

## Bottom-up and Top-down Contributors to Pilot Perceptions of Display Clutter in Advanced Flight Deck Technologies

Amy L. Alexander<sup>1</sup>, Emily M. Stelzer<sup>1</sup>, Sang-Hwan Kim<sup>2</sup>, David B. Kaber<sup>2</sup>

<sup>1</sup>Aptima, Inc.  
Woburn, MA

<sup>2</sup>Edward P. Fitts Department of Industrial & Systems Engineering  
North Carolina State University  
Raleigh, NC

Future concepts for the National Airspace System rely on technologies, such as synthetic and enhanced vision systems, to support flight efficiency associated with improved terrain and traffic awareness. While these technologies provide the pilot access to information not available with traditional flight instrumentation, the presentation of this additional information may serve to produce display clutter, thus inhibiting the processes and tasks they are designed to support. An experiment was conducted to assess pilot perceptions and identification of both bottom-up (data-driven) and top-down (knowledge-driven) contributing factors to display clutter. Results revealed the importance of both visual and information density (bottom-up and top-down factors, respectively) to the perception of clutter. Although added display elements provided pilots with critical flight information, pilots considered displays to be cluttered when the imposed visual density exceeded the information density required for specific flight tasks. These findings suggest that moderate levels of display clutter may be tolerable, to the extent that the information is relevant to the tasks at hand.

### INTRODUCTION

Future concepts for the National Airspace System rely on technologies to support flight efficiency associated with improved terrain and traffic awareness. A subset of these technologies is centered on the development of advanced information display technologies, such as synthetic and enhanced vision systems (SVS and EVS). SVS presents pilots with an out-the-cockpit view of terrain features and traffic information by using a global positioning system-based terrain model and EVS integrates a forward looking infrared camera (e.g., Alexander, Wickens, & Hardy, 2005; Prinzel, Comstock, Glaab, et al., 2004; Schnell, Kwon, Merchant & Etherington, 2004). While these technologies are designed to provide the pilot access to information that may not be visible with traditional flight instrumentation under certain conditions, the presentation of this additional information may serve to produce *visual display clutter*, thus inhibiting the processes and tasks they are designed to support. Furthermore, display clutter may be worsened as the EVS or SVS technologies are presented in conjunction with one another, or with flight navigation and traffic information on a heads-up display (HUD).

Clutter is an unintended effect of displaying visual imagery that may obscure or confuse other information or that may not be relevant to the task at hand. Clutter has been classified in two forms, namely local and global density clutter (Tullis, 1988). Global display clutter refers to the total number of unique entities or items in a display (Wickens, Vincow, Schopper, & Lincoln, 1997) relative to a spatial area (Currasco, Evert, Chang, & Katz, 1995), or the texture of edge density across the interface (Rotman, Tidhar, & Kowalczyk, 1994). Local density, however, refers to the amount of information surrounding a critical display area and can be

quantitatively defined as the distance between the critical display area (e.g., the aircraft indicator in a HUD) and nearby distracters (Intriligator & Cavanagh, 2001). In addition to definitions that center primarily on density, clutter has also been attributed to the size of a visual target of interest within the display (Ewing et al., 2006), as well as the similarity of objects in physical appearance or luminance to that visual target (Moberly & Langham, 2002; Ververs & Wickens, 1998; Wang et al., 2001). Collectively, these approaches suggest that *data-driven*, or *bottom-up factors* are significant contributors of clutter.

Theories of visual attention, however, recognize the equally important contribution of *knowledge-driven*, or *top-down* processes in guiding and influencing visual attention (e.g., Wickens, Goh, Xu, & Horrey, 2001), in which the role of pilot expectancy and information value can influence attention allocation and visual processes. Research examining the impact of clutter or display density on visual attention and monitoring has concluded that irrelevant information that is located within a scan path or fixation can increase the effort associated with information access (Schons & Wickens, 1993) and negatively impact performance in locating, attending to, or monitoring display features (Sanders & Houtmans, 1985). Focused attention to a key display feature may be inhibited by irrelevant information located in the path of a scan (Wickens & Andre, 1990) or within close proximity to information that must be attended (Intriligator & Cavanagh, 2001). Ahlstrom (2005) provided evidence to suggest that a pilot's perception of clutter is attributed to the presence of redundant pieces of information, where redundancy is shaped by a pilot's knowledge and use of information within the task domain. Collectively, these findings highlight the negative impact that *irrelevant* information can have in heightening perceptions of clutter and inhibiting effective visual attention allocation.

