



COMPUTER SCIENCE

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# A WebGL-based aerobatic visualiser using the OLAN catalogue to provide a means of generating interactive 3D representations of manoeuvres.

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## CS39440 Major Project

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The Ethics Form Application Number for this project is: 1177.

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Finally, I would like to thank my project supervisor. The clear sight of requirements has meant that it was possible to begin the project earlier than expected, giving me more time to work on important design and coding of the application. The request from the supervisor to create initial planning and research at the start of the project helped greatly in the overall analysis of the task, and a check-up of project progress mid-way through the project ensured I did not fall behind or have any substantial issues.

## **Abstract & Background**

The aim of this project is to create a 3D representation of aerobatic manoeuvres, primarily using the OLAN notation(or one letter aerobatic notation). Both real-scale and remote control aerobatic planes and helicopters use the notation to describe a set of manoeuvres in an overall routine, usually including translating the notations into Aresti symbols. The Aresti symbols came before OLAN, but OLAN was developed to make it possible for pilots to write down quickly their planned routines.

The primary element of this project will involve allowing users to insert their notated routines into the application(via an input box on a web-page) thus producing first the ribbon shapes of the manoeuvres, followed by the ability to see a craft fly the route. Although there is only a finite amount of manoeuvres possible from the Aresti catalogue, each OLAN notation can have its own parameters. This can range from entry length into a loop or turn, to the number of rolls in a section of a manoeuvre. The application will also need to be taking into account flight speeds, and possibly wind and gravitational effects. The life cycle will be chosen after the initial list of requirements is apparent and in an organised manor.

WebGL will be the language used to create this application, with hopefully object-orientated Javascript to power the application. Libraries helping towards the graphical/ visual side of the application may be required to give greater flexibility and better aesthetic value. All considerations will be found in the analysis and design stages of this report.

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# Chapter 1

# Background & Objectives

Before commencing the design of the application and the project planning, it is important to have analysed what is hope to have been achieved at the end of the project time, and also what steps will need to be taken to implement each feature. As this report will mention later, choosing the best fitting life cycle methodology will play a big part of how the project will be shaped and how to create each feature whether it be by priority, size or difficulty. This section details the understandings for the project requirements, steps that are going to be needed to take, and as it would preferred that the project to is similar to an FDD one; developing an overall model and building the list of requirements and features.

## 1.1 Background

The choice of undertaking a project such as this one was due to two combining factors: maths and an interest to learn graphical programming. The fact that this application will require the learning graphics, and how to implement visual effects representing the requirements of the project in ways completely new in terms of a skill. As graphics is something the author have not had much to do with in the past, this project appears both exciting and daunting task due to the learning curve that will be needed to be taken. As for the maths factor, it can be assumed that quite a lot of maths will be involved (especially for creating curves, rolls and turns along most of the manoeuvres) which should be enjoyable to learn about.

As an individual currently studying for a degree in software engineering, a project that broadened the skill set from simply programming to graphics was another reason for choosing this topic. Rather than just coding a back-end web application, dealing with the visual side of an application is a new skill that could be gained from performing a project such as this one. Gains in time management and in writing an expansive report detailing findings and more importantly issues is something that will come from creating this project. A big part of choosing an engineering style project such as this one is endorsed from being on a heavily-engineering based degree too.

In terms of the history of the topic, OLAN was originally developed by Michael Gorden in 2006 [18] and was designed to provide shorthand notation for pilots planning out aerobatic routines without having to draw out the full Aresti diagrams. In recent years, the OLAN notation became used much more until because of licensing issues with the original owner was taken off-line. Because of this, a new form of the notation has been created in a more open source way paving the

way for applications such as this project's intended aim. Although in this report and the planned application itself will be still referring the notation as OLAN, the new re-make of the language is known as the 'OpenAero language' [25]. This is based off of the original, yet is open and allows anyone to use it. In combination with this, the creators of the OpenAero language also developed a web-based application [26] that allows the conversion of the notations to 2D Aresti diagrams. This is somewhat similar to what is hoped to have achieved, but alongside plenty more features most importantly the ability to see a plane perform the moves.

As for Aresti, named after its conceiver Jos Luis Aresti Aguirre [29] is the diagram format that OLAN achieves, and represent informative diagrams showing the shape of the routine, direction of travel, rolls and sharpness of turns. Aresti diagrams also can include angles or turns, ranging from 90 degrees to 270. Each diagram usually has a name [32], relating normally to the shape of the manoeuvre, though some are more commonly known to pilots rather than the regular user. The OLAN notation for each diagram usually attempts to try describe the manoeuvre with the letter used, such as 'o' for a loop, or 'z' for a shark tooth. The full list of manoeuvres, including their OLAN notation and full name can be found on the OpenAero [25] site.

Upon starting this project, several meetings with the project supervisor are planned each providing more detail of the initial requirements. The project plan considering the requirements has been made into a rough Gantt chart which can be found in section 1.1 of appendix A showing the plan following. Because several meetings have already happened at this stage, a fairly accurate time-scale to work with can be provided.

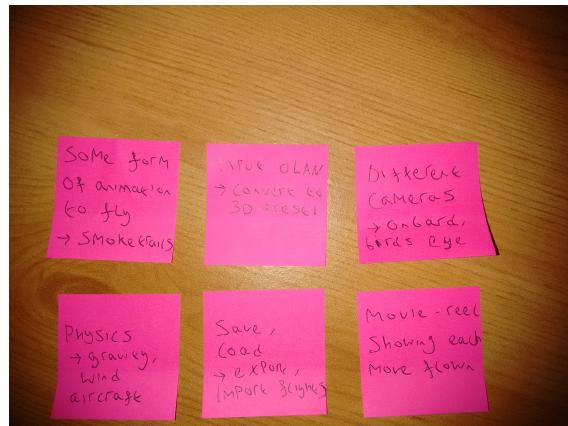


Figure 1.1: Image of the initial user stories after the first meeting, short and concise requirements.

The initial required application can be broken down into an extensive (but less detailed) list of main functional requirements. These are as follows:

1. Provide a web-implemented tool that allows input of the OLAN 1 None-IE due to WebGL capabilities. Will it use a simple JSON file to store notations? Characters as a string format, alongside possible click functionality.
  2. Relate each notation or set of notations to a certain procedural movement (rotations, movements etc.).
- Must consider parameters in some of the notations, such as the speed of entry.

3. Provide a means of linking up these movements in such a way into moves, or the angle of the plane. They should produce a fluid manoeuvre.
4. Display this using WebGL. Libraries to consider that could help. Begin by initially testing simple shapes to move and fly around, then add textures, and plane structure.
5. Are libraries OK to use? With some of the movements:
  - glMatrix- JavaScript library for helping with performing actions to matrices [3]
  - ThreeJS- Another JavaScript library, good with handling cameras and different views [19]
6. Allow user to add different effects such as wind, gravity changes and other physics. Could be better to implement these last, as it will be easier to test pure functionality of rolls etc. first, then figure out natural physics.
7. Add functionalities of different viewpoints (on-board views, side views) to application.
8. Possibility to add function to save (using local storage?) users different sets of manoeuvres?

The list shown above also has an accompanying report in section 1.2 of appendix A which was created after the first project meeting. This report includes the list of initial requirements, alongside footnotes, and also a detailing of the methodology and process that is planned to be followed. The document can be found in the appendices section of this report.

In addition to the list, it is felt that it should be highlighted why and what language will be used to create the application. WebGL was chosen over OpenGL because of two reasons, the first being that the idea of being able to run an application such as this simply in a web browser is a good one, without the need for any compilers or platforms installed on the user's device. The other reason being that is that the author already has good experience using JavaScript, and this will help when it comes to the writing code, making sure the coding style is appropriate, and maximising any features it could bring to the application. JavaScript is a language with one of the most amounts of libraries on the web, meaning that the requirement to develop more specialised code is less. The final reasoning behind choosing JavaScript is because of the running times. Generally, JavaScript can compile and run quicker than other languages, and can also load into the users browser quickly. Because of this trait, it would be the best choice, otherwise the user would have to install locally onto their machine.

## 1.2 Analysis

Before beginning using the chosen life cycle model, It is important to analyse the overall model and requirements of the intended application. It is planned to analyse two items: the requirements analysed by time, effort and difficulty, and also a breakdown of the OLAN and Aresti manoeuvres. The second of which will be broken down to their primitive forms, hopefully finding out how the application can create each manoeuvre as simple and efficiently as possible.

### 1.2.1 OLAN and Aresti interpretations

The best place to begin with the analysis is to look in more detail at the OLAN manoeuvres individually, by breaking down each manoeuvre into their primitive elements. As with the previous section, alongside this section there is an attached document to the appendices of this report, detailing the main and most important manoeuvres that are key to finding primitive shapes. This began by firstly organising each OLAN and their corresponding Aresti shapes into sub groups.

Of these, there were:

- Single element- These include manoeuvres that can be described as one fluid movement. For instance, the OLAN letter 'd' would mean diagonal line up, which requires only one action to complete the manoeuvre.
- Two-element- This group includes any manoeuvres that require two separate manoeuvres to complete a given manoeuvre. An example of this could be the 'z' notation, also known as a shark tooth. This shape requires both a diagonal line up followed by a vertical line down.
- Loops- These like the single element moves, consist of a single manoeuvre, and can be combined to make other manoeuvres.
- Loop-line combinations- These are loops that are a combination of a loop and a single or two-element manoeuvre.
- Double-loops- As the name states, these are manoeuvres that contain two loops.
- Humpty-Dumplings, Hammerheads and Tailslides- Each of these manoeuvres represent specific shapes, such as a 'humpty dumpty' which consists of a bump shape comprised of a 180 degree turn to come back down vertically. As the previous, these shapes can simply be combined from single element pieces.
- Complex 3 rolling elements- The naming behind this group of manoeuvres comes from the fact that each contain a set of 3 elements to create the entire figure.
- Special and 'oddball' figures- The group of manoeuvres that are more complex in such a way that they require special sections not available from any of the other groups. One example of this is the OLAN letter 'f' which represents a flick. This comprises of rolling the aircraft 360 degrees along its horizontal line.

Another important part of the OLAN analysis that had to be understood before proceeding was the possible parameters, prefixes and postfixes that can be attached to manoeuvres.

Looking at prefixes first, each one-letter-notation, **some moves** are able to be reversed, or inverted. These are so:

- r - Reverse, meaning to order of how each part of the manoeuvre is done. For example, placing the letter 'r' before 'c', would represent a Cuban loop flown in the opposite order.
- i - Inverse, meaning that each part of the manoeuvre is done in the same order, but inverted in terms of value. For example, the letter 'i' before 'c' would mean that rather than looping upwards, the loop would go down. A diagonal line upwards would become a diagonal line downwards.

- ir - This is simply a mixture of both the previous. The manoeuvre fixed to the end of this postfix would both be inverted and then reversed.

In addition, there are a number of postfixes that can be used with some manoeuvres particularly with roll or turn based figures. For example, manoeuvres containing rolls can be represented with the prefix angle of turn in multiples of 90 degrees, and a postfix of the amount of rolls along the same part of the path. So in one example, the notation '2j2' would represent a 180 degree turn, whilst rolling the aircraft twice. Alike the prefixes for inverting and reversing manoeuvres, the parameters are not available on all the manoeuvres in the OLAN catalogue. Again, the full list can be found on the the OpenArea site, or see the the OLAN understandings in section 1.3 of appendix A.

One final set of optional parameters that could be required of the application to handle are the positions of manoeuvres. Although not strictly in part of the OLAN catalogue, it is already available in the OpenAero application. These parameters are structured (X, Y) with x representing the amount of horizontal distance and y the vertical distance from the end of the previous manoeuvre to the start of the current manoeuvre. These can also be negative values to ensure the user can control the position fully.

The main reason for the need of this is that simply all manoeuvres cannot fully follow each other straight after each other. In real-life if a manoeuvre made the pilot finish near the ground, and the next move required them to perform a diagonal line down, they would hit the ground. Obviously the application will attempt some form of validation and checks, but offering the option to the user is a very useful feature.

From analysis in the groups listed above, a number of assumptions can be made.

1. it has already been deduced that all none-single manoeuvres that do not include loops or rolls should be possible to be made from a set of single element manoeuvres.
2. In total, any manoeuvre can be constructed from one of three primary moves: diagonal and straight lines, curved lines, and turns and rolls. Each of which should be able to carry parameters.
3. Each curve should be possible to be created based on 45 degree increments, as this is the smallest change of angle in any manoeuvre, and all other angles seem to be in multiples of this number. This will shorten the need for multiple commands for different ranges of angles when programming in the manoeuvres. Because the changes in angle will need to be by a curve, interpolation will be required to make the change in angle smooth and realistic.
4. Turns, curves and rolls will all need parameters, as some curves are steeper and shorter than others. The same goes for rolls, where you can choose anything from quarter to 3 rolls, and in turns the angle of turn should be specifiable.

By considering the analysis of the set of manoeuvres, it can now envision what manoeuvres will be possible to create easiest, and prioritise the work better. The next section of this report will group up the functionality of the application with the OLAN manoeuvre findings.

### 1.2.2 Application functionality interpretations

Upon having the initial meetings with the project supervisor, and on analysis of the OLAN catalogue, more final judgments can be made on what is desired to have been achieved by the end of this project. As discussed in the background section, a set of initial assumed requirements have already been created. Though, some of the features raised questions, such as the possibilities to use libraries for the physics and graphical side. After some research, a cohesive and stable list of features and requirements of the application can now be defined. Rather than in a list format though, features will be grouped together and discuss the most important factors. The use-case for the grouped together requirements can be seen in figure 1.2. Following the use-case is a ranked table 1.1 of the requirements, in order of priority.

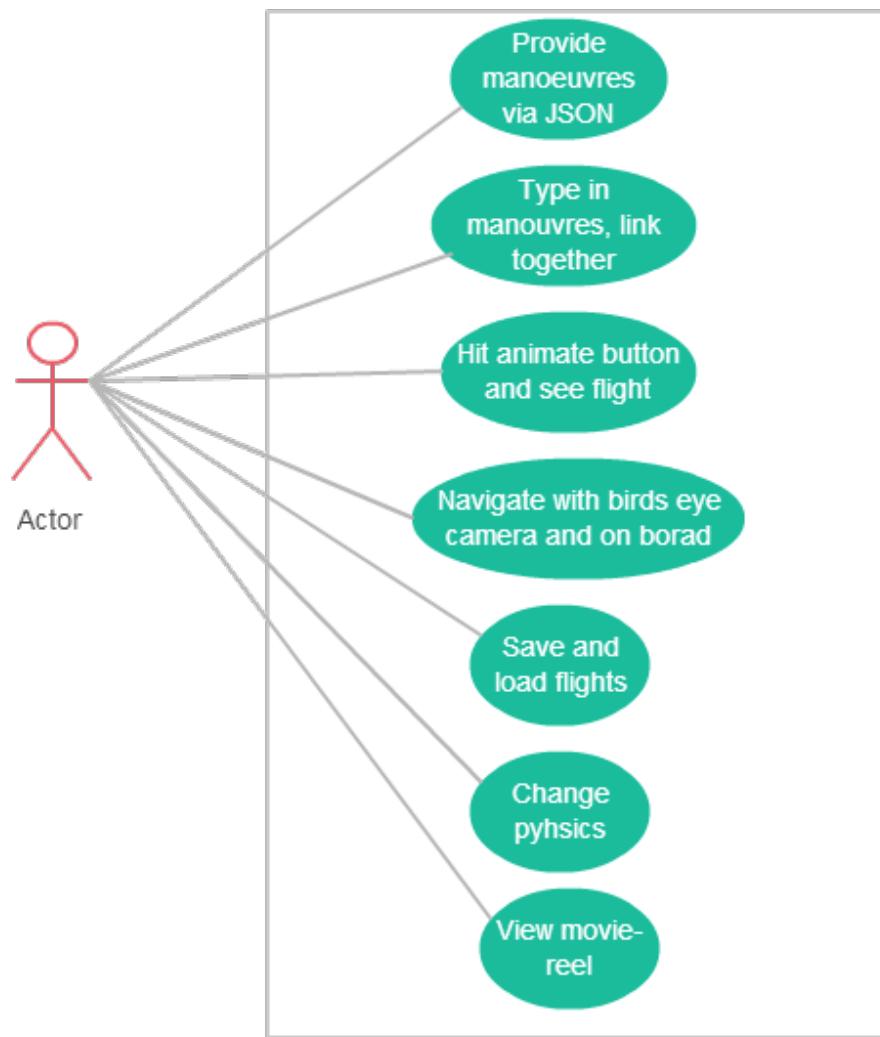


Figure 1.2: Use-case of grouped requirements from initial research

Table 1.1: A table of prioritised features and tasks that would like to have implemented by the end of the project. The lower ranked items will only be started on completion of higher tasks.

Rank	Description
1	Support broken down manoeuvres, via JSON, convert to vectors and ultimately figures
2	Allow for each manoeuvre to link together, start at end of previous
3	Animate along a path of the manoeuvres
4	Create cameras, on-board and birds eye
5	Ground and lighting additions
6	Saving and loading of inputs
7	Manoeuvre validation
8	Physics options, different aircrafts
9	Movie reel functionality
10	Mobile compatibility and nice GUI

Starting with the underlying functionality based on the OLAN interpretations, what is hoped to have been achievable by the end of this project is the possibility to allow users to enter any length of space separated OLAN characters into an input box, alongside any possible prefixes, postfixes and parameters. It is hoped to have achieved this by making the system as general as possible, and by using very abstract methods that can support any given move input. One way of implementing this now would be to break each manoeuvre into a set of instructions, each one saying which direction to move, the angle and length. By breaking each manoeuvre into these, a single method could be used to construct each manoeuvre on the fly. This is important as it would then allow for the user to play through the manoeuvre in an animated fashion and see the aircraft move.

More generally, one of the questions asked at the start of this project was if libraries could be used to help create the graphics and physics. By now, more meetings with the project supervisor have taken place and found this was allowable. The main library to have been considered after this has been the ThreeJS [19] library which acts as a good wrapper for controlling a wide range of objects in a scene. This library will allow vectors, cameras and lighting to be easily manipulated, which will form the basis of the application. A discussion of the use of this library when it comes to planning each of the features in the design will take place.

This will lead up to the scene and cameras that is hoped to be working to a good standard. For the scene, things such as the ground terrain are not so important, and can simply represent a flat land, while lighting could be added, but perhaps after fundamental features are added. As for cameras, it would be preferred that there is a set of two cameras: one for navigating and viewing flight paths at different locations and angles, and another camera which would be on-board, like a nose-cam.

The save/ loading of flight paths is a lower ranked task, but is something that will definitely be planned to have been implemented by the end of the project. Having looked into various methods of saving the OLAN entries, the best way that was found is to use a combination. One which would use local storage, and one that would export to JSON. The first of which was found out here [15] is particularly useful as the project is web based.

Physics is also an option that would preferably be included, such as wind, type of aircraft(each aircraft could be more difficult to navigate corners, meaning wider curves). And relating back to the function of playing the animation once the manoeuvres are drawn, an idea given from the project supervisor was of a 'movie-reel' function that would show a mini image of the current manoeuvre being played, showing the animation progressing through each one. Again, this is

another feature that would be prioritised less, and implemented after other key features.

Finally, a smaller task that could be performed is to make the application mobile compatible. As most phones also now have WebGL capabilities, making the application run on mobiles should be possible. This is more a GUI centred feature on the site itself though, and should be added nearer the end of the project.

### 1.3 Process

Moving onto more project and time management specific items, the process which is followed can have a large effect on what features are complete on time. At this stage, it is suggested that a hybrid of both the waterfall methodology alongside feature-driven development is used to create the application. The reasoning for this starts with the way a list of features in the analysis has already been created, which is already part of the FDD life cycle. This would mean by following this, it would be possible to simply iterate over each feature, plan, implement and test one by one. This is an ideal trait that comes from using this methodology which allows the creation of each feature separately, and more importantly by priority. Then for instance if the entire list outlined was not finished, the application would still have a good deal of functionality on offer. A guide found on the agile modelling site [28] explained backed this up, and explained FDD to a good understanding. If the waterfall method was used alone, It might mean that too many items are implemented at once, even though some features rely on others completed. This would result in an incomplete and less functional program. There is also a clear part of the scrum methodology put to use here, as it is showed with some user stories, and the prioritised list of features.

The second reason, and reason for including the waterfall cycle in this hybrid approach is because it would allow the creation of a more big up front design before beginning implementation. This is where this approach is going to be different from a solely FDD way, where it would usually require having to design each feature before implementation and testing. In some opinions, this is because of the preference of knowing how the entirety of the structure of code should look before it is begun, yet keeping the structure as loosely connected as possible to ensure that features avoid relying on each other to an extent where if one is broken, the rest is broken.

Because the methodology has been chosen in this fashion, it has meant a Gantt chart based on stages of planning and design has been created, and also what features are hoped to have been accomplished at times throughout the project. This, coupled with a work blog, will allow it to be possible to track progress throughout, and compromise when time is needed, or move along the list of features if time is available. The Gantt chart will be updated as time progresses in relation to the blog, where it will then be possible to see where progress is up to overall.

As for implementation and testing, these will be carried out in the FDD way by implementing and testing each feature one at a time. In the implementation stage of each, it will be ensured that decoupling is a priority meaning that any developing code does not damage any current working functionality of another feature. The implementation and testing schedules of each feature can be seen on the updated Gantt chart in section 1.4 of appendix A. This time, the Gantt chart tasks in to consideration the difficulty and time required to implement and test each feature.

# Chapter 2

## Design

On completion of my analysis and background planning for the project, I can now look at more detailed design for the application overview, and the individual component it comprises of. Because my application will present both a front-end GUI and back-end JavaScript and WebGL, I will split my design into two sections. The reasoning for this is because I would prefer to have the GUI and logic of the application to be decoupled, so that the code can be changed in the JavaScript easily without having to affect the user interface. Other than planning the application itself, it is also important I plan what key assisting services I use, such as how I intend on versioning my code, to how I will deploy my code.

### 2.1 Overall Architecture

As a summary of the architecture of my planned application, the best way to design in more detail is to lay out a primary design pattern. For the purpose of an application which will allow for user interaction, which will be processed by code in the back-end, I have decided to go ahead with a Model-view-controller approach. Using the MVC pattern means I can separate the GUI from the logic code as I wanted to, and have the GUI exists without knowledge of the back-end. This is also the same with the model, where the primary code for calculating manoeuvre movements and animations should be possible without knowledge of the view, but instead use the controller as a intermediary. See figure 2.1 for the MVC pattern I plan to use.

Because I have already chosen three.js as library of choice for creating any graphics and physics objects, these will already form my model or models. Each manoeuvre for instance will be reflected as a set of vectors which will form the shapes of the Aresti flight paths, and should be accessible and changeable through the controller to the view (in this case the canvas in my GUI).

The controller will be the most crucial part I implement, as it will need to be able to communicate with the three.js objects, the canvas displaying the animation, and detect controls from the user. For this piece of the pattern, I will enforce some other design patterns to

Finally, the view will be represented as the canvas and controls on the web page. Since on both the canvas and the options menu can have an effect on the model, the controller will listen for changes on either, and then call the relevant operations to affect the model, and again reflect this back onto the view. The view will not know anything of the controller nor the model, so adding any new options or displayable information will be easier and not conflict with any current elements.

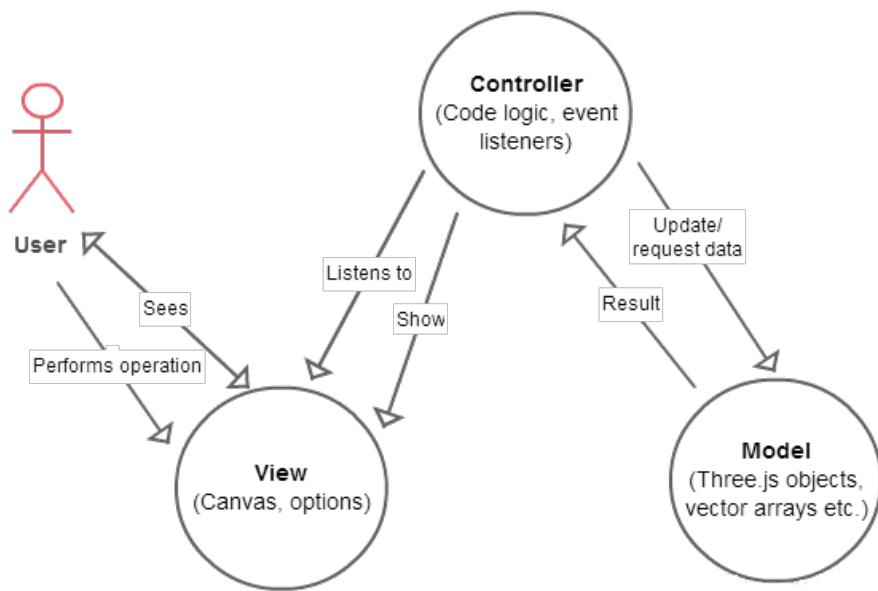


Figure 2.1: Model View Controller diagram for my proposed application. Shows the planned interactions between different subjects within my application.

## 2.2 Back-end logic and design

The first of the two design categories concentrates on the JavaScript that will act as the functions to run each of the proposed features of the application. The code on this side will be responsible for maintaining contact with the GUI, and more importantly the WebGL canvas on the web page. To make the code be as maintainable and run effectively as possible, I will look into a variety of design patterns.

