Pilot Preferences on Vector Moving-Map Displays

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Vector map databases offer the potential for customised cockpit moving-map displays, in which user-specified cartographic features can be layered to meet mission requirements. The disadvantage of vector moving-maps is the potential for increased user workload. In 1995, the Naval Research Laboratory and the Naval Air Weapons Center jointly performed a preference study, during which aircrew viewed demonstrations of prototype moving-map displays and responded to a detailed questionnaire concerning the usefulness of each display. This paper summarises aircrew interviews from that study pertaining to both vector moving-map displays and vector feature overlays, including Height-Above-Threshold (HAT), threat rings, and Clear Line-of-Sight (CLOS).

KEY WORDS

1. Maps/Charts.   2. Displays.   3. Human Factors.

1. INTRODUCTION.   Today's military pilots are inundated with information from moving-maps and other advanced cockpit displays. Current map displays are based on scanned aeronautical charts that, while relatively familiar to pilots, present an unalterable – and often illegible – display. The scanned chart is an example of a raster data set, as is a satellite image or digital photograph. *Raster* refers to the electronic, pixel-by-pixel reproduction of a picture. Individual symbols on a raster image cannot be manipulated separately, since they are bound to the entire image. Thus, for example, rotating a raster image results in inverted symbols and text (Willis and Goodson, 1997).

Figure 1(a) illustrates several undesirable aspects of some raster chart displays, including clutter and non-standard cartography (Lohrenz et al., 1997a). Clutter results when too much information is presented on the display at one time (Clay, 1993), and it becomes even more apparent when mission planning symbols are displayed over the base-map (Figure 1(b)). Non-standard cartography refers to the use of source charts that use different colours, shading patterns, text fonts, etc., as seen near the top of the displays in Figure 1. Both problems can render a chart less effective as a navigational tool, due to the increased time required for the pilot to comprehend and assimilate the information being presented. When the chart is
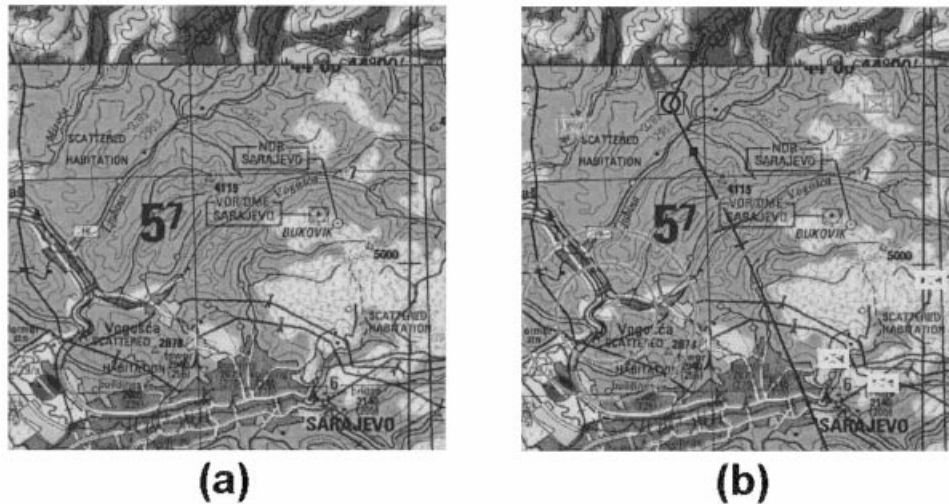
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Figure 1. Example of current scanned chart display: (a) base-map only;
(b) base-map overlaid with mission planning symbols.

moving at a high rate of speed, as in a fighter jet's moving-map, the chart's effectiveness can decrease substantially.

In contrast, so-called vector map databases offer the potential for customised moving-map displays, in which user-specified geographic features can be layered (with or without a raster base-map, such as satellite imagery) for specific mission requirements. *Vector* refers to a relational database of cartographic features, including points (e.g., airports and landmarks), lines (e.g., rivers and roads) and areas (e.g., forests and urban regions). Descriptive information, such as a name, size, or colour, is usually tied to each feature in the database. Similar features may be stored together in thematic layers, resulting in powerful functionality and the ability to customise an output (Willis and Goodson, 1997). For example, symbols and text can remain upright when the rest of a vector map is rotated, since these features can be stored without respect to orientation.

Likewise, a user may specify certain map features to be displayed and others to be omitted, depending on the mission. Vector displays can therefore be 'de-cluttered' to improve a user's ability to assimilate and understand the information presented. Waruszewski (1993) found that, when a map is to be used as a situational awareness (SA) tool, it must be capable of removing extraneous information. The map also should display relationships between the vehicle, surrounding threats, borders and terrain. Vector maps store necessary spatial information to define these relationships, but current raster-scanned maps do not. One obvious disadvantage of customised vector-based moving-maps is the potential for increased user workload, unless these new map displays are carefully designed for the target user (Ruffner and Trenchard, 1998).

This paper presents the results of a pilot and aircrew preference study with respect to vector-based moving-map displays and feature overlays. The paper is organised into six sections. Following this *Introduction*, a *Background* section provides some history behind the study. An *Approach* section describes the series of demonstrations performed, as well as surveys and interviews that were conducted. The *Results* section

Table 1. Demonstrations discussed in this paper.

Category	Demonstration Description
Vector Maps Vector Overlays	■ Vector Moving-Map Display ■ Height-Above-Terrain (HAT) ■ Clear-Line-Of-Sight (CLOS) ■ Threat intervisibility

documents the survey results and the authors' interpretations for each of four moving-map displays: a. Height-Above-Terrain (HAT); b. Clear Line-of-Sight (CLOS); c. threat intervisibility; and d. vector moving-map displays. The first three displays incorporated vector-like overlays to improve a standard raster base-map. Hybrid vector/raster displays such as these may be the optimal configuration for an aircraft moving-map display (Spiker and Rogers, 1986). The fourth display demonstrates a 'pure' vector moving-map and its capacity to be customised. *Results* are followed by *Conclusions* and *References*.

2. BACKGROUND. In 1995, investigators from the Naval Research Laboratory (NRL) Mapping Sciences Branch elicited one-on-one aircrew evaluations of a variety of map data types being considered for advanced cockpit map displays, including vector map features and overlays. The evaluations were conducted at the US Naval Air Warfare Centre (NAWC), Aircraft Division at Patuxent River, Maryland. The study was sponsored by the US Naval Air Systems Command (NAVAIR) as part of an effort to develop specifications for the Tactical Aircraft Moving-Map Capability (TAMMAC) system. During these evaluations, NRL and NAWC captured more than 40 hours of audiotaped interviews with aircrew representing 14 different aircraft platforms. Previous publications resulting from this study (Lohrenz, *et al.*, 1997a, b; Ruffner and Trenchard, 1997) documented aircrew responses to a detailed questionnaire, but most of the taped interviews were never published. This paper summarises the questionnaire results and the aircrew interviews that pertain to vector moving-map capabilities and certain vector-feature overlays, including HAT, CLOS, and threat intervisibility. The information contained in these interviews sheds new light on how pilots and aircrew assimilate and utilise specific map features, as well as how to better design moving-maps for the cockpit.

