RTCA, Inc.
1150 18th Street NW, Suite 910
Washington, DC 20036
USA

Recommended Solutions to Address TAWS Manual Inhibition CFIT Cases Raised by NTSB Safety Recommendations A-17-035 and A-18-015 and GAJSC CFIT WG SE-54

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Prepared by: SC-231

FOREWORD

This document was prepared by Special Committee 231 (SC-231) and submitted to the RTCA Program Management Committee (PMC) on June 11, 2020. The enclosed material includes recommendations to the PMC on potential options to address NTSB Safety Recommendations as requested. This document is informational to the PMC and is not intended for use outside the PMC.

EXECUTIVE SUMMARY

This paper summarizes the recommendations from Special Committee 231 (SC-231), Terrain Awareness and Warning Systems (TAWS), to the Program Management Committee (PMC) regarding NTSB Safety Recommendations A-17-035 and A-18-015 and recommendations from the General Aviation Joint Steering Committee Controlled Flight Into Terrain Working Group (GAJSC CFIT WG).

SC-231 held several meetings to review the NTSB and GAJSC data and came up with potential means to address the recommendations The most promising ideas were then presented at a plenary meeting in Anchorage, AK, which allowed several representatives from the Alaskan aviation community to provide feedback on the various proposals.

The solution that seemed the most promising is development of a Situational Awareness Tool based on NASA's Ground Collision Avoidance System (section 2.6). The fact that a product could be developed in a relatively short period, that there would be no regulatory work to be done, and that use of the product would be on a voluntary basis were all aspects that made this option very desirable.

Several additional solutions were rated almost as highly by the Alaskan operators. Among those solutions, those that were also rated the most promising by the committee were re-enabling alerts at power up, allowing Class C TAWS for Class B Operations, ensuring that the terrain display remained active even when the inhibition function was selected, and defining a height based inhibition function that still provided last moment alerts.

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1 PURPOSE AND SCOPE

This paper summarizes the recommendations from Special Committee 231 (SC-231), Terrain Awareness and Warning Systems (TAWS), to the Program Management Committee (PMC) regarding NTSB Safety Recommendations A-17-035 and A-18-015 and recommendations from the General Aviation Joint Steering Committee Controlled Flight Into Terrain Working Group (GAJSC CFIT WG).

1.1 Introduction

There have been several Controlled Flight into Terrain (CFIT) accidents where the TAWS had been manually inhibited by the pilot. The National Transportation Safety Board (NTSB) investigations of these accidents revealed that many Part 135 and Part 91 operators regularly fly with their TAWS inhibited due to the frequent occurrence of nuisance alerts during routine operations.

In April 2019, the PMC requested SC-231 to provide recommended solutions based on consideration of NTSB Safety Recommendations A-17-035 and A-18-015 and recommendations from the GAJSC CFIT WG.

1.2 NTSB and GAJSC Recommendations

The NTSB and GAJSC recommendations that were the starting point for the SC-231 activity are the following.

NTSB Safety Recommendation A-17-035:

Implement ways to provide effective terrain awareness and warning system (TAWS) protections while mitigating nuisance alerts for single-engine airplanes operated under 14 Code of Federal Regulations Part 135 that frequently operate at altitudes below their respective TAWS class design alerting threshold.

NTSB Safety Recommendation A-18-015:

Modify the terrain awareness and warning system requirements in Technical Standard Order C151 such that, once the alerts are manually inhibited, they do not remain inhibited indefinitely if the pilot does not uninhibit them.

GAJSC Recommendations:

SE-54 Output 1:

RTCA to explore the use of existing Class C TAWS for unique operations such as mountainous/low altitude operations.

SE-54 Output 2:

1. RTCA to explore whether or not H-TAWS algorithms could be helpful in preventing CFIT accidents in certain environments for fixed wing aircraft. Incorporate analysis into final recommendation.
2. If the RTCA analysis indicates H-TAWS could benefit fixed-wing aircraft the FAA should update regulations and policies, as necessary, to allow for installation.

SE-54 Output 3:

1. RTCA SC-231 to explore hardware/technology solutions that ensure protections against the permanent inhibiting of TAWS ‘nuisance’ alerts, such as a time-limited uninhibit switch.
2. Issue recommendation

1.3 Underlying Issue

The alerting thresholds defined for Class A and Class B TAWS under TSO C151() were originally designed to be compatible with fixed-wing aircraft operating between charted airports under Instrument Flight Rules (IFR). The alerting criteria ensure nuisance alerts do not occur when aircraft have terrain clearance that is consistent with FAA Order 8260.3B United Stated Standard for Terminal Instrument Procedures (TERPS), and International Civil Aviation Organization (ICAO) Procedures for Air Navigation Services-Aircraft Operations (PAN-OPS) 8168, Volume 2. These documents define a minimum terrain clearance of 1000ft in the enroute environment. The TAWS alerting thresholds for Reduced Terrain Clearance for Class A and Class B systems are 700ft under TSO C151c and earlier versions. (This value was reduced to 500ft in DO-367, Minimum Operational Performance Standards (MOPS) for Terrain Awareness and Warning Systems (TAWS) Airborne Equipment in order to resolve inconsistency in level flight and descending flight requirements. DO-367 is invoked by TSO C151d.)

During IFR operations, enroute terrain clearances can be expected to be 1000ft or more. In these cases, an alerting threshold of 700ft or less will not result in nuisance alerts. As an aircraft gets closer to an airport, where terrain clearances are expected to be reduced, the TAWS alerting thresholds are reduced accordingly.

However, the TAWS alerting thresholds are not compatible with VFR operations nor are they compatible with landings at locations other than a runway in the TAWS database. Part 135 operators on VFR flights may cruise at an enroute altitude of 500ft AGL. Additionally, operators of seaplanes and operators who serve remote destinations routinely land at locations that are not identified as runways in the TAWS database, and therefore cause terrain alerts. These types of operations can result in frequent if not continuous nuisance alerts. As a result, pilots manually inhibit the TAWS function to avoid these nuisance alerts.

1.4 Methodology

SC-231 held several meetings to review the NTSB and GAJSC data and came up with potential means to address the recommendations. A brainstorming exercise was used to generate an initial list of potential solutions. The ideas were then evaluated further to identify those ideas with the most merit. Knowing that this type of nuisance alerting and CFIT cases in question are occurring in Alaska, this target audience was identified for feedback. The most promising ideas were then presented at a plenary meeting in Anchorage, AK, which allowed several representatives from the Alaskan aviation community to provide feedback on the various proposals.

1.5 Aspects Considered

For each potential solution, the Committee considered the following aspects.

Operational Impact: What is the effect of the proposed change in the cockpit?

Training Impact: What new pilot training would be required?

Implementation Effort: What is the scope of the effort to effect the change? This was considered qualitatively, from both a manufacturing standpoint as well as an aircraft installation standpoint.

Regulatory Implications: Would changes be necessary to the MOPS, TSO, and Part 91/135 rules?

Relevance: How well does the proposed change address the NTSB Safety Recommendations?

Collateral Impacts: Would the proposed change impact operators who are not currently experiencing problems with their Class B installations?

2 POTENTIAL SOLUTIONS

The Committee considered the following solutions. The solutions below are not sequenced in a particular order. Details on many of these concepts are included in the Appendices. After introducing each concept in Section 2, the recommended solutions are identified in Section 3.

2.1 Allow Operators to Use Class C TAWS in lieu of Class B TAWS

2.1.1 Overview

Currently, turbine-powered aircraft with six to nine passenger seats used in Part 135 operations and turbine-powered aircraft with six or more passenger seats used in Part 91 operations must be equipped with a Class B TAWS (14CFR 135.154, 14CFR 91.223).

If aircraft that are normally required to be equipped with Class B TAWS were instead allowed to be equipped with Class C TAWS, some types of nuisance alerts would be reduced.

Class C TAWS have the same required modes and functionality as Class B TAWS, but the alerting thresholds are smaller, which allows the aircraft to operate at lower altitudes before an alert occurs. As an example, a Class C TAWS must alert when the predicted terrain clearance is less than 200ft when the aircraft is in level flight and is more than 5nm from the nearest airport. By comparison, a Class B TAWS must alert when the predicted terrain clearance is less than 500ft when the aircraft is in level flight and is more than 15nm from the nearest airport.

There is at least one exemption that has been submitted to the FAA on behalf of a group of Part 135 operators to allow the operators to use a Class C TAWS in lieu of a Class B TAWS. As of this writing, the exemption is under review by the FAA. The exemption would only apply to aircraft that exclusively fly VFR flights. No IFR operations would be allowed on an aircraft with a Class C TAWS under this exemption.

2.1.2 Benefits

Allowing the use of Class C TAWS would reduce nuisance alerts for operators flying at 500ft AGL. This could prompt those operators to fly with TAWS active on flights where they would otherwise inhibit TAWS.

If the allowance for use of Class C TAWS were done through the exemption process, no rulemaking activity would be required.

No change to the TAWS MOPS would be required.

Class C TAWS products are currently available on the market, which reduces the potential lead-time to field this change.

Some Class B TAWS units may be able to be converted to Class C by a software update, which could reduce the effort associated with retrofit.

Operators for whom Class B TAWS is working well would not be affected.

2.1.3 Limitations

Use of a Class C TAWS would not be a cure-all for nuisance alerts. Alerts could still occur for operators landing off-airport. Alerts could also occur when the desired flight path was in a winding valley.

The reduced alerting thresholds of a Class C TAWS would result in later alerts in actual CFIT scenarios. No analysis has been performed by the Committee to determine if Class C levels of protection would provide an acceptable level of safety for Part 135 operators.

For aircraft that fly both low-level VFR flights as well as IFR flights, a Class C TAWS installation may not be appropriate.

Feedback from several operators was that the Class C alert threshold was too low during IFR operations.

2.2 Allow Operators to Use HTAWS in lieu of Class B TAWS

2.2.1 Overview

Currently, turbine-powered aircraft with six to nine passenger seats used in Part 135 operations and turbine-powered aircraft with six or more passenger seats used in Part 91 operations must be equipped with a Class B TAWS (14CFR 135.154, 14CFR 91.223).

If aircraft that are normally required to be equipped with Class B TAWS were instead allowed to be equipped with HTAWS, some types of nuisance alerts would be reduced and some of the features incorporated in HTAWS already address some of the recommendations discussed in this paper.

