Dr. Daniel C. McFarlane and Paul H. Berger

The HSI Implications of a New Naval Combat System Alerting Technology Based on Negotiation-Based Coordination: The HAIL Technology

ABSTRACT

The Human Alerting and Interruption Logistics (HAIL) technology is introduced into the Aegis surface warfare platform to increase warfighter capability to deal with high alerting rates. A spiral development and evaluation process investigated the implications of this new technology on operator performance. The Aegis-HAIL application, as compared to the B/L-7/1 alert processing, increased human capacity for processing critical alerts in four ways: (1) reroute non-critical alerts to other display areas, (2) provide negotiation-based control to enable operator-centric navigation of information, (3) providing only critical alerts improved alert SA, and (4) eased transition and recovery back to the original task.

INTRODUCTION

Successful U.S. naval operations depend on surface ship crews taking decisive actions under stress, and this requires good situational awareness (SA). Alert mechanisms deliver a significant portion of this information. However, the volume of alerts has grown exponentially, overwhelming some operators and undermining their ability to maintain SA. Current human alerting mechanisms in surface ship Command and Control (C2) systems are insufficient for future mission requirements. They must be replaced or the Next Navy will not be "fully mission capable."

Human Alerting and Interruption Logistics (HAIL) is a new alerting technology being developed to improve the warfighter's ability to maintain SA during high rates of alerting [McFarlane, 2002; McFarlane and Latorella, 2002]. HAIL is a platform-independent, open architecture software component that delivers human-centric alert mediation support. HAIL capabilities are realized through improvements to the user interface (UI) that improve the operator's performance in processing alerts and through the reduction in interruptions during complex, stressful tactical situations.

Lockheed Martin Advanced Technology Laboratory (LM ATL) is leading the development team that includes: Lockheed Martin Maritime Systems and Sensors (LM MS2), Computer Sciences Corporation (CSC), Basic Commerce & Industries (BCI), and the Naval Research Laboratory (NRL).

BACKGROUND

Automated notification systems can perform the constant monitoring required to generate alerts, but these alerts often interrupt other activities. Research has shown that people do not perform sustained, simultaneous, multi-channel sampling well; however, they have great capacity to manage concurrent activities when given specific kinds of interface support [McFarlane and Latorella 2002]. An alert-based information stream can deliver tasks and information that have the potential to help operators perform effectively. This informa-

Report Documentation Page			Form Approved OMB No. 0704-0188
Public reporting burden for the collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington Headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington VA 22202-4302. Respondents should be aware that notwithstanding any other provision of law, no person shall be subject to a penalty for failing to comply with a collection of information if it does not display a currently valid OMB control number.			
1. REPORT DATE **MAY 2004**	2. REPORT TYPE		3. DATES COVERED **00-05-2004 to 00-05-2004**
4. TITLE AND SUBTITLE **The HSI Implications of a New Naval Combat System Alerting Technology Based on Negotiation-Based Coordination: The HAIL Technology**			5a. CONTRACT NUMBER 5b. GRANT NUMBER 5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)			5d. PROJECT NUMBER 5e. TASK NUMBER 5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **Lockheed-Martin Advanced Technology Laboratories,3 Executive Campus, 6th Floor,Cherry Hill,NJ,08002**			8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)			10. SPONSOR/MONITOR’S ACRONYM(S) 11. SPONSOR/MONITOR’S REPORT NUMBER(S)
12. DISTRIBUTION/AVAILABILITY STATEMENT **Approved for public release; distribution unlimited**			
13. SUPPLEMENTARY NOTES **The original document contains color images.**			
14. ABSTRACT			
15. SUBJECT TERMS			

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT **unclassified**	b. ABSTRACT **unclassified**	c. THIS PAGE **unclassified**		**8**	

tion source can support the capability to (a) constantly monitor their dynamically changing information environments, (b) collaborate and communicate with other people in the system, and (c) supervise background autonomous services.

