

Evaluation of Synthetic Vision Display Concepts for Improved Awareness in Unusual Attitude Recovery Scenarios

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Outline

1. Background
2. Experiment Design
3. Evaluation Tasks and Procedures
4. Data Analysis
5. Q&A

- Background
- Experiment Design
- Evaluation Tasks and Procedures
- Data Analysis
- Q&A



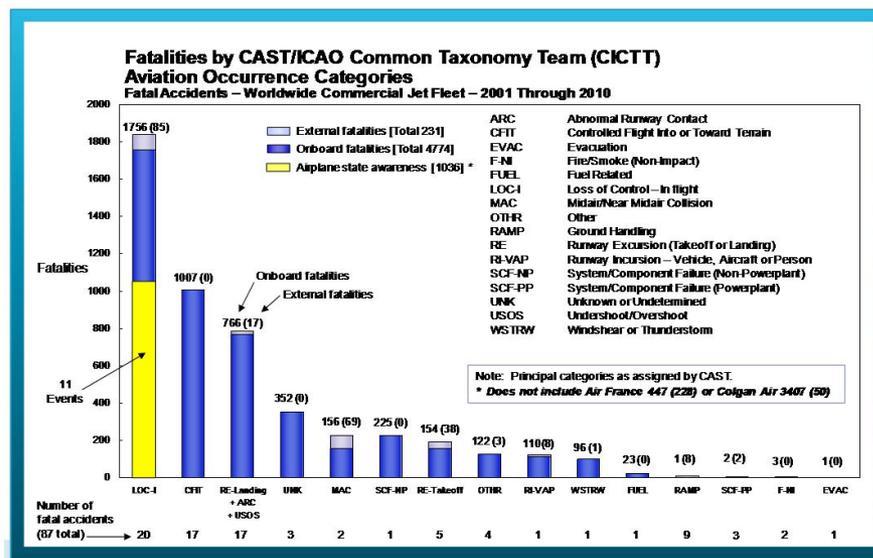
Commercial Aviation Safety Team (CAST)

1. Background
2. Experiment Design
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CAST – Commercial Aviation Safety Team

• Aircraft State Awareness (ASA)

- In August 2010, CAST chartered the Airplane State Awareness Joint Safety Analysis Team (ASA JSAT) as a follow-on activity to previous CAST work done by the Loss of Control Joint Safety Analysis Team (LOC JSAT) in 2002
- Specific ASA Focus:
 - Loss-of-Attitude Awareness (Spatial Disorientation – SD)
 - Loss-of-Energy State Awareness (LESA)





CAST ASA

1. Background
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CAST ASA

- The ASA JSAT studied 18 events that occurred no more than 10 years prior to the JSAT kick-off. The ASA JSAT identified 12 major themes that appeared across a multitude of the accidents/incidents which were representative of common issues.
- The ASA Joint Safety Implementation Team (ASA JSIT) subsequently recommended 5 *research* safety enhancements (SEs)
- The JSIT also developed one SE wherein successful completion of research is in the critical path of a *design* SE (SE-200).

Summary of Significant Themes Across All Events	Summary of Significant Themes Across All Events											
	Lack of External Visual References	Flight Crew Impairment	Training	Airplane Maintenance	Safety Culture	Invalid Source Data	Distraction	Systems Knowledge	Crew Resource Management Awareness	Automation Confusion / Ineffective Alerting	Inappropriate Control Actions	Total
Formosa Airlines Saab 340	x	x			x		x	x	x	x		7
Korean Air 747-200F	x			x		x	x			x		6
Flash Airlines 737-300	x		x		x		x		x	x	x	8
Adam Air 737-400	x		x	x			x	x	x	x	x	9
Kenya Airways 737-800	x		x				x	x	x	x	x	7
Aeroflot-Nord 737-500	x	x	x	x	x		x	x	x	x	x	11
Gulf Air A320	x		x				x	x		x	x	6
Icelandair 757-200 (Oslo)	x						x		x	x	x	6
Armavia A320	x	x			x		x		x	x	x	8
Icelandair 757-200 (Baltimore)	x				x	x	x	x	x	x	x	9
Midwest Express 717	x				x	x	x	x		x	x	7
Colgan Air DHC-8-Q400	x	x	x		x		x	x	x	x	x	10
Provincial Airlines DHC-8	x		x				x			x	x	6
Thomsonfly 737-300	x		x	x	x		x		x	x		7
West Caribbean MD-82	x	x			x		x	x	x	x	x	9
XL Airways A320		x	x	x	x	x	x	x	x	x		10
Turkish Airlines 737-800	x			x	x	x		x	x	x		8
Empire Air ATR-42	x	x			x		x		x	x	x	7
Overall	17	7	9	6	12	5	18	7	16	14	18	12



ASA Technical Challenge

1. Background
2. Experiment Design
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Mitigate the problems and Contributing Factors that lead to flight crew loss of airplane state awareness

GOAL: *“Develop data, systems, models, training methods and technologies for transition to the aviation community (Original Equipment Manufactures, Regulators, Training Organizations, and Operators) which can reduce the flight crew’s loss of airplane state awareness as a causal factor in commercial aviation accidents and incidents.*

CAST SE focus for Augmented Flight Deck Countermeasures (AFDC) experiments:

211 – ASA-Research: Training for Attention Management

200 – ASA-Design: Virtual Day-Visual Meteorological Conditions (VMC) Displays



SE- 200 – Virtual Day-VMC Displays

1. Background
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Objective: Study the Effectiveness and Publish Minimum Aviation System Performance Standards for the design of virtual day-VMC displays to improve flight crew awareness of airplane attitude as a function of various system characteristics

