National Aeronautics and Space Administration

Fundamental Aeronautics Program

Subsonic Rotary Wing Project

Large Civil Tiltrotor Flight Control and Handling Qualities Simulation Investigations

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Outline

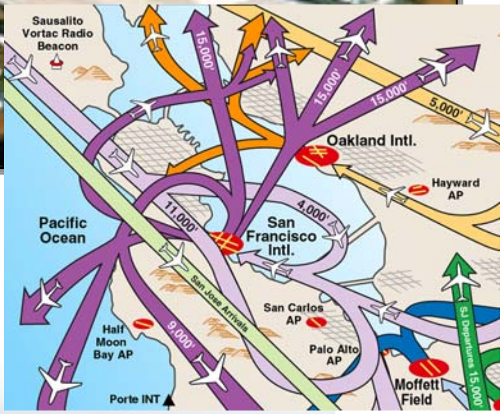
- Motivation / Objectives
- Previous Simulations
- Current 2010 Simulation
- Preliminary Results
- Conclusions
- Future Work

Rotary Wing Vehicles in NextGen

- SRW Goal: Radically improve the transportation system using rotary wing vehicles by increasing speed, range and payload while decreasing noise and emissions

- Systems studies show: Large, advanced technology tiltrotors consistently outpace other rotorcraft configurations in the ability to meet the civil mission

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

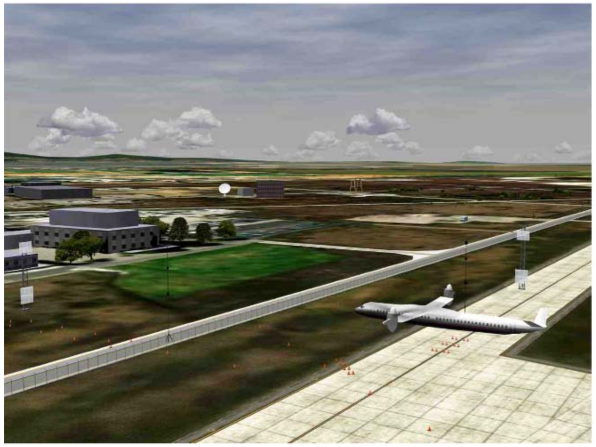


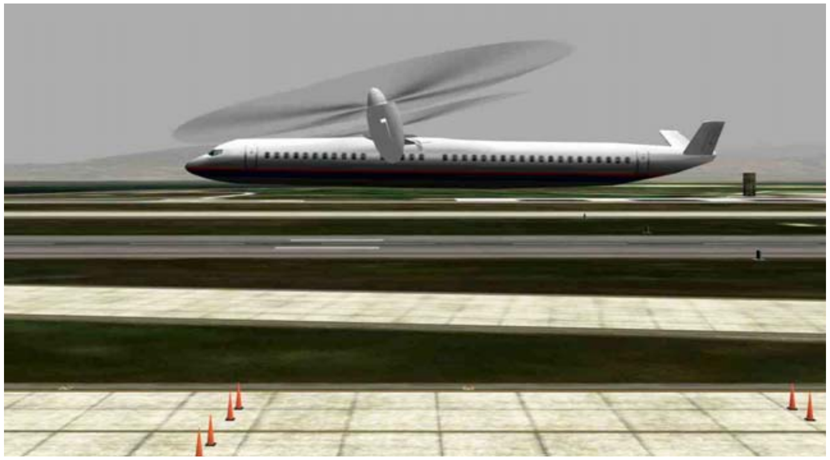
SRW – Five Technical Challenges

- Integrated Aeromechanics/Propulsion System (IAPS): Develop and demonstrate technologies enabling variable-speed rotor concepts
  - **Goal**: 50% main rotor speed reduction while retaining propulsion efficiency
  - **Benefits:** very high-speed, efficient cruise; efficient hover; reduced noise, increased range
- Actively-Controlled, Efficient Rotorcraft (ACER): Simultaneously increase aerodynamic efficiency, control dynamic stall, reduce vibration, reduce noise
  - **Goal**: 100 kt speed improvement over SOA; noise contained within landing area; 90 pax /10 ton payload
  - **Benefits**: very high-speed, efficient cruise; efficient hover; reduced noise; improve ride quality
- Quiet Cabin (QC): Reduce interior noise and vibration
  - **Goal**: Internal cabin noise at level of regional jet with no weight penalty
  - **Benefit**: passenger acceptability; increased efficiency through weight reduction
- NextGen Rotorcraft: Foster, develop and demonstrate technologies that contribute to the commercial viability of large rotary wing transport systems in NextGen.
  - **Goal**: mature technologies (icing, crashworthiness, condition based maintenance, low noise flight operations, damage mitigation, etc) needed for civil, commercial operations
  - **Benefit**: enables vehicle acceptability for passengers and operators
- High Fidelity Validated Design Tools: Develop the next generation comprehensive rotorcraft analysis and design tools using high-fidelity models.
  - **Goal:** first-principles modeling in all disciplines; ensure design tools are hardware flexible and scalable to a large numbers of processors
  - **Benefit:** Reduce design cycle time and cost of NextGen rotorcraft; increase confidence in new concept design

