

HUMAN FACTORS ISSUES IN THE DEVELOPMENT OF AN ADVANCED DIGITAL MOVING MAP SYSTEM

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The U.S. Navy is currently sponsoring a Tactical Aircraft Moving Map Capability (TAMMAC) program that will provide the standard cockpit digital moving map system for Naval Aviation. The TAMMAC system will be used by a variety of Navy aircraft with differing operational needs and resources and can be tailored to meet aircraft-specific operational requirements. A major design goal of the TAMMAC program is to increase mission effectiveness and situation awareness without further burdening pilot workload. Human factors engineering (HFE) specialists from the government and industry have played an important role in the execution of the TAMMAC program throughout all phases. This paper provides examples of the contributions HFE specialists have made to the program, discusses baseline and planned growth capabilities of the TAMMAC digital map computer, discusses human factors issues regarding these capabilities, and identifies future research needs.

INTRODUCTION

Digital moving map systems are designed to replace cumbersome paper maps in aircraft cockpits. They provide information that is useful for navigation and tactical tasks. In addition, they can provide a means for enhancing mission effectiveness and situation awareness. They allow the pilot to focus his or her attention on navigation tasks with a minimum amount of head-down time. Digital moving map systems integrate information from several sources. When properly designed, they can serve to display information more efficiently such that the pilot should be able to obtain all the information needed to assess a situation and accomplish a task with a quick glance at the display. In addition, digital moving map systems can provide the aircrew with control of the displayed information (Rogers and Spiker, 1998; Unger and Schopper, 1995).

The U.S. Navy is currently sponsoring a Tactical Aircraft Moving Map Capability (TAMMAC) program that will provide the standard cockpit digital moving map system for Naval Aviation. The TAMMAC system consists of a Digital Map Computer (DMC), an Advanced Memory Unit (AMU) for loading of mission planning data and logging of maintenance data, and a High Speed Interface Bus. A schematic overview of the TAMMAC system and its relation to on-board and off-board maintenance systems (AME), mission planning systems (JPMS), mission computer (MC), and avionics systems is shown in Figure 1.

TAMMAC will provide a plan view map display with overlays to enhance mission effectiveness and situation awareness. The TAMMAC system will incorporate a new map loading concept that separates mission from maintenance data using PCMCIA cards, eliminating contention for data between pilots and maintenance personnel. TAMMAC will also provide expanded memory capacity, and video processing throughput over previous airborne digital map systems. In addition, TAMMAC will provide the potential for use as a general aircraft memory and processing resource. TAMMAC will be used by a wide variety of Navy aircraft (e.g., F-18 C/D, F-18 E/F, AV-8B, AH-1Z, UH-1Y, V-22, and CH-60)

with different operational needs. It can be tailored to meet each aircraft's operational requirements by selecting from several available capabilities (Ruffner and Trenchard, 1997, 1998; Williams, 1998).

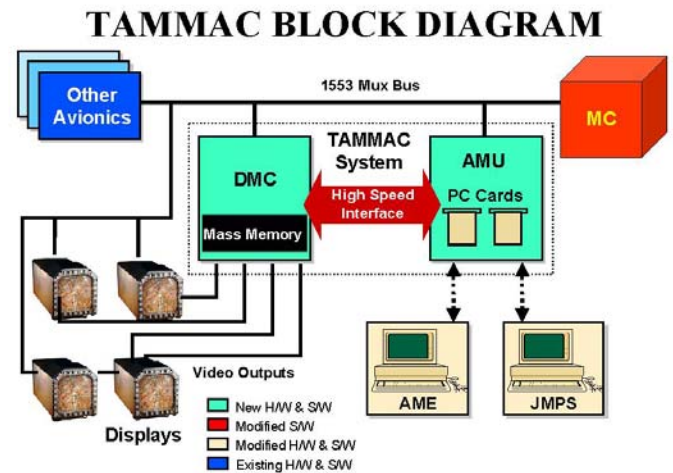


Figure 1. Schematic overview of the TAMMAC system and relationships between onboard avionics and off-board maintenance and mission planning systems.

Human factors engineering (HFE) specialists have played an important role in the specification and development of the TAMMAC system as part of the Integrated Product Team (IPT). This support has included assisting in creating the system design, defining overall system and aircraft-specific baseline performance requirements, updating baseline performance requirements, defining user-interface characteristics, providing HFE input for engineering design trade studies, and designing for system maintainability. In a previous paper (Ruffner and Trenchard, 1997), we discussed the contributions of HFE specialists through the Engineering, Manufacturing, and Development (EMD) phase. Since that time, the TAMMAC system has progressed through

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Preliminary and Critical System Design Reviews and has determined system capabilities.

