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Analysis of Factors Affecting Landing Performance of Civil Aircraft

Chen Shouke[1,a], Liu Qiaoyao[1,b], Zhang Jinbao[1,c], Hua Longfei[1,d]

[1]CAST Zhongyu (Beijing) New Technology Development Co. Ltd, Beijing, China
[a]chensk@zy-cast.com, [b]liuqiaoy@zy-cast.com, [c]zhangjb@zy-cast.com, [d]hualf@zy-cast.com

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Abstract: The landing stage is the stage with the highest accident rate in the flight process. China's current landing standards prohibit the use of autopilot in the landing stage, so the research on the factors affecting landing safety is particularly key. Taking the real landing data of a certain aircraft as an example, this paper discusses the aircraft landing distance under different landing conditions under the condition of meeting the requirements of laws and regulations, so as to judge the impact of relevant influencing factors on land performance, analyze its deep causes, and provide relevant personnel with some reference and help.

1. Introduction

In recent years, the rapid development of China's economic level has promoted the development process of civil aviation. The safety problems existing in various works of civil aviation cause widespread concern. According to the investigation of previous civil aviation accidents, the accident rate is the highest within 8 minutes after taking off and 5 minutes before landing. Therefore, during the take-off and landing stage of civil aircraft, relevant employees are required to invest more efforts to avoid potential safety hazards.

Factors affecting the safe landing of passenger aircraft, such as downwind and crosswind landing; Heavy landing; High speed approach; Wind shear, etc. For the above factors threatening aviation flight safety, in order to effectively ensure the safe operation of civil aircraft, we should analyze them from theory and practice, and take scientific and reasonable measures to solve the corresponding problems, so as to lay a good foundation for the healthy and stable development of civil aviation.

2. Landing performance analysis

2.1. Landing distance

The key criterion of landing performance is the calculation of landing distance. Landing distance is divided into approved landing distance, actual landing distance, required landing distance and available landing distance. According to Article 125 of CCAR-25[1], the approved landing distance refers to manual pilot landing, manual maximum braking, corrected airspeed (minimum control speed during full engine working landing and approach), 50 foot high approach runway, horizontal dry runway The demonstrated landing distance from the runway threshold to full stop calculated by the standard atmospheric temperature does not include any safety margin, nor does it use automatic braking, automatic landing system, head up guidance system or backstepping. In the actual situation, reference shall be made to the standard landing procedure. The actual situation shall be that the landing distance given in the flight manual of each aircraft type is obtained by adding 67% safety margin, of which 67% safety margin is used to correct the influence of runway slope and approach glide angle deviation under non-standard atmospheric conditions[2]. The result obtained is the required landing distance, that is, the required landing distance is equal to 1.67 times of the approved landing distance. The actual landing distance is the landing distance corresponding to some actual conditions (such as weather conditions in the meteorological report, conditions of airport runway, elevation, slope, aircraft configuration, approach speed, combined with some auxiliary equipment - automatic landing system or HUD system), and the deceleration equipment expected to be used during landing, It represents the best performance of the aircraft under this condition; The available landing distance is the runway length announced by the landing airport.

2.2. Calculation of approved landing distance

According to China's regulations, the use of autopilot is prohibited in the landing phase of civil aircraft. Therefore, the deviation of environmental factors such as airport conditions, field pressure height, airport temperature, runway slope and pavement conditions and pilot technology will lead to different landing distances[3]. The deviation on the leads to the inconsistency of the landing distance. The landing distance of the required distance required for release refers to the total distance (S_L) of the aircraft after entering the runway through the flattening landing section (S_A), transition section (S_T) and deceleration taxiing section (S_B):

$$S_L = S_A + S_T + S_B \tag{1}$$

Calculation formula of leveling section:

$$S_A = \int_{V_T}^{V_W} \frac{(V - V_W)}{a} dV \tag{2}$$

$$t_A = \int_{V_T}^{V_W} \frac{dV}{a} \tag{3}$$

Where, V_W is the upwind wind speed. The grounding speed and time can be determined by flight test:

$$S_A = (V + V_T - 0.15V_W) \times t_A \tag{4}$$

Under normal conditions, the time of leveling section is about 5s, and the length of leveling section is about 300-450m. The efficiency of large deceleration only relying on aerodynamic resistance is very low. Generally, more than 120m runway distance is required for each deceleration of 1m/s. Therefore, the leveling section should be controlled within a certain range to avoid waste of runway distance caused by too long leveling section.

The transition section refers to the running distance from the aircraft grounding to the full start of the braking system.

The deceleration and taxiing stage are the key stage to determine the landing performance, which can be expressed as

$$S_T = \frac{1}{g}\int_{V_T}^{V_B} dV \tag{5}$$

In combination with the flight test, the transition section distance formula is:

$$S_T = (V_T + V_B - 0.15V_W) \times t_T \tag{6}$$

The time required for the transition section under the condition of using manual braking is about 2s, and 0.15s if using automatic braking.

