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Optimizing Cockpit Moving-Map Displays for Enhanced Situational Awareness

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INTRODUCTION

OBJECTIVE

The objective of this project is to establish the map data requirements for a next-generation digital moving-map system that will replace existing map systems in the AV-8B, F/A-18, UH-1N, V-22, and potentially other aircraft. A primary NAVAIR goal in specifying the new moving-map system is to enhance situational awareness and aircrew mission effectiveness, without further burdening pilot task workload. To ensure that the end-users' explicit map needs are taken into consideration, investigators elicited one-on-one aircrew evaluations of a wide variety of map data types (both topographic and tactical) and map display parameters, including feature size, orientation, color, symbology, etc., to help define an optimum map design for cockpit displays.

BACKGROUND

In support of this objective, the Tactical Aircraft Moving-Map Capabilities (TAMMAC) team at NAVAIR (PMA 209) funded investigators from the Naval Research Laboratory - Stennis Space Center (NRL-SSC) to identify and demonstrate which digital map products would best support end-user requirements for advanced cockpit map displays. Results may benefit mission planning displays as well, although mission planners are not explicitly targeted in this study.

NRL-SSC designed 17 task-structured demonstrations of various digital moving-map scenarios, using standard DMA (Defense Mapping Agency) products, and presented the displays to experienced aircrew from diverse aircraft platforms. We asked participants to evaluate each map display in terms of its potential usefulness for their specific applications.

We simulated realistic mission scenarios, but due to time and funding constraints we were unable to incorporate the map displays into a flight simulator. Instead, we developed and presented the demonstrations on a Silicon Graphics, Inc. (SGI) workstation. We conducted the demonstrations and aircrew surveys at the Naval Air Warfare Center, Aircraft Division, Patuxent River, MD (NAWC-ADP), in conjunction with their Human Factors group.

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APPROACH AND METHODS

QUESTIONNAIRE AND INTERVIEWS

The aircrew questionnaire consisted of a pilot identification page, followed by one survey for each of the 17 demonstrations. The entire questionnaire is provided in Lohrenz, et al. (1996). Each map display survey started with a brief description of the demo, followed by a series of questions. We designed the surveys to be as quantitative as possible, to facilitate data entry and analysis. Most questions required answers in one of the following forms:

a) 5-point ranking of map data or display items (table 1);
b) Rating items as either *satisfactory* or *unsatisfactory*;
c) Multiple choice (e.g., "Which option(s) would you prefer: *A*, *B*, and/or *C* ?");
d) Questions requiring short, 1-2 sentence answers.

Rating	***Description***
1	Of no use
2	Not very useful
3	Of use
4	Of considerable use
5	Extremely useful

Table 1. Demo rating scale.

NRL interviewers conducted the demonstration for each pilot separately to encourage individual responses. Each pilot viewed all 17 demonstrations, each of which was between 1-5 minutes long. For each demonstration, the interviewer asked the pilot to read the brief description and all questions on that demo's survey sheet before viewing the demo. The pilot could view the demo more than once, if desired. Each pilot could take as much time as necessary to answer all the questions about one demo before viewing the next. We tape-recorded each session to capture all participants' comments.

We developed each demonstration as a computer-generated movie loop using ArcInfo GIS (Geographic Information System) software and SGI Moviemaker software on SGI Crimson and Indigo workstations. We simulated realistic ground-speeds, aircraft turn rates, display refresh rates, and other parameters via Moviemaker, by controlling the window of map data displayed in each frame (including geographic area, image orientation, zoom factor, etc.) and the number of frames displayed per second. ArcInfo handled map projection and scale compatibility (between overlaid data sets). The simulated map display window was the same size as the current ASQ-196 cockpit map display in F/A-18 and AV-8B aircraft: 4.5″ × 4.5″.

Each of the 17 demonstrations addressed one or more specific map data or display issues of particular interest to the TAMMAC team at NAVAIR. NAWC-ADP and NRL-SSC developed a matrix of 46 map issues from the TAMMAC Requirements Database, which NAWC-ADP compiled. The complete database may be found in Lohrenz, et al. (1996).

Based on TAMMAC requirements, we selected six principal map data types for evaluation: scanned chart data, satellite imagery, terrain elevation data, data frames (such as reconnaissance photographs), vector map data, and mission planning symbols. Table 2 provides descriptions and source information for each of these data types. We grouped the 17 demonstrations into six general categories, based on the map data and display issues to be addressed: *Timing*; *Map positioning*; *Zooming*; *Terrain elevation data*; *Overlay data*; and *Vector moving-map displays*. In this paper, we have included selected results for those demos that pertain specifically to Situational Awareness (SA). We include results for every category except *Timing*; results from that category are presented in Lohrenz, et al. (1996).

