Command and Control Concepts for a Lift Plus Cruise Electric Vertical Takeoff and Landing Vehicle

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NASA Ames Research Center

Outline

- Introduction
- Simulation Model
- Control and Command Concepts
- Flight Test Maneuvers
  - Rejected Takeoff
  - Heliport Approach
  - Precision Hover
- General Observations and Future Plans

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NASA Ames VTOL Wind Tunnel & Simulation Facilities

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NASA Ames VTOL Research Legacy

Bell XV-15 experimental tiltrotor

AV-8B Harrier VSTOL research aircraft

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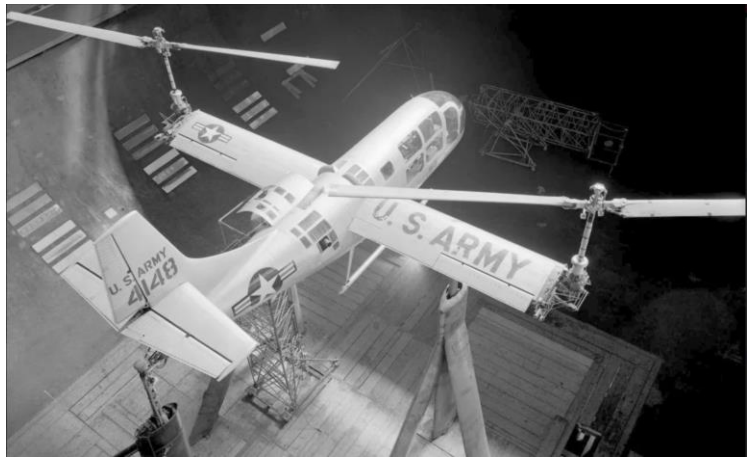
NASA Ames VTOL Research Legacy

Bell XV-3 experimental tiltrotor



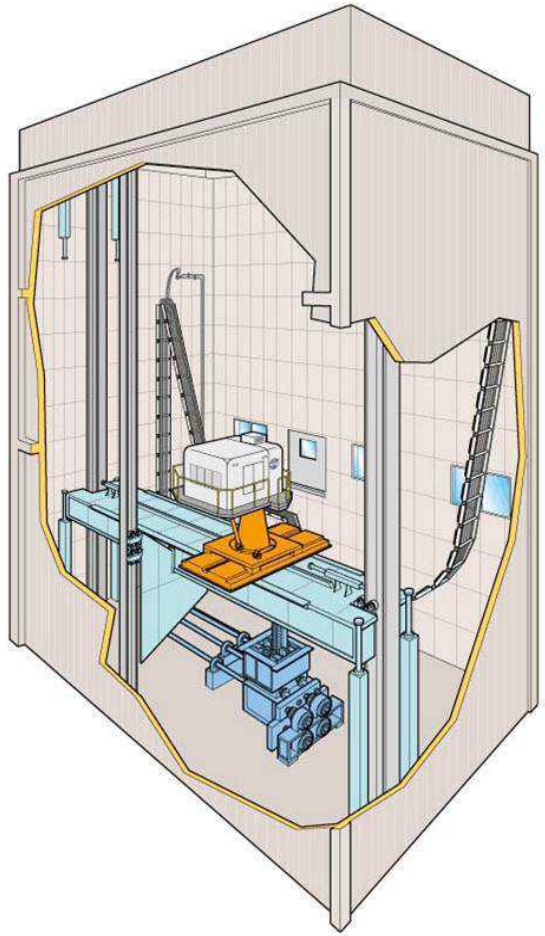
Bell X-14 VTOL experimental aircraft

Ling-Temco-Vought XC-142

NASA Ames VTOL Research Legacy

Vertical Motion Simulator

VMS cab interior with pilot station



Motion system performance limits

Degrees of freedom	Displacement System limits	Displacement Operational limits	Velocity System limits	Velocity Operational limits	Acceleration System limits	Acceleration Operational limits
Longitudinal	±4ft	±4ft	±5ft/s	±4ft/s	±16ft/s^2	±10ft/s^2
Lateral	±20ft	±15ft	±8ft/s	±8ft/s	±13ft/s^2	±13ft/s^2
Vertical	±30ft	±22ft	±16ft/s	±15ft/s	±22ft/s^2	±22ft/s^2
Roll	±18°	±14°	±52°/s	±40°/s	±229°/s^2	±115°/s^2
Pitch	±18°	±14°	±52°/s	±40°/s	±229°/s^2	±115°/s^2
Yaw	±24°	±14°	±52°/s	±46°/s	±229°/s^2	±115°/s^2

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Introduction

Recent vehicle configuration survey counts 500 different vehicle designs!

