University of Glasgow | School of Computing Science

Using a 3D Visualisation to Enhance Users Perception of Aircraft Noise in the Vicinity of Airports

Michael A. Roddy

School of Computing Science
Sir Alwyn Williams Building
University of Glasgow
G12 8QQ

Level 4 Project — March 27, 2015

Abstract

The noise created by aircraft arriving or departing from airports is one of the major concerns for members of the public who live in the vicinity of the airport. One method of helping people understand how aircraft noise could potentially effect them is to use maps of the area with noise contour lines superimposed on top of the map. This report details a 3D visualisation aimed at helping users perceive potential noise levels better than if they were to such contour maps. This 3D visualisation can be focused on any location in the world and also incorporates both satellite imagery and terrain elevation data. The system is designed to be extensible, allowing more complex noise calculations to be introduced in the future. The evaluation shows that the 3D visualisation's performance matches that of contour maps.

Education Use Consent

I hereby give my permission for this project to be shown to other University of Glasgow students and to be distributed in an electronic format. **Please note that you are under no obligation to sign this declaration, but doing so would help future students.**

Name: ____________________ Signature: ____________________

Acknowledgements

I wish to thank Chris Johnson for his continued support throughout the year. Edward Weston and Darren Rhodes from the ERCD at the CAA, for their invaluable contribution of knowledge and sample data to the project. Sean Cleary and Rhian Williams from NATS Prestwick for their advice and guidance during the requirements and evaluation phase. I'd also like to thank all those who took time to participate in the evaluation.

Contents

1 **Introduction and Background** **1**

1.1 Aims and Motivation . . . 2

1.2 Background . . . 2

1.2.1 Methodologies . . . 2

1.3 Noise Modelling . . . 2

1.3.1 Noise Sources . . . 3

1.3.2 Grid . . . 3

1.3.3 Noise, Power, Distance Curves . . . 3

1.3.4 Noise Calculation . . . 4

1.3.5 Installation Effect . . . 5

1.3.6 Lateral Attenuation . . . 5

1.3.7 Existing Software Implementations . . . 6

1.4 Applications . . . 8

1.4.1 Nice Airport & EGNOS . . . 8

1.4.2 Virtual Reality . . . 8

2 **Requirements** **9**

2.1 Requirements Gathering . . . 9

2.1.1 Previous Work . . . 9

2.1.2 Initial Requirements . . . 9

2.1.3 CAA Interview . . . 10

2.1.4 NATS Interview . . . 10

2.2 Functional Requirements 11
2.3 Non-Functional Requirements 12

3 Design **13**
3.1 Previous Versions 13
3.2 Simulation 13
3.3 System Architecture 14

4 Implementation **16**
4.1 Tools 16
    4.1.1 Java 16
    4.1.2 JME3 16
    4.1.3 Google APIs 16
4.2 Program 17
    4.2.1 Scene Graph 17
    4.2.2 Grid Generation & Terrain 17
    4.2.3 Model 20
    4.2.4 Displaying Levels 22
4.3 Results 23

5 Evaluation **25**
5.1 Hypothesis 25
5.2 Approach and Technique 25
    5.2.1 Introduction 25
    5.2.2 Evaluation Sections 26
    5.2.3 Tasks 26
    5.2.4 Notes 27
5.3 Analysis 27
    5.3.1 Choice of Analysis Method 28
    5.3.2 Results 28

5.4 Usability 30
    5.4.1 System Usability Scale (SUS) 30
    5.4.2 Feedback 30
    5.4.3 NATS 31
5.5 Evaluation Conclusion 31
    5.5.1 Potential Flaws 32

6 Conclusion **33**
6.1 Future Work 33
6.2 Conclusion 34

Appendices **35**

Acronyms

- **AERC** - Aviation Environment Research Centre
- **AIRPROX** - Aircraft Proximity Event
- **ANP** - Aircraft Noise and Performance database
- **ANCON** - Aircraft Noise Contour Model
- **CAA** - Civil Aviation Authority
- **DGAC** - Direction gÃl’nÃl’rale de l’aviation civile (French Aviation Authority)
- **ECAC (CEAC)** - European Civil Aviation Conference (ConfÃl’rence EuropÃl’enne de l’aviation Civile)
- **ESA** - European Space
- **ERCD** - Environmental Research and Consultancy Department (CAA)
- **FAA** - Federal Aviation Administration
- **INM** - Integrated Noise Model

Chapter 1

Introduction and Background

The main consequence of living in the vicinity of an airport is typically the noise produced by arriving and departing aircraft. This is a common concern for the public as the noise from airport operations stretches far beyond the grounds of the airport; indeed it can stretch along the flightpath for many kilometres as seen in Figure 1.1. The fact that many airports also have a high turnover of flights throughout the day only exacerbates the problem as the public find themselves dealing with the frequent aircraft noise as part of their daily lives. Since aircraft in use today produce high levels of noise, mainly from their engines, the noise associated with airports is and will continue to be a concern to the public in the coming years. In the future, aircraft are likely to run at reduced levels of noise, the Clean Sky initiative already has concepts for aircraft running at levels of noise 50-80% quieter than today[24]. Until and even including then however, it is still important to be able to model aircraft noise as it is an element which can never fully be removed from airport operation.

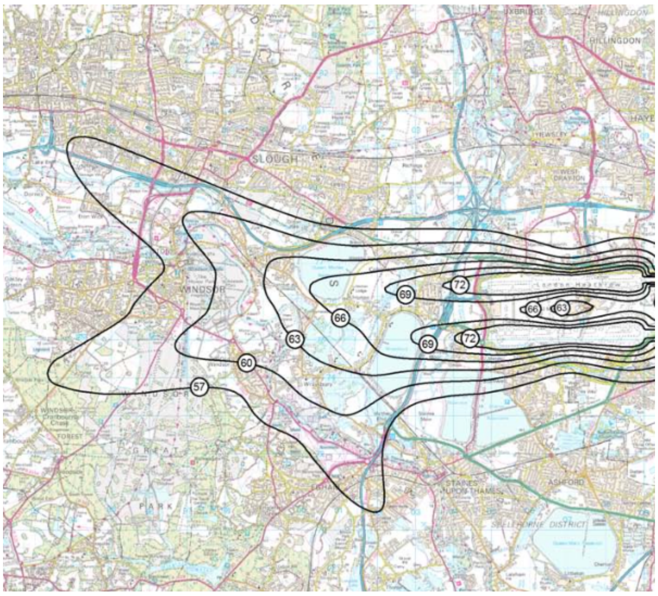


Figure 1.1: Noise levels around London Heathrow

It is also important to address the concern of noise as the aviation industry constantly grows year on year, with commercial usage forecasted to rise by 1-3% yearly until at least 2050 in the United Kingdom [12]. At this rate, many airports could find themselves reaching full capacity, requiring the construction of extensions or entirely new airports. In this case, the ability to predict noise will be one of the key concerns for the public as new runways and airports invariably create additional noise in the surrounding area.

1.1 Aims and Motivation

Through decades of research, it is possible to provide good models of aircraft noise which can be used to make accurate predictions. The contoured output seen in Figure 1.1 is one of the most common methods for conveying noise levels. Yet whilst intuitive enough to follow, this approach may not fully allow the user to grasp quite how loud the noise level at a particular point will be and then estimate the resulting annoyance.

The aim of this project is to create a tool which expands on the common 2D noise contours by producing a 3D visualisation instead. The intention is that by providing users with a 3D visualisation which they can interact with, it will provide a better understanding of the how the noise from an aircraft propagates to the surrounding area and as a result provide the user with a better ability to perceive how loud aircraft noise might be at a given point.

1.2 Background

1.2.1 Methodologies

In 1986, the European Civil Aviation Conference released ECAC.CEAC Doc 29 [9] which details methods for calculating aircraft noise. The document has become standard in the field and even to this day is the basis of models used by authorities worldwide such as the CAA and FAA [17]. It consolidates many techniques and algorithms into a single document and discusses some of the necessary simplifications that must be made to conduct a feasible noise study, since there are often too many variables to contend with. The focus is on commercial aviation and specifically jet-powered aircraft although with appropriate data to work from, the methods can be applied to propeller aircraft. The document however cannot be applied to rotor-craft as they produce distinctly different noise patterns.

ECAC Doc 29 works from a set of baseline noise levels tabulated as a function of power level and distance which can be found in the Aircraft Noise and Performance (ANP) database. These tabulated values come from real measurements made from underneath overhead aircraft. These baseline values are then augmented to account for different acoustical effects which commonly affect the propagation of aircraft noise. The specific methodology can be found in section 1.3 Noise Modelling.

There are other techniques used to model aircraft noise, such as the Japanese AERC method. This method is similar to ECAC Doc 29 in many respects but differs in certain areas. For example, with AERC different sound source models can be chosen such as omni-directional or cardioid whereas ECAC Doc 29 only accounts for a dipole sound source [14]. AERC also disregards certain acoustical effects, such as engine installation effect or aircraft banking. Unlike the equations in ECAC Doc 29, the AERC method draws aircraft performance data directly from the airlines instead of from the ANP database.

Since it is the more widely used method and therefore more well documented, this project bases itself on the methodology and equations presented in ECAC Doc 29.

1.3 Noise Modelling

The following information was gained from an interview held with the Environmental Research and Consultancy Department (ERCD) of the CAA. The techniques described are based off of those in described in ECAC Doc 29.

It was not feasible to consider all the possible factors described in ECAC Doc 29, the ones that are included here however are the most pertinent.

1.3.1 Noise Sources

Trying to model sound accurately is very complex and even defining a suitable audio source to use for an aircraft is complicated. Aircraft have two main sources of noise, the engines and the body. Each of these have internal components which also contribute to the overall noise. The engines are the loudest, for example they have the fan, which outputs across a range of spectral frequencies. They also contain a compressor, which is typically a quieter component. The jet and jet internals are other sources within the engines, typically radiating sound in different directions at different frequencies.

A basic approach is to assume a singular source for the whole aircraft. In this case, we suppose that there is an acoustic power value propagating outwards from the aircraft's position into 3D space.

1.3.2 Grid

Noise levels are calculated by traversing a grid of points on the ground and calculating a noise level at each. From this grid, a contour may be interpolated between each of the grid points. The spacing between grid points is important, if the points are too coarse then this can result in poor estimates since a large interpolation must be made between each point. Grids which are too fine suffer from being computationally time consuming. The CAA use a 100m grid spacing for their calculations. For smaller models, grids of 10m may be used, despite their complexity, they can be very accurate and can model shadow-zones behind obstacles. The CAA's contours for Heathrow are based over a 80×50km area using a 100m grid spacing and even in this case, run-times can extend to a number of days.

Recursive Grids

One solution to long run-times is the use of a recursive grid. Such grids work by measuring the rate of change of noise levels across grid points and if the change is greater than a given threshold, that section of the grid is subdivided for further accuracy. The advantage of this approach is that in areas where there is little change, such as at a distance from the airport, less accuracy is required and so calculations are not wasted where interpolation would work just as well.

Recursive grids aren't widely used at the CAA. One common technique that is used is to calculate two different scenarios and then the resulting grids are subtracted from each other, so that any differences may be seen. Since recursive grids do not have a regular structure, this subtraction becomes more complicated as one of the grids must be interpolated to match the other.

1.3.3 Noise, Power, Distance Curves

Noise models based off ECAC Doc 29 use data from noise-power-distance (NPD) curves as baseline values in their calculations. NPD curves are sets of data which tabulate noise level values L_{max} to a given propagation distance d and power setting P. These curves are held in the Aircraft Noise and Performance (ANP) database where there are entries for multiple aircraft types, each at different settings. When looking up a value for a given d and P it is unlikely that the combination will appear in the table and it will be necessary to do an interpolation between the two nearest values to retrieve the desired answer (linear interpolation for power and logarithmic interpolation for distance) (see Figure 1.2). There are also equations available to extrapolate beyond tabulated values.

