National Aeronautics and Space Administration

ARMD Transformative Aeronautics Concepts Program

Convergent Aeronautics Solutions Project

Design Environment for Novel Vertical Lift Vehicles
DELIVER

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Contents

DELIVER Vision

"Can we bring 100 years of aeronautics knowledge to the new entrepreneurs' desktop with a design environment for emerging vertical lift vehicles?"

Entrepreneur's Vision

New markets / Use cases:
- Package delivery
- Surveillance / inspection
- On-demand mobility
- Aerial taxi
- Law Enforcement
- Disaster Relief
- Agriculture

Vehicle Design

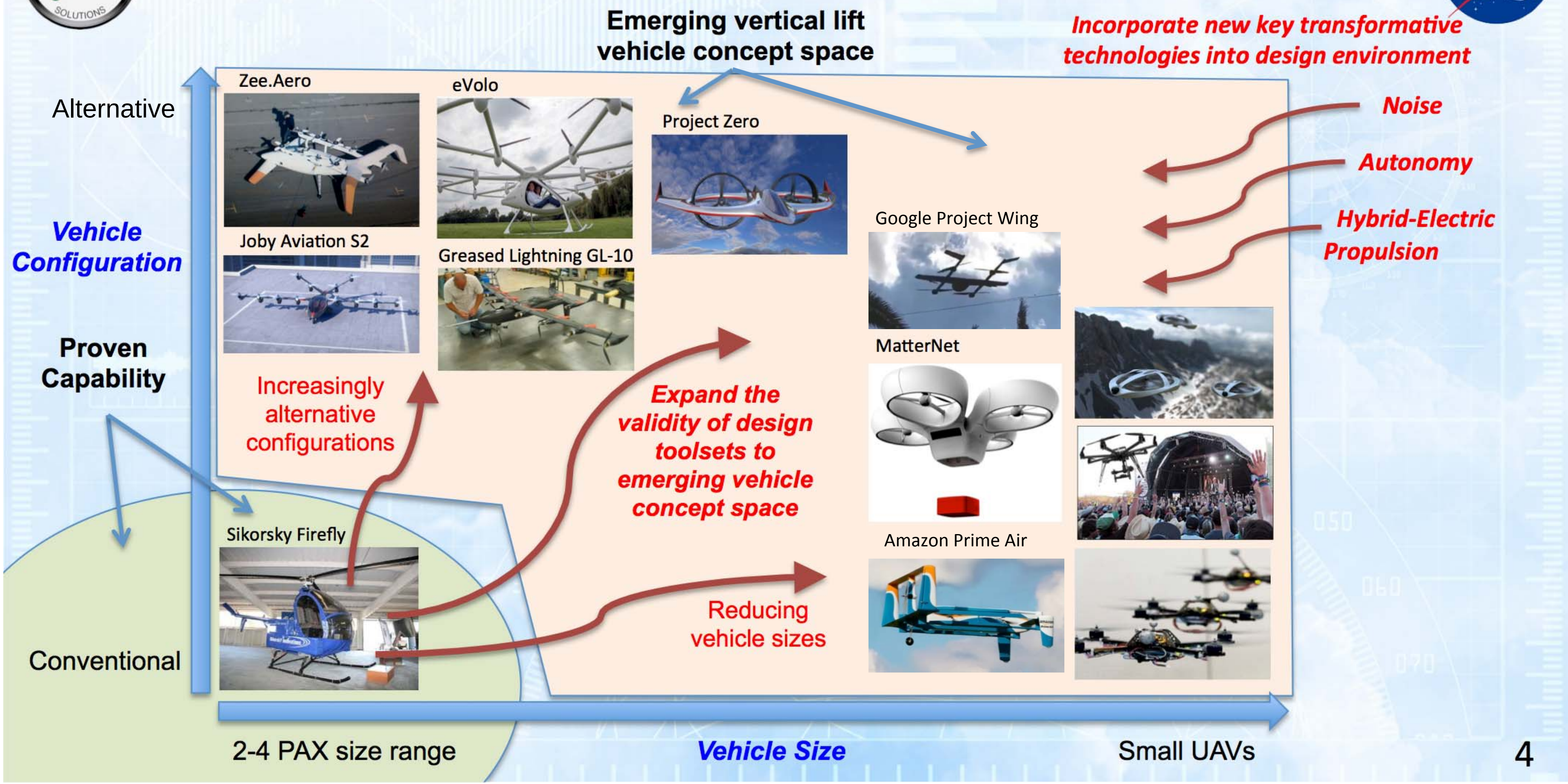
- Vehicle sized and optimized for the particular use case

Amazon Prime Air

Google Project Wing

Project Zero

Transformative Vertical Lift Vehicle Markets



How is Conceptual Design Done Now?

