

[EN-032] HIGH DENSITY EN ROUTE AIRSPACE SAFETY LEVEL AND COLLISION RISK ESTIMATION BASED ON STORED AIRCRAFT TRACKS

(EIWAC 2010)

[†]E. Garcia*, F. Saez**, R. Arnaldo**

* CRIDA (ATM Research, Development and Innovation Reference Centre)
Madrid, Spain
egarcia@crida.es

**Air Navigation Department
Universidad Politécnica de Madrid (UPM)
Madrid, Spain
franciscojavier.saez@upm.es
rosamaria.arnaldo@upm.es

Abstract: The major constraint in developing appropriate monitoring methodologies and tools to assess the level of safety in en-route airspaces where controllers monitor air traffic by means of radar surveillance and provide aircraft with tactical instructions lies in the estimation of the operational risk. The operational risk estimate normally relies on incident reports provided by the air navigation service providers (ANSPs). The provision of incident reports is highly dependent on the safety management practices of each ANSP and requires the complete cooperation of both controllers (in identifying and reporting altitude deviations) and incident investigators (in providing operational reports to the RMA in good time). The EUROCONTROL 2009 SRC Annual Safety Report concludes that whilst "there has been an improvement in reporting of safety occurrences, overall progress towards full reporting by states is too slow."

This paper presents a new and innovative approach to assessing aircraft safety level within En-route Airspaces based upon the process and analysis of radar tracks. The proposed methodology has been designed to complement the information collected in the accident and incident databases, thereby providing the following information inferred from the in depth assessment of proximate events.

Keywords: collision risk model, software tool, safety metrics, radar data, level of safety

1. INTRODUCTION

EUROCONTROL has worked in the last years to implement as a software prototype tool the 3-D collision risk model (CRM). The 3-D collision risk model was developed as a general mathematical framework to assess the level of safety in continental en-route airspace, where controllers monitor air traffic by means of radar surveillance and provide aircraft with tactical instructions as required for safety or operational reasons [1], with the necessary skills and experience to achieve the challenge of automation. This paper presents the work which is currently carried out by CRIDA and the Polytechnic University of Madrid on this model.

The objective of the software prototype tool is not only to eventually produce an estimation of the level of safety achieved in the airspace under assessment but also to provide safety-related metrics and trends, which can be monitored over time.

1.1 A Brief Introduction to CRMs

The risk of collision between aircraft was initially studied in the early 1960s by B. L. Marks [2] and P. G. Reich [3]. The Reich model assesses the collision risk for an airway structure consisting of one or more parallel routes. ICAO has used the Reich model with some minor modifications to, for example, assess the minimum safe separations between parallel routes in the North Atlantic Organised Track System [4].

However, the main problem with the application of the Reich CRM in the European airspace is that the model assumes procedural control and takes no account of the intervention capability of Air Traffic Control (ATC) to monitor and prevent conflicts and hence collisions.

In the past years great effort has been invested in the development and improvement of Collision Risk Models. Some authors have extended the original Reich model (Anderson/Karppinen [5] 1994, Bakker/Blom [6] 1993). Others researchers have worked on new models applied to different geographic regions (i.e. USA [7], en-route

controlled airspace [8]), to different flight regimes (i.e. landing on closely [9] and ultra closely spaced runways [10]), to specific flight phases (i.e. separation between aircraft on final approach and landing [11]), to different types of separation (vertical and longitudinal as well as lateral) and to current and future operational concepts [12].

Nevertheless none of the previous models is appropriate to assess and monitor the level of safety in high density en-route radar airspaces using as a sole source of input data the recorded aircraft trajectories. Traditional approaches to Collision Risk Models (CRM), generally based upon statistical or probabilistic concepts do not capture the complexity inherent to an operational radar environment like the one in Europe, with high amount of traffic, a large number of crossings tracks, climbing and descending aircrafts and complicated route structure. It has to be noticed that, besides its importance and potentiality for safety level assessment, not too much effort have been devoted until now to the development of risk and collision models based upon the analysis of the stored aircraft tracks that have flown in it within a given time frame.

1.2 Need for a New Collision Risk Model

On behalf of ICAO, EUROCONTROL has been acting as the European Regional Monitoring Agency (EUR RMA) since the reduced vertical separation minimum (RVSM) was implemented in Europe. The EUR RMA continuously monitors RVSM operations and provides an annual estimate of the overall vertical collision risk for the EUR RVSM airspace. A collision risk model is used to provide that estimate. The major constraint of the methodology lies in the estimation of the operational risk. The operational risk estimate relies on altitude deviation reports provided by the air navigation service providers (ANSPs). The provision of altitude deviation reports is highly dependent on the safety management practices of each ANSP and requires the complete cooperation of both controllers (in identifying and reporting altitude deviations) and incident investigators (in providing operational reports to the RMA in good time). The EUROCONTROL 2009 SRC Annual Safety Report [13] concludes that whilst "there has been an improvement in reporting of safety occurrences, overall progress towards full reporting by states is too slow."

