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Aircraft Alerting Systems Standardization Study

Volume II

Aircraft Alerting Systems Design Guidelines

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Final Report

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16. Abstract

This report is one of a series of documented studies directed to the improvement and standardization of aircraft alerting systems. The purpose of the study was to develop and validate, through simulation, functional design criteria that can be used in designing effective aircraft alerting systems. The major objectives of this phase of the study were to:

- o Resolve system component questions.
- o Validate the two candidate system concepts by comparison to a representative baseline system, for both the pilot and flight engineer stations.
- o Evaluate presentation media and display formats for time-critical warnings.
- o Develop guidelines for the design of alerting systems.

This document presents a set of design guidelines directed to the improvement and standardization of aircraft alerting systems. The objective of the guidelines is not to define a simple hardware design that each manufacturer must use, but rather to provide functional design criteria that can be used to develop effective alerting systems, and to promote standardization within the industry. The results of the experiments and the validation tests, which formed the basis for the design criteria, are documented in Volume I of this report entitled, "Candidate System Validation and Time-Critical Display Evaluation," Report Number DOT/FAA/RD-81/38/I.

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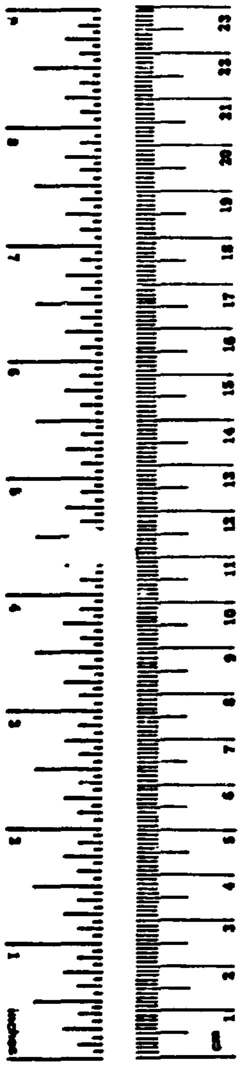
METRIC CONVERSION FACTORS

Approximate Conversions to Metric Measures

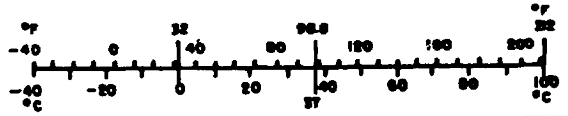
Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
		MASS (weight)		
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
		VOLUME		
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

*1 in = 2.54 (exactly). For other exact conversions and more detailed tables, see NBS Misc. Publ. 286, Units of Weights and Measures, Price $2.25, SD Catalog No. C13.10:286.



Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
		AREA		
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
		MASS (weight)		
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
		VOLUME		
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
		TEMPERATURE (exact)		
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



PREFACE

This report is the result of several years of research sponsored by the FAA directed toward the improvement and standardization of aircraft alerting systems. This present study was conducted as a joint effort by the three major U.S.A. manufacturers of commercial transport aircraft: Boeing, Lockheed, and McDonnell Douglas. The primary purpose of this volume of the report is to provide a set of guidelines for the design of future alerting systems. The objective of the guidelines is not to define a single hardware design that each manufacturer must use, but rather to define functional criteria that can be used to design effective alerting systems and to promote standardization within the industry.

The authors want to express appreciation to the many pilots from the three aircraft companies and from Continental, Western, American, United, TWA, Eastern, Northwest Orient, and SAS Airlines who participated in this project. Also, the experience and guidance of Wayne Smith, the Boeing Program Manager, was of great value, as were the contributions of Dr. Richard Gabriel, Don Stanley, and Art Torosian of Douglas, and Ralph Cokeley, Les Susser and Chuck Mercer of Lockheed. The efforts of Russell White in the preparation of the simulator and his help in conducting the tests are also appreciated. The contract sponsor is the Federal Aviation Administration, and technical guidance was provided by John Hendrickson, ARD 340, the contract monitor.

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LIST OF ABBREVIATIONS

AI	Articulation Index
ADI	Attitude Director Indicator
ARP	Aerospace Recommended Practice
ATC	Air Traffic Control
CRT	Cathode Ray Tube
dB	Decibel
DEG	Degrees
DETAC	Digital Equipment Technology and Analysis Center
EADI	Electronic Attitude Director Indicators
F	Fahrenheit
FAA	Federal Aviation Administration
FAR	Federal Aviation Regulation
Ft-L	Foot-Lambert
Hz	Hertz
lbs	Pounds
MRT	Modified Rhyme Test
PAWS	Phase Adaptive Warning System
PB	Harvard Phonetically Balanced Word List
ROM	Read Only Memory
SAE	Society of Automotive Engineers
$\bar{X}$	Arithmetic Mean

1.0 INTRODUCTION AND SUMMARY

1.1 PROGRAM HISTORY

The guidelines contained in this document represent the culmination of several years of research sponsored by the FAA and directed toward the improvement and standardization of flight deck alerting systems. Table 1.1-1 lists the previous contract, consisting of three studies, that led to the present effort. That effort began in 1973 with a study of concepts for an independent altitude monitor. The goals of the study were to identify the causes for inadvertent terrain impact alerts, and methods for reducing them. The second study, an extension of the first, investigated operational philosophies for implementing an effective and reliable alerting system. This led to the third study which investigated present day alerting methods used on commercial transports. The objectives of the third study were to:

Table 1.1-1. Previous Alerting System Contracts—Contract DOT-FA73WA-3233

Title	Development of an independent altitude monitor concept (FAA-RD-73-168)	Independent altitude monitor alert methods and modes study (FAA-RD-75-86)	Collation and analysis of aircraft alerting systems data (FAA-RD-76-222)
Objectives	Identify nature of typical inadvertent terrain impact accident scenarios Identify techniques whereby inadvertent terrain impact accidents might be reduced Identify functional elements of an independent altitude monitor concept Identify methods of implementing independent monitor systems	Develop operational alert philosophy and concepts Demonstrate and refine selected independent altitude monitor alerting methods Develop independent altitude monitor implementation plan	Tabulate current alerting methods and requirements for all cockpit alerting functions Develop method for prioritizing alerting functions Prioritize alerting functions Correlate requirements with prioritized functions and note conflicts Broaden stimuli response data base Define tests for acquiring stimuli response data not available in literature but required for designing alerting systems Provide recommendations for standardization of alerting functions and methods
Period	February 1973 to September 1973	June 1974 to July 1975	January 1976 to May 1977

- Investigate the type of alerting signals used on the flight decks of commercial transports.

- Identify and evaluate the factors that affect pilot detection and response time to alerting signals

- Identify inconsistencies/problems with present day alerting systems

- Define tests for acquiring pilot stimulus-response data, not available in the literature, but required for designing a safe, reliable and effective aircraft alerting system

- Formulate preliminary design guidelines for maximizing the effectiveness of alerting systems

The major findings of the third study were:

- There had been a significant increase in the number of alerting signals being used on newer commercial transports. For example, in going from the B-707 to the B-747, the number of alerting signals increased from 188 to 455, or 142 percent. The increase from the DC-8 to DC-10 was from 172 to 418, or 143 percent (Veitengruber, Boucek, and Smith, 1977). Figure 1.1-1 shows the number of warning, caution and advisory alerts as a function of aircraft type.

- Very little standardization had been used by the airframe manufacturers in implementing alerting system elements. Not only were there vast differences between airframe manufacturers, but individual manufacturers were inconsistent in the application of alerting signals within their airplanes. Table 1.1-2 provides some examples of this inconsistency.

For these two reasons, proliferation of alerts, and the lack of standardization, airline pilots began to view alerting systems as a nuisance

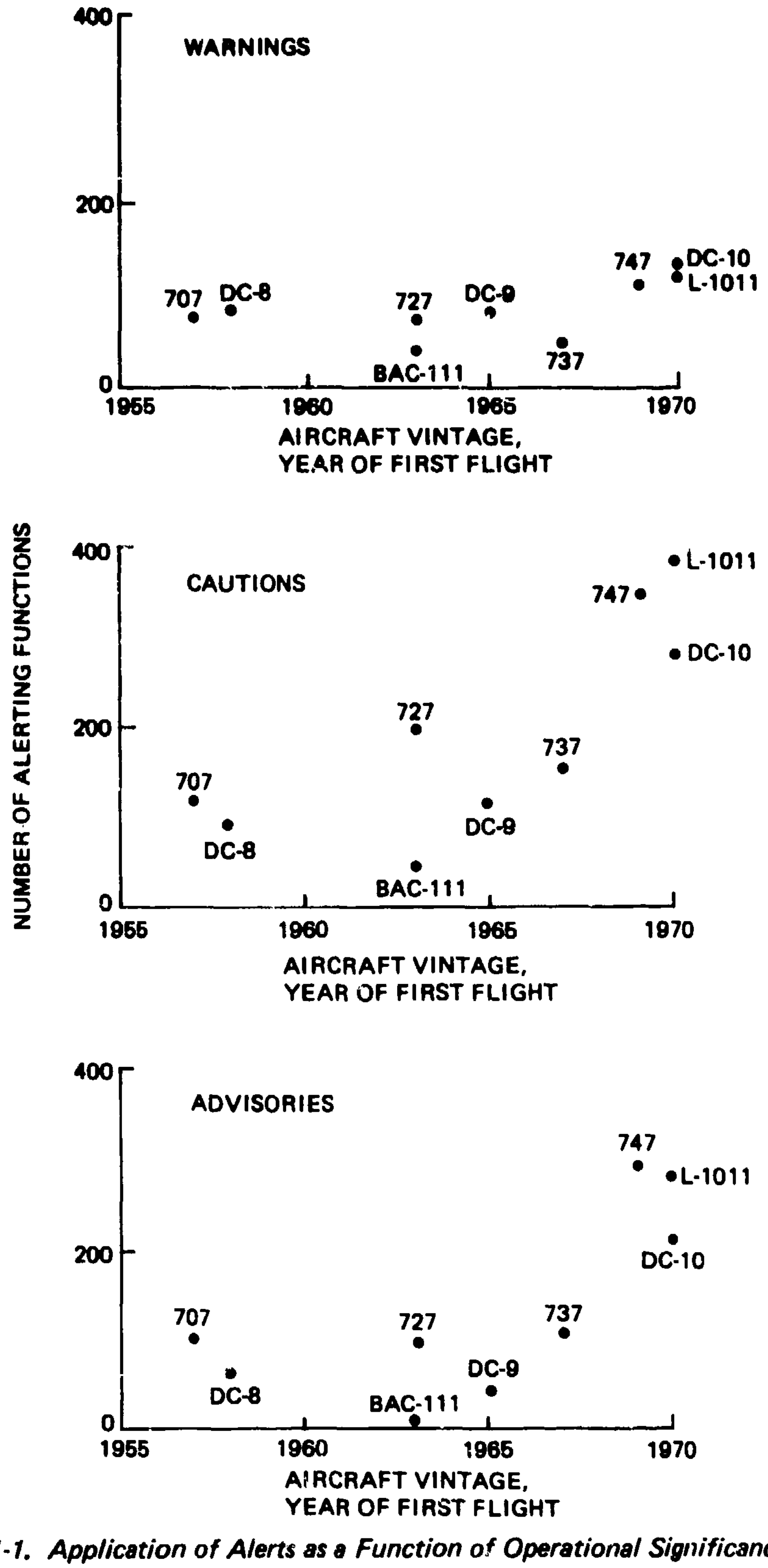


Figure 1.1-1. Application of Alerts as a Function of Operational Significance and Aircraft Vintage

Table 1.1-2. Application of Alerting Signals as a Function of Aircraft Manufacturer and Aircraft Type

Alert condition \ Airplane	Type of aural alert applied								
	707/727	727	737	747	DC-8	DC-9	DC-10	L-1011	BAC-111
Altitude alert	"C" chord A	Tone A, B "C" chord A	"C" chord A	"C" chord A	Horn	Horn**	"C" chord B	"C" chord B	*
APU fire	None	Bell A	Bell A	Bell A	None	None	None	Bell E	Bell
Attitude displays disagree	None	None	None	Tone B	None	None	Wailer (provisional)	None	*
Autopilot disengage	None	Wailer A (some acft)	None	Wailer A	None	Click	Wailer B	Wailer C	*
Call on interphone	Chime G	Chime G	Chime G	None	Chime	Chime	Chime	Chime N	*
Close proximity to ground, gear up	Warbler & voice	Warbler & voice	Warbler & voice	Warbler & voice	Warbler & voice	Warbler & voice	Warbler & voice	Warbler & voice	Warbler & voice
Cockpit call from flight attendants	Chime	Chime	Chime	Chime	Chime B Chime C	Chime B Chime C	Chime B Chime C	Chime H	*
Cockpit call from ground crew	None	None	None	Chime E	Chime	Chime	Chime	Chime P	*
Cockpit call to flight attendants	Chime	Chime	Chime	Chime D Chime L	Chime	Chime	Chime	Chime M	*
Decision height	Tone C	Tone C	Tone C	"C" chord A	None	Tone	None	Tone H	*
500-foot terrain warning	None	Tone	None	Tone	None	Tone	None	Tone	*
Emergency evacuation	Tone B	Tone B	None	Chime F Tone B	None	Horn	Horn	Tone F	*
Engine fire	Bell A	Bell A	Bell A	Bell A	Bell B	Bell B	Bell C	Bell E	Bell
Excessive airspeed	Bell D	Clacker A	Clacker A	Clacker A	Clacker D	Clacker D	Clacker C	Clacker F	Bell
Excessive sink rate	Warbler & voice	Warbler & voice	Warbler & voice	Warbler & voice	Warbler & voice	Warbler & voice	Warbler & voice	Warbler & voice	Warbler & voice

*Characteristics unknown

**Not delivered but available

rather than a help. Cooper (1977) stated that "caution and warning systems were originally installed as a reasonable means of assisting pilots to maintain safe, reliable, economical system operation in the face of high workloads. However, these systems, intended to reduce hazards, are themselves becoming hazards. The vast increase in the number of alerts and the frequent occurrence of false or nuisance alerts impose heavy demands on the aircrew. More alerts require more memorization, higher workloads, and could induce a higher probability of error."

The identification of these problems in current day alerting systems led to the present study, conducted under Contract DOT-FA79WA-4268 in three phases (see Table 1.1-3). It was performed as a joint effort by the Boeing, Lockheed and McDonnell Douglas Aircraft Companies. The first phase consisted of identifying and evaluating alerting system components that could alleviate current alerting system problems, and of combining the individual components (e.g., master visual and aural alerts, visual information display, verbal messages) into candidate alerting concepts for subsequent test and evaluation. The second phase consisted of developing a detailed test plan for evaluating

Table 1.1-3. Aircraft Alerting Systems Standardization Study (DOT-FA79WA-4268)

	Phase I	Phase II	Phase III
Title	Define prototype alerting system concepts	Test planning for prototype alerting system concept evaluations	Evaluate prototype alerting system concepts
Objective	• Acquire missing stimuli response data via appropriate simulator tests • Define alerting system concepts • Assess physical characteristics of each concept • Assess implementation feasibility of each concept • Select alerting system concepts for comparative evaluation	• Select simulation facility • Develop test plan • Coordinate test plan with FAA	• Develop brassboard hardware for selected alerting system concepts • Perform comparative simulator evaluation of selected concepts • Finalize design guidelines for standardized alerting system • Assess certification impact

Table 1.1-4. Aircraft Alerting System Study Program Ground Rules

- Three study techniques to provide data
  - Experimental testing—quantifiable variables applied to specific dependent variables to be tested to provide objective and quantifiable data to answer system questions; i.e., what effect do the signal formats have on crew response time?
  - Analytical—data obtained from pertinent literature or studies of system questions; i.e., defining an appropriate number of lines for the central display
  - Subjective—that data not conducive to gathering and analyzing subjective responses of experienced pilots on system questions; i.e., the need for stereotypical aurals or the best way to implement cancel/recall logic; this study method also to be used with the other two methods
- Controls and test conditions should be similar if tests are carried out at several locations
- Experienced transport pilots—to be used as subjects for experimental and subjective testing
- Guidelines document to contain—
  - Design objectives
  - Minimum performance standards
  - Methods and procedures for development and evaluation

the candidate concepts. In the third phase, a number of line-qualified pilots exercised systems reflecting these candidate concepts in a fixed-based simulator. The results of this effort were combined with the data obtained from all previous relevant studies to develop the design guidelines contained in this report. The ground rules established for the present study are shown in Table 1.1-4, and the major assumptions about system design that were used in developing the alerting system guidelines are contained in Table 1.1-5.

1.2 PURPOSE

The purpose of this document is to provide a set of guidelines for the design of future aircraft alerting systems. These guidelines are directed toward the next generation of commercial transports which are anticipated to have all-electronic flight decks. The objective of the guidelines is not to define a single hardware design that each manufacturer must use, but rather to provide functional design criteria that can be used to develop effective alerting systems, and to promote standardization within the industry. Guidelines are

Table 1.1-5. System Assumptions for Aircraft Alerting Systems Standardization Study

- No nonverbal aural alerting system with different alerts for each condition or alert (large number of aurals)
- No incandescent light or fixed-legend display for primary central display unit
- Secondary subsystem indicators will be reflected on the central display
- Dual-channel auditory and visual presentation for some if not all alerts
- Primary visual system will be programmable; subsystem indication may be fixer.
- Auditory system voice components
- Auditory system tone components
- System direction toward an electronic flight deck
- Form of prioritization implemented
- Form of automated inhibition needed; e.g., don't use voice when it might conflight with ATC communications
- Computing capability (smart system) to handle prioritization, inhibit, and other system logic
- Design for the quiet, dark cockpit
- May want some alerts to bypass computer for backup in a failure mode
- Central display primarily alphanumeric but may have graphic or symbolic capabilities
- Automatic indication clearing when fault or alert condition no longer exists
- Best available speech-generation equipment
- System based on four condition levels; i.e., ARP450D:
  - Warning
  - Caution
  - Advisory
  - Information
- Central display with color capability
- Capability of readily accommodating all present and future alerting functions; e.g., BCAS, GPWS
- Basic functions to include—
  - Alert (attention getting)
  - Inform (identify the problem)
  - Guide crew action
  - Provide feedback
- Includes interactive capabilities

presented for the design of individual alerting system components, and for methods of combining them to optimize crew performance and minimize the number of missed alerts.

The guidelines contained in this document have been substantiated by empirical, analytical, and pilot preference data. Where sufficient data does not exist to support a definitive statement, the alerting system components are defined and suggestions are provided for obtaining the required data.

These general objectives should serve to guide the design of aircraft alerting systems:

- REDUCE THE OVERALL NUMBER OF DISCRETE VISUAL AND AURAL ALERTS
- CONFORM TO A QUIET DARK FLIGHT DECK WHEN ALL SYSTEMS ARE OPERATING NORMALLY
- REDUCE THE DEMANDS ON CREW INFORMATION PROCESSING AND MEMORY REQUIREMENTS
- MINIMIZE THE TIME REQUIRED FOR THE FLIGHT CREW TO DETECT AND ASSESS FAILURE CONDITIONS, AND TO INITIATE CORRECTIVE ACTIONS
- MINIMIZE THE DISTRACTING EFFECTS OF THE ALERTING SYSTEM ON OTHER FLIGHT CREW TASKS (e.g., AIRCRAFT CONTROL, CREW-ATC COMMUNICATIONS)
- FACILITATE ALERTING SYSTEM STANDARDIZATION BETWEEN AIRFRAME MANUFACTURERS, AIRCRAFT TYPES AND COMMERCIAL AIRLINE OPERATORS
- PROVIDE FOR ALERTING SYSTEM GROWTH CAPABILITY IN A FORM THAT DOES NOT NECESSITATE ADDITIONAL SYSTEM COMPONENTS

1.3 SUMMARY

This section summarizes the guidelines for the design of aircraft alerting systems.

1.3.1 GENERAL ALERTING SYSTEMS GUIDELINES

- The primary functions of an alerting system should include the following: attract the attention of the flight crew and direct it to the information display so that appropriate action can be taken; inform the flight crew as to the urgency of the alert; provide information to the crew as to the adequacy of their corrective actions; and to provide control over the alerting system to enable the crew to monitor the status of the aircraft, and to store and recall existing alerts.

- The alerting requirements in the flight deck should be handled by a single, well defined, dedicated system. The alerting system components should be functionally related, and have a common purpose.

- The alerting system should provide unique combinations of components to inform the aircrew of the urgency level of the alerting situation (i.e., warnings, cautions or advisories).

- The alerting system design should be flexible enough to be able to accommodate new alerts in a manner that does not require additional discrete annunciators.

- The alerting system should be highly reliable. It should be activated only when an alerting situation exists; it should not be activated when one does not exist.

- The components of an alerting system should include master alerts (visual and aural), a visual information display, a voice information display, and a time-critical display.

1.3.2 MASTER VISUAL ALERT GUIDELINES

- Purpose - Master visual alerts should be used to attract the attention of the crew and to provide preliminary information about alert urgency level.

- Number - Two master visual alerts should be provided, one for warnings and one for cautions.

- Location - Master visual alerts should be located within fifteen degrees of each pilot's centerline of vision (head up and head down) and within reach when the pilots are seated in line with their eye reference points.

- Duration/Cancellation - The onset of the master visual alert should occur simultaneously with the onset of the master aural alert, and within 0.5 second after aircraft sensors detect the alerting situation. The master visual alert should remain on until it is cancelled by a pilot (either by depressing the master visual alert switch or by activating the optional voice message), or cancelled automatically when the problem has been corrected. Upon cancellation the master visual and aural alerts should be reset to be able to annunciate new alerting situations.

- Brightness - Master visual alerts should be bright enough to attract crew attention. The range of brightness should provide sufficient contrast for both high and low ambient light conditions. Their brightness should be adjusted automatically as ambient light conditions inside the flight station change, however they should never be able to be dimmed below 15 $\pm$ 3 ft-L.

- Display Size and Character Dimensions - The master visual alerts should subtend at least one square degree of visual angle. All characters should be upper case and at least fourteen arc minutes high, with a height-to-width ratio of 5:3, a stroke width 1:6 to 1:10 of the height, and with between-character spacing 25 to 63 percent of the height. To assure legibility, character sizes and fonts should be evaluated prior to implementation.

- Format - The master visual warning and caution alerts should be red and amber, respectively. A steady indication should be used instead of flashing. The master visual legends should be opaque with translucent backgrounds, and implementation should minimize the probability of thinking that the alert is on when it is not.

- Test Requirements - Provisions should be made to check the operational status of the master visual alerts.

- Reliability - The reliability of the master visual alerts should be high to minimize or eliminate undetected, false, or nuisance alerts.

- Miscellaneous - Accepted human factors guidelines recommend that cancellation of a master visual alert should occur when the face of the master alert switch-indicator is depressed a distance of at least 0.115 inch. The required actuation force should be 3.5 lbs. ± 1.5 lbs. The master alerts, both visual and aural, and the accompanying voice message, should be deactivated and reset when the master visual alert is cancelled. Switch face temperatures should not exceed 109°F at an ambient temperature of 77°F. The technology used to accomplish the visual alerting function should be left to the airframe manufacturer as long as the guidelines in this section are satisfied.

1.3.3 VISUAL INFORMATION DISPLAY GUIDELINES

- Purpose - The display provides a single location for the presentation of all warning, caution, and advisory messages. It presents a concise alphanumeric message for each alerting situation, information about alert urgency level, and provide feedback to the crew when faults are corrected.

- Location-Number - The number of displays should be determined by a combination of operational and reliability criteria. The location of the visual information display and its viewing angle should not degrade readability. If interactive functions are included with the display they should be within reach of the pilot(s) using them.

- Message Format

Syntax - Alert messages should generally contain three elements: the general heading of the alert, the specific subsystem or location, and the nature of the problem (e.g. ENGINE NO. 1 FIRE).

Prioritization - Alerts should be grouped by urgency level and listed chronologically within each category. Warnings should be presented at the top of the display, with cautions and advisories listed below. The most recent alert should be listed at the top of its own category.

Overflow - A combination of overflow and paging should be used when the number of current alerts exceeds the capacity of the display. The bottom alert (oldest and least important) should be displaced when a newer/higher priority alerting situation occurs. The displaced alert should be stored in memory. A paging capability should be provided to recall alerts so stored.

Color Coding - To provide a unique and easily distinguishable coding method for all three alerting categories, a third color in addition to red (warnings) and amber (cautions) should be used to represent advisory level alerts.

Cues and Aids - An indication should be provided to aid the crew in identifying/locating new alerts. The indication should be color coded to correspond to the alert urgency level. An overflow indicator should be presented to inform the crew that the number of active alerts has exceeded the display capacity; and a page number indicator should be used to inform the crew that additional alerts are stored in overflow memory.

- Brightness - The display should be bright enough to be easily readable from the pilot's eye reference point in all ambient light conditions. Its brightness should be adjusted automatically as the flight station lighting conditions change. A manual control should be provided to enable the pilot to adjust the display contrast.

- Display Size - Specific aircraft design characteristics should determine the minimum number of alert lines to be displayed, taking into account the need to have characters large enough to be legible to the pilots when seated in their normal flight positions. The display should be wide enough so that any alert message will fit on one line.

- Character Dimensions - The alphanumeric character dimensions should be selected for speed and accuracy of interpretation. Literature suggests that all characters should be upper case, with a height-to-width ratio of 2:1, a stroke width of 1:6 to 1:10 of the height, and with a between-character spacing of 25 to 63 percent of the height. Graphic symbols should be at least 20 arc minutes. Character dimensions and fonts should be evaluated prior to their implementation to assure their legibility.

- Display Type - The presentation medium used for the visual information display should be left to the discretion of the airframe manufacturer. However, the display must be able to meet/exceed the guidelines listed in this section.

- Reliability - In the event of a failure of the visual information display the failure should be annunciated elsewhere in the pilot's primary or secondary field of view.

- Test Requirements - The capability to test all display characters and functions should be provided.

1.3.4 TIME-CRITICAL DISPLAY GUIDELINES

- Purpose - A separate display should be provided to enable the crew to detect and respond to time-critical warnings accurately and rapidly.

- Location-Number - The time-critical display should be located in the pilot's primary field of view (within 15° of the center line of vision). A separate display should be provided for each pilot.

- Format

  Information Content - The display should provide the crew with guidance information to direct corrective actions.

  Presentation Media - The primary information should be presented graphically.

  Color Coding - The display should be color coded to facilitate crew action.

  Cancellation - The display should cancel/erase automatically when the appropriate crew action has been taken, or when the alerting situation no longer exists.

- Display Size - The time-critical display should subtend at least two degrees of visual angle.

- Reliability

  System Reliability - The time-critical display and associated system components should be highly reliable. The display should be actuated whenever a time-critical alerting situation exists, and never when one does not exist.

Redundancy - Sufficient redundancy should be provided to enable the flight crew to respond to time-critical warnings expediently and accurately in the event of a single display failure.

1.3.5 MASTER AURAL ALERT GUIDELINES

- Purpose - Master aural alerts should be used to alert the crew to impending or existing conditions that require their attention, and to advise them of the alert urgency level.

- Number - The number of flight deck alerting sounds should be limited to three, one for each urgency level (i.e, warning, caution and advisory). Each sound should differ from the others in more than one dimension (e.g., frequency, duration), and the sounds should be selected to reflect their alert urgency level.

- Frequency - The frequency of aural alerting signals should be between 250 and 4000 Hz. High-urgency signals should be composed of at least two different frequencies spaced widely apart, and to minimize masking, the alerting signal frequencies should differ from those that dominate background noise.

- Intensity - Aural signals should exceed masked threshold by 8 ± 3 dB, and an automatic gain control should be used to maintain this signal-to-noise ratio.

- Signal Duration and Signal-Message Onset Coordination - Signal duration should vary depending upon the alert urgency level. For time-critical warnings, the signal should be approximately 0.75 second in duration, and should be followed by the corresponding voice message. For other warnings, the signal should be continued until a pilot initiates the optional voice message, or otherwise cancels the signal. For cautions and advisories, the signals should last 1.2 to 2.0 seconds, and 0.6 to 0.8 second, respectively. The off time between the aural signal and the voice message should be at least 0.15 second, and not more than 0.5 second.

- Sound Source Location - Dichotic methods of presentation, presenting the signal to both ears, should be used for aural alerts. If a single earphone is used, it should be worn on the dominant ear, and the alerting signals should be perceptually separated from competing sound sources by at least 90 degrees.

- Cancellation - For time-critical warnings, the alerting signal should be followed by the continued annunciation of the appropriate voice message until the alert is cancelled manually, or until the problem is corrected. For other warnings, the alerting signal should continue until it is cancelled manually by a pilot, or automatically when the problem is corrected. For cautions, the signal should be annunciated once for its set duration and stop. If the pilots do not acknowledge the signal after 10 seconds it should be repeated. This sequence should continue until some acknowledgment is made. For advisories, a single alert signal should be presented, and it should cancel automatically.

1.3.6 VOICE INFORMATION DISPLAY GUIDELINES

- Purpose - Voice messages should be used when the crew must act rapidly, and to enable the pilots to transfer workload from the visual channel to the auditory channel.

- Speech Generating Technique - State-of-the-art speech generating techniques should be used, and empirical testing should be used to assess the intelligibility of voice messages prior to their implementation in a flight deck.

- Voice Characteristics - Empirical testing should be used to select voice characteristics that are highly distinctive and intelligible.

- Voice Inflection - Voice messages should be presented with a monotone inflection.

- Intensity - Voice messages should be presented at an intensity level that is 8±3 dB above the ambient noise level. An automatic gain control should be used to maintain the desired intensity level.

- Location - Dichotic methods of presentation should be used for voice messages. If a single earphone is used, it should be worn on the pilot's dominant ear, and the alert message should be perceptually separated from competing sound sources (e.g., air traffic control) by at least 90 degrees.

- Onset Coordination - The off time between the alerting signal and the voice message should be at least 0.15 second, and not more than 0.5 second. For time-critical warnings, the alerting signal plus the essential elements of the voice message should be conveyed within 2.5 seconds.

- Message Content, Format, and Syntax - For time-critical warnings, voice messages should provide guidance information. For the remainder of warnings and cautions, the voice messages should provide status information. Voice messages should be constructed of short phrases that clearly identify the problem or action to be taken. Voice messages for time-critical warnings should contain two elements (action and direction, "PULL UP"). Voice messages for other warnings and cautions should contain three elements (general heading, subsystem or location, and nature of the problem, "ENGINE 1 FIRE").

- Accommodation of Multiple Voice Messages - When feasible, a prioritization scheme should be used to enable the alerting system to present multiple voice messages in order of criticality. In the absence of a suitable prioritization scheme, multiple voice messages should be accommodated as follows:

  - Time-critical warnings should always be presented before lower priority alerts.

  - When two or more time-critical warnings occur simultaneously, or in close succession, they should be presented in chronological order, with one full annunciation of each message.

  In multiple failure situations for other warnings and cautions, the urgency level should be used as the criterion for determining which voice message should be presented, for example, warnings should take precedence over cautions. The voice message, "MULTIPLE ALERTS" should be presented when: (1) two or more warnings occur simultaneously, or in close succession, and, (2) two or more cautions occur simultaneously, and no higher priority alerts have occurred.

- Message Cancellation - Time-critical voice messages should be able to be cancelled manually, or automatically when the alerting situation no longer exists. Elective voice messages (warnings and cautions) should cancel automatically after one annunciation. Subsequent activations of the voice message should also cancel after one presentation.

1.3.7 CREW OPTION AND CONTROL GUIDELINES

- Alert Prioritization - A prioritization scheme should be incorporated in the alerting system. The scheme should be flight phase adaptive. Prior to implementation the feasibility of the prioritization scheme should be demonstrated in terms of a prioritization data base, and aircraft configuration variations and exceptions should be considered in tailoring a scheme to a specific aircraft. As a minimum, alerts should be prioritized by urgency level.

- Inhibit Logic - Inhibit logic should be incorporated in the alerting system. The inhibit scheme should be flight phase adaptive, i.e., components of non-critical alerts should be inhibited during critical phases of flight and during multiple failure situations. Finally, a specific methodology for applying inhibit logic should be evaluated prior to its implementation.

- Store and Recall - A capability should be provided to enable the crew to store and recall caution and advisory level alerts. Both selective and total store and recall capabilities should be provided, and the visual information display should provide an indication of the number and type of alert messages that are in memory.

- Additional Alerting System Features - A line address capability should be provided to allow the crew to select specific fault messages. A paging function should be provided to enable the crew to access stored fault messages.

1.3.8 TACTILE SIGNAL GUIDELINES

Tactile signals are not recommended because of their possible disruptive effects. The exception to this recommendation is where this type of signal is currently being used, e.g., stick shaker. If they are to be used, they should be of such amplitude as to be detected by the part of the body being stimulated, and should be delivered by an apparatus that will always be in contact with the body.

1.4 REPORT ORGANIZATION

General alerting system design guidelines are contained in Section 2 of this report. Sections 3, 4, and 5 present guidelines for the design of the visual, and aural components and crew option and control features of the aircraft alerting system, respectively. Section 6 describes the certification impact of implementing these guidelines.

2.0 GENERAL SYSTEM GUIDELINES

The guidelines presented in this section are general and apply to the overall design of an alerting system. A summary of the design guidelines for this section is provided below; the guidelines are discussed in more detail in the following paragraphs.

- The primary functions of an alerting system are to: attract the attention of the flight crew and direct it to the information display so that appropriate action can be taken; inform the flight crew as to the urgency of the alert; provide information to enable the flight crew to determine the adequacy of their corrective actions; and to provide control over the alerting system to enable the crew to monitor the present status of the aircraft, and to store and recall existing alerts.

- An alerting system should consist of master alerts (visual and aural), a visual information display, a voice information display, and a time-critical display.

- The alerting system should be treated as a system. Its components should be functionally related, and have a common purpose.

- The alerting system should provide unique combinations of components to attract the attention of the aircrew and inform them of the level of urgency of the alerting situation (i.e., warnings, cautions and advisories).

- The alerting system design should be flexible enough to accommodate new alerts without requiring additional discrete annunciators.

- The alerting system should be highly reliable. It should be activated whenever an alerting situation exists; and never when one does not exist.

2.1 ALERTING SYSTEM FUNCTIONS

The basic functions of an alerting system are to:

- Attract the attention of the crew and direct that attention to the alerting condition so that corrective action can be taken.

- Inform the flight crew of the location and nature of the alerting condition. Sufficient information should be provided to enable the crew to initiate timely, corrective action.

- Provide the crew with a mechanism(s) to control the system to enable them to assess aircraft status quickly, to identify new alerts, and to store/recall alerts.

The need for each of these functions was identified by Cooper (1977), Boucek, Erickson, Berson, Hanson, Leffler, and Po-Chedley (1980), and in ARP-450D (1979). The manner in which these basic functions are implemented will determine the effectiveness of the alerting system. ARD 450D (1980) states that "safety of flight is greatly enhanced by an alerting system designed to provide early crew recognition of flight crew operational error, as well as aircraft system or component status or malfunctions". For example, the system should attract the crew's attention to an alerting situation, but should not be so disruptive that it degrades other crew task performance, information processing, or the decision-making required to take corrective actions. The guidelines for designing these basic functions are described in the following paragraphs.

2.2 ALERTING SYSTEM COMPONENTS

To accomplish the functions described above, the following components should be provided:

- Master Visual Alerts - Required to attract the crew's attention to situations requiring immediate crew awareness, and to provide a preliminary indication of alert urgency level.

- Master Aural Alerts - Provides a redundant means of attracting the crew's attention, and a preliminary indication of alert urgency level.

- Visual Information Display - Provides a single location for the alphanumeric annunciation of all alerts. Presents the aircrew with data on the location and nature of the alerting situation.

- Voice Information Display - Provides a means for informing the crew of the location and nature of the problem.

- Time-Critical Display - Provides the crew with information concerning the nature of the problem to guide the corrective action in situations requiring an unconditionally immediate crew response examples of such situations include collision avoidance, ground proximity.

Sufficient redundancy should be provided for these components and their functions to assure that the objectives of the alerting system are met.

2.3 ALERTING SYSTEM INTEGRATION

One of the fundamental problems of past crew alerting is that there was no standardized alerting systems approach. The lack of a systems approach has led to the proliferation of alerts and the scattering of alerting devices throughout the flight station. As aircraft and their associated systems have become more sophisticated, new alerts and alerting devices have been added, with little regard to integrating them with other alerting system components already in the flight station (Cooper, 1977). To alleviate this condition, the presentation of all alerting signals should be accomplished through a single, integrated alerting system.

For example, the onset of the master visual alert should occur simultaneously with the onset of the master aural alert. Similarly, the voice information message should be identical to the alphanumeric message presented on the visual information display. The master visual, master aural, and voice information display should all be cancellable by pilot action, or should cancel automatically when the alerting situation no longer exists. The message on the visual information display should be cleared automatically when the problem is corrected. However, the message should be stored by the alerting system computer for post-flight maintenance analysis.

In addition, logic should be incorporated to ensure that the alerting system components are coordinated and provide the proper alert presentation format for each alert urgency level. Table 2.3-1 shows the recommended alerting system logic for single and multiple alerts. As can be seen, all alerts should be annunciated when they occur. For example, if a warning and caution alert occur simultaneously, both master visual and aural alerts should be presented, and both alerts should be shown on the visual information display. In this case, activation of the voice message selector should cause the highest level alert (i.e., warning) to be delivered. If two alerts of the same urgency level are sensed at the same time, the message "MULTIPLE ALERTS" should be presented when the operator activates the voice message. The message "MULTIPLE ALERTS" informs the pilot that more than one alert has been sensed and to consult the visual information display to assess aircraft status.

The occurrence and display of a time-critical warning inhibits the real time presentation of all other alerts. Since time-critical alerting situations require a rapid response to avoid a potentiality hazardous condition, all other alerting situations (other than another time-critical alert) should be inhibited until the time-critical situation has been rectified.

2.4 ALERTING SYSTEM CATEGORIZATION

The results of two surveys (Cooper, 1977 and Veitengruber, et al., 1977) indicate that a unique audio, visual, or combination of audio-visual methods should be associated with each alert category to provide rapid definition of the criticality/urgency of an alerting situation. Most researchers agree that a four-level system should be used to denote the urgency of aircraft alerts. These four urgency levels are defined as operational or aircraft systems conditions which require:

WARNING - immediate corrective or compensatory crew action

Table 2.3-1. Alerting System Integration for Single and Multiple Alerts

Event	Alerting system components: Master visual – Warning	Master visual – Caution	Visual information display	Time-critical display	Master aural – Warning	Master aural – Caution	Master aural – Advisory	Verbal message – Elective	Verbal message – Mandatory	Cancellation – Master visual	Cancellation – Control wheel switch	Comments
0) No alerts												No system response.
1) Single advisory			X				X					In all cases where advisory-level alerts occur, the corresponding master aural sounds once and then cancels automatically.
2) Single caution		X	X			X		X		X	X	See note 1; master aural sounds once, and repeats at 10-sec intervals if no action is taken.
3) Single warning	X		X		X			X		X	X	See note 1; master aural continues until manually canceled by either method described in note 1.
4) Single time-critical warning	X		X	X	X				X	X		See notes 1 and 2; guidance information presented in both graphics and alphanumerics on the time-critical display.
5) 1 advisory and 1 caution		X	Both messages displayed			X	X	X		X	X	See notes 1, 3, and 4.
6) 1 advisory and 1 warning	X		Both messages displayed		X		X	X		X	X	See notes 1, 3, and 4.
7) 1 advisory and 1 time-critical warning	X		Both messages displayed	Only time-critical alert displayed	X				X	X		See notes 2, 3, and 5.
8) 1 or more cautions and 1 warning	X	X	All messages displayed		X	X		X		X	X	See notes 1, 3, and 4. If control wheel switch is depressed, only the voice message for the warning is presented.
9) 1 or more cautions and 1 time-critical warning			All messages displayed	Only time-critical alert displayed	X				X	X		See notes 2, 3, and 5.
10) 1 or more warnings and 1 time-critical warning	X		All messages displayed	Only time-critical alert displayed	X				X	X		See notes 2, 3, and 5.
11) 2 or more advisories			All messages displayed				X					See note 3.
12) 2 or more cautions		X	All messages displayed			X		X		X	X	See notes 1 and 3. Depression of control wheel switch will activate the voice message "multiple alert."

Notes:

1. Master aural and visual alerts can be canceled by either depressing the master visual light switch or by actuating the control wheel switch to present the voice message.
2. Time-critical voice messages can be canceled after one iteration by depressing the master visual light. Regardless of when the master visual light is depressed, the voice message will be annunciated at least once.
3. Simultaneous alerts are defined as two or more alerts occurring before any overt physical action is taken by the crew (for example, manual cancelation of the master visual and aural alerts).
4. Depressing the control wheel switch will activate a voice message for the most recent warning or caution level alert.
5. The occurrence of time-critical warnings will cause the automatic inhibition of all components of lower priority alerts until the pilot manually cancels the voice alert message or corrects the problem (except for the visual information display).

Table 2.3-1. Alerting System Integration for Single and Multiple Alerts (Concluded)

Event	Alerting system components									Cancellation		Comments
	Master visual		Central information display	Time-critical display	Master aural			Verbal message				
	Warning	Caution			Warning	Caution	Advisory	Elective	Mandatory	Master visual	Control wheel switch	
13) 2 or more warnings	X		All messages displayed		X			X		X	X	See notes 1 and 3. Depression of control wheel switch will activate the voice message "multiple alerts."
14) 2 or more time-critical warnings	X		All messages displayed	All time-critical messages in succession	X				X	X		Master aural followed by alternating repetitions of each voice message, which will correspond to visual messages presented on time-critical display. See notes 2, 3, and 5.
15) 1 or more advisory and 2 or more cautions		X	All messages displayed			X	X	X		X	X	See notes 1 and 3. Depression of control wheel switch will activate the voice message "multiple alerts."
16) 1 or more advisories and 2 or more warnings	X		All messages displayed		X		X	X		X	X	See notes 1 and 3. Depression of control wheel switch will activate the voice message "multiple alerts."
17) 1 or more advisories and 2 or more time-critical warnings	X		All messages displayed	All time-critical messages in succession	X				X	X		Master aural followed by alternating repetitions of each voice message, which will correspond to visual messages presented on time-critical display. See notes 2, 3, and 5.
18) 1 or more cautions and 2 or more warnings	X	X	All messages displayed		X	X		X		X	X	See notes 1 and 3. Depression of control wheel switch will activate the voice message "multiple alerts."
19) 1 or more cautions and 2 or more time-critical warnings	X		All messages displayed	All time-critical messages in succession	X				X	X		Master aural followed by alternating repetitions of each voice message, which will correspond to visual messages presented on time-critical display. See notes 2, 3, and 5,
20) 1 or more warnings and 2 or more time-critical warnings	X		All messages displayed	All time-critical messages in succession	X				X	X		Master aural followed by alternating repetitions of each voice message, which will correspond to visual messages presented on time-critical display. See notes 2, 3, and 5.
21) 1 or more advisories, 1 or more cautions, and 1 warning	X	X	All messages displayed		X	X	X	X		X	X	See notes 1, 3, and 4. If control wheel switch is depressed, only the voice message for the warning is presented.
22) 1 or more cautions, 1 or more warnings, and 1 time-critical warning	X		All messages displayed	All time-critical messages in succession	X				X	X		Master aural followed by alternating repetitions of each voice message, which will correspond to visual messages presented on time-critical display. See notes 2, 3, and 5.
23) 1 or more advisories, 1 or more cautions, and 2 or more warnings	X	X	All messages displayed		X	X	X	X		X	X	See notes 1 and 3. Depression of control wheel switch will activate the voice message "multiple alerts."
24) 1 or more cautions, 1 or more warnings, and 2 time-critical warnings	X			All time-critical messages in succession	X				X	X		Master aural followed by alternating repetitions of each voice message, which will correspond to visual messages presented on time-critical display. See notes 2, 3, and 5.

Notes:

1. Master aural and visual alerts can be canceled by either depressing the master visual light switch or by actuating the control wheel switch to present the voice message.
2. Time-critical voice messages can be canceled after on iteration by depressing the master visual light. Regardless of when the master visual light is depressed, the voice message will be annunciated at least once.
3. Simultaneous alerts are defined as two or more alerts occurring before any overt physical action is taken by the crew (for example, manual cancelation of the master visual and aural alerts).
4. Depressing the control wheel switch will activate a voice message for the most recent warning or caution-level alert.
5. The occurrence of time-critical warnings will cause the automatic inhibition of all components of lower priority alerts until the pilot manually cancels the voice alert message or corrects the problem (except for the visual information display).

CAUTION - immediate crew awareness, and subsequent crew action

ADVISORY - crew awareness, and may require subsequent or future crew action

INFORMATION - flight deck indication, but not necessarily as part of the integrated alerting system.

