

Method of Risk Minimization in 4D Trajectory Control of Aircraft in a Unified Airspace

Approach on resolving conflict situation and ensure maximum efficiency using methods of 4D trajectory ATM and minimizing risks of operation, basing on proposed method.

Simulating of potential conflict situation

We will use pre-defined situation in order to represent a conflict resolution on real-life based situation. Resolution of conflict is supposed to be taken by ATC instructions, basing on provided advisory on conflict solution or as automated process with usage of aircraft information interchange.

Table 1. Input Data

Aircraft model	Initial speed (kt)	Initial Altitude (ft)	Heading	Wind (kt)	Wind Direction	Time of zone entering (UTC)
Dash-8 Q400	240	15000	180	20	360	13:00:00
CRJ-700	300	15000	180			13:05:00

Our airspace is described as a narrow corridor with dimensions of 100x20 nautical miles. For simplifying of calculations and visual representation of the process of conflict resolution we will ignore these factors next factors: aircraft engine types, air density, wind effect on each aircraft cross-section.

Path of both of our aircraft lays from imaginary beacon “FTPAS”, set as an zone enter waypoint, to imaginary beacon “ATPAE”, set as zone exit waypoint. Coordinates of “FTPAS” set as [10,100, 15000] in zone dimensions, coordinates of “ATPAE” set as [10,0,15000] in zone dimensions.

Dash-8 Q400 (Aircraft #1) enters the zone first, CRJ-700 (Aircraft #2) second, 5 minutes after Aircraft #1. The main task is to reconfigure formation of aircraft in a way that CRJ-700 will leave the airspace first, in order to avoid potential conflict after leaving controlled airspace and Dash-8 Q400 second, with minimum possible safe distance to Aircraft #2. Additionally none of the aircraft should leave the dedicated airspace zone and both of them should exit at the altitude of enter: 15000ft.

Aircraft measured speed remains constant. Wind directly affects on aircraft true airspeed and aircraft behavior during maneuver.

Calculations:

Time for potential conflict we can define by formula

$$t_{conflict} = \frac{S_{in} - S_{req}}{V_r}$$

Where:

$t_{conflict}$ – is a time remaining to condition of separation loss;

S_{in} – initial distance between aircraft;

S_{req} – minimum required distance for longitudinal separation;

V_r – relative speed between 2 aircraft

Minimum required distance is taken as 10 nautical miles, per standard. $V_r = 60$ nm/hour. Time until separation loss is 8 minutes 20 seconds, after Aircraft #2 entered.

With respect to ATC/pilot communication delay – avoiding maneuver is conducted 1 minute prior separation loss point for Aircraft #1.

Normal distribution function for vertical speed:

$$V_{ver}(t) = V_{max} \cdot \frac{1}{\sigma\sqrt{2\pi}} \cdot e^{-\frac{(t-\mu)^2}{2\sigma^2}}$$

Where:

V_{ver} – vertical speed of the aircraft at time t during descent;

V_{max} – maximum vertical speed during descent;

μ – mean value of time;

σ – standard deviation.

Formula for wind effect during descent:

$$S_{lon}(t) = \int_0^t (V_{aircraft} - V_{wind} \cdot \cos(\theta)) dt'$$

Where:

S_{lon} – distance passed in longitudinal dimension;

θ – angle between aircraft and wind direction.

Descent maneuver, with respect to communication delay is completed within 1 minute, with average speed of descent 2000ft/min and total time of descent 35s.

Descent establishes vertical separation between Aircraft #1 and #2, however this is not enough for exiting the zone at the altitude of 15000ft for both aircraft, as horizontal separation not yet established. For mentioned purpose turning maneuver will be conducted. Deviation from original direct path should be on 6.9 miles (or 1min 54s) longer, than original path. For simplicity the trajectory for deviation are consist of: two 45° turns, one 90° turn and direct flight path between arcs. Turn speed of Aircraft #1 is 5deg/sec.

Average speed during a turn:

$$V_{average} = \frac{1}{\theta_{fin}} \int_0^{\theta_{fin}} (V_{aircraft} - V_{wind} \cdot \cos(\theta)) d\theta$$

Where:

θ_{fin} – angle of turn through maneuver.

Wind lateral drifting effect:

$$S_{lat} = \int_0^{\theta_{fin}} V_{wind} * \sin(\theta) d\theta$$

With formula application we find out full length of maneuver is 23.56nm, with distance of each 45° turn being 0.57nm. The maximum lateral deviation from initial path is 7.53nm.

After returning on previous heading of 180° Aircraft#1 continue flight on FL140, until Aircraft #2 reaches the “ATPAE” point. With conducted maneuvers longitudinal separation between Aircraft #1 and #2 will be established as 10nm. After Aircraft #2 leaves airspace command on climbing to FL150 for Aircraft #1 should be issued

Conclusion

Provided example of maneuver performance in conflict situation will positively affect air traffic flow management and significantly decrease risk of potential conflict in similar situations. In case if automatization of process of conflict resolution would be implemented for all airspace participants or alternatively as advisory for conflict resolution for ATC. Decrease of influence of human factor in conflict resolution leads for safe and efficient ATM.

References

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