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AN AIRSPACE COLLISION RISK SIMULATOR FOR SAFETY ASSESSMENT

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ABSTRACT

Modelling the spatio-temporal dynamics and evolution of collision risk in an airspace is critical for multiple purposes. First, the model could be used to diagnose the critical points where the level of risk has escalated due to particular airspace configurations and/or events. Second, the model could reveal information on the rate of risk-escalation in an airspace, which could be used as a risk indicator in its own right. The aim of this paper is to present an Airspace Collision Risk Simulator for safety assessment. This is achieved by developing a fast-time simulator with a suitable fidelity for spatial-temporal analysis of collision risk using clustering methods. This simulator integrates the airspace model, flight aerodynamic model and traffic flow model to facilitate the collision risk computations and visualization. The proposed simulator is a first attempt to provide actionable information on the evolution of airspace collision risk for airspace safety assessment, offering practical benefits to the operational air traffic control environment.

1 INTRODUCTION

One of the most congested sub-system of a national airspace system is its en-route airspace. This part of the airspace typically ranges vertically from 29,000 feet, or flight level 290 (FL290), to 41,000 feet (FL410). It is known as Reduced Vertical Separation Minima (RVSM) airspace (ICAO 2002) where the vertical separation of 2000 ft (due to the Altimeter System Errors of an aircraft owing to reduced sensitivity of the altimeter to atmospheric pressure at that altitude) is reduced to 1000 ft.

The International Civil Aviation Organization (ICAO) has put in place stringent measures, both regulatory (criminal offenses to fly a non-certified RVSM aircraft in the RVSM airspace) as well as technical (ICAO requires all aircraft flying in the RVSM airspace to be certified for ASE performance by height monitoring at least once every 2 years or 1000 flying hours whichever occurs first), to ensure vertical separation safety in the RVSM airspace.

ICAO uses Airspace collision risk estimates (ICAO 2002), as a key indicator for estimating safety in a given en-route airspace. The level of risk that is deemed acceptable is termed the target level of safety (TLS), which is 2.5×10^{-9} collisions per flight hour (ICAO 2008). The collision risk is computed using mathematical models based on Reich Model proposed in early 60's (Reich 1966). The model is probabilistic in nature and focuses mainly on convolution of statistical distribution of height deviations (technical due to altimeter errors or actual due to pilot or ATC error) of two aircraft on crossing tracks averaged over flying time in a given airspace.

However, this quantitative basis fails to provide any insight regarding the spatial-temporal distribution of collision risk in an airspace. Without this understanding, airspace managers have limited opportunity to improve the safety in their airspace. In recent research (Nguyen and Alam 2018), authors have proposed a clustering approach to identify collision risk hot-spots. However, a key limitation of that approach is that

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it does not account for temporal dimension of collision risk. Airspace managers need an insight into how the collision risk clusters are formed, disperse and move over time with different traffic scenarios.

The ICAO report of the fifteenth meeting of the Middle-East Regional Monitoring Board, held in January 2018 (ICAO 2018), identified a need for a spatial-temporal simulation and visualization of airspace collision risk for improving our understanding of traffic patterns that may have contributed to collision risk.

In this paper, we propose an airspace collision risk simulator that can process airspace and air traffic data, simulate air traffic, compute necessary collision risk parameters and visualize the spatial-temporal distribution and evolution of collision risk for a given airspace. The simulator is developed for the Middle-East region, which covers 16 national airspace. The proposed collision risk simulator provides spatial and temporal insights into the evolution of airspace collision risk over time.

The rest of this paper is organized as following: background information on airspace collision risks is introduced in the next Section. Section 3 details the modelling process and simulator implementation for our proposed low fidelity air traffic simulation. We then present a case study which analyzes a daily collision risk evolution in the Middle East region in Section 4. We conclude the paper with our future research directions in the last section.

2 BACKGROUND

The definition of collision risk given by ICAO is: "the expected number of mid-air aircraft accidents in a prescribed volume of airspace for a specific number of flight hours due to loss of planned separation" (ICAO 2008). ICAO also defines TLS as the level of risk that is deemed acceptable (ICAO 2013). Hence, the collision risk assessment methodology requires risk estimation and risk evaluation. Risk estimation estimates the actual level of risk of an air traffic activity in an airspace. Meanwhile, the risk evaluation process consists of comparing the estimated risk against a TLS to provide a quantitative basis for judging the safety of air traffic operations in a given volume of the airspace.

Flight levels are organized such that traffic on the same flight level is moving in the same direction. A mid-air collision between two aircraft nominally separated by 1,000ft is more likely to occur if either one or both aircraft were to deviate vertically from their assigned flight level such that the vertical separation between the aircraft is lost. There are two main reasons why an aircraft may not be at its assigned flight level: normal height deviations and large height deviations. Normal height deviations arise because of typical assigned altitude deviations (AADs) and altimetry system errors (ASE), which are technical in nature whereas large height deviations occur because of operational issues such as a coordination failure, level burst or Traffic Collision Avoidance System (TCAS) maneuver.