Roughly divided into 3 sub-groups, based on their propulsion configuration:

1. Vertical propulsion system only (30%)
2. Separate vertical and forward propulsion system (20%)
3. Tilting propulsion system (50%)

} Winged vehicles

Winged vehicles:

- Higher degree of efficiency ⇒ increased operational capabilities (range)
- Wings and tail make them more susceptible to wind changes
- Maximize efficiency by faster transitions (longer on the wing)

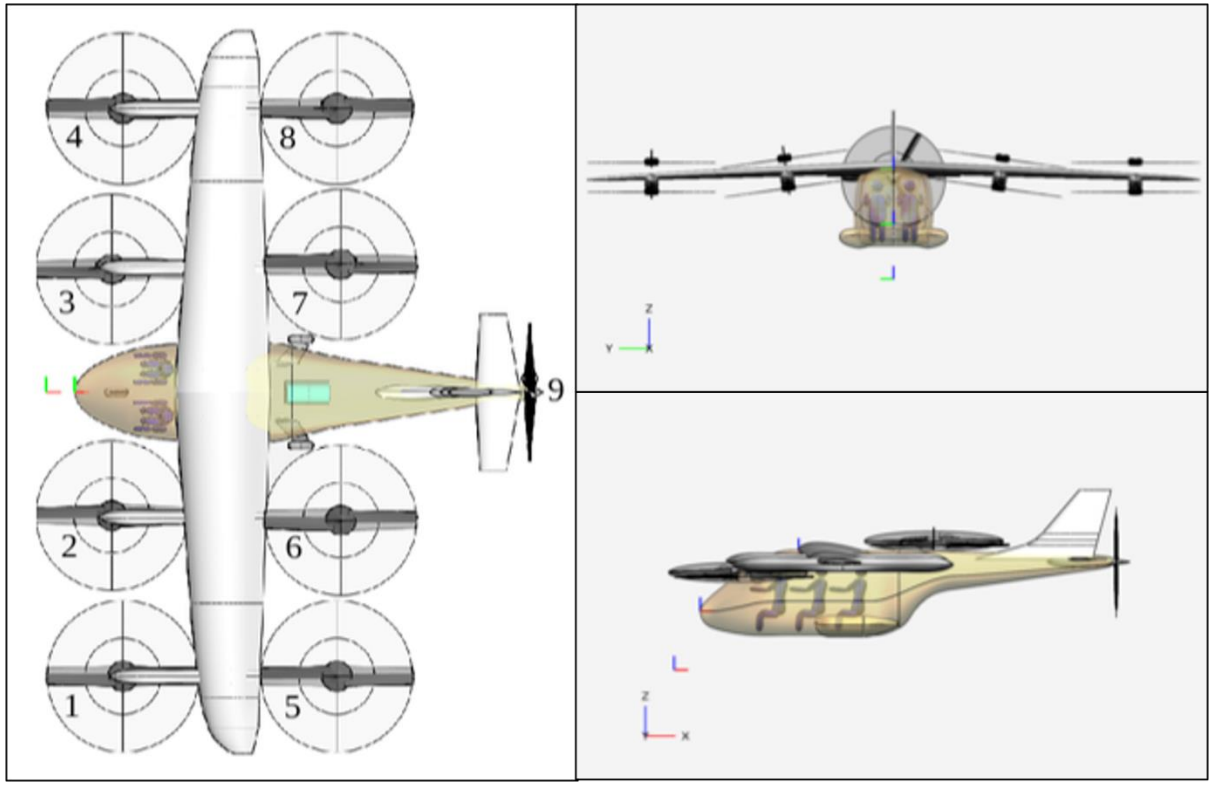
} Challenging with slow maneuvering response times

Indirect flight control systems and higher levels of automation needed to deal with these transition challenges, simplify piloting operations as well as handle hover instabilities

Lift Plus Cruise: Aircraft Model

NASA Revolutionary Vertical Lift Technology (RVLT) Lift-Plus-Cruise vehicle

- 6,000 lbs (1,200 lbs. payload)
- 50 nm range
- 120 kts max speed
- 8 variable RPM lifting rotors
- 1 var blade angle pusher prop
- Ailerons, elevator, rudder
- Designed using NDARC
- Data generated with FlightLAB



Advanced Rotorcraft Technology, Inc.

