Design Criteria for Aircraft Warning, Caution, and Advisory Alerting Systems

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An overbundance of warning, caution, and advisory alerts will exist in the cockpits of future commercial transport aircraft if current cockpit design trends are not altered. Coupled with this proliferation of alerts is a lack of correlation between alert-type applications and significance. The potential for pilot saturation and/or confusion exists with these alerts. A study was performed for the FAA to identify these problem areas and to develop design guidelines for alerting systems in new aircraft. Recommendations resulting therefrom include: 1) improve pilots' audio/visual environment by minimizing exposure to unnecessary alerts; 2) incorporate central alphanumeric alert readout devices; and 3) improve categorization and/or prioritization of alerts.

I. Introduction

PILOTS of the latest generation of commercial transport aircraft are pressing the FAA and airframe manufacturers into developing warning/caution/advisory systems design criteria that will curtail the trends within this system toward more complexity and detail as each new generation of aircraft emerges. These pilots have seen the number of visual alerts incorporated into cockpits double since the advent of the commercial jet transport. Concurrently, the number of flags has approximately doubled and the number of aural signals has increased approximately 50%.

These pilots also have observed a transition from relatively simple uncluttered cockpits to space-saturated cockpits. No more space is available for instrumentation. Multifunctioning of alerting and display devices is now being used to get around the space restriction possibly creating additional operational complexity for the pilots.

An overview of this situation indicates a trend toward pilot saturation and possibly confusion. We have not reached that point yet, as attested to by the airline industry's excellent safety record. However, based on the number and type of pilot complaints being received, we are near the break point. No one knows exactly where that point lies, but if these trends continue, we will have an unacceptable cockpit.

This paper discusses the nature and magnitude of these problems and presents preliminary guidelines for avoiding similar problems with the next generation of aircraft.

II. Characteristics of Current Alerting Systems

The discussion in this paper will depend heavily on the following terms: alert, alerting function, alerting devices, warning, caution, and advisory. Definitions are probably in order. An "alert" is the activation of any aural alarm, indicator light, or flag used to make the pilots aware of a particular situation. The term also 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: fire-engine 1, fire-engine 2, and fire-engine 3. "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. 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. Each aircraft type has fewer physical alerting devices than alerting functions.

The terms "warning," "caution," and "advisory" identify the three alert classifications used to analyze the type of alerts applied to each operational situation or aircraft system malfunction. Definitions of these terms are provided in Table 1.

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

Historical Application of Alerts†

Comparison of the total number of visual alerting functions used on each type of aircraft provides an overview of the current situation. Figure 1 shows that the number of alerting functions incorporated into the cockpit varies as a function of design vintage and aircraft size, i.e., wide body vs narrow body. The 727, DC-9, and 737 were designed several years after the 707 and DC-8 and, in general, have fewer systems than the 707 or DC-8. Yet 727, DC-9, and 737 aircraft utilize as many or more alerting functions than the larger but earlier designed aircraft. It also is interesting to note that in the wide-body aircraft the number of alerting functions is approximately twice the number found in narrow-body aircraft.

Each generation of new aircraft had to comply with additional regulatory requirements that mandated more alerts in the cockpit, incorporated more complex flight control and autopilot systems to cope with Categories II and III landing weather conditions, and incorporated more maintenance-oriented alerts into the cockpit to cope with the airlines' escalating maintenance costs. The increased use of more complex, but lighter systems, on the wide-body aircraft in particular, also contributed to the increased number of alerting functions.

The historical application of various types of alerts is portrayed in Figs. 2-4. Figure 2 indicates that the number of warning-type alerting functions increased, but not significantly. However, the number of cautions and advisories did increase significantly with the introduction of wide-body

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†Data source: Flight operation manuals and manufacturers' design data for at least one airline configuration of each model aircraft.

