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Aircraft Alerting Systems Criteria Study

Volume I

Collation and Analysis of Aircraft Alerting System Data

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FINAL REPORT

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16. Abstract

Several recent studies, performed to develop optimum alerting methods for new alerts that had to be retrofitted to existing aircraft, identified as major alerting system problems the proliferation of alerting systems and the inconsistent application of alerting concepts in current commercial transport aircraft. The objective of this study was to address these problem areas in the following manner: (1) refine and augment the stimuli response data collected under the previous studies, (2) provide test plans for additional stimuli response tests required to complete the stimuli response data base, (3) provide tabulations of the alerting methods and alerting requirements used on current commercial transport aircraft, (4) develop a method for prioritizing alerting functions and prioritizing the alerting functions accordingly, (5) note conflicts between current alerting requirements and the prioritized list of alerts, and (6) provide recommendations for standardization of alerting functions/methods. The output includes a collation of human factors data pertinent to alerting systems, cursory test plans for obtaining missing human factors data required to complete definition of and validate the standards recommended for alerting systems, criteria for alert priority levels, an example tabulation of alerts that might fall within each priority level, and recommended methods of annunciating the alerts within each priority level.

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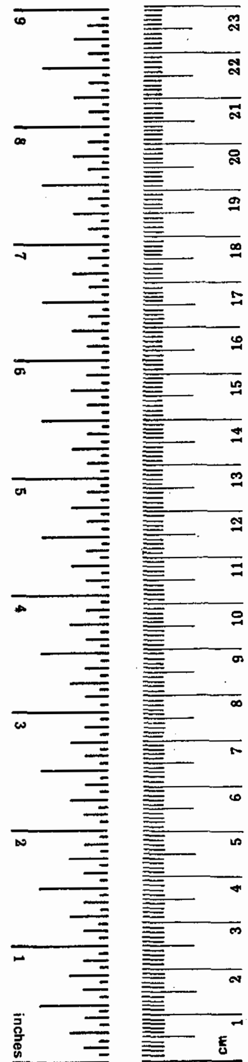
METRIC CONVERSION FACTORS

Approximate Conversions to Metric Measures

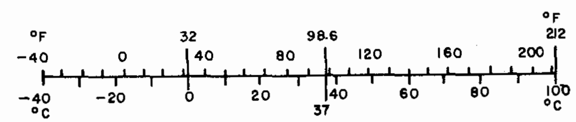
Symbol	When You Know	Multiply by	To Find	Symbol
	LENGTH			
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
	AREA			
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	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



FOREWORD

This final technical report covers work performed under the third phase of FAA contract DOT-FA73WA-3233, "Collation and Analysis of Aircraft Alerting Systems Data." The study was initiated to establish an alerting philosophy for aircraft cockpit alerting systems.

The contract sponsor was FAA Systems Research and Development Service (SRDS) and performed by the Boeing Commercial Airplane Company. Technical guidance for this contract was provided by Mr. John Hendrickson, ARD-743, the contract monitor.

Study conduct covered the period January 1976 through November 1976. The performing organization was Systems Technology–Crew Systems, of the Boeing Commercial Airplane Company, Seattle, Washington. W. D. Smith was program manager, J. E. Veitengruber was principal investigator, and G. P. Boucek was the signal/response analyst.

SYNOPSIS

The purpose of this study was to develop preliminary design guidelines and standards for aircraft alerting systems.

The scope of the study encompassed five major tasks. Task I consisted of tabulating current alerting methods and deciphering factors causing proliferation of the alerts. In Task II, criteria for prioritizing the alerting functions were developed and applied. In Task III, standards and regulations applicable to alerting system standards were reviewed and compared with the results of Task II to identify conflicts. Tasks IV and V consisted of broadening the stimuli response data base developed in a previous study and defining tests required to obtain missing data.

Preliminary alerting system design guidelines (standards) were developed from the results of each task. The guidelines included: (1) criteria for four alert priority levels, (2) a tabulation of the alerts that might fit the criteria for the two highest priority levels, (3) an example tabulation of alert priorities within each alert category, and (4) recommended methods of annunciating the alerts within each priority category. In addition to these guidelines, cursory test plans for obtaining the missing human factors data required to complete definition of and validate these guidelines are also provided.

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FIGURES (Cont)

TABLES

ABBREVIATIONS & SYMBOLS

ACFT	Aircraft
ADI	Attitude Director Indicator
AG	Attention Getter
ALT	Altitude
AMB	Amber
A/P	Autopilot
APU	Auxiliary Power Unit
ATM	Air Turbine Motor
A/T	Autothrottle
ASS ALT	Assigned Attitude
BLK	Black
BLU	Blue
BRT	Bright
CADC	Central Air Data Computer
CAS	Collision Avoidance System
CONT	Continued
CONFIG	Configuration
CSD	Constant Speed Drive (Electrical Generator)
CWS	Control Wheel Steering
dB	Decibels
DME	Distance Measuring Equipment
EGT	Exhaust Gas Temperature
EMER	Emergency
ENG	Engine
EVAC	Evacuation
FAR	Federal Aviation Regulation
FE	Flight Engineer
FL	Flashing
FLT INST	Flight Instrument
ft-L	Foot Lamberts
GRD PROX	Ground Proximity
GRN	Green
HORIZ	Horizontal
HSI	Horizontal Situation Indicator
Hz	Hertz
IAM	Independent Altitude Monitor
IATA	International Air Transport Association
IDG	Integrated Drive Generator (Electrical)
ILS	Instrument Landing System
INS	Inertial Navigation System
LDG	Landing
LTS	Lights
MDA	Minimum Descent Altitude
ORN	Orange
PRESS	Pressure
QUAN	Quantity

ABBREVIATIONS & SYMBOLS (Cont)

RA	Radio Altitude
RTCA	Radio Technical Commission for Aeronautics
SAE	Society of Automotive Engineers, Inc.
SAS	Stability Augmentation System
SELCAL	Selective Call System (Company Communication)
STAB	Stabilizer
SYST	System
VOR	Very High Frequency Omnidirectional Radio Range
WHT	White
YEL	Yellow

1.0 INTRODUCTION AND SUMMARY

1.1 INTRODUCTION

This contract is the third of a series of contracts that have evolved from studies of independent altitude monitor requirements to this, a study of cockpit alerting system problems. Under the first contract, "Development of an Independent Altitude Monitoring (IAM) System Concept," sensor principles and control-display-alerting methods for IAM systems were studied. That study indicated that additional research was required to assess the effectiveness of various IAM control-display-alerting methods. A second contract was issued to study these alerting problems. A summary of alert philosophies used in current aircraft and IAM systems, a data base of currently used alerting characteristics including stimulus response characteristics, three recommended IAM alerting methods for each category of aircraft (light private aircraft, commercial transports, etc.), and guidelines for developing or completing development and implementation of an IAM system were produced. The proliferation of alerting devices in the cockpit, the inconsistent application of alerting concepts in current commercial transport aircraft, nonadherence to existing alerting system standards because they were outdated, and the need for a set of design objectives and design guidelines acceptable to all commercial transport aircraft operators and manufacturers became evident in this second study. The current contract therefore was issued to study the entire cockpit problem.

The objectives of this study were: (1) refine and augment the stimuli response data collected under the previous contract, (2) provide test plans for additional stimuli response tests required to complete the stimuli response data base, (3) provide tabulations of the alerting methods and alerting requirements used on current commercial transport aircraft, (4) develop a method for prioritizing alerting functions and prioritizing the alerting functions accordingly, (5) note conflicts between current alerting requirements and the prioritized list of alerts, and (6) provide recommendations for standardization of alerting functions/methods. The results of this study represent a first cut at design objectives and design guidelines for alerting systems in new aircraft. Considerable more refinement, testing, and analysis of the hardware/implementation impact of the alerting system concepts that resulted from this study are required.

1.2 SUMMARY

At the beginning of this study, numerous inconsistencies in the alerting concepts applied to each type of aircraft were known to exist (ref. 1). Specific inconsistencies in the aural alerts were known and similar inconsistencies in the visual alerts were suspected. These suspicions were proven to be correct. In addition to verifying that these inconsistencies existed and the type of inconsistencies that were occurring, the study showed that a proliferation of alerts occurred in the latest generation of aircraft. Analyses of the type of alerts involved in the proliferations revealed the following facts:

- Each new aircraft has incorporated more alerting functions than previous similar aircraft because of:

    1. Differences in the operators' alerting system utilization philosophies

    2. Differences in the airframers' cockpit design philosophies

    3. Additional regulatory requirements

4. Increased size of the later vintage aircraft

5. Use of more complex systems to save weight

- Number of warning-type alerts used in commercial turbojet transport aircraft nearly doubled in the transition from narrow body to wide body aircraft.

- Number of caution- and advisory-type alerts used in commercial turbojet aircraft has increased substantially with each new aircraft design.

- A trend exists toward providing the crew with more detailed subsystem information (more lights and bands) so that the pilots can try to resolve malfunctions in flight and record better maintenance data.

- Among the narrow body aircraft no significant change in the number of alert lights, aurals, flags or bands occurred. Aircraft size, types of operation, and vintage had little effect on the design of the alerting systems in these aircraft.

- Wide body aircraft use substantially more alert lights, flags, and aurals than narrow body aircraft.

- A trend exists toward more multifunctioning of the alerting devices.

- The number of warnings increased primarily because of the red flags required to annunciate the new failure modes of more complex autopilots and avionics on board wide body aircraft.

- Amber and yellow lights are being used more extensively with each new generation of aircraft to annunciate detailed subsystem operations.

- A trend toward annunciating more positive GO and SAFE conditions with green light exists.

- White-lighted pushbuttons are being used more extensively in place of toggle switches in each new generation of aircraft.

- Discrete alerts lights are being used to replace traditional color bands.

- No consistent utilization philosophy has been applied to the aural alerts, not even within any operator's or airframer's line of aircraft. Somewhat of a standard appears to have been established for only 5 of the 9 to 17 aural alerts used on each aircraft today.

- The number of aural alerts is increasing.

- Most rapid growth in the number of subsystems alerts has occurred in the electrical and automatic flight control systems. Negligible growth has occurred in the air conditioning, altitude alert, APU, communications, emergency equipment, flight instrument, air data, fuel, and powerplant systems.

- Master caution and/or master warning systems are used in all two-man-crew aircraft but in only a few three-man-crew aircraft.

- Master warning systems are activated by only a small percentage of the red lights, approximately half of the red lights in the cockpit. Similarly, master caution systems are activated by only about half of the amber and yellow lights in the cockpit.

- Only a very small percentage of the aural alerts, less than 7%, activate the master warning system.

- Alert prioritization currently is not used on any aircraft except late production models of the 737 and a few 727s.

- Inhibiting of subsystem fault alerts is not used on any aircraft except the DC-10.

- The correlation between the type of alert and type of checklist applied to each situation is poor.

In addition to these facts, most pilots agreed with the following issues:

- The number of alerts, especially the number of aural alerts, needs to be reduced.

- Most aural alerts, as currently designed, are too loud.

- Noncritical alerts should be inhibited during high workload periods, such as takeoff and flare/ landing.

- Selected alerts should be prioritized.

- A unique audio, visual, or combination audio-visual method of alerting should be associated with each priority to provide an instantaneous assessment of the situation's criticality.

- A definite correlation between the type of alert and the type of checklist or procedure applied to each situation should be established. (Note: This does not imply that a checklist is required for each alert.)

A study of the human factors data relevant to the design of alerting systems was then conducted (ref. 2). The following *preliminary* guidelines resulted:

- High-priority alerts should be located no more than 15° from the pilot's normal line of vision. Similarly caution signals should be located no more than 30° from the pilot's line of vision. Normal line of vision is defined as the line between the pilot's eye reference point and the center of the ADI.

- High-priority visual alerting devices should be no less than 1° visual angle in size. Secondary visual alerts should be no less than 0.5° visual angle in size.

- High-priority visual signals should have a brightness capability of at least 150 ft-L and be twice as bright as secondary displays. Secondary visual alerts should have a brightness of at least 15 ft-L and be at least 10% brighter than lesser priority displays in the same area.

- Automatic brightness adjustment for varying ambient light conditions should be provided.

- High-priority (LEVEL 1) visual alerts should flash.
- Each aural alerting signal should be composed of two or more widely separated frequencies in the range from 250 to 4000 Hz.
- The maximum intensity of aural alerts should be 15 dB above threshold noise level or halfway between the threshold noise level and 110 dB, whichever is less. Threshold equals level at which 50% of the alerts are detected.
- Automatic intensity adjustment for varying ambient noise conditions should be provided.
- Aural alerts should be presented dichotically to the pilot's dominant ear. If dichotic separation is not possible, the source of aural alert signals should be located 90^{o} from the primary sources of interfering noise or messages.
- Intermittent sounds should be used for aural alerts.
- Aural alerting messages (voice annunciations) should be preceded by an identifier to which the pilot is more than normally sensitive.
- Voice warnings should be used only to annunciate highest priority situations.
- Voice warning messages should be constructed of short sentences of polysyllabic words.
- Pilots should be familiar with all voice warning messages.
- Use of tactile alerts should be minimized.

A method of prioritizing the alerting functions was then sought. Criteria defining the priority categories are presented in table 1. These priority categories were applied to the alerting systems data collected at the beginning of this study, i.e., the alerts were categorized as shown in section 2.3.2. During application of these alert priority criteria, it was noted that the LEVEL 3 and LEVEL 4 alerts were very sensitive to the peculiar design characteristics of each aircraft. Thus, it was recommended that alert priority guidelines be established only for the LEVEL 1 and possibly some LEVEL 2 alerts, and that the airframe manufacturers and operators define the LEVEL 3 and LEVEL 4 priorities for each type of aircraft.

The results of the alerting systems data analyses, the pilot surveys, the human factors guidelines study, and the alert prioritization study were combined to formulate preliminary recommendations for standardization of alerting methods. A synopsis of the proposed guidelines for alerting methods is presented in table 1. Complete listing of the recommended guidelines is presented in section 2.5.1.

Table 1 Guidelines for Standardization of Alerting Functions and Methods

Level	Condition	Criteria	Alert system characteristics		
			Visual	Aural	Tactile
1	Emergency (warning)	Emergency operational or aircraft systems conditions which require immediate corrective or compensatory action by the crew.	Centrally located alphanumeric readout	Discrete sounds, or attention getting tone plus voice	Stick shaker (if required)
2	Abnormal (caution)	Abnormal operational or aircraft systems conditions which require immediate crew awareness and require corrective or compensatory crew action.	Centrally located alphanumeric readout	Attention getting tone	None
3	Advisory	Operational or aircraft systems conditions which require crew awareness and may require crew action.	Centrally located alphanumeric readout	None	None
4	Information	Operational or aircraft systems conditions which require cockpit indication but not necessarily as part of the integrated warning system.	Discrete lights (green, blue and white)	None	None

The recommended guidelines should be interpreted as (1) preliminary, not final, design guidelines, and (2) design objectives, not minimum performance standards. At this time, the recommended design guidelines are only partially substantiated by quantitative data. Additional testing to derive directly applicable human factors data, additional comparative testing of elements of alerting systems, additional comparative testing of full alerting system concepts and an analysis of the hardware/implementation impact of these concepts are required to complete and validate the proposed design guidelines.

2.0 TECHNICAL REPORT

The methods of analysis used in studying this alerting system problem, the data used in and resulting from these analyses, and the conclusions derived therefrom are presented in this section. This study was divided into five tasks:

- Tabulating current alerting methods and requirements
- Establishing alerting function requirements
- Developing a method for categorizing/prioritizing alerting functions
- Developing human factors design guidelines for alerting systems
- Developing recommendations for standardization of alerting functions and methods

The first task consisted of selecting a baseline aircraft configuration for each basic type of turbojet transport used in the U.S., tabulating the physical characteristics of all alerting functions in these aircraft, and analyzing the implementation differences between the various types of aircraft. The second task consisted of reviewing applicable standards, accident data, maintenance and operations records concerned with current alerting systems problems, and checklists in an attempt to establish functional requirements for alerting systems. The third task consisted of numerous discussions with pilot organizations to obtain a consensus of pilot opinions on how an optimum aircraft warning system would be designed and then correlating the results of these meetings with the results of the requirements analyses to develop a rationale for categorizing and prioritizing the alerting functions. In the fourth task, a literature search for human factors data applicable to alerting systems was performed, a survey of human factors data requirements was made, and a set of test plans aimed at obtaining the missing data were developed. The requirements, categorization/prioritization rationale, and existing human factors design guidelines were then combined to develop recommendations for standardization of alerting methods. The details of each of these subtasks are presented in the following sections.

2.1 CURRENT ALERTING METHODS

A data base consisting of tabulations of the characteristics of the alerting subsystems in each basic type of commercial turbojet transport airplane was established to analyze differences between various types of aircraft and to correlate pilot comments with specific design features. From these analyses, alerting system characteristics that appear to be either good and should be retained, or bad and should be avoided were discerned. Descriptions of the data base, analyses, and results of this effort follow.

2.1.1 BASELINE AIRCRAFT CONFIGURATIONS

Aircraft types used by each major U.S. and European airline were tabulated as shown in table 2. The quantity of each type of aircraft operated by several of these airlines was also tabulated. From this tabulation, aircraft from several airlines operating a broad range of aircraft and a significant number of each type of aircraft were selected to use as baseline configurations. The airlines and aircraft selected for this purpose are specified in table 3. Airbus (A300) and Concorde data also were sought but were not available in sufficient detail to be useful to this study.

Table 2 Aircraft Types Used by Airline

AIRLINE	707/720	727	737	747	DC-8	DC-9	DC-10	L-1011	BAC-111	A-300	CON – CORDE
AMERICAN	X	X		X	X		X				
BRANIFF		X		X	X						
CONTINENTAL	X	X		X			X				
DELTA		X (62)		X (3)	X (34)	X (62)		X (18)			
EASTERN		X			X	X		X			
NATIONAL		X		X			X				
NORTHWEST	X (11)	X (55)		X (18)			X (22)				
PAN AMERICAN	X (78)	X (15)		X (30)							
TWA	X (72)	X (74)		X (12)		X (10)		X (18)			
UNITED		X (146)	X (46)	X (18)	X (33)		X (37)				
WESTERN	X (22)	X (21)	X (25)				X (6)				
AIR CANADA		X		X	X	X		X			
ALITALIA				X	X	X	X				
ALLEGHENY						X (43)			X (31)		
BRITISH AIRWAYS	X			X				X	X		X (5)
CANADIAN PACIFIC AIR		X	X	X	X						

DATA SOURCE:

WORLD COMMERCIAL AIRCRAFT INVENTORY
(DATA AS OF JUNE 30, 1975)
DOUGLAS AIRCRAFT COMPANY

NOTE: 1. X INDICATES AIRLINE USES THIS TYPE AIRCRAFT
2. ( ) INDICATES NUMBER OF AIRCRAFT OF THIS TYPE OPERATED BY THE AIRLINE.

Table 2 Aircraft Types Used by Airline (Cont)

AIRLINE	707/720	727	737	747	DC-8	DC-9	DC-10	L-1011	BAC-111	A-300	CON – CORDE
IBERIA		X		X	X	X	X				
IRAN AIR	X	X	X	X							
JAL		X		X	X		X				
KLM				X	X	X	X				
LUFTHANSA	X (19)	X (29)	X (28)	X (5)			X (9)			X (3)	
AIR FRANCE	X	X	X	X						X (6)	X (4)
OLYMPIC	X	X		X							
PACIFIC WESTERN	X	X	X								
SAA (S. AFRICA)	X	X	X	X							
SABENA	X	X	X	X			X				
SAS				X	X	X	X				
SAUDIA	X										
SINGAPORE	X		X	X							
SWISS AIR				X	X	X	X				
VARIG	X	X	X	X							

DATA SOURCE:

WORLD COMMERCIAL AIRCRAFT INVENTORY
(DATA AS OF JUNE 30, 1975)
DOUGLAS AIRCRAFT COMPANY

NOTE:
1. X INDICATES AIRLINE USES THIS TYPE AIRCRAFT
2. ( ) INDICATES NUMBER OF AIRCRAFT OF THIS TYPE OPERATED BY THE AIRLINE.

Table 3 Aircraft Types Selected for Data Base

Aircraft	Baseline Airline(s)
707-720	TWA
727	TWA
737	Western
747	TWA
DC-8	United
DC-9	TWA
DC-10	Western
L-1011	TWA
BAC-111	Allegheny

Ideally all aircraft used in developing the baseline configuration data would have been from one airline to eliminate airline-to-airline differences from the data. A mixture of airlines had to be used because no single airline operated all the aircraft covered by the study. This mixture of aircraft from several airlines caused small biases in the comparative data that reflect airline differences, not basic aircraft differences. Comparisons of the alerting system features in various aircraft from one airline should be valid, but comparisons between aircraft from several airlines must be made with cognizance of these differences. In general therefore, *comparisons of the aircraft alerting systems data must be analyzed with caution.*

2.1.2 ALERTING FUNCTIONS

Aircraft system malfunctions and operational situations for which alerts are provided vary as a function of the size of the aircraft, type of operations for which the aircraft is used, and cockpit design features specified by the first major customer of each new aircraft type. As an example, a four-engine 747 might be expected to have approximately twice as many alerts as a two-engine 737 because both aircraft were designed during the same time period (1964-1968). However, the 747 has substantially more than twice the number of alerts of the 737. The differences are due to the groundrules to which the cockpits were designed:

737 Significant automation of systems controls to be compatible with the workload capabilities of a two-man crew

747 Maintain similarity with 707 cockpit to allow easy transition of senior 707 crews to the 747

Because these variations are not predictable, a detailed tabulation of the type of alerts used for each function in these aircraft was constructed.

The alerting function tabulations specify the number and type of alerts used for each function. A sample of this tabulation is provided in figure 1. The complete tabulation is provided in appendix A.

Three new terms requiring definition have entered the discussion now, i.e., alert, alerting function, and alerting devices. An alert is the activation of any aural alarm, indicator light, or flag. The term alert includes the situation wherein a pointer or tape on an analog indicator displays a parameter value in the green, yellow, orange, or red band range. Alerting functions are the operational situations or aircraft system conditions annunciated to the crew. More than one alerting function generally exists for each basic alerting situation. The 727, for example, has three alerting functions for engine fire warning. Alerting devices are the physical devices used to annunciate alerts. Note that a separate alerting device is not provided in the cockpit for each alerting function specified in the tabulation. In many cases, a specific alerting device will perform several alerting functions. An example of this type of situation is a multicolor light that illuminates green to indicate a system is ON and amber to indicate the system is armed or has malfunctioned. Therefore each aircraft type would in general have fewer physical alerting devices than alerting functions.

2.1.3 CHARACTERISTICS OF ALERTING SIGNALS

No consistent utilization philosophy has been applied to the alerting systems in the types of aircraft covered by this study. Even within each airframer's product line of aircraft and each operator's aircraft, numerous inconsistencies in the utilization of the alerting systems appear. These differences were analyzed by searching the alerting function tabulations for comparable alerting situations and noting the similarities or differences. The rationale behind obvious differences was then investigated. These observations were combined with analyses of several dissections of the data in the alerting function tabulations. In particular the alerting systems data were dissected to analyze the following characteristics of the alerts:

- Operational distribution
- Mechanical distribution
- Color distribution
- Aural alert applications
- Color of visual alerts associated with aural alerts
- Aircraft systems causing the proliferation of alerts
- Effects of a master caution and master warning subsystems on the overall alerting system design
- Effects of alert prioritization and inhibits on the overall alerting system design

The results of these analyses were then combined to develop guidelines for categorizing/prioritizing and designing alerting systems in future aircraft. Each of these analyses is discussed individually in the following sections.

Fire protection (sheet 1)

	Alerting function	Type of alert								
		707/727	727	737	747	DC-8	DC-9	DC-10	L-1011	BAC-111
1	Master fire warning	Bell	2 fl red lts & bell	2 red lts & bell	2 red lts & bell	2 red lts & bell			2 red lts & bell	
2	Fire extinguisher bottle discharged	4 amb lts	2 amb lts	3 amb lts	11 blu & 11 amb lts	4 amb lts	2 amb lts	6 amb lts	8 amb lts	
4	Engine and APU fire extinguishing system circuits ok								8 amb lts	
5	Engine and APU fire detection system activated (test)		6 amb lts				6 amb lts	8 amb lts	1 fl amb lt & 8 amb lts (* 17 & 24)	
6	Wheelwell fire detection system activated (test)								2 amb lts	
7	Engine overheat			2 amb lts		4 yel/red bands	2 yel/red bands	3 amb lts & 3 yel/ red bands	3 red lts & 3 fl red lts	2 red lts
8	Engine overheat detection system circuits ok								2 wht lts	
9	Galley smoke								1 fl amb lt (* 10) & tone	
10	Galley overheat							1 amb lt & horn	1 amb lt (* 9) & tone	
11	Nacelle/pylon overheat				4 yel/red bands				3 fl amb lts	
12	Engine fire	4 red lts		3 red lts	4 red lts	4 r[illegible]		4 red lts	3 red lts	

* Same as

Figure 1 Alerting Function Tabulation Example

2.1.3.1 Operational Distribution of Visual Alerts

Three alert classifications, defined in table 4, were established to allow analysis of differences in the operational distribution of visual alerts.

The term "bands" in these definitions includes radial arcs and "tick marks" on round dial and pointer displays, and linear bands on horizontal or vertical scale displays.

Some engineers contend that since instruments and advisory/status lights are often functionally interchangeable, all informational functions contained within the instruments also should be tabulated under the advisory/status alert classification. However, basic instruments do not pollute the visual environment of the alerting system in the same manner as extraneous lights or flags. Only the parameter limit information (bands) on the instruments was considered to have a significant impact on the visual effectiveness of the alerting system. Thus the basic informational functions of the instruments were not included in these analyses.

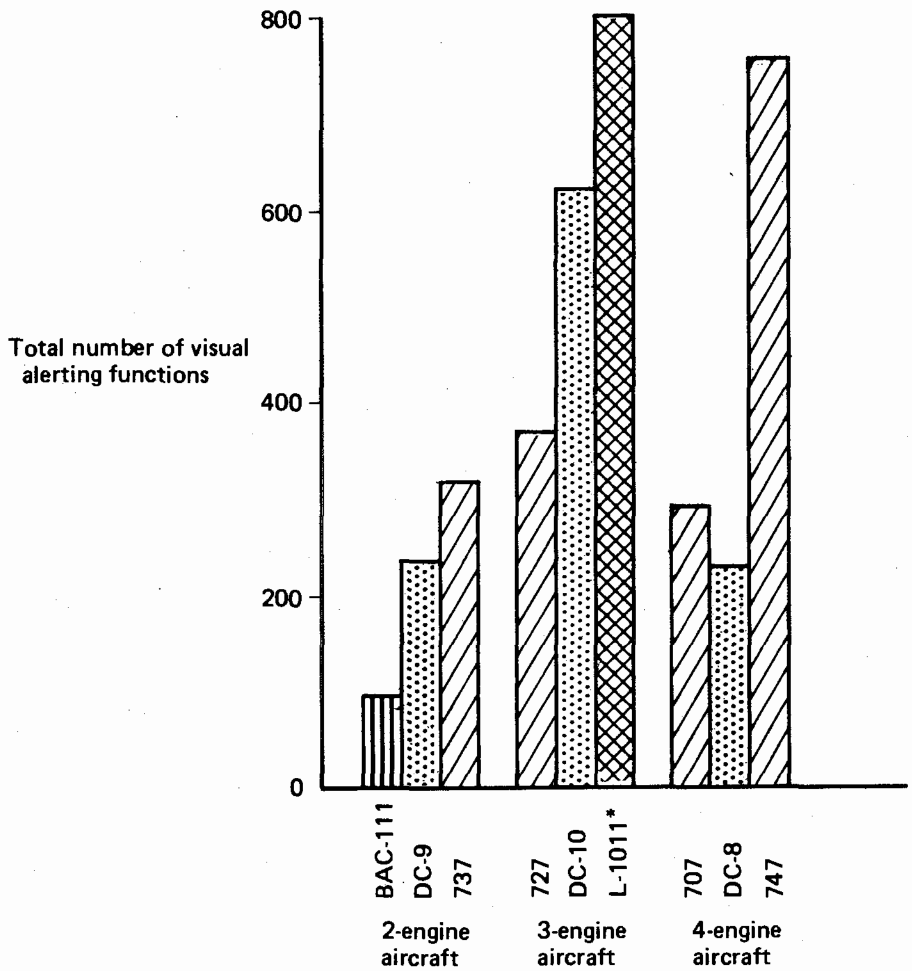
Figures 2 and 3 specify the total number of alerting functions on these aircraft and the historical application of these alerts. Figures 4 and 5 specify the number of visual alerting functions on each basic type of aircraft that fall within each of these classifications and the ratio of visual alerting functions in each classification. These data are also presented in tabular form in appendix B (tables B-1 and B-2).

Analyses of these data for alerting system differences as a function design vintage, aircraft size, and types of usage were made. The number of engines on these aircraft was used to group the aircraft into usage categories. These usage categories were selected because, in general, two-engine aircraft are used on short-haul operations, three-engine aircraft are used on medium-range operations, and four-engine aircraft are used on long-range operations. These categories also conveniently provide groups of aircraft with a similar number of onboard systems, e.g., same number of hydraulic systems.

Figures 2 and 3 illustrate that at least among the two-engine aircraft, the number of visual alerting functions increased with each new aircraft type. The question that arises is whether this increase was due to an increase in the number of regulatory requirements or basic philosophical differences between the manufacturer's cockpit designers. A quick survey of the FARs indicated that a significant number of new regulations that affected alerting systems evolved between the BAC-111 and 737 design eras. The DC-9 was designed 2 years after the BAC-111 and the 737 was designed 4 years after the BAC-111; however, not all this increase was due to new regulatory requirements. Thus the growth in the number of alerting functions as a function of time among the two-engine aircraft is attributed to both differences in the airframers' cockpit design philosophies and new regulatory requirements.

Table 4 Alert Type Classifications

Classification	Alert types included in classification
Warning	Red lights, red or orange flags and red bands
Caution	Amber or yellow lights, flags or bands
Advisory/status	Green, blue or white lights, flags or bands



*L-1011 utilizes lighted pushbutton switches with color modes to indicate switch state in place of toggle switches.

Figure 2 Number of Visual Alerting Functions on Each Basic Aircraft Type

Among the three-engine aircraft, a similar trend toward increasing the number of alerting functions was noted. In general, the 727, DC-10, and L-1011 have the same number of systems of each type, e.g., all have three main electrical generator systems. However, in a few cases, such as air conditioning, the number of channels was increased from two for the 727 to three for the DC-10 and L-1011. Their difference in size (narrow body 727 versus wide body DC-10 and L-1011) may have influenced these statistics. The increased use of late technology and more complex systems may also have attributed to the growth in the number of alerting functions. As an example, on McDonnell Douglas aircraft, all narrow body aircraft had a mechanical flap blow-back system; the DC-10, for weight-savings reasons, utilized a more complex but lighter electronic flap blow-back system. Two additional annunciator lights were required with the electronic system. Additionally, between the 727 and DC-10/L-1011 design eras, a significant number of regulatory requirements were added. The interaction between these factors is not known; the increase in the number of visual alerting functions among three-engine aircraft must be attributed to all these factors.

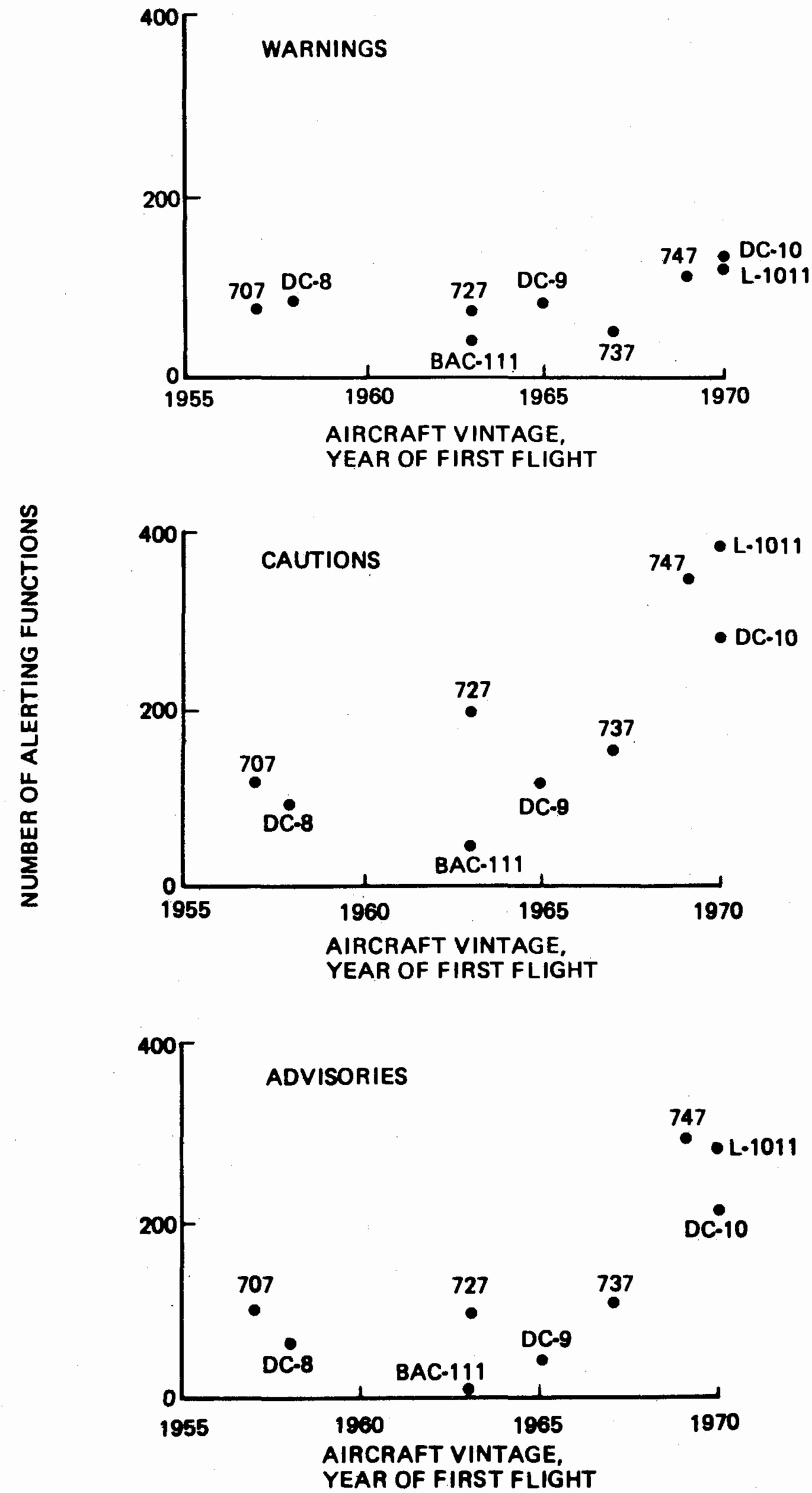
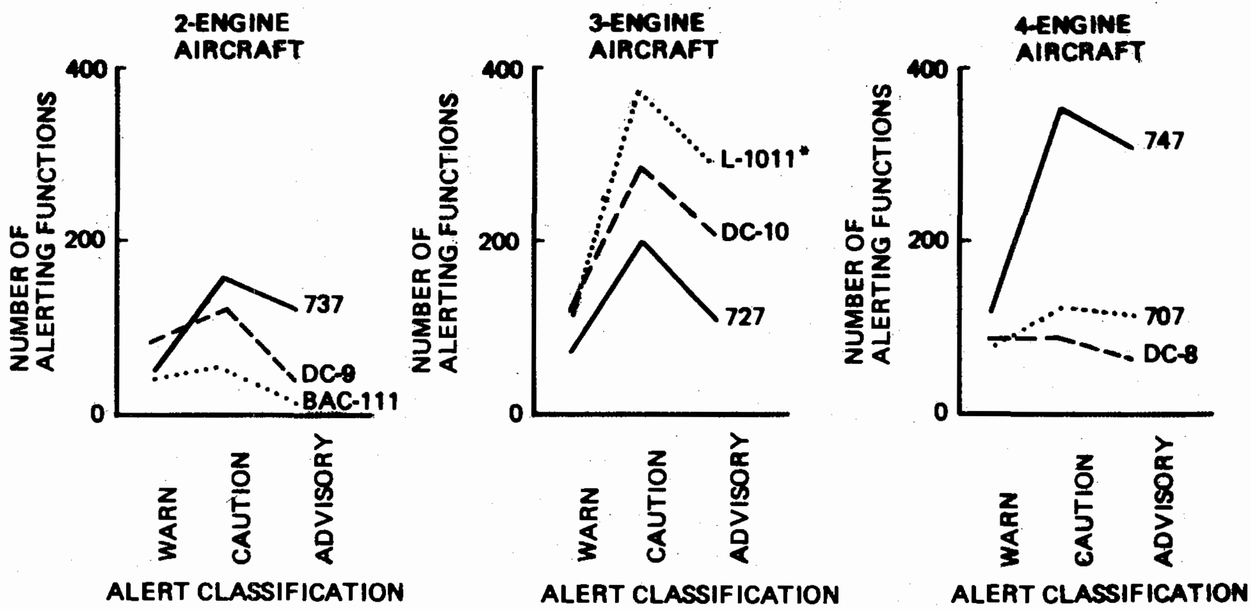
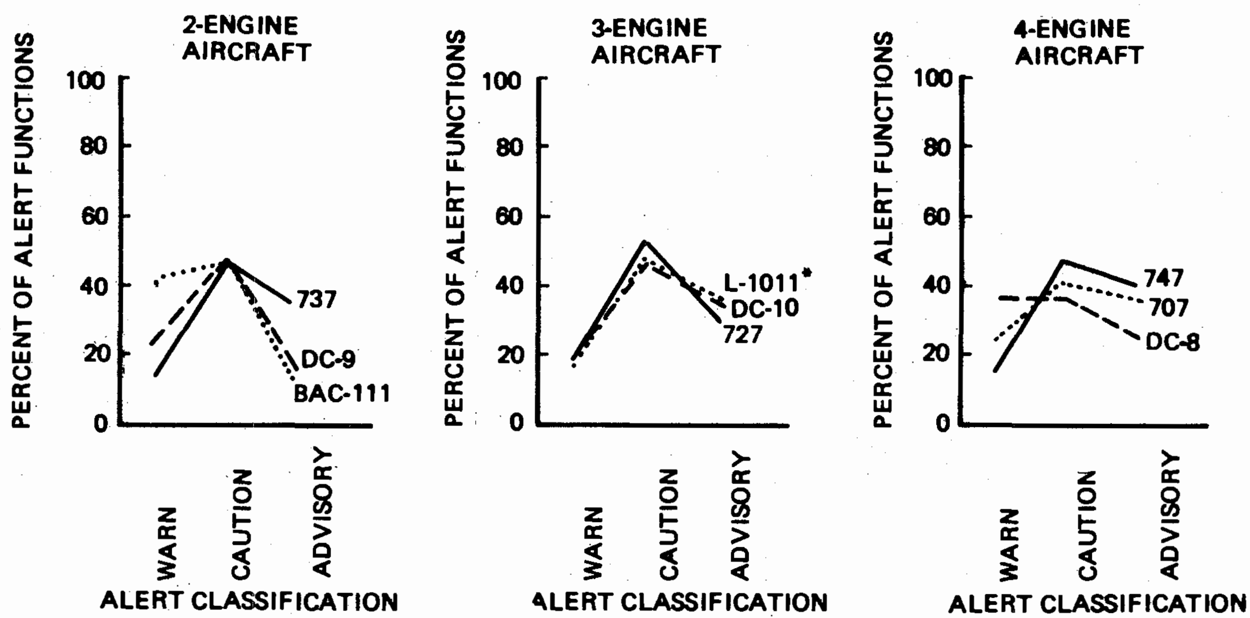


Figure 3 Application of Alerts as a Function of Operational Significance and Aircraft Vintage



*L-1011 utilizes lighted pushbutton switches with color modes to indicate switch state in place of toggle switches.

Figure 4 Operational Distribution of Visual Alert Functions



*L-1011 utilizes lighted pushbutton switches with color modes to indicate switch state in place of toggle switches.

Figure 5 Percentage Distribution of Visual Alert Functions Among Operational Classifications

The 707 and DC-8 were designed with approximately the same number of alerting functions. The 747, which was designed 12 years later, emerged with a significant increase in the number of alerting functions. In general, the 747 required more channels of each type of system than the 707 or DC-8. This was primarily because of its massive size as compared to the 707 or DC-8. McDonnell Douglas claims that a significant portion of the increase in the number of alerting functions on the wide body aircraft is attributable to the application of modern weight-savings technology. More complex but lighter systems were often used to save weight on the wide body aircraft. The wide body aircraft also had to contend with a significant number of new regulatory requirements that emerged between 1957 and 1969. Therefore, the cause of the increase in the number of alerting functions among the four-engine aircraft can be attributed to the size of aircraft, use of more complex systems on the wide body aircraft to save weight, and additional regulatory requirements.

In the foregoing discussion it was concluded that the number of alerting functions in the cockpit increased as a function of time. The question that arises is "what type of alerts were added and how did the alert distributions change with these additions?" The data presented in figures 4 and 5 for two-engine aircraft indicate that the DC-9 and 737 designs incorporated substantially more caution and advisory alerts than the BAC-111. All three aircraft rely approximately equally on caution-type alerts as shown by the percentage distribution curves. However, the BAC-111 alerting system design relies heavily on warning functions whereas the 737 relies heavily on advisory functions.

Among the three-engine aircraft, a significant growth in the number of alerting functions from the 727 to the DC-10 and L-1011 is again noted in these data. However, the ratio of warnings-to-cautions-to-advisories did not change appreciably.

Note that many of the advisory functions in the L-1011 data have no equivalent alerting function in the 727 or DC-10 because the L-1011 cockpit design utilized lighted pushbutton switches with color or ON/OFF illumination modes to indicate switch state in place of conventional toggle switches. These lighted pushbutton switches were generally considered to be advisory-type alerting functions whereas the toggle switches were presumed to have no alerting function. If these functions on the L-1011 were deleted from the data so as to get more equivalent sets of data, the L-1011 would have heavier reliance on warning and caution functions than the 727 or DC-10.

The increase in the number of alerting functions from the 707/DC-8 aircraft to the 747 is also evident in the four-engine aircraft data presented in figure 4. The 747 alerting system design incorporates approximately the same number of warnings, substantially more cautions, and also substantially more advisories. On a percentage distribution basis, the 747 relies the least of any four-engine commercial transport on warning functions, approximately the same as older designs on caution-type alerts and more heavily on advisory-type alerts than older four-engine transports.

From these analyses three significant factors were noted:

- Each new aircraft has incorporated more alerting functions than previous similar aircraft because of:

  (1) Differences in the operators' alerting system utilization philosophies

  (2) Differences in the airframers' cockpit design philosophies

  (3) Additional regulatory requirements

(4) Increased size of the later vintage aircraft

(5) Use of more complex systems to save weight

- Number of warning-type alerts used in commercial turbojet transport aircraft nearly doubled in the transition from narrow body aircraft to wide body aircraft.

- Number of caution- and advisory-type alerts used in commercial turbojet transport aircraft has increased substantially with each new aircraft design.

2.1.3.2 **Mechanical Distribution of Alerts**

Trends in the type of mechanical devices used to present the alerts were analyzed by dissecting the alerting function information into the following categories:

- Distribution of the alerts between lights, aurals, flags, and bands as a function of type of aircraft operation (short haul, medium range, long range), aircraft size, and aircraft vintage.

- Amount of multifunctioning of the alert devices.

From these analyses, characteristics of the alerting systems that are considered good and should be retained, or causing problems for the pilots and should be eliminated, were sought.

Figure 6 specifies the number of alerting functions to which each basic type of alerting device has been applied. Figure 7 presents the same data as a function of aircraft vintage. In the analysis of these data, it was noted that among two-engine short-haul aircraft, the 737 and DC-9 alerting systems incorporate significantly more lights and bands than the BAC-111. However, the application of aurals and flags is approximately equal in these two-engine aircraft.

The difference in the number of lights incorporated in these cockpits is due primarily to the cockpit design philosophy applied to these aircraft. The design philosophy on the BAC-111 appears to have been "keep the cockpit very simple—give the pilots just enough information to fly the airplane, don't provide detailed subsystem operation information that the pilots have no control over, and don't burden them with maintenance information." In contrast to this philosophy, the DC-9 and 737 cockpits appear to have been designed to provide the crew with more detailed subsystem information (more lights and bands) so that the pilots can try to resolve malfunctions in flight and can record better maintenance data. Additionally, the DC-9 and 737 had to meet more regulatory requirements as noted earlier.

The three-engine aircraft data indicate that discrete lights were used in place of round dial instrument alert bands on the L-1011. The newer wide body three-engine aircraft also used more flags than older narrow body aircraft. This is probably due to more complex autopilot and avionics systems.

The four-engine aircraft data indicate similar trends. The increase in the number of alerting functions on the 747 over 707/DC-8 vintage aircraft occurred primarily in the number of lights used to annunciate detailed subsystem information. A slight decrease in the number of colored bands used to annunciate alerts accompanied this increased dependence on discrete alert lights.

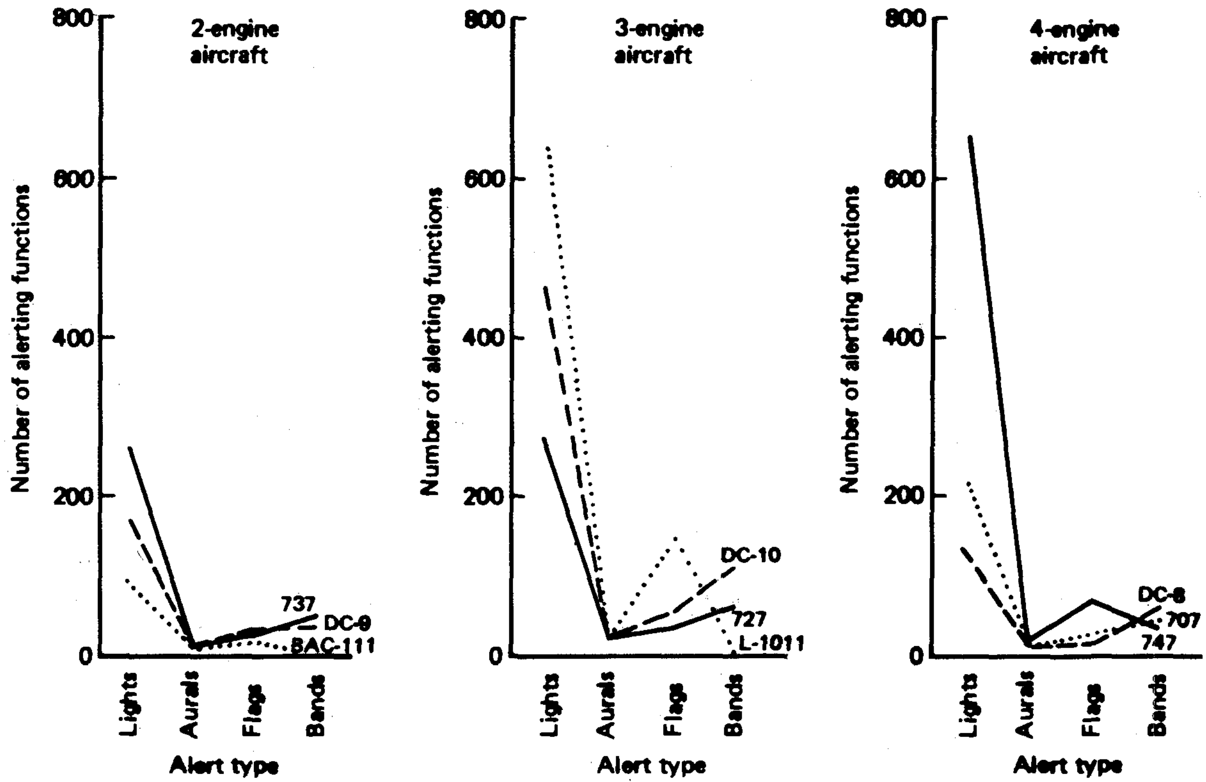


Figure 6 Mechanical Distribution of Alerting Functions

The total number of alert lights, aurals, flags, and bands may have changed significantly from one aircraft to another. However, the proportionate mixture of types of alerting devices did not change significantly between aircraft. Figure 8 illustrates this situation for alert lights.

The aircraft vintage data presented in figure 7 indicate that among the narrow body aircraft no significant change in the number of alert lights, aurals, flags, or bands occurred. Aircraft size, types of operation, and vintage had not effect on the design of alerting systems during this era. However, the wide body aircraft utilize substantially more alert lights and flags than narrow body aircraft. The wide body aircraft also rely slightly more on aural alerts than narrow body aircraft. The use of color bands as alert devices increased with the DC-10, decreased slightly with the 747, and decreased significantly with the L-1011. Thus, in general it can be stated that a trend currently exists toward incorporating more and more alerting devices into the cockpit.

Figures 9 and 10 illustrate the amount of multifunctioning of the alert lights on these aircraft. Multifunctioning is defined as any situation in which an alerting device is used to annunciate more than one hazardous or abnormal situation. The distinctions between the various situations annunciated by a device could be made by any obvious mode change, such as a color change, steady versus flashing or intermittent annunciation, or a change in brightness. The data in these figures indicate that a trend toward more multifunctioning exists. The BAC-111 and 727 did not utilize multifunctioning whereas the wide body aircraft used considerable multifunctioning. Increased usage of multifunction alert lights is the result of attempts to crowd more and more information into the cockpit. Available panel space became saturated and multifunction devices had to be used to get the information into the cockpit.

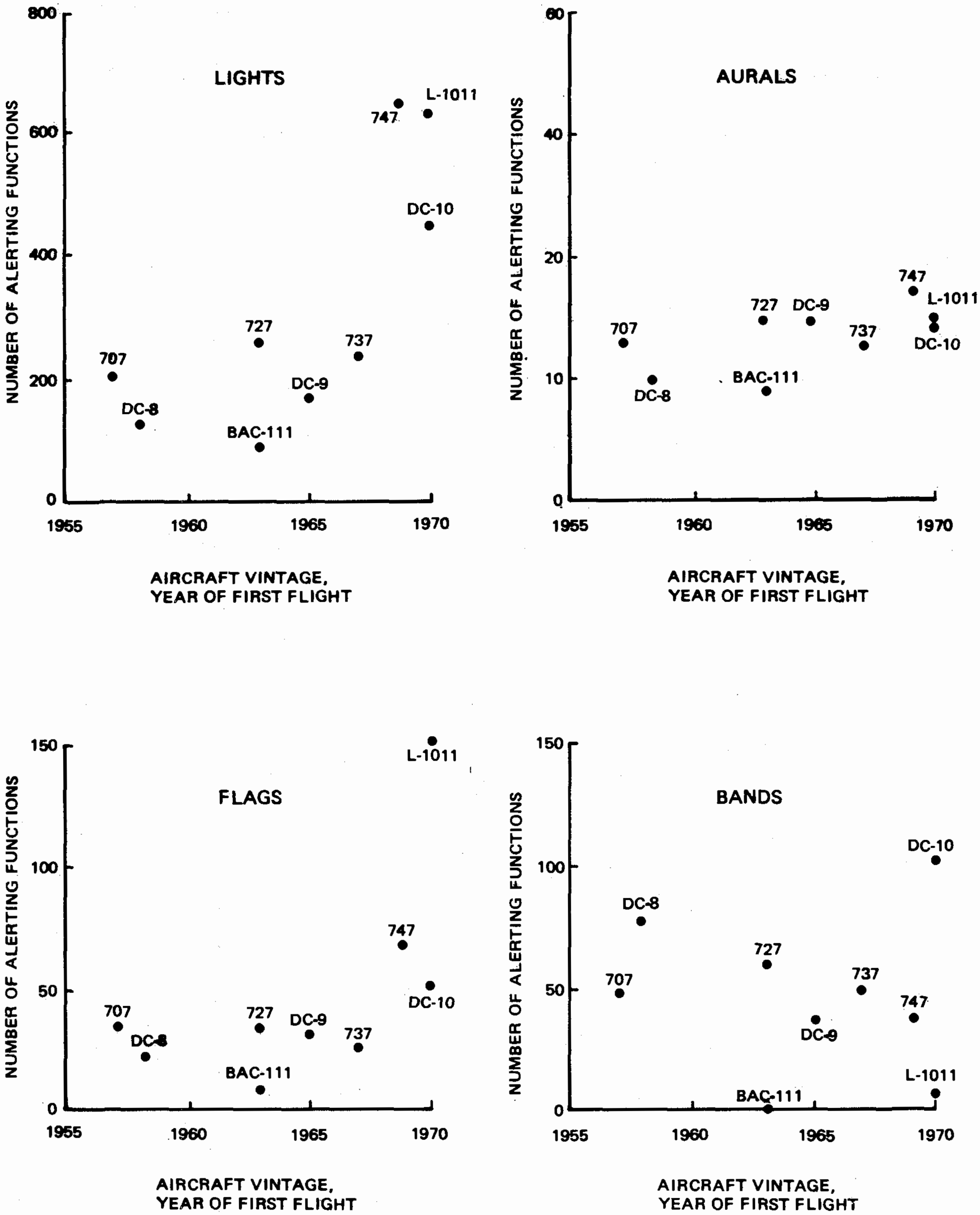


Figure 7 Application of Alerting Devices as a Function of Aircraft Vintage

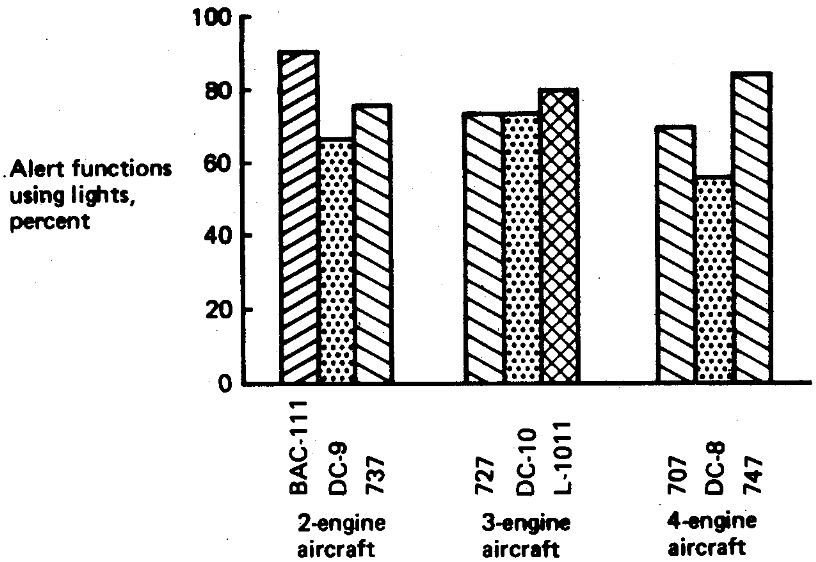


Figure 8 Proportion of Alerts That Use Lights

Based on the results of these analyses, the alerting system utilization philosophies applied to the wide body aircraft appear to have included the following premises/suppositions:

- The crew should perform more system debug and maintenance functions; to do this, more detailed systems information needs to be displayed.
- Multifunction alert devices would not degrade the effectiveness of the alerting systems.
- Discrete alert lights are more effective than analog displays (dial type instruments).
- A slight increase in the large number of already existing aural alerts would not degrade the effectiveness of the alerting system.
- The narrow body aircraft cockpit designs did not saturate the crew. A typical crew can handle substantially more complex situations than exists on narrow body aircraft.

The validity of these premises will be discussed in further detail in later sections.

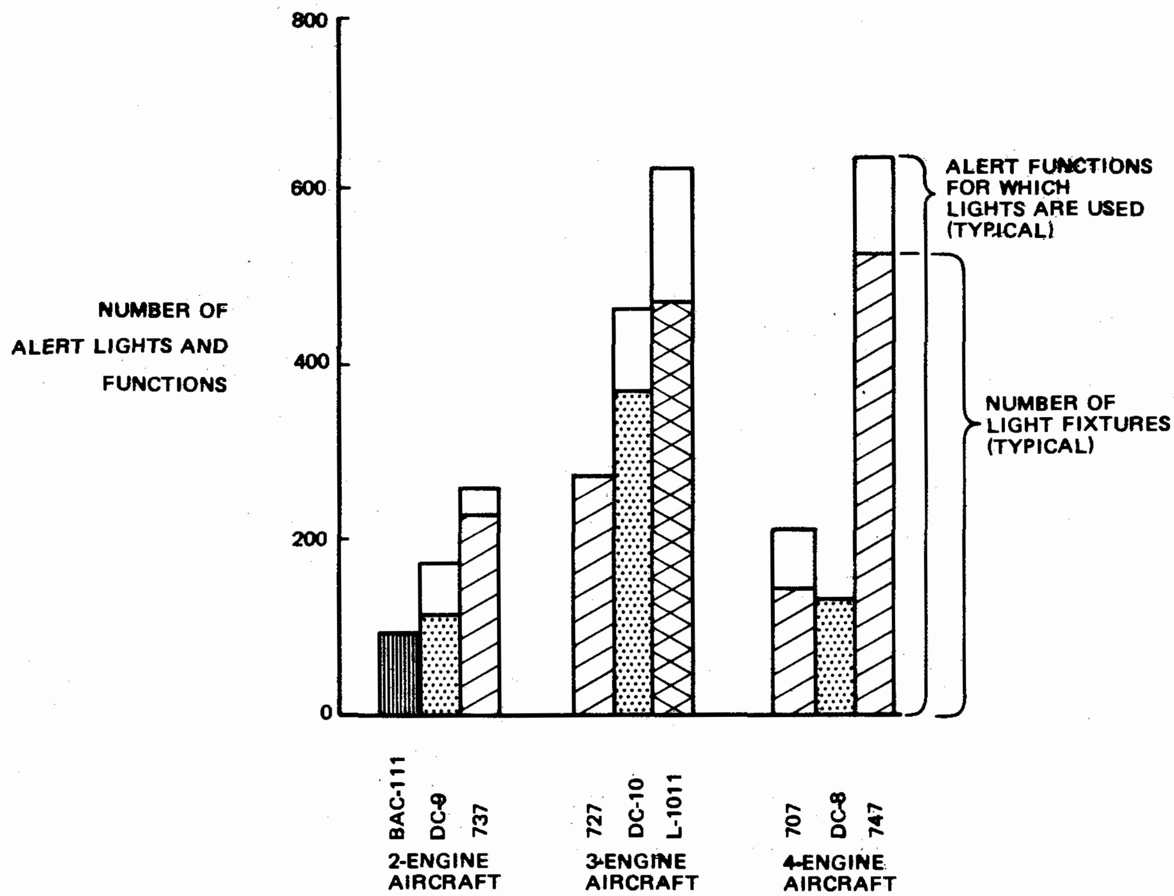


Figure 9 Number of Alerts Using Lights on Each Basic Aircraft Type

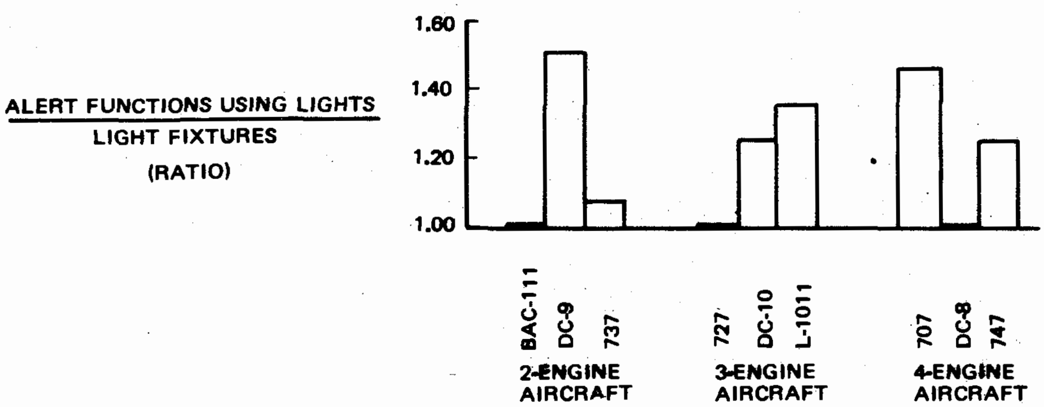


Figure 10 Amount of Multifunctioning of Alert Lights

2.1.3.3 Color Distribution of Visual Alerts

Red, fire orange, and dayglow orange colored alerts are generally used to present warnings; amber and yellow colored alerts are used to present caution; and blue, green, or white colored alerts are used to present advisories and status indications. More specifically, blue alerts usually indicate that something is intransit, green alerts usually indicate that a system is operating satisfactorily and/or has attained a SAFE/GO status; and white alerts usually indicate a system is ON. The distribution of alerts among these colors was analyzed to determine whether a trend toward presenting any particular type of information exists. To perform these analyses, the alerting functions data was again dissected into the type of aircraft operation, size of aircraft, and vintage of the aircraft.

These data are presented in graphical form in figures 11 through 14 and in tabular form in appendix B (table B-3).

The data in figure 11 indicate the following significant factors:

- Essentially no difference between aircraft in the application of red lights
- L-1011 and 747 aircraft rely on amber/yellow lights more heavily than other aircraft
- BAC-111 utilizes very few blue lights
- 737, 747, and DC-10 aircraft rely more heavily on green annunciators than all other aircraft
- L-1011 aircraft use white lights extensively (to replace conventional toggle switch functions)

The data in figure 12 indicate that the wide body aircraft use significantly more red flags than narrow body aircraft and the 707 uses substantially more white flags than other aircraft. The heavy reliance on red flags in the wide body aircraft is due to incorporation of more complex autopilot and navigation systems. The 707 occasionally used white flags where other aircraft generally used red or amber lights.

The data on the application of color bands as alerting devices (figure 13) indicate that the DC-10 utilizes substantially more amber/yellow bands than other aircraft, the L-1011 does not utilize green bands, and L-1011 and BAC-111 aircraft utilize very few bands.

Analyses of the historical application of alert colors (figure 14) revealed significant trends toward more amber/yellow and white lights, more red flags, and fewer red and green bands. The increase in amber lights is due to requirements for more detailed subsystems information in the cockpit. More red flags are being incorporated because of more complex autopilot and navigation systems in the newer aircraft. The traditional red and green bands are being replaced by amber lights.

The following conclusions were derived from these analyses:

- The number of warnings has increased slightly because of red flags that are required to annunciate the new failure modes of more complex autopilots and navigation systems

- Amber and yellow lights are being used more extensively with each new generation of aircraft to annunciate detailed subsystem operations
- A trend toward annunciating more SAFE and GO conditions with green lights exists
- White lighted pushbuttons are being used more extensively in place of toggle switches in each new generation of aircraft.
- Discrete alert lights are being used to replace traditional color bands

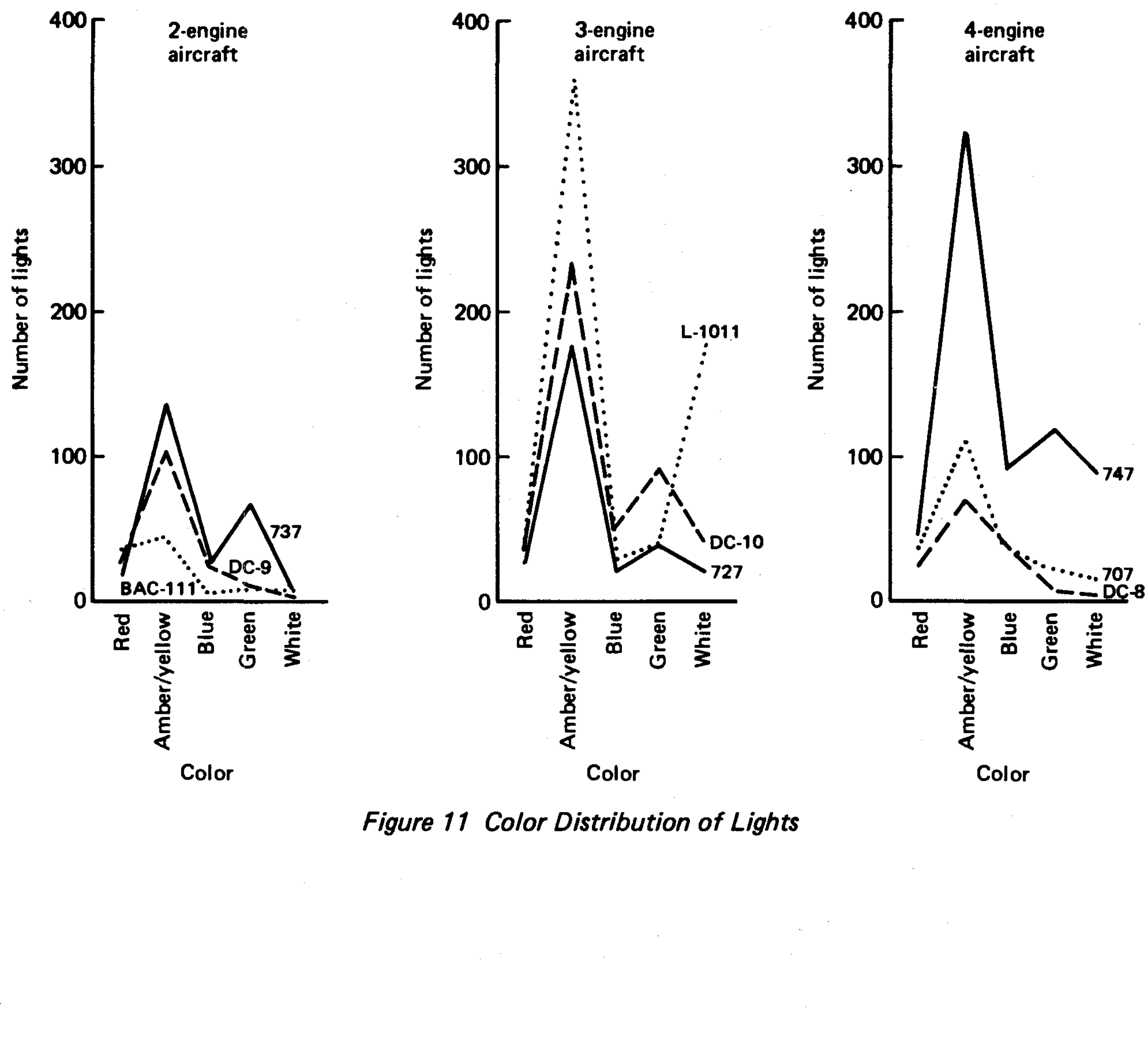


Figure 11 Color Distribution of Lights

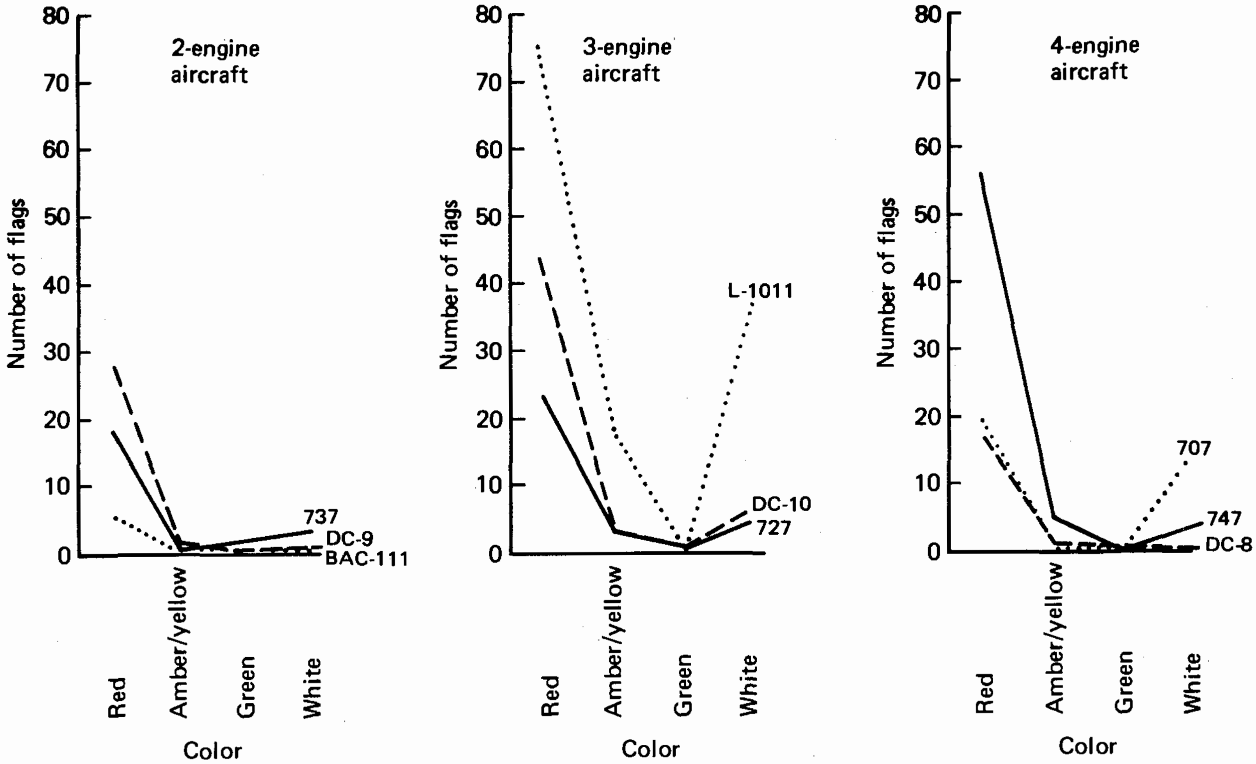


Figure 12 Color Distribution of Flags

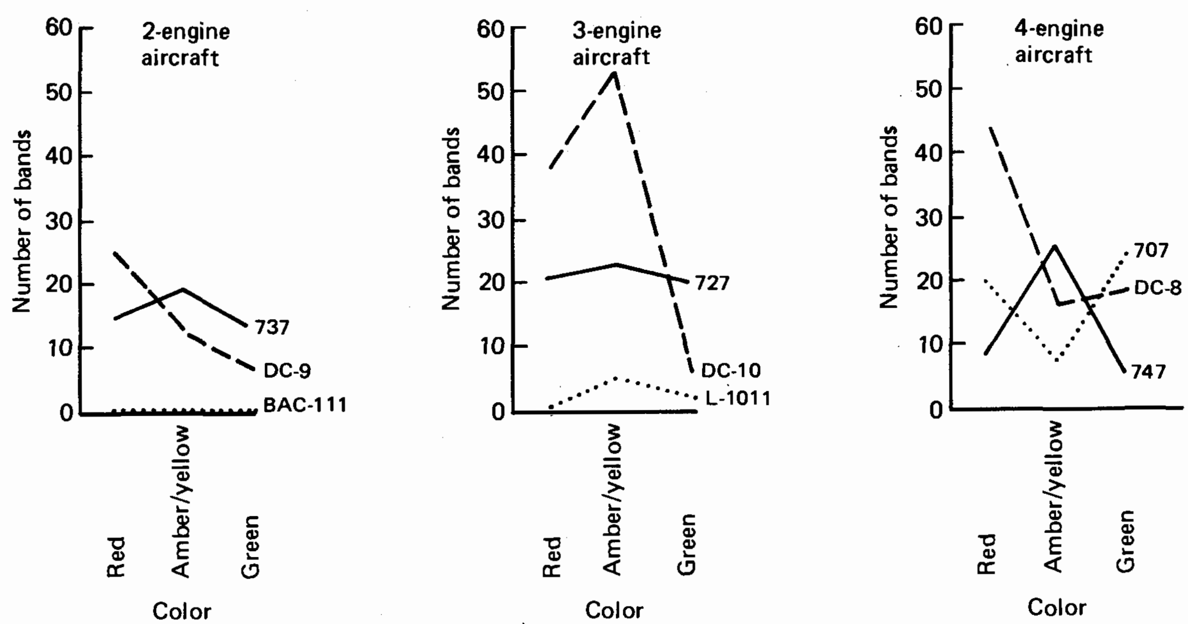


Figure 13 Color Distribution of Bands

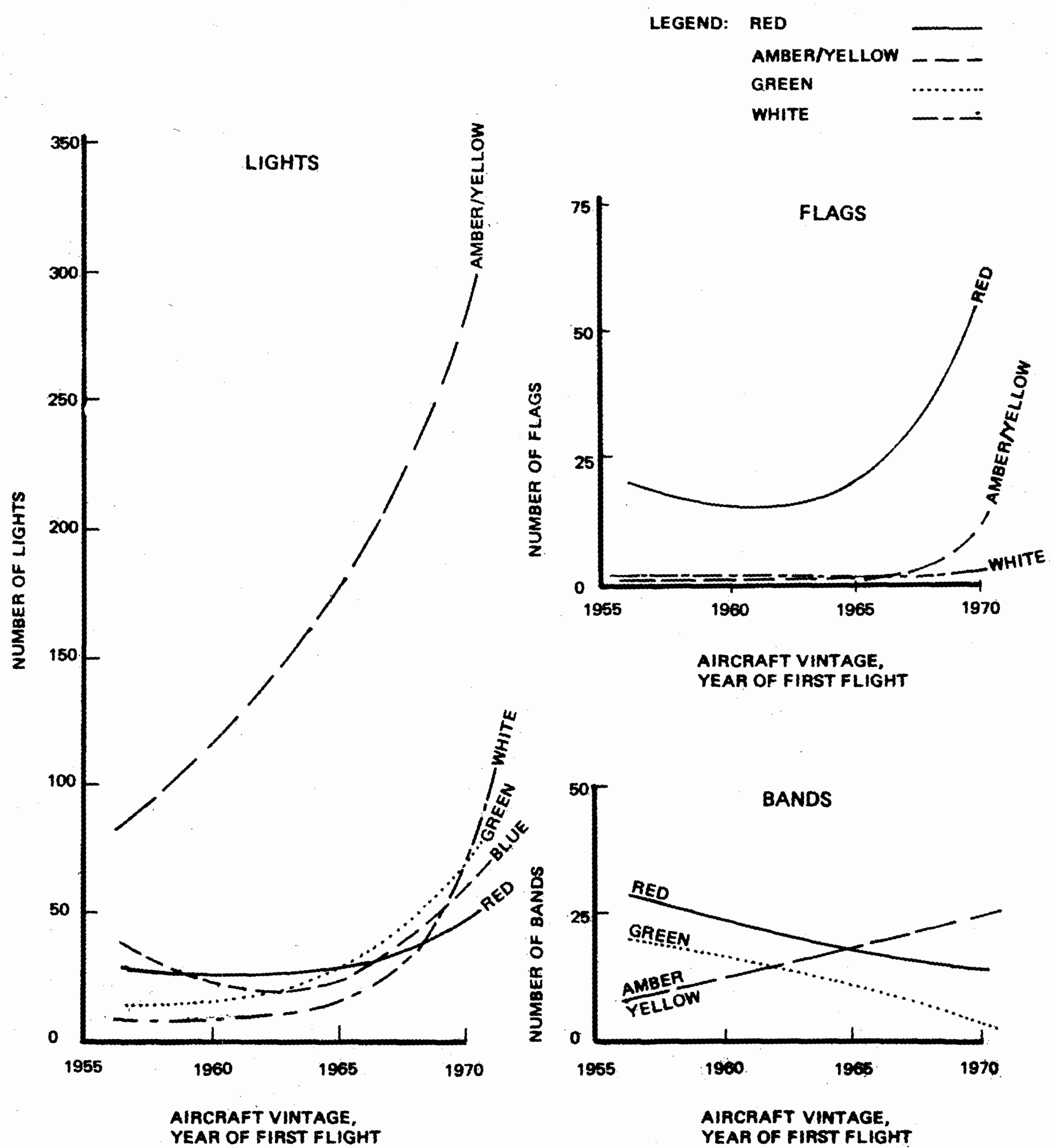


Figure 14 Application of Alert Colors as a Function of Aircraft Vintage

2.1.3.4 Aural Alert Applications

Table 5 provides a listing of the various situations for which aural alerts are used. For each situation listed, the type of aural alert used on each aircraft type is specified. Where it could be determined that no aural alert is provided for the situation, "none" is entered; if it could not be determined, the space is blank.