Data Type	***Database Name and Description***	***Source(s)***
Scanned Chart Data	ARC Digitized Raster Graphics (ADRG), subsampled to 169 pixels / inch to emulate Compressed ADRG (CADRG), including the following scanned aeronautical charts: Acronym — Scale* — Range† — Full name GNC — 1:5M — 160 nmi — Global Navigation Charts JNC — 1:2M — 80 nmi — Jet Navigation Charts ONC — 1:1M — 40 nmi — Operational Navigation Charts TPC — 1:500k — 20 nmi — Tactical Pilotage Charts JOG — 1:250k — 10 nmi — Joint Operational Graphics TLM-100 — 1:100k — 4 nmi — Topographic Line Map-100 TLM-50 — 1:50k — 2 nmi — Topographic Line Map-50 * For scales: M = million, k = thousand. † Range based on ASQ-196 display (top to bottom of screen).	DMA
Satellite Imagery	Controlled Image Base (CIB): 10 m / pixel panchromatic SPOT imagery enhanced via contrast-stretch algorithm (in ArcInfo). Equivalent scale: 1:50k (2 nmi range).	DMA
Vector Map Data	Digital Chart of the World (DCW): vectorized version of the 1:1M scale ONC series (40 nmi range, pre-zoom).	DMA
Terrain Data	Digital Terrain Elevation Data (DTED) Level 1: gridded elevation database (one grid point approximately every 3 arc-seconds of latitude). Equivalent scale: 1:250k (10 nmi range).	DMA
Data Frames	Any static image, such as a reconnaissance photograph, emergency checklist, etc. Samples used in this study were reconnaissance photos at varying scales.	TAMPS, MOMS
Mission Planning Symbols	Bitmapped (digitized) versions of cartographic symbols representing threats, targets, routes, waypoints, etc. Included symbols from AV-8B and V-22 mission planning sets.	TAMPS, MOMS

Table 2. Data selected for cockpit moving-map demonstrations

PILOT PROFILE

NRL and NAWC-ADP interviewed a total of 30 pilots, representing 14 different aircraft platforms (table 5) from the Navy, Marine Corps, and Air Force (figure 1). Although we originally intended to survey only tactical pilots, several non-tactical groups were also represented (e.g., helicopter pilots, Anti-Submarine Warfare (ASW) pilots and aircrew). In hopes that this diversity would shed insight on the potential differences in map data requirements as a function of aircraft type and mission, we categorized many of the survey results by general aircraft category (*Tactical*, *Helicopter*, and *ASW*, as listed in table 3).

Tactical: 15		***Helicopter: 9***		***ASW: 6***	
A/C	***#pilots***	***A/C***	***#pilots***	***A/C***	***#pilots***
F/A-18	6	AH-1W	2	P-3	3
A-6	2	CH-46	2	S-3	2
AV-8B	2	CH-53E	2	V-22	1
EA-7	2	UH-1N	2		
F-14	2	H-60	1		
A-10*	1				

* Note: the A-10 pilot was interviewed during a preliminary survey. This pilot did not respond to all questions, resulting in a total of 14 tactical pilots (29 total pilots) for some demos.

Table 3. Aircraft types represented in survey.

The pilot introduction survey gauged pilot experience in several ways: number of flight hours (average: 2400 hours); percentage of hours flown at night (average: 30% of flight time); combat flight experience (*no experience:* 50% of participants; *limited experience:* 33%; *experienced combat pilot:* 10%); and flight instructor experience (57% of participants responded *yes*). The survey also measured digital moving-map experience (*no experience*; *familiar with concept*; *limited experience*; *occasional use*; or *current and experienced user*). 77% of the participants had some experience with cockpit moving-maps: 54% had flown (frequently or occasionally) with a cockpit moving-map, and 23% had limited experience. Another 20% of the pilots had no first-hand experience with moving-maps but were familiar with the concept. Only one pilot claimed to have no experience with this technology. These responses suggest a fairly sophisticated pilot population that is familiar with digital cockpit moving-maps.

RESULTS AND RECOMMENDATIONS

This section presents the results of the map display surveys, including a brief description of each demonstration, organized by demo category. Relevant aircraft program specifications for each demonstration may be found in Lohrenz, et al. (1996).

MAP POSITIONING REQUIREMENTS

Description

The one demo in this category illustrated the relationship between aircraft cursor position and resultant map coverage on the display. We demonstrated four different aircraft cursor positions: centered; 1/4-up (aircraft cursor 25% up from screen bottom), 1/7-up (aircraft cursor 14% up from the bottom) and bottom-of-screen. Each of these positions was displayed first in north-up mode, then track-up.

Results

Table 4 presents the results of the map positioning survey.

North-up: As could be expected, all pilots preferred a centered display over any degree of decenter while the map was displayed north-up. Some pilots found a slightly decentered position (1/4-up) to be useful, but very few liked the 1/7-up position in north-up mode, and none of the pilots liked the bottom-of-screen position for north-up, since any aircraft headings other than due-north would result in a significant loss of forward-looking map information.

Track-up: The majority of pilots in all categories found both centered and 1/4-up positions to be *extremely useful* (most ratings were 4 or 5 on a 5-point scale) in track-up mode. Most pilots also found the 1/7-up position to be of some use. Fewer pilots liked the bottom-of-screen position, even in track-up, citing a loss of SA. Many pilots commented on the need for some map information behind the aircraft, which is lost in a bottom-of-screen position. Nearly all pilots stated a preference for track-up over north-up, and some helicopter pilots also stated a need for a heading-up mode.

Demo Description	Average rating (of a possible 5)	
	North-up	Track-up
Centered	***4.0***	***4.5***
Tactical	3.7	4.5
Helicopter	4.3	4.4
ASW	4.2	4.5
1/4 Up	***2.2***	***4.5***
Tactical	2.2	4.5
Helicopter	2.9	4.7
ASW	1.8	4.2
1/7 Up	***1.7***	***3.7***
Tactical	1.5	3.6
Helicopter	2.0	4.1
ASW	1.7	3.2
Bottom	***1.2***	***2.8***
Tactical	1.1	2.7
Helicopter	1.4	2.8
ASW	1.2	3.2

Table 4. Average Ratings for Map Positions (Demo 5). 1 = Of no use; 2 = Not very useful; 3 = Of use; 4 = Of considerable use; 5 = Extremely useful

The questionnaire also asked pilots if they would want to have control over the degree of decenter for their aircraft cursor (e.g., to change it from 1/4-up to bottom-of-screen). Of the 30 pilots surveyed, only 3 wanted no control over the cursor position. Most wanted to be able to change the aircraft cursor position at any time (during mission planning or in the cockpit). Participants' reasons for wanting this control centered on their need for improved SA and more flexibility to address the wide variety of pilot preferences and tactical situations. One of the pilots who did not want in-flight control over map positioning suggested customizing the default position to each aircraft platform, via software.