### 2.2.1 Design patterns

Because I am using a hybrid of waterfall and FDD at this stage of the project, using a changing range of design patterns for my JavaScript and GUI architecture is possible. Through the implementation stage of this report, some of these may patterns mentioned may not be used anymore and replaced for different ones depending on changing requirements and progress. Using the implement, refactor and test iteration approach should allow for this.

The first design pattern that would be good useful relating to the controller is known as an observer pattern. The observer pattern means to listen on an event or events in an application, and then call the relevant action. The JQuery library, which I plan to use throughout any GUI related tasks will be of a great use here. This library will allow me to add simple listeners on elements on the web page, and set methods to be called on any click, hover or other events. In terms of how I will place this pattern in my architecture, a standalone file will be responsible for listening to any options or menu changes, whilst another JavaScript file will be responsible for listening to the canvas events such as rotation or zoom. One web article here [4] supports the advantage that the observer pattern will help towards decoupling.

The next design pattern I plan on implementing into my application relates again to the MVC

architecture I will be using. The builder pattern will allow me to append and edit any HTML on the page (such as options, check-boxes, loading content back into the OLAN input box) easily with data retrieved from the model. JQuery again should help to provide a means of changing content, because of more built-in method it comes with. There should be a handler class in my application specifically for controlling the page content.

A third design pattern which will be important when it comes to loading up the application will ensure that all the data necessary to run the application is ready before the user can perform any actions. Known as the Lazy initialisation pattern, this is a style of coding that means whenever files or data is being loaded, the rest of the application should either wait, or prevent other relying features from being initialized. One motivation for the need for this pattern in my program is because of the vast amount of manoeuvre data, and model data for terrain or for aircrafts means that functionality such as animating and drawing flight paths on the canvas may be already ready for use from the user before all the data is ready. In this case, it could cause errors and even crash the application. Therefore, making sure that the application does not progress loading before data is ready is of great importance. Martin Fowler mentions this pattern in his site [16] and whilst says this pattern should be avoided if possible due to responsiveness being hindered, he agrees that this could be used to solve performance problems.

Although the previous design patterns have been chosen, others were considered when planning the application but were not suitable or better options were available. One such pattern, the Mixin pattern allows JavaScript functions to be inherited from other classes or inner functions. For instance, these would be useful as a means of decreasing repetition of functions. In my proposed application, I thought about the possibility of using a Mixin style architecture to allow functions that would draw both the manoeuvres on the canvas, and the manoeuvres on the movie-reel. The reason I have decided not to use this pattern falls to the issue that by making an object extend and hold code from elsewhere could make it harder to maintain, see where the function comes from, and uncertainty of location of any bugs I may come across while developing. While researching other possible design patterns, a book written by Addy Osmani [2] was especially useful as most known JavaScript design patterns were explained, and their advantages and disadvantages pointed out.

## 2.2.2 Module diagram

Because much of the code I will be implementing will hold various Three.Js objects, I have decided that modulating methods and objects will be better than simulating classes seeing as JavaScript is a class-less language. This is a pattern known as the module pattern. Although this may appear less object orientated, modules allow for more robust architecture where units of code can be separated and organised. Modules are slightly similar to classes in the way they can hide code that should not be accessible to other modules by encapsulates privacy. When code is modulated, and then that module is called upon by another, only a public API is returned, and other methods in that module are kept private from being used in other parts of the application. These private methods are good for use as supporting methods, holding such things as calculations, or private variables for getters and setters. Again, this is a similar case to the traditional class diagram.

There are currently a selection of libraries that allow for modules in JavaScript. The most prominent, and the one I would like to use is called RequireJS, which promises the increase in speed and quality of code. RequireJS works by dynamically loading JavaScript files on the fly, where the code has from the other module is usable once loaded into the module calling it. Once modules

are loaded into an object form in whatever the developer needs to name it, its public variables and methods can then be accessed. See figure 2.2.2 on how modules are used. In my case, modules would be useful in enforcing the MVC pattern in the way that it will help towards hiding code between the view and the model.

```

1 require(["helper/util"], function(util) {
2
3     // This function can not be called by another module
4     function private_function() {
5         util.Method() // Can call public methods in the util file
6     }
7     return {
8         public_function: function() {
9             // can be called if this module is loaded into another
10        }
11    }
12 });

```

Listing 2.1: Example showing how RequireJS loads in another module or JavaScript file which in this case is loading up the util JavaScript module and naming it as object 'util' for use in the code

In order to create a basis for modulating code, I should first look to separate the features I listed in the analysis section of this report into categories. These categories will then help me to determine how I could structure my application in as best object orientated way as possible.

The categories I have been able to come to are:

- Main- initiating other modules, beginning the application.
- Animation- Playing, and controlling speed, physics of animation.
- Loading manoeuvres at start of application.
- Saving and loading animations
- Cameras- Creating and controlling cameras movements
- GUI controlling- control and edit GUI controls, and appearance from back-end. Also including the possible movie reel live animation.
- Canvas controls- Allowing the user to move along the canvas, and zoom.

Now I have a stable list of categorised features, I am able to create a diagram shown in figure 2.2 to represent what modulated layout my application will use. Because of the way modules handle public and private variables, have public and have private methods, means that this is very reminiscent of a standard class diagram.

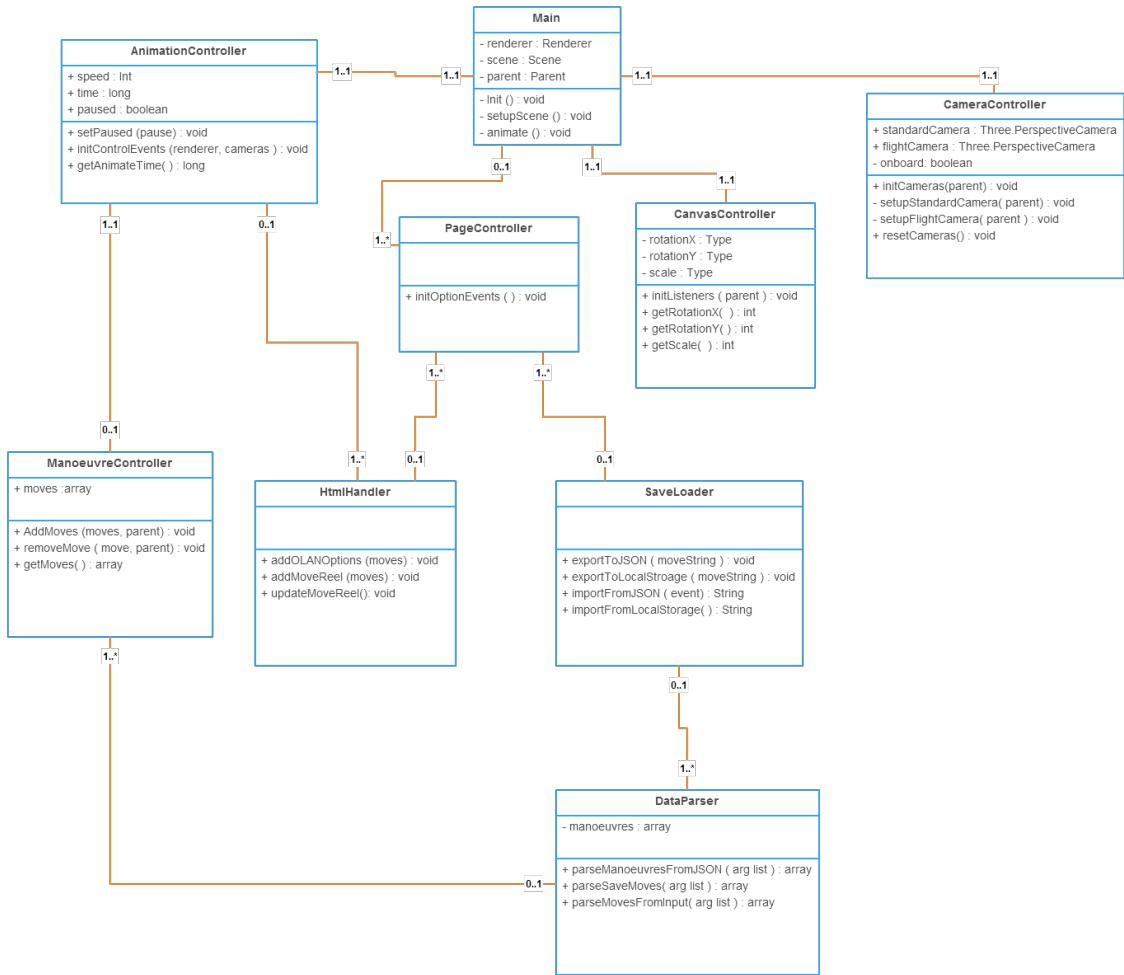


Figure 2.2: Module diagram displaying the various communications between modules, and how they are connected to the GUI in the MVC way.

This module diagram shows what will be the communications between modules in the application, providing insight into what each module should contain in terms of important variables and methods. Ensuring that only modules that require certain pieces of information from another module has sole access is important to reinforce the module pattern mentioned earlier. It should be noted here that although the diagram shows the main modules that will oversee most of the features of the application, when implementation occurs later on in the project, more modules or JavaScript files may be added to support or lighten the load of functions. This is supported by the good practice of **keeping files and functions short and concise** for easier maintenance and readability. The following descriptions have been kept brief, and key connections within the diagram discussed.

The first module proposed from the diagram will be the module entitled 'Main', which will be responsible for setting up the application, and hold onto key variables such as the renderer and scene objects to allow for anything to be drawn and animated on the canvas. This module will be called from the HTML and then will begin any necessary calls to set up the listeners for the cameras, canvas and options. The most important call will be the call to set up the animation controller module.

Following on, the animation controller module will be one of the largest and most important parts

of the overall architecture, as it will be responsible for both animating flight paths, loading up the OLAN manoeuvres at start of the application, and relating any actions from the user to do with OLAN selections or playing and pausing, as well as changing animation speeds.

The animation controller module will be in communication with the manoeuvre controller, which will be a logic heavy class because of the calculations it will require to compute and construct the sets of vectors of the Aresti shapes representing each OLAN notation. As the diagram shows, the application will first get the user OLAN input from the web page via the HTML handler module, then search via the dataParse module and create the manoeuvres array object within the manoeuvre controller holding all the calculated manoeuvres, and return this in a 'get' method to the animation module for placing on the canvas.

As mentioned earlier, the HTML handler module will be the first means of contact to the user of the application, retrieving input from the OLAN box, getting values of any check-boxes, and also setting any values. This module will be using the JQuery library as well as the Handlebars library as the primary way to communicate with the front-end, by directly referencing ID's of divs on the web page.

Two other controllers that should be mentioned are the camera and canvas modules. Both modules will be responsible for setting up their elements when the application starts up (including the different sets of cameras, locations, lighting and ground effects) and for listening to events on both of their respective related front-end sections. Whilst the canvas module will only need to listen for events on the canvas and then reflect this by modifying the canvas directly, the camera controller will need to communicate with the manoeuvre module if the user is using the on-board view to get the current location on the flight path and then place the camera there.

The final module to be highlighted in the diagram is the save and loading module, responsible for the storage of user input and flight paths. Because I suggested two means of saving flight paths which were JSON and Local storage, there is the option to create a module for both of these, one for handling saving data to files, and one for in the browser. At this stage, keeping all the save and load logic in one module will suffice, as there should not be many methods required, so files would be relatively short. The module will then be able to share methods between both means of saving for preparing data. There is a trade-off currently between saving OLAN as the rendered set of vectors, or simply saving user input. The first would mean the application would be ready as soon as a flight is loaded, but would take more space to save, whilst the other way would mean slower loading but much shorter save data. I will consider both methods when implementation occurs.

### 2.2.3 Object structure and storage formatting

It is imperative that the structure of data, especially the OLAN instructions for construction of each manoeuvre is organised efficiently and be as accessible as possible, to consider the speed of the application running in a user's browser. As it is planned to represent each broken down manoeuvre into a JSON string of instructions, they should be easy to read, maintain and add to. The proposed structure of the file holding the JSON will be as follows:

```

1  {
2      "catalogue": {
3          "manoeuvre": [
4              "variant": [
5                  "component": [
6                      {"_pitch": "NIL",
7                          "_roll": "NIL",
8                          "_yaw": "NIL",
9                          "_length": "1"
10                     },
11                     {"_pitch": "POS",
12                         "_roll": "NIL",
13                         "_yaw": "NIL",
14                         "_length": "1"
15                     ],
16                     "_olanPrefix": "",
17                     "_name": "example cuvre up"
18                 ],
19                 "_olan": "u"
20             }
21         ]
22     }
}

```

Listing 2.2: A JSON means of holding break downs of manoeuvres with each one holding information on different variants of the move such as inverse and reverse and description of the OLAN notation

The JSON example shown in listing 2.2.3 displays the planned layout of my manoeuvre breakdown. The first element labelled 'catalogue' will hold the entire list of OLAN notations (without the prefixes and postfixes for reversing or inverting moves), with each holding another array of variants. Within each variant, the data acting as instructions for the how the application draws the paths is contained. Each 'component' will hold four key pieces of data:

1. Pitch - Instruct to direct the manoeuvre to fly upwards or downwards on the Y axis
2. Roll - To roll to the left or right on the aircraft's Z axis
3. Pitch - To turn left or right on the X axis
4. Length - length of the manoeuvre

By using these four attributes, the manoeuvre module will be able to go one by one through each creating a new vector based on the previous vector with these effects added. As you will see in listing 2.2.3, the value of each will either be Nil, positive or negative. This makes it simple to tell the application if the manoeuvre is for example banking up, down, or remaining on a straight

flight. The length attribute will be used to tell the application how far to move along the paths current Z axis after performing a move. If pitch, roll and yaw are all nil, the plane will follow a straight line. The length attribute will be very useful for adjusting the amount a pitch up spans; if it is small, the curve upwards will be tighter, and a larger length will mean a longer less noticeable curve. This will be especially useful for some requirements outlined in the analysis and feature list of the project concerning different aircraft types carrying different traits (some aircrafts may require more distance to bank to the same angle as others).

As mentioned in section 2.2.2, there are two options for the data structure of the saved data from flight plans. The first option which discussed storing the pre-compile vectors from OLAN entry before saving could appear as such:

```

1 {
2   "Manoeuvres": [
3     "Move": {
4       "Vectors": [
5         {
6           "Vector": "2, 1, 0"
7           "Rotation": "0"
8         },
9         {
10           "Vector": "5, 1, 0"
11           "Rotation": "0"
12         }
13       ],
14       "OLAN": "u"
15     }
16   ]
17 }
```

Listing 2.3: A JSON means of holding break downs of manoeuvres with each one holding information on different variants of the move such as inverse and reverse and description of the OLAN notation

While the second option will be the preferred one to implement, due to time limitations. This could be simply:

```

1 {
2   "OLAN": "o id b"
3 }
```

Listing 2.4: A JSON means of holding break downs of manoeuvres with each one holding information on different variants of the move such as inverse and reverse and description of the OLAN notation

Once other proceeding features have been created and time is available to add the save/load feature, then both options will be considered again. For the time being, it would be easier to choose the second option because functions created to build flight paths will already be there so they could be re-used to process the OLAN input again.

### 2.2.4 Naming conventions

The final considerations that need to be looked at in the back-end are naming conventions. It is important that variables, methods and modules are named accordingly to their function, and so that they are easily readable. For the purpose of my application, I will be ensuring to use the Google recommendations for naming conventions in JavaScript. The guide, which can be found on their style-guide site [1], details variables, global variables, functions and class names that should be used when coding any system. The naming conventions in my application should all follow the same style throughout.

## 2.3 User Interface

Moving onto the GUI design, which will provide the users a means of adding OLAN input and animating the simulator must also be designed taking into account the placement of features to maximize space on the users screen. The canvas that holds the WebGL should be the main element on the page, and the options and menu should be placed in the most optimal location to not effect or restrict the view too much. Alongside considerations for this, there should also be a use case for the GUI, so that it is possible to group functions, and place options together making the application easier to use. Although the primary objective is not to concentrate too much on the front-end in this project, it should be made sure that it is attractive and well laid-out. Because FDD has been chosen, it is better to have a good looking and less functional program rather than more functions but unusable program due to the front-end.

### 2.3.1 GUI Use-case

As mentioned earlier, use-case would be a good way to group initial front-end functionality. For my application, creating a use-case means it can then be decided which group of options go where on the site. The following use case in figure 2.3.

As you can see, there is the possibility of four sets of options each of which could have its own category in my GUI. By grouping them this way, it means the user could find the options much easier, and give a less unorganised feel to the application. Starting with the OLAN options, there are going to be two primary functions that should be required here: entering the space separated OLAN and parameters, and a drop down to allow for input from a list. The latter of which should be in its own section in the menu, whilst the first will be a simple input box at the top of the web page about the canvas. Following this, there will be the animation controls next to the input box, to begin and pause playing the flight. I have chosen the input and play button to be at the top of the page not in a menu because these will be the primary elements of the application and should be quick to use.

As for other menu pieces, there is the possibility that physics and animation related options will be available, and should be listed together in a menu. These options contain some of the extra features mentioned in my analysis, such as wind and other items that will be implemented after key functionality. Therefore, although there will be a menu for these, there may not be very many options depending on what work is complete at the end of the project. The next menu that would be required, and the last one, is the saving and loading of projects. There should be four or five options here, for saving in both formats, and loading in both formats. One of which will contain

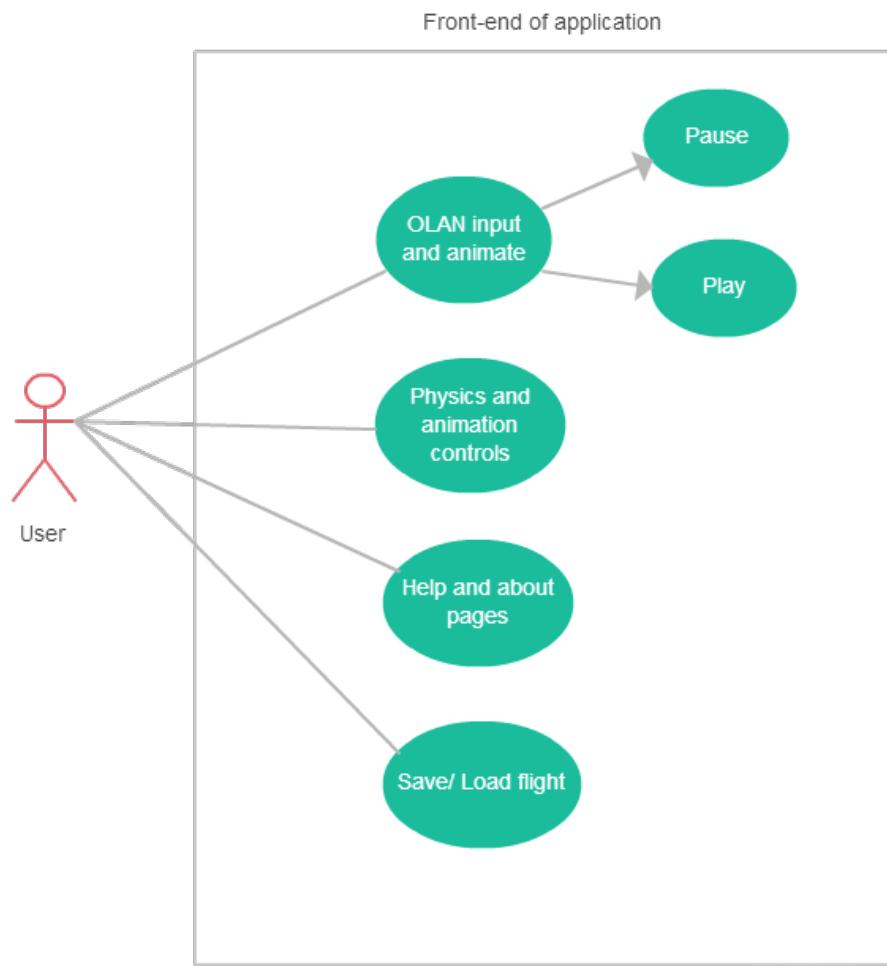


Figure 2.3: Use-case diagram detailing user options, the canvas and OLAN input.

a file browser for selecting JSON files that were exported from the OLAN flight input, and then a button to begin uploading and inserting into the application. An idea alongside this would be to have some form of status bar when the application loads up a flight, depending on the size of the file. If the save files only store OLAN input and not rendered vectors, the need for the loading information would not be required.

An additional set of options, but rather extra pages will be the about and help sections. Instead of placing these alongside the other menus, these can simply sit onto the top menu bar next to the OLAN input box. Rather than options, these should be simple HTML pages that give the user some insight into the application.

It was mentioned earlier in the report about using the lazy initialisation pattern, and simply disabling options could help towards this. For example, a user may try to enter OLAN and press the play button before the manoeuvres have loaded up causing an error. An idea could be to make the input box disabled by default, and then enable it form the back-end once the application is fully loaded. To help understand this, a flow chart in figure 2.4 shows what the user should be able to at what stage in loading of the application.

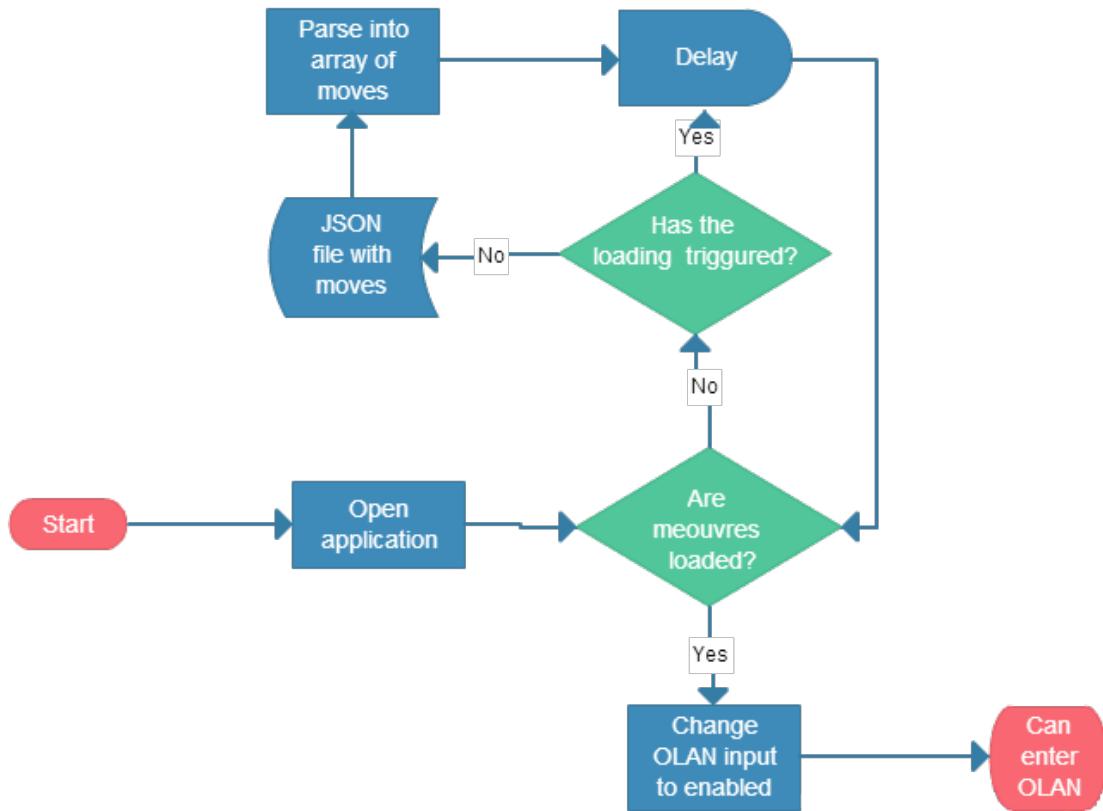


Figure 2.4: Flow chart showing how the application should run in accordance to loading up and then allowing the user to begin using various functions.

As you can see from the flowchart above, the input box that allows OLAN entry will be disabled until loading of the aircraft model, manoeuvre JSON file and setting up of the various controllers. Options should already be enabled when loading up, as back-end checking can be performed separately to lighten the front-end. In any case, because listeners are set up last, any options in the GUI will not function until the rest of the application loads up anyway.

### 2.3.2 CSS and wire-frame design

Following finding of all the required use cases on the application, it is now possible to create draft wire-frame designs for the front-end of the application. Because it would be ideal that the web page works on both mobile and desktop, a CSS library could help to create this easily and quickly. After considering the two main CSS libraries used on the web (Zurb Foundation [33] and Twitter Bootstrap [31]), it was decided that the first would be more appropriate for the application due to some built in functionality that could be useful to the application. The functionality that was found to be most useful was an off-canvas menu. This menu allowed content to be hidden to the side of the page, and then when opened pushed content on the page to the right. This is especially useful for this application where getting maximum space is best for the canvas. In addition to this, the menu allowed for stacking, so it is possible to add sub menus that also push in from the left.

Alongside the menu feature, the general appearance and flexibility of the library will give the application a more attractive and professional appearance, for example replacing check-boxes for

options with sliding switches. To give a more detailed insight into the idea of what the application could look like using this library see the following wire-frame in figure 2.5.

