

2014



Arnaud PROUZEAU

M2IHM

### **End of Studies Project Memoir**

September 2014

**Simulating the Risks of Aviation Debris on the Public,  
University of Glasgow, UK**



La référence aéronautique



University  
of Glasgow

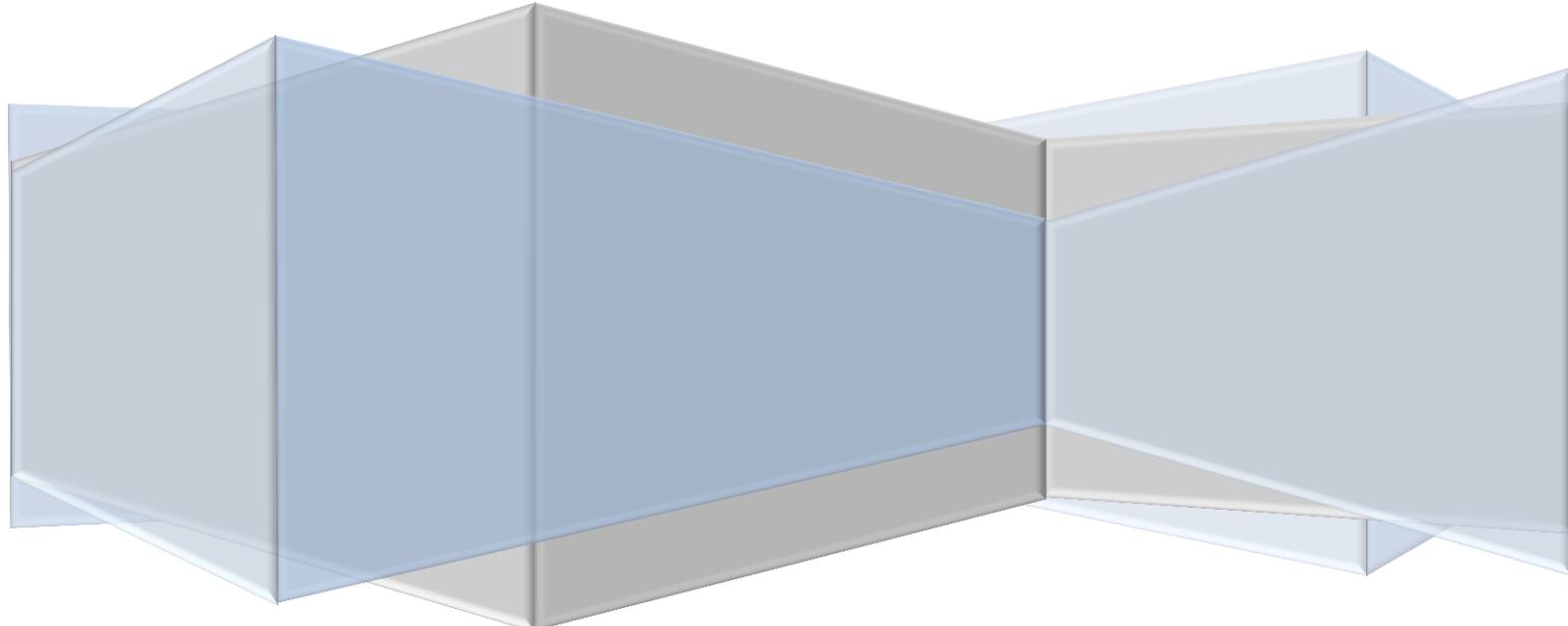
# Simulating the Risks of Aviation Debris on the Public

**End of Studies Project Memoir –  
University of Glasgow, UK**

**Arnaud Prouzeau**

**Supervisor : Chris Johnson (University of Glasgow), Philippe  
Palanque (UPS) and Yannick Jestin (ENAC)**

**From 17th of March, 2014 to 17th of September, 2014**



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- Rhian Williams and Kerry-Anne Curran from the National Air Traffic Services (NATS) who allowed me to visit the control centre of Prestwick in order to meet the Airprox investigation team and Air Traffic Controllers.
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- All the people who accepted to answer to my question during interviews: Philippe Plantin de Hugues from the French Air Accident Investigation Board (BEA), Jerome Dufossez from the French Civil Aviation Authority (DGAC) and John Thomson from the UK Civil Aviation Authority (CAA).
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## Abstract

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This report presents the work performed at the laboratory of computing science of the University of Glasgow on a software application that simulates Mid-Air collisions and calculates the impact of the debris on the ground population.

A previous version of this mid-air collision simulator was developed by two students from the University of Glasgow. And it was decided to base this project on the last version of this simulator.

This report shows how the interface was re-designed in such a way that it is efficient and usable for investigators to use it in order to assess the potential danger of an Airprox incident. The interface needs to clearly highlight summary information, such as calculate the people at risk if the aircrafts had collided, but also allow investigators to drill down to specific details such as identify any sensible sites that could be hit.

To this end, a User Centered Design process was applied with an analysis of the activity and the needs of the potential users, including Airprox inspectors of the UK Airprox Board (UKAB) and the French Civil Aviation, but also investigators from the French Accident Investigation Board (BEA) and Aviation Safety Researcher, and prototyping. In this phase, three iterations were performed and finally the new system was implemented using Java and OpenGL.

**Keywords:**

Aviation Safety, Airprox, Collision, Risk Assessment, Human Computer Interaction, Air Traffic Management.

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Ce rapport présente le travail effectué au laboratoire d'informatique de l'université de Glasgow sur un logiciel permettant la simulation d'une collision aérienne et le calcul de l'impact des débris sur la population au sol.

Une première version du simulateur a déjà été développée par deux élèves de l'Université de Glasgow et il a été décidé de baser ce projet sur cette version.

Plus précisément, ce rapport montre la manière dont l'interface a été reconçue pour rendre son utilisation par des enquêteurs d'Airprox simple et efficace pour évaluer le danger potentiel d'un Airprox. L'interface doit mettre en valeurs les informations clés qui sont, le nombre de personnes en danger en cas de collision mais aussi les éventuels sites à caractère sensible qui pourrait être touchés.

Pour cela, un processus de Conception Centré Utilisateur a été utilisé avec une analyse de l'activité et des besoins des potentiels utilisateurs, comme par exemple les enquêteurs d'Airprox de l'UK Airprox Board (UKAB) et de la Direction Général de l'Aviation Civil (DGAC). A ces analyses s'ajoute une phase de prototypage, avec la réalisation de maquettes papier et logicielles de la future interface. Durant cette phase, trois itérations furent réalisées et finalement, l'outil fut implémenté en Java en utilisant le moteur 3D OpenGL.

## Mots Clés :

Sureté Aérienne, Airprox, Collision, Evaluation du risque, Interaction Homme Machine, Gestion du Trafic Aérien.

## 1. Presentation of the project

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### a. Context of the Project

The number of passengers increased by 5% each year between 2004 and 2013 according to the International Air Transport Association (IATA), but the number of accident in the same period reduced by 50% [1]. This decrease is a result of a big improvement of the safety systems in the aircraft, but also in the Air Traffic Control system and in all the organisations involved in Air Transport (for example the Military and Civil Aviation Authority or the International Civil Aviation Organization - ICAO). These safety improvements were possible thanks to more reliable systems [2], a more suitable training but also thanks to the investigation made by an independent team for each accident according to the Annex 13 of ICAO. The ICAO also recommends investigating the incident in order to identify safety issues and avoid the accident [3].

In the case of a Mid-air collision, it is really difficult to study the causes and consequences because of the low number of occurrences. Indeed, the probability of a mid-air collision is estimated by ICAO around  $1.5 \times 10^{-8}$  fatal aircraft accidents per flying hour in en route flight in controlled airspace [4] (By comparison, the probability to win the National French Lottery is around  $5.2 \times 10^{-8}$ ). The last mid-air collision involving commercial planes in Europe is the collision between a Boeing 757 of DHL and a Tupolev Tu-154 of Bashkirian Airline in 2002 over the town of Überlingen in Germany [5] (Figure 1). The causes of this accident are the fact that the TU-154 pilot followed the order from the Air Traffic Controller (ATC), which was the opposite of the Traffic Collision Avoidance System (TCAS) order, and the fact that the ATC was in charge of 2 positions which is not allowed by Skyguide (the Swiss air navigation service provider) but tolerated during times of low traffic at night. The 71 passengers and crews of the two flights died, the debris of the two aircrafts fall into the city of Überlingen without made any casualties.



Figure 1 - Reconstruction of the collision of Überlingen according to FDR Data

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To identify the safety issues before the collision, a possibility is to investigate Airprox. The ICAO defines an Airprox as "A situation in which, in the opinion of a pilot or air traffic service personnel, the distance between aircraft as well as their relative positions and speed have been such that the safety of the aircraft involved may have been compromised" [6]. It means that in this situation, the pilot or air traffic controller estimate that there was a substantial risk of collision. An Airprox report by an airspace user leads to an investigation by a national authority. In the UK, it is the UKAB which are responsible to investigate on Airprox and to determine the facts, the causes and the degree of risk, the French equivalent is the Quality of service and Safety unit (QS) which is a part of the French Air Navigation Service Provider (DSNA).

At the end of the investigation, according to the causes and the facts, the investigator can give some recommendations about the training of the controller or the pilot, or about the creation and modification of safety rules. In 2012, the UKAB led 161 investigations, and 45 of them were considered as risk-bearing (it means that the safety was not assured) [7]. The UKAB published every investigation on its website, which is not the case for the DGAC, which published only the number of Airprox considered as risk-bearing, there were 18 of them in 2012 [8]. These numbers have been slowly decreasing in both countries for ten years.

To help the investigation authorities, Eurocontrol publishes guidelines on incident investigation [9], one of them is that "Reconstruction should consider the worst, plausible scenarios". It is indeed really important to consider what could have happened if the condition were worse (traffic heavier, worse weather, etc...), and to make recommendations to avoid this situation. In the case of an Airprox, the worst case scenario could be a mid-air collision over a populated area which can imply ground population casualties.

The ground population was not really taken into consideration in aviation safety issues before 1992 with the crash of a Boeing 747 of the airline El Al. The aircraft physically lost two engines which broke the hydraulic systems and made the aircraft uncontrollable. The plane crashed in a suburb of Amsterdam destroying 31 apartments and killing 39 people on the ground [10]. One of the recommendations of the Nederland Aviation Safety Board was to "Expand the training of pilots and ATC personnel to include the awareness that in the handling of emergency situations not only the safety of airplane/passengers but also the risk to third parties especially residential areas should be considered" [10]. To answer to this recommendation, the Dutch Air Navigation Services Provider (ANSP) LVNL set up a tool which shows on the radar screen of the controller the residential areas, it is turned off by default but can be activated by the controller.

Third party casualties have also been taken into consideration in the United Kingdom, especially around airports, with the creation of Publics Safety Zones (PSZ) (Figure 2). A PSZ is an area adjacent to the end of the runway in which development of land is restricted [11]. In this area, the risk being killed as a result of an aircraft accident is approximately 1 in 100,000 per year.

Even if the number of accident per year is decreasing, the third party risk is more and more taken into consideration especially around airports, which face an increase in traffic. To be able to assess the risk for the population in case of an accident is becoming more and more important, despite the low probability of occurrence. Especially around Airport, where accidents can be fatal for the vicinity, as it was showed at the accident of the El Al 1862 in Amsterdam.

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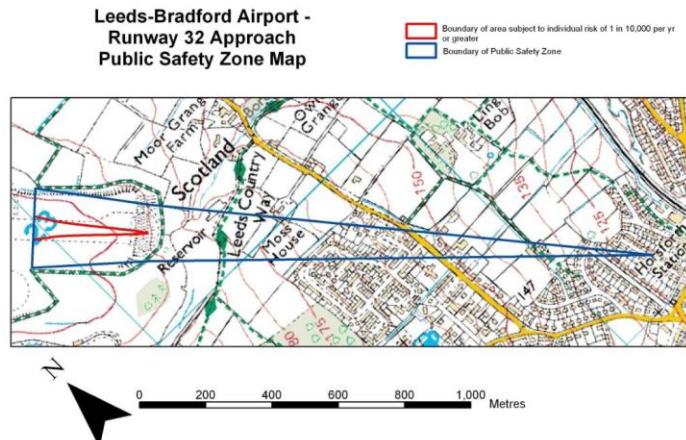


Figure 2 - Leeds-Bradford Airport - Runway 32 Approach Public Safety Zone Map

### b. The Project

This project was started by Marco Sarconi a student of the Professor Chris Johnson from the University of Glasgow. At first the software was designed to simulate an In-Flight breakup of a Sub-Orbital vehicle and calculate the impact of the debris for commercial aviation [12]. The software was at the end of the project tested by the Debris Safety Manager of the European Space Agency (ESA). The next year, two students, Craig Martin and Michael Bell, chose to use the same software to simulate a Mid-air collision and calculate the impact of the debris for the ground population [13].

The purpose of the project is now to allow an Airprox Investigator to use the software to assess the risk of an Airprox for the population on the ground. It means to calculate the people at risk if the aircraft would have collided and to identify any sensitive sites which could have been hit by a debris (power plant, petrochemical factory, etc...).

An aircraft accident is considered as a Major Hazard, it means that the probability that it happens is really low but the consequences are important (fatalities, material damage). There are two ways to express the risk of this hazard, we can consider the individual risk that is the risk for a person to be hit by this hazard in a period of time and the population risk that takes into consideration the number of individuals exposed. In our case, we will not consider the individual risk, because the probability for a person to be hit by debris from a mid-air collision is not significant, but the number of people exposed to the debris is what interests us. The population risk is the multiplication of the probability of the hazard by the number of person exposed.

The purpose of the project is to help people, and especially Airprox Inspectors, to properly assess the risk for the population. Ulrich Beck, a German sociologist, in his concept of 'risk society' pointed out the fact that the perception of the risk depends on several factors like for example the frequency of appearance in mass media, and more generally the awareness of this risk by the public [14]. It will thus be important to work on its visual representation, and evaluate the perception of it, and measure the impact of our software application on this perception.

More generally, the purpose of this project is to show how the use of new interaction paradigm (Direct Manipulation but also the use of a three dimension visualization) and the use of data from multiple sources accessible from the internet (Automatic Dependent Surveillance-Broadcast - ADS-B,

Weather Forecast, population and geographical information) give to the user a more efficient way to understand and analyse a situation.

## c. The Stakeholders

### i. The University of Glasgow

Founded in 1451, the University of Glasgow is the fourth-oldest university in the English-speaking world. This university has an important role in the scientific world and especially in the engineering world, and had in its student famous scientists like Lord Kelvin or James Watt. The University is ranked 51<sup>st</sup> in the QS World University Rankings 2013 and the 9<sup>th</sup> university in the UK.

The School of Computing Science has built a reputation for the excellence of its research in fields such as Computer Vision, Human Computer Interaction and Information Security. The project is hosted by the “Software Engineering and Information Security” group, which has number of research themes including Software for space based systems, safety critical software and computer forensics.

Chris Johnson is the head of the School of Computing Science of the University of Glasgow. His research focuses on the security and safety of critical systems. He works with important aviation stakeholders as the NATS, Eurocontrol or the National Aeronautics and Space Administration (NASA). He is my supervisor and I had a meeting with him each week to present him my progress and discuss with him about the next step in the project. He also helped me to contact the different users and prepare the interviews.

### ii. The users

This project is a research project, it was initiated by Professor Chris Johnson for one of his 4<sup>th</sup> year student, Marco Sarconi. The software was not designed to be used by a high number of people, but by student and researcher in Aviation Safety. One of the first steps of my internship was to identify other potential users, this step will be detailed later in this report (Section 6.a). I succeed to identify new users:

- Airprox Inspectors, from the UKAB [15] or the DGAC: They are in charge of the investigation on Airprox, at the end of it they decide the causes and give some recommendations. The reports of the investigation are published in UK but not in France.
- Accident Investigators from the Air Accident Investigation Branch (AAIB) [16] and BEA [17]: They are in charge of the investigation on important incidents and aircraft accidents, these organizations are independent from the Civil Aviation Authority and their purpose are not to punished the person responsible for the accident, but to give recommendations in the goal of avoid the same situations.
- Airport Safety Manager: There are in charge of the safety in an Airport, they have to manage the safety of the operation on the airport and to make sure that each modifications on the airport will not alter the safety of the passengers and workers.
- Aviation Safety Analyst: They analysed more general safety issues in order to find how to avoid them.

### iii. The Project Team

I am, at the moment, the only person on the project team. I am an engineer student at the ENAC. Currently in third year, I am studying Computing Science and Air Traffic Management and performing a double degree with Paul Sabatier University in Toulouse to pass a Master Degree in Human Computer Interaction.

## d. The Process

To design a system which satisfies the needs of the users, it is important to consult them in the design phase. It is important to understand the tasks that the user has to perform, his/her workplace, it is important to think about several solutions, prototype them and then have them tested by users. Because the needs can evolve, it is important to have a flexible process which allows us to iterate several times.

### i. User Centered Design

The User Centered Design (Figure 3) [18] is a Design process defined in the ISO norm 9241-210 [19] which is based on 6 key principles:

- The design is based upon an explicit understanding of users, tasks and environments.
- Users are involved throughout design and development.
- The design is driven and refined by user-centered evaluation.
- The process is iterative.
- The design addresses the whole user experience.
- The design team includes multidisciplinary skills and perspectives.

In the project, I will consider that the main users of the software are the Airprox Inspectors, it implies that they will be in the center of the design process.

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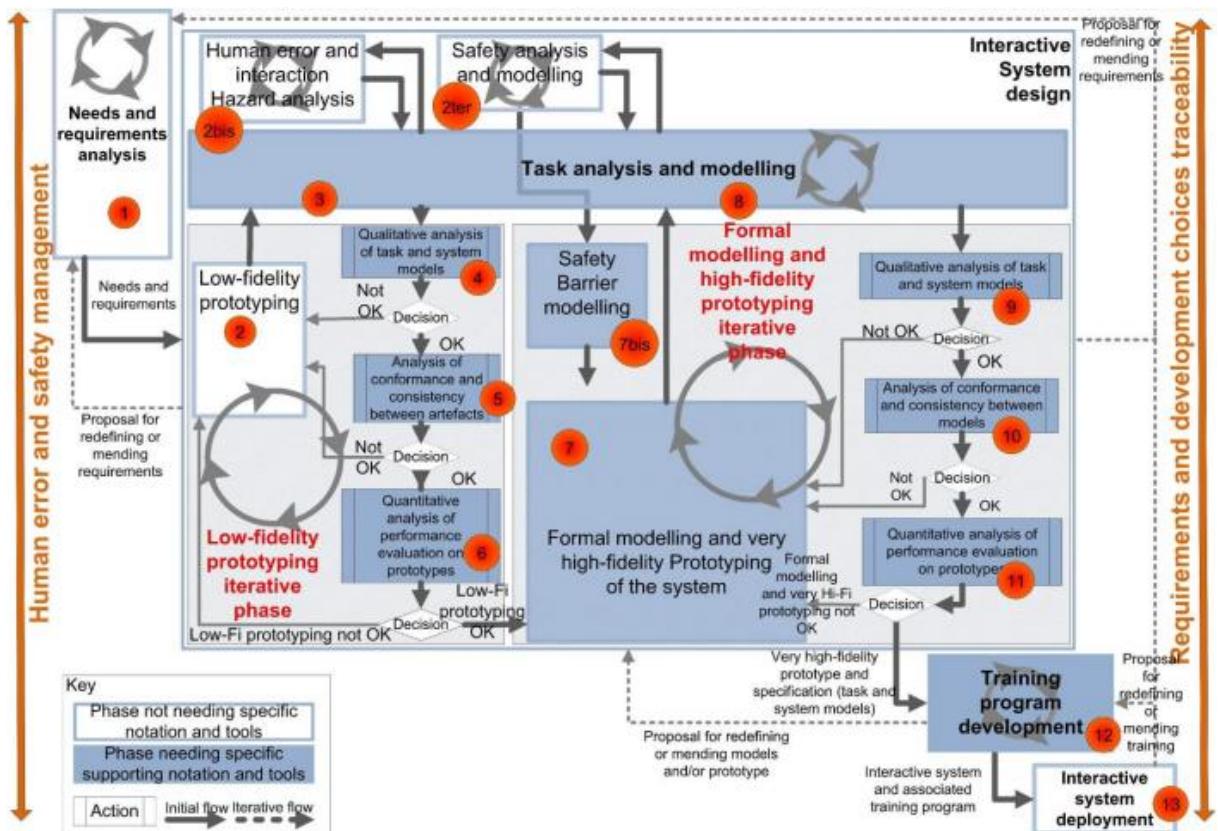


Figure 3 - The User Centered Design Process

The first steps are analysis phases, during it I will understand the context of use, the tasks and the needs of the user. Then, the phase 3 is a phase of producing design solutions, the process used can be brainstorming and prototyping. Finally, it's important to evaluate the solutions with the user, and produce other solutions if the system doesn't meet the needs.

## Analysis Phase

During this phase, it is important to understand the context of use and the tasks of the user to define its needs. The methods employed depend of the availability of users, you can make interviews, observations of the activity on the workplace, task modelling. This phase leads to the definition of the needs of the users, these needs can evolve during the design phase. At the end of this phase, a Task Modelling report (Annex E), a requirements and Needs report (Annex F), A Heuristic Evaluation (Annex B) and a report with all the transcript of the interviews (Annex C) were done.

## Prototyping Phase

The purpose of this phase is to produce design solutions which can meet the needs of the users. The method to produce this solution depends on the iteration, in the first iterations, the purpose is to propose several solutions to the user but in the last iterations the purpose is to validate the solutions. In order to prototype quickly several interface, you use low fidelity prototype in the first iterations, it can be paper prototype, or prototyping software like Balsamiq Mockup [20] can be used. To validate the solution, one can use high fidelity prototype in order to give a precise idea of the

interface to the user. The higher a prototype is, the harder it is to perform important changes on the design.

This phase is also the opportunity to prototype the interaction between the user and the interface. It can be hard to prototype on paper or thanks to Balsamiq Mockup because the interface in that case is “static”, nevertheless, solutions exist to do it, like the use of a “Wizard of Oz” process [21]. In this process, the user use the prototype and one of the designer is playing the role of the computer and change the interface in function of the user’s actions. It is also possible to prototype interactions by prototyping with a programming language like JavaScript or C#.

In this project, 29 paper prototypes were realised for the first iteration, then one JavaScript prototype was realised in the second iteration with 9 pages, this prototype was incremental and reused in the third iteration, and it had at the end 6 pages. All the prototypes are available in the Annex G.

### Evaluation Phase

The purpose of this phase is to present the solutions designed in the previous phase to the users and evaluate how they meet the requirements and needs defined in the analysis phase. There are many ways to evaluate a solution, the Nielsen Heuristics can be used to find big usability problem or we can use user testing or Design Walkthrough. The most important is to know what the user thinks of the system, and if the system doesn’t meet the needs, what do you need to change. One protocol to understand how the user reacts to your solution is the “Thinking aloud protocol”, you ask the user to say out loud what he is thinking during the evaluation.

It is also possible to evaluate the software application in a more formal way, by performing usability testing. This evaluation is more efficient if a big part of the software is developed (or at least prototyped), else the result will not be significant. During a usability testing, different variables can be evaluated like the efficiency, the learnability and the satisfaction by measuring the time to perform a task or the number of mistakes done by the user for example. A report about all the evaluation is available in the Annex C.

Finally, it could be interesting to perform user experience evaluations in order to see how the user feel about the product, how the user identify himself/herself with it and how he/she is given inspiration by it.

## ii. The Development Phase

As in the design phase, a good solution to develop a system which meet the need of the users is to iterate several times and to perform user testing each times. But if it is easy to prototype different solutions with paper and makes important change on it, it costs a lot of time on the final software. And because project are limited in time, it is a better idea to perform one more iteration in the design phase to be sure of the needs of the user than doing a lot of iteration in the development phase.

The development of the software application was done using Java and JMonkeyEngine to manage the 3 dimensions development. To develop the Graphical User Interface, the Swing API was used. At the end of this phase, a first version of the software application was available.

In order to imply the user in the development, it is possible to make them evaluate a diagonal prototype which is the developed system without all the functionalities. The purpose of these evaluations is to check the usability of the system, but also if the system helps the user to perceive the risk of a mid-Air collision.

### iii. Planning

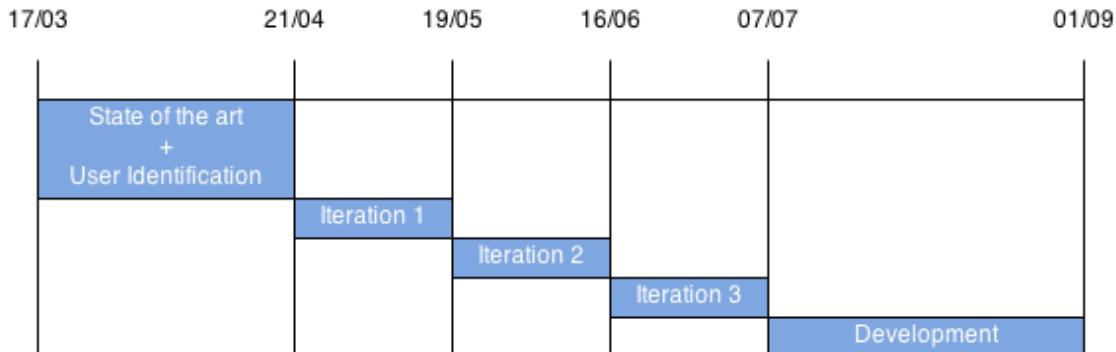


Figure 4 - Planning of the project

The Figure 4 shows the simplified Gantt diagram of the project, the design phase (Chapter 6) lasts around four months when the development phase (Chapter 7) lasts two months. At the end of the development phase, a functional prototype of the software application developed in java and a report about the project process were delivered to the University of Glasgow. A full Project Management Report is available in Annex A.

## 2. Analysis of existing systems

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In order to avoid redesigning a system identical to an existing system, to sharpen the creativity and to begin to understand the context of use, it is important to begin the project by an analysis of existing systems. It began by focussing on the tools used to replay Airprox and Air Accident, to find out which tools are used, Airprox Inspectors, Air Accident Investigator and Software Engineers from the Civil Aviation Authority from France and United Kingdom were interviewed (See Annex C). Then a Heuristic Evaluation of the actual tool developed by the students of Chris Johnson was performed to detect major usability problems. The tools presented are the tools used by the French DGAC and the UK Airprox Board only, it was decided to analyse only theirs because, in general, all the investigation boards use the tools they developed, and so to not restrict the area of study would have led to the analysis of too much tools.

### a. Tools to replay Airprox and Air Accidents

The reconstruction of the event is one of the important phases described in the guidelines for incident investigation by Eurocontrol [9]. It is important to give the inspectors tools able to reproduce the context of the Incident and to assess well the risk of it. The replay of an Aircraft is normally done after the step of data gathering, when the inspectors have most of the information to reconstruct the whole context. But to assess the danger of the airprox would be usually done in the last step of the investigation when the inspectors assess the risk of it. It means that all the information in the reconstruction phase will be accurate when the inspectors will assess the danger for the population.

#### EPOQUES

EPOQUES is designed by the DGAC [22] (Figure 5). This tool can replay radar data and synchronize them with communication data. Instead of using a classic Windows, Icons, Menus and Pointing devices (WIMP) interface, EPOQUES uses a direct manipulation interface [23], it is possible for the user to pilot the time of the replay thanks to a VCR-like toolkit, to measure the distance between two points and to take snapshots. The main representation of the situation is the radar screen, well-known by the Air Traffic Controller, but two other representations are available:

- A horizontal representation more focussed on the two planes involved.
- A vertical representation, which shows the vertical evolution of each planes.

In figure 4, it is possible to observe a prototype of the software (Which is nowadays developed and used), it has a radar screen that take the whole size of the screen, and on it there are four toolglasses that can be moved by the user. Each toolglass are oriented in a particular field, one is for the radio synchronization, one for the geographic manipulation, one for the distance measurement and one for the time-control. The purpose of the toolglasses is to be as intuitive as possible.

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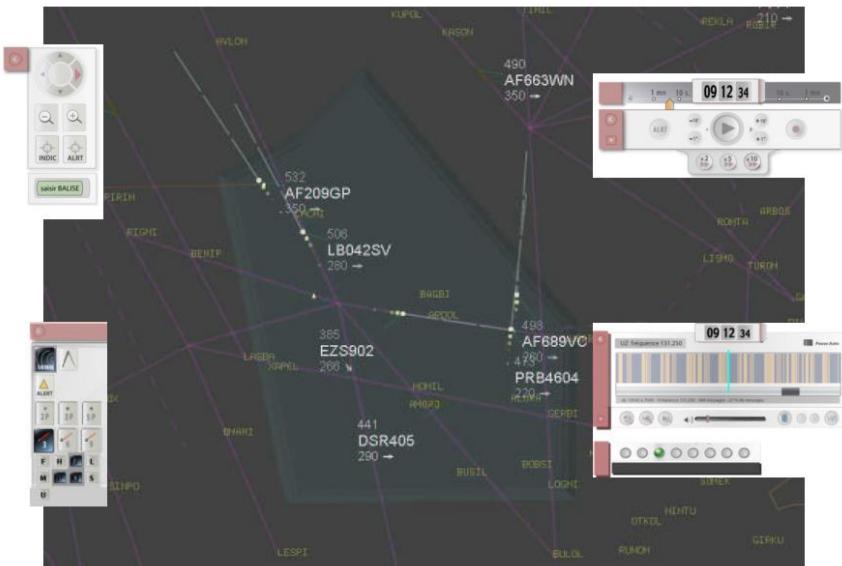


Figure 5 - Prototype of EPOQUES

## ELVIRA

ELVIRA is another tool developed by the DGAC, its main purpose is to analyse aircraft's trajectory (Figure 6). With ELVIRA, the user can use different filters to sort the trajectories (QFU, aircraft type, destination, etc...) [24]. It uses radar data and the result is in 3D. It is mostly used to identify the average trajectory of aircraft around airports and calculate the noise exposure map. But this tool can be used to investigate on an Airprox to isolate the two trajectories involved, or to visualize the context of the aircraft and the complexity of the other aircraft's trajectory.

It is not possible to interact directly with the trajectories, all the interactions are done thanks to a form. The information about them are not present in the screen (ID of Flight, altitude, ...), which could be confusing for the user.

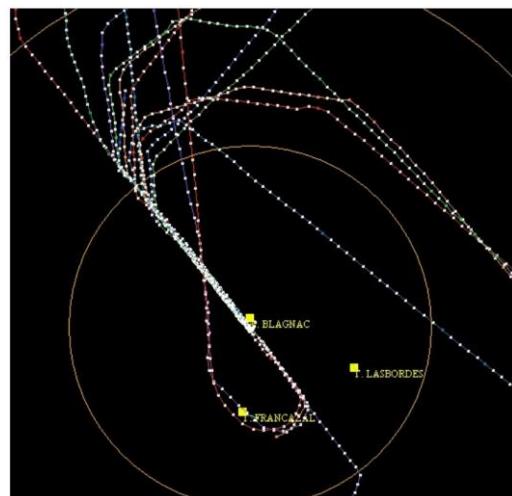


Figure 6 - Trajectory Management with Elvira

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## FromDaDy

From Data to Display (FromDaDy) is developed by the laboratory of interactive computing of the ENAC, it is designed to easily explore Multi-Dimensional dataset, and especially trajectory [25]. It is not used yet by Airprox Investigator, the purpose of this tool is to have several interactions in order to manipulate easily a massive volume of data, like aircraft trajectories over France in a year.

The user can directly manipulate the trajectories to isolate them, to sort them and juxtapose different views. FromDaDy can be used to understand a conflict. This tool is really powerful and easy to use thanks to direct manipulation of the dataset.

The Figure 7 shows how it is possible to drag and drop trajectories with FromDaDy. In order to isolate trajectories to and from Paris, it is possible to brush the cursor around Paris to select the trajectories concerned, then pick them and drag them in a separate display.

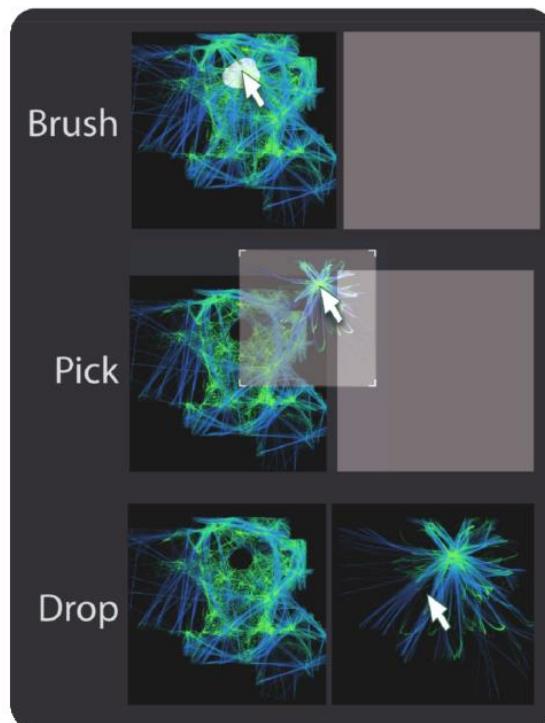
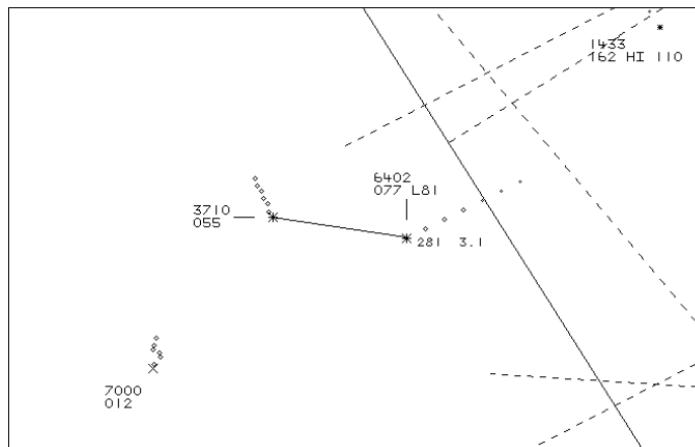


Figure 7 - Pick and Drop of FromDaDy

## NATS Tool

The UKAB uses a tool developed by NATS (Figure 8). It is used to measure the distance between the two Aircraft, and understand the context (Workload of the ATC, number of Aircraft in the airspace, etc...). Screenshot of the situation can be taken with this tool to illustrate the final report. They use the software Camtasia to synchronize the radio and the radar data. Normally the radar data can be available after 24 hours.

The only interaction allowed with this software is to increase or decrease the geographic area concerned and to control the time of the replay.



**Figure 8 - NATS Tool**

## MAGE

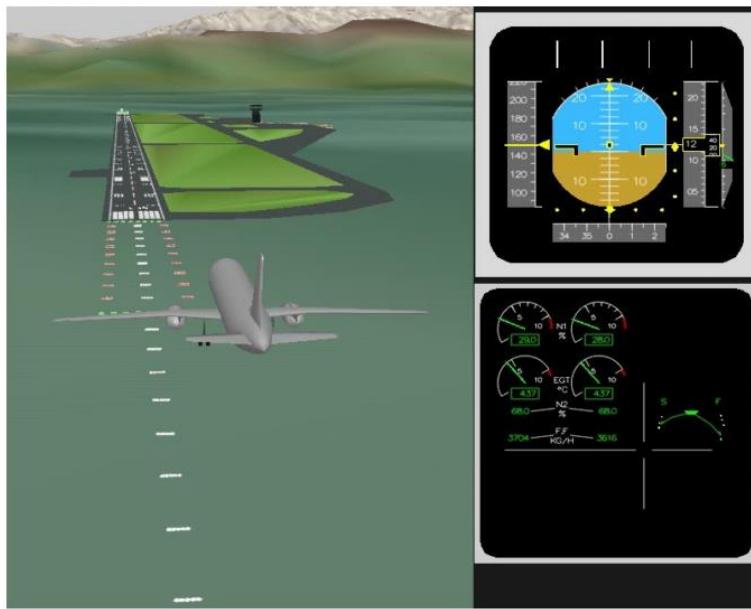
MAGE is a tool used by the French Quality of Service and Safety to visualise he controller screen at the time of the Airprox, but it only shows the radar data, it cannot be synchronize with Radio and Phone data.

## 3D Flight Reconstruction

The tools presented before use only data from the ANSP, which means Radar and Radio data. But in case of a collision, it is national investigators who conduct the investigation (The BEA for the France and the AAIB for the UK). In addition to the Radar and Radio data, they have BlackBox data: The Cockpit Voice Recorder which contains the last 2 hours of the flight cockpit conversation and the Flight Data Recorder which record more than 1300 flight parameters. Thanks to these, the investigator can simulate the flight on 3D visualization software [26]. Here is a non-exhaustive list of this kind of software:

- FlightTracer
- CEFA FAS
- SimAuthor
- FlightScape
- Flight Data Vision
- Flight Animator [27] (Figure 9)

These tools can also take into consideration the weather data, building, and other data to make the flight realistic.



**Figure 9 - Reconstruction with Flight Animator**

## Summary Table

We can conclude this first part with a summary table (Table 1) for the presented tools, we can see that the recent software applications push forward the direct manipulation instead of a WIMP interface because it is easier to manipulate for the user. Even if EPOQUES doesn't have a 3D visualization, it is possible to have a vertical and a horizontal representation of the situation, which could be easier to understand for the user than 3D. The other tools in 2D are a reproduction of the radar screen of the controller. But the vertical/horizontal representation of the situation is convenient to observe the vertical and horizontal distance between the two aircraft, but in the danger assessment step, you don't need to observe the distance between both because you consider that the aircraft collided.

FromDaDy goes further in the direct manipulation, it allows the user to directly manipulate the air traffic flux. More generally, the interactions available are really efficient to manipulate a large amount of data, you just have to "brush" an area with your pointer in order to select all the trajectories that cross this area. But an Airprox is localised, there are not a lot of Aircraft trajectories to analyse and the interactions used in FromDaDy could not be useful.

3D flight reconstruction tools mostly include interaction to control the camera, which is really useful in the 3D environment, indeed, it is really easy to do perception error due to the third dimension (distance evaluation, comparison of 2 height), especially if information is represented in three dimensions.

Finally the data comes from different sources and it is possible to synchronize them in order to recreate the context of the Airprox. During the Analysis phase, it is important to understand what the pilots and ATC were thinking and how they perceived the situation. But to assess the consequences of the collision if the aircraft would have collided, you don't need the radio data. Moreover, none of this software application (except some 3D flight reconstruction tool) gather data about the weather or the population on the ground.

	Interaction Technique	Origin of data	Visualization	Number of Planes simulated
EPOQUES	Direct Manipulation	Radar, Radio	2D	Multiple
ELVIRA	WIMP	Radar	3D	Multiple
FromDaDy	Direct Manipulation	Radar	3D	Multiple
Nats Tool	WIMP	Radar	2D	Multiple
Mage	WIMP	Controller Display	2D	Multiple
3D Flight Reconstruction	WIMP	Blackbox, Radar, Radio	3D	One

**Table 1 - Summary Table**

To conclude, it was decided to keep the 3D visualization in the software, to try to include more direct manipulation interaction in the software, especially in the visualization and the functionality proposed by EPOQUES to take snapshot of the situation. The data would come from different sources available on the internet (ADS-B, Weather...). Finally, the software application will simulate only the two aircraft involved, but still display the other aircraft around.

## **b. Heuristic Evaluation of the Actual Software**

This part is the conclusion of the heuristic analysis performed on the actual software application, the full analysis is in the Annex B.

Heuristic evaluation is a method used to assess the usability of software, it was designed by Jacob Nielsen, a Danish usability expert [28]. He defined ten key principles of usability for software, and in this method, one or several experts have to check if the software follows these principles. This is an easy way to evaluate usability, indeed, with only few people you can find the majority of the usability problems. A drawback of this method is that only some kinds of usability problems are covered.

We applied this to the existing Glasgow tools (Figure 10 - Figure 11). The main conclusions of this analysis are:

- The lack of feedback to the user
- The lack of error messages when the user makes mistakes
- The software doesn't speak the language of the user
- The system doesn't respect conventions (Back/next button in the wrong order, Filepath textfield not used).

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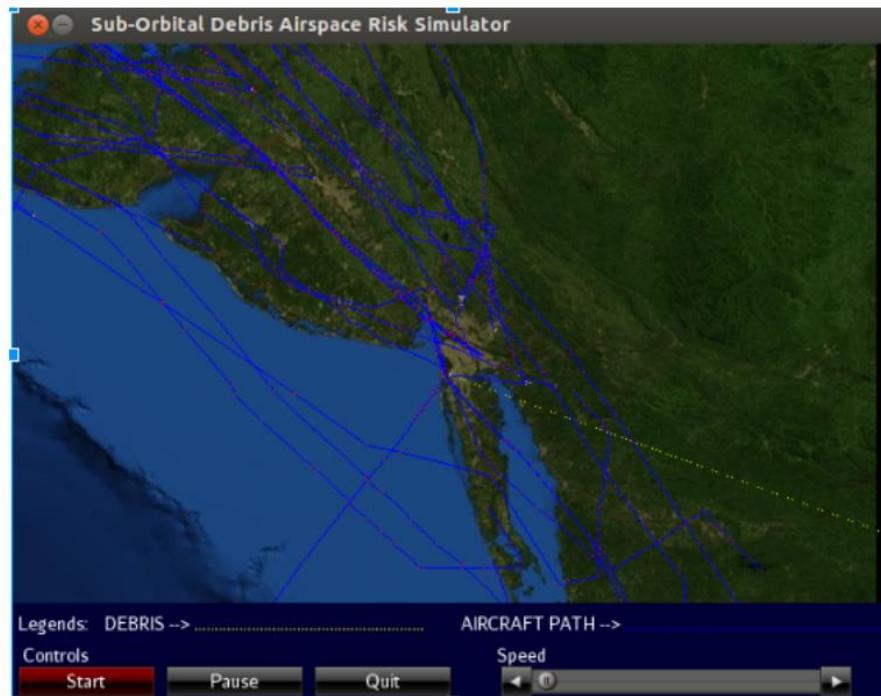


Figure 10 - Screenshot of the actual tool

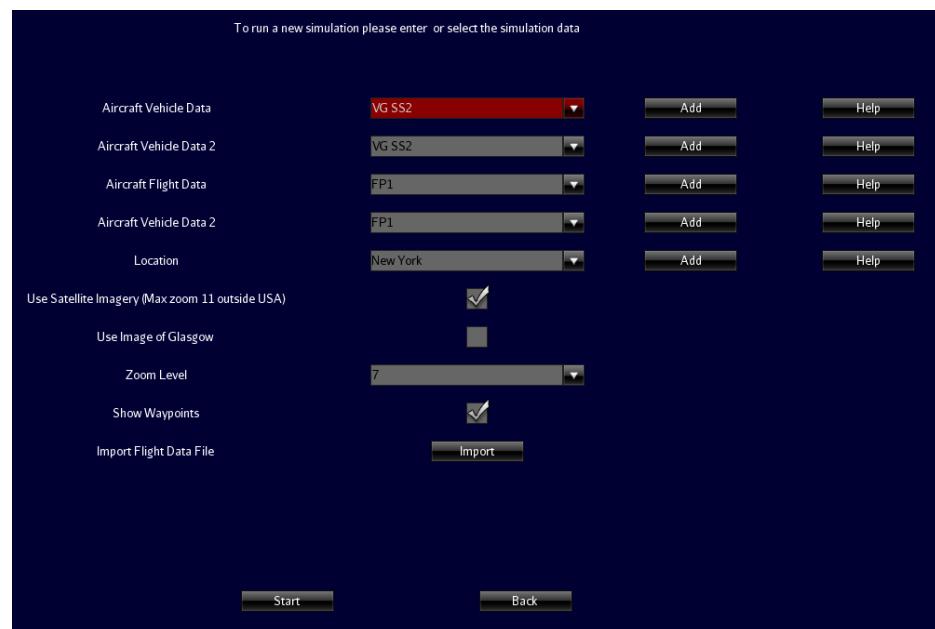


Figure 11 - Preparation of the collision scenario

These kinds of conclusions are really common in an Academic Project (a project performed for a course by students in a university context) [29], indeed, its purpose is to introduce the student to software engineering and in this case, aviation safety. Furthermore, the time to produce the system is really limited and the students have other classes to work, all of these explain that students more focus on the functional code, which is the most interesting part, than error management and usability issue.

Knowing the importance of error management, usability and user experience it is important to fix these problems in the next version of the project.

## c. Conclusion

All the software presented before are used by aviation incident and accident investigation teams, their goal is to reconstruct the Airprox situation to give a visual representation of the incident and allow the inspector to understand the context (Availability of the frequency, ATC Workload ...). But none of them show the risk for the population and none of them can be used to imagine the “worst case scenario”. The actual version of the software is not usable enough for the moment to be used by end users, especially to investigate on an Airprox. The actual version of the tool also lack of functionalities like for example the visualization of the debris density on the map, the visualization of the population density or a better control of the time during the simulation. Finally the Debris model should be reviewed in order to fits more to the reality.

In order to represent the risk for the population, our software application will use population data besides ADS-B Data. ADS-B data are data sent by planes to ground stations with information about their position, altitude, speed. Unlike radar data, it doesn't need transmission from the ground, the data can be collected by anyone. ADS-B will be deployed by Eurocontrol in Europe from 2015 in order to replace radar [30], and that is why we decide to use ADS-B data, moreover, several website make available live ADS-B data for developers. The choice between a WIMP and a Direct Manipulation interface will be made during the design process in the first iteration. The main thing that distinguishes our system from the others is that it will simulate the consequences of the collision while they strictly reconstruct the situation.

It is important for the inspector to have the most complete vision possible of the incident and to be aware of all the possible consequences to be able to make accurate recommendations. Then these conclusions can be communicated to the local civil aviation authority but also to the ANSP and to the airlines. All of the investigation can also be used in order to train new inspectors.

## 3. Design

This part will explain how the User Centered Design process is applied to the project. The process is really general and there are many ways to apply it. It depends of multiple factors: budget, time, number of users available and the diversity of the skills in the team.

This phase lasts a little more than three months and is essential to begin an efficient development phase. The ideal design phase is not limited in the time and is finished when the system meets the needs. But every project has time constraints, and this one is not an exception. To deal with this constraint while also performing enough iteration to have an efficient design phase, It was decided to plan three iterations between April and June.

The purpose of this chapter is to explain how was applied each phases of the design process to the project and how it evolves. Important results and how they impact the project will be presented.

To have a vision more exhaustive and global of this phase, all the transcripts and the meeting reports are available in the Annex C.

### a. User identification and task analysis

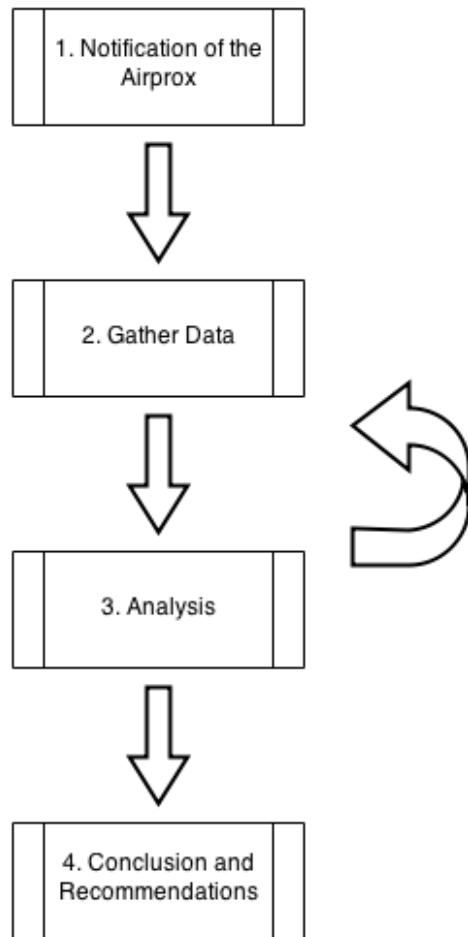
The first task is to identify the users of the tool, it is developed to help the Airprox Investigation, and so the main users are the Airprox Inspectors. It can also be used in an investigation about a mid-air collision by the Air Accident Investigators. Finally, due to the indication of the risk for the population given by the tool, it can be used by Safety Manager of Airport to help them to plan Emergency rescue in case of a Mid-Air collision close to the airport.

#### i. Airprox Inspectors

An Airprox is considered as an incident, it means that it is a situation where the safety of the flight is not assured. They are useful in aviation safety to define, for example, a causal risk model of collision [11]. Indeed, the number of collision is so low that there is too much randomness in the data and it is impossible to use only this one. This is why Aviation Authorities collect and investigate on incident even if there were no fatalities.

The Airprox investigation is performed in by the UK Airprox Board in United Kingdom, there are only 3 inspectors for all Airprox. They are based at the Royal Air Force (RAF) airport of Northolt, a suburb of London. Because of the Geographic location of their office, it was not possible to perform observations on one of their investigations. But a phone interview was performed with one of the inspector and it helped to understand who they are and all the tasks in an Airprox investigation (Figure 12). Nevertheless a visit of the offices of the UKAB was performed on the 25<sup>th</sup> of June in order to assist to the board meeting and to perform user evaluations (See the transcript of the interview and report of the visit of the UKAB in Annex C).

The common background of Airprox inspectors are a strong experience in the field of aviation and safety. They can be former Air Traffic Controllers, pilots or Aeronautical Engineers.



**Figure 12 - Main steps in an Airprox Investigation**

The first step of the investigation is the notification of the Airprox, this one can be made by one the pilots involved in the Airprox or by the Air Traffic Controller. The notification can be done by the pilot to the ATC on the radio or done directly by the pilot to the civil aviation authority, an ATC can also make a notification even if none of the pilots ask for it. This notification is done to the Military or the Civil Authority, which informs the UKAB. Then, the first job of the inspector is to gather data, he/she has to understand the event and the context. It means, ask for the radar and radio data from NATS, collect the NOTAM and the Weather data, and finally interview the pilots and the Air Traffic Controller. At the end of this step, the inspector writes a factual report with a reconstruction of the situation. Once a month, the inspectors organize a meeting with various aviation specialist (Glider pilots, ATC ...), they analyse the facts, decide on the causes of the Airprox, eventual recommendation and the level of risk of the Airprox.

At the meeting, the investigators and other people from the CAA, the MAA are here as advisors and user of the Airspace are here as members of the board. The members of the board represent the civil and military pilot, but also the Air Traffic Controller from the NATS and the army (RAF, Navy and Joint Helicopter Command). Contrary to the advisors, they have the right to vote and they decide the conclusion about the airprox. Observers can be allowed to the meeting but they don't

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have the right to participate to the discussion, it is mostly people from the army or the industry who works on project related to incident investigation. Finally the director of the UKAB, Steve Forward, is the chairman of the board, consequently he holds a casting vote should the Members find they are unable to agree.

A first draft of the investigation report is sent to the entire member before the meeting, it is composed by the factual report and an analysis written by the UKAB, but also comments from organizations involved like the ATC or the army. After the meeting, the UKAB adds a summary of the discussion of the board and the conclusion, then it is sent to the stakeholders in order to make them check the information in it and finally it is published on the UKAB website, generally six weeks after (See an example of an Airprox Report Annex K).

To assess the level of Risk, the UKAB use the ICAO categories which goes from A to E (A: Risk of Collision and E: Safety Standards). The problem with this classification is that you can't compare the risk of two Airprox. Indeed, an Airprox with the risk A in a controlled airspace can be less dangerous than an Airprox with the risk B in a non-controlled airspace, this is because the ICAO classification doesn't take into account the safety barriers (TCAS, ATC ...). For this reason, the UKAB is working on a new risk assessment notation based on the Event Risk Classification (ERC) system defined by the Airline Risk Management Solutions (ARMS) Working Group [31]. The ERC system considers the possible outcomes of an event, considers the severity of the most credible one and then considers the safety barriers which are available (See the Annex H).

The average duration of an investigation is 4 months, and around 142 Airprox were investigated in 2013.

The UKAB is not the only organization to investigate on Aiprox, the NATS, the ANSP in UK, also performed its own investigation to first, identify any organization or training problems, and then give its own conclusion to the UKAB. A visit was organized at the control centre of Prestwick on the 21st of July in order to meet the NATS investigation team. The investigation consists in gathering all the data from radar and radio, interviewing the ATC and the pilots if it is possible (more generally, the commercial pilots try to be available for the investigation, it is harder with private pilots). They also replay the airprox with the ATC involved and ask how they were picturing the situation at this time. Finally they assess the severity of the Airprox (Last safety barriers available and separation distance between the two aircrafts) and write a report with recommendations. These recommendations are sent to the operational centre of the NATS, they can accept it or reject it but a rejection has to be justified. The report and the recommendation (the accepted and the rejected one with the justification) is sent to the UKAB maximum thirty days after.

