Analysis of Civil Aircraft Terrain Avoidance Warning System “Terrain Terrain” Issue Based on QAR Data

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Abstract—As an important instruction recording device for civil aircraft, Quick Access Recorder (QAR) records the operating status of various aircraft systems. Therefore, QAR data is an important basis for aircraft safety assessment, maintenance inspection and failure analysis[1][2]. The Terrain Avoidance Warning System (TAWS) provides the crew with a near-ground warning based on the aircraft’s current track information (including the aircraft's current position, air pressure altitude, ground speed and track angle, etc.) and referring to terrain altitude data, obstacle data and airport data information. Generally, the QAR data can be used to obtain a more accurate judgment when a warning occurs in the TAWS system. Through the quantitative analysis of QAR data, this paper finds out the root cause of over speed approaching terrain warning in the flight process of an aircraft

1. INTRODUCTION
The Terrain Avoidance Warning System (TAWS) of civil aircraft is a safety system used to avoid controlled ground collisions. TAWS provides Ground Proximity Warning System (GPWS) function and predictive obstacle reminder function using the current trajectory information, terrain altitude data, obstacle data and airport data information[3]. The GPWS provides predictive warning based on the current position of the aircraft. For example, when the speed of the current trajectory and terrain approaching is too large, an audible warning of "Terrain Terrain" will be generated to alert the crew of the aircraft that there is a risk of collision with the current descent speed according to the radio altimeter, indicated airspeed, landing configuration and flap configuration. A certain type of aircraft also has triggered this audible warning during high-altitude cruise flight frequently, which has a greater impact on the crew. However, there should be no terrain below the 10000-meter high-altitude of aircraft. Therefore, to determine whether the "Terrain Terrain" audible warning is caused by system failure or triggered by system's normal warning logic, a specific analysis needs to be carried out in conjunction with the system principle and QAR data. Quick Access Recorder (QAR) is a fast transcription recorder getting the aircraft data from the Data Concentration Unit (DCU) and recording them on a small flash memory card. The flash memory card can be detached, or you can use the USB interface with a laptop or the portable data downloader. Then the recorded aircraft data are downloaded and sent to the ground station for reading. The maintenance engineers decode the original data into identifiable data, which can be used to analyze and monitor the flight status of the aircraft system. Unless otherwise specified, all analyses are for this specific model aircraft.
2. TAWS SYSTEM FUNCTION INTRODUCTION
The reactive near earth warning (GPWS) function of TAWS generally includes the following 6 working modes:

Mode 1: excessive descent rate
When the current track descends at an excessive rate, a reactive medium-term alert level warning and a reactive short-term warning will be generated according to the radio altitude and vertical speed.

Mode 2: too close to terrain speed
When the speed of the current track and terrain approaching is too high, according to the radio altimeter, indicated airspeed, landing structure and flap configuration, a continuous "terrain terrain" sound warning will be sent out, which will become more and more serious. After "terrain terrain", an audible warning "pull up" (Fig.1).

Mode 3: altitude drop after takeoff
In this mode, when there is altitude loss after takeoff or in the process of go around, alert will be generated according to the radio altitude and aircraft altitude, and an audible alarm "don't sink" will be given at the same time. When the aircraft is outside the warning envelope or within the warning envelope but the aircraft vertical speed is positive for more than 1 second, the audible alarm stops.

Mode 4: incorrect landing configuration
When the aircraft is in an incorrect landing configuration and the ground separation is insufficient, the mode generates "too low terrain", "too low gear" or "too low flaps" alert according to the radio altitude, landing structure, flap configuration and airspeed. The "too low flaps" audible alarm can be suppressed through the flaps alarm (TAWS flap) switch.

Mode 5: excessive g / s deviation
When the aircraft approaches and lands, if the glide slope deviates too much, it is necessary to analyze the aircraft LOC offset. If the offset exceeds the threshold value set by the aircraft, GPWS will trigger an alarm to remind the pilot to adjust the height of the aircraft, so as to make the aircraft approach and land according to the safe glide slope.

Mode 6: altitude call and excessive slope angle
Altitude report is a function that the aircraft reports altitude to the pilot at a fixed altitude to remind the pilot of the current altitude; excessive inclination is a warning function that reminds the pilot to operate when the aircraft inclination exceeds the maximum inclination set by the aircraft to avoid dangerous situations.