For conventional vertical lift vehicles (> 2 passengers):

- Suite of proven multi-disciplinary conceptual design and sizing tools that incorporate '100 years of aeronautics knowledge'
- Able to perform mission synthesis to optimize vehicle for desired mission
- Able to assess trade-offs in mission parameters and vehicle configurations
- Lots of confidence in design – leads to less design iterations

For alternative vehicle configurations:

- Reliant on significant expert knowledge
- Develop simplified tools for specific vehicle configurations
- Iterations on vehicle builds starting from small scale and working up
- Slow process of design, build, test, iteration to build confidence in design

For small UAVs:

- Same design approach as '100 years ago'
  - Sketch, build, fly, iterate
- No confidence that the concept will work for the mission
- No systematic way to explore trade-offs or determine logical next steps
- Not possible to account for multiple real-world constraints up front in design
- Do not know what performance is possible with given design

Sikorsky Firefly

Joby Aviation S2

Zee.Aero

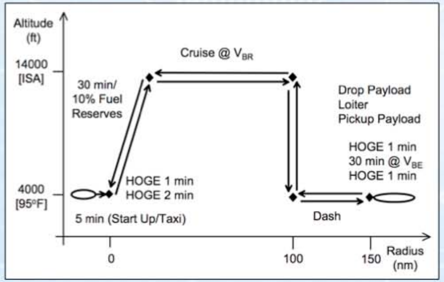
Amazon Prime Air

Google Project Wing

Conceptual Design Process

Design Environment

Mission/application:
- What does the vehicle have to do?
- What are the mission constraints/ objectives?



Vehicle Configurations:
- Trade-space of vehicle options

Conceptual Design and Sizing Tools:

NDARC (NASA Design and Analysis for Rotorcraft):

For design and sizing task, uses a combination of:
- Simplified analysis models (eg. rotors, engines)
- Look-up tables and curve fits based on empirical data
- Surrogate models based on high-fidelity calculations
- Tech factors for advanced future technologies
- Historical vehicle design and configuration data

Gaps in NDARC modeling for novel / sUAV vehicles:
- Calibrated with existing component and vehicle data, limited mostly to larger / manned vehicles
- No current ability to account for noise
- Limited hybrid-electric propulsion system models
- No models of autonomous systems constraints

Note: NDARC is available free of charge from NASA via Software Usage Agreement

Vehicle optimized (size and configuration) for mission performance

Analysis of trade-offs in vehicle configuration and mission performance

Challenges Addressed in DELIVER

Emerging Vertical Lift Vehicle Concept Space

Vehicle Data & Missions

Conceptual Design (NDARC):

- Enables design and sizing of vehicles for specific missions

Gaps / Challenges:

- Validated only for larger (>2 PAX), convention vehicles
- Tools not calibrated to small and alternative configurations
- Limited validation for novel and small vehicles

Data & Models

Autonomy:

- High impact on mission and operational capability

Gaps / Challenges:

- No current ability to include autonomy constraints in conceptual design

Data & Models

Hybrid Electric Propulsion:

- Enabling technology for all vehicles in concept space

Gaps / Challenges:

- Limited hybrid-electric propulsion system models – for large vehicles only
- No data for novel cryogenically cooled power systems

Data & Models

Noise:

- Key for community acceptance

Gaps / Challenges:

- No current ability to account for noise in conceptual design

Conceptual Design Modeling

NDARC Calibration / Validation:

Partnerships:
- sUAV vehicle data / testing
- GL-10 vehicle and flight data
- Joby Aviation S4 data / testing

Vehicle / component testing:
- Multi-copter / component test stand
- Multi-copter wind tunnel test