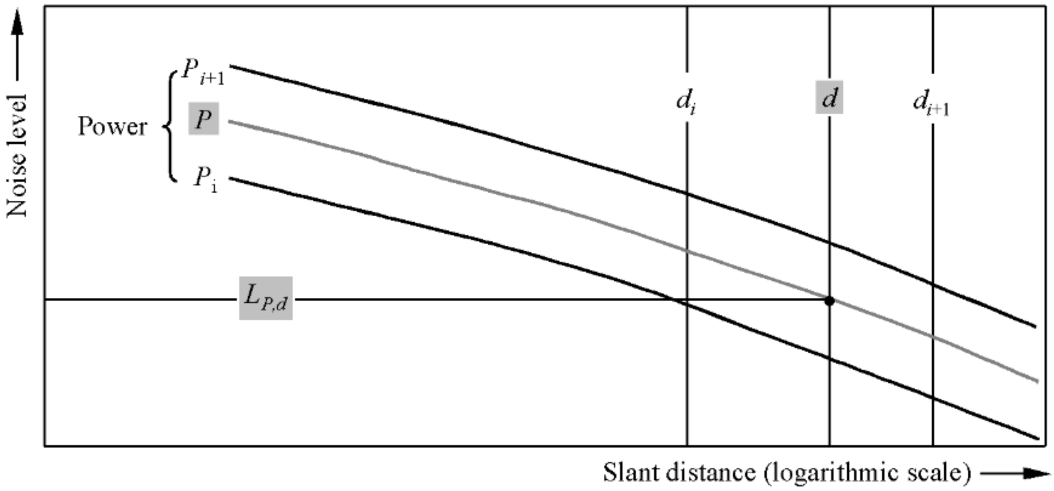


Figure 1.2: Interpolation of noise-power-distance curves. The values of P_i, P_{i+1} and d_i, d_{i+1} are tabulated values and two interpolations must be performed to retrieve the value of $L_{P,d}$.

1.3.4 Noise Calculation

To calculate a noise level at a grid point for a given aircraft position, the baseline value is read from the NPD tables and augmented by two additional factors, the installation effect $\Delta_I(\varphi)$ and lateral attenuation $\Lambda(\beta, \vartheta)$. This calculation must be carried out at each grid point.

$$L_{max} = L_{max}(P, d) + \Delta_I(\varphi) - \Lambda(\beta, \vartheta)$$

The values of d, ϑ and β can be found in the geometry laid out in Figure 1.3, as s_p, d_p and β respectively.

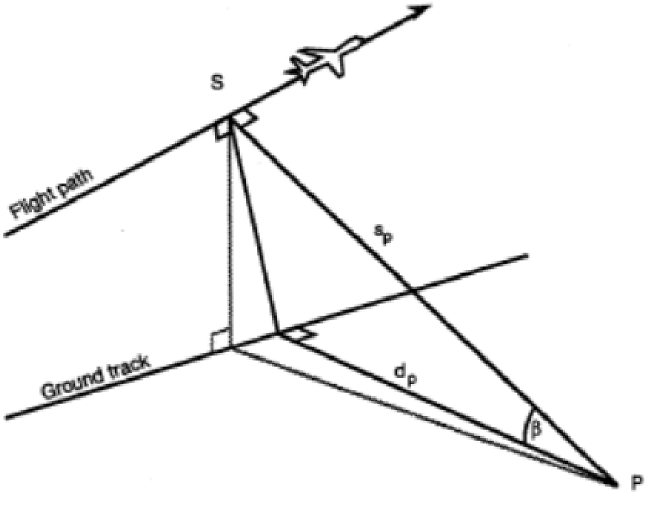


Figure 1.3: Necessary geometry for calculations [1]

1.3.5 Installation Effect

As described in section 1.3.1 Noise Sources, aircraft are complex sources of noise. The airframe configuration and particularly the engine placement greatly influence how noise radiates from the aircraft due to reflection, refraction and scattering off of solid surfaces. This effect is referred to *lateral directivity* and can be calculated with the following equation.

$$\Delta_I(\varphi) = 10 \cdot \lg \left[\frac{(a \cdot \cos^2 \varphi + \sin^2 \varphi)^b}{c \cdot \sin^2 2\varphi + \cos^2 2\varphi} \right] dB$$

Figure 1.4: Equation for lateral directivity

φ is the angle between the aircraft and the ground. The values a, b and c are parameters used to denote the positioning of the engines. For aircraft with wing-mounted engines, the values are $a = 0.00384, b = 0.0621, c = 0.8786$ and for fuselage-mounted aircraft the values are $a = 0.1225, b = 0.3290, c = 1$. Propeller aircraft are exempt from this effect as their sound propagates differently and therefore their lateral directivity is $\Delta_I(\varphi) = 0$. Figure 1.5 shows how the lateral directivity changes along the roll axis.

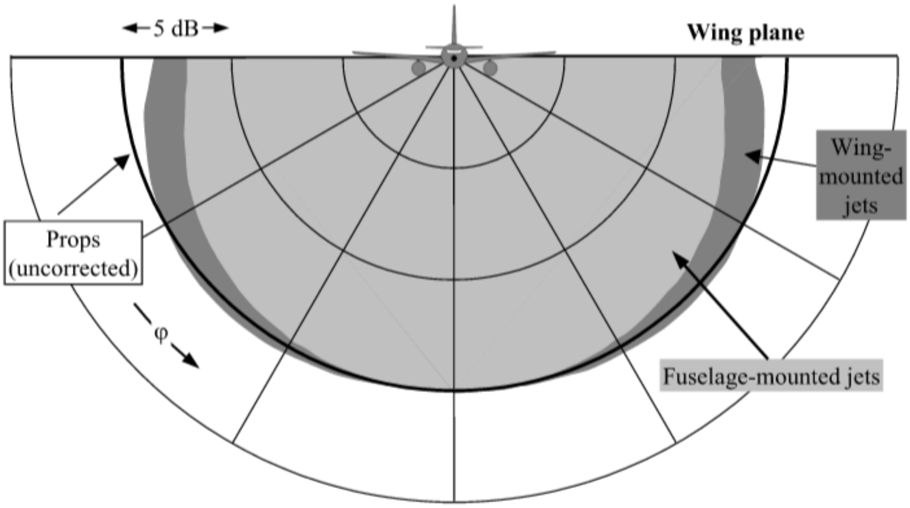


Figure 4-4: Lateral directivity of installation effects

Figure 1.5: Lateral directivity of installation effects

1.3.6 Lateral Attenuation

Another key effect that must be considered is *lateral attenuation*. The values in the NPD curves are from measurements made underneath the aircraft and do not account for any sideways dispersion of the sound. In most cases, the sound levels to the side of an aircraft will be lower than directly underneath it, this is lateral attenuation. It happens for a variety of reasons, such as directly radiated sound interfering with sound reflected from the ground. It can also be affected by temperature and wind speeds. Currently, there is not enough understanding of the process to provide a full calculation of its effects so it is estimated through a calculation (Equation 1.6) set out in AIR-5662 [22]. This lateral attenuation equation can be applied to all aircraft, propeller and both wing and fuselage mounted jets.

$$\Lambda\left(\beta,\vartheta\right) = \Gamma(\vartheta)\cdot\Lambda(\beta)$$

where:
$\Gamma(\vartheta) = 1.089 \cdot [1 - \exp(-0.00274\vartheta)] \quad \text{for} \quad 0 \leq \vartheta \leq 914m$
$\Gamma(\vartheta) = 1 \quad \text{for} \quad \vartheta \geq 914m$

$\Sigma(\beta) = 1.137 - 0.0229\beta + 9.72 \cdot \exp(-0.0142\beta) \quad \text{for} \quad 0° \leq \beta \leq 50°$
$\Sigma(\beta) = 1 \quad \text{for} \quad 50° \leq \beta \leq 90°$

Figure 1.6: Equation for lateral attenuation. ϑ is the distance between the aircraft and the grid point. β is the angle between the ground and the aircraft.

1.3.7 Existing Software Implementations

INM

One of the first and now most popular [17] implementations of ECAC Doc 29 is the Integrated Noise Model (INM), developed by the FAA [25]. The model began as a collection of programs in the 1970's and was consolidated into a single package in 1979. This version of the INM was written in FORTRAN and was released for general use by authorities worldwide. The INM has become the benchmark for aircraft noise modelling software and is used to this day around the world in countries such as Australia, Belgium, Greece, Hong Kong, Spain and the USA as well as other countries such as Denmark and Finland who use variants of the INM [17]. It is also used by over 1000 other organisations worldwide [13].

The INM is in Version 7 as of 2007 [13] and now includes features such as helicopter noise modelling. Other features include the ability to produce recursive grids as well as run multi-threaded to shorten runtimes.

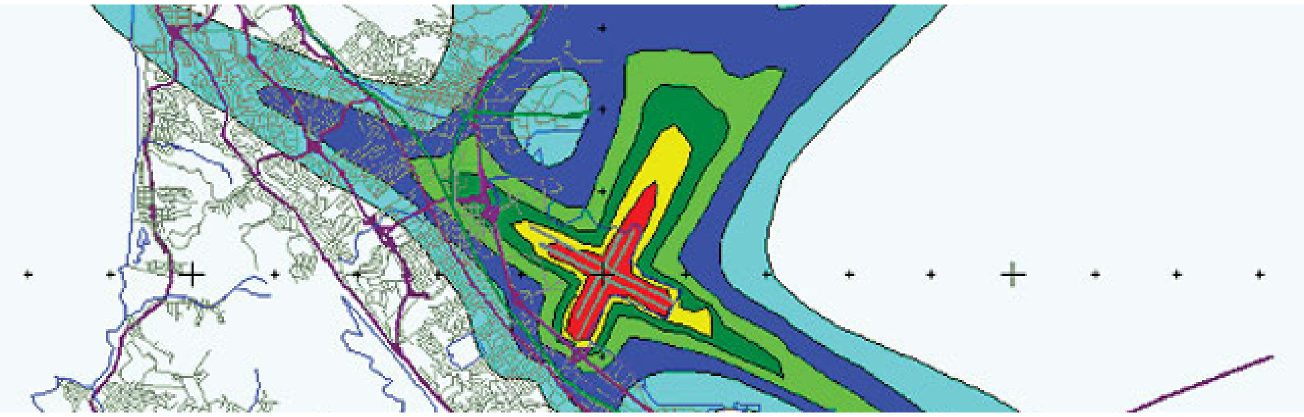


Figure 1.7: Integrated Noise Model output

ANCON

The Aircraft Noise Contour Model (ANCON) is a program developed by the CAA as an alternative to INM. It is based off of the same techniques as INM but the two can often produce different sets of contours given the same sets of starting parameters. The CAA note two main reasons for this [17]:

- **Flight Profile Data** In the INM, the default built-in flight profiles (the aircraft's descent or climb when arriving or departing) make certain assumptions about how the aircraft does so. INM assumes that aircraft which are departing do so at full power whilst following standard departure procedure for flap management. In reality, the CAA found that this was not the case in practice, airlines would typically use the minimum safe take-off speed instead to help preserve engine life (Figure 1.8). Flap management procedures also differed between airlines. As such, ANCON's profiles are based on empirical data to provide a more accurate flight profile for UK airports.

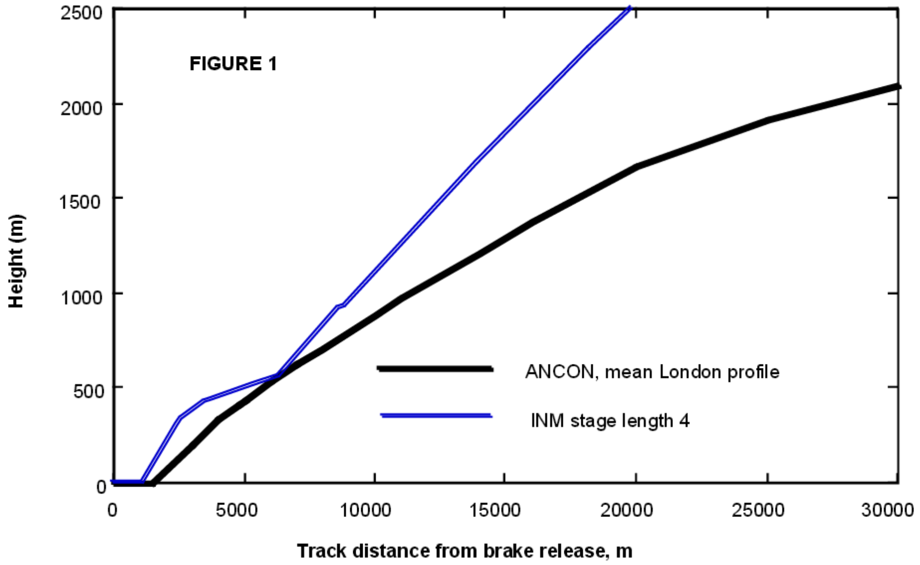


Figure 1.8: ANCON Flight Profile - Average height profile of B767-300

- **Noise, Power, Distance (NPD) Curves** Analysis by the CAA shows that over one third of aircraft movement in the London area do not have any corresponding NPD data in the INM database [18]. Instead, ANCON uses modified NPD curves for the specific aircraft types found flying in UK airspace. These curves are further enhanced by feedback from real noise measurements made around airports to further verify the NPD data. The difference between INM, ANCON and real measurements can be seen in Figure 1.9.