Display Characteristics:

- Presented full time in the primary field-of-view
- Presented to both flight crew members
- Include display of energy state cues, including flight path, acceleration, and speed deviation, in a manner similar to modern head-up displays

Design Criteria:

- Field of View
- Presentation/Removal of concept while in unusual attitude
- Image Minification
- Optical Flow Cues:
 - Display elements over water or featureless terrain
 - Use of color and texture
- Potential unintended consequences (i.e., attentional issues)



Simulation Facility

1. Background
2. Experiment Design
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- Experiment conducted in the NASA LaRC Visual Imaging Simulation for Transport Aircraft Systems (VISTAS) lab
 - Rapid-prototype flight simulator
 - Fully functioning Sterling side-stick controllers
 - 144-degree out-the-window visuals
 - Four, 15 inch head-down display panels
 - General Aviation trainer throttle quadrant





Experiment Design

1. Background
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- 12 pilot participants
- 2- part experiment series:
 - Part 1: Unusual Attitude Recovery (UAR) Scenarios
 - 25 trials
 - Part 2: Attitude Memory Recall (ADMR) Tasks
 - 50 trials
- Training block allotted for UAR and ADMR
 - Familiarization of simulation flight deck and experimental tasks
 - Briefed on Boeing Airplane Upset Recovery Training Operations
 - Pilots asked to maintain safe flight operations
 - fly as if he/she were carrying passengers in Part 121 operations.



Part 1: UAR

1. Background
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Primary Flight Display (PFD) Concepts (3)



Baseline



Synthetic Vision (SV) with Color Gradient Sky



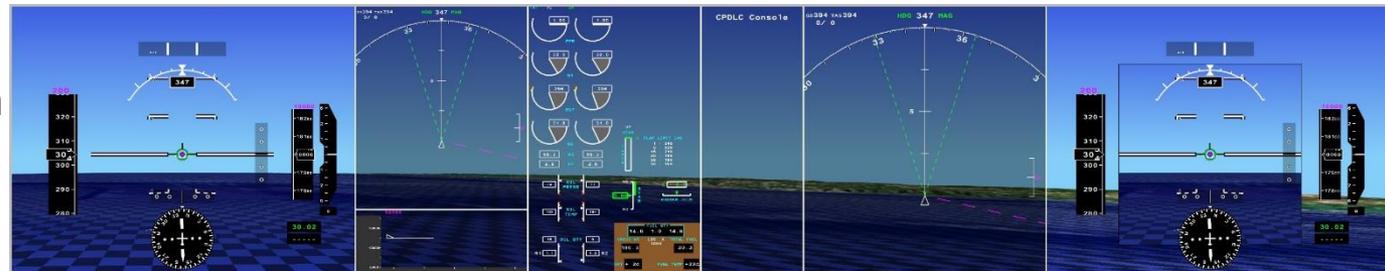
SV with Water Texture

Background Attitude Indicator (BAI) Concepts (2)

Off



On





UAR Trials – Initial Conditions

1. Background
2. Experiment Design
3. Evaluation Tasks and Procedures
4. Data Analysis
5. Q&A

Initial aircraft configuration:

- IAS: 300 kts
- ALT: FL180
- CONFIG:
 - Flaps Retracted
 - Spoilers Retracted
 - Gear Retracted

Initial UA Conditions:

- The following five initial UA conditions were presented to pilots:
 - Identifier 501:
 - **Nose-down** (30 degrees), left bank angle (10 degrees)
 - Identifier 502:
 - **Nose-up** (25 degrees), left bank angle (60 degrees)
 - Identifier 504:
 - **Nose-up** (25 degrees), right bank angle (60 degrees)
 - Identifier 505:
 - **Nose-down** (30 degrees), right bank angle (100 degrees)
 - Identifier 506:
 - **Nose-down** (30 degrees), left bank angle (100 degrees)





Post-Run Questionnaires

1. Background
2. Experiment Design
3. Evaluation Tasks and Procedures
4. Data Analysis
5. Q&A

NASA Task-Load Index (TLX):

- A 0-100 subjective rating scale used to evaluate six categories of mental and physical demand, as well as personal performance.

Name	Task	Date
------	------	------

Mental Demand How mentally demanding was the task?

Very Low Very High

Physical Demand How physically demanding was the task?

Very Low Very High

Temporal Demand How hurried or rushed was the pace of the task?

Very Low Very High

Performance How successful were you in accomplishing what you were asked to do?

Perfect Failure

Effort How hard did you have to work to accomplish your level of performance?

Very Low Very High

Frustration How insecure, discouraged, irritated, stressed, and annoyed were you?

Very Low Very High

Situation Awareness Rating Technique (SART):

- A 0-100 subjective rating scale that evaluated demand on attentional resources, supply of attentional resources, and understanding of a given task.

SART

Attentional Demand How much demand was placed on attention due to complexity and variability of the task?

0 100

Very Low 25 50 75 Very High

Supply of Attentional Resources How much spare attention and mental ability was available to accomplish the task?

0 100

Very Low 25 50 75 Very High

Understanding What was the level of understanding of information and familiarity of the situation?

0 100

Very Low 25 50 75 Very High



Paired-Comparisons

1. Background
2. Experiment Design
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- At the conclusion of the Part I experiment set, pilots were asked to complete a paired-comparison questionnaire.
 - Evaluated preference of displays when compared to one another.

