A Summary of Results from Technologies for Aircraft State Awareness Safety Enhancement 210 Output 2

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In 2014, the Commercial Aviation Safety Team produced a report describing the results of an analysis intended to understand and mitigate airplane incidents and accidents associated with flight crew loss of attitude or energy state awareness. That report described several "Safety Enhancements" including a new category of "Research Safety Enhancements". This paper focuses on Safety Enhancement (SE) 210 Output 2, investigating improvements in design methods and guidelines to "assess flight crew performance in situations associated with loss of energy and/or attitude state awareness".

I. Introduction

The Commercial Aviation Safety Team (CAST) created a subgroup to analyze a set of incidents and accidents associated with a flight crew's loss of awareness of aircraft attitude or energy state. These events are referred to more broadly as a loss of Airplane State Awareness (ASA), and they are a substantial subset of loss of control (LOC) accidents. A subsequent CAST ASA team developed a set of mitigation strategies—referred to as Safety Enhancements (SEs)—to reduce the likelihood of ASA events occurring in the future.

This paper describes research conducted in support of Safety Enhancement 210[1]. SE 210 consists of three research activities described below.

> "A CAST study showed that flight crew performance limitations were involved in half of the18 loss-of-control events. The aviation community (government, industry, and academia) should conduct research and development to enhance tools and methods for analyzing flight crew performance for use in design practices and processes. The research should focus on flight crew responses to situations associated with loss of energy and/or attitude state awareness, and should encompass the following:
> 1. Develop a database of historical flight crew performance response situations associated with loss of energy and/or attitude state awareness.
> 2. Enhance methods and guidelines used in the design process to assess flight crew performance in these situations.
> 3. Develop and validate prototype technologies for detection and mitigation of attention issues for use in design evaluation."

This paper summarizes research in support of SE 210 Output 2, which addresses the development of improved assessment methods and guidance. More specifically, the focus is on assessing or evaluating the flight deck interface to determine how well it supports ASA. We are in the process of publishing a series of reports on each of the following five research activities:

1) **Factors that influenced Airplane State Awareness accidents and incidents**
2) **The Role of alerting system failures in loss of control accidents**
3) **Evaluation issues for flight deck interfaces**
4) **Identification of scenarios for system interface design evaluation**

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5) **Best practices for evaluating flight deck interfaces for transport category aircraft with respect to issues of attention, awareness, and understanding**

In the next sections we provide selected summaries of findings from each of the research activities.

II. Factors that influenced Airplane State Awareness accidents and incidents

The CAST Airplane State Awareness activity focused on a set of 18 Loss of Control (LOC) accidents and incidents. In those events, the pilot seemed to lose awareness of the state of the airplane, especially related to its energy state or its attitude. To understand the root of that loss of awareness, we analyzed the events in relation to a set of factors that were present in many of them. We showed how these factors contributed to lost awareness and we use that understanding to identify potentially useful changes to the flight deck interface and how those flight deck changes could be evaluated.

The primary source of information about situations in which the pilot lost ASA is the analysis performed by CAST. The CAST Airplane State Awareness (ASA) Joint Safety Analysis Team (JSAT) analyzed 18 safety events to better understand Loss of Control In flight (LOC-I) and, more specifically, loss of airplane state awareness. Table 1 lists the 18 events on the left. The events in the top half are related to attitude awareness, and those in the bottom half are related to energy-state awareness. Also, note that some of these events were accidents (bolded), and some were incidents (not bolded).

The columns of this table provide a set of factors that contributed to one or more events; an "x" indicates that it was relevant for an event. For example, lack of external visual references indicates that the weather conditions were such that the flight crew likely could not see ground references (e.g., horizon). This factor was present in 17 of the 18 events. The right-most column shows the total number of factors in each event. There were at least six and as many as 11 factors for each event.

