Response Timing

Low Airspeed (energy) Alerting

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Introduction. The assignment described in this paper is associated with the July 6, 2013, Asiana Flight 214 Accident and NTSB Safety Recommendation A-14-43. The underlying question in this assignment is whether flightcrews have enough time to respond[1][2] to a low airspeed/energy alert leading to a successful airplane recovery. In general, "time is a widely accepted means for evaluation of procedures used in the management and control of complex, dynamic systems, such as airliners. Time is also correlated with errors, operational efficiency, and task loading."[3]

The NTSB had concluded that in the case of the Asiana Flight 214 accident that the low-airspeed/energy alert was presented too late to be effective. The following is a quote from the NTSB report on the Asiana Flight 214 Accident: "The warning still would have occurred about 11 seconds before impact, and additional time would have been required for the flight crew to take corrective action."

Assignment History. The initial assignment was made by Clark Badie, ASHWG Chairman during the first ASHWG face to face meeting (14 November 2018) in Phoenix. Loran Haworth (ASHWG/NASA) was asked by the ASHWG chair to prepare and draft responses to the assigned questions for review by the ASHWG, FAA and in particular the flight test harmonization working group. The initial assignment was then delivered to the ASHWG before the second ASHWG meeting in Phoenix on May 1-2, 2019.

During the second ASHWG meeting, Haworth was asked to update the initial assignment, which is presented in this paper. Recommendations and rationale for both assignments were prepared, reviewed and coordinated among the following individuals at NASA Ames: Loran Haworth, (ASHWG/SJSUF/ARC), Dr. Michael Feary (ARC-TH) NASA Lead and Dr. Randall Mumaw (SJSUF/ARC). These authors wish to acknowledge at the beginning of this paper that there are many elements associated with an effective flightcrew alert but, also want to emphasize the criticality of alerts presented early enough to enable the flightcrew to respond and successfully recover the airplane.

The information presented in this assignment refers to current applicable regulatory airworthiness information. Also covered are principles/points of agreement, methods/means [4] of compliance (MOC), and an introduction to a new recommended MOC which is based on the time the low airspeed/energy recovery procedure must be completed compared to the actual time on procedure making this MOC consistent with the requirement in §25.101 (h)(3) [5].

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[1] A successful response mentioned above is defined as one that would enable the flightcrew and airplane to continue safe flight following the alert.

[2] FR Doc. 2018-00821 Filed 1-17-18; 8:45 am

[3] "Available Operational Time Window: A Method for Evaluating and Monitoring Airline Procedures," H K Kourdali & Lance Sherry George Mason University ,Journal of Cognitive Engineering and Decision Making · August 2017

[4] The words "methods" and "means" in terms of FAA compliance have the same meaning.

[5] Our current interpretation of this rule includes the procedures associated with recovery from low airspeed/energy conditions. If there are other interpretations, the principle associated with including any time delays seems fundamental.

The assignment: "Response times - what to follow, and why? How does that have an impact on design and evaluation?"

Impact on design. The ASHWG Chairman's question about the "impact to design" regarding "response times" should be answered first because it asks why identifying response time allowances are important in airplane design? The answer is straightforward since determining the Time on Procedure(s) (ToP) allowances[6] (time delays) for the flightcrew, the equipment, and the airplane allows airplane designers to determine when (how early) the low airspeed (energy) flightcrew alert needs to be presented to the flightcrew to be effective[7].

Comparing the ToP to the Allowable Operational Time Windows (AOTW)[8] also allows the designer to define the limitations of the alert as to when the alert cannot be timely[9] or useful[10]. Knowledge of the limitations of the alert should become part of the risk assessment[11] (identified failure conditions[12]) and also distinguishes those areas to the designer and certification team as to when mitigation or improved design is warranted if the alert cannot also be successful (timely) for all operational conditions.