Ruffner and Trenchard (1997) discussed HFE contributions to the TAMMAC program in the areas of system requirements definition, the operator/maintainer interface, and maintainability design. In addition, Ruffner and Trenchard (1998) discussed issues for enhancing situation awareness with the digital map system. The present paper updates and extends the findings reported in the two previous papers. The objectives of this paper are (1) to summarize contributions of HFE specialists to TAMMAC system development, (2) to summarize the baseline and growth capabilities of the TAMMAC digital map computer, (3) to discuss human factors issues relevant to these capabilities, and (4) to identify future research needs.

FINDINGS

The findings are summarized in four parts: (1) HFE role in requirements identification; (2) baseline and growth map capabilities, (3) relevant human factors issues, and (4) directions for future research.

Identification of System Requirements.

Early in the TAMMAC program, HFE specialists contributed to the identification of user requirements (Lohrenz, et al., 1996; Ruffner and Puccetti, 1996). A study of user preferences for map features and capabilities was conducted during a coordinated effort by the Naval Air Warfare Center Aircraft Division at Patuxent River, MD (NAWC-AD), and the Naval Research Laboratory (NRL) Mapping Sciences Section, Stennis Space Center, MS (Lohrenz, et al., 1996). Investigators from NRL and NAWC-AD presented a series of map display scenarios to Navy and Marine Corps pilots and aircrew, representing a variety of aviation platforms. The investigators interviewed and surveyed the participants for their preferences with respect to map features envisioned for the TAMMAC system.

This study was performed to help verify the various platforms' requirements prior to finalizing TAMMAC system specifications. Features targeted in this study included the following: (1) usefulness of different digital map data types (e.g., scanned charts, satellite imagery, terrain elevation data, non-georeferenced images (data frames)); (2) timing issues (e.g., switching between map modes or between different chart series); (3) map positioning capabilities (e.g., center vs. decenter, north-up vs. track-up, slewing); (4) zooming capabilities (e.g., zoom steps, zoom-in vs. zoom-out); (5) presentation of terrain elevation data (e.g., contour lines, shading, dynamic sun-angle shading, 2-D vs. 3-D); (6) map overlay data (e.g., height above threshold, calculated line-of-sight, threat location and range); and (7) vector map display capabilities (e.g., upright text in track-up mode, de-cluttering, customization of map features).

The study results indicated that pilots found scanned charts, satellite imagery, terrain elevation data and data frames all to be of considerable use in navigating. Current naval moving-map systems only display scanned charts. Pilots

preferred a track-up orientation for most tactical applications, although they rated north-up highly for certain situations, such as preflight checking or waypoint insertion. Helicopter pilots suggested including a heading-up orientation as well. Most pilots preferred continuous over stepwise zoom, provided this function could be performed with a minimum of operator workload. Most pilots preferred a sun-angle shaded representation of terrain elevations, although there was not a strong preference for 2-D vs. 3-D views.

Pilots preferred threat rings over threat spokes and shaded threat areas, since rings obscured the fewest underlying map features. Many pilots desired the capability to display height-above-terrain color overlays (e.g., where yellow shading indicates current aircraft altitude relative to mountainous terrain on the map display, and red shading indicates terrain that is higher than aircraft altitude). Pilots also desired a clear line-of-sight display capability. Finally, the pilots judged that customizable vector maps would provide enhanced flexibility but were concerned about the potential for increased complexity and workload resulting from their use. The Navy used the results from this study to determine and refine baseline aircraft platform performance requirements for the TAMMAC system.

In another requirements study, Ruffner and Puccetti (1996) conducted a survey of existing or developmental digital moving map systems to identify user interface characteristics that should be incorporated into the design of the digital moving map system for the AH-1W helicopter. Based on their findings, Ruffner and Puccetti recommended several capabilities that should be implemented in the AH-1W digital map that had the potential for enhancing mission effectiveness and situation awareness. These included: (1) allowing the pilot to select the contour line interval appropriate for the mission phase; (2) showing areas of masking and intervisibility to depict the likelihood of being observed or detected; (3) allowing north-up, track-up, and heading-up map orientations; (4) allowing centered or decentered location of ownship; and (5) allowing slewing of the map to another selected area.