HTAWS is created based on a completely different TAWS MOPS, DO-309, made specific for helicopter operations. HTAWS, in general, has smaller alerting thresholds, which allows the aircraft to operate at lower altitudes before an alert occurs. Many, if not all, HTAWS use higher resolution terrain database such as 6 arc-second or 3 arc-second.

Similar to Class C TAWS exemption, the exemption to install HTAWS, if granted, would only apply to aircraft that exclusively fly VFR flights. No IFR operations would be allowed on an aircraft with a HTAWS under this exemption.

2.2.2 Benefits

Allowing the use of HTAWS would reduce nuisance alerts for operators flying at 500ft AGL. This could prompt those operators to fly with TAWS active on flights where they would otherwise inhibit TAWS.

Allowance for use of HTAWS could be done through the exemption process.

No change to the TAWS MOPS would be required.

HTAWS products are currently available on the market, which reduces the potential lead-time to field this change.

Some Class B TAWS units may be able to be converted to HTAWS by a software update, which could reduce the effort associated with retrofit.

Operators for whom Class B TAWS is working well would not be affected.

2.2.3 Limitations

Use of HTAWS would not be a cure-all for nuisance alerts. Alerts could still occur for operators landing the airplane off-airport. Alerts could also occur when the desired flight path is in a winding valley.

The reduced alerting thresholds of HTAWS would result in later alerts in actual CFIT scenarios. No analysis has been performed by the Committee to determine if HTAWS protection would provide an acceptable level of safety for Part 135 operators.

For aircraft that fly both low-level VFR flights as well as IFR flights, an HTAWS installation may not be appropriate.

Feedback from several operators was that the Class C alert threshold was too low during IFR operations. HTAWS alert threshold would be even lower.

The existing Class B TAWS hardware on the aircraft may not support HTAWS functions, thus requiring new hardware as well as HTAWS software.

HTAWS as defined by DO-309 does not have Mode 1 (Excessive Rate of Descent) or Mode 3 (Negative Climb Rate or Altitude Loss after Take-off). The loss of these modes would further reduce the level of safety of these systems, as the Forward Looking alerting does not fully account for these aural/alert combinations.

2.3 Modify TAWS Alert Requirements

The Class B alert criteria defined in the MOPS are not compatible with certain Part 135 flight operations. Two different means of directly rectifying this situation were considered: lowering the alert thresholds for Class B TAWS and defining a new Class D TAWS with lower thresholds. These two possible solutions are discussed below.

2.3.1 Modify Class B Alert Requirements

2.3.1.1 Overview

The MOPS requirements for Class B alerting could be updated to reduce the volume of airspace that is protected by the Forward Looking Terrain Awareness (FLTA) function. Per DO-367, Class B TAWS must alert when the predicted terrain clearance is less than 500ft with a lateral margin of 0.3 Nm when the aircraft is in level flight and is more than 15nm from the nearest airport. An analysis would be required to determine how much the FLTA alert thresholds could be reduced while still providing an acceptable level of safety.

Additionally, a decision would need to be made as to whether the MOPS was updated to allow Class B TAWS to have a smaller alert threshold or to require Class B TAWS to have a smaller alert threshold.

2.3.1.2 Benefits

Updating the MOPS to reduce the Class B alert threshold would reduce nuisance alerts for operators flying at 500ft AGL. This could prompt those operators to fly with TAWS active on flights where they would otherwise inhibit TAWS.

The lateral limits for the alerting threshold could be modified to reduce the likelihood of nuisance alerts when operating in winding valleys.

The vertical limits for the alerting threshold would not need to be reduced all of the way to the values defined by Class C. Several operators provided feedback that the Class C thresholds were too low.

2.3.1.3 Limitations

Modified Class B alert thresholds would not be a cure-all for nuisance alerts. Alerts could still occur for operators landing off-airport. Alerts could also occur when the desired flight path was in a winding valley.

Changing the definition of Class B could affect other Class B operators who do not currently have issues.

An update to the MOPS would be required and a new TSO invoking the MOPS would be required.

There could be confusion as to what level of protection a “Class B” TAWS provided, once units certified to the new Class B standard were fielded.

2.3.2 Define New TAWS Class D

2.3.2.1 Overview

A new class of TAWS, "Class D", could be created in the MOPS. The new Class D requirements could allow a smaller protected volume of airspace (vertically, longitudinally, and/or laterally) that is provided by the Forward Looking Terrain Awareness (FLTA) function. Conceptually, the Class D alerting thresholds would be somewhere between the current Class B and Class C thresholds. An analysis would be required to determine how much the FLTA alert thresholds could be reduced while still providing an acceptable level of safety.

Additionally, Class D could be defined to include features that could accommodate off-airport landing.

FAA regulations could then be updated to prescribe which operations were allowed to use Class D and which operations were still required to use Class B.

2.3.2.2 Benefits

The Class D alert threshold would reduce nuisance alerts for operators flying at 500ft AGL. This could prompt those operators to fly with TAWS active on flights where they would otherwise inhibit TAWS.

The lateral limits for the alerting threshold could be modified to reduce the likelihood of nuisance alerts when operating in winding valleys.

The vertical limits for the alerting threshold would not need to be reduced all of the way to the values defined by Class C. Several operators provided feedback that the Class C thresholds were too low.

Because Class D TAWS would be targeted to a specific type of operator, the requirements could be tailored to best fit the type of operation.

Off-airport landings could be taken into account in the requirements, which would further reduce the occurrence of nuisance alerts.

Creating Class D allows the existing Class B to remain unchanged.

2.3.2.3 Limitations

An update to the MOPS would be required and a new TSO invoking the MOPS would be required.

FAA regulations would need to be updated to prescribe which operations were allowed to use Class D and which operations were still required to use Class B.

2.3.3 Incorporate pilot selectable VFR mode within Class B TAWS

2.3.3.1 Overview

The reduced alerting thresholds of a Class C TAWS would result in later alerts in actual CFIT scenarios. For aircraft that fly both low-level VFR flights as well as IFR flights, a Class C TAWS installation may not be appropriate. Feedback from several operators was that the Class C alert threshold was too low. Adding a capability for a pilot to select a reduced FLTA envelope in flight within Class B TAWS allows operators to maintain Class B levels of protection in IFR flights and reduced envelope operations as necessary in VFR flights. The VFR mode may be simply enabling Class C TAWS by a pilot selection or may include larger changes similar to Class D TAWS.

2.3.3.2 Benefits

This option maintains Class B TAWS protection during IFR flights while allowing selection of reduced envelope by a pilot in VFR flight as necessary.

This could prompt those operators to fly with TAWS active on flights where they would otherwise inhibit TAWS.

The lateral limits for the alerting threshold could be modified to reduce the likelihood of nuisance alerts when operating in winding valleys.

Operators who are satisfied with existing Class B TAWS are not affected by the change.

If the optional switch activates Class C TAWS, the minimum operational performance standards (MOPS) for both Class B and Class C TAWS are already defined.

2.3.3.3 Limitations

An update to the MOPS would be required and a new TSO invoking the MOPS would be required.

2.4 Allow TAWS to Consider Lateral Escape Maneuvers

2.4.1 Overview

The current MOPS requirements for Class A, B, and C TAWS are based on the assumption that the aircraft will perform a wings-level climb to escape the terrain following the onset of the alert. For an aircraft that is intentionally flying VFR through a valley or mountain pass, this can result in nuisance alerts when a safe, level route of flight will avoid the terrain.

If TAWS were allowed to consider lateral maneuvers, in addition to climb maneuvers, as viable escape paths, the onset of the alert could be delayed in scenarios where there was a clear path to the left and/or right of the aircraft. This could help reduce nuisance alerts in certain mountain scenarios, while still proving sufficient alert time when the straight-ahead climb was the best or only escape path.

2.4.2 Benefits

Lateral escape maneuvers may be more desirable than a climb maneuver in certain scenarios. For instance, a pilot operating VFR below an overcast layer may not wish to climb into IMC when an alert occurs. In addition to losing the ability to maintain visual terrain separation, icing may be a factor when the aircraft climbs into visible moisture.

2.4.3 Limitations

Allowing for lateral maneuvers increases the criticality of the TAWS and the terrain database. When the only prescribed escape maneuver is a climb, an inadvertent TAWS alert cannot directly cause a CFIT accident. If the pilot responds to a false TAWS alert by climbing, the aircraft will not hit terrain that it would not also have hit if it had not climbed. However, if the pilot responds to a false TAWS alert by turning, the aircraft could turn into terrain that it otherwise would have missed.

In order for the TAWS to correctly evaluate the need for a lateral escape maneuver, high integrity terrain data is required. While the quality of terrain data improves every year, the availability of data with sufficient quality to support lateral maneuvers may be an issue in certain areas, particularly at high latitudes.

2.5 Make TAWS Aural Alerts Non-repetitive

2.5.1 Overview

The current MOPS requires that the alert aurals such as “terrain ahead” or “pull up” be repeated periodically as long as the threat condition persists. In the case of an alert that is triggered as a nuisance, the repeating aural alert can be very distracting, causing pilots to inhibit the TAWS as soon as an alert occurs.

The requirements could be changed to allow a single aural to be generated for each threat condition or to remove the aural once a change in aircraft trajectory occurs despite the threat remaining present. This would be analogous to TCAS aural alerts which do not repeat as long as the threat category remains unchanged. While this change would not prevent nuisance alerts from occurring, it would make them less annoying.

2.5.2 Benefits

A single aural would not be as intrusive in the event of a nuisance alert.

While this may not be an adequate standalone solution, in combination with other solutions (reduced alerting envelope for example), this concept may have value for aural control.

2.5.3 Limitations

Removing the repetition of the aural alert does nothing to prevent the alert from occurring in the first place.

In a scenario where the aircraft was right at the edge of an alert condition, an intermittent alert condition could still result in the aural alert being generated multiple times.

Training to continue to monitor the terrain situation after the first aural is heard may not be intuitive. Therefore, there is risk of the flight crew not responding to worsening conditions.

Pilots currently may rely on the persistence of the aural to help them determine when they have adjusted the flight path angle sufficiently to clear the terrain. If the aural is only issued a single time, a pilot might think that their initial, small response was sufficient.

