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CONFLICT RISK ASSESSMENT MODEL FOR AIRSPACE STRATEGIC PLANNING*

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Abstract: *This paper presents a conflict risk assessment model developed for the purposes of airspace strategic planning. The model is intended for comparison and sensitivity analysis of different airspace design and organization scenarios under different traffic flow levels. Risk is assessed using two variables: probability of conflict occurrences and number of conflicts in the observed airspace under given circumstances. The model is based on the concept of critical sections which are traversed by the aircraft during level flight or climb or descent through them. Critical time values (estimated by the critical section length) as well as total duration of flight through the given airspace are used to define the probability of conflict. The number of conflicts is defined as the product of conflict probability and estimated traffic flows for the given airways. Final values for conflict numbers are determined taking into account all available flight levels and airway combinations in the given airspace. The developed model enables analysis of separation reduction influence on conflict risk and could be used in both en-route and terminal maneuvering airspaces.*

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

1. INTRODUCTION

Ultimate (unconstrained) airspace capacity (given as number of flights per hour) depends on traffic flows on certain or all airways (trajectories) as well as applied aircraft separation rules (minima).

One of possibilities to increase traffic throughput through the given airspace is to reduce separation minima. Separation minima reductions will, on one side increase the traffic throughput but on the other side will affect the safety of the aircraft operations, probably decreasing it. This is way it is necessary to develop a model which will help assess safety and make a certain balance between the increase of capacity and the unwanted decrease of safety.

This paper considers airspace design and organization at the strategic planning level. Data about forecasted (estimated) traffic flows, given as number of aircraft per hour, is used on the strategic level as traffic demand indicator. From the supply side, data about airspace, especially network of airways, is used. Flights exposure to conflict situations, which is represented by the average number of potential conflict situations and probability of conflict occurrence, serves as a risk and safety indicator on this planning level.

The presented model is inspired by the work of Siddiqee [1, 2] and Schmidt [3] which is modified and adjusted to support risk assessment needs.

2. OBJECTIVES AND ASSUMPTIONS

The main objective is to develop a method for risk and safety assessment, which could be used for estimating alternative solutions of the airspace (re)design aiming to increase available airspace capacity. The main starting point is that safety depends on airspace geometry (static element) and air traffic using it (dynamic element). Because of their inherently generic structure, this model could be used as follows:

- Planning purposes at strategic level, i.e. initial assessment of risk and safety of the current, transitional, and future airspace, following slight modifications (in the process of re-planning and re-design of the given airspace); and
- Evaluation of technical/technological feasibility of alternative airspace design, supported by particular technologies.

The following assumptions are introduced in developing the method for safety assessment:

- Airspace geometry and characteristics are known (number and length of the airways, number of intersecting points, available flight levels, etc.);
- Traffic characteristics are known (distribution of traffic flows, portion of level flights vs. climb/descent flights, fraction of specific aircraft category in total traffic volume);
- Two categories of aircraft are considered in the study (fast and slow); for each aircraft category the average ground speed is known;

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- Human operator's issues (pilots and air traffic controllers) are not considered.

3. DEVELOPMENT OF THE MODEL

The model developed 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 regarding forecasted traffic flows on specific airways.

Let us consider an airway i (i=1, …, n) of length D_i in the given airspace (sector). It contains r flight levels (FL) (r=1, …, s), vertically separated by 1000 ft. Airways can be uni-directional or bi-directional. Applied horizontal separation (both longitudinal and lateral) is S_{min} and vertical H_{min}. Further, let us assume that the aircraft fleet flying through this airspace consists of j aircraft classes (wake turbulence classes) and they are flying along route i in either level flight (cruising phase) or they are climbing/descending. The fraction of the aircraft in the fleet mix is given by p_j (j=1, …, m) and the fraction in different flight phase by p_k (k=1, …, .l).

The model is based on identification of conflict situations and calculation of potential conflict occurrence probabilities. For the purpose of the conflict identification a critical section length and flying time through it (critical time) are defined. Knowledge about the critical time and flight duration through the given airspace allows for the calculation of the probability of conflict occurrence. The average number of conflicts per hour could be estimated by multiplying the obtained probability with hourly traffic flows through the intersecting or non-intersecting airways.

3.1 Critical Section Length

A conflict situation is a situation when two aircraft come closer then a specified minimum distance both in horizontal and vertical plane. In order to determine whether or not conflict situation exist a cylinder-shaped "forbidden volume" is defined around the aircraft, the dimensions of which are determined by the minimum horizontal (S_{min}) and vertical separation (H_{min}) (Figure 1). A potential conflict situation exists between two aircraft if one of them enters the other's forbidden volume. Conflicts could be of crossing or overtaking type, depending on the aircraft trajectory relations.

