Baseline Assumptions and Future Research Areas for Urban Air Mobility Vehicles

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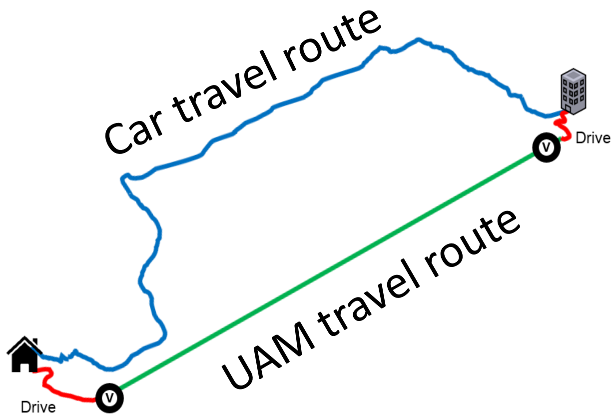
What is Urban Air Mobility (UAM)?

- A safe, efficient, accessible air transportation system for passengers and cargo within urban areas
- Enabled by convergence of electric propulsion and autonomous technologies in aviation
- Concept of Operations:
    - 10-100 mile trips (2-3x faster than cars[1])
    - Operate from new 'vertiport' infrastructure and/or existing heliports as a part of multi-modal transportation
    - 1-9 passengers (up to ~2000 lb payload)
    - Single pilot, remote operator, or 'autonomous'



[1] AIAA 2016-3466

Key Feasibility Barriers to UAM

Ease of certification	Average trip delay
Affordability	Community noise
Safety	Ride quality
Ease of use	Efficiency
Door-to-door trip speed	Lifecycle emissions

NASA On-Demand Mobility Roadmapping Workshops, 2015-16
http://www.nianet.org/ODM/roadmap.htm

NASA UAM Reference Vehicles

- Consistent, known assumptions
- Fully documented & publicly available

Objectives

- Common reference models for researchers across UAM community
- Investigate vehicle technologies & identify enabling technologies
- Expose design trades and constraints
- Allow simulation of vehicle operations
- Develop tools & methods

