SYM-OP-IS-2010
XXXVII Symposium on Operational Research
Ministry of Defence Republic of Serbia
Serbian Armed Forces

CONFLICT RISK ASSESSMENT MODEL FOR AIRSPACE TACTICAL PLANNING*

FEDJA NETJASOV
Faculty of Transport and Traffic Engineering, Belgrade, f.netjasov@sf.bg.ac.rs

Abstract: *This paper presents a conflict risk assessment model developed for the purposes of airspace tactical planning. The model is intended for comparison of different alternative flight scheduling scenarios for a given airspace sectorization, from a risk and safety point of view. Conflict Risk is assessed using two variables: duration and severity of conflict situation in the observed airspace under given circumstances. The model is based on the assumption that conflict between pair of aircraft exists when both horizontal and vertical separation minima are violated. Risk of conflict is defined as the ratio between product of conflict duration and conflict severity, and considered time interval. Apart from individual risk an assessment of total risk is also considered. Simple illustration of model application shows that in addition to airspace geometry, the individual and total conflict risk also depends on traffic demand, aircraft speed, spatial and temporal distribution of traffic in the airspace as well as applied separation minima. The developed model is intended for use both in en-route as well as terminal airspace and allows for the determination of the most suitable flight schedule which will be balanced with risk and capacity requirements (less risk, more capacity).*

Keywords: *Risk Assessment, Aviation Safety, Air Traffic Control, Air Traffic Management*

1. INTRODUCTION

The increase of airspace capacity is a prerequisite for satisfying the growing air traffic demand but is also affects safety of the aircraft operations. This is why it is necessary to develop models which will help assess safety and achieve a balance between the increase of capacity and the unwanted decrease of safety at different planning levels. A review of these kinds of models is given in [1].

In order to cope with this requirement the research presented in this paper adopts the assumption that different planning levels in ATC/ATM require different models for risk assessment. A modelling framework containing three planning levels (strategic, tactical and operational) is proposed. Each planning level requires some specific inputs.

In previous work [2] a risk assessment model for strategic planning was presented. The research presented in this paper considers airspace design and organization at the tactical planning level (e.g. one season up to one week in advance). For that purpose data about seasonal traffic, i.e. schedules with designated aircraft types, is used as traffic demand indicators.

Supply is, similarly like in case of strategic planning, represented by airspace geometry (number and length of airways as well as airway headings). The influence of Humans – operators (pilots, air traffic controllers, etc.) is not considered at this level.

At the tactical level we are concerned with the exposure to conflict situations (expressed by duration of single or all conflict situations) and the severity of conflict situations (expressed by spacing at closest point of approach between two aircraft).

A model could serve for comparison of different alternative flight scheduling scenarios for a given airspace sectorization or comparison of different alternative airspace sectorization scenarios for a given flight schedule, both from risk and safety point of view.

2. OBJECTIVES AND ASSUMPTIONS

The main objective is to develop a method for risk and safety assessment, which could be used for estimating alternative flight schedule scenarios at tactical planning level aiming to increase safety.

The starting point is that risk depends on airspace geometry (static element) and the air traffic using it (dynamic element).

Because of their inherently generic structure, this model could be used for the following:

- Flight plans approval;
- Planning purposes at tactical level, i.e. initial assessment of risk and safety, under given flight schedules;
- Flight re-scheduling with aim to reduce conflict risk;
- Slot assignment for certain flights as a measure to reduce conflict risk.

* This paper is part of the project No. 15023 sponsored by the Ministry of Science and Technological Development of Republic of Serbia.

The following assumptions are introduced in developing the model for conflict risk assessment:

- Airspace geometry and characteristics are known (e.g. number and length of the airways, airway headings, number of intersecting points, available flight levels, etc.);
- Traffic characteristics are known (temporal and spatial distribution of traffic flows over airspace entry points, aircraft types, flight plans – planned routes, speeds, altitudes, etc.);
- No deviations from flight planned routes and altitudes;
- Human operator's issues (pilots and air traffic controllers) are not considered.

