CRANFIELD UNIVERSITY

DHANUSH SHASHIDHARA

MODELLING, INTERFACING AND VISUALISATION OF SAAB 340B G-NFLB AIRCRAFT

SCHOOL OF AEROSPACE, TRANSPORT AND MANUFACTURING
Aerospace Vehicle Design

MSc
Academic Year: 2020–2021

Supervisor: Dr James Whidborne
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This thesis is submitted in partial fulfilment of the requirements for the degree of MSc.

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List of Abbreviations

SATM	School of Aerospace, Transport and Manufacturing
T/C	Thickness to chord ratio
Deg	Degrees
6DOF	6 Degrees of Freedom
FDM	Flight Dynamics Model
AIRC	Aerospace Integration Research Centre

Abstract

Simulations of the National Flying Laboratory aircraft have been the topic of many past theses. However these simulations were the focus of the Jetstream 31. Cranfield University is about to replace the Jetstream 31 aircraft with the new Saab340B G-NFLB aircraft. Thus this thesis presents the first of its kind in geometrically representing the Saab340B aircraft as a three dimensional model which is then interfaced with a system which mathematically represents the Saab340B aircraft as a non-linear model developed within a MATLAB/Simulink® environment. The intention is to eventually incorporate the model into the Large Flight Simulator (LFS) located at the University.

The previous work in this area done by Mr. Gaëtan MARTIN related to the modelling and visualisation of the Jetstream 31 aircraft and the Aerosonde UAV done by Dr.James F Whidborne were used to carry out ground work in the development of the project. The development of the mathematical 6 Degrees-of-freedom (6-DOF) model has been carried out in parallel by Mr. Sarth Patel during the same period.

In the interfacing part of the project, the geometrical model of the Saab340B aircraft has been linked with the 6-DOF model using the MATLAB/Simulink® environment. The control inputs to the model from the joystick are also interfaced with the 6-DOF model to provide a better simulation experience. The visualisation of the model has been carried out using the FligthGear Flight Simulator which is an open source simulation platform. The capabilities of the program were put to use by the development of various in-flight instruments and view points of the simulation.

Validation in the following areas were conducted: The inputs from the flight joystick were being processed by the 6DOF model. The interfacing of the 3D model of the aircraft with the mathematical model showed the expected results. Lastly, the behaviour of the aircraft in response to the control inputs were verified. Where an area of deficiency was evident, recommendations for future improvements were documented. Improvements to detailed animations and cockpit design were underlined. Recommendations for future modelling for increased simulation fidelity have also been highlighted.

Acknowledgements

In the first place, I would like to express deep gratitude to my supervisor Dr. James F Whidborne for accepting me on this project and for his guidance, encouragement, gracious support throughout the course of my work. His expertise in the field motivated me to work in this area and I am indebted to his faith in me at every stage of the research project.

Also, Special thanks to Mr. Julien Enconniere for providing an opportunity to experience the aircraft simulator at the Aerospace Integration Research Centre (AIRC), Cranfield University.

Secondly, I would like to thank my colleague Sarth Patel, without whom this project would not have been complete. I thank him For his co-operation and hard-work.Also, for helping me to make the most of my downtime.

The most deserved acknowledgements to my parents and my brother Adarsh. It was because of their wholehearted support that I was able to undertake this MSc program.

I am grateful to all my closest friends and relatives in India and the new friends I have made here at Cranfield for their intellectual and moral support. Be it in the classroom or at the basketball court, the discussions have been very encouraging and supportive.

Chapter 1

Introduction

1.1 Overview

The idea of aerospace simulation is to create tools capable of recreating the behaviour of an aerospace vehicle in the most realistic form as possible using digital resources and computational capabilities. The essential form of flight simulation is the creation the dynamic representation of the behaviour of an aircraft in a manner which allows the human operator to interact with the simulation as a part of the simulation. The form of simulation development undertaken in this project involves the combination of science, technology and art to create artificial realism for the purpose of research and training.

This statement identifies two streams of influence in the development of flight simulation. Firstly, the creation of simulations is as much an art as it is a science and technology. Secondly, the purpose for which the simulation may be employed can be creative i.e., improve aeronautical design and operating efficiency, and recreational.

The streams of influence and application refereed to above can be seen to be present in the historical development and the current state of flight simulation. As an example of the combination of art science and technology to achieve effective simulations Tabs (1964) described how, at the start of the second world war, theatrical set designers were called upon to collaborate in designing training simulators for navy torpedo attack pilots operating against enemy ships.

clearly then, flight simulation presents a multidisciplinary challenge to skill and ingenuity. This position has been described most succinctly by a former Chief Test Pilot of the British Civil Aviation Authority (Davis 1975).

Flight simulation is a fascinating and challenging field of science. It encompasses a wide field of disciplines from electronics to aerodynamics, performance to optics as well as a massive contribution in terms of human engineering. The biggest challenge is the overcoming of the limitations of not being able to establish all the root equations of motion as fundamental parameters and the need to cook the system so that these compromises are not significant. In many ways working with simulators is much more demanding than working with real aeroplanes.

1.2 Saab340B G-NFLB Aircraft

The aircraft Saab340B is a 34 seater aircraft purchased by Cranfield University to replace the BAe Jetstream 31 which is acting as the current flying laboratory operated by the national Flying Laboratory Center (NFLC). The Saab 340B was transferred to Cranfield University's ownership 12 months ago. It is the latest edition to the National Flying Laboratory Centre (NFLC) fleet at the University. This aircraft being larger compared to the Jetstream 31 will allow for teaching and research with minimum reconfiguration. The modifications will ensure the aircraft is upgraded from a standard commercial plane to a fully bespoke facility, with all the technical equipment necessary to ensure the testing of the boundaries of aviation.

As well as the increased size, the students who fly in the Saab will have improved interface between them and the aircraft. The flight data is captured and displayed on a computer tablet mounted into the headrest of the seat in front of the student. This will show information such as aircraft speed, engine performance, angle of attack and angle of sideslip. All of this information is used to analyse the aircraft performance and can

Figure 1.1: Saab340B G-NFLB aircraft

validate the students' theoretical studies.

1.3 Aims and objectives of the thesis

The aim is to create a desktop simulator for Saab 340b by bringing together the graphical model, the mathematical model and aircraft control levers to be implemented on a desktop computer.

1. The objectives of this individual research project are to develop a graphical model of Saab 340B which can then be incorporated into the mathematical model of the aircraft which is developed using MATLAB and Simulink software.

2. The Interfacing of the flight controls will be done which will enable the aircraft to respond to the control inputs through the Saitek Flight Yoke system and the throttle inputs through the Throttle quadrant.

3. Visualisation of the aircraft will be made possible using Open source Flight visualisation software FlightGear. The objective is to successfully develop the simulator of the Saab 340B which can be used on the large aircraft simulator available at Cranfield University.

1.4 Software tools

The development of the flight simulator has two phases.

1. Development of the graphical model of Saab340B:

   The development of the graphical model of the aircraft will be done using a 3D modelling software such as Blender and AC3D. Most of the individual parts will be modelled using the Blender software and then the assembly of the parts will be carried out in AC3D which is the compatible geometry file type for the open source flight simulator FligthGear.

2. Interfacing of the Flight simulator with the 6 Degrees of Freedom (6DOF) model of the aircraft:

   The 6 DOF model of the aircraft is developed using the Aerospace toolbox available in the Simulink library. Therefore, the interfacing of the simulator and the FDM should also be done on Simulink. Also, the integration of the joystick control input will be done using the Simulink software.

3. Visualisation:

   The visualisation of the aircraft geometry in flight will be done by using the open source flight simulation software FlightGear.

1.5 Scope of the Thesis

This thesis encompasses the development of the graphical 3D model of the Saab340B G-NFLB aircraft using 3D modelling software. The aim of the 3D model is to showcase the exterior geometry which includes the wings, tail plane, fuselage. The modelling of the undercarriage, the passenger cabin, cockpit layout with seats, control columns, basic instrumentation and windshields are also done.

The development of the interface between the 6DOF model and the simulator has been done using Mathworks Simulink software. This part also encompasses the integration of the joystick control input into the simulator.

The scope of the visualisation part of the work encompasses the development of camera view points, positioning of cockpit and passenger instruments, development of animations for undercarriage and control surfaces of the aircraft.

Chapter 2

Literature Survey

1. Six-degree-of-freedom simulation has long been a valuable tool for achieving mission success. It Plays a major role during vehicle design and development, ground testing, mission planning and post flight data analysis. These efforts reduce both cost and time spent for resource development of tools and expand capabilities of simulation from vehicle design to preparation of flight. [11]

2. During the development of aircraft systems, a simulator can provide valuable insight into system behaviour and performance, recording data to verify the design. In addition, a simulator can be used to analyse human factor issues which are often required in pilot-in-loop studies.[12]

3. The major dimensions of the aircraft as given in the type-certificate sheet of SAAB340B described in figure 2.1. [13].

Dimensions

	Dimensions		Observations
Span	21,44 m	(70 ft 4 in)	Pre Modification 2571 (Extended Wing Tip)
	22,75 m	(74 ft 8 in)	Post Modification 2571 (Extended Wing Tip)
Length	19,73 m	(64 ft 9 in)	
Height	7.00 m	(23 ft)	
Wing Area	41.8 m2	(450 ft2)	

Figure 2.1: Saab 340 major dimensions

4. The data output by joystick is sent to the Simulink model to control the rudder, the ailerons, the elevator and the throttle. The step of time selected for the simulation should reflect a real time simulation otherwise the change of rates of the pitch, bank and yaw angles are too high.[10]

5. In order to visualise the aircraft attitude within the outside world view and for display on pilot's instrumentation in case of pilot in the loop simulation for instance, the Euler Angles need to be calculated.[3]

Chapter 3

Geometric modelling of Saab 340B G-NFLB

3.1 Aircraft drawings and dimensions

In order to start the geometric modelling of the aircraft, the blue-prints were gathered to extract the dimensions of the aircraft. The available blueprint drawings were of the modified Saab 340 fitted with AEW&S system. It was observed that the original dimensions of the aircraft did not change due to the modification.

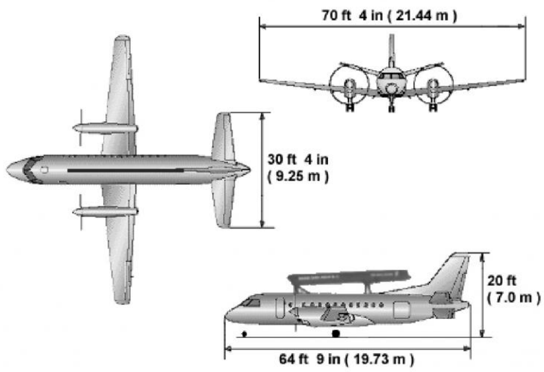


Figure 3.1: Saab 340 with AEW&S

Therefore, the dimensions of the air-frame were gathered using the drawings depicted by figure 3.1. The data was verified using the JANES aircraft data on Saab 340 and the major dimensions matched the drawing used above.

3.1.1 Data comparison and validation

The data on the blueprint was measured using the plot digitization technique. For the purpose of comparison of the measurements with JANES aircraft data, the following data was extracted from the blueprint.

1. Wing span

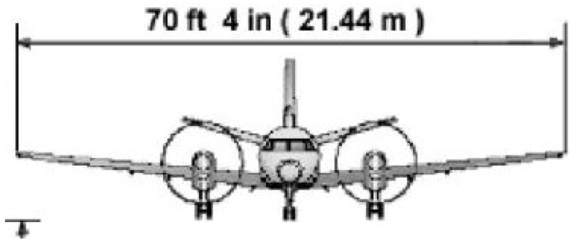


Figure 3.2: Saab 340 wingspan

2. Horizontal stabilizer span

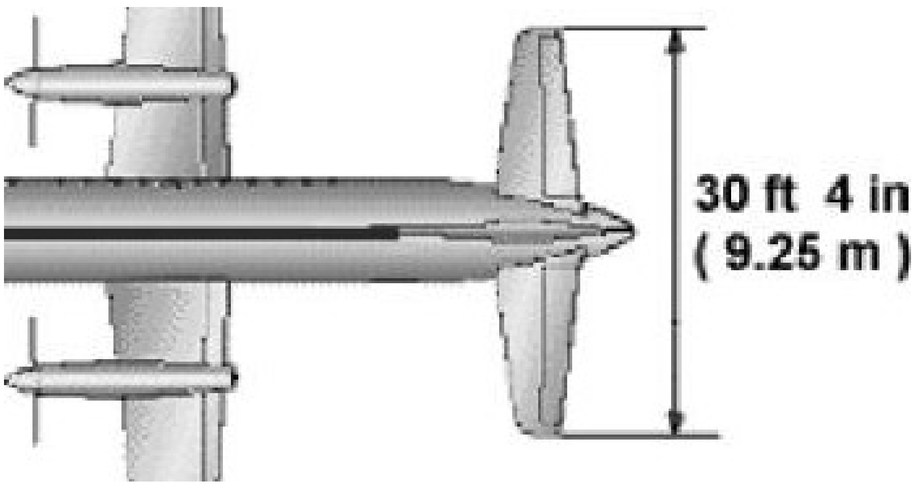


Figure 3.3: Saab 340 Horizontal stabilizer span

3. Total Aircraft length

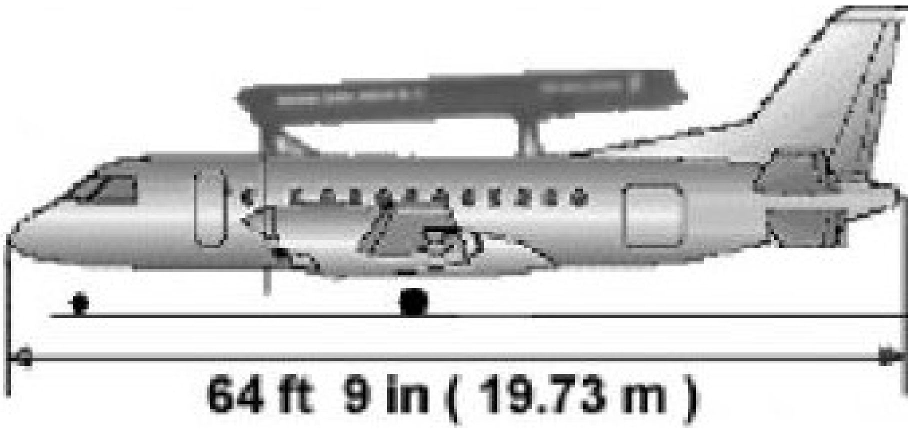


Figure 3.4: Saab 340 Total aircraft length

4. Total aircraft height

Figure 3.5: Saab 340 Total aircraft height

5. Fuselage width

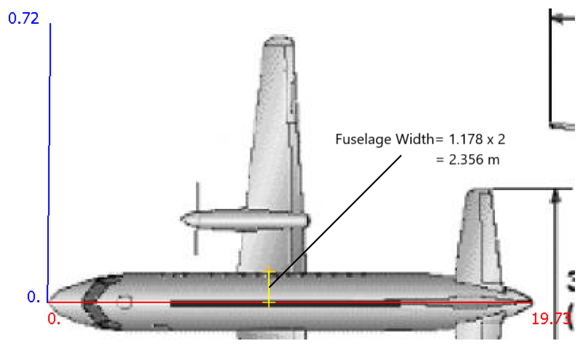


Figure 3.6: Saab 340 Fuselage width

The measurements of the propeller were taken to be compared with the propeller data which is also available at the JANES aircraft data source.

