A Pilot-Centered Evaluation of Geospatial Data for Proposed Navy Helicopter Moving-Map Displays

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Abstract

Cockpit moving-maps have provided heightened situation awareness to Navy fighter pilots for over ten years. The Navy now plans to install a moving-map into its multifunction MH-60S helicopter, which will perform sea-based missions such as combat search and rescue and mine countermeasures. The authors surveyed 49 Navy helicopter aircrew for their preferences with respect to four map types and six graphic overlays. Participants rated each resultant display for its potential to support naval helicopter missions. Aeronautical charts were rated highest, followed by bathymetric displays, nautical charts, and acoustic imagery. Preferred overlays included flight path, threat rings, historical mine data and seafloor bottom type.

Introduction

Objective

The objective of this project was to demonstrate and evaluate the potential usefulness of a cockpit moving-map system in a multifunction naval helicopter. Specifically, the Navy plans to install a moving-map in its new MH-60S helicopter, which will perform missions such as Anti-Submarine Warfare (ASW), combat search and rescue (CSAR) and mine countermeasures (MCM). Since few pilots had experience with the MH-60S at the time of this evaluation, we targeted pilots of other naval helicopters with similar missions, such as the SH-60, other H-60 variants, and the MH-53, to try to understand how a moving-map system might benefit these missions.

Background

Cockpit moving-maps in the F/A-18 Hornet and AV-8B Harrier aircraft have provided heightened situation awareness to Navy and Marine Corps fighter pilots for over ten years. The Navy's latest moving-map system, known as TAMMAC (Tactical Aircraft Moving-Map Capability), displays terrain elevation, satellite imagery, and scanned aeronautical charts as pilot-selected map modes (Harris 2001). While these products are excellent situation awareness tools for land-based flight, they provide limited information for littoral (shallow-water) operations, such as ASW, CSAR and MCM. We wanted to demonstrate that littoral situation awareness needs could be addressed in a moving-map that displayed appropriate sea-based data products, such as bathymetry (depth of the seafloor), acoustic imagery (sonar images of the seafloor), and scanned nautical charts, in place of the standard land-based data.

This report presents sample moving-map display scenarios shown to helicopter pilots and aircrew during a 2001 Navy training exercise (Kernel Blitz'01) at Camp Pendleton, CA, and summarizes the results of a coincident web-hosted pilot preference survey to evaluate the display scenarios for ASW, CSAR and MCM missions.

Approach

This project consisted of two tasks:

1. Select task-appropriate, sea-based geospatial data and graphical mission overlays for demonstration and evaluation; process these data into standard formats for display in an existing TAMMAC system; and demonstrate the resultant sea-based moving-maps on TAMMAC during Kernel Blitz'01.
2. Conduct a web-hosted survey of ASW and MCM aircrew for their preferences with respect to the selected geospatial data in a simulated moving-map; analyze survey results; and provide recommendations to the Naval Air Systems Command regarding the use of moving-maps for ASW / MCM operations.

Base-maps selected

Based on preliminary interviews with H-60 pilots and sensor operators, four geospatial data types were selected for demonstration and evaluation as potential moving-maps for naval helicopter missions: aeronautical charts, nautical charts, bathymetry, and acoustic imagery (table 1 and figure 1). These are referred to as "base-maps," on which other mission-specific information can be overlaid.

Aeronautical Chart (AC). The chart shown in the survey (figure 1a) was taken from the Joint Operations Graphic-Air (JOG-A) series published by the National Imagery and Mapping Agency (NIMA) as part of the Compressed Arc

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Digitized Raster Graphics (CADRG) database. Numerous aeronautical chart series are available, each providing a different geographic scale and set of map features. Participants were told to assume access to all standard aeronautical series when rating this base-map.

