The Challenge of Developing Objective and Subjective Metrics for Rotorcraft Flight Simulators

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UK VERTICAL LIFT NETWORK

Overview

- Quantifying Fidelity
- Challenge Areas for Rotorcraft Simulation
- Flight and Simulator Facilities
- Predictive Fidelity
- Perceptual Fidelity
- Simulator Motion
- Ongoing Research Activities

Quantifying Fidelity

- Not all airplanes are “equal”…

…so we assess their handling qualities.

- Not all simulators are “equal”…

…so we assess their fidelity.

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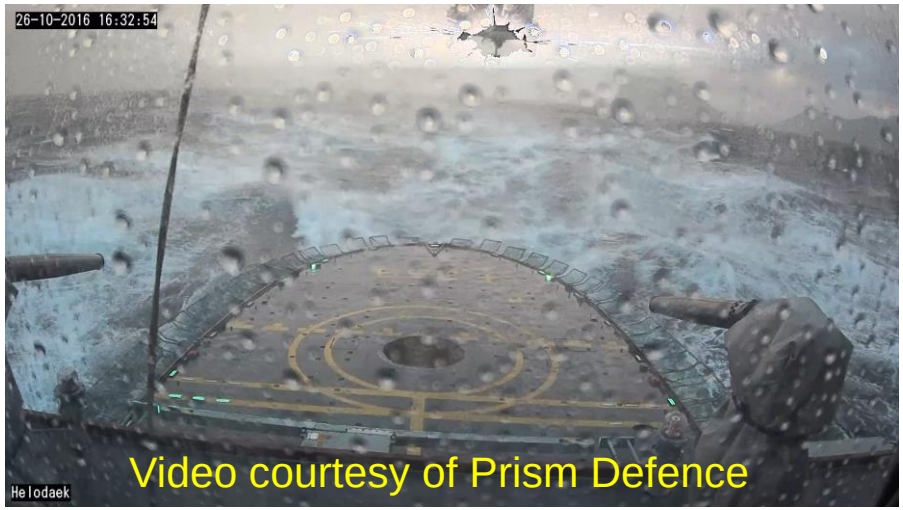
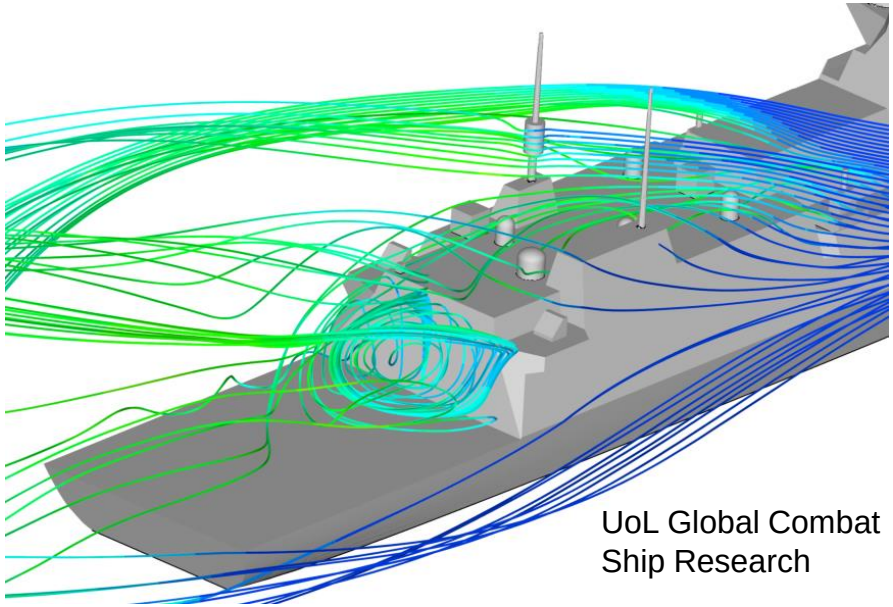
Challenge: How shall we evaluate and quantify simulator fidelity?