Since the information level alert is generally not considered as part of the integrated alerting system, it was not included in the present study. However, a distinct class of warning alerts was identified. These alerts, called time-critical warnings, are defined as alerts that require an unconditionally immediate corrective or compensatory crew action. For these alerts, insufficient time may be available to elicit crew detection and response in time to avoid a potentially hazardous condition through the use of alerting system components prescribed for other warnings (Parks, 1979). For this reason, time-critical warnings were identified and a unique presentation format was designed to provide the crew with guidance information to facilitate their response to these alerts.

Veitengruber (1977), ARP 450D (1980), Boucek, et al., (1980) and the present study all used a hierarchical approach in associating alerting system components with urgency level; the higher the level of urgency, the more alerting system components utilized to assure that the aircrew detects and responds to the alert in a manner appropriate for the alerting situation. In these studies, various aural and visual alerting system components were combined to identify those that produced the best crew performance (i.e., shorter detection and response times, and fewer missed alerts). Table 2.4-1 presents a summary of the guidelines for combination of alerting system components for standardizing alerting functions and methods.

2.4.1 ADVISORY ALERTS

The alerting and informing functions for advisories should be accomplished by an aural alert and a message on the visual information display, respectively. The aural alert attracts the crew's attention providing preliminary urgency

Table 2.4-1. Alerting System Categorization

Condition	Criteria	Alert system characteristics		
		Visual	Aural	Tactile
Warning	Emergency operational or aircraft system conditions that require immediate corrective or compensatory crew action	Master visual (red) plus centrally located alphanumeric readout (red)	Unique attention-getting warning sound plus voice*	Stick shaker (if required)
Caution	Abnormal operational or aircraft system conditions that require immediate crew awareness and require prompt corrective or compensatory crew action	Master visual (amber) plus centrally located alphanumeric readout (amber)	Unique attention-getting caution sound plus voice*	None
Advisory	Operational or aircraft system conditions that require crew awareness and may require crew action	Centrally located alphanumeric readout (unique color)	Unique attention-getting advisory sound	None
Information	Operational or aircraft system conditions that require cockpit indications, but not necessarily as part of the integrated warning system	Discrete indication (green and white)	None	None

*Voice is pilot selectable.

information, and the message presented on the visual information display gives them the nature and location of the alerting situation. To aid in the identification of advisory alerts, a unique aural sound (single stroke chime) and color code (blue) were identified. To identify a unique advisory sound, Boucek, et al., (1980) presented current line pilots with a series of alerting sounds, ranging from a mechanical bell to a high chime, and asked them to evaluate the urgency level of the sounds. The results indicated that low frequency, single-stroke sounds were most often classified as representing advisory alerts (see Table 2.4.1-1). On the other hand, sounds that were intermittent/wavering, and which contained both low and high frequency components were categorized as warnings. Cautions were most often associated with steady state midrange frequency sounds.

To facilitate the identification of advisory level information on the visual information display, several researchers (Cooper, 1977 and Veitengruber, 1978) have advocated a third color in addition to red (warnings) and amber

Table 2.4.1-1. Summary of Pilot Judgment of Selected Alerting Sounds

Priority level assigned (% of 28 pilots)			
Alerting tone	Warning	Caution	Advisory
Mechanical bell	100.0	–	–
High wailer	92.0	3.5	3.5
Electronic bell	82.1	14.2	3.5
Low wailer	67.9	28.6	3.5
Clacker	60.7	35.7	3.5
Low C-chord	7.1	57.1	35.7
High horn	3.5	60.7	35.7
Low buzzer	3.5	46.4	50.0
High C-chord	–	35.7	64.3
Low chime	–	21.0	78.6
Low horn	–	25.0	75.0
High chime	–	7.1	92.8

- Criteria for assigning sounds to priority levels

  Warning: Emergency operational or aircraft system conditions that require immediate corrective or compensatory action by the crew.

  Caution: Abnormal operational or aircraft system conditions that require immediate crew awareness and subsequent corrective or compensatory crew action.

  Advisory: Operational or aircraft system conditions that require crew awareness and may require crew action.

(cautions). Boucek, et al., (1980) solicited pilots' opinions on whether a third color was needed. All pilots surveyed preferred the use of a third color over positional cues especially when alerts were displayed in order of alert urgency level (i.e., warnings listed on top of the visual information display, cautions in the middle, and advisories below cautions).

Pilot performance and preference data was also obtained by Boucek, et al., (1980) to determine whether a master visual alert or an aural message should be used for advisory level alerts. Pilot performance data indicated that significantly more advisories were missed (not detected) when a master visual alert was not used. However, this effect was reduced significantly when a box was put around the most recent alert to indicate new alerts on the visual information display. Pilot preference data indicated that the combination of a master aural alert and a box on the visual information display was adequate to satisfy the advisory alerting and informing functions. They stated that the master visual alerts and voice messages should only be used to denote situations requiring immediate crew awareness. For these reasons, a master visual alert and a voice message are not required for advisory level alerts.

2.4.2 CAUTION ALERTS

The alerting system components used to accomplish the alerting and informing functions for cautions should include:

- Master Visual and Aural Alerts - These provide a dual channel presentation to attract the attention of the crew as well as to provide preliminary urgency level information. Redundant alerting methods should be used to minimize the probability of missed alerts, and to reduce detection times. There is a general consensus that bimodal presentations of alerting situations are better than single mode presentations (Hammer, 1958; Adams and Chambers, 1962; Bate, 1969; and MIL-STD-1472B, 1978).

- Visual Information Display - The visual information display should be used to display all alerts included in the alerting system (i.e, warnings, cautions, and advisories).

- Voice Information Display - A voice information display (i.e., verbal messages) should be used as a redundant channel to provide the same information as the visual display. However, due to the possibility of the voice message interfering with other communications in the flight station (e.g., ATC, crew intercommunications), the pilot should be provided with control over the onset of the voice message (Boucek, et al., 1980). This selection capability would allow the crew to get the voice messages in those cases where they have a high visual workload (e.g., takeoffs, landings), and not to get it while they are receiving other verbal communications.

2.4.3 WARNING ALERTS

All of the alerting system components used to attract the attention of the crew and to inform them of the criticality, location, and nature of caution alerts should also be used for warnings. To provide a unique alerting method for warnings: a red master visual alert should be used, the alphanumeric message on the visual information should be red and located above caution and advisory messages, and a distinct master aural sound should be used. The selection of the voice information display and its format should be the same for warnings and cautions.

2.4.4 TIME-CRITICAL WARNINGS

The alerting system components used to announce time-critical warnings are the same as for non-time-critical warnings, except for the use of the time-critical display. This display, located in both pilot's primary fields of view, should be used to provide the crew with guidance information which they can use to respond to the alert. A second exception is the onset of the voice information display which is automatic rather than a pilot option.

2.5 ALERTING SYSTEM FLEXIBILITY

System flexibility is a highly desirable feature, especially in an environment of rapidly expanding technology. As systems, techniques, and procedures offering improved safety and reduced operating costs become available, the alerting system must be capable of quickly and easily supporting the needs of these systems for crew alerting.

As in any evolutionary process, original design thresholds, operational procedures, or presentation techniques may be proven inadequate or less desirable when compared with later developments. To take advantage of such innovations, the design of the alerting system should preferably be designed to allow future growth and modification with minimal effort.

To prevent the proliferation of alerts, the components of an advanced alerting system should be able to accommodate all alerting functions, present and future (e.g., BCAS, GPWS), without the addition of new discrete aural or visual alerting components (Veitengruber, et al., 1977). The attention-getting function for all alerts (present and future) should be accommodated by the master visual and aural alerts. New master lights and master sounds should not be required. Likewise, the visual and voice information displays should be programmable and flexible to provide a growth capability. Each new warning and caution alert should receive a unique annunciation (message) that will enable the flight crew to easily identify the criticality, location, and nature of the problem. In addition, if the new alert is determined to be time-critical, a graphic format should be developed for presentation on the time-critical display.

2.6 ALERTING SYSTEM RELIABILITY

To promote confidence in the alerting system, it should always be activated when an alerting situation exists, and never when one does not exist (Cooper, 1977, and Veitengruber, 1978). The alerting system should be designed to reduce the pilot's workload by presenting information on the status of the aircraft and the alerting situation. Frequent false or nuisance alarms not only add to aircrew workload, but also contribute to the pilot's failure to detect and correctly interpret a real indication.

The reliability of the alerting system has a significant effect on its operational utility. In a survey of commercial airline pilots (Cooper, 1977) the pilots stated that "nuisance alerts, whether caused by unreliable systems or by design error, contribute to a pilot ignoring an indication when it is a real one". As an example, they considered the altitude alert to be a nuisance in some cases. They stated "that if a warning sounds too often, pilots may develop a habit of 'punching it out' without thinking and therefore it can lose its value".

In general, pilots had high praise for the reliability achieved with present day avionics systems. However, several ideas were presented for improving hardware reliability (Cooper, 1977): use dual lamps/displays to provide alerting signal redundancy; provide a system test function so the operation of the alerting system can be tested either on the ground, or in the air; and to incorporate built-in test logic to detect sensor malfunctions and broken wires.

2.7 GENERAL SYSTEM GUIDELINES—SUMMARY

In summary, alerting systems should inform the crew of conditions requiring their attention, indicate the criticality, location, and nature of the problem, provide feedback on the adequacy of the aircrew's corrective or compensatory actions, and provide a capability to interact with the alerting system. Master visual and master aural alerts, a visual information display, and a voice information display should be provided to accomplish the attention-getting and informing functions. A separate display should be provided to give guidance information to enable the pilot to respond quickly to time-critical situations. The visual information display should be programmable to accommodate new alerts and interactive to enable the crew to exert control over the alerting system.

The design of future alerting systems should use a systems approach. The alerting system should provide unique attention-getting and informing methods for each urgency level. The system should be flexible and possess a capability to accommodate new alerts without requiring additional discrete aural or visual annunciators. To be effective the alerting system must be reliable. The alerting system should always be activated when an alerting situation exists, and never when one does not. The overall reliability of the alerting system depends on both the reliability of the hardware, and its associated logic, and on the performance of the pilots.

3.0 VISUAL SYSTEM COMPONENTS DESIGN GUIDELINES

This section presents design guidelines for the visual components of an aircraft alerting system. Guidelines are presented for the three primary visual components:

- Master Visual Alert
- Visual Information Display
- Time-Critical Warning Display

The primary functions of the master visual alert are to attract the attention of the flight crew, and to provide a preliminary indication of alert urgency level. The visual information display provides a centralized location for the annunciation of all alerts. A time-critical warning display provides immediate guidance for the pilots to enable them to react quickly and accurately in situations where time is extremely limited, and where reaction to the alert is critical.

The use of the visual components of the alerting system are dependent upon the nature of the alerting situation. The master visual alert for warning should be activated whenever a warning situation is detected by the aircraft's sensors; the same principle applies for the visual master caution alert. The visual information display is used to list all alerts. The time-critical display should be used only in emergency situations where time is extremely limited, and the correct action can be specified.

The guidelines for the visual components of an aircraft alerting system are presented in the following paragraphs.

3.1 MASTER VISUAL ALERT

3.1.1 PURPOSE

THE MASTER VISUAL ALERT SERVES TWO PRIMARY FUNCTIONS:

- ATTRACT THE ATTENTION OF THE CREW
- PROVIDE PRELIMINARY ALERT URGENCY LEVEL INFORMATION

Siegel and Crain (1960), and Boucek, et al., (1980) have shown that the use of a master visual alert reduces pilot detection time, as well as the number of missed alerts. Figure 3.1.1-1 shows a comparison of mean detection times for warning and caution alerts, with and without the use of a master visual alert. As can be seen from the figure, mean detection times were significantly shorter when the master alert was used. Similarly, response times were also found to be shorter for warnings and cautions when a master visual alert was used.

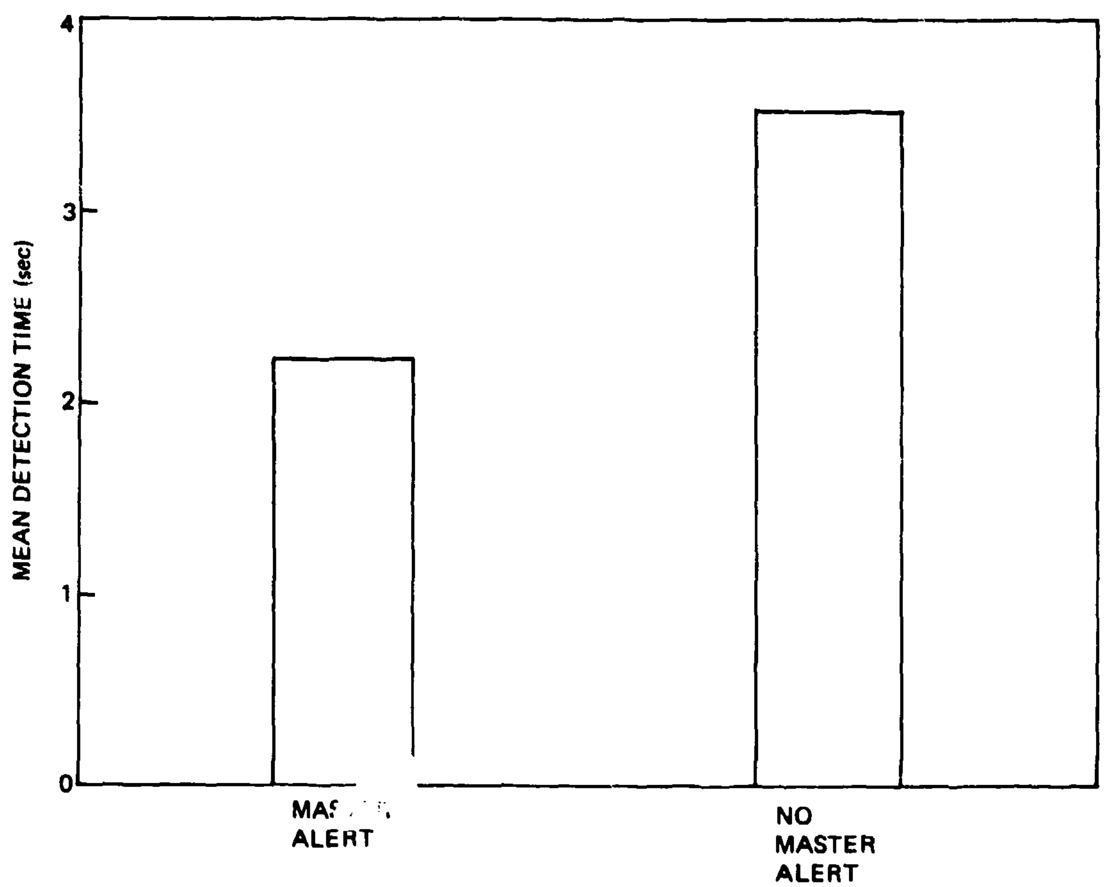


Figure 3.1.1-1. Mean Detection Times for Warnings and Cautions (Combined) With and Without a Visual Master Alert (Boucek, et al., 1980)

Boucek, et al., (1980) also found that significantly more alerts were missed (not detected) by pilots when the alert was not accompanied by a master visual signal. Figure 3.1.1-2 presents these results. This study also found that the master visual alert not only served to get the pilot's attention, but also provided information upon which the pilot could base response decisions. The urgency level information provided by two master warning and caution alerts enabled the pilots to respond more quickly to warnings ($\bar{x}$ = 5.1 seconds) than they did for cautions ($\bar{x}$ = 6.4 seconds). This finding, shown in Figure 3.1.1-3, was consistent even though the mean detection times for warnings and cautions were not significantly different.

IN SUMMARY, MASTER VISUAL ALERTS SHOULD BE USED TO ATTRACT CREW ATTENTION, AND TO PROVIDE THEM WITH INFORMATION ON ALERT URGENCY LEVEL.

3.1.2 NUMBER

- MASTER VISUAL ALERTS FOR WARNINGS AND FOR CAUTIONS SHOULD BE PROVIDED

To satisfy the requirement for immediate crew awareness master visual alerts should be used for warning and caution alerts. These two alerts, one for warnings and one for cautions, should be located directly in front of each pilot, in their primary field of view. Since advisory events do not require immediate crew awareness, a master advisory light is not recommended. The results of the survey of airline pilots reported in Volume 1 of this study indicated that most pilots preferred to have advisory information contained on a central visual display rather than by the onset of a master advisory light. The pilots also indicated that providing a master light for advisories would tend to reduce the importance of warnings and cautions, since all alerts would be annunciated in the same manner.

The pilots were further asked whether they preferred separate warning and caution master visual alerts, or a single split-legend light with warnings annunciated on the top half and cautions on the lower half. No strong preference was voiced by the pilots; fifty-six percent of the pilots surveyed preferred separate master lights. The pilots indicated that they were more

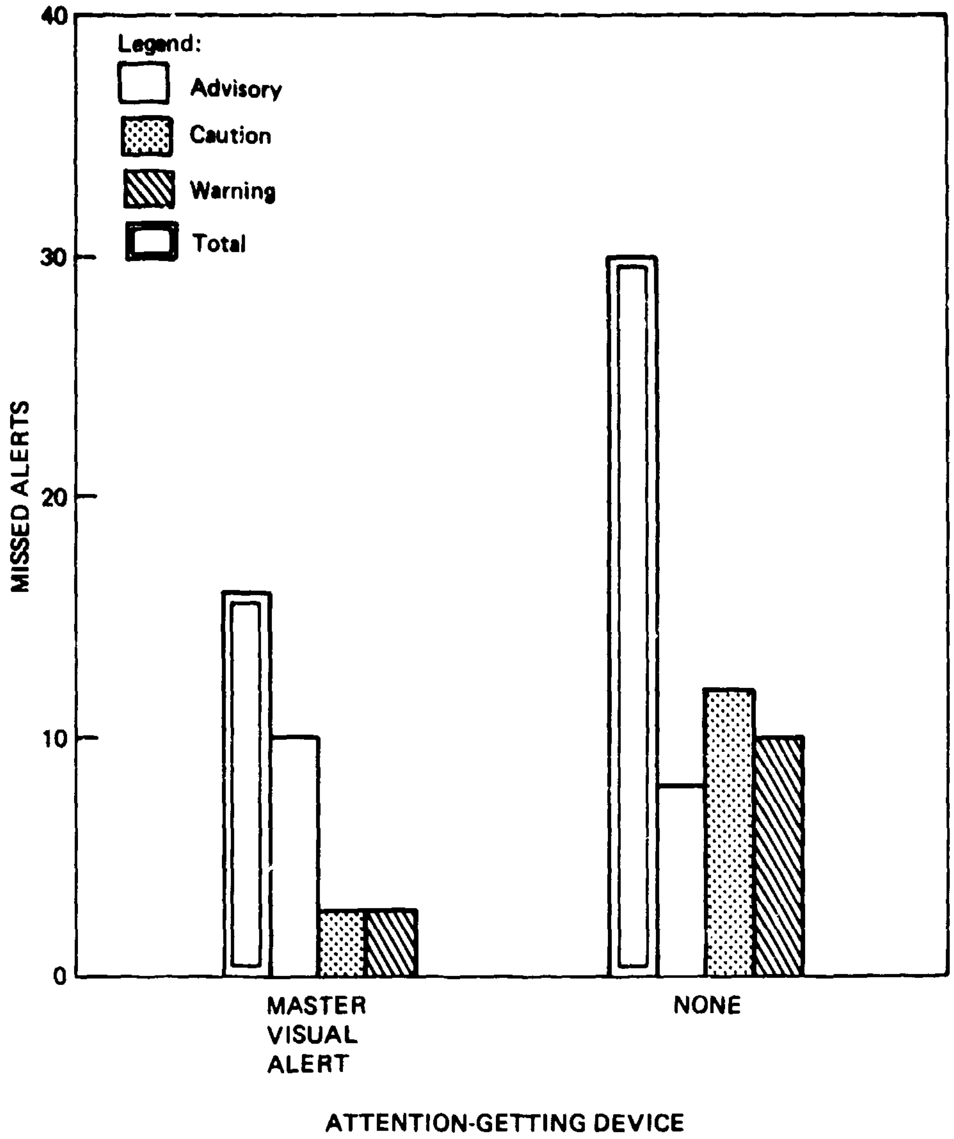


Figure 3.1.1-2. Missed Alerts as a Function of Master Visual Alert (Boucek, et al., 1980)

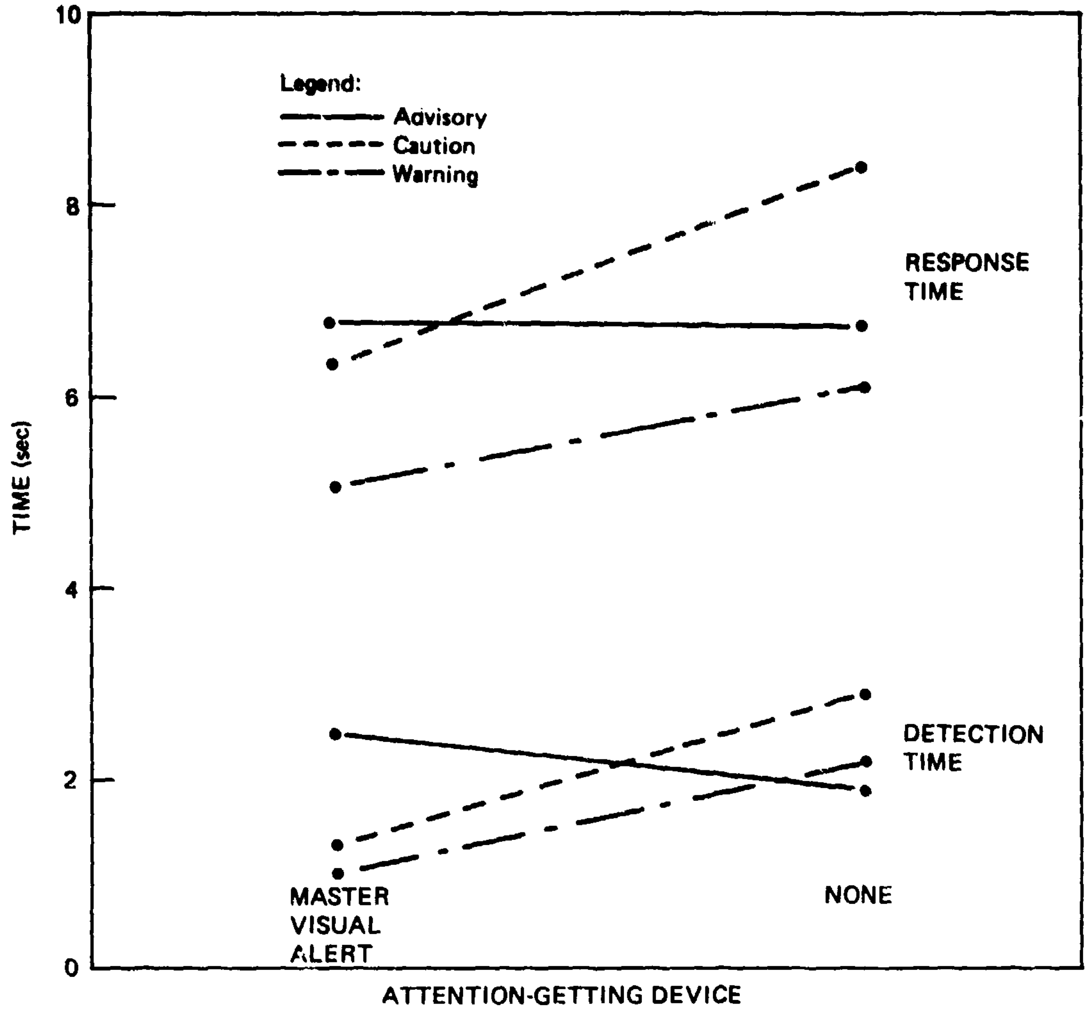


Figure 3.1.1-3. Mean Detection and Response Times for Alert Urgency Levels With and Without a Master Visual Alert (Boucek, et al., 1980)

concerned with the size and location of these lights than whether they were separated or combined.

IN CONCLUSION, TWO MASTER VISUAL ALERTS (EITHER SEPARATE OR SPLIT-LEGEND) SHOULD BE PROVIDED FOR EACH PILOT TO ANNUNCIATE WARNING AND CAUTION LEVEL ALERTING SITUATIONS.

3.1.3 LOCATION

- MASTER VISUAL ALERTS SHOULD BE LOCATED WITHIN 15 DEGREES OF EACH PILOT'S CENTERLINE OF VISION, AND WITHIN REACH WHEN THE PILOTS ARE SEATED IN LINE WITH THEIR EYE REFERENCE POINTS.

The location of visual signals relative to the pilot's centerline of vision has a significant effect on not only the time to respond to a signal but also the probability that it will be seen at all. Boucek, et al., (1980) found that response times and error rates were significantly lower when master warning and caution lights were located within the pilot's primary field of view.

Military-Standard-411, MIL-STD-1472, and industry design guidelines (Van Cott and Kinkade, 1972; and McCormick, 1970), define the pilot's centerline of sight as a vector emanating from the pilot's eye, extending forward and angled 10 degrees below horizontal. Commercial airframe manufacturers have several definitions of the centerline of sight, all of which differ from the military definition; the most consistently used is that it is the line between the pilot's eye reference point and the center of the ADI. Both of these definitions were used in the recommended guidelines to insure the alerts attention-getting quality regardless of whether the pilot is head-up or head-down.

The definitions of primary and secondary field of view also vary. The military standards define primary field of view as the region within 15 degrees of the centerline of vision and the secondary field of view as the region between 15 degrees and 30 degrees. Commercial aircraft manufacturers generally define the primary field of view as a binocular-shaped area covering most of the pilot's primary instrument panel containing the ADI, HSI, airspeed, and altitude indicators, and the secondary field of view as a binocular-shaped area covering most of the pilot's front panel which contains the engine instruments and autopilot mode select panels.

To enable the pilots to deactivate the master visual and aural alerts the master visual switch indicators should be within their reach. Anthropometric data should be used to ensure that all pilots are able to reach the master alert switch lights from their normal seated position at the eye reference point. In addition, the master alerts should be located so that the viewing angle is not greater than 15 degrees off the perpendicular axis of the indicator (Meister and Sullivan, 1969). The following criteria for locating visual alerting signals is recommended (refer to Figure 3.1.3-1). THE MASTER VISUAL ALERTS SHOULD BE LOCATED NO MORE THAN 15 DEGREES FROM EACH PILOT'S CENTERLINE OF VISION (BOTH HEAD-UP AND HEAD-DOWN), AND THE MASTER VISUAL ALERTS SHOULD BE WITHIN REACH OF ALL PILOTS IN THEIR NORMAL SEATED POSITIONS.

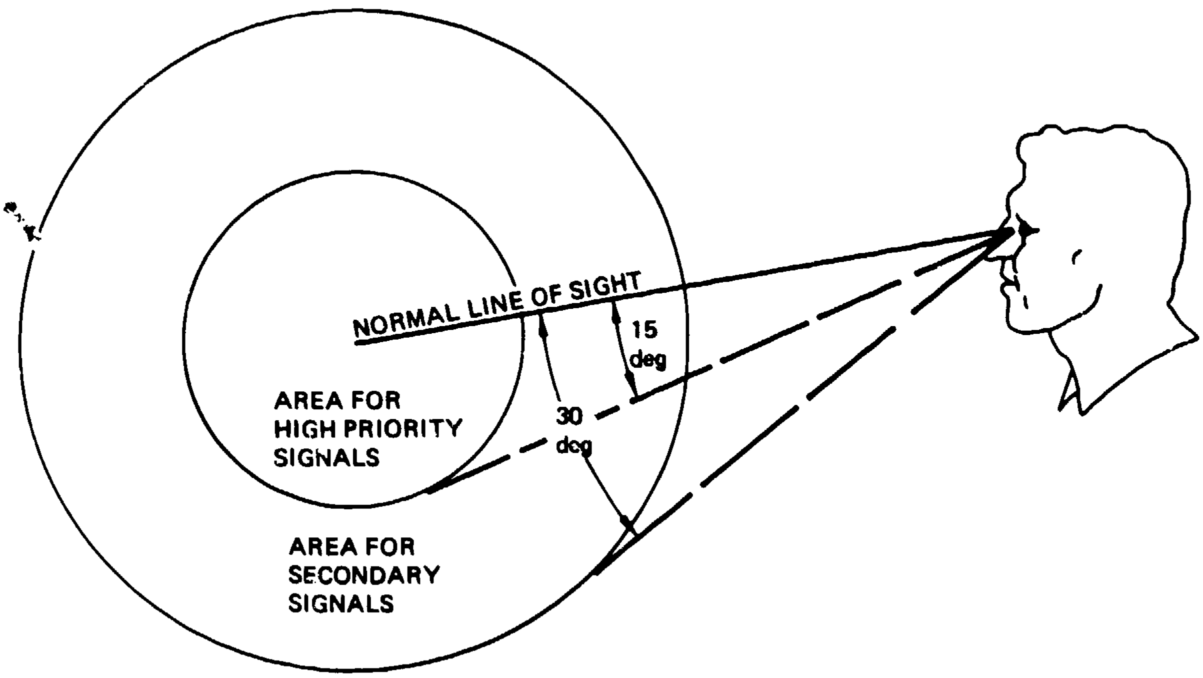


Figure 3.1.3-1. Recommended Placement of Visual Signals

3.1.4 DURATION/CANCELLATION

- THE ONSET OF THE MASTER VISUAL ALERT SHOULD OCCUR SIMULTANEOUSLY WITH THE ONSET OF THE MASTER AURAL ALERT, AND WITHIN 0.5 SECOND AFTER THE ALERTING SITUATION HAS OCCURRED

- THE MASTER VISUAL ALERT SHOULD REMAIN ON UNTIL IT IS CANCELLED EITHER MANUALLY BY A PILOT, OR AUTOMATICALLY WHEN THE ALERTING SITUATION NO LONGER EXISTS

- UPON CANCELLATION THE ALERTING MECHANISMS SHOULD BE RESET TO ANNUNCIATE ANY SUBSEQUENT FAULT CONDITION

One of the general requirements described earlier is that all of the components of the alerting system should be coordinated. That is, immediately after the alerting computer signals an alert, the annunciation of the alert via the visual and auditory components should be coordinated. The onset of the master aural and master visual alerts should occur simultaneously, along with the appearance of the alert message on the visual information display.

In several surveys (Cooper, 1977; and Boucek, et al., 1977 and 1980) pilots indicated that any device which is sufficiently attention-getting to alert a crew member also has the potential for creating a distraction. Extremely loud or visually distracting alerting devices can interfere with flight deck communications, pilot decision-making, and crew coordination. For these reasons, most pilots favored cancelling the visual and aural master alerts after they have served their primary purposes of attracting the attention of the crew and providing preliminary urgency information. A large majority favored manual cancellation of the master visual alert by depressing the master visual alert switch-indicator. The pilots stated that this action should also cancel the master aural alert and the verbal message, and should reset the master alerts to annunciate subsequent alerting situations. However, cancellation of the master alerts should not cancel the alert message on the visual information display. Cancellation of alert messages on the visual information display is described in Section 5. In addition, a large majority of pilots preferred automatic cancellation of alert messages after the alerting situation had been corrected.

IN SUMMARY, THE ONSET OF THE MASTER VISUAL ALERT SHOULD OCCUR SIMULTANEOUSLY WITH THE ONSET OF THE MASTER AURAL ALERT, AND AS SOON AS POSSIBLE AFTER THE ALERTING SITUATION HAS OCCURRED. THE MASTER ALERTS SHOULD REMAIN ON UNTIL THEY ARE CANCELLED EITHER MANUALLY BY A PILOT, OR AUTOMATICALLY WHEN THE ALERTING SITUATION NO LONGER EXISTS. UPON CANCELLATION THE ALERTING MECHANISMS SHOULD BE RESET TO ANNUNCIATE NEW ALERTS.

3.1.5 STEADY STATE/FLASHING

- STEADY STATE MASTER VISUAL ALERTS SHOULD BE USED

Master visual alerts can be either steady state (constant brightness) or flashing (alternately bright and dim/off). Numerous experiments have been conducted on the detectability of steady and flashing lights. However, the results have been highly dependent on the procedures used by the researchers. Gerathewohl (1953) reported that the mean detection times for flashing lights were shorter than for steady lights of the same brightness. Crawford (1962 and 1963) found that the response to steady or flashing signal lights was affected by background conditions. Crawford's subjects were required to detect and indicate the location of signal lights when presented against various background conditions. When the background was blank, no differences were obtained in the detection of flashing or steady lights. When the background consisted of all steady lights, flashing signals were detected significantly faster than the steady lights. Figure 3.1.5-1 summarizes this data.

On the other hand, evidence suggests that flashing lights are much more distracting than steady lights. Since the master caution and warning visual alerts are generally separated from all other instruments or displays in the flight station, steady lights should be detected as fast as flashing lights, while being less distracting after their initial detection (Boucek et al., 1980). For these reasons the use of steady state master visual alerting signals is recommended.

IN SUMMARY, STEADY STATE MASTER VISUAL ALERTS SHOULD BE USED.

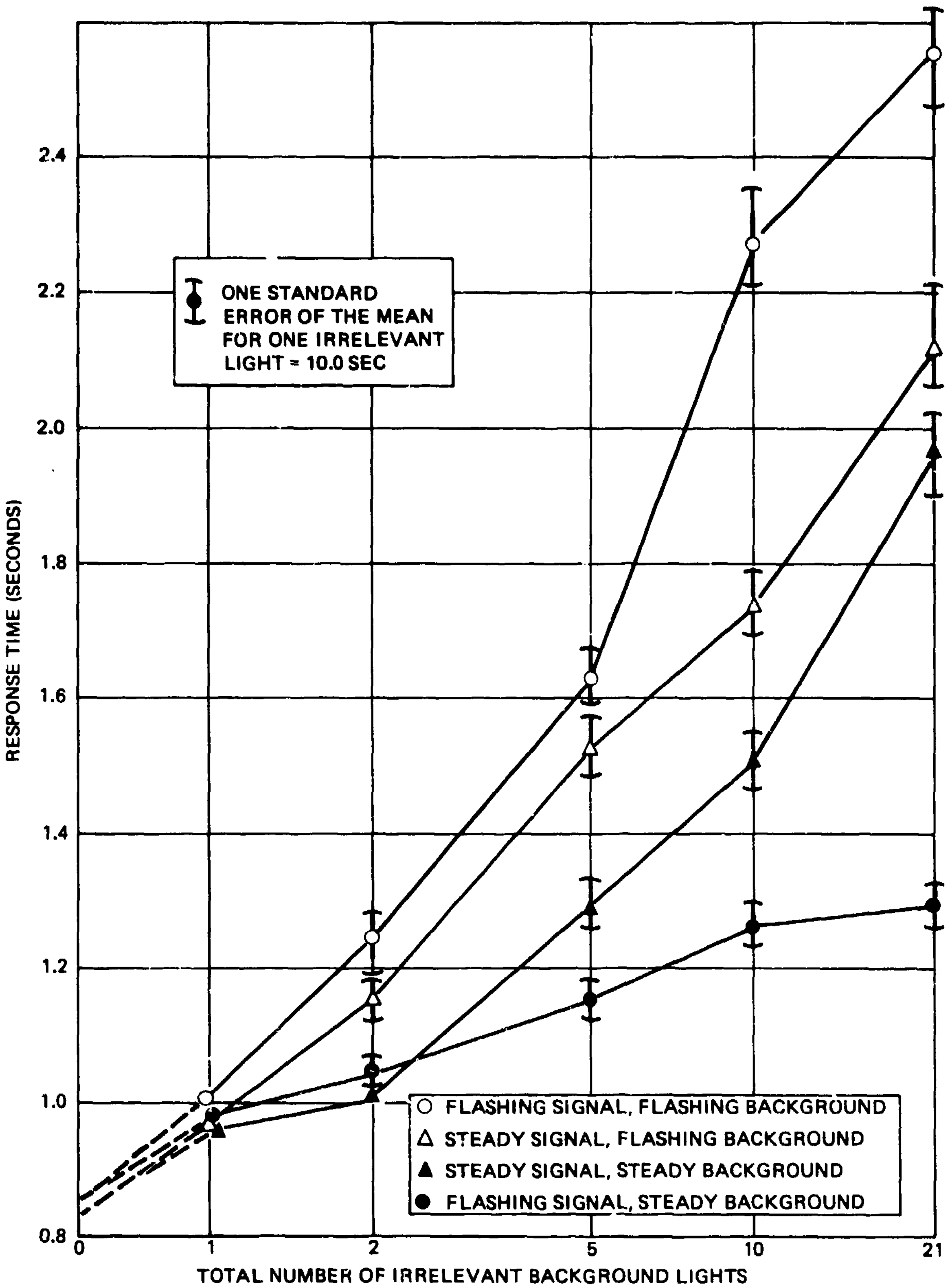


Figure 3.1.5-1. Effects of Irrelevant Background Lights on Response Time (Crawford, 1962)

3.1.6 BRIGHTNESS

- MASTER VISUAL ALERTS SHOULD BE BRIGHT ENOUGH TO ATTRACT THE ATTENTION OF THE CREW

- THE AVAILABLE RANGE OF BRIGHTNESS SHOULD PROVIDE SUFFICIENT CONTRAST FOR BOTH LOW AND HIGH AMBIENT LIGHT CONDITIONS

The effect of signal brightness on detection is directly related to the amount of light reflected by the display panel. Industry design recommendations and military standards give various approaches to the problem. Van Cott and Kinkade (1972) recommended that visual signals should be bright enough to stand out clearly against the panel on which they appear under all expected lighting conditions, but they should not be so bright as to impair the vision of the operator. Meister and Sullivan (1969) stated that "the intensity of a high priority signal should be at least twice as bright as the immediate background; the background should be dark in contrast to the display, and should have a dull finish."

Although the brightness requirement of a signal is primarily determined by its need to be seen, the range of intensity is dictated by the detection threshold on one end, and disruption of normal activities on the other. MIL-STD-411D requirements are as follows: The brightness of any rear-lighted signal shall be at least 10 percent greater than the brightness of the area around the signal. High priority signals require a recommended minimum of 150 ft-L for high ambient situations and 15 $\pm$ 3 ft-L for low ambient lighting conditions.

In following any recommendation, care must be taken in choosing the signal brightness. Even though it would take a signal of 10^5 ft-L to produce actual discomfort, a direct look at a 4 ft-L signal will cause a loss of dark adaptation for a full minute (Stevens, 1951).

Research indicates that as signal intensity increases, simple reaction time will decrease (Davis, 1947; Luckiesk, 1944; Steinman, 1944; and, Steinman and Venias, 1944). The relationship between signal intensity and reaction time is nonlinear and has been described by exponential, hyperbolic, and parabolic functions.

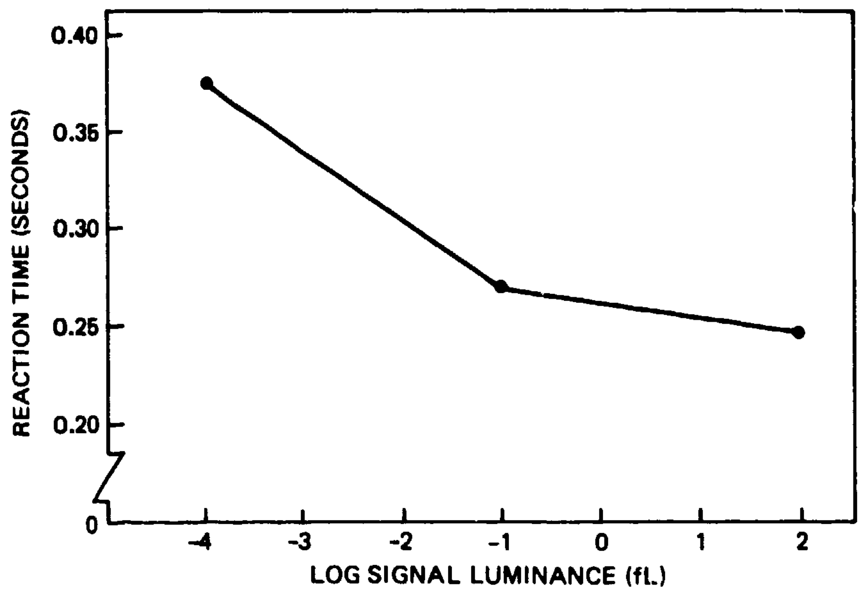


Figure 3.1.6-1. Simple Reaction Time as a Function of Signal Luminance (Kohfeld, 1971)

Raab and Fehrer (1962) studied the effect of flash luminance on simple reaction time using circular signals subtending 1 degree and 10 minutes of visual angle when viewed binocularly in a darkened room. Reduction of reaction time was noted out to brightness levels of 3000 ft-L. Significant improvement in reaction time occurred as brightness was increased to 30 ft-L. At the higher brightness levels, however, further improvements were thought to be attributed to startle reponses. Kohfeld (1971), using a white signal of 23 degrees visual angle found that simple reaction time improved rapidly as brightness was increased from 0.0001 to 0.1 ft-L; less improvement was noted as brightness was increased to 100 ft-L (see Figure 3.1.6-1).

Cooper (1977) and Boucek, et al., (1981) surveyed pilots' opinions on the brightness of warning and caution lights. They indicated that while in general the brightness of these lights were adequate in present day airplanes, the brightness of these lights should be adjusted automatically as ambient light conditions in the aircraft change.

IN SUMMARY, HIGH PRIORITY SIGNALS SHOULD BE BRIGHT ENOUGH TO ATTRACT THE ATTENTION OF THE CREW AND SHOULD PROVIDE SUFFICIENT CONTRAST FOR HIGH AND LOW AMBIENT LIGHT CONDITIONS. BRIGHTNESS OF THE ALERTS SHOULD ADJUST AUTOMATICALLY AS LIGHTING CONDITIONS CHANGE.

3.1.7 DISPLAY SIZE AND CHARACTER DIMENSIONS

- MASTER VISUAL ALERTS SHOULD SUBTEND AT LEAST 1 SQUARE DEGREE OF VISUAL ANGLE
- MASTER VISUAL ALERT LEGENDS SHOULD BE UPPER CASE, 15 TO 20 MINUTES OF ARC IN SIZE, WITH A HEIGHT-TO-WIDTH RATIO OF 5:3, A STROKE WIDTH 1:6 TO 1:10 OF THE HEIGHT, AND WITH A BETWEEN-CHARACTER SPACING OF 25 TO 63 PERCENT OF THE CHARACTER HEIGHT
- CHARACTER SIZES AND FONTS SHOULD BE EVALUATED PRIOR TO IMPLEMENTATION TO ENSURE LEGIBILITY

For visual stimuli that subtend a visual angle of 1 square degree or less, detectability is positively related to size. However, no consistent effect of size has been demonstrated for visual stimuli larger than 1 square degree. Sheehan (1972) measured the response times to alphanumeric legends presented on an A-7E head-up display simulator. Subjects were required to detect one of three different visual warnings (FIRE, SAM HI, or HYD PRESS), while performing a two-dimensional visual tracking task, and to respond by pushing buttons to indicate which of the three messages had been presented. The visual warnings were projected on the head-up display in one of three different alphanumeric character sizes. The character heights in degrees of visual angle and the corresponding reaction times were as follows: 0.5°, 1.97 seconds; 1°, 1.00 second; and 2°, 0.98 second. As shown in Figure 3.1.7-1, increasing the height of the characters from 0.5° to 1° reduced the mean response time by about one-half; however, an additional increase in height from 1° to 2° did not have a significant effect on the response time. It should be noted that the response time recorded by Sheehan included the time for detection of a message as well as the time to decide which message had been presented, and to make the correct response.