3. APPROACH
3.1. *Demonstrations.* The authors prepared 16 task-structured demonstrations of various moving-map scenarios, using standard National Imagery and Mapping Agency (NIMA) digital products, and presented the displays to experienced aircrew from diverse aircraft platforms. Participants were instructed to evaluate each map display in terms of its potential usefulness for their applications. Of the 16 demonstrations, four are relevant to a discussion of vector-map preferences and are discussed in this paper (Table 1). Survey results for the other demonstrations may be found in Lohrenz et al. (1997a, b).

Each demonstration was developed on a Silicon Graphics, Inc. (SGI) workstation as a computer-generated movie loop using ArcInfo GIS (Geographic Information System) and SGI Moviemaker software. We simulated realistic groundspeeds,

aircraft turn rates, display refresh rates and other parameters by controlling the window of the 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 approximately 11·5 cm × 11·5 cm (4·5″ × 4·5″) – the same size as current map displays in F/A-18 and AV-8B cockpits.

Based on TAMMAC requirements, we selected six principal map data types for evaluation, four of which are used in the demonstrations discussed in this paper: scanned charts, satellite imagery, terrain elevation data, and vector map data. Table 2 summarises each of these data types, including NIMA sources, geographic scales,

Table 2. NIMA data used in cockpit moving-map demonstrations.

Data Type	NIMA Source Database Information
Scanned charts	*Compressed ARC Digitised Raster Graphics* (*CADRG*) Source: scanned Joint Operational Graphics (JOG) Scale: 1:250 000 Display range: 10 nm
Satellite imagery	*Controlled Image Base* (*CIB*) Source: 10 m/pixel panchromatic SPOT imagery Scale: 1:50 000 Display range: 2 nm
Terrain data	*Digital Terrain Elevation Data* (*DTED*) *Level 1* Source: matrix of elevation points (1 point/3 arc-sec lat.) Scale: 1:250 000 Display range: 10 nm
Vector map data	*Digital Chart of the World* (*DCW*) Source: digitised Operational Navigation Charts (ONC) Scale: 1:1 000 000 Display range: 40 nm

and display ranges (i.e., the equivalent range in nautical miles (nm) from top to bottom on the simulated aircraft display screen).

3.2. *Questionnaire and Interviews.* The aircrew questionnaire consisted of a pilot identification page, followed by one survey for each demonstration. The entire questionnaire is provided in Lohrenz et al. (1997a). Most questions required the participants to rate the usefulness of a given display or function from 1 (*of no use*) to 5 (*extremely useful*). We also tape-recorded each session to capture all participants' comments. NRL and NAWC interviewed a total of 30 pilots and aircrew, representing 14 different aircraft platforms (Table 3) from the Navy, Marine Corps, and Air Force. Survey and interview results were categorised into Tactical, Helicopter, and Anti-Submarine Warfare (ASW) groups, in an attempt to highlight potential differences in map data requirements as a function of aircraft type and mission.

The survey gauged pilot experience by total flight hours (average: 2400), combat experience (43% had some combat experience), and flight instructor experience (57% were instructors). It also assessed digital moving-map experience and determined that 77% of participants had some experience with cockpit moving-maps, and another 20% were familiar with the concept. These responses suggest a fairly sophisticated pilot population that is familiar with digital cockpit moving-maps.

Table 3. Aircraft types represented in the study.

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 only interviewed during a test survey. This pilot did not respond to every question, resulting in a total of 14 tactical pilots (29 total pilots) for some items.
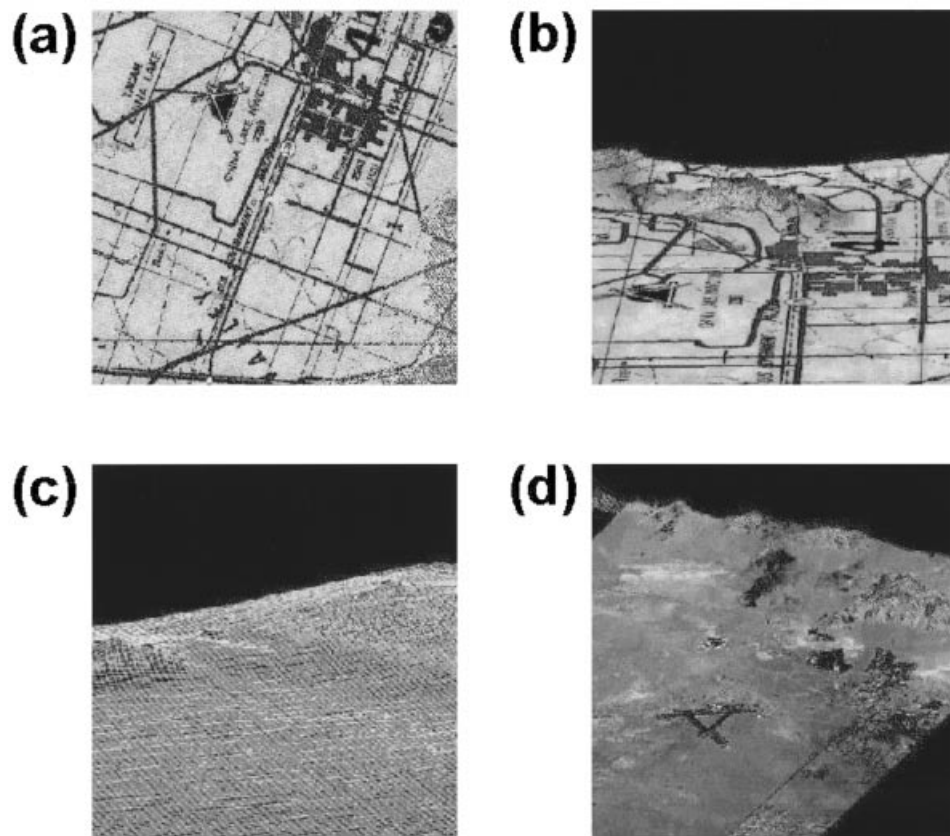

Figure 2. Height-Above-Terrain (HAT) displayed over (a) scanned chart in 2-D; (b) scanned chart in 3-D; (c) matrix terrain elevation data in 3-D; (d) satellite imagery in 3-D.

4. RESULTS. This section documents survey results and interviews for four moving-map displays: a, HAT overlays; b, CLOS overlays; c, threat intervisibility overlays; and d, vector moving-map displays. The first three displays incorporated both vector and raster technologies. Participants were asked to evaluate these as potential tools to improve a typical raster map display (e.g., by increasing the pilot's assimilation of the chart information or enhancing his SA). The fourth display
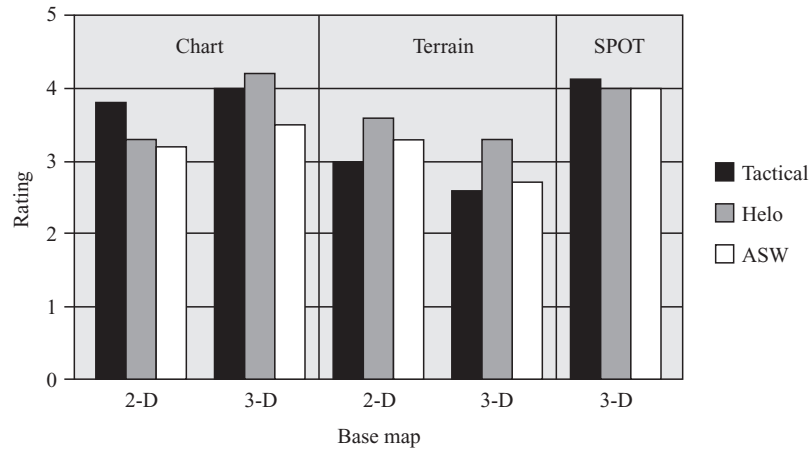
Figure 3. Pilots' ratings of HAT over different base-maps: 1 = of no use; 2 = not very useful; 3 = of use; 4 = of considerable use; 5 = extremely useful.

