eVTOL Aircraft and Automation

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eVTOL Evaluation Challenges

• Diversity in proposed aircraft and control concepts

• Operations in low speed and hover may be restricted for some candidate eVTOL aircraft due to lack of cyclic and/or collective control

• Powered Lift (e.g., winged eVTOL) have additional control challenges in transition

• Automation is proposed to help with these challenges
  • Industry concepts proposing Indirect Flight Controls (IFCS)

• Existing Means of Compliance inadequate for IFCS and increasing automated functions
  • IFCS airplanes have only been certified under Special Conditions

• How do we evaluate whether proposed concepts of operations are compatible with eVTOL aircraft and automation?
NASA Model and Simulation Development

Vehicle Models
- RVLT design concepts with stability/control analysis

Vehicle Transitions
- Lift and control mode transitions (e.g., winged eVTOL taxonomy)

Command Concepts
- Enabling operations with command response types

Inceptors, Controls and Displays

Dual Inceptors

Left Stick with Hover
Engage/Disengage Buttons

Right Stick with Automation
Command Concept Selector Buttons

Controls & Automation

Pilot Inputs

Command System

Envelop Protection

Envelop Protected Commands

“Outer Loop” Control System

Command Response

Control Commands

Indirect Flight Control System

Enhanced/Synthetic Vision Displays

MAP with Hover Prediction

PFD with Commanded Velocity Vector
Command Concepts

Baseline

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Increasing level of augmentation

(axis commands)

5 axes (Independent heave/thrust axes only applies for LPC)

4 axes (Extra DoF used to trim AoA/pitch for LPC)
Pilot Automation Interaction (PAI) Framework

**PAI-0**
- **Axis Control**: Conventional pilot interfaces with stability augmentation

**PAI-1**
- **Stability Augmented Control (Human-Within-the-Loop)**

**PAI-2**
- **Vector Control**: Mapping of axis commands to vectors to simplify aircraft control

**PAI-3**
- **Target Command**: Autopilot without Flight Path Management

**PAI-4**
- **Path Command**: Autopilot with Aircraft Flight Path Management

**PAI-5**
- **Maneuver Command**: Autopilot with specified, linkable maneuvers

**PAI-6**
- **Task Management (Human-Over-the-Loop)**

**PAI-7**
- **Task Management**: Integrated aircraft automated functions including response to hazards

**Mission Management**
- **Mission Management Operations**: Management and optimization across operational contingencies (e.g., m:n Operations)

**Full Aircraft Automation**
- No real-time intervention capability required
Pilot Automation Interaction (PAI) Framework

Stability Augmented Control (Human-Within-the-Loop)

Axis Control
Conventional pilot interfaces with stability augmentation

PAI -0

PAI -1

Vector Control
Mapping of axis commands to vectors to simplify aircraft control

PAI -2

Target Command
Autopilot with specified, linkable maneuvers

PAI -3

Autoflight Command (Human-On-the-Loop)

PAI -4

Path Command
Autopilot with Aircraft Flight Path Management

PAI -5

Task Management (Human-Over-the-Loop)

PAI -6

Mission Management
Full Aircraft Automation
no real-time intervention capability required

PAI -7

Path Command
Integrated aircraft automated functions including response to hazards

Mission Management Operations
Management and optimization across operational contingencies (e.g., m:n Operations)
Automation Enabled Pilot Studies

- Objective: Evaluate challenges associated with information and automation requirements for expected Urban Air Mobility (UAM) operations using representative powered lift aircraft
- Developed 11 candidate maneuvers
- Evaluated through series of three VMS experiments
- Findings provided lessons on automation design and supported means of compliance evaluation
Future Interfaces, Automation, Information

Mission Management Interfaces
- Human over the loop (HOVTL)
- Human on the loop (HOTL)
- Human within the loop (HWTL)
- Pilot in the loop (PITL)

Flight Management and Autopilot Interfaces
- Strategic Commands
- Tactical Commands
- Control Commands

Controls & Automation
- Mission Management
- Flight Management
- Command

System Health Displays
- NAV/MAP Display
- Primary Flight Display (PFD)

Increasing Automation
- Hands On Throttle And Stick (HOTAS) Inceptors
Questions?