB 1643:** Adds telecommunications services structures, animal feeding operations, and oil and gas facilities to the definition of critical infrastructure as it relates to UAS operation. Prohibits localities from regulating UAS except during special events and when the UAS is used by the locality	
Land Use, Environmental and Restrictions	14 CFR 21, 23, 25, 27, 36, 61, 91, 119	**HR 3035:** Identifies 19 legitimate commercial purposes for UAS operations and prohibits UAS photography and filming of property or persons without prior consent **HB 1424**: Prohibits UAS operation over correctional and detention facilities and over a sports venue except in certain instances. **SB 840**: Telecommunications providers may use UAS to capture images. Only law enforcement may use UAS to captures images of real property that is within 25 miles of the U.S. border for border security purposes.	
Airports	None yet		

VARIATION IN STATE AND LOCAL LAWS *(3 OF 4)*

State and Local Laws

States do not regulate or govern manned aviation. State policy does guide where, when, and how much air commerce it attracts.

Owners of Airports enter into agreements for service at the local level.

Bay Area / California

	On-Board Pilot	Remotely Piloted	Autonomous
Public Use	None yet	**SB 807** - Limits the exposure to civil liability of an emergency responder for damage to a UAS, if the damage was caused while the emergency responder was performing specific emergency services and the UAS was interfering.	
Land Use, Environmental and Restrictions	None yet	**AB1680** - UAS going to the scene of an emergency or stopping at the scene of an emergency, for the purpose of viewing the scene or the activities is a misdemeanor.	
Airports	None yet		

New York Urban Area/ New York

	On-Board Pilot	Remotely Piloted	Autonomous
Public Use	None yet	**Int 0614-2015** NY DOT registration and insurance requirements aimed at protecting the public.	
Land Use, Environmental and Restrictions	None yet		
Airports	None yet		

New York Urban Area/ Connecticut

	On-Board Pilot	Remotely Piloted	Autonomous
Public Use	None yet	**SB975**: Prohibits municipalities from regulating UAS. It allows a municipality that is also a water company to enact ordinances that regulate or prohibit the use or operation of UAS over the municipality's public water supply and land.	
Land Use, Environmental and Restrictions	None yet		
Airports	None yet		

Houston/ Texas

	On-Board Pilot	Remotely Piloted	Autonomous
Public Use	None yet	**HB1643:** Adds telecommunications services structures, animal feeding operations, and oil and gas facilities to the definition of critical infrastructure as it relates to UAS operation. Prohibits localities from regulating UAS except during special events and when the UAS is used by the locality	
Land Use, Environmental and Restrictions	None yet	**HR 3035:** Identifies 19 legitimate commercial purposes for UAS operations and prohibits UAS photography and filming of property or persons without prior consent **HB1424**: Prohibits UAS operation over correctional and detention facilities and over a sports venue except in certain instances. **SB840**: Telecommunications providers may use UAS to capture images. Only law enforcement may use UAS to captures images of real property that is within 25 miles of the U.S. border for border security purposes.	
Airports	None yet		

VARIATION IN STATE AND LOCAL LAWS *(4 OF 4)*

State and Local Laws

Denver/ Colorado

		On-Board Pilot	Remotely Piloted	Autonomous
States do not regulate or govern manned aviation. State policy does guide where, when, and how much air commerce it attracts.	Public Use	None yet	**HB1070**: It requires the center of excellence within the department of public safety to perform a study. The study must identify ways to integrate UAS within local and state government functions relating to firefighting, search and rescue, accident reconstruction, crime scene documentation, emergency management, and emergencies involving significant property loss, injury or death. The study must also consider privacy concerns, costs, and timeliness of deployment for each of these uses. The legislation also creates a pilot program, requiring the deployment of at least one team of UAS operators to a region of the state that has been designated as a fire hazard where they will be trained on the use of UAS for the above specifies functions.	
	Land Use, Environmental and Restrictions	None yet		
Owners of Airports enter into agreements for service at the local level.	Airports	None yet		

Phoenix/ Arizona

		On-Board Pilot	Remotely Piloted	Autonomous
States do not regulate or govern manned aviation. State policy does guide where, when, and how much air commerce it attracts.	Public Use	None yet	SB1449: Makes it illegal to operate UAS if operation: a. Is prohibited by federal law, aeronautic regulations or specified FAA regulations; or b. Interferes with first responder operations. 2. Prohibits a person from operating a UAS to intentionally photograph or loiter over or near a critical facility in the furtherance of a criminal offense. 3. Prohibits a city, town or county from enacting an ordinance, rule or policy relating to the ownership or operation of a UAS. Voids any ordinance, rule or policy in violation.	
	Land Use, Environmental and Restrictions	None yet		
Owners of Airports enter into agreements for service at the local level.	Airports	None yet		

LEGAL AND REGULATORY BARRIERS SOURCES

14 CFR 107 https://www.ecfr.gov/cgi-bin/text-idx?SID=e331c2fe611df1717386d29eee38b000&mc=true&node=pt14.2.107&rgn=div5
FMRA 2012 https://www.faa.gov/uas/media/Sec_331_336_UAS.pdf
AC 107-2 https://www.faa.gov/documentLibrary/media/Advisory_Circular/AC_107-2.pdf
Singer v. City of Newton https://www.documentcloud.org/documents/4058344-Singer-v-Newton-Decision.html
UAS Pilot Integration Program https://www.faa.gov/uas/programs_partnerships/uas_integration_pilot_program/splash/
SB 807 https://legiscan.com/CA/bill/SB807/2015
AB 1680 http://www.leginfo.ca.gov/pub/15-16/bill/asm/ab_1651-1700/ab_1680_bill_20160929_chaptered.pdf
Los Angeles Municipal Code 183912 http://clkrep.lacity.org/onlinedocs/2015/15-0927_ord_183912_12-02-15.pdf
HB 1027 https://www.flsenate.gov/Session/Bill/2017/1027
SB 92 https://www.flsenate.gov/Session/Bill/2013/0092
SB 766 https://www.flsenate.gov/Session/Bill/2015/0766
Miami Ordinance 37-12 https://library.municode.com/fl/miami/codes/code_of_ordinances?nodeId=PTIITHCO_CH37OFIS_S37-12PUSAUNAISYCOKNDR
SB 2608 https://www.capitol.hawaii.gov/Archives/measure_indiv_Archives.aspx?billtype=SB&billnumber=2608&year=2014
HB 1643 http://www.capitol.state.tx.us/tlodocs/85R/billtext/pdf/HB01643F.pdf#navpanes=0
HR 3035 http://www.statutes.legis.state.tx.us/Docs/GV/htm/GV.423.htm
HB 1424 http://www.capitol.state.tx.us/tlodocs/85R/billtext/pdf/HB01424F.pdf#navpanes=0
SB 840 http://www.capitol.state.tx.us/tlodocs/85R/billtext/pdf/SB00840F.pdf#navpanes=0
HB 412 https://legiscan.com/VA/bill/HB412/2016
HB 2350 http://lis.virginia.gov/cgi-bin/legp604.exe?171+ful+HB2350ER+pdf
SB 1301 http://lis.virginia.gov/cgi-bin/legp604.exe?ses=151&typ=bil&val=sb1301
SB 370 https://legiscan.com/MD/bill/SB370/2015

LEGAL AND REGULATORY BARRIERS SOURCES

14 CFR 107 https://www.ecfr.gov/cgi-bin/text-idx?SID=e331c2fe611df1717386d29eee38b000&mc=true&node=pt14.2.107&rgn=div5
FMRA 2012 https://www.faa.gov/uas/media/Sec_331_336_UAS.pdf
AC 107-2 https://www.faa.gov/documentLibrary/media/Advisory_Circular/AC_107-2.pdf
Singer v. City of Newton https://www.documentcloud.org/documents/4058344-Singer-v-Newton-Decision.html
UAS Pilot Integration Program https://www.faa.gov/uas/programs_partnerships/uas_integration_pilot_program/splash/
SB 807 https://legiscan.com/CA/bill/SB807/2015

AB1680 http://www.leginfo.ca.gov/pub/15-16/bill/asm/ab_1651-1700/ab_1680_bill_20160929_chaptered.pdf

Int 0614-2015 http://legistar.council.nyc.gov/LegislationDetail.aspx?ID=2119765&GUID=85AA1161-E2D5-42A5-AE4C-D2F1CC1BFF6F&Options=ID%7c&Search

NY City http://www1.nyc.gov/nyc-resources/service/5521/drones

SB975 https://openstates.org/ct/bills/2017/SB975/

SB1449 https://www.azleg.gov/legtext/52leg/2r/bills/sb1449p.pdf

HB1643 http://www.capitol.state.tx.us/tlodocs/85R/billtext/pdf/HB01643F.pdf#navpanes=0

HR 3035 http://www.statutes.legis.state.tx.us/Docs/GV/htm/GV.423.htm
HB1424 http://www.capitol.state.tx.us/tlodocs/85R/billtext/pdf/HB01424F.pdf#navpanes=0

SB840 http://www.capitol.state.tx.us/tlodocs/85R/billtext/pdf/SB00840F.pdf#navpanes=0

HB1070 https://openstates.org/co/bills/2017A/HB17-1070/
EASA NPA 2017-05, Opinion 01/2018
Ireland https://www.iaa.ie/general-aviation/drones
UK https://www.caa.co.uk/Commercial-industry/Aircraft/Unmanned-aircraft/Small-drones/Guidance-on-using-small-drones-for-commercial-work/
NZ https://www.caa.govt.nz/unmanned-aircraft/intro-to-part-101/#Shielded_Operations
Canada http://www.tc.gc.ca/en/services/aviation/drone-safety/flying-drone-safely-legally.html

AIRPORT SHUTTLE AND AIR TAXI ANALYSIS APPENDIX

APPENDIX 4.1A: INITIAL FOCUS MARKET - URBAN AIRPORT SHUTTLE

THE URBAN AIRPORT SHUTTLE MARKET IS AN INTERESTING POTENTIAL EARLY MARKET

URBAN AIRPORT SHUTTLE MARKET OVERVIEW

Definition: Market comprises establishments primarily engaged in furnishing passenger to, from, or between airports over fixed routes. The Airport Shuttle market is a pure play market related to the Air Taxi aggregate market.

Legacy Airport Shuttle Market (in 2016)

- **Revenue**: $842M beachhead market in U.S. (limo market comparable); potential to grow significantly
- **Limo Shuttle Market Growth Rate:** 0.5% Compound Annual Growth Rate (CAGR)

Key Drivers of the Market

- Disposable income
- International tourism and domestic travels
- Corporate profit
- Time spent on leisure and sports

Operational Geography

- Core urban to airport
- Edge-city to airport

RELATED AGGREGATE MARKET OVERVIEW: AIR COMMUTE/TAXI

Definition: The On Demand Air Commuter/Taxi market includes regular commute services, point-to-point transportation for occasional events and business meetings, air-taxi and shuttle services combined with goods delivery. This transportation occurs from transportation deserts and between edge-city and urban and off-shore to urban.

WHY URBAN AIRPORT SHUTTLE MARKET?

Feasibility (most feasible listed first)

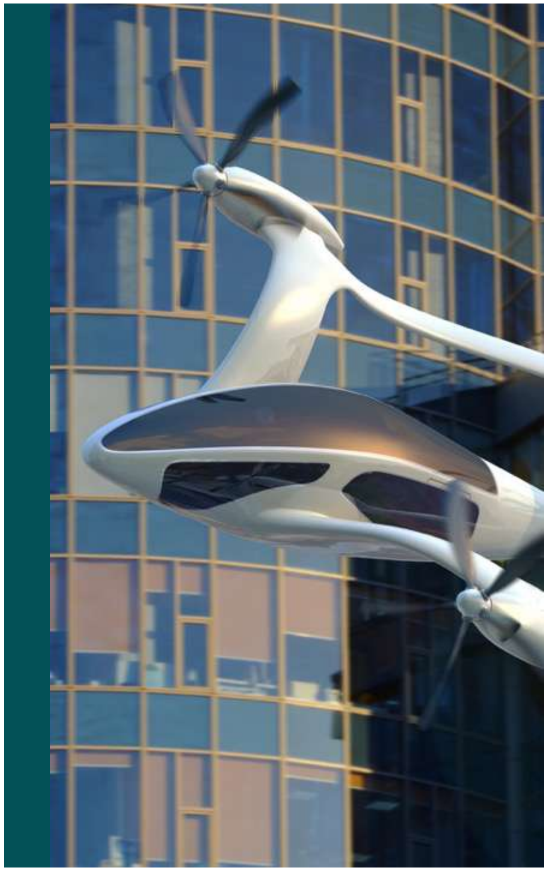
- **Infrastructure for Takeoff/Landing Areas**
  - Airports can provide necessary infrastructure to operate UAM craft
  - Lower density of takeoff/landing areas expected in urban areas
- **Air Traffic Management**
  - Airport shuttle will likely operate under "controlled airspace" of ATC, which is likely favorable in terms of safety and FAA regulations
- **Technology Requirements**
  - Current technology will likely serve the market
- **Community Acceptance**
  - Potentially similar to the airports
- **Operational Efficiency**
  - Airport as common demand source reduces complexity of supply/demand matching

Market Enablers

- **Travel & Hospitality Industry:** Seeking to provide a better experience to their premium customers who have high willingness to pay
- **Airports:** Seeking to generate new source of revenue

EXPECTED OUTCOMES

- Initial market assessment methodology to be reviewed by SAG and NASA SMEs
- Legal and regulatory requirements at local, state, and federal levels to satisfy the Airport Shuttle market that are likely to set the foundation for the Air Taxi aggregate market
- The pure play market could highlight some unique potential barriers related to proximity to legacy aircraft in addition to public acceptance



APPENDIX 4.1B: URBAN AIR TAXI MARKET IS AN INTERESTING POTENTIAL MASS MARKET

URBAN AIR TAXI MARKET OVERVIEW

Definition: The On Demand Air Commuter/Taxi market includes regular commute services, point-to-point transportation for occasional events and business meetings, air-taxi and taxi services combined with goods delivery. This transportation occurs from transportation deserts and between edge-city and urban and off-shore to urban.

