of displaying one symbol overlaying another symbol by editing out the secondary symbol) to ensure that higher priority symbols remain viewable.

New symbols (a new design or a new symbol for a function which historically had an associated symbol) should be tested for distinguishability and flight crew comprehension and retention.

The applicant should show that display text and auditory messages are distinct and meaningful for the information presented. Assess messages for whether they convey the intended meaning. Equipment should display standard and/or non-ambiguous abbreviations and nomenclature, consistent within a function and across the flight deck.

5.4.3 Accessibility and Usability of Information

a. Accessibility of information [CS 25.1302]

Some information may at certain times be immediately needed by the flight crew, while other information may not be necessary during all phases of flight. The applicant should show that the flight crew can access and manage (configure) all necessary information on the dedicated and multifunction displays for the phase of flight. The applicant should show that any information required for continued safe flight and landing is accessible in the relevant degraded display modes following failures as defined by CS 25.1309. The applicant should specifically assess what information is necessary in those conditions, and how such information will be simultaneously displayed. The applicant should also show that supplemental information does not displace or otherwise interfere with required information.

Analysis as the sole means of compliance is not sufficient for new or novel display management schemes. The applicant should use simulation of typical operational scenarios to validate the flight crew's ability to manage available information.

b. Clutter [CS 25.1302]

Clutter is the presentation of information in a way that distracts flight-crew members from their primary task. Visual or auditory clutter is undesirable. To reduce flight-crew member's interpretation time, equipment should present information simply and in a well-ordered way. Applicants should show that an information delivery method (whether visual or auditory) presents the information the flight-crew member actually requires to perform the task at hand. The flight crew can use their own discretion to limit the amount of information that needs to be presented at any point in time. For instance, a design might allow the flight crew to program a system so that it displays the most important information all the time, and less important information on request. When a design allows, flight crew selection of additional information, the basic display modes should remain uncluttered.

Automatically de-cluttering display options can hide needed information from the flight-crew member. The applicant should show that equipment that uses automatic de-selection of data to enhance the flight-crew member's performance in certain emergency conditions provides the information the flight-crew member requires. Use of part-time displays depends not only on information de-clutter goals but also on display availability and criticality. Therefore, when designing such features, the applicant should follow the guidance in AMC 25-11.

Because of the transient nature of auditory information presentation, designers should be careful to avoid the potential for competing auditory presentations that may conflict with each other and hinder interpretation. Prioritisation and timing may be useful to avoid this potential problem.

Prioritise information according to task criticality. Lower priority information should not mask higher priority information and higher priority information should be available, readily detectable, easily distinguishable and usable. This does not mean that the display format needs to change based on phase of flight.

c. System response to control input [CS 25.1302]

Long or variable response times between control input and system response can adversely affect system usability. The applicant should show that response to control input, such as setting values, displaying parameters, or moving a cursor symbol on a graphical display is fast enough to allow the flight crew to complete the task at an acceptable performance level. For actions requiring noticeable system processing time equipment should indicate that system response is pending.

5.5 System Behaviour

5.5.1 Introduction

Flight crew task demands vary depending on the characteristics of the system design. Systems differ in their responses to relevant flight crew input. The response can be direct and unique as in mechanical systems or it can vary as a function of an intervening subsystem (such as hydraulics or electrics). Some systems even automatically vary their response to capture or maintain a desired aeroplane or system state.

As described in paragraph 5.1, CS 25.1302(c) states that installed equipment must be designed so that the behaviour of the equipment that is operationally relevant to the flight crew's tasks is: (1) predictable and unambiguous, and (2) designed to enable the flight crew to intervene in a manner appropriate to the task (and intended function).

The requirement for operationally relevant system behaviour to be predictable and unambiguous will enable a qualified flight crew to know what the system is doing and why. This means that a crew should have enough information about what the system will do under foreseeable circumstances as a result of their action or a changing situation that they can operate the system safely. This distinguishes system behaviour from the functional logic within the system design, much of which the flight crew does not know or need to know.

If flight crew intervention is part of the intended function or non-normal procedures for the system, the crewmember may need to take some action, or change an input to the system. The system must be designed accordingly. The requirement for flight crew intervention capabilities recognises this reality.

Improved technologies, which have increased safety and performance, have also introduced the need to ensure proper cooperation between the flight crew and the integrated, complex information and control systems. If system behaviour is not understood or expected by the flight crew, confusion may result.

