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Research on the Identification of Abnormal Flight Status Based on ADS-B Data

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***Abstract*—Abnormal flight monitoring is an important part of the daily operation of airlines, and its effective implementation is a key element to improve the safety of aviation. It is of great significance for the development of aviation industry to identify abnormal flight status and give prompt alert to it. Automatic Dependent Surveillance-Broadcast (ADS-B) is a real time air-ground data link, of which the minimum interval for data distribution can be up to 1 second. It has been widely used in flight surveillance in recent years. Based on the ADS-B data, we propose three kinds of alert logics to automatically identify the flight status of holding, aborted takeoff and go around, and specifically analyze the flight track parameters in abnormal scenes. The three algorithm logics proposed in this paper have been used in actual system operation. The actual operation results indicate that ADS-B data improves the real time and accuracy of the identification of abnormal flight status, and greatly improves the safety of flight operation.**

Keywords—ADS-B track, Abnormal flight monitoring, Identification of abnormal flight status, Logic of alert

I. INTRODUCTION

With the rapid development of civil aviation, air traffic flow continues to increase, and airspace resources are increasingly scarce. Problems such as flight delays, aircraft conflicts, and abnormal status of flight also followed one after another. The contradiction between the ever-increasing flight demand and the existing air traffic service capabilities has become increasingly prominent, which brings great hazards to the safety of air transportation. Safe and efficient operation has become the focus of the aviation industry.

In May 2019, the Flight Standards Department of the Civil Aviation Administration of China (CAAC) issued the "Aircraft Tracking and Monitoring Implementation Guidelines for Operators", which further emphasized the need to develop automated operation monitoring systems, with risk prevention and control capabilities as the core, big data applications as the foundation, and information technology as the means. The operation monitoring system integrates all necessary resources about operation information to connects "information isolated islands", and realizes timely and effective identification, early alerting, mitigation and elimination of risks.

ADS-B[1-3] is one of the new surveillance methods of the Communication, Navigation and Surveillance/Air Traffic Management (CNS/ATM). It automatically sends the position information acquired based on the Global Navigation Satellite System (GNSS) through the 1090ES data link, and the update frequency of the position information is once per second. Because of its ability to track aircraft efficiently, ADS-B is the main surveillance technology in the Next Generation Air Transportation System (NGATS) [4] and the Single European Sky ATM Research (SESAR) [5]. CAAC plans to use ADS-B as the main new surveillance method for air traffic in the future. It is imperative to build an ADS-B-based operation guarantee and information service system.

Compared with the primary and secondary radar surveillance technology in Air Traffic Control (ATC), ADS-B surveillance methods have many advantages such as high accuracy, short target update cycle, and low cost. At the same time, compared with the Aircraft Communications Addressing and Reporting System (ACARS), the update frequency of ADS-B data can reach the second level. The parameters transmitted by ADS-B can be used to promptly alert the abnormal status of the aircraft.

II. ANALYSIS OF ADS-B TRACK DATA

ADS-B is introduced into the ATM system due to its high positioning accuracy and high broadcast frequency. It continuously sends out ADS-B messages to inform the current flight parameters and specific position information of the aircraft. ADS-B periodically sends track messages, the message information includes the ICAO 24-bit address code, time, latitude and longitude, altitude, etc. Through the analysis of the track message, the flight status information of the aircraft can be easily obtained.

A. ADS-B Technology and Application

ADS-B is a new ATC surveillance technology based on GNSS. It uses air-to-ground and air-to-air data links to realize traffic monitoring and information transmission. The aircraft automatically broadcasts precise positioning information and other information generated by the navigation system, which is received by ground equipment and other aircraft through a data link. The ADS-B surveillance system can provide aircraft with the required flight information, complete the mutual surveillance of aircraft in the airspace, and also help the ground control center to monitor the flight status of aircraft in the limited airspace. The ADS-B system is mainly composed of airborne equipment, data link, and ground station. The principle of the system [6] is shown in Figure 1.

