The Design Of A Use(r)-Centered Pilot-IMS Interface

An Overview of the Activities, Plans, and Findings of the Cognitive Engineering Group
Cognitive Engineering

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Graduate Student: John M. McGuirl
SMART ICING SYSTEMS
Research Organization

Core Technologies

Aerodynamics and Propulsion
Flight Mechanics
Controls and Sensor Integration
Human Factors/ Cognitive Engineering
Aircraft Icing Technology

IMS Functions

Characterize Icing Effects
Operate and Monitor IPS
Inform and Advise Pilots
Envelope Protection
Adaptive Control

Flight Simulation Demonstration
Safety and Economics Trade Study
Cognitive Engineering

Goal: Improve the safety of flight in icing conditions. Develop smart system to improve ice tolerance.

Objectives: Design human-centered interface that
- a) informs pilots about presence/changes and performance effects of icing conditions
- b) communicates IMS/IPS status/activities/limitations to crew in timely and effective manner
- c) provides pilots with advisories for handling inflight icing encounters safely

Approach: Identify pilots’ information requirements
- Develop candidates for human-centered cockpit interface
- Evaluate effectiveness and robustness of candidates in simulator studies
Cognitive Engineering

Icing Encounter

Detection → Diagnosis → Monitoring → Action Selection → Execution of Action

Possible IMS Functions

Attention Capture/Guidance

Decision Support

Status Display
Trend Display
Command Display
Envelope Protection; Flight Control Adaptation

Cognitive Engineering
Attention Capture and Guidance

- What captures attention in an effective manner?

  “Contingent Orienting”

- One promising approach:

  A central alerting mechanisms that extends horizontally across forward field of view…..

  … and guides attention to location where additional information on specific problem is presented
Attention Capture and Guidance
Attention Capture and Guidance
Attention Capture and Guidance
Cognitive Engineering

Icing Encounter

- Detection
- Diagnosis
- Monitoring
- Action Selection
- Execution of Action

IMS Functions

- Attention Capture/Guidance
- Status Display
- Trend Display
- Command Display
- Envelope Protection; Flight Control Adaptation
Information Requirements In Icing Conditions: A Pilot Survey

McGuirl, Schroeder, McCray, and Sarter

Note: Copies of report now available on-line

(http://csel.eng.ohio-state.edu/smart_icing/)
Information Requirements

8 Most Highly Rated Items
(>70% of pilots rate as “critical/needed at all times”)

- IMS/IPS Status: 77.1%
- Reliability of IMS/Sensors: 71.8%
- Outside Air Temperature: 81.8%
- Loss of Airspeed: 78.1%
- Current Flap Setting: 71.4%
- Autopilot Status: 70.6%
- Rate of Ice Accretion: 85.5%
- Amount of Ice Accretion: 77.4%

(Note: Location of Ice Accretion: 55%)
# Information Requirements

## Detection of in-flight icing

<table>
<thead>
<tr>
<th>Condition</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Visual check for ice accretion</td>
<td>93%</td>
</tr>
<tr>
<td>Loss of airspeed</td>
<td>69%</td>
</tr>
<tr>
<td>Need for additional power to maintain altitude/climb</td>
<td>20%</td>
</tr>
<tr>
<td>Unusual trim adjustments by auto-pilot</td>
<td>9%</td>
</tr>
</tbody>
</table>

- **Data-Driven/Violation of Expectations**
- **Expectation-Driven Active Search/Information May Not Be Available**

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4-14
Cognitive Engineering

Icing Encounter

Detection → IMS Functions → Status Display

Diagnosis

Monitoring → Trend Display

Action Selection

Execution of Action → Command Display

Attention Capture/Guidance → Envelope Protection;
Flight Control Adaptation
Multimodal Information Presentation

Comparison of Effectiveness of Visual and Tactile Cues For Presenting Icing-Related Information

- Modern flight decks impose considerable demands on visual and auditory channels

- Tactile channel is underutilized although powerful means of capturing attention and useful for providing some diagnostic information

- As more systems/data are added, multimodal information presentation becomes more important to avoid resource competition (Multiple Resource Theory)
Multimodal Information Presentation

Processing Code

Modality

Multiple Resource Theory (Wickens)

Processing Stage
Presenting In-flight Icing Information: A Comparison of Visual and Tactile Cues

John McGuirl
The Ohio State University
Motivation

• Flight decks impose high demands on visual and auditory channels.

• Further distributing information across sensory channels can improve performance (MRT)

• Tactile cues are rarely used and afford higher detection rates than visual cues. (Sklar and Sarter, 1999)

• Study objective: Compare effectiveness of tactile and visual feedback for icing information presentation.
Participants

- 24 volunteers from the OSU aviation program and local airports.

