The Design Of A Human-Centered Pilot-IMS Interface

An Overview of Human Factors/Cognitive Engineering Plans, Findings, and Activities
SMART ICING SYSTEMS
Research Organization

Core Technologies

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

Smart Icing Systems

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
Smart Icing System Research

McGuirl, Schroeder, and Sarter
McGuirl, Schroeder, McCray, and Sarter
Schroeder and Sarter
McGuirl and Sarter

Pilot Survey + Accident/Incident Reviews
Large-Scale Pilot Survey
Design of Alerting and Status Display
Design of Trend Display(s)
Simulator Study Comparing Command vs. Status Display

Information Requirements
WHAT?
Information Automation/Representation
HOW?
Advisory Functions/Decision Support

 WHAT? HOW? HOW?
Information Requirements

Information Requirements In Icing Conditions: A Pilot Survey

McGuirl, Schroeder, McCray, and Sarter
Pilot Survey (in collaboration with ALPA)

- Sent to 6,400 pilots from 9 regional carriers
- Ratings, and explanation of importance, of information on 3 areas:
  - Characteristics of icing
  - Aircraft configuration and performance
  - IMS/IPS status/activities
Open-ended questions about:

- company policies/procedures
- operational experiences
- training
- monitoring behavior
- frequency of encounters
- suggestions for IMS functions/design
# Information Requirements

## Background of Responding Pilots

<table>
<thead>
<tr>
<th></th>
<th>Capt.’s (n=238)</th>
<th>F/O’s (n=148)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean</td>
<td>Range</td>
</tr>
<tr>
<td>Total Hours</td>
<td>9,326</td>
<td>2,600-26,750</td>
</tr>
<tr>
<td>Time In Type</td>
<td>3,133</td>
<td>40-12,000</td>
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**Average:** 800 hrs/yr  
**Rookie:** <1,000/100  
**Expert:** >4,000/500
Information Requirements

Aircraft

- SF 340 (25.2%)
- DHC-8 (19.7%)
- ATR-42/72
- EMB 145
- RJ 85
- RJ65
- BaE3200
- EMB 120
- Others (8.3%)
- Others (9.8%)
Information Requirements

Detection of In-flight Icing

- Visual check for ice accretion: 93%
- Loss of airspeed: 69%
- Need for additional power to maintain altitude/ climb: 20%
- Unusual trim adjustments by auto-pilot: 9%

Active Search

Data-Driven
Information Requirements

8 Most Highly Rated Items

(received a ‘critical’ rating from more than 70% of pilots)

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

6 Next Important Items

(received a ‘critical’ rating from about 60-70% of pilots)

- Excessive Trim Requirements: 67.9%
- Stall Margin/AOA: 66.1%
- Engine Performance: 63.6%
- Degree of Loss of Long. Stab.: 62.5%
- Reliability of IMS Advice: 62.2%
- Climb Performance Degradation: 61.3%
Information Requirements

Pilots ask for **trend information** on:

- Stall Margin 24 pilots
- AOA 24 pilots
- Airspeed 23 pilots
- Rate of Ice Accretion 21 pilots
- Climb Performance 9 pilots
- Stability 9 pilots
- Trim Requirements 7 pilots
- Safe Time in Conditions 7 pilots
Information Requirements

Smart Icing Systems

Worst Icing Encounter

- Very high rate of ice accretion: 32%
- Sudden change in conditions: 9%
- IPS overwhelmed: 10%
- Very high amount of ice accretion: 6%
- Unexpected icing conditions: 9%
- Build-up on unprotected areas: 6%
Information Requirements

Summary

• Pilots ask for more/better information on:
  • AOA/Stall Margin/Airspeed Changes
  • Rate and Amount of Ice Accretion
  • Climb Performance Degradation
  • (Longitudinal) Stability

• Worst encounters are perceived to be those that are highly dynamic, very severe, and/or unexpected
Human Factors/Cognitive Engineering

Smart Icing Systems

IMS Functions

Icing Encounter

Detection

Diagnosis

Monitoring

Action Selection

Execution of Action

Attention Capture/Guidance

Status Display

Trend Display

Command Display

Decision Support

Envelope Protection; Flight Control Adaptation
Notification and Initial Status

Notification and initial diagnosis of icing conditions

McGuirl and Sarter
Notification and Initial Status

“Highlight Changes and Events”

- Onset of Ice Accretion
- Significant Change in Rate of Ice Accretion
- Significant Change in Performance Effects of Icing
- Reversals
- IPS/IMS Problems/Failures
Notification and Initial Status

Smart Icing Systems

NASA Review, June 13-14, 2000

Attention Capture and Guidance

- Onsets in peripheral vision and/or feedback that extends across forward field of view

- (Redundant) Feedback via other modalities to support task-sharing (e.g., auditory, tactile cues)
No Icing

Smart Icing Systems  NASA Review, June 13-14, 2000
Onset of Light Icing
Continued Light Icing
Transition From Light To Severe Icing

NASA Review, June 13-14, 2000

University of Illinois at Urbana-Champaign
National Aeronautics and Space Administration
To Time-Share or Not To Time-Share...
Alarm Likelihood Display