Table 1. Contributing factors identified by the CAST ASA JSAT

	Lack of External Visual References	Flight Crew Impairment	Training	Airplane Maintenance	Safety Culture	Invalid Source Data	Distraction	Systems Knowledge	Crew Resource Management	Automation Confusion / Awareness	Ineffective Alerting	Inappropriate Control Actions	Total
Formosa Airlines Saab 340	x	x			x		x	x	x		x		7
Korean Air 747-200F	x			x		x	x		x		x		6
Flash Airlines 737-300	x		x		x		x		x	x	x	x	8
Adam Air 737-400	x		x	x			x	x	x	x	x	x	9
Kenya Airways 737-800	x		x				x		x	x	x	x	7
Aeroflot-Nord 737-500	x	x	x	x	x		x	x	x	x	x	x	11
Gulf Air A320	x		x				x		x		x	x	6
Icelandair 757-200 (Oslo)	x						x		x	x	x	x	6
Armavia A320	x	x			x		x		x	x	x	x	8
Icelandair 757-200 (Baltimore)	x				x	x	x	x	x	x	x	x	9
Midwest Express 717	x				x	x	x		x		x	x	7
Colgan Air DHC-8-Q400	x	x	x		x		x	x	x	x	x	x	10
Provincial Airlines DHC-8	x		x				x			x	x	x	6
Thomsonfly 737-800	x		x	x	x		x			x	x		7
West Caribbean MD-82	x	x			x		x	x	x	x	x	x	9
XL Airways A320		x	x	x	x	x	x	x	x	x	x		10
Turkish Airlines 737-800	x			x	x	x	x		x	x	x		8
Empire Air ATR-42	x	x			x		x		x	x	x		7
Overall	17	7	9	6	12	5	18	7	16	14	18	12	
Column	A	B	C	D	E	F	G	H	I	J	K	L	

While these factors do not have a simple causal relationship to the accidents, it is worth considering how some of these factors might be removed or mitigated by changes to the flight deck interface and might, therefore, improve ASA. More specifically, it might be possible to make changes to the flight deck interface in a way that removes or reduces the effect of some of these factors. Specifically, we considered the following subset of factors, selected because we believe they may lead to useful interventions:

- Automation Confusion / Awareness (column J), refers to the pilot's lack of understanding about the behavior of the autoflight or autothrottle system
- Invalid Source Data (column F), refers to a loss of basic airplane sensed data (e.g. air data)
- Distraction (column G), refers to situations in which the flight crew was distracted by some other task and failed to focus sufficiently on flying the airplane.
- Inappropriate Control Actions (column L), refers to pilot actions that were counter to the actions that would have restored the airplane to safe and stable flight; e.g., the pilot rolled away from wings level.
- Lack of External Visual Reference, (column A), refers to flight in IMC or night conditions where it is not possible to get orienting information from the outside world.
- Crew Resource Management (CRM), (column I), refers to how well the flight crew works together to identify problems and take appropriate actions. In particular, there were events in which the pilot monitoring (PM) knew that the pilot flying (PF) was making inappropriate control inputs but failed to intervene.
- Ineffective Alerting (column K), refers to alerts that either didn't not catch the attention of the flight crew, or did not activate in response to the hazard in a timely manner.

We identified a number of flight situations or contextual factors that could lead to loss of airplane state awareness, which, in turn, can lead to loss of control. The goal for identifying and describing these situations is to consider

- changes to the flight deck design that have potential for removing or mitigating these factors or situations
- the aspects of the flight deck interface that should be evaluated, as it relates to the ways in which it supports flight crew performance.
- considerations in developing evaluation scenarios
- aspects of human performance that are relevant for assessing the flight deck interface

The details of our analysis can be found in the NASA Technical Memorandum entitled **""Factors that influenced Airplane State Awareness accidents and incidents,"** [2].

As illustrated in Table 1, "Distraction" (i.e. flight crew attention, awareness and understanding) and "Ineffective Alerting", were identified as major contributors to ASA events. In our research we investigated the role of attention, awareness and understanding across multiple aspects of design and evaluation, and conducted a specific analysis on the role of alerting system failures in Loss of Control (LOC) accidents.