People have a cognitive limitation in dealing with alert-based interruptions. Without support for coordinating interruptions, they fail at Situational Awareness (SA) and their decision quality drops. The Identification Supervisor (IDS) operator for the Aegis Weapon System is a good example. The IDS is responsible for determining and maintaining the accuracy of the identity of hundreds of contacts (aircraft and other vehicular tracks) visible to the ship's radar. The frequency of alerts was determined during the ASCIET (All Services Combat Identification Evaluation Team 1996). The IDS operators received alerts at an average sustained frequency of one every 11.5 seconds. The overall alert frequency for IDS has decreased since 1996, but there has been net increase in the workload for alert-based information and tasks. Aegis is currently "fully mission capable," however it will not continue to be without improved alerting technology.

The IDS submode is a primary candidate for HAIL technology. HAIL will: (1) reduce the number of interruptions, (2) improve the operators' SA for each alert, (3) improve control of alerts requiring action responses, (4) improve SA for element status information, and (5) assist in returning to the operator's original task [NSWCDD 2003]. Figure 1 depicts a comparison of today's alert processing versus using the HAIL technology. Figure 2 shows the specific processing path that the current Aegis operator would take to process alerts.

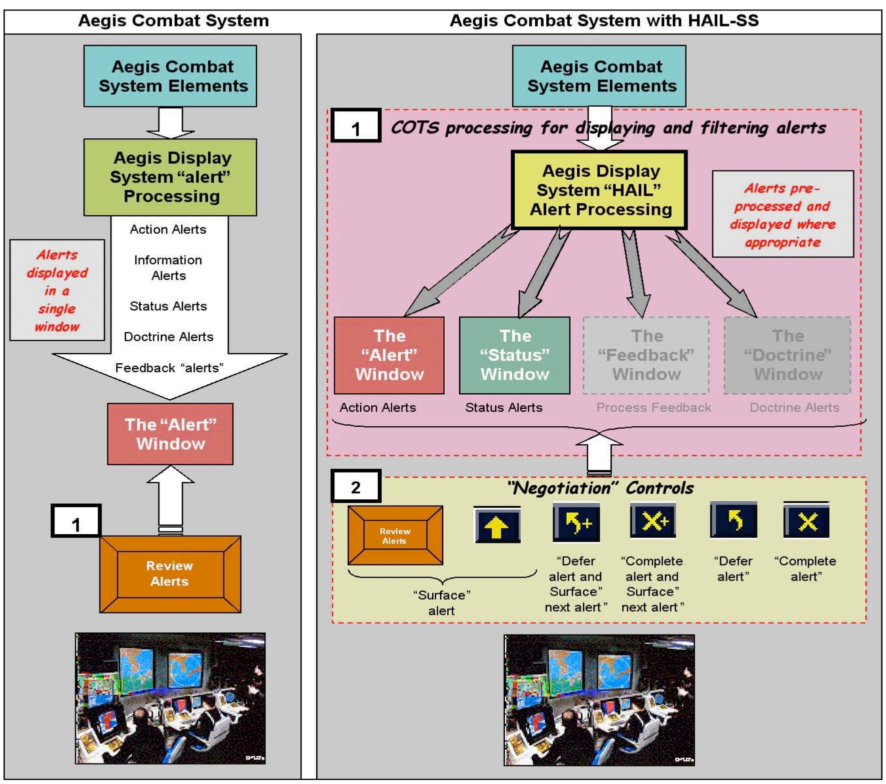

FIGURE 1. The Current Aegis Alerting System versus the HAIL-Aegis Alerting System.