Value Proposition: Moving traditional taxi services to the air will relieve congestion on legacy infrastructure and engage more individuals in the urban air mobility economy

Market Dynamics:

- **Market Size:** Current markets are substantial in urban areas
- **Market Drivers:**
  - Consumer spending
  - Domestic trips by U.S. residents
  - Federal funding for transportation
- **Potential Business Models at Play:** Pay per ride and subscription model

Barriers to Be Explored:

- **Societal Barriers:** High (expected). Travel times relative to other modes, cost, overall health/comfort, general safety, noise and visual disruption
- **Legal and Regulatory Barriers:** High (expected). New regulations required, though not limited to: aircraft design, certification, operation, personnel qualifications (air and ground based), inspection, security, airspace management and control, etc.; along with state/local/community based regulatory requirements (e.g., environmental)

APPENDIX 4.2A: BLADE OVERVIEW

- Blade offers chartered and crowdsourced flights all around the East Coast, Los Angeles, to and from special events, airport shuttle service and private air travel anywhere in the world.
- Users can schedule their flights via an app, go to one of the many Blade Lounges before their flight where they are then picked up and sent off to their location.
- Users have the option of either chartering and scheduling their own flight and then selling any unused seats to the public for credit, or buying unused seats on already scheduled flights.
- Estimate of price per mile traveled: $31.80
- Does not own or operate any aircraft.

APPENDIX 4.2B: SKYRYDE OVERVIEW

- Skyryde is a brand new service that offers on demand flights in Southern California.
- Trips are dispatchable in less than an hour and users can take up to two other people with them.
- Service is offered to and from 13 different locations in the LA, Santa Barbara, and San Diego Area. Opening at the end of April 2018, they have flown around 20 people so far. Flights can be scheduled up to 3 days in advance and can operate at any hour.
- SKYRYDE books you in a Cessna 182 Turbo. The airplane boasts a comfortable interior and seats up to 4 people (including the pilot).
- Estimate of price per mile traveled: $32.57
- Does not own or operate any aircraft.

APPENDIX 4.2C: VOOM OVERVIEW

- Voom (Subsidiary of Airbus) offers on demand helicopter flights in both Sao Paulo and Mexico City.
- Users can log on to the website with no membership required. Booking can be up to 7 days in advance or as little as 60 minutes.
- Users arrive at their flight 15 minutes before the flight and “pay up to 80% less” than traditional helicopter services.
- No ride sharing offered, users book a helicopter and go.
- Estimate of price per mile traveled: $9.95.
- Like Blade and Skyryde, Voom does not own or operate any aircraft, it connects passengers with licensed operators.

APPENDIX 4.3A: PARAMETER SENSITIVITY

Parameter Assumption	2 Seat		3 Seat		4 Seat		5 Seat	
	Min	Max	Min	Max	Min	Max	Min	Max
Load Factor	NA		-14%	11%	-14%	12%	-15%	12%
Dead End Trips	-9%	12%	-8%	14%	-8%	15%	-11%	15%
Utilization	NA		-11%	10%	-12%	9%	-13%	9%
Utilization 2 Seat	-15%	19%	NA					
Climb Descent Distance	-3%	10%	-5%	11%	-6%	13%	-7%	15%
Cruise Altitude	-4%	9%	-5%	10%	-7%	12%	-8%	13%
Mission Distance	-8%	26%	-8%	26%	-9%	20%	-10%	21%
Embarkation Time	-4%	9%	-6%	10%	-7%	11%	-8%	13%
Disembarkation Time	-4%	9%	-6%	10%	-7%	12%	-8%	13%
Delay at Vertiport	-2%	10%	-3%	12%	-5%	14%	-6%	15%
Wait Time for Ground Service	-3%	10%	-5%	11%	-6%	13%	-7%	14%
Parking at Work	-3%	10%	-5%	11%	-7%	12%	-8%	14%
Parking at Vertiport	-3%	10%	-5%	11%	-6%	13%	-8%	14%
Detour Factor	-4%	9%	-6%	10%	-7%	12%	-8%	13%
Route Cost per Mile	-4%	9%	-6%	10%	-7%	12%	-8%	13%
Indirect Operating Cost Percent	-6%	8%	-8%	9%	-9%	11%	-9%	14%
Profit Margins	-7%	6%	-6%	10%	-7%	11%	-7%	13%
Taxes	-2%	8%	-3%	10%	-17%	14%	-4%	15%
Mechanic Wrap Rate	-7%	6%	-10%	6%	-8%	10%	-7%	13%
MMH / FH	-8%	13%	-8%	13%	-9%	12%	-8%	14%
Take Off Site Altitude	-3%	10%	-5%	11%	-6%	13%	-8%	14%

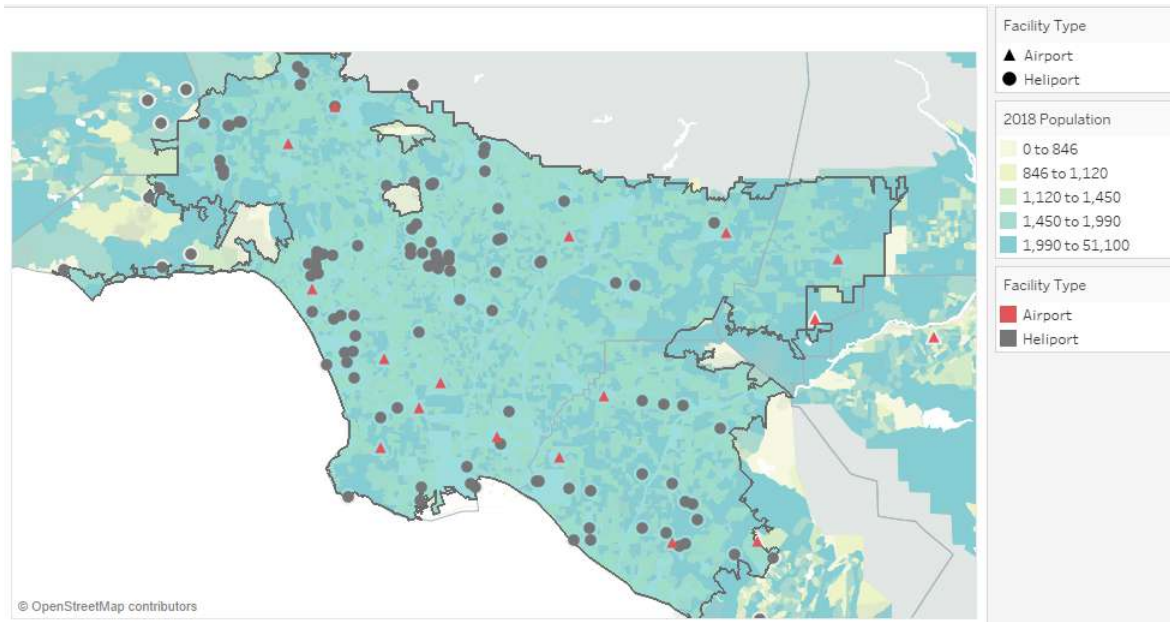
APPENDIX 4.3B: PARAMETER SENSITIVITY (CONTINUED)

	2 Seat		3 Seat		4 Seat		5 Seat	
Parameter Assumption	**Min**	**Max**	**Min**	**Max**	**Min**	**Max**	**Min**	**Max**
Landing Site Altitude	-3%	10%	-5%	11%	-6%	13%	-7%	14%
Tip to Tip Length of Aircraft	-5%	7%	-8%	7%	-9%	9%	-9%	11%
Number of Landing Spots	-3%	8%	-3%	10%	-5%	12%	-5%	15%
Cost of One Supercharger	-4%	9%	-5%	10%	-5%	12%	-6%	12%
Cost of Regular Charger	-3%	10%	-5%	11%	-7%	13%	-8%	14%
Indirect Costs	-4%	9%	-5%	11%	-7%	12%	-8%	13%
Amortization Period	-3%	9%	-5%	11%	-6%	13%	-7%	14%
Parking Costs	-3%	10%	-5%	11%	-6%	13%	-7%	14%
Parking Occupied	-4%	10%	-5%	11%	-7%	12%	-8%	14%
Electricity Price	-3%	7%	-5%	9%	-7%	11%	-8%	12%
Profit Margin Infra	-3%	10%	-5%	11%	-6%	13%	-8%	14%
Vehicle Cost	-5%	6%	-7%	7%	-8%	9%	-9%	10%
Cruise Speed	-7%	12%	-8%	10%	-10%	10%	-11%	11%
MTOW	-4%	7%	-7%	8%	-9%	9%	-10%	11%
Hover Power	-3%	9%	-5%	10%	-7%	12%	-8%	13%
Cruise Power	-3%	9%	-5%	10%	-7%	11%	-8%	12%
Climb Descent Speed	-3%	9%	-5%	10%	-7%	12%	-8%	13%
LTO Height	-4%	10%	-5%	11%	-7%	12%	-8%	14%
LTO Time	-3%	9%	-5%	11%	-6%	12%	-7%	14%
Depreciation Rate	-3%	8%	-4%	10%	-5%	12%	-6%	13%
Finance Rate	-3%	9%	-3%	11%	-4%	13%	-5%	14%

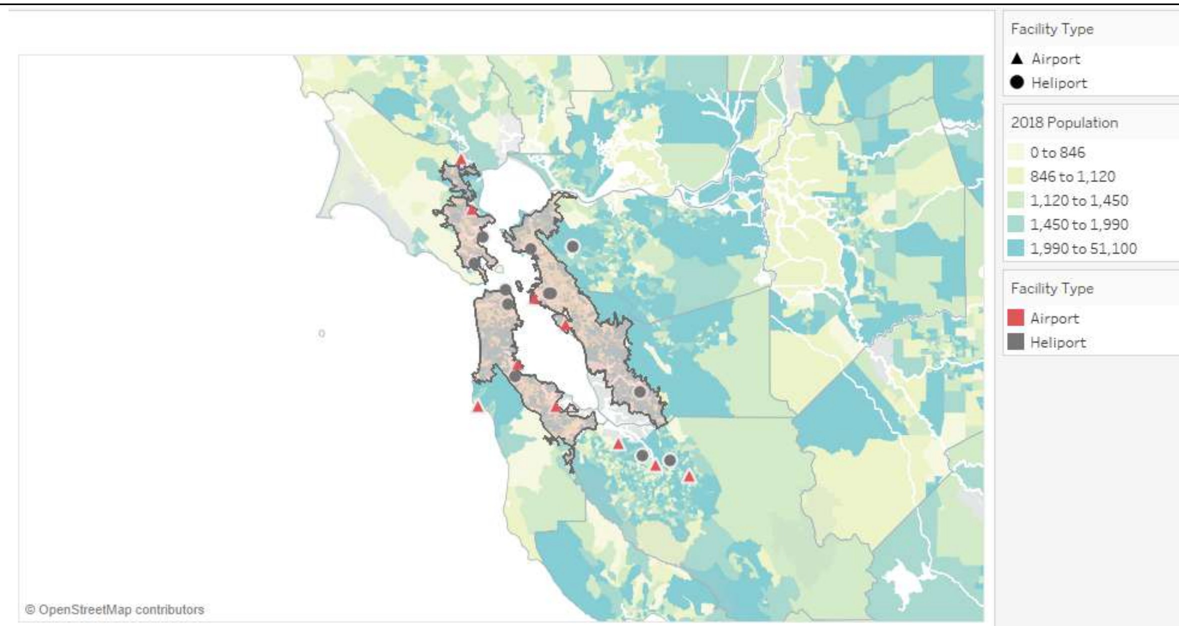
APPENDIX 4.3C: PARAMETER SENSITIVITY (CONTINUED)

Parameter Assumption	2 Seat		3 Seat		4 Seat		5 Seat	
	Min	Max	Min	Max	Min	Max	Min	Max
Loan Term	-3%	9%	-4%	10%	-5%	12%	-6%	13%
Power Required in Landing	-3%	10%	-5%	11%	-6%	12%	-8%	14%
Power Required in Taxi	-4%	9%	-5%	11%	-7%	12%	-8%	13%
Reserve Time	-4%	7%	-4%	10%	-6%	11%	-7%	12%
Energy Conversion Efficiency	-3%	10%	-5%	12%	-6%	14%	-7%	15%
Battery Specific Energy	-4%	9%	-5%	11%	-7%	12%	-8%	13%
Battery Capacity Specific Cost	-4%	9%	-5%	10%	-7%	12%	-8%	13%
Depth of Discharge	-3%	10%	-5%	11%	-6%	13%	-7%	14%
Pilot Salary	-3%	8%	-4%	12%	-4%	14%	-6%	16%
Ground Staff Salary	-4%	8%	-6%	10%	-7%	12%	-8%	13%
Pilot Training	-4%	9%	-6%	10%	-7%	12%	-8%	13%
Ground Crew Training	-4%	9%	-6%	10%	-7%	12%	-8%	13%