III. The role of alerting system failures in Loss of Control (LOC)accidents

In this analysis, we examined how alerting for LOC-related hazards, such as low airspeed, unreliable airspeed, and approach to stall, can fail to lead to an upset recovery. Alerting is the last line of defense against flight path management hazards; it is there to ensure awareness when pilot-driven attention and awareness fail. This analysis looks at why alerting does not always save the day. We broadened the idea of alerting to include all of the steps of what we are calling the integrated alerting-to-recovery sequence. The primary objective of using this level of description is that the flight deck interface, operational procedures, and pilot training should be designed to support the pilot in moving from a hazardous condition to an effective recovery from the hazard. When accidents or significant incidents occur, we should look at how well this integrated alerting-to-recovery sequence worked—did it fail, and, if so, where?

We defined a set of steps in the sequence and then analyzed reports of safety events to identify if a failure occurred along that sequence. These results led us to try to understand why these specific failures occurred. Studying the performance of alerting systems in events in which they failed has helped identify the types of alerting-system design changes (or other changes) that are needed.

Starting with an analysis of 57 recent safety events [3] we identified subset of 28 ASA type incidents and accidents to determine how well alerting functioned. We identified a failure point for each of the 28 events. Notably, 20 of 28 failed in the initial step of orienting to a failure, which speaks to the alerting mechanism itself. Clearly, there are still cases in which basic flight path management hazards are not alerted sufficiently to make the PF aware of the hazard. Further analysis showed that these orienting failures are occurring even for recently manufactured airplanes; that is, it is not only a problem for airplanes that were manufactured 30 years ago. The truth is that there are many airplanes in the world-wide operational fleet that do not sufficiently alert some of these basic flight path management parameters (e.g., low airspeed, unreliable airspeed, bank angle).

The failures for alerting hazards such as low airspeed sometimes led to the airplane entering into an approach to stall or full aerodynamic stall situation. In these cases, the failure was tied to the actions of the pilot. The pilot made control actions that run counter to what is recommended for this situation. Training is now being developed and delivered in the US and other parts of the world to address that lack of skill or knowledge.

A significant factor in the current design of alerting systems is that these flight path management hazard alerts have evolved in a fragmented or piecemeal fashion, unlike the approach to airplane system failures, which is well-integrated in most airplanes. Additional alerts are being introduced to the flight deck and there is a strong need to develop integration schemes to ensure aural and visual alerting fully supports effective alerting-to recovery performance.

The primary findings from these data were the following:

1) ***Failures in the integrated alerting-to-recovery sequence played a role in every accident or incident analyzed.*** In each of the 28 events that we analyzed, there was at least one failure in the integrated alerting-to-recovery sequence; that is, there was not a succession from hazard to alert to appropriate response and recovery, and the hazard or string of hazards resulted in a major upset or accident. Twenty of the 28 events had a failure in the orientation step. Another seven had a failure in the understand step or the link to selecting appropriate actions. These early steps are strongly connected to the performance of the alerting system. There was one event that did not fail until the execution step; specifically, there was inadequate performance of the appropriate actions. This failure is beyond what is traditionally considered to be the alerting system.
2) **Orientation was the most frequent failure.** Slightly more than half of the failures (26/51; 51%) occurred in the first step of the integrated alerting-to-recovery sequence: Orientation. Sixteen failures were due to no alert, and 10 failures were due to an alert that was not detected.
3) **Identifying appropriate actions was the next most frequent failure.** The second most-frequent failure point was identifying the appropriate actions to respond to the hazard (15/51; 29%); 9 of those 15 cases were for approach to stall / stall.
4) **The majority of the hazards were tied to basic flight path management.** As one might expect since these were identified as LOC accidents, approach to stall/stall, low airspeed, unreliable airspeed, bank angle, and ground proximity accounted for 84% (43/51) of the hazards that occurred. Further, 100% of the events included one of those five hazards.
5) **Approach to stall was the most-frequent hazard in the set.** Overall, there were 16 cases in which an approach to stall / stall hazard was handled poorly, resulting in an accident or major upset. Pilots transitioned into an approach to stall / stall situation in a number of different ways; roughly two thirds of these were preceded by a low airspeed. This finding shows that other hazards that occur initially and are not handled quickly can lead to a more difficult recovery situation.
6) **Ground Proximity alerts failed in two different ways.** TAWS alerting is loud and persistent. However, for this set of 28 events, there were six cases in which a ground proximity hazard was not avoided. In five cases, the pilot was presented with a salient alert but seemed unable to detect it, probably due to limitations in attention. In another case, the pilot received an alert and seemed to understand it but did not respond adequately to avoid the hazard. It is worth noting that in the larger set of events (57) that were analyzed, we also saw a handful of cases in which TAWS alerts failed to occur (no alert).
7) **Newer airplanes have problems as well.** Orientation failures are not just an issue with airplanes built more than 30 years ago, or just with unsophisticated, 2nd-generation airplanes. The majority of these failures occurred in airplanes built in 1990 or later. More than one third (8/22) of the airplanes that failed to present an effective alert for hazards such as low airspeed or ground proximity were built after 2000.
8) **Alerting is a key safety system that can be improved**. Although significant safety events are rare, there is value in a thorough analysis of the performance of the alerting system design. The presence of an alert for a known hazard can have significant weight in a system's safety analysis. However, the analysis here shows that there are numerous ways in which that alert may not guarantee an effective recovery. Indeed, one outcome of this analysis was a fuller understanding of how alerts can fail to be detected and understood [4].

Important caveats when considering these findings:

1) **Accidents are a result of many factors**. Any review of accidents will quickly reveal that accident causality is typically complex, and, arguably, there is never a single factor or cause. Other significant factors that contributed to one or more of these events are CRM (crew resource management), flight deck interface design, pilot training, manual flying skills, fatigue, airline safety culture, non-normal procedures, vestibular illusions and other forms of pilot impairment, air data system design, and pilot's understanding of the autoflight system. This list is certainly not complete, and many of the accident reports provide a much more complete account of the tragic outcomes addressed here.
2) **There are no base-rate data that are publicly available on recovery from these hazards.** It is difficult to extract data on how frequently these hazard alerts are handled well across world-wide operations, and, thus, we cannot know the overall level of system reliability. The CAST team has looked at recorded aircraft flight data to identify how often some ASA-type (airplane state awareness) situations occur in US-based operations, and, while there is evidence that accident precursors do occur, specific numbers have not been shared publicly.
3) **Effective system operation involves interface design, pilot training, and operational procedures.** The analysis of these safety events demonstrated that the presence of a hazard alert is not always sufficient to guarantee an effective response. However, a focus solely on alerting system design ignores the other factors that can influence pilot performance—namely, pilot training or performance and non-normal procedure design. In many cases, these other disciplines can mitigate a failure on the interface side.

The details of our analysis can be found in the NASA Technical Memorandum entitled **"The role of alerting system failures in loss of control accidents"** [5]. The next section describes issues related to evaluation of the interface elements beyond alerting.

IV. Evaluation issues for flight deck interfaces

Evaluation and certification of flight deck interface elements consider a broad range of flight crew performance topics. In this analysis, we describe the broader scope of flight crew performance issues to show how awareness and attention issues fit within the larger set. We also do an inventory of FAA certification rules to demonstrate that there are not rules that apply to every issue. We then narrowed the focus of our work to flight crew awareness, attention, and understanding, and specifically examined these aspects of human performance in relation to new rules (e.g., 14 CFR 25.1302) and advisory material (e.g., AC 25.1302-1).

The systems being considered in this analysis are complex, highly interconnected, safety-critical systems. Operations can be highly dynamic and task priorities can shift quickly. While the ability to perform each and every operational task is a critical element of evaluating the system interface, equally important is supporting pilots in determining which tasks have the highest priority and what tasks should be performed. Determining this depends on understanding the current situation, which, in turn, depends on being aware of relevant variables and integrating this information into a useful mental model of the situation.