Large Rotorcraft Flight Control and HQ Studies

- 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 and helicopter industry
- Current status:
  - Three successful hover and low speed experiments in the VMS (2008, 2009 & 2010)





Large Civil Tiltrotor 2nd Generation (LCTR2)

- NASA's notional high-speed configuration:
  - Baseline gross weight 103,600lb (47,000kg)
  - 65ft (20m) Diameter rotors, 107ft (32.6m) Wingspan
  - Cockpit 40ft ahead of Center of Gravity
- Capabilities:
  - 90 passengers, Speed 300kts, Range 1000nm (nominal)

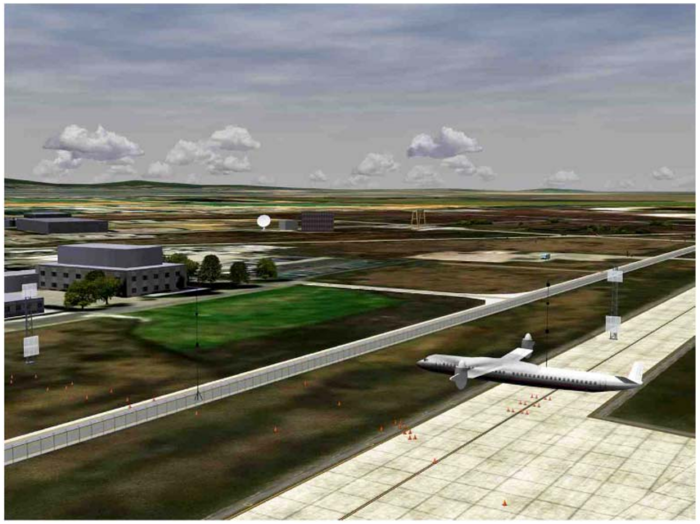
Reference: Acree, C. W., Hyeonsoo, Y., and Sinsay, J. D., "Performance Optimization of the NASA Large Civil Tiltrotor" International Powered Lift Conference, London, UK, July 22-24, 2008

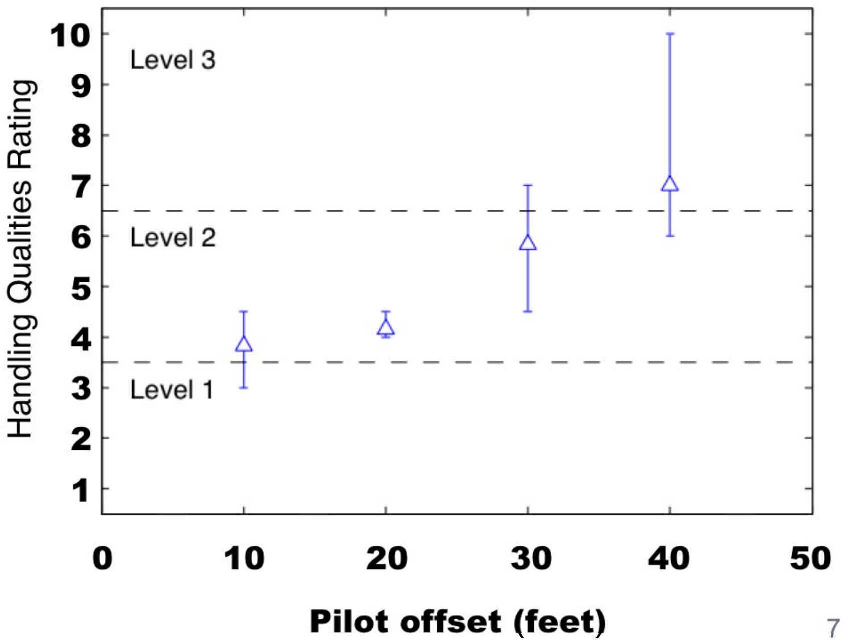
2008 & 2009 Experiments

- 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)
  - Impact of large (40 feet) cockpit to CG distance immediately evident