From this table, it is noted that all aircraft considered in this study use a bell to annunciate an engine fire. However, the characteristics of the bell vary from one aircraft to another. Similar situations exist among all the other aural alerts. Thus, another listing (table 6) that describes the frequency, loudness, and continuity characteristics of each specified aural alert is provided.

The cockpit ambient noise environment in which these aural alerts must function is specified, as a point of reference, in table 7. The ambient noise levels specified in this table represent the maximum average octave band value within the specified frequency ranges. These values were taken from the cockpit noise curves provided in appendix C.

Examination of these data for (1) consistency of application, (2) factors that may contribute to confusion in the cockpit and should be avoided in the design of future alerting systems, and (3) aural alerts that have been standardized on and should be retained, revealed the following facts:

- No consistent utilization philosophy has been applied to the aural alerts, not even within any airframer's or operator's aircraft.

- The number of aural alerts is increasing. Older narrow body aircraft incorporated 9 to 15 aural alerts and newer wide body aircraft have 14 to 17 aural alerts. Human factors data indicate that pilots can rapidly and accurately interpret only a limited number of discrete aural alerts and that this number decreases as a function of time since recurrent training. The exact number of alerts that the average pilot can effectively recognize is not known. However, the potential for confusion is known to exist currently and should be eliminated.

- A standard appears to have been established for the following aural alerts:

Alert Situations	Type of Aural Alert
Engine fire	Bell
Excessive airspeed	Clacker
Unsafe landing condition	Horn
Unsafe takeoff condition	Horn
Ground proximity	Warbler and voice message or tone and voice message

The specific characteristics of the aural alerts used for each of these situations varies slightly but the basic function appears to be identical in all cases.

Table 5 Summary of Currently Used Cockpit Aural Alerts

Alert condition \ Airplane	707/727	727	737	747	DC-8	DC-9	DC-10	L-1011	BAC-111
	Type of aural alert applied								
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

Table 5 Summary of Currently Used Cockpit Aural Alerts (Cont)

	Type of aural alert applied								
Alert condition \ Airplane	707/727	727	737	747	DC-8	DC-9	DC-10	L-1011	BAC-111
Excessive terrain closure rate	Warbler & voice	Warbler & voice	Warbler & voice	Warbler & voice	Warbler & voice	Warbler & voice	Warbler & voice	Warbler & voice	Warbler & voice
Flap load relieve inoperative	None	None	None	None	None	None	None	Buzzer B	*
Galley overheat	None	None	None	None	None	None	None	Tone E	*
Inadvertent "duck under" GS	Voice	Voice	Voice	Voice	Voice	Voice	Voice	Voice	Voice
Low cabin pressure	Horn E	Horn E	Horn E	Horn F	Horn L	Horn L	Horn H	Horn S	*
Negative climb after takeoff	Warbler & voice	Warbler & voice	Warbler & voice	Warbler & voice	Warbler & voice	Warbler & voice	Warbler & voice	Warbler & voice	Warbler & voice
SELCAL	Chime J	Chime J Chime H	Chime H	Chime K	Chime	Chime	Bell	Chime M	*
Instrument comparator alert	Clacker B	Clacker B	Clacker B	None	None	None	None	None	*
Smoke in cargo area	Bell A	None	Bell A	Bell A	None	None	None	None	*
Smoke in lower galley	None	None	None	None	None	None	None	Tone E	*
Stabilizer in motion	Clacker	Clacker	Clacker	Clacker	Horn J (on -60 models)	Horn K	Horn G	None	*
Unsafe ground condition	None	Horn A	None	None	None	None	None	None	*
Unsafe in-flight condition	None	Horn E	None	None	None	None	None	None	*
Unsafe landing condition	Horn A	Horn A	Horn A	Horn B	Horn C	Horn C	Horn D	Horn R	*
Unsafe takeoff condition	Horn E	Horn E	Horn E	Horn F	Horn L	Horn L	Horn H	Horn S	Horn S
Wheelwell overheat or fire	Bell A	Bell A	Bell A	Bell A	None	None	None	Bell E	*

*Characteristics unknown

Table 6 Aural Alert Characteristics

AURAL ALERT	FREQUENCY, Hz	LOUDNESS, dB	DESCRIPTION
HORN A	200 TO 443	90 ± 5	Continuous
HORN B	220 TO 280	93 ± 5	Continuous
HORN C	635	89	Continuous
HORN D	602 AND 657	85 ± 5	Continuous
HORN E	200 TO 443	90 ± 5	Same as horn A, except interrupted
HORN F	220 TO 280	93 ± 5	Same as horn B, except interrupted at 3 Hz
HORN G	116 AND 259		Continuous
HORN H	602 AND 657		Same as horn D, except interrupted at 1Hz
HORN J	140	91	On 0.5 seconds; off 0.8 seconds in variable-sized groups; 2 seconds between groups
HORN K	60	85	On for 0.5 seconds; off for 1 second
HORN L	635	84 TO 98	Interrupted at 0.6 Hz
HORN M	625	95	Interrupted at 0.6 Hz
HORN N	325 AND 390	94	Tow tones alternating at 0.25 Hz
HORN P			"Ooga" horn
HORN R	300	86	Continuous
HORN S	300	90	333-ms period with a 50% duty cycle
TONE A	1000		Continuous
TONE B	2800 ± 300	90 ± 5	Beeper tone, pulsating at 1.5 to 5.0 Hz
TONE C	800	INCREASING	Tone that increases in volume over a 3-second period
TONE D	400	INCREASING	New system for McDonnell Douglas airplanes, application uncertain
TONE E	1.4 k TO 2.0 K	90	Alternating tone
TONE F	3 k	77	333-ms period with a 50% duty cycle
TONE G	700 TO 1.7 k	90	Pulsating tone
TONE H	1.0 K		Pulsating tone
"C" CHORD A	461 TO 563 567 TO 704 691 TO 845	95 ± 5	Intermittent
"C" CHORD B	512, 640, 768	90	Sound duration 2 seconds
BUZZER A	300, 600, AND 900	90 ± 5	
BUZZER B	90	81	2 seconds
WARBLER & VOICE	400 TO 800	85 TO 96	Three "whoops" per second; followed by voice saying "pull up." Some of the airplanes indicated do not have this system and some have the warbler without voice
WAILER A	130 ± 20 TO 200 ± 30	93 ± 3	2 to 4 Hz of variation between longer and higher frequencies—minimum variation 49 Hz—mod 4.76 Hz
WAILER B	640		
WAILER C	130 TO 200	88	
BELL A	600 TO 10,000	93 ± 5	Continuous
BELL B	750	87	Continuous; striker frequency, 1.8 Hz similar to telephone
BELL C	640 AND 648		Continuous; two tones alternating, striker frequency, 12.5 Hz
BELL D	600 TO 10,000	95 ± 5	Same as bell A, except interrupted

Table 6 Aural Alert Characteristics (Cont)

AURAL ALERT	FREQUENCY, Hz	LOUDNESS, dB	DESCRIPTION
BELL E	100		"Gong" type bell—electrically activated
CLACKER A	1000 TO 2400	86	Modulated at 5 to 10 Hz
CLACKER B			Repetition frequency, 1 Hz
CLACKER C	512		Repetition frequency, 4.76 Hz, sounds like clucking of a chicken
CLACKER D	TWO TONES, CLICKS	84 TO 96	Repetition frequency, 9 Hz
CLACKER E	335	87	Similar to a square wave, modulated with very distinctive clicks at 10 Hz
CLACKER F	2500	86	Two bursts in a 20-ms interval repeated at a 140-ms rate
CHIME A	620	87	Repeating, 1.5 second repetition rate
CHIME B	750	76 TO 84	Single stroke gong-like sound; when mechanics call, interrupted at 0.85 Hz
CHIME C	4700	76	Single stroke gong-like sound
CHIME D	727 TO 947	95 ± 5	"High chime", single stroke gong-like sound
CHIME E	477 TO 497	95 ± 5	"Low chime", single stroke gong-like sound
CHIME F	727 TO 947 AND 477 TO 497	95 ± 5	High-low chime combination of chimes; D and E repeated at a rate of 3 ± 1 Hz
CHIME G	588	95 ± 5	"High chime", single stroke gong-like sound
CHIME H	588 AND 488	95 ± 5	High-low chime not repeated
CHIME J	588 AND 488	95 ± 5	Same as chime H except fast repeat
CHIME K	588 AND 488	95 ± 5	Same as chime H except it does two cycles and stops
CHIME L	727 TO 947 AND 477 TO 497	95 ± 5	Same as chime F except it does two cycles and stops
CHIME M	587	85	Single chime in most configurations
CHIME N	587/487	85	Single high-low chime
CHIME P	487	85	Low chime not repeated
CLICK			Actual sound of disconnect of the autopilot lever

Table 7 Cockpit Ambient Noise Environment

AIRCRAFT	FLIGHT PHASE \ FREQUENCY RANGE, Hz	AMBIENT NOISE LEVEL, dB*			
		0–200	200–1000	1000–4000	4000–10,000
707-720	TAKEOFF	99	93	79	73
	FINAL APPROACH	90	81	75	72
727	TAKEOFF	88	79	66	61
	FINAL APPROACH	87	73	66	61
737	TAKEOFF	88	84	70	66
	FINAL APPROACH	84	82	78	75
747	TAKEOFF	100	83	77	70
	FINAL APPROACH	90	81	76	71
DC-8	TAKEOFF	96	95	79	73
	FINAL APPROACH	85	81	71	67
DC-9	TAKEOFF	84	77	68	51
	FINAL APPROACH	85	72	69	56
DC-10	TAKEOFF	91	91	78	70
	FINAL APPROACH	82	75	67	66
L-1011	TAKEOFF	84	76	75	68
	FINAL APPROACH	84	72	70	63

*VALUES LISTED ARE THE MAXIMUM LEVELS TO OCCUR WITHIN THE SPECIFIED FREQUENCY RANGES

2.1.3.5 Color of Visual Alerts Associated With Aural Alerts

The number of aural alerts has increased to the point where the potential for confusion exists. To avoid confusion over the significance of an aural alert, cockpit designers have augmented them with identification lights. Figure 15 illustrates the type of visual alerts that are activated when aural alerts occur. These data indicate that the best correlation between the aural alerts and red visual alerts exists on the 737. It is generally assumed that aural alerts are used for high priority annunciations and incoming communication alerts. However, these data show that a significant number of amber and yellow alerts indicating caution conditions also are associated with the aural alerts. The blue lights are associated primarily with incoming communication alerts.

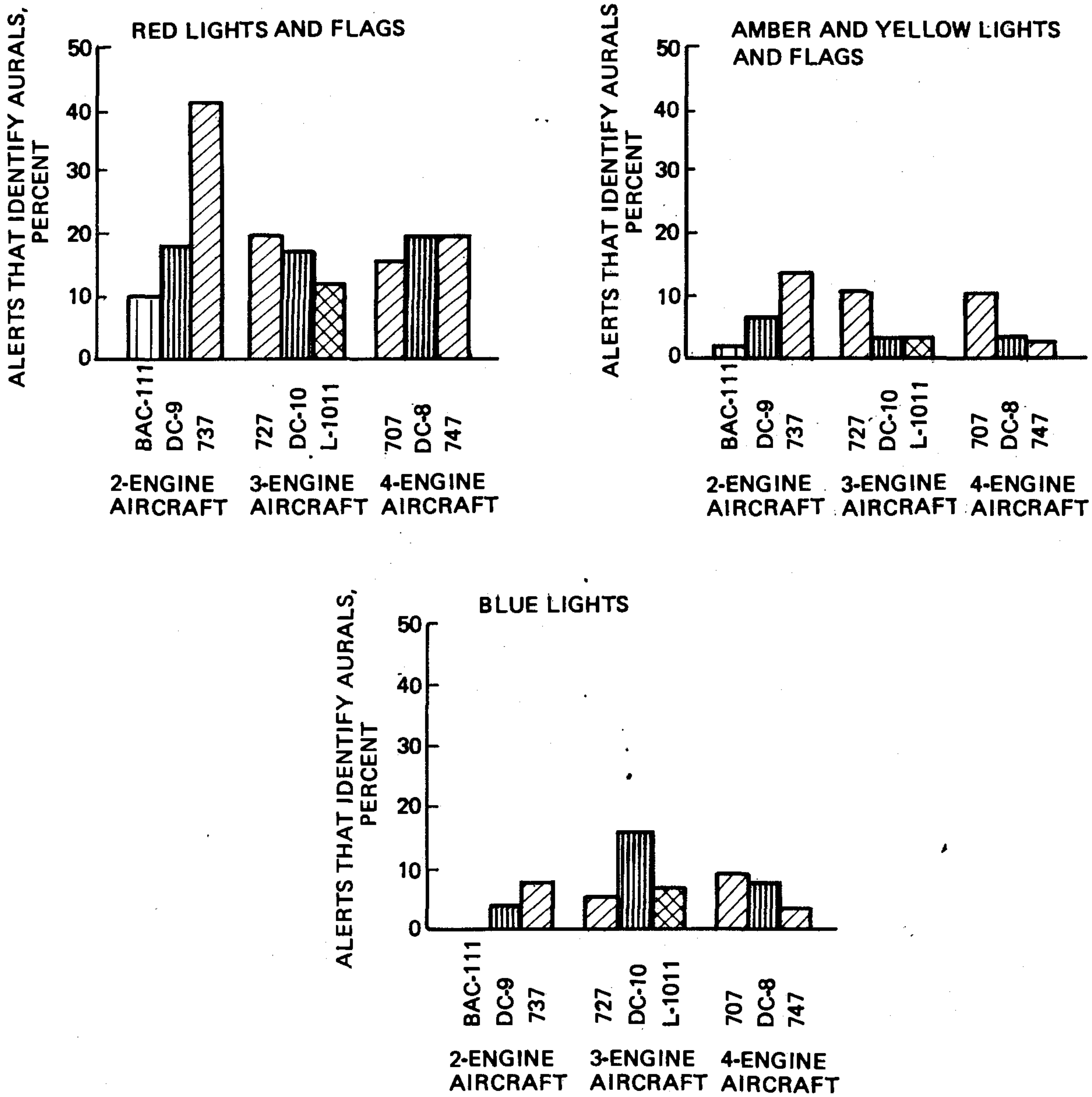


Figure 15 Percent of Lights and Flags Associated with Aural Alerts

Figure 16 specifies the color distribution of visual alerts associated with the aural alerts. The heavy reliance of Boeing 707, 727, and 737 aircraft on amber lights that identify aural alerts is reflected in these data. These data also indicate that DC-8 and DC-10 aircraft utilize significantly blue lights than all other aircraft to help identify aural alerts.

The historical correlation between the growth in aural alerts and the total number of lights and flags to help identify the aurals was analyzed from the data presented in figure 17. These data indicate that all aircraft, except the BAC-111, have multiple lights and flags associated with each aural alert; 727, 737, and DC-10 aircraft have significantly more visual backup lights for each aural alert than similar type aircraft; the BAC-111 relies least of all aircraft on visual backup lights; and the wide body jets rely less than narrow body aircraft on visual backup lights even though they have more aural alerts. All aircraft also were noted to have several aural alerts that operate without visual backup alerts as indicated in table 8.

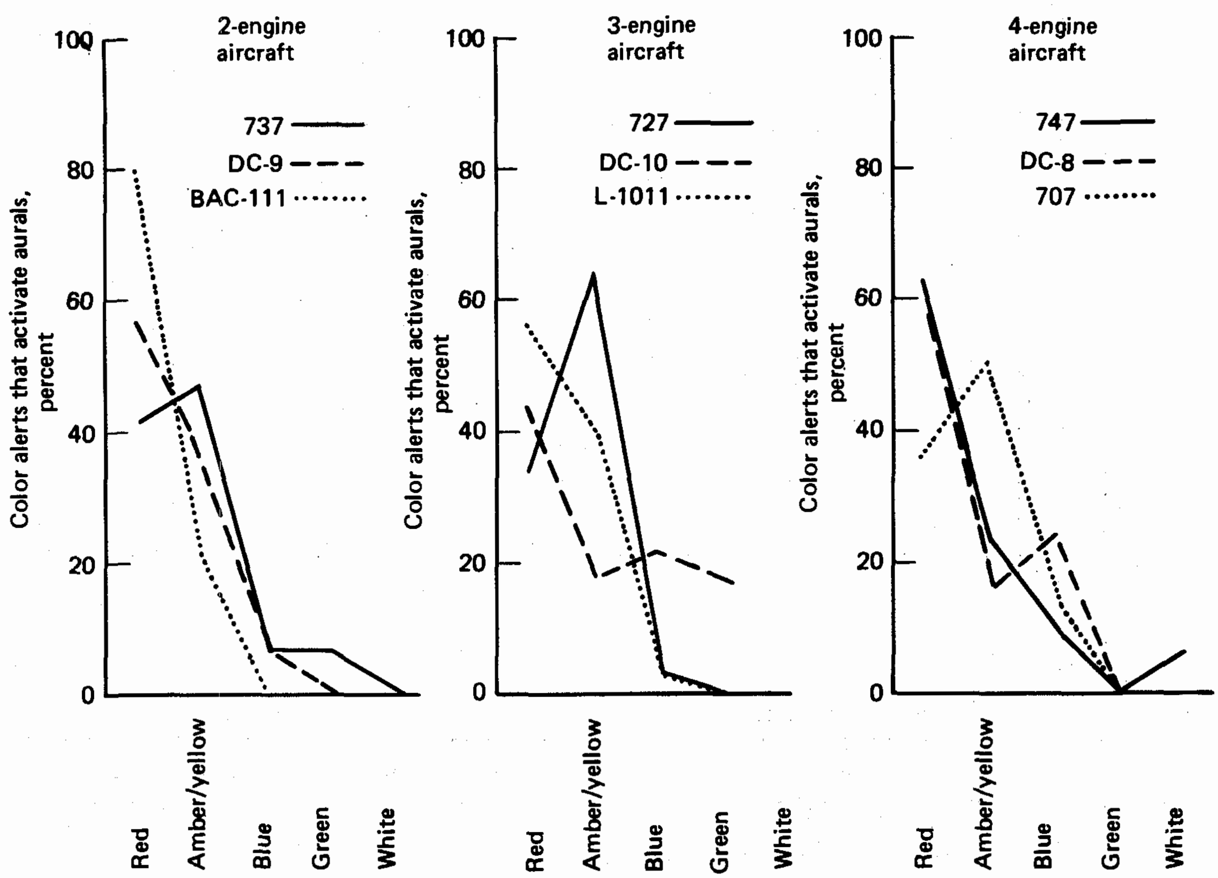


Figure 16 Color Distribution of Visual Alerts That Activate Aurals

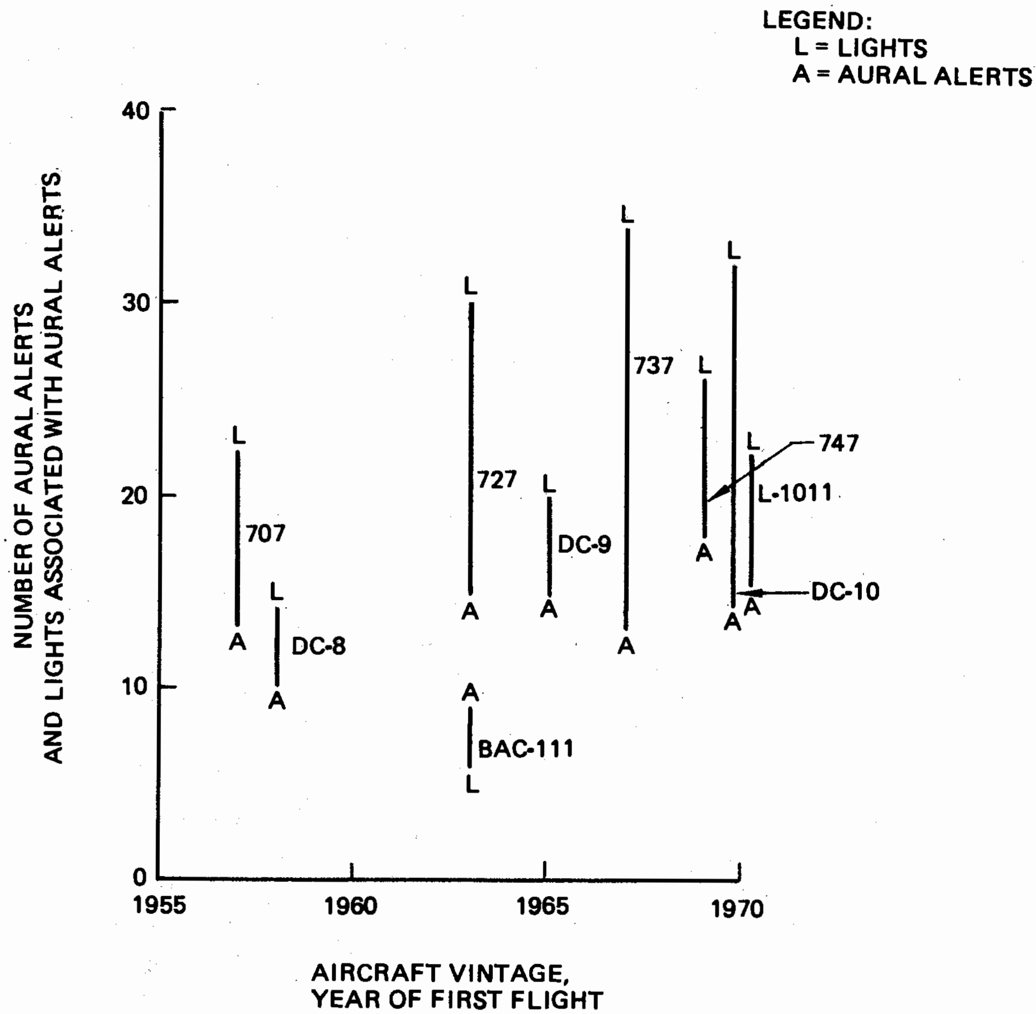


Figure 17 Historical Application of Aural Alerts and Identification Lights Supporting Aural Alerts

Table 8 Application of Aural Alerts Without Visual Backup Lights

Aircraft type	Number aurals without visual backup lights
707	5
727	6
737	3
747	6
DC-8	4
DC-9	3
DC-10	3
L-1011	4
BAC-111	6

2.1.3.6 Aircraft Systems Causing Proliferation of Alerts

Tables D-1 through D-9 in appendix D specify the distribution of alerts used by each subsystem on each basic type of airplane. These data are summarized in figure 18 in a form that illustrates which subsystems are causing increases in the number of alerts. Caution must be used in interpreting the data curves presented in this figure because (1) not all systems incorporated in the newer model aircraft were incorporated in the older model aircraft, e.g., autoland systems; (2) the aircraft developed in the mid-1960s were the midsize and smaller narrow body aircraft as opposed to the larger narrow body aircraft that constitute the data points at the start of the curve and the large wide body aircraft that constitute the data points at the end of the curve. Therefore, if all aircraft were equal, the left end of some curves would be lower than the right end and/or some curves would dip in the middle. A third factor that influences these data is the trades made between presenting systems information via alert lights as opposed to dial-type indicators. For example, on most Boeing aircraft, the air-conditioning and electrical systems require approximately an equal number of functions presented to the pilot. Most of these functions could be presented by either lights or dial-type indicators. However, the electrical systems have transitioned to lights and the air-conditioning systems have retained dial-type indicators without alert bands as the primary method of presenting information. Operating limits are generally downgraded, deemed less critical, if dial-type indicators are used. Thus electrical systems would be more likely to show a proliferation of alerts than air-conditioning systems. Cognizance of all these factors and the magnitude of influence of these factors is required when interpreting these data.

Examination of these data reveals that the most rapid growth in the number of subsystem alerts has occurred in the following systems:

- Electrical
- Automatic flight control system (AFCS)

Secondary offenders are the following systems:

- Hydraulics
- Ice and rain protection
- Landing gear and brakes
- Navigation
- Pneumatics

Subsystems in which negligible growth in the number of alerts has occurred are the following:

- Air-conditioning
- Altitude alert
- APU

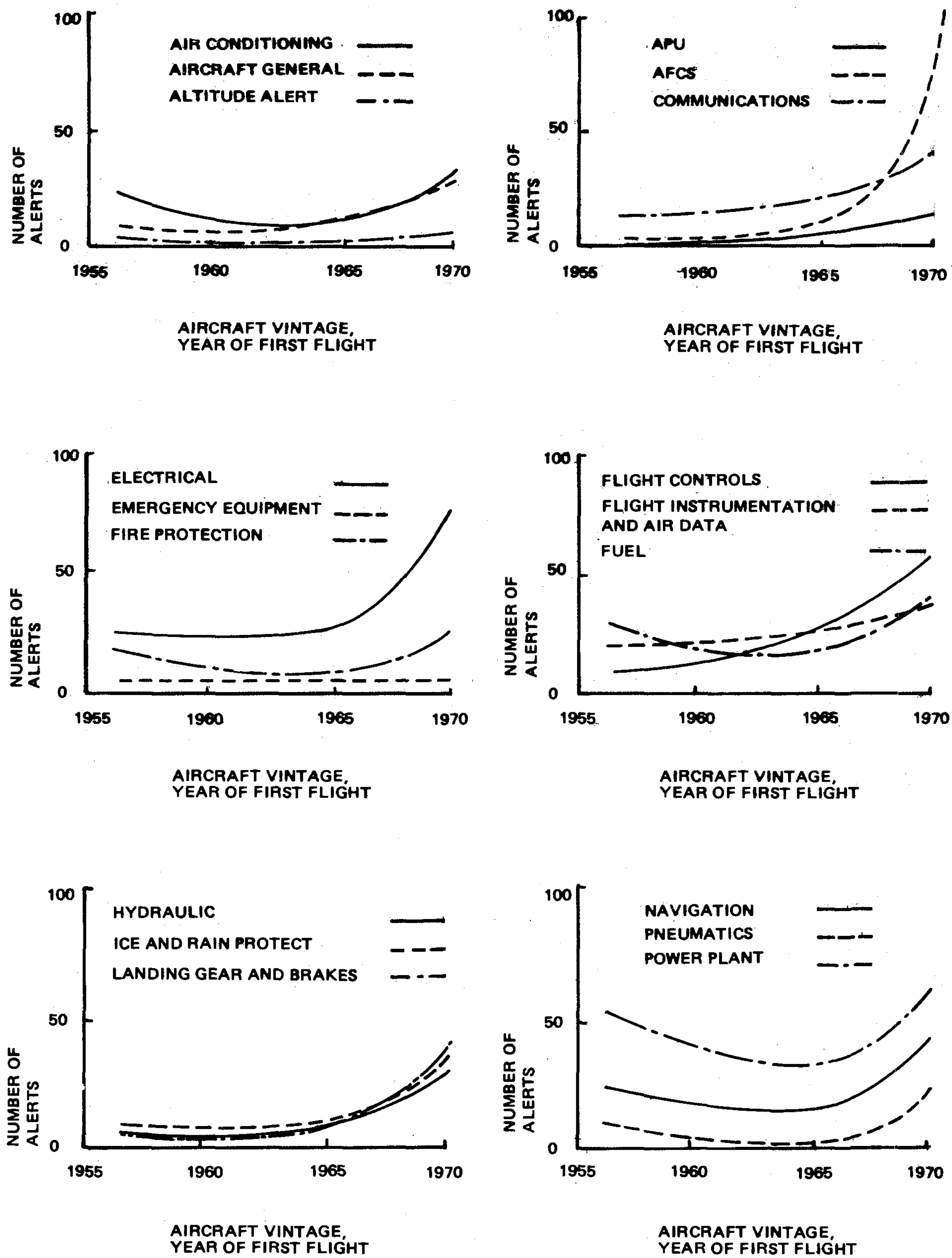


Figure 18 Growth History of Subsystem Alerts

- Communications
- Emergency equipment
- Flight instruments and air data
- Fuel
- Powerplant

Inspection of the detailed data in appendix D indicates that most of this growth is occurring among the caution and advisory lights.

2.1.3.7 Applications of Master Caution/Master Warning Systems

Table 9 specifies the aircraft that utilize master caution and master warning systems, the location and number of lights provided for these functions, and the characteristics of associated aural alerts. Table 10 specifies the proportions of lights that will actuate either the master caution or the master warning.

Analyses of these data indicated that master caution and/or master warning systems are used in all two-man-crew aircraft but in only a few three-man-crew aircraft. The majority of the three-man-crew aircraft use a central block of lights to annunciate caution and warning situations. The 737, DC-9, and DC-10 aircraft use a combination of the central block of annunciation lights and master caution/master warning.

The type of secondary alerts that actuate the master warning alert(s) also varies considerably from aircraft to aircraft. For example, on the DC-10 nearly two-thirds of the red lights actuate the master warning signal whereas on the DC-9 only one-third of the red lights activate the master warning. No amber, blue, green, white, or clear lights on these aircraft, except the BAC-111, activate the master warning signal.

Two amber lights on the BAC-111 activate the master warning. The rationale behind this discrepancy may be that the situation (CSD failure) deserves special attention and, since no master caution exists in this aircraft, the master warning signal was utilized.

The DC-9 and DC-10 alerting systems are designed to augment recognition of the cabin pressurization aural alert with the master warning. No other aural alerts activate the master warning systems. No inconsistencies appeared in the master caution system implementations. The master caution systems in these aircraft activate only when an amber light on the overhead panel or flight engineer's station illuminates.

2.1.3.8 Applications of Alert Prioritization and Inhibits

Figures 19 and 20 indicate respectively (1) the aircraft that have alerting systems with prioritized aural alerts and (2) the aural alert prioritization scheme incorporated on recent production models of the 737. No aircraft except late model 737s and a few 727s have an aural alert prioritization system. The priority scheme implemented on these 737s allows the aural alerts for FIRE and OVER-

Table 9 Master Caution and Master Warning Applications

ALERT TYPE	AIRCRAFT TYPE	VISUAL ALERT		AURAL ALERT
		LOCATION	QUANTITY	
MASTER WARNING	BAC-111	PILOTS MAIN PANEL	2	↑
	DC-8	GLARESHIELD	1	
	DC-9	GLARESHIELD	2	
	DC-10	GLARESHIELD AND FLIGHT ENGINEER'S STATION	2+1 RESPECTIVELY	
MASTER CAUTION	737	GLARESHIELD	2	
	DC-9	GLARESHIELD	2	NONE
	DC-10	GLARESHIELD AND FLIGHT ENGINEER'S STATION	2 + 1 RESPECTIVELY	
CENTRAL WARNING AND CAUTION BLOCK OF ANNUNCIATIONS	737	GLARESHIELD	2	
	747	PILOTS ENGINE INSTRUMENT PANEL AND FLIGHT ENGINEER'S STATION	1+1 RESPECTIVELY	
	DC-9	OVERHEAD	1	
	DC-10	OVERHEAD AND FLIGHT ENGINEER'S STATION	1+1 RESPECTIVELY	
	L-1011	PILOTS ENGINE INSTRUMENT PANEL AND FLIGHT ENGINEER'S STATION	1+1 RESPECTIVELY	↓

Table 10 Number of Alerts that Also Activate Master Caution and Master Warning Alerts

ALERT TYPE	PERCENT OF ALERTS THAT ACTIVATE MASTER WARNING				PERCENT OF ALERTS THAT ACTIVATE MASTER CAUTION		
	AIRCRAFT TYPE				AIRCRAFT TYPE		
	DC-8	DC-9	DC-10	BAC-111	737	DC-9	DC-10
RED LIGHTS	41	32	62	42	0	0	0
AMBER/YELLOW LIGHTS	0	0	0	5	54	66	20
BLUE LIGHTS	0	0	0	0	0	0	0
GREEN LIGHTS	0	0	0	0	0	0	0
WHITE/CLEAR LIGHTS	0	0	0	0	0	0	0
AURAL ALERTS	0	7 *	7 *	0	0	0	0

*CABIN PRESSURIZATION

PRIORITY	ARINC 577	AIRCRAFT TYPE								
		707/720	727	737	747	DC-8	DC-9	DC-10	L-1011	BAC-111
1	-CAS									
	-GRD PROX	NO PRIORITIZATION								
	-ENG FIRE									
	-APU FIRE									
	-STALL		NO PRIORITIZATION ON MOST AIRCRAFT							
	-OVERSPEED									
	-LDG GEAR									
	-TAKEOFF CONFIG			SEE FIGURE 20						
	-AUTO PILOT DISCONNECT									
	-ALTITUDE ALERT*				NO PRIORITIZATION					
	-SPARE									
1	-SPARE									
2	-STAB. IN MOTION					NO PRIORITIZATION				
3	-FLAP LOAD RELIEF						NO PRIORITIZATION			
4	-SPARE							NO PRIORITIZATION		
5	-SPARE									
6	-CABIN ALT									
7	-SPARE									
8	-GALLEY SMOKE								NO PRIORITIZATION	
9	-EMER EVAC									NO PRIORITIZATION
10	-SPARE									
11	-SELCAL									
12	-CABIN CALL									
13	-GRD CALL									
14	-SPARE									
15	-SPARE									

* PART OF A SEPARATE ALERTING SYSTEM THAT CAN BE ACTIVATED AT ANY TIME.

Figure 19 Prioritization of Aural Alerts

SPEED to occur simultaneously; causes the aural alert for CABIN ALTITUDE and UNSAFE TAKEOFF CONFIGURATION to override any alert listed below it and the aural alert for UNSAFE LANDING GEAR to override any alert listed below it, etc.; and causes the aural alert for SELCAL to override the aural alert for CREW CALL. The aural alerts for FIRE, OVERSPEED, one item from the middle groups, and one item from the right group can occur simultaneously in this priority scheme.

In ARINC 577 a priority scheme for all aural alerting functions, currently used and anticipatable in the near future, was proposed. Three problems are immediately noted with this scheme: (1) too many aural alerts are allowed, (2) too many alerting functions have equal priority on the priority 1 level, and (3) the significance and urgency of an alert are somewhat aircraft design dependent and therefore will vary from aircraft to aircraft. The standard for prioritizing the aural alerts should provide:

- Criteria for determining whether alert prioritization is necessary
- Criteria for determining the priority level of each alert if prioritization is required
- Design guidelines for equipment that allows aircraft dependent priority assignment of the alerts

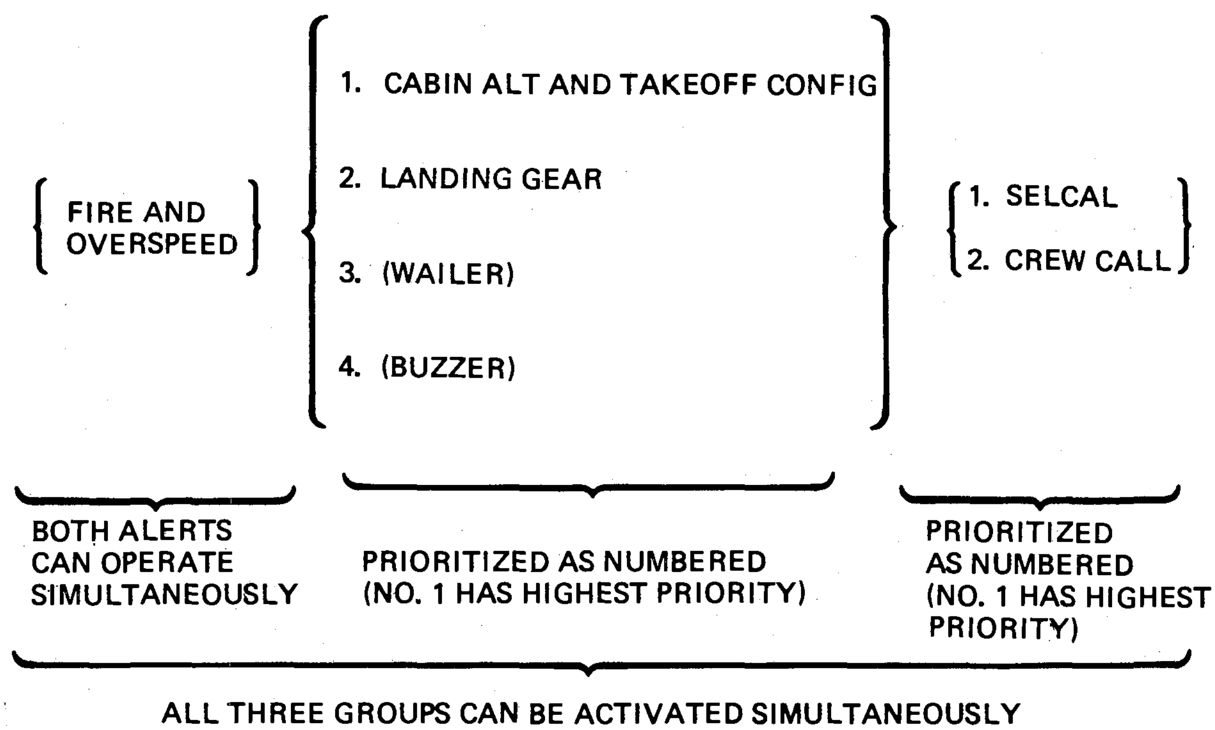


Figure 20 737 Aural Alert Priority Scheme

Alert inhibits also have not been applied extensively. The application of alert inhibits has been restricted primarily to enabling and/or disabling the aural alerts associated with aircraft configuration management, e.g., flaps extended and throttles at idle but no landing gear extended.

Not all alert inhibits are intentional, i.e., some inhibits result because the system with which they are associated or a sensor that feeds this system has exceeded its region of valid operation. An example of this situation is the ground proximity warning. Above 2500 or 5000 feet radio altitude, depending on type of equipment used, the ground proximity alert is inhibited because the radio altitude signal is not valid.

The DC-10 is the only aircraft that incorporates intentional inhibits of selected subsystem fault alerts, as described in figure 21, in addition to the traditional configuration-related alert inhibits. The inhibits on the DC-10 are designed to eliminate potential disturbances to the pilot during the critical segment of the landing maneuver, i.e., below 100 feet.

2.2 ALERTING FUNCTION AND SYSTEM REQUIREMENTS

In section 2.1, the good and bad features of existing alerting systems were discerned. Alerting function and system requirements were implied therefrom. In this section, a survey of applicable standards, accident data, operations and maintenance data, and pilot opinion data are discussed. An analysis of the correlation between the checklists and the alerts applied to each situation is also discussed. Additional alerting system requirements were derived from these analyses. These requirements are combined in later sections to derive "preliminary" alerting system implementation concepts. "Preliminary" is emphasized because these concepts need further human factors and operational testing to validate their effectiveness.

2.2.1 APPLICABLE STANDARDS

Federal Aviation Regulations pertinent to this study are parts 21, 25, 37, 91, and 121. Commercial aircraft standards applicable to this study are ARINC 577, which was discussed in section 2.1.3.8; SAE documents ARP 450, ARP 571, ARP 1068, and ARP 1161; and RTCA document D0-161A. Pertinent military standards and specifications are MIL-STD-411, MIL-STD-1472, and MIL-C-81774.

AIRPLANE	INHIBIT CRITERIA	ALERTING FUNCTIONS INHIBITED
DC-10	BELOW 100 FT RADIO ALTITUDE WHEN IN DUAL LAND MODE	• MASTER CAUTION AND MASTER WARNING LIGHTS • AMBER AUTOPILOT OUT-OF-TRIM AND DISCONNECT LIGHTS • AMBER AUTOTHROTTLE DISENGAGE LIGHTS

Figure 21 Inhibit Philosophies Applied to Subsystem Fault Annunciations

Applicable sections of the FARs are copied verbatim and tabulated in appendix A opposite the alerting functions to which they apply. In cases where the FARs specified a general requirement applicable to an entire system, the requirement was listed at the end of the tabulation for that system.

ARP 450 provides guidelines relative to the design of flight deck visual, audible, and tactile signals; ARP 571 specifies requirements for visual and aural alerts associated with nav/comm systems, and methods of annunciating flight director, autopilot, and autothrottle system operating modes; ARP 1068 specifies design objectives for all instrumentation and displays on the flight deck; and ARP 1161 specifies lighting and color requirements for each basic type of alert. DO-161A specifies minimum performance standards, including minimum alerting requirements for ground proximity warning systems. The alerting system requirements/guidelines contained in these standards are summarized in tables E-1, -2, -3, -4, and -5 (appendix E). Hardware requirements are not included. In most cases the requirement is copied verbatim; however, in a few cases, these statements are paraphrased to minimize similar statements.

The military standards and specifications do not provide specific requirements relevant to alerting systems in commercial transport category aircraft. These requirements are primarily of a general nature and not directly applicable unless referred to in a FAR or ARP. They do contain substantial human factors data pertinent to the design of alerting systems. The bulk of these data are covered in the survey of pertinent human factors data (section 2.4 and ref. 2). The key points in the remaining guidelines provided by these standards are listed in tables E-6, E-7, and E-8 of appendix E.

2.2.2 SURVEY OF PROBLEMS WITH CURRENT ALERTING SYSTEMS

The International Air Transport Association (IATA) Technical Committee performed a study of the operational problems its member airlines had experienced with aircraft warning systems. They became concerned over the number of accidents that have occurred where the aircraft warning system was a factor or may have contributed significantly to the chain of casual events, and concluded that an analysis of these problems was required to protect present fleets and future aircraft from similar accidents. Unfortunately, no systematic effort had been made previously to collect detailed data regarding operational experiences with the warning systems found in current transport aircraft. As an initial step in this direction, IATA surveyed its member airlines to determine the current complement of cockpit warning systems in transport aircraft, and to identify problems experienced by airline crews with the functioning of these systems.

Dr. John Lauber at NASA Ames Research Center was commissioned to perform this survey for IATA. The survey covered 46 airlines operating the following aircraft:

- DC-3, DC-8, DC-9, and DC-10
- 707, 727, 737, and 747
- L-188 and L-1011
- F-27 and F-28

- A300B
- BAC-111 and VC-10
- SE 210, C-160P, YS-11A, and HS-748

Included in this fleet were 2614 aircraft.

The survey resulted in identification of 270 operational alerting system problems classified as follows:

- 146 false positive warnings
- 36 false negative warnings
- 74 system problems
- 9 display problems

False positive warnings are failures of the alerting system to notify the crew that a hazardous or abnormal situation demanding their attention existed. False negative warnings are nuisance alerts, i.e., an alert was given when no hazardous or abnormal situation existed.

The system problems consisted of all cases wherein the operators were forced by regulation to modify or voluntarily modified the basic alerting system to avoid specific operational problems.

The specific alerting system features that constituted each of these statistics were not identified in Dr. Lauber's study beyond the level shown in table 11. A more detailed analysis of these data by The Boeing Company was only partially completed during this study. No specific alerting system requirements evolved from the partial analysis. Completion of the detailed analysis is planned for the near future.

2.2.3 CORRELATION BETWEEN CHECKLIST AND ALERTS

A cursory review was made of the correlation between the number of alerts in each alerting classification (warning, caution, or advisory/status) and the number of checklists or procedures in each of the following procedure categories:

- Emergency checklists
- Abnormal checklists
- Additional procedures

Aural alerts were not considered in this survey because the alerting classification that each aural alert belongs in is questionable.

Table 11 Alerting System Problems and Modifications Reported in IATA Survey of Airlines

WARNING SYSTEM CATEGORY	NUMBER OF OPERATIONAL PROBLEMS	NUMBER OF MODIFICATIONS
ENGINE/POWER SYSTEMS:		
ENGINE FAILURE WARNING SYSTEM	10	6
ELECTRICAL SYSTEM WARNINGS	10	8
HYDRAULIC SYSTEM WARNINGS	6	3
PNEUMATIC SYSTEM WARNINGS	7	5
FUEL SYSTEM WARNINGS	6	3
CABIN ENVIRONMENT SYSTEMS:		
AIR-CONDITIONING WARNINGS	3	1
PRESSURIZATION SYSTEM WARNINGS	2	4
CABIN DOOR WARNINGS	27	12
OXYGEN SYSTEM WARNINGS	2	2
ICE PROTECTION SYSTEMS:		
WING ANTI-/DE-ICE SYSTEM WARNINGS	3	2
ENGINE ANTI-ICE WARNINGS	4	0
PITOT/STATIC HEATING SYSTEM WARNINGS	10	4
OTHER WARNINGS	2	3
FIRE DETECTION AND WARNINGS SYSTEMS:		
ENGINE FIRE WARNINGS	34	20
AUXILIARY POWER UNIT FIRE WARNINGS	5	6
CARGO BAY FIRE WARNINGS	8	9
WHEELWELL FIRE WARNINGS	0	0
OTHER WARNINGS	4	2
PRIMARY FLIGHT CONTROL SYSTEMS:		
HORIZ STABILIZER MOVEMENT WARNINGS	6	4
FLAP AND SLAT SYSTEM WARNINGS	9	12
SPOILER WARNINGS	4	2
AILERON, ELEVATOR, RUDDER SYS WARNINGS	2	2
TAKEOFF CONFIGURATION WARNING SYSTEM	14	15
LANDING CONFIGURATION WARNING SYSTEM	16	9

Table 11 Alerting System Problems and Modifications Reported in IATA Survey of Airlines (Cont)

WARNING SYSTEM CATEGORY	NUMBER OF OPERATIONAL PROBLEMS	NUMBER OF MODIFICATIONS
BRAKING SYSTEMS:		
BRAKE OVERHEAT WARNINGS	5	0
ANTISKID FAILURE WARNINGS	5	2
REVERSE THRUST SYSTEM WARNINGS	11	4
PRIMARY FLIGHT PERFORMANCE SYSTEMS:		
STALL WARNING SYSTEM	10	8
MACH/OVERSPEED WARNING SYSTEM	2	0
ALTITUDE AND TERRAIN WARNING SYSTEMS	1	0
BAROMETRIC ALTITUDE DEVIATION	6	7
RADIO ALTITUDE WARNING	0	11
GROUND PROXIMITY WARNING	0	13
INSTRUMENT FAILURE WARNING SYSTEMS:		
FLIGHT INSTRUMENT COMPARATOR WARNING	9	8
FLIGHT INSTRUMENT FAILURE WARNINGS	6	5
NAVIGATION INSTRUMENT FAILURE WARNINGS	3	2
ENGINE/POWER INSTRUMENT FAILURE	3	0
AUTOPILOT SYSTEM WARNINGS	9	8

The category ADDITIONAL PROCEDURES includes all procedures listed in the flight operations manual that do not warrant a distinct checklist in the pilot's checklist summary booklet but are required for the crew to remedy aircraft malfunctions. Normal checklists, such as engine start, landing, secure, etc., also are not included in this category because their design is very dependent on the nature of each airline's operation.

Table 12 specifies the number of alerts and checklists or procedures that fall into each of these categories. Table 13 specifies the ratio of alerts to checklists and procedures in each category. No correlative pattern between the application of alerts and the usage of checklists was discerned in these data. However, the ratio of warning-type alerts to emergency procedures nearly doubled with the advent of wide body aircraft. This ratio jumped from an average of 4.5 for narrow body aircraft to an average of 8.8 for wide body aircraft. The difference apparently developed because of requirements for additional red lights and flags to annunciate the failure modes of more complex autopilot systems incorporated in wide body aircraft. No emergency checklist is usually associated with these autopilot failure situations.

The correlation between the type of checklist and the type of alert applied to each situation also was analyzed. The analysis showed that the majority of the checklists do correlate with the color of the alert light(s) used to annunciate the situation. However, several examples of noncorrelation were

Table 12 Correlation Between Number of Alerts and Number of Checklists

		NUMBER OF ALERTS AND CHECKLISTS PER AIRCRAFT TYPE								
		707	727	737	747	DC-8	DC-9	DC-10	L-1011	BAC-111
TYPE OF ALERT	WARNING	70	69	49	109	85	81	127	118	39
	CAUTION	118	197	153	346	87	123	291	385	44
	ADVISORY/ STATUS	105	103	115	302	59	40	208	295	13
TYPE OF CHECKLIST/ PROCEDURES	EMERGENCY	14	17	12	16	16	17	12	13	11
	ABNORMAL	15	15	50*	26	76	27	46	25	26
	ADDITIONAL	130	94	–	74	–	83	37	84	–

*THIS AIRLINE COMBINED ALL NONEMERGENCY CHECKLISTS AND PROCEDURES INTO THE ABNORMAL CHECKLIST CATEGORY.

Table 13 Ratio of Alerts to Checklists and Procedures

	707	727	737	747	DC-8	DC-9	DC-10	L-1011	BAC-111
WARNING ALERTS / EMERGENCY PROCEDURES	5.0	4.1	4.1	6.8	5.3	4.8	10.6	9.1	3.6
CAUTION ALERTS / ABNORMAL PROCEDURES	7.9	13.1	3.1	13.3	1.1	4.6	6.3	15.4	1.7
ADVISORY ALERTS / ADDITIONAL PROCEDURES	0.8	1.1	–	4.1	–	0.5	5.6	3.5	–

also found. On the 737, for example, an abnormal checklist is associated with the two blue lights that annunciate "generator breaker tripped open." On the BAC-111, an abnormal checklist is associated with the two red lights that annunciate "fuel boost pump low pressure." A definite correlation between the type of alert and the type of checklist or procedure applied to each situation should be established. If an emergency procedure is required, a warning-type alert should be used to annunciate the situation and if an abnormal procedure is required, a caution-type alert should be used. Advisory and status lights should be used to annunciate situations that do not require crew action and/or do not have a specific corrective or compensatory procedure associated with them. The reverse of these situations also should be applied, e.g., a warning-type alert should not be used unless an emergency procedure is required. Again, a definite correlation of these functions needs to be established.

2.2.4 PILOT PREFERENCES

A survey of several pilot organizations resulted in the following consensus relevant to the design of alerting systems:

- Reduce the number of alerts, especially the number of aural alerts.
- Most aural alerts, as currently designed, are too loud.
- Noncritical alerts should be inhibited during high workload periods, such as takeoff and flare/landing.
- Selected alerts should be prioritized.
- Audio-visual characteristics of the alerts should be designed to instantaneously inform the pilot of the criticality of the situation.
- Direct correlation between the type of alerts and the type of checklists should be established, i.e., warning and emergency, caution and abnormal, etc.

The survey included ALPA representatives and chief technical pilots from most large airlines, plus pilots from the Boeing, McDonnell Douglas, and Lockheed flight test organizations and the Boeing crew training organization.

The pilots unanimously agree that the current number of aural alerts is excessive and provides the potential for confusion in the cockpit. Even the most proficient pilots questioned whether they, in a high-stress situation, could rapidly interpret the significance of some of the less frequently heard aural alerts. They indicated that part of the confusion is caused by multifunction applications of some of the aural alerts, i.e., designing the alerting system such that an aural alert has one meaning during takeoff and another meaning during airborne operations. The number of aural alerts acceptable to most pilots is four, preferably one. If four aural alerts are used, they must be four familiar alerts.

The intensity of many currently used aural alerts is too high. Most aural alerts are so loud that normal crew coordination cannot be carried on. Their intensity should be reduced and/or a manual cutoff capability should be provided.

Many of the pilots felt that the potential for too many noncritical alerts exists in the critical operating regimes where the crew cannot afford to divert their attention from the primary flying tasks. The pilots were particularly concerned about distracting alerts in the following two flight regimes:

- Takeoff (from slightly below V_1 through climb to several hundred feet altitude)
- Landing (from 200 feet altitude through braking and thrust reverse)

An inhibit scheme of the type shown in figure 22 was suggested.

Inhibits were also suggested for the following purposes:

- Minimize nuisance alerts by inhibiting appropriate sections of the alerting system in flight phases wherein the alert has no meaning
- Override background noise, such as radio chatter, that interferes with aural alerts
- Method of prioritizing alerts

The application of inhibits to suppress nuisance alerts and to prioritize alerts received extensive pilot support. However, the concept of inhibiting radio communications when an aural alert is activated received numerous objections; the pilots were wary of the potential failure mode wherein the alerting system could inhibit their radio communication capability.

The majority of these pilots also felt that alert effectiveness could be improved by selective prioritization. The alerts should be grouped into three or four categories wherein each category denotes a level of criticality. Alerts within each category should also be prioritized. The capability for an alert to transition from one category to another as a function of flight phase should be incorporated into the priority system. The priority of the alerts will vary from one aircraft to another. Accordingly, variable prioritization capability must be provided.

These pilots favored prioritization; however, they could not define criteria for when prioritization was necessary. In a very simple alerting system, prioritization might not be required; in a complex alerting system, prioritization probably would be beneficial.

A unique audio-visual method of alerting should be associated with each priority category so as to provide an instantaneous assessment of the situation's criticality. Current alerting systems do not provide this information, thereby necessitating somewhat drastic methods of alerting for the highest priority alerts. The need for drastic alerting methods should be eliminated by incorporating this alerting system characteristic.

The pilots expressed concern over the lack of correlation between the type of alert and the type of checklist applied to each situation. They want emergency checklists to be associated with warning-type alerts, abnormal checklists to be associated with caution-type alerts, and the additional procedures specified in the flight operations manual to be associated with the advisory/status alerts.

Other preferences were also expressed by the pilots; however, none as strongly or as uniformly as these six points.

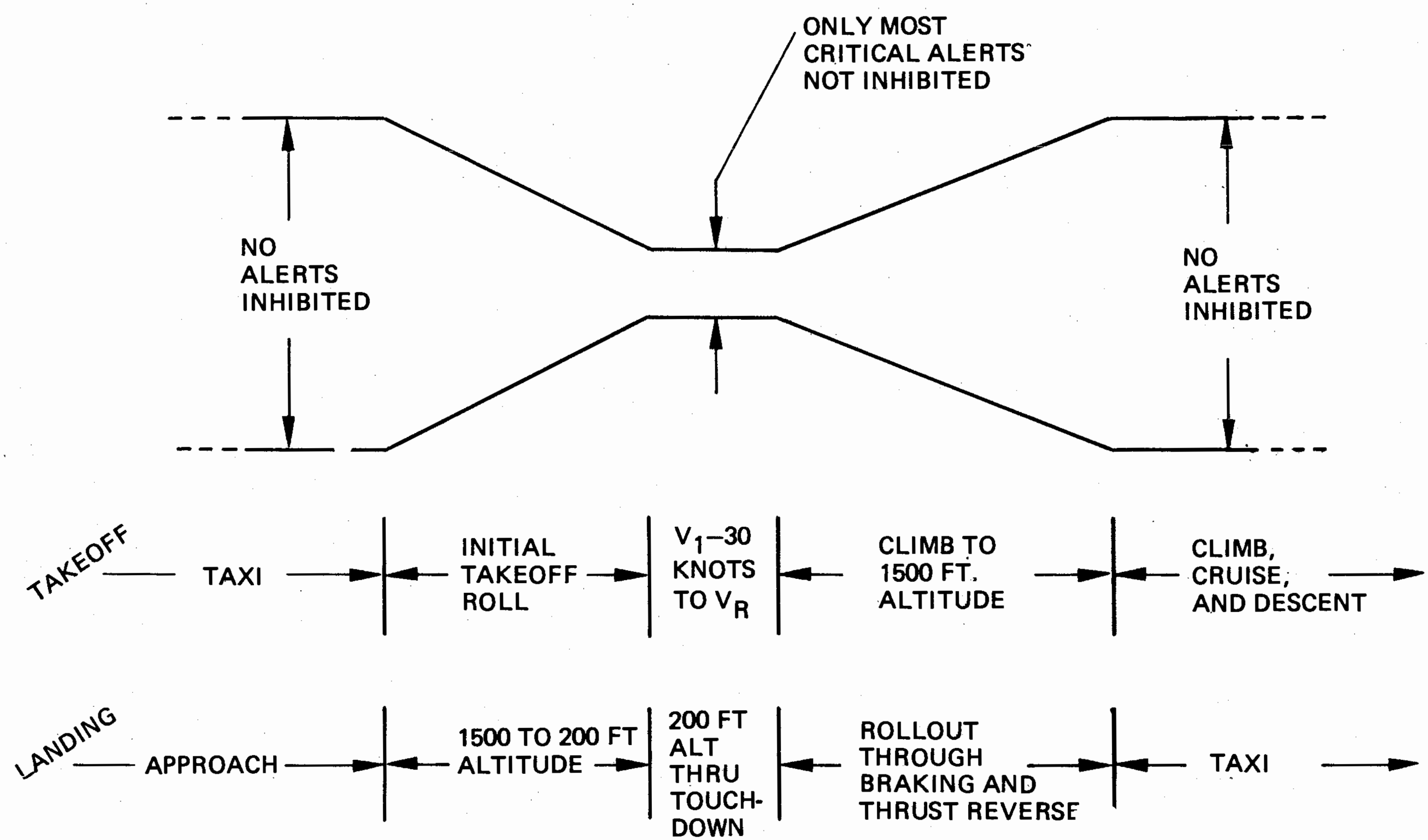


Figure 22 Alert Inhibit Scheme

2.3 ALERTING FUNCTION CATEGORIES AND PRIORITIES

The requirements established in previous sections were utilized in this portion of the study to (1) define alerting function categories, (2) develop a method for assigning alerting functions to these categories, and (3) develop a method for prioritizing the alerting functions within each category. The validity of these definitions and category/priority allocation methods was tested by (1) applying them to a 737 and (2) noting conflicts between established standards and the results of the application. Each of these tasks is discussed in detail in the following sections.

2.3.1 CATEGORY AND PRIORITY DEFINITIONS

Many cockpit designers and pilots believe that current alerting system problems could be resolved if firm category definitions and requirements to design to these definitions were established. Attempts at establishing firm definitions for alerting categories were made long before the current study. Thus, a historical review of recent developments in this subject will be utilized to develop the rationale for the category definitions and prioritization methods proposed by this study.

Two SAE standards—ARP 450 and ARP 1068—established a set of groundrules for mechanizing alerting systems encompassing single-function aural alerts, discrete visual alerts, a master caution system, and a master warning system. No alerting categories or priority schemes were established in these standards.

During the era in which the aircraft analyzed by this study were designed, these ARP standards often were not adhered to because they had not been updated to reflect latest methods of implementing cockpits. This lack of operational guidelines resulted in each airframer and each operator developing and implementing their own unique alerting system philosophy. Pilot encouragement finally caused the SAE S-7 Committee to direct their attention to updating these ARP standards and the FAA to initiate this research program which is aimed at developing a universally agreed to set of design objectives/guidelines for alerting systems.

The SAE S-7 committee, "Flight Deck and Handling Qualities Standards for Transport Category Aircraft," recognized this flaw in their standards and requested inputs from the airlines and airframe manufacturers. Boeing responded with two proposed sets of alerting system categories plus a list of typical alerting functions that fall within each category. SAS airlines responded with a dissertation on alerting system implementation requirements. Copies of both responses are provided in appendix F.

The Boeing response (see section F.1) provided a "first-cut" at categories that were oriented toward importance of the alert rather than the categories of configuration, flight profile, and systems as had been suggested by earlier studies. Three basic levels of importance (categories) were established therein:

LEVEL 1 — Highest priority alerts requiring immediate crew action. It was recommended that the dedicated alerting systems currently used for these functions be retained.

LEVEL 2 — Safety of flight items requiring crew action but not immediately. Three sublevels were defined in this category. LEVEL 2-A consisted primarily of alerts currently annunciated by an aural alert; LEVEL 2-B consisted primarily of system malfunctions and aircraft misconfigurations with which the pilot would not want to take off with; and LEVEL 2-C consisted primarily of aircraft misconfiguration items that should be corrected prior to taxiing.

LEVEL 3 Checklist items that have only a minor effect on safety of flight. Included passenger service items.

The requirement for a central readout device that identifies the nature of each alert and provides for graduations in the boldness of the alert was established therein.

In an attachment, Boeing also proposed a secondary set of category definitions based on crew recognition and action requirements. This concept identified the various types of pilot responses that are required and suggested alerting methods that would provide such response.

The SAS response (see section F.1) to the SAE S-7 committee's request for guidelines relevant to the operation and design of alerting systems was very similar to Boeing's but did not provide category definitions. Both responses indicated a need for (1) minimizing the application of discrete aural alerts and (2) an alphanumeric display located in front of each pilot that describes the exact nature of the alerted situation. SAS also provided a detailed description of how the central alphanumeric display should operate.

The FAA simultaneously initiated a series of studies aimed at developing standards for alerting systems in new aircraft. This study is one of that series. Based on knowledge acquired in earlier phases of this study, two more detailed alert category definitions were suggested (see section F.2, appendix F). These category definitions were amplifications of the alerting levels suggested earlier and as integrated by Boeing engineers as opposed to Boeing pilots. A slight diversity of opinion existed between the two groups; however, the fundamentals of both concepts were identical.

A numerical method of analyzing the criticality of each alerting situation and accordingly assigning it to an alerting category was then sought. The purpose of resorting to a numerical method was to eliminate the subjective aspects of assigning alerting categories. The relationship between the probability of an alerting situation occurring and the severity of its effects, as established in BCAR paper number 670, was used as a basic for this numerical method. Figure F-1 in appendix F defines this relationship as applied to alerting systems. The numerical method consisted of calculating the probability of a failure or hazardous situation occurring in conjunction with (1) the crew not recognizing the alert and (2) the situation resulting in injuries, as a function of time, and then equating the resulting probability value to the levels specified in figure F-1. The resulting probability value defined the type of alert required. Figure F-2 defines this relationship.

Several potential problems were encountered with the probability method of categorizing and prioritizing alerting functions:

- How to compensate for pilot latency?
- How to distinguish between major and catastrophic events?
- What crew workload level to assume?

- What "time allowance for corrective crew action" distinguishes a warning from a caution?

- Should "crew reliability" be utilized to design and certify aircraft systems?

No substantive answer exists to the first four questions. The answers to the questions were very dependent on subjective opinions. The last question is dominated with many legal implications. Thus, although the probability method of categorizing and prioritizing alerting functions is viable, it was abandoned.

Nonquantitative methods of prioritization and the definition of firmer nonnumerical categorization/prioritization criteria were then resorted to again. Two more sets of category criteria were proposed. A Boeing engineer proposed the four category definitions defined in table F-2 (appendix F). The key factor in this proposal was the definitions of crew recognition and response time requirements. The SAE S-7 committee simultaneously developed the alerting system philosophy and category criteria defined in section F-5. The comments of Swissair's chief technical pilot on the SAE S-7 committee's alerting system philosophy are also provided. These three concepts were integrated to formulate the category criteria defined in table 14.

The category criteria provide guidelines for cockpit designers to roughly prioritize the alerting functions. However, they do not provide a detailed method for analyzing the priority of each alerting situation as a function of flight phase and within each category. An air-conditioning systems failure, for example, would have higher priority during cruise than during takeoff or final approach. During final approach the crew is almost totally occupied with flying the aircraft down the ILS and landing. Annunciation of an air-conditioning failure during cruise could result in a very uncomfortable situation of the remainder of the flight. The crew usually is not busy during this time period and would try to remedy the air-conditioning problem promptly.

The impact of various types of alerts on the crew's primary tasks during each of the following flight phases were analyzed:

- Preflight
- Engine start
- Taxi
- Takeoff
- Climb
- Cruise
- Descent
- Approach
- Landing
- Taxi and shutdown

Note that in a practical situation this many flight phases probably would not be used. For this analysis, excess detail was felt to be better than lack of detail. Therefore, since the optimum combination of flight segments was not known, excessive segmentation was used.

Table 14 Criteria for Categorizing Alerting Functions

LEVEL	CONDITION	CRITERIA
1	EMERGENCY (WARNING)	EMERGENCY OPERATIONAL OR AIRCRAFT SYSTEMS CONDITIONS WHICH REQUIRE IMMEDIATE CORRECTIVE OR COMPENSATORY ACTION BY THE CREW.
2	ABNORMAL (CAUTION)	ABNORMAL OPERATIONAL OR AIRCRAFT SYSTEMS CONDITIONS WHICH REQUIRE IMMEDIATE CREW AWARENESS AND REQUIRE CORRECTIVE OR COMPENSATORY CREW ACTION.
3	ADVISORY	OPERATIONAL OR AIRCRAFT SYSTEMS CONDITIONS WHICH REQUIRE CREW AWARENESS AND MAY REQUIRE CREW ACTION.
4	INFORMATION	OPERATIONAL OR AIRCRAFT SYSTEMS CONDITIONS WHICH REQUIRE COCKPIT INDICATION BUT NOT NECESSARILY AS PART OF THE INTEGRATED WARNING SYSTEM.

This analysis showed that a considerable change in the crew's level of concentration on their primary flying tasks occurs midway through each of these flight phases. During takeoff for example, the crew's concentration on the takeoff flying tasks increases as V_1 is approached, remains very high through rotation and climb to a safe altitude, and then decreases again. A period of GO/NO GO uncertainty also exists during takeoff roll from approximately 30 knots prior to V_1 or V_R. Any noncritical alert during this period would disturb the crew and possibly cause the pilot to make an erroneous GO/NO GO decision. Only the most critical situations with which the crew would not want to take off should be annunciated during this period. A similar situation exists in the landing phase wherein the crew should not be disturbed during the last 200 feet of descent, flare, and touchdown. Distinctions also exist between operations above and below 14,000 feet altitude due to aircraft pressurization requirements.

Ground maintenance operations were reviewed and found to require many of the same alerting functions that the flight crews need. When trimming an engine, for example, the maintenance crew requires all the engine malfunction and fire protection alerts. However, the criticality of these functions may not be as high in maintenance operations as in flight operations.

Based on these types of analyses, the flight phases or flight-phase segments defined in table 15 were selected for further prioritizing the alerting functions. The two problems that still remained were (1) how to prioritize compound malfunctions and (2) how to prioritize the alerting functions within each category.

The compound malfunction situation is very aircraft and type of system dependent. The failure, for example, of one hydraulic system does not pose as critical a situation on the 747 as on the 737 because the 747 has four parallel hydraulic systems, whereas the 737 has only two parallel systems. Is the failure of two hydraulic systems or three hydraulic systems on the 747 equivalent to the failure of a single system on the 737? Figure 23 illustrates the general type of logic that had to be applied to prioritize these alerting situations. The logic in this diagram was developed primarily for nonavionic systems. The general application of this logic to all systems, however, is not feasible. In attempts to develop and verify prioritization logic of this type, it was determined that parallel sets of logic were required—one set of logic for each type of system malfunction and operational situation. The development of these detailed prioritization logic sets required more expertise on the compound effects and safety implications of each alerting situation than was available to the group performing this study. An analysis of the effects and safety implications of each compound malfunction was required for each basic type of aircraft in order to assign relative priorities to these alerting situations.

Similar situations arise with regard to compound malfunctions involving various types of systems. For example, what should the priority be of an alert annunciating a pneumatic system failure after an air-conditioning system failure has already occurred? Should it be the same priority as, or a higher priority than, a pneumatic system failure without any previous air-conditioning failures? Another example, how should the relative priorities of an autopilot channel failure as compared to an electrical generator be established? The electrical generator failure would have broader effects on operation of other aircraft systems, including the autopilot, but the autopilot could have an immediate effect on controlling the flightpath of the aircraft. Which is more important?

Some pilots argue that compound effects should not be considered in prioritizing the alerts. The priority assigned to the basic alerting function should be used for all situations, irrespective of compound effects, and the assessment of compound effects should be left up to the pilots. Other pilots want an elaborate alerting system that makes all the compound effect judgments for them. The analyses performed in this study indicate that the elaborate versions of the system would:

- Require substantial computation capability
- Require software that is very sensitive to aircraft configuration modifications and frequent modifications of this software to keep it current (as with the checklists)

Table 15 Flight Phases Used in Prioritizing Alerting Functions

DEFINITION	COMMENTS
GROUND MAINTENANCE	
PREFLIGHT	PRIOR TO ENGINE START
ENGINE START	PRIOR TO TAXI
TAXI	PRIOR TO APPLYING TAKEOFF THRUST
INITIAL TAKEOFF ROLL	PRIOR TO ATTAINING A SPEED OF V_1-30 KNOTS
FINAL TAKEOFF ROLL	DURING ACCELERATION FROM V_1-30 TO V_R
INITIAL CLIMB	FROM V_R THROUGH ROTATION AND CLIMB TO 1500 FT
LOW-ALTITUDE CLIMB, CRUISE, OR DESCENT	BETWEEN 1500 AND 14,000 FT ALTITUDE
HIGH-ALTITUDE CLIMB, CRUISE, OR DESCENT	OPERATIONS ABOVE 14,000 FT
APPROACH	FROM 1500 TO 200 FT ALTITUDE
LANDING	FROM 200 FT ALTITUDE THROUGH FLARE, TOUCHDOWN AND SPEED REDUCTION TO TAXI SPEED
TAXI AND SHUTDOWN	

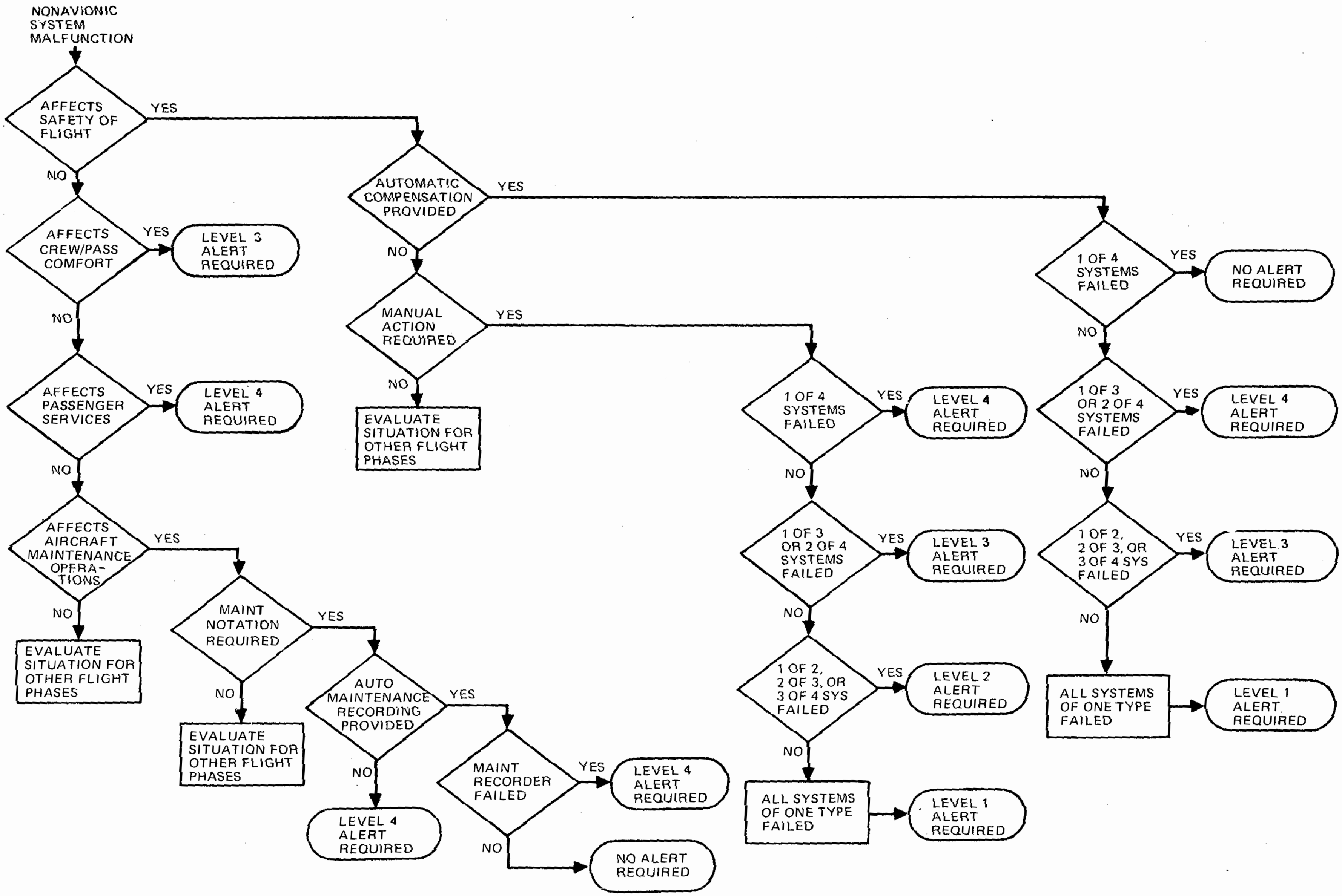


Figure 23 General Type of Logic Required to Prioritize Alerting Functions

- Make the logic unique to each aircraft—differences could exist between aircraft of the same type, even within an airline's fleet

The elaborate version of the system could become an expensive maintenance item for the airlines. For these reasons, therefore, it is recommended that alert prioritization as a function of compound effects be minimized.

The prioritization of alerts within each category was also studied. An example of such a case is prioritization of the stall warning relative to the ground proximity warning. Both alerts will probably be LEVEL 1 alerts as defined in table 14. If a ground proximity warning occurs and then a stall warning occurs while the pilot is pulling up, should the stall warning take precedence, should the ground proximity warning take precedence, or should both be allowed to occur simultaneously? Ideally, a numerical rating method would be utilized to prioritize these alerting functions within each category; however, none was conceived. The ranking of these alerts is very subjective; pilot opinion on these rankings currently is diverse. Much of the diversity results from differences in the designs of the aircraft. However, better agreement exists among the high priority alerting functions than on the middle or low priority alerts. Thus it is recommended that priority sequence guidelines be established only for the LEVEL 1 and possibly LEVEL 2 alerts, and that the prioritization of LEVEL 3 and LEVEL 4 alerts to be left up to the airframe manufacturers and operators.

2.3.2 APPLICATION OF CATEGORY/PRIORITY RATIONALE

Category criteria for defining alert priorities were specified in table 14. The flight phases and flight phase segments for which alert priorities have to be specified were defined in table 15. Consideration of compound effects was deemed unnecessary. Standardization on alert priorities within the categories was deemed feasible only within the two highest priority alert categories. The low priority alerts are too dependent on aircraft design differences to allow standardization. These alert prioritization philosophies were applied to a 737 to validate the concepts and to identify conflicts with existing standards.

Each alerting function specified in appendix A for the 737 was assigned a priority as a function of flight phase (see appendix G). The alerting functions within LEVELS 1 and 2 were then prioritized as shown in table 16. Note that prioritization of the LEVEL 3 and LEVEL 4 alerts was not attempted because these alerts are too aircraft design dependent. Significant differences in the alert priorities will exist in these two categories between aircraft models.

2.4 HUMAN FACTORS DESIGN GUIDELINES

In section 2.1, current alerting methods were reviewed and the good and bad features of each design were discussed. In section 2.2, existing standards, operational data, and pilot preferences were analyzed to obtain a composite listing of requirements that apply to existing alerting systems and to develop an alternate set of requirements that should be applied to future alerting systems. In section 2.3, alerting function category criteria and a set of alert priorities matching these criteria were established. The problem that then remained was "what human factors guidelines should be applied when implementing the results of these analyses?" A survey of the human factors data applicable to alerting systems was performed to develop these missing guidelines. The derivation of these guidelines and the types of data required to complete and validate these guidelines are discussed in the following sections.