This set of evaluation issues is largely about the interface's role in managing attention and supporting pilots in directing attention to important tasks. We focus on six aspects as a way to organize the evaluation issues, and provide guidance on evaluation methods addressing five of these: alerting, monitoring, system/state awareness, situation assessment, and display management.

This analysis listed a broad set of issues that can be applied to evaluating a flight deck interface. The set of issues represents the various aspects of flight crew performance, from ergonomic issues to crew performance issues. These 41 evaluation issues are written to express how the flight deck interface should support the pilot or the flight crew in operations, which, ideally, suggests a set of appropriate evaluation measures. Actual measures, and methods, are discussed for the attention/awareness-related issues in a separate report, titled "Evaluation of Attention and Awareness Issues".

For each of the 41 issues, we also identified existing rules and guidance that may be relevant to that issue since it is often important to have an existing rule to call out an interface design issue during certification. In many cases, the recently developed 14 CFR 25.1302 rule was a relevant rule, and the accompanying AC 25.1302-1 had the most relevant guidance.

The analysis's objective is to aid the identification of a range of issues that may be useful when looking at a new flight deck interface element. Flight deck interface technology has been shifting in a number of ways—for example, using more integrated depictions of data, offering more flexibility in configuring displays, and having more task-oriented or decision-oriented displays that might be used infrequently. As technology shifts, the evaluation issues need to shift as well to ensure that potential human performance issues are identified early and evaluated appropriately.

In the past, the FAA has had to rely on general human performance rules, such as 25.771(a), which states "Each pilot compartment and its equipment must allow the minimum flight crew to perform their duties without unreasonable concentration or fatigue." This rule speaks generally to the overall workload or effort that may result from a poor interface design; it does not speak more specifically to the full range of design issues in this analysis.

The full details of our analysis can be found in the NASA Technical Memorandum entitled **"Evaluation issues for a flight deck interface**" [6].

An important component to evaluation is the identification of appropriate scenarios to ensure coverage of operational tasks and context. This is discussed in the next section.

V. Identification of scenarios for system interface design evaluation

This analysis partially responds to Safety Enhancement (SE) 210.2 [1] by describing development of operational scenarios for evaluation of flight crew interaction. Evaluations of flight crew performance with the interface rely on asking humans to perform operational tasks in an appropriate operational context. The analysis includes the major sources of material for developing operational scenarios, and a method for developing an appropriate set of operational scenarios for interface evaluation.

The primary focus of a scenario is on an operational task or set of tasks, which should be broadly defined to include activities such as taking actions on the system, monitoring the interface to understand system state, diagnosing a failure, or coordinating actions with a crew member. In this section, we describe multiple ways to identify the operator tasks that need to be supported by the interface.

Operational context captures a range of operational factors that can occur around the task performance at the heart of the scenario. Task performance is affected by many aspects of the operational environment, and identifying and including relevant factors can create a more realistic scenario. The operational context should also cover more extreme cases (e.g., very high workload) that allow the evaluation of performance near the edges of operations or human performance.

The analysis discusses a range of operational context issues, including:

- Time pressure
- Workload
- Distraction
- Environmental factors, such as vibration, turbulence, temperature
- Weather / visibility
- Expectation/Anticipation
- "Garden path" situations
- Discounting
- Uncertainty
- Masking
- Effects at a distance
- Violate expectations
- Sleight of hand
- Special knowledge
- Judgment
- Teamwork
- Unfamiliar
- Goal conflict

It is important to describe system state when specifying tasks, particularly whether the system is operating normally or is in some degraded or compromised condition. It is also valuable to evaluate how the interface communicates the full range of system state and supports operators in managing the system in each state. Describing the interface behavior for conditions outside those expected to occur by the system designer is particularly useful.