Regulatory concerns. A flightcrew alert presented too late is ineffective, will lead to unintended consequences (e.g., Inability of the flightcrew to control the airplane in time to avoid the low airspeed (energy) state and will potentially lead to subsequent airplane accidents. Therefore the low airspeed (energy) flightcrew alert presented too late would not:

1. meet its proposed intended function[13] as required by §25.1301(a)(1) and §25.1309(a)

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[6] The Time on Procedure (ToP) for this paper considers all the response time allowances/delays from all sources and are similar in definition to time delays found in the §25.101(h)(3) rule that states the following: "Include allowance for any time delays, in the execution of the procedures, that may reasonably be expected in service. "

[7] In this sentence an effective alert is one that is presented early enough to the flightcrew for the flightcrew to continue flying the airplane safely.

[8] "Available Operational Time Window: A Method for Evaluating and Monitoring Airline Procedures," H K Kourdali & Lance Sherry George Mason University ,Journal of Cognitive Engineering and Decision Making · August 2017

[9] The word timely in this sentence is an alert presented early enough to the flightcrew that will enable the flightcrew to properly respond and continue flying the airplane safely.

[10] Example of limitation based on timely. AC 25.1329-1C para 57 a.2. "Standard stall warning and high-speed alerts are not always timely enough for the flightcrew to intervene to prevent unacceptable speed excursions during FGS operation".

[11] One of the initial steps in establishing compliance with § 25.1309 for a system is to identify the failure conditions that are associated with that system (AC 25.1329-1C para 100 a.(1).)

[12] This depends somewhat on the stated intended function of the alert.

[13] The currently proposed intended function of this alert is to attract the flight crew's attention to an impending low energy condition early enough during approach and landing that the flightcrew can avoid or recover from the low energy condition and continue safe flight.

2. be considered a timely attention-getting cue required by §25.1322(c)(2) when an appropriate and timely reponse (AC 25.1322-1 Paragraph 4.a.)[14] is expected.
3. meet the requirement §25.1309 **(c)** Warning information must be provided to alert the crew to unsafe system operating conditions, and to enable them to take appropriate corrective action.
4. be accessible and usable by the flightcrew in a manner consistent with the urgency, frequency, and duration of their tasks (§25.1302(b)(2));
5. be designed to enable the flightcrew to intervene in a manner appropriate to the task (§25.1302(c)(2))
6. enable flightcrew awareness, if awareness is required for safe operation, of the effects on the airplane or systems resulting from flightcrew actions (§25.1302(b)(3)).
7. include allowance for any time delays, in the execution of the procedures, that may reasonably be expected in service (§25.101 (h)(3))[15]. Note the wording "any time delays."
8. meet the safe operation and flightcrew workload requirements in §25.1523 as determined in appendix D of Part 25. Areas of consideration include accessibility, directing proper corrective action, urgency, and complexity of operating procedures, degree of duration of conentrated mental effort and diagnosing, and coping with malfunctions and emergencies.

Principles/points of agreement and discussion. Recommend ASHWG agreement and or discussion on the points listed below. Some of the following language may be considered redundant, but each captures one specific point or principle.

1. that a low airspeed (energy) flightcrew alert presented too late will not meet the proposed intended function for the low airspeed (energy) alert or the other requirements as discussed and listed in the paragraph above (Impact on designing). The effect of a flightcrew alert presented too late to the flightcrew is similar to no alert.[16][17] That is the alert cannot be successful as a low airspeed/energy flightcrew alert.

[14] "the provision of an alerting system that aids the flightcrew in identifying non-normal operational or airplane system conditions and in responding in an appropriate and timely manner is an essential feature of every flight deck design"

[15] Our current interpretation of this rule includes the procedures associated with low airspeed/energy conditions. If there are other interpretations, the principle associated with including any time delays seems fundamental.

[16] Descent Below Visual Glidepath and Impact With Seawall Asiana Airlines Flight 214 Boeing 777-200ER, HL7742 San Francisco, California July 6, 2013 NTSB/AAR-14/01 PB2014-105984 Notation 8518 Adopted June 24, 2014 (page 105).