Summary and Recommendations

Most pilots wanted both centered and decentered cursor positions on the digital moving-map display, and they wanted both track-up and north-up modes. Helicopter pilots also requested a heading-up mode for more accurate map tracking without "display flopping." Nearly all pilots wanted some flexibility in the degree of decenter; most wanted to have control over decentering both in mission planning and in the cockpit.

In track-up mode, pilots found both the centered position and the 1/4-up position to be *extremely useful*, and the 1/7-up position was rated *of considerable use*. The bottom-of-screen was not as popular, primarily due to a loss of SA behind the aircraft, but it was still rated *of use*. A few pilots said they would occasionally switch from a more centered position to a bottom-of-screen position, particularly at higher speeds, to keep as much map in front of the aircraft as possible.

In north-up mode, all pilots favored the centered position (which they rated *of considerable use*), and they found all decentered positions to be *not very useful* or *of no use*.

Regardless of aircraft cursor position, most participants rated the track-up mode as significantly more useful than north-up, citing improved SA. This result is consistent with earlier studies, such as Aretz and Wickens (1992), who found that people interpret maps more easily in a track-up alignment, and that track-up may be the best alternative for electronic map displays. A north-up map was only practical with a centered aircraft cursor position, and it was considered inappropriate or even hazardous with a decentered aircraft cursor position.

ZOOMING REQUIREMENTS

Description

All four demos in this category address issues pertaining to zooming in or out on the moving-map display. The first demo illustrated the difference between zooming in on a chart from a particular series (e.g., JNC) *vs*. switching the chart to a new series (e.g., ONC). The second demo illustrated several variations on a 2:1 zoom – in a single step, in eight steps, and as a continuum (simulated with >30 steps). The third demo illustrated zoom-out capabilities. The last demo in the zoom category illustrated the difference in range and effective display scale between the chart database (CAC) used in existing ASQ-196 systems and the new, joint-standard chart database (CADRG) that the future TAMMAC system will employ.

Results

Most participating pilots rated "zooming within a chart series" *of use* or better. Twelve pilots (41%) rated it *extremely useful*, and the average rating for this capability for each pilot group (tactical, helicopter, and ASW) was 4 (*of considerable use*). The pilots were given three choices for implementing zooms: A) "Only zoom up to scale of next chart series, then switch series (e.g., zoom a TPC by no more than 2:1, then switch to JOG);" B) "Allow zooms beyond scale of next chart series;" or C) no preference. 18 pilots (62%) preferred option A, 7 pilots (24%) preferred option B, and 4 pilots (14%) had no preference. Preferences varied somewhat by pilot group: 12 of the 14 tactical pilots (86%) and half of the ASW pilots preferred option A; only 1 of each of these groups preferred B. On the other hand, only one-third of the helicopter pilots preferred option A, but more than half of helicopter pilots preferred B.

Figure 1 presents preferences with respect to the number of steps to zoom the map. Most pilots preferred the continuous zoom, rating it *of considerable use* (average rating: 3.9). Participants commented that a continuous zoom could "tailor the zoom factor to display the information of interest", and that it "maintained SA in a controlled, predictable, and fast manner". One participant said the continuous change allowed him to "follow the zoom" more easily, allowing him to keep track of important map features without the disorientation that sometimes occurs with large zoom increments. On the negative side, a few participants commented that the continuous zoom was too slow, if the desired result was a 2:1 increase in scale. Another pilot said he lost his "feel for the range" (i.e., the amount of map coverage displayed, in nautical miles).

The 8-step zoom was rated nearly as useful as the continuous zoom (average rating: 3.6). Participants commented that it provided "more control" and avoided "inadvertently zooming in too far". Several said the 8-step was a "nice compromise between the 1-step and continuous zooms." However, a few said the 8-step was labor intensive (e.g., pushing a button 8 times to get a 2:1 zoom), and others disliked the potential of "over-shooting" a desired zoom factor with too many button pushes if they were in a hurry. Several suggested that a 4-step zoom would work better for their applications.

The 1-step zoom was much less desirable than the other two zooms (average rating: 2.7). Several pilots commented that it was "difficult to keep track of where everything is (on the map) and where you zoomed to." Many participants stated they would simply switch charts (e.g., from a JNC to an ONC) rather than zoom 2:1 in a single step, and others concurred that a 1-step 2:1 zoom was only useful if the next-larger chart series was not available.

