Airport Movement Area Safety System Human Factors Evaluation

Final Report

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1. Introduction

The Airport Movement Area Safety System (AMASS) is an enhancement to the Airport Surface Detection Equipment (ASDE-3) radar. It provides automated visual and aural alerts regarding potential runway collisions. AMASS will be installed in 34 air traffic control (ATC) towers and is being built by the Northrop Grumman Corporation. AMASS has been in development for about 10 years and has been evaluated at San Francisco International Airport (SFO) in prototype form. Final testing and deployment are scheduled for late 1999.

1.1 Background

The AMASS Working Group requested support from the National Airspace System Human Factors Branch (ACT-530) of the William J. Hughes Technical Center to evaluate human factors concerns regarding AMASS. This report provides the methodology and results of the AMASS human factors evaluation.

The working group identified several potential human factors issues at meetings on January 6 and February 3, 1999. Among the major issues was the potential impact of the AMASS computer-human interface (CHI) on controller response time to detect an alert. Total response time to resolve a runway conflict has several components. These include

a. Alert: AMASS signals a potential conflict with a visual and aural alert,
b. Detection: The controller detects or notices the alert,
c. Evaluation: The controller determines the location and nature of the problem,
d. Decision: A decision is made that an action is necessary,
e. Action: The appropriate controller contacts the vehicle or aircraft concerned,
f. Response: The vehicle or aircraft takes the correct action to resolve the conflict, and
g. Resolution: The conflict is resolved.

Alert and Resolution are the start and end points. The intervening elements require human perception, information processing, and actions. The AMASS provides the information for the controller to complete the first three stages of the conflict resolution process (Detection, Evaluation, and Decision).

1.2 Purpose

The purpose of this study was to evaluate various aspects of the AMASS CHI. At the request of the AMASS Working Group, ACT-530 assessed

a. the functionality and ease of inputting AMASS information using the ASDE-3 keypad/keyboard,
b. the readability of the ASDE Operational Display Unit (ODU) for AMASS information,
c. head-down time requirements for the operation of AMASS,

d. AMASS voice quality and effectiveness of alerts, and
e. tower cab crew coordination.

2. Evaluation Methodology

The evaluation was conducted at the William J. Hughes Technical Center Research Tower Cab and consisted of display, response time, and usability assessments. During these activities, the controllers participated in parallel discussions convened at the Research Development and Human Factors Laboratory (RDHFL) to identify potential human factors issues and their resolutions. AMASS Project Office engineering staff provided technical support and feedback on the feasibility of proposed solutions. Engineering research psychologists and subject matter experts (SMEs) from ACT-530 supported by local contractors composed the team that planned and directed the study.

2.1 Participants

The working group recruited 10 ATC specialists and two ATC supervisors to participate in the evaluation. These participants represented ATC towers where AMASS will be deployed. They came from different geographic areas and their age and experience varied. A summary of their air traffic control and ASDE experience is presented in Table 1.

Table 1. Participants Experience

Air Traffic Control Experience		**ASDE Experience**	
Years	**Count**	**Years**	**Count**
10 – 14.9	7	0 – 1.9	2
15 – 19.9	3	2 – 3.9	6
20 – 24.9	1	4 – 5.9	1
More than 25	1	More than 6	3

2.2 Equipment

The AMASS Working Group and Integrated Product Team coordinated installation of the AMASS equipment racks at the base of the tower cab and two 17-inch AMASS ODUs in the tower cab. One ODU was situated on the tower console at a 20-30 degree upward angle, and the second was ceiling mounted next to the Digital-Bright Radar Indicator Tower Equipment (D-BRITE), approximately 7 feet above the floor and tilted downward. Both ODUs displayed the same image. Figure 1 presents the equipment layout employed for the evaluation.

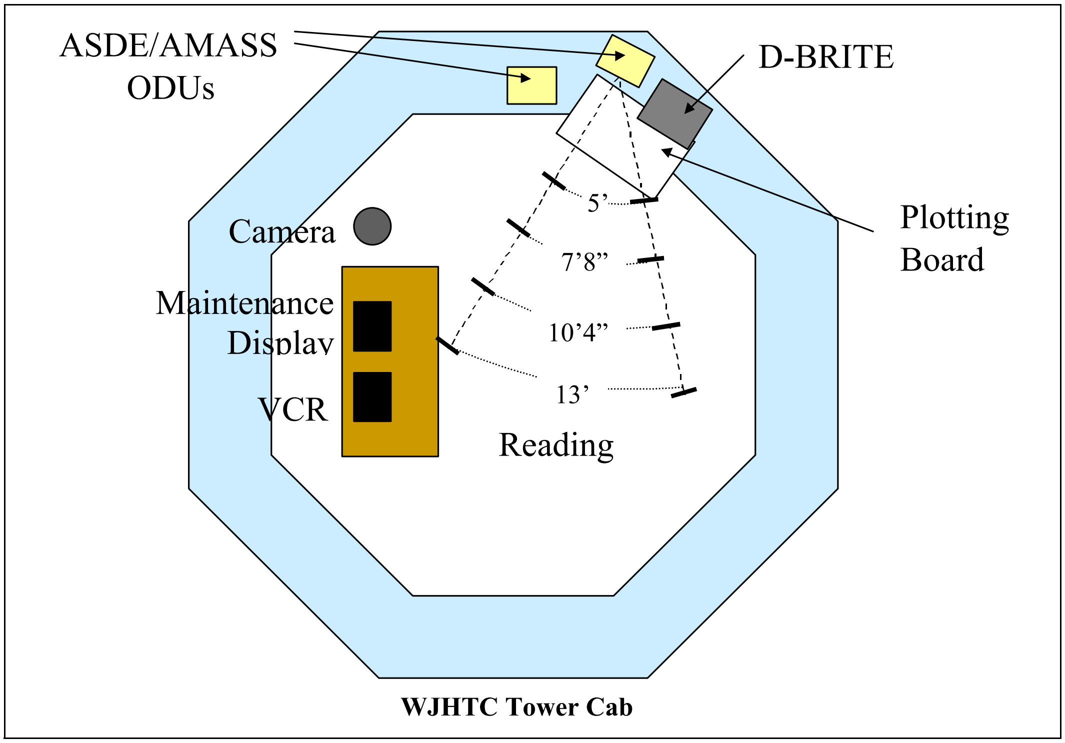

Figure 1. Equipment layout for AMASS human factors evaluation at the William J. Hughes Technical Center.

The research team placed the ASDE keyboard and keypad below the ceiling mounted display. The controllers performed ASDE and AMASS operations using either the keyboard or keypad with the keys arranged as presented in Figure 2. Both input devices were available during the evaluation, but the keypad was used for all data collection sessions. It was only possible to use the data entry devices one at a time during the evaluation. This study focused on the keypad in that the working group indicated it would predominantly be used in the field. The team installed the AMASS Maintenance Display Terminal Workstation in the tower cab to control the system and to inject targets on the ODU. A small video camera recorded controller activity during portions of the evaluations.

A pre-recorded tape of SFO ASDE data was used to provide targets during the readability and timing portions of the evaluation. The team placed a video cassette recorder with simulated voice traffic for the pre-recorded SFO ASDE data in the tower cab. This tape provided the controllers with sufficient information to track the air traffic during the timing task. The research team configured the ASDE/AMASS display as it would be at SFO with the whole airport shown, with no inset map windows, and the correct map range (12,900) and center. The team located the default location the alert text box at the top of the display.

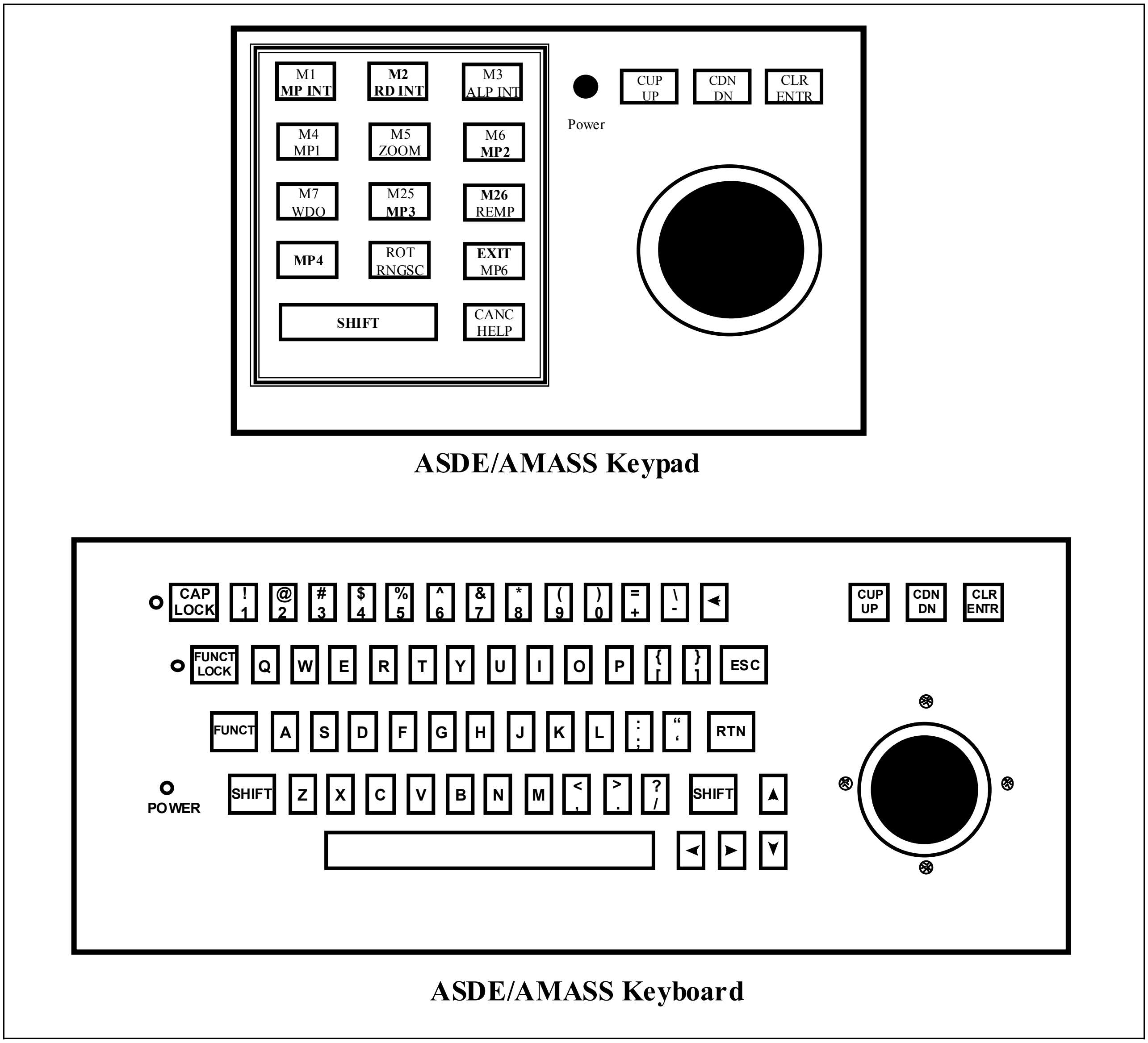

Figure 2. ASDE/AMASS keypad and keyboard.

The team conducted group discussions and rapid prototyping at the RDHFL. The rapid prototyping tools permitted both the auditory and visual interface of the AMASS to be emulated, enabling the participants to review potential solutions to human factors concerns. The auditory emulation tool permitted us to play recordings of auditory alerts and to modify them as directed by the participants. For the screen related aspects of the system, the team used a personal computer emulation that showed SFO, moving targets, and AMASS symbols and alerts.

2.3 Procedures

This evaluation consisted of a display readability component, a response time evaluation, and a structured usability assessment. The readability test determined the quality of text and symbol presentations on the AMASS displays. The response time and usability segments used recorded traffic with synthetic test targets inserted to create conflicts. Controllers took turns responding to alerts and evaluating the features of the system. Parallel discussion and demonstration activities took place in the RDHFL to identify possible human factors issues and their resolutions. All readability, response time, and usability scenarios showed text alerts, the octagonal alert symbol, and hold bars. The team turned on the triangular direction symbol to assist controllers in localizing targets.

During the orientation, the ACT-530 team divided the participants into two groups to expedite the evaluation and supplied them with individual code numbers to ensure confidentiality. The participants completed a background information form (see Appendix A) and received an overview of the test procedures. They were also trained in AMASS operations and provided with an overview of the SFO runway configuration and operations as well as relevant procedures.

The team tested and modified all scenarios and test procedures during the week of April 5. SMEs were present to assist the human factors team. The formal test began on Tuesday, April 13. (Monday and Friday of that week were travel days.) Table 2 provides the evaluation schedule.

