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Tail Strike Risk Prediction of A320 during Takeoff

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***Abstract*—The aim of this paper is to predict the risk probability of the tail strike event in A320 fleet by calculating the minimum distance between the ground and the tailskid of each flight during takeoff phase. By studying the distributing disciplinarian of the measured values of tail strike, we find that the sample data subjected to different normal distributions since the aircrafts are equipped with different types of engines. Then we can obtain the tail strike event probability according to the probability density function of each sample. The prediction results can provide reference for airlines to manage the risk of tail strike events, and to decide whether it is necessary to propose targeted training plans or not according to the possibility of incidents and the severity of the consequences.**

Keywords—tail strike, normal distribution, risk prediction

I. INTRODUCTION

According to A Statistical Analysis of Commercial Aviation Accidents by AIRBUS [1], most percentages of both fatal accidents and hull loses over the last 20 years happened during takeoff, approach and landing phases. The Statistical Summary of Commercial Jet Airplane Accidents by Boeing [2] also illustrated that 19.15% of aboard fatalities and 29.09% of fatal accidents occurred during takeoff and landing phases, though the flight time of these two phases only account for about 2% of the entire flight. Through the analysis of the safety data statistics of ten main airlines for nearly ten years, such as the largest airlines in North America and China, Emirates, ANA et al., tail strike accounted for the highest proportion of serious incidents of work and skill reasons, with a total of 33 cases, accounting for 35%.

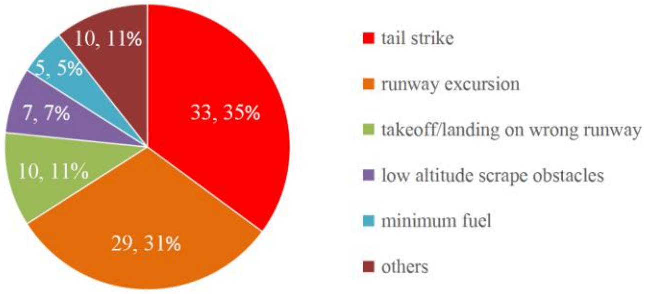

Fig. 1. Proportion of serious accidents in ten airlines in the past ten years

As a kind of incident that occurs frequently during takeoff and landing, tail strike may causes damage to the tail structure of the aircraft, which is a serious unsafe event. For example, A Jetstar A320 occured a tail strike because of the higher than normal rotation rate during takeoff [3], which caused the aircraft's APU (auxiliary power unit) deverter and APU drain mast to be damaged. In 2014, an A321 of Swiss International Airlines was seriously damaged under the tail of the aircraft due to the crew pulled the side stick abruptly to the aft stop during go-around and resulted in the aircraft contacted the runway surface [4]. In 2015, also due to the continuous progressive aft sidestick control input, a British Airways A321 bounced slightly and nose-up pitch continued to increase and lead to tail strike at the second touch [5]. And the crew were not aware it until they arrive on stand.

According to the statistical results of China Civil Aviation, there were 54 tail strike incidents occurred from 1991 to 2013[6], of which 52% occurred during the landing phase. Compared to the landing phase, the tail strike which happened during takeoff brings greater potential risk. Because it is not easy to be discovered in time, especially when the aircraft continues to climb the height, there will be a risk of pressurized. In this paper we analyze the QAR(Quick Access Recorder) data of A320 fleet of one airlines and predict its tail strike risk.

II. TAIL STRIKE EVENT

Tail strike occurs when the tail of the aircraft contacts the runway surface during takeoff of landing. When the pitch of the aircraft increases, and the aircraft will gain greater lift. During takeoff, if the airspeed is not enough, only by continuously increasing the pitch is still not enough to make the aircraft leave the ground, which will lead to the occurrence of the tail strike event. According to the design of A320, If the pitch attitude reaches a certain degree with both gears on the ground then lead to tail strike. The FCOM calls for a pitch limitation of 13.5 degrees with the main landing gear fully extended and 11.7 degrees with the main landing gear fully compressed. Sun and Yang [7] extracted the pitch attitude at the moment of the aircraft leaving the ground based on the status of the air-ground switch which in the main landing gear changing from GND to AIR. And made a prediction of the tail strike risk. However, it is necessary to consider the error caused by the inconsistent sampling frequency of the pitch attitude and the air/ground switch. Besides, there will still be the risk of tail strike as the pitch attitude increases while the aircraft is just liftoff. Marc Baillion [8] described a case where the pitch attitude exceeded the limitation and was mistaken as a tail strike. Due to the damping function of the gear, there was a time difference between the main landing gear leaving the ground and reaching the fully extension condition.