Baseline and Growth Capabilities

As a result of these studies and input from the various aircraft platforms, the TAMMAC digital map computer incorporated several features as baseline capabilities and others as growth capabilities. These capabilities are described in detail in Williams (1998). TAMMAC digital map system baseline features and capabilities include the following:

- Multiple Display Modes (e.g., chart, terrain elevation, imagery, scanned images)
- Multiple Display Scales (e.g., 1:12,500, 1:5,00,000)
- Selectable Map Orientation/Reference (e.g., north-up, track-up, heading-up)
- Overlay Symbolology (e.g., ownship, waypoints, geographic point and linear features)
- Dual Independent Outputs (e.g., pilot and copilot crew stations)
- Dynamic Display Overlays (e.g., preplanned/pop-up threats, elevation color banding)

- Zooming Capability (e.g., zoom in, zoom out)
- Selectable Contour Lines Intervals (e.g., 50 feet, 100 feet)
- Trend Dots (indicating aircraft position at selectable intervals, e.g., 10, 20, and 30 seconds)

Figure 2 shows an example of the Dynamic Display Overlay baseline feature showing elevation color banding and threat rings overlaid on a scanned aeronautical chart. Using color banding, one color is used to indicate the areas that are above the current aircraft altitude and a second color is used to show the areas that are below the aircraft altitude but above the set clearance altitude. The tinted areas change size as the aircraft changes altitude to convey an indication of safe flying areas. Threats are denoted by the presence of threat symbols. Each threat has an associated ring that identifies the range of its lethality (Williams, 1998).

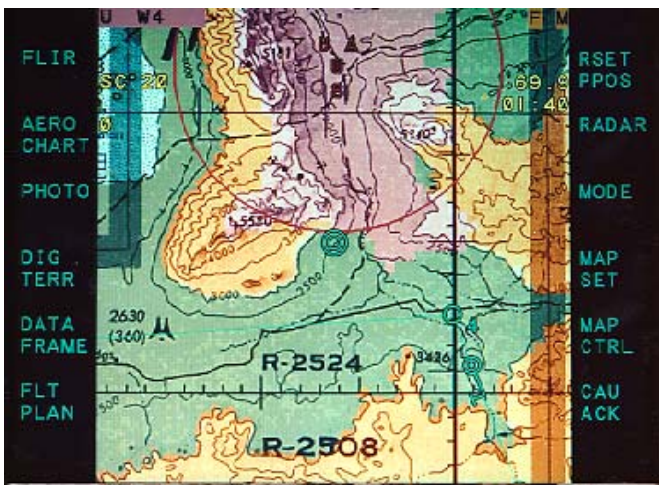


Figure 2. Example of a TAMMAC baseline feature: Dynamic Display Overlay.

Throughout the development of the TAMMAC system, several advanced display features were considered that offer unique capabilities for enhancing mission effectiveness and situation awareness but that will not be implemented immediately. These are included in the TAMMAC “road map.” TAMMAC growth features include:

- Terrain Awareness Warning System (TAWS)
- Declutterable Vector Map
- 3-D Perspective View
- Dynamic Threat Rings
- Picture-in Picture Inset Window
- In-flight Mission Re-planning
- Digital Video
- Real-time Imagery in the Cockpit
- Three Independent Channels

In fact, a TAWS prototype is already under development and is scheduled to be the first upgrade to the TAMMAC system for at least one platform (F/A-18).

In addition, the TAMMAC system will be able to incorporate emerging databases from the National Imagery and Mapping Agency (NIMA), including Digital Aeronautical Flight Information File (DAFIF), Vector Product Format (VPF) databases (e.g., Vector Map (VMAP), illustrated in Figure 3), Digital Nautical Chart (DNC), Digital Flight Information Publication (DFLIP), Vector Vertical Obstruction Database (VVOD), Feature Foundation Data (FFD), and Shuttle Radar Topography Mapper (SRTM) data (e.g., higher accuracy Digital Terrain Elevation Data [DTED] Levels 1 and 2).

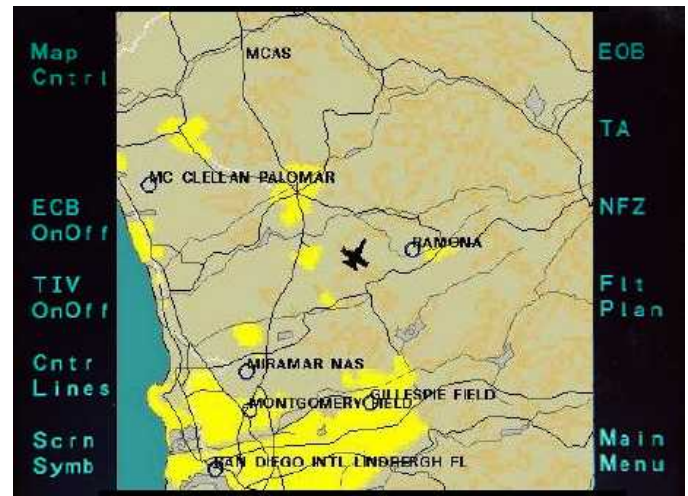


Figure 3. Example of a TAMMAC growth feature: Declutterable Vector Map

Figure 4 illustrates an example of the picture-in-picture growth feature, which could incorporate real-time imagery in the cockpit. This feature would allow the pilot to have a smaller picture within the current map presentation. This picture could be used to show a different map mode (e.g. data frame, imagery, terrain elevation).