Table 2. AMASS Human Factors Evaluation Schedule

Time	Tuesday 4/13	Wednesday 4/14	Thursday 4/15	Friday 4/16
Morning		Group 1: (Tower) - Day Readability - Reaction Time Group 2: (RDHFL) - Issue Discussion	Group 1: (Tower) - Reaction Time - Usability Group 2: (RDHFL) - Issue Discussion	Groups 1 & 2: (RDHFL) - Final Caucus
Afternoon	Groups 1 & 2: (RDHFL) - Orientation Groups 1 & 2: (Tower) - Initial Review	Group 1: (RDHFL) Issue Discussion Group 2: (Tower) - Day Readability - Reaction Time	Group 1: (RDHFL) - Issue Discussion Group 2: (Tower) - Reaction Time - Usability	
Evening	Groups 1 & 2: (Tower) - Night Readability			

2.3.1 Display Evaluation

The display evaluation included a readability assessment and the application of human factors visual display standards to the ODU. The readability test determined if text and symbols critical for AMASS were discernable at a range of distances typical for tower controllers. The research team collected measurements of font size, luminance, and contrast to compare against human factors display standards and guidelines (ANSI, 1988; Wagner, Birt, Snyder, & Duncanson, 1996). The team determined original display requirements from the ASDE/AMASS specification.

The team selected the ceiling mounted unit for the readability evaluation because it represented the most visually challenging condition. Controllers read alert messages and AMASS symbols from four randomly assigned viewing distances (5 feet, 7 feet 8 inches, 10 feet 4 inches, and 13 feet) and two viewing angles (0 and 45 degrees off axis). It was not feasible to include arrival aircraft so aircraft arrival bars were not included in this test. The screen items for the test included

a. alert octagon (1 or 2 observed),
b. aircraft target (1 or 2 observed),
c. AMASS hold bar ('yes' if observed, 'no' if not observed),
d. category of alert (i.e., CAUTION or WARNING),
e. runway identification (i.e., 28R, 28L, 01L, or 01R), and
f. AMASS text message (e.g., OCCUPIED RWY).

The research team collected readability data using a group methodology approach (six participants at a time). Appendix B provides the test procedures and alert message content. They marked the tower cab floor with tape to show standing positions for each of the viewing points. Participants were given clipboards with response forms prior to the initiation of each run (Appendix C). All readability trials were videotaped.

The team created eight short scenarios consisting of only synthetic targets to produce alert messages. The messages varied in message content, focusing mostly on warning messages. Table 3 presents the alert number, number of octagons, number of targets, category of alert, runway identification, and text message for each scenario. The team injected these display elements from the Maintenance Terminal Workstation.

Table 3. Readability Scenarios

Alert Number	No. of Octagons	Number of targets	Category of Alert	Runway Identification	Text Message
1	1	2	CAUTION	28L	OCCUPIED RWY
2	2	2	WARNING	28R	HEAD-ON TRAFFIC
3	2	2	WARNING	28L	LDG, OCCUPIED RWY
4	2	2	WARNING	28R	MULTIPLE DEPS
5	2	2	WARNING	28R	HEAD-ON LDGS
6	2	2	WARNING	01L	DEP, OCCUPIED RWY
7	2	2	WARNING	01R	HEAD-ON TRAFFIC
8	2	2	WARNING	28L	LDG, OCCUPIED RWY

After disabling the auditory alerts, the research team set the text alerts to remain on the screen for a minimum of 30 seconds. They asked the first six participants to stand on one of the tape marking at 0 or 45 degrees and conducted two training trials. At the conclusion of these trials, they instructed the participants to stand on the first set of assigned distances on the 0 and 45 degree lines. The beginning of the first conflict event triggered the participants to write down the text of the alert message and any symbols they observed. They read the text box, located the aircraft on the airport map, and wrote down the content of the text alert.

The participants then moved to the next randomly assigned distance at the same viewing angle and another trial was initiated. This procedure was followed for the two remaining distances. The participants then changed viewing angles and repeated the procedure at the four new positions.

The research team collected readability data for three lighting conditions. These were night, day with shades down, and day with some shades down (representing a likely operational configuration). It was not feasible to control daylight ambient lighting levels in the Research Tower cab (except by using the window shades). However, the team collected photometer readings during the evaluation sessions. There was one run per participant for each lighting condition, which resulted in 12 data points for each viewing position. The team set ODU brightness at maximum for day trials and to SME-determined levels for night trials. SMEs also defined the brightness levels for screen elements.

2.3.2 Response Time Evaluation

The research team focused response time measurement on the controller elements of Detection, Evaluation, and Decision. They presented participants with an alert and asked them to respond when they decided on an action. This assessment helped determine how well the alert data displayed by AMASS supports a rapid reaction.

A response time evaluation was useful because it helped concentrate attention on the features of the AMASS displays and alerts that either facilitate or impede rapid detection, evaluation, and decision making.

Data blocks are not displayed on the ASDE/AMASS monitor. Controllers would normally remember the identification information on arriving and departing aircraft. When an AMASS alert is triggered, if the controller does not recall the call sign of the aircraft, the reference would be as follows.

a. For arrivals, the controller would look at the Automated Radar Terminal System arrival list on the D-BRITE or a paper arrival list on which arrivals are printed in two columns.
b. For departures, if the call sign was not memorized, it would be found on a paper departure strip.

During this evaluation the team created an arrival list and a set of departure strips for each run corresponding to the traffic in the recorded scenarios. The synthetic targets were not included in these lists.

The research team constructed the response time scenarios from SFO ASDE radar data recordings with injected synthetic targets. The response time scenarios had five conflicts spaced at varying intervals over a period of 15-20 minutes. They developed the events from two separate segments of recorded SFO traffic, reflecting the 19/10 and 28/01 runway configurations during moderately busy traffic periods. Each scenario was completed twice, resulting in a total of 12 data points. Table 4 presents the types of events for each of the six timing scenarios.

Table 4. Timing Scenarios

Scenario Number	Conflict Number	Injection Time (mins)	Type of Conflict
1	1	2:15	Arrival, occupied runway
	2	7:00	Departure, occupied runway/Head on traffic
	3	10:20	Head on traffic
	4	11:30	Head on traffic
	5	15:00	Arrival, occupied runway
2	1	1:30	Departure, occupied runway
	2	5:20	Landing, occupied runway/Head on traffic
	3	6:45	Departure, occupied runway
	4	10:15	Head on traffic
	5	14:25	Departure, occupied runway
3	1	2:00	Arrival chasing a landing
	2	7:20	Head-on landing and taxi
	3	12:35	Head-on arrival and taxi
	4	13:15	Departure chasing a taxi
	5	14:25	Landing with a stopped target on runway
4	1	2:27	Departure, occupied runway
	2	4:53	Arrival, occupied runway
	3	7:52	Departure, occupied runway/Head on traffic
	4	9:52	Head on traffic
	5	14:20	Arrival, occupied runway
5	1	2:25	Departure, occupied runway
	2	4:40	Head on traffic
	3	7:48	Departure, occupied runway
	4	9:18	Head on traffic
	5	14:06	Landing, occupied runway
6	1	4:40	Arrival chasing a landing
	2	7:47	Departure chasing a taxi
	3	8:30	Arrival chasing a taxi
	4	13:22	Departure chasing a taxi
	5	16:42	Head-on arrival and taxi

During the response time evaluation, one participant at a time played the role of the active controller. The rest of the group observed. The active controller had to detect and respond to each alert by speaking into a microphone connected to the video camera. After a short training trial, they played pre-recorded ASDE data from SFO and injected probe targets at varying intervals. They videotaped the response time assessment to enable time calculations and support an estimation of the proportion of time controllers had to look away from the window to interact with AMASS. The team used a stopwatch to provide a backup set of timing data. The correct response was to call the aircraft involved in the incident and provide instructions. There was one response time run (with five trials each) for each participant, providing a total of 60 data points. They employed six different but equivalent scenarios and a variety of events and times so that observers did not become too familiar with the response time sessions.

During this assessment, the research team asked the active controllers to focus their attention on a secondary task. This activity required the controller to monitor a prerecorded re-enactment of voice communications between the control tower and pilots for the ongoing scenario using a typical one-earphone controller headset. The team prepared the controller-pilot verbal interchange prior to commencement of the evaluation. Based on the audiotape, the controllers moved physical representations of each of the aircraft on a 30-inch by 40-inch SFO map to mimic the aircraft movements in the scenario. This task supported the controllers' situational awareness so that they were prepared to respond to the AMASS alert. Though it did not provide the identical workload or complexity of normal tower operational tasks, it served to distract attention from the AMASS display while generating some knowledge of the operations playing on the ASDE tape.

The research team provided each participant with instructions before starting. They based display setup and window shades on user preference. However, map range, map position, and alert window location represented typical SFO settings. After each run, a short debriefing gathered immediate information concerning how the system supported the detection and resolution of conflicts.

2.3.3 Usability Evaluation

The usability components of the evaluation consisted of an AMASS set-up time analysis and a usability questionnaire. The procedures for each component are detailed below.

2.3.3.1 AMASS Set-up Time

This component assessed the ease of performing common ASDE/AMASS controller tasks. Pairs of controllers worked through the list of ASDE and AMASS functions presented in Table 5. The last two AMASS tasks (Select Operational Configuration and Close/Open Runway) represent tasks that supervisors would typically complete.

2.3.3.2 Usability Questionnaire

During the timing assessment, the team asked the non-working participants to make a general evaluation of AMASS and to complete a usability questionnaire (Appendix D). After the completion of the response time assessment, they started the structured usability study. This was a general evaluation of system features with a background of ASDE data and AMASS alerts. Participants observed a series of alerts under varying conditions and made observations on the strengths and weaknesses of the display, user interface, alerts, keyboards, and procedures using a script of system actions.

Table 5. Controller AMASS/ASDE Tasks

System	Function
ASDE	Center/De-center Map
	Size Map
	Rotate Map
	Set Map Intensity
	Set Radar Intensity
	Set Alphanumeric Intensity
	Open Set Window
	Set Brightness/Contrast
	Filter Arrival Alerts
AMASS	Enable Arrival Alerts
	Move Alert Window
	Filter all Alerts for the Specified Ground Track
	Enable All Alerts for the Selected Ground Track
	Toggle AMASS and ASDE Control
	Select Operational Configuration (Supervisor Function)
	Close/Open Runway (Supervisor Function)

For the structured usability evaluation, the team identified two 60-minute, SFO, traffic scenarios (one for each runway configuration) on the ASDE tapes. Alerts were manually generated every few minutes depending upon the needs of the usability assessment. Multiple alerts were among the events that the team generated for the controllers to review during this portion of the evaluation.

The team encouraged controllers and supervisors to interact with the system in various ways using a preplanned script of activities and note their responses on the usability questionnaire forms. The participants exercised the scripts contained in Appendix E. These included ASDE and AMASS tasks that controllers would typically be expected to perform, and some supervisory actions were included. They videotaped these sessions to determine the amount of time the controller looked at the AMASS screen.

The team arranged the schedule so that pairs of participants had sessions on the system to step through the script. They measured the time required looking at the display and keypad for actions that controllers would have to take while controlling traffic. They also addressed other issues that could not be adequately covered during the display and response time evaluations. These included

a. viewing both the console and ceiling mounted displays from various positions,

b. visibility and usefulness of arrival bars and other screen elements,

c. using the system in towers with more than one local controller,

d. dealing with multiple alerts, and
e. tower cab crew coordination.

2.3.4 Issue Analysis and Resolution

This phase began by holding meetings with the participant groups and listing the AMASS human factors issues that emerged during the tower-based evaluations. A human factors specialist facilitated the groups. The participants analyzed the elements and criticality of each problem and began to discuss potential solutions. During this phase, the participants discussed several aspects of the system, which included

a. keyboard and keypad use,
b. display readability,
c. display presentation and map orientation,
d. head-down time,
e. alert message content,
f. multiple alerts,
g. AMASS icons and symbols,
h. quality of auditory alerts,
i. need for data blocks in AMASS, and
j. crew coordination.

To support this process, a computer emulation of the ASDE/AMASS provided an emulation of the ASDE/AMASS screen, traffic moving on the airport surface, and both auditory and visual alerts. Using this tool, the research team demonstrated potential solutions generated by the participants in a very short time. On the final day, the participants and the team convened to review the human factors issues and recommended solutions identified by the two controller teams.

3. Results

The AMASS human factors evaluation results are presented in terms of the display, response time, and usability assessments. The display evaluation includes the readability data and the results of a human factors analysis of the ODU. The response time results provide minimum and maximum time for responses to AMASS alerts during the simulated operational condition and results of the controller debriefing. The usability evaluation section includes comments on the scripted walk through and responses to the usability questionnaire.

3.1 Display Evaluation

This section provides results of the readability evaluation and assessment of the ODU based on applicable human factors visual display standards.

3.1.1 Readability

The research team conducted the readability evaluation using the procedures detailed in Section 2.3.1. The participants were asked to identify components of the AMASS CHI from the ceiling mounted, 17-inch, ODU during three lighting conditions. The readability evaluation data are presented in two sections: symbol and character recognition and reading meaningful components.