The collision risk simulator focuses on technical vertical collision risk only. The vertical risk is computed, using historic flight data and takes into account, among several factors, the accuracy of navigation, the airway structure, the aircraft population, and the total flying time within the airsapce. The simulator uses ICAO Collision Risk model (ICAO 2008) to compute Vertical Collision Risk. While this model is based on the Reich collision risk model, it differs from the Reich model (for oceanic traffic) as it accounts for the complexity and variability of the traffic patterns in continental radar controlled airspace. The model has three main parameters: the probability of vertical overlap, the frequency of horizontal overlap events per flight hour, and the weighted average of kinematic factors. The latter is the combined parameters dependent on the geometry of the proximate pairs.

3 METHODOLOGY

There are three important concepts in the design of a collision risk simulator; these are: resolution, abstraction, and fidelity. Resolution is a level of detail at which we see a system. Abstraction is a level of detail at which we represent a system by a model according to the resolution. Fidelity is a level of detail at which a model or a simulation actually reflects a system according to the abstraction, and fidelity also affects the level of detail on the outputs from a simulation (Abbass 2014). Usually, there is a trade-off between the fidelity and efficiency of a simulator. A simulation with higher fidelity requires higher computational resources and longer time. A decision to choose the right fidelity level is critical during design for the simulator to successfully meet the design requirements. In this paper, our objective is to design and implement a simulator which has the low fidelity of the flight aerodynamics model but can capture the air traffic flow characteristics for undertaking collision risk analysis on-the-fly. Therefore, a fast simulation with efficient and effective aerodynamic modelling is essential.

Since the objective of this research is to design and develop a fast simulator for spatial-temporal analysis of airspace collision risk, the proposed simulator has to be fast enough to generate and synchronize flight trajectories for a given airspace, and be able to perform collision risk computations. To satisfy the requirement for efficiency, the behaviour of a flight as being governed by aircraft aerodynamics is one aspect to consider. Aircraft aerodynamics could be modelled in different detailed and complex ways for a high fidelity simulation, but will require significant computational resources. Here, the collision risk analysis requires a flight's 4-Dimensional trajectories (aircraft position with time) and flight velocities rather than the detailed aircraft behaviours, such as yawing, rolling, and pitching. Therefore, we map the aircraft aerodynamic into a highly abstracted model based on Total Energy Model (TEM). As a result, the proposed model simulates flights and produce 4D trajectories in an efficient and effective way such that collision risk computations can be performed with the simulator.

Based on this principle, we propose an airspace collision risk simulator with low aerodynamics fidelity. In addition, an intuitive spatial-temporal representation of the collision risk evolution is proposed that visualizes risk clusters over time.

3.1 Simulator Architecture

The architecture of the proposed simulator is illustrated in Figure 1. The simulator takes aeronautical and Geographic Information System (GIS) data as input for modelling a given airspace, and uses the Base of Aircraft Data (BADA) (Nuic 2004) for aircraft aerodynamic model to construct the individual 4D flight motions. Based on the flight plans, Air traffic flow model syntheses individual flight trajectories into air traffic flows within the modelled airspace. The crossing tracks between flights from the simulated traffic are computed for collision risk analysis by using the collision risk model. Meanwhile, the air traffic and collision risks are visualized and presented as shown in the figure.

The following sections describe each model in the sequence of the data flow within the proposed collision risk simulator.

3.2 Airspace Model

First, the airspace model takes the aeronautical and GIS data as input to produce a digitized airspace. A number of aeronautical and GIS data types are required including Flight Information Regions (see figure Figure 2), Waypoints (see Figure 2c), and Airway (see Figure 2d). Figure 2b shows the aerodromes and airports in the Middle-East region.

3.3 Flight Aerodynamic Model

A typical approach for modelling aircraft aerodynamic is by using Eurocontrol's Base of Aircraft Database (BADA) (Nuic 2004) that provide for computations of various aerodynamic parameter for a given aircraft type. The aircraft model applied in BADA 3.6 is a point-mass model which balances the rate of work done by forces acting on the aircraft and the rate of increase in potential and kinetic energy. This approach, referred to as a Total Energy Model (TEM), is represented by the following equation:

$$[h](T-D)\times v_{TAS} = m\times g\times\frac{dh}{dt}+m\times v_{TAS}\times\frac{dv_{TAS}}{dt} \quad (1)$$