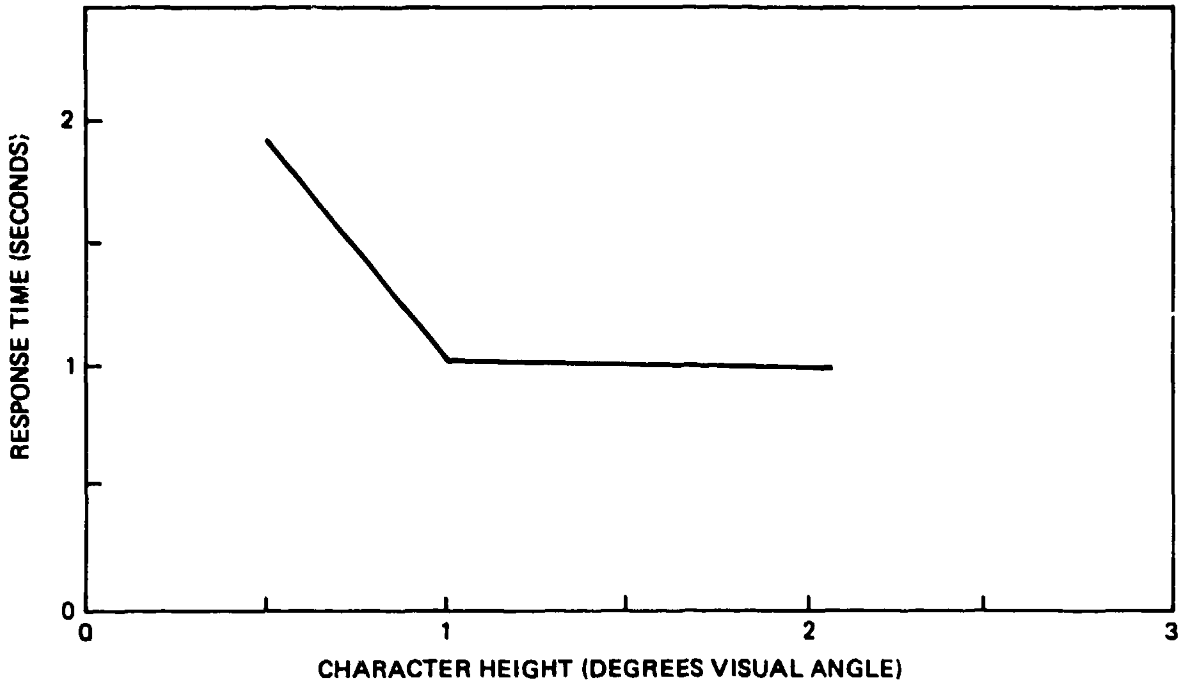


Figure 3.1.7-1. Effect of Character Height on Reaction Time (Sheehan, 1972)

Merriman (1969) investigated the effect of display size on the attention/intrusion ability of border-lit red warning lights. His stimuli consisted of red transilluminated borders around an 0.25" high by 1.4" wide opaque black strip. Six different widths of red borders were used as warning lights (see Table 3.1.7-1). The subjects had to detect and respond to the red warning lights while monitoring another set of lights. Even though the data from this study can be presented in a number of ways, the most appropriate measures to use are the visual angle of the border and square degrees of angle for signal size, because this eliminates viewing distance from consideration (a square that has sides 1 degree of visual angle in length has an area of 1 square degree of visual angle). The former measurement should give the smallest signal size possible for detection and the latter the largest. A practical value should lie somewhere in between.

Table 3.1.7-1. Border-Width Test Conditions (Merriman, 1969)

Border width (in)	0.031	0.063	0.125	0.188	0.250	0.313
Border visual angle (deg)	0.06	0.13	0.26	0.39	0.51	0.64
Lighted area (deg^2)	0.28	0.51	1.15	1.92	3.88	2.74

Results obtained for the six test conditions are shown in Figure 3.1.7-2. The mean response times and their standard deviations decreased as the area of the red warning light was increased from 0.28 to 2.74 deg^2. An additional increase in the size of the warning light from 2.74 to 3.88 deg^2 had no observable effect on reaction time. The increases in mean response time and standard deviations for decreasingly small signal lights was largely ascribed to a tendency for the smaller signal lights to occasionally go undetected for extended periods of time.

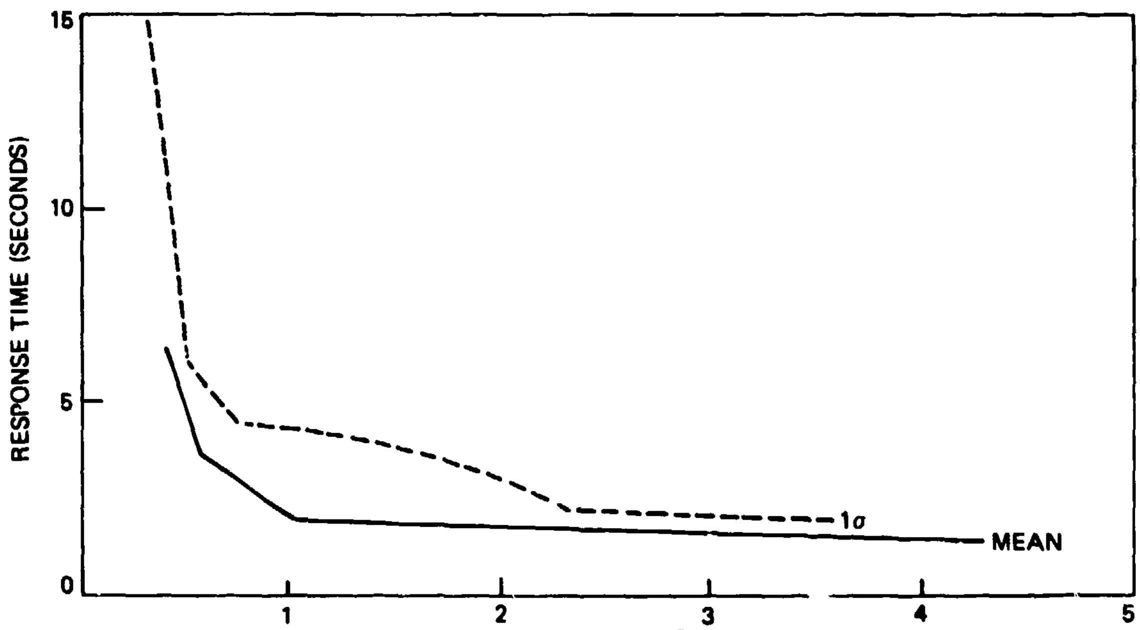


Figure 3.1.7-2. Effect of Warning Light Size on Reaction Time (Merriman, 1969)

Boucek, et al., (1977) reported that the use of positive legend displays (black legend on a light background) were found to improve response times to alerts. They found that the character height, of high priority legends should be between 15 and 22 arc minutes. MIL-M-18012B delineates the height-to-width ratio for capitalized warning legends to be 5:3, the stroke width to be 1:6 to 1:10 of the height and spacing between characters of 25 to 63% of character height. The legends should read "WARNING" and "CAUTION" for the two visual master alerts. The font of the legends should be futura medium.

IN SUMMARY, MASTER VISUAL SIGNALS SHOULD SUBTEND NO LESS THAN 1 SQUARE DEGREE OF VISUAL ANGLE, AND THE CHARACTERISTICS OF THE WARNING AND CAUTION LEGENDS SHOULD BE OPTIMIZED TO FACILITATE THEIR READABILITY

3.1.8 COLOR

- STANDARD COLOR CONVENTIONS SHOULD BE FOLLOWED FOR THE MASTER VISUAL ALERTS:

  RED - WARNING
  AMBER - CAUTION

- MASTER VISUAL LEGENDS SHOULD BE OPAQUE WITH TRANSLUCENT BACKGROUNDS. IMPLEMENTATION SHOULD MINIMIZE THE PROBABILITY OF THINKING THE ALERT IS ON WHEN IT IS NOT.

The master visual alerts should conform to the following color coding scheme, in accordance with Type 1- Aviation Colors of MIL-C-25050, and Federal Aviation Regulation 25.1322.

Red of the type FED-STD COLOR 311-05 - used to inform the aircrew of the existence of a hazardous safety-of-flight condition requiring immediate crew corrective or compensatory action.

Amber of the type FED-STD COLOR 325-44 - used to inform the aircrew of an impending dangerous condition requiring immediate crew awareness and subsequent corrective or compensatory action.

Siegel and Crain (1960), reported that dark lettering on a lighted background produces faster response times than light legends on a black background, independent of character height (see Figures 3.1.8-1 and 3.1.8-2). In addition, MIL-STD-411D requires that warning legends be opaque with a translucent background.

IN SUMMARY, RED AND AMBER SWITCH-INDICATORS SHOULD BE USED FOR THE VISUAL MASTER WARNING AND CAUTION ALERTS. OPAQUE LETTERING SHOULD BE USED ON A TRANSLUCENT BACKGROUND. IMPLEMENTATION SHOULD MINIMIZE THE PROBABILITY THAT THE ALERT WILL BE PERCEIVED AS ON WHEN IT IS NOT.

3.1.9 TEST REQUIREMENTS

- PROVISIONS SHOULD BE PROVIDED TO TEST/VERIFY THE OPERABILITY OF THE MASTER VISUAL ALERTS

A control (press-to-test) should be used to test the operability of the master visual alert. Whenever practical, the test circuitry should be designed to test the operation of the total indicator circuit (MIL-STD-1472B). This press-to-test control should also test the other components of the alerting system (i.e., aural alerts, verbal messages, and the presentation of alerts on the visual information and time-critical displays).

3.1.10 RELIABILITY

- THE RELIABILITY OF THE MASTER VISUAL ALERTS SHOULD MINIMIZE THE PROBABILITY OF UNDETECTED, FALSE OR NUISANCE ALERTS

The alerting system information is highly important, and therefore the components must be highly reliable. The visual components of the alerting system should be designed so that the failure of any single component will not dystroy the operational utility of the alerting system or endanger the aircraft. The system design must provide adequate redundancy to assure that this requirement can be met.

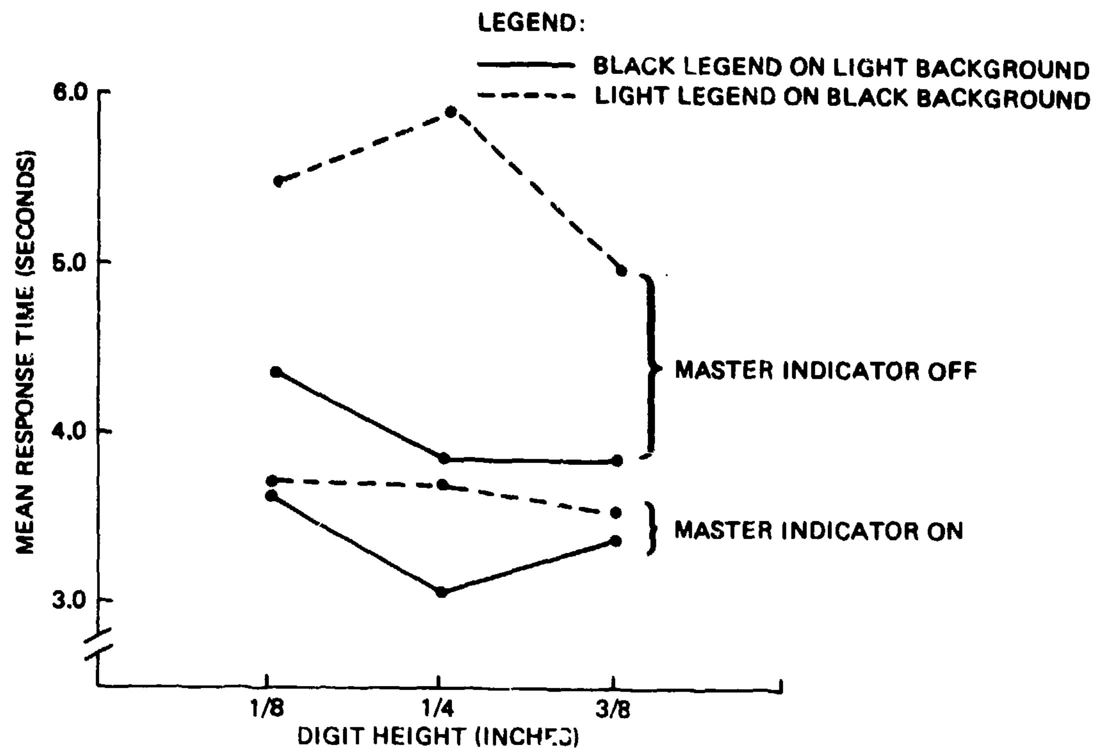


Figure 3.1.8-1. Mean Response Times as a Function of Legend Height and Polarity (Siegel and Crain, 1960)

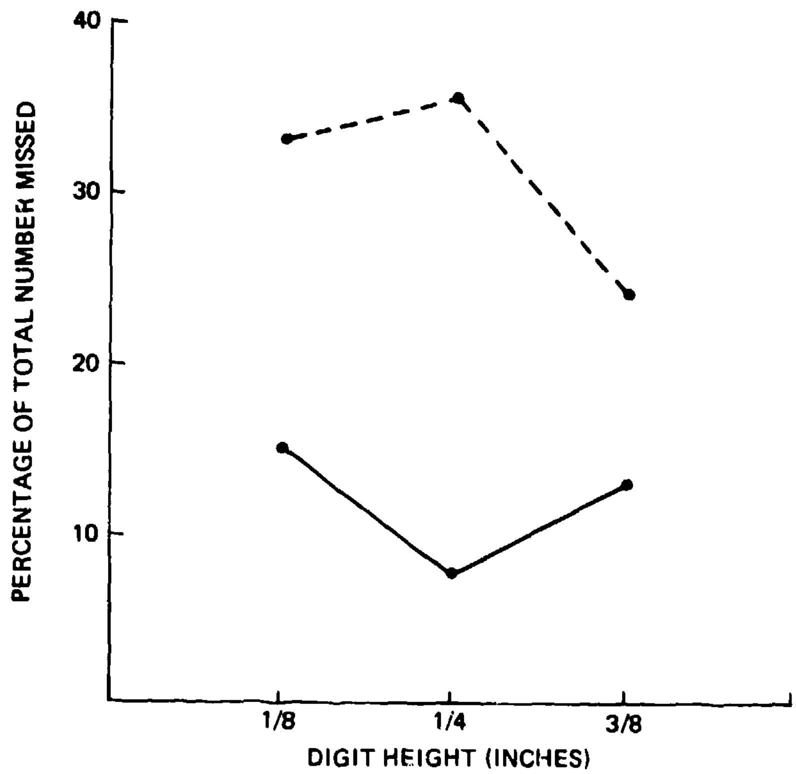


Figure 3.1.8-2. Accuracy of Definition as a Function of Legend Height and Polarity (Siegel and Crain, 1960)

All master visual alerts should be provided with component redundancy such as two lamps, two filaments. For example, to provide a positive indication of a lamp/bulb failure, the intensity of the light should decrease sufficiently to indicate the need for replacement, but not so much as to prevent the detectability of the master visual alert.

In a survey by Cooper (1977), pilots indicated that the reliability of the caution and warning system was extremely important. Cooper stated that warnings and cautions that actuate too often are useless as alerting system devices. Nuisance warnings, whether caused by an unreliable system or by design error, affect pilot confidence in the alerting system and contribute to a pilot ignoring an indication when it is real. The ultimate objective of an alert is to ensure safe operations. If this does not occur the system is not reliable. True reliability, therefore, includes the human element as well as hardware and software reliability.

IN SUMMARY, RELIABLE COMPONENTS, ALERTING LOGIC AND SUFFICIENT REDUNDANCY SHOULD BE PROVIDED TO MINIMIZE OR ELIMINATE THE PROBABILITY OF UNDETECTED, FALSE, OR NUISANCE ALERTS. ALL WARNINGS SHOULD ACTUATE THE MASTER VISUAL WARNING LIGHT AND ALL CAUTIONS SHOULD ACTUATE THE MASTER VISUAL CAUTION LIGHT.

3.1.11 MISCELLANEOUS GUIDELINES

- SWITCHLIGHT OPERATION - Cancellation of a master visual alert should occur when the face of the switch-indicator is depressed a distance of at least 0.115 inch. The required activation force should be 3.5 $\pm$ 1.5 lbs.

- FEEDBACK - The pilots should receive feedback that they have depressed the switch indicator. The feedback should be provided tactually and by extinguishing of the switchlight. The feedback should be provided within 0.5 second.

- SURFACE TEMPERATURE - Under operational conditions, the front switch-face temperature of the master visual alerts should not exceed 109°F (43°C) at an ambient temperature of 77°F (25°C).

- TECHNIQUE - The use of incandescent bulbs or other suitable technology for the master visual alert should be left up to the airframe manufacturer. However, the technique used must satisfy all of the guidelines presented for master visual alerts.

3.2 VISUAL INFORMATION DISPLAY

This section describes the guidelines for the design of the visual information display component of an alerting system.

3.2.1 PURPOSE

The visual information display serves five primary functions:

- PROVIDES ONE LOCATION WHERE ALL WARNING, CAUTION AND ADVISORY MESSAGES ARE DISPLAYED
- PROVIDES A CONCISE ALERT MESSAGE FOR EACH PROBLEM
- PROVIDES INFORMATION ABOUT ALERT URGENCY
- PROVIDES SOME DIRECTION FOR CREW CORRECTIVE ACTIONS
- PROVIDES FEEDBACK TO THE CREW WHEN FAULTS ARE CORRECTED

The current trend in aircraft alerting is to allow the placement of warning lights within a 30 degree cone of vision, and to centralize caution alerts within an annunciator panel, even if this does not lie within the 30 degree cone. In some cases the proliferation of alerts and the limitation of usable flight deck panel space has resulted in positioning some alerts outside the 30 degree cone. The competition for central panel space is so severe that little or no consistency has been achieved to date in the location of warning lights or annunciator panels (Cooper, 1977). To alleviate this problem, pilots surveyed by Cooper (1977), and by Boucek, et al., (1980) suggested the use of a centrally located display to present all alerts. The pilots stated that such a display would reduce the number of alerts that go undetected, and should also reduce the time required to detect and respond to alerting situations.

To aid pilots in responding to alerts, a concise alert message describing the problem should be provided and the information coded according to alert urgency (Boucek, et al., 1980). The message can be provided by dedicated annunciator lights, or presented on a visual information display. Each message should indicate the general heading of the problem (e.g.,"ENGINE"), the subsystem or location (e.g., "NUMBER ONE"), and the nature of the problem ("OVERSPEED"). Standardization, using the above order is desirable, but should be subordinated to a clear statement of the problem (e.g., LEFT ENGINE FIRE). Specific guidelines for recommended message syntax are provided in Section 3.2.3. In addition, the visual information display should provide the crew with data to assess the urgency level of the alert. Color (red for warnings, amber for cautions, and a third color for advisories) is the preferred means of coding this information on the visual display (see Section 3.2.3 for color-coding guidelines).

The final purpose for the visual information display is to provide the crew with feedback concerning the corrective action taken. This feedback is provided when alerts are cancelled automatically when the situation causing the alert has been corrected.

IN SUMMARY, A VISUAL INFORMATION DISPLAY SHOULD BE PROVIDED TO: CONSOLIDATE THE PRESENTATION OF ALL ALERTING INFORMATION INTO A CENTRAL AREA WITHIN THE PILOT'S PRIMARY OR SECONDARY FIELD OF VIEW; PRESENT A CONCISE STATEMENT OF THE ALERT AND ITS URGENCY LEVEL; ENABLE PILOTS TO OBTAIN A QUICK AND DIRECT INDICATION OF AIRCRAFT STATUS; PRESENT PRELIMINARY INFORMATION TO BE USED BY THE PILOT TO CORRECT THE ALERTING SITUATION; AND TO PROVIDE FEEDBACK TO THE PILOTS WHEN ALERTING SITUATIONS HAVE BEEN CORRECTED.

3.2.2 LOCATION – NUMBER

- THE LOCATION OF THE VISUAL INFORMATION DISPLAY AND ITS VIEWING ANGLE, RELATIVE TO THE PILOT, SHOULD NOT DEGRADE CREW PERFORMANCE

- VISUAL INFORMATION DISPLAYS LOCATIONS BEYOND 30° FROM THE PILOT'S CENTERLINE OF VISION SHOULD BE TESTED EMPIRICALLY BEFORE IMPLEMENTATION.

- ALL WARNING, CAUTION, AND ADVISORY ALERTS SHOULD BE PRESENTED ON THE SAME DISPLAY. THIS DISPLAY SHOULD BE USED ONLY TO PRESENT ALERTING MESSAGES

- THE DISPLAY SHOULD BE WITHIN REACH OF THE PILOT TO PERMIT OPERATION OF ITS CONTROLS

- THE NUMBER OF THE DISPLAYS SHOULD BE DETERMINED BY A COMBINATION OF OPERATIONAL AND RELIABILITY CRITERIA

The location of visual signals relative to the pilot's centerline of vision has a significant effect not only on the speed with which a signal is detected, but also on the probability that it will be seen at all. Boucek, et al., (1980) investigated pilot detection and response times, and the number of missed alerts as a function of the location of the visual information display. Two locations were evaluated: (1) below the ADI on the pilot's instrument panel, (within the pilots primary field of view) and, (2) on the left side of the central instrument panel, (within the pilot's secondary field of view), see Figure 3.2.2-1. Other variables investigated in this test included the presence or absence of a master visual alert, and the locations used for presenting various urgency level alerts (i.e., all alerts displayed on both the pilot and central panels, or only warnings presented on the pilot panel, and cautions and advisories on the central panel). The results of this test indicated that when a master visual alert was used, the location of the visual information display had no measurable effect on mean detection and response times (see Figure 3.2.2-2), or on the number of missed alerts. Pilot preference data indicated that locating the visual information display on the central instrument panel was acceptable as long as a master visual alert was located within the pilot's primary field of view.

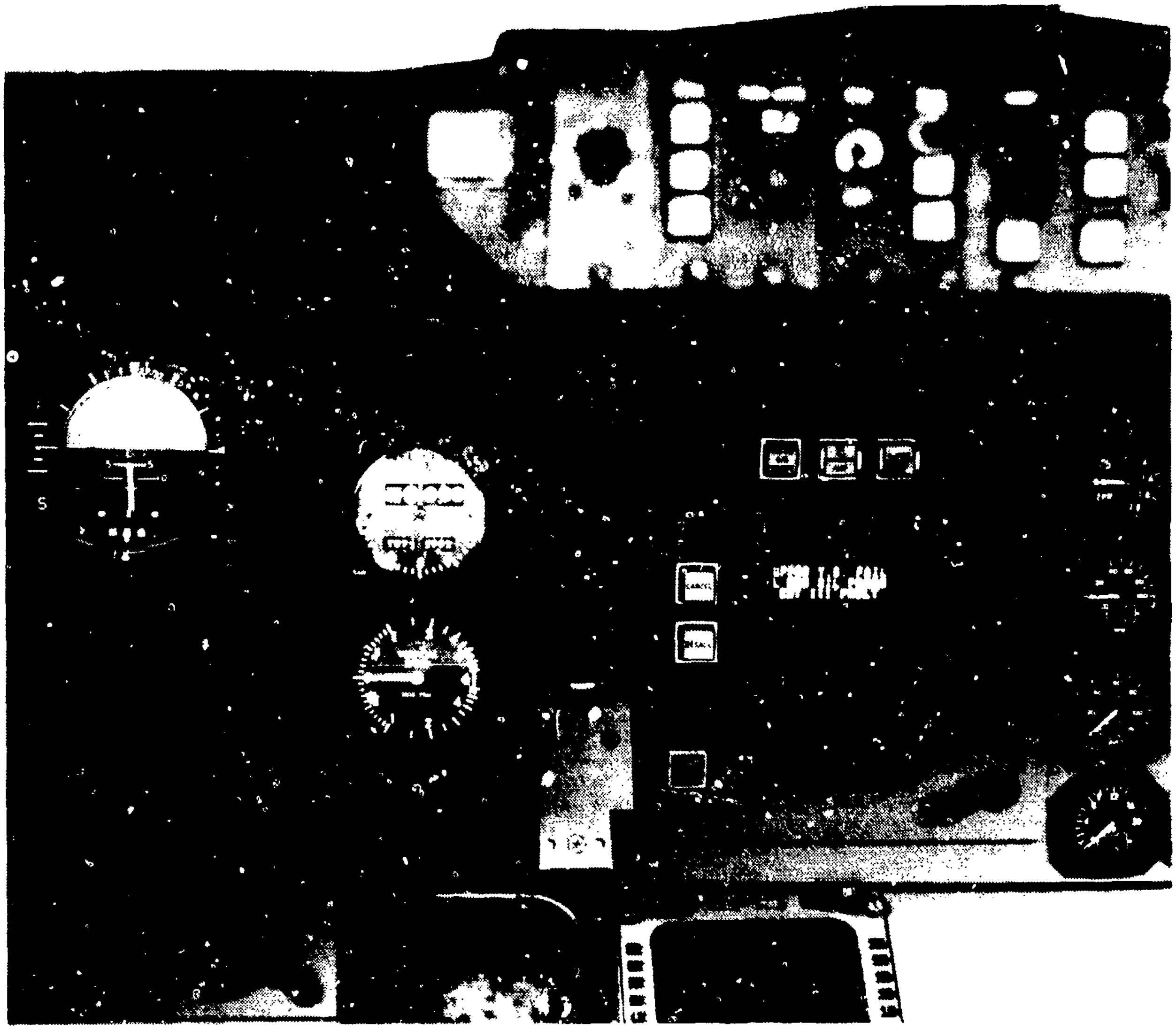


Figure 3.2.2-1. Visual Information Display Locations

Another finding of the study was that pilots demonstrated shorter mean detection and response times when all of the alerts were presented on a single display. By presenting all alerts on one display, a strong habit pattern may be developed to facilitate crew responses; whenever a master visual alert was activated the pilots would refer automatically to the visual information display. If one display was used for warnings and another for cautions and advisories, two habit patterns would have to be developed; and some amount of pilot information processing would have to be performed to tie the urgency level of the alert to the location in the flight station where further information was displayed. Pilots participating in this study favored putting all alert information on a single display. They also indicated that this display should be used to present only alerting information.

Another variable that affects the location of the visual information display is the pilot's reach requirements. Since controls for brightness adjustment, paging, selective store, etc., may be included with the display, it should be

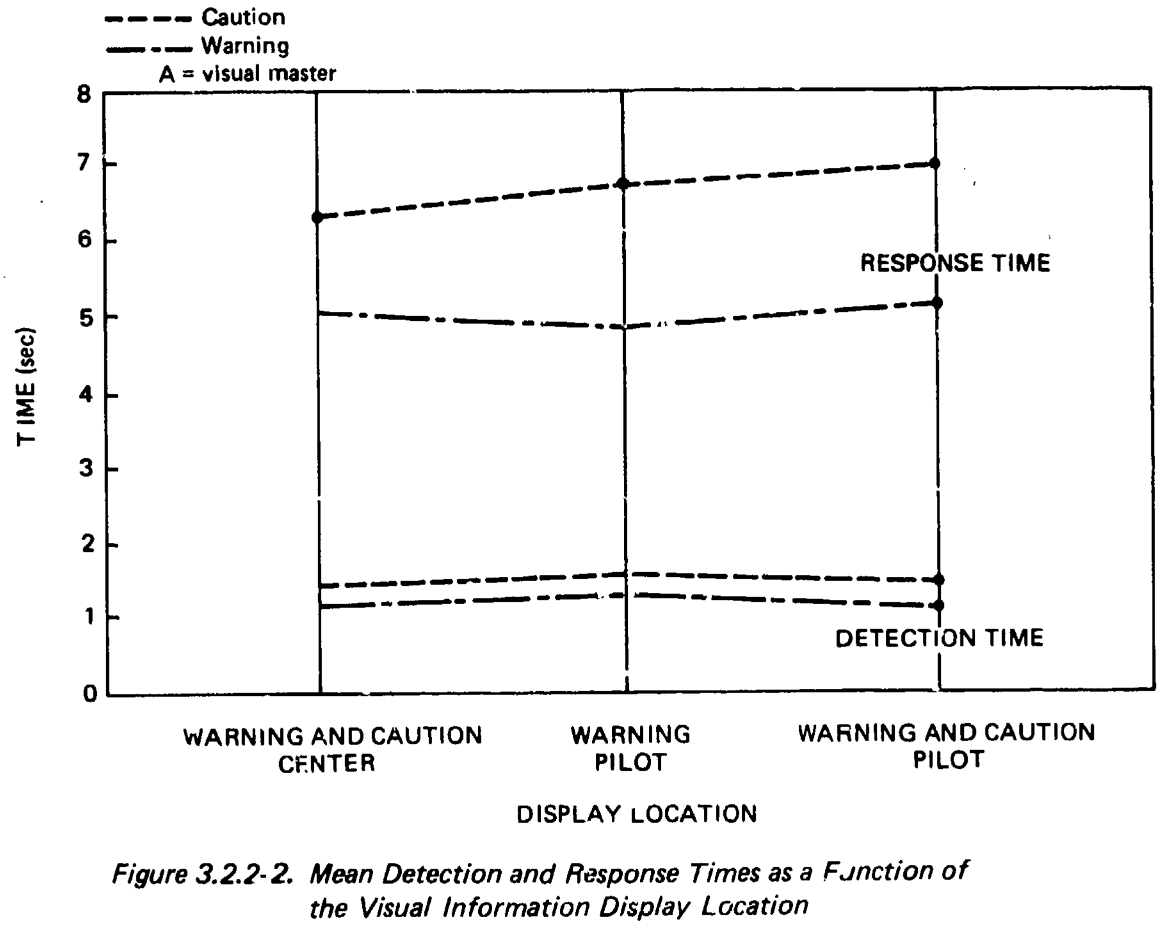


Figure 3.2.2-2. Mean Detection and Response Times as a Function of the Visual Information Display Location

located within reach of the pilots. Appropriate anthropometric data should be used to ensure that pilots can reach and actuate the controls from their normal flight positions.

The number of the displays should be determined by a combination of operational and reliability criteria. In terms of operational criteria, the main considerations are ease of use, and whether both pilots are to be able to monitor and control the data presented on a single visual information display. As mentioned earlier, pilots preferred that a single display be used to present all caution and warning system alerts. However, no data was solicited on whether a separate display should be provided for each pilot. The major operational problem in using a single display would be whether both pilots would be able to read the messages presented or reach any associated controls. In the Boucek, et al., study (1980) the display was located on the left hand side of the central instrument panel, within reach of the pilot, but within reach of only a small percentage of first officers (greater than 90th percentile) without bending from their normal seated position. If a requirement exists for both pilots to have easy access to the controls on this display, a more central location should be sought. If this requirement exists, and a centralized location cannot be found, separate displays should be provided for the pilot and first officer.

Most pilots preferred that a redundant means be provided to annunciate all alerts in the event that the visual display fails (Cooper, 1977). Redundancy could be accomplished in a number of ways such as, separate pilot and first officer displays, two pilot displays, a dedicated central hard-wired annunciator panel in addition to the visual display, etc. However, the manner in which system reliability is accomplished should be left to the individual airplane manufacturer.

IN SUMMARY, THE LOCATION OF THE VISUAL INFORMATION DISPLAY SHOULD NOT DEGRADE CREW PERFORMANCE. DISPLAY LOCATIONS WITHIN 30^{o} OF THE PILOTS' CENTER LINE OF VISION HAVE BEEN SHOWN TO BE ACCEPTABLE, LOCATIONS OUTSIDE THIS AREA MUST BE VALIDATED. THE CONTROLS ASSOCIATED WITH THE VISUAL DISPLAY SHOULD BE WITHIN REACH OF ALL PILOTS USING THE DISPLAY. REDUNDANT PROVISIONS FOR PRESENTING WARNING AND CAUTION ALERTS SHOULD BE PROVIDED. THE NUMBER OF DISPLAYS SHOULD BE DETERMINED BY A COMBINATION OF OPERATIONAL AND RELIABILITY CRITERIA.

3.2.3 FORMAT

- ALERT MESSAGES SHOULD GENERALLY CONTAIN THREE ELEMENTS: THE GENERAL HEADING OF THE ALERT, THE SPECIFIC SUBSYSTEM OR LOCATION, AND THE NATURE OF THE PROBLEM

- ALERTS SHOULD BE GROUPED BY URGENCY LEVEL AND LISTED CHRONOLOGICALLY WITHIN EACH GROUP (WARNINGS FIRST, FOLLOWED BY CAUTIONS AND ADVISORIES, WITH THE MOST RECENT ALERT LISTED AT THE TOP OF ITS OWN CATEGORY)

- AN OVERFLOW INDICATION SHOULD BE USED TO INFORM THE CREW THAT THE NUMBER OF CURRENT ALERTS HAS EXCEEDED THE DISPLAY CAPACITY

- A PAGE NUMBER INDICATION SHOULD BE USED TO INFORM THE CREW THAT ADDITIONAL ALERTS ARE CONTAINED IN THE SYSTEM ON PAGES THAT MAY BE CALLED UP FOR REVIEW

- A MEMORY INDICATION SHOULD BE USED TO INDICATE THE NUMBER AND URGENCY LEVEL OF THE ALERTS THAT HAVE BEEN STORED

- IN ADDITION TO RED (FOR WARNING) AND AMBER (FOR CAUTION), A THIRD COLOR SHOULD BE USED TO INDICATE ADVISORY LEVEL ALERTS TO PROVIDE A UNIQUE AND EASILY DISTINGUISHABLE CODING METHOD FOR ALL ALERTING CATEGORIES

- AN INDICATION SHOULD BE PROVIDED TO DISTINGUISH NEW ALERTS

The format used to present warning, caution and advisory messages on the visual information display has a considerable impact on pilot detection and response times (Boucek, et al., 1980). Since a poorly formatted display could lead to a decrement in performance, care must be taken to optimize the transfer of information from the alerting system to the crew. The major format variables and their impact on pilot performance are described below.

3.2.3.1 Syntax - The present study surveyed the major airframe manufacturers for the various message syntaxes in use, and to identify a prevalent alerting format for warning and cautions, if one existed. The results of this survey indicate that no standard alerting format exists. However, in most cases, alert messages were structured with the general heading followed by the subsystem, and then the nature of the problem. This finding is in agreement with MIL-STD-411D which recommends the following format:

	General Heading	Specific Subsystem or Location	Nature of Emergency
Example:	ENGINE	NUMBER 1	FIRE

Since very little agreement exists among the airframe manufacturers concerning syntax, a survey was conducted with 25 pilots from Boeing, Lockheed, and Douglas Aircraft, and from Continental and Western Airlines providing their opinions on alert message syntax. Although the majority of the pilots (80%) preferred the format recommended in MIL-STD-411D, they stated that the format was not appropriate for all alerts. The conclusion was that syntax standardization should be the goal, but it is imperative that the alert message present a clear statement of the problem.

3.2.3.2 Prioritization - This variable is concerned with how the alerts are ordered on the visual information display. In a simulation study that used current airline pilots (Boucek, et al., 1980), the following three formats were evaluated:

(1) Category and Chronology - Alert messages were displayed by category (i.e., warnings, cautions, and advisories) with the most recent alert presented at the top of its category. The warning category appeared at the top of the display, cautions in the middle, and advisories on the bottom. The order of occurrence of alerts could therefore be determined only within categories.

(2) Chronology - Alert messages were listed chronologically with the most recent alert always presented at the top of the display. As new alerts were presented, all existing alerts would be scrolled down.

(3) Warnings Separate - Warning alert messages were always listed as a group at the top of the display, with cautions and advisories below, mixed, in their order of their occurrence.

In all three formats, alert categories were color-coded, red for warnings, amber for cautions, and blue for advisories. Figures 3.2.3.2-1 through 3.2.3.2-3 illustrate the three display formats. No significant differences were obtained in the detection and response times or in the number of missed alerts for the three display formats. The data did indicate, however, that responses to cautions were slower when the caution alert messages appeared in the midst of other alerts than when appearing at the top. However, this disadvantage was alleviated when a flashing box was used to identify the most recent alert. Pilot preference data obtained in this study indicated that alerts should be grouped by urgency, especially to aid in assessing overall aircraft status and for handling display overflows (i.e., when more alerts were in the system than could be displayed at one time the least important alerts, advisories or cautions, would leave the screen first). However, the pilots also preferred that alerts be displayed chronologically (i.e., new alerts displayed on top, independent of category), to aid in finding the most recent alert. This problem was eliminated when a cue (flashing box) was added to indicate new alerts.

3.2.3.3 Overflow - This concept applies to situations when the number of active alerts in the system exceeds the display capacity. In the Boucek, et al., study (1980) a display capable of presenting twelve alerts at one time was used. Pilot opinion was solicited on three distinct overflow concepts:

(1) Dropoff/Reverse Chronology - In this concept the oldest message would be dropped off the screen, with the newest alert being displayed at the top of the display or alert category.

(2) Scroll - In this concept the alert messages could be scrolled up or down on the display to provide access to all alerts. Individual alerts could be moved up or down, one at a time, until the pilot had assessed aircraft status.

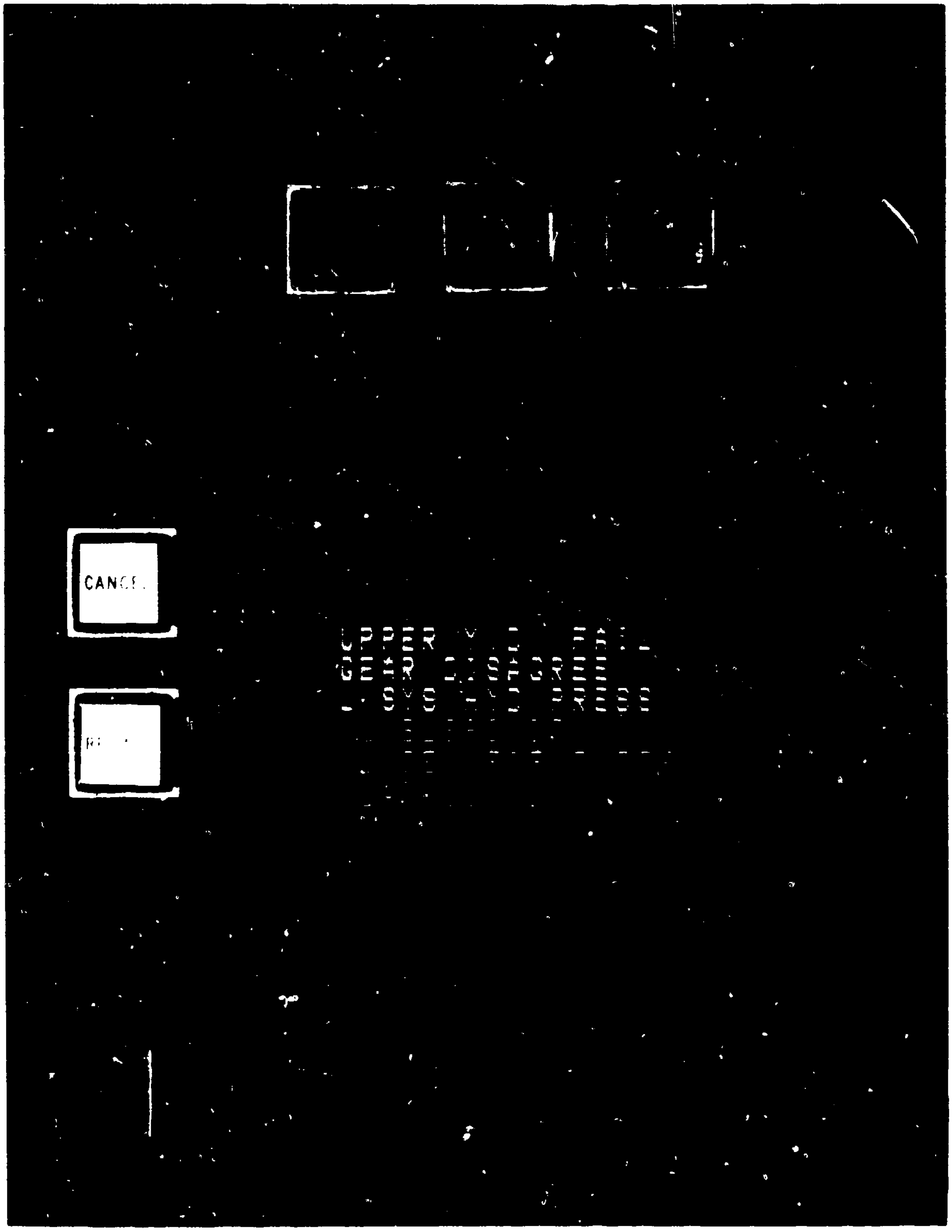


Figure 3.2.3.2-1. Alerts Grouped by Urgency Category—Most Recent Alert Appears at the Top of Its Group

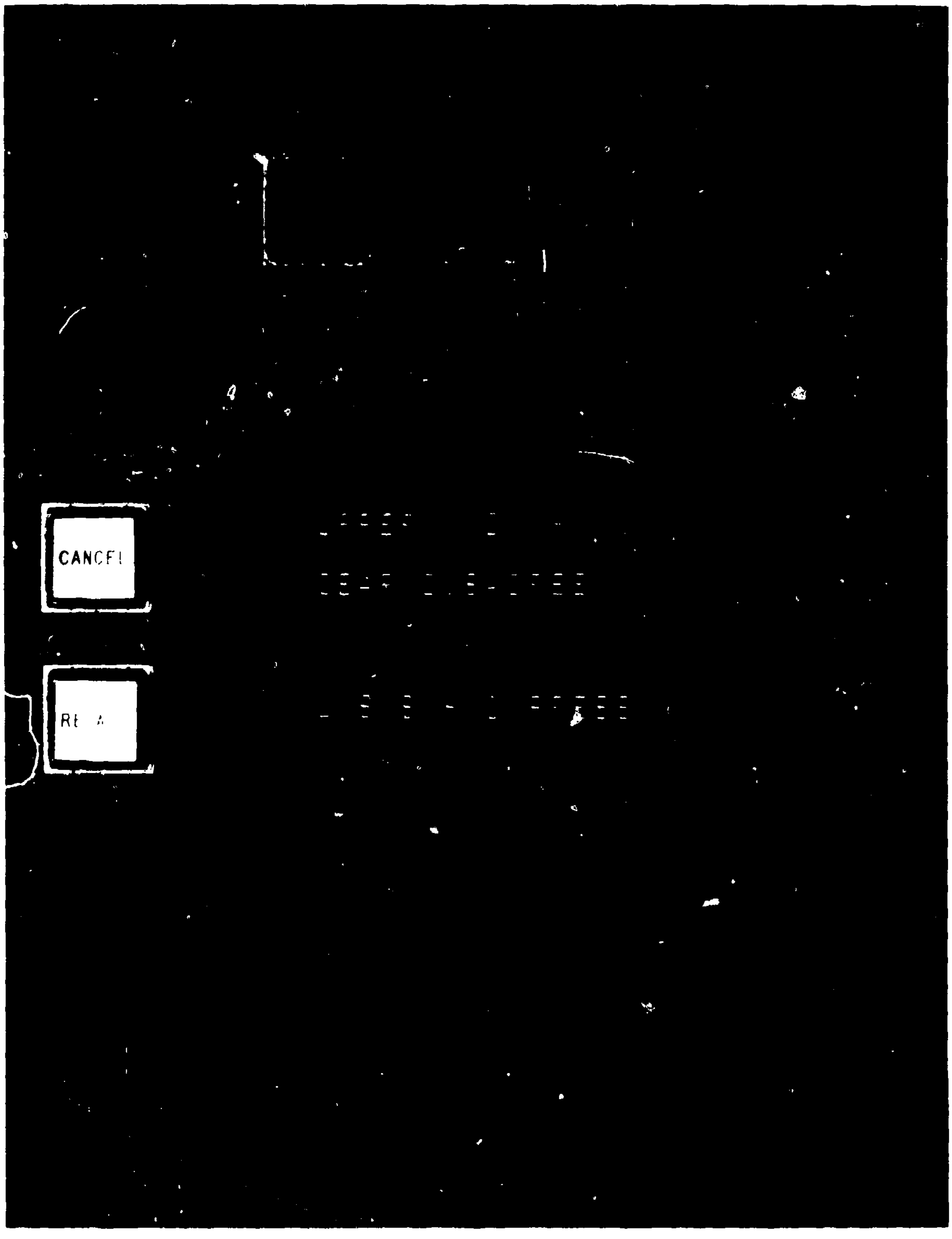


Figure 3.2.3.2-2. No Alert Grouping Most Recent Alert Appears at Top of Screen

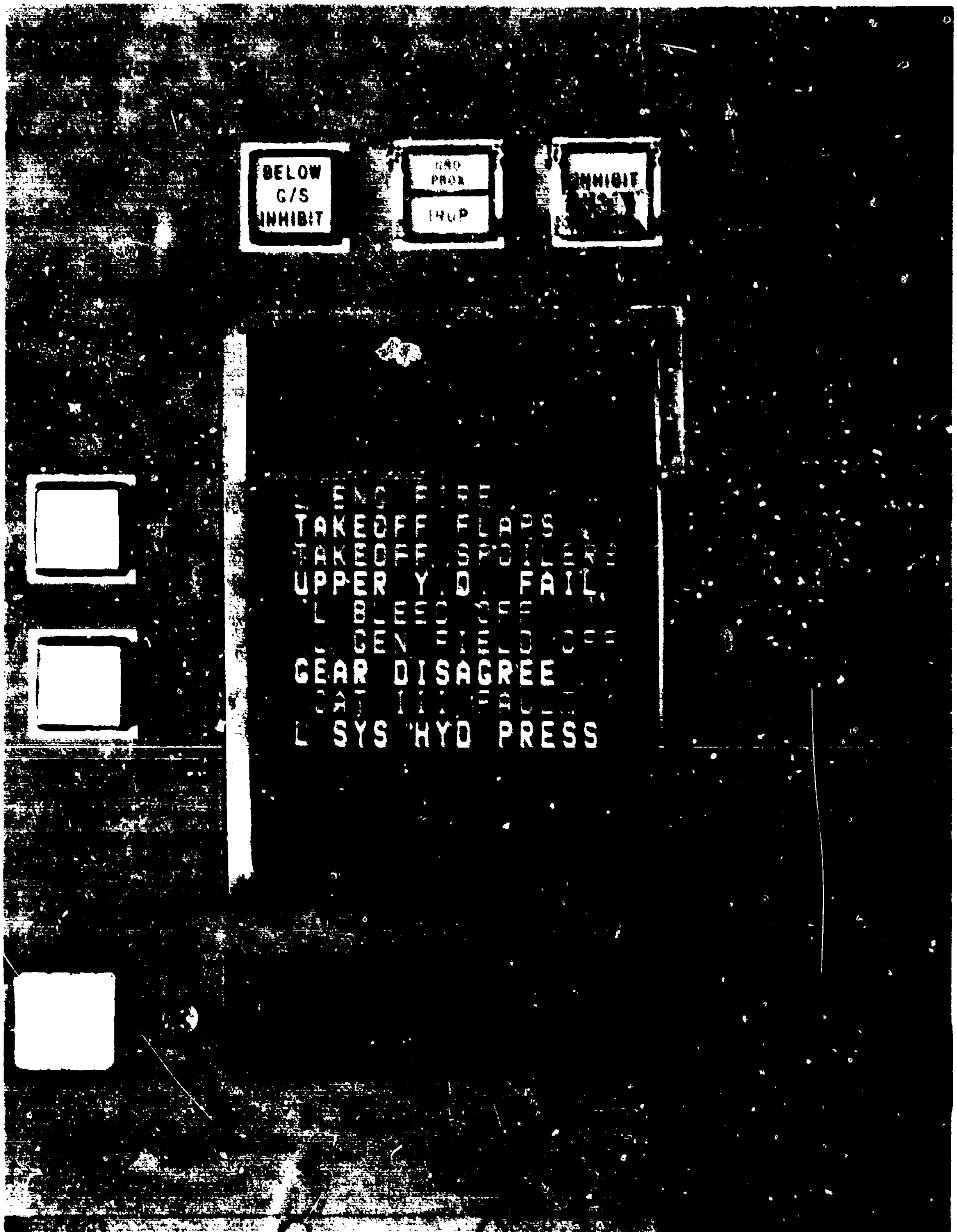


Figure 3.2.3.2-3. Warnings on Top With Cautions and Advisories Grouped by Chronology Below Warnings

(3) Subsystem Reversion - For this alternative the display would revert to a subsystem display monitor, with all of the system caution and advisory alerts (e.g., engine, hydraulic, electrical) combined into a single message (see Figure 3.2.3.3-1). In this concept the bottom five lines of the display were reserved for subsystem messages, with a particular location reserved for each particular subsystem. The upper seven display lines were used to display warning alerts.