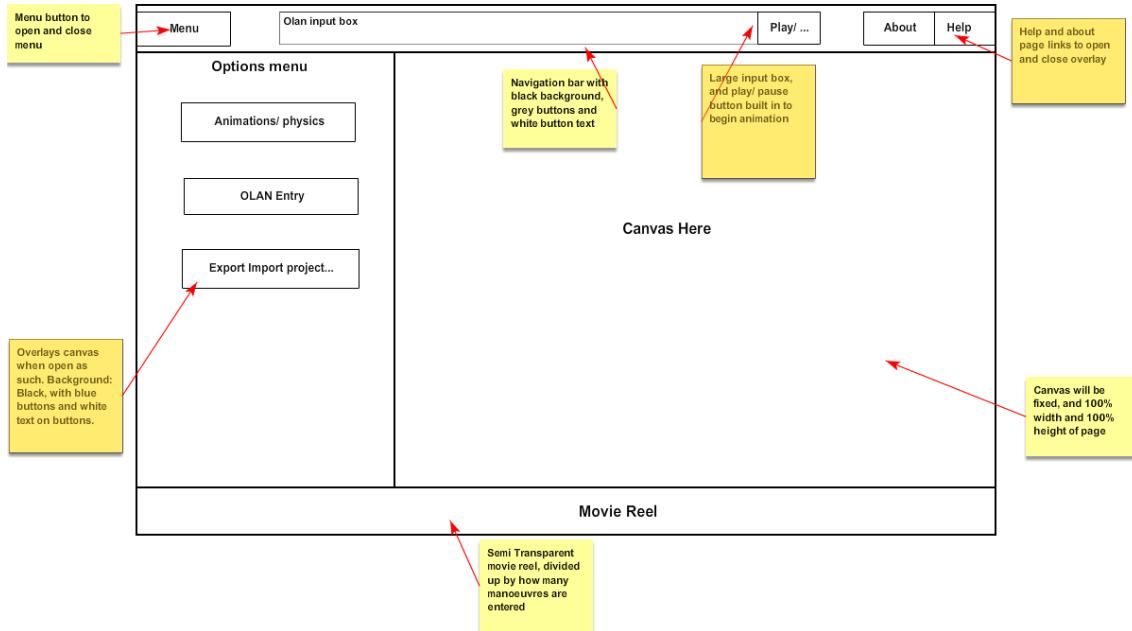


Figure 2.5: Wire-frame design detailing desktop view of the application, including the open menu for the 'off canvas feature'.

As well as the desktop design of the site, a design of the proposed mobile view can be found in the following figure 2.6.

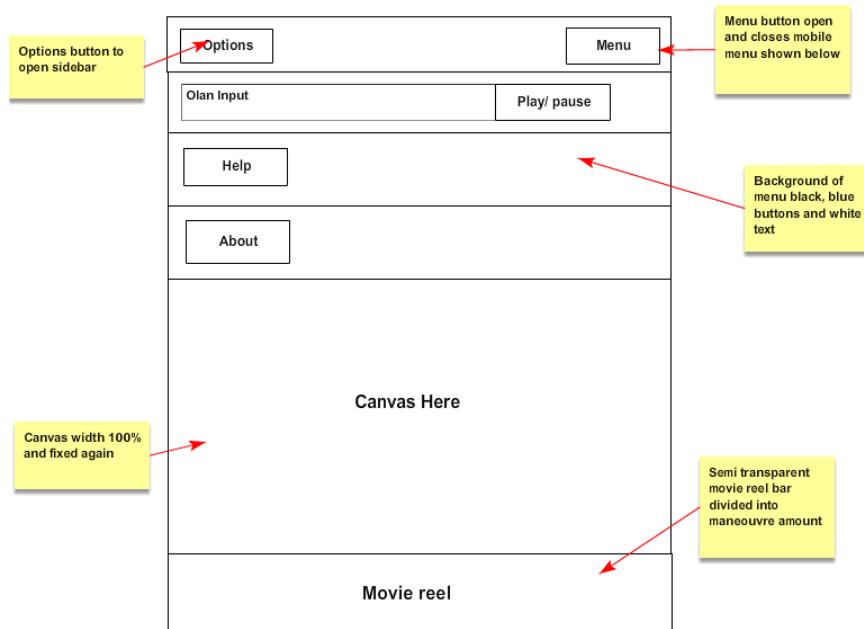


Figure 2.6: Wire-frame design detailing mobile view of application with navigation bar in minified version.

It can be seen that the mobile view follows the same style as the desktop version in the fact that menus and other elements are kept hidden away while showing the canvas for maximum space usage. Again, the off-canvas menu will be used to hide all the option menus, whilst the navigation containing the OLAN input and play button will be hidden at the top of the screen like a standard mobile navigation bar. Items like the about and help pages will take up the entire page on mobile to make text easier to scroll through, whilst on the mobile the help pages will only take around 50% and overlay the canvas.

In addition to both wire-frames and their respective descriptions, it should be pointed out the reasoning for colour scheme choice and other accessibility issues. It was decided that the black background with white text was best for readability and a cleaner look. If the colours were flipped, the application edges such as the navigation would not stand out enough, and finding the edge of the canvas harder. Because the foundation library is being used, it is possible to change the colour scheme from its default blue to white easily through its custom download page. It will also be endeavoured to create the site as responsive as possible, with menus and navigation elements correctly scaled on different sizes systems. This should mean the application should appear as well as a tablet than a mobile.

## 2.4 Planned use of services

Throughout the development of the application, it is planned that a range of tools will be explored and used to help make implementation, testing and documentation more efficient. The first of these is Github [11], which will give two features: allow version control of the development work, so to keep it safe and secure, and to provide a free web hosting service. This can be achieved by creating a 'gh-pages' branch in a repository as seen on the Github site [10], and then any files in that branch can be navigated to on-line. This will be especially useful for my application, as after each commit, the results of changes will be reflected on this branch's web-link. Github will allow work to be carried out on any machine, and to revert any changes that may produce errors when implementing features.

Working alongside Github, a service called Travis [30] will be used to test the application. The Travis continuous development server will allow the application test files to run on each commit to the Github repository. It works by firstly linking to Github, then by reading a file in the repository containing instructions of running any test files that exist. Travis brings with it lots of useful features, as it is possible to run a wide set of different languages and libraries from the Travis file in the repository. The testing library toolkit that will be used in the development of the application will be JUnit, alongside a framework called Jasmine [12]. JUnit acts a lot like any other unit based test, allowing a set of tests to be run after another testing different scenarios across an applications functions. Jasmine will allow for cleaner behaviour driven testing of JavaScript code and will run headless, meaning the application can be tested without loading up the web-page.

A library that will be used during the implementation stage will be the JSDoc library [14], which will help when creating organised documentation for all the JavaScript methods and variables. It is important that each JavaScript module implemented has easily understandable comments to help future development for times when it may have become unclear what one part of the code is doing. In order to keep up with documentation, with each function that is implemented, relevant JSDoc animated comments will be added at the same stage. This means of documenting will make it effortless to create the documentation when the application is complete, by simply running the

library from the command line to generate the documenting HTML pages.

Another technology that will be used to implement the application looks towards the front-end. Rather than standalone CSS for styling the web-page, Sass [13] will be used. In order to use Sass to style a page, it must be complied into its primitive CSS form before adding it to a site. Therefore, while developing the site locally, a software known as Koala [9] will be used to automatically compile the Sass file holding style information after each change to any Sass files. The main reason for using Sass follows the rule of keeping the application as maintainable as possible, and easy to understand for future referencing. As Sass uses a good layered structure, it enforces this easy readability.

The final supporting service that would be useful to have to increase productivity during development is a local server application. As I have had past experience using a program called EasyPHP [7], this will be used when performing coding. The main advantage of using this is that it will be possible to edit and see the site live, rather than having to commit each time. The local server is needed due to issues loading JSON files dynamically through JavaScript which is not possible to do through simply opening the HTML file in a browser.

## Chapter 3

# Implementation & Testing

Following from the analysis and design of the application, it is now possible to start implementing the features produced from investigating the requirements earlier in the project. As it was already stated that the project would be running under an FDD means, rather than having two sections (one for implementation and one for testing), this section will show each feature one-by-one. By following this scheme, the feature priority list will be utilised to ensure the more important features are done first, and that they fulfil their function before moving on. However, this should not hide the fact that issues are possible when implementing and any such issues could hamper further development. If this does occur, the issues and reasons will be explained, followed by what judgment was made to continue on with development of the application as a whole.

### 3.1 FDD project approach

As mentioned, the feature driven development methodology will now shape the approach that is taken to create each feature. Although design has already been completed for all features, there are still elements to each iteration that should be outlined before proceeding. The best way to plan this is to give a brief list of steps that will be performed in each iteration. This is as follows:

1. Give a re-cap on the requirements of the feature
2. Provide a walkthrough of implementation (with code samples)
3. Show tests used (JUnit, usability tests) and results
4. Describe and differences with the feature and original design
5. If there are any issues, describe and give explanations
6. Give a progress log on the item, and provide dates and length of completion for use in accordance with the Gantt chart originally constructed

It should also be noted that once the duration of the time in the project for the implementation and testing stage is complete, a burn down and progress report will be possible to generate and will be done so. This will give a good idea of exactly the status of the project (with a calculated percentage), to see how much work was done compared to estimates, and to find out how successful the project was overall.

### 3.1.1 Iterative Implementation

Before the iterations begin, it should be mentioned that although the order of features to be implemented were decided in the analysis, in order to implement any back end things and allow for proper testing (usability testing), some basic GUI must be created first. Because of this, this will be the first iteration, followed by creation of the JSON manoeuvres. Following these iterations, it will then be much easier to test future features created. Without a basic GUI and canvas, it will be impossible to see the effects created whilst adding features such as drawing flight paths or moving cameras. After these two moved features are complete, the prioritised list will run as planned initially.

#### 3.1.1.1 Feature 1- Create a basic GUI

The first feature that was to be implemented was less of a feature but more a requirement so the other features could be then created. The GUI or front-end of the application is important to be created, otherwise testing future WebGL features will not be possible. The requirements of the front end were:

- A responsive front-end that is mobile compatible
- Have hidden menus that can push in from the left
- Have basic inputs such as the OLAN input, and menu options
- Provide a help and about page that overlays the application web page

The first task that was performed to create this task was to create a minimalistic layout matching the wire frames designed in chapter 2 of this report. The first action performed was to get the latest Foundation [33] css library file, and then to create a layout using the features from the library. The navigation was made using the 'navbar' markup, which helps stick the navigation bar to the top of the page, alongside automatically changing into a mobile pull down menu once the screen size reaches a certain amount.

The most important part of the GUI which has now been implemented is the off-canvas feature menus. The code for this can be seen in section 3.1 of appendix C. The way that Foundation helps create this off canvas option is by wrapping everything in one div, then separating the menu and content in half. When a user then pushes the designated button with the wrapper id, the entirety of the wrapper is pushed to the right to display the menu and less of the content. The about and help pages were also added successfully, with the addition of another library called Modernizer. This library allowed for a clean effect to overlay the information on top of the web-page.

Once the basic HTML elements with relevant ID tags were added to the index page of the application, it was then possible to add some custom style to the page. As mentioned in the design stage, it was possible to download Foundation modified with the colour scheme designed for the application. Changing backgrounds to black and text to white was very easy, and then added to the site. The colour and design of the page can be seen below in figure 3.1.

As planned, Sass was used to style specific elements of the page, such as the width of the OLAN input box, and to change text placement on the help and about pages. Setting up the Sass with Koala was easy, and upon each save of the file, CSS was compiled.

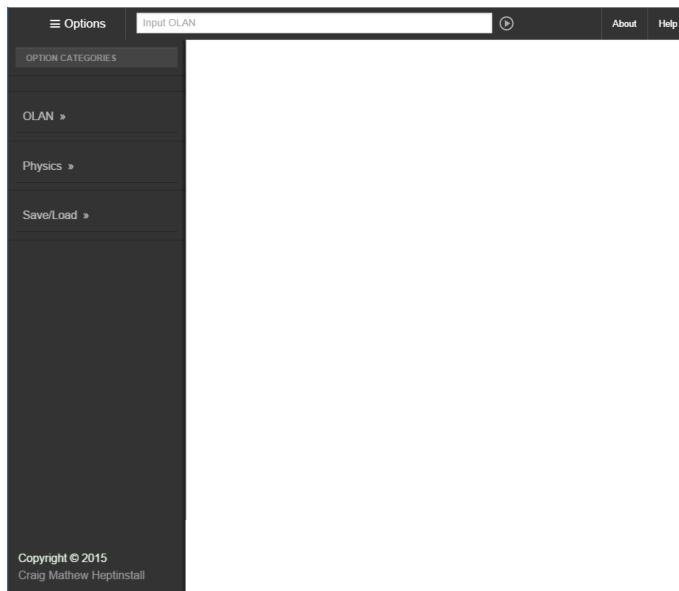


Figure 3.1: Screenshot of GUI created with Foundation, JQuery and HTML markup.

One final mention goes to the creation of the WebGL canvas. To create the basic canvas, only a few lines of JavaScript was needed. To create it, a renderer was created using the 'THREE.WebGLRenderer' object. Because this is early in the implementation stage, it was created without RequireJS as the architecture is only one JS file. Once the object is created, JQuery appends the '.domElement' of this object to the container div created in the basic HTML. For future features, the WebGLRenderer object will be where any objects such as flight paths are added to.

As for testing this feature, because very little JavaScript was required to be coded here, usability testing was the only way to check for the completion of what was required. The test results can be found in Appendix D under section 4.1. Overall, this feature has been made to 100% of the requirements laid out, and matches the design very well. Therefore, the progress tracker for this feature can be shown as:

Start	End	Duration	Progress	Comments
09-03-2015	10-03-2015	2 Days	100%	Complete, though once new features are under way, RequireJS will be utilised and the WebGL Canvas code will be moved.
11-03-2015	11-03-2015	1 Day	100%	Testing complete, usability table created and tested on mobile and desktop devices.

#### Feature overall progress: 100%

##### 3.1.1.2 Feature 2- Convert OLAN and Aresti to JSON form

The second feature, which was of high importance to the rest of the application was to create OLAN interpreted JSON which would give instructions on how to construct each manoeuvre. Because this was quite thoroughly planned and then designed how each instruction was going to be broken down, the time designated for this task felt generous. Simply using the template created

in the design, it was possible to fill in each instruction part by part through each OLAN manoeuvre. An example of some instructions can be seen in Appendix C in section 3.2.

The only time consuming part of this feature was the sheer amount of different manoeuvres that had to be converted. For this reason, not every OLAN letter was created. The reason for this is because some moves are possible to be created from others, so further in development, more will be possible to be added.

To support this feature, more JavaScript code had to be added to allow the JSON to be read into an object to begin drawing moves onto the canvas. Because the code would be in a different module to the WebGL canvas that was created in the previous feature, RequireJS now had to be added to the source code. To do this, the RequireJS library was added and initiated in the HTML page of the application as shown here in Appendix C section 3.3. Then a new module was created, named 'Dataparser' as designated in the design. The method for converting the JSON can also be found in the data parser module shown again in the appendix under section 3.4.

Once the coding and converting to JSON was complete, testing the code that performed the conversion to an object was required. By using JSUnit, it was possible to call the method that was created to instantiate the manoeuvres array, and pass in some raw JSON string, then compare to what the result should be. The JSUnit code can be found in appendix D, section 4.3.

Like the last feature, no changes from the original design were performed, resulting in a good standing of time compared to the Gantt chart for the project. The feature progress can be expressed as percentages and final comments added again.

Start	End	Duration	Progress	Comments
12-03-2015	16-03-2015	5 Days	80%	JSON created to represent most manoeuvres, for that reason it is not an exact 100% progress. JavaScript code and RequireJS functionality added to support the rest of the application.
17-03-2015	18-03-2015	2 Days	100%	JSUnit tests created and passed successfully, showing JSON matches up with manoeuvre array object.

**Feature overall progress: 90%**

### 3.1.1.3 Feature 3- Creating a scene with terrain and lighting

The third feature, which is another to be brought forward ahead of flight path creation is the terrain and lighting effects. The reason for creating this before the OLAN construction is the same as creating the canvas, because without an area to see where the paths are drawn onto, the effects of that feature will be hard to test if it is working. Especially terrain, where the need for this is to see where the X axis of 0 will be. Without this, when implementing checks such as if the path would hit the ground would be harder to test. Again, the three.js library was of great use here, especially with built in methods to allow for lighting to be added.

In order to have started this feature, another module was added to the architecture named 'Terrain-Handler', which was where both lighting and ground was to then have their methods of adding to the canvas. This feature was found to be the shortest of the features, as it only required two

simple methods. Rather than passing the renderer canvas object to this module to add the ground and lighting, it was decided to simply make both methods like factories to return the ground and lighting objects to where they were called from.

Some refactoring was done here also, including the change from having a grid drawn with threeJS alongside an image to changing the image to have a built in grid. The reasoning for this change was because with a large grid on the scene, the amount of power required to render the scene was too large making it lag. To fix this, a simple edit to the terrain texture image was done by adding a thin black line on each edge of the image. Because each image measures 10 by 10 pixels, the grid remains accurate. Figure 3.2 shows the terrain with grid.

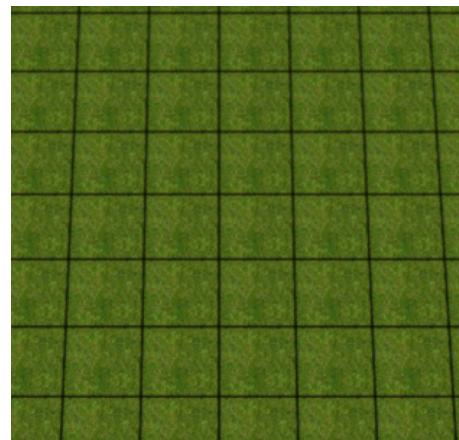


Figure 3.2: Grid on top of terrain after editing the image for the terrain texture.

As for testing, by keeping the terrain and lighting in their own module also helped towards testing the new methods. Two very simple tests were made using JSUnit to check the returns of each method, and both were added to the Jasmine instructions under each Github commit through the Travis builds. As with other tests, the test cases can be found in the appendices under appendix D section 4.4. This feature was fairly straight forward to implement and test with help from the three.js documentation site, therefore the feature was done in less time than originally planned.

Start	End	Duration	Progress	Comments
19-03-2015	20-03-2015	1 Day	100%	Completed module for terrain and lighting, linked up to main module.
20-03-2015	20-03-2015	1 Day	100%	Two JSUnit tests created, and passing successfully.

#### Feature overall progress: 100%

##### 3.1.1.4 Feature 4- Cameras

The penultimate feature before the creation of OLAN paths that was decided should be ready were the various cameras that will look around the canvas. The initial requirements for cameras was to have two different views: one for navigating around the canvas, and the other for being on-board the flight path. At this stage of the project, creating the second was only possible to a certain extent, because without the construction of the paths yet, getting the location of where the

on-board camera should be is not possible. Therefore, for this requirement both cameras were created, with the exception of the on-board camera where functionality is currently restricted.

To start, another module was created for the 'CameraController'. Because it was best to keep the cameras completely separated from other parts of the application to reduce decoupling, both camera objects were stored in this module and provided get and set methods for calls from other modules. An initiator method was created for use from the main module, to create both camera objects at start up. Both these objects were again available from the three.js library as 'THREE.PerspectiveCamera'. Then by passing the module around to any other modules, it will then be possible to update and retrieve each camera object again. Alongside the camera creation, a controller for changing the angle of view, zoom and co-ordinates was created as another module. Figure 3.3 shows the entire 5000 by 5000 canvas on maximum zoom-out.

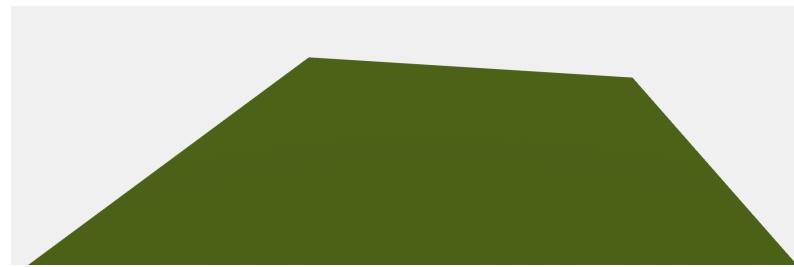


Figure 3.3: Canvas from maximum zoom-out of perspective camera.

This module, which has been called 'CanvasController' as designed in the module diagram, adds event listeners for dragging the mouse around the canvas, keyboard presses to move up and down, and scroll for zooming. Then by getting the new updated values of view-point angles, these are passed back to the camera controller which updates the values of each camera. By repeating this in a render loop in the main module, the updating of cameras is done several times a second, to make movements appear fluid. To help this, the code was redacted several times to ensure that the amount of work done by the browser is as little as possible on each loop of the animation.

As for testing, alike the first feature where usability testing was the primary and sole means of checking the implementation fulfils the feature, JSUnit testing was not used. Usability testing was found the best option here, and results can be found in appendix D section 4.5. During testing, it was found that there was an issue that when rotating the camera around the canvas, it seemed to always rotate around the point (0,0,0). This meant that navigating the canvas was slightly harder than it should have been. This was though, by simply moving the camera rather than the scene in the canvas. As for the camera that was designed to be as on board view, a model airplane was added to represent the camera so it could be seen on the canvas. Although it does not move yet, the plane loads up at the start of the application and can be placed anywhere on the scene. You can see the plane on the canvas at point (0,0,0) below in figure 3.4. The plane model is constructed from a JSON file from a page on the web with thousands of free models.



Figure 3.4: Model of plane loaded up using JSON and three.js object loader. This plane will represent the on-board camera, and fill be the object that will be assigned locations along an OLAN path to show flying the flight plans entered by users.

The progress of the task is shown below. This feature was done exactly to its requirements in the design, and the modulation of code is still being followed.

Start	End	Duration	Progress	Comments
21-03-2015	23-03-2015	3 Days	100%	Both cameras now usable, with constructor methods, and update methods. On board camera ready but not linkable to rest of application until animation of flight paths is ready.
24-03-2015	24-03-2015	1 Day	100%	Usability tests complete, one change made to code following a failed test.

**Feature overall progress: 100%**

### 3.1.1.5 Feature 5- Construction of 3D paths from OLAN

The most important feature, drawing shapes onto the canvas using the instructions read in from JSON files was next to be implemented. The main requirement here was to draw smooth shapes that match the Aresti shapes as accurately as possible, also bearing in mind that they should be linkable.

Using the array of manoeuvre objects imported from JSON in the first feature implemented, creating shapes based on these was a matter of building up an array of vectors with each new vector being copied from the previous and then having the next instruction take effect on it. To do this, under a new module 'ManoeuvreController', a method was created that firstly found which manoeuvre was to be built, then loop through the instructions of that manoeuvre creating it vector-by-vector. The means in which each manoeuvre is constructed from the OLAN JSON can be seen in appendix C section 3.4. On each iteration, once the amount in each direction (X, Y, Z) has been

found, these values are applied to a new vector with values copied from the previous one in the array.

Once vectors were created, they were passed to a three.js object which was a spline curve. A spline curve is one that interpolates along all its points to create a smooth shape. Once points are added to this object, it can then be added to the canvas. Upon initial usability testing of this, it was found that many of the joins between points were well-off centre, due to the interpolation being too large. This was down to the fact that with each turn instruction being a 45 degree angle, meant that the change was too sharp from a straight to curved line, so the straight line was affected too much. To fix this, by dividing up the 45 degree into smaller pieces meant that interpolation was needed much less, therefore the curves appeared smoother and had much less effect on any previous straight lines.

Another big issue that appeared during testing was that any manoeuvres that had a change in angle through a turn always seemed to revert back to a straight line, meaning the rest of the manoeuvre was out of sync and did not look correct. This was an especially time-consuming bug, and an example of it can be seen in figure 3.5. Because finding out the problem and attempting to fix it was eating away at other feature time, the issue was left for the time being, in order to complete other key features outlined in the requirements. In order to ensure this issue would not remain at the end of the project, a strict time limit was set on the next features to allow for a good amount of time to fix the issue here.

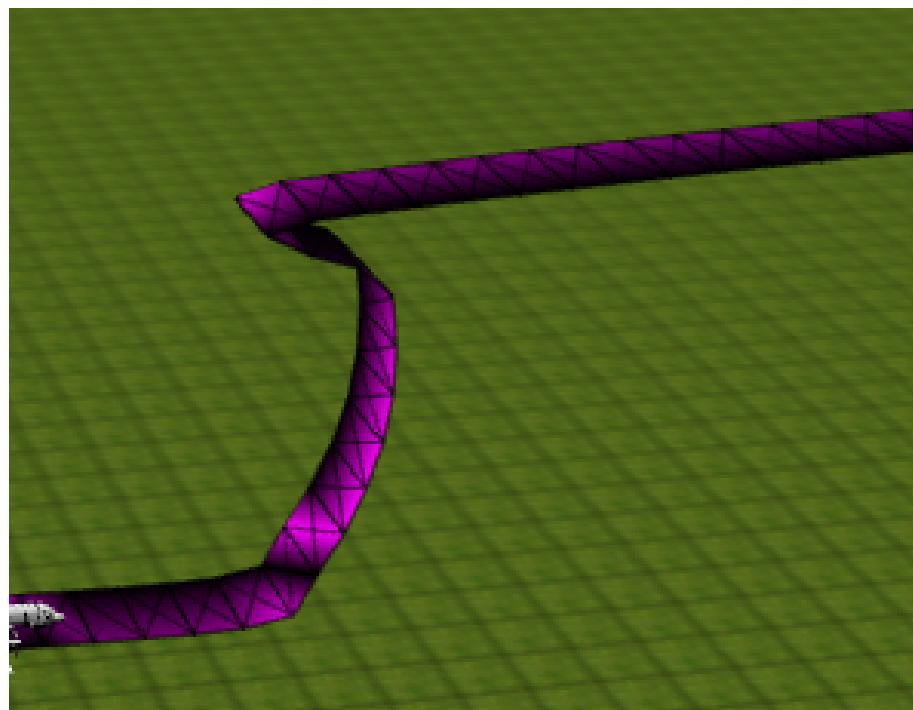


Figure 3.5: Figure illustrating that where the vector is turning right to complete the diagonal line up, it is becoming flat with the X axis rather than curving to the correct angle.