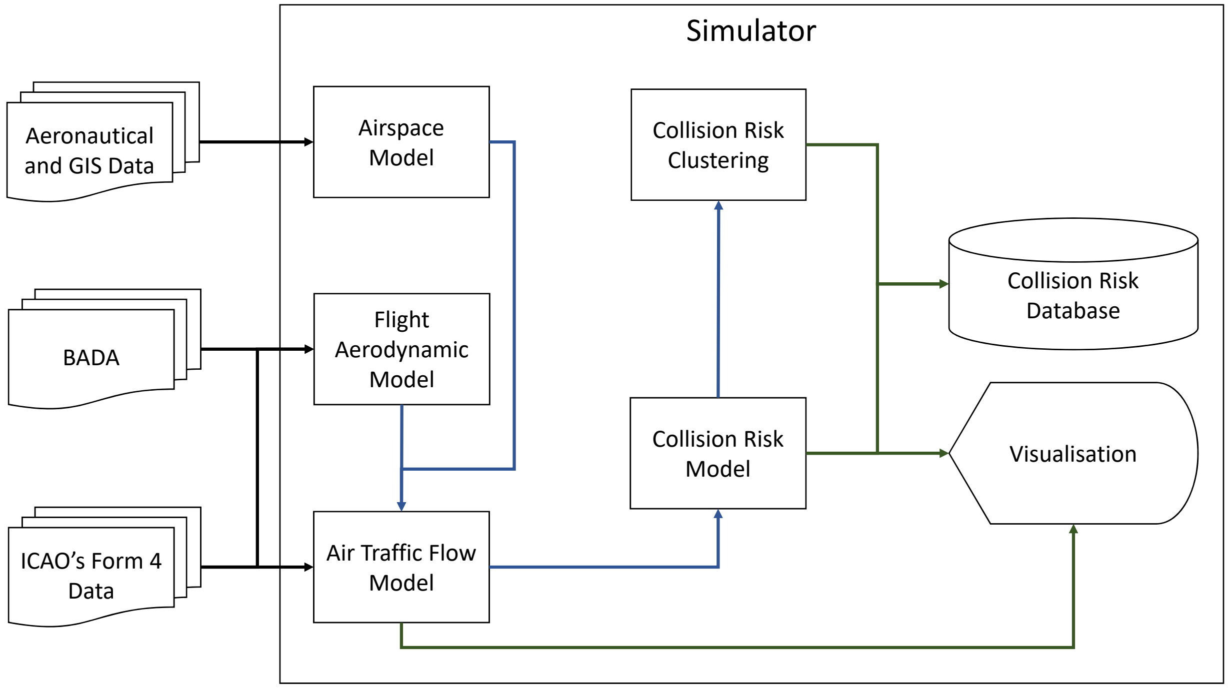


Figure 1: The architecture of the simulator.

where, T is the thrust, D is the aerodynamic drag, m is the aircraft mass, g is the gravitational acceleration, v_{TAS} is the true air speed of the aircraft, and h is the altitude of the aircraft.

Given an aircraft type and flight phase, the aerodynamics of the aircraft (such as air speed (TAS), rate of climb and descent (ROCD), and thrust) at any time instance can be esatimated by using "BADA Performance Tables Files" (BADA PTF) to obtain two essential aircraft states, TAS and ROCD, for updating aircraft 4D positions.

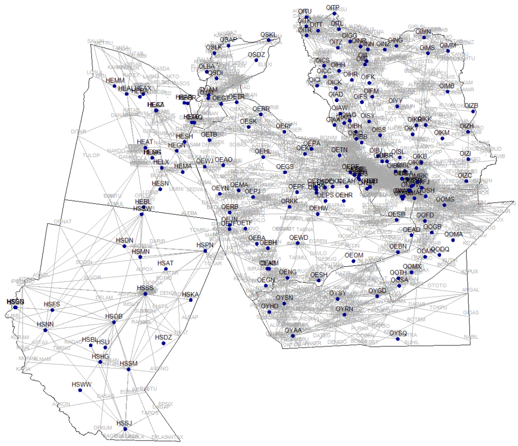
However, BADA PTF doesn't provide TAS and ROCD of an aircraft at any given flight levels. Therefore, a linear interpolation method is applied in our model to estimate the TAS and ROCD at a given flight level (h) by Equation 2.

$$TAS_h = TAS_{h_1} + \frac{TAS_{h_2} - TAS_{h_1}}{h_2 - h_1} \tag{2a}$$

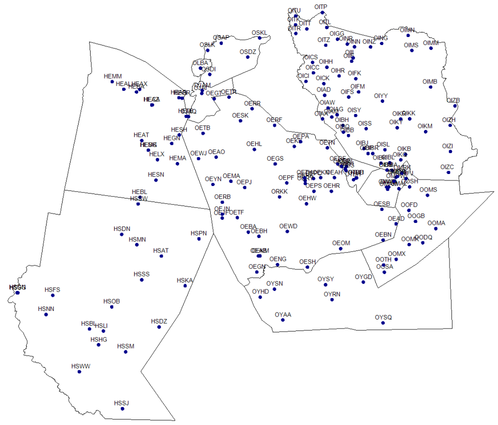
$$ROCD_h = ROCD_{h_1} + \frac{ROCD_{h_2} - ROCD_{h_1}}{h_2 - h_1} \tag{2b}$$

where $h_1 < h < h_2$, and both true air speed and rate of climb and descent are available at flight level of h_1 and h_2 in BADA PFT for a given aircraft. Based on Equation 2, the cruising TAS of an Airbus 330-200 is 272 knots at FL70. Similarly, the climb rate of this aircraft type with nominal weight is 3015 feet per minute at FL70.

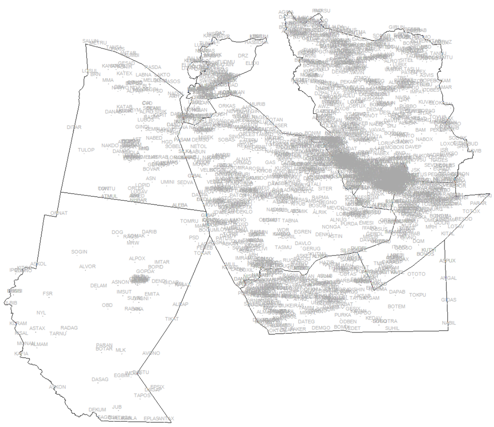
It is worth noting that both TAS and ROCD of a given aircraft can be extracted from BADA PTF if the aircraft's type, mass, flight phases, and flying altitude are known. The aircraft type can be known from flight plan; and the proposed simulation model assumes that all aircraft mass are nominal for estimating the ROCD for a climbing aircraft. The altitude of an aircraft can be calculated by its ROCD and flight phase during the simulation. However, the flight phase is an unknown parameter.