Alternatively, a growing body of research has shown that relevant information, which can be grouped and aggregated by expert users, can actually reduce perceptions of clutter in extremely dense displays (Burns, 2000), as this information can produce emergent features on the display when presented in conjunction with one another. In general, these findings provide evidence of the role of *relevance* to perceptions of display clutter, suggesting that task context plays a substantial role and that the utility of the information to the task at hand may directly influence the level of reported display clutter.

The reviewed empirical studies provide evidence of the important roles of both bottom-up (i.e., visual density, physical appearance and location) and top-down parameters (i.e., information relevance and redundancy) in how a pilot visually distinguishes, groups, and uses information. In these evaluations, however, bottom-up and top-down parameters that influence clutter were largely evaluated and considered in isolation from one another, with few studies examining these dual contributors to perceptions of clutter. In the present study, we report an experiment designed to assess pilot perceptions of and identification of both bottom-up and top-down contributing factors to display clutter in static images of HUD displays presented with EVS and/or SVS technologies. We hypothesized that pilots will report the utility of both bottom-up and top-down factors in describing the clutter associated with displays, and that manipulations of these factors will directly influence perceptions of clutter.

**METHOD**

**Participants**

Four expert test pilots (age, *M* = 47.5 years; experience, *M* = 5325 total flight hours) participated in the experiment. Three pilots were male and one was female. All participants were experienced in flying commercial transport aircraft and were familiar with advanced HUD technologies such as SVS and EVS.

**HUD Configurations**

Five types of information elements were manipulated to create 32 total HUD configurations, ranging from a basic display containing only one information element to a “full-featured” display including all information elements, as shown in Figure 1.

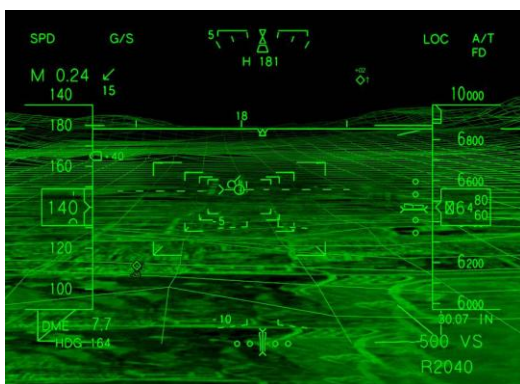


Figure 1. Full-featured display including all five information elements.

The information elements were manipulated as follows:

- SVS: wire-frame representation of a terrain model turned on or off;
- EVS: thermal imagery collected on previously-flown approaches turned on or off;
- TCAS: presentation of traffic icons turned on or off;
- Tunnel: pathway guidance “highway-in-the-sky” turned on or off; and
- Symbolology: primary mode instrumentation turned on or off.

**Experimental Design and Task**

A 2<sup>5-1</sup> Resolution V fractional factorial design, as described by Montgomery (1991, p. 627) was selected to accommodate constraints on experimental resources, resulting in a ½ replicate design including the five factors and presenting half of the HUD configurations through 16 runs across pilots. Pilots were presented 16 different static HUD images at specific points along a standard ILS Runway 16R approach to Reno/Tahoe International Airport. A flight scenario was developed around this approach to provide a context in which to present the HUD images. The scenario involved a low ceiling with reduced visibility conditions and guided pilots to seek information from the HUD images, including SVS and EVS, pertinent to specific flight tasks. A script describing the scenario was read to participants by an Airline Transport Professionals (ATP) certified pilot. The script provided pilots with information on aircraft state not available in the HUD as well as appropriate air traffic control communications, including an automatic terminal information system broadcast at the beginning of the scenario, approach and landing clearances, and a frequency change from the approach control to tower frequency.

At 16 specified points within the script, participants were shown one static image of the HUD imagery, in which clutter was manipulated by turning each of the five specified information elements on or off. Following the presentation of each display image in a scenario, pilots were asked to rate the overall perceived clutter for the display configuration along a 20-point scale from “low clutter” to “high clutter.” Pilots also rated the usefulness of pairs of descriptor terms to characterize clutter along a 20-point scale from “low” relevance to “high” relevance. We identified the following descriptor terms based on a literature review on the development of measures of display clutter as well as a semantic analysis for redundant terms (see Table 1). Note that these terms address both bottom-up (e.g., sparse/dense) and top-down (e.g., redundant/orthogonal) proposed descriptors of clutter.