1. Propeller Diameter

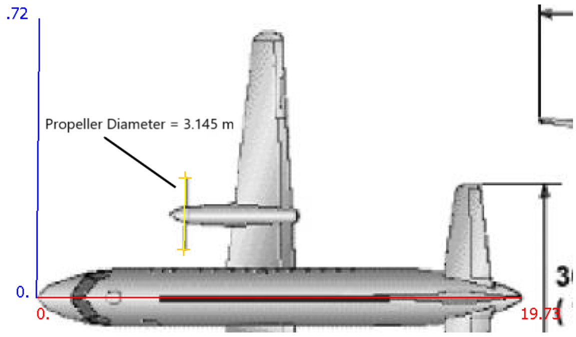


Figure 3.7: Saab 340 propeller diameter

2. Propeller tip ground clearance

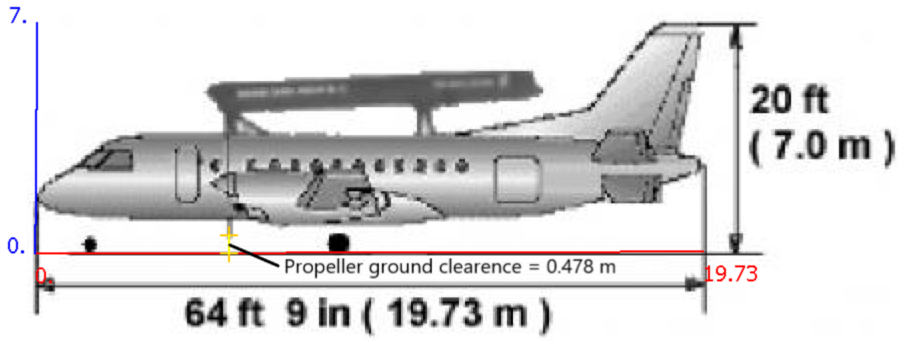


Figure 3.8: Saab 340 propeller tip clearance

3.1.2 Data accuracy report

The data collected using the plot digitization technique was compared with the validated data available on the JANES aircraft data sheet and the result of comparison is as follows.

1. Comparison of major aircraft dimensions

2. Comparison of propeller data

Major aircraft Dimensions		
Dimension	**Drawing data (m)**	**JANES data (m)**
Wing span	21.440	21.44
Horizontal tail span	9.250	9.25
Total length	19.730	19.73
Total height	7.000	6.9700
Fuselage width	2.365	2.310

Table 3.1: Saab 340 major aircraft dimensions

Propeller Data		
Propeller data-point	**Drawing data (m)**	**JANES data (m)**
Diameter	3.145	3.35
Ground Clarence	0.478	0.51

Table 3.2: Saab 340 Propeller dimensions

As per the comparison of data listed in figure 3.1 and figure 3.2, it can be concluded that the blue print data is accurate and can be used for the geometric modelling of the aircraft using 3D modelling software techniques.

3.2 Geometric data collection and part sizing

The blueprint drawing and the JANES data sheet was used to determine detailed information regarding geometric parameters required to create a 3D model of the aircraft. A major portion of the data presented below is measured using the plot digitization technique and available data from JANES aircraft data is used for the sizing of major components of the aircraft model.

3.2.1 Wing and Empennage sizing

Using the above mentioned methods and data sources, information related to the major lifting surfaces was collected. The enlisted information in tables 3.3, table 3.4, table 3.5 was used for the creation of the wing and tail plan forms of the aircraft model.

Wing data	
Parameter	**Value**
Wing span-b (m)	21.44
Wing root Airfoil	NASA MS(1)-0313
Wing tip airfoil	NASA MS(1)-0312
Root chord (m)	2.8
Tip chord (m)	1.21
Sweep c/4 (deg)	3.36
Aspect ratio	11.0
Dihedral (root) (deg)	7.0
Surface area ($\hat{m2}$)	41.81
T/C (root)	16.0
T/C (tip)	12.0
Incidence (root) (deg)	2.0

Table 3.3: Saab 340 Wing data

Horizontal stabilizer	
Parameter	**Value**
Root chord (m)	1.812
Tip chord (m)	1.014

Table 3.4: Saab 340 horizontal tail data

3.2.2 Fuselage sizing

The fuselage sizing was done by measuring the blue print at various section along the fuselage length. The control points for measurement were chosen based on the amount of flexibility needed to model the fuselage curvature at every section. The major control point dimensions are as shown in table 3.6.

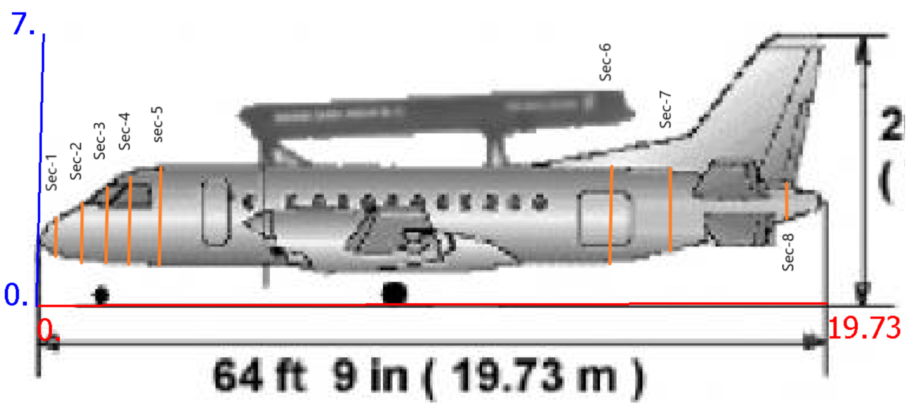


Figure 3.9: Saab 340 Fuselage sections

Veritical stabilizer	
Parameter	**Value**
Root chord (m)	2.68
Tip chord (m)	1.625

Table 3.5: Saab 340 Vertical tail data

Fuselage section data	
Fuselage section	**Fuselage height (m)**
Sec-1	0.9712
sec-2	1.427
sec-3	2.033
sec-4	2.398
sec-5	2.5
sec-6	2.5
sec-7	2.136
sec-8	0.713

Table 3.6: Saab 340 fuselage section data

3.2.3 Positioning of landing gear

The positions of the landing gear were measured along the length of the fuselage. Nose of the fuselage was considered as the datum. The positions of the nose landing gear was taken to the centre of the nose wheel and similar measurement was taken for the main landing gear wheel. The measured data is as recorded in table 3.7.

Undercarriage positions	
Parameter	**Distance from nose (m)**
Nose landing gear	1.6
Main landing gear	8.9

Table 3.7: Saab 340 Undercarriage positions along the fuselage

3.2.4 Positioning of control surfaces

The control surfaces positions were made estimated based on the blueprint drawings using the plot digitization technique. Comparison was made to other available drawings in order to verify but similarity of measurements proved the accuracy of the data collected.The data measured is as shown in the table 3.8, table 3.9, table 3.10.

Aileron positions	
Aileron Parameter	**Value (m)**
inboard span position	7.241
Outboard span position	10.72
Root chord	0.446
Tip chord	0.428

Table 3.8: Saab 340 Aileron positions

Elevator positions	
Elevator Parameter	**Value (m)**
Root chord	0.833
Tip chord	0.49
span	3.632

Table 3.9: Saab 340 Elevator positions

Rudder positions	
Rudder Parameter	**Value (m)**
Root chord	0.928
Tip chord	0.358
span	full VT span

Table 3.10: Saab 340 Rudder positions

3.2.5 Location of lifting surfaces with respect to fuselage

It is necessary to know the positions of the wing and tail with respect to the length of the fuselage. Measurements were taken from the blue print and the data is as described in the table 3.11.

Lifting Surface positions	
Wing Placement	**Distance from nose (m)**
Leading edge	7.7
Trainling edge	10.5437
Horizontal tail Placement	
Leading edge	16.6885
Trainling edge	18.51
Vertical tail Placement	
Leading edge	13.72
Trainling edge	19.09

Table 3.11: Saab 340 Lifting surface positions

3.2.6 Cockpit windshields

The Saab 340 has 4 main windshield elements. Two of the main windshields are positioned for forward line of sight vision and there are two other additional windshields which are located on either side to enable vision on starboard and port side of the aircraft. The major dimension elements of the windshields were recorded from the blue-prints and the points are presented in the table 3.12 and point designation is presented in figure 3.10

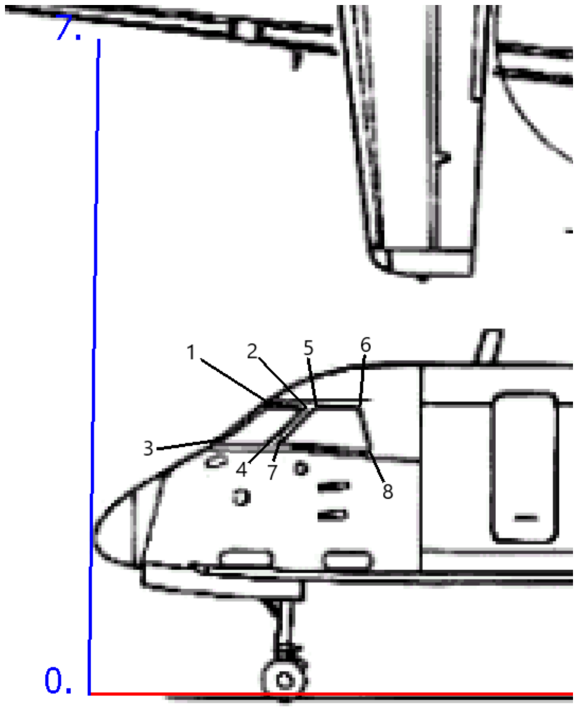


Figure 3.10: Saab 340 Windshield positions

3.2.7 Creation of windows for passengers

The number and dimensions of the passenger windows were extracted from the blueprint. The positioning of the window cavity in the fuselage was done after the seating configuration of the aircraft was modelled. The data extracted from the drawings is as described in table 3.13

Windshield Dimensions		
Point designation	**Horizontal Distance from nose (m)**	**Vertical distance from datum (m)**
Point 1 - main	1.8	3.133
point 2 - main	2.21	3.133
point 3 - main	1.2	2.67
point 4 - main	1.784	2.67
Point 5 - rear	2.306	3.099
point 6 - rear	2.75	3.099
point 7 - rear	1.906	2.68
point 8 - rear	2.88	2.68

Table 3.12: Saab 340 Windshield dimensions

Passenger window data	
Parameter	**Value**
No. of windows	12
Window pitch(m)	0.6
Height(m)	2.5
First window position(m)	5.38

Table 3.13: Saab 340 passenger window positions

3.2.8 Passenger seating - configuration and positioning for G-NFLB

The passenger seating configuration was modelled in reference to the previous configuration used on the Jet-stream J31 - NFLA aircraft. The aircraft used 1-2 configuration with a single aisle. A similar configuration was created for the G-NFLB considering the requirements of the aircraft which is to be used for flight testing and on-board data collection. There are 11 rows of seats in the 1-2 configuration which gives a total passenger cabin occupancy of 33. The floor plan of the aircraft is described in the figure 3.11

3.2.9 cabin compartment walls

The cabin compartment was created with reference to the figure 3.11. The main separation wall is created at the junction of cockpit section and passenger compartment. The dimensions of the wall is created with reference to the fuselage diameter and the floor height of the cabins.

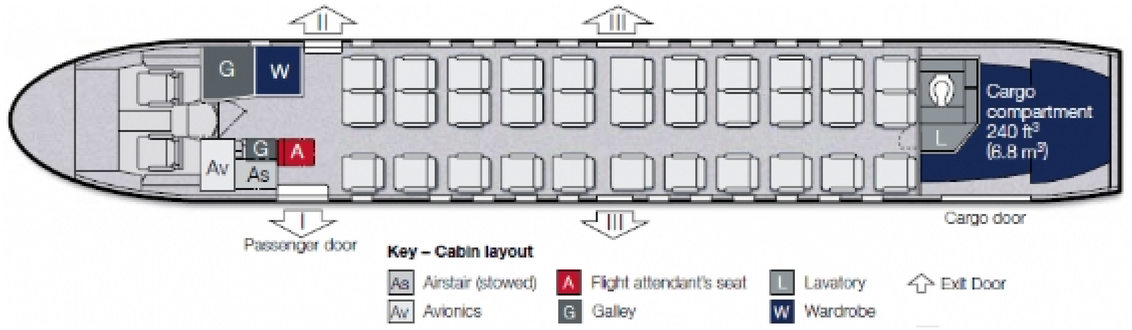


Figure 3.11: Saab 340 Floor plan

3.2.10 Undercarriage doors

The sizing of the undercarriage doors was done with extraction of the dimensions from the reference blue-print. The doors are created in double hinged door configuration with 2 doors per landing gear strut. The positioning of the doors were done in relation to the undercarriage positioning.

3.2.11 Positioning of Cockpit seats

The cockpit seats were positioned with reference to the positions as depicted in the figure 3.11. The type of the yoke to be used was referenced from figure 3.12.

3.2.12 Positioning of yokes

The Positioning of yokes was done with visibility and reach as driving elements.

3.2.13 Positioning of cockpit instruments

The cockpit instruments were positioned separately for pilot and first officer positions. The reference positions of the instruments were selected based on the image of the aircraft cockpit as depicted by figure 3.12.

Figure 3.12: Saab 340 cockpit

Chapter 4

3D Modelling of major exterior components

The 3D modelling of the aircraft was done using a combination of two 3D modelling software. Blender and AC3D were used in different phases of the modelling. The detailed description of the work is given below.

4.1 Wing modelling

The Wing geometry was created in Blender. The dimensions of the wing geometry is as described in table 3.3.

