STRATEGIC AVIONICS BATTLE-MANAGEMENT EVALUATION AND RESEARCH

(SABER)

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ABSTRACT

This paper describes the design criteria, development, and research program associated with a new, multiplace crew system simulation facility. The Strategic Avionics Battle-Management Evaluation and Research (SABER) facility and associated exploratory development program were established in order to support the resolution of technology base issues in the areas of intelligence fusion and analysis, command and control, adaptive mission planning, force management, and force element execution. The SABER facility consists of four advanced conceptual crew stations and a master experimenter station. SABER supports man-in-the-loop simulation experiments in which the dependent measures are associated with crew systems performance, crew workload, task allocation, dynamic crew tasking, tailored logic, crew situational assessment, and the evaluation of information portrayal schema.

INTRODUCTION

The strategic bomber has been a major component of US warfighting capability since WW II. Its continued importance is supported by existing and evolving Air Force missions and by the changing nature of the enemy threat to be countered. During the past two decades, the Human Engineering Division of the Armstrong Aerospace Medical Research Laboratory (AAMRL) has provided research and development support in human factors to virtually every bomber-related system acquisition/upgrade activity undertaken by the Air Force.

Lt Gen McCarthy (1987) described the Strategic Air Command (SAC) mission areas, as projected into the 21st century. The SAC weapon systems include standoff and penetrating bombers, air- and ground-launched missiles, and reconnaissance platforms. These are supported by ground-based and airborne command and control centers and a fleet of tanker aircraft. SAC's mission areas include strategic offense and conventional warfighting.

Ulsamer (1987) stated that "one of the most formidable and weighty technological challenges confronting the US is how to neutralize the burgeoning number of RTs [relocatable targets] in the Soviet Union in case of war." He reported that a Defense Department RT master plan was being prepared to lay the groundwork for the development of the required sensors, command/control/communications/intelligence (C^3I) architectures, and force structure required "to put RTs at risk." He went on to report that an RT Capability Program had been established to "upgrade the sensor and avionics systems for strategic bombers."

The Commander of SAC, General Chain (1987), in reviewing SAC's current and evolving mission and capabilities, stated that:

> "with regard to the manned bomber, I consider the human presence in the manned bomber crucial to detecting, identifying, and attacking the growing number of Soviet relocatable targets."

Chain defined RTs as "warfighting assets that could disperse and relocate, primarily to avoid detection and destruction." He continued by emphasizing that:

> "The capability of the manned bomber to penetrate enemy airspace and search out and destroy relocatable targets, particularly the highly threatening mobile ICBMs [intercontinental ballistic missiles], is essential."

Thus, a major, evolving, SAC mission, finding and striking RTs, relies heavily on the flexibility provided by the human component of the bomber weapon system. Advanced sensors and operator aiding subsystems are seen as supporting this flexibility. Sweetman (1987) pointed out that:

> "Unlike a missile, the bomber has a crew in the loop up to the moment of attack. In the B-52, thermal or electro-optical imagers permit the assessment of damage from previous strikes. In future bombers, imaging radar will provide positive, all-weather stand-off target recognition"

Seares (1987) wrote that "despite having a 'man-in-the-loop,' this most flexible leg of our strategic Triad currently flies highly structured missions that are preprogrammed for each aircraft's offensive avionics system (OAS)" and that "once the bomber is airborne, we lack the flexibility we need to change the mission." Bomber flexibility may well be a highly desireable attribute in the course of the RT mission. An adaptive mission planning system (AMPS) capability, as described by Sears (1987), may be required since "enemy defenses and enemy targets will relocate and new directions from higher headquarters must be processed." Seares pointed out that "a viable on-board AMPS, if combined with evolutionary improvements to aircraft sensors and command, control, communications (C^3) systems, would improve the weapon system's capability to deal with these eventualities." He stressed that "the fully mature bomber AMPS would provide a battle management system that could respond adaptively to real-time changes in guidance, direction, threat, or aircraft status." Seares suggested that "the AMPS rule tables could be revised and refined as new sensors, communications systems, and computer technologies evolve." He concluded his discussion of the bomber application by writing that:

> "The bomber's inherent adaptability in conflict, coupled with its enhanced capability to avoid or destroy threats during the mission, would mean more weapons on target before the aircraft reached its poststrike base. In short, the on-board replanning capability of the AMPS would represent an important force multiplier in that the manned bomber would adapt better to the 'fog of war' and hence would realize the full war-fighting potential of the 'man-in-the-loop.' "

As can be seen from these sources, the manned bomber, providing unparalleled flexibility, will continue to play a major role in national defense, will be tasked to meet more complex missions (e. g., RTs), and will be enhanced with advanced sensors, C^3I systems, and other avionics capabilities (including expert systems) in order to meet these challanges. The human factors issues inherent in this probable trend are manifold.

