Booz | Allen | Hamilton

EXECUTIVE BRIEFING

URBAN AIR MOBILITY (UAM) MARKET STUDY

Presented to: *National Aeronautics and Space Administration - Aeronautics Research Mission Directorate*

OCTOBER 5, 2018

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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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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.

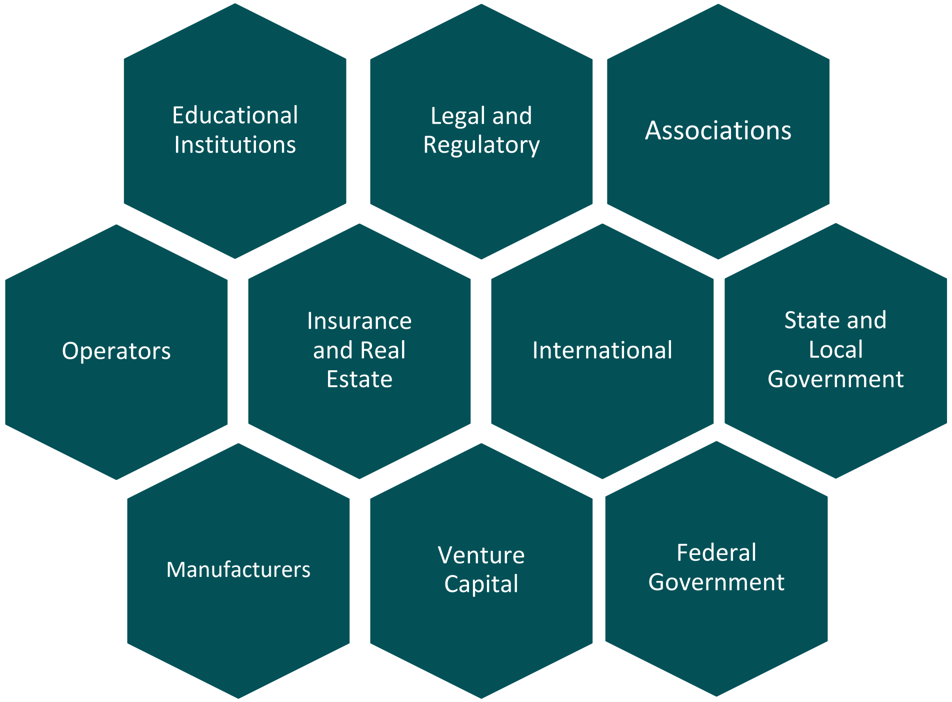
STRATEGIC ADVISORY GROUP (SAG)

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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THREE FOCUS MARKETS

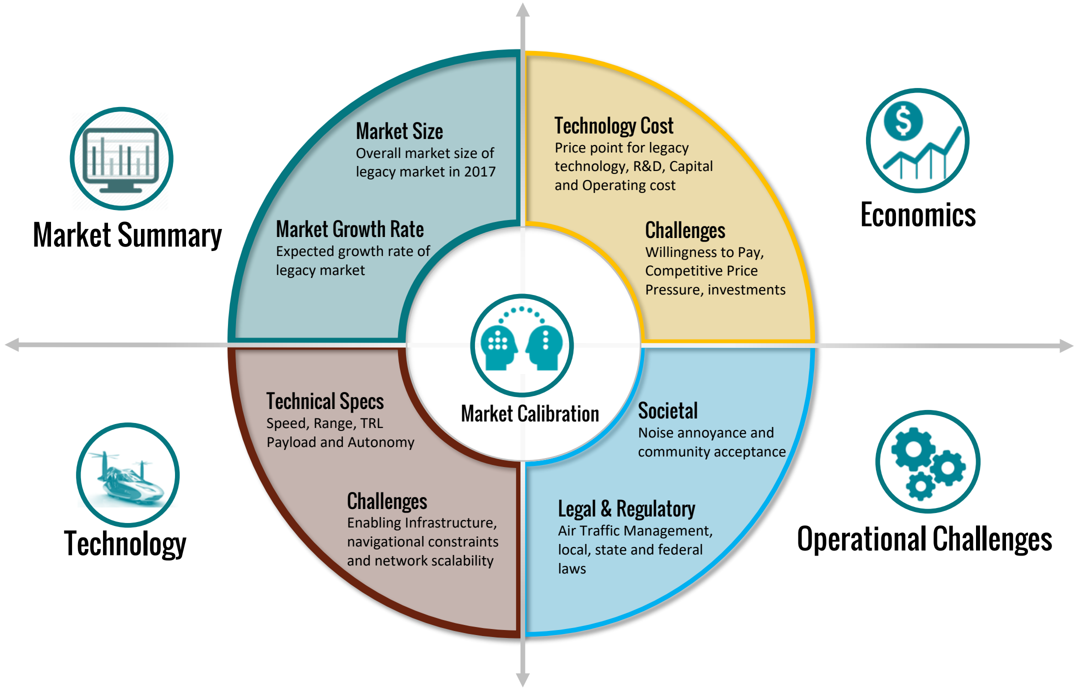
OUR METHODOLOGY CENTERS ON EVALUATING MARKETS WITH INTERESTING BARRIERS

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)

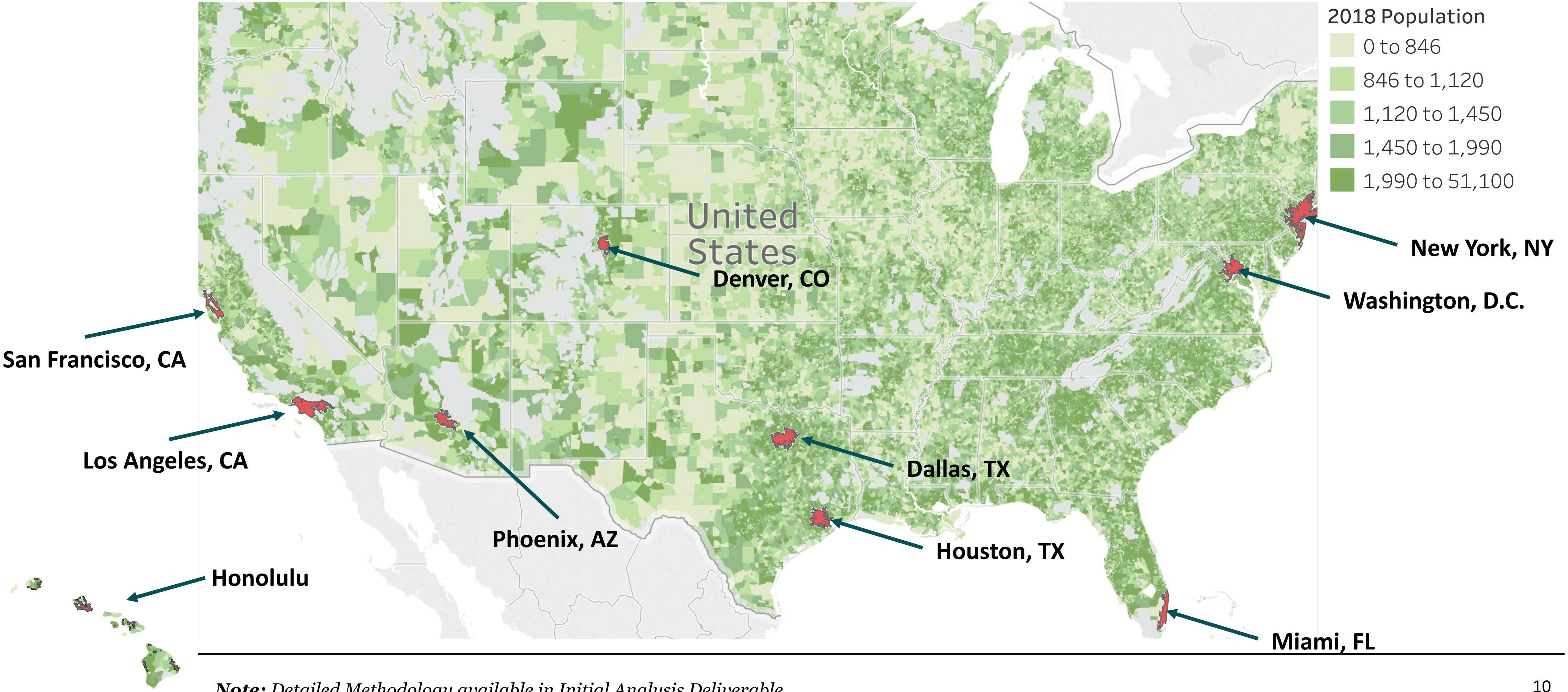
Air Taxi (Mass Market)

Air Ambulance (Complex Market)

Note: *Detailed Methodology available in Market Selection Deliverable*

FOCUSED TEN URBAN AREAS

All analysis is focused on the following ten urban areas from a shortlisted pool of 40 urban areas. These 10 urban areas that are representative of the US and will illuminate a wide set of barriers for UAM that could be operated with human pilots or autonomously.