2.6 Situational Awareness Tool based on NASA GCAS

2.6.1 Overview

Current TAWS systems provide warning alerts that call for a climb in the current direction of flight. For flight crews whose flight profile requires operating at low altitudes in the vicinity of proximate terrain, the TAWS Forward Looking Terrain Avoidance (FLTA) algorithms often result in numerous, or even continuous, nuisance alerts, causing the flight crew to inhibit TAWS warnings and therefore bypass the TAWS safety benefit. An improved quality of terrain warnings, in the sense of ensuring that a terrain warning is issued only when immediate action is required to avoid a ground collision, considers escape paths in both the vertical and lateral directions.

The NASA developed Ground Collision Avoidance System (GCAS) provides the flight crew with escape paths in both the vertical and lateral directions, enhancing situational awareness with respect to available terrain avoidance options, and ultimately provides a warning alert depicting a viable escape path. GCAS functionality is being configured by NASA for initial general aviation use as a Tablet/EFB application in the near future.

2.6.2 Benefits

Initial implementation could be accomplished via Electronic Flight Bag (EFB) or other Personal Electronic Device (PED) based solution, minimizing the cost to implement and take advantage of the safety benefit. NASA has indicated the potential for PED-based solutions within a year.

Regulatory activity would not be required. GCAS functionality could be fielded as a stand-alone application or integrated with existing EFB offerings (ForeFlight, Pilot, etc.)

This change would not require an existing TAWS installation. If there were an existing TAWS installation, no change to it would be required. Keeping the existing TAWS installation unchanged would allow equipped operators to continue IFR flights with TAWS active.

2.6.3 Limitations

These solutions would require some input from external data sources, potentially from installed aircraft systems.

EFB functionality would not be subject to a certification and standards compliance process, with associated verification of systems and database integrity.

Implementation by Part 135 operators would require review to ensure that their existing operations with Class B TAWS installations suffer from the nuisance alerting issues, and obtain OpSpec approval of the EFB application. Part 121 installations must follow 14 CFR 121.354, and using EFB-based TAWS would not be permitted.

In order for the GCAS configured TAWS to correctly evaluate the need for a lateral escape maneuver, high resolution, high integrity terrain data is required.

2.7 Certified TAWS based on NASA GCAS

2.7.1 Overview

Current TAWS systems provide warning alerts that call for a climb in the current direction of flight. For flight crews whose flight profile requires operating at low altitudes in the vicinity of proximate terrain, the TAWS Forward Looking Terrain Avoidance (FLTA) algorithms often result in numerous, or even continuous, nuisance alerts, causing the flight crew to inhibit TAWS warnings and therefore bypass the TAWS safety benefit. The loss of the TAWS safety benefit has been cited as contributing factor in a number of CFIT accidents. Further, the response to a warning alert of climbing may be undesirable and present an additional hazard due to icing conditions when climbing into visible moisture.

Similar to the proposals of Section2.6, an improved quality of the terrain warnings, in the sense of ensuring that the TAWS provides a terrain warning only when immediate action is required to avoid a ground collision, GCAS considers escape paths in both the vertical and lateral directions. Such a system would provide lateral alert guidance based on surrounding terrain and aircraft performance capability as an enhancement to existing TAWS capabilities and has been researched and tested by NASA. A key element of the GCAS is the ‘Viable Escape Maneuver Display’, which provides the flight crew with enhanced situational awareness with respect to available terrain avoidance options, and ultimately provides a warning alert depicting the only remaining viable escape path.

2.7.2 Benefits

A certified system based on the NASA GCAS design would significantly enhanced situational awareness, particularly for flight crews operating in the vicinity of lateral terrain.

Such a system would also minimize FLTA nuisance alerts by considering lateral, as well as vertical, escape maneuvers, thereby reducing the need to inhibit terrain warnings.

Additionally, a GCAS-based system could be configured to allow for limitations on vertical maneuvers in order to avoid IMC and/or icing conditions, while still providing CFIT protection.

A new GCAS-based system could be incorporated as a discrete TAWS Class (Class D?) so as not to create an equipage requirement for operators who would not benefit.

2.7.3 Limitations

A certified system based on the NASA GCAS design would require installation of TAWS equipment supporting GCAS functions, including display capability for aircraft not already equipped.

Rulemaking action would be required to allow installation of GCAS-configured TAWS for affected operators, along with associated standards activity.

In order for the GCAS-configured TAWS to correctly evaluate the need for a lateral escape maneuver, high resolution, high integrity terrain data would be required.

2.8 Inhibit Logic Change

NTSB Safety Recommendation A-18-015 states that the pilot should not be able to inhibit the TAWS function for an arbitrarily long time. Various approaches to change the way in which the TAWS inhibit works were considered. Each approach directly addresses the NTSB Safety Recommendation.

2.8.1 Uninhibit After Time Delay

2.8.1.1 Overview

The TAWS inhibit could be limited to a certain period, such as five minutes. This would preclude the pilot from inhibiting the TAWS function once and leaving the function inhibited for the entire flight or even days at a time.

2.8.1.2 Benefits

In installations where the TAWS inhibit switch is a discrete electrical switch, the switch could be replaced with an electromechanical timer switch. This change could be accomplished at the aircraft level, with no change required to the TAWS unit. Changes of this nature could be accomplished in a shorter timeframe than changes that require an update to the TAWS unit.

Operators often have regions of known alerting and this solution would be desirable to help with nuisance alerts in those regions.

Nothing in the current regulations or guidance currently prohibits an operator from making this change.

2.8.1.3 Limitations

Not all TAWS installations use a discrete switch for the inhibition function. Installations that have the inhibit function activated through a display menu selection would require a software update.

A nuisance alert could occur when the inhibition times out and reactivates the TAWS function. This could occur at an inopportune time, such as when the aircraft is on short final to an off-airport landing.

For an aircraft flying VFR within the alert envelope, each time the inhibition timed out the system would generate an alert, requiring the pilot to re-inhibit the function. These repetitive alerts could lead a pilot to have a reflex to reach for the inhibit switch when they hear an alert, rather than treating the alert like an actual threat.

There are regions where threats are nearly continuous, so another solution (such as new TAWS Class D envelope, section2.3.2) may be required in addition to this inhibit logic change.

2.8.2 Uninhibit At Power Up

2.8.2.1 Overview

The inhibition condition could be cleared when electrical power was applied to the aircraft. This would ensure that TAWS was enabled at the start of each flight, provided electrical power is removed between every flight.

2.8.2.2 Benefits

On aircraft with a discrete switch, the switch could be replaced with a switch that is electrically held in place and automatically resets when power is removed. This change could be accomplished at the aircraft level, with no change required to the TAWS unit. Changes of this nature could be accomplished in a shorter timeframe than changes that require an update to the TAWS unit.

Nothing in the current regulations or guidance currently prohibits an operator from making this change.

2.8.2.3 Limitations

On aircraft where the inhibition is selected though a display menu selection, a software update would be required (unless the inhibition function is already implemented to be cleared at power up).

2.8.3 Uninhibit Upon Landing

2.8.3.1 Overview

The inhibition condition could be cleared upon landing. This would ensure that TAWS was enabled at the start of each flight. For aircraft not equipped with a weight-on-wheels (WOW) indication, logic based on the aircraft state could be used to detect a landing.

2.8.3.2 Benefits

Clearing the inhibition condition upon landing avoids the possibility of terrain alerting remaining inhibited at the start of a flight when the avionics were not powered off following the preceding flight.

2.8.3.3 Limitations

Installations will likely require a software update due to the logic involved in this concept to incorporate either WOW state or aircraft state.

2.8.4 Uninhibit After Exiting Threat Condition

2.8.4.1 Overview

The inhibition function could be redesigned such that the inhibition condition was limited to a single terrain threat. After the pilot selected the inhibit switch, the first terrain threat that was subsequently detected would not result in an alert. However, if the aircraft exited the threat envelope and then encountered another threat, an alert would be generated for this second threat.

This behavior, which would require a software update within the TAWS unit, would resemble the operation of an alert cancel function. Typically, the mechanization of an alert cancel (as opposed to an alert inhibit) is that it will stop an active alert but allow subsequent alerts to be generated. Thus, the inhibition logic contemplated here could be considered to be a "preemptive alert cancel function".

2.8.4.2 Benefits

Ensuring that the alerting logic would automatically be rearmed after the initial threat went away would prevent the inhibition condition from inadvertently being left active.

Operators often have regions of known alerting and this solution would be desirable to help with nuisance alerts in those regions.

2.8.4.3 Limitations

In scenarios where the aircraft may be near the edge of the alert envelope and oscillates between being barely in the envelope and being barely out of the envelope, the temporary nature of the inhibition would result in the pilot needing to repeatedly reactivate the inhibition switch. This could present a workload issue and result in the TAWS being even more of a nuisance than previously.

Because the MOPS currently requires that the pilot have the ability to completely inhibit alerts, an update to the MOPS would be required and a new TSO invoking the MOPS would be required.

2.8.5 Variable Height Inhibition

2.8.5.1 Overview

The inhibition function could be limited in such a way that it did not inhibit all alerts. Rather than inhibiting all alerts, the inhibition condition could be used to inhibit only some alerts, based on a pilot-selectable inhibition height. This concept is analogous to changing the alerting envelope to desensitize the alert thresholds. Two possibilities exist. The first would be to set a lower limit, such as 200ft vertically, below which the pilot could not adjust the inhibition threshold. The second possibility would be to allow the pilot to adjust the inhibition height all the way to zero if they so choose.

2.8.5.2 Benefits

A variable inhibition height would allow the pilot to select an inhibition height that was appropriate for the particular operation. While offering reduced protection compared to the nominal alert envelopes, envelopes that had been reduced through a partial inhibition would still offer some protection.

2.8.5.3 Limitations

If the inhibition height had a lower limit greater than zero, the pilot would not be able to completely inhibit alerts. In the case of scenarios such as ditching (or the normal use of a seaplane) where the inhibition was specifically selected to allow an off-airport landing, the delayed alert would systematically occur during landing, which would not be desirable.

Because the MOPS currently requires that the pilot have the ability to completely inhibit alerts, an update to the MOPS would be required and a new TSO invoking the MOPS would be required unless the pilot could adjust the inhibition height all of the way to zero.

If the pilot could set the inhibition height all the way to zero, nothing would prevent the pilot from leaving it at zero all of the time. In this case, there would be no improvement over the current scenario where a pilot leaves the inhibition switch on all of the time.