[17] The Role of Alerting System Failures in Loss of Control Accidents CAST SE-210 Output 2Report 3 of 6, NASA/TM—2019–220176. The material in this report was also presented to the ASHWG via WebEx on 2 May 2019 by Randy Mumaw at NASA-Ames

2. that the time delay allowance requirement found in § 25.101 (h) is the applicable regulation regarding pilot, equipment and airplane time delay allowances. § 25.101 (h)(3) says the following "Include allowance for any time delays, in the execution of the procedures, that may reasonably be expected in service." AC 25-7D only partly supports that requirement by stating the following in para 4.3.2, which lists §25.101(h) as the applicable regulation "regarding pilot[18] action time delay allowances." The actual rule language, however, takes account of all time delays (not just pilot delay allowance), which would include equipment and airplane response delays. Since §25.101 is not accompanied by its own AC, modification of the AC 25-7 to correct and expand on the actual rule language delays is highly recommended.

3. all sources of delay (e.g., flightcrew, equipment, and airplane) must be considered (§25.101(h)(3)) in determining how far in advance the low and slow airspeed (energy) alert should be presented to be timely as stated above. It is also critical that allowances for the flightcrew, equipment, and airplane be based on qualified flightcrews and the representative equipment and airplane undergoing certification. These delays are directly dependent on the equipment installed (information displays, access to lookup tables, access to display menus, controls, systems, and airplane) and should not be generalized. The ToP should be compared to the AOTW to determine the limitations of the alert.

4. that while predetermined in-service delay times associated with pilot actions such as those found in AC 25-7D provide a standardized methodology during flight test, the use of any predetermined delay time values to represent delays should be questioned. The source and rationale behind the predetermined times should be provided and justified by the FAA and industry. For example, some predetermined times maybe based on outdated civil air regulations and some test techniques are likely maintained because they worked in the past but are perhaps founded on earlier airplane designs that were mostly manually flown. Also predetermined in service delay times may not consider multiple pilots (flightcrews), airplane design variations, limitations of the alert, and continued safe flight following the alert.

5. that the flightcrew response time allowances be determined from measured flightcrew reaction times (human capability) using empirical methods of establishing minimum response times associated with the low airspeed (energy) flightcrew alert. It is recommended that the flightcrew reaction time allowance be structured on the 95th percentile statistical distribution tail (slower cases) rather than an average time allowance value. Using the average or mean would imply that roughly half of the population distribution (many flightcrews) could not achieve the average reaction time. Also, flightcrew time allowances should be adequate for the flightcrew to not only respond to the alert but

[18] Note the reference to "pilot" rather than "flightcrew". Time delays/response time should be associated with flightcrew actions when applicable. The time delay associated with a flightcrew are probably different than the response time of one pilot.

also minimize flight crew error, per § 25.1302 (e.g., follow specified procedure in their response) and then continue to safely fly the airplane. As mentioned earlier, time is correlated with errors, operational efficiency, and task loading. It is important that time measures be based on flightcrew (2 or more crewmembers) response times rather than one pilot except in the case of the incapacitated flightcrew situation (AC 25.1523-1).

6. that a complete response to a hazard (e.g., low airspeed/energy condition) may involve a series of responses (actions taken) by the flightcrew leading to avoidance of the low and slow airspeed (energy) state. Some actions will be discrete (moving a switch) while others may involve continued adjustments to flight controls over time. While the initial response to an alert is critical, so are the follow on flightcrew responses and actions leading to successful avoidance of the low airspeed (energy) condition[19]. Some flightcrew actions affecting airplane equipment will generate equipment response delays (e.g., the time to spool up engines using thrust levers, changing flap settings, raising landing gear, etc.) some of which are lengthy (According to one propulsion expert, the delay for large engines on transport airplanes to spool up could be substantial (e.g., more than 30 seconds). The emphasis here considers the delay allowances associated with equipment activation and response.