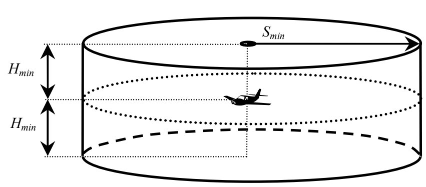

Figure 1: Forbidden volume around an aircraft

Let us consider the situation when two aircraft are flying on the same level and their trajectories are intersecting in horizontal plane, with intersection angle α. Let the speeds of both aircraft be V. The questions arises, if aircraft *1* is in intersection point O where aircraft *2* should be at the same time in order that [2]: a potential conflict is not occurring at this moment, will not develop in some further moment; and would not have occurred in the some previous moment?

In order to answer those questions a "critical section" was defined and its length was determined. The length depends on the plane in which the potential conflicts has occurred (horizontal or vertical) and on the flight phase combination (level flight, climb, descent). In Figure 2 a critical section in the horizontal plane (level flight vs. level flight) is shown. Critical section length d_h (segment X_h-Y_h) can be calculated using the following expression:

$$d_h = \frac{2 \cdot S_{min}}{sin\alpha} \tag{1}$$

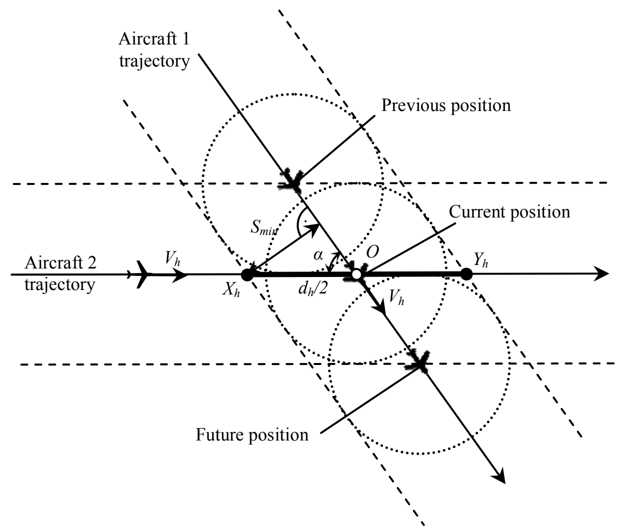

Figure 2: Critical section in the horizontal plane

3.2 Critical Time

If we assume that the average ground speed of the aircraft is V then, in the general case, an aircraft will traverse the critical section length by some average critical time τ. The average time during which an aircraft occupies the critical segment of another trajectory depends on the combination of flights. In case when both aircraft are flying at the same level (horizontal plain) critical time τ_h can be estimated as follows:

$$\tau_h = \frac{2 \cdot S_{\min}}{V_h \cdot sin\alpha} \tag{2}$$

3.3 Conflict probability

Knowing the length D_i of airway i in the given airspace and average ground speed V, flight time t^i through the airspace over airway i can be calculated. During the flight, aircraft passes through the critical section in time τ. The ratio between critical time τ and flight time t^i represents the probability of the critical section occupancy $P_{occ}^{\ i}$. Similarly, for airway j intersecting with airway i, we can calculate t^j and $P_{occ}^{\ j}$. The conflict can occur when both aircraft from airway i and j are inside the critical section of the corresponding airways. Assuming that occupancies of critical sections are mutually independent events, the probability of conflict occurrence P_c can be calculated using the following expression:

$$P_c = P_{occ}{}^{i} \cdot P_{occ}{}^{j} \quad (3)$$

Theoretically, if we let $S_{min} \rightarrow 0$ and $H_{min} \rightarrow 0$, P_c becomes accident (collision) probability P_a in the following expression:

$$\lim_{\substack{S_{\min}\to 0 \\ H_{\min}\to 0}} P_c = P_a \quad (4)$$

3.4 Risk of Conflict

In the situation when an aircraft flying on trajectory i occupies the critical length of trajectory j, then a potential exists for the occurrence of a conflict situation with aircraft flying on trajectory j. This potential is higher if the traffic flow from trajectory j is higher. The situation is worsened when we take into account the traffic flows from both trajectories. For the known average maximum traffic flows on both trajectories Q_i^{max} and Q_j^{max} we can estimate the average maximum number of crossing conflicts per hour N_c^{max} for that intersection point, at given FL:

$$N_c^{max} = Q_i^{max} \cdot Q_j^{max} \cdot P_c \quad (5)$$

The product of traffic flows in expression for N_c^{max} represents the maximum number of aircraft pairs (one aircraft belongs to flow i, the other to flow j) which could enter into a crossing conflict situation. According to the definition of risk given in [4][1] which is accepted in this research, it is assumed that the average number of crossing conflicts per hour N_c (where is $0 \leq N_c \leq N_c^{max}$) represents the risk of conflict. This is also in line with some previous results such as [5]. In the case of overtaking conflicts expression (5) becomes simpler.