Note: *Detailed Methodology available in Initial Analysis Deliverable*

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LEGAL AND REGULATORY BARRIERS - SUMMARY

- Surveyed and analyzed the Federal Acts, Federal regulations, State laws, and local ordinances 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**.
- 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**.

*Additional details on the legal and regulatory analysis can be found in the accompanying 'Legal/Regulatory – Interim Analysis' document.

LEGAL AND REGULATORY BARRIERS

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)****, as the current regulatory structure does not fully allow for these activities to be performed:*

- Regulations for **beyond visual line of sight** (currently only with lengthy waiver process)
- Regulations for **operations over people, streets, etc**. (currently only with lengthy waiver process)
- Regulations for when **air cargo** is being carried commercially and across state lines
- Regulations for when a **passenger or patient** is being transported in a UAM (remotely or autonomously piloted) either within visual line of sight or beyond
- Regulations for flight in **instrument conditions**
- Regulations for **airworthiness certific**ation of remotely piloted and autonomous aircraft
- **Training and knowledge** requirements for pilots and operators

A **legal framework for addressing privacy concerns** should be developed outside of the aviation regulatory framework.

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.

CERTIFICATION GAPS AND STRATEGIES

There are some gaps in the existing certification framework where UAM will experience challenges, particularly along system redundancy and failure management:

- The standards and methods required to meet **system redundancy and failure management** requirements for complex software could be onerous to meet (e.g., DO-178C testing requirements for the large number of states **automation software** can take)
- A **multi-copter will need a standard for how subsystems, such as distributed electric propulsion and energy storage, will address redundancy and failures** (e.g., helicopters may have redundant engines and can autorotate to handle certain failures)
- Determining the **standard for a failure scenario for an autonomous vehicle** (e.g., will a pilot or remote operator need to be available to take over, and what are the medical requirements for any "pilot/operator")
- Defining **how an autonomous vehicle makes judgements in a failure scenario**, based on the literal standard, such as when to "land immediately," vs. "when practical," vs. "closest available airport" in the context of the operating environment

Strategies to enable certifications by considering existing framework:

- We **reviewed domestic and international (e.g., EASA, NATO) airworthiness regulations** and supporting industry standards and identified potential strategies
- **Strategies depend on vehicle characteristics,** such as propulsion and aircraft design, and may leverage Part 21.17(b) to take portions of **Parts 23, 27, 33, and 35.** Platforms similar to ZeeAero may be closer to Part 23 than 27, while Volocopter-like designs may borrow more from Part 27.
- **Part 23 amendment 64** provides great flexibility for SDOs to develop new technology requirements to support certification. ASTM, SAE, RTCA are actively working on standards in many topics that will benefit UAM airworthiness.

Zee.Aero Z-P1

Volocopter

KEY FINDINGS

Enabling UAM highlights critical legal, regulatory, and certification challenges that must be addressed in order to bring urban air transportation to the market. This analysis draws comparison of legal and regulatory challenges for enabling UAM with Unmanned Aircraft Systems (UAS).

- **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 for Remotely Operated and Automated Piloting System:** Current legal framework does not address issues related to operations over people, beyond visual line of sight, commercial operations carrying cargo or people, and airworthiness certifications. 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., NATO, EASA)
  - 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

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SOCIETAL BARRIERS - KEY FINDINGS

Key Concerns:

- Safety
  - Unruly and/or violent passengers
  - "Lasing"
  - Aircraft sabotage (by passengers or people on the ground)
- Privacy and Noise
- Preference for piloted aircraft
- Presence of flight attendant did not impact willingness to fly for automated or remote piloted UAM aircraft
- A flight attendant did increase confidence in automated and remote piloted operations from the non-user perspective (someone on the ground)
- Preference for short inter-regional travel
  - DC to Baltimore; LA to San Diego
- Possible market for peer-to-peer (P2P) operations that could provide additional supply to scale a UAM market (similar to Lyft and Uber)

SOCIETAL BARRIERS - METHODOLOGY

- **Research Process**
  - Literature Review, Focus Groups, Survey
- **Why Do We Do Research on Societal Barriers?**
  - Understand potential viability of use cases, business model, partnership, and impacts
  - Identify problems to address, hypotheses, and/or key metrics
  - Predictive understanding of supply/demand patterns
  - Inform proactive policy development (maximize benefits and minimize adverse effects)
- **How Do We Conduct Research on Societal Barriers?**
  - Self-reported surveys can inform how public could respond to the advent of an innovative transportation technology, such as UAM

Societal Adoption Hypothesis
Based on a variety of factors (culture, trends, existing opportunities, challenges, etc.)

Survey Analysis & Evaluation
Quantitative & qualitative analysis methods

e.g., surveys, focus groups, and stakeholder interviews, etc.

Evaluation Hypothesis
Based on project specific goals/target impacts

Performance Metrics
Metrics established in line with project targets/ hypotheses

Data Sources
Based on performance metrics and data collection plan

Analysis & Evaluation
Quantitative & qualitative analysis methods

e.g., surveys, focus groups, stakeholder interviews, and statistical and data analysis, and GIS analysis

SOCIETAL BARRIERS ANALYSIS FRAMEWORK

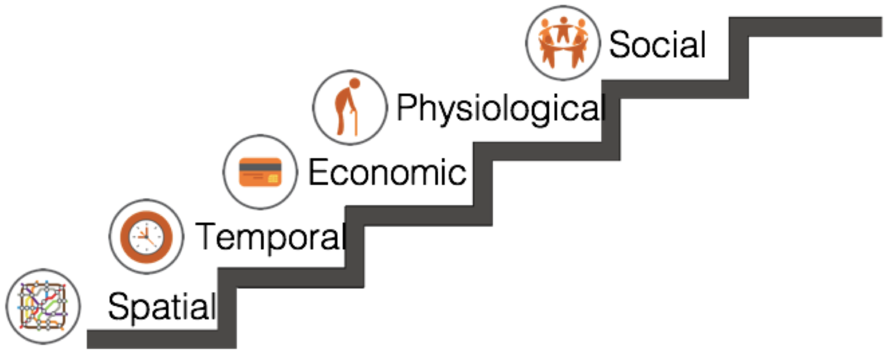
OVERVIEW OF THE STEPS FRAMEWORK

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

- **Spatial:** Factors that compromise daily travel needs (e.g., excessively long distances between destinations, lack of public transit within walking distance)
- **Temporal:** Travel time barriers that inhibit a user from completing time-sensitive trips, such as arriving to work (e.g. public transit reliability issues, limited operating hours, traffic congestion)
- **Economic:** Direct costs (e.g., ownership, operational, and indirect costs) and indirect costs that create economic hardship or preclude users from completing basic travel

