Generic Research Simulator Requirements for Prediction of Adverse Rotorcraft Pilot Couplings in the Heave Axis

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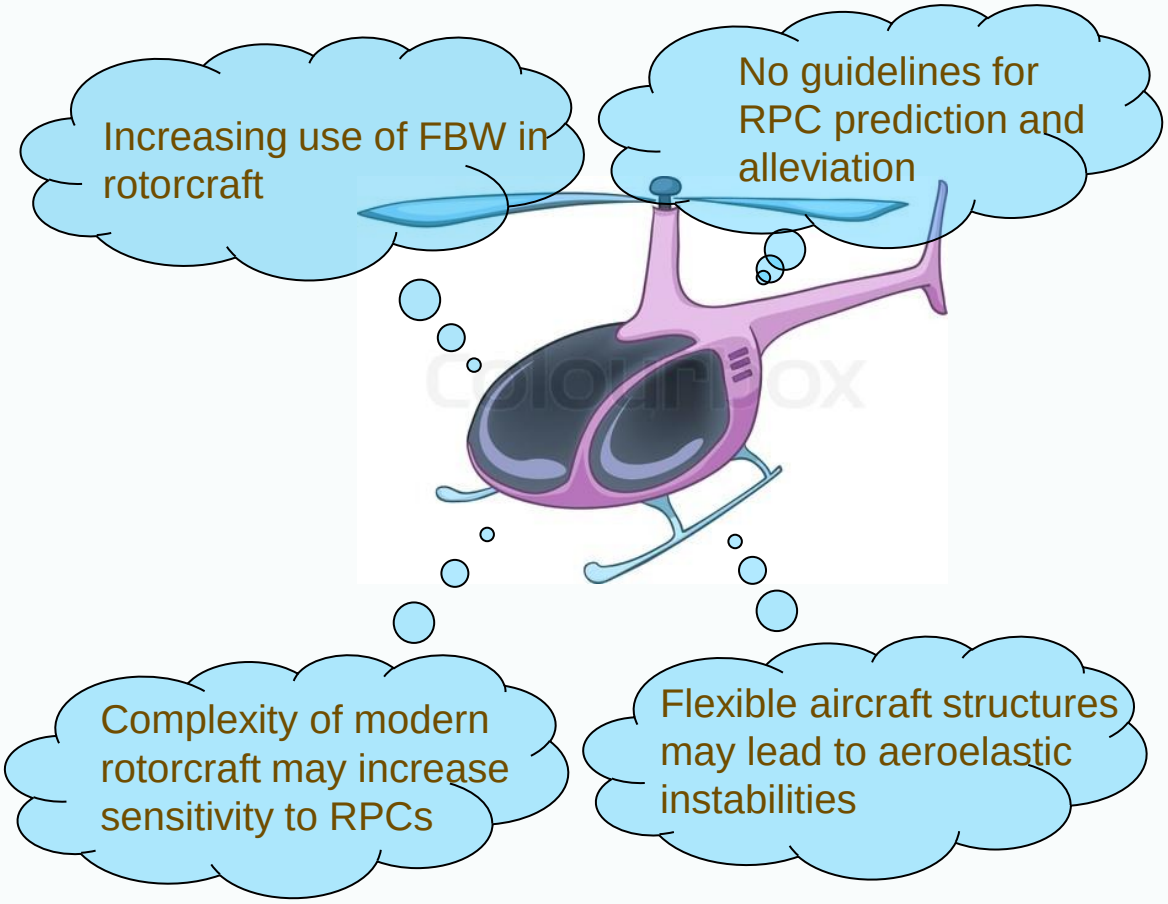
Outline

1. Use of flight simulation to expose RPCs
   a. The RPC problem
   b. Goals of the research
   c. Simulator cueing environment
   d. Baseline experiments
2. Influence of Vestibular Motion Cueing
   a. Previous work
   b. Subjective opinion
   c. Performance metrics
3. Preliminary Conclusions and Future Research

Rotorcraft Pilot Couplings

- Undesirable and unwanted, potentially dangerous interactions between the pilot and the vehicle.
- Concern that frequency and severity of RPCs is to increase
- EC Funded Project ARISTOTEL intends to develop understanding of potentially dangerous interactions,
  - to contribute to EC initiative to reduce aviation accidents by 80% by 2020 (similar to IHST initiative, 2006-2016, 80%)
- www.aristotel-project.eu



[1] Pavel et. al, A Retrospective Survey of Adverse Rotorcraft Pilot Couplings in European Perspective
[2] Masarati et. al, Theoretical and Experimental Investigation of Aeroelastic Rotorcraft Pilot Couplings

Rotorcraft Pilot Couplings

- Much of the understanding about RPCs comes from Handling Qualities research campaigns
- Some recent (2000-) research relating specifically to RPCs:
  - Ongoing research
    - Real-time prediction algorithms
    - Underslung/external loads
    - Pilot performance aids/warning systems
  - GARTEUR Action Group 16
    - Rigid body, aeroelastic and biodynamic research themes
    - Some limited evidence that fixed-wing criteria suitable for rigid-body rotary-wing RPC prediction
    - Tau theory applied to Boundary-Avoidance Tracking PIOs
    - Modelling and testing methods developed for biodynamic/aeroelastic simulations
    - Limited but useful results led to the funding of ARISTOTEL

Goals of this Research

ARISTOTEL Problem 5

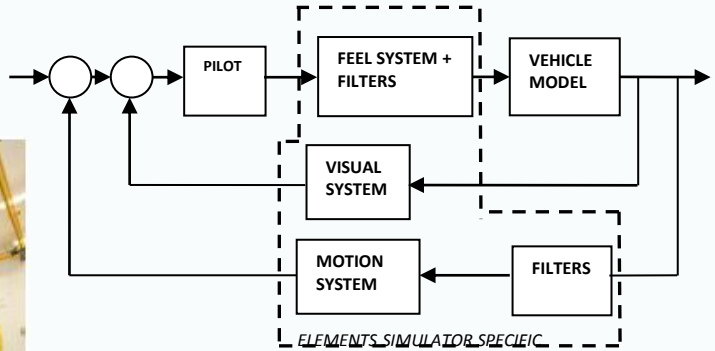
- No Simulator practices available to unmask RPCs