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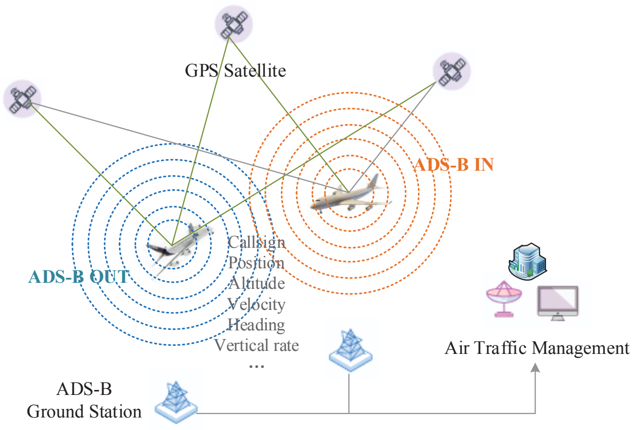

Fig. 1. ADS-B monitoring system

As can be seen from Figure 1, ADS-B connects satellite, aircraft and ground station together to forming a comprehensive system involving three levels of space, sky and earth. The position information of the aircraft comes from the satellites. ADS-B encapsulates the satellite data and sends it to the air, so that it can be received on the ground and in the air.

According to the different direction of aircraft information transmission, ADS-B surveillance technology can be divided into two types, that is ADS-B OUT and ADS-B IN. ADS-B OUT means that the airborne ADS-B transmitter sends out various information of the aircraft in a certain period, including aircraft identification information (ID), position, altitude, speed, direction and rate of climb, etc. ADS-B IN means that the airborne ADS-B receiver receives the ADS-B OUT information sent by other aircraft or the information sent by the ADS-B ground station to provide operational support for the crew. ADS-B IN enables the crew to "see" the operating conditions of other aircraft on the Cockpit Display of Traffic Information (CDTI), thereby enhancing their air traffic situational awareness. ADS-B OUT technology is relatively mature at present, this paper is to use ADS-B OUT technology to monitor and alert abnormal flight status.

B. Format of ADS-B Track Data

The ADS-B message returns the track point information of each aircraft at a certain time in the whole flight process [7]. Therefore, the track of each aircraft is not continuous, but consists of a series of discrete points.

Suppose there is a historical track set T, which includes the number of N historical tracks [8], expressed as

$$T = \{T_1, T_2, \ldots T_k, \ldots, T_N\} \tag{1}$$

Where, T_k represents the k-th track in the set T.

Suppose that each track contains n track points, there are

$$T_k = \{m_1, m_2, \ldots m_i, \ldots, m_n\} \tag{2}$$

Where, m_i represents the i-th track point on T_k.

If each track point consists of p features, then

$$m_i = \{m_{i1}, m_{i2}, \ldots, m_{ij}, \ldots, m_{ip}\} \tag{3}$$

Where, m_{ij} represents the j-th feature of the track point m_i.

III. Design of the Alerting Algorithm Logic for Abnormal Flight Status

In addition to regular flight monitoring, holding, aborted takeoff, and go around are abnormal flight statuses, which attract more attention from airlines. The above three types of basic alerts can be formed based on ADS-B data. Table I gives the logical description of the alerts for three abnormal flight status. The algorithm is described in detail below.

TABLE I. LOGIC OF ABNORMAL ALERT

Abnormal Status	Logic of Alert
Holding	• The flight altitude is more than 300 meters; • Sample a heading angle every 30 seconds, and iteratively calculate the heading angle difference; • Count and accumulate the difference value in a certain minute, and if 360° is satisfied, the alert of holding is triggered.
Aborted takeoff	• After the speed of departure flight exceeds 60 knots; • There is a continuous speed reduction for 5 seconds.
Go around	• The flight altitude is under 4500 meters; • The altitude drops for 2 minutes and then rises for 90 seconds; • The height difference of 100 meters must be met both in the descending and ascending phases.