A special case for identifying tasks and operational contexts for evaluation scenarios focuses on looking at safety events that have occurred in actual operations. Indeed, a new/modified interface element is sometimes developed to address a specific operational risk that was revealed from one or more safety events. Especially when the analysis of several aviation accidents points to a potential interface issue, such as missing information or confusing information, there is a desire to make changes to the interface as a means to reduce the risk of future mishaps. Based on these findings, we have identified some characteristics of good scenarios.

1) Exploiting Diversity. A single evaluation scenario should draw from several of these sets of considerations.

For example, a scenario can be about performing specific recovery tasks when the system is in a degraded state and there are performance pressures on the operators due to the potential for a catastrophic outcome. The framework presented here is intended to make the case that any set of evaluation scenarios should at least consider the very large set of potential scenarios.

2) Covering a Range of Tasks. It is not possible to evaluate all operational tasks. Decisions will need to be made about which operational tasks to study in which contexts. How can you sample from the set of all possible scenarios?

For any interface or interface element, you want to know that operators can perform the full set of operational tasks that are required. Any interface must first and foremost demonstrate that it can support the full range of task performance. However, in many cases, it will not be possible to include all tasks in a formal evaluation.

In these situations, there are several techniques for selecting a subset of tasks for evaluation.

- System functionality – Especially when the interface element being evaluated introduces new system functionality—for example, generating options in a decision-making task—it is important to select a set of tasks that provide a representative sample of the functionality (tasks that touch all the elements of the new functionality). In many cases, the interface element's new functionality actually adds tasks that did not exist in the previous interface.
- Interface functionality – When the interface element being evaluated is more about a change or upgrade in interface technology—for example, a new interaction widget—then the tasks selected for evaluation should provide a representative sample of the interface functions. Examples might be navigating between displays, taking actions on display-based controls, or entering data.
- Critical tasks – In some cases, the purpose of the new interface element is to better support task performance that is linked to critical system operations or, in the past, was linked to a safety event. In these cases, an analysis of the situations that led to those events can identify tasks for evaluation (see the analysis from section II [2] for examples of this approach).
- Frequency and importance – Another method for down-selecting tasks is to identify the tasks that are performed more frequently or the tasks that are rated as the most important tasks for operator performance. While this approach ensures a more complete evaluation of tasks that are probably trained and more frequently performed, it may not sample as widely across all the display elements and functions.

3) Including Critical Tasks. The analysis described in IV ("Evaluation issues for a flight deck interface,") and its accompanying report [6] describes a range of interface evaluation issues. This analysis describes 41 broad issues that may have relevance for evaluating an interface element. For a newly designed, complete interface for a complex system, it may make sense to address every one of these issues. However, for an interface element that represents additional functionality or some refinement or upgrade in interface technology, not all of these evaluation issues will be required.

Many elements of the interface will have been evaluated when the larger system interface was developed and certified and will not need to be revisited when a new display or control is added. For example, issues concerning viewability and reach to the interface displays are unlikely to change with the addition of a new interface element. Similarly, some basic usability issues, such as the design of interaction widgets or display navigation, are likely to have been evaluated previously, assuming they do not change significantly in the new interface element. However, when there are relevant issues that were not addressed in previous evaluations, such as, perhaps, support for crew coordination, those issues should be addressed for this interface element.

One way to focus on specific evaluation issues is to try to anticipate the ways in which interface design and operator performance might lead to system performance issues or system safety issues. Design trade-offs are inevitable and can create vulnerabilities for operator performance. For example, the development of more task-oriented displays can lead to a greater need to manage displays to ensure that the appropriate displays can be seen at a critical time. Or, new task-specific alarms can lead to poor integration across the full set of alarms. Try to determine how new uses of technology can create unintended consequences for human performance.

4. **Adding Operational Context.** The section above described a wide array of modifications that could be used to further develop a scenario. It is important to also identify aspects of the operational context that can improve the evaluation setting.