APPENDIX 4.4A: LOS ANGELES-LONG BEACH-ANAHEIM, CA

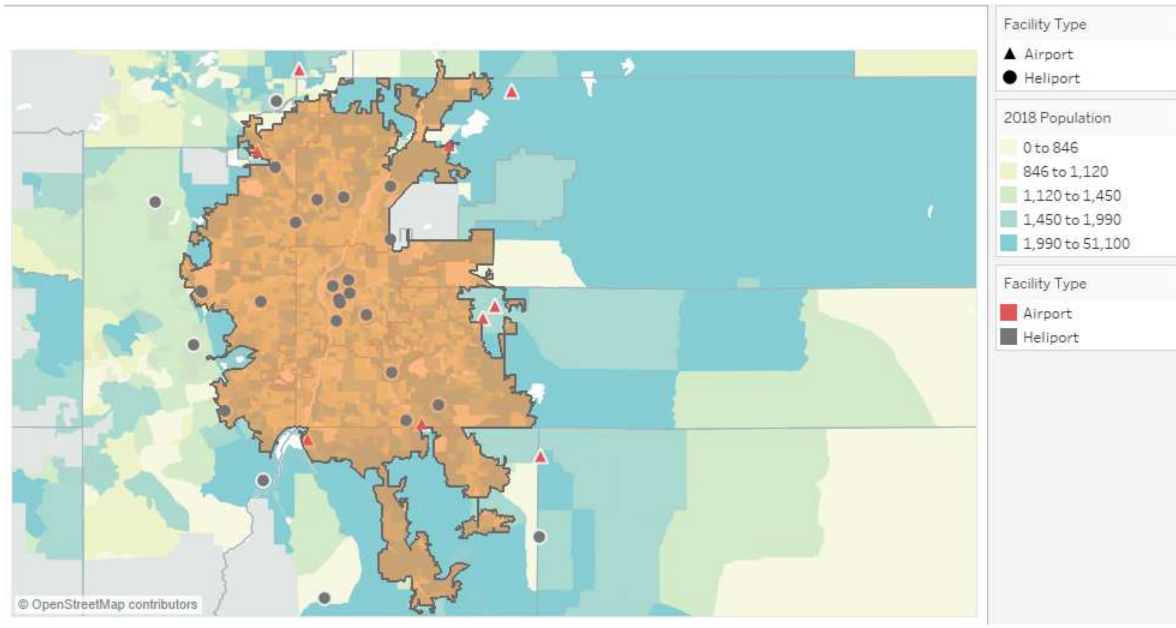


APPENDIX 4.4B: SAN FRANCISCO-OAKLAND, CA

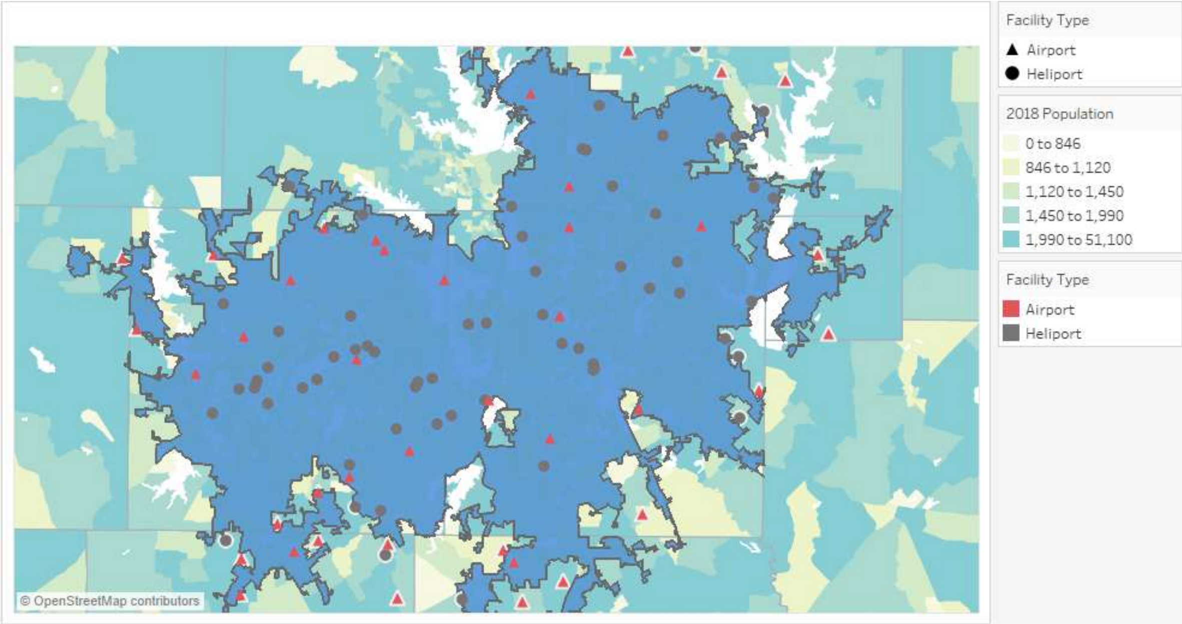


APPENDIX 4.4C: URBAN HONOLULU, HI

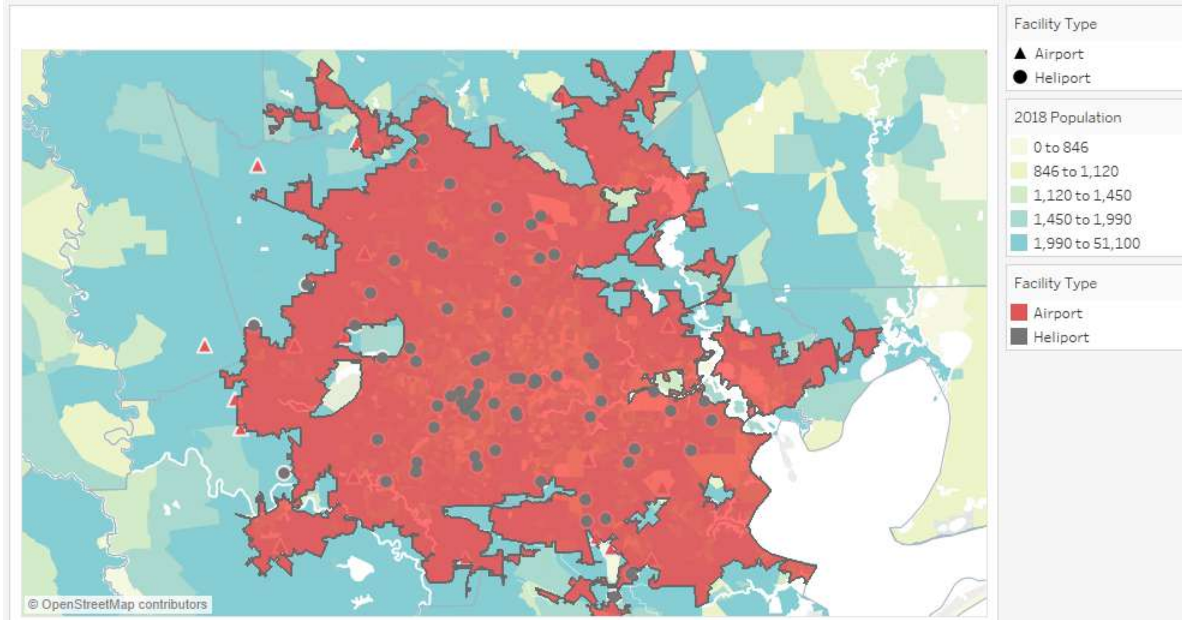
APPENDIX 4.4D: DENVER-AURORA, CO



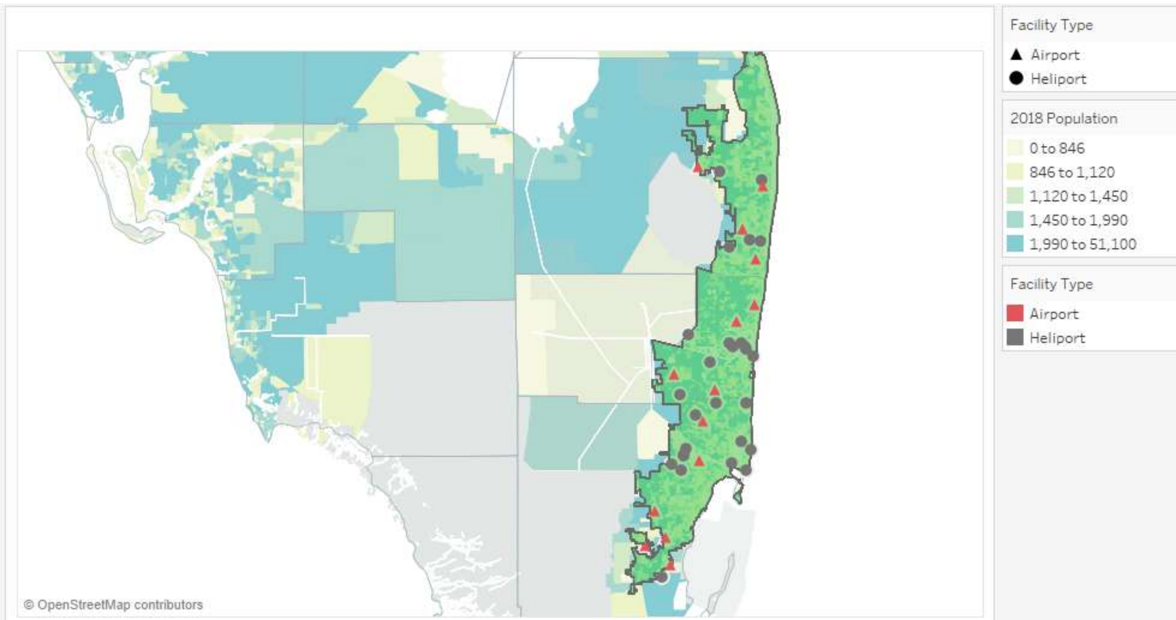
APPENDIX 4.4E: DALLAS-FORT WORTH-ARLINGTON, TX



APPENDIX 4.4F: HOUSTON, TX

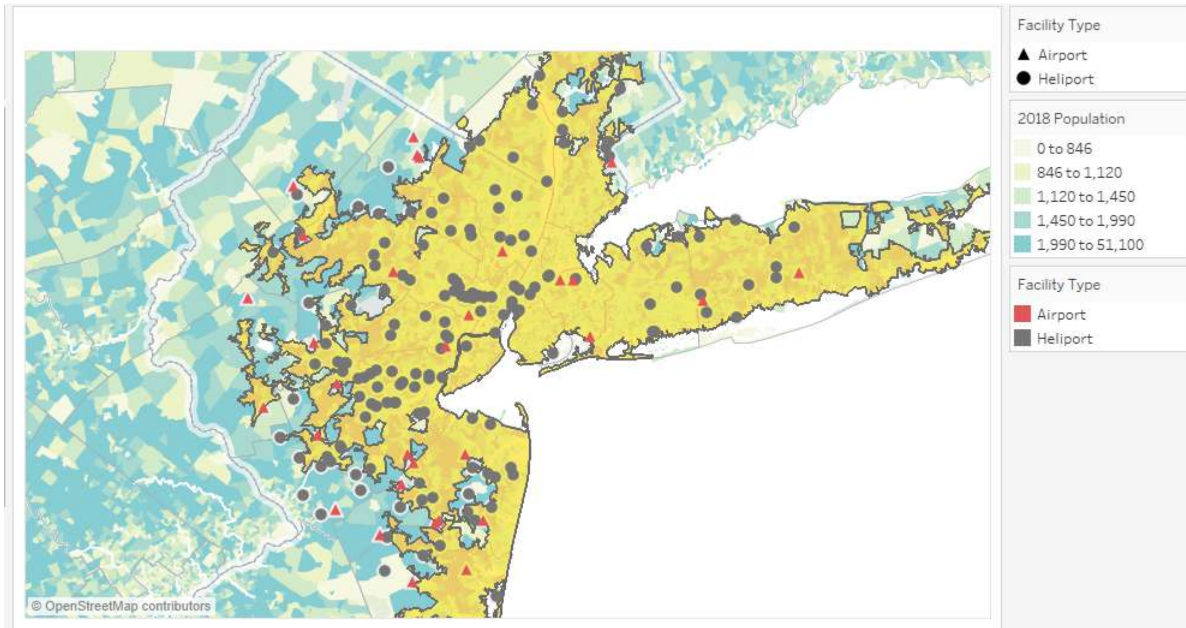


APPENDIX 4.4G: MIAMI, FL



APPENDIX 4.4H: WASHINGTON, DC-MARYLAND-VIRGINIA

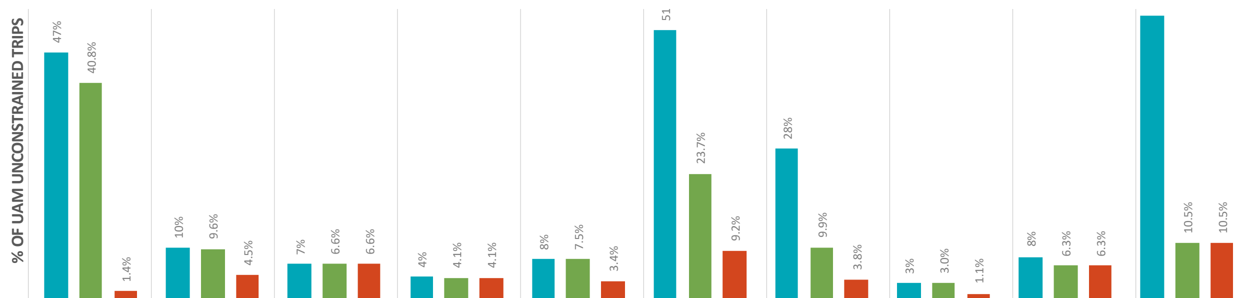
APPENDIX 4.4I: NEW YORK-NEWARK, NY-NJ-CT



Results

APPENDIX 4.45: AIRPORT SHUTTLE BASE YEAR DEMAND COMPARISON FOR ALL URBAN AREAS

- On average **~4.5% of daily unconstrained trips are captured** after applying constraints.
- **San Francisco, Denver and Dallas** are potential urban areas of high daily demand. New York demand capture is highly restricted due to current airport capacity constraint



	NEW YORK	LOS ANGELES	DALLAS	MIAMI	HOUSTON	SAN FRANCISCO	WASHINGTON DC	PHOENIX	DENVER	HONOLULU
Un-constrained	21,000	12,000	13,000	10,000	11,000	14,000	11,000	7,000	11,000	2,000
Infra + WTP Constrained	9,900	1,100	900	400	900	7,100	3,100	200	900	1,000
Capacity Constraint	8,600	1,100	900	400	800	3,300	1,100	200	700	200
APT capacity Constraint[1]	310	530	870	410	390	1,290	410	80	690	190

1 Demand reduction due to Airport operational capacity. Since eVTOL is expected to operate under Visual Flight Rules (VFR) for the initial years, we obtained Visual Flight Capacity profiles from the FAA for all the airports. These profiles indicate an airport current operational capacity using the existing runways, which might not be the case for Airport Shuttles. Therefore, the estimates may be conservative.