Lift Plus Cruise: Taxonomy

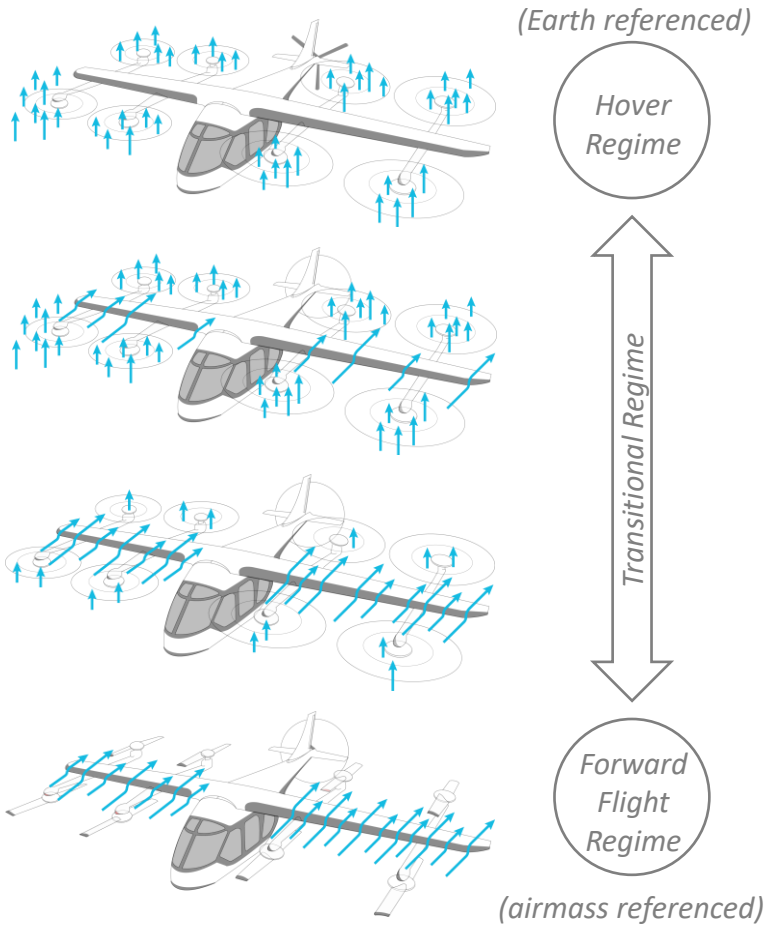
0 – 20 kts

15 – 40 kts

35 – 100 kts

95 – 120 kts

- **Thrust Borne Lift (TBL)**
  - Lift by lifting rotors, minimal aero effects by airframe
  - Level acceleration by pitching airframe (vectoring thrust)
- **Semi-Thrust Borne Lift (STBL)**
  - Primary lift by lifting rotors, moderate aero effects by airframe
  - Level acceleration by thrust (pusher prop, tilted wing/rotors)
- **Semi-Wing Borne Lift (SWBL)**
  - Primary lift by airframe, rotors for angle-of-attack protection
  - Level acceleration by thrust
- **Wing Borne Lift (WBL)**
  - Lift by airframe (lifting rotors stopped)
  - Level acceleration by thrust



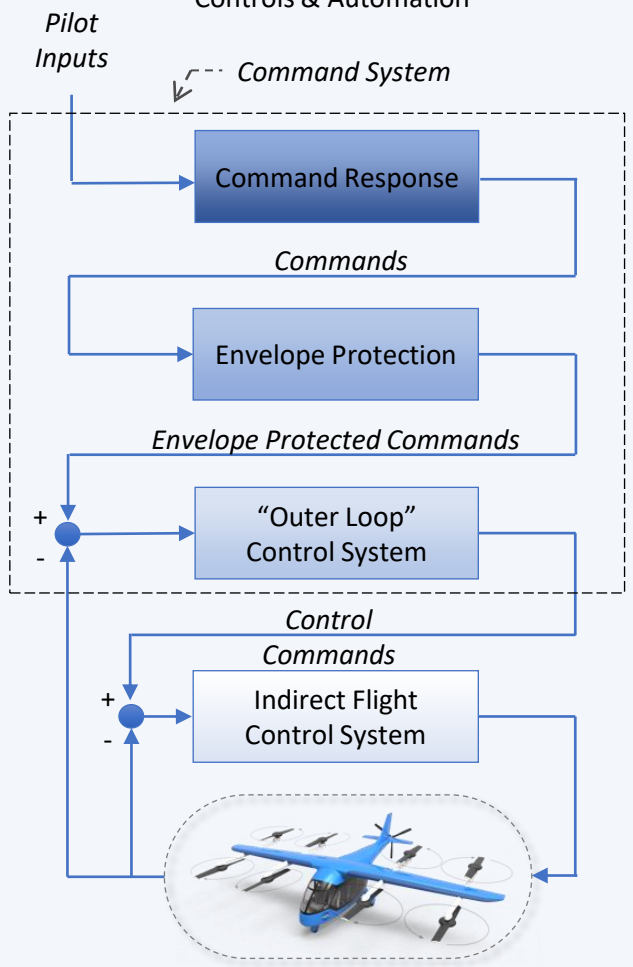
Control concepts: inceptors, controls, displays

Dual Inceptors

Left Stick with Hover Engage/Disengage Buttons

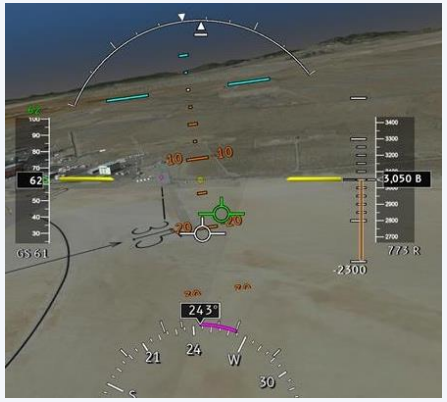
Right Stick with Automation Command Concept Selector Buttons