	If not equal , how much more or how much less ?						
	Barely						Substantially
Baseline + NO BAI							
results in (___ more)(___ equal)(___ less) situation awareness than							
SV + NO BAI							
Baseline + NO BAI							
results in (___ more)(___ equal)(___ less) situation awareness than							
SV w/ texture + NO BAI							
Baseline + NO BAI							
results in (___ more)(___ equal)(___ less) situation awareness than							
SV + BAI							
Baseline + NO BAI							
results in (___ more)(___ equal)(___ less) situation awareness than							
SV w/ texture + BAI							
SV + NO BAI							
results in (___ more)(___ equal)(___ less) situation awareness than							
SV w/ texture + NO BAI							
SV + BAI							
results in (___ more)(___ equal)(___ less) situation awareness than							
SV w/ texture + BAI							

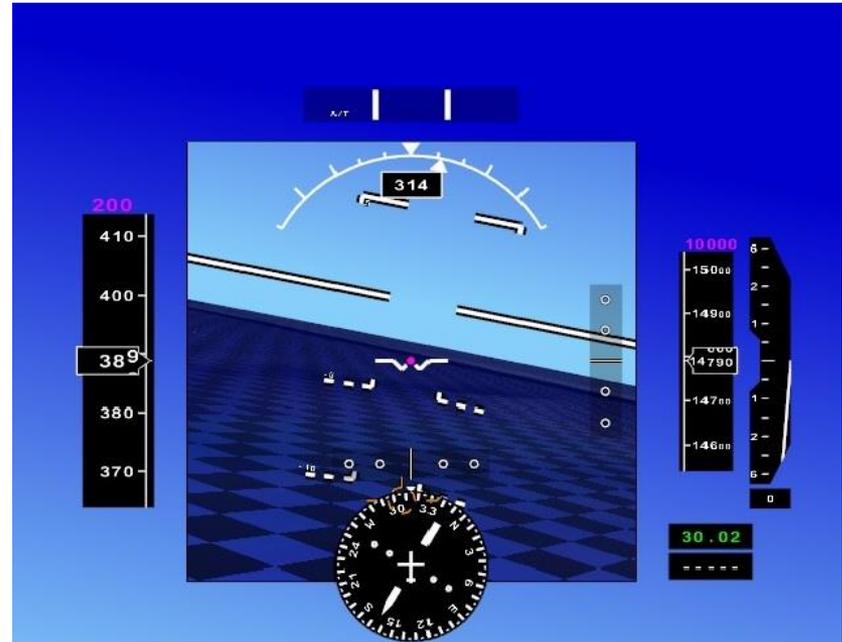


Part 2: ADMR Trials

1. Background
2. Experimental Design
3. Evaluation Tasks and Procedures
4. Data Collection & Analysis
5. Q&A

Quick Static Display Evaluation

- Displays were blank between runs
- Pilot sat in seat waiting for display to activate
- Display concept presented for a short duration and then removed
- Pilot asked to recall attitude (Pitch & Roll)
- NASA TLX administered after each run
- Paired-Comparison administered after Part 2 experiment set

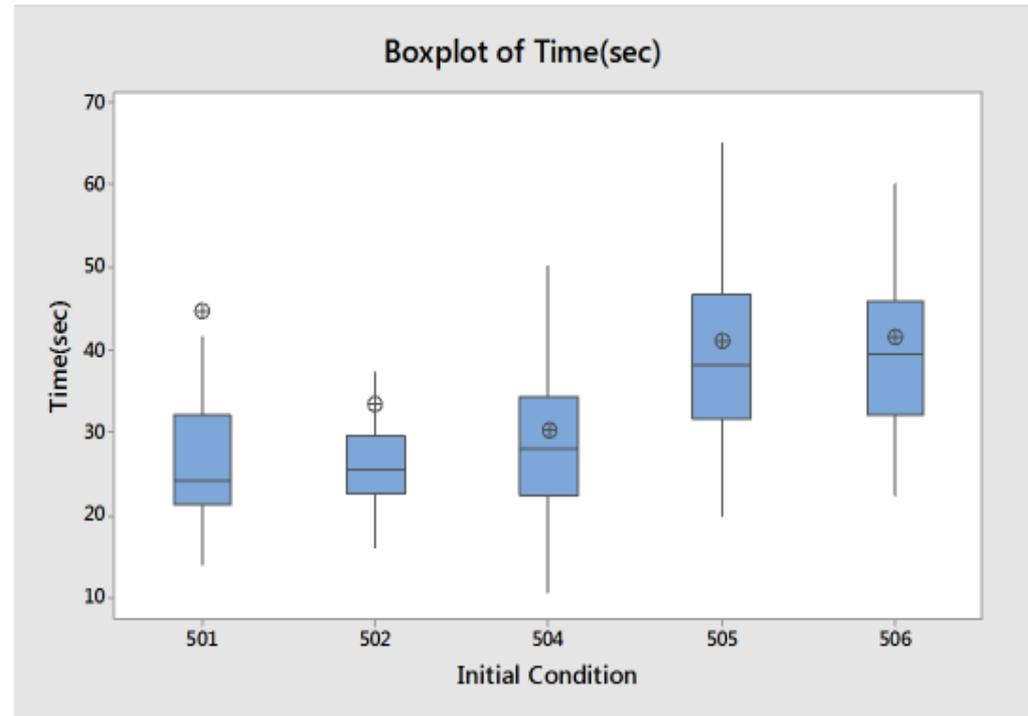




Data Analysis - UAR

1. Background
2. Experiment Design
3. Evaluation Tasks and Procedures
4. Data Analysis
5. Q&A

- Unusual Attitude Recovery:
 - ANOVA conducted:
 - No significant effects for initial conditions $F(4,321) = 1.69, p = 0.152$
- Overall, pilots performed faster recoveries after entering into a nose-high unusual attitude
 - 31.75 sec vs 42.43 sec (Nose-down)