The Human Systems Division (HSD), AAMRL's parent command, was identified in the RT Capability advanced development program's management documentation as the "associate product division for human factors requirements and analysis." As the performing agency, AAMRL is to establish a crew systems technology program to quantify crew workload and operator performance in the context of RT missions. Further, as a result of 1987 RT Capability Program planning activities, AAMRL's Strategic Avionics Battle-Management Evaluation and Research (SABER) advanced conceptual bomber crew system simulation facility was selected as the Program's crew station simulation facility for use in proof-of-concept demonstrations.

SABER

The SABER simulation facility and associated research program were established to support SAC in the development of advanced bomber capabilities. SABER is a key part of an exploratory development effort directed to investigate the human factors implications inherent in the application of advanced sensors, advanced signal and data processing (including artificial intelligence, AI) architectures, advanced man-machine interface (MMI) technologies, and advanced C^3I systems to the manned bomber. SABER is an Air Force owned and operated research facility that supports the application of the Cockpit Automation Technology (CAT) process. The CAT methodology and toolset address four major steps in the crew station design process:

1. Mission Characterization
2. Function Allocation
3. Integration and Design
4. Validation

CAT is an HSD-managed advanced development project directed to establishing and validating through demonstration a structured human factors crew station design methodology. (CAT is described in Aretz [1984] and McNeese, et al., [1985], while more traditional crew station development/refinement methods are presented in Kuperman, et al., [1983].)

The SABER Facility

The SABER simulation facility consists of four, integrated, crew positions (nominally termed offensive, defensive, and flight [aircraft commander and pilot]) and an experimenter's station. The aircraft flight model, weapon flyout models, and threat beddown are hosted on a VAX 11/785 which also records experimental data. Crew station control inputs are monitored by a high speed multiprocessor. Sixteen graphics processors generate the display formats called for at each crew position. These formats include combinations of graphics, alphanumerics, and bit-mapped imagery. A video switcher directs the graphics processors output to the required crew station display surface. A seventeenth graphics processor generates an out-the-window visual scene. The SABER simulation facility is located in a TEMPEST environment.

Rapid Prototyping

A commercial graphics design software package has been applied in support of the SABER crew system design activity. One of the graphics processors, hosting this software, is used as a rapid prototyping station. The human factors engineer/crew station designer employs this station to design, modify, and refine display format concepts. Rapid iteration/change capability, together with both softcopy and hardcopy (print and transparency) outputs, has supported a high level of interaction with operational command personnel (from the SAC liaison offices at Wright-Patterson Air Force Base). The finished display format concepts are then furnished to graphics processor programers for coding as dynamic displays.

The SABER Crew Station

Each of the four SABER crew stations follows the same basic design. Four, color multipurpose displays (MPDs) are arranged in a "T" configuration. The design philosophy, in terms of the probable use of the MPD arrangement, was:

MPD1 (left):	Status Information
MPD2 (center):	Current Action
MPD3 (right):	Last Action/Reference
MPD4 (lower):	Situational Awareness

Each MPD is surrounded by 20 bezel-mounted pushbuttons whose functions are identified by labels on the MPD. An integrated keyboard (IKB), supporting a tree structure switching logic like that applied in the B-1B, is to the right of the lower MPD. A multifunction keyboard (MFK) is located to the left of MPD4. When the operator selects a "display of interest" (DOI), the programmable buttons of the MFK take on the functionality of the bezel buttons for the DOI. Above the MFK are five master mode selection buttons. The SABER master modes are: cruise, navigation, attack, defense, and take off/landing. (These same master modes can also be accessed from every primary display format through the lower bezel switches.) Selection of a master mode changes every display format at that station to an operator pre-selected configuration.

The "scratch pad" display, located above the master mode buttons, has ten panel mounted pushbuttons associated with it, a row of five above and below. The scratch pad displays the labels for the functionality of these switches. Scratch pad functionality is intended to allow the crewman quick access to frequently used or time critical weapon system functions. For example, the defense station provides for expending countermeasures while the offensive station allows for immediate selection of navigation update mode.