Some automated systems involve tasks that require flight crew attention for effective and safe performance. Examples include the flight management system (FMS) or flight guidance systems. Alternatively, systems designed to operate autonomously, in the sense that they require very limited or no human interaction, are referred to as 'automatic systems'. Such systems are switched 'on' or 'off 'or run automatically and are not covered in this paragraph. Examples include fly-by-wire systems, full authority digital engine controls (FADEC), and yaw dampers. Detailed specific guidance for automatic systems can be found in relevant parts of CS-25.

Service experience shows that automated system behaviour that is excessively complex or dependent on logical states, or mode transitions are not understood or expected by the flight crew can lead to flight crew confusion. Design characteristics such as these have been determined to contribute to incidents and accidents.

This sub-paragraph provides guidance material for showing compliance with these design considerations for requirements found in CS 25.1302(c), CS 25.1301(a), CS 25.1309(c), or any other relevant paragraphs of CS-25.

5.5.2 System Function Allocation

The applicant should show that functions of the proposed design are allocated so that:

— The flight crew can be expected to complete their allocated tasks successfully in both normal and non-normal operational conditions, within the bounds of acceptable workload and without requiring undue concentration or causing undue fatigue. (See CS 25.1523 and CS-25 Appendix D for workload evaluation);

— Flight crew interaction with the system enables them to understand the situation, and enables timely detection of failures and crew intervention when appropriate;

— Task sharing and distribution of tasks among flight-crew members and the system during normal and non-normal operations is considered.

5.5.3 System Functional Behaviour

A system's behaviour results from the interaction between the flight crew and the automated system and is determined by:

— The system's functions and the logic that governs its operation; and

— The user interface, which consists of the controls and information displays that communicate the flight crew's inputs to the system and provide feedback on system behaviour to the crew.

It is important that the design reflect a consideration of both of these together. This will avoid a design in which the functional logic governing system behaviour can have an unacceptable effect on crew performance. Examples of system functional logic and behaviour issues that may be associated with errors and other difficulties for the flight crew are the following:

— Complexity of the flight crew interface for both inputs (entering data) and outputs.

— Inadequate understanding and inaccurate expectations of system behaviour by the flight crew following mode selections and transitions.

Inadequate understanding and incorrect expectations by the flight crew of system intentions and behaviour.

Predictable and Unambiguous System Behaviour (CS 25.1302(c)(1))

Applicants should propose the means they will use to show that system or system mode behaviour in the proposed design is predictable and unambiguous to the flight crew.

System or system mode behaviour that is ambiguous or unpredictable to the flight crew has been found to cause or contribute to flight crew errors. It can also potentially degrade the flight crew's ability to perform their tasks in both normal and non-normal conditions. Certain design characteristics have been found to minimise flight crew errors and other crew performance problems.

The following design considerations are applicable to operationally relevant system or system mode behaviours:

— Simplicity of design (for example, number of modes, mode transitions).

— Clear and unambiguous mode annunciation. For example, a mode engagement or arming selection by the flight crew should result in annunciation, indication or display feedback adequate to provide awareness of the effect of their action.

— Accessible and usable methods of mode arming, engagement and de-selection. For example, the control action necessary to arm, engage, disarm or disengage a mode should not depend on the mode that is currently armed or engaged, on the setting of one or more other controls, or on the state or status of that or another system.

— Predictable un-commanded mode change and reversions. For example, there should be sufficient annunciation, indication or display information to provide awareness of uncommanded changes of the engaged or armed mode of a system.

Note that formal descriptions of modes typically define them as mutually exclusive, so that a system cannot be in more than one mode at a particular time. For instance, a display can be in "north up" mode or "track up" mode, but not both at the same time.

For specific guidance on flight guidance system modes, see AMC 25.1329.

Flight Crew Intervention (CS 25.1302(c)(2))

Applicants should propose the means that they will use to show that system behaviour in the proposed design allows the flight crew to intervene in operation of the system without compromising safety. This should include descriptions of how they will determine that functions and conditions in which intervention should be possible have been addressed.

If done by analysis, the completeness of the analysis may be established either by defining acceptable criteria for the depth and breadth of the analysis, or by proposing an analysis method that is inherently complete. In addition, applicant's proposed methods should describe how they would determine that each intervention means is appropriate to the task.