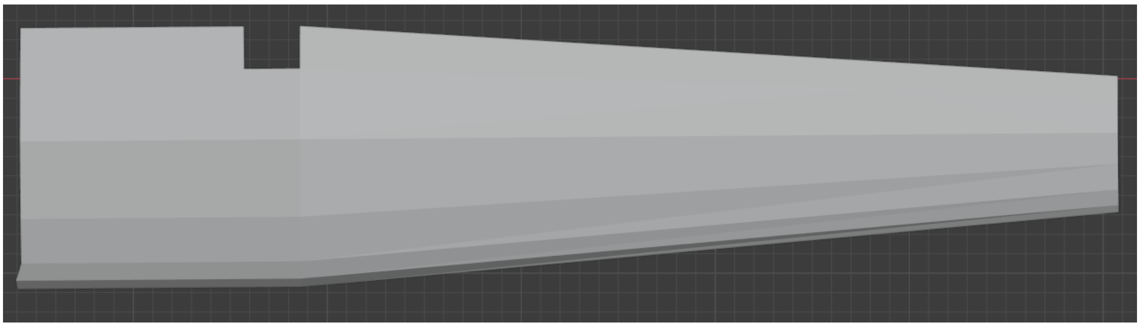


Figure 4.1: Saab 340 Wing Planform view

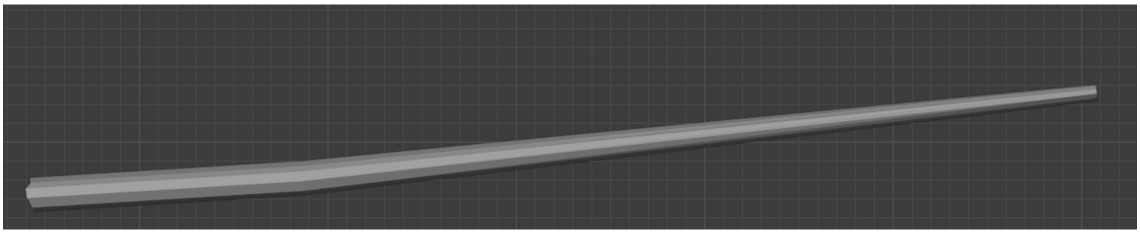


Figure 4.2: Saab 340 Wing front view

4.2 Empennage modelling

The horizontal and vertical tail of the aircraft was modelled using the dimensional data as described in table 3.4 and table 3.5. The geometric model is as shown in figures 4.3,4.4,4.5.

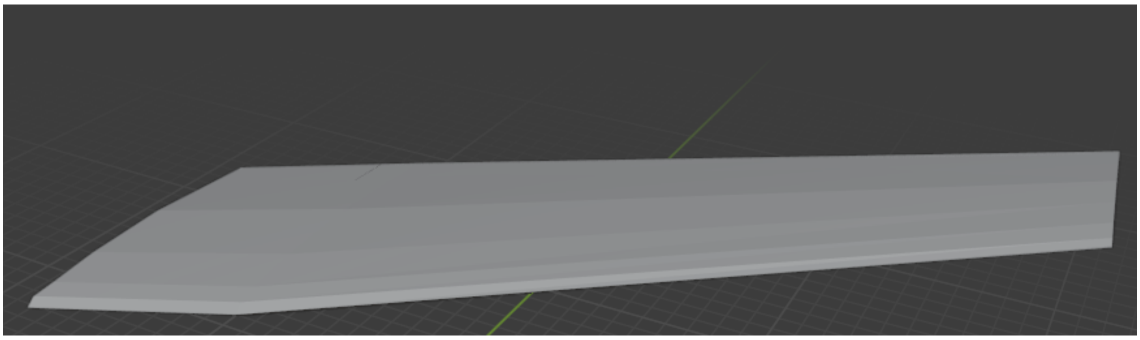


Figure 4.3: Saab 340 Horizontal stabilizer Planform view

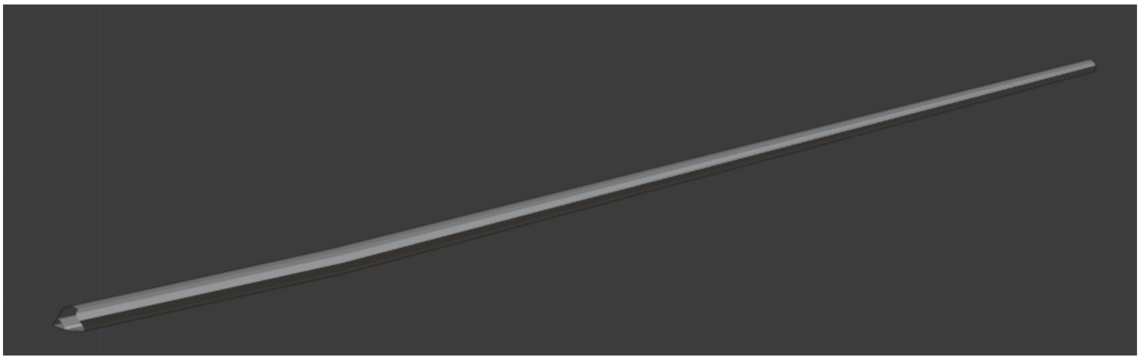


Figure 4.4: Saab 340 Horizontal stabilizer front view

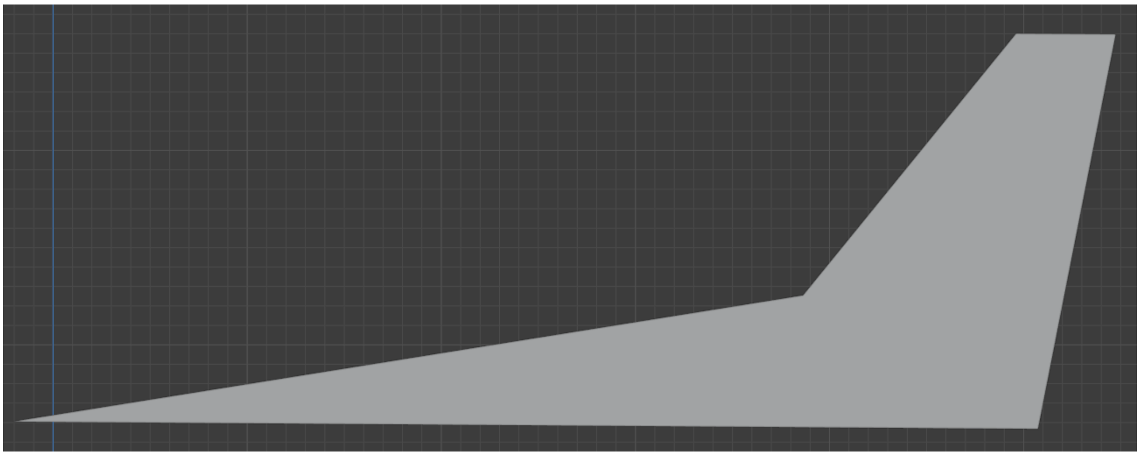


Figure 4.5: Saab 340 Vertical stabilizer Planform view

4.3 Fuselage modelling

The modelling of the fuselage was done in sections as described in table 3.6. The Nose and tail part of the fuselage were modelled individually and then assembled with the central section of the fuselage which has an uniform cross-section. The fuselage model is as described in images below.

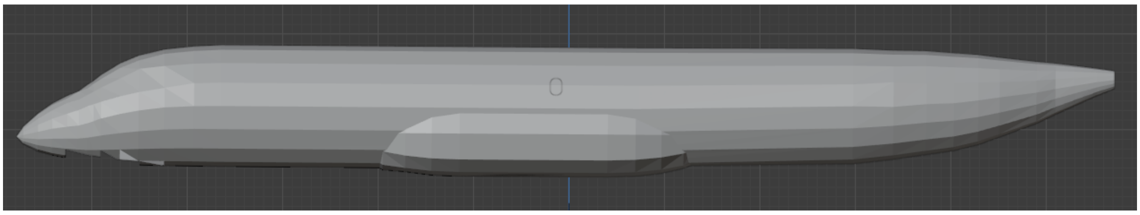


Figure 4.6: Saab 340 Fuselage port side view

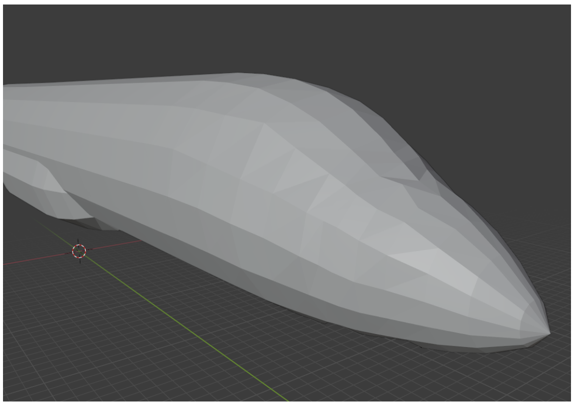


Figure 4.7: Saab 340 Fuselage Nose section view

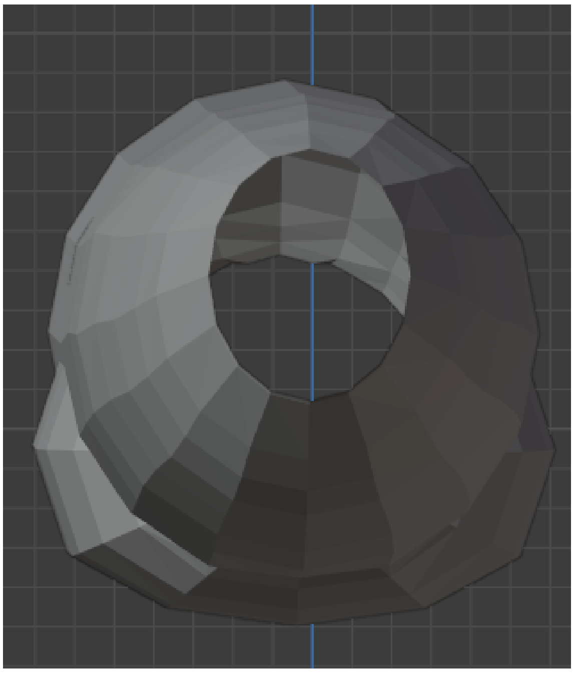


Figure 4.8: Saab 340 Fuselage rear view

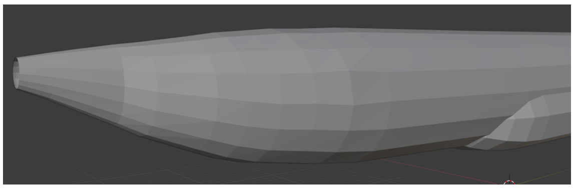


Figure 4.9: Saab 340 Fuselage Tail section view

4.4 PowerPlants

The modelling of the power plants were done in 2 major sub-sections. The Engine cowlings were modelled according to the blue-print measurements. The modelling of the propeller and the propeller hub was done separately and then the two sections were mated to create one body.

4.4.1 engine cowlings

The modelling of the engine cowlings was done as described in the images below. The modelling of the engine cowling sections were done by blue-print drawing measurement at various parts of the drawings. The drawings provide data of the top profile, front section view and side view. These measurements were used to create the engine pods.

The modelling can be observed in figures 4.10, 4.11, 4.12 and is comparable to the data provided on the blue-print.

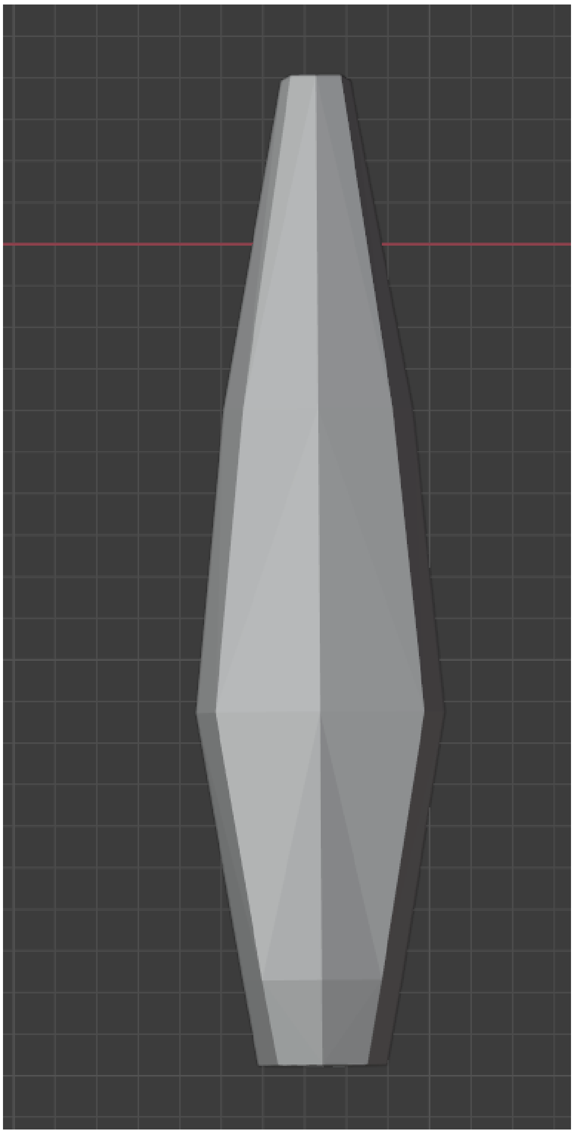


Figure 4.10: Saab 340 Engine cowling Top view

4.4.2 Propellers

The modelling of the propeller was undertaken with the available propeller data on the blue-print and on JANES aircraft data. The basic geometrical data of the propeller can be found in table 3.2. The propeller models are displayed in figures 4.13. However, the propeller blades are modelled as flat plates for simulation purposes and does not contain

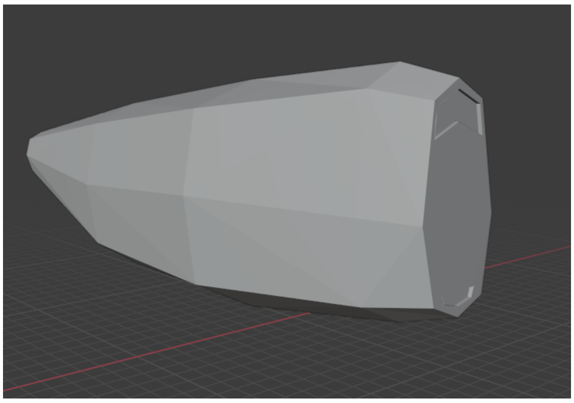


Figure 4.11: Saab 340 Engine cowling Leading edge view

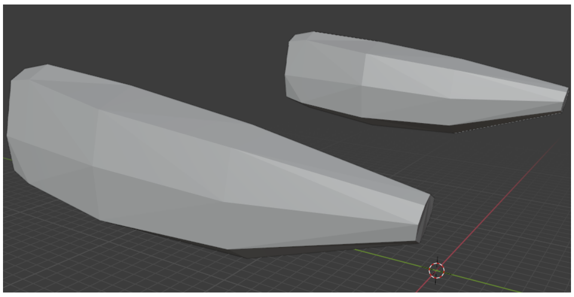
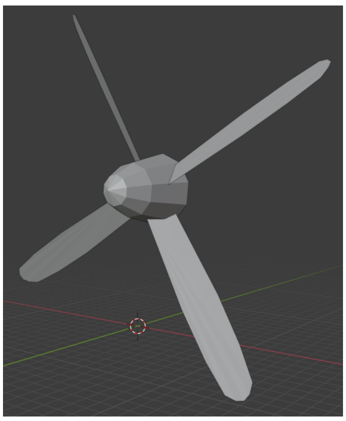
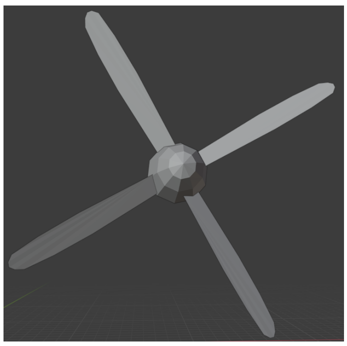


Figure 4.12: Saab 340 Engine cowling Trailing edge view

airfoil geometry.



