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.GRAPHICS ISSUES OF AVIATION INTEGRATED HAZARD DISPLAYS

Larry Arend
NASA Ames Research Center
Moffett Field, CA

Designers of cockpit displays are currently considering how to graphically display hazard and navigation information in a single, integrated four-space view. This paper addresses graphic-design issues in relation to legibility, clutter, and color-coding. Initially we address issues in simultaneously presenting navigation, air traffic, convective weather, special-use airspace, and terrain hazard information in the cockpit. This large quantity of overlaid information requires a salience-manipulation strategy to avoid clutter problems. Conflicts among standards for color-coding of the several area variables must be resolved. Transitions from current weather, traffic and SUA information to predictions pose several display problems. Display scale interacts with density of information sampling.. Appropriate display of the information depends on which hazards warrant high-priority display and how they can be safely flown, but there is currently little consensus in the aviation community concerning these operational issues.

Background

Designers of aviation displays are currently considering how to graphically display weather information in the cockpit and on Air Traffic Management displays. There are important advantages to providing a single, integrated four-space view of hazard and navigation information. In current systems the information is usually displayed in spatially or temporally separated displays so that the information must be integrated in the user's mind, including the spatial locations of hazards in relation to ownship and each other. The users must also manage the multiple displays. These separated systems require more cognitive work of the users and impose accuracy and precision concerns. Integrating the graphic information of the systems is, however, not trivial.

The Graphics Issues

Range of Design Challenges

Design of an integrated hazard display presents significant challenges, ranging from low-level graphics questions to operational and procedural issues. This paper focuses primarily on graphic-design issues in relation to legibility, clutter, and color-coding, but, as in any adequate display-design process, operational issues must be kept clearly in mind.

Which Information Should be Integrated

In recent years the candidate hazard information that might be integrated has expanded immensely. Communication, computing, and display capabilities in the cockpit are rapidly expanding, for all classes of user (George, 1997). The question is no longer how to get more information to the cockpit but how to present the information the pilot needs in a usable form.

As a starting point we consider here issues in simultaneously presenting navigation, air traffic, convective weather, special-use airspace, and terrain hazard information in the commercial cockpit. The corresponding problems in ATSP displays are treated in less detail. These hazards were selected as a minimum set for aircrew to consider in their enroute course planning and execution.

For this discussion we use NASA's AMES display (Figure 1) as our initial integrated representation of navigation and air traffic. This plan-view display has undergone extensive development and testing (Johnson, et al, 1997). Graphic features include representation of route and waypoints in standard colors, with graphic support for trial route planning in collaboration (by datalink) with controllers. Potential conflict aircraft are displayed, with or without data tags, and color-coded for altitude relative to ownship.

We want to add to this display information about terrain and weather hazards and special-use airspace. Ground-based radar has a number of advantages over airborne radar, but it has important disadvantages as well (e.g., 5 min updates, service gaps). A system combining the advantages of the two would be desirable but very difficult to achieve. For this discussion we use NEXRAD ground-based weather radar. Several terrain options are discussed below in the section on operationally relevant detail.

Clutter and Legibility

Overlaying the hazard displays makes it more difficult to guarantee legibility of all of the critical information while using the desired color codes. Symbols (e.g., aircraft) can lie on any of a set of colored backgrounds instead of uniform black or white. Color selection is much more constrained than in the separate hazard displays. To be legible, symbols of each color must have sufficient luminance contrast on each of the possible background colors (SAE, 1993). This requirement, when paired with conventional color-coding for caution and warning status, leaves only narrow latitude for other design choices.

The legibility issue is further complicated by clutter concerns. The large quantity of overlaid information requires that the users' attention be directed to critical information by means of some salience-manipulation strategy. Variation of luminance contrasts is a common, powerful tool to manage attention in dense graphics. Instead of deleting less important information (losing valuable context information) less important information is rendered in lower luminance contrasts (Figure 2). Other possible de-emphasis techniques, such as thinner strokes or smaller symbols, are less practical in small, rapidly scanned displays and pose similar legibility concerns. To produce several legible luminance contrasts within consistent symbol and background color codes requires expert color design.