3. DESCRIPTION OF THE MODEL

The model presented in this paper is of macroscopic nature. It looks at a given portion of the airspace (en-route sector or terminal maneuvering area - TMA) and focuses on the geometry of airways. Also, it uses data from filled flight plans.

A pair of aircraft is identified in a Cartesian coordinate system (Figure 1). Let x^i_t and v^i_t be the 3D position and 3D velocity of aircraft i given in expressions (1) and (2); the superscripts x and y refer to the axis system in horizontal plane, and z stands for the altitude. Let θ^i_t represent an orientation of velocity vector v^i_t in the horizontal plane (measured from the x axis in counter-clockwise direction, where $0 \leq \theta^i_t \leq 2\pi$) and let ψ^i_t represent the orientation of velocity vector v^i_t in the vertical plane (measured from the horizontal plane up as positive and down as negative, where $-\pi/2 \leq \psi^i_t \leq \pi/2$) [3].

$$x^i_t = \begin{bmatrix} x^i_{x,t} \\ x^i_{y,t} \\ x^i_{z,t} \end{bmatrix} \tag{1}$$

$$v^i_t = \frac{dx^i_t}{dt} = \begin{bmatrix} v^i_{x,t} \\ v^i_{y,t} \\ v^i_{z,t} \end{bmatrix} = \begin{bmatrix} v^i_t \cos\psi^i_t \cos\theta^i_t \\ v^i_t \cos\psi^i_t \sin\theta^i_t \\ v^i_t \sin\psi^i_t \end{bmatrix} \tag{2}$$

At each moment t, the distance (spacing) between pairs of aircraft in the horizontal and vertical plane are calculated. Let $x^i_{h,t} = (x^i_{x,t}\,,\ x^i_{y,t})^T$ be the position of aircraft i in the horizontal plane, and similarly for aircraft k. Knowledge about those values is required in order to identify potential conflicts.

Let $x^{ik}_{h,t} = x^i_{h,t} - x^k_{h,t}$ be the distance in the horizontal plane h and $x^{ik}_{z,t} = x^i_{z,t} - x^k_{z,t}$ be the distance in the vertical plane z, between aircraft i and k at time t [3].

Whenever the following set of conditions are satisfied, potential conflict exists between aircraft i and k:

$$x^{ik}_{h,t} < R_{min} \text{ and } x^{ik}_{z,t} < H_{min} \tag{3}$$

where: R_{min} is horizontal separation minima and H_{min} is vertical separation minima.

Condition (3) means that whenever both the horizontal and the vertical separation minima are violated, potential conflict exist.

3.1 Conflict duration

The duration of the conflict depends on the moments when the violations of both the horizontal and the vertical separations begin and end. In order to determine the duration the following conditions are proposed:

a) Duration of the potential conflict in the horizontal plane

Moments t_h' and t_h'' represent the beginning and end of horizontal separation violation. The difference between those two moments presents the duration of the potential conflict in the horizontal plane $\Delta t_h = t_h'' - t_h'$. The set of conditions which should be satisfied in order to determine duration is:

$$\text{If } x^{ik}_{h,t-1} \geq R_{min} \text{ and } x^{ik}_{h,t} < R_{min} \text{ then } t_h' = t \tag{4}$$

$$\text{If } x^{ik}_{h,t-1} < R_{min} \text{ and } x^{ik}_{h,t} \geq R_{min} \text{ then } t_h'' = t \tag{5}$$

At moment $t_h^* \in [t_h', t_h'']$ the distance between aircraft i and k reaches the minimal value ${}_{min}x^{ik}_{h,t}$, i.e. (Figure 1a)):

$$\text{If } \frac{dx^{ik}_{h,t}}{dt} = 0 \text{ then } t_h^* = t \text{ and } {}_{min}x^{ik}_{h,t} = x^{ik}_{h,t} \tag{6}$$

b) Duration of the potential conflict in the vertical plane

Similarly stands for vertical separation. A duration of potential conflict in vertical plane $\Delta t_z = t_z'' - t_z'$. A set of conditions which should be satisfied in order to determine duration is:

$$\text{If } x^{ik}_{z,t-1} \geq R_{min} \text{ and } x^{ik}_{z,t} < R_{min} \text{ then } t_z' = t \tag{7}$$

$$\text{If } x^{ik}_{z,t-1} < R_{min} \text{ and } x^{ik}_{z,t} \geq R_{min} \text{ then } t_z'' = t \tag{8}$$

