Baseline Assumptions and Future Research Areas for Urban Air Mobility Vehicles

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Presentation: TF-03, AIAA Aviation Forum, 17-21 Jun 2019
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
- Affordability
- Safety
- Ease of use
- Door-to-door trip speed
- Average trip delay
- Community noise
- Ride quality
- Efficiency
- 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
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*

**Network and Mission Model**

- Vertiport Model
- Vehicle Model
- Demand Model
Background

Initial Reference Vehicles: 
Johnson et al.

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

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

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

UAM Mission Requirements: 
Patterson et al.

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

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

N+1 Reference Vehicles – add:
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Further vehicle research:
- UAM vehicle workshops
- Technology development
- Tool development
- Design trades
- Network modeling

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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

**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
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)

**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

**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

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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

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

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

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
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?
Paper References