(a) Isometric view

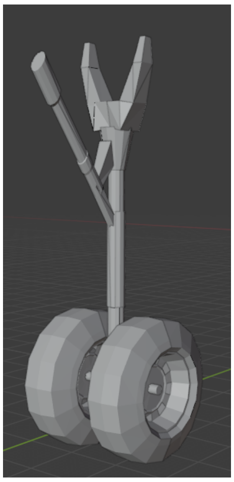


(b) Front view

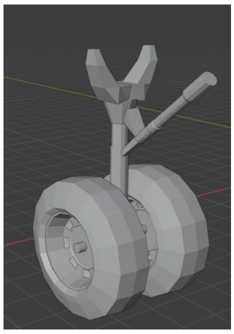
Figure 4.13: Saab340 Propeller geometry

4.5 Undercarriage modelling

The modelling of the undercarriage was done in 3 major parts. The Nose landing gear and the 2 main landing gear units.The geometry was segregated into translating and rotating parts. The tyres and the main oleo strut were considered to be modelled first. The parts of the landing gear which are mainly used in the translation actuation animation of the aircraft were modeled later. The V shaped attachment of the nose landing gear unit was modelled in the rotating elements of the structure. The retracting actuator cum drag stay unit of the nose landing gear which is a part of both rotating and translation mechanism was made as a separate unit and them mated to the main oleo strut structure. The measurements for the undercarriage were taken from the blue-print. The model of the undercarriages can be observed in figure 4.14.



(a) Nose landing gear



(b) Main landing gear unit

Figure 4.14: Saab340 undercarriage geometry

4.6 Material assignment to parts

The materials were assigned to the parts using AC3D software. The colour and optical properties of various parts were also set simultaneously.

Chapter 5

Study of FlightGear Flight Simulator

FlightGear is an open-source flight simulator. The main goal of the FligthGear project is to create a sophisticated and open flight simulator framework to be used in research and academic environments, pilot training and as an industry engineering tool and last but certainly not least a realistic and challenging flight simulator. Initial time was spent in understanding the file structure of the FlightGear program. It was important to fully understand the networking structure of the program in order to develop the model for Saab 340.

There are major files which contribute to the basic working of the simulator. They dictate the aircraft geometry, aircraft control algorithm, the on-board system configuration of the aircraft and simulation visual parameters. The major files and folder structure has been described in the sections below.

5.1 Folder and file structure

The flight simulator contains a number of folders in its installation folder which help in supporting the simulation in various ways. The description and functions of a them are discussed in this section.

The top-level folder structure is:

- **FG 2018.3.6**

  The root installation folder which contains all the files related to the software. Under this Root folder lie two major folders which are described in the below sections.

  - **bin**

    Contains file which help in smooth execution of the software. We do not directly interact with this folder. The items in this folder do not play a major role in modelling of the aircraft.

  - **data**

    Contains all the files which help in the simulation of the aircraft geometry, the environment of simulation and all the external elements of the simulation such as objects in the simulation world. The functions of the files in this folder are described in the sections below.

5.2 Functions of various files

The contents of the data folder as described contribute to the creations and simulation of the aircraft geometry and the simulation environment. This section describes the sub-folders of the .data folder, major files and their functions.

- **Aircraft**

  The Aircraft folder contains the files and folders which are responsible for the generation of the geometry of the aircraft. The sub-folders of this folder are listed below with their descriptions. The folders and files listed below can be found after entering into one of the aircraft folders.

  - **Models folder**

    This folder describes the actual geometry of the aircraft during the simulation.

The geometry is divided into many parts and the items are as described below.

* **Cockpit folder**

  This folder contains the XML document (cockpit.xml) which describes the cockpit of the respective aircraft. This file is used to model the functions of the instruments in the cockpit such as the yoke. The positions of the cockpit instruments and other external instruments can be described in this file.

* **Instruments**

  This folder contains all the files which help in simulating the basic flight instruments such as Altimeter and Airspeed indicator. The Geometry, animations and data inputs to the instruments are described within the files in this folder.

* **Liveries**

  This folder contains the aircraft paint scheme which is generally known as the aircraft livery. The images of the painting scheme and the graphics can be input into this folder and then allocated to the aircraft geometry using the graphics file.

* **S340b.AC**

  This is the main aircraft assembly geometry in AC3D format. This is the compatible geometry file type to simulate the aircraft in FlightGear.

* **S340b.XML**

  This script is used to point out to the different resources which are present in various folders. Major functions of this file include defining the path of the aircraft model file, positioning the cockpit model into the aircraft geometry co-ordinates. All the animations related to various parts of the aircraft such as landing gear, control surfaces are defined in this script. The positioning of the cockpit instrument geometry is defined in this file.

– **Previews folder**

  The Previews folder contains all the images and description that should be displayed at the beginning of the simulation. These describe the aircraft and the development work undertaken. Also, the flight scenery can be displayed while the background simulation and scenery is being started. Here, the SAAB340 with Cranfield University livery has been displayed with its name as the label.

– **XMLs folder**

  This folder contains all the external XML files which act as supporting scripts for the functions to be performed by different parts of the aircraft. For example, the positioning of the landing gear assembly can be done using external scripts and also contain the definition of centers of rotation to perform rotation and translation animations during the simulation.

– **instrumentation.XML**

  The instrumentation.XML script is used to allocate the cockpit instruments to be used on the aircraft with their identification number based on number of instances the instrument is used in the aircraft. This file is also used to provide input to the instruments from the basic systems which has been integrated in the aircraft. The other major function in this script is the definition of parameters such as total pressure and static pressure using the pitot and the static system which can be used as an input parameter for other data systems in the simulation.

– **S340b-set.XML**

  This file is used to define the visuals of the simulation. The initial lines include the description of the simulation ”Cranfield University SAAB340 simulation”. The definition of the systems.XML file is done here. The aircraft XML file ”S340b.XML” which contains the geometric definition of the aircraft is used here to point out to the model file and its path for the simulation.

  The other major work done in this script is the definition of the camera views.

A number of camera views can be defined with variation in parameters like camera heading and pitch to create unique angles to aid the pilot during simulation. The most necessary views are the pilot view, First-officer view and the tail view. The configuration of the Cranfield University SAAB340 is to be used as a testing aircraft. To support this function and to simulate this experience, a student/ passenger seat view has been created. This simulates a passenger view from the seat facing the instruments positioned on the seat in front of the person.

The help menu which describes different aircraft velocities is also created in this script. other information related to the functions of the aircraft and the simulation in general can also be included in the help menu. Last but not the least, the path to the instrumentation.XML file is defined here.

– **systems.XML**

This script is used to add basic systems to the aircraft. the most basic systems which help in generating data to the instruments are the pitot probe system, static port system and the aircraft vacuum system. These systems aid the the air data instruments such as the altimeter (AI) and the air speed indicator (ASI) in the cockpit providing vital information to the pilot and the co-pilot.

- **Airports**

The Airports folder contains all the files which help in simulating the airport ecosystem. There are a lot of possible use cases which can be built by using the airport. The main feature of simulating the aircraft operations within an airport environment can be done. The tasks such as embarking-disembarking of passengers and crew, loading of cargo, fuelling the aircraft and other functions which are part of flight operations can be simulated here. The ICAO codes link to the Flight Gear map server, which among other things contains information about current status of the FlightGear Scenery Database. During the simulation, you will be able to visualise the current airport layout with runways, taxiways and aprons, Static objects made for the airport, shared models of common objects which are found at every airport and taxi signs placed at the airport. For the purpose of the current simulation Cranfield Airport is used. The red dots in the figure 5.1 are static objects in the scenery database made especially for this airport. The available static objects are as listed below.

- Control Tower
- Building 83
- Building 84
- Hanger
- Generic AVGAS storage
- petrol Storage
- EGTC 21 ILS-cat-I (ICR)
- Cranfield VOR (CFD)
- EGTC 21 GS
- EGTC 21 MM

Figure 5.1: Cranfield Airport as seen on the FlightGear Scenemodels Map

Chapter 6

Creation of aircraft assembly and component positioning

In this section, the creation of aircraft assembly is discussed. The component naming and positioning with respect to the aircraft FlightGear axis system is described. The interior components of the aircraft and their assembly is also described.

6.1 File structure and part naming scheme

The file structure which has been followed during the creation of various parts of the aircraft has been discussed here. The initial design work was done using the Blender 3D modelling software and the following file naming scheme was followed.

S340b - part-name - position

After the creation of the basic parts which make up the exterior of the aircraft, further division of surfaces were created to incorporate the control surfaces. Table 6.2 shows the divided surfaces.

Saab 340 - part list	
Part code	**Part name and position**
S340b_Engine-nac_PS	Engine nacelle - Port side
S340b_Engine-nac_SB	Engine nacelle - starboard side
S340b_Fuselage	Fuselage
S340b_HT_PS	Horizontal tail - Port side
S340b_HT_SB	Horizontal tail - starboard side
S340b_MLG_PS	Main landing gear - Port side
S340b_MLG_PS-door_inner	Main landing gear inner door - Port side
S340b_MLG_PS-door_outer	Main landing gear outer door - Port side
S340b_MLG_SB	Main landing gear - starboard side
S340b_MLG_SB-door_inner	Main landing gear inner door - starboard side
S340b_MLG_SB-door_outer	Main landing gear outer door - starboard side
S340b_NLG	Nose landing gear
S340b_NLG-door_PS	Nose landing gear - Port side
S340b_NLG-door_SB	Nose landing gear - starboard side
S340b_prop_PS	Propeller - Port side
S340b_prop_SB	Propeller - starboard side
S340b_VT	Vertical tail
S340b_Wings_PS	Wing - Port side
S340b_Wings_SB	Wing - starboard side

Table 6.1: Saab 340 list of parts

Saab 340 - Control surfaces	
Part code	**Part name and position**
S340b_Aileron_PS	Aileron - Port side
S340b_Aileron_SB	Aileron - starboard side
S340b_HT_elevator_PS	Elevator - Port side
S340b_HT_elevator_PS	Elevator - starboard side
S340b_VT_rudder	Rudder

Table 6.2: Saab 340 divided surfaces

6.2 Aircraft Exterior Assembly

The exterior assembly of the aircraft was carried out with the part geometric co-ordinates in Blender software and then then it was converted to the FlightGear axis system using the AC3D software as shown in figure 6.5. The assembly view of the aircraft is shown in figures below. It can be observed from the figure 6.1 that the origin co-ordinates of the geometry are located at 0,0,0 (x,y,z axis locations).

Figure 6.1: Saab 340 assembly view 1

6.3 Aircraft interior components Assembly

The interiors of the aircraft was developed by addition of major elements which make up the cabin of the aircraft. The parts used on the interior of the aircraft are listed in the table. The cabin walls were created as per the aircraft fuselage dimensions. The seats used are the generic aircraft pilot and passenger seats available in the FligthGear library. However, The configuration of the passenger seating was created using AC3D software to match that of the current university aircraft Jet stream J31. The floor panel was created to match the fuselage dimensions of the Saab 340. The interior components are displayed in the figure 6.6 and figure 6.7.

The part naming convention and hierarchy in AC3D software is similar to that created for Blender as shown in table 6.1. The figure 6.8 shows the hierarchy view of the parts as seen on the AC3D software.