In France, the Airprox investigation, and more generally the Incident investigation is performed by the Quality of Service and Safety Unit, which is based in each Control Centre, it is composed of former Air Traffic Controllers and Civil Aviation Technicians trained at ENAC. For the same reasons than with the UKAB, It was not possible to go to France to perform observation in the field, but again a phone interview was performed with one of the Airprox inspectors of the En-route Control Centre of Aix-en-Provence. The investigation in France is a little different because the unit is a part of the French ANSP when it is independent from any Aviation Authority in the UK. First, the notification can also be done by the ATC system itself, indeed, if it detects a loss of separation using for example the alerts sent by a safety net. Then in the second step, the more severe is the Airprox, the more data the inspector will try to gather, it also depends on the probability of recurrence, if the Airprox happens during a day without any unexpected event, it has a better probability of recurrence than if the Airprox happens in a particular situation (unusual workload, bad weather ...). Finally, the analysis of the

investigation is done by the inspector, except for the most important Airprox, they are analysed by a local safety board composed of inspectors and Air Traffic Controller.

The maximum allowed duration of an investigation working is four months, this time is mostly due to the difficulty to coordinate the investigation with the work hours of ATC and the military.

In both case, such data like ADS-B are not used yet, but with the new Air Traffic Management (ATM) system (4-Flight in France) and the CASCADE program [30] (Program of Eurocontrol to implement ADS-B and Wide-Area Multilateration in ground and airborne surveillance in Europe) they are going to be more used. This kind of data will be useful in Airprox Investigation because ADS-B has a wider coverage than secondary Radar and the data is more accessible.

## i. Air Accident Investigator

Air Accident investigators are in charge of the investigation of Air crashes or important Airprox (for example in France, if the distance between the two aircraft is less than 50% of the safe distance). In France the counterpart agency is the BEA and the equivalent in the UK is the AAIB (Air Accident Investigation Branch). These agencies have to investigate in all accidents which take place in the national territory, a "Go Team" can be sent abroad if the accident involve a manufacturer, an airliner or casualties from the country they represent.

To understand their work and how they investigate an air accident, a senior investigator from the BEA was interviewed (See Annex C). Most of the investigators in France are civil servant engineers trained at the ENAC, few of them are former military with an experience in Aircraft Accident Investigation. The first step in an investigation is to collect the evidence on the place of the accident, all the debris from the wreckage, but also interview from the potential witness. A mapping of the wreckage is done, it can help to determine how the plane fall and if it hits the ground in one piece. Then the investigators bring back the flight recorder to the laboratory in France to be read, only a few lab in the world can read flight recorder, lots of National Accident Investigation Branch ask France to read the flight recorders. After the first month of investigation, a factual report is written, it can be after the first month, for example in the case of the crash of the flight AF 447, the report was written when they found the wreckage, two years after. Then the team is divided into several workgroup, and analyse the evidences, a workgroup will work on the engines, one on the wreckage, on the radar data, etc... At the end, investigators decide of the possible causes, the contributive factors and propose recommendations.

The duration of an investigation depends on the aircrafts involved, if it is only general aviation then it takes a year, but when a commercial aircraft is involved, it can take a little more than sixteen months. These durations don't take into consideration the time to find the wreckage, which could be longer if the plane crash into the sea. During the investigation, all the contributory are studied independently to see their influence on the accident, it allowed the BEA to include in its recommendation, information about what influenced really the accident and what could have been worst.

During the interview, the investigator talked about a past study performed by the laboratory of the BEA about a tool to predict the trajectory of the debris in the water after a crash, it could have helped the team to find easily the important part of the wreckage (Flight Recorder, Aircraft Computer System ...). Unfortunately the project was stopped because of the difficulty to predict the position of the plane when it hits the sea, but the concept is close to our project and the BEA is really interested in debris trajectory prediction systems.

## ii. Airport Safety Manager

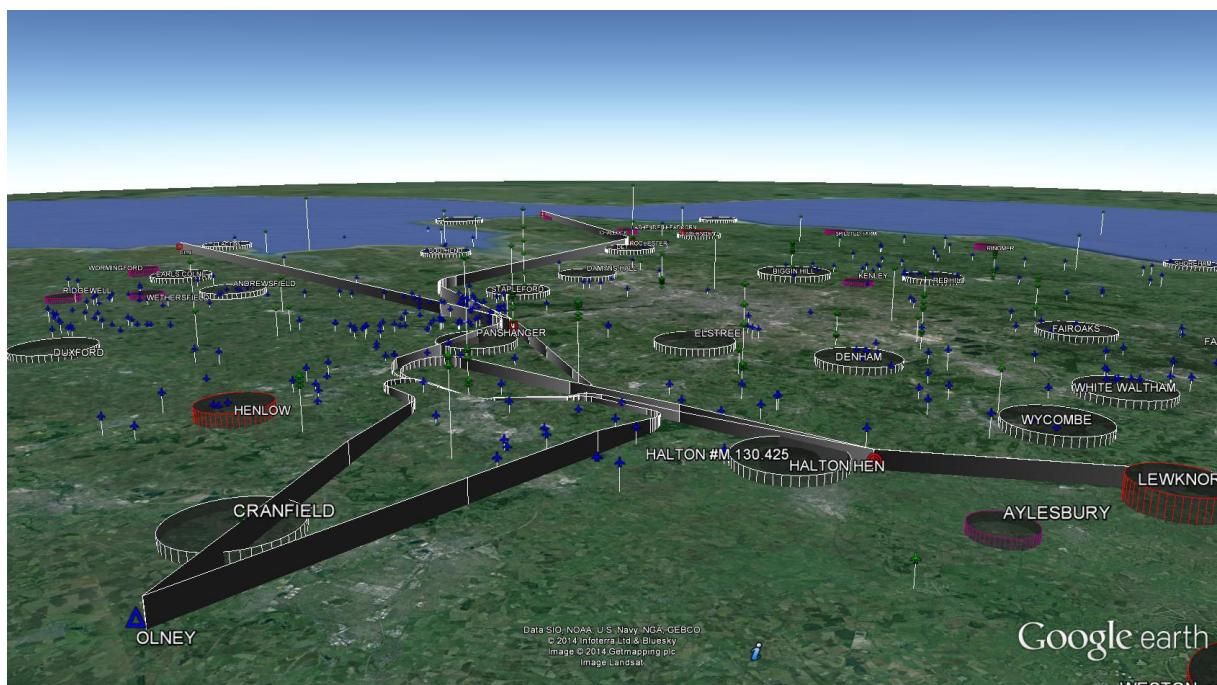
The airport safety manager is a person in charge of the safety of aircraft, passengers, employees and the people who live in the vicinity of the airport. Around 68% of air accidents happen during take-off and landing [32], and can impact all the stakeholders (For example in 2001, Concord crashed during the take-off into the Gonesse Hotel, it cost the life to 109 people in the aircraft and 4 people in the hotel [33]). Each disturbance in the normal functioning of the airport can have important consequences. To prevent these consequences, a risk analysis is performed before each creation and modification of any infrastructure on the airport. This analysis assesses the impact of each hazard which can happen due to the disturbance. For each hazard, the airport operator has to evaluate the frequency and the consequences, and with these both pieces of information, calculate the risk. If the risk is considered as too high, it has to propose solution to reduce it [34].

The Airport Safety Manager's role is also to produce an emergency plan in case of accident in accordance with ICAO: "An aerodrome emergency plan shall be established at an aerodrome, commensurate with the aircraft operations and other activities conducted at the aerodrome." (ICAO Annex 14, 9.1.1). This emergency plan can be called in case of aircraft crash, bomb attack, fire, sabotage or natural disaster in the aerodrome or its vicinity. In France, this emergency is called the ORSEC plan, it give the detail of an emergency intervention in the airport but also in an area around it [35] and it is written for each aerodrome. This plan takes into consideration the possibility of an accident during the approach or the initial climb phase, including a mid-air collision, to define the area around the airport concerned by the ORSEC plan. The size of this area is not fixed, it has to take into consideration the sensible site around, we can take the example of the Marseille Provence Airport, its ORSEC plan take into consideration the presence of the petrochemical factory of Berre 5 kilometres far from the airport [36].

## iii. Safety Analyst

To assess the risk of an incident is not only important for Airprox inspectors, it is also for the airlines, the manufacturer or other stakeholders. Some of them have their own Safety Analyst to do that, but the Civil Aviation Authority performs also Safety Analysis and diffuses them. In UK, the Airborne Conflict Action Group was created in order to assess and then minimise the risk of airborne conflict (An interview of a Safety Analyst from this group is available in the Annex C).

In order to do those, the analyst from this group try to identify Airprox "hotspot" and they try to understand the nature of these hotspots by analysing what causes the incidents (Airspace Infringement, Weather ...) and also by overlaying the air traffic flux on it. Finally, if the hotspot is in an urbanised area, they tried to assess the impact on the population on the ground, but also the impact on the economic activity (Motorway, Railroad, Factory ...). They are not using specific tool to do this assessment for now.



**Figure 13 - Map of the Airprox reported in the Luton SID**

The Figure 13 is a map realised by the Airborne conflict Action Group with the location of all the Airprox reported in the Luton SID (Standard Instrument Departure). The group uses Google Earth in order to easily represent the geographic location of each occurrence.

#### IV. Conclusion

The subject of this report is to improve the software to allow its use for Airprox investigation. In order to do this, the Airprox inspectors are considered as the main users and the interviews were used to perform a task analysis. The purpose of this analysis is to help the designer to understand the task performed by the users, and to help him to design a system which meets the needs of the users, in order to do that, it is important to modelling the tasks with a formatted language. The task analysis is realised with the Hamsters software [37], it allows building task diagram and scenario of use, in total, 5 task modelling diagrams were performed. The task analysis is available in the Annex E.

Most of the work performed by Airprox inspectors is done in an office (except some interview of ATC and pilot), and most of them don't have access to tablet at the office, they do their job with a desktop computer, so the software application is developed to be run on computer. Then they have a different level in computer practice [22], the tool should have a short period of learning and easy to use.

#### b. Requirements and Needs Analysis

After identifying the users it is important to analyse their needs in order to design a system which the tasks they need to perform in the way they want to. In order to do that, the task analysis was

used from the previous part and the Needs analysis realised by the student who worked on the project before (The detailed requirements and needs analysis is in the Annex F).

Two main use cases were identified:

- To execute a visual simulation: A visual simulation is a single situation with a 3D display (the map of the location, the air traffic and the debris falling).
- To execute a statistical simulation: A statistical simulation is a series of situation without 3D display, it only averages the risk for the ground population with the result of each situation.

These use cases are described in the following use cases diagram (Figure 14), and the description of this diagram is in the Annex F. Again, in order to be understandable by anyone, and especially by someone who is going to work on the project, the use case analysis is transcribed in the formatted language that is the use case diagram. Contrary to the task diagram, which shows the tasks performed by the user, the use case diagram shows the tasks done thanks to the system. It can be slightly different, in our case, the system only allows the Airprox Investigator to reconstruct the situation and assess the danger of the airprox.

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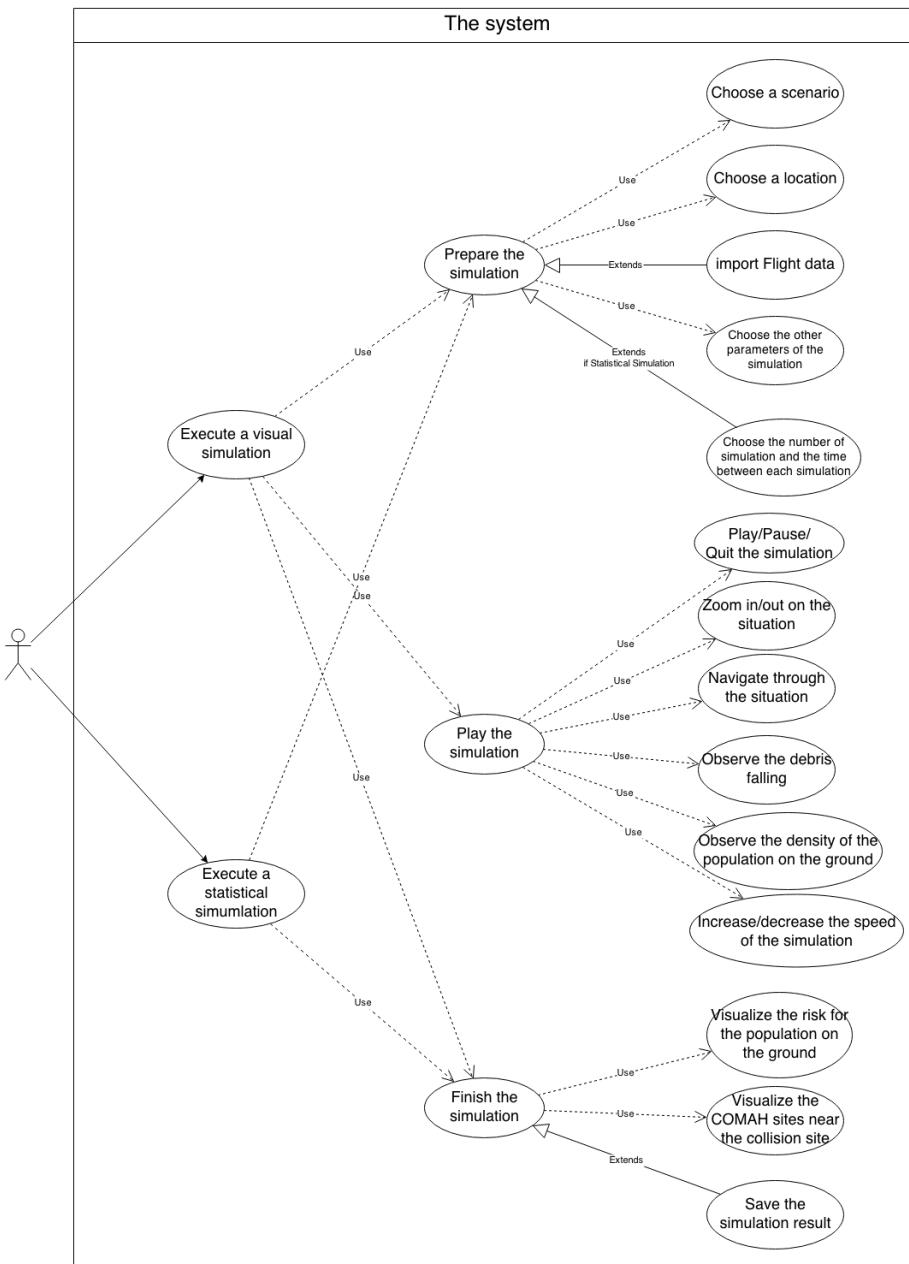


Figure 14 - Use Cases Diagram

The needs were finally grouped in categories in a table (Annex F) and given a priority level (Table 2). Indeed, the priority level is between 10 and 1, a need with a 10 is high-priority need and be developed in the first part of the development phase, while a need with a 1 can wait the end the phase, in a case of lack of time, the work will focus only on needs with a higher level. All the needs where not defined at the beginning of this phase, the list evolved during all the design phase.

<b>Id</b>	<b>Need</b>	<b>Priority Level</b>
<b>N1</b>	Needs.	
<b>N1.1</b>	Needs about the population model.	
<b>N1.1.1</b>	The system should integrate a population model.	10

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<b>N1.1.2</b>	The system should integrate different population models.	3
<b>N1.1.3</b>	The system should represent the population in the simulation.	8
<b>N1.1.4</b>	The system should have a server for population data.	1
<b>N1.1.5</b>	The system should include the COMAH sites (And equivalent outside UK).	7
<b>N1.1.6</b>	The system should represent the ambient population in the simulation.	3
<b>N1.2</b>	Needs about the crash model.	
<b>N1.2.1</b>	The system should perform a simulation of aircraft crashes.	10
<b>N1.2.2</b>	The system should simulate Mid-air collision.	10
<b>N1.2.3</b>	The system should integrate a Crash Consequence model.	1
<b>N1.2.4</b>	The system should show the density of debris falling at one place.	9
<b>N1.3</b>	Needs about the Scenario.	
<b>N1.3.1</b>	The system shall allow the user to define the flight path of two aircraft involved in the collision.	8
<b>N1.3.2</b>	The system shall allow the user to define the type of each aircraft involved in the collision.	7
<b>N1.3.3</b>	The system shall allow the user to define the weather of the scenario or import live data from the internet.	7
<b>N1.3.4</b>	The system shall allow the user to import his own ADS-B flight data or import live data from the internet.	7
<b>N1.3.5</b>	The system should show the population at risk at the end of the simulation	10
<b>N1.4</b>	Needs about the Statistical Simulation.	
<b>N1.4.1</b>	The system should allow the user to perform a series of simulation and see the average risk for the population.	5
<b>N1.5</b>	Other needs.	
<b>N1.5.1</b>	The user should be able to change the API Key used for the ADS-b, Weather Data and Map websites.	7
<b>N1.5.2</b>	The user should be able to change the colour used in the 3D simulation.	7
<b>N1.5.3</b>	The system should be able to calculate the safest flight path between two points.	1
<b>N1.5.4</b>	The system should allow the user to save the result of the simulation.	8
<b>N2</b>	Interfaces.	
<b>N2.1</b>	The system should allow the user to Pause, accelerate and rewind the simulation.	7
<b>N2.2</b>	The system should allow the user to take screenshot of the simulation.	8
<b>N2.3</b>	The interface of the system should give a feedback for each action of the user.	9
<b>N2.4</b>	The interface should use vocabulary and concept familiar to the user.	9
<b>N3</b>	Use Cases.	
<b>N3.1</b>	The system must allow reproduce the use cases.	10
<b>N4</b>	Constraints.	

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<b>N4.1</b>	The loading of the simulation should take less than 10 seconds.	8
<b>N4.2</b>	The representation of the density of debris and the population as physically measured should be directly proportional to the quantities represented (Lie Factor between 0.95 and 1.05).	8
<b>N4.3</b>	The data used has to be available easily for an Airprox Inspector	8

Table 2 - Needs Table

The constraints on our system are about the time of execution of the system and the fact that it should give an appropriate representation of the risk. Indeed, it is really easy to emphasize with a chart, especially in 3D. To have an accurate picture of the risk, we can calculate the Lie Factor [38] of each, but also do user test and see with which one the user understand well the right information. Another constraint is about the data the user can use, indeed our software has to be able to reproduce an Airprox only with the data that an Airprox inspector has in his possession. To have information about these data, Airprox reports from the UKAB (Figure 15) and from the DGAC (Figure 16) were analysed (See Annex K), because the French reports are confidential, only a blank one was available.

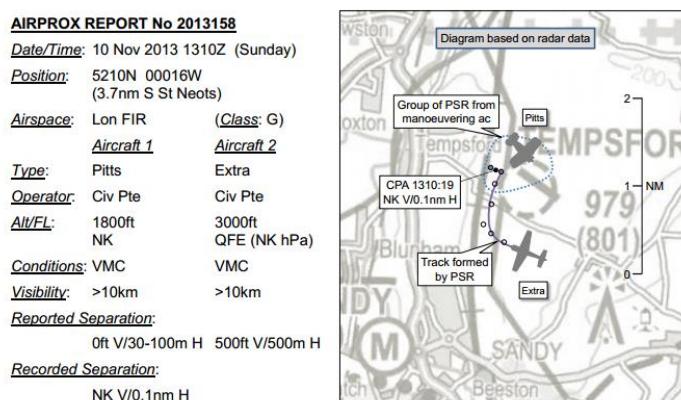


Figure 15 - UK Airprox Board Report

	<i>Mobile 1</i>	<i>Mobile 2</i>
<b>I.4 Configuration des vols</b>		
Vitesse Sol (précisez l'unité)		
Altitude au QNH ou FL(1013)		
Dernier niveau clairé		
Configuration (ex : montée, descente, palier ...)		
Phase de vol (ex : «roulage», approche finale, ...)		
<b>I.5 Informations sur les vols</b>		
Type d'appareil / véhicule		
Exploitant		
Aérodrome de départ		
Aérodrome de destination		
Nature du vol		
Type de circulation		
Régime de vol		
Contact radio		
Transpondeur		
Conditions de vol (selon pilote)		

**Figure 16 - DGAC Airprox Report**

We can see that both reports contain the Altitude and the type of the two aircraft. In the English one, it also contains the position and a diagram of the situation which can help to find the heading of both aircrafts. With the context of the Airprox (Which is summed up in the factual report) we can guess the stage of flight. But the ground speed and the vertical speed are misses, and they are information which can be useful for the simulation. One solution would be to define them in function of the type of aircraft and the stage of flight, another solution would be to extract them from radar data. In the French report, it misses the position, which is in fact given in another part of the report, the heading and the vertical speed. About the heading, the Airprox Inspector can read it on the radar screen, and we can use the same solution than before about the vertical speed. All the other information should not be mandatory.

About information like the weather and the other traffics, the software should allow the Airprox inspector to define them himself, we can see in the English Airprox report that the METAR are given to indicate the weather forecast of the day.

## c. Idea Generation and Prototyping

### 1. Idea Generation

In order to not prototype an exact copy of the previous system, it is important to think about new ideas. One way to generate new ideas is to study similar systems and this is what it was done in the analysis of existing systems. The 3D visualization could be compared to a video of the collision and the falling of the debris, the investigators want to be able to control the time of the simulation and be able to easily watch it again. For example, we can see that EPOQUES use a VCR-like toolkit to pilot the time, users are used to use it on their computer to play video or music (Figure 17). Some tools have direct manipulation interaction and other have a standard WIMP interaction, it is possible to prototype different alternatives with different interaction technique and let the users choose the best one.

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Figure 17 - A Video Controller to Control the Simulation

Another way to generate idea is to do a brainstorming, a brainstorming is a creativity technique that consists in gathering ideas spontaneously about a predefined subject. This method is used in system engineering in order to produce different alternatives, it can be performed with users, with other team members or alone. In this project, because of the fact that the users was not available, only individual brainstorming was performed, each idea was sketched up in order to use them in the prototyping phase. One way to perform a brainstorming is to think about the vocabulary of the subject, in this case, it was possible to think about Aircraft, Air Traffic Control, but also Hazard and Risk. For example, the idea of choose the altitude, attitude, heading with sliders around a picture of an aircraft that move in functions of these settings came by thinking about a Primary Flight Display (PFD) and a Navigation Display (ND) that are indicators in the cockpit of the position of the aircraft and its main parameters (Altitude, Attitude, Speed, ...) (Figure 18).

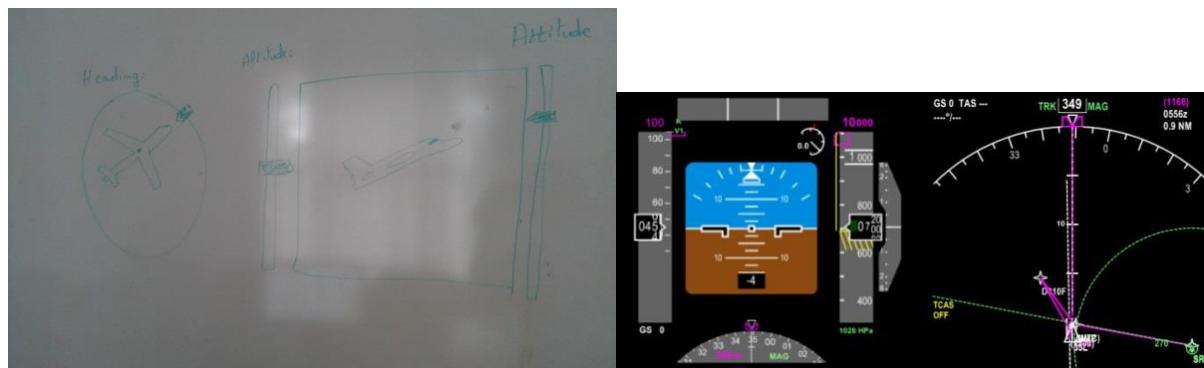


Figure 18 - An idea inspired by the PFD and ND

Another idea was to use a 2D map to prepare the scenario, it was inspired from the 2D radar screen used by Air Traffic Controller (the majority of the Airprox Inspector are former ATC) (Figure 19).

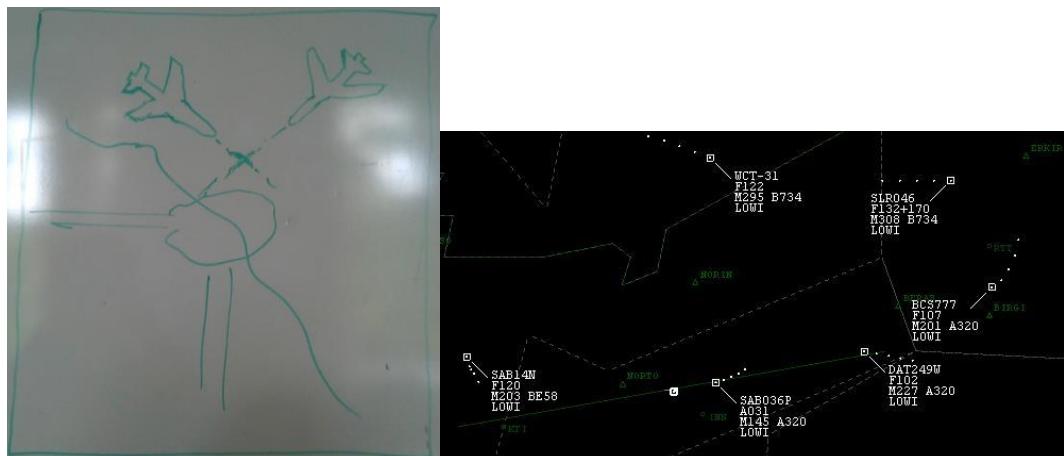


Figure 19 - A 2D representation to prepare the simulation

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This idea generation allow us to have several alternatives to prototype different solution. The prototyping can have different level of fidelity, it depends mostly on the progress of design process. The fidelity is the similarity of the presentation between the prototype and the final product.

### 2. Paper Prototyping

The purpose of the first iteration is to prototype several solutions which can be tested by the users, it is also to define the general architecture of the software. In order to do that and to produce quickly several prototypes, it was chosen to use paper prototype. Another advantage is that the user will not focus in graphic details like the colour of a button or the font, but he will focus on the general architecture of the software. The Table 3 present the prototypes of the first iteration.

Paper Prototype – 1 <sup>st</sup> Iteration	
Technology used	Paper.
Number of prototypes	29 pages.
Accuracy Level	Low level, Informal.
Representation (Online/Offline)	Offline (The prototype is not a software application).
Interactivity	The user can interact with the prototype thanks to a Wizard of Oz process.
Lifetime	Throwaway (The prototype won't be used in another phase).
Role in the design phase	Expanding the design space by proposing several solutions.
Horizontal/diagonal/vertical	Horizontal (Only the interface is prototyped).

Table 3 - Prototype presentation for the 1st iteration

This step started by prototyping the form to create the scenario, it means the form which contains all the important information to begin a simulation. The information has to be as easy to manipulate as possible because Airprox report can be sometimes not that accurate, it depends on the class of Airspace (Controlled or not), the aircrafts' equipment (TCAS, Squawk ...). I decided to use direct manipulation to make them easy to manipulate. Some solutions were proposed as:

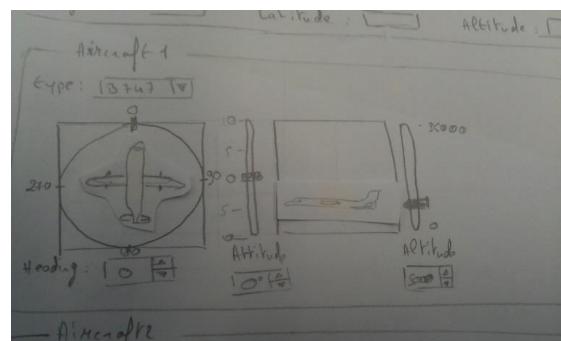
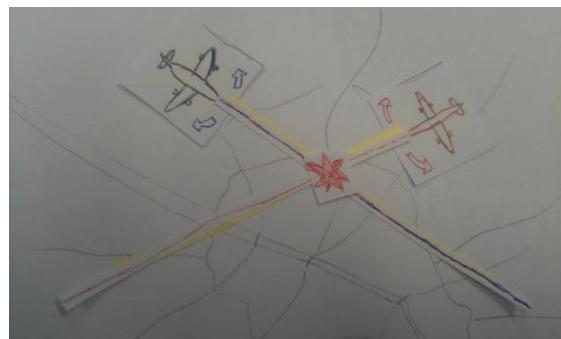


Figure 20 - Aircraft Settings Alternative Solution 1



**Figure 21 - Aircraft Settings Alternative Solution 2**

In the first solution (Figure 20), the user can manipulate sliders in order to adjust the aircraft settings, a feedback helps the user to visualise the aircraft situation. In order to choose the altitude and the pitch of the aircraft vertical slider are used, and to define the heading of the aircraft, a Knob (A circular slider) is used. The effects of the action of the users are directly visible thanks to the feedback and reversible. Each time, the value selected is represented in a number field that can also be modified by the user, this solution allow the user to be accurate in his/her choice. In the second solution (Figure 21), the user can manipulate directly the aircraft on the map with the pointer of the mouse and then apply to them a rotation. The advantage of the first solution is that the user can be accurate in the definition of the settings (Heading, altitude, Pitch), but in the second solution, the user manipulate directly the aircraft, which could be more intuitive. All the paper prototypes are available on the Annex G.

### 3. JavaScript prototype

The paper prototype is a good way to prototype the main architecture of the application and to produce several alternatives. But in order to test the interaction and 3D visualization with the users, it is important to produce an online prototype (An online prototype is a software prototype). There are several solutions in order to produce online prototype, it is possible to use languages like Flash, Flex or HTML5 which are more adapted to prototype interaction because they are easy to learn and really powerful. It is also possible to use language like Java or C#, they are harder to use and to learn but it is possible to reuse the prototype in the software application during the development phase. The Table 4 present the prototypes of the second iteration.

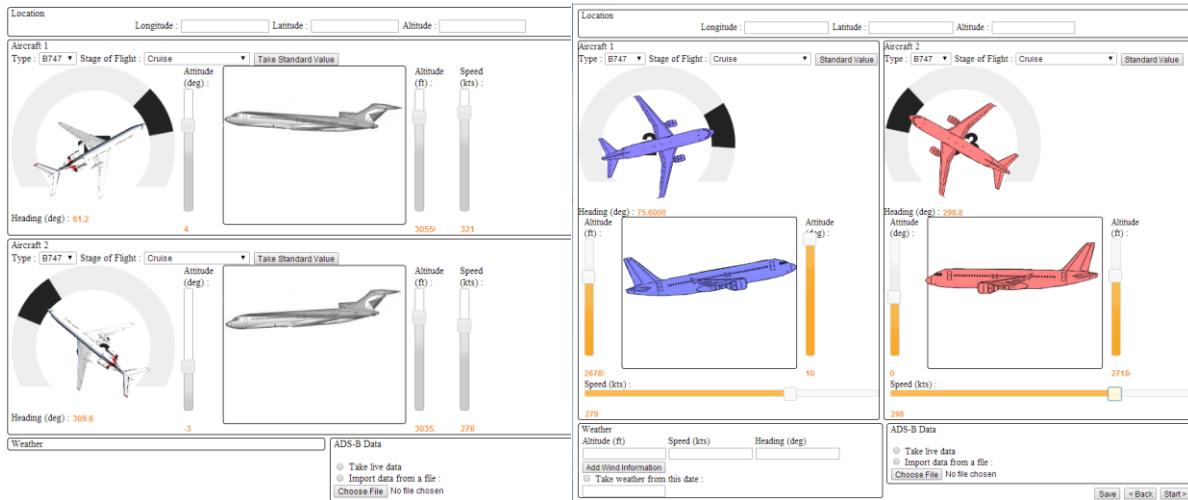
JavaScript Prototype – 2 <sup>nd</sup> Iteration	
Technology used	CSS/HTML, JavaScript/JQuery, Google Earth.
Number of prototypes	9 pages
Accuracy Level	Medium level.
Representation (Online/Offline)	Online (The prototype is a software application).
Interactivity	The user can interact with the prototype.
Lifetime	Iterative (The prototype will be used in the next phase).
Role in the design phase	Expanding the design space for the 3D Visualization/Validating the solutions for the rest.
Horizontal/diagonal/vertical	Diagonal (Some data are implemented)/Based on a scenario.

**Table 4 - Prototype presentation for the 2nd iteration**

For the project, it was decided to develop the online prototype with HTML5 and JavaScript with the library JQuery, a library that allows developing easily interactive software application. The purpose was to prototype quickly a first demo version of the software application in order to present it to the Airprox inspectors in London on the 25<sup>th</sup> of June. The first JavaScript prototypes take into

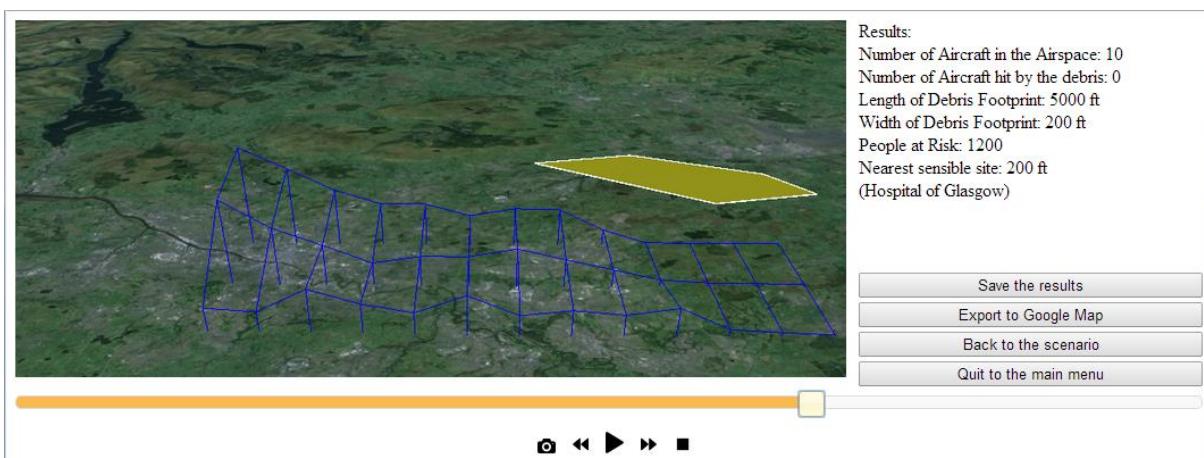
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consideration the comments made by the user during the test with the paper prototypes, but the design is still simplistic, because we don't want the users to focus on the design during the first tests.



**Figure 22 - Two alternative architectures for the scenario preparation**

Two different architectures for the scenario preparation part were prototyped (Figure 22), the second has the advantages to give the user the opportunity to have a better visualization of the relative position of one aircraft compared to the other. About the heading, the altitude and the attitude, each move of the cursor provoke a feedback on one of the draws of aircraft. The button "Standard Value" allows the user to apply standard values for the speed and the attitude in function of the type of aircraft and stage of flight.



**Figure 23 - The Visual Simulation**

The 3D visualization was not prototyped in the paper version because it won't be accurate enough to be useful in the user evaluation. That is why it was decided to prototype several alternatives for the 3D visualization (Figure 23), one of the problems of the actual version of the software application is the lack of representation of the population. Another problem is the lack of representation of the risk for the population.

One way to represent this risk is to show the density of debris fallen on the ground. The higher is the density, the higher is the risk for the people who live in this place. The colour is a good way to

show the danger on a map; it is easy to understand because some colours are associated to safety status in the daily life [39]: the red means a high danger, the yellow means an average danger and the green means safety.

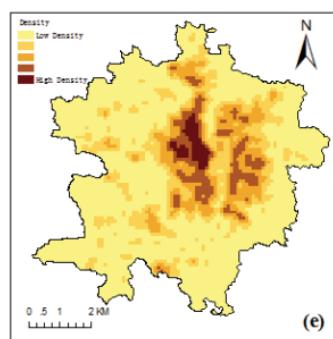
To represent the population, many ways exists, only few were selected which could suit the needs of the project:

- A choropleth map (Figure 24) is a map which uses colour contrast to represent a statistical variable, this kind of map is very popular to represent the population variation [40]. But because we use the colour attribute to represent the probability, it will be too confusing for the user if the colour also represent the population density.



**Figure 24 - Choropleth Map**

- A Kernel Density map (Figure 25) is a map where the density is estimated with the Kernel Density Estimation [41]. This estimation gives us a density function of a variable thanks to a finite data sample. The dataset is smoothed, which means that the value is less accurate, but this method suppress the noise and allow the user to capture important patterns, for example, with a Kernel density map of population, it become easier to localize the main city. This kind of map is used when the general trend is more important than the accurate value. The density is representing by a colour gradient, like the choropleth map, we can't use it in our software.



**Figure 25 - Kernel Density Map**

- A prism map (Figure 26) is a 3D version of a choropleth map, it uses the height of the area to represent the value of a statistical variable [42]. This kind of map is really visual, it shows immediately the places with a high density, but it is harder for the user to read the value of the density, it is also harder to compare two areas which are not side by side.

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Finally this kind of map can overcrowd the map, and the density is not the only information to display [43].

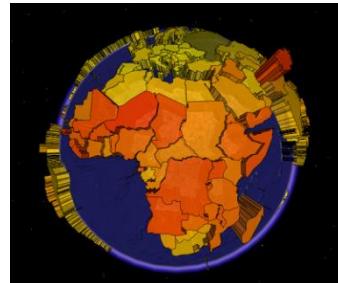


Figure 26 - Prism Map

- A spike map (Figure 27) is a 3D density map, one of the most known spike map is published in the time magazine by Feilding Cage, and it represents the population density in the United States of America. This kind of map make the visualization of general trend really easy, but the use of 3D can obscure values, for example a low value can be hidden by a high value. This problem can be solved by the fact that the user can rotate and move the view.

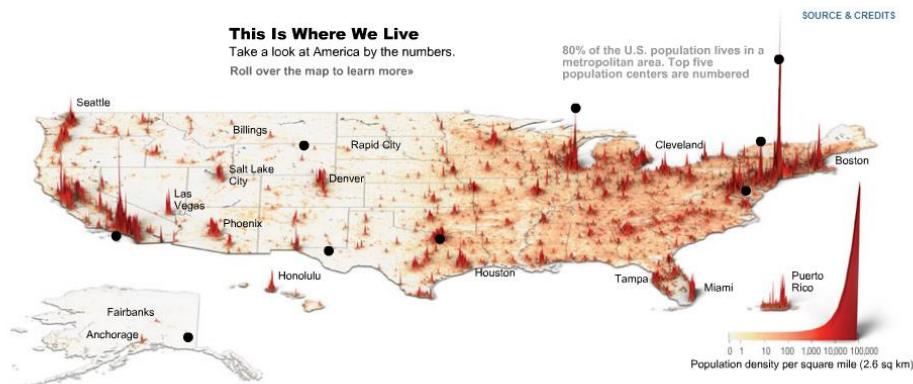


Figure 27 - Spike Map

To use a Choropleth or a Kernel Density map would imply the use of colours for two variables: the population and the probability, which could be confusing for the user, and how to deal with the fact that for one place it could be necessary to represent the risk and the population with only colours. The other reason to choose a 3D representation is that size is a visual variable that can be easily quantified. To represent the risk with colour and population in 3D could be explained by the fact that colour value can represent an order, but the quantification of the difference between two values is hard. That is why three different 3D visualizations were prototyped on Google Earth with population data from the Gridded Population of the World. The yellow layer represents the debris falling. It was chosen to prototype two versions of the 3D Choropleth map, one with histogram without space (Figure 28.1) and one with space (Figure 28.2), then to prototype a version of a spike map (Figure 28.3).

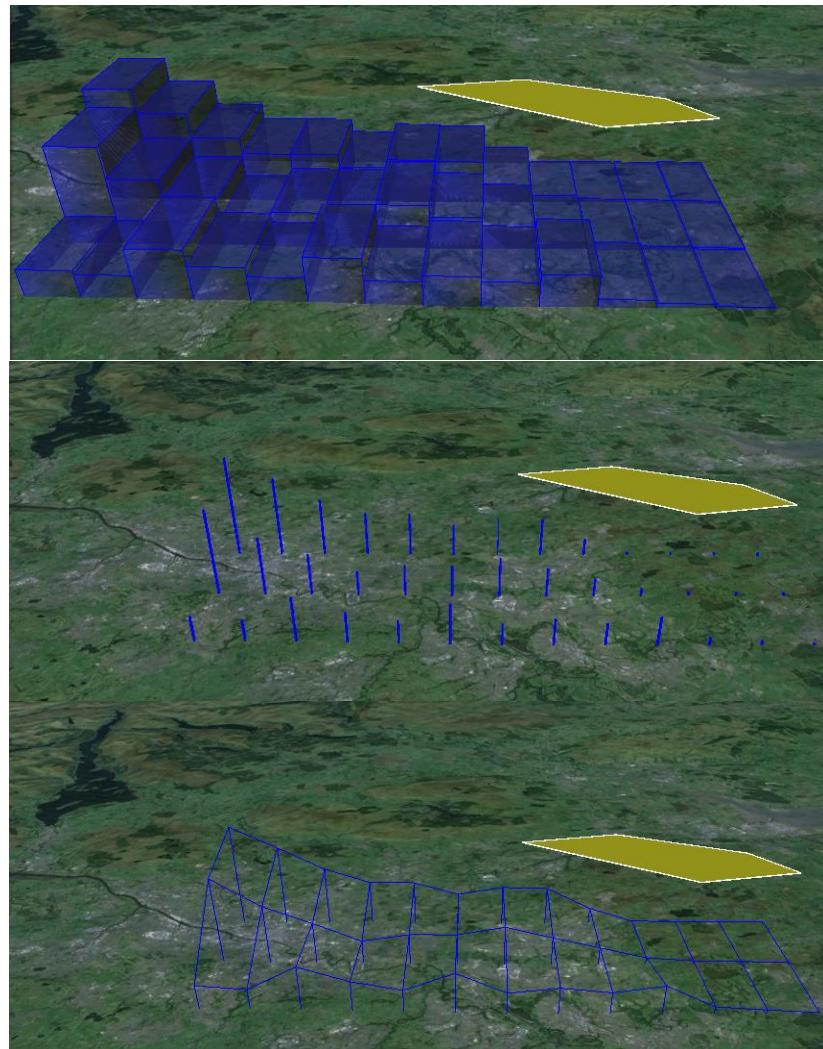


Figure 28 - Three representations of the population of Glasgow

The evaluation with the user will allow determining the best representation without implying a too high lie factor. By default, the colour to represent the density would be from red to orange, but it could be configurable by the user (Figure 29). The configuration of colour allow user with an handicap (Colour blind,...) to choose an adequate visualization.

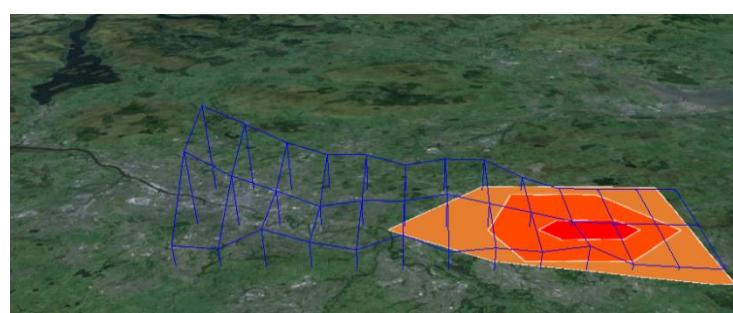


Figure 29 – The representation of the risk

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In the third iteration, a second JavaScript prototype was made (Figure 31 - Figure 32), it was supposed to be the last one in order to begin the development phase soon enough. Only big usability problems could lead to a forth iteration. This one is focussed on the design of the software application and on the reduction of the number of steps between two sections. The Table 5 presents the prototypes of the third iteration.

JavaScript Prototype – 3 <sup>nd</sup> Iteration	
Technology used	CSS/HTML, JavaScript/JQuery, Google Earth.
Number of prototypes	6 pages
Accuracy Level	High level.
Representation (Online/Offline)	Online (The prototype is a software application).
Interactivity	The user can interact with the prototype.
Lifetime	Throwaway (The prototype won't be used in the next phase).
Role in the design phase	Validating the solutions.
Horizontal/diagonal/vertical	Diagonal (Some data are implemented)/Based on a scenario.

Table 5 - Prototype presentation for the 2nd iteration

The idea for the second issue of this prototype came from a famous software application used a lot in pilot training and in aeronautical research: Microsoft Flight Simulator [44]. The main menu is on the left side of the frame (it could make think about a web page), which allow the user to change section at any time (Figure 30). It is important that the user could change section without losing his/her work in it, like in a tab system. More screenshots of this prototype are available in the Annex G.

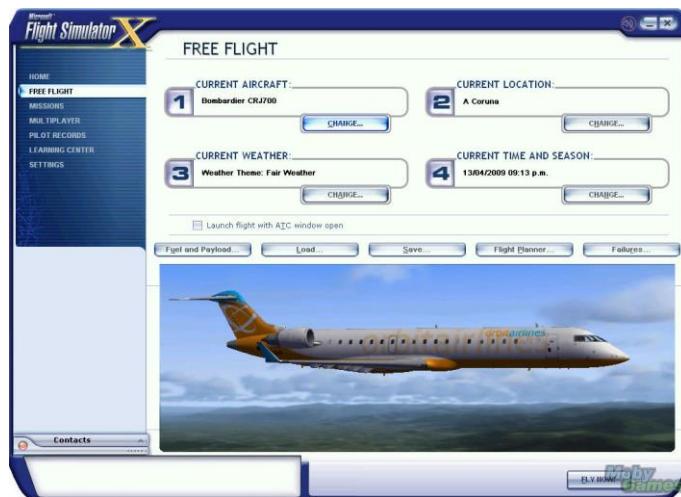


Figure 30 - Microsoft Flight Simulator Main Menu

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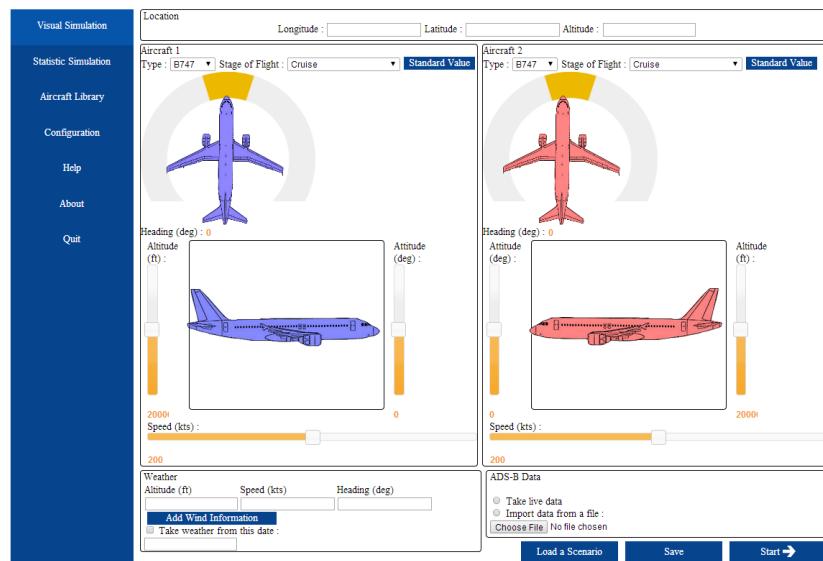


Figure 31 - Scenario Preparation Form

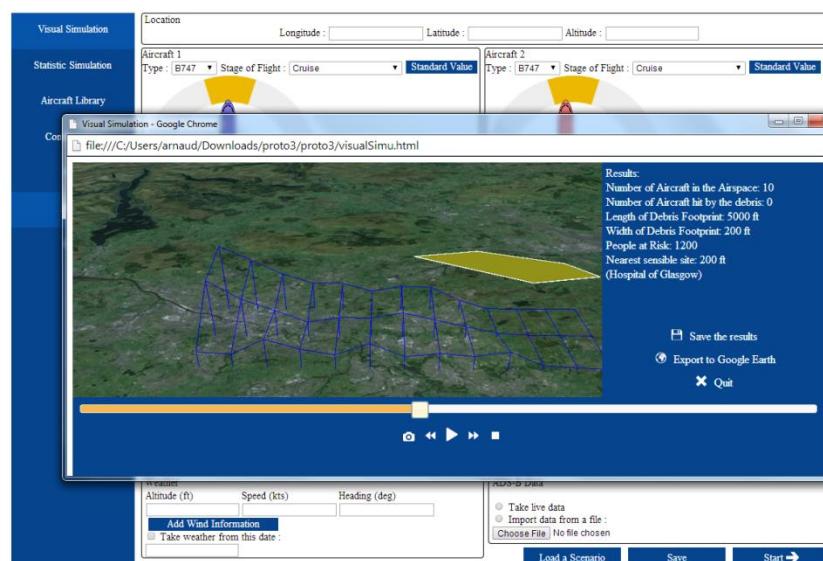


Figure 32 - Visual Simulation

One of the main colour used in the software application is the blue, the first reason is that blue that makes think about Aeronautics and Aircraft. Then this colour is really neutral (unlike for example the red or the green).

## d. User Evaluation

In order to evaluate the prototype it is important to show them to users and allow them to use them. It was decided to apply a design walkthrough process. It means that all users test the different prototypes, and they are asked to give their opinion about them, and any comments they think appropriate about the interface, the interactions and the software application in general. I also ask

them to apply a “think aloud” protocol, which means that they tell me how they are thinking during the test.

It was hard to find users with enough knowledge in Air Traffic Management to understand the different issues of the software. Also, for the third iteration, real users (airprox investigators from the UK Airprox Board) agreed to test the software application, but they didn't have a lot of time and it was not possible to perform a formal usability evaluation.

A scenario was given to the users in order to make them use the prototype under normal conditions. The scenario is based on an Airprox report from the UKAB, which reports an Airprox that happens in the Scottish Terminal Control Area (TCA) between a Saab2000 and an A319 at the FL180 (the report is available in the Annex C). The full report of the Airprox is available in the Annex K.

## i. Evaluation with the paper prototypes

In order to have interesting result it was important to have users with a minimum aviation background (because of the lack of Airprox inspectors in Glasgow). To this end, the user evaluations were done with three students from the Master of Aerospace Engineering of the University of Glasgow. They all got an experience in Aviation Industry and they know how Air Traffic Management works, the different stage of a flight, the basic information about a flight (Altitude, heading, air speed, pitch, vertical speed ...) and what an Airprox is. In addition to the Airprox report, the users were given additional information which was not in the report (Standard attitude for climbing, weather of the day), in the final version, these pieces of information would be filled by the software application.

The results of this evaluation show that users preferred the interface more visual with a visual representation of the situation, but it must not be confusing. For example, about the scenario preparation interface, Users found the version with the sliders (fig 19) and the “moving” aircraft more visual than the classic form (fig 18) and less confusing than the version with the map (fig 22), so that is why it was decided to continue with this version.

## ii. Evaluation with the JavaScript prototypes

In the second and third iteration, the prototypes were made in JavaScript. So the evaluation of the second iteration was made with a PhD student of the University of Glasgow, he studies Air Traffic Management and Computing Network, so he has a good knowledge of how Air Traffic Management works and what is an Airprox. His background in computing science was also really helpful because he was aware of what was expected during the evaluation and the difference between a prototype and the real product at the end.

The results of the evaluation show that the user was satisfied by the interface of the software application. It was pointed out some terms could be confusing and some small usability problems. About the representation of the population, the big histogram was a good way to see the population and to compare the different place, but it makes hard to see the map. With the small histogram it was hard to compare the population of two places which was not close from each other. Finally, the spike-like representation was defined by the user as a good compromise between the necessity of being able to compare the population in different places and not hiding the map. It was so decided to continue with this solution. The user also pointed out that the navigation between different sections could be a little long. For example, if you want to create a scenario and then begin a statistic

simulation, you have to go back to the main menu between the two steps. The third iteration tried to find a solution to this problem.

The user evaluation of the third iteration was done with three Airprox Inspectors from the UK Airprox Board at the RAF Airbase of Northolt. Each of them tried the prototype and gave his opinion and eventual comments. They really liked the purpose of the software application, indeed in order to assess the risk for the population of an Airprox nowadays they don't use any tools, they just looked for populated city. They also were really interested by the fact that the visualization is in three dimensions, the tools used to investigate are really basic, but the CAA is working on 3D Visualization software application to investigate on incidents and accidents, the software developed in this project could be in that case really interesting.

They really liked the visual representation of the aircraft in the scenario preparation form, it is faster to give an approximate value of the settings of the aircraft and they said that it doesn't need to be really accurate (a difference of 5-10 knots about the speed is not important in the investigation). It was the first time for that I could meet real end-users for evaluation, I decided to show them the different alternatives solution I imagined in the past iteration, and then they could confirm me that the choices made in these iterations were good.