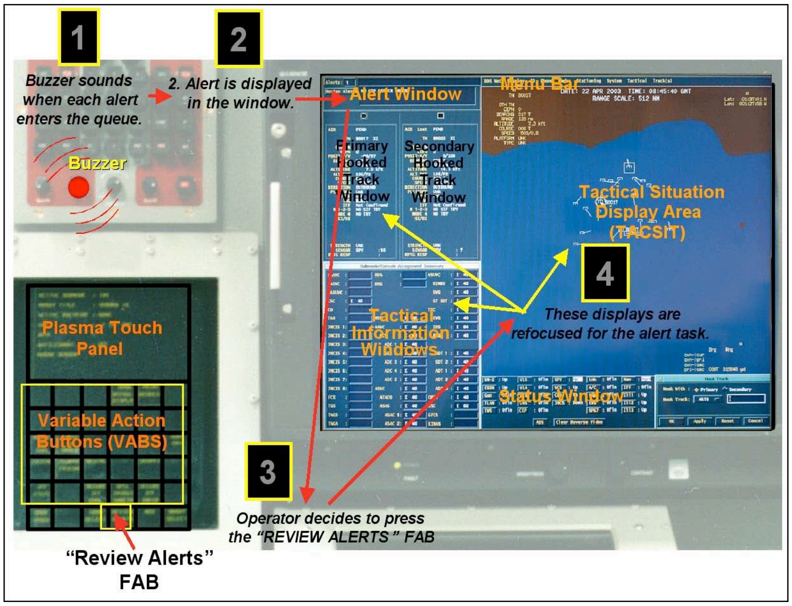

FIGURE 2. The Aegis BL7P1 IDS console showing the steps required to process alerts.

APPROACH

The Taxonomy of Human Interruption [McFarlane and Latorella 2002] identifies four methods for coordinating the interruption of people: (1) immediate, interrupt them now and get it over with, (2) negotiated, give the recipient the authority to negotiate when, if, and how they will handle interruptions, (3) mediated, a third party brokers all interruptions and decides when and how best to interrupt the recipient, and (4) scheduled, a prearranged convention for the times to interrupt the user.

Empirical research with human subjects found that negotiation-based interruptions best support operator performance except where small differences in the timeliness of handling interruptions is critical; then the immediate solution is best [McFarlane 2002]. The HAIL technology is founded on this result and is engineered to provide negotiation-based coordination support to increase naval operators' capability to work effectively during high rates of alerting.

The HAIL negotiation-based coordination support provides the capability to: (1) quickly notice each alert and the precise minimum information needed to make instant judgments of alert criticality, (2) negotiate control over when and how to process alerts, (3) easily visualize the contents of alert-based information without explicit user interface actions required of operators, (4) differentiate among alerts based on context and processing requirements, and (5) automatically help resume pre-interruption work after completing an alert.

METHOD

The first objective of the HAIL team was to demonstrate the technology maturity and operational utility of HAIL at TRL7 in May 2004[1]. The team's second objective was to

---

[1] The Technology Readiness Levels (TRL) range from values of 1 – 9 where TRL1 = "Basic principles observed and reported" to TRL9 = "Actual system proven through successful mission operations." TRL7 = "System prototype demonstration in an operational environment."

facilitate the transition of HAIL into the Aegis Open Architecture platform. Figure 3 depicts the nine TRL levels and Figure 4 depicts were these levels where satisfied within the HAIL-SS program plan.

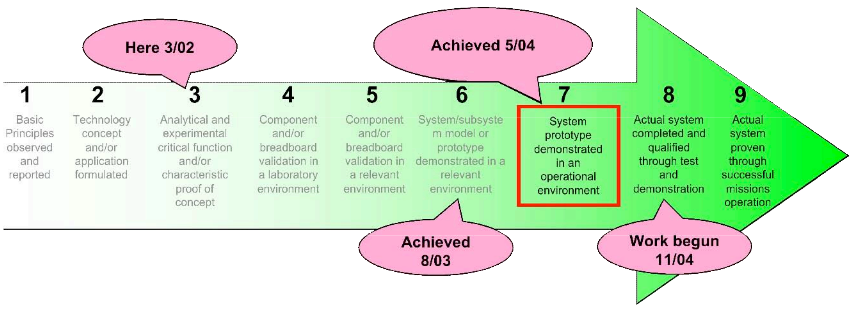

FIGURE 3. Technology Readiness Levels Rating Scale for HAIL Technology.

