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Application of Forewarning Based on CFL

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Keywords: Drones, short-term conflicts (STCA), medium-term conflicts (MTCD), ROC&ROD, potential conflict detection, horizontal/vertical prediction

Abstract: With the rapid development of civil aviation and rapid growth in the number of drones in China, the pressure of air traffic control is gradually increasing. Potential conflicts need to be found earlier to have enough time to deal with potential conflicts. A new warning method has been explored to detect the possibility of conflict through more perfect horizontal and vertical model prediction, and reduce the impact of 4D trajectory uncertainty. The forewarning based on the CFL can detect the possibility of conflict in the next 3-5 minutes from the horizontal and vertical directions which can be used as a supplement means of STCA and MTCD, and provide a more powerful and perfect warning function.

1. Background

The ATC automation system provides two kinds of conflict alerts, STCA and MTCD. Short Term Conflict Alert (STCA) is an important safety net feature of ATMAS as collision avoidance tool, or to provide a separation alert for a potential or actual infringement of separation minima between aircraft. STCA can work between targets associated with an FPL and unknown targets without an FPL. Medium Term Conflict Detection (MTCD) is designed as a safety advisory tool that provides warnings to controllers for potential conflict for “aircraft-to aircraft” or “aircraft-to-airspace” encounters up to a looking ahead time. The aim of MTCD is to proactively provide possible conflict in advance during sector planning to reduce tactical workload [1].

But according to the feedback, from the operation site, there are different degrees of defects. The problems with STCA, The general prediction time, is 60-90 seconds, which is not conducive to the conflict relief, of the controller, after the alert is generated; Planned routes not take into account. The problems with MTCD, the prediction time is longer, Rate of climb (ROC) and rate of descent (ROD) uncertain, there are many uncertain factors of 4D track.

In 2022, the "Roadmap for the Construction of Smart Civil Aviation[2]" was issued, announcing the proposal for manned unmanned integrated operation, conducting research on key flight technologies and operating rules, gradually integrating unmanned aviation into the national airspace system according to the principles of universal use followed by transportation, isolation followed by integration, and improving the real-time situational awareness, safety warning, and efficient operational control capabilities of manned unmanned aerial vehicle integrated flight based on computing power. It is expected that by 2035, transportation aviation will achieve coordinated operation with general aviation and unmanned aerial vehicles.

The integration of manned and unmanned aircraft operations highlights the heightened importance of monitoring safe separation between aircraft. Compared to manned aerial vehicles, drones have a smaller volume, poorer maneuverability, lower speed, climb rate, and descent rate, so flight conflicts need to be detected earlier.

With the rapid development of CAAC and rapid growth in the number of drones, the pressure of ATC is gradually increasing. It is necessary to find potential conflicts earlier in the control work, so as to have enough time to deal with potential conflicts [3]. However, due to the longer prediction time and more uncertain factors, the reference value of medium-term conflicts is relatively low. Therefore, it is necessary to consider how to enable controllers to detect potential conflicts earlier in their work while providing high-quality alerts.

2. Discussion Questions

2.1 Limitations of Short-term and Medium-term Conflicts

Short-term conflicts are predicted according to the tracks. The general prediction time is 60-90 seconds, which is not conducive to the conflict relief of the controller after the alert is generated. However, the medium-term conflict prediction time is longer, there are many uncertain factors of 4D track, and the reference value of giving the alert is relatively low, so the short-term conflict and medium-term conflict cannot be complementary in the control work.

2.2 Short-term Conflict Prediction Doesn't Take into Account the Routes

Aircrafts often make turns. At present, the prediction of short-term conflict horizontal track completely depends on the current heading of the track as shown in Figure 1. When there is a turning point within the predicted time, there is a large gap between the predicted track and the real flight track of the aircraft, which may lead to false alert or missing alert.

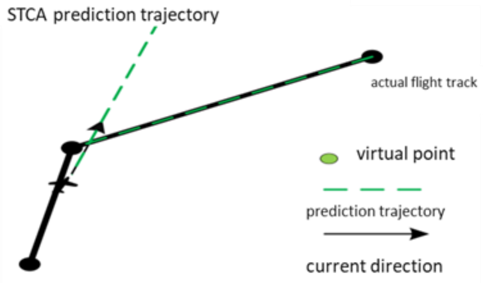

Figure 1: Traditional horizontal trajectory prediction

2.3 The Uncertain Rate of Climb (ROC) and Rate of Descent (ROD) Lead to Delayed and Inaccurate Alert

In the control work, there is a certain time difference between the command issued by the controller and the change of track situation. At present, as shown in Figure 2, the short-term conflict alert (STCA) depends on the change of track situation, which delays the alert time.