The two aft crew stations differ somewhat from each other in the addition of special panel-mounted controls. The defensive station contains the keyboard, printer, and dedicated display that would be associated with a satellite communications system while the offensive station has hardware control panels for weapons jettison and coded switch setting. In both stations, these interfaces are located to the left of the IKB.

The flight or forward stations follow the basic SABER crew station layout. They are somewhat lower in profile to support-out-the window visibility. They also include force stick, throttles, and rudder pedal for flight control. Every crew station and the experimenter's station is interconnected through an intercommunications system.

Control Alternatives/Priorities

Since SABER is an exploratory development facility, provision was made for a greater variety of control mechanizations than would be found in an actual weapon system. Six control methods have been integrated into the simulator (listed in a rough prioritization order):

1. Tracking Handle
2. MFK
3. Bezel Buttons
4. Touch Screens
5. IKB
6. Speech Recognition

The SABER tracking handle, TH, serves two distinct functions: target designation cursor movement and DOI selection and control. Invoking the DOI function allows the operator to select any one of the four MPDs as the DOI. The TH slewing functions then allow the operator to select any of the functions associated with the bezel buttons. Use of the TH as a controller is similar to the "hands on stick and throttle" approach followed in modern air-to-air fighter crew systems. MFK and IKB control functions were identified above. Depressing bezel buttons invokes the control function of the associated MPD label. Each of the MPDs has a touch control panel overlayed on the display surface. Touching the bezel button label invokes that function. Speech recognition (i. e., "voice control") is reserved for non-mission-critical functions (e. g., changing a map scale).

Primary Display Formats

Interaction with every major information source/aircraft subsystem takes place at the SABER MMI, through one or more display format pages. Major subsystems include stores management, radar, action point, horizontal/tactical situation, etc. The highest level of interaction takes place at the "primary format" page. One or more secondary pages allow more specific interaction or control of subsystem modes. The radar subsystem, for example, has five secondary formats: real beam, HRGM (high resolution ground map), beacon, sea search, and ISAR (inverse synthetic aperture radar). On the primary radar format, these five modes are addressed through the five button labels appearing across the top of the MPD.

The left side bezel buttons associated with each display format are reserved for system-level functions. The top button label is a warnings/cautions/advisories indicator which, when invoked, allows a quick look at the system/subsystem problem. A subsystems (SUBS) label allows the operator to bring up any information source/subsystem on any MPD. Invoking SUBS brings up a menu of the subsystems normally associated with the station. (The operator may use a secondary screen to his SUBS page to bring up the SUBS menu associated with any other crew position.) The bottom button is always reserved for built-in test, BIT.

Primary Data Items

The SABER display formats present critical information on every primary display format. Aircraft heading, vertical velocity indication, and altitude appear as moving tapes. Additional primary display items (PDIs) appear as alphanumeric information. PDIs include: time to go to reach next destination/turnpoint, sequence number, expected time of arrival (including early/late flag), aircraft location (latitude/longitude), safe and in range (missile cue), distance to next destination point, weapon "away" indication, true heading, ground speed, and selected weapon identification.

Imaging Sensor Simulation

SABER includes the presentation of (non-real time) sensor imagery. The primary sensor (mode) integrated in SABER is HRGM. Defense Mapping Agency ditital terrain elevation and feature analysis data is preprocessed to produce static images that resemble syntheic aperture radar imagery. These images are prepared, in multiple resolution/patch size versions, for every fix taking point and target. They are stored on disk and recalled for display as bit mapped gray scale images when the operator initiates a HRGM of a specific, preplanned point. Electro-optical sensor imagery, such as from a forward looking infrared sensor, is digitized from video recordings (using a time base corrector/frame grabber) and also stored on digital disk. The static frames that are available for display to the operator correspond to the type of presentation that might result from the use of an automatic target cuer between the sensor and display in the imaging chain.

Reference Imagery

Annotated color maps are digitized off-line and stored on disk for operator recall. Aerial photographs, such as from reconnaissance sensors, are also incorporated in this same way.

Experimenter's Station

The experimenter's station consists of two consoles. The first resembles one of the aft SABER crew positions. It may be used (for subject training, monitoring simulation progress, or briefing/demonstration purposes) to repeat the displays being used at any selected crew position. (It is, in fact, fully functional and could be employed as a fifth crew station.)

The second major element of the station is the simulation control console. Simulator power, intercomm, sound generation, and NWTB data collection are all integrated into this position.

The functions of the SABER experimenter's station are to:

1. Monitor simulation progress.
2. Control the insertion of subsystem malfunctions/battle damage,
3. Perform quality assurance on data being collected,
4. Support subject briefing/debriefing,
5. Support "role play" of unoccupied crew positions.