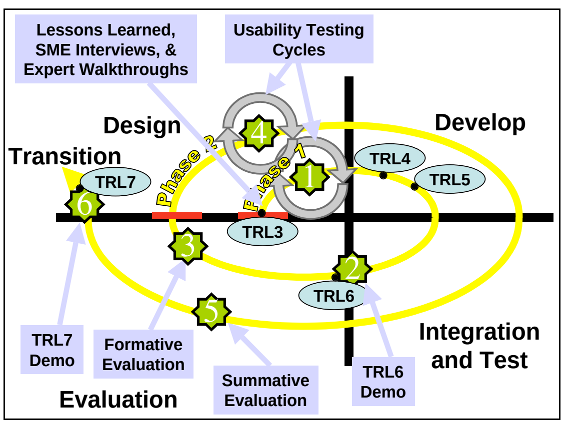

FIGURE 4. HAIL Technology Reached TRL7 through a Spiral Development Program Plan.

HAIL applied a human-centered analysis and design process to define, develop, and test the technology. The analysis includes two initiatives: (1) evaluation of 20 years of Aegis 'lessons learned' data related to alert processing and (2) user experience efforts that include current fleet sailors to assess current alert processing. These efforts have enabled the HAIL team to develop a prototype interface that has been submitted to five cycles of formal usability testing and two cycles of formal evaluation. Each of these tests clarified the strengths and weaknesses of the Aegis HAIL user interface (UI) and these results have been used in 8 full cycles of redesign and testing. The final solution is based on this foundation and has been proven useful under highly realistic conditions.

SUMMATIVE EVALUATION

Participants

Twenty-two experienced naval operators participated from the Aegis Training and Readiness Center (ATRC) Norfolk and from ATRC Dahlgren (five were former Navy personnel and now contractors). They had combined experience of over 280 years (3-28 years experience individually, 14.5 years on average). Technical problems with data collection prevented the use of the data from two participants.

Evaluation Design and Conditions

A "within subjects single factor Latin Squares" design was used. The testing evaluated two conditions: a control condition without the HAIL engine, Baseline 7 Phase 1 (BL7P1), and an experimental condition with the HAIL engine, Aegis HAIL. Each subject was tested in both conditions. The order in which they were tested was counterbalanced, and subjects were randomly assigned to the two orders. Each condition was tested using a different scenario, scenario 1 or 2. Ten of the twenty participants were given the BL7P1 condition first, five with scenario 1 and the other five with scenario 2. Ten of the twenty participants were given the HAIL condition first, five with scenario 1, the remaining five with scenario 2.

Task

The highly realistic scenario was designed and developed by former Aegis combat officers.

The summative evaluation used two similar 35-minute scenarios to allow for cross-subject and intra-subject comparison. The scenarios were composed mostly of action alerts (70%), with a minimal amount of informational alerts (30%). The scenarios were designed and scripted using ACTS Exercise Request Development System II (AERDS II) software to simulate a Link 16 tactical picture of the Arabian Gulf with 240-260 tracks. The AERDS files were then converted to a character-delimited file capable of being handled by the Altia mockup. Each scenario contained a 5-minute warm up period followed by a 15-minute low-stress period and a 15-minute high-stress period of action. Within the high-stress period, there is a 10-15 second surge of alerts where the test participant is bombarded with an alert every second for the duration of the surge.

Apparatus

The formative evaluation was conducted on Aegis BL7P1 AN/UYQ-70 console suites running in the Aegis CSETC testing lab at LM MS2, Moorestown, NJ. Evaluating on the actual Aegis hardware dramatically increased the external validity of our findings. However, the actual Aegis hardware did not adequately support the type of simulation capabilities necessary for rigorous evaluation. To meet our internal validity requirement, the evaluation platform needed the following attributes that could not be achieved in an Aegis hardware platform: (1) Able to simulate a large number of tracks and alerts without overloading system capabilities; (2) Scenarios are repeat able in the exact configuration of tracks and alerts for numerous runs with multiple subjects; (3) All user actions that need to be logged can be reliably captured and time-stamped (preferably with automated capture methods); (4) Scenario and environment are extremely realistic replications of the operational environment; and (5) Evaluation efforts remain cost-effective and reasonable to complete with available resources.