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

- *Key Result: Advanced control modes required for improved Handling Qualities*



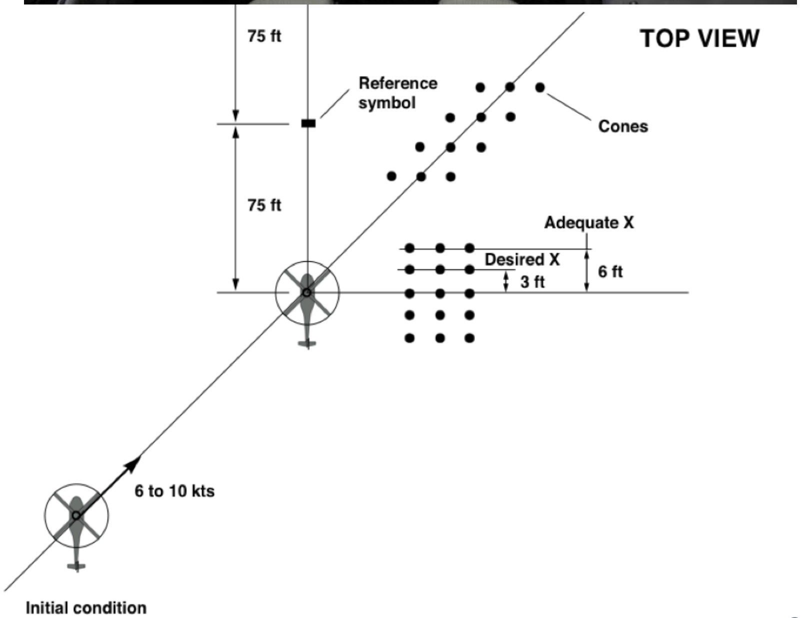


2010 LCTR Experiment

- Objectives:
  - Investigate Translational Rate Command (TRC) using automatic nacelle motion
  - Evaluate Handling Qualities beyond hover into the low speed flight regime

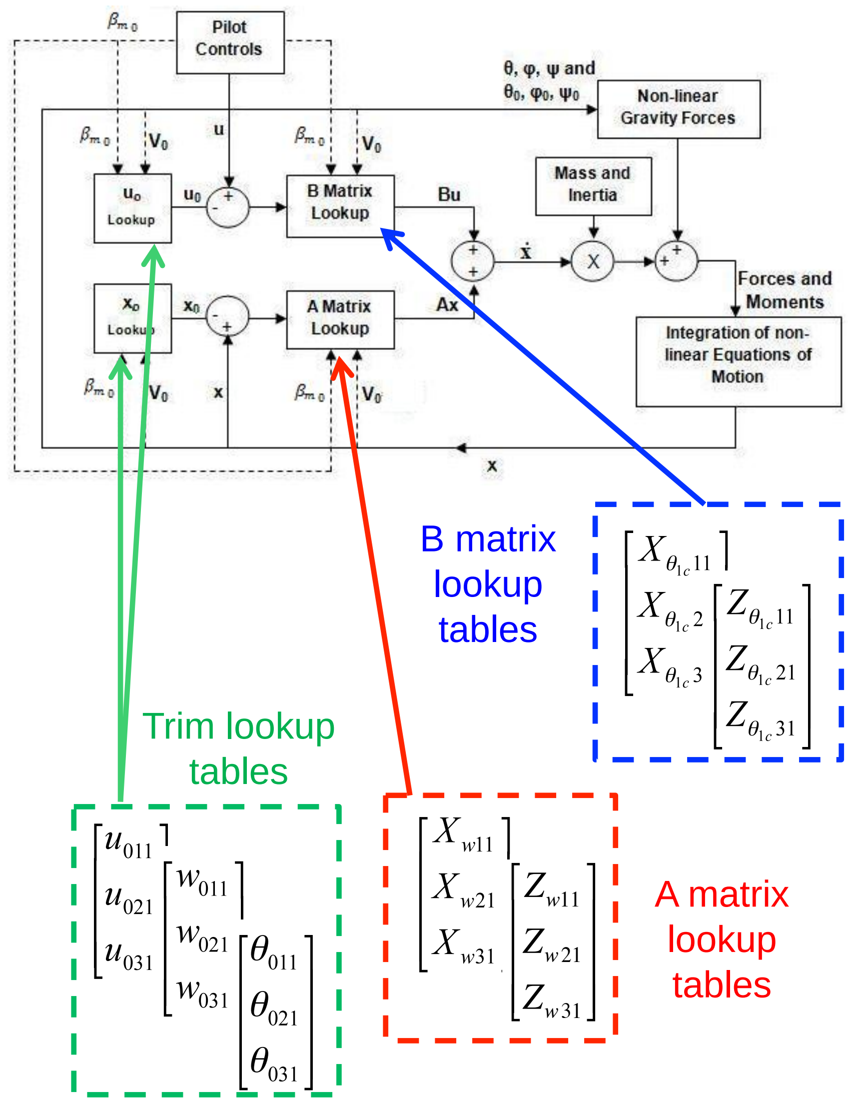
- Control Modes:
  - ACAH
  - TRC
  - Hybrid (TRC with non-zero roll attitude)

- Evaluation maneuvers:
  - Precision hover task
  - Lateral reposition
  - Depart/Abort (ACAH mode only)