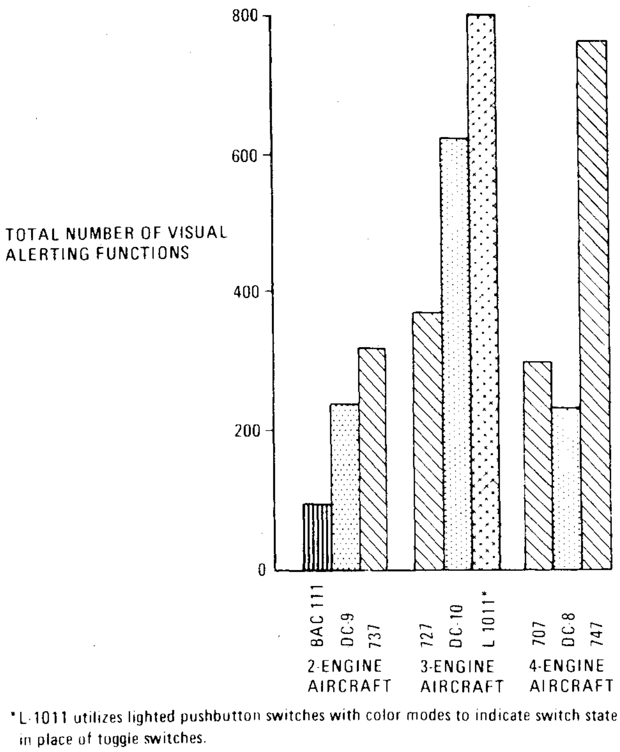
Table 1 Alert-type classification

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	Green, blue, or white lights, flags or bands

aircraft. These data again reflect the increased emphasis airlines placed on the acquisition and displaying of more detailed maintenance-oriented data in the cockpit.

The aircraft historical data presented in Fig. 3 indicates that among the narrow-body aircraft no significant change occurred in the number of alert lights, aurals, flags, or bands. Aircraft size, types of operation, and vintage had no effect on the design of alerting systems during their design 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 is generally decreasing. Individual alert lights were used in place of most bands on the 747 and the L-1011.

The historical application of the colors red, amber, green, blue, and white is portrayed in Fig. 4. Red, fire orange, and dayglow orange colored alerts are generally used to present warnings; amber and yellow colored alerts are used to present cautions; blue, green, or white colored alerts are used to present advisory and status indications. More specifically, blue alerts usually indicate that something is in-transit; green alert usually indicate that a system is operating satisfactory and/or has attained a SAFE/GO status; white alerts usually indicate a system is ON. Analyses of these data revealed significant trends toward more amber/yellow 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. Traditional red and green bands are being replaced by amber lights.



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

Fig. 1 Number of visual alerting functions on each basic aircraft type.

With the emphasis airlines have recently placed on presenting more detailed subsystem information to the crew, all aircraft systems should show increased dependence on discrete alerting functions. However, the bulk of the proliferation of alerts can be attributed to the operating and design philosophies applied to only a few systems. Figure 5 indicates that the most rapid growth in the number of subsystem alerts has occurred in the automatic flight control system (AFCS) and the electrical system.