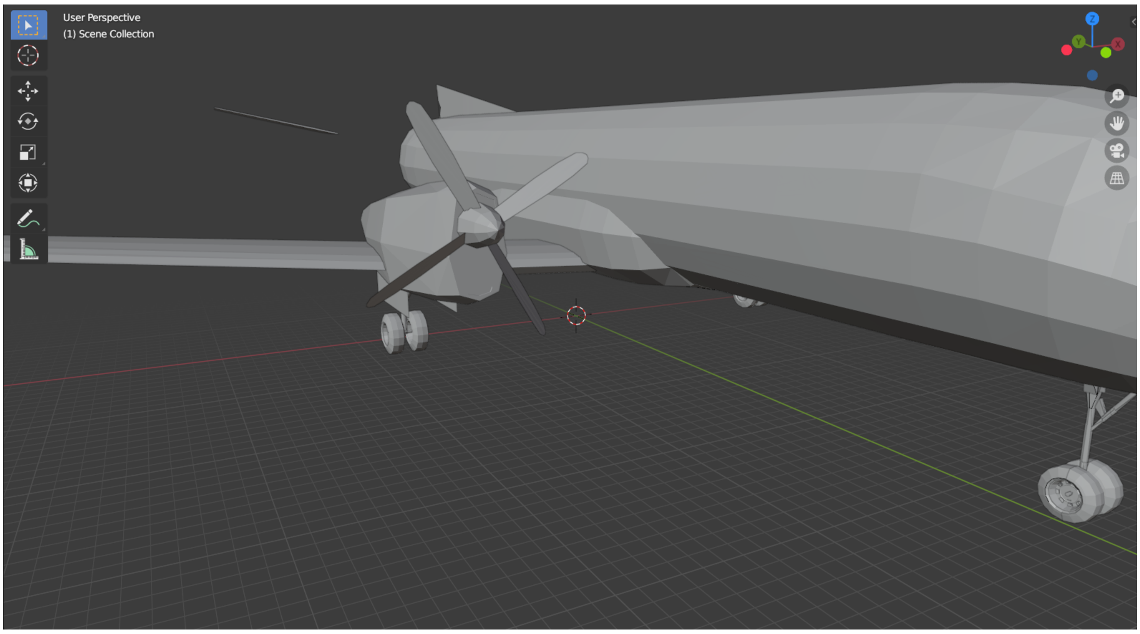


Figure 6.2: Saab 340 assembly view 2

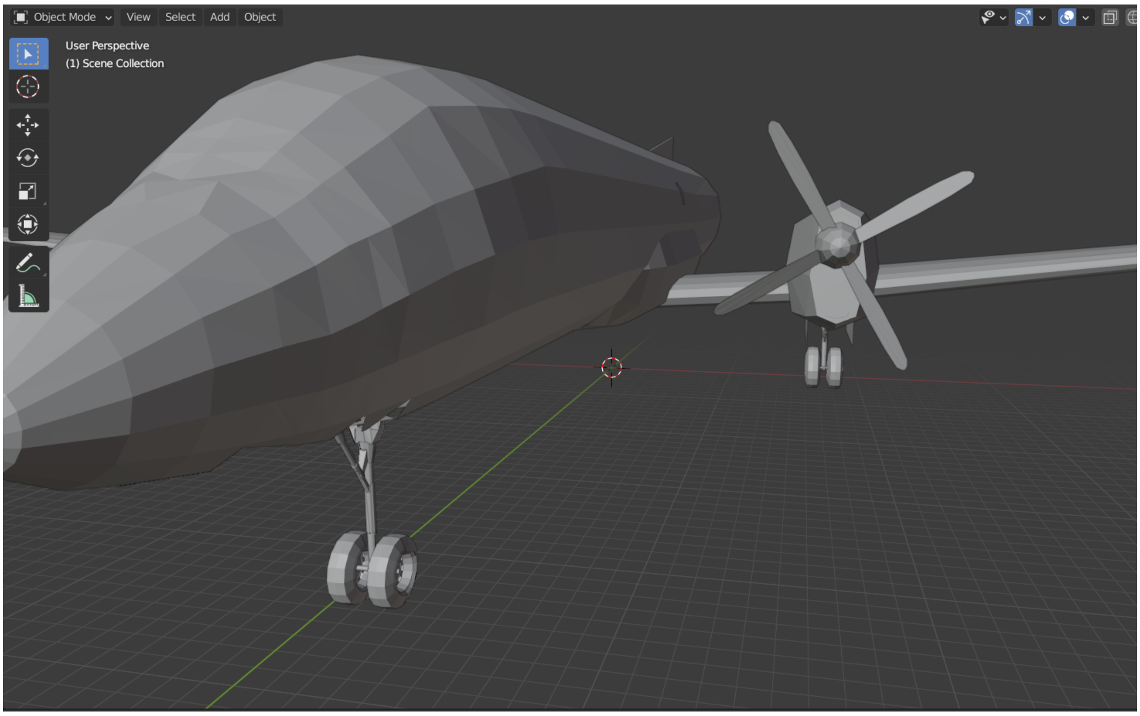


Figure 6.3: Saab 340 assembly view 3

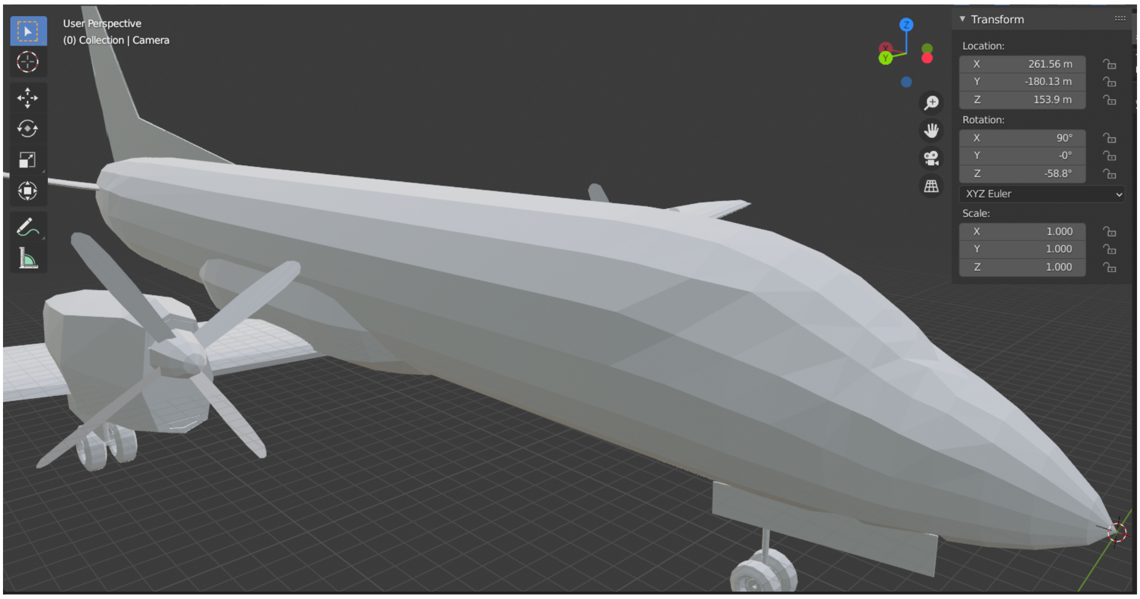


Figure 6.4: Saab 340 assembly view 4

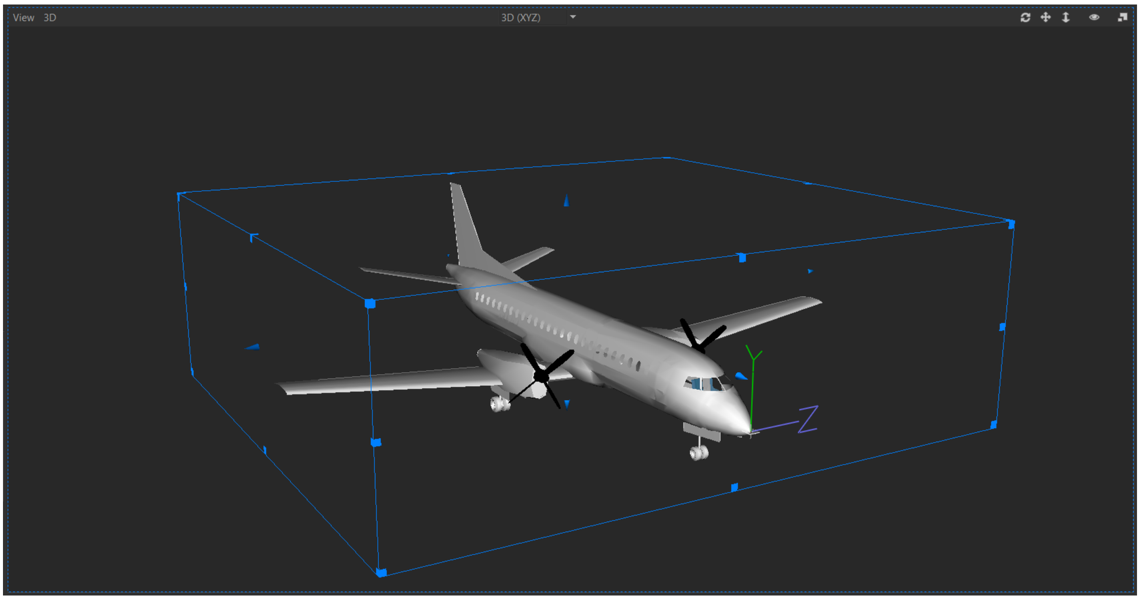


Figure 6.5: Saab 340 AC3D co-ordinate transformation

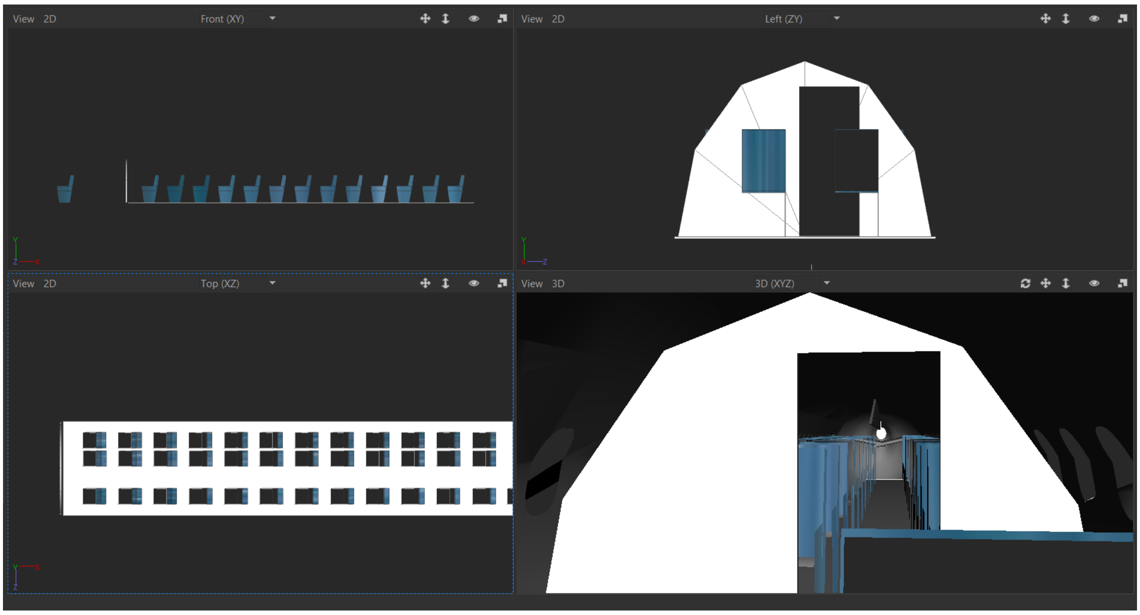


Figure 6.6: Saab 340 interior assembly view 1

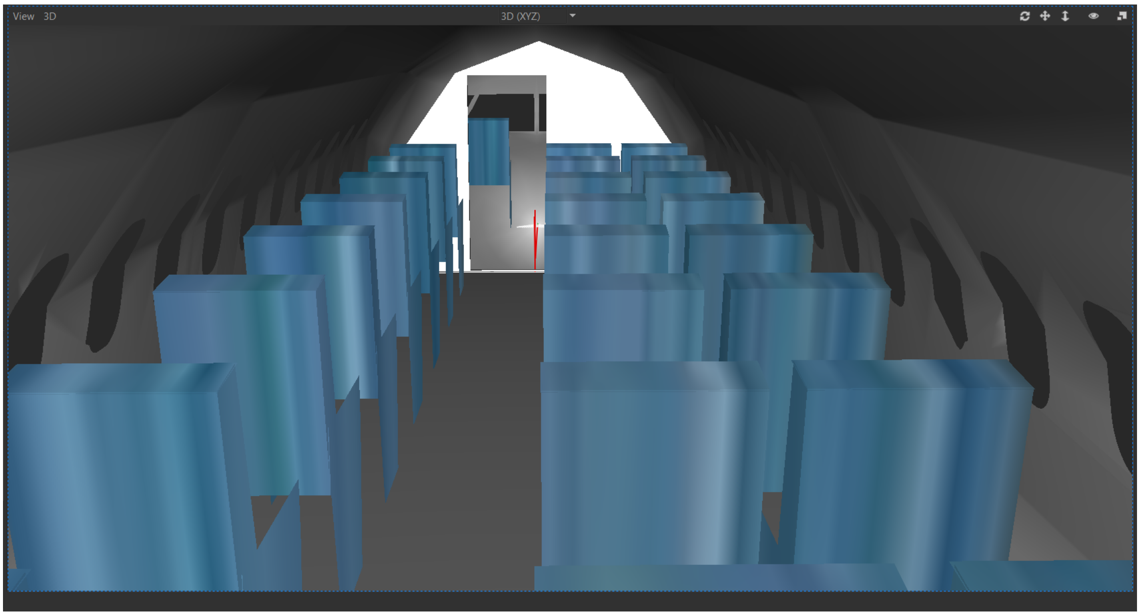


Figure 6.7: Saab 340 interior assembly view 2

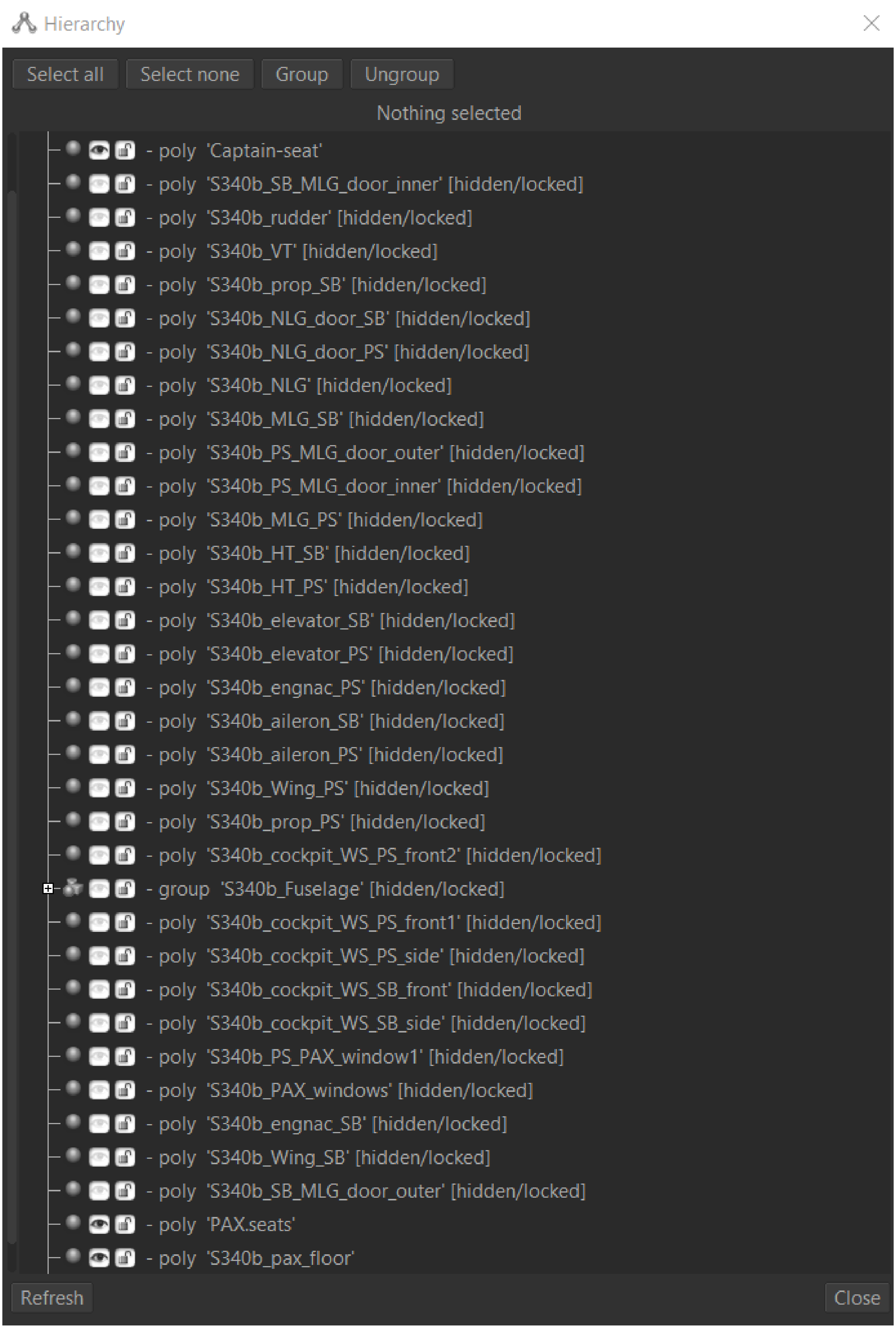


Figure 6.8: Saab 340 AC3D part hierarchy list

Chapter 7

Interfacing of FlightGear with Simulink model of Saab340B

7.1 Simulink model of Saab340

The Simulink model is a mathematical representation of the Saab 340 aircraft. This section will describe the top level model architecture. Then the interfacing section of the model will be described to understand its functions. The top level model is shown in figure 7.5.

7.1.1 Data flow Diagram

The top level of the mathematical model of Saab340 consists of 5 major blocks: The Pilot inputs block, Aerodynamics block, Propulsion block, Forces and moments block and the mass & CG block. These make up the input data generating blocks of the model. The Processing of the data takes place in the 6DOF (Euler angles) block taken from the Simulink aerospace blockset. The outputs from the data processing block are then fed into two major blocks associated with Flight Gear. The Flight Gear Data transfer block is responsible for the transfer of flight variables which are extracted from the outputs of the 6DOF block and the Flight Gear simulation visualisation helps in providing real time position and Euler angles data to Flight Gear. The details of the parameters which are being used in the simulation are discussed in the sections which follow. The control input data is generated from the joystick which is fed into the 6DOF model. The input data is processed by the 6DOF model to generate the position data consisting of the latitude, longitude and altitude., and the flight dynamics data consisting of the roll, pitch and yaw parameters.The Data flow diagram is shown in figure 7.1.