APPENDIX 4.5: CLASSES OF AIRSPACE - OPERATING PROTOCOLS

	Class A	Class B	Class C	Class D	Class E	Class G
Entry Requirements	ATC clearance	ATC clearance	Prior two-way communications	Prior two-way communications	Prior two-way communications*	Prior two-way communications*
Minimum Pilot Qualifications	Instrument Rating	Private or Student certification—local restrictions apply.	Student certificate	Student certificate	Student certificate	Student certificate
Two-Way Radio Communications	Yes	Yes	Yes	Yes	Yes, under IFR flight plan*	Yes*
Special VFR Allowed	No	Yes	Yes	Yes	Yes	N/A
VFR Visibility Minimum	N/A	3 statute miles	3 statute miles	3 statute miles	3 statute miles**	1 statute mile†
VFR Minimum Distance from Clouds	N/A	Clear of clouds	500' below, 1,000' above, 2,000' horizontal	500' below, 1,000' above, 2,000' horizontal	500' below,** 1,000' above, 2,000' horizontal	Clear of clouds†
VFR Aircraft Separation	N/A	All	IFR aircraft	Runway operations	None	None
Traffic Advisories	Yes	Yes	Yes	Workload permitting	Workload permitting	Workload permitting
Airport Application	N/A	• Radar • Instrument approaches • Weather • Control tower • High density	• Radar • Instrument approaches • Weather • Control tower	• Instrument approaches • Weather • Control tower	• Instrument approaches • Weather	• Control tower

*Exception: temporary tower or control tower present
**True only below 10,000 feet
†True only during day at or below 1,200 feet AGL (see 14 CFR part 91)

AGL—above ground level
FL—flight level
MSL—mean sea level

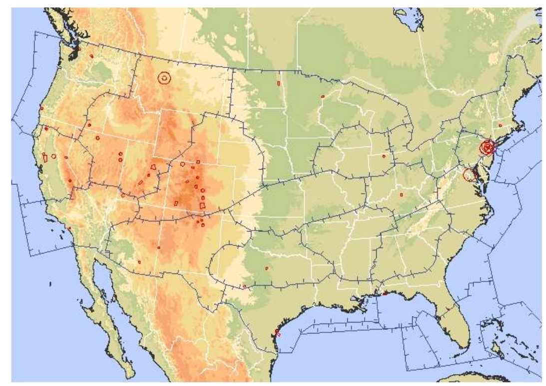
Source: FAA Website

APPENDIX 4.6: TEMPORARY FLIGHT RESTRICTIONS

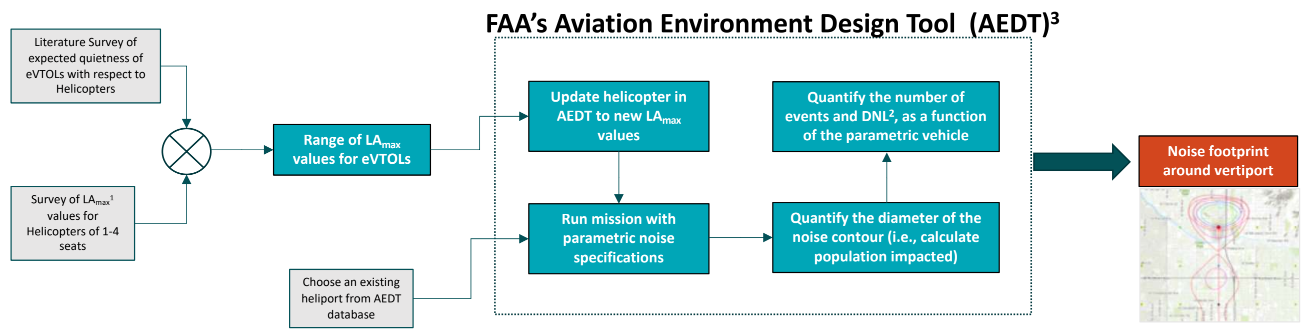
- A Temporary Flight Restriction (TFR) is a type of Notices to Airmen (NOTAM). A TFR defines an area restricted to air travel due to a hazardous condition, a special event, or a general warning for the entire FAA airspace. The text of the actual TFR contains the fine points of the restriction.
- Sample text for DC: “Flight restrictions, Washington, DC. Effective until further notice. Pursuant to Title 14 CFR section 99.7, special security instructions. A. Except for FAA approved DOD, law enforcement, and waivered lifeguard/air ambulance flights, all VFR aircraft operations within 30nm of 385134n/0770211w or the Washington /DCA/ VOR/DME, from the surface up to but not including fl180, are restricted to an indicated airspeed of 180 knots or less, if capable…”

tfr.faa.gov/tfr2/list.jsp?p=list&type=all&sort=s&up=Y

07/03/2018	8/7778	ZOA	CA	SECURITY	Beale AFB, CA, Sunday, July 08, 2018 through Sunday, July 15, 2018 Local
07/02/2018	8/6160	ZOA	CA	HAZARDS	3 NM SE OF CECILVILLE, CA, Monday, July 02, 2018 through Sunday, September 02, 2018 UTC
10/27/2014	4/3635	ZLA	CA	SECURITY	DISNEYLAND THEME PARK, ANAHEIM, CA, Monday, October 27, 2014 UTC
06/29/2018	8/5437	ZDV	CO	HAZARDS	14 MILES SOUTHWEST OF WINTER PARK, CO, Saturday, June 30, 2018 through Wednesday, August 29, 2018 UTC
07/05/2018	8/8282	ZDV	CO	HAZARDS	23 MILES NORTHWEST OF CRAIG, CO, Thursday, July 05, 2018 through Saturday, August 04, 2018 UTC New
07/04/2018	8/7963	ZDV	CO	HAZARDS	5.4 MILES SOUTHWEST OF SOUTH FORK, CO, Wednesday, July 04, 2018 through Tuesday, September 04, 2018 UTC
07/03/2018	8/7048	ZDV	CO	HAZARDS	6NM WSW OF WETMORE, CO, Tuesday, July 03, 2018 through Sunday, September 02, 2018 UTC
07/01/2018	8/5815	ZDV	CO	HAZARDS	12NM 046 DEGREES STEAMBOAT SPRINGS, CO, Monday, July 02, 2018 through Sunday, September 02, 2018 UTC
07/01/2018	8/6080	ZDV	CO	HAZARDS	15NM SE OF LEADVILLE, CO, Sunday, July 01, 2018 through Saturday, September 01, 2018 UTC
06/18/2018	8/7287	ZDV	CO	HAZARDS	8NM NORTH OF DURANGO, CO, Tuesday, June 19, 2018 through Thursday, July 19, 2018 UTC
07/05/2018	8/8280	ZDV	CO	HAZARDS	1.5 NM NORTHWEST OF BASALT, CO, Thursday, July 05, 2018 through Saturday, August 04, 2018 UTC New
07/01/2018	8/5854	ZDV	CO	HAZARDS	15 NM @ 119 DEGREES FROM LEADVILLE, CO, Sunday, July 01, 2018 through Saturday, September 01, 2018 UTC
01/10/2011	1/1155	ZDC	DC	SECURITY	WASHINGTON, DC
10/27/2014	4/3634	ZJX	FL	SECURITY	DISNEY WORLD THEME PARK, ORLANDO, FL, Monday, October 27, 2014 UTC



APPENDIX 4.7A: FIRST ORDER NOISE IMPACT MODELING

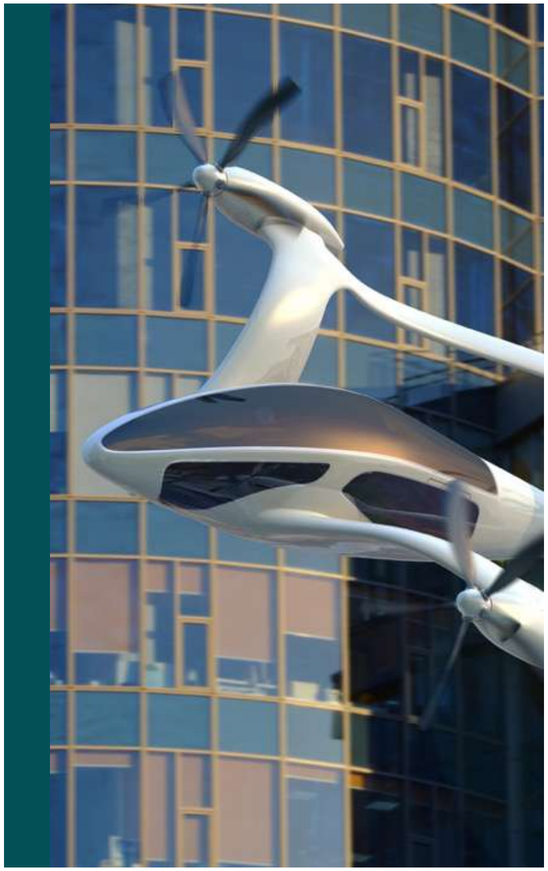


Influenced by Demand
Key Steps
Input
Output

[1] *LA_{max}: Maximum A - weighted sound pressure level recorded over the period stated*

[2] *DNL: Day-Night Average Sound Level (DNL) is a 24-hour equivalent sound level*

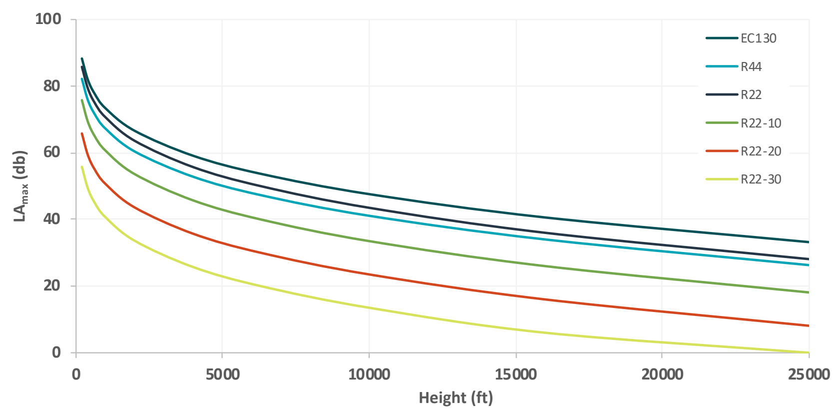
[3] *AEDT: FAA's AEDT is a software system that models aircraft performance in space and time to estimate fuel consumption, emissions, noise, and air quality consequences*



APPENDIX 4.7B: AEDT HELICOPTER NOISE IMPACT MODELING

- *Noise propagation is represented in AEDT with a database of Noise Power Distance (NPD) data, which are specific according to aircraft type, aircraft operation type, and noise metric (and, in the case of helicopters, directivity), combinations of aircraft operational modes (approach, departure, overflight), engine power states and slant distances from receptor to aircraft.*

- *Helicopters like Eurocopter 130, Robinson R44 and Robinson R22 are considered to be closest helicopter type to the proposed eVTOLs. For first order analysis, we replicate R22 (2 seats, 2350 lb MTOW) by adding quietness levels of 10 db., 20 db. and 30 db. Chart below shows sample NPD curves for Approach.*



Source: aedt.faa.gov

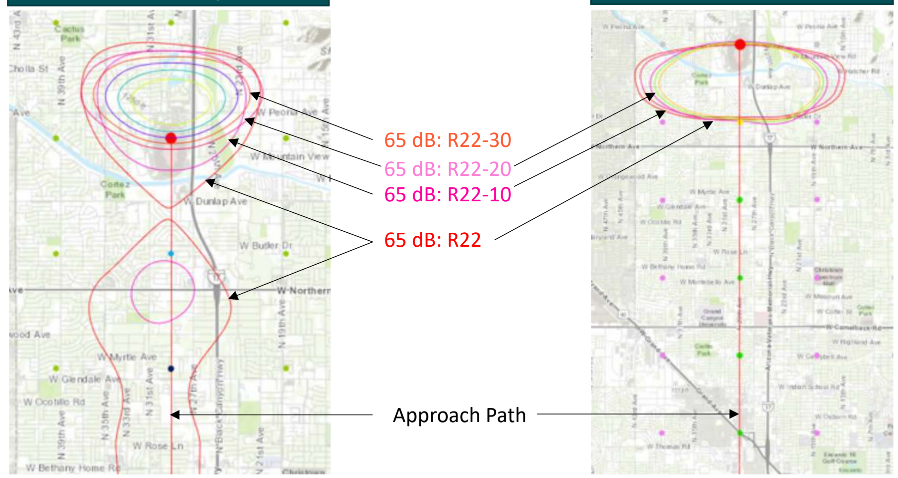
APPENDIX 4.7C: NOISE LEVEL COMPARISONS FOR ARRIVAL AND DEPARTURE MODE - PHOENIX

Noise level comparisons are shown for Robinson R22 and it's quieter versions. Figure shows picture of arrival mode only. Following specifications were followed:

- ***Profile type:*** *Approach and Departure*
- ***Noise Metrics:*** *LA_{max}, DNL*
- ***Heliport****: Inn Place, Phoenix*
- ***Number of Operations per day:*** *100*
- ***Cruise Altitude:*** *1000 ft*
- ***Landing Speed:*** *70 mph*
- ***Contour Type****: 65 dB*

Size of noise contour represents enclosed area exposed to noise levels of 65 dB and above. It is observed that even in a scenario where the helicopter is 30 dB quieter than original helicopter (i.e., R22-30), there is small area for arrival and larger area for departure mode around the heliport that experiences maximum noise level of 65 dB or more.