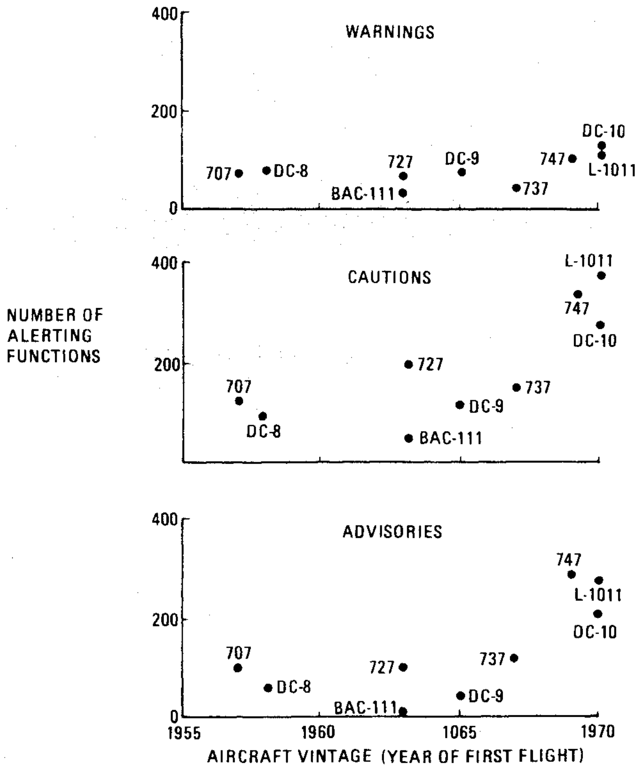


Fig. 2 Application of alerts as a function of operational significance and aircraft vintage.

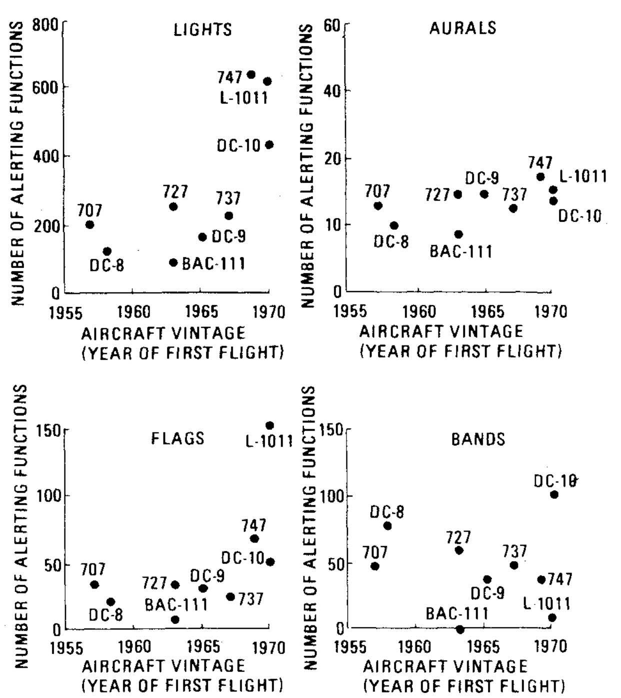


Fig. 3 Application of alerting devices as a function of aircraft vintage.

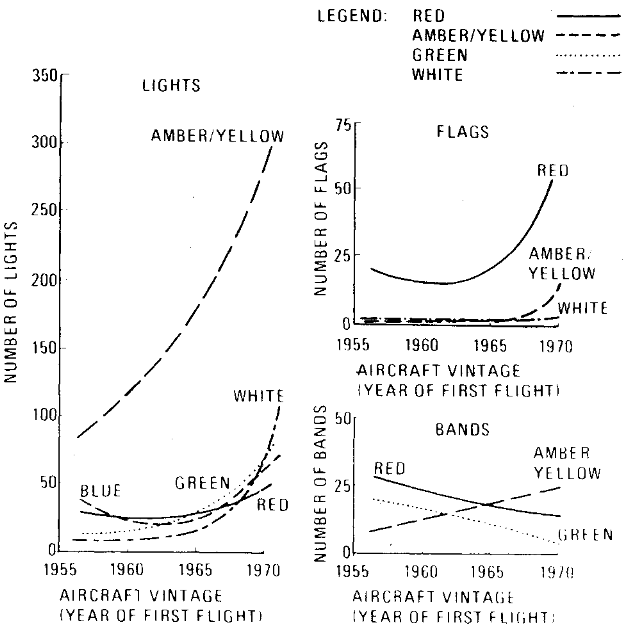


Fig. 4 Application of alert colors as a function of aircraft vintage.