Vehicle Dynamics Modeling

- New modeling requirements:
  - Movable nacelles from hover to 60 deg
  - Model valid from hover to 60 knots
  - Independent rotor control to enable TRC
- Modeling approach:
  - Linear models from CAMRAD II
  - Linear Parameter Variation (LPV) stitched model
  - Independent parameters:
    - Forward speed
    - Nacelle angle
- Addition of nacelle degree of freedom
  - Modeled as 2nd order dynamic system
  - Fixed bandwidth and damping
  - Variable rate and position limits

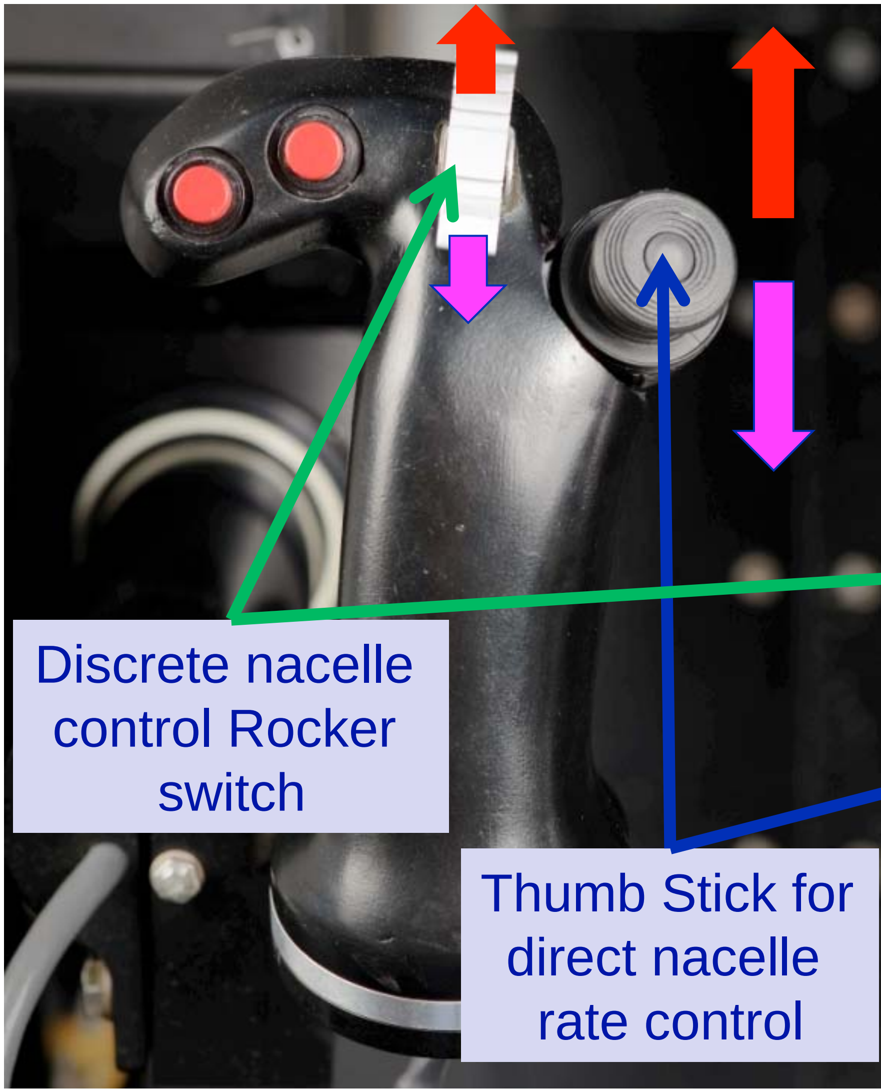


Experiment Variables

- Variables:
  - Control system response type: ACAH, TRC, Hybrid
  - Nacelle actuator rate and position limits in TRC mode
  - TRC inception methods of thumb stick and center stick
  - TRC inceptor stick sensitivity