Metric: LA_{max} | Metric: DNL



Metric: LA_{max}

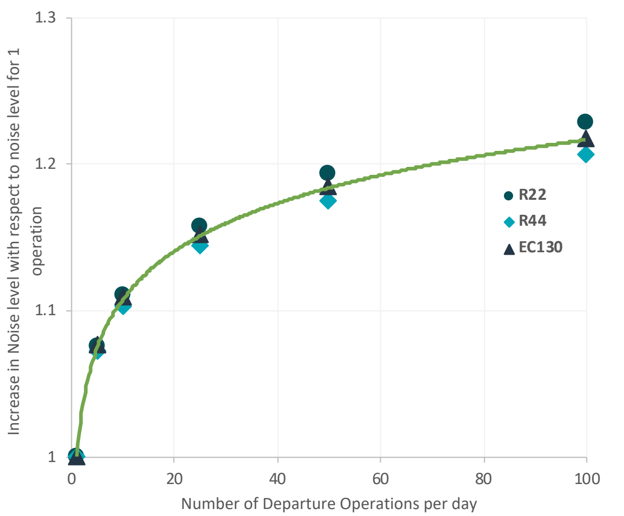
Helicopter	Contour Area – Arrival (sq. miles)	Contour Area – Departure (sq. miles)
R22	20.88	25.11
R22-10	2.22	17.30
R22 -20	1.80	7.63
R22-30	1.37	7.14

Metric: DNL

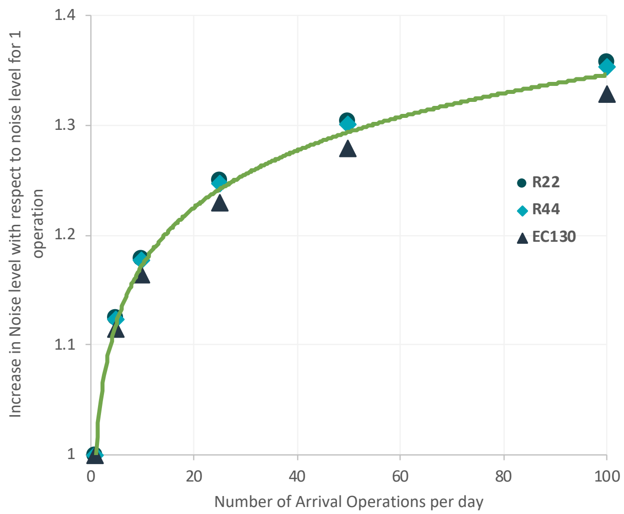
Helicopter	Contour Area – Arrival (sq. miles)	Contour Area – Departure (sq. miles)
R22	5.84	16.07
R22-10	4.95	7.54
R22 -20	4.81	6.61
R22-30	0.00	6.23

APPENDIX 4.7D: FIRST ORDER RELATIONSHIP BETWEEN NUMBER OF OPERATIONS AND NOISE LEVEL (DNL)

- *Figure shows relationship between number of **departure** operations per day and increase in noise levels indexed at noise level for one departure operation*



- *Figure shows relationship between number of **arrival** operations per day and increase in noise levels indexed at noise level for one arrival operation*



APPENDIX 4.8A: SCENARIOS

	% change in demand	
Scenario	**Mean**	**Median**
Time-Significance-0-Battery-Improvements-0-Vehicle-Cost-1-AVs [1]	-88%	-73%
Time-Significance-0.25-Battery-Improvements-0-Vehicle-Cost-1-AVs	-51%	-58%
Time-Significance-0.25-Battery-Improvements--50-Vehicle-Cost-1-AVs	-49%	-56%
Time-Significance-0.25-Battery-Improvements--100-Vehicle-Cost-1-AVs-AUs (Autonomous eVTOLs)	-46%	-54%
Time-Significance-0.25-Battery-Improvements-0-Vehicle-Cost-0.85-AVs	-45%	-52%
Time-Significance-0.25-Battery-Improvements--50-Vehicle-Cost-1-AVs-AUs	-45%	-52%
Time-Significance-0.25-Battery-Improvements--50-Vehicle-Cost-0.85-AVs	-43%	-51%
Time-Significance-0.25-Battery-Improvements--100-Vehicle-Cost-0.85-AVs-AUs	-40%	-48%
Time-Significance-0.25-Battery-Improvements--50-Vehicle-Cost-0.85-AVs-AUs	-38%	-46%
Autonomous Cars	-37%	-44%
Time-Significance-0.75-Battery-Improvements-0-Vehicle-Cost-1-AVs	-27%	-35%
Time-Significance-0.75-Battery-Improvements--50-Vehicle-Cost-1-AVs	-25%	-33%
Time-Significance-0.75-Battery-Improvements--100-Vehicle-Cost-1-AVs-AUs	-22%	-30%
time significance-0	-27%	-29%
Time-Significance-0.75-Battery-Improvements--50-Vehicle-Cost-1-AVs-AUs	-20%	-28%
Time-Significance-0.75-Battery-Improvements-0-Vehicle-Cost-0.85-AVs	-20%	-28%
Time-Significance-0-Battery-Improvements--50-Vehicle-Cost-1	-25%	-27%
Time-Significance-0.75-Battery-Improvements--50-Vehicle-Cost-0.85-AVs	-17%	-26%
Time-Significance-0-Battery-Improvements--100-Vehicle-Cost-1	-22%	-24%
Time-Significance-0.75-Battery-Improvements--100-Vehicle-Cost-0.85-AVs-AUs	-14%	-22%
Time-Significance-0.75-Battery-Improvements--50-Vehicle-Cost-0.85-AVs-AUs	-11%	-20%
Time-Significance-0-Battery-Improvements-0-Vehicle-Cost-0.85	-18%	-19%

[1] *Means zero time significance, no battery improvements, no vehicle cost reduction and competing with Autonomous Vehicles*

APPENDIX 4.8B: SCENARIOS (CONT….)

	% change in demand	
Scenario	Mean	Median
time significance-0.25	-15%	-16%
Time-Significance-0.25-Battery-Improvements-0-Vehicle-Cost-1	-15%	-16%
Time-Significance-0-Battery-Improvements--50-Vehicle-Cost-0.85	-15%	-16%
Time-Significance-0.25-Battery-Improvements--50-Vehicle-Cost-1	-12%	-14%
Time-Significance-0-Battery-Improvements--100-Vehicle-Cost-0.85	-12%	-13%
Time-Significance-0.25-Battery-Improvements--100-Vehicle-Cost-1	-10%	-11%
Time-Significance-0.25-Battery-Improvements-0-Vehicle-Cost-0.85	-5%	-7%
Time-Significance-0-Battery-Improvements-0-Vehicle-Cost-0.7	-6%	-7%
Time-Significance-0-Battery-Improvements--50-Vehicle-Cost-0.7	-3%	-4%
Time-Significance-0.25-Battery-Improvements--50-Vehicle-Cost-0.85	-3%	-4%
Telecommuting	-3%	-3%
Time-Significance-0.25-Battery-Improvements-0-Vehicle-Cost-1-AUs	-2%	-3%
Time-Significance-0-Battery-Improvements--100-Vehicle-Cost-0.7	1%	-2%
Time-Significance-0.25-Battery-Improvements--100-Vehicle-Cost-0.85	0%	-1%
Time-Significance-0.5-Battery-Improvements--50-Vehicle-Cost-1	8%	3%
Time-Significance-0.25-Battery-Improvements-0-Vehicle-Cost-0.7	6%	6%
Time-Significance-0.5-Battery-Improvements--100-Vehicle-Cost-1	11%	6%
Time-Significance-0.25-Battery-Improvements--50-Vehicle-Cost-0.7	9%	10%
Time-Significance-0.25-Battery-Improvements-0-Vehicle-Cost-0.85-AUs	9%	10%
time significance-0.75	19%	13%
Time-Significance-0.75-Battery-Improvements-0-Vehicle-Cost-1	19%	13%
vehicle cost % of original-0.85	16%	13%

APPENDIX 4.8C: SCENARIOS (CONT….)

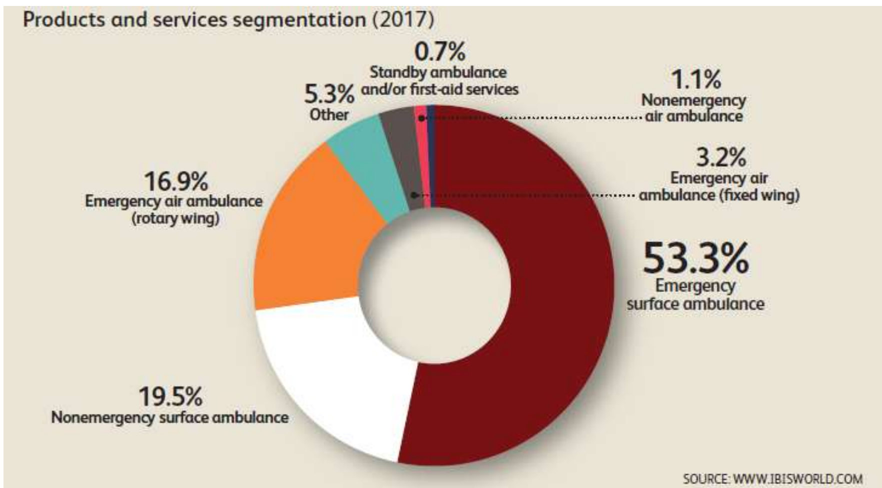
	% change in demand	
Scenario	**Mean**	**Median**
Time-Significance-0.5-Battery-Improvements-0-Vehicle-Cost-0.85	16%	13%
Time-Significance-0.25-Battery-Improvements--100-Vehicle-Cost-0.7	12%	13%
Time-Significance-0.25-Battery-Improvements--50-Vehicle-Cost-0.85-AUs	13%	14%
Time-Significance-0.75-Battery-Improvements--50-Vehicle-Cost-1	22%	16%
Time-Significance-0.5-Battery-Improvements--50-Vehicle-Cost-0.85	20%	17%
Time-Significance-0.75-Battery-Improvements--100-Vehicle-Cost-1	25%	19%
Time-Significance-0.5-Battery-Improvements--100-Vehicle-Cost-0.85	23%	21%
Time-Significance-0.75-Battery-Improvements-0-Vehicle-Cost-0.85	31%	25%
Time-Significance-0.75-Battery-Improvements-0-Vehicle-Cost-1-AUs	34%	28%
vehicle cost % of original-0.7	29%	29%
Time-Significance-0.5-Battery-Improvements-0-Vehicle-Cost-0.7	29%	29%
Time-Significance-0.75-Battery-Improvements--50-Vehicle-Cost-0.85	34%	29%
Time-Significance-0.75-Battery-Improvements--50-Vehicle-Cost-1-AUs	37%	33%
Time-Significance-0.5-Battery-Improvements--50-Vehicle-Cost-0.7	33%	33%
Time-Significance-0.75-Battery-Improvements--100-Vehicle-Cost-0.85	38%	33%
Time-Significance-0.5-Battery-Improvements--100-Vehicle-Cost-0.7	37%	37%
Time-Significance-0.75-Battery-Improvements-0-Vehicle-Cost-0.7	44%	41%
Time-Significance-0.75-Battery-Improvements-0-Vehicle-Cost-0.85-AUs	48%	46%
Time-Significance-0.75-Battery-Improvements--50-Vehicle-Cost-0.7	48%	46%
Time-Significance-0.75-Battery-Improvements--50-Vehicle-Cost-0.85-AUs	52%	51%
Time-Significance-0.75-Battery-Improvements--100-Vehicle-Cost-0.7	53%	52%
time significance-1	67%	66%

APPENDIX 4.8D: SCENARIOS (CONT….)

	% change in demand	
Scenario	**Mean**	**Median**
Time-Significance-1-Battery-Improvements-0-Vehicle-Cost-1	67%	66%
2x Vertiport Capacity	68%	68%
Time-Significance-1-Battery-Improvements--50-Vehicle-Cost-1	72%	71%
Time-Significance-1-Battery-Improvements--100-Vehicle-Cost-1	77%	77%
Time-Significance-1-Battery-Improvements-0-Vehicle-Cost-0.85	85%	87%
Time-Significance-1-Battery-Improvements--50-Vehicle-Cost-0.85	91%	93%
Time-Significance-1-Battery-Improvements--100-Vehicle-Cost-0.85	96%	99%
2x Number of Vertiports	100%	100%
Autonomous eVTOL	19%	105%
Time-Significance-1-Battery-Improvements-0-Vehicle-Cost-0.7	106%	112%
Time-Significance-1-Battery-Improvements--50-Vehicle-Cost-0.7	112%	119%
Time-Significance-1-Battery-Improvements--100-Vehicle-Cost-0.7	119%	127%
High Network Efficiency	221%	230%
Time-Significance-1-Battery-Improvements--100-Vehicle-Cost-0.7-High Efficiency-AUs	463%	464%

AIR AMBULANCE ANALYSIS APPENDIX

APPENDIX 5.1: PRODUCTS AND SERVICES IN AMBULANCE INDUSTRY



Key Drivers and Numbers

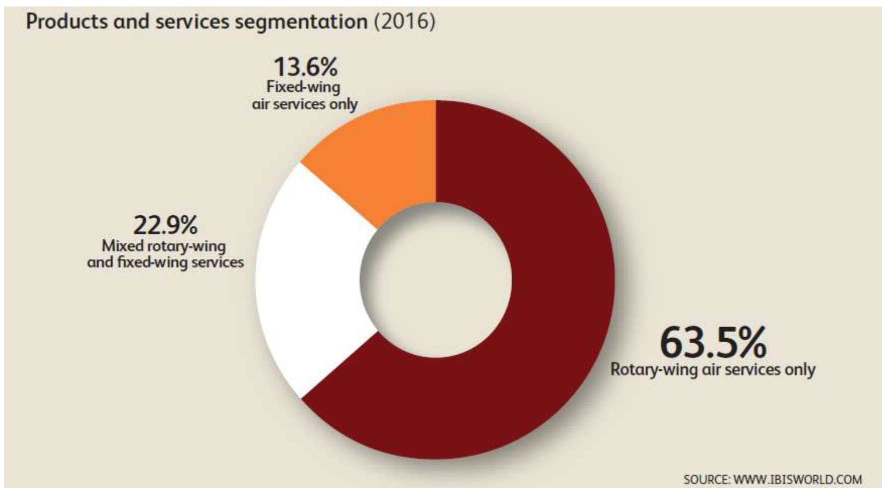
- Total health expenditure
- Number of adults aged 65 and older
- Federal funding for Medicare and Medicaid
- Number of people with private health insurance
- Healthy eating index

