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

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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.

Challenge: How shall we evaluate and quantify simulator fidelity?
Not all simulation tasks are equal…

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.
• 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*

- 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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Flight and Simulation Facilities

- Bell 412 Advanced Systems Research Aircraft
  - 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

PREDICTIVE FIDELITY
Flight Model Tolerances, Manoeuvres – One Size fits All?

What manoeuvres & metrics should be used for fidelity assessments?
Predictive Fidelity – Dynamic Response Criteria

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

**Bandwidth** $\omega_{bw}$, **Phase**

**Delay** $\tau$: reflect behaviour of the pilot-vehicle system

**Quickness** $Q$: ease with which new attitudes can be achieved

**Control Power**: maximum manoeuvre capability of aircraft

- **Stability**
  - High
  - Medium
  - Low

- **Agility**
  - Small
  - Moderate
  - Large

**Open Loop Stability**

**Stability Envelope**

**Manoeuvre Envelope**

**Frequency**

**Amplitude**

- **Bandwidth** $\omega_{bw}$:
  - **High**
  - **Medium**
  - **Low**

- **Phase**
  - **Small**
  - **Moderate**
  - **Large**

- **Delay** $\tau$
  - Reflect behaviour of the pilot-vehicle system

- **Quickness** $Q$:
  - Ease with which new attitudes can be achieved

- **Control Power**:
  - Maximum manoeuvre capability of aircraft

**Open Loop Stability**

- **Flight Test - Hover**
- **Simulation - Hover**

**LEVEL 1**

**LEVEL 2**
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”

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:

<table>
<thead>
<tr>
<th>Comparative Performance</th>
<th>Equivalent</th>
<th>Similar</th>
<th>Not Similar</th>
</tr>
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</table>

The SFR Scale

- Similar Performance
- Moderate Adaptation

**FIDELITY CHARACTERISTICS**

**FIT FOR PURPOSE**
- Full transfer of training for the selected task.
- Simulator training sufficient for acquisition/maintenance of operational performance.

**Is equivalent performance attainable with a minimal level of adaptation?**
- YES → Level 1
- NO → FIDELITY WARRANTS IMPROVEMENT

**FIDELITY WARRANTS IMPROVEMENT**
- Limited transfer of training for the selected task.
- Additional training required for operational performance.

**Is similar or better performance attainable without excessive adaptation?**
- YES → Level 2
- NO → FIDELITY WARRANTS IMPROVEMENT

**NOT FIT FOR PURPOSE**
- Negative transfer of training occurs.

**Is fidelity permit task execution?**
- YES → Level 3
- NO → FIDELITY WARRANTS IMPROVEMENT

**NOT FIT FOR PURPOSE**
- Task cannot be performed.

**COMPARATIVE TASK PERFORMANCE**

**Level 1**
- Equivalent performance attainable

**Level 2**
- Similar performance attainable
- Equivalent performance attainable
- Similar or equivalent performance attainable

**Level 3**
- Similar or equivalent performance attainable
- Similar performance not attainable
- Similar performance not attainable

**Level 4**
- Similar performance not attainable
- Or: An entirely inappropriate task strategy is required

**PILOT’S TASK STRATEGY**

- Negligible or no adaptation of task strategy
- Minimal adaptation of task strategy
- Minimal adaptation of task strategy

**FIDELITY RATING**

1. Level 1
2. Level 2
3. Level 3
4. Level 4

**FIDELITY LEVEL**

1. 1
2. 2
3. 3
4. 4
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
  - Frequency Domain
    - RMS value calculated from PSD of control activity
    - Cut-off frequency

\[
\text{Attack} = \frac{\dot{\eta}_{pk}}{\Delta \eta}
\]
Example – Acceleration-Deceleration MTE

- Accelerate from 0kts to 40kts; return to 0kts
- Performance targets for:
  - Lateral position ($\pm 10\text{ft}$, $\pm 20\text{ft}$)
  - Height ($<70\text{ft}$, $<100\text{ft}$)
  - Heading ($\pm 10^\circ$, $\pm 20^\circ$)

- 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

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

Motion… Precision Hover Task

Handling Qualities

Simulator Fidelity
Without Motion

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

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- US Army
- Test pilot community

Thank you for attention