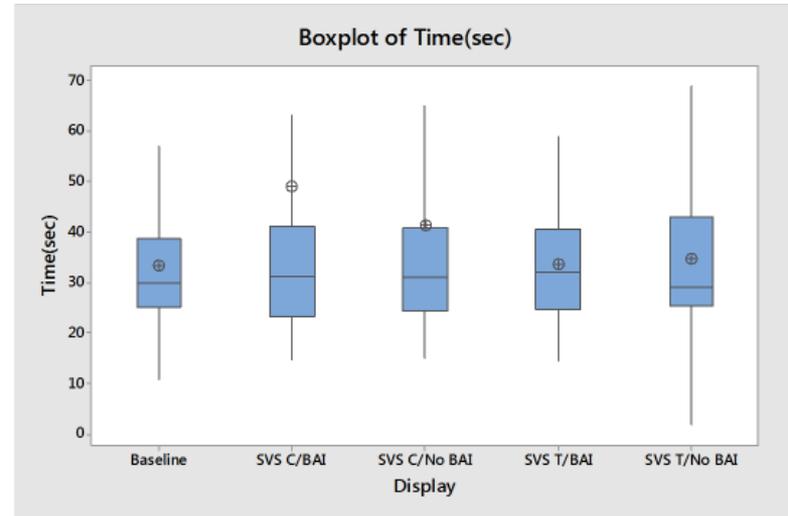
Identifier 501: Nose-down (30 degrees), left bank angle (10 degrees)
Identifier 502: Nose-up (25 degrees), left bank angle (60 degrees)
Identifier 504: Nose-up (25 degrees), right bank angle (60 degrees)
Identifier 505: Nose-down (30 degrees), right bank angle (100 degrees)
Identifier 506: Nose-down (30 degrees), left bank angle (100 degrees)



Data Analysis - UAR

1. Background
2. Experiment Design
3. Evaluation Tasks and Procedures
4. Data Analysis
5. Q&A

- Unusual Attitude Recovery:
 - ANOVA conducted:
 - No significant effects for display type, $F(4,321) = 2.21$, $p = 0.068$
- Faster recovery using baseline display (33.27 sec) as opposed to all SV display types (39.63 sec).

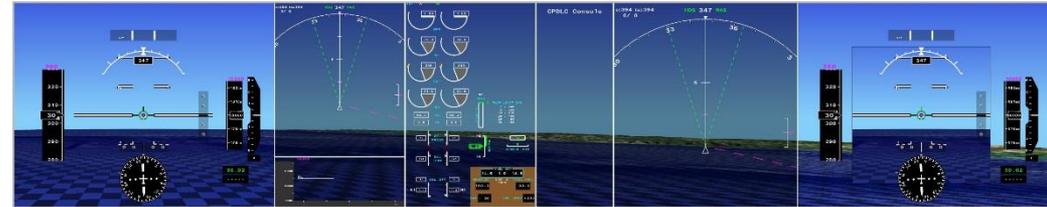




Data Analysis - UAR

1. Background
2. Experiment Design
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5. Q&A

- SV comparisons:
 - Faster mean recovery times when flying the SV with texture display
 - 34.17 sec vs 45.09 sec with color gradient display
 - Faster recovery times with BAI on for textured display
 - 33.65 sec vs 34.69 sec with BAI off
 - Slower recovery times with BAI on for color gradient display:
 - 48.89 sec vs 41.29 sec with BAI on



SV with Texture, BAI On



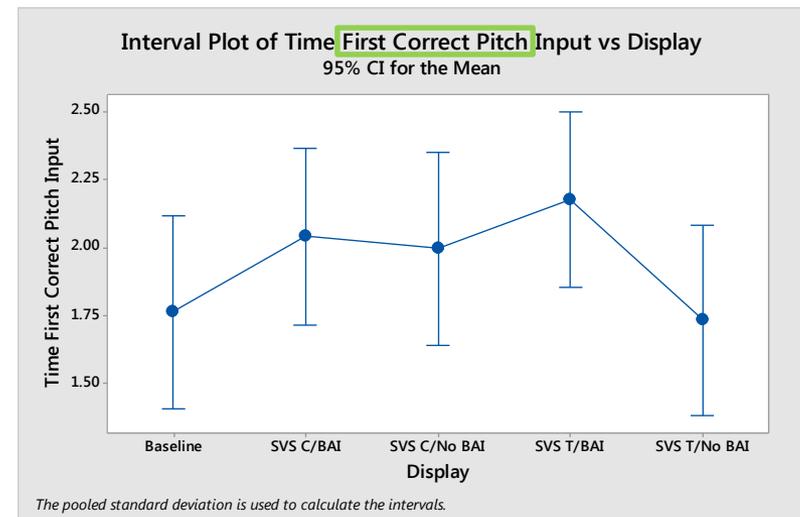
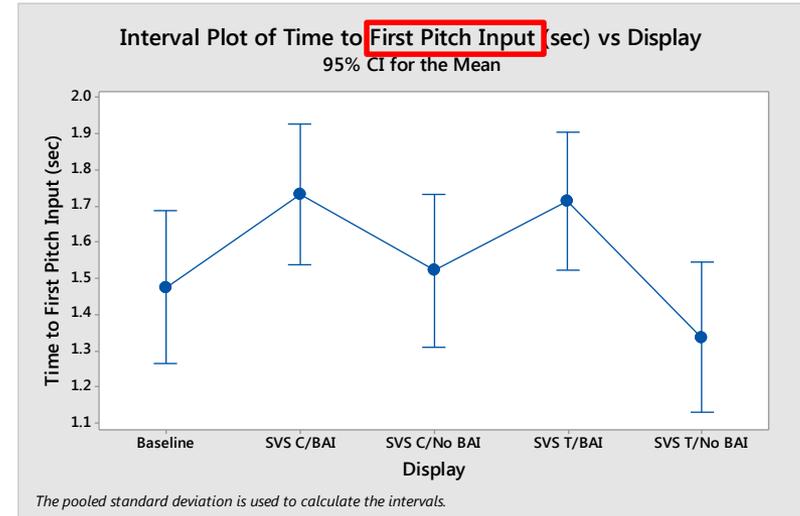
SV with Color Gradient, BAI Off