An evaluation platform was created to satisfy these evaluation requirements. This platform is a hybrid combination of the real HAIL system running on a Solaris workstation fully integrated with a mockup of the rest of the Aegis displays built with Altia Design. The result is an extremely realistic, fully functional replication of the BL7P1 system with the scenarios being driven by a local simulator. Integrating HAIL into this platform enabled a rigorous engineering assessment of the HAIL code and user evaluation data. The resulting platform was designed to present stressful scenarios that exercised HAIL capabilities and to log all user actions for analysis purposes.

Procedure

Evaluation data were recorded with three objective measures and five subjective instruments. Objective data were recorded with: (1) automatic logging of all user interface events; (2) two-channel synchronous digital video of the operators interaction with the console; and (3) expert observers to assess operator performance that could not be automatically logged. Subjective data were recorded with four questionnaires and an exit interview. The four questionnaires used were: (1) the NASA Task Load (TLX) to measure workload; (2) a modified NASA Bipolar Rating Scale to measure stress level; (3) a HAIL functionality scale to measure utility of the new functions; (4) a comparison of HAIL to the Aegis BL7P1 baseline without HAIL to measure the relative value of the before and after solutions; and (5) formal exit interview recorded with a digital audio recorder.

Results

The two main utility assessment objectives for the HAIL-SS Phase 2 Evaluation mentioned in Section 1.2, Evaluation Goals: (1) Which HAIL capabilities are most valuable for improving warfighter performance? and (2) Does the introduction of HAIL cause any degradation in warfighter performance; i.e., “did we break anything?” can be answered by looking at the results. HAIL was found to increase warfighter performance in four ways: immunity to the effects of trash alerts, fewer interruptions, better alert SA, and easier recovery of non-alert work after handling alerts. Through discussions with actual operators, it has been determined that errors can cause meaningless noise alerts to be inserted into the queue along with important alerts. These important alerts become buried in the alert queue beneath the noise alerts. HAIL makes it easy for operators to see the difference between noise alerts and important alerts. Operators can sort through and select the important alerts, eliminating the critical problem that the noise alerts can present.

Results show that HAIL produces a reduction in interruption frequency by sending fewer alerts to the operator. Redirecting status alerts to the Status Display Window reduces the number of alerts presented to the operator in the alert queue. While the SAGAT scores of the Baseline Aegis and the HAIL systems showed no statistical difference in the Situational Awareness (SA) score, the Difference questionnaire reported a higher SA in the HAIL condition. Participants perceived that their overall Situation Awareness was better with HAIL than without it.

HAIL increases operator capability to efficiently switch between alert-based work and non-alert work. HAIL automatically resets the TACSIT configuration to its pre-alert settings (e.g. range scale) and therefore reduces the amount of time and effort required for the operator to retrieve his pre-alert context.

In an analysis of the surge phase only, the HAIL condition produced an overall average reduction in surface latency that was greater than the Baseline. This result indicates that HAIL accomplishes one of the main goals the technology set out to achieve: it allows operators to find, surface, and address critical alerts in a timely manner during high-stress periods in the operational environment.

Subjective data was analyzed primarily to determine which features have been successfully designed and implemented to be useful to the operational community. The most important findings of the subjective data include: (1) Advantage ratings of HAIL over Aegis baseline:

a. Ability to recognize important alerts
b. Ability to surface important alerts
c. Minimize less important alert work
d. Alert Situation Assessment
e. Alert tool control

Figure 5 shows the average relative rating for HAIL capabilities versus Aegis BL7P1 capabilities without HAIL. The results are sorted from highest rated HAIL capabilities to least.

