Improving Novice Flight Performance Using a Functional Avionics Display

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Supporters of functional interface design argue that direct interaction with the essential functional relationships of a system may aid in the acquisition of domain-specific skill. To evaluate the potential use of a functional display in assisting in the development of piloting skill, twenty novices were trained on either a conventional display or an alternative display that displays the functional relationship of power and airspeed (the Oz display). Novices trained on the functional display showed greater control of power and less deviation from a flight profile over multiple maneuvers. Implications for future research and potential uses in training are discussed.

**Introduction**

Research suggests that interfaces designed to provide system operators with high-level, perceptual information regarding system properties may improve overall performance (Rasmussen and Vicente, 1992). It is argued that such interfaces should allow for direct perception of the system goal as well as successful performance boundaries (Rasmussen, 1999). One method for accomplishing this may be through displaying information about the abstract, functional relationships occurring within a system. Multiple laboratory studies have shown performance advantages in employing such interfaces (see Vicente, 2002 for a review).

The potential of such functional interfaces has also been noted in the aviation community. Lintern, Waite, and Talleur (1999) argued for cockpit design that allows pilots to directly perceive and interact with essential functional properties of flight, reasoning that direct observation of functional flight relationships may improve pilots’ ability to acquire and maintain basic piloting skills.

Limitations in technology and costs associated with implementing and testing functional devices limited empirical evaluations of many functional displays, often reducing the implementation of such designs to proof-of-concept tests (Dinadis and Vicente, 1999). However, progress in display design has led to the implementation of prototype devices that allow for empirical evaluation of the effect of functional displays in an aviation domain.

One alternative cockpit display that displays some functional properties is the Oz system, a graphic interface designed for general aviation (See Figure 1). The Oz display integrates the physical information expressed on a conventional display into a series of basic perceptual forms, creating a display that leverages several emergent feature properties (Bennett & Flach, 1992) to communicate physical and functional flight information. One functional relationship represented by the Oz display is the functional relationship between power and airspeed. A colored vertical line is employed with one color (green) communicating the amount of power being used and another (blue) communicating the amount of power available. The same vertical line’s position on a horizontal axis communicates current airspeed. The intersection of the green portion of the vertical line with the angular wings indicates the optimal power setting needed to maintain the current airspeed. Using this graphic, a pilot can directly perceive the most effective and efficient use of power to attain a given airspeed.

The Oz display provides an effective testing ground to examine the effect of functional visualizations in an aviation domain. By comparing performance using a functional (OZ) and conventional display in an aviation task, the effect of employing a functional visualization can be examined.

Smith, Boehm-Davis, and Chong (2004) compared experienced pilots’ performance using the OZ system against a conventional general aviation display. Results showed pilots using the Oz system were better able to set and maintain optimal power settings, and showed less deviation from power settings overall. Multiple maneuvers revealed less variability among pilots using the Oz display than those pilots using the conventional display.

The previous findings support the use of a functional display to maintain pilots’ current skill set – specifically, the efficient use of power to attain and maintain airspeed. However, these results apply to already knowledgeable experts, and do not directly address the potential for improvements in skill and knowledge acquisition through functional display use.
The current research was conducted to examine the effect of a functional display on novice performance and knowledge acquisition. By comparing novices learning to fly using a functional display (Oz) against novices learning to fly using conventional instrumentation, we can evaluate the effectiveness of each interface in supporting novice performance.

If the assumptions of functional interface design are accurate, we would expect to see greater control of power in the Oz display condition than the conventional display condition. A greater control of power would be seen as less deviation from the optimal power setting. Greater understanding of the functional relationships of flight should also lead to greater overall performance, which would be reflected as less deviation from the target flight profile in the functional (Oz) condition.

Method

Participants. Participants consisted of undergraduate students drawn from the George Mason University undergraduate subject pool. Twenty undergraduates (13 males and 7 females) participated, ranging in age from 18-23 years (mean = 20.3 years). None of the participants had any prior flight training or experience. All participants were compensated with class credit for participation. All participants reported normal or corrected-to-normal vision, and reported that they were not colorblind.

Apparatus. An Elite iGATE Personal Computer Aided Training Device (PCATD) driven by a PC running Microsoft Flight Simulator 2002 (MSFS 2002) was employed to simulate the flight environment. MSFS 2002 was configured to simulate a Cessna 172D flying over Dade County Airfield (KDCD). The OZ display was run by the same PC, and covered the central 6 dials of a conventional Cessna instrument panel (see Figure 1). Flight performance data produced by Microsoft Flight Simulator 2002 was broadcast on a local network to another computer for data collection.

Participants were given a demographic questionnaire prior to participation, and then given a packet of slides to follow along with during flight training. Participants were given a paper pretest and a series of questions to answer at the completion of the performance segment of the experiment.