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

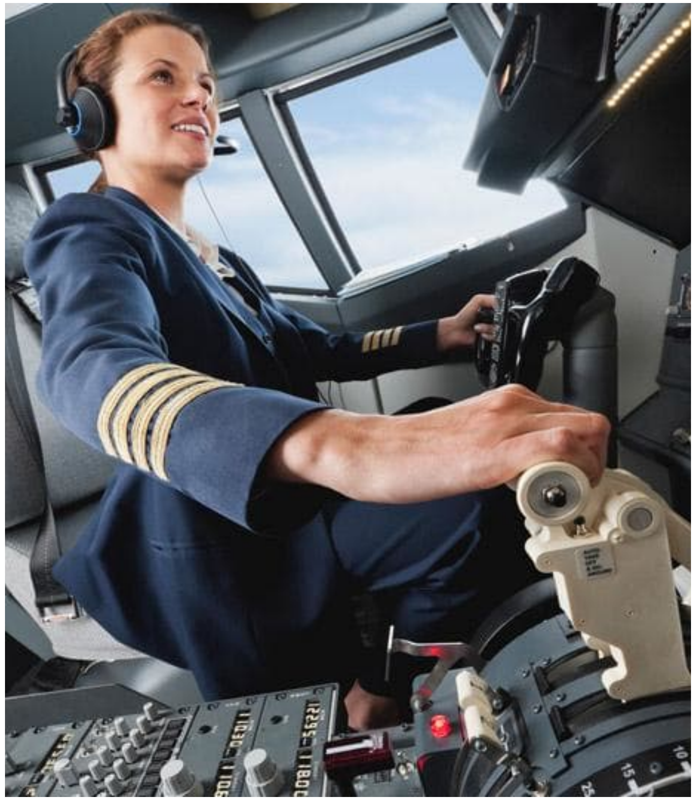
- **Physiological:** Physical and cognitive limitations that make using standard transportation modes difficult or impossible (e.g., infants, older adults, and disabled)
- **Social:** Cultural, perceptions, safety, security, and language barriers that inhibit a user's comfort with using transportation (e.g. Am I safe sharing this mode with other passengers that I don't know?)



SOCIETAL BARRIERS - KEY FINDINGS FROM LITERATURE

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:** 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 ranging from –2 (strongly disagree) to +2 (strongly agree) with a neutral option (0)



SOCIETAL BARRIERS - FOCUS GROUPS

Focus Group Key Findings

- ***Public perception of fully automated aircraft is one of the largest barriers.***
  - Lack of willingness to fly on fully automated aircraft OR aircraft designed by small companies lacking brand recognition
  - Influence of factors, such as pilot and crew age / perceived experience
- ***Cost is a primary consideration for public users when choosing a transportation mode.***
- ***Personal security*** was an important factor. Personal security includes confidence in aircraft, as well as feeling of security / safety from flying with potentially dangerous or unruly passengers.
- Some participants expressed ***privacy concerns*** (people flying overhead, sight lines into homes/yards) and increased noise levels as detractors.
- ***Most would use UAM for short inter-regional trips*** (DC to Baltimore, LA to OC) rather than inter-city.

See Appendix 3 for more details on focus group methodology and demographics

SOCIETAL BARRIERS - SURVEY METHODOLOGY

Status Update

- Research team obtained CPHS/IRB approval in Spring 2018
- Exploratory survey target approximately 1,700 respondents in five U.S. cities (~350 respondents per city)
- Cities selected based on a variety of demography, geography, weather, availability of past or present air taxi services, built environments/densities, traffic, etc.

Survey Structure

- Respondent Demographics
- Recent Travel Behavior
- Typical Commute Behavior
- Familiarity with Aviation
- Existing Aviation Experience & Preferences
- Familiarity with UAM
- Perceptions about UAM
- Perceptions toward Technology and UAM
- Weather
- Market Preferences
- Perceptions from Non-User Perspective

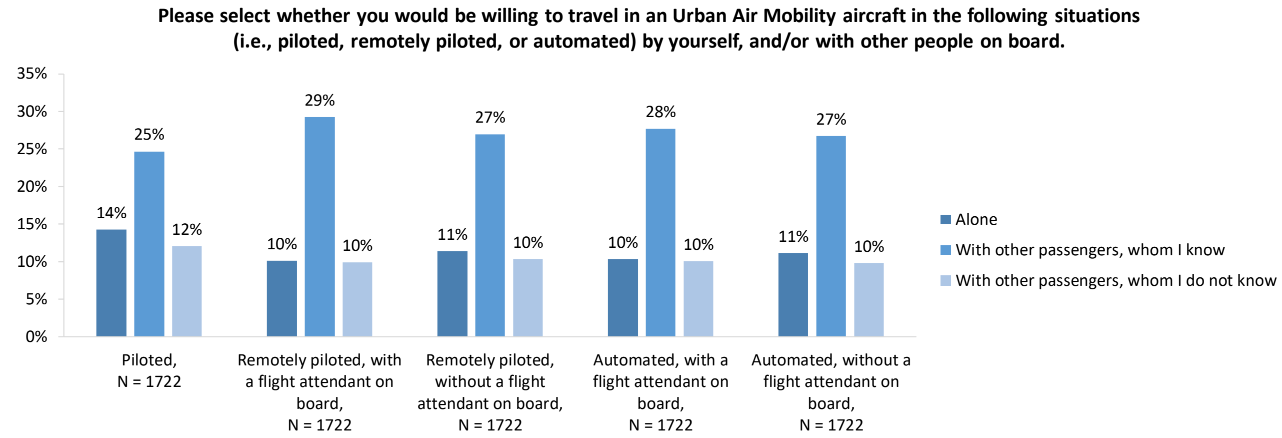
See Appendix 3 for more details on respondents demographics

SOCIETAL BARRIERS - SURVEY KEY FINDINGS

Survey Key Findings

- Generally, ***neutral to positive reactions*** to the UAM concept
- Respondents ***most comfortable flying with passengers they know***; least comfortable flying with passengers they do not 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
- Presence of ***a flight attendant did not impact willingness to fly*** on ***an automated or remote piloted*** UAM ***aircraft***.
- However, presence of ***a flight attendant did increase confidence in automated and remote piloted operations from the non-user perspective***

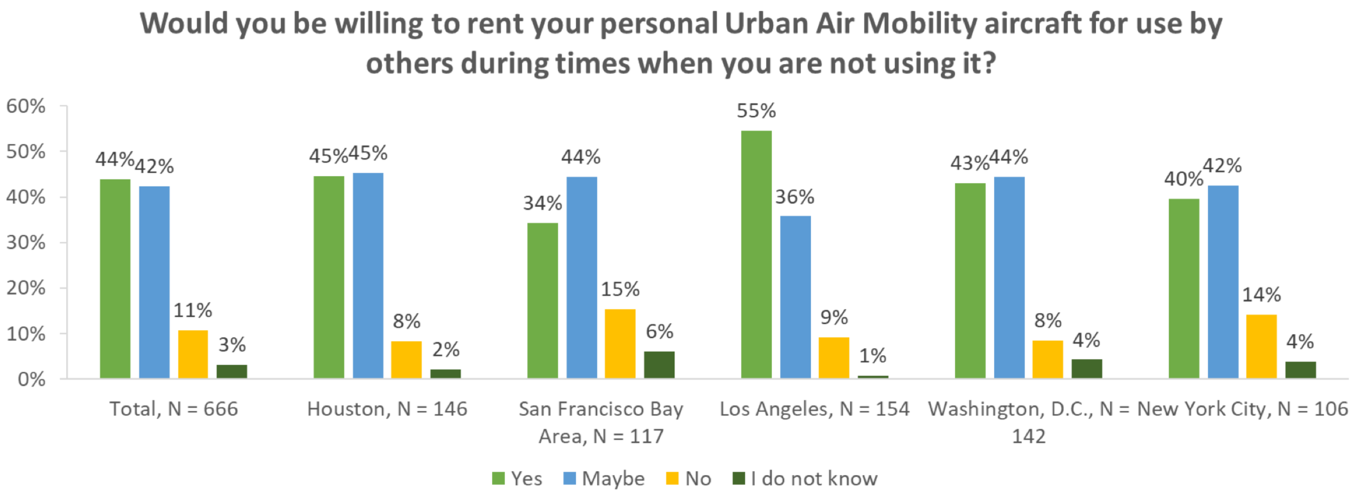
	Excited	Happy	Neutral	Confused	Concerned	Surprised	Skeptical	Amused
GEOGRAPHIC LOCATION	Survey Results							
Houston, N = 344	32%	24%	27%	8%	9%	11%	19%	3%
San Francisco Bay Area, N = 337	33%	25%	27%	8%	9%	11%	20%	3%
Los Angeles, N = 345	32%	24%	27%	8%	9%	11%	19%	3%
Washington, D.C., N = 341	32%	24%	27%	8%	9%	11%	20%	3%
New York City, N = 344	32%	24%	27%	8%	9%	11%	19%	3%