Background Information

<table>
<thead>
<tr>
<th></th>
<th>Average</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age</td>
<td>27.4</td>
<td>19-55</td>
</tr>
<tr>
<td>Flight Time</td>
<td>248.8</td>
<td>10-3500</td>
</tr>
</tbody>
</table>
Experimental Conditions

Tactile Condition

- Vibrotactors placed on inside of the forearm.
- Cues were presented sequentially (wing → tail) cycled for 5 seconds.
### Experimental Conditions

<table>
<thead>
<tr>
<th>Condition</th>
<th>Light</th>
<th>Moderate</th>
<th>Severe</th>
<th>Clear</th>
</tr>
</thead>
<tbody>
<tr>
<td>Visual</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>additive</td>
<td><img src="image" alt="Light Blue" /></td>
<td><img src="image" alt="Moderate Blue" /></td>
<td><img src="image" alt="Severe Blue" /></td>
<td><img src="image" alt="Clear Blue" /></td>
</tr>
<tr>
<td>substitutive</td>
<td><img src="image" alt="Light Yellow" /></td>
<td><img src="image" alt="Moderate Yellow" /></td>
<td><img src="image" alt="Severe Yellow" /></td>
<td><img src="image" alt="Clear Yellow" /></td>
</tr>
<tr>
<td>Tactile</td>
<td><img src="image" alt="Light Tactile" /></td>
<td><img src="image" alt="Moderate Tactile" /></td>
<td><img src="image" alt="Severe Tactile" /></td>
<td><img src="image" alt="Clear Tactile" /></td>
</tr>
<tr>
<td>additive</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>substitutive</td>
<td></td>
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</tbody>
</table>

The lack of any learned mapping of tactile patterns precluded having an substitutive tactile condition.
Apparatus

- Ambient strip
- Secondary visual task (oil pressure gauges)
- IMS Display
Independent Variables

- Modality (representation) of icing cue
  - tactile (additive)
  - visual (additive)
  - visual (substitutive)
- Interference between icing and other flight related cues
  - modality
  - simultaneity
- Flying task difficulty (low / high)
Dependent Variables

- Detection of icing onset / update cue
- Correct identification of icing condition
  - location
  - severity
- Correct identification of change in conditions
- Detection of secondary visual cue
Experiment Design/Procedure

- Briefing / experience questionnaire
- Training session (3 sets of 32 cues)
  - cues repeated twice, in ascending order with answers shown on screen.
  - randomized order with answers shown.
  - randomized order, subject read back answer.
- 2 x 25 min flights / questionnaire
- De-briefing
Experiment Design/Procedure

• Each subject received:
  - 98 icing signals (each wing / tail)
  - 64 changes in icing levels
  - 16 engine gauge deviations
  - 16 auditory messages
Detection of Icing Cues

Tactile group performed as well as the two visual groups

![Bar graph showing detection rates: VA 96.9%, VS 98.6%, TA 100%]
Accuracy in Identifying Icing Cues

61% of misidentifications involved light and medium icing levels.

Refinement to tactor cues resulted in a 59% reduction in misidentifications.

<table>
<thead>
<tr>
<th></th>
<th>VA</th>
<th>VS</th>
<th>TA</th>
<th>TA new</th>
</tr>
</thead>
<tbody>
<tr>
<td>%</td>
<td>97.7</td>
<td>99.8</td>
<td>96.9</td>
<td>98.3</td>
</tr>
</tbody>
</table>
Detection/Accuracy for Changes in Icing Severity

Again: Tactile performed as well as visual

Detection of Change

Correct ID of Change
Secondary Visual Task Performance

Tactile cues afforded better divided attention

<table>
<thead>
<tr>
<th></th>
<th>Not concurrent with icing cue</th>
<th>Concurrent with icing cue</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tactile cues</td>
<td>52.2</td>
<td>84</td>
</tr>
<tr>
<td>Tactile cues</td>
<td>42.3</td>
<td>41.6</td>
</tr>
<tr>
<td>Tactile cues</td>
<td>57.9</td>
<td>37.5</td>
</tr>
</tbody>
</table>
## Effects of Auditory Interference on Detection and Accuracy

<table>
<thead>
<tr>
<th></th>
<th>Missed Icing Cues</th>
<th>Incorrect Icing ID</th>
<th>Missed Changes in Icing</th>
<th>ATC Repeated</th>
</tr>
</thead>
<tbody>
<tr>
<td>Visual substitutive</td>
<td>25%</td>
<td>50%</td>
<td>18%</td>
<td>6%</td>
</tr>
<tr>
<td>Visual additive</td>
<td>17%</td>
<td>25%</td>
<td>21%</td>
<td>4%</td>
</tr>
<tr>
<td>Tactile additive</td>
<td>None</td>
<td>17%</td>
<td>13%</td>
<td>11%</td>
</tr>
</tbody>
</table>
Auditory Interference

- All three groups were affected by the auditory interruptions, but in different ways.
- Novelty of tactile cues may have resulted in focus on that modality (may be reduced through training)
- Visual cues appeared to be more vulnerable to pre-emption by the auditory messages.
Summary

- All groups performed equally well in terms of detection and identification.
- Tactile cues
  - resulted in improved visual scanning
  - were less vulnerable to auditory interference
  - requires minimal additional training
- Results suggest use of tactile feedback.