Experimental Design. A repeated-measures mixed design was used, in which display was between subjects, and trials and maneuvers were within subject variables. This yielded a 2 (Conventional/Oz display) X 6 (Trials) design, with 11 maneuvers nested within trials. Trials were administered in three sessions per display, with each session divided into two sets of trials. In the first trial for each of the first two sessions, the novices received feedback from the experimenter during performance. In the third session, the novices received no feedback. Each participant performed the same maneuvers, though the presentation order of maneuvers was counterbalanced across participants. Each participant performed eleven maneuvers per trial (see Table 1).

Procedure. Participants attended a lecture detailing the basic principles of flight and introducing the instrument panel. Principles and maneuvers that were not readily understood by the participants were demonstrated by the flight instructor on the simulator. The time required to complete the training session was approximately ninety minutes.

Following the training session, participants were seated at the simulator and familiarized with its controls. When operating the conventional display, participants were presented with a power table reference for the simulated Cessna.

Participants were then instructed to perform maneuvers by the experimenter, who was seated at a station to the right of the simulator. Participants were given specific instructions on the objective of the maneuver and told to fly each maneuver as accurately as possible. Each maneuver was ended when the participant leveled off within 10 feet of the target altitude and 3 degrees of heading. After a maneuver was completed, the aircraft was adjusted by the
Participants performed each maneuver for a total of 11 maneuvers, or one trial. After the 11 maneuvers were performed, participants were excused for a short break, and then returned to perform another trial of 11 maneuvers. A set of two trials were considered one session.

For each trial involving experimenter feedback, the experimenter monitored participant performance of the novice and offered guidance based on the principles taught in the instruction session. To ensure consistency and avoid bias, guidance was limited to a series of phrases directly related to the material initially taught to the novices (See Table 2). After three sessions were completed, the participant was given a document containing a series of open-ended questions requesting an explanation of the procedure the participant followed to complete a given task.

Results

To evaluate performance on each display, root mean squared error (RMSE) was calculated from the differences between optimal performance and observed performance. For altitude and heading, the optimal flight path was calculated and RMSE was calculated for each pilot. For power, RMSE was calculated by comparing actual performance against optimal baseline performance (that is, the optimal power settings for straight and level flight).

A repeated measures, one-way ANOVA was used to analyze performance differences between the two displays. For this report, the results will focus on the performance differences for power and altitude between display conditions.

Straight and Level Flight. Analysis showed novices in the Oz display condition deviated significantly less from optimal power settings ($F (1, 9) =33.148$, $p<.001$) than novices trained on the conventional system (Figure 2). This finding is consistent with differences observed between display conditions in experienced pilots (Smith, Boehm-Davis, and Chong, 2004), and is consistent with the effects of direct perception and direct manipulation (Lintern et al., 1999).

Altitude differences also supported performance advantages in the functional display condition (Figure 3), as novices flying the Oz display deviated significantly less from the flight profile ($F(1,9)=26.403$, $p<.001$). Novices using a functional display flew more efficiently and with greater accuracy.

Increasing Speed
Novices trained on the Oz display deviated significantly less from optimal power settings \((F(1, 9) = 4.808, P<.05)\) when increasing speed (Figure 4) than novices using the conventional display. Novices using the Oz display also deviated less from the flight profile \((F(1, 9) = 14.688, p<.01)\) (Figure 5). No significant differences in speed control were observed between display conditions.

![Figure 4. Power deviations between displays when increasing speed.](image)

![Figure 5. Altitude deviations between displays when increasing speed.](image)

**Standard Rate Turn while Ascending.** Novices trained on the Oz system used significantly more power \((F(1, 9) = 5.815, p<.05)\) than their counterparts trained on a conventional display (Figure 6). These maneuvers, however, require a large amount of the systems available power. It is likely that the amount of power used corresponds with correct operation of the aircraft. Pilots using the functional (Oz) display deviated significantly less \((F(1, 9) = 23.547, p<.001)\) from the optimal flight path in altitude (Figure 7) and heading \((F(1, 9) = 204.26, p<.001)\) than novices trained on a conventional system. No significant differences in speed control were observed between display conditions, even when novices were given direct instructions to control for speed.

![Figure 6. Power deviations between displays when ascending and performing a standard rate turn.](image)

![Figure 7. Altitude deviations between displays when ascending and performing a standard rate turn.](image)

**Discussion**

The results offer support for the potential of functional displays to aid in the acquisition of piloting skill. Across all maneuvers, novices using the Oz display were able to maintain a flight profile (altitude and heading) closer to optimal than novices flying conventional displays.