Objective

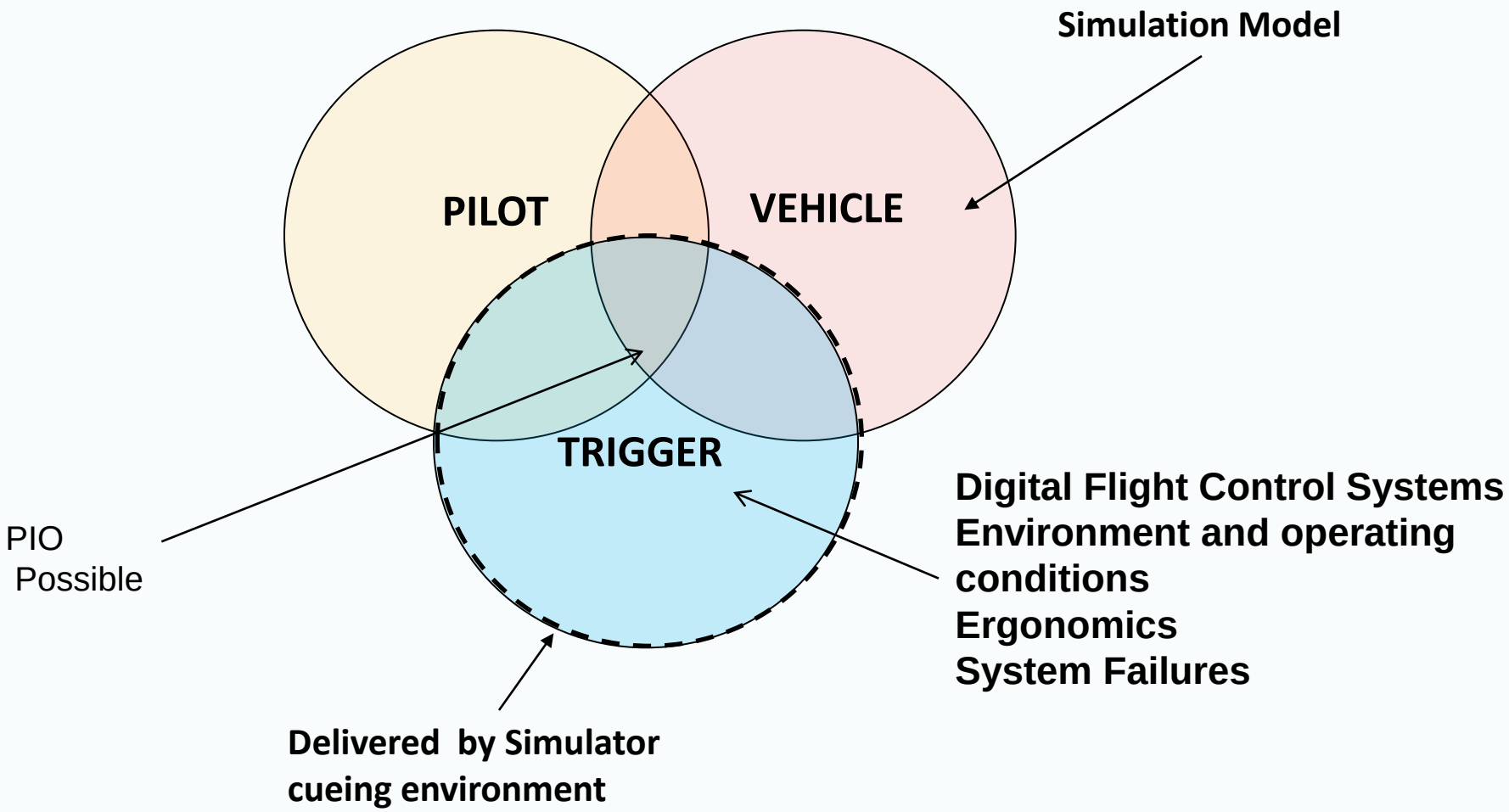
- Gain an initial understanding of effects of simulator cueing environment
- Sensitivity of RPCs

Selection of axis

- Heave axis;
  - Simplified linear models
  - Uncoupled dynamics
  - Rotorcraft specific