Table 16 Example Application of Alerting Function Prioritization

	ALERT LEVEL (CATEGORY)	1. EMERGENCY (WARNING)
ALERT PRIORITIES AS FUNCTION OF FLIGHT PHASE	GROUND MAINTENANCE	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
	1500 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 1500-200 FT ALT	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 16 Example Application of Alerting Function Prioritization (Cont)

ALERT PRIORITIES AS FUNCTION OF FLIGHT PHASE

ALERT LEVEL (CATEGORY)	2. ABNORMAL (CAUTIONS)
GROUND MAINTENANCE	1. FIRE WARNING –MASTER –ENGINE –APU –CARGO 2. EGT OVERTEMP 3. BLEED AIR TEMP HIGH 4. OIL TEMP HIGH 5. AIR CONDITIONING DUCT OVERHEAT 6. PASSENGER OXYGEN SYSTEMS ON 7. BELOW GLIDESLOPE WARNING 8. EQUIPMENT TIRE BURST 9. EXCESSIVE AIRSPEED OR MACH
PRE-FLIGHT	1. FIRE WARNING –MASTER –ENGINE –APU –CARGO 2. AIR CONDITIONING DUCT OVERHEAT 3. PASSENGER OXYGEN SYSTEM ON
ENGINE START	1. FIRE WARNING –MASTER –ENGINE –APU –CARGO 2. EGT OVERTEMP 3. BLEED AIR TEMP HIGH 4. OIL TEMP HIGH 5. AIRCONDITIONING DUCT OVERHEAT
TAXI	1. FIRE WARNING –MASTER –ENGINE –APU –CARGO –WHEELWELL 2. EGT OVERTEMP 3. BLEED AIR TEMP HIGH 4. OIL TEMP HIGH 5. AIRCONDITIONING DUCT OVERHEAT 6. CSD OR IDG OIL TEMP HIGH 7. HYDRAULIC PRESSURE LOW –ELEVATOR –RUDDER –AILERON 8. YAW DAMPER FAIL 9. RADIO ALTIMETER FAIL 10. PASSENGER OXYGEN SYSTEM ON 11. PARKING BRAKE ON
INITIAL TAKEOFF ROLL	1. FIRE WARNING –MASTER –ENGINE –APU –CARGO –WHEELWELL 2. EGT OVERTEMP 3. OIL TEMP HIGH 4. HYDRAULIC PRESSURE LOW –ELEVATOR –RUDDER –AILERON 5. STABILIZER OUT-OF-TRIM 6. GYRO FAIL 7. RADIO ALTIMETER FAIL
FINAL TAKEOFF ROLL	
INITIAL CLIMB	
1500 TO 14,000 FT ALTITUDE	1. FIRE WARNING –MASTER –ENGINE –APU –CARGO –WHEELWELL 2. PRESSURIZATION FAIL 3. EGT OVERTEMP 4. BLEED AIR TEMP HIGH 5. OIL TEMP HIGH 6. AIRCONDITIONING DUCT OVERHEAT 7. APU EGT OVER-TEMP 8. APU OIL TEMP HIGH 9. PU OIL PRESSURE LOW 10. APU OIL QUANTITY LOW 11. HYDRAULIC PRESS. LOW -ELEVATOR RUDDER AILERON 12. YAW DAMPER FAIL 13. EQUIPMENT TIRE BURST 14. GYRO FAIL 15. CSD OR IDG OIL TEMP HIGH 16. CSD OR IDG OIL PRESS. LOW 17. AUTOPILOT DISCONNECT 18. AUTOTHROTTLE DISCONNECT 19. EXCESSIVE AIRSPEED OR MACH 20. GEAR NOT DOWN & THRUST LEVER AT IDLE 21. RADIO ALTIMETER FAIL 22. SPEED BRAKE DO NOT-ARM 23. PASSENGER OXYGEN ON
ABOVE 14,000 FT	1. FIRE WARNING –MASTER –ENGINE –APU –CARGO –WHEEL WELL 2. EGT OVERTEMP 3. BLEED AIR TEMP HIGH 4. OIL TEMP HIGH 5. AIRCONDITIONING DUCT OVERHEAT 6. APU EGT OVERTEMP 7. APU OIL TEMP HIGH 8. APU OIL PRESS. LOW 9. APU OIL QUANTITY LOW 10. HYDRAULIC PRESS. LOW –ELEVATOR –RUDDER –AILERON 11. YAW DAMPER FAIL 12. EQUIPMENT TIRE BURST 13. GYRO FAILURE 14. CSD OR IDG OIL TEMP HIGH 15. CSD OR IDG OIL PRESS. LOW 16. AUTOPILOT DISCONNECT 17. AUTOTHRUTTLE DISCONNECT 18. EXCESSIVE AIRSPEED OR MACH 19. GEAR NOT DOWN & LOCKED & THRUST LEVER AT IDLE
APPROACH (1500-200 FT ALT)	1. FIRE WARNING –MASTER –ENGINE –APU –CARGO –WHEELWELL 2. BELOW GLIDESLOPE WARNING 3. EGT OVERTEMP 4. BLEED AIR TEMP HIGH 5. OIL TEMP HIGH 6. AIRCONDITIONING DUCT OVERHEAT 7. APU EGT OVERTEMP 8. APU OIL TEMP HIGH 9. APU LOW OIL PRESS. 10. APU OIL QUANTITY LOW 11. HYDRAULIC PRESS. LOW –ELEVATOR –RUDDER –AILERON 12. YAW DAMPER FAIL 13. EQUIPMENT TIRE BURST 14. GYRO FAILURE 15. RADIO ALTIMETER FAIL 16. GLIDESLOPE INFO FAIL 17. LOCALIZER INFO FAIL 18. AUTOPILOT DISCONNECT 19. AUTOTHROTTLE DISCONNECT 20. GEAR NOT DOWN & LOCKED & THRUST LEVER AT IDLE 21. BRAKE PRESS. ABNORMAL 22. REVERSER ACCUMULATOR PRESS. LOW 23. SPEED BRAKE - DO NOT ARM 24. CSD OR IDG OIL TEMP HIGH 25. CSD OR IDG OIL PRESS. LOW
LANDING (BELOW 200 FT 200 FT	1. HYDRAULIC PRESSURE LOW –ELEVATOR –RUDDER –AILERON 2. GYRO FAILURE 3. RADIO ALTIMETER FAILURE 4. BRAKE PRESS. ABNORMAL 5. REVERSER ACCUMULATOR PRESS. LOW
TAXI AND SHUTDOWN	1. FIRE WARNING –MASTER –ENGINE –APU –CARGO –WHEELWELL 2. EGT OVERTEMP 3. BLEED AIR TEMP HIGH 4. OIL TEMP HIGH 5. AIRCONDITIONING DUCT OVERHEAT 6. BRAKE PRESS. ABNORMAL 7. CSD OR IDG OIL TEMP HIGH 8. CSD OR IDG OIL PRESS. LOW

NOTE: ALERTS PRIORITIZED AS NUMBERED. NUMBER 1 HAS HIGHEST PRIORITY

Table 16 Example Application of Alerting Function Prioritization (Cont)

ALERT LEVEL		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 & OPERATOR	FUNCTION OF AIRCRAFT DESIGN PRIORITIES TO BE DETERMINED BY AIRFRAME MANUFACTURER & OPERATOR
	FINAL TAKEOFF ROLL		
	INITIAL CLIMB		
	1500 TO 14,000 FT ALTITUDE		
	ABOVE 14,000 FT		
	APPROACH (1500-200 FT ALT)		
	LANDING (BELOW 200 FT)		
	TAXI AND SHUTDOWN		

2.4.1 LITERATURE REVIEW AND RECOMMENDED GUIDELINES

The literature review was structured to investigate how pilots respond to alerting signals. The current variety of signaling devices utilized to transfer information in the cockpit have begun to saturate the pilot and decreased his efficiency to the point where prioritization of the information presented may be necessary. The basis for any prioritization scheme must be the time in which a pilot must react to the situation. Signaling devices must be selected to ensure a response time that is commensurate with the priority of the signal and must convey enough information to maximize the probability of the correct response within a reasonable time. Since current aircraft design practices for alerting systems have evolved with some nonoptimum characteristics due to cost, implementation difficulties, or personal biases of various chief pilots and designers, the literature review was performed with a ground rule to "ignore current aircraft design practices."

The literature review was conducted with the following specific objectives:

- Investigate the type of signals that can be used to transfer information in a cockpit environment.
- Determine the factors that affect the detection of these signals.
- Determine the factors that affect the time from signal detection to a correct action.
- Formulate guidelines for maximizing the effectiveness of signaling systems.
- Evaluate the data with respect to its relevance and applicability and recommend research programs to augment the existing data and refine the guidelines.

The review was divided into two primary areas of concern:

- Factors that affect detection of signals
- Factors that affect time from detection to correct response

The literature review and guidelines are quite lengthy and will therefore only be presented in a condensed form in this section; the full text is contained in reference 2.

2.4.1.1 Factors That Affect Detection of Signals

A summary of the factors that affect visual, auditory, and tactile signals is presented in table 17. These data indicate that the detection of visual signals is affected by the signal location, size, brightness, color, and steady state or intermittent nature.

The location of a visual signal relative to the pilot's centerline of vision has a significant effect on not only the speed with which a signal is detected, but also the probability that it will be seen at all.

Evidence indicates that the likelihood of detecting a small visual signal decreases from 83% for those alerts located directly in the center of the pilot's visual field to 35% for those signals located in the 30^{o} to 40^{o} deviation zone.

Table 17 Stimuli Response Sensitivities and Applications Guidelines Summary

STIMULUS	CHARACTERISTIC	SENSITIVITY/APPLICATION GUIDELINE
VISUAL	LOCATION	15° FROM LINE OF SIGHT (MAX)
	SIZE	1° VISUAL ANGLE
	BRIGHTNESS	BRIGHTER THAN BACKGROUND BUT NOT SO BRIGHT AS TO BLIND OBSERVER
	FLASHING VS STEADY	FLASHING AGAINST STEADY BACKGROUND MOST EFFECTIVE
	COLOR	FASTEST ←——→ SLOWEST RED 1.8 SEC; GREEN 2.0 SEC; YELLOW 2.3 SEC; WHITE 2.7 SEC ← DETECTION TIMES
AUDITORY	PERCEIVED LOUDNESS	MAXIMIZED IN 2000 TO 4000 Hz RANGE
	FREQUENCY DEAFNESS	USE TWO OR MORE FREQUENCIES IN 250 TO 4000 Hz RANGE WITHIN EACH SIGNAL
	SOUND LEVEL	15 dB ABOVE MASKING THRESHOLD OR HALFWAY BETWEEN MASKING THRESHOLD AND 110 dB, WHICHEVER IS LESS
	LOCATION	MONAURAL SIGNALS SHOULD BE PRESENTED TO DOMINANT EAR WARNING SIGNAL SOURCE SHOULD BE SEPARATED AT LEAST 90° FROM THE SOURCE OF INTERFERING NOISE OR MESSAGES
	INTERMITTENT VS STEADY	INTERMITTENT MORE LIKELY TO BE DETECTED
	MESSAGE CONTENT	PRECEDE MESSAGES BY AN ATTENTION GETTER TO WHICH THE PILOT IS MORE THAN NORMAL SENSITIVE
TACTILE	INTERMITTENT VS STEADY	TOUCH SENSE IS ACTIVATED ONLY BY SKIN DE-FORMATION
	VIBRATION	MAXIMUM SENSITIVITY BETWEEN 200 AND 300 Hz
	AREA OF BODY	FINGERS MOST SENSITIVE BUTTOCKS LEAST SENSITIVE
	INTENSITY	50 TO 100 MICRONS

The military standards and design guides define the pilot's centerline of sight as a vector emanating from the pilot's eye, extending straight forward and angled 10° below horizontal. The commercial airframe manufacturers have several definitions of the centerline of sight, all of which differ from the military definition. The most consistently used commercial aircraft definition of centerline of sight appears to be the line between the pilot's eye reference point and the center of his ADI. The definitions of primary and secondary field of view also vary. The military defines primary field of view as the region within a 15° cone around the centerline of vision and the secondary field of view as the region between a 15° and a 30° cone around the centerline of vision. Commercial aircraft manufacturers generally define primary field of view as a binocular-shaped area covering most of the pilot's primary instrument panel (containing ADI, HSI, airspeed, and altitude indicators) and secondary field of view as a binocular-shaped area covering most of the pilot's front panel (including engine instrument and autopilot mode select panels). Considerable variations of these definitions were found in the commercial aircraft industry. The human factors data indicate that most of these definitions are reasonable with respect to location of alerting signals. However, until further testing can be performed to better define these criteria, the following combination of military and commercial criteria for location of visual alerting signals is recommended:

- High priority alerts should be located no more than 15° from the pilot's centerline of vision.
- Caution signals should be located no more than 30° from the pilot's centerline of vision.

To summarize, the higher priority a visual signal is, the closer it should be located to the center of the pilot's visual field. An illustration of these guidelines is provided in figure 24.

The size of the visual signal also has a strong effect on its detection time. Figure 25 presents the effect of increasing the lighted area of a border-lit signal. A moderate improvement in response time is obtained when the border width was increased from 0.26° visual angle (1 square degree of surface area) to 0.64° (2.74 square degrees). However, there is essentially no improvement beyond this point. Other research efforts have also found this signal size of 1° visual angle produces the quickest response times. Therefore it is recommended that: (1) high-priority signals be no less than 1° visual angle in size, and (2) secondary signals be no less than 0.5° visual angle in size.

The higher the priority of a signal, the brighter it should be as long as it is not so bright that it blinds the pilot. High-priority signals should be at least twice as bright as other displays in the same area.

Even though the criticality of the signal dictates the intensity of any signal, the range of intensities is dictated by the detection threshold on one end and the disruption of normal activity on the other. Military standards require rear-lighted signals to have a brightness capability of 150 ft-L (dimmable) for high-priority signals and a 15 ft-L (dimmable) for secondary signals. These standards are consistent with research findings. The resulting recommendations were:

- Highest priority signals should be at least twice as bright as secondary displays.
- Lower priority signals should be at least 10% brighter than lesser priority displays in the same vicinity.
- Highest priority signals should have a brightness capability of at least 150 ft-L and secondary signals 15 ft-L.

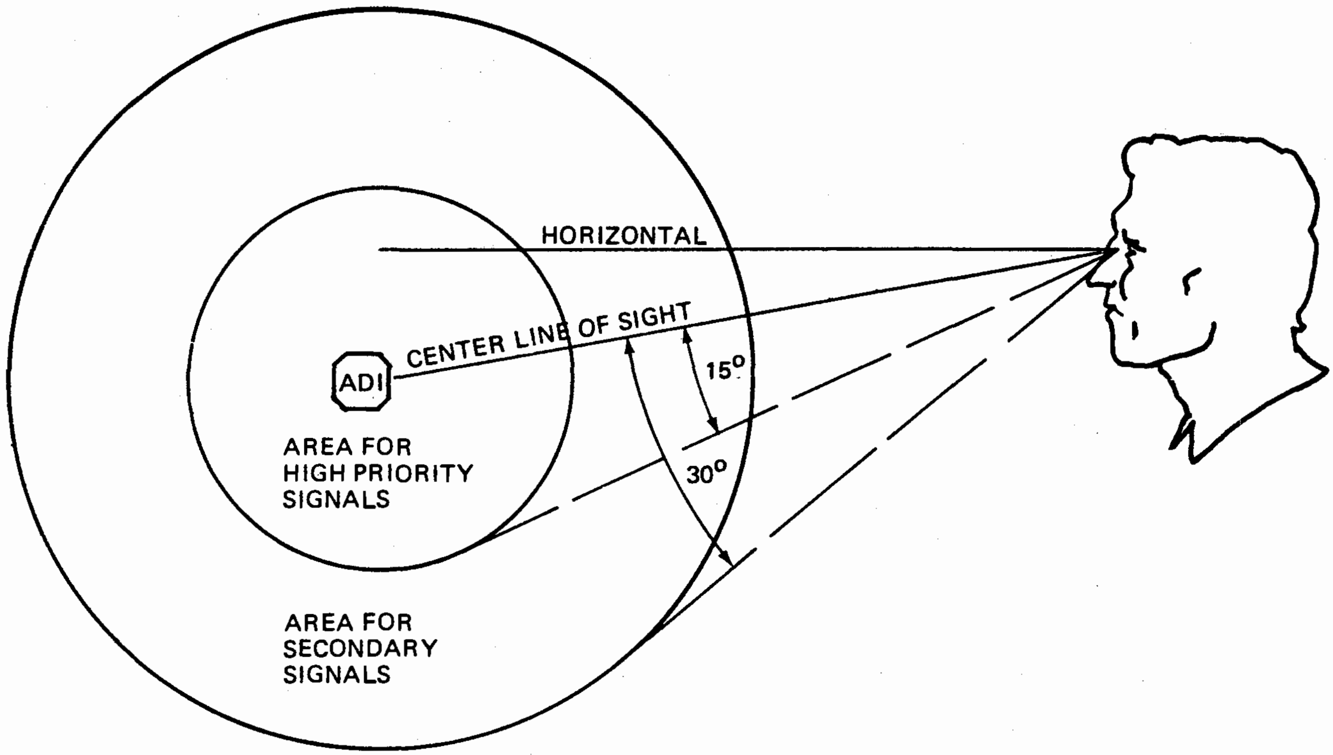


Figure 24 Preferred Placement of Visual Signals

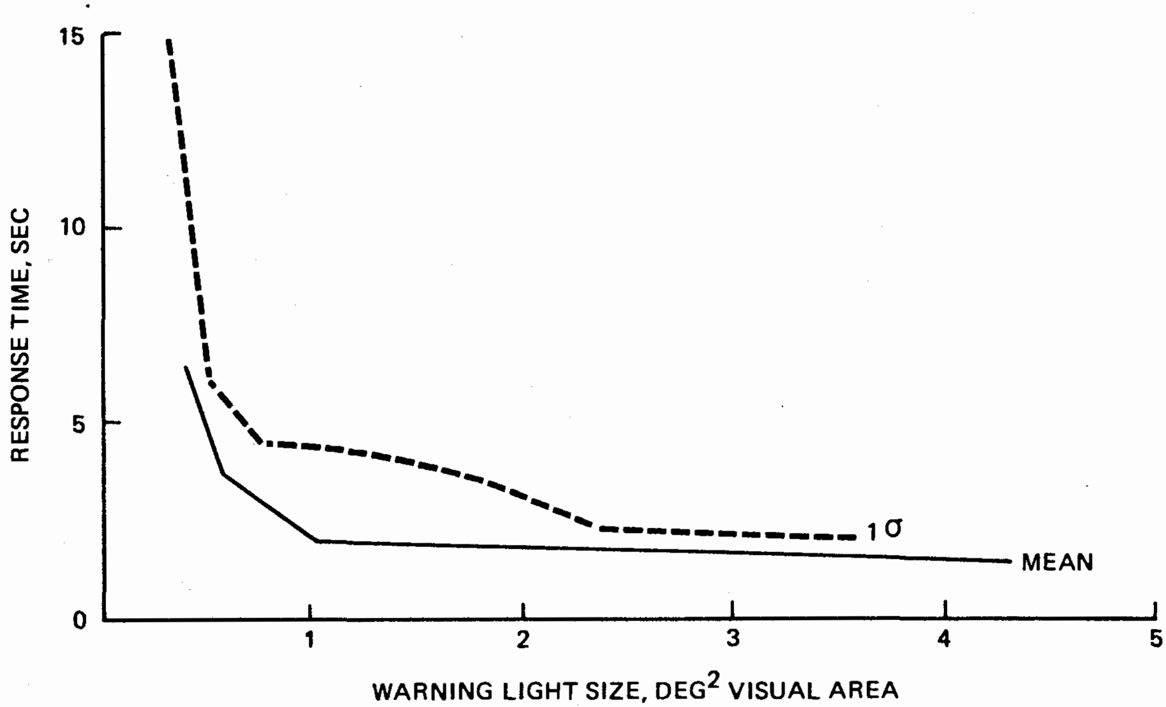


Figure 25 Effect of Warning Light Size on Reaction Time

The detectability of flashing and steady lights is dependent upon whether the other possible distracting signals are flashing or steady. The experimental evidence showed that flashing alert lights are detected 30% faster than steady alert lights when combined with steady distractors, but 24% slower than steady lights when combined with flashing distractors. However, the fastest mean detection times are obtained by flashing alerts with steady distracting signals. Therefore it is recommended that high priority alerts should flash and have the capability of making other lights that may be activated go to a steady state.

The effects of color are small as shown in table 17. In most situations, the 0.9 sec (maximum found in the data; in most of the data, the difference is closer to 0.1 sec) in detection time between the most efficient and least efficient colors probably has no practical significance. It was, therefore, recommended to continue using the existing ground rules for colors of alerting lights:

- Red — for warning annunciations indicating a hazard that requires immediate action
- Amber — for caution annunciations indicating the possible need for future corrective action
- Green — for SAFE annunciations

Any other color for lights not described above is acceptable provided the color differs sufficiently from the colors described above to avoid possible confusion.

The auditory stimuli data indicate that the primary factors affecting detection of such signals are:

- Frequency
- Loudness
- Location
- Intermittency
- Message content

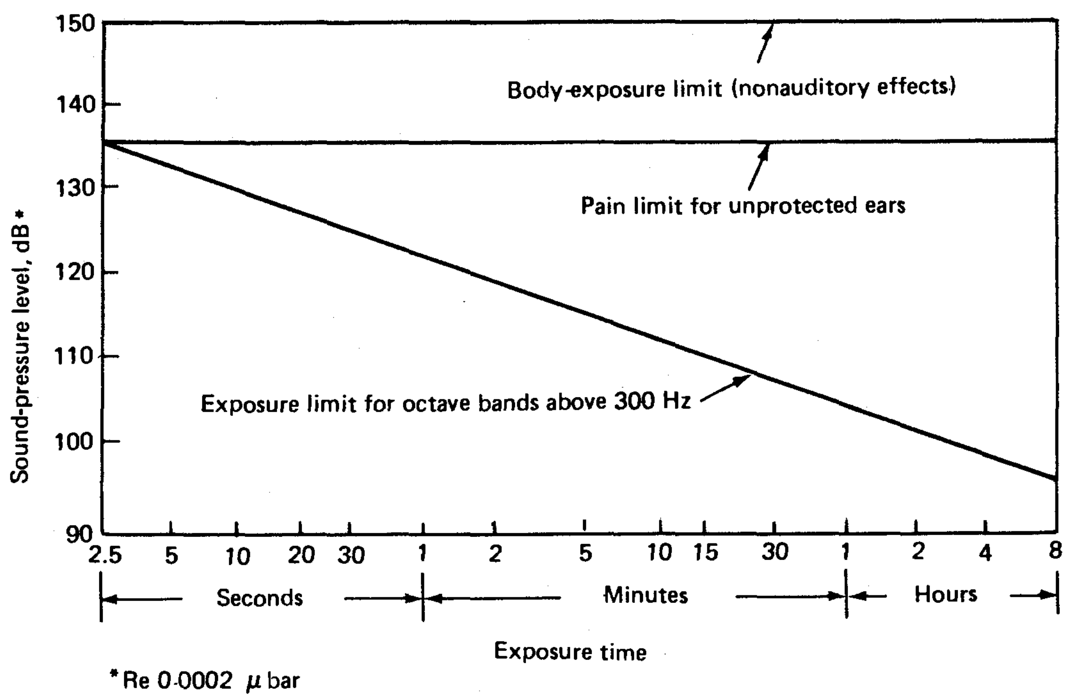
Young humans can detect sounds with frequencies ranging from 20 Hz to about 20,000 Hz. Frequency has a strong effect on perceived loudness. Midfrequency (2000-4000 Hz) sounds tend to sound louder than either high- or low-frequency sounds of the same energy level. Two additional frequency-related factors that impact the detection of aural signals are aging which causes a progressive loss of hearing in the higher frequencies, and ear injuries, which occasionally produce unsensitivities or deafness to particular frequencies. For these reasons it is recommended that each aural signal be composed of two or more widely spaced frequencies in the range from 250-4000 Hz.

The guidelines recommended for determining the loudness required of aural alerting signals were expressed as delta loudness required above the masked threshold created by ambient noise. It is important to distinguish between this threshold and ambient noise. "Threshold" is defined as the loudness level required of an aural alerting signal to assure 50% detection. This factor usually has a value that is less than the overall ambient noise level. Methods of calculating this threshold value are presented in reference 2. With cognizance of these factors, the following guidelines for presenting high priority aural alerting signals were derived:

- 15 dB above threshold
- Halfway between threshold and 110 dB

However, these guidelines may in some cases conflict with the pilot criticism that most aural alerts as currently implemented are too loud. Care must be taken when applying these guidelines to the actual cockpit environment because it is possible to introduce sound levels that are intolerable to the pilot. The range of signal intensity by necessity must be limited on one end by the auditory threshold and at the other end by the onset of pain (110 dB). The intensity/exposure time interaction, which imposes limits after which there is a high risk of damage for unprotected ears (figure 26) must also be considered. Thus, until data that resolves this conflict are obtained, it is recommended that the following guideline be used:

$$\text{SIGNAL LOUDNESS} = \left\{ \begin{array}{c} \text{THRESHOLD} + 15 \text{ dB} \\ \text{OR} \\ \text{THRESHOLD} + 1/2\,(110 \text{ dB-THRESHOLD}) \end{array} \right\} \text{WHICHEVER IS LESS}$$



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 NON-AUDITORY EFFECTS OCCUR. THIS LEVEL SHOULD NOT BE EXCEEDED IN ANY CASE (ELDRED ET AL' 1955).

Figure 26 Damage Risk Criteria for Various Exposure Times Up to 8 Hours

The experimental data also indicate that aural signals, which are perceived as coming from a different location than the background sounds, are more likely to be detected than signals that cannot be separated in location from background sounds. It was found, as shown in figure 27, that detectability of an aural signal can be improved 40% by going from 0^{o} to 90^{o} directional separation between the sources of background noise and the aural alerting signals. It was also shown that if earphones are used, a substantial improvement in detectability can be obtained by presenting all aural alerting signals only to the pilot's dominant ear. The resulting recommendations from this area of study were:

- Present aural warning signals dichotically to the pilot's dominant ear. (In dichotic listening the alert is presented by an earphone to one ear, and interfering noise or messages are restricted to the other ear.)

- If dichotic separation is not possible, locate the source of aural alerting signals 90^{o} from the source of interfering noise or messages.

Another factor that must be noted is that the human auditory system rapidly becomes used to hearing steady-state signals. Therefore, it is recommended that intermittent sound signals should be utilized for aural alerting.

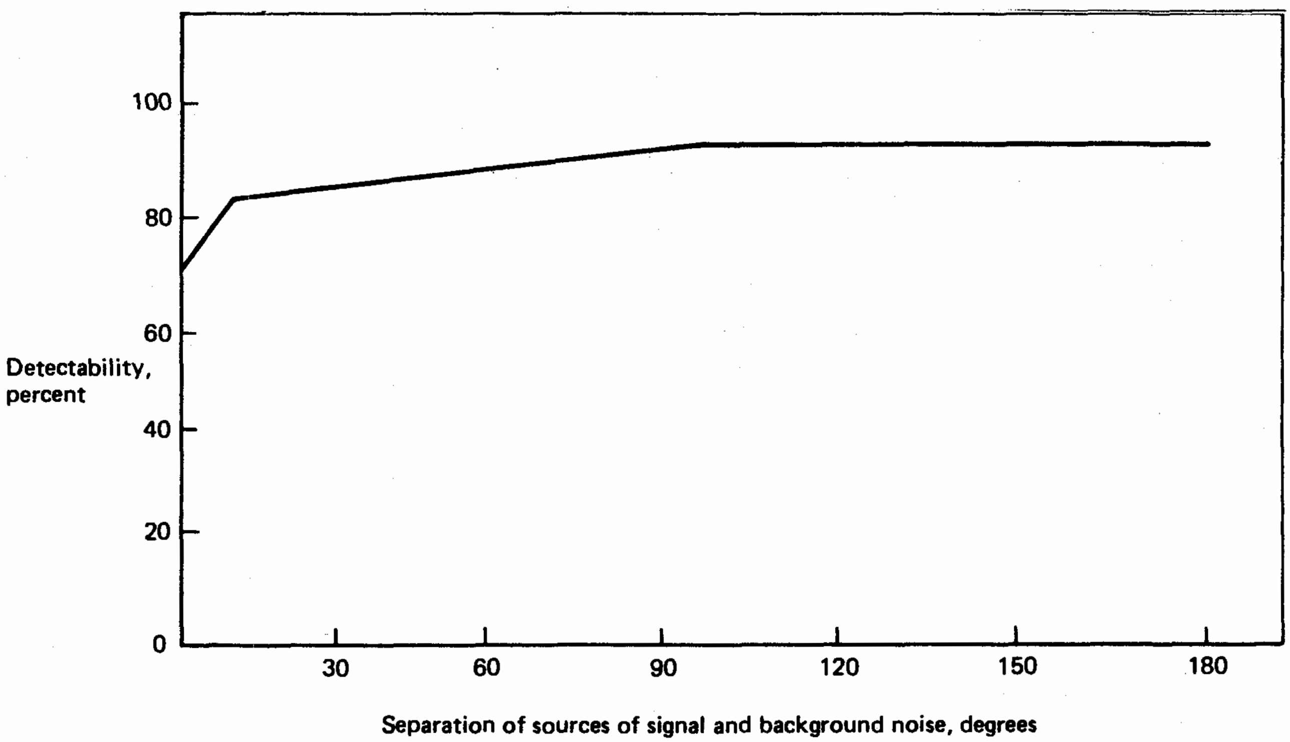


Figure 27 Effect of Aural Alerting Signal Source Location

The detection of a sound signal is often affected by the content of the signal. For example, a person's name is usually more attention attracting than any other auditory message of the same volume. Experimental data indicate that having a person's name precede an auditory message appears to have about the same effect on detection as increasing the loudness of the message by 3 dB. Thus, it is recommended that aural alerting messages can be preceded by an identifier to which the pilot is more than normally sensitivite, e.g., the pilot's name or aircraft identification.

Tactile signals consist of such things as vibration, shock, heat, etc. The data indicate that the primary factors affecting the effectiveness of a tactile type signal are intermittency, intensity, and part of body stimulated.

Continuous skin movement is required to stimulate the touch or pressure sense. It has been shown that this sense is maximally sensitive on the fingers at vibrations in the 200- to 3000-Hz range. The intensity of these signals has nominally been given the range of 50-microns. This range is directly related to the area of the body receiving the signal. The sensitivity to touch varies widely from one section of the body to another; the fingers are the most sensitive and the buttocks the least. Therefore, the amplitude of any tactile signal must be calibrated to produce a sensation on the body area where it is placed.

Other types of tactile stimuli should be used very cautiously. They are either dangerous to use, cause excessive startle or adverse reactions, or otherwise inhibit normal pilot actions. The magnitude of an electrical shock, for example, is very difficult to control because of its sensitivity to perspiration. Electrical shock also frequently startles the subject to the extent that he is momentarily incapacitated and then reacts excessively in an inappropriate manner. Other tactile devices such as seatbelt jerkers or seat jabbers tend to inhibit normal pilot movement. These problems are typical of difficulties that are encountered with most tactile stimuli.

Environmental factors such as distractors, existing cognitive workload, and vigilance also have a significant effect on pilot response to a signal. Any kind of distracting stimuli (visual, auditory, or tactile) will have an adverse effect on the detection of alerting signals. In the presence of visual and/or auditory distractors, the effectiveness of types of warning signals from best to poorest are tactile, auditory, and visual. However, tactile distractors have a more disruptive effect than visual or auditory distractors on other activities.

Vigilance and cognitive workloads are a function of the rate at which information is presented. There is a limited range of rates at which human beings process information effectively. When information is presented at rates slower than the optimum rate, an individual will tend not to monitor the information sources effectively and will miss a substantial proportion of the information being presented. Information rates above the optimum range produce cognitive overload. Individuals under a cognitive overload will miss part of the information being presented and will process other parts of the information incorrectly. General characteristics such as these were found in the literature. However, consistent quantitative definitions of the minimum information rate necessary to maintain vigilance and the maximum information rate allowed so as not to cause cognitive overload were not found.

A tabulation was made of response times obtained in the experiments covered by the literature and the conditions under which these times were obtained. This tabulation was used to detect trends and unique characteristics of combinations of stimuli. These data are presented in table 18. From an

Table 18 Typical Stimuli Response Times

NATURE OF STIMULI	RESPONSE TIME, SEC	TEST CONDITIONS
VISUAL VISUAL AND BUZZER VISUAL AND VOICE	12.12 4.02 2.40	TRACKING TASK; NO IMPACT ON CONCURRENT TRACKING TASK PERFORMANCE
VISUAL AND BUZZER VISUAL AND VOICE	4.57 1.94	TRACKING TASK; BETTER TRACKING WITH VOICE WARNING
VISUAL AND TONE VISUAL AND VOICE	9.35 7.89	
VISUAL AND BUZZER VISUAL AND VOICE	2.63 1.62	
VISUAL VOICE	128.27 3.03	HIGH-SPEED LOW-LEVEL MILITARY FLIGHT TESTS
VISUAL VOICE	44.05 2.93	VISUAL CONSISTED OF ANALOG INSTRUMENTS AND LIGHTS IN AN F-100 AIRCRAFT
VISUAL (STEADY) VISUAL (FLASHING)	2.0 1.3	HUMAN FACTORS TEST IN A STERILE LABORATORY ENVIRONMENT
AUDITORY VISUAL	2.2 2.7	SIMULATION OF A TYPICAL COCKPIT ENVIRONMENT
VOICE BUZZER	1.94 2.57	
TONE VOICE	9.35 7.89	F-111 SIMULATOR; EACH ALERT CONSISTED OF A MASTER CAUTION LIGHT, AN ALERT IDENTIFICATION LIGHT, AND AN AURAL ANNUNCIATION OF THE TYPE DESCRIBED TO THE LEFT
VISUAL AUDITORY TACTILE	0.494 0.453 0.381	NO LOADING
VISUAL AUDITORY TACTILE	SLOWEST FASTEST	NO LOADING EXCEPT VISUAL AND AUDITORY DISTRACTORS

overview of these data, it is obvious that tactile signals produce the fastest response in the non-loaded situation and a combination of visual and aural signals produce the fastest response when used with aircraft-related tasks. Of the combination visual and aural stimuli, the visual/voice combination appears to be more effective than the visual/tone combination. Voice stimuli consistently produce a faster response than visual stimuli. Based on these data, these types of alerting stimuli and combinations thereof might be ranked as shown in figures 28 and 29.

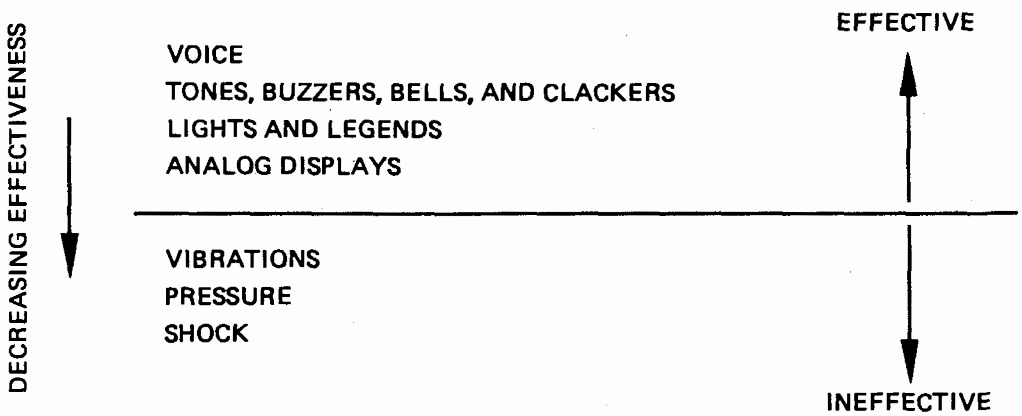


Figure 28 Alert-Type Effectiveness

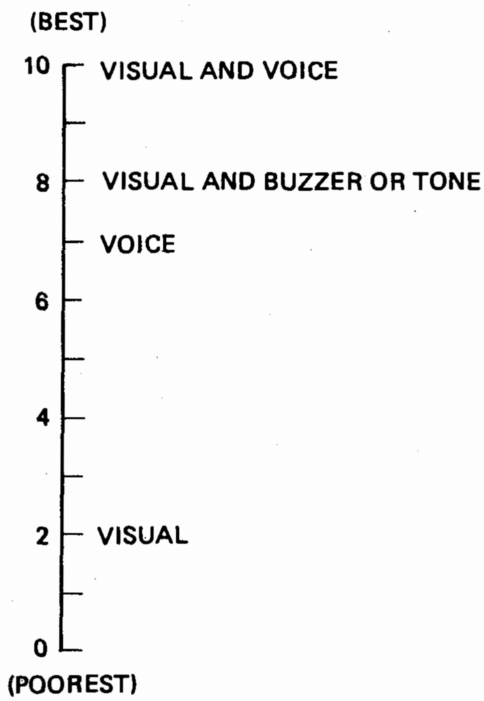


Figure 29 Relative Effectiveness of Acceptable Types of Alert Stimuli

2.4.1.2 Time From Detection to Response

The foregoing discussion has dealt mainly with the detection of signals. However, if an alerting signal is to be effective, the pilot must both detect the alert and make the appropriate response. Therefore, a warning signal must convey information about the nature of the problem and/or tell the pilot how to respond. There will always be a finite interval of time between the detection of the alert and the completion of the response. The length of this interval is primarily dependent on signal-related factors, environmental factors, and previous experience.

The major signal-related factors that affect the time from detection to response are number of steps in the data collection and length of the signal.

A pilot cannot make a correct response to an alerting signal until he has deduced the proper response. If the initial alerting signal contains adequate information, the pilot may initiate action at once. However, if the initial alert does not give adequate information of the nature of the problem, then the pilot must obtain more information before he can take corrective action. Thus, the extra steps in the data acquisition will increase the time to the correct response.

Two experiments were reviewed to obtain a quantified estimate of this effect. In both experiments, alert detection and identification times were measured for visual, buzzer, and voice alerts and combinations thereof. The visual and voice alerts provided enough information so the subjects did not have to scan the other displays to identify the nature of the alert, i.e., a single-step process. The buzzer alerts required the subject to scan one or more visual displays in order to identify the cases, the voice alerts resulted in the shortest identification times. Another advantage of both systems is that under high-stress conditions with peak visual load, this type of system permits the pilot to evaluate the criticality of the problem without adding to his visual workload. It was concluded, therefore, that the number of information-gathering steps required to identify the nature of an alert should be minimized and that voice warnings should be used wherever possible for high-priority alerts. Based on these data and other experiments with voice alerting systems, the recommended practices for voice alerting systems are:

- Reserve voice warnings for highest priority alerting situations.
- Voice alerts, when actuated, should attenuate messages and signals of lower priority.
- Pilots should be familiar with all the messages.
- Messages should be constructed of short sentences of polysyllabic words.

The time from detection to response is also affected by the time required for each step in the data collection. At each step in the data collection, the observer must detect and locate a signal and then process the information in that signal. The time for each step is dependent upon the following factors:

- Time required to process the information in the present step
- Time required to change from one signal source to the next

The time to process the information in any one step is dependent upon the amount of information in that step and the rate at which the information can be assimilated. The rate of data assimilation is directly related to the number of absolutely identifiable signals used for data transmission. The experimental data indicated that the fastest assimilation rates occur with larger signal vocabularies than those currently used for alerts on commercial aircraft. However, this conclusion is valid if, and only if, the signals are not confusable. The inclusion of confusable signals reduced the information assimilation rate and led to errors.

The primary factor affecting the time required to change from one signal to the next is search time, i.e., the number of stimuli the subject must reference to obtain the required information and the data assimilation characteristics of each stimulus. From the exterimental data, it was concluded that the longest time required for shifting from one signal to another occurs when the first signal does not give the precise location of the second signal, and the second signal is a visual stimulus.

The environment in which pilots must operate may also affect their alert reaction time. No directly applicable quantified data were available on this effect. However, the experimental evidence does indicate that the response to any stimulus is very much dependent upon the number of possible responses to that stimulus as well as the number of possible responses to all other stimuli. In general, any environmental factor that increases the demands on the pilot will increase the time signal detection to response.

The performance of airplane pilots is strongly affected by skills that they have learned previously in other situations. The effect of a previously learned skill on performance in a new situation is called transfer of training. There are two types of transfer of training—positive transfer and negative transfer. Positive transfer is any improvement in performance due to previous experience and usually occurs when the response to be made in a new situation is similar to the response made in a previous situation. Negative transfer is any detriment in performance due to previous experience and usually occurs when the response to be made in a new situation is different than the response that was made in a previous situation.

The signal-response relationships are often not the same in different aircraft. This may result in negative transfer of the pilot's experience. A study of the effects of negative transfer on crew performance was reviewed in order to assess the significance of this factor. It was found that pilots who are crosstrained to fly several different types of aircraft do make incorrect responses that can be attributed to this negative transfer effect. To minimize this effect, it was concluded that all alerting signals, particularly high-priority alerts, should be standardized on all aircraft.

2.4.2 REQUIREMENTS FOR ADDITIONAL DATA

In addition to providing data for the formulation of alerting system design guidelines, another major objective of the literature review was to assess the adequacy of the existing data and recommend research efforts necessary to complete the data base. Three tasks were undertaken to accomplish this objective. First the data were evaluated and categorized into two groups, those research efforts directly applicable to the design of alerting systems and those that provided data which, while not quantitatively applicable, provided indications of the direction of the effects. Short abstracts of the data from the studies and military standards that fall into these two categories are tabulated in appendix H. The second task was (1) to delineate those areas where more data are required to provide an adequate data base, and (2) to prioritize those needs so that appropriate research objectives and plans could be formulated in the third task.

2.4.2.1 Adequacy of Data in Literature

The data evaluation portion of the review assessed each of the areas of concern listed in table 19. Two aspects of the research data for each area were evaluated to determine their usefulness in developing design requirements. Most important was the relevance of the data to the signal detection and response process. Many of the studies that were evaluated were not applicable even though they dealt with human sensory mechanisms. The remaining data were then reviewed and classified as to the applicability of the quantitative results.

Those data that were obtained in an actual or simulated aircraft cockpit using a flight-type task were considered to be directly applicable. In these studies the observer was required to do a primary task (i.e, tracking a prescribed course or listening to an air traffic controller) and simultaneously respond correctly to any alerting signal. The quantitative results of this type of study closely resembled what may be expected in the "real" flight situation. This class of study included approximately 20% of

Table 19 Areas of Concern of the Literature Search

1. Visual signals

Size	Location
Brightness	Workload
Contrast	Vigilance
Format	Pilot age
Color	Legend characteristics

2. Auditory signals

Frequency	False signals
Intensity	Workload
Ambient noise	Vigilance
Disruptions	Ear dominance
Number of signals	

3. Bimodal presentation (auditory—visual)

Interstimulus interval	Workload
Format	Vigilance
Intensity	

4. Tactile signals

Detectability	Frequency
Effectiveness	Disruptiveness
Number of signals	
Intensity	

the cited works (see appendix H). The other 80% of the studies were primarily laboratory studies to obtain basic research data. These studies in general used as their unit of measurement the time it takes the observer to react to the signal (reactive time) when that was the only task that he had to do. The quantitative applicability of these types of data to in-flight alerting situations is suspect because of the unrealistic nature of the data-collection process. What can be said is that the time data gathered in these studies is the minimum expected response time for a particular sensory channel and that the highest priority alerts should attempt to produce this time as optimum. Even though the actual quantitative time data from these studies may not be directly relevant to cockpit situations, the information gained about the relationship between variables can be used in many cases.

For example, the real effect of signal location on detection time has not been quantified in the literature for the full range of signals. However, there are simple reaction time data that indicate a trend toward slower reaction as deviation from the line-of-sight increases. These data may be used as an indication of the relative effect of different locations if detection time is a design criteria. Another and possible more important source of information in these types of data is the number of times the observer missed the signal or gave "no response." These data, although still not directly applicable, quantitatively will come closer to "real world" values because they are not time dependent.

These types of evaluations were made for the data collected in each of the areas of concern. Following this process, it was determined that the amount of directly usable data for all areas of concern was sufficiently low to warrant augmentation. Since the amount of data needed was large, a method of prioritization was needed.

2.4.2.2 Prioritization of Missing Data

Rating, ranking, and paired comparison techniques were used to prioritize the data needs. Two questionnaires were developed using the matrices illustrated in figures 30 through 33. Each questionnaire was distributed to one of two groups of seven people in the Boeing flight deck design organization along with the data that had been gathered and abstracted (see appendix H). The first group of seven were told that "each cell in the matrices (excluding the diagonals) represented a comparison between two variables, i.e., size and location." Their task was to (1) review the data that had been collected, (2) compare the importance of obtaining more data about each variable, and (3) indicate the variable for which more data were most needed by putting its number in the cell. This paired comparison technique allowed the comparison of each variable with every other variable and the ranking of the variables according to their importance.

Another objective of the prioritization scheme was to determine how the variables should be combined in the testing phase to produce the most effective data. To accomplish this objective, a second group of seven raters was told that "each cell in the matrices represented either a single variable (the diagonals) or a combination of two variables, i.e., size and location." They were to assume for the latter case that the combinations of the variables was producing an effect on signal detection and that it was the importance of obtaining additional data on that effect which they were rating. Two variables were used as the maximum number of combined variables because it was felt that the difficulty of rating any more combinations would detract from the usefulness of the findings. The rater's task was to rate the importance of collecting data for each cell on a four-point scale.

		1 Size	2 Brightness	3 Contrast	4 Location *	5 Color	6 Workload	7 Pilot age	8 False signals	9 Flash rate	10 Frequency of occurrence	11 Number of distracting signals	12 Signal duration
1	Size	■											
2	Brightness	■	✹										
3	Contrast	■	■	■									
4	Location *	■	✹	☆	✹								
5	Color	■	■	■	■	■							
6	Workload	☆	✹	☆	✹	☆	✹						
7	Pilot age	■	■	■	■	■	☆	■					
8	False signals	☆	☆	☆	☆	■	✹	■	☆				
9	Flash rate	■	■	■	✹	■	■	■	■	■			
10	Frequency of occurrence	■	■	■	■	■	☆	■	✹	☆	■		
11	Number of distracting signals	■	✹	☆	✹	■	✹	■	✹	■	✹	✹	
12	Signal duration	■	■	■	☆	■	☆	■	■	■	■	✹	☆

* Location with respect to the straightahead

✹ Highest priority data ☆ Secondary priority data ■ Lowest priority data

Figure 30 Data Collection Priority for Visual Caution and Warning Signals

		1 Intensity	2 Types of background noise	3 Frequency (pitch)	4 Workload	5 Pilot age	6 False signals	7 Number of different signals	8 Frequency of occurrence	9 Location *	10 Signal-to-noise intensity ratio	11 Signal duration	12
1	Intensity	☆											
2	Types of background noise	☆	✹										
3	Frequency (pitch)	☆	■	■									
4	Workload	☆	✹	☆	☆								
5	Pilot age	☆	☆	☆	☆	■							
6	False signals	■	☆	☆	✹	☆	☆						
7	Number of different signals	■	✹	✹	✹	☆	✹	✹					
8	Frequency of occurrence	■	☆	✹	✹	☆	✹	✹	■				
9	Location *	■	■	■	✹	■	■	✹	■	■			
10	Signal-to-noise intensity ratio	☆	☆	☆	☆	✹	☆	☆	■	■	☆		
11	Signal duration	■	☆	☆	☆	☆	☆	■	■	■	■	■	
		■	■	■	■	■	☆	☆	■	■	■	■	■

* Spatial location of the sound or one- vs two-ear presentation

✹ Highest priorty data ☆ Secondary priority data ■ Lowest priority data

Figure 31 Data Collection Priority for Nonverbal Auditory Caution and Warning Signals

		1	2	3	4	5	6	7	8	9	10	11
		Intensity	Types of background noise	Signal-to-noise intensity ratio	Number of distracting messages	Message content	Voice type *	Familiarity with messages	Intelligibility of speech	Pilot age	Workload	False signals
1	Intensity	✸										
2	Types of background noise	✸	■									
3	Signal-to-noise intensity ratio	✸	✸	✸								
4	Number of distracting messages	✸	☆	☆	■							
5	Message content	✸	✸	✸	☆	✸						
6	Voice type *	✸	✸	✸	■	☆	✸					
7	Familiarity with messages	☆	✸	☆	☆	✸	■	✸				
8	Intelligibility of speech	✸	✸	☆	■	✸	☆	☆	✸			
9	Pilot age	■	■	■	■	■	☆	■	■	■		
10	Workload	☆	☆	☆	✸	✸	☆	☆	☆	☆	☆	
11	False signals	☆	■	☆	☆	☆	■	☆	☆	■	☆	☆

* Voice differences may occur in such things as: male, female, pitch, stress, intonation, etc.

✸ Highest priority data ☆ Secondary priority data ■ Lowest priority data

Figure 32 Data Collection Priority for Verbal Auditory Caution and Warning Signals

		1 Modal priority *	2 Interstimulus interval **	3 Signal duration	4 Differential signal intensity	5 False signals	6 Location ***	7 Pilot age	8 Workload
1	Modal priority *	✸							
2	Interstimulus interval **	✸	☆						
3	Signal duration	✸	✸	■					
4	Differential signal intensity	✸	☆	☆	☆				
5	False signals	☆	☆	☆	☆	☆			
6	Location ***	✸	☆	☆	✸	☆	✸		
7	Pilot age	☆	☆	■	☆	■	■	■	
8	Workload	✸	✸	☆	☆	✸	✸	✸	☆

* Which signal (auditory or visual) should be presented first?
** How much time should be given between the two signals?
*** Spatial location of each of the signals

✸ Highest priority data ☆ Secondary priority data ■ Lowest priority data

Figure 33 Data Collection for Bimodal (Auditory-Visual) Caution and Warning Signals

The results from the two sets of matrices were combined to form the prioritization that can also be seen in figures 30 through 33. The diagonal priorities represent the importance of individual variables and the other cell priorities the importance of the two variable interactions. To assess the validity of the responses, two variables—visual signal size and aural intensity—were included even though they were covered by directly applicable data in the literature review. Both of these variables were low priority in the survey.

2.4.2.3 Test Plans for Acquiring Missing Data

The high-priority data requirements established in figures 30 through 33 were evaluated and a set of 19 three-page test plans was constructed. The groundrules followed for the first cut at defining required test programs were:

- Use as many of the high-priority data cells as possible.
- The number of variables and levels should be chosen to provide approximately 2 weeks of testing per test plan.
- The test design should be statistically sound.

The resulting test designs are presented in appendix I. It should be noted that if the time restraints (2 weeks testing per test plan) are relaxed, some of the test plans can be expanded quite easily to include a larger number of variables.

These test plans define only the testing necessary to fill the most important gaps in the human factors data required to design alerting systems. Elements of alerting systems will be evaluated by these tests. Then alerting system concepts based on substantiated design data can be developed. Another set of tests that provide comparative evaluations of these concepts are then required in order to validate the ideas incorporated therein. The exact nature of these comparative tests has not been defined yet.

2.5 PRELIMINARY RECOMMENDATIONS FOR STANDARDIZATION OF ALERTING METHODS AND FUNCTIONS

Current alerting methods and the inconsistencies in the alerting philosophies applied thereto were reviewed in section 2.1. Alerting function and system requirements were established in section 2.2. The rationale, criteria, and method for prioritizing the alerting functions were developed in section 2.3. A review of the human factors data applicable to designing alerting systems was presented in section 2.4. These four aspects of developing alerting systems were combined to formulate *preliminary recommendations* for standardizing alerting methods and functions. The recommendations, a sample alerting system concept that conforms with these recommendations, and an analysis of the conflicts between the proposed prioritized alerting systems, tradition and existing requirements are presented in this section.

2.5.1 RECOMMENDED DESIGN GUIDELINES

> The recommendations presented in this section should *not* be interpreted as firm design guidelines or as minimum performance standards. At this time, these guidelines have been only partially substantiated. Significant testing is still required to validate these guidelines.

The interactions between the data presented in the previous sections were analyzed, agreements, correlation and conflicts were noted, and preliminary design guidelines (not minimum performance standards) for alerting systems were formulated.

The design guidelines were oriented to provide the following type of alerting system characteristics and cockpit environment:

- A consistent design philosophy that can be applied to all new aircraft, irrespective of manufacturer.
- Quiet, dark cockpit when all systems are operating normally and when abnormal situations have been "cleaned-up" (except automatic flight control mode annunciators).
- Associate a unique audio, visual, or combination audio-visual method of alerting with each alert priority level.
- Provide alerting system growth capability in a form that does not necessitate additional discrete annunciators.

Accordingly, the following preliminary design guidelines are recommended.

Prioritization

- Selected alerts should be categorized as a function of criticality and flight phase. Category criteria are presented in table 14. Flight phases that might be considered are defined in table 15.
- Selected alerts within each category should also be prioritized as a function of criticality.

Inhibits

- The number and type of alerts that can be annunciated during critical phases of flight should be restricted.
- Prioritization of the alerts may be used as a method of inhibiting or at least attenuating nonessential alerts.

Visual Alerts

- An alphanumeric readout device, located in front of each pilot, should be provided to identify warning- and caution-type alerts.

- Discrete alerts—Wherever possible, reduce the number of annunciations in the cockpit.

  —Advisory lights should not illuminate unless a discrete crew action, such as pushing a button, is performed (except automatic flight control mode annunciators).

- Red alerts—Apply only to situations where immediate action is required, i.e., only LEVEL 1 alerts.

  —Use when annunciation by an aural alert plus the alphanumeric readout devices is not adequate.

- Amber/yellow alerts—Apply only to situations that require immediate crew awareness and eventual action, i.e., only to LEVEL 2 alerts.

  —Use when annunciation by the common aural alert for all LEVEL 2 items and the alphanumeric readout devices is not adequate.

- Green alerts—Use to confirm the SAFE OPERATION or GO status of a system.

  —A manual action by the crew, such as pushing a button, should be required to illuminate green lights (except automatic flight mode annunciators).

- Blue alerts—Use to annunciate intransit conditions.

  —A manual action by the crew, such as pushing a button, should be required to illuminate blue lights (except automatic flight mode annunciators).

- White alerts—Use for illuminating keyboards and annunciating ON/OFF system modes, i.e., when used in place of toggle switches.

- Location—LEVEL 1 alerting devices (warnings) should be located within 15° of the pilot's centerline of vision (centerline of vision is defined as the line between the pilot's eye reference point and the center of the ADI).

  —LEVEL 2 alerting devices (cautions) should be located within 30° of the pilot's centerline of vision.

  —Green, blue, and white lights can be located anywhere in the cockpit that is readily visible to the crew.

  —All alerts presented by discrete lights, flags, or bands should be repeated on the alphanumeric readout device (except automatic flight mode annunciators).

- Size—High priority lights (associated with LEVEL 1 and 2 alerts) should be no less than 1^{o} visual angle in size.

  —Secondary lights (associated with LEVEL 3 and lower priority alerts) should be no less than 0.5^{o} visual angle in size.

- Brightness—LEVEL 1 alerts should have a brightness capability of at least 150 ft-L and should be at least twice as bright as other displays in the vicinity of the alert.

  —LEVEL 3 and lower priority alerts should have a brightness capability of at least 15 ft-L and should be at least 10% brighter than nonalert displays in the vicinity of the alert.

  —Automatic brightness adjustment for varying ambient light conditions should be provided.

- Flashing—Use only for highest priority (LEVEL 1) alerts.

Aural Alerts

- Application—Use discrete aural alerts to annunciate highest priority situations (LEVEL 1 alerts) and to attract attention to LEVEL 2 alerts on the alphanumeric readout device.

- Maximum number—Less than four familiar alerts (based on pilot opinion).

  —If the number of discrete aural and tactile alerts exceeds seven, they should be supplemented by voice annunciations.

- Intensity—Should be less than intensity of most currently used aural alerts.

  —Maximum intensity of 15 dB above threshold noise level or halfway between threshold level and 110 dB, whichever is less.

  —Automatic intensity adjustment for varying ambient noise conditions should be provided.

  —Aural alerts associated with LEVEL 1 items should be noncancellable without correction of the fault or situation.

  —A means of reducing the annoyance of continuous aural alerts after initial recognition is achieved should be provided.

  —A means of disabling any nuisance actuation of an aural alert should be provided in a form that does not affect the integrity of the other aural alerts (e.g., one circuit breaker or guarded/wired shutoff switch for each aural alert).

- Sound characteristics–Each signal should be composed of two or more widely separated frequencies in the range from 250-4000 Hz.

  –Intermittent signals should be used.

- Voice characteristics–Messages should be preceded by an identifier to which the pilot is more than normally sensitive (attention getter).

  –Messages should be constructed of short sentences of polysyllabic words.

  –Pilots should be familiar with all voice messages.

- Location–Aural alerts should appear to emanate from the vicinity of the alphanumeric readout device.

Tactile Alerts

- Minimize use of tactile alerts.

Master Warning/Master Caution

- A master warning signal and a master caution signal should be located in front of each pilot if the alphanumeric readout display is located outside the pilot's primary field of view.
- All LEVEL 1 alerts should activate the master warning signal (if utilized).
- All LEVEL 2 alerts should activate the master caution signal (if utilized).
- No LEVEL 3 or 4 alerts should activate the master warning or master caution signals (if utilized).

Checklists

- Type of alert and type of checklist used to rectify an annunciated situation should correlate.
- Emergency procedures should be associated only with LEVEL 1 (warning type) alerts.
- Abnormal procedures should be associated only with LEVEL 2 (caution type) alerts.

  NOTE: A checklist is not necessarily associated with each LEVEL 1 or LEVEL 2 item, and an alert is not necessarily associated with each checklist.

2.5.2 SAMPLE ALERTING SYSTEM CONCEPT THAT CONFORMS WITH RECOMMENDED DESIGN GUIDELINES

One of the primary goals of this study is to provide preliminary design guidelines for achieving a quite, dark cockpit when all systems are operating normally and when abnormal situations have been "cleaned-up." With the quiet, dark cockpit concept, all visual and auditory alerting devices except automatic flight mode annunciators would be OFF unless (1) an abnormal situation exists or (2) the crew desires annunciation of a specific situation. The amount of advisory and status information in the cockpit would be minimized. The crew would have the capability to enable or disable certain annunciations, primarily status information. Manual action by the crew would be required to get a momentary display of certain annunciations, e.g., the annunciation of intransit conditions. The crew would then have a "clean" cockpit to work in, would not become insensitive to common annunciations, and would recognize and be able to correct abnormal situations more rapidly than in current cockpits.

The recommended preliminary design guidelines could be applied as follows to fulfill this objective. Discrete aural alerts were recommended for annunciating LEVEL 1 situations, for attracting attention to the alphanumeric display when LEVEL 2 situations arise, for annunciating assigned altitude deviations and decision height, and possibly for annunciating incoming communications. Accordingly, a unique discrete aural alert might be required for each of the following situations:

- Gear down and locked but lever not in down detent
- Unsafe takeoff configuration
- Unsafe landing configuration
- Ground proximity warning
- Rapid depressurization
- Autopilot disconnect
- Common attention-getting tone for all LEVEL 2 alerts
- SELCAL
- Cabin call
- Data link
- Decision height
- Altitude alert (altitude deviations)

Thus 12 discrete aural alerts would be required; however, another guideline stated that the number of aural alerts should not exceed 4 (pilot opinion). The number of discrete aurals can be reduced almost to this number by retaining the traditional horn for all LEVEL 1 "unsafe configuration" warnings; by incorporating the alerts for SELCAL, cabin call, and data link into the integrated alerting system as LEVEL 2 alerts; and by using a command aural alert for decision height and altitude deviations. One aural alert could be used for unsafe takeoff configuration, unsafe landing configuration, and gear down and locked but lever not in down detent.

The central alphanumeric readout device could simultaneously denote the exact nature of the configuration problem. Similarly, the common tone used for all LEVEL 2 alerts could be used for annunciating incoming SELCAL, cabin call, and data link messages, and the alphanumeric readout device could denote the specific communication channel requiring attention. Decision height could not be included as a LEVEL 2 alert because the pilot cannot afford to divert his attention to reading the alphanumeric display at the critical time when this is annunciated. Thus decision height and altitude alert require a separate, distinct aural alert. By implementing the system in this manner, the number of aural and tactile alerts would be reduced to six.

The number of potentially ambiguous aural alerts could be even further reduced by using voice annunciations for all other LEVEL 1 alert situations listed above. However, the effects of extensive application of voice alert annunciations are not known at this point. Current experience with voice alerting systems has not been satisfactory. The type of systems described above wherein a small number of discrete aurals are used in conjunction with an alphanumeric display is thus recommended at this time.

In addition to these types of annunciation for the high-priority alerts, a very limited number of green, blue, and white advisory alerts would be utilized. A third switch state might be added to the lights test switch to handle these alerting functions. The three lights test switch positions would be reassigned to provide the following functions:

- TEST–All lights ON to test light sources plus test pattern on alphanumeric display to validate operation of display.
- IMMEDIATE SITUATION–All faults, intransit conditions, etc., would be annunciated as they occur. Existing alert situations would also be annunciated. Alerting system operation would as in current aircraft.
- CLEAR–This would cancel all currently displayed alerts except warnings and automatic flight mode annunciations and provide a relatively quiet, dark cockpit. No intransit or SAFE/GO conditions would be automatically annunciated while the system is in this state. Only new cautions and warnings would be automatically annunciated. Any new caution annunciation could be "cleared" by switching from CLEAR to IMMEDIATE SITUATION and back to CLEAR. A small pushbutton might be added to each system's panel. While in this alerting system operating mode, the crew could get all green, blue, and white light annunciations on that system panel by pushing this button. This would provide the crew with selective alert annunciation capability.

These alerting system implementation ideas are at this point only preliminary suggestions and examples of how the design guidelines could be applied to (1) clean up the cockpit, (2) provide the crew with the capability to select an alerting system operating mode that is similar to current aircraft, and (3) provide the crew with the capability to select an alerting system operating mode that results in a relatively quite, dark cockpit when all systems are operating normally and when abnormal situations have been "cleaned up." These ideas represent only several of many ways in which an alerting system could be implemented and still conform to the recommended design guidelines. More refinement, testing, and analysis of the hardware/implementation impact of these concepts are required to validate them.

2.5.3 CONFLICTS BETWEEN TRADITION, REQUIREMENTS, AND RECOMMENDED DESIGN GUIDELINES

The preliminary design guidelines recommended in section 2.5.1 conflict with traditional alerting system concepts and with the requirements in the following areas:

- Elimination of traditional aurals
- Downgrading of several alerts previously considered high-priority items
- Terminology used in the FARs

The priority system proposed in table 16 conflicts with tradition by eliminating several traditional aural alerts. This priority system would eliminate the unique aural alerts associated with fire, excessive airspeed, stabilizer in motion, and below glide slope warnings. Many pilots feel that these aural alerts are sacrosanct. However, the analyses showed that the required pilot response to these alerts is not immediate action. Thus, they do not qualify as LEVEL 1 alerts and do not deserve unique discrete aurals.

The proposed priority system also conflicts with tradition by downgrading several alerts previously considered high-priority alerts from red lights to amber lights or no lights at all (just an alphanumeric identification). In the case of the 737, autopilot disconnect, fire, gear unlocked, and gear not down and locked with thrust lever at idle are examples of traditionally large, red light alerting functions that might be downgraded. The amber flight director mode "armed" annunciations are examples of alerting functions that might be downgraded or modified so as not to imply a "caution" situation. Similarly, other functions might be upgraded. The blue lights used to annunciate APU oil quantity low and thrust reverser armed are examples of such alerts. In a new aircraft, these alerts might be upgraded to amber lights and green lights, respectively, so as to make the color of the light reflect the criticality of the situation.

Federal Aviation Regulations (FARs) use the word "warning" indiscriminately. Examples of where such usage occurs in the FARs are tabulated in table 20. If the guidelines recommended herein are adopted, the language in these FARs will have to be modified. It is suggested that the type of terminology used in other sections of these FARs to indicate a requirement for an alert be extended to all FARs and that the term "warning" be deleted. Examples of such terminology are the following:

- "Means to indicate"
- "An aural or visual signal"
- "Means must be provided to alert the crew"

Table 20 Federal Aviation Regulations Using the Term "Warning"

25.207(b)
25.729(e)(2), (3) and (4)
25.777(c)
25.812(e)(2)
25.841(b)(6) and (7)
25.859(e)(3)
25.1165(g)
25.1203(b)(3)
25.1303(c)(1)
25.1305
25.1309(c)
25.1353(c)(5)(ii) and (iii)
37.201(a)(3)
91.49
121.289(a) and (b)
121.360(b) and (c)

3.0 CONCLUSIONS

The alerting system implementation guidelines specified herein should be interpreted as (1) *preliminary*, not final, design guidelines, and (2) design objectives, not minimum performance standards. The recommended design guidelines are only partially substantiated by quantitative data—they represent our best implementation ideas at this time. Additional testing to (1) derive directly applicable human factors data, (2) quantify the effectiveness of various elements of alerting systems, and (3) quantify the effectiveness of various full alerting system concepts plus an analysis of the hardware/implementation impact of these concepts are required to complete and validate the proposed design guidelines.

The following conclusions are the results of analyses of current alerting methods and requirements, the development of alert prioritization criteria, and a survey of human factors data pertinent to the design of alerting systems.

The aircraft operators and manufacturers apparently feel the pilots need more in-flight malfunction resolution capability and need to record better maintenance data. Thus each new aircraft has incorporated more alerting functions specifically due to a trend toward providing the crew with more detailed subsystem information. The most rapid growth in the number of subsystem alerts has occurred in the electrical, navigation, and automatic flight control systems. Negligible growth has occurred in the air-conditioning, altitude alert, APU, communications, emergency equipment, flight instrument, air data, fuel, and powerplant systems. All other systems have exhibited moderate growth in the number of alerts. With this proliferation of alerts, the cockpits have become saturated with information systems. More multifunctioning of the alerts is being used to get around the lack of panel space problem. The inclusion of these devices is adding to the potential for confusion in the cockpit.

The number of alerts, especially the number of aural alerts, should be reduced. The potential for confusion exists with this many alerts. To maximize the effectiveness of the alerts, noncritical alerts should be inhibited during high workload periods such as takeoff and flare/landing. Prioritization of the alerts, so as to identify the most critical problem, should also be considered.

Prioritization of the alerting functions currently must be accomplished via subjective methods. Numerical methods require additional quantitative data about crew reliability and pilot latency, and the effects of workload on these two factors, or the time history of the aircraft's/system's performance degradation as related to each alert.

Criteria for four levels of alerting function prioritization are available. Most organizations working toward developing standards for alerting systems basically agree with the four levels of priority established in this study and the criteria defining these levels. Minor grammatical differences remain to be "ironed out."

Standardization of the alerting function priorities may be possible for alerts within the two highest priority levels. However, the alerts within the two lowest priority levels are too dependent on each aircraft's unique design features to be amenable to priority standardization.

A unique audio, visual, or combination audio-visual method of alerting should be associated with each priority category to provide an instantaneous assessment of the alerting situation's criticality. Human factors data pertinent to optimizing this audio-visual interface with the pilot are available. However, the data are incomplete and further testing of specific elements of alerting systems is required to fill the major data gaps.

Preliminary design guidelines for standardization of alerting functions and methods are available. The basic guidelines specified in section 2.5.1 are recommended. Numerous conflicts exist between these guidelines, traditional alerting system concepts, and existing regulations. Most conflicts with existing regulations can be resolved with minor modifications of the language used to indicate a requirement for an alert.

Additional comparative testing of elements of alerting systems and full alerting system concepts plus analyses of the hardware implementation characteristics of these concepts are required to complete and validate the proposed design guidelines.

APPENDIX A

TABULATION OF ALERTING FUNCTIONS AND IMPLEMENTATION CHARACTERISTICS

This appendix provides detailed descriptions of the alerting functions in a typical configuration of each basic type of commercial turbojet transport aircraft. To simplify this tabulation, similar types of indications were consolidated under one title. Examples are: (1) red bands, red limit marks, and pink limit marks were consolidated under the title "red bands" because they have similar operational implications; (2) fire orange flags used as warning indications were tabulated as red flags; and (3) yellow lights were tabulated as amber lights.

The asterisks on tables contained in this section mean "same as."

Air-conditioning (sheet 1)

	Alerting function	Type of alert									Applicable federal aviation regulations (FAR)
		707/720	727	737	747	DC-8	DC-9	DC-10	L-1011	BAC-111	
1	Air conditioning system malfunction			1 amb lt					1 fl amb lt		
2	Air supply temp high						2 amb lts				
3	Avionics cooling air valve open								2 amb lts		
4	Avionics vent duct air too warm or flow restricted								2 amb lts		
5	No air flow in cockpit or eqpmt cooling compt	1 amb lt	2 amb lts	1 amb lt	1 amb lt			1 amb lt			
6	Cargo heat on				1 grn lt						
7	Cargo compartment too hot or too cold				1 amb lt	1 amb lt (* 15)			6 amb lts		
8	Center accessory compartment overheat							1 amb lt			
9	Cool air oved valve closed (galley & avionics exhaust)								1 amb lt		
10	Differential pressure excessive			1 yel/red band			1 red band				
11	Duct overheat	2 amb lts	3 amb lts	2 amb lts	5 amb lts (* 49)			1 amb lt (* 15)	1 wht lt		
12	Equipment cooling valve position (open)	1 grn lt									
13	Floor heat failed								1 amb lt		
14	Floor heat off								1 wht lt		
15	Forward avionics compartment overheat					1 amb lt (* 7)		1 amb lt (* 11)	2 amb lts		
16	Freon pack on	2 grn lts				2 blu lts					
17	Freon system compressor off	2 amb lts									
18	Cabin compressor overspeed					4 red bands					
19	Freon compressor overheat					2 amb lts					
20	Abnormal freon temperature					4 grn/red bands					
21	Humidity control override								1 wht lt		

Air conditioning (sheet 2)

	Alerting function	Type of alert									Applicable federal aviation regulations (FAR)
		707/720	727	737	747	DC-8	DC-9	DC-10	L-1011	BAC-111	
22	INS flow off							2 amb lts			
23	Off schedule descent			1 amb lt							
24	Outflow valve operating mode manual (auto fail)				1 amb lt				2 wht lts		
25	Outflow valves position			1 blu lt					2 grn bands		
26	Pack control mode (auto/manual)								6 wht lts		
27	Pack temp, valve & door indicators mode				3 wht/blu dual legend lts						
28	Pack area overheat								3 amb lts		
29	Pack overheat trip off		2 amb lts (* 31)	2 amb lts	3 amb lts	4 red lts		3 amb lts	3 amb lts	2 amb lts	25.859(e) (3) There must be means to warn the crew when any heater whose heat output is essential for safe operation has been shut off by the automatic means prescribed in subparagraph (1) of this paragraph.
30	Auto pack trip armed		1 grn lt								
31	Pack valve closed		2 amb lts (* 29)								
32	Pressurization failure	intermittent horn	intermittent horn	1 amb lt & intermittent horn	intermittent horn	intermittent horn	1 red lt & horn	2 red lts & horn	1 amb lt & intermittent horn	1 red lt	25.841(b) Pressurized cabins must have at least the following valves, controls, and indicators for controlling cabin pressure: (6) Warning indication at the pilot or flight engineer station to indicate when the safe or preset pressure differential and absolute cabin pressure limits are exceeded. Appropriate warning markings on the cabin pressure differential indicator meet the warning requirement for pressure differential limits and an aural or visual signal (in addition to cabin altitude indicating means) meets the warning requirement for absolute cabin pressure limits if it warns the flight crew when the cabin absolute pressure is below that equivalent to 10,000 feet. (7) A *warning placard at the pilot or flight engineer* station if the structure is not designed for pressure differentials up to the maximum relief valve setting in combination with landing loads.
33	Pressurization system operating mode			2 grn lts				1 blu lt			
34	Standby pressurization system operating mode							1 blu lt			
35	Pressure safety valves open								2 amb lts		
36	Radio rack fan off						1 amb lt			1 amb lt	

Air conditioning (sheet 3)

	Alerting function	Type of alert									Applicable federal aviation regulations (FAR)
		707/720	727	737	747	DC-8	DC-9	DC-10	L-1011	BAC-111	
37	Ram air door open			2 blu lts							
38	Ram air door operating automatically								1 amb lt		
39	Pack discharge temp high							1 yel/orn band			
40	Relief valve open				2 amb lts			1 amb lt			
41	Smoke in equipment cooling compartment				1 amb lt						
42	Tail compartment temp high						1 red lt				
43	Temperature indicator mode selected				3 wht/blu dual legend lts				2 wht lts		
44	Temperature regulator fault	2 wht lts									
45	Trim air press hi				1 grn band			1 amb lt			
46	Turbine inlet temp hi							1 yel/orn band			
47	Water separator anti-ice system—manual control		2 amb lts								
48	Zone overheat	1 amb lt					1 red band				
49	Zone trim valves closed				5 amb lts (* 11)				5 wht lts		
50	Freon superheat					4 red bands					

Aircraft general (sheet 1)

	Alerting function	Type of alert									Applicable federal aviation regulations (FAR)
		707/720	727	737	747	DC-8	DC-9	DC-10	L-1011	BAC-111	
1	Position lights off								1 amb lt		
2	Strobe lights off								1 amb lt		
3	Anti-collision lights off								1 amb lt		
4	Wing flood lights on								1 amb lt		
5	Wheel well lights on								1 amb lt		
6	Fasten seat belts sign on				1 blu/wht lt & tone				1 wht lt		
7	No smoking light on				1 blu/wht lt & tone				1 wht lt		
8	Thunderstorm lights on								1 wht lt		
9	Eye locator light on								1 wht lt		
10	Pilot's warning, caution advisory lights intensity bright-dim							1 wht lt	2 wht lts		
11	Pilot's warning, caution & advisory lights test mode							1 wht lt	1 wht lt		
12	Flight engineer's warning, caution & advisory lights intensity bright/dim								2 wht lts		
13	Flight engineer's warning, caution & advisory lights test mode								1 wht lt		
14	Master caution			2 amb lts			2 amb lts	3 amb lts			25.771(c) If provision is made for a second pilot, the airplane must be controllable with equal safety from either pilot seat. 25.777(a) Each cockpit control must be located to provide convenient operations and to prevent confusion and inadvertent operation. 25.1309(c) Warning information must be provided to alert the crew to unsafe system operating conditions, and to enable them to take appropriate corrective action. Systems, controls, and associated monitoring and warning means must be designed so that crew errors that would create additional hazards are improbable.
15	Master warning	1 fl red lt	1 fl red lt			1 red lt	2 red lts	3 red lts		2 fl red lts	
18	Flight recorder off		1 amb lt	1 amb lt	1 amb lt	1 amb lt	1 amb lt	1 amb lt	1 amb lt		25.1459(a) Each flight recorder required by the operating rules of this chapter must be installed so that–(4) There is an aural or visual means for preflight checking of the recorder for proper recorder tape movement.
19	Cockpit voice recorder test ok										25.1457(d) Each cockpit voice recorder must be installed so that–(3) There is an aural or visual means for preflight checking of the recorder for proper operation.
20	Movie projectors on					3 blu lts			2 wht lts		

Aircraft general (sheet 2)

	Alerting function	Type of alert									Applicable federal aviation regulations (FAR)
		707/720	727	737	747	DC-8	DC-9	DC-10	L-1011	BAC-111	
21	Movie projectors off								1 wht lt		
25	Water system pressure limit							1 wht/yel band			
27	Flt. deck door lock released			1 amb lt	1 blu/wht lt						
30	Aft airstair locked down		1 grn lt								
31	Galley fault								1 amb lt		
32	Malfunction annunciation on overhead panel			1 amb lt							
33	Water line heater failure								1 amb lt		
34	Door fault/open	8 amb lts	13 amb lts	9 amb lts	16 amb lts	2 red lts	7 amb lts	20 amb lts	12 amb lts & 1 fl amb lt	5 red lts	
35	General requirement										25.1322 If warning, caution or advisory lights are installed in the cockpit, they must, unless otherwise approved by the Administrator, be—(a) Red, for warning lights (Lights indicating a hazard which may require immediate corrective action) (b) Amber, for caution lights (lights indicating the possible need for future corrective action) (c) Green, for safe operation lights; and (d) Any other color, including white, for lights not described in paragraphs (a) through (c) of this section, provided the color differs significantly from the colors prescribed in paragraphs (a) through (c) of this section to avoid possible confusion.