A. Holding

Holding usually occur in the event of mechanical failure or dangerous weather at the landing airport. At this time, it is generally necessary for the ground to timely monitor and provide decision-making information support to ensure flight safety. The core of holding is to continuously turn and fly in a circle in the air. How to determine whether a holding occurs is essentially to judge whether the aircraft is flying around a closed curve. The specific logic of the holding pattern is as follows. Connect the latitude and longitude coordinates of the flight in turn to form the flight track of the aircraft. Take a point on the flight track every 30 seconds, and connect these points in chronological order so that every two points form a line segment. Determine whether these line segments intersect, if the line segments intersect, the aircraft is in the process of holding procedure.

Holding mapped on a two-dimensional plane is a closed curve. Using the idea of definite integral [9], the closed curve is subdivided into an M-sided polygon composed of m straight lines. The supplementary angle of the angle between the two subdivided straight lines is the outer angle $\theta_i (i = 1, 2, \ldots, n)$ of the M polygon, which is the heading angle of the aircraft. In order to reduce the length of the m sides indefinitely, the longest side of the M-sided polygon tends to zero. Use λ to represent the longest side of m

sides, when $\lambda \to 0, m \to \infty$, Taking the limit of the sum, the sum of the outer angles of the M-sided polygon is obtained.

$$S = \lim_{\lambda \to 0} \sum_{i=1}^{n} \theta_i \quad (4)$$

It can be judged whether the track of the aircraft is a closed curve by whether the polygon's sum of the exterior angle S is equal to 360°, and then it can be judged whether the aircraft is holding.

According to the statistical analysis of the historical holding data of domestic and foreign aircraft, the time for an aircraft to hold in the air is less than 20 minutes [10]. Choose 20 minutes as the cycle of judging the holding event, the specific algorithm flow is shown in Figure 2.

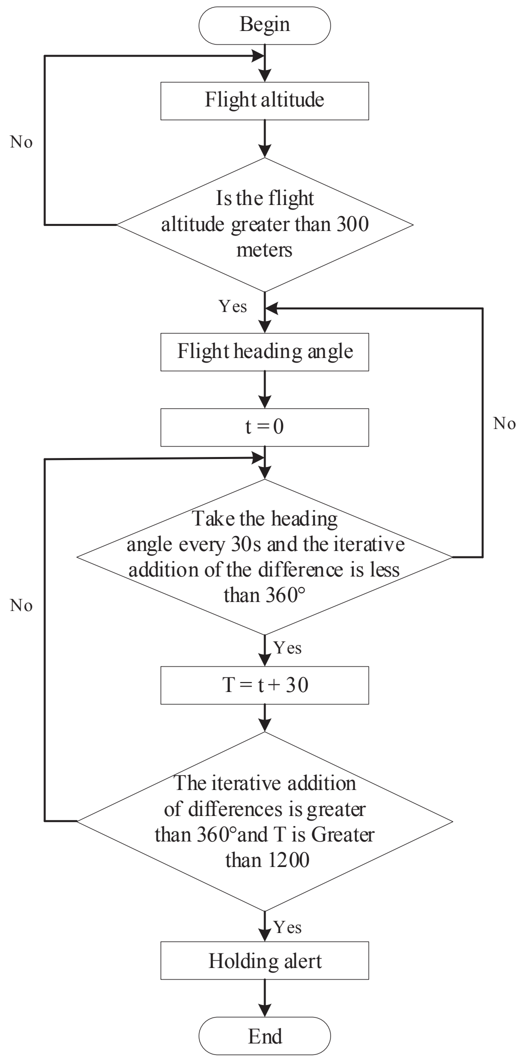

Fig. 2. Flow chart of holding alert algorithm

B. Aborted takeoff

Aborted takeoff refers to emergency measures taken for an aircraft that is taking off and taxiing, if its safety cannot be guaranteed by continuing to take off. The takeoff decision speed V_1 is the limit speed for an aborted takeoff, and any aborted takeoff above V_1 is dangerous. Therefore, the decision to aborted takeoff must be made before the aircraft speed reaches V_1. If the aborted takeoff is still made when the takeoff run speed is greater than V_1, the aircraft may overrun the runway. As an abnormal situation during takeoff run, the monitoring of aircraft speed needs to be paid more attention.