Consequently, the EUR RMA sought an alternative method to assess operational risk, and a method of assessing the operational collision risk due to all causes for European en-route airspace has been developed using radar data. The basis of this method is a 3-dimensional mathematical framework (3-D CRM) developed in 2000 [14].

The two main features of the 3-D CRM are that it does not rely on altitude deviation reports for the assessment of operational risk and that it explicitly accounts for the effect of ATC/aircrew intervention in European en-route airspace within radar cover and under tactical control. A major

element of the development of the 3-D CRM for European airspace is therefore to quantify the role of ATC (and aircrews) in preventing mid-air collisions.

A basic problem in collision risk modeling is that, fortunately, collisions between aircraft are rare events. The 3-D CRM relates aircraft collision events, therefore, to more frequently occurring events involving pairs of aircraft for which the 3-D distance between the aircraft is less than a horizontal proximity distance, say, d_h , and a vertical proximity distance, say, d_v . The values of d_h and d_v are to be chosen such that the proximate event frequency can be estimated from the radar data with a high level of precision and confidence. These more frequently occurring events are called proximate events.

Conflicts and potential conflicts are examples of proximate events with the proximity distances d_h and d_v taken as the prevailing horizontal and vertical separation minima respectively, i.e. a conflict is taken to mean a simultaneous violation of horizontal and vertical separation minima and a potential conflict is a situation which would result in conflict if not corrected within a given look-ahead time (LAT) by the ATC and aircrew of one or both aircraft. In other words, a potential conflict is a situation where aircraft on conflicting paths would lose both vertical and horizontal separation within the look-ahead time.

Given that an aircraft pair is involved in a proximate event, the 3-D CRM then models the probability of the event developing into a collision, i.e. a situation in which the minimum horizontal and vertical distance between the centers of the aircraft is less than the average aircraft length denoted λ_{xy} and the average aircraft height denoted λ_z .

This probability is modeled as the product of two conditional probabilities, namely the probability that a potential conflict results in an actual conflict and the probability that, once a conflict has occurred, a collision follows. This can be expressed as:

$$P(\text{collision} | \text{potential conflict}) = P(\text{collision} | \text{conflict}) \times P(\text{conflict} | \text{potential conflict}).$$

More precisely, the conditional probability $P(\text{conflict} | \text{potential conflict})$ assumes that no corrective action to prevent the conflict is taken by either aircraft and that they continue in straight flight at constant speed at least until the closest point of approach (CPA). Similarly, the conditional probability $P(\text{collision} | \text{conflict})$ assumes a failure of the ATC/aircrew safety monitoring and prevention capability.

Finally, to complete the definition of the model, look-ahead time, LAT, is taken to mean the time-horizon within which all aircraft positions are projected in order to explore the existence of "potential conflicts". The main trade-off with regard to the look-ahead time is between

avoiding the identification of “potential conflicts” by extrapolation too far into the future and between avoiding to filter out any risk-bearing potential conflicts.

A prototype software tool has been developed for the benefit of the application of the 3-D CRM framework to the assessment of European en-route airspace scenarios using radar data. The following sections of this paper provide a detailed description of the functionality of this prototype tool.

2. BACKGROUND

As stated in [15], “accidents are dramatic examples, among other less critical events, pointing out how prospective assessment methods often poorly represent human and organizational aspects and hence limit their value for accident prevention”.

According to the above statement a Collision Risk Model should give both level of safety figures and useful safety metrics to identify “system weaknesses” that require mitigation. These metrics are vital in explaining the variation in collision risk estimates provided by the model upon analyzing different airspaces, or the same airspace in different time-periods.

Nowadays, ANSP and Civil Aviation Authorities (CAA) mainly use ATM accident and incident databases to monitor and provide evidence of levels of safety. However, although these databases are very powerful tools and are improving constantly, they still have some weak points that need to be considered:

- Not all incidents are reported by pilots and air traffic controllers. In fact, it is very difficult to infer how many real incidents have occurred for each one that is reported.
- Incident severity is generally ranked solely on how close aircraft get, without considering the geometry of the event or other parameters, e.g. closure rate.
- Incident Classification is not homogeneous in all databases. Furthermore, special care has to be taken to train database personnel so that the same classification criteria always apply.

Sometimes the evolution of a mid-air incident is very complex making it difficult to capture all of the information relating to this incident in a database.

A major objective of the 3-D CRM tool is to complement the information collected in the accident and incident databases, thereby providing:

- Identification of all proximate events based on radar data.
- Complete classification of all proximate events using clear and consistent criteria.