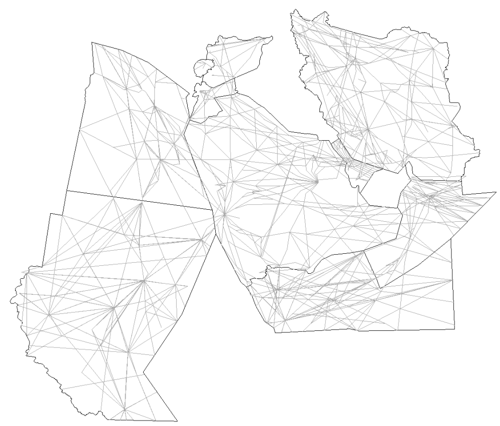
(a) FIR all information



(b) Airports



(c) Waypoints



(d) airway routes

Figure 2: Digitized aeronautical and GIS data of Middle East Region visualized in simulator.

3.4 Air Traffic Flow Model

The Flight aerodynamic model provides a method for simulating individual flight behaviours, and the airspace model provides the environment within which the aircraft movement is simulated. However, collision risk analysis works on the totality of air traffic flows in a given airspace within a time period. Therefore, the Air Traffic Flow Model is proposed to synthesize all planned flights in the given airspace.

The simulation model needs flight plans as input. As shown in Figure 1, ICAO's Form 4 Data is our main source to acquire flight plans, which describes a flight within an FIR by a set of data fields including the following fields:

- *Flight Date*: the Coordinated Universal Time (UTC) date that a flight is activated in an FIR.
- *Aircraft Call Sign*: the unique communication identifier of a flight.
- *Aircraft Type*: the aircraft type of a flight.
- *Departure Aerodrome*: the origin aerodrome where a flight departs.
- *Arrival Aerodrome*: the destination aerodrome where a flight goes.
- *Entry Waypoint*: the first waypoint where a flight enters an FIR.
  - An "Entry Waypoint" of a flight is as same as its "Departure Aerodrome" if both are within the same FIR and flight is activated at departure aerodrome.

  - Otherwise, they are different and and the flight is activated at the "Entry Waypoint" in airspace in our model.
- *Entry Level*: the flight level at which a flight enters an FIR.
- *Entry Time*: the UTC time when a flight enters an FIR or departs from an aerodrome.
- *Exit Waypoint*: the last waypoint where a flight exits a FIR.
  - An "Exit Waypoint" of a flight is as same as its "Arrival Aerodrome" if both are within the same FIR and the flight is deactivated at the arrival aerodrome.
  - Otherwise, they are different and the flight is deactivated when it reaches the "Exit Waypoint" in our model.
- *Exit Level*: the flight level at which a flight exits a FIR.
- *Exit Time*: the UTC time when a flight exits an FIR or arrives at an aerodrome.

Some sample flight plans in the format of ICAO's Form 4 Data within the Bahrain FIR are shown in Table 1. For example, the first flight "GFA275" (call sign) departs from Rajiv Gandhi International Airport (VOHS) to the destination Bahrain International Airport. It enters Bahrain FIR at the waypoint "ORMID" at FL340 (34000ft) at 08:43 on 1st September 2017 UTC. The estimated arrival time (ETA) at the Bahrain airport is 09:10.

Table 1: ICAO's Form 4 Data examples show flight plans within Bahrain FIR.

DATE	ACFT C/S	ACFT TYPE	DEP ADM	DEST ADM	ENTRY POINT	ENTRY LEVEL	ENTRY TIME	EXIT POINT	EXIT LEVEL	EXIT TIME
170901	GFA275	A321	VOHS	OBBI	ORMID	340	0843	OBBI	340	910
170901	PGT824	B738	LTFJ	OBBI	LONOS	290	2210	OBBI	290	2240
170901	GFA154	A332	OBBI	RPLL	OBBI	290	1805	NALPO	290	1832

Given the ICAO's Form 4 Data of a flight, both the "Flight Date" and "Entry Time" are used for determining the activation time for a flight in our model. The airway route for a flight within an FIR can be found by matching the first and last waypoints of an airway with the "Entry Waypoint" and "Exit waypoint" in the flight plan. As ICAO's Form 4 Data have only the information for flights within a given FIR, there are two cases for activating a flight:

- If the "Entry Waypoint" is the "Departure Aerodrome", then the flight activation time is the flight's departure time and the flight takes off from the origin aerodrome, climbs to the cruising altitude, and then cruises. The third flight plan in Table 1 is one example of this case.
- If the "Entry Waypoint" is not the "Departure Aerodrome", the flight is activated at the "Entry Waypoint" at the activation time and it starts cruising at the cruising altitude immediately. Both the first and second flight plans in Table 1 are examples of this case.

Although a flight is always deactivated within an FIR at the "Exit Time", there are also two cases of deactivating a flight:

- If the "Exit Waypoint" is the "Arrival Aerodrome", then the flight is deactivated when it arrives at the destination airport and it has at least cruise and descent phases. This case can be seen as the first two flight plans shown in Table 1.
- If the "Exit Waypoint" is not the "Arrival Aerodrome", the flight is deactivated once it reaches the "Exit Waypoint". This flight may have only cruise phase in the FIR if its "Entry Waypoint" is not "Departure Aerodrome". One example is the last flight in Table 1 going to Ninoy Aquino International Airport which is outside of Bahrain FIR.