3. "TERRAIN TERRAIN" WARNING PRINCIPLE OF TAWS SYSTEM
TAWS system provides topographic maps for PFD and MFD display via ARINC-453/708 on the specific model aircraft. The system is highly cross-linked to the Radio Altitude (RA), Angle of Attack (AOA), airspeed, glide path deviation, landing gear position, flap position, altitude, roll attitude, position, track, and heading (and any other necessary inputs)⁴⁵, which are used to calculate the ground collision hazard caused by terrain differences or controlled ground collisions (Fig.2).

The radio altitude is provided by RA; the AOA is provided by the weathervane; the airspeed is provided by the atmospheric data computer (ADC); the landing gear position is provided by the
Position and Actuation Control Unit (PACU); the flap position is provided by the Flap Slat Electronic Control Unit (FSECU); other heading, attitude, position and other information can be provided by Inertial Reference Unit (IRU).

![Diagram of TAWS system](image1)

Figure 2. Interface of the TAWS system

![Mode 2 warning logic](image2)

Figure 3. Mode 2 (Terrain Terrain) warning logic

**Fig.3** shows the logical envelope of the "Terrain Terrain" warning of the TAWS system\[^{[3]}\]. The horizontal axis is the terrain approach rate, and the vertical axis is the radio altitude. The warning belongs to TAWS Mode 2: the rate close to terrain is too high (alert level warning). The aircraft's radio altitude is monitored and a warning is issued when the rate of radio altitude change is too large. For example, the aircraft is in the landing configuration: the flaps are released and the landing gear is released. The maximum descent rate of the aircraft cannot exceed 2277 ft/min at the height of 220 feet and the value cannot exceed 3000 ft min at the height of 790 feet. The two height points and the corresponding descent speed values form a linear function and the entire warning envelope in the figure can be obtained.

4. **ANALYSIS OF WARNING CAUSES BASED ON QAR DATA**

Illustrated by the example of the actual route operation of a certain type of aircraft, the "Terrain Terrain" warning appeared multiple times during the cruise phase. According to the QAR data of the flight at that time, the plane flew at a pressure altitude of 32100 feet and an airspeed of 271 knots. The radio altitude jumped from 2600 to 2073 feet and maintained the altitude between 1850 and 2000 feet for 20 seconds shown as the **Table I**. The value of the RA dropped rapidly within a few seconds before the warning, and entered the warning envelope of TAWS Mode 2 during the warning which triggered the "TERRAIN TERRAIN" warning (**Fig.4**).
Figure 4. Aircraft entering the envelope of Mode 2

| TAWS GPWS ALERT | RADIAO Altitude | Baro Altitude | Airspeed |
|-----------------|----------------|--------------|----------|
| NO-ALERT        | 0              | 32050        | 260      |
| NO-ALERT        | 0              | 32052        | 260      |
| NO-ALERT        | 0              | 32054        | 260      |
| NO-ALERT        | 2073           | 32055        | 260      |
| NO-ALERT        | 2049           | 32053        | 260      |
| NO-ALERT        | 1988           | 32053        | 261      |
| NO-ALERT        | 0              | 32056        | 261      |
| NO-ALERT        | 0              | 32056        | 261      |
| NO-ALERT        | 0              | 32057        | 261      |
| NO-ALERT        | 1970           | 32057        | 261      |
| NO-ALERT        | 1960           | 32057        | 261      |
| NO-ALERT        | 1954           | 32058        | 261      |
| NO-ALERT        | 1948           | 32058        | 261      |
| NO-ALERT        | 1921           | 32057        | 261      |
| NO-ALERT        | 1938           | 32055        | 261      |
| NO-ALERT        | 1934           | 32107        | 261      |
| NO-ALERT        | 1929           | 32054        | 261      |
| NO-ALERT        | 1927           | 32054        | 261      |
| NO-ALERT        | 0              | 32052        | 261      |
| NO-ALERT        | 0              | 32052        | 261      |
| NO-ALERT        | 0              | 32053        | 261      |
| NO-ALERT        | 1943           | 32053        | 261      |
| ALERT           | 1830           | 32052        | 261      |
| NO-ALERT        | 0              | 32051        | 261      |
According to the altitude of the aircraft at that time and the description of the pilot, there was no terrain threat in the area. Therefore, the warning was caused by the aircraft passing below bringing about a RA jump, which in turn triggered the TAWS Mode 2 false warning.