Not all simulation tasks are equal…



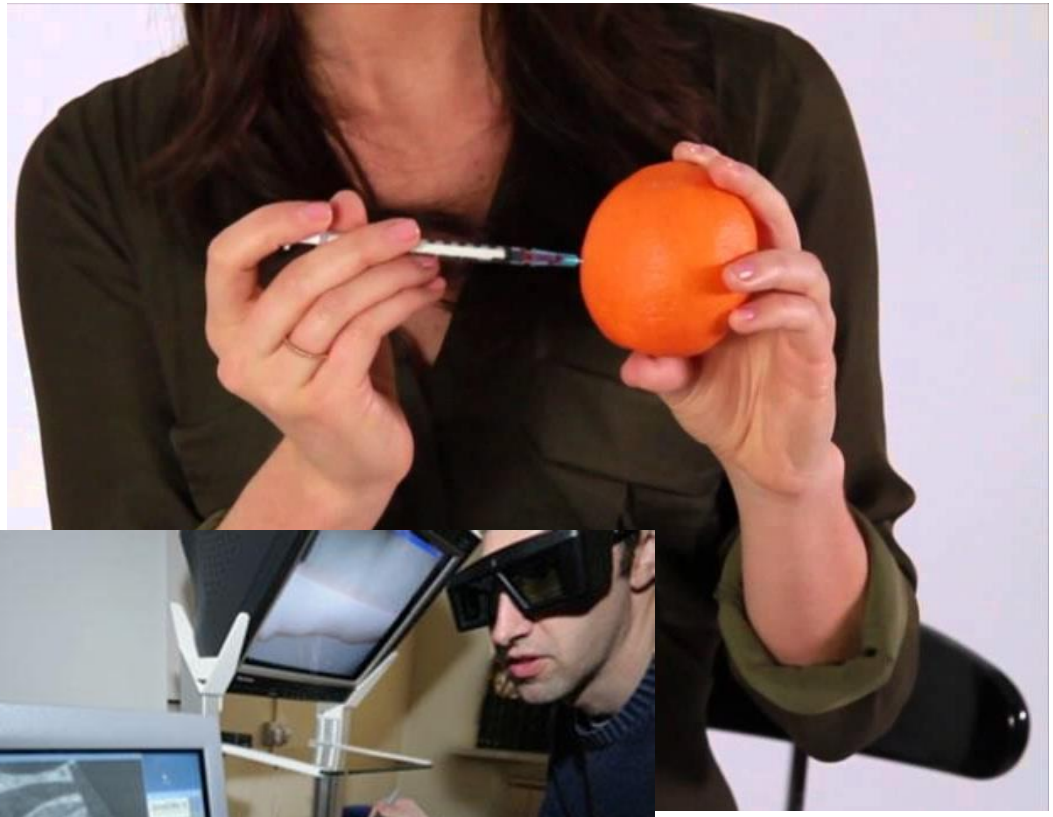


UoL Global Combat Ship Research

Flight simulation is becoming increasingly important in the support of rotorcraft operations

- Training
- Design & Development
- Certification
- Research & Teaching

Wise words – someone else's…



"Don't confuse complexity with fidelity"

Fidelity: Definitions..

- Fidelity: *"the physical and functional similarity of the training device to the actual equipment for which training is undertaken"*
  - Typically centers on the *device*
  - Problems: (1) measuring it, and (2) relating the measurement to the simulator's utility.

- Fidelity:

  (1) the degree to which a simulator imparts correct behaviours upon a trainee, or

  (2) the extent of positive training transfer.

Rotorcraft Simulation Fidelity Standards

- Current simulation qualification standards, such as CS-FSTD H and FAA AC 120-63 provide requirements for component level fidelity.
  - There is no quantitative test of the fidelity of the overall simulation
  - A subjective test is required, but is limited in scope
  - *“For the highest level of qualification, fidelity should be very close to the aircraft”*

Challenges for Rotorcraft Simulation Fidelity

GARTEUR HC Action Group AG-12: Validation Criteria for Helicopter Real-Time Simulation Models[1]

- Appropriateness of some CS-FSTD H criteria should be questioned
- Required tolerances for high fidelity sensitive to nature of manoeuvre flown
- A model that satisfies CS tolerances may give different HQs compared to flight test
- Use of ADS-33E-PRF (Handling Qualities Requirements for Military Rotorcraft) HQ metrics as a supplement for CS-FSTD H
- Need to bridge the gap between pilot subjective opinion and formal metrics
- Determine an objective means for assessing overall fidelity of a simulator

Other Challenges:

- Correct trend & magnitude, Inflow, Aerodynamic/Elastic, Interactional Aero
- Access to reliable datasets
- Simulator Motion……

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[1]Pavel MD, White MD, Padfield MD, Roth G, Hamers M, and Taghizad A, "Validation of mathematical models for helicopter flight simulators current and future challenges ", *The Aeronautical Journal*, RAeS, Volume 117, Number 1190, pp. 343 – 388 April 2013

Flight and Simulation Facilities

- Full authority, simplex Fly By Wire research system
- Handling qualities and control systems research, airborne simulation