Statistics

- **$16.1 billion** revenue
- **$1.2 billion** profit
- **2.4%** annual growth 12-17
- **2.1%** annual growth 17-22
- **$6.5** billion in wages
- **3,403** businesses

Source: Ibis, 2017

APPENDIX 5.2: PRODUCTS AND SERVICES IN AIR AMBULANCE INDUSTRY



Key Drivers and Numbers

- Number of people with private health insurance
- Federal funding for Medicare and Medicaid
- Number of adults aged 65 and older
- World price of crude oil
- Total health expenditure

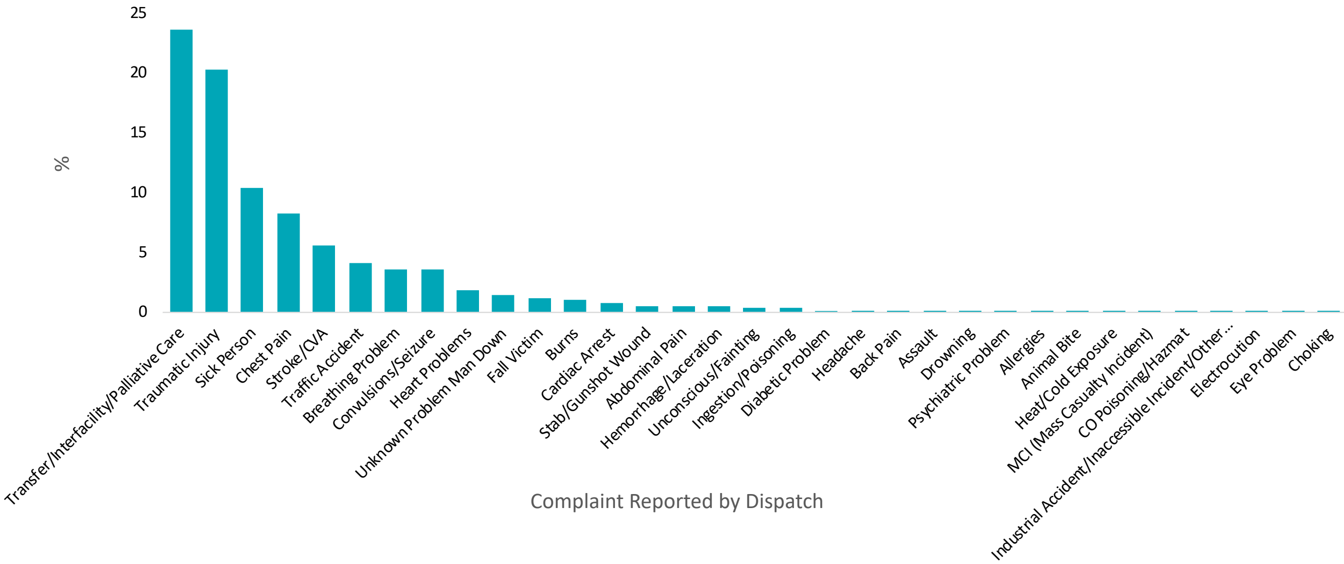
Statistics

- **\$5.0 billion** revenue
- **\$737.2 million** profit
- **1.9%** annual growth 11-16
- **2.8%** annual growth 16-21
- **\$2.0** billion in wages
- **302** businesses

Source: Ibis, 2016

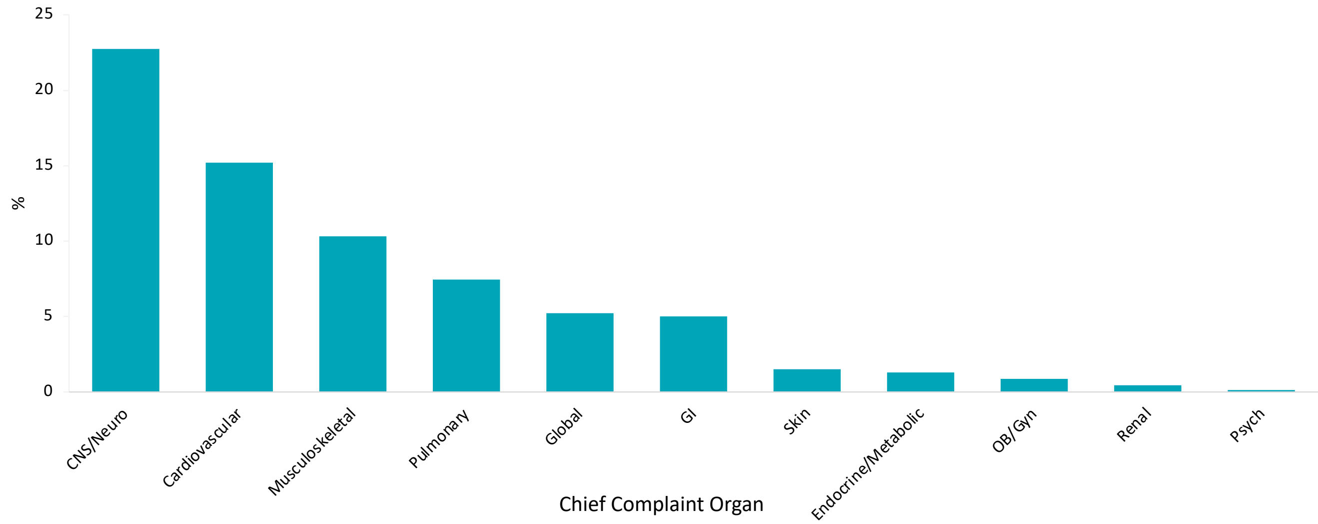
APPENDIX 5.3 - ROTARY WING EVENTS - COMPLAINT RECORDED BY DISPATCH

Most RW aircraft are dispatched for patient transfer or palliative care. The most common complaint recorded by dispatchers requiring RW transport are traumatic injury, chest pain, stroke, and traffic accidents.



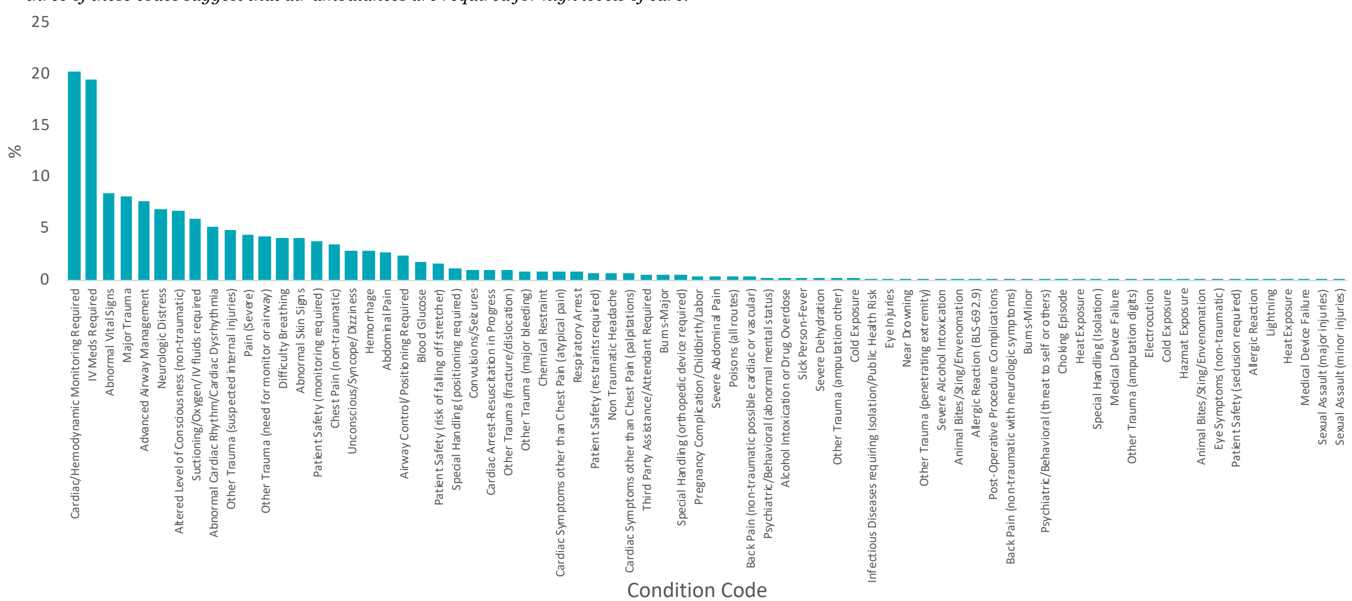
APPENDIX 5.4 - ROTARY WING EVENTS - CHIEF COMPLAINT ORGAN

The chief complaint organ system for RW events is listed as "CNS/Neuro," followed by Cardiovascular and Musculoskeletal. This suggests a high reliance on air ambulances for sensitive organ systems.



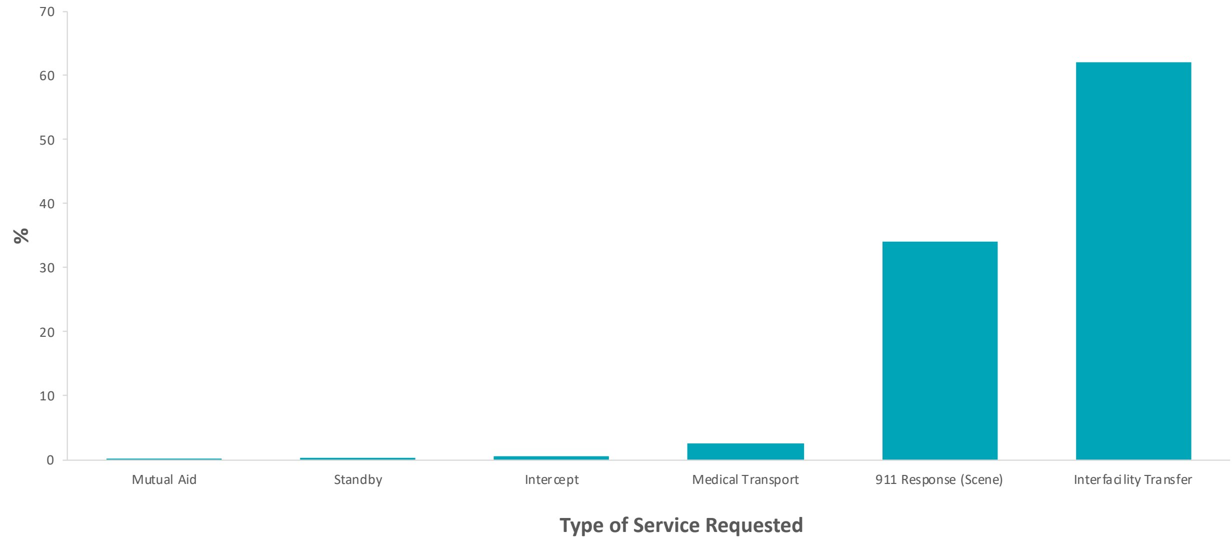
APPENDIX 5.5: ROTARY WING EVENTS - CONDITION CODE

The primary condition codes logged for RW events are Cardiac/Hemodynamic Monitoring Required, Abnormal Vital Signs, and Advanced Airway Management. The three of these codes suggest that air ambulances are required for high levels of care.



APPENDIX 5.6: ROTARY WING EVENTS - TYPE OF SERVICE REQUESTED

Over 2/3 of all RW dispatches are requested for interfacility transfers and medical transports. The other 1/3 represent 911 scene responses. This suggests the market for intercity transport could be high, depending on how many interfacility transfers occur within each urban area.