Altitude alert system

	Alerting function	Type of alert									Applicable federal aviation regulations (FAR)
		707/720	727	737	747	DC-8	DC-9	DC-10	L-1011	BAC-111	
1	Approaching altitude	1 amb lt & C chord	1 amb lt & tone	1 blu lt & tone	1 amb lt & tone	2 amb lts, horn & beeper (*3)	1 amb lt & tone	1 amb lt & 1 tone (*3)	2 amb lts & tone	Tone	91.51(b) Each altitude alerting system or device required by paragraph (a) of this section must be able to (1) alert the pilot, upon approaching a preselected altitude in either ascent or descent, by a sequence of both aural and visual signals in sufficient time to establish level flight at that preselected altitude; (4) be tested without special equipment to determine proper operation of the alerting signals; however, for operations below 3,000 feet AGL, the system or device need only provide one signal, either visual or aural, to comply with this paragraph.
2	On-altitude	1 grn lt	1 grn lt		1 grn lt		1 grn lt		2 grn lts		
3	Altitude deviation	1 fl red lt	1 fl red lt		1 red dual legend lt	2 amb lts & beeper (*1)	1 fl red lt & tone	1 fl amb lt (*1)	2 fl red lts & tone		
4	Altitude alert failure	1 red barber pole flag	1 red barber pole flag	1 red flag		1 red flag	1 red flag		1 red flag		

APU (sheet 1)

Alerting function	Type of alert									Applicable federal aviation regulations (FAR)
	707/720	727	737	747	DC-8	DC-9	DC-10	L-1011	BAC-111	
APU N2 overspeed/auto shutdown								1 red flag		
APU low oil pressure/ auto shutdown			1 amb lt					1 red flag		
APU high oil temp/ auto shutdown								1 red flag		
APU turbine gas temp overtemp/auto shutdown								1 red flag		
APU don't load alert								1 amb lt		
APU compartment vent closed								1 amb lt		
APU inlet flow restriction/ auto shutdown								1 amb lt		
APU oil quantity low			1 blu lt					1 amb lt		
APU battery shorted or overheated								1 amb lt		
APU doors-in-transit								1 amb lt		
APU fuel filter clogged or icing								1 amb lt		
APU max mode (max. air flow)								1 amb lt		
APU auto fire shutdown system armed								1 amb lt		
APU bleed air valve open								1 amb lt	1 ( ) lt	
APU start switch on		1 amb lt						1 wht lt		
APU EGT overtemp		1 grn/yel/ red band	1 grn/yel/ red band			1 yel/red band	1 orn band			
APU tachometer— normal & overspeed ranges						1 grn/yel/ red band				
APU oil temp hi			1 amb lt			1 amb lt	1 amb lt			
APU oil press low						1 amb lt	1 amb lt			
APU fuel valve in-transit				1 blu lt						
APU DC fuel pump on				1 grn lt						

APU (sheet 2)

Alerting function	Type of alert									Applicable federal aviation regulations (FAR)
	707/720	727	737	747	DC-8	DC-9	DC-10	L-1011	BAC-111	
APU failure			1 amb lt	1 amb lt						
APU inlet door in-transit				1 blu lt						
APU fuel valve not closed		1 amb lt								
APU overspeed			1 amb lt				2 wht/yel/ orn bands			
APU fuel pressure low							1 amb lt	1 amb lt		
APU fuel pump switch on							1 blu lt			
APU door open							1 blu lt			
APU operating in standby control mode using electrical power							1 blu lt			
APU fuel valve open									1 ( ) lt	

Automatic flight control system (sheet 1)

	Alerting function	707/720	727	737	747	DC-8	DC-9	DC-10	L-1011	BAC-111	Applicable federal aviation regulations (FAR)
8	Autopilot/flight director cat. I approach mode armed								1 wht lt		
9	Flight director altitude hold mode armed				2 amb lts (* 10)				2 blk flags (* 11)		
10	Flight director–selected altitude captured				2 grn lts (* 9)				2 wht flags (* 12)		
11	Autopilot altitude hold mode armed				2 amb lts (* 12)				2 blk flags (* 9)		
12	Autopilot--selected altitude captured				2 grn lts (* 11)				2 wht flags (* 10)		
16	Flight director approach speed command mode armed				2 amb lts (* 17)						
17	Flight director approach speed command captured				2 grn lts (* 16)						
18	Autopilot disconnect	2 fl red lts	2 fl red lts	2 fl red lts	2 fl red lts (* 21, 55, 56, 57) & WAILER	2 red lts	1 fl red lt & click	(See 101 & 102)	2 red flags & wailer	1 fl amb lt	37.119(a) (3) Additions. In addition to the means of indication specified in section 4.3 of AS 102A, the following shall be included: (i) Power, malfunction indication. Means shall be provided to indicate readily to the pilot in a positive manner when each phase of the primary power (voltage and/or current) to the automatic pilot is not adequate for safe operation. (ii) Airborne navigation reference indication. A visual means shall be provided to indicate readily to the pilot in a positive manner when the automatic pilot is not engaged to the airborne navigation reference.
19	Improper AFCS configuration for autoland engage								Indicated by flags 20, 21, 133, 134, 135		
20	Autopilot failure during autoland approach								2 amb flags (* 21)		
21	Marginal AFCS condition for autoland operation				2 fl amb lts (* 18, 55, 56, 57)				2 amb flags (* 20)		
22	Autopilot's stabilizer control at limit								2 red flags		
23	AFCS failure–master warning signal								2 fl amb lts		
24	Autothrottle disconnect	1 fl amb lt	1 fl amb lt	2 red lts (Inop)	2 fl red lts (* 53, 54)		1 red lt	(See 99 & 100)	2 red flags		
25	Autothrottle channel failure								2 red flags		
26	Go-around computation failure								2 amb flags		

Automatic flight control sytsem (sheet 2)

	Alerting function	Type of alert									Applicable federal aviation regulations (FAR)
		707/720	727	737	747	DC-8	DC-9	DC-10	L-1011	BAC-111	
27	Flare computation failure								2 amb flags		
28	Autopilot tripped from command to CWS because of faulty inputs								2 amb flags		
43	Automatic landing mode armed								2 blk flags		
44	Runway align mode of autoland armed								2 blk flags		
45	Flare mode of autoland armed				4 amb/grn lts				2 blk flags		
46	Flight director in takeoff mode								2 wht flags		
47	R-nav mode engaged								2 wht flags		
52	AFCS mode annunciator test switch							2 wht lts			
53	Autothrottle self-test switch on				2 red lts (* 24, 54)						
54	Speed error more than 10 knots				2 amb lts (* 24, 53)						
55	Autopilot fault without disengage				2 red lts (* 18, 21, 56 & 57)						
56	Autopilot self-test switch on				2 red lts (* 18, 21, 55 & 57)						
57	Autopilot channels not in agreement while in autoland mode				2 red lts (* 18, 21, 55 & 56)						
58	Flight director on				2 grn lts						
60	Flight director VOR/LOC capture mode armed			2 amb lts (* 61)	2 amb lts (* 61)						
61	Flight director VOR course/LOC captured			2 grn lts (* 60)	2 grn lts (* 60)						
62	Flight director glide slope capture mode armed			2 amb lts (* 63)	2 amb lts (* 63)				2 blk flags (* 66)	2 ( ) flags	
63	Flight director glide slope captured			2 grn lts (* 62)	2 grn lts (* 62)				2 wht flags (* 67)	2 ( ) flags	
64	Autopilot VOR/LOC capture mode armed	1 amb lt (* 65)	1 amb lt (* 65)	2 amb lts (* 65)	2 amb lts (* 65)						

Automatic flight control system (sheet 3)

	Alerting function	Type of alert									Applicable federal aviation regulations (FAR)
		707/720	727	737	747	DC-8	DC-9	DC-10	L-1011	BAC-111	
65	Autopilot VOR course/ LOC captured	1 grn lt (*64)	1 grn lt (*64)	2 grn lts (*64)	2 grn lts (*64)						
66	Autopilot glide slope capture mode armed	1 amb lt (*67)	1 amb lt (*67)	2 amb lts (*67)	2 amb lts (*67)	1 blu lt			2 blk flags (*62)		
67	Autopilot glide slope capture	1 grn lt (*66)	1 grn lt (*66)	2 grn lts (*66)	2 grn lts (*66)				2 wht flags (*63)		
69	Autopilot/manual ILS approach extended		2 grn lts (–31C only)								
70	Flight director speed command mode selected		2 ( ) flags								
72	Go-around mode engaged			2 grn lts					2 wht flags		
73	N1 autothrottle mode in use							2 grn lts			
74	Alpha speed hold Autothrottle mode in use							2 grn lts	1 blu flag		
75	Airspeed hold more in use							2 grn lts	2 wht flags		
76	Retard (flare) autothrottle mode in use							2 grn lts			
77	INS nav mode armed							2 amb lts			
78	INS nav/altitude capture mode armed							2 amb lts			
79	VOR nav mode armed							2 amb lts			
80	VOR nav/altitude capture mode armed							2 amb lts			
81	Altitude capture mode armed							2 amb lts			
82	Localizer/altitude capture mode armed							2 amb lts			
83	Localizer capture mode armed							2 amb lts	1 wht lt & 2 blk flags		
84	ILS/altitude capture mode armed							2 amb lts			
85	ILS capture mode armed							2 amb lts			
86	Autoland mode armed							2 amb lts	1 wht lt & 2 blk flags		

▷ (rows 73–86) On the DC-10, these lights are part of the multi-legend autopilot flight mode annunciator, not individual light units.

Automatic flight control system (sheet 4)

No.	Alerting function	707/720	727	737	747	DC-8	DC-9	DC-10	L-1011	BAC-111	Applicable federal aviation regulations (FAR)
		Type of alert									
87 ▷	Autoland/altitude capture mode armed							2 amb lts			
88 ▷	Dual autoland mode in use							2 grn lts	2 wht flags		
89 ▷	Single autoland mode in use							2 amb lts			
90 ▷	Auto-approach only mode in use							2 amb lts			
91	Flight director localizer back course/altitude capture mode armed							2 amb lts			
92	Flight director localizer back course capture mode armed							2 amb lts			
93	Back course sensing mode activated							2 wht lts			
94	N1 autothrottle mode selector (ED)							1 wht lt			
95	Radio/ins nav mode selector (ED)							1 wht lt			
96	ILS nav mode selector (ED)							1 wht lt			
97	Autoland mode selector (ED)							1 wht lt			
98	CWS mode selected							1 wht lt			
99	Both auththrottle systems disconnected							4 fl red lts			
100	Signal, autothrottle system disconnected							4 amb lts			
101	Autopilot disconnect during single A/P autoland operation							2 fl red lts & wailer (* 102)			
102	Autopilot disconnect during dual A/P autoland operation							4 amb lts or 4 fl red lts & wailer (* 101)			
103	Flight guidance system mode annunciator test ok							8 grn lts			
104 ▷	Heading select mode engaged							2 grn lts	2 wht flags & 1 wht lt		
105 ▷	Heading hold mode engaged							2 grn lts			
106 ▷	INS capture mode engaged							2 grn lts			

▷ On the DC-10, these lights are part of the multi-legend autopilot flight mode annunciator, not individual light units.

Automatic flight control system (sheet 5)

No.	Alerting function	707/720	727	737	747	DC-8	DC-9	DC-10	L-1011	BAC-111	Applicable federal aviation regulations (FAR)
107	INS track mode engaged							2 grn lts			
108	VOR capture mode engaged (armed)							2 grn lts	2 blk flags		
108a	VOR track mode engaged							2 grn lts	2 wht flags		
109	Roll CWS engaged							2 grn lts			
110	Back course capture mode engaged							2 grn lts			
111	Back course track mode engaged							2 grn lts			
112	Localizer capture mode engaged (armed)							2 grn lts	2 blk flags		
113	Localizer track mode engaged							2 grn lts	2 wht flags		
114	Runway alignment mode engaged							2 grn lts	2 wht flags		
115	Roll out mode engaged							2 grn lts	2 wht flags		
116	Roll go-around mode engaged							2 grn lts			
117	Roll takeoff mode engaged							2 grn lts			
118	VOR course capture mode engaged							2 grn lts	2 blk flags		
119	Autopilots out-of-trim					1 amb lt		2 amb lts			
120	Airspeed hold mode engaged				1 grn lt			2 grn & 1 wht lts	1 wht lt & 2 wht flags		
121	Mach hold mode engaged							2 grn & 1 wht lts	1 wht lt & 2 wht flags		
122	Turbulence mode engaged							2 grn lts	1 wht lt & 2 wht flags		
123	Vertical speed mode engaged				1 grn lt			2 grn lts	1 wht lt & 2 wht flags		
124	Altitude capture mode engaged							2 grn lts			
125	Altitude hold mode engaged				1 grn lt			2 grn lts	1 wht lt & 2 wht flags		

▷ On the DC-10, these lights are part of the multi-legend autopilot flight mode annunciator, not individual light units.

Automatic flight control system (sheet 6)

No.	Alerting function	707/720	727	737	747	DC-8	DC-9	DC-10	L-1011	BAC-111	Applicable federal aviation regulations (FAR)
126	Pitch CWS engaged							2 grn lts			
127	Glide slope capture mode engaged							2 grn lts			
128	Glide slope track mode engaged							2 grn lts			
129	Flare mode engaged							2 grn lts	2 wht flags		
130	Pitch go-around mode engaged							2 grn lts			
131	Pitch takeoff mode engaged							2 grn lts			
132	Dual autoland not available								1 fl amb lt		
133	Autoland selected and no autopilot engaged								2 amb flags		
134	Automatic runway alignment mode failure								2 amb flags		
135	Flight director glide slope extend mode activated									2 ( ) flags	
136	Autopilot & glide path extend activated					1 amb lt					
137	Glide path on					1 amb lt					

▷ (items 126–131) On the DC-10, these lights are part of the multi-legend autopilot flight mode annunciator, not individual light units.

	Alerting function	Type of alert									Applicable federal aviation regulations (FAR)
		707/720	727	737	747	DC-8	DC-9	DC-10	L-1011	BAC-111	
1	Service interphone active								1 wht lt		
2	Flight station call								1 blu lt		
3	Alternate SATCOM amplifier in use				2 wht lts						
4	Microphone/transmitter combination selected		9 wht lts	15 grn lts	18 wht lts	8 blu lts		18 wht & 3 red lts	18 wht lts		
5	Ground crew call	1 ( ) lt			1 blu lt & chime (incoming) & 1 wht lt (out)					1 amb lt	121.319 (b) The crewmember interphone system required by paragraph (a) of this section must be approved in accordance with Section 21.305 of this chapter and meet the following requirements: (5) for large turbojet powered airplanes—(i) It must have an alerting system incorporating aural or visual signals for use by flight crewmembers to alert flight attendants and for use by flight attendants to alert flight crewmembers; (iii) The alerting system required by subparagraph (b) (5) (ii) of this section must have a means for the recipient of a call to determine whether it is a normal call or an emergency call.
6	Attendant call	1 blu lt & chime	1 blu lt & chime	1 blu lt & chime			1 blu lt			1 amb lt & chime	
7	Flight interphone on				1 wht lt						
8	Cockpit call (normal incoming call)				1 blu lt & chime (*9)	chime	chime	6 dual legend wht/blu lts, 1 wht lt & chime	1 blue lt & chime		
9	Cockpit call (incoming all stations or pilot priority call)				1 fl blu lt & chime (*8)						
10	PA on		1 amb lt		1 grn lt	1 blu lt	1 blu lt	1 dual legend wht/blu lt	2 amb lts		
11	VHF comm channel selected by transfer switch		4 grn lts	6 grn lts	6 grn lts			4 grn lts	6 grn lts		
12	SELCAL activated	2 amb lts & chime	2 amb lts & chime	2 grn lts & chime	2 amb lts & chime	3 blu lts & chime	2 amb lts & chime	2 blu lts & bell	2 amb lts & hi chime		
13	HF tuned light	2 amb lts									
14	Tape on tape annunciator rewinding	1 yel lt									
15	Tape annunciator playing	1 grn lt									
16	Tape annunciator stopped	1 red lt									
17	VOR test warning	2 red lts					2 red lts				

Electrical systems (sheet 1)

	Alerting function	Type of alert									Applicable federal aviation regulations (FAR)
		707/720	727	737	747	DC-8	DC-9	DC-10	L-1011	BAC-111	
1	Galley power off				4 amb lts			3 amb lts	3 wht lts		
2	APU generator oil overheated								1 amb lt		
3	APU generator low oil pressure								1 amb lt		
4	External power available	2 clear lts	1 clear lt	1 blu lt	2 wht lts	1 blu lt	2 blu lts	1 grn lt	1 grn lt	1 amb lt	
5	External power on	2 blu lts			2 grn lts			1 blu lt	1 wht lt		
6	Generator field relay tripped open	4 amb lts	3 amb lts		4 amb lts				4 amb lts		
7	Generator differential fault		3 amb lts						4 amb lts		
8	Generator bearing fault				4 amb lts				4 amb lts		
9	Flight station AC bus failure								3 amb lts		
10	CSD or IDG oil temp high		3 yel bands	2 amb lts & 4 yel bands	4 yel bands		2 yel/red bands	3 orn 6 yel bands	3 yel bands	2 amb lts (* 11, 48, 57 & 76)	
11	CSD or IDG-low oil pressure	4 amb lts	3 amb lts	2 amb lts	4 amb lts	4 amb lts	2 amb lts	3 amb lts	3 amb lts	2 amb lts (* 10, 48, 57 & 76)	
12	Generator breaker or relay tripped open	4 amb lts	3 amb lts	2 blu lts	4 amb lts			3 amb lts	4 amb lts		
13	AC bus tie open	4 amb lts	3 amb lts		4 amb lts	4 amb lts (* 34)		3 amb lts & 3 blu lts	3 amb lt		
14	AC standby bus fail/off			1 amb lt					3 red lts (* 15)		
15	DC standby bus fail								3 red lts (* 14)		
16	AC essential bus fail or off	1 red lt	1 red lt		2 amb lts				1 red lt		
17	DC essential bus fail								1 red lt		
	DC tie breakers open & DC busses isolated from DC tie bus				3 grn lts				1 amb lt		
	Essential AC bus on alternate power source	1 amb lt							1 amb lt		
	AC and/or DC standby busses switched to battery bus								1 amb lt		

Electrical systems (sheet 2)

Alerting function	Type of alert									Applicable federal aviation regulations (FAR)
	707/720	727	737	747	DC-8	DC-9	DC-10	L-1011	BAC-111	
Standby power switch or battery switch off								1 amb lt		
Ground service busses energized								1 wht lt		
Standby power on				1 grn lt						
Essential master radio power off								2 amb lts		
Emergency power in-use alert		1 amb lt				1 wht lt	2 wht lts			25.1165 (g) There must be means to warn appropriate flight crewmembers if the malfunctioning of any part of the electrical system is causing the continous discharge of any battery necessary for engine ignition.
APU power available						2 blu lts	1 grn lt			
AC bus on APU						2 blu lts				
AC bus on ext. pwr						2 blu lts				
AC crosstie lockout						1 amb lt				
Ground service bus on APU power						1 blu lt				
Ground service bus on external power						1 blu lt				
Generator feeder fault						2 amb lts				
Generator off						2 amb lts				
AC bus off			2 amb lts		4 amb lts (* 13)	2 amb lts	3 amb lts		2 red lts	
AC emergency bus off					2 red lts	1 red lt	2 red lts			
DC bus off						1 amb lt	3 amb lts		1 red lt	
DC transfer bus off						1 amb lt				
DC emergency bus off						1 red lt	2 red lts			25.1353 (c) (5) Nickel cadmium battery installations capable of being used to start an engine or auxiliary power unit must have—(iii) A battery temperature sensing and over-temperature warning system with a means for disconnecting the battery from its charging source in the event of an over-temperature condition; and (iii) A battery failure sensing and warning system with a means for disconnecting the battery from its charging source in the event of battery failure.

Electrical systems (sheet 3)

	Alerting function	Type of alert									Applicable federal aviation regulations (FAR)
		707/720	727	737	747	DC-8	DC-9	DC-10	L-1011	BAC-111	
	Split system breaker open				1 grn lt						
	APU generator bearing failure				2 amb lts						
	APU generator field off		1 amb lt		2 amb lts						
	APU generator relay open		1 amb lt	1 blu lt	2 amb lts						
	CSD oil temp low				4 yel bands						
	DC ammeter reading selected				6 blu/wht lts						
	AC ammeter reading selected				9 blu/wht lts						
46	Generator fault				4 amb lts	4 amb lts		3 amb lts		3 amb lts	
47	Generator control unit fault				4 amb lts						
48	CSD fault				4 amb lts					2 amb lts (* 10, 11, 57 & 76)	
49	Load control fault				4 amb lts						
50	Gen/feeder fault	4 red lts			4 amb lts						
51	AC bus synchronization		2 fl clear lts								
52	APU generator fault				2 amb lts			1 amb lt		1 ( ) lt	
53	APU bus power unit fault				2 amb lts						
54	APU gen/feeder fault				2 amb lts		1 amb lt				
55	AC overvoltage		3 amb lts					1 wht/yel band (* 56, 57 & 58)			
56	AC undervoltage		3 amb lts					1 wht/yel band (* 55, 57 & 58)			
57	AC system over excited		3 amb lts					1 wht/yel band (* 55, 56 & 58)		2 amb lts (* 10, 11, 48 & 76)	

Electrical systems (sheet 4)

	Alerting function	Type of alert									Applicable federal aviation regulations (FAR)
		707/720	727	737	747	DC-8	DC-9	DC-10	L-1011	BAC-111	
58	AC system under excited		3 amb lts					1 wht/yel band (* 55, 56 & 57)			
59	Phase unbalance		1 amb lt								
60	AC transfer bus off			2 amb lts							
61	Electrical system fault			1 amb lt				1 amb lt	1 fl amb lt		
62	APU generator off						1 amb lt	1 amb lt			
63	APU power in use							3 blu lts			
64	AC overload					1 amb lt		3 yel bands			
65	DC crosstie closed							3 blu lts			
67	DC overload							4 yel bands			
68	Dual land electrical system operating mode selected							1 blu lt			
69	Dual land power on							1 grn lt			
70	Battery bus off							1 amb lt			
71	Galley external power available							1 grn lt			
72	Galley external power in-use							1 blu lt			
73	Coffee bar power off							1 amb lt			
74	APU ac overload							1 yel band			
75	Emergency bus off							1 red lt			
76	Turbine overspeed									2 amb lts (* 10, 11, 43 & 57)	
	DC system volt/amp limitations							1 orn, 1 yel, 3 grn & 2 wht bands			

Electrical systems (sheet 5)

Alerting function	Type of alert									Applicable federal aviation regulations (FAR)
	707/720	727	737	747	DC-8	DC-9	DC-10	L-1011	BAC-111	
AC or DC essential or standby bus failure								1 fl red lt		
Generator unparalleled					4 amb lts					

Alerting function	Type of alert									Applicable federal aviation regulations (FAR)
	707/720	727	737	747	DC-8	DC-9	DC-10	L-1011	BAC-111	
Evacuation command activated	1 fl red lt & tone	1 fl red lt & tone		1 fl red lt & tone & chime		1 fl red lt & horn	1 fl red lt & horn	1 fl red lt & beeper		
Oxygen press low							2 wht bands			
Passenger oxygen system on	1 amb lt	1 amb lt	1 amb lt	2 amb lts		1 blu lt		1 grn lt		
Oxygen flow–pressure regulator	3 wht flags	3 wht flags	3 wht flags	3 wht flags		1 wht flag		1 wht blinking flag		
Emergency lights not armed		1 amb lt	1 amb lt		1 amb lt	1 amb lt	1 amb lt	1 amb lt		25.812 (e) (2) There must be a flight crew warning light which illuminates when power is on in the airplane and emergency lighting control device is neither armed nor turned on.
Emergency lights test ok							1 grn lt			25.1555 (d) For accessory, auxiliary, and emergency controls—(1) Each emergency control (including each fuel jettisoning and fluid shutoff control) must be colored red.
Evacuation command system energized								1 amb lt		

Fire protection (sheet 1)

	Alerting function	Type of alert									Applicable federal aviation regulations (FAR)
		707/720	727	737	747	DC-8	DC-9	DC-10	L-1011	BAC-111	
1	Master fire warning	Bell	2 fl red lts & bell	2 red lts & bell	2 red lts & bell	2 red lts & bell			2 red lts & bell		
2	Fire extinguisher bottle discharged	4 amb lts	2 amb lts	3 amb lts	11 blu & 11 amb lts	4 amb lts	2 amb lts	6 amb lts	8 amb lts		25.1199(c) There must be a means for each fire extinguishing agent container to indicate that the container has discharged or that the charging pressure is below the established minimum necessary for proper functioning.
4	Engine & APU fire extinguishing system circuits ok								8 amb lts		
5	Engine & APU fire detection system activated (test)		6 amb lts				6 amb lts	8 amb lts	1 fl amb lt & 8 amb lts (* 17, 24)		
6	Wheel well fire detection system activated (test)								2 amb lts		25.1203(d) There must be means to allow the crew to check, in flight, the functioning of each fire or overheat detector electric circuit.
7	Engine overheat			2 amb lts		4 yel/red bands	2 yel/red bands	3 amb lts & 3 yel/red bands	3 red lts & 3 fl red lts	2 red lts	
8	Engine overheat detection system circuits ok								2 wht lts		
9	Galley smoke								1 fl amb lt (* 10) & tone		
10	Galley overheat							1 amb lt	1 amb lt (* 9) & tone		
11	Nacelle/Pylon overheat				4 yel & red bands on vert scale indicators				3 fl amb lts		
12	Engine fire	4 red lts	3 red lts	2 red lts	4 red lts	4 red lts	2 red lts & bell	4 red lts & bell	3 red lts	2 red lts & bell	25.1305 The following are required powerplant instruments: (a) For all airplanes. (7) Fire-warning indicators.
13	APU fire		1 red lt	1 red lt	2 red lts		1 red lt	2 red lts	1 red lt	1 red lt & bell	
14	Wheel well fire	1 red lt	1 red lt	1 red lt	1 red lt				1 fl red lt		
15	Cargo compartment smoke	1 red lt (cargo only)		2 red lts	3 red lts						25.863(c) If action by the flight crew is required to prevent or counteract a fluid fire (e.g., equipment shutdown or actuation of a fire extinguisher) quick acting means must be provided to alert the crew.
16	Fire bottle squibs ok			3 grn lts	6 grn lts						
17	Engine fire detector failure				2 amb lts		1 amb lt (* 24)		6 amb lts (* 5, 24)		25.1203(b) Each fire detector system must be constructed and installed so that—(3) There is a means to warn the crew in the event of a short circuit in the sensor or associated wiring within a designated fire zone, unless the system continues to function as a satisfactory detection system after the short circuit.

Fire protection (sheet 2)

	Alerting function	Type of alert									Applicable federal aviation regulations (FAR)
		707/720	727	737	747	DC-8	DC-9	DC-10	L-1011	BAC-111	
18	Surge tank protection system operative				2 grn lts						
19	APU fire detector loop fault				2 amb lts						
20	Smoke detector system on	4 grn lts (cargo only)									
21	Smoke	4 blk/wht flags (cargo only)									
22	Engine area overheat		3 amb lts								
23	Engine overheat or APU fire detector inop			1 amb lt							
24	APU fire detection system failure			1 amb lt			1 amb lt (* 17)		2 amb lts (* 5,17)		
	Fire bell isolated									1 amb lt	
	Nacelle/Pylon overheat detection system failure or test								6 amb lts		

Flight controls (sheet 1)

	Alerting function	Type of alert									Applicable federal aviation regulations (FAR)
		707/720	727	737	747	DC-8	DC-9	DC-10	L-1011	BAC-111	
1	Rudder feel system malfunction									1 amb lt	
2	Stabilizer jammed								4 amb lts		
3	Stabilizer hydraulics inop								4 wht lts		
4	Aileron jammed								4 amb lts		
5	Aileron jam monitor off								2 wht lts		
6	Spoiler jammed								5 amb lts		
7	Spoiler servos off								6 wht lts		
8	Rudder hydraulics off					1 amb lt (* 85)	1 amb lt (* 85)		1 red lt		
9	Pitch channels disconnected								1 amb lt		
10	Aft coupler open								1 amb lt		
11	Roll control patch jammed								1 amb lt		
12	No. 1 spoilers off								1 wht lt		
13	Yaw SAS off								2 wht lts		
14	Yaw SAS fail								2 amb lts		
15	Stall warn system off		1 amb lt (* 16)						2 wht lts		
16	Stall warn system fail		1 amb lt (* 15)	1 amb lt	1 amb lt				2 amb lts	1 red lt	
17	Stall warning	Stick shaker	Stick shaker	Stick shaker	Stick shaker	Stick shaker	2 red fl lts & stick shaker	Stick shaker	Stick shaker	Stick shaker & 2 horns	25.207(b) The warning may be furnished either through the inherent aerodynamic qualities of the airplane or by a device that will give clearly distinguishable indications under expected conditions of flight. However, a visual stall warning device that requires the attention of the crew within the cockpit is not acceptable by itself.
18	Pitch trim system off								2 wht lts		
19	Pitch trim fail								2 amb lts		

Flight controls (sheet 2)

	Alerting function	Type of alert									Applicable federal aviation regulations (FAR)
		707/720	727	737	747	DC-8	DC-9	DC-10	L-1011	BAC-111	
20	Direct lift/auto spoilers off								2 wht lts		
21	Direct lift/auto spoilers fail								2 amb lts		
22	Auto thrust off								2 wht lts		
23	Auto thrust fail								2 amb lts		
24	Mach trim off	1 red lt (* 25)							2 wht lts		
25	Mach trim fail	1 red lt (* 24)		1 amb lt			1 amb lt		2 amb lts	1 amb lt (* 103)	
26	Slats locked								3 amb lts		
27	Slat monitor system on								1 wht lt		
28	Leading edge flaps & slats extension status		14 grn & 14 amb lts	12 grn & 10 amb lts	16 amb & 16 grn lts			2 blu & 1 amb lt (* 70, 71 & 72)	14 grn lts		
29	Pitch trim compensator >80% or fail					1 amb lt					
30	Speed brake handle not down and flaps extended		Horn (* used for low cabin pressure)								
33	Mechanical rudder limiter incorrect position								2 amb lts & 1 fl amb lt		
34	Automatic mechanical rudder limiter deactivated								1 wht lt		
35	Rudder travel unrestricted						1 blu lt		1 wht lt		
36	Rudder travel limited								1 wht lt		
37	Out-of-trim (with autopilot engaged)								2 yel flags		
38	Leading edge slats or flaps in-transit		1 amb lt	1 amb lt	2 amb lts (* 40)				1 amb lt		
39	Leading edge slats fully extended		1 grn lt (* 40)	1 grn lt					1 grn lt		

Flight controls (sheet 3)

	Alerting function	Type of alert									Applicable federal aviation regulations (FAR)
		707/720	727	737	747	DC-8	DC-9	DC-10	L-1011	BAC-111	
40	Leading edge flaps extended	2 grn lts	1 grn lt (* 39)	1 grn lt	2 grn lts (* 38)						
41	Elevator hydraulic power on						1 blu lt				
42	*Auto spoiler system failure*						1 amb lt	1 amb lt	1 fl amb lt		
43	Speed brake handle not retracted						1 amb lt	1 fl amb lt			
44	Elevator servo off						1 red lt				
45	Aileron servo off						1 red lt		4 wht lts		
46	Stabilizer out-of-trim		1 amb lt	1 amb lt			1 amb lt				
48	Auto stab trim system failure				2 amb lts						
49	Yaw damper failure		2 yel flags	1 amb lt	2 amb lts			2 amb lts			
50	Rudder ratio comparator circuit normal				1 wht lt						
51	Rudder ratio discrepancy				1 amb lt						
52	Flight controls hydraulic power on/off				8 amb lts					2 red lts	
53	*Stabilizer trim operating*	*1 amb lt*	*1 amb lt*	*1 amb lt*							
55	Rudder and spoiler hydraulic pump low pressure	1 amb lt									
56	Stabilizer in motion	Clacker	Clacker	Clacker	Clacker	Horn (on –60 models)	Horn	Horn			
57	Aileron hydraulics off/manual control					1 amb lt					
58	Elevator hydraulics low pressure		2 amb lts	2 amb lts (* 59, 60)							
59	Rudder hydraulics low pressure	1 red lt & 2 grn, 1 yel & 1 red band	2 amb lts	2 amb lts (* 58, 60)					1 amb lt		
60	Aileron hydraulics low pressure		2 amb lts	2 amb lts (* 58, 59)							

Flight controls (sheet 4)

	Alerting function	Type of alert									Applicable federal aviation regulations (FAR)
		707/720	727	737	747	DC-8	DC-9	DC-10	L-1011	BAC-111	
61	Rudder load limiter failure		1 amb lt								
62	Stab trim cutout brake release				2 amb lts						
63	Flight control system malfunction			1 amb lt					1 fl amb lt		
64	Rudder or elevator feel differential pressure excessive		1 amb lt	1 amb lt							
65	Speed-brake—do not arm		1 amb lt	1 amb lt							
66	Speed brake armed			1 grn lt							
67	Yaw damper test in progress							1 blu dual legend lt			
68	Yaw damper test failure							2 amb lts			
69	Auto slat extension system reset							1 amb lt			
70	Flap limit system failure (1 channel)							1 blu lt (* 28)			
71	Flap limit system failure (all channels)							1 amb lt (* 28)			
72	Flap limit overriden							1 blu lt (* 28)			
73	Inboard flap positions disagree							1 orn flag			
74	Flap limit speed indication failure							1 yel flag			
75	Rudder standby power off					1 blu lt		1 amb lt			
76	Elevator feel system inop (1 channel)							1 blu lt			
77	Elevator feel system inop (all channels)							1 amb lt			
78	Elevator emergency power in-use									1 red lt	
79	Flap primary shaft failure									1 amb lt	
80	Unsafe takeoff configuration	Intermittent horn	Intermittent horn	Intermittent horn	Intermittent horn	Intermittent horn	Intermittent horn	Intermittent horn	Intermittent horn	Horn	
81	Rudder travel—not in agreement						1 amb lt				
82	Flap load relief system failure								1 fl amb lt (& buzzer DELTA)		

Flight controls (sheet 5)

	Alerting function	Type of alert									Applicable federal aviation regulations (FAR)
		707/720	727	737	747	DC-8	DC-9	DC-10	L-1011	BAC-111	
83	Spoiler extended					1 blu lt					
85	Rudder control manual					1 amb lt (*8)	1 amb lt (*8)				
86	Wing slots					1 amb lt					
87	Rudder hydraulic pressure incorrect for flight condition								1 fl amb lt		
88	Roll speed brakes mode of operation improper								1 fl amb lt		
89	Flap load relief system functioning								1 fl amb lt		
90	Pitch and roll jam monitor fail								4 amb lts		
91	Pitch and roll jam monitor off								4 wht lts		
92	Automatic hydraulic rudder limiting deactivated								1 wht lt		
93	Flap load relief system overriden								1 wht lt		
94	Assymetric flap/slat detection system failure								1 amb lt		
96	Gust damper mode engaged—ground only									1 grn lt	
97	Spoiler system failure									2 amb lts	
98	Stall protection system valve open									2 red lts	
99	Stick pusher system—low pressure									1 red lt	
100	Stick pusher activated									2 amb lts	
101	Elevator emergency power system—low pressure									1 amb lt	
103	Mach trim system operating									1 intermittent amb lt (*25)	
104	Stall identification master warning									2 red lts	
113	Flap position info failure							2 orn flags			

Flight instruments and air data (sheet 1)

	Alerting function	Type of alert									Applicable federal aviation regulations (FAR)
		707/720	727	737	747	DC-8	DC-9	DC-10	L-1011	BAC-111	
1	V_{mo} indication bad								2 red flags		
2	Mach indication bad		2 red flags		2 red flags			2 orn flags	2 red flags		
3	Airspeed indication bad							2 orn flags	2 red flags		
4	Radio altimeter failure		2 red flags & 2 ( ) flags (* 5)				2 red flags				
5	Radio altitude info fail	2 red flags	2 red flags & 2 ( ) flags (* 4)	2 red flags	2 red flags	2 red flags	2 red flags	2 yel flags	2 red flags		
6	Turn and slip indicator/ info fail					2 red flags					
7	Instrument source selections								14 amb lts		
8	Attitude displays disagree				Tone			Wailer (prov.)			
9	Instrument indications comparisons	6 yel lts & clacker	12 yel lts & clacker	12 yel lts & clacker	2 fl red lts & 8 amb lts		12 amb lts		8 amb flags		
10	Instrument comparison monitor failure	1 yel lt	2 yel lts	2 yel lts			2 amb lts		8 amb flags		
11	Static source error correction failure	2 wht flags	2 wht flags	2 blk flags			2 orn flags		2 red flags		
12	Barometric altitude info failure			2 grn flags		2 red flags		2 orn flags	2 red flags		
13	Vertical speed info fail							2 orn flags	2 red flags		
14	Static air temp fail				1 red flag			1 orn flag (* 15)	1 red flag		
15	True airspeed fail				1 red flag	1 red flag		1 orn flag (* 14)	1 red flag		
16	Standby attitude fail/ off	1 red flag	1 red flag	1 red flag	1 red flag	1 red flag	1 red flag	1 red flag	1 red flag		
17	Ground proximity warning	2 fl red lts wailer & message	2 fl red lts & message	2 red lts & message	2 fl red lts wailer & message	1 red lt wailer & message	2 red lts wailer & message	2 red lts & message	2 red lts & message	Wailer & message	121.360(f) Except as provided in paragraph (g) of this section, after June 1, 1976, no person may operate a large turbine-powered airplane unless it is equipped with a ground proximity warning-glide slope deviation alerting system.
18	Below glideslope warning	2 amb lts & message	2 amb lts & message	2 amb lts & message	2 amb lts & message	2 amb lts & message	2 amb lts & message	2 amb lts & message	2 amb lts & message	(?)	
											37.201(a) (3) Aural and visual warnings. The required aural and visual warnings must initiate simultaneously. (4) Deactivation control. If the equipment incorporates a deactivation control other than a circuit breaker, the control must be a switch with a protective cover. The

Flight instruments and air data (sheet 2)

No.	Alerting function	Type of alert: 707/720	727	737	747	DC-8	DC-9	DC-10	L-1011	BAC-111	Applicable federal aviation regulations (FAR)
											cover must be safety wired so that the wire must be broken in order to gain access to the switch. (Note. Specific requirements for these alerts provided in RTCA Document No. DO-161A. These requirements are summarized in Appendix E, Table E-5).
19	Ground proximity system fail	1 amb lt	1 amb lt	1 amb lt	1 amb lt	1 amb lt	1 amb lt	1 amb lt	1 amb lt		
20	500 foot terrain warning		Tone		Tone		2-second beep tone		Beep tone		
21	Decision height/MDA	2 blu lts & tone	2 amb lts & tone	2 amb lts & tone	2 amb lts & tone	2 amb lts	2 amb lts & tone	2 amb lts	2 amb lts & tone		
22	Below sea level				2 red flags						
23	Total air temp indications bad	1 yel flag	1 yel flag	1 red flag	1 red flag & 1 yel flag			1 orn flag			
24	Over outer marker	1 blu lt	2 blu lts	2 fl blu lts	2 blu lts	2 blu lts	1 blu lt	2 blu lts	2 blu lts	2 fl blu lts	
25	Over middle marker	1 amb lt	2 amb lts	2 fl amb lts	2 amb lts	2 amb lts	1 amb lt	2 amb lts	2 amb lts	2 fl amb lts	
26	Airways marker beacon	1 clear lt	2 clear lts	2 fl clear lts	2 clear lts	2 clear lts	1 clear lt	2 clear lts	2 wht lts	2 fl wht lts	
27	CADC switched							1 amb lt			
28	Excessive airspeed or mach	Bell	Clacker	Clacker	Clacker	2 red lts & clacker	Clacker & 4 yel red bands	Clacker	Clacker	Intermittent bell	25.1303(c) (1) A speed warning device is required for Turbine engine powered airplanes and for airplanes with V_{mo}/M_{mo} greater than 0.8 V_{df}/M_{df} of 0.8 V_d/M_d. The speed warning device must give effective aural warning (differing distinctively from, aural warnings used for other purposes) to the pilots, whenever the speed exceeds V_{mo} plus 6 knots or M_{mo} + 0.01. The upper limit of the production tolerance for the warning device may not exceed the prescribed warning speed. 91.49 Aural speed warning device. No person may operate a transport category airplane in air commerce unless that airplane is equipped with an aural speed warning device that complies with Section 25.1303(c) (1).
29	RMI failed							2 orn flags			

Fuel (sheet 1)

	Alerting function	Type of alert									Applicable federal aviation regulations (FAR)
		707/720	727	737	747	DC-8	DC-9	DC-10	L-1011	BAC-111	
1	Fuel Limiting system overridden								3 wht lts		
2	Fuel jettison valves operating in automatic dump control mode							2 amb lts	4 amb lts		
3	Jettison valves in-transit	6 blu lts	6 blu lts		6 blu lts				2 blu lts		
4	Master jettison control switch status								1 amb lt		
5	APU emergency shutoff valve in-transit								2 amb lts		
6	Engine fuel shutoff valve in-transit	4 blu lts	3 blu lts	2 brt blu lts (*23)	4 wht lts				3 blu lts		
7	Cross-ship fuel isolation valves in-transit								1 blu lt		
8	Master switch at refuel panel armed								1 amb lt		
9	Fuel quantity readout selection								2 wht lts		
10	Fuel quantity low					2 amb lts			2 amb lts		
11	Fuel boost pump low pressure	10 amb lts	8 amb lts	6 amb lts	10 amb lts	4 amb lts & 4 gren/red bands	6 amb lts	12 amb lts	8 amb lts	2 red lts	25.1305 The following are required powerplant instruments: (a) For all airplanes. (1) A fuel pressure warning means for each engine, or a master warning means for all engines with provisions for isolating the individual warning means from the master warning means.
12	Engine fuel pump low pressure								3 amb lts	2 amb lts	
13	Fuel used indication bad				4 ( ) flags						
14	Fuel flow indicator failure				4 yel flags						
15	Fuel filter icing	4 amb lts	3 amb lts	2 amb lts	4 amb lts						
16	Fuel temp readout selected				5 blu/wht lts						
17	Scavenge pump pressure lost				1 amb lt						
18	Reserve tank fuel valve in-transit	2 blu lts			2 blu lts						
19	Crossfeed valve in-transit	4 blu lts	3 blu lts	1 brt blu lt (*26)	4 blu lts				3 blu lts		
20	Fuel jettison pump low pressure				4 amb lts						

Fuel (sheet 2)

	Alerting function	Type of alert									Applicable federal aviation regulations (FAR)
		707/720	727	737	747	DC-8	DC-9	DC-10	L-1011	BAC-111	
21	Fuel jettison dump chute not retracted and latched	2 amb lts									
22	Fuel crossfeed valve position disagrees with switch position							3 amb lts			
23	Engine fuel shutoff valve closed			2 dim blu lts (* 6)		4 blu lts					
24	Fuel heat valve open			2 dim blu lts (* 25)			2 blu lts				23.1305(c) For turbine engine-powered airplanes. In addition to the powerplant instruments required by paragraph (a) of this section, the following power plant instruments are required: (8) An indicator to indicate the proper functioning of any heater used to prevent ice clogging of fuel system components.
25	Fuel heat valve in-transit			2 brt blu lts (* 24)							
26	*Crossfeed valve open*			1 dim blu lt (* 19)							
27	Fuel system malfunction			1 amb lt				1 fl amb lt	1 amb lt		
28	Fuel usage or transfer off schedule							2 amb lts			
29	Fuel fill valve open							3 blu lts			
30	Tank overfilled							1 amb lt			
31	Fuel used indication reset								1 wht lt		
32	Emergency shutoff valve in-transit								4 amb lts		
33	Fuel jettison valves in-transit								4 blu lts		
34	Alternate tank fuel shutoff valve closed					4 blu lts					

Hydraulic power (sheet 1)

	Alerting function	Type of alert									Applicable federal aviation regulations (FAR)
		707/720	727	737	747	DC-8	DC-9	DC-10	L-1011	BAC-111	
1	ATM oil temp high								2 amb lts		
2	ATM oil pressure low								2 amb lts		
3	ATM pump high temp								3 amb lts		
4	ATM pump low press								3 amb lts		
5	Ram air turbine unlocked								1 amb lt		
6	Ram air turbine pressure being supplied								1 grn lt		
7	Reservoir fluid quantity low	2 amb lts			4 grn bands & 4 amb lts		2 red bands	3 yel bands	4 amb lts		
8	Reservoir fluid temp high							3 yel bands	4 amb lts	2 red lts	
9	Pump suction valve closed								4 wht lts		
10	Pump depressurizing valve closed								4 wht lts		
11	AC pump on								2 wht lts		
12	Engine driven dump case drain fluid high temperature								3 amb lts		
13	Engine driven pump low output pressure	4 amb lts	2 amb lts	2 amb lts	4 amb lts				3 amb lts		
14	Hydraulic temp hi	1 red lt	3 amb lts			1 amb lt & 1 red band	2 amb lts	6 amb lts & 3 yel bands		1 red lt	
15	Hydraulic pressure low		2 grn/yel/ red bands		4 amb lts		2 amb lts	6 amb lts & 3 orn bands		2 amb lts (* 22, 30)	
16	Hydraulic pump case drain fluid temp high			2 amb lts	4 amb lts						
17	Air driven pump low pressure				4 amb lts						
18	Standby system hydraulic fluid quantity low			1 amb lt		1 amb lt					
19	Air driven pump operating				4 blu lts						
20	Break interconnect valve open		1 grn lt								
21	Electric-driven pump low output pressure		3 amb lts	2 amb lts							

Hydraulic power (sheet 2)

	Alerting function	Type of alert									Applicable federal aviation regulations (FAR)
		707/720	727	737	747	DC-8	DC-9	DC-10	L-1011	BAC-111	
22	Hydraulic system malfunction			1 amb lt				1 amb lt	1 fl amb lt	2 amb lts (* 15, 30)	
23	Hydraulic pressure abnormal			1 grn, 2 yel & 1 red band			2 grn bands				
24	Hydraulic filter pressure high							1 blu lt			
25	Auxiliary hydraulic pump(s) on					1 blu lt		3 blu lts			
26	Hydraulic system ground test controls							3 amb lts			
27	Ram air turbine deployed								1 fl amb lt		
28	Power transfer unit on								2 wht lts		
29	Auxiliary hydraulic pump overheat									1 amb lt	
30	Hydraulic reservoir air pressure low									2 amb lts (* 15,22)	
31	Standby hydraulic pump–low pressure			1 amb lt							
32	Utility hydraulic pumps–low pressure	2 amb lts & 1 grn 2 yel & 2 red bands									

Ice and rain protection (sheet 1)

	Alerting function	Type of alert									Applicable federal aviation regulations (FAR)
		707/720	727	737	747	DC-8	DC-9	DC-10	L-1011	BAC-111	
1	Wing anti-ice duct failure		1 amb lt (* 34, 35)						2 amb lts		
2	Wing anti-ice on						1 blu lt	1 blu lt	4 wht lts		
3	Wing anti-ice temp hi	1 amb lt					2 amb lts		2 amb lts		
4	Engine anti-ice heat available in cowl leading edge								3 grn lts		
5	Engine anti-ice on					4 amb lts	2 blu lts	1 blu lt	3 wht lts		
6	Engine anti-ice over pressure								3 amb lts		
7	Engine anti-ice valve and switch disagreement		3 grn lts				2 amb lts	3 amb lts (* 38)			
8	Wing anti-ice auto tripped to off		1 amb lt								
9	Pitot heat off							1 amb lt	4 amb lts		
10	Temperature probe heat off								2 amb lts		
11	Angle of attack sensor heat off								2 amb lts	4 amb lts	
12	Pitot heat on	3 blu lts	2 blu lts	7 grn lts	6 grn lts		1 blu lt				
13	Tail de-ice on					1 amb lt	1 blu lt				
14	Airfoil anti-ice press low						1 amb lt				
15	Nacelle anti-ice press high				4 amb lts						
16	Wing anti-ice valve in-transit			2 brt blu lts (* 37)	2 blu lts						
17	Waste water pump failure								2 amb lts		
18	Insufficient heat in drain masts								4 amb lts		
19	Temperature probe and scat heat on	2 blu lts									
20	Window underheat						1 amb lt			2 amb lts	
21	Window heat fault							2 amb lts	6 amb lts		

Ice and rain protection (sheet 2)

	Alerting function	Type of alert: 707/720	727	737	747	DC-8	DC-9	DC-10	L-1011	BAC-111	Applicable federal aviation regulations (FAR)
22	Defog fan on/off switch status								1 wht lt		
23	Window overheat	2 amb lts	4 amb lts	4 amb lts	3 amb lts		1 amb lt			2 amb lts	
24	Window heat on/off		4 grn lts	4 grn lts	6 grn lts				6 wht lts		
25	Windshield washer pump on								1 amb lt		
26	Nacelle valve position synched with switch	4 grn lts (* 27)									
27	Nacelle anti-ice valve open	4 grn lts (* 26)			4 grn lts						
28	Stator anti-ice valve open				4 grn lts						
29	Window heat lights operating mode				1 blu/wht lt						
30	Window heat test				1 blu/wht lt						
31	Window overheat test				1 blu/wht lt						
32	Attitude warning transducer heat on	2 blu lts									
33	Q-inlet heater fail/off	1 amb lt									
34	Engine 2 anti-ice duct overheat		1 amb lt (* 1, 35)								
35	Wing anti-ice duct overheat		1 amb lt (* 1, 34)								
36	Wing anti-ice valve and switch disagreement		2 grn lts					2 amb lts			
37	Wing anti-ice valve open			2 dim blu lts (* 16)					2 wht lts		
38	Engine anti-ice valves in-transit			6 brt blu lts (* 39)				3 amb lts (* 7)			
39	Engine anti-ice valves open			6 dim blu lts (* 38)							
40	Anti-ice system malfunction			1 amb lt							
41	APU anti-ice on							1 blu lt			

Ice and rain protection (sheet 3)

	Alerting function	Type of alert									Applicable federal aviation regulations (FAR)
		707/720	727	737	747	DC-8	DC-9	DC-10	L-1011	BAC-111	
42	Ice protection temp low						2 amb lts				
43	Rain repellent reserve in use						1 blu lt				
44	Nacelle overheat								3 amb lts		
45	Ice forming on icing probe								1 fl amb lt		
46	VHF antenna anti-ice failure								1 amb lt		
47	Ice protection press high						1 amb lt				

Landing gear and brakes (sheet 1)

	Alerting function	Type of alert									Applicable federal aviation regulations (FAR)
		707/720	727	737	747	DC-8	DC-9	DC-10	L-1011	BAC-111	
2	Gear door(s) open	1 red lt	1 red lt		1 red lt & 5 amb lts		1 amb lt		1 red & 3 amb lts		
3	Gear or doors in-transit								1 red lt (* 4)		
4	Gear unlocked or gear & doors not in agreement with gear lever		3 red lts		1 red lt	1 red lt & horn	3 red lts (* 29, 31)	3 red lts (* 7, 29)	1 red lt (* 3)	1 red lt	
5	Truck not level (in gear down position)	1 amb lt							1 amb lt		
6	Gear unsafe	1 red lt									
7	Gear down and locked	3 grn lts	3 grn lts	3 grn lts	6 grn lts	3 grn lts	3 grn lts	3 grn lts (* 4, 29)	3 grn lts	3 grn lts	**25.729(c) If a retractable landing gear is used, there must be a landing gear position indicator or other means to inform the pilot that the gear is secured in the extended (or retracted) position.**
8	Brake high temp				4 red bands & 4 amb bands		4 amb lts		1 amb lt & 1 fl amb lt		
9	Brake overheat				2 amb lts		4 red lts		1 red lt		
10	Anti-skid hydraulic valve not fully open				1 amb lt						
11	Anti-skid failure			2 amb lts (* 12)	21 amb lts	1 amb lt		4 amb lts	1 fl amb lt		
12	Anti-skid off			2 amb lts (* 11)			4 amb lts		2 amb lts		
13	Anti-skid system test ok								8 amb lts (* 14)		
14	Anti-skid operated	4 wht flags	5 amb lts						8 amb lts (* 13)		
15	Tail skid not in agreement with landing gear lever position		1 amb lt						1 amb lt		
16	Body gear not centered				1 amb lt						
17	Gear and gear door position lights operating mode				6 blu/wht lts						
18	Brakes—low pressure		1 grn 1 yel & 2 red bands		2 amb lts	1 red band	2 grn/ red bands		2 amb lts & 1 fl amb lt & 2 yel bands		
19	Secondary system supplying brake pressure				1 grn lt						
20	Brake pressure indicator off								1 red flag		
21	Reserve brake valve open				1 grn lt						

Landing gear and brakes (sheet 2)

	Alerting function	Type of alert									Applicable federal aviation regulations (FAR)
		707/720	727	737	747	DC-8	DC-9	DC-10	L-1011	BAC-111	
22	Brake pressure abnormal			1 grn, 1 yel & 2 red bands							
23	Parking brakes on	1 red lt	1 red lt	1 red lt	1 red lt		1 amb lt	2 amb lts	1 red lt		
26	Body gear steering hyd. Pressure available				1 amb lt						
27	Body gear steering cylinders unlocked				2 amb lts						
28	Gear compartment not sealed			1 amb lt							
29	Gear not down and locked & thrust lever at idle			3 red lts & horn (*30, 31, 38)			3 red lts & horn (*4, 31)	3 red lts & horn (*4, 7)	Steady horn	Horn (*34, 38)	25.729(e) (2) Landplanes must have an aural warning device that will function continuously when one or more throttles are closed, if the landing gear is not fully extended and locked. (3) If there is a manual shutoff for the warning device prescribed in subparagraph (2) of this paragraph, it must be installed so that reopening the throttles will reset the warning mechanism.
30	Gear unlocked			3 red lts & horn (*29, 31, 38)							
31	Gear down and locked and lever not in down detent			3 red lts & horn (*29, 30, 38)			3 red lts (*4, 29)				
32	Equipment tire burst			1 amb lt							
34	Gear not down and locked with flaps extended beyond the approach position									Horn (*29, 38)	
35	Gear not down & locked & throttle retarded to idle with flaps 1, 5, 10 or 20				Steady horn (*36, 38)						
36	Gear not down and locked with flaps 25 or 30				Steady horn (*35, 38)						25.729(e) (4) Landplanes must have an aural warning device that will function continuously, when the wing flaps are extended beyond the maximum approach position determined under Section 25.67(e), if the gear is not fully extended and locked. There may not be a manual shutoff for this warning device. 121.289(a) Each large airplane must have a landing gear aural warning device that functions continuously under the following conditions: (1) For airplanes with an established approach wing-flap position, whenever the wing flaps are extended beyond the maximum certificated approach climb configuration position in the Airplane Flight Manual and the landing gear is not fully extended and locked. (2) For airplanes without an established approach climb wing-flap position, whenever the wing flaps are extended beyond the position at which landing gear extension is normally performed and the landing gear is not fully extended and locked. (b) The warning
37	Gear not down and locked with flaps extended beyond 15°						Horn				

Landing gear and brakes (sheet 3)

	Alerting function	Type of alert									Applicable federal aviation regulations (FAR)
		707/720	727	737	747	DC-8	DC-9	DC-10	L-1011	BAC-111	
											system required by paragraph (a) of this section—(1) May not have a manual shutoff; (2) Must be in addition to the throttle-actuated device installed under the type cerficication airworthiness requirements.
38	Unsafe landing configuration	Horn	Horn	Horn (* 29, 30, 31)	Horn (*35, 36)	Horn	Horn	Horn		Horn (* 29, 34)	
39	Anti-skid on								1 grn lt		
40	Truck not tilted (in gear up position)				4 amb lts						

Navigation (sheet 1)

	Alerting function	Type of alert									Applicable federal aviation regulations (FAR)
		707/720	727	737	747	DC-8	DC-9	DC-10	L-1011	BAC-111	
1	Attitude info unreliable or failure				2 red flags		2 red flags (*6)	2 orn flags	2 red flags		25.1331(a) For each instrument required by paragraph 25.1303(b) that uses a power supply, the following apply: (1) Each instrument must have a visual means integral with, or adjacent to, the instrument, to indicate when power adequate to sustain proper instrument performance is not being supplied.
2	Approach gate info failure								2 red flags		
3	Slow-fast into failure		2 red flags		2 red flags		2 red/blk striped shutters	2 orn flags	2 red flags		
4	Rollout command info failure								2 red flags		
5	Flight director info failure	2 red flags	2 red flags	2 red flags	2 red flags	2 red flags	2 red flags	2 orn flags	2 red flags	2 red flags	
6	Gyro failure	2 red flags	2 red flags	2 red flags		2 red flags	2 red flags (*1)			2 red flags	
9	Magnetic heading info fail				2 red flags			4 orn flags (*46)			
10	Magnetic compass info unreliable								2 red flags		
11	Nav info failure	2 fl red lts			2 red flags	2 yel flags			2 red flags		
12	Compass system failure	2 red flags	2 red flags	4 red flags		4 red flags	2 red flags			2 ( ) flags	
13	Compass caged	2 red flags									
15	Auxiliary vertical gyro inop			1 wht flag				1 amb lt	1 fl amb lt		
16	Drift info fail				2 red flags						
17	Ground speed info fail				2 red flags						
18	Transponder failure		1 amb lt						1 yel lt		
19	Transponder tests ok				1 grn lt						
20	VHF nav inoperative								2 red lts		
21	ILS receiver failure								2 amb lts		
22	Auto/manual tuning failure								2 wht lts		
23	VOR receiver in test mode	2 red lts	2 red lts								

Navigation (sheet 2)

	Alerting function	Type of alert 707/720	727	737	747	DC-8	DC-9	DC-10	L-1011	BAC-111	Applicable federal aviation regulations (FAR)
24	Transponder in test mode	1 grn lt		1 grn lt							
25	Rising runway/localizer info fail							2 orn flags		2 ( ) shutters	
26	DME receiver power fail	4 red flags (* 27)	4 red flags (* 27)				4 red flags (* 27)	2 striped orn flags	4 red flags		
27	DME data failure	4 red flags (* 26)	4 red flags (* 26)		4 red flags	2 red flags	4 red flags (* 26)	2 wht lines in place of digits (* 46)	4 red flags		
28	Localizer info fail	2 red flags (* 32)	2 red flags (* 32)	2 red flags (* 32)			2 red flags (* 32)			2 ( ) flags (* 32)	
32	VOR info fail	2 red flags (* 28)	2 red flags (* 28)	2 red flags (* 28)	4 red flags		2 red flags (* 28)		2 red flags	2 ( ) flags (* 28)	
33	Heading info fail		2 red flags		2 red flags		2 red flags	2 orn flags (* 9, 46)	2 red flags		
34	Glide slope info fail	2 red flags	2'red flags	2 red flags	2 red flags		4 red flags	4 orn flags		2 red flags	
35	Weather radar mode annunciation	6 wht lts	6 wht lts						6 wht lts		
36	Weather radar antenna failure	1 amb lt	1 amb lt		1 amb lt				1 amb lt		
37	Weather radar receiver/ transmitter failure	1 amb lt	1 amb lt		1 amb lt				1 amb lt		
40	Heading system using *magnetic heading* data							2 blk/wht flags	2 wht lts		
41	Heading system using gyro compass data without magnetic corrections								2 wht lts		
42	Heading info sources				10 lts on 2 HSIs			2 blk/wht flags			
45	INS out-of-tolerance				3 red lts						
46	INS failure				6 red lts			4 orn flags (* 9) & 2 red lts			121—APPENDIX G2. Equipment and equipment installation—Inertial Navigation Systems (INS) or Doppler Radar System. (c) The equipment must provide, by visual, mechanical or electrical output signals, indications of the invalidity of output data upon the occurrence of probable failures or malfunction within the system. 3. Equipment and equipment installation—Inertial Navigation Systems (INS). (d) The equipment must provide such visual, mechanical or electrical output signals as may be required to permit the flight crew to detect probable failures or malfunctions in the system.
47	INS computer operating in *nav mode*				3 grn lts						
49	INS ready to accept remotely loaded waypoint data				3 amb lts						

Navigation (sheet 3)

	Alerting function	Type of alert: 707/720	727	737	747	DC-8	DC-9	DC-10	L-1011	BAC-111	Applicable federal aviation regulations (FAR)
50	Waypoint alert				3 amb lts & 2 ( ) Lights on HSIs			4 amb lts			
51	INS on battery				6 amb lts			2 amb lts			
52	Doppler 10-mile staging alert	2 fl wht & 2 amb lts									
53	Rate-of-turn info fail							2 orn flags			
54	Clock power interrupter							3 red flags			
55	INS alignment in progress							2 amb/grn dual legend lts (*56)			121—APPENDIX G3. Equipment and equipment installation—Inertial Navigation Systems (INS). (2) A display of alignment status or a ready to navigate light showing completed alignment to the flight crew.
56	INS ready for nav mode							2 amb/grn dual legend lts (*55)			
57	INS battery power less than minimum							2 red lts			
58	Avionics failure								1 amb lt		
59	Doppler sensor failure	2 wht lts									

Pneumatics (sheet 1)

	Alerting function	Type of alert									Applicable federal aviation regulations (FAR)
		707/720	727	737	747	DC-8	DC-9	DC-10	L-1011	BAC-111	
1	Engine isolation valve off (closed)								3 wht lts		
2	Engine area overheat								3 amb lts	2 amb lts (*5,25,27)	
3	Crossbleed valve off (closed)								2 wht lts		
4	Crossbleed area overheat								1 amb lt		
5	Duct overheat				4 amb lts	1 red lt			4 amb lts	2 amb lts (*2,25,27)	
6	High pressure bleed valve closed								3 wht lts		
7	ATM isolation valve off (closed)								1 wht lt		
8	Pneumatic press hi and relief valve open				4 amb lts	4 amb lts	1 red band				
10	Bleed air valve closed				4 amb lts						
11	High stage bleed valve open				4 grn lts			3 amb lts			
13	Turbocompressor low oil press	3 amb lts									
14	Turbocompressor overspeed	3 amb lts									
15	Bleed air overheat/trip-off		2 amb lts								
16	Bleed air temp high		1 amb lt	2 amb lts		2 grn/red bands		4 red lts & 3 orn bands	6 red lts		
18	Bleed trip off			2 amb lts							
19	Dual bleed sources			1 amb lt							
20	Manifold failure					2 amb lts		4 red lts			
21	Abnormal pneumatic press					1 amb lt		3 amb lts & 3 yel/orn bands			
22	Isolation valve and switch positions disagree							2 amb lts			
23	Use engine pneumatic supply							1 amb lt			

Pneumatics (sheet 2)

	Alerting function	Type of alert									Applicable federal aviation regulations (FAR)
		707/720	727	737	747	DC-8	DC-9	DC-10	L-1011	BAC-111	
24	APU isolation valve open							1 blu lt			
25	Pneumatic system failure							1 amb lt		2 amb lts (* 2,5,27)	
26	Supply duct failure								2 amb lts		
27	Bleed duct overpressure								1 amb lt	2 amb lts (*2,5,25)	
28	Abnormal pneumatic air flow rate							3 wht bands			

Power plant (sheet 1)

Alerting function	Type of alert: 707/720	727	737	747	DC-8	DC-9	DC-10	L-1011	BAC-111	Applicable federal aviation regulations (FAR)
Reverser in-transit (or doors open—DC-8)	4 blu lts	3 blu lts		4 blu lts	4 amb lts	2 blu lts		3 grn lts		
Reverser operating	4 amb lts	3 amb lts		4 amb lts	4 amb lts	2 amb lts	3 grn lts	3 amb lts		
Reverser accumulator pressure low			1 amb lt			2 amb lts				
No. 2 engine failure								2 amb lts		
N2 overspeed	4 grn/red bands	3 grn/yel/ red bands	2 grn/yel/ red bands	4 amb lts	4 red bands	2 red bands	3 orn bands & 3 orn pointers	3 red flags		25.1549 For each required power-plant instrument, as appropriate to the type of instrument, (a) Each maximum and, if applicable, minimum safe operating limit must be marked with a red radial or red horizontal line; (b) Each normal operating range must be marked with a green arc or green vertical line, not extending beyond the maximum and minimum safe limits; (c) Each takeoff and precautionary range must be marked with a yellow arc or yellow vertical line; and (d) Each engine or propeller range that is restricted because of excessive vibration stresses must be marked with red arcs or red vertical lines.
N1 overspeed	4 grn/red bands	3 grn/yel/ red bands	2 grn/yel/ red bands	4 amb lts	4 red bands	2 red bands	3 orn bands & 3 orn pointers	3 amb lts		
TGT overtemp								3 fl (for 5 seconds, then steady red lts		
Ignition systems off				4 blu/wht lts						
N3 overspeed								3 amb lts		
Maximum indications on engine instruments reset								1 wht lt		
EPR indication fail			1 red flag					3 red flags		
Loss of power to any engine instrument channel				20 red barber pole flags				15 red/wht barber pole flags		
EGT overtemp	4 grn/yel/ red bands	3 grn/yel/ red bands	2 grn/yel/ red bands	4 amb lts & 4 fl/steady red lts	4 yel/red bands	2 yel/red bands	3 amb lts, 3 yel/orn bands & 3 orn pointers			
Continuous ignition on								1 wht lt		
Ground start switch pressed and N3 < 51%								1 amb lt		

Power plant (sheet 2)

Alerting function	Type of alert									Applicable federal aviation regulations (FAR)
	707/720	727	737	747	DC-8	DC-9	DC-10	L-1011	BAC-111	
Ground start valve open		3 amb lts		4 grn lts		2 amb lts		3 grn lts		
Flight start system on				4 blu/wht lts				3 amb lts		
EPR mode selected				6 wht lts			5 blu lts	4 wht lts & 1 ( ) flag		
N1 or N2 indicator failure off							6 blk/orn flags			
Excessive engine vibration								3 amb lts	2 wht lts	
Vibration pickup selection								2 wht lts		
Oil pressure indicator in test mode								1 wht lt		
Oil temperatures high	4 grn & 4 red bands	3 grn/yel/ red bands	2 grn/yel/ red bands	4 yel bands	4 grn/yel/ red bands	2 yel/red bands	3 yel/orn bands			
Ground start system on				4 blu/wht lts						
Ignition system(s) on	1 amb lt			1 grn lt	4 blu lts		3 amb lts		4 amb lts	
Fuel filter pressure drop						2 amb lts	3 amb lts			
Engine fail		2 amb lts					2 amb lts			
Oil filter clogged	4 amb lts	3 red lts	2 amb lts	4 amb lts		2 amb lts	3 amb lts	3 amb lts		25.1305(c) For turbine engine-powered airplanes. In addition to the powerplant instruments required by paragraph (a) of this section, the following powerplant instruments are required: (7) A warning means for the oil strainer or filter required by Section 25.1019, if it has no bypass, to warn the pilot of the occurrence of contamination of the strainer or filter screen before it reaches the capacity established in accordance with Section 25.1019(a) (2)
Engine oil pressure low	4 amb lts & 4 grn bands	3 amb lts & 3 grn/yel/ red bands	2 amb lts & 2 grn/yel/ red bands	4 amb lts & 4 yel bands	4 amb lts & 4 grn/yel/ red bands	2 amb lts & 2 grn/yel/ red bands	3 amb lts	3 fl amb lts	2 red lts	25.1305 The following are required powerplant instruments: For all airplanes. (5) An oil pressure warning means for each engine, or a master warning means for all engines with provision for isolating the individual warning means from the master warning means.
Ground idle relay in ground idle mode				1 amb lt						
Water injection pump pressurized				4 grn lts						
Loss of water injection pump pressure				1 amb lt						

Power plant (sheet 3)

Alerting function	Type of alert									Applicable federal aviation regulations (FAR)
	707/720	727	737	747	DC-8	DC-9	DC-10	L-1011	BAC-111	
Water injection/flow to engine on				4 grn lts						25.1305(f) For airplanes equipped with fluid augmentation systems (other than fuel), an approved means must be provided to indicate the proper functioning of that system to the flight crew.
Engine 2 failure monitor armed								1 grn lt		
Reverser unlocked			2 amb lts				3 amb lts		2 amb lts	
Reverser armed			1 blu lt							
N1 (EPR) limit data unusable				1 yel flag			1 blk/orn flag			
EGT info fail/off							3 blk/orn flags			
Engine oil pressure abnormal							3 yel/grn/orn bands			
Reverser valve open							3 amb lts			
Engine low pressure shaft rotation									1 variable rate fl grn lt	
Engine/APU malfunction								1 fl amb lt		
Ground cooling & blowaway jet shut off					1 blu lt					

Weight and balance system

Alerting function	Type of alert									Applicable federal aviation regulations (FAR)
	707/720	727	737	747	DC-8	DC-9	DC-10	L-1011	BAC-111	
Gross weight indication selected								1 wht lt		
Center of gravity indication selected								1 wht lt		
Center of gravity at forward or aft limit				1 amb lt				2 amb lts		
Weight and balance system power on				1 wht lt				1 wht lt		
Weight and balance system in test mode								1 wht lt		
Hard landing								3 red & 3 amb lts		
Weight and balance system operational status				1 grn & 2 amb lts						
Hard landing indications reset								1 wht lt		

APPENDIX B

DETAILED DATA USED IN ALERTING FUNCTION AND CHARACTERISTICS ANALYSES

Table B-1 Operational Distribution of Visual Alerting Functions

ALERT CLASSIFICATION	AIRCRAFT TYPE								
	707	727	737	747	DC-8	DC-9	DC-10	L-1011*	BAC-111
WARNING	70	69	49	109	85	81	127	118	39
CAUTION	118	197	153	346	87	123	291	385	44
ADVISORY/STATUS	105	103	115	302	59	40	208	295	13
TOTAL	293	369	317	757	231	244	626	798	96

*L-1011 utilizes lighted pushbutton switches, with color modes to indicate switch state, instead of toggle switches.

Table B-2 Percentage Distribution of Visual Alerting Functions Among Operational Classifications

ALERT CLASSIFICATION	AIRCRAFT TYPE								
	707	727	737	747	DC-8	DC-9	DC-10	L-1011*	BAC-111
WARNING	24%	19%	16%	14%	37%	33%	20%	15%	41%
CAUTION	40%	53%	48%	46%	38%	50%	47%	48%	46%
ADVISORY/STATUS	36%	28%	36%	40%	25%	16%	33%	37%	13%

*L-1011 utilizes lighted pushbutton switches, with color modes to indicate switch state, instead of toggle switches.