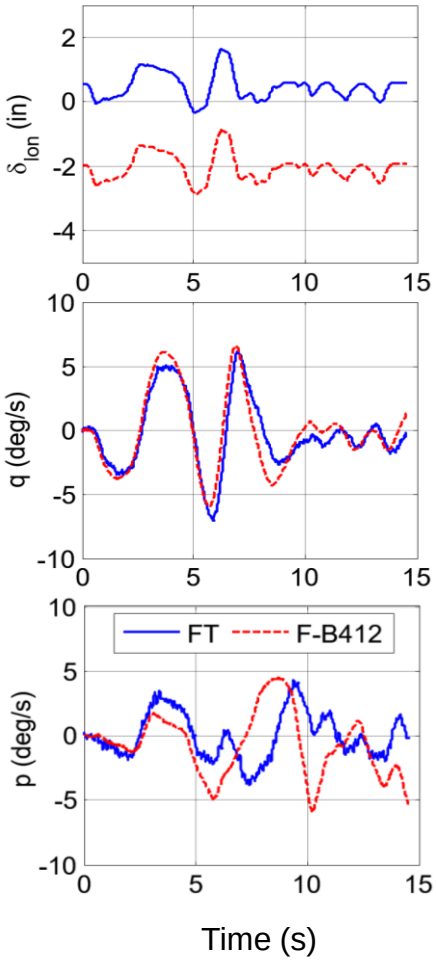
- 2 flight campaigns:
  - Gathering of flight test data for JAR FSTD H model validation
  - Assessment of new fidelity rating scale
  - Development of simulation manoeuvres

- 2 seat, interchangeable crew station
- 4 axis control loading
- Moog electric motion system
- Reconfigurable instruments
- 12 ft. diameter dome, 3 HD projectors 220x70 deg. FOV

White MD et al, “Acceptance testing and commissioning of a flight simulator for rotorcraft simulation fidelity research” in *Proceedings of the Institution of Mechanical Engineers, Part G: Journal of Aerospace Engineering*, Volume 227 Issue 4, pp. 663 – 686, April 2013

PREDICTIVE FIDELITY

Flight Model Tolerances, Manoeuvres – One Size fits All?