At the end of the iterations in this report, this issue will be re-evaluated once the fix is in place. Other than this issue, the rest of the feature was implemented well, and entering OLAN now drew fairly accurate shapes. Again with testing, usability was the primary case here, because checking for correct spline curves created would be too time consuming and difficult with the use of JSUnit.

The overall progress of the task at this point of the project is as follows:

Start	End	Duration	Progress	Comments
25-03-2015	05-04-2015	2 Weeks	75%	Although OLAN now is represented by shapes and they link up correctly, the issue mentioned os straight lines being drawn on change of angle remains. This will be fixed fully after implementation of other tasks.
06-03-2015	08-03-2015	2 Days	75%	Usability tests complete, changed step of angles from 45 to 15 to get smoother interpolation. More tests will be required after fixing the issue.

**Feature overall progress: 75%**

### 3.1.1.6 Feature 6- Animate OLAN flight path

Although there was an issue implementing the drawing of flight paths in the previous feature, the functionality that was complete allowed for the animation feature to be done. Three.js provided a good means of getting points along the spline curves to a percentage of the length of the shape. For example, by using the method 'getPointAt' with 50 as the parameter value gave the return vector value of the point on the line halfway. By doing this iteratively using the render loop used in the cameras meant a value could be incremented over time, thus getting points along each curve. Each time a point was received, the on-board camera could then be set to the position of it, and by doing this as fast as the render loop meant that a smooth animation was created. Again, a new module was created 'AnimationController' with various methods for playing and pausing the animation, and setting the distance of time between each point received in order to speed up or slow down the animation.

With each curve being stored in an array object, meant if linked up manoeuvres were being animated along, once one manoeuvre had reach 100% for getting points along its line, the next manoeuvre would be selected from the array and the get-point percentage reset back to 0. By doing this, a flawless smooth cross between manoeuvres has been achieved.

As for testing this feature, more JSUnit was used, but mainly for the getters and setters of the controller. For instance, checking that the pause, play and speed setters worked correctly required simple test cases that checked the private variables holding the values were correct. Alongside these tests, usability tests were also completed because of the new buttons in the GUI representing the play/pause and speed options. Both tests can be found in the appendices under section 4.6.

In addition to this part of the report, a blog post was created to also reflect the changes, and can be found on the dissertation blog [5].

Following the completion of this feature, the progress can be reported on.

**Feature overall progress: 100%**

Start	End	Duration	Progress	Comments
09-04-2015	10-04-2015	2 Days	100%	Animation is now possible through all manoeuvres in a flight, alongside options to pause, play and change speed.
11-04-2015	11-04-2015	1 Day	100%	Simple JSUnit and usability tests performed to check values from GUI are being sent to the back-end correctly.

### 3.1.1.7 Feature 7- Exporting and importing routines

The last of the primary features planned for the application was the saving and loading of flight plans. Because up to this stage the project time was behind, and time was required to fix other issues, it was decided that the initial format of saving the OLAN input directly would be quicker to implement than the rendered vector values.

To start this, a final module was created for the handling of JSON files and local storage, and this was then linked up to the HTML handler module to get the user's current OLAN input value. Four methods were required for this:

1. Exporting to JSON- This method makes a simple JSON file with one object contained ("OLAN" :olan string)
2. Importing from JSON- Allowing selection of a user file from the browser, and selecting the OLAN from it, then entering this into the input box to be rendered.
3. Exporting to local storage- The same format as the JSON, but saving in the browser. See appendix C section 3.5.
4. Importing from local storage- same, should be automatic when application loads up

In addition to the requirements that were implemented, it was decided that user should be able to choose whether automatic backup of the entered OLAN would load up at the start of the application. Because of the observer pattern that is being used throughout implementation, it took a very short space of time to add this feature to the HTML handler listener.

As for the GUI, to ensure a nice clean and well informed interface for importing, both loading bar and progress pop up were added to ensure the users would not be left in the dark about progress of the import of the JSON file. Figure 3.6 shows the loading of the import, while figure 3.7 shows the completion pop-up.

Testing involved some JSUnit again, where test data was entered and checked against the resulting JSON and local storage objects. The tests can be seen in appendix D section 4.7. Up to this point and for future tests, it was ensured that the Travis builds were passing when running all the JSUnit tests through Jasmine. This feature was completed quicker than the allocated time due to the research into Local storage previously, and therefore helped gain back some valuable time for other features.

As for any future development, it was mentioned that it could have been better to export the vectors directly, but the space in files and in time was considerable here therefore helping towards efficiency in this part of the project. The ending progress of this feature follows in the table below.

**Feature overall progress: 100%**

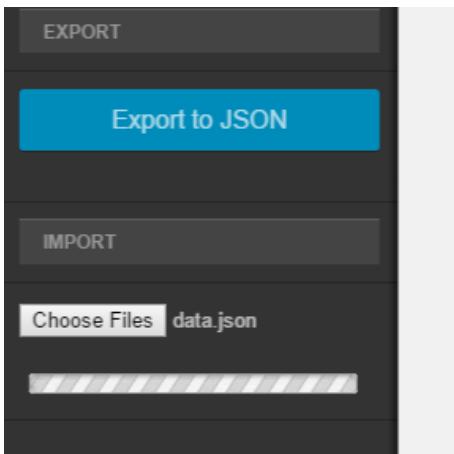


Figure 3.6: Movie-reel shown with minimise button displayed.

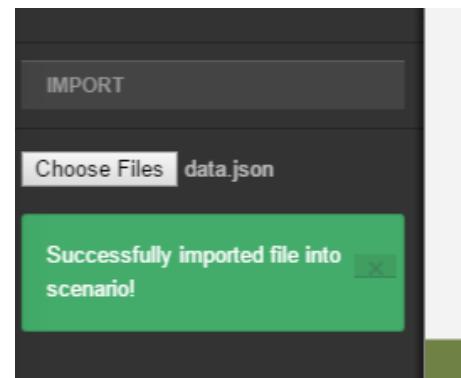


Figure 3.7: Movie-reel hidden with display button shown.

Start	End	Duration	Progress	Comments
12-04-2015	14-04-2015	3 Days	100%	Both importing and exporting of JSON and local storage complete, with an additional feature of giving the user the option to auto save when they enter any OLAN.
14-04-2015	15-04-2015	2 Days	100%	Implemented JSUnit tests linked to the Travis build, testing the format and content of exported flight plans.

### 3.1.1.8 Feature 8- Adding further GUI options

By this point, quite a few of the features installed into the application had the possibility of allowing the user to interact with a range of different parameters and options. For example, with the spline curves, there were options such as the smoothness of interpolation (the number of extrusion segments), options to switch between cameras, and the scale of flight paths amongst others. As with other options that had been added along the way with some features such as speed and auto-save, linking each to the GUI was fairly straight forward, with all that being required was to create an ID for the HTML element to be an option, and then listen for a change or click using the HTML handler, finally calling its respected method.

The options that were added can be shown in a comprehensive list with reasons for each.

- Extrusion segments- The smoothness of paths, where the more the user chooses the more segments each curve is made of. This can help users with less powerful systems, as there is less to render with less segments.
- On-board view- an option that changes the current camera view to one where the user will view the canvas environment from the point of view of the front of the aircraft. This gives the feel of actually flying the OLAN path, which could be helpful to users such as pilots who may want to learn a routine from the inside of a cockpit.
- Scale- The scale of all the OLAN paths drawn, defaulted at 1, but can be increased in multiples. Useful if the user wants to fit more onto the canvas, or wants to get a larger better

view of a move.

- Radius segments- The initial line that is drawn to show the manoeuvre may be changed to have more sides. For example, the default being 2 means a flat ribbon is drawn. 1 would be a single line, whilst 0 would make the path invisible. This would then allow the user to have an aircraft fly the path without any shapes behind it.

An additional GUI feature that was added here was the check for the loading of the OLAN JSON file before activating the input box in the navigation bar. As mentioned in design, this box should not be editable until the application is fully loaded, so a method was created in the HTML handler to activate the box when needed. This method was called by the camera controller module once the model aircraft was loaded, as this was the last and largest file to load.

As with any GUI interface features, usability testing was the best option here, and therefore each new option added was tested after being created. The tests checked if the proper function was called and had an effect on the application as was planned. The tests follow the previous ones in appendix D under section 4.8. It should be noted that the tests were done both on mobile and on desktop, to keep up with the added requirement that the application should be usable on both platforms. The tests ensured that all the options worked well, and worked when they were supposed to. The following table shows this feature's progress.

Start	End	Duration	Progress	Comments
15-04-2015	15-04-2015	1 Day	100%	Options added to reflect changes in various aspects of the application, alongside the lazy initialisation check added to the OLAN input box.
16-04-2015	16-04-2015	1 Day	100%	Usability tests performed on desktop and mobile browsers, all passing after multiple times refactoring.

**Feature overall progress: 100%**

### 3.1.1.9 Feature 9- Flight 'movie reel'

The movie reel feature was one that would be added if there was enough remaining time, though in this case it was decided that it would be implemented to a set time limit. The aim of the reel would be to show the user what manoeuvre is currently being flown in the animation, by having images or the manoeuvre from the OLAN input box converted to simple 2D Aresti, and then shown along a reel with current progress across them in relation to the entire flight. To start this, it was firstly considered that using the logic from the manoeuvre controller that built flight paths could be used to the same effect for drawing the movie reel figures.

Upon starting this though, it was found that many aspects of the feature would take too much time to implement, and that they could cause performance issues for the user. The first of these was that if the application was going to draw mini figures at the bottom of the page in a fixed location, it would mean having to create a set of mini-canvases to interact with, rather than using the main canvas and drawing at the bottom of it. Each figure would thus need its own canvas, and after so many are added, this can dramatically affect the browser's performance. Another issue found when looking how to create the reel was the complex style of Aresti figures required.

For example, creating arrows to represent rolls, and for annotations to be generated in the correct places alongside curves would require detailed mechanics in the back-end in order to produce them. This and the first issue was decided would take up too much development time, thus pushing back the remaining features left to fix and implement. Therefore a compromise was made, where the reel has a range of images of the Aresti figures loaded and put in place alongside each other. These images have already been created using the OpenAero application, so saving these to a folder in the application was easy, and each was saved with the name of the OLAN letter.

The movie reel was incorporated into the HTML handler, as this was a dom-element related item and required JQuery to manipulate the space at the bottom of the canvas. Then, added to the listeners in the HTML handler file was an event where when the user enters an OLAN letter, and this is found in the manoeuvres array (to ensure it is a real OLAN notation), an image representing the Aresti figure with the letter for the filename was loaded into a div floated at the bottom of the page where it was appended. Although this means of creating the figure was not what was initially planned, due to time constraints this means of creating the feature ensured it was done as quickly as possible, but also to a good standard of presentation that fit well with the rest of the application. It can be seen in figure 3.8 the reel with some figures loaded up, with the current animation progress highlighted over the manoeuvres.

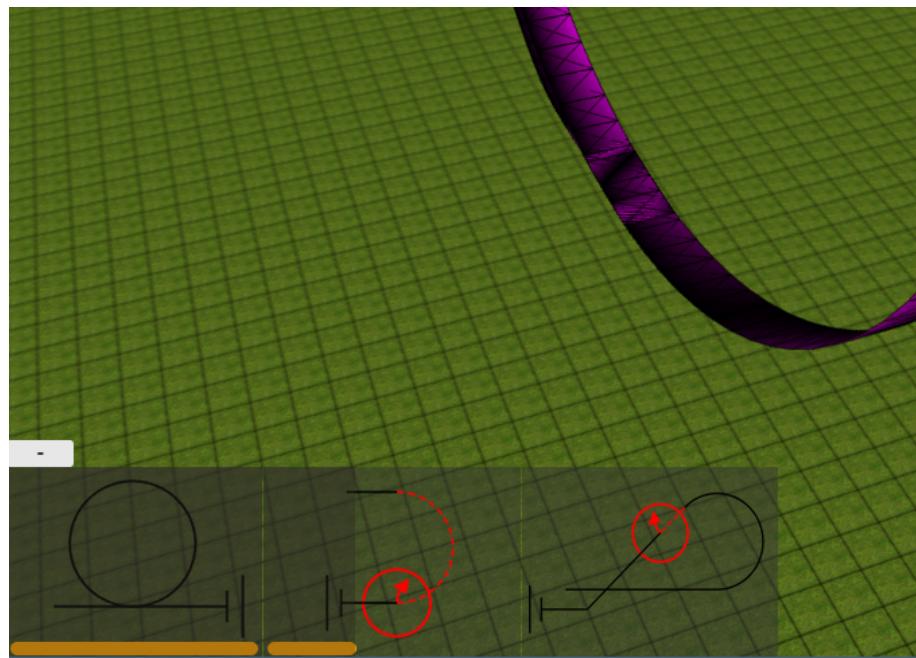


Figure 3.8: Movie reel overlaying the bottom of the canvas, with some figures loaded after the user typed in a string of OLAN.

Figure 3.8 also shows the animation progress, which was achieved by simply getting the current value of time which was used earlier in the 'getPointAt' method, then getting the percentage of this for the amount of moves entered. After this, a simple div was placed again using Jquery over the width of that percentage to achieve a darker coloured semi-transparent status bar. During tests of this feature (usability), one such issue was found that was caused when more than five manoeuvres were entered, the remaining Aresti figures were not present on the page, as it had been split into five sections. This means at this point of the project only the first five manoeuvres have their animation status shown. This is another feature that is hoped to be fixed before the end of the project implementation stage.

Start	End	Duration	Progress	Comments
17-04-2015	19-04-2015	3 Days	50%	Movie-reel implemented using images rather than constructing, though they show correctly the Aresti figures when the user enters OLAN. Issue found that requires fixing, concerning having more than five manoeuvres available on the reel.
20-04-2015	20-04-2015	1 Day	100%	Usability tests complete, found the issue using them, and will test again once the issue is addressed.

**Feature overall progress: 75%**

### 3.1.1.10 Feature 10- Parameterisation of OLAN input

The final feature that was added to the implementation Gantt chart was the one that would allow users to enter both parameters to OLAN notation (such as roll amount, length of entry and decent or others), and to tell the manoeuvre controller to move the start location of the next manoeuvre so many co-ordinates along the X or Y axis. Current progress on this feature after moving on in this stage of the project was that the second part functioned, allowing users to enter elements to move the start position of the following manoeuvres. However, as with some other features being implemented, it was felt that the time required to add the various prefixes and postfixes for each and every OLAN shape was too consuming on the overall project time. As with features where it was taking too long for specific parts, this will also be left in accordance with how the Gantt chart stands for time left for implementing and testing. The function for calculating the parameters was added besides the existing method that reads input from the OLAN box, then creating vectors to create a path between a previous and next manoeuvre.

For the part of testing the half of the feature that worked, usability testing was the best approach here. In appendix D section 4.9 the test table can be found, and shows the feature passing for this aspect. By attempting to keep the workings of the application as similar as possible as to how OpenAero handles parameters keeps consistency for users across the web, and to keep consistency in the OLAN language. While testing, it was found that the input of the user should be heavily restricted and strictly typed, ensuring the user types the exact format that the parameters should follow. After testing and evaluating the way that the OpenAero application handles this, it was decided the format should also be '(X, Y)' where it is space separated from other elements, and where x and y can be either negative or positive.

Following the completion of this particular parameterisation, the progress of the feature can now be reviewed.

Start	End	Duration	Progress	Comments
21-04-2015	23-04-2015	3 Days	50%	Parameters for moving start position of next manoeuvre ready, but individual OLAN manoeuvre parameters not implemented yet.
24-04-2015	24-04-2015	1 Day	50%	Can only test first half of the feature up to this point, will implement tests if second half is complete.

**Feature overall progress: 50%**

## 3.2 Final status and progress

At this stage of the project, it is now possible to get a grasp of the overall status of the application concerning implementation and testing. Using the progress reports from each feature, a general idea of the entire progress will combine all the completed features and then allow the creation of a burn-down chart to compare the current status with projected status. Although Burn-down charts are not FDD, it was chosen that the Scrum approach here would reveal more information around what work still needs to be completed, and when by. In order to create the burn-down chart, the overall percentages of progress for each task should be collected. The list of features is shown in table 3.1.

Feature	Start	End	Duration	Progress
1	09-03-2015	11-03-2015	3 Days	100%
2	12-03-2015	18-03-2015	7 Days	90%
3	19-03-2015	20-03-2015	2 Days	100%
4	21-03-2015	24-03-2015	4 Days	100%
5	25-03-2015	08-04-2015	2 Weeks 2 Days	75%
6	11-04-2015	09-04-2015	3 Days	100%
7	12-04-2015	15-04-2015	5 Days	100%
8	15-04-2015	16-04-2015	2 Days	100%
9	17-04-2015	20-04-2015	4 Days	75%
10	21-04-2015	24-04-2015	4 Days	50%

Table 3.1: Collected statuses of all features required, with their duration and percentage complete. Note: the dates shown the task was completed working on also include time done testing, and writing this stage of the report.

Therefore, using the above table with dates of completion, a burn-down chart up to this point can be created. The chart in figure 3.9 shows the amount of features predicted remaining to implement versus the amount remaining at this time in the project.

Although work appears to be behind schedule here, it should be noted that there is still both time remaining and some features are more than half complete. For strict purposes though and following the FDD manifesto, a feature can not be said to be complete until it is 100% complete.

Analysing the graph further, the main problem can be seen where work was halted on feature five, the creation of manoeuvres on the canvas. Because issues prolonged work here, it meant other features were pushed back until it was decided that they should be completed in order to make a more whole application. Due to moving onto and completing other features first alongside writing this part of the report, considerable time has been made up. The time remaining will now allow for any completion of features that are most important, and also fixes to others if possible.

In addition to the graph shown, the features can be expressed as feature sets in traditional FDD progress reports. The progress reports using the due dates, and current progress are highlighted in figure 3.10, where the name of the feature set is shown, followed by how many parts the feature set contains, and the percentage. Where the background is green, the feature set is complete, yellow means it is currently ongoing, and red means the feature set is behind schedule. It expands on the tasks that need to be done more promptly, so for this project the main issue that will be addressed first is the OLAN to flight path creation.

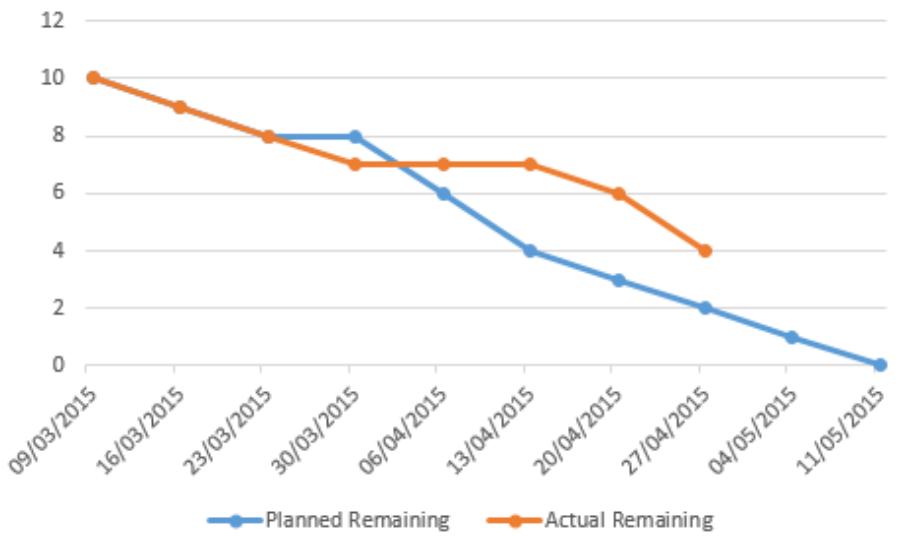


Figure 3.9: Burn-down chart of features implemented and tested fully. X axis represents number of features to implement, whilst Y axis shows the date that the features have been implemented by.

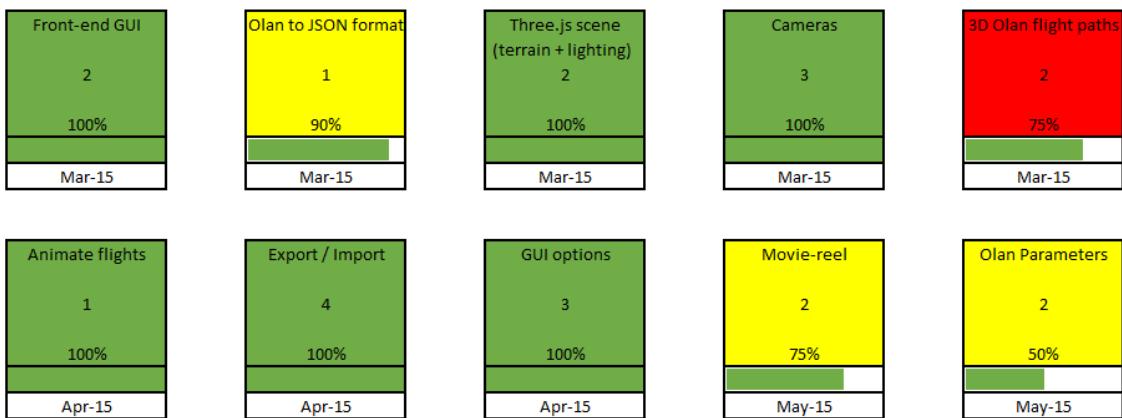


Figure 3.10: Feature progress reports for each of the feature sets implemented up to this point in time. The predicted month of completion is shown at the bottom, and tasks where they are not complete and tested fully are ones without a green background.

### 3.2.1 After-test fixes and developments

Before a look at what fixes were done to solve issues found earlier in the iteration stage, developments to do with testing can be mentioned. Since starting using both requireJS and Jasmine, it was noticed that it could be useful to have a helper module where different tests could share set-up or tear down code. The snippet from the test utility module can be found in appendix D section 4.2, and was used where it was required that some GUI elements had to be created before they could be tested using fake event triggers.

Moving onto feature developments, the first which was the most important was the issue concerning the creation of Aresti figures for OLAN entered. Because this issue was the largest and held back quite integral parts of the project, it is important that a comprehensive amount of detail was

given, and shown how the issue was debugged. Finding out the main issues and sources of the problem helped in looking for a fix for this part of the application. Although this task is still ongoing, due to the time restraining of both the printing and binding of this report, the final findings and solution if one is created will be created in an appending document which will be placed at the end of this document before the bibliography. Appendix E will contain findings if there are any developments.

As for the issue itself, to explain it best see figures 3.11 and 3.12 to see what happens currently when one loop is added after another. It can be seen that the second loop currently spans the outside of the first, which is not what is desired at this stage. Rather, the second loop should be a set length (in this case 10 pixels) to the right, and be the same size as the first. This issue also seems to extend to any scenario where a flat piece of the path is followed by another change of direction, which then appears to not go into the correct form desired.

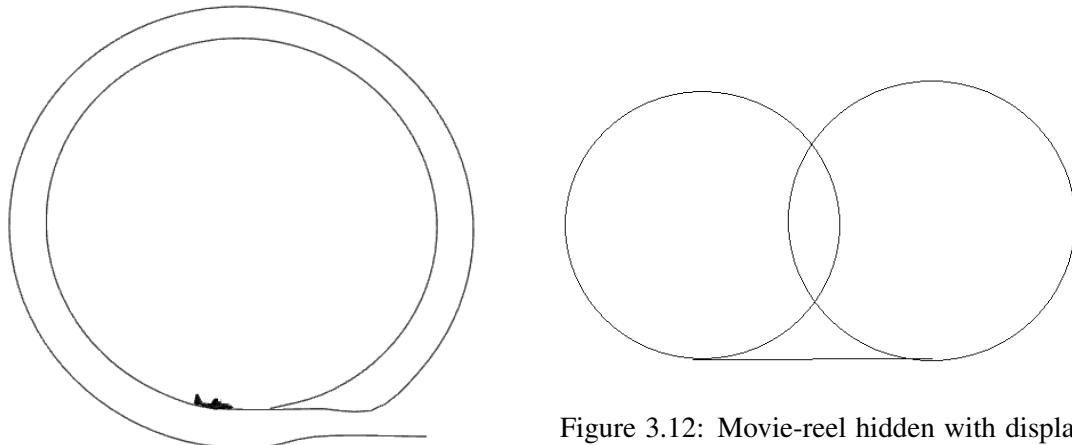


Figure 3.12: Movie-reel hidden with display button shown.