## e. Conclusion

After three months of design, the third prototype that was the closest from the final software application was tested with real-end users from the UK Airprox Board in London. At the end of this design phase, it is possible to resume the major design choices that were made thanks notably to the evaluations with users:

- A vertical menu at the left side in order to make the navigation between the different parts of the software easy for the user.
- Interactions between WIMP and Manipulation Direct to choose the aircraft settings, with the use of Knob and Vertical Slider.
- The possibility of Saving/Loading scenario.
- A loading frame with a recap of the situation and the possibility for the user to cancel the loading if the situation is not what it should be.
- The use of a spike map to represent the population and colours to represent the debris density.
- A display of the result permanently, and then the important information are always accessible for the user.
- An interface to control the time of the simulation.
- The possibility of taking screenshot of the situation.
- The possibility of exporting the result to Google Earth.
- The possibility of changing the colour for the representation of the debris density.
- The creation of an Aircraft library, to allow the user to add easily aircrafts.

All the steps of this phase allow this version to meet the needs of the users. It is really important that this phase is well performed and well documented, then the development phase only consists to transform the prototype into java code and to add the different data sources. It is also important because this project will be given to other students and if they know what was done before they will not have to do all the previous steps.

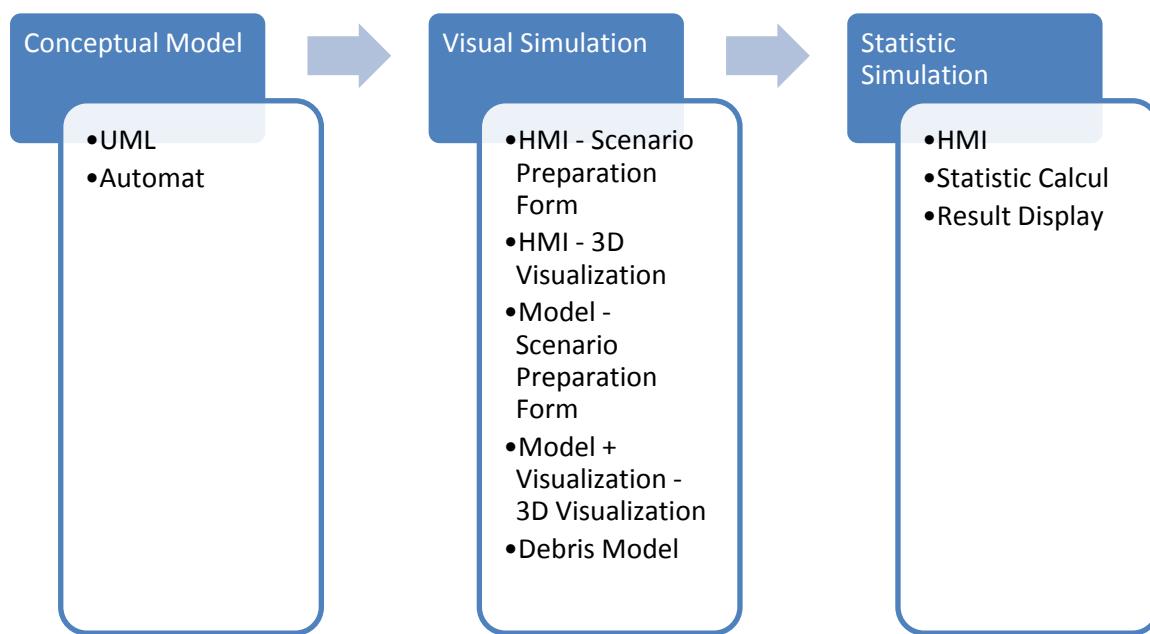
## 4. Development Phase

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This phase concluded this project, it lasted two months and finished with a user evaluation of the final version, if it is possible, a user evaluation will be done during this phase in order to be able to detect problems in the software before finishing it. Because a version of the software was already developed, modifications could just have been added to this previous version, but because of major change of technologies, it was decided to develop a whole new software application and to get just part of the code from the previous version.

### a. Development Planning

The purpose of this internship is first to improve the interface of the software application, that's why it was decided that the Human Machine Interface (HMI) would be the first step of this phase. Then because the visual simulation is one of the main requirements of this software application, it would be the first functionalities to be implemented entirely, then the statistic simulation would be developed. In the Visual Simulation, the debris model would be developed at last.



It was planned that the first phase would last a week, then that the development of the Visual Simulation functionalities would last a month and a half, and finally two weeks for the last phase.

### b. Used Technologies

The previous version of the software application was developed thanks to the API JMonkeyEngine (JME) and Java, but it was noticed that if JME was a really efficient tool to develop in

3 Dimensions in Java, it was not the most efficient to developed form and menu interface. This is why it was decided to redevelop the entire software application.

In fact it was necessary to use an efficient API to develop the main Graphical User Interface (GUI) which is a WIMP Interface, but this API should also be able to support customized components (Like the Knob). Then a second API is necessary to deal with the 3D visualization.

Different APIs are available to develop WIMP interface:

- Abstract Window Toolkit (AWT): The Java's original GUI API.
- Standard Widget Toolkit (SWT): A GUI API that uses the native toolkit of the Operating System (OS).
- JavaFx: A GUI API created to develop Rich Internet Applications.
- Swing: A GUI API that doesn't use the native toolkit of the OS, it is completely independent from it.

AWT is considered as the less flexible as the three other, because of the fact that AWT is more low-level. The fact that SWT uses the native toolkit of the OS implies worse performance to display a window with lots of components like our scenario preparation window than Swing. Finally, JavaFx is relatively new (2008), and people are for the moment more familiar with Swing, especially the team on the project. It was chosen to use Swing to develop the GUI.

The last project was developed with JME, and because some parts of the project were reused in the new version, it was decided to use again JME for the 3D Visualization.

## i. JMonkeyEngine

JMonkeyEngine is a game engine especially designed for 3D Development, it uses LightWeight Java Game Library (LWJGL) as a renderer, which itself use OpenGL, the renderer is the process that generate the image displayed on the screen from a model, in the case of OpenGL, the renderer use a scene graph, the position of the "camera" and the position of the light sources. OpenGL furnishes also a set of control in order to rotate and translate the objects in the scene graph and the camera. JME also proposed its own IDE that is based on Netbeans. This IDE furnished an efficient interface to manage the Assets of the project (GUI, Models, Texture ...).

JME is an open source project and is under the Berkeley Software Distribution (BSD) license, it means that JME can be used in any projects without any restrictions. It is still in development and the community is becoming more and more important.

JME is used in the development of lots of Video Games like 3089 or Pirate Hell, and it is even used by professional game studio like SLX Games.

## ii. Swing

Swing is a powerful API used to develop GUI in Java. It is more sophisticated than Abstract Windows Toolkit and it works on every platform because the components are developed in Java (Figure 33). Swing uses a Model-View-Controller Architecture, which allows having several views for one model.

Finally Swing is implemented in most of the Java IDE like Eclipse or Netbeans, and so on JME.

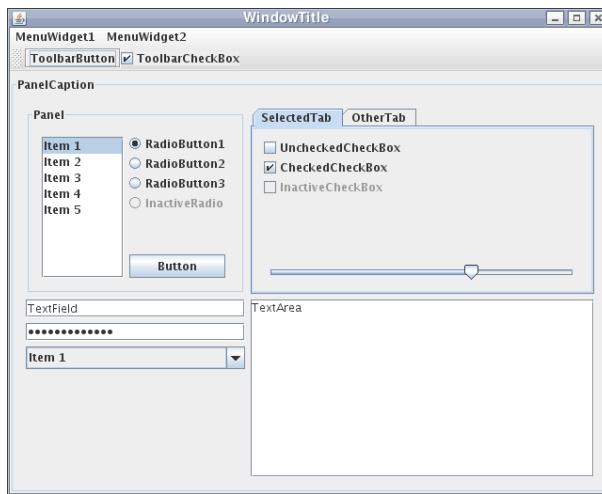


Figure 33 - A GUI developed with Swing

## c. Conceptual Model

The development phase began with a conception phase in which all the needs found in the design phase were translated into technical requirements. The accurate mechanics of the software application was first detailed with Unified Modelling Language (UML) diagrams, but also sequences diagrams and automats.

This phase is really important because:

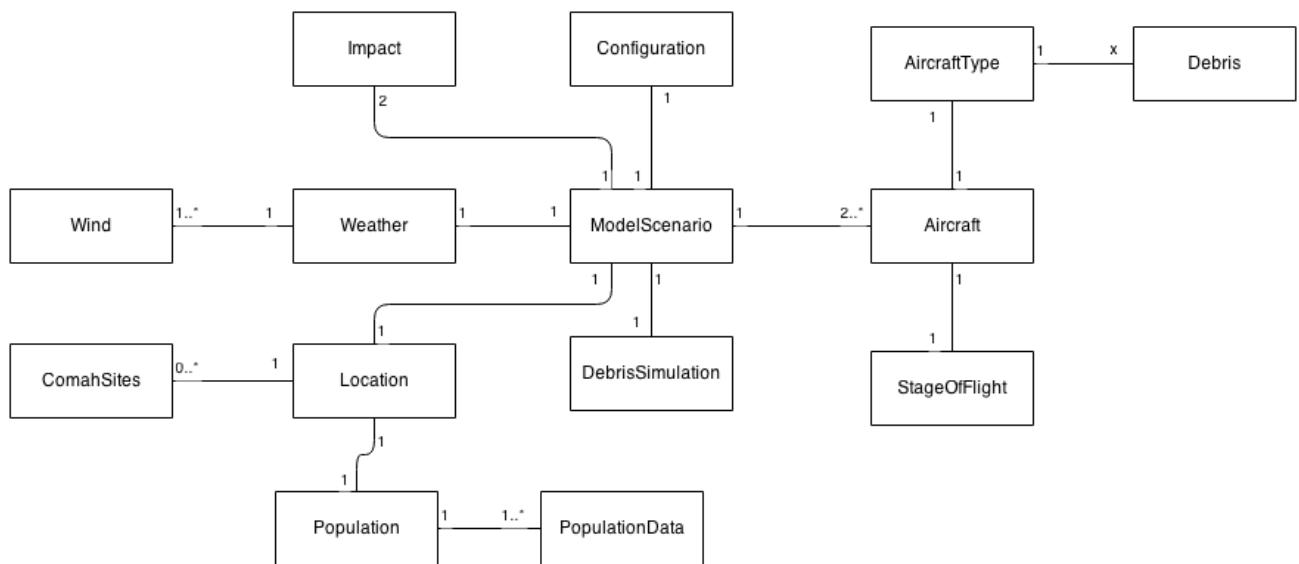
- It leads the coding of the software application, each part of the code should have been thinking and there is less incoherence in the code at the end.
- It allows doing "Model Checking" without reading the code.
- It helps eventual successors to understand the code.

The first step of this phase is to do the general model of the software and to define all the conceptual Java classes needed for a simulation (Figure 34).

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**Figure 34 - Conceptual Model of the Software Application**

Then, it is important to define all the other classes relative to the interactions and the interface. In order to be able to change the interface or the model without having to change the other, it was decided to use a design pattern Model-View-Controller (MVC) [45]. It is a design pattern that divides the software application into three inter-connected parts:

- A controller: This part receive all the commands from the user
- A View: This part generates an output to the user
- A model: This part manages the data, but also receives information from the controllers and sends them to the views.

It is possible to have multiple views and controllers, but normally only one model. It is also possible to have classes that are views and controllers, in that case, it is better to not mix the methods for the view and the methods for the controller.

In this project, the Scenario Preparation form is a view and a controller, and the 3D Visualization is only a View. Indeed, the user can modify the scenario from the 3D Visualization. Of course the user can control other thing on the 3D visualization, but it doesn't impact the model (Figure 35).

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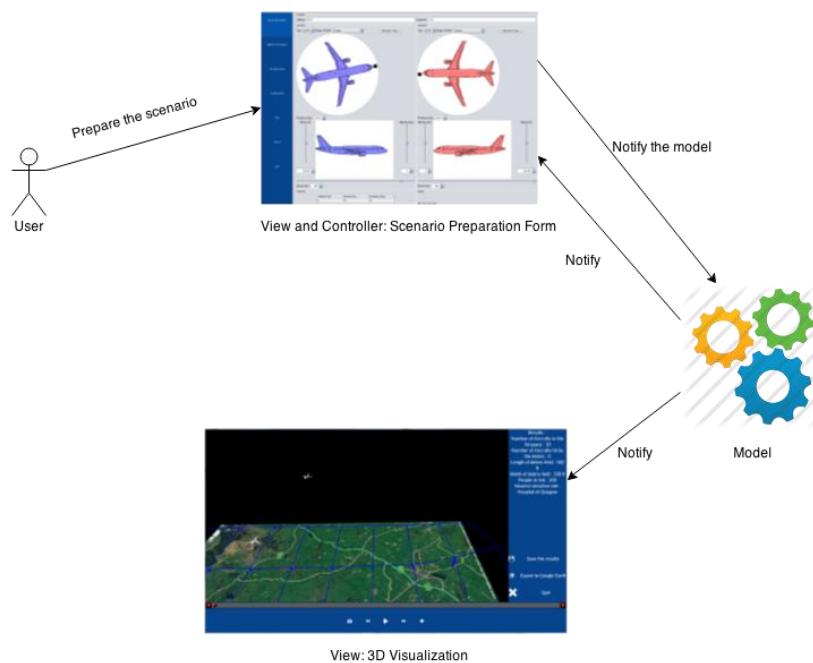
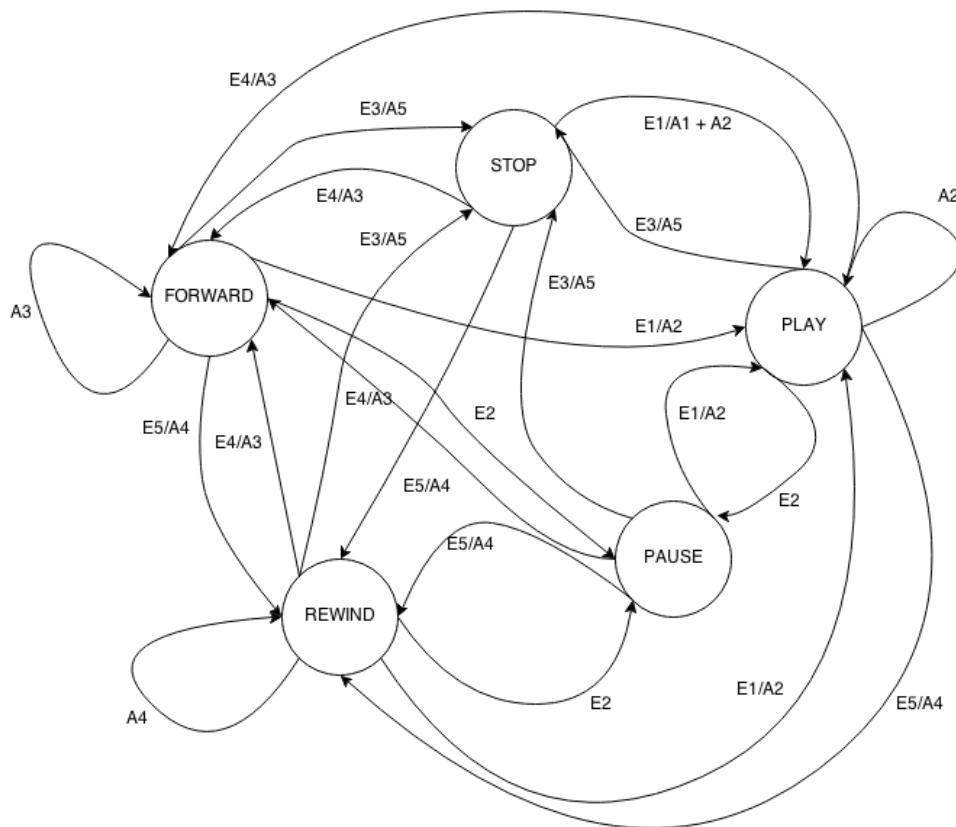


Figure 35 - MVC in the software application

In order to be able to control the time of the simulation and then be able to pause it, to accelerate it, to go back on time, a time controller was designed (Figure 36). This time controller updates a variable time which represents the time on the simulation, it also manipulates the state of the simulation (PAUSE, START ...). The main class of the 3D Simulation called contains a method “update()” which is called every x milliseconds (x depends on the computer), this method calculate all the position of the dynamic objects (Aircrafts, Debris Layer and Impact Layer) in function of the time of the simulation.



T: Time of the simulation, initially T=0  
Tmax: Duration of the simulation  
TPF: Refreshing Time of the Simulation

E1: Click Button "Play"  
E2: Click Button "Pause"  
E3: Click Button "Stop"  
E4: Click Button "Forward"  
E5: Click Button "Rewind"

A1: T = 0  
A2 : IF T < (Tmax - TPF) THEN T = T + TPF  
A3: IF T < (Tmax - 5 \* TPF) THEN T = T + 5 \* TPF  
A4: IF T > \*5TPF THEN T = T - 5 \* TPF  
A5: T = Tmax

**Figure 36 - Time Controller**

Finally, Automats and sequences diagrams are performed in order to identify the different states of the application and the interactions between the different classes. All the diagrams and the files template used are available in the Annex I (In total, 9 UML, sequence diagrams and automats were performed).

#### d. Different Data Sources

In order to be interesting and accurate, the simulation has to take into consideration several data:

- Weather
- Population
- Geographic Information
- Sensitive Sites
- Aircraft Flight Plan

All of these pieces of information can be taken from different sources, it is important to choose the best solution in function of several criteria:

- Reliability of the information
- Origin of the information (The internet/Files)
- Size of the information
- Time of loading

It is also important for the model and the interface of the software application to be the least dependant possible on the data sources. To this end, it was decided to apply a Facade design pattern, the purpose of this pattern is to abstract some part of the application to the rest of it, in our case, the recovering of all the data is done in a facade class and the application uses this class to get all the data (Figure 37). The main purpose is to make any change of sources easy and transparent for the application.

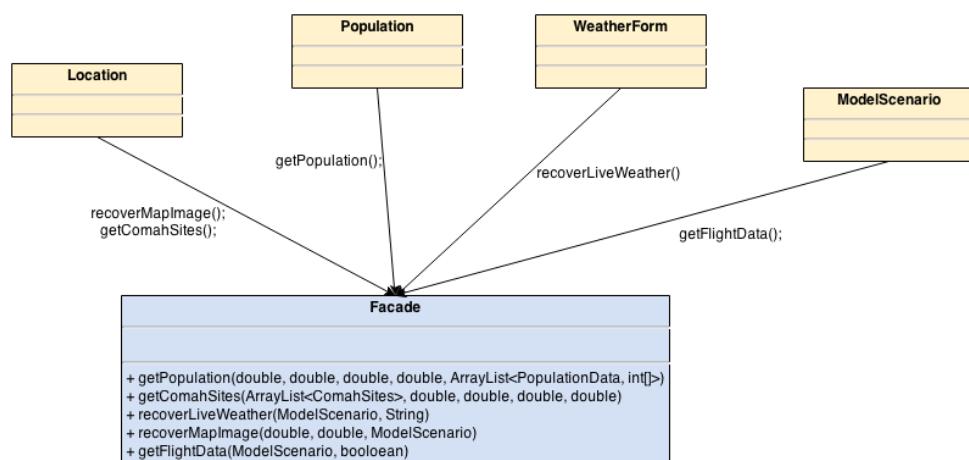


Figure 37 - Facade Pattern

## i. Weather

To calculate the trajectory of the debris after the collision, it is important to know the speed and heading of the wind, that is why it is important to gather weather information. Many library and website propose live weather data, but to reproduce a past situation (A specific Airprox), the simulation needed the weather information of a specific day.

The website forecast.io propose a Java API, the v2 Forecast API [46], that gives the current weather condition for a given latitude and longitude. It also gives the weather condition for a specific time in the last sixty years for a given latitude and longitude.

The conditions give several indications like the temperature, the precipitation type, the humidity and of course the wind speed and heading.

The first thousand calls per days are free, but after it would be necessary to pay for it (1\$ / 10,000 calls). But it is unlikely that the software application will be used more than a thousand times in a day, so it is a good solution for now.

## ii. Population

To calculate the population at risk, which is one of the key functionalities of this software application, the density of the population in one place was needed. In the previous version of this project it was decided to use the density given by the Gridded Population of the World [47], a dataset developed by the NASA [13]. It is a database that gives the density of population in the world for a square of 2.5 angular minutes between the latitude 85 North and 58 South. The fact that the size of the area where is given the density of population is known makes the calculus of the population at risk easier. This kind of database is also more convenient to represent it on a map.

The data are in a file that can be downloaded freely on the website of the Gridded Population of the World. The file used in this project contains the predicted density in the world in 2015, it is also possible to have the density in several years between 1990 and 2010.

The functions used to find the population density in the file are detailed in the report written by Craig Martin [13].

## iii. Geographic Information

One of the key components of the simulation is the map imagery, in the previous version, sixteen tiles were retrieved from the Map Quest Server [12]. Map Quest is one of the only solutions working with Java and compatible with JME [48]. The problems with the tiles are that sixteen was needed and it was only satellite map without any indications. Since that time, Map Quest developed another web service that allows everyone with a free API Key to recover a satellite map of any size with basic indications (road, city, ...) (Figure 38).

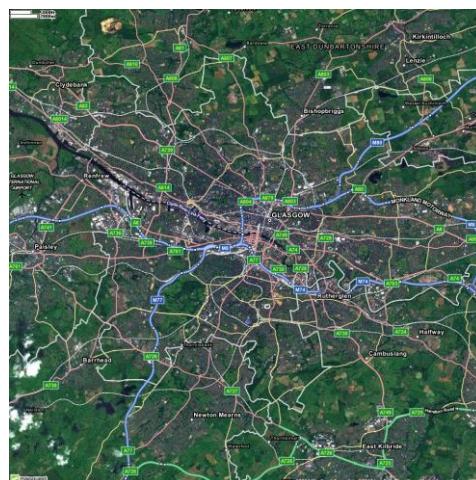


Figure 38 - Map recovered with MapQuest

It is possible to ask a map centred on one geographic coordinate with a certain level of zoom, or it is possible to ask a map contains in two geographic coordinates. The second solution will be used in the project in order to have a precise indication of the scale of the map.

## iv. Sensitive Sites

The idea of indicate the nearest sensitive site is developed in the previous version and is for now only available in the UK. The indications about the sensitive sites in the UK come from the Control of Major Accident Hazards Regulations (COMAH) which is in charge of the identification of potentially dangerous sites.

The information is available in a file that contains the geographic coordinates, the name and the level of risk of each dangerous site.

## v. Aircraft Flight Plans

In order to see if other aircrafts (Not the aircraft involved in the collision) in the area could have been hit by debris, it is important to get their flight plan. No websites that give flight information for flights in a certain geographic area at a specific time was found. But some website proposes API to recover live flight data, in the previous version of the project, the API FlightXML designed by FlightAware was used [49].

This API gets the data from a Flight Data Server hosted by FlightAware, this kind of server recovers Live Flight Data thanks to an ADS-B Receiver. ADS-B is a cooperative surveillance technology for tracking aircraft. Unlike secondary radar, the ADS-B system doesn't require expansive infrastructures on the ground, only little receivers, because that's the aircraft that send the information (Figure 39). It is already used in some aircraft systems like new version of the TCAS and researches are performed in US and Europe in order to use it in their Air Traffic Management system [30].

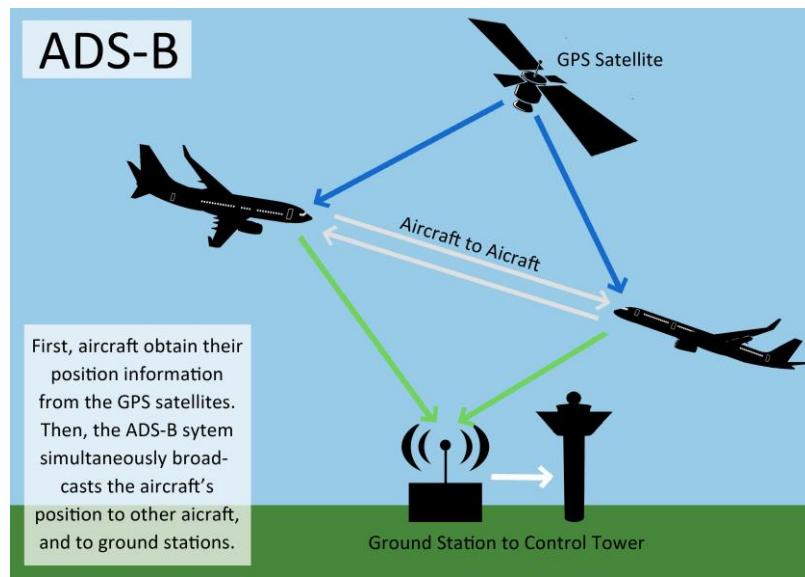


Figure 39 - ADS-B functioning

An ADS-B receiver is not very expensive (800€) and anyone can buy one and have a clear vision of the air traffic around his/her place. It implies that some website decided to buy some receivers and to propose to their user to have a live vision of the air traffic in a large area of the world (Europe, US, Asia) [50]. The use of ADS-B in Air Traffic Management is a little controversial, indeed, the data are not encrypted or checked, which implies important problem of confidentiality, integrity and

availability [51]. In this project, it was actually noticed some incoherences in the ADS-B, like for example an aircraft reported at the Flight Level 250 but with a groundspeed equal to zero. In this case, a standard speed is given to the aircraft in function of its type.

## e. Debris Model

To calculate the impact of the debris on the ground, it is important to calculate the trajectory of the debris. In order to do that a debris model was developed based on existing debris model that is open source. In order to calculate all the trajectories, three steps were necessary:

- Generating the debris
- Calculate the trajectory of each debris
- Calculate the density on the ground

### i. Generation of the debris

One important setting to calculate a debris trajectory is its ballistic coefficient, it take into consideration its weight, surface area and drag coefficient. This coefficient determines the debris' ability to overcome air resistance in flight. It was considered that the ballistic coefficient of the debris of one aircraft follows a normal distribution, the mean and standard deviation of this distribution were calculated thanks to debris catalogue [52].

### ii. Trajectory of a debris

Once the debris' ballistic coefficients are generated, it is possible to apply the second law of Newton in 3 dimensions to calculate the acceleration and then the velocity of the piece of debris. Using the Euler method with a time interval, it is possible to determine all the position of the debris during the falling (Figure 40).

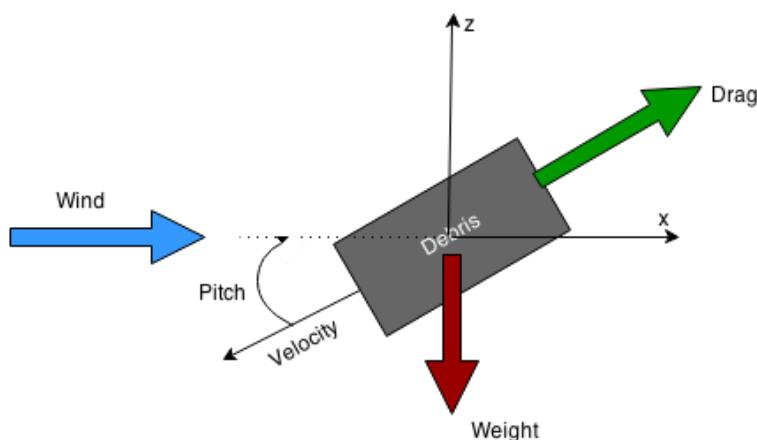


Figure 40 - Second law of Newton applied to a piece of debris

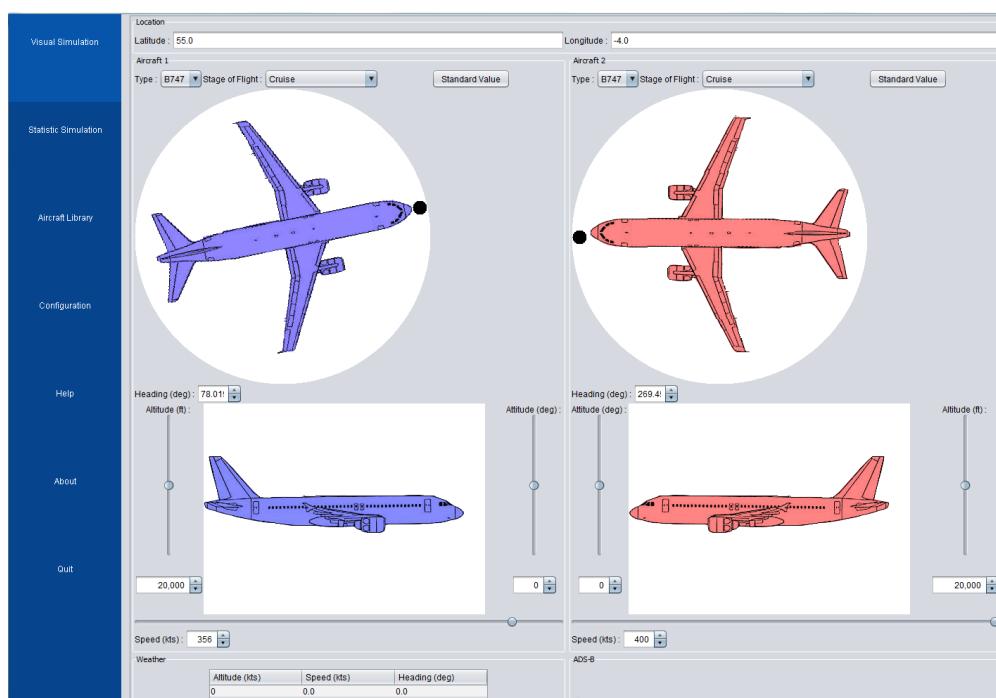
### iii. Density of debris on the ground

A list of all the positions of the debris on the ground is recovered, we can consider that the debris followed multivariate normal distribution, so it becomes easy to calculate the density function.

A detailed explanation of this process is available in the annex D. It is accompanied by a literature review about debris trajectory modelling and some reflexions about how calculate the trajectory and the impact more accurately.

## f. Result

This part presents the final version of the software application and a comparison with the last prototype.

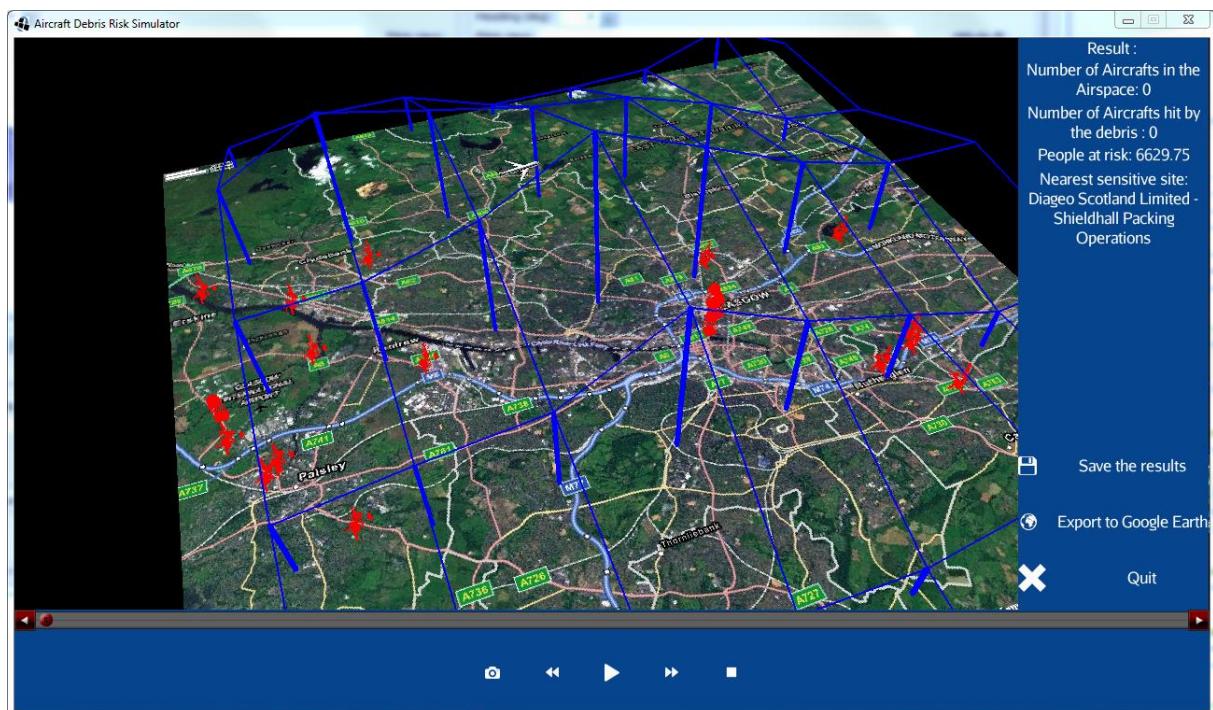


**Figure 41 - Scenario Preparation Form**

The scenario preparation form is really similar to the prototype (Figure 41), all the planned components were implemented. But the loading frame between the scenario preparation form and the 3D Visualization was deleted because the loading time due to the trajectory calculation is inferior to 1 second.

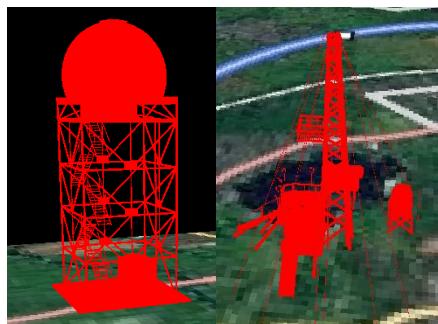
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**Figure 42 - 3 Dimension Visualization**

On the 3D Visualization it is possible to see two new elements on the map (Figure 42):



**Figure 43 - Airport and Train Station Symbol (left) and COMAH Symbol (right)**

- The COMAH Sites (Figure 43 right): They are the sensitive sites in UK (Petrochemical factory, power plant...).
- Airport and Train Station (Figure 43 left): They are sites that are usually populated and they can have an important economic impact if they are hit by debris.

The choice of these symbols was limited by the fact that JME doesn't accept all 3D format for the model.

Finally the results (textual form) are available on the right side of the window. The people at risk are calculated with the formula:

$$\text{People at risk} = \frac{\text{Area of Impact}}{\text{Area of the map}} * \text{Population represented on the map}$$

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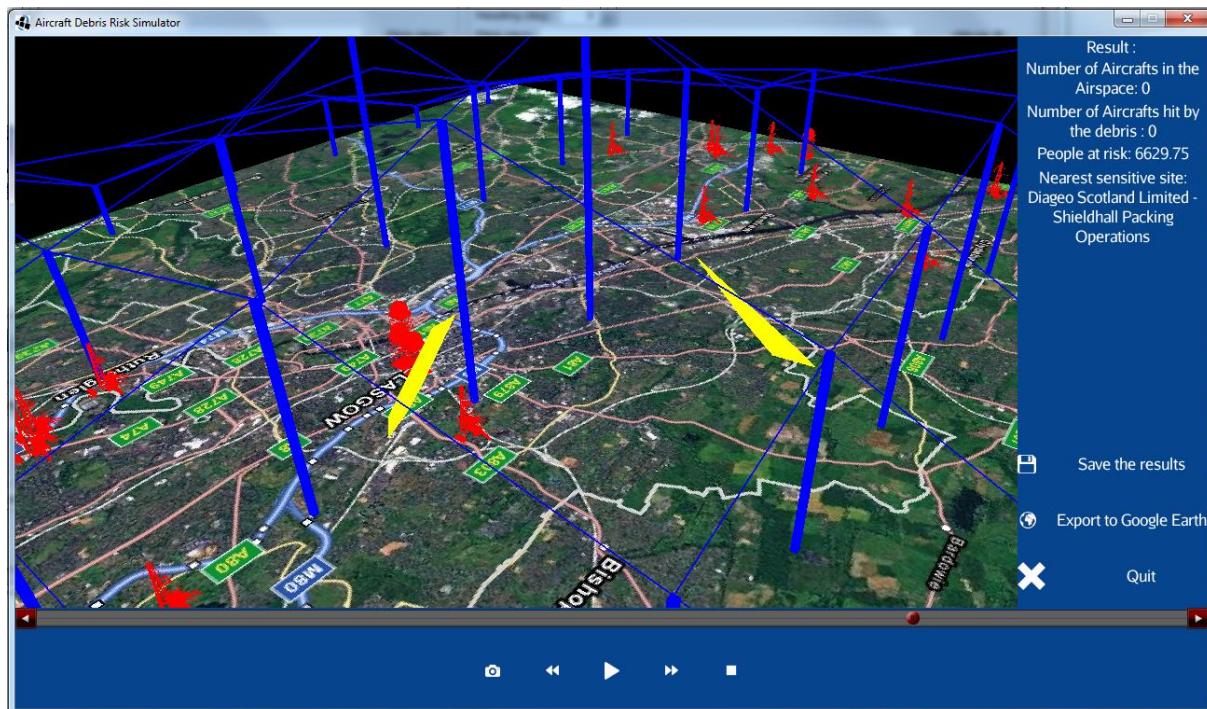


Figure 44 - Visualization of the debris

Contrary to the prototype, two debris layer are displayed, one per aircraft. Indeed, the distance between the debris of each aircraft was bigger than the length of the debris field, to display only one layer would have bring perception error (Figure 44).



Figure 45 - Visualization of the debris density

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For the same reason than expressed previously, the density of the debris was separated into two layers (Figure 45). Thanks to the sensitive sites symbols, it is possible to see if one has a chance to be hit by a piece of debris.

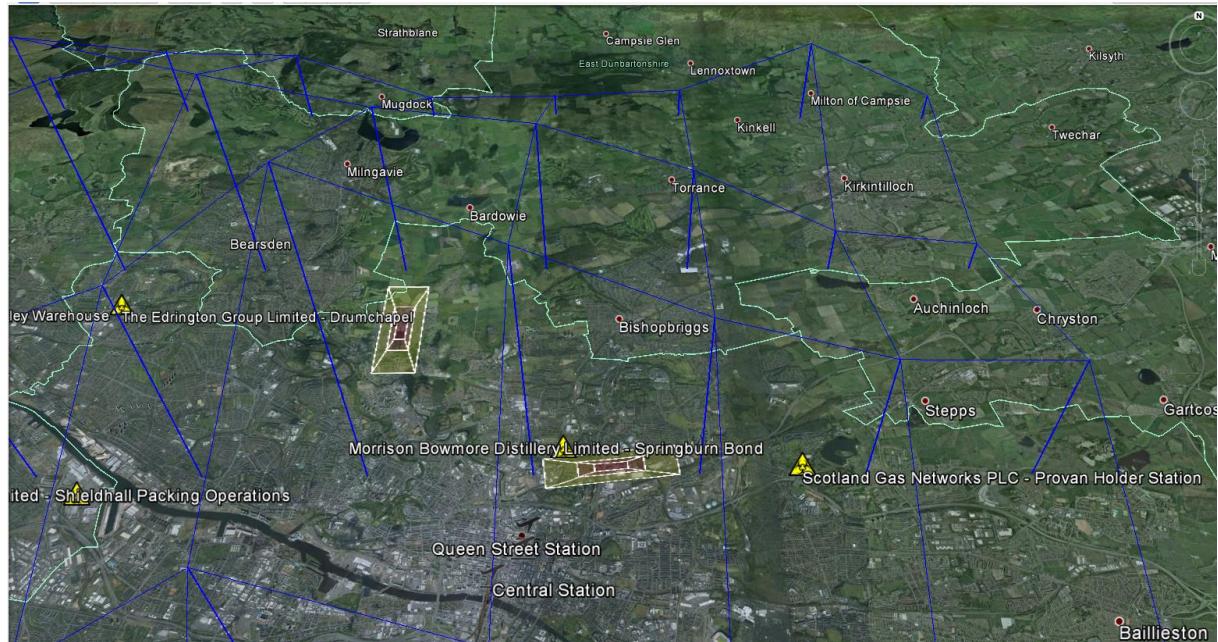


Figure 46 - Export of the result to Google Earth

This screenshot (Figure 46) shows how is displayed the result of the simulation on Google Earth, the representation of the population and the debris density is the same than in the software application. But the symbol for the sensitive sites are different (Figure 47), this is due to the fact that in Google Earth, it is possible to have a 2 dimension picture always visible.



Figure 47 - Airport and Train Station Symbol (left) and COMAH Symbol (right)

## g. User Evaluation

To check if the software meets the requirements and the needs defined in the design phase is one thing, but it is important to confront the final system to users. This evaluation is the opportunity to test the usability of the software but also if the software changes the perception of user about the risk from Mid-Air Collision. Indeed, the software has to give all the information about a possible collision, but it shouldn't change the risk perception of the user in order to not make them under or over react.

### i. Scenario

To test the usability, the user had to perform a series of task with the software, each task was timed, and each errors made by the user were reported. At the end of each task, the user had to say if the task was easy to perform or not and give any comments about it. At the end of the series, the user had to answer to a System Usability Scale (SUS) questionnaire.

To assess the change about the perception of the risk from a Mid-Air collision, it was decided to assess the user's risk perception about collision before the use of the software and after the use of the software. Two variables were identified for the experience:

- An independent variable: the use of the system
- A dependant variable: the risk perception

Therefore, the null hypothesis of the experience is:

*H0: Using the system will not affect the user's risk perception of a mid-air collision impacting the public.*

In order to prove this hypothesis, it is necessary to disprove the alternate hypothesis:

*H1: Using the system will affect the user's risk perception of a mid-air collision impacting the public.*

In order to measure the risk perception, it was decided to use the same test used in the past report [13]. It is developed by Baruch Fischhoff [53] and in addition to ask the user to rate his/her risk perception level, it also ask the user to rate nine scales that could influence this perception:

- Voluntariness of risk
- Immediacy of effect
- Knowledge about risk (by the person exposed)
- Knowledge about risk (by science)
- Control over risk
- Newness
- Chronic-catastrophic
- Common-dread
- Severity of consequences

For the same reasons that in the past user evaluation (except in the third), it was not possible to find real end-user, to that end it was decided to perform the final evaluation with post graduate student from the university of Glasgow. To have aviation background knowledge is a plus, but a quick explanation of the terms used and the purpose of the software were given when it was necessary at the beginning of the test.

## ii. The process

These two cases will be separated during the experiment. To this end, two scenarios were presented to the user (they are based on true facts, the Airprox reports used are available in the Annex K).

**Scenario 1:** It happened at a distance of 12 nm form the centre of Glasgow (lat: 55.86666 and long: -4.08333). A commercial aircraft, a Cessna 560, was flying at its cruise altitude (18000 ft), heading

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355° at 360 kts. A climbing traffic appeared on the TCAS display 5-10 nm in front of him at 1200 ft below. When the traffic became proximate by less than 1000 ft, the ATC transmitted an avoiding action, the pilot could see the traffic directly in front of him. The traffic was an Airbus A320 operating a passenger's flight, he was climbing to 25000 ft, heading 240° at 290 kts. The weather was calm, on the ground, the wind had a speed of 10 kts, heading 0° and at 20000 ft, the wind had a speed of 50 kts, heading 10°. (*This scenario is based on the Airprox 2012094*).

**Scenario 2:** It happened over Scotland (lat: 56.7 and long: -4.55) at 34000 ft on the 23<sup>rd</sup> of June 2013. Two Boeing 747 passenger planes were on a course to cross the Atlantic. The first 747 is in cruise at 480 kts, heading 340°, the second is in cruise at 500 kts, heading 300°. At 12h52 UTC, the ATC of the Prestwick centre noticed that the two trajectories are converging and instructed an avoiding action for each of the aircrafts. 4 minutes later, the trajectories are still converging, and the ATC transmitted again the avoiding instruction to the pilot. Finally, 2 minutes later, the pilot of one aircraft reported a TCAS resolution advisory, one aircraft climb and the other descent. The minimum separations were 100 ft vertical/ 3.9 nm horizontal and 1100 feet vertical/2.8 nm horizontal. No weather information is available. (*This scenario is based on the Airprox 2013054*).

### 1<sup>st</sup> Task

In their first task, the users were asked to rate the risk of a mid-air collision to the local population over a city and over the country side. For each case, they were asked to rate the nine scales described previously.

### 2<sup>nd</sup> Task

In the second task, the users were asked to use the software application to simulate the two scenarios. For the first simulation, they were asked additional subtasks in order to assess the usability:

- Fill the preparation scenario form
- Save the scenario and reload it
- Play the simulation
- Export the result to Google Earth

For each subtask, they were timed, the mistakes were recognized and the easiness was rated. Finally at the end of these four tasks, the users had to fill a SUS questionnaire.

### 3<sup>rd</sup> Task

Finally, the users were asked to rate again the risk of a mid-air collision to the local population over a city and over the country side, with each time to rate the nine scales.

The precise process of the user evaluations and the detailed results is available in the annex C.

### iii. The result

All the precise result (with all the data used) are available in the Annex C.

In order to assess if the use of the software application changes the user's risk perception about mid-air collision, it is necessary to prove that for each question, the answer of the user are not different in the task 1 than in the task 3. To do that, a Wilcoxon signed-rank test was performed for each question. It shows that there is not difference between the risk perception in task 1 and 3, for both mid-air collision over a city or a country side. It is the same result for 8 of the 9 scales that could influence the perception. The only scale which had changed (if we accept a 10% margin for the test) is "**Knowledge about risk**: To what extent is the risk known to science?", which could be explained by the fact that the software application itself is a proof that the risk is known to science.

The result of the usability test shows that all the three subtasks were performed in a good time without doing more than two mistakes. Finally with an average of 71.67 for the SUS questionnaire, it is possible to say that the users found the software application usable. This evaluation finally shows what comments were done by the users. It shows some recurrent comments like the fact that Altitude and pitch are not in the same side for each aircraft is really confusing, then that the weather table is also confusing and the users took some time to understand it. One user said it could be easier to understand if it was only textfield.

## iv. Conclusion

We can conclude with the fact that the software application doesn't change the risk perception of the users about mid-air collision, and they found it usable enough. It also provides some issues to improve in the next version of the software application. Nevertheless these results should be taken with caution, because the evaluation was performed with only 6 users, and some of them didn't have any Aviation background, contrary to Airprox inspectors.

## 5. Final Results

After the development phase it is important to make sure that the final product meets the needs of the user defined sooner in this project. User evaluations were also performed in order to see if the system is usable and how the use of new interaction paradigms can give a better way to understand and analyse a complex situation. Finally these evaluations showed that the system meets its main purpose: To allow the user to assess the risk for the population of an Airprox.

### a. Project Assessment with respect to the requirements and needs

This part presents all the requirements and needs define previously and how the final product answers to them (Table 6). The requirements and needs with a priority higher than 5 which are implemented are in bold, and the requirements and needs with a priority higher than 5 but which are not implemented are in red and bold.

Id	Need	Taken into account
N1	Needs.	
N1.1	Needs about the population model.	
N1.1.1	<b>The system should integrate a population model.</b>	Implemented (Data from GPW).
N1.1.2	The system should integrate different population models.	Not implemented.
N1.1.3	<b>The system should represent the population in the simulation.</b>	Implemented (3D Spike map).
N1.1.4	The system should have a server for population data.	Not Implemented.
N1.1.5	<b>The system should include the COMAH sites (And equivalent outside UK).</b>	Implemented (COMAH in UK and Airport and Train Station everywhere).
N1.1.6	The system should represent the ambient population in the simulation.	Not implemented.
N1.2	Needs about the crash model.	
N1.2.1	<b>The system should perform a simulation of aircraft crashes.</b>	Implemented
N1.2.2	<b>The system should simulate Mid-air collision.</b>	Implemented
N1.2.3	The system should integrate a Crash Consequence model.	Not Implemented
N1.2.4	<b>The system should show the density of debris falling at one place.</b>	Implemented (Visualization of the Density of debris)
N1.3	Needs about the Scenario.	
N1.3.1	<b>The system shall allow the user to define the flight path of two aircraft involved in the collision.</b>	Implemented (Scenario Preparation Form).
N1.3.2	<b>The system shall allow the user to define the type of each aircraft involved in the collision.</b>	Implemented (Scenario Preparation Form).
N1.3.3	<b>The system shall allow the user to define the</b>	Implemented (Scenario

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	weather of the scenario or import live data from the internet.	Preparation Form + forecast.io).
N1.3.4	The system shall allow the user to import his own ADS-B flight data or import live data from the internet.	Implemented (Scenario Preparation Form + FlightAware).
N1.3.5	The system should show the population at risk at the end of the simulation	Implemented (Textual Result + Density of Debris).
N1.4	Needs about the Statistical Simulation.	
N1.4.1	<b>The system should allow the user to perform a series of simulation and see the average risk for the population.</b>	Not Implemented
N1.5	Other needs.	
N1.5.1	The user should be able to change the API Key used for the ADS-b, Weather Data and Map websites.	Implemented (Configuration Part).
N1.5.2	The user should be able to change the colour used in the 3D simulation.	Implemented (Configuration Part).
N1.5.3	The system should be able to calculate the safest flight path between two points.	Not Implemented.
N1.5.4	<b>The system should allow the user to save the result of the simulation.</b>	Implemented (Textual Result + Export Google Earth).
N2	Interfaces.	
N2.1	The system should allow the user to Pause, accelerate and rewind the simulation.	Implemented
N2.2	The system should allow the user to take screenshot of the simulation.	Implemented
N2.3	The interface of the system should give a feedback for each action of the user.	Implemented
N2.4	The interface should use vocabulary and concept familiar to the user.	Implemented
N3	Use Cases.	
N3.1	<b>The system must allow reproduce the use cases.</b>	Partially Implemented (Only the Visual Simulation).
N4	Constraints.	
N4.1	The loading of the simulation should take less than 10 seconds.	Implemented (>1 seconds).
N4.2	The representation of the probability and the population as physically measured should be directly proportional to the quantities represented (Lie Factor between 0.95 and 1.05).	Implemented
N4.3	The data used has to be available easily for an Airprox Inspector	Implemented.

Table 6 – Requirements and Needs Assessment

Only one need with a high priority is not implemented in the final version: “The system should allow the user to perform a series of simulation and see the average risk for the population.” This is due to a lack of time in the development phase and it was decided to focus on the Visual Simulation and have it fully implemented than having two parts only partially implemented.

The need 4.2 said that the representation of the density of debris and the population should have a lie factor between 0.95 and 1.05. The Lie Factor is a value to describe the relation between the size of effect shown in a graphic and the size of effect shown in the data [38]. About the density of

debris, it is not possible to calculate it because it is represented by a colour. But one dimension (the colour) represents one dimension (the density), so we can consider that the Lie Factor is around 1. About the representation of the population, it is possible to calculate it:

$$\text{Lie Factor} = \frac{\text{size of effect shown in graphic}}{\text{size of effect in data}}$$

$$\text{size of effect} = \frac{|\text{second value} - \text{first value}|}{\text{first value}}$$

With two values of the population:

- 20055, which is represented by the volume  $(20055/50)^2 * 2 = 1604.4$
- 60997.91, which is represented by the volume  $(60997.91/50)^2 * 2 = 4879.832$

It gives the Lie Factor: 0.99999992, which is between 0.95 and 1.05.

Finally, a report explaining how the system was designed and a user manual (Annex J) was done and delivered to the University with the software application.

## b. User Evaluations

All along the design and development phase, the user evaluations allowed the user to give their opinions about the software, it also allowed to make some choice and to point out some usability problems.

It was not easy to find real end users for the software application because there is not a lot in UK or in France, and there were not available during the project, except for the last user evaluation of the design phase but it was not possible to make a long formal usability test.

The last user evaluation at the end of the development phase, it was decided to perform a formal usability test, even if the results are good, it has to be taken with caution because it had been performed with only six users, and these users didn't have all an aviation background. The misunderstanding of some terms in the scenario led users to some mistakes and to take more time to perform the task.

We can conclude with the fact that except some usability problems, which were pointed out during by users, the software application is usable. It also doesn't change the user's risk perception about mid-air collision. The first task of a future team on the project would be to fix the problems pointed out.

## c. Personal Assessment

This internship gives me the opportunity to apply the knowledge acquired during my Master Degree in HCI in Toulouse and more generally the knowledge acquired during the three years of my engineering degree. It allows me to deepen my experience in the use of the User Centered Design

<sup>1</sup> 1/50 is the scale of the representation in the 3D Visualization.

process and in Air Traffic Management, and to discover the field of air incident investigation. This internship allows me to meet really interesting people from both France (DGAC, BEA) and UK (NATS, CAA, UKAB).

This internship also makes me discovered the research community and how it is to work in a laboratory, which is really different than working in a company. First you have more autonomy, but when a company will give you the data you need, you will have to find them by yourself in a lab.