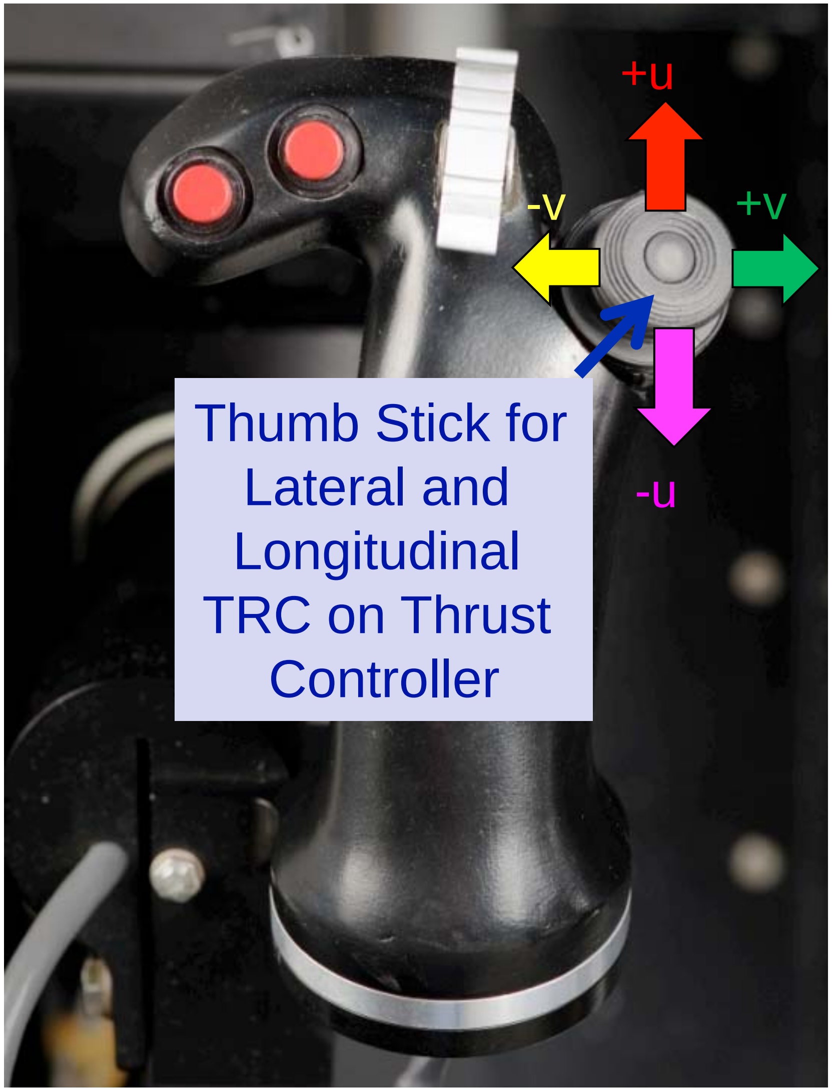
- Experiment performed in July 2010:
  - 4-weeks of motion in VMS
  - 10 pilots from NASA, US Army, Marine Corps, rotorcraft industry

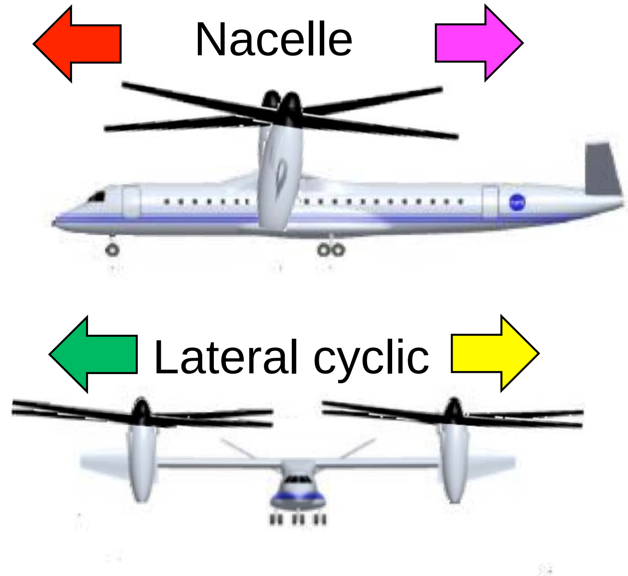
Direct Nacelle Control (ACAH)



Discrete 'Beep' Mode		Direct rate command
Stops at 95^0, 86^0, (80^0), 75^0, 60^0	±2 deg/s	±7.5 deg/s max