7. that following flightcrew control inputs to increase airspeed, decrease drag and climb the airplane, additional time delays associated with altering the total energy vector of the airplane to avoid the low and slow airspeed (energy) condition are expected. The emphasis here is the delay associated with the complete airplane response itself (e.g., from a low, slow descent to a climb at a faster airspeed).

8. that the forcing function behind the flightcrew response allowance be established on measured flightcrew reaction times (human capability) for the low and slow airspeed (energy) flightcrew alert rather than other methods such as airspeed margins that do not directly consider time as required by §25.101(h)(3). However, airspeed margins could be used to trigger a low airspeed/energy alert as long as it can be fully demonstrated that the margin will reliably and accurately provide sufficient time for the flightcrew, equipment, and airplane to respond within the AOTW and continue safe flight.

9. that we should discuss mitigation as an alternative when qualified flightcrews cannot adequately respond in time to successfully operate the equipment and airplane to avoid the low airspeed (energy) state. Examples of mitigation already exist with automated systems that provide early flight control responses in specific conditions. Another type of mitigation

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[19] It is worth mentioning that operational data shows that autopilots are used more than 90% of the time. Any mode confusion as to autopilot control of the airplane could significantly impact the flightcrew's reaction time and responses. Reference: Addressing Mode Confusion Using an Interpreter Display, Randall J. Mumaw, San José State University Research Foundation, April 2018. DOI 10.13140/RG.2.2.27980.92801

for the low airspeed/energy case recommended for investigation is that of establishing an earlier alert such as an alert for an unstable approach that can be a precursor to a low energy situation on approach.

10. that the ASHWG discuss cueing on the flight deck associated with low airspeed (energy) situations (e.g., airspeed indications as one example). The ASHWG should provide recommendations on this subject.

11. that the ASHWG discuss and recommend the level or category for the low airspeed/energy alert (Warning, Caution, Advisory). §25.1322 does not establish the alerting level/category for a specific alert, but, it can be established within the rule requiring the alert. Should it be considered a time critical warning as an example?

What to follow, and why?

History

Before the ASHWG 2-3 May 2019 meeting the ASHWG recommended the following rule language:

> For a low airspeed (energy) alert to be effective, it must be presented early enough for qualified flightcrew and aircraft equipment to avoid the low energy condition/state and safely recover. Time allowances should be adequate:
>
> - for the flightcrew to respond to the alert within the AOTW while, minimize flight crew error, per §25.1302 (e.g., access displayed information, follow specified procedure, etc.),
> - for the airplane equipment to respond (e.g., engine spool up time) and,
> - for the airplane to be safely recovered (e.g., manual or automatic)

The first bullet, in combination with the general statement above, assumes that qualified flightcrews will have adequate time to correctly/adequately respond to the alert to avoid the low energy condition/state, including a safe recovery. Flightcrew correctly responding (minimizing error) means that flightcrews will follow the required procedures ideally without error.

Update

The proposed rule language from above was updated on 2 May 2019 at the ASHWG meeting in Phoenix. That proposed language is shown below.

> “Alerting that informs the flightcrew in a timely manner in advance of a low energy condition during the approach phase of flight to enable the flightcrew to continue to Safely fly the airplane”.

Discussion.

The proposed rule was trimmed to the language provided above during the ASHWG 1-2 May 2019 meeting. The newer wording removes the word "qualified." as in qualified flightcrew. The language "qualified flightcrew" is used explicitly in the new FAA regulation §25.1302 to indicate the qualification of the flightcrew that airplane systems and equipment are designed to meet. This recent modification (removing the word qualified) may create future conflicts and confusion with airworthiness rules since it opens the opportunity to satisfy the rule based on other means such as the ambiguous "average pilot" used in older FAA requirements. Rule 25.1302 uses the following specific words: "The applicant must show that these systems and installed equipment, individually and in combination with other such systems and equipment, are designed so that qualified flightcrew members trained in their use can safely perform all of the tasks associated with the systems' and equipment's intended functions". In summary, consistent and standardized language among regulatory requirements lowers potential confusion during the certification process and also legally.