Even if I had a meeting twice a month with Chris Johnson, he tried to never impose a decision because he wanted me to make my own ones. This freedom in the project was sometimes hard to manage, indeed making good decisions is not always easy. But each time I faced a difficulty, he always tried to show me how to deal with it. I also got advices from my supervisors in France, Philippe Palanque and Yannick Jestin and other teachers at the ENAC.

Finally, this was an opportunity for me to discover this great country that is Scotland. In which if the weather is not always warm, people are. And it didn't take long for me to feel in Glasgow like at home.

## d. Future work

Unfortunately, the project couldn't be finished, the statistical simulation part wasn't implemented. In a future work, it could be possible to implement it using the documentation from the design phase. It is also possible to improve the debris model, by working on the trajectory calculation or in the statistical model used to calculate the density of the debris, some ways forward are proposed in the Annex D. The population model can also be improved by adding an ambient population model which should simulate the density of the population in one day (people are going to work during the day and go back home at night). Some research are already performed about this subject [54].

Finally, it is possible to add some functionality in the Visual simulation, recently, the CAA informed us that it was interested by the project. Indeed, its Airborne Conflict Action Group wants to use our software to assess the impact of a mid-air collision at Airprox hotspots in urbanized area. But in addition to the population at risk, they are also interested by the economic impact, like for example if any motorway or railroad can be hit by debris. In order to try the system, the group will give us data to make a simulation about a real case. But it could be possible to find what kind of information they are looking for and improve the system in this way.

It is also identified that lots of Airprox occurred around Airport, because there are lots of aircraft in a constraint area, furthermore, take-off and landing are two flight phases when the pilot has to be focussed on his/her instruments, so he/she could be less focussed about what happen around him. Especially with the development of EGNOS, the new European Satellite Navigation System, that could give more freedom to pilots to departure and arrival procedure due to its precision (around 20 meters) [55]. It could be possible to focus more the system on the Airport and TCA environment.

## 6. Glossary

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- AAIB:** Air Accident Investigation Branch – The air accident investigation board in UK.
- ADS-B:** Automatic Dependent Surveillance-Broadcast – A cooperative surveillance technology.
- Airprox:** A situation in which, in the opinion of a pilot or air traffic service personnel, the distance between aircraft as well as their relative positions and speed have been such that the safety of the aircraft involved may have been compromised”[6].
- ANSP:** Air Navigation Services Provider.
- API:** Application Programming Interface.
- ATC:** Air Traffic Controller.
- ATM:** Air Traffic Management.
- AWT:** Abstract Window Toolkit.
- BEA:** Bureau d’Enquête et d’Analyse – The air accident investigation board in France.
- BSD:** Berkeley Software Distribution.
- CAA:** Civil Aviation Authority – The civil aviation authority in UK.
- COMAH:** Control of Major Accident Hazards Regulations.
- DGAC:** Direction Générale de l’Aviation Civile - The civil aviation authority in France.
- DSNA:** Direction des Services de la Navigation Aérienne – The French Air Navigation Services Provider.
- ENAC:** Ecole Nationale de l’Aviation Civile – The French school of Civil Aviation.
- ESA:** European Space Agency
- Eurocontrol:** European Organisation for the Safety of Air Navigation.
- GUI:** Graphical User Interface.
- HMI:** Human Machine Interface.
- IATA:** International Air Transport Association.
- ICAO:** International Civil Aviation Organization.
- IDE:** Integrated Development Environment.
- JME:** JMonkeyEngine.
- LVNL:** Luchtverkeersleiding Nederland – The Dutch Air Navigation Services Provider.
- LWJGL:** LightWeight Java Game Library.
- MAA:** Military Aviation Authority - The military aviation authority in UK.
- METAR:** METeorological Aerodrome Report.
- MVC:** Model-View-Controller.
- NASA:** National Aeronautics and Space Administration.
- NATS:** National Air Traffic Services – The Air Navigation Services Provider in UK.
- ND:** Navigation Display.
- NOTAM:** NOTice To AirMen.
- ORSEC:** Organisation de la Réponse de la Sécurité Civile – The French emergency plan.
- OS:** Operating System.
- PFD:** Primary Flight Display.
- PSZ:** Publics Safety Zone.
- QFU:** Magnetic direction of a runway.
- QS:** Quality of service and Safety unit.
- RAF:** Royal Air Force – The Air Army in UK.
- Skyguide:** The Swiss Air Navigation Services Provider.
- SUS:** System Usability Scale.
- SWT:** Standard Widget Toolkit.
- TCA:** Terminal Control Area.
- TCAS:** Traffic Collision Avoidance System.
- UK:** United Kingdom.
- UKAB:** UK Airprox Board.
- UML:** Unified Modelling Language.

# Simulating the Risks of Aviation Debris on the Public

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**VCR:** Video Cassette Recording.

**WIMP:** Windows, Icons, Menus and Pointing devices.

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## 8. Annex

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# Annex A – Project Management Report

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## 1. Hypotheses and Constraints

### a. Hypotheses

To work on the project, a minimum knowledge in Air Traffic management and aviation safety is required.

The university give me the necessary devices to work and make the test of the software application, in this case a computer.

### b. Constraints

The software application has to work on a casual computer, without needing too much performance.

There are not end-users in Glasgow, all the user test should be done with other people available at the university (students, teachers ...).

The product should be working, stable and safe at the end of the internship.

Other students will work on the product after this internship, all the code and documents should be documented.

## 2. PBS

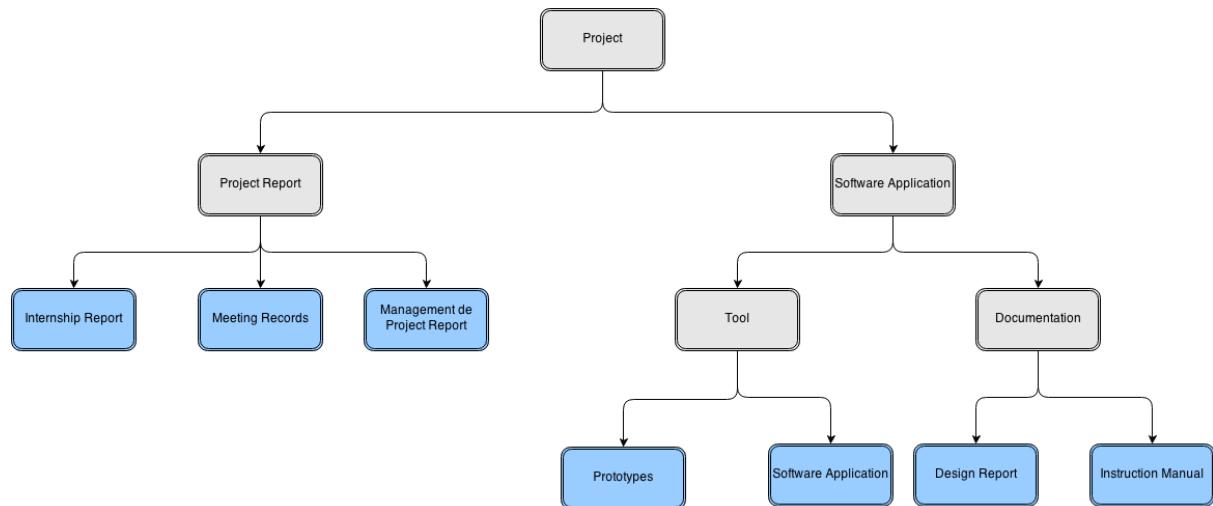


Figure 1 - PBS of the project

### 3. Process

To design a system which satisfies the requirements of the users, it is important to imply them in the design phase. In that aim, it is important to understand well the tasks that the user has to perform, his workplace, it is important to think about several solutions, prototype them and then have them tested by users. Because the requirements can evolve, it is important to have a flexible process which allows us to iterate several times.

#### a. User Centered Design

The User Centered Design is a Design process defined in the ISO norm 9241-210 which is based on 6 key principles:

- The design is based upon an explicit understanding of users, tasks and environments.
- Users are involved throughout design and development.
- The design is driven and refined by user-centered evaluation.
- The process is iterative.
- The design addresses the whole user experience.
- The design team includes multidisciplinary skills and perspectives.

In the project, I will consider that the main users of the software are the Airprox Inspectors, it implies that they will be in the center of the design process.

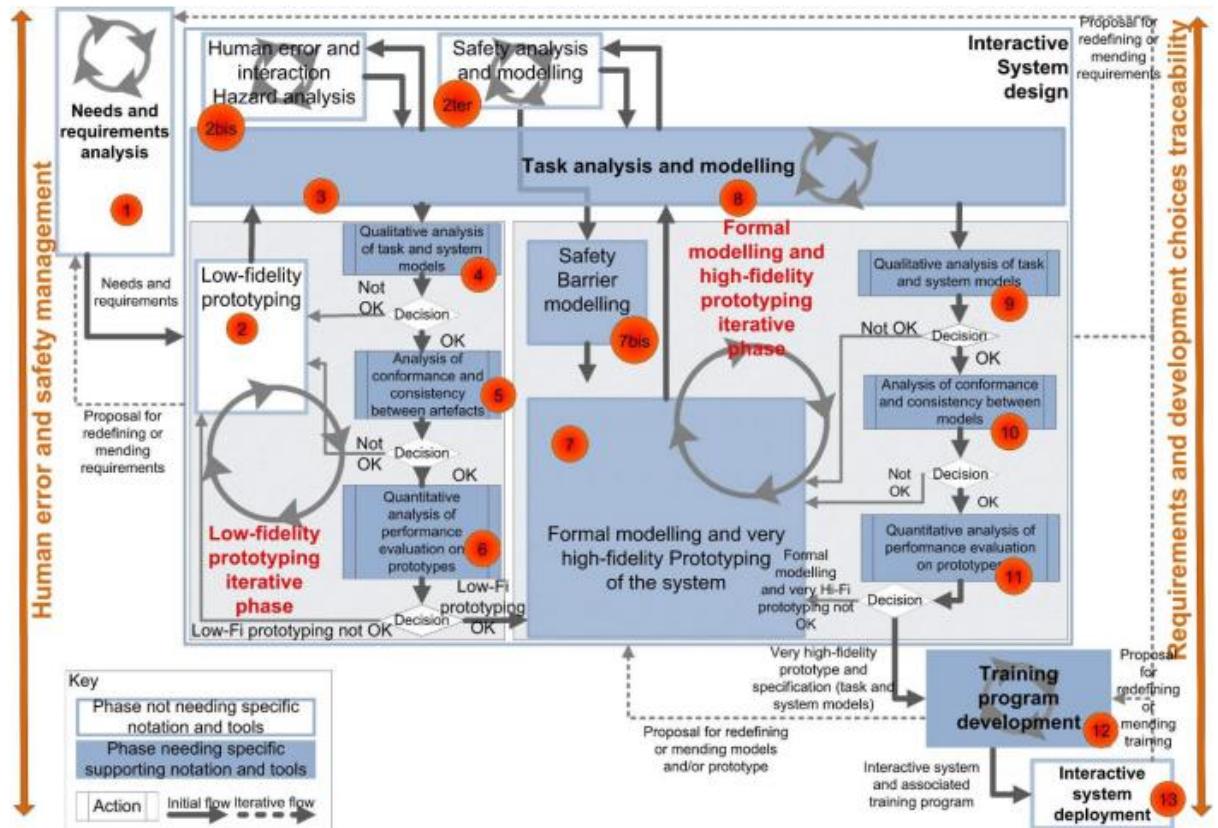


Figure 2 - The User Centered Design Process

## **b. The Development Phase**

As in the design phase, a good solution to develop a system which meet the need of the users is to iterate several times and to perform user testing each times. But if it is easy to prototype different solutions with paper and makes important change on it, it costs a lot of time on the final software. And because project are limited in time, it is a better idea to perform one more iteration in the design phase to be sure of the needs of the user than doing a lot of iteration in the development phase.

In order to imply the user in the development, it is possible to make them evaluate a functionality when it is developed without evaluate the whole system.

## 4. StakeHolders

Table 1 - Stakeholders of the Project

Role	Name	Organization/Function	Interest in the project
<b>Team Member</b>	Arnaud Prouzeau	ENAC - Student	Working on the project for his internship.
<b>Supervisor</b>	Chris Johnson	University of Glasgow – Professor of Computing Science	Proposed the subject and helping during the internship
<b>Supervisor</b>	Philippe Palanque	IRIT – Professor of Computing Science	Making sure that the internship is in accordance with the Master's Courses and helping during the internship.

## 5. WBS

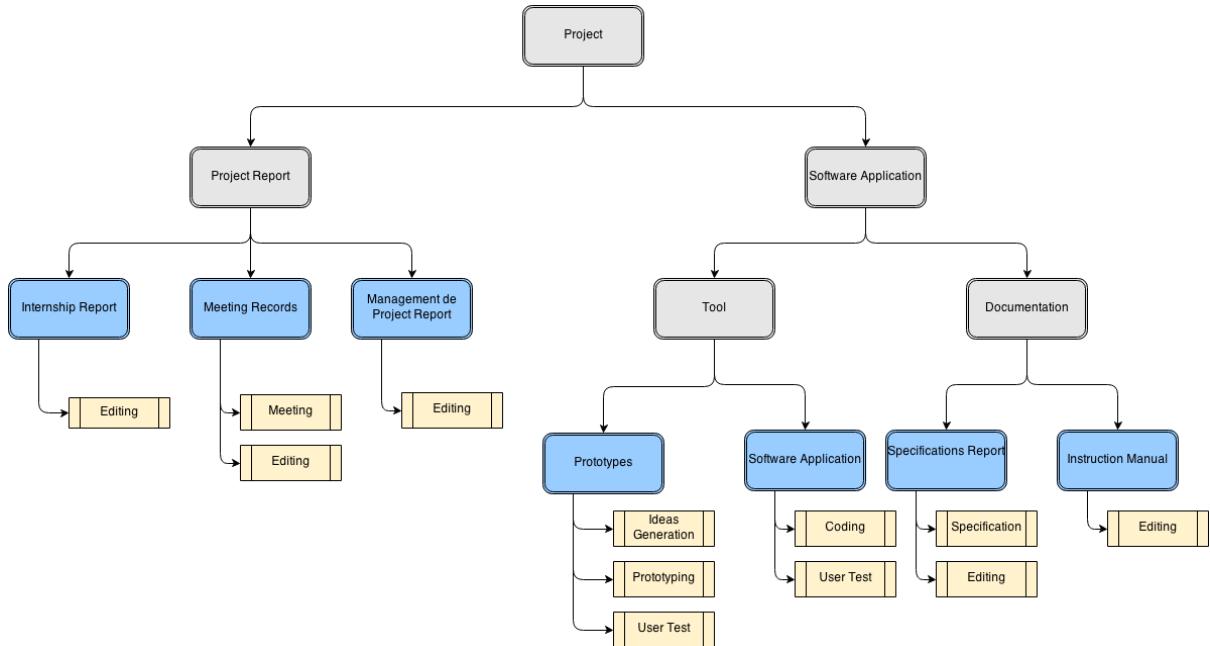


Figure 3 - WBS of the project

Table 2 - Table of Activities

Description of the activity	Number of hours (estimation)	Ressources
<b>State of the art</b>	40	Arnaud Prouzeau
<b>User identification + Activity analysis</b>	40	Arnaud Prouzeau
<b>Requirements</b>	30	Arnaud Prouzeau
<b>Ideas Generation 1</b>	30	Arnaud Prouzeau
<b>Prototyping 1</b>	20	Arnaud Prouzeau
<b>User Testing 1</b>	26	Arnaud Prouzeau
<b>Ideas Generation 2</b>	40	Arnaud Prouzeau
<b>Prototyping 2</b>	20	Arnaud Prouzeau
<b>User Testing 2</b>	20	Arnaud Prouzeau
<b>Ideas Generation 3</b>	20	Arnaud Prouzeau
<b>Prototyping 3</b>	40	Arnaud Prouzeau
<b>User Testing 3</b>	20	Arnaud Prouzeau
<b>Oral Preparation</b>	40	Arnaud Prouzeau
<b>Report Writing</b>	80	Arnaud Prouzeau
<b>Debris Model</b>	40	Arnaud Prouzeau
<b>Population Visualization</b>	20	Arnaud Prouzeau
<b>Usability Testing of the old tool</b>	10	Arnaud Prouzeau
<b>Specification</b>	40	Arnaud Prouzeau
<b>Development</b>	340	Arnaud Prouzeau
<b>User Testing 4</b>	20	Arnaud Prouzeau
<b>Meeting</b>	24	Arnaud Prouzeau
<b>Total</b>	960	Arnaud Prouzeau

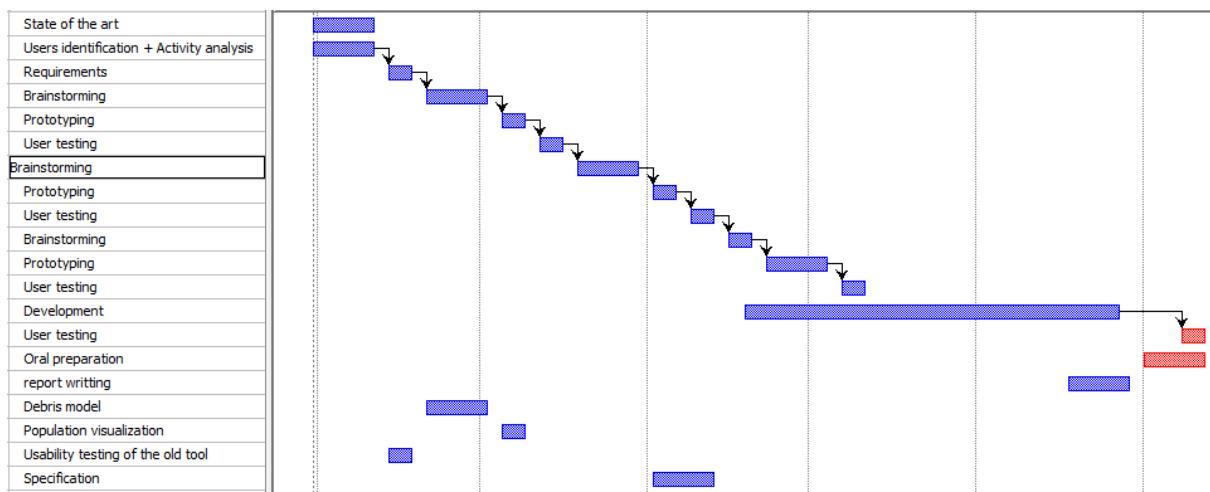


Figure 4 - GANTT Diagram of the Project

## 6. Planning

Table 3 - Planing of the Project

Deliverable/Milestone	Date
Activity Analysis	31/03/2014
State of the art	31/03/2014
Design - Iteration 1	16/05/2014
Design - Iteration 2	13/06/2014
Design – Iteration 3	11/07/2014
Development	29/08/2014
Oral exam	Beginning September
Internship Report	Beginning September

## 7. Budget

Table 4 - Table of the Budget

Budget	
Human Budget	
<b>Team</b>	960 hours
<b>Users</b>	16 hours
<b>Supervisors</b>	24 hours
<b>Risk Provision</b>	65.2 hours
Other Budgets	
<b>Computer</b>	0€
<b>Software : JMonkeyEngine, Java, Gimp, Word</b>	0€

## 8. Risk Management

This project is under the following main risks:

- Corporate risks (Stakeholders unavailable ...)
- Project management risks (Lack of time ...)
- Technical risks (inexperience ...)

To assess these risks and their impact, I defined 3 level of probability of occurrence and 3 level of impact:

Probability of occurrence:

- Low (0.2)
- Medium (0.4)
- High (0.6)

Impact:

- Low (1): The impact is limited and the solution to solve the problem doesn't cost lots of ressources.
- Medium (2): The impact could be hard to handle by the team.
- High (3): The impact could imply important delays.

Table 5 - Table of the Project Exposure

Probability	Impact	Low (1)	Medium (2)	High (3)
	Low (0.2)	0.2	0.4	0.6
Medium (0.4)	0.4	0.8	1.2	
High (0.6)	0.6	1.2		1.8

### a. Identification of the risks

Table 6 - Identification of the risks

ID	Description	Risk factor	Probability	Impact	Exposure (P*I)	Priority
1	Unavailability of users	Users not in Glasgow	0.6	3	1.8	1
2	Wrong UML Specification	Lack of experience in UML	0.2	2	0.4	9
3	Loss of data	Accident	0.2	3	0.6	7
4	Lack of knowledge about tools	Use of unknown tools	0.4	2	0.8	4
5	System doesn't meet the users'	Misunderstanding with the users'	0.2	3	0.6	5

requirements						
6	Under Estimation of coding hours	Lack of experience in project planning	0.4	3	1.2	2
7	Delay in the project	Lack of experience in project planning	0.4	3	1.2	3
8	System not finished	Lack of experience in project planning	0.2	3	0.6	6
9	Lack of Data for the debris model	Data not Open Source	0.6	1	0.6	8

### b. Responses to the risks

Table 7 - Responses to the risks

Id	Priority	Responses	Cost (hours)	Risk provision (P*C)
1	1	Organize meeting with user long time in advance. Try to find users on Glasgow (Aerospace engineering Student).	20	12
2	9	Check the specification with a professor.	8	1.6
3	7	Save the data on the internet (Google Drive).	8	1.6
4	4	Schedule training time on the tools.	20	8
5	5	Test of the prototype with users.	20	4
6	2	Schedule of several hours of coding.	50	20
7	3	Project Management and Planning.	10	4
8	6	Project Management and Planning.	10	2
9	8	Search for data or Person which used these kind of data.	20	12

Table 8 - Status of the responses

Id	Start date of the Response	Status
1	The beginning of the project	On-going
2	The beginning of the specification phase	Awaiting
3	The beginning of the project	On-going
4	The beginning of the project	On-going
5	The beginning of the design phase	Awaiting
6	The beginning of the development phase	Awaiting
7	The beginning of the project	On-going
8	The beginning of the project	On-going
9	The beginning of the project	On-going

## 9. Communication Management

Between who and who?	Type	Frequency	What ?
The team and Chris Johnson	Meeting	Weekly	Progress of the project, Report, Issues.
The team and Philippe Palanque	E-mail	Monthly	Progress of the project and Issues.
The team and Philippe Palanque	Skype	Mid-Project	Progress of the project and Issues.

## 10. Mid-Internship Results

### a. Activity Progress

After 3 months of internship it is important to evaluate the progress of each activity and to check if there are no delays.

Description of the activity	Number of hours (estimation)	Progress (%)	Progress (hours)
<b>State of the art</b>	40	100	40
<b>User identification + Activity analysis</b>	40	100	40
<b>Requirements</b>	30	100	30
<b>Ideas Generation 1</b>	30	100	30
<b>Prototyping 1</b>	20	100	20
<b>User Testing 1</b>	26	100	26
<b>Ideas Generation 2</b>	40	100	40
<b>Prototyping 2</b>	20	100	20
<b>User Testing 2</b>	20	50	10
<b>Ideas Generation 3</b>	20	20	4
<b>Prototyping 3</b>	40	0	0
<b>User Testing 3</b>	20	0	0
<b>Oral Preparation</b>	40	0	0
<b>Report Writing</b>	80	60	48
<b>Debris Model</b>	40	70	28
<b>Population Visualization</b>	20	100	20
<b>Usability Testing of the old tool</b>	10	100	10
<b>Specification</b>	40	50	20
<b>Development</b>	340	5	17
<b>User Testing 4</b>	20	0	0
<b>Meeting</b>	24	60	14.4
<b>Total</b>	960	43.47916667	417.4

On the 17<sup>th</sup> of June, the first iteration has been finishing and the second one will be finished after the user evaluation during the same week. It left only the last iteration that will be finished at the end of June in order to begin the development as soon as possible. More than half of the report has been written, in order to not have all the report to write at the end of the internship, after each step, the report is completed.

### b. Risk Management

It is also important to assess the status of the risk identified at the beginning of the internship, in order to see if some responses have to be done.

<b>Id</b>	<b>Response</b>	<b>Status</b>
<b>1</b>	Meetings have been planned with Airprox Inspectors of the UK Airprox Board and the NATS.  The first test has been done with users from the Master of Aerospace Engineering.	Finished
<b>2</b>	Check of the UML Specification.	On-going
<b>3</b>	The beginning of the project.	On-going
<b>4</b>	Training has been done on the unknown tool.	Finished
<b>5</b>	Prototyping and evaluation with users.	On-going
<b>6</b>	Schedule of several hours of development.	Awaiting
<b>7</b>	Project management and planning.	On-going
<b>8</b>	Project management and planning.	On-going
<b>9</b>	Interview with person who used this kind of data.	On-going

# Annex B - Heuristic Evaluation of the SODART project

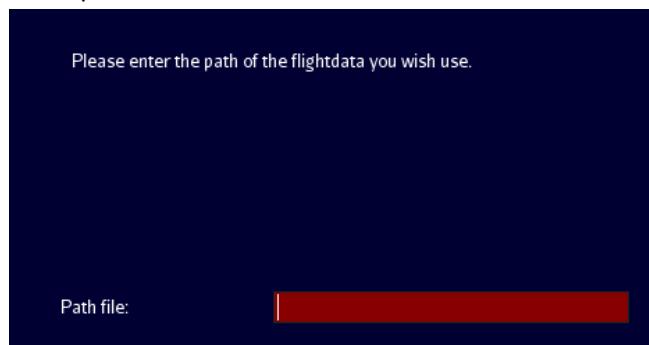
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1: The system should always keep users informed about what is going on, through appropriate feedback within reasonable time.

- Waiting time for the loading of a simulation: 14-30 seconds without any message or progress bar.
- You don't have any feedback to tell the user that the Location or plane created is well created.
- You don't have any feedback to tell the user that he saved the result of the simulation.
- You don't have any feedback when you load flight data, you don't know if they are well loaded in the situation.

2: The system should speak the users' language, with words, phrases and concepts familiar to the user, rather than system-oriented terms. Follow real-world conventions, making information appear in a natural and logical order.

- The loading and saving form are not similar to the one used in most software, in this one, the user has to write the path.



- To talk about the second plane, it says: "Aircraft Vehicle Data 2".

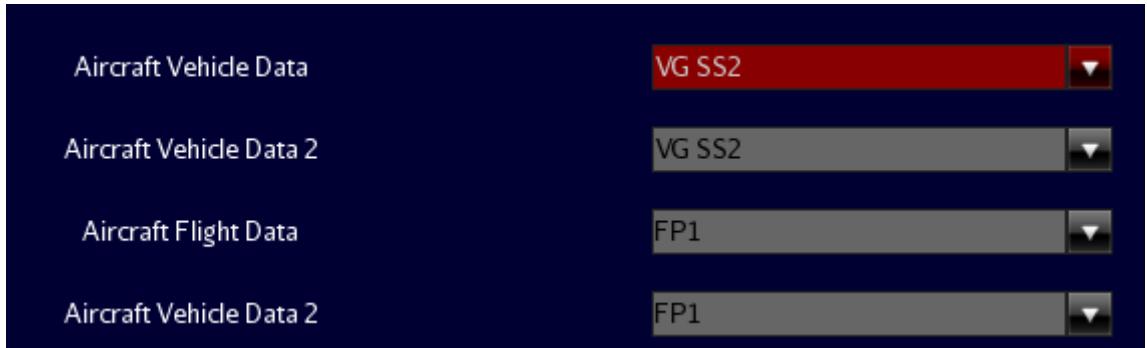


3: Users often choose system functions by making mistake and will need a clearly marked "emergency exit" to leave the unwanted state without having to go through an extended dialogue. Support undo and redo.

- When you add a location or flight data, if you click on back it doesn't erase the information on the field.

4: Users should not have to wonder whether different words, situations, or actions mean the same things. Follow platform conventions.

- There are 3 types of simulation and one: “Collision Simulation” is not explained.
- For the first plane, you define the “Aircraft Flight Data”, but for the second you define the “Aircraft Vehicle Data”.



- The order of button can be unconventional, for example, you have the “start” button on the left and the “back” button on the right.



Conventionally, back/next button are more like that :



- The button “New Simulation” at the end of a simulation go to the menu “New Simulation” and not directly to the configuration page.

5: Even better than good error messages is a careful design which prevents a problem from occurring in the first place. Either eliminate error-prone conditions or check for them and present users with a confirmation option before they commit to the action.

- You can add an empty location.

6: Minimize the user’s memory load by making objects, actions, and options visible. The user should not have to remember information from one part of the dialogue to another. Instruction for use of the system should be visible or easily retrievable whenever appropriate.

- When you add a location or a vehicle data, you come back to the menu and not to the simulation page.
- When you add a location, you don’t have examples for the latitude and longitude.

Name	<input type="text" value=""/>
Latitude	<input type="text" value=""/>
Longitude	<input type="text" value=""/>

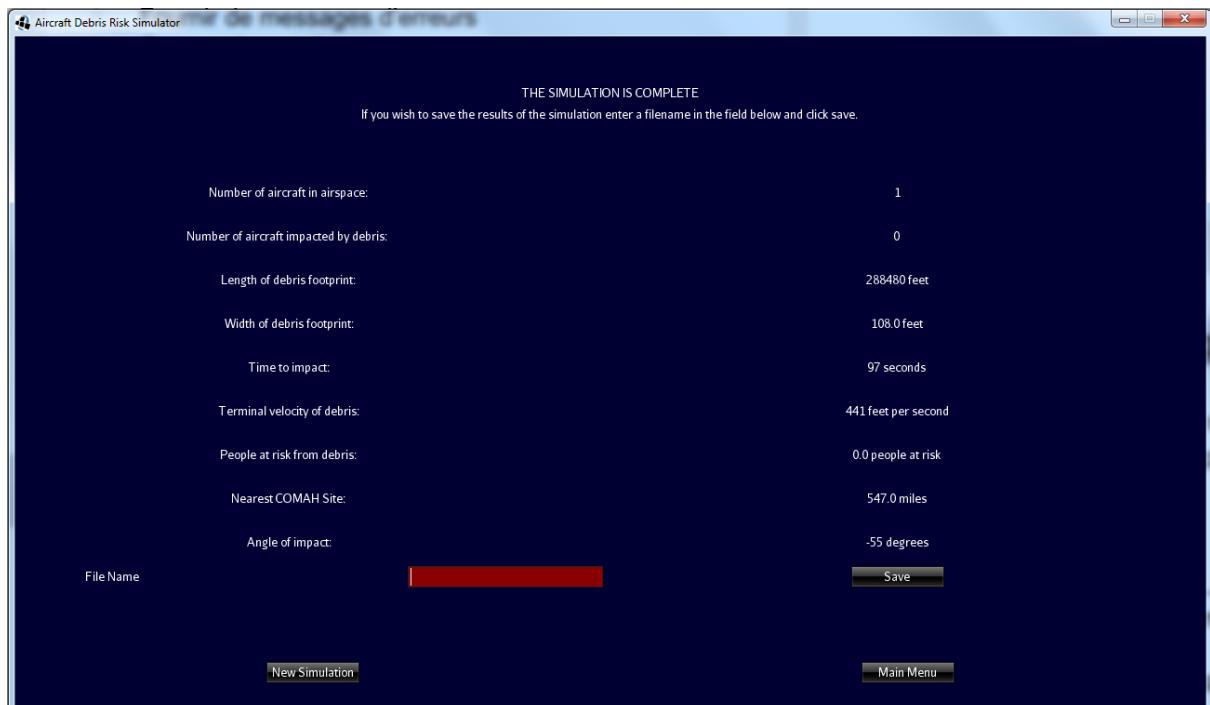
7: Accelerators – unseen by the novice user – may often speed up the interaction for the expert user such that the system can cater to both inexperienced and experienced users. Allow users to tailor frequent actions.

- It misses a button to focus the simulation on the debris field.

8: Dialogues should not contain information which is irrelevant or rarely needed. Every extra unit of information in a dialogue competes with the relevant units of information and diminishes their relative visibility.

- In each pages there are a lot of information and they are not grouped.





- No information about the weather in the configuration page or in the result page or during the simulation.
- The two first menus are really similar.



## 9: Error messages should be expressed in plain language (no code), precisely indicate the problem, and constructively suggest a solution.

- No error message, even if you tried to create a new empty location.
- You have java error message.

10: Even though it is better if the system can be used without documentation, it may be necessary to provide help and documentation. Any such information should be easy to search, focused on the user's task, list concrete steps to be carried out, and not be too large.

- Few documentation

# Annex C – Report of Meetings, Interviews and User Evaluations

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## 1. Meeting with Professor Chris Johnson

Date: 19/03/2014

This meeting is the first meeting of the internship, the purpose was to talk more about the subject. Chris gave the choice between two subjects, on which one of his student worked this year:

- Christopher Butler: He worked on a subject about “Situation Awareness” with an experiment on Flight Gear (An open source flight simulator). The idea would be to take this simulator and to play runway incursion scenario in order to see the impact on the airport and the number of casualties.
- Craig Martin: He worked on the Debris Simulator and he added the possibility of playing mid-air collision on it. It would be great to add functionalities in order to be able to replay Airprox Scenario and change the location to see the impact. It is also possible to work on runway incursion with this software application.

As runway incursion accident we have:

- Milan Lenate
- CDG

I have to contact both students to see their experiments and read their reports in order to choose the one I want to continue.

Date: 31/03/2014

During this meeting i told Chris that i wanted to work on the SODART project (The Airprox Simulator). So he told me to begin my research about it by contacting Aviation Accident and Airprox inspector from France and UK to talk to them about the methods and tools used for an investigation. Indeed because the purpose of this software is to Animate an Airprox scenario and simulate the impact of debris on the ground population.

He also told me to check the possibility to use this tool in Airport planning and route creation, especially for departure and arrival routes at the airport which use EGNOS system.

Finally he ask me to check about the Debris model, indeed, for now it uses the TAP model developed by Oldham but it doesn't take into account the engine for example.

For the next meeting i have to write a state of the art about similar tools.

Date: 11/04/2014

I gave Chris my state of the art, in it i talked about the similar tools use in France, i didn't have a lot of information from the UK. I have to keep contacting the BEA and UK Airprox Board. He

doesn't want to give me his contact now, he'd rather wait that i have something serious to show. In my state of the art i talked about the visualization of the risk and of the population, i talked about 3D visualization, he asked me to read books written by Edward Tufte and especially about the problems i could meet with the 3D visualization, but also about the use of colour in a map (Necessity of taking into account the Colour Deficiency). He also asked me to take a look about OLIVE an Online Visualization Library developed by the professor Ben Shneiderman.

Then we talked about the planning of the project, i thought about doing 3 iterations in the design phase and began the development phase in July (2 months). He agreed about the 3 iterations but he suggested me to begin the development earlier, indeed, the students who developed it before won't be available in July or August.

Date: 16/04/2014

During this meeting I told Chris i wanted to perform an usability test of the actual version of the tool, to see what i should improve in term of usability. He told me that i will find a lot of usability problem and it wasn't maybe that necessary. The tool is a Research tool (different from an Industrial product), and its goal is not to be usable because it won't be used by a lot of different people (Maybe only use by the person who developed it). He told me that i should check a little the literature about the difference between a research tool and an industrial tool.

I can do the usability test but maybe only focus it on on part (Delay, the menu, ...), about the user, i can find some computer science student, aerospace student, but also lecturer (I should solicit them only when i have something serious).

Date: 24/04/2014

During this meeting, i told Chris about the interview of the Airprox Inspector Ronnie Smith, and the fact that he asked me if i want to assist to one of the board meeting. chris thinks it can be a great idea. He asks me for a transcription of the interview, because it can be really interesting to use it in the final report, he also asks me to send the task analysis i realised with Hamster.

I told him, i checked the TAP model used in the actual version of the software, and about the "mistakes" i found in it. I asked him if it could be relevant to take care about the lateral wind in the debris. According to him, i should take into account all the information i can about the weather, but i should ask a user like an Airprox Inspector to get the answer. He warned me about the fact that my report should be like a story, so i should take care about not work on too much different things and focussed on one big thing, in my case the HCI. I gave me the email of Guy Boy, who has a student who works on the visual representation in 3D of the weather on tablet, it could be an idea to implements something like that in the simulator.

Date: 28/05/2014

During this meeting, Chris and I talked about my trip to London, what I need to do to have the trip paid by the university, the fact that i should bring the prototype to make the Airprox Inspectors test them. Then I asked him how can i find student to do the first user test with the paper prototypes. He told me to check with the Aerospace Engineering Department to see if they can ask some of their students.

Then we agreed to have another meeting next week to talk about the final report. He also wants me to begin the development phase because he is afraid that I will miss time at the end of the internship.

Date: 04/06/2014

4 days before the meeting I sent the first part of my final report to Chris in order to correct it, he told me that in general it was great, except few parts :

- In the state of the art, it could be interesting to show the pros and cons related to each tools.
- In the chapter about the requirements, I talk about “functions”, which is a mistake, It’s better to say “needs” or “requirements”.
- In the chapter about the Heuristic Evaluation, I should put some screenshots.
- In the whole report, I shouldn’t use “I”.
- The part about the stakeholders is not that much interesting, I can put it in the Appendix, I should ask Philippe Palanque about that.

We also talked about my visit of the NATS control centre of Prestwick, Chris told me to take more than the paper prototype. I should take screenshot of the other existing tools, screenshots of the existing tools and if possible online prototype. It will be easier for them to understand. He also told me that he could come with me to the NATS centre, but it would be better if I go there alone.

Date: 12/06/2014

In the correction of my report, Chris talked about a Mid-Air Collision in ex-USSR that could be more recent than the Überlingen Accident. but after we checked we couldn’t find something about it.

I showed him my javascript prototypes, he found them good especially the 3D visualization with Google Earth, it is this kind of prototypes that I have to show to the UKAB and NATS.

I asked him his comments about the possibility to use an interface developed with Swing with the 3D visualization developed with JME. He thinks that it’s my choice and there is no problem, I have to check the compatibility before trying anything.

Then I asked him if I can interview him about his work and especially his accident investigation article. He found it was a good idea but I have to ask Philippe Palanque if the jury won’t think that there are too much biases because he is my supervisor.

Finally, I asked him if he knew any professor at Cranfield University, the university developed a software application with a debris prediction trajectory. He gave me a name and if he doesn’t answer Chris will contact him himself.

I will begin the development phase, I won’t need to see Chris once a week anymore but only if I have any troubles.

Date: 15/07/2014

I began the development phase for two weeks and I showed a demonstration of what I have done until now. All the preparation form is done, and I am now working on the time management of the 3D visualization. I said Chris that I will work on the debris model at the end because I want to focus first on the HMI. About the debris model, he will contact the professor of the University of Cranfield who is in charge of the debris simulator they developed.

He will not be in Glasgow for the beginning of August, I will try to give him to read a big part of my report before he leave.

## 2. Meeting with Professor Philippe Palanque

Date: 17/02/2014

The purpose of this meeting is to discuss about my internship before I leave for Glasgow. His goal is to check that I apply the methodology that I learnt during the HMI Master's classes. Because this internship is not traditional, I have to be really careful and to keep him update about my progress, I have to warned him if I thought that it doesn't respect the HMI Master's constraint.

In my report I have to be really clear about the process used, the user identified and how I apply a User Centered Design process.

It is really important to show that I used the knowledge learnt in the 6 months of classes.

One approach could be to analyse the HMI of the mid-air collision, it is important to identify the users of this kind of tools and the different tasks available of the system (The HMI could change in function of the tasks).

For the user evaluation, if Chris is the only user, I can ask other students, it is better than nothing. In this case I have to explain why I do that and what would be the best option.

It could also be interesting to focus the subject about risk perception: How people understand probability.

It is important for me to read accident analysis done by Chris, for example the accident analysis of the Überlingen Mid-air collision.

In the first report sent after the first month:

- Needs
- Process
- Quantity of Development
- Quality of the code

All our e-mails should be in English because it could be possible that we have to include Chris in the conversation.

Date: 23/06/2014

I first sum up all the beginning of my internship, what was done and what kind of process I was going to use.

He agreed with my choice in terms of prototyping, but for the users evaluation, he told me it was important to show to the expert user the paper prototypes in order to have their opinion about my choice, even if I made user evaluation with it already, I didn't do it with expert user.

It is also important for me to plan a validation phase after the development phase. For example, I can ask the investigator from the NATS or the UKAB to show them my product when it is done.

In my report, it is important to show only what is important and in the good order, it could be good to show each iteration and the result of it.

Finally, Philippe will see Chris on Friday 27<sup>th</sup> of June, and they will talk about my work.

### 3. Meeting at the UK Airprox Board

Location: RAF Airport of Northolt

Date: 25<sup>th</sup> of June 2014

The UK Airprox Board is in charge of the investigation about Airprox in UK, it is composed by 5 investigators and one director. It is based in Northolt Airport, a base of the Royal Air Force in the suburb of London. Once a month, they have a meeting with other aviation specialist in order to share the results of their investigation and decided the causes, contributory factory and the risk.

At the meeting, the investigators and other people from the CAA, the MAA are here as advisors and user of the Airspace are here as members of the board. The members of the board represent the civil and military pilot, but also the Air Traffic Controller from the NATS and the army (RAF, Navy and Joint Helicopter Command). Contrary to the advisors, they have the right to vote and it is them who decide the conclusion about the airprox. Observers can be allowed to the meeting but they don't have the right to participate to the discussion, it is mostly people from the army or the industry who works on project related to incident investigation. Finally the director of the UKAB, Steve Forward, is the chairman of the board, consequently he holds a casting vote should the Members find they are unable to agree.

A first draft of the investigation report is sent to all the member before the meeting, it is composed by the factual report and an analysis written by the UKAB, but also comments from organizations involved like the ATC or the army. After the meeting, the UKAB adds a summary of the discussion of the board and the conclusion, then it is sent to the stakeholders in order to make them check the information in it and finally it is published on the UKAB website, generally six weeks after.

The meeting begins with a presentation by the director of the UKAB, he presents some statistics like the evolution of the number of Airprox in the last five years. For example, the number of Airprox is really higher than the years before. It could be explain by two factors, the fact that reporting is becoming more and more systematic for pilots, and the weather is better than last years, so amateur pilots are more likely to fly. Finally he sums up the last recommendations of the board and the measures taken by the organizations involved.

The main part of the meeting begins after this introduction, the inspector who performed the investigation start by presenting the situation, a map is shown. Then there is the discussion, it can last from a few minutes to an hour in function of the complexity of the situation. The members of the board can all say what they think happen and accuse or defend one of the people involved in the Airprox. Because there are no sanctions at the end, members can blame a person from their own sectors if they think he/she is responsible. The director of the board leads the discussion and when there is no more things to add, ask the board for the causes and the possible contributory factors. At the end, he asks for the risk, if the board disagree about the conclusion, there is a vote in which the director holds a casting vote.

As it was said before, the discussion can be very long when the members of the board disagree about the causes and the responsibility of each people involved. For example about the Airprox 2014020, the debate went quickly on the fact that the ATC didn't see quickly enough the conflict and so didn't do the Traffic Information in a good time. The Military ATC said that the ATC didn't see it because he was first filling the squawk number and then one of the aircraft descended with a high vertical speed (more than 10000 ft/min) so it was hard predict his trajectory. But the military pilot and the civil ATC said that it his fault because he should have seen it.

Other cases can be really interesting, for example the Airprox 2014021 is about one helicopter and one UAV (Unmanned Aerial Vehicle). The problem with UAV is that you can't have the assessment of the pilot because he is not in the aircraft. In this case, the meeting board decided to not conclude about the causes of this airprox because they considered that they didn't have enough information about the UAV. The airprox with UAV are for now rare because they don't fly normally in the same airspace than the aircraft, but they are going to be integrated one day, and they will have to give enough information for Airprox investigation.

Most of the time, an airprox involves only two aircrafts, but a few time it can involve more. In the airprox 2014023, two fighter jets flied too close from a civil helicopter. This Airprox is also interesting for another reason, the helicopter pilots estimates that the fighter jets were at an altitude of 700 ft., but the instruments of the fighters jets indicated an altitude higher than 5000 ft. the difference is huge and the conclusion depends on this difference. The risk is A if the helicopter pilots are right but D if the fighter jet pilots are right. the board thought that the helicopter pilots had been subject to an illusion due to the fact that the fighter jets were turning.

Finally, in some Airprox, the investigators didn't have the radar tracks, so the investigation is really harder. Like for example in the Airprox 2014034, 2014035 and 2014038.

## 4. Meeting at the NATS Control Centre of Prestwick

Location: NATS Control Centre of Prestwick

Date: 21<sup>st</sup> of July 2014

The National Air Traffic Service (NATS) is the Air Navigation Service Provider of the United Kingdom. It is in charge of three control centre in the UK: Prestwick, Manchester and Swanwick, and more than fifteen Airports. The control centre of Prestwick is in charge of the en-route control in Scotland and Northern Ireland, but also of the Oceanic Area of Shanwick over the Atlantic Ocean.

In each of this control centre, a team is in charge of the investigation about all the incidents and accidents in its area. This team has to investigate each occurrences and especially how the controller deal with the situation, then it sends its conclusion to the UK Airprox Board.

First the controller has to fill a report that is sent to the investigation team, the team gather all the necessary information (radio and radar data), then it interviews the controllers involved and sometimes the pilots. During the first interviews they just want to hear about the facts, other interviews are performed after with the radar replay in order to understand how the controller understand the situation.

The video of the replay is synchronized with the recording of the radio thanks to the software application "Camtasia".

Finally they assess the severity of the incident, it is composed by two grades, one is a number between 1 and 4, it is the last barrier available in which 1 means that only the providence allows the accident to be avoided and 4 means that the controller reacts quickly enough to avoid it. The second grade is a letter between "a" and "e" that refers to the distance between the two aircraft.

The team proposed to the NATS some recommendations, they can be accepted or rejected, in case of a rejection, the justification has to be given. The report and the recommendations are then sent to the UK Airprox Board maximum thirty days after the incident.

They don't have yet an automatic reporting of Airprox based on the STCA but they have special software that collect all the STCA alerts, it is not connected yet to their reporting software application. The NATS is working also on Map Interactive of incidents in order to identify spot of high occurrence of Airprox.

## 5. Interview of Ronnie Smith (UK Airprox Board)

Ronnie Smith is an Airprox Inspector at the UK Airprox Board, before that he was an Air Traffic Controller for the Royal Air Force for twenty years and performed two Master's Degree at Cranfield University in the field of Safety and Aviation.

Question 1: What is the necessary training to be an Airprox Inspector?

Each inspector has a strong experience in the field of aviation and safety, but this experience can be various, inspectors can have an Air Traffic Controller, an engineer or a pilot background.

Question 2: What are the big steps in an Airprox investigation? And for each steps what are the outcomes?

The first step is the notification, a pilot, or an Air Traffic Controller report an Airprox to the Civil Aviation Authority (CAA) (Or the Military Aviation Authority (MAA) for the military pilot). Then the CAA and MAA give the report to the UK Airprox Board for the investigation (The UKAB is independent from CAA or MAA). The inspector of the UKAB have to collect all the data they can find about the Airprox: Weather data, NOTAM, radar data and GPS data if it is possible. They also have to trace and interview all the pilots and controller involved. If the ATC did an investigation, it has to be given to the inspector. Then the inspector writes a factual report about the Airprox.

Finally, once a month, there is a meeting with the members of the Airprox Board who are specialist in various field of Aviation (ATC, Glide pilot, etc..), the inspector gives them the factual report and all the evidences, and they have to analyse the cause and the risk level of the Airprox, they also can make recommendations. All the conclusions of the meeting are published in the website of the UK Airprox Board.

Question 3: Which step is the most time consuming?

The step of data gathering could be really long (around 3 months), it depends on the pilots and controller the inspector has to interview. The inspector wants this step to be as fast as possible because with the time the people involved forget a lot of information. The average duration of an investigation is around 4 months (From the notification to the board meeting), there are only 3 Airprox inspectors in UK, and around 142 Airprox to investigate in 2013. The problem is that in general aviation, pilot can take a little time before reporting the Airprox, and when they are interviewed, they had forgotten important information.

Question 4: What are the tools used to replay Airprox?

The inspector uses a tool given by NATS to replay radar data, it can be used with any computer. It is used to measure the distance between the two Aircraft, and understand the context (Workload of the ATC, number of Aircraft in the airspace, etc...). Screenshot of the situation can be taken with this tool to illustrate the final report.

Question 5: What are taken into consideration to assess the risk of an Airprox?

For now, the UKAB use the ICAO categories to rate the risks: A to E (A: Risk of collision, B: Safety not assured, C: No risk of collision, D: Risk not determined and E: Safety standards). The problem with this classification is that you can't compare two Airprox, indeed, an Airprox with a risk of A in a controlled airspace can be less dangerous than an Airprox with a risk of B in a class G Airspace, because there are more protection in controlled airspace (ATC or aircraft equipped with TCAS). The UKAB is working in a new risk assessment system based on the ERC system from the Methodology for Operational Risk Assessment for Aviation Organisations. The ERC system considers all the possible outcomes of an event, and then considers the severity of the most credible one, finally it takes into account the availability and effectiveness of relevant safety barriers.

The assessment doesn't take into account the ground population because they don't have the data to, but it could be an improvement. The CAA and the MAA can be really interested by this kind of assessment to deal with problems about Airways over really populated areas.

Question 6: Are you involved in special projects (Studies on special part on the flight? Special area like Airport?)

The database of the UKAB is really old, you can't select Airprox around special area, the only selection you can do is to select Airprox around a particular airport. It could be changed if they decide to use the ECCARS system to manage Airprox report. ECCARS is developed by Eurocontrol to manage the reporting of aviation incidents.

Question 7: Are you using ADS-B and Datalink data?

ADS-B and Datalink data are not used yet in the Airprox investigation, but they were available it could make the investigation easier. Especially to calculate the distance between aircrafts. The other information can be useful (Speed, altitude ...), but they don't need a good accuracy about it, it's not important if the speed of the plane is 122 knots instead of 120.

## 6. Interview of Jérôme Dufossez (DGAC-SE)

Jérôme Dufossez is the leader of the unit Quality of Service and Safety of the En-route Control centre of Aix-en-Provence in France. This unit is in charge of the investigation of incident which happens in the South East of France, like Airprox, but also Flight Plan problem or En Route centre coordination problems.

Question 1: What is the necessary training to be an Airprox Inspector?

Most of the inspector at the unit Quality of Service and Safety are former Air Traffic Controller, they were trained at the French School of Civil Aviation (The ENAC).

Question 2: What are the big steps in an Airprox investigation? And for each steps what are the outcomes?

The first step is the notification of the Airprox, it can be done by the controller by filling an FNE (Fiche de Notification d'Evenement), by one of the pilot involved or by the system itself, indeed, French civil aviation authority (DGAC) sets up tools to detect automatically losses of separation using for example the alerts send by the safety net to the controller. This last method is for the moment not applied in another country.

Not all the incidents reported are investigating the same way, it depends of how grave it is but also of its probability of recurrence. The gravest is the incident the more complete is the investigation, the inspector can use the Radar/Radio and phone data, but also interview of the pilots and the controller. After he has to identify the cause of the incidents, if the first cause is a human error, the inspector has to understand this human error by analysing the environment, the workload, the availability of information and other human factor related issues.

The gravest incident are finally analyse by a local safety board composed of Air Traffic Controllers and Incident inspectors, after the analysis they give recommendations. This board is independent from the DGAC, they can analyse any incidents and make any recommendations.

Question 3: Which step is the most time consuming?

The duration of each step depends on how grave is the incident, the whole investigation can be done in two days, but the maximum duration allowed for an investigation is four months. It can be difficult to meet the actors involved in the Airprox, especially the controllers who work staggered hours. It also takes time to coordinate the investigation with the military if the Airprox involved military aircrafts.

Question 4: What are the tools used to replay Airprox?

The official tool to replay an Airprox on IRMA2000 visualization (The radar screen) is SNER, it can synchronize radar/radio/ phone data. The DGAC developed a software more office oriented called EPOQUES can also synchronize radar/radio/phone data. A more radar oriented tool, ELVIRA, can be used to visualise all the trajectories and measure the distance between the two aircrafts.

Finally MAGE is a tool used to show the controller screen at the time of the Airprox, but you only have the radar data.

Question 5: What are taken into consideration to assess the risk of an Airprox?

To assess the risk of an Airprox, they used the Risk Analysis Tool (RAT) developed by Eurocontrol. This tool takes into account two risks:

- The risk of collision: they analyse the geometry of the conflict, how the controller handle the situation, the solutions of the conflicts, the technical barrier (ACAS, Safety net ...).
- The risk of recurrence of the incident: they analyse the context of the Airprox, the more casual is the context and the more recurrent can be the incident.

They also perform a systemic analysis, to identify any problems in procedures or in the training of the controllers.

They don't take into consideration the consequence of the collision for the ground population but they have demands from company for traffic data to calculate the probability of a plane to fall in a precise location, for example, to evaluate the risk that a plane crash in a Nuclear Plant (EDF) or in a Forest and start a fire (Government office). These risks can be used to define safety plan and set safety structures.