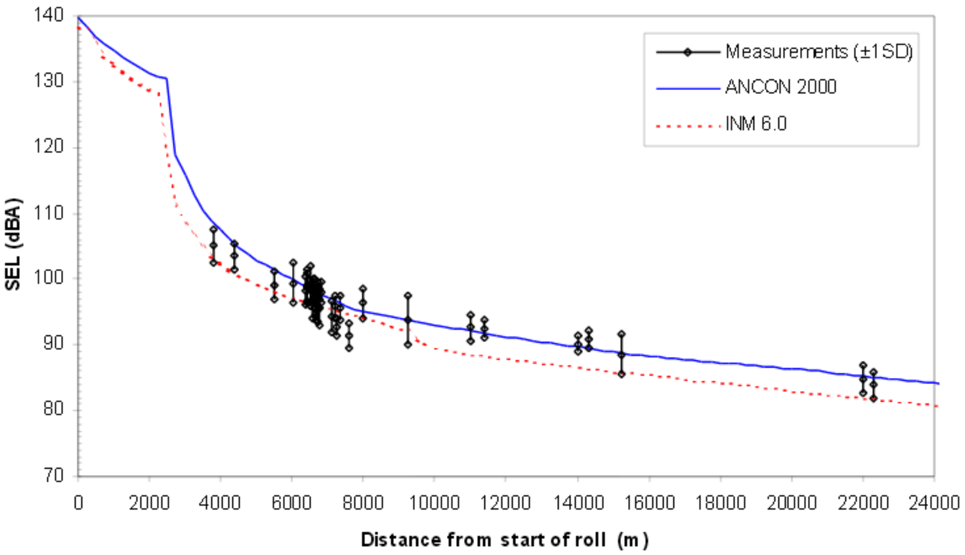


Figure 1.9: Predicted and measured levels vs distance from start of roll

1.4 Applications

Aircraft noise modelling has a range of applications other than just planning. Integration with new technologies gives the opportunity for many new and interesting applications.

1.4.1 Nice Airport & EGNOS

EGNOS is the European Geostationary Navigation Overlay Service and is an example of a satellite based augmentation system (SBAS) which can provide higher accuracy than GPS as well as the ability to determine vertical position. One usage for EGNOS is that of performing precision approaches to airports. Aircraft typically use ILS (instrument landing system) to guide their approach. The ILS system relies on radio signals as well as high-intensity lighting arrays to guide the aircraft towards the runway on a straight path.

In Nice, France, this ILS path passes over the Cap D'Antibes, a promontory little more than 10km from Nice airport. In an attempt to reduce noise over the town, EUROCONTROL in conjunction with the ESA and DGAC showed how EGNOS could be utilised to perform a precision approach which bypassed the Cap D'Antibes (Figure 1.10) [10]. These contours were produced using INM and were necessary to determine whether the suggested flight path would in fact reduce noise levels.

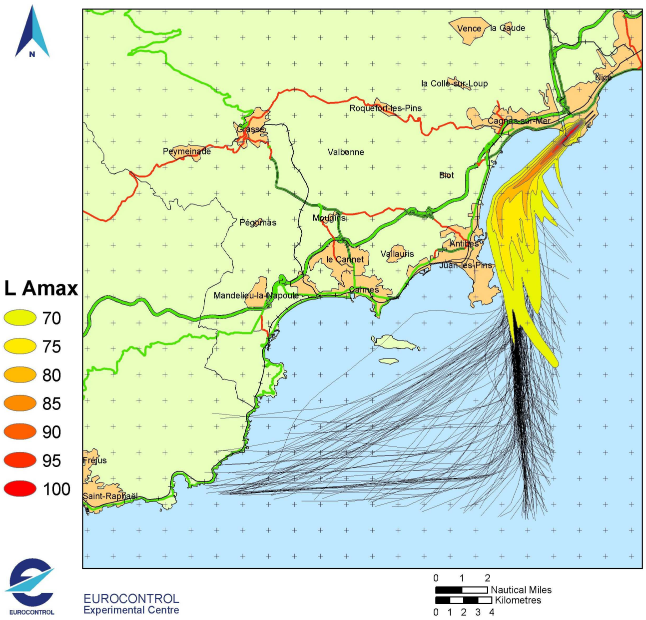


Figure 1.10: Precision approaches bypassing the Cap D'Antibes

1.4.2 Virtual Reality

Noise perception can be difficult to evaluate. Humans do not perceive all frequencies at equal volumes as the ear is less sensitive to lower frequencies. A decibel value on a contour map can be difficult to translate into a tangible sound. RWTH Aachen University has developed a tool to allow users to experience sound levels along with a visual representation of the aircraft in a virtual reality environment [5]. The project recognised that by giving users an audio-visual experience, it would allow them to gain an immediate impression of the annoyance caused by aircraft passing overhead.

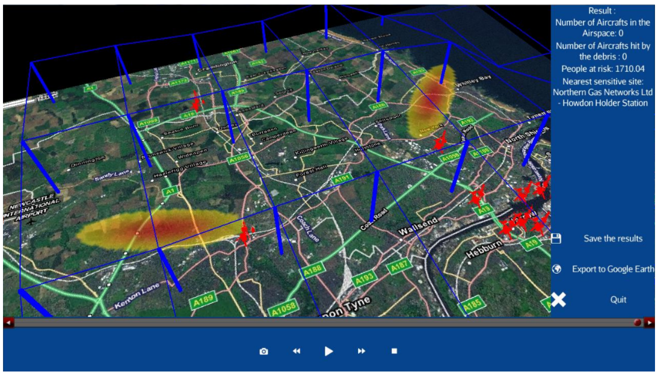
Chapter 2

Requirements

2.1 Requirements Gathering

2.1.1 Previous Work

When setting out requirements for the project, it was useful to look at previous projects from within the department concerning the 3D visualisation of aircraft. A prime example was simulator that modelled sub-orbital debris which later evolved into a AIRPROX[1] simulator (Figure 2.1). These programs shared similar functionality to this projects such as the 3D visualisation of an environment and the plotting of flight paths. Time was spent using this visualisation to gather potential requirements and also to see if and how it could be adapted for this project.



Result :
Number of Aircrafts in the Airspace: 0
Number of Aircrafts hit by the debris : 0
People at risk: 1710.04
Nearest sensitive site: Northern Gas Networks Ltd - Howdon Holder Station

Figure 2.1: Previous AIRPROX Simulator

2.1.2 Initial Requirements

The initial goal of the project was self-defined. The aim was to provide a tool which could be used in conjunction with precision approaches (see 1.4.1 Nice & Egnos), giving controllers the ability to quickly determine potential noise disturbances in the flight paths they were plotting. One application was to be planning night-time arrivals and departures. Most airports have restrictions on the times and types of flights permitted to arrive or depart at

---

[1] An AIRPROX is an air proximity event where the relative speed and position of two aircraft are such that the safety of the aircraft involved has been compromised.

night [6] and therefore our aim was to give airlines the ability convince the authorities that for a given night-time arrival, the noise to be mitigated sufficiently enough that they would be granted permission to fly after-hours.

2.1.3 CAA Interview

To further shape and also validate the requirements, an interview was held in December with the members of Environmental Research and Consultancy Department at the CAA's London offices. Whilst each airport handles their noise issues separately, the ERCD is performs much of the UK wide research into noise reduction. The ERCD use the ANCON noise model and were able to provide substantial insight into its workings. Alongside providing an understanding of the noise modelling process, they helped reshape the requirements for a tool they felt would have value to departments such as theirs. There was a strong interest in the project as there was discussion during the interview about the potential upgrading of their ANCON noise model in the near future.

The ERCD felt that being able to reproduce the current models in 3D would be a good aid for conveying information to the public and upper-management as it would provide a clearer and more intuitive explanation than the 2D contour maps currently. There was particular interest in using such a tool for public consultations, they spoke of the challenges they often had trying to convey potential noise issues to the public and media. It was acknowledged that trying to implement a full noise model was far beyond the scope of the project due to the time constraints of the project. From here there was discussion about the technical aspects of the project, specifically how noise models work and how this could be implemented into the project. This information can be found in section 1.3 Noise Modelling.

The department also offered to provide the necessary information for the techniques they had described. This included flight and thrust profile data for an Airbus A319 as well as the relevant NPD curves.

2.1.4 NATS Interview

With the requirements set out from the interview at the CAA, they were taken to NATS Prestwick for validation. Here, an interview was held with a human factors specialist and an air traffic controller. The requirements that had been laid out were reiterated for discussion. It was agreed that such a visualisation would be useful and could have many potential applications. Afterwards, a short demonstration was given of how the air traffic control devices worked which proved useful for determining the potential style and layout of the visualisation.

Shift in Requirements

?? The interview with the CAA was extremely helpful and fundamental in shaping the requirements. However, since this shift in requirements came almost halfway into the project, much work had already been done on the project. At this point, a prototype of the visualisation based on self-defined requirements was already almost complete. Since the project had been following the waterfall model[2], this seriously affected progression of the project since the waterfall development process does not provide much room for reiteration due to it being a sequential development model. Much of the initial work that was done was incompatible with the new requirements, particularly caused by the need to integrate new noise modelling techniques. Development had to begin again to accommodate for these changes and whilst some of the program could be carried over, much of it had to be rewritten. This would become a hinderence as the project progressed by putting serious time constraints on the implementation phase.

---

[2] The waterfall model is is a sequential development process which 'flows' downwards through the stages of: requirements, design, implementation, verification and maintenance

2.2 Functional Requirements

Functional requirements are used to determine the intended behaviour of the system. To document these requirements, the MoSCoW method was used. This is a management technique which is used to group requirements in terms of their importance to the system by categorising them as must have, should have, could have and would have.

Must Have

Requirements which must be satisfied in the final product for the solution to be considered a success.

Requirement	Description
Calculation of noise levels	The system calculates genuine noise estimates for each point on the terrain
Display aircraft and noise output	The system outputs the results of the calculations relative to the aircraft
Geographic information	The system provides geographic information for context
Time control	The user can investigate different points of the flight path

Should Have

Requirements that have a high-profile that should be included in the solution if possible.

Requirement	Description
Plotting custom flight paths	Users can plot their own flights paths to be calculated
Terrain	The system should provide elevation data on top of its geographic data
Additive levels	Contours at each point in time can be layered into a single contour spanning the entire path

Could Have

Requirements which are considerably desirable but not necessary.

Requirement	Description
Population Data	Population data is overlaid on the maps to allow deeper analysis
Save & Load Scenarios	Custom defined paths and contours can be saved to a file
Different Aircraft	Data to perform calculations with different aircraft types
Comparisons	Ability to compare two or more contours for differences
Noise Abatement Procedures	Data to perform calculations for different flight procedures

Would Have

Requirements which will not be included in the release but may be included through future work.

Requirement	Description
Audio Synthesis	Generation of audio with respect to a given location which the user can then hear
Multiple Paths	Combine contours from multiple paths over a period of time

2.3 Non-Functional Requirements

Non-functional requirements are used to denote non-behavioural qualities of the system.