When the number of displayed alerts decreased to twelve or less, the system would automatically revert to the normal, full message format. Again, color coding was used to denote alert urgency.

The results of this survey indicated that the majority of the pilots preferred a combination of the dropoff and scrolling concepts. The vast majority (83%) stated that they would prefer the oldest and lowest category alerts to be dropped off the screen when newer/higher priority alerts occurred. They also stated that when the display capacity was exceeded they would prefer to have the capability to call up the additional alerts one page at a time, rather than scrolling up or down, one alert at a time. Those pilots who preferred the concept of subsystem reversion also identified several problems with its use. For example, they stated that a new alert occurring in a previously faulted system could not be identified since the display would not change.

Independent of the technique used to handle overflows the vast majority of pilots wanted an indication of overflow to be presented on the visual information display. Guidelines for display cues and aids (e.g., overflow indicator, new alert indicator, and paging indicator) are provided in Section 3.2.3.5.

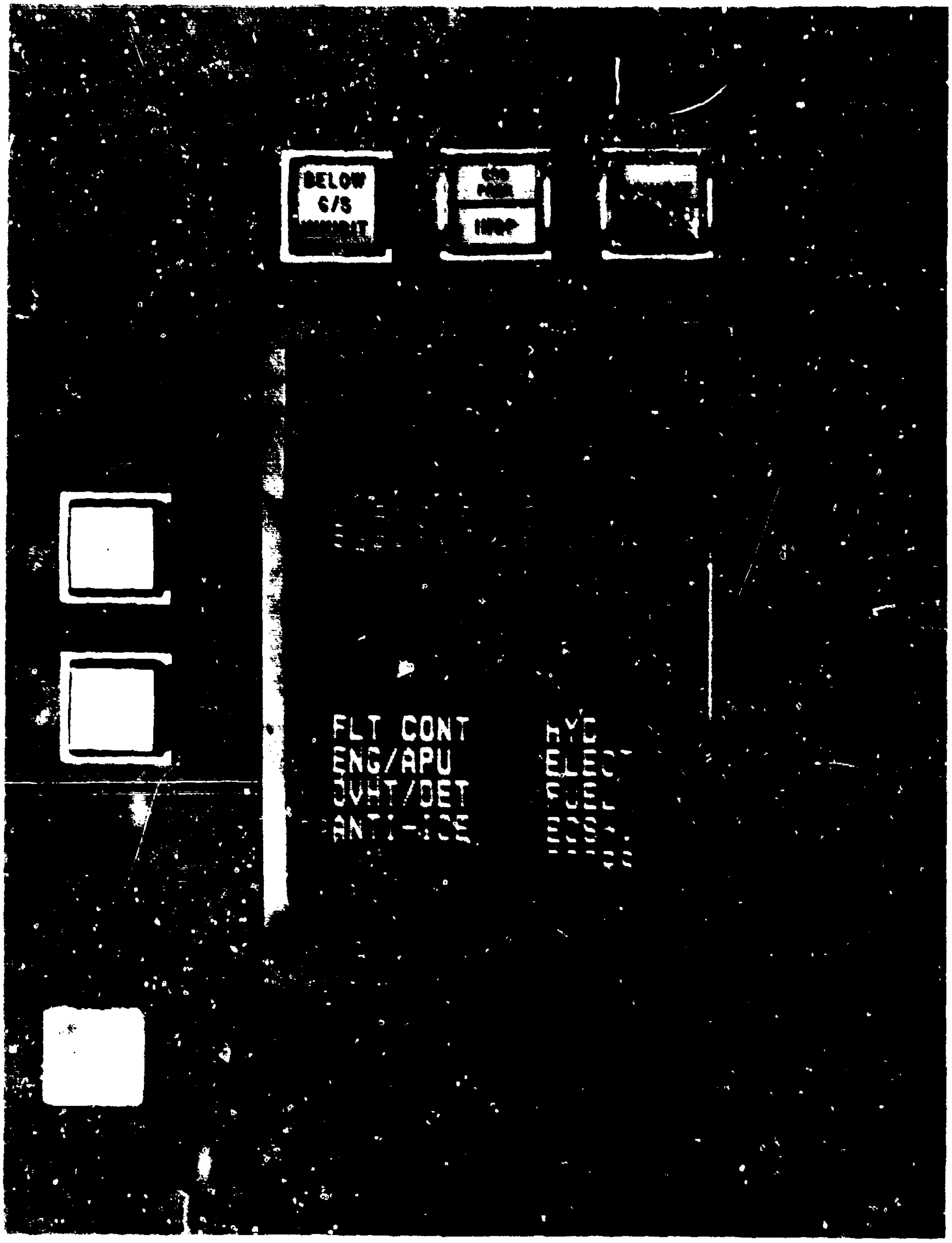


Figure 3.2.3.3-1. Subsystem Reversion for Overflow—All Cautions and Advisories Revert to System Designation

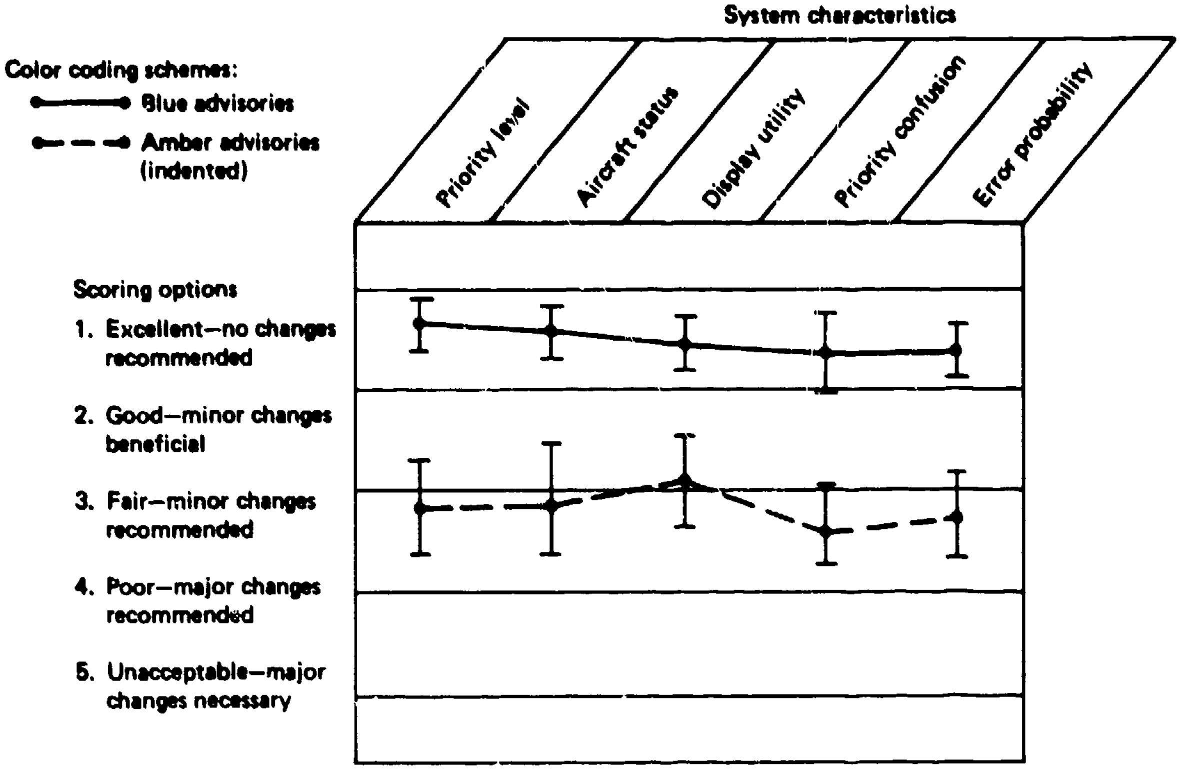


Figure 3.2.3.4-1. Color Coding Pilot Preferences as a Function of Five System Characteristics

3.2.3.4 Color Coding - Pilot surveys (Cooper, 1977, and Boucek, et al., 1980) indicated that pilots prefer unique and easily distinguishable categories to quickly and accurately differentiate between alert urgency levels on the visual information display. In Cooper's survey, pilots indicated that a third color, in addition to red and amber, was needed to identify a third category of alerts. Pilots stated that while red and amber in general refer to immediate and deferred action items, a third color is needed to indicate that something is wrong but that no action is presently required. No clear preference was stated for this third color; however, blue, green and white were suggested. Cooper's survey also identified the need for color standardization; similar feelings have also been expressed by the SAE S-7 committee, which is studying the need for a third level of alerts.

In the Boucek et al., study (1980), pilots preferred a color coding technique (blue used for advisories) to a location coding technique (advisories indented). Pilots evaluated the two coding schemes on five system characteristics (i.e., priority level, aircraft status, display utility, priority confusion, and error probability). These data are shown in Figure 3.2.3.4-1. As can be seen from this figure, the distinct color code was clearly preferred for all five system characteristics. However, in those cases where flight station or operational considerations restrict/inhibit the use of color other coding techniques may be used. If another coding technique is used it should be applied consistently across all three alert urgency levels, and empirical test data must be obtained to establish the acceptability of the selected coding technique.

3.2.3.5 Cues and Aids - The present study determined that cues and aids are required for the crew to interact effectively with the visual information display. Pilot opinions on various display cues and aids were surveyed to determine procedures for using the visual information display to communicate alerting system status information. The following cues and aids were addressed:

- New message indicator
- Overflow and page indicator
- Memory indicator

Alerting system components that deal with crew option and control over the alerting system (e.g., prioritization, store/recall, inhibition) are described in Section 5.

New Message Indicator - To provide an indication of display status changes (e.g., the occurrence of a new alert), a new message indicator is required. Boucek et al., (1980) and the present effort performed tests and surveyed pilot opinions on new message indicators to determine their impact on pilot detection and response times to alerts. The 1980 study compared pilot detection and response times and the number of missed alerts, as a function of a master visual alert (yes/no) and a flashing box around the newest alert (yes/no). The data indicated that new alerts were detected significantly faster when there was a flashing box around the alert. Since this data may be misleading because the master visual alert was present for half of the trials, the interaction between the master visual alert and the flashing box was investigated. A significant interaction was found. The detection time for the test condition with neither a master alert or flashing box was significantly longer than for all other combinations. When the flashing box was added, the detection time was improved, but was still significantly longer than either of the conditions with the master alert. This data indicates that the shortest detection times result when both a master visual alert and a flashing box around the newest alert are used (see Figure 3.2.3.5-1).

The data for pilot response times were similar to the detection time data, (i.e., shortest response times were obtained when both a visual master light and flashing box were used to annunciate new alerts). Also, significantly fewer alerts were missed when a flashing box was used. The results of pilot preference data obtained during this study indicated that the combination of

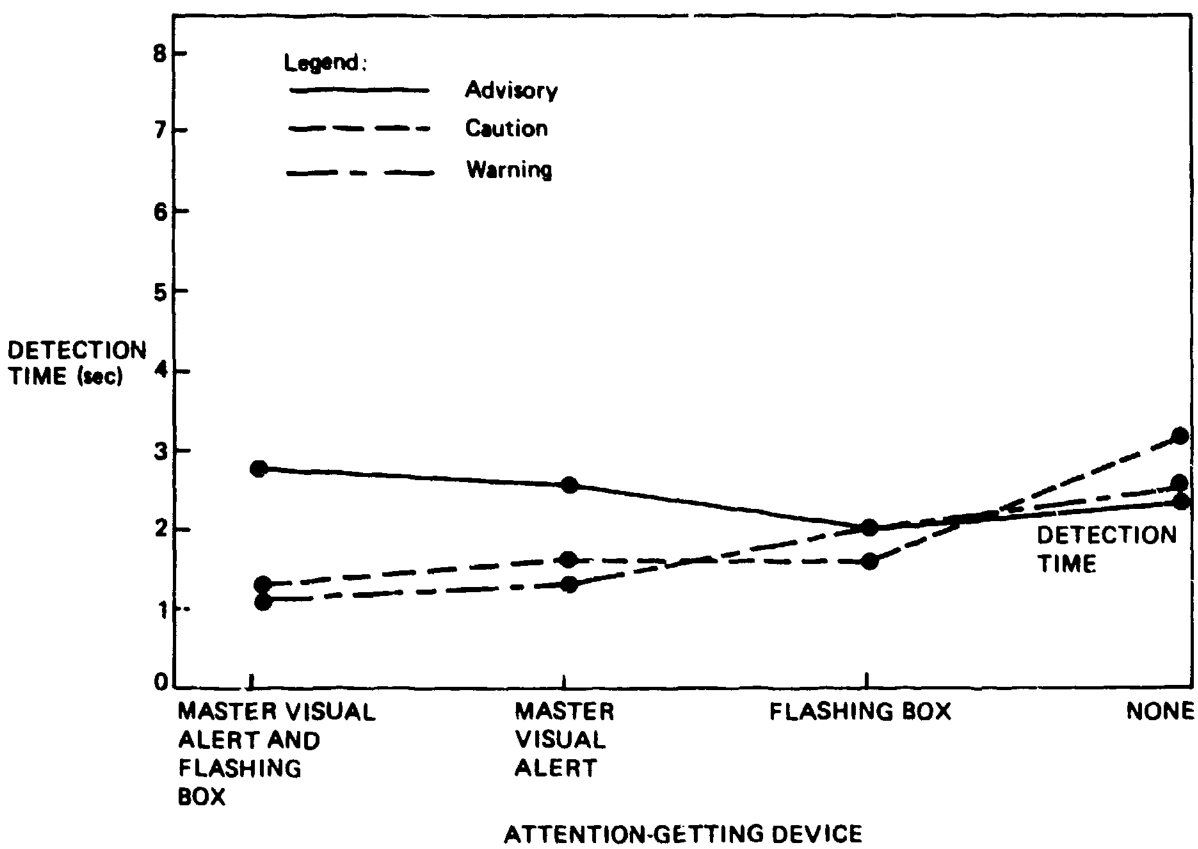


Figure 3.2.3.5-1. Mean Detection Times as a Function of a Master Visual Alert and a Flashing Box Around New Alerts (Boucek, et al., 1980)

the master visual alert and flashing box provided the most information and would result in both shorter alert detection and response times.

In the present study pilots were surveyed on what type of new message indicator they preferred. Two choices were presented:

- An asterisk adjacent to the latest alert
- A flashing box around the latest alert.

The majority of pilots preferred the flashing box and indicated that it was better for both aiding in the identification of the most recent alert and in attracting attention to a new alert. However, since the main function of the cue is to aid the crew in locating new alerts, a non-flashing box should be just as effective as a flashing one. The flashing box is only required in the case when master visual alerts are not used. For this case the flashing box serves not only to aid the crew in locating a new alert but also as the attention-getter.

Overflow and Page Indicator - As discussed previously most pilots (86%) wanted an overflow indicator to inform them when the number of current alerts exceeds the capacity of the visual information display (Boucek, et al., 1980). No consensus was reached on the type of indicator that should be used. Several pilots favored using an arrow (↓) to indicate overflow. Others recommended that the total number of overflowed cautions and advisories should be presented at the bottom of the display along with the number of alert pages. No overflow indication should be required for warnings. The likelihood of having more than twelve warnings displayed at any one time is extremely small.

The present study also solicited the opinions of pilots on overflow indicators. The pilots were asked to compare the "Arrow" concept to the use of color-coded boxes, which would indicate the number of alerts present for each category. The color-coded boxes would illuminate only if more than one page of alerts were present. The majority of pilots stated a preference for the colored boxes since they felt that the boxes provided more information. They also liked the idea of the number of alert pages being clearly presented on the display.

Memory Indicator - Pilot preference data obtained in the Boucek, et al., study (1980) indicated that a positive indication should be provided to inform the aircrew of the number of caution and advisory messages that have been stored in memory. They also indicated that since warnings should not be storable, no memory indicator is required for warnings. Most pilots stated a preference for numeric color coded data to provide this information, for example, if six cautions and four advisories were stored, an amber '6' and a blue '4', or whatever color is selected for advisories, be shown on the bottom of the visual information display.

The example shown below in Figure 3.2.3.5-2 illustrates a method for placing overflow, page and memory indicators on the bottom of the visual information display. This example, assumes a 16 character per row display.

IN SUMMARY, THE SYNTAX OF ALERT MESSAGES SHOULD CONTAIN THREE ELEMENTS: THE GENERAL HEADING OF THE ALERT, THE SPECIFIC SUBSYSTEM/LOCATION, AND THE NATURE

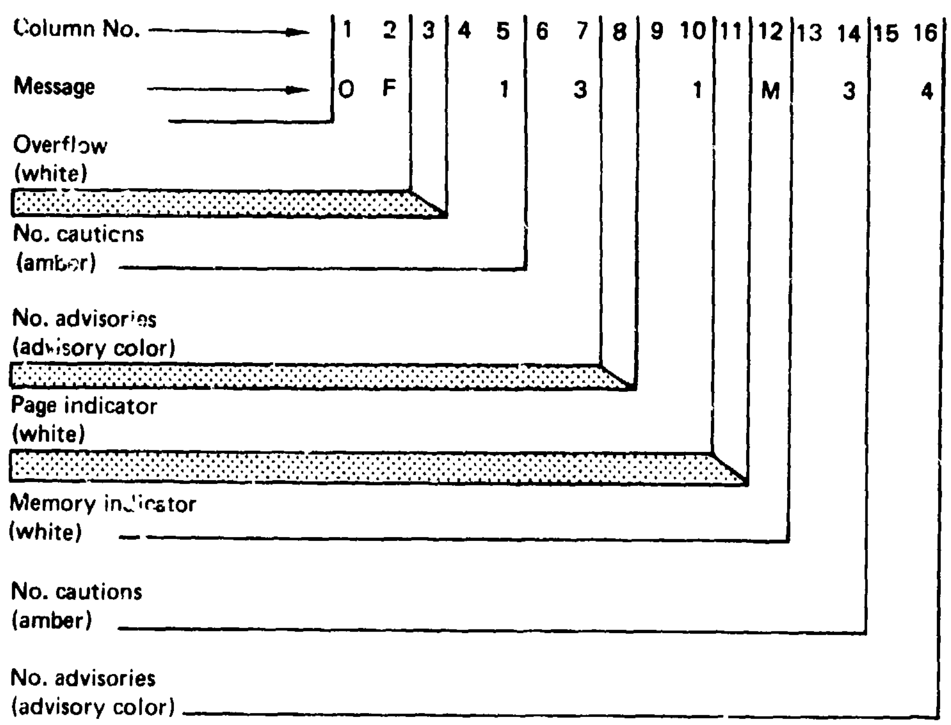


Figure 3.2.3.5-2. Example Display Format for Presenting Overflow, Paging, and Memory Indications

OF THE PROBLEM. ALERTS SHOULD BE GROUPED BY PRIORITY LEVEL AND LISTED CHRONOLOGICALLY WITHIN EACH GROUP. AN OVERFLOW INDICATOR SHOULD BE USED TO INFORM THE CREW THAT THE NUMBER OF CURRENT ALERTS EXCEEDS THE CAPACITY OF THE DISPLAY. A PAGE NUMBER INDICATOR SHOULD BE USED TO INFORM THE CREW THAT ADDITIONAL ALERTS ARE CONTAINED IN THE SYSTEM, AND THAT TO ACCESS THESE ALERTS OTHER PAGES HAVE TO BE DISPLAYED, AND A MEMORY INDICATOR SHOULD BE PROVIDED TO INFORM THE AIRCREW OF THE NUMBER OF CAUTION AND ADVISORY MESSAGES THAT HAVE BEEN STORED IN MEMORY. TO PROVIDE A UNIQUE AND EASILY DISTINGUISHABLE CODING METHOD FOR EACH ALERTING SYSTEM CATEGORY, A THIRD COLOR (IN ADDITION TO RED (WARNINGS) AND AMBER (CAUTIONS)) SHOULD BE USED, AND A BOX AROUND NEW ALERTS ON THE VISUAL INFORMATION DISPLAY SHOULD BE USED TO AID IN ALERT IDENTIFICATION/LOCALIZATION.

3.2.4 BRIGHTNESS

- THE DISPLAY SHOULD BE BRIGHT ENOUGH TO BE EASILY READABLE FROM THE PILOT'S EYE REFERENCE POINT IN ALL AMBIENT LIGHT CONDITIONS

- THE BRIGHTNESS OF THE VISUAL INFORMATION DISPLAY SHOULD BE ADJUSTED AUTOMATICALLY AS AMBIENT LIGHTING CONDITIONS INSIDE THE FLIGHT STATION CHANGE. HOWEVER, A MANUAL OVERRIDE CONTROL SHOULD BE PROVIDED TO ENABLE THE PILOTS TO ADJUST DISPLAY CONTRAST

The rationale for these guidelines are identical to the requirements for the master visual alerts, except for contrast.

Cooper (1977) and Boucek, et al., (1980) surveyed pilots on warning and caution indicator light brightness. The vast majority of pilots preferred automatic brightness adjustment for varying ambient light conditions. The pilots also indicated that they would want a manual brightness control to enable them to override the automatic brightness setting to suit their individual requirements. This can be accomplished perceptually by providing a manual contrast control allowing the pilots to adjust the brightness relative to the display background. However, the visual information display should never be able to be dimmed below 15 $\pm$ 3 ft-L.

3.2.5 SIZE

- SPECIFIC AIRCRAFT CONFIGURATION REQUIREMENTS SHOULD DICTATE THE MINIMUM NUMBER OF LINES TO BE DISPLAYED, WITH CHARACTERS LARGE ENOUGH TO BE LEGIBLE TO THE PILOTS WHEN SEATED IN THEIR NORMAL FLIGHT POSITIONS

- THE DISPLAY SHOULD BE WIDE ENOUGH TO PRESENT ANY ALERT MESSAGE ON A SINGLE LINE

In the past, the size of a display has been determined primarily by the constraint of available panel space and not by good design practices which consider display characteristics and human factors requirements. The following guidelines (based on character size, number of alerts, line length, etc.) should be used to determine the required display area.

Character size should be determined after the display has been located in the flight station and the distance from the display to the eye reference point defined. For example, if the display is located 42 inches away from the eye reference point and a character subtending 14 minutes of arc is required, multiplying distance (42 inches) by the tangent of half the angle (7 arc-minutes) result in a half character size of 0.085 inch or a character size of 0.17 inch (distance x tangent of one half visual angle = one half the character size).

The height of the display should be contingent upon character height, spacing between lines, number of lines, and the space necessary for showing supplemental data (e.g., page number and overflow indicators). For a character height of 0.17 inch and a minimum line spacing of 0.085 inch (half the character height), a vertical dimension of approximately three inches would be required to display twelve alerts. This does not include the space necessary for page and overflow indicators or for margins on the top and bottom of the display. In terms of the number of lines required for the visual information display, Boeing has conducted several studies for their present aircraft programs and have identified twelve lines as being acceptable.

The width of the display should be contingent upon character width, spacing between characters, number of words, and the number of characters. If a 5:7 height to width ratio is used, character width for the above example would be 0.12 inch. Assuming a space at both sides of the display, spacing between characters 25% of the character height and a one character separation between words, a 2.6 inch width would be necessary to present 16 characters. Sixteen characters has been suggested by Boeing as a reasonable number for presenting alerts. In their new aircraft programs, all alerts could be represented by 16 characters or less.

Once the height and width of the display have been determined, the designer must examine the flight station geometry to determine the width of the margin necessary around the display area. Bezels, protruding knobs, etc., should be considered to assure that the display area is readable in all flight station configurations. Given the above considerations, the minimum size that should be considered for the visual information display is 3.5 by 4.0 inches.

IN SUMMARY, SPECIFIC AIRCRAFT CONFIGURATION REQUIREMENTS SHOULD DICTATE THE MINIMUM NUMBER OF LINES TO BE DISPLAYED WITH CHARACTERS THAT ARE LEGIBLE TO PILOTS WHEN SEATED IN THE NORMAL FLIGHT POSITION. THE DISPLAY SHOULD BE WIDE ENOUGH SO THAT ALL ALERTS WILL FIT ON ONE LINE, AND CAN BE EASILY READ BY THE PILOTS.

3.2.6 CHARACTERS

- THE ALPHANUMERIC CHARACTERS USED ON THE VISUAL INFORMATION DISPLAY SHOULD BE AT LEAST 12 TO 15 ARC MINUTES. ALL CHARACTERS SHOULD BE UPPER CASE, WITH A HEIGHT-TO-WIDTH RATIO OF 2:1, A STROKE WIDTH OF 1:6 TO 1:10, AND A BETWEEN CHARACTER SPACING OF 25 TO 63 PERCENT OF THE HEIGHT. GRAPHIC SYMBOLS SHOULD BE AT LEAST 20 ARC MINUTES.

- CHARACTER SIZES AND FONTS SHOULD BE EVALUATED PRIOR TO THEIR IMPLEMENTATION

The accurate recognition of symbols, including alphanumeric characters, is an important requirement in determining the presentation format for alerting information as there are a large number of parameters that affect the accuracy of message recognition. The following data were derived primarily from three sources: Meister and Sullivan (1969); MIL-STD-1472B (1978), and Eike, Malone, and Fleger (1980).

PARAMETER	RECOMMENDATION
Character Size (minimum)	12-15 arc minutes
Graphic Symbol Size (minimum)	20 arc minutes
Resolution	10 raster lines or resolution units per character
Stroke Width	1:6 to 1:10 character height
Height/Width Ratio	5:7, 2:1 or 1:1
Contrast Ratio	(minimum) 10:1; (preferred) 20-30:1
Background Color	Black
Font	Sans Serif/Futura Demibold
Character Spacing	25-63% character height (horizontal) 50-100% character height (vertical)
Case	Upper Case
Mis-registration	(maximum) ± 65% stroke width
Frame Rate	(minimum) 7.5-15 frames per second
Linearity	(minimum) ± 1%; (preferred) ± .2%
Display Aspect Ratio (width/height)	4:3, 5:7, 2:3
Viewing Angle	Not more than 30 degrees off perpendicular axis
Bandwidth	4.0-10.0 MHz
Equipment Reaction Time	Less than 1 second
Line Density	20 points/centimeter
Signal to Noise Ratio	(minimum) 100:1

IN SUMMARY, THE SIZE AND SHAPE OF CHARACTERS AND SYMBOLS USED ON THE VISUAL INFORMATION DISPLAY SHOULD FACILITATE THEIR LEGIBILITY AND INTERPRETABILITY.

3.2.7 DISPLAY TYPE

- THE PRESENTATION MEDIUM USED SHOULD BE LEFT TO THE DISCRETION OF THE AIRFRAME MANUFACTURER, ASSUMING THE SELECTED DISPLAY TYPE MEETS/EXCEEDS THE GUIDELINES DESCRIBED FOR THE VISUAL INFORMATION DISPLAY

Since the mid-1950's many researchers have forecast the replacement of the cathode ray tube (CRT) by newer, "solid-state" flat-panel displays. Today, such forecasts seem even less likely to come true; the CRT and flat-panel displays have both improved, but flat-panel problems have proven to be more formidable than first realized (Tannas and Goede, 1978).

In a study comparing CRT and flat-panel displays, Hatfield, Robertson and Bates (1979) indicated that although CRT's are presently the best choice for most aircraft applications, their inherent limitations (e.g., high voltage requirements, large volume, extra circuitry required to achieve corner edge focus, limited useful life under high ambient light conditions and implosion hazards) will increase the desirability of using flat-panels in the 1990's.

IN SUMMARY, THE DISPLAY TYPE SHOULD BE LEFT TO THE DISCRETION OF THE AIRFRAME MANUFACTURER; HOWEVER IT SHOULD MEET OR EXCEED ALL GUIDELINES LISTED IN THIS SECTION.

3.2.8 TEST REQUIREMENTS

- PROVISIONS SHOULD BE INCLUDED TO TEST/VERIFY THE OPERABILITY OF THE VISUAL INFORMATION DISPLAY

As stated in Section 3.1.9, a mechanism should be used to test the operability of all of the components of the advanced aircraft alerting system. Specifically, for the visual information display this test function should include testing/verifying that:

- All colors are present
- All characters and symbols are complete and legible
- All interactive functions are operational
- All lines of the display are active
- All character spaces (display columns) are operational

3.2.9 RELIABILITY

- IN THE EVENT OF A DISPLAY FAILURE THE DATA PRESENTED ON THE VISUAL INFORMATION DISPLAY SHOULD BE CAPABLE OF BEING DISPLAYED ELSEWHERE IN THE PILOT'S PRIMARY OR SECONDARY FIELD OF VIEW.

As stated earlier, the alerting system information is flight critical, and therefore the components must be highly reliable. The visual components of the alerting system should be designed so that the failure of any single component will not degrade the operational utility of the alerting system or of the aircraft. The system design must provide adequate redundancy to assure that this requirement can be met. A positive indication should be provided on the display to inform the aircrew of a display failure, or a failure associated with the alerting system equipment.

For Boeing's new airplane programs, several methods were investigated for providing this redundancy. In the B-757, a backup CRT display is provided to annunciate alerting system messages/alerts in the event that the primary display fails. The B-767 accomplishes this by using a dedicated annunciator panel to back up the alerting system display. Either of these methods will provide the required component redundancy. For this reason, one or both of these techniques should be incorporated in the design and implementation of advanced alerting systems. However, the method used to attain system reliability should be left to the discretion of the individual airframe manufacturer.

IN SUMMARY, IN THE EVENT OF DISPLAY FAILURE THE DATA PRESENTED ON THE VISUAL INFORMATION DISPLAY SHOULD BE CAPABLE OF BEING PRESENTED ELSEWHERE IN THE PILOT'S PRIMARY OR SECONDARY FIELD OF VIEW.

3.3 TIME-CRITICAL WARNING DISPLAY

This section presents design guidelines for displaying time-critical warnings. Time-critical warnings are a high-urgency subset of warnings (e.g., collision avoidance, ground proximity, windshear) that require an unconditionally immediate crew response to assure flight safety. Due to the extremely urgent nature of these alerts and the limited time available for response, a time-critical display is required, in addition to the other alerting components.

Since many characteristics of the time-critical display (e.g., brightness, reliability, flexibility, coordination with aural alerts) are basically similar to those of the other visual elements, they will not be repeated in this section. Only those characteristics unique to the time-critical display are discussed in the following paragraphs.

3.3.1 PURPOSE

- THE TIME-CRITICAL DISPLAY PROVIDES THE CREW WITH DIRECT CUES FOR RESPONDING TO THE HIGHEST-URGENCY LEVEL OF WARNINGS RELATING TO FLIGHT SAFETY

For certain high-urgency situations, enough time may not be available to alert the crew by conventional means. In a study of collision avoidance display requirements, Parks (1979) found that a very short period of time (6 to 9 seconds) is available to respond to this type of time-critical warnings. If this data is valid, then a separate time-critical display is required to provide direct cues to pilots. Data obtained in simulator studies (Boucek, et al., 1977, 1980, and the present study) indicate that approximately 5 to 8 seconds are required to detect and respond to warnings. In these studies the responses required to correct the alerting situations were dramatically simplified. For example, the response time began immediately after detection and ended when the pilots began to take corrective action; in no case were the pilots required to perform an entire sequence of actions to remedy a problem. For this reason, the data obtained in the simulator studies are an underestimate of the times required to respond to and correct problems in an aircraft. Also, the fact that these studies were conducted in a simulator tend to make the pilot responses faster than in an operational environment (e.g., the subjects were "primed" to respond to alerts; the alerts were time-compressed, in that significantly more alerts were experienced in a short period of time; the subjects knew they were performing in an artificial environment and, therefore, stress did not affect their responses nearly as much as in the operational environment). For these reasons the data obtained in these simulator studies provide a gross underestimation of the time required to respond to warnings in an aircraft. If the 5 to 8 seconds obtained in the Boucek studies are truly underestimates of the time required to respond to alerts, and if only 6 to 9 seconds are available to respond to time-critical alerts (Parks, 1979), then present day alerting systems may not enable pilots to respond quickly enough to avoid impending hazardous conditions.

Cooper (1977) stated that response times can be reduced by as much as 6 to 9 seconds by providing pilots with direct cues to guide their responses. These reasons seem to justify the inclusion of a time-critical display into advanced alerting systems. The time-critical display must, therefore, provide direct visual cues which not only convey information about the situation at hand, but also guide corrective action.

IN SUMMARY, A DISPLAY SHOULD BE PROVIDED TO FACILITATE THE RAPID DETECTION AND RESPONSE REQUIRED FOR TIME-CRITICAL WARNINGS.

3.3.2 LOCATION—NUMBER

- THE TIME-CRITICAL DISPLAY SHOULD BE LOCATED WITHIN THE PILOT'S PRIMARY FIELD OF VIEW

- SEPARATE TIME-CRITICAL DISPLAYS SHOULD BE PROVIDED FOR EACH PILOT

Available data indicates that time-critical warnings should be displayed within the pilot's primary field of view. In a survey conducted by Cooper (1977), pilots stated "that the most urgent warnings should be located adjacent to the control involved in alleviating the warning", and that "these warnings should not be lost in the middle of a central or master warning panel."

They also stated that "warnings related to aircraft control, such as 'PULL UP' should be located adjacent to the instrument that the pilot is using, such as the ADI."

The present program performed a test to identify optimum areas in the flight station for the location of time-critical displays. A simulator evaluation of two locations - one directly below the EADI, and one above the visual information display was conducted. The data indicated that pilot detection and response times were significantly shorter when the time-critical display was located directly below the EADI, (see Figure 3.3.2-1). After the pilots completed the simulations, they were asked which location they preferred. No clear preference was expressed. However, a majority (70%) of these pilots wanted the time-critical display to be integrated directly into the EADI. They stated that since the EADI was the basic command instrument on the aircraft it would make sense to integrate the time-critical guidance information onto it.

For reliability and flight safety considerations, pilots indicated that a separate display should be provided for each pilot to enable either one to respond to the alert.

IN SUMMARY, TIME-CRITICAL DISPLAYS SHOULD BE LOCATED WITHIN THE PILOTS' PRIMARY FIELD OF VIEW. A SEPARATE DISPLAY SHOULD BE PROVIDED FOR EACH PILOT.

3.3.3 FORMAT

- THE TIME-CRITICAL DISPLAY SHOULD PROVIDE GUIDANCE RATHER THAN STATUS INFORMATION

- GRAPHIC FORMATS SHOULD BE USED

- COLOR CODING SHOULD BE USED TO AID THE CREW IN RESPONDING TO TIME-CRITICAL WARNINGS

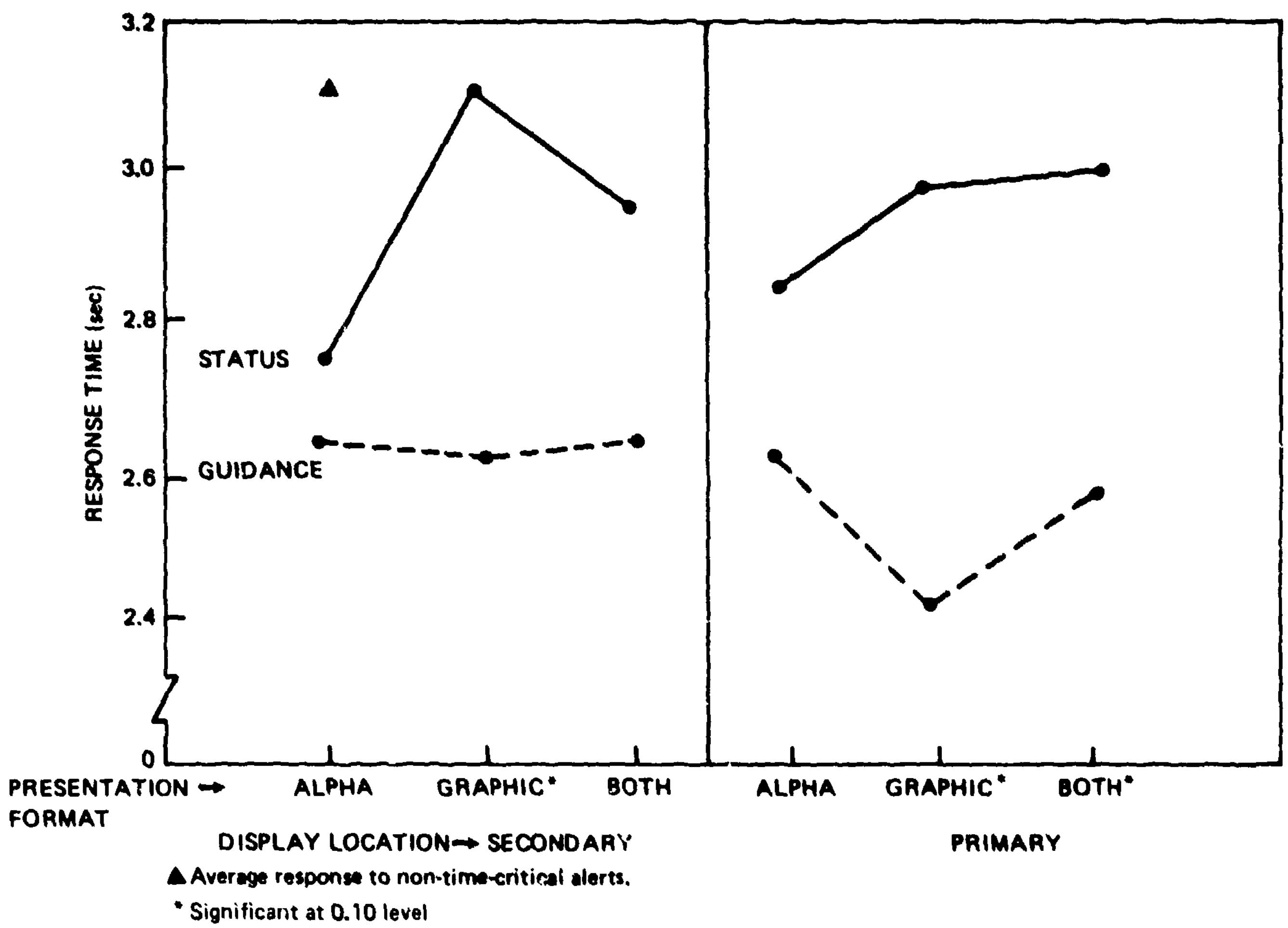


Figure 3.3.2-1. Mean Response Times as a Function of the Interaction Between Display Location, Presentation Format, and Message Content

- THE TIME-CRITICAL INFORMATION SHOULD BE ERASED WHEN CORRECTIVE ACTIONS HAVE BEEN TAKEN, OR THE ALERTING SITUATION NO LONGER EXISTS.

The format of the time-critical display differs from that of the visual information display in that graphic or symbolic presentations can be used, and only one alert can be presented at a time. Volume 1 of this report identifies several variables that were related to the format of time-critical alerts. The major findings are summarized below.

3.3.3.1 Guidance Versus Status Information Cues - Assessment of this variable involved a comparison of pilot performance data as a function of whether the information presented was guidance or status oriented. Figure 3.3.3.1-1 shows these alternative concepts. The guidance presentation provided a direct cue to guide crew action (e.g., indicated that the pilot should "DIVE" to avoid a collision). The status presentation indicated that a hazardous condition existed in the proximity of the aircraft (e.g., "COLLISION ABOVE"). The status presentation provides a less direct cue because the pilot has to first interpret the display before making a response (e.g., "COLLISION ABOVE" means dive). The data obtained in this study indicated that pilots had shorter mean detection and response times for guidance presentations (2.4 seconds compared to 3.1 seconds for the status information), see Figure 3.3.2.-1. This data agrees with Cooper (1977) who stated that the use of direct cues can decrease pilot response times to alerts. Pilot preference data also favored the guidance presentation.

3.3.3.2 Alphanumeric Versus Graphic Presentation Format - Investigation of this variable involved a comparision of pilot detection and response times as a function of the symbology used to present the time-critical information. Three conditions were investigated - graphic, alphanumeric, and a combination of the two. Figure 3.3.3.1-1 displays these conditions. An example of the type of information presented on the time-critical display would be the corrective action necessary to avoid a mid-air collision. For this case the appropriate display might be a pictorial representation of the surrounding airspace, color-coded to show the direction of the threat. Direct cues prompting the required evasive action would be backed up by a corresponding

STATUS GUIDANCE

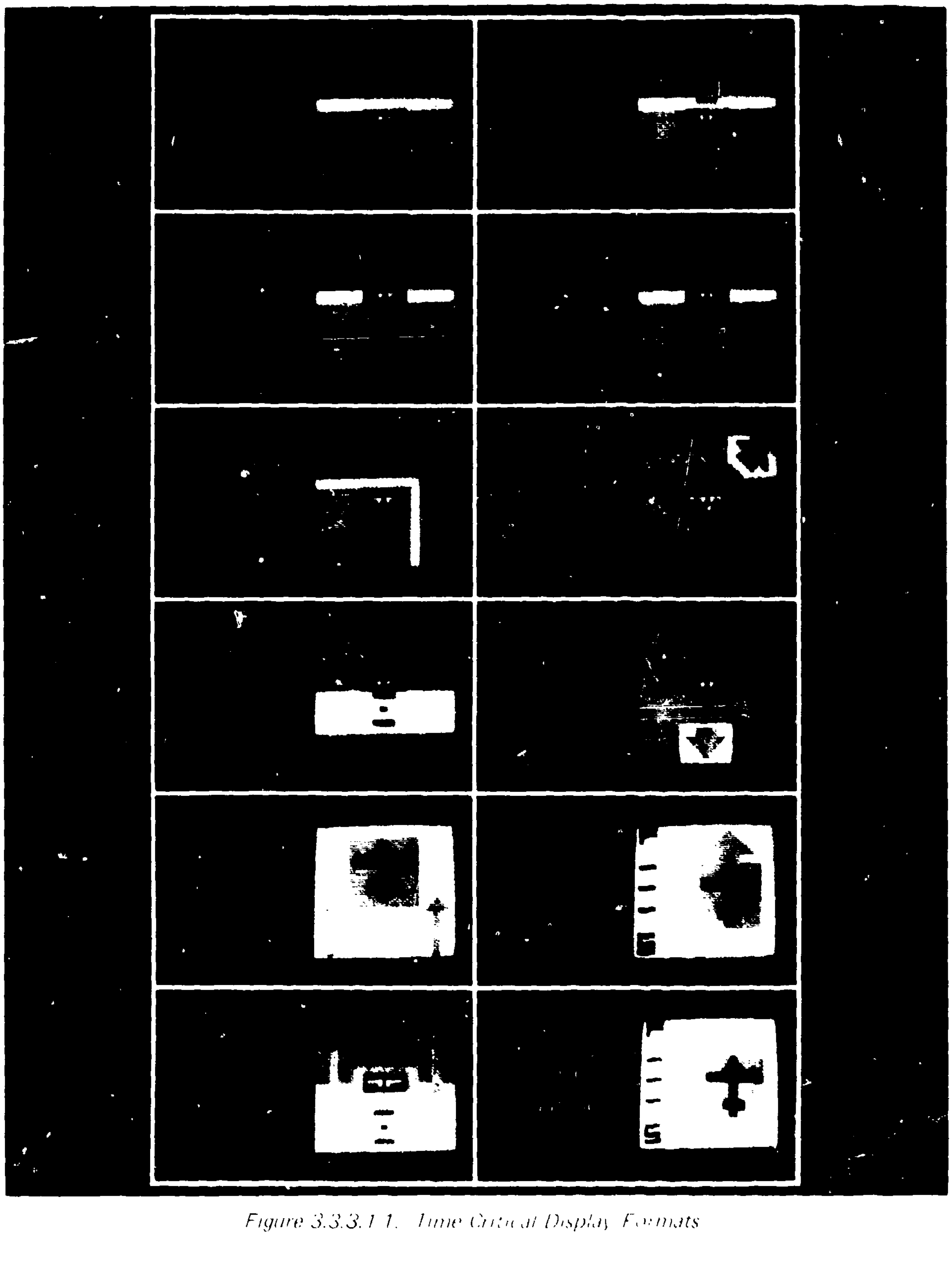


Figure 3.3.3.1-1. Time Critical Display Formats

message on the time-critical display and by a verbal message, e.g.,"CLIMB." The data indicated that the best performance (i.e., shortest detection and response times) was obtained in those trials that used a graphic presentation.