At moment $t_z^* \in [t_z', t_z'']$ the distance between aircraft i and k reaches the minimal value ${}_{min}x^{ik}_{z,t}$, i.e. (Figure 1b)):

$$\text{If } \frac{dx^{ik}_{z,t}}{dt} = 0 \text{ then } t_z^* = t \text{ and } {}_{min}x^{ik}_{z,t} = x^{ik}_{z,t} \tag{9}$$

c) Duration of the potential conflict

As stated previously, potential conflict exists whenever both the horizontal and the vertical separation minima are violated. That means that following conditions should be met in order to determine duration of potential conflict (Figure 1)):

1) beginning of the potential conflict

$$t_c' = \begin{cases} t_h', & if\ t_h' \geq t_z' \\ t_z', & if\ t_h' < t_z' \end{cases} \tag{10}$$

2) end of the potential conflict

$$t_c'' = \begin{cases} t_h'', & if\ t_h'' \geq t_z'' \\ t_z'', & if\ t_h'' < t_z'' \end{cases} \tag{11}$$

Duration of the potential conflict is given by the following equation (Figure 1)): $\Delta t_c = t_c'' - t_c'$.

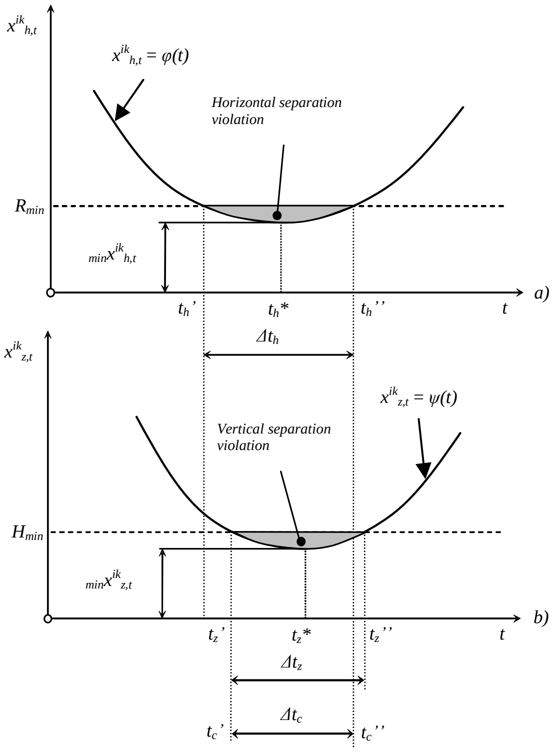

Figure 1. Representation of potential conflict duration and severity

3.2 Conflict severity

Severity of the potential conflict depends on the minimum distance (spacing) between pair of aircraft and the applied separation minima. It is defined both for violation of separation in horizontal and vertical plane:

a) Severity of the potential conflict in horizontal plane is

$$S_h = (R_{min} - {}_{min}x^{ik}_{h,t})/R_{min} \qquad (12)$$

where $0 \le S_h \le 1$, $S_h = 1$ in the case when both aircraft are in the same point in horizontal plane, i.e. when ${}_{min}x^{ik}_{h,t} = 0$, although they could be properly vertically separated.

b) Severity of the potential conflict in vertical plane is

$$S_z = (H_{min} - {}_{min}x^{ik}_{z,t})/H_{min} \qquad (13)$$

where $0 \le S_z \le 1$, $S_z = 1$ in case when both aircraft are at the same altitude, i.e. when ${}_{min}x^{ik}_{z,t} = 0$, although they could be properly horizontally separated.

c) Severity of the potential conflict

Assuming that conflicts exist when both horizontal and vertical separations are violated, a severity of potential conflict is defined as a product of severity in horizontal and vertical plane:

$$S_c = S_h \cdot S_z, \text{ where } 0 \le S_c \le 1 \qquad (14)$$

If the $S_c = 0$ that means that either conflict doesn't exist, or there is a potential conflict in horizontal but not in vertical plane (aircraft are in the same point but vertically well separated) and vice versa (aircraft are on the same altitude but horizontally well separated). But if the $S_c = 1$ that means that both potential conflicts in horizontal and vertical plane exist, i.e. collision occurred.