- Detailed information on the evolution of each proximate event.
- Collision risk estimate

3. GENERAL DESCRIPTION OF THE 3-D CRM PROTOTYPE SOFTWARE TOOL

The objective of the 3-D CRM prototype software tool is to process the radar data in order to eventually provide an estimate of the operational risk in the airspace under assessment. In the development of the 3-D CRM software prototype tool, the following criteria have been taken into account:

- The capability to handle large amounts of radar data in an efficient way with a high level of automation;
- The provision of a user-friendly interface;
- The provision of a graphical interface to visualise potential conflicts and conflict areas; and
- A modular development to allow different modules to be run either individually or jointly.

The 3-D CRM tool processes are grouped into two main functionalities that can be run independently or sequentially: the Radar Data Processing (RDP) Module, and the Safety Metrics Estimation (SFE) Module.

The RDP Module reads the radar data in ASTERIX format performs track segmentation and identifies all proximate events within a selected scenario.

The SME Module calculates all the parameters of the mathematical model; providing estimates of the probability of collision within the scenario and several other safety metrics.

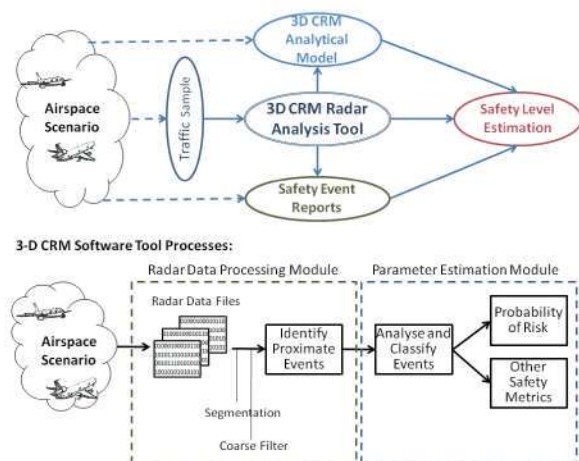


Figure 1. 3-D CRM Software Tool

4. RADAR DATA PROCESSING

The basic input data required to run this module of the 3-D CRM prototype software tool are radar data files, but the prototype software tool can also handle flight plan data, if

available, to optimise the performance of some of its functions (e.g. identification of military traffic).

The processing of radar data poses two major problems, namely:

- the large amount of information held to represent the track followed by each aircraft; and
- the complexity of the proximate event identification and characterisation, which is carried out using algorithms of the short-term conflict alert (STCA) type to determine the distance between the actual or potential (projected) position of each aircraft, and the positions of all other aircraft at that moment.

These problems can be simplified, given that, in the scenarios corresponding to en-route airspace, most aircraft behave in a fairly regular manner, with "segmented" paths. This means that the paths are made up of an ordered sequence of "straight" sections, with altitude or course changes at specific points. In addition, the speed of the aircraft in each segment is mainly uniform. To take advantage of these characteristics, an aircraft track segmentation process has been implemented. The identification and analysis of potential conflicts (section 4) is based on this aircraft track segmentation (see [1]).

The radar data pre-processing module therefore comprises two different sub-modules to perform important pre-processing functions: decoding and storage of radar track and flight plan files, and track segmentation of radar data.

4.1 Decoding and storage of radar track and flight plan files

This sub-module decodes all the information contained in the selected input files. The minimum set of data needed to perform the 3-D CRM calculations is the aircraft state vector, consisting of position, velocity, rate of climb/descent, flight level, track number and time of track information for each aircraft flying into the airspace under assessment.

4.2 Track Segmentation

The purpose of segmentation is to represent the real track of each aircraft by a segmented track, composed of a series of segments. The track segmentation process identifies when an aircraft is turning, changing its vertical attitude, or modifying its speed. Based on this, the full detailed track of each aircraft is replaced by a series of line segments between the points of change. This segmented track is characterised by the sequence of points of change with defined coordinates, the times at which an aircraft passes the points of change, and the speeds for each segment.

Each point of the segmented track is supplemented by certain characteristics, indicating whether the aircraft is starting a turn, finishing a turn, changing attitude, rate of climb/descent, speed, etc.

A segmentation criterion is used that minimises the number of segments in the trajectory which represents the real path of an aircraft, whilst ensuring that a specified maximum error limit is not exceeded at the same time.

4.3 Proximate Event Identification

The main task of this function is to identify all the proximate events of a scenario. In order to perform this task, the following parameters must be introduced in the 3-D CRM tool:

1. **Scenario Definition:** time interval and airspace boundaries of the scenario.
2. **Look-ahead time (LAT):** is the time horizon within which all aircraft positions are projected to explore existence of "potential conflicts". The main purpose of the look-ahead time is to ensure that "potential conflicts" are not identified by extrapolation too far into the future. However, it needs to be long enough so that no risk-bearing potential conflicts are filtered out. After several meetings with air traffic controllers and pilots, and careful analysis of the literature (e.g., [16]) a look-ahead time of 10 minutes was initially chosen for the model. However, the 3-D CRM tool allows filtering of events based on any of the model parameters.
3. **Conflict Definition:** The conflict zone is represented by a cylinder of radius R and height $2H$ centred about one of the aircraft, where R and H are the horizontal and vertical separation minima. R and H are often taken to mean the actual radar separation minima of 5 NM and 1000 ft applicable in the European airspace.
 - R : radius of the conflict volume
 - H : height of the conflict volume
4. **Collision Definition:** Two aircraft, represented by cylinders with a circular base of diameter λ_{xy} and height λ_z , are in collision when the horizontal component of the separation vector between their centres is within λ_{xy} and the vertical component between $-\lambda_z$ and $+\lambda_z$; in other words, if one aircraft (represented by a point at its centre) sits inside a cylinder centred on the other aircraft with radius λ_{xy} , and height $2\lambda_z$.
 - λ_{xy} : Aircraft length (or wingspan if longer)
 - λ_z : Aircraft height

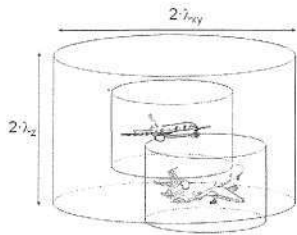


Figure 2. Collision Definition

After segmentation of the paths of all aircraft in the scenario, two aircraft will be in potential conflict when the two following conditions are met at the same time:

- The vertical separation between the projected positions of both aircraft is less than or equal to the vertical separation minimum established by H; and
- The separation in the horizontal plane between the projected positions of the aircraft is less than or equal to the horizontal separation minimum established by R.

The formulae to obtain the instant of time of minimum separation and the corresponding distance are based on the hypothesis of the aircraft flying straight and at constant speed.

5. SAFETY METRICS ESTIMATION

The following processes are performed in the 3-D CRM safety metrics estimation module:

5.1 Analysis of Proximate Events

The 3-D CRM tool initially identifies all proximate events and then performs an in-depth analysis of each of them, thereby determining:

- 1) The time that the proximate event was first identified (t_{CI}), the predicted time of Closest Point of Approach (CPA) (t_{CPA}) and other event information, such as, relative speeds between aircraft, real separation at that time and vertical and horizontal separation at CPA. To illustrate the parameters calculated in the proximity analysis, the following figure describes the vertical positions and attitudes of two aircraft, in potential conflict, flying on the same route.

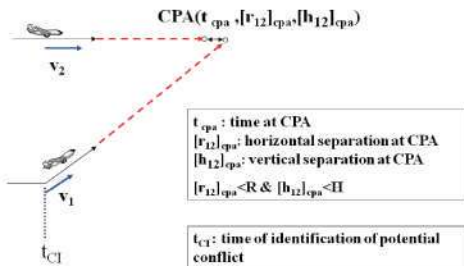


Figure 3. Example: First time to identify the proximate event

- 2) Turns, changes in the speed or in the vertical attitude of the aircraft. Track segmentation identifies a turn or change in vertical attitude or speed of the aircraft. The

analysis carried out by the 3-D CRM tool uses the information provided by track segmentation to identify the time of a manoeuvre and stores all of the parameters associated with this change: relative speeds between aircraft, real separation at that time and new vertical and horizontal separation at the CPA (Fig. 4).

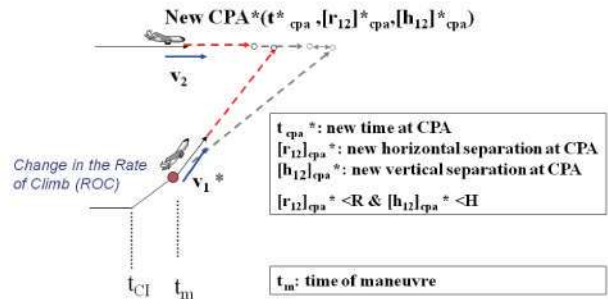


Figure 4. Example: Detection of Manoeuvres. Potential Conflict still exists.

- 3) Manoeuvres performed by the aircraft to erase the potential conflict. The software tool identifies what type of manoeuvre was performed and when such actions were initiated. See Fig. 5-3.

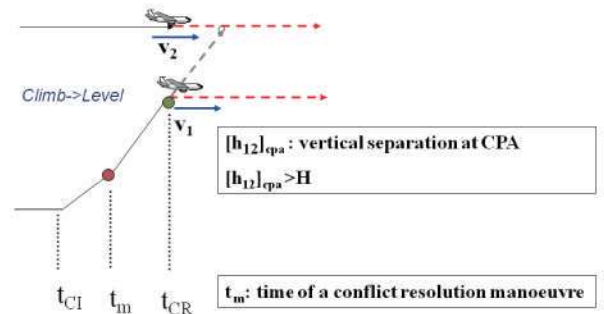


Figure 5. Example: Detection of Manoeuvre. Resolution of Potential Conflict.

- 4) The time when two aircraft enter in conflict (t_{CF}). The software tool monitors the actual separation between the aircraft and detects when they simultaneously lose both horizontal and vertical separation. The tool stores all of the information related to this event.