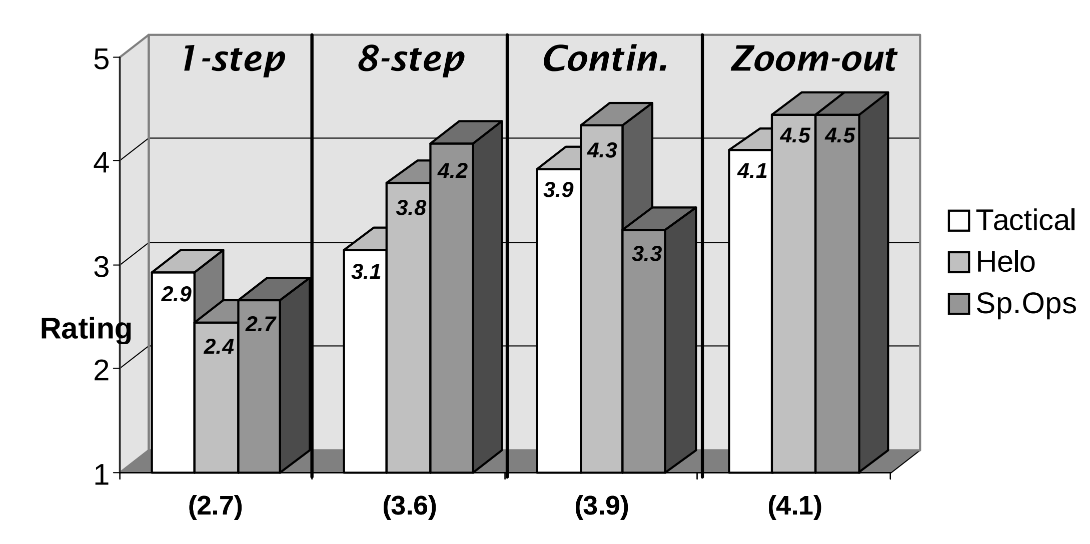

Figure 1. Zoom preferences

Pilots found a zoom-out capability to be *of considerable use* over both of the demonstrated base-maps (chart and imagery), as shown in the fourth bar-chart in figure 1. Pilots commented that a zoom-out capability would be very useful for getting a "quick-look" at the big picture, without having to "process a different set of reference symbols." One pilot mentioned that zooming out over a base-map of satellite imagery "would be most useful and informative with overlays (e.g., threats, navigational symbology, etc.)". Participants listed numerous applications that would be supported by a zoom-out, including the following: for "big-picture SA"; target acquisition; flying outbound from a target; hi-altitude transit (climbout); post-mission egress; mission aborts; and emergency contingencies. As in zooming in, many pilots stated they would want to be able to return to the pre-zoom-out map display quickly, with a single button push.

For the final Zooming demonstration, pilots evaluated the differences in range (coverage) and detail (legibility) for the current chart database (CAC) and the new, joint-standard chart database (CADRG). Both CAC and CADRG are compressed forms of DMA ADRG. The major differences between the two databases are resolution (CAC is 128 pixels per inch, CADRG is 169 pixels per inch) and compression ratio (CAC = 48:1, CADRG = 55:1). In addition, CADRG has been filtered somewhat to clarify the image. As a result, we would expect CADRG to produce a higher quality map display than CAC, despite its greater compression ratio. However, we were concerned that the higher resolution of CADRG would noticeably reduce the resultant map coverage (assuming the display screen is not upgraded). For example, CAC data for the TPC series displays 20 nmi of chart from top to bottom of the screen in current display systems, while TPC CADRG data would display 15.2 nmi on the same screen. Similarly, JOG CAC displays 10 nmi on the current system, and JOG CADRG would display 7.6 nmi. We felt these differences in display range must be taken into consideration when designing the new cockpit displays.

Therefore, we asked pilots to evaluate the geographic range (map coverage) and chart detail (legibility) for CAC and CADRG first using TPCs, then JOGs. For providing optimum range, 70% of surveyed pilots preferred CAC over CADRG, for both TPC and JOG series. Only 10% of pilots preferred CADRG for optimum range, and 20% had no preference. For chart detail and legibility, 33% of pilots preferred CAC, 24% preferred CADRG, and 43% had no preference.

Summary and Recommendations

Based on the results of our surveys, we recommend implementing the following zoom options: a continuous zoom-in (with a wheel control), a 4-step 2:1 zoom-in (as opposed to 8-step or 1-step zooms), and a 1-step 2:1 zoom-out. The 4-step zoom-in should allow "buffered button pushing" so the pilot could hit the zoom-in button quickly 4 times, and the display would "catch-up" with stepped zooms. This seems to be a good compromise among all the pilots' stated requirements for controlled zooms, constant SA, rapid implementation, and minimum pilot workload. Whether using the continuous or stepped zoom option, the pilot needs to be able to return to the original scale with a single button push. If all of these zoom options would be too expensive to implement initially, then we recommend omitting the continuous zoom until it is feasible.

Zooms in either direction (in or out) should only be permitted to the next available chart series, at which point the computer should automatically switch series. Therefore, the computer will need to "know" which chart series have been loaded in the cockpit moving-map computer.

Finally, we must consider the altered map coverage of CADRG (as compared to CAC) in the TAMMAC display. One option would be to make the new display about 1.3× larger (about 5.3" square, compared to the current 4") to accommodate the increased resolution of CADRG. If the display will not be upgraded in TAMMAC, then consider zooming out CADRG by about 0.8:1 to ensure adequate map coverage on the screen. Pilots are accustomed to having a full 20 nmi of coverage when they choose TPC (for example). In fact, they typically refer to a chart series in terms of its coverage (i.e., TPC is referred to as a "20 nmi chart.") It would be confusing and potentially dangerous to display 15.2 nmi coverage for a TPC when pilots are conditioned to viewing 20 nmi. Pilots also commented (in the taped interviews) on the usefulness of having an integer range value (e.g., 10 nmi, 20 nmi, 40 nmi, etc.) and that it would be more difficult to calculate distances on-the-fly with non-integer values (e.g., 7.6 nmi, 15.2 nmi, 30.4 nmi, etc.).

TERRAIN ELEVATION DATA

Description

We demonstrated six different types of terrain elevation map: contour lines in 2-d (planimetric) and 3-d (perspective) views, gray-shaded contours in 2-d and 3-d, and sun-angle shaded maps in 2-d and 3-d. We portrayed contour lines at 32 m, and we depicted gray-shaded contour maps with 16 gray levels. We portrayed 3-d sun-angle displays using 15° sun-angle increments (i.e., 13 steps from 0° to 180°: 0°, 15°, 30°, 45°, … 180°) *vs.* 1° increments (i.e., 181 steps: 0°, 1°, 2°, 3°, … 180°), and we asked participants to select which model they preferred; e.g., "Movie A," which used 15° increments, or "Movie B," which used 1° increments.