Another complex issue is conflicting standards for color-coding of the area variables, i.e., terrain, weather, and SUA. Standards and guidelines currently call for the safety color series (green/yellow/red) to be used for terrain, weather, and traffic information. Using these colors in the same way they are currently used in separate displays is unacceptable due to clutter, loss of legibility, and mis-identifications. In current displays hazardous terrain is coded in red blobs with geometry that is often similar to that of hazardous weather regions. While it may be possible to adopt a different color set for weather or terrain, the current conventions are well established. It may be better to distinguish them by means of other graphic variables, for example, texture. The legibility of symbols on textured backgrounds is reduced unless the symbols are protected by outlining (Figure 3), but this graphic complication may be justified to retain bright red coding of hazards.

Operationally Relevant Detail

Given the limited range of luminance contrasts and limited uncluttered spatial density it is important to represent only the spatial and intensity resolution justified by operational decisions. Spatial resolution will be considered along with display scale in the next section.

Current dedicated terrain hazard displays show warning and caution terrain levels as red and yellow regions, respectively. The main consideration regarding altitude resolution is in non-hazardous regions. While these could be displayed in uniform green or the background black (or white), showing the vertical structure in the region would support orientation during ascent and descent phases of flight. NOAA's aviation section charts show detailed topographic information by means of contour lines, color-coded elevation, and shading. Such high detail in the background consumes much of the available luminance range, making it difficult to select symbol colors with sufficient luminance-contrast. Terminal procedure charts show less detail by filling widely-spaced contour lines (1000 ft) with low-saturation colors to show 4-6 levels of elevation. This occupies little of the luminance range, leaving reasonable choice for symbol colors. It is an open research issue whether there is operational benefit to presenting continuously shaded terrain.

NEXRAD weather is coded in 15 levels, the VIP scale is in 6 levels, and most airborne radars code weather in 3 or 4 levels. As with terrain, the higher resolution scales necessarily consume a large fraction of the available luminance range. Since the purpose of displaying convective weather is to assist tactical decisions about routes to avoid the weather, it is unclear what benefits the higher resolutions provide. Thus caution areas coded in red, warning areas in yellow, and mild return areas in pale green may be sufficient. The pale green is needed to show the area and shape of the weather system, areas where new cells might rapidly develop.

Predictive Display and Display Scale

Transitions from current weather, traffic and SUA information to predictions pose several data and display problems. At larger scales (shorter distances) the traffic, weather, and SUA at the edge of the display are 10 min or less away. Intent information provides reasonable predictions of future locations for at least some of the traffic. Weather cells typically move laterally less than a few miles over that time. A simple vector graphic indicating cell motion may be adequate to support tactical decisions on this time scale. For strategic route decisions smaller scales (> 100 nm) will be used. Even if reroute planning remains mostly in the hands of air traffic managers and dispatchers, clear communications and full collaborative decision making between ground personnel and aircrew would be greatly aided by appropriately coordinated data display for both partners. At smaller scales, however, pilots can view hazards an hour or more away. To usefully display weather at these scales requires accurate predictions about cell motions and development, and a suitable graphic depiction of the current data and predicted positions. Even at the 10-min scale rapid vertical development of cells (> 3000 ft/min) can make the difference between overflight and lateral avoidance (FAA, 1983).

Display scale also interacts with the displayable spatial resolution of the data. At the larger scales appropriate for tactical decisions all traffic can be displayed without clutter if contrast and color saturation are used to de-emphasize traffic that is not a factor for conflicts. At strategic spatial scales it would produce unusable clutter to display all the details of individual flights, and the flight time to that traffic makes the information less useful. At tactical spatial scales the details of squall lines (altitudes of cell tops and motion vectors of individual cells) are important and can be usably displayed. At strategic scales some aggregation of the graphics is appropriate, and tops and motion vectors should be reduced to typical cell tops and storm motion. At the larger scales, some kind of smoothing of the weather data is needed (Figure 4). On a 40 nm range setting NEXRAD data gridded to 1 km occupies only 74 NEXRAD pixels. The high-spatial-frequency content of the NEXRAD pixels is distracting and carries no information. It is only an artifact of the sampling and resolution of the weather data. Converting the NEXRAD data from gridded format to a smooth vector representation might allow graceful and efficient transition from scale to scale.