2.8.6 Keeping Terrain Display Functional while TAWS alerting is inhibited

2.8.6.1 Overview

The inhibition function could be limited in such a way that it inhibited the alerting, while retaining the terrain display, if installed,

2.8.6.2 Benefits

Maintaining the terrain display when alerting is inhibited would provide some terrain situational awareness to the pilot.

From an implementation standpoint, this change could likely be performed with a software update only and not require a more time intensive hardware or additional equipment change.

2.8.6.3 Limitations

In cases where the inhibition is selected due to an inaccurate position, leaving the terrain image displayed could be hazardously misleading.

After several minutes of the inhibition being present, the flight crew could lose track of the aural inhibition. Although the terrain inhibit is present, pilot training would be needed when seeing the terrain displayed with no alert and assuming that the alert is not occurring.

3 RECOMMENDED SOLUTIONS

In coming up with their recommendations, the committee put significant weight on the input received from the Alaskan operators who participated in the committee's meeting in December 2019. A list was created and a ranking system deployed to consider the relative merits of each solution.

The solution that seemed the most promising is development of a Situational Awareness Tool based on NASA's Ground Collision Avoidance System (section2.6). The fact that a product could be developed in a relatively short period, that there would be no regulatory work to be done, and that use of the product would be on a voluntary basis were all aspects that made this option very desirable.

Several additional solutions were rated almost as highly by the Alaskan operators. Among those solutions, those that were also rated the most promising by the committee were re-enabling alerts at power up (section2.8.2), allowing Class C TAWS for Class B Operations (section 2.1), ensuring that the terrain display remained active even when the inhibition function was selected (section2.8.6), and defining a height based inhibition function that still provided last moment alerts (section2.8.5). However, it was noted that if last moment alerts were to be presented, pre-requisites for that would include allowing pilots to define off-airport landing sites and keeping the terrain display enabled at all times, regardless of inhibition status.

4 MEMBERSHIP

Co-Chairs	Organization
Yasuo Ishihara	Honeywell International, Inc
Rich Ridenour	L3Harris

Government Authorized Representative	Organization
Charisse Green	Federal Aviation Administration (FAA)

Secretary	Organization
Zach Reynolds	L3Harris

RTCA Program Director
Rebecca Morrison

Name	Organization
Richard Adler	Federal Aviation Administration (FAA)
Timothy Bleakley	General Atomics Aeronautical Systems, Inc.
Stefan Blom	Saab Group
Linda Chism	Alaska Airlines
Garfield Dean	EUROCONTROL
Rune Duke	Aircraft Owners and Pilots Association
Paal Franzen	Astronautics Corporation of America
Charisse Green	Federal Aviation Administration (FAA)
Edward Hahn	Air Line Pilots Association (ALPA)
Yasuo Ishihara	Honeywell International, Inc.
Tom Jacky	National Transportation Safety Board
Steve Johnson	Honeywell International, Inc.
John Judge	Lockheed Martin Corporation
Jon Kirtz	Collins Aerospace
Peter Korns	National Business Aviation Association
Marcus Labay	Federal Aviation Administration (FAA)
Tom Lawrence	Universal Avionics Systems Corp.
Mikaela Lokatt	Saab Group
Janiece Lorey	Gulfstream Aerospace Corporation
Rebecca Morrison	RTCA, Inc.
Gary Ostrom	Honeywell International, Inc.
Kevin Prosser	Gulfstream Aerospace Corporation
Zach Reynolds	L3Harris
Rick Ridenour	L3Harris
Angelo Rossi	The MITRE Corporation
Rocky Stone	United Airlines, Inc.
Nicholas Tubb	The Boeing Company
Shaun Williams	National Transportation Safety Board
Garry Wilson	Gulfstream Aerospace Corporation
Steven Zapoluch	Garmin Ltd.

APPENDIX A WHITE PAPERS ON POTENTIAL SOLUTIONS

The following white papers were presented and reviewed by the committee in support of this effort. They are each included in this section with a section reference indicating which recommendation they support. Due to subsequent operator or committee feedback, a newer recommendation may not have an accompanying Appendix section. In some cases, the original Appendix concept has been modified or narrowed to create the eventual recommendation. However, the original thought process in each Appendix section may aid in the evaluation of the recommendations.

A.1 Allowing Class C for Class B Operations (Section 2.1)

A.1.1 Purpose

Most turboprop aircraft flown by tour operators are required to install Class B TAWS. However, it has been known that Class B TAWS are often not compatible with their operations. Although Class C TAWS does not solve all known issues, study suggests that some operators in Alaska, especially those who operate outside of Northeast Alaska, may benefit greatly from using Class C TAWS with reduced RTC.

A.1.2 Description

Some avionics manufacturers already provide Class C TAWS software in the existing Class B TAWS equipment. Activation of Class C TAWS can be a simple software configuration change without any hardware change. However, FAA would have to allow a use of Class C TAWS for the aircraft that is required to have Class B TAWS under current regulation.

A.1.3 Operational Effect

Cockpit effect in terms of pilot procedures and training requirements should be minimal with switching to Class C TAWS.

A.1.4 Training Associated with This Concept

Training requirement should be minimal with switching to Class C TAWS.

A.1.5 Implementation Effort

With Class B TAWS equipment that already have Class C capability would require minimal change such as changing software configuration. Installing a new Class C would require the same effort as installing class B TAWS.

A.1.6 Regulatory Implications

For aircraft that is required to have Class B TAWS will have to seek exemption or special approval to install Class C TAWS in lieu of Class B TAWS.

A.1.7 Description of Advantages

This option can be implemented now on many applicable aircraft with Class B TAWS today by very minimal change as long as a use of Class C is permitted by FAA.

A.1.8 Description of Disadvantages

Class C TAWS does not solve everyone’s nuisance alert issues.

The current Class C TAWS exemption by FAA prohibits the Class C TAWS equipped aircraft to operate under IFR. Unless the aircraft can be dedicated for VFR flights only, this option cannot be exercised.

A.2 TAWS Envelope Changes (Section 2.3.1)

A.2.1 Purpose

Most turboprop aircraft flown by tour operators are required to install Class B TAWS. However, it has been known that the current Class B TAWS are often not compatible with their operations. Class B TAWS requirements may be modified to become compatible with their operations.

A.2.2 Description

This change would modify TAWS envelope(s) to accommodate operations conducted by general aviation and small turbo-prop aircraft in mountainous terrain environment. Changes may include:

- Reduced RTC in FLTA as a mission setting or specialized mode
- Reduced look-ahead time/distance in FLTA
- Vertical component of FLTA matched to aircraft performance
- Modified shape to look-ahead envelope with less splay
- Field of regard widening in turns limited and/or field of regard turn anticipation improved
- Modified alert logic to avoid alerting for terrain directly in front of the aircraft during a turn
- Smaller lateral FLTA envelope when following a flight plan with assured terrain clearance
- Pilot selectable “VFR” or “Reduced Envelope” mode with reduced sensitivity

A.2.3 Operational Effect

Some of the changes may require installing additional wiring and a switch. Additional input from other aircraft avionics (such as aircraft performance and flight plan information) may be necessary.

A.2.4 Training Associated with This Concept

Minimum training impact is expected.

A.2.5 Implementation Effort

Many of the changes listed above may be achieved by software only update. In that scenario, the installation requires minimal time. When wiring change or installing a switch becomes necessary, moderate installation time may be required.

A.2.6 Regulatory Implications

Unless an existing TAWS MOPS is changed or a new class of TAWS is created in MOPS, TAWS with the above changes will not satisfy the existing TSO C-151d.

A.2.7 Description of Advantages

The following is a list of some advantages of this approach:

- Reduction in nuisance alerts
- Limited training impacts as compared to adding lateral alerting
- Potentially a software-only update, depending on platform
- Shorter time to implement and get approval as compared to adding lateral alerting

A.2.8 Description of Disadvantages

The following is a list of some disadvantages of this approach

- Impact to existing Class B systems
- Potential impact to known accident test cases and Imminent Terrain Impact test cases in the MOPS
- Need of a safety analysis to determine if a reduced margin is still adequate
- Need of a use case analysis to determine if nuisance alerts are actually avoided
- Potential reduction in effectiveness of vertical only escapes due to limited aircraft performance in conjunction with reduced alerting margins
- Potential need of regulatory/guidance changes (AC23-18, 135.154, 91.223, etc.)
- Potential need of increased database resolution
- Implementation costs
- Adoption rate/effectiveness

A.3 TAWS New Class (Section 2.3.2)

A.3.1 Purpose

TAWS with changes discussed in this documents may not satisfy the existing TAWS Class A, B or C requirements. Instead of modifying requirements in one of the existing classes, a new Class D can be created to cover new TAWS.

A.3.2 Description

Create new TAWS Class D requirements to accommodate modified TAWS.

A.3.3 Operational Effect

Operational effect may be different depending on which options are implemented. However, cockpit effect in terms of pilot procedures and training requirements should be minimal with a new TAWS Class D with most options discussed in this document,

A.3.4 Training Associated with This Concept

Training requirement may be different depending on which options are implemented. If changes involve new or different pilot procedures from the existing TAWS, moderate amount of training may become necessary.

A.3.5 Implementation Effort

Installation effort may be different depending on which options are implemented. When wring change or installing a switch becomes necessary, moderate installation time may be required.

A.3.6 Regulatory Implications

This will be a new TAWS Class or new options within the existing Class(es) in DO-367 and TSO C-151.

A.3.7 Description of Advantages

Advantage of defining new TAWS class specifically for those operators who routinely operate at low altitudes. (A-17-035) is:

- It provides acceptable level of safety for those operators without affecting remaining Class B and C user community.

A.3.8 Description of Disadvantages

No disadvantage for creating new TAWS class was identified.

A.4 Class B TAWS with Optional Reduced FLTA Envelopes (Section2.3.3)

A.4.1 Purpose

The current Class C exemption only allows VFR operations. Therefore, the aircraft needs to dedicated to VFR flights if Class C TAWS is installed. This new option in Class B TAWS allows a pilot to activate Class C or reduced envelopes in flight when permissible.

A.4.2 Description

Modify Class B TAWS to accommodate a manual switch that activates reduced FLTA envelopes in flight. The reduced FLTA envelopes may be ones defined for Class C TAWS or may be ones between Class B and Class C. The reduced FLTA envelopes are activated by a manual switch by a pilot while flying in VMC as necessary.