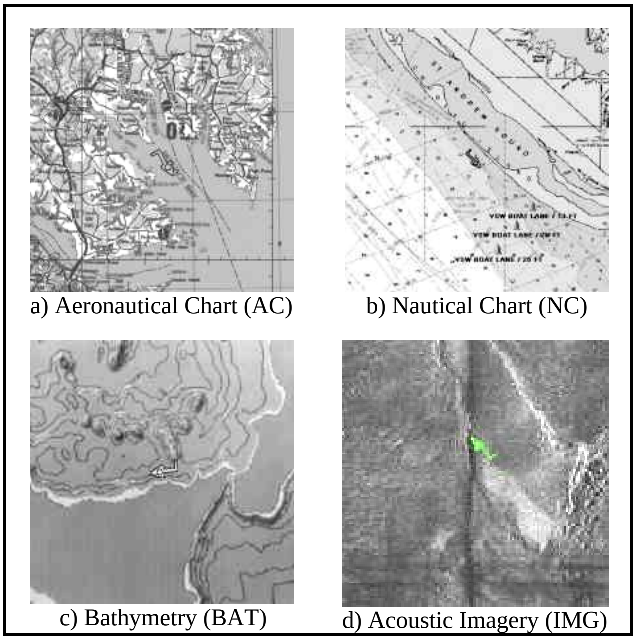


Figure 1. Base-maps selected for evaluation.

Table 1. Relevant characteristics of sample base-maps.

Base-map	Source	Scale	Range
Aeronautical Chart	NIMA CADRG	1:250,000	10 nmi
Nautical Chart	NOAA	1:50,000	2 nmi
Bathymetry	NAVO DBDB-V	1:1,000,000	40 nmi
Acoustic Imagery	AQS-14 sonar	~ 1:1,000	50-75 meters

Nautical Chart (NC). The nautical chart shown in the survey (figure 1b) was published by the National Oceanic and Atmospheric Administration (NOAA). Nautical charts are available at various geographic scales. Participants were told to assume access to all required nautical charts when rating this base-map.

Bathymetry (BAT). The bathymetry sample (figure 1c) was taken from the Digital Bathymetric Data Base-Variable Grid (DBDB-V) distributed by the Naval Oceanographic Office (NAVO). Source data was collected at a spacing of 1 grid point per minute latitude, resampled to a resolution equivalent to a 1:1,000,000 scale chart, and displayed as contour lines of constant depth. Participants were to assume access to various resolutions, depending on how well the area had been surveyed.

Acoustic Imagery (IMG). The acoustic imagery sample (figure 1d) was collected with a towed AQS-14 sonar system. Participants were instructed to assume they would have access to various resolutions of acoustic imagery, depending on which sensors were used to survey the area.

Graphic Overlays Evaluated

Based on preliminary interviews with H-60 aircrew, six sample mission overlays (figure 2) were selected for display on the base-maps: tow fish location, tow fish depth, flight path, sediment bottom type, threat rings, and targets of interest. A seventh overlay (helicopter location) was also shown on every display, but not evaluated in this study. For these evaluations, the helicopter symbol was centered on a north-up display, and the orientation of the symbol indicated helicopter heading. Participants were told to assume that they could switch among north-up, track-up, and heading-up orientations, as well as centered or decentered display formats. The overlays depicted are only mockups (i.e., not actual TAMMAC overlays), but they are similar to existing TAMMAC symbols.

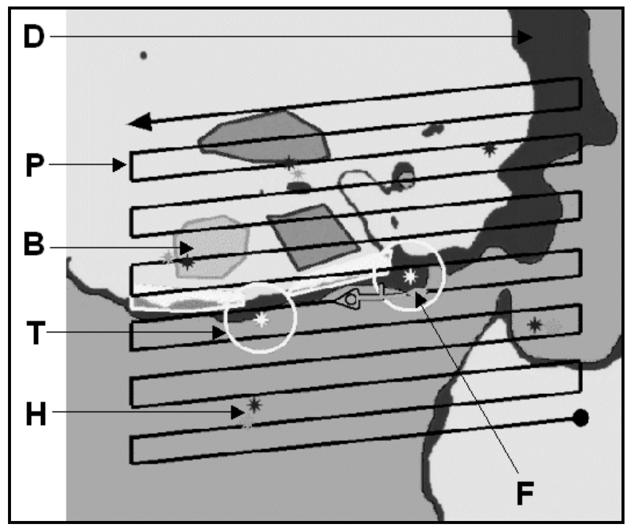


*Figure 2. Overlays evaluated: **D**epth of Tow Fish; Flight **P**ath; Seafloor **B**ottom Type (sand, mud, rock); **T**hreats; **H**istorical Mine-like Contacts; and Tow **F**ish*

Location of Tow Fish (**F** in figure 2). This overlay represents the instrument "fish" towed behind the helicopter to carry sensors. The location and orientation of the symbol on the map would mimic those of the actual fish, based on helicopter flight speed, length and gauge of the cable connecting the fish to the helicopter, and pertinent environmental information (e.g., winds).