Table 1. Display Clutter Descriptor Terms.

Sparse / Dense	Monotonous / Variable
Not Salient / Salient	Indiscernible / Discernible
Dull / Sharp	Monochromatic / Colorful
Static / Dynamic	Low Workload / High Workload
Unsafe / Safe	Redundant / Orthogonal
Empty / Crowded	Low Attention / High Attention
Dissimilar / Similar	Ungrouped / Grouped

Subjective pilot comments related to the HUD images were collected throughout the experiment. In summary, the dependent measures collected in the experiment included: (1) overall ratings of clutter, (2) ratings of descriptor term relevance for describing clutter, and (3) qualitative data on participant comments.

**RESULTS**

**Overall Clutter Ratings**

In general, clutter ratings were found to increase as the number of active display features increased (see Table 2). The number of active display features represents a bottom-up contributor to perceptions of display clutter. A correlation analysis indicated that as the major active HUD information elements changed from one to three to five, overall perceived clutter significantly increased ( $r = 0.42, p < 0.01$ ). Because of the fractional factorial design, the tested HUD configurations only included odd numbers of active features.

Table 2. Mean Clutter Ratings by Numbers of Active HUD Information Elements.

Number of Features	1	3	5
Number of Observations	50	100	10
Mean Clutter Rating	9.79	12.94	16

**Multidimensional Preference Mapping**

A multidimensional preference analysis was conducted to identify underlying dimensions of perceived clutter that might

explain similarities/dissimilarities among the various HUD configurations tested and the usefulness of pairs of descriptor terms for describing overall clutter. We conducted a factor analysis using principal components and two factors, with Eigenvalues of 0.56 and 0.76, were selected. Two biplots with the two principal components as dimensions were then generated using the Multidimensional Preference procedure in SAS. The plots were based on a data matrix including the HUD configurations as rows and the pairs of descriptor terms as columns. The ratings of the usefulness of the descriptor terms for describing display clutter were considered to be continuous variables for the FA and plot.

Figure 2 shows a biplot with HUD images positioned relative to others in terms of the underlying factors in perceived clutter, given the mix of information elements. The analysis revealed those displays considered to be less cluttered on the left end of the first principal component (on the X-axis of the biplot) and those considered to be more cluttered on the right end. Results suggested HUDs incorporating EVS with IMC symbology or path guidance were considered more cluttered; whereas those incorporating only path guidance or primary mode symbology were considered less cluttered. Sparse HUD images incorporating only IMC symbology with TCAS or pathway guidance appeared towards the bottom of the second principal component (the Y-axis in the biplot). “Fully-loaded” displays incorporating all five information elements appeared at the top of this dimension; in other words, they were considered to be characteristic of cluttered displays.