3.1.1.1 Symbol and Character Recognition

The section provides the average percent of symbols recognized for each lighting condition, viewing angle, and distance. Table 6 presents the average recognition rate across participants for the alert octagon, target, and AMASS hold bars. It includes the night, day with shades up, and day with shades down lighting conditions for each viewing angle and distance.

Table 6. Average Recognition Percent of Alert Octagons, Targets, and Hold Bars

Component	Condition	0 Degrees				45 Degrees			
		5'	7'8"	10'4"	13'	5'	7'8"	10'4"	13'
Octagon	Night	96	100	100	100	100	92	100	100
	Day Shades Down	100	100	96	100	100	100	100	100
	Day Shades up	100	100	100	92	100	96	96	100
Target	Night	100	100	88	92	100	100	79	83
	Day Shades Down	96	100	100	100	100	100	96	92
	Day Shades up	100	100	100	92	100	100	100	92
Hold Bar	Night	92	92	100	100	100	92	83	92
	Day Shades Down	100	100	100	92	92	100	100	100
	Day Shades up	100	100	100	100	100	100	100	92

The participants experienced little difficulty identifying the alert octagon, aircraft target, and AMASS hold bar at each distance and viewing angle regardless of lighting conditions. They readily identified the octagon in virtually all lighting conditions and distances. They indicated that in an operational setting this would be the first item they would attempt to locate. The octagons provided an indication of the category of alert (steady for a caution and flashing for a warning), the affected runway, and, in some cases, the type of alert (based on the octagon location). The only type of information that was not always immediately available once the octagon was identified was the alert type. This information is provided through the text message.

The average accuracy rate on the category, runway identification, and AMASS text message varied widely and so they are presented independently. These graphs show how many characters or numbers were correctly recognized. Figure 3 presents the average recognition rate for the AMASS alert category (i.e., “C” or “W”) across each lighting condition and distance. The left graph presents the average results for each viewing distance at 0 degrees incidence, and the right at 45 degrees.

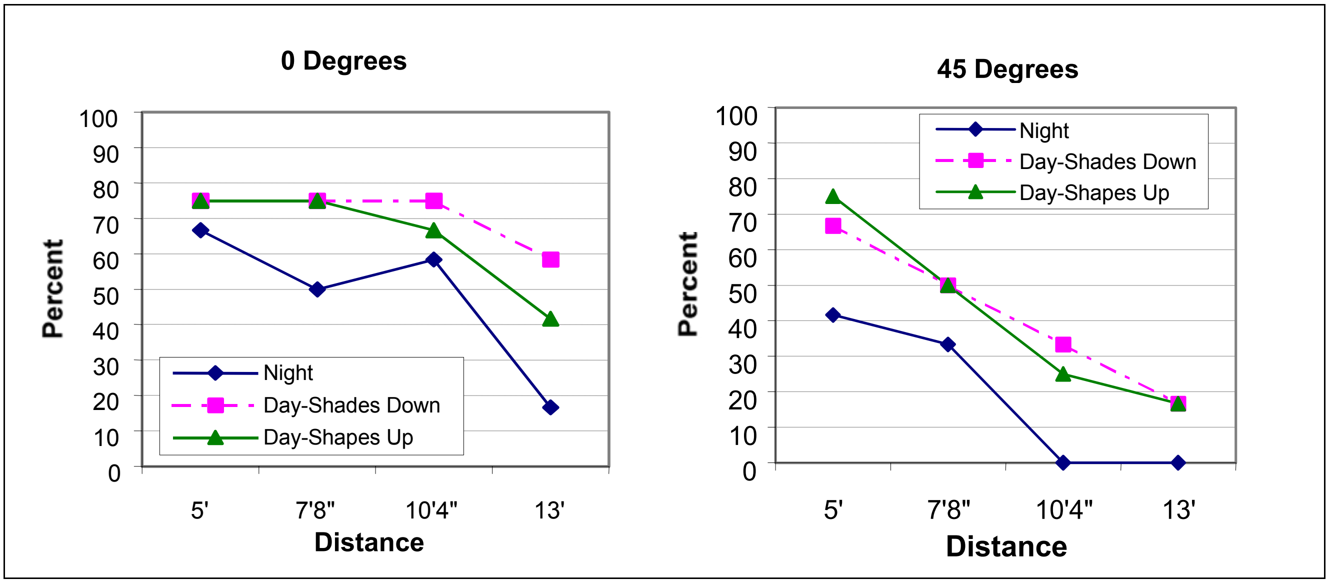

Figure 3. Average alert category percent correct across participants for both viewing angles.

The average percent of runway identification characters correctly recognized across participants is presented in Figure 4. The graph on the left presents the average recognition percent at 0 degrees incidence for each of the four viewing distances. The graph on the right depicts the results at 45 degrees.

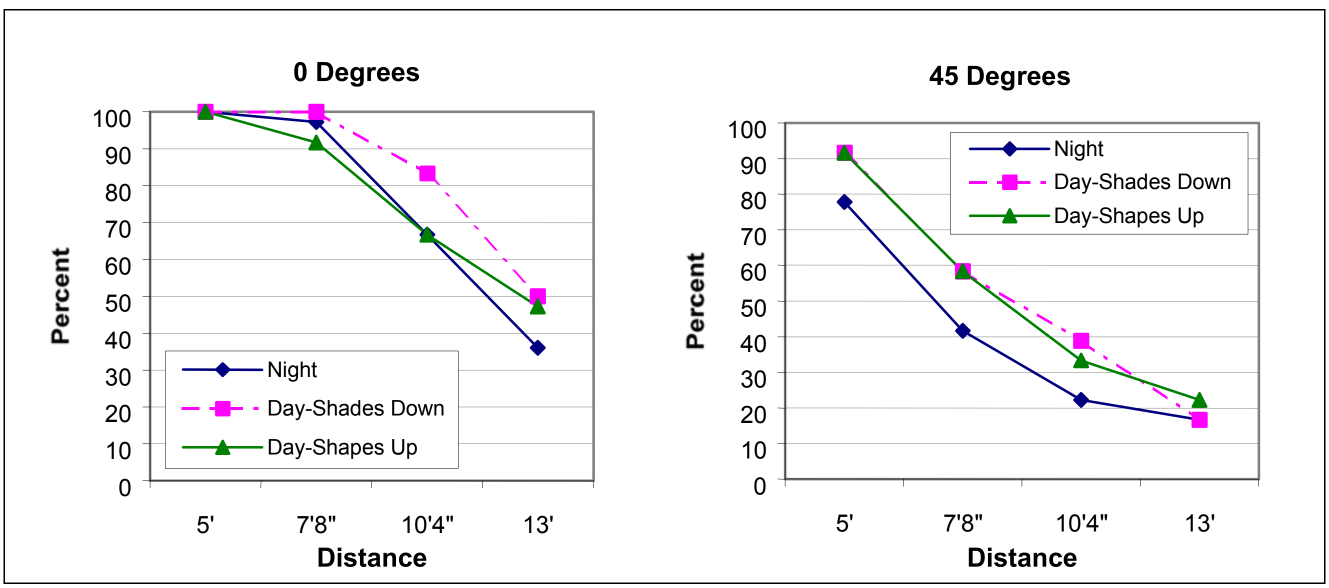

Figure 4. Average runway identification percent correct across participants for both viewing angles.

The average text message character recognition across participants is presented in Figure 5. The left graph depicts the average percent of characters identified at 0 degrees incidence, and the right provides the results at 45 degrees incidence, during each of the lighting conditions.

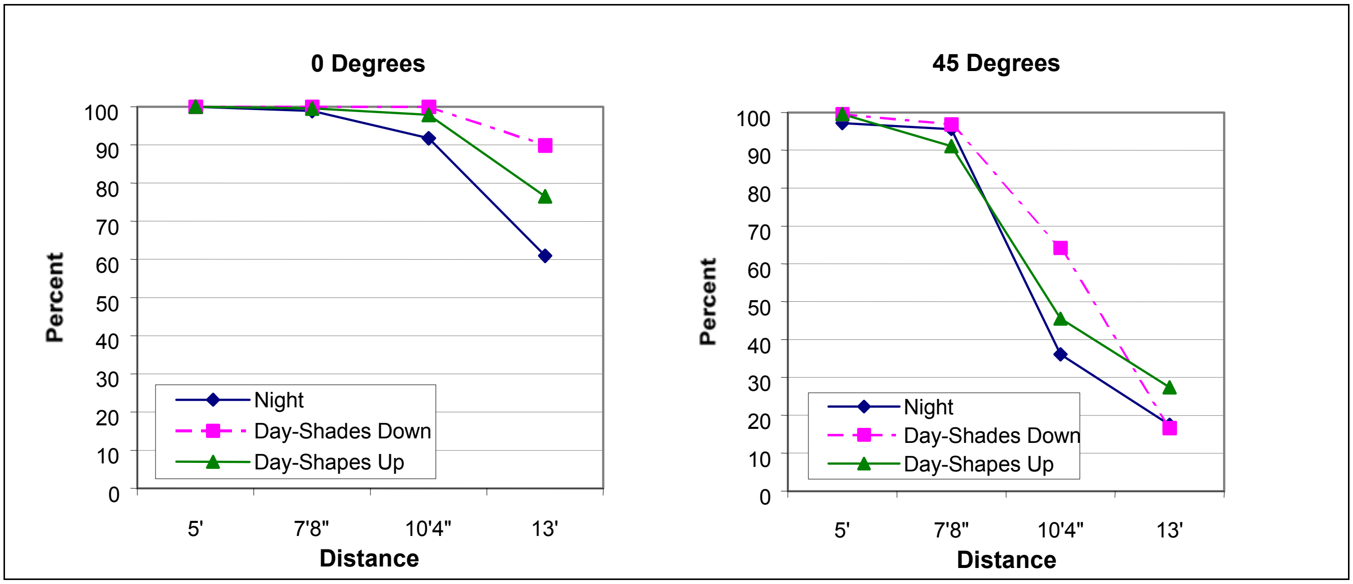

Figure 5. Average text message percent correct across participants for both viewing angles.

The participants experienced little difficulty recognizing the octagon, target, and AMASS hold bar. The average recognition for these elements did not drop below 79%, even during the worst lighting condition (night) and viewing angle (45 degrees). The participants experienced some difficulty identifying the alert category. Only 75% of them correctly identified the category at 5 feet. They performed better identifying the runway identification and text message. At 5 feet and 0 degrees incidence, all participants were able to correctly identify the runway identification and text message regardless of lighting condition. Their average text message recognition remained near 100% at 5 feet from the display and 45 degrees off axis.

3.1.1.2 Reading Meaningful Components

The purpose of this analysis was to determine if the controller understood the meaning or intent of each display component. It presents the number of controllers that identified the meaning of each test component. Participants' accuracy on alert category, runway identification, and text message varied widely based on distance, viewing angle, and lighting conditions. Alert category recognition was addressed in Section 3.1.1.1.

The number of participants correctly identifying the runway is provided in Figure 6. The graph on the left presents the data at 0 degrees incidence for each of the four viewing distances. The graph on the right depicts the results at 45 degrees. Only those cases in which the participant accurately identified the runway are presented. For example, if a participant indicated 28L, or 26R, when the runway identification was actually 28R, then the response was not considered accurate and consequently not incorporated in the count.

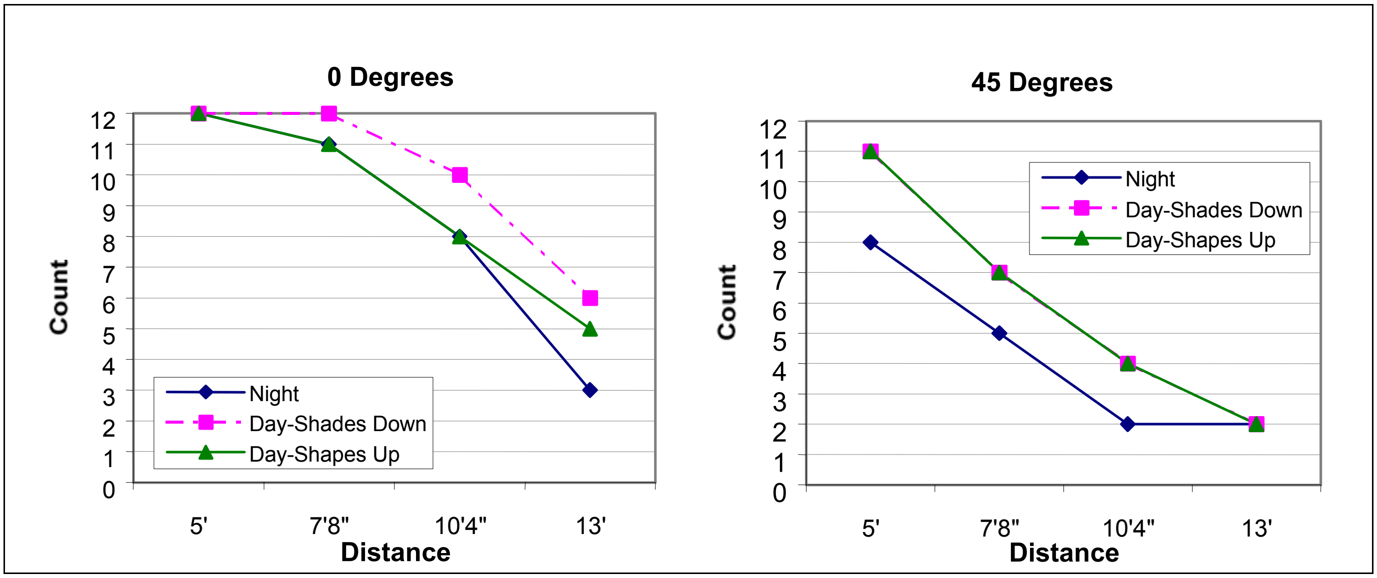

Figure 6. Number of participants correctly identifying runway at both viewing angles.