3.5 Model Extension

a) Multiple Trajectories Intersection

The situation is made more complicated if the number of trajectories intersecting at one point is increased. Conflict between aircraft can occur at the intersection point for any possible pair of intersecting airways. For each airway pair a probability of conflict can be estimated. The total probability of conflict at intersection point $P^O{}_c$, at the given FL can be estimated using the following expression:

$$P_c^O = \sum_{i=1}^{m-1} \sum_{q=i+1}^{m} P_{c_{iq}} \quad (6)$$

were: Pc_{iq} is conflict probability between trajectories i and q ($q \in (i+1, m)$). Similarly, a total number of conflicts $N^O{}_c$ is estimated:

$$N_c^O = \sum_{i=1}^{m-1} \sum_{q=i+1}^{m} N_{c_{iq}} \quad (7)$$

were: Nc_{iq} is the average number of conflicts at the intersection point between trajectories i and q ($q \in (i+1, m)$).

b) Dependant and Independent Airways

Usually, in a given airspace a numerous dependant airways appear, creating the set with a finite number of intersecting points.

[1] Risk is considered as product of the probability (or frequency of occurrence) and the magnitude of consequences (or severity) of a hazardous event [4]

So, in that case the total number of crossing conflicts per given airspace for all intersecting points $N_c^{T,dep}$ can be estimated using the following expression[2]:

$$N_c^{T,dep} = \sum_{O \in INT} N_c^O \quad (8)$$

where: INT is the set of intersecting points O contained in the given airspace at the given FL.

In case of independent airways the total number of overtaking conflicts per given airspace $N_c^{T,indep}$ can be estimated using the following expression:

$$N_c^{T,indep} = \sum_{R_i \in RP} N_c^{R_i} \quad (9)$$

where: $N^{Ri}{}_c$ is the total number of overtaking conflicts per airway i and the given FL in the case of independent airways; RP is the set of points R_i belonging to the reference plane and within the given airspace, at given FL.

c) Number of Flight Levels

Taking into account the fact that more flight levels r could appear in one airway, a total number of conflicts for all available flight levels per given airspace N_c^{air} can be estimated using the following expression:

$$N_c^{air} = \sum_{r \in F} (N_c^{T,dep} + N_c^{T,indep}) \quad (10)$$

where: F is the set of available FL's contained in the given airspace.

4. MODEL APPLICATION

In order to illustrate the developed model, a hypothetic en-route sector is considered. The sector (Figure 3) contains two uni-directional and one bi-directional airway as well as four flight levels. Total traffic flow through the given sector is Q=28 aircraft/hour of which Q_1=Q_2=10 aircraft/hour on both airway AWY_1 and AWY_2, respectively, and Q_3=8 aircraft/hour on AWY_3. The airways are mutually dependant creating two intersection points $O_{1,3}$ and $O_{2,3}$. Aircraft speeds are 450 kt on AWY_1 and AWY_2 and 400 kt on AWY_3. The sector defined in such a way is used as a baseline for sensitivity analysis in further scenarios which analyze the impact of changes in demand (traffic volume) and supply (sector geometry). Distribution of aircraft on FL's, in each airway, is given in the Table 1.

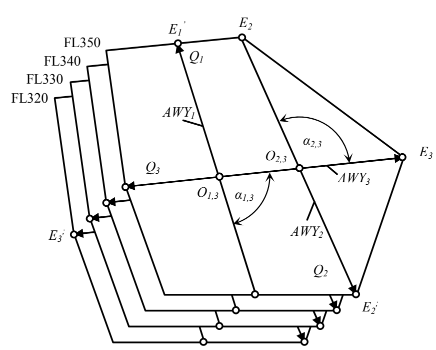

Figure 3: Sector geometry

[2] Risk is additive according to [6]

Table 1: Distribution of aircraft on FL's

	FL320	FL330	FL340	FL350
AWY_1	0	50%	0	50%
AWY_2	50%	0	50%	0
AWY_3	30%	30%	20%	20%

4.1 Scenario 1 – Demand change

Traffic flow on AWY_3 is varied in order to see how sensitive risk values are to demand change. For illustration purposes traffic flow values of Q_3 = 1, 4 and 8 aircraft/hour are considered. S_{min} values are also varied taking the following values: 10, 5, 3 and 0.038[3] nm while H_{min} was unchanged. Figure 4 represents the hourly number of conflicts for the given sector dependent on traffic flow on AWY_3. It can be observed that an increase of traffic flow as well as S_{min} yields an increase of hourly number of potential conflicts. This fact is in relation with the conclusions of some previous papers [7, 8, 9]. In the case of separation minima equal to 0.038 nm, obtained result presents an hourly number of potential collisions and their values are $5.41 \cdot 10^{-6}$, $2.47 \cdot 10^{-5}$ and $5.75 \cdot 10^{-5}$ for Q_3 = 1, 4 and 8 aircraft/hour, respectively.