Table B-3 Color Distribution of Warning/Caution/Advisory Alerts

ALERT TYPE	AIRCRAFT TYPE								
	707	727	737	747	DC-8	DC-9	DC-10	L-1011	BAC-111
LIGHTS									
RED	31	25	16	45	22	28	45	43	33
AMBER OR YELLOW	110	172	134	316	69	109	235	362	44
BLUE	33	20	26	90	36	26	49	17	2
GREEN	21	39	68	116	3	4	93	40	7
WHITE	15	20	2	88	2	2	41	177	4
FLAGS									
RED	20	24	18	56	19	28	44	75	6
AMBER OR YELLOW	1	3	0	6	2	2	3	18	0
GREEN	0	0	2	0	0	0	0	0	0
WHITE	13	5	4	3	0	1	6	37	0
BLACK	0	0	0	0	0	0	0	22	0
BANDS									
RED	19	20	15	8	44	25	38	0	0
AMBER OR YELLOW	7	22	19	24	16	12	53	5	0
GREEN	23	19	13	5	18	7	6	2	0
WHITE	0	0	0	0	0	0	13	0	0
AURAL	13	15	13	17	10	15	14	15	9

Table B-4 Number of Visual Alerts Which Also Activate an Aural Alert

ALERT TYPE	NUMBER OF ALERTS PER AIRCRAFT								
	707	727	737	747	DC-8	DC-9	DC-10	L-1011	BAC-111
RED LIGHTS OR FLAGS	8	10	14	20	8	10	16	14	4
AMBER AND YELLOW LIGHTS OR FLAGS	11	19	16	7	2	7	7	10	1
BLUE LIGHTS OR FLAGS	3	1	2	3	3	1	8	1	0
GREEN LIGHTS OR FLAGS	0	0	2	0	0	0	0	0	0
WHITE/CLEAR LIGHTS OR FLAGS	0	0	0	2	0	0	7	0	0

APPENDIX C

COCKPIT NOISE DATA

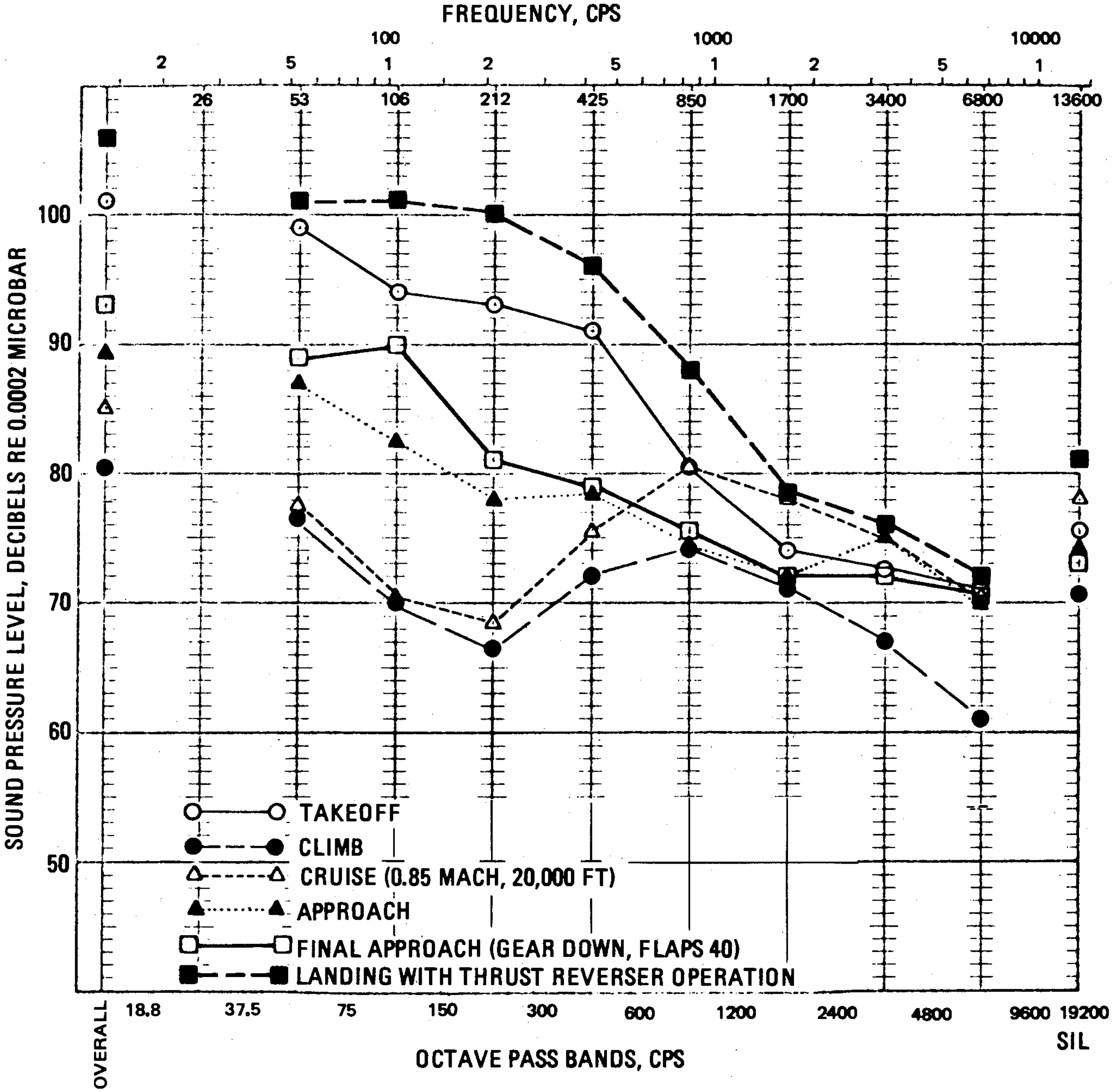


Figure C-1 Maximum Cockpit Noise Levels During Various Flight Operations For 707-320B/C Aircraft

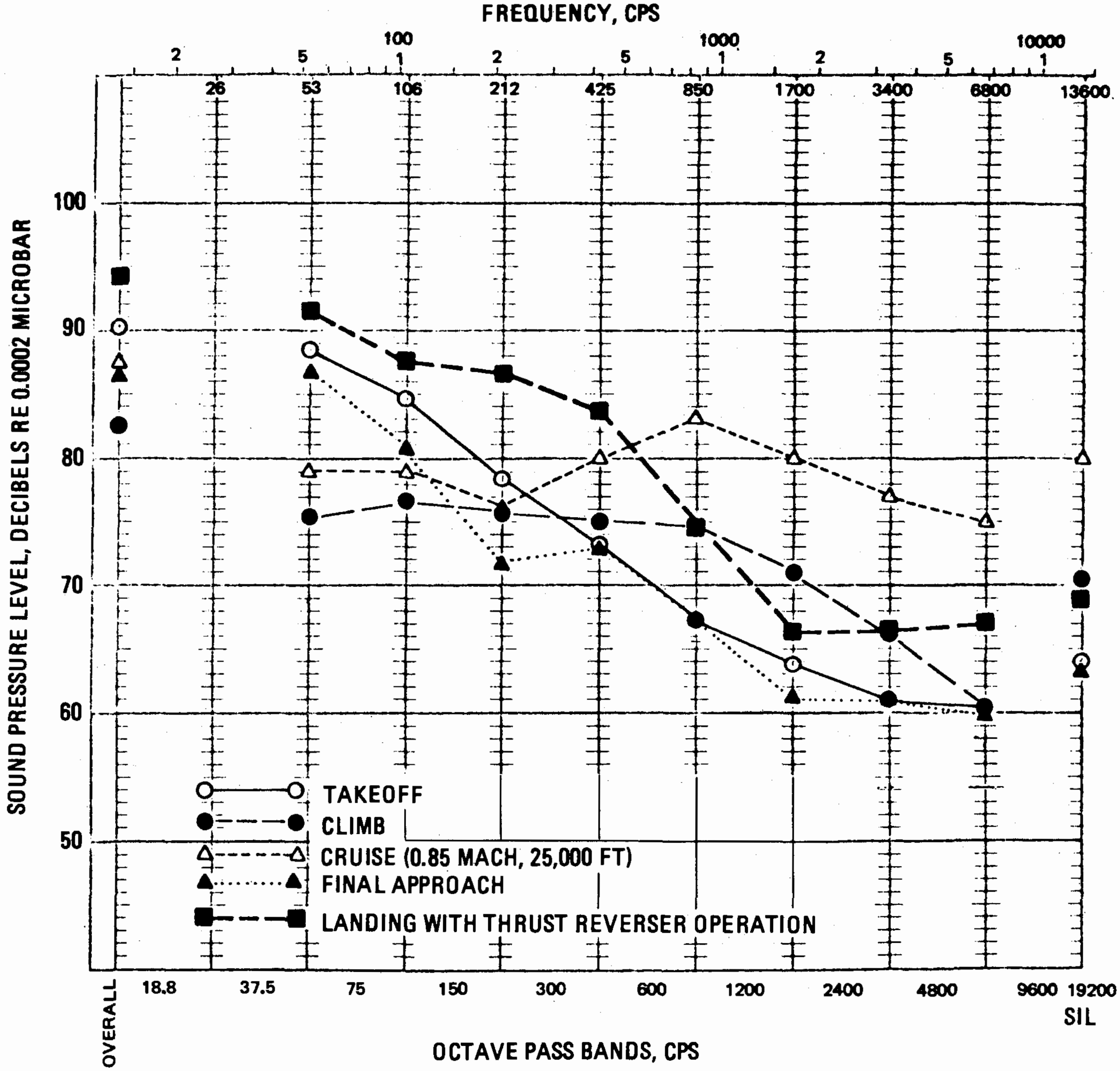


Figure C-2 Maximum Cockpit Noise Levels During Various Flight Operations For 727-100/200 Aircraft

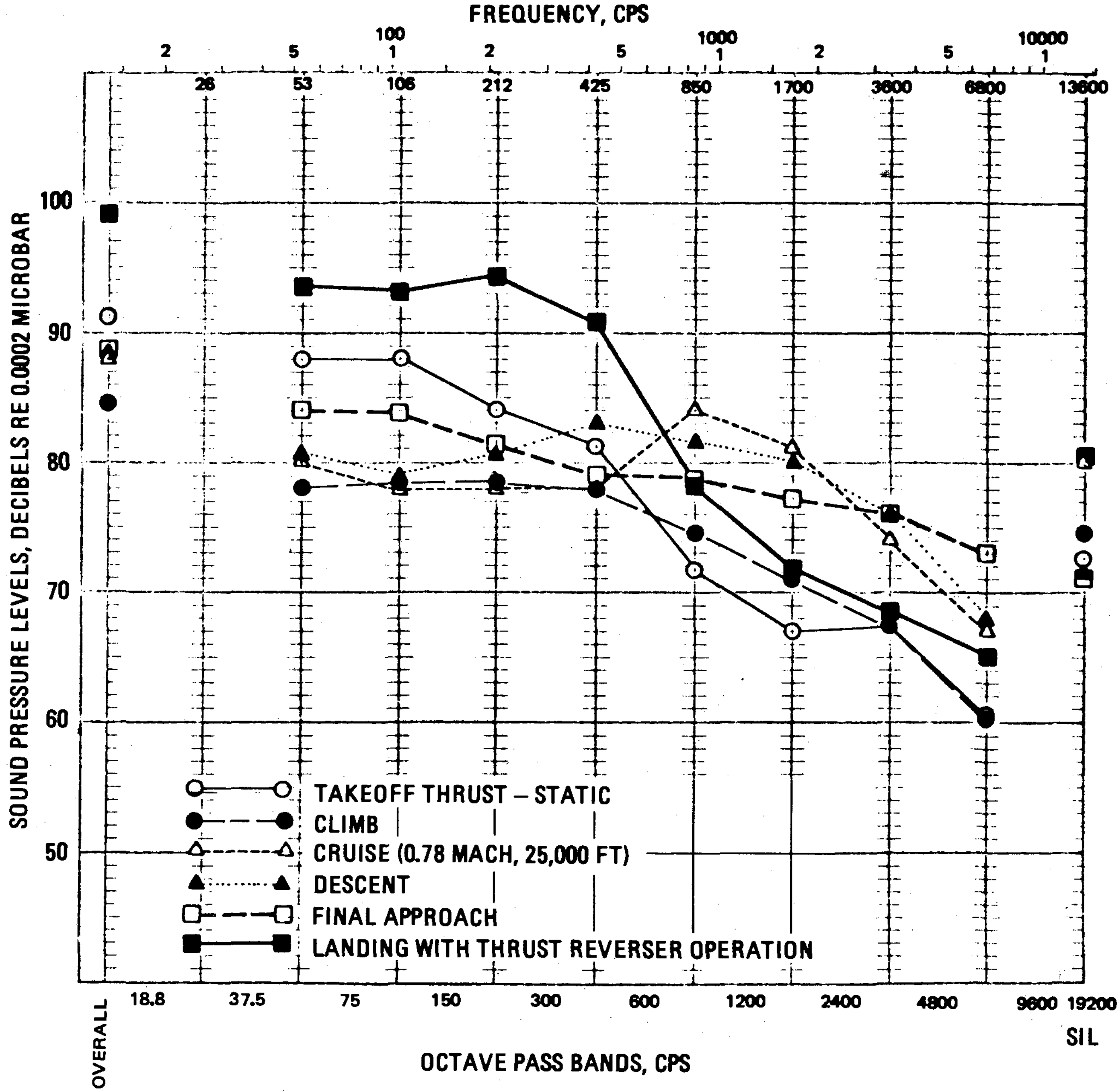


Figure C-3 Maximum Cockpit Noise Levels During Various Flight Operations For 737-200 Aircraft

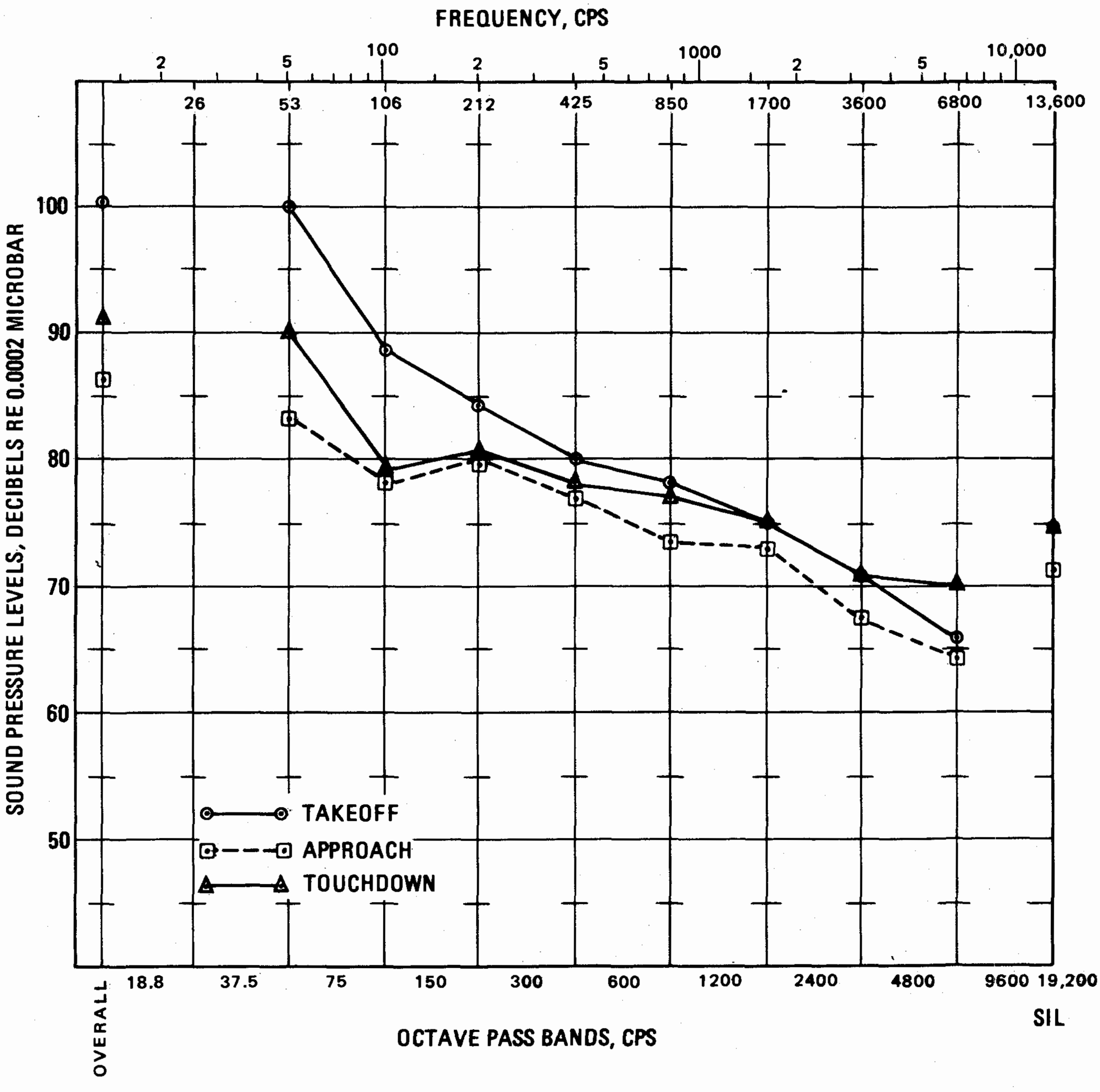
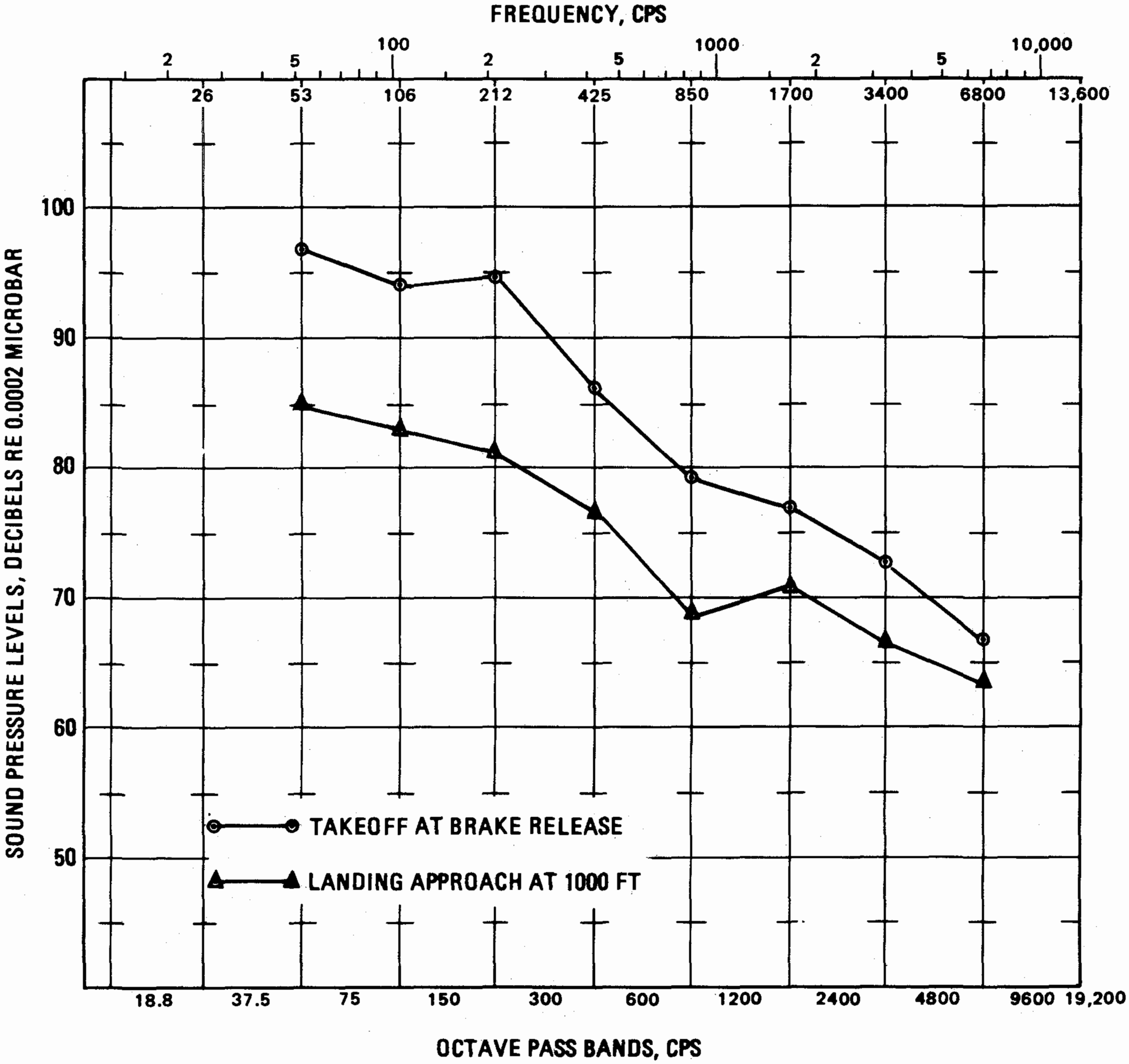


Figure C-4 Maximum Cockpit Noise Levels During Various Flight Conditions For 747-100 Aircraft



NOTE: NOISE LEVELS MEASURED BETWEEN PILOT AND COPILOT—40 INCHES ABOVE FLOOR

Figure C-5 Maximum Cockpit Noise Levels During Various Flight Conditions for DC-8-63 Aircraft

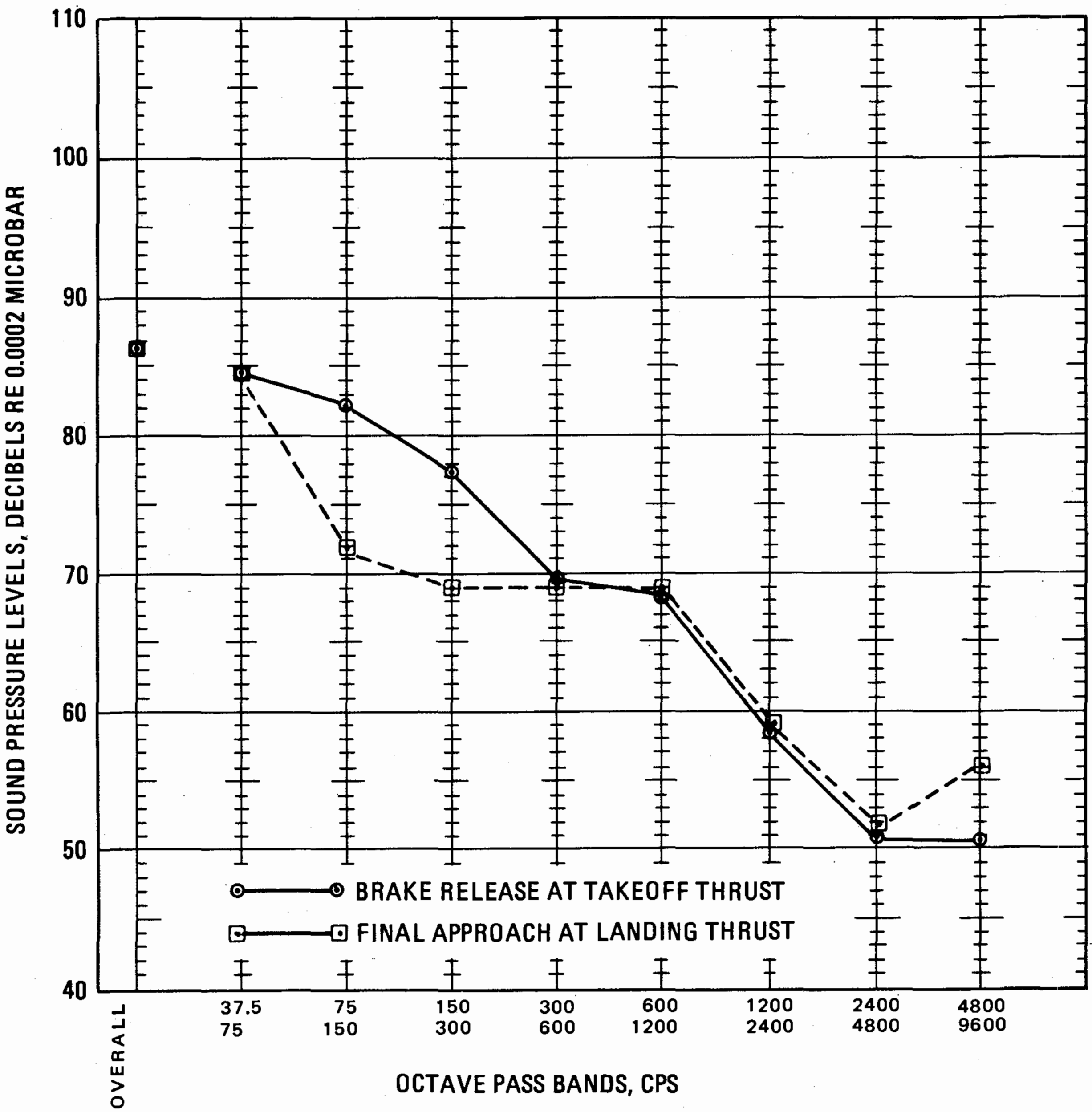
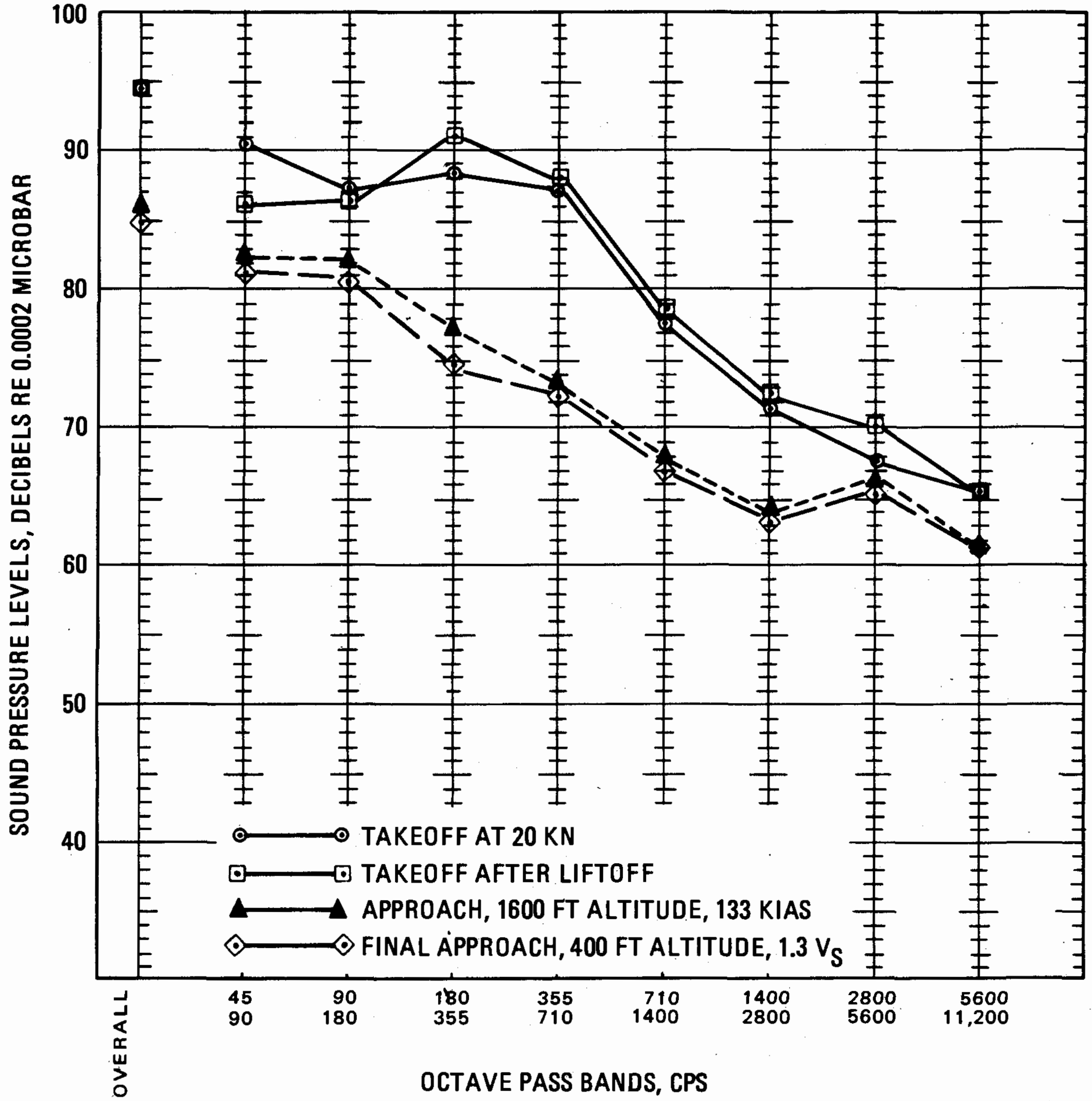


Figure C-6 Estimated Cockpit Noise Levels During Various Flight Conditions For DC-9-30 Aircraft



NOTE: SOUND PRESSURE LEVELS MEASURED 40 INCHES ABOVE FLOOR BETWEEN PILOT AND COPILOT

Figure C-7 Cockpit Noise Levels During Various Flight Conditions for DC-10-30 Aircraft

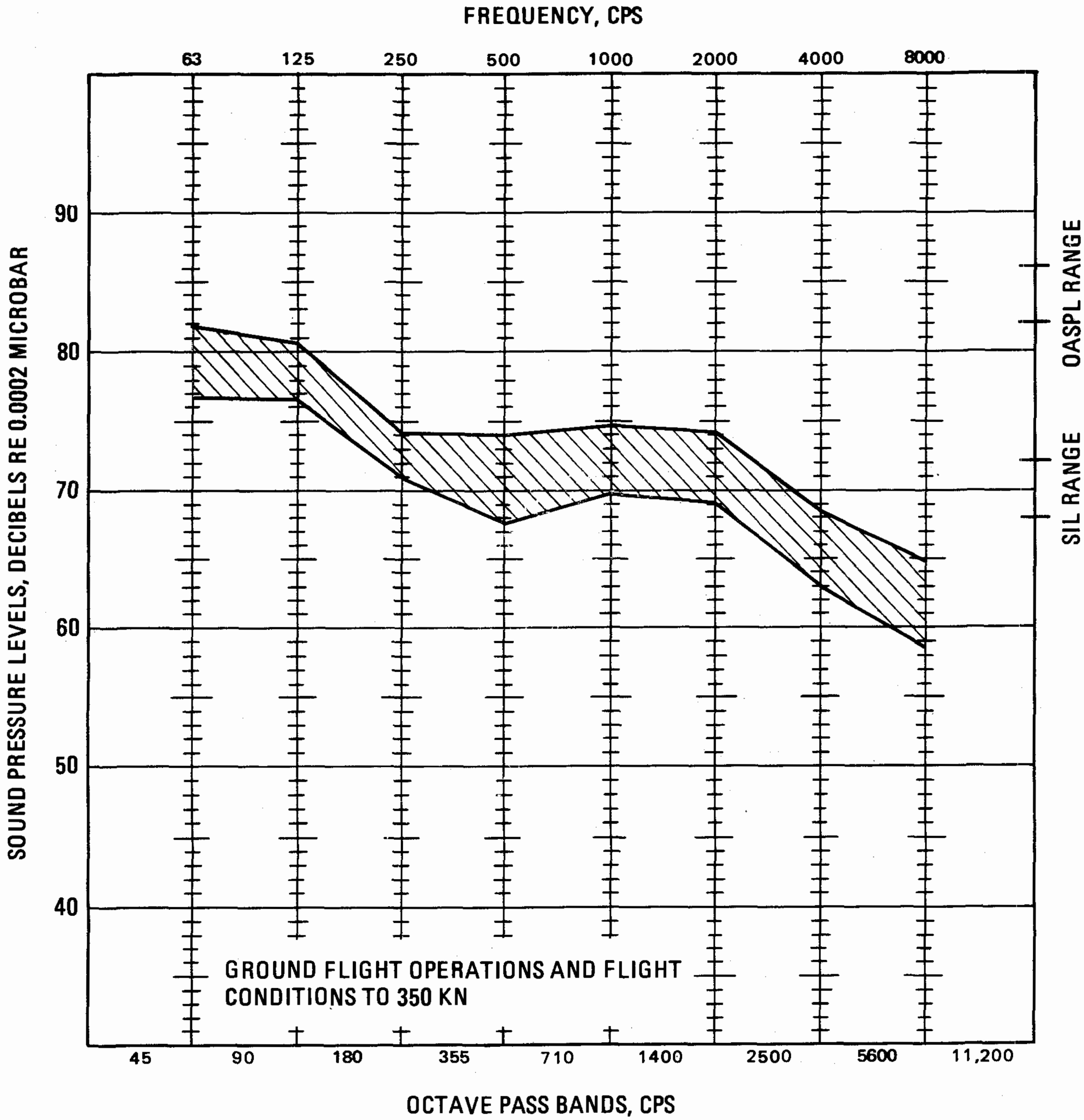


Figure C-8 Cockpit Noise Levels During Various Flight Operations For L-1011 Aircraft

APPENDIX D

TABULATIONS OF FUNCTIONAL DISTRIBUTION OF ALERTS ON EACH BASIC TYPE OF AIRCRAFT

Table D-1 Functional Distribution of Warning/Caution/Advisory Alerts For 707 Aircraft

SYSTEM CLASSIFICATIONS	AURALS	WARNINGS			CAUTIONS			ADVISORY/STATUS					
		RED LIGHT	RED FLAG	RED BAND	AMBER/ YELLOW LIGHT	AMBER/ YELLOW FLAG	AMBER/ YELLOW BAND	GREEN LIGHT	BLUE LIGHT	WHITE LIGHT	GREEN BAND	GREEN FLAG	WHITE FLAG
AIR CONDITIONING	1				6			3		2			
AIRCRAFT GENERAL		1F			8								
ALTITUDE ALERT SYSTEM	1	1F	1		1			1					
APU													
AFCS		2F			1F+2			2					
COMMUNICATIONS	2	3			5			1	1				
ELECTRICAL		5			17				2	2			
EMERGENCY EQUIPMENT	1	1F			1								3
FIRE PROTECTION	1	6			4			4					4
FLIGHT CONTROLS	2	2		1	2		1	2			2		
FLIGHT INSTRUMENTATION AND AIR DATA	4	2F	3		11	1			3	1			2
FUEL					16				16				
HYDRAULIC		1		2	8		2				1		
ICE AND RAIN PROTECTION					4			4	7				
LANDING GEAR AND BRAKES	1	3			1			3					4
NAVIGATION		2F+2	16		4			1		2F+8			
PNEUMATICS					6								
POWER PLANT				16	13		4		4		20		
WEIGHT AND BALANCE													

NOTE: ( )F denotes flashing light.
1 light of undefined nature not included in listing above

Table D-2 Functional Distribution of Warning/Caution/Advisory Alerts For 727 Aircraft

SYSTEM CLASSIFICATIONS	AURALS	WARNINGS			CAUTIONS			ADVISORY/STATUS					
		RED LIGHT	RED FLAG	RED BAND	AMBER/ YELLOW LIGHT	AMBER/ YELLOW FLAG	AMBER/ YELLOW BAND	GREEN LIGHT	BLUE LIGHT	WHITE LIGHT	GREEN BAND	GREEN FLAG	WHITE FLAG
AIR CONDITIONING	1				9			1					
AIRCRAFT GENERAL		1F			14			1					
ALTITUDE ALERT SYSTEM	1	1F	1		1			1					
APU				1	2		1				1		
AFCS		2F			1F+2			4					
COMMUNICATIONS	2				3			4	1	9			
ELECTRICAL		1			31		3			2F+1			
EMERGENCY EQUIPMENT	1	1F			2								3
FIRE PROTECTION	1	2F+5			11								
FLIGHT CONTROLS	3				27	2		15					
FLIGHT INSTRUMENTATION AND AIR DATA	5	2F	5		21	1			2	2			2
FUEL					11				12				
HYDRAULIC				2	8		2	1			2		
ICE AND RAIN PROTECTION					6			9	2				
LANDING GEAR AND BRAKES	1	5		2	6		1	3			1		
NAVIGATION		2	18		3					6			
PNEUMATICS					3								
POWER PLANT		3		15	11		15		3		15		
WEIGHT AND BALANCE													

NOTE: ( )F denotes flashing light.
8 flags of undefined nature not included in listing above.

Table D-3 Functional Distribution of Warning/Caution/Advisory Alerts for 737 Aircraft

SYSTEM CLASSIFICATIONS	AURALS	WARNINGS			CAUTIONS			ADVISORY/STATUS					
		RED LIGHT	RED FLAG	RED BAND	AMBER/ YELLOW LIGHT	AMBER/ YELLOW FLAG	AMBER/ YELLOW BAND	GREEN LIGHT	BLUE LIGHT	WHITE LIGHT	GREEN BAND	GREEN FLAG	WHITE FLAG
AIR CONDITIONING	1			1	8		1	2	3				
AIRCRAFT GENERAL					14								
ALTITUDE ALERT SYSTEM	1		1						1				
APU				1	4		1		1		1		
AFCS		2F			8			10					
COMMUNICATIONS	2							23	1				
ELECTRICAL					10		4		4				
EMERGENCY EQUIPMENT					2								3
FIRE PROTECTION	1	8			7			3					
FLIGHT CONTROLS	2				21			15					
FLIGHT INSTRUMENTATION AND AIR DATA	5	2	4		2F+19				2F	2F		2	
FUEL					9				5				
HYDRAULIC				1	9		2				1		
ICE AND RAIN PROTECTION					5			11	8				
LANDING GEAR AND BRAKES	1	4		2	4		1	3			1		
NAVIGATION			12					1					1
PNEUMATICS					5								
POWER PLANT			1	10	7		10		1		10		
WEIGHT AND BALANCE													

NOTE: ( )F denotes flashing light.

Table D-4 Functional Distribution of Warning/Caution/Advisory Alerts For 747 Aircraft

SYSTEM CLASSIFICATIONS	AURALS	WARNINGS			CAUTIONS			ADVISORY/STATUS					
		RED LIGHT	RED FLAG	RED BAND	AMBER/ YELLOW LIGHT	AMBER/ YELLOW FLAG	AMBER/ YELLOW BAND	GREEN LIGHT	BLUE LIGHT	WHITE LIGHT	GREEN BAND	GREEN FLAG	WHITE FLAG
AIR CONDITIONING	1				14			1	6	6	1		
AIRCRAFT GENERAL	1				17				3	3			
ALTITUDE ALERT SYSTEM	1	2			1			1					
APU					1			1	2				
AFCS	1	4F+2			2F+20			23					
COMMUNICATIONS	2				2			7	1F+2	22			
ELECTRICAL					58		8	7	15	17			
EMERGENCY EQUIPMENT	1	1F			2								3
FIRE PROTECTION	1	12		4	15		4	8	11				
FLIGHT CONTROLS	2				34			18		1			
FLIGHT INSTRUMENTATION AND AIR DATA	6	4F	10		15	1			2	2			
FUEL					19	4			17	9			
HYDRAULIC					20				4		4		
ICE AND RAIN PROTECTION					7			20	5	3			
LANDING GEAR AND BRAKES	1	3		4	34		4	8	6	6			
NAVIGATION		9	26		14			4					
PNEUMATICS					12			4					
POWER PLANT		4F+4	20		26	1	8	13	16	18			
WEIGHT AND BALANCE					3			1		1			

NOTE: ( )F denotes flashing light.
5 flags and 12 lights of undefined nature not included in listing above.

Table D-5 Functional Distribution of Warning/Caution/Advisory Alerts for DC-8 Aircraft

SYSTEM CLASSIFICATIONS	AURALS	WARNINGS			CAUTIONS			ADVISORY/STATUS					
		RED LIGHT	RED FLAG	RED BAND	AMBER/ YELLOW LIGHT	AMBER/ YELLOW FLAG	AMBER/ YELLOW BAND	GREEN LIGHT	BLUE LIGHT	WHITE LIGHT	GREEN BAND	GREEN FLAG	WHITE FLAG
AIR CONDITIONING	1	4		12	3				2		4		
AIRCRAFT GENERAL		3			1				3				
ALTITUDE ALERT SYSTEM	1		1		2								
APU													
AFCS		2			3				1				
COMMUNICATIONS	2								12				
ELECTRICAL		2			13				1				
EMERGENCY EQUIPMENT					1								
FIRE PROTECTION	1	6		4	4		4						
FLIGHT CONTROLS	2				4				2				
FLIGHT INSTRUMENTATION AND AIR DATA	2	3	8		5				2	2			
FUEL				4	6				8		4		
HYDRAULIC				1	2				1				
ICE AND RAIN PROTECTION					5								
LANDING GEAR AND BRAKES	1	1		1	1			3					
NAVIGATION			10			2							
PNEUMATICS		1		2	7						2		
POWER PLANT				20	12		12		4		8		
WEIGHT AND BALANCE													

NOTE: ( )F denotes flashing light.
8 lights of undefined nature not included in listing above

Table D-6 Functional Distribution of Warning/Caution/Advisory Alerts For DC-9 Aircraft

SYSTEM CLASSIFICATIONS	AURALS	WARNINGS			CAUTIONS			ADVISORY/STATUS					
		RED LIGHT	RED FLAG	RED BAND	AMBER/ YELLOW LIGHT	AMBER/ YELLOW FLAG	AMBER/ YELLOW BAND	GREEN LIGHT	BLUE LIGHT	WHITE LIGHT	GREEN BAND	GREEN FLAG	WHITE FLAG
AIR CONDITIONING	1	2		2	3								
AIRCRAFT GENERAL		2			10								
ALTITUDE ALERT SYSTEM	1	1	1		1			1					
APU				2	2		2				1		
AFCS	1	1F+1											
COMMUNICATIONS	2	2			2				2				
ELECTRICAL		2		2	13		2		10	1			
EMERGENCY EQUIPMENT	1	1F			1				1				1
FIRE PROTECTION	1	3		2	9		2						
FLIGHT CONTROLS	2	2F+2			6				2				
FLIGHT INSTRUMENTATION AND AIR DATA	5	2	5	4	20	2			1	1			
FUEL					6				2				
HYDRAULIC			2		4						2		
ICE AND RAIN PROTECTION					10				6				
LANDING GEAR AND BRAKES	1	7		2	10			3			2		
NAVIGATION			20										
PNEUMATICS				1									
POWER PLANT				10	12		6		2		2		
WEIGHT AND BALANCE													

NOTE: ( )F denotes flashing light.
2 flags of undefined nature not included in listing above.

Table D-7 Functional Distribution of Warning/Caution/Advisory Alerts for DC-10 Aircraft

SYSTEM CLASSIFICATIONS	AURALS	WARNINGS			CAUTIONS			ADVISORY/STATUS					
		RED LIGHT	RED FLAG	RED BAND	AMBER/ YELLOW LIGHT	AMBER/ YELLOW FLAG	AMBER/ YELLOW BAND	GREEN LIGHT	BLUE LIGHT	WHITE LIGHT	GREEN BAND	WHITE FLAG	WHITE BAND
AIR CONDITIONING	1	2		2	10		2		2				
AIRCRAFT GENERAL		3			24		1			2			1
ALTITUDE ALERT SYSTEM	1				1F+1								
APU				3	3		2		3				2
AFCS'	1	8F			40			76		10			
COMMUNICATIONS	2	3						4	9	25			
ELECTRICAL		5		4	26		16	4	12	2	3		3
EMERGENCY EQUIPMENT	1	1F			1			1					2
FIRE PROTECTION	1	6		3	18		3						
FLIGHT CONTROLS	2		1		1F+9	1			5				
FLIGHT INSTRUMENTATION AND AIR DATA	5	2	13		8	2			2	2			
FUEL					1F+20				3				
HYDRAULIC				3	16		9		4				
ICE AND RAIN PROTECTION					8				3				
LANDING GEAR AND BRAKES	1	3		2	6		2	3					2
NAVIGATION		4	20		9			2				6	
PNEUMATICS		8		6	10		3		1				3
POWER PLANT			10	15	23		15	3	5		3		
WEIGHT AND BALANCE													

NOTE: ( )F denotes flashing light.

Table D-8 Functional Distribution of Warning/Caution/Advisory Alerts for L-1011 Aircraft

SYSTEM CLASSIFICATIONS	AURALS	WARNINGS			CAUTIONS			ADVISORY/STATUS						
		RED LIGHT	RED FLAG	RED BAND	AMBER/ YELLOW LIGHT	AMBER/ YELLOW FLAG	AMBER/ YELLOW BAND	GREEN LIGHT	BLUE LIGHT	WHITE LIGHT	GREEN BAND	GREEN FLAG	WHITE FLAG	BLACK FLAGS
AIR CONDITIONING	1				1F+24					18	2			
AIRCRAFT GENERAL					1F+20					13				
ALTITUDE ALERT SYSTEM	1	2F	2		2			2						
APU			4		11					1				
AFCS	1		8		3F					9			36	22
COMMUNICATIONS	2				4			6	2	19				
ELECTRICAL		1F+5			1F+33		3	1		5				
EMERGENCY EQUIPMENT	1	1F			2			1					1	
FIRE PROTECTION	2	4F+9			4F+33					2				
FLIGHT CONTROLS	2	1			7F+40	2		15		39				
FLIGHT INSTRUMENTATION AND AIR DATA	4	2	17		21	16			2	2				
FUEL					26				13	6				
HYDRAULIC					2F+25			1		12				
ICE AND RAIN PROTECTION					3F+30			3		16				
LANDING GEAR AND BRAKES	1	4	1		3F+18		2	4						
NAVIGATION		2	26		1F+6					12				
PNEUMATICS		6			11					9				
POWER PLANT		3F	17		4F+21			7		9				
WEIGHT AND BALANCE		3			5					5				

NOTE: ( )F denotes flashing light.

Table D-9 Functional Distribution of Warning/Caution/Advisory Alerts for BAC-111 Aircraft

SYSTEM CLASSIFICATIONS	AURALS	WARNINGS			CAUTIONS			ADVISORY/STATUS					
		RED LIGHT	RED FLAG	RED BAND	AMBER/ YELLOW LIGHT	AMBER/ YELLOW FLAG	AMBER/ YELLOW BAND	GREEN LIGHT	BLUE LIGHT	WHITE LIGHT	GREEN BAND	GREEN FLAG	WHITE FLAG
AIR CONDITIONING		1			3								
AIRCRAFT GENERAL		2F+5											
ALTITUDE ALERT SYSTEM	1												
APU			(2	LIGH	TS)								
AFCS					1F		(6	FLA	GS)				
COMMUNICATIONS	1				2								
ELECTRICAL		3			8								
EMERGENCY EQUIPMENT													
FIRE PROTECTION	1	5											
FLIGHT CONTROLS	3	9			7			1					
FLIGHT INSTRUMENTATION AND AIR DATA	2				2F				2F	2F			
FUEL		2			2								
HYDRAULIC		3			3								
ICE AND RAIN PROTECTION					8								
LANDING GEAR AND BRAKES	1	1						4					
NAVIGATION			6										
PNEUMATICS					2								
POWER PLANT		2			6			2F		2			
WEIGHT AND BALANCE													

NOTE: ( )F denotes flashing light.
3 lights and 12 flags of undefined nature not included in listing above.

APPENDIX E

SYNOPSIS OF ALERTING SYSTEM REQUIREMENTS FOUND IN SAE, MILITARY, AND RTCA STANDARDS

TABLE E-1
ALERTING SYSTEM REQUIREMENTS FOUND IN ARP 450

2. FLIGHT DECK SIGNALS

2.1 GENERAL PHILOSOPHY; AIRCRAFT FLIGHT DECK SIGNAL SYSTEMS MAY CONSIST OF ONE OR MORE OF THE SIGNALS HEREIN DEFINED.

INSOFAR AS IS TECHNICALLY FEASIBLE, IT IS DESIRABLE TO PREVENT WARNING OR CAUTION SIGNALS FROM EXISTING OR OCCURRING WHEN NOT APPLICABLE IN VIEW OF THE BASIC INTENT OR DESIGN AIM OF THE SIGNAL SYSTEM. THIS DESIGN PHILOSOPHY IS DESIRABLE IN ORDER TO PREVENT A BUILD-UP OF FLIGHT CREW TOLERANCE AND DISREGARD FOR THE SIGNAL.

IF THE PRIME FUNCTION OF A MASTER VISUAL SIGNAL, OR OF ONE OF THE VISUAL SIGNALS IN AN ANNUNCIATOR PANEL, IS TO DIRECT ATTENTION TO AN INDICATOR OR CONTROL DEVICE, IT SHALL SUPPLEMENT A SEPARATE VISUAL SIGNAL AT THAT LOCATION. THE INDIVIDUAL VISUAL SIGNALS USED WITH MASTER WARNING SIGNALS, MASTER CAUTION SIGNALS OR ANNUNCIATOR PANELS, SHOULD BE IDENTIFIED WITH TRANSILLUMINATED NOMENCLATURE.

SIGNALS SHOULD BE OF LIMITED INTENSITY SO THAT ATTENTION IS NOT DRAWN MORE TO THE NOISE OR LIGHT THAN IT IS TO THE SITUATION WHICH IS CAUSING THE SIGNAL. OVERWHELMING SIGNALS SHOULD BE AVOIDED SINCE THEY INTERFERE WITH CREW COORDINATION AND COMMUNICATION AND MAY ALARM A CREW MEMBER ENOUGH TO REDUCE HIS EFFICIENCY IN AN EMERGENCY SITUATION.

2.1.1 VISUAL SIGNALS: MAY CONSIST OF LIGHTS (WITH OR WITHOUT TRANSILLUMINATED NOMENCLATURE), WARNING FLAGS OR INDICATORS, OR, IN THE CASE OF INSTRUMENT INDICATIONS, IN THE TOTAL REMOVAL OF THE PERTINENT INSTRUMENT DISPLAY.

2.1.1.1 MASTER WARNING LIGHT(S): A MASTER WARNING LIGHT IS A LIGHT WHICH IS USED WHERE WARNING LIGHTS ARE LOCATED OUTSIDE OF THE DIRECT VISION OF EITHER PLOT.

NOTE: A MASTER WARNING LIGHT OR LIGHTS MAY BE REQUIRED BECAUSE OF THE LIMITATIONS OF VISIBILITY OF COLORED LIGHTS AND THE VARIABILITY OF LIGHTING CONDITIONS IN THE FLIGHT DECK.

2.1.1.2 WARNING LIGHTS: LIGHTS PROVIDED TO WARN THE CREWMEMBER, OR THE CREW, OF A CONDITION WHICH REQUIRES IMMEDIATE PROTECTIVE OR CORRECTIVE ACTION.

2.1.1.3 MASTER CAUTION LIGHT(S): A MASTER CAUTION LIGHT IS A LIGHT WHICH IS USED WHERE CAUTION LIGHTS ARE LOCATED OUTSIDE OF THE NORMAL FIELD OF VISION OF EITHER PILOT.

2.1.1.4 CAUTION LIGHTS: LIGHTS PROVIDED TO INDICATE MALFUNCTIONS WHICH DO NOT REQUIRE IMMEDIATE ACTION, BUT WHICH MAY HAVE A SUBSEQUENT SIGNIFICANT EFFECT ON THE OPERATION OF THE AIRCRAFT.

2.1.1.5 ADVISORY LIGHTS: LIGHTS PROVIDED TO INDICATE SAFE OR NORMAL CONFIGURATION, CONDITION OF PERFORMANCE, OPERATION OF ESSENTIAL EQUIPMENT, OR FOR ATTRACTING ATTENTION FOR ROUTINE PURPOSES.

2.1.1.7 WARNING FLAGS OR INDICATORS: MECHANICALLY OR ELECTRICALLY ACTUATED DISPLAYS USED TO WARN OF AN UNSAFE SETTING OR MALFUNCTION OF INSTRUMENTS OR MECHANICAL DEVICES.

2.1.2 AUDIBLE SIGNALS: IF ONE AUDIBLE SIGNAL IS USED FOR MORE THAN ONE FUNCTION, IT SHALL BE ACCOMPANIED BY VISUAL SIGNALS WHICH WILL INDICATE THE MALFUNCTION WHICH IS CAUSING THE AUDIBLE SIGNAL.

2.1.2.1 WARNING BELL: A BELL WHICH OPERATES IN CONJUNCTION WITH A WARNING LIGHT ONLY TO INDICATE THE EXISTENCE OF A FIRE.

2.1.2.2 WARNING HORN: A HORN WHICH OPERATES TO INDICATE AN UNSAFE CONFIGURATION.

TABLE E-1 (CONT)
ALERTING SYSTEM REQUIREMENTS FOUND IN ARP 450

2.1.2.3 WARNING GONG: A SINGLE BEAT SOUND USED TO WARN OF AN UNSAFE FLIGHT CONDITION OR INDICATION.

2.1.2.4 WARNING "CRICKET": A DEVICE WHICH GENERATES A CRICKET-LIKE SOUND TO WARN OF SPEEDS IN EXCESS OF V_{MO}-M_{MO}.

2.1.2.5 CHIMES: USED IN CONJUNCTION WITH COMMUNICATION SYSTEMS OF THE AIRCRAFT. FOR EXAMPLE: CABIN 10-FLIGHT DECK; SELCAL, ETC.

2.1.2.6 TONE: AN 800-CYCLE THREE-NOTE CORD OF INCREASING AMPLITUDE USED TO INDICATE APPROACHING THE DECISION HEIGHT AND CUTTING OFF WHEN REACHING DECISION HEIGHT.

2.1.3.1 STICK-SHAKER: A DEVICE WHICH CAUSES THE PILOT'S CONTROL WHEEL TO VIBRATE TO WARN OF APPROACHING TO, OR OF OPERATION IN, A STALLED CONDITION.

2.1.3.2 FOOT-THUMPER: A DEVICE WHICH VIBRATES THE PILOTS FOOT ON THE BRAKE PEDAL TO INDICATE THE CYCLING OF THE ANTI-SKID SYSTEM, OR TO WARN OF WHEEL SKIDDING'

2.2.1.1 STEADY MASTER WARNING LIGHT: THE STEADY MASTER WARNING LIGHT SHALL BE USED EXCLUSIVELY TO WARN OF FIRE AND WILL BE ACCOMPANIED BY THE WARNING BELL.

2.2.1.2 FLASHING MASTER WARNING LIGHT: THE FLASHING MASTER WARNING LIGHT SHALL BE USED TO INDICATE AN UNSAFE CONDITION OTHER THAN FIRE.

2.2.1.3 LOCATION: THE MASTER WARNING LIGHT, OR LIGHTS, AND THE MASTER CAUTION LIGHT, WILL BE LOCATED NEAR THE CENTER LINE OF THE AIRCRAFT NEAR THE TOP OF THE CENTER INSTRUMENT PANEL.

2.2.2.1 WARNING, CAUTION AND ADVISORY LIGHTS: AN INDEPENDENT LIGHT SYSTEM SHALL BE PROVIDED FOR EACH INDIVIDUAL FUNCTION OR SYSTEM TO BE MONITORED. WHERE A MASTER WARNING LIGHT IS REQUIRED, IT WILL SUPPLEMENT A SPECIFIC STEADY WARNING LIGHT AT THE INDICATOR OR CONTROL OF THE AREA OR EQUIPMENT AFFECTED.

2.2.2.2 WARNING LIGHTS SHALL BE WITHIN THE CONTROL DEVICE, OR SHALL BE LOCATED IN CLOSE PROXIMITY TO THE INDICATOR OR CONTROL DEVICE, WHERE ATTENTION TO THE INDICATOR OR CONTROL DEVICE IS THE PRIME FUNCTION OF THE WARNING SIGNAL.

2.2.2.4 THE WARNING LIGHTS FOR THE FOLLOWING SPECIFIC INDICATORS OR CONTROL DEVICES WILL BE LOCATED IN THE INDICATOR OR CONTROL DEVICE, OR ON THE CONTROL PANEL IMMEDIATELY ADJACENT THERE TO IN SUCH A MANNER AS TO POSITIVELY IDENTIFY THE INDICATOR OR CONTROL REQUIRING ACTION.

A. LANDING GEAR
B. FIRE CONTROL

2.2.3.3 CAUTION AND ADVISORY LIGHTS SHALL BE LOCATED IN CLOSE PROXIMITY TO THE INDICATOR OR CONTROL DEVICE WHERE ATTENTION TO THE INDICATOR OR CONTROL DEVICE IS THE PRIME FUNCTION OF THE SIGNAL.

2.2.5 SIGNAL FLAGS–WARNING AND ADVISORY: SIGNAL FLAGS MAY BE USED WHERE SPECIFIC INDICATION IS ASSOCIATED WITH AN INSTRUMENT OR MECHANICAL DEVICE. WHERE THEY ARE SO USED THE FLAG SIGNAL WILL BE AN INTEGRAL PART OF THE INSTRUMENT OR DEVICE.

2.2.6 AUDIBLE SIGNALS: AUDIBLE SIGNALS ARE REQUIRED FOR ALL FIRE WARNING SYSTEMS AND OTHER CRITICAL SYSTEMS OR DEVICES WHERE VISUAL CHECKS OR WARNING MAY BE INSUFFICIENT TO GUARANTEE SAFETY. THEY MAY ALSO BE USED FOR OTHER FUNCTIONS NOT BEARING ON SAFETY BUT OF SUFFICIENT IMPORTANCE TO REQUIRE THEIR USE.

TABLE E-1 (CONT)
ALERTING SYSTEM REQUIREMENTS FOUND IN ARP 450

2.2.7 TACTUAL SIGNALS: TACTUAL SIGNALS MAY BE EMPLOYED TO ALERT PILOTS' ATTENTION WHERE VISUAL CHECK OR NORMAL SENSATIONS MAY BE INSUFFICIENT TO GUARANTEE SAFETY' THEY MAY ALSO BE USED FOR OTHER FUNCTIONS NOT BEARING ON SAFETY, BUT OF SUFFICIENT IMPORTANCE TO REQUIRE THEIR USE.

2.2.8 VOICE WARNING SYSTEMS: A SYSTEM THAT INDICATES TO THE FLIGHT CREW BY MEANS OF SPOKEN WORDS, A SAFETY FLIGHT MALFUNCTION OR ABNORMALITY.

2.2.8.1 WHEN A VOICE WARNING SYSTEM IS USED, IT MAY INCLUDE, BUT NOT BE LIMITED TO, ALL WARNINGS REQUIRING AN AUDIBLE SIGNAL AND SHALL INDICATE THE SPECIFIC ITEM CAUSING THE UNSAFE CONDITION.

2.2.8.2 THE WARNING MAY INCLUDE AN APPROPRIATE SIGNAL CORRESPONDING TO THE SPECIFIC ABNORMALITY AND SHALL OCCUR ALTERNATELY WITH THE VOICE SIGNAL.

2.2.8.3 AN ANNUNCIATOR PANEL SHALL BE INCLUDED IN THE SYSTEM TO INDICATE ABNORMAL CONDITIONS AS LONG AS THEY EXIST, IF A CANCELLABLE AURAL SIGNAL IS EMPLOYED.

2.2.8.4 A SILENCE SWITCH SHALL BE PROVIDED TO SILENCE THE AURAL SIGNALS ONLY AFTER THEY HAVE COMPLETED ONE CYCLE AND WILL RESET THE SYSTEM. NONCANCELLABLE TAKE-OFF AND LANDING WARNINGS CANNOT BE SILENCED.

2.2.8.5 THE VOICE WARNING SYSTEM WILL USE SEPARATE COCKPIT SPEAKERS AND THE COCKPIT INTERPHONE TO DISSEMINATE INFORMATION.

2.3.2 COLOR CODE–LIGHTS:

2.3.1 WARNING LIGHTS: WARNING LIGHTS WILL BE COLORED AVIATION RED. THE COLOR IS DEFINED IN SPECIFICATION AN-C-56-2, SECTION D–GENERAL REQUIREMENTS.

2.3 CAUTION LIGHTS: SHALL BE AMBER, AS DEFINED IN AN-C-56-2, SECTION D.

2.3.3 ADVISORY LIGHTS: MAY BE GREEN, BLUE, OR WHITE, AS DEFINED IN AN-C-56-2, SECTION D.

2.3.3.1 GREEN: USED TO INDICATE A SAFE CONFIGURATION OR CONDITION, WHEN USED IN CONJUNCTION WITH A WARNING LIGHT THE GREEN LIGHT WILL INDICATE THAT THE ACTION TAKEN HAS RESULTED IN COMPLETE SYSTEM OPERATION AND THE RESULTING CONFIGURATION IS SAFE.

2.3.3.2 BLUE: USED TO INDICATE THAT A SYSTEM IS ON AND OPERATING NORMALLY, OR THAT TRANSITORY ACTION IS TAKING PLACE (WITH THE EXCEPTION OF THE LANDING GEAR WARNING SYSTEM).

2.4.1.1 MASTER WARNING LIGHTS: THE INTENSITY OF THE MASTER WARNING, MASTER CAUTION AND WARNING LIGHTS WILL BE 275 MILLILAMBERTS FOR THE BRIGHT INTENSITY, AND 140 MILLILAMBERTS IF DIMMING IS USED.

2.4.1.4 CAUTION LIGHTS: THE INTENSITY OF CAUTION AND ADVISORY LIGHTS WILL BE 275 MILLILAMBERTS FOR THE BRIGHT INTENSITY AND CAPABLE OF DIMMING TO NOT LESS THAN 25 MILLILAMBERTS. IF CAUTION LIGHTS ARE LOCATED NEAR THE PRINCIPAL FLIGHT INSTRUMENTS THEY SHOULD DIM SO AS NOT TO INTERFERE WITH READING THE INSTRUMENTS DURING NIGHT FLIGHT WITH THE INSTRUMENT LIGHTS TURNED DOWN.

2.6.1 WARNING LIGHTS: WARNING, CAUTION AND ADVISORY LIGHTS WILL ILLUMINATE WHEN THE CONDITION TO BE WARNED REMAINS ILLUMINATED UNTIL ITS CAP IS PUSHED IN, OR UNTIL THE CONDITION IS CORRECTED, EITHER OF WHICH EXTINGUISHES THE MASTER WARNING AND RESETS IT FOR OTHER POSSIBLE FAILURES.

2.6.2 WARNING LIGHTS: WARNING CAUTION AND ADVISORY LIGHTS WILL ILLUMINATE WHEN THE CONDITION TO BE WARNED OR ADVISED OF OCCURS. THESE LIGHTS WILL REMAIN ON AS LONG AS THE CONDITION EXISTS OR UNTIL THE SYSTEM IS DEACTIVATED.

TABLE E-1 (CONT)
ALERTING SYSTEM REQUIREMENTS FOUND IN ARP 450

2.6.3 MASTER CAUTION LIGHT: WILL ILLUMINATE WHEN THE CONDITION TO BE ADVISED OF OCCURS. THE MASTER CAUTION SIGNAL REMAINS ILLUMINATED UNTIL ITS CAP IS PUSHED IN OR UNTIL THE CONDITION IS CORRECTED. EITHER OF WHICH EXTINGUISHES THE MASTER CAUTION SIGNAL AND RESETS IT FOR OTHER POSSIBLE ABNORMALITIES.

2.7.1 COLOR CODE: WHERE WARNING FLAGS ARE USED EXTERNALLY OR INDEPENDENTLY FROM INSTRUMENTATION, THEY SHOULD BE OF A BRIGHT YELLOW WITH BLACK DIAGONALS TO PROVIDE CONTRAST TO THE SURROUNDING AREA.

WHERE WARNING FLAG INDICATORS ARE USED INTERNALLY IN INSTRUMENTS, THE COLOR SHOULD BE YELLOW, OR FLUORESCENT RED, WITH BLACK WORDING THEREON, IF REQUIRED.

2.7.2 WARNING FLAG OR INDICATORS INDEPENDENT FROM INSTRUMENT: FLAGS USED IN CONJUNCTION WITH MECHANICAL DEVICES INDEPENDENT OF INSTRUMENTATION WILL PROVIDE A CLEAR, UNMISTAKABLE WARNING THAT THE CONDITION TO BE WARNED OF HAS OCCURRED.

2.7.3 INSTRUMENT WARNING FLAGS OR INDICATORS: FLAGS USED IN CONJUNCTION WITH INSTRUMENTS WILL PROVIDE A CLEAR, UNMISTAKABLE WARNING THAT THE CONDITION TO BE WARNED OF HAS OCCURRED.

2.8 AUDIBLE SIGNAL–CODE:

2.8.1 BELL: INDICATES "FIRE," FUNCTIONS AUTOMATICALLY AND SIMULTANEOUSLY WITH A FIRE WARNING LIGHT.

2.8.2 HORN: INDICATES AN UNSAFE AIRCRAFT CONFIGURATION.
SPECIFIC APPLICATIONS:

A. LANDING GEAR UNSAFE WITH THROTTLES RETARDED, OR WITH WING FLAPS IN THE LANDING CONFIGURATION, STEADY SOUND.

B. UNSAFE TAKEOFF CONFIGURATION UPON THROTTLE OPENING INTERMITTENT SOUND.

C. CABIN PRESSURE ABOVE 10,000 FEET INTERMITTENT SOUND.

2.8.3 "CRICKET": INDICATES SPEED IN EXCESS OF V_{MO}-M_{MO}.

2.8.4 GONG: USED FOR ALTITUDE ALERTING SYSTEM AND SPECIFIC WARNING ASSOCIATED WITH FLIGHT INFORMATION.

2.8.5 CHIME: USED FOR ROUTINE OPERATIONAL INFORMATION.

2.8.6 TONE: AN 800 CYCLE THREE NOTE CORD OF INCREASING AMPLITUDE MADE UP OF THE FOLLOWING FREQUENCIES: 512/640/768 Hz.

2.9 AUDIBLE SIGNAL SOUND LEVEL: THE LEVEL OF SOUND FOR ALL AURAL SIGNALS SHOULD BE THE MINIMUM LEVEL WHICH WILL BE CLEARLY DISTINGUISHABLE ABOVE THE NOISE LEVEL OF THE FLIGHT DECK FOR ALL CONDITIONS OF FLIGHT OPERATIONS OVER THE ENTIRE DESIGN ENVELOPE.

2.10 AUDIBLE SIGNALS TESTING: MEANS SHALL BE PROVIDED IN THE FLIGHT DECK AREA FOR TESTING AUDIBLE SIGNALS.

2.11 OPERATION OF AUDIBLE SIGNALS: THE AUDIBLE SIGNALS WILL SOUND WHEN THE CONDITION TO BE WARNED OF EXISTS.

2.11.1 BELL:

A. THE WARNING BELL SHALL HAVE A PROVISION FOR CUT-OFF. IF CUT-OFF IS AUTOMATIC, THE BELL WILL RING NOT LESS THAN ONE OR MORE THAN THREE SECONDS.

TABLE E-1 (CONT)
ALERTING SYSTEM REQUIREMENTS FOUND IN ARP 450

B. THE CUT-OFF WILL NOT AFFECT CONTINUED OPERATION OF THE SIGNAL LIGHT.

C. THE CUT-OFF WILL AUTOMATICALLY RESET THE WARNING BELL FOR RECURRING FIRE IN THE SAME SYSTEM, OR FOR OCCURRENCE OF FIRE IN ANY OTHER SYSTEM, FOR EITHER MANUAL OR AUTOMATIC CUT-OFF.

2.11.2 HORN: THE WARNING HORN SHALL BE PROVIDED WITH A MANUAL CUT-OFF SWITCH. IT SHALL NOT BE POSSIBLE, HOWEVER, TO SILENCE THE HORN WITH THE CUT-OFF SWITCH:

A. DURING TAKEOFF, EXCEPT BY CORRECTING THE UNSAFE TAKEOFF CONDITION.

B. IN FLIGHT WHEN THE WING FLAPS ARE IN THE LANDING CONFIGURATION.

IF THE HORN SOUNDS IN FLIGHT AS A RESULT OF RETARDING THROTTLES AND THE HORN IS THEN SILENCED WITH THE CUT-OFF SWITCH, THE WARNING SYSTEM SHALL AUTOMATICALLY RESET FOR OPERATION UPON ADVANCEMENT OF THROTTLES.

2.11.3 "CRICKET": WILL BE FULLY AUTOMATIC IN OPERATION WITH NO CUT-OFF PROVIDED.

2.11.4 GONG: WILL BE FULLY AUTOMATIC IN OPERATION WITH NO CUT-OFF PROVIDED.

2.11.5 CHIME: WILL BE SOUNDED BY AN ACTUATING SWITCH OR BUTTON, AS REQUIRED.

2.12 TACTUAL SIGNALS PERCEPTIBILITY: THE INTENSITY OF TACTICAL SIGNALS SHALL BE SUCH AS TO ASSURE THEIR PERCEPTIBILITY UNDER ALL CONDITIONS.

2.13 TACTUAL SIGNALS TESTING: MEANS SHALL BE PROVIDED IN THE FLIGHT DECK AREA FOR TESTING TACTUAL SIGNALS.

2.14 OPERATION OF TACTUAL SIGNALS: THE TACTUAL SIGNALS WILL BE ACTIVATED WHEN THE CONDITION TO BE WARNED OF EXISTS, OR IMPENDS, AND WILL PERSIST UNTIL THE CONDITION IS CORRECTED.

WHEN THE CONDITION IS CORRECTED THE TACTUAL SIGNAL WILL BE AUTOMATICALLY DEACTIVATED AND RESET FOR FUTURE RECURRENCE.

TABLE E-2
ALERTING SYSTEM REQUIREMENTS FOUND IN ARP 571

3.2.2	SELCAL: A SYSTEM MAY BE INSTALLED FOR PROVIDING VISUAL AND AURAL INDICATION OF A RADIO CALL INTENDED FOR THAT PARTICULAR AIRCRAFT.
3.2.2.1	VISUAL INDICATION SHALL BE PROVIDED FOR EACH RECEIVER FOR WHICH THE CALLING SYSTEM IS PROVIDED, BY AN ADVISORY LIGHT (OF A COLOR CONFORMING TO ARP 450). EACH LIGHT SHALL BE LOCATED AS CLOSE AS PRACTICAL TO THE RESPECTIVE RECEIVER'S FREQUENCY SELECTOR AND/OR VOLUME CONTROL.
5.1.1	THE FLIGHT DIRECTOR, AUTOPILOT, AND AUTOTHROTTLE SYSTEM MODE ANNUNCIATION DISPLAY SHALL PROVIDE A VISUAL INDICATION OF THE ARMING AND ENGAGEMENT OF ALL SELECTED MODES; AND, FOR SPECIFIED CASES, A VISUAL AND AURAL WARNING OF DISCONNECT CAUSED BY A SYSTEM FAULT OR BY PILOT ACTION.
5.1.3	THE MODE ANNUNCIATION DISPLAY SHALL BE LOCATED ON EACH PILOT'S FLIGHT INSTRUMENT PANEL WITHIN THE AREA OF THE "BASIC T" LAYOUT, PREFERABLY CENTRALLY ABOVE EACH ATTITUDE DIRECTOR INDICATOR (ADI).
5.5	MARKER EQUIPMENT INDICATION: A SET OF MARKER LIGHTS SHALL BE PROVIDED FOR THE CAPTAIN; IT IS CONSIDERED DESIRABLE TO ALSO PROVIDE A SET FOR THE CO-PILOT.
5.5.1	THE MARKER LIGHTS SHALL BE POSITIONED AT THE RIGHT END OF THE TOP ROW OF FLIGHT INSTRUMENTS AND SHALL BE FURTHER ARRANGED VERTICALLY AS FOLLOWS: UPPERMOST, WHITE–3000 CYCLE; MIDDLE, AMBER–1300 CYCLE; BOTTOM, BLUE–400 CYCLE. THE COLOR OF THE AMBER AND THE BLUE LIGHTS SHALL BE AS DEFINED IN AN-C-56-2, SECTION P.

TABLE E-3
ALERTING SYSTEM REQUIREMENTS FOUND IN ARP 1068

5.2	FAILURE WARNINGS: FAILURE WARNINGS FOR THE VARIOUS FUNCTIONS SHALL BE PROVIDED FOR THE PRIMARY FLIGHT PATH CONTROL INSTRUMENT SYSTEMS WHERE OTHER MEANS ARE NOT AVAILABLE FOR THE CREW TO IMMEDIATELY DETERMINE A FAILURE.
5.2.1	INDIVIDUAL FAILURE WARNING SHALL BE PROVIDED FOR EACH INSTRUMENT FUNCTION WHICH IS ESSENTIAL FOR CONTINUATION OF FLIGHT UNDER ANY OPERATION CONDITION.
5.2.2	FAILURE WARNINGS SHALL COVER MECHANICAL AND ELECTRICAL MALFUNCTIONS AS WELL AS POWER FAILURES. POWER FAILURE IS CONSIDERED AS ANY TYPE OF POWER DISCREPANCY WHICH WILL RESULT IN A MALFUNCTION OF THE DISPLAY.
5.2.3	PREFERRED METHOD OF FAILURE WARNING IS TO REMOVE THE AFFECTED DISPLAY FROM VIEW OR OTHERWISE PREVENT INADVERTENT USE OF THE FAILED DISPLAY.
5.2.4	WHEN A WARNING FLAG IS USED, IF PRACTICAL, IT SHOULD OBSCURE THE FUNCTION INDICATOR FOR WHICH THE WARNING IS PERTINENT.
5.3.1.2	THE AIRSPEED SYSTEMS SHALL INCORPORATE A WARNING FEATURE FOR SIGNIFICANT DISCREPANCIES IN EITHER OF THE SYSTEMS, INCLUDING THE INSTRUMENT READOUT.
5.3.2.6	THE VSI DISPLAY SHALL PROVIDE WARNING OF SIGNIFICANT DIFFERENCES IN SYSTEMS OUTPUT.
5.3.2.11	THE FLIGHT DIRECTOR COMPUTER FAILURE WARNING SHALL BE ACTIVATED BY FAILURE IN THE COMPUTER AND SHALL ALSO INDICATE FAILURES THAT HAVE OCCURRED IN ANY OF THE INPUTS TO THE COMPUTER THAT ARE BEING MONITORED.
5.3.3.1	A VISUAL ADVISORY SIGNAL SHALL BE PROVIDED TO ALERT THE CREW WHEN THE ASSIGNED ALTITUDE IS BEING APPROACHED OR VACATED.
5.3.3.3	THE RADIO ALTIMETERS SHALL INCORPORATE AN AURAL AND VISUAL WARNING OR ALERT SIGNAL AT DESIGNATED ALTITUDES ABOVE THE TERRAIN. THIS ALERT SIGNAL SHALL BE SEPARATE AND DISTINCT FROM THE SIGNAL IN PARAGRAPH 5.3.3.1. SEE ARP 450B FOR DESIGN CRITERIA OF THESE WARNING SIGNALS.
5.3.3.4	A WARNING SYSTEM SHALL WARN THE PILOT (VISUAL SIGNAL) WHEN A SIGNIFICANT DISCREPANCY EXISTS IN EITHER OF THE TWO BAROMETRIC DISPLAYS. THIS ALSO SHALL APPLY TO THE RADAR ALTIMETER DISPLAYS.
5.3.4.2	A WARNING SHALL BE PROVIDED TO INDICATE SIGNIFICANT DISCREPANCIES IN THE H81 SYSTEMS.
5.3.5.2	WARNING, AUDIO AND VISUAL SIGNALS SHALL AUGMENT THE DISPLAY IN 5.3.5.1 ABOVE.
5.3.5.3	IT IS DESIRABLE THAT A RATE OF APPROACH TOWARD AN OPERATIONAL SITUATION OR LIMIT ALSO BE DISPLAYED AND WHERE NECESSARY SUITABLE WARNINGS BE PROVIDED.

TABLE E-4
ALERTING SYSTEM REQUIREMENTS FOUND IN ARP 1161

5.5.2.2 BLACK BACKGROUNDS:

5.5.2.2.1 NONTRANSILLUMINATED SYSTEMS: THE BRIGHTNESS OF THE BLACK BACKGROUND SHALL HAVE A MAXIMUM VALUE OF 7% OF THE BRIGHTNESS OF NEARBY WHITE MARKINGS (WITHIN AN APPROXIMATE 0.25 IN. (6.35 MM) RADIUS), AND WHEREVER PRACTICAL NO LIGHT SHALL BE EMITTED FROM THE BLACK BACKGROUND.

TABLE I – DISPLAY COLORS

USE – TYPICAL	COLOR	COLOR DESCRIPTION*
DISPLAY MARKINGS:		
PRIMARY	WHITE	37875
SECONDARY	BLUE	35177
EXTRANEOUS	BLACK	27038
FLAG	BLACK	37038
BACKGROUNDS:		
DISPLAY	BLACK	37038
	DK. GRAY	36118
FLAG	RED	DAY-GLO FIRE ORANGE
	YELLOW	DAY-GLO SATURN YELLOW
POINTERS, LUBBER LINES & BUGS:		
PRIMARY	WHITE	37875
SECONDARY	ORANGE	DAY-GLO ARC YELLOW
	RED	DAY-GLO FIRE ORANGE
NON-LIT AREAS	YELLOW	DAY-GLO SATURN YELLOW
	BLACK	37038
LIMIT MARKS:		
WARNING	RED	DAY-GLO FIRE ORANGE
CAUTION	YELLOW	DAY-GLO SATURN YELLOW
RANGE BANDS:		
	WHITE	37878
	YELLOW	DAY-GLO SATURN YELLOW
	GREEN	DAY-GLO SIGNAL GREEN
	RED	DAY-GLO FIRE ORANGE
KNOBS:		
HANDLE	LT. GRAY	36440
SKIRT	BLACK	37038
MARKINGS	WHITE	37875

*1. COLOR NUMBERS NOTED IN THIS TABLE, INCLUDING THEIR FINISH, ARE PER FED-STD-595.

2. ALTHOUGH THE COLORS IDENTIFIED AS DAY-GLO SHALL MATCH IN COLOR THE RESPECTIVE COLORS OF THE DAY-GLO DAYLIGHT FLUORESCENT PAINTS MADE BY THE DAY-GLO COLOR DIVISION OF

TABLE E-4 (CONT)
ALERTING SYSTEM REQUIREMENTS FOUND IN ARP 1161

SWITZER BROS., INC., CLEVELAND, OHIO, THEY ARE NOT NECESSARILY REQUIRED TO HAVE THE FLUORESCENT CHARACTERISTICS OF THOSE PAINTS.

8. WARNING, CAUTION, AND ADVISORY SYSTEM LIGHTING

REFER TO THE LATEST ISSUE OF SAE ARP 450 FOR RECOMMENDATIONS ON WARNING, CAUTION, AND ADVISORY LIGHTING. AS AN OPTION, SECTIONS 8.1 THROUGH 8.10 CAN BE OMITTED.

8.1 PURPOSE: THE PURPOSE OF THIS SECTION IS TO PRESENT THE LIGHTING REQUIREMENTS FOR WARNING, CAUTION, AND ADVISORY SYSTEMS.

8.2 SCOPE: THIS SECTION SETS FORTH THE LIGHTING REQUIREMENTS FOR WARNING, CAUTION, AND ADVISORY SYSTEMS.

8.3 DEFINITIONS:

8.3.1 MASTER WARNING: A SIGNAL INDICATING A CONDITION REQUIRING IMMEDIATE ACTION. THE SPECIFIC CONDITION IS SHOWN BY A SEPARATE INDICATION.