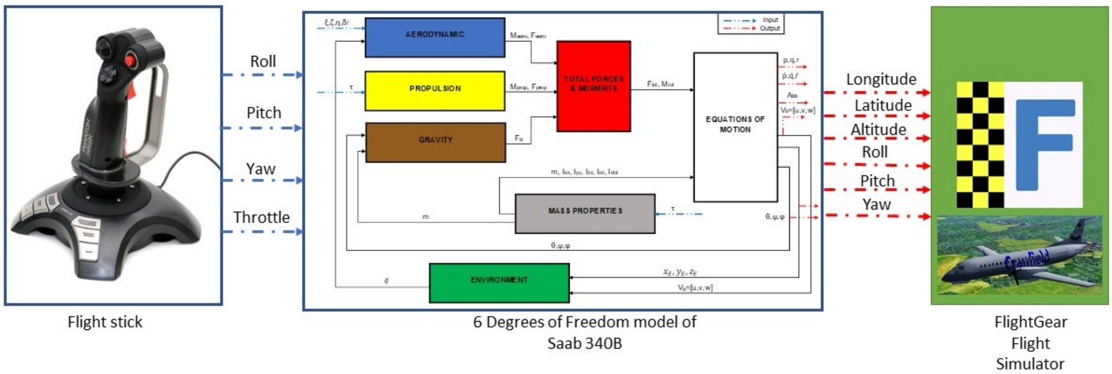


Figure 7.1: Saab 340B data flow diagram

7.1.2 Input parameters

The inputs to this model are the velocities, control surface angles, throttle percentage, total mass of the aircraft, Lift coefficients, Drag coefficients, moment coefficients. Also, the aircraft wing parameters, passenger data, aircraft mass and inertia are specified. The input file is defines in a Matlab script which also defines the trim conditions of the aircraft. The detailed explanation of the input script can be found in work done by Patel [1].

7.1.3 Environment subsystem

The environment subsystem provides the air density data using the ISA Atmosphere model[5]. The input to this system is the altitude of the aircraft. The dynamic pressure (q) is calculated using the density of air and velocity of the aircraft.

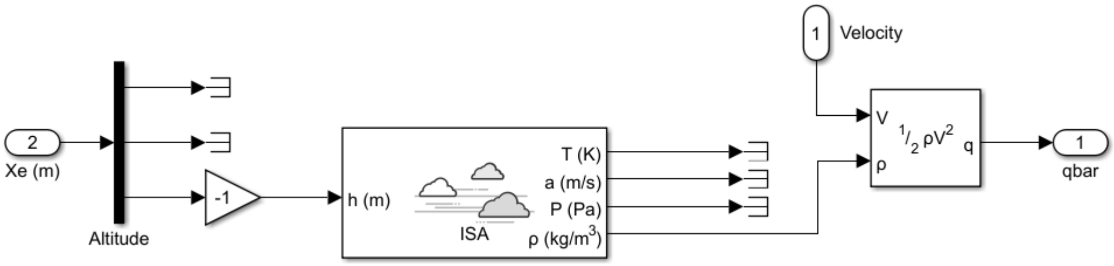


Figure 7.2: Saab 340 Simulink model - Environment subsystem

7.1.4 Aerodynamic subsystem

The Aerodynamic subsystem is used to calculate the forces and moments generated due to the aerodynamic coefficients of the lifting surfaces and various control surfaces on the aircraft. The input body axis velocity (Vb) is used to calculate the angles between the body and the velocity vector (incidence and sideslip), and the velocity magnitude.

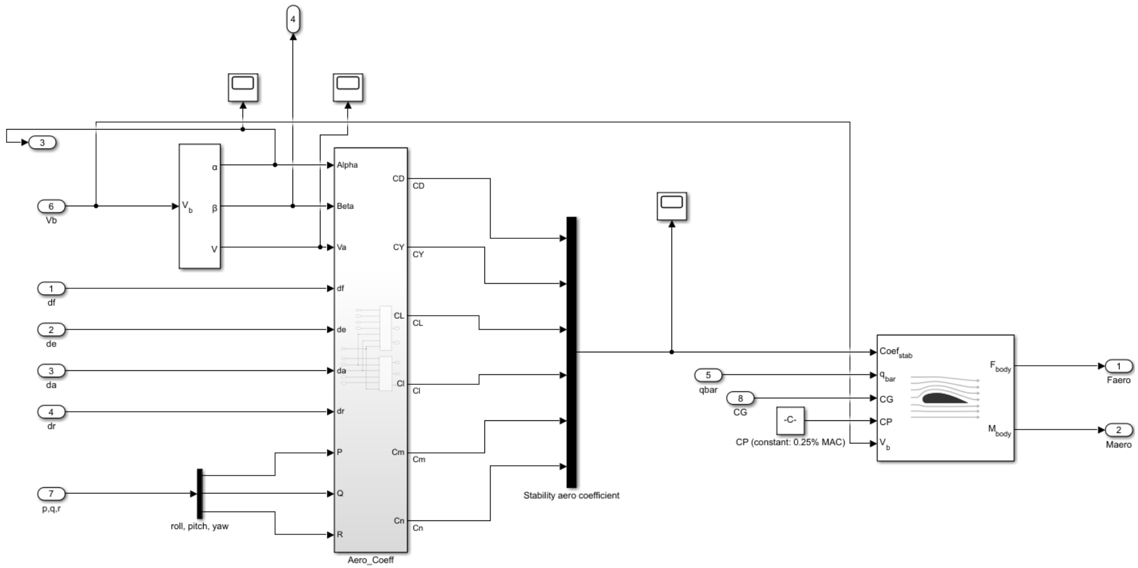


Figure 7.3: Saab 340 Simulink model - Aerodynamic subsystem

7.1.5 Mass subsystem

The mass subsystem is used to calculate the position of center of gravity and the inertia tensor of the aircraft. The inputs to this system include the fuel flow and empty mass properties. The fuel flow parameter has a major impact on the Center of gravity of the aircraft and the handling characteristics change with the shift in Center of gravity. In this model a linear interpolation is used to determine Center of gravity as a function of mass [5].

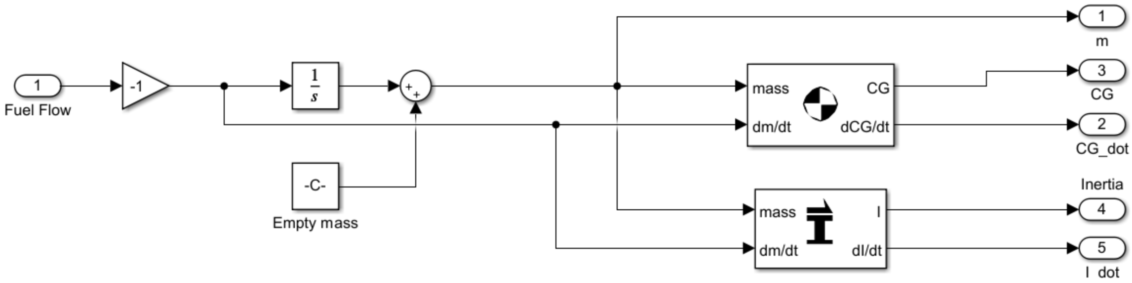


Figure 7.4: Saab 340 Simulink model - mass subsystem

7.1.6 6 degree-of-freedom (DOF) block

This block is used to implement the Euler angle representation of six-degrees-of-freedom equations of motion, taking into consideration the rotation of a body-fixed coordinate frame about a flat earth reference frame [5]. The input parameters to this block consists of Forces (N) and Moments (N-m) in X,Y,Z directions, Mass (kg), Rate of change of inertia tensor (dI/dt) (kg-m^2/s) and Inertia (kg-m^2). There are major outputs from this block which are the most important parameters for simulation and visualisation of the aircraft. The list of outputs are:

1. States of the aircraft

   Position [Xe] (m)

   Euler angles [phi, theta, psi] (rad)

   Body velocity [V_b] (m/s)

   Initial body rotation rates [p,q,r] (rad/s)

2. Ground speed [V_e] (m/s)

3. Airspeed [Vel W] (m/s)

4. Altitude [h] (m)

These outputs are then fed into the Flight Gear visualisation block, the functions of which are described in the sections that follow.

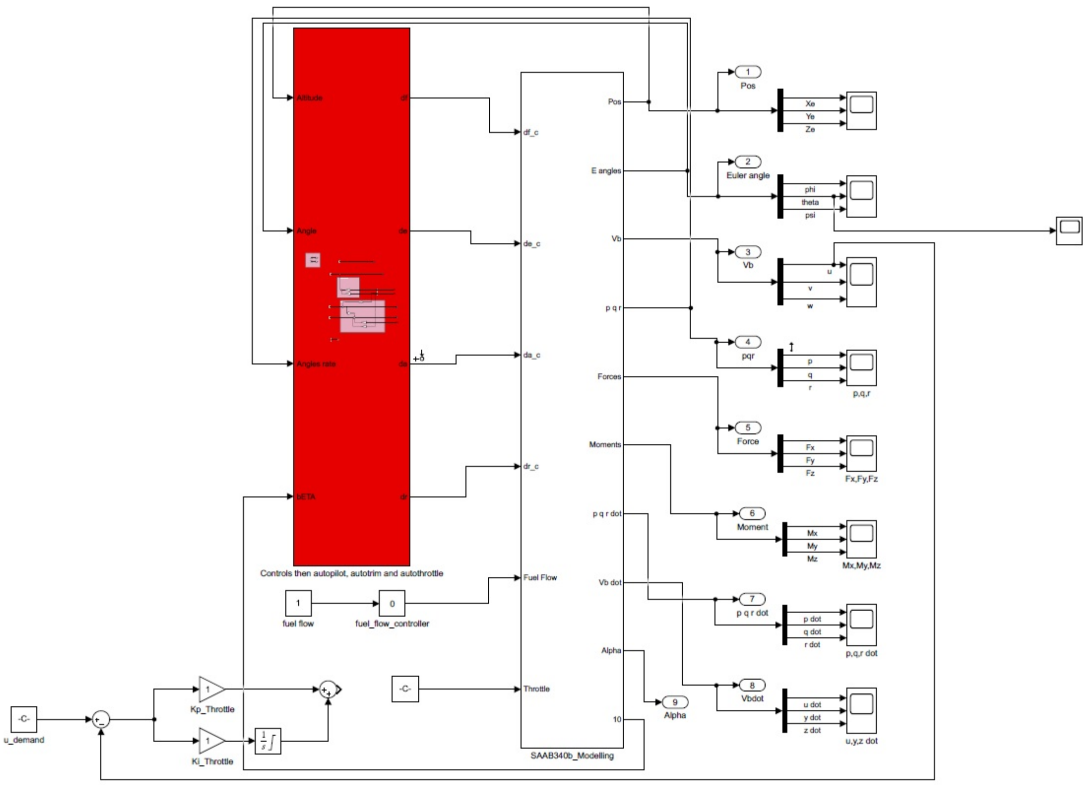


Figure 7.5: Saab 340 Simulink model - top level view

7.2 Interfacing of FlightGear and Simulink

The data generated from the Simulink model needs to converted to a particular form which can be useful to the Flight gear software to simulate the aircraft. The Interface needs to be created between the two which will be responsible for data conversion and transfer to Flight Gear. The FG visualisation block contains the Flat earth to LLA block which converts a 3-by-1 vector of flat Earth position(p) into geodetic latitude, longitude,and altitude. The conversion algorithm used in the flat earth to LLA block can be found in [7].

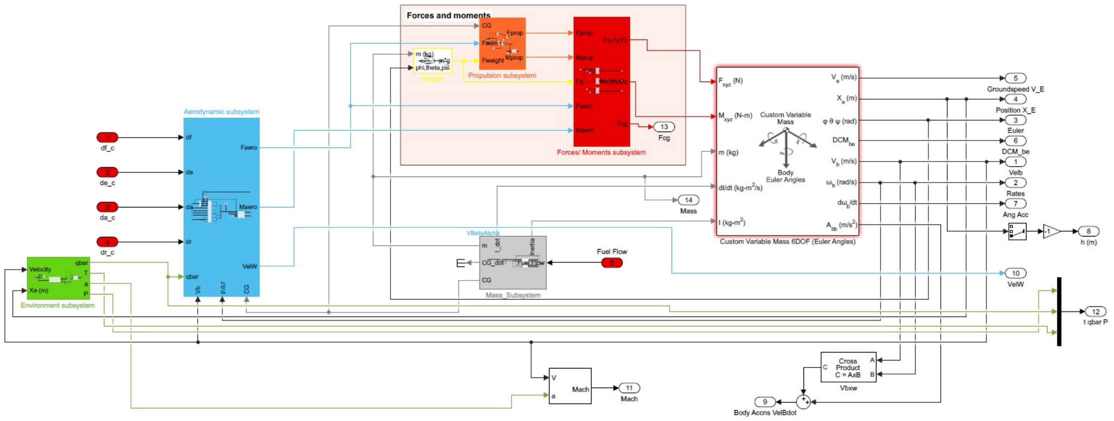


Figure 7.6: Saab 340 Simulink model - first level view

These parameters along with Euler angels are fed into FlightGear Preconfigured 6DoF Animation block. This is illustrated in the figure 7.7.

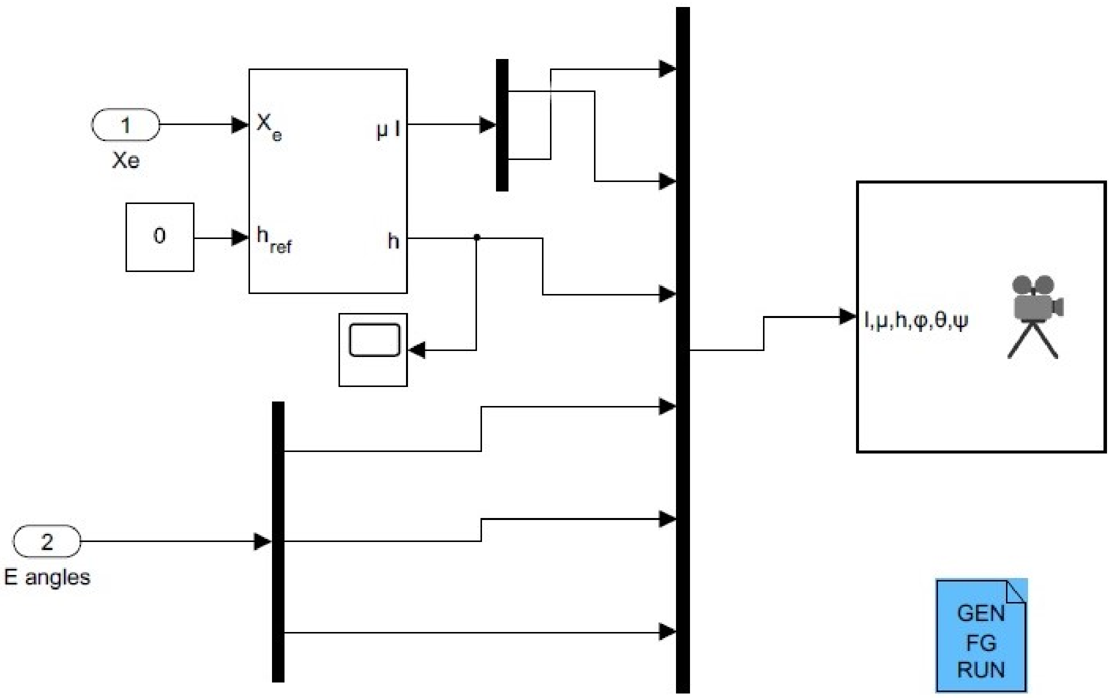


Figure 7.7: Saab 340 Simulink model - interfacing with flight gear

For the data transfer to take place between Simulink and Flight Gear, two different blocks are used. The "Pack net_fdm Packet for FlightGear" block creates a FlightGear Net_fdm (Network flight dynamics model) data packet compatible with a particular version of the Flight Gear flight simulator. This data packet is them sent to "Send net_fdm

Packet to FlightGear" block whose function is to transmit a Net_fdm packet to Flight Gear flight simulator via UDP at a specific IP address and a UDP port. The input to these blocks are illustrated in the figure 7.8.