A. Data Preprocessing

The QAR data of A320 fleet are extracted and imported into the EMS system. Some are shown in Fig. 2. And the whole data analysis process is shown in Fig. 3. It should be noted that we only use QAR data for analysis in this paper. From Fig. 2, it is found that the QAR data acquisition equipment has different sampling frequencies for air-ground switch, radio altitude and pitch angle, which are 2HZ, 4HZ and 8HZ respectively.

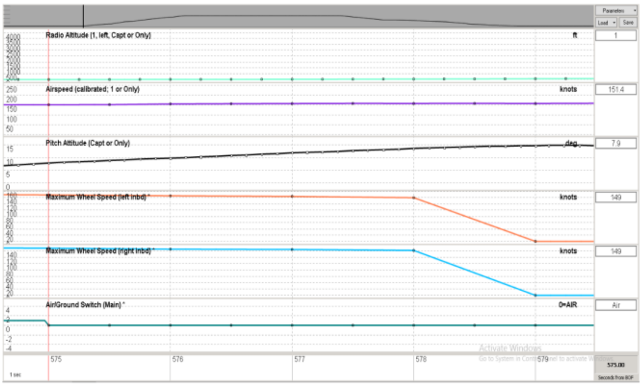

Fig. 2. Examples of some QAR original data

Therefore, it is hard to grasp the real pitch attitude at the moment of leaving the ground. In addition, it can be found that when judging the air/ground status by wheel speed, the tire will continue to run for about 4s after liftoff. Therefore, in our research, we measure the tail strike by establishing the minimum distance between the tailskid and the ground during takeoff. And this method is expected to be more intuitive and effective.

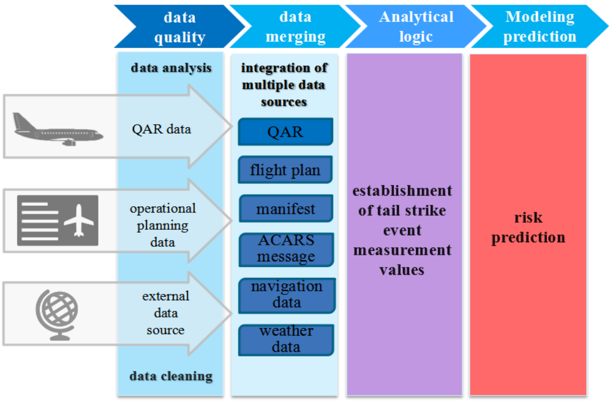

Fig. 3. QAR data analysis process

B. Parameter Establishment

The pitch during takeoff is shown in Fig. 4. According to the triangle similarity principle, the distance of the tail clearance can be calculated from the pitch attitude and the radio altitude. As in:

$$a + b = H - L\sin\theta + N\cos\theta \quad (1)$$

where H is the radio altitude. L is the distance of the radio radar altimeter antenna from the horizontal direction of the tailskid, N is the distance of the radio radar altimeter antenna from the vertical direction of the tailskid. And q is the pitch attitude.

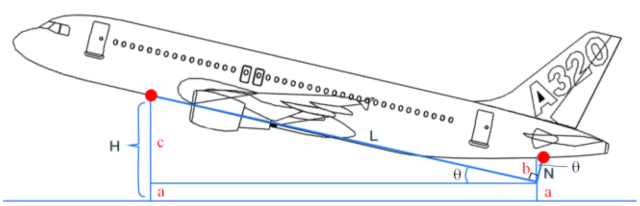

Fig. 4. Aircraft pitch during takeoff

In order to make the evaluation results more accurate, which means to get the value of tail clearance is the one with greatest risk of tail strike during takeoff phase of each flight, we capture the minimum distance value of a plus b between the time of the speed reaches V_1 and the time of the height reaches 35ft from the ground.