- Providing more than just a single level of alert to signal system’s own confidence that alarming conditions are present (visual coding, auditory/tactile patterns)

- Ensures that alarm is effective without imposing considerable attentional costs

- Addresses false alarm problem and supports pilots’ trust calibration
Human Factors/Cognitive Engineering

Smart Icing Systems

NASA Review, June 13-14, 2000

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

University of Illinois at Urbana-Champaign
National Aeronautics and Space Administration
The IMS as a Decision-Support System: A Simulator Study Comparing Status and Command Displays

Schroeder and Sarter
## Decision Support

**Stages of Decision-Making**

- **Cue detection**
- **Cue interpretation/integration**
- **Hypothesis generation**
- **Action selection**

**Possible Problems**

- **Status**
  - Time pressure
  - High workload
  - Attentional narrowing

- **Command**
  - Cues are few, ambiguous, scattered, of poor quality
  - Lack of information in long-term memory (e.g., prior experiences)
Decision Support

Smart Icing Systems

Simulator Study On the Effectiveness/Limitations of Command vs. Status Displays

- Participants: 27 instructor pilots from UofI Institute of Aviation

- 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

Smart Icing Systems NASA Review, June 13-14, 2000

Procedure and Tasks

Session 1 (1 hr long):
Introduction to icing, simulator, and experiment

Sessions 2 and 3 (experimental - 2 hrs each):
Simulator practice
10 ILS approaches to various Michigan airports
Debriefing
Experimental Design

Within-subjects variables: - accuracy of IMS-provided information
- familiarity with condition (wing vs. tail icing)
- manual vs. autopilot control
- timing of icing onset
  (outside/at/inside outer marker)

Dependent variables: - RT to probe onset
- early buffet
- stall
- RT/response to stall
- tracking performance
- detection of G/S failure
Wing versus Tail Icing

Symptoms

- increase in descent rate
- airframe buffet

- forward pull on yoke
- increase in descent rate
- yoke buffet

Response

- add power
- maintain/extend flaps
- reduce pitch

- reduce power
- retract flaps
- increase pitch
Decision Support

The Status Display
Decision Support

The Command Display
Decision Support

Mean reaction time to icing probe as function of autopilot usage

- A/P: 4.45 secs
- No A/P: 6.46 secs
Decision Support

Mean reaction time to icing probe as function of icing onset location

- Outside marker: 6.8 secs
- At marker: 4.9 secs
- Inside marker: 4.6 secs
Early buffet as function of display condition and accuracy of IMS information.

% of Pilots Experiencing Early Buffet

Display Condition X Accuracy

Baseline: 20.56
Acc Stat: 7.14
Acc Com: 6.30
Inacc Stat: 42.59
Stat Inacc: 54.72
Com:
Early buffet:
Interaction display condition by accuracy of IMS information

Diagram:
- % of Pilots Experiencing Early Buffet
- Advisory Information
  - Accurate
  - Inaccurate
- Status
- Command

Graph showing the relationship between accurate and inaccurate advisory information and the percentage of pilots experiencing early buffet.
Stall frequency as function of display condition and accuracy of IMS information

Display Condition X Accuracy

- Baseline: 30.00%
- Acc S: 18.25%
- Acc C: 12.60%
- Inacc S: 57.41%
- Inacc C: 60.38%
Decision Support

Stall frequency as function of display condition, accuracy of IMS information, and familiarity with icing condition

![Bar chart showing % Stall for different display conditions and accuracies.]

- **Baseline**: 32.72% (Wing), 42.66% (Tail)
- **Acc Stat**: 22.59% (Wing), 20.37% (Tail)
- **Acc Com**: 9.26% (Wing), 20.11% (Tail)
- **Inacc Stat**: 88.89% (Wing), 83.33% (Tail)
- **Inacc Com**: 83.33% (Wing), 83.33% (Tail)

*Display Condition X Accuracy X Location*
Decision Support

Response time to stall as function of display condition and accuracy of IMS information

- **Accuracy**
  - RT in seconds
  - Status
  - Command

- **Response time to stall** as function of display condition and accuracy of IMS information.
Decision Support

Stall recovery errors as function of display condition and accuracy of IMS information

Accuracy

% Stall Recovery Error

Status
Command

Accurate Inaccurate
Detection of glide slope failure as function of display condition and accuracy of advisory information
Summary

• Status display is preferable.

Equally beneficial with accurate information, less vulnerable to effects of inaccurate information than command, and fewer recovery errors

• Need for training and design to improve trust calibration and familiarity with rare icing scenarios
Human Factors Waterfall Chart

Smart Icing Systems

NASA Review, June 13-14, 2000

Federal Fiscal Years

98 99 00 01 02

Information Requirements

Command vs. Status Displays

Alerting and Status Display

Trend Displays/Decision Support/Envelope Protection and Flight Control Adaptation Implementation

Evaluation/Refinement of Integrated IMS Cockpit Interface
Future Activities

- Refine and evaluate IMS display for notification of significant changes and events
- Examine benefits and risks associated with different implementations of decision support
- Develop and evaluate trend display(s)
- Collaborate with other team members on defining the approach to and implementation of envelope protection/control adaptation