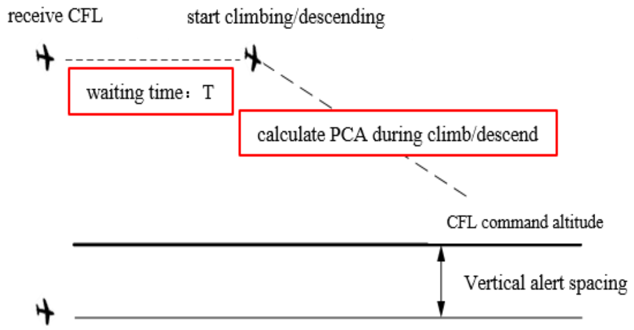

Figure 2: Traditional alert calculation timing

STCA uses the ROC and ROD of the track in real time to calculate altitude changes, which may causes inaccurate alert.

3. Solution

To explore a new alert method to detect the possibility of conflict through more perfect horizontal and vertical model prediction. It is between short-term conflict and medium-term conflict, and the prediction time is shorter than medium-term conflict, so as to reduce the impact of 4D trajectory uncertainty [4]. The alert can better complement the short-term conflict and provide a more powerful and perfect alert function for the control work.

To comprehensively consider the track dynamics and planned route information of multiple cycles, update the 4D track in real time, and calculate the alert time independent of the track change. When the horizontal and vertical conflict conditions are met at the same time, an alert will be given according to the actual risk situation.

3.1 Horizontal Prediction

Combined with the aircraft's planned route and the situation of multiple cycles of the track, a more intelligent and more suitable prediction model for the actual flight trajectory is provided to make a fine prediction of the aircraft's flight trajectory in the future. The main prediction methods include: along route model, maintain off-way route model, return route model, direct flight model and maintain current heading model, etc. [5]

- When the track position and movement trend closely fit the current route, it is considered to meet the along route model.
- When the track deviates from the current route to a certain extent, and the track movement trend closely fits the planned route, it is considered to meet the maintain off-way route model.
- When the track deviates from the current route to a certain extent, and the track movement trend gradually fits the planned route, it is considered to meet the return route model.
- When the track position and movement trend deviate from the current route, but the track trend is expanded and close to the subsequent route, it is considered to meet the direct flight model.
- When the current position and movement trend of the track cannot meet the above four models, the maintain current heading model is adopted.

Figure 3 lists several common scenarios of aircraft flight. When the altitude conflict threshold is met, the above horizontal prediction model can better identify the risk situation.

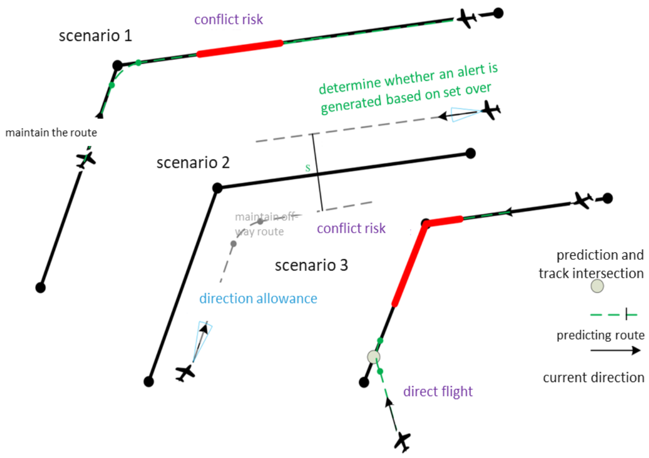

Figure 3: Horizontal scene diagram

3.2 Vertical Prediction

The aircraft execution time and the ROC and ROD adopted during execution will directly affect the altitude change in the 4D track. The altitude change stage of the aircraft is determined by the difference between command altitude and current altitude. As shown in Figure 4, the altitude change stage is divided into three stages: command delay level flight stage, climbing and descending stage and command completion level flight stage.

