Construction of standard aircraft turns in relation to the return point to the path line

V V Markelov
Faculty of Information Security and Computer Technologies, Saint Petersburg National Research University of Information Technologies, Mechanics and Optics. 49 Kronverksky Av., St Petersburg, 197101, Russia
E-mail: vvmarkel@gmail.com

Abstract. The trend of development of modern on-board aircraft systems causes the emergence of new requirements, in particular, to maintain the specified accuracy characteristics while the air navigation. One of these requirements is the implementation of reverse flight schemes, which include standard turns and final turns with the control of the exit to the line of a given path with the return course. Taking into account the fact that the reverse schemes do not solve the problem of providing an exit to the line of a given path at a given control point. The method of using alternative reverse schemes is proposed to solve the problem of ensuring the end of the reversal in the reverse schemes at a given point. The given point of the exit on the path line with the return course is applied as a reference control point in these schemes. The presented method provides the construction of standard turns in relation to the point of return to the path line. The method is used in the preparation of schemes of turns and is used by the onboard aircraft navigation system when flying according to these schemes. The method allows to ensure the end of the turn with the exit to the line of a given path at a given point, as well as to reduce the area of the protected space of the turn zone.

1. Introduction

Return schemes, which are used in piloting (turns schemes) include: standard turn on 45/180°, standard turn on 80/260°, final turn [1,2]. These schemes are shown in figure 1.

The parameters of the standard turn include: the reference control point, the distance or the flight time determining this distance from the control point along the path to the beginning of the turn, the turn angle of 45° or 80° and, additionally, for a turn at 45/180° – the distance or flight time along the removal trajectory. A turn to the path line begins, respectively, for turns at 45/180° and 45/180°, either on the span of the given distance along the line of the removal path, or when the angle of the turn reaches 80° [1,2].

The parameters of the standard turn to the final approach include: the reference control point, the distance or the flight time determining this distance from the control point along the given path line to the beginning of the turn. A turn to the path line begins along the span of a given distance along the line of the removal path line.

Thus, when implementing reverse schemes, the exit point to the given path line with the reverse course is the only parameter which is not determined. Depending on the flight speed and wind parameters, the position of this point can vary within several kilometers [3,4]. This entails the need to
have an additional margin in the distance and flight time to ensure guaranteed access to the given course, and also causes an increase in the protected space of the turn zone [5,6].

The use of high-precision navigation causes increased requirements for the accuracy of maintaining a given flight trajectory, including turns [7,8]. One of these requirements when performing reverse schemes is the exit to the given path line at the given point, in particular, the exit to the final approach at the given distance from runway end [9,10]. At the same time, the use of the reverse schemes described above, to solve the problem of reaching a given path line at a given point does not provide acceptable accuracy characteristics [11,12].

Figure 1. The applied variants of the reverse schemes: standard turn (a) and final turn (b) (FIX – the control point relative to which the turn is performed, S0(t0) –the flight distance from the control point to the beginning of the turn, Sr(tr)- the flight distance along the removal line, A0 – the angle of the turn or the divergence angle of the removal path).

Alternative reverse schemes are proposed as one of the methods of solving the problem of the turn with providing access to the path line at the given point. The control point of these schemes is the point of exit to the given path line with a reverse course. The variants of the proposed alternative reverse schemes are shown in figure 2.

Figure 2. Proposed alternative options for reverse schemes: standard turn (a) final turn (b) (FIX - control point relative to which the turn is performed, FIX0 – the control point of the start of the removal line, St (A0) - distance of the start of the turn, A0 is the given angle of the turn).

Accordingly, for schemes of the standard turn, the boundary of the beginning of the turn is determined. It is separated by the calculated distance from the control point, determined depending on the specified angle of the turn: 45 ° or 80 °. For schemes of the final turn, the boundary of the start of the turn is the specified control point of the beginning of the line of the removal path. At the intersection of the starting point of the turn, the aircraft management system provides access to the calculated starting point of the turn to the given path line, determined depending on the parameters of the aircraft’s
movement and wind parameters. The beginning of a turn with the given angle of heel at the calculated point provides an exit to the line of the given path at the given exit point. That solves the problem.

2. Materials and methods

Implementation of the flight according to an alternative return scheme provided by the on-board aircraft management system includes: flying along the line of the given path to the turnaround line, reaching the calculated point of the start of a turn to the line of the given path with a return course, actually turning to the line of the given path provided by standard procedures of trajectory management.

The boundary of the beginning of the turn for the standard turn maneuvers is calculated at the stage of constructing the scheme. The boundary of the start of the maneuver of the turn to the landing line coincides either with the control point or with the radio reference from the approach scheme or arrival scheme and is selected either at the stage of constructing the scheme or promptly in flight.

The exit to the calculated point of the start of a turn to the line of the given path is realized by the aircraft management system in the form of a typical flight procedure directly to the navigation point. In this case, the position of this calculated point in space is subject to determination and constant recalculation depending on the flight parameters and the environment.