APPENDIX 5.7: REFERENCES

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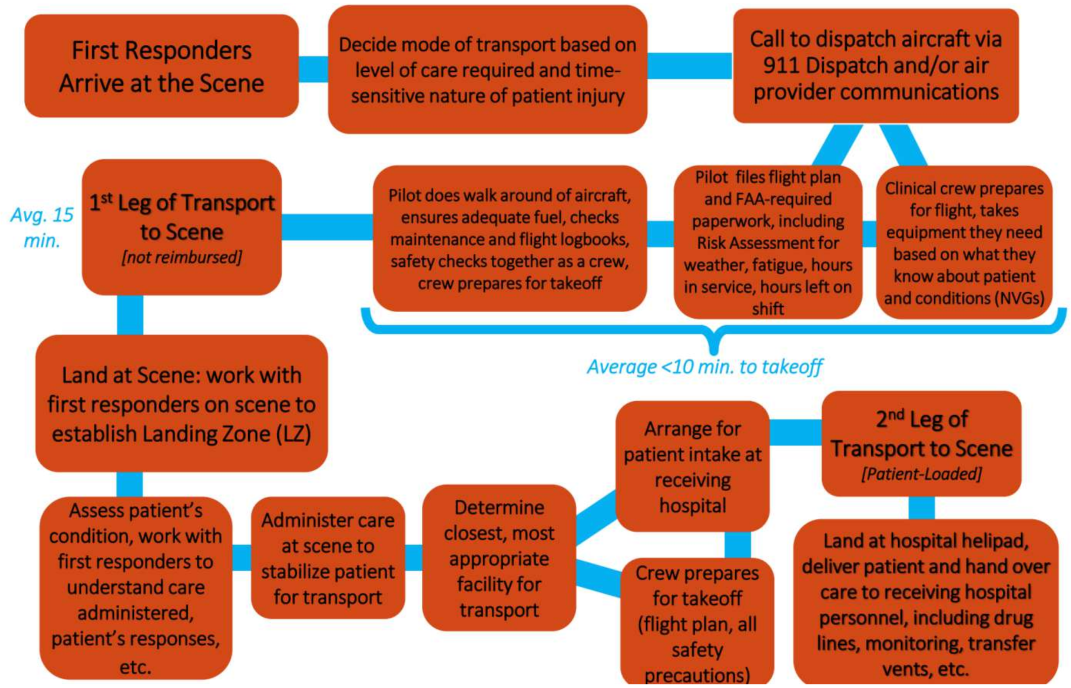
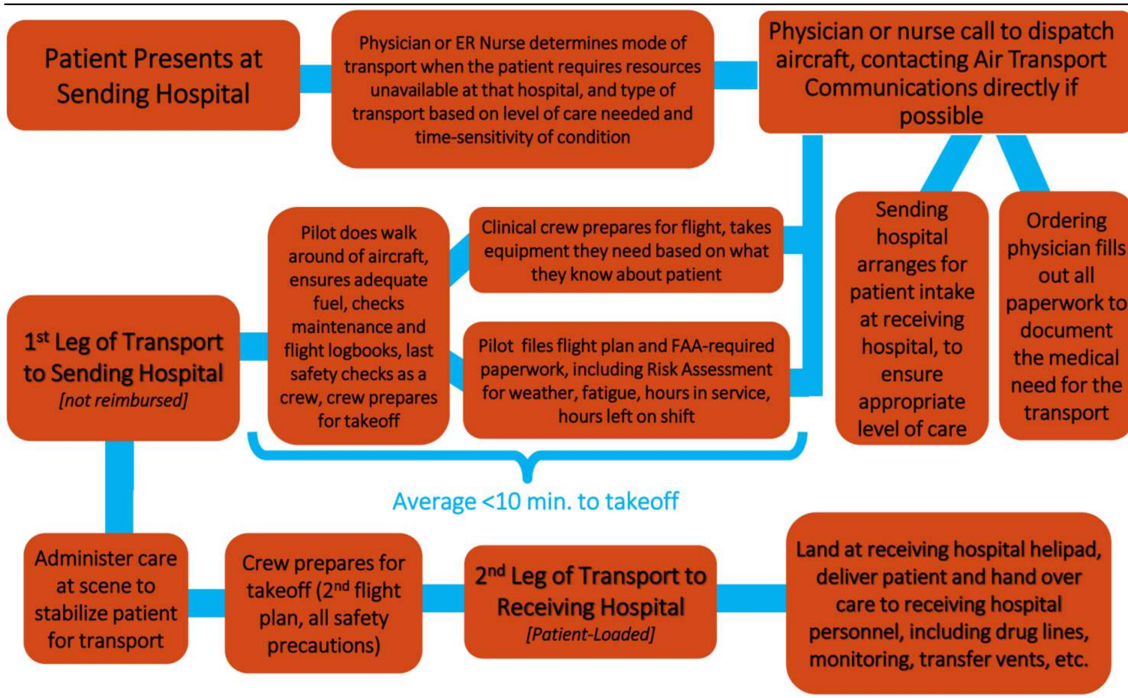
APPENDIX 5.8A: CONOPS FOR AIR AMBULANCE - SCENE



Source: Florida Office of the Insurance Consumer Advocate

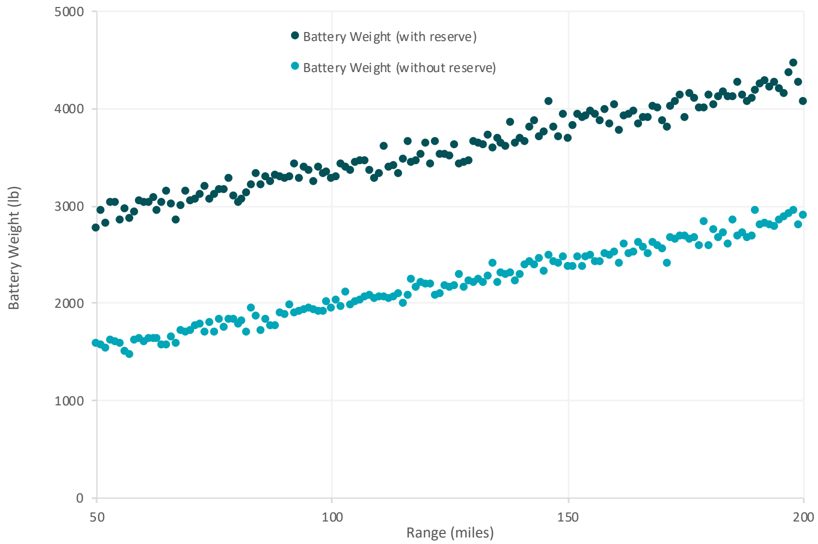
APPENDIX 5.8B: CONOPS FOR AIR AMBULANCE - INTERFACILITY TRANSFER



Source: Florida Office of the Insurance Consumer Advocate

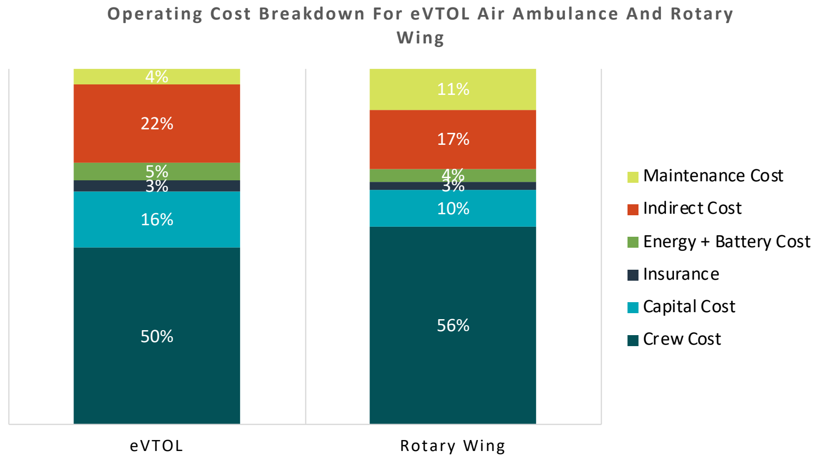
APPENDIX 5.9: BATTERY WEIGHT AS FUNCTION OF RANGE

Our analysis shows that eVTOL air ambulance total battery weight requirements are significantly high that could limit its capability to compete on long missions



APPENDIX 5.10: TOTAL COST BREAKDOWN

- Crew requirements remain the same for both types of equipment, therefore, no significant difference is observed in cost breakdown.
- Maintenance costs decrease for eVTOLs as compared to Rotary Wing while no significant difference is observed for energy and insurance cost.



APPENDIX 5.11: 6-HOUR METAR ANALYSIS

- The Booz Allen team took hourly METAR data from 2010 - 2017 and analyzed key environmental variables for the 10 focus urban areas
- This initial effort focused on **temperature** due to it's influence on battery performance other flight parameters
- This data was analyzed seasonally according to meteorological definition:
  - **Winter**: December 1st to February 28th
  - **Spring**: March 1st to May 31st
  - **Summer**: June 1st to August 31st
  - **Fall**: September 1st to November 30th
- Within each season, this hourly data was aggregated across the following 6-hr blocks:
  - **12AM to 6AM**, **6AM to 12PM**, **12PM to 6PM**, and **6PM to 12AM**
- This approach allowed us to begin identifying any temporal or seasonal trends within the data at our market locations.

Sample METAR 6-Hour Output

Local Tim	Variable	DAL	DCA	DEN	DFW	EWR
00-06:00	Average Temperature	81.10	74.21	62.91	80.04	71.28
00-06:00	TMax	97.00	91.00	81.00	96.00	91.00
00-06:00	Temp95P	89.00	82.00	73.00	88.00	81.00
00-06:00	Temp50P	81.00	74.00	63.00	80.00	72.00
00-06:00	Temp5P	72.00	65.00	53.00	71.00	61.00
00-06:00	TMin	62.00	53.00	40.00	62.00	49.00
00-06:00	Temp Range	35.00	38.00	41.00	34.00	42.00
06-12:00	Average Temperature	83.16	78.00	72.00	82.88	75.76
06-12:00	TMax	106.00	102.00	99.00	106.00	104.00
06-12:00	Temp95P	94.00	90.00	89.00	94.00	89.00
06-12:00	Temp50P	83.00	78.00	71.00	82.00	76.00
06-12:00	Temp5P	73.00	67.00	56.00	72.00	63.00
06-12:00	TMin	62.00	53.00	43.00	62.00	51.00
06-12:00	Temp Range	44.00	49.00	56.00	44.00	53.00

Temperature Statistics Generated:

- Average Temperature
- Maximum Temperature (TMax)
- 95th Percentile Temperature
- 50th Percentile Temperature
- 5th Percentile Temperature
- Minimum Temperature (TMin)
- Temperature Range (TMax – TMin)

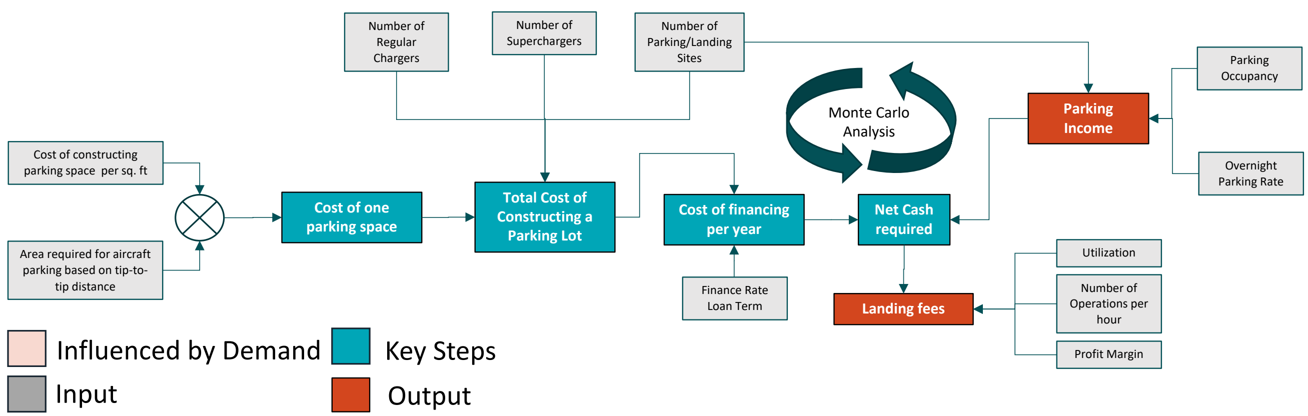
APPENDIX 5.12: INFRASTRUCTURE COST MODEL (BUNDLED UNDER INDIRECT OPERATING COST)

*Our first order infrastructure model assumes **car parking garage style architecture** and construction with certain number of parking sites. Our assumption is based on market's interest to use a **multi-purpose garages** (like top of garage roof) for operating Air Ambulances in the near term. However, there are number of terminal type designs proposed by OEMs, which is expected to have higher cost*

***Step 1:** We retrieve cost of constructing a parking space from literature adjusted by area required for aircraft size. Depending on the number of chargers and parking sites, **total cost** of building is calculated (financed over a certain amortization period)*

***Step 2:** Each parking garage is expected to have **yearly parking income** from overnight parking of Air Ambulances*

***Step 3:** The net cash required (yearly cost of building – yearly parking income) is divided by utilization and number of operations per hour to calculate landing fees per hour (which is further divided by trip speed to calculate landing fees per mile)*



APPENDIX 5.13: ROUTE COST (BUNDLED UNDER INDIRECT OPERATING COST)

- Route cost in commercial aviation refers to **fees paid to air traffic control** while crossing their managed airspace. In urban air mobility, this fees may be collected at administrative zone level
- The route charge is usually calculated using three basic elements:
  - **Distance factor** (for each charging zone) i.e., distance flown in a particular zone
  - **Aircraft Weight**
  - **Unit Rate of Charge** (for each charging zone)
- For this analysis , we obtained historical route cost per seat per mile for commercial business jets flown in United States to develop the minimum and maximum range as shown in table below

Business jet Type	Route cost per seat per mile	
Very Light Business Jet	0.0079	MIN
Light Business Jet	0.0081	
Corporate Business Jet	0.0162	MAX

Source: Bureau of Transportation Statistics, OAG

APPENDIX 5.14: INDIRECT OPERATING COST

NON-EXHAUSTIVE

Indirect Cost Component	Min	Max
1. **Reservation Cost** – Need to arrange booking and connect passengers with vehicles 2. **Ticketing Costs** – Administrative costs to ensure that passengers can fly 3. **Credit Card Processing Fees** – Recently upheld by the Supreme Court, credit card companies charge merchants for using their cards 4. **Marketing –** "If you don't keep giving customers reasons to buy from you, they won't." – Sergio Zyman, former head of marketing at Coca Cola 5. **Building –** Need a place for vehicles to land and take off 6. **Hangar –** Need a place to store and repair/maintain vehicles	5%	50%

APPENDIX 5.15: OPERATING COSTS OF GROUND AMBULANCES (TRB, 2008)

- Maintenance Cost per Mile:
  - Type I - $0.61
  - Type II - $0.78
  - Type III - $0.59
  - Medium Duty (MD) - $1.03
- Vehicle Maintenance as a % of annual operating budget
  - 2005 – 8%
  - 2006 – 7%
  - 2007 – 5%
  - 2008 – 5%
- Estimated Total Cost for Life (based on 185k miles average)
  - Type I - $256,850
  - Type II - $211,300
  - Type III - $249,400
  - MD - $375,550

http://www.medicaire.net/images/kenbeers.pdf

APPENDIX 5.15: OPERATING COSTS OF GROUND AMBULANCES - YEAR 1 ESTIMATED COSTS FOR FULL EMS SYSTEM

- Personnel
  - Director: $80k
  - Deputy Director / Educational Coordinator: $50k
  - Crew Chiefs (Total of 5 @ $45k/year): $225k
  - Office Manager: $30k
  - EMT-B (total of 20, 4 working per shift at gross pay on average of $2k/month/employee): $480k
  - EMT-P (total of 20, 4 working per shift at gross pay on average of $2k/month/employee): $792k
  - Benefits for FTE: $331k
  - Continuing Education for EMTs: $25k
  - TOTAL: $2,013,000
- Vehicles
  - 5 ALS Ambulances stocked to the ALS level equipment requirements ($80k each): $400k
  - Medical Equipment Maintenance and Repair: $10k
  - Fuel: $100k
  - Vehicle Repair and Maintenance: $30k
  - TOTAL: $515,000
- Communications
  - Vehicle: $20k total
  - Personnel: $15k total
  - Repeater Station: $8k total
  - Misc. Items: $8k total
  - TOTAL: $51,000
- Miscellaneous Costs
  - Insurance: $80k
  - Utilities: $30k
  - Dispatch: $50k
  - Billing: $65k
  - Office Supplies: $30k (includes computers/printers)
  - Professional Services: $12.5k
  - Medical Direction: $10k
  - Licensing: $8k
  - EMS Reporting System: $10k
  - TOTAL: $295,500

Estimated Initial Operational Costs for EMS System:

$2.8 million

Per Ambulance:

$560,000

http://www.pettiscomo.com/ems/OperationalExpenses.pdf

APPENDIX 5.16 - NASEMSO

- The National Association of State Emergency Medical Services Officials (NASEMSO) is a professional association for state emergency medical services officials
- It was formed in 1980
- Mission: NASEMSO supports its members in developing EMS policy and oversight, as well as in providing vision, leadership and resources in the development and improvement of state, regional and local EMS and emergency care systems.
- Goals:
  - To promote the orderly development of coordinated EMS systems across the nation.
  - To promote uniformly high quality care of acutely ill and injured patients.
  - To provide a forum for the exchange of information and the discussion of common concerns among state EMS officials.
  - To facilitate interstate cooperation in such areas as patient transfer, communications and reciprocity of EMS personnel.
  - To disseminate pertinent information to our membership and others.
  - To maintain ongoing and effective liaison with state and national governments, professional organizations, and other appropriate public and private entities.
  - To improve the quality and efficiency of state EMS program administration.
  - To enhance the professional knowledge, skill and abilities of state EMS officials and staff.
  - To encourage research and evaluation in all areas of EMS.
  - To serve as a permanent national advocacy group for EMS.