NASA's Role in UAM Vehicle Concepts

N

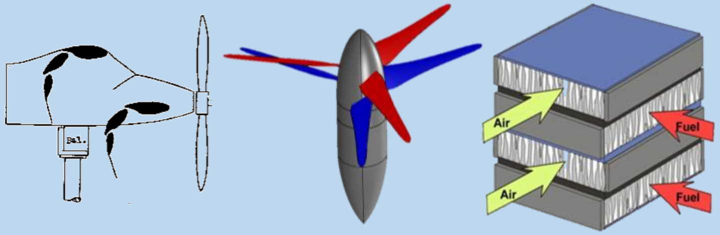
Current helicopter operations

N+1 ***2023-25***

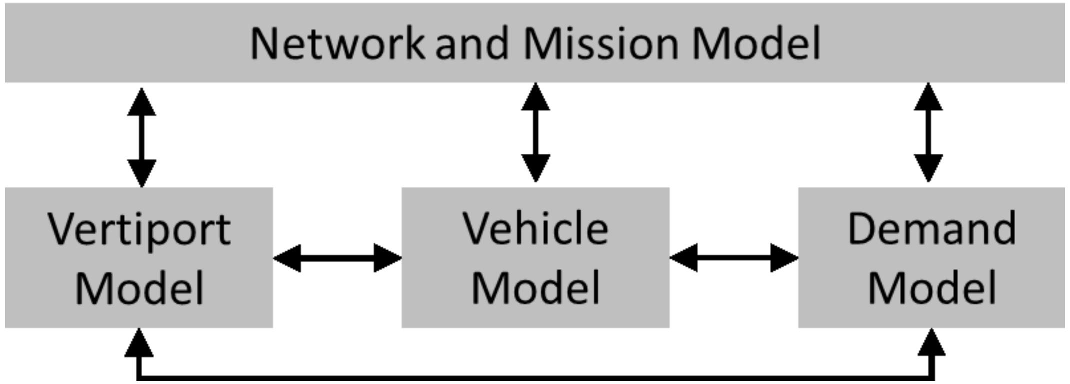
First operational UAM vehicles

N+2 ***2030-35***

Next generation UAM vehicles

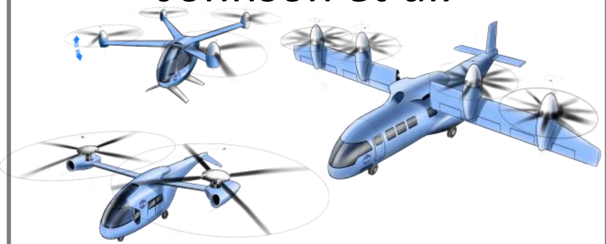


1. Develop N+1 Reference Vehicles → *Use for technology, system, and market studies*
2. Explore N+2 UAM vehicles & technologies → *Determine high-payoff technologies and research areas*
3. UAM network modeling → *Analyze the impact of a vehicle-level technology at the network-system level*



Background

Initial Reference Vehicles
Johnson et al.

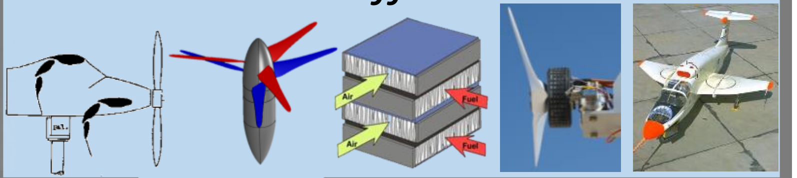


AHS SM_AEROMECH_2018_05

Updated Reference Vehicles: Sized to UAM Mission
Silva et al.

AIAA 2018-3847

Vehicle Technologies: N+1 Assumptions; N+2 Research Areas
Antcliff et al.



AIAA 2019-0528

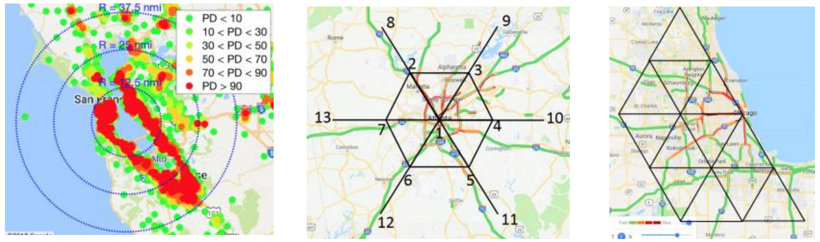
N+1 Reference Vehicles – add:
- Tiltwing
- Tiltduct
- Quiet Single Main Rotor

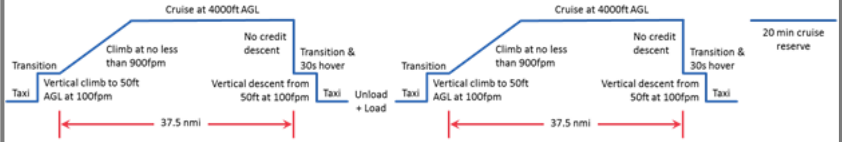
Jan 2018 — May 2018 — Jun 2018 — Jan 2019 — Feb 2019 — 2020 — 2020+

AIAA 2018-3677
NASA TM-2019-220072

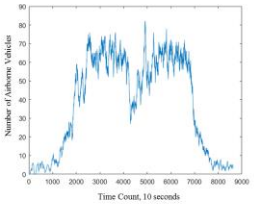
AHS 74-2018-0185

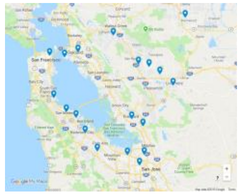
UAM Mission Requirements
Patterson et al.





UAM Network Modeling
Kohlman et al.





Network and Mission Model

Vertiport Model ↔ Vehicle Model ↔ Demand Model

Further vehicle research:
- UAM vehicle workshops
- Technology development
- Tool development
- Design trades
- Network modeling