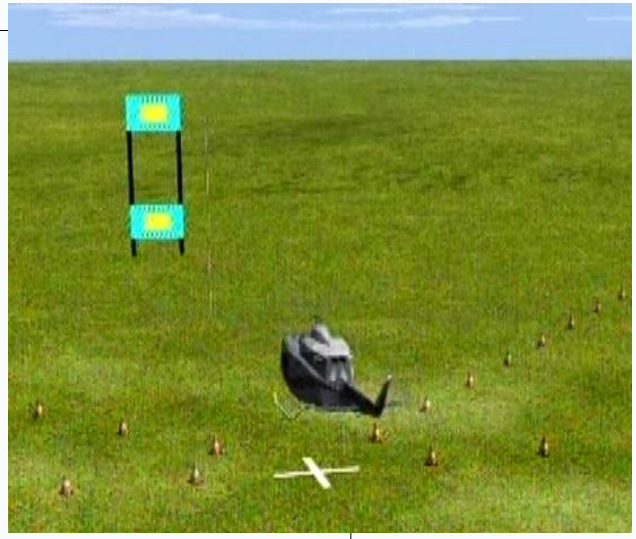
Simulator Cueing Environment



Experimental Method

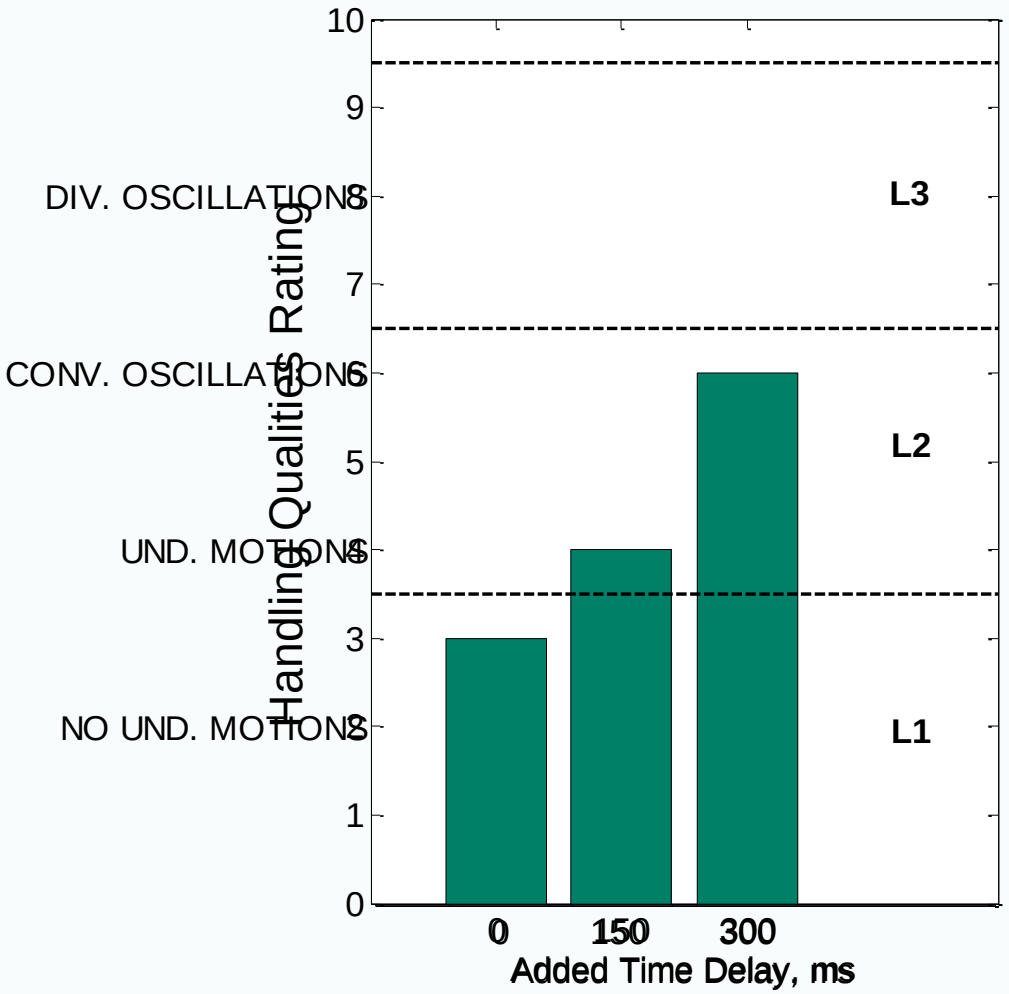
$$\frac{w}{\delta_c} = \frac{Z_{\vartheta c}}{s + Z_w} e^{\tau s}$$

- Single axis heave model with variable damping and added time delay
- Task derived from an ADS-33E-PRF maneuver
  - Complete 25ft translation within 5s
- Motion, visuals and control force-feel settings varied
- Analysis of results using:
  - Pilot Subjective Opinion
  - Performance Metrics
  - Statistical Analysis

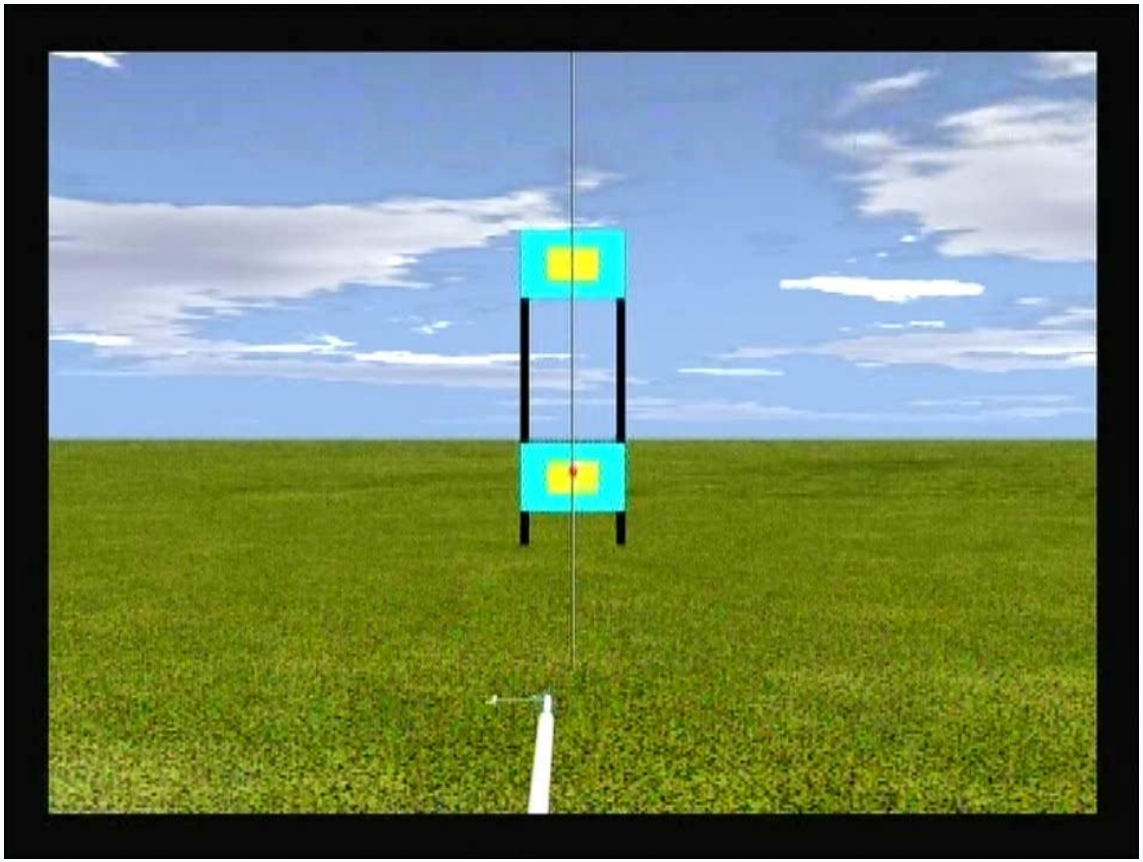


Baseline Investigation

- To gain an understanding of model RPC susceptibility
- Combinations of heave damping and time delays
- Comparison with current ADS-33 heave axis criteria
- Handling Qualities Ratings
- Pilot Induced Oscillation Scale Ratings