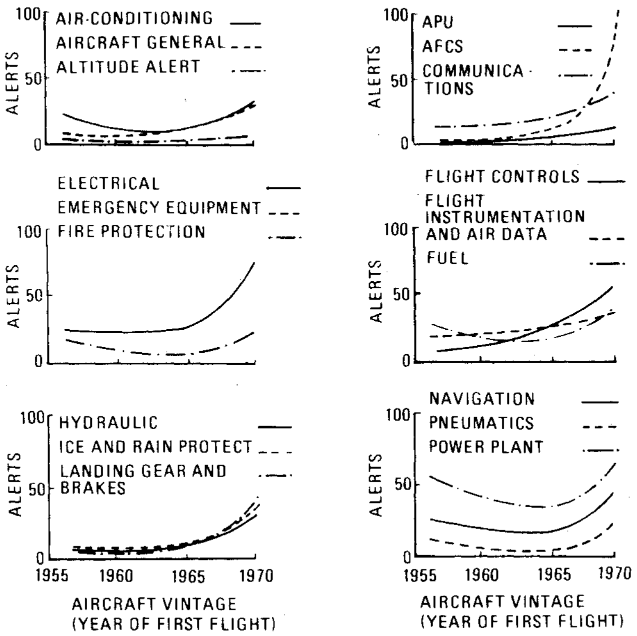


Fig. 5 Growth history of subsystem alerts.

Secondary offenders, if these systems can be called such, are: hydraulics, ice and rain protection, landing gear and brakes, navigation, and pneumatics.

Subsystems in which negligible growth in the number of alerts has occurred are: air-conditioning, altitude alert, auxiliary power unit (APU), communications, emergency equipment, flight instruments and air data, fuel, and powerplant.

These data are influenced somewhat by 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 air-conditioning systems have retained dial-type indicators without alert bands as the primary method of presenting information. 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.

Efficiency Enhancement Features

Four secondary alerting system characteristics that influence the efficiency of the system are: master alerts, central alert annunciation panel, prioritization of alerts, and inhibiting of selected alerts during certain flight phases. All four of these features enhance the pilot's ability to detect, identify, and react to alerts in the cockpit.

Master alerts usually consist of one or two lights located in each crewmember's primary field of view. High-priority red alerts trigger a master warning light and high-priority amber alerts trigger a master caution light. These master alerts work well as attention-getters and urgency-identifiers.

The central alert annunciation panel usually consists of a block (matrix) of lights that specify the exact nature of the alert. In some aircraft, these annunciations are repeats of alerts activated on the subsystem panels; in other aircraft, these alerts are the only indications of the alerted situation; i.e., no alert on subsystem panel. These central annunciators help the crewmembers identify the urgency and exact nature of the alert.

Prioritization of alerts exists in two forms: 1) grouping of the alerts into criticality categories, e.g. warning, caution, advisory, etc., and 2) ranking the importance of the alert so that when several alerts are activated simultaneously the more urgent alert suppresses, partially or completely, the less urgent alerts. Prioritization promotes consistency of application of alert types and enhances the pilot's ability to focus on the most urgent problem.

Alert inhibits are used on all modern commercial transport aircraft to minimize nuisance actuations of configuration-related alerts, particularly the aural alerts associated with inadequate/unsafe configurations of flaps, landing gear, etc. However, very few aircraft utilize inhibits to suppress nuisance subsystem fault alerts during high-workload periods. Alert inhibits help minimize disturbing the pilots with nuisance alerts and aid the flying pilot, in particular, to concentrate on critical flying tasks, i.e., unburdens him from nonurgent subsystem management tasks during high-workload (flying) periods.

Some aircraft have these features in their alerting systems, others do not. Table 2 identifies the aircraft having these alerting system efficiency enhancement features. The important factor to note in these data is the number of aircraft that do not have these efficiency enhancement features.

