Analysis of Influencing Factors of Flight Technical Error in PBN Operation

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Abstract: The total system error (TSE) reflects that the lateral track deviation of performance-based navigation (PBN) is mainly flight technical error (FTE). In order to ensure the operation safety of PBN, this paper first introduces the control and constraint of flight technical error (FTE), and then analyzes the influencing factors and characteristics of flight technical error from three aspects of human factors, atmospheric environment and aircraft performance. Human factors are caused by pilots' subjective factors, mainly including pilots' attention distribution, flight technology, flight strategy, etc., which are important components to control flight technical errors. In PBN operation, real-time monitoring of flight technical error should be carried out to reduce the influence of human factors on flight technical error, so as to ensure the track tracking and maintenance ability in flight.

Keywords: PBN; Flight technical error; Human factors; Atmospheric environment

1. Introduction

Performance based navigation (PBN) operation is a kind of operation mode that replaces equipment requirements by specifying performance requirements, which marks the transition from sensor based navigation to performance-based navigation.PBN operation includes RNAV (Area Navigation, RNAV) and RNP (Required Navigation Performance, RNP) two types of navigation specifications. RNP is a navigation and operation concept built on RNAV, which is an additional onboard performance monitoring and warning (Onboard Performance Monitoring and Alerting (OPMA) function requires area navigation operation [1].Therefore, under the PBN operation framework, RNP operation does not need ground monitoring, but the airborne system must have OPMA function. The function of OPMA is mainly used to describe the lateral navigation performance of aircraft with total system error (TSE). Flight technical error (FTE) is the main error, including FTE in manual mode and FTE in AFCS control mode. FTE can be understood as the concept of traditional yaw distance, which will be displayed in real time by the main flight display (PFD) of the aircraft. During RNP operation, flight technical error should be monitored and intervened in time to ensure the aircraft to fly accurately along the scheduled route.

2. FTE Control

The aircraft's lateral position error is related to the aircraft's ability to maintain track and navigation and positioning errors. It is expressed in total system error (TSE). TSE includes path definition error (PDE), FTE and navigation system error (Navigation) System Error, NSE) Three aspects of NSE error [2], as shown in Figure 1:

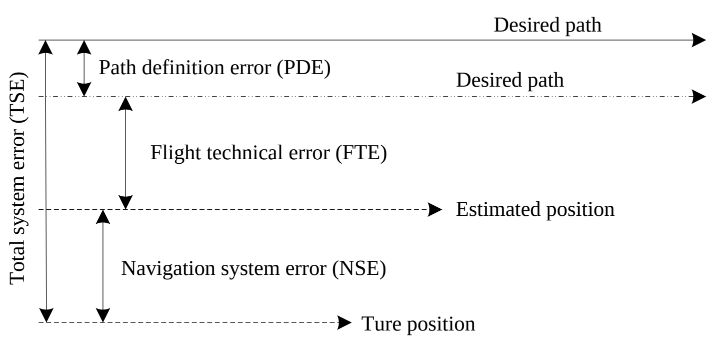

Figure 1. Lateral navigation errors

The statistical analysis results show that PDE, FTE and NSE are independent and zero mean Gaussian distribution.

$$TSE = \sqrt{FTE^2 + NSE^2 + PDE^2} \quad (1)$$

TSE is not just the vector sum of PDE, FTE and NSE, but also the basis for the design and protection of flight procedures. Once the width of the route lateral protection zone, TSE must be controlled within the width of the protection zone. However, since the monitoring elements of airborne performance monitoring and warning are related to FTE and NSE, the integrity of the PDE and the navigation database and the function requirements of defining the track are mutually constrained, so they can be ignored.

FTE indicates the ability of the aircraft to track the horizontal track, which is related to the control method of the aircraft. In general, the FTE of manual control is larger than that of coupled autopilot (A/P), and the FTE will be reduced after manual control of coupled flight director (F/D). When the PBN is running, it is required that with 95% probability, TSE is not allowed to exceed the RNP value, and FTE is not allowed to exceed RNP is worth half. The following table lists the typical FTE values of Boeing in different flight stages and different flight modes [3], as shown in Table 1:

Table 1. FTE of different flight modes is adopted at different flight stages

Flight Phase	Manual (NM)	Coupling	
		F/D(NM)	A/P(NM)
Ocean	2.0	0.5	0.25
Enroute	1.0	0.5	0.25
Terminal	1.0	0.5	0.25
Approach	0.5	0.25	0.125

FTE does not include errors caused by operational errors or major track deviations caused by equipment failures, such as instrument display errors, which are not included in flight technical errors. Due to the random error of FTE, aircraft manufacturers firstly conduct statistical evaluation on the FTE value of flight test, and compare the evaluation value with the existing navigation specification requirements as one of the criteria to judge whether the aircraft has the corresponding RNP navigation capability.In actual operation, different RNP navigation specifications have clear quantitative requirements for FTE [4], see Table 2:

Table2. Accuracy requirements(95%) of FTE in different navigation specifications

Navigation specification		FTE lateral accuracy requirements(NM)
RNAV5		2.5
RNAV2		1
RNAV1		0.5
RNP4		2
RNP2		1
RNP1		0.5
RNP APCH	Initial and Intermediate approach segment	0.5
	Final approach segment	0.2
	Missed approach segment	0.5

OPMA enables the flight crew to check whether the RNP system meets the navigation performance required by the navigation specifications by monitoring the FTE and other errors related to the control. If the aircraft's navigation system performance is insufficient or the track tracking ability is insufficient, it will be sent to the flight crew in time Alarm information.