Figure 3.11: Movie-reel shown with minimise button displayed.

There seem to be three primary issues found with the example shown above:

- The angle at which the second loop begins to start its upward direction is larger than the first.
- On each iteration of the second curves incline, the amount spanned between vector points is larger than the first.
- The centre point on the second loop looks the same as the first, resulting in the loop to end lower than the planned point, because the loop is larger.

With these three issues in mind, the next step was to perform further tests to see if this affected different angles, amount of angles, and the length of straight lines. The first test carried out was to replace the 15 degrees used for curving with 90 degree turns, to see if a square loop would act the same. This test can be seen in figure 3.13, and shows again the same issue as before with round loops.

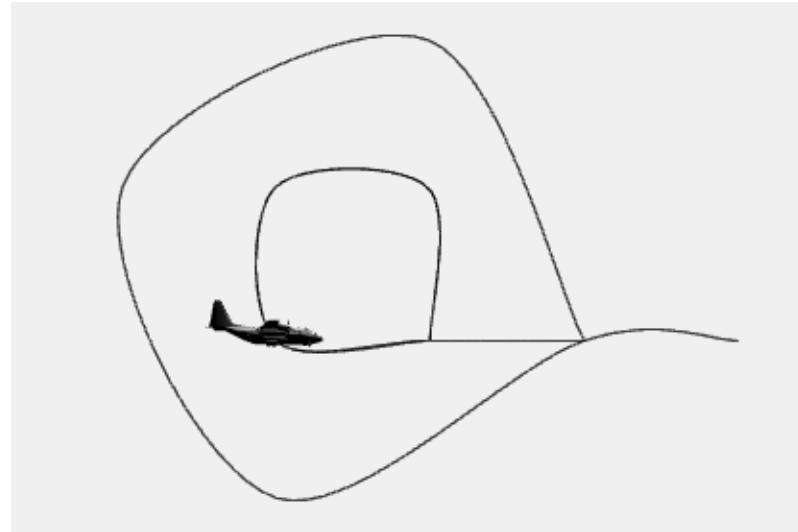


Figure 3.13: Flow chart showing how movie-reel knows when to move.

By also printing out points and drawing vector points on the canvas as it is rendered, it can be seen that interpolation is not the culprit for this issue. Figure 3.14 shows that before interpolation, the points reflect the loops perfectly and are not being changed by interpolation.

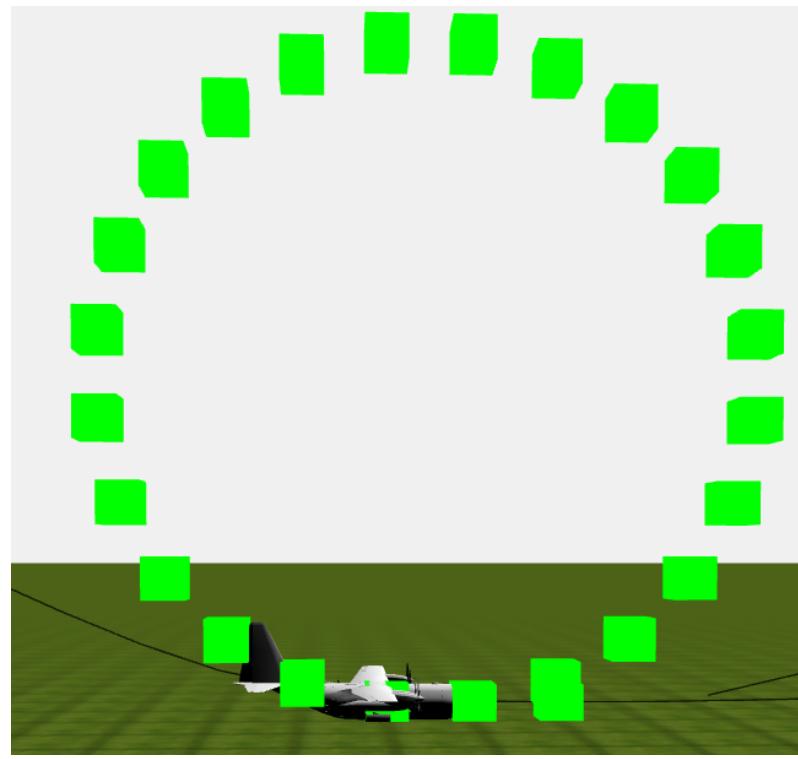


Figure 3.14: Flow chart showing how movie-reel knows when to move.

The next step taken to try and find the reasoning behind the bug was to console log an array of different values concerning rotation, vector positioning, and distances between vectors. The first of which was added so that each angle between every vector was printed. The result of this found

that on each iteration, the same amount of rotation on the X axis was being performed each time. This led to the thought that perhaps the amount of rotation was building up on each loop, resulting in a larger rotation at the start of a new loop.

Checking the distance between points on the Z axis was next, because mentioned earlier the points looked further away from each other. To do this, Pythagoras' theorem was applied between points, by getting the square of the difference in X values, adding this to the square of the difference in Y values, and then performing the square root of the result. The way this was added to the current code can be shown in figure 3.15.

```

1  var x = updateVector.x - prevVector.x;
2  var y = updateVector.y - prevVector.y;
3  var total = (x * x) + (y*y);
4  console.log(Math.sqrt(total));

```

Figure 3.15: Code placed after each iteration of creating a vector point from each instruction for manoeuvres.

The results showed that the length between each vector seemed to exponentially increase on each additional loop. And because the distance of the Z axis was currently being hard written into each manoeuvre, the only reasoning for this part of the issue was that the rotation of a vector was being based off of the initial starting vector, and not the starting vector of the second loop, which began (in this case) 10 pixels to the right.

An initial thought solution for this issue was to simply subtract the starting vector of the second loop from the first initial vector of the flight, and then rotate around the vector that would be calculated. Upon searching through various sources on the threeJS site, examples helped to provide code on how to do this, but this ended up unsuccessful.

There were points during this stage where attempts were made to use different libraries (such as glMatrix) to generate separate matrices for each vector and rotate around them rather than the previous vector. Due to time constraints though, this part of the project fell short. Although at this stage of the project the problem remains, see Appendix E for any fixes completed to this during the latter stages of the project where time will allow.

Moving on from this issue and back to other changes, a small feature that was added from a look and usability view was a button to hide the movie-reel. At times where all 5 slots were taken up from the amount of manoeuvres entered, it could be obstructing to the view. Having the option to minimise the reel was added, thus allowing the user to hide and show it if they so desired. Figure 3.16 shows the new button which can be used to hide the reel, whilst figure 3.17 shows the ability to make the reel appear again.

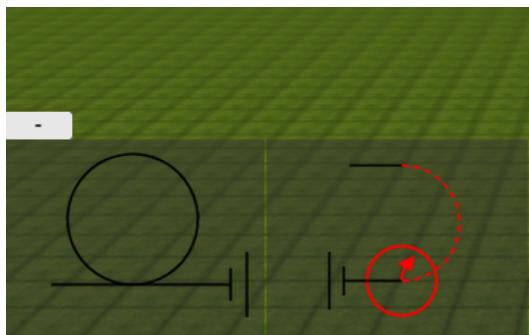


Figure 3.16: Movie-reel shown with minimise button displayed.



Figure 3.17: Movie-reel hidden with display button shown.

A fix that was added to the application also looking towards the movie-reel was the issue found where when more than 10 manoeuvres were present, then the reel did not scroll onto the next five when the first five had been animated across. This issue has now been addressed, and now correctly shows the next five manoeuvres after animating across the previous five. A flow chart shown in figure 3.18 illustrates how the application knows when to move to the next five manoeuvres.

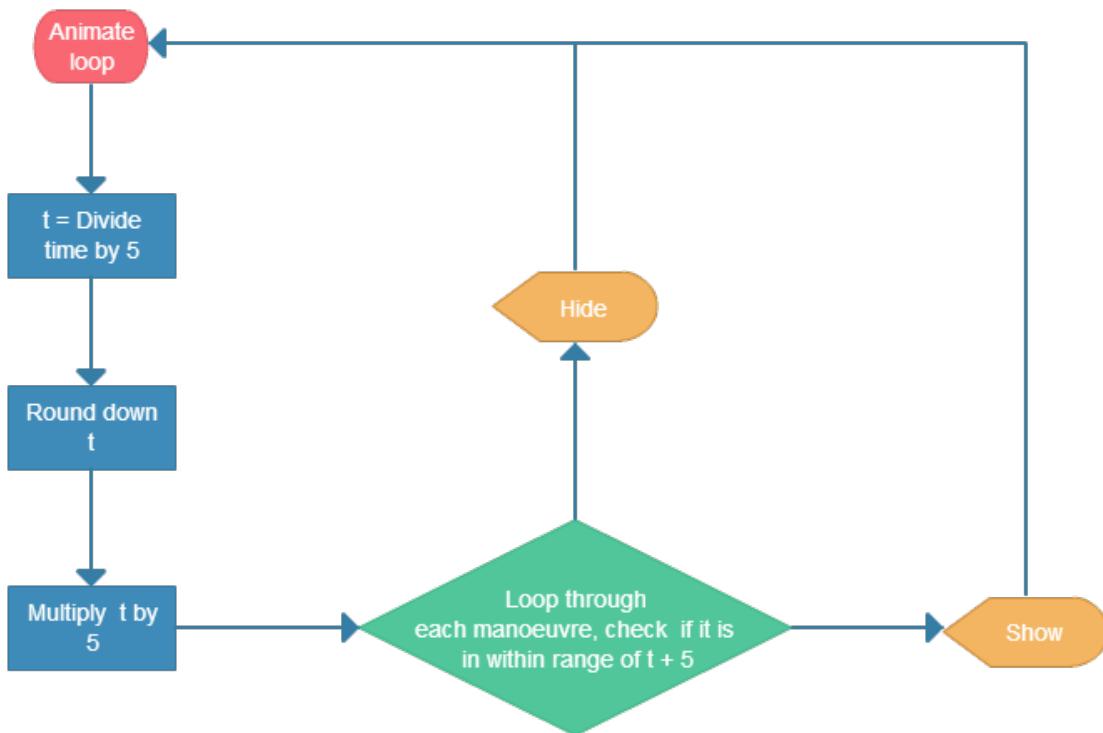


Figure 3.18: Flow chart showing how movie-reel knows when to move.

A couple of smaller but integral improvements added before this report progressed to the evaluation stage was the addition of both checks to OLAN compatibilities on the scene, and smoke trails. In the OpenAero application discussed in the analysis, it had checks which looked at making sure OLAN entry was only allowed to be added when it was valid. One such check that has been added to this project's application is the ability to generate a warning when the user enters an OLAN manoeuvre which would cause the flight path to pass through the ground. To do this, a check which

looked at all the vectors in each flight path made sure that both the x and y value co-ordinates were above zero, or an error was shown. The same foundation element was used as with the save-load message, which appears over the canvas to show the warning as seen in figure 3.19. By crossing off the error, it will not appear again throughout use of the application.

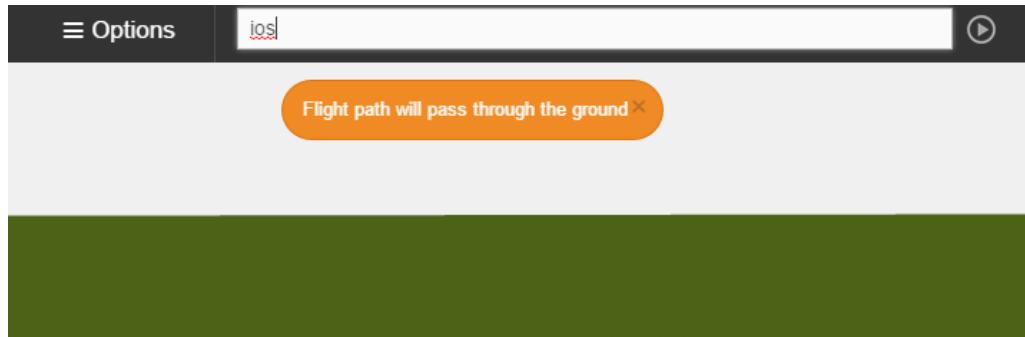


Figure 3.19: Warning message on entry of OLAN that passes through negative values.

The smoke trails were more complicated to create, as after a meeting with the project supervisor, an example of what would be desired of them initially meant that where the aircrafts rotation was upside down the smoke should be red, and gradually become green as the orientation is more stable. The application with this feature added can be seen in figure 3.20. In order to implement this, it was required to firstly get the value of the rotation of the vector, and then draw a square fragment of the smoke depending on how close to the required angles to make the smoke red. By multiplying the percentage of closeness to the angles being upside down, the red and green values of a RGB colour could be increased and decreased by multiplying the strength percentage by 255.

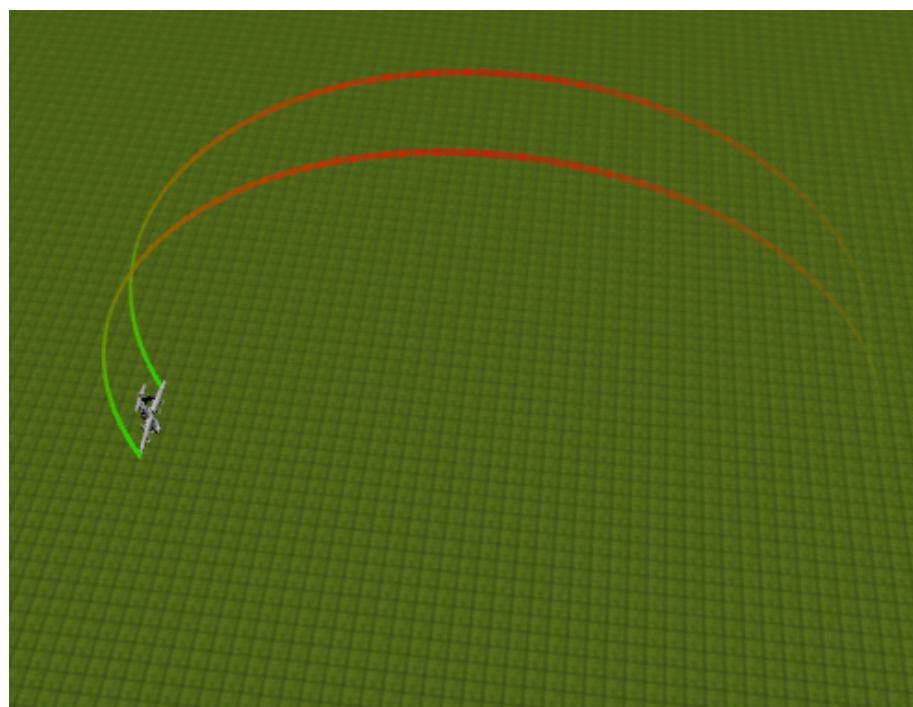


Figure 3.20: Smoke trails for mid-flight showing more red as the flight went upside down in a loop.

A final change performed within the allocated time left was the re-factoring of code. A book that was used for guidance with this was 'Clean Code' [27] by Robert C. Martin who mentioned that methods should do one thing only, and not be longer than four or five lines. Following this principles, this was performed on the application code, and JSDoc re-compiled.

After all changes were complete, a reconstruction of both the burn down chart from the start of implementation(in figure 3.21) and module diagram from the design section was possible. The diagram in figure 3.22 shows which modules communicate with each other, with the main module initiating a lot of other modules, this has many links. Modules like the htmlHandler were used a lot because many events or actions from the user required the GUI to be updated.

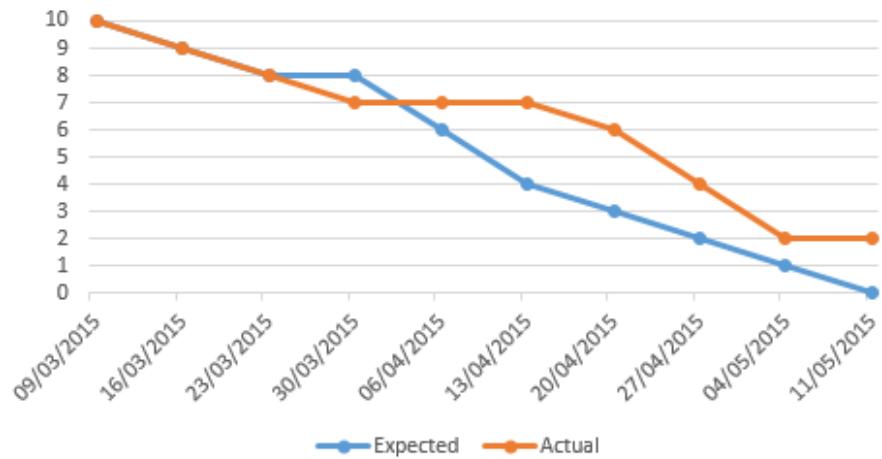


Figure 3.21: Updated burn-down graph with fully implemented features updated. Note, the movie-reel feature was considered complete because using images seemed more practical.

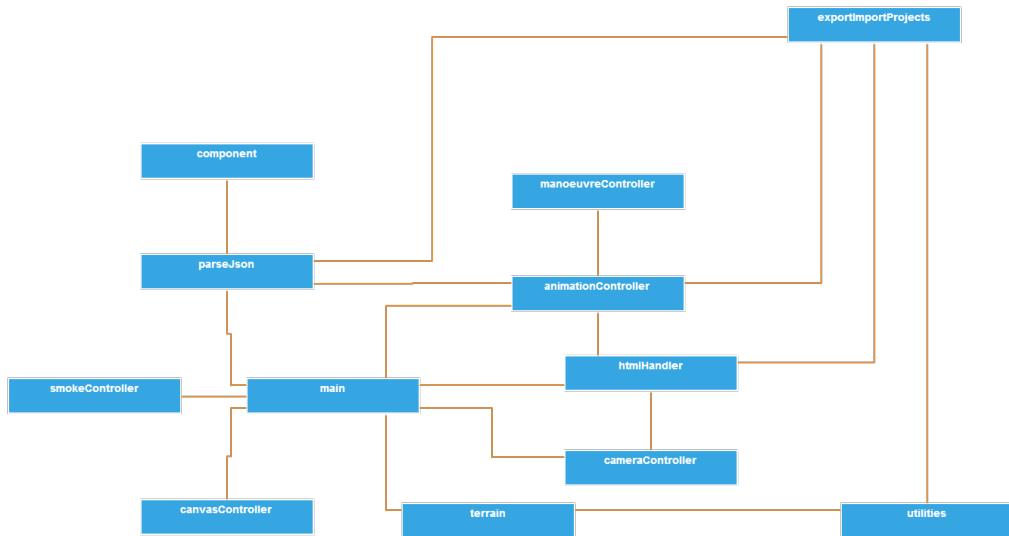
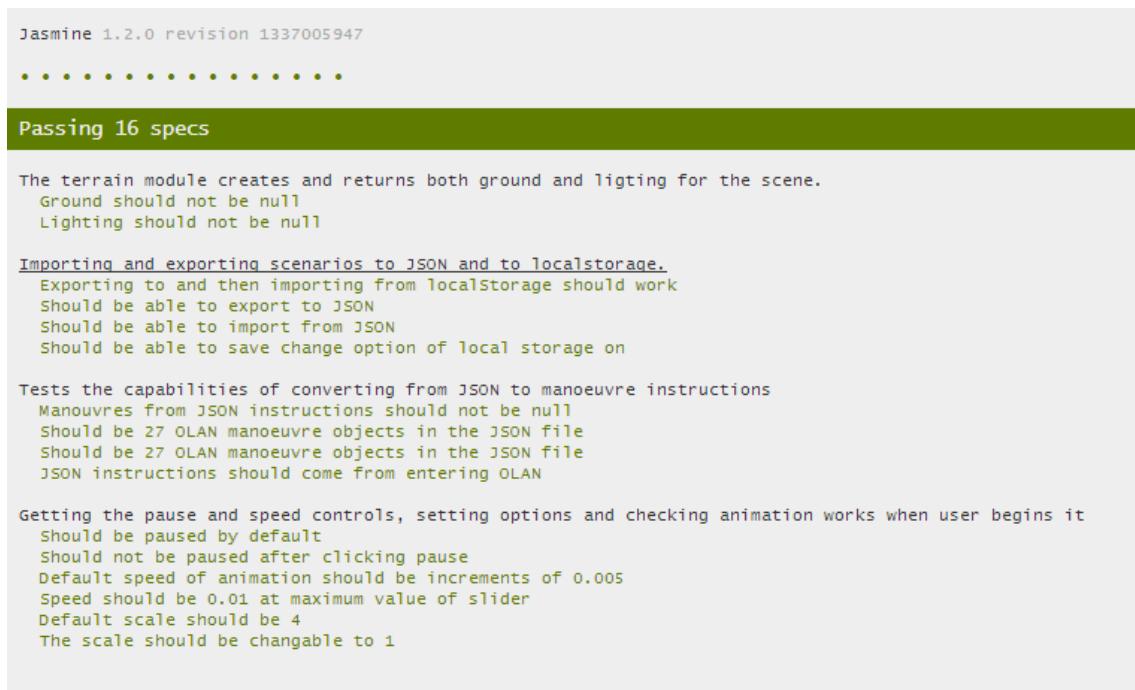


Figure 3.22: Module diagram showing links between each module at the end of the implementation stage.

### 3.3 Jasmine testing

Following all changes and completion of project time for implementation and testing, it was decided that all Jasmine tests should be checked, appended to where required, and then ensured they all passed. New tests added included testing the new auto-save function for local storage. For this, a new test which checked the getter for the value of the auto-save-on feature was added to the import/export test specification. At the end of testing, there was a total of 16 unit tests, each one compromised with a set of instructions to the array of modules in the application followed by an expect statement which checked the return objects of the particular feature that was being tested.

A great advantage of Jasmine is the ability to run the tests in both the browser and through the Travis build server. Each time new tests were added, Travis would alert on a failed test enabling time to be taken to fix the failing feature. Figure 3.23 shown below highlights the results of running the tests locally from the browser, and with each of the test specifications passing. There was one issue that was found testing this way though, which was if for instance the application had been running in the same browser, local storage tests were sometimes affected if the application had been changing the local storage content. This is because it is saved across the entire browser, so if the check-box for auto save was checked, it would be checked while testing, causing opposite results when testing for checking the box. A simple solution was to test in one browser, and run the application in another.



Jasmine 1.2.0 revision 1337005947  
.....  
**Passing 16 specs**  
The terrain module creates and returns both ground and lighting for the scene.  
Ground should not be null  
Lighting should not be null  
Importing and exporting scenarios to JSON and to localStorage.  
Exporting to and then importing from localStorage should work  
Should be able to export to JSON  
Should be able to import from JSON  
Should be able to save change option of local storage on  
Tests the capabilities of converting from JSON to manoeuvre instructions  
Manoeuvres from JSON instructions should not be null  
Should be 27 OLAN manoeuvre objects in the JSON file  
Should be 27 OLAN manoeuvre objects in the JSON file  
JSON instructions should come from entering OLAN  
Getting the pause and speed controls, setting options and checking animation works when user begins it  
Should be paused by default  
Should not be paused after clicking pause  
Default speed of animation should be increments of 0.005  
Speed should be 0.01 at maximum value of slider  
Default scale should be 4  
The scale should be changable to 1

Figure 3.23: Screenshot of all Jasmine tests passing in the browser.

### 3.4 User testing

Along with the JSUnit tests and the usability tests that were created, user testing is a means of testing ideal for front-end applications where the usability of the application is paramount. There are a few routes that can be taken to perform user testing, one of which is a questionnaire. Rather than allowing the user to send feedback through suggestions or pros and cons, a quicker and more direct way to check the applications fulfils its needs is to provide the user with a set of direct questions, allowing them to state if they agree or disagree.

The questionnaire, which can be found in the appendices under appendix D, section 4.10 provided ten agree or disagree questions that the users had to answer. Upon creating the questionnaire, these were then handed to a pick of 10 users, in technical and none-technical backgrounds to ensure a good spread of opinion. If just technical users were chosen, they might not see the application from the aspect of GUI as much as a standard user, as some users may find it harder to find things on a page. Things such as menus for instance may not be as visible and easy to find for users who have not seen similar layouts in the past, and it is important that the application has a level of being self-documenting.

The users selected to perform the testing comprised of eight students and two none-students. It was also ensured that half the students selected were not on a computer science related degree to ensure a wider set of technological knowledge. For each test, a brief description of the application was given to the user explaining the purpose and requirements of the project and application, followed by the user trying out different features in the GUI and canvas. With one of the users selected actually being a pilot, meant that finding out if the application is actually useful for its purpose, and if the users the application was created for actually found it useful and easy to use.

The questionnaires handed out were created using Google forms, to keep the process on the Internet for easier tracking. Because this form of testing was not planned out originally on the Gantt chart at the start of this project, it was important that the tests were carried out as quickly as possible, so Google forms were sent out and asked they could be returned a couple of days later.

The results of each question can be found in appendix D section 4.11. One of the questions that was disagreed with most was the speed at which the application loaded, and this was reflected in two comments alongside this. The main reasoning for this seemed to be that the model aircraft loaded by default looked to be too large to load up. Because most browsers now have the ability to cache objects and images, this should not be a problem for future use of the application once the page is loaded up.