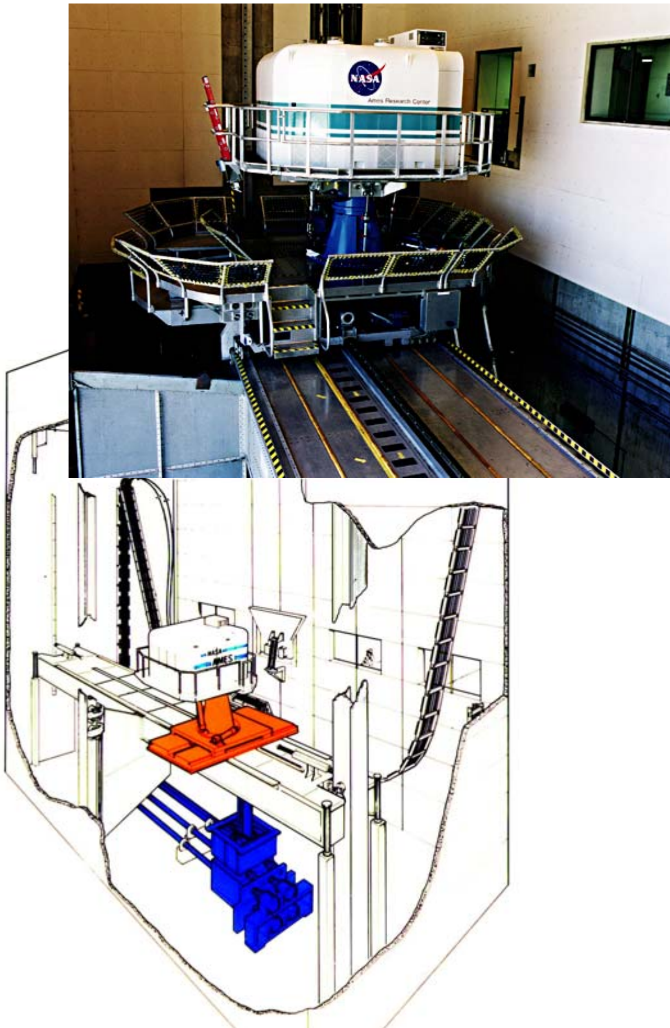
Translational Rate Control





- Thumb stick provides 2-axis proportional control of longitudinal and lateral TRC
- TRC also commanded through center stick
- Nacelle actuators featured separate configurable angle and rate limits in TRC

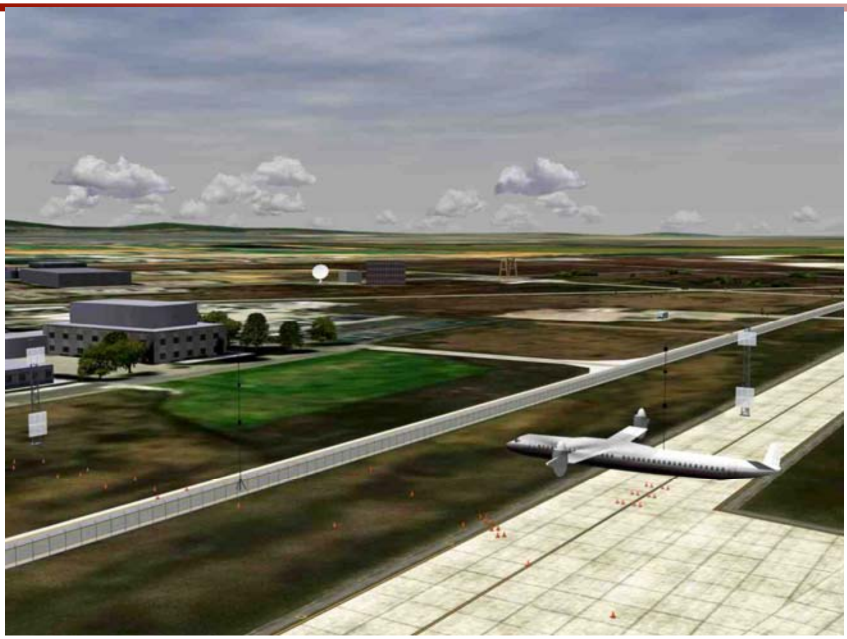
Vertical Motion Simulator (VMS)