Approach

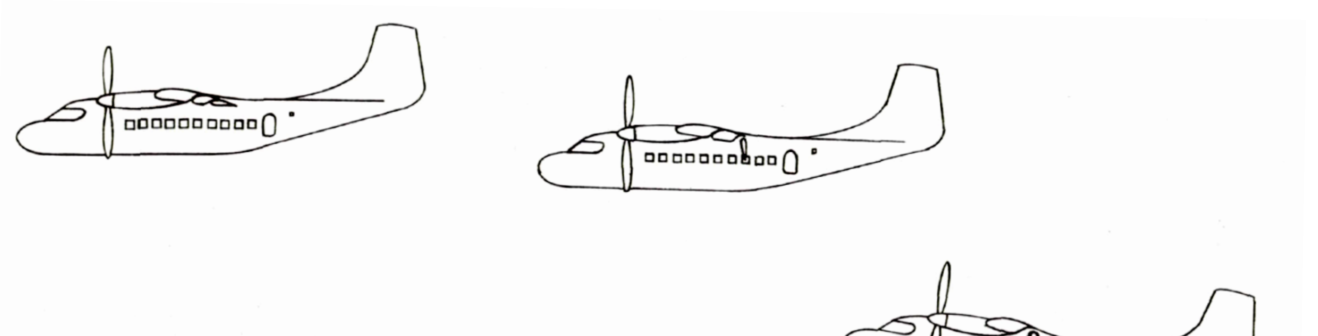
- Document assumptions for N+1 reference vehicles
- Explore potential additional research areas for N+2 vehicles

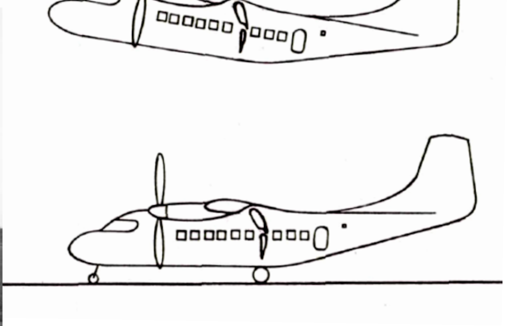
- Five major systems:
  1. Wing
  2. Rotor
  3. Propeller/fan installation
  4. Energy (Fuel) system
  5. Engine system

1. Wing

N+1 Assumptions

- Carbon composite construction:
  - Intermediate-modulus carbon composites
  - Parametric wing weight, with technology factors
- NASA general aviation airfoils:
  - Partial laminar flow
  - Benign stall characteristics
  - Benign performance degradation with contaminants





Fairchild VZ-5

N+2 Research Area

Deflected Slipstream

- Benefits: ‘rigid’ aircraft; efficient cruise flight; improved transition characteristics; optional short takeoff and landing (STOL) capability
- Tested in 1950s/1960s: Ryan VZ-3; Fairchild VZ-5; Robertson VTOL
- Enabling technologies: distributed electric propulsion; improved control systems; improved construction materials; active flow control

Ryan VZ-3

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2. Rotor

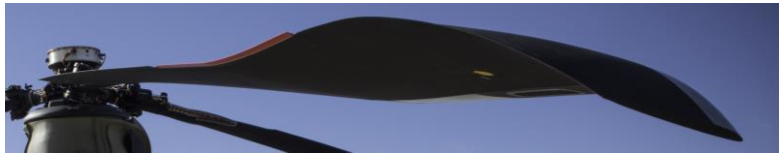
N+1 Assumptions:

- Carbon composite construction, with lightweight cores
- Leading edge erosion strips; anti-icing treatments
- Airfoil: Boeing VR-12 (working section); SSC-A09 (tip)

N+2 Research Area

Low-Noise Edgewise-Flight Rotors

- Recent improvements in single main rotor helicopters: potential total noise reduction ≥ 6dB
    - Variable rotor speed operation
    - Higher harmonic control (HHC); individual blade control (IBC)
    - Blade shaping (airfoil, planform, tip)
    - NOTAR (no tail rotor)-type solution
    - Trim state modification by X-force
    - Operational adjustments