Human Factors Issues

As a result of a review of relevant research on digital moving map system design and utilization in support of the TAMMAC program, several HFE issues emerge that need to be addressed to improve the contribution of the TAMMAC system to enhancing mission effectiveness and situation awareness (Ruffner and Trenchard, 1998). These issues include:

- Which TAMMAC road map growth capabilities (e.g., vector maps, real-time imagery) offer the most potential for enhancing mission effectiveness and situation awareness and warrant future funding and adaptation?
- How should the contribution of the TAMMAC baseline and growth capabilities to enhancing mission effectiveness and situation awareness and their effect on pilot workload be evaluated?

- How can the capabilities in the TAMMAC digital map computer be best used to support the pilot's mission and situation awareness information needs while reducing pilot workload?
- How can the capabilities in the TAMMAC digital map computer be best used to support the pilot's global and local situation awareness information needs?
- What is the most appropriate way to measure situation awareness for the TAMMAC system so that the aircrew's global and local situation awareness information needs are adequately reflected?
- How can human factors principles and guidelines be used to recommend the selection and implementation of TAMMAC capabilities to maximize pilot effectiveness?

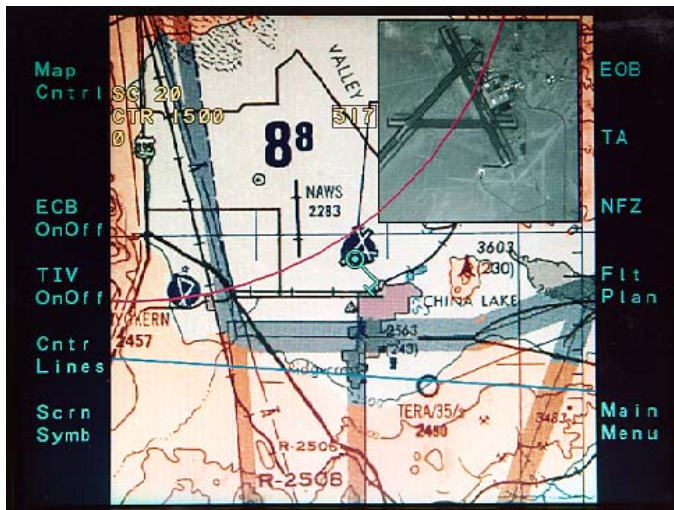


Figure 4. Example of a TAMMAC growth feature: Picture-in-picture window showing image of the area of interest in the inset window.

Future Research Needs

The existing TAMMAC baseline and growth requirements and capabilities were validated based on user preferences from demonstrations of candidate moving map capabilities (e.g., Lohrenz et al., 1996; Lohrenz et al., 1997). However, research suggests that preference and performance data are not always consistent (Wickens and Andre, 1994).

While serving as an important source of information to guide the design and selection of digital moving map system features and capabilities, preference data need to be validated using part-task or full-task simulation scenarios with realistic task loadings and appropriate performance measures that are sensitive to critical digital moving map system parameters. Specifically, advanced capabilities planned for TAMMAC, such as vector maps and real-time imagery, need to be evaluated in user-performance simulations.

Also, the utility and effectiveness of incorporating standard symbology (MIL-STD-2525) in both ground-based mission planning and in airborne moving map displays should be evaluated to ensure proper implementation and avoid confusion with platform-specific symbology. The results of these simulations could then be used to recommend the most effective suite of map functions and capabilities.

DISCUSSION

The TAMMAC system will have a variety of features and capabilities that have the potential for achieving the goal of enhancing aircrew mission effectiveness and situation awareness without further burdening pilot workload. The extent to which this potential can be realized will depend largely on the successful application of previous digital moving map system research findings and the thoughtful tailoring of HFE guidelines to the design and selection of digital map system capabilities.

The TAMMAC system provides a great deal of flexibility to the aircrew for selecting features and capabilities to support their specific aircraft mission. Care must be exercised that this flexibility does not become a contributor to overall aircrew workload. Accordingly, more specific guidelines need to be developed and validated for designing and selecting digital map system features to enhance mission effectiveness and situation awareness for different aircraft platforms. Developing and validating these guidelines poses a significant challenge for the HFE aviation community.

CONCLUSION

In conclusion, the TAMMAC program successfully brought human factors engineering expertise to bear for the design of a common digital moving map solution to multiple aircraft needs. This program has provided an excellent opportunity for HFE specialists from the government and contractor organizations to combine their skills with those of systems, avionics, and mechanical engineers toward the integrated development of a modern avionics system which can serve as a valuable situation awareness and navigation tool. In addition, the TAMMAC program has provided the opportunity for HFE specialists to demonstrate their abilities to be active and effective participants in the systems engineering process.

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