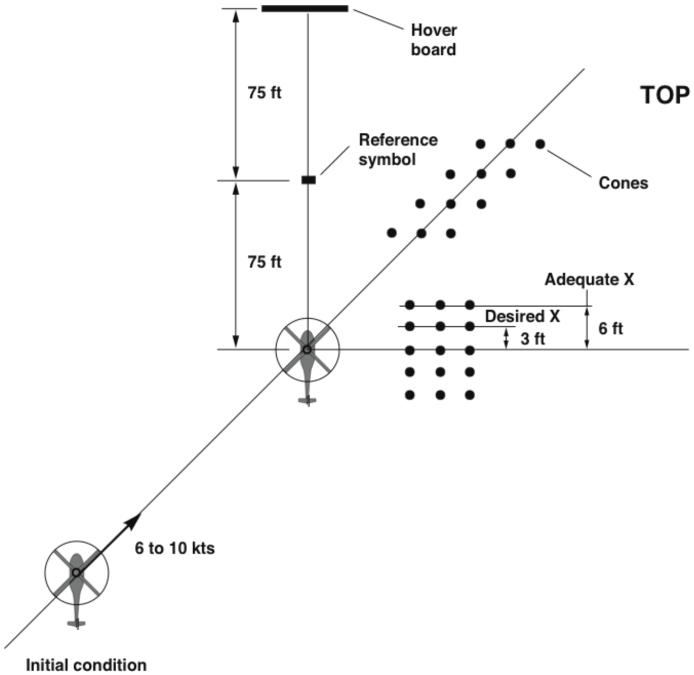


Large motion platform

Overview of two-seat transport cockpit

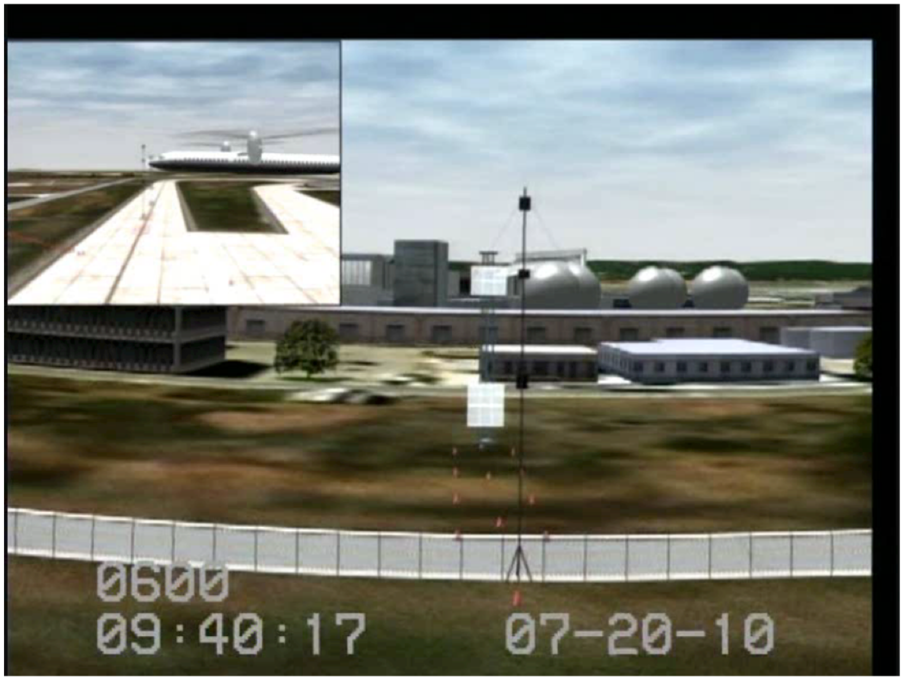
Precision Hover Task Description



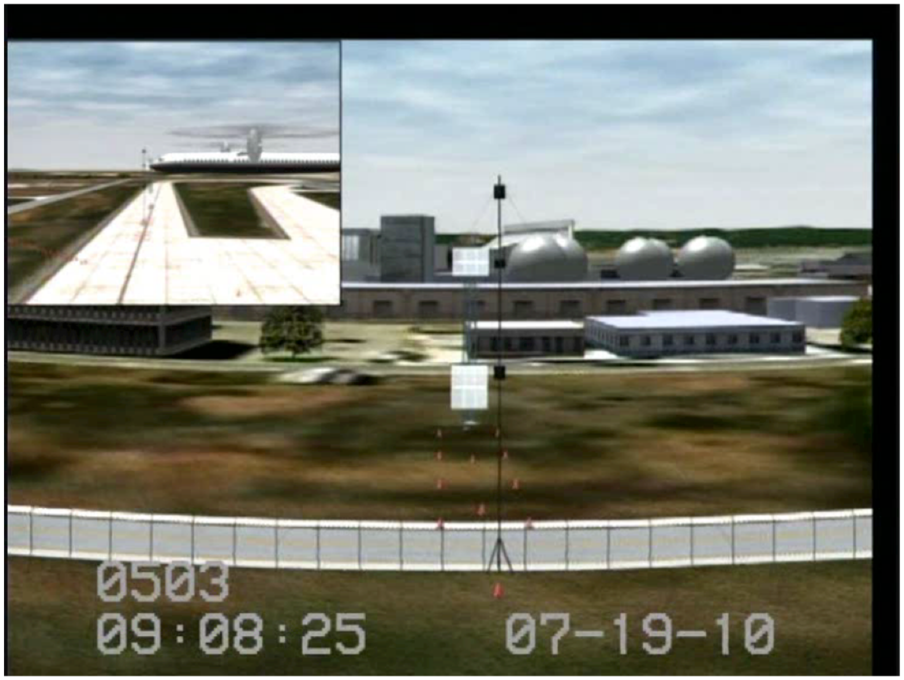


1. Diagonal translation @ 6 - 10 kts.
2. Decelerate within 5 sec.
3. Station keeping for 30 sec.

Control Comparison (Hover)