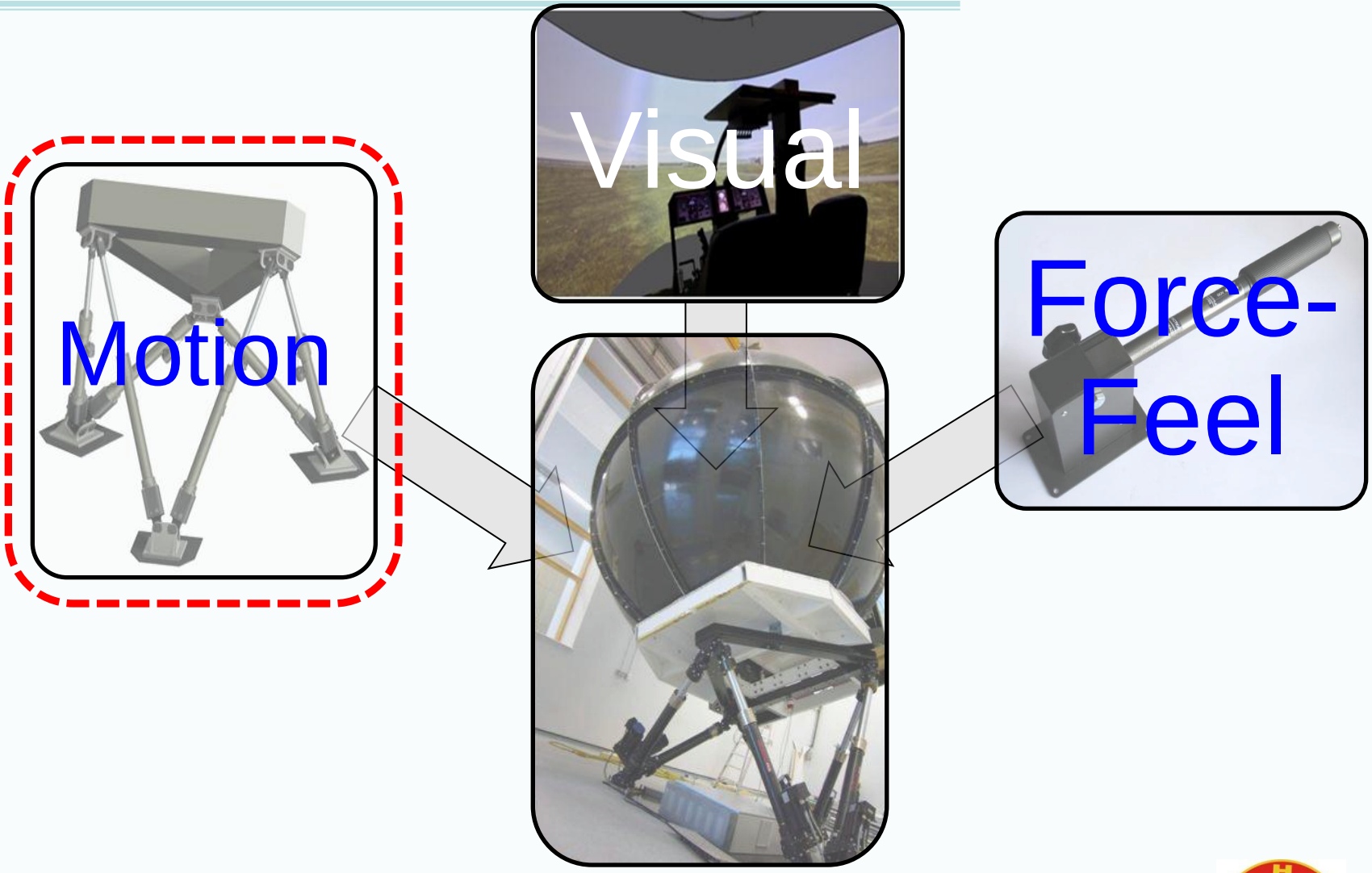


Baseline Investigation



- 0ms delay case;
  - RPC resistant case, no tendency for PIOs, Level 1 HQRs
- 150ms delay case;
  - RPC incipient, PIOs not found during baseline investigation
  - Increase in HQR suggests tendency for RPC
- 300ms delay case;
  - RPC prone (likely); PIOs apparent during baseline tests
  - Also shown through HQRs

Cueing Environment Investigations



Effects of Vestibular Motion Cueing

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Vestibular Motion Cueing – Previous Work

- Motion enhances task performance and handling qualities rating award correlation with flight test
  - Proven for vertical re-mask and compensatory tracking tasks
  - Change pilot subjective opinion, HQRs, from L2 to L1
- Pilot's more comfortable assessing their performance with motion
  - Higher confidence factor
  - Promotes realism (levels of stress, immersion)
- Its absence can be compensated by visual motion cueing
  - Simulator visual system can provide strong motion cues

[1] National Research Council. "*Aviation Safety and Pilot Control: Understanding and Preventing Unfavorable Pilot-Vehicle Interactions"*, Washington, DC: The National Academies Press, 1997.

[2] Schroeder,J. A. , "Helicopter Flight Simulation Motion Platform Requirements," National Aeronautics and Space Administration, Washington, District of Columbia, 1999.