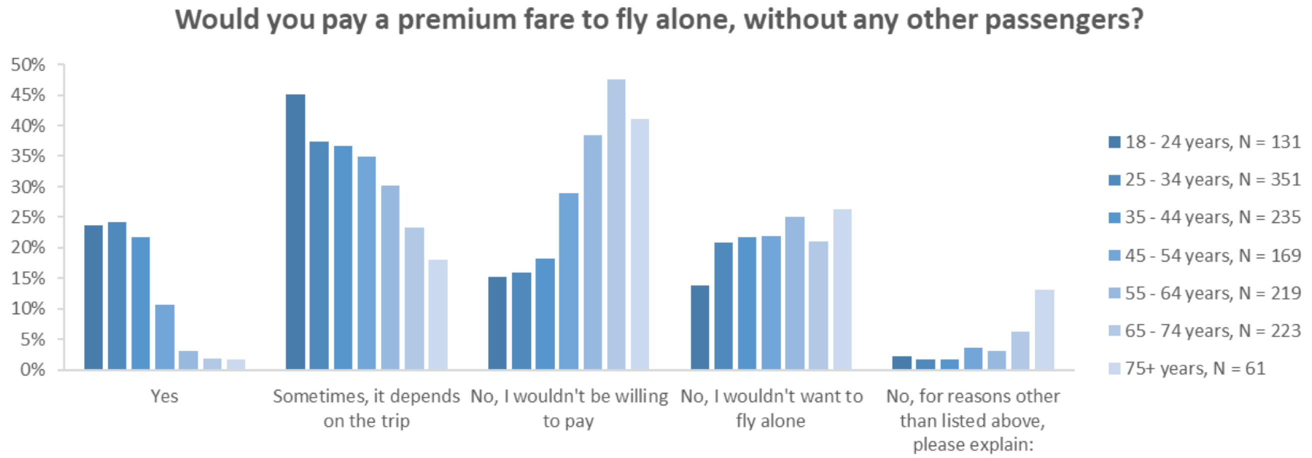


SOCIETAL BARRIERS - SURVEY KEY FINDINGS (CONT'D)

Survey Key Findings

- ***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 and potential inconvenience*** *(e.g., modal transfers, competitive travel times and price of other modes)*
- Some desire among younger and male respondents to pay a premium to fly alone
- 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 barrier in future as electric vehicles become more mainstream (potentially causing a reduction in overall ambient noise, making UAM more noticeable)





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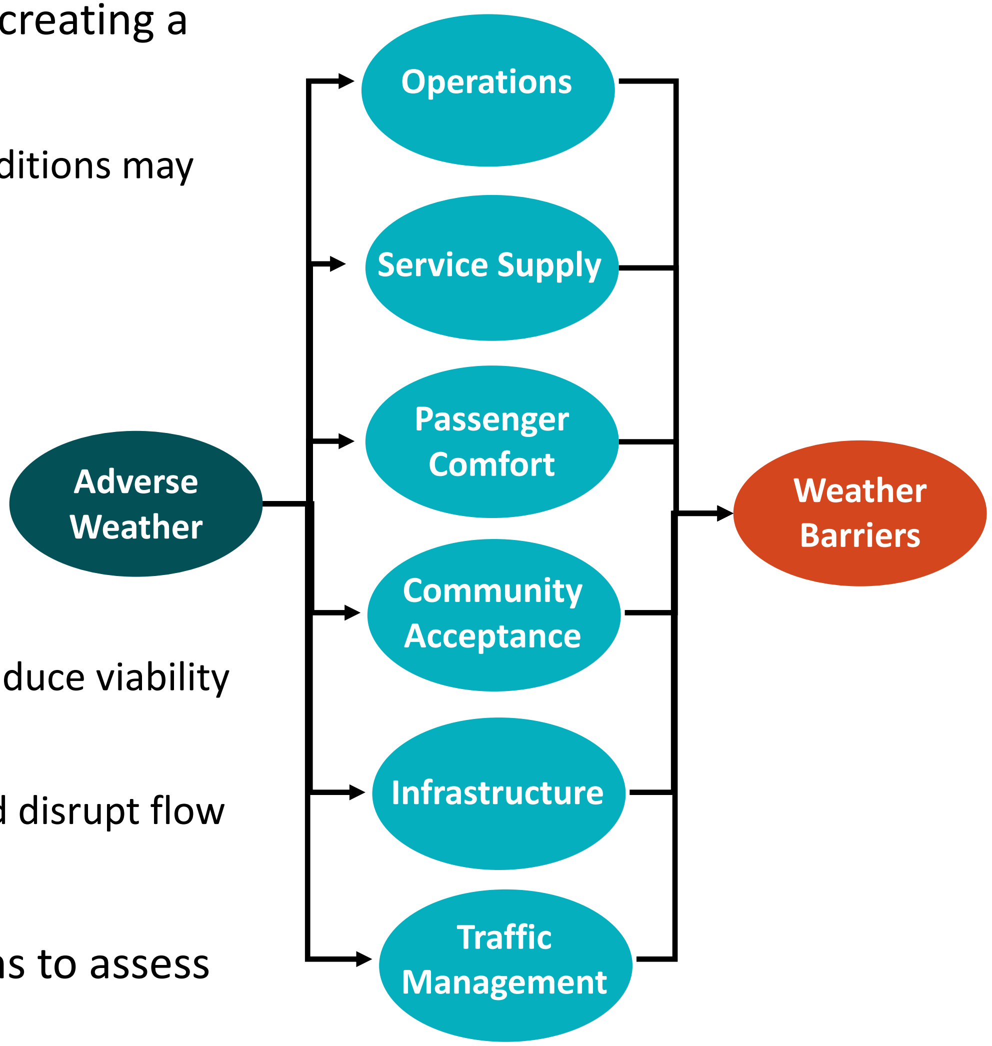
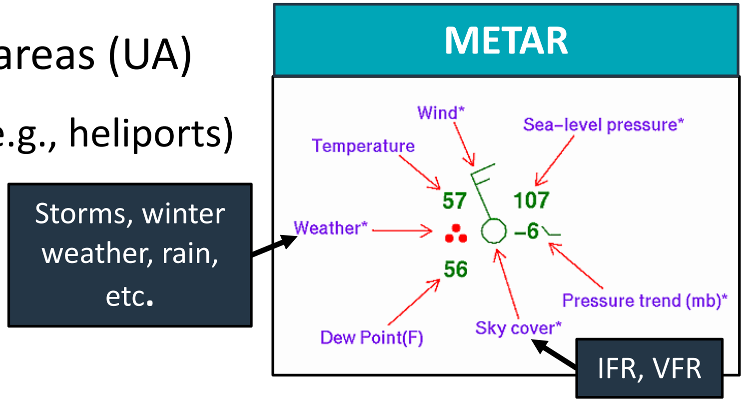
WEATHER ANALYSIS - MOTIVATION