Figure 7 presents the number of participants who captured message meaning content at each viewing angle and distance. The left graph presents the results at 0 degrees incidence, and the graph on the right presents the data for 45 degrees. The graphs provide the results for the night, day with shades down, and day with shades up light conditions at each of the viewing distances. Unlike the data presented for text message character recognition, these data are a reflection of whether the controller captured sufficient information to understand the meaning of the text.

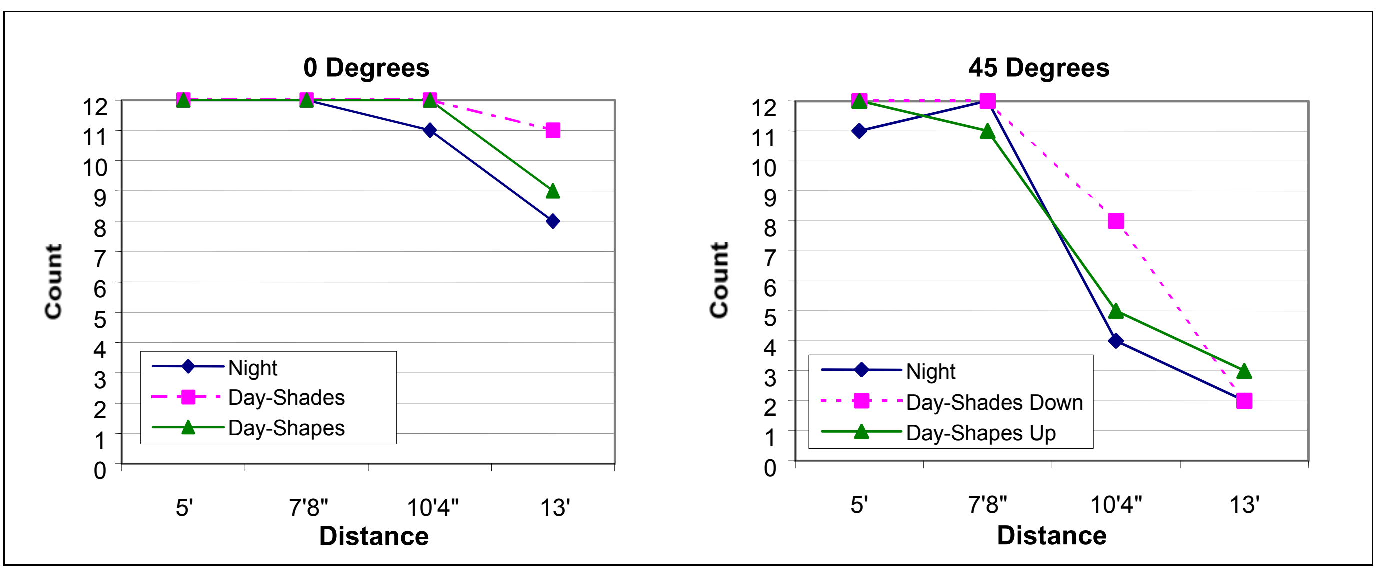

Figure 7. Number of participants correctly identifying text message content at both viewing angles.

The participants experience difficulty reading the alert category. Only 9 participants were able to read the alert category during day conditions and 8 during night conditions at 5 feet. They performed much better reading the runway identification and text message content. All participants correctly identified these display components at 5 feet and 0 degrees incidence.

3.1.2 Visual Display Standards

The human factors research team conducted an analysis of the ANSI display standard (ANSI, 1988) and Human Factors Design Guide (Wagner et al., 1996) for the ODU. The font style used in AMASS is a serif font. A sans serif font is recommended. The preferred character height for visual displays is 20 to 22 min of arc (visual angle). The AMASS character height meets minimum acceptable visual angle requirements at 38 inches. Character height-to-width ratios were in the acceptable range. The size of the octagon symbol (at a map range of 12,080) was acceptable out to a maximum of five feet viewing distance. The target symbol and "A" were only viewable to about two feet. Appendix F details the results of the application of human factors visual display workstation standards to the ODU.

The team calculated the recommended character height for the measured viewing distance (Sanders & McCormick, 1993) using the following formula:

$$\text{Character Height} = \frac{\text{Visual Angle X Viewing Distance}}{3438}$$

Figure 8 presents the minimum and preferred character heights based on the measured viewing distances. The figure provides the recommend minimum visual angle of 16 minutes of arc and a preferred angle of 21 minutes of arc (ANSI, 1988) for visual display terminals. The existing character height (0.18 inches) meets minimum acceptable visual angle requirements at 38 inches and preferred visual angle requirements at 29 inches. Based on the information presented in Figure 8, the minimum recommended character height is 0.28 inches (0.37 preferred) when viewed from 5 feet, 0.43 inches (0.56 inches preferred) from 7 feet 8 inches, 0.58 inches (0.76 preferred) from 10 feet 4 inches, and 0.73 inches (0.95 preferred) from 13 feet.

Display luminance of patches of green phosphor was 66.6 foot-Lamberts under 152 footcandles (fc) of illumination. The contrast of the screen elements to the background under 152 fc of illumination was 78:1. These values are more than adequate, according to human factors guidelines.

The flash rate of the AMASS octagon was about four per second. This falls within human factors guidelines recommendations. Mounting and glare control seem to have been adequately addressed in the original ASDE design.

The loudness of the auditory alarm varied depending upon the airport adaptation. Alarm loudness varied between about 62 and 88 dB, depending upon location and adaptation. Guidelines recommend that alarm loudness be 10 dB above the ambient background noise. Measurements in air traffic control towers would have to be collected to adequately evaluate this.

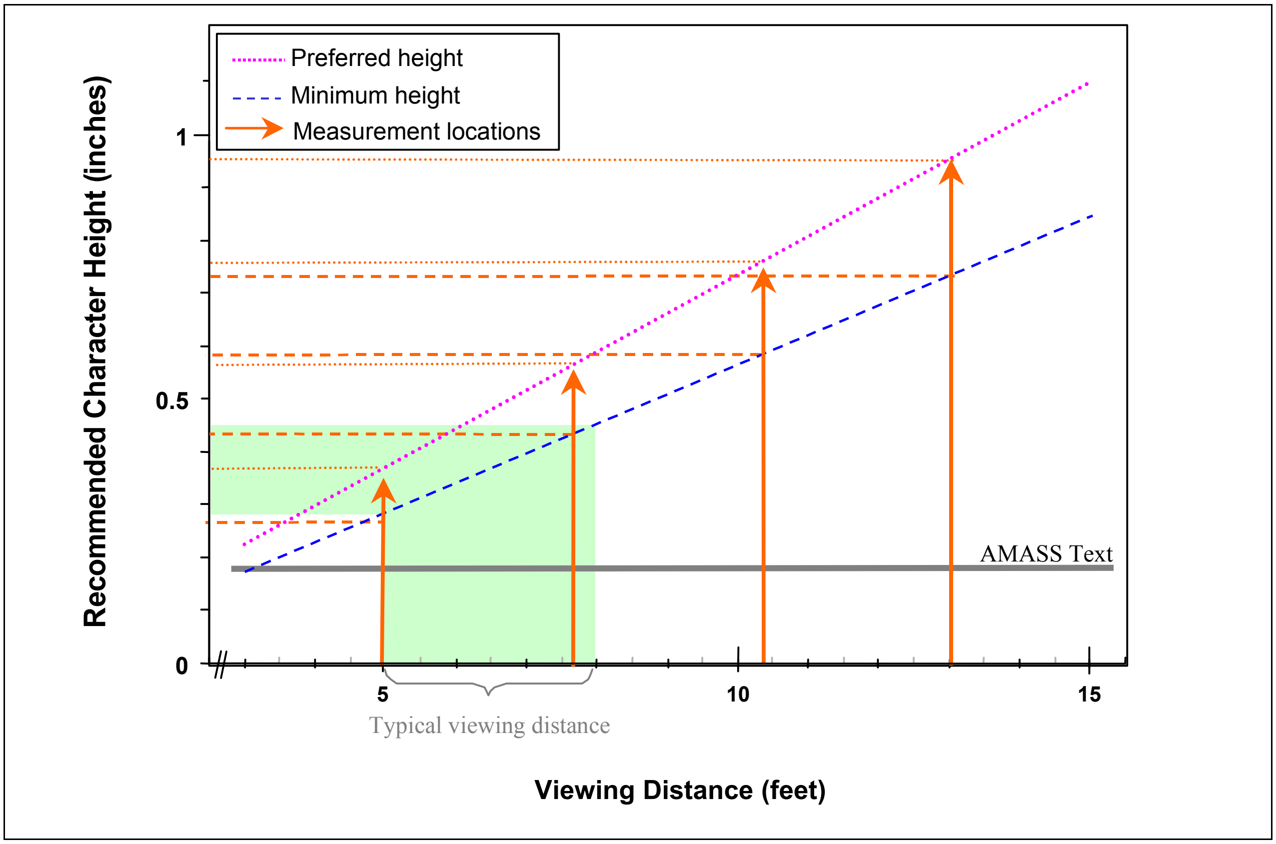

Figure 8. Recommended character heights for measured viewing distances.

3.2 Response Time Evaluation

Each controller completed one trial on the timing task. This included six conflict events, resulting in two sets of data for each scenario. The response times to react to a conflict event ranged from 1.43 to 11.47 seconds. However, the research team believes these data are not a valid representation because the test conditions did not represent a realistic operational environment. For example, D-BRITE information was not available, the controllers were not able to view the aircraft out of the window, the response time available varied widely between conflict events, and the events presented varying degrees of difficulty.

The research team debriefed the participants immediately after each response time scenario. They asked them to retrace their responses to the conflict alert incidents. There was a consistent pattern in that their first indication of an alert was the initial part of the voice message saying "caution" or "warning." This oriented them to look at the ODU for the octagon symbols to determine the location of the conflict. Sometimes they read the text message to locate which runway the alert was on. The controllers' visual scan would normally then include looking out of the window for the aircraft and checking the D-BRITE if an arrival was involved.

Most participants reported that they did not listen to the aural alert after the initial word or two. Many also said they read little or none of the text alert. Their attention was focused on locating the conflicting aircraft on the airport map. They stressed that a rapid response time was essential and that this left little time for listening to or reading the alert messages. Screen symbols seemed to carry the most valuable information.

The controllers mentioned that the hold bars might be distracting in that they came on when there was an alert but also at other times. They might be seen as preceding an alert when there was none.

3.3 Usability Evaluation

The usability evaluation results consisted of two elements. These included an assessment of the time to perform common ASDE/AMASS controller tasks and participant ratings of the usability of aspects of the AMASS CHI. The procedures are detailed in Section 2.3.3.

3.3.1 AMASS Set-up Time

Pairs of controllers worked through the list of common ASDE/AMASS functions presented in Section 2.3.3.1. The time to complete these AMASS functions is not presented because the test conditions did not replicate a realistic operational situation and the controllers did not receive formal AMASS training. The research team recommends that the time to perform these functions be addressed in a more controlled test. However, the controllers reported that some functions were more problematic and should be reviewed. These included centering/de-centering the map, filtering arrival alerts, moving alert windows, and filtering all alerts for the specified ground track. Some controllers noted that the ASDE radar intensity can be inadvertently set to zero, a runway may appear to be closed if the cursor is placed at the end of the runway, the use of the SHIFT and ENTER keys is confusing, and it was difficult to locate the MP2 and MP4 keys. The last two items appear to be attributable, at least in part, to the brief training that the controllers received on AMASS.

During the usability evaluation, some controllers suggested that the map rotation function (using on-screen graphics) was difficult to use. When adjusting map range, it would be good if the map changed as the up and down arrows are pressed (providing direct feedback) instead of after pressing ENTER. The menu that controls the brightness of screen elements could inadvertently be set to zero brightness. This could require focused attention to the ODU while trying to re-establish the menu. Also, they questioned the ability to set radar targets and alphanumerics to a zero brightness level.

Most of the participants indicated that it was difficult to remember ASDE and AMASS keypad entries and suggested that an instruction card be provided as a work aid. Some commented that a menu driven user interface would be easier for occasional use. It was sometimes difficult to determine if the system was in ASDE or AMASS mode. There were also many abbreviations used on the screen.