HFE IMPLICATIONS

Operator Involvement in Scheduling Alerts

In the current Aegis alert design operators must scroll through each alert to see the full alert message. The HAIL approach allows the operator to review all alerts and select the ones that require immediate attention. In addition, there are visual indications of the associated track and pertinent positional information to help determine whether or not to address it immediately.

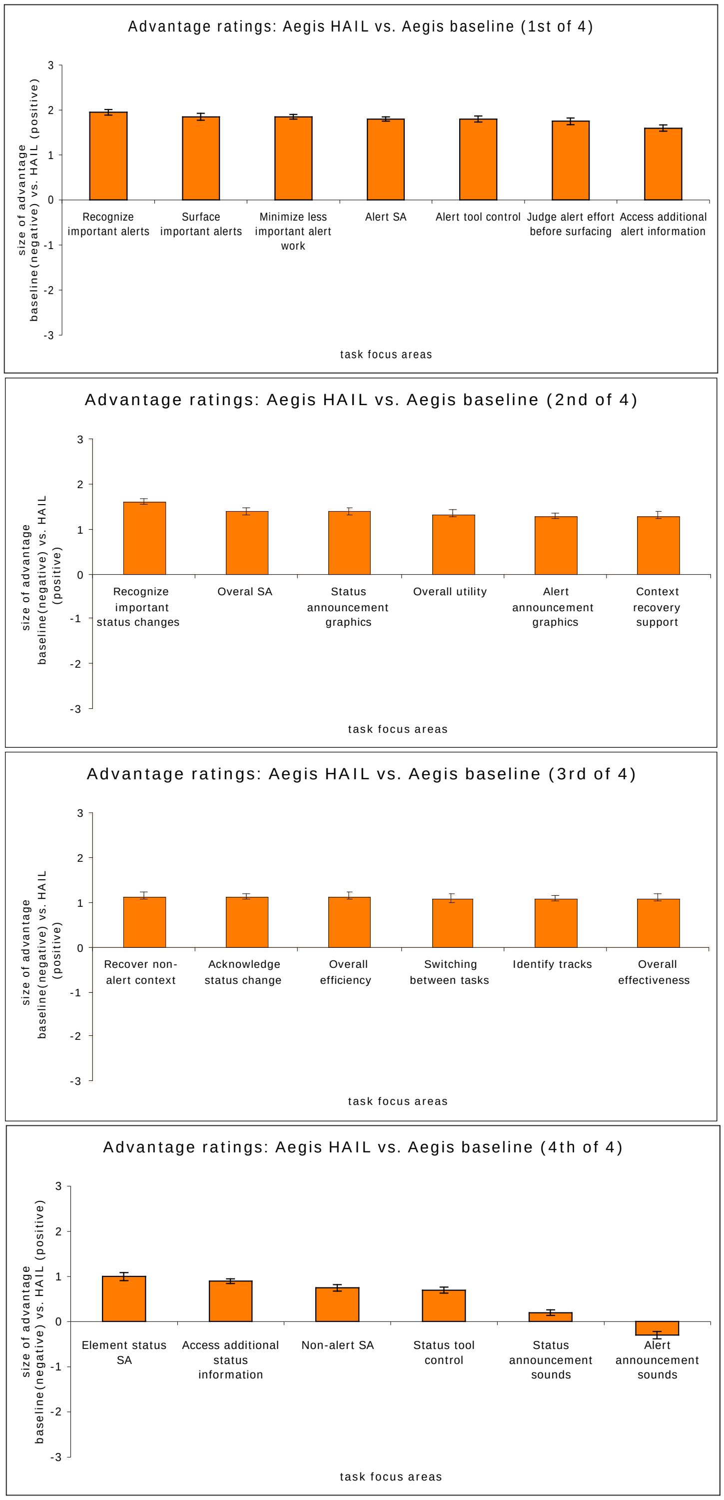

FIGURE 5. The sorted average relative ratings of HAIL capabilities compared to non-HAIL Aegis BL7P1 capabilities.