A.4.3 Operational Effect

The change may require installing additional wiring and a switch for the existing TAWS installation. This allows the aircraft to operate in IMC using Class B TAWS while a pilot can activate Class C TAWS envelopes or other reduced FLTA envelopes when necessary in VMC.

A.4.4 Training Associated with This Concept

Minimum training impact is expected. The training needs to focus on when to use the reduced FLTA envelopes.

A.4.5 Implementation Effort

This option may be achieved by software only update. In that scenario, the installation requires minimal time. When wiring change or installing a switch becomes necessary, moderate installation time may be required.

A.4.6 Regulatory Implications

Unless an existing TAWS MOPS for Class B is changed to allow the optional reduced FLTA envelopes, TAWS with this option will not satisfy the existing TSO C-151d.

A.4.7 Description of Advantages

Following are some advantages:

- It will continue to work as Class B TAWS unless the reduced FLTA envelopes are activated by a pilot
- Reduction in nuisance alerts when using the reduced FLTA envelopes
- Limited training impacts as compared to adding lateral alerting
- Potentially a software-only update, depending on platform
- Shorter time to implement and get approval as compared to adding lateral alerting

A.4.8 Description of Disadvantages

Following are some disadvantages or issues:

- Impact to existing Class B systems
- Need a safety analysis to determine if a reduced margin is still adequate
- Need use of case analysis to determine if nuisance alerts are actually avoided
- Reducing the look-ahead time/distance coupled with limited performance in the target aircraft may preclude vertical only escapes
- Regulatory/guidance changes may be required (AC23-18, 135.154, 91.223, etc.)
- Potential requirement for higher database resolution
- Implementation costs
- Adoption rate/effectiveness

A.5 Lateral Escape (Section2.4)

A.5.1 Background

The terrain awareness and warning systems (TAWS) is intended to provide the flight crew with information and alerts to detect a potentially hazardous terrain situation so appropriate action can be made to avoid a CFIT event. Current systems FLTA (forward looking terrain avoidance) mainly addresses terrain awareness and associated warnings along and below the airplane's lateral and vertical flight path (TSO-C151 1.3a). System designs that enhance terrain awareness and warnings in the lateral direction have been investigated, but are limited [1]. While TAWS can provide useful situational awareness to the flight crew, a group of operators flying non-regular types of missions have inhibited the TAWS function due to the occurrence of excessive nuisance alerts. In the present context, the phrase nuisance alert refers to a warning that is issued even though the aircraft can be expected to clear the terrain with a satisfactory safety margin considering its full maneuverability, either vertically or horizontally. An excessive number of nuisance alerts will cause the flight crew to ignore the terrain warnings and/or disable the terrain warning system [2]. As such, the ability of TAWS to provide situational awareness that results in enhanced flight safety may be reduced by the frequent occurrence of nuisance alerts.

An improved quality of the terrain warnings, in the sense of ensuring that the TAWS provides a terrain warning if and only if there is an actual risk of a ground collision considering escape paths in both the vertical and lateral direction, would presumably reduce the number of nuisance alerts. A reduction of nuisance alerts is expected to provide the flight crew with a higher confidence that warnings issued by the system indicate an actual risk of terrain collision, thereby increasing the likelihood that correct operational decisions are taken based on information provided by the system. As such, an improved quality of the terrain warnings is expected to have a positive contribution to the TAWS's ability to contribute to enhanced flight safety.

One possible reason for the occurrence of nuisance alerts is that the vertical flight path assumed in the forward looking terrain avoidance function (FLTA) that forms part of TAWS [3] may underestimate the climb performance achievable by the aircraft and thereby also its ability to perform escape maneuvers. As such, the aircraft may be able to clear upcoming terrain even in scenarios where the TAWS predicts that there will be a terrain conflict. A fourth reason is that the aircraft's turn may be interrupted sooner than the algorithm anticipates. An algorithm anticipates a continuous turn rather than recognizing the angle at which the aircraft will return to wings level flight.

Another reason is that a lateral escape maneuver may be feasible in scenarios where a vertical escape maneuver does not provide a feasible way of avoiding a potential terrain conflict. The aircraft may thus be able to perform an escape maneuver that is not considered by the system. Further, a limited accuracy of the terrain elevation data that is used to evaluate potential terrain conflicts may result in unnecessarily cautious terrain warnings. The reason being that the actual terrain elevation may be lower than the terrain elevation that is specified in the data that is provided to the algorithm used to evaluate the existence of potential terrain conflicts.

Database inaccuracy could cause alerts where performance is in fact adequate for a vertical escape and no alert is necessary.

A.5.2 Purpose

The aim of the present work is to investigate alternative methods for flight path prediction, terrain detection and flight crew alerting that may improve the quality of the terrain warnings and thereby reduce the occurrences of nuisance alerts. The focus is on the investigation of combined vertical and lateral escape maneuvers. Aspects related to performance based flight path predictions as well as to accuracy, integrity and availability properties of algorithms and data that form part of the TAWS will also be addressed.

A.5.3 Functional Enhancement Concepts

This section provides a description of a combined vertical and lateral terrain awareness concept that is aimed at adding functionality to terrain awareness and warning systems as well as enhancing the dependability on terrain warnings issued by the system. Since it has been identified as a function where significant improvements can be made, the main focus is on an extension of the FLTA function that forms part of TAWS [3] to consider lateral escape maneuvers as a complement to vertical escape maneuvers. The concept description is divided into two parts, Secondary Concept 1 and Secondary Concept 2. The two secondary concepts may be implemented separately from each other, but should preferably be combined to achieve a distinct performance enhancement.

A.5.3.1 Secondary Concept 1: Combined Vertical And Lateral Terrain Awareness

The governing idea of Secondary Concept 1, combined vertical and lateral terrain awareness, is to extend the specification of the FLTA function that forms part of TAWS [3] to cover the identification of combined vertical and lateral maneuvers as potential escape routes. The algorithm that forms the basis for the combined vertical and lateral terrain awareness concept is summarized below. A few aspects to consider in relation to the algorithm are discussed in the paragraphs following the algorithm.

Step 1. Compute a set of flight paths, corresponding to combined vertical and lateral escape maneuvers, in a range of lateral flight path directions using a suitable algorithm.

Step 2. Read terrain elevation data from a suitable source.

Step 3. Compare the altitude of the predicted escape paths to the terrain elevation data at a suitable set of points. If at some point the altitude between the predicted escape path and the corresponding terrain elevation is less than the required terrain clearance, a potential terrain conflict exists at that point.

Step 4. Perform one of the actions described in the item list below. Choose action based on whether or not one or more potential terrain conflicts have been identified in Step 3.

a. If no potential terrain conflict has been identified, do not issue any terrain caution or terrain warning.

b. If one or more potential terrain conflicts have been identified but a significant number of escape paths along which no terrain conflicts are present exist, optionally issue a terrain caution. The terrain caution may not be issued despite a conflict being present if the mission is a short, low flight or touring flight. Do not issue a terrain warning.

c. If one or more potential terrain conflicts have been identified and only a small number of escape paths along which no terrain conflicts are present exist, issue a terrain caution. Do not issue a terrain warning.

d. When only one viable escape maneuver, at minimum margin, remains, issue a terrain warning.

An illustration of the scenarios a. to d. described in Step 4 of the terrain awareness and warning algorithm is provided in Figure A-1 to Figure A-6. In the figures, the dot mark indicates the position of the aircraft. Red lines indicate flight paths where potential terrain conflicts are present whereas green lines indicate feasible escape paths. The yellow line in Figure A-6 illustrates a flight path that touches the required terrain clearance altitude, thus indicating the point where a terrain warning should be issued since this is the only path that remains viable. It should be noted that the scenario depicted in Figure A-1 to Figure A-6 only comprises an example illustration. Further work would be needed to determine distinct criteria regarding what should be considered to comprise sufficient escape options to not issue a terrain caution or warning, i.e. to clearly distinguish between scenario b., c. and d. in Step 4 of the terrain awareness and warning algorithm.

The terrain caution and warning messages (aural and graphical) may need updating to include additional terrain avoidance information. At minimum, the messages should provide information regarding in what flight path directions potential terrain conflicts exist and/or in what flight path directions feasible escape paths exist. Preferably, the messages should also include flight path recommendations that the pilot should consider to avoid the identified terrain conflict. It could also be beneficial to include information that indicates whether the pilot is following the suggested escape path well enough or whether the applied control needs to be modified to improve the path following. The escape path recommendations should be continuously updated, to ensure that the pilot receives relevant information all through the escape maneuver. To identify suitable recommendations regarding the frequency of the updates, further work would be needed.

To ensure that it is possible to perform an escape maneuver along the recommended flight path once a terrain caution or terrain warning has been issued, it is important that the predicted escape paths include a sufficient reaction time for the pilot to respond to the warning (as is the case in the current FLTA specifications [3]). It is also important that the predicted escape paths describe flight paths that can be followed with a reasonable pilot workload.

To avoid a scenario where escape paths that touch upon the side of nearly vertical terrain are considered to be feasible, it is recommended to include a requirement regarding horizontal terrain clearance (similar to the required ground clearance in the vertical direction [3]). Further work would be needed to determine detailed criteria to impose on the horizontal terrain clearance.

While a strictly vertical FLTA algorithm would provide a terrain warning as soon as a potential terrain conflict is present in a given flight path direction, the combined vertical and lateral algorithm will not issue a warning for the same scenario provided that a sufficient number of combined lateral and vertical escape paths are feasible. Per DO-367 2.2.1.1.6, “the search volume consists of a computed look ahead distance, a lateral distance on both sides of the airplane’s flight path, and a specified look down distance based upon the airplane’s vertical flight path. This search volume should vary as a function of flight environment, distance from runway and the TERPS-defined required obstacle clearance (ROC) in order to perform its intended function and minimize nuisance alerts.”

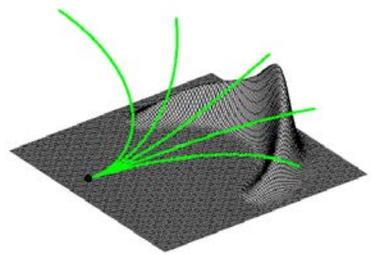

Figure A-1: Illustration of scenario a.