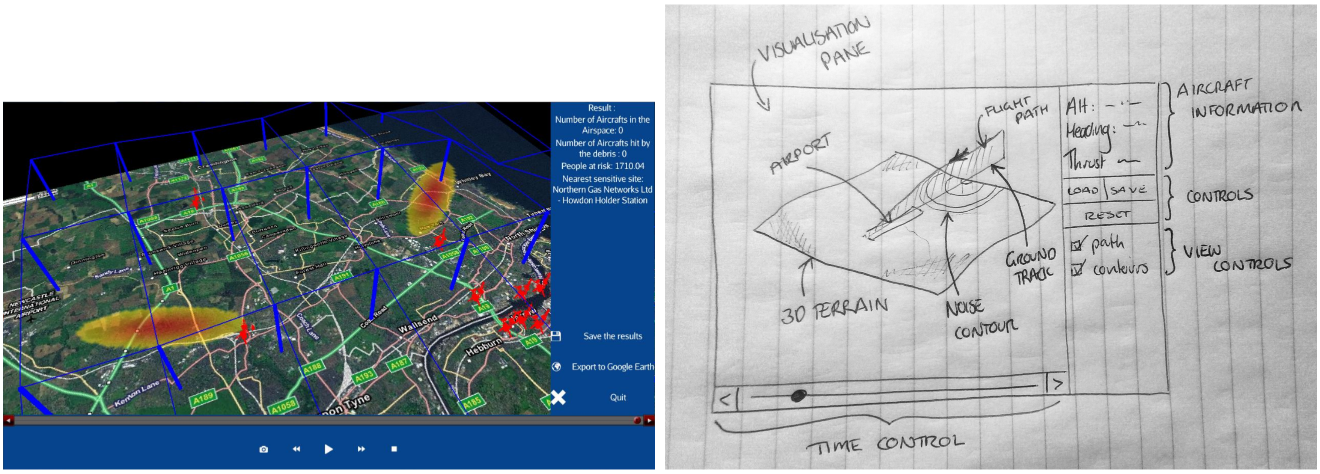
Requirement	Description
Modular design	The system (particularly the noise model) should be easily extendible and replaceable
Portable	The system should run on common operating systems (Windows, OSX and Linux)
Efficient	The program should not be computationally taxing
Ease of use	The program should be usable by untrained users

Chapter 3

Design

3.1 Previous Versions

As discussed in section 2.1.1 Previous Work, there are previous projects from within the department which relate to this one. The most relevant was the AIRPROX simulator which shared many features such as flight paths, geographic information, time control and 3D interactivity. It was written in Java, in conjunction with the 3D engine JMonkeyEngine3[3]. Without much knowledge of 3D visualisations in Java, this previous project was a prime place to start. The simulation can be focused at any world position, a feature that would be carried over to the noise simulation. The interfaces too would be very similar, with a view pane, time slider at the bottom and control panel to the left. The preliminary design wireframes show the similarity (Figure 3.1).


Result :
Number of Aircrafts in the Airspace: 0
Number of Aircrafts hit by the debris : 0
People at risk: 1710.04
Nearest sensitive site: Northern Gas Networks Ltd - Howdon Holder Station

(a) Previous AIRPROX simulator

(b) Wireframe design

Figure 3.1: Similiarity between previous projects and the design wireframes

3.2 Simulation

The simulation would be performed in a manner similar to the one described at the CAA (see 1.3). The simulation would be centred using a set of coordinates at any world position, from here the program would retrieve the relevant satellite imagery and elevation data to build a model of the terrain. As described in ECAC Doc 29, a grid of points would then be generated and overlaid onto the terrain, acting as markers to perform noise calculations at.

Once this preliminary setup was completed, the user can plot a flight path by clicking on the terrain. Once the path is laid out, the simulation will then generate contours for each potential point in time. The user can then use a slider at the bottom of the screen to move through each time step in the simulation. During this time, the user can also navigate around the visualisation and interact using the mouse to read off noise level values.

3.3 System Architecture

From the beginning, it was important to design with an extensible system architecture in mind. It was particularly important to ensure the code which performed the noise calculations was modular and could be replaced with different and more complex models in the future.

To do this, a model view controller (MVC) architecture was adopted. The MVC approach separates the program into three distinct components; the model for performing the programs main function, the view which displays the output and the controller which acts as an intermediary between the model and view. This is an appropriate architecture for this project as it too can be broken into similar components. In this project, an additional model is included, one model exists to contain and control the state of the simulation, containing objects such as the grid, terrain and flight paths. This first model is not designed to be modular, it is the framework for performing simulations, it is however extensible as it make use of other modular components. The second model is the noise model itself, which is called from the simulation. This particular model is designed to be modular. Figure 3.2 shows how MVC has been applied to this project.

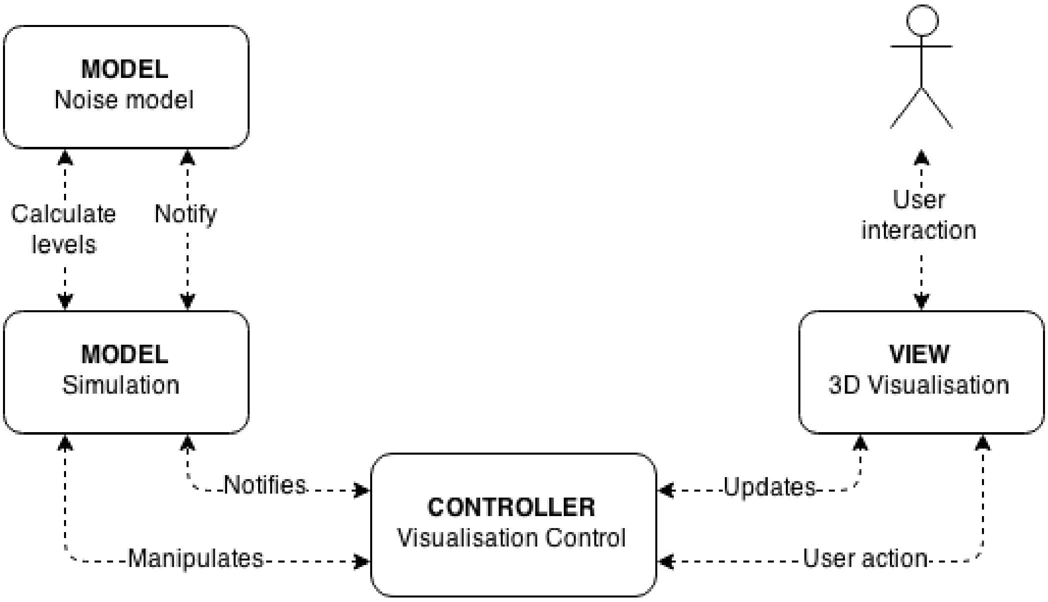


Figure 3.2: MVC architecture applied to the design

One main focus was that the noise modelling code was modular and therefore easily replaceable. Due to time constraints on the project, it would not be possible to implement a fully-featured noise model so it was important that there was a sufficient framework for replaceable models. Abstracting this functionality out to its own module is one way of doing this. The noise model should take an aircraft location and grid point and calculate the noise level there. It is also important that the noise model implementation has access to the simulation object itself, so it may make use of any other information the simulation contains.

The whole system architecture can be seen in Figure 3.3. This outlines all the major components of the system. As previously described, the `Simulation` is in control of the entire visualisation. It has a reference to an `Aircraft` object which contains information about the current aircraft being examined and its flight path if it has been plotted. Flight paths are stored as a list of the points users placed to create the path, these are then interpolated into a spline which uses these locations as control points and smoothly interpolates between them. The `InterfaceController` object is an additional class used by the visualisation to control the GUI.

The modular noise model can also be seen. It is recognised using an interface which requires noise model classes to implement the necessary `calculateLevel(...)` method.

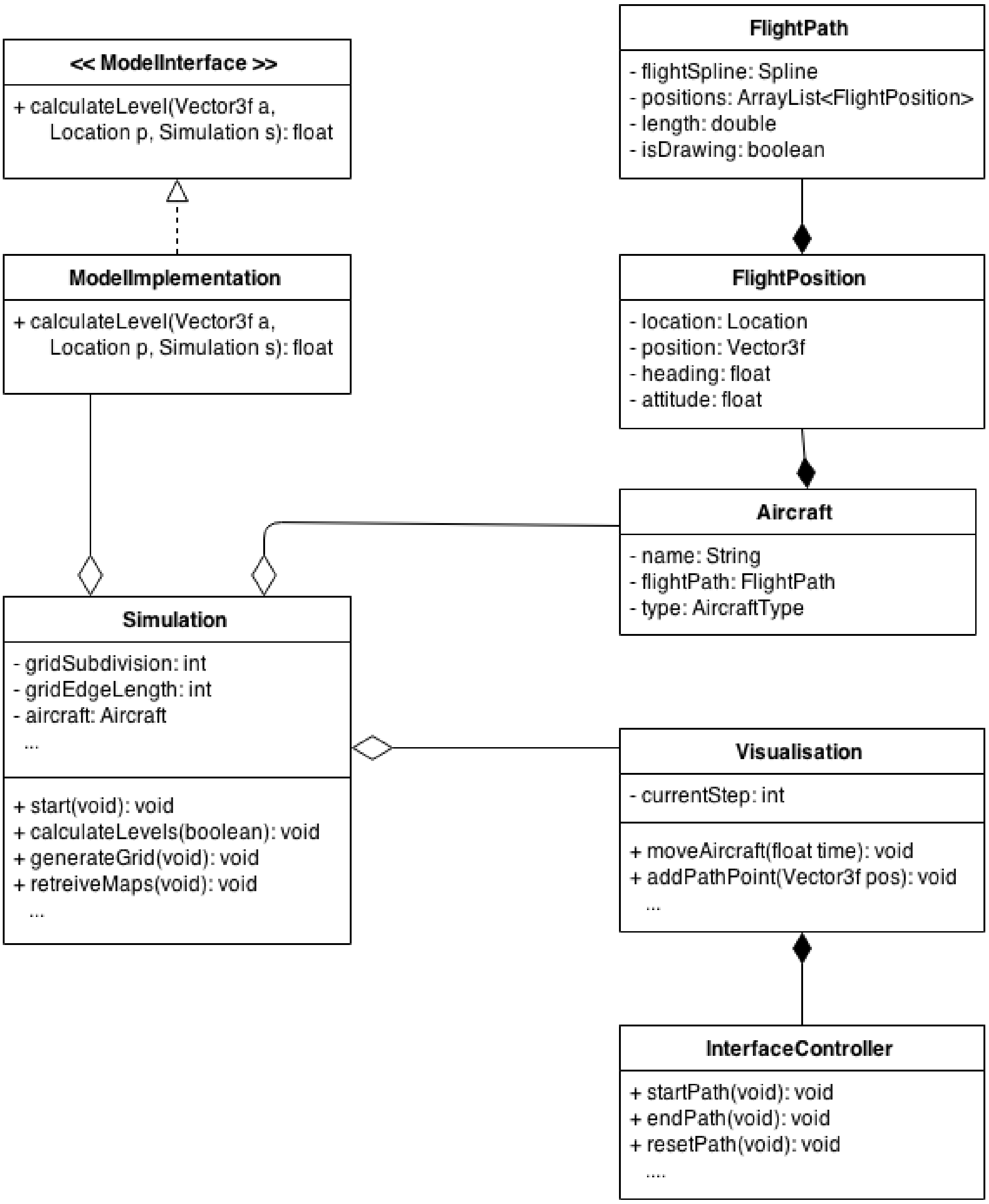


Figure 3.3: Class diagram of the system

Chapter 4

Implementation

4.1 Tools

Since there was access to the source code for the programs mentioned in 2.1.1 Previous Projects, it was beneficial to use the same technologies so that similar code and functionality could be inserted into this project.

4.1.1 Java

Java was initially used in previous projects due to the authors familiarity with the language. This is also the case for this project. Another advantage of using Java is its portability, which would help satisfy the non-functional requirement to run on multiple operating systems. There were other potential choices for language such as C++ which offers markedly increased performance but also comes with added complexity.

4.1.2 JME3

JMonkeyEngine3 is a Java based 3D development engine which provides 3D rendering capabilities. Again, JMonkeyEngine3 was used in previous projects and was therefore a good choice for this project as it would allow similar capabilities to be implemented directly from previous source code. As of 2015, JMonkeyEngine3 is still in continued development and has an active community. The wide range of in-depth tutorials was another reason that the engine was chosen.

