INVESTIGATION OF NAVIGATOR'S ACTIVITY ALGORITHMS AS AN INSTRUMENT FOR TEST FLIGHTS NUMBER REDUCING AT THE ESTIMATION OF RELIABILITY OF NAVIGATION

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At sufficient accuracy of modelling, flight simulators allow investigating algorithms of activity of skilled navigator. Knowledge of these algorithms gives a chance to reduce number of the test flights necessary to estimate the reliability of navigation. The aprioristic estimation of navigational complex (NC) conformity to the minimum navigation requirements of the ICAO is usually made by means of analytical methods with use of experimental data. These methods can be effective only at presence of qualitative models of NC functioning, including the navigator, i.e. NC models as ergatic systems of air navigation. Basing on inclusion of the pattern of navigator into flight management system, modelled in flight simulator, the basic algorithms of navigator activity are investigated. It is shown, that the simulator should be such that lacks of navigator could not be «compensated» by lacks of NC modelling. It means that the mandatory condition for replacing a part of the real test flights by simulated flights is modelled of possible refusals and failures in work of radio correction means, and also correct reproduction of workings coverage of radio aids used for correction.

Keywords: *navigation complex, flight simulator, minimum navigation requirements, reliability of navigation, correction*

Flight simulators at sufficient accuracy of flight modelling allow investigating algorithms of activity of skilled navigator. Knowledge of these algorithms enables to reduce number of test flights for estimation of reliability of navigation [1]. To confirm it we shall examine the scheme of inclusion of navigator in an air simulator modelled flight management system (FMS) (Fig. 1).

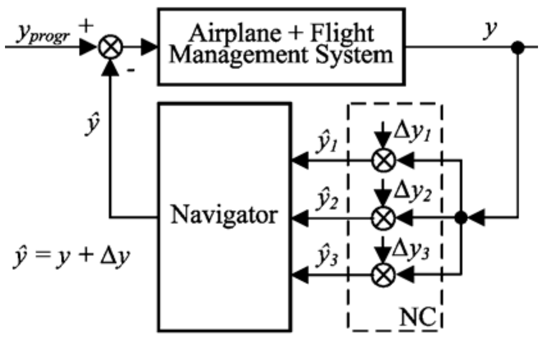

Figure 1. *Scheme of actuation of the navigator in trajectory control system*

Navigator, observing indications $\hat{y}_1, \hat{y}_2, \ldots, \hat{y}_N$ of navigation systems included in navigation complex (NC), produces an estimation $\hat{y}$ of the navigation parameter y.

If $\hat{y}_1, \hat{y}_2, \hat{y}_3$ are cross track deviations from the route axis calculated under indications of various systems of NC, then $\hat{y}$ is an estimation of cross track deviation according to these systems, made by the navigator and entered by him in flight management system.

Notation Δy_i on a Fig. 1 (the case of three navigation systems is examined: i = 1, 2, 3) is used for errors of estimations of cross track deviation, obtained by means of NC, but Δy − an error of estimation by the navigator of real airplane evasion on y_1, y_2, y_3 signals.

Let the probability of that cross track error of an airplane from the axis of route exceeds prescribed value y_0, is equal $P_{OUT} = P(|\Delta y| > \Delta y_0)$, but the probability of that cross track error, calculated from data of the i^{th} system of navigation complex, exceeds Δy_0 value, is equal $P_{INi} = P_i(|\Delta y| > \Delta y_0)$. The skilled navigator acts in such a manner that $P_{OUT} < P_{INi}$.

On the majority of airways maximum permissible value P_{OUT} is 0,05, i.e. is required, that airplanes with probability 0,95 did not evade from the axis of a route on distance, greater, than Δy_0, which depends on that, is provided (or not) the constant radar monitoring over flight of an airplane. At flights on parallel tracks over the North Atlantic all turbojet airplanes should meet the minimum navigation requirements (MNR) [2], [3] of the International Civil Aviation Organization (ICAO). According to modern MNR the maximum permissible value of the standard deviation from the axis of a route should be no more value σ_{MNR} = 5,8 km (first criterion of MNR). Maximum permissible value of probability of flight outside ±27,7 km from axes of tracks of North Atlantic should be no more value $P_{MNR} = 2{,}6 \cdot 10^{-4}$ (second criterion of MNR). In practice of air navigation monitoring of frequency of greater navigational errors is conducted with application of a method of sequential analysis [4].

At designing of new NC the compressed terms of tests do not allow certifying NC on probabilistic criteria because of trifle of P_{MNR} values (it must be confirmed that actual values of the estimated probabilities at confidence probability 0,95 will not exceed the values *of* P_{MNR} twice [4], therefore at aprioristic estimation of conformity of navigation complexes to the minimum navigation requirements are applied analytical methods with the use of experimental data [5]). Analytical methods can be effective only at presence of qualitative models of NC functioning, including the navigator, i.e. NC models as air navigation ergatic systems [1], [4]. Earlier it was noted that skilled navigator acts in such a manner that $P_{OUT} < P_{INi}$. It means, that the probability of big "output" errors of navigator Δy is less then the probability of greater "input" errors Δy_i (Fig. 1).