Design for mission performance:
- Build component models that expand range of current models
- Validate predictions against full vehicle test data
- Identify gaps, lesson learned and roadmap in performance predictions for new configurations

Conceptual Design (NDARC):
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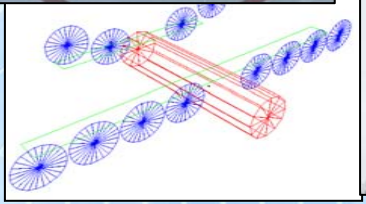
Multi-Copter Wind Tunnel Test

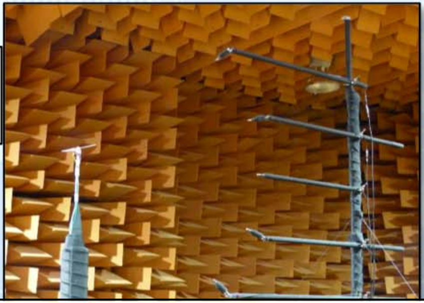
Joby Aviation S4



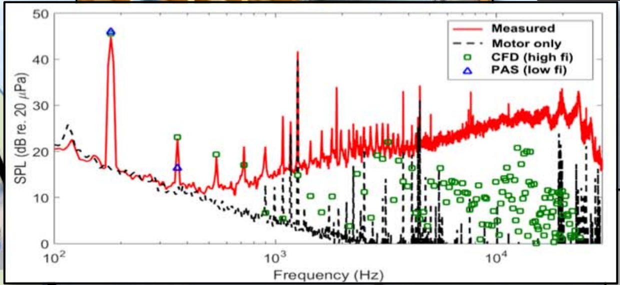
Greased Lightning (GL-10)

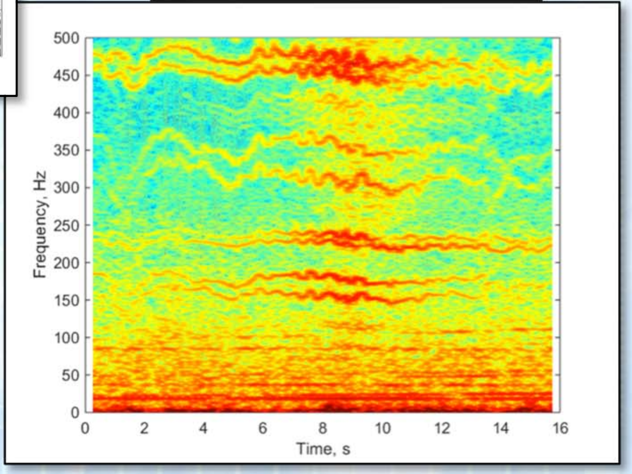
Noise Measurement and Prediction

Anechoic Chamber Testing



UAS Outdoor Flight Testing





Noise modeling:

Characterize and understand noise:
- Anechoic chamber testing of full vehicles and isolated rotors
- Outdoor flight testing

Predict noise:
- Use high and low fidelity approaches to calculate noise
- Identify prediction gaps in current tools

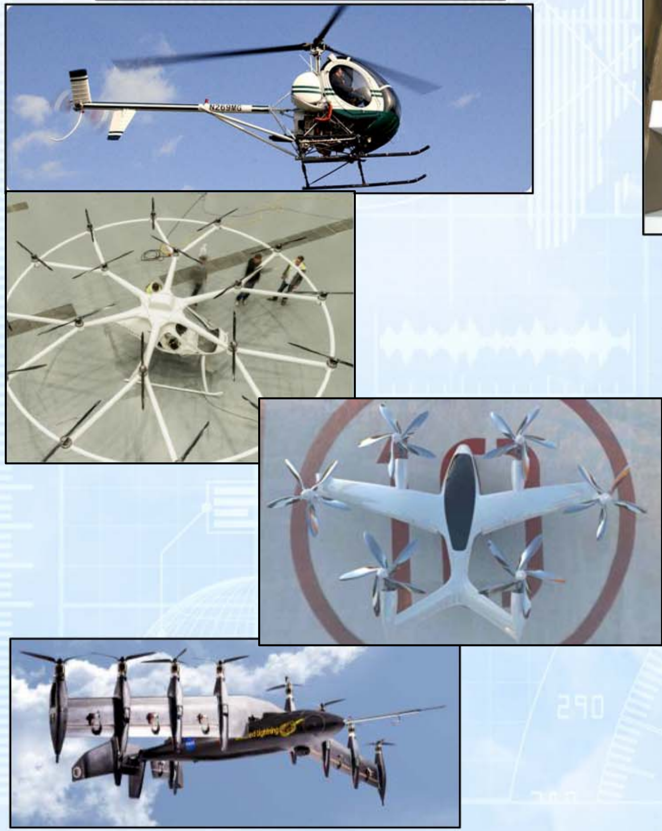
Characterize annoyance:
- Develop auralization models
- Assess human response through human subject testing
- Explore annoyance metrics for conceptual design