Controls & Automation



Enhanced/Synthetic Vision Displays

MAP with Hover Prediction

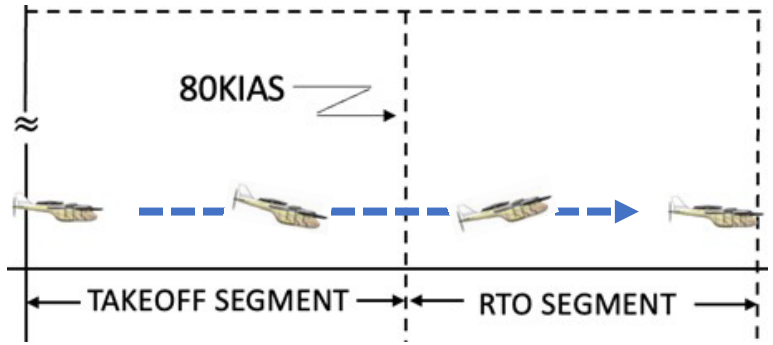


PFD with Commanded Velocity Vector

Flight Test Maneuvers

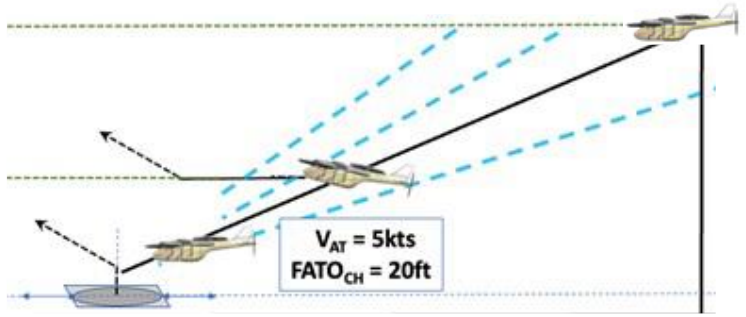
All maneuvers in:
- No wind
- 17 kts crosswind
- with various command concepts

Rejected Takeoff



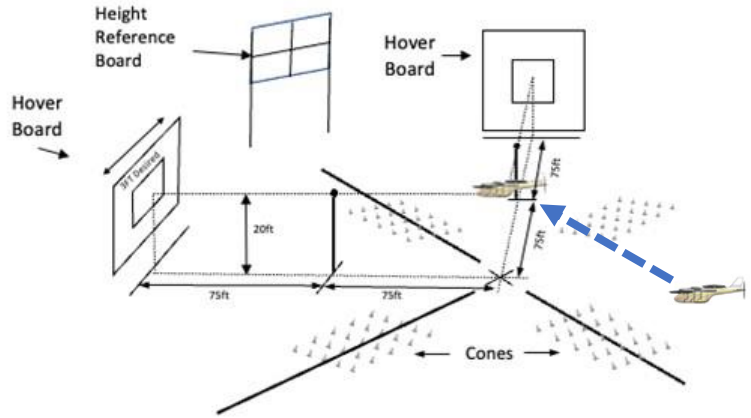
- Accelerate to 80 kts AS
- Fast decelerate to hover
- Dev restrictions for alt & runway centerline