3.3 Conflict risk assessment

Usually, risk is considered as a product of the probability (or frequency of occurrence) and the magnitude of consequences (or severity) of a hazardous event [4].

For the purpose of risk assessment at the tactical planning level, risk R is defined as ratio between product of conflict duration (Δt_c) and conflict severity (S_c) and considered time interval. On such a way same risk could be in situation with long but less severe conflict as well as short and more severe.

Everything previously mentioned is related to a pair of aircraft from different crossing airways or at the same airway. Now if we consider more aircraft pairs then the total risk is given as sum of individual risks (risk is cumulative according to [5]).

4. MODEL APPLICATION

In order to illustrate the developed model, a hypothetic en-route sector is considered. The sector contains two uni-directional airways. For illustration purposes only flights on one flight level are considered (meaning that $S_z = 1$). Five flights entering sector in a six-minute period are considered. For each flight an entry time, together with aircraft type (S - slow aircraft with ground speed of 400kt and F - fast aircraft with ground speed of 450kt) and assigned airway (airway 1: length of 120 Nm and heading 135^0, airway 2: length of 150 Nm and heading 30^0) is given in Table 1.

Table 1: Spatial and temporal distribution of aircraft

Aircraft	Entry time (sec)	Aircraft type	Airway assigned
A11	0	S	1
A21	90	S	2
A12	120	F	1
A22	180	F	2
A13	240	S	1

Simulating the given traffic potential separation violations in the horizontal plane between succeeding aircraft pairs are observed and presented for case of R_{min} = 10 Nm in Figure 2 (only intersecting conflicts are presented). The calculated individual and total risks are presented in Table 2.

Table 2: Individual and total risk (R_{min} = 10Nm)

Aircraft pairs	Minimum separation (Nm)	Duration of potential conflict (sec)	Severity of the potential conflict (S_h)	Risk of the potential conflict
A11-A21	3.94	105	0.606	0.0177
A21-A12	4.20	96	0.580	0.0155
A12-A22	3.21	95	0.679	0.0179
A22-A13	9.33	39	0.067	0.0007
			TOTAL RISK	0.0518

Allowing aircraft A21 to enter into system 30 seconds earlier changes the situation – risk becomes lower (Figure 3, Table 3), actually the total risk value is now reduced from 0.0518 to 0.0475.

Additionally, the same situation, but applying the lower separation value R_{min} = 5Nm, is presented in Figure 4 as well as the risk values in Table 4.

It is apparent that for the same traffic demand the risk of conflict in the case of the lower separation minima (5 Nm) is lower but it should be mentioned that when a separation minima approaches zero, the risk of conflict becomes risk of collision [2]). Risk value is now reduced from 0.0475 to 0.0112.

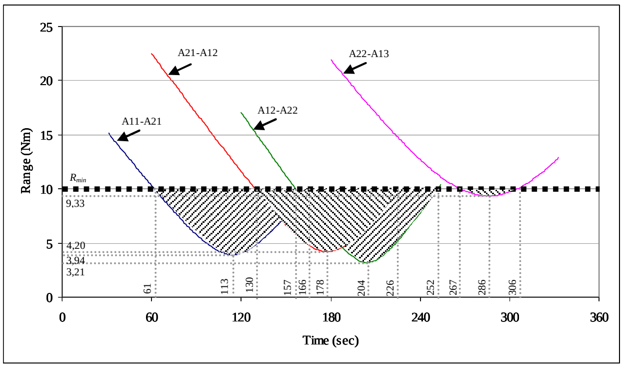

Figure 2. Change of spacing between aircraft pairs and potential conflicts in the horizontal plane (R_{min} = 10Nm)