Data Collection

Workload measurement and operator performance measures are fully integrated into the SABER simulation facility. Every control input (e. g., switch activation) can be recorded for analysis and/or mission replay. Preplanned data analyses can support "quick look" analyses and provide data for subject debriefing. The AAMRL NWTB is used to capture electrophysiological correlates of crewmember workload. Subjective workload data may be collected and recorded in a nonintrusive manner.

SABER RESEARCH ACTIVITIES

Mission Characterization

A multi-year, contracted effort led to the development of a generic RT mission scenario document. The scenario is "technology free" in that no avionics suite is assumed. It is "requirements driven" in that targets, threats, routing, weapons, tactics, etc., were established in close cooperation with SAC. The scenario addresses the decision-making aspects of mission execution as described in Kuperman and Kulwicki (1984).

Function Allocation

Two contracted efforts have been completed which provided proof-of-concept demonstrations of mission decomposition/ function allocation tools. In the first, a network modeling approach was employed while the second effort was developed using frame-based, AI techniques.

Situational Awareness

Crew situational awareness is seen as a critical component in the successful accomplishment of the evolving SAC missions. The AAMRL has performed joint contracted research with the Avionics Laboratory of the Air Force Wright Aeronautical Laboratories in the area of advanced crew station display concepts and technologies. One recent effort, the Panoramic Cockpit Controls and and Displays System (PCCADS), included the development and application of a situational awareness rating scale technique (Arbak, et al., 1987).

The design and assessment of mission-level and tactical situation display formats is emphasized in the information protrayal portion of the SABER research activity. SABER includes capabilities for employing annotated navigation charts (i.e., the current SAC combat mission folder) in both hard- and softcopy (e. g., digitized) formats. The annotations include steering, target, and threat information. In addition, SABER provides for two more advanced levels of horizontal situation display (HSD). A graphics-only display format presents the planned (and replanned/alternate) route, target and fix-taking point locations, and pop-up information windows. A second HSD version, termed the tactical situation display, TSD, adds a digital map underlay. In both cases North Up/Track Up presentation formats are operator selectable as is the scale of the situation display. Research performed in SABER in this area was reported by Marshak, et al. (1987).

Workload Assessment

Contracted research is underway at the Human Factors Engineering Center of the Virginia Polytechnic Institute and State University (HFEC/VPI&SU) which is investigating the relationship between (mental) workload and demands on short term memory. The fundamental hypothesis of this multi-year research activity is that, in the case of highly automated MMIs, crew workload may be equatable with demands on short term memory. This research is expected to impact both the measurement of workload and the design criteria applicable to information portrayal in highly automated systems.

MMI Assessment

In-house research is in progress directed to the development of an assessment tool applicable to MMIs associated with expert systems. The expert system assessment/validation literature was surveyed to identify significant assessment parameters. Eighteen criteria were identified. Subject matter experts (SMEs) were solicited to rate the importance of each criterion for expert systems in general and in the context of each of three "miniature" application scenarios (intelligence analysis, C^2, and AMPS). Analysis of these ratings is currently underway.

Workload Measurement

The AAMRL-developed Neurophysiological Workload Test Battery (NWTB), as described in Wilson, et al. (1987), has been modified for integration into SABER. The SABER version of NWTB supports the collection of heart rate, eyeblink, and auditory evoked cortical event-related potential (ERP) data from two subjects, simultaneously, over a several hour, part-mission simulation experiment. Semi-automated collection of Subjective Workload Assessment Technique (SWAT) data (Reid et al., 1982) has also be integrated into SABER in order to assess individual crew member's perception of workload associated with selected mission-critical events/tasks.

Information Management

The HFEC/VPI&SU has completed an analysis of a generic RT mission from the standpoint of crew information requirements and system information management functions. The scenario emphasized crew decision making under uncertain, incomplete, or erroneous mission information. The results of this research are being published as an AAMRL technical report.

CONCLUSIONS

SABER provides the Air Force with a flexible research and development capability, well-suited to the complex operational requirements associated with current and evolving strategic missions. The utility of the facility has been demonstraed, for example, in the demonstration of touch control concepts, as an advanced MMI option for the B-1B. Dedicated, panel-mounted controls were prototyped in software and displayed on MPD1. The remainder of the SABER offensive station resembled the B-1B's Offensive System Operators station. Touch was used to control subsystems (e. g., stores and radar). The results of control inputs were displayed, in B-1B formats, on the remaining MPDs.

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