Depth of Tow Fish (D). TAMMAC can dynamically display a semi-transparent overlay of "Height above Terrain" generated from a database of terrain elevations. A red-tinted overlay indicates elevations higher than the current aircraft altitude to help pilots avoid Controlled Flight into Terrain accidents. For naval helicopter missions, it would be possible to display a similar overlay of "Depth below

Fish," which could be generated from the bathymetry database and the modeled location and depth of the fish (Trenchard, et al. 2000). Here, the red tint would highlight all depths on the seafloor that are shallower than the modeled depth of the fish. This overlay would be dynamic, changing with fish position, to give the operator a "quick look" at where the fish might be in danger of running into the bottom (figure 3).

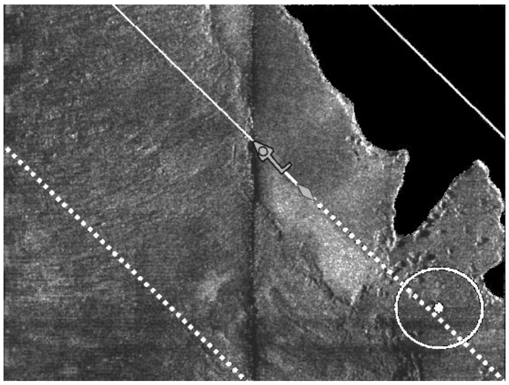


Figure 3. Sample acoustic imagery with flight path, tow-fish location, tow-fish depth, and threat ring graphic overlays.

Flight Path (P). The survey depicted a simple overlay of a planned flight path. Combined with the tow fish location overlay, the flight path might help the sensor operator monitor how closely the sensor is following the intended track, and whether the pilot needs to make any navigational corrections to maintain optimum tracking. Line color and thickness could be varied to improve the visibility of the path against the background map.

Seafloor Bottom Type (B). The example shown in the survey is a semi-transparent overlay indicating seafloor bottom type, which could be generated from an analysis of previously collected acoustic imagery or bottom samples. For example, blue could represent a smooth muddy bottom, green could be mud with a sand veneer, and orange could be a rough hard bottom. This information is traditionally used during mine hunting and sweeping missions to plan optimum search patterns for buried mines (National Research Council 2000). Overlay colors could vary to enhance visibility against the base-map.

Threats (T). TAMMAC can generate and display threat rings around objects and incorporate terrain masking (using the terrain elevation database) to indicate where high areas of terrain might hide a threat or protect one's own-ship. This capability could be exploited for MCM / ASW operations by generating and displaying threat rings around targets of interest and incorporating "bathymetric masking" to indicate where shallower areas of seafloor might hide a potential threat. The color and symbol type could vary to ensure visibility against the base-map.

Historical Data (H). The example in the survey displays fictitious locations of Non-Mine Bottom Objects in the area. Actual object locations could be taken from an historical database maintained by NAVO. The overlay color could vary to ensure visibility against the base-map.

Web-Hosted Survey

Overview. The survey followed the general format of an earlier survey conducted for the Naval Air Systems Command (Lohrenz, et al. 1997): pilots and aircrew were presented with sample maps and questioned about their map requirements and preferences. Like other surveys of its genre (Aleva 1999), the previous study required dedicated interviewers and only reached a limited number of participants who were stationed at a specific location during the interviewing period. The web approach used in the current survey reached more participants in less time, with minimal impact to normal duties.

Pilots and sensor operators were recruited via chain-of-command from Navy wing weapons schools. Encrypted usernames and passwords ensured security and limited participation to authorized users.