The logic for alerting of aborted takeoff is as follows. After the departure flight speed exceeds 60 knots, the speed decreases continuously for 5 seconds. The value of the reference speed of 60 knots [11] can be adjusted according to the actual situation. If the speed is selected too small, it is easy to misjudge the taxi waiting in the taxiing phase as an aborted takeoff. If the speed is selected too large, it will cause the low-speed aborted takeoff alert to be missed. The logic flow of aborted takeoff alert is shown in Figure 3.

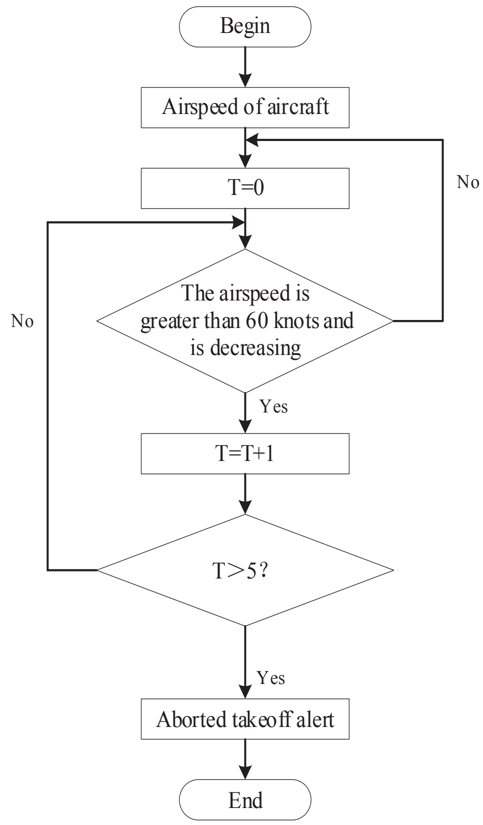

Fig. 3. Flow chart of aborted takeoff alert algorithm

C. Go around

When the aircraft is approaching the destination, during the continuous descent process, due to weather or ATC instructions, the aircraft will go up again, causing the aircraft to go around. According to the altitude of the ADS-B data, the go-around action of the aircraft can be identified. The initial judgment altitude of the go around alert is 4500 meters. For aircraft above 4500 meters, the logic judgment of the go around is not performed.

The logic of go around alert is as follows. When the aircraft descends below 4500 meters, the aircraft altitude drops for 2 minutes and then rises for 90 seconds. Both the descending and ascending stages need to meet the height difference of 100 meters. The specific algorithm logic is shown in Figure 4.

