Motion Cueing for Stall Recovery Training in Commercial Transport Simulators

AIAA-2019-0979

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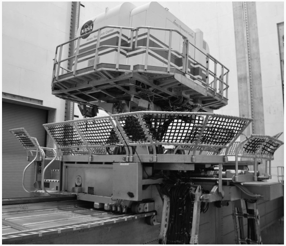
Introduction

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

Simulators



1. Largest vertical motion simulator
2. Transport Cab with sidestick
3. Electric + hydraulic motion system
4. Mid-size transport aircraft dynamics

1. Equivalent to level-D certified
2. B747-400 cockpit with control column
3. Hydraulic hexapod motion system
4. Very-large transport aircraft dynamics

Transfer of Training

Transfer-of-training paradigm most valid to study the training effectiveness of motion

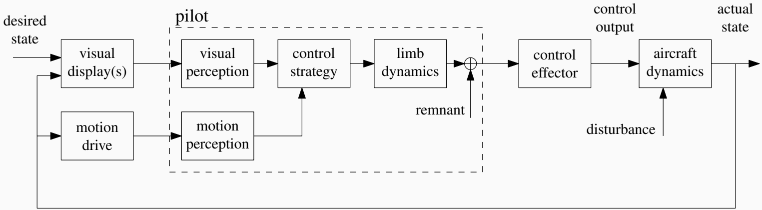
Limitations of past research:

1. Most previous experiments performed with only slightly better motion in transfer condition (quasi transfer)
2. No good understanding and bad reporting of motion settings
3. Mostly outcome-based performance variables for measures

Pilot model parameters give insight into the use of visual and motion cues

Limitations of past research:

1. Single-axis
2. Time-invariant
3. Very structured tracking tasks

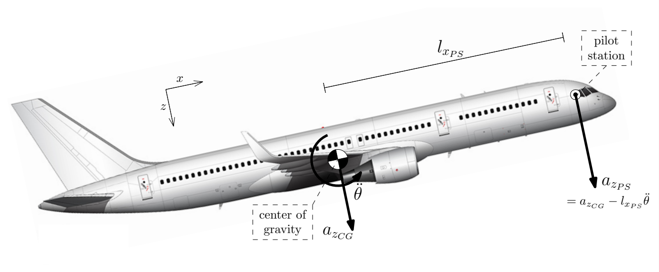


Motion Cueing Strategy

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



Motion Cueing Strategy

Limitations:

1. No sustained g-loads
2. No deceleration cue
3. No turn coordination

Experiments

1. Effects of False Tilt Cues on the Training of Manual Roll Control Skills (AIAA-2015-0655)
2. Effects of Heave Motion Components on Pitch Control Behavior (AIAA-2016-3371)
3. Effects of Motion Cues on the Training of Multi-Axis Manual Control Skills (AIAA-2017-3473)
4. Time-Varying Manual Control Identification in a Stall Recovery Task under Different Simulator Motion Conditions (AIAA-2018-2936)
5. Adaptive Hexapod Simulator Motion based on Aircraft Stability (AIAA-2019-xxxx)
6. Verification of a Motion Cueing Strategy for Stall Recovery Training in a Commercial Transport Simulator (AIAA-2019-0426)

Experiment 1 - AIAA-2015-0655

Goal:

Investigate the effects of false tilt cues on training and transfer of training of manual roll control skills

Approach:

1. Vertical Motion Simulator
2. Transfer-of-training experiment
3. Roll tracking task and multi-modal pilot modeling
4. Three training conditions: no motion, roll motion only, reduced coordinated roll motion
5. Transfer to full coordinated motion
6. Nineteen general aviation pilots

Results:

Pilots training with false tilt cues had significantly higher performance during training and after transfer

Experiment 2 - AIAA-2016-3371

Goal:

Investigate if a different weighting of pilot station heave motion components allowed for control behavior closer to that in real flight

Approach:

1. Vertical Motion Simulator
2. Pitch tracking task and multi-modal pilot modeling
3. Nine different motion conditions
4. 21 general aviation pilots

Results:

Pilot control behavior in conditions with higher levels of rotational pitch heave was closer that in real flight

Experiment 3 - AIAA-2017-3473

Goal:

Investigate the effects of two different hexapod motion configurations on the training and transfer of training of a multi-axis control task

Approach:

1. Vertical Motion Simulator
2. Transfer-of-training experiment
3. Roll-pitch tracking task and multi-modal pilot modeling
4. Two training conditions: baseline and enhanced hexapod
5. Transfer to full motion
6. Twenty general aviation pilots

Results:

Enhanced motion allowed pilots to generate less visual lead, control with higher gains, and have better disturbance-rejection performance at the end of training

Experiment 4 - AIAA-2018-2936

Goal:

Investigate the effects of different motion cueing strategies on pilot control behavior in a stall recovery task

Approach:

1. Vertical Motion Simulator
2. Stall tracking task and single-loop time-varying pilot modeling
3. Four motion conditions: no motion, generic hexapod, enhanced hexapod, and full motion
4. Seventeen general aviation pilots

Results:

Pilot performance was highest for the enhanced and full motion conditions. Pilot control behavior under enhanced hexapod motion was most similar to that under full motion

Experiment 5 - AIAA-2019-xxxx

Goal:

Development of an adaptive motion algorithm based on aircraft stability

Approach:

1. Vertical Motion Simulator
2. Two consecutive tasks: heading capture and stall recovery task
3. Pilot performance
4. Four motion conditions: generic, enhanced, adaptive, and full motion
5. Nineteen general aviation pilots

Results:

Normalized motion ratings reveal the adaptive motion to be most similar to the generic motion for the heading capture task, and most similar to the enhanced motion in the stall recovery tasks

Experiment 6 - AIAA-2019-0426

Goal:

Verify the enhanced motion cueing strategy for improved stall recovery training on a commercial training simulator

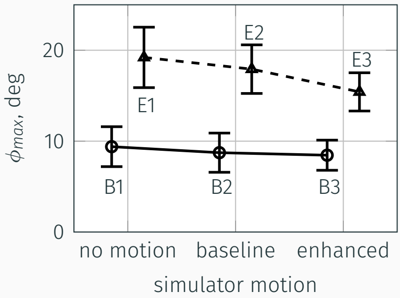
Approach:

1. B747-400 level-D-certified full flight simulator
2. High-altitude stall recovery task
3. Three motion conditions: no motion, baseline motion, enhanced motion
4. Two aircraft dynamic conditions: baseline and enhanced
5. Eight airline pilots

Experiment 6 Results

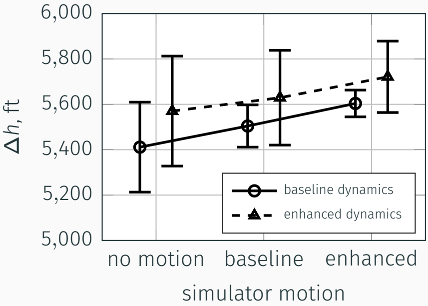
Maximum roll:

1. Significantly higher with enhanced dynamics
2. Significantly lower with higher fidelity motion



Altitude loss:

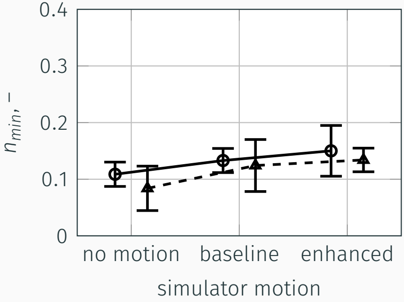
1. No significant differences



Experiment 6 Results

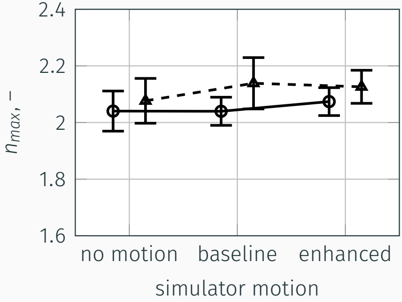
Minimum load factor:

1. Significantly higher with enhanced motion



Maximum load factor:

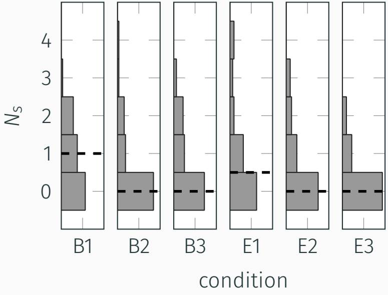
1. No significant differences



Experiment 6 Results

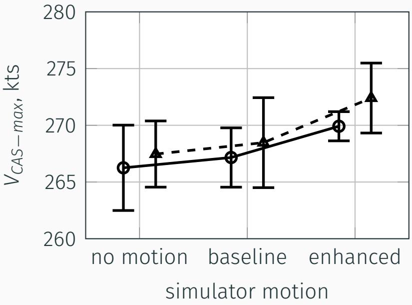
Additional stick shakers:

1. Significantly lower with enhanced motion



Maximum airspeed:

1. Significantly higher with enhanced motion



Conclusions

1. Better stall recovery performance with enhanced motion
    1.1 Lower maximum roll
    1.2 Less additional stick shakers
    1.3 Higher minimum load factor
    1.4 Higher maximum airspeed
2. Relatively minor enhancements allow for better stall recovery performance and potentially better training
3. Significant advancements were made with applying the transfer of training paradigm and time-varying pilot modeling techniques

Questions?

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