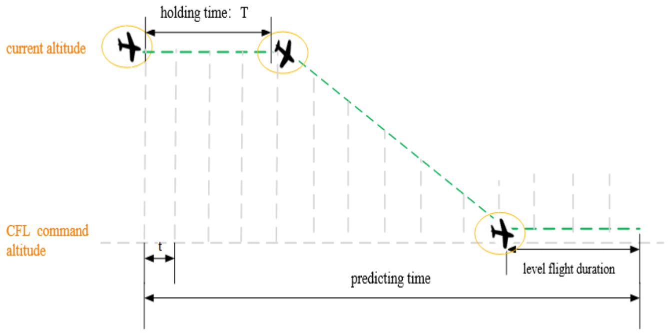

Figure 4: Altitude change stages

When the aircraft receives the command of climbing or descending, if the aircraft situation does not comply with the corresponding climbing and descending trend at this time, it shall maintain a horizontal flight for a certain time before descending.

When the corresponding climbing and descending trend is detected in real time, immediately end the horizontal flight phase and enter the climbing and descending phase.

When entering the climbing and descending prediction stage, the predicted ROC&ROD cannot be completely correct, and it is impossible to determine whether it is really safe when altitude crossing occurs. At the same time, the vertical interval is generally only about 300m, and the small error of the ROC&ROD may lead to the omission of the final alert. In some cases, the aircraft may have conflict as long as it descends or climbs faster as shown in Figure 5.

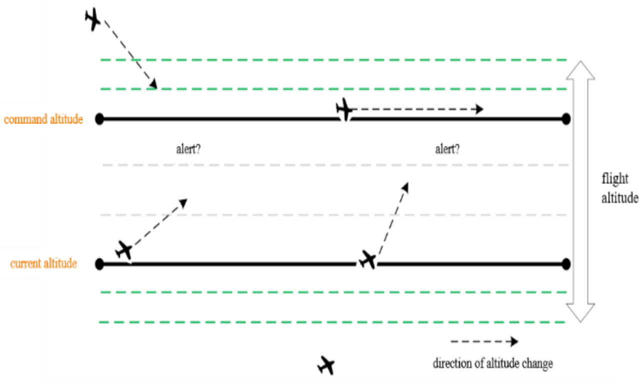

Figure 5: Altitude change scenes

Height detection can be carried out through any combination of three height models to solve the problems caused by the uncertainty of ROC&ROD. The linear model (loose), conical model (relatively strict) and matrix model (extremely strict) are as follows:

• Linear model is an ideal model. Combined with the current altitude situation of the track, it seeks to have the most reasonable ROC&ROD at all times in the prediction time, so as to calculate a reasonable altitude that is most likely to fit the actual situation in theory.

• Conical model is a high probability (PROB) model, which does not seek to find the most reasonable altitude, but seeks a reasonable altitude range. Through the system analysis of the matched maximum and minimum ROC&ROD, the possible altitude range of an aircraft is calculated, and it is considered that the maximum PROB of the aircraft will be in this altitude level. The maximum and minimum ROC&ROD can be matched with empirical data or set manually according to the model and height.

• The matrix model, similar to the cone model, also seeks the altitude range, but it does not care about ROC&ROD. It believes that the aircraft can be any altitude within the altitude change range at any time in the prediction time, that is, it occupies the whole altitude change range in the prediction time.

The linear model infers the most likely result. The conical model infers the PROB result. The matrix model is actually an extension of the conical model, which believes that the ROC&ROD can be infinite.

By selecting one or more altitude models and calculating at the same time, a variety of alert results can be obtained, so as to avoid the uncertainty of command execution timing and ROC&ROD in altitude prediction to the greatest extent, resulting in the decline of the quality of alert.

3.3 Speed Prediction

When the aircraft maintains horizontal flight, the current speed of the trajectory is used for trajectory prediction (as shown in Figure 6).

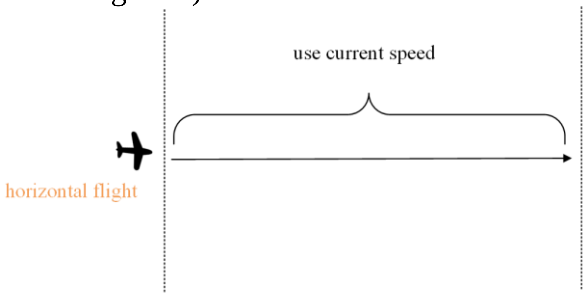

Figure 6: Horizontal flight speed prediction

When the aircraft will climb or descend to an altitude, the calculated value of speed is obtained by weighting the current speed of the trajectory with appropriate Base of Aircraft Data (BADA) at the altitude level of the aircraft type (as shown in Figure 7).