Results

Figure 2 presents aircrew ratings for the six different terrain elevation maps: contour lines, gray-shaded contours, and sun-angle shading in 2-d and 3-d views.

<u>Terrain map types</u>: As shown in figure 2, participants consistently preferred sun-angle-shaded terrain maps over both contour lines and gray-shaded contours. Most participants ranked gray-shaded contours as their second choice. Participants rated contour lines last, with the exception of helicopter pilots, who preferred contour lines over shaded contours (in the 2-d view only).

Most participants did not show an overwhelming preference for 2-d *vs.* 3-d views of terrain. Tactical pilots showed no preference at all for 2-d *vs*. 3-d contours (lines or gray-shaded), but they preferred 3-d over 2-d for sun-angle shading. Helicopter pilots preferred 2-d over 3-d for contour lines, but they preferred 3-d over 2-d for both gray-shaded maps and sun-angle shading. ASW pilots preferred 3-d over 2-d for both contour maps and gray-shaded maps, but they showed no preference at all for 2-d *vs.* 3-d sun-angle shaded maps.

Overall, participants rated both 2-d and 3-d contours *not very useful*, except helicopter pilots, who rated 2-d contours *of use* (possibly because of their familiarity with this type of terrain map). Participants rated 2-d and 3-d gray-shaded terrain maps *of use* and *of considerable use*, respectively; and they rated 2-d and 3-d sun-angle shaded terrain maps *of considerable use*. The following comments illustrate why most participants preferred sun-angle shaded terrain over the other models. Tactical and ASW participants cited SA and anticipation of hazards:

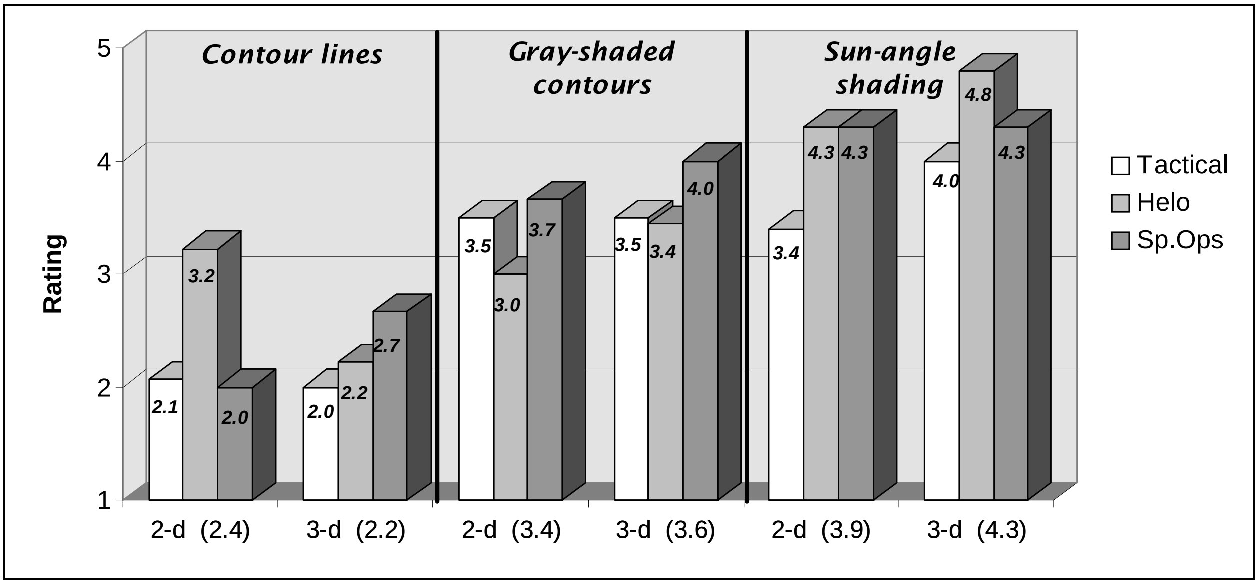

Figure 2. Preferences for terrain elevation map types.

- "Excellent SA builder for flying in terrain; gives a feel for terrain and potential hiding spots."
- "2-d useful for recognizing distant terrain and even doing radar interpretation. 3-d extremely useful when flying low altitudes and collating [the] display to outside world."
- "Best if sun angle corresponds to actual time of day. Would help in target area recognition."

Six of the 15 tactical pilots also stated that sun-angle shaded terrain displays would be useful for pre-flight and mission planning.

Seven of the nine participating helicopter pilots cited the display's realistic appearance:

- "Presents terrain information to the pilot clearly…as it might appear to him out of the cockpit."
- "Day or night: superb! Allows you to see what terrain may be obscured due to shadowing, and if you can find a hiding place … This capability allows you to more effectively plan your tactics, leaving less to guesswork. Being able to see what an area will look like is very useful."

Four helicopter pilots suggested that moon-angle shading would be useful, as well as sun angles. (Moon-angle shading would be as easy to implement as sun angles, since the computer simply processes a generic "light source.")

At least one participant would prefer to "freeze" the shading at some optimum sun angle to provide the most detail, rather than shade the terrain according to the actual flight time. When asked if he might be disoriented by seeing one sun-angle out the cockpit window and another on the display, he replied, "I don't know, but I'd love to go fly it and find out!" Such comments reinforce a need to rigorously flight-test these capabilities in simulators or trainers and define exactly how they will be utilized, so the final implementation will best meet users' demands.