Other possibilities were gaming engines such as Unity3D or UnrealEngine. These are well developed and widely used tools in the industy. Unity3D uses C# and UnrealEngine used C++, both languages which were unfamiliar which is why they were not considered.

4.1.3 Google APIs

Both Google Static Maps and the Google Elevation API were chosen for the geographic elements of the visualisation. Previous projects used the MapQuest API however they did not require elevation data. Google's terms of service require that their elevation API may only be used in conjunction with their own maps [2]. For this reason, the switch to Google static map service was made.

4.2 Program

4.2.1 Scene Graph

JMonkeyEngine3 builds visualisations using a scene graph. This is a hierarchical structure that begins with a `rootNode` to which all other elements are attached (Figure 4.1). This structure is extremely useful when updating the visualisation as JMonkeyEngine3 has built in methods to traverse and access the tree, this means that updating a contour for example requires very few lines of code:

```
Node contour = rootNode.getChildNamed(``contour_overlay'');
// Update contours as required
rootNode.attachChild(newContour);
```

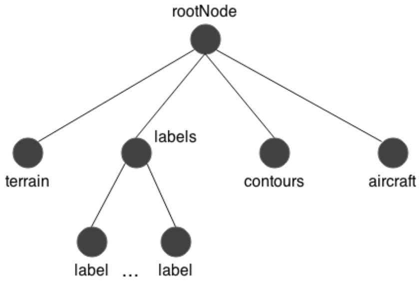


Figure 4.1: JMonkeyEngine3 scene graph structure

4.2.2 Grid Generation & Terrain

The program begins by creating the necessary environment for the simulation. This process includes two steps: generation of the grid and retrieval of the satellite imagery. It is also important to note that JMonkeyEngine3 uses a right-handed coordinate system, this means that for a given coordinate (x, y, z), x and z are the flat ground plane whilst y is height (Figure 4.2).

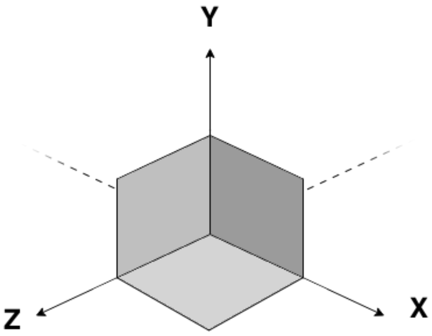


Figure 4.2: JMonkeyEngine3 uses a right-hand coordinate system

Grid Generation

The grid is stored as a singular array of `Location` objects. The `location` objects holds four vital pieces of information for each grid point:

- **Geographic coordinates** - Latitutde and longitude of this grid point's position in the real world
- **3D world coordinates** - Where the grid point is located in the 3D engine
- **Elevation** - The height of this grid point above sea level
- **Noise level** - The sound level calculated at this grid point

The grid is generated by building it from the bottom left corner to the top right corner. First, the position of the bottom left corner of the map is determined and then for each new grid point, incremental values in the x and y directions are added on a row by row basis (see Figure 4.3). The distance between each point is defined in the simulation as `int gridSubdivision` which defines how many times the grid should be broken into smaller sections.

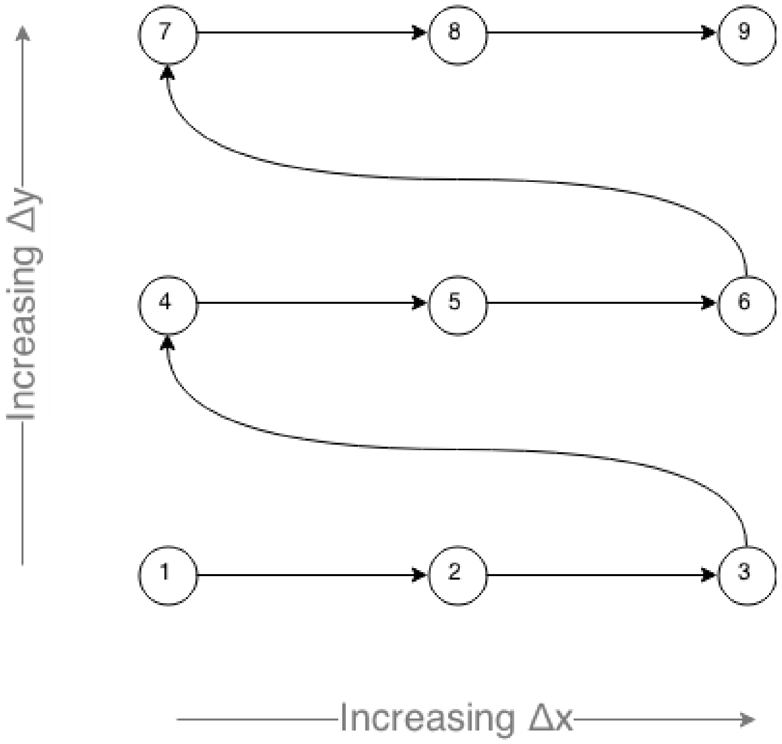
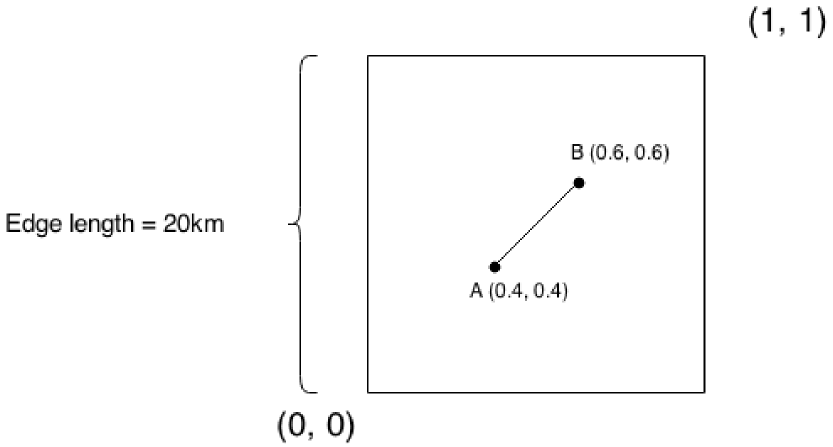


Figure 4.3: Generation of the grid. To calculate new grid points, we take the point in the bottom-left corner and add two separate Δ values which are multiplied to correspond with the new point's respective position.

The grid is square drawn in 3D space between the points $(0, 0, 0)$ and $(1, 0, 1)$. The reason for having the grid as a 1×1 square in 3D space is that it is easy to account for any scale. This means is that to calculate any distance on the map in real world units, it can be calculated by multiplying the (Euclidean) distance in 3D space by the real world length of an edge as seen in Figure 4.4. An alternative that was considered was using the Haversine formula, which calculates the distance between two latitude/longitude coordinates. This method was rejected since the formula becomes inaccurate depending on latitude which is caused by the calculation assuming the earth is a sphere when it is actually an oblate spheroid [19].



Using a 1×1 square to calculate distances.
The distance between A and B is then: $d = 20km \times \sqrt{(0.6^2 - 0.4^2) + (0.6^2 - 0.4^2)} = 12km$

Figure 4.4: Real life distance calculation in 3D space

Terrain

To create the terrain on top of the grid, two requests must be made to the Google Maps API. The first request returns a satellite image with overlaid map, this is saved into the assets folder to be used as a texture in the visualisation. The program is set to request maps of zoom level 12 however the image that is retuned has no guarantee of being a certain scale. A zoom level of 12 may potentially return an image with an edge length ranging from 20 to 30km or more and there is no way to automatically determine what size has been returned. This problem is overcome by allowing the edge length to be adjusted by the user. The second request takes the geographic coordinates from each `Location` in the grid and returns a set of corresponding elevation values. The returned data is XML and must be parsed before each grid `Location` is updated with its respective elevation.

The final step in terrain generation process is to create the mesh which will be displayed by the visualisation. This is done manually as JMonkeyEngine3 has no functionality to do this automatically. To do this, each face of the mesh is considered separately. Since each `Location` in the grid holds a Vector3f [1] containing its 3D position as well as positional and elevation data, the relevant `Location` objects can be connected to form the terrain mesh. The program must determine the corresponding vertices (indices which reference Locations in the grid) for the current face and then prepare two arrays which tell JMonkeyEngine3 how to place the texture over the mesh (`uvmappings[]`) and how to join the vertices to create a face (`indices[]`). The code to perform this is shown below, each step is shown but in a reduced form for brevity. A diagram of how the vertices are joined for form a square face can be found in Figure 4.6.

```
// Bottom left vertex
float blv_x = (face % numFaces) / numFaces;
float blv_y = (face / numFaces) / numFaces;

// Top left vertex
float tlv_x = (face % numFaces) / numFaces;
float tlv_y = ((face / numFaces) + 1) / numFaces;
...

// Mapping of texture to vertices
uvmappings[t++] = new Vector2f(blv_x, blv_y);
uvmappings[t++] = new Vector2f(tlv_x, tlv_y);
```

---

[1] Vector3f objects are JMonkeyEngine3's way of storing a 3D coordinate of form (x, y, z)

```
...

// How to join vertices
int offset = f * 4;
indices[i++] = 2 + offset;
indices[i++] = 0 + offset;
```

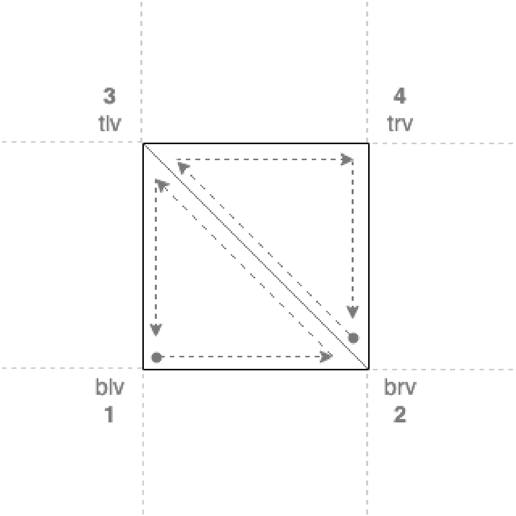


Figure 4.5: The relevant vertices for each face are identified and joined as two triangles to form each square face of the terrain mesh. The arrows represent the how JMonkeyEngine3 builds each face.

Once the mesh is generated, the satellite imagery which was downloaded is can then be loaded as a texture onto the mesh and displayed in the visualisation.

4.2.3 Model

The noise model was recognised through the use of an interface. Any calls to the model made from the simulation are done through this interface and therefore any class which implements this may be used as a noise model. To calculate levels, the simulation iterates across the grid, calling `calculateLevel(...)` (defined in the interface) on each grid point. A reference to simulation is also passed, meaning that models may access other attributes the simulation contains such as the terrain. If additional features were added to the simulation such as wind or temperature values, these too could be accessed through this simulation reference.

```
public void calculateLevels(boolean findMax) {
    // Iterate across grid and calculate levels
    for (Location loc : this.grid) {
        float level =
            this.noiseModel.calculateLevel(this.aircraftPosition.clone(), loc,
            this);

        // Check for maximum value to scale contours
        if (findMax && (level > this.maxLevel)) {
             this.maxLevel = level;
        }

        loc.setNoiseLevel(level);
    }
}
```

```
public interface NoiseModel {
    // Calculate the level at a grid point for a given aircraft position.
    public float calculateLevel(Vector3f aircraftPos, Location gridPoint,
        Simulation sim);
}
```

Obstacles

One of the models included with the project demonstrates the ability to detect obstacles between the aircraft and the each grid point during the calculation of noise levels. This works by taking the aircraft position and grid point and then raycasting a line between both to detect collisions. Raycasting is a typical method used in 3D engines to detect collision, it works by effectively drawing a line from one object to another and any intersections with other meshes are recorded in a `(CollisionResults)` object to be accessed later. If collisions are detected, the level is defaulted to 0dB however this default value could be set differently to reflect how the obstacles realistically affects the noise propagation.