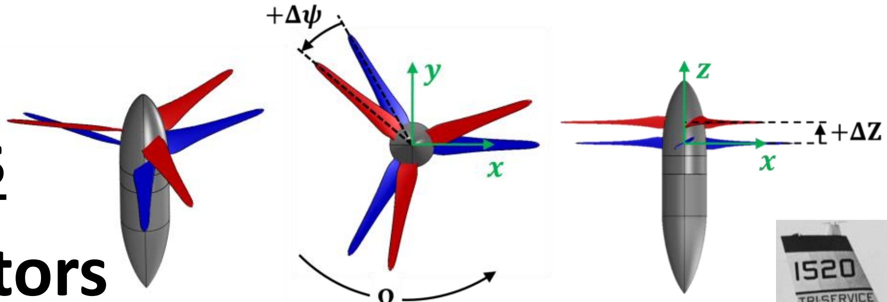


- Multi-rotor UAM: potential for greater noise reduction

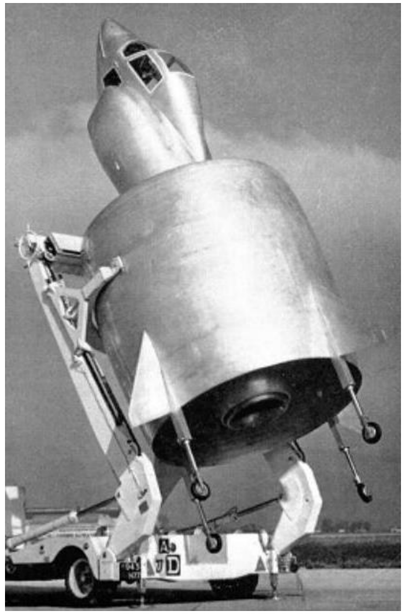
3. Propeller/Fan Installation

N+1 Assumptions

- Composite construction, fixed/variable pitch
- Tip shape (performance); low tip speed (noise)



Ryan XV-5B



SNECMA C450 Coléoptère

N+2 Research Areas

Stacked Propellers/Rotors

- Co-rotating, coaxially spaced propellers/rotors
- Low complexity, applicable to all vehicle sizes
- Benefits: performance and/or acoustics

Bell X-22

Ducted Propellers/Fans

- Benefits: improved thrust/efficiency, reduced noise, terminal safety, passenger acceptability
- Tilting duct, coleopter, and lift fan have shown promise
- Electric propulsion reduces integration challenges

4. Energy (Fuel) System

N+1 Assumptions

- Conventional fuels
- Battery specific energy 400 Wh/kg (pack):
  - 650 Wh/kg (cell-level), 30% packing weight
  - Charge to 95% capacity, discharge to 15% capacity
- Maximum C-rate: 2-3C

NASA X-57 Li-ion Battery

- **Cell: 220Wh/kg**
- **Pack: 120Wh/kg**
- **4.5C**

N+2 Research Areas

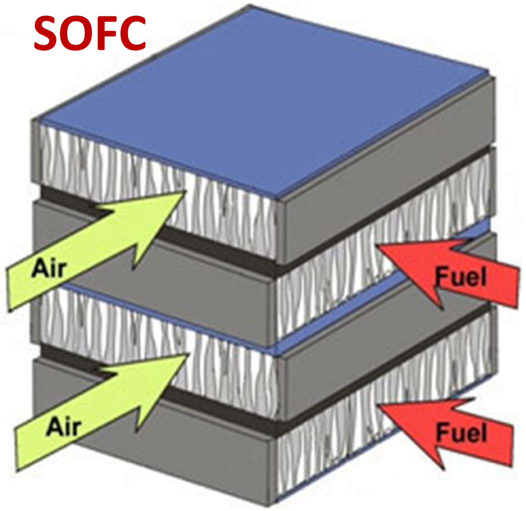
Battery installation infrastructure

- Battery management systems; packing techniques

Solid Oxide Fuel Cell (SOFC) with Liquefied Natural Gas (LNG)

- Compared to 300 Wh/kg battery packs, SOFC with LNG may provide:
  - Increased range
  - Reduced carbon dioxide emissions
  - Faster turn-around times
  - Reduced operating costs & infrastructure costs