The results point to a potential difference in novice understanding of the functional relationships present during flight. Novices trained on a functional display applied power in patterns consistent with the requirements of the maneuver. This was observed consistently in both straight and level and banking maneuvers, as novices trained on the Oz display were better able to maintain consistent power settings closer to baseline (optimal) conditions. In comparison, novices trained on a conventional display employed varying amounts of power, both within trials and between participants. Lacking a direct functional referent, and given only physical information about required power, novices were required to mentally compute the power necessary to maintain straight and level flight.

Further results also support the use of a functional graphic to communicate essential relationships between system properties. In scenarios requiring the combination of multiple maneuvers (for instance, banking while ascending), novices performing on the Oz system maintained a performance advantage by
applying more power with less variability. While novices using the conventional display used less power in relation to baseline power settings (the optimal amount of power for straight and level), they were unable to maintain the required flight profile for the maneuver as accurately as novices employing the functional display. This finding suggests potential differences in understanding the amount of power required to perform a given maneuver between display conditions. The performance differences between displays serve to underscore the potential effectiveness of a functional display. By providing novices with a direct graphical referent to the functional relationship being manipulated, performance in maintaining and controlling that maneuver may be improved.

An interesting approach to these results is to compare the performance of novices in this study with experienced pilots flying the same display. The power settings of novices using the functional (Oz) display in the current study is strikingly similar to that of professional pilots using the Oz display in previous research (Smith, Boehm-Davis, and Chong, 2004). This finding may be construed as novices having a greater understanding of the task requirements, or potentially reflect a greater understanding of the properties of flight. It may also be that the presentation of a direct perceptual graphic in flight provides less skilled pilots a referent to replace mental computations with rule-based, perceptual activity. With either explanation, the results support the notion that displays leveraging direct perception in depicting functional relationships can improve the performance of novice pilots as they execute flight maneuvers.

The challenge for designers of functional displays, then, may be to identify areas within the system where perceptual referents can communicate the functional relationships essential to a novice’s understanding of proper system operation. As Rasmussen (1999) noted, an interface designed to support the operator should make performance boundaries visible. Functional graphics designed for areas such as this could help novice users visually perceive a performance envelope that defines the limits of functionally acceptable performance for each user. By leveraging the strengths of the perceptual system, the designer can assist the novice aviator in adapting to complex and abstract relationships present in modern aircraft.

References
Table 1.  
**Maneuvres Performed by Participants**

<table>
<thead>
<tr>
<th>Presentation Order</th>
<th>Maneuver</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Maintain Straight and Level Flight</td>
</tr>
<tr>
<td>2</td>
<td>Ascend/Descend 1000 Ft.</td>
</tr>
<tr>
<td>3</td>
<td>Ascend/Descend 1000 Ft.</td>
</tr>
<tr>
<td>4</td>
<td>Increase/Decrease Speed from 85-110/110-85</td>
</tr>
<tr>
<td>5</td>
<td>Increase/Decrease Speed from 85-110/110-85</td>
</tr>
<tr>
<td>6</td>
<td>Bank Left/Right 180 degrees</td>
</tr>
<tr>
<td>7</td>
<td>Bank Left/Right 180 degrees</td>
</tr>
<tr>
<td>8</td>
<td>Ascend/Descend 1000 Ft., Bank Left/Right 360 Degrees</td>
</tr>
<tr>
<td>9</td>
<td>Ascend/Descend 1000 Ft., Bank Left/Right 360 Degrees</td>
</tr>
<tr>
<td>10</td>
<td>Ascend/Descend 1000 Ft., Bank Left/Right 360 Degrees, maintain airspeed of 85/105 knots</td>
</tr>
<tr>
<td>11</td>
<td>Ascend/Descend 1000 Ft., Bank Left/Right 360 Degrees, maintain airspeed of 85/105 knots</td>
</tr>
</tbody>
</table>

Table 2.  
**List of Acceptable Feedback Provided by Flight Instructor**

<table>
<thead>
<tr>
<th>Situation</th>
<th>Feedback</th>
</tr>
</thead>
<tbody>
<tr>
<td>Overpowered</td>
<td>“You are overpowered. Reduce power with your throttle.”</td>
</tr>
<tr>
<td>Underpowered</td>
<td>“You are underpowered. Increase power with your throttle.”</td>
</tr>
<tr>
<td>Above Altitude</td>
<td>“You are above the required altitude. Lower your altitude.”</td>
</tr>
<tr>
<td>Below Altitude</td>
<td>“You are below the required altitude. Increase your altitude.”</td>
</tr>
<tr>
<td>Over Speed</td>
<td>“You are over your target speed. Reduce your airspeed.”</td>
</tr>
<tr>
<td>Under Speed</td>
<td>“You are under your target speed. Increase your airspeed.”</td>
</tr>
<tr>
<td>Past Heading</td>
<td>“You are past your required heading. Return to a heading of ____.”</td>
</tr>
</tbody>
</table>