The Effects of Weather Presentation Symbology on General Aviation (GA) Pilot Behavior, Workload, and Visual Scanning

Presented to: FPAW Meeting
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• **Objective:**
  – To explore the effects of cockpit weather presentation symbology on General Aviation (GA) pilot weather avoidance, weather presentation usage, and cognitive workload.

• **Background:**
  – To support the NextGen program, on-going efforts focus on the implementation and use of weather technologies and weather presentations.
  – Currently, there are no Federal Aviation Administration (FAA) or industry standards for the presentation of weather information in the cockpit.
  – Very little empirical data on the effects of weather presentation symbology on pilot decision-making behavior.

• **Method:**
  – Twenty-five instrument-rated GA pilots were randomly allocated to one of three simulation groups.
  – During two 25-min simulation flights, participants flew a Cessna 172 single engine GA aircraft (using autopilot) under Visual Meteorological Conditions (VMC) and Instrument Meteorological Conditions (IMC).
  – The pilots had to avoid the weather using the cockpit weather presentation.
  – We manipulated the cockpit weather presentation so that each pilot group used a different weather presentation symbology.

• **Results:**
  – We found group differences in weather deviations, visual scanning behavior, and cognitive workload.
## Simulation Group Data for Age and Flight Hours

<table>
<thead>
<tr>
<th></th>
<th>Group 1</th>
<th>Group 2</th>
<th>Group 3</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Age</strong></td>
<td>Median = 64, Q1 = 59,</td>
<td>Median = 56, Q1 = 49.5</td>
<td>Median = 53, Q1 = 42,</td>
</tr>
<tr>
<td></td>
<td>Q3 = 69.5, IQR = 10.5</td>
<td>Q3 = 61.5, IQR = 12</td>
<td>Q3 = 61.5, IQR = 19.5</td>
</tr>
<tr>
<td><strong>Total flight hours</strong></td>
<td>Median = 3500, Q1 = 1750, Q3 = 6330, IQR = 4580</td>
<td>Median = 3100, Q1 = 675, Q3 = 5150, IQR = 4475</td>
<td>Median = 4000, Q1 = 1600, Q3 = 5600, IQR = 4000</td>
</tr>
<tr>
<td><strong>Instrument flight hours</strong></td>
<td>Median = 350, Q1 = 225, Q3 = 850, IQR = 625</td>
<td>Median = 150, Q1 = 29, Q3 = 1250, IQR = 1221</td>
<td>Median = 300, Q1 = 175, Q3 = 575, IQR = 400</td>
</tr>
<tr>
<td><strong>Instrument flight hours within the previous 6 months</strong></td>
<td>Median = 2, Q1 = 0, Q3 = 6.5, IQR = 6.5</td>
<td>Median = 2, Q1 = 0.5, Q3 = 21.5, IQR = 21</td>
<td>Median = 7.5, Q1 = 2, Q3 = 3, IQR = 28</td>
</tr>
</tbody>
</table>

Median (middle value of a data set), First Quartile (Q1, median of the lower half of the data set), Third Quartile (Q3, the median for the upper half of the data set), and the Interquartile Range (IQR, the spread of the middle 50% of the values)
The Micro-jet cockpit simulator (Cessna 172)

Cockpit glass and weather presentation display (3 zoom levels: 5, 20, and 50 nmi. Range rings)

Eye tracker and functional near-infrared (fNIR) systems

Flight plan (MIP to KBDL) on a sectional map
<table>
<thead>
<tr>
<th>Weather Data</th>
<th>Weather Parameters</th>
<th>Group 1</th>
<th>Group 2</th>
<th>Group 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>METAR</td>
<td>VFR</td>
<td><img src="image" alt="VFR" /></td>
<td><img src="image" alt="VFR" /></td>
<td><img src="image" alt="VFR" /></td>
</tr>
<tr>
<td></td>
<td>MVFR</td>
<td><img src="image" alt="MVFR" /></td>
<td><img src="image" alt="MVFR" /></td>
<td><img src="image" alt="MVFR" /></td>
</tr>
<tr>
<td></td>
<td>IFR</td>
<td><img src="image" alt="IFR" /></td>
<td><img src="image" alt="IFR" /></td>
<td><img src="image" alt="IFR" /></td>
</tr>
<tr>
<td></td>
<td>LIFR</td>
<td><img src="image" alt="LIFR" /></td>
<td><img src="image" alt="LIFR" /></td>
<td><img src="image" alt="LIFR" /></td>
</tr>
<tr>
<td>SIGMET</td>
<td><img src="image" alt="SIGMET" /></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lightning</td>
<td>&lt;5 min old</td>
<td><img src="image" alt="Lightning &lt;5 min old" /></td>
<td><img src="image" alt="Lightning 5-10 min old" /></td>
<td><img src="image" alt="Lightning 10-15 min old" /></td>
</tr>
<tr>
<td>Precipitation</td>
<td>Nine colors</td>
<td><img src="image" alt="Precipitation Nine colors" /></td>
<td><img src="image" alt="Precipitation Five colors" /></td>
<td><img src="image" alt="Precipitation Nine colors" /></td>
</tr>
</tbody>
</table>