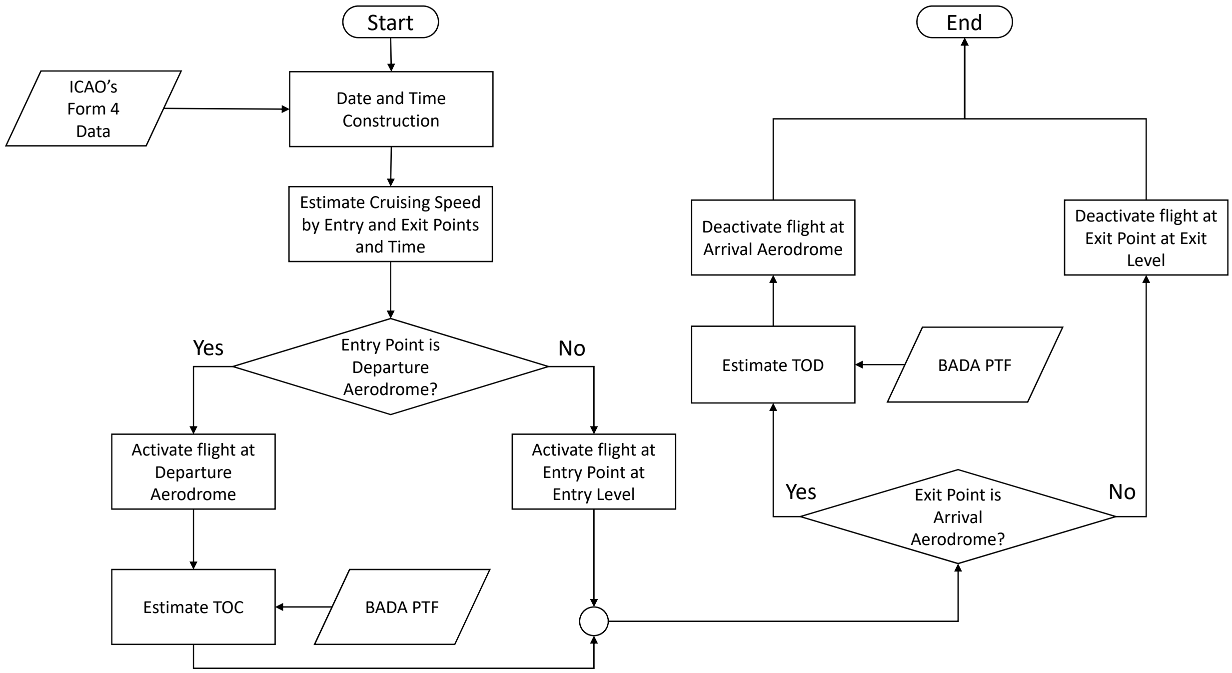


Figure 3: The process of ICAO's Form 4 Data for a flight in the Air Traffic Flow Model.

The Flight Aerodynamic Model also needs the cruising speed and altitude for constructing a complete 4D trajectory of a flight. In our model, the target cruising speed of a flight is estimated by the distance between "Entry Waypoint" and "Exit Waypoint", and the time difference between "Entry time" and "Exit Time". The cruising altitude can be obtained from "Entry Level" and "Exit level" directly if both are same. If the difference between entry and exit levels exists, our model uses "Entry Level" for the most journey and then make the flight climbing or descending to the "Exit level" at the end. Figure 3 summaries the the process for processing an individual flight plan from the ICAO data.

The flight plan with cruising speed, cruising altitude, and flight phases of an individual flight are used by the Flight Aerodynamic Model to simulate its 4D trajectory. In order to advance the simulation's clock and synchronize all flights in a given airspace, the simulator adopts a discrete time simulation approach, with a constant time increment. In other words, the Air Traffic Flow Model checks all flights and updates their status (velocity and 4D positions) by the Flight Aerodynamic Model at each point of time, after which, the simulation clock ticks. This simulation clock starts at the earliest activation time in all available flight plans. Consequently, we can model all flights and synchronize their 4D positions as well as their velocities based on the ICAO's Form 4 data.

3.5 Collision Risk Modelling

Airspace collision risk models are based on the Reich Model (Reich 1966) with some variation to account for radar environment. The assessment of the technical vertical risk requires the risk estimate to be less than the technical TLS of 2.5×10^{-9} fatal accidents per flight hour (noting that a mid-air collision counts as two fatal accidents). The vertical collision risk model for aircraft on adjacent flight levels of the same route, flying in either the same or the opposite direction satisfies Equation 3:

$$N_{az} = 2P_z(S_z)P_y(0)\,n_z(equiv)\left[1+\frac{|\bar{\dot{y}}|}{2\overline{V}}+\frac{\lambda_{xy}\,|\bar{\dot{z}}|}{\lambda_Z 2\overline{V}}\right] \tag{3a}$$