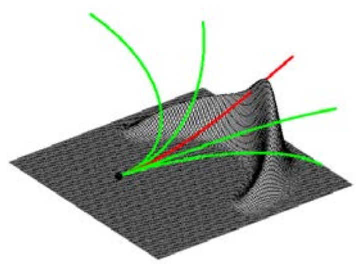

Figure A-2: Illustration of scenario b.

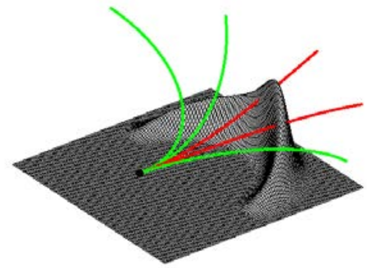

Figure A-3: Another illustration of scenario b.

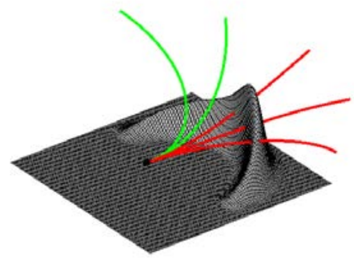

Figure A-4: Illustration of scenario c.

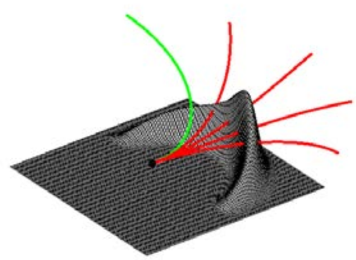

Figure A-5: Another illustration of scenario c.

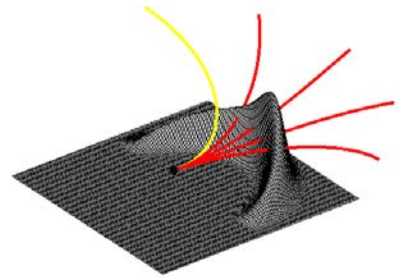

Figure A-6: Illustration of scenario d.

A.5.3.2 Secondary Concept 2: Performance and Data Integrity Specifications

The governing idea for Secondary Concept 2 is to introduce specifications regarding the accuracy, integrity and availability of the flight path prediction algorithm and of the terrain elevation data that are used to identify potential terrain conflicts.

It is suggested to introduce the following specifications regarding the accuracy, integrity and availability of the flight path prediction algorithm.

1. The flight path prediction algorithm should be based on an aircraft response model that comprises an accurate model of the aircraft's maneuver capability as well as a realistic model of the pilot generated control.

2. The aircraft response model should be designed to allow evaluation of relevant accuracy, integrity and availability properties of the 3D flight path predictions generated by the model in different operational scenarios. In addition, any source used to generate input data (e.g. aircraft position data) to the aircraft response model should allow evaluation of relevant accuracy, integrity and availability properties.

Specification number one is aimed at enhancing the confidence that the flight paths predicted by the aircraft specific response model are achievable by the system is installed with a reasonable pilot workload. Specification number two is aimed at ensuring that relevant accuracy, integrity and availability properties of the model can be evaluated, which is of importance to be able to judge how much confidence to place in the predictions generated by the model when making operational decisions. Specification number two could be modified to not only require the possibility to evaluate relevant criteria regarding accuracy, integrity and availability properties but to require compliance with certain accuracy, integrity and availability properties. Further work would be needed to formulate suitable compliance criteria.

Regarding the accuracy, integrity and availability of the terrain elevation data, it is suggested to introduce the following specifications.

1. The terrain elevation data should provide a correct description of the terrain elevation in geographical areas that are covered by the terrain elevation data source.

2. The source used to generate terrain elevation data should allow evaluation of relevant accuracy, integrity and availability properties.

The first specification is aimed at enhancing the confidence that the terrain elevation data provides realistic information regarding the terrain elevation in geographical areas that are covered by the data source. The second specification is aimed at ensuring that relevant accuracy, integrity and reliability properties of the model can be evaluated, which is of importance to be able to judge how much confidence to place in the predictions generated by the model when making operational decisions. Specification number two could be modified to not only require the possibility to evaluate relevant criteria regarding accuracy, integrity and availability properties but to require compliance with certain accuracy, integrity and availability properties. Further work would be needed to formulate suitable compliance criteria.

A.5.4 Operational Effect

As a result of introducing lateral escape options, an update of the means of presenting terrain warning and guidance messages to the flight crew will presumably be needed. The update may comprise the introduction of additional voice call outs, optionally including “terrain ahead”, “terrain left” or directive “pull up left, pull up left”. In addition, a more descriptive visual display may be required for the pilot to be able to comply with the preferred escape option.

A.5.5 Training Associated with This Concept

Secondary Concept 1 addresses procedures for providing terrain caution and terrain warning messages and for how to perform related escape maneuvers. The updates may e.g. encompass pilot familiarization with the new call out messages, displays and combined vertical and lateral escape options. Assuming the new call outs and displays are intuitive and unambiguous, a level of training varies based on a complexity of the implementation. The training would enhance the existing TAWS training.

A.5.6 Implementation Effort

The suggested concept comprises an update of the system software. The software related development effort includes specification, design, implementation, validation and verification of related models, algorithms and software code. In particular, algorithms related to generation of search volumes for escape trajectories will presumably need to be updated. The terrain scanning of those volumes, once developed, would presumably be consistent with existing techniques. Additional voice messages and displays would require human factors evaluations and development. Further work would be needed to provide a reliable estimate of the associated time consumption.

Certification challenges could be attributed to the use of a high integrity terrain database. Adding escape paths or routes might require higher integrity database data. The determination of achievable climb performance and whatever cross checks are needed to ensure the accuracy of this performance represents another implementation aspect. Today’s TAWS designs do not require real time performance assessments, whereas the projected flight path in this proposed concept will require such an assessment.

A.5.7 Regulatory Implications

The introduction of the combined vertical and lateral terrain awareness concept (Secondary Concept 1, see Section 3.1) presumably requires an update of specifications related to the extended FLTA function. The update should address the possibility of avoiding a potential terrain conflict by performing a combined vertical and lateral escape maneuver, as compared to by performing a strictly vertical escape maneuver in accordance with the current FLTA function specifications [3]. Aspects related to how and when to issue terrain caution and terrain warning messages should be considered in the update.

The presently recommended failure condition classification is “major” for Class A- and Class B TAWS and “minor” for Class C TAWS [4]. The introduction of escape path guidance in relation to terrain caution and terrain warning messages (Secondary Concept 1, see Section 3.1) comprises introduction of new functionality therefore requires additional scrutiny. Allowing enhanced confidence in information provided by the TAWS when making operational decisions (Secondary Concept 2, see Section 3.2) comprises an update of how information provided by the system is valued in an operational context. Because of these aspects, it is suggested to perform a functional hazard analysis to evaluate whether the failure condition classification should be updated.

The definition of a terrain database that is sufficiently accurate to support lateral escapes is presumed to be a primary concern of this design.

A.5.8 Description of Advantages

By considering multiple escape options, the combined vertical and lateral algorithm (Secondary Concept 1, see Section 3.1) is believed to better capture an actual flight scenario and thereby enable a reduction of nuisance alerts. As an example, consider an aircraft that has nearly zero climb capability either due to density altitude or engine failure. For those cases, a straight ahead climb is simply not possible and a lateral escape is the only available terrain avoidance maneuver. If lateral escapes are not considered, anytime the aircraft points toward a terrain of higher altitude than ownship, a warning will be issued. If the warning is followed, a mishap will ensue because the aircraft is not capable of climbing. If the warning is ignored, and a lateral escape is used instead, the system will be turned off due to nuisances. A common method of addressing the problem of nuisance warnings under these circumstances is to shorten the look ahead volume and/or to assume a better climb capability than actually exists. Both these methods reduce false alarms, but they also reduce protection as the terrain may not actually be cleared if the aircraft rolls out and attempts a “pull up” climb over the terrain.

Another advantage of considering multiple escape options is that it can enable the escape path guidance to be adapted to the weather conditions. In cases of low clouds and icing, a max performance climb may not be the preferred escape option or accurate aircraft performance model may not be available. In those cases, a lateral escape should be considered.

Introducing specifications regarding the accuracy of algorithms and data that form part of the FLTA function (Secondary Concept 2, see Section 3.2) is expected to increase the likelihood that the results generated by the function are correct and that they accurately depict the operational scenario. This could allow an increased confidence in basing operational decisions on information provided by the FLTA function.

An increased reliability in the TAWS’s ability to issue terrain warnings in the correct scenarios (Secondary Concept 2, see Section 3.2) is presumed to comprise an important step in enabling the implementation of reliable automatic terrain avoidance functions. Such functions should be designed to maneuver the aircraft onto a feasible escape path in scenarios where an immediate risk of a terrain conflict exists and the pilot has not yet been successful in performing an escape maneuver.

A.5.9 Description of Disadvantages

Allowing for lateral maneuvers increases the criticality of the TAWS and the terrain database. When the only prescribed escape maneuver is a climb, an inadvertent TAWS alert cannot directly cause a CFIT accident. If the pilot responds to a false TAWS alert by climbing, the aircraft will not hit terrain that it would not also have hit if it had not climbed. However, if the pilot responds to a false TAWS alert by turning, the aircraft could turn into terrain that it otherwise would have missed.

In order for the TAWS to correctly evaluate the need for a lateral escape maneuver, high integrity terrain data is required. While the quality of terrain data improves every year, the availability of data with sufficient quality to support lateral maneuvers may be an issue in certain areas, particularly at high latitudes.

A.5.10 References

[1] J. J. Arthur III et. al., "Flight Simulator Evaluation of Synthetic Vision Display Concepts to Prevent Controlled Flight Into Terrain (CFIT)," National Auronautics and Space Administration, Langley Research Center, Hampton, Virginia, 2004.

[2] International Air Transport Association, "CFIT- Controlled Flight into Terrain A study of Terrain Awareness Warning System Capability and Human Factors in CFIT Accidents 2005-2014," 2016.

[3] RTCA, "Minimum Operational Performance Standards (MOPS) for Terrain Awareness and Warning Systems (TAWS) Airborne Equipment (RTCA DO-367)," 2017.

[4] Federal Aviation Administration, "Technical Standard Order, Subject: Terrain Awareness and Warning Systems (TAWS) (TSO-C151d)," 2017.