III. TAIL STRIKE RISK PREDICTION OF A320

After obtaining the minimum distance between the tailskid of A320 and the ground during takeoff phase, 3000 effective samples are selected, and the distribution of the measured values are shown in Fig. 5. We can notice that the samples are approximately subjected to normal distribution. Actually it is a bimodel distribution with two peaks and they are very close to each other, one is less than 4ft and the other is about 4.5ft, which indicates that our samples come from at least two groups.

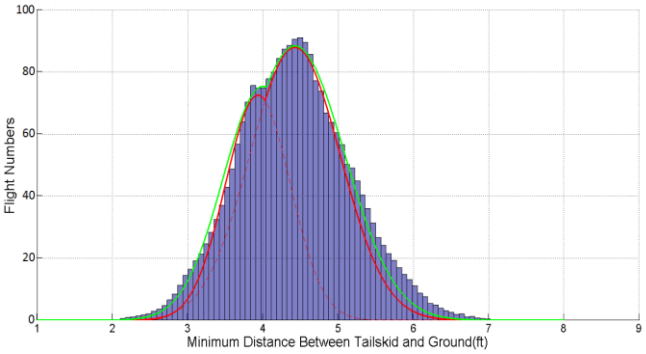

Fig. 5. Distribution of the minimum distance between tailskid and ground

After comparison of various parameters, the reason for the above phenomenon is found to be caused by the airline's A320 are equipped with three different types of engines: LEAP-1A, CFM56 series and V2500-A5/D5. The new generation LEAP-1A engine put into use since June, 2018, which was power the A320neo. And it’s fan diameter is significantly larger than the other two series which also brings heavier weight and more air drag [9]. Besides, the center of gravity and the thrust of the engine also changes subsequently which will influence the aircraft flight performance during takeoff phase and also the risk probability of tail strike event.

It can be seen from Fig. 6 that the data of the first peak is mainly contributed by the flight equipped with the LEAP engine, while the other two series of engines have little difference, the standard deviation of CFM is slightly smaller, thus the data are more concentrated.

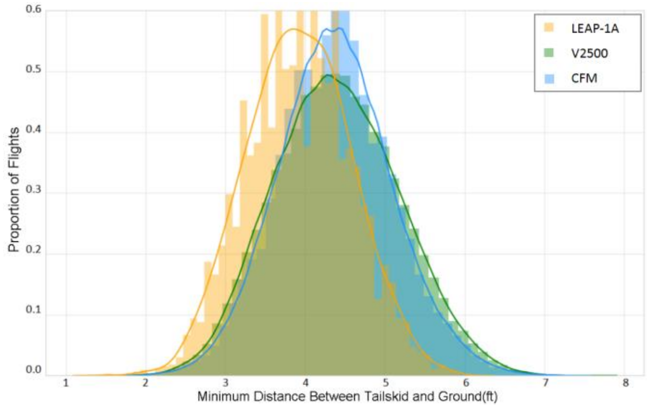

Fig. 6. Influence of the engine types on data sample

A. Normality test

From the data distribution chart of view, the minimum distances between the tailskid of the A320 and the ground during takeoff from different engine types are generally subjected to normal distribution. In order to avoid the later forecasting errors, normality test is applied. The commonly used testing methods include graphical method of subjective judgment and calculation examine of objective quantification [10].

Firstly, we try to examine the normality of the three groups of sample data through the Q-Q plot. The Q-Q plot is a graphic method to help assess if the sample data plausibly came from normal or exponential distribution. Here, we create a scatterplot by plotting two different quantiles against one another. If both quantiles came from the same distribution, we should see that the points roughly forming a straight line [11]. Based on Fig. 7 to Fig. 9, it can be seen that three groups of scatter plots have a high degree of coincidence with the straight line, and only a small number of scattered points at both ends deviate, so it can be preliminarily determined that all three sample data subjected to normal distribution. This method can perform a quick visual inspection of the data, but using the statistical graph to determine the normality has somewhat subjectivity.