4.2 Scenario 2 – Supply change

Length of AWY_3 is used to represent a supply side change. Changing the length of the airway, the shape of the airspace is also changed. Length of D_3 = 20, 45 and 70 nm are considered for illustration purposes. Separation minima values are the same as in Scenario 1. Figure 5 represents the hourly number of conflicts for the given sector, dependent on airway length D_3. It can be observed that an increase in airway length as well as decrease of S_{min} produce decrease of hourly number of conflicts for unchanged demand. This fact is related to the conclusions of some previous work [8, 9]. In the case of separation minima equal to 0.038 nm, the obtained result presents hourly numbers of potential collisions and their values are $2.01 \cdot 10^{-4}$, $8.95 \cdot 10^{-5}$ and $5.75\ 10^{-5}$ for D_3 = 20, 45 and 70 nm respectively.

5. CONCLUSION

The aim of the developed risk assessment model is to be used for comparison purposes at the strategic planning level. Namely, during the process of airspace design and organization one can seek to find design with lower risk of conflict and higher capacity. The model developed in this research allows for the estimation of the number of conflicts at intersections or along airways as well as probability of conflicts. These two metrics are taken as risk indicators. Also, the model allows for the determination of the most suitable combination of demand and supply indicators which will be balanced with risk and capacity requirements (less risk, more capacity). The model is intended for use both in en-route as well as TMA's airspace. Further research will consider application of the developed model on real life cases as well as development of planning models for tactical and operational levels.

[3] Current separation minima values in en-route and TMA airspaces are 3, 5 and 10 nm. Value of 0.038 nm represents a dimension of an aircraft (approximately of 70 m in length and wing span).

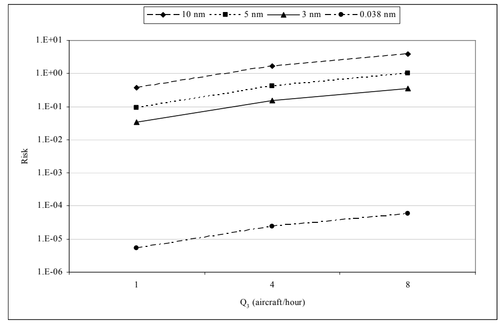

Figure 4: Hourly number of conflicts for the given sector dependent on traffic flow on AWY_3

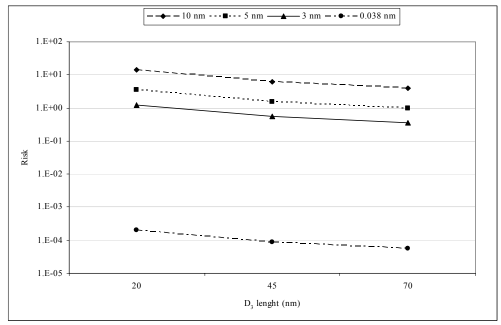

Figure 5: Hourly number of conflicts for the given sector dependent on length D_3

REFERENCES

[1] Siddiqee, W., "A Mathematical Model for Predicting the Number of Potential Conflict Situations at Intersecting Air Routes", *Transportation Science*, 7(2) (1973) 158-67.

[2] Siddiqee, W., "A Mathematical Model for Predicting the Duration of Potential Conflict Situations at Intersecting Air Routes", *Transportation Science*, 8(1) (1974) 58-64.

[3] Schmidt, D., "On the Conflict Frequency at Air Route Intersections", *Transportation Research*, 11 (1977) 351-5.

[4] Bahr, N., *System Safety Engineering and Risk Assessment: A Practical Approach*, Taylor & Francis, London, 1997.

[5] Geisinger, K., "Airspace conflict equations", *Transportation Science*, 19(2) (1985) 139-53.

[6] Campbell, S., "Determining overall risk", *Journal of Risk Research*, 8(7-8) (2005) 569-81.

[7] Willemain, T., "Factors Influencing Blind Conflict Risk in En Route Sectors Under Free-Flight Conditions", *Transportation Science*, 37(4) (2003) 457–70.

[8] Datta, K., Oliver, R., "Predicting risk of near midair collisions in controlled airspace", *Transportation Research Part B*, 25 (1991) 237–52.

[9] Sherali, H., Smith, J., Trani, A., Sale, S., "National airspace sector occupancy and conflict analysis models for evaluating scenarios under the free-flight paradigm", *Transportation Science*, 34(4) (2000) 321–36.