Question 6: Are you involved in special projects (Studies on special part on the flight ? Special area like Airport ?)

The unit is not involved in this kind of projects but the inspectors try to identify the key risk areas and the waypoint where there are the most conflicts.

Question 7: Are you using ADS-B and Datalink data?

They are not using any ADS-B data or Datalink data for the moment. But with the new ATM system 4-Flight normally delivered in 3-4 years, the ADS-B will be used by the Air Traffic Controller for example to check the flight level entered into the FMS by the pilot or to change the frequency of an Aircraft automatically. So these data will be used also during the investigation, but it is not their main purpose.

## 7. Interview of Philippe Plantin de Hugues (BEA)

Philippe Plantin de Hugues is senior investigator at the BEA (Bureau d'Enquête et d'Analyse), which is the board in charge of the Aircraft Accident Investigation in France, he worked in the laboratory of the BEA for 19 years as a CVR analyst. He is now in charge of the BEA international affairs program.

Question 1: What is the necessary training to be an investigator at the BEA?

Most of the investigators at the BEA were trained at the ENAC (French School of Civil Aviation) as engineer or technician, they are all civil servants. There are also former military that has an experience in Aircraft Accident Investigation and Aviation Safety.

Question 2: In what case the BEA investigate in an Airprox incident?

The BEA has the obligation to investigate in all accidents which take place in the French territory, a "Go Team" can be send abroad if the accident involve an Aircraft built by a French manufacturer (Airbus, ATR, Airbus Helicopter - Previously Eurocopter), a French airliner or if there are French fatalities. The BEA can also investigate on incident, the purpose is to identify the main safety issue in it and to avoid the accident before it happens.

The BEA investigates in an Airprox incident if the distance between the two Aircraft is less than 50% of the safety distance (in France, in En-route space, the safety distance is 5 nm and 1000ft).

Question 3: What are the big steps in an investigation?

The first step is to find the site of the accident and collect all the evidence (Piece of Wreckage, black boxes), a mapping of the wreckage is done, it could help to determine if the plane hit the ground in one piece. Then the black boxes are brought back to the laboratory of the BEA to be read. There are few labs able to read damaged flight recorder, even if the accident takes place in another country, the flight recorder are sent back to France. After the first month of investigation, a factual report is written, there are in it only facts. If there are some difficulties to find the wreckage, it could be written after more than a month, it was the case in the accident of the flight AF 447. Then, the team of investigator are divided in different workgroup which each analyse a different part, it could be the engine, the Cockpit Voice Recorder or the Flight Data Recorder. At the end, the investigators decide of the possible causes and the contributory factors of the accident, and propose safety recommendations.

Question 4: How long does an investigation take?

The duration of an investigation depends on the type of accident, if the accident involves only aircraft from general aviation (non-commercial), the investigation takes normally a little less than a year. But if commercial aircraft are involved, it could take a little longer, the average duration in this case is 16 months.

Question 5: What are the tools used to investigate?

Most of the tools used during the investigation are developed by the engineer of the BEA, it can, for example, reproduce the trajectory of the plane in 2D or 3D thanks to multiple sources like FDR, GPS, Primary and Secondary Radar. Primary Radar can be really useful to identify the debris falling in case of In-Flight break up.

Question 6: To write the recommendation, do you only look at the accident, or do you try to imagine the “Worst Case Scenario”?

The recommendations take into account the possible cause of the accident and the contributory factors. All the contributory factors are studied independently of each other to see their influence on the accident. The BEA can make an additional study more general about one factor, for example, the BEA made a study about the “Aeroplane State Awareness during Go-around”. This kind of study takes elements from several accidents to make general recommendations.

Question 7: Did the BEA perform general studies about trajectory of debris after a Mid-air collision or an In-flight breakup?

This kind of study has not been done at the BEA, but cartography of the wreckage is done at each investigation, it can help to determine a general pattern of debris repartition on the ground. A study of the trajectory of the debris can help the investigator to find faster the important piece of the wreckage (Engines, flight recorders, aircraft computer systems), especially in the sea. An analogy can be made between a Mid Air collision and a Collision between an aircraft and the sea, in the first case the debris fall into the air and the second the debris fall into the water. In the case of a crash into the sea, the length of the debris field is between 400 and 600 meters in the same direction of the trajectory of the aircraft.

Couple years ago, the BEA started a study about the trajectory of debris into the water, but the difficulty to predict the position of the aircraft when it hits the sea makes the determination of the trajectory of important pieces of the aircraft too unreliable and the study was stopped.

Question 8: Do you use ADS-B data in your investigation?

To determine the trajectory of the aircraft, all the data available are used, including the ADS-B data. Even if most of the time the more reliable information, the S Mode radar data, come from the Air Traffic Controller Centre.

## 8. Interview of John Thomson (CAA)

John Thomson is an analyst who is working for the CAA (Civil Aviation Authority) in UK. He analyses safety performances of airlines or aircraft in general and more especially he is on the Airborne Conflict Action Group. This group focussed its work on Airprox and mid-air collision.

Question 1: What are the objectives of the Airborne Conflict Action Groupe ?

The Airborne Conflict Action Group is formed to act as a new coordinating body for the work being undertaken to minimise the risk of airborne conflict for all types of air operations within and outside of UK airspace.

- To establish formal links with other industry bodies engaged in activities associated with reducing the risk of a mid-air collision.
- To establish a consolidated risk assessment and mitigation document identifying the airborne conflict key risks, actions in place to mitigate these risks and desired outcomes.
- To review the work being undertaken globally in the area of airborne conflict and identify areas for CAA/UK engagement.
- To identify potential lead indicators to be used for gauging the risk of mid-air collision.
- To determine safety performance indicators to monitor the performance of the agreed actions and measure the effectiveness of the desired outcomes.
- To develop strategies and actions for reducing the key risks to be included in the CAA Safety Plan

Question 2: How does the group do to achieve these objectives?

One of the main tasks performed by this group is to investigate on incidents and try to find any recurrence. For example the group is analysing the location to Airprox in order to see if there are some “hotspots”. It is important to understand the nature of these hotspots by analysing what causes the incidents (TCAS, Airspace Infringement, etc...), and by overlaying the air traffic flux. Indeed, if there are lots of incidents but not a lot of traffic, it means that there is a real problem at this point.

At first, the group was gather incidents from all UK, but now they are focussing only on some areas, like for example airport SIDs (Standard Instrument Departure).

Question 3: How do you gather all the information about the incident? What kind of data are you using?

The majority of the data comes from pilot and Air traffic Controller reports, which causes a problem of accuracy on the location of the incident. They want to use ADS-B data and data from the Flight Data Recorder of the aircrafts but they are not allowed yet.

Question 4: Are you looking at the possible consequences of a mid-air collision at these hotspots?

First the group is trying to identify how many safety barriers are still in place during the incidents and how they can hold on. For example, if the only safety barriers left is the ultimate action of the pilots to avoid each other, it means that an accident is likely to happen. In order to do that they use BOWTIE, a risk model developed by the CAA.

Then, if the hotspot is located in an industrial area, they tried to evaluate the possible economic impact, like for example if any motorways or railroads can be hit by debris and be closed. In order to do that, the Airprox Simulator can interest the group.

## 9. User Evaluation of the 04/06/2014 (Paper Prototypes)

The purpose of this test was to test the first paper prototypes of the software application. I decided to use a design walkthrough process. It means that I make all users test the different paper prototypes, and I ask them to give me their opinion about them. I also ask them to apply a “think aloud” protocol, which means that they tell me how they are thinking during the test.

### The users:

Because it was not possible to test the software with Airprox Inspector (they are not any in Glasgow), it was important at least to test it with people with a minimum aviation background. I found 3 students who just finished their Master in aerospace engineering, they all got an experience in Aviation Industry. They know how Air Traffic Management works, the different stage of a flight, the basic information about a flight (Altitude, heading, air speed, attitude, vertical speed ...) and what an Airprox is.

### The scenario:

I begin the session with a brief explanation of the purpose of my project, and I presented few screenshots of the actual software application (the 3D visualization but also the form to define a scenario). Then I give them a UK Airprox Board report that they have to read (only the first part about the fact, the discussions of the board weren't interesting in this test).

After I made them simulate the airprox on each solutions, and observe their reaction, difficulties, preferences. They interacted with the paper prototype and I was playing the computer. For this phase, I gave them a paper with additional information: The translation of the METAR, the different standard speed and vertical speed for the two aircrafts involved. Indeed, the speeds are not in the report, so a solution is to use standard speed, in the software application it will be an option in the form.

### The result of the test:

The first solution the students test was the classic form, they found it easy to use, each field were clear. They like the fact that they can use standard speed if they don't have the information. They wondered what could happen if the location of the Airprox doesn't fit with the settings of the two aircrafts (for example, if the altitude of the collision is 32000 ft and the altitude of the two flights are 30000 ft), I will have to deal with this problem. I will have to decide if I give the priority to the aircraft settings or to the collision place settings, I can ask the Airprox Inspectors. The users like the fact that they can take the weather forecast of the day of the Airprox online.

The second solution was the one without the map, they found it directly more visual and they liked it. They liked the fact that it was easy to match the heading of the plane with the illustration of the report. The fact that the Altitude and Attitude are more visual was also according to them a good idea. It was the same reaction for the Weather information. They don't understand directly that they can add wind information, the table in the first solution has more affordance. But the fact that the sliders for the wind information are not accurate enough could be a problem, one solution could be to put a textfield with the value of the slider and the possibility to change it.

The third solution is the one with the map, they found it directly a little more confusing than the two previous solutions. One reason was the fact that the map couldn't be representative of the real situation, indeed if one aircraft was turning, it is not possible to represent it, so the information given by the map doesn't fit with the reality. The issue with the fact that the settings of the two aircrafts could not fit with the collision location is more present in this situation. A user gave the idea that the map could be used to allow the user to check the situation before beginning the simulation, but without the possibility of changing the information (but of course the possibility to come back to the scenario configuration page).

After the scenario configuration page, they arrived on the Visual Simulation page (Without 3D Visualization). They liked the fact that you see at the same time the text synopsis of the results and the 3D visualization. They really liked the fact that you can export the visual result on Google Earth, because it is really to manipulate after. A user said that in lots of software, it is hard to find the "save" functionality, but in this case, the button was easy to find. Another ask me if the simulation take into consideration the fact that an aircraft hit by a debris will also produce a debris field, it could be a good idea but it is not the priority of this project. Finally they thought that it could be a good idea to do 2 debris field, a "best" and a "worst" case scenario for the debris field (One could be an instant break up and the other a break up that takes more time, so the debris field would be bigger), it is a good idea, but again it is not the priority of this project. These two ideas would be done at the end of the project if there is time.

The test finished with the Aircraft Library, in general they prefer the first solution with the list of aircrafts on the left side, the table would be really too busy when there will be more planes in it. An idea was to use an existing aircraft to create a new one with similar settings.

#### Conclusion:

This test was really useful for my work, it allows me to make decisions and begin the second iteration in function of the results of this test.

## 10. User Evaluation of the 17/06/2014 (JavaScript Prototype)

The purpose of this test was to test the first JavaScript prototype of the software application. I decided to use a design walkthrough process. It means that I make the user test the prototype, and I ask him to give me his opinion about it. I also ask him to apply a “think aloud” protocol, which means that he tells me how he is thinking during the test.

### The users:

Because it was not possible to test the software with Airprox Inspector (they are not any in Glasgow), it was important at least to test it with people with a minimum aviation background. I found a student who is studying Air Traffic Management and computing network for a PhD. He knows how Air Traffic Management works, the different stage of a flight, the basic information about a flight (Altitude, heading, air speed, attitude, vertical speed ...) and what an Airprox is.

### The scenario:

I begin the session with a brief explanation of the purpose of my project, and I presented few screenshots of the actual software application (the 3D visualization but also the form to define a scenario). Then I give him a UK Airprox Board report that he has to read (only the first part about the fact, the discussions of the board weren't interesting in this test).

After I made him simulate the airprox with the prototype and I show him the different alternatives for the 3D simulation, and observe his reaction, difficulties, and preferences.

### The result of the test:

He began by prepare the scenario of the collision. First he was confusing about the altitude of the collision, indeed the two aircrafts have 2 different altitudes so he didn't know which one to take. The altitude of the collision can be calculated with the altitude and attitude of both aircrafts. He tried to move the aircraft for the heading instead of moving the cursor. The arrow of the Number fields for all the setting of the aircraft was not visible enough, he didn't notice that he could use these fields.

During the loading of the Visualisation, he thought he could be nicer if the two aircraft were moving.

About the representation of the population, the big histogram was a good way to see the population and to compare the different place, but it makes hard to see the map. With the small histogram it was hard to compare the population of two places which was not close from each other. Finally, the spike-like representation was defined by the user as a good compromise between the necessity of being able to compare the population in different places and not hiding the map.

Finally he pointed out that the navigation between different sections could be a little long. For example, if you want to create a scenario and then begin a statistic simulation, you have to go back to the main menu between the two steps.

### Conclusion:

This test was really interesting, it was the first test with an online prototype and it shows that the main functionalities of the software were easy to understand. It also helped to make choice about the visualization. Finally he pointed out a usability problem that could be solved in the next iteration.

## **11. User Evaluation of the 25/06/2014 (JavaScript Prototype)**

The purpose of this test was to test the third prototype of the software application. I decided to use a design walkthrough process. It means that I make the users test the prototype, and I ask them to give me their opinion about it. I also ask them to apply a “think aloud” protocol, which means that they tell me how they are thinking during the test.

### The users:

I was invited on the 25<sup>th</sup> of June to assist to a meeting of the UK Airprox Board at the RAF base of Northolt. I had the occasion to test my final prototype with three Airprox Inspectors who represent the end users of the software application.

### The scenario:

I begin the session with a brief explanation of the purpose of my project, and I presented few screenshots of the actual software application (the 3D visualization but also the form to define a scenario). Then I made them test the prototypes. It was also an occasion for me to confirm the choice that was made with the user evaluations before. To that purpose I showed them the prototype of the past iteration.

### The result of the test:

They really liked the purpose of the software application, indeed in order to assess the risk for the population of an Airprox nowadays they don't use any tools, they just looked for populated city. They also were really interested by the fact that the visualization is in three dimensions, the tools used to investigate are really basic, but the CAA is working on 3D Visualization software application to investigate on incidents and accidents, the software developed in this project could be in that case really interesting.

They really liked the visual representation of the aircraft in the scenario preparation form, it is faster to give an approximate value of the settings of the aircraft and they said that it doesn't need to be really accurate (a difference of 5-10 knots about the speed is not important in the investigation).

### Conclusion:

We have reached a satisfactory outcome and confirmed the choices that were made before, it is now possible to developed the real software application in java.

## 12. User Evaluation of the week of the 18<sup>th</sup> of august (Final System)

To check if the software meets the requirements defined in the design phase is one thing, but it is important to confront the final system to users. This evaluation is the opportunity to test the usability of the software but also if the software changes the perception of user about the risk from Mid-Air Collision.

### a. Hypothesis

To test the usability, the user had to perform a series of task with the software, each task was timed, and each errors made by the user were reported. At the end of each task, the user had to say if the task was easy to perform or not and give any comments about it. At the end of the series, the user had to answer to a System Usability Scale (SUS) questionnaire.

To assess the change about the perception of the risk from a Mid-Air collision, it was decided to assess the user's risk perception about collision before the use of the software and after the use of the software.

Therefore, the null hypothesis of the experience is:

*H0: Using the system will not affect the user's risk perception of a mid-air collision impacting the public.*

In order to prove this hypothesis, it is necessary to disprove the hypothesis:

*H1: Using the system will affect the user's risk perception of a mid-air collision impacting the public.*

### b. Variables

Two variables were identified for the experience:

- An independent variable: the use of the system
- A dependant variable: the risk perception

In order to measure the risk perception, it was decided to use the same test used in the past report [12]. It is developed by Baruch Fischhoff [50] and in addition to ask the user to rate his/her risk perception level, it also ask the user to rate nine scales that could influence this perception:

- Voluntariness of risk
- Immediacy of effect
- Knowledge about risk (by the person exposed)
- Knowledge about risk (by science)
- Control over risk

- Newness
- Chronic-catastrophic
- Common-dread
- Severity of consequences

### c. Users

For the same reasons that in the past user evaluation (except in the third), it was not possible to find real end-user, to that end it was decided to perform the final evaluation with post graduate student from the university of Glasgow. To have aviation background knowledge is a plus, but a quick explanation of the terms used and the purpose of the software is enough at the beginning of the test were given when it was necessary.

All the users had a Master's degree and some of them were studying to have a PhD degree. They were all studying engineering, and the majority of them were studying computing science. This means that they all feel comfortable with a computer and with all the means of interaction used (Mouse and Keyboard). During the week, x users participated to the evaluation.

### d. The process

It could be interesting to see if the change of risk perception is different for a Mid-Air collision over a city or over the country side. These two cases will be separated during the experiment. To this end, two scenarios were presented to the user (they are based on true facts, the Airprox reports used are available in the Annex D).

**Scenario 1:** It happened at a distance of 12 nm from the centre of Glasgow (lat: 55.86666 and long: -4.08333). A commercial aircraft, a Cessna 560, was flying at its cruise altitude (18000 ft), heading 355° at 360 kts. A climbing traffic appeared on the TCAS display 5-10 nm in front of him at 1200 ft below. When the traffic became proximate by less than 1000 ft, the ATC transmitted an avoiding action, the pilot could see the traffic directly in front of him. The traffic was an Airbus A320 operating a passenger's flight, he was climbing to 25000 ft, heading 240° at 290 kts. The weather was calm, on the ground, the wind had a speed of 10 kts, heading 0° and at 20000 ft, the wind had a speed of 50 kts, heading 10°.

**Scenario 2:** It happened over Scotland (lat: 56.7 and long: -4.55) at 34000 ft on the 23<sup>rd</sup> of June 2013. Two Boeing 747 passenger planes were on a course to cross the Atlantic. The first 747 is in cruise at 480 kts, heading 340°, the second is in cruise at 500 kts, heading 300°. At 12h52 UTC, the ATC of the Prestwick centre noticed that the two trajectories are converging and instructed an avoiding action for each of the aircrafts. 4 minutes later, the trajectories are still converging, and the ATC transmitted again the avoiding instruction to the pilot. Finally, 2 minutes later, the pilot of one aircraft reported a TCAS resolution advisory, one aircraft climb and the other descent. The minimum separations were 100 ft vertical/ 3.9 nm horizontal and 1100 feet vertical/2.8 nm horizontal. No weather information is available.

## 1<sup>st</sup> Task

In their first task, the users were asked to rate the risk of a mid-air collision to the local population in each Scenario. For each case, they were asked to answer to the following questionnaire.

### Questionnaire

Consider the scenario outlined above. Answer the following questions on a scale from 1 to 7.

1 – Both aircrafts are colliding. Consider the risk to the local population being struck by the falling debris. (7 = least risky, 1 = most risky).

2 – **Voluntariness of risk:** Do people get into this risky situation voluntarily? For example the pedestrians affected. (1 = Voluntary, 7 = involuntary).

3 – **Immediacy of effect:** To what extent is the risk of death immediate or is death likely to occur at some later time? (1 = Immediate, 7 = Delayed).

4 – **Knowledge about risk:** To what extent is the risk known precisely by the persons who are exposed to this risk? (1 = known precisely, 7 = not known).

5 – **Knowledge about risk:** To what extent is the risk known to science? (1 = known precisely, 7 = not known).

6 – **Control over risk:** If you are exposed to this risk, to what extent can you, by personal skill or diligence, avoid death? (1 = uncontrollable, 7 = controllable).

7 – **Newness:** Is the risk new novel one or an old, familiar one? (1 = new, 7 = old).

8 – **Chronic-catastrophic:** Is this risk that kills people one at a time (chronic risk) or a risk that kills a large numbers of people at once (catastrophic risk)? (1 = chronic, 7 = catastrophic).

9 – **Common-dread:** Is this risk that people have learned to live with and can think about reasonably calmly, or is it one that people have great dread for-on the level of a gut reaction? (1 = common, 7 = dread).

10 – **Severity of consequences:** When the scenario above is realised in the form of an accident, how likely is it that the consequence will be fatal? (1 = certain not to be fatal, 7 = certain to be fatal).

## 2<sup>nd</sup> Task

In the second task, the users were asked to use the software application to simulate the two scenarios. For the first simulation, they were asked additional subtasks in order to assess the usability:

- Fill the preparation scenario form
- Save the scenario and reload it
- Play the simulation

For each subtask, they were timed, the mistakes were recognized and the easiness was rated on a scale from 1 to 5. Finally at the end of these four tasks, the users had to fill a System Usability Scale questionnaire. A SUS questionnaire is one way to measure the usability of a system by asking the user to rate 10 criteria on a scale from 1 to 5 (1: Strongly Disagree and 5: Strongly Agree). A system is considered as usable if the SUS score is above 68.

#### **SUS Questionnaire:**

- 1 – I think that I would like to use this system frequently.
- 2 – I found the system unnecessarily complex.
- 3 – I thought the system was easy to use.
- 4 – I think that I would need the support of a technical person to be able to use this system.
- 5 – I found the various functions in this system were well integrated.
- 6 – I thought there was too much inconsistency in this system.
- 7 – I would imagine that most people would learn to use this system very quickly.
- 8 – I found the system very cumbersome to use.
- 9 – I felt very confident using the system.
- 10 – I needed to learn a lot of things before I could get going with this system.

#### **3<sup>rd</sup> Task**

Finally, the users were asked to rate again the risk of a mid-air collision to the local population over a city and over the country side, with each time to rate the nine scales.

#### **e. The result**

In order to assess if the use of the software application changes the user's risk perception about mid-air collision, it is necessary to prove that for each question, the answer of the user are not different in the task 1 than in the task 3. To do that, a Wilcoxon signed-rank test was performed for each question (Table 9). It shows that there is not difference between the risk perception in task 1 and 3, for both mid-air collision over a city or a country side. It is the same result for 8 of the 9 scales that could influence the perception. The only scale which had changed (if we accept a 10% margin for the test) is "**Knowledge about risk**: To what extent is the risk known to science?", which could be explained by the fact that the software application itself is a proof that the risk is known to science.

	user 1	user 2	user 3	user 4	user 5	user 6	p-Value
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Over a city	Task 1.1	7	2	1	1	2	3	0.5862
	Task 3.1	1	2	1	2	2	2	
	Task 1.2	7	6	7	2	2	4	1
	Task 3.2	7	3	7	2	2	5	
	Task 1.3	1	3	2	6	4	1	0.7728
	Task 3.3	2	3	2	5	4	2	
	Task 1.4	6	5	5	5	1	2	0.3458
	Task 3.4	6	5	5	4	1	1	
	Task 1.5	3	2	3	5	3	1	0.07186
	Task 3.5	2	1	2	4	3	1	
Over the country side	Task 1.6	2	5	2	2	1	5	0.1696
	Task 3.6	3	7	1	6	1	6	
	Task 1.7	6	5	3	1	1	2	0.1736
	Task 3.7	6	7	3	4	1	5	
	Task 1.8	7	6	3	3	5	5	0.5862
	Task 3.8	6	6	3	4	5	7	
	Task 1.9	5	3	1	2	2	6	0.5862
	Task 3.9	2	2	1	3	2	6	
	Task 1.10	6	6	7	6	6	4	1
	Task 3.10	6	7	7	4	6	5	

Table 9 - Result of the final experiment

		user 1	user 2	user 3	user 4	user 5	user 6	Average	Standard Deviation
Fill the scenario form	Time (s)	229	266	248	480	284	340	307.8333	84.44804451
	Mistakes	1	0	1	2	2	2	1.333333	0.745355992
	Easiness	1	2	2	3	4	1	2.166667	1.067187373
Save and load	Time (s)	61	59	36	40	35	77	51.333333	15.49910392
	Mistakes	0	0	0	0	0	1	0.166667	0.372677996
	Easiness	1	2	1	1	2	1	1.333333	0.471404521
play the simulation	Time (s)	165	125	130	120	190	206	156	33.34166563
	Mistakes	1	0	0	0	0	0	0.166667	0.372677996
	Easiness	1	2	1	1	3	1	1.5	0.763762616
SUS	1	5	4	4	4	2	3	3.666667	0.942809042
	2	1	1	2	1	4	4	2.166667	1.343709625
	3	5	5	4	5	2	4	4.166667	1.067187373
	4	5	1	3	3	4	3	3.166667	1.213351648
	5	5	5	5	4	4	4	4.5	0.5
	6	2	1	1	2	4	2	2	1
	7	5	5	3	4	2	4	3.833333	1.067187373
	8	1	1	2	2	4	3	2.166667	1.067187373
	9	5	4	5	5	2	4	4.166667	1.067187373
	10	1	1	1	2	4	4	2.166667	1.343709625
	Total	87.5	95	80	80	30	57.5	71.66667	21.87400791

Table 10 - Result of the Usability test

The result of the usability test shows that all the three subtasks were performed in a good time without doing more than two mistakes (Table 10). Finally with an average of 71.67 for the SUS questionnaire, it is possible to say that the users found the software application usable. This evaluation finally shows what comments were done by the users (Table 11). It shows some recurrent comments like the fact that Altitude and pitch are not in the same side for each aircraft is really confusing, then that the weather table is also confusing and the users took some time to understand it. One user said it could be easier to understand if it was onlytextfield.

Comments	Number of occurrences
Altitude/Pitch not in the same order for both Aircrafts.	5
Weather Table is confusing.	4
To validate the name of the file you want to save, you have to click on "Open".	3
No possibility to delete a wind information.	2
The right click is not working.	1
It could be difficult to control the camera in the 3D Visualization.	1
Smaller aircraft picture.	1
Big distance between each information to fill in the scenario preparation form.	1
Sliders should be more accurate.	1
Load and Save button in a Jmenu.	1
Start button should be more visible.	1
Weather and ADS-B information in the same group than Location.	1

Automatically follow the debris during the simulation.	1
The settings window of JME is confusing.	1
The scrolling is a little slow in the form.	1
The 3D visualization needs a legend.	1
To have the number of the population density with each histograms.	1
Camera always over the Aircrafts at the beginning.	1
A button to centre the camera if you get lost.	1

Table 11 - Comments from the users

We can conclude with the fact that the software application doesn't change the risk perception of the users about mid-air collision, and they found it usable enough. It also provides some issues to improve in the next version of the software application. Nevertheless these results should be taken with caution, because the evaluation was performed with only 6 users, and some of them didn't have any Aviation background, contrary to airprox inspectors.

## 13. Interview of Peter Schmollgruber

Peter SchmollGruber is a an Aircraft Design researcher at ONERA (Office National d'Etude et de Recherche Aérospatiale), the French aerospace lab. He is also lecturer at the ENAC (Ecole Nationale de l'Aviation Civile), the French School of Civil Aviation, in the field of aerodynamics. I called him to ask him some questions about a way to deal with the trajectory of the debris.

According to him, there wasn't any physics model to describe an airplane crash, but it could be a good idea to use an aircraft simulator and to degrade the performances (one engine is still working, a part of the cabin is missing, etc...). His first idea was to use JSB Sim, an open source flight simulator, but it's not a easy tool to use, so it would take me too much time to learn how to use it and then use it in my project.

His second idea was to add Thrust and Lift to the debris and study the sensitivity of these forces. Then i can see how the debris react to these forces and use it well in my project.

# Annex D – The Debris Model

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To calculate the trajectory of debris from a mid-air collision is not easy, lots of parameters to take into consideration like the size, the weight of the debris, but also the speed and trajectories of the aircraft and finally the weather, and more especially the wind speed and heading.

In order to calculate this trajectory, it is important to define a debris model. A debris model is theoretical model that calculates the motion, impact locations and areas, and the probability and risks associated with debris falling within a finite area [1].

## 1 Physical Model

We first have to consider that a piece of debris is a solid with a constant mass during all the falling. To determine its trajectory we can use the Newton's second law of motion that says:

$$\sum \vec{F} = m * \vec{a}$$

Where  $\vec{a}$  is the acceleration of the debris,  $m$  its weight and  $\vec{F}$  represents a force that is impacting the motion of the debris. At first we will consider that the debris is no longer under the influence of the engine thrust. Then we can consider four forces that act on the debris:

- The gravity
- The lift: This force depends on the shape of the debris, it is perpendicular to the oncoming flow direction. Lift is the force that keeps an Aircraft in the air.
- The drag: This force is acting opposite to the relative motion of the debris.
- The wind  $C_L$

The Lift is defined by the equation:

$$F_L = \frac{1}{2} * \rho * v^2 * A * C_L$$

With:

- $C_L$ : Coefficient of lift, it depends on the angle of the motion, the debris' Reynold number and its Mach number.
- $A$ : Exposed area surface of the debris.
- $\rho$ : Density of the air.
- $v$ : Velocity of the fragment.

The drag is defined by the equation:

$$F_D = \frac{1}{2} * C_D * A * \rho * v^2$$

With:

- $C_D$ : Coefficient of drag, it depends on the shape and the weight of the fragment and its ballistic coefficient.
- $A$ : Exposed area surface of the debris.
- $\rho$ : Density of the air.
- $v$ : Velocity of the fragment.

The Ballistic Coefficient of a solid is its ability to overcome air resistance in flight. It means that a solid with an initial speed will travel farther with a high ballistic coefficient. It also means that the influence of the wind will be higher on a solid with a low ballistic coefficient.

$$\text{Ballistic Coefficient} = \frac{M}{C_D * A}$$

With:

- $C_D$ : Coefficient of drag, it depends on the shape and the weight of the fragment and its ballistic coefficient.
- $A$ : Exposed area surface of the debris.
- $M$ : weight

The reasons of the in-flight break up can have an impact in the trajectory, indeed, an explosion will give to the fragments another initial speed and angle of trajectory. In the case of a mid-air collision, we will consider that the fragment has the same initial speed and angle of trajectory than the aircraft at the time of the break-up.

## 2 Similar Software

Several researches were performed in order to predict debris trajectory after an in-flight break-up. Most of them are developed by companies that don't want to show their code sources, in that case, it is hard to re-use it.

### a. Trajectory Analysis Program (TAP)

The professor Hugh Oldham develops this program, the purpose is to calculate the distance that the fragment travel in order to calculate the safe distance for the public in an Airshow. The sources of the program are available on the Internet [2].

The program takes:

- Initial altitude of disintegration
- Initial density altitude
- Groundlevel
- Speed and heading of the wind
- True airspeed at disintegration
- Rate of climb at disintegration
- Weight of fragment
- Drag coefficient of the fragment
- Exposed area of the fragment

The outputs of the program are:

- Horizontal distance from the disintegration point
- Velocity of the fragment
- Time to fall
- Flight-path angle

The program is designed to be used for disintegration during an Airshow, it means that the altitude will be no more than 5000 fts. In that case, the wind model used cannot be applied for disintegration at a high altitude. Hugh Oldham also gives some drag coefficient for standard fragment that could be used. Nevertheless, this program doesn't take into consideration the lift of the fragment.

### **b. Debris Risk Assessment Model (DEBRA)**

This model is developed by the APT Research Inc., the purpose is to calculate the debris trajectories from a Reusable Launch Vehicle (RLV) failure. It proposes different failures (explosion, engine shutdown) [3]. The sources of this software are not available for the public.

### **c. Common Real-Time Debris Footprint (CRTF)**

This model is developed by the two US spacelift ranges in order to assist the Mission Flight Control Officer in its decision to abort the launch. It is a probabilistically based dispersion model for debris from in-flight break-up [4]. This model uses six modules to quantify the different uncertainty:

- Location of the flight at the time of the break-up
- The type of debris generated
- The wind condition
- The lift effect
- The initial vector of the fragment
- The tumble turn direction

It has been proven to be capable of generating reliable result during the investigation on the Colombia Shuttle Accident. To determine the type of the debris, the software generates a ballistic coefficient from a normal distribution (Sala). The lift effects are taking into account by simulates the

impact of a fragment with no lift and the impact of a fragment with a ratio drag/lift determined by the user.

#### **d. Range Safety Assessment Tool (RSAT)**

This software is developed by the University of Stanford [5] in order to calculate the debris footprint from a Space Shuttle in-flight break-up. The simulation takes into account the drag and lift of the fragment, but also the wind conditions. In order to generate the debris, the author used a catalogue of debris from an old space shuttle written by the NASA, and then used a Monte Carlo sampling [6].

#### **e. Cranfield Model**

This software is developed by the University of Cranfield in order to calculate the trajectory of debris from an Aircraft in-flight break-up [7]. It had been developed during the investigation of the Lockerbie Accident in order to analyse the break-up. This model was after used in order to find debris in the investigation about the accident of Ustica [8]. This model doesn't take into consideration the lift effect on the debris.

#### **f. Other**

Trajectory analysis was used in some investigations in order to understand the accident, for example in the investigation about the TWA 800 and China Airline CI611 [9][10]. In these analysis, investigators gave sometime the ballistic coefficient of the debris found, it could be used in our case.

### **3 Application**

Because the TAP program is the only open source program available, it was decided to use it and to implements some improvement inspired by the other models. After a phone interview with the professor Peter SchmollGruber an Aircraft Design researcher at ONERA (Office National d'Etude et de Recherche Aérospatiale), the French aerospace lab. His main idea was to add Lift and Drag to a fragment and watch its reaction in order to define what ratio drag/lift it could be good to apply. Yves de Lassat de Pressigny from the DGA (Direction Générale de l'Armement), the French Armaments Authority, think that it was possible to divide the debris in three categories:

- Stable Fragments, like for example the body of an aircraft missing on wings and the tail, the trajectory would be a spin.
- Flat fragment like metal sheet, the trajectory would be helical
- Unstable debris, like the engines, the trajectory would be a ballistic fall.

In this project we will only apply a ballistic trajectory to the debris, but it is possible to apply other forces by including them into the simulator.

### a. Debris Generation

The first step of the trajectory calculation is to generate a population of debris that comes from the collision. In order to apply to them a ballistic trajectory, we only need their Ballistic coefficient.

Ballistic Coefficient of debris are available in the catalogue of debris form a space shuttle designed by the NASA [6].

	NASA Space Shuttle Orbiter	Airbus A321
Length (m)	37.24	41.51
Wingspan (m)	23.79	34.10
Height (m)	17.25	12.11
Maximal Take-Off Weight (m)	109	93

Table 12 - Comparison between the NASA space shuttle and the Airbus A321

The table show that the NASA Space Shuttle Orbiter can be compared to an Airbus A321 (Except for the wingspan, because of course they don't have the same flight domain). It imply that we can take debris of the Orbiter can be compared to debris from an A321.

In order to generate a wide range of different piece of debris, the mean and standard deviation of the ballistic coefficient of the pieces of debris from the catalogue was calculated, and then it was considered that the ballistic coefficient follow a normal distribution.

Finally, the information about the normal distribution is saved in a file an each time, an aircraft is created, and pieces of debris are generated following this normal distribution.

### b. Trajectory Calculation

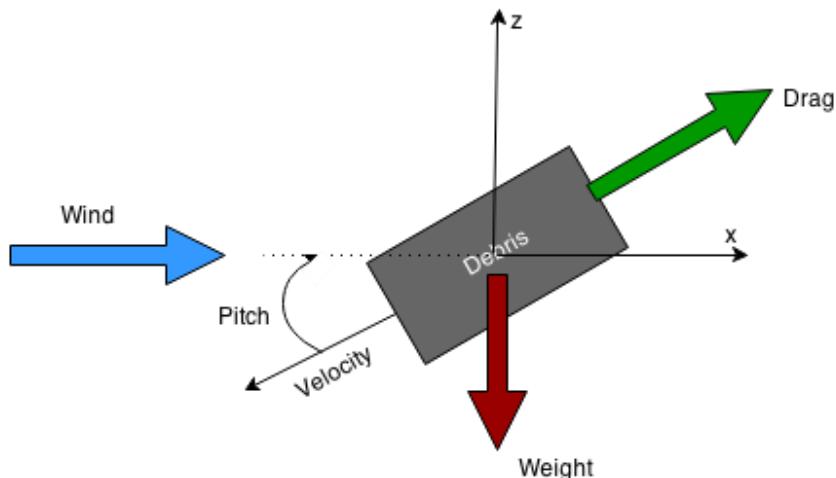


Figure 5 - Application of the second law of Newton on a piece of debris

When the user start the simulation, the ballistic trajectory of each piece of debris is calculated. The Figure 1 shows how the second law of Newton was applied to a piece of Debris. We have the initial condition:

- $z$  = Altitude of collision
- $x = 0$  and  $y = 0$
- $Vx$  = True Air Speed of the Aircraft
- $Vy$  = Random Number between -10 and 10 m/s to simulates the explosion
- $Vz$  = Vertical speed of the aircraft

With these initial conditions, it is possible to use the Euler Method to calculate the different point of the trajectory in 3 Dimensions (position of the debris at each time interval). At each point, it is possible to calculate the ground speed thanks to the velocity and the wind information.

To calculate the wind heading and speed at an altitude  $z$ , which is between two Wind information given by the user  $z_1$  and  $z_2$ , the linear function between these 2 altitudes is calculated.

The trajectory is stopped when the altitude of the debris is under 0. For each time interval, the position was saved in a list in order to be displayed in the 3D visualization.

### c. The density on the ground

A list of all the positions of the debris on the ground is recovered, we can consider that the debris followed multivariate normal distribution, so it is easy to calculate the density function.

In order to have a more accurate result about the density it is possible to use non-parametric method to calculate it:

- Kernel Density Estimation (KDE)
- Local Polynomial Estimation

But these methods won't be implemented yet in this project.

## 4 Reference

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# Annex E - Task analysis

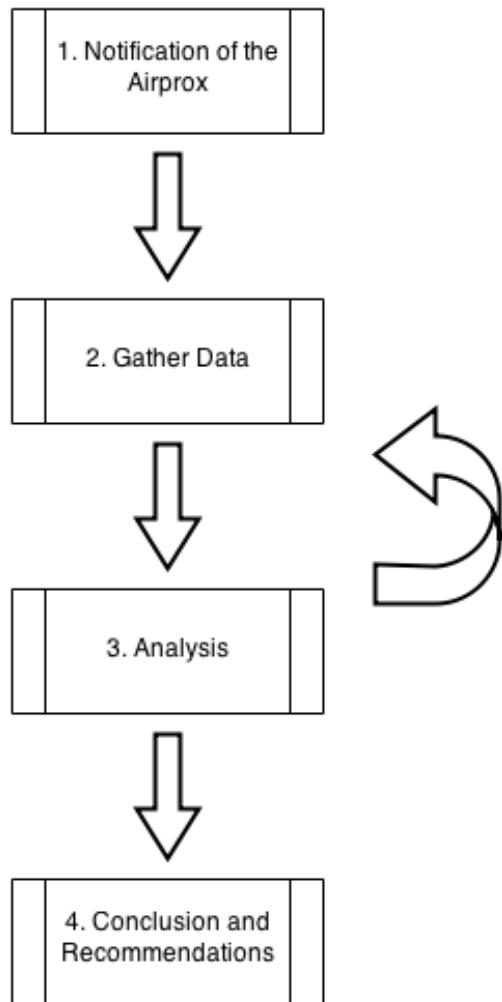
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In order to develop a software application that meets the needs of a user, it is important to understand the tasks performed by this user. In order to do that several interviews were performed with Airprox Investigators in France and UK but also with Air Accident Investigators from the BEA. Then visits of the Investigation department of the NATS and CAA were done.

After gathering all these information about the tasks performed by the users, it was decided to make a model of these tasks thanks to the software application Hamster. And finally scenarios of use were done to show how the tool can be used to perform these tasks. The scenarios were then used in the user's evaluations.

## 1. Tasks Identification

In this project, the main users are Airprox Investigators, but the software application can also be used by Air Accident Investigators, Safety Analyst or Airport Safety Manager. The investigation about Airprox is done by the UK Airprox Board in UK and the Civil Aviation Authority (DGAC) in France. But in this analysis only the task performed by Airprox Investigators will be described. The identification was done thanks to interviews and meeting with Airprox Inspectors from the UK Airprox Board, the NATS and the DGAC, but also thanks to a task analysis performed by researcher from the DGAC [1].



**Figure 6 - Airprox Investigation Process**

The whole process can be decomposed in 4 main steps (Figure 1) from the notification to the conclusion and recommendations.

### a. Notification of the Airprox

The first step of the investigation is the notification of the Airprox, this one can be made by one the pilots involved in the Airprox or by the Air Traffic Controller. This notification is done to the Military or the Civil Authority, which informs the UKAB in UK, and at the DGAC in France. The notification can be first done by radio to the ATC, but the pilot has to confirm it by sending a form. In France, the notification can also be done by the ATC system itself, indeed, if it detects a loss of separation using for example the alerts sent by a safety net.

### b. Gather Data

Then, the inspector has to gather data, he/she has to understand the event and the context. It means, ask for the radar and radio data from ANSP, collect the NOTAM and the Weather data, and

finally interview the pilots and the Air Traffic Controller. In France, the amount of data gathered depends on the severity of the Airprox.

### c. Analysis

When they have all the data, the inspector can reconstruct the situation, and analyse the cause and the reaction of all the people involved. In some team (At the NATS for example), one way to do it is to show to the pilot the radar data and ask him/her to apply a “think aloud” protocol. During the reconstruction, the inspector tries to synchronize all the data. In this phase, he can see that some data are missing and gather other data. At the UKAB, an analysis of the cause is done during a meeting with aviation specialists, each stakeholder is represented. The same kind of meeting can be done in France for some severe incidents.

### d. Conclusion and Recommendations

To conclude, the inspector and in some situation, the board, decide about the causes of the airprox, they also assess the risk of it. To assess the level of Risk, the UKAB use the ICAO categories which goes from A to E (A: Risk of Collision and E: Safety Standards). The problem with this classification is that you can't compare the risk of two Airprox. Indeed, an Airprox with the risk A in a controlled airspace can be less dangerous than an Airprox with the risk B in a non-controlled airspace, this is because the ICAO classification doesn't take into account the safety barriers (TCAS, ATC ...). For this reason, the UKAB is working on a new risk assessment system based on the Event Risk Classification (ERC) system defined by the Airline Risk Management Solutions (ARMS) Working Group. The ERC system considers the possible outcomes of an event, considers the severity of the most credible one and then considers the safety barriers which are available.

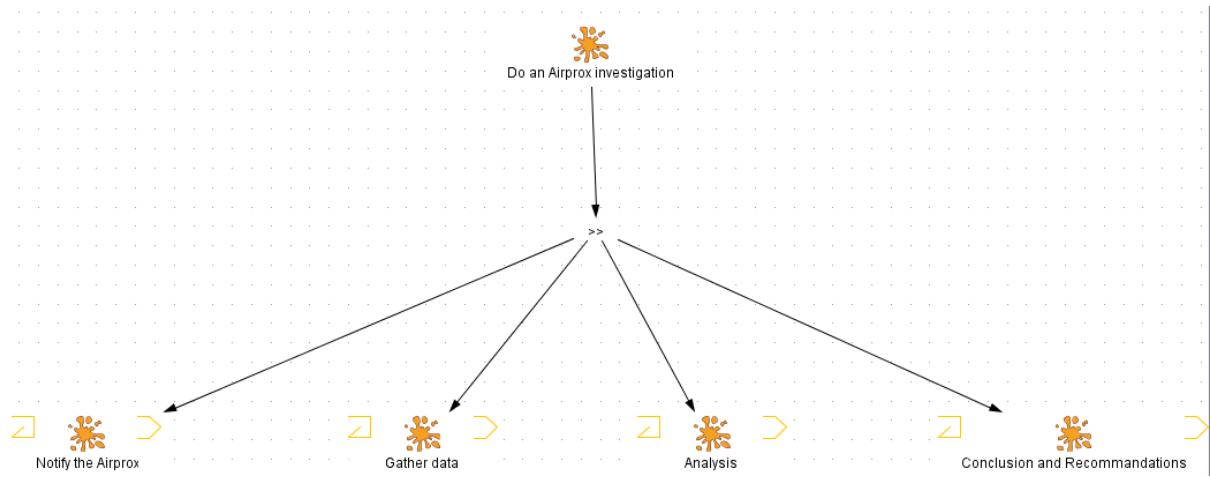
Finally, they make recommendations that are then proposed to the ANSP and the Civil Aviation Authority. If the recommendations are refused, it has to be justified.

The duration of an Airprox is around four months, and in UK around 142 Airprox were investigated in 2013.

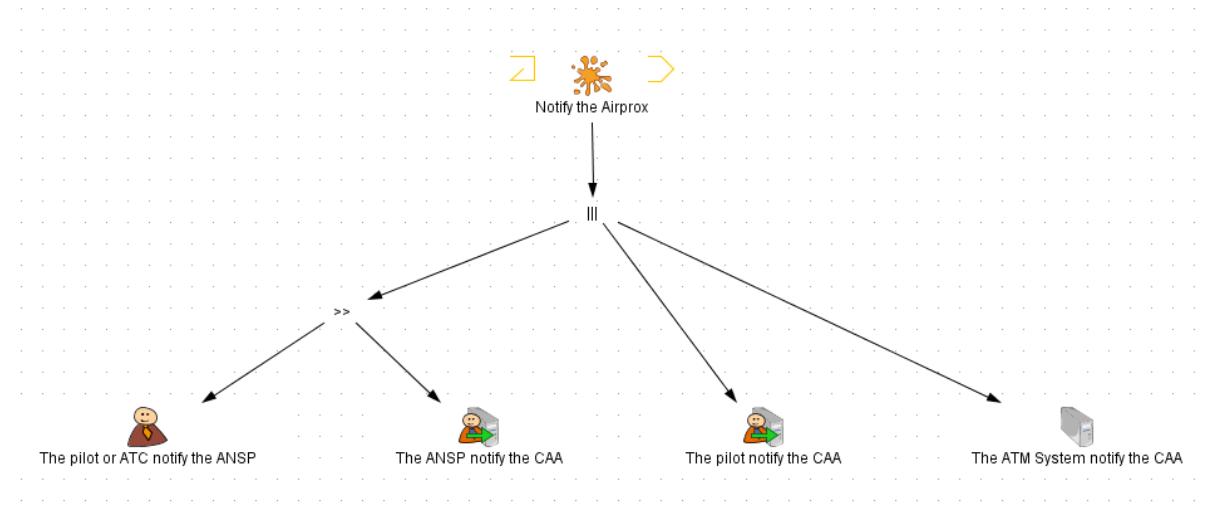
## 2. Modelling of the tasks

After gathering all the information, it is important to transcript all of it in a strict notation that can be used after to developed prototypes and to make scenarios for the user evaluations but also to developed the final software application. To have a modelling of the task is important to make sure that the final product meets the requirement of the user.

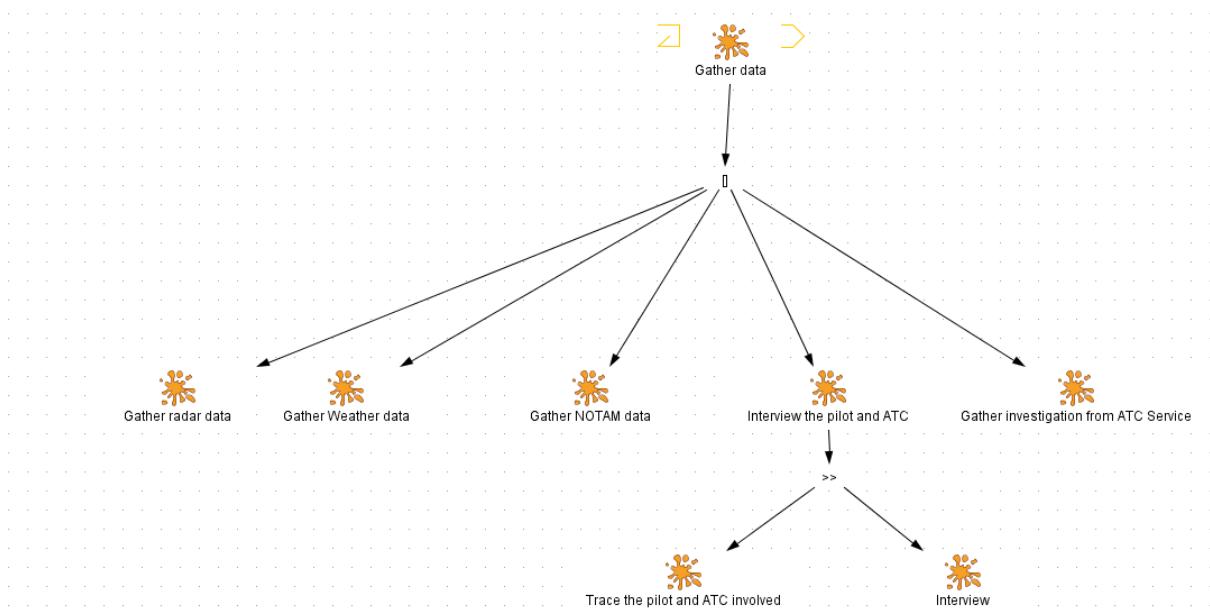
It was decided to use hamsters as language for task modelling, it has been developed by the French laboratory of computing science in Toulouse.



**Figure 7 - The main task**



**Figure 8 - The Notification of the Airprox**



**Figure 9 – The gathering of the data**

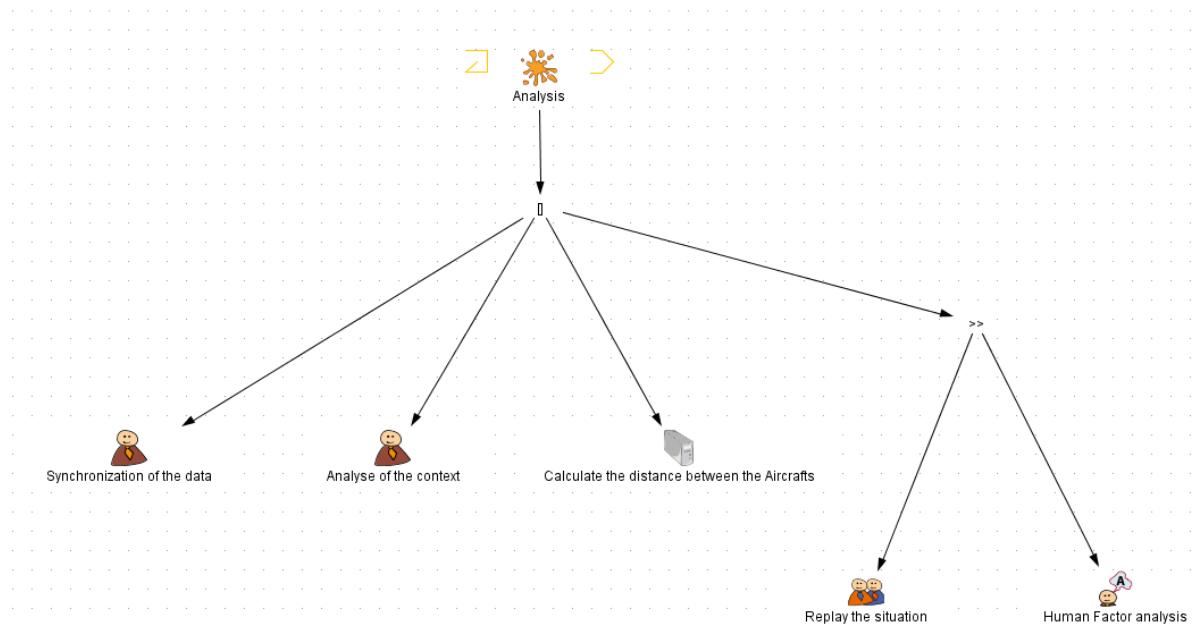
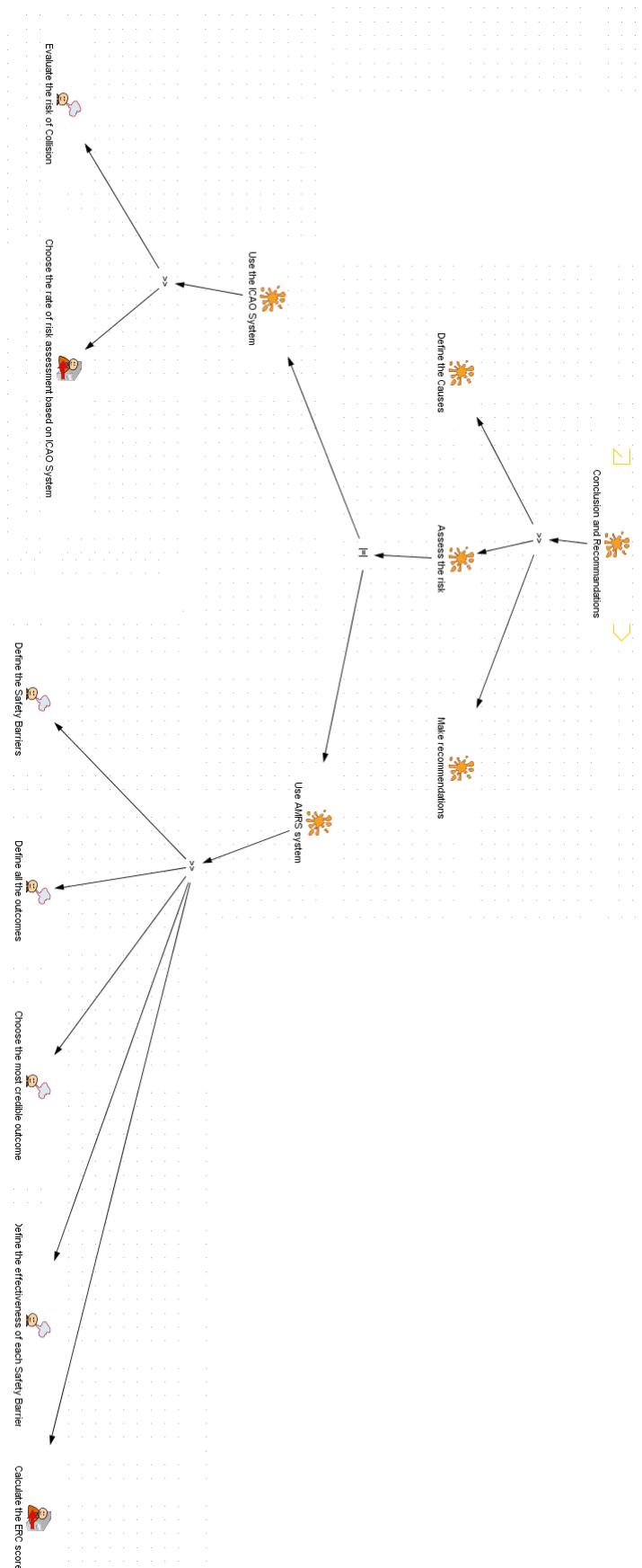


Figure 10 - The Analysis



**Figure 11 - Conclusion and Recommendations**

### **3. Scenario**

Thanks to the modelling of the task we can define scenarios. These scenarios are important in order to check if the final system meets the requirement of the users.