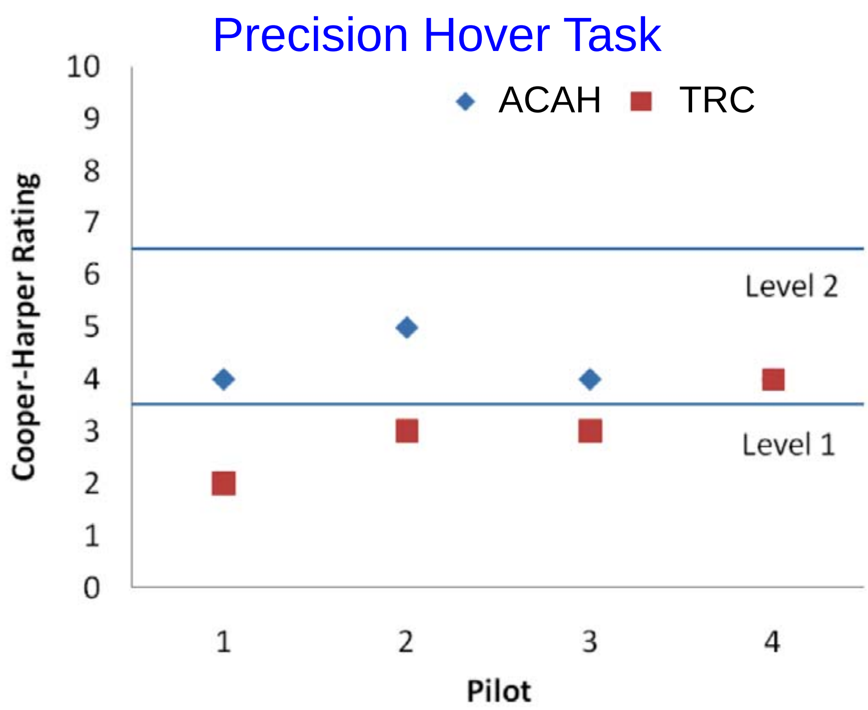


Attitude
Command
Attitude Hold



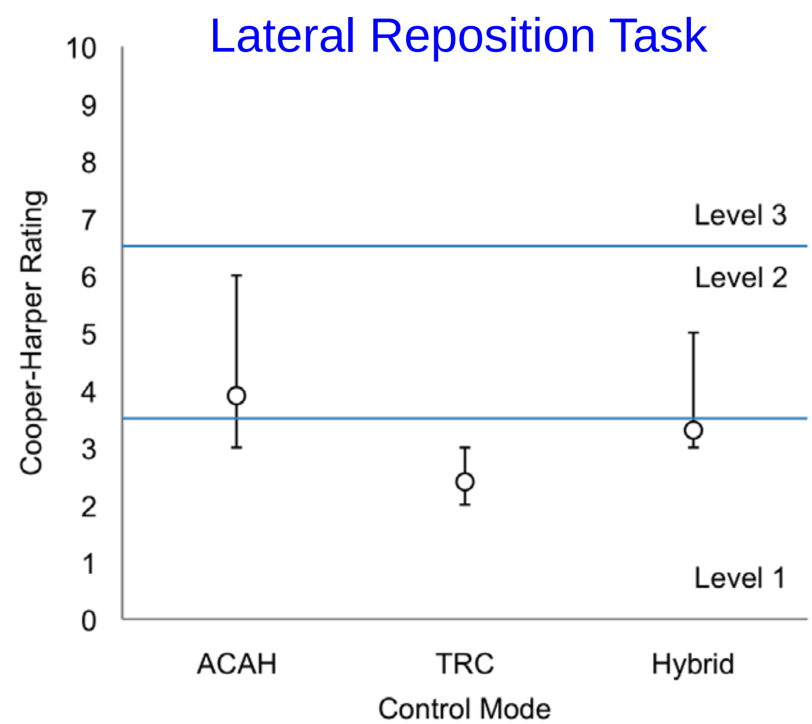
Translational
Rate Control

Preliminary Results



Precision hover task evaluations for 4-pilots

Level 1 HQ achieved for 3 of 4 pilots with TRC control mode



Lateral reposition evaluations for all pilots combined

Level 1 HQ with TRC for all pilots with low scatter in data

Depart/Abort Maneuver

ACAH – Nacelles being controlled directly by pilot

Conclusions

- Current achievements:
  - Possible to achieve Level 1 Handling Qualities in hover and low speed flight with a TRC control system and automatic nacelle motions
  - Understanding of fundamental effects of aircraft size (mass and inertias) and pilot to C.G. offset on handling qualities

- 2011 VMS Experiment:
  - Continue hover/low speed HQ work with advanced control model (TRC and others) and low bandwidth nacelle actuator response
  - Study initial terminal area operations:
    - Expand speed envelope out to 120 knots
    - Develop initial set of evaluation tasks and metrics

Future VMS / Handling Qualities Research

- 2011 – 2012 Experiments:
  - Continue hover/low speed HQ work with advanced control modes (TRC and others), control mode switching and low bandwidth actuator response
  - Assess aspects of operation of large rotary wing vehicles in terminal areas
- 2013 – 2014 Experiments:
  - Handling Qualities and pilot workload analysis of candidate advanced acoustics flight profiles
  - Develop pilot interface guidance displays to support advanced flight profiles
- 2015 – 2016 Experiments:
  - Full-envelope mission simulation with rotor speed shifting and noise abatement guidance using candidate NextGen operating procedures
- 2017 – 2018 Experiments:
  - Real-time coupling of LCTR VMS simulation and air-traffic simulations for NextGen integration studies and experimentation

NASA