A.6 Reduction in Annoyance – Single Aural (Section 2.5)

A.6.1 Purpose

The concept being explored in this paper are ways to reduce the annoyance level of an undesired TAWS alert. The problem being addressed is that the nuisance alerting is so loud and continuous that cockpit communication or communication with ATC becomes almost impossible. This solution assumes that the TAWS alert is still heard, but different methods are deployed to reduce the continuous aural alerting.

A.6.2 Description

Two concepts are explored to reduce the annoyance level of potential nuisance alerting. The first method is described as the Single Aural process. The second method is described as the Aircraft Response process.

A.6.2.1 Description of Method 1 - Single Aural Process

The single aural response process uses the same principle as is present on current TCAS systems. On a TCAS system, the current alert is annunciated once, followed by a continuous display depiction of the given threat and the red/green band on the vertical speed indicator noting the desired vertical response. However, the system does not continue producing the same aural alert repeatedly. Given that the alert has been heard once, the system ceases the aural alert while continuing to display alert areas so that continued situational awareness remains available.

A block diagram contrasting the current and proposed behavior is shown in the figure below.

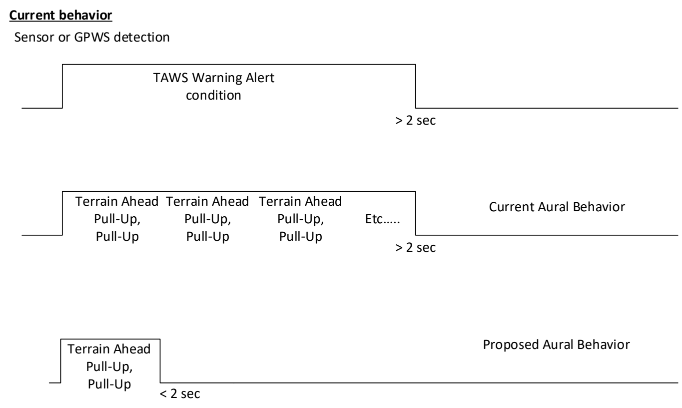

Figure A-7: Block Diagram of Current and Proposed Aural Behavior

A.6.2.2 Description of Method 2 - Aircraft Response Process

A similar concept would remove the aural alert when a pilot response has been seen in the corresponding input parameters. For example, a Pull-up alert aural would only be produced until a flight path angle change took place. Given that a pilot response has been observed, the system ceases the aural alert while continuing to display alert areas so that continued situational awareness remains available.

A.6.3 Operational Effect

The operational effect is negligible – aircraft wiring would remain the same except for a possible configuration setting. A configuration setting would presumably be added to allow the given airline or operator to enable this function.

A.6.4 Training Associated with This Concept

A pilot training would be necessary to ensure that continued diligence is applied after the first appearance of the alert. Current behavior of pressing the terrain inhibit at the first occurrence of an alert would also need to be adjusted, where presumably no terrain inhibit should be necessary for these cases.

If deploying the Aircraft Response process, training would be needed to ensure that a recovery maneuver is not ceased when the aural alert is no longer heard, but to instead rely on the displayed alert areas to determine if alert conditions are still present.

A.6.5 Implementation Effort

The Method 1 – Single Aural Process change would require relatively low amount of effort for the change in aural response. The concept of a single aural alert is already present in TAWS systems for altitude callouts and this can be transferred to the various alerts when configured for the Single Aural. Part of this change would be the introduction of a configuration option. Certification costs are not included in this estimate, where this change is assumed to be part of a larger overall program.

The Method 2 – Aircraft Response Process change would require relatively moderate amount of effort for defining the conditions in which a given alert would cease and in addition, determining when the alert would need to be returned if the aircraft response were discontinued while the alert conditions are still present. Part of this change would be the introduction of a configuration option. Certification costs are not included in this estimate, where this change is assumed to be part of a larger overall program.

A.6.6 Regulatory Implications

Existing DO-367 would need to be modified for either Method 1 – Single Aural Process or Method 2 – Aircraft Response Process. Specifically, the below paragraph for Class B and/or C would need to be adjusted to make allowance for single alerting systems:

A.6.7 Description of Advantages

The advantages of Method 1 – Single Aural Process include several considerations:

- Because of similarity to TCAS alerting and crew response to TCAS alerting, training may be more generic for the two systems.

- The reduction to a single aural alert will reduce the desire for the flight crew to press the Terrain Inhibit. After a single alert which does not continue, the conditions driving the pilot response to shut off the annoying alert are present for less than 2 seconds.

The advantages of Method 2 – Aircraft Response Process include a few considerations:

- The reduction to fewer aural alerts will reduce the desire for the flight crew to press the Terrain Inhibit. After a reduced duration of alert which does not continue, the conditions driving the pilot response to shut off the annoying alert are present for lesser time.

A.6.8 Description of Disadvantages

The disadvantages of Method 1 – Single Aural Process include several considerations:

- Pilot training to continue to respond to the displayed alert conditions despite no longer hearing the alert. This is counterintuitive compared to past training where flight crews can rely on the ceasing of the aural alert to correspond to reaching a level where a level off maneuver can take place.

- An additional reason for the use of Terrain Inhibit in current scenarios is to avoid alarming the passengers on smaller aircraft who can hear the alerts. Even a single "Pull-up, Pull-up" alert can upset passengers and lead to concluding that the aircraft is getting too close to terrain. The Single Aural Process does not address this concern.

- Making a determination of when to issue a new alert will be tricky. For TCAS systems, this is the appearance of a different intruder aircraft. In the TAWS analogous case, one can not simply choose the alert being caused by a different terrain cell because this may drive several consecutive alerts and therefore produce the same nearly continuous alert conditions. Instead, after the first alert is heard, a design determination is needed for what time duration of non-alerting is needed before continuing to alert. This kind of decision will have safety impacts.

The disadvantages of Method 2 – Aircraft Response Process include several considerations:

- Pilot training to continue to respond to the displayed alert conditions after making a manuever despite no longer hearing the alert. This is counterintuitive compared to past training where flight crews can rely on the ceasing of the aural alert to correspond to reaching a level where a level off maneuver can take place.

- An additional reason for the use of Terrain Inhibit in current scenarios is to avoid alarming the passengers on smaller aircraft who can hear the alerts. Even a single "Pull-up, Pull-up" alert can upset passengers and lead to concluding that the aircraft is getting too close to terrain. The Single Aural Process does not address this concern.

- The determination of what change in input parameters is sufficient to consider the alert response to be present will be subjective. In some situations, changing from a descent to a level off may be sufficient to clear the terrain but not have the DO-367 prescribed terrain clearance. Deciding what clearance level is sufficient will be difficult to determine.

• Whichever aircraft maneuver is determined to be sufficient, the flight crew and passengers are still subject to some level of continuously alerting. Thus, the problem may be reduced, but the problem conditions of continuous alerting may still be present.

• After responding to a single alert, if the aircraft remains in a high terrain area, the next few seconds may have a new alert from a different terrain cell come into play. This too would potentially cause an alert and may result in the aircraft taking several alert clearing maneuvers while at the same time having to hear the TAWS alerts more often than desired.

• The flight crew may not engage in a maneuver to change the alert conditions. In some cases, the required terrain clearance level as described in the MOPS, places the aircraft into a must alert zone yet the aircraft can continue on its current path and pass above the terrain. In this situation, the problem still exists of the continuous nuisance alert.

A.7 Inhibit Changes (Section 2.8)

A.7.1 Purpose

Inhibition changes are being considered as part of NTSB Safety Recommendation A-18-015. There are many instances where Part 135 operators have set a terrain inhibit on ground before flight. It has also been shown that terrain warning has been inhibited for nearly 80% of all flight time for Alaskan operators.

A.7.2 Description

NTSB Safety Recommendation A-18-015 suggests modifying terrain awareness and warning system requirements in Technical Standard Order C151 such that, once the alerts are manually inhibited, they do not remain inhibited indefinitely if the pilot does not un-inhibit them. Options that would meet this suggestion include:

- Re-enabling terrain alerting on power up (un-inhibit at power up)
- Re-enabling terrain alerting upon landing (logic concepts: WOW, speed<x, etc)
- Re-enabling terrain alerting after a set period of time (by software or mechanical switch)
- Re-enabling terrain alerting after exiting area of terrain threat

Other inhibition changes to be considered are:

- Keeping terrain display functional during inhibition
- Better Annunciation of Inhibition Condition
- Inhibition that still allows last-second alerts to be annunciated
- Inhibit cautions but do not inhibit warnings
- Add pilot-selectable height-based alert inhibition

The above topics are discussed further below.

A.7.2.1 Re-enabling Alerting at Power Up

Re-enabling the terrain alerting upon power up would avoid the terrain inhibit selection from one flight from persisting into the subsequent flight, assuming the avionics are shut down between each flight. For the category of aircraft on which this class of TAWS equipment is installed, it is expected that the avionics will be shut down after nearly every flight.

Re-enabling the alerting at power up would require the pilot in command of a particular flight to take a specific action in order to inhibit alerting for that flight.

A.7.2.2 Re-enabling Alerting upon Landing

Re-enabling the terrain alerting upon landing would be another means to avoid the terrain inhibit selection from one flight from persisting into the subsequent flight. For aircraft not equipped with a weight-on-wheels indication, logic based on the aircraft state could be used to detect a landing. This approach avoids the possibility of terrain alerting remaining inhibited at the start of a flight when the avionics were not powered off following the preceding flight.

Re-enabling the alerting after landing would require the pilot in command of a particular flight to take a specific action in order to inhibit alerting for that flight.

A.7.2.3 Re-enabling Alerting After a Set Period of Time

Re-enabling the terrain alerting after a set period of time would limit the duration when the terrain alerting could be inhibited without additional pilot action. This approach could be performed either with a software update or through the use of a mechanical timer switch. The latter approach has the advantage of being easy to retrofit without the need for a software update.

However, the timer approach could result in the inhibition ending at an inopportune time that could trigger a nuisance alert at a critical point in the flight.

A.7.2.4 Re-enabling Alerting After Exiting the Threat Condition

Re-enabling the terrain alerting after a terrain threat has ended would limit the number of near-terrain encounters where the inhibition condition could persist. This approach could be described as a preemptive alert cancel function. The pilot could inhibit alerting in order to completely avoid a first terrain alert, but if the first threat passed and a second threat appeared, an alert would be generated for the second threat.

Such an approach would be subject to inadvertent un-inhibiting of the alerting function when the aircraft was flying in and out of the edge of an alerting boundary.