Of course with the current issue of the OLAN not being constructed properly at the time the questionnaires were handed out, the results showed all users disagreed with the question regarding the expected output of OLAN.

Another possible improvement that was found from feedback during the questionnaire stage was how the application could provide better initial first use information. The second question from the results showed how that forty percent of those questioned answered disagree to the easiness of using the application. Suggested by one of the users was to include some form of initial help page or pop-up when loading the page up.

Other than these two suggestions, there was one which suggested better compatibility with mobile devices. Items such as tablets had too high a resolution to request the mobile page, thus meaning tablets had the desktop version. This meant buttons appeared small and text hard to read. Again,

this could be an easy fix, by adding another level to the different sizes the page can set to. More compatibility could be possible with browsers too, with one user reporting that an old version of Safari allowed them to input into the OLAN box before the models were loaded, causing errors.

### 3.5 Testing review

Starting with the pre-coding tasks that had to be completed, Github was initially set up on the machines the application as going to be created on, followed shortly by the set-up of Travis and Grunt which was used later for automatic running of tests. The latest build status can be seen on the repository, and also in figure 3.24. Once the repository and branch that would be used to host the application was set up, Sublime text was used to perform the coding, and was used because of the package compatibility to assist with code formatting. In terms of how long it took to prepare the environment for coding and testing, this took less than a day, including the work blog.

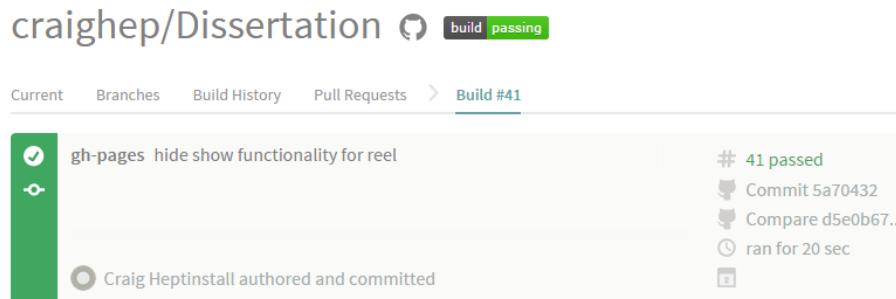


Figure 3.24: Latest Travis build after a commit, running all the Jasmine tests in the application.

Throughout testing the application, it was ensured the performance levels were checked to be fast enough to run on most devices, primarily using a library called stats.js [20]. This allowed a small frame-rate counter in the corner of the application, which monitored how many frames or iterations of the animation the application achieved each second. Values between 40 and 60 was the aim, and 60 was the value throughout the heaviest work (having lots of manoeuvres being flown). The frame-rate counter was displayed as shown in figure 3.25 with an example of frame-rate values on different devices in figure 3.26.



Figure 3.25: Frame-rate counter shown in bottom right of the application.

In addition to monitoring the stats from the display whilst developing, it was a useful idea to have a more accurate track of how well the application was performing under different browsers and devices. To do this, whilst under the development environment a line of code was inserted into the iteration that got the latest frames per second, and logged this into a csv file. After one minute,

the application was then closed, and the average rate was gathered. Each time this was performed on the certain device or browser, it was ensured the same operation occurred to a good accuracy of similarity. The results can be seen in figures 3.27 and 3.26. These tests created a good platform for ensuring a stable application and more efficient code improvements where the frame-rate may have been dropping.

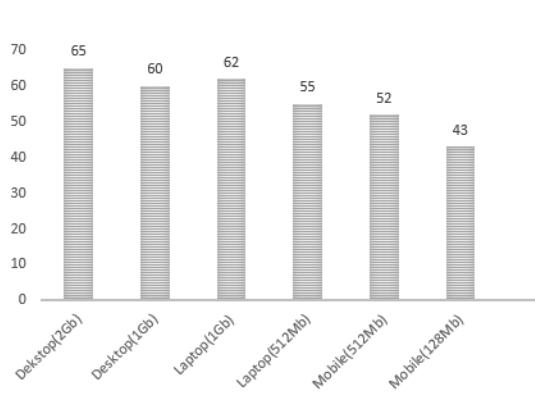


Figure 3.26: Average rate per device(Graphics RAM in brackets)

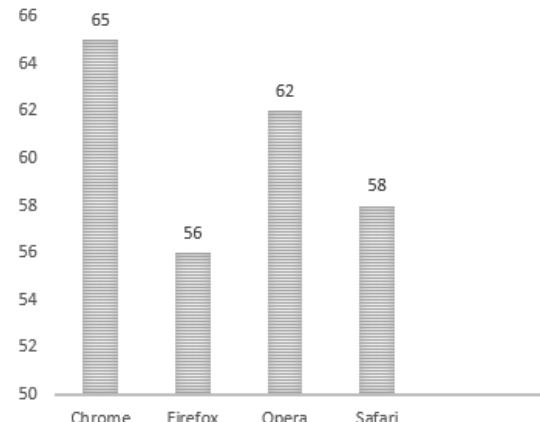


Figure 3.27: Average frame rate per browser (all latest versions of browser on 04/05/2015)

It can be seen that there was one anomaly result, in the desktop with the same graphics memory as the laptop had a lower rate. This could be explained by a number of factors, one such way could be that the processor that would be executing the code may have been slower on the desktop. This was another consideration that ensured optimal coding methods.

It was found that during the implantation stage, by regularly updating both the work blog [6] and the JSDoc, both were useful guides for reviewing the completed application. The JSDoc which can be found in the 'docs' folder in the code structure contains descriptions of every method in the application, and has a good front-end website to view each. Although it was key to ensure that all code contained in the application was self-explanatory to a certain amount for future developments, it was important to include a description above each method to help any readers know the general layout and workings of the application.

The completed application which can be seen in figure 3.28 can be found and viewed on-line at:  
<http://craighep.github.io/Dissertation/>

For other screenshots of the application in its current completed form, see appendix D section 4.12.

And all documentation including the JSDoc can be viewed on-line at: <http://craighep.github.io/Dissertation/docs/>

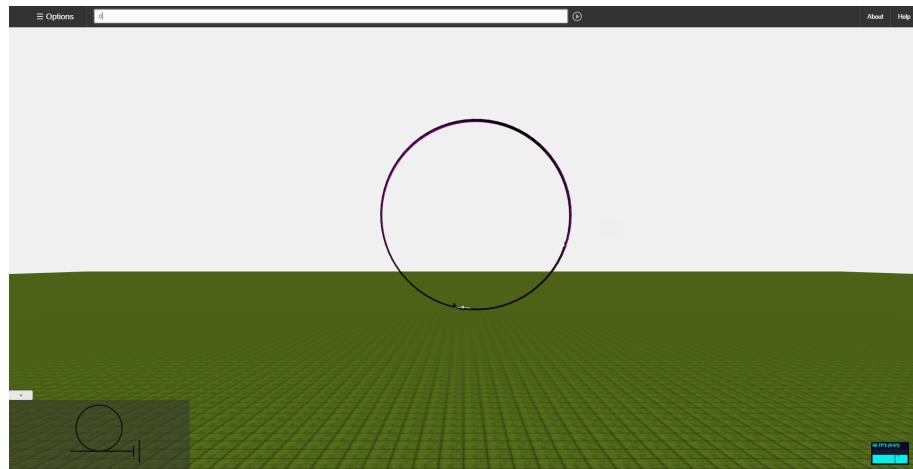


Figure 3.28: Final state of the application, with menus, canvas and movie reel added.

# Chapter 4

## Evaluation

Upon completion of the application, it is now necessary to evaluate both the application and project as a whole. This section will address a number of topics, in order to grasp an overall effectiveness of the project. For the purposes of highlighting points such as how well requirements were set out, or how well the application fulfilled its purpose, this evaluation has been broken down into the principle stages of the project. At the end, a small self-evaluation will describe what the author of this paper and application has felt was learned through this project in terms of personal and technical achievements.

### 4.1 Analysis and design decisions

Firstly, answering the question of how successful gathering requirements, the process of this started with looking at the initial project choice and language choice. After giving a brief overview of what the purpose and reasoning for this project, the language choice was an easy decision because WebGL could only run under the JavaScript language. Identifying this, analysing what technologies to use was then found to be much easier.

The amount of research into the background topics was to a good amount that lead up to the discovery of the 15 degree increments idea (though later revised to 45 for interpolation issues), and meetings ensured that a sensible list of feature sets were created. By preparing questions in the initial project specification, having meetings clarified some of the technology choices, and discovered in more detail functions required of the application. In addition to the research shown in the primary report, the appendix added a even greater level of detail into the research of OLAN, and the expect Aresti figures to be generated.

Looking at the methodology choice in more detail, the reasoning for create a hybrid of the waterfall and feature driven was backed up for personal views towards the two processes, and technical efficiency reasons. By outlining the process in as much detail as possible ensured that the project allowed the design, implementation and testing phases to follow a strict plan. In order to support the methodology choice, both project and implementation Gantt charts helped to show where the project would be divided in terms of project time. Where this assignment was more heavily weighted towards implementation and testing, this was taken into account when assigning amounts of project time.

Diagrams helped tremendously in designing the project including the model view controller pat-

tern mock-up, which provided the design for how the application would interact with the front and back end. Using the MVC diagram, it was possible to see what kind of general modules or classes would be required to run the application and communicate with the canvas. The MVC pattern also paved the way to introduce the idea of using a whole set of different design patterns, such as the observer pattern, which like MVC provided a way of connecting with front-end elements whilst keeping the model unaware of the them. A lot of research into various design patterns possible for JavaScript was taken into account, with reasoning given for choosing to use or not to use different patterns.

Researching into some of the technologies before beginning implementation also helped a great deal later on in the project, as it reduced set up time for items like RequireJS. By browsing example applications and work on-line also using Three.js, it gave a wider more general idea on what the most efficient way of creating a Three.js application, and what practices to follow. This was the same for the plain JavaScript code, where items such as local storage were researched and samples viewed before thinking how this application could implement them.

## 4.2 Application and testing evaluation

The second section of the project evaluation concerns how well the methodology was put to use, and overall, how successful the completed application was at fulfilling requirements. As FDD would be the principle means of implementation, an iteration approach to creating each feature set was used. At the start of the section, the iteration method was outlined, to ensure that each iteration followed the same procedures and testing methods. By doing this, it made sure that the time given to each task was fair and gave as best possible to finish as many features as possible.

As it can be seen in the section itself, not all features were completed initially, with some issues and features remaining missing even at the end of the time given to implementation. Features such as the movie-reel, where it was initially planned that the same part of code logic used to construct manoeuvres would be used to construct mini Aresti figures at the bottom of the page. During some investigation into how it could be achieved though, it was thought it would be firstly too consuming on the speed of the application, and too consuming in terms of development time. Therefore, a compromise was made, and simple images were loaded onto the movie-reel.

Issues with the manoeuvres that were drawn on the canvas led to some delays in the project, and a decision was taken to move to the next feature implementation meant that some of the features that may have not been done at all if the problem causing task was continued with. Although in FDD practice each feature should be done one at a time, moving on when the previous is complete, by going back to the problem later on but making sure there would be enough time to fix the issue was remaining, gave a better chance of a more complete application.

As mentioned in the implementation stage of this report, although the issue was not fixed at the time of that specific stage, the issue with rotations causing the drawing problem was continually worked on. At the latter stage of this report and following a meeting with the project supervisor, it was decided it would be better to ensure a full report is ready and append any fixes documented extra to the actual printed and binded report. Due to this, the changes after the print date were appended to the end of this report in appendix E.

There were three primary means of testing during this stage of the project, each of which were chosen were it was felt appropriate. For instance, creating JSUnit tests where the feature was

heavily animation based would be sufficient to test the entire feature, so usability tests solved that problem. It was ensured that each feature set had its own tests created, whether it be usability or JUnit. Because of the use of the Jasmine framework, and linking this up to Travis, it was possible to see if any tests were failing due to refactoring or fixes. By getting alerts on a build failure, it meant the speed in which bug fixing could occur was faster.

The user questionnaire helped to evaluate the completed application and define how well the application met its needs. By creating a questionnaire where only two options were possible, meant that users would be more inclined to reply to the questionnaire quicker. This was true when all handed out were returned the next day, allowing reviewing and charts to be created from the answers. Using Google forms also provided a nice return style of data, allowing easy charts to be made and assumptions created. One key suggestion that appeared from the questionnaires involved the loading time of the application, where the model aircraft seemed too slow.

The parts of the completed application that should be highlighted as meeting or not meeting major requirements:

- OLAN to 3D manoeuvres- These caused problematic, and were debugged thoroughly, but due to time constraints, were not fixed within the project time, unless mentioned within appendix E. Parameters for individual OLAN was not possible though moving the start position was.
- The ability to animate the flight- Manoeuvres were linkable, and could be animated along with the aircraft model. The ability to pause and change speed was also an added feature.
- A scene with cameras, lighting and various options- All of these were implemented, with added features such as on-board view for flights.
- Added features such as the movie-reel- Although only pictures, this feature proved useful to users, and gave a live update to the progress of animation.
- Control sticks- Not implemented due to time constraints.
- Saving and loading of flights- Both JSON and local storage implemented as planned, and ahead of time.
- A suitable GUI- Both a mobile and desktop responsive site created.
- Documentation and testing- JSDoc for code, and this report for explaining the project, and the application was tested successfully and thoroughly.

The GUI should be particularly mentioned here also, with it being very user orientated. This was a feature that was felt it had been quite professionally made and a good level of detail added. Items like pop-ups were made not be annoying, and loading bars were added to allow users to always know when and what the status of events were while running certain operations. Menus were also usefully made to be hidden to allow for maximum workspace on the canvas.

### 4.3 Project improvements

Now that the walk-through of the project has been completed, each detailed with issues highlighted, there are some possible improvements that could have been made to the way the project was

done if it was started again knowing what happened the first time.

A feature improvement that would have been useful to be added, but due to time constraints did not happen, was an extension of the warnings when entering OLAN, which was to check for none-compatible OLAN. For example, an OLAN move which exited facing upside down followed by another upwards orientated manoeuvre should not be allowed.

The first project improvement would be to research more into both how to construct shapes in Three.js, so that issues that were found when creating manoeuvres could have been avoided. An alternative approach could have also been to change libraries all together. By looking for similar libraries to Three.js, a library may be present that could have made the task much easier or simpler.

It could have also been that the size of the feature sets during implementation were too large, and could have been broken down more. By having smaller feature sets, then the application would have suffered less if one fell behind schedule. This would be because project time would have been divided more fairly, and would have been easier to track.

This leads onto the idea of better time tracking tools used. If there were some form of issue tracker used, then each feature during implementation could have a detailed task representation, including issues created where they may have occurred. A bug tracker such as Jira could have proved very useful, and would have also automatically have been able to generate informative graphs and statistics on implementation for use in progress checking.

The use of appendix is something that could be considered in a future project of this kind, where it could have been taken advantage of much more. Items such as testing could be expanded more for usability testing, where screen shots or more supporting diagrams could be shown. It is important to make sure that there are as much supporting facts and figures as required when explaining why something was tested in such a way.

## 4.4 Future work

Personally, I will be continuing on with this project after the assessment of this module is complete. I would like to expand the simulator to allow for the remote controller to be shown where joysticks would be pushed for each manoeuvre, alongside adding better compatibility for tablet devices. Issues like the drawing of OLAN shapes will also be high on the list for changes I will be performing if they still remain issues after the hand-in. On a project which I enjoyed so much, this is something I want to continue adding to for the foreseeable future, hopefully introducing to Internet community for suggestions or changes directly from others.

## 4.5 Self-Evaluation

For this final section of the report, I the author can now evaluate my own personal experiences whilst creating the application. I will explain what skills were developed through my time during the project, and what if any I struggled to get working or working in a desired way.

The way I used a wide range of different supporting applications in order to design, create and test the application I think was more than sufficient for a project of this size. The use of a build sever like Travis helped lots due to its on-commit build function. Each time I received any email stating

a build had failed meant I was able to act quickly fixing an issue before continuing on with current development.

There were a lot of applications I had not been involved with before too, such as Jasmine. I showed the willingness to try unknown frameworks such as these in order to make a more professional project. In the analysis section of the project I showed how I made sure to research and try out some of the technologies like Three.js before using them for my application.

The way I handled problems during implementation meant I could not let the rest of the application suffer from issues with certain features such as generating the manoeuvre shapes. However, I did have to decide at the time how much project time I should have used before moving on. In all, I believe I handled the pressure well, and ensured that even though the feature was complete, it did not push back the rest of the project. I then set myself personal aims to complete each feature ahead of time in order to create time to fix previous problems.

One rather large issue which I will learn from for any project I do in the future is to ensure binding and printing are taken away from project time from the beginning, to make sure absolute deadlines are earlier to allow for the report to contain everything that is required. By having the issue I had generating OLAN shapes tested me on how to tackle an issue that the report relied on, causing me to ask advice from my supervisor on whether to stop development as soon as the report is printed, or whether to carry on with code even though the report would not reflect it. By printing a separate document, later, this was a clever way of getting round such an issue.

Overall, I have learned a great deal of time management skills during this project, and due to this being the first time I have put FDD to practice, it has given me the chance to explore new means of creating an application and seeing how effective performing all the stages in different orders can affect how project time is divided up. Since this report was written in-line with the project, I found it very easy to pick out important and relevant topics for each section, as they were 'fresh on the mind'.

I have put to use many practices I have picked up from modules at my time in university, from choosing methodologies, to choosing the license type for my application. Choosing WebGL and Javascript as the primary languages for this project was also heavily endorsed by my experiences with a range of languages throughout my previous years at university, and I simply wanted to work with a language I would enjoy working with the most.

Using a work blog helped tremendously throughout this project, as it allowed me to keep track of what work had been done when, and gave me accurate dates on which I had completed parts of the project. I plan to use blog as tracking mechanisms for any future projects.

If I were to perform a project like this again though, I may stick to a stricter waterfall methodology method of working, to ensure that work that needs to be done is concentrated on more and given more flexibility on time. I would have also been happier testing the entire application after development, as this could have meant time could have been spent more on developing rather than forcing myself to break away every so often and test.

## 4.6 Word count

It was important to keep the word count of the document under the project requirements limit. I found this to be manageable by keeping track of each section's word count throughout the time writing this report. The count of this report can be seen in 4.1.

Table 4.1: Word count calculated using Tex-count [8] Perl script.

Count	Value
Body of document, not including figure captions, table captions, or table contents.	20,105

## 4.7 Licensing the application

As found in Appendix B, all the libraries used in this project were created with the MIT license allowing me to also license my application under this. The reasoning for this is because I plan on both continuing work on the application, and allowing others to do the same, or even branching off and creating their own take on the application. I believe in freely spreading code and functionality, and if my application can help anyone else in any needs they may have, the MIT license allows this. The full license can be found in the 'LICENSE' file in the source code folder or in appendix B section 2.

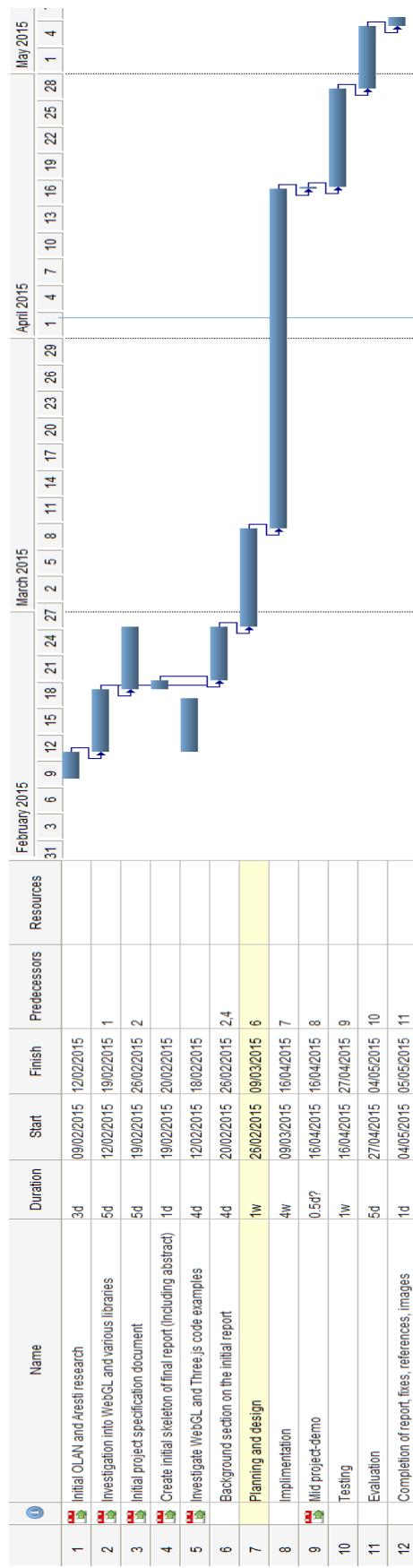
# **Appendices**

## **Appendix A**

## **Background research and analysis**

## 1.1 Initial project Gantt chart

Figure A.1: Initial gantt chart, outline times throughout project activities, to be updated as time passes during the project span.



## 1.2 Initial requirements analysis

Figure A.2: Requirements brief created before a meeting to clarify questions on the initial requirements. The pdf continues onto the next page.

*A WebGL based flight simulator derived from OLAN  
(One letter aerobatic notation) inputs.*

*Craig Heptinstall (Crh13)*

*January 21, 2015*

This document describes initial requirements and features proposed for the simulator and a broad set of terms detailing technologies and processes used during the project.

### *Initial general requirements*

The listed general requirements are as follows:

1. Provide a web-implemented tool<sup>1</sup> that allows input of the OLAN characters as a string format, alongside possible click functionality.
2. Relate each notation or set of notations to a certain procedural movement<sup>2</sup> (rotations, movements etc.).
3. Provide a means of linking up these movements in such a way they produce a fluid manoeuvre.
4. Display this using WebGL<sup>3</sup>. Libraries<sup>4</sup> to consider that could help with some of the movements:
  - glMatrix- Javascript library for helping with performing actions to matrices- <http://glmatrix.net>
  - ThreeJS- Another Javascript library, good with handling cameras and different views- <http://threejs.org>
5. Allow user to add different effects such as wind, gravity changes and other physics<sup>5</sup>.
6. Add functionalities of different viewpoints(on-board views, side views) to application.
7. Possibility to add function to save (using local storage?) users different sets of manoeuvres?

<sup>1</sup> None-IE due to WebGL capabilities. Will it use a simple JSON file to store notations?

<sup>2</sup> Must consider parameters in some of the notations, such as the speed of entry into moves, or the angle of the plane.

<sup>3</sup> Begin by initially testing simple shapes to move and fly around, then add textures, and plane structure.

<sup>4</sup> Are libraries ok to use?

<sup>5</sup> Could be better to implement these last, as it will be easier to test pure functionality of rolls etc first, then figure out natural physics.

### *Development environments, testing and bug tracking*

To develop the project, I have decided on a set of technologies I wish to use:

- To develop on a Github basis- Easier to maintain, links up to build trackers, good room for documentation, code comments etc.
- Use a Travis build server to run tests after each commit- This can be done automatically, provide me some nice statistics, links up to test libraries well.

**A WEBGL BASED FLIGHT SIMULATOR DERIVED FROM OLAN (ONE LETTER AEROBATIC NOTATION) INPUTS.**

2

- Testing frameworks- I plan to use either libraries such as PhantomJS or Grunt to test my client side code.<sup>6</sup>
- Bug-trackers- For instance inbuilt into Github. Allows me to prioritise higher importance issues. Also helpful for time tracking when adding functionality.

<sup>6</sup> Need to ensure good de-coupling between data and the shaders etc within WebGL.

*Project course specifics*

Alongside the functionality of the actual simulator, there are the methods and stages of the project I need to consider:

- Using FDD as a methodology through the process.
  - Using the list given in the first section, make a list of requirements(change these into features).<sup>7</sup>
  - Plan each feature, and design functionality logically and narratively.<sup>8</sup>
  - Implement each feature accordingly, running through coding and testing, then reviewing.
  - Iterate over each feature, until all(or as many as possible) have been completed.
- Document throughout process, any issues, and findings
- Use LaTeX to document<sup>9</sup>

<sup>7</sup> This could include an overall plan of the project, timing using Gantt charts?

<sup>8</sup> Sketch-up of plane and angles, and maths behind different transformations.

<sup>9</sup> Perhaps initial tests or large sets of data can be done by hand and transferred later

### 1.3 OLAN understandings

Figure A.3: A document created before a second meeting, outlining my current understanding of the OLAN language, and how manoeuvres can be constructed from smaller single-element ones.

Craig Heptinstall (Crh13)

29/01/2015

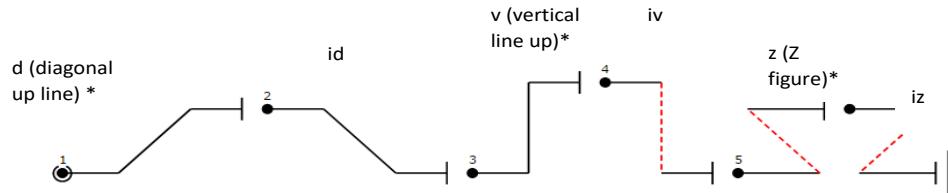
## Evaluation of OLAN manoeuvres

This document highlights some of the movements, be that single-element, double-element, loops, double-loops or special and complex moves. Although not all the notated movements presented in the OLAN base figures document are shown here, the most important ones shall be. With each, an explanation of the figure will be displayed, alongside some explanation to the primitive sections of the manoeuvre. This document will serve as a basis of deciding which key line transformations will be required in the simulator, alongside any potential hazardous manoeuvres that may prove difficult.