$$\begin{aligned} n_z(equiv) =& n_z(opp)+n_z(same)\left(\frac{|\bar{\dot{y}}|}{|\overline{\Delta V}|}+\frac{\lambda_{xy}}{\lambda_z}\frac{|\bar{\dot{z}}|}{|\overline{\Delta V}|}\right) \\ &+\frac{1}{P_y(0)}\frac{1}{\left\{1+\frac{|\bar{\dot{y}}|}{2\overline{V}}+\frac{\lambda_{xy}|\bar{\dot{z}}|}{\lambda_z 2\overline{V}}\right\}}\sum_{i=1}^{n} n_z(\theta_i)\left(1+\frac{\pi/2\lambda_{xy}}{V_{rel}(\theta_i)}\frac{|\bar{\dot{z}}|}{2\lambda_z}\right) \end{aligned} \tag{3b}$$

where,

- N_{az} represents the expected number of aircraft accidents due to normal technical height deviations of RVSM approved aircraft for the given traffic geometry.
- $P_z(S_z)$ is the probability of vertical overlap; that is the probability of two aircraft overlapping vertically, separated by S_z (1000ft).
- $P_y(0)$ is the probability of lateral overlap; that is the probability of two aircraft being in lateral overlap.
- n_z is the longitudinal overlap frequency parameter together with the kinematics factors in brackets (as functions of the relative speeds and aircraft dimensions). The subscript z is either "same" or "opposite" that refers to aircraft on adjacent flight levels. n_z represents a major part of the different levels of exposure to the risk of the loss of vertical separation for the two traffic geometries covered by the collision risk model.
- There are two aircraft dimensions used by the technical vertical risk (TVR):
  - λ_{xy} is the average diameter of an aircraft.
  - λ_z is the average height.
- $\overline{V}$ is the average ground speed of the aircraft.
- $\overline{\Delta V}$ is the relative along-track airspeed between two aircraft flying at adjacent flight levels and flying in the same direction.
- $|\bar{\dot{y}}|$ is the average relative cross-track speed between two aircraft flying at adjacent flight levels.
- $|\overline{\Delta V}|$ is the average relative cross-track vertical speed between two aircraft that have lost feet of vertical separation.
- $V_{rel}(\theta)$ is the average relative horizontal speed between aircraft flying at adjacent flight levels and intersecting at an angle, θ, where $V_{rel}(\theta) = \overline{V}\sqrt{2(1-\cos\theta)}$.

The information related to cross-tracks are extracted from the 4D flight trajectories during the simulation by applying a conflict detection method. The nominal projection method (Kuchar and Yang 2000) based conflict detection algorithm is adopted in our model. The information of the cross-track are fed into Equation 3 to calculate the TVR during the simulation. Meanwhile, the crossing points estimated from detected cross-tracks are also calculated.

For spatial visualization of collision risk, the modified K-mean clustering algorithm (Nguyen and Alam 2018) is applied to cluster crossing points and visualized along with the TVR values.

The K-Means clustering method is a partitioning procedure where the data are grouped into K groups defined by the user. The routine tries to find the best positioning of the K centres and then assigns each point to the centre that is nearest. K-Means represents an attempt to define an optimal number of K locations where the sum of the distance from every point to each of the K centres is minimized. Following (Nguyen and Alam 2018), there are four types of clusters presented in the simulation: convex hull for crossing points cluster, crossing points cluster without scaling, crossing points cluster scaled by number of crossing points, and crossing points cluster scaled by TVR. Instead of doing risk clustering on the data from the whole simulation period, we use time windows for risk clustering. This provides the temporal dimension to collision risk analysis. The time windows in the risk model can be 1 hour, 3 hours, 6 hours, 12 hours, or 24 hours depending on a user's preferences. In this way, the evolution of the collision risk cluster can be presented to users when the simulation is running; affording the collision risk simulator with the ability to provide spatial-temporal risk visualization.

3.6 Model Integration and Simulator Implementation

We integrated the above models and implemented the collision risk simulator by applying a three-phase world view (Pidd 2004) as shown in Figure 4.

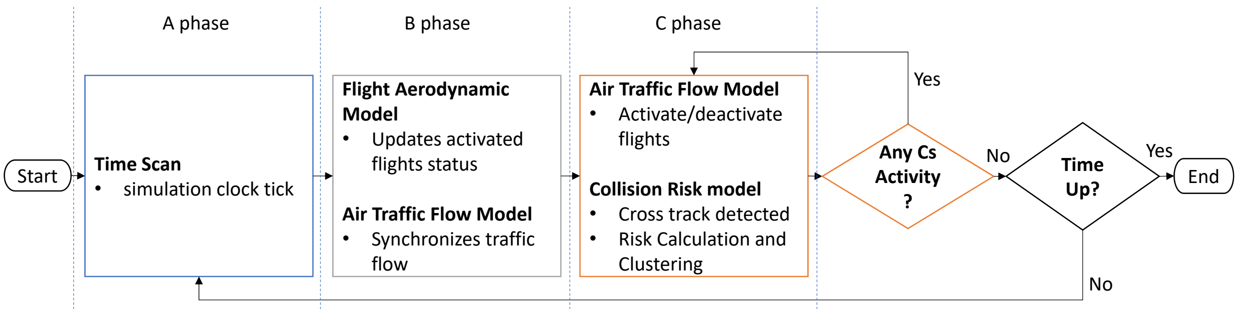


Figure 4: The three-phase world view of Simulator.