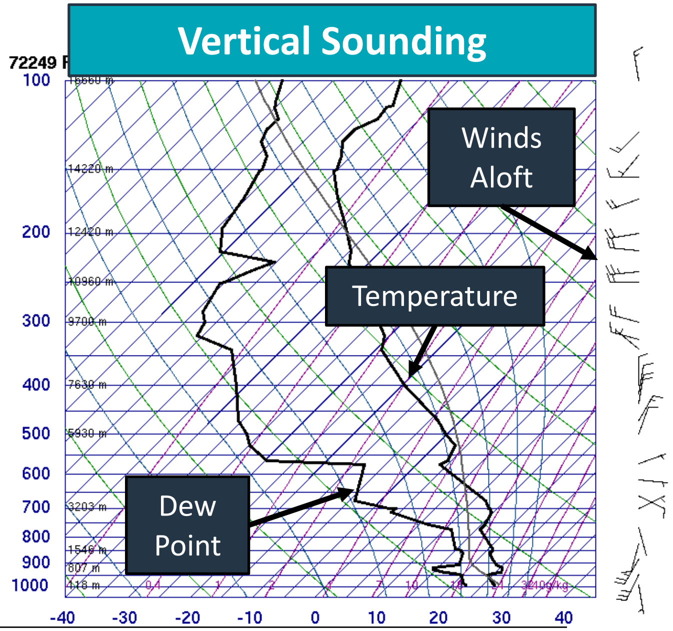
- Weather can influence many components of Urban Air Mobility, creating a variety of potential barriers
  - **Operations**: Reduction or cessation of operations during adverse conditions may occur due to safety concerns
  - **Service Supply**: Conditions may extend trip distance or reduce battery life
  - **Passenger Comfort**: May be impacted due to conditions such as extreme temperatures and winds
  - **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 storms could disrupt flow patterns and structure
- Need to evaluate underlying frequent adverse weather conditions to assess range of potential barriers



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)
- Computed seasonal average conditions from historical archives of 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 00Z and 12Z 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 ad hoc information on weather deemed impactful by pilots





PIREP Output

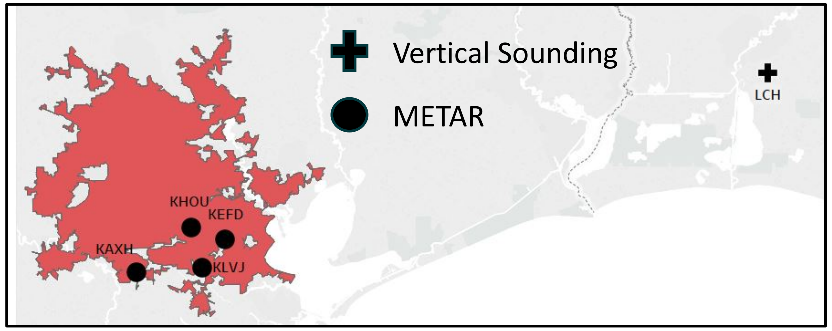
TEB UA /OV TEB010003/TM 1931/FLDURD/TP E35L/RM LLWS +/-10KT

Airport | Location | Time | Flight Level | Aircraft Type | Remark

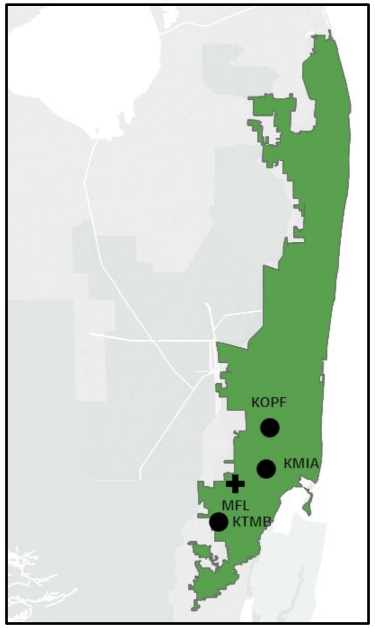
DATA SPATIAL COVERAGE - EASTERN AND CENTRAL UA