3.3.3.3 Color - While color was not used as a variable in this study, pilot preference data and standardization criteria indicate that red should be used for the presentation of time-critical information. Red should be used for the alphanumeric message (e.g., "PULL UP") and for the area on the display where the hazard is located (e.g., the area below the own aircraft symbol on the EADI and the arrow indicating the direction of control to avoid the hazard; safe areas on the display should be colored green). These findings are consistent with a study done by Parks (1979) investigating the use of color coding for collision avoidance displays.

Although the present study investigated a wide variety of formats, it did not compare all possible formats appropriate for the display of time-critical information. Moreover, several pilots in the study stated that they did not like the graphics that were used because they were cluttered, and they did not provide sufficient emphasis on the action to be taken. For this reason, the symbols used to direct the crew's response should be emphasized in the display (e.g., brighter, larger). Further research is required to identify the combinations of display variables that will produce the quickest and most efficient responses to time-critical warnings.

As with the other components of the advanced alerting system, the information on the time-critical display should be cleared automatically when the appropriate action has been taken, or when the alerting situation no longer exists.

IN SUMMARY, TIME-CRITICAL ALERTS SHOULD PROVIDE GUIDANCE INFORMATION TO DIRECT CREW CORRECTIVE ACTIONS. GRAPHIC DATA SHOULD BE PRESENTED. THE DISPLAY SHOULD BE COLOR CODED TO AID CREW ACTION. THE DISPLAY SHOULD CANCEL AUTOMATICALLY WHEN APPROPRIATE CORRECTIVE ACTION HAS BEEN TAKEN, OR WHEN THE ALERTING SITUATION NO LONGER EXISTS.

3.3.4 DISPLAY SIZE

- THE TIME-CRITICAL DISPLAY SHOULD SUBTEND AT LEAST TWO SQUARE DEGREES OF VISUAL ANGLE

As indicated in Section 3.1.7, the size of the master visual alert should subtend a visual angle of at least one square degree. The time-critical display should be larger to assure that the pilot's attention is immediately drawn to it. Since the vast majority of alerts will consist of warnings, cautions, and advisories, the pilots will develop a habit pattern of looking at the visual information display after detecting an alert. To "short circuit" this habit pattern the time-critical display should be at least twice as large as the master visual alert.

In the present study, a time-critical display of two degrees visual angle was used (1.5 x 1.5 inches). The pilots who participated in the study indicated that the display size was large enough to immediately attract their attention and to overcome their established habit pattern.

IN SUMMARY, THE TIME-CRITICAL DISPLAY SHOULD SUBTEND AT LEAST TWO DEGREES OF VISUAL ANGLE TO IMMEDIATELY ATTRACT THE ATTENTION OF THE PILOTS AND TO MODIFY THEIR HABIT PATTERN FOR RESPONDING TO NON-TIME-CRITICAL ALERTS.

3.3.5 RELIABILITY

- THE TIME-CRITICAL DISPLAY AND ITS ASSOCIATED SENSORS AND LOGIC SHOULD BE HIGHLY RELIABLE

- SUFFICIENT REDUNDANCY SHOULD BE PROVIDED TO ENABLE THE FLIGHT CREW TO RESPOND TO TIME-CRITICAL WARNINGS EXPEDIENTLY AND ACCURATELY IN THE EVENT OF A SINGLE DISPLAY FAILURE

- THE RELIABILITY OF TIME-CRITICAL WARNINGS INCLUDES NOT ONLY THE RELIABILITY OF THE ALERTING SYSTEM HARDWARE BUT ALSO THE VALIDITY OF ITS LOGIC (I.E., A TIME-CRITICAL WARNING SHOULD BE ANNUNCIATED WHENEVER A TIME-CRITICAL ALERTING SITUATION EXISTS, AND NEVER WHEN ONE DOES NOT EXIST)

The warnings presently identified as "time-critical" are all associated with aircraft flight path management. They also involve actions which must be performed immediately for the safety of flight; the alert requires that the pilot follow the guidance provided, e.g., "CLIMB RIGHT". Considering these aspects, it is extremely important that the pilot have enough confidence in the alert to respond without hesitation. The only way that the alerting system can achieve and/or warrant this confidence is to provide reliable information to the crew.

Having highly reliable hardware is not enough to assure crew acceptance. It is also necessary for the system to contain highly reliable alert logic; the system should not tell the pilot to perform an unnecessary flight path change. Therefore, since the time-critical warnings are directly associated with flight management, the recommended reliability should meet/exceed the standards imposed on other systems related to flight management.

One aspect of the hardware reliability is the display itself. A backup capability must be provided in the event of failure. This requirement can be met by providing separate displays for both pilots. A positive indication should be provided to inform the aircrew of a failure in the time-critical display or in associated equipment.

IN SUMMARY, THE RELIABILITY OF THE TIME-CRITICAL WARNING COMPONENT OF AN ADVANCED AIRCRAFT ALERTING SYSTEM (INCLUDING BOTH HARDWARE AND SOFTWARE) SHOULD BE VERY HIGH. THE TIME-CRITICAL WARNING DISPLAY SHOULD BE ACTIVATED WHEREVER A TIME-CRITICAL ALERTING SITUATION EXISTS, AND NEVER WHEN ONE DOES NOT EXIST.

4.0 AURAL SYSTEM COMPONENTS DESIGN GUIDELINES

The aural components of an alerting system should include a master aural alert and a voice information display. The master aural alert provides an attention-getting sound for each urgency level. The voice information display provides specific information that can be used as a primary or secondary (optional) source for fault correction. This section contains guidelines for the design and implementation of these two components of an advanced aircraft alerting system.

4.1 MASTER AURAL ALERT

This section contains the guidelines for the master aural alert. The following paragraphs describe the parameters that impact the detection of and response to the master aural alert.

4.1.1 PURPOSE

- THE MASTER AURAL ALERT SERVES TWO PRIMARY PURPOSES:
  - TO ALERT THE FLIGHT CREW TO IMPENDING OR EXISTING DANGEROUS SITUATIONS
  - TO PROVIDE A PRELIMINARY INDICATION OF ALERT URGENCY LEVEL

The master aural alert should provide a unique sound for each alert urgency level, to obtain and direct the attention of the flight crew to the information display(s). The primary utility of this alerting system component lies in its attention demanding capability. In addition, the use of unique sounds for each alert urgency level will provide the operator with a designation of the general category (i.e., warning, caution, or advisory) within which the signaled emergency lies. This is important when one considers that the master aural alert will always be used in conjunction with a visual information display upon which all alerts will be displayed. In high visual workload conditions (e.g., final approach), the pilot can determine the necessity of interrupting visual task activity with no alteration of visual scan. The unique sounds used to designate each urgency level will allow the pilot to make this determination via the auditory channel. The pilot may then read the specific alert message on the visual display, or if visual task loading is quite high, activate a voice presentation which provides the same information through the auditory channel.

In a recent study (Boucek, et al., 1980), pilot performance was improved when a tone-visual system was employed. The alerting tone in conjunction with a visual readout on an alphanumeric display was also preferred by a majority of pilots when compared to other systems employing tone-voice, voice only, and tone-voice-visual alert presentation formats. Although voice alerts contain useful attention demanding characteristics, they do not provide any information relative to alert urgency level. In addition, when voice alerts are not preceded by an attention-getting sound, it is possible for the pilot to miss the first few syllables of the voice message, because the human ear does not respond instantaneously to sound. In 1979, Douglas Aircraft Company administered an alerting system concepts questionnaire to 131 flight operations personnel from various airlines. Seventy-one percent favored the use of a precursor tone with voice alerts. In the ambient noise environment that characterizes most commercial flight decks, an alerting tone or sound will generally contain better noise penetrating characteristics than will an independently employed verbal alert. An effective alerting system, then, should precede all visual and verbal alert messages with a master aural alert.

The design of the master aural alert should take advantage of the inherent properties of sound to increase its effectiveness. Where feasible, the selection of signal dimensions and their encoding should exploit the learned and natural predispositions of the users, such as wailing signals being associated with emergency conditions.

IN SUMMARY, THE MASTER AURAL ALERT SHOULD BE USED TO ATTRACT THE ATTENTION OF THE CREW TO EXISTING OR IMPENDING DANGEROUS SITUATIONS, AND TO PROVIDE A PRELIMINARY INDICATION OF ALERT URGENCY LEVEL.

4.1.2 FREQUENCY

- AURAL SIGNALS SHOULD USE FREQUENCIES BETWEEN 250 AND 4000 Hz.
- HIGH PRIORITY AURAL SIGNALS SHOULD BE COMPOSED OF AT LEAST TWO DIFFERENT FREQUENCIES SPACED WIDELY APART
- TO MINIMIZE MASKING, FREQUENCIES DIFFERENT FROM THOSE THAT DOMINATE BACKGROUND NOISE SHOULD BE USED

The frequency at which an aural signal is presented will have a significant effect on its detectability as well as its perceived loudness. Although children can detect sound with frequencies ranging from 20 to about 20,000 Hz, maximum sensitivity is generally achieved in the range of 2000 to 4000 Hz (Fletcher and Munson, 1933). As can be seen in Figure 4.1.2-1, midfrequency sounds (2000 to 4000 Hz) tend to sound louder than either lower or higher frequency sounds of the same intensity. At low intensity levels, high frequency signals will sound louder than low frequency sounds of the same intensity. Conversely, at high intensity levels, all tones are perceived as being equally loud, regardless of frequency. Thus, at low intensity levels, it is possible to vary two properties of a sound by systematically altering its frequency, i.e., frequency and loudness level. By varying more than one dimension of the sound, a greater attention demanding capability is achieved. Siegel and Crain (1960) found that a two tone auditory signal resulted in significantly shorter reaction times than did the use of a single tone or a light.

When using attention getting sounds in conjunction with voice alerts, it is important to note that, just as it takes time for a sound to "build up" in the listeners' ear, time is also required for sound to decay. High frequency sounds dissipate at a faster rate than do low frequency sounds. Therefore, warbling or wailer type sounds used to precede high priority voice alert messages should end with a high, rather than a low frequency sound component. When steady alerting sounds are desired, the highest perceived loudness levels will be achieved by using lower intensity sounds at frequencies between 2000 and 4000 Hz. For example, to present a pure tone of 80 phons (sound levels)

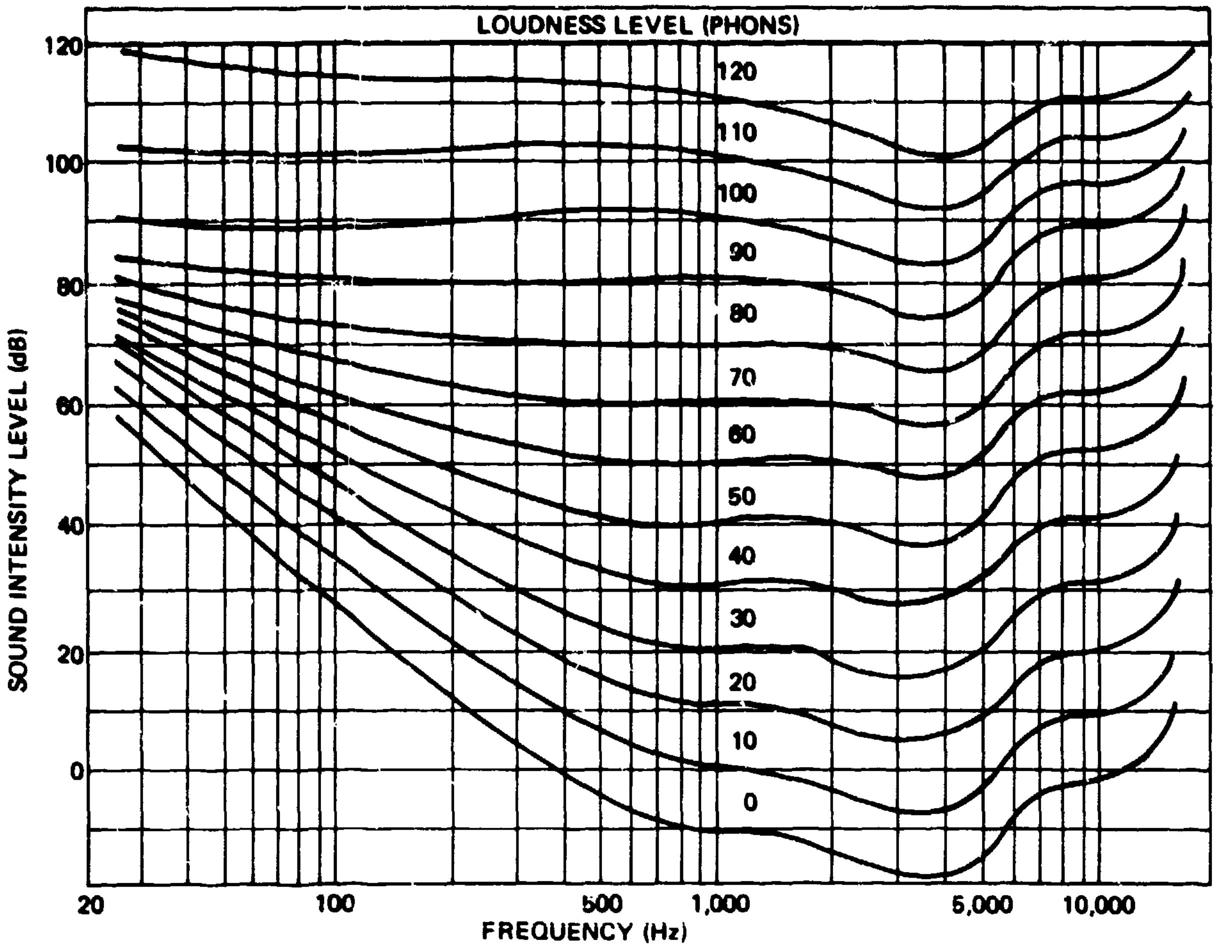
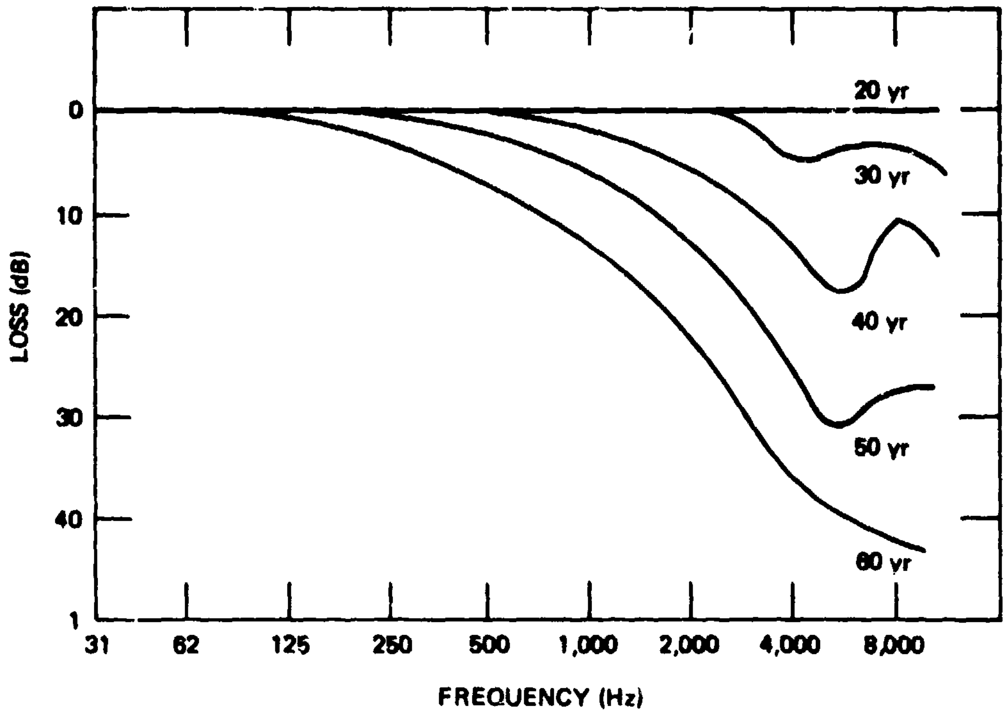


Figure 4.1.2-1. Curves of Sounds of Same Perceived Loudness (Fletcher and Munson, 1933)

at 100 Hz, an intensity level of approximately 74 dB is required. Conversely, the same sound level can be achieved by employing a 4000 Hz tone with an intensity level of only 66 dB.

Because high frequency sounds tend to be more irritating than low frequencies, care should be used in determining what frequencies to use in alerting system applications.

Another aspect of signal frequency that impacts the detection of auditory signals is that aging causes a progressive loss of hearing in higher



Note: The audiogram at 20 years of age is taken as a basis of comparison. (From Morgan, 1943, after Bunch, 1929.)

Figure 4.1.2-2. Progressive Loss of Sensitivity at High Frequencies With Increasing Age

frequencies (see Figure 4.1.2-2). In addition, ear injuries can cause insensitivities or deafness to selected frequencies. For these reasons, it is important that high priority alerting signals use a combination of frequencies to produce a highly detectable sound. Further, since age causes loss in the higher frequencies and the perceived loudness is greatest between 2000 and 4000 Hz, sounds between 250 and 4000 Hz would most likely be detected by the majority of people.

The alerting sounds used should be as different as possible from the sounds/frequencies that dominate the ambient background noise. Licklider (1961) provides a useful guide for identifying ambient conditions under which the aural alerting system should operate. Estimates of dominant frequencies information sources (e.g., ATC transmissions, electrical system interference, power system hum). It may be necessary to obtain the values for each flight phase since different sound sources may make varying contributions to the ambient environment as a function of time. Furthermore, the criticality of some flight phases (i.e, final approach) may warrant more emphasis in terms of noise spectrum analysis than others. So, to minimize masking, frequencies different from those that dominate background noise should be used.

IN SUMMARY, AURAL SIGNALS SHOULD BE COMPOSED OF FREQUENCIES BETWEEN 250 AND 4000 Hz. HIGH PRIORITY SIGNALS SHOULD BE COMPOSED OF AT LEAST TWO DIFFERENT FREQUENCIES SPACED WIDELY APART, AND TO MINIMIZE MASKING, FREQUENCIES OTHER THAN THOSE THAT DOMINATE BACKGROUND NOISE SHOULD BE USED.

4.1.3 INTENSITY

- AURAL SIGNALS SHOULD EXCEED AMBIENT NOISE BY 8 ± 3 dB
- AUTOMATIC GAIN CONTROL SHOULD BE EMPLOYED TO MAINTAIN THIS OPTIMUM SIGNAL-TO-NOISE RATIO
- CONSIDERATION SHOULD BE GIVEN TO HUMAN TIME EXPOSURE LIMITS

4.1.3.1 Intensity Versus Loudness - Before discussing the effects of intensity on signal detection, the distinction between intensity and loudness will be described. Intensity is a physical measure of the energy level of a sound transmitted per unit of time through a unit of area within some medium. In terms of application to an alerting system, intensity refers to the level of fluctuation above and below the normal atmospheric pressure with which sound waves are propagated through the air. Loudness, on the other hand, is an attribute of the sound as heard and reacted to subjectively by the listener. Loudness is primarily dependent on intensity, frequency and the sound reception characteristics of the human ear. In measuring loudness, it is also important to distinguish between loudness level (measured in phons) and loudness (measured in sones). The phon provides a measurement of the subjective equality of various sounds (see Figure 4.1.2-1) while the sone

Table 4.1.3.1-1. Noise-Emitting Activities and Their Associated Loudness Values (Bonvallet, 1952)

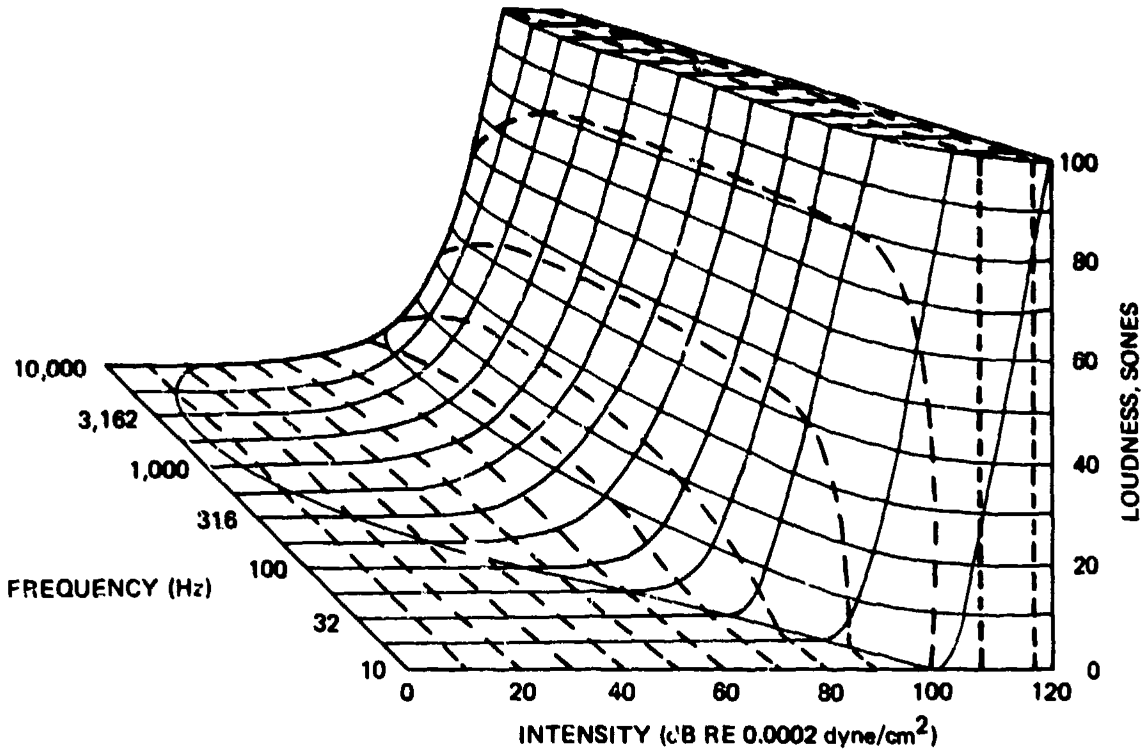
Noise source	Intensity (dB)	Loudness (sones)
Residential inside, quiet	42	1
Household ventilating fan	56	7
Automobile, 50 ft	68	14
"Quiet" factory area	76	54
18-in automatic lathe	89	127
Punch press, 3 ft	103	350
Nailmaking machine, 6 ft	111	800
Pneumatic riveter, 4 ft	128	3,000

describes the relative subjective loudness of different sounds. One sone is defined as the loudness of a 1000 Hz tone at 40 dB. A sound that is judged to be twice as loud as the reference sound has a loudness of 2 sones. In turn, a sound judged to be one-half as loud has a loudness of one-half sone. Table 4.1.3.1-1 presents the loudness values and intensity levels for a variety of noise sources.

4.1.3.2 Maintenance of Optimum Signal-to-Noise Ratio - A number of available guideline documents recommend a signal-to-noise ratio of 15 to 20 dB above masked threshold (Van Cott and Kincade, 1972; MIL-STD-1472B, 1978; and, Boucek, Veitengruber, and Smith, 1977). However, these recommendations are rules of thumb and a requirement to accommodate the worst case conditions with a single intensity which may result in alerting signal intensity requirements that are too loud. The general consensus among pilots is that most aural alerts currently in use in commercial aircraft are too loud (Cooper, 1977). For these reasons, an aural alerting adjustment capability may be required in the flight deck. If such a capability is not provided, pilot aggravation may occur, accompanied by possible ear damage.

As a general rule, a more intense sound is more likely to be detected than a quieter sound of the same frequency. However, the detectability of any particular sound is primarily dependent on background noise. For any given background condition, there is an intensity of a signal that will be detected 50% of the time by a particular individual. This level of intensity is referred to as the threshold intensity. An increase of as little as 3 dB above this threshold can result in nearly 100% detection. The relationship between frequency and loudness is illustrated in Figure 4.1.3.2-1.

Since auditory alerts will be used in an environment where the background noise is constantly changing not only in amplitude but also in frequency, it is important to determine what aspects of the background noise require adjustments in signal intensity.



Note: Subjective loudness in sones is represented vertically above the intensity-frequency plane. The heavy curves coursing from front to rear in the diagram are equal-loudness contours for pure tones.

Figure 4.1.3.2-1. Three-Dimensional Surface Showing Loudness as a Function of Intensity and Frequency (Stevens and Davis, 1938)

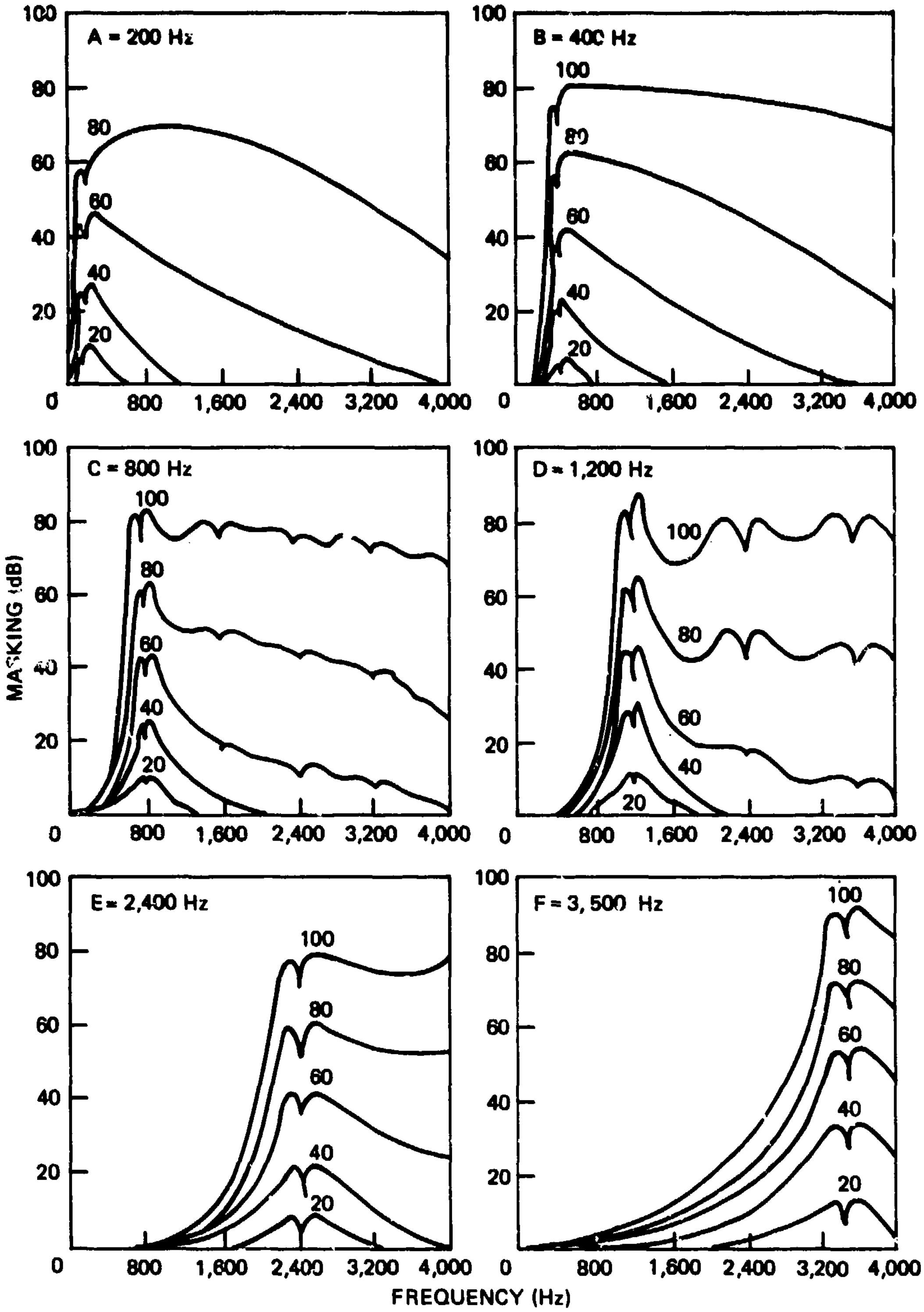
Noise mixed with a signal tends to raise the detection threshold above the "threshold in quiet". This effect is referred to as masking. For flight deck applications of aural alerting signals, the effects of masking should be evaluated for three types of ambient noise:

NOISE TYPE	DISTINGUISHING CHARACTERISTICS
Pure tone	Bandwidth = nominal frequency ±0 Hz
Narrow-band noise	Bandwidth = nominal frequency ±45 Hz
Wide-band noise	Bandwidth = wide spectrum

The masking effect of each of these types of ambient noise on aural alerts is discussed in the following paragraphs.

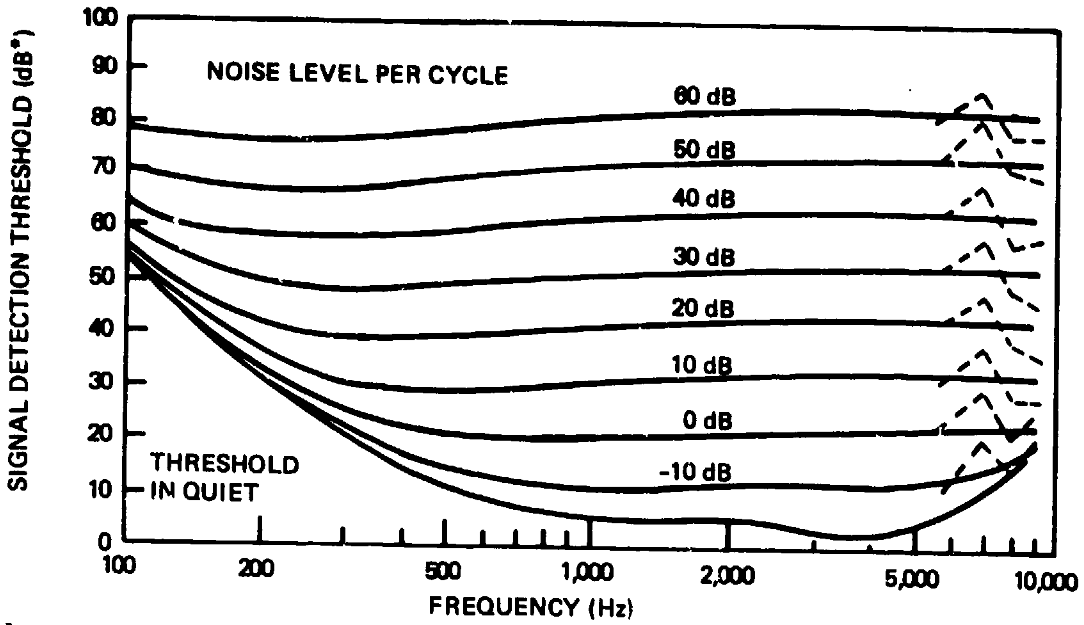
Quantitative relationships between the frequency of the masking noise and the amount of masking of auditory signals of various frequencies as applied to pure-tones are shown in Figures 4.1.3.2-2 to 4. In Figure 4.1.3.2-2, the frequency of the masked auditory signals are given on the abscissa of each graph. The ordinate presents the masking level, i.e., the amount above the threshold-in-quiet, that the auditory signal must be elevated in the presence of the masking tone. The number on each curve represents the intensity of the masking tone, measured as the amount above the threshold-in-quiet level. The lowest curve in Figure 4.1.3.2-3 gives the threshold-in-quiet values.

As an example, assuming the ambient noise consists of a 400 Hz pure masking tone presented at 95 dB, determine the levels required of 200-, 400-, and 800-Hz auditory signals to achieve 50% detectability. The threshold-in-quiet levels of these signals are 30, 15, and 6 dB, respectively (derived from Figure 4.1.3.2-3); the 80 dB curve on the B = 400 Hz graph in Figure 4.1.3.2-2) must be used to determine the intensity required of these alerting signals (95 dB Tone - 15 dB Threshold = 80 dB). Interpolation of these curves provide the following results:



Note: Number at top of each graph is frequency of masking tone.
Number on each curve is level above threshold of masking tone.

Figure 4.1.3.2-2. Masking of One Tone by Another Tone (Wegel and Lane, 1924)



*Re 0.0002 μbar.

Figure 4.1.3.2-3. Masking Effect of White Noise on Pure Tone (Hawkins and Stevens, 1950)

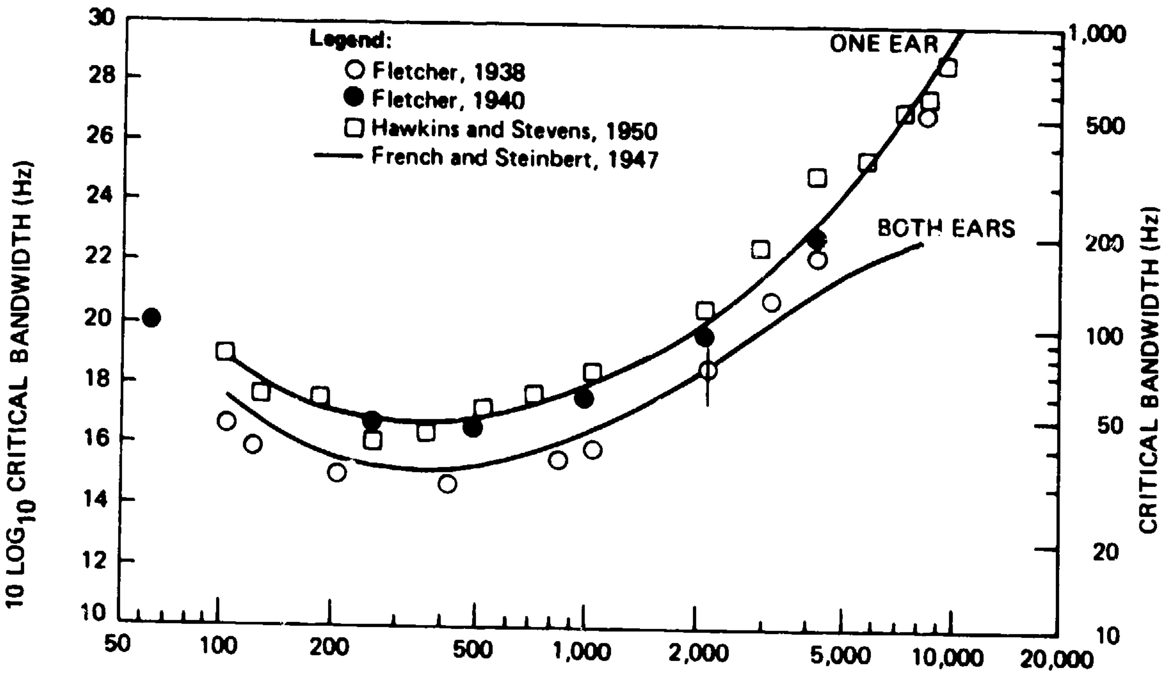


Figure 4.1.3.2-4. Critical Bandwidth of Masking in Wideband Noise (Fletcher, 1953)

AUDITORY SIGNAL FREQUENCY Hz	DELTA INTENSITY REQUIRED dB	TOTAL* INTENSITY REQUIRED dB
200	15	45
400	55	70
800	62	68

*Total intensity = DELTA intensity + threshold in quiet

Note that maximum masking of a pure-tone occurs when the background sound is of the same frequency range as the signal. Substantial masking also occurs when the auditory signal is composed of frequencies higher than those in the ambient environment. Lower frequency alerting signals are significantly less subject to masking.

The masking effects of narrow-band ambient noise are similar to the effects described above for a pure-tone environment. The primary difference occurs in the shape of the curves (see Figure 4.1.3.2-3). For pure-tone ambient noise, small dips occur in these curves where the alerting signal frequency equals the ambient noise frequency. These dips are due to beats produced by two pure-tones of slightly different frequencies. For narrow-band ambient noise, these beats do not occur and the masking curves smooth out.

Thus far only the effects of pure-tone and narrow-band ambient noise on auditory signals have been discussed. For flight deck applications, wide-band noise effects must also be considered. Morgan, Cook, Chapanis, and Lund (1963) state that masking effects of wide-band ambient noise are considerably different than the masking effects of narrow-band and pure-tone ambient noise. The effects of wide-band noise extend beyond the spectrum of the noise itself. The masking effect of wide-band noise that has the same intensity throughout the spectrum (white noise) is approximately linear with respect to the increase in intensity of the noise. This is apparent from the regular spacing of the threshold contours in Figure 4.1.3.2-4. These are true thresholds - not DELTA thresholds as used in the pure-tone discusssion. For wide-band noise that does not have uniform intensity over the frequency spectrum, the ear has the ability to filter or reject the part of the noise that is outside a certain range around the signal, thus eliminating some of the noise and making the signal more audible. The width (in Hz) of this range is called the "critical bandwidth" and varies dependent on the frequency of the signal being used (see Figure 4.1.3.2-4). Morgan, et al., (1963) state that the threshold of a pure-tone alerting signal can be predicted if the spectrum of the noise near the frequency of the tone is known. In making this prediction, it is assumed that the masking is being done by the noise near the frequency of the signal, that which lies in the critical bandwidth. When used to predict masking, the critical bandwidth is defined so that the sound pressure level of the noise in the critical band is equal to the sound pressure level of the signal at its masked threshold (the intensity where 50% of the signals are detected when noise is present). Morgan, et al., presented the following procedure for predicting the masked threshold of an aural alert signal at any signal frequency in wide-band ambient noise:

1. Measure the level of the ambient noise at the frequency of the auditory signal. This includes ambient flight deck noise as well as a representative sample of typical voice communications.

2. Correct this measured level for the wide-band effect by adding the 10-log value of the critical bandwidth (read directly from the left ordinate in Figure 4.1.3.2-4).

3. This corrected value is the masked threshold of the auditory signal.

The question remains as to how the pilots' attention can be obtained without aggravation or injury. One possibility is to repeat the desired signal at progressively increasing intensity levels until the pilot hears it. An essential part of this system would be a silencing switch (usually contained in the alerting system as part of the master visual alert) which the user would press to silence the signal as soon as it was heard and understood. This would protect the pilot from exposure to the very intense repetitions. This arrangement has a number of significant drawbacks, the most serious of which is the introduction of delay into the alerting process. It would be undesirable to present low level (and hence potentially inaudible) signals before those that are effective, particularly for a time-critical warning.

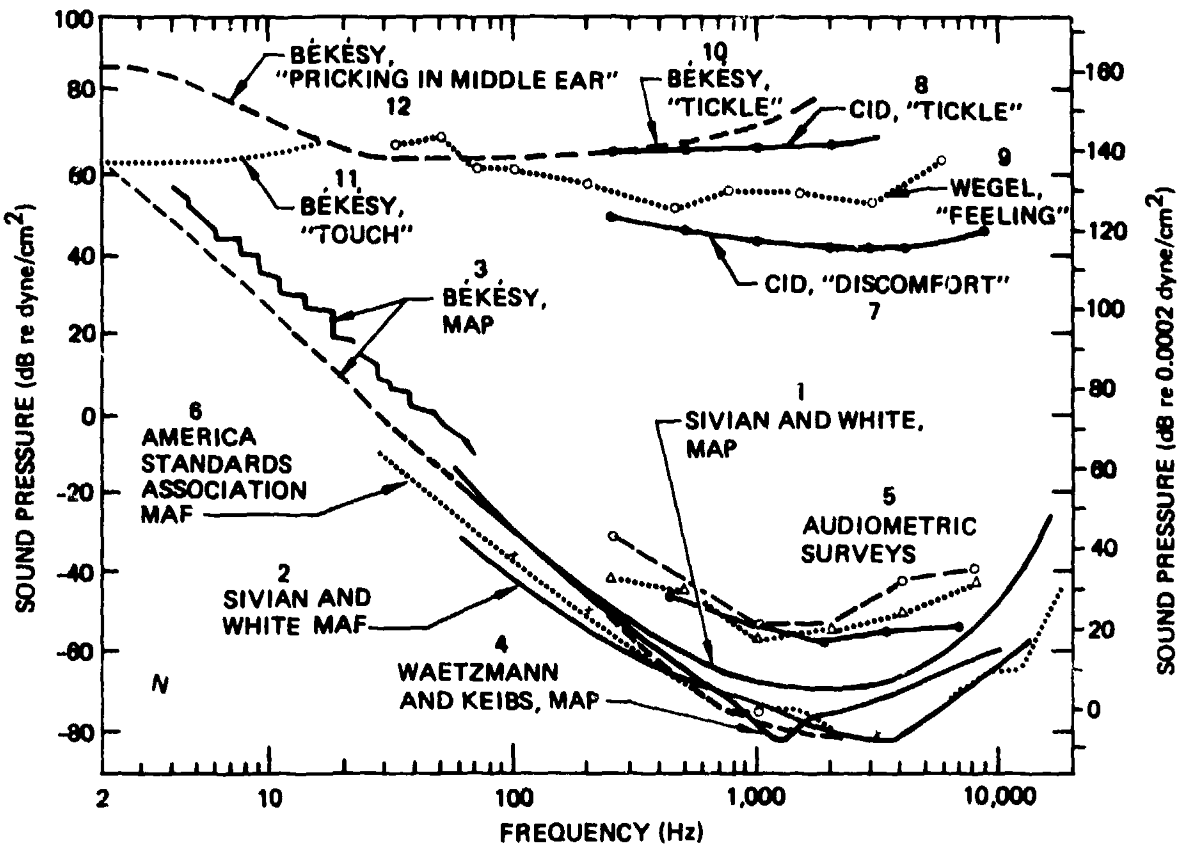
A more effective way of solving the problem could be to employ an automatic noise gain control. This would provide for a constant signal-to-noise ratio which would assure audibility in all expected ambient noise conditions. It would also prevent the occurrence of unnecessarily intense signals and, thereby, reduce the possibility of distracting pilots. Operating personnel tend to place more importance on the attribute "nondistracting", than a person without much operational experience might suppose. In an effort to incorporate high attention demanding value into a signal, it is easy to create signals that operating personnel will judge to be prohibitively distracting. In a recent study, a 99 percent intelligibility rate was achieved using both male and female voice models at a zero signal-to-noise ratio (Kerce, 1979). Volume 1 of the present study reported that in a subjective post-test evaluation, the majority of the pilots questioned felt that an 8 dB signal-to-noise ratio was acceptable. Since interpreting aural information is more difficult than detecting its presence, a controlled signal-to-noise ratio will aid in the elimination of the annoyance factor that is characteristic of most present day alerting systems.