The survey consisted of 10 web pages and took about 45 minutes to complete. Participants were instructed to finish each page before moving to the next. After completing each page, they could either continue or exit from the website and return later without having to repeat any pages. All acronyms and terms were defined and easily accessed via a hyperlinked glossary page.

Registration Page. This page consisted of four sections:
1. Contact information (name, rank, email address, etc.);
2. Flight experience (aircraft, crew position, flight hours);
3. Cockpit moving-map experience; and
4. Mission experience (ASW, MCM, CSAR, or other).

Moving-Map Survey Pages. The survey provided pictures and brief descriptions of sample displays, followed by several questions to ascertain how useful each display might be to participants during naval helicopter missions. The survey was designed to be primarily quantitative to facilitate data analysis; qualitative information was captured in comment fields. Prior to starting the survey, participants were told to make several assumptions when evaluating the sample map displays:

- Assume you could switch between "north-up," "track-up," and "heading-up" display orientations.
- Assume a symbol depicting the helicopter's position would always be displayed.
- Assume you could choose between having the helicopter symbol centered in the display or near the bottom of the display ("decentered").
- Assume other standard aircraft tactical symbology would be available as needed.
- Assume you could change some overlay colors (e.g., the helicopter symbol wouldn't have to be green).
- Assume symbol and map colors would be NVG-compatible, if necessary.

The first part of the survey instructed participants to evaluate each of the four base-maps (figure 1) according to the following criteria:

1. Rate the overall usefulness of each map on a scale from 1 (of no use) to 5 (extremely useful);
2. Predict specific uses for each map: general navigation, situation awareness, target location, towed sensor control, or hazard avoidance;
3. Specify required coverage: land, sea, both or neither;
4. Specify preferred display mode: moving-map, static picture, both or neither;
5. Specify required display ranges: 0.5 nmi to 200 nmi.

The second part of the survey told participants to evaluate each of the six mission overlays (figure 2) using questions (1) and (2), above. Participants then were instructed to select and combine any two or more overlays together and evaluate the result using questions (1) and (2) plus a question to evaluate "clutter" (i.e., data content) on a scale from 1 (not enough information) to 5 (much too cluttered), with 3 indicating "just enough information." Users could build and evaluate displays with as many different overlay combinations as they wanted, first with no base-map, and then on each of the four base-maps.

Results

Survey Population

Participants consisted of 49 aircrew from six platforms; the majority (73%) of participants were SH-60B pilots (figure 4). This paper presents the survey results by primary mission (figure 5), rather than by aircraft.

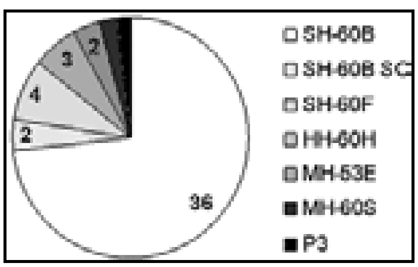


Figure 4. Survey population included 47 pilots and 2 sensor operators (SO) representing six aircraft platforms.

As shown in figure 5, the survey population had considerably more experience with missions not included in this study (47,795 total flight hours) than with ASW (22,201 hrs), CSAR (5,690 hrs) or MCM (3,195 hrs), but participants were instructed to specifically consider their ASW, MCM, and CSAR experience when completing the survey. Therefore, ASW-related results are the most significant in this study. While the MCM (MH-53) population is too small to produce statistically significant results, these MH-53 pilots are experts in MCM and had flown MCM missions almost exclusively, so their answers should shed light on potential contributions of a moving-map to MCM. Likewise, CSAR experience of the SH-60F and HH-60H pilots should help us understand how a moving-map could be designed for CSAR missions, although their populations in this study also were too small to produce statistically significant results.

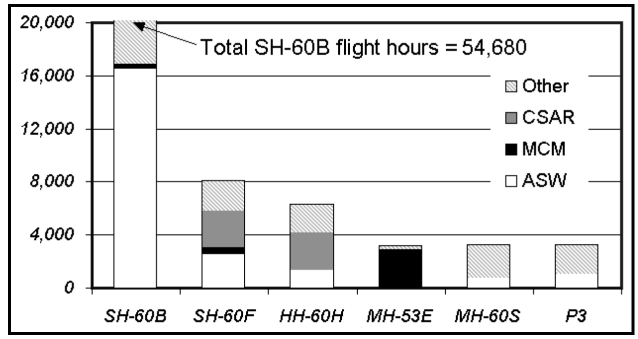


Figure 5. Total flight hours, by mission, for each aircraft.