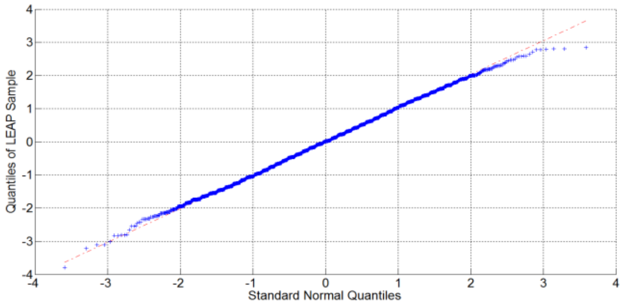

Fig. 7. Q-Q plot of the LEAP data sample

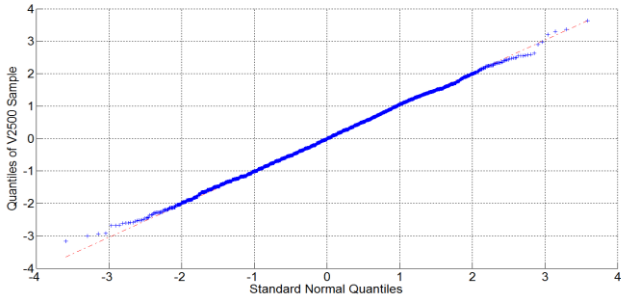

Fig. 8. Q-Q plot of the V2500 data sample

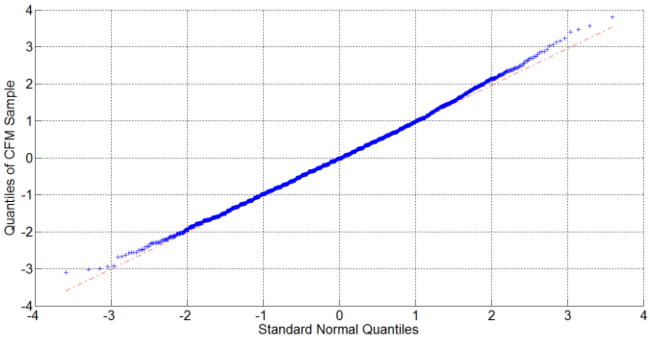

Fig. 9. Q-Q plot of the CFM data sample

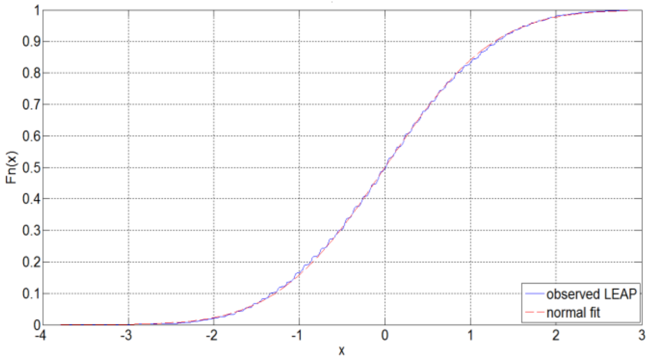

Fig. 10. Empirical CDF plot of the LEAP data sample

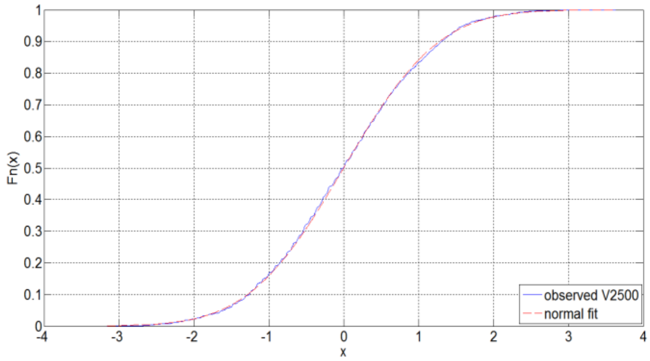

Fig. 11. Empirical CDF plot of the V2500 data sample

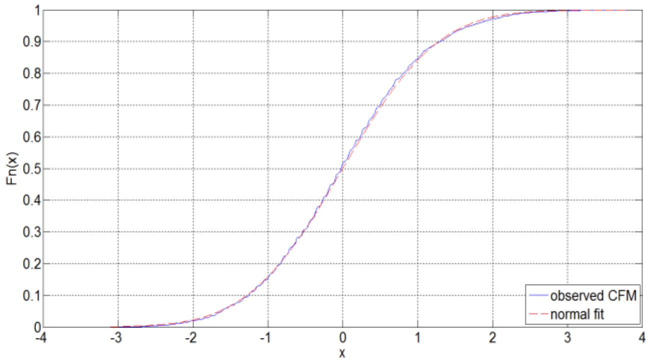

Fig. 12. Empirical CDF plot of the CFM data sample

In order to make the statistical test of normality more convinced, the Kolmogorov-Smirnov (K-S) test is used. This is a method based on the empirical distribution function to test whether two empirical distributions are different or whether one empirical distribution is different from another ideal distribution[12]. And better to be used under large sample conditions [13]. We determine a null hypothesis H_0: that the two samples to be tested come from the same distribution. If the likelihood of the samples coming from different distributions exceeds the confidence level, then we reject H_0 and accept the alternative hypothesis H_1: the two samples are from different distributions. The general steps to run the K-S test are as follows:

1) Calculating the theoretical distribution function $F_0(x)$ of the sample data and the cumulative distribution function $F_n(x)$;

2) Graph the two distributions together and measure the greatest vertical distance between the two graphs:

$$D_n = \max_{1\le i\le n}\left\{\left|F_n(x_i)-F_0(x_i)\right|,\left|F_n(x_{i-1})-F_0(x_i)\right|\right\} \quad (2)$$

TABLE I. K-S TEST RESULTS OF THE DIFFERENT SAMPLES

Sample Name	***Sample Size***	***Mean Value(ft)***	***Standard Deviation***	***P Value***
A320 LEAP engine series	3000	3.9449	0.6485	0.4639
A320 V2500 engine series	3000	4.4409	0.7975	0.3128
A320 CFM engine series	3000	4.4116	0.7239	0.2936

TABLE II. RISK PROBABILITY CALCULATION RESULTS OF THE A320 TAIL STRIKE EVENT

Sample Name	***Minimum Value(ft)***	***Maximum Value(ft)***	***95% Confidence Interval(ft)***	***Risk Probability***
A320 LEAP engine series	1.4864	5.7844	(3.9201,3.9404)	3.5261e-10
A320 V2500 engine series	1.9228	7.3425	(4.4317,4.4384)	7.9916e-09