A.7.2.5 Keeping Terrain Display Functional During Inhibition

TAWS systems typically disable the terrain display when alerts have been inhibited. The rationale behind this is that if the pilot has selected the inhibition because of a gross navigation error, the display of terrain based on an incorrect position could result in hazardously misleading information. However, in practice, the inhibition function is typically used because of operational constraints rather than faulty position information. Keeping the terrain display visible when alerts have been inhibited would provide the pilot with situational awareness regarding the terrain.

A.7.2.6 Better Annunciation of Inhibition Condition

Current regulations allow the position of a toggle switch to be the sole indication that the terrain function has been inhibited. If the persistent use of the inhibition is unintentional and results from pilots not noticing that the inhibition switch has been selected, an additional annunciation such as a lamp could reduce the probability that the pilot inadvertently leaves the inhibit condition selected.

A.7.2.7 Inhibition that Allows Last-Second Alerts

Rather than inhibiting all alerts, the inhibition condition could be used to inhibit only most alerts, while still allowing the system to provide last-second alerts when a collision is imminent. This concept is analogous to changing the alerting envelope to desensitize the alert thresholds.

In the case of scenarios such as ditching (or the normal use of seaplane) where the inhibition was specifically selected to allow an off-airport landing, the last-second alert would systematically occur during landing, which would not be desirable.

A.7.2.8 Inhibition of Caution Alerts Only

Rather than inhibiting all alerts, the inhibition condition could be used to inhibit only caution alerts, while still allowing the system to provide warning alerts. Since the caution alert thresholds are typically reached before the warning alert thresholds, inhibiting cautions would help reduce nuisance alerts while aircraft are operating at the edge of the alert envelope, while still allowing warning alerts to occur when the threat level increases.

In the case of scenarios such as ditching (or the normal use of seaplane) where the inhibition was specifically selected to allow an off-airport landing, the warning alert would systematically occur during landing, which would not be desirable.

A.7.2.9 Addition of Pilot-Selectable Inhibition Height

Rather than inhibiting all alerts, the inhibition condition could be used to inhibit only some alerts, based on a pilot-selectable inhibition height. This concept is analogous to changing the alerting envelope to desensitize the alert thresholds.

In the case of scenarios such as ditching (or the normal use of seaplane) where the inhibition was specifically selected to allow an off-airport landing, the delayed alert would systematically occur during landing, which would not be desirable.

A.7.3 Operational Effect

The intended operational effect would be a reduced amount of flight time where terrain alerting is inhibited. It can reduce the amount of pilot’s recovery time for those changes described in Section 2.7 – 2.9.

A.7.4 Training Associated with This Concept

For any of the inhibition changes described in section 2, there would be a small increase in terrain awareness and warning system training, if any.

A.7.5 Implementation Effort

There could be a large variety of installation efforts for the different inhibition logic changes presented. Mechanical switches and software logic implementations are both viable options and have very different impacts regarding installation and financial burden. Automatic inhibit/un-inhibit feature needs special consideration when using a mechanical toggle switch.

A.7.6 Regulatory Implications

The existing TAWS MOPS will have to be revised to allow for the inclusion of these inhibition changes. TAWS with these changes will not satisfy the existing TSO-C151d.

A.7.7 Description of Advantages

The advantages of the inhibition logic changes associated with the NTSB Safety Recommendation A-18-015 are that they can be relatively quick to field and inexpensive if integrated via mechanical switches. They are also widely implementable.

A.7.8 Description of Disadvantages

There are also disadvantages of the inhibition logic changes. Regarding time-based re-enabling of terrain alerting, this could occur at an inopportune time. Also, with all the re-enabling terrain alerting options, there is still the option for the crew to repetitive press the inhibit button. It could even have the unintended consequence of the pilots pulling a circuit breaker to more permanently inhibit the alerting.

An additional disadvantage could occur in a mixed fleet installation. If a given flight crew begins to perceive that the terrain inhibition is temporary rather than permanent, when flying an older installation the flight crew may mistakenly believe that the inhibition will be lifted after X minutes and disregard their inhibition action at a later, more critical time of the flight.

A.8 Situational Awareness Tool based on NASA GCAS

A.8.1 Background

The terrain awareness and warning system (TAWS) is intended to provide the flight crew with caution/warning alerts of a hazardous terrain situation so action can be taken to avoid a CFIT event. Current TAWS systems provide warning alerts that call for a climb in the current direction of flight.

For flight crews whose flight profile requires operating at low altitudes in the vicinity of proximate terrain, the TAWS Forward Looking Terrain Avoidance (FLTA) algorithms often result in numerous, or even continuous, nuisance alerts, causing the flight crew to inhibit TAWS warnings and therefore bypass the TAWS safety benefit. The loss of the TAWS safety benefit has been cited as contributing factor in a number of CFIT accidents.

As cited by parallel papers on lateral escape concepts, an improved quality of the terrain warnings, in the sense of ensuring that the TAWS provides a terrain warning only when immediate action is required to avoid a ground collision, considers escape paths in both the vertical and lateral directions and should significantly reduce the number of nuisance alerts. Such a system has been researched and tested by NASA, with a key element of the system being a ‘Viable Escape Maneuver Display’(VEMD) to provide the flight crew with enhanced situational awareness with respect to available terrain avoidance options, and ultimately provide a warning alert depicting the only remaining viable escape path.

A.8.2 Purpose

This work is intended to highlight existing viable escape display symbology as developed by NASA, highlight important elements of the display, and provide parameters for alternative display concepts.

A.8.3 Description

The goal of the VEMD is twofold; 1) Provide the flightcrew with enhanced situational awareness of proximate terrain and potential escape paths, and 2) Use the display symbology to provide awareness of increasing threat levels, ultimately leading to an immediate action warning. The display should provide information that allows comprehension without significant attention, so as not to distract the flight crew from other safety critical tasks.

The display symbology developed by NASA is depicted in figures A-8 and A-9 below. Figure A-8 shows the progression of maneuver options that provide situational awareness to the flight crew as the number of viable escape options decreases, but prior to a warning and required action. Figure A-9 shows the progression of displays as margins to proximate terrain decrease, ultimately requiring a terrain warning and associated escape maneuver, terminating with an ‘all clear’ display when terrain is no longer a factor.

Key elements of these displays, and also applicable to alternative presentations, are as follows:

- Directionality, to advise the flight crew of acceptable escape paths. In the case of the NASA display, arrows are used to depict acceptable directions.
- Preferential routing, to advise the flight crew of those paths that provide the greatest margins to proximate terrain. In the case of the NASA display, color shading of the arrows is used to depict margins.
- Clear indication of those paths that do not provide a viable escape maneuver based on terrain proximity and available aircraft performance. In the case of the NASA display, the directional arrow is removed and replaced by a red X, a warning that terrain cannot be cleared along that path. It is important to note that a red X visual warning for a given path does not result in a terrain warning as long as other viable escape paths are still available
- When a terrain warning, and associated escape maneuver, is required, a clear indication of the only viable escape path and the required flight crew actions associated with the maneuver. In the case of the NASA avoidance director display, only the viable escape arrow is depicted, along with required power setting for the maneuver. Although this discussion is centered on symbology, it is assumed that the avoidance director display, which is associated with a terrain warning, will be simultaneously accompanied by an audio warning that includes required crew action.

Figure A-8: Progression of Maneuver Options

Figure A-9: Display Progression

A.8.4 Operational Effect

While some affected aircraft are equipped with TAWS visual displays, TAWS Class B and C do not require a display. In the near term, VEMD's could be implemented on EFB's and similar PED devices. A long term solution would require updates of existing displays or installation of VEMD devices.

A.8.5 Training Associated with This Concept

While existing TAWS training would provide a base level of knowledge with respect to CFIT avoidance, specific additional training would be necessary to familiarize flight crews with the specific differences and benefits of the availability of lateral escape maneuvers and the viable escape maneuver symbology. A particular aspect of the training may involve reversing the flight crew response associated with TAWS nuisance alerts and make them aware of the need for immediate response to a terrain warning/ avoidance maneuver. Training could be computer based or simulator based, with sim based training considered the most effective means of developing flight crew acknowledgement of the safety benefits.

A.8.6 Implementation Effort

As previously indicated, initial implementation could be accomplished via EFB or other PED based solution. NASA has indicated the potential for PED based solutions within a year. These solutions would require some input from external data sources, potentially from installed aircraft systems.

For installed solutions on aircraft equipped with TAWS displays, viable escape maneuver symbology could be incorporated into existing displays via software upgrades. For aircraft not equipped with TAWS displays, a display installation would be required and subject to certification compliance.

A.8.7 Regulatory Implications

EFB/PED implementations would require compliance with the requirements of 14 CFR §91.21, Portable Electronic Devices. Additionally, for operations under 14 CFR Part 135, compliance with §135.144(b)(6) would be required.

For airworthiness approved installations, the safety benefit of viable escape maneuver symbology requires, by default, a display. Those aircraft and operations most at risk from CFIT would require display installations as a requirement in order to take full advantage of the safety benefit. This requirement could come in the form of a change to the TAWS MOPS for Class B systems, or a change in the applicable CFR requirements. The best means of implementing these technologies has yet to be determined.

A.8.8 Description of Advantages

- Providing the flight crew with progressive situational awareness of proximate terrain.
- Minimizing nuisance alerts by examining all possible viable escape maneuvers
- PED-based implementation would be relatively low cost as compared to implementation in certified TAWS product.
- NASA has already done a lot of the basic research on the concept.

A.8.9 Description of Disadvantages

- Full implementation requires installation of display
- Obtaining safety benefit for at-risk operators requires revision to TAWS MOPS and/or CFR

A.8.10 REFERENCES

[1] M. Skoog, "GCAS brief1 for GA JSC Rev 4," National Aeronautics and Space Administration, Neil A. Armstrong Flight Research Center, Edwards, CA, 2018.

A.8.11 LIST OF ABBREVIATIONS

TAWS	Terrain Awareness and Warning System
CFIT	Controlled Flight into Terrain
FLTA	Forward Looking Terrain Avoidance
VEMD	Viable Escape Maneuver Display
NASA	National Aeronautics and Space Administration
EFB	Electronic Flight Bag
PED	Portable Electronic Device
CFR	Code of Federal Regulations
MOPS	Minimum Operational Performance Standards