Evaluation of Base-maps

The mean rating of each base-map was greater than 3 (*of use*) for all missions combined (figure 6): aeronautical charts were rated highest overall (μ = 4.4), followed closely by bathymetry (3.7), nautical charts (3.6), and acoustic imagery (3.1). A series of pair-wise T-tests showed no significant difference between the bathymetry and nautical chart ratings for all missions combined, but showed significant differences (α = 0.025) between all other pairs of ratings (t ranged from 2.3 to 6.2, with 98 degrees of freedom). ASW and CSAR pilots rated all base-maps similarly to the overall means; the MCM pilots rated imagery (4.5) and nautical charts (5.0) much higher than the overall means for those base-maps.

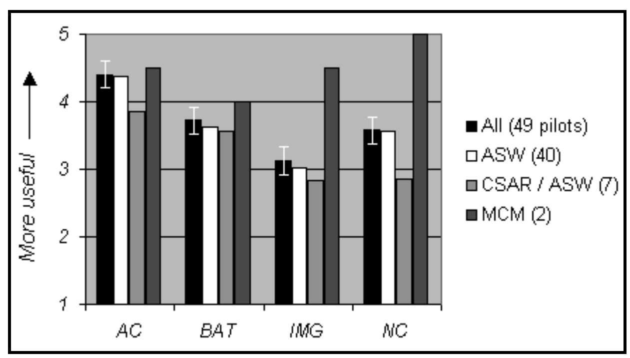


Figure 6. Usefulness ratings of evaluated base-maps, by primary mission (1 = of no use … 5 = extremely useful).

Figure 7 summarizes how participants anticipated using each base-map in the survey. For example, both ASW and CSAR pilots (top two plots) would use aeronautical and nautical chart displays for all suggested tasks except tow-fish control (which is not a typical task during these missions). They would use bathymetry and acoustic imagery for situation awareness and target location. The MCM pilots (bottom plot) would rely on nautical chart displays for all listed tasks; they would use bathymetry and imagery to support target location (e.g., locating mine-like objects) and tow-fish control.

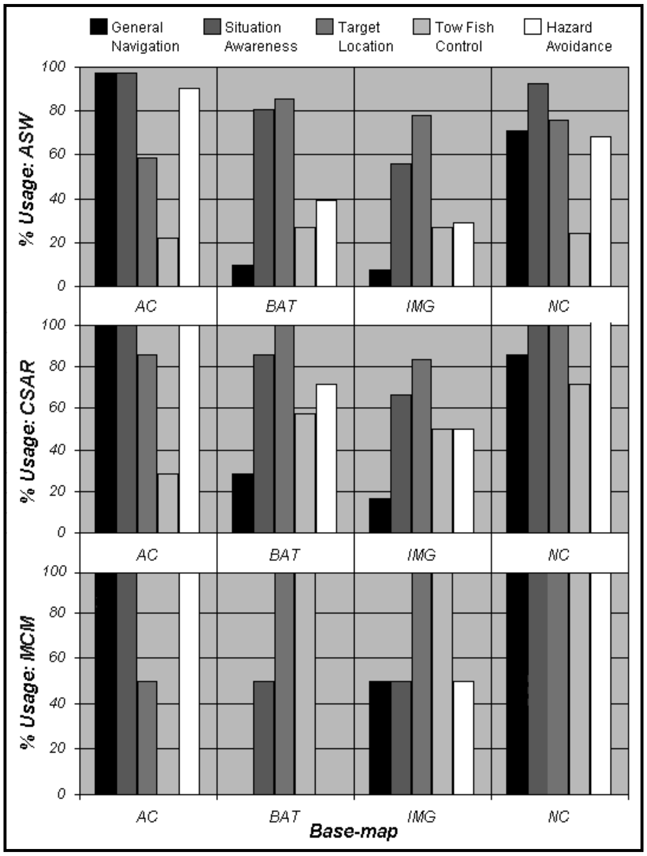


Figure 7. Intended uses for each base-map, by mission.