IN SUMMARY, AUTOMATIC GAIN CONTROL SHOULD BE USED TO MAINTAIN AN INTENSITY LEVEL OF 8±3 OVER THE CRITICAL BANDWIDTH AMBIENT NOISE.

4.1.3.3 Human Time Exposure Limits - Stevens (1951) presents a composite of the work relating feeling to sound pressure levels (see Figure 4.1.3.3-1). This work did not take exposure time into consideration. Eldred, Gannon, and VonGierke, (1955) considered this aspect of the auditory environment when they produced the limits set forth in Figure 4.1.3.3-2. As can be seen, the upper limit for sound tolerance is 135 dB. More important, however, is that there is a time exposure limit, after which there is a risk of damage for unprotected hearing. In developing an advanced alerting system, CONSIDERATION SHOULD BE GIVEN TO HUMAN TIME EXPOSURE LIMITS.

4.1.4 NUMBER OF SOUNDS

- THE NUMBER OF FLIGHT DECK ALERTING SOUNDS SHOULD BE LIMITED TO THREE, ONE FOR EACH URGENCY LEVEL



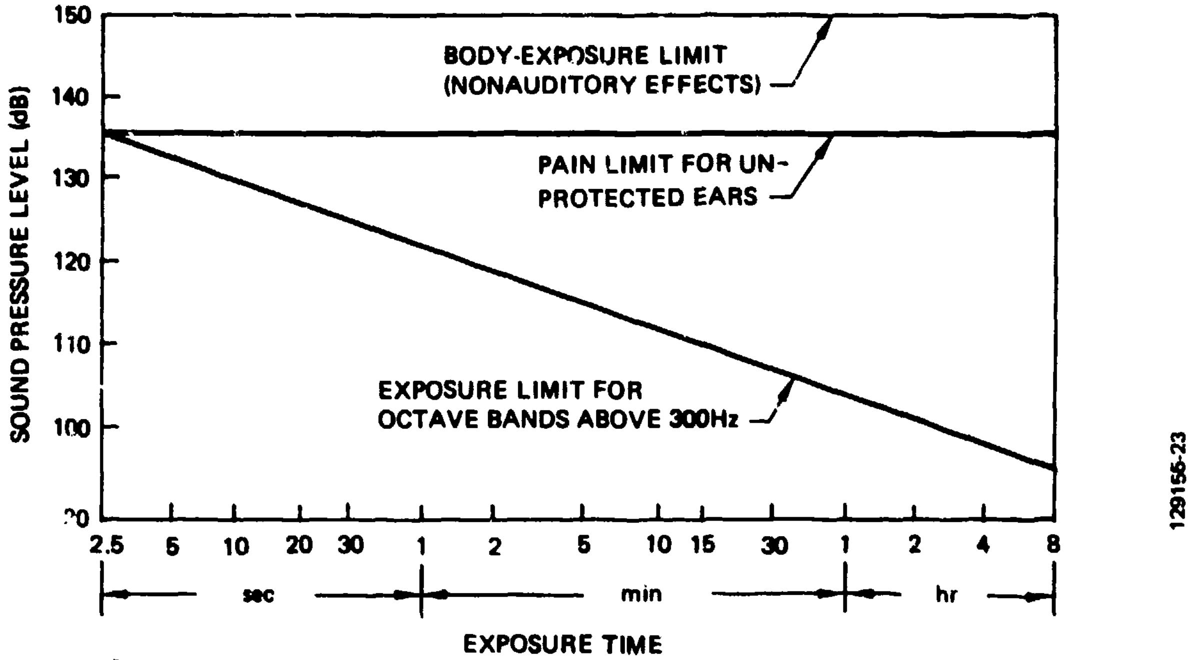
Curves 1 to 6 represent attempts to determine the absolute threshold of hearing at various frequencies. MAP —minimum audible pressure at the eardrum; MAF—minimum audible pressure in a free-sound field, measured at the place where the listener's head had been. Curves 7 to 12 represent attempts to determine the upper boundary of the auditory realm, beyond which sounds are too intense for comfort and give rise to nonauditory sensations of tickle and pain, etc.

Figure 4.1.3.3-1. Determinations of Threshold of Audibility and Threshold of Feeling (Stevens, 1951)

- EACH SOUND SHOULD DIFFER FROM OTHER SOUNDS IN MORE THAN ONE DIMENSION, (i.e., FREQUENCY, INTENSITY, LOUDNESS, ETC.)

- THE SOUNDS SHOULD BE SELECTED TO REFLECT THE ALERT URGENCY LEVEL:

  - WARNING - ALTERNATING HIGH AND LOW FREQUENCY SOUNDS
  - CAUTION - STEADY-STATE SOUND
  - ADVISORY - SINGLE STROKE SOUND



*Re 0.0002 μbar

Note: Pain limit for unprotected ears is shown at 135 dB. When ear protectors are used, sound pressure level in sound field can exceed these criteria by amount of attenuation provided by protectors. Body-exposure limit at 150 dB is point at which potentially dangerous nonauditory effects occur. This level should not be exceeded in any case.

Figure 4.1.3.3-2. Damage Risk Criteria for Various Exposure Times Up to 8 hr (Eldred et. al., 1955)

There are three perceptual processes in the reception of auditory stimuli:

1. Detection - determining when a signal is present
2. Relative discrimination - differentiating between two or more signals presented in close succession
3. Absolute identification - identifying a signal of some class, when the signal is presented alone

Clearly, the most difficult aspect of auditory information processing is absolute identification. Experimental testing has shown that humans can make precise judgements about minute differences between stimuli (relative discrimination). However, they are limited in their ability to make absolute judgements (Miller, 1956). Shower and Biddulph (1931) reported that under ideal conditions, subjects could detect frequency differences as small as 2 or 3 Hz. Pollack (1952) had listeners make absolute identifications of tones of different frequencies by assigning numbers to them. When only 2 or 3 tones were used, the listeners never confused them, but with 5 or more tones, confusion was frequent. Several available guideline documents recommend that the number of discrete sounds used in an alerting system be limited to 3 to 5 (Erickson, 1978; MIL-STD-1472B, 1978; annd Van Cott and Kinkade, 1972). Cooper (1977) surveyed the major airframe manufacturers and found that they recommend the number of audio warning signals be limited to 4 or 5.

In determining the number of sounds to use in the alerting system, several points must be considered. The purpose of the master aural alert must be identified; consideration must also be given to the way pilots perceive and respond to all the stimuli that are competing for their attention. Finally, the attention-getting and stereotypical qualities of sounds must be examined to determine appropriate usage.

As stated earlier, the master aural alert serves two functions; getting the pilots attention and providing preliminary information about the urgency of the alert. However, without accomplishing the attention-getting function the alert is unable to perform the second. Therefore, the master aural for immediate-attention alerts (warnings and cautions), should be designed with primary emphasis on the attention-getting requirements and secondarily on information content. The function of the advisory master aural, however, is slightly different. Boucek, et. al., (1980) demonstrated that when alerts were detected without a master alert to provide preliminary information, these alerts were responded to differently than those that were accompanied by a master attention-getter. The conclusion drawn from the results was that if the pilot's scans were interrupted by the appearance of an advisory alert on the visual information display, they would respond to the alert before resuming their flight task. The time at which an advisory alert is most likely to be detected is when it first flashes on the display. Therefore, it is a function of the advisory master aural to provide the pilots with urgency level information immediately so that if they have detected the alert, they need not visually identify it as an advisory, thereby permitting the pilots to decide when to respond.

The difficulty with some systems which are designed to be used by human operators is that too often, the design is developed using an approximation of the "ideal observer" to dictate the requirements. In other words, the limits for stimuli provided to the operator are derived under ideal conditions with a passive observer. Under these conditions a model can be built which will predict the point at which a stimulus will be detected all the time. Gibson (1966) states that, "the notion of a wholly passive observer, an 'ideal' observer as called by sensory physiologists, is a myth". Observers in real situations have to be motivated to observe, and their attention fluctuates with motivation. Consequently the idea of a statistical threshold has had to be substituted for the idea of a psychophysiological threshold. It is therefore worthwhile to consider one process that may affect the pilots motivation to perceive the master aural alert. Gibson identified "selective attention" as one of the main perceptual processes. In an eventful environment, such as flying an airplane, the pilot cannot register everything at once, and his perception must therefore become selective. In the face of this situation the pilot develops a highly economical strategy of perception. According to Gibson, "this strategy includes the ability to avoid distraction - to concentrate on one thing at a time in the face of everything going on in the environment - and yet to accomplish as much knowing as possible." He goes on to state that, "as a result (of selective attention), the information registered about objects and events becomes only what is needed, not all that could be obtained." This information is then used to reduce the perceptions to a manageable number of categories, with subcategories or cross-categories being neglected. The determination of what information is needed is a learned process. The pilot has an ability to assign "value" to each perception or event and to filter out those with lower value when perceptually loaded. In this "filtering" process the pilot may not consciously recognize that the event has taken place. This process is illustrated by the chiming of a clock which is well above the threshold of hearing but is rarely heard when other activity is going on. Gibson states that, "all this discrimination, wonderful to say, has to be based on the education of attention." The impact of selective attention on the crew alerting system is very important and should be recognized. If, in fact, the conditions and/or faults announced by the system can be partitioned into different categories, and if the expected pilot response differs for each of the categories, then the perceptual event (master aural alert) associated with each category should be unique so that the pilot can assign a value to each event (alert). If the same alerting sound is used for all urgency categories, its associated value will have a tendency to reflect the category which occurs most often. This is relevant to an alerting system because the most frequently encountered urgency category is the advisory, which represents the lowest urgency level. Using the same sound for warnings, cautions and advisories would tend to reduce the perceptual value of the warning thus decreasing the probability that it will get the pilots attention, especially under high workload conditions.

Design of the auditory component of the alerting system should take advantage of the inherent properties of sound to increase the effectiveness of the system. Mudd (1961) developed a set of principles for auditory signals. He stated that, "the efficiency of any given auditory display is dependent upon the total situation in which the display is used....where feasible, the selection of signal dimensions and their encoding should exploit learned or natural relationships on the part of the user such as wailing signals to indicate emergency." The stereotypical nature of sounds was demonstrated in a previous study where pilots were able to classify sounds with respect to the urgency level implied by the sound itself (Boucek, et al., 1980). In support of Mudd, intermittent or modulated sounds were most often said to connote warning, and single stroke sounds such as a chime were most often identified as advisory.

Mudd goes on to recommend that the same sound should designate the same information at all times. This display principle would not permit the same sound to be used for all three levels of urgency.

When a signal has the primary purpose to alert the pilot and a secondary purpose to inform him of the urgency level, it is imperative that the design be directed toward optimizing the alerting process. Due to the amount of stimuli existing on the flight deck, both visual and aural, it is necessary for the pilot to selectively attend to these stimuli. This selection is done with respect to the importance of the stimuli to the job. Since abnormal conditions or faults can be separated into urgency categories, these categories should each have a different signal to allow the pilot to separate them in terms of their relative importance. It is not sufficient to use the same sound and merely change the number of repetitions for each urgency category because it is the sound itself that is the attention-getter, not the number of repetitions. Furthermore, it has been demonstrated that the pilot's value judgement can be facilitated by using a sound which can be stereotypically associated with the urgency category it represents. For example, the use of a chime for a warning level alert is especially inadvisable because the combination of an advisory stereotypical meaning and the greater proportion of advisories to any other alert - could have a very strong impact on the pilots' perception and value judgement of the sound - and could drastically affect his attending to a problem.

IN SUMMARY, THE NUMBER OF FLIGHT DECK ALERTING SOUNDS SHOULD BE LIMITED TO THREE, ONE FOR EACH URGENCY LEVEL. EACH SOUND SHOULD DIFFER FROM OTHER SOUNDS IN MORE THAN ONE DIMENSION, AND THE SOUNDS SHOULD BE SELECTED TO REFLECT ALERT URGENCY LEVEL.

4.1.5 SOUND DURATION AND TONE-MESSAGE ONSET COORDINATION

- SIGNAL DURATION SHOULD VARY, DEPENDING ON THE ALERT URGENCY LEVEL
- AURAL SIGNALS FOR TIME-CRITICAL WARNINGS SHOULD BE APPROXIMATELY 0.75 SECOND IN DURATION. THE HIGH AND LOW FREQUENCY SOUNDS USED FOR THIS SIGNAL SHOULD BE PRESENTED IN SUCCESSION, EACH BEING INTRODUCED FOR 0.2 TO 0.3 SECOND AT A TIME
- FOR ALL OTHER WARNINGS, THE SOUND SHOULD BE CONTINUED UNTIL A PILOT INITIATES AN OPTIONAL VOICE MESSAGE OR OTHERWISE CANCELS THE SIGNAL
- FOR CAUTION LEVEL ALERTS, THE SIGNAL DURATION SHOULD BE 1.2 TO 2.0 SECONDS
- THE ADVISORY SOUND SHOULD BE 0.6 TO 0.8 SECOND IN DURATION

- THE "OFF" TIME BETWEEN THE ALERTING SIGNAL AND THE ENSUING VOICE MESSAGE SHOULD BE AT LEAST 0.15 SECOND AND NOT MORE THAN 0.5 SECOND

In determining the duration of the alerting sound, there are two somewhat conflicting constraints to consider. The sound must continue long enough to assure proper detection and interpretation by the operator; and when used with verbal alert messages, it must be brief enough so as not to delay the onset of the critical voice message.

The ear does not respond instantaneously to sound. For pure-tones, it takes approximately 0.2 to 0.3 second for the sound to "build up" (Munson, 1947). Wide-band sounds build up and decay more rapidly. To compensate for these lags, auditory signals of less than 0.2 to 0.5 second in duration do not sound as loud as those of longer duration. Adams, Humes, and Stevenson (1962) found that low signal presentation rates have a detrimental effect on their detection. To minimize the possibility of missed alerts, auditory signals should be presented for at least 0.5 second, and THE DURATION SHOULD VARY, DEPENDING ON THE ALERT URGENCY LEVEL.

By varying the duration of the alerting signals used for each alert urgency level, it is possible to produce multi-dimensional signal variation (i.e., frequency and duration). In time-critical situations, the essential elements of the voice message should be conveyed to the listener as rapidly as possible. MIL-STD-1472B (1978) states that all essential information should be conveyed to the pilot within the first 2.5 seconds of the identifying or action signal. It is, therefore, recommended that for time-critical alerts, the alerting signal and intervening "off" time be minimized to avoid unnecessary delay. The multi-frequency characteristics of the alerting signal should be sufficient to obtain the pilots attention. THEREFORE, AURAL SIGNALS FOR TIME-CRITICAL WARNINGS SHOULD BE APPROXIMATELY 0.75 SECOND IN DURATION. THE HIGH AND LOW FREQUENCY SOUNDS SHOULD BE PRESENTED IN IMMEDIATE SUCCESSION, EACH BEING INTRODUCED FOR 0.2 TO 0.3 SECOND AT A TIME.

SHOULD CONTINUE UNTIL THE OPTIONAL VOICE MESSAGE IS INITIATED BY THE PILOT, OR THE SIGNAL IS OTHERWISE CANCELLED.

Caution level alerts require immediate crew awareness but, again, this should not be done at the expense of safe flight management. Given that a caution signal, optimized for rapid detection, is not detected by the crew, it can be assumed that the workload level is too high for them to adequately attend to the failure being annunciated. For this reason, the caution alerting signal duration should be from 1.2 to 2.0 seconds, and should not be repeated for 8 to 12 seconds. This will allow the crew to attend to the high workload item before being confronted again with the caution level alerting signal. As mentioned earlier, the signal onset for all alert urgency levels will be concurrent with the appearance of the master visual alert, and the appropriate message on the visual display unit. Due to the differing urgency levels for warnings and cautions, it is reasonable to accept a slightly lower probability of immediate alert acknowledgement for 8-12 seconds in the case of cautions. The present study demonstrated that the use of a master visual alert for cautions (with no alerting sound) resulted in detection times of 1.0 to 1.5 seconds with fewer than one percent of these alerts being missed by the pilots. FOR CAUTION LEVEL ALERTS, THE SIGNAL DURATION SHOULD BE BETWEEN 1.2 AND 2.0 SECONDS.

Since advisory level alerts do not require immediate awareness or action and the function of identifying alert urgency level is required only when the alert has been detected, it is acceptable for the master aural signal to be low in attention-getting value and short in duration without repetition (i.e., a low chime). THE DURATION OF THE ADVISORY SIGNAL SHOULD BE 0.6 TO 0.8 SECOND.

In terms of cycle time between an alerting signal and the corresponding voice message, it is imperative that sufficient time be allowed for signal decay. In contrast to the 0.2 to 0.3 second required for pure-tones to build up in the listeners' ear, it takes about 0.14 second for signal decay. Thus, to assure adequate signal-voice separation, BETWEEN 0.15 AND 0.50 SECOND SHOULD BE ALLOWED FOR "OFF" TIME BETWEEN THE ALERTING SIGNAL AND VOICE MESSAGE.

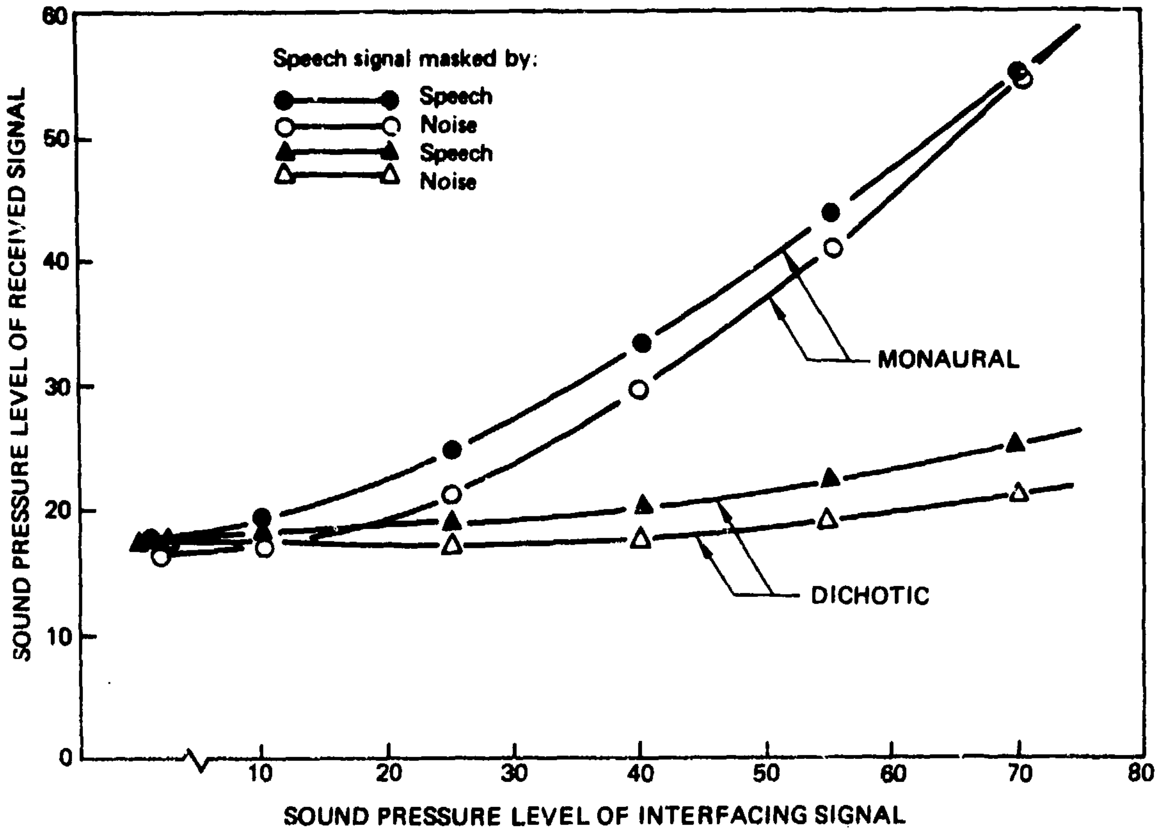
4.1.6 LOCATION OF SOUND SOURCE

- DICHOTIC METHODS OF PRESENTATION SHOULD BE USED FOR AURAL ALERTS
- IF A SINGLE EARPHONE IS USED, IT SHOULD BE WORN ON THE DOMINANT EAR
- THE ALERTING SYSTEM SOUNDS SHOULD BE PERCEPTUALLY SEPARATED FROM COMPETING SOUND SOURCES BY AT LEAST 90 DEGREES
- BROAD-BAND SIGNALS SHOULD BE USED WHEN LOCALIZATION IS NOT POSSIBLE

The audibility of alerting signals is affected by its source relative to the source location of competing sounds. An alerting signal presented together with an unwanted sound or masking noise is easier to detect if the desired signal emanates from one apparent azimuthal location and the noise from another (Van Cott and Kinkade, 1972).

Egan, Carterette, and Thwing (1954) had subjects listen to messages under monaural or dichotic conditions. It was found that dichotic listening provide location cues that helped subjects discriminate between signals and noise. As can be seen in Figure 4.1.6-1, the advantage of dichotic listening is equivalent to an increase of up to 30 dB in signal intensity. However, this increase should not be expected in a noisy environment where the pilot will not be using dual earphones.

If the pilot is going to wear a single earphone and the aural signal is going to be presented over the system, the pilot's "dominant" ear should be identified. (The ear that receives messages better is referred to as the dominant ear). Messages presented to the dominant ear are slightly more likely to intrude upon attention than messages presented to the non-dominant ear. Gopher and Kahneman (1971) used earphones to present one series of numbers to the right ear and another series of numbers to the left ear of a group of Israeli Air Force cadets and pilots. The subjects were required to repeat one series of numbers and to ignore the other series. An average of



Note: Curves show threshold sound pressure level for perception of a received signal masked by an interfering signal.

Figure 4.1.6-1. Comparison of Dichotic and Monaural Masking (Egan, et al., 1954)

1.1% of the numbers that were to be ignored intruded and were repeated by the test subjects. Most of the intrusions (74%) occurred when the numbers presented to the right ear were to be ignored. The observed higher intrusion rate for messages presented to the right ear is due to the majority of people being right-ear dominant.

Therefore, auditory warning signals that are presented monaurally should be received by the dominant ear. This guideline may be overridden by operational considerations which may require the captain to wear a earphone on the left ear while the first officer wears it on the right ear to facilitate more efficient intra-cockpit communication. This being the case, the alert should also be presented over a speaker.

Speith, Curtis, and Webster (1954) asked subjects questions about visual displays over loudspeakers to approximate an open (dichotic) situation. The questions were always presented in simultaneous pairs, with each question in a pair being preceded by a code name. The subjects were to answer the question in each pair that was preceded by their code name and to ignore the other question. Three loudspeakers were used to transmit the messages and were separated from each other horizontally in 10° to 90° increments. A pair of questions could either be transmitted from the same loudspeaker (single-source condition) or from two different loudspeakers. When a pair of questions were transmitted from the same loudspeaker, the subjects answered 66% of the questions correctly. The percentage of correct answers increased to 86% for 10° to 20° separation and to 92% for 90° and 180° separation (see Figure 4.1.6-2).

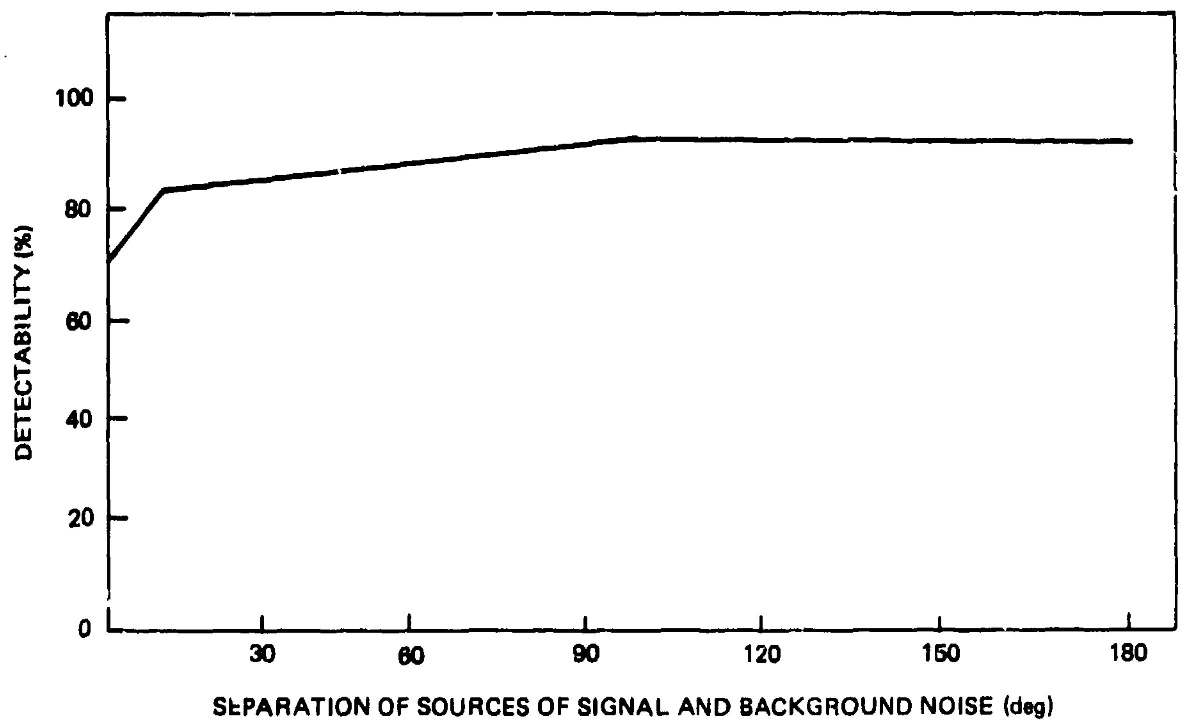


Figure 4.1.6-2. Effect of Aural Alerting Signal Source Location (Speith, et al., 1954)

The ability to localize a signal is also dependent upon its frequency. Mills (1958) found that localization for pure-tones was optimum for frequencies between 250 to 1000 Hz and between 3000 and 6000 Hz. Localization was poor when frequencies between 1000 and 1500 Hz and at approximately 8000 Hz were used. Broad-band signals are generally localized much better than pure-tones. Thus, with dichotic listening, broad-band signals that can be localized easily are more likely to be detected than signals that cannot be localized.

IN SUMMARY, DICHOTIC METHODS OF PRESENTATION SHOULD BE USED FOR AURAL ALERTS. IF A SINGLE EARPHONE IS USED, IT SHOULD BE WORN ON THE DOMINANT EAR. IN ADDITION, THE ALERTING SYSTEM SOUNDS SHOULD BE PERCEPTUALLY SEPARATED FROM COMPETING SOUNDS BY AT LEAST 90°, AND FINALLY, BROAD-BAND SIGNALS SHOULD BE USED WHEN LOCALIZATION IS NOT POSSIBLE.

4.1.7 CANCELLATION

- FOR TIME-CRITICAL WARNINGS, THE ALERTING SIGNAL SHOULD BE FOLLOWED BY CONTINUED REPETITIONS OF THE APPROPRIATE VOICE ALERT UNTIL IT IS CANCELLED OR THE PROBLEM IS CORRECTED

- FOR WARNING LEVEL ALERTS, THE ALERTING SIGNAL SHOULD CONTINUE UNTIL THE PILOT MANUALLY CANCELS IT OR INITIATES THE OPTIONAL VOICE MESSAGE

- FOR CAUTION LEVEL ALERTS, THE SIGNAL SHOULD CONTINUE THROUGH ONE PRESENTATION AND CANCEL AUTOMATICALLY. IF, AFTER 10 SECONDS, THE PILOTS DO NOT INITIATE THE OPTIONAL VOICE MESSAGE OR OTHERWISE ACKNOWLEDGE THE SIGNAL, THE SIGNAL SHOULD BE REPEATED AT 10 SECOND INTERVALS UNTIL SOME ACKNOWLEDGMENT IS MADE

- FOR ADVISORY LEVEL ALERTS, THE ALERTING SIGNAL SHOULD BE PRESENTED ONCE AND THEN CANCEL AUTOMATICALLY

As soon as the operator perceives and interprets an alerting signal, it has served its purpose and hence, should be discontinued. In attempting to assure that the pilot does, in fact, perceive and correctly interpret the alerting signal, there are two opposing points to consider. The first is that the only certain method for verifying perception of a signal is to require the operator to take some positive action to signify detection. Requiring the operator to physically acknowledge the alerting signal is undesirable in time-critical or high visual workload situations because it forces the pilot to take action that does not contribute to expedient problem correction. The second point to consider is that it would be equally undesirable for a signal to continue after it was detected, since it can provide additional distraction and confusion in an emergency situation.

Van Cott and Kinkade (1972) recommend that signals be provided with a manual shut off capability, so that a signal will sound continuously until manually cancelled or some corrective action is taken. In a survey of industry representatives, Cooper (1977) found that most respondents preferred manual cancellation of the alerting signal. In the supplemental tests reported in Volume 1 a significant majority of the 25 commercial and industry flight test pilots, favored manual cancellation combined with automatic cancellation upon correction or removal of the problem. A very small minority preferred some type of attenuation, either automatic or manual. There was also a small group who preferred automatic cancellation after a fixed number of repetitions.

For time-critical warnings, it would be extremely undesirable to require the pilot to acknowledge the alerting signal prior to initiating the corrective action. Since voice should always be used as an action signal for time-critical warnings, it will only be necessary to present the attention-getting sound once, followed by the voice message. The combination of the intermittent warning sound and the voice message (repeated as necessary) should assure pilot recognition of an emergency situation. The primary rationale for only one repetition of the alerting signal in time-critical situations is that the need for immediate action obviates the requirement for expeditious presentation of the action signal (in this case, a voice message).

Since most warning level alerts do not require unconditionally immediate action, they all should not be treated with the same sense of urgency. In general, time-critical warnings deal with flight management (e.g., control of the aircraft) while the remainder of warnings address system management (e.g., APU fire). Emergency system management situations such as engine fires require immediate awareness and action, but should not in any way jeapordize safe flight management. For this reason, the flight crew should be made aware of these failures immediately and acknowledgment should be made by cancelling the alerting signal through manual initiation of the voice message, or by simply cancelling the sound. This will facilitate immediate awareness of the emergency situation while at the same time allow the pilot to perform more critical flight management tasks before dealing with a system management problem.

Caution alerts can be approached in the same manner as that for warnings, but with a somewhat lower level of urgency. Immediate awareness and subsequent action are required, but, as with non-time-critical warnings, not at the expense of safe flight management. If after 10 seconds, the pilot has not initiated the optional voice message, or otherwise acknowledged the alert by depressing the master visual switch-indicator, the aural alerting signal should be repeated. This should continue every 10 seconds until acknowledgment has been made.

Immediate crew awareness and action are not required for advisory level alerts. One iteration of the alerting signal should be provided, along with presentation of the failure information on the visual display. With this arrangement, the alerting signal is introduced and contingent upon crew workload level, the information can be attended to at any time thereafter. No crew acknowledgment should be required for advisory level alerts.

IN SUMMARY, THE MASTER AURAL ALERT FOR TIME-CRITIAL WARNINGS SHOULD BE FOLLOWED BY CONTINUED REPETITION OF THE APPROPRIATE VOICE ALERT UNTIL IT IS MANUALLY CANCELLED, OR CANCELS AUTOMATICALLY WHEN THE PROBLEM IS CORRECTED. FOR WARNING LEVEL ALERTS, THE ALERTING SIGNAL SHOULD CONTINUE UNTIL THE PILOT MANUALLY CANCELS IT, OR INITIATES THE OPTIONAL VOICE MESSAGE. FOR CAUTIONS, THE SIGNAL SHOULD CONTINUE THROUGH ONE ITERATION AND CANCEL AUTOMATICALLY. IF, AFTER APPROXIMATELY 10 SECONDS, THE PILOT DOES NOT INITIATE THE OPTIONAL VOICE MESSAGE OR OTHERWISE ACKNOWLEDGE THE SIGNAL, IT SHOULD BE REPEATED AT PREDETERMINED INTERVALS UNTIL SOME ACKNOWLEDGMENT IS MADE. FINALLY, ADVISORY LEVEL ALERTS SHOULD BE PRESENTED ONCE AND THEN CANCEL AUTOMATICALLY.

4.1.8 RECOMMENDED SOUND CHARACTERISTICS

This section provides a summary of the recommended sound characteristics for the master aural alert. As shown in Table 4.1.8-1, the sounds used for the three urgency levels should vary in frequency and duration. Although all sounds may come from the same frequency range, it is important that different frequencies within the range be used for each sound. The specific frequencies used should be dictated by the ambient noise environment within the flight deck.

The onset of the master aural alert should, in all cases, coincide with the presentation of the alert on the visual information display; and for warnings and cautions, the master aural and visual alerts should be activated simultaneously. The intensity and sound source location should be the same for all alert urgency levels, while the method used for alert cancellation should depend on the alert urgency level.

4.2 VOICE INFORMATION DISPLAY

This section contains guidelines for the design of the voice information component of an advanced alerting system. The factors that contribute to the effectiveness of voice alerts are addressed in the following pages.

4.2.1 PURPOSE

- VOICE MESSAGES SHOULD BE USED WHEN RAPID ACTION IS REQUIRED

- VOICE MESSAGES SHOULD BE USED, WHEN NECESSARY, TO TRANSFER WORK-LOAD FROM THE VISUAL TO THE AUDITORY CHANNEL

For most flight deck applications, an alerting system containing master visual and aural alerts along with a visual information display will provide an effective means for facilitating fault awareness and correction. In a recent study by Boucek, et al., (1980) eight airline qualified pilots were required to attend to failure situations and ATC communications while flying a

Table 4.1.8-1. Recommended Characteristics for Master Aural Alerting Sounds

Urgency level	Frequency	Intensity	Duration	Onset coordination with master visual alert and visual information display	Location of sound source	Cancellation
Warning (time-critical)	Two alternating frequencies in the 400- to 1,000-Hz range, separated by at least 300 Hz	5 to 10 dB above ambient	Approximately 0.75 sec	Simultaneous	Perceptual separation of at least 90 deg	Automatic, followed by voice alert
Warning	Same as time-critical warnings	5 to 10 dB above ambient	Continues until cancelled	Simultaneous	Perceptual separation of at least 90 deg	Manual, by depression of master visual switch or initiation of optional voice message
Caution	Two concurrent frequencies in the 300- to 1,500-Hz range	5 to 10 dB above ambient	1.2 to 2.0 sec	Simultaneous	Perceptual separation of at least 90 deg	Cancels automatically after one presentation; repeats at 8- to 12-sec intervals until some acknowledgment is made
Advisory	One frequency in the 300- to 1,200-Hz range	5 to 10 dB above ambient	0.6 to 0.8 sec	Simultaneous with presentation of information on visual information display (no master visual alert)	Perceptual separation of at least 90 deg	Automatic after one presentation

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simulated approach using head up display symbology. The alerting modes (formats) tested in this study included the following:

Tone-Visual	-	A master aural alert preceded by a visual readout on an alphanumeric display
Tone-Voice	-	A voice message preceded by a master aural alert
Voice-Only	-	A voice message with no precursor tone
Tone-Voice-Visual	-	A master aural alert presented concurrently with a visual readout, with the tone being followed by a voice message

Figure 4.2.1-1 illustrates the response times that were generated using the four alerting modes under high and low auditory workload conditions, which consisted of concurrent and non-concurrent presentations of ATC communications and fault messages. Although response times using the tone-visual mode were shorter than those recorded for the tone-voice-visual mode under high auditory workload, this difference was not statistically significant. The tone-visual mode resulted in fewer errors on the ATC recognition task (see Figure 4.2.1-2) when pilots were required to read back the essential elements of the ATC message, although fewer serious errors were made when the voice component was included (serious errors were defined as instances where the pilot did not hear the ATC communication or read it back incorrectly).

Inspection of Figures 4.2.1-1 and 4.2.1-2 reveals that, in low auditory workload conditions, the addition of a voice component to the alerting system resulted in shorter response times and fewer ATC recognition errors for both high and low visual workload conditions. Regarding ATC recognition errors, it should be remembered that time-critical warnings represent the most important activity the pilot should be engaged in at that time; so ATC message recognition should be subordinated to safe flight management until the alerting condition is corrected or accommodated.

In time-critical situations, the addition of a voice component will enhance alerting system effectiveness. In the present study response times were consistently shorter for time-critical warnings when voice alert messages were used. Voice alert messages are effective in reducing workload in high stress

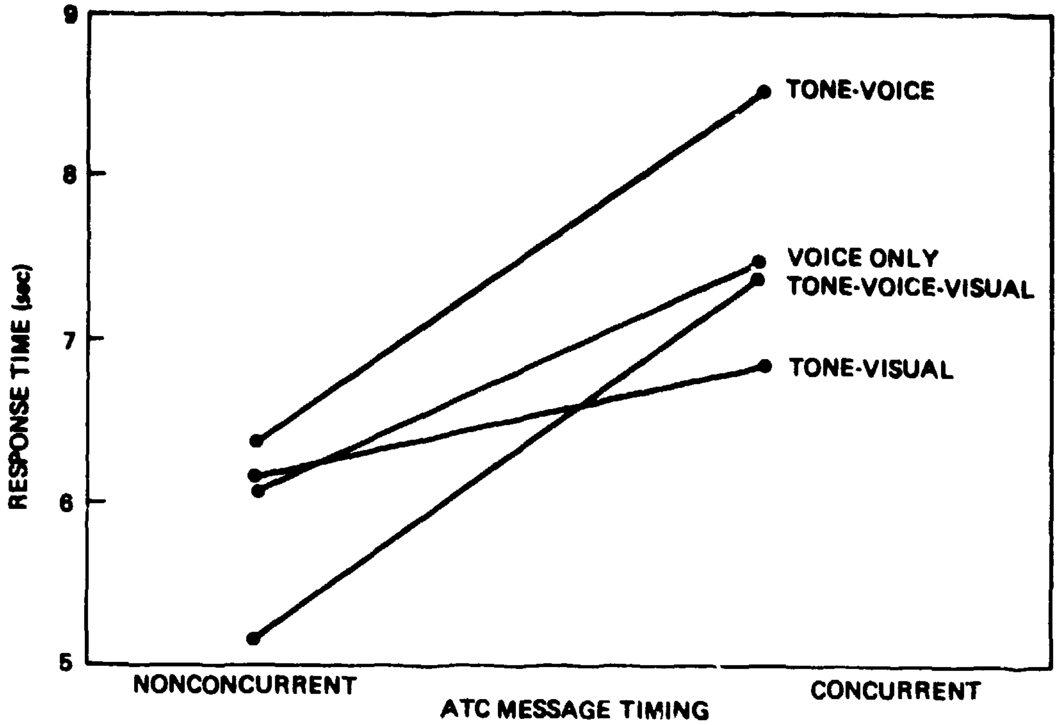


Figure 4.2.1-1. Response Time as a Function of Alerting Mode and ATC Message Timing; Combined Data for High- and Low-Turbulence Levels

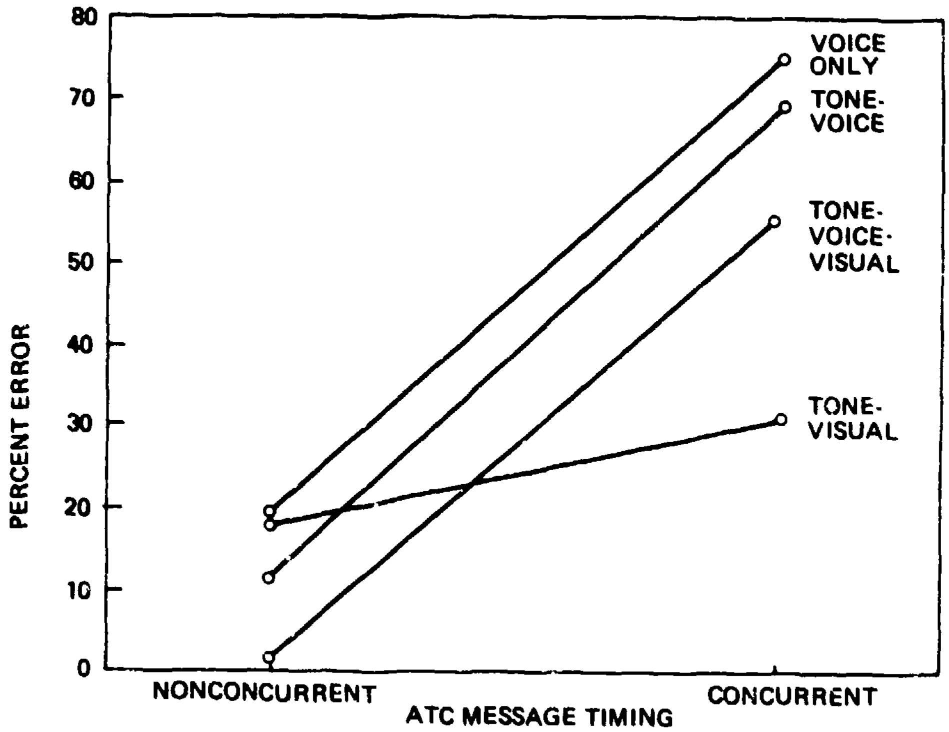


Figure 4.2.1-2. Percent Error on ATC R- ognition Task as Function of Alerting Mode and ATC Message Timing; Combined Data for High- and Low-Turbulence Levels

situations (Van Cott and Kinkade, 1972). They are also useful for conveying high priority messages because the operator can be provided with essential information in a short period of time, without altering scan patterns. This feature could be quite valuable in high visual workload conditions (e.g. final approach and final takeoff).

Van Cott and Kinkade (1972) provide a number of situations that lend themselves to the successful utilization of voice messages:

1) When flexibility is required
2) When the message source needs to be identified
3) When listeners are without special training in coded signals
4) When there is a necessity for rapid 2-way exchanges of information
5) The message deals with a future time requiring some preparation (i.e., the countdown preparation to firing a missile where total signals could be miscounted)
6) When situations of stress might cause the listener to "forget" the meaning of a code

Items 1, 3, and 6 are particularly relevant to the flight deck alerting system. The use of voice will enhance the effectiveness of the alerting system under some but not all conditions; therefore, verbal messages, when applied properly, will add to the effectiveness of the system. Pilots are required to remember the meanings of the various sounds that comprise the aural component of most conventional alerting systems. In present day commercial aircraft, there may be as many as 17 discrete aural alerts. This point was discussed earlier in the document and a recommendation was made regarding the number of discrete sounds (3) to be used. However, the high level of stress that may be induced by a multiple failure or time-critical situation may cause the pilot to temporarily "forget" the meaning of a particular sound. So, for extremely time-critical situations, voice messages may be considered a necessity while in situations of lower time priority, they may be used selectively to reduce workload. These recommendations are also supported by the work of other researchers who found that the use of voice alerts significantly reduce response times, especially during periods of high workload or stress (Pollack and Tecce, 1958; and, Kemmerling, Geiselhart, Thorburn, and Cronburg, 1969).

IN SUMMARY, VOICE MESSAGES SHOULD BE USED IN TIME-CRITICAL SITUATIONS AND WHEN REQUIRED TO TRANSFER WORKLOAD FROM THE VISUAL TO THE AUDITORY CHANNEL.

4.2.2 SPEECH GENERATING TECHNIQUE

- THE BEST SPEECH GENERATING TECHNIQUE AVAILABLE SHOULD BE USED TO PRESENT VOICE MESSAGES

- EMPIRICAL TESTING SHOULD BE USED TO ASSESS THE INTELLIGIBILITY OF THE VOICE MESSAGES USED

Presently, there are two approaches that can be taken in developing a voice information display. The first is to use voice modeling, where actual human speech recordings of alert messages are digitized and stored until needed. In contrast to this method, phoneme synthesis uses a digital voice synthesizer to generate messages by combining distinct phonemes. Each methodology has assets and liabilities. The voice modeling technique can provide a very close approximation to human speech. It is relatively easy to understand because the inherent properites of human speech are clearly represented (e.g. intonation, pitch, etc.). The problem with this technique is that a relatively large amount of computer storage is required. Present day techniques can store digitized speech using approximately 3200 bits for one second of stored speech, or 16K bits per word in read only memory (ROM). Phoneme synthesis, on the other hand, requires only about 100 bits per second of ROM. Presently, the major drawback of phoneme synthesis is that the voice reproduction is not realistic because many of the human voice characteristics contained in "real world" speech are not reproduced.

In surveys conducted to assess industry attitudes toward voice alerting systems, Douglas Aircraft found that a majority of domestic and Far Eastern airline representatives favored voice modeling over phoneme synthesis. In the Far Eastern survey, 84% of the pilots, engineers, and training specialists questioned preferred either male or female voice modeling over phoneme synthesis. This preference was stronger in the domestic survey, where 91% favored voice modeling.