It is clear, that sufficiently accurate estimation of P_{OUT} value with high (0,95) confidence probability at P_{OUT} values about 10^{-4} requires too big number of test flights. At the same time, the P_{INi} probability, being greater (often on two orders), demands smaller number of expensive test flights. However, knowledge of P_{INi} values does not allow predicting the P_{OUT} value without knowledge of algorithm of navigator activity.

In [6], [7], it becomes firmly established that an experienced navigator at measuring of one navigation parameter by three systems widely uses algorithm of a secondary median. In this case

$$P_{OUT} = \frac{1}{2}(P_{IN1}P_{IN2} + P_{IN2}P_{IN3} + P_{IN1}P_{IN3} - P_{IN1}P_{IN2}P_{IN3}) \qquad (1)$$

If all three systems are identical, for example, triplex inertial navigation system (INS), then $P_{IN1} = P_{IN2} = P_{IN3}$, and as these probabilities considerably less than 1, we can consider that approximately

$$P_{OUT} = 1{,}5 P_{IN1}^2 . \qquad (2)$$

At P_{IN1} = 0,01 from (2) we have $P_{OUT} = 1{,}5 \cdot 10^{-4}$. It is obvious, that estimation of value of the order 0,01 will demand considerably smaller number of test flights, that value of size of $P_{OUT} = 1{,}5 \cdot 10^{-4}$.

Another way of activity of the navigator, providing small value of P_{OUT} also is possible. It is INS or on the base of compass system and Doppler radar built dead reckoning system (DRS) correction according to data of the radio navigation systems.

Let's consider the case of radio correction of the DRS system. It will allow analysing some features of the statistical situation, related to the radio correction and on the basis of this analysis to formulate one of important principles of construction of imitators.

As it is known, navigational training of the operator intends mastering of methods of both recognition of constant components of instrumental errors during the flight, and of inputting of corresponding correction in navigation systems. In the case of the DRS navigator should be able to reveal a constant component of directional gyroscope drift and compensate its influence by inputting of necessary amendment via latitudinal correction desk of compass system.

Suppose that uncompensated component of care rate on great number of flights is random value, having the two-sided exponential distribution with zero average of distribution and mean square value, equal to σ_ω. Then at correction of cross track error through intervals of time, not greater than T, probability of flight outside $\pm\Delta y_0$ from an axis of route will not exceed

$$P_{вых} = e^{-\frac{\sqrt{2}\Delta y_0}{\sigma_y}} , \qquad (3)$$

$$\sigma_y = \sigma_\omega W \frac{T^2}{2} , \qquad (4)$$

where W – cruising speed, σ_y – mean square value of cross track error.

At σ_ω = 0,4 °/h; W = 900 km/h; T = 1 h we shall receive: σ_y = 3,15 km; P_{OUT} = 6,210^{-7}, i.e. airplane overrun of ±27,7 km from the route base line at such frequent correction of cross track error is practically impossible.

The received result is trivial enough: absolute reliability of the radio correction, allowed to conduct corrections of cross track error with an interval of time less than T, has "compensated" insufficient qualification of the navigator. Now we shall change conditions concerning capabilities of cross error correction. Let now assume that T is a mean interval of correction, i.e. are possible both smaller and larger intervals of correction, the last – due to possible failures of correction at an unfavourable navigation situation or because of refusals of corrector.

Now let's suppose that the random interval of correction is the Rayleigh random value with the mean of distribution, equal to T. We shall get:

$$P_{OUT} = dK_1(d)\,, \tag{5}$$

where $$\sigma_y = \frac{\sqrt{8}}{\pi}\sigma_\omega W T^2\,;\quad d = \sqrt{\frac{8\Delta y_0}{\sigma_y}}\,, \tag{6}$$

$K1(d)$ – McDonald's function of the first order.

In view of the known asymptotic representation of function $K1(d)$ for great values of d (at $d > 4$) from (5) approximately follows:

$$P_{OUT} = \sqrt{\frac{\pi d}{2}}e^{-d}\,. \tag{7}$$

At the same, as earlier values of parameters, entering in (6), we shall receive: σ_y = 5,65 km; P_{OUT} = 6·10^{-3}. Apparently, results on accuracy in both cases satisfy MNR (σ_{MNR} = 5,8 km). On reliability results are absolutely various: in the first case *of* $P_{OUT} \approx 0$, i.e. not taking into account the unreliability of correction has led to practically absolute reliability of navigation. In the second case reliability of navigation has appeared as inadmissible low – probability P_{OUT} is on the order below minimum requirements (P_{OUT} = 2,6·10^{-4}).

From this it is clear – an air simulator should be such that lacks of navigator could not be "compensated" by lacks of NC modelling [8]. With reference to the case considered above it means that in flight simulator it is necessary to model possible refusals and failures in radio correction as well as correct workings areas of radio means. At observance of these conditions flight simulators will allow to investigate ways of skilled navigator actions and to form a databank, describing the "group portrait" of the navigator.

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