Fast track certification anyone ?? 😊
Cognitive Engineering

Icing Encounter

- Detection
- Diagnosis
- Monitoring
- Action Selection
- Execution of Action

IMS Functions

- Attention Capture/Guidance
- Status Display
- Trend Display
- Command Display
- Envelope Protection;
  Flight Control Adaptation

Decision Support
Decision Support

The IMS as a Decision-Support System:
A Simulator Study Comparing
Status and Command Displays

Beth Schroeder and Nadine Sarter

Note: Thesis document is included on the CD
- **Participants:** 27 instructor pilots

- **Flight experience:** average: 777 (827) hrs
  range: 200-4,600 hrs

- **3 conditions:**
  - baseline (no aid, except for icing probe)
  - status display
  - command display

- Medium-fidelity simulation of twin-engine aircraft
Decision Support

The Status Display
Decision Support

The Command Display
## Decision Support

<table>
<thead>
<tr>
<th>Stages of Decision-Making</th>
<th>Possible Problems</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cue detection</td>
<td>Time pressure</td>
</tr>
<tr>
<td></td>
<td>High workload</td>
</tr>
<tr>
<td></td>
<td>Attentional narrowing</td>
</tr>
<tr>
<td>Cue interpretation/</td>
<td>Cues are few,</td>
</tr>
<tr>
<td>integration</td>
<td>ambiguous, scattered,</td>
</tr>
<tr>
<td></td>
<td>of poor quality</td>
</tr>
<tr>
<td>Hypothesis generation</td>
<td>Lack of information in</td>
</tr>
<tr>
<td></td>
<td>long-term memory</td>
</tr>
<tr>
<td>Command</td>
<td>(e.g., prior experiences)</td>
</tr>
<tr>
<td>Action selection</td>
<td></td>
</tr>
</tbody>
</table>
Decision Support

Stall frequency as function of display condition and accuracy of IMS information

<table>
<thead>
<tr>
<th>Display Condition X Accuracy</th>
<th>Baseline</th>
<th>Acc S</th>
<th>Acc C</th>
<th>Inacc S</th>
<th>Inacc C</th>
</tr>
</thead>
<tbody>
<tr>
<td>% Stall</td>
<td>30.00</td>
<td>18.25</td>
<td>12.60</td>
<td>57.41</td>
<td>60.38</td>
</tr>
</tbody>
</table>
Reaction Time To Stall As Function of Display Condition and Accuracy of Advisory Information

Mean RT to Stall (sec)

- Baseline: 1.99
- Accurate: 1.73
- Inaccurate: 2.87
Stall Recovery Errors in the Different Conditions

- Baseline: 57.41%
- Accurate: 56.41%
- Inaccurate: 80.95%

Accuracy of Display
Decision Support

Summary

- Status display appears to be preferable.
  - equally beneficial with accurate information
  - less vulnerable to effects of inaccurate information than command
  - fewer recovery errors

- Still need better support for trust calibration as well as long-term planning and decision-making
Current and Future Activities

Icing Encounter

 Detection → Diagnosis → Monitoring → Action Selection → Execution of Action

IMS Functions

Attention Capture/Guidance

Status Display

Trend Display

Command Display

Decision Support

Envelope Protection; Flight Control Adaptation
Current and Future Activities

Two Important Principles of Information Design

1) Put data in context

2) Highlight changes and events
Trend Display Concept

Prediction of “Icing Severity”

Warning
Caution

min
Support longer-term monitoring and planning through projection and history information

- Indicate (dynamically changing) level of certainty
Another Promising Approach: Object Displays

- Loss of symmetry supports at-a-glance monitoring and detection of problems
- Plus: Information available on nature of problem, assuming multiple limit parameters will be available
Preliminary Overall Design Concept

Sample Sequence of Possible Icing Encounter and Associated IMS Indications
No Icing
Icing Onset – Wing and Tail Moderate
Continued Wing and Tail Moderate
Continued Moderate Icing + Trend Display
Wing Severe Icing, Tail Moderate Icing
Continued Wing Severe, Tail Moderate Icing
Back to Wing and Tail Moderate Icing
Back to No Icing
Cognitive Engineering Waterfall Chart

Federal Fiscal Years

- Information Requirements
- Command vs. Status Displays
- Alerting and Status Display Multimodal Information Presentation
- Trend Display/Decision Support/Envelope Protection and Flight Control Adaptation Implementation
- Evaluation/Refinement of Integrated IMS Cockpit Interface