#### **Scenario 1:**

On the 3<sup>rd</sup> of July 2012, a commercial pilot of a Saab 2000 notified an Airprox to the NATS. The Airprox was between his aircraft and an A319 in the Scottish TCA near Glasgow. The NATS reported then to the CAA that gave the investigation to the UKAB. The inspector gathered the information about the weather, the NOTAM and the radar. He also interviewed the pilots and ATC. He analysed the context of the situation and performed a human factor analysis about the reaction of the pilots and controllers. Finally he presented his conclusion to the UK Airprox Board meeting in order to assess the risk and make recommendations.

#### **Scenario 2:**

On the 3<sup>rd</sup> of July 2012, the safety net of the radar of the South-East of France control centre notified the DGAC an Airprox. The inspector gathered the information about the weather, the NOTAM and the radar. He also interviewed the pilots and ATC. He analysed the context of the situation and performed a human factor analysis about the reaction of the pilots and controllers. Finally the Airprox was not severe enough to call a safety meeting, the inspector just made recommendations.

# Annex F – Requirements and Needs Analysis

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## Introduction and system presentation

SODART is a tool developed by the laboratory of computing of the University of Glasgow, its purpose is to simulate a mid-air collision and calculate its impact on the ground population.

The actual version of the tool was developed by Craig Martin and Michael Bell, in this report we will begin with an analysis of this first tool and identify potential users. Then we will talk about the requirements and needs of the future system.

This kind of tool can be used by Airprox Inspector and Aviation Accident inspector to investigate the worst case scenario of an Airprox or a Mid-Air collision. It also can be used by Airport Safety Manager to assess the risk for the ground population around the airport and help to define the emergency planning of the airport. Finally it can be used by Aviation Safety Consultants, Researchers or Students.

## Analysis of present situation

In their report, the two developer of the actual version give the requirement of their system with the MoSCoW (Must, Should, Could, Would) method, this method is used to prioritize the requirements for a system. We will analyse these requirements and see if the system fits them.

**Table 13 - MoSCoW Analysis**

MoSCoW Rating	Requirement title
Must	Integrate population model Perform Simulation of Aircraft Crashes Simulate Mid-Air Collision
Should	Inclusion of COMAH Sites Update Graphical User Interface Integrate Different Population Models
Could	Represent Ambient Population
Would	Add Algorithm to Calculate flight Paths Add Functionality of a Crash Consequence Model Create Server for Population Data

### *Integrate population model*

The population model is implemented with the Gridded Population of the World data. This data is actually a grid with the density population in each square.

### *Perform Simulation of Aircraft Crashes*

The Aircraft crashes model is implemented using the TAP model (Trajectory Analysis Program), this program developed by Hugh E. Oldham doesn't take into consideration the lift of the

debris and the thrust of the engine. In the case of a collision, the algorithm doesn't consider two planes but the association of the both planes which collide.

#### *Simulate Mid-Air Collision*

It is possible to simulate a Mid-Air collision with the system.

#### *Inclusion of COMAH Sites*

The COMAH Sites are all the sensible sites in UK, it is possible to have a list with the position of all the COMAH sites. In each collision, the system gives the closest COMAH site.

#### *Update Graphical User interface*

With this need, the students wanted to implement to visualization of the population. In the actual version, the population visualization is only available for Glasgow using Luminocity images (the density of the population is represented by blue brightness).

#### *Integrate Different Population Models*

To integrate different population models would allow a more realistic representation of the population in an area. In the actual system, only one population model is implemented.

#### *Represent Ambient Population*

Some models can be used to describe the general behaviour of a population, less people in the residential areas during the day but more in the Industrial and business areas. It is not implemented in the system.

#### *Add Algorithm to Calculate Flight Paths*

This kind of algorithm could be used to calculate the "Safest" route between two points. In this case we talk about safety for the population and not for the plane. It could be used to calculate arrival and departure trajectory, indeed, the use of SBAS, and more particularly EGNOS, to approach surveillance will allow the aircraft to no longer follow the ILS paths, and have more free trajectories.

#### *Add Functionality of a Crash Consequence Model*

It could increase the accuracy of the risk for the ground population. It is not implemented yet on the actual version.

#### *Create Server for Population Data*

It was an idea to host the population data, but in the actual version, this solution is not implemented yet.

#### Requirements and Needs

#### Use Case

1 Execute a visual simulation

A visual simulation is a single situation with a 3D display (The map of the location, the air traffic and the debris falling).

### 1.1 Prepare the simulation

- The user chooses the scenario of the simulation he wants to play, it could be a scenario from an Airprox or accident report or a scenario he invented.
- The user chooses the location of the simulation.
- The user chooses the other parameters of the simulation (It could be the zoom level, the satellite images to display, etc...).
- The user can import flight data instead of using real time flight data.

### 1.2 Play the simulation

- The user have to start the simulation, he can pause it or quit it to go directly to the result.
- The user can zoom in/out on the situation with two keys (For now it is “w” to zoom in and “s” to zoom out).
- The user can navigate through the situation with the mouse.
- The user can see the debris falling.
- The user can observe the density of the population on the ground.
- The user can increase or decrease the speed of the simulation.

### 1.3 Finish the simulation

- At the end, the tool gives the risk for the population (For now it's a text form but we can think about a map visualization of the risk for the population).
- The tool gives the COMAH site near the collision site. (Only in UK, COMAH sites are the sensible sites like hospital, chemical factory, etc...).
- The user can save the result at the end, for now it is a text file, but we can think about saving a picture of the map at the end.

## 2 Execute a statistical simulation

A statistical simulation is a series of situation without 3D display, it only averages the risk for the ground population with the result of each situation.

### 2.1 Prepare the simulation

- The user chooses the number of simulation and the time between each of them.
- The user chooses the scenario of the simulation he wants to play, it could be a scenario from an Airprox or accident report or a scenario he invented.
- The user chooses the location of the simulation.
- The user chooses the other parameters of the simulation (It could be the zoom level, the satellite images to display, etc...).
- The user can import flight data instead of using real time flight data.

### 2.2 Finish the simulation

- At the end, the tool gives the risk for the population (For now it's a text form but we can think about a map visualization of the risk for the population).
- The tool gives the COMAH site near the collision site. (Only in UK, COMAH sites are the sensible sites like hospital, chemical factory, etc....).
- The user can save the result at the end, for now it is a text file, but we can think about saving a picture of the map at the end.

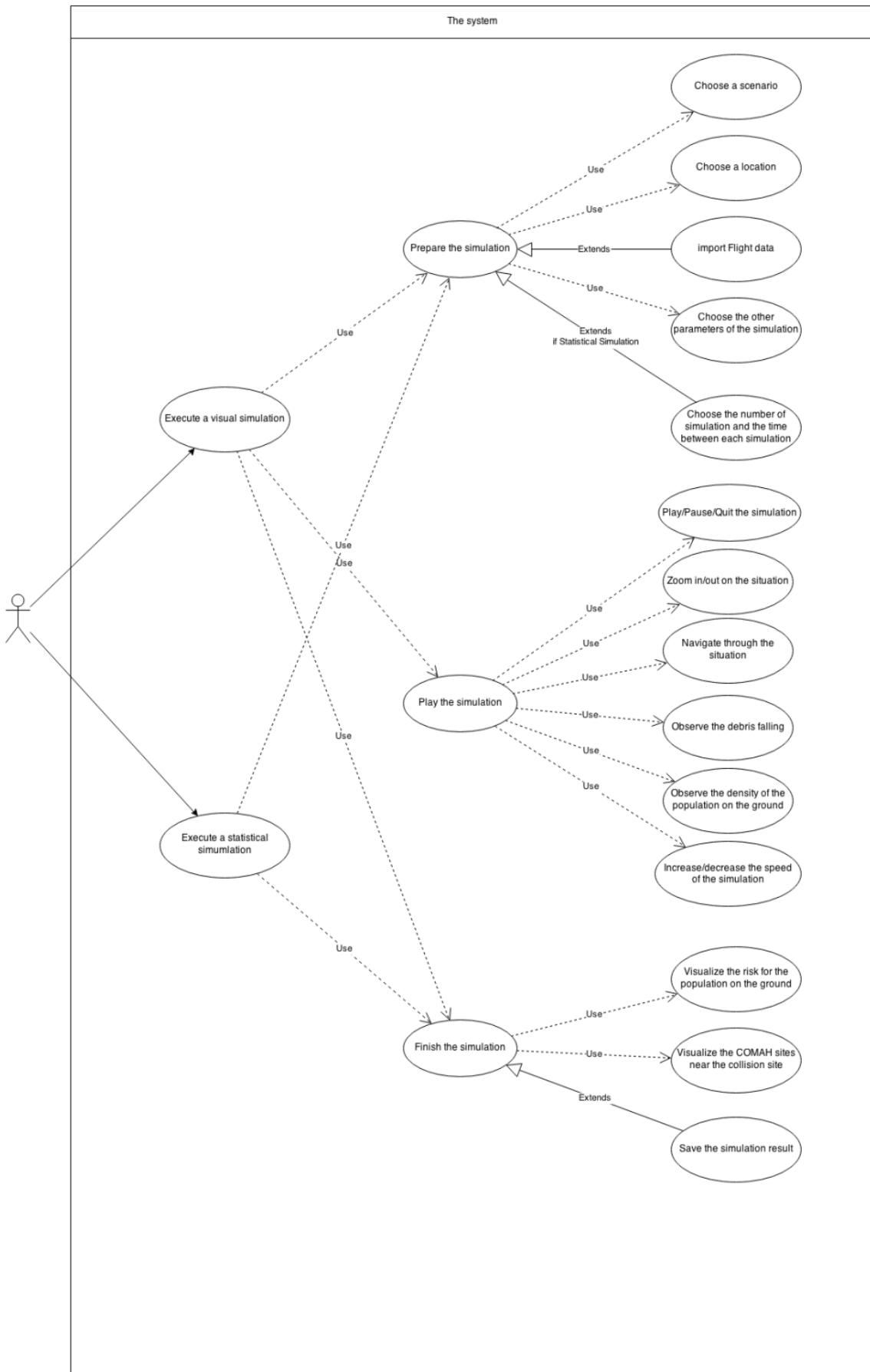


Figure 12 - Use Cases Diagram

## User Needs

Table 14 - Needs and Requirements

Id	Need	Priority Level
<b>N1</b>	Needs.	
<b>N1.1</b>	Needs about the population model.	
<b>N1.1.1</b>	The system should integrate a population model.	10
<b>N1.1.2</b>	The system should integrate different population models.	3
<b>N1.1.3</b>	The system should represent the population in the simulation.	8
<b>N1.1.4</b>	The system should have a server for population data.	1
<b>N1.1.5</b>	The system should include the COMAH sites (And equivalent outside UK).	7
<b>N1.1.6</b>	The system should represent the ambient population in the simulation.	3
<b>N1.2</b>	Needs about the crash model.	
<b>N1.2.1</b>	The system should perform a simulation of aircraft crashes.	10
<b>N1.2.2</b>	The system should simulate Mid-air collision.	10
<b>N1.2.3</b>	The system should integrate a Crash Consequence model.	1
<b>N1.2.4</b>	The system should show the density of debris falling at one place.	9
<b>N1.3</b>	Needs about the Scenario.	
<b>N1.3.1</b>	The system shall allow the user to define the flight path of two aircraft involved in the collision.	8
<b>N1.3.2</b>	The system shall allow the user to define the type of each aircraft involved in the collision.	7
<b>N1.3.3</b>	The system shall allow the user to define the weather of the scenario or import live data from the internet.	7
<b>N1.3.4</b>	The system shall allow the user to import his own ADS-B flight data or import live data from the internet.	7
<b>N1.3.5</b>	The system should show the population at risk at the end of the simulation	10
<b>N1.4</b>	Needs about the Statistical Simulation.	
<b>N1.4.1</b>	The system should allow the user to perform a series of simulation and see the average risk for the population.	5
<b>N1.5</b>	Other needs.	
<b>N1.5.1</b>	The user should be able to change the API Key used for the ADS-b, Weather Data and Map websites.	7
<b>N1.5.2</b>	The user should be able to change the colour used in the 3D simulation.	7
<b>N1.5.3</b>	The system should be able to calculate the safest flight path between two points.	1
<b>N1.5.4</b>	The system should allow the user to save the	8

result of the simulation.

<b>N2</b>	Interfaces.	
<b>N2.1</b>	The system should allow the user to Pause, accelerate and rewind the simulation.	7
<b>N2.2</b>	The system should allow the user to take screenshot of the simulation.	8
<b>N2.3</b>	The interface of the system should give a feedback for each action of the user.	9
<b>N2.4</b>	The interface should use vocabulary and concept familiar to the user.	9
<b>N3</b>	Use Cases.	
<b>N3.1</b>	The system must allow reproduce the use cases.	10
<b>N4</b>	Constraints.	
<b>N4.1</b>	The loading of the simulation should take less than 10 seconds.	8
<b>N4.2</b>	The representation of the density of debris and the population as physically measured should be directly proportional to the quantities represented (Lie Factor between 0.95 and 1.05).	8
<b>N4.3</b>	The data used has to be available easily for an Airprox Inspector	8

# Annex G – Prototypes

## 1. Paper Prototypes (1st Iteration)

The Table 15 present the prototypes of the first iteration.

Table 15 - Prototype presentation for the 1st iteration

Paper Prototype – 1 <sup>st</sup> Iteration	
Technology used	Paper.
Number of prototypes	29 pages.
Accuracy Level	Low level, Informal.
Representation (Online/Offline)	Offline (The prototype is not a software application).
Interactivity	The user can interact with the prototype thanks to a Wizard of Oz process.
Lifetime	Throwaway (The prototype won't be used in another phase).
Role in the design phase	Expanding the design space by proposing several solutions.
Horizontal/diagonal/vertical	Horizontal (Only the interface is prototyped).

### a. Menu

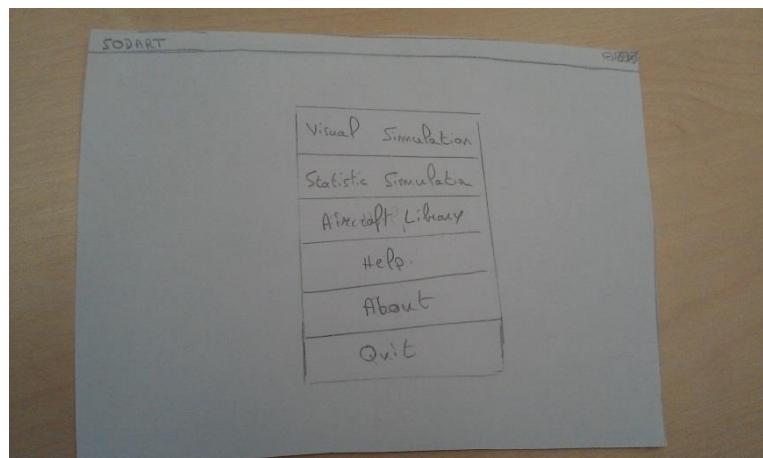
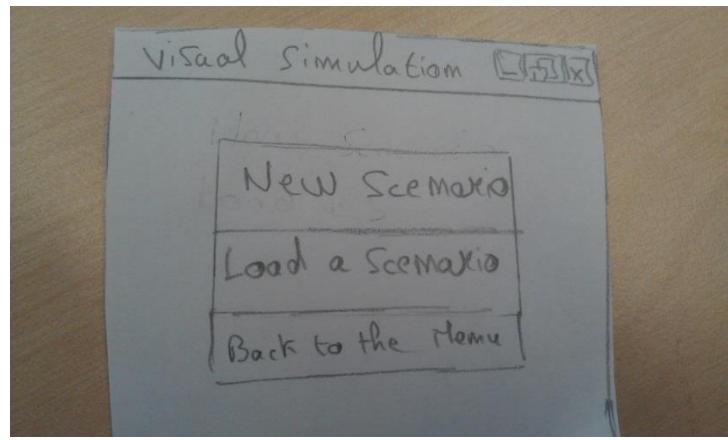
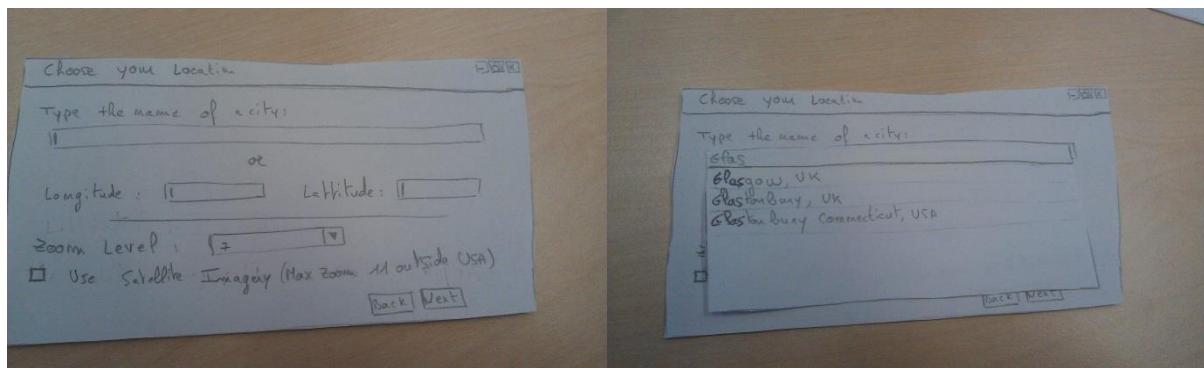


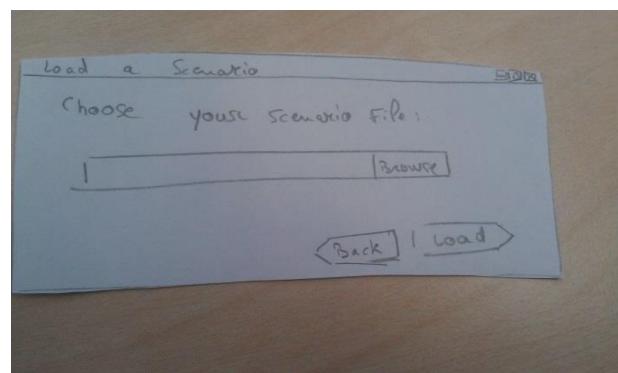
Figure 13 - Main Menu



**Figure 14 - Visual Simulation Menu**



**Figure 15 - New Simulation Menu**



**Figure 16 - Load a Scenario**

TOUR Scenario

Collision place

Longitude : [ ]	Latitude : [ ]	Altitude : [ ]	<input type="checkbox"/> <input checked="" type="checkbox"/> <input type="checkbox"/>
-----------------	----------------	----------------	---

Aircraft 1

Type : [B747] <input checked="" type="checkbox"/>
Heading (°) : [ ]
Air Speed (kt) : [ ]
Stage of flight : [Cruise] <input checked="" type="checkbox"/>
Vertical Speed (ft/s) : [ ]

Aircraft 2

Type : [B747] <input checked="" type="checkbox"/>
Heading : [ ]
Air Speed (kt) : [ ]
Stage of flight : [Cruise] <input checked="" type="checkbox"/>
Vertical Speed (ft/s) : [ ]

Weather

Wind:	Altitude (ft)	Heading (°)	Speed (kt/s)
	00ft		

Take Weather forecast from this date : [15/08/14]

ADS-B Data

- Take live data
- Import data from this file :

[BROWSE]

Figure 17 - The first solution: A classic form

This first solution is a classic form with the basic information about the Airprox, the position of the Airprox, the information about the Aircrafts (type, heading, Speed, stage of flight and the vertical speed). The user can decide if he uses live data or a file with ADS-B Data, and finally he can use Weather forecast from the internet or give the Wind information himself. About the Weather it is a table, indeed, if the user can give information about the wind at various altitude, the trajectory of the debris would be more accurate.

Save Scenario

Collision Place

Longitude: [ ] Latitude: [ ] Altitude: [ ]

Aircraft 1

Type: B747 [▼]

Heading: 10 [ ]

Aircraft 2

Weather

Wind: Heading 0, Speed 3000

Add a Wind Information

Take weather forecast from this date: 15/06/18

ADS-B Data

- Take live data
- Import data from this pilot:

[Browse]

[Save the Scenario] [Back] [Start]

Figure 18 - The second solution

In this solution, the form has no more textfield, the user has to manipulate widget to determine the aircrafts' parameters.

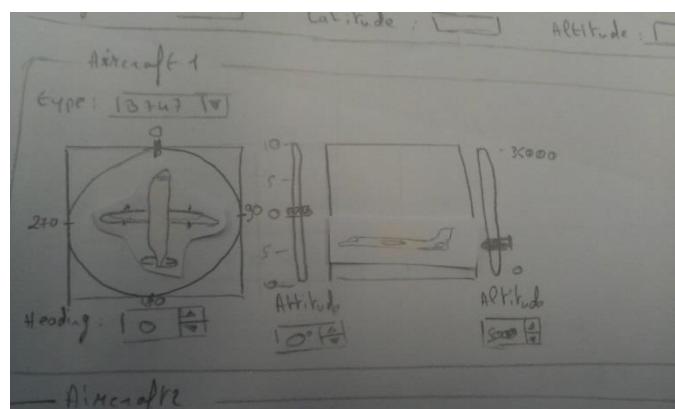


Figure 19 - Definition of the aircraft's parameters

The user has just to move cursors to define the heading, the altitude and the vertical speed of the aircraft. A representation of the aircraft is presented to allow the user to understand the consequences of each parameter.

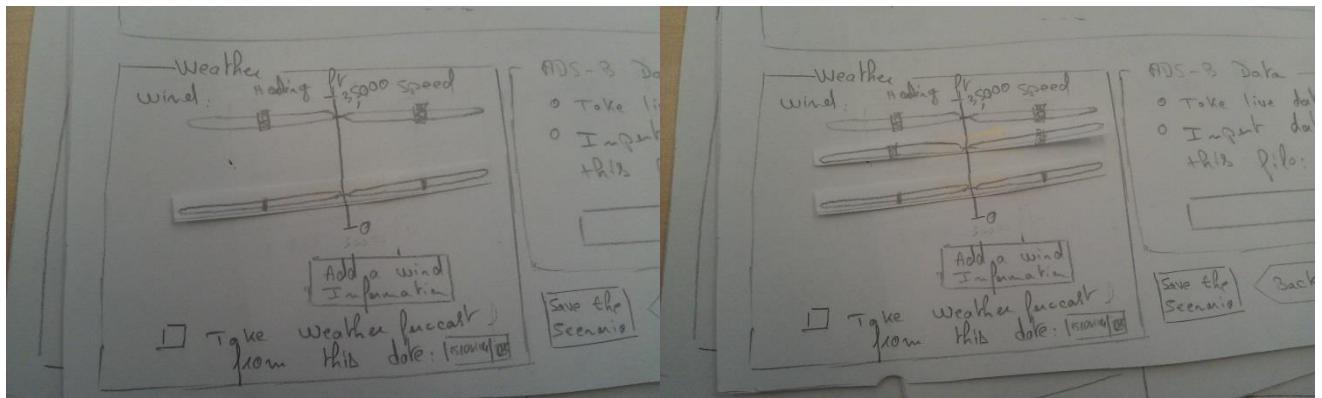


Figure 20 - Weather parameters

The user can manipulate the wind information in function of the altitude (vertical axis), and for each wind information he can define the heading and the speed. By clicking on the button “Add wind information”, the user adds a cursor which can be moved also on the altitude axe.

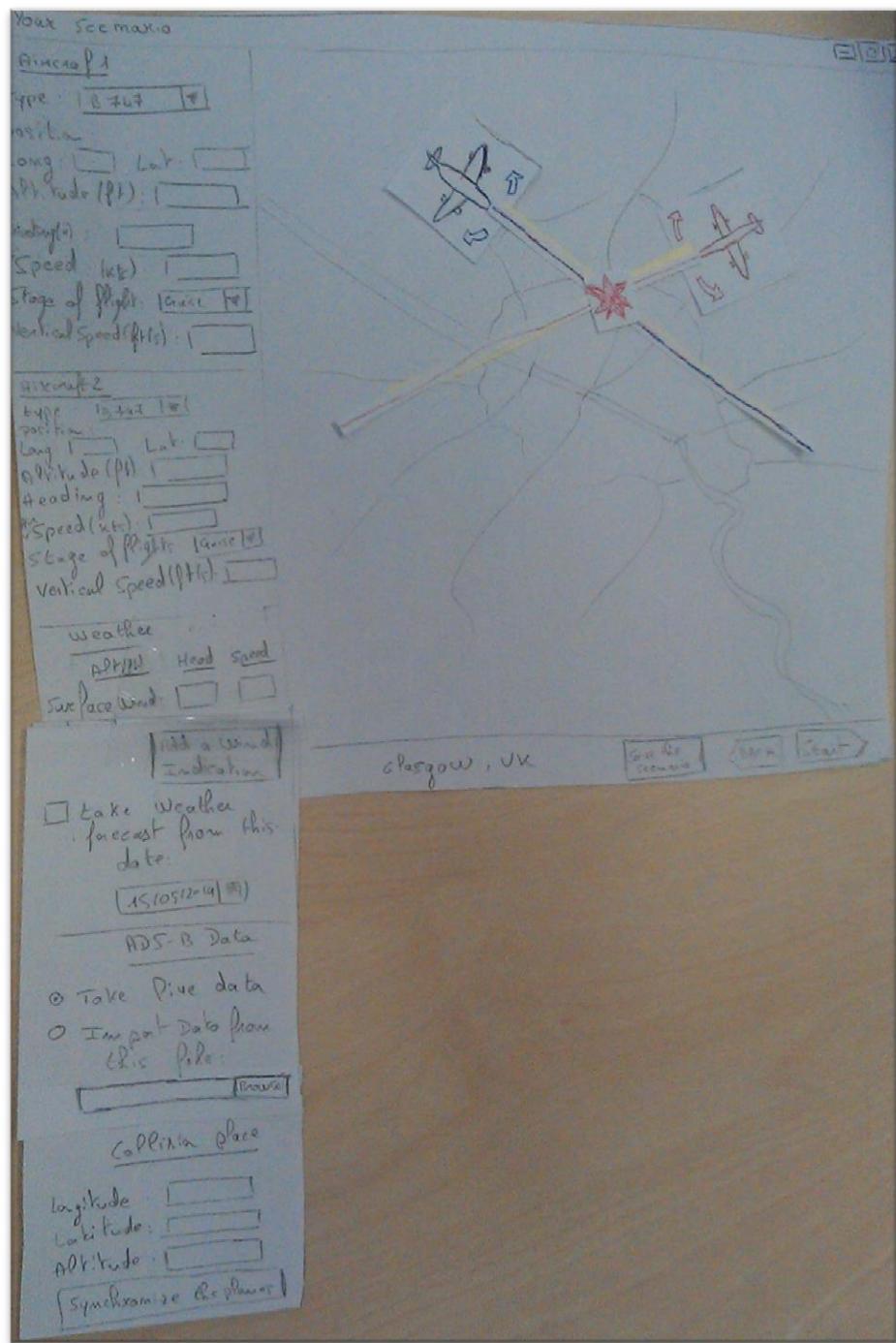


Figure 21 - Third solution

This last solution proposed a form and direct manipulation, indeed, the user has a map of the area of the Airprox, and he can move both aircraft, but also the collision position.

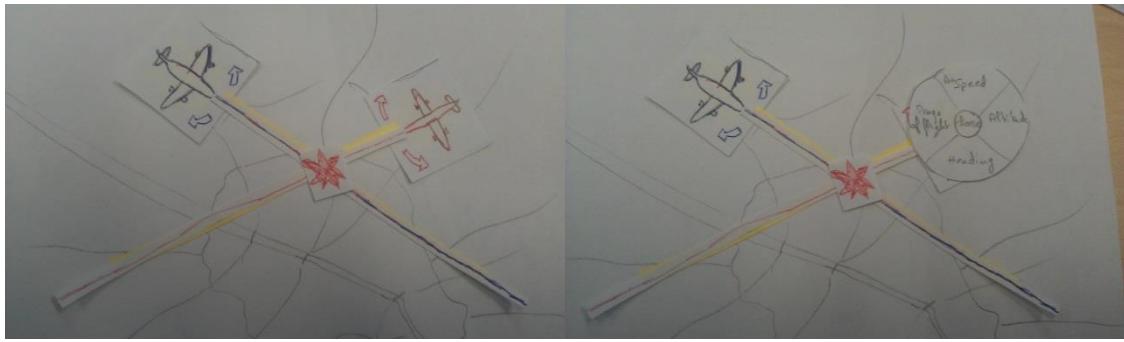


Figure 22 - The aircraft manipulation

The user can define the heading of the aircraft thanks to the two arrows at each side of it. With the right click, the user accesses to a pie menu in order to change the aircraft parameters.

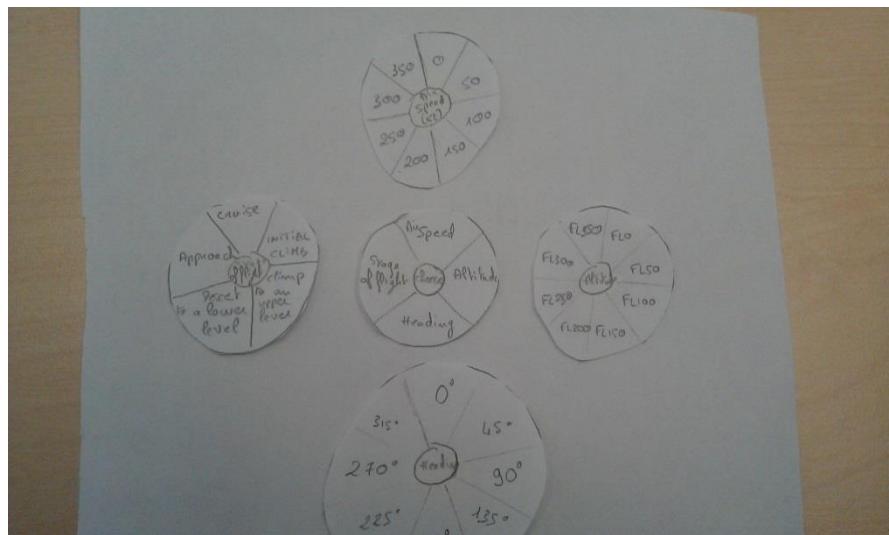


Figure 23 - Pie menu

Pie menu are considered faster and more reliable to select than linear menu, it is proved thanks to the Fitts's law (The time to move to a target area is a function of the distance to target and the size of the target) [36]. But pie menus are not really common in traditional software, and a solution with linear menu was also proposed.

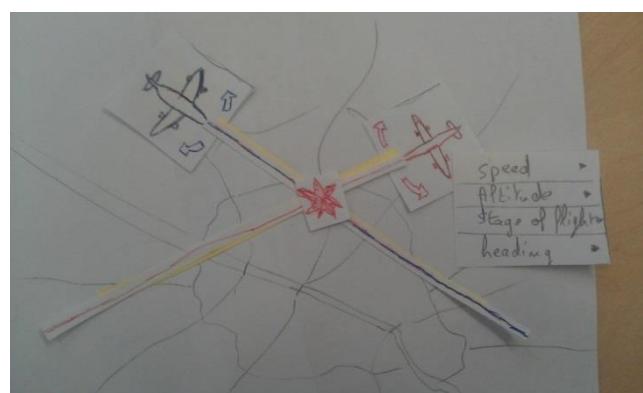


Figure 24 - Use of linear menu

When the user finished preparing his scenario, he can begin the simulation. It was decided to present only one solution and see the opinions of the user. The 3D simulation wasn't prototyped, because it would be hard to do it with only paper. On the second iteration different propositions for the representation of the population and the risk were presented.

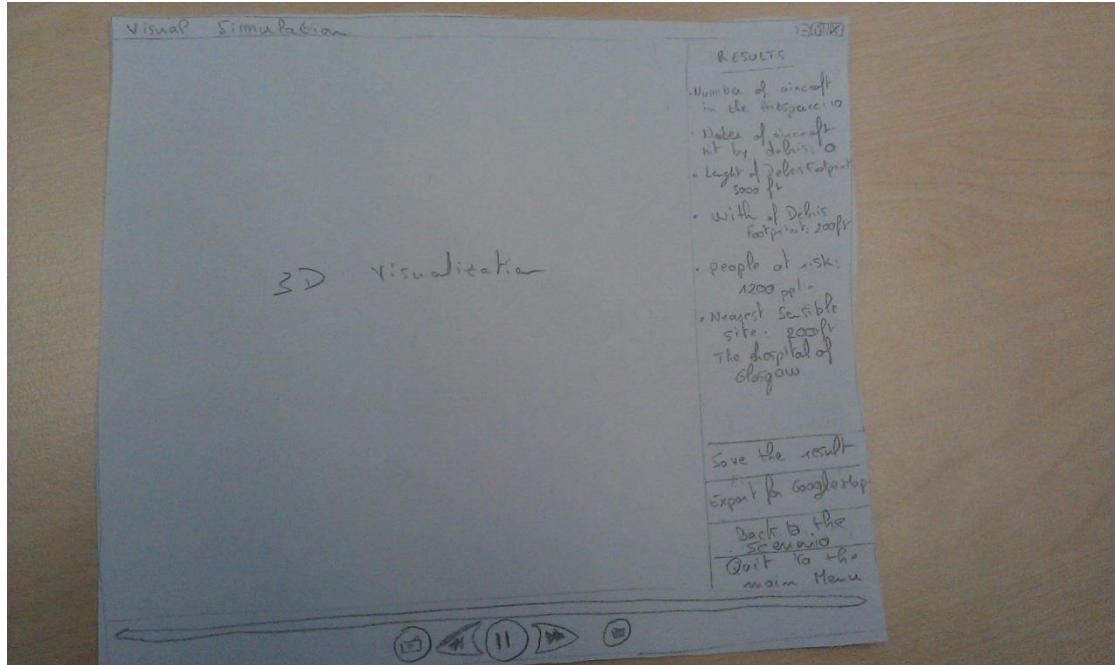


Figure 25 - The Visual Simulation

The user can see the 3D simulation and the result all the time, he can stop the simulation, go backward and go forward, he also can take screenshots of the simulation in order to put them in a report or show them in a meeting. The user has the possibility to save the result in a text file and to export the result for Google map.

## b. Aircraft Library

Name	Length	Wingspan	Max. Take-off weight	Climbing speed	# of engines
A320	37.54	34.10	78	0.78	2
A380	85.82	60.3	242	0.82	4
[Empty]	[Empty]	[Empty]	[Empty]	[Empty]	[Empty]

Delete the Aircraft selected

BACK

Figure 26 - Alternative 1

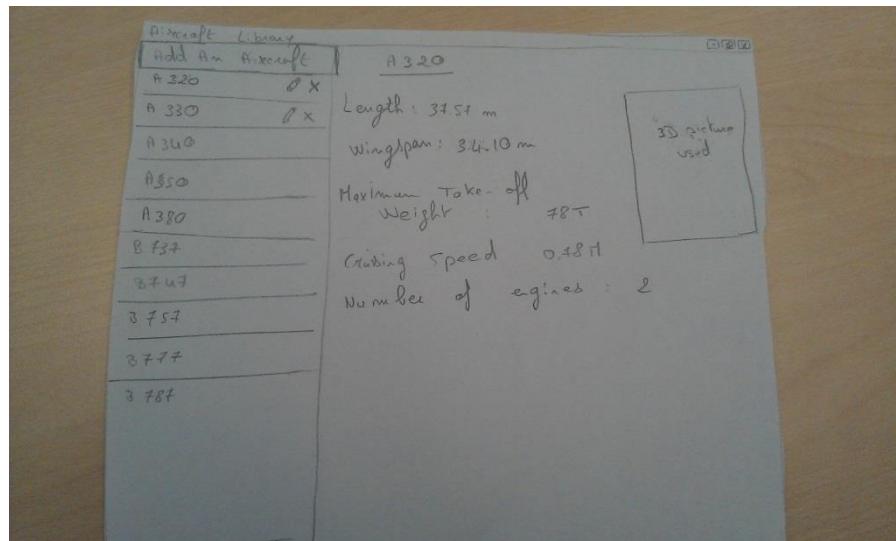


Figure 27 - Alternative 2

## 2. JavaScript Prototype (2<sup>nd</sup> Iteration)

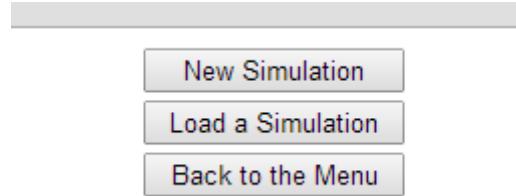
The Table 16 present the prototypes of the second iteration.

Table 16 - Prototype presentation for the 2nd iteration

JavaScript Prototype – 2 <sup>nd</sup> Iteration	
Technology used	CSS/HTML, JavaScript/JQuery, Google Earth.
Number of prototypes	9 pages
Accuracy Level	Medium level.
Representation (Online/Offline)	Online (The prototype is a software application).
Interactivity	The user can interact with the prototype.
Lifetime	Iterative (The prototype will be used in the next phase).
Role in the design phase	Expanding the design space for the 3D Visualization/Validating the solutions for the rest.
Horizontal/diagonal/vertical	Diagonal (Some data are implemented)/Based on a scenario.



Figure 28 – Main Menu



**Figure 29 - Visual Simulation Menu**

**Aircraft 1**  
Type : B747 • Stage of Flight : Cruise      Take Standard Value

Altitude (deg) : 30559      Speed (kts) : 321

Heading (deg) : 61.2

**Aircraft 2**  
Type : B747 • Stage of Flight : Cruise      Take Standard Value

Altitude (ft) : 2628      Speed (kts) : 10

Heading (deg) : 279

**Weather**

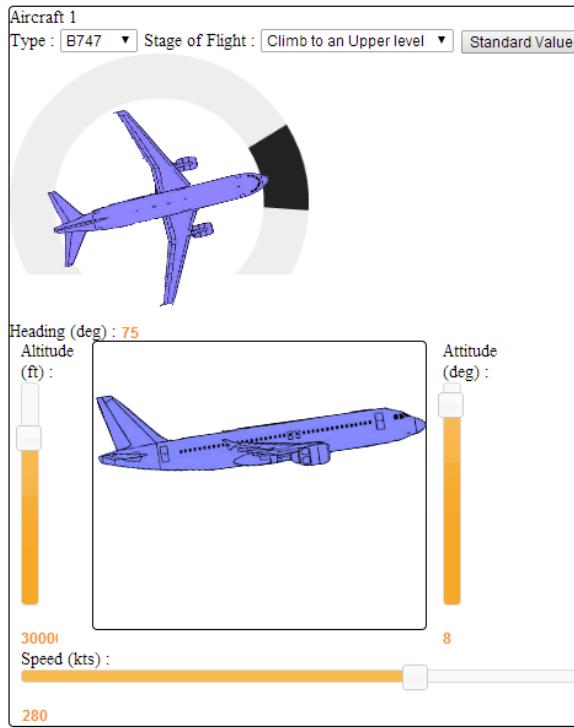
- Take live data
- Import data from a file :
- Choose File / No file chosen

**ADS-B Data**

- Take live data
- Import data from a file :
- Choose File / No file chosen

**Figure 30 - Two alternative architectures for the scenario preparation**

Two different architectures for the scenario preparation part were prototyped, the second has the advantages to give the user the opportunity to have a better visualization of the relative position of one aircraft compared to the other. About the heading, the altitude and the attitude, each move of the cursor provoke a feedback on one of the draws of aircraft. The button “Standard Value” allows the user to apply standard value for the speed and the attitude in function of the type of aircraft and stage of flight.



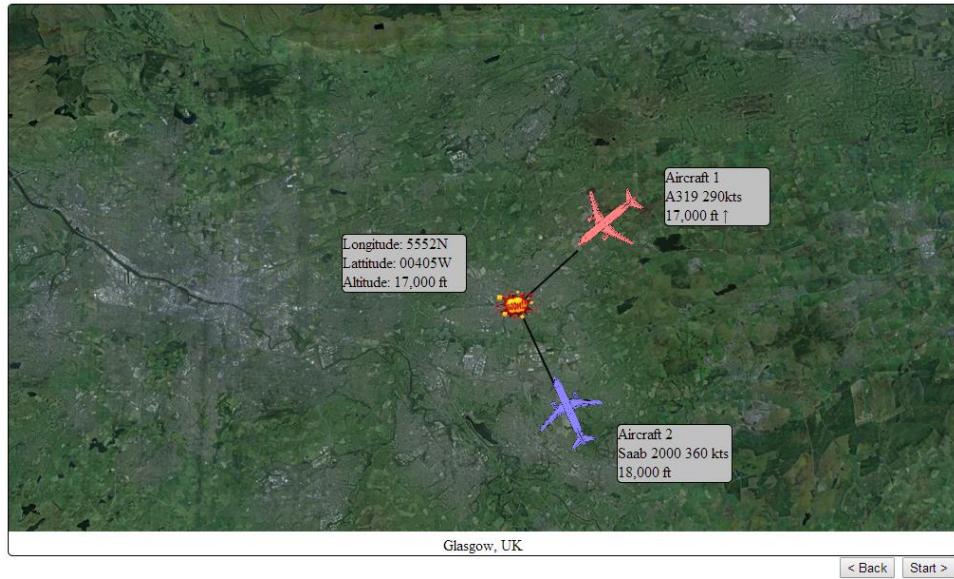
**Figure 31 - Aircraft Settings**

It is also possible to define the weather of the scenario, and especially the wind at different altitude. For example, the button “Add Wind Information” allows the user to add another field in order to add the speed and heading of the wind at another altitude. The user can finally ask the weather of a particular date.

Weather		
Altitude (ft)	Speed (kts)	Heading (deg)
<input type="text"/>	<input type="text"/>	<input type="text"/>
<input type="text"/>	<input type="text"/>	<input type="text"/>
<input type="button" value="Add Wind Information"/>		
<input type="checkbox"/> Take weather from this date : <input type="text"/>		

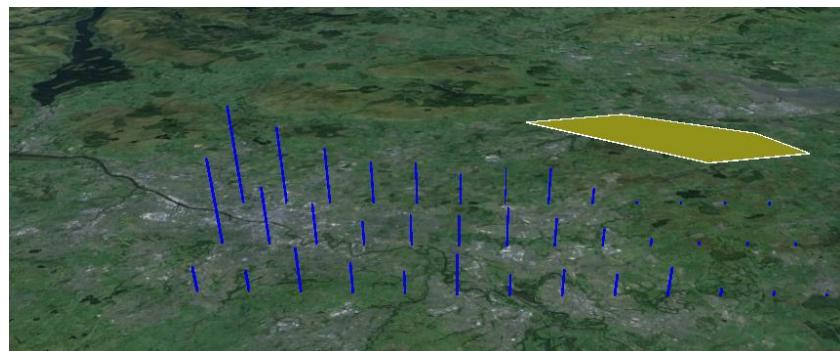
**Figure 32 - Weather Settings**

Before beginning the simulation, it is proposed to the user to check the scenario information with on 2 Dimensional map. It represents one more step and one more click for the user, but it could avoid the user to stop the simulation if the situation is not the one intended, which could imply an extra time to wait with the reloading of the simulation. An idea is that this step would be during the loading of the simulation and the user would have the possibility to stop it to change the scenario.

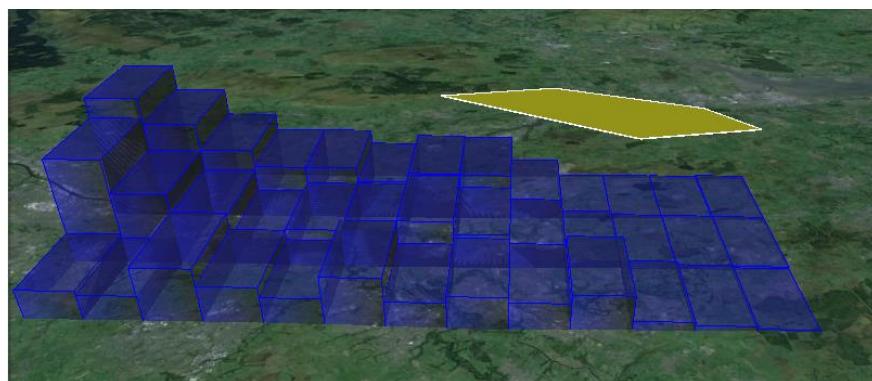


**Figure 33 - The step to check the scenario**

Finally, the user arrive on the visual simulation page, it is possible to control it with a media controller. The user can also take a screenshot of the situation in order to illustrate his/her report. A summary of the result is available and can be saved in a text file. Finally the user can export the map in a Google map readable format (kml file), in order to be able to manipulate the final data.



**Figure 34 - 2nd Alternative for the population representation**



**Figure 35 – 3rd alternative for the population representation**

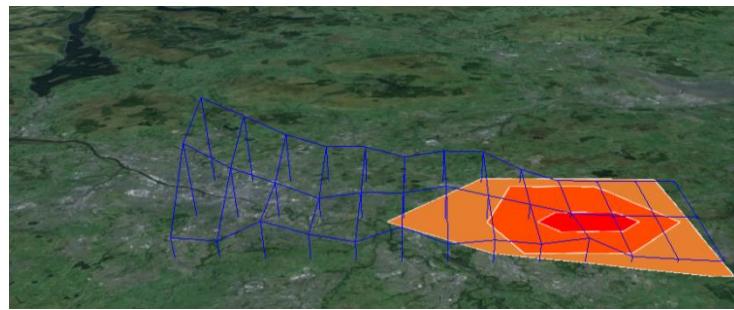


Figure 36 - Representation of the risk

### 3. JavaScript Prototype (3<sup>rd</sup> Iteration)

The Table 17 presents the prototypes of the third iteration.

Table 17 - Prototype presentation for the 3rd iteration

JavaScript Prototype – 3 <sup>nd</sup> Iteration	
Technology used	CSS/HTML, JavaScript/JQuery, Google Earth.
Number of prototypes	6 pages
Accuracy Level	High level.
Representation (Online/Offline)	Online (The prototype is a software application).
Interactivity	The user can interact with the prototype.
Lifetime	Throwaway (The prototype won't be used in the next phase).
Role in the design phase	Validating the solutions.
Horizontal/diagonal/vertical	Diagonal (Some data are implemented)/Based on a scenario.

Figure 37 - Scenario preparation form



Figure 38 - Loading of the simulation

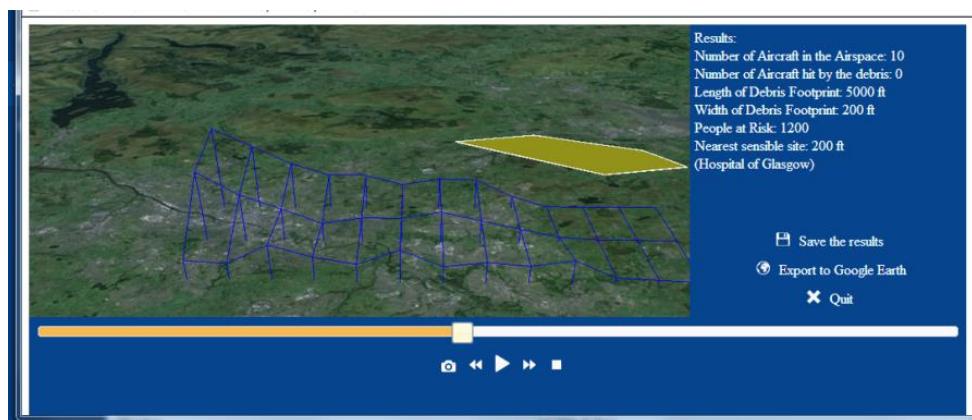


Figure 39 - 3D Visualization

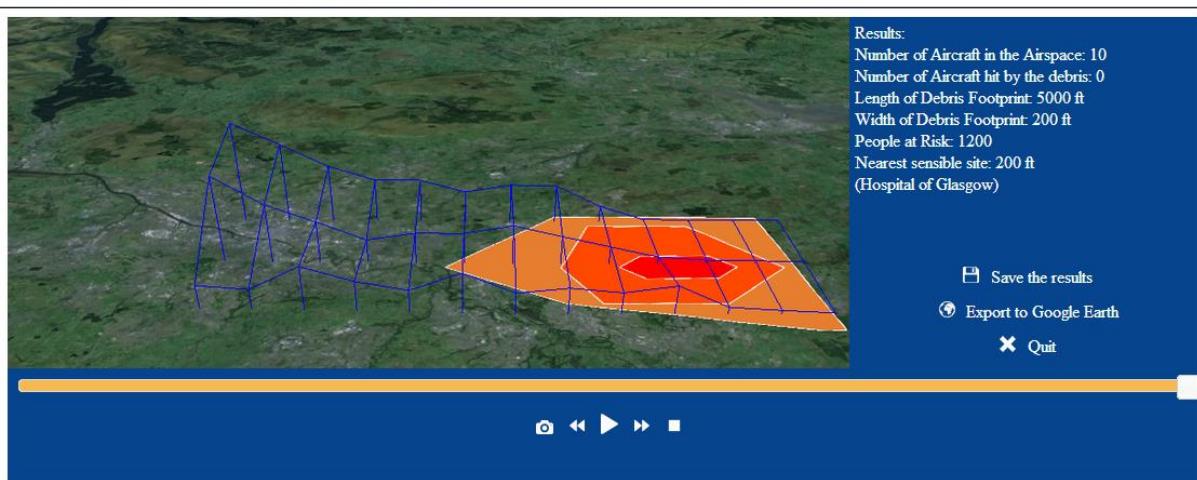


Figure 40 - Result of the simulation



Figure 41 - Statistic Simulation

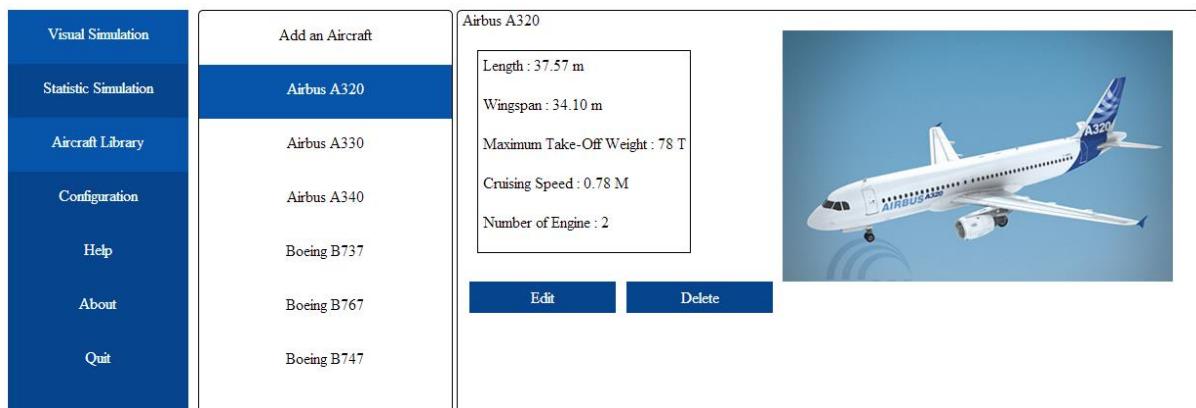


Figure 42 - Aircraft Library

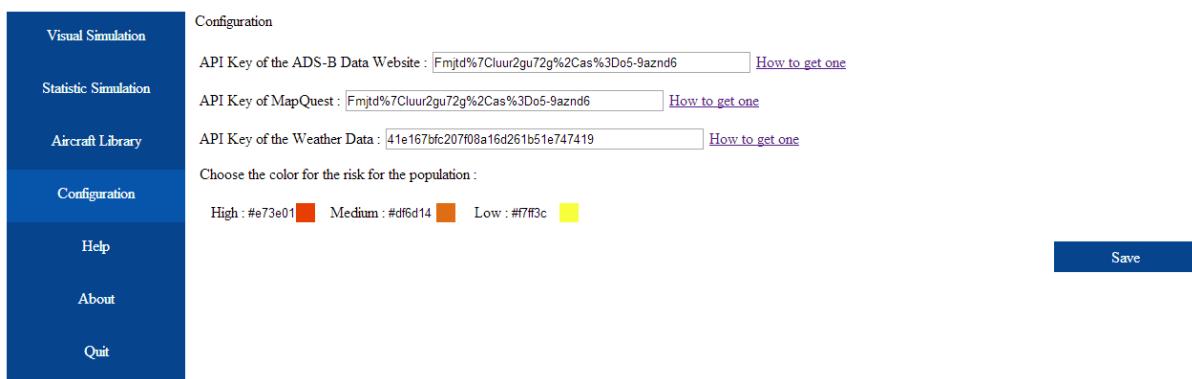


Figure 43 - Configuration or the Simulator

# Annex H - UKAB RISK ASSESSMENT AND CLASSIFICATION TRIAL (V3)

Source: UKAB

## PROCESS

Question 1		Question 2			
		What was the effectiveness of the remaining barriers between this event and the most credible accident scenario?			
		Effective	Limited	Minimal	Not effective
Category 1	Multiple fatalities on ac with >19 PoB or seats or MTOW >5700kg or significant 3 <sup>rd</sup> party risk.	50	102	502	2500
Category 2	Multiple fatalities on ac with 5-19 PoB or seats.	10	21	101	500
Category 3	Multiple fatalities on ac with <5 PoB or seats or multiple injuries or ac damage	2	4	20	100
Category 4	No accident outcome. May be operational implications (eg diversion)	1			

Note: The descriptions of catastrophic accident, major accident etc are for trial purposes; they do not reflect CAA or MoD policy or risk appetites. The reference to 19 seats and MTOW of 5700kg is for coherence with the requirement to fit TCAS.