8.3.2 INDEPENDENT WARNING: A SIGNAL INDICATING A CONDITION REQUIRING IMMEDIATE ACTION. THE SPECIFIC CONDITION IS DEFINED BY THE LOCATION OF THE SIGNAL OR THE LEGEND ASSOCIATED WITH THE SIGNAL.

8.3.3 MASTER CAUTION: A SIGNAL INDICATING A CONDITION WHICH MAY REQUIRE ACTION. THE SPECIFIC CONDITION IS SHOWN BY A SEPARATE INDICATION.

8.3.4 ADVISORY, SAFE: A SIGNAL INDICATING A SAFE CONDITION.

8.3.5 ADVISORY, STATUS: A SIGNAL INDICATING A STATUS CONDITION ONLY, NOT NECESSARILY A SAFE CONDITION.

8.3.6 DEPENDENT WARNING OR CAUTION: A SIGNAL INDICATING THE SPECIFIC CAUSE OF ACTIVATION OF THE MASTER WARNING OR CAUTION SIGNALS, RESPECTIVELY.

8.4 COLORS:

A. WARNING SIGNALS: AVIATION RED PER MIL-C-25050.
B. CAUTION SIGNALS: AVIATION YELLOW PER MIL-C-25050.
C. ADVISORY, SAFE: LIGHT GREEN PER DEVICE SPECIFICATION.
D. ADVISORY, STATUS: ANY COLOR INCLUDING WHITE EXCEPT THOSE ABOVE OR COLORS EASILY CONFUSED WITH THE ABOVE COLORS. A LIGHT (ICE) BLUE IS RECOMMENDED.

8.5 MASTER WARNING INDICATOR AND MASTER CAUTION INDICATOR: THE PURPOSE OF THESE INDICATORS IS TO INTRUDE UPON THE ATTENTION OF THE CREW MEMBERS UNDER ALL OPERATING CONDITIONS. THUS THE DESIGNER MUST CONSIDER PLACEMENT OF INDICATOR, AMBIENT LIGHTING, SHADING FROM DIRECT SUNLIGHT, SIZE OF LIT AREA, STEADY STATE VERSUS FLASHING AND BRIGHTNESS. MINIMUM BRIGHTNESS SHALL BE 150 FOOTLAMBERTS AT RATED VOLTAGE PROVIDED THE INDICATORS CAN BE PLACED OUT OF DIRECT SUNLIGHT. THE INDICATORS SHALL BE DIMMABLE TO 15 FOOTLAMBERTS. THE BRIGHT-DIM CONTROL SHALL RETURN TO FULL BRIGHT POSITION WHENEVER POWER IS REMOVED FROM THE CONTROL OR THE AMBIENT BRIGHTNESS REACHES A PREDETERMINED LEVEL. THE INDICATORS SHALL BE RESETTABLE SO THAT A SECOND SIGNAL SHALL REACTIVATE THE MASTER INDICATOR.

8.6 INDEPENDENT WARNING INDICATOR: IN GENERAL, THE INDEPENDENT WARNING INDICATOR SHALL MEET THE REQUIREMENTS OF 8.5 WITH THE FOLLOWING EXCEPTIONS: THE INDICATOR NEED NOT BE RESETTABLE; EITHER THE PLACEMENT OF THE INDICATOR OR AN ASSOCIATED LEGEND SHALL CLEARLY SHOW THE NATURE OF THE WARNING; THE DESIGNER SHALL CONSIDER ADDITIONAL DIMMING TO 5 FOOTLAMBERTS.

TABLE E-4 (CONT)
ALERTING SYSTEM REQUIREMENTS FOUND IN ARP 1161

8.7 DEPENDENT WARNING AND CAUTION INDICATORS: THESE INDICATORS SHALL BE ACTIVATED SIMULTANEOUSLY WITH THEIR RESPECTIVE MASTER INDICATOR AND SHALL SHOW THE SPECIFIC CAUSE OF THE MASTER INDICATOR ACTIVATION. IN GENERAL, THEIR BRIGHTNESS SHALL BE 150 FOOTLAMBERTS MINIMUM AT RATED VOLTAGE BUT THE REQUIRED BRIGHTNESS SHALL BE EVALUATED IN TERM OF OPERATING CONDITIONS AND LOWER BRIGHTNESS USED WHERE PRACTICABLE. THE INDICATORS SHALL BE DIMMABLE TO 15 FOOTLAMBERTS AND THE DESIGNER SHALL CONSIDER DIMMING TO VALUES APPROXIMATELY TWICE THE NOMINAL VALUES OF THE INTEGRALLY LIGHTED DISPLAYS.

THE BRIGHT-DIM CONTROL SHALL RETURN TO FULL BRIGHT POSITION UNDER THE CONDITIONS DESCRIBED IN 8.5. THE INDICATORS SHALL NOT BE RESETTABLE WHILE THE ACTIVATING CONDITION EXISTS.

8.8 STATUS INDICATORS: THE STATUS INDICATORS SHALL HAVE A BRIGHTNESS SUFFICIENT FOR LEGIBILITY UNDER ALL CONDITIONS OF FLIGHT OPERATION. THE DESIGNER SHALL CONSIDER LOCATION AND SHADING FROM SUNLIGHT TO ENHANCE READABILITY AT LOWER BRIGHTNESSES. THE INDICATORS SHALL BE DIMMABLE TO VALUES COMPARABLE TO THE INTEGRALLY LIT DISPLAYS OF SECTION 5.

8.9 LEGENDS: IN GENERAL, WHERE INDICATORS HAVE LEGENDS, THE LEGEND SHOULD BE ON AN OPAQUE BACKGROUND. CONSIDERATION MAY BE GIVEN TO AN OPAQUE LEGEND ON A TRANSLUCENT BACKGROUND WHERE ADDITIONAL VISUAL STIMULUS IS CONSIDERED ESSENTIAL. LEGENDS SHOULD BE AS BRIEF AS POSSIBLE AND ONE LINE PRESENTATIONS ARE PREFERRED. IF ABBREVIATIONS ARE USED, THEIR MEANING SHOULD BE CLEAR TO AVOID MISINTERPRETATION.

TABLE E-5
SYNOPSIS OF ALERTING SYSTEM REQUIREMENTS FOUND IN RTCA DOCUMENT NO. D0-161A

1.6 WARNING AND ALERT INDICATIONS: DISTINCTIVE AURAL AND VISUAL WARNING MUST BE PROVIDED FOR MODES 1 THROUGH 4. A SEPARATE DISTINCTIVE AURAL ALERT MUST BE PROVIDED FOR MODE 5.

1.6.1 AURAL WARNING/ALERT: THE AURAL WARNING FOR MODES 1 THROUGH 4 SHALL CONSIST OF THE SOUND "WHOOP-WHOOP", FOLLOWED BY EITHER "PULL-UP" OR "TERRAIN" (OR OTHER ACCEPTABLE ANNUNCIATION) REPEATED UNTIL THE HAZARDOUS CONDITION NO LONGER EXISTS. THE WARNING MAY BE PROVIDED BY THE GPW EQUIPMENT ITSELF OR AN AUXILIARY WARNING UNIT WHICH IS ACTIVATED BY THE GPW EQUIPMENT.

THE AURAL ALERT FOR MODE 5 SHALL CONSIST OF THE ANNUNCIATION "GLIDE SLOPE" (OR OTHER ACCEPTABLE PHRASE) REPEATED UNTIL THE CONDITION RESPONSIBLE FOR THE ALERT NO LONGER EXISTS OR THE ALERT IS INHIBITED.

1.6.2 VISUAL WARNING CHARACTERISTICS (MODES 1 THROUGH 4): THE VISUAL WARNING PROVIDED FOR MODES 1 THROUGH 4 SHALL BE DISTINCTIVE UNDER ALL NORMAL LIGHTING CONDITIONS AND COMMENSURATE WITH OTHER COCKPIT WARNINGS.

1.6.3 EMERGENCY/PLANNED ABNORMAL DEACTIVATION: MEANS TO DEACTIVATE THE WARNING INDICATIONS (MODES 1 THROUGH 4) MAY BE PROVIDED, AND MEANS TO DEACTIVATE THE ALERT INDICATION (MODE 5) MUST BE PROVIDED FOR FLIGHT CREW USE IN PLANNED ABNORMAL OR EMERGENCY CONDITIONS.

2.3 CHARACTERISTICS OF WARNING INDICATIONS (MODES 1 THROUGH 4)

2.3.1 AURAL WARNING CHARACTERISTICS: THE AURAL WARNING FOR MODES 1 THROUGH 4 CONSISTS OF THE SOUND "WHOOP-WHOOP," FOLLOWED BY EITHER "PULL-UP" OR "TERRAIN" (OR OTHER ACCEPTABLE ANNUNCIATION) REPEATED UNTIL THE HAZARDOUS CONDITION NO LONGER EXISTS. IT IS NOT NECESSARY FOR ANY WARNING CYCLE ("WHOOP-WHOOP" PLUS VOICE ANNUNCIATION) TO BE COMPLETED FOLLOWING THE TERMINATION OF A HAZARDOUS CONDITION. "WHOOP-WHOOP" IS DESCRIBED AS A TONE SWEEP FROM 400 Hz ±10% TO 800 Hz ±10% AT A PERIOD OF 0.3 SECONDS ±20% AND WITH INCREASING AMPLITUDE OF 9 dB ±3 dB. THE COMPLETE CYCLE OF TWO TONE SWEEPS PLUS VOICE ANNUNCIATION SHOULD TAKE 1.4 SECONDS ±20%, WITH THE CYCLE REPEATED IMMEDIATELY. THE GAIN MAY BE AUTOMATICALLY REDUCED AFTER THREE COMPLETE WARNING CYCLES TO A LOWER, BUT DISCERNABLE, LEVEL.

2.3.1.1 SPEAKER OUTPUT LEVEL: THE VOICE WARNING SIGNAL SHALL HAVE AN OUTPUT LEVEL OF AT LEAST 2W RMS.

2.3.1.2 HEADSET OUTPUT LEVEL: IF PROVIDED, THE HEADSET VOICE WARNING SIGNAL SHALL HAVE AN OUTPUT LEVEL OF AT LEAST 50 mW.

2.3.2 VISUAL WARNING: THE VISUAL WARNING FOR MODES 1 THROUGH 4 SHALL BE RED AND INCLUDE, IN DISTINCTIVE LETTERS, THE LETTERS GPWS (OR OTHER ACCEPTABLE LEGEND).

2.4 DEACTIVATION CONTROL: THE CONTROL FOR DEACTIVATION OF THE WARNING INDICATIONS UNDER PLANNED ABNORMAL OR EMERGENCY CONDITIONS SHALL BE A CIRCUIT BREAKER. ALTERNATIVELY A SWITCH WHICH IS PROTECTED FROM INADVERTENT CREW OPERATION MAY BE USED. SUCH A SWITCH SHALL PROVIDE OBVIOUS INDICATION IT HAS BEEN OPERATED.

2.6 GLIDE SLOPE DEVIATION ALTERING (MODE 5)

2.6.1 ENVELOPE OF CONDITIONS FOR ALERTING: AN ALERT SHALL BE PROVIDED WHEN THE COMBINATION OF DEVIATION BELOW AN ILS GLIDE SLOPE AND THE HEIGHT ABOVE TERRAIN IS WITHIN THE ENVELOPE FOR MODE 5 PRESCRIBED IN APPENDIX A.

2.6.2 DEACTIVATION: IT SHALL BE POSSIBLE FOR THE FLIGHT CREW TO DEACTIVATE MODE 5. THE CONTROL PROVIDED FOR THIS PURPOSE SHALL BE SEPARATE FROM ANY CONTROL PROVIDED TO DEACTI-

TABLE E-5 (CONT)
SYNOPSIS OF ALERTING SYSTEM REQUIREMENTS
FOUND IN RTCA DOCUMENT NO. D0-161A

VATE MODES 1 THROUGH 4. THE MODE 1 THROUGH 4 DEACTIVATION CONTROL, HOWEVER, MAY ALSO DEACTIVATE MODE 5.

2.6.3 REACTIVATION: IF MODE 5 IS DEACTIVATED BY THE PILOT, IT SHALL BE AUTOMATICALLY REACTIVATED FOR THE NEXT APPROACH.

2.6.4 ARMING/DISARMING: MODE 5 SHALL BE ARMED WHEN THE LANDING GEAR IS SELECTED TO THE LANDING POSITION AND DISARMED EITHER WHEN THE FLAPS ARE RETRACTED FROM THE LANDING POSITION OR THE LANDING GEAR IS SELECTED TO THE NON-LANDING POSITION.

2.6.5 GLIDE SLOPE MODE ALERT: THE GLIDE SLOPE DEVIATION ALERT SHALL CONSIST OF THE AURAL ANNUNCIATION "GLIDE SLOPE" (OR OTHER ACCEPTABLE ANNUNCIATION) REPEATED UNTIL THE CONDITION RESPONSIBLE FOR THE ALERT NO LONGER EXISTS OR THE ALERT IS INHIBITED. AN AURAL WARNING RELATED TO GPWS MODES 1 THROUGH 4 SHALL TAKE PRECEDENCE OVER THIS ALERT.

THE EQUIPMENT MAY PROVIDE A CONSTANT ALERT REPETITION RATE AND AUDIO OUTPUT LEVEL, OR ONE OR BOTH OF THESE QUANTITIES MAY INCREASE AS THE BELOW GLIDE SLOPE DEVIATION INCREASES AND/OR THE TERRAIN CLEARANCE DECREASES. IN THE FORMER CASE THE ALERT SHALL BE REPEATED AT LEAST ONCE EVERY THREE SECONDS. THE AUDIO OUTPUT POWER LEVELS MAY TAKE ON ANY VALUE BETWEEN 0 AND 6dB BELOW THOSE VALUES SPECIFIED FOR THE MODES 1 THROUGH 4 AURAL WARNING IN PARAGRAPHS 2.3.1.1 AND 2.3.1.2.

IF THE REPETITION RATE/AUDIO OUTPUT LEVEL IS/ARE VARIED WITH TERRAIN CLEARANCE/GLIDE SLOPE DEVIATION, THE ALERT SHOULD BE REPEATED ONCE EVERY SEVEN SECONDS (NOMINAL) AT 1000 FEET TERRAIN CLEARANCE AND THE AUDIO LEVELS BE DISCERNABLE TO THE PILOT. AS THE TERRAIN CLEARANCE DECREASES AND/OR THE GLIDE SLOPE DEVIATION INCREASES, THE ALERT RATE SHOULD INCREASE TO A MAXIMUM OF ONCE EVERY 0.7 SECONDS AND THE AUDIO OUTPUT POWER LEVELS TO THE MAXIMUM OF THOSE VALUES SPECIFIED FOR THE MODES 1 THROUGH 4 AURAL WARNING IN PARAGRAPHS 2.3.1.1 AND 2.3.1.2.

TABLE E-6
SYNOPSIS OF ALERTING SYSTEM REQUIREMENTS IN MIL-STD-1472

3.1 LIGHT SIGNALS:

3.1.1 NON-LEGEND TYPE: A NON-LEGEND LIGHT SIGNAL ASSEMBLY IS ONE WHICH HAS NO MARKINGS ON ITS LIGHT TRANSMITTING SURFACE.

3.1.2 LEGEND TYPE: A LEGEND LIGHT SIGNAL ASSEMBLY IS ONE WHICH HAS THE LEGEND ON ITS LIGHT TRANSMITTING SURFACE.

3.1.3 WARNING LIGHT: A WARNING LIGHT IS A SIGNAL ASSEMBLY WHICH INDICATES THE EXISTENCE OF A HAZARDOUS CONDITION REQUIRING IMMEDIATE CORRECTIVE ACTION.

3.1.1.5 MASTER WARNING LIGHT RESET: THE MASTER WARNING LIGHT SHALL HAVE A PUSH-TO-RESET CAPABILITY WHICH DEENERGIZES THE MASTER WARNING LIGHT WHILE THE APPLICABLE LEGEND WARNING LIGHT REMAINS "ON." THE MASTER WARNING LIGHT AND ANY APPLICABLE WARNING LIGHT(S) SHALL BE ENERGIZED SIMULTANEOUSLY.

A. THE AIRCRAFT POWER SETTING IS LESS THAN THAT REQUIRED TO MAINTAIN LEVEL FLIGHT IN THE POWER APPROACH CONFIGURATION.

B. THE FLAPS OR OTHER HIGH-LIFT DEVICES ARE NOT FULLY RETRACTED.

C. THE WHEELS ARE NOT DOWN AND LOCKED.

3.1.4 MASTER WARNING LIGHT: A MASTER WARNING LIGHT IS A SIGNAL ASSEMBLY WHICH INDICATES THAT AT LEAST ONE OR MORE WARNING LIGHTS HAVE BEEN ENERGIZED.

3.1.5 CAUTION LIGHT: A CAUTION LIGHT IS A SIGNAL ASSEMBLY WHICH INDICATES THE EXISTENCE OF AN IMPENDING DANGEROUS CONDITION REQUIRING ATTENTION BUT NOT NECESSARILY IMMEDIATE ACTION.

3.1.6 MASTER CAUTION LIGHT: A MASTER CAUTION LIGHT IS A SIGNAL ASSEMBLY WHICH INDICATES THAT ONE OR MORE CAUTION LIGHTS HAVE BEEN ACTUATED.

3.1.7 ADVISORY LIGHT: AN ADVISORY LIGHT IS A SIGNAL ASSEMBLY TO INDICATE SAFE OR NORMAL CONFIGURATION, CONDITION OF PERFORMANCE, OPERATION OF ESSENTIAL EQUIPMENT, OR TO ATTRACT ATTENTION AND IMPART INFORMATION FOR ROUTINE ACTION PURPOSES.

3.2 AUDITORY WARNING SIGNALS: AUDITORY WARNING SIGNALS ARE AUDIBLE SIGNALS INDICATING THE EXISTENCE OF A HAZARDOUS CONDITION(S) REQUIRING IMMEDIATE CORRECTIVE ACTION.

5.1.1 WARNING LIGHTS: LEGEND WARNING LIGHTS SHALL BE USED IN ALL AIRCREW STATIONS. A MASTER WARNING LIGHT, WHEN REQUIRED, SHALL BE ENERGIZED SIMULTANEOUSLY WITH ANY APPLICABLE WARNING LIGHT.

5.1.1.1 COLOR: THE COLOR OF THE WARNING LIGHTS SHALL BE AVIATION RED.

5.1.2 CAUTION LIGHTS: LEGEND TYPE MASTER CAUTION AND LEGEND TYPE CAUTION LIGHTS SHALL BE USED IN ALL AIRCREW STATIONS. THE MASTER CAUTION LIGHT AND ANY APPLICABLE LEGEND CAUTION LIGHT SHALL BE ENERGIZED SIMULTANEOUSLY.

5.1.2.1 COLOR: THE COLOR OF THE CAUTION LIGHTS SHALL BE AVIATION YELLOW.

5.1.2.6 MASTER CAUTION LIGHT RESET: THE MASTER CAUTION LIGHT SHALL HAVE A PUSH-TO-RESET CAPABILITY WHICH DEENERGIZES THE MASTER CAUTION LIGHT WHILE THE APPLICABLE LEGEND CAUTION LIGHT REMAINS "ON."

5.1.3 ADVISORY LIGHTS: EVERY ATTEMPT SHOULD BE MADE TO MINIMIZE THE USE OF ADVISORY LIGHTS IN THE COCKPIT AREA, PRIMARILY TO AVOID UNNECESSARY DISTRACTION OF THE PILOTS AND TO MINI-

MIZE THOSE FACTORS WHICH DETERIORATE NIGHT VISION CAPABILITY OF THE CREW. THEY SHALL NOT BE USED WHERE OTHER METHODS, SUCH AS SWITCH LABELING, MECHANICAL VISUAL SIGNALS, ETC., MAY BE EMPLOYED. ADVISORY LIGHTS MAY BE EITHER OF THE LEGEND OR NON-LEGEND TYPE, IN THE EVENT THAT A LEGEND LIGHT IS NOT EMPLOYED, A READILY IDENTIFIABLE LABEL SHALL BE PROVIDED ADJACENT TO THE LIGHT, PREFERABLY ABOVE.

5.1.3.1 COLOR: THE COLOR OF ADVISORY LIGHTS IN THE FLIGHT COMPARTMENT SHALL BE AVIATION GREEN. GREEN, BLUE, OR WHITE COLORS MAY BE USED IN OTHER CREW STATIONS.

5.2.1 MASTER WARNING SIGNALS: A NON-VERBAL AUDIO MASTER WARNING SIGNAL SHALL PRODUCE AN OUTPUT WITH THE FOLLOWING FREQUENCY AND INTERRUPTION RATES:

A. FUNDAMENTAL AUDIO OUTPUT FREQUENCY SHALL SWEEP FROM 700 Hz TO 1,700 Hz IN 0.85 SECOND.

B. INTERRUPTION INTERVAL 0.12 SECOND.

C. THE CYCLE SHALL BE REPEATED UNTIL THE SIGNAL GENERATOR IS DEENERGIZED.

5.2.3 WHEELS-UP-SIGNAL: WHEN A NON-VERBAL AUDIO WHEELS-UP SIGNAL IS USED, IT SHALL HAVE THE FOLLOWING TONE:

FREQUENCY 250 ±50 Hz, FUNDAMENTAL TONE INTERRUPTED AT 5.0 ±1.0 Hz
WITH A 50 ±10 PERCENT ON-OFF CYCLE.

5.2.4 AUDIO ANGLE OF ATTACK/AIRSPEED/STALL WARNING SIGNAL: WHEN A NON-VERBAL AUDIO SIGNAL IS USED FOR PRESENTING ANGLE OF ATTACK/AIRSPEED/STALL WARNING INFORMATION, REFERENCED TO A SELECTED ANGLE OF ATTACK/AIRSPEED/STALL SPEED, IT SHALL BE AS NOTED IN TABLE IV. THE DISCRETE POSITION AT WHICH THE CHOPPED SIGNAL COMMENCES ON EITHER SIDE OF THE "CORRECT" SIGNAL WILL BE READILY ADJUSTABLE.

5.2.5 VERBAL AUDITORY WARNING SIGNALS: VERBAL WARNING SIGNALS SHALL BE AUDIBLE SIGNALS IN VERBAL FORM INDICATING THE EXISTENCE OF A HAZARDOUS OR IMMINENT CATASTROPHIC CONDITION REQUIRING IMMEDIATE ACTION AND SHALL ONLY BE USED TO COMPLEMENT RED WARNING OR OTHER CRITICAL VISUAL SIGNALS. THE VERBAL WARNING SIGNALS SHALL BE PRESENTED AT LEVELS WHICH WILL INSURE OPERATOR RECEPTION UNDER NOISE CONDITIONS IN THE SPECIFIC AIRCRAFT, THERE SHALL BE PROVISION FOR OVERRIDING AND RESETTING THE SIGNALS. THE SIGNAL, WHEN ACTIVATED, SHALL ALWAYS START AT THE BEGINNING OF THE MESSAGE AND SHALL CONTINUE TO BE PRESENTED UNTIL EITHER:

A. THE CAUSATIVE CONDITION IS CORRECTED.

B. A WARNING OF HIGHER PRIORITY IS PRESENTED.

C. THE SIGNAL IS SILENCED BY MANUAL ACTUATION OF THE OVERRIDE SWITCH.

THE STRUCTURE FOR VERBAL WARNINGS SHALL BE:

A. GENERAL HEADING–I.E., THE SYSTEM OR SERVICE INVOLVED

B. SPECIFIC SUBSYSTEM OR LOCATION

C. NATURE OF EMERGENCY

TABLE IV
AUDIO ANGLE OF ATTACK/AIRSPEED/STALL
WARNING SIGNAL

ANGLE OF ATTACK	AIRSPEED	TONE SIGNAL
LOW	FAST	1,600 TONE INTERRUPTED AT A RATE OF 1 TO 10 Hz, THE RATE INCREASING LINEARLY WITH DECREASING ANGLE OF ATTACK/INCREASING AIRSPEED.
SAFE LOW	SAFE FAST	900 Hz STEADY TONE, PLUS 1,600 Hz TONE INTERRUPTED AT A RATE OF ZERO TO 1 Hz, THE RATE INCREASING LINEARLY WITH DECREASING ANGLE OF ATTACK/ INCREASING AIRSPEED.
CORRECT	CORRECT	900 Hz STEADY TONE.
SAFE HIGH	SAFE LOW	900 Hz STEADY TONE, PLUS 400 Hz TONE INTERRUPTED AT A RATE OF ZERO TO 1 Hz, THE RATE INCREASING LINEARLY WITH INCREASING ANGLE OF ATTACK/ DECREASING AIRSPEED.
HIGH	SLOW	400 Hz TONE INTERRUPTED AT A RATE OF 1 Hz TO 10 Hz, THE RATE INCREASING LINEARLY WITH INCREASING ANGLE OF ATTACK/DECREASING AIRSPEED (STALL WARNING).

5.4.1.2 WARNING LIGHTS: WARNING LIGHTS SHALL BE INSTALLED WITHIN THE PILOT'S 30-DEGREE CONE OF VISION. WHEN SPACE IS LIMITED OR THE REQUIRED NUMBER OF WARNING LIGHTS IS EXCESSIVE, WARNING LIGHTS MAY BE GROUPED OUTSIDE OF THE PILOT'S 30-DEGREE CONE OF VISION. IN THESE CASES, A MASTER WARNING LIGHT SHALL BE INSTALLED IN THE PILOT'S 30-DEGREE CONE OF VISION, AND IN ADDITION, A MASTER AUDITORY WARNING SIGNAL MAY BE USED.

5.4.1.3.2 SIDE-BY-SIDE PILOT COCKPITS: CAUTION LIGHTS SHALL BE GROUPED AT THE LOWER PORTION OF THE CENTER INSTRUMENT PANEL BELOW THE INSTRUMENTS OR ON THE CENTER PEDESTAL IMMEDIATELY AFT OF THE POWER QUADRANT. THE LIGHTS SHALL BE VISIBLE TO BOTH PILOTS.

5.4.4.5 SIDE-BY-SIDE PILOT COCKPITS: A MASTER CUATION LIGHT SHALL BE INSTALLED ON THE UPPER PORTION OF THE INSTRUMENT PANEL WITHIN BOTH PILOTS' 30-DEGREE CONE OF VISION. IF THE ABOVE CRITERIA CANNOT BE MET WITH ONE LIGHT ASSEMBLY, THEN TWO MASTER CAUTION LIGHTS SHALL BE INSTALLED.

5.4.4.4.2 ADVISORY LIGHTS: ADVISORY LIGHTS SHALL BE GROUPED CATEGORICALLY OR FUNCTIONALLY WHERE PRACTICAL, OR ASSOCIATED WITH A SPECIFIC UNIT OR COMPONENT, AND SHALL BE SO LOCATED THAT THEY CAN BE OBSERVED FROM THE OPERATOR'S NORMAL POSITION. EXCEPT WHERE SPECIFICALLY AUTHORIZED, ADVISORY LIGHTS SHALL NOT BE LOCATED ON THE MAIN INSTRUMENT PANEL OR SUBPANEL IN THE COCKPIT.

TABLE E-7
SYNOPSIS OF ALERTING SYSTEM REQUIREMENTS IN MIL-STD-1472

5.2.2.1.1 USE: TRANSILLUMINATED INDICATORS SHOULD BE USED TO DISPLAY QUALITATIVE INFORMATION TO THE OPERATOR (PRIMARILY, INFORMATION THAT REQUIRES EITHER AN IMMEDIATE REACTION ON THE PART OF THE OPERATOR, OR THAT HIS ATTENTION BE CALLED TO AN IMPORTANT SYSTEM STATUS). SUCH INDICATORS MAY ALSO BE USED OCCASSIONALLY FOR MAINTENANCE AND ADJUSTMENT FUNCTIONS.

5.2.2.1.5 GROUPING: MASTER CAUTION, MASTER WARNING, MASTER ADVISORY AND SUMMATION LIGHTS USED TO INDICATE THE CONDITION OF AN ENTIRE SUBSYSTEM SHALL BE SET APART FROM THE LIGHTS WHICH SHOW THE STATUS OF THE SUBSYSTEM COMPONENTS, EXCEPT AS REQUIRED UNDER PARAGRAPH 5.2.2.1.8.

5.2.2.1.6 LOCATION: WHEN A TRANSILLUMINATED INDICATOR IS ASSOCIATED WITH A CONTROL, THE INDICATOR LIGHT SHALL BE SO LOCATED AS TO BE IMMEDIATELY AND UNAMBIGUOUSLY ASSOCIATED WITH THE CONTROL AND VISIBLE TO THE OPERATOR DURING CONTROL OPERATION.

5.2.2.1.7 LOCATION, CRITICAL FUNCTIONS: FOR CRITICAL FUNCTIONS, INDICATORS SHALL BE LOCATED WITHIN 15^{o} OF THE OPERATOR'S NORMAL LINE OF SIGHT (SEE FIGURE 2). WARNING LIGHTS SHALL BE AN INTEGRAL PART OF, OR LOCATED ADJACENT TO, THE LEVER, SWITCH, OR OTHER CONTROL DEVICE BY WHICH THE OPERATOR IS TO TAKE ACTION.

5.2.2.1.18 COLOR CODING: WITH THE EXCEPTION OF AIRCREW STATION SIGNALS WHICH SHALL CONFORM TO MIL-STD-411, AND TRAINING EQUIPMENT WHICH SHALL CONFORM TO MIL-T-23991, TRANSILLUMINATED LIGHT EMITTING DIODE (LED) AND INCANDESCENT DISPLAYS SHALL CONFORM TO THE FOLLOWING COLOR CODING SCHEME, IN ACCORDANCE WITH TYPE I–AVIATION COLORS OF MIL-C-25050.

A. RED SHALL BE USED TO ALERT AN OPERATOR THAT THE SYSTEM OR ANY PORTION OF THE SYSTEM IS INOPERATIVE, OR THAT A SUCCESSFUL MISSION IS NOT POSSIBLE UNTIL APPROPRIATE CORRECTIVE OR OVERRIDE ACTION IS TAKEN. EXAMPLES OF INDICATORS WHICH SHOULD BE CODED RED ARE THOSE WHICH DISPLAY SUCH INFORMATION AS "NO-GO", "ERROR", "FAILURE", "MALFUNCTION", ETC.

B. FLASHING RED SHALL BE USED ONLY TO DENOTE EMERGENCY CONDITIONS WHICH REQUIRE OPERATOR ACTION TO BE TAKEN WITHOUT UNDUE DELAY, TO AVERT IMPENDING PERSONNEL INJURY, EQUIPMENT DAMAGE, OR BOTH.

C. YELLOW SHALL BE USED TO ADVISE AN OPERATOR THAT A CONDITION EXISTS WHICH IS MARGINAL. YELLOW SHALL ALSO BE USED TO ALERT THE OPERATOR TO SITUATIONS WHERE CAUTION, RECHECK, OR UNEXPECTED DELAY IS NECESSARY.

D. GREEN SHALL BE USED TO INDICATE THAT THE MONITORED EQUIPMENT IS IN TOLERANCE OR A CONDITION IS SATISFACTORY AND THAT IT IS ALL RIGHT TO PROCEED (E.G., "GO-AHEAD", "IN-TOLERANCE", "READY", "FUNCTION ACTIVATED," "POWER ON", ETC.).

E. WHITE SHALL BE USED TO INDICATE SYSTEM CONDITIONS THAT DO NOT HAVE "RIGHT" OR "WRONG" IMPLICATIONS, SUCH AS ALTERNATIVE FUNCTIONS (E.G., MISSILE NO. 1 SELECTED FOR LAUNCH, ETC.) OR TRANSITORY CONDITIONS (E.G., ACTION OR TEST IN PROGRESS, FUNCTION AVAILABLE), PROVIDED SUCH INDICATION DOES NOT IMPLY SUCCESS OR FAILURE OF OPERATIONS.

F. BLUE MAY BE USED FOR AN ADVISORY LIGHT, BUT PREFERENTIAL USE OF BLUE SHOULD BE AVOIDED.

5.2.2.1.19 FLASHING LIGHTS: THE USE OF FLASHING LIGHTS SHALL BE MINIMIZED. FLASHING LIGHTS MAY BE USED ONLY WHEN IT IS NECESSARY TO CALL THE OPERATOR'S ATTENTION TO SOME CONDITION REQUIRING ACTION. THE FLASH RATE SHALL BE WITHIN 3 TO 5 FLASHES PER SECOND WITH APPROXIMATELY EQUAL AMOUNTS OF ON AND OFF TIME. THE INDICATOR SHALL BE SO DESIGNED THAT, IF IT IS ENERGIZED AND THE FLASHER DEVICE FAILS, THE LIGHT WILL ILLUMINATE AND BURN STEADILY (SEE 5.3.2.4).

TABLE E-7 (CONT)
SYNOPSIS OF ALERTING SYSTEM REQUIREMENTS IN MIL-STD-1472

5.2.6.5 FLAGS:

5.2.6.5.1 APPLICATION: FLAGS SHOULD BE USED TO DISPLAY QUALITATIVE, NON-EMERGENCY CONDITIONS.

5.2.6.5.5 MALFUNCTION INDICATION: WHEN FLAGS ARE USED TO INDICATE THE MALFUNCTION OF A VISUAL DISPLAY, THE MALFUNCTION POSITION OF THE FLAG SHALL AT LEAST PARTIALLY OBSCURE THE OPERATOR'S VIEW OF THE MALFUNCTIONING DISPLAY AND SHALL BE READILY APPARENT TO THE OPERATOR UNDER ALL EXPECTED LEVELS OF ILLUMINATION.

5.2.6.5.6 TEST PROVISION: A CONVENIENT MEANS SHALL BE PROVIDED FOR TESTING THE OPERATION OF FLAGS.

5.3.4.3.6 PROHIBITED TYPES OF SIGNALS; THE FOLLOWING TYPES OF SIGNALS SHALL NOT BE USED AS WARNING DEVICES WHERE POSSIBLE CONFUSION MIGHT EXIST BECAUSE OF THE OPERATIONAL ENVIRONMENT:

A. MODULATED OR INTERRUPTED TONES THAT RESEMBLE NAVIGATION SIGNALS OR CODED RADIO TRANSMISSIONS.

B. STEADY SIGNALS THAT RESEMBLE HISSES, STATIC, OR SPORADIC RADIO SIGNALS.

C. TRAINS OF IMPULSES THAT RESEMBLE ELECTRICAL INTERFERENCE WHETHER REGULARLY OR IRREGULARLY SPACED IN TIME.

D. SIMPLE WARBLES WHICH MAY BE CONFUSED WITH THE TYPE MADE BY TWO CARRIERS WHEN ONE IS BEING SHIFTED IN FREQUENCY (BEAT-FREQUENCY-OSCILLATOR EFFECT).

E. SCRAMBLED SPEECH EFFECTS THAT MAY BE CONFUSED WITH CROSS MODULATION SIGNALS FROM ADJACENT CHANNELS.

F. SIGNALS THAT RESEMBLE RANDOM NOISE, PERIODIC PULSES, STEADY OR FREQUENCY MODULATED SIMPLE TONES, OR ANY OTHER SIGNALS GENERATED BY STANDARD COUNTERMEASURE DEVICES (E.G., "BAGPIPES").

G. SIGNALS SIMILAR TO RANDOM NOISE GENERATED BY AIR CONDITIONING OR ANY OTHER EQUIPMENT.

H. SIGNALS THAT RESEMBLE SOUNDS LIKELY TO OCCUR ACCIDENTLY UNDER OPERATIONAL CONDITIONS.

5.3.5 VERBAL WARNING SIGNALS:

5.3.5.1 NATURE OF SIGNALS: VERBAL WARNING SIGNALS SHALL CONSIST OF:

A. AN INITIAL ALERTING SIGNAL (NONSPEECH) TO ATTRACT ATTENTION AND TO DESIGNATE THE GENERAL PROBLEM.

B. A BRIEF STANDARDIZED SPEECH SIGNAL (VERBAL MESSAGE) WHICH IDENTIFIES THE SPECIFIC CONDITION AND SUGGESTS APPROPRIATE ACTION.

5.3.5.6.1 CRITICAL WARNING SIGNALS: CRITICAL WARNING SIGNALS SHALL BE REPEATED WITH NOT MORE THAN A 3-SECOND PAUSE BETWEEN MESSAGES UNTIL THE CONDITION IS CORRECTED ON OVERRIDDEN BY THE CREW.

5.3.6.2 AUTOMATIC RESET: WHETHER AUDIO WARNING SIGNALS ARE DESIGNED TO BE TERMINATED AUTOMATICALLY, BY MANUAL CONTROL, OR BOTH, AN AUTOMATIC RESET FUNCTION SHALL BE PROVIDED. THE AUTOMATIC RESET FUNCTION SHALL BE CONTROLLED BY THE SENSING MECHANISM WHICH SHALL RECYCLE THE SIGNAL SYSTEM TO A SPECIFIED CONDITION AS A FUNCTION OF TIME OR THE STATE OF THE SIGNALING SYSTEM.

TABLE E-8
SYNOPSIS OF ALERTING SYSTEM REQUIREMENTS IN MIL-C-81774

3.5.7	PANEL MARKINGS SHALL BE WHITE EXCEPT WHEN ILLUMINATED OR WHEN THEY DENOTE EMERGENCY -ACTION CONTROLS.
3.6.2.1	LEGEND ILLUMINATED PUSHBUTTONS SHOULD HAVE A STROKE WIDTH BORDER.
3.6.3	LIGHTED DISPLAYS (INCLUDING ALERTING DEVICES) SHALL HAVE A MINIMUM CONTRAST RATIO OF 3 IN A 10,000 FOOT-CANDLE AMBIENT.
3.9.1 D.	REDUNDANCY IN THE DISPLAY OF INFORMATION TO A SINGLE OPERATOR SHOULD BE AVOIDED UNLESS REDUNDANCY IS REQUIRED TO ACHIEVE A SPECIFIED RELIABILITY.
E.	INFORMATION NECESSARY FOR PERFORMING DIFFERENT ACTIVITIES, SUCH AS OPERATION AND TROUBLE-SHOOTING, SHOULD NOT BE COMBINED IN A SINGLE DISPLAY UNLESS THE ACTIVITIES ARE COMPARABLE FUNCTIONS AND REQUIRE THE SAME INFORMATION.
3.9.2.1.3	AN ADVISORY LIGHT IS AN ILLUMINATED SIGNAL ASSEMBLY WHICH INDICATES SAFE OR NORMAL CONFIGURATION, CONDITION OF PERFORMANCE, OR OPERATION OF ESSENTIAL EQUIPMENT, OR WHICH ATTRACTS ATTENTION AND IMPARTS INFORMATION FOR ROUTINE ACTION PURPOSES. THE USE OF ADVISORY LIGHTS SHOULD BE MINIMIZED. THEY SHOULD NOT BE USED WHERE OTHER METHODS, SUCH AS SWITCH LABELING, MECHANICAL VISUAL SIGNALS, ETC., MAY BE EMPLOYED.
3.11.9	AN ARRAY OF PUSHBUTTONS SERVING AS AN INTEGRATED CONTROL SHOULD BE ARRANGED SUCH THAT, IN A LATERAL ARRAY, LEFT-TO-RIGHT PROGRESSION IS IN THE ORDER OF INCREASING PRIORITY OR SEQUENCE, AND IN A LONGITUDINAL ARRAY, THE FORWARD PROGRESSION INDICATES ORDER OF INCREASING PRIORITY OR SEQUENCE.

APPENDIX F

BACKGROUND DATA FOR FORMULATION OF ALERT PRIORITIZATION RATIONALE

F.0 INTRODUCTION

This appendix presents a historical series of working papers and dissertations used to develop the proposed method of prioritizing alerting functions. The papers are presented in chronological sequence. Each major section in this appendix denotes a historical break point in the commercial aviation industry's development of alerting system standards.

49TH MEETING OF SAE S-7 COMMITTEE
APRIL 1976

STANDARDS AND CRITERIA FOR DESIGN OF AN INTEGRATED WARNING SYSTEM

The lists of warnings that are presented here are oriented more to importance of the warning rather than being broken into the categories of configuration, flight profile, and systems as had been suggested. The reason for this was that it seemed that a system or installation designed to accomplish our objectives would at least address the Level I and part of Level II, as appropriate, depending on cost and complexity. Level III type of items are lower priority and would reduce the checklist significantly but quite likely would be of higher cost and complexity.

In considering an operational installation, one concept might be to use a multiline readout (see Figure 1) with the computer logic as noted under the visual and audio alert columns. By tying the audio alert to takeoff thrust application, or to being airborne, or to descent to a height near the ground most of the nuisance audio alerts can be eliminated. This would mean that the system would be in the "ground mode" or "before takeoff mode" all the time when on the ground – the readout would show items not set for takeoff but the audio would be silent until the throttles are advanced. Similarly, in flight below 2500' the "landing mode" would be energized and the readout would show items not in proper configuration for landing but no audio would sound until descent through 1000' had occurred with the aircraft still not in configuration. This type of logic must be thoroughly thought out and evaluated so please, let us have your ideas!!

If there were more than five or six discrepancies, the remaining ones would appear on the readout device or devices as soon as the previous discrepancies were cleared. Also, there would have to be a provision to cancel the audio in the event of an engine shutdown or loss of a particular system and for other reasons. It may not be desirable to cancel the visual; let it serve as a reminder. Possibly we might need more than five or six lines for discrepancies after we look at all possibilities. The readout device would provide the crew a self-check or confidence check during the pre-start and pre-takeoff phase since its monitoring of the various items would be apparent to the crew.

Level I items would remain as currently implemented, i.e., specially dedicated systems. Level II A consists mostly of the present-day warnings that excite an audio signal. An integrated warning system would offer the most benefit by including the items in this group. Items in Level II B and II C are highly desirable but the associated costs would require individual consideration for each item.

AIRCRAFT OPERATIONS AND SYSTEMS MONITOR

It is recommended that an integrated monitor and warning system be implemented wherein a visual alert or annunciation provision and a single audio alert signal be employed to bring to the flight crew's attention any faults or airplane configuration incompatibilities. The aircraft monitor and warning system should not in any way create confusion on the part of the flight crew, should alert them to a fault or discrepancy in a timely fashion and should result in reduced crew workload.

The aircraft faults and discrepancies can be broken into three levels of importance or urgency:

Level I (Immediate Action)	Tactile Alert	Visual Alert	Audio Alert
1. Engine Fire	None	Cont.	Cont.
2. Stall or Sudden Loss of Lift	Cont.	None	Cont.-Airborne
3. Inadvertent Ground Proximity	None	Cont.	Voice/Cont.

Level II (Flight Safety-Action Required) A.)	Visual Alert	Audio Alert
1. Cabin Altitude-Too Hi (rate & height)	Cont.	Cont.
2. Spoilers-Extended	On Flaps Ext.	* Tg&1000' R.A.
3. T.E. & L.E. Flaps-Improp. Set	On Ground	Tg&1000' R.A.
4. Airspeed-V_{MO}, M_{MO} Exceedance	Cont.	Cont.
5. Altitude Diversion-(Flight Profile)	200' After Cptr.	300' Aft. Cptr.
6. Landing Gear-UP	Landing Flaps	1000' R.A.
7. Stabilizer-Improp. Set	On Ground	Tg
8. Other A/C Config-Unsafe	Ldg.Flaps&/or On Grnd.	Tg&1000' R.A.
9. Flap Placard-Exceeded	Cont.	Cont.
10. Landing Gear Placard-Exceeded	Cont.	Cont.
11. Engine Thrust Setting-Over Limits	Cont.	Cont.
12. Wheel Well Fire	Cont.	Cont.
13. APU Fire	Cont.	Cont.
14. Radio Altimeter	Cont.	Cont.

Level II B.)	Visual Alert	Audio Alert (Optional)
1. Hydraulic Press. & Quant-Low	Cont.	Cont. After Tg
2. Engine Oil Press. & Quant-Low	Cont.	Cont. After Tg
3. Essential Elect. Pwr-Fail	Cont.	Cont. After Tg
*4. Auto-Pilot & Autothrottle-Disconnect	*Cont.	*Cont.
5. Instr. Comparator Sys-Alert	Cont.	Cont.
6. Gyro & Compass Flags-Visible	Cont.	Cont.
7. Cabin & Exterior Doors-Not Closed	Cont.	Cont. After Tg
8. Pitot Heat-Off	Cont.	Cont. After Tg
9. Window Heat-Off	Cont.	Cont. After Tg
10. Anti-Skid-Off	Cont.	Cont. After Tg
11. Engine Fuel Switch-Off	Cont.	Cont. After Tg
12. CADC-Failed	Cont.	Cont.
13. Nav System-Failed	Cont.	Cont.

Level II C.)	Visual Alert	Audio Alert
1. Emergency Flap Switch-Not Off	On Ground	None
2. Rudder & Spoiler Switch-Not On	On Ground	None
3. INS-Not Nav	On Ground	None

4.	Yaw Damper-Not On	On Ground	None
5.	Rudder & Aileron Trim-Not Zero	On Ground	None
6.	Battery-Not On	On Ground	None
7.	Compass Cont-Not Mag	Cont.	None
8.	Instr. Transfer Switch-Not Norm	On Ground	None

Level III (All other items that have less effect on basic safety of flight, i.e., additional checklist items)

		Visual Alert	Audio Alert
1.	Emerg. Exit Lights-Not Armed	Cont.	None
2.	Pneumatic Brake Press-Below 1200 psi	Cont.	None
3.	Static Source-Not Norm	Cont.	None
4.	Start Levers-Not as Req'd	Cont.	None
5.	Gear Pins-Not Pulled	Cont.	None
6.	Air Cond-Not as Req'd	Cont.	None
7.	Galley Power-Not as Req'd	Cont.	None
8.	Beacon-Not On	Cont.	None
9.	Parking Brakes-Not as Req'd	Cont.	None
10.	Eng. Fuel Heat-Not Off	Cont.	None
11.	No Smoking & Seat Belts-Not as Req'd.	Cont.	None
12.	Anti-ice, Engine-Not Off	Cont.	None
13.	Smoke Detector System-Not On	Cont.	None
14.	Ground Start Switches-Not Off	Cont.	None
15.	Elect. System-Not Norm (No Lights)	Cont.	None

*II B.)4. Two pushes on Disconnect button cancels warning
*Tg = Application of T.O. Thrust on Ground
*1000' R.A. = 1000 Ft. Radio Altitude on Approach
Cont. = Continuous Monitor
A/B = Airborne

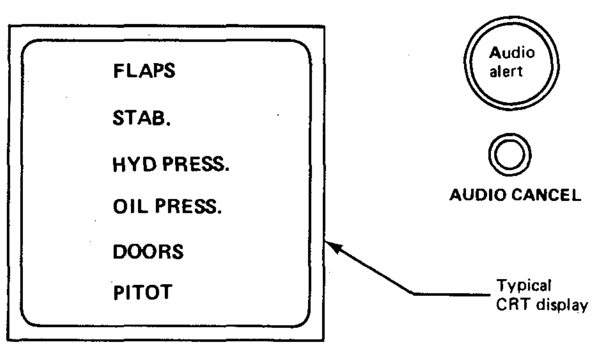


Figure 1. Sample Readout During Engine Start

CAUTION WARNING SYSTEM

PRIORITY		REQUIREMENTS		STIMULI			
		CREW RECOGNITION TIME	CREW ACTION TIME	AURAL/ TACTILE	LIGHT/ ANNUNCIATORS	TYPE OF FAULTS	REMARKS
WARNING	I	IMMEDIATE RECOGNITION REQUIRED	IMMEDIATE ACTION REQUIRED	DISTINCTIVE AURAL/TACTILE	ANNUNCIATOR AND RED MASTER LIGHT	SUDDEN LIFT LOSS GRO PROX ENGINE FIRE	SHOULD CONSIDER AUTOMATIC ACTION AND/OR LOWER PRIORITY WARNING BEFORE CONDITION IS CRITICAL. (ENGINE OVERHEAT, ETC.)
WARNING	II	IMMEDIATE RECOGNITION REQUIRED	ACTION REQUIRED SOON	AURAL (HORN)	ANNUNCIATOR AND RED LIGHT	CABIN ALT UNSAFE CONF AIRSPEED WARN ALTITUDE APU/WW FIRE ENGINE RED LINE	
CAUTION	III	RECOGNITION REQUIRED	ACTION REQUIRED WITHIN 10 MINUTES	NO AURAL	CAUTION ANNUNCIATOR AND MASTER AMBER LIGHT	PRIMARY INSTR/ SENSOR FAILURE MAJOR SYSTEM FAILURE ITEMS REQUIRING ALTERNATE CREW PROCEDURES	INHIBIT MASTER FOR T/O ROLL TO ___ FEET AND FINAL APPROACH EXCEPT FOR RECALL ON BEFORE TO AND LANDING
CAUTION	IV	RECOGNITION DESIRED	NO ACTION REQUIRED	NO AURAL	ANNUNCIATOR	SYSTEM STATUS CHANGES THAT HAVE NO EFFECT ON FLIGHT, BUT WHICH ADDITIONAL FAILURE WOULD ALTER FLIGHT OR REQUIRE ACTION	
ADVISORY	V	RECOGNITION ONLY WHEN CHECKING SYSTEM	NO ACTION	NO AURAL	NO MASTER LIGHT OR ANNUNCIATION	MINOR SYSTEM FAILURE OR CHANGES THAT ARE NOT IN I, II, III, OR IV	

VIEWPOINTS ON DESIGN OF WARNING/CAUTION SYSTEMS

1. GENERAL

In today's aircraft aural and visual warnings/cautions have proliferated to an extent that makes it difficult for the pilot to distinguish between them. It is, therefore, desirable to centralize the warnings and more carefully scrutinize the need for individual warnings and, where needed, make them more explicit.

In order to minimize nuisance warnings, the warning systems should be provided with logic that inhibits the warning in case of a technical failure in the system or the stage of flight is such that a warning is irrelevant or distracting, for example a fire warning at lift-off or at low altitude during an approach.

2. AURAL WARNINGS

Warnings that require immediate recognition and actions shall be aural, each using a specific sound supplemented by a visual display and preferably also by voice.

If the number of aural warnings, including tactile warnings, exceeds 7 they must be supplemented by voice.

Other warnings and cautions should be announced by a common sound supplemented by voice and/or a visual display.

Aural warnings shall be loud enough to be heard under all flight conditions but low enough not to interfere with cockpit communication.

3. VISUAL WARNINGS

Warnings and cautions should be presented on an alphanumeric display in front of each pilot.

The display should be capable of displaying at least 3 warnings simultaneously.

The light intensity of the alphanumeric display should be manually adjustable with automatic compensation for changes in cockpit light level.

Individual lights should be connected to a central dimming circuit.

Failures in redundant systems should not be announced as warnings or cautions when no pilot action is required. Such failures should be shown on a system status display.

Whenever possible, controls that must be actuated in case of a warning should be illuminated or indicated by some other means.

It should be possible to clear the display by a push-button, but the warning should be stored in a memory as long as it persists and be redisplayed in case of a new warning.

It should be possible to recall warnings from the memory with a recall button. A test button for confidence check should be provided.

Since it is doubtful that all individual warning and caution lights can be eliminated the remaining ones should have dual light bulbs separated by a light barrier and if peripherally located they should be flashing.

Instrument failure warnings should be designed in such a way that the affected display is removed or, if this is not possible, obscured by a warning flag. Even if the display is removed a warning flag shall be displayed.

4. SHORT TERM ACTION ITEMS

1. Make up a proposal for a centralized visual/aural integrated warning system.
2. Enumerate warnings and cautions that need to be fed to the Central Warning system.
3. Define inhibit logics that are necessary to minimize nuisance warnings.

5. STUDY ITEMS

Simulator studies should be made to determine if there is any benefit to be gained from the following refinements.

1. Display of the checklist valid, for the warning condition, on a malfunction display.
2. Automatic execution of this checklist after pilot's initiation.
3. Schematic display of failed system with indication of failed and usable portion of system.

F.2 CRITERIA FOR ALERTING FUNCTION CATEGORIES DEVELOPED BY THE BOEING COMPANY EARLY IN THIS STUDY

Table F-1 Criteria for Caution and Warning Categories

CATEGORY*	CATEGORY CRITERIA: CRITERIA RECOMMENDED BY BOEING ENGINEERS	CATEGORY CRITERIA: CRITERIA RECOMMENDED BY BOEING PILOTS
1	Hazardous flight conditions or aircraft systems conditions which require immediate corrective or compensatory action by the crew	Hazardous flight conditions or aircraft systems conditions which require immediate corrective or compensatory action by the crew
2	Hazardous flight conditions or aircraft systems conditions which require (1) if the aircraft is stable, immediate corrective or compensatory crew action, or (2) if the aircraft is not stable, corrective or compensatory crew action as soon as the aircraft can be stabilized	Potentially hazardous flight conditions or aircraft systems conditions which require immediate corrective or compensatory crew action if the flight is to proceed further
3	Hazardous flight conditions or aircraft systems conditions which require near term corrective or compensatory crew action. "Near term" indicates that action should be taken during the next low workload period	System failures that require operation with degraded capability could affect the planned flight
4	Potentially hazardous flight conditions or aircraft systems conditions which require crew awareness of the condition and no near term corrective or compensatory crew action. However, these conditions may require modification of the planned or usual aircraft operating conditions during the remainder of the flight so as to avoid getting into a hazardous situation	Checklist items that should be accomplished for safe operation. This category is for "crew failure to accomplish" items
5	Non-hazardous flight conditions or transitory aircraft systems conditions which require crew awareness, but no crew action, near term or long term	Non-hazardous flight conditions or transitory aircraft systems conditions which require crew awareness, but no crew action, near term or long term

*These categories represent broad groups of alerts having approximately equal levels of importance/priority. Category 1 alerts have highest priority and Category 5 alerts have lowest priority. Higher priority alerts may interrupt lower priority alerts at any time.

The alerts falling within each category will vary from one aircraft to another. The alert priorities within each category (if required) and the application of alert inhibits during certain phases of flight will also vary from one aircraft to another. Specific criteria for defining these priorities and inhibit philosophies need to be developed.

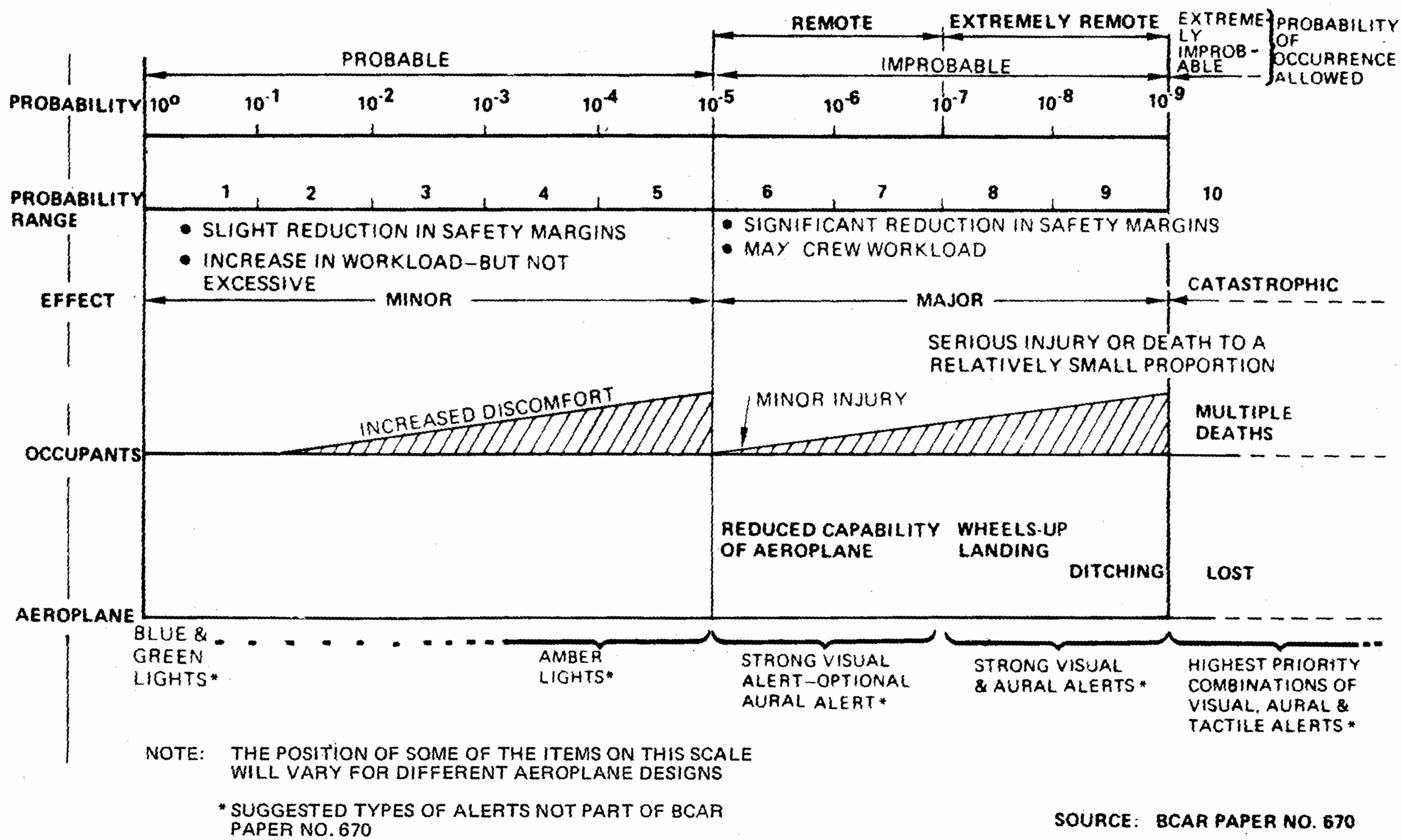


Figure F-1 Relationship Between Probability and Severity of Effects

$$P\left\{\left(\text{FAILURE}\right) + \left(\begin{array}{l}\text{FAILURE RESULTING}\\ \text{IN INJURIES IF NOT}\\ \text{CORRECTED OR COMPEN-}\\ \text{SATED FOR WITHIN}\\ \text{\_\_\_\_\_ SECONDS}\end{array}\right) + \left(\begin{array}{l}\text{FAILURE RESULTING}\\ \text{IN INJURIES DURING}\\ \text{A LATER PART OF THE}\\ \text{FLIGHT IF NOT COM-}\\ \text{PENSATED FOR OR}\\ \text{CORRECTED}\end{array}\right) + \left(\begin{array}{l}\text{CREW NOT}\\ \text{DETECTING}\\ \text{ALERT WITHIN}\\ \text{\_\_\_\_\_ SECONDS}\end{array}\right)\right.$$

$$\left. + \left(\begin{array}{l}\text{CREW NOT}\\ \text{RESPONDING}\\ \text{TO SITUATION}\\ \text{CORRECTLY}\\ \text{WITHIN}\\ \text{\_\_\_\_\_ SECONDS}\end{array}\right) + \left(\begin{array}{l}\text{CREW NOT}\\ \text{RECALLING}\\ \text{EARLIER}\\ \text{FAILURES}\\ \text{THAT HAVE}\\ \text{A MAJOR}\\ \text{EFFECT ON}\\ \text{CURRENT}\\ \text{OPERATIONS}\end{array}\right)\right\} < P\left\{\begin{array}{l}\text{MAJOR}\\ \text{EVENT}\\ \text{CAUSING}\\ \text{INJURY}\end{array}\right\}$$

Figure F-2 Potential Method for Prioritizing Alerting Functions

F.4 ALTERNATE SET OF ALERTING FUNCTION CATEGORY CRITERIA DEVELOPED AT THE BOEING COMPANY

Table F-2 Caution and Warning System Concept

AIRPLANE CONDITION CRITERIA	CATEGORY	CREW RECOGNITION/ RESPONSE TIME	EXAMPLES OF CONDITIONS OR EVENTS
INTRINSICALLY HAZARDOUS	1	MINIMUM CREW REACTION TIME. WITHOUT HESITATION OR LOSS OF TIME. "IMMEDIATE"	• STALL WARN • GROUND PROX • EMER CABIN ALT RATE/LEVEL
EXTRINSICALLY HAZARDOUS. THOSE WHICH IN THEMSELVES ARE NOT HAZARDOUS, BUT ARE KNOWN THROUGH EXPERIENCE TO BE CONDITIONALLY HAZARDOUS.	2	DEFERRED POSITIVE (PREDETERMINED COURSE OF ACTION)	• EXCEED V_{MO}/M_{MO} • ENGINE FIRE • ENGINE OIL PRESS./QTY LOW
	3	DEFERRED CONDITIONAL (COURSE OF ACTION CONTINGENT UPON OTHER CONDITIONS)	• PROBE HEAT INOP • WINDOW HEAT FAIL • HYD PRESS/QTY • GEN DISCONNECT • A/T DISC
HAZARDOUS UNDER NO CONDITIONS. SUPER-NUMERARY BY NATURE.	4	ACTION REQUIRED AT NO TIME	• FLIGHT RECORDER INOP • SELCAL • STEW CALL

*DEVELOPED BY J. OHLSON, THE BOEING COMPANY, 1976

F.5 PAPERS FROM THE 50TH MEETING OF THE SAE S-7 COMMITTEE, SEPTEMBER 1976

WORKING PAPER
AN INTEGRATED AIRCRAFT WARNING SYSTEM
FOR
SAE COMMITTEE S-7

I THE DELIVERY SYSTEM AND ITS PHILOSOPHY

A. As a first step toward evolving a delivery system, it was necessary to enumerate the faults of present systems.

1. Present warning systems have "grown like Topsy" with more added, it seems, each time there is an accident. The result has been a proliferation of discrete aural warnings to the extent that there can be confusion as to the meaning of a specific aural warning. The crew must first determine which of several potential problems is triggering the aural warning being heard before taking action.

2. The level of urgency in terms of flight conditions is not presently annunciated. The crew must evaluate this level to determine the requirements for immediacy of action and division of attention between the problem and conduct of the flight.

3. Too many warnings occur during normal operational conditions. Any warning that is heard repeatedly when no action is really required will be psychologically "blocked out", including any recollection of inhibiting the warning. Even if the warning "gets through", the crew must still determine if it is a real or a nuisance warning before taking action. There are several reasons for the occurrence of warnings in normal conditions:

   a. Faulty design logic
   b. Poorly considered regulatory requirements
   c. Lack of reliability resulting in nuisance warnings

4. Noise levels of existing audio warnings may be so high and so annoying as to degrade the human response capability. This is often due to a regulatory requirement for a minimum decibel limit to "get attention", which, in turn, is related to several of the problems listed above. As a spinoff of this specific problem, an inhibit capability is often required to remove the raucous audio before intelligent action can be taken.

B. In seeking solutions to existing faults in warning system philosophy, the working group was able to construct a model of a desirable system.

1. To replace the multitude of aural warnings, a single unique tone should be utilized for all problems requiring aural alert. This tone should be complemented by a visual display, and oral annunciation, declaring the nature and location of the problem.

2. The level of urgency should be annunciated by repeating the tone one, two or three times, or by otherwise modifying the tone while retaining its unique nature. Urgency level should also be annunciated by color coding of the message on the visual display.

3. Design logic, very high reliability, and regulatory changes must be created to eliminate the problem of unnecessary and nuisance warnings.

4. The tone, being unique and meaningful can be soft and non-irritating. It is believed that its very uniquesness and dedication will allow it to "cut through" ambient noise because crews will be attuned to its sound, much as the sound of an engine room telegraph will raise a ship captain from the deepest sleep. Having heard one tone the crew will be immediately attentive to see if a second will occur and, that happening, will be doubly attentive for a third. We do not wish to see a button required to inhibit the tone and voice warning. Since they are compelling enough to get attention and specific enough to spell out the problem, they should be non-repetitive. Any requirements for recall can be provided for by the visual display.

5. Several cases came up where our design philosophy was at odds with present regulation. In order to achieve the optimum logic, the group elected to proceed as though there were no regulatory constraints. This may soon have to be resolved.

6. It was argued that some may wish to retain existing discrete audio warnings on the grounds that they have withstood the test of time. (The fire bell is an example.) Though wishing to discourage such a prospect, we decided to include an option for a limited number of discrete aural warnings with the admonition that these should be kept to a minimum and used only for the highest urgency level.

II LEVELS OF URGENCY (See Table One)

A. After lengthy discussion it was concluded that four, rather than three levels of urgency would be needed. This concept made it difficult to accommodate the levels with the desired tone repetitions of one, two and three times. An acceptable solution was reached by creating a fourth level, zero, to be the lowest level of urgency. Thus, level zero would have no aural tone, no visual display and no voice annunciation. Warning would be provided by lights much as they exist today.

1. Level III would be described as *emergency, urgent* or *serious.* Action required would be *immediate*. Warning would be provided by three aural tones, a visual display and voice annunciation of the problem.

2. Level II would be described as *caution* or *abnormal.* Action required would be *prompt*. Warning would be provided by two aural tones and a visual display, with voice annunciation recommended.

3. Level I would be described as *irregular*. Action would be required but may be deferred. Warning would be provided by one aural tone and a visual display, with voice annunciation optional.

4. Level Zero would be described as *advisory*. Later action may or may not be required. Warning would be provided by visual means, such as a light or flag.

B. The various warnings are categorized by urgency level in tables two through five. Some points of discussion follow:

1. Decision height, selcal, and cabin call alerts present a special problem. By nature they are of the lowest priority level, but placing these in level Zero would deprive them of aural alerting. If they are placed in level I, then the aural tone would be applied, but we would be violating our philosophy of having no warnings for normal conditions. To create a discrete aural sound for these conditions is one solution, but would add an extra audio. This needs further discussion.

2. The ground proximity/high sink warning has been included in the three higher levels to account for different flight conditions. This was not unanimous and the logic for this problem needs further exploration.

3. We have assigned low urgency level (level I) to a CADC failure, although such a failure has far reaching significance. The rationale for this is that several other failure warnings would be displayed simultaneously in case of a CADC failure. Some of these, such as autopilot disconnect, have a higher urgency level.

4. The warnings for landing gear door open and gear not properly stowed we assigned to level Zero, so that lights presently used would be applicable to these problems.

5. On the engine over limit warning for level II, we believe the annunciation should be simply "engine number 2 over limit". The crew then could refer to their engine instruments to determine which parameter is over limit.

6. On the instrument comparator warning for level I, we believe we should have the soft aural tone and the visual display would annunciate the parameter that is out of order, such as compass, altitude indicator, etc.

III INHIBIT AND OTHER LOGIC

A. In some cases we were able to apply logic to the conditions. In many other cases, the considerations were so complex that time did not permit our completing this task. Where we assigned logic it appears in the tables under "remarks". Much work remains to be done in this area.

B. One theory that was agreed to is that, during critical flight phases, such as takeoff and landing, selective inhibits should be applied as the aircraft approaches the most critical point until at that point perhaps no warning would be given. Then the inhibits may be selectively removed as the aircraft progresses toward a less critical condition so that all warnings would be active at some later point.

IV PRIORITIES

Time permitted assigning priorities only to level III. (Illustrated by A, B, and C on table two.) A great deal of work remains to be done on this task.

V OTHER UNRESOLVED ISSUES

A. Consideration must be given to the effects of radio altimeter failure, both on dispatch and warning capability. Much logic will probably be based on radio altitude.

B. Autopilot malfunctions and their effects need further expansion.

C. There is a need to find the optimum aural tone for crew alert. Tape samples should be constructed.

D. Some philosophy must be added on dimming, cancellation and recall of the visual display. (Sture Bostrom has done some work on this.)

E. The precise means of color-coding the visual display must be developed.

F. This working paper must be hardened and worked into format of ARP 1068.

TABLE ONE

General System Concepts

1. Aural attention getter
   –prefer unique tone for all problems
   –should define level of urgency by 2 or 3 repetitions or by slightly modifying tone
   –should not be annoyingly loud
   –should not require silencing (NON repetitive)

2. Discrete sounds may be used on a selective basis
   –should be limited in number
   –suggest for most urgent level only

3. Checklist Requirements not incorporated (?)

4. Should have priority system which includes phase of flight

5. The visual display should employ color-coding to indicate the urgency level of the warning being annunciation.

6. Consideration should be given to inhibiting certain warnings during critical phases of flight, such as takeoff, low approach, etc.

7. In some cases the priority system should inhibit secondary mode warnings.

Levels of Urgency

III	Emergency Urgent Serious		Immediate Action Required	
	(1) Aural	AG*	(2) Visual	(3) Voice Annunciation Recommended
II	Caution Abnormal		Prompt Action Required	
	(1) Aural	AG	(2) Visual	(3) Voice Annunciation Optional
I	Irregular		Action Required	
	(1) Aural	AG	(2) Visual	
0	Advisory		May Require Action Later	
	(1) Visual	AG#		

*Very limited number of discrete aural warnings is optional
#such as light or flag
AG = attention getter

TABLE TWO

LEVEL III

Typical Problem	Remarks
(A) III Stall ———	Inhibited on ground
(B) III Ground Prox/hi sink	–
(C) III A/P - inadvertent disconnect	(non red syst. & below 500 R/A)

TABLE THREE

LEVEL II

Typical Problem	Remarks
Engine fire	Phase of flight
Engine Failure (catastrophic)	Phase of flight
Degraded takeoff performance	Possible future
Overrotation (rate or angle)	Takeoff
Excessive wind shear	Possible future below 1000' RA, TO or APP
High Cabin alt.	10,000 ft.
A/P - Inadvertent disconnect	Non-redundant syst. above 500' RA
A/T - Inadvertent disconnect	
Takeoff Warning (spoilers, hi lift dev., brakes stab.)	Early speed warning (60 KGS)
Ground prox/high sink	Logic to be determined
Dev. from Ass. Alt. Mmo, Vmo, Tmo	Regulatory considerations
Cargo compt. Fire/smoke	only where cockpit action is possible
A.P.U. fire Galley fire/smoke Wheel well fire	only where cockpit action is possible
Engine over limit	Appropriate parameters for eng. first limit
Hydraulic press./quant.	single syst. remaining
Flt. inst. power failure	Where manual switching req.
Gear unsafe for landing	Logic to be determined.

TABLE FOUR

LEVEL I

Excessive rate of change of cabin press.

Instrument warning

Prognosis of wind shear potential

Lavatory fire/smoke

Hydraulic press./quan. Multiple systems remaining

Engine oil press./quan.

Flight inst. power failure where syst. restoration is automatic

Inst. comparator alert

CADC failure

Inadvertent stabilizer in motion

Ground prox./high sink

TABLE FIVE

LEVEL 0

A/P in reversion (i.e., Turb Mode, etc.)

Navigation system fail (recommend to sys. designers that if a guidance input has failed that the appropriate command bar, etc., be removed from view ARP 1068)

Antiskid off/fail (if this item were on Level I could eliminate from the approach checklist)

Radio altimeter failure

Gyro or compass flag visible

Exterior doors not closed

Yaw damper fail

Instrument transfer switch not normal

Landing gear door open

Gear not properly stowed

Autopilot stabilizer out of trim

Capt. B. Schmitt September 15th, 1976

WORKING PAPER

AN INTEGRATED AIRCRAFT WARNING SYSTEM

SAE - COMMITTEE S-7

Comments on the above Working Paper

I THE DELIVERY SYSTEM AND ITS PHILOSOPHY

A.

Item 2: I am of the opinion that using the MASTER WARNING/MASTER CAUTION system, as installed in most of the present day aircraft, the level of urgency is annunciated - maybe not optimal but at least usable. As a consequence, two different kinds of checklists exist, namely the EMERGENCY CHECKLIST and the MALFUNCTION OR ABNORMAL CHECLIST.

Item 3: I fully agree; too high a noise level can even lead to a wrong decision.

B.

Item 1/2: I fully support the statement that too many aural warnings are used today.

Instead of repeating the tone once, twice or three times, I suggest that we look into the aural warning as used on the French Caravelle, e.g., I could think of using one tone for Level II, but a GING/GONG type tone for Level III, etc. I am pretty sure that this would be more suggestive than always repeating the same tone.

Item 3-5: No comment.

Item 6: During evaluation of the present warnings it also occurred to me that a discrete audio warning is in certain cases a must, e.g.,

- DH aural warning
- SELCAL
- CABIN to COCKPIT, etc.

Since these tones are routinely heard, the meaning is well understood.

II LEVELS OF URGENCY

A.

Item 1-4: I generally agree, but I suggest that the present philosophy of having a lot of recall or memory items should be reviewed. The only memory item we have retained at SWISSAIR is the EMERGENCY DESCENT. All other items may only be performed using the EMERGENCY Checklist except for the 2-man cockpit. Only this guarantees that the right action is performed in the correct sequence.

It may be worthwhile to convince the FAA to review their philosophy.

B.

Item 1: Based on my experience, I think that it will be very difficult to delete the aural warning for DH, especially with regard to CAT II/CAT III A operation, where the DH is a very important element for decision making. Also Selcal as well as the Cabin to Cockpit call - even routine - calls for a discrete aural signal unless somebody has a really good solution.

Item 2: GPWS. If a warning occurs, this at least calls for investigation. Therefore, it might not be necessary to put logic in, in order to identify phase of flight. Of course this can differ from company to company and may also depend on whether the warning "TERRAIN" or the order "PULL-UP" has been selected.

Item 3: No comments.

Item 4: Agreed.

Item 5: The present used "over-limit" light in the respective engine instrument has been proved to be a good idea. So I think it could be deleted from the warning system.

Item 6: Needs further discussion.

III INHIBIT AND OTHER LOGIC

A. + B. Agree.

IV PRIORITIES

See comments on Tables.

V OTHER UNRESOLVED ISSUES

A. Agreed; fortunately the newest brand of radio altimeters has a very high reliability and/or MTBF.

B. - E. Agree.

TABLE ONE

No comments at present.

TABLE TWO LEVEL III

(A) Stall: Aural warning is just enough. I don't think that voice warning and visual display are necessary.

The stall warnings today were mostly a result of improper crew procedure, e.g., flaps/slats retraction at wrong speed, erroneous approach speed, wrong configuration, etc., etc.

I suggest that the industry be invited to study a design which tackles the problem at its root, e.g., speed command system with floor speed for approach and take-off with full time redundant autothrottles as a standard equipment. Inhibit logic to avoid flaps/slats retraction at too slow speeds, etc.

I think that a lot of warnings could be eliminated if the system were to be properly designed.

(B) No comment.

(C) A/P - inadvertent disconnect (non red. system & below R/A)

During this phase of the flight the crew is much more alert than in cruise. Do we really need 3 tones/voice/visual display at this very critical point? If the answer is No, then we are back to a discrete autopilot disconnect signal - aural or visual!

TABLE THREE LEVEL II

–Over-rotation is another example where a speed command system for take-off may help. No warning but proper design!

–Otherwise no comments yet.

TABLE FOUR LEVEL I

No comments.

TABLE FIVE LEVEL 0

No comments.

APPENDIX G

APPLICATION OF ALERT PRIORITIZATION SCHEME TO A 737 AIRCRAFT

This appendix provides a tabulation of the priority levels that each alerting function on a 737 aircraft might be assigned by the proposed prioritization criteria. The alert levels specified for each flight phase correlate with the categories defined in table 14. A dash in these columns indicates that the alert is (1) not required in that flight phase or (2) should be inhibited in that flight phase.