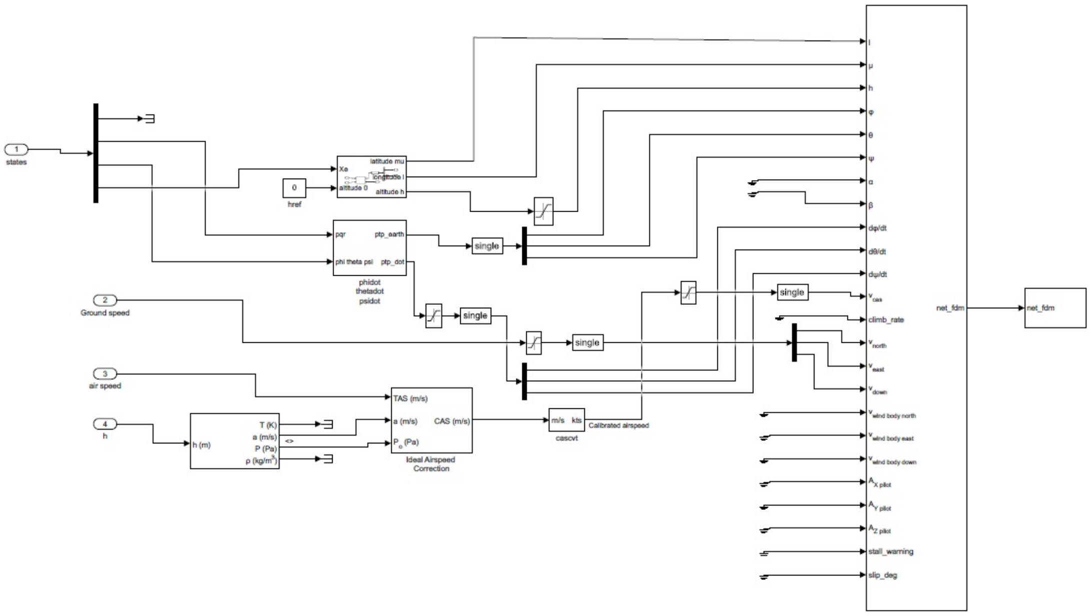


Figure 7.8: Saab 340 Simulink model - data transfer between Simulink and FligthGear

7.3 Joystick integration into Simulink model

The implementation of joystick for simulation is described in this section. The pilot joystick block is used here to process the inputs from the joystick hardware. The pilot joystick block provides a pilot joystick interface for a Windows® platform. Roll, pitch, yaw, and throttle are mapped to the joystick X, Y, R, and Z channels respectively. Roll command, specified in the range [-1, 1], that corresponds to the joystick left and right directions. Pitch command, specified in the range [-1, 1], that corresponds to the joystick forward or down and back and up directions. Yaw command, specified in the range [-1, 1], that corresponds to the joystick twist left and twist right directions.Throttle command, specified in the range [0, 1], that corresponds to the joystick min and max position.

To use all the buttons and additional functions on the joystick, the pilot joystick all block must be used. It provides option to input commands from the buttons available on the joystick which can be further mapped to various non-vital functions in the simulation such as flaps and slats actuation, landing gear actuation of the aircraft. The Pilot Joystick All block provides a pilot joystick interface for a Windows® platform. Analog is mapped to the joystick X, Y, Z, R, U, and V channels. Buttons and POV are mapped to up to 32 joystick button states and the joystick point-of-view hat. The different joystick blocks available in the Aerospace blockset of the Simulink Library are shown in figure.

The pilot input from the joystick block is then segregated into their respective control surface functions to process the signal and direct them. In the current simulation, the vital input were given the first importance and are segregated as shown in figure 7.10. The 4 major inputs signals which control the Aileron, Elevator, rudder and throttle inputs are directed to their respective blocks to be combined with the trim condition coefficients of the aircraft.

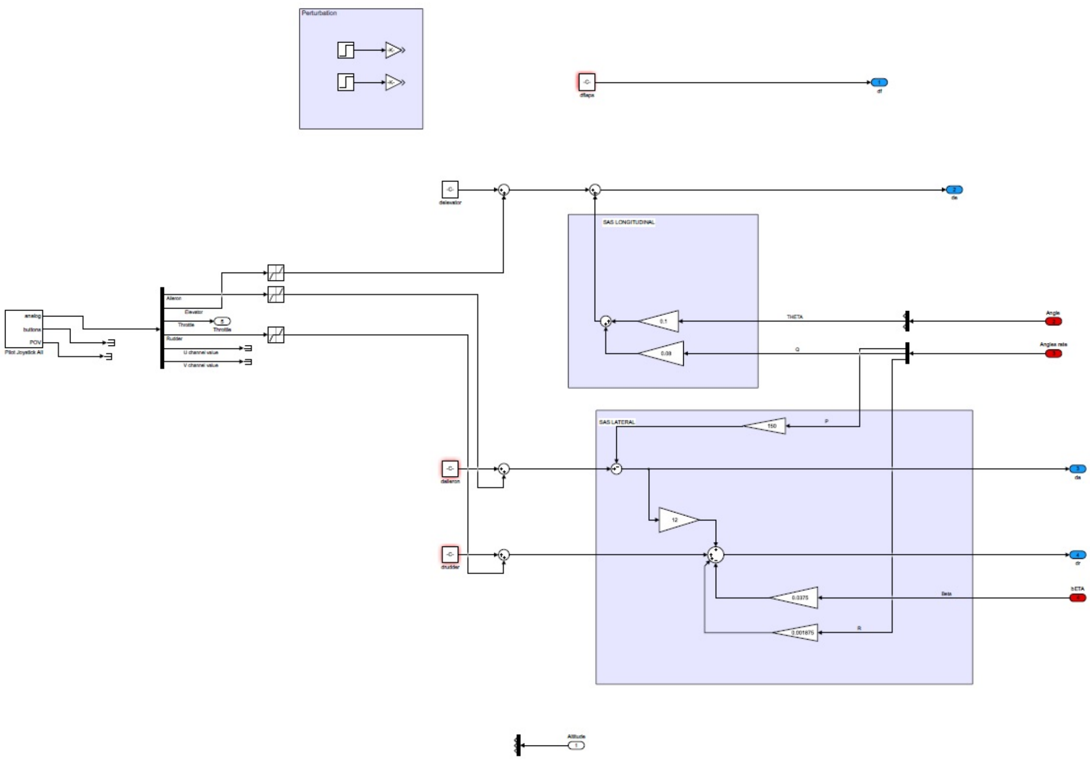


Figure 7.9: Saab 340 Joystick input data track

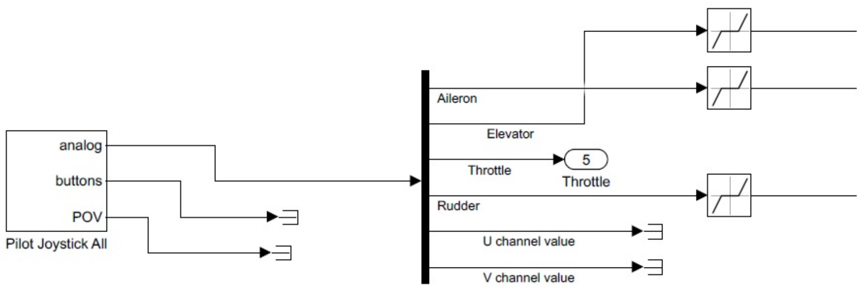


Figure 7.10: Saab 340 Joystick input data configuration

7.3.1 Verification of control inputs

The inputs from the joystick had to verified before being added to the trim conditions as inputs. The Scope function available in the Simulink library was used to visualise by plotting the input signals from the joystick movements for a duration of about 20 seconds. The signals were visualised by dividing the input into 4 basic movements of aileron, elevator, rudder and throttle. The limits of the signal are same for the control surface inputs whose range is from 1 to -1 as depicted in the figures 7.11, 7.12, 7.13 respectively. But the signal does not go to a negative value in case of throttle and must be limited between 0 indicating minimum throttle position and 1 indicating the maximum position as shown in figure 7.14. The joystick which was intended to be used was the Saitek Flight Yoke system available at Cranfield University but could not be accessed due to the COVID 19 Pandemic. Instead, Speedlink Phantom Hawk Flight Stick with a rotatable z-axis for yaw inputs was used which is shown in figure 7.15.