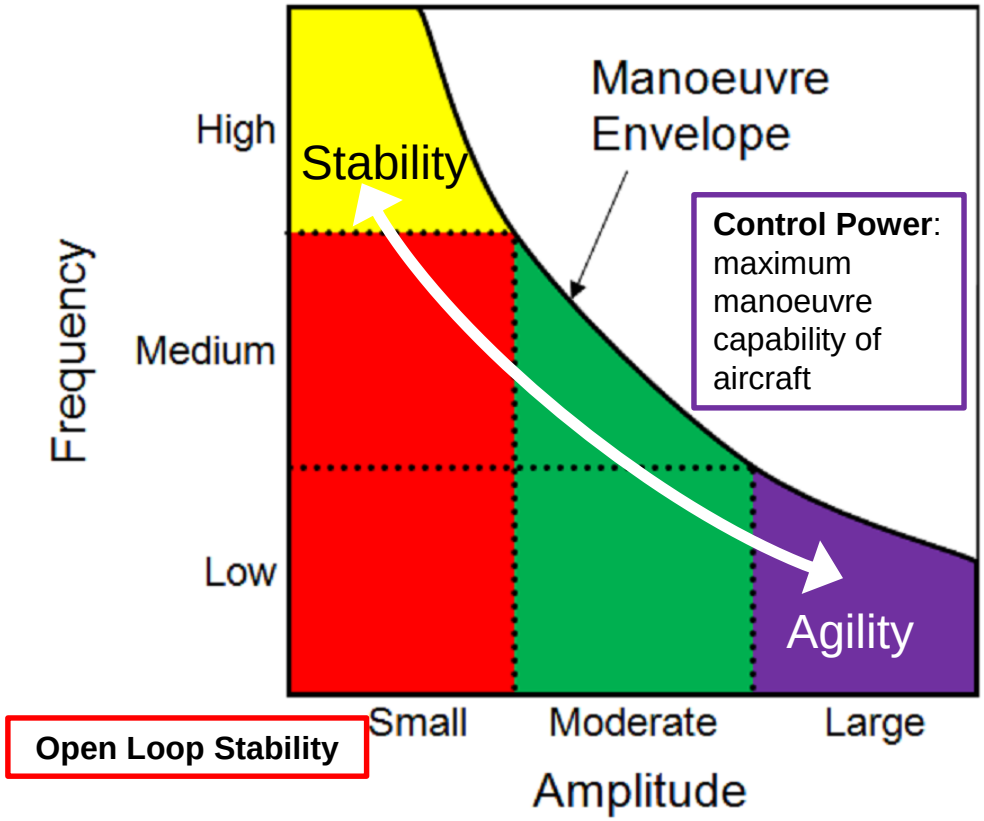


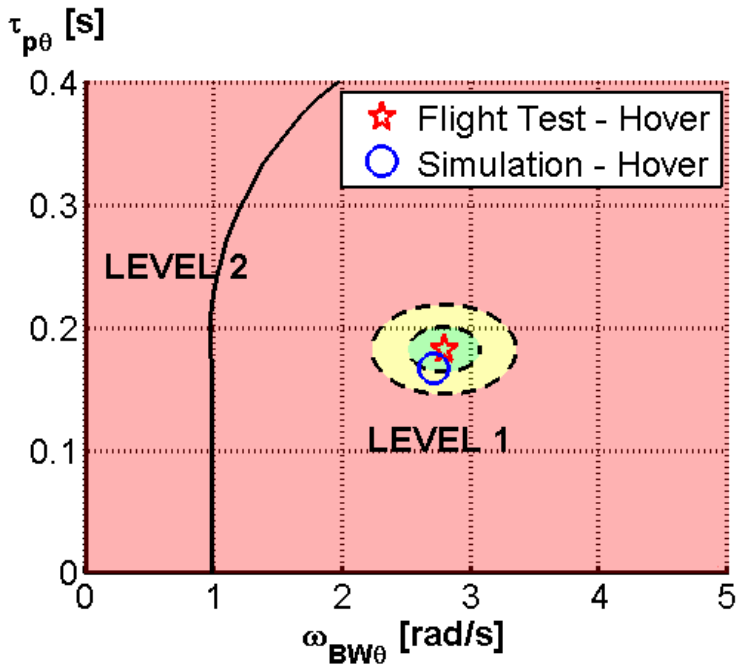
What manoeuvres & metrics should be used for fidelity assessments?

Predictive Fidelity – Dynamic Response Criteria

Bandwidth ω_{bw}, Phase Delay τ : reflect behaviour of the pilot-vehicle system

Quickness Q: ease with which new attitudes can be achieved





- ADS-33E-PRF Handling Qualities criteria employed
- Cross-coupling effects are also considered

Flight Model Updating

- Need to rationalise the ‘tuning’ process required to match CS-FSTD H criteria
- Model Renovation*
  - ***The process of improving the structure and performance of a nonlinear vehicle simulation model based on comparison with flight test data***
- Use of System Identification to create linear representations of both flight test vehicle and nonlinear simulation model
- NATO STO AVT-296 RTG3 “*Rotorcraft Flight Simulation Model Fidelity Improvement and Assessment*”

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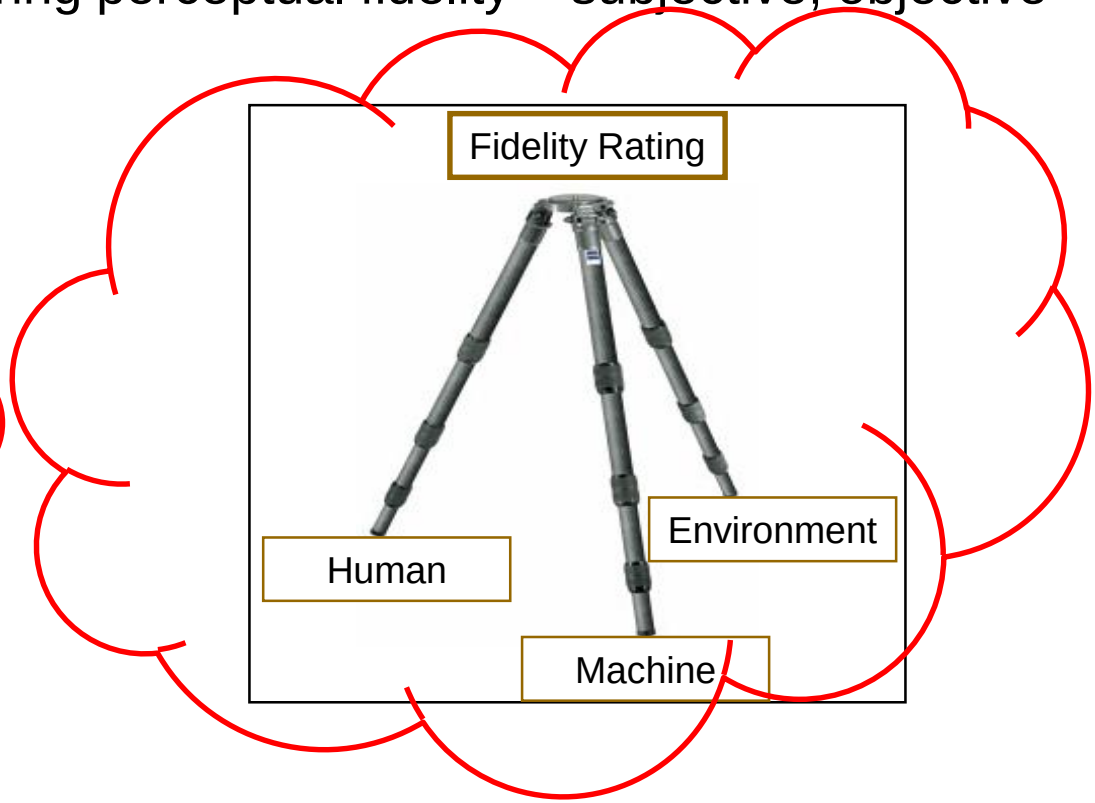
*Lu L, Padfield GD, White, MD, Perfect, P “Fidelity Enhancement of a Rotorcraft Simulation Model Through System Identification”, *The Aeronautical Journal*, Volume 115, No. 1170, pp. 453-470 August 2011