[3] Mitchell,D. G. and Hoh,R. H. , "Ground-Based Simulation Evaluation of the Effects of Time Delays and Motion on Rotorcraft Handling Qualities," Systems Technology Inc., Ames Research Centre, Moffett Field, CA, 1986.

[4] Schroeder,J. A. and Chung,W. W. Y. , "Simulator Platform Motion Effects on Pilot-Induced Oscillation Prediction," *AIAA, Journal of Guidance, Control, and Dynamics,* 2000,

Motion Filter Selection

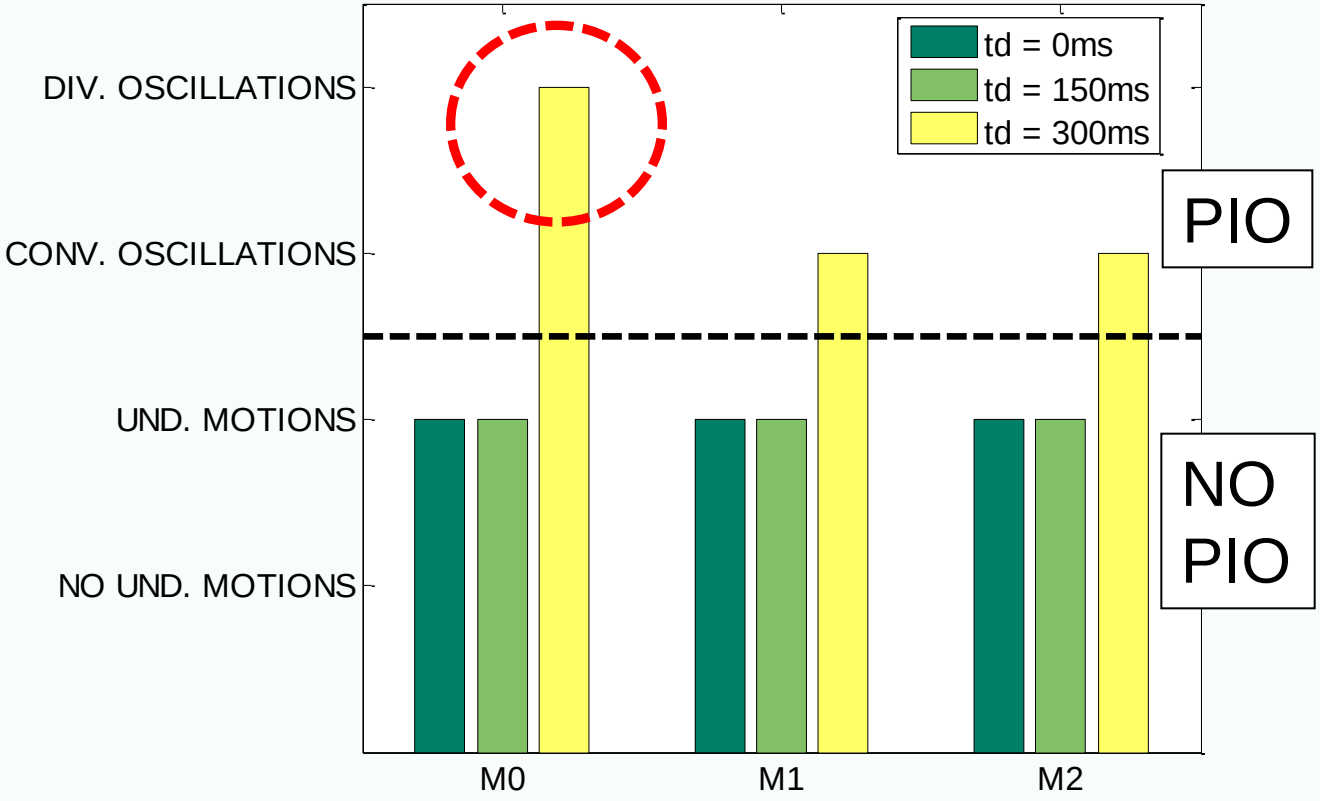
$$\frac{\ddot{h}_{com}}{\ddot{h}} = \left(\frac{Ks^2}{s^2 + 2\zeta_z \omega_z s + \omega_z^2} \right) \frac{s}{(s + \omega_b)}$$

Conf.	K	ω_z (rad/s)	ω_b (rad/s)	ζ_z
M0	0.0	-	-	-
M1	0.3	0.8	0.1	0.9
M2	0.6	0.8	0.1	0.9