737

ALERTING FUNCTION	CURRENTLY USED TYPE OF ALERT	ALERT LEVEL AS FUNCTION OF FLIGHT PHASE											
		GRD MAINT	PRE-FLT	ENG ST	TAXI	INITIAL T.O. ROLL	FINAL T.O. ROLL	INITIAL CLIMB	1500 TO 14,000 FT	ABOVE 14,000 FT	APPR 1500 TO 200 FT	LDG	TAXI AND SHUT-DOWN
AIR CONDITIONING													
AIR CONDITIONING SYSTEM MALFUNCTION	1 AMBER LIGHT	3	3	3	3	–	–	–	3	3	3	–	3
NO AIRFLOW IN COCKPIT OR EQUIPMENT COOLING COMPARTMENT	1 AMBER LIGHT	3	3	3	3	–	–	–	3	3	3	–	3
EXCESSIVE DIFFEREN-TIAL PRESSURE	1 YELLOW/RED BAND	2	2	–	–	–	–	–	2	2	–	–	–
DUCT OVERHEAT	2 AMBER LIGHTS	2	2	2	2	3	–	–	2	2	3	–	3
OFF SCHEDULE DESCENT	1 AMBER LIGHT	2	3	–	–	–	–	–	3	3	–	–	–
OUTFLOW VALVES POSITION	1 BLUE LIGHT	4	4	4	4	–	–	–	4	4	4	–	4
PACK OVERHEAT/ TRIP OFF	2 AMBER LIGHTS	3	3	3	3	3	–	–	3	3	3	–	3
PRESSURIZATION FAILURE	1 AMBER LIGHT AND HORN	2	2	–	–	–	–	–	2	1	–	–	–
PRESSURIZATION SYSTEM OPERATING MODE	2 GREEN LIGHTS	4	4	–	–	–	–	–	4	4	4	–	–
RAM AIR DOOR OPEN	2 BLUE LIGHTS	4	4	4	4	–	–	–	4	4	4	–	4

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ALERTING FUNCTION	CURRENTLY USED TYPE OF ALERT	ALERT LEVEL AS FUNCTION OF FLIGHT PHASE											
		GRD. MAINT	PRE-FLT	ENG ST.	TAXI	INITIAL T.O. ROLL	FINAL T.O. ROLL	INITIAL CLIMB	1500 TO 14,000 FT	ABOVE 14,000 FT	APPR. 1500 TO 200 FT	LDG.	TAXI & SHUT-DOWN
AIRCRAFT GENERAL													
MASTER CAUTION	2 AMBER LIGHTS	2	2	2	2	2	–	–	2	2	2	–	2
ALTITUDE ALERT													
APPROACHING ALTITUDE	1 BLUE LIGHT & TONE	3	3	–	–	–	–	–	3	3	–	–	–
ALTITUDE ALERT FAILURE	1 RED FLAG	3	3	–	–	–	–	–	3	3	–	–	–
APU													
APU LOW OIL PRESS/ AUTO SHUTDOWN	1 AMBER LIGHT	3	3	3	3	3	–	–	2	2	2	–	3
APU OIL QUANTITY LOW	1 BLUE LIGHT	3	3	3	3	–	–	–	3	3	3	–	3
APU EGT OVERTEMP	1 GREEN/YELLOW/ RED BAND	3	3	3	3	–	–	–	3	3	3	–	3
APU OIL TEMP HI	1 AMBER LIGHT	3	3	3	3	–	–	–	3	3	3	–	3
APU FAILURE	1 AMBER LIGHT	3	3	3	3	–	–	–	3	3	3	–	3
APU OVERSPEED	1 AMBER LIGHT	3	3	3	3	–	–	–	3	3	3	–	3

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ALERTING FUNCTION	CURRENTLY USED TYPE OF ALERT	ALERT LEVEL AS FUNCTION OF FLIGHT PHASE											
		GRD MAINT	PRE-FLT	ENG ST	TAXI	INITIAL T.O. ROLL	FINAL T.O. ROLL	INITIAL CLIMB	1500 TO 14,000 FT	ABOVE 14,000 FT	APPR 1500 TO 200 FT	LDG	TAXI AND SHUT-DOWN
AUTOMATIC FLIGHT CONTROL SYSTEM													
AUTOPILOT DISCONNECT	2 FLASHING RED LIGHTS	2	2	–	–	–	–	–	2	2	2	1	–
AUTOTHROTTLE DISCONNECT	2 RED LIGHTS (INOP)	2	2	–	–	–	–	–	2	2	2	1	–
FLIGHT DIRECTOR VOR/LOC CAPTURE MODE ARMED	2 AMBER LIGHTS	4	4	–	–	–	–	–	4	4	4	–	–
FLIGHT DIRECTOR–VOR COURSE/LOC CAPTURED	2 GREEN LIGHTS	4	4	–	–	–	–	–	4	4	4	4	–
FLIGHT DIRECTOR GLIDE SCOPE CAPTURE MODE ARMED	2 AMBER LIGHTS	4	4	–	–	–	–	–	4	–	4	–	–
FLIGHT DIRECTOR–GLIDE SLOPE CAPTURED	2 GREEN LIGHTS	4	4	–	–	–	–	–	4	–	4	–	–
AUTOPILOT VOR/LOC CAPTURE MODE ARMED	2 AMBER LIGHTS	4	4	–	–	–	–	–	4	4	4	–	–
AUTOPILOT VOR COURSE/LOC CAPTURED	2 GREEN LIGHTS	4	4	–	–	–	–	–	4	4	4	4	–
AUTOPILOT GLIDE SLOPE CAPTURE MODE ARMED	2 AMBER LIGHTS	4	4	–	–	–	–	–	4	–	4	–	–
AUTOPILOT–GLIDE SLOPE CAPTURED	2 GREEN LIGHTS	4	4	–	–	–	–	–	4	–	4	–	–
GO-AROUND MODE ENGAGED	2 GREEN LIGHTS	4	4	–	–	–	–	4	–	–	4	4	–

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ALERTING FUNCTION	CURRENTLY USED TYPE OF ALERT	ALERT LEVEL AS FUNCTION OF FLIGHT PHASE											
		GRD MAINT	PRE-FLT	ENG ST	TAXI	INITIAL T.O. ROLL	FINAL T.O. ROLL	INITIAL CLIMB	1500 TO 14,000 FT	ABOVE 14,000 FT	APPR 1500 TO 200 FT	LDG	TAXI AND SHUT-DOWN
COMMUNICATIONS													
MICROPHONE/TRANS-MITTER COMBINATION SELECTED	15 GREEN LIGHTS	4	4	4	4	4	4	4	4	4	4	4	4
VHF COMM CHANNEL SELECTED BY TRANSFER SWITCH	6 GREEN LIGHTS	4	4	4	4	4	4	4	4	4	4	4	4
SELCAL ACTIVATED	2 GREEN LIGHTS AND CHIME	3	3	3	3	3	3	3	3	3	3	3	3
ATTENDANT CALL	1 BLUE LIGHT AND CHIME	3	3	3	3	–	–	–	3	3	3	–	3
ELECTRICAL SYSTEMS													
EXTERNAL POWER AVAILABLE	1 BLUE LIGHT	4	4	4	–	–	–	–	–	–	–	–	4
CSD OR IDG OIL TEMP HIGH	2 AMBER LIGHTS AND 4 YELLOW BANDS	2	2	2	2	–	–	–	2	2	2	–	2
CSD OR IDG OIL PRESSURE LOW	2 AMBER LIGHTS	2	2	2	2	–	–	–	2	2	2	–	2
GENERATOR BREAKER OR RELAY TRIPPED OPEN	2 BLUE LIGHTS	3	3	3	3	–	–	–	3	3	3	–	3
AC STANDBY BUS FAILED OR OFF	1 AMBER LIGHT	2	3	2	2	–	–	–	2	2	2	–	2
AC BUS OFF	2 AMBER LIGHTS	3	3	3	3	–	–	–	3	3	3	–	3

ALERTING FUNCTION	CURRENTLY USED TYPE OF ALERT	ALERT LEVEL AS FUNCTION OF FLIGHT PHASE											
		GRD MAINT	PRE-FLT	ENG ST	TAXI	INITIAL T.O. ROLL	FINAL T.O. ROLL	INITIAL CLIMB	1500 TO 14,000 FT	ABOVE 14,000 FT	APPR 1500 TO 200 FT	LDG	TAXI AND SHUT-DOWN
(CONT) ELECTRICAL SYSTEMS													
APU GENERATOR RELAY OPEN	1 BLUE LIGHT	3	3	3	3	–	–	–	3	3	3	–	3
AC TRANSFER BUS OFF	2 AMBER LIGHTS	3	3	3	3	–	–	–	3	3	3	–	3
ELECTRICAL SYSTEM FAULT	1 AMBER LIGHT	4	4	4	4	–	–	–	4	4	4	–	4
EMERGENCY EQUIPMENT													
PASSENGER OXYGEN SYSTEMS ON	1 AMBER LIGHT	2	2	2	2	–	–	–	2	2	2	–	2
OXYGEN FLOW—PRESSURE REGULATOR	3 WHITE FLAGS	4	4	4	4	4	4	4	4	4	4	4	4
EMERGENCY LIGHTS NOT ARMED	1 AMBER LIGHT	3	3	3	3	–	–	–	3	3	3	–	3
FIRE PROTECTION													
MASTER FIRE WARNING	2 RED LIGHTS AND BELL	2	2	2	2	2	–	–	2	2	2	–	2
FIRE EXTINGUISHER BOTTLE DISCHARGED	3 AMBER LIGHTS	4	4	4	4	4	–	–	4	4	4	–	4
ENGINE OVERHEAT	2 AMBER LIGHTS	3	3	3	3	3	–	–	3	3	3	–	3

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ALERTING FUNCTION	CURRENTLY USED TYPE OF ALERT	ALERT LEVEL AS FUNCTION OF FLIGHT PHASE											
		GRD MAINT	PRE-FLT	ENG ST	TAXI	INITIAL T.O. ROLL	FINAL T.O. ROLL	INITIAL CLIMB	1500 TO 14,000 FT	ABOVE 14,000 FT	APPR 1500 TO 200 FT	LDG	TAXI AND SHUT-DOWN
(CONT) <u>FIRE PROTECTION</u>													
ENGINE FIRE	2 RED LIGHTS	2	2	2	2	2	–	–	2	2	2	–	2
APU FIRE	1 RED LIGHT	2	2	2	2	2	–	–	2	2	2	–	2
WHEEL WELL FIRE	1 RED LIGHT	2	2	–	2	2	–	–	2	2	2	–	2
CARGO COMPARTMENT FIRE	2 RED LIGHTS	2	2	2	2	2	–	–	2	2	2	–	2
FIRE BOTTLE SQUIBS OK	3 GREEN LIGHTS	4	4	4	4	–	–	–	4	4	4	–	4
ENGINE OVERHEAT OR APU FIRE DETECTOR INOP	1 AMBER LIGHT	3	3	3	3	–	–	–	3	3	3	–	3
APU FIRE DETECTION SYSTEM FAILURE	1 AMBER LIGHT	3	3	3	3	–	–	–	3	3	3	–	3
<u>FLIGHT CONTROLS</u>													
STALL WARNING SYSTEM FAILURE	1 AMBER LIGHT	3	3	3	3	–	–	–	3	3	3	–	3
STALL WARNING	STICK SHAKER	1	1	–	–	–	–	1	1	1	1	1	–
MACH TRIM FAIL	1 AMBER LIGHT	3	3	3	3	–	–	–	3	3	3	–	3
LEADING EDGE FLAPS AND SLATS EXTENSION STATUS	12 GREEN AND 10 AMBER LIGHTS	4	4	4	4	4	–	4	4	4	4	–	4

ALERTING FUNCTION	CURRENTLY USED TYPE OF ALERT	ALERT LEVEL AS FUNCTION OF FLIGHT PHASE											
		GRD MAINT	PRE-FLT	ENG ST	TAXI	INITIAL T.O. ROLL	FINAL T.O. ROLL	INITIAL CLIMB	1500 TO 14,000 FT	ABOVE 14,000 FT	APPR 1500 TO 200 FT	LDG	TAXI AND SHUT-DOWN
(CONT) FLIGHT CONTROL													
LEADING EDGE SLATS OR FLAPS IN-TRANSIT	1 AMBER LIGHT	4	4	4	4	–	–	–	4	4	4	–	4
LEADING EDGE SLATS FULLY EXTENDED	1 GREEN LIGHT	4	4	4	4	–	–	–	4	4	4	–	4
LEADING EDGE FLAPS FULLY EXTENDED	1 GREEN LIGHT	4	4	4	4	–	–	–	4	4	4	–	4
STABILIZER OUT-OF-TRIM	1 AMBER LIGHT	4	4	4	3	2	–	–	3	3	3	–	4
YAW DAMPER FAILURE	1 AMBER LIGHT	3	3	3	2	2	–	–	2	2	2	–	3
STABILIZER TRIM OPERATING	1 AMBER LIGHT	4	4	4	4	–	–	–	4	4	4	–	4
ELEVATOR HYDRAULICS LOW PRESSURE	2 AMBER LIGHTS	2	2	2	2	2	–	–	2	2	2	2	2
RUDDER HYDRAULICS LOW PRESSURE	2 AMBER LIGHTS	2	2	2	2	2	–	–	2	2	2	2	2
AILERON HYDRAULICS LOW PRESSURE	2 AMBER LIGHTS	2	2	2	2	2	–	–	2	2	2	2	2
FLIGHT CONTROL SYSTEM MALFUNCTION	1 AMBER LIGHT	3	3	3	3	3	–	–	3	3	3	–	3
RUDDER OR ELEVATOR FEEL DIFFERENTIAL PRESSURE EXCESSIVE	1 AMBER LIGHT	3	3	3	3	3	–	–	3	3	3	–	3

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ALERTING FUNCTION	CURRENTLY USED TYPED OF ALERT	ALERT LEVEL AS FUNCTION OF FLIGHT PHASE											
		GRD MAINT	PRE-FLT	ENG ST	TAXI	INITIAL T.O. ROLL	FINAL T.O. ROLL	INITIAL CLIMB	1500 TO 14,000 FT	ABOVE 14,000 FT	APPR 1500 TO 200 FT	LDG	TAXI AND SHUT-DOWN
(CONT) FLIGHT CONTROL													
SPEED BRAKE– DO NOT ARM	1 AMBER LIGHT	2	2	–	–	–	–	–	2	–	2	–	–
SPEED BRAKE ARMED	1 GREEN LIGHT	3	3	–	–	–	–	–	3	–	3	3	–
UNSAFE TAKEOFF CONFIGURATION	INTERMITTENT HORN	1	1	–	3	1	–	–	–	–	–	–	–
FLIGHT INSTRUMENTS AND AIR DATA													
RADIO ALTIMETER FAIL	2 RED FLAGS	3	3	3	3	3	–	–	3	–	3	3	3
INSTRUMENT INDICATION COMPARISON	12 YELLOW LIGHTS AND CLACKER	3	3	3	3	3	–	–	3	3	3	–	3
INSTRUMENT COMPARISON MONITOR FAILURE	2 YELLOW LIGHTS	3	3	3	3	3	–	–	3	3	3	–	3
STATIC SOURCE ERROR CORRECTION FAILURE	2 BLACK FLAGS	3	3	3	3	3	–	–	3	3	3	–	3
BAROMETRIC ALTITUDE INFO FAIL	2 GREEN FLAGS	3	3	3	3	3	–	–	3	3	3	–	3
STANDBY ATTITUDE FAIL/OFF	1 RED FLAG	3	3	3	3	3	–	–	3	3	3	–	3
GROUND PROXIMITY WARNING	2 RED LIGHTS AND MESSAGE	1	1	–	–	–	–	1	1	1	1	1	–

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ALERTING FUNCTION	CURRENTLY USED TYPE OF ALERT	ALERT LEVEL AS FUNCTION OF FLIGHT PHASE											
		GRD MAINT	PRE-FLT	ENG ST	TAXI	INITIAL T.O. ROLL	FINAL T.O. ROLL	INITIAL CLIMB	1500 TO 14,000 FT	ABOVE 14,000 FT	APPR 1500 TO 200 FT	LDG	TAXI AND SHUT-DOWN
(CONT) FLIGHT INSTRUMENTS AND AIR DATA													
BELOW GLIDESLOPE WARNING	2 AMBER LIGHTS AND MESSAGE	2	2	–	–	–	–	–	–	–	2	3	–
GROUND PROXIMITY SYSTEM FAIL	1 AMBER LIGHT	3	3	–		–	–	–	3	3	3	–	3
DECISION HEIGHT	2 AMBER LIGHTS AND TONE	2	2	–	–	–	–	–	–	–	2	2	–
TOTAL AIR TEMP INDICATION BAD	1 RED FLAG	3	3	3	3	–	–	–	3	3	3	–	3
OVER OUTER MARKER	2 FLASHING BLUE LIGHTS AND TONE	4	4	–	–	–	–	–	4	–	4	–	–
OVER MIDDLE MARKER	2 FLASHING AMBER LIGHTS AND TONE	4	4	–	–	–	–	–	–	–	4	–	–
OVER AIRWAYS MARKER BEACON	2 FLASHING CLEAR LIGHTS	4	4	–	–	–	–	–	4	4	4	–	–
EXCESSIVE AIRSPEED OR MACH	CLACKER	2	2	2	2	–	–	–	2	2	2	–	–
FUEL													
ENGINE FUEL SHUTOFF VALVE IN-TRANSIT	2 BRIGHT BLUE LIGHTS	4	4	4	4	–	–	–	4	4	4	–	4
ENGINE FUEL SHUTOFF VALVE CLOSED	2 DIM BLUE LIGHTS	3	3	3	3	2	–	–	3	3	3	–	3

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ALERTING FUNCTION	CURRENTLY USED TYPE OF ALERT	ALERT LEVEL AS FUNCTION OF FLIGHT PHASE											
		GRD MAINT	PRE-FLT	ENG ST	TAXI	INITIAL T.O. ROLL	FINAL T.O. ROLL	INITIAL CLIMB	1500 TO 14,000 FT	ABOVE 14,000 FT	APPR 1500 TO 200 FT	LDG	TAXI AND SHUT-DOWN
(CONT) FUEL													
FUEL BOOST PUMP LOW PRESSURE	6 AMBER LIGHTS	3	3	3	3	3	–	–	3	3	3	–	3
CROSSFEED VALVE IN-TRANSIT	1 BRIGHT BLUE LIGHT	4	4	4	4	4	–	–	4	4	4	–	4
CROSSFEED VALVE OPEN	1 DIM BLUE LIGHT	4	4	4	4	4	–	–	4	4	4	–	4
FUEL FILTER ICING	2 AMBER LIGHTS	2	2	2	2	2	–	–	2	2	2	–	2
FUEL HEAT VALVE IN-TRANSIT	2 BRIGHT BLUE LIGHTS	4	4	4	4	–	–	–	4	4	4	–	4
FUEL HEAT VALVE OPEN	2 DIM BLUE LIGHTS	4	4	4	4	–	–	–	4	4	4	–	4
FUEL SYSTEM MALFUNCTION	1 AMBER LIGHT	3	3	3	3	3	–	–	3	3	3	–	3
HYDRAULIC POWER													
ENGINE DRIVEN PUMP OUTPUT PRESSURE LOW	2 AMBER LIGHTS	3	3	3	3	–	–	–	3	3	3	–	3
HYDRAULIC PUMP CASE DRAIN FLUID TEMP HIGH	2 AMBER LIGHTS	3	3	3	3	–	–	–	3	3	3	–	3
STANDBY SYSTEM HYDRAULIC FLUID QUANTITY LOW	1 AMBER LIGHT	3	3	3	3	–	–	–	3	3	3	–	3

ALERTING FUNCTION	CURRENTLY USED TYPE OF ALERT	ALERT LEVEL AS FUNCTION OF FLIGHT PHASE											
		GRD MAINT	PRE-FLT	ENG ST	TAXI	INITIAL T.O. ROLL	FINAL T.O. ROLL	INITIAL CLIMB	1500 TO 14,000 FEET	ABOVE 14,000 FEET	APPR 1500 TO 200 FT	LDG	TAXI AND SHUT-DOWN
(CONT) HYDRAULIC POWER													
ELECTRIC DRIVEN PUMP–LOW OUTPUT PRESSURE	2 AMBER LIGHTS	3	3	3	3	–	–	–	3	3	3	–	3
HYDRAULIC SYSTEM MALFUNCTION	1 AMBER LIGHT	3	3	3	3	3	–	–	3	3	3	–	3
HYDRAULIC PRESSURE ABNORMAL	1 GREEN, 2 YELLOW AND 1 RED BAND	3	3	3	3	–	–	–	3	3	3	–	3
STANDBY HYDRAULIC PUMP–LOW PRESSURE	1 AMBER LIGHT	3	3	3	3	–	–	–	3	3	3	–	3
ICE AND RAIN PROTECTION													
PITOT HEAT ON	7 GREEN LIGHTS	4	4	4	4	–	–	–	4	4	4	–	4
WING ANTI-ICE VALVE IN-TRANSIT	2 BRIGHT BLUE LIGHTS	4	4	4	4	–	–	–	4	4	4	–	4
WINDOW OVERHEAT	4 AMBER LIGHTS	3	3	3	3	–	–	–	3	3	3	–	3
WINDOW HEAT ON/OFF	4 GREEN LIGHTS	4	4	4	4	–	–	–	4	4	4	–	4
WING ANTI-ICE VALVE OPEN	2 DIM BLUE LIGHTS	4	4	4	4	–	–	–	4	4	4	–	4
ENGINE ANTI-ICE VALVES IN-TRANSIT	6 BRIGHT BLUE LIGHTS	4	4	4	4	–	–	–	4	4	4	–	4
ENGINE ANTI-ICE VALVES OPEN	6 DIM BLUE LIGHTS	4	4	4	4	–	–	–	4	4	4	–	4

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ALERTING FUNCTION	CURRENTLY USED TYPE OF ALERT	ALERT LEVEL AS FUNCTION OF FLIGHT PHASE											
		GRD MAINT	PRE-FLT	ENG ST	TAXI	INITIAL T.O. ROLL	FINAL T.O. ROLL	INITIAL CLIMB	1500 TO 14,000 FEET	ABOVE 14,000 FEET	APPR 1500 TO 200 FT	LDG	TAXI AND SHUT-DOWN
(CONT) ICE AND RAIN PROTECTION													
ANTI-ICE SYSTEM MALFUNCTION	1 AMBER LIGHT	3	3	3	3	3	–	–	3	3	3	–	3
LANDING GEAR													
GEAR DOWN AND LOCKED	3 GREEN LIGHTS	3	3	3	3	–	–	–	3	3	3	3	3
ANTI-SKID FAILURE	2 AMBER LIGHTS	3	3	3	3	3	–	–	3	3	3	3	3
ANTI-SKID OFF	2 AMBER LIGHTS	4	4	4	4	–	–	–	4	4	4	4	4
BRAKE PRESSURE ABNORMAL	1 GREEN, 1 YELLOW AND 2 RED BANDS	2	2	2	2	2	–		2	–	2	2	2
PARKING BRAKES ON	1 RED LIGHT	2	2	2	2	2	–	–	–	–	–	–	2
GEAR COMPARTMENT NOT SEALED	1 AMBER LIGHT	3	3	–	–	–	–	–	3	3	–	–	–
GEAR NOT DOWN AND LOCKED AND THRUST LEVER AT IDLE	3 RED LIGHTS AND HORN	2	2	–	–	–	–	–	2	2	2	2	–
GEAR UNLOCKED	3 RED LIGHTS AND HORN	2	2	2	2	2	2	2	2	2	2	1	2
GEAR DOWN AND LOCKED BUT LEVER NOT IN DOWN DETENT	3 RED LIGHTS AND HORN	1	1	1	1	1	–	–	–	–	1	1	1
EQUIPMENT TIRE BURST	1 AMBER LIGHT	2	2	–	–	–	–	–	2	2	2	2	2

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ALERTING FUNCTION	CURRENTLY USED TYPE OF ALERT	ALERT LEVEL AS FUNCTION OF FLIGHT PHASE											
		GRD MAINT	PRE-FLT	ENG ST	TAXI	INITIAL T.O. ROLL	FINAL T.O. ROLL	INITIAL CLIMB	1500 TO 14,000 FEET	ABOVE 14,000 FEET	APPR 1500 TO 200 FT	LDG	TAXI AND SHUT-DOWN
(CONT) LANDING GEAR													
UNSAFE LANDING CONFIGURATION	HORN	1	1	–	–	–	–	–	–	–	1	1	–
NAVIGATION													
FLIGHT DIRECTOR INFO FAIL	2 RED FLAGS	3	3	3	3	3	–	3	3	3	3	3	3
GYRO FAILURE	2 RED FLAGS	2	2	2	2	2	–	2	2	2	2	2	2
COMPASS SYSTEM FAILURE	4 RED FLAGS	3	3	3	3	3	–	3	3	3	3	3	3
AUXILIARY VERTICAL GYRO INOP	1 WHITE FLAG	3	3	3	3	–	–	–	3	3	3	–	3
TRANSPONDER IN TEST MODE	1 GREEN LIGHT	4	4	4	4	–	–	–	4	4	4	–	4
LOCALIZER INFO FAIL	2 RED FLAGS	3	3	3	3	–	–	–	3	3	3	3	–
VOR INFO FAIL	2 RED FLAGS	3	3	3	3	3	–	–	3	3	3	–	–
GLIDE SLOPE INFO FAIL	2 RED FLAGS	3	3	3	3	–	–	–	3	–	3	3	–
PNEUMATICS													
BLEED AIR TEMP HIGH	2 AMBER LIGHTS	2	2	2	2	–	–	–	2	2	2	–	2
BLEED TRIP OFF	2 AMBER LIGHTS	3	3	3	3	–	–	–	3	3	3	–	3

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ALERTING FUNCTION	CURRENTLY USED TYPE OF ALERT	ALERT LEVEL AS FUNCTION OF FLIGHT PHASE											
		GRD MAINT	PRE-FLT	ENG ST	TAXI	INITIAL T.O. ROLL	FINAL T.O. ROLL	INITIAL CLIMB	1500 TO 14,000 FEET	ABOVE 14,000 FEET	APPR 1500 TO 200 FT	LDG	TAXI AND SHUT-DOWN
(CONT) <u>PNEUMATICS</u>													
DUAL BLEED SOURCES	1 AMBER LIGHT	3	3	3	3	–	–	–	3	3	3	–	3
<u>POWER PLANT</u>													
REVERSER ACCUMULATOR PRESSURE LOW	1 AMBER LIGHT	2	2	2	2	–	–	–	2	–	2	2	2
N2 OVERSPEED	2 GREEN/YELLOW/ RED BANDS	2	2	2	2	2	–	–	2	2	2	–	2
N1 OVERSPEED	2 GREEN/YELLOW/ RED BANDS	2	2	2	2	2	–	–	2	2	2	–	2
EPR INDICATION FAIL	1 RED FLAG	2	2	2	2	2	–	–	2	2	2	–	2
EGT OVERTEMP	2 GREEN/YELLOW/ RED BANDS	2	2	2	2	2	–	–	2	2	2	–	2
OIL TEMPERATURE HIGH	2 GREEN/YELLOW/ RED BANDS	2	2	2	2	2	–	–	2	2	2	–	2
OIL FILTER CLOGGED	2 AMBER LIGHTS	3	3	3	3	3	–	–	3	3	3	–	3
ENGINE OIL PRESSURE LOW	2 AMBER LIGHTS PLUS 2 GREEN/ YELLOW/RED BANDS	2	2	2	2	2	–	–	2	2	2	–	2
REVERSER UNLOCKED	2 AMBER LIGHTS	3	3	3	3	3	–	–	3	3	3	3	3
REVERSER ARMED	1 BLUE LIGHT	3	3	3	3	3	–	–	3	3	3	3	3

APPENDIX H

TABULATION OF ABSTRACTS FROM HUMAN FACTORS PAPERS RELEVANT TO ALERTING SYSTEMS AS A FUNCTION OF DIRECT APPLICABILITY

Area of concern	Author	Nonaircraft related test data findings	Author	Aircraft related test data findings	Mil std/ guide no.	Military standard/design guideline
Visual signals – size	Elliott 1968	For a simple reaction time* (RT) task, the RT for a 1^{o} visual angle light was no different than for a 3^{o} light *Simple reaction time is the time to react to a stimulus when that is the only task to be accomplished	Merriman 1969	Reaction time to Grimes warning lights (1/8" x 7/10" legend with border illumination) decreased as the width of the border increased leveling off at .75 sec for a width of 1/4"	MIL-STD 411D	• A 3/16 inch border shall surround legends
	Freoberg 1907	Simple RT decreased as the size increased leveling off at 2^{o} visual angle	Sheehan 1972	Response times to alphanumeric legends decreased as size increased leveling off at 1 sec for 1^{o} visual angle		
Visual signals – brightness and contrast	Pabb 1962	Simple RT decreased as brightness increased leveling off at 180 msec for 30-ft-L. Signal size was 1^{o} 10 min of visual angle. Lighted signal was presented in a dark room.			MIL-STD 411D	• The legend on a signal when energized shall be readable under direct sunlight (10,000 ft-L). When not energized the legend should not be readable and shall not appear energized in direct sunlight.
	Rains 1962	Found that a 1.59 mL signal with a 4 minute visual angle and a .023 sec flash was the detection threshold for a white signal in a simple RT task. Lighted signal was presented in a dark room.				• Brightness shall be no less than 150 ft-L. Warning lights should be dimmed to 15+3 ft-L when the pilots primary instrument light control is "on". Advisory lights should be dimmed to 1+5 ft-L, when the primary light control is at max. intensity.
	Kohfeld 1971	Simple RT decreased as intensity increased leveling off at 220 msec between 1 and 100 mL for white light. Signal was presented in a dark room.			MIL-STD 1472B	• Brightness of rear lighted displays shall be at least 10^{o} greater than the brightness of the area around the display. A dimming control should be provided.
	Hoyland 1936	Found that for moderate brightness levels there was no relationship between brightness and RT except for completely dark adapted subject who reacted to a 250 ft-C signal faster.			MIL-C 81774A	• Contrast between lighted and unlighted portions of a display, under high ambient illumination (10,000 ft-C) shall be a minimum of 3 when calculated as: $C = \frac{E_1 - B_2}{B_2}$ B_1 = Brightness of illuminated portion; B_2 = Brightness of unlighted portion
	Matteson 1971	A low level of brightness of the area surrounding the signal caused a small decrease in RT (25 msec) over no surrounding light. There was no further effect of surround on RT until the surround became brighter than the signal.				
	Teichner 1954	Simple RT decreased as intensity increased leveling off at 25 ft-C for larger objects (3-5.2 minutes visual angle) and 45 ft-C for smaller objects (1-2 minutes)				
	Gerathewohl 1953	Flashing signals produced faster RT (2 sec) than steady signals when contrast levels were less than one. For levels greater than one there was no significant difference between the signals for the lowest contrast $\frac{\text{Signal Luminance} - \text{Background Luminance}}{\text{Background Luminance}}$ Level (.15) the average number of misses for the steady signal was 50% and for the flashing signal was 5%.				
Visual signals – location	Coates 1972	For monocular viewing simple RT was fastest at the middle position $+4^{o}$ for the gazing scan pattern and at $+24^{o}$ for the scanning pattern	Rich 1971	Using very small (4 minutes visual angle) stationary targets 83% were detected when the target was on the line of sight and 35% when it was 30^{o} to 40^{o} left or right.	MIL-STD 411D	• Nominal envelope of vision for both pilot and copilot is a 30^{o} cone symmetrical about a line from eye position to the top of the instrument panel

Area of concern	Author	Nonaircraft related test data findings	Author	Aircraft related test data findings	Mil std/ guide no.	Military standard/design guideline
Visual signals – location (cont)	Rains 1962	Simple RT for the right eye was fastest at 0° and increased as the horizontal angle increased. It had not leveled out at 30°. Signals to the left produced faster RT's than to the right and signals above horizontal produced faster RT's than those below.	Siegel 1960	Found that response to signals located at 0° horizontal displacement from pilot's centerline of vision was faster than to signals located at either 33° or 95°. Mean response time for signals at 95° was 1.2 seconds slower than for signals at 0°.		• Light signals shall not be located within the pilots or copilots basic flight instrument group when warning lights have to be located outside the 30° cone of vision a master signal must be provided within the cone.
	Sharp 1967	Using a sound as a cue for a visual signal found no difference in visual RT as the horizontal displacement of the signal increased from 0° to 75°.				• Except where specifically authorized advisory lights shall not be located on the main instrument panel.
	Sharp 1968	For visual RT with no auditory cue there was an increase in the RT variability as the horizontal displacement of the signal increased from 57° to 83°. However, the mean RT did not change over this range. The RT increased sharply at displacements greater than 83° and, 96°, 25 percent of the signals were missed entirely.			MIL-STD 1472B	• Viewing distance from eye reference to diaplay shall not be less than 13 inches preferrably not less than 20 inches or greater than 28 inches.
	Haines 1975	Described zones of equal RT for different colored signals. The lowest RT zone (330 msec) for red lights covered a signal displacement of 30° left, 35° right, 20° up and 25° down. The lowest RT zone (270 msec) for white lights was from 45° left to 50° right and 20° up to 25° down.				
	Teichner 1954	Simple RT to a white light increased from .004 sec at 3° horizontal displacement from the centerline of vision to .024 sec at 45°.				
Visual signals – format	Crawford 1962	Used white signals with red and green distractors. Found no difference in a simple RT task between steady and flashing signals with no distractors. Flashing signals with steady distractor produced fastest RT.	Noble 1958	Alternating and flashing lights produced superior detection (not qualtified) in both day and night conditions. If a steady light was missed it was more likely to remain missed.	MIL-STD 411D	• Flashing light presentation shall have flash rates of 3 to 5 per second. The "on" time shall be approximately equal to the "off" time.
	Gerathewohl 1953	Flashing signals produced a faster response time (by 2 sec) when contrast levels were less than one. For levels greater than one, there was not a significant difference in response time to flashing and steady signals.				
	Edwards 1971	Built a relable statistical model (utilizing paired comparison techniques) to classify flashing lights of various characteristics in order of their attention-attracting value.				
Visual signals – color	Coates 1972	Red lights were detected significantly faster than green in a vigilance task. However, the difference was only 17 msec.			MIL-STD 411D	• Warning signals will have red background with opaque letters. Caution signals will have yellow letters with opaque background. Advisory signals will have green, blue or white letters on an opaque background.
	Jones 1960	Color coding is not suited for situations that demand rapid and precise identification but it is valuable in tasks that require a "locate" process.			MIL-C 25050A	• Red lights shall not be yellower nor less saturated than the light transmitted by an NBS 3215 filter from a 2854°K source. Other colors are given as coordinates of the O.I.E. chromaticity diagram.
	Weingarten 1972	Simple RT to a red light was significantly faster than to a green one. However, the difference was only 25 msec.				
	Haines 1974 1975	In a simple RT task, the RT to a red light was 16° slower than to green or yellow lights. RT was significantly slower (up to 28°) in the peripheral field. Red signals were affected more by displacement than the others in both RT and misses. The fastest RT (288 msec) was for yellow signals. 150 RT maps are provided for each color for the full visual field.				

Area of concern	Author	Nonaircraft related test data findings	Author	Aircraft related test data findings	Mil std/ guide no.	Military standard/design guideline
Visual signals – color (cont)	Pollack 1968	The effect of color on RT decreased as brightness increased and there is relatively little effect due to color above .0023 ft-L. For brightnesses where there was an RT difference due to color RT's increased as the spectrum went from blue to red.				
	Bartlett 1968	Simple RT to red signals was significantly faster at the line of sight than at a displacement of 12° horizontally.				
	Warm 1967	In a simple RT task during vigilance the RT to signal off-set was faster than to onset. There was no difference in RT between red and green signals.				
	Reynolds 1972	Performed simple response time task varying signal color, background color, and ambient light level. A red signal on blue background with dim ambient resulted in the fastest response time (1 sec). Response time for red was the fastest (2.019 sec). The other colors were as follows: green 2.341 sec, yellow 2.992 sec and white 3.93 sec. Results indicate that red signals attract the greatest amount of attention.				
	Hill 1947	Detection thresholds for red, white, yellow and green lights were nearly equal over a range of background luminance from 10^{-6} to 10^{4} ft-C.				
Visual signals – workload, fatigue, and vigilance	Singleton 1953	Response time in a 4 choice task increased significantly from the first to the second half of the trails during a 1 hour test period.	Adams 1961	Contrary to experiments with only a single stimulus source there was no decrement in percent correct over a 3 hr period for more complex tasks (6 or 36 stimuli) Response latency declined significantly for the single stimulus task and not at all for the complex tasks.		
	McCormack 1960	Simple RT increased significantly throughout a 30 minute task.				
	Malomsoki 1970	Simple RT showed an immediate increase with physical exercise.				
	Crawford 1962	Found that simple RT doubles when going from 0 to 10 distractors (.8 to 1.5 sec) and trebles when going to 21.				
	Teichner 1974	Loss of detection performance on displays requiring no eye movement was relatively small over the 3 hour vigilance period.				
	Poulton 1966	Detection performance during vigilance will be better if the pilot's senses are kept active or if he is a member of a team.				
	Hyman 1952	Simple RT to a given signal increased as the information in the signal increased. A linear function was described for the relationship between RT and signal information (0 to 3 bits).				
	Bowen 1964	For a high probability event (20/hr) the RT (7 sec) was less affected by the time on the task than the RT (14 sec) for low probability events (1/hr).				
	Ware 1964	Detection decreased from 85 to 65 percent when going from 1 to 4 signal sources and a 5-10 percent decrease was observed over a 3 hr period for all conditions.				

Area of concern	Author	Nonaircraft related test data findings	Author	Aircraft related test data findings	Mil std/ guide no.	Military standard/design guideline
Visual signals – pilot age	Tolin 1968	Older subjects (66-87 years) exhibited a 30% slower RT and a 76% slower movement time. Increasing the task complexity did not have a differential effect for RT but the older subjects did show increasingly slower movement times.				
	Szafran 1969	Visual accommodation drops from 6 diopters in younger pilots (30) to 4 diopters in older pilots (45). Flash rate fusion frequency reaches a minimum at age 35 and increases with age. There is no evidence of change in dark adaptation. Information processing, effective auditory threshold or auditory detection.				
	Talland 1966	Percent correct detections decreased significantly (10 to 15%) with age for a range of signal durations from .5 to 3 seconds.				
	Teichner 1954	Simple RT decreases to age 30 then increases. However, at age 60 it was still faster than at age 10.				
	Rabbit 1967	*Subjects over the age of 60 do not get as much advantage* out of redundant information as the 17-28 year olds.				
Visual signals – legend characteristics	Van Laer 1961	Visual acuity is satisfactory at brightness levels of .1 to .01 mL in a dark room.	Siegel 1960	Dark legend on luminated background was superior in both RT and accuracy to luminated legend on dark background. For dark legends with a height-width ratio of 5:3 1/4 in. height was superior to 1/8 in. but the same as 3/8 in. for a 28 in. viewing distance.	MIL-STD 411D	• For warning signals use a red background with opaque letters, for caution signals use yellow letters on an opaque background and for advisory signals use green, blue or white letters on an opaque background.
	Taylor 1961	Near threshold legends must be within 1^{o} of direct line-of-sight. Legends must be twice threshold size when the displacement angle gets to 4^{o}.	Bendix 1959	For dark legend on luminated background a bold character with a stroke width of 1/5 of the height should be used. For lighted legends a medium to light character style with stroke widths of 1/8 - 1/10 of the height should be used.		• Legends shall be 1/8 to 1/4 inch high. A 3/16 border should surround the legend.
	Peters 1959	Developed a height formula for legends where $H = .0022D + K_1 + K_2$. H = Height in inches D = Viewing distance K_1 = Correction factor for illumination & viewing conditions K_2 = Correction for importance	Brown 1953	The optimum height-width ratio for transluminated legends is 1:1 for uniform stroke block letters. The width should be no less than 2/3 the height use 9/64 in. height for the bulk of legends and 11/64 for emphasis for 28 in. viewing distance.	MIL-C 81774A	• Width of letters shall be 3/5 of the height except for "I" which shall be one stroke in width and the "M" and "W" which shall be 4/5 the height. Stroke width of the characters shall be 1/7 of the height.
			White 1960	At 28 in. viewing distance for critical markings legends height should be from .15 to .3 in. in low brightness (down to .03 ft-L) 4.1 in. to 2 in. in high brightness (down to 1.0 ft-L) and for non-critical markings it should be from .05 in. to .2 in. in any brightness.	MIL-M 18012B	• With a 28 inch viewing distance legend height shall be between .15 and .30 inches except critical markings which shall be no less than .2 inches. Width shall be 3/5 the height except "4" which shall be one stroke wider and "1" and "I" which shall be one stroke wide.
			Atkinson 1952	NAMEL style of legend produced fewer reading errors than either the Berger or the AND styles.	MIL-M 18012B	• Stroke width shall be from 1/8 to 1/6 of the height and shall be uniform. There shall be one stroke width between letters in a word and one letter width between words.
			Van Cott 1972	When legend is used to report status the legend should be lighted and the background dark.		
Memory for signals	King 1963	Found in 3 experiments that subjects could reproduce brightness, flash rate and duration up to 28 days after seeing the standard with little difference from a reproduction made 2 min. after seeing the standard signal. However, only brightness was not significantly different from the standard.				

Area of concern	Author	Nonaircraft related test data findings	Author	Aircraft related test data findings	Mil std/ guide no.	Military standard/design guideline
Auditory signals–format	Howarth 1961	A person has a lower recognition threshold to his own name than to other names.	Pollack 1958	Voice warning was superior to a buzzer in time to identify a malfunction. Voice warning was superior even when extraneous messages were presented.	MIL-STD 411D	• A non-verbal audio master warning signal should, (1) sweep from 700 cps to 1700 cps in .85 sec, (2) have intervation interval of .12 sec, (3) repeat until unit is de-energized. Actual signal specs. are given in the standard for specific events.
	Moray 1959	When attending to one ear, a person can pick up messages in the other ear if the message is preceeded by his name.	Siegel 1960	A two tone master signal was superior to a single tone.		• Voice messages shall be used only for "hazardous or imminent catastrophic conditions requiring immediate action." They shall only be used in conjunction with red warning signals. They shall always start at the beginning of the message.
	Keuss 1972	By varying the intensity and interstimulus intervals of two auditory signals, found that simple RT to the second signal decreased leveling off at an 85 dB intensity and a 200 msec interval.	Simpson 1975	Familiarity with phraseology contributes to intelligibility. Pilots scored 96.4% correct on a synthesized speech system.	MIL-STD 1472B	• Audio warning signals should normally consist of 2 elements, an alerting signal and an action signal. With a two element signal a .5 sec alerting tone shall be provided. If speed is essential all information should be transmitted in the first 2 seconds, for a single element this time should be .5 sec.
	Geblewiczowa 1963	Auditory signals that are judged pleasant always give a slower RT than those judged unpleasant. There is an inverse relationship between RT and the number of ready signals (prealert signals).	Thorburn 1971	Experienced 358 pilots felt that a voice warning system contributes to flight safety, it reduces pilot workload.		• Tone frequency shall be between 200 and 5000 cps and shall be different from electrical power sounds in the system.
			Kemmerling 1969	Voice warning system allowed the pilot to analyze the situation without bringing his visual attention into the cockpit.		• Verbal signals shall consist of an initial alerting signal and a brief standardized speech message.
Auditory signals – workload, fatigue, and vigilance	Hohmuth 1970	When an auditory and visual vigilance task are performed simultaneously the performance on the primary visual task is not affected by the secondary auditory task. However, performance on a primary auditory task is affected by a secondary visual task.			MIL-STD 1472B	• For verbal systems a message priority system shall be established and more critical messages shall override less critical ones.
	Zwislocki 1958	Deterioration of the auditory threshold is linear with regard to the square of the time on the task.				
	McGrath 1965	Signal detections (recognition of change in signal state) decreased over a 90 min. period for both easy and hard auditory signals.				
	Davenport 1968	By increasing either signal duration or intensity the detection performance could be improved over an 80 min. test. General detection performance degraded with time.				
	Alluisi 1963	Even with high multiple (5) task activity auditory vigilance performance declined (number of missed signals increased) over a 4 hour period.				
	Pope 1962	Found no correlation between subjects visual and auditory vigilance performance.				

Area of concern	Author	Nonaircraft related test data findings	Author	Aircraft related test data findings	Mil std/ guide no.	Military standard/design guideline
Auditory signals – loudness and ambient noise	Egan 1950	Gives curves that show the masking effect of a 400 cps tone and a 90 cps band of noise at different levels of intensity.	Webster 1964	When either the speaker (microphone) or the listener (earphones) are in quiet, satisfactory intelligibility has been obtained to 125 dB jet noise. Good intelligibility has been obtained in noise by using a wide speech bandwidth (3 octaves) centered between 1000 cps and 1800 cps, using minimum or no sidetones, conforming AVC circuit to preferred listening levels, peak clipping of 12 dB at maximum power, having a flat response and minimum distortion in audio circuitry.	MIL-STD 1472B	• A signal to noise ratio of at least 20 dB shall be provided.
	Fletcher 1933	Presents a definition of loudness and techniques for measuring it. Gives equal loudness contours for different frequencies. Demonstrates how to calculate the loudness of a complex tone.				• Verbal alarms for critical functions shall be at least 20 dB above the speech interference level.
	Hirsh 1950	When speech and noise are presented simultaneously, the lowest threshold to the speech occurs when the speech is presented directly to an ear and the noise is separated by at least 90°.	Van Cott 1972	A sound signal should exceed its masked detection threshold by at least 15 dB and the optimum sound level in noise is halfway between the masked threshold and 110 dB.		• Volume shall be designed to be controlled by the operator.
	Kohfeld 1969	Simple RT is inversely related to the intensity of a ready signal.				
Auditory signals – disruptive effects	Harcum 1973	Target detection deteriorated significantly in a 60-85 dB noise. A sorting task was not affected. When difficulty was rated both tasks were rated more difficult with noise.	Kemmerling 1969	Pilots presented a tone warning scanned the annunciator panel to determine the severity of the problem where those with a voice system did not have to.	MIL-STD 1472B	• Audio signals should not be of such intensity as to cause discomfort or "ringing" in the ears as an after effect.
	Glass 1972	Performance is less disrupted when the noise is seen as necessary.				• When audio signals delivered to a headset might mask other essential audio information separate channels may be provided.
Auditory signals – one vs two ears	Cherry 1953	Selective attention can be exhibited with very high accuracy when different information is presented to each ear. Subjects did not detect a language change in the rejected ear but they did detect a change from male to female and from speech to a tone. They had no trouble switching attention from ear to ear.			MIL-STD 1472B	• When earphones are worn a dichotic presentation should be used when feasible, alternating the signal from ear to ear.
	Egan 1954	When presenting a message and a distractor the message can be 30 dB less intense when each is presented to a different ear than when they are both presented to the same ear.				
	Gopher 1971	During selective attention there are significantly more intrusions from the interfering ear when it is the right ear than when it is the left. There is no difference in omissions.				
	Poulton 1953	When a message and distractor are presented simultaneous the predominant mistake is mis hearing.				
Auditory signals – signal number and memory effects	Miller 1956	For a signal that varied only in one dimension (frequency, intensity, duration, etc.) only 7 ± 2 signals could be identified accurately.				• When several different audio signals are to be used discriminal differences in intensity, pitch, etc. shall be provided. If absolute discrimination is required the number of signals shall not exceed 4.
	Pollack 1952	A trained listener can identify 40-60 sounds presented individually. However, subjects could only identify 5 tones which differed only in frequency.				
	Schulman 1970	When looking at the slope (m) of the line formed by relating the probability of false alarms to the probability of signal detection it was found that m increases with the increase in the probability of signal occurrence.				

Area of concern	Author	Nonaircraft related test data findings	Author	Aircraft related test data findings	Mil std/ guide no.	Military standard/design guideline
Auditory signals – signal number and memory effects (cont)	King 1963	Found in 3 experiments that subjects could reproduce loudness, frequency and duration up to 28 days after hearing the standard sound with little difference from a reproduction produced 2 min. after hearing the standard sound. However, all reproductions were significantly different from the standard.				
Auditory signals– effects of pilot age	ASA 1954	One of the more reliable signs of aging in males is a progressive loss of hearing in higher frequencies.				
Bimodal presentation visual and auditory	Klemmer 1958	Found no difference in the accuracy of response to three tones or 3 colored lights. When tone and light were presented simultaneously accuracy increased from 84% to 95%. Performance declined if senses were alternated faster than once every 2 seconds.	Bate 1969	Median response time was fastest to a tone-visual warning signal (1.7 sec) and slowest to a visual signal (4.5 sec).		• When used with a visual display audio signals shall be supplementary or supportive in nature.
	Morrell 1967	Simple RT to a visual signal decreased when the time between the visual signal and a following auditory signal decreased from 120-20 msec.	Siegel 1960	The fewest number of warning signals were missed when visual and auditory signals were presented together. For the individual signals auditory was superior to visual.		
	Morrell 1968	Simple RT was faster over a wider range of interstimulus intervals when the sequence was visual-auditory than when it was the reverse.	Bate 1967	Response time to a tone-visual warning signal was faster (6.7 sec) than to a visual signal (7.8 sec). However, missed targets in the primary task were much less for the voice (74) or tone visual (83) systems than for the straight visual (111).		
	Perriment 1969	In Bimodal presentations simple RT was faster when the two signals came from the same side.				
	Doumas 1969	Simple RT to a visual signal was fastest with a preceeding tone of 400 msec length. RT was also inversely related to the intensity of the auditory signal.				
	Fidell 1969	Simultaneous presentation of visual and auditory signals improved detection sensitivity as much as 3 dB.				
	Geblewiczowa 1963	Simple RT is directly related to the interval between visual and auditory signals. A .5 sec interval produced the fastest RT when the auditory signal preceeds the visual.				
	Klingberg 1962	The probability of signal detection was significantly higher with a bimodal presentation. Detection was superior for auditory signals. Bimodal detection was the only task that did not deteriorate over the 1 hour test period.				
	Buckner 1963	Simultaneous presentation of visual and auditory signals improved detection probability during prolonged vigilance				
	Carroll 1973	Simple visual RT decreased from .49 sec to .27 sec with the introduction of a 60 dB tone.				
	Bertelson 1968	Simple RT to a visual signal decreased when preceeded by a click (RT = 270 msec with a 20 msec interval and RT = 240 msec with a 150 msec interval). Simultaneous presentation produced a faster (20 msec) RT than no click.				
Tactile signals– detectability	Geldard 1957	The lowest vibration detected 100% of the time was 50 micrometers. In a range from 50 - 400 micrometers 3 levels can be identified.				

Area of concern	Author	Nonaircraft related test data findings	Author	Aircraft related test data findings	Mil std/ guide no.	Military standard/design guideline
Tactile signals – detectability (cont)	Geschneider	The intensity of vibrotactile signal is directly related to probability of detection and inversely related to RT.				
	Hill 1968	Tactile displays were corrently interpreted more often when their location was on a body part not involved in motion.				
	Shiffirn 1974	Performance was not reduced when 3 senses are used simultaneously for signals as compared to using senses individually.				
	Swets 1969	d′ for a vibrotactile signal is linearly related to signal intensity.				
Tactile signals – effectiveness	Johnston 1972	Simple RT was fastest to tactile signal under all work-load conditions.				
	Davenport 1969	Bimodal presentation of auditory and tactile signals was superior to either individually. Auditory was superior to tactile.				
	Loeb 1962	Auditory signals were superior to tactile in both number of misses and RT. Tactile signals were more affected by vigilance.				
Tactile signals – signal number	Diespecker 1969	Subjects were able to learn a 9 element (3 intensities and 3 durations) code and perform over a range of durations.				

APPENDIX I

TEST PLANS FOR ADDITIONAL HUMAN FACTORS TESTS REQUIRED TO COMPLETE DEFINITION OF AND VALIDATE RECOMMENDED ALERTING SYSTEM DESIGN STANDARDS

TITLE: CAUTION AND WARNING SYSTEMS DATA BASE AUGMENTATION - VISUAL SYSTEMS

VARIABLES: SIGNAL BRIGHTNESS x SIGNAL STYLE x PILOT WORKLOAD x AMBIENT LIGHT LEVEL

PROBLEM: The effectiveness of any visual caution and/or warning system is dependent on the detection and correct interpretation of the signals by the user. Information is required on the effect of certain variables on detection performance and design constraints produced by these variables.

TEST OBJECTIVES:

I Augment the existing data base of information on caution and warning signal detection.

II Provide definitive data on the effect of signal brightness, signal style, pilot workload and ambient light intensity on the detection of visual caution and warning signals.

III Determine the impact of these findings on system design and standardization.

OUTPUT/PRODUCT:

Comparative pilot performance data on visual caution and warning signals which differ as a function of style and brightness. Interactions of different signals with the surrounding light and the amount of pilot workload. Recommendations on signal requirements and design specifications.

DATA MEASUREMENTS:

The measurements will describe the time it takes a pilot to detect a signal, the time to respond to the signal, the accuracy of both detection and response, and a subjective evaluation of the aesthetic value of each of the signals.

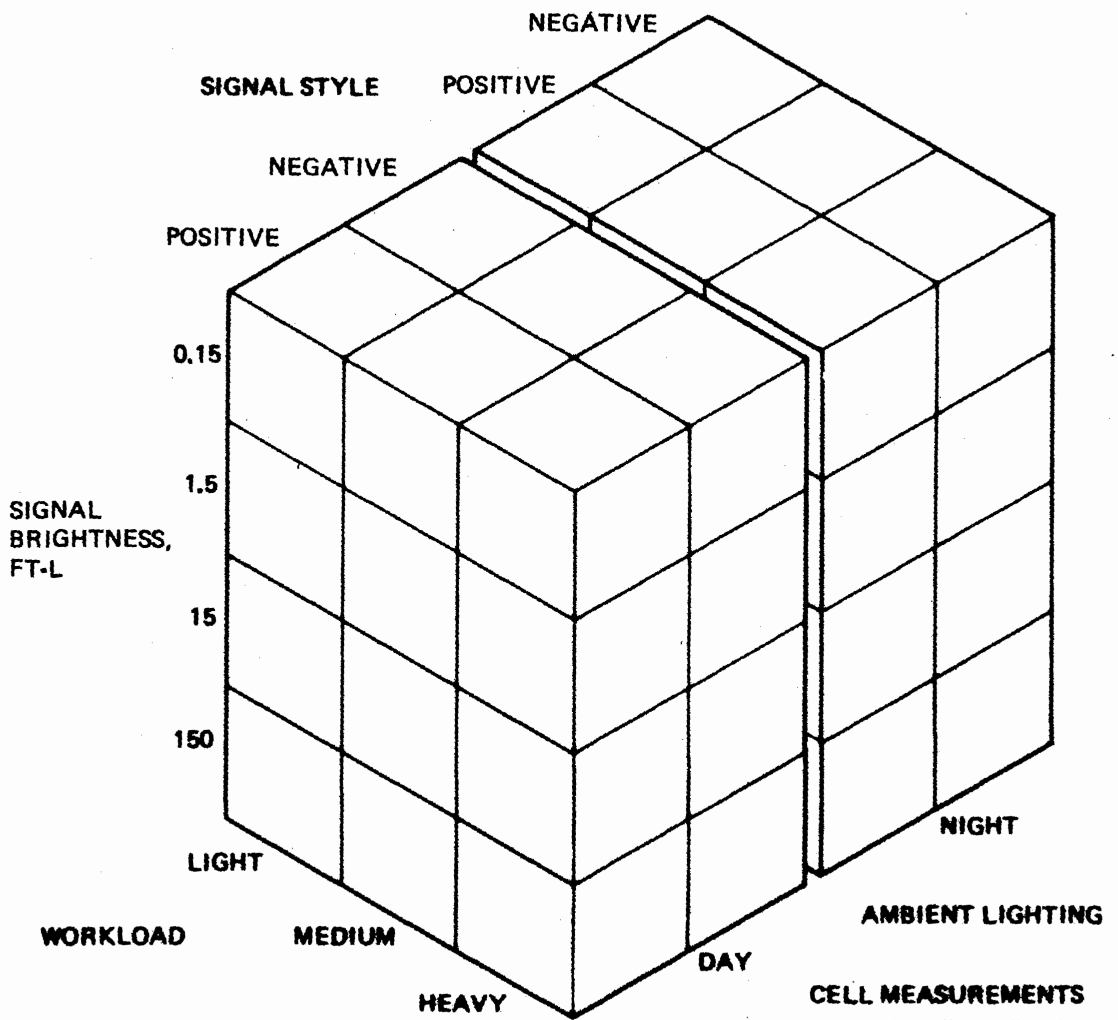
TEST APPROACH:

This effort will develop empirical statistical data describing caution and warning signal detection performance in a cockpit environment. The measurements will be taken in a simulated aircraft cockpit using two different styles (positive & negative) and four different brightness levels for the signal (0.15 to 150 ft-L). The cockpit environment will also be changed with respect to the ambient lighting (0 to 7000 ft-L).

To simulate the circumstance surrounding the pilot in an actual aircraft environment, the pilots will be assigned flight related tasks (i.e., IFR flight) to accomplish. The workload imposed by these tasks will have three levels (high, medium, low), and the appearance of the caution and/or warning signals will occur simultaneously with the flight tasks.

The data from this study will be used to make recommendations on the selection of style and brightness for caution and warning signal lights to be used under different lighting and workload conditions.

EXPERIMENTAL DESIGN



CELL MEASUREMENTS

1. REACTION TIME
2. RESPONSE TIME
3. RESPONSE ACCURACY
4. AESTHETIC VALUE

SCHEDULE

TESTING		ANALYSIS	
WEEK 1	WEEK 2	WEEK 3	WEEK 4

TITLE: CAUTION AND WARNING SYSTEMS DATA BASE AUGMENTATION - VISUAL SYSTEMS

VARIABLES: SIGNAL BRIGHTNESS x SIGNAL LOCATION x FLASH RATE x PILOT WORKLOAD

PROBLEM: The effectiveness of any visual caution and/or warning system is dependent on the detection and correct interpretation of the signals by the user. Information is required on the effect of certain variables on detection performance and design constraints produced by these variables.

TEST OBJECTIVES:

I Augment the existing data base of information on caution and warning signal detection.

II Provide definitive data on the effect of signal brightness, signal location, signal flash rate, and pilot workload on the detection of visual caution and warning signals.

III Determine the impact of these findings on system design and standardization.

OUTPUT/PRODUCT:

Comparative pilot performance data on caution and warning signals which differ as a function of brightness, location and flash rate. Interactions of different signals with the amount of pilot workload. Recommendations on signal requirements and design specifications.

DATA MEASUREMENTS:

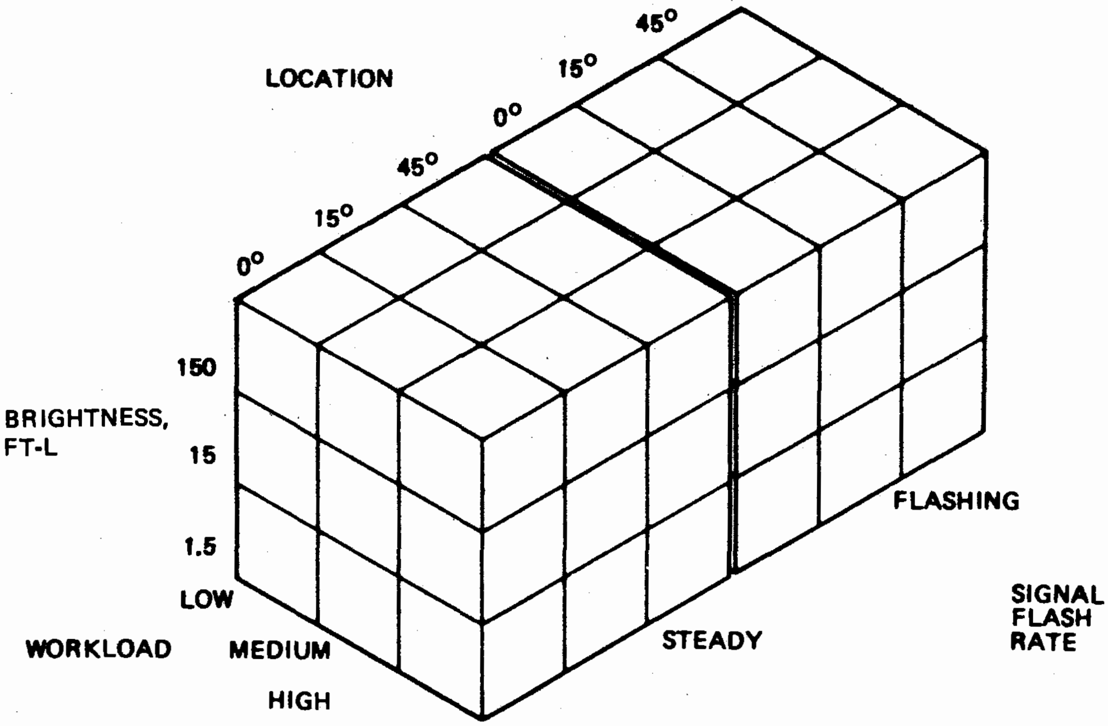
The measurements will describe the time it takes a pilot to detect a signal, the time to respond to the signal, the accuracy of both detection and response and a subjective evaluation of the aesthetic value of the signal.

TEST APPROACH:

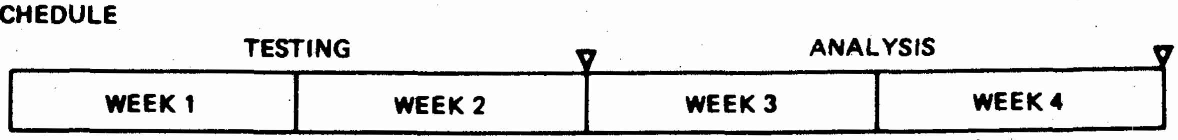
This effort will develop empirical statistical data describing caution and warning signal detection performance in an actual cockpit environment. The measurements will be taken in a simulated aircraft cockpit using either steady or flashing signals of three different brightness levels (1.5 to 150 ft-L) at three locations (0°, 15°, and 45° horizontal displacement from the pilot's centerline of vision). In an attempt to simulate the circumstances surrounding the pilot in an aircraft environment, the pilots will be assigned flight related tasks (i.e., IFR flight) to accomplish. The workload imposed by these tasks will have three levels (high, medium, and low). The appearance of the caution and/or warning signals and the flight tasks will occur simultaneously.

The data from this study will be used to make recommendations on the selection of location, brightness and flash rate for caution and warning signal lights to be used under different workload conditions.

EXPERIMENTAL DESIGN



SCHEDULE



TITLE: CAUTION AND WARNING SYSTEMS DATA BASE AUGMENTATION - VISUAL SYSTEMS

VARIABLES: SIGNAL BRIGHTNESS x SIGNAL LOCATION x NUMBER OF DISTRACTING SIGNALS x AMBIENT LIGHT LEVEL

PROBLEM: The effectiveness of any visual caution and/or warning system is dependent on the detection and correct interpretation of the signals by the user. Information is required on the effect of certain variables on detection performance and design constraints produced by these variables.

TEST OBJECTIVES:

I Augment the existing data base of information on caution and warning signal detection.

II Provide definitive data on the effect of signal brightness, signal location, number of distracting signals and the brightness of the ambient light on the detection of visual caution and warning signals.

III Determine the impact of these findings on system design and standardization.

OUTPUT/PRODUCT:

Comparative pilot performance data on caution and warning signals which differ as function of location and brightness. Interactions of different signals with distracting signals and the brightness of the ambient light. Recommendations on signal requirements and design specifications.

DATA MEASUREMENTS:

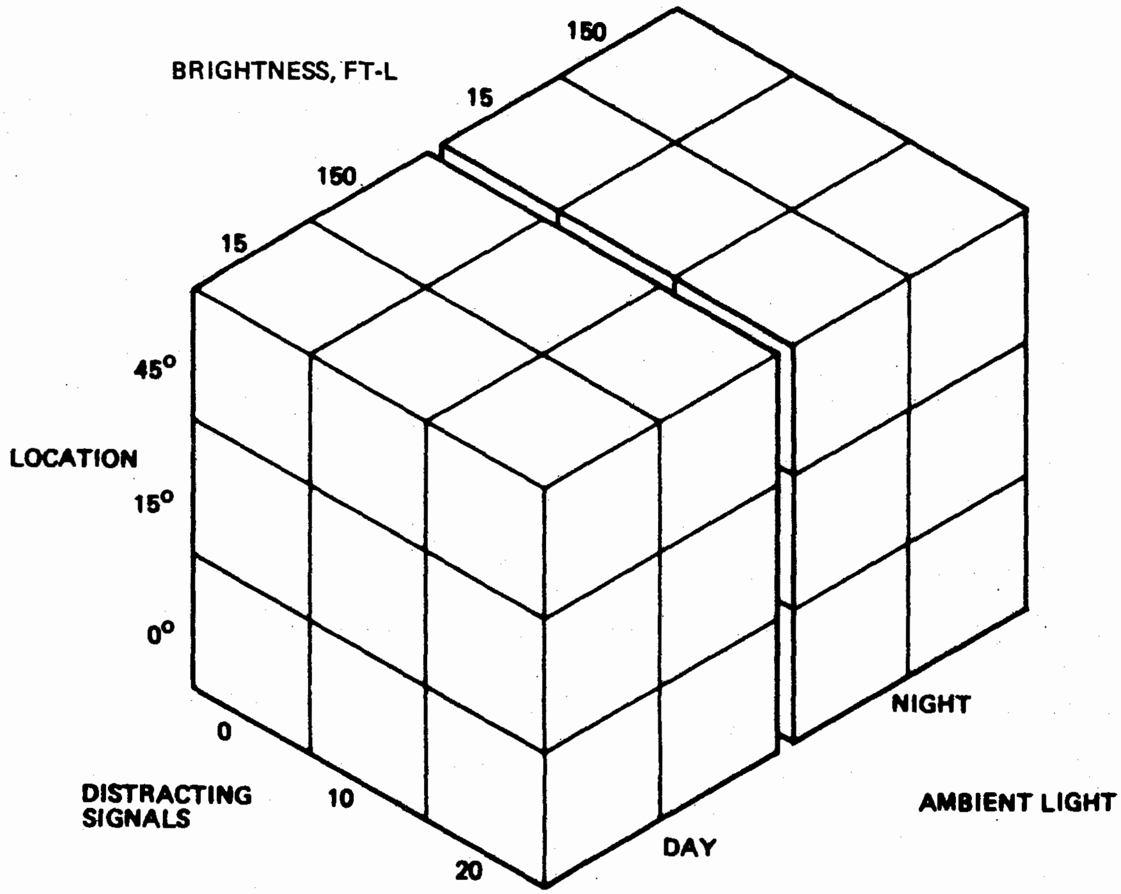
The measurements will describe the time it takes a pilot to detect a signal, the time to respond to the signal, the accuracy of both detection and response, and a subjective evaluation of the aesthetic value of each of the signals.

TEST APPROACH:

This effort will develop empirical statistical data describing caution and warning signal detection performance in an actual cockpit environment. The measurements will be taken in a simulated aircraft cockpit using signals of two different brightnesses (15 and 150 ft-L) at three different locations (0^{o}, 15^{o}, and 45^{o} horizontal displacement from the pilot's centerline of vision). Distribution will be created by using three different numbers of similar lights (0, 10, 20 lights differing only in color and format) placed in a circular area around the signal with a diameter of 30^{o} visual angle. During the test the cockpit will be changed with respect to the ambient lighting (approximately 0 to 7000 ft-L). In an attempt to simulate the circumstances surrounding the pilot in an aircraft environment, the pilot will be assigned a flight related task (i.e., IFR flight) of medium workload to accomplish simultaneously with detecting signals.

The data from this study will be used to make recommendations on the selection of location and brightness for caution and/or warning signals to be used under different levels of ambient lighting and distracting conditions.

EXPERIMENTAL DESIGN



SCHEDULE

TITLE: CAUTION AND WARNING SYSTEMS DATA BASE AUGMENTATION - VISUAL SYSTEMS

VARIABLES: FALSE SIGNALS x FREQUENCY OF OCCURRENCE x NUMBER OF DISTRACTING SIGNALS x WORKLOAD

PROBLEM: The effectiveness of any visual caution and/or warning system is dependent on the detection and correct interpretation of the signals by the user. Information is required on the effect of certain variables on detection performance and design constraints produced by these variables.

TEST OBJECTIVES:

I Augment the existing data base of information on caution and warning signal detection.

II Provide definitive data on the effect of false signals, frequency of occurrence pilot workload and the number of distracting signals on the detection of visual caution and warning signals.

III Determine the impact of these findings on system design and standardization.

OUTPUT/PRODUCT:

Comparative pilot performance data on caution and warning signals when the surrounding environment is changing as a function of false signals and the number of distracting signals. Interactions of the environment with the amount of pilot workload and the frequency of signal occurrence. Recommendations of signal requirements and design specifications.

DATA MEASUREMENTS:

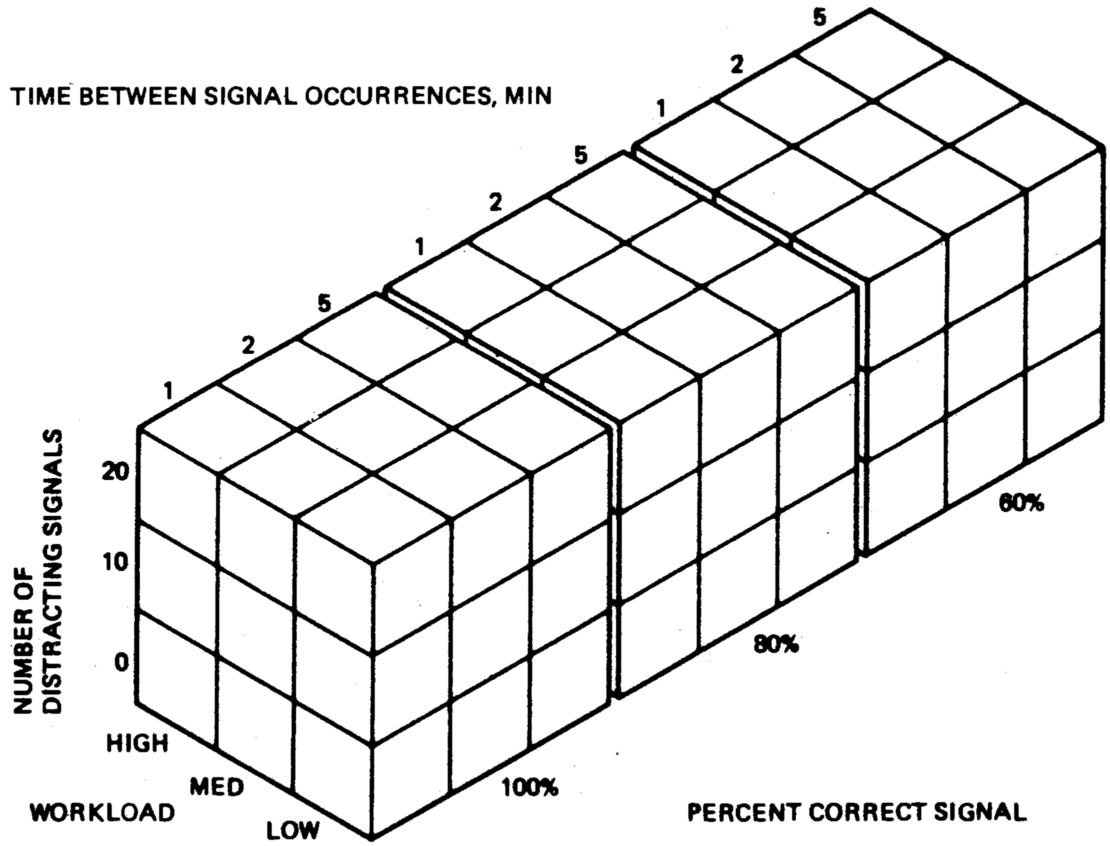
The measurements will describe the time it takes a pilot to detect a signal, the time to respond to the signal and the accuracy of the detection and response.

TEST APPROACH:

This effort will develop empirical statistical data describing caution and warning signal detection performance in an actual cockpit environment. The measurements will be taken in a simulated aircraft cockpit using a signal of moderate intensity (50 ft-L). This signal will indicate a valid warning either 100, 80, or 60 percent of the time and will be activated at either 1, 2 or 5 minute (±30 sec) intervals. Distraction will be created by using 3 different numbers (0, 10 and 20) of similar (differing only in color and format) lights placed in a circular area around the signal with a diameter of 30° visual angle. To simulate the circumstances surrounding the pilot in an aircraft environment the pilots will be assigned flight related tasks (i.e., IFR flight) to accomplish. The workload imposed by these tasks will have 3 levels (high, medium and low). The appearance of the caution and warning signals and the flight tasks will occur simultaneously.

The data from this study will provide guidelines for controlling the environment into which a caution and warning signal light is placed and an assessment of the effect of uncertainty and workload on these situations.

EXPERIMENTAL DESIGN



SCHEDULE

TESTING			ANALYSIS	
WEEK 1	WEEK 2	WEEK 3	WEEK 4	WEEK 5

TITLE: CAUTION AND WARNING SYSTEMS DATA BASE AUGMENTATION - AUDITORY NON-VERBAL SYSTEMS

VARIABLES: NUMBER OF DIFFERENT SIGNALS x FREQUENCY OF OCCURRENCE x WORKLOAD

PROBLEM: The effectiveness of any auditory caution and/or warning system is dependent on the detection and correct interpretation of the signals by the user. Information is required on the effect of certain variables on detection performance and design constraints produced by these variables.

TEST OBJECTIVES:

I Augment the existing data base of information on caution and warning signal detection.

II Provide definitive data on the effect of the number of different signals, frequency of occurrence, and pilot workload on the detection of auditory non-verbal caution and warning signals.

III Determine the impact of the findings on system design and standardization.

OUTPUT/PRODUCT:

Comparative pilot performance data on caution and warning signals which differ as a function of number and frequency. Interaction of different signals with the amount of pilot workload. Recommendations on signal requirements and design specifications.

DATA MEASUREMENTS:

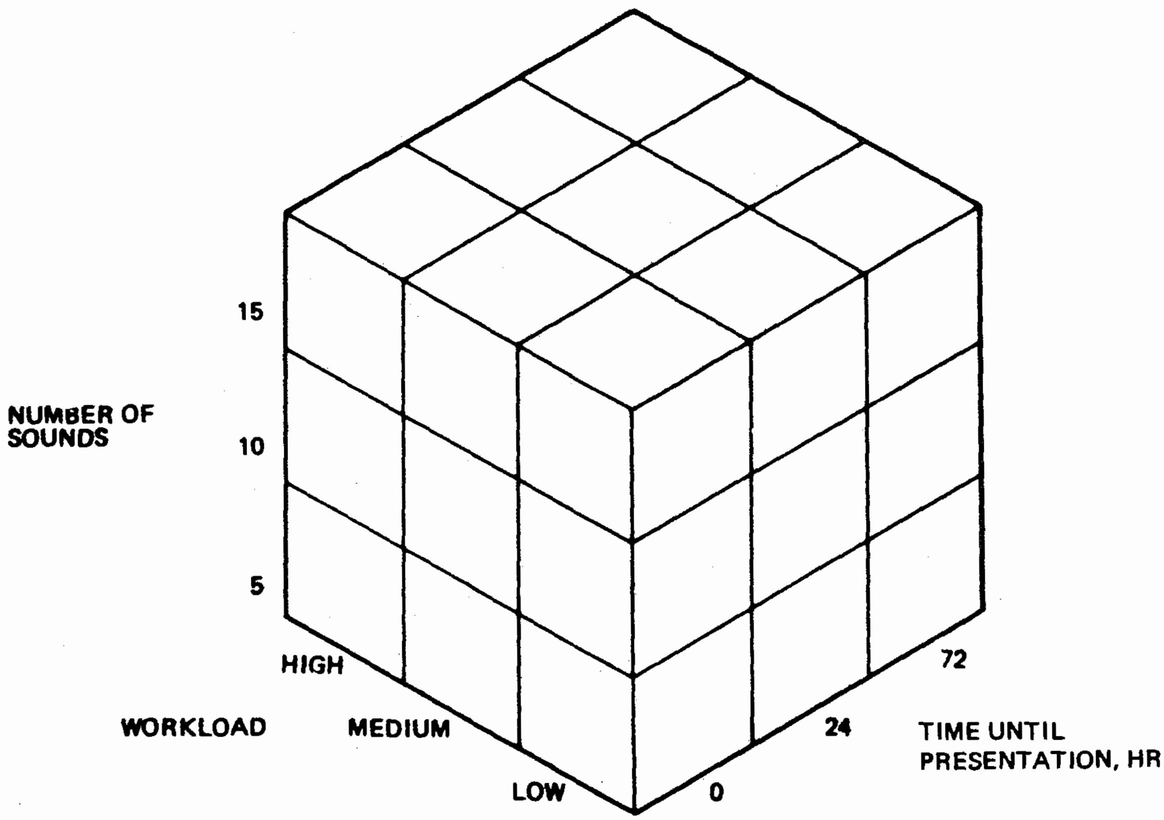
The measurements will describe the time it takes a pilot to detect a signal, the time to respond to the signal and accuracy of the detection and response.