Table 2 Application of alerting system efficiency enhancement features

Aircraft type	Master alerts signal: Warning	Master alerts signal: Caution	Central alert	Alert prioritization	Subsystem fault alert inhibits
707					
727				x[a]	
737		x	x	x[b]	
747			x		
DC-8	x				
DC-9	x	x	x		
DC-10	x	x	x		x[c]
L-1011			x		
BAC-111	x				

[a] Aural alert prioritization used by only several small operators

[b] Aural alerts prioritized on 737's using the electronic aural warning system. Aircraft equipped with electromechanical aural warning systems do not have prioritization.

[c] DC-10 inhibits master warning and master caution lights, amber autopilot out-of-trim and disconnect lights, and amber autothrottle disengage lights when below 100 feet radio altitude in dual autoland operations.

Summary of Current Alerting System Characteristics

In summary, the following alerting system characteristics were particularly noted in the analyses of these data:

1) Each new aircraft has incorporated more alerting functions than previous similar aircraft due to: a) differences in the operators' alerting system utilization philosophies, b) differences in the airframe manufacturers' cockpit design philosophies, c) additional regulatory requirements, d) increased size of the later design aircraft, and e) use of more complex systems to save weight.

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

3) Most rapid growth in the number of subsystem 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.

III. Derivation of Requirements for Future Systems

The derivation of requirements for alerting systems was oriented strictly toward new aircraft implementation. Retrofit was not considered because the safety record of the existing aircraft fleet does not justify major changes in equipment, training, etc. Specification of precise requirements also was not considered practical because the configuration and operating characteristics of commercial transport aircraft vary greatly. To accommodate these variations, some design latitude/flexibility must be allowed in the requirements. Thus, these requirements are aimed at developing an umbrella of requirements within which multiple near-optimum alerting system concepts can be implemented.

To develop the requirements umbrella, a pilot survey and the following sequence of analyses were necessary:

1) Define categories of alerts.

2) Define types of alerts that apply to each category.

3) Define flight phases that signify gross changes in the crew's workload level or in the type of tasks the pilot must perform.

4) Categorize alerts as a function of flight phase.

5) If necessary, prioritize the alerts within these categories.

Pilot Survey

The pilot 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. Pilot concensus was noted on the following issues relevant to the design of alerting systems:

1) Reduce the number of alerts, especially the number of aural alerts.

2) Most aural alerts, as currently designed, are too loud.

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

4) Selected alerts should be prioritized.

5) Audio-visual characteristics of the alerts should be designed to instantaneously inform the pilot of the criticality of the situation.

6) Direct correlation between the type of alerts and the type of checklists should be established, i.e., warnings and emergency checklists, cautions and abnormal checklists, etc.

The pilots unanimously agreed that any further increase in the number of aural alerts would not be acceptable. The potential for pilot confusion already exists with the number of aural alerts used in modern cockpits. Reduction of the number of aural alerts to one, if possible, is desirable. The number of aural alerts acceptable to most pilots is four. If four aural alerts are used, they must be four familiar alerts.

The intensity of many currently used aural alerts is high. Most aural alerts are so loud that normal crew coordination is difficult. Their intensity should be reduced in future cockpits and/or a manual cutoff capability should be provided for *all* aural alerts in the cockpit. (Several engineering organization representatives disagreed with the requirement for manual cutoff capability of *all* aurals alerts.)

Many of the pilots felt that the potential for too many nonurgent alerts exists in the critical operating regimes, wherein the crew cannot afford to divert their attention from the primary flying tasks. The pilots were particularly concerned about distracting alerts during takeoff (from slightly below V_1 through climb to several hundred feet altitude) and landing (from 200-ft altitude through braking and thrust reverse). An inhibit scheme of the type shown in Fig. 6 was suggested.

Inhibits also were suggested for the following purposes:

1) Minimize nuisance alerts by inhibiting appropriate sections of the alerting system in flight phases wherein the alert has no meaning.

2) Override background noise, such as radio chatter, that interfere with aural alerts.

