Fundamental Aeronautics Program
Subsonic Rotary Wing Project

Flight Dynamics and Controls Discipline Overview

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Objectives and Challenges

• Flight Dynamics and Controls deals with the pilot and cockpit technologies as a bridge between the vehicle and operations concepts

• Flight control of large, complex rotorcraft
  – Implications of large aircraft size
  – Obtaining high bandwidth control
  – Emerging blade control concepts
  – Rotor speed changes
  – Flexible structures
  – Cockpit and pilot inceptors

• Complex flight operations management
  – Hover to cruise to hover conversions
  – Control mode changes
  – Noise abatement
  – Obstacle rich, poor visibility, low altitude operations
  – Congested airspace operations
FD&C Discipline Tasks

• Control Theory and Intelligent Automation
  – Full envelope flight dynamics modeling
  – Optimal trajectories for noise abatement
  – Human pilot interface modeling

• Applied Flight Dynamics and Controls
  – Handling qualities design envelope requirements
  – Guidance and control for advanced rotorcraft in NextGen airspace
  – Safety analysis of helicopter accidents
Full Envelope Flight Dynamics Modeling

• Simplified hover dynamics model: 2008-2009
• Enhanced low-speed model: 2010-2011
  – Expanded speed envelope
  – Nacelle tilt, independent rotor control
• Full flight envelope stability derivative model: 2012-2013
  – Full nacelle range, flaps, rotor speed changes
  – Supports research with modest computational requirements
• Total force and moment model: ~ 2014
  – Higher fidelity physics-based full flight envelope simulation model
• LCTR/HETR test in Army AFDD 7x10 foot wind tunnel at Ames: 2011
  – Measure basic low-speed aerodynamics of fuselage/tail/wing/nacelle

Set of linear models through flight envelope and configuration
LPV model ‘stitching’ procedure
Continuous bare-airframe model with variations in trim and flight dynamics with flight condition
LCTR 7x10-ft Wind Tunnel Test

- First wind tunnel test to measure complete LCTR airframe aerodynamics (without rotors)
- Part of a joint test between NASA and US Army
- Test objectives:
  - Airplane mode (shown) - High speed (200 knots) for lateral-directional airframe stability assessment
  - Helicopter mode - Low speed data (<60 knots) with pitch (+/- 10 deg) and yaw (+/- 180 deg) variations for low speed aerodynamics
- Tasks completed to date:
  - LCTR model installed in the test section
  - Oil flow visualization in airplane mode (shown)
  - Aerodynamic forces and moments measured in airplane mode for three different wingtip/nacelle configurations
- Data to be used for:
  - Comparison/validation of CFD tool predictions
  - Development of flight dynamics simulation models
Optimal Trajectories for Noise Abatement

Objective:
• Apply state of the art optimization techniques to design rotorcraft approach techniques that minimize ground noise.

Approach:
• Configuration space for motion planning defines the set of transformations that can be applied to the rotorcraft during approach.
• State of the art constraint optimization and path planning algorithms (A*, Field D*, Probabilistic Roadmaps) search for best trajectories, straight and maneuvers.
• Noise predictions from Rotorcraft Noise Model (RNM) used to evaluate candidate trajectories.
• Realistic terrain representations (water, residential, industrial, etc.) allow for solutions that can be applied to real landing environments.

1999 XV-15 Proposed Approach Profiles

Field D* 3D Path Planning

Land Use Model around Pensacola Airport
Optimal Trajectories for Noise Abatement

Status:

- Joint work with SRW Acoustics team
- SAA with University of Padua, Italy to develop noise 'cost' functions based on RNM output to be used by optimizer.
- WYE support for developers at Florida Human and Machine Cognition (IHMC) for implementing path planning algorithms, develop land-use models around real airports

Results:

- Optimizer based on stochastic local search finds trajectories that are roughly 20% quieter on average than 'pilot-defined' quiet paths.
- Pilot-defined 'flyability constraints' means that the optimal trajectories adhere to requirements for safety and passenger comfort.
Active Inceptor Handling Qualities Study

• Joint Army-NASA investigation
• Objectives:
  – Study interaction between inceptor force-feel characteristics and handling qualities
  – Investigate flight control system optimization including inceptor characteristics
• Approach:
  – Systematic investigation of varying inceptor force-feel parameters and different types of command response
  – Piloted ground simulation and flight tests
• Current status:
  – Flight tests conducted in 2011 with US Army RASCAL and DLR FHS helicopters
• Next Steps:
  – Piloted simulation experiment at NASA-Ames Vertical Motion Simulator (VMS)

Analysis of gradients shows sensitivity of handling qualities to inceptor damping ratio, but not to the natural frequency.
LCTR2 Handling Qualities Investigations