Operator Responsibility for Judging Alert Criticality

While the combat system displays the alerts in the order of receipt, the operator is able to view all the alerts in the queue and assess the relative criticality of one alert versus another. If the operator is responsible for pre-engagement and engagement response they obviously will respond to these alerts before others.

Improved Visualization of Alert-Generated Information

The HAIL interface has been designed to visually distinguish between the types of alerts. There are ‘action’ and ‘inform-tion’ alerts in the Aegis system. While the ‘action’ alerts are listed in the new alert queue, the ‘information’ alerts relative to equipment status are rerouted to the “Status Board” display.

Mediation Control Suite

Unlike the Aegis system that only provides a single button for processing alerts, the HAIL system provides five buttons that allow the operator to better manage the alerts.

Improved Context Switching

Currently, the operators have to find their own way back to the pre-alert task. HAIL—when the operator indicates that the alert has been ‘completed’—returns the original displays and controls to the tactical display surface.

Improved Situational Awareness between the Graphical TACSIT and the Textual Alert List

The HAIL system provides operators with an enhanced level of situational awareness. Currently, the operator must surface the alert in order to see the associated track on the TACSIT display. With the HAIL interface, the operator mouses over the alert in the list to see the highlighted track on the TACSIT. This visually confirms the track's position and aids in tactical decision-making.

CONCLUSIONS

The most significant impact of HAIL technology into Aegis is the increase in the operator's capability to remain in constant contact with the stream of critical alert-based tasks and information regardless of the alerting rate or the amount of non-critical alerts. Operators are able to recognize critical alerts as they arrive and can then reach into the alert queue and pull out whatever is most important at the moment.

REFERENCES

McFarlane, D.C. (2002). Comparison of Four Primary Methods for Coordinating the Interruption of People in Human-Computer Interaction, Human-Computer Interaction, vol. 17, num. 3, Laurence Erlbaum Associates, Mahwah, New Jersey.

McFarlane, D.C. and Latorella, K.A. (2002). The Scope and Importance of Human Interruption in HCI Design, Human-Computer Interaction, vol. 17, num. 3, Laurence Erlbaum Associates, Mahwah, New Jersey.

NSWCDD and Lockheed Martin Internal Memorandum, "Final Report of the "Navy/ Lockheed Martin Alert & Tutorial Working Group," August, 2003.

ACKNOWLEDGEMENT

Major parts of this work were accomplished with funding from the ONR KSA FNC program on contract N00014-02-C-0014.

Dr. Daniel McFarlane *received his DSc in Computer Science from George Washington University. He is a senior engineer focused on research and development of decision support architectures for operational systems. He is currently investigating applications of negotiation-based coordination architectures for service oriented command and control systems. Dr. McFarlane serves as principle investigator for the HAIL-SS program, where he is transitioning his basic research on human alerting done at the Naval Research Laboratory into an open architecture software product for the Aegis Weapon System. He also serves as Transition IPT lead for the DARPA FASTC2AP program. In 2002, he co-authored a standalone issue of the Human Computer Interaction journal about his research in human interruption.*

Paul Berger *is a co-author of this paper. He is currently a Lead Member of the Engineering Staff at Lockheed Martin's Maritime Systems and Sensors facility at Moorestown, NJ. Mr. Berger has been instrumental in the design of the Aegis UI since 1982. This included the specification and display of improved alert messages for Aegis baselines 4 – 7. In 2000, Mr. Berger was a co-lead with the Navy of the "Alert and Tutorial Working Group". The findings of that group helped in the conduct of the HAIL effort. For the HAIL program, Mr. Berger was the Integration Test Lead and coordinated the test and integration efforts of the Aegis - HAIL product at the Production Test Coordination (PTC) facility in Moorestown, NJ.*