Data Analysis UAR – Pitch Response

1. Background
2. Experiment Design
3. Evaluation Tasks and Procedures
4. Data Analysis
5. Q&A

- ANOVAS Conducted:
 - Significant effect on time of initial pilot pitch input based on display concepts $F(4,321) = 2.67, p = 0.032$.
 - Faster initial pitch change times for SV with texture display, no BAI
 - No significant effect of display type on correct pitch input $F(4,321) = 1.20, p = 0.309$.
 - Faster pitch input in correct direction for SV with texture, no BAI

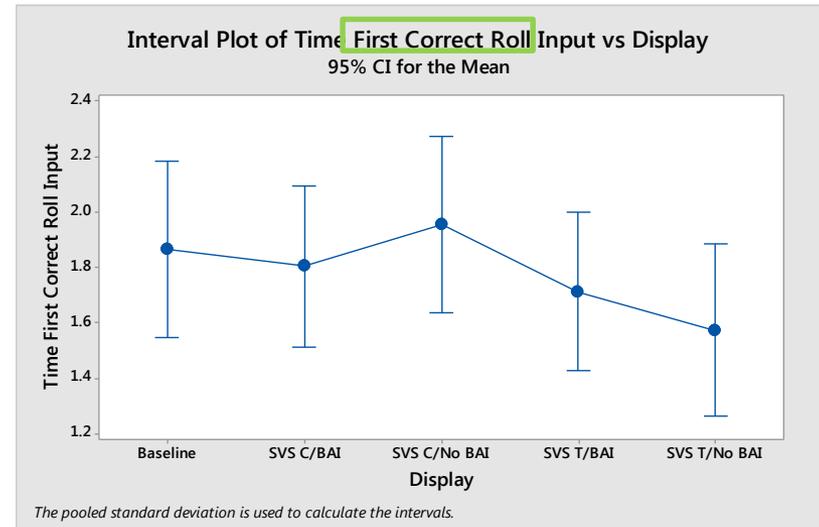
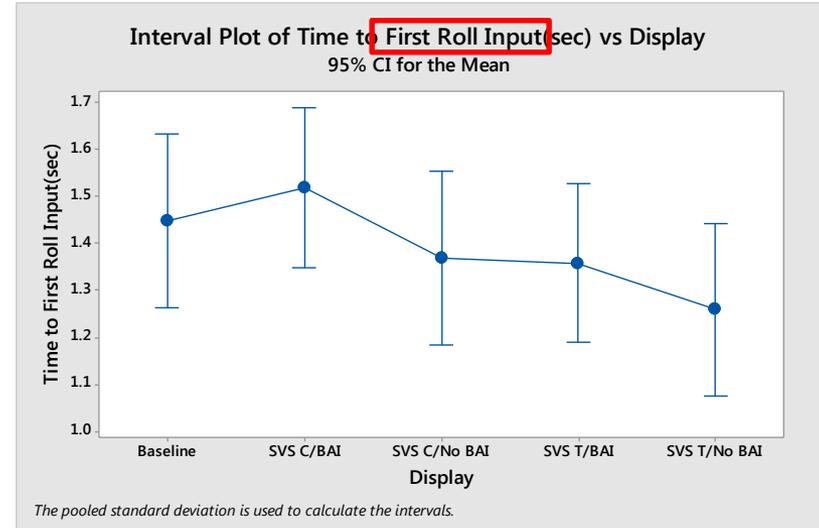




Data Analysis UAR – Roll Response

1. Background
2. Experiment Design
3. Evaluation Tasks and Procedures
4. Data Analysis
5. Q&A

- ANOVAS Conducted:
 - No significant effect on first roll input based on the displays types, $F(4,321) = 1.18, p = 0.319$
 - Faster initial pitch change times for SV with texture display, no BAI
 - No significant effect on first correct roll input based on display type, $F(4,321) = 2.67, p = 0.497$
 - Faster roll input in correct direction for SV with texture display, no BAI