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

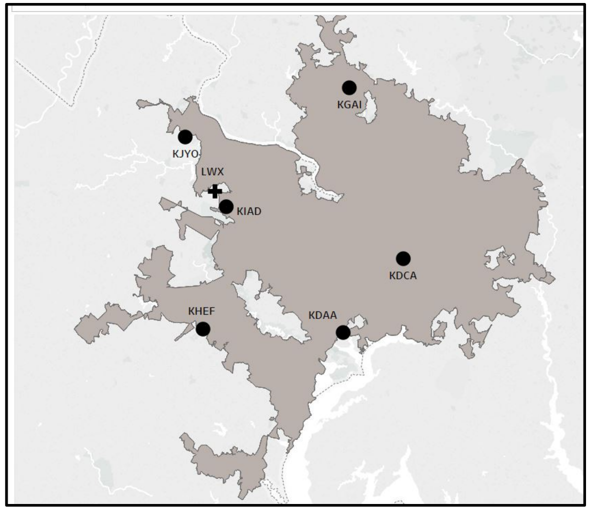
Houston



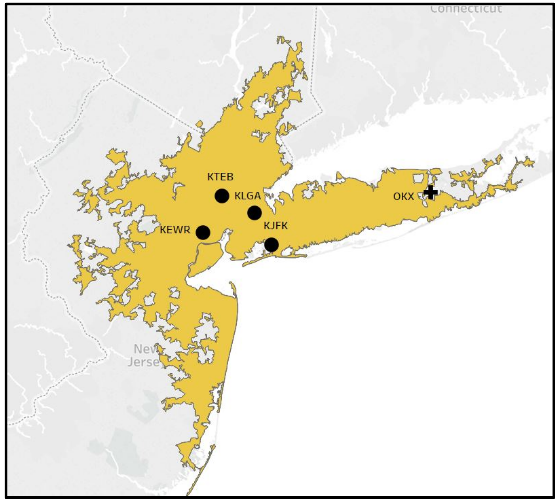
Miami



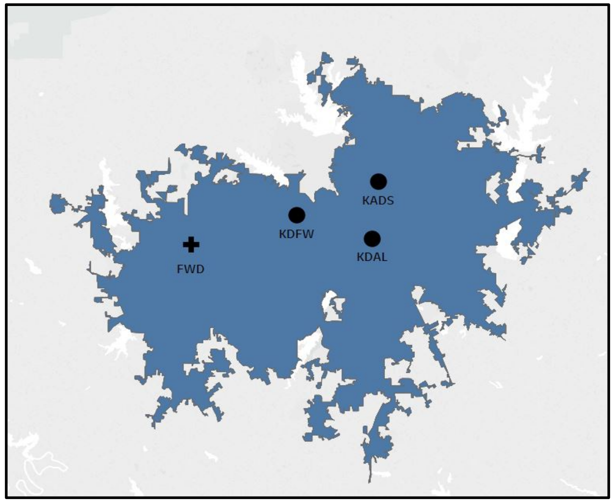
Washington DC



New York



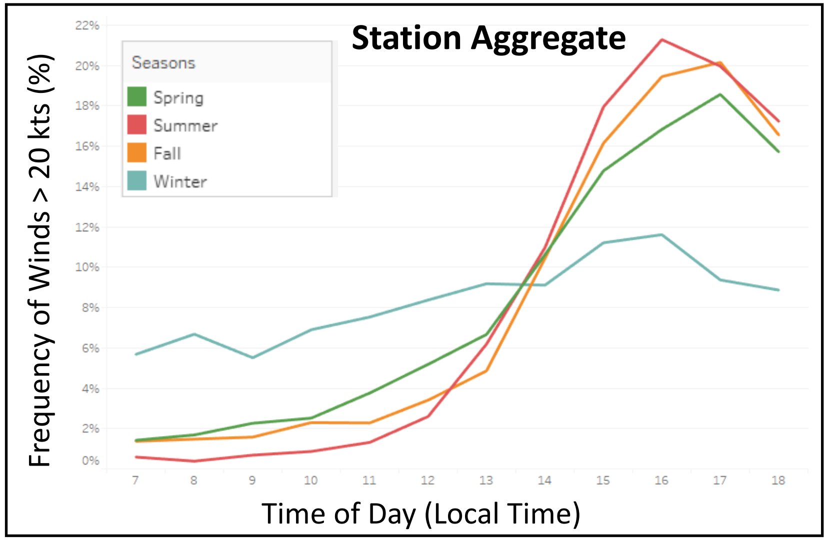
Dallas

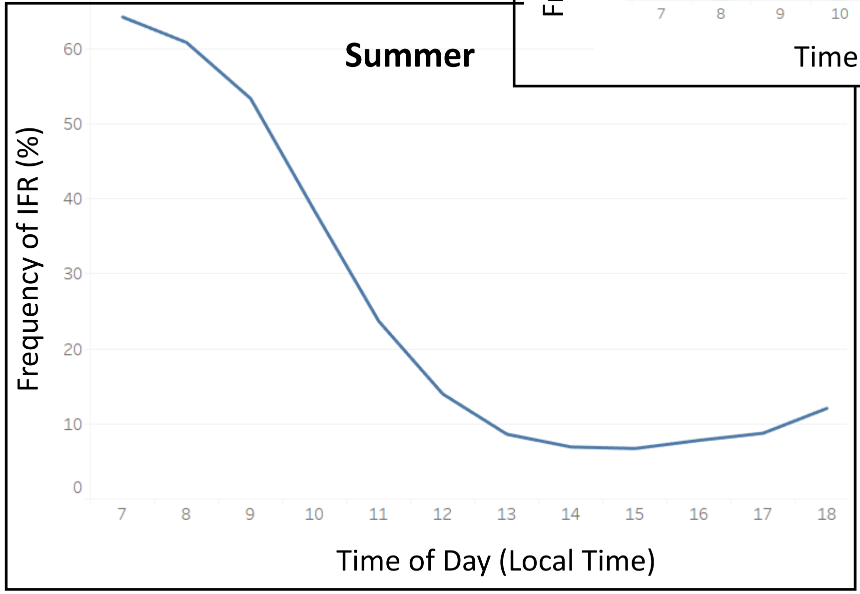


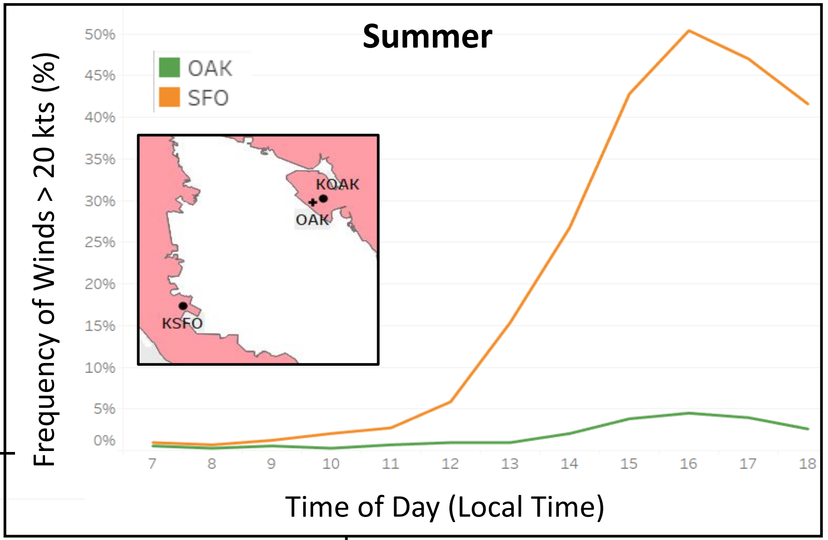
**Urban area maps based on U.S. Census definition*

RESULTS - SAN FRANCISCO UA

- Instrument Flying Rules (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

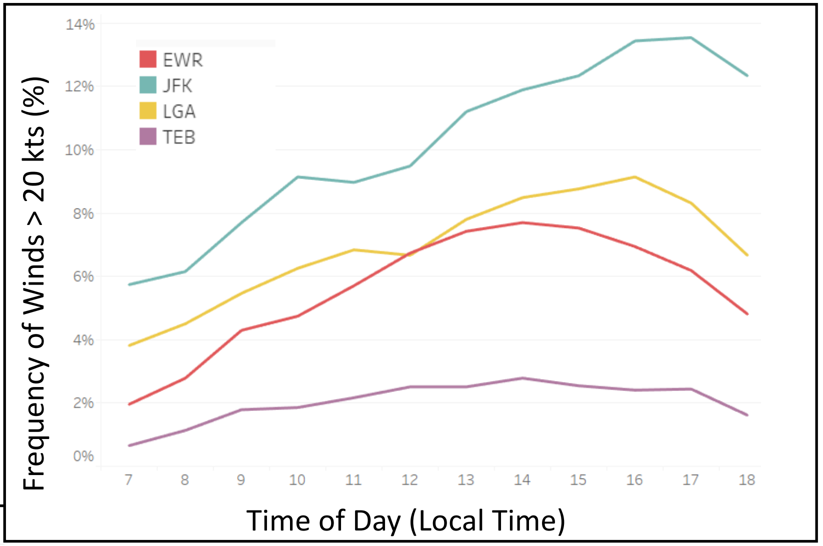


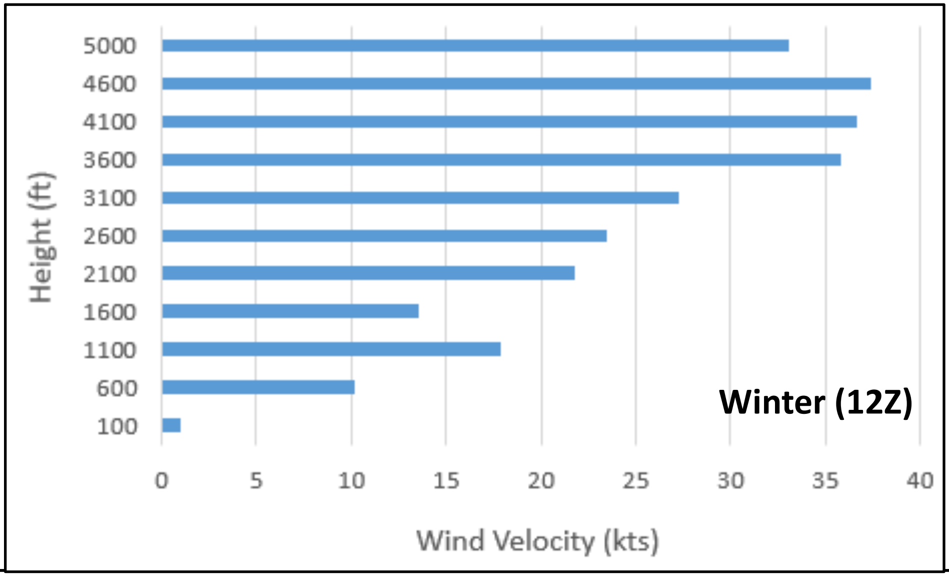


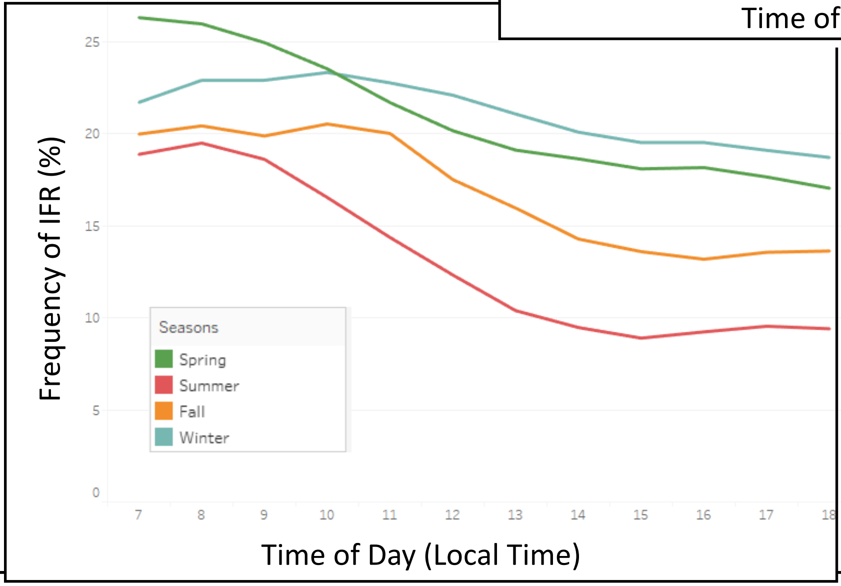


RESULTS - NEW YORK UA

- 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 in all seasons
  - Strong winds and shear (change in winds with height) aloft observed above 500 ft during morning in winter