Table 4. Percentage of participants who approved of HAT colours as demonstrated.

	Tactical (%)	Helo (%)	ASW (%)	Total (%)
# Colours (2)	86	78	100	87
Yellow, Red	80	56	83	73

demonstrates a 'pure' vector moving-map. Participants were asked to evaluate this display's capacity to be customised.

4.1. *Height-Above-Terrain* (*HAT*). HAT consisted of a two-colour shaded overlay to a base-map, in which yellow denoted terrain elevations at the aircraft altitude ± 16 m, and red denoted all terrain elevations above that. This colouration was intended to reduce pilot workload in interpreting contours, shaded elevations and hypsographic tinting. We displayed HAT over several base-maps some of which are shown in Figure 2:

  (i) Scanned chart data in both two-dimensional (2-D, or planimetric) and 3-D (or perspective) views;
 (ii) Terrain data in both 2-D (with terrain displayed as contour lines) and 3-D (with terrain displayed as a mesh grid);
(iii) Satellite imagery in 3-D only.

4.1.1. *Evaluation Summary*. Figure 3 summarises participants' ratings of HAT over the various base-maps. Pilots rated HAT over 3-D imagery highest, with an average rating of 4.1 (*of considerable use*). This may be due in part to the high visual contrast between the black-and-white imagery and the vivid HAT colours, which made interpretation particularly easy. Ratings of HAT over aeronautical charts were also favourable, although difficulty in interpretation arose when HAT colours blended with similar chart colours or obscured important chart information.

4.1.2. *Colour preferences*. Most pilots responded favourably to the HAT colours used in these demonstrations (Table 4). 87% of respondents judged two colours (as opposed to one or many) to be appropriate. Fewer participants approved of the

choice of colours (yellow and red), including only half of the helicopter pilots. Our choice of yellow and red were based on recognised conventions (yellow signifies 'warning;' red signifies 'danger'). During the interview sessions, several participants remarked that these colours and their meanings were immediately understood. However, others expressed concern about colour compatibility (red, in particular) with Night Vision Goggles (NVG), which block all red light when fitted with the appropriate filter. Alternate colour schemes for blue-light cockpits (i.e., night missions versus day missions) were also discussed. Other pilots noted that the colours of the base-map and other overlay colours (e.g. threat rings) should be taken into consideration when determining the HAT overlay colours, to ensure maximum contrast between the different features. In particular, yellow overlays displayed poorly against the mostly-yellow scanned charts that were used in this demonstration (Figure 2*a*, *b*).

4.1.3. *Preferences with respect to Standardisation.*   Regardless of which colours are used, participants exhibited a strong preference for a standard colour set. One pilot noted: *It should be standardised so you get used to seeing one thing. When you see it, you know immediately what it is.* Most pilots were concerned that the use of non-standard, pilot-selectable colours would result in confusion. With no established conventions, pilots would choose their own colours tailored to their specific needs. Use of the information by other pilots unfamiliar with the scheme could result in misinterpretation. As one pilot aptly explained, *if I'm used to yellow and red, I don't want to get in an airplane where someone just flew with pink and blue.* Likewise, post-flight mission playback of the moving-map display for training purposes would require clarification of haphazard pilot-selected colours before they could be properly understood.

4.1.4. *Utilisation of HAT overlays.*   Pilots' comments regarding their anticipated use of HAT fell into three general categories: terrain avoidance, aid to navigation, and overall SA (Table 5). Participants emphasised that HAT would be most valuable

Table 5. Representative excerpts of pilot responses to the question,
'How would you use the HAT display?'

| Topic and pilot responses |
| --- |
| Terrain Avoidance |
| • To identify obstacle clearances |
| • During low-level terrain-following/avoidance |
| • To spot shadowed terrain features |
| • For hazard avoidance in low visibility conditions |
| • For terrain masking (avoiding enemy radar) |
| Situational awareness |
| • Keeping situational awareness on rising terrain |
| • As an extra reminder of my altitude and that of the terrain around me |
| • At night, when there is no visible horizon |
| General navigation |
| • To reduce workload during en-route navigation |
| • To aid in ingress/egress route selection |
| • To graphically highlight valleys and other possible avenues of approach |
| • During any Visual Flight Rules (VFR) or tactical flight |
| • During low-level or 'nap-of-the-earth' (NOE) flying |
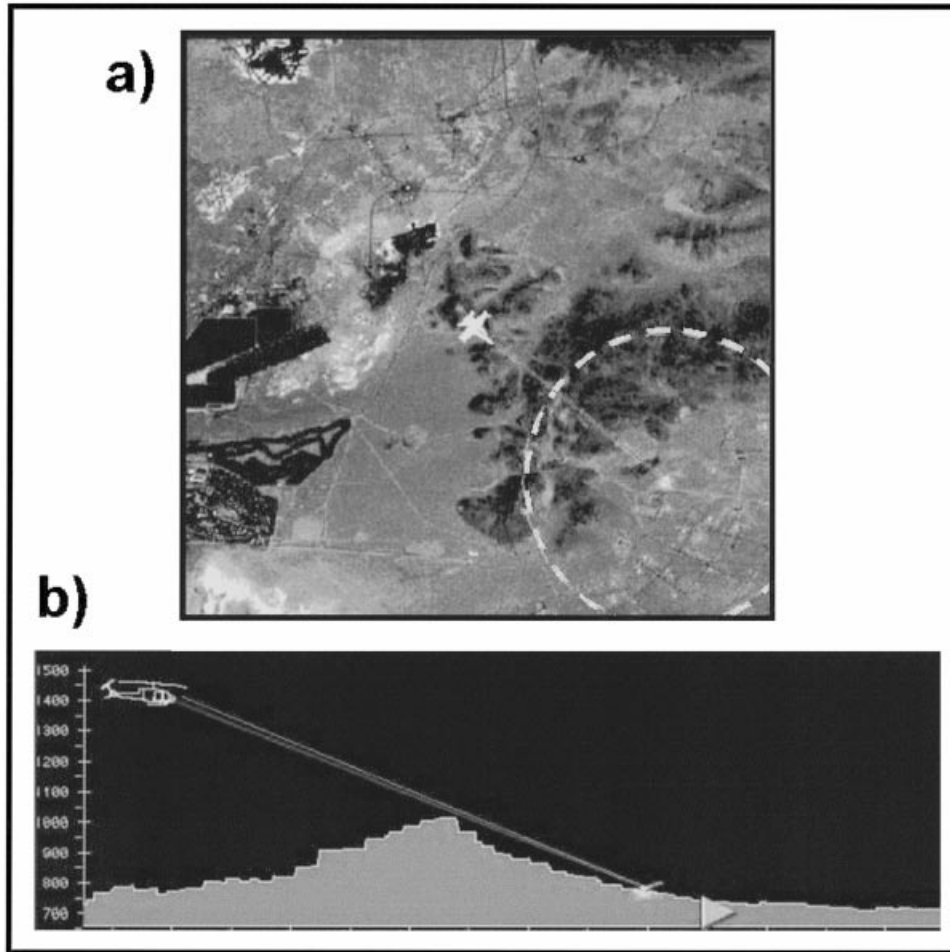
Figure 4. Clear Line-of-Sight (CLOS) displayed in two views: (a) plan and (b) transect.

for terrain avoidance and terrain masking. HAT enhanced the base-maps by boldly highlighting the most critical terrain elevations – those that were at or above the aircraft's current altitude. As one pilot put it, HAT would address his two primary concerns during low-level flight: *I want to know if I'm close, and if I'm going to hit something*! A few participants commented that HAT was the single most important feature they had seen in all of the map display demonstrations.