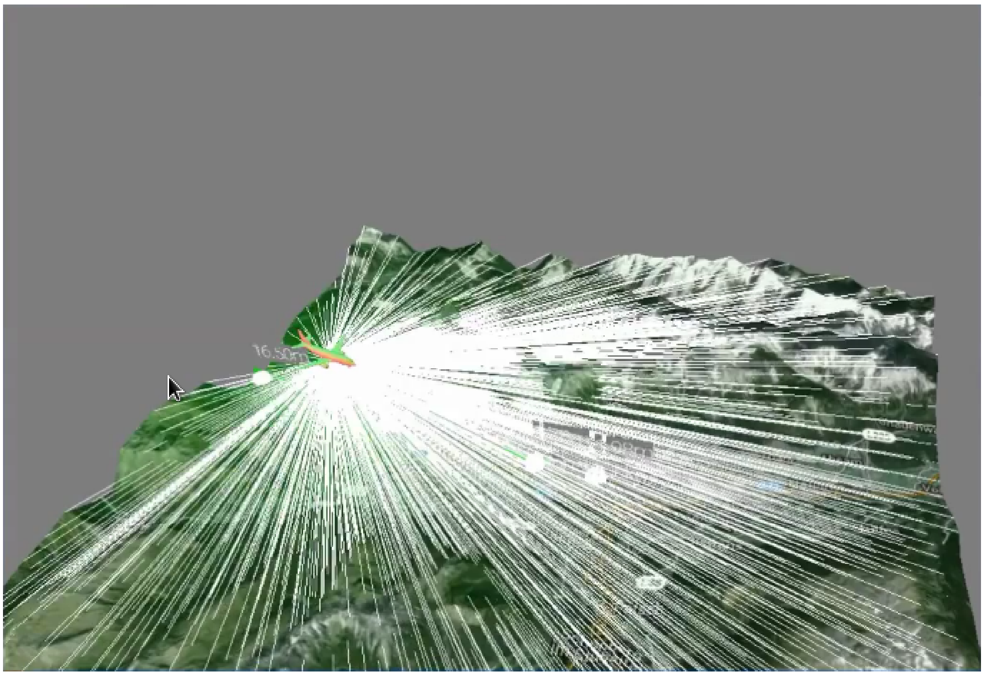


Figure 4.6: For the current aircraft position, raycasts are made to every grid point to detect obstacles.

CAA Model

Another model which is included is based off the recommendations made by the CAA and ECAC Doc 29. Whilst this model is still relatively basic in noise modelling terms, it includes some of the most important factors such as flight profiles, NPD curves, installation effect and lateral attenuation.

The NPD curves this model is based on data provided from the CAA's own database. The data is only based on one aircraft, an Airbus A319. The tables were stored as 2D `float` arrays in the model itself, however if more data became available, these could be extracted out to an individual class. The sample NPD received can be seen in Table 4.1. To calculate a level at a given point with a certain aircraft position, we must determine the geometry which was outlined in Figure 1.3. Once each of these values had been determined, we can then perform the calculations outlined in 1.3 Noise Modelling. Since it is unlikely that when reading from the NPD curves that we will find an exact match, an interpolation between the nearest values is required.

Power Setting (lb)	L_200ft	L_400ft	L_630ft	L_1000ft	L_2000ft	L_4000ft	L_6300ft	L_10000ft	L_16000ft	L_25000ft
2700	91.7	84.4	79.7	74.8	67.0	58.5	52.2	45.3	37.5	29.5
6000	93.8	86.1	80.9	75.6	67.4	58.7	52.4	45.5	37.7	29.7
12000	100.3	92.0	86.2	80.3	71.1	61.7	55.4	48.6	40.9	33.1
15550	102.5	94.9	89.5	83.6	74.0	65.0	58.8	52.1	44.7	36.8
19000	104.3	96.6	91.1	85.7	77.2	68.2	62.2	55.5	47.9	40.0
22500	105.9	98.9	94.1	88.9	80.9	72.5	66.1	59.4	51.7	43.3

Table 4.1: Noise-power-distance curves for an Airbus A319. Values are in dB.

4.2.4 Displaying Levels

Once the noise levels have been calculated across the grid, they then must be displayed in the visualisation. The contours are produced by converting the noise level values from the grid array into pixels values in an image. Currently, the contour varies its alpha channel to display the noise level. In future iterations, the colours of the contour could also vary with noise level. This image is then used as a texture which is overlaid over the map texture of the terrain as shown in Figure 4.7. A static `Contour` class is used to perform all contour related tasks.

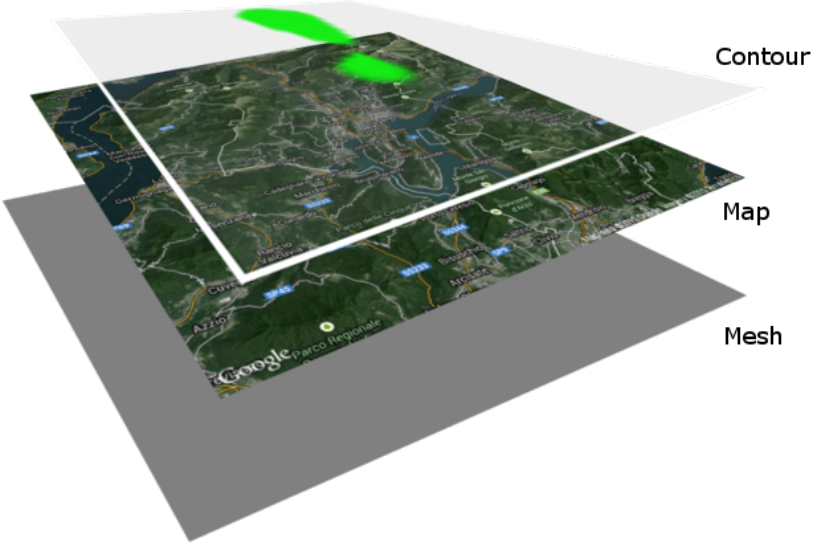
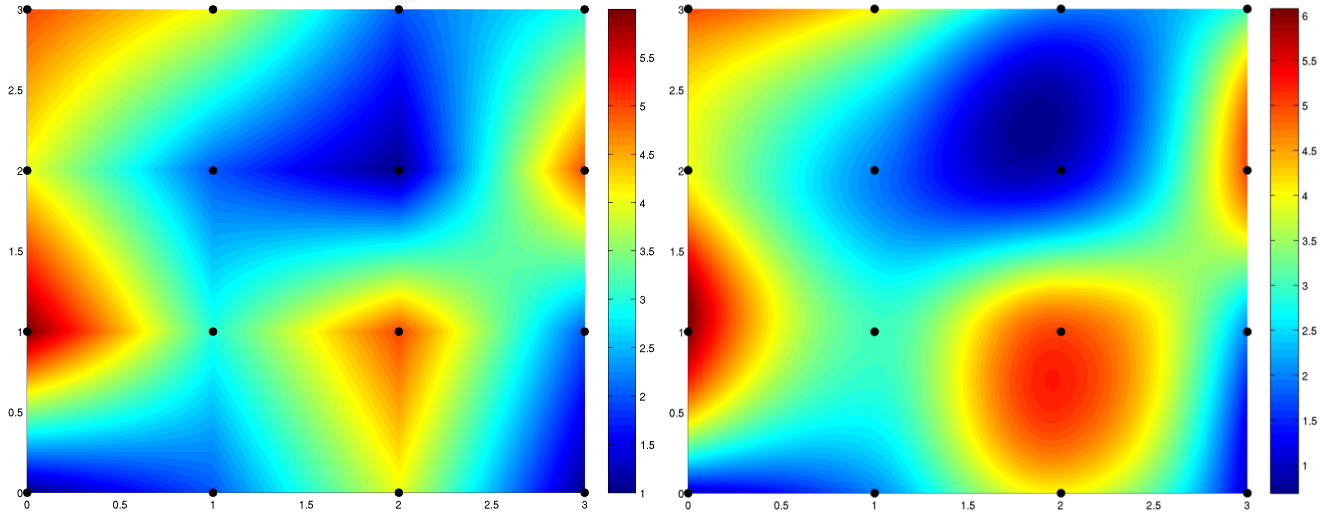


Figure 4.7: These three layers are combined in the visualisation

Since the grid size is unlike to match the resolution of the map texture (which is $1024 \times 1024px$), the produced contour map must be scaled to match this resolution so they can be overlaid. To do this, a bilinear interpolation is performed which effectively resizes the image and smooths the pixel values. Bilinear interpolation was chosen for its ease of implementation, however it does not produce perfectly smooth contours, it is often possible to see the original grid structure underneath the result (see Figure 4.8). A better option would be a bicubic interpolation although this is currently not implemented due to its higher complexity.



(a) Bilinear interpolation. Note the underlying pattern

(b) Bicubic interpolation

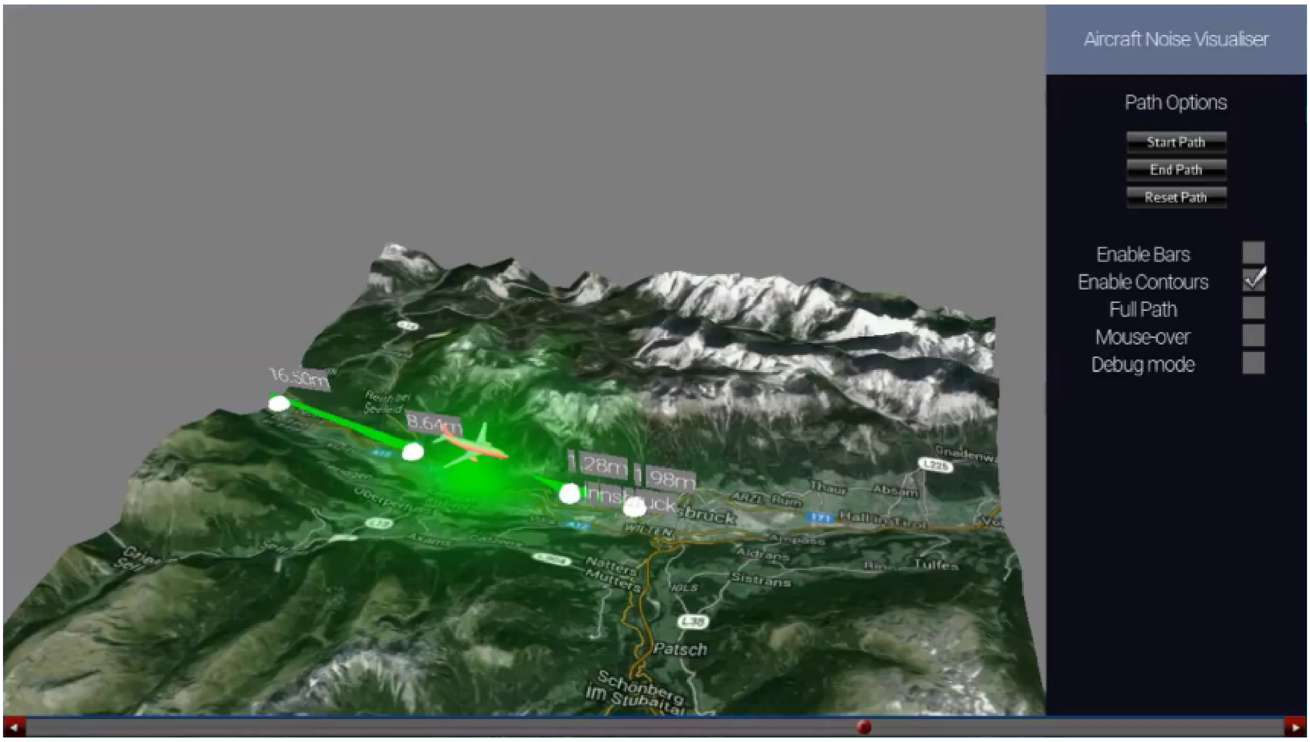
Figure 4.8: Differences between interpolation methods

4.3 Results

The resulting visualisation can be seen in Figures 4.9 and 4.10.

☐ Enable Bars
☑ Enable Contours
☐ Full Path
☑ Mouse-over
☐ Debug mode

Figure 4.9: Aircraft landing at Tromso airport. The green area depicts the noise levels on the ground. The user has used the mouse-over feature to measure the noise level at a specific point.