*Note: for our weather presentations we used commercially available weather symbols*
Weather presentations (Group 1-3)
<table>
<thead>
<tr>
<th>Dependent variables</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Distance to weather</td>
<td>Lat/long difference between straight path to destination versus flown path</td>
</tr>
<tr>
<td>Weather presentation zoom</td>
<td>The number and duration of all zoom activations</td>
</tr>
<tr>
<td>Pilot / ATC communication</td>
<td>The number and duration of PTT communications</td>
</tr>
<tr>
<td>Aircraft position, altitude, and heading</td>
<td>Cockpit system measures</td>
</tr>
<tr>
<td>Eye movement metrics</td>
<td>Fixations and saccades from point-of-gaze recordings</td>
</tr>
<tr>
<td>Visual areas of Interest (AOI)</td>
<td>Cockpit out-the-window, glass display, weather presentation</td>
</tr>
<tr>
<td>Workload</td>
<td>Oxygenation changes from the fNIR recordings</td>
</tr>
</tbody>
</table>
Data Collection Procedure

- Flight briefing
- Weather briefing
- Simulator briefing
- Practice scenario
- Fitting of fNIR and eye tracking equipment
- Calibration
- Simulation scenarios (25 min)
Weather deviations

Bayesian model comparison [null (no effect) vs. alternative (effect)]

- **Group 1 \((n=8)\)** versus **Group 2 \((n=9)\)** ‘substantial’ evidence for the alternative hypothesis \((t=3.34, \text{Bayes factor}= 0.10)\).
- **Group 2** versus **Group 3 \((n=8)\)** ‘anecdotal’ evidence for the alternative hypothesis \((t=2.08, \text{Bayes factor}= 0.64)\).
- **Group 1** ($n=2$) versus **Group 2** ($n=5$) 'substantial' evidence for the alternative ($t=4.6$, Bayes factor=$0.12$).

- **Group 2** versus **Group 3** ($n=5$) 'substantial' evidence for the alternative ($t=3.2$, Bayes factor=$0.20$).

- **Group 1** versus **Group 3** 'anecdotal' evidence for the alternative ($t=1.96$, BF=$0.76$).
Mental Workload
Functional Near Infrared (fNIR) Analysis

- All groups showed a larger mean oxygenation during the IFR portion of the flight compared to the VFR portion of the flight.
- Group 1 versus Group 2 for the VFR portion (0-1 min) of the flight provides ‘anecdotal’ evidence for the alternative ($t=2.22$, $BF=0.54$).

Visual Workload
Eye Movement Workload (EMW)

- EMW – the average degrees per second that the eyes move around during the course of a flight scenario
- Group 2 (n=6) versus Group 3 (n=6), ‘anecdotal’ evidence for the alternative ($t=2.44$, $BF=0.43$)
What’s next?

• Are these effects of weather symbology operationally important?

• Are certain weather symbology presentations causing pilots to make non-optimal decisions?

• The participants in this study were experienced GA pilots. What about pilots with much less experience?

• Weather presentation time stamps?

• Are there combinations of symbols and colors that reduce the scan pattern variability among pilots?

Conduct part-task study
Common Weather Situation Awareness?
Example presentation illustrating a color palette supporting legibility, color identification, and attention management.

... provides sufficient luminance contrast for legibility of all symbols and alphanumerics on all backgrounds.

... manipulates luminance contrasts to produce a hierarchy of salience that corresponds to the urgency of the coded data elements.

... color-coding of graphic elements only for specific operational purposes - grouping, caution and warning status, and category labels.

Benefits of symbols and colors

- Symbols and colors have several advantages in weather presentations like indicating class membership of data elements (e.g., METAR symbols).
- Symbols and colors can be used to represent weather hazards, traffic emergencies, terrain, and the status of military special use airspace.
- Symbols and colors can provide visual grouping of spatially distributed but related graphic elements (e.g., METAR symbols).
- Symbols and colors can contribute to a salience hierarchy that visually segregates more urgent display information from less critical context information.

Human Factors Concerns

- **Legibility, salience manipulation** (clutter avoidance), and color recognition.

- **Symbols and alphanumeric data must be readable** on all weather backgrounds and fixed background areas.

- Current weather visualizations have map-like complexity, requires a unified design that considers relations among all of the graphic elements.

- **Conflicts among industry standards for color-coding.**

- **Reduced symbol legibility** on some textured backgrounds.

- **Colors and graphics interact with display scale.**

- **Perceptual grouping based on colors and features** – unintended visual grouping!