Note: \* Symbols indicate the move can be inverted (using the letter 'l'), ^ indicates the move can be reversed (using the letter 'r').

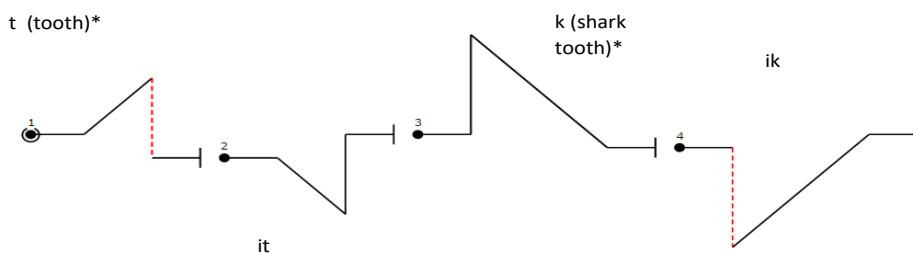
### Single-element

Single elements are simply moves that are described as one movement. For example, the first move shown in the figure below is described as a diagonal line up, while move 6 can be simply described as inverted Z figure.



### Two-element

A two-element move is a manoeuvre that requires two separate moves to form the entire move. For instance, in the first move, described as a 'tooth' requires firstly a diagonal line up, then an inverted line down. A simple assumption can state that any move in this two-element case can be formed using any of the single-element lines. In move 3, this move known as a 'shark tooth' is comprised of a vertical line up and diagonal line down, though is special in that it can be inverted (by placing an 'i' before the OLAN notation) to mirror the commands.



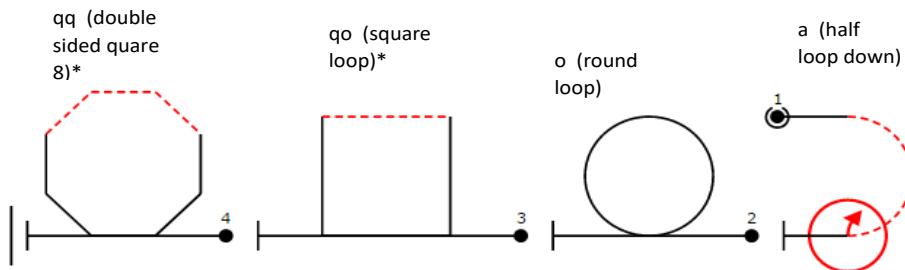
1

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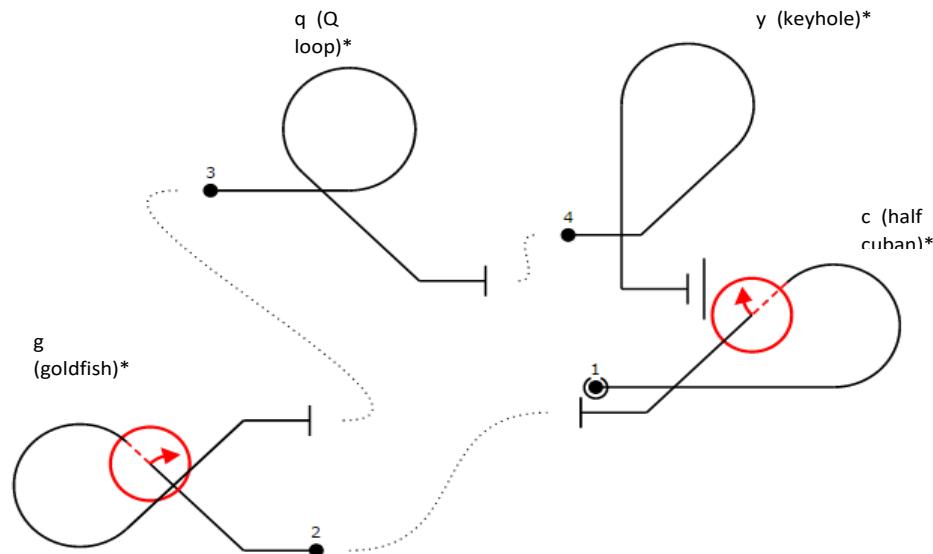
### Loops

Loops can be deduced to be single element moves, where the flight consists of one simple move, for instance in move 1, these can be understood to be simply one half loop, containing rolls at the top and bottom of the arc. For each of these loops, they all work by multiples of 45 again, though with examples 4 and 3, rather than a smooth curve, a more square or sudden turn is expected to achieve the desired result. This is one thing that will need to be considered.



### Loop-line combinations

A loop-line combination defines moves where both single and two-element lines are combined with loops as shown in the previous section. The first example, which shows a half-Cuban requires a line through to a 5/8 loop (again this is a multiple of 45 degrees) followed by a roll and diagonal line down. Another example shown in move 3, is comprised of a full loop followed by a diagonal line down.

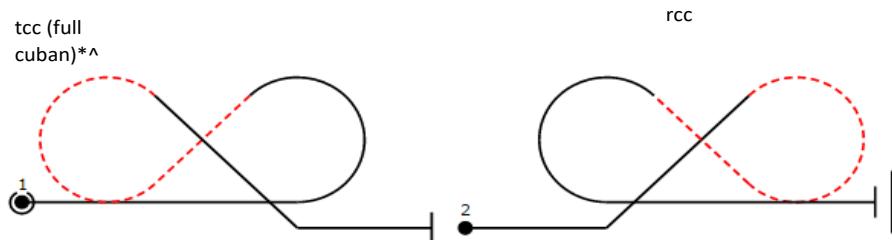


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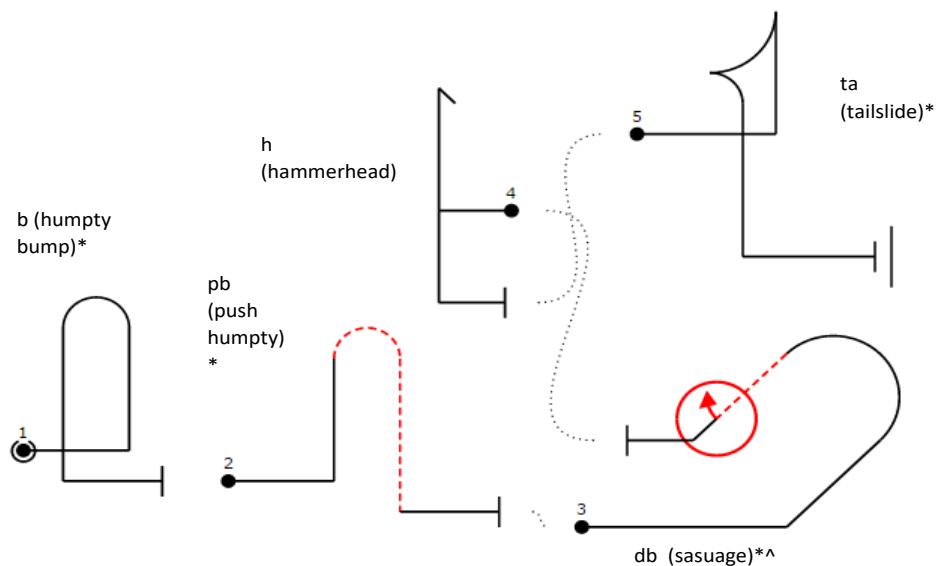
### Double-Loops

Double loops are cases where two loops are used after one another to achieve the desired result. The two examples here reflect each other because of the letter 'r' meaning reverse in the second diagram. As you can see, this should be easily achieved by simply swapping over the roll from one loop to the other. Again with these, it is a matter of the angle of turn creating the loop that must be correct to be able to run a diagonal line down to create the next.



### Humpty-Dumplings, Hammerheads and Tailslides

A humpty dumpty (1) consists of a bump, followed by a 180 degree turn to come back down vertically. Meanwhile the hammerhead manoeuvre described in move 4 consists of flying straight up, and then rotating on the wing so to fall back down. In diagram 5, the tailslide move also looks a tricky one to implement, as it requires falling back on itself after slowing down. This change of direction in this and in the hammerhead moves could be an issue as simply giving the plane a constant speed in the WebGL program would not work.

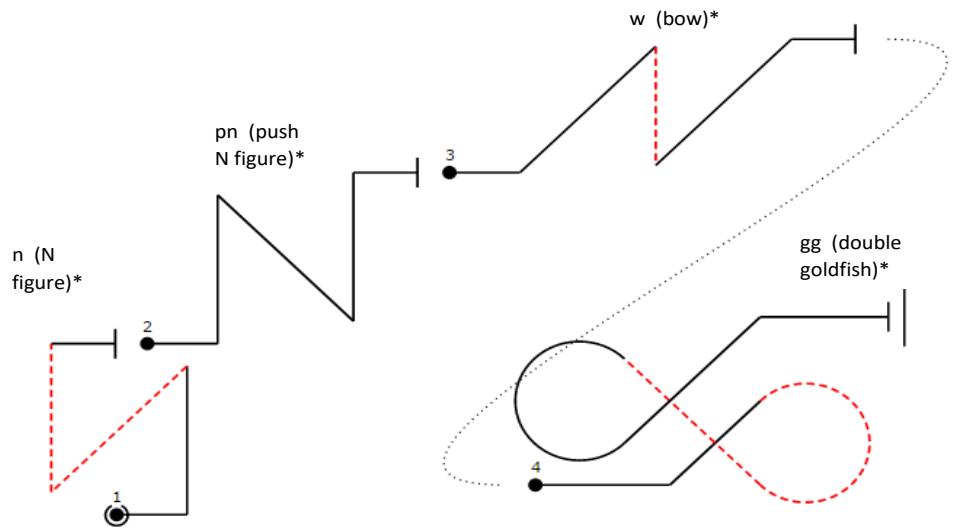


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### Complex 3-Rolling elements

This set of maneuverers contain a total of three different elements, so in diagram one an N figure, which itself is comprised of two moves, followed by a pull back to the diagonal. These moves should not be too difficult to recreate, as each of which should be easily modified previous moves. An example of this is the double goldfish move shown in diagram 4, which is simple a double loop but with more of a tighter loop on either side (this could be defined by size of radius).



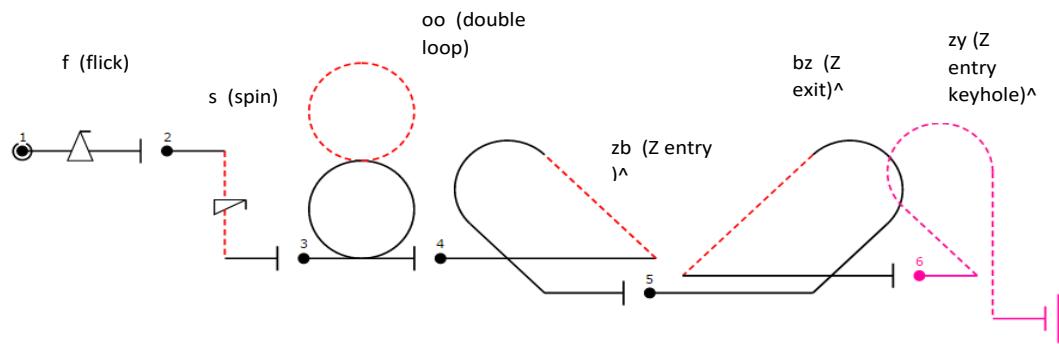
4

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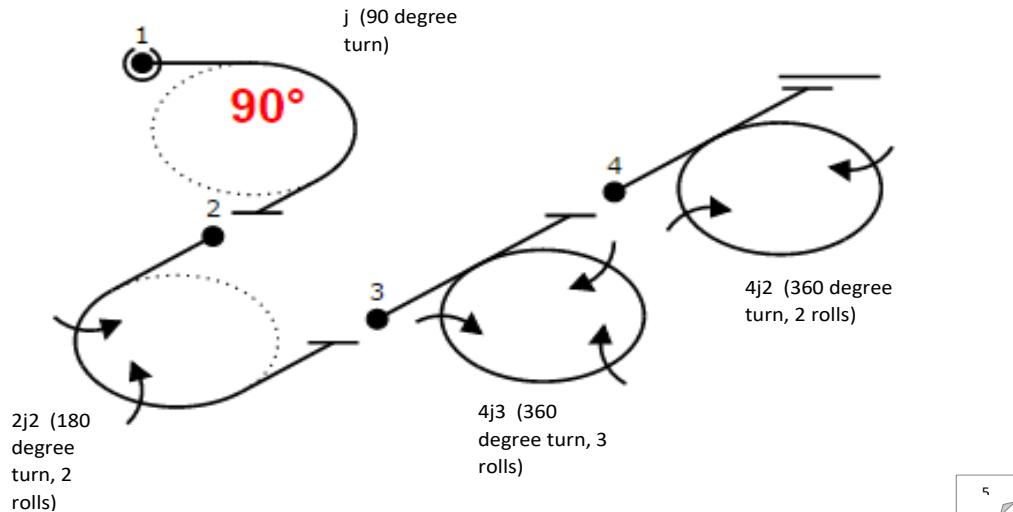
29/01/2015

### Oddball and special figures

The moves shown in this sections are ones that are more complex in the way that they require special manoeuvres. Starting with diagrams one and two, they both have a triangle shape placed on the line, indicating a flick roll. This means rolling the plane a total 360 on the horizontal line to return it to its original rotation. Other moves shown below could be recreated again with a use of different single and two element moves. Moves such as diagram 3, would be comprised of two full loops, one inverted, and these loops can be broken down again into 45 degree segments. As the plane leaves the first loop, it should be easy to enter the second already inverted.

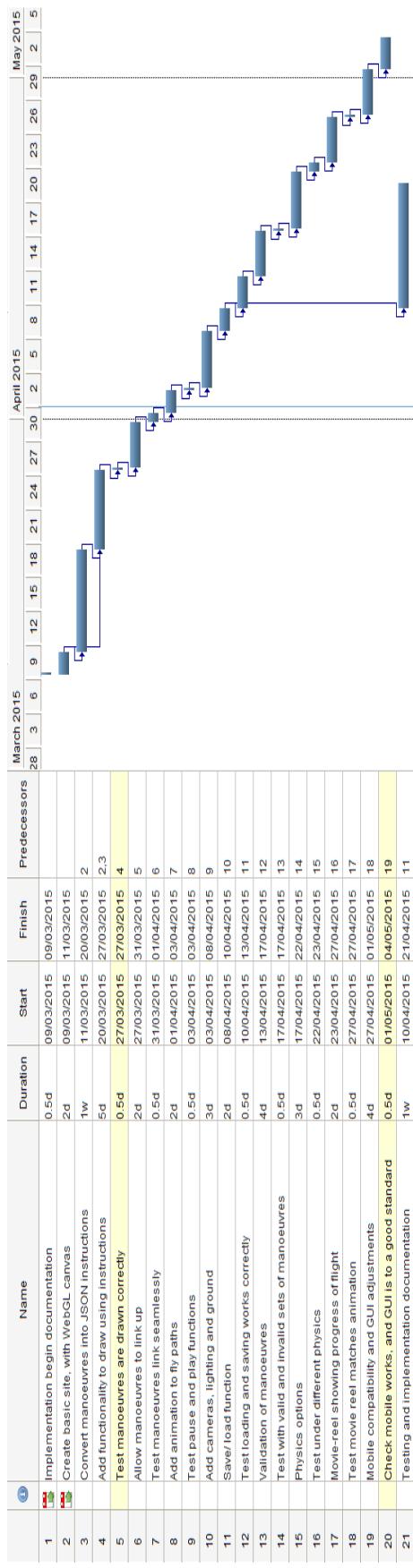


The final set of Aresti moves illustrated here look at turns and rolling turns. The angle in the first move shows a simple 90 degree turn, whilst in the second, because '2' has been placed both sides of the 'j', this signifies 2 90 degree turns, and 2 rolls. This parameter set can be shown in the other two examples, with the last showing 4 90 degree turns (creating a loop), containing 2 rolls.



## 1.4 Revised FDD Gantt chart

Figure A.4: More detailed Gantt chart, focuses on the implementation and testing strategy of each feature. As you can see, prioritised tasks are the first to be completed.



## Appendix B

# Third-Party Code, Libraries and tools

There are some libraries and tools that were used during the project to design and implement the application. The libraries mentioned here have a description of what they are, why they were used in my the application, and links to both the library home page and library license. In addition to this, a few tools that were used behind the scenes of this project have been mentioned.

## 2.1 Libraries and licenses

**Three.js** - This project has been used to handle all the WebGL features of the application, providing methods to access the shader code and handle any animations. From loading up models to creating cameras, this library was used extensively through the project. Available on the three.js site [19], licensed under MIT [21].

**StatsJs** - A library for monitoring performance of JavaScript code. This was used to see how well my code was performing in relation to frames per second. The library places a FPS counter onto the page, and helped monitor how different effects can reduce performance. Available on the Javascripttoo page [20], licensed under MIT [21].

**JQuery** - A library for interacting with both HTML and some back end methods. This library was used for support of RequireJS, foundation CSS and used for connecting the back end of the application with the GUI. Licensed under MIT [21], currently available from the JQuery site [22].

**Foundation** - A CSS framework used to help build a responsive site. Similar to the bootstrap library, it comes with lots of pre-styled classes, so it made building the site a matter of created nested div tags. Currently available from the foundation page [33], licensed under MIT [21].

**RequireJS** - A framework for creating modulation of JavaScript code. Used to modulate the application, and dynamically load up JavaScript files defined in each module. Dual licensed under MIT [21] and BSD [23], require is available from the RequireJS site [24].

Alongside the libraries mentioned above, there were some tools which helped form this report. Mainly diagram creators, they helped in the creation of supporting illustrations.

**Gannter** - A an on-line application allowing the creation of Gantt charts, with export capabilities. This was used to create both Gantt charts present in this report.

**Creately** - On-line diagram creation tool for projects. Used to create all use-cases, class diagram,

flow charts and MVC diagrams, this proved a handy tool throughout design.

**Mockflow** - An on-line application for the designing of wire-frames. Allowed me to draw and style mock ups of the site before creating it. Had a very useful feature which allowed me to export the mock up to HTML code, instantly creating the site.

**TeXcount** - L<sup>A</sup>T<sub>E</sub>X word counter used to keep check on the amount of words in the report. Available as a Perl script as well as on-line.

## 2.2 MIT license

The MIT License (MIT)

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# Appendix C

## Code samples

### 3.1 Off-canvas HTML code, showing how menus are hidden

Figure C.1: HTML code showing the page is divided into two, one for the canvas, and one for the menu. The 'off-canvas-list' has sub menus that allow more menus to be hidden to the left.

```
1 <div class="off-canvas-wrap" data-offcanvas>
2   <div class="inner-wrap">
3     <aside class="left-off-canvas-menu">
4       <ul class="off-canvas-list">
5         <li>
6           <label>Option Categories</label>
7         </li>
8         <li class="has-submenu">
9           <li class="has-submenu">
10             <a href="#">OLAN</a>
11           </li>
12           <li class="has-submenu">
13             <a href="#">Physics</a>
14           </li>
15           <li class="has-submenu">
16             <a href="#">Save/Load</a>
17           </li>
18         </li>
19       </ul>
20       <footer id="footer" class="row">
21         </footer>
22     </aside>
23     <div id="container">
24
25       </div>
26       <a class="exit-off-canvas"></a>
27     </div>
28   </div>
```

Figure C.2: JSON code showing a vertical upline defined by JSON instructions.

```

1  {
2      "variant": [
3          "component": [
4              {"_pitch": "NIL",
5               "_roll": "NIL",
6               "_yaw": "NIL",
7               "_length": "10"
8           },
9           {
10              {"_pitch": "POS",
11               "_roll": "NIL",
12               "_yaw": "NIL",
13               "_length": "1"
14           },
15           {
16               {"_pitch": "POS",
17                "_roll": "NIL",
18                "_yaw": "NIL",
19                "_length": "1"
20            },
21            "_olanPrefix": "",
22            "_name": "Vertical up line"
23        },
24        "_olan": "q"
25    },

```

## 3.2 JSON OLAN instructions example

### 3.3 RequireJS setup code

Figure C.3: Snippet of code showing how RequireJS starts the application. The RequireJS library is loaded onto the page, the configuration telling the library the base of the application JavaScript files is set, and then is told to start by running the main.js file.

```

1 <script>
2     require.config({
3         baseUrl: 'js',
4     });
5     require(["main"]);
6 </script>

```

### 3.4 Converting JSON representations into vectors

Figure C.4: Snippet of code responsible for converting the manoeuvre objects into vectors, allowing the creation of Three.js spline curves.

```

1 for (m in values) {
2
3     var components = values[m]["components"];
4
5     for (var i = 0; i < components.length; i++) {
6         var component = components[i];
7         var prevVector = new THREE.Vector3(0, 0, 0);
8
9         if (linePoints.length > 0)
10            prevVector.copy(linePoints[linePoints.length - 1]);
11
12         if (component.PITCH == 0 && component.YAW == 0 && component.ROLL == 0)
13             {
14                 prevVector.setZ(prevVector.z + (component.LENGTH * 10));
15                 linePoints.push(prevVector);
16             } else {
17                 var axis = new THREE.Vector3(1, 0, 0);
18                 var angle = Math.PI / 180 * angleDiv * -component.PITCH;
19                 prevVector.applyAxisAngle(axis, angle);
20
21                 var axis = new THREE.Vector3(0, 1, 0);
22                 var angle = Math.PI / 180 * angleDiv * component.YAW;
23                 prevVector.applyAxisAngle(axis, angle);
24
25                 prevVector.setZ(prevVector.z + (component.LENGTH * 10));
26                 linePoints.push(prevVector);
27             }
28         var startVector = new THREE.Vector3(0, 0, 0);
29         startVector.copy(prevVector);
30         linePoints.push(startVector);
31     }

```

### 3.5 Using local storage to export scenarios

Figure C.5: Code used for checking local storage compatibility.

```

1 exportToLocalStorage: function(manoeuvres) {
2     if (checkLocalStoragePermitted()) {
3         if (!localStorage.getItem("autoLoad"))
4             return;
5         // Store
6         localStorage.setItem("manoeuvres", manoeuvres);
7     }
8 }

```

## Appendix D

# Application tests

### 4.1 Usability testing for the GUI front-end

Test	Pred. Result	Pass/ Fail	Comment
Open menu	Menu is displayed on the left, canvas moves right.	Pass	
Close menu	Menu hides to the left, canvas is pulled back in to fill page.	Pass	
Resize window to mobile size	Menu changes to mobile view, canvas still fills page.	Pass	
Open mobile menu	Menu displaying OLAN input, about and help pages listed.	Pass	
Open help page	Overlay appears from above, covers canvas with white box and text.	Pass	
Open about page	Overlay appears from above, covers canvas with white box and text.	Pass	
Close about page	Box fades away.	Pass	
Open sub-menu	Menu pulls in from left in side to cover current menu. Shows options of certain menu chosen.	Pass	
Click back on sub-menu	Sub-menu slides to left and reveals original top level menu.	Pass	

Table D.1: Usability test table for testing the GUI.

## 4.2 Test utility code for creating GUI before testing

Figure D.1: RequireJS module for allowing test units to share methods providing them with GUI elements before tests. Tear down code removes the elements after each test.

```

1 define(function() {
2     return {
3         setUpAppend: function(toAppend) {
4             toAppend = "<div id='added'>" + toAppend + "</div>";
5             $('body').append(toAppend);
6         },
7         removeAppended: function() {
8             $("#added").remove();
9         }
10    }
11 });

```

## 4.3 Test Unit code for converting JSON to manoeuvre instruction object

Figure D.2: JSUnit code created to test the capabilities of changing the JSON instructions into objects.

```

1 it(
2     "Manouevres from JSON instructions should not be null",
3     function() {
4         ParseJson.init();
5         expect( ParseJson.getManoeuvreArray() ).not.toBe(null);
6     }
7 );
8 // There should be 27 OLAN manoeuvres
9 it(
10     "Should be 27 OLAN manoeuvre objects in the JSON file",
11     function() {
12         ParseJson.init();
13         expect( ParseJson.getManoeuvreArray().length ).toBe(27);
14     }
15 );
16 // JSON instructions should come from input.
17 it(
18     "JSON instructions should come from entering OLAN",
19     function() {
20         TestUtils.setUpAppend("<input id='input' />");
21         AnimationController.initControlEvents();
22         ParseJson.init();
23         $('#input').val('o');
24         $('#input').keyup();
25         expect( ParseJson.getManoeuvreArray().length ).toBe(27);
26         TestUtils.removeAppended();
27     });

```

## 4.4 Test Unit code for checking lights and ground are created successfully

Figure D.3: Checks if objects for both are created at runtime of the application.

```

1 // Load the terrain module and describe tests.
2 define(
3   [
4     ".../.../terrain"
5   ],
6   function( terrain ) {
7
8     // Describe the test suite for this module.
9     describe(
10       "The terrain module creates and returns both ground and lighting for
11         the scene.",
12       function() {
13
14         // Check that terrain module creates a ground object, and
15         // returns it
16         it(
17           "Ground should not be null",
18           function() {
19
20             expect( terrain.createGround() ).not.toBe(null);
21           }
22         );
23
24         // Check that the lighting object is successfully created and
25         // returned
26         it(
27           "Lighting should not be null",
28           function() {
29
30             expect( terrain.setupLight() ).not.toBe(null);
31           }
32         );
33       );
34     );
35   );
36 );
37 );

```

## 4.5 Usability testing for cameras

Test	Pred. Result	Pass/ Fail	Comment
Test drag mouse to rotate around canvas	Camera should rotate around the scene.	Fail	Changed after fail, due to camera rotation around the point(0,0,0). Changed now so that it rotates around current camera location.
Scroll zoom in	Camera should focus in on the center of the canvas.	Pass	
Scroll zoom out	Camera should see more of the canvas as mouse scrolls out.	Pass	
Left keyboard key to move left	Camera moves 10px to the left.	Pass	
Right keyboard key to move right	Camera moves 10px to the right.	Pass	
Up keyboard key to move forward	Camera moves 10px forward its Z axis.	Pass	
Down keyboard key to move backwards	Camera moves 10px backwards its Z axis.	Pass	
Switch to onboard camera view	Camera changes to 0,0,0 looking ahead.	Pass	

Table D.2: Tests various actions from the user to do with both cameras.