APPENDIX 5.17 - NASEMSO'S NATIONAL EMS ASSESSMENT

- The 2011 National EMS Assessment was commissioned by the Federal Interagency Committee for Emergency Medical Services (FICEMS) and funded through the National Highway Traffic Safety Administration (NHTSA).
- NHTSA's objectives were to understand data that is currently being collected at the state, regional, and national levels that pertain to EMS systems, EMS emergency preparedness, and 911 communications.
- An initial inventory of existing data systems throughout the U.S. at the state and national levels identified several data sources relative to EMS. Only two had the ability to comprehensively describe EMS, EMS emergency preparedness, and 911 communications at the state and national levels within all 50 States and four of the six U.S. Territories.
- The National EMS Database maintained by the National EMS Information System Technical Assistance Center (NEMSIS TAC) provided extensive information describing EMS service and patient care through the 2010 EMS data submitted by the 30 participating states.
- In addition, the National Association of State EMS Officials via an extensive assessment known as the "EMS Industry Snapshot" collected this information in early 2011. Although the EMS Industry Snapshot was not a part of the National EMS Assessment Project, the NASEMSO released the data for use in the National EMS Assessment report.
- The National EMS Assessment is a comprehensive report describing the estimated 19,971 EMS Agencies, their 81,295 vehicles, and the 826, 111 EMS professionals licensed and credentialed within the United States. Over 200 data points provide detailed information and insight into EMS, emergency management, and 911 communications.

All 50 (100%) State EMS Offices license EMS Agencies that respond to 911 emergencies. Other EMS Agencies licensed in decreasing order include: Specialty Care Air Medical Transport (88%), 911 Response (Scene) without Transport (82%), Non-Emergency Medical Transport (67%), and Specialty Care Ground Transport (67%).

Only 18 (37%) states license Emergency Medical Dispatch Centers.

EMS Agency Types Licensed by State

EMS Agency Types	States		Territories	
	N	%	N	%
911 Response (Scene) with Transport	49	100.0%	4	100.0%
911 Response (Scene) without Transport	40	81.6%	1	25.0%
Medical Transport (Non-Emergent Convalescent)	33	67.4%	2	50.0%
Specialty Care Transport Ground	33	67.4%	2	50.0%
Specialty Care Transport Air	43	87.8%	3	75.0%
Emergency Medical Dispatch (EMD) Center	18	36.7%	3	75.0%

***CA state data was unavailable. AS and DC territory data was unavailable.*

Data obtained from the NASEMSO 2011 EMS Industry Snapshot was collected using a survey distributed to the Director of each state's regulatory EMS office. It should be noted that the aggregate results of any survey question is based on a combination of fact and opinion. This is dependent on each state's available data sources and operational awareness relative to each specific question. The NASEMSO Snapshot question used for this analysis was the following: "What licensed EMS Agency Types exist in your state?"

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A total of 46 (92%) State EMS Offices license EMS Agencies at the EMT-Paramedic level of service. EMT-Basic level EMS Agencies are licensed in 45 (90%) of the states. There were 38 (76%) states that license EMT-Intermediate level EMS Agencies. Less that 50% of the states license First Responder EMS Agencies. Very few states (20%) license Emergency Medical Dispatch Centers.

EMS Agency Licensure by Level of Service	States		Territories	
	N	%	N	%
First Responder	24	48.0%	0	0.0%
Emergency Medical Dispatch (EMD)	10	20.0%	3	75.0%
EMT Basic	45	90.0%	4	100.0%
EMT Intermediate	38	76.0%	2	50.0%
EMT Paramedic	46	92.0%	2	50.0%
Other level of service	6	12.0%	1	25.0%

***All states participated. AS and DC territory data was unavailable.*

Data obtained from the NASEMSO 2011 EMS Industry Snapshot was collected using a survey distributed to the Director of each state's regulatory EMS office. It should be noted that the aggregate results of any survey question is based on a combination of fact and opinion. This is dependent on each state's available data sources and operational awareness relative to each specific question. The NASEMSO Snapshot question used for this analysis was the following: "What levels of service are associated with the EMS Agencies that are licensed in your state?"

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EMS Vehicle Totals by Type

Vehicle Type	States	Mean	Median	Min	Max	Sum
BLS non-transport	14	352.9	212.5	1	1,357	**4,941 (7%)**
BLS transport	34	512.9	346	5	1,959	**17,438 (26%)**
ALS non-transport	21	274.1	150	1	1,408	**5,757 (9%)**
ALS transport	37	981.8	643	6	4,232	**36,327 (55%)**
Specialty care	18	41.1	14	1	230	**740 (1%)**
Air medical	37	34.2	27	1	158	**1,267 (2%)**
Boats	4	4.8	4.5	1	0	**19 (0%)**
Grand Total						**66,489**

AK, CA, ID, KS, MO, NE, OK, and RI state data unavailable. Territories not included.

Data obtained from the NASEMSO 2011 EMS Industry Snapshot was collected using a survey distributed to the Director of each state's regulatory EMS office. It should be noted that the aggregate results of any survey question is based on a combination of fact and opinion. This is dependent on each state's available data sources and operational awareness relative to each specific question. The NASEMSO Snapshot question used for this analysis was the following: "How many of the following EMS vehicle types are currently credentialed in your state?"

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Of the 24 states that track EMS patient transports, only 17 states provided 2010 EMS patient transport numbers. At total of 10,777,441 EMS patient transports were identified in 2010.

2010 EMS Patient Transports by EMS Agency Type and State

EMS Agency Type	States	Mean	Median	Min	Max	Total
911 Response with Transport Capability	17	541,660	200,831	6,322	2,800,000	9,208,220 (85%)
911 Response without Transport Capability	5	104,184	1,675	496	500,000	520,921 (5%)
Medical Transport (Non-Emergent Convalescent)	7	107,939	65,000	334	276,902	755,572 (7%)
Specialty Care Transport (Ground)	5	42,915	200	92	137,539	214,573 (2%)
Specialty Care Transport (Air)	11	7,105	2,355	243	34,385	78,155 (1%)
Grand Total						**10,777,441**

***** OK, ME, IN, CT, WV, UT, ID indicated they track EMS Transports but did not provide data***

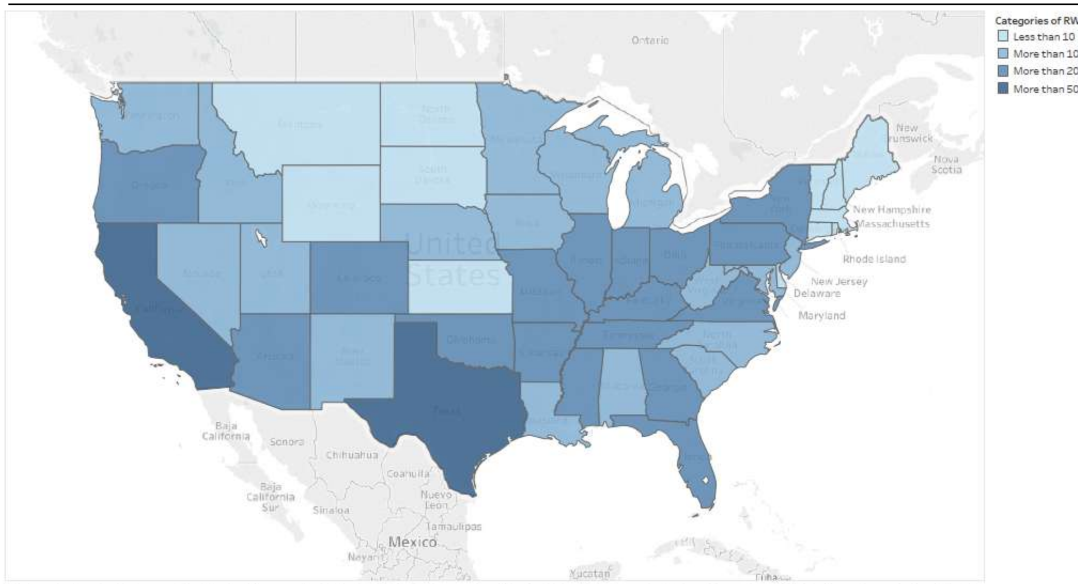
Data obtained from the NASEMSO 2011 EMS Industry Snapshot was collected using a survey distributed to the Director of each state's regulatory EMS office. It should be noted that the aggregate results of any survey question is based on a combination of fact and opinion. This is dependent on each state's available data sources and operational awareness relative to each specific question. The NASEMSO Snapshot question used for this analysis was the following: "If yes to the previous question, what is the approximate number of EMS Transports in the past 12 months? (if yes, number for each)"

APPENDIX 5.22 - AIR AMBULANCE VOLUME AND SAFETY

- Helicopter EMS (HEMS) safely transports nearly 400,000 patients each year in U.S.
- From 2003-2008:
  - 85 accidents
  - 77 fatalities
- In 2007, HEMS crew was nearly twice as dangerous as aircraft pilots generally, and over five times more dangerous than police officers
- Varying degrees of helicopter quality, yet Medicare reimbursement is the same no matter the vehicle used
- No standard requirement for helicopters to have the same navigation and safety equipment
- Varying degrees of pilot training, only certain agencies provide simulator training

Source: NTSB

APPENDIX 5.23 - ROTARY-WING VEHICLES BY STATE



Map based on Longitude (generated) and Latitude (generated). Alaska has 21 RW vehicles and Hawaii has 5 vehicles. Color shows details about Categories of RW. Details are shown for State. The view is filtered on Exclusions (Categories of RW,State), which keeps 50 members. Source: Atlas & Database of Air Medical Services

APPENDIX 6.1: UAM PROJECT TEAM

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Senior Associate
Aviation & UAS

- 15+ years of experience in leading projects related to aviation /transportation modeling, analysis, and policy
- Principal Investigator on ACRP 03-42: Airports and UAS
- Extensive knowledge in aviation, data, ATM, and airspace re-design

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Aviation and Weather

- Ph.D. in atmospheric science from Purdue University
- 10+ years of experience in technical project leadership of aviation research
- Management and technical oversight of a diverse portfolio of FAA and NASA projects related to weather, forecast capabilities, and impact translation

ROHIT GOYAL
Dy. Project Manager
UAM Market Analysis Lead

- Expert in aviation modeling, market analysis, and policy
- Comprehensive knowledge in aviation technology, data, and UAVs
- Advanced studies in Aerospace Engineering from Harvard University and MIT

DR. SUSAN SHAHEEN
Societal Barriers Lead
Sustainable Transportation

- Oversees leading center at UC Berkeley focused on sustainable transportation
- Performs research tasks focused on the future of mobility and emerging transportation
- Authored 60 journal articles, over 100 reports and proceedings articles, nine book chapters, and co-edited two books

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- Ph.D. in Engineering Systems from Massachusetts Institute of Technology
- 15+ years in aviation modeling and policy analysis with experience in leading projects related to Aviation, Energy, and Environment
- Lead of several groups within the International Civil Aviation Organization (ICAO)

JACQUELINE SERRAO, JD, LLM
Legal and Regulatory
Aviation Law

- 18+ years in leading projects relating to U.S. and international aviation policy, law, and regulations, legal and institutional capacity building
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Transportation

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UAS Law Professor and Attorney

- SME on aviation and space law, UAS regulations worldwide, flight instruction, aviation safety and education.
- Full-time faculty at Embry-Riddle Aeronautical University (ERAU) in Prescott, Arizona, teaching Aviation Law, Global UAS, Unmanned Aircraft Ground School, Business Law, and Business Ethics

ADAM COHEN

UAM

- SME on the future of mobility, innovative and emerging transportation technologies, shared mobility and Smart Cities
- Conducts global industry benchmarking on shared mobility and co-author of industry market outlooks

DOMINIC MCCONACHIE

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- 7+ years of experience in leading projects in air transportation and data analytics focusing on economic and environment impact analysis
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- Specializes in emerging aerospace markets
- Works with global aerospace OEM on emerging technology strategy across multiple aerospace markets
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- BS in Astronautical Engineering from Univ. of Wisconsin; Yale MBA

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- Project lead for ACRP 03-42: UAS and Airports
- Project lead for regulatory analysis in support of viability of UAM for Global OEM
- Analytical expertise in ATM operations and transportation technology analyses.