The deceleration and taxiing section are the key stage to determine the landing performance, the influence of spoiler opening on lift coefficient and drag coefficient should be considered[3]. At this stage, the landing gear is lowered, the flap is lowered, the brake works, the spoiler is opened, and the reverse thrust is not opened. The calculation formula is as follows:

$$S_T = \frac{1}{g}\int_{V_B}^{V_W} dV \tag{7}$$

$$a_B = [(F_N - \mu W) - (C - \Delta C)S_W - W\cos\theta]\frac{g}{W} \tag{8}$$

In this formula, a_B is the deceleration rate; F_N is engine thrust; W is the landing weight; Lift and drag coefficients (C, ΔC) are flight test results with ground effects included; μ is the brake friction coefficient; θ is runway slope; S_W is the wing area. Deceleration rate a is the decisive factor, which mainly depends on the strength and sooner or later of the braking system[4].

3. Factors affecting landing performance

3.1. Inlet speed and inlet height

In actual flight, a common tendency is to approach at high altitude and high speed, which will cause a significant increase in landing distance. Generally speaking, the landing distance will increase by 60m for every 3m increase in the entrance height. The impact of entrance speed on the distance depends on the model and deceleration mode: for B737-300 aircraft, if it decelerates in the air in the leveling section, the landing distance will increase by more than 120m for every 1 m increase in V_{THR}. If it decelerates in the ground taxiing section, the landing distance will be extended by 18 ~ 30m.

According to the standard landing procedure, taking Boeing 737-300 as an example, the entrance height is represented by HTHR and the entrance speed is represented by VTHR. with different combinations of entrance height and entrance speed, the corresponding landing distance is calculated when using the two braking methods of maximum braking force (brake + reducer + reverse thrust) and automatic brake "3", and the combination is as follows:

1)V_{THR} and H_{THR};

2) V_{THR} and H_{THR}+3m;

3) V_{THR}+5fi and H_{THR};

4) V_{THR}+5fi and H_{THR}+3m;

For the far landing site length (i.e. the minimum landing runway length) that should be calculated as an example, the data in band 3 in Table 1 indicates that the landing distance under this condition exceeds the far landing site length, that is, the aircraft is in danger of rushing out of the runway.

Table 1: Calculation results of landing distance of Boeing 737-300 aircraft

Braking mode	**S_{L1}**	**S_{L2}**	**S_{L3}**	**S_{L4}**
brake + reducer + reverse thrust	1032	1392	1152	1632^3
Automatic brake "3"	1410	1490	1560^3	2010^3

As can be seen from the example:

(1) The increase of entrance speed and entrance height will significantly increase the landing distance, especially the impact of entrance speed. Therefore, civil aircraft should strictly limit the approach of high altitude and high speed. In view of this, it is generally stipulated in the approach and landing procedure of civil aviation transport aircraft that when approaching near the decision altitude, the pilot must check the altitude and speed. If the glide path (GP) indication deviation exceeds 1 point or the approach speed deviation exceeds 5m, the approach must be terminated and go around.

(2) Similarly, when the entrance speed is increased, the landing distance corresponding to different deceleration modes varies greatly. Therefore, in order to avoid excessive increase of landing distance, even if the entrance speed is too large, efforts should be made to control the aircraft to be grounded within the normal grounding range to avoid flying.

In addition, the harm of excessive entrance speed lies in: first, high-speed approach is likely to lead to heavy landing, in order to avoid heavy landing; Pilots often need to carry rods excessively, which leads to drift deceleration, resulting in aircraft grounding and delayed start of braking system; Second, when the grounding speed is too high, the large lifting force of the wing is not conducive to the compression of the landing gear damping strut, which will delay the timely start of the braking system. When a Lufthansa A320 aircraft landed at Warsaw airport in 1993, the grounding speed reached 315 km (the normal grounding speed should be 222~240km). The excessive grounding speed caused the normal load borne by the landing gear damping strut to be too small to connect the air ground safety door, resulting in the delay of 9 s in the start of the braking system and the aircraft rushed out of the runway; Third, excessive grounding speed may lead to dynamic sliding[4]. According to the research of NASA and FAA, if the pavement is not grooved, water skiing will occur when the accumulated water exceeds 215mm, The critical speed Vi of water skiing during landing can be estimated by the following formula:

$$v_i = 0.10464P \tag{9}$$

Where, P (N) is the inflation pressure of the wheel. Water skiing may be caused when the grounding speed exceeds the critical speed of water skiing. In actual flight, the main reason for high altitude and high speed approach is that some pilots set the approach speed too high for the sake of approach and go around safety. This is tantamount to transferring the risk of entering the runway threshold during landing to the risk of rushing out of the runway due to too long landing distance, rather than transferring the risk from one end of the runway to the other, It is better to set the entrance altitude and speed with reference to the characteristics of the piloted aircraft under the provisions of the standard landing procedure.