As a navigation aid, participants recommended HAT overlays for Visual Flight Rules (VFR) and tactical (particularly low-level) flights. Pilots remarked that HAT provided *extended terrain orientation* (i.e., increased the pilot's ability to determine his position relative to the terrain) and *reduced aircrew workload by augmenting the cockpit instrumentation suite* (i.e., radar/altimeter data and night vision goggles), reducing his need to refer continually to instrumentation. Many pilots perceived HAT as providing increased SA by *graphically highlighting valleys and other possible avenues of approach*, which would be useful in target of opportunity ingress/egress route selection and masking (i.e. avoiding enemy radar).

4.2. *Clear Line-of-Sight* (*CLOS*). The CLOS model used two simultaneous display windows: (1) a planimetric moving-map of satellite imagery overlaid with a threat ring surrounding a potential target/threat; and (2) a profile of the terrain between the target and the aircraft. In this demonstration, a helicopter initially was 'hidden' from its target by an intervening mountain. When the aircraft ascended to bring the target in sight, a red line appeared (in both display windows) to connect the aircraft with the target symbols (Figure 4). As shown in Figure 5, helicopter and
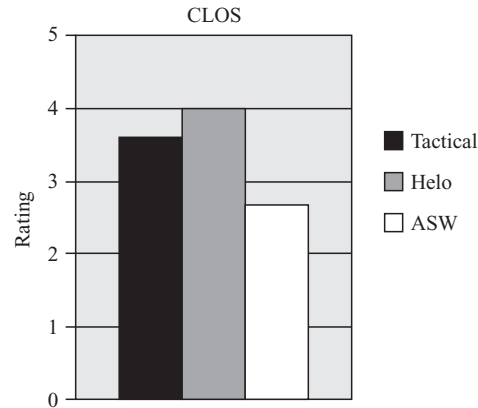
Figure 5. Pilots' ratings of CLOS display: 1, of no use; 2, not very useful; 3, of use; 4, of considerable use; 5, extremely useful.

tactical pilots rated CLOS *of considerable use* (average ratings: 4·0 and 3·6, respectively), while ASW aircrew rated CLOS barely *of use* (2·7). These ratings reflect the relative importance of terrain information for each group's flight needs. The utility of CLOS appeared to be greatest when specific information was required for terrain masking, relative to a single target or threat. A representative sample of the pilots' comments is presented in Table 6. Most responses were from helicopter and tactical pilots; ASW pilots had few significant comments concerning CLOS.

Most helicopter pilots and aircrew liked both views of the CLOS display and found them clear, concise, and easy to interpret. These participants commented that the CLOS display would be particularly useful for performing terrain analyses during mission planning, as well as maintaining terrain masking while in-flight. However, one pilot indicated that the demonstrated display was too cluttered; i.e. too much information was being presented at once. He would rather see a CLOS display during mission planning than in the cockpit.

Most tactical pilots found the CLOS display to be very useful for targeting, threat avoidance and terrain masking tasks, both for mission planning and in-flight navigation. However, several indicated that CLOS would be more useful for helicopters than for faster, higher-flying aircraft. A few pilots wanted the capability to predict line-of-sight (LOS) for certain scenarios, such as just prior to entering a threat range or based on possible maneuvers (e.g. how would LOS be affected if the aircraft turned left or right?). One pilot cautioned that future systems might use similar symbology with very different – even opposite – meanings, such as displaying a red line to guide the aircraft into a target, as opposed to warning the aircraft to stay clear of a threat.

Table 6. Representative excerpts of pilot responses to the CLOS display. Responses are indicated as generally favourable (+) or unfavourable (−).

Aircraft		Pilot responses
Helicopter	+	Bottom view shows your trend, which you don't get off the map display.
	+	Very useful for maintaining maximum terrain masking while manoeuvring to a target or landmark.
	+	Presents a simple, clearly understood display of altitude, terrain, and threat relationships.
	+	Graph is clear and concise. Really good [for] mission planning, to figure what altitude your aircraft will be, if you can see the [target/threat] and vice versa.
	−	I could see using [CLOS] for the big picture … but if I'm down in the terrain, that's way too much stuff to look at.
Tactical	+	Very beneficial for threat avoidance/terrain masking tasks. Adding a voice warning would be extremely useful for 'heads out-of-cockpit' tasks.
	+	Useful to distinguish threat range from threat LOS.
	+	Determine attitude required for sensor LOS for targeting. May be useful in terrain masking, but might be more useful in mission planning.
	+	Survivability enhancement! Good for taking out [a weapons] site or just ingress or egress.
	+	Often, you know you'll be exposed, being up high. [But] if you're down low, you'll need to see [your environment] quickly and understand it ... [so CLOS] has potential for a fighter.
	−	Great for helicopters; not so for fast movers.
	−	What I want to know is: Can I go left? Can I go right? Where will that mask be without having to go any lower?
	−	Prefer to have just one window; top view more useful than bottom.
	−	May conflict with future [mission] symbology. [CLOS as depicted here may be confused with other linear symbols].
	−	More useful to see some prediction of [LOS] … i.e. I should be able to see it in three seconds.
ASW	+	Good for low-level visual NAV to let you know what you should be able to see.
	−	You're going to give up half of your screen for that? No. [But for] mission planning, it might be nice.

4.3. *Threat Symbology*. We demonstrated three depictions of threat inter-visibility: 1) open threat rings, 2) threat rings filled with coloured, cross-hatched, fine lines, and 3) threat rings with 'wheel-spokes' radiating from the center (Figure 6). Each type of threat overlay was evaluated with two different base-maps: scanned chart and satellite imagery. Figure 7 presents participants' ratings, and Table 7 provides a representative sample of their comments.