3) Develop a method of prioritizing alerts.

Selective 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.

A majority of 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. Selected alerts within each category also should 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, but used sparingly. The priority of the alerts will vary from one aircraft to another. Accordingly, variable prioritization capability should be provided.

The pilots favored limited application of alert prioritization; however, they could do 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, or combination audio-visual method of alerting should be associated with each priority category so as to provide instantaneous definition of the situation's criticality. Current alerting systems do not provide this information, thereby necessitating 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

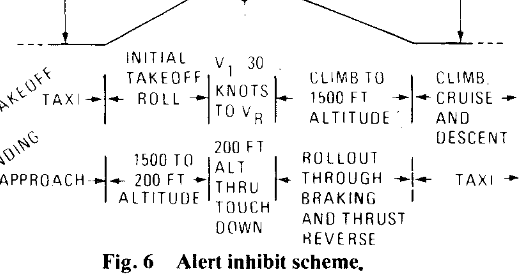


Fig. 6 Alert inhibit scheme.

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

Alert Category Definition

Category definition based on the urgency of crew action and crew awareness were developed in conjunction with the SAE S-7 committee for Flight Deck and Handling Qualities Standards for Transport Category Aircraft. A synopsis of these definitions is provided in Table 3.

Type of Alerts Applicable to Each Category

The application of various types of alerts should meet the following criteria:

1) Latest human factors guidelines are used in conjuction with tradition considerations to select types of alerts applying to each category.

2) A unique type of alert or combination of types of alerts is associated with each alert category so as to make the urgency of the situation immediately obvious.

3) Aural alerts whose significance is not inherently obvious are minimized.

4) Number of aural alerts is reduced to four or less.

5) Consistency of application of types of alerts is maintained.

Table 3 Criteria for categorizing alerting function

Level	Condition	Criteria
1	Emergency (Warning)	Emergency operational or aircraft systems conditions that require immediate corrective orcompensatory action by the crew.
2	Abnormal (Caution)	Abnormal operational or aircraft systems conditions that require immediate crew awareness and eventual corrective or compensatory crew action
3	Advisory	Operational or aircraft systems conditions that require crew awareness and may require crew action.
4	Information	Operational or aircraft systems conditions that require cockpit indication but not necessarily as part of the integrated warning system.

Human Factors Guidelines

A survey of the human factors data applicable to aircraft alerting systems provided the guidelines shown in Table 4. Typical response times to various types of alerts are presented in Table 5. Based on these two inputs, the relative effectiveness of various types of alert stimuli was determined to be approximately as shown in Fig. 7.

Criteria for the location of high-priority alerts are very controversial. These criteria are heavily dependent on the definitions of primary field of view, secondary field of view, and centerline of sight. The controversy arises from the variability in these definitions. 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 deg below horizontal. Commercial airframe manufacturers have several definitions of the centerline of sight, all of which differ from the military definition. The most consistently used 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 standards and guides define primary field of view as an elliptically shaped area covering most of the pilots' primary instrumented panel (containing ADI, HSI, airspeed, and altitude indicators) and secondary field of view as an elliptically 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: 1) high-priority alerts should be located no more than 15 deg from the pilot's centerline of vision, and 2) caution signals should be located no more than 30 deg from the pilot's centerline of vision.

Flight Phase Definitions

An analysis of crew tasks and levels of workload was made to identify periods of gross change in either of these parameters. This analysis showed that a considerable change in the crew's level of concentration on their primary flying tasks occurs midway through each of the flight phases defined in Table 6. During takeoff, for example, the crew's concentration on the takeoff flying tasks increases as V_1 is ap-