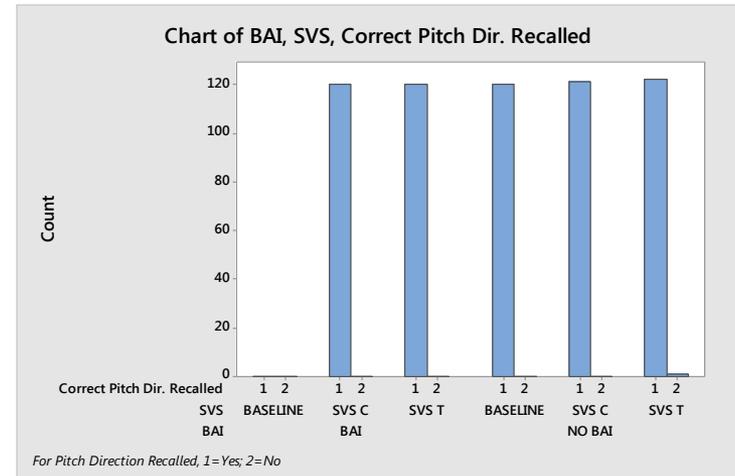
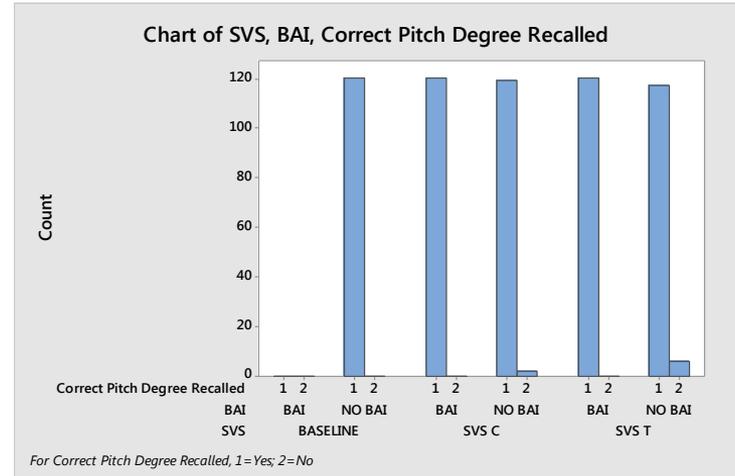




Data Analysis ADMR- Pitch Recall

1. Background
2. Experiment Design
3. Evaluation Tasks and Procedures
4. Data Analysis
5. Q&A

- Correct Pitch Degree and Direction:
 - ANOVA conducted:
 - No significant effects for correct recall of pitch degree for SVS or BAI, $F(2,599) = 1.13, p = 0.323$, and $F(1,599) = 2.69, p = 0.102$, respectively
 - No significant effects for correct recall of pitch direction for SVS or BAI, $F(2,597) = 0.75, p = 0.473$, and $F(1,598) = 0.67, p = 0.415$, respectively

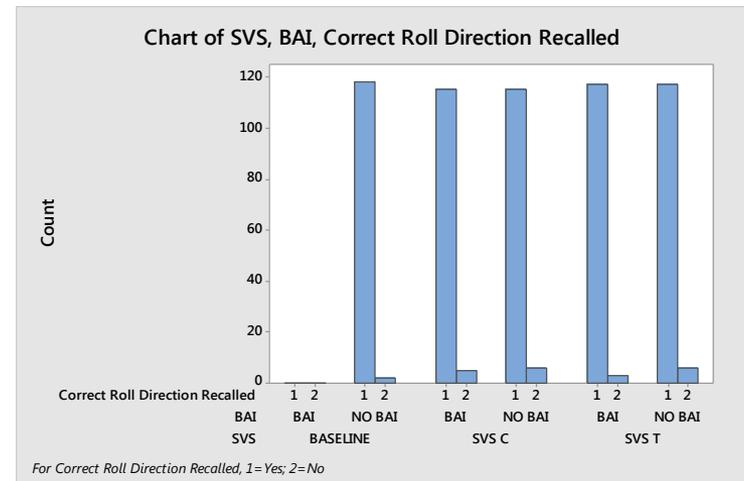
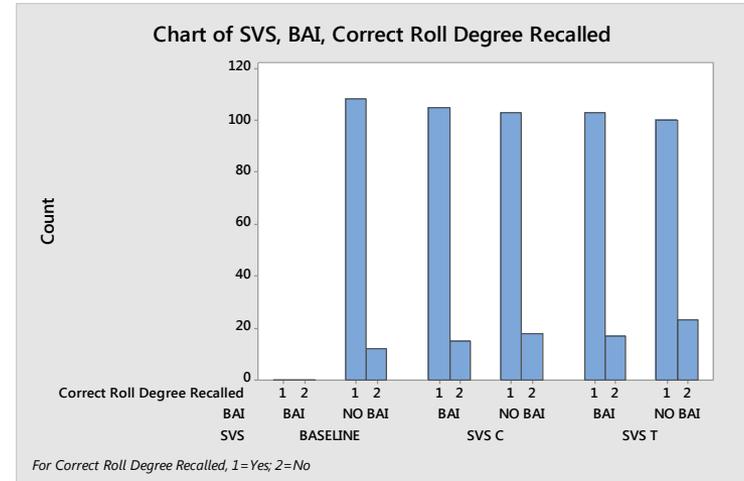




Data Analysis ADMR- Roll Recall

1. Background
2. Experiment Design
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- Correct Roll Degree and Direction:
 - ANOVAs conducted:
 - No significant effects for correct recall of roll degree for SVS or BAI, $F(2,597) = 1.35$, $p = 0.259$, and $F(1,598) = 0.08$, $p = 0.773$, respectively
 - ANOVAs conducted:
 - No significant effects for correct recall of roll degree for SVS or BAI, $F(2,597) = 0.97$, $p = 0.381$, and $F(1,598) = 0.13$, $p = 0.723$, respectively