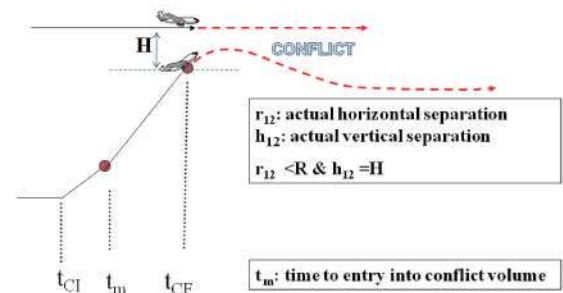


Figure 6. Example: Loss of both horizontal and vertical separation.

- 5) Activation of traffic alert and collision avoidance system (TCAS) and the short-term conflict alert system (STCA). The software tool tries to reproduce the logic of the TCAS and the STCA to identify situations in which it is believed that a TCAS resolution advisory, a TCAS traffic advisory or an STCA alert would have been triggered.
- 6) When the distance between a pair of aircraft increases as a function of time, the pair is said to be diverging. A diverging pair is no longer analysed, provided that the present separation is equal to or greater than the horizontal separation minima.

As a result, the 3-D CRM prototype software tool calculates and stores for each proximate event: the time of identification of a potential conflict (t_{CI}), the start of a conflict resolution manoeuvre (t_{CR}), the predicted time of entry into the conflict volume (t_{CF}), and the predicted time of CPA (t_{CPA}). It also tries to distinguish whether no action was taken, or whether the potential conflict was resolved either by an action in the horizontal plane or by one in the vertical plane

Once the analysis of the proximate event is complete, the 3-D CRM prototype tool automatically generates a report describing the proximate event in terms of the changes in the main parameters.

5.2 Classification of Proximate Events

The 3-D CRM prototype software tool classifies proximate events on the basis of the following criteria: nature, traffic type, vertical regime, relative heading, aircraft reaction and activated alert system (TCAS, STCA).

The information for the last criterion (activated alert system) is obtained from analysis of times-to-go to CPA.

This classification is essential in order to carry out the statistical analysis required to provide an estimate of the level of collision risk.

CRITERIA OF CLASSIFICATION OF PROXIMATE EVENTS					
NATURE	TRAFFIC TYPE	VERTICAL REGIME	RELATIVE HEADING	A/C REACTION	ACTIVATED ALERT SYSTEM
Conflict	Civil Traffic	Level-Level	Same	Change vertical Profile	TCAS RA
Potential conflict	Both Military Aircraft	Climb-Level	Opposite	Modify Heading	TCAS TA
Potential Collision	One Military Aircraft	Descend-Level	Crossing	Change of Speed	STCA
		Climb-Climb		No Reaction	No Alert
		Climb-Descend			
		Descent-descent			

Figure 7 Classification of Proximate Events

5.3 Detection of Activated Alert Systems

To characterize the severity of a conflict not just by infringement of the horizontal and vertical separation regulations – actual or potential –, the 3-D CRM software

tool reproduces the logic of the TCAS system to identify if and when a TCAS alert was activated.

The TCAS system is based on time-to-go to CPA, rather than distance-to-go to CPA. A warning time or threshold is compared with the time-to-go to CPA, computed by dividing the slant range, between aircraft, by the closure rate. The warning time values are a function of the altitude of the aircraft. In an en-route scenario, above FL 200, the warning time of a TCAS Resolution Advisory (RA) is 35 seconds and for a TCAS Traffic Advisory (TA) 48 seconds (see [17] and [18]).

Furthermore, the algorithms implemented in the 3-D CRM software tool have extended the logic of the TCAS system to include the logic of the Short Term Conflict Alert (STCA) system (see [8]).

The STCA is also based on Time-to-Go to CPA and normally uses a warning time of two minutes, as described in [19]. This threshold of two minutes can also be used to distinguish between tactical ATC actions (when a proximate event is resolved with time-to-go to CPA lower than two minutes) and strategic ATC actions (when a proximate event is resolved with time-to-go to CPA larger than two minutes).

The logic implemented in the 3-D CRM can be represented as follows:

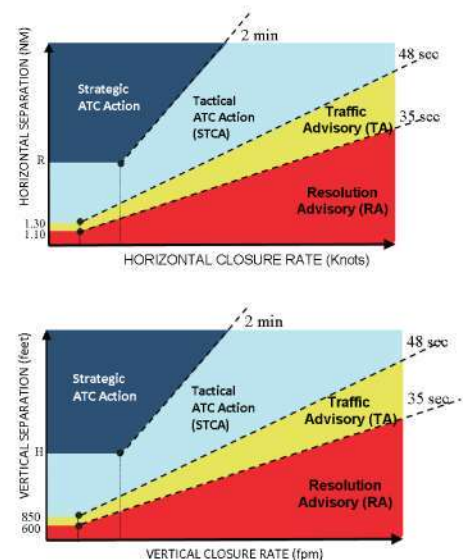


Figure 8. TCAS and STCA logic diagrams

A TCAS RA is activated if the kinetic and geometric characteristics of the event in the horizontal and vertical planes are in the red area at the same time.