Enable Bars ☐
Enable Contours ☑
Full Path ☐
Mouse-over ☐
Debug mode ☐

Figure 4.10: An aircraft landing at Innsbruck airport. This simulation detects the presence of the mountain ridges north of the aircraft and adjusts the noise propagation accordingly.

Chapter 5

Evaluation

The purpose of the evaluation was to see whether use of the 3D visualisation can enhance a users perception of aircraft noise disturbance. Users would be asked to perform a series of tasks to determine whether there was any noticeable difference. To detect differences, statistical methods of analysis would be used. The evaluation was designed with assistance from human factors specialists at NATS Prestwick.

5.1 Hypothesis

The hypotheses for the evaluation are as follows:

- H_1 - *'Using the visualisation will affect how the user perceives aircraft noise disturbance'*
- H_0 - *'Using the visualisation has no effect on how the user perceives aircraft noise disturbance'*

H_0 is the null hypothesis and must be rejected for the main hypothesis H_1 to be considered proven.

5.2 Approach and Technique

To determine whether there was a change in user perceptions, a baseline level of perception would have to be identified. In order to do this, the evaluation was split across three sections. In each of these sections, users would perform a set of tasks identifying noise levels at specific points on a series of maps. Another element of the evaluation would be to look for correlations between the results and users learning styles. The evaluation hand-out can be seen in Appendix A.

5.2.1 Introduction

Before beginning, all users were introduced to the project and its aims. A brief background of aircraft noise disturbance was given and users were then asked to listen a recording of an aircraft flying overhead to provide additional context to the evaluation [4]. At this point participants completed a form which would determine their learning style. The chosen test to determine learning styles was a Honey & Mumford Learning Styles Questionnaire [15]. The Honey & Mumford questionnaire is a list of 80 yes or no questions which classify a person into one of four learning styles: theorist, pragmatist, activist or reflector. As the learning styles were only an additional factor in the evaluation, a shortened, 40 question version of the test was used [21]. The Honey & Mumford questionnaire is a widely used test for various types of evaluation and therefore appropriate for this evaluation.

5.2.2 Evaluation Sections

The first section required users to answer a set of questions aided only by a plain map with a trace of the flight path on it. This provided the baseline level of perception as there was no indication of noise at all on these maps so users would have to estimate both the noise level and the disturbance caused.

The second section was similar although this time users were presented with a different set of maps. These maps, in addition to the flight paths, had noise contours overlaid, similar to the contours output by models such as INM or ANCON. Users were also provided with a key which denoted the levels at each contour and provided an example of how loud that might be in real life. The purpose of this second test was to provide a comparison between existing techniques and the 3D visualisation. It is more likely that if the public were consulted about changes in air traffic, they would be presented with this sort of map.

The final section used the 3D visualisation described in this project. This formed the most important part of the evaluation as it concerned the product of this project. For this reason, alongside the tasks described in section 5.2.3 Tasks, users would also complete a System Usability Scale (SUS) evaluation upon completion of this section. The SUS is a widely used measure of software usability [7].

Whilst there was a feedback section at the end of the evaluation, users were encouraged to adopt the *think-aloud* protocol to voice their thoughts as they used the program. The purpose of this was to raise any potential issues which may not be captured in the feedback form.

5.2.3 Tasks

Users were asked to complete 4 questions in each section. The first two questions were based off those found in a study conducted by the UK Department of Transport in the 1980's known as the UK Aircraft Noise Study [11]. As part of this, members of the public took part in another study, the Aircraft Noise Annoyance Study (ANAS). One of the response scales detailed in the document was:

"How much does aircraft noise bother you?"

a) Very much?

b) Moderately?

c) A little?

d) Not at all?

This is a simple annoyance-based scale. It should be noted that there is no middle ranking meaning that participant cannot take an 'easy way out' by selecting the most average of answers. To turn this into a usable question in the evaluation, users were asked to imagine they lived at a specific point near the airport and asked how much they believe noise would bother them at this position.

The second question was also based off ANAS. This question was more focused and strictly boolean, with the intention of removing any subtle views from participants by forcing one answer or the other. In a similar fashion to the first question, users were asked to imagine living at a specific location for answering this question.

"All things considered, do you personally think the amount of aircraft noise at this location is acceptable or unacceptable?"

The third question was designed to be a qualitative one as this would allow analysis of participants accuracy. Users were asked to look at 4 marked locations on a map and rate them from what they believed would be the loudest to quietest. Participants answers were marked on how similar their ranking was to the real values, which were predetermined before the evaluation.

The final question dealt with the participants opinion on how well the particular medium they were using aided their perception of aircraft noise. It is a self-evaluation question and is based on a technique used to measure core self-evaluation [20]. There a five responses which are based off a Likert scale (strongly agree, agree, neutral, disagree, strongly disagree) which the user may select. The question asked was:

"How well do you feel these maps help you perceive potential noise levels at specific locations?"

a) I am very able to perceive how loud it would be

b) I am mainly able to perceive how loud it would be

c) I can roughly perceive how loud it would be

d) I struggle to perceive how loud it would be

e) I cannot perceive how loud it would be.

5.2.4 Notes

To avoid any learning effects between sections, each section used a different selection of maps so that users could not answer the questions based of previous sections they had seen.

Another consideration made was that any maps with noise contours which were presented to participants should have similar contours to those produced in the visualisation. This was important so that neither the maps or the 3D visualisation had an advantage in terms of the shape of the contour produced. To do this, the contours were generated in the program and traced onto the maps.

5.3 Analysis

It would be necessary to perform statistical analysis on the evaluation results to determine whether there was a significant statistical difference when using the 3D visualisation.

5.3.1 Choice of Analysis Method

Parametric vs Non-Parametric

Parametric and non-parametric tests are two different ways of analysing data. The main difference between the two is that parametric tests makes assumptions about the shape of the data, for example that it comes from a gaussian or some other distribution. Non-parametric tests do not make such assumptions [16].

A non-parametric test was chosen, this was because parametric tests are better suited to large data sets since the assumptions they are based on begin to break down with smaller sample sizes of $n < 30$. It was unlikely that the evaluation would involve this number of participants. It should also be noted that parametric tests become inaccurate if the underlying assumption is incorrect.

Choice of Non-Parametric Test

A range of non-parametric tests were considered such as Kruskal-Wallis, Wilcoxon signed rank or Kolmogorov-Smirnov. The chosen test was a Wilcoxon signed rank test, this decision was based on information from two tables published by the Mayo Clinic and UCLA [16][26]. The Wilcoxon signed rank test is appropriate for this evaluation because it specifically deals with comparing two quantitative measures taken from the same individual.

A Wilcoxon signed rank test calculates a W value between the datasets which represents the difference between the two sets. To determine whether there is a statistical difference between the datasets, W is compared to the value $W_{critical}$ which is tabulated for each specific dataset size. If $W \geq W_{critical}$ then this means the result is significant and that H_0 is rejected.

W is calculated as:

$$W = \left| \sum_{i=1}^{N_r} [sgn(x_{2,i} - x_{1,i}) \cdot R_i] \right|$$

$$where\ R_i\ is\ the\ signed\ rank$$

5.3.2 Results

Two sets of statistical anaylses were performed on the evaluation results.The first test analysed the accuracy of participants answers for the question where they were asked to rank 4 locations in terms of the noise level there. The second test analysed the participants self-evaluation of their perception. The first two questions could not be analysed in this manner since they were qualitative. The follow tests compare the contour maps with the 3D visualisation.

There were 7 participants in the evaluation. Therefore for both analyses, $W_{critical}$ is ± 15. In the following calculations, X_a represents results from the contour maps and X_b from the visualisation.

Accuracy

In question 3, participants were asked to rate 4 locations in order of increasing noise. Each correctly identified location was awarded 1 point. The total of these points are used to perform the analysis. The following table is used to calculate a value for W.

X_a	X_b	$abs(X_b - X_a)$	$sgn(X_b - X_a)$	R_i	Signed rank
3	2	1	+1	1	+1
4	4	0	N/A	N/A	N/A
4	4	0	N/A	N/A	N/A
3	3	0	N/A	N/A	N/A
4	4	0	N/A	N/A	N/A
4	4	0	N/A	N/A	N/A
4	4	0	N/A	N/A	N/A

$$W = \sum sgn(X_b - X_a) \cdot R_i = 1$$

Since the number of ranks in the table is only 1, we cannot check for significance as the minimum number required to do so is 5. The problem is that by only using 4 locations in the question limits the total number of ranks there can be. This issue is furthered by the fact that the answers were discrete meaning the results set was limited.

In light of this, we can compare means and standard deviations instead, however such measurements do not offer as much insight into the data as the analytical tests.

$$\bar{X_a} = 3.71 \qquad \sigma_a = 0.49$$

$$\bar{X_b} = 3.57 \qquad \sigma_b = 0.78$$

Both the contour maps and 3D visualisation rank very similarly in terms of performance. The contour maps offer a slightly higher accuracy and smaller standard deviation. It can be concluded that the 3D visualisation is just as good at helping users perceive aircraft noise.

Self-Evaluation

X_a	X_b	$abs(X_b - X_a)$	$sgn(X_b - X_a)$	R_i	Signed rank
5	10	5	-1	5	-5
7.5	7.5	0	N/A	N/A	N/A
5	7.5	2.5	-1	2.5	-2.5
5	7.5	2.5	-1	2.5	-2.5
5	7.5	2.5	-1	2.5	-2.5
10	10	0	N/A	N/A	N/A
5	7.5	2.5	-1	2.5	-2.5

$$W = \sum sgn(X_b - X_a) \cdot R_i = -15$$

Since $W = -15$ and the condition for statistical significance is $W \geq \pm 15$ the null hypothesis is rejected and confirms that using a 3D visualisation over a contour map affects how participants believe they perceive noise disturbance. Despite both methods performing similarly in terms of accuracy, this result may reflect that users felt they better understood the concepts of noise disturbance while using the 3D visualisation.

5.4 Usability

5.4.1 System Usability Scale (SUS)

The system usability scale is a scale commonly used to rate the usability of interfaces. The scale consists of 10 questions, each with a five-point scale which ranges from *Strongly Disagree* to *Strongly Agree*. The output is a value between 0 and 100 which rates the usability of the system, though it should be noted that this value is not a percentage. This usability test was chosen because of its ease-of-use for both the participant and the evaluation coordinator's part. It also is unaffected by sample size.

Research has shown that a SUS score of 68 is average [23]. From user feedback at the end of the evaluation, the 3D visualisation receives a score of 60 and is therefore below average. The reasons for this could be seen in both the SUS forms themselves and the open-ended feedback session that followed. One particular SUS question that regularly scored low was *"I found the various functions in this system were well integrated"*. When asked to expand on this answer, users often said that it was not obvious that certain functions such as the mouse-over were available for use.

5.4.2 Feedback

The final part of the evaluation involved users filling out a feedback for about their experience. The results are consolidated below:

- Control scheme: Some users struggled when controlling the visualisation. The controls which were implemented were default to JMonkeyEngine3. Any change in controls would have to begin with further investigation as many users when asked what they would change replied they did not know exactly what the problem was and that the controls just felt 'off'.
- Contours: The system displays the noise levels as a green layer which fades as the noise level decreases. Users suggested they would prefer a colour scale, similar to the ones seen in the 2D contour maps.
- dB scale: Whilst users were provided with a paper copy of a dB scale with accompanying examples of each level, some users felt this would be more helpful if integrated into the visualisation itself.
- Mouse-over: Users commented that the ability to mouse over the map and read off a noise level was a useful feature when performing the tasks. However, due to a JMonkeyEngine3 limitation, these labels were only oriented in a single direction and could often not be seen depending on camera position.
- Markers: A common suggestion was that instead of hovering over a position to read off a noise level, the user could plot certain points on the map which would constantly display the noise level there as they scrolled back and forth through the flight path.
- Visual: Users said that the 3D visualisation was more engaging than the 2D contour maps.

A general observation was that users often felt more engaged and excited when using the 3D visualisation than when performing tasks on the 2D maps.