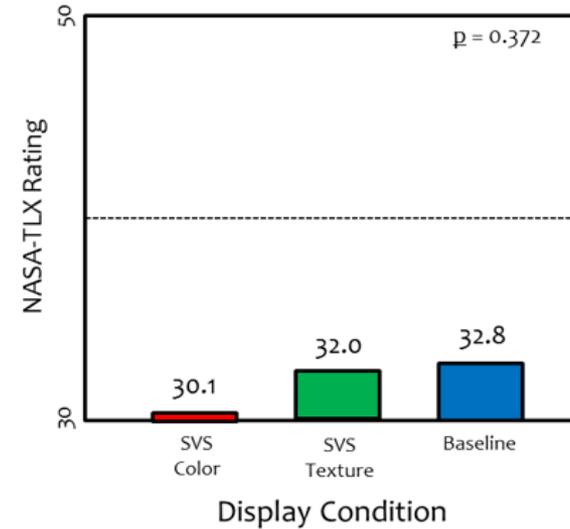




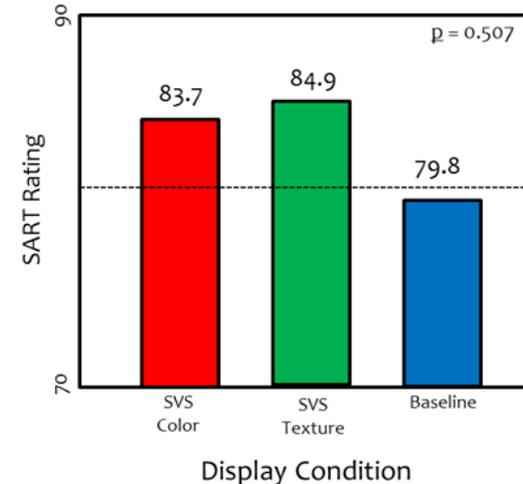
Data Analysis – TLX and SART

1. Background
2. Experiment Design
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5. Q&A

- NASA TLX:
 - Based on display concepts, no significant effects were found on overall EP workload, $F(4,321) = 1.10, p = 0.372$.
 - Pilots reported overall less workload when attempting UAR scenarios using a SV with color display (30.1 percent) as opposed to the baseline display (32.8 percent).



- SART:
 - No significant effects on UA recovery time based on display concepts $F(4,321) = 1.18, p = 0.507$,
 - Pilots identified a higher sense of situation awareness (84.9 percent) when flying with a SV display with texture as opposed to the baseline display (79.9 percent).





Data Analysis – Paired Comparison

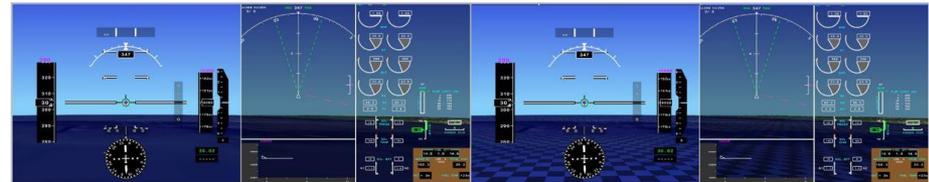
1. Background
2. Experiment Design
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Pilots evaluated the display concepts in the following combinations:

- Baseline, No BAI vs SV with color gradient, No BAI
 - Baseline, No BAI vs SV with texture, No BAI
 - Baseline, No BAI vs SV with color gradient, BAI On
 - Baseline, No BAI vs SV with texture, BAI On
 - SV with color gradient, No BAI vs SV with texture, No BAI
 - SV with color gradient, BAI On vs SV with texture, BAI On
- Overall, pilots identified the SV displays (color, texture) with BAI On as most preferred for both UA recognition and recovery when compared with the baseline display.
 - Pilots showed equal preference between the SV with color gradient and SV with texture when BAI was off.
 - If using the BAI, pilots preferred the SV with color gradient over the SV with texture.



Baseline vs SV with Color Gradient, No BAI



SV with Color Gradient vs SV with Texture, BAI on



Conclusions

1. Background
2. Experiment Design
3. Evaluation Tasks and Procedures
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- Quantitative results showed that there were no significant statistical effects on UA recovery times when utilizing SV with or without the presence of a BAI.
- Qualitative results show the SV displays (color, texture) with BAI On are most preferred for both UA recognition and recovery when compared with the baseline display.
- When only comparing SV display concepts, pilots performed better when using the SV with texture, BAI On, than any other display configuration.
 - Pilots, however, noted their preference towards the SV with color gradient when the BAI was on.



Future Work

1. Background
2. Experiment Design
3. Evaluation Tasks and Procedures
4. Data Analysis
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- Data collected from this experiment will be used to improve SV and BAI displays for featureless terrain in possible follow-on study
 - Larger data pool may be required to determine significant trends for performance standards development in support of SE-200 objectives
- Additional work currently on-going in NASA LaRC's Research Flight Deck, Full-Motion Simulator
 - Improved SV and BAI concepts over featured-terrain





References

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1. Background
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Questions?