Approach



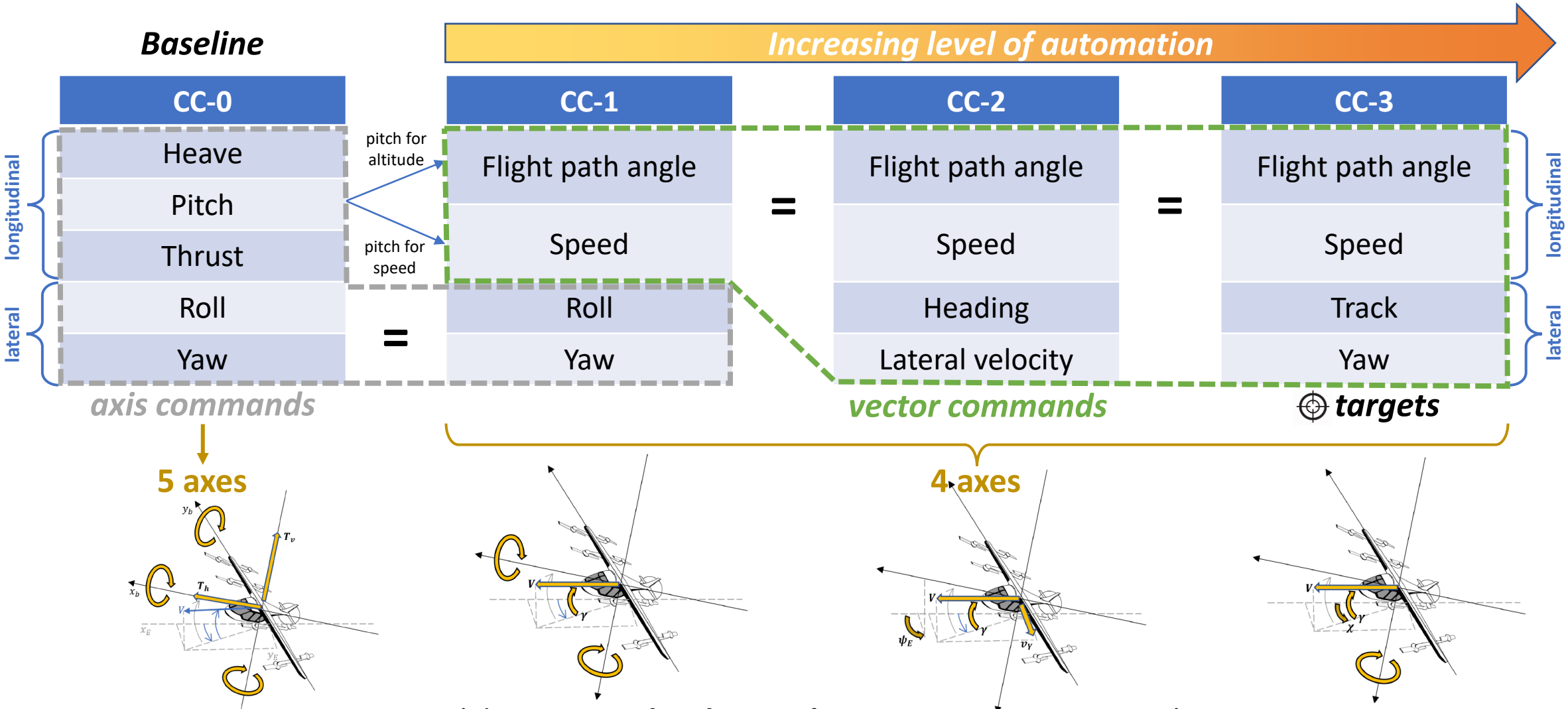
- Initial 70 kts @ 500 ft, 6 deg
- Dev restrictions wrt ILS ref
- Decelerate @ 200ft alt
- Target: 5 kts GS @ 20 ft alt

Precision Hover



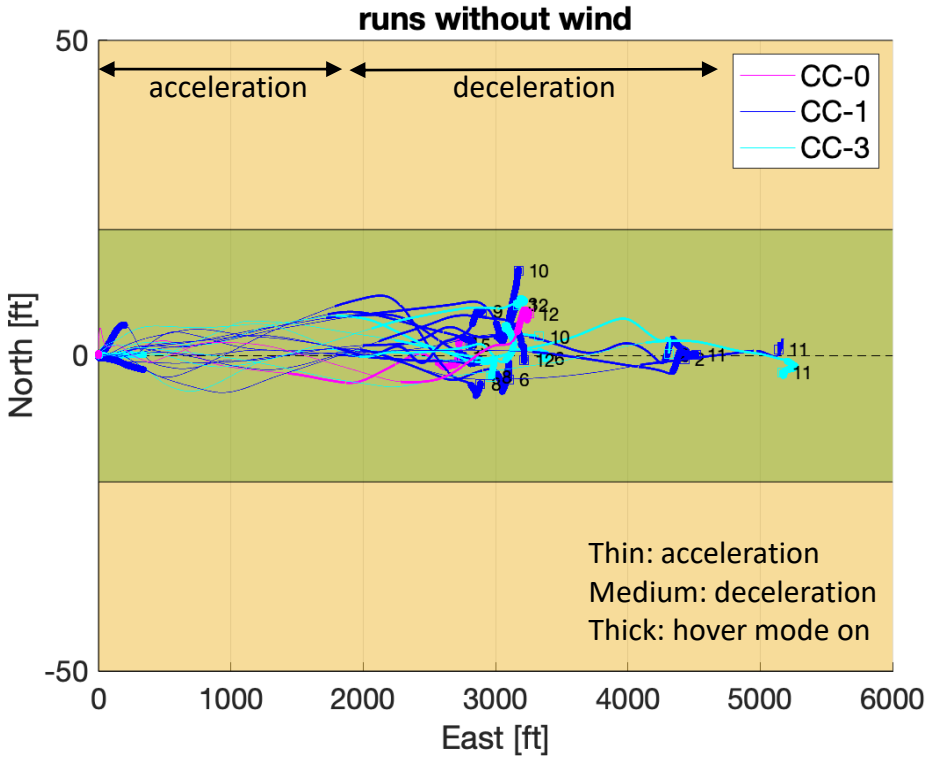
- Slide along 45 deg line
- Accelerate to 10 kts
- Capture target hover point within dist/alt restrictions

