Wind uncertainty and MTCD efficiency

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Abstract

A large part of the controller's workload comes from conflict detection and monitoring. The SESAR project aims at giving tools (such as MTCD) to air traffic controllers that will lighten this part of their burden and help them to have a more strategic planning activity while letting the computer take into account some of those "housekeeping" tasks. In this article we will show that because some uncertainties like wind prediction errors are unavoidable, even a perfect MTCD will always detect more conflict than the actual number of conflicts that really occur.

Understanding conflict detection from a mathematical point of view

Figure 1 shows a classical two aircraft conflict. Aircraft on the lower segment flies at speed v_1, and aircraft on the upper segment flies at speed v_2. The angle of incidence is α:

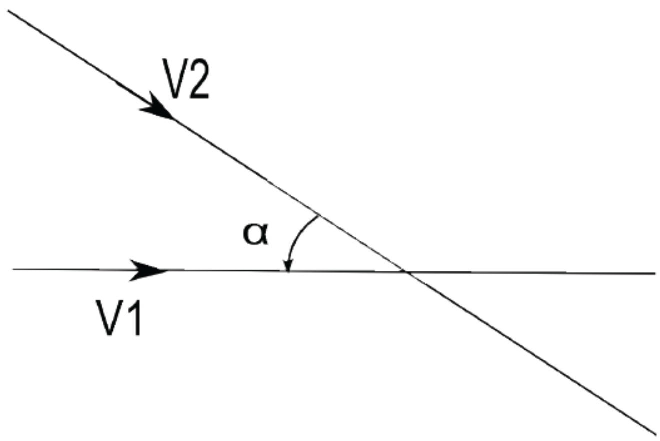


Figure 1

Let's make a simple numerical application: aircraft p_1 is flying at 400kts and is at a distance $l_1 = 60$Nm of the conflict point, aircraft p_2 is flying at 380kts, the crossing angle is 45° and the separation standard is D=5Nm. Then $p_2$will be in conflict with $p_1$if its distance to the crossing point is in the interval $[r_1, r_2]$with:

$$r_1 = l_1 \frac{v_2}{v_1} + D \frac{\sqrt{1 + (\frac{v_2}{v_1})^2 - 2(\frac{v_2}{v_1}) \cos \alpha}}{\sin \alpha} = 60 \frac{380}{400} + 5 \frac{\sqrt{1 + (\frac{380}{400})^2 - 2 \frac{380}{400} \cos 45}}{\sin 45} = 62$$

$$r_2 = l_1 \frac{v_2}{v_1} - D \frac{\sqrt{1 + (\frac{v_2}{v_1})^2 - 2(\frac{v_2}{v_1}) \cos \alpha}}{\sin \alpha} = 60 \frac{380}{400} - 5 \frac{\sqrt{1 + (\frac{380}{400})^2 - 2 \frac{380}{400} \cos 45}}{\sin 45} = 52$$

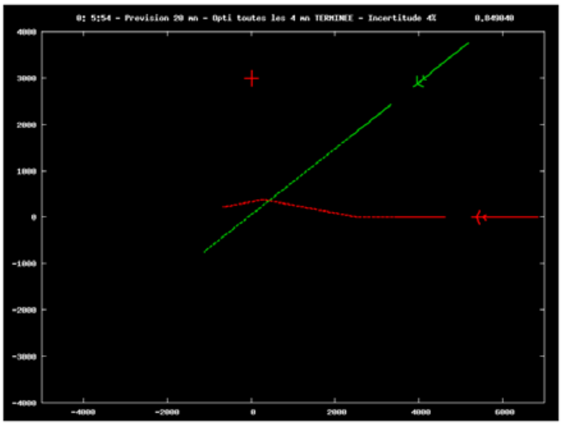
If p_2, flying at 380kts, is closer to the crossing point than 52Nm, it will safely pass in front of p_1 and if it is further than 62Nm of the crossing point it will safely pass behind p_1.

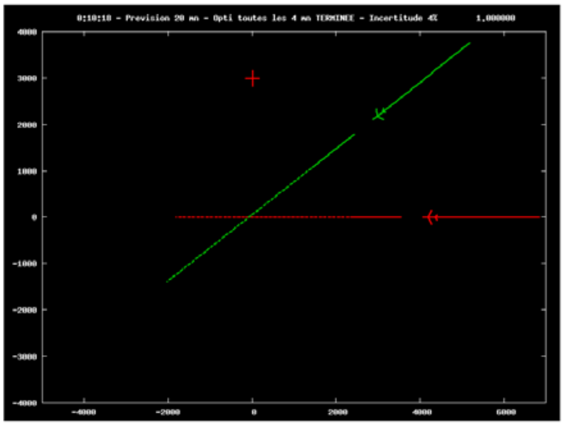
A very interesting value is the length of the segment to monitor:

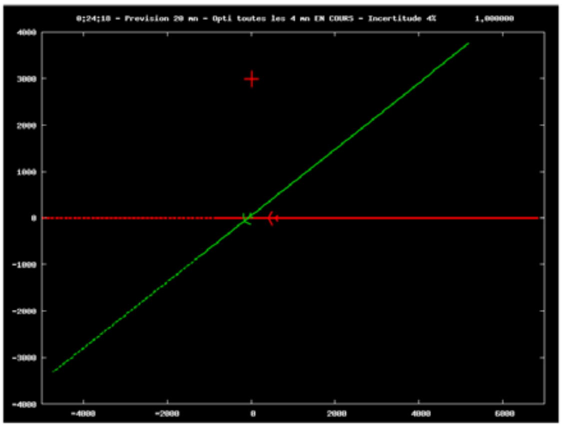
$$L = r_1 - r_2 = 2D \frac{\sqrt{1 + (\frac{v_2}{v_1})^2 - 2(\frac{v_2}{v_1}) \cos \alpha}}{\sin \alpha} = 2 * 5 \frac{\sqrt{1 + (\frac{380}{400})^2 - 2 \frac{380}{400} \cos 45}}{\sin 45} = 10$$

Thus we have to monitor a 10Nm segment and the length to monitor does not depend on l_1 (the distance to the crossing point). This is a very important result: if information was perfect and there was no uncertainty of any kind, conflicts could be exactly predicted as soon as the positions of the aircraft are known, even if they are very far away from the crossing point.

The importance of uncertainties







1) Up and left: aircraft are far away from the crossing point. Uncertainty is large, the controller detects a potential conflict and gets ready to solve this conflict by turning the red aircraft to the right. However he still has time before the conflict occurs and he decides to wait and monitor the situation.

2) Up and right: the aircraft are closer to the conflict point and uncertainty is much smaller. Now it looks quite clear that aircraft won't be in conflict, and the controller can either monitor the aircraft or rely on an ATC tool to monitor the situation for him.

3) Down and left: aircraft have crossed and the problem is over.

Controllers have to monitor and even sometimes solve conflicts that will often never occur: their priority is safety and they have to take into account uncertainty margins the best they can. The advocates of MTCD tools claim that it is possible to enhance the efficiency of conflict detection by using information downloaded from the aircraft FMS in order to reduce uncertainties. This is only partially true. The FMS can provide a very accurate information on air speed. However, for detection purpose, its accuracy on ground speed depends on the accuracy of wind prediction. Of course, for resolution purpose, it would be possible to have the FMS enter a “closed loop” mode, where it would guarantee a given ETA on the crossing point (this is the idea behind the TCSA concept of SESAR). But it is impossible to use this mode for every conflict detection, because we would have to compel aircraft to have an ETA for every crossing point, which would be much too complex and expensive. For conflict detection, even if the FMS provides perfect information on air speed and aircraft intentions, wind uncertainties have to be taken into account.

We suppose that aircraft automatically correct their heading by a drifting angle to maintain their course whatever the wind, and that they also take into account the wind prediction. But the wind prediction is never perfect and we have an unknown error on the wind defined by its maximal module W_m. Then it is possible to show that the additional number of conflicts to monitor is given by:

$$\frac{W_m}{D}\frac{t_a}{60}\sin\alpha$$

t_a is the anticipation time, W_m is the wind maximal error, D the separation standard and α the crossing angle. Let’s make a simple numerical application: the wind maximal error is $W_m = 18$kts, we want to detect conflicts $t_a = 5$ minutes before the crossing point, and the separation standard D=5 Nm, with a crossing angle $\alpha = 90°$. Then:

$$\frac{W_m}{D}\frac{t_a}{60}\sin\alpha = \frac{18}{5}\frac{5}{60}\sin 90 = 0.3$$

The MTCD will detect 30% conflicts more than the number of conflicts that will really occur to be sure to miss none of them. This number linearly increases with the anticipation. If conflicts are detected 15 minutes before the crossing point, the MTCD will detect 90% conflicts more, almost twice the actual number of conflicts, and this even if the MTCD is perfect (perfect FMS air trajectory prediction, no unexpected maneuvers by the pilots, etc).

Conclusion

SESAR promotes the “business owned” trajectory concept, the use of contract between air and ground to reduce the number of conflicts, and the development of ATC tools to ease the air traffic controller’s tasks regarding conflict detection, resolution and monitoring. Enhanced on board navigation systems and data-link facilities offer new opportunities to develop these tools but even with a perfect collaboration between the board and the ground, the above results show that future tools' efficiency will strongly rely on accurate wind prediction.

Thus a sustained effort is necessary to increase the quality of wind modeling and to reinforce the relationship between people working in both fields (meteorology and civil aviation) in order to promote a better understanding of the needs of both of them.

Note: for the interested reader, the full paper including mathematical proof is available at **http://www.alliot.fr/papers/ifatca.pdf**