PERCEPTUAL FIDELITY

Practical Considerations in Fidelity Assessment

1. Pilot must be proficient in vehicle and task
2. Pilot must have recency of experience
3. Vehicle must be similarly configured
4. Test conditions must be comparable
5. Methodology for measuring perceptual fidelity – subjective, objective



Subjective Fidelity Assessment – Simulation Fidelity Rating (SFR) Scale

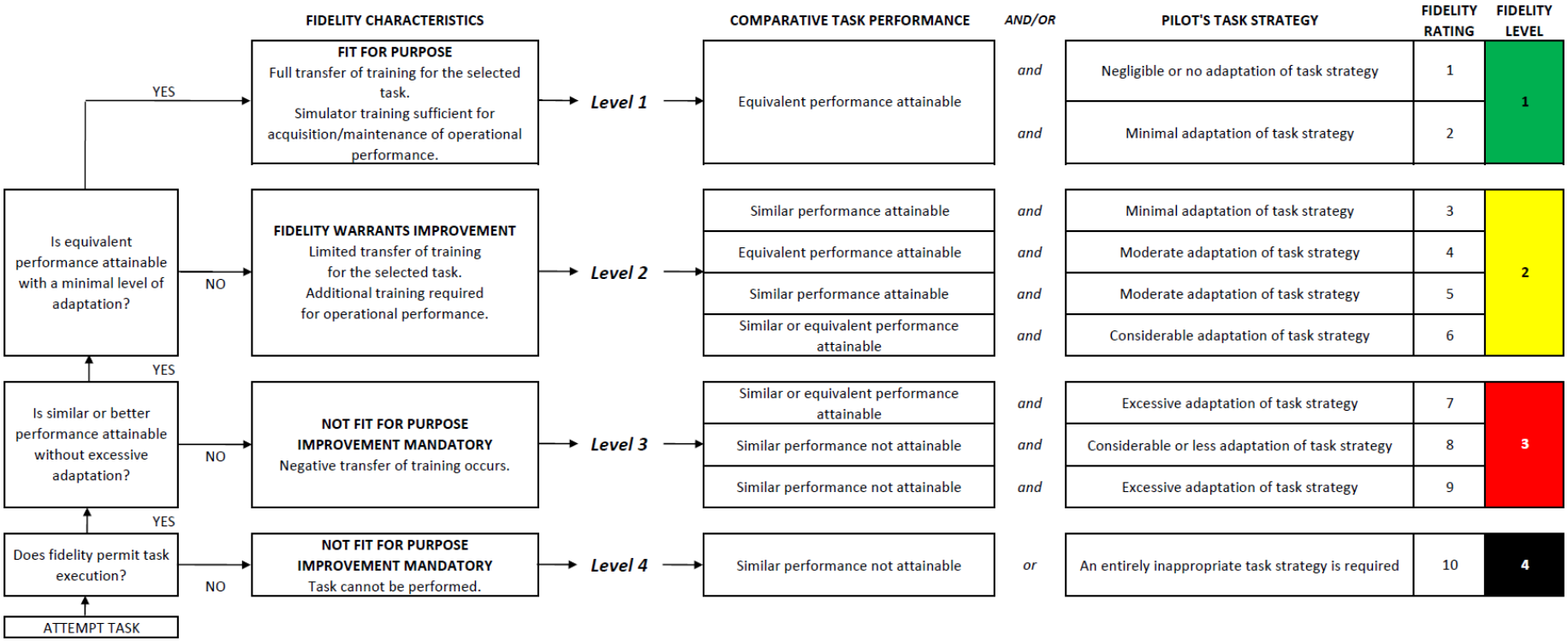
- A number of concepts are considered to be essential to measurement of simulator utility:
  - Comparative Task Performance
  - Task Strategy Adaptation
  - Transfer of Training
- Performance and Adaptation combine into a ‘matrix’ to define the Levels of fidelity:

Comparative Performance		
Equivalent	**Similar**	**Not Similar**

Perfect P, Timson E, White MD, Padfield GD, Erdos R and Gubbels AW, “A Rating Scale for the Subjective Assessment of Simulation Fidelity”, *The Aeronautical Journal*, August, Volume 11, No 1206, pp. 953 – 974, 2014

The SFR Scale

- Similar Performance
- Moderate Adaptation



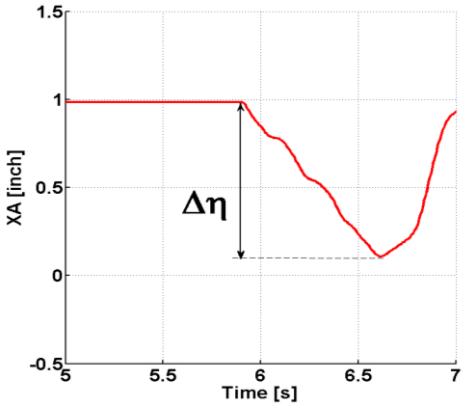
Objective Perceptual Metrics

The performance and compensation metrics are methods of assessing what the pilot perceived during the flight:

- **Performance**
  - Task time – total, in desired, adequate, beyond
  - Closed-loop quickness

- **Adaptation**
  - Time Domain
    - Control attack

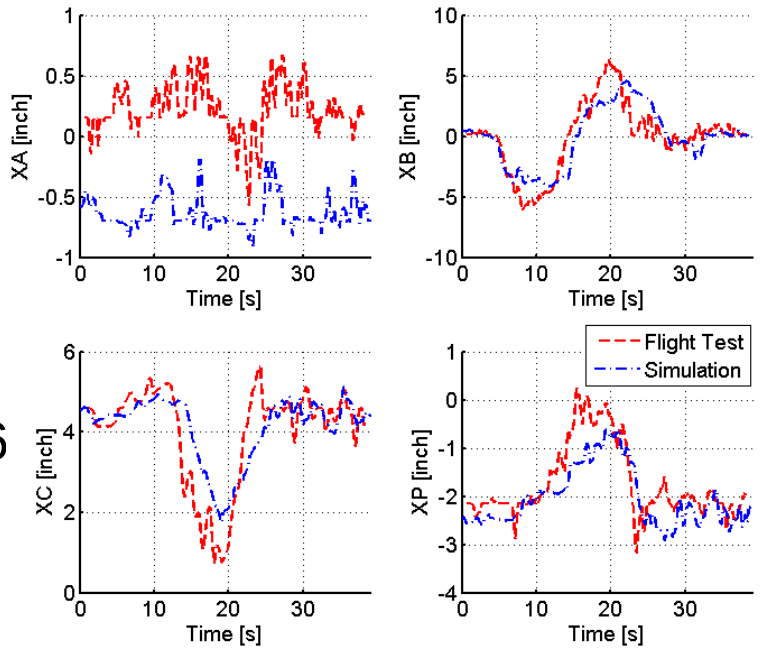
$$\text{Attack} = \frac{\dot{\eta}_{pk}}{\Delta\eta}$$



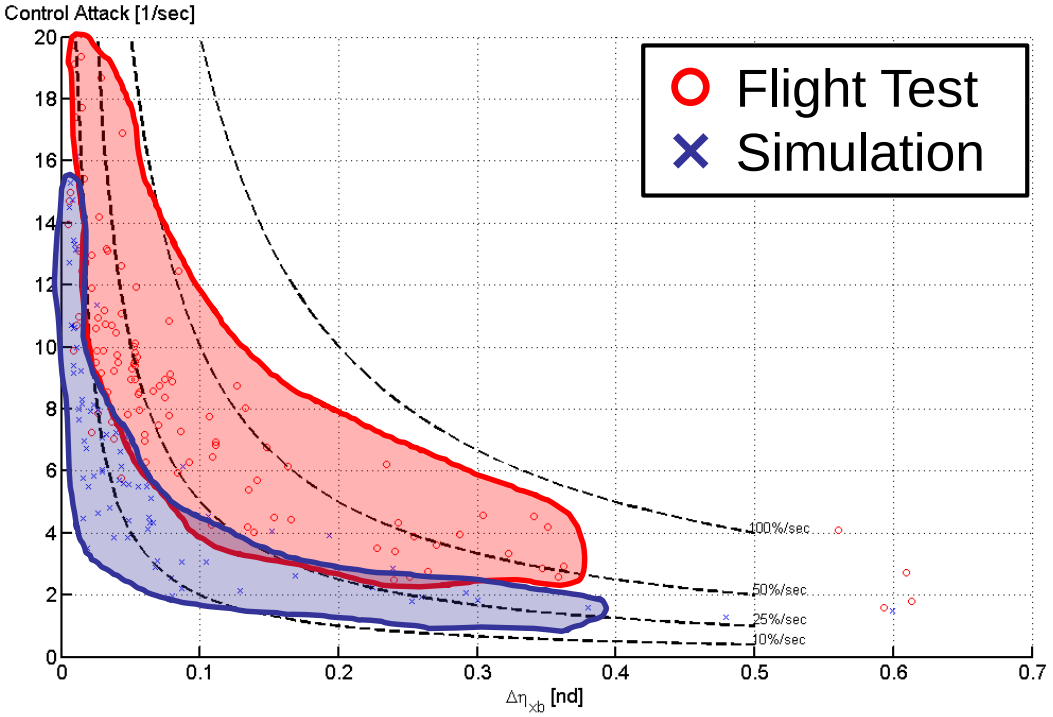
  - Frequency Domain
    - RMS value calculated from PSD of control activity
    - Cut-off frequency