In order to uninhibit targets, the controller would have to slew to all the aircraft on the screen. The maintenance mode indicator on the ODU could cover part of the alert box if positioned at the top of the screen. They also noted that a unique aural alert for AMASS is needed in the tower, given the number of alerts already possible from various pieces of equipment.

3.3.2 Usability Questionnaire

All participants completed the post-evaluation, CHI, usability questionnaire. For Items 1 through 14, they were asked to indicate whether or not that aspect of the system was acceptable. A 'Yes' or 'Yes with comment' response indicated that the item was effectively supported by the AMASS CHI. For those items not considered to be adequately supported by the current build, they indicated 'No' and then rated the need to address the issue as Low, Medium, or High. Comments were also requested if a "no" answer was given.

Table 7 provides a summary of the responses to the first 14 items. It includes the item, the total number of yes responses (including the number 'Yes with comment' ratings in parentheses), the total number of 'No' responses, and the importance rating for those items rated as 'No.'

Ten additional usability items focused on the controllers assessment of general aspects of the AMASS and the test methodology (Table 8). For these items, the questionnaire provided a 5-point, Likert-type scale. The anchors were Strongly Agree (1) to Strongly Disagree (5) for all but the first two items. For item 15, the scale was Very Fast (1) to Very Slow (5), and, on item 16, it was Very Easy (1) to Very Difficult (5).

During the evaluation, the controllers commented on various other aspects of the system, as follows:

a. When the ASDE/AMASS menu choice is selected, the menu does not automatically disappear, and the controller must manually close it.

b. Acceleration on departure runways should trigger alerts, not only the 50 miles an hour speed.

c. If there are multiple position specific workstations, the supervisor might not have time to configure them.

d. A flat panel color display should be considered for use in future tower systems.

e. Although the target symbol is not useful for aircraft, it does help them identify the location and direction of travel of small vehicles.

4. Discussion

4.1 General

This section discusses the results from each of the three evaluation components: display evaluation, response time evaluation, and structured usability assessment. Results of discussion sessions conducted at the RDHFL also are addressed.

The display evaluation consisted of a readability component and the application of human factors standards and guidelines to AMASS. The readability assessment indicated that, with the exception of alert category (i.e., caution or warning), controllers were capable of identifying AMASS screen elements from 5 feet directly in front of the display. The controllers experienced more difficulty during the night viewing condition than during the day conditions. They also exhibited poorer readability at 45 degrees off axis under all lighting conditions.

Table 7. Count of Controller Response for Usability Questionnaire Items 1 through 14

Item	Total 'Yes' Responses ('Yes' with Comment)	Total 'No' Responses*	Importance of Issue* Low	Medium	High
I. Data Entry					
1. Does the main keyboard adequately support AMASS functions?	6 (5)	1	1	0	0
2. Does the keypad adequately support AMASS functions?	10 (9)	2	0	1	1
3. Is the trackball acceptable for controlling AMASS?	12 (2)	0	0	0	0
4. Are the hot keys acceptable for those tasks you must perform regularly?	7 (2)	5	1	2	2
5. Is the number of keystrokes or other actions to control AMASS acceptable?	9 (0)	3	1	2	0
6. Is the amount of head-down time required to set up AMASS for your shift acceptable?	9 (5)	3	0	2	1
7. Can AMASS control tasks (such as inhibiting a track) be completed efficiently, without significant head-down time?	5 (2)	7	0	5	2
II. Display					
8. Did you find the on-screen text messages readable at your typical viewing distance? [Typical distance 5-8 feet, 5.9 average overall]	7 (5)	5	0	1	4
9. Did you find the content of the on screen text messages easy to understand?	7 (4)	5	1	1	3
10. Did you find the symbols easy to identify at your typical viewing distance?	5 (3)	7	2	2	3
11. Did you find the symbols easy to interpret?	10 (5)	2	1	0	1
12. Is the quality of the digitized voice acceptable (i.e., speed, intelligibility, etc.)?	8 (3)	3	0	1	2
III. General					
13. Can you easily perform the AMASS actions you commonly need to undertake?	7 (4)	2	0	2	0
14. Is it clear which controller is responsible for coordinating/responding to an alert?	9 (4)	2	0	0	2

Table 8. Count of Controller Ratings for Usability Questionnaire Items 15 through 25

Item (Scale)*	Count of Ratings 1	2	3	4	5	Average
	← Favorable		——	Unfavorable	→	
IV. Overall						
15. The AMASS system response time is: (Very fast – Very slow)	0	6	5	1	0	**2.6**
16. Performing the AMASS actions I commonly need to undertake is: (Very easy – Very difficult)	1	1	8	1	0	**2.8**
17. AMASS supports my ability to control traffic:	2	5	1	1	2	**2.6**
18. When responding to an AMASS alert, it is clear which controller is responsible for coordinating/ responding:	3	4	1	3	0	**2.4**
19. AMASS is easy to learn:	0	6	6	0	0	**2.5**
20. AMASS is easy to use:	1	3	6	2	0	**2.8**
21. Overall, I am satisfied with the AMASS functions I used:	1	2	2	5	2	**3.4**
22. Overall, the current AMASS design is acceptable:	0	1	5	3	2	**3.6**
23. Based on my experience during this evaluation AMASS provides adequate time to react:	0	5	3	3	1	**3.0**
24. The tasks I performed during the usability evaluation were representative of the tasks I will be required to regularly perform in my everyday duties:	0	2	1	7	1	**3.6**
25. The secondary task (i.e., moving the aircraft on the SFO map) did not interfere with my ability to respond to the AMASS alerts:	2	6	0	2	2	**2.7**

* Scale anchors are **Strongly agree – Strongly Disagree** unless otherwise noted.

The visual display standards indicated that the current AMASS character height is acceptable at a viewing distance of 29 inches. The AMASS screen elements met visual display standards for contrast, display luminance, flash rate, and auditory alarm loudness.

The test environment in the response time evaluation was not representative of real world conditions and did not provide a valid measure of controller performance. However, this part of the assessment was valuable in determining controller activities in response to an AMASS alert. When the aural alert occurred, the controller looked at the ODU to find the octagon symbols and identify the location of the conflict. A few controllers read the text message to determine which runway the conflict occurred on before taking the appropriate action. Most controllers did not listen to the aural alert beyond the first word or two.

Some controllers expressed concern regarding the fidelity of the response-time task. They did not believe that the tasks that they performed were representative of their every day duties. For example, some controllers commented that the tests did not include a sufficient range of common tasks and that too much attention had to be focused on just waiting for the next alarm. Therefore, caution is warranted in extrapolating these data to real world situations.

The structured usability component included an assessment of AMASS set-up time and a usability questionnaire. During the set-up time component, some functions were reported to be potentially problematic. These included centering/de-centering the map, filtering arrival alerts, moving alert windows, use of the SHIFT and ENTER keys, and filtering all alerts for the specified ground track.

The usability questionnaire assessed controller satisfaction with the current AMASS design, functions used, time to react, system response time, ease of learning, and ease of use. Overall, the ratings were neutral to slightly negative. The responses averaged from 2.4 to 3.6 on the 5-point scale, on which a rating of 1 represented a favorable rating and 5 an unfavorable rating. These ratings reflect the controller opinions that some aspects of the existing system need to be addressed. Among the items that some controllers rated negatively were head-down time to perform AMASS control tasks, readability of AMASS text messages, and use of function keys. They rated the AMASS symbols, use of the trackball, and system response time favorably.

The researchers conducted group discussions at the RDHFL to identify AMASS issues. During these sessions, the controllers used rapid prototyping tools to evaluate potential solutions. The controllers indicated that one potential item, crew coordination, was not significant because it was clear which controller was responsible based on the location of the alerting target. However, the controllers proposed the addition of a conflict location box, which might support crew coordination. The controllers recommended that procedures for coordination between a controller and supervisor be clearly identified.

4.2 Issues

During the final caucus, the controller participants, human factors specialists, AMASS Working Group members, and other study participants identified and categorized 14 preliminary AMASS human factors issues. They grouped each issue in terms of High, Medium, or Low importance and provided the importance rating in Italics immediately following the item title. Two issues warranted a Medium-high rating because they fell between the anchor points. The team provided issue numbers to facilitate tracking. However, these numbers do not reflect the priority of the issue. Data from the study are included in the discussion as they relate directly to that issue. Potential recommendations are provided following the discussion of each issue.

1. Runway closure icons (*High*)

In the current AMASS build, closed runways are indicated by an 'X.' Many of the participants experienced difficulty differentiating between these icons and the existing ASDE/AMASS cursor. Furthermore, if the cursor is positioned at the end of a runway, a controller may believe that the runway is closed when it is not.

During the group discussions, the participants utilized the AMASS emulation platform to identify potential solutions. First, they requested solid shading be used to represent closed runways. However, the group later realized that this solution was unacceptable because the fill pattern obscured ASDE targets within the shaded area. The group developed a second alternative in which the existing runway closure 'X' was made bolder and the stroke lengths were increased, as illustrated in Figure 9. The modified symbology clearly identified closed runways, did not obscure ASDE targets, and was easily differentiated from the cursor.

Figure 9. Modified runway closure icons.

Recommendation: *Investigate methods to enhance the AMASS runway closure symbol and to differentiate it from the ASDE/AMASS cursor. The alternative developed by the participants should be considered.*

2. Mandatory Procedures (*High*)

The working group tentatively identified two situations for which the controllers' action is a mandatory go-around (arrival to an occupied runway and arrival to a closed runway). The controllers were trained in these procedures at the beginning of the week. During the

RDHFL discussions, some controllers suggested that for those situations in which their action is mandated, the visual and auditory alerts should present the required action. For example, in the case of an arrival to an occupied runway, AMASS would state "go-around, 28L, go-around" instead of just indicating the type of conflict. Presenting the mandatory procedure may help to decrease controller reaction time because it does not require them to assess the situation. However, other controllers recommended relying on their training and did not believe the system should indicate the required action. During the final caucus, the controllers recommended that mandatory procedures be presented in the alerts.

Recommendation: *Review whether providing required controller actions in the AMASS alerts is appropriate. Regardless of the solution employed, human factors guidelines dictate the need to maintain consistency in the auditory and text messages.*

3. Aural alert message content and quality (*High*)

When questioned about voice quality in the usability questionnaire, eight participants rated the current implementation as acceptable, though three qualified it with a comment. Three participants rated the voice quality as unacceptable, with one rating it as a Medium issue and two providing a High rating. The comments indicated that the voice was a monotone and sounded choppy and slow. They noted that there was no preceding tone to draw attention to the alert and that the AMASS voice alert could be confused with other systems that employ voice alerts such as the Aircraft Target Identification System. Some controllers noted that the sequence was not consistent with existing terminology (e.g., "28 left, Occupied Runway" instead of "Runway 28 left, Occupied") and that it did not repeat important elements that might have been missed. Unlike visual information, auditory information is transitory, therefore human factors guidelines recommend repeating important oral messages. Though the ratings on the questionnaire were relatively favorable, the participants applied a High overall rating to this issue during the final caucus.

During prototyping sessions held at the RDHFL, the research team used sound editing software to implement controller recommended modifications to an existing AMASS voice alert. The session resulted in an alternative for the existing aural alert. Both versions of the alert are presented in Table 9. In the new alert, the group added three leading alert tones, increased the speech rate by approximately 15%, rearranged the message structure, and repeated critical information. Human factors guidelines recommend that alert tones be provided to orient the user to the impending information and that important message elements be repeated with less than a 3-second interceding pause (Wagner et al., 1996). This would likely necessitate an increase in the current speech rate to avoid lengthy voice alert. However, this would serve to address the controller concern regarding the current speech rate.

Speech alerts are appropriate in situations where the user must respond quickly and when qualitative information is required, which is the case with AMASS. These alerts also support tower cab crew situation awareness.

Table 9. Existing and Modified AMASS Auditory Alert

Existing Auditory Alert:
"Caution . . . Zero one right, occupied runway"
Modified Auditory Alert:
"Caution . . . Runway one-right occupied . . . Runway one-right occupied"

Recommendation: *Review the content of the existing AMASS voice alert messages to ensure consistency with current controller terminology. Any resulting changes in the auditory alerts should be reflected in the accompanying text message.*

4. Alphanumeric Symbols (*High*)

AMASS uses several symbols to provide information regarding the status of targets on the ODU. The primary symbol is an octagon that identifies the targets associated with the alert condition. Alphanumeric symbols are placed on target icons to indicate several conditions. An 'M' denotes false tracks (multipath targets), 'S,' a stopped track, '1,' a single-track alert, and 'A,' an inhibited track. On Item 11 of the usability questionnaire, 10 of the participants indicated that the AMASS symbols were easy to interpret. During the discussions held at the RDHFL and on the usability questionnaire, the controllers indicated that the octagon was very useful, but they suggested that it be made bolder. The majority of controllers indicated that the alphanumeric symbols, in particular the "A" superimposed on inhibited target icons, were difficult to discern. On Item 10 of the usability questionnaire, 7 of the 12 controllers indicated that the alphanumeric symbols were not discernible at the typical 3 to 8 foot viewing distance. This was supported by the readability data. Three participants rated the issue as High, 2 as Medium, and 2 as Low.