The position of the calculated start point of the turn relative to the exit point to the line of the given path with the return course in the orthodromic coordinate system is determined by solving the system of equations:

\[ \begin{align*}
X_t &= TDF \cdot R \cdot (\sin(A - \alpha_0) + \sin(\alpha)) - U_x \cdot tp \\
Y_t &= TDF \cdot R \cdot (\cos(A + \alpha_0) - \cos(\alpha) - U_z \cdot tp)
\end{align*} \]

when \( TDF = 1 \):
\[ tp = \frac{R}{V} \cdot A; \]
when \( TDF = -1 \):
\[ tp = \pi - \frac{R}{V} \cdot (2\pi - A); \]
\[ A = \arctg \left( \frac{(Y_t - Y)}{(X_t - X)} \right). \]

where: \( X_t, Y_t \) - the linear distance of the calculated starting point of the turn from the exit point to the line of the given path in the orthodromic coordinate system constructed from the exit point with the X axis directed along the directional exit corner;

\( X, Y \) - linear distance between the current location and the exit point to the line of the given path in the given orthodromic coordinate system;

\( TDF \) - the given direction of the turn when entering the line of the given path (1 - clockwise, minus 1 - against);

\( R \) - turning radius, determined by the current true airspeed and a given roll angle during the turn;

\( V \) - current true airspeed;

\( U_x, U_z \) - projections of the wind vector on the axis of the corresponding orthodromic coordinate system;

\( tp \) - turn time;

\( \alpha_0 \) - drift angle on the track line, counted from the track exit angle;

\( \alpha \) - current drift angle;

\( A \) - estimated azimuth to the start point of the turn from the current location, counted from the given path angle of exit to the track line.

Thus, the value of the set course (\( \psi d \)) in the flight mode to the start point of the turn used in the aircraft management system is:

\[ \psi d = \frac{\pi}{2} - A + \psi_0 - \alpha. \]

where: \( \psi_0 \) - is the given path angle of exit to the track line.

Reaching the start point of the reversal is determined on the condition:

\[ (Y_t - Y)^2 + (X_t - X)^2 < (2 \cdot Rt \cdot \sin(\psi d - \psi))^2, \]
where: \( \psi \) – current course.

Upon reaching the start point of the turn, the aircraft management system ensures a turn with the given constant angle of heel. A typical flight procedure begins along the line of the given path.

When constructing a diagram such as standard turns, the turn start distance, measured along the path line from the exit control point, must be previously determined. The standard accepted distance value (St) depending on the value of the received angle of the turn is determined as:

\[
St = 2 \frac{R}{\sin(A0)} + V \cdot t0 + 2 \pi \cdot R \cdot \frac{U0}{V},
\]

where:
- \( A0 \) - accepted turn angle (45° or 80°);
- \( U0 \) - estimated maximum wind speed;
- \( t0 \) - standard time of a turn enter (3...5s).

The desired value of the distance of the beginning of a turn, together with the coordinates of the exit control point, uniquely determines the construction of standard turn schemes.

At the same time, the known parameters of the alternative reverse schemes presented, such as the position of the control point of access to the line of the given path, the control point of the beginning of the line of the removal path for a turn to the landing line,

At the same time, the known parameters of the alternative inverse circuits presented, such as the position of the control point of access to the line of the given path, the control point of the start of the line of the removal path for a turn to the landing line, the distance of the start of the turn for standard turns, allow to build a protected area for these turns.

3. Conclusion

The alternative method of constructing reverse schemes, including standard turns and final turns to the landing line, has been presented. This method provides the construction of turns in relation to the point of return to the line of the given path. The method is implemented in the preparation of turn schemes with the control of the exit to the line of the given path with the return course and is used when flying according to these schemes with an on-board aircraft management system.

This method ensures the fulfillment of the requirements at the end of a turn with the exit to the line of the given path at the given point, and also reduces the area of the protected space of the turn.

References

[1] Doc 8168 2014 Aircraft Operations. Volume 2. Construction of visual and instrument flight procedures, – Montréal: International Civil Aviation Organisation, 2014
[2] Doc 9613 2013 Performance based navigation (pbn) manual, – Montréal: International Civil Aviation Organisation, 2013
[3] Reddy G S and Saraswat V K 2013 Defence Science Journal 63 131-7
[4] Mazzotta D G, Sirigu G, Cassaro M, Battipede M and Gili P 2017 WSEAS transactions on systems 12 2210231
[5] Reddy G S, Saraswat V K 2013 Defence Science Journal 63 131-7
[6] Markelov V V, Shukalov A V, Zharinov I O, Kostishin M O and Kniga I 2016 IOP Conference Series: Materials Science and Engineering 124 012020
[7] Parnian N, Golnaraghi F 2010 Sensors 10 5378-94
[8] Markelov V V, Shukalov A V, Zharinov I O, Kostishin M O and Ershov A N 2016 Indian Journal of Science and Technology 9 95219
[9] Gao W, Zhang Y, Wang J 2015 Sensors 15 3154-71
[10] Yu F, Sun Q 2014 Sensors 14 7156-80
[11] Gao Z, Zhang H, Ge M, Niu X, Shen W, Wickert J and Schuh H 2015 Sensors 15 5783-02
[12] Jiang W, Wang L, Niu X, Zhang Q, Zhang H, Tang M and Hu X 2014 Sensors 14 19371-401
[13] Jwo D-J, Shih J-H, Hsu C-S, Yu K-L 2014 Journal of Marine Science and Technology 22 381-94