Example – Acceleration-Deceleration MTE

- Accelerate from 0kts to 40kts; return to 0kts
- Performance targets for:
  - Lateral position (±10ft, ±20ft)
  - Height (<70ft, <100ft)
  - Heading (±10°, ±20°)
- Perceived performance & workload:
  - Flight HQR = 4
  - Simulation HQR = 5
- Generally good match between predicted fidelity and HQR
- Significant differences in the control techniques required to fly the MTE – SFR 6



Acceleration-Deceleration – Longitudinal

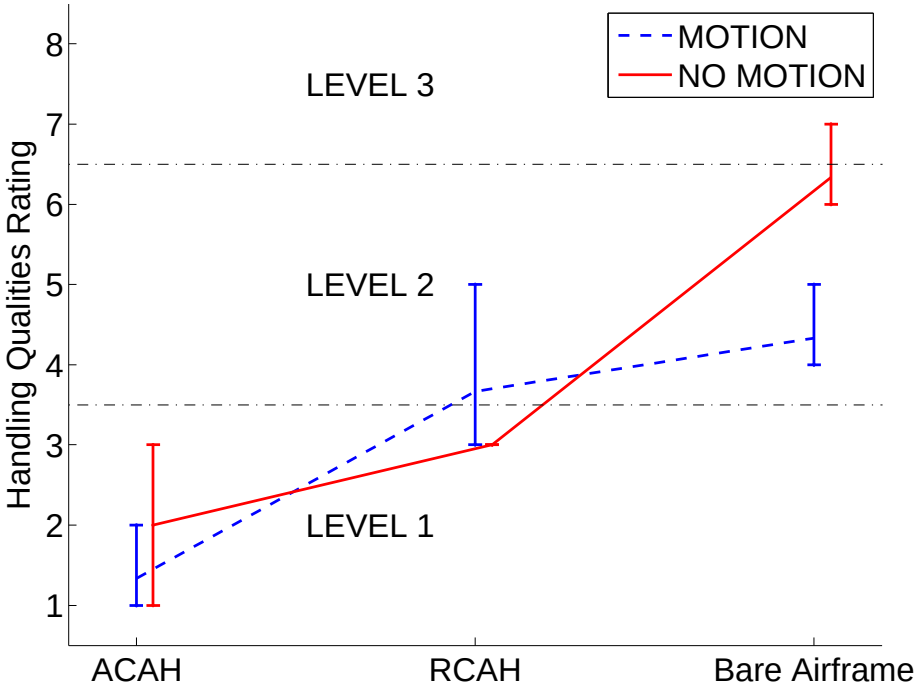


	Flight	Simulator	%Δ
No of attack points (1/sec)	3.07	1.97	-36
Mean attack rate (% per sec)	28.8	13.0	-55
Mean control displacement (%)	10.6	7.8	-26
PSD RMS	0.088	0.058	-34
Cut-off Frequency [Hz]	0.97	0.81	-16