In the prototyping sessions, both controller groups modified the same potential solution to the issue. They denoted inhibited targets by placing a box around the target, as illustrated in Figure 10. The modification allowed controllers to identify the box at extended viewing distances and ensured that other members of the tower cab crew would be immediately aware of the inhibited target when viewing the ODU.

Recommendation: *Identify appropriate methods to support the controller's ability to readily identify inhibited targets. The solution presented in Figure 10 may be a viable alternative.*

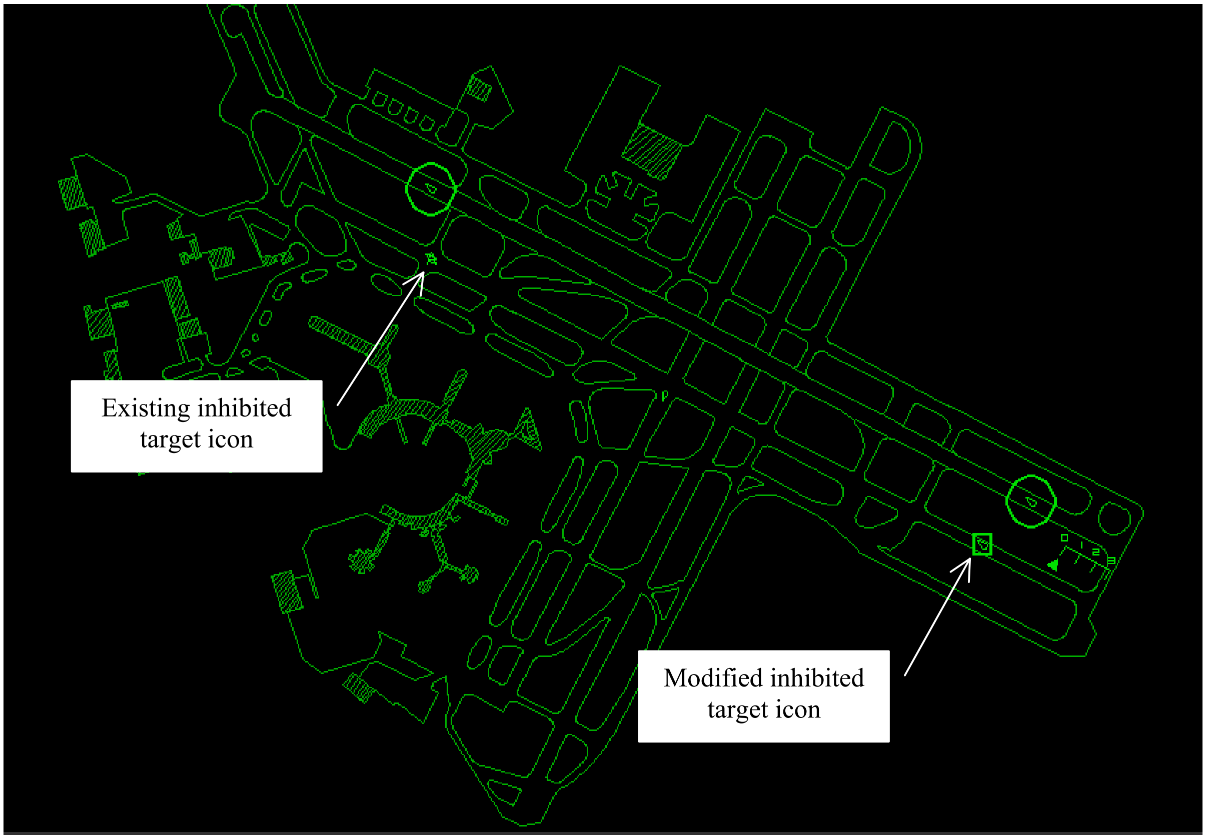

Figure 10. Existing and modified icons for inhibited targets.

5. Text alert message font size (*High*)

Seven participants indicated on the usability questionnaire that they found the AMASS text screen readable at their typical viewing distance (Item 8), whereas five indicated that it was not. The responses identified the typical viewing distance to range from 5 feet to 8 feet with an average distance of 5.9 feet. Of the seven acceptable ratings, five rated it as acceptable with a comment. The comments all addressed the need to increase font size. For the no responses, four rated the issue as High, whereas the remaining individuals rated it as Medium.

The readability data showed that participants were much better at identifying the octagon, target, and hold bars regardless of lighting condition than the category, runway identification, or message text elements. At the 0-degrees viewing angle, the comprehension of AMASS text information (runway and alert message) was only readable by all controllers at 5 feet from the ODU. These data support the controllers' concerns.

During the discussion sessions, the controllers indicated that they focused almost exclusively on the octagons when responding to alerts. Most said that they did not read the text containing the runway identification and alert description or attend to the auditory alert message before responding. This may be explained in part by the immediate need for the controller to respond to the alert and the amount of information conveyed by the octagon alone. The octagon conveys the conflicting target location, the category of alert, and the nature of the alert (e.g., number of targets involved, rate of speed and direction, and whether they are converging). The readability data indicate that the participants were very successful at identifying the octagons regardless of lighting condition or viewing angle. At least 11 of the 12 participants identified the octagons even at the 13-foot viewing distance. However, these data should be interpreted with caution because, in the case of the symbols, there were only 3 possible choices (i.e., octagon, target, or hold bar), but for the text message, there were 35 (i.e., 26 letters plus 9 digits).

Even if the controllers rely almost exclusively on the octagons to respond to an alert, increasing the text message font size should be considered. During the group discussions, the participants recommended that the font size be doubled and that the text message box be removed. The current text size meets minimum display-viewing standards at just over 3 feet. However, some of the controllers noted that they may be as far as 15 feet from the ODU. The controller in-charge may also be located up to 15 feet from the ASDE and supervisors even further. Based on visual display terminal guidelines (ANSI, 1988), a font size of 0.84 inches (1.10 inches preferred) would support accurate readability at this distance. The message box appears to offer little utility to the controller and removing it would help to minimize screen clutter.

Though the controller can rely on the voice alert, there is significant value in providing both visual and auditory alerts. Research conducted by the Air Force and Navy indicates that faster response times are achieved when voice-warning alerts are used in conjunction with visual displays (Kantowitz & Sorkin, 1983). Increasing font size would also enable other personnel in the tower cab to gain critical information on the conflict and potentially support resolution.

Recommendation: *Increase the existing AMASS font size to support controllers and other members of the tower cab crew. The team recommends that the font be increased to between 0.84 and 1.10 inches and that removal of the text box be considered.*

6. Arrival aircraft (*High*)

Another issue that the controllers identified during the final caucus was the need to include data blocks for arrival and lander aircraft. During preliminary discussions at the RDHFL, some controllers suggested that this might not be required because this information is available on the D-BRITE. By requiring the controller to refer to an additional display before responding to the alert, response time might be increased. The participants recommended that a data block like the one provided in Figure 11 be included on the ODU.

Recommendation: *Consider the addition of a data block similar to that presented in Figure 11 for all arrival and landing aircraft. If included, the data block should be the same brightness as the octagon and other AMASS elements.*

Figure 11. Arrival aircraft data block

7. Multiple alerts (*High*)

AMASS provides multiple text alerts in the event of multiple conflicts for a single target or when conflicts occur between several different targets. The current text area provides sufficient space for five alerts to be displayed simultaneously. The text alerts are not prioritized but presented sequentially in the order of occurrence. The controllers indicated that, in these cases, they had difficulty determining the priority of the messages and identifying which octagons were associated with each alert.

Recommendation: *Conduct further analysis. Color coding of alert messages could be considered if supported by future ASDE/AMASS displays.*

8. Hold bars (*Medium-High*)

Hold bars are displayed whenever a target is above a threshold speed, regardless of whether an alert exists or not. The controllers stated that they found the hold bars distracting and did not serve a useful function. During busy periods, the bars appear constantly, and this activity on the screen may cause controllers to divert their attention to the ODU when there was no conflict. They also indicated that, in the case of a conflict, the hold bars may draw their attention away from the area of conflict, potentially slowing their reaction time.

Recommendation: *Consider removing the hold bars.*

9. Conflict Location (*Medium-High*)

The controllers indicated that the octagons are very effective in identifying the targets involved in a conflict. Many stated that they focused almost exclusively on these symbols and did not attend to the additional visual and auditory information available before responding to the alert. On many occasions, the controller had responded to a conflict situation before the auditory message was complete. The controllers stated during the discussion groups that there were occasions when they had some difficulty locating the octagon symbols. They suggested that the value of the octagons might be augmented by adding a conflict location box placed around the runway involved in the conflict, similar to the one presented in Figure 12.

Recommendation: *Consider providing a conflict location box to support the ability of controllers to readily identify the area of conflict.*

Figure 12. Conflict location box.

10. AMASS keypad (*Medium*)

The controllers perform ASDE/AMASS operations using either a keyboard or keypad. Both input devices were available during the evaluation, but the keypad was used for all data collection sessions. The first two usability questions addressed whether the keyboard and keypad provided adequate support for AMASS functions. The keyboard item drew few comments other than that they typically do not use it. Ten of the respondents indicated that the keypad provided adequate support for AMASS. The two respondents who stated it did not rated the need to address the item as Medium and High. All participants indicated on the usability questionnaire (Item 3) that the trackball effectively supported AMASS functions.

The controllers commented during the discussion sessions and on the questionnaire that, unlike ARTS, AMASS functions will be used infrequently and so they expected to have difficulty remembering function key assignments. This could result in increased head-down time. The controllers exercise AMASS functions infrequently, therefore some form of reminder is necessary.

The AMASS user interface is consistent in style with existing ASDE functions thereby avoiding the need for users to adapt to a different interface. Five users indicated that the

AMASS hot keys are not acceptable in their current form. The research team believed that this concern may diminish as users gain more familiarity with the system and when they have access to reference materials for AMASS functions. They also noted that the brightness intensity of menus and radar targets could be inadvertently changed to zero. The controllers commented that the clear and enter keys are combined onto one key, requiring multiple keystrokes and potentially increasing controller head-down time. This is related to the ASDE system.

Recommendation: *Provide quick reference materials identifying key combinations for common AMASS functions. Laminated quick reference cards, engraved function templates, or color-coded ASDE/AMASS function keys may be appropriate choices. The team suggests that minimum intensity levels be established for menus and radar targets. Separate CLEAR and ENTER keys should be considered when the existing ASDE/AMASS keyboard is upgraded.*

11. Arrival indicator line (*Medium*)

AMASS presents an arrival indicator line for all arrivals. The line includes a scale with mile increments and a small marker reflecting the arriving targets distance from the runway. The line default position is at the arrival end of the runway, but its location can be modified through site adaptation. Most of the controllers were unaware of the presence of these lines and did not use them during the response time trials. In its current form, the arrival indicator line is difficult to see, contributes to screen clutter, and may obscure targets on the runway. Although the information that it provides is redundant with the D-BRITE, some controllers believed that it might be beneficial to have this information immediately available on the ODU.

Recommendation: *Increase the size of the arrival indicator line and position it in a location that will not obscure ASDE radar reflections.*

12. Cursor (*Low*)

The participants noted that the AMASS cursor is easily lost among ODU screen elements, that it may be placed off the screen, and that it cannot be forced to a known location. Additionally, the cursor icon is easily confused with the AMASS closed runway icon, as discussed in Issue 1. The controllers indicated that, for these reasons, they could spend considerable time trying to locate the cursor, potentially resulting in increased head-down time.

This issue is not specific to AMASS. The cursor is part of ASDE and represents the system currently used in the tower environment. This may account for the low importance rating the participants applied to the issue. However, they recommended considering increasing the cursor intensity, inhibiting the ability to place the cursor off the screen and incorporating a cursor homing function.

Recommendation: *Modify the existing runway closure icon so that it can easily be distinguished from the ASDE/AMASS cursor. The research team recommends that inhibiting the ability to move the cursor off the screen and providing a cursor homing capability be considered during future ASDE upgrades.*

13. Mode awareness (*Low*)

The participants indicated that they could not determine which mode (ASDE or AMASS) would appear when they invoked the menu after a period of inactivity. When AMASS is online, the word "OPERATIONAL" appears in the second text box at the bottom of the display. However, this provides no indication as to whether the AMASS or ASDE menu will appear. The controllers recommended that, after a period of inactivity, the system default to ASDE mode because that system contains the functions they most commonly invoke.