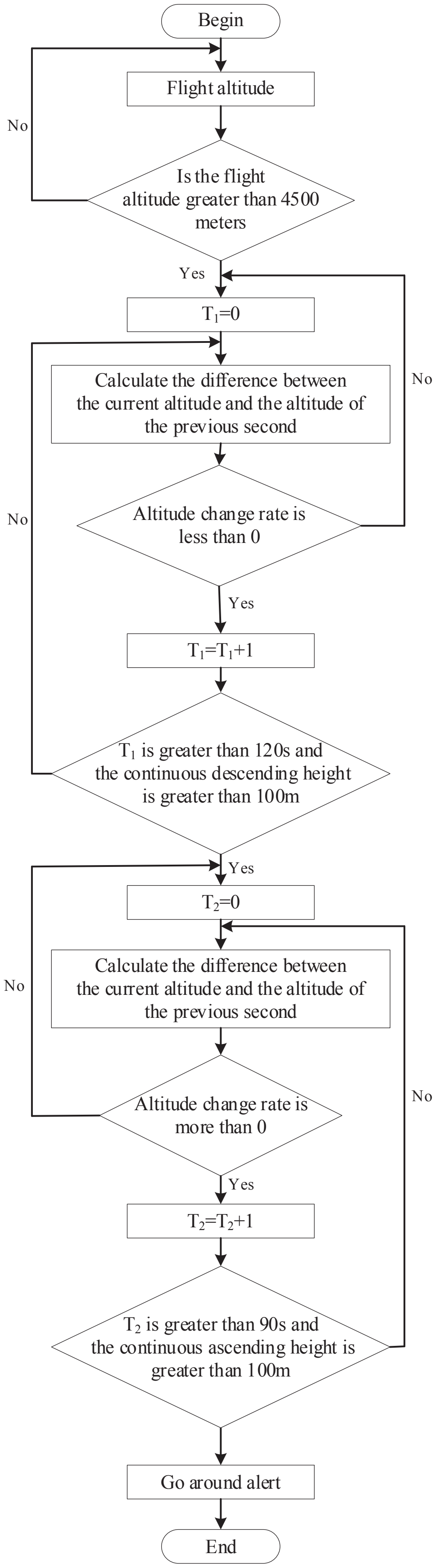

Fig. 4. Flow chart of go around alert algorithm

IV. TRACK PARAMETERS SIMULATION IN ABNORMAL SCENES

The real ADS-B historical track data from April to June 2021 is selected to analyze the track parameters in the three abnormal flight status of holding, aborted takeoff, and go around.

A. Track of Holding

Due to thunderstorms at the destination airport, the flight CBJ5503 joined a holding pattern during the flight On April 29, 2021. Through the analysis of the two parameters of longitude and latitude in the track data, it can be seen that the track of the aircraft meets the requirements of the identification of holding. Figure 5 shows the holding track of the flight.

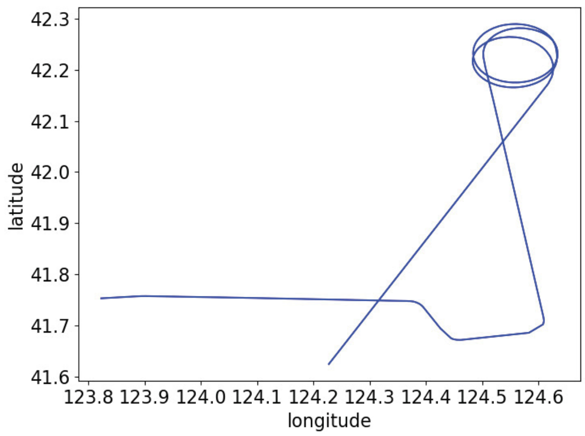

Fig. 5. Flight track of holding

B. Airspeed Change of Aborted takeoff

On June 26, 2021, the Air China flight CCA1257 from Yinchuan Hedong to Shanghai Pudong was aborted takeoff. By analyzing the two parameters of airspeed and time in the flight path data, it can be seen that the variation trend of airspeed meets the requirement of aborted takeoff identification. The variation trend of airspeed in the process of aborted takeoff is shown in Figure 6.

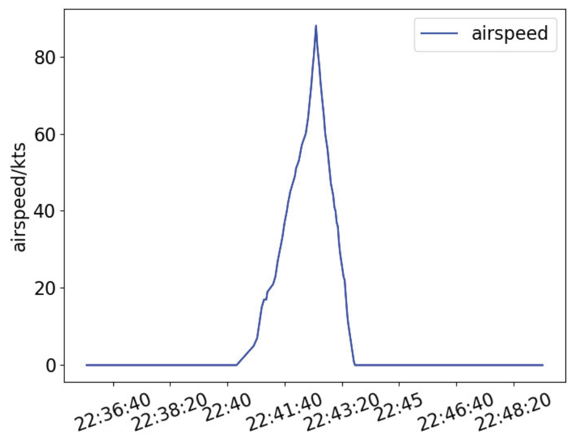

Fig. 6. The variation trend of airspeed in aborted takeoff

C. Altitude Change of Go around

On May 30, 2021, China Eastern Airlines Flight CES9015, flying from Xianyang, Xi 'an to Hotan, Xinjiang, go around due to the weather at the destination airport.

Through the analysis of the altitude and time parameters in the track data, it can be found that the altitude change of the aircraft is consistent to the identification of a missed approach. The trend of altitude changes during the flight's go-around process is shown in Figure 7.