Automation Command Concepts

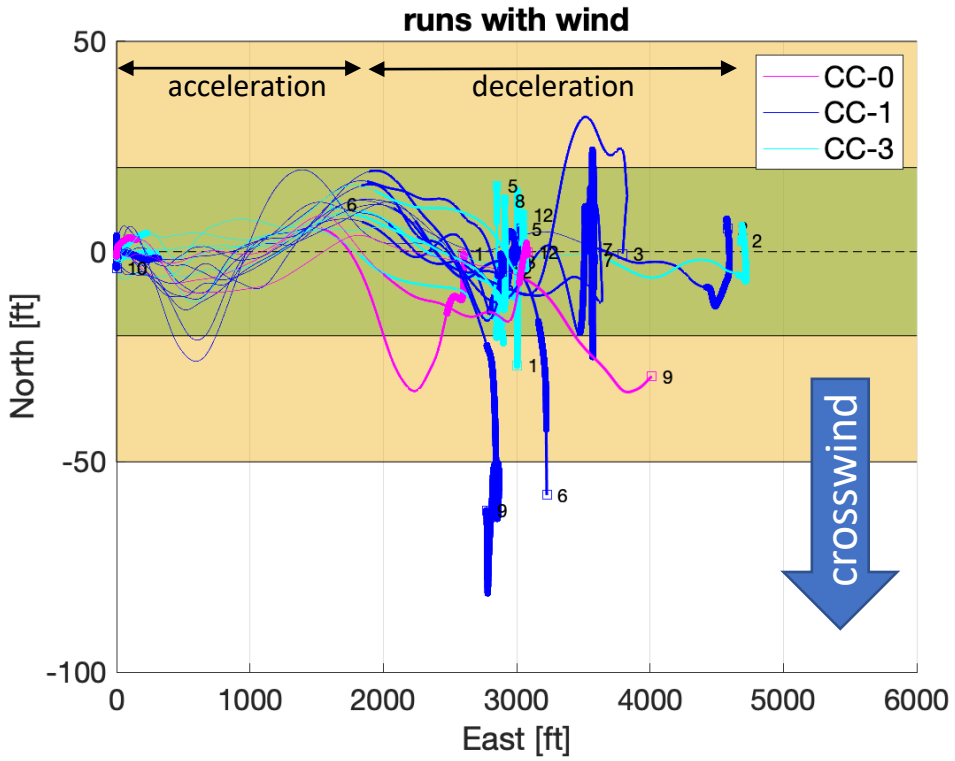


Flight Test Maneuvers: Rejected Takeoff

Trajectories without crosswind

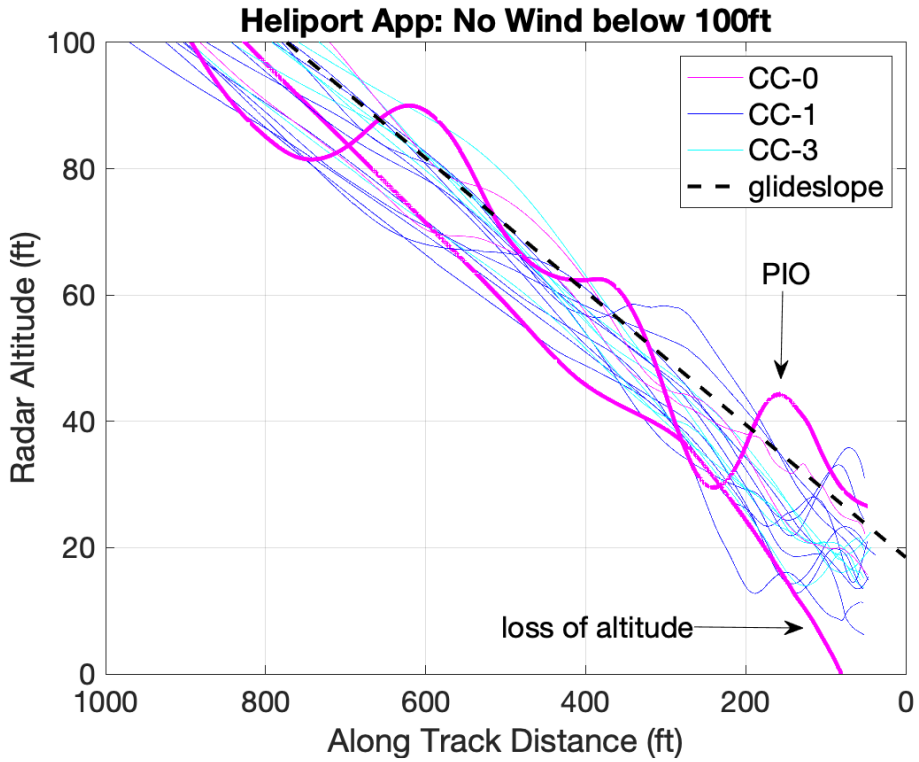


Trajectories with crosswind

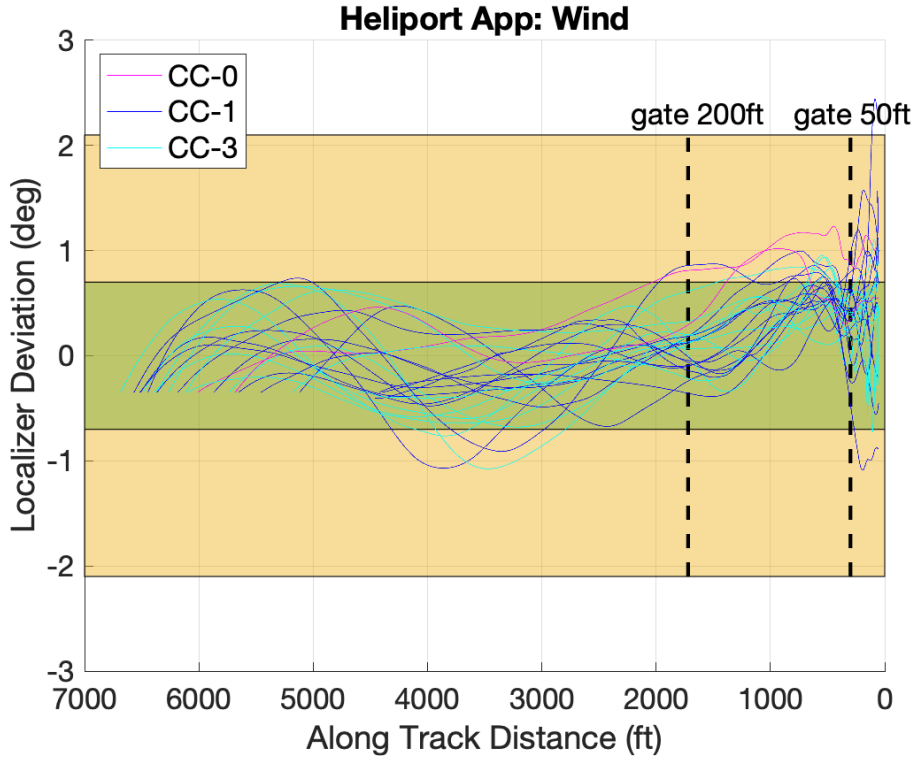


Flight Test Maneuvers: Approach

Glideslope performance approach

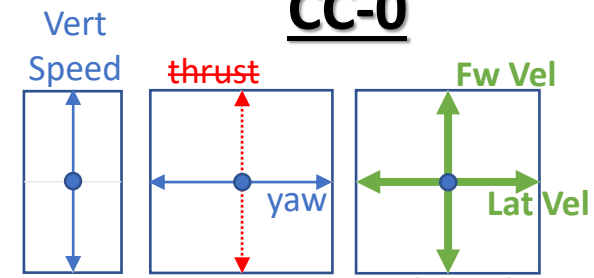


Localizer performance approach + wind



Hover mode

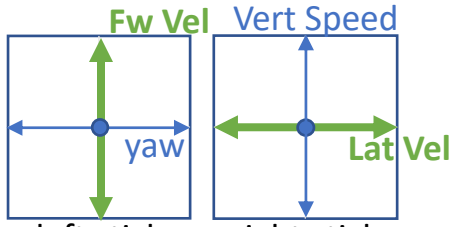
CC-0



Translational Rate Control TRC

Predicted Hover Point
Along Current Track

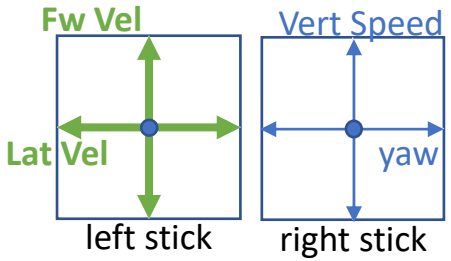
CC-1



Translational Rate Control TRC

Predicted Hover Point
Along Commanded Track

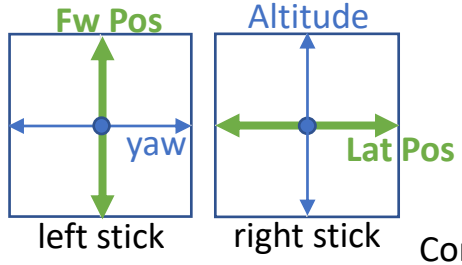
CC-2



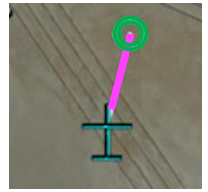
Translational Rate Control TRC

Predicted Hover Point
Along Commanded Track

CC-3



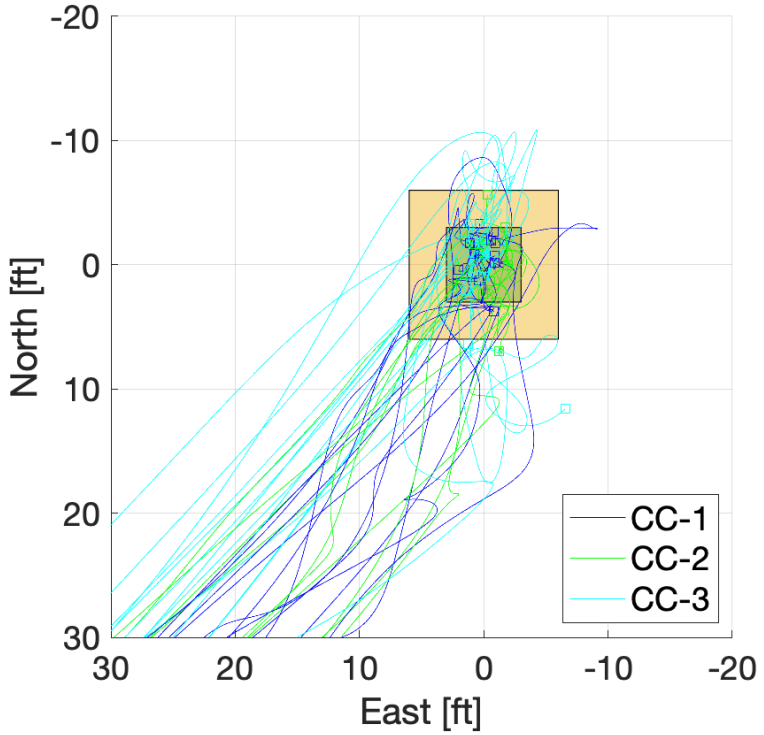
targets



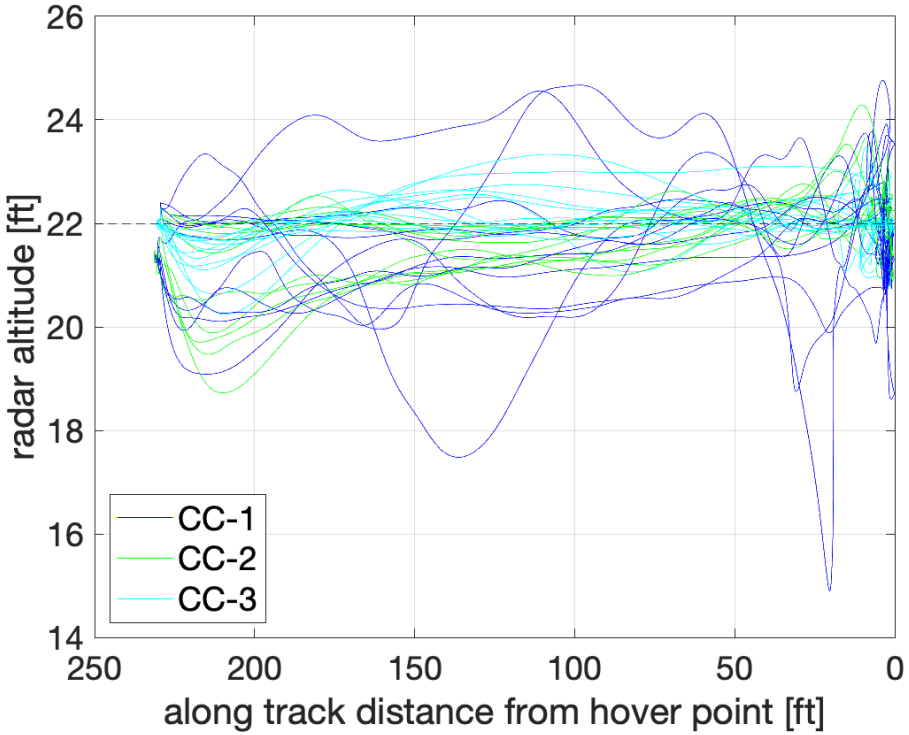
Commanded Hover Point