Back-Ups



Baseline + NO BAI

SV + NO BAI

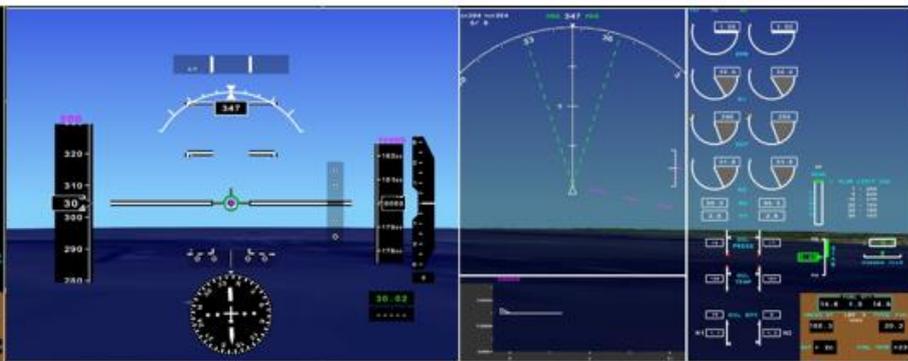


Baseline + NO BAI

SV w/ texture + NO BAI



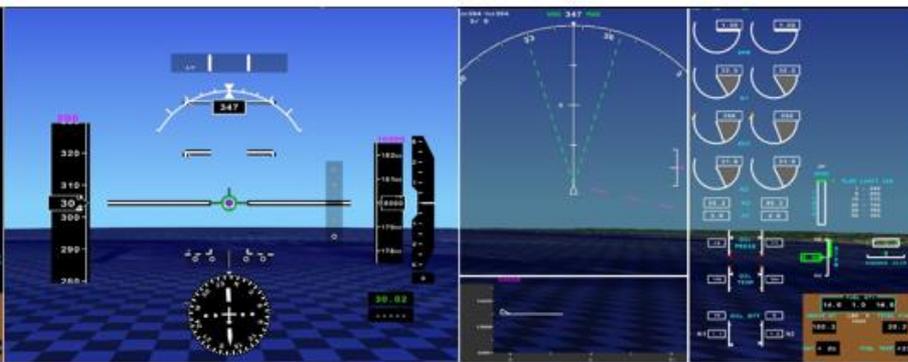
Baseline + NO BAI



SV + BAI



Baseline + NO BAI

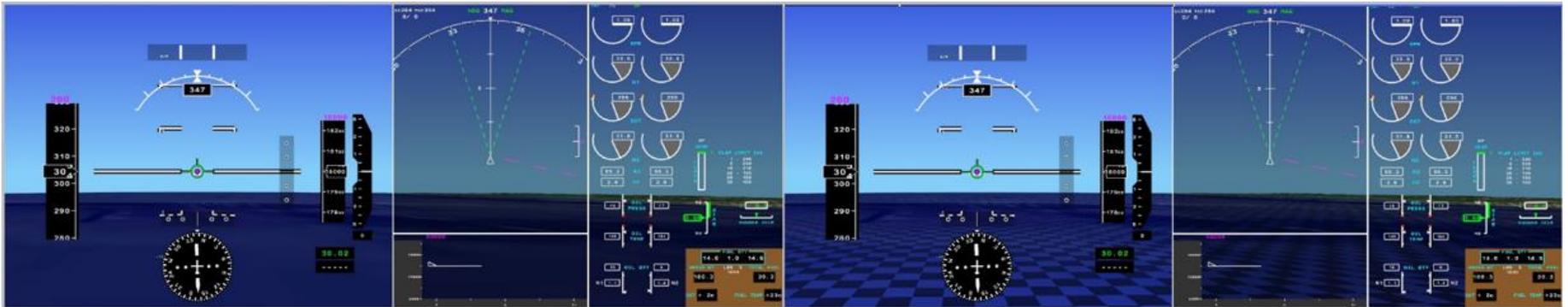


SV w/ texture + BAI



SV + NO BAI

SV w/ texture + NO BAI



SV + BAI

SV w/ texture + BAI



VISTAS Systems Integration

1. Background
2. Experiment Matrix
3. Task and Procedures
4. Data Collection & Analysis
5. Q&A



Body Motion - *Microsoft Kinect*



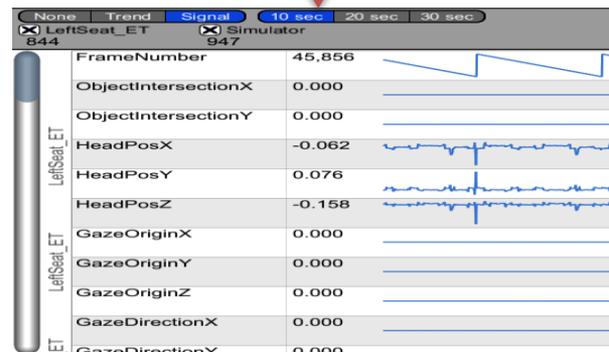
EEG - *ABM x24*



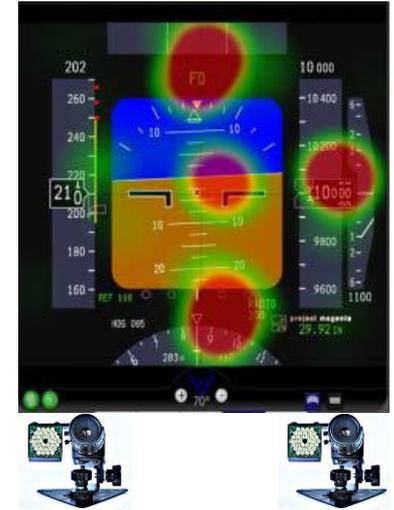
fNIRS - *Biopac*



Pilot and Aircraft State
Data Streams



Data Synchronization and Analysis - *MAPPS*



Eye Tracking - *SmartEye*



Physio - *Nexus 10*

- EKG (BPM/HRV)
- Respiration Rate
- Skin Temperature
- Galvanic Skin Response