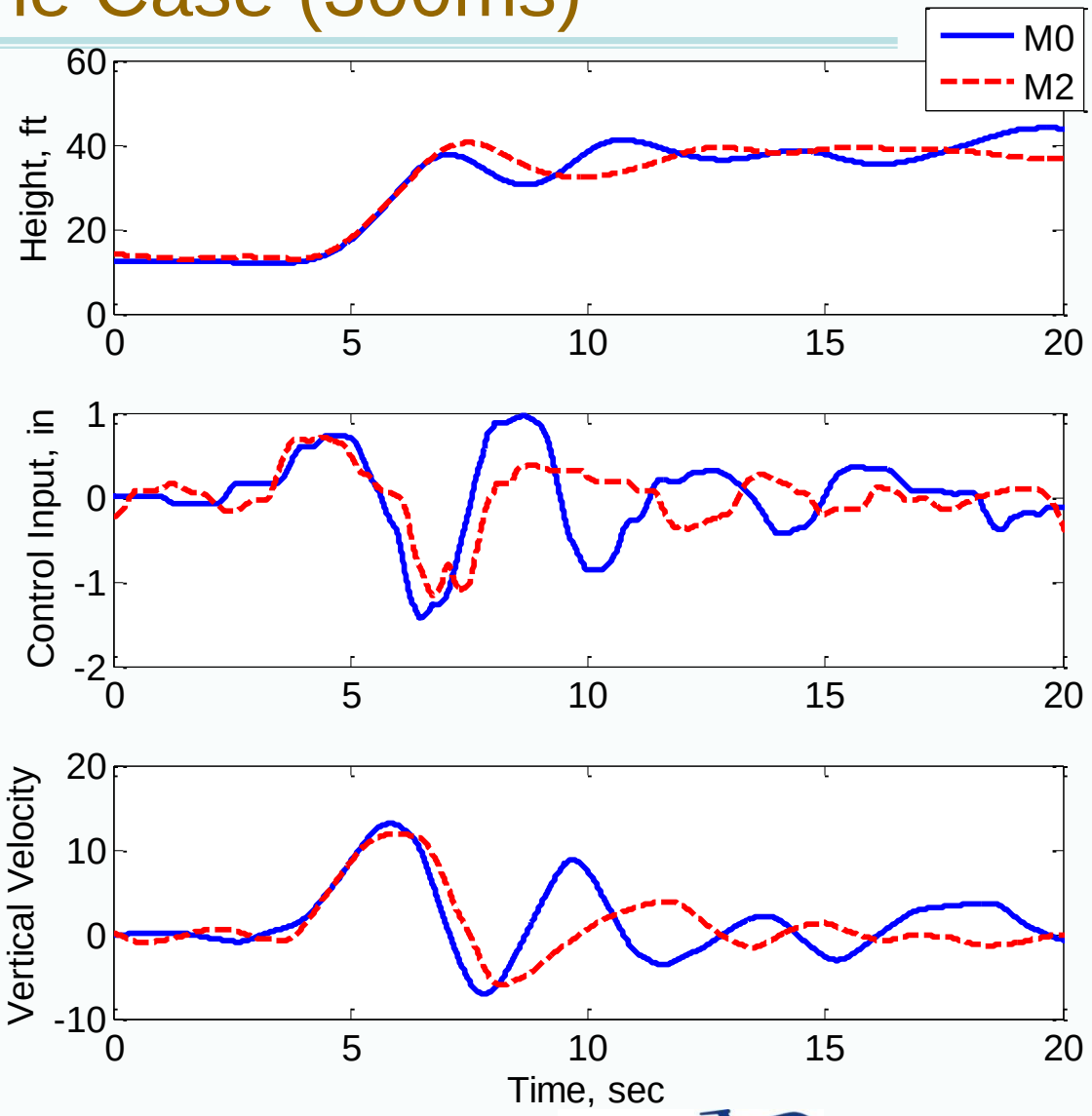
- 3rd order filter used
- Gain 'K' varied (3 values)
- Motion cues subjectively assessed:
  - No undesirable characteristics
  - Washout not perceptible
  - Pilot found it difficult to differentiate between 'no motion' (M0) with 'light motion' (M1)

Pilot Subjective Opinion

- Similar PIOR trend for all motion cases
- All 300ms time delay cases showed PIO (RPC) susceptibility
- Only ‘motion off’ led to oscillations that the pilot felt would be divergent



RPC Prone Case (300ms)

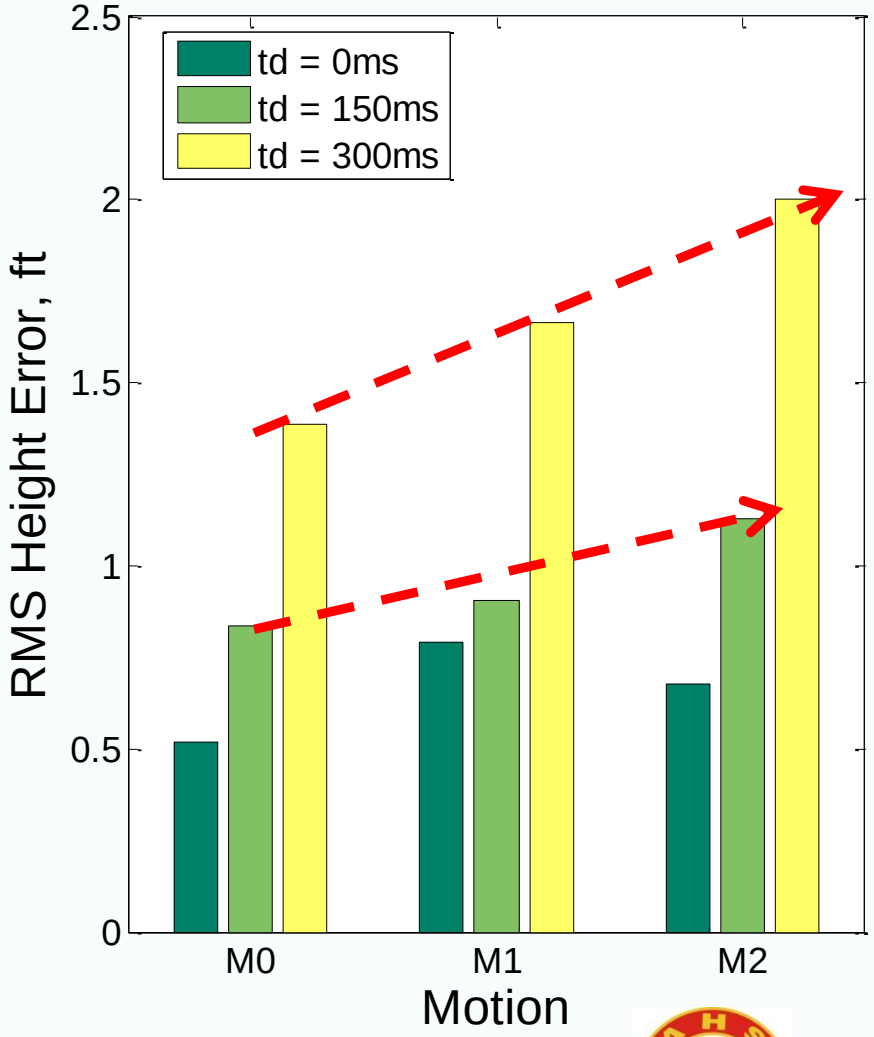


Performance Metrics

- Pilot Subjective opinion gives results for one case
  - The final case, ‘assessment run’
  - Result of learning curve
- Gives no indication of frequency of results
- Metrics calculated from average of all test points conducted, for stabilization element of task
  - Root-Mean Square Height Error
  - Root-Mean Square Control Input
  - Pilot Vehicle Phase difference