Along Computed Track

Flight Test Maneuvers: Precision hover

Final capture performance



Altitude performance



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Summary & Future Plans

- Winged eVTOL vehicles present unique handling and control challenges: changing aerodynamic effects and limited rotor control power (slow responses). We need automation concepts to simplify control & command.
- This study evaluated several simplified control and handling concepts with various levels of automation to automatically transition between lift modes and to produce consistent vehicle responses.
  - Baseline command concept: fastest & most familiar response, but needs most anticipation (especially vertical axis) and complex multi-axis inputs, more training, more frequent loss of control
  - Higher automation concepts: improved performance for higher precision, negative habit transfer with high workload
  - Highest automation concept: slower response to inceptor inputs, needs predictive display symbology, problematic for aggressive high gain tasks which result in PIO's.
- These vehicles have inherent limited control authority and responsiveness in transition: combined high precision and high level of aggressiveness is not achievable. Tradeoff between the operational concepts and the capabilities of the vehicle design:
  - Vehicle design capabilities:
    - electric motors that produce more torque (at the expense of vehicle range)
    - lifting rotors with variable blade pitch designs (at the expense of payload capacity)
  - Operational concepts: slower and less efficient transitions (at the expense of vehicle range)
- Future work: comparisons with blade pitch control or tilt-wing and tilt-rotor designs for enhanced performance, investigate benefits of automation and concepts of operations, better understanding of transition flight dynamics.

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