TEST APPROACH:

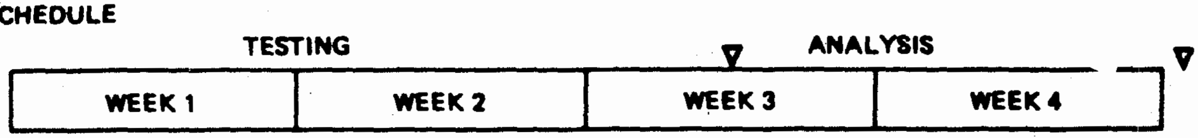
This effort will develop empirical statistical data describing caution and warning signal detection performance in an actual cockpit environment. The measurements will be taken in a simulated aircraft cockpit using a 747 aural warning box to provide discrete caution and warning signals. The pilots will learn to perform specific responses to a number of sounds (either 5, 10 or 15) and will be presented each sound immediately after training for a baseline measure and then again at 24 hours and at 72 hours. To simulate the circumstances surrounding the pilot in an aircraft environment the pilots will be assigned flight related tasks (i.e., IFR flight with ATC) to accomplish. The workload imposed by these tasks will have three levels (high, medium, and low). The caution and warning signals will be presented simultaneously with the flight tasks.

The data from this study will be used to make recommendations on the number of non-verbal auditory caution and warning signals that should be expected to be correctly identified under different workload conditions.

EXPERIMENTAL DESIGN



SCHEDULE



TITLE: CAUTION AND WARNING SYSTEMS DATA BASE AUGMENTATION - AUDITORY NON-VERBAL SYSTEMS

VARIABLES: INTENSITY x SIGNAL TO NOISE RATIO x TYPE OF BACKGROUND NOISE x WORKLOAD

PROBLEM: The effectiveness of any auditory caution and/or warning system is dependent on the detection and correct interpretation of the signals by the user. Information is required on the effect of certain variables on detection performance and design constraints produced by these variables.

TEST OBJECTIVES:

I Augment the existing data base of information on caution and warning signal detection.

II Provide definitive data on the effect of signal intensity, signal to noise ratio, pilot workload and type of background noise on the detection of auditory caution and warning signals.

OUTPUT/PRODUCT:

Comparative pilot performance data on caution and warning signals which differ as a function of intensity and signal to noise ratio. Interactions of different signals with type of background noise and the amount of pilot workload. Recommendations on signal requirements and design specifications.

DATA MEASUREMENTS:

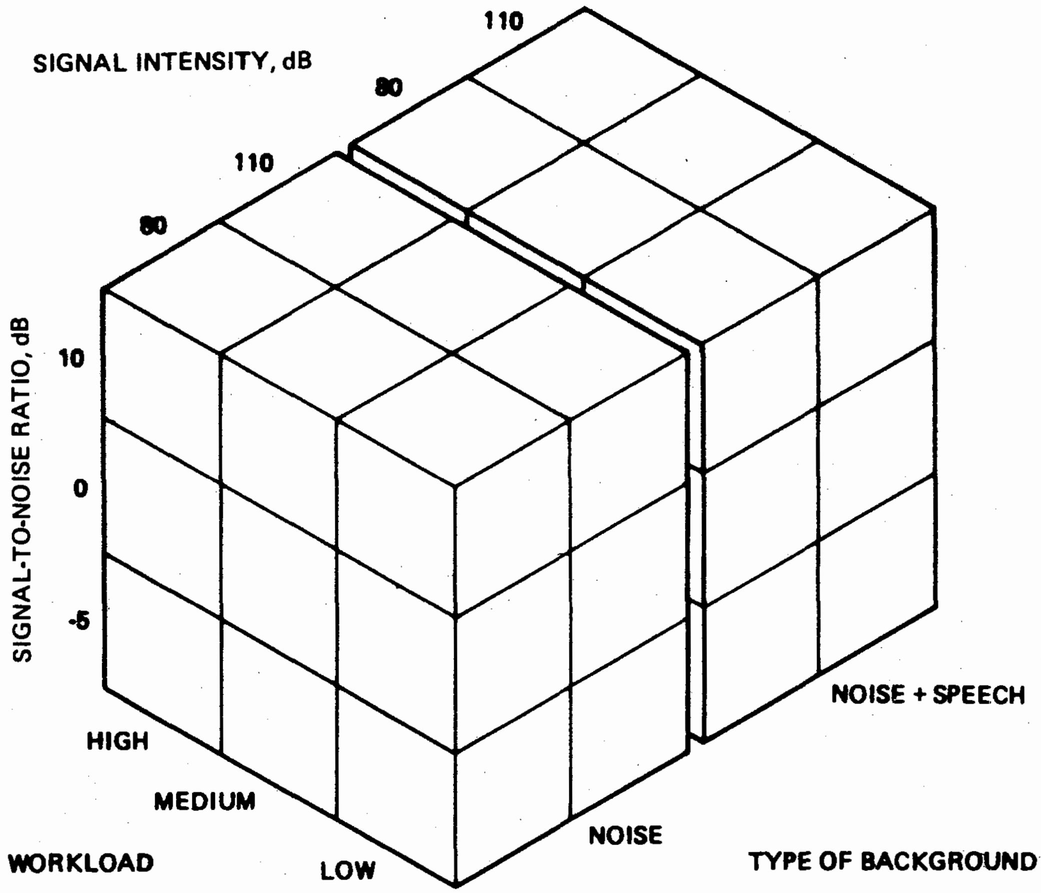
The measurements will describe the time it takes a pilot to detect a signal, the time to respond to the signal and the accuracy of the detection and response.

TEST APPROACH:

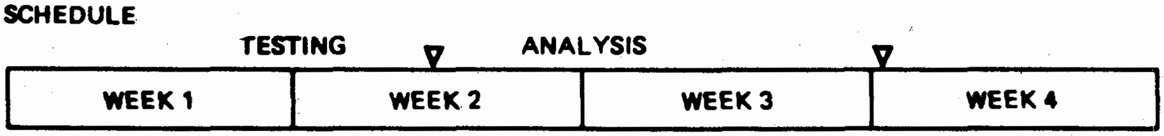
This effort will develop empirical statistical data describing caution and warning signal detection performance in an actual cockpit environment. The measurements will be taken in a simulated aircraft cockpit using a 747 aural warning box to provide discrete warning signals. Using one standard warning signal two different signal intensities (80 dB and 110 dB) will be tested at three different signal to noise intensity levels (-5, 0, and 10 dB). The cockpit environment will also be changed with respect to the type of background noise (aircraft noise, aircraft noise and speech). In an attempt to simulate the circumstances surrounding the pilot in an aircraft environment the pilots will be assigned flight related tasks (i.e., IFR flight) to accomplish. The workload imposed by these tasks will have three levels (high, medium, and low) and the signals will be presented simultaneously with the flight tasks.

The data from this study will be used to make recommendations on the intensity and signal to noise ratio for non-verbal auditory caution and warning signals which are to be used with different types of background noise and under different workload conditions.

EXPERIMENTAL DESIGN



SCHEDULE



TITLE: CAUTION AND WARNING SYSTEMS DATA BASE AUGMENTATION - AUDITORY NON-VERBAL SYSTEMS

VARIABLES: FALSE SIGNALS x FREQUENCY OF OCCURRENCE x LOCATION x WORKLOAD

PROBLEM: The effectiveness of any auditory caution and/or warning system is dependent on the detection and correct interpretation of the signals by the user. Information is required on the effect of certain variables on detection performance and design constraints produced by these variables.

TEST OBJECTIVES:

I Augment the existing data base of information on caution and warning signal detection.

II Provide definite data on the effect of signal location, false signals, pilot workload and frequency of signal occurrence on the detection of auditory caution and warning signals.

III Determine the impact of these findings on system design and standardization.

OUTPUT/PRODUCT:

Comparative pilot performance data on the location of the sound in an auditory non-verbal caution and warning system when the surrounding environment is changing as a function of the number of false signals, the frequency of signal occurrence and the amount of workload imposed on the pilot. Recommendations on signal requirements and design specification.

DATA MEASUREMENTS:

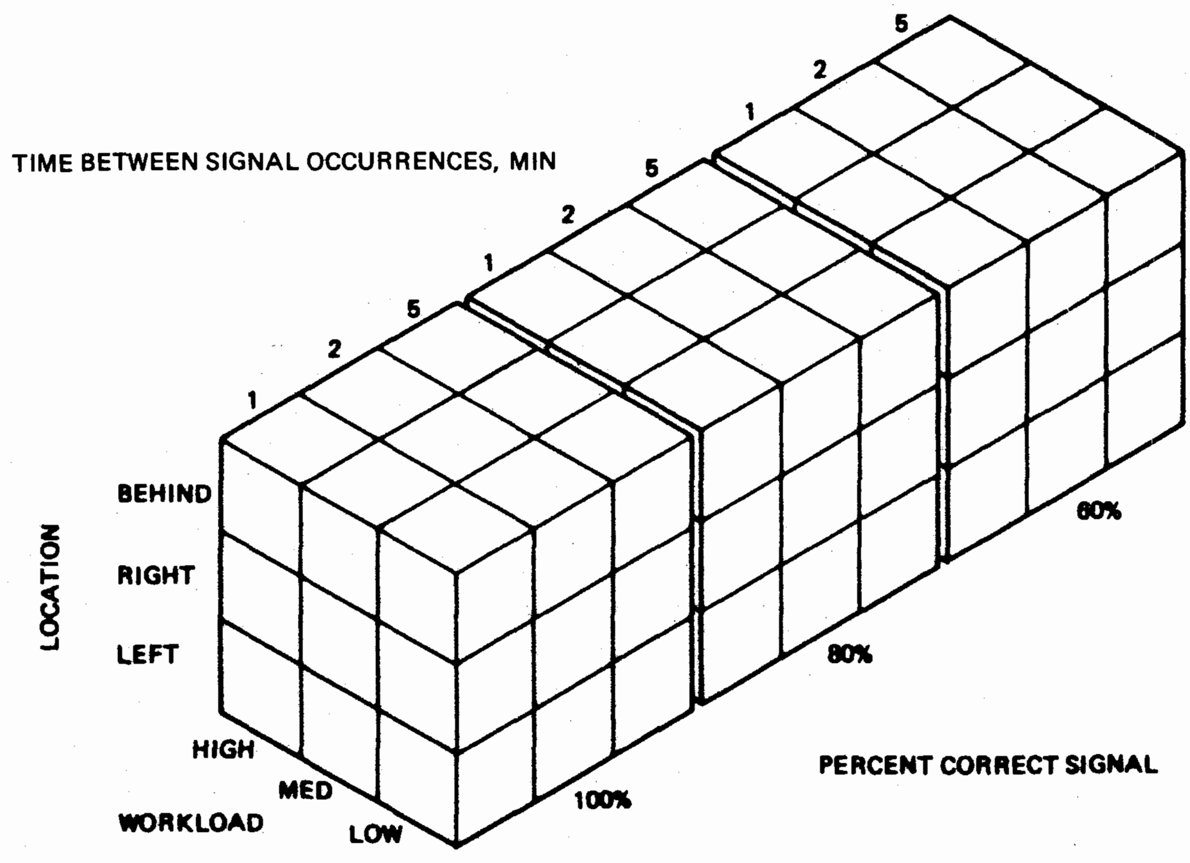
The measurements will describe the time it takes a pilot to detect the signal, the time to respond to the signal and the accuracy of the detection and response.

TEST APPROACH:

This effort will develop empirical statistical data describing caution and warning signal detection in an aircraft environment. The measurements will be taken in a simulated aircraft cockpit using a 747 aural warning box to provide discrete caution and warning signals. A standard aural warning signal will be presented at three different locations (left, right and behind) and at 1, 2 or 5 minute (±3 sec) intervals. This signal will signify a valid warning either 100, 80 or 60 percent of the time. To simulate the circumstances surrounding the pilot in an aircraft environment the pilot will be assigned flight related tasks (i.e., IFR flight with ATC) to accomplish. The workload imposed by these tasks will have three levels (high, medium and low). The signal will be presented simultaneously with the flight task.

The data from the study will be used to make recommendations on the environment in which discrete aural warnings can be used.

EXPERIMENTAL DESIGN



SCHEDULE

TESTING		▼	ANALYSIS	▼
WEEK 1	WEEK 2	WEEK 3	WEEK 4	WEEK 5

TITLE: CAUTION AND WARNING SYSTEMS DATA BASE AUGMENTATION - AUDITORY NON-VERBAL SYSTEMS

VARIABLES: LOCATION x FALSE SIGNALS x TYPES OF BACKGROUND NOISE x NUMBER OF DIFFERENT SIGNALS

PROBLEM: The effectiveness of any auditory caution and/or warning system is dependent on the detection and correct interpretation of the signals by the user. Information is required on the effect of certain variables on detection performance and design constraints produced by these variables.

TEST OBJECTIVES:

I Augment the existing data base of information on caution and warning signal detection.

II Provide definitive data on the effect of signal location, false signals, types of background noise and number of different signals on the detection of auditory and warning signals.

III Determine the impact of these findings on system design and standardization.

OUTPUT/PRODUCT:

Comparative pilot performance data on the location of sound in a auditory non-verbal caution and warning system when the surrounding environment is changing as a function of the type of background noise, the number of different signals and the number of false signals. Recommendations on signal requirements and design specifications.

DATA MEASUREMENTS:

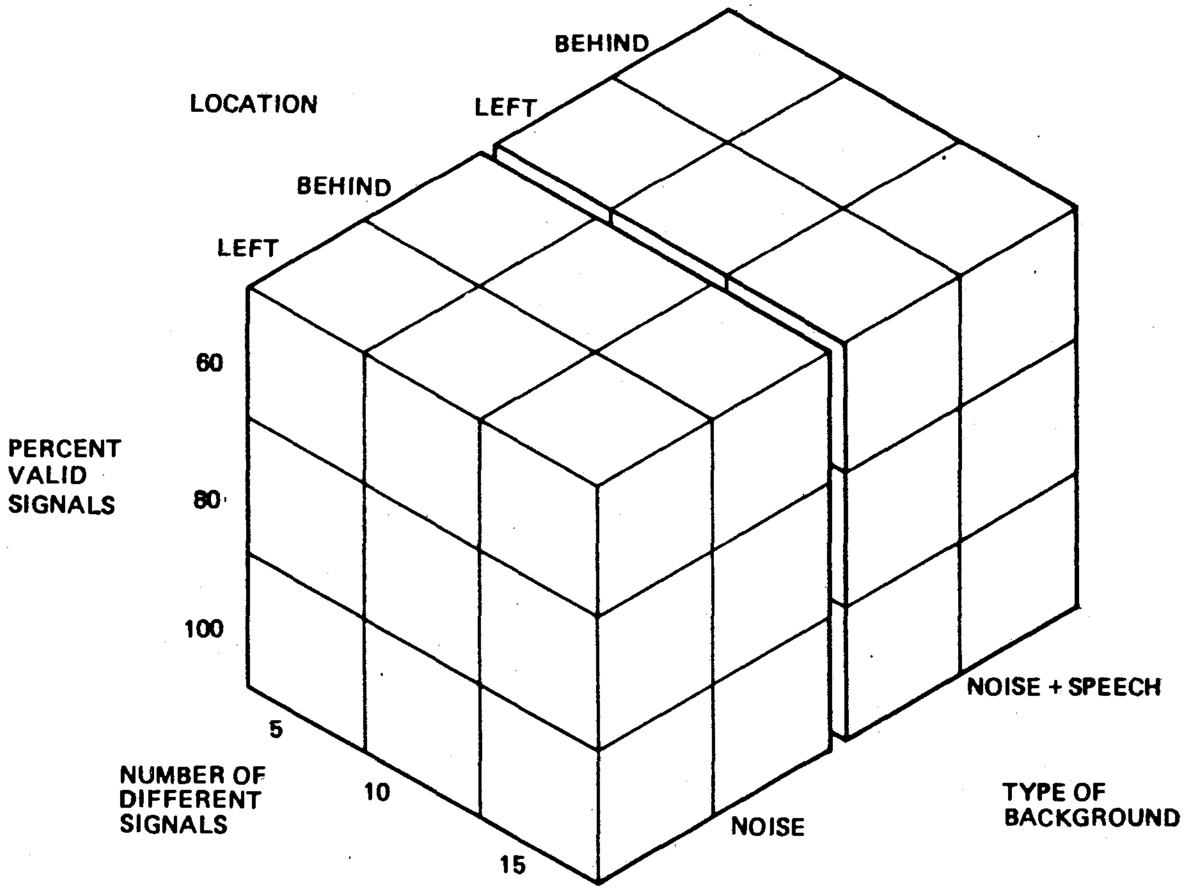
The measurements will describe the time it takes a pilot to detect the signal, the time to respond to the signal and the accuracy of the detection and response.

TEST APPROACH:

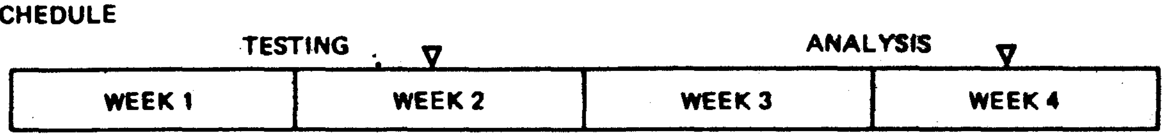
This effort will develop empirical statistical data describing caution and warning signal detection in an actual cockpit environment. The measurements will be taken in a simulated aircraft cockpit using a 747 aural warning box to provide the caution and warning signals. The pilots will learn to perform specific responses to a number of discrete warning signals (either 5, 10 or 15) The aural warning signals will be presented in two locations (left, and behind) and will be a valid warning either 100, 80 or 60 percent of the time. The background noise will either be aircraft noise or aircraft noise combined with speech. To simulate the circumstances surrounding the pilot in an aircraft environment the pilot will be assigned a flight related task (i.e., IFR flight) of medium workload to accomplish simultaneously with detecting the signals.

The data from this study will be used to make recommendations on the environment in which discrete aural warnings can be used.

EXPERIMENTAL DESIGN



SCHEDULE



TITLE: CAUTION AND WARNING SYSTEMS DATA BASE AUGMENTATION - AUDITORY VERBAL SYSTEMS

VARIABLES: SIGNAL INTENSITY, SIGNAL CONTENT, TYPES OF BACKGROUND NOISE

PROBLEM: The effectiveness of any verbal caution and/or warning system is dependent on the detection and correct interpretation of the signals by the user. Information is required on the effect of certain variables on detection performance and design constraints produced by these variables.

TEST OBJECTIVES:

I Augment the existing data base of information on caution and warning signal detection.

II Provide definite data on the effect of signal content, signal intensity, and types of background noise on the detection of verbal caution and warning signals.

III Determine the impact of these findings on system design and standardization.

OUTPUT/PRODUCT:

Comparative pilot performance data on caution and warning signals which differ as a function of content and intensity; and the interactions of different signals with the types of background noise. Recommendations on signal requirements and design specifications.

DATA MEASUREMENTS:

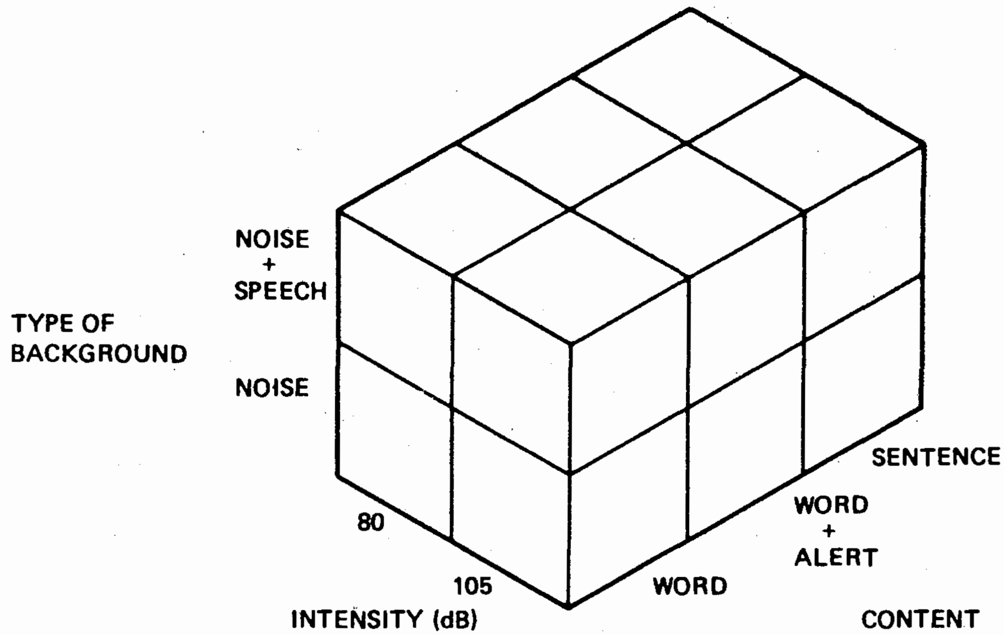
The measurements will describe the time it takes a pilot to detect the signal, the time to respond to the signal, the accuracy of the detection and response and a subjective evaluation of the aesthetic value of the signals.

TEST APPROACH:

This effort will develop empirical statistical data describing verbal caution and warning signal detection and interpretation in a cockpit environment. The measurements will be taken in a simulated aircraft cockpit using a series of messages which will have been previously developed and classified as to their intelligibility. Messages of a medium intelligibility will be presented at different intensities (80 and 105 dB) with the signal to noise ratio being held constant at 15 dB. The messages will be of three types; (1) one or two keywords with short presentation time, (2) the same messages preceded by an alerting signal, and (3) sentences with longer presentation time. The background sound will be either aircraft noise or aircraft noise combined with speech (ATC or weather). To simulate the circumstances surrounding the pilot in an actual aircraft environment the pilot will be assigned a flight related task (i.e., IFR flight) of medium workload to accomplish simultaneously with detecting and interpreting the warning signal.

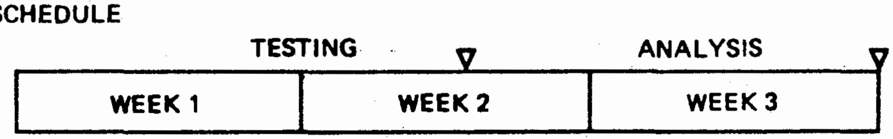
The data from this study will be used to make recommendations on the intensity and content of verbal warnings which are to be used with different types of background sounds.

EXPERIMENTAL DESIGN



4 WARNINGS PER CELL

SCHEDULE



TITLE: CAUTION AND WARNING SYSTEMS DATA BASE AUGMENTATION - AUDITORY VERBAL SYSTEMS

VARIABLES: SIGNAL INTENSITY x SIGNAL CONTENT x PILOT WORKLOAD

PROBLEM: The effectiveness of any verbal caution and/or warning system is dependent on the detection and correct interpretation of the signals by the user. Information is required on the effect of certain variables on detection performance and design constraints produced by these variables.

TEST OBJECTIVES:

I Augment the existing data base of information on caution and warning signal detection.

II Provide definite data on the effect of signal intensity, signal content, and pilot workload on the detection of verbal caution and warning signals.

III Determine the impact of these findings on system design and standardization.

OUTPUT/PRODUCT:

Comparative pilot performance data on caution and warning signals which differ as a function of intensity and content. Interactions of different signals with the amount of pilot workload. Recommendations on signal requirements and design specifications.

DATA MEASUREMENTS:

The measurements will describe the time it takes a pilot to detect the signal, the time to respond to the signal, the accuracy of the detection and response, and a subjective evaluation of the aesthetic value of the signals.

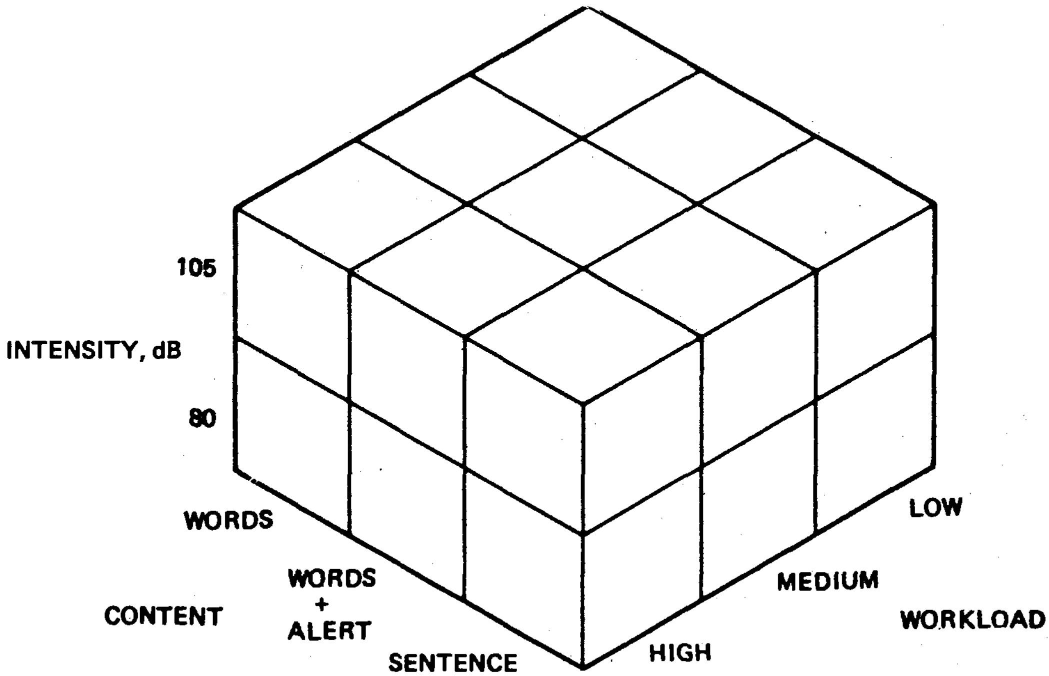
TEST APPROACH:

This effort will develop empirical statistical data describing verbal caution and warning signal detection and interpretation in a cockpit environment. The measurements will be taken in a simulated aircraft cockpit using a series of messages which will have been previously developed and classified as to their intelligibility. Messages of a medium intelligibility level will be presented at either 80 or 105 dB intensity with a constant signal to noise ratio of 15 dB.

These messages will be of three types: (1) one or two key words with a short presentation time; (2) the same messages preceded by an alerting signal; and (3) sentences with the same key words and a longer presentation time. In an attempt to simulate the circumstances surrounding the pilot in an actual aircraft environment, the pilots will be assigned flight related tasks (i.e., IFR flight) to accomplish simultaneously with detecting and interpreting the warning signals. These tasks will impose three levels of workload, (high, medium and low) on the pilots.

The data from this study will be used to make recommendations on the intensity and content of verbal warnings which are to be used under different workload conditions.

EXPERIMENTAL DESIGN



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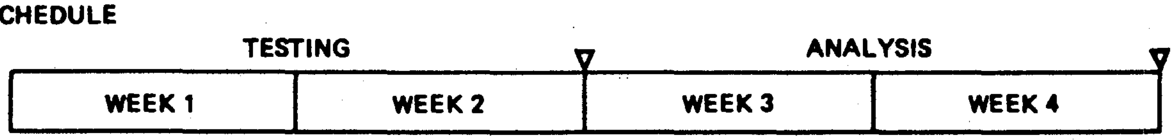


TITLE: CAUTION AND WARNING SYSTEMS DATA BASE AUGMENTATION - AUDITORY VERBAL SYSTEMS

VARIABLES: SIGNAL INTENSITY x VOICE TYPE x MESSAGE INTELLIGIBILITY

PROBLEM: The effectiveness of any auditory caution and/or warning system is dependent on the detection and correct interpretation of the signals by the user. Information is required on the effect of certain variables on detection performance and design constraints produced by these variables.

TEST OBJECTIVES:

I Augment the existing data base of information on caution and warning detection.

II Provide definitive data on the effect of signal intensity, message intelligibility and voice type on the detection of verbal caution and warning signals.

III Determine the impact of these findings on system design and standardization.

OUTPUT/PRODUCT:

Comparative pilot performance data on caution and warning signals which differ as a function of intensity, intelligibility and voice type. Recommendations on signal requirements and design specifications.

DATA MEASUREMENTS:

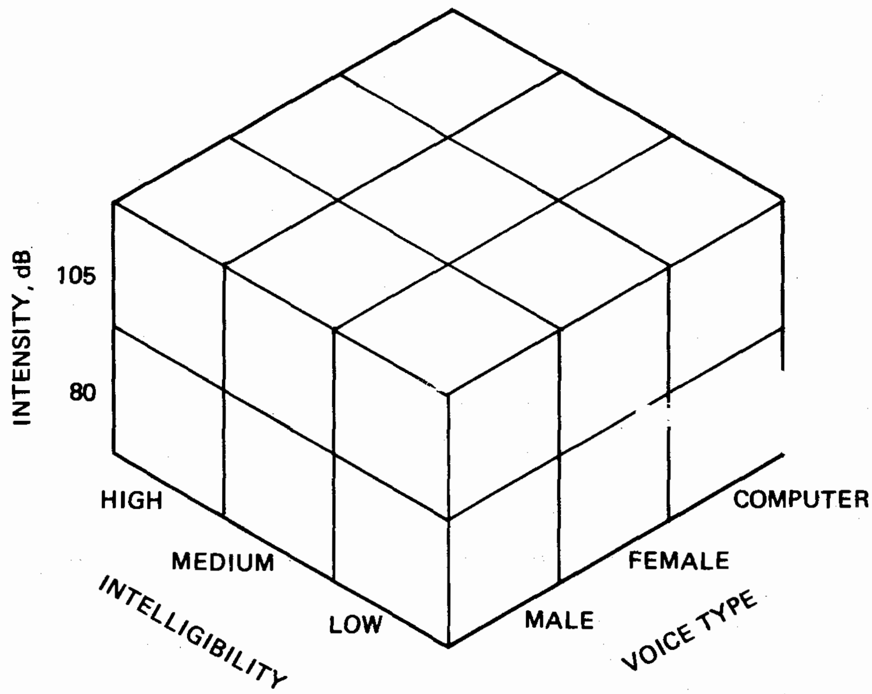
The measurements will describe the time it takes a pilot to detect the signal, the time to respond to the signal, the accuracy of the detection and response, and a subjective evaluation of the aesthetic value of the signals.

TEST APPROACH:

This effort will develop empirical statistical data describing verbal caution and warning signal detection and interpretation in a cockpit environment. The measurements will be taken in a simulated aircraft cockpit using a series of messages which will have been previously developed and classified as to their intelligibility. Messages of three intelligibility levels (high, medium and low) will be presented at two different intensities (80 and 105 dB) with a constant signal to noise ratio of 15 dB. Each message will be recorded three times, once using a male voice, once using a female voice, and once using a computer generated voice. To simulate the circumstances surrounding the pilot in an actual aircraft environment, the pilot will be assigned a flight related task (i.e., IFR flight) of medium workload to perform simultaneously with detecting and interpreting the warning signals.

The data from the study will be used to make recommendations on the intensity, intelligibility and voice type of verbal warnings which are to be used in an aircraft cockpit.

EXPERIMENTAL DESIGN



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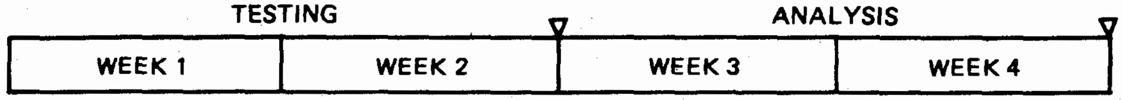


TITLE: CAUTION AND WARNING SYSTEMS DATA BASE AUGMENTATION - AUDITORY VERBAL SYSTEMS

VARIABLES: SIGNAL TO NOISE RATIO x TYPES OF BACKGROUND NOISE x TYPE OF VOICE

PROBLEM: The effectiveness of any verbal caution and/or warning system is dependent on the detection and correct interpretation of the signals by the user. Information is required on the effect of certain variables on detection performance and design constraints produced by these variables.

TEST OBJECTIVES:

I Augment the existing data base of information on caution and warning signal detection.

II Provide definitive data on the effect of voice type, signal to noise ratio, types of background noise on the detection of verbal caution and warning signals.

III Determine the impact of these findings on system design and standardization.

OUTPUT/PRODUCT:

Comparative pilot performance data on caution and warning signals which differ as a function of voice type and the interactions of different signals with the signal to noise ratio and types of background noise. Recommendations on signal requirements and design specifications.

DATA MEASUREMENTS:

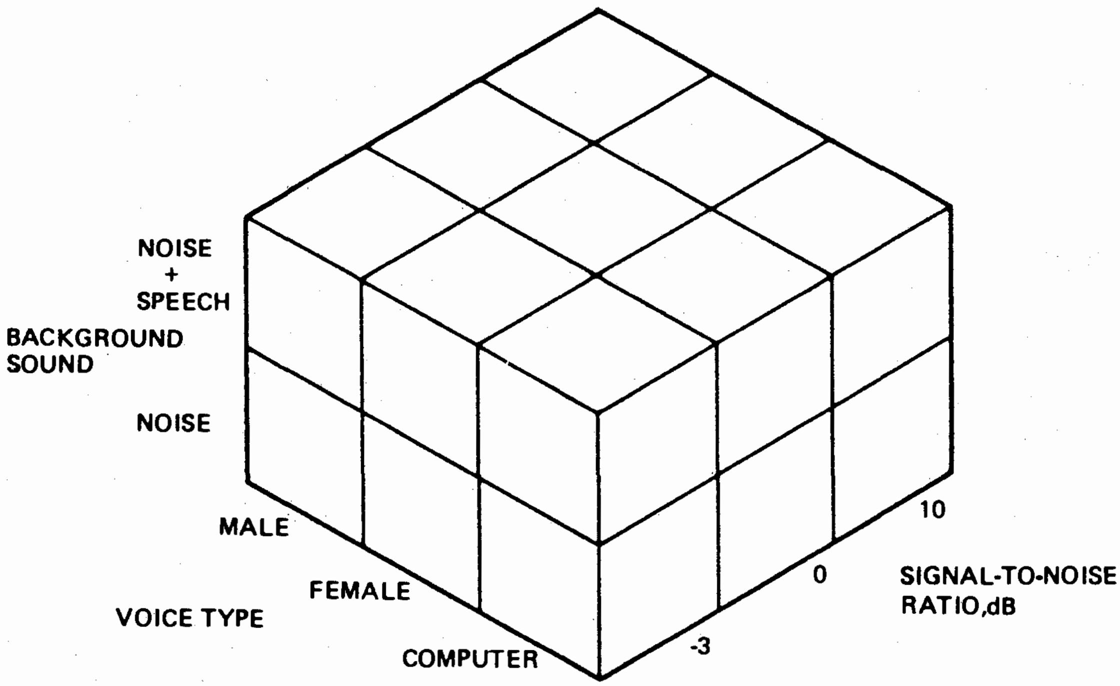
The measurements will describe the time it takes a pilot to detect the signal, the time to respond to the signal, the accuracy of the detection and response, and a subjective evaluation of the aesthetic value of the signal.

TEST APPROACH:

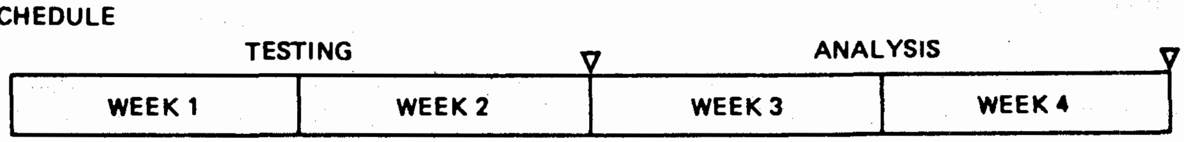
This effort will develop empirical statistical data describing verbal caution and warning signal detection and interpretation in a cockpit environment. The measurements will be taken in a simulated aircraft cockpit using a series of messages which will have been previously developed and classified as to their intelligibility. Messages of a medium intelligibility will be presented at an intensity of 80 dB and the signal to noise ratio will be varied in three levels, (-3, 0 and 10 dB). Each message will be recorded three times, once using a male voice, once a female voice, and once a computer generated voice. The background sound will either be aircraft noise or a combination of aircraft noise and speech (ATC or weather). In an attempt to simulate the circumstances surrounding the pilot in an actual aircraft environment, the pilot will be assigned a flight related task (i.e., IFR flight) of medium workload to accomplish simultaneously with detecting and interpreting the warning signal.

The data from this study will be used to make recommendations on the type of voice presentation in a verbal warning system to be used under conditions of different signal to noise ratios and different types of background sound.

EXPERIMENTAL DESIGN



SCHEDULE



TITLE: CAUTION AND WARNING SYSTEMS DATA BASE AUGMENTATION - AUDITORY VERBAL SYSTEMS

VARIABLES: MESSAGE CONTENT x MESSAGE INTELLIGIBILITY x FAMILIARITY WITH MESSAGE

PROBLEM: The effectiveness of any auditory caution and/or warning system is dependent on the detection and correct interpretation of the signals by the user. Information is required on the effect of certain variables on detection performance and design constraints produced by these variables.

TEST OBJECTIVES:

I Augment the existing data base of information on caution and warning signals detection.

II Provide definitive data on the effect of message content, message intelligibility, and the pilot's familiarity with the messages on the detection of verbal caution and warning signals.

III Determine the impact of these findings on system design and standardization.

OUTPUT/PRODUCT:

Comparative pilot performance data on caution and warning signals which differ as a function of content and intelligibility and the interactions of different signals with the pilot's familiarity with the messages. Recommendations on signal requirements and design specifications.

DATA MEASUREMENT:

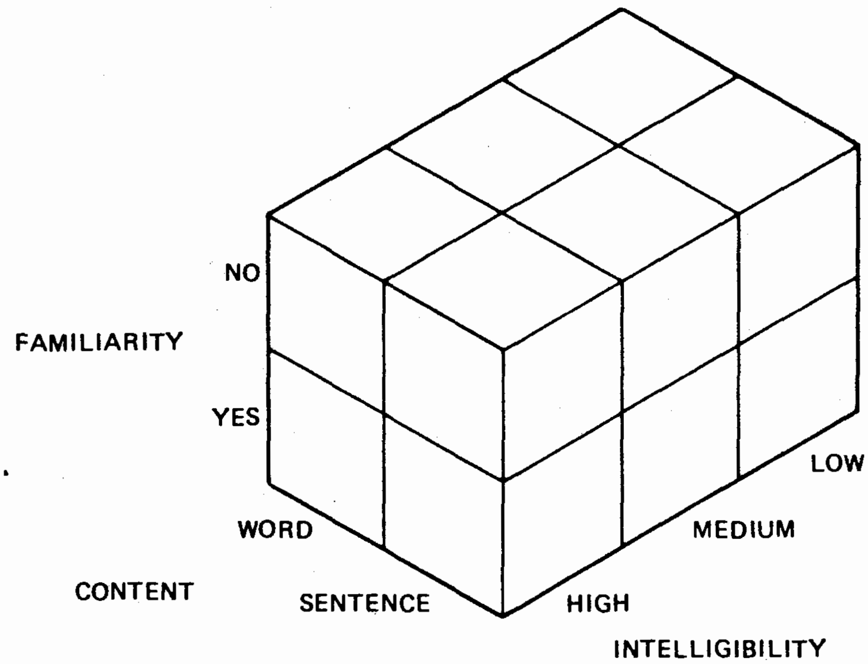
The measurements will describe the time it takes a pilot to detect the signal, the time to respond to the signal and the accuracy of the detection and response.

TEST APPROACH:

This effort will develop empirical statistical data describing verbal caution and warning signal detection and interpretation in a cockpit environment. The measurements will be taken in a simulated aircraft cockpit using a series of verbal messages which will have been previously developed and classified as to their intelligibility. Messages of three intelligibility levels (high, medium and low) will be presented at an intensity of 80 dB and a signal to noise ratio of 15 dB. These messages will be of two types: (1) one or two key words with a short presentation time; and (2) sentences with the same key words and a longer presentation time. Half of the pilots will review the messages before testing to familiarize themselves with the warnings. The other half will not be introduced to the messages until testing. To simulate the circumstances surrounding the pilot in an actual aircraft environment, the pilot will be assigned a flight related task (i.e., IFR flight) of medium workload to perform simultaneously with detecting and interpreting the warning signals.

The data from this study will be used to make recommendations on the content and intelligibility of verbal warnings which are to be used in an aircraft cockpit.

EXPERIMENTAL DESIGN



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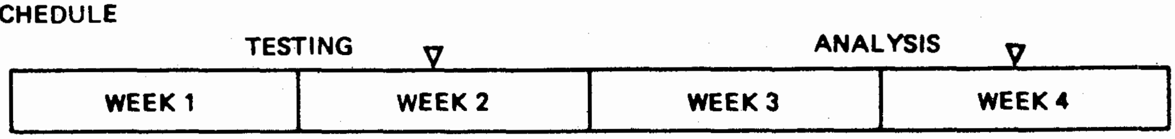


TITLE: CAUTION AND WARNING SYSTEMS DATA BASE AUGMENTATION - AUDITORY VERBAL SYSTEMS

VARIABLES: SIGNAL CONTENT x SIGNAL INTENSITY x SIGNAL TO NOISE RATIO x NUMBER OF FALSE SIGNALS

PROBLEM: The effectiveness of any verbal caution and/or warning system is dependent on the detection and correct interpretation of the signals by the user. Information is required on the effect of certain variables on detection performance and design constraints produced by these variables.

TEST OBJECTIVES:

I Augment the existing data base of information on caution and warning signal detection.

II Provide definitive data on the effect of signal content, signal to noise ratio, and the number of false signals on the detection of verbal caution and warning signals.

III Determine the impact of these findings on system design and standardization.

OUTPUT/PRODUCT:

Comparative pilot performance data on caution and warning signals which differ as a function of content and signal to noise ratio. Interactions of different signals with the number of false signals. Recommendations on signal requirements and design specifications.

DATA MEASUREMENTS:

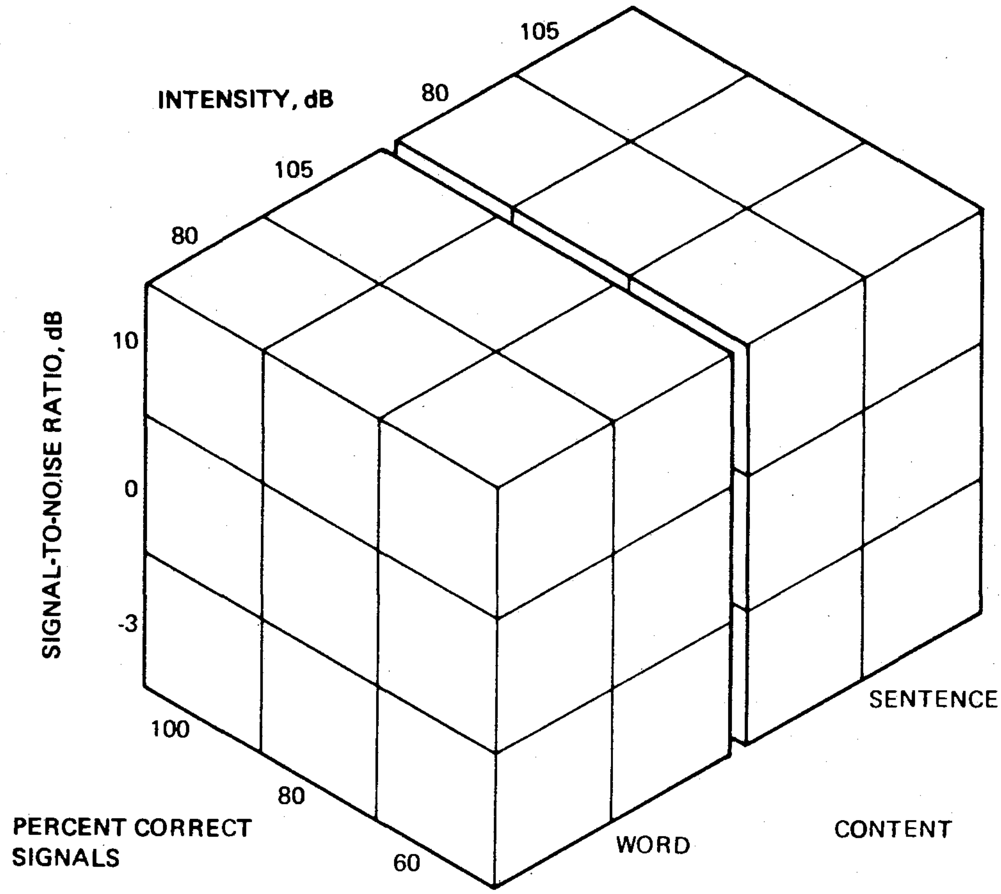
The measurements will describe the time it takes a pilot to detect the signal, the time to respond to the signal and the accuracy of the detection and response.

TEST APPROACH:

This effort will develop empirical statistical data describing verbal caution and warning signal detection and interpretation in a cockpit environment. The measurements will be taken in a simulated aircraft cockpit using a series of messages which will have been previously developed and classified as to their intelligibility. Messages of a moderate intelligibility level will be presented at an intensity of either 80 or 105 dB with a signal to noise ratio of -3, 0, or 10 dB. The messages will be of two types: (1) one or two key words with a short presentation time; and (2) sentences with the same key words and a longer presentation time. The signals that occur will be valid signals either 100, 80 or 60 percent of the time. To simulate the circumstances surrounding the pilot in an actual aircraft environment, the pilot will be assigned a flight related task (i.e., IFR flight) of medium workload to perform simultaneously with detecting and interpreting the warning signals.

The data from this study will be used to make recommendations on the message content and signal to noise ratio for verbal caution and warning messages to be used when there is a possibility of false signals.

EXPERIMENTAL DESIGN



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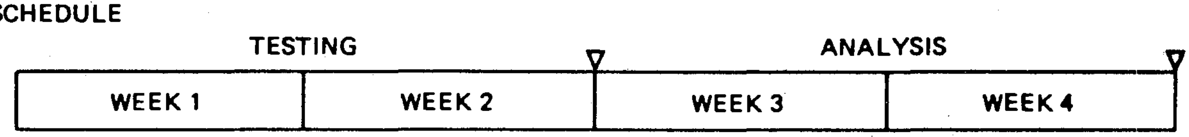


TITLE: CAUTION AND WARNING SYSTEMS DATA BASE AUGMENTATION - AUDITORY VERBAL SYSTEMS

VARIABLES: INTELLIGIBILITY OF MESSAGE x TYPES OF BACKGROUND NOISE x FAMILIARITY WITH MESSAGES

PROBLEM: The effectiveness of any verbal caution and/or warning system is dependent on the detection and correct interpretation of the signals by the user. Information is required on the effect of certain variables on detection performance and design constraints produced by these variables.

TEST OBJECTIVES:

I Augment the existing data base of information on caution and warning signal detection.

II Provide definitive data on the effect of signal intelligibility, type of background noise and the pilot's familiarity with the messages on the detection of verbal caution and warning signals.

III Determine the impact of these findings on system design and standardization.

OUTPUT/PRODUCT:

Comparative pilot performance data on caution and warning signals which differ as a function of intelligibility. Interactions of different signals with the type of background noise and familiarity with the messages. Recommendations on signal requirements and design specifications.

DATA MEASUREMENTS:

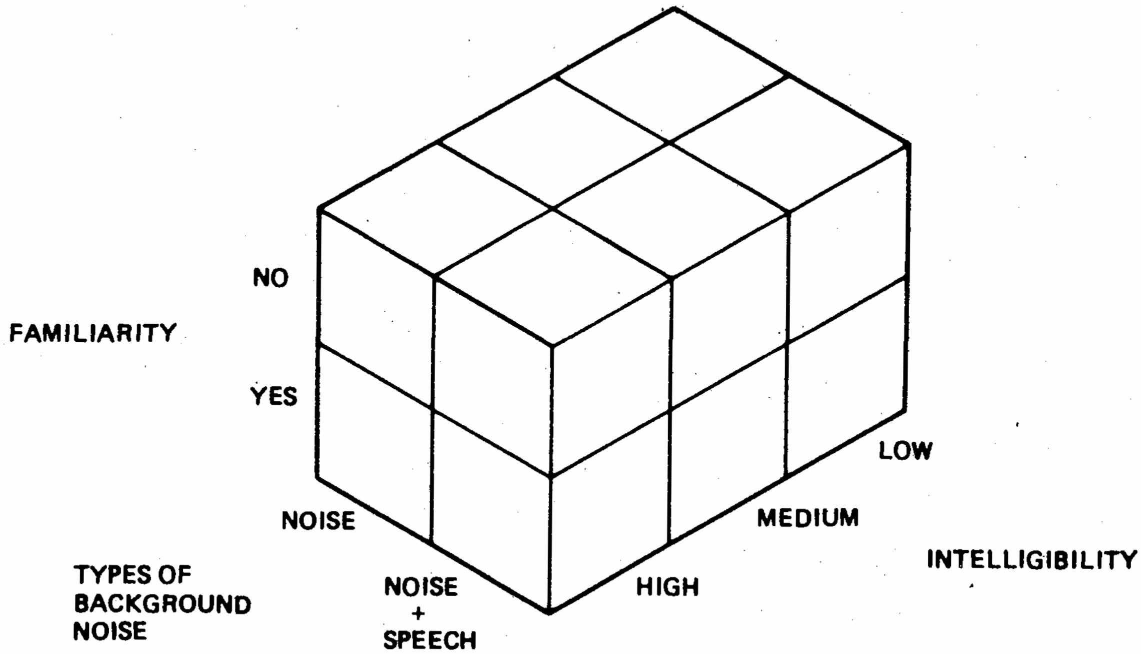
The measurements will describe the time it takes a pilot to detect the signal, the time to respond to the signal and the accuracy of the detection and response.

TEST APPROACH:

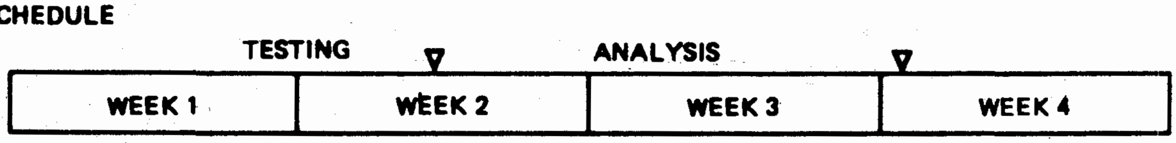
This effort will develop empirical statistical data describing verbal caution and warning signal detection and interpretation in a cockpit environment. The measurements will be taken in a simulated aircraft cockpit using a series of messages which will have been previously developed and classified as to their intelligibility. Messages of three intelligibility levels (high, medium and low) will be presented at an 80 dB intensity and a signal to noise ratio of 15 dB. The background sound will either be aircraft noise or a combination of aircraft noise and speech (ATC or weather). Half of the pilots will review the warning messages before they begin the test, thus familiarizing themselves with the content. The other half will not be introduced to the messages until their test. In an attempt to simulate the circumstances surrounding the pilot in an actual aircraft environment, the pilot will be assigned a flight related task (i.e., IFR flight) of medium workload to perform simultaneously with detecting and interpreting the warning signal.

The data from this study will be used to make recommendations on the content and intelligibility needed for messages to be given with different types of background noise.

EXPERIMENTAL DESIGN



SCHEDULE



TITLE: CAUTION AND WARNING SYSTEMS DATA BASE AUGMENTATION - BIMODAL SYSTEMS

VARIABLES: MODAL PRIORITY x SIGNAL LOCATION x DIFFERENTIAL INTENSITY

PROBLEM: The effectiveness of any bimodal caution and/or warning system is dependent on the detection and correct interpretation of the signals by the user. Information is required on the effect of certain variables on detection performance and design constraints produced by these variables.

TEST OBJECTIVES:

I Augment the existing data base of information on caution and warning signal detection.

II Provide definitive data on the effect of signal location, differential intensity and which signal comes first on the detection of visual and auditory caution and warning signals.

III Determine the impact of these findings on system design and standardization.

OUTPUT/PRODUCT:

Comparative pilot performance data on bimodal caution and warning signals which differ as a function of the modal priority and differential signal intensity. Interactions of different signals with the location of the signals. Recommendations on signal requirements and design specifications.

DATA MEASUREMENTS:

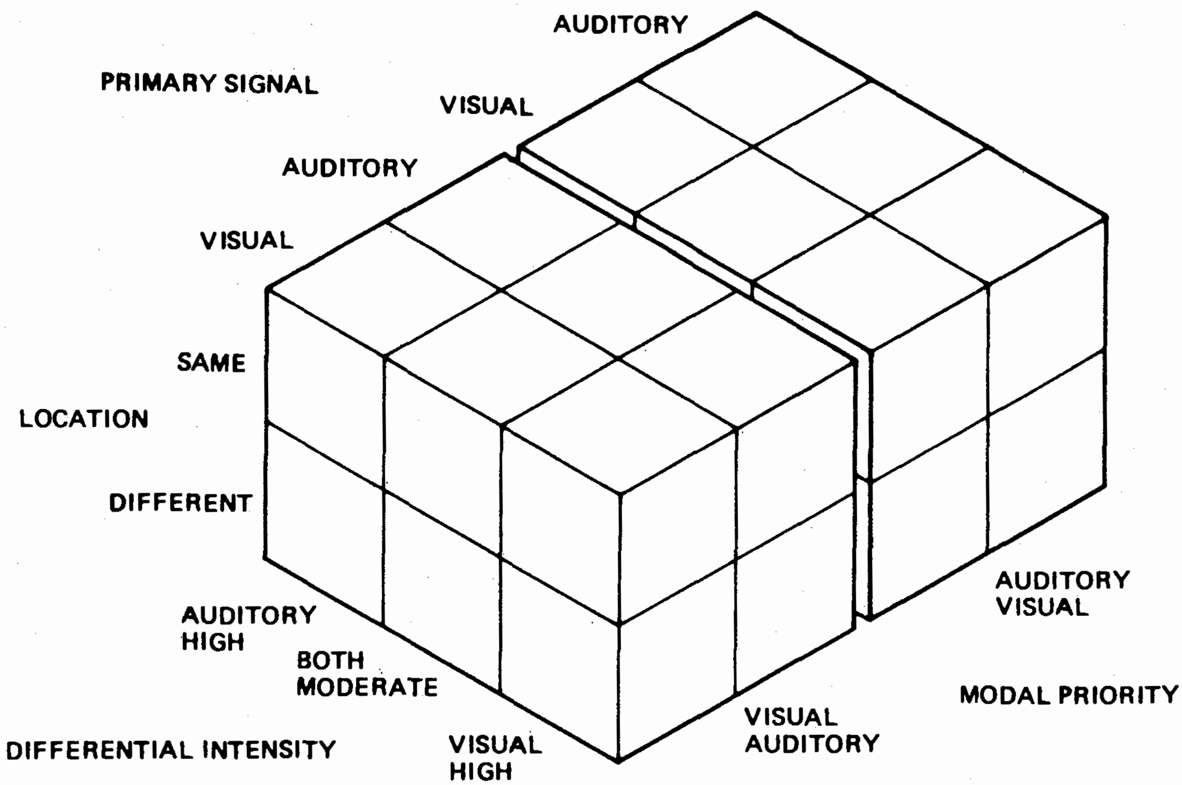
The measurements will describe the time it takes a pilot to detect the signal, the time to respond to the signal, the accuracy of the detection and response and a subjective evaluation of the aesthetic value of the signal.

TEST APPROACH:

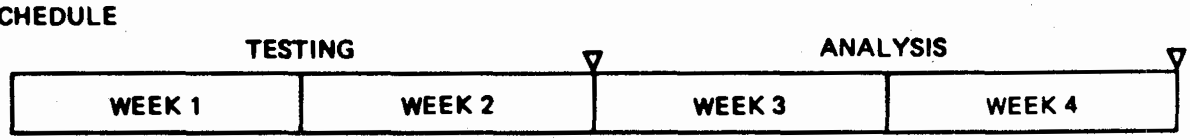
This effort will develop empirical statistical data describing bimodal caution and warning signal detection and interpretation in a cockpit environment. The measurements will be taken in a simulated aircraft cockpit using both visual and auditory warnings. The spatial location of the two signals will be varied so that either the two signals come from the same location or from different locations. The intensities of the two signals will vary such that both signals will be presented at a moderate intensity or either the visual or auditory signal will be at a high intensity and the other at a low intensity. Finally, the order in which the signals will be presented will differ with visual being first half of the time and auditory first the other half. To simulate the circumstances surrounding the pilot in an actual aircraft environment, the pilot will be assigned a flight related task (i.e., IFR flight) of moderate workload to perform simultaneously with detecting and interpreting the warning signals.

The data from this study will be used to make recommendations on modal priority, signal location and intensity for bimodal systems to be used in the cockpit.

EXPERIMENTAL DESIGN



SCHEDULE



TITLE: CAUTION AND WARNING SYSTEMS DATA BASE AUGMENTATION - BIMODAL SYSTEMS

VARIABLES: SIGNAL LOCATION x FALSE SIGNALS x WORKLOAD x PILOT AGE

PROBLEM: The effectiveness of any bimodal caution and/or warning system is dependent on the detection and correct interpretation of the signals by the user. Information is required on the effect of certain variables on detection performance and design constraints produced by these variables.

TEST OBJECTIVES:

I Augment the existing data base of information on caution and warning signal detection.

II Provide definitive data on the effect of signal location, false signals, pilot workload and pilot age intensity on the detection of visual and auditory caution and warning signals.

III Determine the impact of these findings on system design and standardization.

OUTPUT/PRODUCT:

Comparative pilot performance data on caution and warning signals which differ as a function of location and number of false signals. Interactions of different signals with the pilot age and the amount of pilot workloads. Recommendations on signal requirements and design specifications.

DATA MEASUREMENTS:

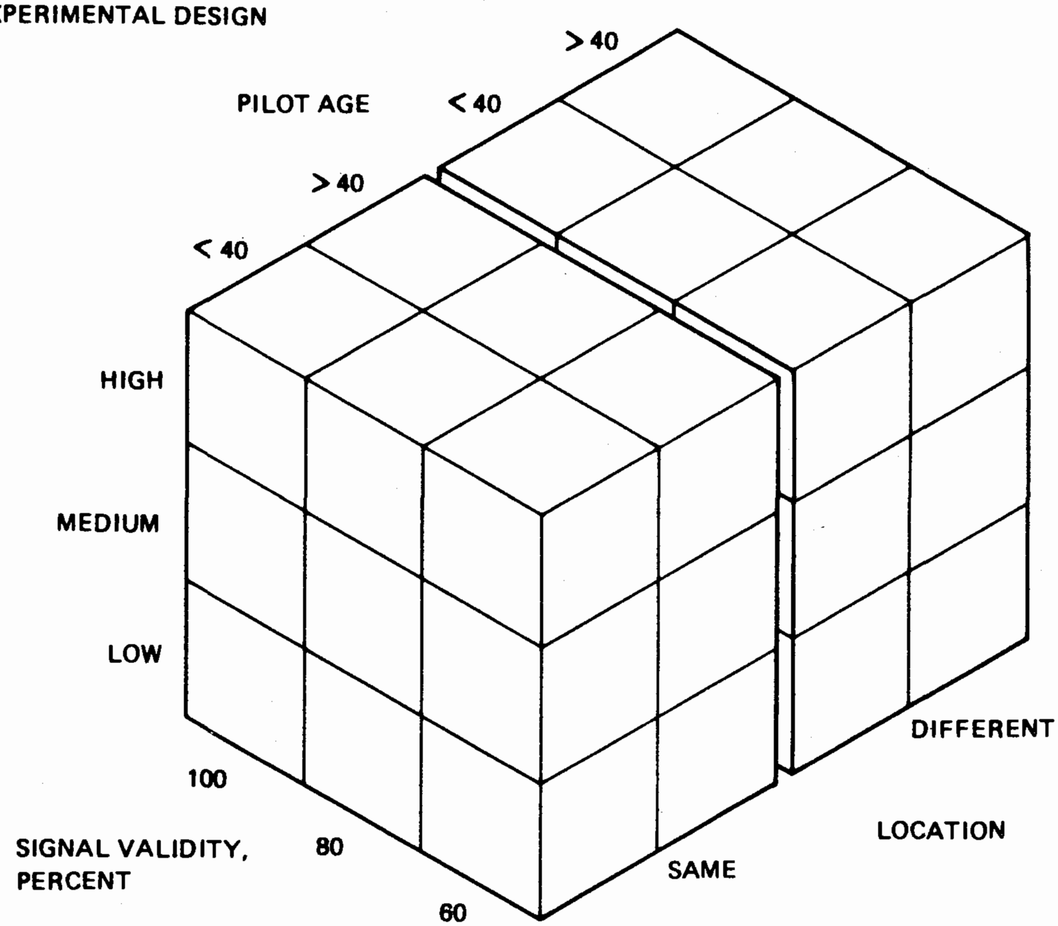
The measurements will describe the time it takes a pilot to detect the signal, the time to respond to the signal, and the accuracy of the detection and response.

TEST APPROACH:

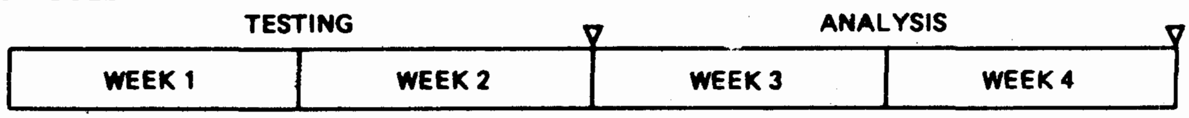
This effort will develop empirical statistical data describing bimodal caution and warning signal detection and interpretation in a cockpit environment. The measurements will be taken in a simulated aircraft cockpit using both visual and auditory warnings. The spatial location of the two signals will be varied so that they either come from the same place or from at least 90^{o} apart. The auditory signal will always be presented first and be the alerting signal to the primary visual signal. The visual signal will be a valid warning 100, 80 and 60 percent of the time. Pilots will be classified as to their age (over 40 and under 40). To simulate the circumstances surrounding the pilot in an actual aircraft environment, the pilot will be assigned flight related tasks (i.e., IFR flight) to perform simultaneously with detecting and interpreting the warning signal. These tasks will be one of three workload levels (high, medium or low).

The data from this study will be used to make recommendations on signal location for bimodal systems to be used under different workload conditions by pilots in different age groups.

EXPERIMENTAL DESIGN



SCHEDULE



TITLE: CAUTION AND WARNING SYSTEMS DATA BASE AUGMENTATION - BIMODAL SYSTEMS

VARIABLES: MODAL PRIORITY x INTERSTIMULUS INTERVAL x SIGNAL DURATION x PILOT WORKLOAD

PROBLEM: The effectiveness of any bimodal caution and/or warning system is dependent on the detection and correct interpretation of the signals by the user. Information is required on the effect of certain variables on detection performance and design constraints produced by these variables.

TEST OBJECTIVES:

I Augment the existing data base of information on caution and warning signal detection.

II Provide definitive data on the effect of the interval between the two signals, which signal comes first, the duration of the signals, and the pilot workload on the detection of visual and auditory caution and warning signals.

III Determine the impact of these findings on system design and standardization.

OUTPUT/PRODUCT:

Comparative pilot performance data on bimodal caution and warning signals which differ as a function of the stimulus duration, the modal priority and interstimulus interval. Interactions of different signals with the amount of pilot workload. Recommendations on signal requirements and design specifications.

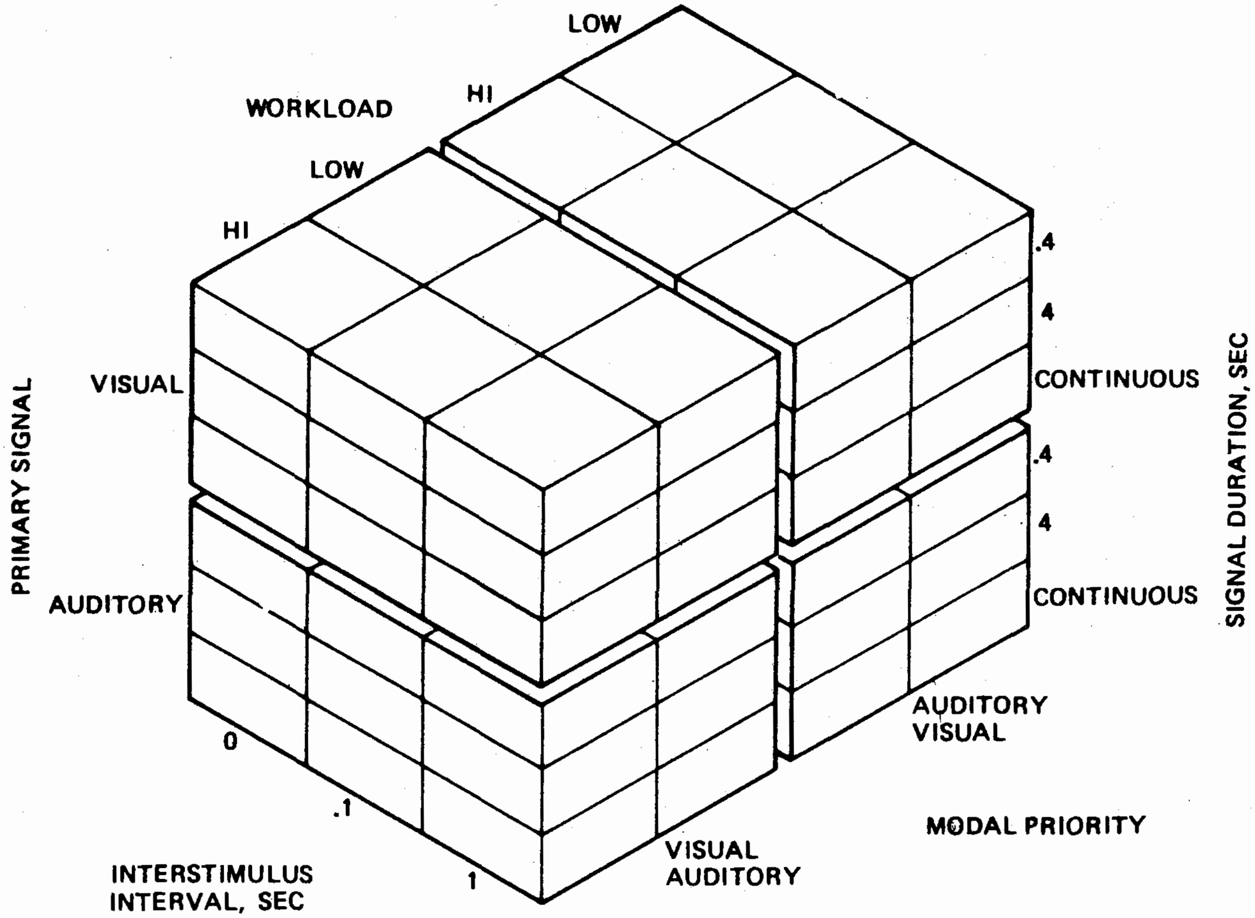
DATA MEASUREMENTS:

The measurements will describe the time it takes a pilot to detect the signal, the time to respond to the signal, the accuracy of the detection and response and a subjective evaluation of the aesthetic value of the signal.

TEST APPROACH:

The effort will develop empirical statistical data describing bimodal caution and warning signal detection and interpretation in a cockpit environment. The measurements will be taken in a simulated aircraft cockpit using both visual and auditory warnings. The visual warnings will be lighted signals of moderate brightness presented in the pilot's natural line of vision while the auditory signal will be of moderate pitch and intensity with a signal to noise ratio of 15 dB. The order in which the signals will be presented will be varied, visual first and auditory second or vice versa with three intervals between the signals (0, 0.1 and 1 sec). For half of the pilots, the visual signal will be the primary warning and the auditory signal will be an alert. This relationship will be reversed for the second half of the pilots. Each signal will be present for one of three durations (0.4 and 4 sec or constantly). To simulate the circumstances surrounding the pilot in an actual aircraft environment, the pilot will be assigned flight related tasks (i.e., IFR flight) to accomplish simultaneously with detecting and interpreting the warning signals. These tasks will impose one of two workload levels (high and low) on the pilots.

EXPERIMENTAL DESIGN



SCHEDULE

TESTING			ANALYSIS	
WEEK 1	WEEK 2	WEEK 3	WEEK 4	WEEK 5

The data from this study will be used to make recommendations on modal priority, interstimulus interval and signal duration for bimodal caution and warning signals to be used under different workload conditions.

TITLE: CAUTION AND WARNING SYSTEMS DATA BASE AUGMENTATION - BIMODAL SYSTEMS

VARIABLES: SIGNAL CONTENT x PILOT WORKLOAD

PROBLEM: The effectiveness of any bimodal caution and/or warning system is dependent on the detection and correct interpretation of the signals by the user. Information is required on the effect of certain variables on detection performance and design constraints produced by these variables.

TEST OBJECTIVES:

I Augment the existing data base of information on caution and warning signal detection.

II Provide definitive data on the effect of signal content and pilot workload on the detection of visual and auditory caution and warning signals.

III Determine the impact of these findings on system design and standardization.

OUTPUT/PRODUCT:

Comparative pilot performance data on caution and warning signals which differ as a function of content; and the interactions of different signals with the amount of pilot workload. Recommendations on signal requirements and design specifications.

DATA MEASUREMENTS:

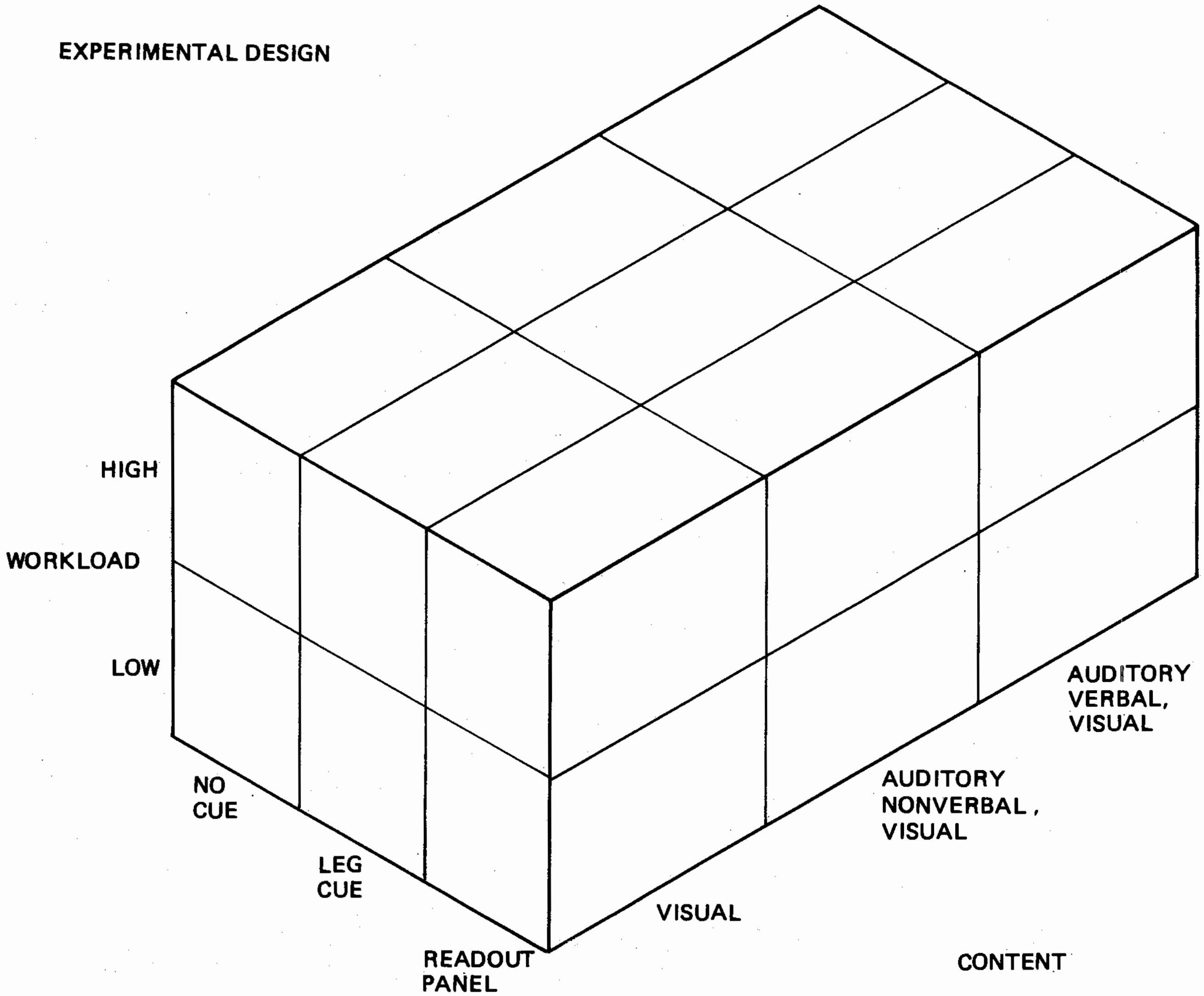
The measurements will describe the time it takes a pilot to detect the signal, the time to respond to the signal, the accuracy of the detection and response and a subjective evaluation of the aesthetic value of the signal.

TEST APPROACH:

This effort will develop empirical statistical data describing bimodal caution and warning signal detection and interpretation in a cockpit environment. The measurements will be taken in a simulated aircraft cockpit using both visual and auditory warnings. The warnings will have three types of content: (1) visual signal tones; (2) auditory non-verbal signal with visual signal; and (3) auditory verbal signal (sentence) with a visual signal. In order to direct the pilot to the correct annunciator panel for response two types of cueing will be tested, (1) a legend cue on the visual signal and (2) an alphanumeric readout panel. To simulate the circumstances surrounding the pilot in an actual aircraft environment, the pilot will be assigned flight related tasks (i.e., IFR flight) to perform simultaneously with detecting and interpreting the warning signals. These tasks will impose one of two workload levels (high or low) on the pilot.

The data from this study will be used to make recommendations on the signal content for bimodal systems to be used under different workload conditions.

EXPERIMENTAL DESIGN



SCHEDULE

TESTING		ANALYSIS	
WEEK 1	WEEK 2	WEEK 3	WEEK 4

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