Controls for Automated Systems

Automated systems can perform various tasks selected by and under supervision of the flight crew. Controls should be provided for managing functionalities of such a system or set of systems. The design of such “automation specific” controls should enable the crew to:

— Safely prepare the system for the task to be executed or the subsequent task to be executed. Preparation of a new task (for example, new flight trajectory) should not interfere with, or be confused with, the task being executed by the automated system.

— Activate the appropriate system function without confusion about what is being controlled, in accordance with crew expectations. For example, the flight crew should have no confusion when using a vertical speed selector which could set either vertical speed or flight path angle.

— Manually intervene in any system function, as required by operational conditions, or to revert to manual control. For example, manual intervention might be needed during loss of system functionality, system abnormalities, or failure conditions.

Displays for Automated Systems

Automated systems can perform various tasks with minimal crew interventions, but under the supervision of the flight crew. To ensure effective supervision and maintain crew awareness of system state and system “intention” (future states), displays should provide recognisable feedback on:

— Entries made by the crew into the system so that the crew can detect and correct errors.

— Present state of the automated system or mode of operation. (What is it doing?)

— Actions taken by the system to achieve or maintain a desired state. (What is it trying to do?)

— Future states scheduled by the automation. (What is it going to do next?)

— Transitions between system states.

The applicant should consider the following aspects of automated system design:

— Indications of commanded and actual values should enable the flight crew to determine whether the automated systems will perform according to their expectations;

— If the automated system nears its operational authority or is operating abnormally for the conditions, or is unable to perform at the selected level, it should inform the flight crew, as appropriate for the task;

— The automated system should support crew coordination and cooperation by ensuring shared awareness of system status and crew inputs to the system; and

— The automated system should enable the flight crew to review and confirm the accuracy of commands constructed before being activated. This is particularly important for automated systems because they can require complex input tasks.

5.6 Flight Crew Error Management

5.6.1 Showing Compliance with CS 25.1302(d)

It is important to recognise that flight crews will make errors, even when well trained, experienced and rested individuals are using well-designed systems. Therefore, CS 25.1302(d) requires that “To the extent practicable, the installed equipment must enable the flight crew to manage errors resulting from flight crew interaction with the equipment that can be reasonably expected in service, assuming flight crews acting in good faith. This sub-paragraph does not apply to skill-related errors associated with manual control of the aeroplane.”

To comply with CS 25.1302(d), the design should meet at least one of the following criteria. It should:

— Enable the flight crew to detect (see 5.6.2), and/or recover from errors (see 5.6.3); or

— Ensure that effects of flight crew errors on the aeroplane functions or capabilities are evident to the flight crew and continued safe flight and landing is possible (see 5.6.4); or

— Discourage flight crew errors by using switch guards, interlocks, confirmation actions, or similar means, or preclude the effects of errors through system logic and/or redundant, robust, or fault tolerant system design (see 5.6.5).

These objectives:

— Are, in a general sense, in a preferred order.

— Recognise and assume that flight crew errors cannot be entirely prevented, and that no validated methods exist to reliably predict either their probability or all the sequences of events with which they may be associated.

— Call for means of compliance that are methodical and complementary to, and separate and distinct from, aeroplane system analysis methods such as system safety assessments.

As discussed previously in paragraph 5.1, Compliance with CS 25.1302(d) is not intended to require consideration of errors resulting from acts of violence or threats of violence. Additionally, the requirement is intended to require consideration of only those errors that are design related.

Errors that do have a design-related component are considered to be within the scope of this regulatory and advisory material. Examples are a procedure that is inconsistent with the design of the equipment, or indications and controls that are complex and inconsistent with each other or other systems on the flight deck.

When demonstrating compliance, the applicant should evaluate flight crew tasks in both normal and non-normal conditions, considering that many of the same design characteristics are relevant in either case. For example, under non-normal conditions, the flying tasks (navigation, communication and monitoring), required for normal conditions are generally still present, although they may be more difficult in some non-normal conditions. So tasks associated with the non-normal conditions should be considered as additive. The applicant should not expect the errors considered to be different from those in normal conditions, but any evaluation should account for the change in expected tasks.