In addition, the crew should not ignore the monitoring of flight instruments, especially the throttle speed. Another main reason for excessive approach speed is the improper application of automatic throttle by pilots in bad weather, especially in the case of automatic throttle approach. Some pilots overestimate the ability of automatic throttle to maintain speed stability and rely too much on automatic throttle, so they lack necessary understanding of speed instability during approach in heavy rain[5].

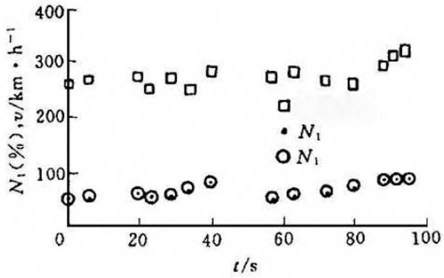

Figure 1: Effect of throttle on approach speed stability

Figure 1 shows the relationship curve between aircraft hourly speed and throttle. From the relationship between automatic throttle deceleration time and aircraft hourly speed distributed in the curve, it can be seen that under the influence of strong turbulence air flow, the response of automatic throttle to the change of approach speed lags seriously, which has basically lost the ability to maintain the stability of approach speed, and even exacerbated the fluctuation of approach speed to a certain extent, Due to the influence of automatic throttle, the approach speed deviates from the set value (263km) up to 59km. Therefore, even when using automatic throttle approach, the pilot should closely monitor the flight instruments.

3.2. Control of landing grounding point

In any case, the correct landing technical essentials should be: control the aircraft to make solid grounding within 300-450m from the runway entrance, which will ensure the maximum effectiveness of the braking system. However, in the actual flight, many passengers are used to excessive pole carrying in order to control the sinking rate due to the habit of flat landing on small aircraft, or in pursuit of light grounding, so as to prolong the leveling section and significantly increase the landing distance. In fact, this is another key reason for the vast majority of runway accidents. From the above analysis, it can be seen that even under the condition of ponding pavement, the deceleration effect of the braking system during ground taxiing is five times higher than that in the air of leveling section[7]. Taking B737-300 aircraft as an example, every 1m of deceleration during ground taxiing, runway 24-30m is required, while 120m runway is required for floating grounding. Therefore, the flat floating grounding of large transport aircraft is not conducive to give full play to the efficiency of braking system. In addition, the harm of light grounding lies in: on the one hand, it is easy to cause water skiing, resulting in brake failure and out of control in the direction of taxiing; on the other hand, it will delay the start of the braking system, especially affect the timely release of the deceleration brake, because light grounding is not conducive to the timely rotation of the wheel and the full compression of the damping strut of the main landing gear, so as to connect the open space safety switch, These two points are the prerequisites for starting the braking system. In view of this, Boeing suggests that pilots should control the aircraft to be solidly grounded in the normal grounding area as much as possible even when the approach speed is too high and the altitude is too high.

3.3. Use of brakes

Improper use of brakes is also a major cause of the increase in landing distance. A common mistake is that the brake gear setting is too low when using automatic braking on short runway and ponding pavement, so it fails to give full play to the role of braking[6]. For example, B737-300 aircraft should use automatic braking gear above "3" when using automatic braking on ponding pavement. At this time, the maximum deceleration rate can reach "only runway 24 ~ 30m per deceleration 1m", When using the "1" gear of automatic brake, the deceleration effect will be doubled;

Another common mistake is the improper use of manual braking. Especially on the ponding pavement, some pilots are used to using the braking method of small aircraft, namely "pump the brakes", and repeatedly move the brake pedal to prevent wheel slip. In fact, this will not only prevent wheel slip, but also lead to almost no effect of braking at all. As the advanced anti-skid system has been widely used in modern transport aircraft, the wheel can be maintained at the best slip rate of about 10% under any pavement conditions, which can not only avoid wheel slip, but also obtain the best braking effect[8]. However, one of the prerequisites for the normal operation of the system is the stability of the brake pressure, because whenever the pilot moves the brake pedal, the brake anti-skid system needs to release the brake pressure applied to the wheel to accelerate the rotation of the wheel, and then increase the brake pressure according to the speed, that is, it needs to go through a process of re-establishing the brake pressure, In this process, the braking efficiency is very low. The correct braking method should be: step on the brake with both feet.

4. Conclusion

It can be seen from the above that the key factors affecting the landing of civil aircraft are the entrance height, entrance speed, the control of grounding position and the pilot's use of brakes. China's laws and regulations prohibit the use of autopilot in the landing stage of civil aircraft. Therefore, the current problems affecting the landing safety of civil aircraft are caused by human factors in addition to objective reasons such as weather and aircraft type. The operation habits and training fineness of aircraft pilots jointly affect the pilots' judgment of aircraft landing quality. Civil aviation practitioners should understand the relevant flight principles, take scientific and reasonable measures for corresponding problems according to the actual situation, eliminate interference sources through research, calculation and actual situation analysis, and treat every link of the work meticulously. Relevant management units should assess the training effect of participants. Maintaining aviation safety requires the joint efforts of staff in all posts.

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