In the proposed approach, the simulation clock ticks are the "A" phase's events. As the fixed-increment time advancing mechanism is adopted in our simulator, each simulation clock tick is equivalent to 1 second in the real world. At each simulation clock tick, all activated flight statuses are updated by Flight Aerodynamic Model, and then all flights are synthesized by Air Traffic flow model. The flight status updates and synchronization are the "B" phase's events in the simulator. There are three types of "C" phase events in our simulator. The first type is flights activation and deactivation "C" phase events, where flights are triggered only when the simulation clock time is the activation or deactivation time ("Entry Time" or "Exit Time" in the ICAO's 4 From data). The second type of a "C" phase events is when cross-tracks are detected (the interaction between paired flights). When a cross-track between two flights is detected, our Collision Risk Model records the cross points and prepare them for collision risk calculation. The third type of "C" phase events is when the simulation clock reaches the clustering time window at which the Collision Risk Model starts calculating the collision risk based on the detected cross-tracks, and then performing the risk clustering for visualization.

Figure 5 illustrates the collision risk simulator interface. As shown in the figure, the top menu bar have a number of options for loading scenarios including ICAO's 4 Form data, aeronautics and GIS data, and for controlling simulation runs. The left panel is for parameter settings of a simulation run. The right side panel visualizes the flight movements and collision risk clusters. Airports are visualized by black dots and the waypoints are presented in grey triangles. The connected grey lines are airways in the given airspace. Blue dots are activated flights within the given airspace and their call signs are presented in blue text. There are four different clusters for spatial representation of collision risk: the convex hulls (light green polygons), clustering without scaling (green ellipse), clustering scaled by number of crossing points (brown ellipses), and clustering scaled by TVR (red ellipses). Scaled ellipses (the last two types) allow users to visually compare hot spots in terms of how risky they are relative to each other. A simulation clock is located at the top-right corner.

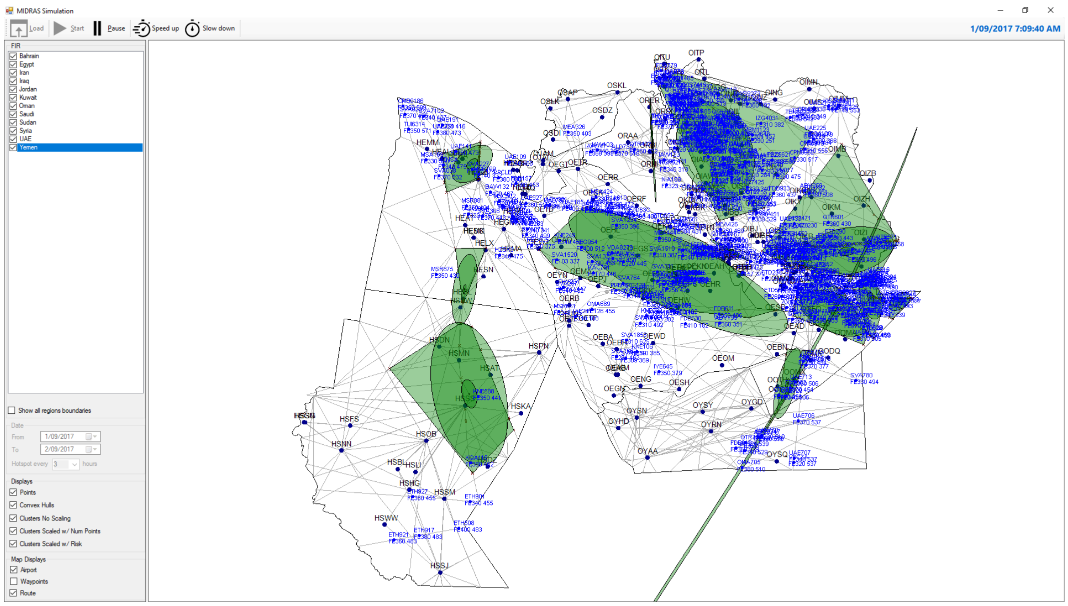


Figure 5: The interface of the Collision Risk Simulator.