Although the thresholds or warning times of the Alert System considered (TCAS and STCA) are fixed on the specifications of each system, a sensitivity test have been undertaken to examine the possible effects of using different values to the thresholds of the Alert System (i.e.

values other than the 120, 48, and 35 sec). Figure 9 shows the sensitivity analysis of the identified proximate events for different values of look-ahead time using one day's radar data from the Maastricht Area of Responsibility (AoR):

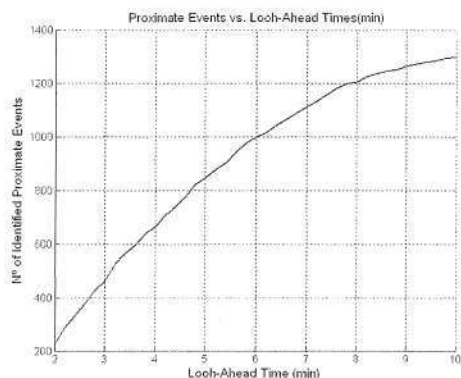


Figure 9. Proximate Events vs. Look-Ahead Time (1 day of traffic, Maastricht AoR)

As can be seen on figure 9 the longer the look-ahead time is a higher number of proximate events are identified, giving place to false detections. In the conflict detection process certain allowances for errors are granted in both the track speed and rate of climb, which imply the acceptance of a certain number of false alerts. This is particularly the case for early detections of proximate events when using long look-ahead times.

5.4 Identification of ATM System Weaknesses

To provide more comprehensive and accurate information on the level of safety of the selected airspace and time frame, the 3-D CRM tool calculates several metrics. These may be grouped in two categories:

- Risk context, which provide information on the initiating events which lead to potential collisions.
- Safety metrics, which indicate the effectiveness and stress level of safety barriers.

The risk context metrics represents traffic complexity of a selected airspace. It is defined in the 3-D CRM model in terms of the following traffic statistics:

1. Flight-Time: the sum of flight-times of all flights within the selected airspace and within a selected time period.
2. Number of Movements: the numbers of flights within the selected airspace and during a selected time period.
3. Number of Entries and Exits in the selected airspace and within a selected time period.
4. Traffic Density of the selected airspace and during a selected time period.
 - Horizontal: obtained using a grid overlay to the analyzed airspace. Depending on the number of flights flying over each cell, a colour scale is

displayed with red and yellow denoting the highest and lowest figures respectively.

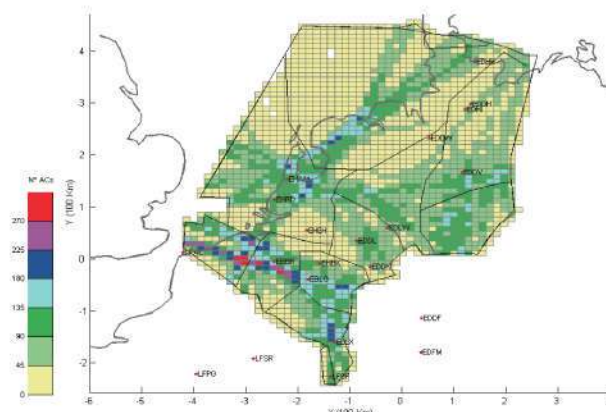


Figure 10. Maastricht Upper Airspace Traffic Density (1 day of traffic). Grid Side Length: 7.5 NM.

- Vertical: the number of aircraft per flight level, can also be displayed using a colour scale.
5. Route Structure: analysis of the traffic density map enables identification of the main flying routes of the airspace (without using flight plan data). The route structure complexity of a selected airspace can be measured using the number of flying routes and the percentage of aircraft flying outside the main routes during a selected time period.
 6. Evolving Aircraft: percentage of non-level aircraft within the selected airspace and during a selected time period.
 7. Kinematics: velocity distribution of aircraft flying in each of the main flying routes.

The safety metrics provide complete information of the main characteristics associated with the proximate events identified within the selected airspace:

1. Total number of conflicts, number of potential collisions and number of potential conflicts within the selected airspace and during a selected time period.
2. Hot Spots: Spatial and Temporal Location of Proximate Events.
3. Classification of Proximate Events by:
 - a) Nature: conflicts, potential conflict or potential collision, passing event
 - b) Traffic Type: civil or military
 - c) Vertical Regime: level, climb or descent
 - d) Relative Heading: same, opposite or crossing.
 - e) A/C Reaction: change vertical profile; modify heading or change speed.