To show compliance with CS 25.1302(d), an applicant may employ any of the general types of methods of compliance discussed in Paragraph 6, singly or in combination. These methods must be consistent with an approved certification plan as discussed in Paragraph 4, and account for the objectives above and the considerations described below. When using some of these methods, it may be helpful for some applicants to refer to other references relating to understanding error occurrence. Here is a brief summary of those methods and how they can be applied to address flight crew error considerations:

— Statement of Similarity (paragraph 6.3.1): A statement of similarity may be used to substantiate that the design has sufficient certification precedent to conclude that the ability of the flight crew to manage errors is not significantly changed. Applicants may also use service experience data to identify errors known to commonly occur for similar crew interfaces or system behaviour. As part of showing compliance, the applicant should identify steps taken in the new design to avoid or mitigate similar errors.

— Design Descriptions (paragraph 6.3.2): Applicants may structure design descriptions and rationale to show how various types of errors are considered in the design and addressed, mitigated or managed. Applicants can also use a description of how the design adheres to an established and valid design philosophy to substantiate that the design enables flight crews to manage errors.

— Calculation and Engineering Analysis (paragraph 6.3.3): As one possible means of showing compliance with CS 25.1302(d), an applicant may document means of error management through analysis of controls, indications, system behaviour, and related flight crew tasks. This would need to be done in conjunction with an understanding of potential error opportunities and the means available for the flight crew to manage those errors. In most cases it is not considered feasible to predict the probability of flight crew errors with sufficient validity or precision to support a means of compliance. If an applicant chooses to use a quantitative approach, the validity of the approach should be established.

— Evaluations, Demonstrations, and Tests (paragraph 6.3.4-6): For compliance purposes, evaluations are intended to identify error possibilities that may be considered for mitigation in design or training. In any case, scenario objectives and assumptions should be clearly stated before running the evaluations, demonstrations, or tests. In that way, any discrepancy in those expectations can be discussed and explained in the analysis of the results.

As discussed further in Paragraph 6, these evaluations, demonstrations, or tests should use appropriate scenarios that reflect intended function and tasks, including use of the equipment in normal and non-normal conditions. Scenarios should be designed to consider flight crew error. If inappropriate scenarios are used or important conditions are not considered, incorrect conclusions can result. For example, if no errors occur during an evaluation it may mean only that the scenarios are too simple. On the other hand, if some errors do occur, it may mean any of the following:

— The design, procedures, or training should be modified,

— The scenarios are unrealistically challenging, or

— Insufficient training occurred prior to the evaluation.

In such evaluations it is not considered feasible to establish criteria for error frequency.

5.6.2 Error Detection

Applicants should design equipment to provide information so the flight crew can become aware of an error or a system/aeroplane state resulting from a system action. Applicants should show that this information is available to the flight crew, adequately detectable, and clearly related to the error in order to enable recovery in a timely manner.

Information for error detection may take three basic forms:

Indications provided to the flight crew during normal monitoring tasks. As an example, if an incorrect knob was used, resulting in an unintended heading change, the change would be detected through the display of target values. Presentation of a temporary flight plan for flight crew review before accepting it would be another way of providing crew awareness of errors.

Indications on instruments in the primary field of view that are used during normal operation may be adequate if the indications themselves contain information used on a regular basis and are provided in a readily accessible form. These may include mode annunciations and normal aeroplane state information such as altitude or heading. Other locations for the information may be appropriate depending on the flight crew's tasks, such as on the control-display unit when the task involves dealing with a flight plan. Paragraph 5.4, Presentation of Information, contains additional guidance to determine whether information is adequately detectable.

Flight crew indications that provide information of an error or a resulting aeroplane system condition. An example might be an alert to the flight crew about the system state resulting from accidentally shutting down a hydraulic pump. Note that if the indication is an alert, it is related to the resulting system state, not necessarily directly to the error itself. Existence of a flight crew alert that occurs in response to flight crew error may be sufficient to establish that information exists and is adequately detectable, if the alert directly and appropriately relates to the error. Definitions of alert levels in CS 25.1322 are sufficient to establish that the urgency of the alert is appropriate. Content of the indication should directly relate to the error. Indications for indirect effects of an error may lead the flight crew to believe there may be non-error causes for the annunciated condition.

"Global" alerts that cover a multitude of possible errors by annunciating external hazards or aeroplane envelope or operational conditions. Examples include monitoring systems such as terrain awareness warning systems (TAWS) and traffic collision avoidance systems (TCAS). An example would be a TAWS alert resulting from turning the wrong direction in a holding pattern in mountainous terrain.