FTE includes display error (such as CDI / HSI centering error of yaw indicator), which is related to the flight crew or autopilot's ability to operate along the defined track. Flight technical error can be monitored by autopilot or flight crew program, which, to a large extent, requires the assistance of other means, depending on factors such as flight stage and operation type, which can be provided by map display.

3. Analysis of FTE Influencing Factors

The factors affecting flight technical error mainly include pilot, atmospheric environment and airborne equipment, and the three factors are coupled with each other, which may affect flight technical error at the same time [5-6].

3.1. Pilot human factor

Pilot attention allocation strategy. In different flight phases, the pilot's attention distribution strategy is different. Especially in the visual phase of descent and landing, the majority of the crew's attention is focused on the course and altitude control, and the alignment of the runway, but the pilot's attention needs to be Frequently switch between the display of the cockpit instruments and the surrounding environment of the airport. Therefore, in the actual flight, the crew should carry out reasonable crew resource management according to the flight procedures and standard operating procedures (SOP), so as to avoid visual fixation, resulting in loss of control of the aircraft state and yaw [7].

Pilot driving skills. In manual flight control, the pilot is the main body that controls and operates the aircraft. Its performance will affect whether the aircraft can fly along the predetermined route. Therefore, the pilot's driving skill level is one of the main influencing factors of flight technical errors. Pilot's driving skills are usually measured by flight hours, which are embodied in the degree of operation proficiency and the number of misoperations, the idle time to deal with emergencies, and the configuration of cockpit instrument scanning. For example, the number of fixation points when the pilot scans the cockpit instruments can reflect the fixation allocation of pilots in different flight stages or in different flight tasks, and can show the pilot's driving skills.

Pilot flight strategy. Flight strategy refers to the control strategy of pilots when they fly the aircraft in maneuvering flight. Unlike flight technology, flight strategy has no clear evaluation index. Especially in manual flight, the influence of pilot's flight strategy on flight technical error is particularly obvious in maneuvering flight. For example, if the aircraft flying along the route deviates from the scheduled route, the pilot wants to control the aircraft to cut into the scheduled route at a certain angle, and then turn in advance before cutting into the scheduled route, otherwise the aircraft will lean to the other side again. At this time, different pilots use different advances when flying, and their flight trajectories are different. If there is more advance, they should press a small slope and a large turning radius when flying. In addition to the above-mentioned turning maneuvers, it also includes visual circling flight, final alignment at the runway, initial go-around, etc. Compared with driving technology, the influence of different flight strategies on flight technical errors is more important [8].

3.2. Atmospheric environment

When PBN is in operation, it has the highest requirements on performance indexes of accuracy and integrity. Atmospheric turbulence, wake, wind shear and other factors will affect the flight technical errors of each flight segment, which may cause PBN to fail to meet the requirements of relevant performance indexes during operation [9] .

Atmospheric turbulence acts on ailerons, rudders and elevators of aircraft randomly, which hinders the aircraft from accurately tracking the target flight height, flight speed and target path, resulting in lateral, altitude and speed related flight technical errors. In manual control mode or automatic flight control mode, atmospheric turbulence will lead to flight technical error.

Wake is a pair of counter-rotating cyclones rolled up at the wing tip due to the pressure difference between the upper and lower surfaces of the wing, which will cause the following aircraft to change drastically in a very short period of time, resulting in flight technical errors. .

Wind shear refers to the change of wind direction and wind speed in the horizontal or vertical distance in the air. If the aircraft encounters low altitude wind shear in the landing approach or take-off climbing stage, the flight attitude may be uncontrollable. Due to the low altitude and short reaction time of pilots, the aircraft track deviation or off-site grounding will be caused, which will have serious consequences.

3.3. Aircraft performance

Aircraft airborne equipment, flight control system, aerodynamic performance, etc. will affect lateral track control, altitude control and speed control, and directly affect the size of flight technical errors [10]. For example, on-board equipment aircraft head-up display (HUD), HUD can project flight information such as trajectory, altitude, speed and attitude onto the transparent display component directly in front of the pilot, and display the displayed flight trajectory symbol with the cockpit exterior target Together, they can effectively provide the aircraft's operational capabilities. The pilot can see the main information on the dashboard of the cockpit and relevant flight guidance information through the transparent display screen in front of the pilot. At the same time, combined with the automatic landing system and airborne electronic system, it can reduce the minimum weather standards for landing and takeoff, accurately predict the landing point, reduce the occurrence of heavy landing and tail rubbing events, help to implement stable approach and enhance the awareness of flight scenarios, So as to reduce the flight technical error.

4. Conclusions

The main purpose of PBN operation is to strictly control and give full play to the aircraft's navigation performance, meet the operational requirements of each flight stage under different navigation specifications, and improve flight operation safety and efficiency. If the navigation database manufacturer is provided with high-quality waypoint coordinates, PDE can be ignored, and the preferred navigation source for PBN operation is GNSS, and the NSE is also very small during actual operation. Therefore, the TSE representing the deviation of the aircraft side track mainly includes FTE. There are many factors that affect FTE, such as improving the cognitive structure of flight cadets, cultivating good attention quality, improving situational awareness, learning mature pilots' driving skills and flight strategies, paying attention to the level of attention distribution in ground or simulator training, the impact of human factors on FTE will be greatly reduced.

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