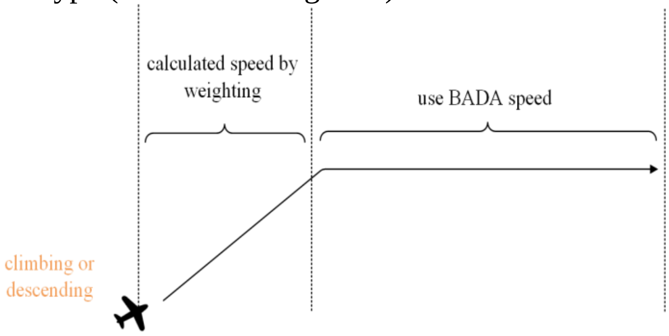

Figure 7: Climbing and descending speed prediction

The calculation formula for speed transition changes is as follows:

$$v = v_C \times (1 - w) + v_B \times w \quad (1)$$

$$w = T \times w_s \quad (2)$$

Where v_C is the current speed and v_B is the BADA empirical speed. w is the weight of BADA empirical data in the transition speed, which increases over time until it reaches 1. w_s is the rate of change of the weight per second, and T is the difference between the predicted time and the current time, measured in seconds.

3.4 Alert Output

1) Command Conflict Alert

After the controller gives the commands, the horizontal and vertical alert models are used for calculation and combined with the 4D trajectory of the current area to determine whether there is a risk. When there is a risk, the following alerts are given as shown in Figure 8:

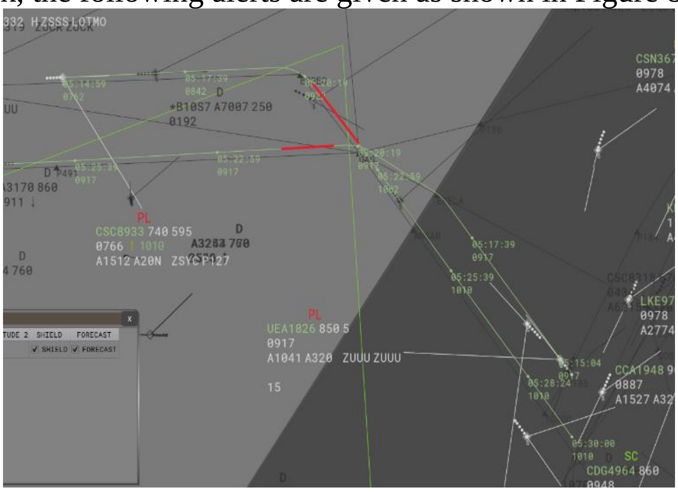

Figure 8: Alert rendering

2) Alert prompt

In the actual control work, when there are many aircraft in the area, the controller has great working pressure. The better thing is to try to prevent the instruction height with risk from being issued, so as to avoid the risk to the greatest extent.

To predict the risk level of a command altitude, multiple altitudes are detected based on the current altitude of the aircraft and inbound or outbound type of the flight. Simulate the aircraft targets one by one, set the required command altitude, calculate the 4D trajectory, replace the new 4D trajectory of the aircraft into the 4D trajectory model of the current controlled airspace, calculate in the conflict calculation model, and obtain the risk degree of the command altitude.

The effect is shown in Figure 9, suggesting that there is an orange crossing risk at the nearby altitude levels 1070 and 0920.

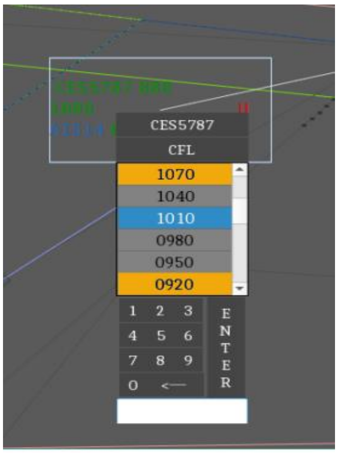

Figure 9: Command height selection

4. Conclusion

This alert method combines the advantages of short-term conflict and medium-term conflict, and uses more intelligent and refined methods to find potential conflicts between aircraft earlier. At present, Chengdu ACC has been put into use. In the actual control work, it has accurately identified the conflict risk for many times and assisted the controller to find and solve the potential conflict risk. According to the actual operation statistics, the effective alarm rate has reached more than 95%, and meets the requirements of the control on the alert prediction time. It has high reference value in the route stage.

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