Recommendation: *Investigate the value of defaulting to the ASDE menu after a period of inactivity, possibly 45 seconds to 1 minute.*

14. Enable/disable multiple targets (*Low*)

AMASS does not permit multiple targets to be simultaneously enabled or disabled. The user must select one target at a time and then invoke the AMASS menu to inhibit or re-enable conflict logic on that target. Therefore, if a controller needed to inhibit five targets, they would have to perform the procedure five separate times. Items 5 and 7 of the usability questionnaire addressed aspects related to this issue. Item 5 focused on the number of keystrokes or other actions required to control AMASS. In response to this item, nine controllers indicated that the current interface was acceptable, and three indicated that it was not. Item 7 of the usability questionnaire addressed whether the system permitted efficient operation of AMASS functions without significant head-down time, particularly when inhibiting a track. Seven controllers indicated that the current implementation is not efficient, with 5 of them rating the importance of the item as Medium, and the two remaining respondents indicating that it was High. The participants forwarded no specific recommendations for a solution to this issue. However, they mentioned the analogy of current Microsoft Office products in which the shift key supports the selection of multiple objects.

Recommendation: *Investigate the feasibility of providing the ability to enable/disable multiple targets simultaneously.*

5. Conclusions

The AMASS human factors evaluation included assessments of keypad usability, ODU readability, head-down time required for AMASS operation, voice alert quality, and tower cab crew coordination. The team divided the evaluation into display, response time, and usability components.

The following paragraphs present some of the more important results from the human factors viewpoint. They do not address all of the 14 usability issues that emerged from this evaluation.

The AMASS Working Group, with support from the human factors team, should review these issues in detail to make implementation recommendations.

The readability data indicate that text message readability is only adequate at 5 feet or less directly in front of the display for recognition of critical information. Although the text message was not usually found to be the primary source of guidance for conflict resolution, its usefulness is limited by poor readability. If the text is primarily for the active controller, this may be a problem in that study participants said they sometimes look at the display from further away. The text also may not be helpful for others in the tower cab trying to view the ODU. Increasing the size of the alert text is supported by the human factors guidelines and the data from this study.

Although it was not relevant to report the observed controller response time data for conflict alerts, the research team gained valuable information by debriefing the participants after each scenario. This underscored the importance of a rapid reaction to an AMASS conflict alert. There are often only seconds available for the controller to determine the source of the conflict and the correct intervention. It was found that the participants did not usually listen to the full aural alert message. It was primarily a signal that alerted them to a conflict event and directed their attention to the ODU. The controllers looked for the octagons on the airport map to locate the conflict. The on-screen text message was often only read after the conflict resolution action had been completed.

The results indicate that the AMASS alerting scheme should be reviewed. A distinctive and attention-getting aural alert should be used to quickly gain the controller's attention. On-screen symbols should be emphasized to enable quick orientation to the conflict situation. Text messages should be considered mainly as supportive, redundant information. However, the text and voice alerts should be retained and improved to reinforce the intent of the symbols and so that other controllers in the tower can quickly become aware of the situation. The primary informational components of aural alert and on-screen symbology should be refined to enable a rapid evaluation of the conflict. Other messages should be enhanced and improved but should not be permitted to negatively affect the critical information path.

The issue of whether to change some aural and text alerts to provide an instruction (such as in the case of mandatory procedures) needs further consideration. It may not be wise to change the intent of some of the messages and not others. Given that alerts will occur infrequently, controllers might expect instructions with all messages and delay slightly to wait for them. The team suggests that this be discussed further within the AMASS Working Group.

The usability part of the evaluation permitted a review of AMASS functions. In the process of collecting the data, it became evident that participants were also not very familiar with the selected ASDE functions. This could be because they do not have to change ASDE settings frequently or because it is difficult to do so, or a combination of both. In this report, it was possible to determine which functions might be especially problematic by viewing the videotape and analyzing comments and questionnaires.

The study did not provide accurate data to establish the amount of time needed to complete ASDE or AMASS functions. A more controlled experiment in a realistic simulation environment would be needed to definitively address this question. Questionnaire data suggest that most of the participants thought that head-down time was acceptable. However, several controllers thought this was a problem and observations during the walkthrough of system functions shows that some of the functions are difficult to remember and use. The provision of regular refresher training and a fixed instruction card would improve this situation. This might be sufficient for initial field implementation, but redesign of the ODU user interface and keypad would reduce head-down time to a minimum.

Tower cab crew coordination is a complex issue that was partly addressed in the study. Good teamwork during an alert will require the design and practice of effective procedures. However, the AMASS itself can support this by providing useful information. As has already been mentioned, much of the aural and text alert message content may be more helpful for observers than the controller responding to the conflict. Improvements to screen symbols, fonts, and aural message content will support the situation awareness of others in the tower cab. However, further work should be completed on how the tower cab crew should respond to alerts.

In this evaluation, the research team has addressed most of the original goals in the test plan. In the long term, substantial changes to the system are needed to improve its effectiveness and usability. The research team believes that it is important to ensure that installation of the system with the agreed upon modifications will not create problems. For example, a high false alarm rate may cause the system to be shut off or real alerts to be ignored. Errors in applying procedures in response to an alert might create undesirable situations. However, implementation of AMASS, even in a form close to its present state, may prevent some accidents. The research team recommends that the AMASS Working Group review the issues published in this report in terms of the minimum set needed to safely deploy the system. A follow-up assessment should be conducted prior to deployment to validate the improvements and check for any unforeseen problems.

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Appendix A

Participant Background Questionnaire

Participant Background

Participant Code: _________________

1. What is your current job title? ____

2. To which facility are you currently assigned? ____

3. How much experience do you have as an ATCT specialist? Years: ________ Months: ____________

4. How much experience do you have using ASDE? Years: ________ Months: ____________

5. Have you participated in previous AMASS evaluations? Yes _____ No _____

   If so, when? Date: _____________________ Which Version? ______________________________

6. What do you feel is your general computer experience level?
   beginner ________ intermediate __________ advanced __________ expert ____________

7. Have you received training on AMASS? Yes _____ No _____ If so, when? Date: _________________
   What type of training did you receive? Please check each that applies.
   Classroom _____ Hands on _____ Other (please specify): ______________________________

8. When controlling traffic, what is your typical distance from the ODU? _____________ (feet)

9. What is the maximum distance you stand from the ODU? _____________ (feet)

10. Is there anything else you would like to add regarding your participation in this assessment? __________

    ____

    ____

Appendix B

AMASS Text Readability Procedures

Instructions to Load Readability Scenarios

1) Launch AMASS in Maintenance Mode (wait for tests to complete and “passed” to be displayed).

Configure System:

2) System Window/Sys Option/DP to ODU Options:
   a) Deselect “Suppress DPO output”
   b) Deselect “Suppress DPG output”
   c) **Enable “Icons/Alert text to ODU**”
   d) **Deselect “Voice Alerts**”
   e) Set alert persistence to 30 seconds (Movement Area Adaptation/Edit/Site/Alert persistence)

Load Configuration and Scenario:

3) Movement Area Window/Adaptations/File/Load/Op Configuration XXXX-XX (select appropriate **Op Configuration** from table)
4) Synthetic Scenario Window/Options/File/Load Scenario/X.X.X.X-X (Select appropriate **Scenario** from table)
5) System Window/go online
6) Synthetic Scenario Window/Inject tracks
7) *Perform readability test*
8) System Window/go offline
9) Repeat Steps 3 through 8 until all conditions complete

Test Scenarios:

Alert	Table 3-12 Ref. No.	Ops Configuration	Scenario	Alert Text (Displayed on ODU)
1	13	2801-04	1.1.3.c-0	W: 28L, OCCUPIED RUNWAY
2	19	2801-04	1.3.4.d-0	W: 28R, HEAD-ON TRAFFIC
3	8	2801-04	1.3.6.b-0	W: 28L, LDG OCCUPIED RWY
4	10	2801-05	1.1.1.c-0	W: 28R, MULTIPLE DEPS
5	21	2801-05	1.3.3.d-0	W: 28R, HEAD-ON LDGS
6	11	2801-04	1.1.4.c-0	W: 01L, DEP, OCCUPIED RWY
7	17	2801-06	1.1.3.d-0	W: 01R, HEAD-ON TRAFFIC
8	14	2801-06	1.3.3.c-0	W: 28L, LDG, OCCUPIED RWY

Appendix C

AMASS Text Readability Data Collection Form

***Items to be completed by test director*:**

Sunglasses: On Off **Date:** ____________ **Time:** ____________ **Participant Code:** ________

***Items to be completed by controller*:**

Distance (circle): 5' 7'8" 10'4" 13' **Angle (circle):** 0 degrees off axis 45 degrees off axis

AMASS Symbol

Octagon ☐ None ☐ 1 ☐ 2

Target ☐ None ☐ 1 ☐ 2

Hold Bar ☐ Yes ☐ No

Text Message ______________________________

Distance (circle): 5' 7'8" 10'4" 13' **Angle (circle):** 0 degrees off axis 45 degrees off axis

AMASS Symbol

Octagon ☐ None ☐ 1 ☐ 2

Target ☐ None ☐ 1 ☐ 2

Hold Bar ☐ Yes ☐ No

Text Message ______________________________

Distance (circle): 5' 7'8" 10'4" 13' **Angle (circle):** 0 degrees off axis 45 degrees off axis

AMASS Symbol

Octagon ☐ None ☐ 1 ☐ 2

Target ☐ None ☐ 1 ☐ 2

Hold Bar ☐ Yes ☐ No

Text Message ______________________________

Distance (circle): 5' 7'8" 10'4" 13' **Angle (circle):** 0 degrees off axis 45 degrees off axis

AMASS Symbol

Octagon ☐ None ☐ 1 ☐ 2

Target ☐ None ☐ 1 ☐ 2

Hold Bar ☐ Yes ☐ No

Text Message ______________________________

Appendix D

AMASS Usability Questionnaire

AMASS Usability Questionnaire

Participant Code: ______________________

Purpose:

The following questions are designed to assess your opinion of the usability AMASS in support of your duties.

Instructions:

1. Read each item carefully. Please restrict your answers to AMASS. Review your notes for each item before entering your rating.
2. **Check** the box that most accurately reflects your experience using AMASS. Each item includes a statement followed by two scales.
   - For items 1 through 14. Check the box that represents your experience using the following three options: **Yes**, **Yes with Comment**, or **No**.
   - For item 15 through 26. Enter your rating on the 5-point scale provided.
3. If you indicated **No** to any item then rate the importance of addressing the issue in terms of **Low**, **Medium**, or **High**. Enter your rating based on the following descriptions.
   - **Importance**
     - **Low** The problem will result in little impact to the way you perform but should be addressed in future builds.
     - **Medium** The problem will result in a change in the way you perform your duties and should be addressed as soon as possible.
     - **High** The problem is safety critical and should be addressed immediately.
4. A comment field is provided for each item. Please provide an explanation for any items that you identified as a problem.

5. If you have any questions, or do not understand an item, please contact the usability evaluation administrator.

The information you provide will be kept strictly confidential.

Thank you for your participation.

Item	Rating	Comments
I. Data Entry		
1. Does the main keyboard adequately support AMASS functions?	☐ Yes ☐ Yes (with comment) ☐ No* *** Importance:** Low ☐ Medium ☐ High ☐	
2. Does the keypad adequately support AMASS functions?	☐ Yes ☐ Yes (with comment) ☐ No* *** Importance:** Low ☐ Medium ☐ High ☐	
3. Is the trackball acceptable for controlling AMASS?	☐ Yes ☐ Yes (with comment) ☐ No* *** Importance:** Low ☐ Medium ☐ High ☐	
4. Are the hot keys acceptable for those tasks you must perform regularly?	☐ Yes ☐ Yes (with comment) ☐ No* *** Importance:** Low ☐ Medium ☐ High ☐	
5. Is the number of keystrokes or other actions to control AMASS acceptable?	☐ Yes ☐ Yes (with comment) ☐ No* *** Importance:** Low ☐ Medium ☐ High ☐	

Item	Rating	Comments
6. Is the amount of head-down time required to set up AMASS for your shift acceptable?	☐ Yes ☐ Yes (with comment) ☐ No* *** Importance:** Low Medium High ☐ ☐ ☐	
7. Can AMASS control tasks (such as inhibiting a track) be completed efficiently, without significant head-down time?	☐ Yes ☐ Yes (with comment) ☐ No* *** Importance:** Low Medium High ☐ ☐ ☐	
II. Displays		
8. Did you find the on-screen text messages readable at your typical viewing distance? (_______ feet)	☐ Yes ☐ Yes (with comment) ☐ No* *** Importance:** Low Medium High ☐ ☐ ☐	
9. Did you find the content of the on screen text messages easy to understand?	☐ Yes ☐ Yes (with comment) ☐ No* *** Importance:** Low Medium High ☐ ☐ ☐	
10. Did you find the symbols easy to identify at your typical viewing distance? (_____ feet)	☐ Yes ☐ Yes (with comment) ☐ No* *** Importance:** Low Medium High ☐ ☐ ☐	