- f) Activated Alert System: TCAS Resolution Advisory (RA), TCAS Traffic Advisory (TA) or STCA or No Alert.
- 4. Percentage of potential conflicts resolved in the vertical and horizontal planes.
- 5. Correlation between Hot Spots and traffic density maps.
- 6. Overall Reaction Time (t_1): represents the duration of the potential conflict, from the first time that the potential conflict is identified (t_{CI}) to the Conflict Resolution Time (t_{CR}) or the time of entry into conflict volume (t_{CF}) if no action is taken to resolve the encounter.
- 7. Time-to-Conflict (t_2): the period of time between the detection of the potential conflict (t_{CI}) and the (predicted) time to entry into conflict volume (t_{CF})
- 8. Time-to-go to the CPA (t_3): period of time between the detection of the potential conflict (t_{CI}) and the (predicted) time of the CPA (t_{CPA}).

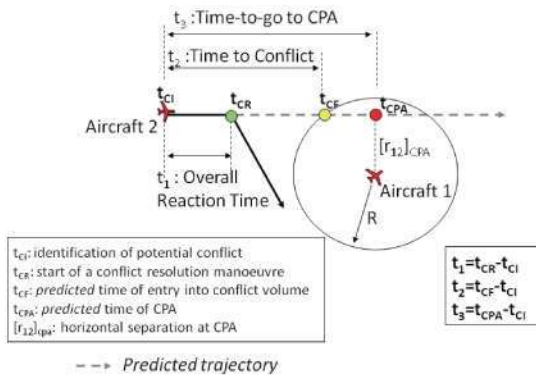


Figure 11. Overall Reaction Time, Time to Conflict and Time to CPA
 As an example, using a traffic data sample of 31 days of the Maastricht Area of Responsibility, the following figure shows a 2D histogram of the time-to-go to CPA (t_3) and the overall reaction time (t_1) obtained from the analysis of radar tracks for aircraft pairs in potential conflict:

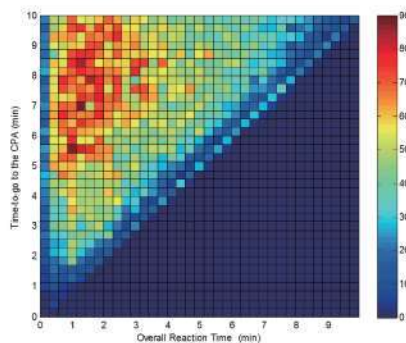


Figure 12. 2D histogram of the times-to-go to CPA and overall reaction time (31 days of radar data)

The risk context and safety metrics described above can be classified into three categories based on their relation with the three factors of the mathematical formulation of the 3-D CRM:

SAFETY METRICS		
Risk Context	Qualification of Hazards	Effectiveness of ATC Barriers
Flight-Time	Hot Spots	Number of Real Conflicts
Number of Movements	Classification of PE: Nature Traffic Type Vertical regime Relative heading A/C Reaction	Overall Reaction Time
Kinematics (Speed, Type of Aircraft)		Time Margin
N° of Entries and Exits		Time to Conflict
Route structure		Time-to-go to the CPA
N° of Potential Conflicts	Activated Alert System (TCAS, STCA)	% of Potential Conflicts Solved in the vertical plane and in the horizontal plane
Traffic Density	Correlation between Hot Spots and Traffic Density Maps	Average N° of Aircraft "near" Proximate Events
Number of Routes	N° of potential collisions	
% Evolving Aircraft		

Table 1. List of Safety Metrics

At present, clear and comprehensive thresholds and relationships for the parameters identified in the previous table are not yet available in the literature despite the fact that several past studies (e.g. Ratcliffe and Ford [20]) have attempted to clarify what could be an acceptable value for those metrics. Ratcliffe and Ford found in their study that hourly conflict rates are proportional to the aircraft warning time, the number of aircraft in the study area (quadratic function) and inversely proportional to the radius of the airspace area (also quadratic). A detailed analysis of those metrics is thought to provide a better understanding of the operational scenario under assessment and by extension a useful tool for ATM service providers.

6. CONCLUSIONS

This paper presents a new and innovative tool as a first step for building up a 3-D Collision Risk Model to assessing aircraft safety level within European Airspace based upon the process and analysis of radar tracks.

The 3-D CRM tool has been designed to complement the information collected in the accident and incident databases, thereby providing the following information inferred from the in depth assessment of proximate events:

1. Identification of all proximate events based on radar data.
2. Complete classification of all proximate events using clear and consistent criteria.
3. Detailed information on the evolution of each proximate event.
4. Safety metrics and other air traffic factors.

The paper describes the 3-D CRM tool developed to carry out this assessment describing its main functions and modules. The technical details and methodologies used in the assessment are explained and the mayor outputs are presented to illustrate the potential of on-route radar data

exploitation for Collision Risk Modelling. Further work should be carried out to:

- apply the 3-D CRM too to traffic samples of different airspaces and extend the principles of 3-D CRM from en-route to Terminal Manoeuvring Area (TMA) scenarios;
- develop a methodology to provide a complete risk picture of the scenario, identifying the ATM system weakness and characterizing the performance of the safety barriers, using all the information provided by the 3-D CRM tool that could be used by ATM service providers to monitor and improve safety levels in their operation;
- complete an analytical model based on the 3-D CRM too to provide true collision risk values.