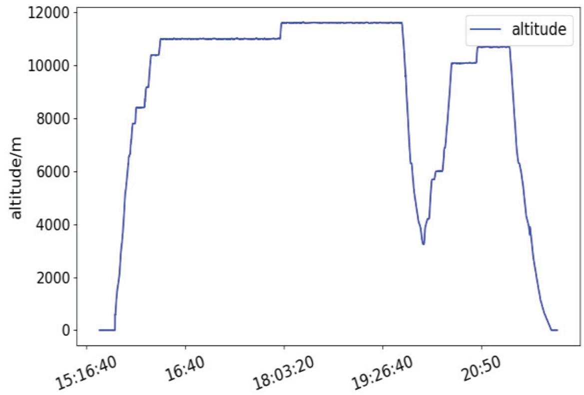

Fig. 7. The altitude change trend of go around

V. SYSTEM IMPLEMENTATION

We developed the ADS-B flight monitoring system based on the ADS-B data and Geographic Information System (GIS). The alert logic for holding, aborted takeoff and go around described in this paper has been applied in the system and the effect is good. The system has been used for actual flight operation monitoring, providing strong technical support for the operation control departments of many domestic airlines. The system interface is shown in Figure 8.

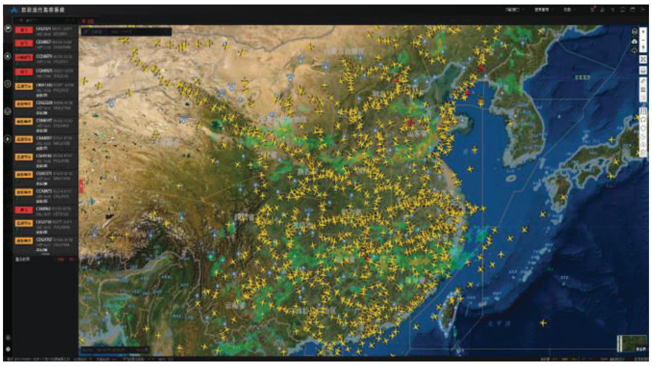

Fig. 8 ADS-B flight operation monitoring system

Fig.9 Real time alert of holding

Figure 9 illustrates the real time alert function of the system for the event of holding. Air China flight CCA8673, from Chongqing Jiangbei International Airport to Beijing Daxing International Airport, due to ATC instructions, the aircraft flight two circles of the holding pattern. The system identifies the holding action in real time and gives an alert promptly, which provides powerful help for the flight monitoring seats.

In actual flight operation, an aircraft may need to join a holding pattern due to sequencing, air traffic flow control or some other reasons. In this case, the flight data received from the aircraft would meet the requirements of holding alert, which will trigger an alert in the monitoring system. There is a list of alert on the left panel of the system, which will give real time alerting for abnormal situations such as holding, aborted takeoff, and go around, and display the alert name, alert time and specific information of the alert flight, so that the monitoring personnel can check and handle it in time. The actual operation results prove that the selection of monitoring parameters and the design of alert logic in this paper are feasible. On this basis, the flight monitoring personnel can grasp the status of the aircraft in real time, monitor the abnormal actions of the flight, and ensure the safety of the aircraft.

VI. CONCLUSION

In this paper, the identification algorithms for three kinds of abnormal flight action are proposed, and the design of the alert logic for holding, aborted takeoff and go round is completed. Through the analysis of flight track data under the abnormal circumstances, it is demonstrated that the selection of monitoring parameters in this paper is feasible. Three kinds of abnormal action alert logic have been successfully applied to the actual monitoring system. The actual operation results prove that the research on abnormal status monitoring of flight based on ADS-B can help reduce the burden of monitoring personnel, optimize the efficiency of flight operation, and improve the safety of flight operation. Due to the increasingly higher requirements for flight tracking and the diversification of abnormal statuses, more and more parameters need to be monitored and the logic requirements are more complicated. In the future, the alert logic of abnormal status will be further optimized.

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