- **Objectives:**
  - Develop understanding of the flight control and HQ effects of unique characteristics of large helicopters, including tilt-rotors: low bandwidth response, large pilot offset
  - Develop handling qualities and control system requirements for large helicopters

- **Approach:**
  - Series of experiments to systematically study fundamental Handling Qualities and control system effects throughout flight envelope and airspace integration
  - Piloted simulation experiments in Vertical Motion Simulator (VMS)
  - Partnership with US Army, US Marines and helicopter industry (Bell, Boeing, Sikorsky)

- **Current status:**
  - Four successful hover and low speed experiments in the VMS (2008 - 2011)
Previous Experiments (2008 -- 2010)

- **2008** – Studied basic effects of rotorcraft size on piloted handling qualities in hover
  - UH-60 Blackhawk, CH-53, and LCTR
  - LCTR only achieved Level 2 Handling Qualities with Attitude Command-Attitude Hold (ACAH)

- **2009** – Investigated fundamental pitch, roll and yaw response requirements and effect of C.G. to pilot offset on handling qualities
  - Level 2 Handling Qualities was best that could be achieved with ACAH control
  - New yaw bandwidth criteria suggested
  - Ride quality degrades due to pitch/heave coupling with larger pilot offsets

- **2010** – Investigated advanced control mode of Translational Rate Command (TRC) using automatic nacelle motion
  - Level 1 Handling Qualities achieved with ‘Improved’ TRC including nacelle rate cross-feed to longitudinal cyclic
  - Actuator dynamics set at 8 rad/sec
2011 VMS Experiment

• Objectives:
  – Investigate control allocation between automatic nacelle actuation and rotor cyclic for control redundant tilt-rotor aircraft
    • **Automatic nacelle**: Low bandwidth
    • **Longitudinal cyclic**: High bandwidth
  – Investigate nacelle actuation requirements and TRC architectures to achieve Level 1 Handling Qualities

• Approach:
  – Vary nacelle actuator dynamics with TRC architecture from 2010 experiment
  – Investigate alternative TRC architectures to achieve Level 1 Handling Qualities with low bandwidth nacelle actuator
2011 Experiment Results

- Left Figure: Varying nacelle actuator bandwidth (Nacelle-only control)
  - Level 1 HQ achieved with nacelle actuator rates greater than 4 rad/sec
  - Solid Level 2 HQ with 3 rad/sec nacelle actuator bandwidth
- Right Figure: Add feed-forward of velocity command and feedback of velocity error to longitudinal cyclic (3 rad/sec nacelle actuator bandwidth)
  - Level 1 HQ achieved with ‘augmented’ TRC and 3 rad/sec
  - Shows augmenting TRC control architecture can recover Level 1 HQ with lower bandwidth actuators
Concluding Remarks

• Simulation Model Development:
  – Working on full-envelope LCTR physics-based non-linear simulation model for use in piloted-in-the-loop VMS experiments
  – Completing LCTR wing tunnel test in 7x10 foot wind tunnel at Ames to measure basic wing/fuselage/nacelle/tail aerodynamic through flight envelope
  – Continuing development of LPV-based stitched linear model to support flight control and handling qualities research activities

• Trajectory Optimization for Noise Abatement:
  – Joint work with SRW Acoustics discipline including flight test support (Bell 430) and Rotorcraft Noise Model (RNM) in trajectory optimization
  – Currently includes pilot handling qualities and vehicle performance limits and working towards including terrain constraints in trajectory planning

• Cockpit and Pilot Inceptors:
  – Active inceptor handling qualities study jointly with US Army examining interaction between inceptor force-feel characteristics and handling qualities
  – Completed flight tests on US Army RASCAL and DLR FHS helicopters
  – Planning piloted simulation in the NASA-Ames Vertical Motion Simulator (VMS)
Concluding Remarks

• Handling Qualities Design Envelope Requirements:
  – Completed 4 VMS entries examining basic low-speed handling qualities of large rotorcraft
  • Developed basic understanding of effect of vehicle size on handling qualities
  • Suggested new design requirements for large rotorcraft handing qualities
  • Examined advanced control modes including TRC with automatic nacelle control
  • Explored control redundancy to improve handing qualities
  – Working on a summary report combining results of 4 experiments

• Future Work in Handling Qualities:
  – Define follow-on experiments in the VMS
  • Trajectory optimization for noise abatement
  • Guidance and control of advanced rotorcraft in NextGen
  – Develop basic handing qualities analysis in preliminary design / sizing phase with tools such as NDARC
  – Develop higher fidelity handling qualities scale as an addition to Cooper-Harper handling qualities ratings scale