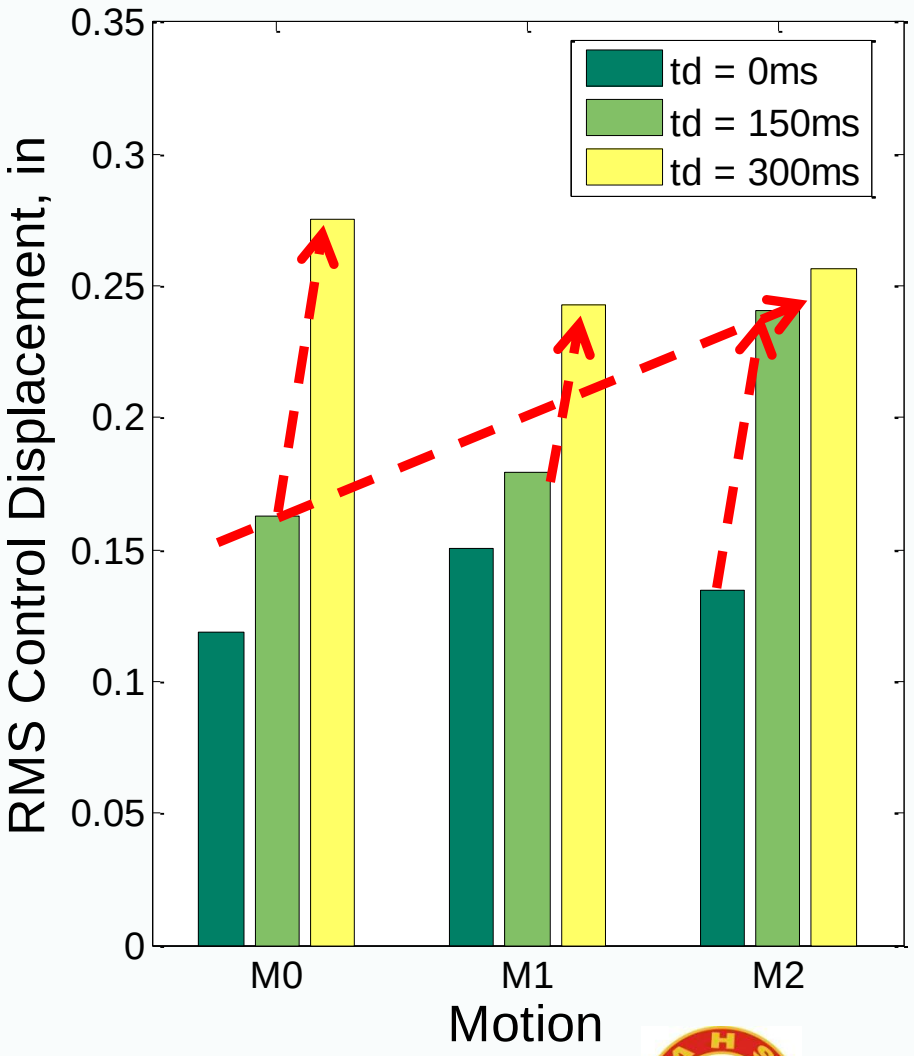
Height Error

- RMS Height Error
  - Increase gives indication of increase in task difficultly
  - In presence of time delays, indicates tendency for RPCs
- RPC prone case: RMS height error increases with increasing vestibular cueing
- Suggests frequency of RPC triggers may be increased using motion for ‘high gain’ pilots
- Similar but less pronounced trend for incipient case
- Agrees with previous research