Number of increments for 3-d sun-angle shading: About 50% of pilots preferred the sun-angle shading model with 180 increments, which provided a continuous transition in shadows and lighting from sunrise to sunset. About 20% of participants preferred the model with 15 increments, and about 30% had no preference.

Summary and Recommendations

Based on these results, we highly recommend the implementation of sun-angle (and moon-angle) shaded terrain maps in both 2-d and 3-d. Pilots should have a choice between viewing a preset, "ideal" sun-angle (which could be set in mission planning) or viewing the terrain display with a true sun-angle that would change dynamically in-flight with the time of day. Participants judged contour lines and gray-shaded contour charts to be too confusing, too cluttered, and too hard to interpret for most applications.

OVERLAY DATA

Description

The next three demos examined pilots' responses to different types of new, mission-specific information overlaid on traditional charts and imagery. We illustrated three different kinds of mission information in this set of demos: Height-Above-Terrain (HAT), Clear Line of Sight (CLOS), and threat intervisibility (e.g., threat rings).

HAT consisted of a bi-color overlay: yellow denoted terrain elevations at the aircraft altitude ±16m, and red denoted all terrain elevations above that. We displayed HAT over chart data in 2-d and 3-d, terrain data in 2-d and 3-d, and satellite imagery in 3-d. This coloration was intended to reduce pilot workload in interpreting contours, shaded elevations and hypsographic tinting.

The CLOS model used two display windows: 1) a moving-map of satellite imagery overlaid with a threat ring, with the aircraft cursor centered over a north-up display; 2) a profile of the terrain between the target and the aircraft (in this case, a helicopter). The helicopter started out "hidden" behind a mountain, then it ascended to bring the threat in sight, at which point, a red line appeared (in both views) to connect the aircraft and target symbols.

We demonstrated four different ways of depicting threat intervisibility over chart and imagery: threat rings, hatched overlays, threat rings with spokes, and a 3-d threat dome.

Results

HAT over Chart or Imagery: Figure 3 reflects participants' ratings of HAT over various base maps. Pilots rated HAT over imagery highest overall, with only one response below a score of 3 (*of use*). This may be due in part to the high visual contrast between the black-and-white imagery and the red and yellow HAT colors, which made interpretation particularly easy.

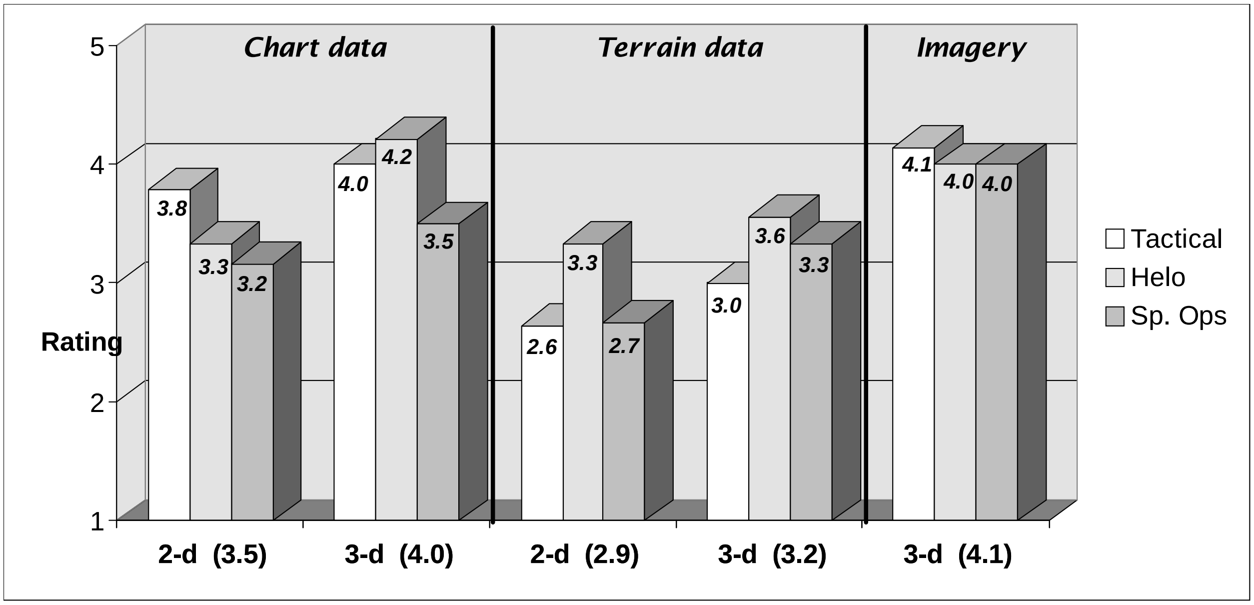

Figure 3. Ratings of Height-above-terrain (HAT) over different base-maps.

Responses to HAT shading over aeronautical charts were also favorable. Some participants commented that the HAT symbology would be useful for both terrain masking and terrain avoidance. Difficulty in interpretation sometimes arose when HAT colors blended with similar chart colors or obscured important chart information. The 3-d (perspective) view of HAT over chart data was slightly favored over the comparable 2-d (planimetric) view, despite the novelty of 3-d chart displays to many participants.

Overall, many pilots noted that HAT would be extremely valuable for terrain avoidance, and a few commented that this was the single most useful feature they had seen in all of our map display demonstrations. HAT enhanced the base maps by boldly highlighting the most critical terrain elevations – those that were at or above the aircraft's current altitude.