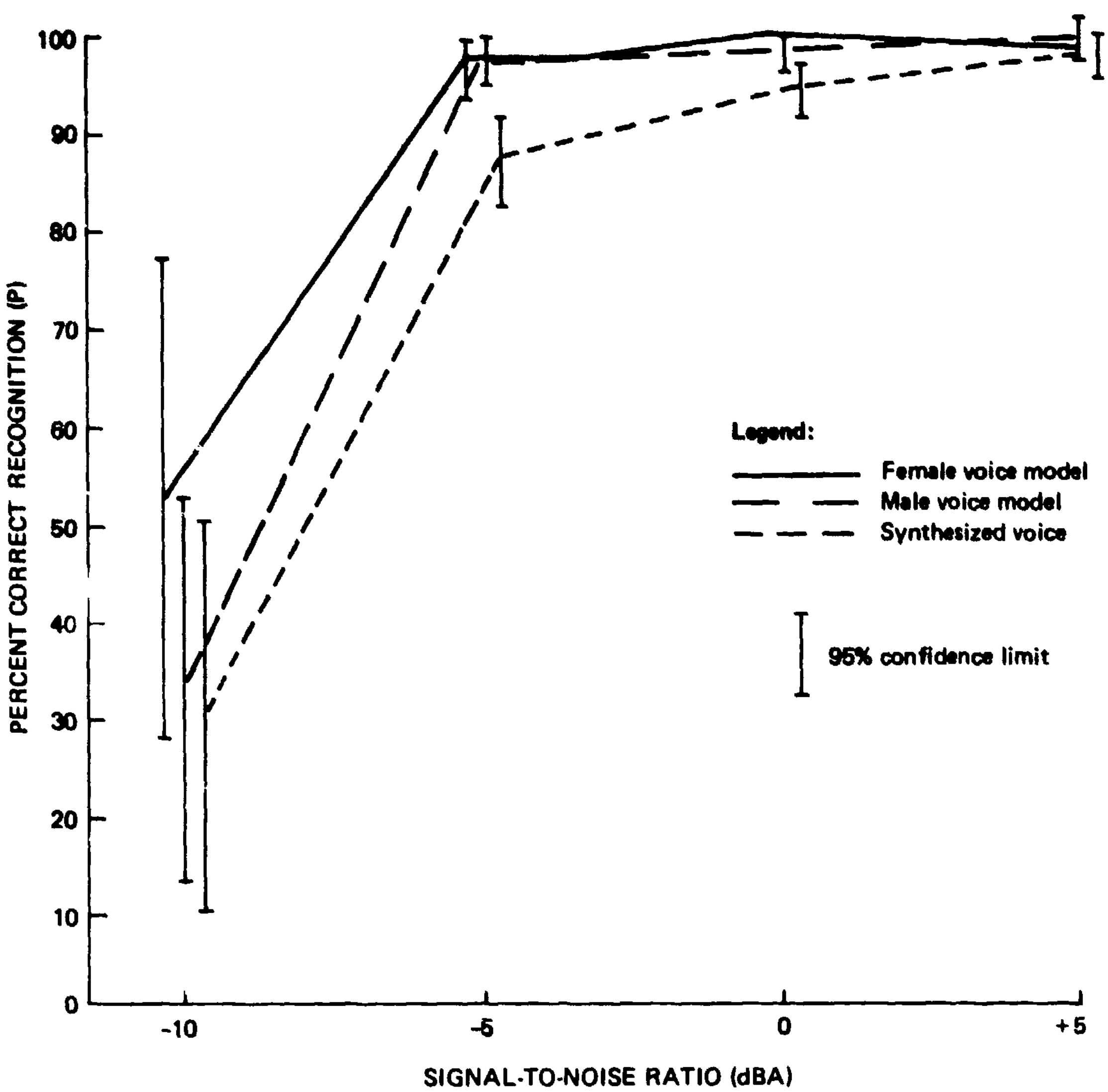


Figure 4.2.2-1. Intelligibility as Function of Voice Quality and Signal-to-Noise Ratio With Ambient Noise Level Held Constant of 76 dBA (Kerce, 1979)

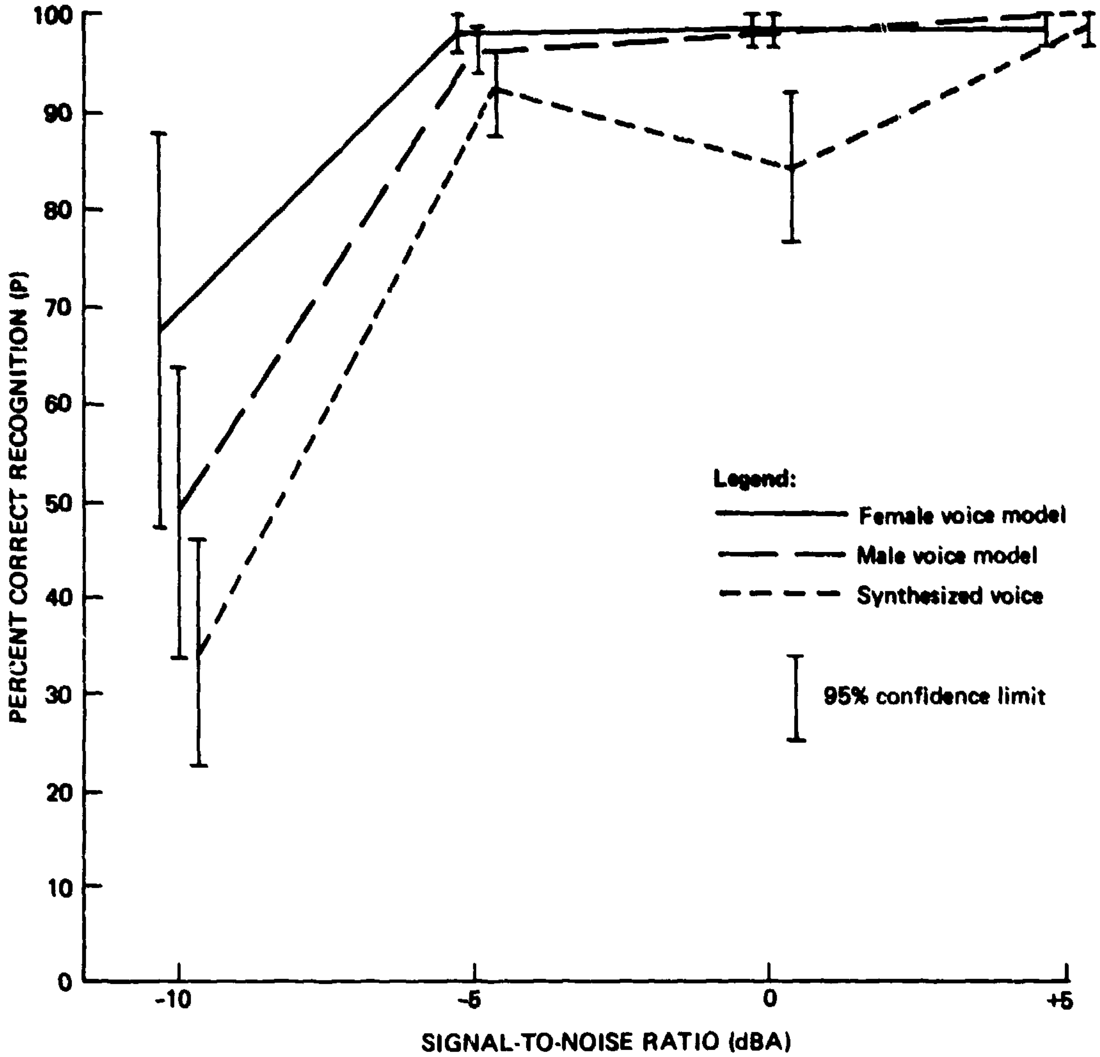


Figure 4.2.2-2. Intelligibility as Function of Voice Quality and Signal-to-Noise Ratio With Competing Speech Noise Background (Kerce, 1979)

Kerce (1979) conducted a study to compare phoneme synthesis and voice modeling. A total of 64 test subjects were instructed to record each alert message manually as it was presented to them through wall mounted speakers in a sound proof demonstration facility. Using a number of signal-to-noise ratios, she found that performance with the synthesized messages was substantially worse when signal-to-noise ratios were held at 0 and -5 dB. These results are illustrated in Figures 4.2.2-1 and 4.2.2-2. As can be seen in these figures, a signal-to-noise ratio of +5 dB does not produce a significant performance difference between voice modeling and phoneme synthesis, although overall performance was slightly better with voice modeling.

At present, the number of voice warnings that will be used as part of an advanced alerting system will be small enough so that the memory requirements associated with voice modeling should not be prohibitive. It is anticipated that continued development and improvement of the phoneme synthesis technique will make it a more viable alternative for incorporation into flight deck alerting systems.

IN SUMMARY, THE BEST SPEECH GENERATING TECHNIQUE AVAILABLE SHOULD BE USED TO PRESENT VOICE MESSAGES, AND EMPIRICAL TESTING SHOULD BE USED TO ASSESS INTELLIGIBILITY.

4.2.3 VOICE MODEL

- THE VOICE CHARACTERISTICS SHOULD BE HIGHLY DISTINCTIVE AND INTELLIGIBLE

- EMPIRICAL TESTING SHOULD BE USED FOR VOICE MODEL SELECTION

At present, the consensus among industry representatives is that voice modeling is superior to phoneme synthesis as a method of producing voice alerts. This finding is supported by the results of objective evaluations (Kerce, 1979). In the two surveys that Douglas Aircraft administered to the airlines, respondents were presented with voice messages generated by phoneme synthesis, and by male and female voice models. The results are shown in

Table 4.2.3-1. Voice Model Preferences of Domestic and Far Eastern Airline Representatives

• Question: Which voice would be most distinctive in a cockpit environment?

	Design options	Percent	Total	Pilot	Nonpilot
Domestic airlines	Male	8	7	6	1
	Female	83	72	62	10
	Synthesized	9	8	6	2
Far Eastern airlines	Male	26	20	15	5
	Female	58	44	37	7
	Synthesized	16	12	8	4

In the past, most operational personnel felt that a female voice would be best suited for the presentation of verbal alert messages because the presence of females in the flight deck as well as the ATC centers was relatively rare, thus making it quite distinctive for alerting system application. However, as more and more females become active in air transport (both as pilots and ATC personnel) this advantage will disappear.

Kerce (1979) conducted two studies that compared the relative intelligibility of voice models. The results indicated that the female voice was more intelligible than the male voice and that both were more intelligible than a synthetic voice.

Kerce went on to say that a female voice will generally be more intelligible than a male voice when both have been optimized through careful selection and recording. However, voice characteristic selection should be based on empirical testing or detailed spectral analysis of the voice model and ambient noise environment to assure that the voice characteristics chosen are distinctive and intelligible. Empirical testing can be carried out using standardized tests of speech intelligibility, in conjunction with noise tracks of background sounds that represent the ambient noise environment of the particular aircraft. Two such tests are the Modified Rhyme Test (MRT) and the

Harvard Phonetically Balanced (PB) Word List. The MRT consists of 50 six-word sets, each one comprised of rhyming monosyllabic words of the form CVC or CVVC where C is any consonant and V is any vowel. The PB lists consist of monosyllabic words in which the frequencies of occurrence of various fundamental speech sounds are proportional to their frequency of occurrence in everyday speech. These tests can be used to select the most effective voice models when a large number of models are available. When making the final selection of a voice model from a small number of candidates, laboratory tests should employ a representative set of voice messages and the signal-to-noise ratio should be systematically varied through an operationally relevant range.

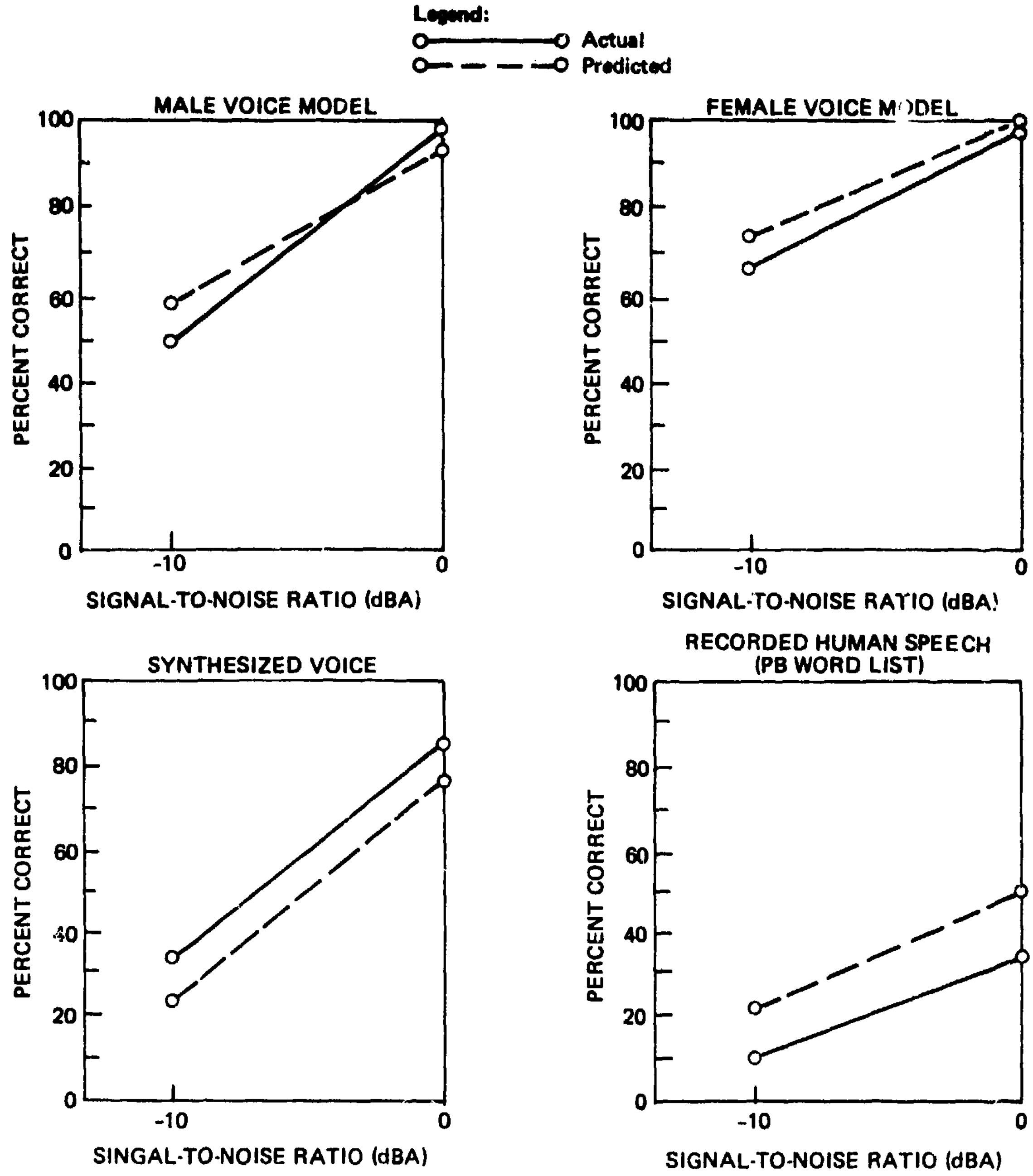
Schedule and budget constraints may prohibit the use of comprehensive laboratory testing of a large number of voice model candidates. The Articulation Index (AI) represents an alternative to this method. This technique involves the comparative analysis of time-averaged spectrograms obtained from calibrated records of synthesized speech, with ambient noise spectograms based on available acoustic data that represent the ambient flight deck environment. The difference between signal and noise amplitudes in selected frequency bands are combined according to an empirically derived weighting scheme which yields an index value. This index value may then be converted to a prediction (in percent) of successful intelligibility. The AI was used successfully in a study by Kerce (1979) where actual intelligibility scores were compared to those that were estimated using this method. The results are illustrated in Figure 4.2.3-1.

IN SUMMARY, THE VOICE CHARACTERISTICS USED TO GENERATE VOICE ALERTS SHOULD BE DISTINCTIVE AND INTELLIGIBLE. SELECTION OF THE VOICE CHARACTERISTICS SHOULD BE DONE THROUGH EMPIRICAL TESTING TO ENSURE THE INTELLIGIBILITY OF THE VOICE COMPONENT OF THE ALERTING SYSTEM.

4.2.4 VOICE INFLECTION

- VOICE MESSAGES SHOULD BE PRESENTED USING A MONOTONE INFLECTION

Very little work has been done to determine the relative effectiveness of various inflection patterns. To the authors knowledge, no objective



Note: Background noise includes a conflicting speech source.

Figure 4.2.3-1. Comparison of Actual Intelligibility Scores and Estimated Values Based on Articulation Index (Kerce, 1979) performance studies have been done and very limited subjective data have been collected on voice inflection. As part of the Douglas Aircraft survey mentioned earlier, airline representatives were asked which type of voice inflection should be used for voice messages. About half of those questioned felt that the inflection should vary with the urgency of the alert, while the remainder preferred either a monotone, conversational or urgent intonation. Varying the voice inflection with the alert priority level would require the incorporation of various degrees of urgency into the voice inflection. In developing these guidelines, it was felt that an urgent sounding message for time-critical warnings might contribute additional stress into an already tense situation. In addition, less than seven percent of those questioned actually felt that an urgent voice inflection would be appropriate. The priority coding provided by the three distinct master aural alerts was seen as a more effective means for presenting aural information on alert urgency level. Douglas Aircraft chose a monotone inflection for use in the DC-9-80 voice warning system; this was received positively by both customers and flight operations personnel. One potential advantage of a monotone inflection is that it may take less time to annunciate the various phonemes when compared to a conversational intonation because of the natural pauses that are characteristic of conversational speech. Since voice alerts should be used primarily in time-critical situations where expeditious presentation of the essential message elements is important, the use of a monotone inflection for a voice warning system is appropriate.

TO SUMMARIZE, THE VOICE INFORMATION DISPLAY SHOULD USE A MONOTONE INFLECTION FOR ALL VERBAL ALERTS. THIS WILL ALLOW THE MASTER AURAL ALERT TO FUNCTION AS THE MAIN PRIORITY CODING DEVICE FOR AURAL MESSAGES.

4.2.5 INTENSITY

- VOICE MESSAGES SHOULD BE PRESENTED AT AN INTENSITY OF 8 ± 3 ABOVE THE AMBIENT NOISE LEVEL

- AUTOMATIC GAIN CONTROL SHOULD BE PROVIDED TO MAINTAIN THIS SIGNAL-TO-NOISE RATIO

The same guidelines provided for the intensity of the master aural alert should be applied to the voice information display.

4.2.6 LOCATION OF SOUND SOURCE

- DICHOTIC METHODS OF PRESENTATION SHOULD BE USED FOR VOICE MESSAGES

- IF A SINGLE EARPHONE IS USED, IT SHOULD BE WORN ON THE DOMINANT EAR

- THE MESSAGES SHOULD BE PERCEPTUALLY SEPARATED FROM COMPETING SPEECH SOURCES BY AT LEAST 90 DEGREES

The guidelines provided for master aural alert source location should also be applied to the voice information display.

4.2.7 ONSET COORDINATION

- THE "OFF" TIME BETWEEN THE ALERTING SIGNAL AND VOICE MESSAGE SHOULD BE AT LEAST 0.15 SECOND AND NOT MORE THAN 0.5 SECOND

- FOR TIME-CRITICAL WARNINGS, THE ALERTING SIGNAL AND ESSENTIAL ELEMENTS OF THE VOICE MESSAGE SHOULD BE CONVEYED IN 2.5 SECONDS OR LESS

For background information on these guidelines, refer to Section 4.1.5: SOUND DURATION AND TONE-MESSAGE ONSET COORDINATION.

4.2.8 MESSAGE CONTENT, FORMAT, AND SYNTAX

- FOR TIME-CRITICAL WARNINGS, THE VOICE ALERTS SHOULD PROVIDE GUIDANCE INFORMATION

- FOR THE REMAINDER OF WARNING AND CAUTION ALERTS, THE VOICE MESSAGES SHOULD STATE THE NATURE AND LOCATION OF THE PROBLEM

- VOICE MESSAGES SHOULD BE CONSTRUCTED OF SHORT PHRASES THAT CLEARLY IDENTIFY THE PROBLEM OR ACTION TO BE TAKEN

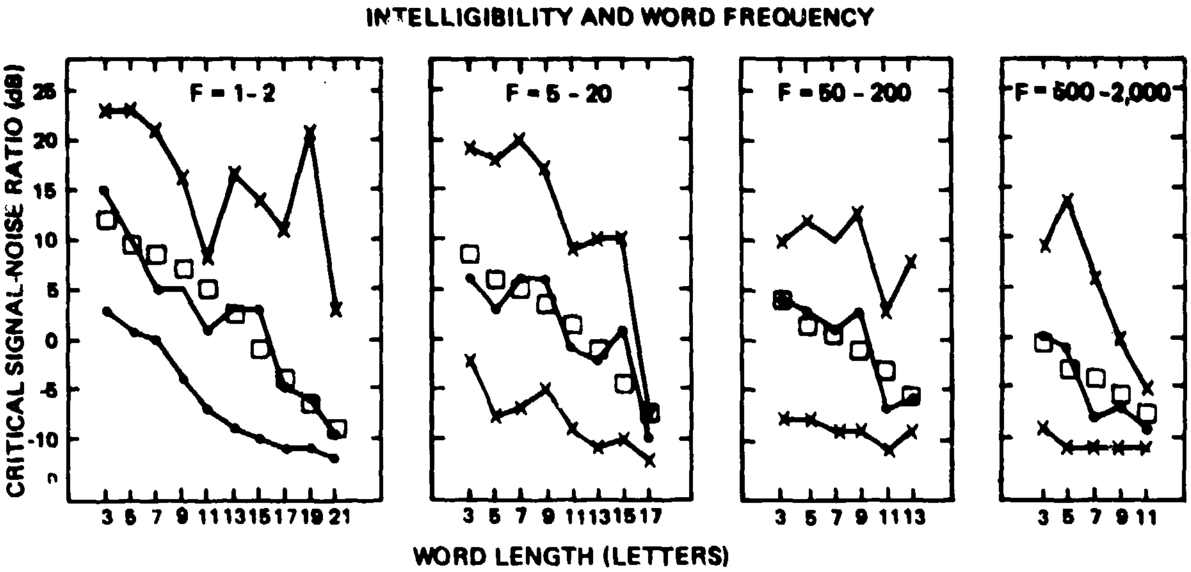
- VOICE MESSAGES FOR TIME-CRITICAL WARNINGS SHOULD GENERALLY CONTAIN 2 ELEMENTS (ACTION AND DIRECTION) WHILE VOICE MESSAGES FOR OTHER ALERTS SHOULD GENERALLY CONTAIN 3 ELEMENTS (GENERAL HEADING; SUBSYSTEM OR LOCATION; AND NATURE OF THE EMERGENCY) THE STANDARDIZED STRUCTURING OF THESE ELEMENTS, WHILE DESIRABLE, SHOULD BE SUBORDINATED TO A CLEAR STATEMENT OF THE PROBLEM OR ACTION TO BE TAKEN

4.2.8.1 Message Content (Status/Guidance). Very limited data exists on the relative merits of providing status or guidance information to the crew when a fault condition exists. Ideally, the pilot should be able to absorb all available data pertaining to a failure condition, assimilate it and decide on the best course of action. There may be instances, however, where the criticality of the situation and severe time constraints will not permit this mental data processing to occur. It should be understood that a situation generally becomes critical when the maximum time available for action approaches the minimum time required for safe removal or accommodation of the failure condition. If the time available for information processing decreases to the point where an effective decision cannot be made, the pilot will require assistance in the form of automated information processing, or response automation. Unfortunately, conventional sensor capabilities do not allow the pilot sufficient time to process information in all cases where impending catastrophies exist. For these cases, the system designer has two options. If there is only one possible corrective action that can be taken in a particular situation, that action can be automated and thus, taken out of the pilots' hands. The other option is to let the pilot know what the action is and advise him to carry it out immediately. The determination of which is most appropriate (status, guidance or automation) should be made based on the previously discussed relationship between maximum time available and minimum response time requirements.

In the present study pilots were provided with both status and guidance information for time-critical alerts. In addition to the significant performance benefits associated with the use of guidance, 13 of the 14 pilots who participated preferred guidance over status information for the display of time-critical alert messages. Guidance information should be displayed only when it is clear that failure to take a specific corrective action immediately will result in a hazardous condition that will severely jeopardize flight safety.

IN SUMMARY, TIME-CRITICAL WARNING MESSAGES SHOULD GUIDE THE CREW IN TAKING THE APPROPRIATE CORRECTIVE ACTION. FOR THE REMAINDER OF WARNING AND CAUTION LEVEL ALERTS, THE VOICE MESSAGES SHOULD PROVIDE A DECLARATIVE STATEMENT OF THE NATURE AND LOCATION OF THE PROBLEM.

4.2.8.2 Message Format. There are a number of formatting characteristics that will impact the intelligibility of and reaction to voice alert messages. The frequency of use and length of a word will significantly effect its intelligibility (Howes, 1957). Howes also found that observers experience with a word as a distinctive unit appears to be a primary determinant of its intelligibility. Figure 4.2.8.2-1 shows the relationship between word frequency (of use) and intelligibility at various signal-to-noise ratios. As can be seen, both word length and frequency have a significant effect on intelligibility. Thus, it is strongly recommended that the vocabulary used for voice messages be representative of standard flight deck nomenclature and conventional pilot usage. Simpson (1976) states that highly discriminable keywords or phrases should be used such that the messages are easily understood with as little demand on pilot workload and attention as possible. Several studies have been conducted to determine whether additional syllables or words, or a sentence context would increase intelligibility. The results of these studies indicate that linguistic redundancy facilitates the comprehension of aural messages and tends to reduce response times. Hart and Simpson (1976) found that aural messages presented in a sentence format were more intelligible than two-word messages and required fewer repetitions for comprehension. Simpson (1976) presented synthesized mono- and polysyllabic keywords and sentence-length messages to airline pilots under several signal-to-noise ratios. She found that sentence messages consisting of monosyllabic keywords were responded to more accurately, over a wider range of signal-to-noise ratios (see Figure 4.2.8.2-2). Polysyllabic words did not



Note: As in figure 1, circles, crosses, and plusses indicate data for P = 0.5, 0.9, and 0.1, respectively, and n represents the number of words pooled at each length. Large squares present the theoretical values calculated from the word-frequency effect.

Figure 4.2.8.2-1. Empirical Functions Relating Critical Speech-to-Noise Ratios to Word Length at Four Different Ranges of Word Frequency (Howes, 1957)

show this tendency; scores for both sentences and isolated words were approximately the same (see Figure 4.2.8.2-3). These data seem to indicate that pilots need some "warmup" or alert to provide time to receive the verbal message rapidly and accurately; the monosyllabic words did not give the pilot enough time to prepare for message reception. Response time results for these data are shown in Figure 4.2.8.2-4.

Using low information emitting words to precede the critical message elements of a voice message serves the purpose of demanding crew attention. It does not, however, provide any information on alert urgency level. Another problem associated with this approach is that the potential for mutual interference between different sources of voice communications is increased as more words are added to the voice warning vocabulary. The use of brief keywords in phrases allows the system designer to develop the structure and content of aural messages such that they will be similar to the messages presented on the visual information display. In the operational flight deck environment, the frequency of alert message annunciations will be far lower than that for a typical simulation study. It may be that the attention getting value of

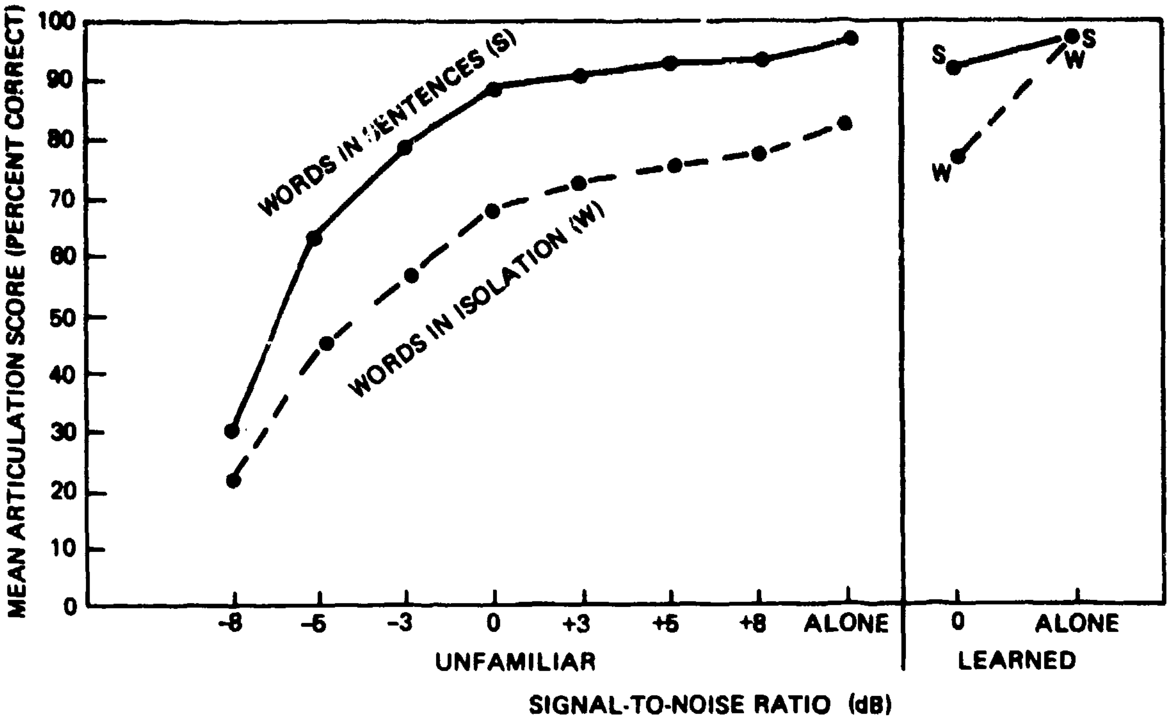


Figure 4.2.8.2-2. Monosyllabic Words in Isolation and in Sentence Context (Simpson, 1976)

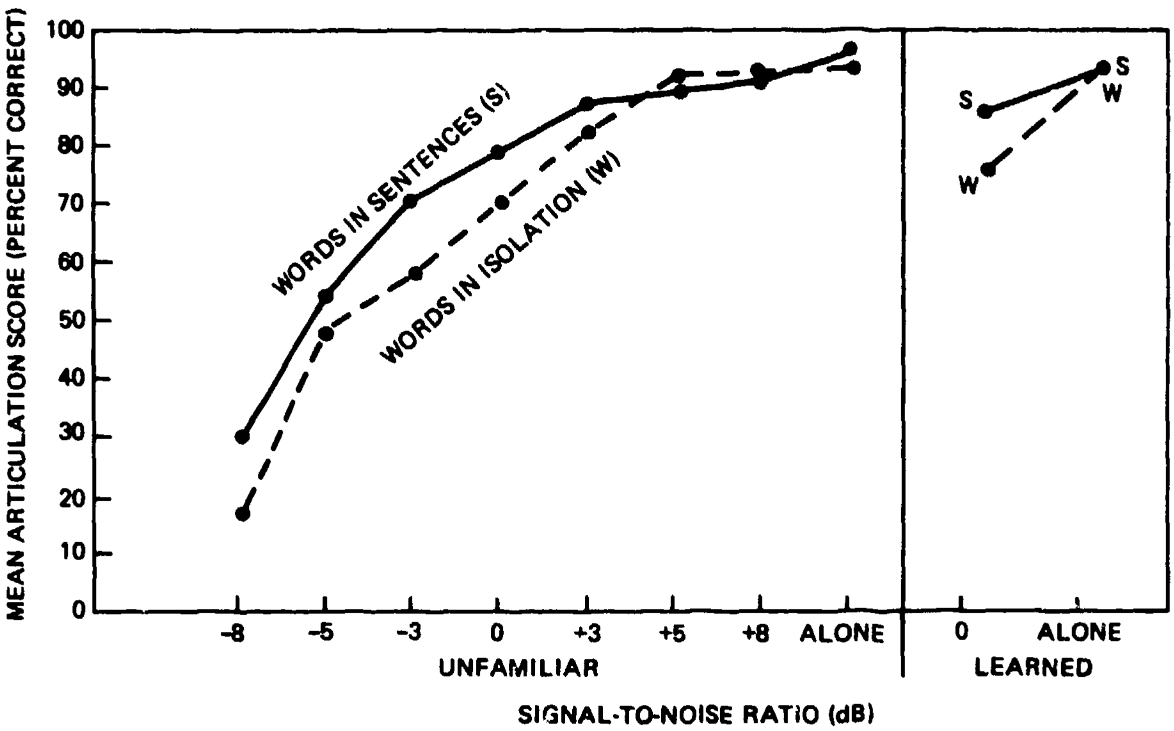


Figure 4.2.8.2-3. Polysyllabic Words in Isolation and in Sentence Context (Simpson, 1976)

Note (both figures): Mean articulation scores for keywords in synthesized speech cockpit warnin heard in background of continuous weather broadcast at seven signal-to-noise ratios and in silence. Eight airline pilots per group for unfamiliar messages; four airline pilots per group for the same messages learned before testing.

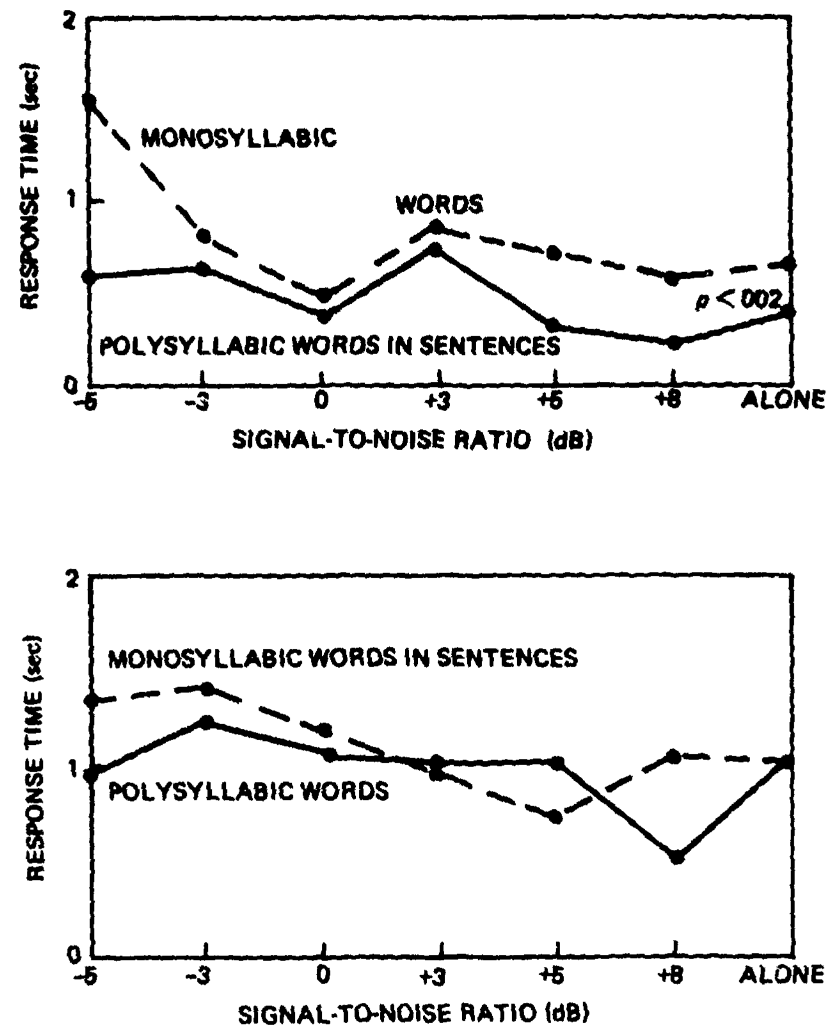


Figure 4.2.8.2-4. Response Times for Two Groups of Pilots and Messages of Different Contextual Makeup (Simpson, 1976)

precursor sounds will increase as the frequency of alerts decreases, primarily because of their unique noise-penetrating characteristics.

IN SUMMARY, VOICE MESSAGES SHOULD BE CONSTRUCTED OF SHORT PHRASES THAT CLEARLY IDENTIFY THE PROBLEM OR ACTION TO BE TAKEN.

4.2.8.3 Message Syntax. In determining an appropriate syntax to use in structuring voice alerts, the elements of the message should be arranged so as to clearly state the problem and/or action to be taken. In presenting situation (or status) alerts, three elements should be included in each message: The general heading; the specific subsystem or location; and the nature of the emergency. Of course, when no subsystem or location cues are appropriate (e.g., APU FIRE), this element should be omitted. Ideally, when these three elements are included, they should be arranged in a standardized order, as recommended by MIL-STD-411D (1974):

GENERAL HEADING	SPECIFIC SUBSYSTEM OR LOCATION	NATURE OF EMERGENCY
GENERATOR	NUMBER 2	OFF

This order was preferred by a majority of the twenty-five pilots surveyed on alert message syntax during the supplemental tests reported in Volume 1 of the document. Although a majority of the pilots (80%) preferred the format recommended by MIL-STD-411D, they could also foresee instances where it would be inappropriate (e.g., LEFT WINDSHIELD ANTI-ICE INOPERATIVE). Since the primary objective is to state the nature and location of the problem clearly, the actual syntax used should be standardized only to the extent that this goal is consistently met.

This same principle applies to voice messages that provide guidance information. A standardized message syntax, although desirable, must be subordinated to a clear statement of the problem and the action to be taken. In general, it is recommended that time-critical messages contain two primary elements (action and direction) and be structured as follows:

ACTION	DIRECTION
PULL	UP

There may be cases where a brief description of the problem or nature of the emergency is required. In such cases, this description should be limited to one or two words and, when possible, it should precede the action elements:

NATURE OF EMERGENCY	ACTION	DIRECTION
COLLISION	CLIMB	RIGHT

Again, these guidelines should be used only as an aid, not a rule, in structuring voice messages.

IN SUMMARY, VOICE MESSAGES FOR TIME-CRITICAL WARNINGS SHOULD CONTAIN TWO ELEMENTS (ACTION AND DIRECTION) WHILE OTHER WARNING AND CAUTION LEVEL ALERT MESSAGES SHOULD GENERALLY CONTAIN THREE ELEMENTS (GENERAL HEADING, SUBSYSTEM/LOCATION, AND NATURE OF EMERGENCY). THE STANDARDIZED STRUCTURING OF THESE ELEMENTS, WHILE DESIRABLE, SHOULD BE SUBORDINATED TO A CLEAR STATEMENT OF THE PROBLEM AND ACTION TO BE TAKEN.

4.2.9 ACCOMMODATION OF MULTIPLE VOICE ALERTS

- WHERE FEASIBLE, A PRIORITIZATION SCHEME SHOULD BE INCORPORATED TO ENABLE THE ALERTING SYSTEM TO PRESENT MULTIPLE VOICE MESSAGES IN ORDER OF CRITICALITY
- IN THE ABSENCE OF A SUITABLE PRIORITIZATION SCHEME, MULTIPLE VERBAL ALERTS SHOULD BE ACCOMMODATED AS FOLLOWS:
  - TIME-CRITICAL WARNINGS SHOULD ALWAYS BE ANNUNCIATED BEFORE ALERTS FROM OTHER URGENCY LEVELS
  - TIME-CRITICAL WARNINGS SHOULD BE PRESENTED IN CHRONOLOGICAL ORDER WITH ONE FULL CYCLE OF EACH MESSAGE BEING ANNUNCIATED

    - IN A MULTIPLE FAILURE SITUATION FOR OTHER WARNING AND CAUTION LEVEL ALERTS, THE GROSS ALERT PRIORITY LEVELS (WARNING, CAUTION) SHOULD BE USED AS THE INITIAL CRITERION IN DETERMINING WHICH VOICE MESSAGE SHOULD BE ANNUNCIATED

- THE VOICE MESSAGE "MULTIPLE ALERTS" SHOULD BE ANNUNCIATED WHEN

    - TWO OR MORE WARNINGS OCCUR SIMULTANEOUSLY
    - TWO OR MORE CAUTIONS OCCUR SIMULTANEOUSLY AND NO HIGHER PRIORITY ALERTS ARE PRESENT

The incorporation of voice messages into the alerting system brings with it two unique problems. The first involves the potential for confusion due to the concurrent onset of voice alerts and other voice communications in the flight deck. A second area of concern is the methodology to be used in accommodating multiple voice alerts. Unfortunately, very limited data exists to aid system designers in handling this situation.

As stated previously, the objective of voice messages is to provide a clear statement of the problem or action to be taken in as brief a period of time as possible. Obviously, if one voice message is aborted by the onset of a second message, or if one is superimposed over another, one or both of the messages may be missed and the crew will have only a fragmented understanding of the situation.

Using manual initiation for most warning and caution level voice messages will serve as a means to restrict the uncontrolled onset of voice alerts. This is not appropriate, however, for time-critical warnings. Since time-critical warnings take priority over all other alert urgency levels, it is imperative that, when two or more occur, they be conveyed to the listener quickly and efficiently. The most effective way to accomplish this would be to develop a prioritization scheme that would automatically order the onset of voice messages according to a pre-programmed sequencing logic. In this way, the voice message corresponding to the most critical alert would be annunciated first; and the remainder would follow relative to their predetermined priority level. In the absence of a suitable prioritization scheme, another method will be required. Two options are presently available. The first involves simply providing one complete annunciation of each alert in order of occurrence. The second would provide for the continued annunciation of the first alert message until the situation is corrected; followed by annunciation of the second message until it is corrected, and so on. The second option yields to the inherent human limitation of being capable of addressing only one emergency at a time. It also contains a severe limitation in that it does not allow the pilot to perform a situation assessment. Although time is extremely limited, it may be that awareness of the second or third failure will impact how the first is handled. For example, if the message "PULL UP", is followed by annunciation of the message "COLLISION - DIVE RIGHT" the pilot will need to assimilate these two pieces of guidance information to determine the correct action - CLIMB RIGHT. SO, IN THE ABSENCE OF A SUITABLE PRIORITIZATION SYSTEM, TIME-CRITICAL WARNINGS SHOULD ALWAYS BE ANNUNCIATED BEFORE MESSAGES FROM OTHER URGENCY LEVELS. MULTIPLE TIME-CRITICAL WARNINGS SHOULD BE PRESENTED IN CHRONOLOGICAL ORDER WITH ONE FULL CYCLE OF EACH MESSAGE BEING ANNUNCIATED UNTIL THEY ARE EITHER CANCELLED MANUALLY OR AUTOMATICALLY WHEN THE PROBLEMS ARE CORRECTED.

Because manual initiation is required for other warning and caution level alerts, accommodation of multiple alerts is somewhat easier. In the present study, a number of pilots were asked to rate several methodologies available for sequencing multiple verbal alerts. A number of pilots (32%) stated that a prioritization scheme should be employed that would allow annunciation of only the most severe problem. A majority (56%) favored annunciation of the message "MULTIPLE ALERTS" which would require the crew to direct their attention to the visual information display for specific fault information. The "MULTPLE ALERTS" approach lends itself well to a system that requires manual initiation of voice alerts. IN A MULTIPLE FAILURE SITUATION INVOLVING SEVERAL WARNING AND CAUTION LEVEL ALERTS, THE GROSS ALERT PRIORITY LEVELS (WARNING OR CAUTION) SHOULD BE USED AS THE INITIAL CRITERION TO DETERMINE WHICH VOICE MESSAGE SHOULD BE ANNUNCIATED. IF MORE THAN ONE FAILURE FROM THE HIGHEST PRIORITY CATEGORY OCCURS, THE MESSAGE "MULTIPLE ALERTS" SHOULD BE ANNUNCIATED.

4.2.10 MESSAGE CANCELLATION

- MANUAL CANCELLATION SHOULD BE PROVIDED FOR TIME-CRITICAL WARNINGS

- VOICE MESSAGES MANUALLY ACTIVATED FOR OTHER WARNING AND CAUTION LEVEL ALERTS SHOULD CANCEL AUTOMATICALLY AFTER ONE PRESENTATION. SUBSEQUENT ITERATIONS OF THE VOICE MESSAGE (EACH MANUALLY ACTIVATED) SHOULD ALSO CANCEL AUTOMATICALLY AFT[illegible]E ANNUNCIATION

- ALL VOICE MESSAGES SHOULD CANCEL AUTOMATICALLY UPON ELIMINATION OF THE ALERTING SITUATION

Surveys of airframe manufacturers, pilots and other airline representatives indicate a clear preference for a manual cancellation capability for voice alerts (Cooper, 1977; the present study). The primary reason for this strong preference is that, as with the master aural alert, once the crew hears and understands the voice alert, it has served its purpose and hence is no longer necessary. While a manual cancellation capability should be made available for time-critical warnings as well as other warnings and caution level alerts, it is recommended that for time-critical warnings, corrective action be used to silence the voice message because of the time limitation involved.