Item	Rating	Comments
11. Did you find the symbols easy to interpret?	☐ Yes ☐ Yes (with comment) ☐ No* *** Importance:** Low ☐ Medium ☐ High ☐	
12. Is the quality of the digitized voice acceptable (i.e., speed, intelligibility, etc.)?	☐ Yes ☐ Yes (with comment) ☐ No* *** Importance:** Low ☐ Medium ☐ High ☐	
III. General		
13. Can you easily perform the AMASS actions you commonly need to undertake?	☐ Yes ☐ Yes (with comment) ☐ No* *** Importance:** Low ☐ Medium ☐ High ☐	
14. Is it clear which controller is responsible for coordinating/ responding to an alert?	☐ Yes ☐ Yes (with comment) ☐ No* *** Importance:** Low ☐ Medium ☐ High ☐	

Item	Rating	Comments
IV. Overall		
15. The AMASS system response time is:	Very fast ☐ ☐ ☐ ☐ ☐ Very Slow	

Item	Rating	Comments
IV. Overall		
16. Performing the AMASS actions I commonly need to undertake is:	Very Easy ☐ ☐ ☐ ☐ ☐ Very Difficult	
17. AMASS supports my ability to control traffic:	Strongly Agree ☐ ☐ ☐ ☐ ☐ Strongly Disagree	
18. When responding to an AMASS alert, it is clear which controller is responsible for coordinating/ responding:	Strongly Agree ☐ ☐ ☐ ☐ ☐ Strongly Disagree	
19. AMASS is easy to learn:	Strongly Agree ☐ ☐ ☐ ☐ ☐ Strongly Disagree	
20. AMASS is easy to use:	Strongly Agree ☐ ☐ ☐ ☐ ☐ Strongly Disagree	
21. Overall, I am satisfied with the AMASS functions I used:	Strongly Agree ☐ ☐ ☐ ☐ ☐ Strongly Disagree	
22. Overall, the current AMASS design is acceptable:	Strongly Agree ☐ ☐ ☐ ☐ ☐ Strongly Disagree	
23. Based on my experience during this evaluation AMASS provides adequate time to react:	Strongly Agree ☐ ☐ ☐ ☐ ☐ Strongly Disagree	

Item	Rating	Comments
IV. Overall		
24. The tasks I performed during the usability evaluation were representative of the tasks I will be required to regularly perform in my everyday duties:	Strongly Agree ☐ ☐ ☐ ☐ ☐ Strongly Disagree	
25. The secondary task (i.e., moving the aircraft on the SFO map) **did not** interfere with my ability to respond to the AMASS alerts:	Strongly Agree ☐ ☐ ☐ ☐ ☐ Strongly Disagree	

IV. General Comments

26. Please provide any additional comments regarding AMASS:

____

____

____

____

____

Appendix E

AMASS Air Traffic Controller Tasks

Task No.	Task	Task Description	Maxi-Keypad (Hot Keys)	*Mini-Keypad (Hot Keys)*	Procedure
1	Filter Arrival Alerts	Filters all alerts involving arrival aircraft. This action only lasts for a parameter time.	Funct Y	SHIFT + EXIT	1. Press [*SHIFT* + *EXIT*] or [Funct Y] 2. Confirm hot key function (FLTR ARR ALRTS) is displayed on ODU 3. Press [*ENTR*] or [RTN]. 4. Observe no arrival alerts appear
2	Enable Arrival Alerts	Enables alerts involving approaching aircraft (arrivals) with tracks on the movement area or closed runways.	Funct I	MP INT (or MP3)	1. Press [Funct I] or [*MP INT*] 2. Confirm hot key function (ENABLE ARR ALRTS) is displayed on ODU 3. Press [*ENTR*] or [RTN] 4. Observe octagon is overlaid on arrival target symbol
3	Move Alert Window	Enables moving the alert window to any desired position.	Funct S	M2	1. Press [*M2*] or [Funct S] 2. Confirm hot key function (MOVE ALRT WINDOW) is displayed on ODU. 3. Using the trackball, move alert window to desired position 4. Press [*ENTR*] or [RTN]
4	Filter All Alerts for the Specified Ground Track	Filters all alerts involving a specified ground track. The track icon is replaced by an "A" to indicate the filter is enabled. The action will only last for a parameter time.	Funct W	MP2	1. Press [*MP2*] or [Funct W] 2. Confirm hot key function (FLTR ALL ALRTS ON GND TRK) is displayed on ODU 3. Using the trackball, move cursor over track 4. Press [*ENTR*] or [RTN]. If the track is improperly hooked, an improper alert message will appear. 5. Observe "A" is placed over the track
5	Enable All Alerts for the Selected Ground Track	Removes any filter (single or multiple target alerts) for a specified ground track	Funct R	MP4	1. Press [*MP4*] or [Funct R] 2. Confirm hot key function (ENABLE ALL ALRTS ON GND TRK) is displayed on ODU 3. Using the trackball, move cursor over track 4. Press [*ENTR*] or [RTN]. 5. Observe all alert icons over the target are removed

Task No.	Task	Task Description	Maxi-Keypad (Hot Keys)	*Mini-Keypad (Hot Keys)*	Procedure
6	Toggle AMASS and ASDE Control	Shifts DCU and ODU control between AMASS and ASDE	Funct U	SHIFT + MP4	1. Press [*SHIFT* + *MP4*] or [Funct U] 2. Confirm hot key function (ASDE FUNCTIONS) is displayed on ODU 3. Press [*ENTR*] or [RTN]. 4. Observe the applicable display appears
7	Select Operational Configuration **(Supervisor)**	Selects and loads a specified operational airport configuration. The AMASS main menu becomes invisible and the AMASS operational configuration is displayed on ODU.	Select Operation Configuration using UP/DN	Select Operation Configuration using CUP/CDN	1. Observe AMASS main menu is displayed 2. Highlight Select Operation Configuration using [*CUP/CDN*] or [UP/DN] 3. Press [*ENTR*] or [RTN] 4. Observe the AMASS operational configuration menu is displayed 5. Select desired operation configuration using [*CUP/CDN*] or [UP/DN] 6. Press [*ENTR*] or [RTN] 7. Observe the selected operational configuration appears in the AMASS operation configuration text-window
8	Close/Open Runway **(Supervisor)**	Closes or opens runways on the current operational configuration.	Select Closed/Open Runway using UP/DN	Select Closed/Open Runway CUP/CDN	1. Observe AMASS main menu is displayed 2. Highlight the Select Closed/Open Runway using [*CUP/CDN*] or [UP/DN] 3. Press [*ENTR*] or [RTN] 4. Observe the AMASS Closed/Open Runway menu is displayed 5. Select desired runway by using [*CUP/CDN*] or [UP/DN] 6. Press [*ENTR*] or [RTN] 7. Observe the highlight bar moves to the runway state (closed or open) 8. Select desired runway state by using [*CUP/CDN*] or [UP/DN] 9. Press [*ENTR*] or [RTN] 10. Observed the highlight bar has moved to the runway designation, desired state is displayed and an 'X' appears on each end of the runway

Appendix F

Operational Display Unit Compliance with Visual Display Standards

Display Characteristics	ANSI	HFDG	ODU
I. Font	NA	The font style shall allow discrimination of similar characters. Fonts with serifs, variable stroke widths, and slanting characters shall be avoided.	Bit mapped (hard coded) font. AMASS typeface font contains a serif font. This is not a recommended font type.
A. Font Size and Visual Angles	Size of characters is dependent on the task and display parameters. Character height is measured as the top and bottom edges of a nonaccented capital letter. Minimum character height shall be 16 min of arc and the maximum shall be 24 min of arc for tasks in which readability is important. The preferred character height shall be 20-22 min of arc for both readability and legibility tasks.	The vertical viewing angle for alphanumeric characters shall be 21 min of arc for color displays, and 16 mins for black and white displays. The preferred angle for color displays is 30 mins, and 20 mins for black and white displays.	AMASS characters are green on a black background. The character height is .18in (4.5mm). The HFDG preferred text height is 21 min of arc and the minimum acceptable height is 16 min of arc. The current AMASS text height meets preferred visual angle requirements out to a distance of 29 in and minimum visual angle at 38 in. The current AMASS character size is not adequate beyond 38 in.
B. Character Height-to-Width Ratio	For fixed column presentations, the height-to-width ratio shall be between 1:0.7 to 1:0.9.	The ratio of character height to width shall be 1:0.7 to 1:0.9 for equally spaced characters and lines of 80 or fewer characters.	The AMASS character height-to-width ratios were 1:0.7 for letters such as "E." Larger letters W or R were 1:0.8. These values meet the recommended criteria.

Display Characteristics	ANSI	HFDG	ODU
II. Viewing Distances: Text	Addresses only seated position distances with a minimum viewing distance of equal to or greater than 30 cm (12 inches).	The viewing distance is the relationship between the viewing angles of the display, character size, and distances. The color display is a visual angle of 21 min of arc.	The visual angle for the current AMASS text size (.18 inches) is presented below with the minimum (16 min of arc) and preferred (21 min of arc) character heights at each of the readability distances. Distance / AMASS Min of Arc / Minimum Character Ht. / Preferred Character Ht. 5' / 10.3 / 0.28 / 0.37 7' 8" / 6.7 / 0.43 / 0.56 10' 4" / 5.0 / 0.58 / 0.76 13' / 4.0 / 0.73 / 0.95 The current AMASS character size is not adequate for viewing distances beyond 29 in for preferred visual angle requirements and 38 in for minimum visual angle requirements.
III. Viewing Distances: Symbols	Symbol size should be measured from the bottom edge to the top edge of a nonaccented uppercase letter. The size of a specific symbol anywhere on the display should not vary by more than 10 percent.	The symbol should subtend a visual angle of at least 20 min.	Using the viewing angle of 20 min of arc and the following symbol sizes, the viewing distances for the octagon symbol should be at most: 4mm = 2.3 ft. (min. scale: 23960), 9mm = 5.12 ft. (typical viewing scale: 12080), 6cm = 34.2 feet (max. scale: 2050), The following two symbols were measured at the typical viewing scale (i.e., 12080). Triangle Height = .14 in (3.5mm). Adequate to a distance of 2 feet (608mm). Triangle base = .09 in (2.3mm). Height = .14 in (3.5mm) Width = .14 in (3.5mm). The symbol size is adequate to a distance of 2 feet (608mm).

Display Characteristics	ANSI	HFDG	ODU
IV. Flash Rates/Blinking	No more than two different blink rates should be used. The difference between the two blink rates should be at least 2 Hz. The slow blink should be not less than 0.8Hz and the fast blink rate should not be more than 5Hz. A 50% duty cycle is preferred.	The rate of flashing shall be in the range of three to five flashes per second, with equal on and off duration.	4 Hz with an equal on/off duty cycle. This meets recommended standards.
V. Alarms/Loudness		Alarms shall exceed the prevailing ambient noise level by at least 10 dB(A). A message priority system shall be established so that a more critical message shall override the presentation of any message having a lower priority.	The following dB(A) readings of the AMASS voice warning alarms were taken at a distance of 8 ft. in the AMASS lab: 62-66 dB(A), minimum volume 64-67 dB(A), medium volume 68-74 dB(A), max volume. These readings were taken at Build 16. At 6 feet the maximum amplitude reading in the lab was 71-75 dB(A), compared to a reading of 88 dB, for Build 14, in the Research Tower. At 4 ft., the reading in the lab was 73-75 dB(A), compared to 92 dB, for Build 14 in the Research Tower.
VI. Glare Control	The best way to control glare is to eliminate it at its source. Techniques available to eliminate glare effects are: equipment location, control of window luminance, controlled lighting, etc.	Light sources shall not be located within 60 degrees in any direction from the center of the visual field. Ensure that the maximum to average luminance ratio does not exceed 5:1 across the viewing area.	ASDE monitor incorporates glare control that has already been accepted for control tower usage.
VII. Mounting	The angle formed by the intersection of the line of sight and the line normal to the surface of the display at the point where the line of sight intersects the image surface of the display shall be less than or equal to 40 degrees.	The screen should be tilted so that the surface is perpendicular to the line of sight.	The ASDE system and monitors include mounting fixtures to mount on ceilings. These are adjustable so they can be aligned to be perpendicular to the line of sight.

Display Characteristics	ANSI	HFDG	ODU
VIII. Display Luminance	Measurements for character luminance, background luminance, and display pixel size are measured across the width of a line one pixel wide, and can be obtained from the results of a single photometric measurement for each of the test conditions.	Either characters or their background, whichever has higher luminance, shall have a luminance of least 35cd/m^2 or 10 foot –Lamberts (fL).	The ODU measured 66.6 fL under 152 footcandles (fc). This meets human factors standards.
IX. Display Contrast	Character luminance modulation shall be equal to or greater than 0.5 (contrast ratio of 3:1). A luminance modulation of at least 0.75 (contrast ratio of 7:1) is preferred. The measurements shall be made at the following five points: at the intersection of the two diagonals, and at locations that are equal to 10% of the diagonal length, measured from the four corners of the area of the display screen.	Contrast between light characters and a dark screen background shall be at least 6:1. The preferred values are 10:1.	The contrast of the screen elements to the background under 152 fc of illumination was 78:1. These values are more than adequate, according to human factors guidelines.