Context modification can add realism to:

- Settings – A setting should include realistic ATC, weather, or distractions from the cabin crew.
- Focus on interface elements under evaluation – For example, if a role of the interface element is to provide flight guidance, then context modification could create situations in which flight guidance is critical for flight path management.
- Degraded conditions – For example, reducing mental resources available for additional tasks by adding secondary tasks. This is done to assess the interface element's ability to support operators in these conditions.
- Complexity – For example, some interface elements are used in combination with many simultaneous tasks.

For each scenario that is evaluated, the evaluator needs to determine the extent of the operational context provided. This can vary in two ways:

- scope – This specifies the extent to which the full system interface is required. At one extreme, the evaluation includes the entire interface, the operational procedures, full operator staffing, and support personnel (e.g., ATC, dispatch). At the other extreme, the evaluation focuses on an isolated display that supports a small set of narrowly defined tasks.
- integration – Integration is the degree to which the evaluation covers realistic operational tasks. In some evaluations, it may make sense to evaluate performance on isolated tasks, such as the ability to make the correct judgment from a representation on a display, or the ability to discriminate colors, or the strength required to move a controller. In other cases, the tasks being performed rely on having a higher level of integration with the operational system.

Scope and integration are generally highly correlated. However, there are cases in which they can be separated. For example, an evaluation of the ability to view or reach the elements of the system interface requires a complete interface mock-up to assess viewing angles or reach distances from a seated operator position. But, the tasks being performed do not require integration with the operational system.

The full details of our analysis can be found in the NASA Technical Memorandum entitled **"Identification of scenarios for system interface design evaluation**" [7].

Based on the findings from our analyses, we combined some of the lessons learned into an additional report describing best practices for improving evaluation of attention, and awareness in design, as summarized in the next section.

VI. Best practices for evaluating flight deck interfaces for transport category aircraft with respect to issues of attention, awareness, and understanding

This analysis offers guidance for evaluation of flight deck interfaces with a focus on issues concerning attention, awareness, and understanding in current certification practices. We considered the various ways in which the interface can fail to support awareness, attention, and understanding and how potential problems can be efficiently identified. The analysis draws on the characterization of issues and of scenario selection presented in other reports that are relevant to awareness. We specifically aimed to identify methods and guidance that can be used early in the design and evaluation process, as early identification enables less expensive modifications or mitigations.

Regulatory guidance for supporting perception, such as specification of legibility requirements, or movement, such as reachability of controls are more completely specified in than for ensuring that a device provides adequate support for understanding the current situation. The need for additional regulatory structure here is recognized in the addition of newer regulations such as 14 CFR 25.1302 and its associated guidance material. The importance of supporting higher level, cognitive functions will increase as new aircraft introduce increasingly automated systems and the operational environment (e.g. airspace) becomes more complex.

The analyses focused on defining a set of issues that may be relevant to support for attention, awareness, and understanding, and described how these issues may be addressed with methods available at different phases of development. We considered a variety of measures and types of data including expert assessment and pilot response time, and describe the methodological requirements for appropriate use of the measures. Different methods are appropriate for different stages of maturity in design and we describe methods in this context. We do not identify what issues should be assessed, or the extent of assessment needed for any specific aircraft or piece of equipment, as the complexity, novelty, integration may be unique. We hope that the methods are more general applicable to a variety of aircraft types and operations.

The full details of our analysis can be found in the NASA Technical Memorandum entitled **"Identification Best Practices for evaluating attention, awareness, and understanding of flight deck interfaces for transport category aircraft**" [8].

VII. Conclusion

This paper summarized research in support of SE 210 Output 2, which addresses the development of improved methods and guidance for assessing flight crew performance characteristics in design. We summarized a series of reports in publication that support the research, including:

- "**Factors that influenced Airplane State Awareness accidents and incidents**"
- "**The role of alerting system failures in loss of control accidents**"
- "**Evaluation issues for a flight deck interface**"
- "**Identification of scenarios for system interface design evaluation**"
- "**Best practices for evaluating flight deck interfaces for transport category aircraft with respect to issues of attention, awareness, and understanding**"

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