The use of voice messages for other warnings and caution level alerts should be dependent on the level of visual task loading. This is appropriate because safe flight management will always take precedence over system management. By making voice messages elective, the pilot is given the option of referencing the visual information display and avoiding the possibility of missing ATC communications; or, in high visual workload situations, hearing one annunciation of the voice message and maintaining a vigil over the outside visual scene. Only one presentation is recommended because the pilot will, in all likelihood, be ready to listen to the message at the time he chooses to depress the voice initiation switch. This will also minimize the possibility of mutual interference between voice alert messages and other ATC and intra-cockpit communications. Since manual initiation of the voice message for other warning and caution level alerts produces only one presentation of a fault message, cancellation is automatic by virtue of system design.

IN SUMMARY, MANUAL CANCELLATION SHOULD BE PROVIDED FOR TIME-CRITICAL WARNINGS, ALTHOUGH CORRECTIVE ACTION WILL FREQUENTLY BE USED TO SILENCE THE VOICE MESSAGE. VOICE MESSAGES MANUALLY ACTIVIATED FOR OTHER WARNING AND CAUTION LEVEL ALERTS SHOULD CANCEL AUTOMATICALLY AFTER ONE ANNUNCIATION. SUBSEQUENT ITERATIONS OF THE VOICE MESSAGE (EACH MANUALLY ACTIVATED) SHOULD ALSO CANCEL AUTOMATICALLY AFTER ONE PRESENTATION. AS WITH THE MASTER AURAL ALERT, ALL MESSAGES SHOULD CANCEL AUTOMATICALLY UPON ELIMINATION OF THE ALERTING CONDITION(S).

5.0 CREW OPTION AND CONTROL

There are a number of alerting system features that do not fall clearly into the domain of the components previously mentioned. These features serve to facilitate effective crew-system interaction or provide preprogrammed logic to reduce pilot workload. This section contains guidelines for the design and implementation of the alerting system interactive and information processing functions.

5.1 PRIORITIZATION

- A PRIORITIZATION SCHEME SHOULD BE INCORPORATED INTO THE ALERTING SYSTEM

- THE PRIORITIZATION SYSTEM SHOULD BE FLIGHT PHASE ADAPTIVE

- FEASIBILITY SHOULD BE DEMONSTRATED IN TERMS OF
  - PRIORITIZATION DATA BASE
  - AIRCRAFT CONFIGURATION VARIATIONS AND EXPECTATIONS

- AS A MINIMUM, ALERTS SHOULD BE PRIORITIZED BY URGENCY LEVEL (WARNING, CAUTION AND ADVISORY)

As aircraft systems become more sophisticated, flight deck information displays will be required to provide the crew with information in an accurate and expedient manner. This is particulary important in the case of aircraft alerting systems. When a multiple failure situation occurs and time is limited, the pilot must be able to obtain critical information quickly and without causing undue disruption of the flight task. Since an advanced alerting system will include a color display, it will be possible to employ color as a means of categorizing alerts into distinct urgency levels. Table 5.1-1 shows how color is presently used in a number of commercial aircraft (ARP-450D, 1980). Some researchers have suggested that the gross categorization of alert messages into three main urgency levels (warning, caution, and advisory) is not effective enough for conveying essential information to the flight crew (Veitengruber, Boucek, and Smith, 1977). It may be that prioritization within

Table 5.1-1. Application of Color to Alert Urgency Levels

Urgency level	Color	Definition
Warning	Red	Emergency operational or aircraft system conditions that require immediate compensatory or corrective action by the crew
Caution	Amber	Abnormal operational or aircraft system conditions that require immediate crew awareness and subsequent corrective or compensatory crew action
Advisory	Color other than red or amber	Operational or aircraft system conditions that require crew awareness and may require crew action

these three categories would convey valuable information to the pilots which could be used as a decision aid in selecting the most critical problem to be addressed. This prioritization strategy would be used primarily on the visual information display. Described simply, the messages in each alert level would be automatically prioritized by the system so that when a particular fault occurred, the message would appear on the display in its appropriate position relative to the other messages of the same category already present. With this approach the most important or time-critical message would always be at the top of the displayed alerts in its category, regardless of time of occurrence. In this manner, the alerting system could aid the crew in the assessment of aircraft status as well as the selection of conditions requiring expedient action.

A majority of the pilots surveyed by Veitengruber, et al., (1977) felt that alert effectiveness could be improved by prioritization. They foresaw no serious problems as long as it was done sensibly and the pilot was informed of alerts awaiting recognition. The pilots indicated that alerts should be grouped into three or four categories, where each category denotes a critical level; alerts within each category should also be prioritized. Also, the capability for an alert to transition from one category to another as a function of flight phase was proposed for incorporation into the prioritization system. Although the majority of pilots favored prioritization, they could not agree upon criteria for making this capability operational.

Very litle analytical or empirical work has been performed on how alerts can be prioritized as a function of flight phase. Veitengruber, et al., (1977) used numerical and non-numerical methods to develop alerting categories, and to prioritize alerts within these categories as a function of flight phase. The major outputs of this work were a logic tree diagram for prioritizing alerting functions (see Figure 5.1-1) and an example application of prioritization schemes for warning, caution and advisory alerts (see Tables 5.1-2 to 4). Veitengruber, et al., (1977) concluded that more work is necessary to develop useful prioritization schemes. They also concluded that since better agreement was found among pilots for high priority alerting functions, guidelines should be established only for the two highest levels (warnings and cautions), and that the prioritization of lower level alerts be left up to the airframe manufacturers and operators.

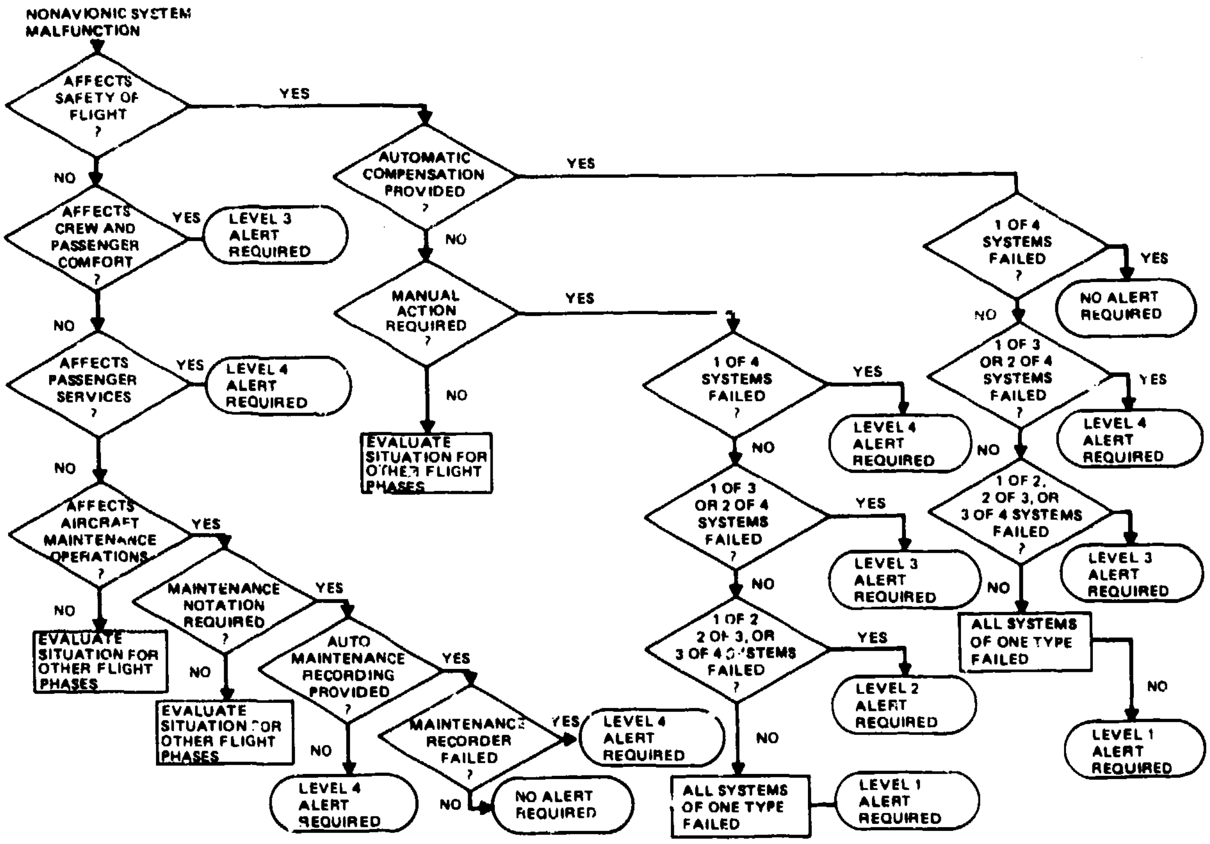


Figure 5.1-1. General Type of Logic Required to Prioritize Alerting Functions

Table 5.1-2. Example Application of Alerting Function Prioritization (Warnings)

	Alert level (category)	1. Emergency (warning)
ALERT PRIORITIES AS FUNCTION OF FLIGHT PHASE	Ground mainte-nance	1. Gear down and locked but lever not in down detent 2. Unsafe takeoff configuration 3. Stall warning 4. Ground proximity warning
	Pre-flight	1. Gear down and locked but lever not in down detent
	Engine start	1. Gear down and locked but lever not in down detent
	Taxi	1. Gear down and locked but lever not in down detent
	Initial takeoff roll	1. Unsafe takeoff configuration 2. Gear down and locked but lever not in down detent
	Final takeoff roll	
	Initial climb	1. Stall warning 2. Ground proximity warning
	1,500- to 14,000-ft altitude	1. Stall warning 2. Ground proximity warning
	Above 14,000 ft	1. Stall warning 2. Ground proximity warning 3. Pressurization failure
	Approach (1,500- to 200-ft altitude)	1. Stall warning 2. Ground proximity warning 3. Gear down and locked but lever not in down detent 4. Unsafe landing configuration
	Landing (below 200 ft)	1. Stall warning 2. Ground proximity warning 3. Gear down and locked but lever not in down detent 4. Unsafe landing configuration 5. Autopilot disconnect
	Taxi and shutdown	1. Gear down and locked but lever not in down detent

Note: Alerts prioritized as numbered; number 1 has highest priority.

Table 5.1-3. Example Application of Alerting Function Prioritization (Cautions)

Alert priorities as function of flight phase

Alert level (category)	2. Abnormal (Cautions)					
Ground mainte-nance	1. Fire warning —Master —Engine —APU —Cargo	2. EGT overtemperature 3. Bleed air temperature high 4. Oil temperature high 5. Air-conditioning duct overheating 6. Passenger oxygen systems on	7. Below glideslope warning 8. Equipment tire burst 9. Excessive airspeed or mach			
Preflight	1. Fire warning —Master —Engine —APU —Cargo	2. Air-conditioning duct overheating 3. Passenger oxygen system on				
Engine start	1. Fire warning —Master —Engine —APU —Cargo	2. EGT overtemperature 3. Bleed air temperature high 4. Oil temperature high 5. Air-conditioning duct overheating				
Taxi	1. Fire warning —Master —Engine —APU —Cargo —Wheelwell	2. EGT overtemperature 3. Bleed air temperature high 4. Oil temperature high 5. Air-conditioning duct overheating 6. CSD or IDG oil temperature high	7. Hydraulic pressure low —Elevator —Rudder —Aileron 8. Yaw damper failure 9. Radio altimeter failure	10. Passenger oxygen system on 11. Parking brake on		
Initial takeoff roll	1. Fire warning —Master —Engine —APU —Cargo —Wheelwell	2. EGT overtemperature 3. Oil temperature high 4. Hydraulic pressure low —Elevator —Rudder —Aileron	5. Stabilizer out of trim 6. Gyro failure 7. Radio altimeter failure			
Final takeoff roll						
Initial climb						
1,500- to 14,000-ft altitude	1. Fire warning —Master —Engine —APU —Cargo —Wheelwell	2. Pressurization failure 3. EGT overtemperature 4. Bleed air temperature high 5. Oil temperature high 6. Air-conditioning duct overheating	7. APU EGT overtemperature 8. APU oil temperature high 9. PU oil pressure low 10. APU oil quantity low	11. Hydraulic pressure low —Elevator —Rudder —Aileron 12. Yaw damper failure 13. Equipment tire burst	14. Gyro failure 15. CSD or IDG oil temperature high 16. CSD or IDG oil pressure low 17. Autopilot disconnect 18. Autothrottle disconnect 19. Excessive airspeed or mach	20. Gear not down and thrust lever at idle 21. Radio altimeter failure 22. Speed brake DO NOT ARM 23. Passenger oxygen on
Above 14,000 ft	1. Fire warning —Master —Engine —APU —Cargo —Wheelwell	2. EGT overtemperature 3. Bleed air temperature high 4. Oil temperature high 5. Air-conditioning duct overheating 6. APU EGT overtemperature 7. APU oil temperature high	8. APU oil pressure low 9. APU oil quantity low 10. Hydraulic pressure low —Elevator —Rudder —Aileron	11. Yaw damper failure 12. Equipment tire burst 13. Gyro failure	14. CSD or IDG oil temperature high 15. CSD or IDG oil pressure low 16. Autopilot disconnect 17. Autothrottle disconnect 18. Excessive airspeed or mach	19. Gear not down and locked and thrust lever at idle
Approach (1,500- to 200-ft altitude)	1. Fire warning —Master —Engine —APU —Cargo —Wheelwell	2. Below glideslope warning 3. EGT overtemperature 4. Bleed air temperature high 5. Oil temperature high 6. Air-conditioning duct overheating 7. APU EGT overtemperature	8. APU oil temperature high 9. APU oil pressure low 10. APU oil quantity low	11. Hydraulic pressure low —Elevator —Rudder —Aileron 12. Yaw damper failure 13. Equipment tire burst	14. Gyro failure 15. Radio altimeter failure 16. Glideslope info failure 17. Localizer info failure 18. Autopilot disconnect 19. Autothrottle disconnect	20. Gear not down and locked and thrust lever at idle 21. Brake pressure abnormal 22. Reverser accumulator pressure low 23. Speed brake DO NOT ARM 24. CSD or IDG oil temperature high 25. CSD or IDG oil pressure low
Landing (below 200 ft)	1. Hydraulic pressure low —Elevator —Rudder —Aileron	2. Gyro failure 3. Radio altimeter failure 4. Brake pressure abnormal 5. Reverser accumulator pressure low				
Taxi and shutdown	1. Fire warning —Master —Engine —APU —Cargo —Wheelwell	2. EGT overtemperature 3. Bleed air temperature high 4. Oil temperature high 5. Air-conditioning duct overheating 6. Brake pressure abnormal 7. CSD or IDG oil temperature high	8. CSD or IDG oil pressure low			

Note: Alerts prioritized as numbered. Number 1 has highest priority.

Table 5.1-4. Example Application of Alerting Function Prioritization (Advisories)

	Alert level (category	3. Advisories	4. Information (not part of integrated warning system)
ALERT PRIORITIES AS FUNCTION OF FLIGHT PHASE	Ground mainte-nance		
	Pre-flight		
	Engine start		
	Taxi		
	Initial takeoff roll	Function of aircraft design Priorities to be determined by airframe manufacturer and operator	Function of aircraft design Priorities to be determined by airframe manufacturer and operator
	Final takeoff roll		
	Initial climb		
	1,500- to 14,000-ft altitude		
	Above 14,000 ft		
	Approach (1,500- to 200-ft altitude)		
	Landing (below 200 ft)		
	Taxi and shutdown		

A study was recently conducted at Douglas Aircraft to assess the performance benefits associated with alert prioritization (Po-Chedley and Burington, 1981). Twelve commercially rated pilots participated, each completing 12 simulated flights during which, they were told, a multiple failure situation might occur. In terms of fault correction activity, the use of prioritization resulted in a significant reduction in response times, to these alerting situations. Pilots also made fewer errors during the fault correction sequences when prioritization was used. In response to a debriefing questionnaire, participants showed a clear preference for use of prioritization as an aid in identifying the appropriate fault correction sequence.

In the present study, 21 pilots were asked to complete a questionnaire that addressed prioritization and inhibit logic. Respondents were asked to prioritize 16 alerts for eight flight phases. For a number of alerts, pilots rated their urgency as being significantly more important in some flight phases than in others. This data lends strength to the argument that an effective prioritization system should be flight phase adaptive. In this regard, Vanderschraaf (1976) proposed a concept called the Phase Adaptive Warning System (PAWS) wherein a switching logic module receives information from a central annunciator panel as well as other sensors and uses it to inhibit and prioritize alerts. This also points indirectly to a need for flight phase inhibit logic. Another finding of interest was the high degree of variability with which the pilots prioritized the alerts. For a majority of the flight segments, pilot ratings indicated no significant differences in the urgency levels for the various alerts. This variability is not surprising in view of the fact that the 21 pilots came from a variety of organizations and aircraft types. This lack of agreement does, however, bring two issues into perspective. First, if a prioritization system is to be used in commercial aircraft, it will probably be aircraft and airline specific; this is primarily due to the differing redundancy levels in present commercial aircraft. Secondly, the development of the actual prioritization order will need to be carried out by design engineers as well as pilots. A combination of flight experience, aircraft familiarity and design expertise will, in all likelihood, produce a more effective prioritization system than any one of these capabilities would yield by itself.

Although the limited subjective and objective data collected thus far reflect positively on the potential utility of alert prioritization, its feasibility has yet to be demonstrated. The source of the actual prioritization data base (e.g., how alerts will be prioritized for each aircraft type) and the large number of possible aircraft configuration variations represent two subjects of special concern to both researchers and system designers. Before prioritization can be seriously considered, these issues must be explored and resolved. Primary attention should be focused on developing a methodology for determining alert priority levels for each flight phase. This methodology will need to be comprehensive enough so that the system can accommodate all aircraft configurations that flight crews can expect to encounter in the operational environment.

As an example, the criticality of a generator failure will vary with the number of generators that are operational; a dual generator failure will be more critical than a single failure. The level of criticality in a multiple generator (or other system) failure will also be dependent upon the number of engines being used to drive the generators (e.g., B737 vs. B747). The utimate goal should be to provide an efficient, reliable alerting system that allows the flight crew to deal effectively with multiple failure situations. Reliability is extremely important because the increased automation which is inherent in this approach requires a high degree of pilot confidence in the capability of the systems to provide accurate information. The foregoing issues must be carefully considered before prioritization is made operational.

TO SUMMARIZE, A PRIORITIZATION SCHEME SHOULD BE INCORPORATED INTO THE ALERTING SYSTEM. IT SHOULD BE FLIGHT PHASE ADAPTIVE. ITS FEASIBILITY SHOULD BE DEMONSTRATED IN TERMS OF THE DATA BASE USED AS WELL AS APPROPRIATE ACCOMMODATION OF AIRCRAFT CONFIGURATION VARIATIONS AND EXCEPTIONS. AS A MINIMUM, ALERTS SHOULD BE PRIORITIZED BY URGENCY LEVEL (WARNING, CAUTION AND ADVISORY).

5.2 INHIBIT LOGIC

- INHIBIT LOGIC SHOULD BE USED TO DELAY THE ONSET OF NON-CRITICAL ALERT MESSAGES DURING HIGH WORKLOAD FLIGHT SEGMENTS

- THE INHIBIT LOGIC SYSTEM SHOULD BE FLIGHT PHASE ADAPTIVE

- A SPECIFIC METHODOLOGY FOR INHIBIT LOGIC APPLICATION SHOULD BE DEVELOPED PRIOR TO ITS IMPLEMENTATION

As mentioned earlier, high workload flight phases (e.g., takeoff and final approach) require a high degree of concentration on the part of the flight crew. During these periods, the crew should only be provided with information that directly impacts the task at hand. This is also true for multiple failure situations. When a number of failures occur, primary attention should be given to the most serious faults, particularly those that jeopardize safe flight management.

Inhibition refers to delaying the onset of non-critical alerts throughout high workload flight phases or multiple failure situations. Alert inhibition is used on all modern commercial transport aircraft to minimize the occurrence of nuisance alerts, particularly those associated with the configuraton of flaps, landing gear, etc. However, very few aircraft utilize inhibit logic to suppress nuisance alerts for less important systems during high workload flight phases. The L-1011 and the DC-10 inhibit alerts for selected subsystems during landing, and a takeoff inhibit mode is used on the Concorde and on the A-300 to suppress all but a few critical warnings.

To date, a comprehensive methodology has not been developed for systematically inhibiting selected alerts during the various flight segments. A majority of aerospace personnel surveyed felt that a carefully conceived inhibit logic scheme will provide a useful supplement to the flight deck alerting system (ARP-450D, 1980; Cooper, 1977; Po-Chedley and Burington, 1981; and Veitengruber, et al., 1977). Methodologies suggested for development in the Cooper survey included both manual and computer driven inhibit logic schemes. Figure 5.2-1 shows a sample inhibit logic scheme that was presented in the Veitengruber, et al., study (1977). As can be seen in this figure, takeoff and final approach were identified as two flight phases where only the most critical alerts should not be inhibited.

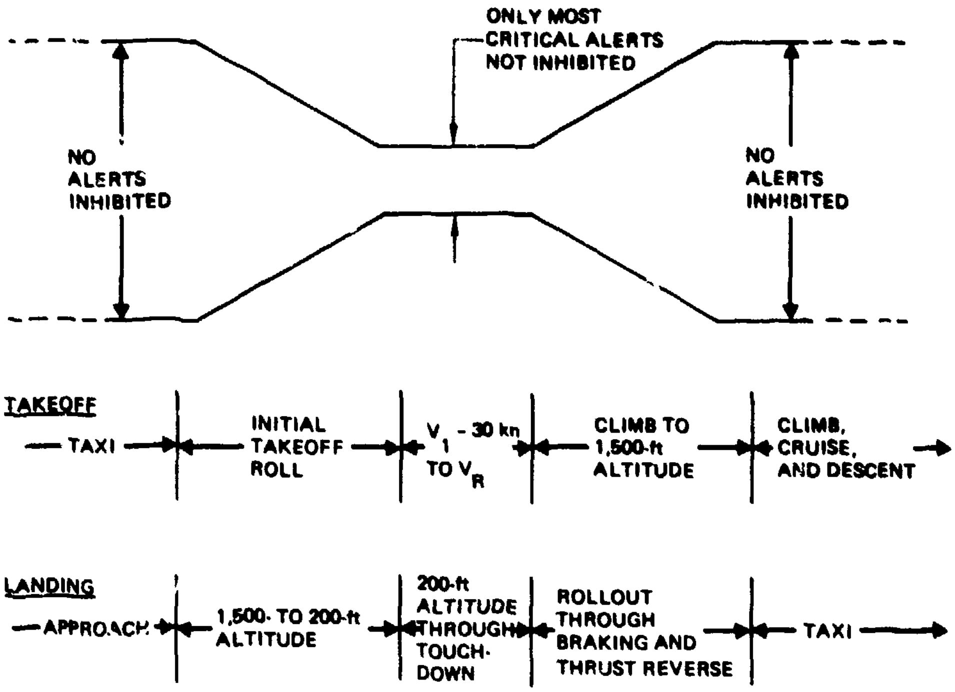


Figure 5.2-1. Sample Alert Inhibit Scheme

The present study asked 21 pilots to identify flight segments in which selected faults should be inhibited. There was little agreement as to which alerts should be inhibited and when. Although a large number favored inhibition of all but the most serious fault messages during the final takeoff and final approach flight segments, 90% favored inhibition of only one component of the alerting medium. For example, if an engine fire were to occur on final approach, many of those questioned responded by stating that the fire bell should be inhibited while the master visual alert should remain operational.

Po-Chedley and Burington (1981) found that pilot performance on a flight simulator task improved significantly when inhibit logic was employed. This improvement was evident in terms of both shorter response times and a lower error rate. Pilot preferences were also clearly in favor of the use of a systematic inhibit logic scheme.

Since currently available data support the use of inhibit logic in commercial aircraft, it would seem a worthwhile effort to develop this concept further.

There are a number of unresolved issues that need to be addressed before alert inhibition can be successfully made operational. A determination should be made as to what information should be withheld from the pilot's decision process, and when. A clear identification of potential inhibit logic applications is quite difficult, however, because of disagreements among pilots.

TO SUMMARIZE, INHIBIT LOGIC SHOULD BE USED TO DELAY THE ONSET OF NON-CRITICAL ALERT MESSAGES DURING HIGH WORKLOAD FLIGHT SEGMENTS. THE INHIBIT LOGIC SYSTEM SHOULD BE FLIGHT PHASE ADAPTIVE, AND A SPECIFIC METHODOLOGY FOR INHIBIT LOGIC APPLICATION SHOULD BE DEVELOPED PRIOR TO ITS IMPLEMENTATION.

5.3 STORE/RECALL

- A STORE/RECALL CAPABILITY SHOULD BE PROVIDED FOR CAUTION AND ADVISORY ALERTS

- PROVISIONS SHOULD BE MADE FOR BOTH SELECTIVE AND TOTAL STORE/RECALL

- A POSITIVE INDICATION SHOULD BE PROVIDED ON THE DISPLAY WHEN MESSAGES ARE STORED IN MEMORY

- HIGH PRIORITY ALERTS (WARNING LEVEL) SHOULD NOT BE STORED IN MEMORY

Store/recall refer to the storage of alert messages in memory and their subsequent recall. Potential applications of a store/recall capability include dispatch inoperative items and faults that have been accommodated but not removed. Clearing these faults from the display allows the crew to remove a potential source of distraction. Providing this capability is also in concert with the philosophy of a quiet, dark cockpit, wherein no alerts are presented unless required for aircraft safety or operability.

In the present study, pilots were asked to assess both selected and total store/recall capabilities. Selective store/recall involves the storage and recall of individual messages, one at a time; while total store/recall will clear the display, placing all active alert messages (except warnings) into memory. A majority of the pilots surveyed (56%) state that a combination of selective and total store/recall should be used, while 32% favored the use of only total store/recall. A minority (12%) preferred that selective store/recall be used independently. Because little additional hardware or software is required to provide both capabilities, BOTH TOTAL AND SELECTIVE STORE/RECALL SHOULD BE MADE OPERATIONAL.

Figure 5.3-1 illustrates one method by which selective store/recall could be operationalized using a deferred item indicator that provides a positive indication when alert messages are stored in memory. The pilots surveyed in the study indicated that the deferred item indicator provided a good indication of the number and type of alerts in memory. They also agreed that high priority alerts should not be stored in memory.

IN SUMMARY, BOTH SELECTIVE AND TOTAL STORE/RECALL CAPABILITIES SHOULD BE PROVIDED FOR CAUTION AND ADVISORY LEVEL ALERTS; WARNINGS SHOULD NOT BE STORED IN MEMORY. A POSITIVE INDICATION SHOULD BE PROVIDED WHEN ALERTS ARE STORED IN MEMORY.

5.4 ADDITIONAL ALERTING SYSTEM FEATURES

- A LINE-ADDRESS CAPABILITY SHOULD BE PROVIDED TO ALLOW THE CREW TO ACCESS OR STORE SPECIFIC FAULT MESSAGES

- THE OVERFLOW LOGIC SYSTEM SHOULD HAVE A PAGING FUNCTION THAT ALLOWS THE CREW TO ACCESS FAULT MESSAGES STORED IN OVERFLOW MEMORY

To make operational a selective store/recall capability and/or a procedural information display (used to expedite fault correction), some method must be provided for addressing specific fault messages. Pilots in the study were presented with two options; the first involved the use of line keys that allow the crew to depress a switch next to a particular message line that brings the line advance indicator directly to that message (see Figure 5.4-1). The second option required continual depression of a rocker switch that indexed the line advance indicator up or down the screen to the desired message (see Figure 5.3-1). A majority of the pilots preferred the line keys over the

Step 1 Depress Line Advance Key (With Triangular Symbol) to Bring Cursor Down to "FLAP LIMIT INOP"

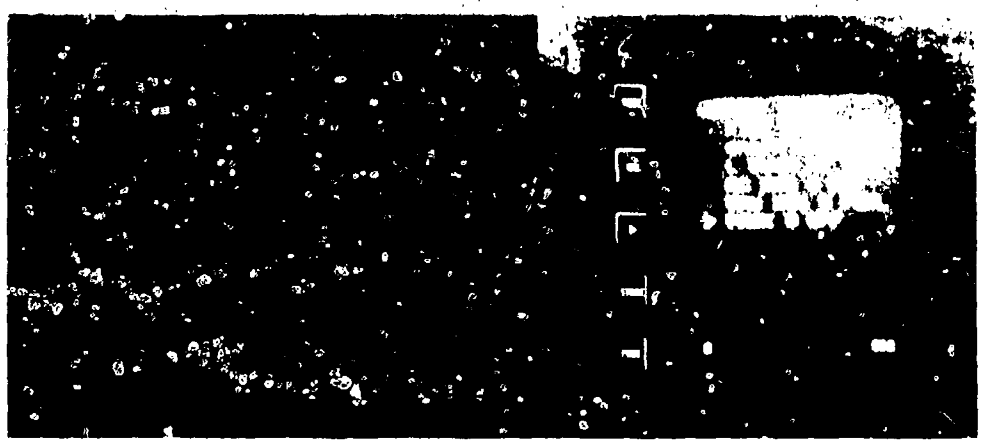
Step 2 Cursor Indexed at "FLAP LIMIT INOP"

Step 3 Depress "STORE" Key to Place Message in Memory

Figure 5.3-1. Example Application of Selective Store/Recall Using a Deferred Item Indicator (Po-Chedley and Burington, 1981)

Step 4 Message ("FLAP LIMIT INCP") Reverts to Memory

Note: Deferred item indicator (MI) in lower right corner



Step 5 Depress "MODE" Key to Enter "MEMORY MODE"

Step 6 Depress "MODE" Key Again to Revert Back to "ALERT MODE"

Figure 5.3-1 (Concluded). Example Application of Selective Store/Recall Using a Deferred Item Indicator (Po-Chedley and Burington, 1981) rocker switch because fewer discrete actions are required for message line selection. However, the line keys require more space that the rocker switch so the methodology employed for this function should be determined by a combination of workload requirements and the availability of flight deck panel space.

As mentioned in the visual information display guidelines, a positive indication should be provided to alert the crew to the presence of additional fault messages. In addition to this, the crew must be provided with a means to gain access to the alerts stored in overflow memory. In a recent study (Boucek, et al., 1980) pilots were asked to assess a scroll concept where messages were arranged in chronological order by level of urgency (see Figure 5.4-2). In an overflow condition, the messages currently displayed on the screen could be moved off the top or bottom of the display by depressing the appropriate switch located at the left of the screen. As these messages were removed from the screen the overflowed messages would appear at the top or bottom, depending on which switch was pressed. A majority of the pilots felt that this method was not acceptable because of the fact that warning level alerts could be removed from the display. In the present study, 25 pilots evaluated a paging function where a page select switch was used in combination with an overflow indication on the display (see Figure 5.4-3). Depression of the page key allowed the crew to recall messages stored in overflow memory. This option was judged as being good to excellent by a majority of the pilots. It should be noted that Figure 5.4-3 does not show the recommended display configuration for alert messages (e.g., warnings on top, followed by cautions and advisories).

TO SUMMARIZE, A LINE ADDRESS CAPABILITY SHOULD BE PROVIDED TO ALLOW THE CREW TO ACCESS OR STORE SPECIFIC FAULT MESSAGES. ALSO, THE OVERFLOW LOGIC SYSTEM SHOULD HAVE A PAGING FUNCTION THAT ALLOWS THE CREW TO ACCESS FAULT MESSAGES STORED IN OVERFLOW MEMORY.

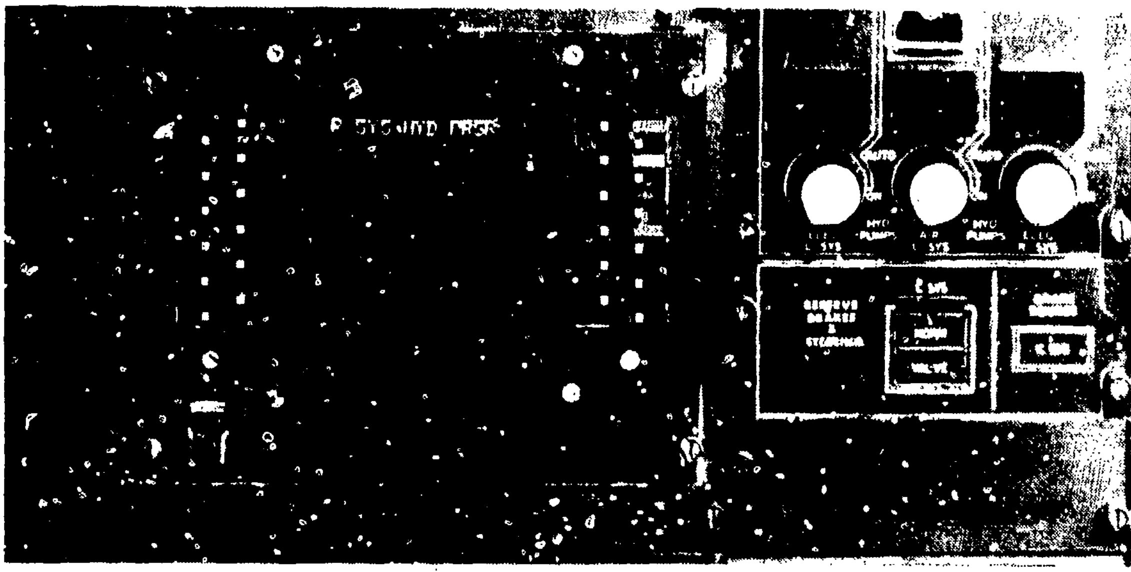


Figure 5.4-1. Line Keys and Rocker Switch as Options for Message Line Selection

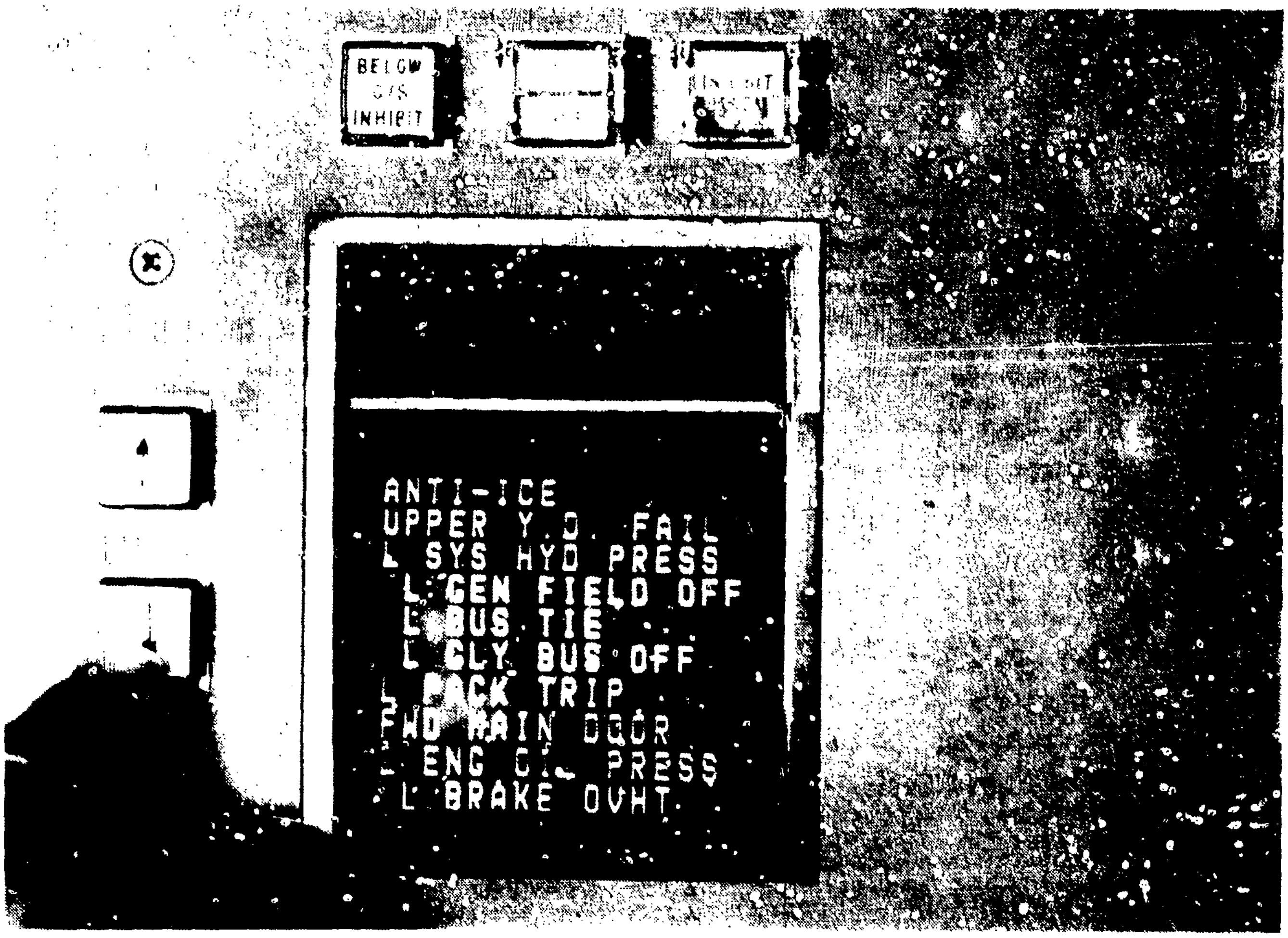


Figure 5.4-2. Scroll Function Used for Accommodation of Overflow Condition

Figure 5.4-3. Paging Function Used for Accommodation of Overflow Condition

6.0 CERTIFICATION IMPACT

As part of this study, an appraisal was made of the impact on certification of new and current aircraft if the recommended guidelines were implemented. The method selected to conduct this appraisal was to compare the requirements specified in the Federal Regulations with the functional guidelines. Copies of the regulations were obtained, and a list of Federal Aviation Regulations (FARs) relevant to crew alerting was compiled. The requirements of the FARs formed the baseline for determining their conformance to the recommended guidelines.

6.1 CONSOLIDATION OF ALERTING REQUIREMENTS

Introduction of the guidelines would essentially be a consolidation of existing requirements, since the Regulations already provide for crew alerting requirements. The most important feature of the guidelines is that all the alerting functions of the aircraft are integrated into a single, physical system for crew annunciation. This systems approach supports the second-most important feature of the guidelines, standardization. A third feature, also made possible by a systems approach, is that once implemented, growth and changes are easily accommodated without additional alerting devices. While implementation of the guidelines would have the alerting system cover nearly all current crew alerting requirements, a few current practices would be precluded.

6.2 GUIDELINE CONFLICTS WITH CURRENT FARs

6.2.1 FARs RELATED TO CREW ALERTING

As mentioned above, applicable regulations were surveyed, and a list of FARs which specified requirements for crew alerting was compiled, see Table 6.2.1-1.

6.2.2 FARs IMPACTED BY IMPLEMENTATION OF THE RECOMMENDATIONS

Only four Regulations would be impacted by the implementation of the design guidelines; all other FAR requirements for crew alerting can be accommodated.

Table 6.2.1-1. Federal Aviation Regulations Pertaining to Alerting Systems

FAR number	Short title
25.207 (b)	Stall Warning
25.672	Stability Augmentation and Automatic and Power-Operated Systems
25.703	Takeoff Warning Systems
25.729 (e) (2), (3), (4)	Retracting Mechanism
25.771	Personnel and Cargo Accommodations
25.777 (a), (c)	Cockpit Controls
25.812 (e) (2)	Emergency Lighting
25.841 (b) (6), (7), (8)	Pressurization
25.859 (e) (3)	Combustion Heater Fire Protection
25.863 (c), (d)	Fluid Fire Alert
25.1165 (g)	Engine Ignition Systems
25.1199 (c)	Extinguishing Agent Containers
25.1203 (b) (3)	Fire-Detector System
25.1303 (c) (1)	Flight and Navigation Instruments
25.1305 (a) (1), (7)	Powerplant Instruments
25.1309 (c)	Equipment, Systems, and Installations
25.1321 (a), (b), (d), (e)	Instruments: Installation
25.1322	Warning, Caution, and Advisory Lights
25.1353 (c) (b) (ii), (iii)	Electrical Equipment and Installations
25.1555 (d)	Control Markings
37.119 (a) (3) (i), (ii)	Automatic Pilots
37.201	Ground Proximity Warning—Glideslope Deviation Alerting Equipment
91.49	Aural Speed Warning Device
91.51 (b)	Altitude Alerting System or Device
121.289 (a), (b)	Landing Gear: Aural Warning Device
121.319 (b) (5) (ii), (iii)	Crewmember Interphone System
121.360 (a)	Ground Proximity Warning—Glideslope Deviation Alerting System

The four FARs that are affected by the recommendations are described in the following paragraphs.

6.2.2.1 FAR 25.729 and FAR 121.289 Configuration - The recommended system deviates from the FAR configuration alert by permitting the pilots to cancel the master aural alert manually. The reason is that as soon as the pilot perceives and interprets the alerting signal, it has served its purposes which are to attract the attention of the crew, and to provide preliminary alert urgency-level information. Having heard or seen the master alert(s), the pilot knows what urgency the alert is and is able to decide between continuing the current task, or to look to the visual display to see what the specific problem is. It would be an undesirable distraction to have the aural signal continue after it had alerted the aircrew.

The primary consideration in the design and operation of the master aural alerts is their attention-getting quality. Their purpose is to gain crew awareness of an abnormal/emergency condition or situation. The demand for awareness is established by the criticality of the situation; warning alerts require immediate action, caution alerts require immediate awareness and subsequent action, and advisory alerts require only crew awareness to a condition which may require action. In attempting to insure that the pilot is aware of and correctly interprets the alerting signal, there are two opposing factors to consider. First, one way for verifying perception of a signal is to require the operator to take some positive action. On the other hand, in high workload situations it is undesirable to require the operator to make such an action. Pilot test and survey data indicated a distinct preference for a manual cancellation capability (Cooper, 1977, and Boucek, et al., 1980). The empirical tests and pilot surveys conducted during this study supported the implementation of manual cancellation, and for automatic cancellation upon correction or removal of the problem.

6.2.2.2 FAR 25.1303 and FAR 91.49 Overspeed - The recommended system differs from these Regulations in that the overspeed alert would not have a discrete aural signal. It would receive the same type of aural-visual-alphanumeric presentation as any other alert of the same urgency level.

The system guidelines would also have the master aural and master visual alerts manually cancellable. The reason for this is that the overt action of manually cancelling the master alerts assures that the pilot's attention to the alert has been acquired. The alert would remain on the alphanumeric visual display until it was stored in memory or corrected. The reason for not allowing discrete alerts for individual systems stems from several design philosophies. First, too many individual lights, sounds, and other alerting devices create problems of confusion when several alert devices are activated simultaneously, or in close succession. Also, to be able to use the discrete aural signals, the pilots must recognize them, creating a greater need for pilot memorization and training. One of the primary reasons for conducting this study was to eliminate the proliferation of alerts in the flight deck. Second, standardization of alerting system concepts and procedures, not only across airplane model lines but across airplane manufacturers as well, was a goal of this study. Standardization will reduce flight deck confusion and pilot training and memory requirements, and will provide pilots with the ability to develop a habit pattern in which to respond to alerting situations.

The guideline for recommendations for the number of alerting sounds are:

- The number of discrete sounds in the flight deck should be limited to three (one for each alerting category, Warning, Caution and Advisory).

- Each sound should differ from the others in more than one dimension (frequency, duration, etc.).

- The alerting signals should be selected to reflect alert urgency level.

The restriction of three aural alerts permits optimum discrimination of the signals and supports the ability of pilots to make a preliminary assessment of the alerting situation before modifying their current activity. The restriction to three aural alerts also supports the requirement that, although the basic design of the three aural alerts is prescribed in the guidelines, provision is made for each airplane to adjust the parameters to fit its noise environment. The aural signals should be designed to minimize the noise masking and noise interference effects of the specific airframe. Minimizing the number of discrete aural signals reduces pilot workload and eases the requirement of keeping the aural signals easily discriminable.

6.3 IMPLIED NEW ALERTING SYSTEM REQUIREMENTS

As a result of the analysis of the Regulations and the alerting system design guidelines, the following implications for new crew alerting requirements are evident and should be considered.

6.3.1 ESTABLISH THE ACCEPTABILITY OF AN ALERTING SYSTEM

Whereas of the Regulations currently state requirements for unique visual, aural or other alerts, they should indicate the acceptability of an integrated alerting system which satisfies the functions of the individual requirements.

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