5.4.3 NATS

Further evaluation was carried out in the form of an interview with a human factors specialist at NATS Prestwick. The evaluation did not follow the evaluation outlined in section 5.2 Approach & Technique but instead consisted of a walkthrough and in-depth discussion. During the interview, the following points were raised:

- Dynamic maps: The ability to load any airport (or location) in the world is very useful.
- Flight details: The ability to be able to see details about the aircraft somewhere on screen would be beneficial (e.g aircraft altitude, thrust level)
- Public consultations: Such a visualisation would be very useful when holding public consultations when airspace changes are being proposed. Members of the public could interact and see how new flight paths would affect their homes.
- Context: When asked about benefits over a 2D contour map, it was mentioned that 3D visualisations inherently have more context as it is more familiar users.

SIDs & STARs

Standard Instrument Departure Routes (SIDs) and Standard Arrival Routes (STARs) are standard procedures followed by aircraft when arriving or departing airports. Their purpose is to ensure the safe and efficient flow of air traffic and the SIDs and STARs are included in the air traffic control flight plan. It was suggested that if possible, it would be both interesting and useful to get this data and put in into the 3D visualisation for analysis of the noise effects they produced.

Restricted Zones

One suggestion was that the visualisation could include specific 'zones' on the map, for example areas that have noise limits. Edinburgh is one example where there is a ban on aircraft flying over the city. It was suggested that being able to include zones like this in the simulation and the monitor any noise there would be beneficial. For example, air-traffic controllers could design a series of potential new flight paths and then prototype them using this visualisation to narrow down the choices. If more detail is still required, a full noise-study could then be conducted.

5.5 Evaluation Conclusion

From the results discussed in this report, it can be said that a 3D visualisation of aircraft noise is one which holds potential value. In terms of the effect on user perception, the visualisation matches the performance of the currently existing 2D contour maps. It can be concluded however that the 3D visualisation is a more engaging method of interacting with users when dealing with noise modelling. The interview at NATS also shows that despite having its flaws, there are many applications for such a system if it were to be expanded.

The main drawback of the visualisation was its usability issues. Many users did not intuitively take to the control scheme and did not make use of the features available to them. Many of the suggestions made by participants would drastically increase the usability of the system which may in turn increase the effect using it has on user perceptions.

No conclusions can be made about learning styles due to the small sample used to evaluate the tool, between the 7 participants there was not enough of each learning types amongst the users meaning that drawing any conclusions would almost certainly be inaccurate.

5.5.1 Potential Flaws

The small sample size was one of the most inhibiting flaws of the evaluation. This meant that some of the intended analysis could not be performed, limiting the power of the evaluation. For example, no statistical result could be found for accuracy differences between the 2D maps and 3D visualisations and there was also not enough data available to analyse learning styles. It should also be notice that whilst the hypothesis was found to be true, H_0 was rejected by a very narrow margin. It is possible that with a different or larger sample size, this may not have been the case.

The questions that were taken from the Aircraft Noise Annoyance Study [11] were also potentially liable to produce inaccurate results. A report release in 2005 [8] suggests that answers to the questions in this study were very subjective. For example, 52% of residents in the Heathrow area answered that aircraft noise 'very much annoyed' them yet 48% said they were less bothered and 2% said they were not bothered at all. This shows the these questions are unlikely to produce consistent results. Since these questions were qualitative they were not used in the analysis though so this does not effect the results of the evaluation greatly.

Another flaw discovered in retrospect was the use of the same maps on each evaluation. While different maps were used for each question, the order was always the same in each evaluation. The problem with this is that some maps may be harder to interpret than others due to features such as geography or the shape of the contours. It could be possible that higher or lower accuracies were simply down to easier maps, not the type of visualisation.

Most participants provided good information in the feedback section of the evaluation, however the think-aloud protocol was less successful. It is common with such protocols that participants forget or are unwilling to share their thoughts. It did return some useful results so can still be considered an important part of the evaluation.

Chapter 6

Conclusion

6.1 Future Work

Usability

Immediate future work would be increasing the usability of the system as this was one of the larger issues raised in the evaluation. Users provided many different improvements they would have made to make the system better to use and the majority of them would be implementable with relative ease.

Expanded Data

Adding extra data such as different aircraft and different height profiles is also a strong consideration for future work. This would allow the visualisation to be far more versatile by covering a wide range of scenarios. The reason the program only has a small set of data is due to the fact it was kindly provided by the CAA, if the project were to continue into the future it would be possible to access a much larger database.

Comparisons

The ability to plot two different flight paths and then make comparisons in the visualisation would be a useful feature for flight planners. Users may also plot a single flight path a compare the effect flying different aircraft of different noise abatement procedures may have. This could be accomplished using grid subtraction as described in section 1.3.2 Grid.

Audio Synthesis

A feature that is very likely to increase users perception of aircraft noise is to take the values output by this visualisation and synthesize a audio clip of that noise level which users could listen to. This helps break down the barrier between reading a value off of a screen or page and allows the user to experience it as they would in real life. This is a concept which has been investigated by RWTH Aachen University[5].

6.2 Conclusion

This report discussed an examination into whether the use of a 3D visualisation could enhance users perception of aircraft noise. A tool based off the industry standard literature has been created to allow users to interact with the noise model. The system can be focused on any world location and is designed to be extended in the future. An evaluation was carried out to determine the effectiveness of the system. The visualisation matched the existing 2 contour maps in terms of users ability to perceive data. Users responded better to the 3D visualisation, feeling it help them perceive better. Certain usability issues were identified that hindered users usage of the tool and solutions to these were offered.

Appendices

Aircraft Noise Perception Evaluation

Michael Roddy

School of Computing Science, Sir Alwyn Williams Building
University of Glasgow, G12 8QQ

This evaluation is designed to measure how different tools can affect a users perception of noise emitted from aircraft in the vicinity of airports. We present a 3D visualisation tool and evaluate its performance.

---

1. DETAILS

Evaluee number: _____

2. AUDIO CLIP

Please listen to the aircraft audio clip.

3. LEARNING STYLE

Please complete the affixed learning styles form.

4. MAP ONLY

1) Look at map ___. Imagine you live at point A, how much do you think aircraft noise would bother you at this location?
    a) Very much
    b) Moderately
    c) A little
    d) Not at all
2) Look at map ___. Again you live at point A, all things considered, do you think the amount of aircraft noise here would be acceptable or unacceptable?
3) Look at map ___. Please rate the locations A to D in order of what you believe the noise level there would be (1 = loudest, 4 = quietest)
4) How well do you feel these maps help you perceive potential noise levels at specific locations?
    a) I am very able to perceive how loud it would be
    b) I am mainly able to perceive how loud it would be
    c) I can roughly perceive how loud it would be
    d) I struggle to perceive how loud it would be
    e) I cannot perceive how loud it would be

5. MAP & CONTOURS

1) Look at map ___. Imagine you live at point A, how much do you think aircraft noise would bother you at this location?
    a) Very much
    b) Moderately
    c) A little
    d) Not at all
2) Look at map ___. Again you live at point A, all things considered, do you think the amount of aircraft noise here would be acceptable or unacceptable?
3) Look at map ___. Please rate the locations A to D in order of what you believe the noise level there would be (1 = loudest, 4 = quietest)
4) How well do you feel these maps help you perceive potential noise levels at specific locations?
    a) I am very able to perceive how loud it would be
    b) I am mainly able to perceive how loud it would be
    c) I can roughly perceive how loud it would be
    d) I struggle to perceive how loud it would be
    e) I cannot perceive how loud it would be

6. 3D VISUALISATION

Before beginning this section, the evaluator will introduce you to the program. Make yourself comfortable with its operation and raise any issues you have before continuing. This part of the evaluation encourages you to 'think-aloud' any thoughts or problems you are experiencing with the program. The goal of this to assist the evaluator in discovering potential flaws in the system.The evaluator will set up each map for you.

1) Look at map ___. Imagine you live at point A, how much do you think aircraft noise would bother you at this location?
    a) Very much
    b) Moderately
    c) A little
    d) Not at all
2) Look at map ___. Again you live at point A, all things considered, do you think the amount of aircraft noise here would be acceptable or unacceptable?
3) Look at map ___. Please rate the locations A to D in order of what you believe the noise level there would be (1 = loudest, 4 = quietest)
4) How well do you feel this visualisation helps you perceive potential noise levels at specific locations?
    a) I am very able to perceive how loud it would be
    b) I am mainly able to perceive how loud it would be
    c) I can roughly perceive how loud it would be
    d) I struggle to perceive how loud it would be
    e) I cannot perceive how loud it would be

7. SYSTEM USABILITY SCALE

Please complete the follow scale in relation to the 3D visualisation part of the evaluation.

	Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree
I think I would like to use this system frequently					
I found the system unnecesarily complex					
I thought the system was easy to use					
I think that I would need the support of a technical person to be able to use this system					
I found the various functions in the system were well integrated					
I thought there was too much inconsistency in this system					
I would imagine that most people would learn to use this system very quickly					
I found the system very cumbersome to use					
I felt very confident using the system					
I needed to learn a lot of things before I could get going with this system					

8. FEEDBACK

1) Was there anything you had a particular problem with?

2) Are there any improvements you would suggest?

3) Please add any additional comments:

Bibliography

[1] Dora report 9120, the caa aircraft noise contour model: Ancon version 1.

[2] Google maps/google earth apis terms of service. https://developers.google.com/maps/terms#section_10_12 (Accessed on 27/03/2015).

[3] Jmonkeyengine3. http://jmonkeyengine.org/ (Accesed on 27/03/2015).

[4] Airplane pass by overhead - sound effect - jet fly by before landing - flugzeug aircraft passes. https://www.youtube.com/watch?v=yayUY8wMrh4, dec 2014.

[5] Eike Stumpf Abhishek Sahai, Eckhard Anton. An interdisciplinary approach for a virtual reality air-traffic system simulation for subjective assessment in vr environments.

[6] Heathrow Airport. Night flights. http://www.heathrowairport.com/static/Heathrow_Noise/Downloads/PDF/Nightflights (Accessed on 23/03/2015).

[7] John Brooke. Sus-a quick and dirty usability scale. *Usability evaluation in industry*, 189(194):4–7, 1996.

[8] Peter Brooker. The uk aircraft noise index study: 20 years on, 2005.

[9] European Civil Aviation Conference. Ecac.ceac doc 29 - report on standard method of computing noise contours around civil airports. 1997.

[10] Ivan de Lépinay. Egnos flight trials at nice airport - noise impact study. 2002.

[11] CAA Department of Transport. United kingdom aircraft noise study: Main report. 1985.

[12] Department for Transport. Uk aviation forecasts. 2013.

[13] Hemann Rickel Mirsky Roof Boeker Gerbi Senzig He, Dinges. Integrated noise model (inm) version 7.0 user's guide.

[14] Kiyoshi Iwasaki Ichiro Yamada Hisashi Yoshioka, Masayuki Sugawara. Comparison of noise calculation method between aerc model and ecac doc.29.

[15] Peter Honey, Alan Mumford, et al. The manual of learning styles. 1992.

[16] Tanya Hoskin. Parametric and nonparametric: Demystifying the terms.

[17] Peter Havelock Ian Jopson, Dr Darren Rhodes. Aircraft noise model validation - how accurate do we need to be?

[18] S White Ian Jopson, Dr Darren Rhodes. Validating the caa aircraft noise model with noise measurements.

[19] Frank Ivis. Calculating geographic distance: Concepts and methods. In *NESUG*, Toronto, Ontario, Canada, 2006. Canadian Institute for Health Information.

[20] Erez A. Bono J. E. & Thoresen C. J. Judge, T. A. The core self-evaluations scale: Development of a measure. *Personnel Psychology*, 2003.

[21] Honey & Mumford. Learning styles questionnaire. http://www.ejtn.eu/PageFiles/6343/Learning_Styles_Questionnaire.

[22] SAE. Method for predicting lateral attenuation of airplane noise. 2012.

[23] Jeff Sauro. Measuring usability with the system usability scale (sus). http://www.measuringu.com/sus.php.

[24] Clean Sky. Skyline - special edition noise reduction. 11 2014.

[25] et al Thomas Connor, Robert Hinckley. Inm, integrated noise model, version 2 - september 1979 - programmer's guide.

[26] UCLA. What statistical analysis should i use? http://www.ats.ucla.edu/stat/mult_pkg/whatstat/.