4.3.1. *Symbol Shape*. For both base-map types, participants generally preferred the simplest representation – an open threat ring – because it obscured the least amount of base-map. Most pilots reported that both cross-hatched areas and spokes obscured too much underlying chart, while adding little information or warning of the threat, compared to open rings. However, pilots in all three aircraft groups (tactical, helicopter, and ASW) suggested using threat rings shaded with a transparent colour, to emphasise the threat location relative to the aircraft (Table 7). For example, on the typical small cockpit display, a large threat ring could conceivably be greater than the display's range, making it difficult for the pilot to know if he were inside or outside of the threat envelope. For this reason, one pilot noted that the spokes worked well to draw his attention to the precise threat location, which was not
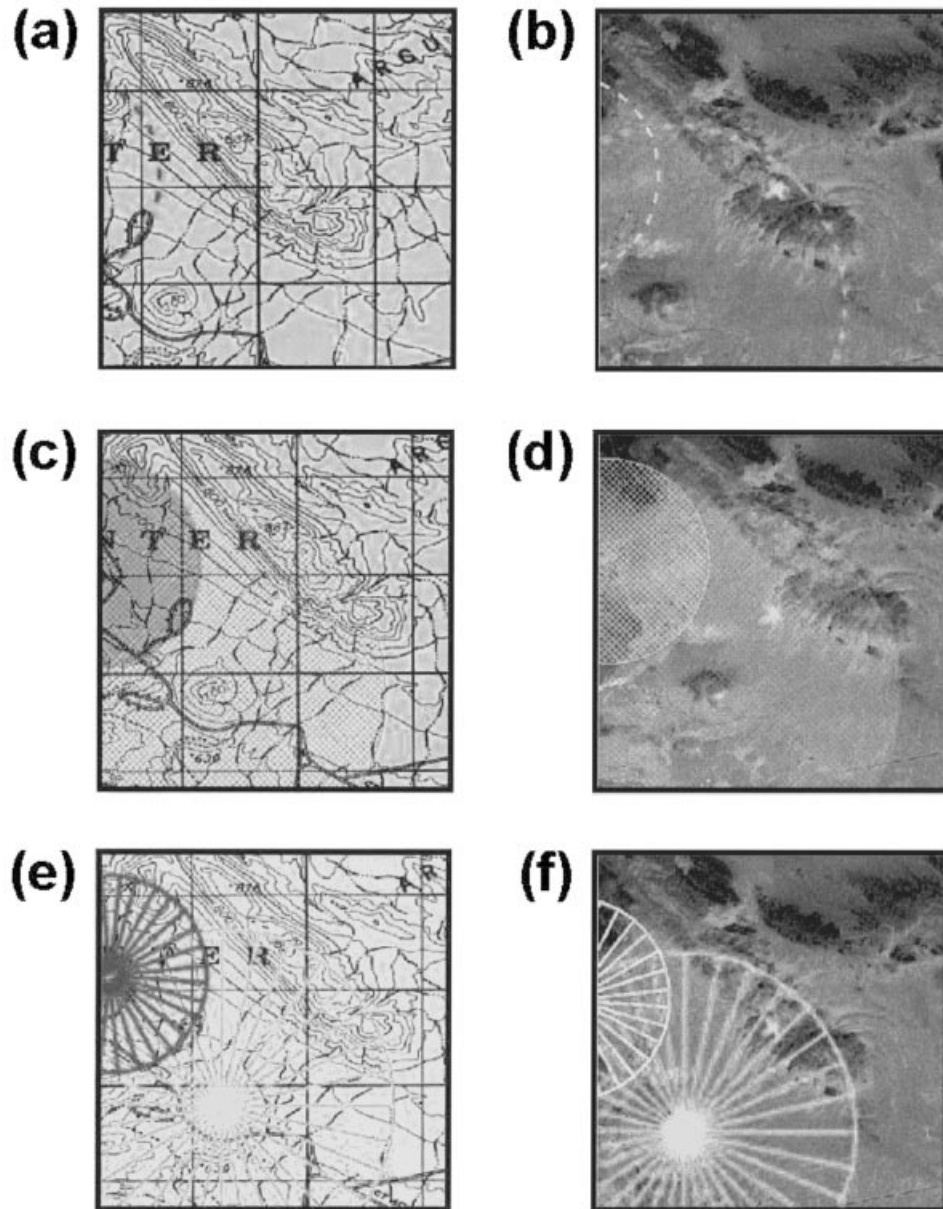
Figure 6. Threat symbology: open rings displayed over (a) chart and (b) satellite imagery; cross-hatched areas displayed over (c) chart and (d) satellite imagery; wheel-spokes displayed over (e) chart and (f) satellite imagery.

as obvious in the other two representations. He suggested using thinner spoke lines and removing the central 'hub' to expose more of the underlying chart.

4.3.2. *Symbol Colour*.   Pilots had mixed reactions to the choice of colour for threat symbology (Table 7). Many expressed concern, as mentioned earlier, about colour compatibility (red, in particular) with NVG, which block red light when fitted
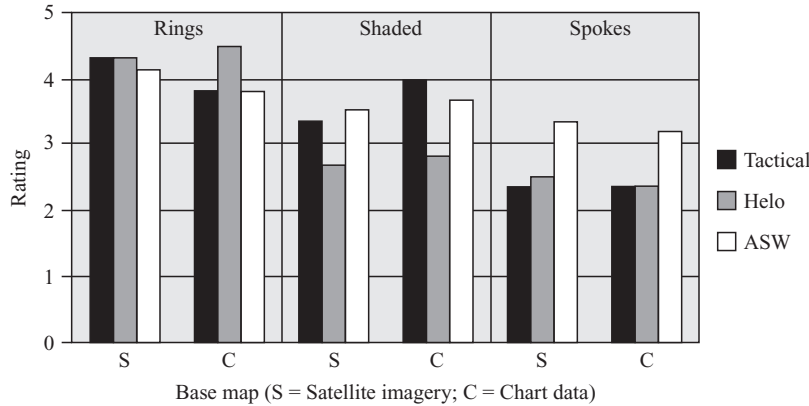
Figure 7. Pilots' ratings of threat symbols: 1 = of no use; 2 = not very useful; 3 = of use; 4 = of considerable use; 5 = extremely useful.

Table 7. Representative excerpts of pilot preferences with respect to threat intervisibility symbols. Within each category, ideas are sorted by number of platform types (T, H, A) responding.

Aircraft type (T = tactical, H = helicopter, A = ASW):	T	H	A
(i) Shape and Colour of Threat Symbols:			
● Hatched areas and spokes covered or cluttered map information	X	X	X
● Suggest using transparent colour shading of threat areas (instead of spokes or hatched areas) to minimise clutter	X	X	X
● De-conflict threat symbol colours with other colours; ensure NVG compatibility	X	X	
● Suggest using red dashed lines while aircraft is outside threat rings, solid red lines inside threat rings	X	X	
● Spokes work well to draw attention to threat. Suggest using thinner spoke lines and removing 'hub' in centre to avoid blob of colour.	X		
● Suggest using different colours to associate each threat ring with specific threats, then make aircraft turn to colour of most lethal threat	X		
● Colour of intersecting threat areas might be confusing (e.g., red and yellow threat areas → orange intersection)	X		
● Suggest using a transparent 'warning' colour with greater intensity to cue pilot when crossing threat boundary		X	
(ii) Colour of Aircraft Symbol:			
● Aircraft colour acceptable: liked aircraft changing colour (from black to red) inside the threat area as additional warning	X	X	
● Don't colour aircraft symbol: red represents enemy (not own-ship)!			X
(iii) Terrain Masking:			
● Suggest incorporating terrain masking: as aircraft ascends/descends, threat ring changes size and shape depending on surrounding terrain	X	X	X
● Suggest incorporating CLOS line to connect 'own aircraft' symbol to threat centre when own aircraft is within threat envelope	X	X	
(iv) Navigation and Improved Situational Awareness (SA):			
● Helps pilot avoid detection and getting shot by navigating around threat and staying out of threat envelopes on ingress/egress	X	X	X
● Helps pilot plan alternate tactics and routeing	X		X
● To navigate inside enemy territory and moving into firing position		X	

with the appropriate filter. A few participants were concerned that too much colour variation would become confusing (e.g. in intersecting areas between two different threat rings), while others would prefer to see *more* colour variety (e.g. different colours assigned to different threat levels – high, medium, or low threat). Likewise, a few tactical and helicopter pilots liked the use of colour to highlight their own-ship symbol (during the demonstration, the aircraft symbol changed from black to red as it entered a threat envelope). This use of colour provided another warning cue to the pilot. However, at least one ASW pilot disliked that feature, since other display systems use red to highlight an *enemy* aircraft, so one's own ship should never be coloured red!