The applicant should consider the following when establishing whether the degree or type of information is available to the flight crew, adequately detectable, and clearly related to the error:

— Effects of some errors are easily and reliably determined by the system (by design), and some are not. For those that cannot be sensed by the system, design and arrangement of the information monitored and scanned by the flight crew can facilitate error detection. An example would be alignment of engine speed indicator needles in the same direction during normal operation.

— Aeroplane alerting and indication systems may not detect whether an action is erroneous because systems cannot know flight crew intent for many operational circumstances. In these cases, reliance is often placed on the flight crew's ability to scan and observe indications that will change as a result of an action such as selecting a new altitude or heading, or making a change to a flight plan in a flight management system. For errors of this nature, detection depends on flight crew interpretation of available information. Training, crew resource management, and monitoring systems such as TAWS and TCAS are examples of ways to provide a redundant level of safety if any or all flight-crew members fail to detect certain errors.

— From a design standpoint, some information, such as heading, altitude, and fuel state, should be provided as readily available indications rather than in the form of alerts when there is potential for them to contribute to excessive nuisance alerts.

The applicant may establish that information is available and clearly related to the error by design description when precedent exists or when a reasonable case may be made that the content of the information is clearly related to the error that caused it. In some cases, piloted evaluations (see 6.3.4) may be needed to assess whether the information provided is adequately available and detectable.

5.6.3 Error Recovery

Assuming that the flight crew detects errors or their effects, the next logical step is to ensure that the error can be reversed, or the effect of the error can be mitigated in some way so that the aeroplane is returned to a safe state.

An acceptable means to establish that an error is recoverable is to show that:

— Controls and indications exist that can be used either to reverse an erroneous action directly so that the aeroplane or system is returned to the original state, or to mitigate the effect so that the aeroplane or system is returned to a safe state, and

— The flight crew can be expected to use those controls and indications to accomplish the corrective actions in a timely manner.

To establish the adequacy of controls and indications that facilitate error recovery, a statement of similarity or design description of the system and crew interface may be sufficient. For simple or familiar types of system interfaces, or systems that are not novel, even if complex, a statement of similarity or design description of the crew interfaces and procedures associated with indications is an acceptable means of compliance.

To establish that the flight crew can be expected to use those controls and indications to accomplish corrective actions in a timely manner, evaluation of flight crew procedures in a simulated flight deck environment can be highly effective. This evaluation should include examination of nomenclature used in alert messages, controls, and other indications. It should also include the logical flow of procedural steps and the effects that executing the procedures have on other systems.

5.6.4 Error Effects

Another means of satisfying the objective of error mitigation is to ensure that effects of the error or relevant effects on aeroplane state:

— Are evident to the flight crew, and

— Do not adversely impact safety (do not prevent continued safe flight and landing).

Piloted evaluations in the aeroplane or in simulation may be relevant if flight crew performance issues are in question for determining whether a state following an error permits continued safe flight and landing. Evaluations and/or analyses may be used to show that, following an error, the flight crew has the information in an effective form and has the aeroplane capability required to continue safe flight and landing.

5.6.5 Precluding Errors or Their Effects

For irreversible errors that have potential safety implications, means to discourage the errors are recommended. Acceptable ways to discourage errors include switch guards, interlocks, or multiple confirmation actions. For example, generator drive controls on many aeroplanes have guards over the switches to discourage inadvertent actuation, because once disengaged, the drives cannot be re-engaged while in flight or with the engine running. An example of multiple confirmations would be presentation of a temporary flight plan that the flight crew can review before accepting.

Another way of avoiding flight crew error is to design systems to remove misleading or inaccurate information, (e.g., sensor failures), from displays. An example would be a system that removes flight director bars from a primary flight display or removing “own-ship” position from an airport surface map display when the data driving the symbols is incorrect.

The applicant should avoid applying an excessive number of protections for a given error. Excessive use of protections could have unintended safety consequences. They might hamper the flight-crew member‘s ability to use judgment and take actions in the best interest of safety in situations not predicted by the applicant. If protections become a nuisance in daily operation flight crews may use well-intentioned and inventive means to circumvent them. This could have further effects not anticipated by the operator or the designer.