7. REFERENCES

- [1] E. Garcia, F.Sáez, I.Izquierdo, "Identification and Analysis of Proximate Events in High Density Enroute Airspaces", 7th USA/Europe ATM R&D Seminar, Barcelona, 2007.
- [2] B. L. Marks, "Air Traffic Control Separation Standards and Collision Risk", Royal Aircraft Establishment, Tech. Note No. Math. 91, 1963.
- [3] Reich P. G, "Analysis of Long-Range Air Traffic Systems: Separation Standards -- I, II, and III"; The Journal of (the Institute of) Navigation, Vol.19,No. 1, pp. 88-98; No. 2, pp. 169-186; No. 3, pp. 331-347, 1966
- [4] P. Brooker and A. White, "Minimum Navigation Specifications and other separation variables in the North Atlantic area, UK Journal of Navigation, Vol. 32, No. 3, pp. 357 – 374.
- [5] D.Anderson. "A General Collision Risk Model for Distance Based Separation on Intersecting And Coincident Tracks"; ICAO SASP WG/A WP 21, May 2001.
- [6] G.J. Bakker and H.A.P. Blom. "Air Traffic Collision Risk Modelling"; NLR. Procedures 32nd IEEE Conference on Decision and Control. December 1993, pp. 1464-1469.
- [7] Dr. H. D. Sherali, C. Smith, Dr. A.A. Trani, S. Safe, Q. Chuanwen. "Analysis of Aircraft Separations and Collision Risk Modeling. NEXTOR", National Center of Excellence for Aviation Operations Research 1998.
- [8] Peter Brooker. "Radar Inaccuracies and Mid-Air Collision Risk: Part 2 En Route Radar Separation Minima", THE JOURNAL OF NAVIGATION (2004), 57, 39–51. f The Royal Institute of Navigation DOI: 10.1017/S037346330300256X Printed in the United Kingdom.
- [9] Carpenter, Brenda D., MIT, Cambridge, MA; Kuchar, James K. "Probability-based collision alerting logic for closely-spaced parallel approach", AIAA-1997-222 Aerospace Sciences Meeting and Exhibit, 35th, Reno, NV, Jan. 6-9, 1997.
- [10] Powell, J. David, Stanford Univ., CA; Houck, Sharon. "Assessment of the possibility of a midair collision during an ultra closely spaced parallel approach", Stanford Univ., CA. AIAA-2001-4205 AIAA Guidance, Navigation, and Control Conference and Exhibit, Montreal, Canada, Aug. 6-9, 2001.
- [11] . R. Shepherd, R. Cassell, T. Rannoch, L. Rajeev, R. Derrick. "A reduced aircraft separation risk assessment model"; AIAA-1997-3735 AIAA Guidance, Navigation, and Control Conference, New Orleans, LA, Aug. 11-13, 1997, Collection of Technical Papers. Pt. 3 (A97-37001 10-63).
- [12] Blom, H.A.P., Bakker, G.J., Blanker, P.J.G., Daams, J., Everdij, M.H.C., and Klompstra, M.B. (2001), "Accident Risk Assessment for Advanced ATM," In: Air Transportation Systems Engineering, G.L. Donohue and A.G. Zellweger (Eds.), AIAA, 2001, pp. 463-480.
- [13] EUROCONTROL, "2009 Safety Regulation Commission Annual Safety Report", 2009
- [14] L. Burt, "3-D Mathematical Model for ECAC Upper Airspace", Eurocontrol, Final Report, October 2000.
- [15] Maria Chiara Leva a, Massimiliano De Ambroggi, Daniela Grippa, Randall De Garis b, Paolo Trucco, Oliver Sträter. "Quantitative analysis of ATM safety issues using retrospective accident data: The dynamic risk modelling project", Safety Science, vol. 47, Issue 2, pp. 250-264, February 2009.
- [16] S. Ternov, R. Akselsson, "A method, DEB analysis, for proactive risk analysis applied to air traffic control", Safety Science , vol. 44, pp. 629-655, 2006.
- [17] Eurocontrol, "ACAS Training Brochure", ACASA-WP6.1/015, Version 2.0, May 2000.
- [18] Federal Aviation Administration (FAA), "Introduction to TCAS II version 7", November 2000.
- [19] W. Janssen, "Conflict Alert for the Support of Radar Control in MADAP", Eurocontrol, GD-0047-03, October 1990.
- [20] Ratchiffe, S. and R.L. Ford, Conflicts Between Random Flights in a Given Area, Journal of Air Navigation , Volume 35, pp.47-71, 1982.