Evaluation of Overlays

Overlay preferences varied with mission (figure 8). ASW pilots preferred flight **P**ath, **T**hreat rings, **H**istorical data, and **B**ottom type, with scores between 3 (*of use*) and 4 (*of considerable use*). Tow **F**ish location and **D**epth were rated *not very useful* (2). CSAR pilots rated all overlays *of use* (3). MCM pilots rated **F**ish location, flight **P**ath, and **H**istorical data as *extremely useful* (5), with **B**ottom type *of considerable use* (4). In contrast, they rated tow fish **D**epth and **T**hreat rings as *not very useful* (2).

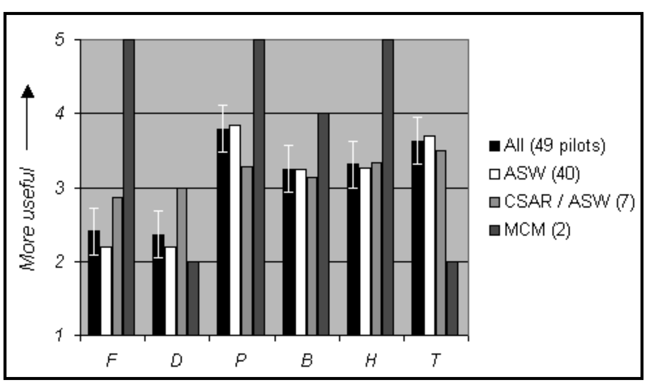


Figure 8. Usefulness ratings of individual overlays, by primary mission (1 = of no use, 5 = extremely useful).

Overlays selected most frequently by participants in the second part of the survey (independent of mission), in order of popularity, were **B**ottom type, flight **P**ath, **T**hreat rings, and **H**istorical data, as shown in figure 9 (inset). The most popular combination of overlays consisted of these four (**PBHT**), followed by a combination of the top three (**PBT**), seen in figure 9 (main graph). The clutter ratings for these two combinations were close to the midpoint (3=just enough information), regardless of the underlying map: clutter ratings ranged from 3.7 (**PBHT** over aeronautical chart) to 3.0 (**PBT** over bathymetry).