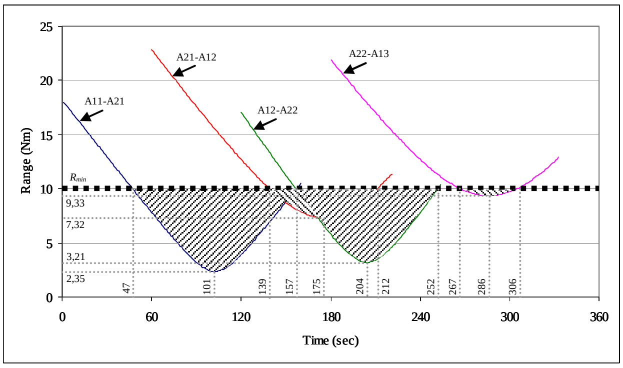

Figure 3. Change of spacing between aircraft pairs and potential conflicts in the horizontal plane (R_{min} = 10Nm)

Table 3: Individual and total risk (R_{min} = 10Nm)

Aircraft pairs	Minimum separation (Nm)	Duration of potential conflict (sec)	Severity of the potential conflict (S_h)	Risk of the potential conflict
A11-A21	2.35	110	0.765	0.0234
A21-A12	7.32	73	0.268	0.0054
A12-A22	3.21	95	0.679	0.0179
A22-A13	9.33	39	0.067	0.0007
			TOTAL RISK	0.0475

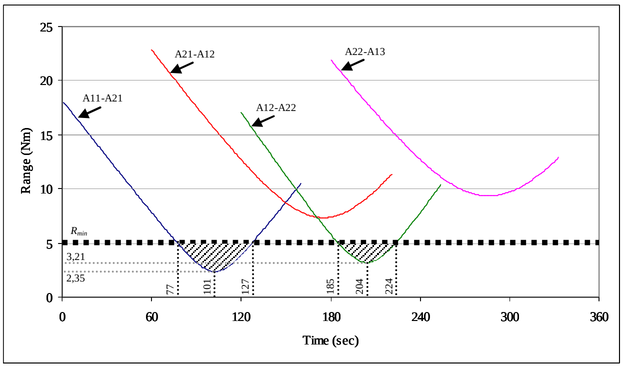

Figure 4. Change of spacing between aircraft pair potential conflicts in the horizontal plane (R_{min} = 5Nm)

Table 4: Individual and total risk (R_{min} = 5Nm)

Aircraft pairs	Minimum separation (Nm)	Duration of potential conflict (sec)	Severity of the potential conflict in (S_h)	Risk of the potential conflict
A11-A21	2.35	50	0.530	0.0074
A21-A12	-	-	-	-
A12-A22	3.21	39	0.358	0.0039
A22-A13	-	-	-	-
			TOTAL RISK	0.0112

5. CONCLUSION

The aim of the developed risk assessment model is to be used for scheduling purposes at the tactical planning level in the given airspace. Namely, during the process of planning one can seek to find flight schedules providing lower risk of conflict.

The model developed in this research allows for the estimation of the duration, severity and number of individual conflicts at intersections or along airways as well as individual and total risk of all conflicts.

The model is intended for use both in en-route as well as in TMA airspace. The model allows for the determination of the most suitable flight schedule which will be balanced with risk and capacity requirements (less risk, more capacity). In order to manage risk, i.e. to try to minimize it, it is possible to change the time of entering of aircraft into a given airspace, to assign different airway or different flight level, or to change an aircraft speed.

Simple illustration of model application shows that in addition to airspace geometry, individual and total conflict risk in the given airspace also depends on traffic demand, aircraft speed, spatial and temporal distribution of aircraft in the airspace as well as applied separation minima.

Further research will consider application of the developed model on real life cases as well as development of models for conflict risk assessment at the operational planning level.

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