Consensus on Operational Constraints

There is currently little consensus in the aviation community concerning which hazards warrant high-priority display nor how they can be safely flown. For example, how storm cells should be displayed depends upon where the airplane may be safely flown in relation to the cells. Official advice (FAA, 1983) calls for avoidance of intense cells by at least 20 miles. Research using storm penetrations indicates that dangerous flight conditions are not confined to the area of highest radar return, but can occur anywhere within a severe cell (FAA, 1982). On the other hand, some pilots use a general rule of thumb, "Don't fly through red." On some days during thunderstorm season squall lines in the Midwestern and southeastern US are so closely spaced that it would be very difficult to find the required 40 nm gap between adjacent cells.

In the current system final decisions about how to fly weather are in the hands of aircrew and their dispatchers, but this may soon change. As the FAA deploys high-quality convective weather information on more traffic displays it is likely that controllers will eventually be asked to take more responsibility for weather avoidance. Enroute decisions based on collaboration among aircrew, air traffic controllers, and possibly dispatchers will require common understanding of the weather situation and appropriate ways to fly it. To make such a collaboration work it is essential that the three partners' graphic displays be consistent.

Figure 5 shows an example integrated design for the cockpit that addresses some of these graphic problems. Weather and terrain are displayed at resolutions appropriate for cockpit operational decisions. Nonhazardous information has low luminance contrast to provide context without distraction. Hazardous weather and terrain are both coded in red, visually distinguished by texturing the latter.

Acknowledgments

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Fig. 1. NASA's AMES display of navigation and traffic information.

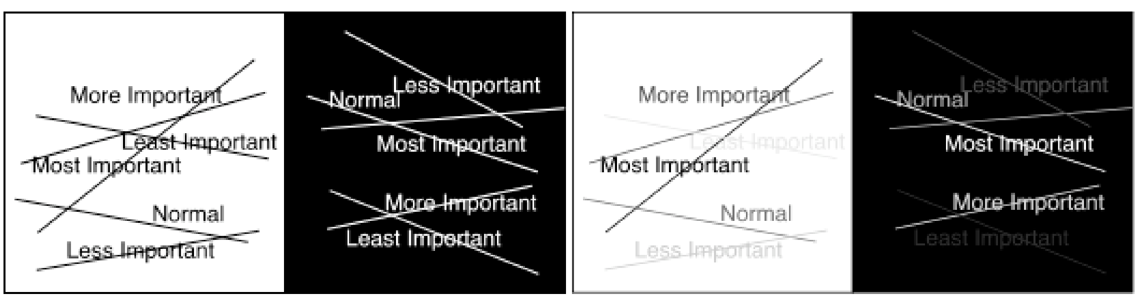

Fig. 2. Manipulation of luminance contrast focuses attention on important information without eliminating context information.

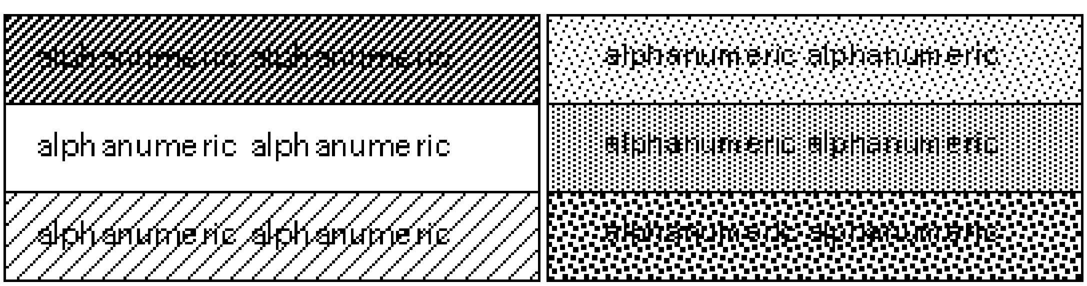

Fig. 3. Textured backgrounds can interfere with legibility of symbols. Interference can be avoided by outlining text or reducing contrast of background texture.