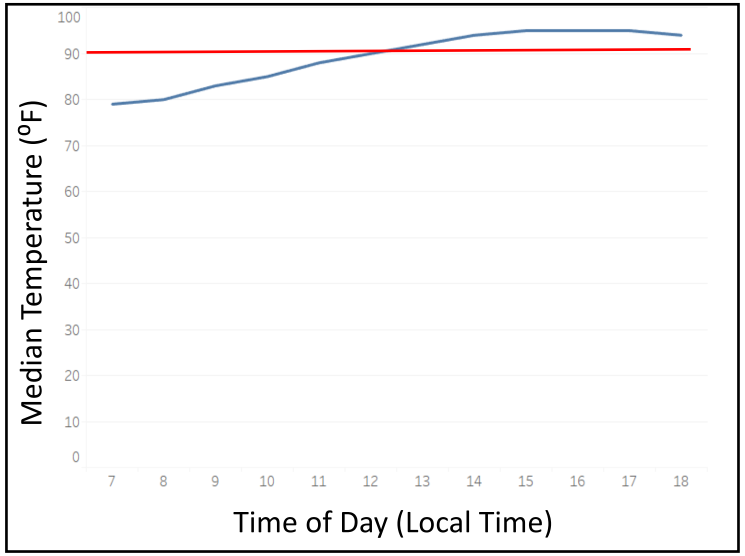


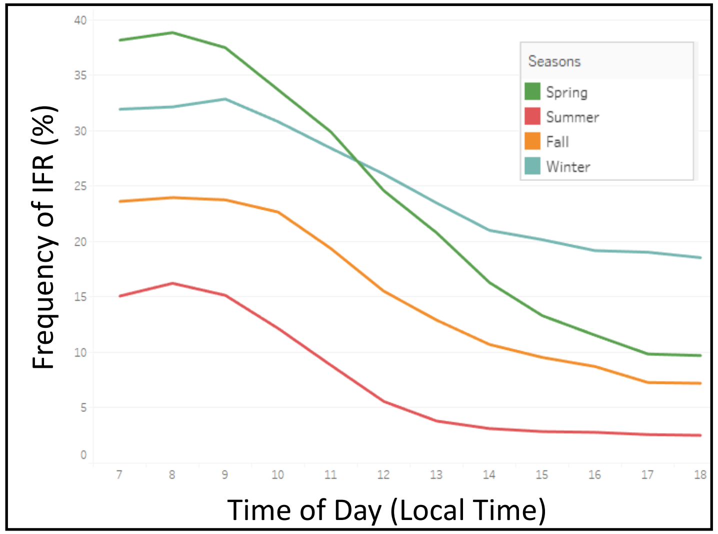


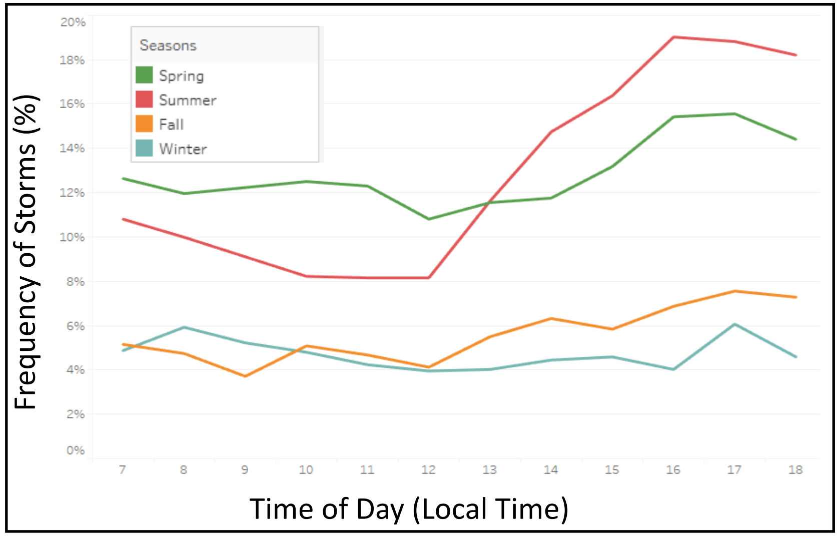


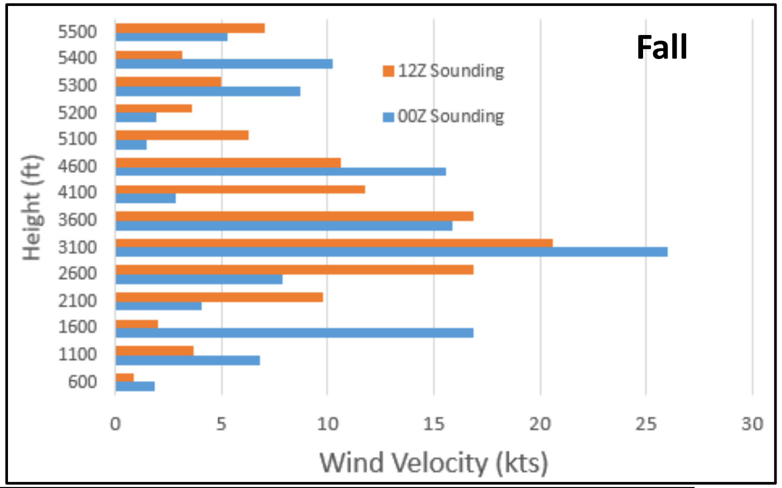
RESULTS - DALLAS UA

- Several adverse conditions possible in all seasons
  - Median temperature exceeds 90^{o} F for all hours after 12PM in summer
  - Storms frequent during afternoon of spring and summer
  - IFR conditions frequent during morning of all seasons, most common in winter and spring
  - Changes in wind speed with height during fall may impact UAM during takeoff and landing