<u>CLOS over Imagery</u>: Helicopter and tactical pilots rated CLOS *of considerable use* (average ratings: 4.0 and 3.6, respectively), while Special Op.s aircrew rated CLOS barely *of use* (2.7). These probably reflect the relative importance of terrain information for each group's flight needs. Pilots' comments focused on the novelty of this display, despite similarities to an instrument approach plate. The utility of CLOS appeared to be greatest when specific information was required for terrain masking, relative to a single target or threat.

<u>Threat Intervisibility</u>: Figure 4 reflects participants' preferences with respect to threat displays. We split the results into two categories, according to the type of base map on which the threats were presented. In the first category, threat symbols were drawn over black and white satellite imagery; in the second category, the symbols were drawn over color aeronautical chart data.

For both categories, participants generally preferred the simplest representation – threat rings – because it obscured the least amount of the base map. Pilots reported that hatched areas and circles with spokes obscured too much underlying information in the threat area, while adding little additional information or warning of the threat, compared to open rings.

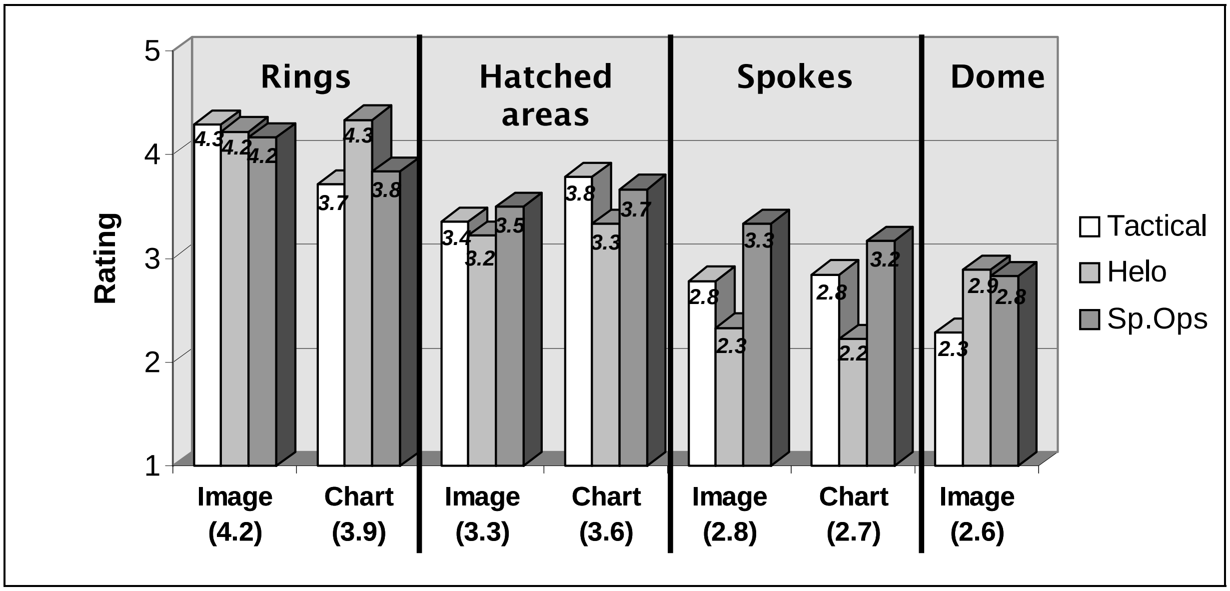

Figure 4. Evaluation of threat symbology over satellite imagery and scanned charts.

In addition to standard 2-d views, participants viewed a 3-d representation of satellite imagery with a threat "dome" appearing above the terrain. The symbology was similar to the previous 2-d displays. Again, pilot reactions were mixed, perhaps because of the novelty of the display or limitations of the computer graphics that we used to depict movement into the threat dome. Many commented that this 3-d view was difficult to interpret, and they could not tell when they had actually entered the dome, or once inside, how best to exit. Several commented that a 3-d threat representation would be very helpful in mission planning, but not in the cockpit.

The use of satellite imagery as a base map was novel to most participants, since it is not used in the current ASQ-196 map display system, yet it produced a generally favorable response. In particular, pilots preferred threat rings displayed over imagery to threats displayed over charts. This was reflected by the fact that most participants rated "rings over imagery" a 4 (*of considerable use*) or 5 (*extremely useful*), and no participant rated this representation less than 3 (*of use*). By comparison, fewer participants rated "rings over chart" a 4 or 5, and two pilots rated this a 2 (*not very useful*). This is probably due to the greater contrast between colored symbols and black & white imagery, as compared to the same symbols over multi-colored charts. This preference was shown previously for HAT overlays, as well. As with the HAT, the symbology and colors of the threat rings often confused or obscured chart symbology, but it stood out well against the monochome satellite imagery.

Summary and Recommendations

<u>HAT</u>: Many pilots in the survey considered HAT to be a very useful addition to electronic charts, but not all participants agreed. Because of this disparity, we recommend that HAT be a user-selectable feature that can be turned on or off, depending on mission requirements. As a supplement to traditional hypsographic tinting, HAT appears to be a useful aid. HAT is particularly effective in conjunction with imagery, because of the lack of absolute altitude information in the image. Overlaid on contour lines, however, HAT does little to aid an already difficult-to-interpret design.

CLOS: Average ratings for both tactical and helicopter pilots indicated that CLOS would be *of considerable use* for their applications. The CLOS model appealed most to helicopter pilots, probably due to its utility in determining terrain masking from threats and targets. Therefore, we recommend including this feature for helicopters and other aircraft that would benefit from advanced terrain masking capabilities.