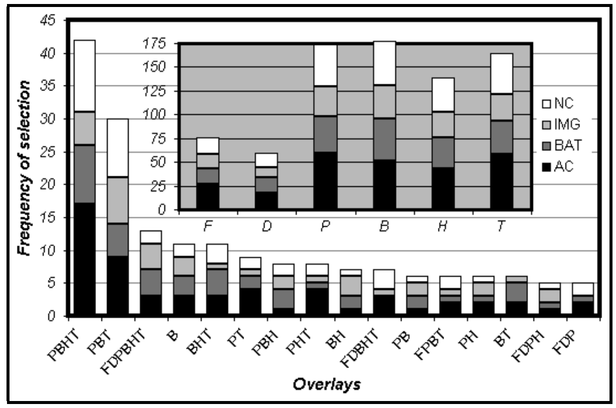


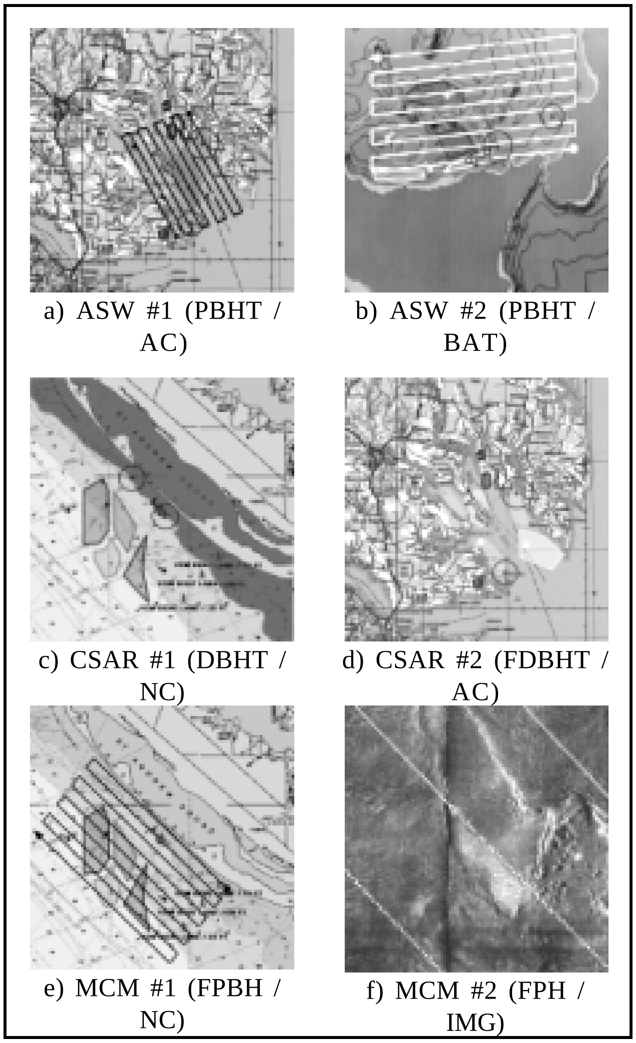
Figure 9. Most frequently selected overlays (inset) and combinations of overlays for each map type (all missions).

Conclusions

The results of this survey indicate that naval helicopter pilots are very interested in the potential of cockpit moving-maps to support littoral operations, and all four map types considered in this survey are worth investigating for these missions. Pilots experienced in ASW, CSAR, and MCM missions all rated the aeronautical chart display very highly, citing its potential for general navigation, improved situational awareness (SA), and avoiding hazards. Most pilots liked the nautical chart display for these tasks as well. It would make sense for helicopters that fly along coastal regions (as most naval helicopters often do) to use the aeronautical chart display for land-based mission segments and the nautical chart display for sea-based segments.

Most pilots liked the bathymetric display, citing improved SA and support for target location. CSAR pilots would also use bathymetry for hazard avoidance, while MCM pilots would use it while monitoring and controlling the tow-fish. Many algorithms already developed for terrain data could readily be applied to bathymetry, including elevation (depth) banding, contour line generation, height-above-threshold (depth-below-threshold) and clear line-of-sight (e.g., to indicate where a target or threat could hide near the seafloor).

Although most ASW pilots only rated acoustic imagery *of use*, both MH-53E (current MCM pilots) and MH-60S (future MCM pilots) rated it very highly, citing target location, hazard avoidance, and towed fish control, suggesting that a moving-map display of acoustic imagery would be especially beneficial to MCM missions.



a) ASW #1 (PBHT / AC) b) ASW #2 (PBHT / BAT)

c) CSAR #1 (DBHT / NC) d) CSAR #2 (FDBHT / AC)

e) MCM #1 (FPBH / NC) f) MCM #2 (FPH / IMG)

Figure 10. Preferred map displays, by mission.

Figure 10 presents the composite displays (base-maps with overlays) most preferred by the pilots in this survey, by mission. These samples depict actual base-maps as they appeared on a TAMMAC system during the Navy Kernel Blitz ’01 exercise. The overlays shown in the survey (and in this figure) are mockups, but are similar to existing mission symbology in TAMMAC. During Kernel Blitz ’01, the authors demonstrated a depth-below-surface overlay (similar to those in figure 10 c, d) on a TAMMAC system by reformatting the gridded bathymetry into the terrain data format expected by TAMMAC (Trenchard, et al. 2000). Currently, the terrain and bathymetric databases do not match well at shorelines, so it would be difficult to display both at one time. Developing algorithms to correlate these databases should be a high priority for littoral missions such as MCM, as the H-60 program office has stated that high resolution ocean bottom mapping and environmental databases would provide the MCM Commander a better view of the battlespace, which will facilitate quicker evaluation and prosecution of threats (Naval Air Systems Command 1999).

Pilot preferences are a good start to an evaluation of moving-map displays, but the ultimate test is mission performance. Unfortunately, subjects often do not prefer the display that actually produced the best performance (e.g., Merwin and Wickens, 1993). We recommend that these preference results be used in conjunction with flight performance tests prior to the development and implementation of any new map display system.

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