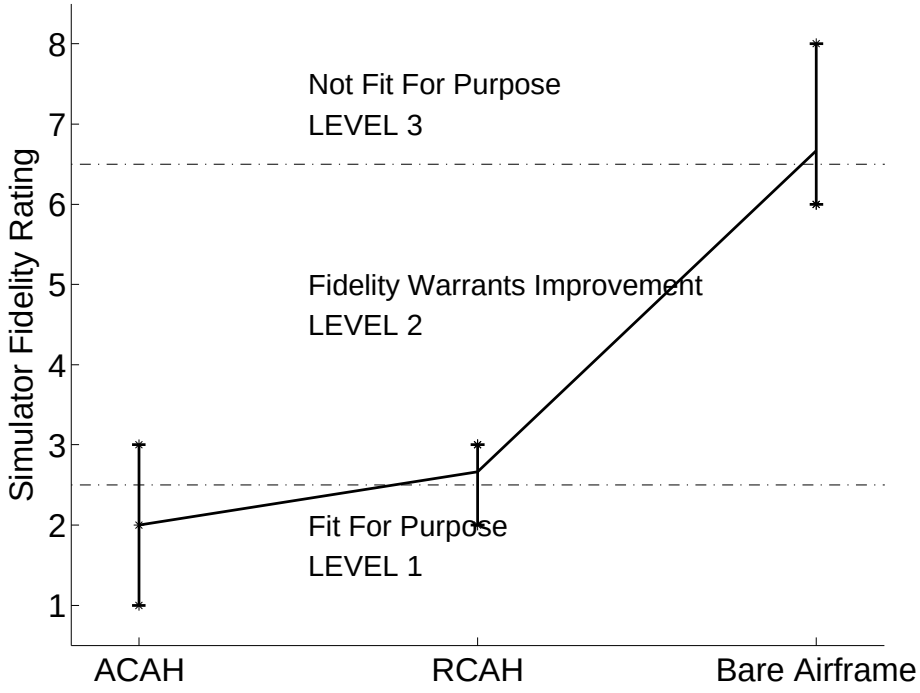
Perfect P, White, MD, Padfield GD, Gubbels AW, "Rotorcraft Simulation Fidelity: New Methods for Quantification and Assessment", *The Aeronautical Journal*, Vol. 117, Issue 1189 pp. 235-282 March 2013

Motion….. Precision Hover Task

Handling Qualities



Simulator Fidelity Without Motion



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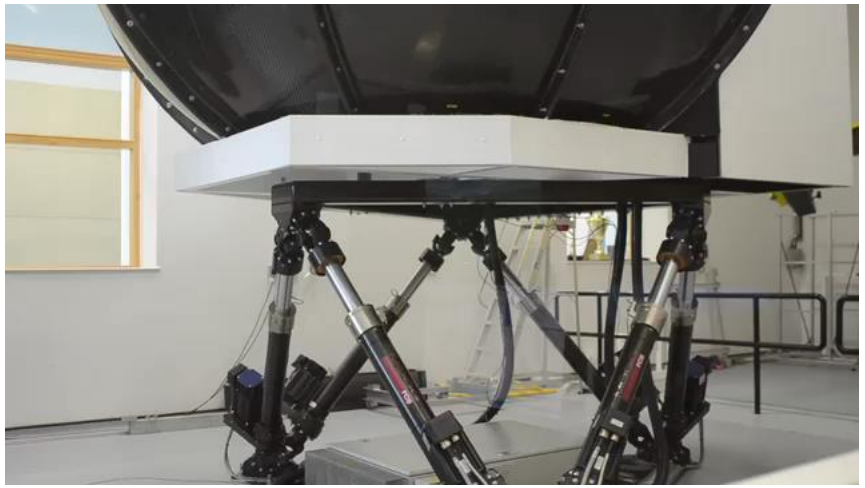
Manso S, White MD, and Hodge S, "An Investigation of Task Specific Motion Cues for Rotorcraft Simulators", Paper AIAA-2016-2138, AIAA Science and Technology Forum and Exposition (SciTech) San Diego 2016

← Attitude Command



Rate Command →

← Bare Airframe

Task and HQ specific motion?

Ongoing Research Challenges & Activities

- Goal
  - Develop practical measures of predictive and perceptual fidelity
- Draft first step
  - Define the standard test manoeuvres for which predictive and perceptual measures will be evaluated
- New EPSRC Project: Rotorcraft Simulation Fidelity Enhancement (EP/P031277/1)
  - Develop a novel toolset for flight simulation fidelity enhancement examining both predictive fidelity (metrics and tolerances) and perceptual fidelity (adaptation metrics and pilot opinion) elements of flight simulation.
  - Develop simulation fidelity manoeuvres
  - Development of flight test and flight simulation databases
  - Task specific motion cueing requirements
- NATO STO AVT-296 RTG3 entitled "*Rotorcraft Flight Simulation Model Fidelity Improvement and Assessment*"

Acknowledgments

- EPSRC – Grants EP/G002932/1, EP/P031277/1
- National Research Council of Canada, Flight Research Laboratory
- Dstl, DSTG (Australia)
- US Army
- Test pilot community

Thank you for attention