A320 CFM engine series	2.1652	7.1634	(4.4228,4.4275)	7.5226e-10

3) Determine the value of confidence level, if the P value of the sample is greater than the confidence level then the null hypothesis is rejected which means the data subjected to normal distribution.

We conduct the K-S test with the help of MATLAB and the graphs below are plots of the empirical distribution function with a normal cumulative distribution function. The K-S test is based on the maximum distance between these two curves. As expected, the P values(listed in TABLE I) of the samples are all greater than the significance level(0.2), so the null hypothesis is accepted. And it can be concluded that the they all follow normal distribution.

B. Risk Prediction of Tail Strike

After confirming that the samples all follow normal distribution, we can calculate the tail strike risk based on the characteristics of the normal distribution, i.e. the mean value and the standard variance:

$$P(a+b\le 0)=\frac{1}{\sqrt{2\pi}\sigma}\int_{-\infty}^{0} e^{-\frac{-(x-\mu)^2}{2\sigma^2}}\,dx \quad (3)$$

According to TABLE II, it is found that the probability of the tail strike event of this airline's A320 fleet is very low, and the risk of which equipped with the V2500 engine is slightly higher than that of the other two engine series. It indicates that the A320 pilots have a good sense of tail strike during takeoff phase, and can perform well according to the SOP(Standard Operating Procedure), which could effectively preventing or reducing the occurrence of tail strike events.

IV. CONCLUSIONS

In summary, we use the QAR big data and mathematical statistics method to predict the risk of the A320 occurrence of the tail strike event on the basis of sufficient effective real samples. The results show that the airline’s A320 fleet has almost no possibility of tail strike. Therefore, this airlines may does not need to do any additional work for this event. However, Considering the significant damage and expensive maintenance costs may brought by tail strike to the operators, we still need to pay enough attention to it. It can be better prevented by improving the crew’s awareness of tail strike and including the tail strike prevention into standard training procedures.

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