Table 4 Stimuli response sensitivities and application guidelines summary

Stimulus	Characteristic	Sensitivity/application guideline
Visual	Location	Warnings: Within 15 deg of centerline of sight Cautions: Within 30 deg of centerline of sight
	Size	1 deg visual angle (minimum for high-priority signals)
	Brightness	Brighter than background but not so bright as to blind observer
	Flashing vs steady	Flashing against steady background most effective
	Color	Detection times (fastest → slowest): red 1.8 s, green 2.0 s, yellow 2.3 s, white 2.7 s
Auditory	Perceived loudness	Maximized in 2000-4000 Hz range
	Frequency deafness	Should use two or more frequencies in 250-4000 Hz range
	Sound level	15 dB above masking threshold or halfway between masking threshold and 110 dB, whichever is least
	Location	Monaural signals should be presented to dominant ear Warning signal source should be separated at least 90 deg from the source of interfering noise or messages
	Intermittent vs steady	Intermittent more likely to be detected
	Message content	Precede messages by person's name (or flight number)
Tactile	Intermittent vs steady	Touch sense is activated only by skin deformation
	Vibration	Maximum sensitivity between 200 and 300 Hz
	Area of body	Fingers most sensitive Buttocks least sensitive
	Intensity	50-100 microns

Table 5 Typical stimuli response times

Nature of stimuli	Response time, s	Test conditions/results
Visual	12.12	Tracking task; no impact on concurrent tracking task performance
Visual and buzzer	4.02	
Visual and voice	2.40	
Visual and buzzer	4.57	Tracking task; better tracking with voice warning
Visual and voice	1.94	
Visual and tone	9.35	
Visual and voice	7.89	
Visual and buzzer	2.63	
Visual and voice	1.62	
Visual	128.27	High-speed, low-level military flight tests
Voice	3.03	
Visual	44.05	Visual consisted of analog instruments and light in an F-100 aircraft
Voice	2.93	
Auditory	2.2	Simulation of a typical cockpit environment
Visual	2.7	
Voice	1.94	
Buzzer	2.57	
Tone	9.35	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
Voice	7.89	

proached, 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_I through 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 ft of descent, flare, and touchdown. Distinctions also exist between operations above and below 14,000 ft 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

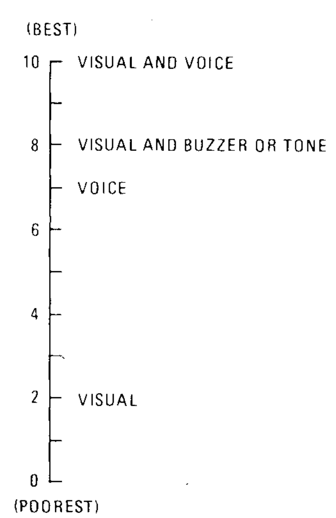


Fig. 7 Relative effectiveness of acceptable types of alert stimuli.

Table 6 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 $V_I - 30$ knots
Final takeoff roll	During acceleration from $V_I - 30$ 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	Operation above 14,000 ft.
Approach	From 1500 ft to 200 ft altitude
Landing	From 200 ft altitude through flare, touchdown, and speed reduction to taxi speed
Taxi and shutdown	

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 6, were selected for prioritizing the alerting functions.

Categorizing Alerts

The categorization of 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. Table 7 lists the alerts that would probably fall within the warning/emergency category.

Some pilots objected to changing the category of an alert as a function of flight phase. To determine the amount of category swapping that might occur, all alerts on an example aircraft (Boeing 737) were categorized. It was interesting to note that less than 6% of the alerts on this example aircraft changed categories as a function of flight phase.

Prioritizing Alerts

The prioritization of alerts within each category also is controversial. For example, what priority should a stall warning have relative to a ground proximity warning? Both alerts will probably be Level 1 alerts. If a ground proximity warning occurs followed by a stall warning 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. Thus, purely subjective techniques had to be used to prioritize the alerts.

The results of these subjective rankings of alerts are very controversial. Good agreement can be obtained on which alerts fall within the warning and caution categories. The lesser priority categories are too dependent on aircraft design characteristics and operating environment to be independently established. The airframers and operators must determine the category of these low-level alerts. Prioritization of the alerts within any of these categories is expected to receive sparce application.