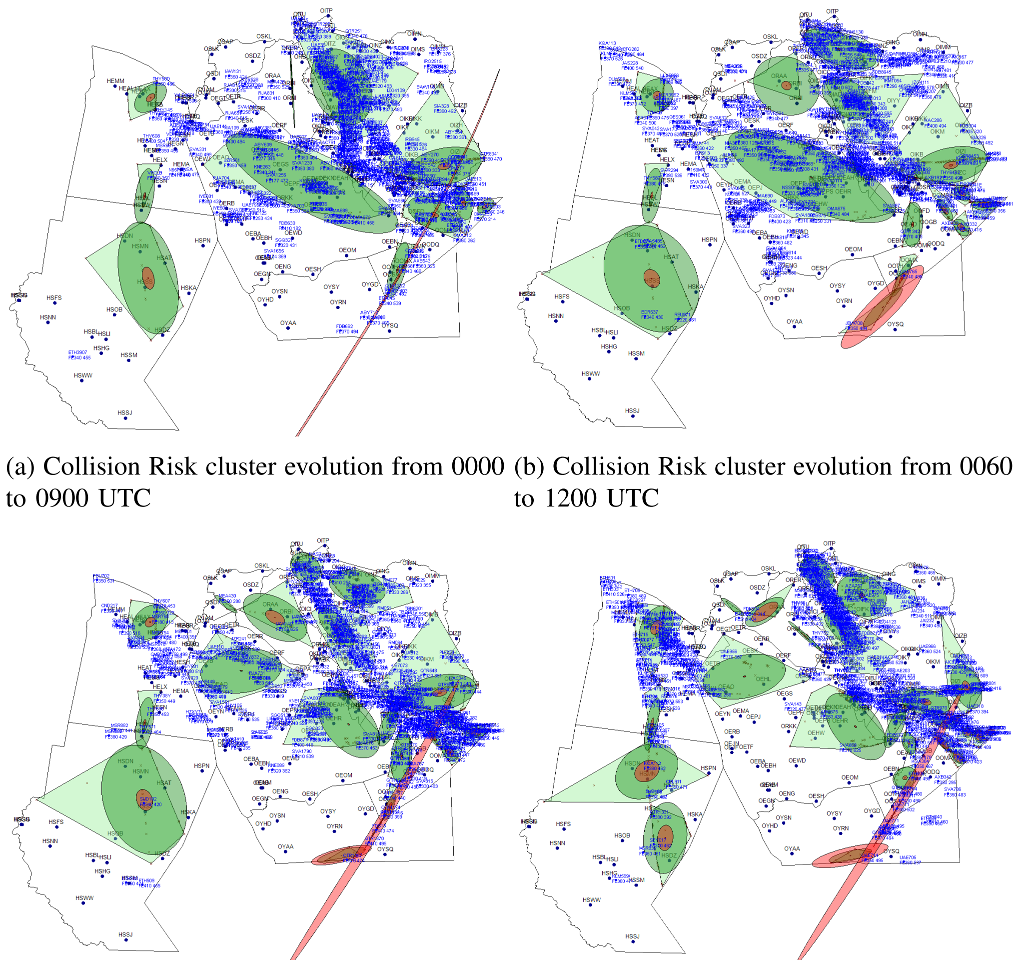
4 COLLISION RISK SIMULATION

As a case study, we performed collision risk simulation for the Middle-East Airspace with 16 national airspace regions. The simulation ran a scenario with one day of air traffic (total 7916 flights) across 16 FIRs in the Middle East Region. The air traffic movements and collision risk evolution over time is illustrated in Figure 6. The spatial and temporal changes in the collision risk clusters can be observed from the figures.

First, there is thin ellipse in red representing the cluster scaled with TVR at the bottom-left changing in each time window. As shown in Figure 6a, it was very slim and long because the crossing points distributed sparsely along one airways and the traffic is dominated by the flight flows of North-East to South-West during that period. From 06UTC to 12UTC, the collision risk cluster in that airspace reduced its vertical length but expanded its horizontal width. It then became a round ellipse as shown in Figure 6b because some traffic in the direction East to West occurred during this time window. There were two clusters appearing in the same airspace shown in Figure 6c from 12UTC to 18UTC as the result of the diversity of traffic increased. The clustering algorithm cannot cluster the risk into only one, therefore, one long and thin ellipse presents the risks for the flights travelling in the direction of North-East to South-West, and a round ellipse present the traffic flow in the direction of East to West. This traffic trends repeated in the next time window (From 18UTC to 00UTC next day). However, both clusters dissipated and expanded as shown in Figure 6d.

Another interesting observation from Figure 6 is the cluster without scale (green ellipse) located in the top-center. The shapes changed dramatically over time. At the beginning, it was very thin ellipse liking a line as shown in Figure 6a. And then it became a circle (Figure 6b), and then an ellipse (Figure 6c and 6d). Meanwhile, the cluster sizes for the cluster scaled with risk (in red color) increased a lot over time. This intuitively show that the cross points dispersed in that airspace along the traffic flows changing but the risk values increased.

As demonstrated in the above case, the collision risk simulator can provide airspace safety managers an insight into the evolution of airspace collision risks and can assist them in making safer management decisions for an airspace.



(a) Collision Risk cluster evolution from 0000 to 0900 UTC

(b) Collision Risk cluster evolution from 0060 to 1200 UTC

(c) Collision Risk cluster evolution from 1200 to 1800 UTC

(d) Collision Risk cluster evolution from 1800 to 0000 UTC

Figure 6: The collision risk evolution in Middle East Region for a given day. The Risk clusters are computed every 6-hour time window.

5 CONCLUSION

Airspace collision risk assessment is vital for assessing the safety of an airspace. However, the numeric nature of collision risk does not offer any insight or understanding into the nature of risk, how it evolved, or any mean to assess how to manage the airspace and traffic in order to mitigate the collision risk. In this paper, we have proposed a collision risk simulator for spatial-temporal visualization of collision risk as it evolves over time in a given airspace. By clustering traffic crossing points with collision risk parameters, the simulator offers interesting insights into the emergent nature of collision risk. It is expected that the simulator will assist organizations to make better safety decisions to reorganize some particular airspace features such as way-points and airways as well as better organization of air traffic in RVSM airspace in order to mitigate collision risk. This model is generic in nature, such that it can be applied to other airspace such as Terminal Manoeuvre Airspace (TMA). However, the collision risk model is more applicable in en-route due to vertically separated nature of airspace which is not the case in a TMA airspace. However, with the availability of ADS-B data, this model can be further refined with better collision risk estimates as well as high fidelity spatio-temporal distribution of collision risk. As ongoing work we will be validating the collision risk simulator results with ICAO subject matter experts and by comparing the results with other collision risk models from EUROCONTROL and US FAA.

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