Recommendations associated with the updated rule language wording is provide below.

Further recommendation and discussion based on the updated wording:

1. Add the adjective "qualified" to the word flightcrew to the proposed rule language. If the word "qualified" is not used other more ambiguous wording could be used.
2. Ensure that the words "timely manner" are defined in the AC 25-7D and associate those words with the requirements in §25.101 and requirements stated above in the AC and method of compliance.
3. Discuss the use of the words "safely fly." For example, is there any other option other than performing a go-around if a low energy condition is experienced during the approach phase? If this is the only option discuss changing the wording "…to enable the flightcrew to safely perform a go-around."
4. The words "continue "to safely fly the airplane" contains a split infinitive. To fly the airplane safely is another wording option for consideration.

What to follow and Evaluation.

Standard methods of compliance (Appendix A) should be followed in addition to the suggestions provided in Appendix B for determining the timeliness of an effective low airspeed (energy) flightcrew alert[20].

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[20] The words in the draft list shown in appendix B can be changed or modified by the ASHWG but the following steps (perhaps additional ones) should be included in determining response times.

Additional Concerns that should be addressed

AC 25-7D. We found both technical and administrative concerns when reviewing AC 25-7D "Flight test Guide for Certification of Transport Category Airplanes" that maybe misleading. The AC 25-7 is a very unique AC that combines many dozens of often complicated rules and policy material associated with flight test into one advisory document. It is the reviewers' opinion, and we believe the opinion of the FAA that AC 25-7 is administratively challenging to update and keep updated. We believe this is primarily due to the many dozens of rules that AC 25-7 encompasses and the length of time it takes to update the AC. Even when this very unique AC "Flight test Guide for Certification of Transport Category Airplanes" is occasionally updated, often only certain areas are updated. As an example the latest update of the AC 25-7 does not reference or include the latest method of compliance updates for other updated rules (e.g., (§25.1322, "Flightcrew Alerting") or for new rules such as the rule §25.1302 for "Installed Systems and Equipment for use by the Flightcrew (that became effective years before). Since AC 25-7 is an authoritative guide for certification, there is a very strong potential that misleading guidance will be provided to or unintentionally used by certification teams.

To be complete, we should mention that AC 25-7D points to §25.101(h) as the rule basis for pilot time delay allowances as previously mentioned. AC 25-7D guidance associates delays with pilot actions as a method of determining the total response time for <u>just</u> pilot procedures as illustrated in figure 4-1 of AC 25-7D. Paragraphs 4.3.4.2, 4.3.6.1, 4.3.6.2 of the AC 25-7D provides additional guidance to include "these procedures must be able to be consistently executed in service by crews of average skill, use methods or devices that are safe and reliable, and include allowances for any time delays in the execution of the procedures that may reasonably be expected in service. These requirements prohibit the use of exceptional piloting techniques".

Mitigation. If the flightcrew low airspeed alert cannot be provided early enough to be effective other methods including mitigation, could be considered. There are existing examples where mitigation has been allowed to aid the flightcrew in their response to an alert. Some forms of mitigation have only been recently available given smarter alerting systems and automation (e.g., automated response to TCAS RAs, automatic rudder compensation with engine failure, and automated braking). Other mitigation methods may involve identifying earlier causal factors such as an unstable approach before a low airspeed/energy condition, thus preventing the low and slow condition.

Conclusion

Flightcrew alerting provided too late is not considered effective and has the same effect as no alert. Also, a late low airspeed/energy alert cannot meet the intent of the new ASHWG proposed rule or its intended function which requires continued safe flight. All time delays associated with the reaction and responses to a flightcrew alert as required by 25.101 (h)(3) must be measured or determined and considered as part of the method of compliance during certification for deciding when an alert must be presented to be successful. This includes all the time delays, including those associated with the flightcrew, installed equipment and system responses and the airplane regaining safe flight.