4.3.3. *Base-maps.* As shown in Figure 7, pilots preferred satellite imagery to scanned charts as a base-map to the threat symbology. As with the HAT overlay, this is possibly due to the greater contrast between coloured symbols and monochromatic imagery, as compared to the same symbols over multi-coloured charts.

4.3.4. *Utilisation of Threat Intervisibility Symbols.* Pilots' comments regarding their anticipated use of threat intervisibility overlays fell into two general categories: terrain masking and navigation with improved SA (Table 7). Pilots from all three aircraft categories wanted to see threat intervisibility symbols in conjunction with an appropriate terrain elevation database to provide effective terrain/threat masking. In other words, as the underlying terrain undulates and the aircraft ascends and descends, the threat ring should automatically adjust in size and shape to more accurately reflect threat intervisibility. This feature could be combined with the CLOS overlay to provide additional information about the threat location relative to the aircraft.

Pilots from all three aircraft categories stated that threat overlays would aid navigation and provide improved situational awareness by helping the pilot navigate around threats, thereby avoiding detection and unwanted engagement. Some tactical and ASW pilots also suggested that the threat overlays would help them plan alternative tactics and routes when necessary. For example, if the pilot identified a new threat during ingress, he could enter the threat's location into the database and use the information to avoid that threat on egress.

4.4. *Vector Moving-map Displays.* This demonstration displayed charts created from a vector database, rather than traditional 'scanned-chart' raster products. The advantage to the database scheme is that any combination of objects can be displayed at will on the screen by the computer. In theory, the pilot can choose from an infinite variety of map scales, object types, and annotations. Each time the map moves, the display can be redrawn so that text remains upright and other characteristics remain constant. One disadvantage is that automatically generated maps often lack the visual quality of those created by trained cartographers. Participants were asked to evaluate three potential benefits of a vector moving-map:

  (i) the ability to keep text upright as the aircraft turned (while the map rotated in a track-up orientation), as illustrated in Figure 8;

 (ii) the ability to declutter the display (e.g., removing some map layers while zooming out to a lower resolution, effectively decreasing the chart scale), shown in Figure 9; and

(iii) the ability to add map features selectively to the display (e.g., after zooming in to a higher resolution, effectively increasing the chart scale).
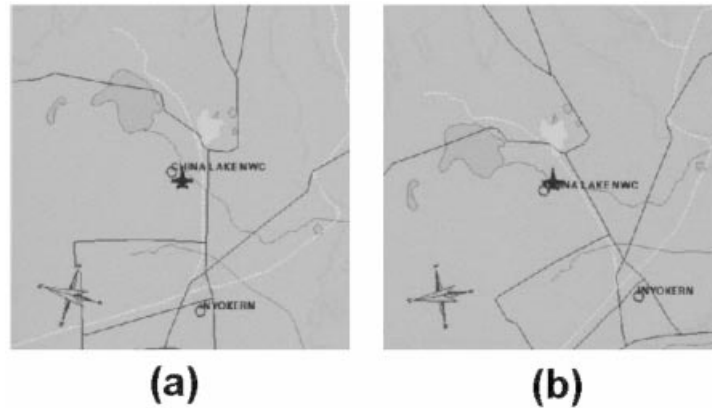
Figure 8. Example of vector map display showing upright text during map rotation:
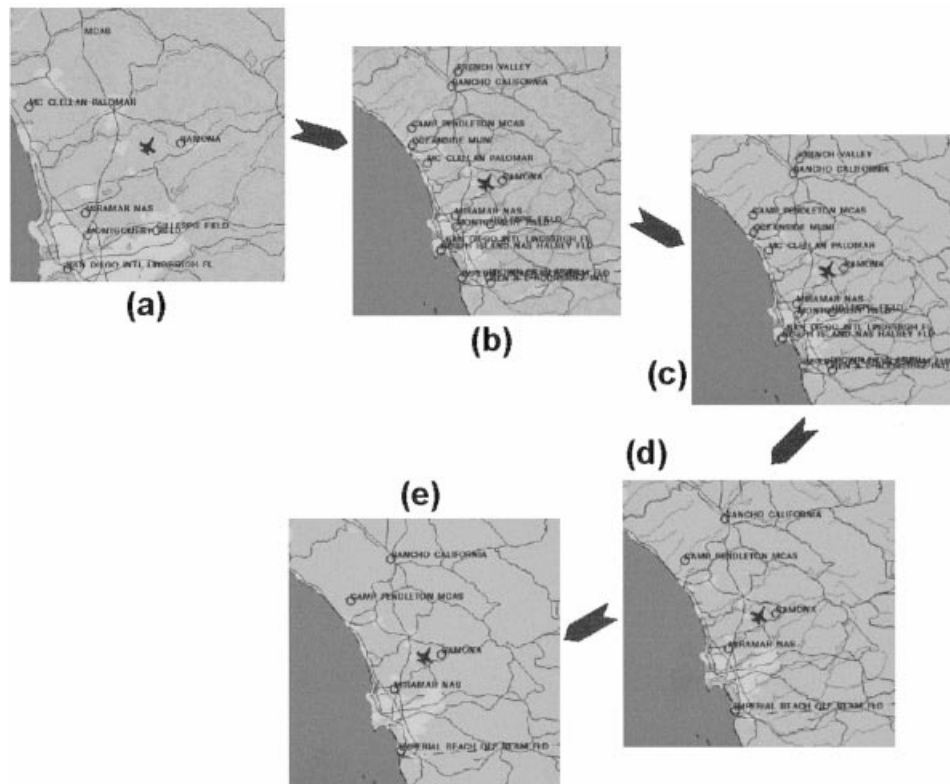(a) aircraft heading NE; (b) aircraft heading SE.

Figure 9. Example of vector map display's declutter capability: (a) original map display;
(b) zooming out results in cluttered map; (c) removing vegetation layer; (d) removing selected
text; (e) removing minor roads.