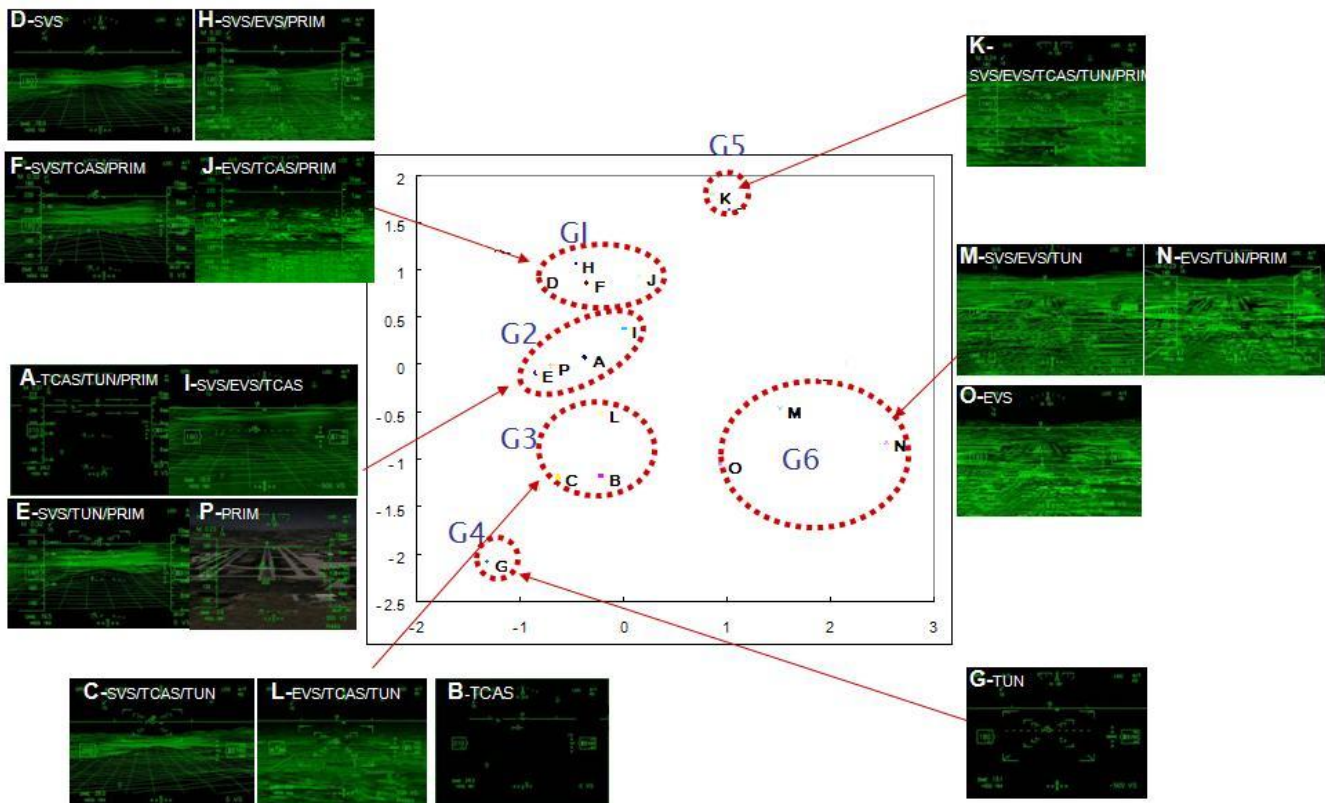


Figure 2. Biplot of loading of display images on underlying factors in perceived clutter. (Note: TUN = Tunnel or pathway guidance; PRIM = Primary display symbology).

Figure 3 shows a biplot with groupings of the pairs of descriptor terms according to the latent variables in clutter. Low-clutter displays along the first principal component were best described by the terms “static/dynamic,” “redundant/orthogonal” and “ungrouped/ grouped.” High-clutter displays were best described by the terms “not salient/salient,” “unsafe/safe,” “indiscernible/discernible” and “monochromatic/colorful.” Along the other principal component (Y-axis), displays at the top are best characterized by the terms “sparse/dense,” “empty/crowded” and “dissimilar/similar”. Displays at the bottom of this dimension were best described by “static/dynamic” and “low/high attention.”

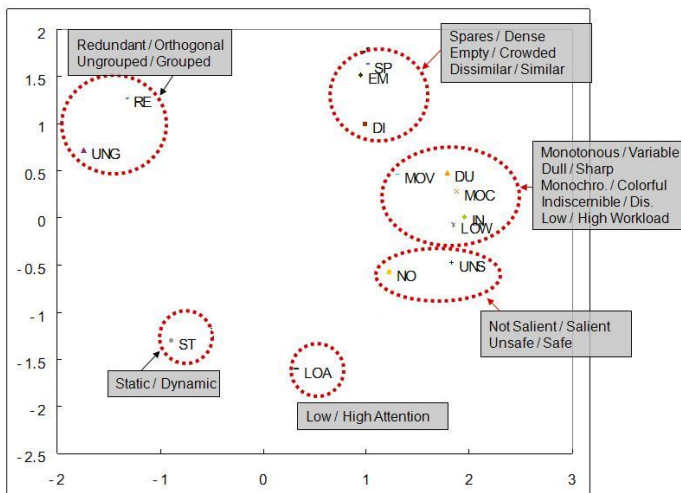


Figure 3. Biplot of loading of descriptor terms on underlying factors in perceived clutter.

In general, across both biplots, it appeared that the first principal component described the bottom-up factor of *visual density* related to the total amount of items within the display; whereas, the second principal component described the top-down factor of *information density* related to the relevance or redundancy of information within the context of the flight task.