## 4.6 Test Unit code for animation controller getters and setters

Figure D.4: Unit code checking information is set correctly, and if it can be changed at stored for various animation properties.

```

1 // Check that terrain module creates a ground object, and returns it
2 it(
3     "Should be paused by default",
4     function() {
5         expect( animation.getIsPaused() ).toBe(true);
6     }
7 );
8
9 // Check pause functionality works
10 it(
11     "Should not be paused after clicking pause",
12     function() {
13         TestUtils.setUpAppend("<button id='pause'></button><input id='input'>")
14         ;
15         $('#input').val("o");
16         animation.initControlEvents();
17         $('#pause').click();
18         expect( animation.getIsPaused() ).toBe(false);
19
20         TestUtils.removeAppended();
21     }
22 );
23
24 // check default speed
25 it(
26     "Default speed of animation should be increments of 0.005",
27     function() {
28         expect( animation.getAnimationSpeed() ).toBe(0.005);
29     }
30 );
31
32 // Check changing speed of animation works
33 it(
34     "Speed should be 0.01 at maximum value of slider",
35     function() {
36         TestUtils.setUpAppend("<input id='speed' type='range' value='0.01' min
37             ='0.001' max='0.01' step='0.001' />");
38
39         animation.initControlEvents();
40         $('#speed').change();
41         expect( animation.getAnimationSpeed() ).toBe(0.01);
42
43         TestUtils.removeAppended();
44     }
45 );

```

## 4.7 Test Unit code for checking import and export to JSON/ local storage functionality

Figure D.5: JSUnit code for checking flight paths export correctly to JSON and local storage, and check importing back works.

```

1 // Should be able to export and import from local storage
2 it(
3     "Exporting to and then importing from localStorage should work",
4     function() {
5         ExportImportProjects.exportToLocalStorage("o a b o");
6         expect( ExportImportProjects.importFromLocalStorage() ).toBe("o a b o")
7             ;
8     }
9 );
10 // Should export manoeuvres to JSON from the scenario
11 it(
12     "Should be able to export to JSON",
13     function() {
14         var manoeuvres = "o a b o";
15         var json = Utilities.convertManoeuvresToJSON(manoeuvres);
16         expect( manoeuvres ).toBe(json["manoeuvres"]);
17     }
18 );
19
20 // Should import manoeuvres from JSON to the scenario
21 it(
22     "Should be able to import from JSON",
23     function() {
24         var manoeuvres = "o a b o";
25         var json = Utilities.convertManoeuvresToJSON(manoeuvres);
26         var result = Utilities.convertJSONToManoeuvres(json);
27         expect( result ).toBe(manoeuvres);
28     }
29 );
30
31 // Checks if local storage auto save switch correctly sets.
32 it(
33     "Should be able to save change option of local storage on",
34     function() {
35         TestUtils.setUpAppend("<input id='autoSave' type='checkbox'>");
36         AnimationController.initControlEvents();
37         $('#autoSave').prop('checked', true);
38         $('#autoSave').change();
39         expect( ExportImportProjects.getAutoLoadLocal() ).toBe(true);
40         $('#autoSave').prop('checked', false);
41         $('#autoSave').change();
42         TestUtils.removeAppended();
43     }
44 );

```

## 4.8 Usability testing for GUI options

Test	Pred. Result	Pass/ Fail	Comment
Type OLAN into input box to create figures	Loop should appear when 'o' is typed in, and movie-reel should show manouvre at bottom.		
Use dropdown in OLAN options to add a figure	Loop should be added to canvas when chosen from dropdown.	Pass	
Increase and decrease scale	Figures on canvas should become bigger or smaller depending on scale.	Pass	
Increase and decrease extrusion segments	Curves should become less and more smooth depending on extrusion.	Pass	
Increase and decrease radius	More sides to the figure should appear the higher the radius.	Pass	
Increase animation speed	Speed of flight should increase depending on slider of speed.		
Turn switch on for auto repeat of animation	When on, when animating, should loop from beginning to end endlessly.	Pass	
Switch auto save on and close application, then re-open	When on, if application is closed and re-opened then routines should be added automatically. Vice versa.	Pass	
Export to JSON using button	JSON file begins to download on click.	Pass	
Import JSON file using file chooser	Routine should load up when selecting a file.	Pass	

Table D.3: Usability test table for user interface options, including OLAN entry box, OLAN dropdown, pyhsics options, animation options and exporting/ importing to JSON.

## 4.9 Usability testing providing parameters between OLAN

Test	Pred. Result	Pass/ Fail	Comment
Enter empty parameters '()'	No change to start location of next manoeuvre should occur.	Pass	
Empty correct format parameters '(10,10)'	Should move start of next manoeuvre 10 pixels up, 10 to the left.	Pass	
Enter parameters without space between OLAN	The manouvre nor parameters will be placed on the canvas.	Pass	
Enter parameters with negative values '(-10,-10)'	Should move start of next manoeuvre 10 pixels down, 10 to the right.	Pass	
Enter parameters on a manoeuvre "o""	Loop should be drawn with three times the length exit travel.	Fail	Parameter had np effect to the loops exit, and prevented the manouvre from being drawn.

Table D.4: Usability test table showing results of typing in parameters alongside maneouvres.

## 4.10 User questionnaire

Figure D.6: A google forms questionnaire created to allow users to give feedback about the application.

4/19/2015 OLAN Simulator user questionnaire Edit this form

### OLAN Simulator user questionnaire

\*Required

**The options were easy to find and navigate \***

Agree  
 Disagree  
 N/A

**It was clear how to use the application \***

Agree  
 Disagree  
 N/A

**The application loaded quickly \***

Agree  
 Disagree  
 N/A

**Flight paths drawn were what was expected from input \***

Agree  
 Disagree  
 N/A

**The application worked well on mobile \***

Agree  
 Disagree  
 N/A

**There was a good amount of controls for the animation \***

Agree  
 Disagree  
 N/A

**The 'movie-reel' feature was useful \***

<https://docs.google.com/forms/d/1TrgGXJMRIPH74NwCQuoQqj6YZtgfCQJelsUisjndJ9Y/viewform>

4/19/2015 OLAN Simulator user questionnaire

Agree  
 Disagree  
 N/A

**The application did not lag or run too slowly \***

Agree  
 Disagree  
 N/A

**The application did not crash or have any bugs \***

Agree  
 Disagree  
 N/A

**Comments or suggestions?**

**Submit**

Never submit passwords through Google Forms.

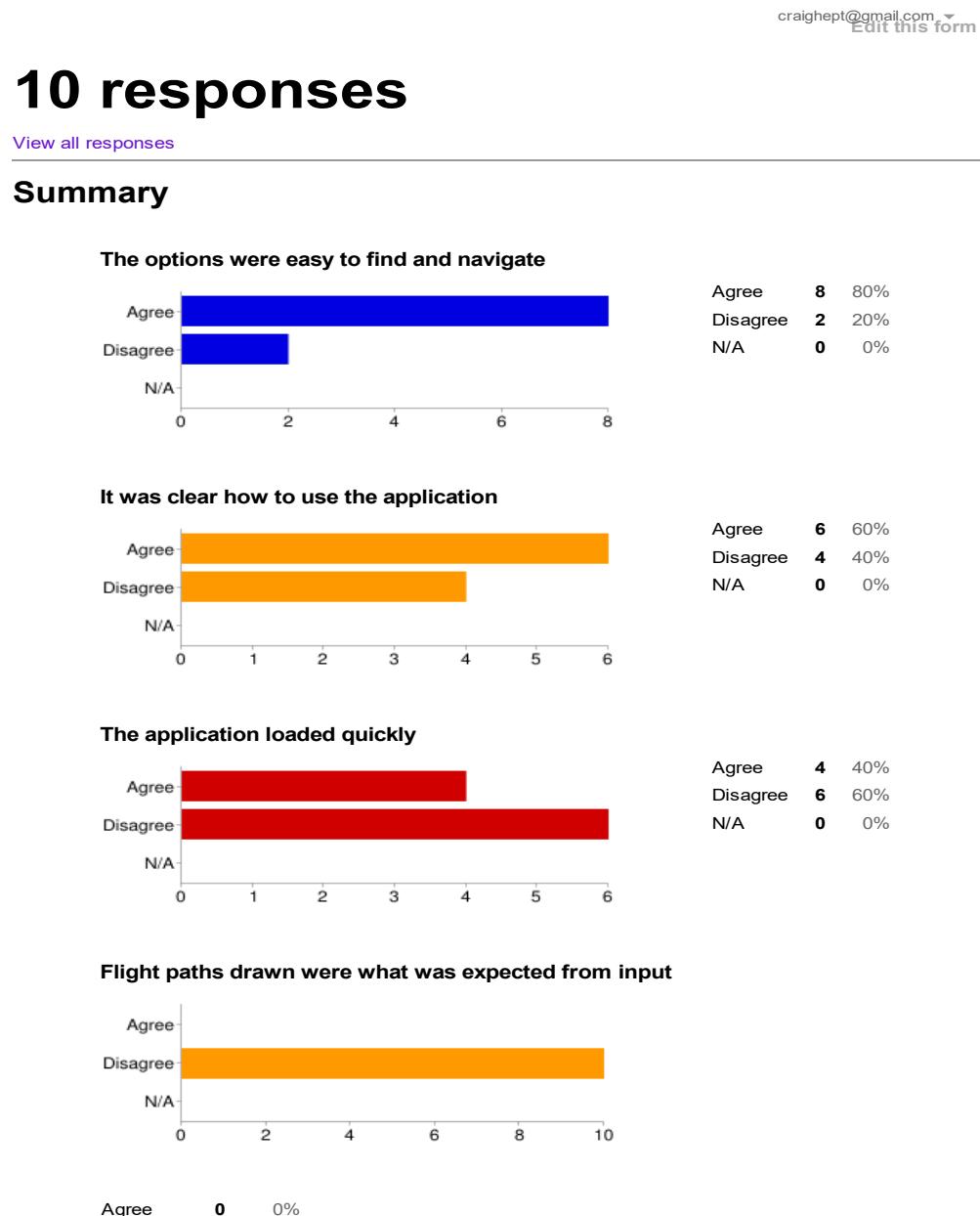
100%: You made it.

Powered by

This content is neither created nor endorsed by Google.  
[Report Abuse](#) - [Terms of Service](#) - [Additional Terms](#)

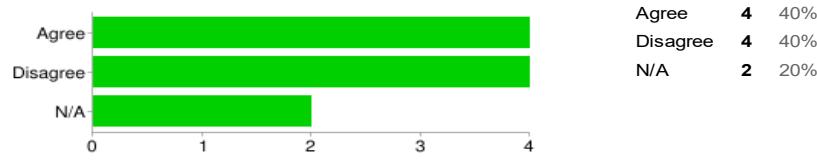
## 4.11 User questionnaire results

Figure D.7: Statistics from the questionnaire results, showing percentages of answers and comments/ suggestions.

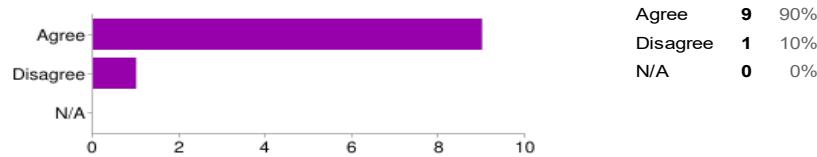


Disagree **10** 100%  
N/A **0** 0%

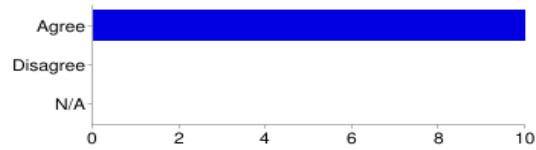
#### The application worked well on mobile



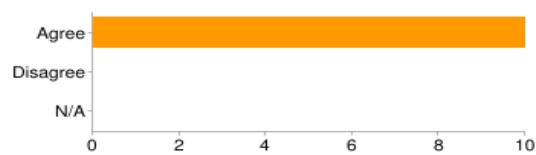
#### There was a good amount of controls for the animation



#### The 'movie-reel' feature was useful

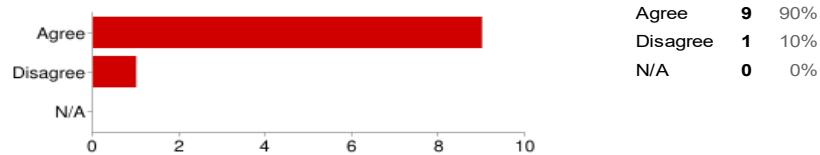


#### The application did not lag or run too slowly



N/A      **0**      0%

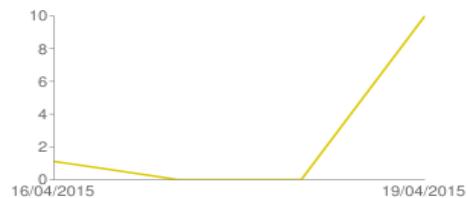
#### The application did not crash or have any bugs



#### Comments or suggestions?

- Used on my tablet and text and buttons were too small
- Was able to enter OLAN on an older version of Safari before it loaded
- Took some time to load on my mobile
- Could have an introductory page to help

#### Number of daily responses



## 4.12 Application screenshots

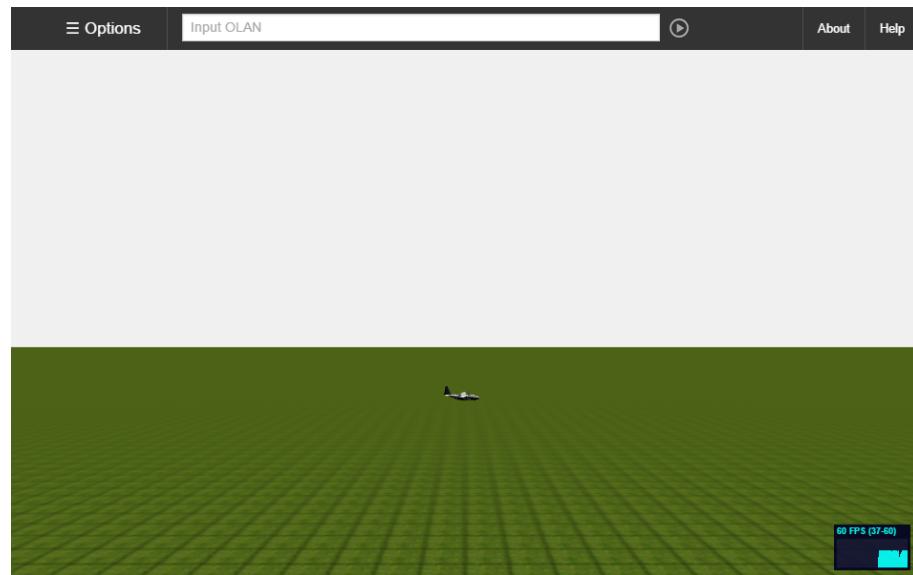


Figure D.8: Canvas after load, with plan placed in center of canvas.

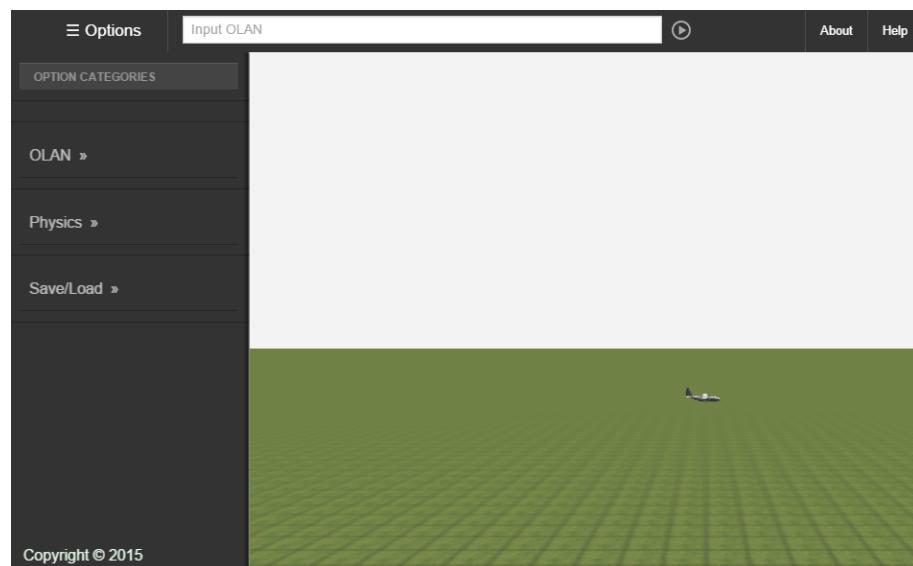


Figure D.9: First level menu open.

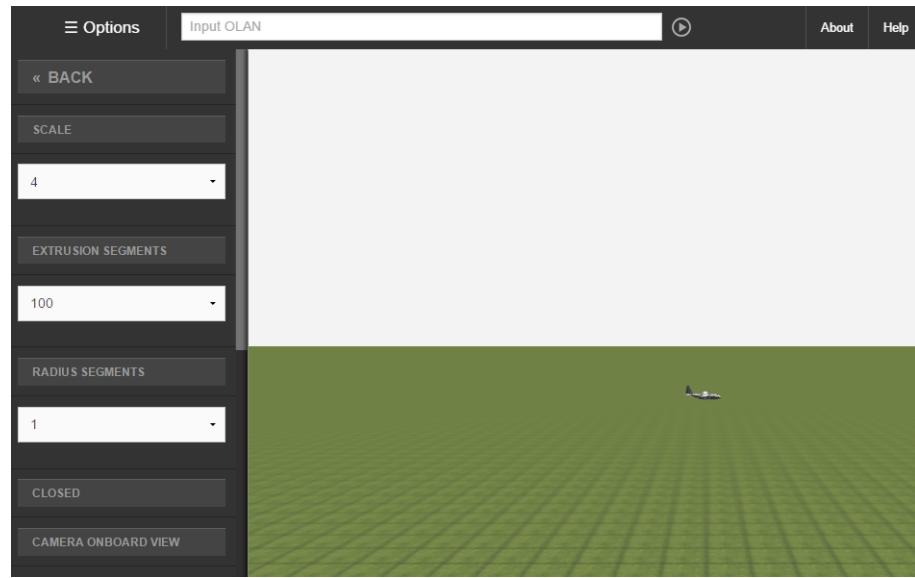


Figure D.10: Second level menu open showing animation options.

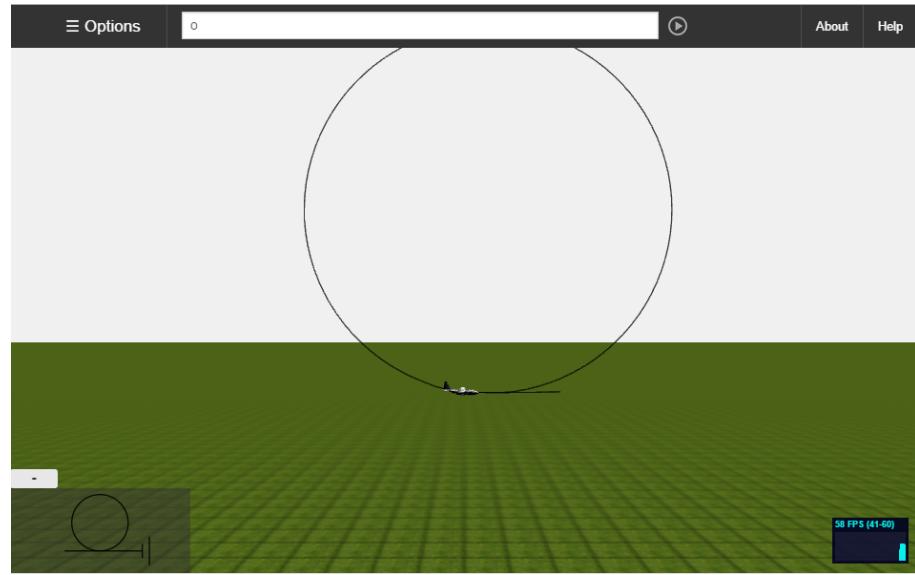


Figure D.11: OLAN entered and drawn onto the canvas with no flight, with the path shown.

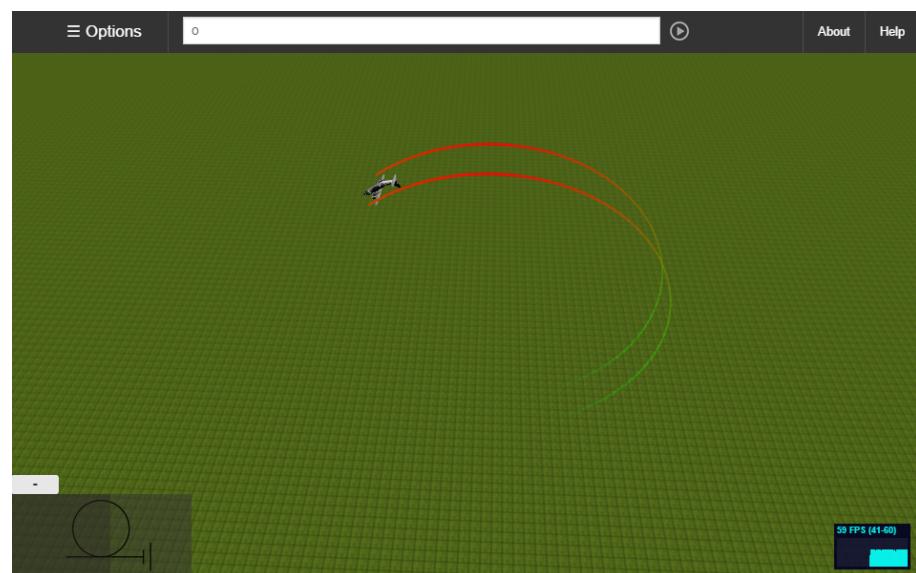


Figure D.12: A flight taking place, with the path invisible, only shown by smoke trails.(This manoeuvre shows a loop, or "o" in OLAN)

## **Appendix E**

# **Post-Report changes**

See any appended pages following this for changes done to code after this report was printed and binded. 2 Pages have been allocated, therefore blank pages will be present if both are not used.

## 5.1 Resulted and on-going work

When this report was printed, there was still the issue present with some of the OLAN manoeuvres. The main issue included the odd behavior of when a new manoeuvre was added, the rotation and thus places where vectors were being added seemed to be out of place to the same distance of how far the manoeuvre started in comparison to the start of the first manoeuvre. Although every effort was taken to attempt to resolve this issue, the application still faces this issue. Following various searches through question/ answer site like 'Stackoverflow', conversations with people who have had experience using the Three.js library and even direct questions on the Github repository with the Three.js developers, it was decided that the issue would take too long and too much restructuring of the current application to create a viable fix.

Furthering the suggested ideas mentioned in the implementation part of this report, the way that vectors were rotated were changed from using a matrices to a Euler. The reason for this was that Three.js handled the matrix automatically, increasing the speed it is done in. It was also thought that this means of rotation of vectors might have fixed the issue above, though this too did not work.

Although the primary issue was never completed in time for the project hand-in, it was ensured that both the JSDoc and refactoring was completed before the end of project. This included adding relevant comments for any new methods created during refactoring, alongside changing current documentation where method existence reasons changed. In addition to this, a read-me file was added to the source code folder, to ensure that any persons that may want to run the application themselves, or edit the application for their own use know how to properly set it up and edit it correctly. A final change performed was creating a general source folder clean up, including deleting unused library classes, and renaming both folders and files in a way that followed a universal standard. Touch ups to the GUI was also added, such as mouse hides on the canvas after a few seconds while animations occur, and checks done to ensure users who try use the application without a WebGL enabled browser are notified.

Overall, although the issue was never fixed in the timescale given, it was a thoroughly enjoyed project to the very end of available time, and because of this not only will the issue be attempted to be fixed, but it will be an application that is developed over the coming months or even years as a hobby. Using time correctly for potential issues as the one experienced in this project will be taken into account for future work, and it will be ensured that considerations and actions are taken faster (e.g. changing library altogether for a solution, though this project was too far in.)



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