IV. Recommended Design Guidelines

Based on data reviewed in previous sections, preliminary design guidelines oriented to provide the following type of alerting system characteristics and cockpit environment were developed.

Table 7 Example application of alerting function prioritization

Flight phase	Alert
Ground maintenance	1) Gear down and locked but lever not in down detent 2) Unsafe takeoff configuration 3) Stall warning 4) Ground proximity warning
Preflight	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 – 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 altitude	1) Stall warning 2) Ground proximity warning 3) Gear down and locked but lever not in down detent 4) Unsafe landing configuration
Landing (below 200 ft)	1) Stall warning 2) Ground proximity warning 3) Gear down and locked but lever not in down detent 4) Unsafe landing configuration 5) Autopilot disconnect
Taxi and shutdown	1) Gear down and locked but lever not in down detent

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

1) A consistent design philosophy that can be applied to all new aircraft, irrespective of manufacturer.

2) Relatively quiet, dark cockpit when all systems are operating normally and when abnormal situations have been cleaned up.

3) A unique, visual, or combination audio-visual method of alerting with each alert priority level.

4) Alerting system growth capability in a form that does not necessitate additional discrete annunciators.

Significant testing is still required to validate these guidelines because they have been only partially substantiated; hence they should not be interpreted as firm design guidelines or as minimum performance standards. Accordingly, the following preliminary design guidelines are recommended.

Prioritization

1) Selected alerts should be categorized as a function of criticality and flight phase (category criteria are presented in Table 3 and flight phases that might be considered are defined in Table 6).

2) Selected alerts within each category might 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.

Visual Alerts

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

2) Red alerts: Apply only to situations where immediate action is required, i.e. only Level 1 alerts.

3) Amber/yellow alerts: Apply only to situations that require immediate crew awareness and eventual action, i.e. only to Level 2 alerts.

4) Green alerts: use to confirm the SAFE OPERATION or GO status of a system.

5) Blue alerts: use to annunciate in transit conditions (or as the basic color associated with all advisories i.e. only Level 3 alerts).

6) White alerts: Use for illuminating keyboards and annunciating ON/OFF system modes i.e. when used in place of toggle switches.

7) Location:

a) Level 1 alerting devices (warnings) should be located within 15 degs 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).

b) Level 2 alerting devices (cautions) should be located within 30 degs of the pilot's centerline of vision.

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

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

8) Brightness: Automatic brightness adjustment for varying ambient light conditions should be provided.

9) Flashing: Use only for highest priority (Level 1/Warning) alerts.

Aural Alerts

1) 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.

2) Maximum number:

a) Less than four familiar alerts (based on pilot opinion).

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

3) Intensity:

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

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

c) Total cancellation of aural alerts associated with Level 1 items without correction of the fault or situation should be prohibited. However, a means of reducing the annoyance of continuous aural alerts after initial recognition is achieved should be provided.

d) 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 shutoff switch for each aural alert.

4) Sound characteristics:

a) Each signal should be composed of two or more widely separated frequencies in the range 250 – 4000 hz.

b) Intermittent signals should be used.

5) Voice characteristics:

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

b) Messages should be constructed of short sentences of polysyllabic words.

c) Pilots should be familiar with all voice messages.

Tactile Alerts

Minimize use of tactile alerts.

Master Warning/Master Caution

1) 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.

2) All Level 1 alerts should activate the master warning signal (if used).

3) All Level 2 alerts should activate the master caution signal (if used).

4) No Level 3 or 4 alerts should activate the master warning or master caution signals (if used).

Checklist Correlation

1) Type of alert and type of checklist used to rectify an annunciated situation should be correlated.

2) Emergency procedures should be associated with Level 1 (warning-type) alerts.

3) Abnormal procedures should be associated 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.

Reiterating, 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.

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