The measured delay times (the ToP) associated with the alerting condition must be compared to the AOTW. If the response times are longer than the AOTW, the alert should not be considered as timely enough to permit the flightcrew to reliability continue safe flight. This comparison (Actual delay times versus AOTWs) will allow the certification authority and industry to identify when the alert is effective as a flightcrew alert. This method will identify the time limitations associated with the intended alert and will factor into identifying failure conditions when the alert cannot be timely enough to meet the alerts intended function. It will also encourage industry to look for and then propose designs that help mitigate for those conditions when the alert is not effective based on identification of the limitations of the alert associated with time delays.

Appendix A

Standard methods of compliance are recommended.

FAA policy statement ANM-01-03A guides FAA Certification Teams conducting a review of applicants' proposed methods of compliance for 14 CFR part 25 regulations related to flight deck human factors[21]. While this is guidance directed at FAA certification teams, this is also an indication to industry what the FAA will bear in mind for certification. While the FAA and industry may agree on additional methods of compliance, the following methods of compliance from ANM-01-03A are recommended. It should also be acknowledged that flightcrew response data can be collected in conjunction when gathering other ongoing compliance information collection.

The following statements are mainly copied from FAA policy ANM-01-03A.

Evaluations, assessments, and analyses:

These are conducted by the applicant or others (not the FAA or a designee), who then provide a report of their results to the FAA. In cases where human subjects (flightcrews, for example) are used when gathering data (subjective or objective), the applicant should fully document the selection of subjects, what data will be collected, and how the data will be collected. Relevant here is that flightcrews are representative of the full cadre of pilots worldwide. This will allow the FAA Certification Team to determine the extent to which the evaluations, assessments, and analyses provide valid and relevant information concerning finding compliance with the regulations.

1) Engineering evaluations or analyses – These assessments can involve some techniques including:

- procedure evaluations (complexity, number of steps/actions, nomenclature, etc.);
- reach or strength analysis via computer modeling;
- Time-Line analysis for assessing task demands, workload[22]. Also flightcrew, equipment and airplane recovery delays; or
- other methods, depending on the issue being considered.

Carefully consider the validity of assessment techniques for analyses that are not based on advisory material or accepted industry standard methods, and request that applicants validate any computation tools used in such analyses. If analysis involves comparing measured

[21] While the methods of compliance listed here in appendix A are considered as standard methods, these standard methods are also considered acceptable for determining response timing. Appendix B is more specific to the question of response timing.
[22] Workload and response time allowances are often correlated.

characteristics to recommendations derived from pre-existing research (internal or public domain), then the applicant may be asked to validate the use of the data derived from the research.

(2) Part-task evaluations – These are evaluations using devices that emulate the crew interfaces for a single system or a related group of systems, using flight hardware, simulated systems, or combinations of these. Typically, these evaluations are limited by the extent to which acceptability may be affected by other flight deck tasks. This MOC is most easily used for stand-alone systems. As flight deck systems become more integrated, part-task evaluations may become less useful as a MOC, although their utility as engineering tools may increase. A typical example of a part-task demonstrator for an integrated system would be an avionics suite installed in a mock-up of a flight deck, with the main displays and autopilot controllers included. Such a tool may be valuable during development and for providing system familiarization to the authorities. However, in a highly integrated architecture, it may be difficult or impossible to assess how well the avionics system will fit into the overall flight deck without complete simulation or use of the actual airplane. Some part-task evaluations may be performed as part of seeking Technical Standard Order (TSO) approval. However, a TSO does not constitute installation approval, which usually requires evaluation in the overall flight deck.

