Verification of a Motion Cueing Strategy for Stall Recovery Training in a Commercial Transport Simulator

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Peter M. T. Zaal¹  William W. Chung²  Diane M. Carpenter³  Kevin Cunningham⁴  Gautam H. Shah⁴

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¹San José State University  NASA Ames Research Center  ²American Systems  NASA Ames Research Center  ³Flight Research Associates  NASA Ames Research Center  ⁴NASA Langley Research Center
1. Introduction

2. Simulator Implementation

3. Experiment Setup

4. Results

5. Conclusions
1. Pilots are required to perform full stall recovery training in simulators starting this year
2. Historically, training simulators were not equipped for this
3. Post-stall aircraft models and representative motion cues need to be implemented

**Research Goal**
Develop motion cueing strategies for stall recovery training in commercial training simulators
Motion Cueing Strategy

1. Simulators have limited motion space
2. Accelerations at pilot station need to be attenuated
3. Center of gravity linear accelerations require most motion space

Approach

Eliminating the center-of-gravity linear accelerations allows for a significant increase of the fidelity of remaining motion cues
Limitations:

1. No sustained g-loads
2. No deceleration cue
3. No turn coordination
B747-400 Full Flight Simulator

1. Equivalent to level-D certified
2. B747-400 cockpit replica
3. Collimated out-the-window visuals
4. Digital control loading system
5. 54-inch legged hexapod
6. Tabled computer for questionnaire
Stall Recovery Task

1. Initially: 36,000 ft, 210 IAS, in the clouds, turbulence
2. Retard throttles to idle and pull up, keeping wings level
3. Continue deceleration through stick shaker until a tone sounds indicating the stall
4. Recover using correct recovery procedure
5. Task evaluation ends when the airspeed is above 210 IAS, the aircraft is climbing, and the wings are level
Modification of a very large, generic, four engine transport aircraft:

1. Roll damping stability coefficient
2. Rolling moment increment due to stall asymmetry
3. Aileron effectiveness gain
1. Disabling adaptiveness

2. Gains in equation for pilot station accelerations:

\[ a_{ps} = K_t a_{cg} + K_r (\omega \times r_{cg-ps} + \omega^2 \times r_{cg-ps}) \]

3. Online adjustment of motion parameters

<table>
<thead>
<tr>
<th>Degree of Freedom</th>
<th>Surge</th>
<th>Sway</th>
<th>Heave</th>
<th>Roll</th>
<th>Pitch</th>
<th>Yaw</th>
</tr>
</thead>
<tbody>
<tr>
<td>High-Pass Gains</td>
<td>0.7</td>
<td>0.7</td>
<td>0.7</td>
<td>1.0</td>
<td>1.0</td>
<td>1.0</td>
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<tr>
<td>High-Pass Break Frequencies</td>
<td>0.6</td>
<td>0.6</td>
<td>0.6</td>
<td>0.3</td>
<td>0.3</td>
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<tr>
<td>Low-Pass Gains</td>
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<tr>
<td>Low-Pass Break Frequencies</td>
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<td>0.6</td>
<td>–</td>
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<td>–</td>
</tr>
</tbody>
</table>

Damping ratios ($\zeta$): 0.707
C.G. acceleration gain ($K_t$): 0.000
Rot. acceleration gain ($K_r$): 1.000
Experiment Setup

1. Six conditions
2. Latin square design
3. Seven replications per condition (42 runs)
4. Last five replications used for results

<table>
<thead>
<tr>
<th>Condition</th>
<th>Aircraft Dynamics</th>
<th>Simulator Motion</th>
</tr>
</thead>
<tbody>
<tr>
<td>B1</td>
<td>baseline</td>
<td>no motion</td>
</tr>
<tr>
<td>B2</td>
<td>baseline</td>
<td>baseline</td>
</tr>
<tr>
<td>B3</td>
<td>baseline</td>
<td>enhanced</td>
</tr>
<tr>
<td>E1</td>
<td>enhanced</td>
<td>no motion</td>
</tr>
<tr>
<td>E2</td>
<td>enhanced</td>
<td>baseline</td>
</tr>
<tr>
<td>E3</td>
<td>enhanced</td>
<td>enhanced</td>
</tr>
</tbody>
</table>
Experiment Setup

1. Eight commercial airline pilots
2. Four different airlines
3. Left or right seat
4. No specifics about conditions
5. Post-run questionnaire
Dependent measures:

1. Four subjective questionnaire responses:
   1.1 Motion rating
   1.2 Motion usefulness question
   1.3 Wing roll-off noticeability question
   1.4 Stall recovery in actual flight question

2. Six objective performance measures:
   2.1 Maximum roll attitude
   2.2 Altitude loss
   2.3 Minimum load factor
   2.4 Maximum load factor
   2.5 Number of secondary stick shakers
   2.6 Maximum airspeed
Results

Motion rating:
1. No significant differences
2. Enhanced motion rated lower?

Roll off question:
1. Significantly higher with enhanced dynamics
Results

Maximum roll:
1. Significantly higher with enhanced dynamics
2. Significantly lower with higher fidelity motion

Altitude loss:
1. No significant differences

![Graph showing roll angles and altitude loss](image-url)
Results

Minimum load factor:
1. Significantly higher with enhanced motion

Maximum load factor:
1. No significant differences
Results

Additional stick shakers:
1. Significantly lower with enhanced motion

Maximum airspeed:
1. Significantly higher with enhanced motion
Conclusions

1. Aircraft dynamics and motion introduced significant differences
   1.1 Motion helpfulness question
   1.2 Maximum roll
   1.3 Additional stick shakers
   1.4 Minimum load factor
   1.5 Maximum airspeed

2. Better stall recovery performance with enhanced motion

3. Relatively minor enhancements to potentially improve training
Questions?
peter.m.t.zaal@nasa.gov