Guidance:

Question 1: If this event had escalated into an accident outcome, what would have been the most credible outcome?

- How could the event have escalated into an accident? Typically, the escalation could be due to actions by the people involved, the way the hazard interferes with the flight and barrier behaviour.
- Do not filter out improbable scenarios. Question 2 will take probability into account.
- Among the scenarios, pick the most credible and select the corresponding row in the matrix

Question 2: What was the effectiveness of the remaining barriers between this event and the most credible accident scenario?

- To assess the remaining safety margin, consider both the number and the robustness of the remaining barriers between this event and the scenario identified in Question 1.
- Barriers that have already failed are ignored.
- Select the column of choice

## BARRIERS

The list below is not exhaustive; there may be more.

### ATCO/Fighter Controller/FAC Barriers

- Rules and procedures
- Controller action
- Controller action prompted by technology

### Aircrew Barriers

- Rules and procedures
- Visual Sighting
- Aircrew Action
- Situational Awareness (SA) provided by RT
- SA provided by on-board systems (eg AI radar, JTIDS)

- SA provided by ACAS (excluding TCAS RA)

ACAS – Resolution Advisory

- Compliance with ACAS RA

Unknown

- Not enough information to determine which barriers were applicable and/or worked as expected.

Providence

- If all other barriers failed and the aircraft missed each other by providence the barriers should be assessed as Not Effective.

# Annex I - Specification Report

This project is developed in Java using the API Swing for the main Graphical User Interface and JMonkeyEngine for the 3D visualization. This report presents how was performed the development phase of the project, how the code is structured, the design pattern applied and the libraries used.

## 1. Conceptual Model

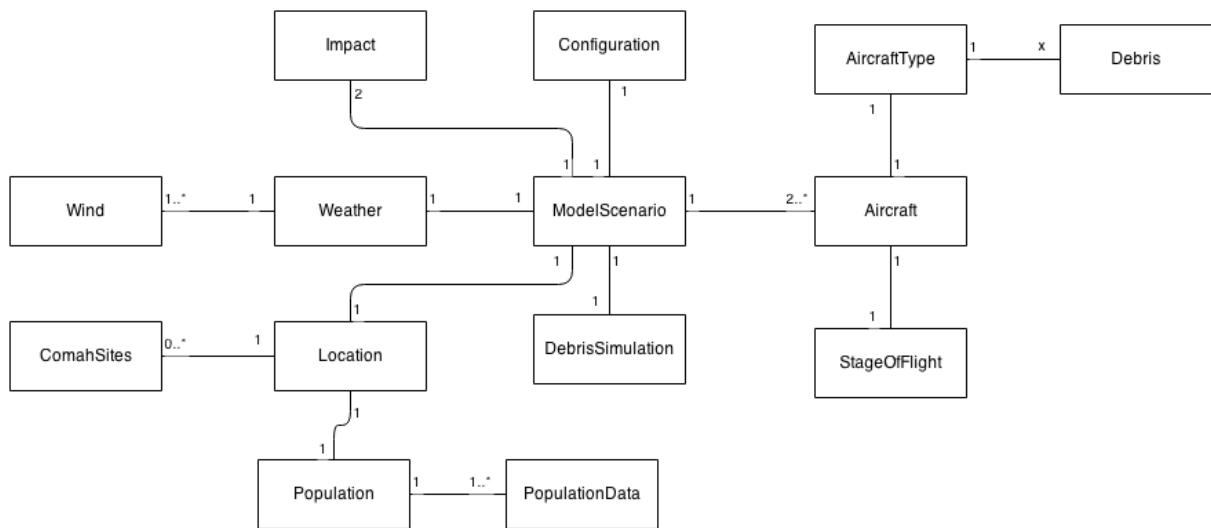


Figure 44 - Conceptual Model of the Software Application

The Figure 1 presents the conceptual model of the software application, only the classes are represented, to indicate all the attributes and methods would make the diagram unreadable. In order to understand this diagram, some explanations can be given about the classes:

- **ModelScenario**: This is the central class of the model, it contains all the information about the situation, it also asks for the simulation of the trajectories of the debris.
- **Configuration**: This class contains the information about the configuration of the software application, the different API keys and the colours the user wants to use for the density of debris.
- **Aircraft**: This class contains the information about the settings of the aircrafts involved in the Airprox, but also just flying in the zone.
- **AircraftType**: This class contains the structural settings of the aircraft (Length, wingspan ...), and a list of the debris of the Aircraft.
- **Debris**: This class contains the information of a piece of debris, like its ballistic coefficient.

- StageOfFlight: This enumeration contains the different stage of flight available: Cruise, Initial Climb, Approach, Climb to an upper level and Descent to a lower level.
- DebrisSimulation: This class perform the calculation of the trajectory of the debris and build the Impact layer of the debris.
- Impact: This class contains the information about the impact layer.
- Weather: This class contains the information about the weather, including a list of all the Wind at different altitude, it contains also a method to calculate the wind at any altitude in function of the wind in the list.
- Wind: This class contains the information concerning a wind information.
- Location: This class contains the information about the picture of the map, the population and the sensitive sites.
- Population: This class contains the information to recover the population in a list of PopulationData.
- PopulationData: This class contains the information about the population at one geographic location.
- ComahSites: this class contains the information about a sensitive site (Location, name).

## 2. Architecture of the software application

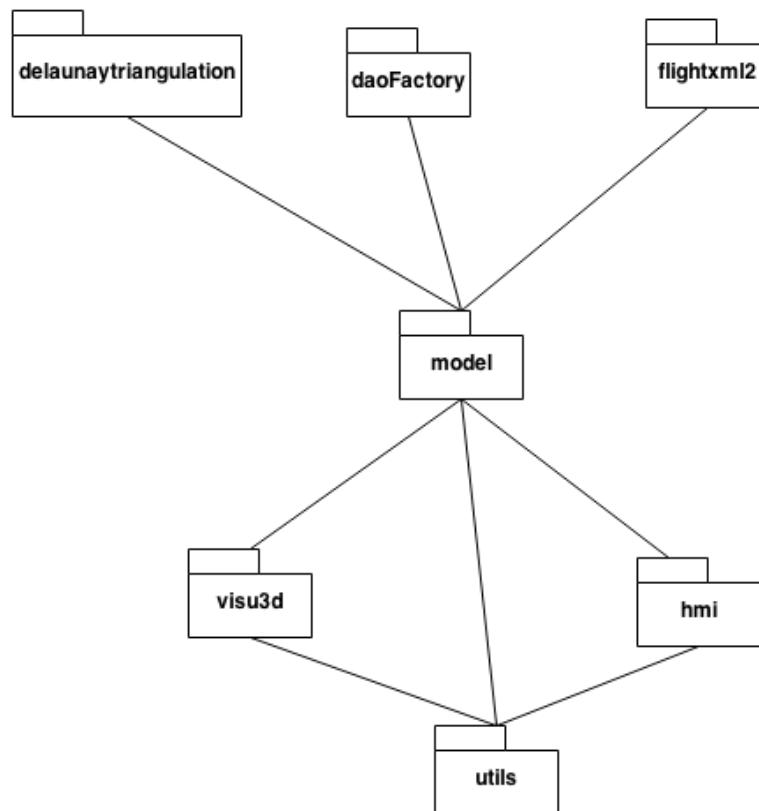


Figure 45 - Package Architecture of the Software Application

The software application is divided in 7 packages (Figure 2), this division was done in order to have a more organized code:

- model: This package contains the classes concerning the conceptual model.
- hmi: This package contains the classes concerning the main GUI (except the GUI used in the 3D simulation).
- visu3d: This package contains the classes concerning the 3D simulation.
- utils: This package contains classes (most of them are static) used to do various operations like calculate the distance between coordinates, to load/save a file or to do the Google Earth export.
- delaunaytriangulation: This package contains the classes used in the algorithm of Delaunay which is used to triangulate the debris layer.
- daoFactory: This package contains the classes used to import the type of Aircraft Information. For now, the information are in XML files but a pattern DAO was implemented in order to be able to change easily the source.
- flightxml2: This package is furnished by FlightAware to be able to read the ADS-B Data from their service.

### a. MVC Pattern

In order to be able to change the interface or the model without having to change the other, it was decided to use a design pattern Model-View-Controller (MVC). It is a design pattern that divides the software application into three inter-connected parts:

- A controller: This part receives all the commands from the user
- A View: This part generates an output to the user
- A model: This part manages the data, but also receives information from the controllers and sends them to the views.

It is possible to have multiple views and controllers, but normally only one model. It is also possible to have classes that are views and controllers, in that case, it is better to not mix the methods for the view and the methods for the controller.

In this case, the package model is the Model, the package hmi is a View and a Controller and the package visu3d is a View (It is not possible to change information about an aircraft during the 3D simulation) (Figure 3).

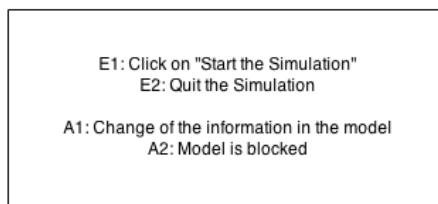
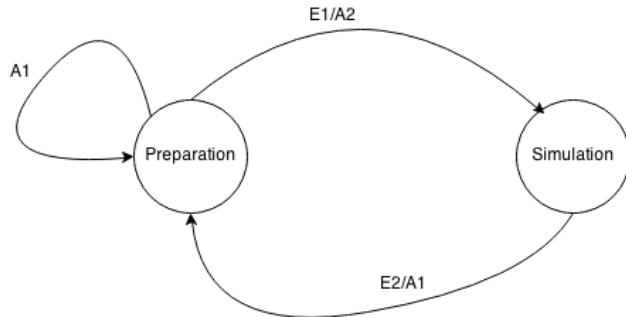


Figure 46 - General Process of the Application

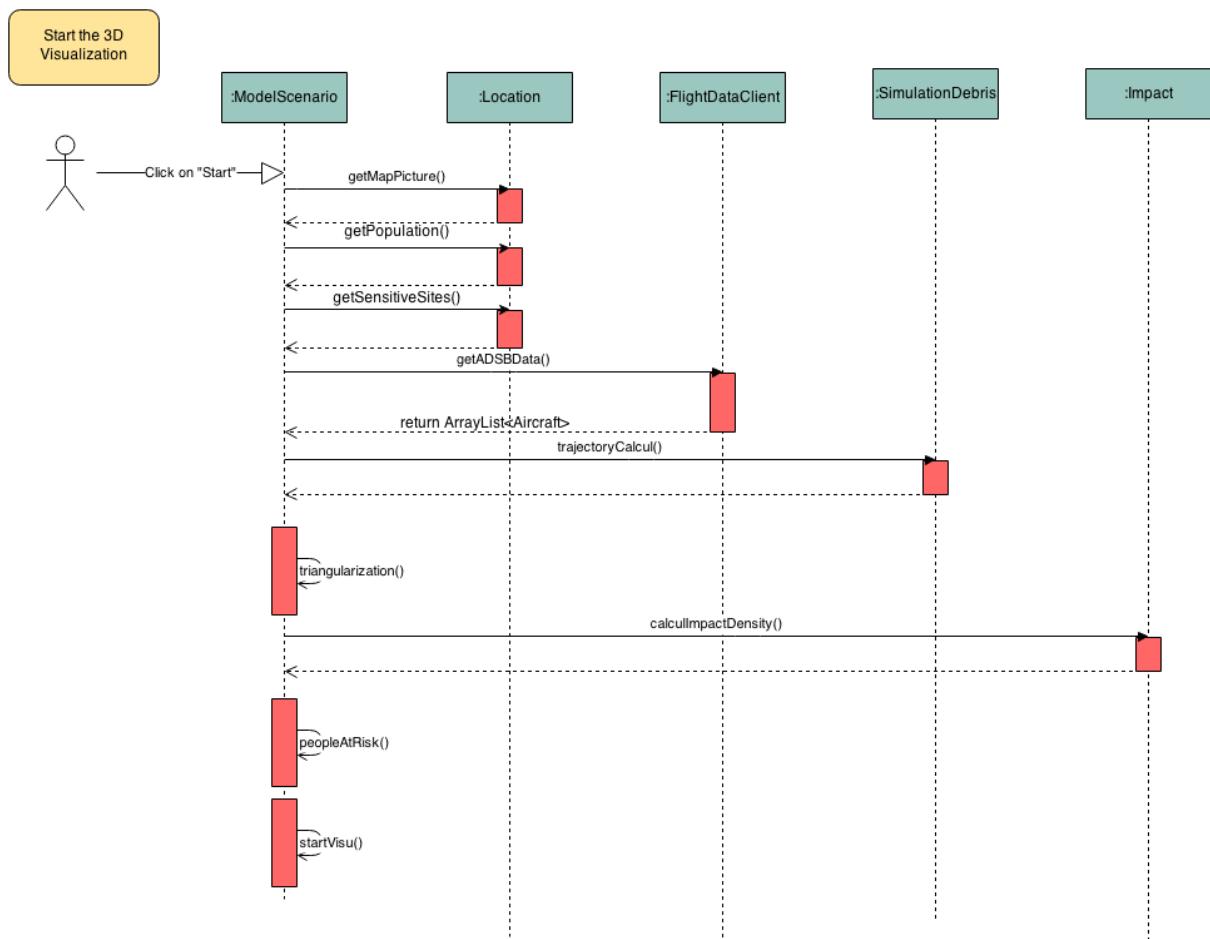


Figure 47 - Sequence Diagram of the Start of the 3D Visualization

## b. DAO Pattern

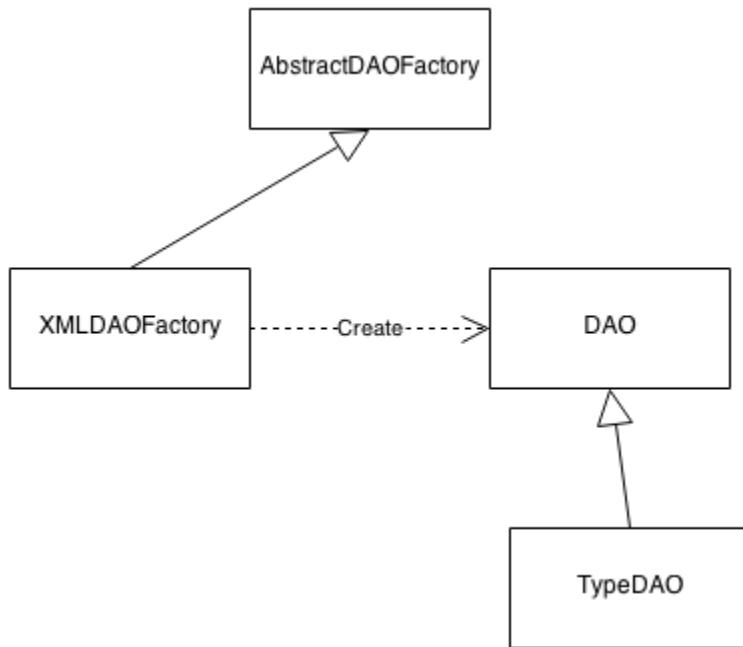
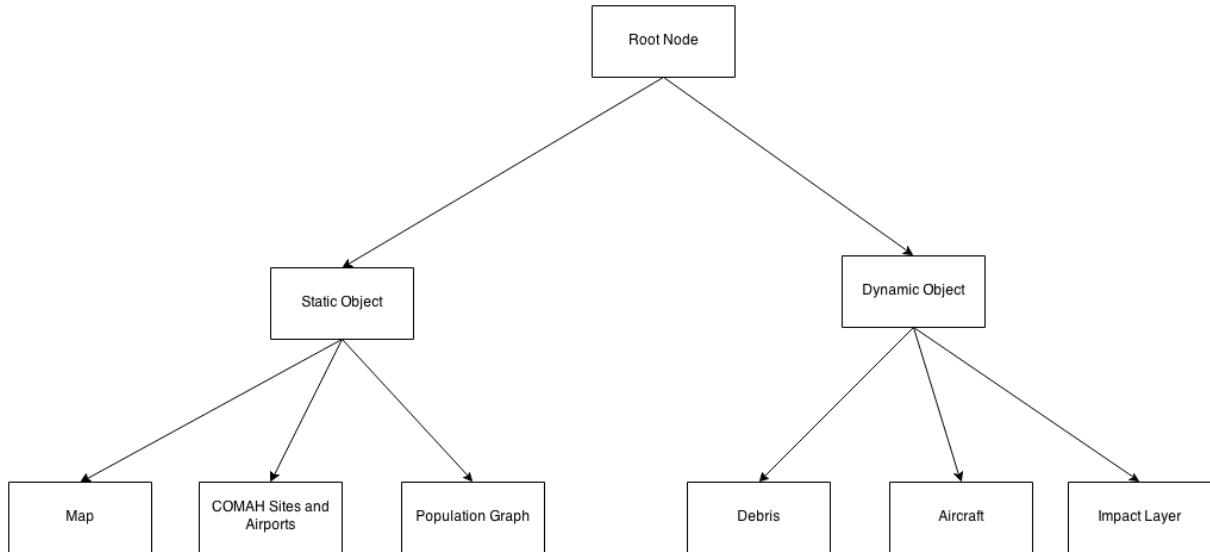


Figure 48 - Pattern DAO

The Figure 4 presents the design pattern DAO, its interest is to transform the data into java object usable in the model. In order to be flexible about the source type of the data, a factory was also created. In the future, it will be easy to change from XML to database without changing the model of the software application.

## c. 3D Simulation

The main class of the 3D simulation is “SimulationState”, this class is in charge of the management of the scene graph and of all the user interaction with the window of the simulation (Play, Pause, Save the result ...). It contains a method “update()” that is called every x milliseconds (x depends on the computer used).

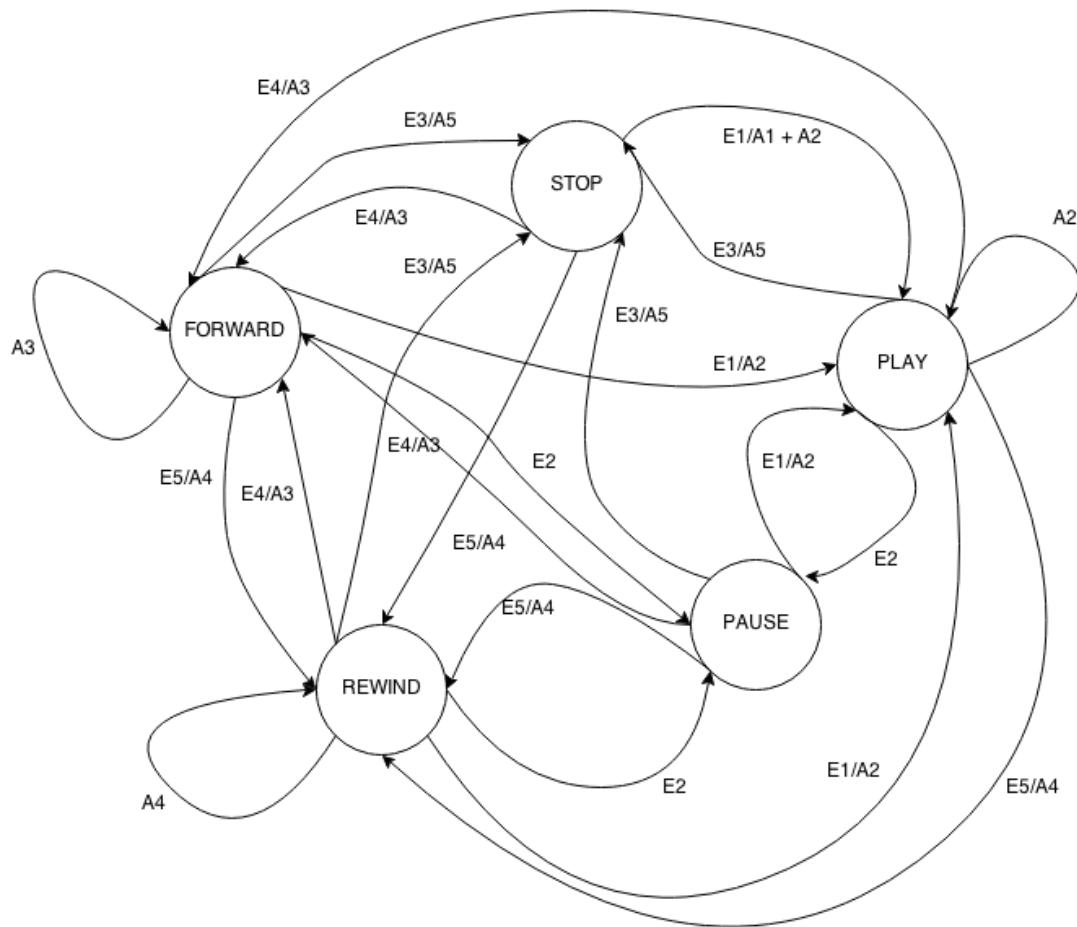


**Figure 49 - Scene Graph of the Simulation**

The Scene Graph is divided in 2 parts :

- The 1<sup>st</sup> part contains the static objects: The map, the sensitive sites and the population graph. They are attached at the beginning of the simulation and they don't move.
- The second part contains all the dynamic objects: The debris, the aircrafts and the impact layer. They implements an interface "moveObject" which has only one method "calculatePosition(float time)". The object are attached at the beginning of the simulation and their first, last and eventual intermediate positions are calculated. Each time the simulationState class called the method update, the calculatePosition method is called for each dynamic object in order to calculate their new position.

In order to allow the user to manage the time in the simulation, he/she can use player button like "play", "stop", "pause", "forward" and "rewind". These buttons change a variable called "state", this variable decide if the time of the simulation should change and how it should change. This behaviour is described in the Figure 5.



$T$ : Time of the simulation, initially  $T=0$   
 $T_{max}$ : Duration of the simulation  
TPF: Refreshing Time of the Simulation

E1: Click Button "Play"  
E2: Click Button "Pause"  
E3: Click Button "Stop"  
E4: Click Button "Forward"  
E5: Click Button "Rewind"

A1:  $T = 0$   
A2 : IF  $T < (T_{max} - TPF)$  THEN  $T = T + TPF$   
A3: IF  $T < (T_{max} - 5 \cdot TPF)$  THEN  $T = T + 5 \cdot TPF$   
A4: IF  $T > *5TPF$  THEN  $T = T - 5 \cdot TPF$   
A5:  $T = T_{max}$

Figure 50 - Management of the time in the simulation

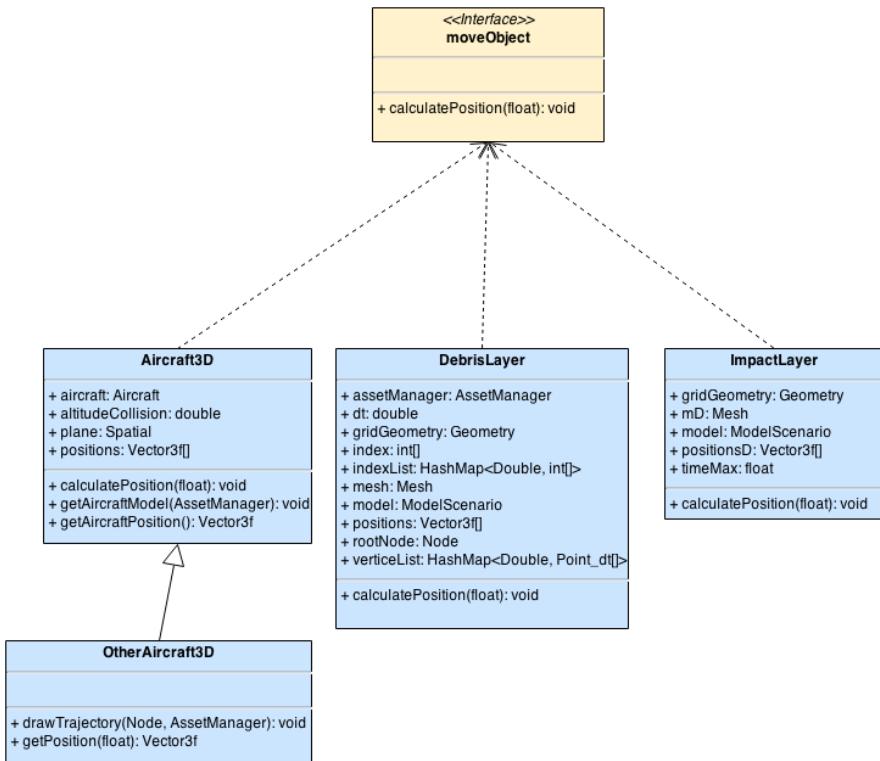


Figure 51 - Class diagram of the moveObject

#### d. Facade Pattern

The project deals with several sources of data like for example: Geographic map, weather data or population. It is important that the model and the interface are the least dependant possible on the data sources. To this purpose it was decided to apply a Facade design pattern, in order to abstract the data sources from the rest of the application and really easy to change the sources of these data in the future without changing anything in the model or the interface Figure 52.

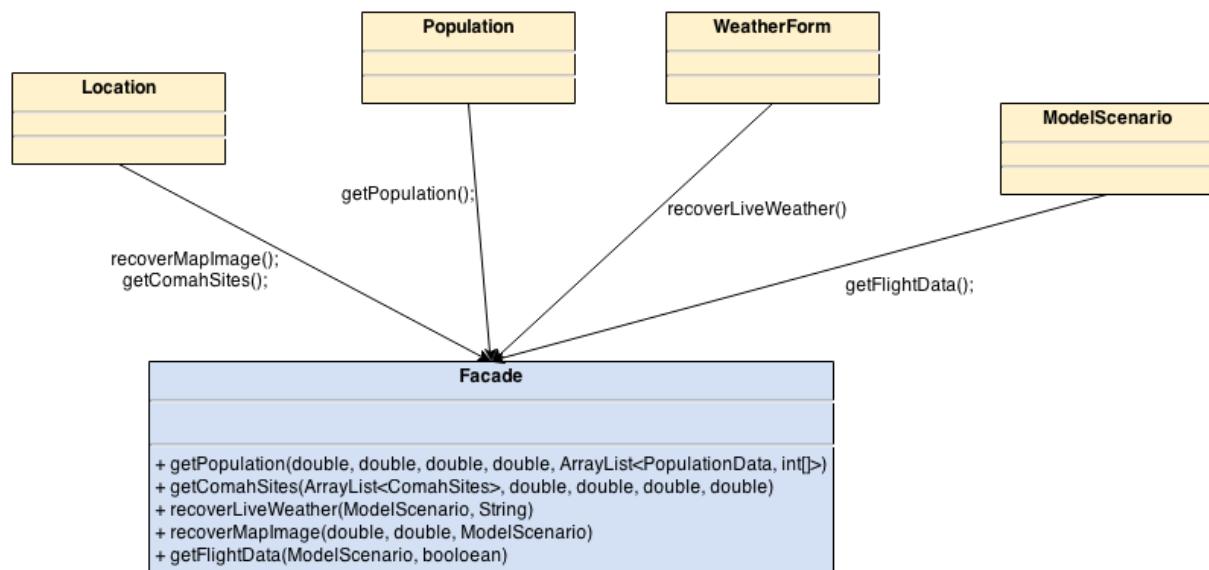


Figure 52 - Facade Design Pattern

### 3. Files Specification

This software application takes data from various files including:

- The list of all the types of aircraft in a XML File
- Debris files
- The configuration file also in XML
- Scenario files
- Result files
- KML files for Google Earth

#### a. Type of Aircraft

The file is called “type.xml”.

```
<?xml version="1.0" encoding="UTF-8"?>
<types>
    <type>
        <id>id of the type</id>
        <name>Name of the Aircraft</name>
        <length> Length of the Aircraft </length>
        <wingspan> Wingspan of the Aircraft </wingspan>
        <mtow> MTOW of the Aircraft </mtow>
        <cruiseSpeed> Cruise of the Aircraft </cruiseSpeed>
        <engine> Number of Engine </engine>
        <debris>Name of the debris file used</debris>
        <model3d>Name of the 3D model used</model3d>
        <angleRotation>Angle of Rotation to apply to the model</angleRotation>
        <material>0 or 1 if the 3D Model has its own material</material>
        <scale>Scale to apply to the 3D Model</scale>
            <speed>
                <cruise>Cruise Speed</cruise>
                <approach> Approach Speed </approach>
                <climb> Climb Speed </climb>
                <CU> Speed to climb upper</CU>
                <DL> Speed to descent lower</DL>
            </speed>
            <attitude>
                <cruise>Pitch in Cruise</cruise>
                <approach> Pitch in Approach </approach>
```

```

    <climb> Pitch in Climb </climb>
    <CU> Pitch to climb upper </CU>
    <DL> Pitch to descent lower </DL>
  </attitude>
</type>
<type>
  (... Another Aircraft)
</type>
</types>

```

## b. Debris Files

These files contains the information to generate a certain amount of debris for one aircraft. Several type of aircraft can have the same debris file. These files located in the folder “debris”. The name of the file is the one defined in the Aircraft Type XML File.

```

<debris>
  <mean>Mean of the normal law used to generate the debris</mean>
  <stD> Standard Deviation of the normal law used to generate the debris
</stD>
  <number>Number of Debris Generated</number>
</debris>

```

## c. The configuration file

This file contains all the configuration settings for the software application. It is loaded when the software is started but also when the user change the configuration settings. The name of the file is “config.xml”

```

<?xml version="1.0" encoding="UTF-8"?>
<config>
<username>Username for the ADS-B API</username>
<apiadsb> API KEY for the ADS-B API </apiadsb>
<apiweather> API KEY for the Weather API </apiweather>
<apimapquest> API KEY for the Map API </apimapquest>
<color>
  <high>Hexadecimal Code of the colour of a high density of debris</high>
  <medium> Hexadecimal Code of the colour of a medium density of debris </medium>
  <low> Hexadecimal Code of the colour of a low density of debris </low>
</color>
</config>

```

## d. Scenario Files

These files contain the scenarios that the user decides to save, he/she can load them in the scenario preparation form. The user chooses their name.

```
<scenario>
<location>
<longitude>Longitude of the collision</longitude>
<latitude> Latitude of the collision </latitude>
</location>
<aircraft1>
<type>Type of the Aircraft 1</type>
<altitude> Altitude of the Aircraft 1</altitude>
<attitude> Pitch of the Aircraft 1</attitude>
<heading> Heading of the Aircraft 1</heading>
<speed> Speed of the Aircraft 1</speed>
<stage> Stage of the Aircraft 1</stage>
</aircraft1>
<aircraft2>
<type>Type of the Aircraft 2</type>
<altitude> Altitude of the Aircraft 2</altitude>
<attitude> Pitch of the Aircraft 2</attitude>
<heading> Heading of the Aircraft 2</heading>
<speed> Speed of the Aircraft 2</speed>
<stage> Stage of the Aircraft 2</stage>
</aircraft2>
<adsb>ADS-B file (if the user asked for Live data, the file is “none” )</adsb>
<weather>
<wind>
<speed>Speed of the wind</speed>
<heading> Heading of the wind </heading>
<altitude> Altitude of the wind </altitude>
</wind>
<wind>
<speed>Speed of the wind</speed>
<heading> Heading of the wind </heading>
<altitude> Altitude of the wind </altitude>
</wind>
</weather>
</scenario>
```

## e. Result Files

These files are generated by the software application when the user asks for saving the result of the simulation. The name is chosen by the user.

Simulation of the DATE TIME

Location:

Longitude:

Latitude:

Aircraft 1

Type:

Altitude:

Pitch:

Heading:

Speed:

Stage of flight:

Aircraft 2

Type: TYPE

Altitude:

Pitch:

Heading:

Speed:

Stage of flight:

Result

Number of Aircraft in the Area:

Number of Aircraft hit:

People at Risk:

Nearest Sensitives Sites:

## f. Google Earth Files

These files are generated by the software application when the user asks for export the result on Google Earth. These are basic files in KML located in the folder “GoogleEarth”. The name is chosen by the user. A documentation of the KML language is available here:

<https://developers.google.com/kml/documentation/>

## **g. Other files**

In the folder “Tiles” are stored the map download by the software application, the user have the possibility to empty it in the configuration of the software application.

The folder “Screenshot” contains the screenshot taken by the user during the simulation.

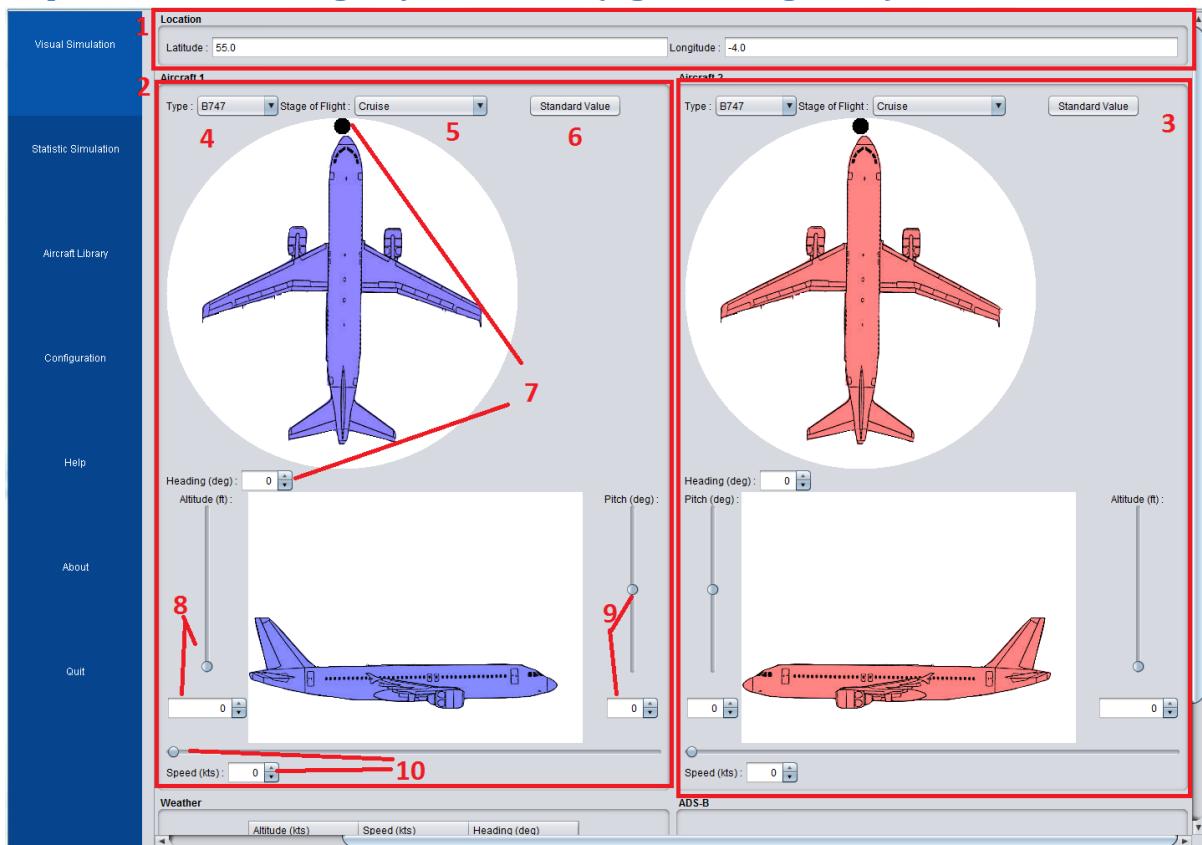
# Annex J – User Manual

## 1. Before Launching the software application

## 2. How to do a Visual Simulation

**Step 1 – Launch the software application by clicking on the file “AirproxSimulator.jar”**

**Step 2 – Fill all the settings of your scenario (Figure 53 - Figure 54):**



**Figure 53 - Scenario Preparation Form**

- 1 = In this part fill the latitude and the longitude of the occurrence.
- 2 = In this part fill the settings about the first aircraft involved.
- 3 = In this part fill the settings about the second aircraft involved.
- 4 = This allows you to select the type of the aircraft (B747, A320...).
- 5 = This allows you to choose the stage of the flight of the aircraft.
- 6 = This allows you to give standard value to the speed and pitch in function of the aircraft type and the stage of the flight.
- 7 = This allows you to choose the heading of the aircraft, it is possible to move the dark circle or to enter a number in the text field.
- 8 = This allows you to choose the Altitude of the aircraft, it is possible to use the slider or to enter a number in the text field.

9 = This allows you to choose the Pitch of the aircraft, it is possible to use the slider or to enter a number in the text field.

10 = This allows you to choose the Speed of the aircraft, it is possible to use the slider or to enter a number in the text field.

 For the second Aircraft, the place of the pitch and the altitude are inverted.

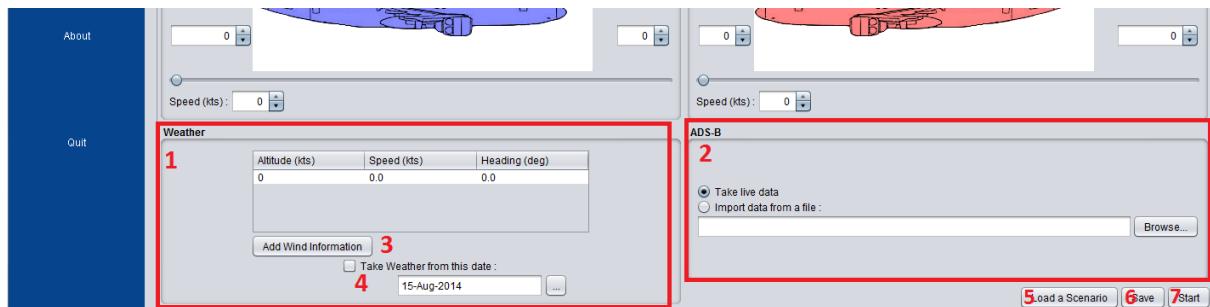


Figure 54 - Scenario Preparation Form (part 2)

1 = In this part fill weather information about the occurrence. You can modify a value in the table by double click on it, if you want to add a new value, you have to click on "Add Wind Information".

 It is not allowed to add multiple wind information for the same altitude.

2 = In this part select "Take Live Data" if you want to use ADS-B data from the internet, if you want to import your own data, select "Import data from a file" and click on "Browse" to select it.

 If you don't want to add traffic data, just select "Import data from a file" without give any file.

3 = Click on this button to add a Wind Information to the table.

4 = It is possible to take Weather information from the internet, select a date and tick the box "Take Weather from this date". It only concerns the wind at the altitude 0.

5 = Click on this button to load a scenario from a file.

6 = Click on this button to save the scenario you just create in a file.

7 = Click on this button to start the simulation.

### Step 3 – Click on the button "Start", and wait the end of the loading (Max 10 seconds)

**Step 4 – Select your settings for the 3D visualization and click on the button “Continue” (Figure 55).**

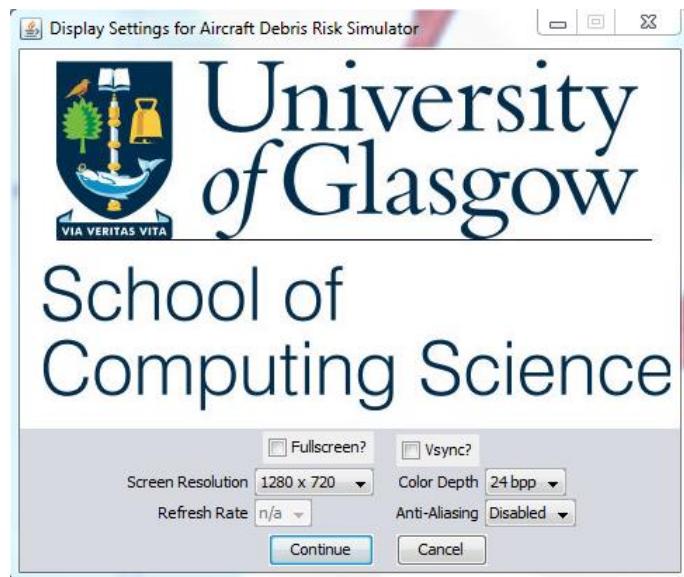


Figure 55 - Screen Settings

- ❶ The best is to only change the screen resolution to fit your screen.
- ⚠ Don't tick the box "Fullscreen?", you won't be able to save or export your results.

**Step 5: Play the simulation (Figure 56 - Figure 57)**

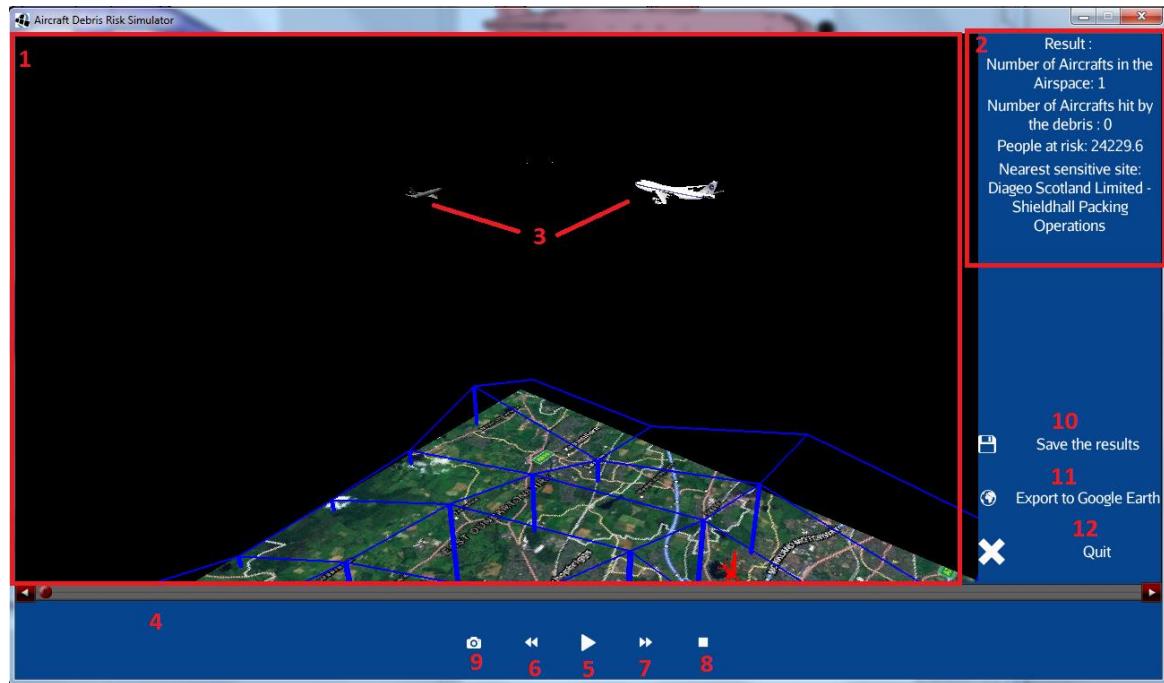


Figure 56 - The 3D Simulation

- 1 = This part represent the visualization of the situation in 3D.
- 2 = This part show the result of the simulation.
- 3 = These are the two aircrafts in the simulation.
- 4 = This is the time controller, is it possible to click at any location on it to go to a certain time in the simulation.
- 5 = Click on this button to play the simulation.
- 6 = Click on this button to rewind the simulation.
- 7 = Click on this button to accelerate the simulation.
- 8 = Click on this button to stop the simulation.
- 9 = Click on this button to take screenshot of the simulation.

 The screenshot are stored in the folder “screenshot” in the folder of the application.

- 10 = Click on this button to save the textual result of the simulation.
- 11 = Click on this button to export the result into a file that could be read by Google Earth.

 Don't change the extension of the file, it has to be .kml.

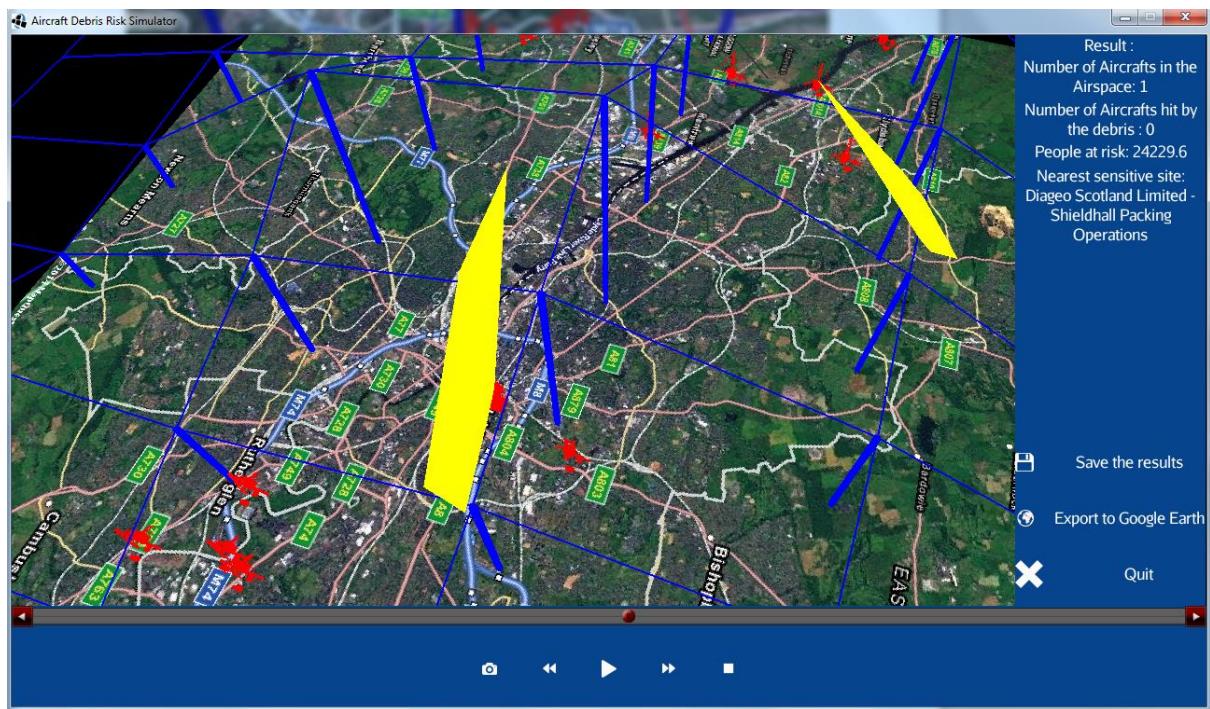
- 12 = Click on quit the software.



Figure 57 – Map

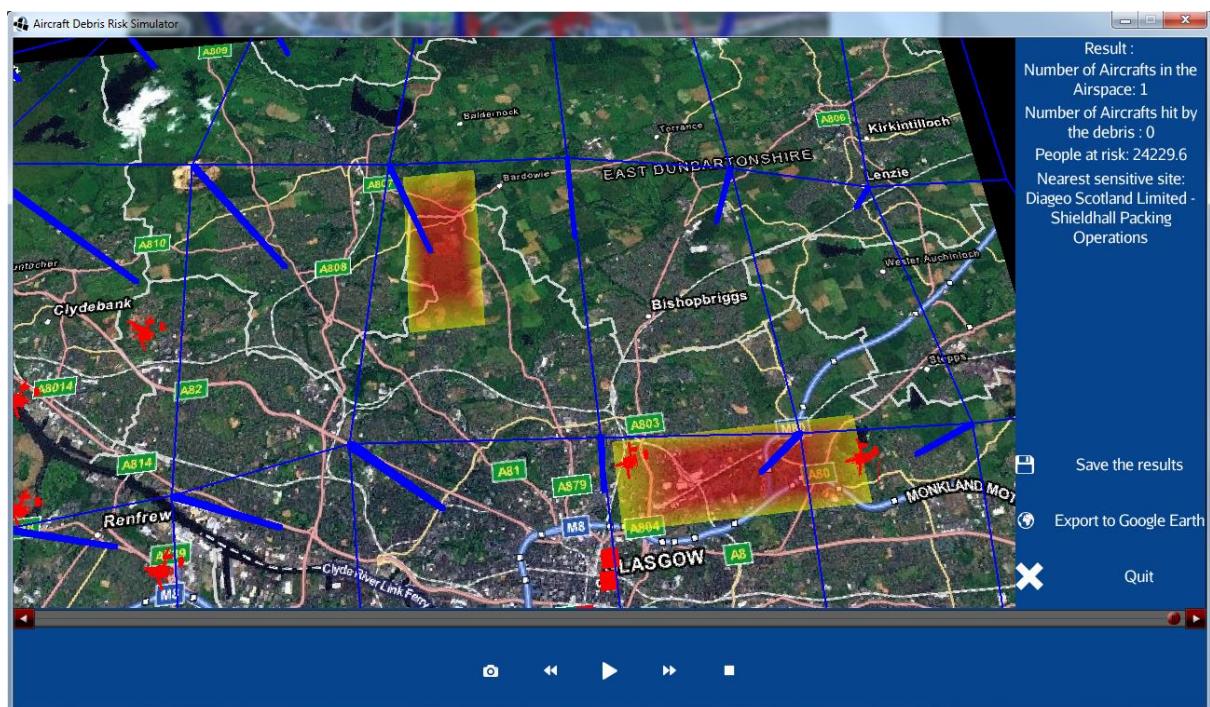
- 1 = The blue line represents the population density
- 2 = The red factory represents the sensitive sites (Factory, Power Plant...), it is only available in UK.
- 3 = The red tower represents airports or train stations.

**Step 6 – Wait for the debris to fall or click on the button “Stop” to go directly to the end of the simulation (Figure 58 - Figure 59)**



**Figure 58 - Debris falling**

The two yellow layers represents the debris of each aircraft.



**Figure 59 - Impact of the debris**

The two colour layer represents the density of the debris on the ground.