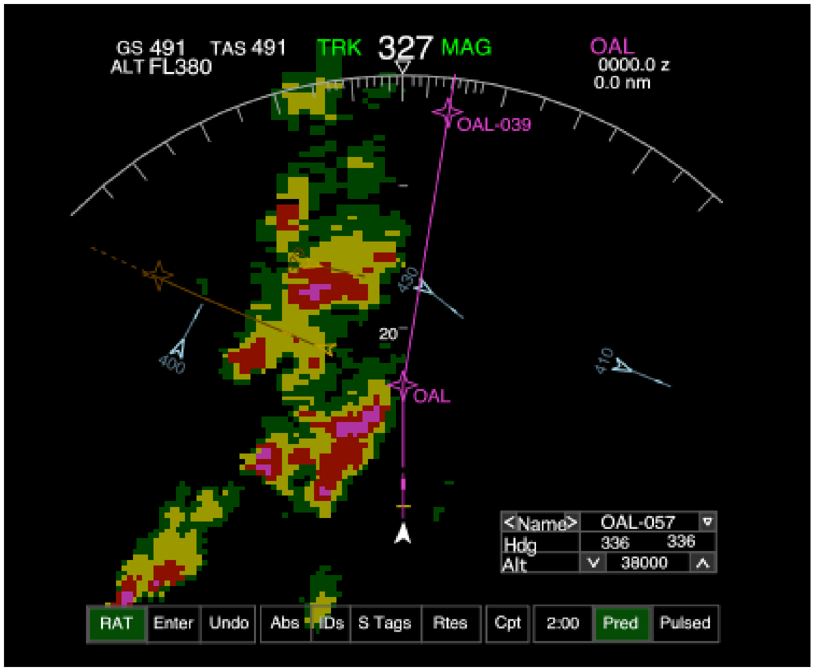

Fig. 4a. At large scales jagged weather pixels distract from important information.

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Fig. 4b. Smoothed weather distracts less from traffic and navigation information.

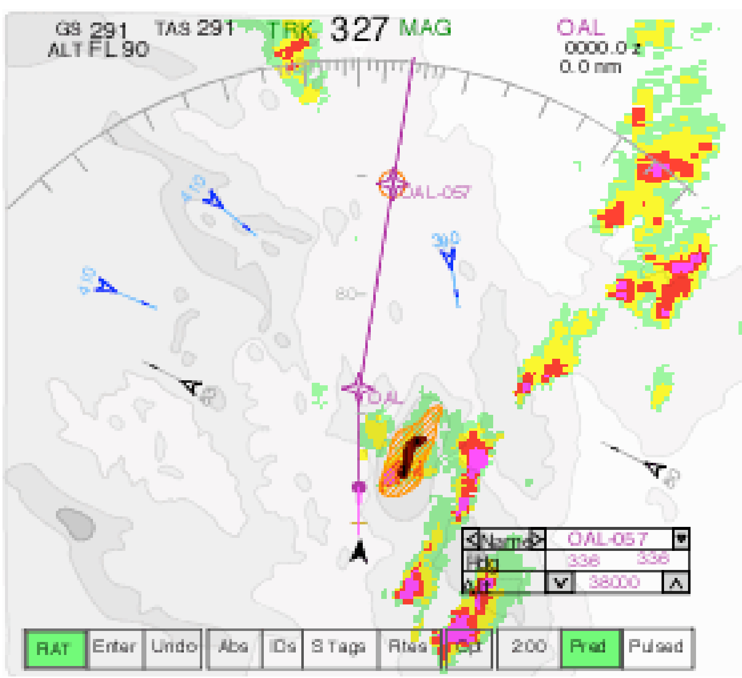

Fig. 5. Integrated cockpit display of navigation information and traffic, weather, and terrain hazards. Nonhazardous terrain and weather have low luminance-contrast to prevent distraction from critical information. Terrain hazard is distinguished from weather hazard by texture.

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