Noise:
- Key for community acceptance

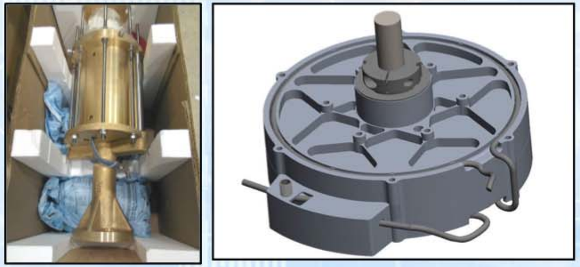
Gaps / Challenges:
- No current ability to account for noise in conceptual design

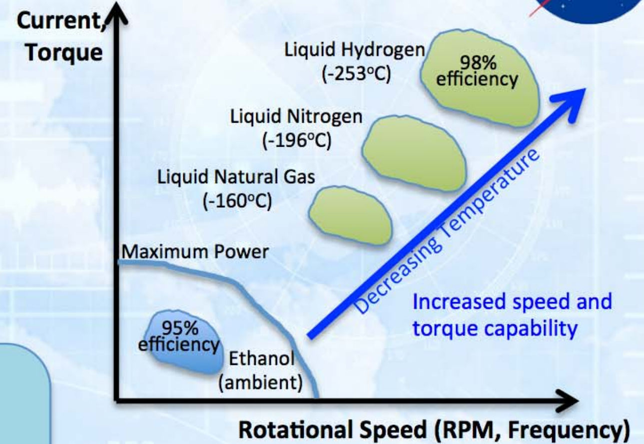
Hybrid-Electric Propulsion Systems

VTOL Vehicle Trade-Studies



Cryo-Cooled Power Systems





HEP modeling:

Assess current modeling capabilities:
- Survey modeling for small vehicles in NDARC, NPSS, etc.
- Perform design trade-studies of various propulsion systems
- Determine gaps for novel and small vehicles

Novel propulsion system concepts:
- Demonstrate feasibility of cryo-cooled propulsion system for V/L applications
- Collect performance data for design

Hybrid Electric Propulsion:
- Enabling technology for all vehicles in concept space

Gaps / Challenges:
- Limited hybrid-electric propulsion system models – for large vehicles only
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Autonomy Modeling

Mission Equipment

Mission objectives:
On-board sensors
Processing
Terrain recognition
Identification / tracking
Payload stabilization

Concepts of Operations

Operational environment:
Day / night operations
Fog, wind, rain, snow
On-board vs. off-board
Decision making

Regulatory Requirements

Required systems:
Communications
ADS-B
Transponder
See And Avoid
Redundancy
Contingency management
Lost link capabilities

Autonomy modeling:

Background / Goal:
- Autonomy is a key enabler to the vision of large numbers of UAS operations
- Understand the impact of autonomy requirements on vehicle design
- NDARC currently has modeling/data to account for 'Mission Systems'

Explore autonomy models:
- Survey current autonomy / automation capabilities and systems
- Examine autonomy requirements and concepts of operations
- Develop lower order models of autonomy capabilities / constraints

Collect data to support modeling:
- Simulation and flight of autonomy concepts – Push state-of-the-art
- "Search and rescue under the canopy"

Autonomy:
- High impact on mission and operational capability

Gaps / Challenges:
- No current ability to include autonomy constraints in conceptual design

Transformative Vertical Lift Vehicle Markets