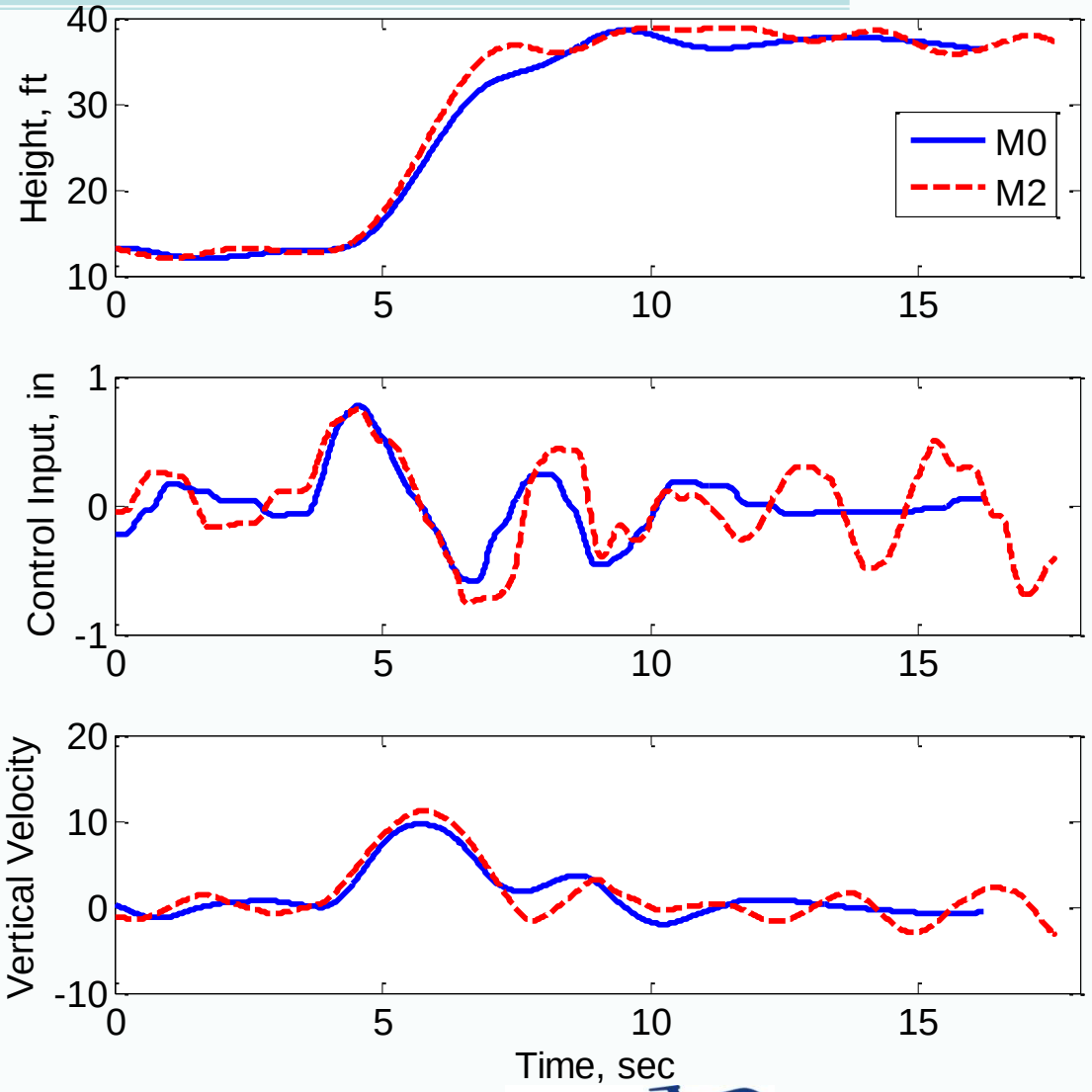


Control Displacement

- Mean Control Displacement
  - Larger values denote pilot exerting increased effort
  - Therefore, significant changes indicative of RPCs
- Motion apparently not affecting pilot strategy for 300ms
- Difference in delay showing marked increase in control displacement
  - M0 and M1 occurs between 150ms – 300ms
  - M2 occurs between 0ms –150ms
- Suggests a difference in RPC trigger boundary
- With larger motion cues, more likely to encounter events with lower time delays

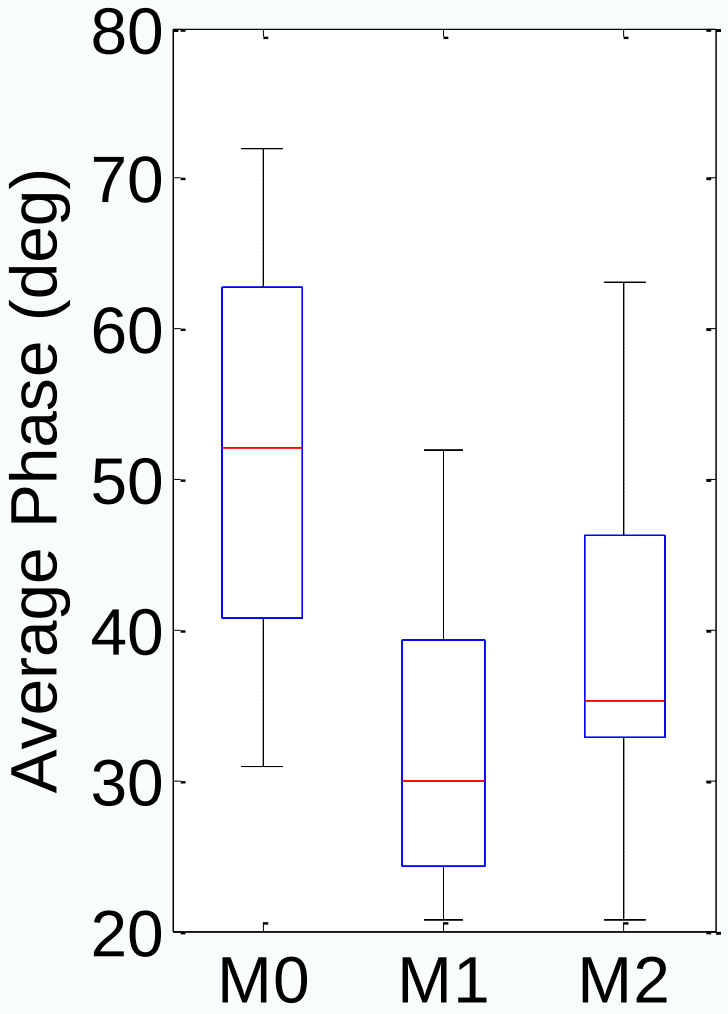


RPC Incipient Case (150ms)



Pilot-Vehicle Phase (300ms)

- Phase between Pilot input and vehicle rate output (vertical velocity)
  - Phase of 90 deg denotes instability
  - Bandwidth margin at 45 deg
- Average PVS phase for 300ms time delay case
- Motion 'off' case shows higher PVS than either of the motion 'on' cases
- Agrees with pilot subjective opinion
- Suggests once RPC encountered, event will be more severe in fixed-base simulators



Tentative Conclusions

1. Vestibular motion cues increase the likelihood of RPC event encounters
   a) Suggestion that as the motion gain increases, the time delay to trigger an RPC reduces

2. Absence of vestibular motion cues can lead to a more severe RPC simulator event
   a) Pilot-vehicle phase significantly increased motion ‘off’ for RPC-prone configuration
   b) In this study, divergent RPC events only encountered motion ‘off’

Recommendations

1. Complete further tests using more pilots and more fine-grained test matrix to ascertain any boundaries or cliff-edges

2. Repeat using different simulation facilities to obtain larger motion gains than possible with HELIFLIGHT-R

3. Repeat investigation using other primary vehicle axes
   a) Investigations already undertaken as part of ARISTOTEL test campaign
   b) Observe whether results found here are repeated for other vehicle axes (including cross-coupling)

QUESTIONS

The research leading to these results has received funding from the European Community's Seventh Framework Programme (FP7/2007-2013) under grant agreement N° 266073.

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