**Pilot Subjective Comments**

In an evaluation of pilot subjective comments on the clutter of presented displays, we grouped open comments into five categories. The categories represented recurring themes related to specific information elements, or pilot concepts of clutter, and accounted for over 60% of all comments offered by pilots:

- *Display Brightness*: The luminance of display features, particularly the EVS symbology, relative to other critical display elements, like the pitch ladder.
- *Information Density contrasted with Visual Density*: The amount of information presented in the interface contrasted with the number of active display elements (regardless of their utility to the flight leg).
- *Information Redundancy*: The degree to which display elements provided the same information in more than one location on the HUD.

- *Trend Information*: The ability of the display elements to provide information about trends in flight, often represented through the pitch ladder.
- *Occlusion*: The degree to which elements overlapped or occluded other display features.

The summary of this analysis is shown in Figure 4, and several key inferences can be made. First, the comments describe clutter in terms of *both* data-driven, bottom-up factors (i.e., brightness, display density, and occlusion) *and* top-down, knowledge driven factors (i.e., information density, redundancy, and trend). In fact, about 25% of comments attributed clutter to display occlusion or brightness, both of which can be categorized as bottom-up factors in display clutter. However, nearly 20% of comments were attributed solely to top-down factors, represented as clutter due to the presentation of semantically redundant information or trend information about predicted flight.

While the reported categories illustrate the roles of both bottom-up and top-down factors in defining clutter, nearly 15% of the comments made during the course of the experiment directly contrasted these two sources of clutter in the comparison of density due to display *visual features* with that due to display *information*. In many cases, pilots reported accepting moderate levels of visual density to the extent that it was providing information relevant to the task at hand.

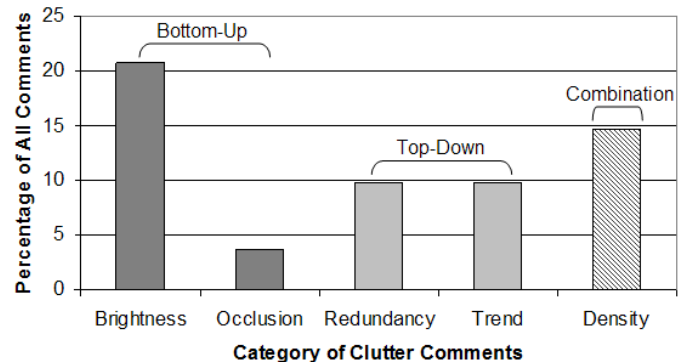


Figure 4. Categorized comments of subjective clutter feedback.

**DISCUSSION**

This experiment was designed to assess pilot perceptions and identification of contributing factors to display clutter in static images of HUD configurations incorporating various types and amounts of information elements. The hypothesis that pilots would report the utility of both bottom-up and top-down factors in describing the clutter associated with displays was confirmed. The multidimensional preference analysis of the HUD images and pairs of clutter descriptor terms revealed two principal components useful for identifying meaningful groupings of displays and descriptor terms: *information density* and *visual density*. Information density relates to the relevance and/or redundancy of display features within the context of the flight task, thereby characterizing top-down, or knowledge-driven contributors to display clutter. Visual density, on the other hand, characterizes bottom-up, or data-driven contributors to display clutter.

The hypothesis that manipulations of bottom-up and top-down factors would directly influence perceptions of clutter was also confirmed. A correlation analysis revealed that as the number of active display features increased so did pilot ratings of clutter. It is possible that the visual density of the displays may have been a key predictor of pilot clutter assessments. Although supplementary information elements, such as the EVS representation, may have provided pilots with additional critical flight information, if the imposed visual density exceeded the information density relative to flight tasks, pilots may have considered the HUDs to be cluttered.

Pilot comments throughout the experiment served to reinforce the notion that the perception of clutter is derived from both bottom-up and top-down factors. These findings have implications for the design of advanced flight deck technologies, such that both visual and information density need to be considered in measuring the overall amount of perceived clutter within a display, as well as in designing low-clutter displays.

#### ACKNOWLEDGMENTS

This paper is based upon work supported by the National Aeronautics and Space Administration (NASA) under Contract No. NNL06AA21A issued through the Aviation Safety Program. Dr. Lance Prinzel was the NASA technical monitor for the project. Any opinions, findings, and conclusions or recommendations expressed in this paper are those of the authors and do not necessarily reflect the views of NASA.

We would like to thank Dr. Nathan Bailey and Dr. Simon Hsiang for their input on the experiment design. We would also like to thank Mr. Karl Kaufmann and Ms. Jennifer Cowley for their assistance in presenting the flight scenarios and recording pilot comments.

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