Despite the fact that only five participants had *any* prior experience with vector-based map displays, 80% of participants considered this demonstration to be easily interpretable, and nearly all participants rated the three demonstrated capabilities
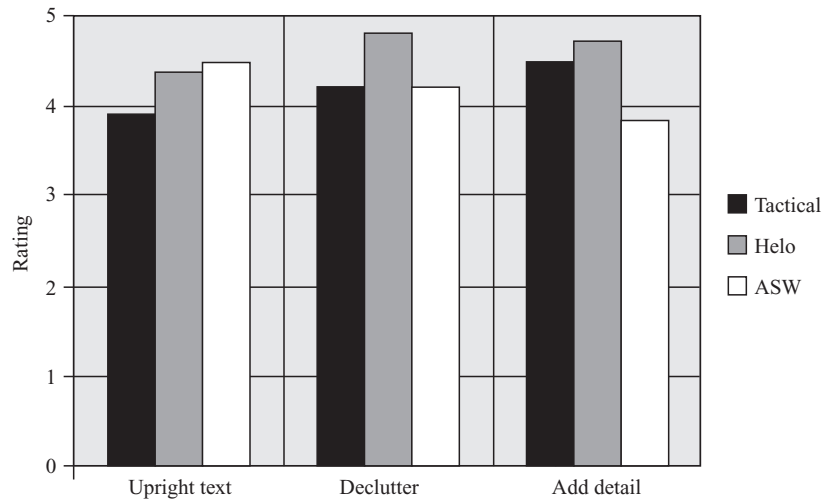
Figure 10. Pilot's ratings of vector map display capabilities: 1, of no use; 2, not very useful; 3, of use; 4, of considerable use; 5, extremely useful.

very highly (Figure 10). No pilot rated any of these capabilities less than 3 (*of use*), and virtually all helicopter pilots gave them all the highest possible rating (*extremely useful*). In the following discussion, we have combined the last two capabilities (adding map detail and decluttering) into a single heading: map customisation.

4.4.1. *Upright Text.* Keeping the text and other symbols upright during a turn (on a track-up map) is not supported by scanned-map displays, since the text is fused with the map image and cannot be manipulated separately. Most participants favoured the upright text function and rated it 4, *of considerable use* (Figure 10). One tactical pilot described the basic Human Factors benefit of this feature: *Normally, when you are turning or the map's not pointed* [*north*], *you will do some eye work to read the chart, so upright text is a very nice feature to have.* After viewing this capability for a few seconds, however, a few participants changed their minds. As one tactical pilot explained, *When the words are no longer upright, you have a better sense of your SA. It is innate. If the words are this way up and down instead of horizontal, I know I'm going east, instead of having to look down at the compass rose and think, 'ok, now I'm going east.' I'd probably have to fly it, take it into battle, but I think I'd probably prefer not having the upright text.* This same pilot later decided that upright text should be a pilot-selectable option, *because it could vary from pilot to pilot: some guys might have a problem reading things sideways or upside down, but guys like me prefer the SA benefit and put up with reading sideways.*

4.4.2. *Customising the Map.* Customising the moving-map display (i.e., de-cluttering and adding map details) is also unique to the vector map. Current scanned-chart displays cannot support this degree of customising for the same reason that they cannot support upright text: the individual map features are fused with the overall image and cannot be manipulated individually. As shown in Figure 10, pilots from all three aircraft types rated both the customising features highly, with an average of between 4 (*of considerable use*) and 5 (*extremely useful*). As one helicopter pilot noted, *De-clutter for 'zoom-outs' is extremely useful: without it, the map becomes too cluttered to read.* Another helicopter pilot stated that the de-clutter function would be

especially significant in urban areas, when he would most likely need a clear, concise map of the region.

When pilots were asked specifically which cartographic features they would want to add to this type of map display, they provided a wide variety of responses – from navigational information and terrain data to obstacle indications (Table 8, part (i)).

Table 8. Representative excerpts of pilot preferences with respect to vector map design issues. Within each category, ideas are sorted by number of platform types (T, H, A) responding.

Aircraft type (T = tactical, H = helicopter, A = ASW):	T	H	A
(i) Map features to select on/off as needed:			
● Mission data (e.g. way-points, threat envelopes, etc.)	X	X	X
● Vertical obstructions (e.g. power lines, towers, bridges, check points)	X	X	X
● Certain text layers (e.g. may not need name of airfield, only location)	X	X	X
● Nearest divert field (selectable with single button-push)	X		X
● Latitude/Longitude grid	X	X	
● HAT overlay/terrain features/contours	X	X	
● Sectional features (e.g. controlled airspace, TACAN & airfield info)	X	X	
● Cultural features (roads, bridges, town symbols, shaded urban areas)	X	X	
● Difference between forest/farm land	X		
● Remove anything 'in the way'; i.e. enemy airports (won't divert there!)	X		
● Retain access to all current (i.e. familiar) map features		X	
● Pilot-entered obstructions discovered during flight		X	
● Projected 'pathway' in the sky		X	
● Dry creek beds and small streams			X
(ii) Manual vs. automatic de-clutter mode:			
● (Selectable) Choose between automatic and manual modes	X	X	X
● (Both) Automatically shrink text and symbols during zoom-out to reduce need for manual de-cluttering	X	X	X
● (Both) Automatically pre-set default, scale-dependent map features, then allow manual de-clutter as required	X	X	
● (Both) In mission planning, manually select items to be removed during de-clutter. In cockpit, activating 'de-clutter' automatically removes them.		X	
● (Manual) Don't hide things on me: I want to hide them myself!			X

Pilots of all three aircraft types indicated a need for vertical obstructions, mission-specific data (e.g., CLOS and threat intervisibility overlays), and some selectable text layers. Tactical and ASW pilots suggested adding the position of the nearest diversion field, in case of emergency. Tactical and helicopter pilots suggested adding a latitude/longitude grid, terrain features (e.g., HAT), some sectional features, and some cultural features to the map display. Other suggested map features are listed in Table 8, part (i).

One tactical pilot stated that the map features used on current charts *should all be available* [for adding detail]. *For example, on the chart you use for 'night low-level' you wouldn't care about railroad tracks. Whereas in 'day low-level' or 'day high-level' a railroad track is really easy to see and makes for great navigation.* [The map features] *need to be selectable depending on what you're trying to do.* In other words, map designers should take care not to eliminate any potentially useful information from the database that will drive the map display. Pilots will need the capability of adding new information, in-flight if required, according to their missions.

Given the potential workload associated with a map display that can be customised, participants were asked how they would envision the implementation of such a display in their cockpits. Would they prefer to choose the map features to be added manually and removed as needed, or would they prefer to have the display system 'choose' the features for them? Most pilots wanted some combination of these two options, as summarised in Table 8, part (ii). Several participants suggested letting the system present a 'default' map display, based on the mission to be flown, which could be modified by the pilot as required. Another suggested letting the pilot program various levels of de-clutter in mission planning. For example, the pilot could preset 'level 1' to remove unnecessary text, small roads and streams. Then, while flying, selecting 'de-clutter level 1' would automatically remove the appropriate information from the map display.

4.4.3. *Overall Utilisation of Vector Moving-Map Displays.* Pilots were asked how they would utilize this new type of moving-map display. Their responses fell into two general categories: Navigation and Improved Situational Awareness (SA) and Mission Planning (Table 9). Many pilots (representing all three aircraft types) stated

Table 9. Representative excerpts of pilot responses to the question, 'How would you use this type of vector moving-map display?'