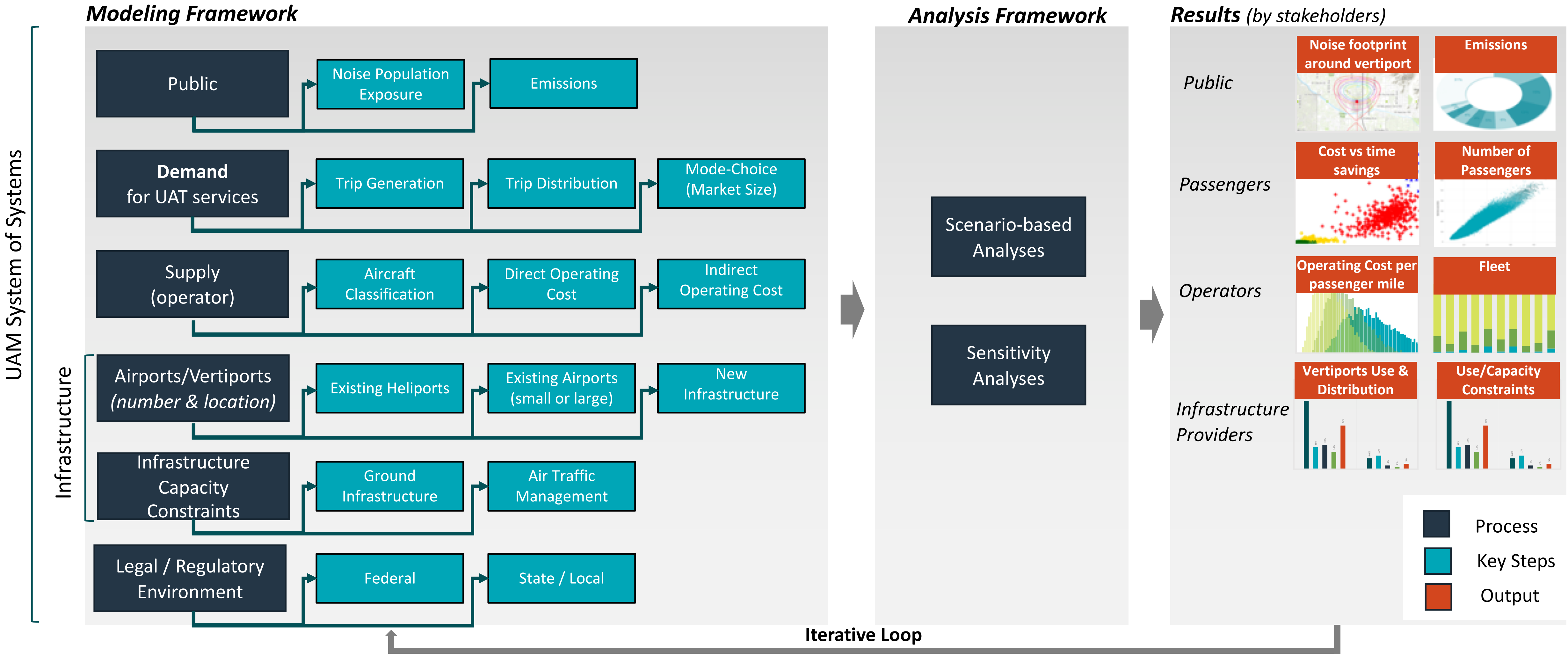
KEY RESULTS

- Weather mostly favorable for UAM operations in Western urban areas with potential for impacts due to low visibility, high temperatures, and strong surface winds
  - Strong surface winds may disrupt takeoff/landing during afternoon in Honolulu, San Francisco, and Phoenix UA's
  - Median temperature exceeds 90⁰ F across most of the day in Phoenix during summer which could contribute to reduced battery life and creates need to cool vehicle for passenger comfort
  - Frequent low visibility conditions during morning hours in summer may reduce visual operations or warrant instrumentation equipage
  - Conditions highly unfavorable for UAM operations in Denver due to frequent adverse weather across all phenomena
- Storms and low visibility conditions are primary adverse weather impacting Eastern urban areas
  - Storms are frequent during summer afternoons in Washington, DC and Miami which may disrupt UAM operations
  - Low visibility conditions are most common during morning hours
  - Strong winds at the surface and aloft likely disrupt UAM operations in New York during winter and spring
- High temperatures, storms, low visibility, and wind shear (low level jet) may impact UAM operations in Texas urban areas
  - Temperatures and storms primary impact during afternoon in summer
  - Low visibility conditions occur most frequently during morning of winter and spring
- Majority of Pilot Reports in most urban areas due to low ceilings/visibility or turbulence conditions

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.



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]

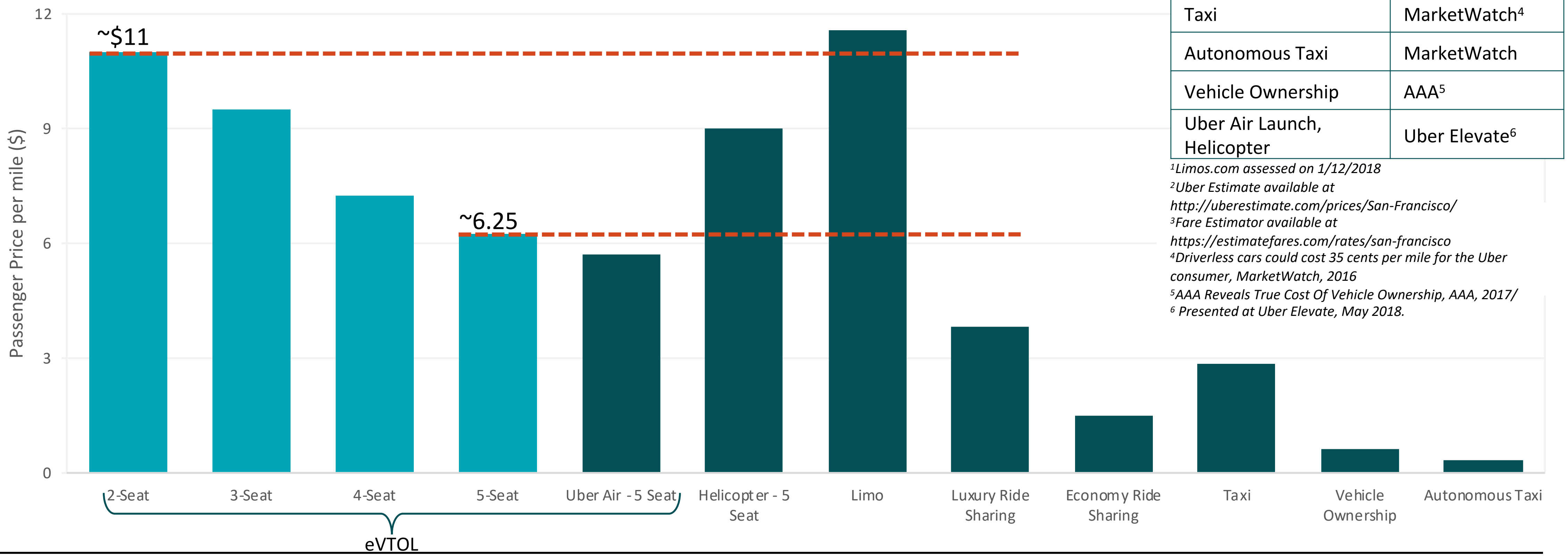
[1]BAH conducted interviews with SAG members in February/April 2018. Their feedback is documented in deliverable 'SAG Interview and Workshop summary'
[2]BAH assumption based on the literature review. See Air Taxi Deliverable for detailed reasoning
[3]FAA. Details available at https://www.law.cornell.edu/cfr/text/14/91.167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

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.

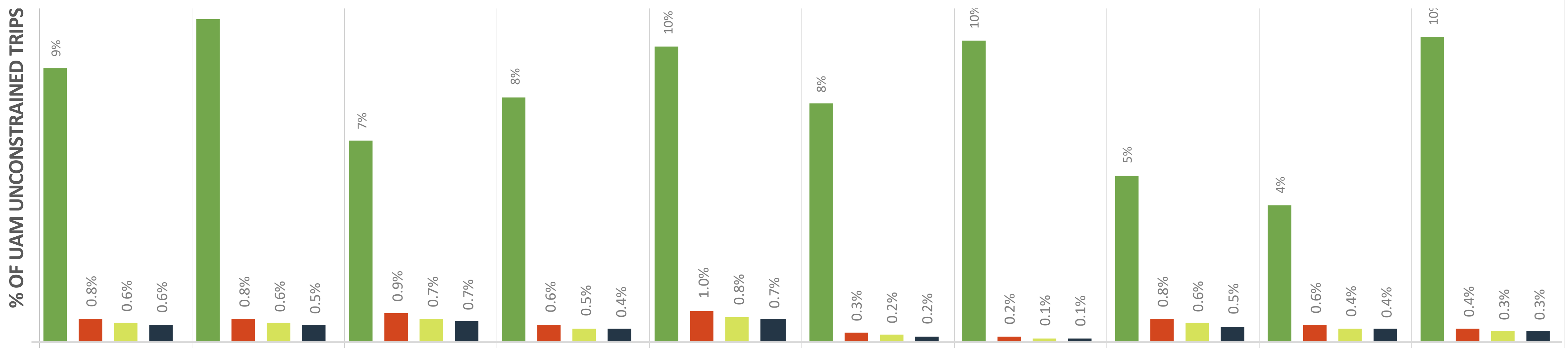


DEMAND SCENARIO DEFINITIONS

- **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

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