Threat Intervisibility: "Rings only" encapsulates most participants' preferences for threat symbology. While there were considerable differences between the ratings for other symbols, depending on pilot categories (i.e., Tactical, Helicopter, Special Operations), all of them rated rings highly. Also, many pilots preferred imagery to charts for threat overlays, probably because of fewer visual conflicts in the display. The 3-D representation (threat "dome"), as presented, was not judged to be of much benefit to pilots. A more sophisticated rendering of the 3-d dome might produce more favorable responses, however.

VECTOR MOVING-MAP DISPLAYS

Description

This demonstration depicted vector charts that included many of the cartographic features seen in previously demonstrated aeronautical charts. Vector maps are rendered from individually stored objects, including lines (e.g., roads), points with associated symbols (e.g., airports), text features (e.g., city names), and areas (e.g., shaded metropolitan areas or tinted areas of constant elevation). In contrast, the charts shown in previous demonstrations were scanned in their entirety from paper products, so individual cartographic features were not individually accessible.

Participants were asked to evaluate three potential benefits of a vector map display: 1) the ability to keep text upright as the aircraft turned (while the map rotated in a track-up orientation); 2) the ability to declutter the display after zooming out to a lower resolution, effectively decreasing the chart scale; and 3) the converse of declutter - adding detail to the display after zooming in to a higher resolution (effectively increasing the chart scale).

Results

When asked to assess their prior experience with vector-type map displays, 25 out of 30 said they had limited (5) or no (20) experience with this type of map. Nevertheless, 24 out of 30 participants considered the vector map demo to be easily interpretable, and nearly all participants rated the three demonstrated capabilities (keeping text upright, selectively decluttering, and adding detail) very highly, as shown in figure 5. No pilot rated any of these features less than 3 (*of use*), and virtually all helicopter pilots gave them all the highest possible rating (*extremely useful*).

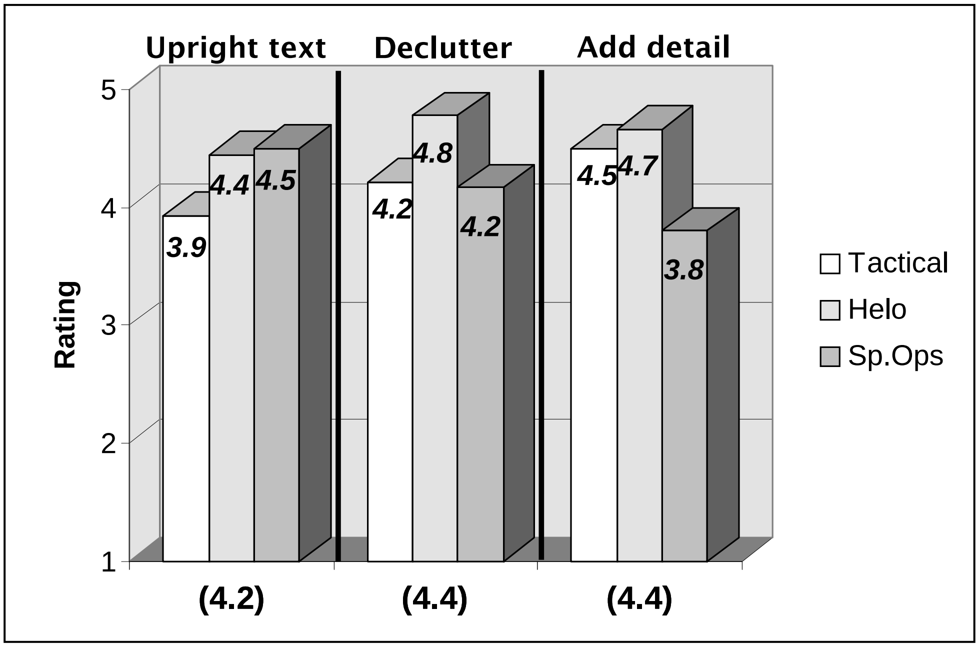

Figure 5. Ratings of demonstrated vector map functions.

When asked specifically what map details they would want to add to this type of display, pilots gave a wide variety of responses – from navigational information and terrain data to obstacle indications. No single type of information was predominant in their requests.

Summary and Recommendations

Based on pilot responses, vector maps clearly have potential for improving pilot performance. Keeping text upright in track-up and selective decluttering are clear advantages over current systems. Almost all pilots wanted to have a choice between manually decluttering the map and using an automatic declutter mode to remove extraneous details.

There are two possible obstacles, however, to effectively implementing vector maps. The first is pilot training, since the customized quality of vector maps inevitably make them look different from standard aeronautical charts. In effect, pilots must acquire new cartographic skills to assist them in configuring their maps for specific mission requirements. If vector maps were integrated into mission planning, the result may be a superior method for displaying spatial information and improving SA. The second obstacle to implementing vector maps in the cockpit is technical, since many cartographic options will have to be handled by the map display system to avoid overburdening the pilot. While storage and display limitations are rapidly being overcome by advances in computer technology, the problems associated with automated cartography are still numerous. Further basic research in this area is sorely needed.

Clearly, vector map technology should be pursued for advanced mission planning and cockpit displays. Implementation of this technology should be carefully tested to ensure optimal pilot performance and enhanced mission success.

SUMMARY

Map designers who attempt to develop optimal maps for electronic cockpit displays must weigh the benefits of cartographic flexibility against pilot workload. Pilots are already overwhelmed by an abundance of information from numerous cockpit displays, electronic or otherwise. A cockpit map system must be capable of conveying critical information concerning navigation, threats, and targets in a manner that is easily interpretable under often stressful conditions. The results of our surveys underscore this requirement. Our specific recommendations are provided throughout this paper, under each demonstration category heading.

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