(3) Simulator evaluations – These are evaluations using devices that present an integrated emulation (using flight hardware, simulated systems, or combinations of these) of the flight deck and the operational environment. They can also be “flown” with response characteristics that replicate, to some extent, the responses of the airplane. Typically, these evaluations are limited by the extent to which the simulation is a realistic, high fidelity representation of the airplane, the flight deck, the external environment, and crew operations. It should be noted that not all aspects of the simulation must have a high level of fidelity for any given compliance issue. Rather, simulator fidelity requirements should be determined given the issue being evaluated. For additional information, see section 4b(1)(iv) of FAA Advisory Circular (AC) 25-11, “Transport Category Airplane Electronic Display Systems,” dated July 16, 1987.

(4) In-flight evaluations – These are evaluations using the actual airplane. Flight tests generally offer the most realistic and comprehensive environment for evaluating the flight crew interface design in realistic scenarios. Assuming that the airplane is fully configured, the integration of the flight crew interface features can be evaluated in a flight environment, including communication tasks and interaction with the ATC environment. However, typically, these evaluations may be limited by the extent to which the critical flight conditions (for example, weather, failures, or unusual attitudes) can be located or generated, and then safely evaluated in flight. While evaluations using the actual airplane are the closest to real operations, in some cases not all of the scenarios of interest can be demonstrated. The applicant may not be able to show certain failures or combinations of failures for a variety of technical or safety reasons. In such cases, applicants may find it necessary to combine flight testing with other MOCs to gain a complete evaluation. For additional information see FAA AC 25-11, section 4b(1).

Demonstrations: These are similar to evaluations (as described above), but conducted by the applicant with participation by the FAA or its designee. The applicant may provide a report or summary, requesting FAA concurrence on the findings. In each case, the applicant should note the limitations of the demonstration and how those limitations relate to the compliance issues being considered. The FAA should carefully consider which of its specialists will participate (for example, pilots, human factors specialists, or systems engineers), what data will be collected (objective and/or subjective), and how the data will be collected. This is to ensure that the demonstration adequately addresses the compliance issues and that there is participation by the appropriate FAA evaluators. Examples of demonstrations include:

- Mock-up demonstrations
- Part-task demonstrations
- Simulator demonstrations

Appendix B

In support of the proposed guidance language shown above the simple equation below is provided to illustrate essential[23] timeline categories (flightcrew, equipment and airplane response times) that should be considered when determining how far in advance a flightcrew low airspeed (energy) alert should precede a low airspeed (energy) condition to be effective. It is recommended that the ASHWG also examine methods that industry already utilizes for determining pilot, equipment, and airplane recovery timelines which could serve as basis for guidance by the ASHWG.

Example delay categories

1) Time for the alerting system to generate the alert (t1). The time to generate the alert can depend on several factors to include the alert's priority when multiple alerts are active. Generally, the time to generate the alert could be less than a second or a matter of many seconds when other alerts are active. It is recommended that the worst case scenario should be examined.
2) Time for the flightcrew to initially recognize the alert, including all interface delays and then correctly perform and complete all actions as required by the recovery procedure (t2). All flightcrew actions should be performed without error while avoiding the low energy condition. Response data tied to incorrect actions (or inaction) should not be included in determining a minimum time, such as actions out of order, actions required but not taken, and so forth.
3) The time required to change the status of the internal airplane equipment required to avoid the low energy condition and go around (e.g., gear up, flaps up, engine spool up, and so forth)[24] (t3).
4) Time to change the energy vector (speed and direction) of the airplane to a successful recovery or go-around[25]. For example, the time to accelerate back to a safe airspeed and climb once additional thrust is applied (t4).
5) The summation of response times (Ta) shown below (taken from values in points 1-4 above) provides a simple illustration of response time delays that must be considered in determining how far in advance, the low airspeed (energy) alert must be provided before entering the low airspeed (energy) state. Obviously most of the delays will occur in parallel rather than in series as can be expressed on a Gant chart, by determining the critical time line or using more advanced methods described in the next paragraph.

$$\mathbf{t1 + t2 + t3 + t4) = Ta}$$

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[23] It is recognized that time is one of many essential elements required for a successful alert.