The RA utilizes frequency difference to measure distance below 2600 feet. The modulation signal is a periodic voltage signal that changes sawtooth with time. The transmission frequencies corresponding to the lowest and highest values of the sawtooth voltage are $f_{01}$ and $f_{02}$, respectively. As the modulation voltage changes, the transmission frequency also changes linearly with time. Assuming that the frequency of the signal transmitted by the transmitting antenna to the ground at time $t_1$ is $f_1$. After the time $\tau_a$, the wave reflected from the ground is received by the receiving antenna at time $t_2$. The signal received by the receiver at $t_2$ is $f_2$, but the transmission frequency is $f_2$. The difference between them is $f_b = f_2 - f_1$. Obviously $\tau_a$ is the propagation time required for the electric wave to travel between the aircraft and the ground. The relationship between $\tau_a$ and the height of the aircraft from the ground is

$$\tau_a = \frac{2h}{c}. \quad (1)$$

Where $h$ is the height of the aircraft from the ground; $c$ is the propagation speed of the electric wave in the atmosphere.

Therefore, according to the principle of altitude measurement, the aircraft altitude calculation is shown as follows:

$$f_b = \frac{f_2 - f_1}{\tau_a} = \frac{\Delta f_b}{\tau_a}, \quad (2)$$

$$f_b = \frac{2\Delta f_m}{c\tau_{0'}} h, \quad (3)$$

$$h = \frac{c\tau_{0'}}{2\Delta f_m} f_b. \quad (4)$$

Where $\Delta f_m$ is the maximum frequency deviation of the transmission frequency; $\tau_{0'}$ is the rise time of the sawtooth wave; $c$ is the propagation speed. These three items are known data, so if the difference frequency $f_b$ is measured, the height $h$ can be calculated.

The antenna beam of the RA is wide. The receiving antenna can not only receive the reflected signal from the vertical direction below, but also receive the reflected waves from other directions. Therefore, the altimeter tracks the first reflected signal to ensure the accuracy of the reading.

According to the principle of the RA antenna beam, the vertical transmission angle is about 50 degrees, and the horizontal transmission angle is about 60 degrees. The elliptical range below 2000 feet of the aircraft may reflect the RA signal when other aircraft passes by, resulting in the altimeter reading to jump. According to the altimeter jump for 20 seconds and the cruise speed of the general route aircraft, it is estimated that the direction of the aircraft below the TAWS false warning aircraft is roughly the same as that of the TAWS false warning aircraft, and the speed difference is below 53 knots, causing the altimeter reading to jump.

According to the logic of TAWS, when the TAWS terrain function works, the Mode 2 warning will be suppressed. The Mode 2 warning only activated when there is an altitude error, position error, or database error. The purpose of the design is to reduce the triggering of the Mode 2 false warning. Generally, the Mode 2 warning will not be triggered. However, in the process of this warning, the altimeter jumps first, then the TAWS system compared the difference between the barometric altitude and the radio altitude with the terrain altitude in the current location terrain database and found that there was a large difference. The TAWS system incorrectly believed that a database error had occurred, thus activating Mode 2 warning. Therefore, the warning was caused by the altimeter jump resulting from the passing of other aircraft, which activated Mode 2. Finally, the altimeter jump data entered the warning envelope to trigger the warning.
5. SUMMARY
This article analyzed the warning logic of the "Terrain Terrain" for practical problems and analyzed the logic trigger conditions based on the QAR data and warning logic. Through the analysis of QAR data, the reason of the "Terrain Terrain" warning triggered was that the altimeter data jump caused by other aircraft passing under the aircraft led to Mode 2 activation, and the jump data entered the Mode 2 warning envelope. Since the working altitude of Mode 2 is below 2,450 feet measured by the radio altitude, the operation should be strictly in accordance with the manual to escape the terrain threat when the "Terrain Terrain" warning occurs at low altitude. When the TAWS GPWS Mode warning is triggered during the high-altitude cruise stage, the crew should eliminate the possibility of false warning by observing the environment outside the aircraft and viewing the display of the TAWS topographic map. If the flight crew does encounter terrain threat, please clear the terrain threat according to the manual.

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