SOFC

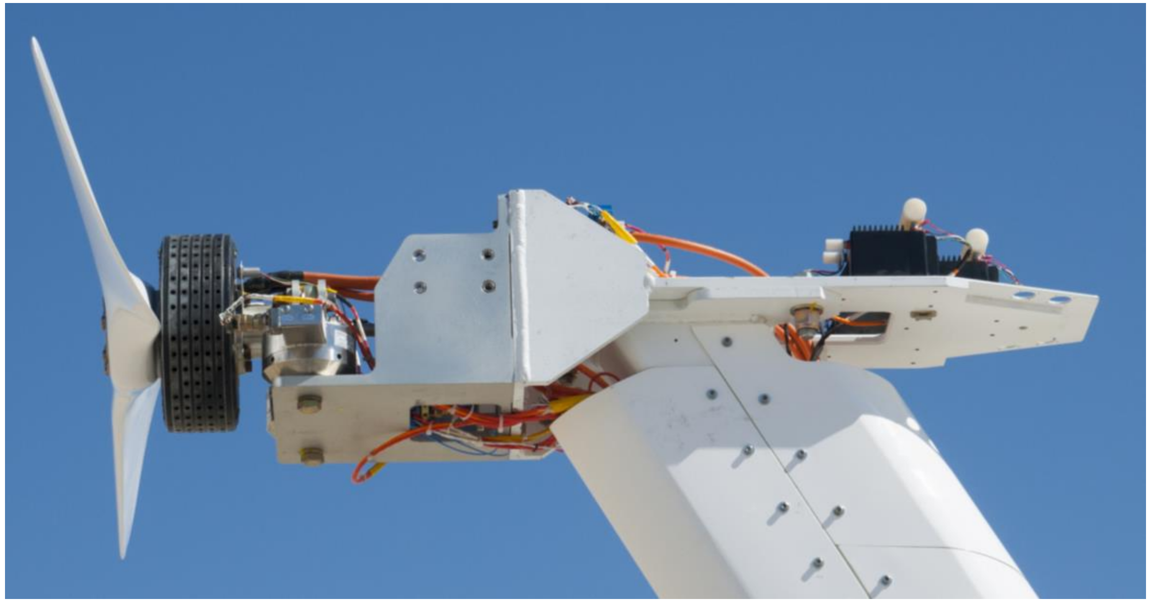


Other alternative energy systems E.g. fuel cells, flow batteries, other battery chemistries

5. Engine System

N+1 Assumptions

- Existing turboshaft engines
- Existing aviation diesel engines (reciprocating internal combustion engines)
- Existing aviation & automotive electric motors
- Various hybrids



X-57 motor test stand

N+2 Research Area

Improved Small Engine Weight Efficiencies (100-1000 shp)

- Small turboshafts: targeted research to improve power-to-weight and specific fuel consumption
  - Metal 3D-printing may enable low-cost manufacturing of recuperation options
- Small aviation diesels: advanced materials and improved design layouts to improve power-to-weight ratio; maintain good specific fuel consumption (SFC)
- Electric motors: improve power-to-weight; lesser vehicle-level payoff relative to improvements in electric energy storage methods or small engine weights

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Summary: N+2 Vehicle Technology Research Areas

1. Wing
    - Deflected slipstream
2. Rotor
    - Low-noise edgewise rotors
3. Propeller/fan Installation
    - Stacked propellers/rotors
    - Ducted propellers
4. Energy (Fuel) System
    - Battery installation infrastructure
    - SOFC with LNG
    - Other alternative fuel systems
5. Engine System
    - Small engine weight efficiencies

Discussion Questions:

1. Do you agree?
2. What are we missing?

Backup

Paper References

Johnson, W., Silva, C., and Solis, E., "**Concept Vehicles for VTOL Air Taxi Operations**," *AHS Technical Conference on Aeromechanics Design for Transformative Vertical Flight*, AHS International, 2018. [AHS SM_AEROMECH_2018_05]

Patterson, M. D., Antcliff, K. R., and Kohlman, L. W., "**A Proposed Approach to Studying Urban Air Mobility Missions Including an Initial Exploration of Mission Requirements**," *AHS International 74th Annual Forum*, AHS International, 2018. [AHS 74-2018-0185]

Silva, C., Johnson, W. R., Solis, E., Patterson, M. D., and Antcliff, K. R., "**VTOL Urban Air Mobility Concept Vehicles for Technology Development**," *2018 Aviation Technology, Integration, and Operations Conference*, American Institute of Aeronautics and Astronautics, 2018. [AIAA 2018-3847]

Kohlman, L. W., and Patterson, M. D., "**System-Level Urban Air Mobility Transportation Modeling and Determination of Energy-Related Constraints**," *2018 Aviation Technology, Integration, and Operations Conference*, American Institute of Aeronautics and Astronautics, 2018. [AIAA 2018-3677]

Antcliff, K. R., Whiteside, S. K. S., Kohlman, L. W., and Silva, C., "**Baseline Assumptions and Future Research Areas for Urban Air Mobility Vehicles**" *2019 SciTech Forum and Exhibition,* American Institute of Aeronautics and Astronautics, 2019. [AIAA 2019-0528]

Kohlman, L. W., Patterson, M. D., and Raabe, B. E., "**Urban Air Mobility Network and Vehicle Type—Modeling and Assessment**," *NASA TM-2019-220072,* 2019. [NASA TM-2019-220072]

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