[24] It is recommended that the equipment cycle times be based on the worst case scenario. For example the time to spool up the engine from a low power situation to TOGA power, however, there is concern that this maybe too severe of a requirement. While this is a matter for discussion AC 25-7D uses the worst case assumption 11 times in the AC as a point of reference.

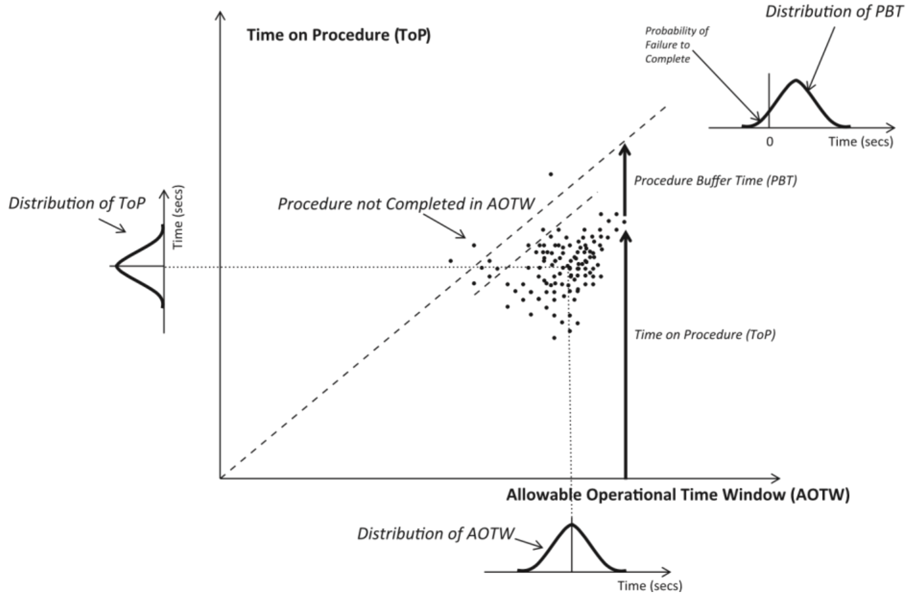
[25] This assumes that a successful recovery or go around represents recovery to a safe flight condition.

Advanced techniques

As stated above, more advanced techniques are recommended, such as a time line analysis introduced in AC 25.1523-1[26] or similar methods that consider both linear and parallel actions and delays be used in the analysis. However, the question that needs to be answered is whether the combined delays (the ToP) allow sufficient time for the flightcrew, equipment, and airplane that experience a low airspeed/energy event to continue to safely fly the airplane based on the AOTW. Comparison of these two times (measured delay times versus AOTW times) will answer whether the alert is timely enough to recover the airplane safely, help define limitations, and open discussions regarding further mitigation.

There has been several higher-tech programs available for making time comparisons and understanding workload dating back to 1976 with the Timeline Analysis Program (TLA-1) produced by Boeing under NASA contract NAS1-13741. Also, modern airplanes provide the availability of flight data monitoring typically used for aircraft performance and maintenance purposes, and provides the means to characterize the statistical properties of the AOTW". We recommend that members of the ASHWG read the paper "Available Operational Time Window: A Method for Evaluating and Monitoring Airline Procedures" by Houda Kerkoub Kourdali and Lance Sherry, George Mason University which describes an analytical method to characterize the statistical properties of the AOTW for use in the design and evaluation of procedures." While the purpose of the paper is not specific to the low airspeed/energy alert, the techniques used to compare the ToP to the AOTW are apparent. The following figure from the Houda Kerboub paper provides a concept illustration of procedures that were and were not completed within the AOTW.

[26] AC 25.1523-1 5.b.(1) provides guidance on the importance of the time line analysis



Scatter plot of time on procedure (ToP) and allowable operational time window (AOTW) for a set of flights yield distributions for ToP relative to the AOTW. The difference between the AOTW and the ToP for a given flight is the procedure buffer time (PBT).

Appendix C

Important Acronyms:

AOTW - Allowable Operational Time Windows

ToP - Time on Procedures