Aircraft type (T = tactical, H = helicopter, A = ASW):	T	H	A
(i) Navigation and Improved Situational Awareness (SA):			
• Would use this type of display all the time	X	X	X
• To optimise primary navigational SA tool and reduce workload	X		
• To build SA prior to and while entering high threat areas	X		
• For navigation on big 'air battle' picture	X		
• For all VFR flying		X	
• For airways navigation and coastal EW missions (i.e. EP-3/EJ-3)			X
(ii) Mission Planning:			
• To optimise display information for mission (only show threats, targets, navigation data required to accomplish mission)	X	X	
• To tailor map to particular mission based on environmental factors and mission profile (e.g. day/night, altitude, airspeed, etc.)		X	
• To 'build' an appropriate map at my mission planning station for the threat, complexity, familiarity of terrain I will fly over			X
(iii) Concerns:			
• Flexibility means integration complexity (cost) and additional pilot workload. He should be flying, not building a map!	X		X
• Need terrain elevations and other details before this map could be used tactically.	X	X	

that they would use this type of display all the time, as a replacement for the existing scanned-chart displays, citing enhanced SA during both general navigation and in high threat situations. Pilots in all three aircraft categories indicated that the vector moving-map would be extremely useful during mission planning to tailor the map to a particular mission. However, participants also recognised the adverse potential for increased workload. As one tactical pilot adamantly put it: *Flexibility means integration complexity and additional pilot workload. He should be flying, not building a map!*

One tactical pilot explained how he would want such a system to work. *It should give me the flexibility to sit down in mission planning and decide, for the way my brain*

works and the way I'm going to be flying this mission, what I need to know and [eliminate] *all the other stuff that will just get in my way. It has to be* [retrievable] *in the cockpit, though, in case something changes. Like if I have an emergency or I get hit and all of a sudden the most important thing in the world is a divert airfield in a neutral country. I might have removed that from my map during the mission plan, but … I'd want to retrieve it with a few button pushes.*

5. CONCLUSIONS. It is essential to weigh the benefits of cartographic flexibility against pilot workload when designing next-generation cockpit moving-map displays. 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 (Unger and Schopper, 1995). The results of our surveys and interviews underscore this need. The following paragraphs provide specific conclusions regarding each of the map displays. In addition, our original recommendations to the TAMMAC program (as reported in Lohrenz et al., 1997a) are summarised, along with the latest TAMMAC plans to implement these display types (Boeing, 1996). Note that since our conclusions and recommendations for both HAT and Threat Overlays are very similar, we have combined these two topics into a single section.

5.1. *HAT and Threat Overlays.* Based on pilot comments and survey results, HAT appears to be a useful supplement to traditional hypsographic tinting on scanned charts. HAT is particularly effective in conjunction with satellite imagery, due to the lack of absolute altitude information in the image. However, not all participants considered HAT to be a useful addition to electronic charts. Therefore, we recommended in our original report that the TAMMAC program incorporate HAT as a user-selectable feature that can be turned on or off, depending on mission requirements (Lohrenz et al., 1997a). We also recommended that TAMMAC carefully evaluate the colours to be used for HAT overlays, to ensure maximum contrast with base-maps and other overlays.

Most participants also rated threat intervisibility overlays very highly, and many suggested that semi-transparent shaded threat rings with a true threat/terrain masking capability would be the best implementation of this feature. Several participants recognised a need for both threat intervisibility and HAT on the same display, reinforcing the need to choose overlay colours and presentation design carefully. Also, as in the case of the HAT overlay, many pilots preferred monochrome imagery to multi-coloured charts for a base-map to threat overlays, probably because of fewer visual conflicts and better colour contrast in the display.

All of these recommendations have been adopted by the TAMMAC program. The baseline system will include user-selectable HAT and threat overlays, which will be displayed in colours that contrast well with the majority of TAMMAC base-maps (including both grey-scale and coloured charts and imagery). The overlays will be semi-transparent, to permit underlying base-map information to show through. Overlay colours will have default values (and a default level of translucency) pre-installed in the display system, but these parameters may be changed via mission planning through a configurable parameters file loaded on the TAMMAC mission card.

5.2. *CLOS.* The CLOS model appealed most to helicopter pilots, probably due

to its utility in determining terrain masking from threats and targets. Therefore, we recommended that TAMMAC include this feature for helicopters and other aircraft that would benefit from advanced terrain masking capabilities. A CLOS display similar to the planimetric view in our demonstration has been accepted as a baseline TAMMAC requirement and will be incorporated into the system. The display system will calculate and display a CLOS symbol over the current 2-D base-map, when required by the pilot. The profile view (which some of our participants deemed excessive) is not currently planned for the TAMMAC system.

5.3. *Vector Moving-Maps.* Based on pilot responses, vector maps clearly have potential for improving pilot performance. Keeping text upright and selective de-cluttering are clear advantages over current systems. Nearly all pilots called for some combination of manual and automatic de-clutter modes to remove extraneous details. Many studies have linked display complexity to pilot performance, especially in terms of the pilot's ability to absorb and utilize the displayed information (Aretz, 1988; Schons and Waruszewski (1993); Wickens, 1993; Wickens and Carswell, 1995). The last two reports found that visual clutter can disrupt the pilot's visual attention, resulting in greater uncertainty concerning target locations. Or, as one of our participants bluntly put it: *If the map is too cluttered, I just turn it off*! Therefore, a vector-based map display with de-clutter capabilities should be a significant improvement over the current, relatively inflexible, raster map displays.

There are three possible obstacles, however, to implementing vector maps effectively. The first two are Human Factors issues: pilot training and pilot workload. Pilot training will be very important, since the customised quality of vector maps inevitably makes 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. This is closely associated with the potential pitfall of pilot workload, which has been discussed at length in this paper. We recommend that these new vector map displays should incorporate so-called intelligent agents (IA) to assist the pilot by building a default map display based on the mission requirements. The IA might be as simple as a user-selectable list of display options and map scales, or it could be as complicated as a full-blown neural network designed to optimise the map display for any number of different mission configurations, aircraft platforms, and environmental factors.

The third obstacle to implementing vector maps in the cockpit is system capacity, 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. Vector map data in current formats – such as NIMA's Vector Product Format (VPF) – are notoriously slow to update and will not support real-time display (Waruszewski (1993)).

Clearly, vector map technology should be pursued for advanced mission planning and cockpit displays. However, implementation of this technology should be carefully tested to ensure optimal pilot performance and enhanced mission success. In light of these recommendations, TAMMAC announced plans to implement vector map technology as a growth feature, to be incorporated in Navy advanced moving-map systems by 2004 (Boeing, 1996). Additional research must be conducted prior to that milestone, to overcome both the Human Factors and technological hurdles associated with using vector moving-maps in cockpit displays.

5.4. *Final Comments.*

5.4.1. *Colour.* Every pilot in this study had an opinion regarding the use of colour in the demonstrated displays. As a result of their collective reasoning, it is strongly recommend that the colour of any new overlay be considered carefully to ensure that it will be clearly visible against the existing map background and 'competing' overlays. Colours also should be easily interpretable (e.g. enemy vs. friendly; obstacle or not). These recommendations are supported by a substantial amount of research that has been conducted to identify optimum colour combinations for digital map displays (e.g. Merwin and Wickens (1993); Nordwall (1999); Rogers and Spiker (1987); Spiker et al., (1984)). The appropriate use of colour can effectively alert pilots to important map features (e.g. threats or terrain obstructions), whereas poorly chosen colours can obscure features and cause the map to be confusing and ineffective (Nordwall, 1999).

5.4.2. *Preference vs. Performance.* This study only measured pilot and aircrew preferences, not actual performance, with respect to the various map presentations. Other studies have shown significant discrepancies between subjective preference ratings and performance measures. Often, subjects do not prefer the display that actually produced the best performance (e.g. Merwin and Wickens, 1993). Therefore, it is highly recommended that these pilot preference results be used in conjunction with flight performance tests in realistic flight simulators, to ensure optimal pilot performance prior to the development and implementation of any new map display system.

ACKNOWLEDGMENTS

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