### 3. Other functionalities

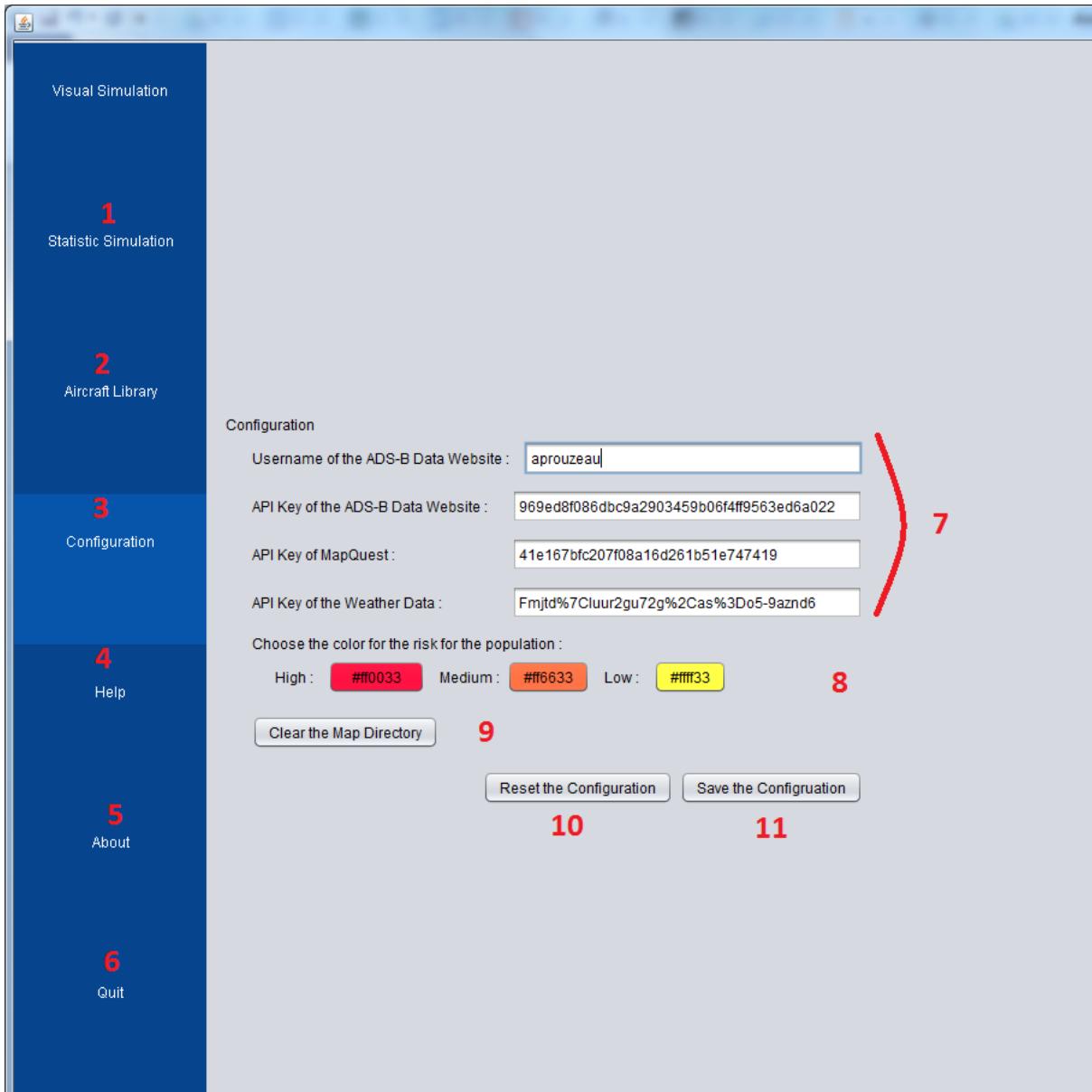


Figure 60 - Other functionalities

- 1 = Click on this button to perform a statistic simulation. **Not Implemented Yet.**
- 2 = Click on this button to manage the aircraft library. **Not Implemented Yet.**
- 3 = Click on this button to manage the configuration of the software application.
- 4 = Click on this button to access to come help.
- 5 = Click on this button to know about who worked on this software application.
- 6 = Click on this button to quit the software application.
- 7 = With this field you can manage the API keys. See Chapter 4 to have more information.
- 8 = Click on these buttons to change the colour of the debris density.
- 9 = Click on this button to clear the folder which contains all the maps loaded during the last simulation.

10 = Click on this button to reset the configuration if you changed it.

11 = Click on this button to save the configuration.

## 4. How to manage the API Keys

### a. The ADS-B Data

The ADS-B Data comes from the website: <http://flightaware.com/>. To get an API key, you have to:

- Create an account (The username on the website will be your username for the API).
- Click on “Commercial Service” in the menu on the left side of the page and choose “FlightXML”.
- Click on the button “Get your FlightAware API key”.

### b. The Weather Data

The weather data comes from an API called forecast.io: <https://developer.forecast.io/>. To get an API key, you have to:

- Create an account.
- Then you can have access to your API Key.

### c. The geographic map

The map comes from a the website MapQuest: <http://developer.mapquest.com/>. To get an API Key you have to:

- Create an account.
- Click on the little arrow at the right side of your username at the top of the page and choose “Manage your AppKey”.
- Click on “Create AppKey”.

## Annex K – Examples of Airprox Reports from UK and France

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## AIRPROX REPORT No 2013054

Date/Time: 23 Jun 2013 1255Z (Sunday)

Position: 5642N 00433W  
(N FINDO)

Airspace: UAR                    (Class: C)  
Reporting Ac                    Reported Ac

Type: B747(1)                    B747(2)

Operator: CAT                    CAT

Alt/FL: FL340                    FL340

Weather: IMC                    VMC

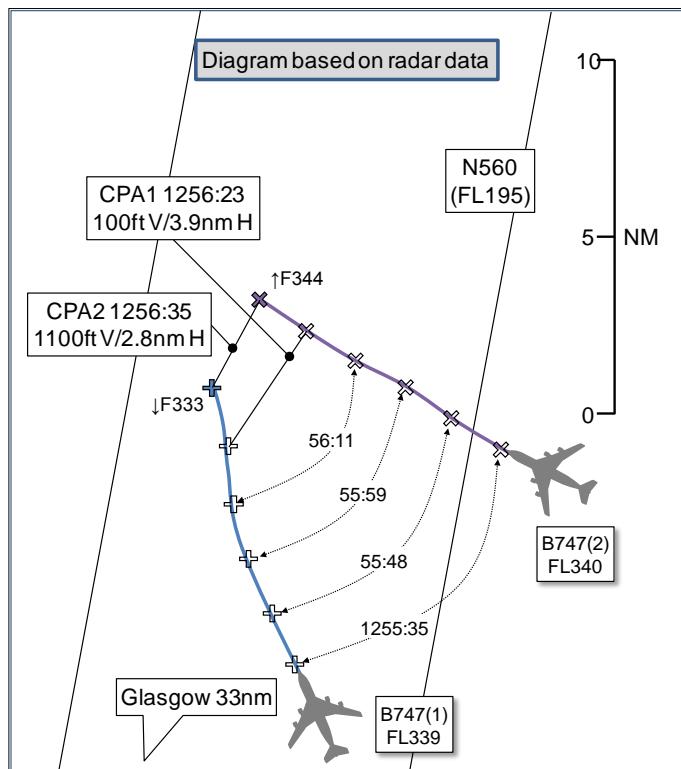
Visibility: 10km                    40km

### Reported Separation:

400ft V/200m H    600ft V/0.5nm H

### Recorded Separation:

100ft V/3.9 nm H  
1100ft V/2.8nm H



## PART A: SUMMARY OF INFORMATION REPORTED TO UKAB

**THE B747(1) PILOT** reports en-route at FL340, M.85, direct to ATSIX. He received ATC instructions for an immediate R turn, he thought, for traffic avoidance. Turn was commenced immediately and traffic observed at same level converging about 2nm distant on RH side. This ac was also given turn instruction but to the L, on to heading 270°, he thought. This combination further reduced separation and the anticipated TCAS RA occurred. A/P was disconnected and TCAS command (descent) followed. Other ac observed to follow turn instruction and then climb. ATC were advised of RA event and gave other traffic further vectors to ensure separation. FL330 was maintained, as instructed, following event.

He perceived the severity of the incident as 'High'.

**THE B747(2) PILOT** reports at M.847 in VMC at FL340, squawking Modes S and C. He was under the control of Scottish Centre. The initial heading advised by Scottish, he thought, was an immediate L turn heading 270°. The other ac was turned R heading 050°, he thought. He started the turn and, after confirmation of the heading, he was advised to turn R immediately heading 050°. He received an RA without TA in the turn, climbing to FL345. After clear of conflict A/P was re-engaged, V/S 500fpm to descend to FL340. Speed increased to the amber band and no level off at FL340. A/P had to be disconnected again to resume FL340. During this phase of flight there were no TA or RA alerts. He did not sight the other aircraft.

He perceived the severity of the incident as 'Medium'.

**THE PRESTWICK CENTRE (PC) MONTROSE T AND P CONTROLLER** reports that sector traffic was moderate but it did not seem too busy. At approximately 1250, he noticed that the two ac were coming into conflict with each other. At that time, the STCA started to activate. He gave an avoiding action L turn to the B747(1) heading 270° and B747(2) a R turn heading 050°. He observed that the B747(1) did not appear to be taking the turn. The pilot of the B747(2) queried whether he had been given a turn and he reissued it. At this point a P Controller asked if any of the ac had been given descent. He replied that no descent had been issued. He promptly instructed the B747(1) to descend. At this point the B747(2) reported a TCAS RA climb.

**THE RELIEF PC MONTROSE P CONTROLLER** reports that on arriving for work he was sent on a break and almost immediately a P was requested urgently for Montrose. He plugged in and saw STCA flashing west of FINDO, 2 ac at FL340. Avoiding action had been issued. He started trying to offer assistance and gain the picture. After a few minutes another controller arrived to relieve T. Instead, he suggested taking over the T position himself as he had more of the picture. He then handed over the P picture as best he could. The B747(1) was instructed to maintain FL330. The B747(2) was returning to FL340. Ac were released on their own navigation. He noticed that the B747(2)'s Mode C was indicating FL337 descending. Avoiding action was issued and the pilot was requested to confirm climbing. The B747(2) showed FL336 on mode C before climbing back to FL340. Mode S indicated FL340 all the time. At all times the sector was moderate to busy with numerous conflicts around Nevis, with FL340, FL350 and FL360 all having conflicts and ac reporting weather.

[UKAB Note(1): The minimum separation for ac operating in Class C airspace of the UAR is 5nm H or 1000ft V.]

**ATSI** reports that the Airprox was reported in Class C airspace, in the vicinity of FINDO, by B747(1) at FL340 following receipt of a TCAS RA against a B747(2), also at FL340.

B747(1) was operating under IFR, and was in receipt of a RCS from PC Montrose Sector [126.925MHz]. B747(2) was operating under IFR and was in receipt of a RCS from PC Montrose Sector on the same frequency.

The Montrose Sector was operating combined T and P with ATCO(1) as operational controller at the time of the Airprox. ATCO(2) provided some P assistance at the time of the Airprox before relieving ATCO(1) from position. ATCO(1) described the traffic loading at the time as moderate.

CAA ATSI had access to written reports from the pilots of both ac, area radar recordings, RTF recording and transcript of the Montrose Sector frequency, together with the PC unit report. CAA ATSI also interviewed ATCO(1) and ATCO (2) on the Montrose sector.

At 1250:40, the B747(2) pilot requested climb from FL320 to FL340 from ATCO(1). The controller replied standby and that he would call him back. The controller reported being aware that he was unable to give the B747(2) pilot a climb at that time due to other traffic and instead dealt with other issues. ATCO(1) then co-ordinated climb for the B747(2) to FL340 with the next sector and at 1251:45 ATCO(1) instructed the B747(2) pilot to climb to FL340. The B747(1) had 20.1nm to run to the Montrose sector boundary (see Figure 1 below).

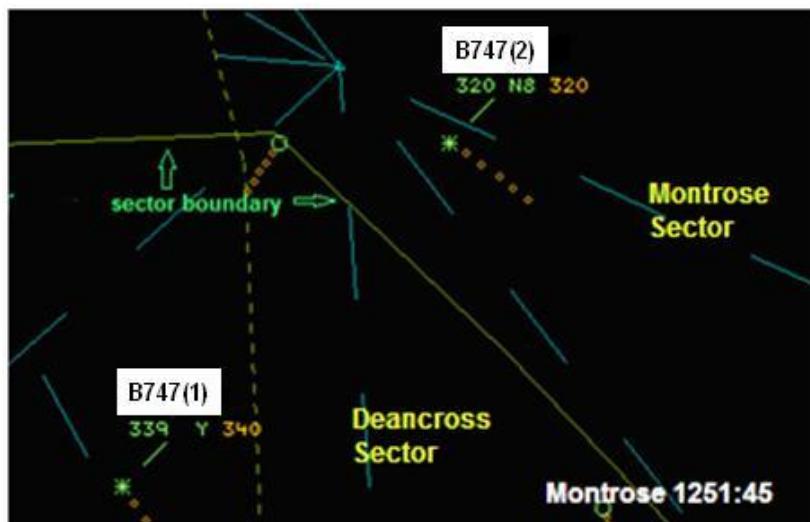


Figure 1.

At 1252:00, the B747(1) pilot contacted the Montrose sector maintaining FL340 (indicating FL339). The two ac were 24.3nm apart on converging tracks (see Figure 2 below). ATCO(1) reported that his usual method of working was to put the electronic strips of conflicting traffic together and suitably highlighted. On this occasion ATCO(1) had not done this.

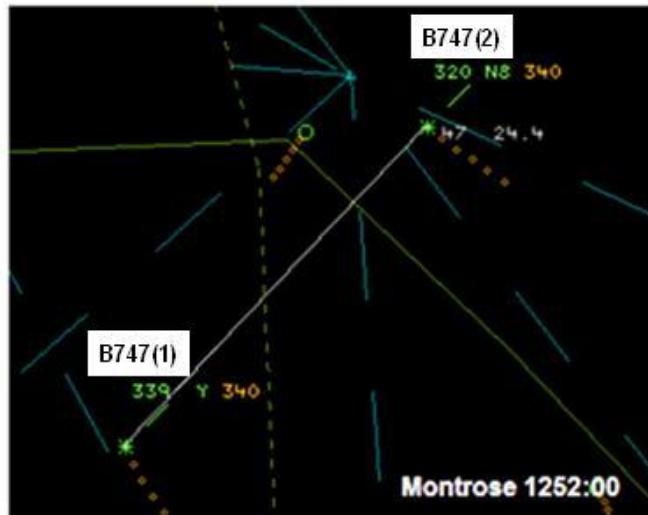


Figure 2.

At 1255:22, low-level STCA was triggered as the two ac were 9.8nm apart (see Figure 3). Just prior to this ATCO(1) had realised that the two ac were in conflict; however, he was unable to issue instructions due to another ac transmitting on the frequency. At the end of this transmission ATCO(1) transmitted, "*avoiding action [B747(1) C/S] turn left immediately heading two seven zero degrees, traffic in your right one o'clock.*" The B747(1) pilot read back, "*two seven zero [B747(1) C/S]*". Avoiding action was then passed to the B747(2) pilot, "*[B747(2) C/S] avoiding action turn right immediately heading zero five zero degrees traffic in your left eleven o'clock*". The B747(2) pilot replied using his C/S digits only.

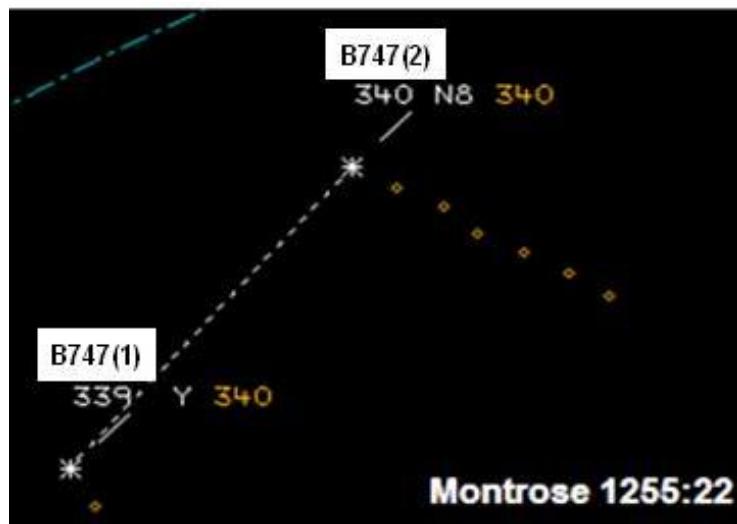


Figure 3.

At 1256:00, the two ac were 6.6nm apart still on converging headings (see Figure 4, with the headings previously given by ATCO(1) superimposed in red). The B747(2) pilot transmitted, "*and just to confirm did you give us a heading for [B747(2) C/S]*". ATCO(1) replied, "*[B747(2) C/S] affirm avoiding action turn right immediately heading zero five zero degrees.*" The B747(2) pilot read back "*zero five zero right turn [B747(2) C/S]*".

At 1256:12, ATCO(1) transmitted to the B747(1) pilot, "*[B747(1) C/S] avoiding action turn left immediately heading two six zero degrees traffic in your right one o'clock*". The B747(1) pilot replied

"two six zero with traffic in sight [B747(1) C/S]". ATCO(1) was aware that he had not received a full readback but was concerned that the crew's workload was high and did not want to distract them further.

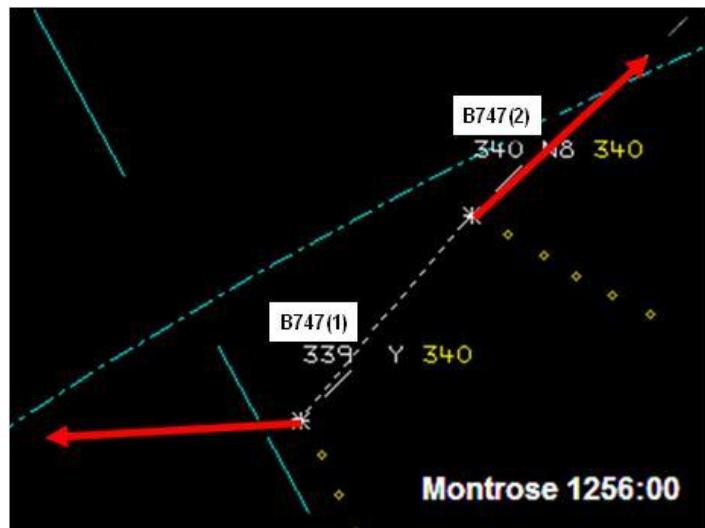


Figure 4.

ATCO(1) stated at interview that he was reluctant to give climb or descent to either ac due to his training, which discouraged it due to the possibility of giving instructions in confliction with TCAS. At 1256:17, high-level STCA alerted as separation was lost: the distance between the B747s had reduced to 4.9nm with both ac at FL340 on converging tracks (see Figure 5). The B747(1) appeared to have turned slightly R. By this time ATCO(2) had arrived on the sector to provide assistance to ATCO(1) and suggested that ATCO(1) give vertical instructions. At 1256:20, ATCO(1) instructed the B747(1) pilot to "*descend now immediately*".

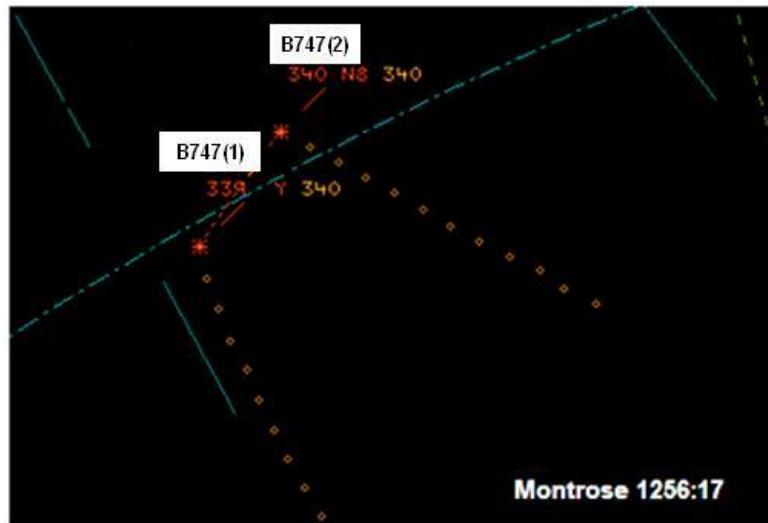


Figure 5.

The B747(2) pilot reported "*resolution advisory in the climb*". This was acknowledged by ATCO(1). Separation between the two ac reduced to 3.5nm/300ft.

At 1256:37, vertical separation between the two ac was regained as B747(1) was at FL332 and B747(2) was climbing through FL344. The lateral distance was 2.8nm with the tracks of the two ac not appearing to have changed significantly (see Figure 6).

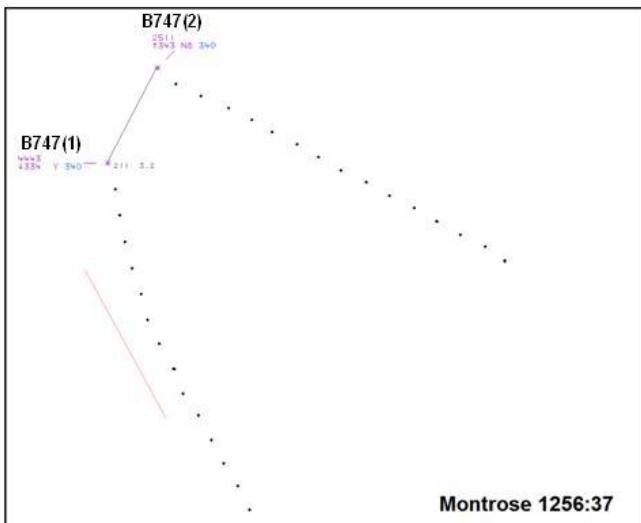


Figure 6.

The B747(1) pilot reported at FL330, and that they would be resuming FL340 in about 10nm. ATCO(1) instructed the B747(1) pilot to maintain FL330. The B747(1) pilot requested to resume the N'ly heading and ATCO(1) approved this. The B747(1) pilot then advised ATCO(1) that he had received a TCAS RA before the instruction to descend.

At 1257:20, the two ac tracks crossed as the B747(1) turned onto a N'ly track, passing 1.6nm behind the B747(2). The B747(1) was indicating FL334 with Mode S Selected Flight Level (SFL) showing FL330 and the B747(2) was indicating FL345 with SFL showing FL340.

ATCO(1) was relieved by ATCO(2), the P, who instructed the B747(2) crew to resume own navigation for ERAKA.

Although not directly relevant to this Airprox, at 1258:20, separation was again lost when B747(2)'s Mode C indicated FL338 descending and STCA activated. ATCO(2) asked the B747(2) to confirm if it was descending. B747(2) replied that they were "*getting back to flight level three four zero.*" ATCO(2) asked the crew to confirm that they were climbing to FL340. The B747(2) replied "*that's affirmative*".

At 1259:09, the Mode C indication of the B747(2) was FL335. The horizontal distance between the two ac was 2.6nm and the vertical distance was 600ft. ATCO(2) advised the crew of the B747(2) that "*we have you descending flight level three three zero*" and re-issued avoiding action, turning the B747(2) L onto a heading of 300°.

At 1259:20, B747(1) was given an avoiding action L turn on to 270°. This instruction had the potential to reduce the distance between the two ac and was queried by the B747(1) pilot. It was then cancelled by the controller as separation was regained at 1259:32, when the B747(2) levelled at FL340 and the track of the B747(1) had not changed. At interview ATCO(2) could provide no explanation for the turn given to the B747(1) except that it was the avoiding action turn issued by the previous controller and the previous incident was still on his mind.

The written report from the captain of B747(1) recollected that they received an ATC instruction for an 'immediate turn right for traffic avoidance'. The crew commenced the turn and traffic was observed at the same level converging at approximately 2nm on their RH side. They heard the other traffic be given avoiding action to the L (onto 270° they thought). The subsequent TCAS RA was followed. Following the incident the B747(1) captain contacted the B747(2) captain who confirmed that they were instructed to turn L.

The written report from the B747(2) captain stated that they were instructed to turn immediate L heading 270° and believed the other ac was to turn R heading 050°. They started the turn and then were instructed to turn immediately heading 050°. They received a TCAS RA and climbed to FL345.

Following the Airprox, PC conducted a simulation of the event where both ac acted on the avoiding action given by ATCO(1) at 1255. Rate one turns were used and the resulting minimum lateral separation was 7.2nm.

ATSI commented that ATCO(1) climbed the B747(2) to FL340, the level occupied by the B747(1) which was not yet on frequency. It is possible that as the Mode C of the B747(1) consistently displayed FL339 it did not alert ATCO(1) to the conflicting level of B747(1).

## **Summary**

Both ac were operating in Class C airspace of the UAR, under the control of the PC Montrose sector. At the time of the incident the sector was operating bandboxed P and T positions. The B747(2) pilot was instructed to climb to FL340, the same level as B747(1). Avoiding action turns were issued by the controller but were not followed by either crew. Both ac received TCAS RAs. Separation was reduced below the minimum required (5nm/1000ft).

## **PART B: SUMMARY OF THE BOARD'S DISCUSSIONS**

Information available included reports from the pilots of both ac, transcript of the relevant RT frequency, radar video recordings, reports from the air traffic controllers involved, and reports from the appropriate ATC and operating authorities.

The Board first discussed the ATC aspects of the incident. At the time of the Airprox both ac were operating in Class C airspace under the control of the Prestwick Centre Montrose Sector before entering Oceanic airspace. The B747(2), cruising at FL320, requested a climb to its Oceanic level of FL340 and, after appropriate co-ordination, the ac was instructed to climb to FL340. Controller members agreed that this clearance resulted in a potential conflict with B747(1), which was on a converging track, at FL340, at a range of approximately 25nm. Although a controller Member commented that it is not unusual in certain circumstances for controllers to climb ac to the same level prior to issuing further instructions, it was apparent to the Board that in doing so in this instance, the ac were placed on conflicting tracks with little distance to go before they merged. However, the Board agreed that, on subsequently identifying the potential conflict, the Montrose controller took timely action in issuing appropriate avoiding instructions to both ac. Had the pilots complied with these instructions, simulation indicated that separation would not have been lost.

The Board then turned its attention to the pilots' actions following the issue of the avoiding instructions. It was apparent that both crews had taken each others' instructions, and the Board found it hard to determine why this had occurred; unfortunately no Human Factor report was available from either crew. The Board was surprised that all four pilots had misheard or misinterpreted the avoiding action instructions despite at least one of the crews reading them back correctly. One airline pilot Member wondered if there could have been callsign confusion; this was discounted because they were not similar, nor could they have been confused with heading information - ATSI confirmed that the transmissions were clear on the RT recording. Having discounted this, the Board considered other potential causes of confusion. It was possible that the crews may have been distracted because this would have been about the time that they would have been receiving their Oceanic clearances on data-link. Another possibility mooted by an airline-pilot Member was that, having settled into their trans-Atlantic routine, it was unusual for pilots to be issued with avoiding action instructions at that altitude and location. Expecting only routine information to be transmitted at that time, they may have been perplexed by the avoiding action information and instinctively responded without properly assimilating it. He also noted that, during simulation training, avoiding action was only practiced as a result of a TCAS alerts, and not as a result of ATC instructions; this was an important consideration as to their potential familiarity with receiving, assimilating and actioning such RT instructions in a timely manner.

The next question that concerned the Board was the action of the B747(1) pilot ,who had turned his ac towards the B747(2). From the information available, it was unclear whether the B747(1) pilot had had B747(2) in sight before or after he turned. Irrespective, a controller Member was disappointed that, contrary to requirements, the B747(1) pilot did not advise ATC that he was reacting to a TCAS RA once it had activated; he considered that the absence of this important information would affect controllers' actions in such situations.

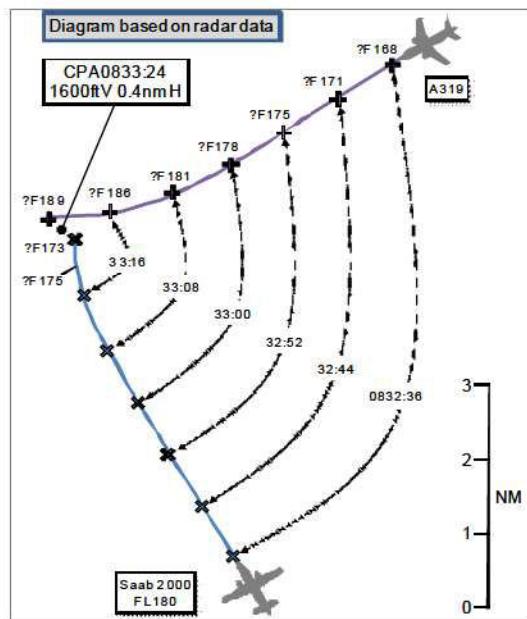
In considering the cause of the Airprox, the Board agreed that there were two issues involved; namely the actions of both the controller and the pilots. There was a prolonged discussion as to whether the controller's actions were part of the cause or were a contributory factor. Bearing in mind that his subsequent recovery actions, if taken, would have resolved the confliction, it was decided that they were a contributory factor. The Board considered that the pilots' actions, by flying each other's avoiding action ATC instructions, caused the Airprox. As to the risk, because B747(1) had B747(2) in sight as it was turning towards it, and both ac reacted to TCAS RAs thereby establishing standard vertical separation by a horizontal distance of 2.8nm, the Board opined that there was no risk of a collision.

## PART C: ASSESSMENT OF CAUSE AND RISK

<u>Cause:</u>	The pilots of ac on converging tracks flew into conflict because, although they acknowledged timely avoiding action, they did not follow it.
<u>Contributory Factor(s):</u>	The Montrose T & P climbed the ac to the same level.
<u>Degree of risk:</u>	C.
<u>ERC Score:</u>	102.

**AIRPROX REPORT NO 2012094**

Date/Time: 3 Jul 2012 0833Z  
Position: 5552N 00405W (12nm E Glasgow)  
Airspace: Scottish TCA (Class: A)  
Reporting Ac Reporting Ac  
Type: Saab 2000 A319  
Operator: CAT CAT  
Alt/FL: FL180 FL170  
Weather: VMC CLAC VMC NK  
Visibility: >10km 10km  
Reported Separation:  
  0ft V/0.5nm H 0ft V/500ft H  
Recorded Separation:  
  0ft V/2.4nm H 1600ft V/0.4nm H

**BOTH PILOTS FILED****PART A: SUMMARY OF INFORMATION REPORTED TO UKAB**

**THE SAAB 2000 PILOT** reports operating a scheduled passenger flight under IFR in VMC, level in the cruise at FL180, heading 355° at 360kts, with a RCS from ScATCC [from the Talla SC]. He was flying a white and blue ac with external lights and strobes selected on. The SSR transponder was selected on with Modes A, C and S selected. TCAS was also fitted. Climbing traffic appeared on the TCAS display [the subject A319] at a range of 5-10nm in the 1 o'clock position and 1200ft below. The traffic continued to climb towards him, becoming proximate when less than 1000ft below his level. ATC then transmitted 'avoiding action, turn left, he thought, onto 090°'. As the autopilot was disengaged and a R turn onto 090° started, a TCAS TA 'traffic traffic' warning was issued, immediately followed by RAs 'monitor vertical speed' and then 'descend descend', which were followed. The conflicting ac was observed directly in front of him, turning R and climbing. The RA ceased and the ac was recovered to the assigned FL and heading.

He assessed the risk of collision as 'Medium'.

**THE A319 PILOT** reports operating a scheduled passenger flight under IFR [with a RCS from the ScATCC Galloway SC], on the initial climb passing FL170, heading 240° at 290kts, and cleared to FL250. During the climb he observed a TCAS TA warning and became visual with the conflicting traffic. ATC issued an avoiding turn R on to heading 300° which was followed by TCAS RAs of 'adjust vertical speed' and 'monitor vertical speed' with a demanded climb of 3000fpm for a short while. This was followed by a vertical speed demand of zero as he passed clear of the conflict.

He reported the severity of risk to the ac as 'Nil'.

**THE GALLOWAY CONTROLLER** reports that he was working Galloway combined with a planner available. He stated that traffic was moderate, occasionally busy, but not unmanageable; that there were departures from Glasgow and Edinburgh, all requiring vectoring and stepped climbs, and that Edinburgh outbound traffic was requiring higher levels as there were several diversions from the N due to poor weather at Aberdeen. He co-ordinated the Saab 2000 at FL180 with the Talla SC, from the original planned level of FL240, routeing to FOYLE from MARGO direction. He took this flight in to consideration for several departures that would be crossing the aircraft's track. The A319 was transferred from Edinburgh on a heading, climbing to FL110 as per co-ordination. He knew prior to the A319 coming on frequency that the Saab 2000 was factor traffic but couldn't explain why he

## AIRPROX REPORT No 2012094

gave the A319 a straight climb to FL250. He stated that he did not know why he had forgotten about the conflict. As the ac converged, STCA activated white with the A319 passing about FL160. He immediately tried to stop the A319 at FL170 but Mode C indicated this was not going to be achievable so he issued an avoiding action turn [R] on to 290°, further increasing to 300° with TI. The A319 pilot advised that he had a TCAS RA and was visual with traffic; in the background he heard the autopilot disconnect alarm on his RT. He advised the pilot he was under his own control. He also heard the Talla SC issuing avoiding action to the Saab 2000 and let him know that the A319 was taking TCAS avoiding action. The STCA turned red for several sweeps as the A319 increased climb rate to pass above the Saab 2000. Once clear of conflict, a revised heading was given and the A319 transferred to DCS. He advised the pilot that he would be filing on the incident. The pilot responded that there was no problem. The Galloway SC stated that he couldn't think of 'any good reason' as to why he didn't take account of the Saab 2000 when climbing the A319, having already identified that there was a possible conflict. He also reported that he had no distractions, that it was 'known traffic' and he had already assessed in my mind that there would be a possible conflict, that workload was busy but not excessive, that he was not fatigued and that he had recency on the sector.

**THE TALLA CONTROLLER** reports working as a combined T & P on the Talla sector with light to moderate traffic. He had taken over the sector approximately 10min before the incident. During the handover, the outgoing controller had said that he had coordinated the Saab 2000 with the Galloway controller at FL180. The outgoing controller said that 'he should point out the Saab 2000 to Galloway again when it was further N, just to confirm whether Galloway wished to work it or not'. When the Saab 2000 was in the vicinity of Lowther Hill he re-coordinated the Saab 2000 with the Galloway controller, specifying that it was locked on a radar heading and asked whether he wished to work it. The Galloway controller declined but said that he would climb his traffic with regard to the Saab 2000. His attention was then taken up by other traffic in his sector. A few minutes later, just after responding to traffic checking in on his frequency S of MARGO, he heard the Galloway controller giving an avoiding action R turn. He immediately looked up and saw that the STCA had activated between the A319 and his traffic, the Saab 2000, and, given that he had heard the Galloway controller turn his traffic R, he too gave the Saab 2000 an avoiding action R turn with TI onto, he believed, 090°. He did not receive a response so reiterated the avoiding action but he thought this transmission might have been 'stepped on' by the Saab 2000 querying the direction of the avoiding action turn. The Galloway controller told him that the A319 had received a TCAS climb instruction, shortly after which the Saab 2000 said that he had received a TCAS descent, which he acknowledged. Once vertical separation had been re-established, he advised the Saab 2000 to resume FL180 and proceed to FOYLE.

**ATSI** reports that an Airprox was reported 40nm S of GRICE when a Saab Scania AB 2000 (Saab 2000) came into proximity with an Airbus Industrie A319 (A319) at FL180. ATSI had access to both pilot reports, controller reports from the Galloway (GAL) and Talla (TLA) sectors and the ANSP's unit investigation.

The Saab 2000 had departed Leeds-Bradford and was IFR, inbound Inverness, in receipt of a RCS from the Prestwick Centre (PC) TLA sector on 126.300MHz. (Mode A code 5403). The A319 had departed Edinburgh for an IFR flight to London Heathrow and was in receipt of a RCS from the PC GAL sector on 124.825MHz. (Mode A code 5415).

The GAL controller described traffic levels as moderate and later stated that the sector was running smoothly at a level that required constant attention but was still easily manageable as a one-man operation. There were no operational or personal distractions. The controller was current on the sector and recalled being very comfortable with the session.

The Saab 2000 had been co-ordinated to transit the GAL sector, maintaining FL180 on a heading of 335°, and remaining in contact with the TLA sector controller.

At 0826:52 Edinburgh APP telephoned the GAL controller and requested co-ordination on the A319, which had just departed, against other traffic. The A319 was co-ordinated into the GAL sector climbing to FL110.

At 0829:34 the GAL controller called the PC West Coast sector and requested a higher level for an ac that had just departed Glasgow. FL250 was agreed and the call ended with the GAL controller affirming, "Roger flight level 250". As the GAL controller's call to West Coast terminated the A319 called on the GAL frequency climbing to FL110. The GAL controller responded immediately by instructing the A319 to continue on its heading and climb FL250. At this time the A319 was climbing through FL105, 30nm NNE of the Saab 2000.

Low-level STCA activated at 0832:34 between the Saab 2000 and A319. Four seconds later the GAL controller issued avoiding action, “[A319 C/S] stop the climb flight level 170 avoiding action turn right heading 290 degrees.” The A319 crew did not respond to this instruction and the ATSI recording indicated simultaneous transmissions. The first instruction was followed-up by the GAL controller with, “avoiding action turn right now heading three zero zero degrees traffic in your left one o'clock range five miles a thousand feet above.” The A319 pilot acknowledged the heading, reported visual with the Saab 2000 and informed the controller that a TCAS RA had been received.

The TLA controller issued an avoiding action turn to the Saab 2000 pilot at 0832:43, “[Saab 2000 C/S] avoiding action turn right now immediately heading zero nine zero degrees traffic right er half past one range of five miles right to left”. The instruction was repeated three times (there were several simultaneous transmissions) before the Saab 2000 pilot reported that a TCAS RA was being responded to.

Separation was lost at 0832:52 as the A319 climbed through FL175 in the Saab 2000 pilot's half-past-one position at a range of 4.6nm. Minimum distance between the two aircraft occurred at 0833:08 as the A319 climbed through FL181, 2.3nm from the Saab 2000 (see Figure 1 below). Separation was restored at 0833:20 as the Saab 2000 pilot descended through FL175 with the A319 crossing right to left through its 12 o'clock climbing through FL188.



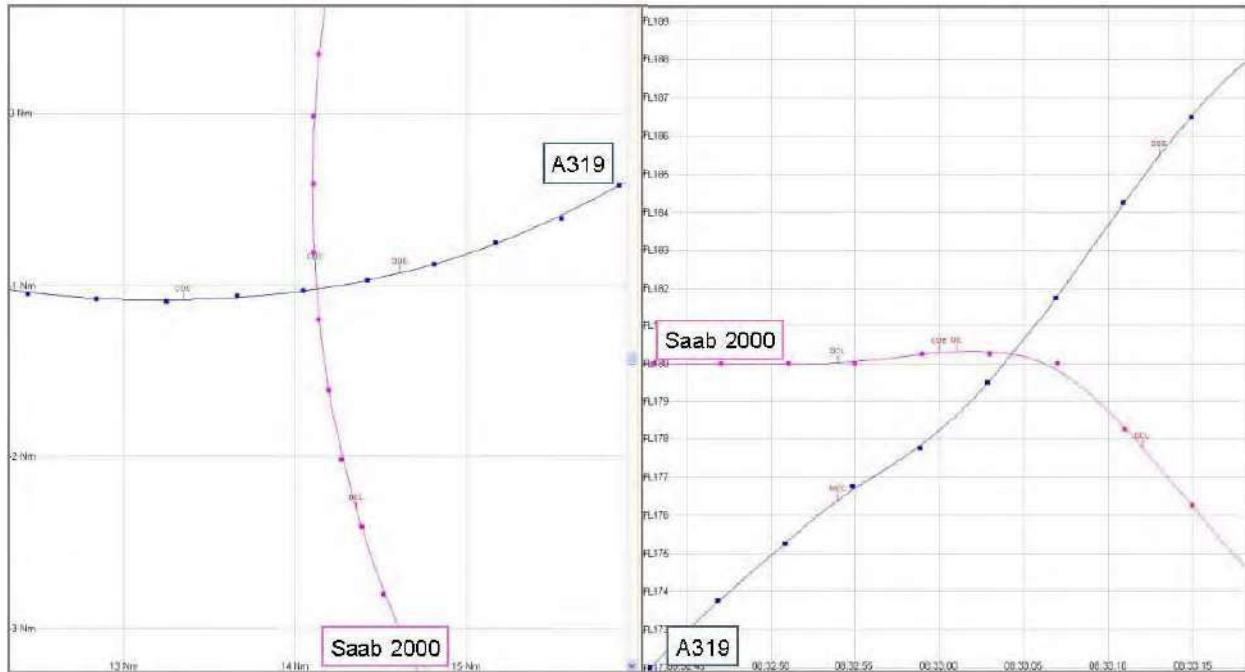
Figure 1: 0833:08 UTC (Prestwick Multi Radar Tracking)

The Airprox occurred 13nm E of Glasgow at FL180 when the GAL controller climbed an A319 through the level of a Saab 2000 without ensuring standard separation would be maintained.

[UKAB Note(1): The radar data that the diagram is based on shows that when range separation of 5nm was lost shortly after 08:32:48, altitude separation was reducing through approximately 650ft, as the A319 climbed through FL173 in the Saab 2000's R 2o'clock position. Minimum vertical separation occurred shortly before 0833:07 when the two ac were co-altitude at a range of approximately 2.4nm. Separation was restored at about 0833:18 as the Saab 2000 descended through FL177 with the A319 crossing R to L through its 12o'clock, climbing through FL187. At this point the range separation was 0.9nm. The minimum slant range occurred some 6sec later, at 0833:24, when the two ac were separated by 0.5nm.]

[UKAB Note(2): A comprehensive HF report was submitted as part of the ANSP's unit investigation and accepted by ATSI. The report covered the Galloway controller HF aspects of the incident in detail, using the Endsley (1999) Taxonomy of SA Errors. The report remained inconclusive in that no positive cause could be identified as to why the controller did not carry out his planned actions.]

[UKAB Note(3): The ANSP helpfully provided a TCAS review of this Airprox using the Eurocontrol Automatic Safety Monitoring Tool (ASMT) to analyse TCAS RA messages downlinked via Mode S (TAs are not downlinked) and the InCAS simulation tool. As TCAS interrogates once every second and the radar recordings used for the simulation give data update rates of up to 8sec intervals, interpolation is necessary. Hence, there can be variations between the InCAS simulation and what actually occurred in the cockpit. The InCAS simulation here used interpolated single source radar data from Glasgow. The main elements of this simulation are summarised herein.]



Encounter Diagram (Note that the square markers on the above image show the positions recorded by the Glasgow radar, while the solid lines show the InCAS-interpolated tracks)

Eurocontrol's Automatic Safety Monitoring Tool (ASMT) recorded several RAs relating to this encounter via Mode S downlink. [A319 C/S] received (in the following order) a Maintain Crossing Climb (MCC), a Keep Vertical Speed and an Adjust Vertical Speed. [Saab 2000 C/S] received an unknown type of RA, followed by Crossing Descend (CDE), Descend (DE) and finally an Adjust Vertical Speed.

The encounter was modelled in InCAS and equivalent RAs were produced with a maximum of two seconds difference between modelled RA time and actual RA time, indicating that the simulation is a reasonable representation of the actual encounter. The Mode S downlink received by the ASMT contains several pieces of information about an RA, from which the type of RA may be deduced. In some cases, these data do not translate directly into a specific RA type and the result is an 'unknown' RA. The data received relating to this unknown RA are consistent with a Don't Climb RA (DCL, enunciated 'Adjust vertical speed, adjust') as seen in simulation. The simulated time of the DCL advisory is within four seconds of the downlinked time of the unknown RA (which itself is only known with a 5 second confidence).

The InCAS modelled TAs were both issued at 08:32:35. From the NODE recordings, STCA activated at 08:32:34 with a low severity alert becoming high severity by 08:32:46. In the simulation, the Maintain Crossing Climb (MCC) and Don't Climb (DCL) RAs were issued at the same time. Shortly after the simulated time of the DCL, the Mode C of [Saab 2000 C/S] increased from reporting 18,000ft to 18,025ft for two radar cycles as shown.

Separation minima were as follows:

#### Minimum Lateral Separation

Min. Latsep Time	Horizontal Sep. (NM)	Vertical Sep. (ft)
08:33:22	0.47	1541

#### Minimum Vertical Separation

Min. Vertsep Time	Horizontal Sep. (NM)	Vertical Sep. (ft)
08:33:04	2.55	18

#### Closest Point of Approach (CPA)

CPA Time	Horizontal Sep. (NM)	Vertical Sep. (ft)
08:33:21	0.48	1505

## PART B: SUMMARY OF THE BOARD'S DISCUSSIONS

Information available included reports from the pilots of both ac, transcripts of the relevant RT frequencies, radar photographs and video recordings, reports from the air traffic controllers involved and reports from the appropriate ATC and operating authorities.

The Board initially considered the pilots' actions, given the adjacency of the sector controllers issuing avoiding action and the generation of TCAS RAs. It was agreed that avoiding action was issued just before each ac's TCAS alerted but in the light of multiple and potentially blocked and misheard transmissions, it was not possible to determine what was heard on each flight deck. Notwithstanding a potential degree of confusion, each pilot could be seen to implement a degree of avoiding action in response to their respective sector controller's transmissions after reacting correctly to their TCAS RA alerts. These combined actions ensured that separation minima were re-established in a timely fashion. The ANSP Advisor commented that, due to the airspace structure in the area, it was common for ac transits of the Galloway sector to take only a few minutes and that ac were therefore not routinely handed over to the sector controller in order to avoid RT congestion. He also noted that STCA was the primary safety trigger in this incident and that TCAS resolved the conflict.

Board Members also discussed ac handling techniques in these circumstances, specifically with regard to manual or autopilot (using autopilot heading selector) manoeuvring in azimuth. It was noted that there is no regulation covering the use or deselection of autopilot in response to an avoiding action turn. Civilian CAT pilot Members were of the opinion that prompt autopilot handling should suffice for most avoiding action instructions but that the SA of the crew played a critical role in the decision; manual handling should be used if the situation was urgent or there was doubt as to the extent to which separation minima had been breached. Civilian ATC Members commented that with older RT equipment it was possible for the controller to detect the interference of simultaneous transmissions, and hence mitigate the consequent risk, and that this was normally not the case with replacement RT equipment. A Member commented on increasing use of the word 'Blocked' by pilots who perceived that RT transmissions had not been received due to simultaneous transmission, law current CAP413 phraseology.

The Board considered the actions of the Galloway Controller and concurred that, as he had agreed coordination with the Talla controller, it was his responsibility to achieve deconfliction between the A319 and the Saab 2000. Members noted the contents of the HF assessment with interest. It was felt however that the Board did not have sufficient competence in HF to validate its conclusions. Regrettably, the Board concluded that it was not possible to establish a definitive reason as to why the Galloway controller did not account for the Saab 2000 when clearing the A319 to FL250, but that this was the Cause of the Airprox.

On the question of risk, the Board considered the degree to which safety had been compromised. It was agreed that separation had deteriorated to such an extent that it was the activation of STCA that provided the trigger to the subsequent controller issued avoiding action and TI. Subsequent to the STCA, it was not possible to establish the chronology of events with regard to pilot-flown avoiding action and TCAS RA compliance with absolute certainty but Members were satisfied that, whilst the degree of risk was probably marginally increased by the initial RT confusion, overall, effective and timely actions had been taken to prevent the risk of ac collision.

## PART C: ASSESSMENT OF CAUSE AND RISK

Cause: The controller cleared the A319 to climb into conflict with the Saab 2000.

Degree of Risk: C.

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Date de l'événement jj/mm/aa

Date de connaissance de l'évènement jj/mm/aa

Date de commission jj/mm/aa

## Type d'événement

*Mobile 1 et Mobile 2*



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## 1 Synopsis

### 1.1 Contexte général

jj/mm/aa ; hh/mn.UTC

Organisme(s) concerné(s):	Lieu géographique :
Type d'espace :	Classe d'espace :

### 1.2 Tenue de position

Position(s) concernée(s)		
Regroupée(s) avec		
Armement (ex : PC+stagiaire, 2PC ...)		
Prise de poste (Indiquer combien de temps avant l'événement ou en cours)		
Dégroupement/Regroupement (Indiquer combien de temps avant l'événement ou en cours)		

### 1.3 Types d'alertes et de manœuvres engagées

#### Alerte(s) ATM SOL :

(STCA, APW, MSAW, RIMCAS...)

	<i>Mobile 1</i>	<i>Mobile 2</i>		
<b>Alerte(s) bord</b> (ex : GPWS, TA-TCAS, RA-TCAS...)				
<b>Type de manœuvre d'évitement bord</b> (ex : montée, descente, virage droite...)				
<b>Visuel avant évènement</b>				
<b>Séparation minimale</b> (selon pilote)	<b>H = NM</b>	<b>V = ft</b>	<b>H = NM</b>	<b>V = ft</b>

*Au point de séparation minimale : (ELVIRA ou EPOQUE précisez) à HHhMM'ss''*

<b>Quasi CFIT</b> (selon enregistrement radar)	Distance minimale par rapport au sol = ft	
	Ecart par rapport à l'altitude minimale de sécurité : ft (ex : écart observé par rapport à l'AMSR, le GLIDE,etc ...)	
<b>Séparation minimale</b> (selon enregistrement radar)	<b>Horizontalement = NM</b>	<b>Verticalement = ft</b>

*Commentaires :*



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	<i>Mobile 1</i>	<i>Mobile 2</i>
<b>1.4 Configuration des vols</b>		
Vitesse Sol (précisez l'unité)		
Altitude au QNH ou FL(1013)		
Dernier niveau clairé		
Configuration (ex : montée, descente, palier ...)		
Phase de vol (ex : «roulage», approche finale, ...)		
<b>1.5 Informations sur les vols</b>		
Type d'appareil / véhicule		
Exploitant		
Aérodrome de départ		
Aérodrome de destination		
Nature du vol		
Type de circulation		
Régime de vol		
Contact radio		
Transpondeur		
Conditions de vol (selon pilote)		

**1.6 Messages associés** Notification immédiate       NES       ASR       FNE       Dépouillement système

Commentaires :



## 2 Chronologie des faits établis

### ATIS

*Si déclenchement STCA, APW, RIMCAS, MSAW, précisez les heures de début et de fin de chaque alerte.*

## 3 Analyse

*Précisez l'instance d'analyse : QS/S, suivi sécurité exploitation, l'AREX ou commission locale de sécurité et/ou mixte.*

*Indiquer ici les éléments prépondérants ressortant de l'analyse de la commission.  
Appréciation argumentée de la charge de travail (volume et complexité du trafic, ...)*

## 4 Cause(s) et Facteur(s) contributif(s) de l'événement

### 4.1 Causes

### 4.2 Facteurs contributifs

## 5 Classement de l'événement

Gravité ATM globale	Gravité ATS	Probabilité de nouvelle occurrence	Niveau de dysfonctionnement technique
A = Incident grave B = Incident majeur C = Incident significatif D = Gravité non déterminée E = Aucune incidence sur la sécurité	a = Très importante b = Important c = Modérée d = Gravité non déterminée e = Nulle	1 = Très élevée 2 = Élevée 3 = Significative 4 = Faible 5 = Très faible 0 = Non déterminée	aa = Incapacité totale a = Incapacité majeure b = Incapacité partielle c = Mode dégradé d = Indéterminé e = Aucune incidence

## 6 Enseignements tirés de l'analyse de l'événement

### 6.1 Mesure(s) prise(s)

### 6.2 Mesure(s) proposée(s) au niveau local

### 6.3 Mesure(s) proposée(s) au niveau national



## 7 Annexes

*Remarques :*

- *Ces annexes sont renseignées en fonction de leur intérêt pour l'analyse de l'événement.*
- *Pour les évènements classés « a/1 à 3 » ou « b/1 à 2 » ou » c-1 » ou présentés en ITES ou CMSA, les annexes 7.1, 7.2, 7.3, et 7.6 sont nécessaires.*



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**7.1 Transcription Radio et si nécessaire teneur des conversations téléphoniques**

**Fréquence (préciser) du secteur (préciser le secteur la position de contrôle) regroupé avec  
(Préciser la situation de dégroupement / regroupement)**

Station émettrice	Station destinatrice	Heure UTC (HHMMSS)	Communications	Observations

La durée de la transcription est de (nombre de minutes) minutes.

Je soussigné : (Nom et prénom), responsable de la transcription, certifie que la présente transcription a été effectuée sous ma direction, qu'elle a été examinée et vérifiée par moi.

Fait à (nom de l'organisme) le (date)

Signature

**7.2 Trajectographies****7.3 Déclarations contrôleurs /pilotes****7.4 Conditions de vol / Météo****7.5 Etat des moyens techniques****7.6 Participants à la commission locale****7.7 Autres données jugées utiles**