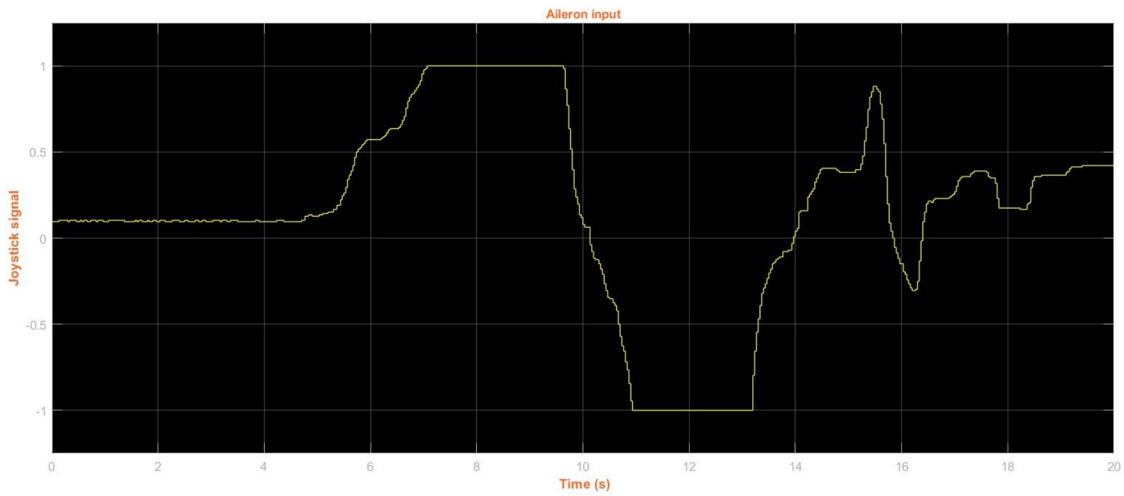


Figure 7.11: Joystick input for Aileron operation

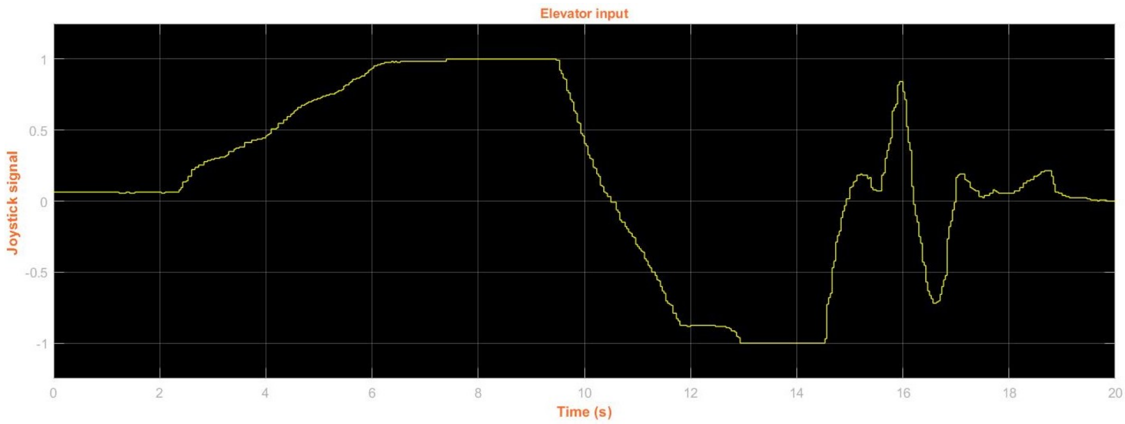


Figure 7.12: Joystick input for Elevator operation

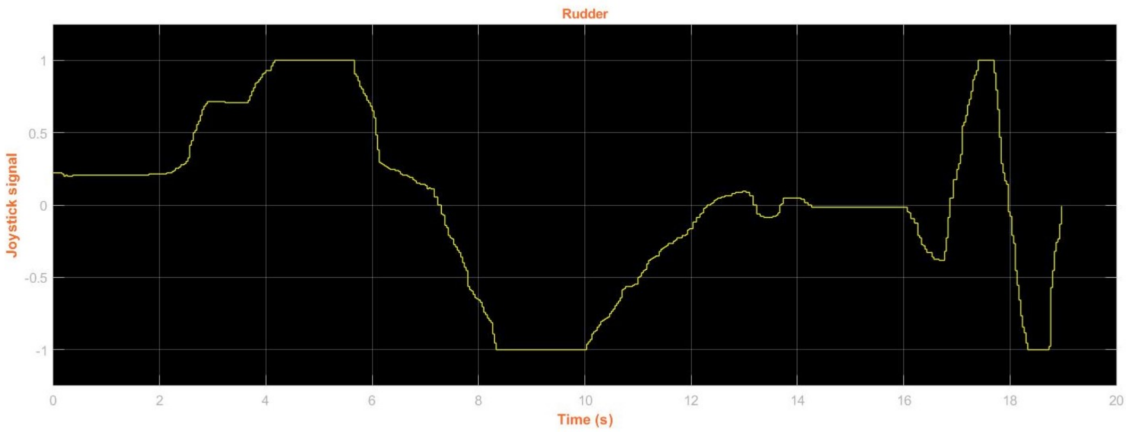


Figure 7.13: Joystick input for Rudder operation

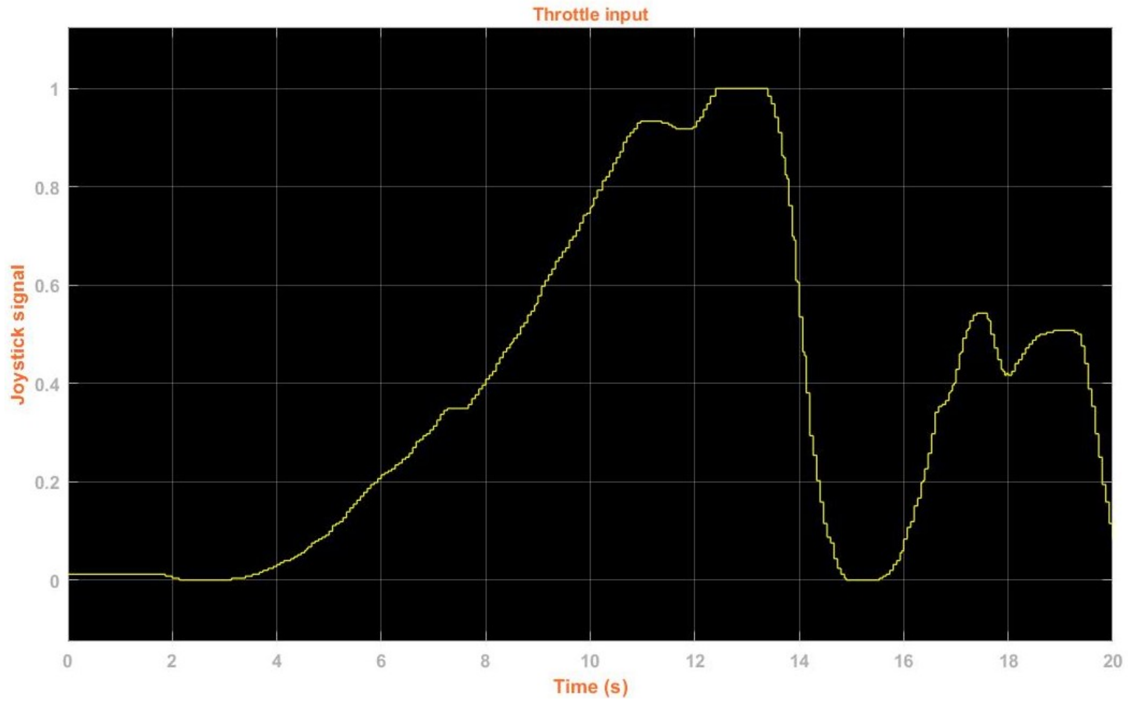


Figure 7.14: Joystick input for Throttle operation

Figure 7.15: Speedlink Phantom Hawk Flight Stick

Chapter 8

Visualisation of Saab340 using FlightGear flight simulator

8.1 Simulation library

The simulation library consists of a set of files which define the aircraft environment and the flight dynamics model (FDM) developed using Simulink and Matlab. Flight Gear must be started with appropriate command line arguments to interact with the FDM model. This file is a windows batch file with an extension .bat which is created using the Generate run script block available in the Aerospace blockset of Simulink library []. The arguments generated consists of geometry model name, Airport ID, Runway ID, initial altitude (ft), initial heading (deg), offset distance (miles) and azimuth (deg). The destination port number can be specified with the respective IP address to establish the communication channel between the two. The file created for the current simulation is as shown in the Appendix A.5.

8.1.1 FlightGear axis system

It becomes very important to understand the co-ordinate axis systems used on the flight simulator to model objects and create different views in the simulation. User will need some knowledge of FlightGear's property system and XML markup. The points mentioned below are the most important to model any geometry or views in FligthGear and can be understood with the help of figure 8.1. There are many similar attributes used in the XML code which are interchangeable to either define a geometry or a view position in the simulation.

- Distances are in metres.
- Angles are in degrees.
- The x-axis runs lengthwise, towards the back.
- The y-axis runs sideways, towards the right.
- The z-axis runs upwards.
- Roll is a rotation around the x-axis, where positive is clockwise viewed towards the back.
- Pitch is a rotation around the y-axis, where positive is clockwise viewed towards the right.
- Heading is a rotation around the z-axis, where positive is clockwise.

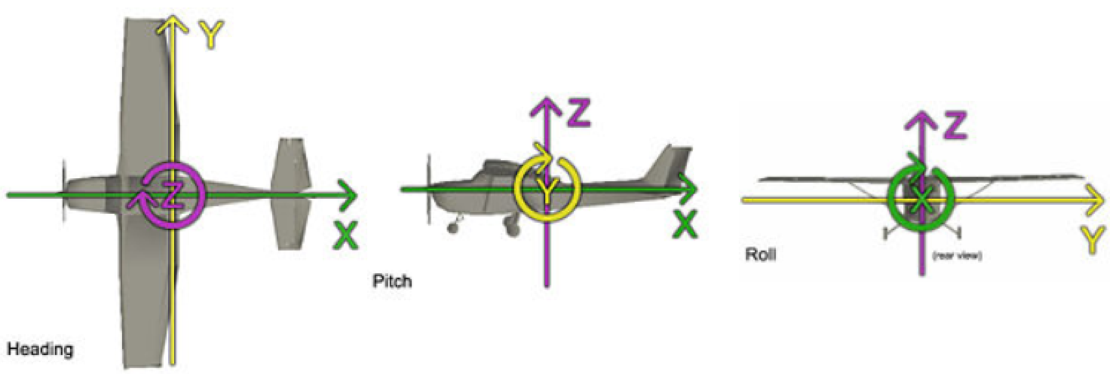


Figure 8.1: FlightGear axis system

8.2 Camera view points

The camera views define the view point of the person who is using the simulator. It becomes very important to define the views which help the pilot or the passenger visualise their position in the aircraft clearly. There are many attributes which help in creating real life like visuals when used appropriately. The position of cockpit instruments and passenger instruments also play a major role in defining the view point and its field of view (FOV). For this particular simulation, seven different view points were created as listed below:

- Tail camera - camera looking forward from the tail of the aircraft as shown in Figure 8.2.

Figure 8.2: Tail camera view

- Model view PS - Camera positioned on the port side (left) of the aircraft as shown in Figure 8.3.

Figure 8.3: Port side camera view

- Model view SB - Camera positioned on the starboard side (right) of the aircraft as shown in Figure 8.4.

Figure 8.4: Starboard side camera view

- Cockpit - Camera positioned at the entrance to the cockpit to simulate a full cockpit view as shown in Figure 8.5.

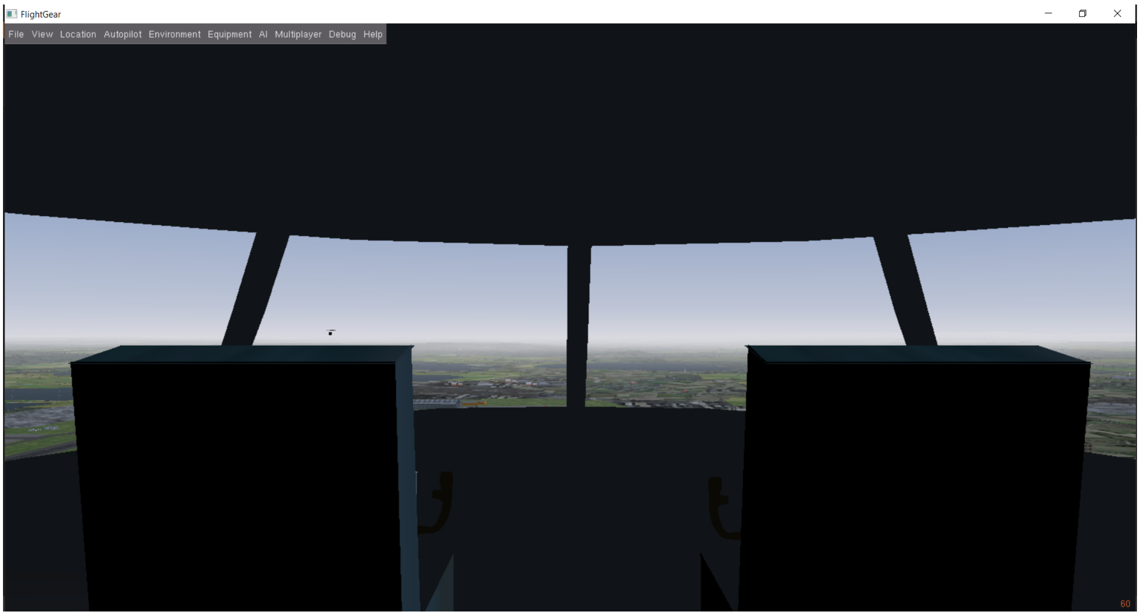


Figure 8.5: cockpit camera view

- Pilot view - Camera positioned at the eye sight height of the pilot with a slightly downward azimuth as shown in Figure 8.6.

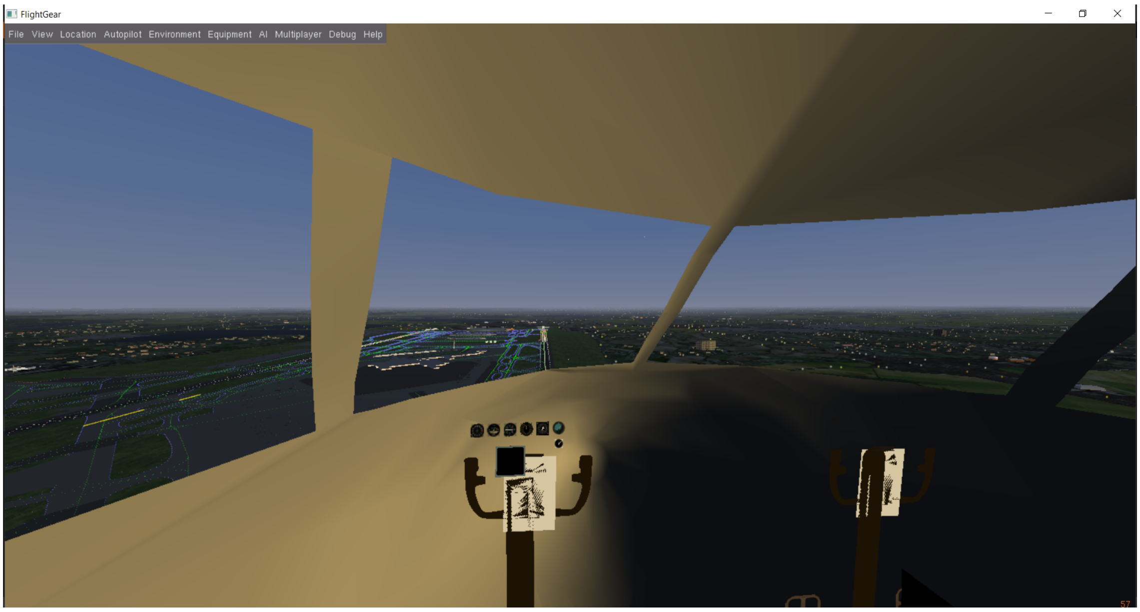


Figure 8.6: Pilot camera view

- Passenger view - Camera positioned at one of the passenger seats looking ahead to have a view of the passenger instruments installed on the back of the seat in front of the passenger as shown in Figure 8.7.

Figure 8.7: Passenger camera view

- Aisle view - Full view of the aisle of the aircraft as shown in Figure 8.8.

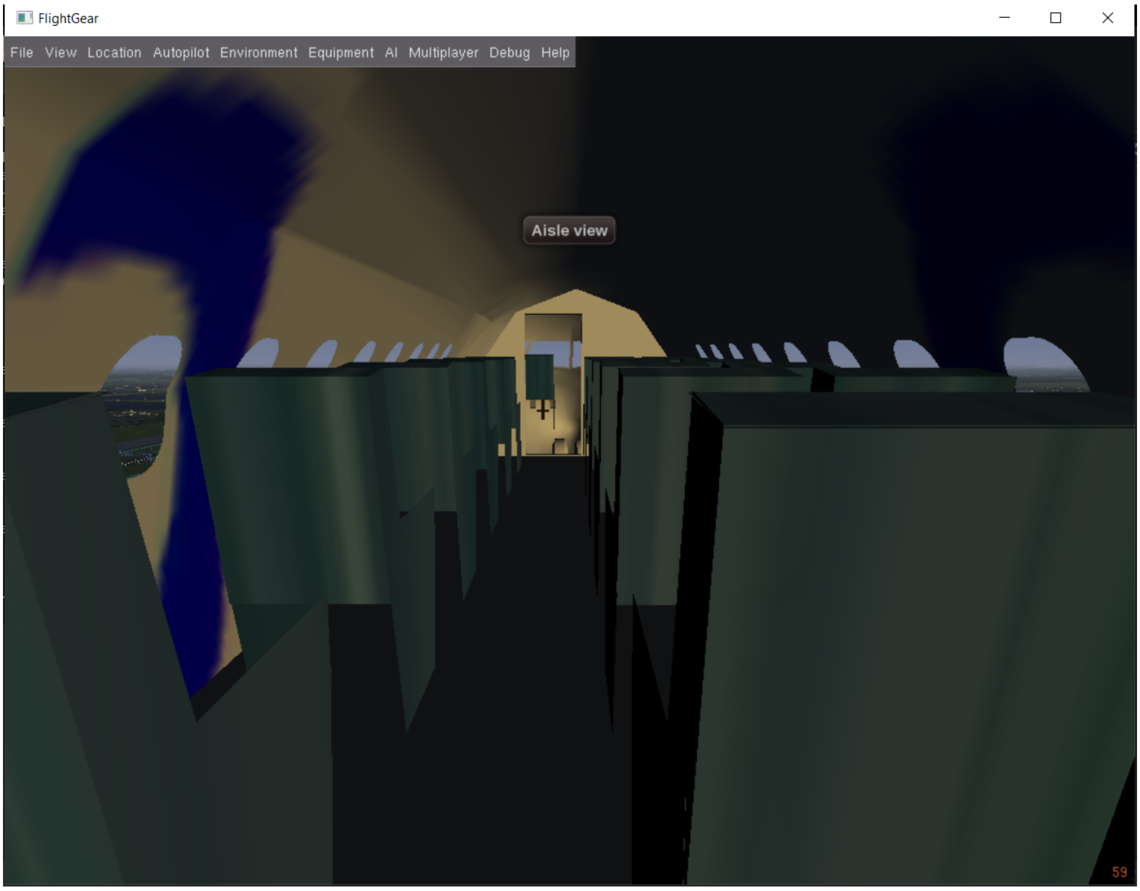


Figure 8.8: cabin aisle camera view

These views are created by defining the various attributes of the camera in the file S340b-set.XML which can be found in the appendix A.2.

8.3 HELP menu

The role of the help menu in the simulation is to provide information related to various phase of flight. It can be used to provide instruction to the user of the simulator in the form of checklists and sequences to perform a particular operation on the aircraft. For the purpose of this simulation, prominent flight speeds have been mentioned in the help menu. The help menu is as shown in figure 8.9. The definition of the help menu should be done in the file S340b-set.XML. This can be found in the Appendix A.2.

Figure 8.9: Help menu as seen on the simulation

8.4 Instrumentation

The instrumentation is related to setting up the various instruments in the cockpit and the passenger cabin to provide vital flight data such as airspeed, altitude and heading. The instruments majorly consist of air-data instruments, radar instruments, flight data display units, etc. This aircraft is configured to serve a special purpose and is fitted with extra instruments. The purpose is to provide flight testing experience to students who will be recording real time flight data while the pilot is performing various manoeuvres. The data recorded will be used in further calculations to determine the performance of the aircraft from various aspects. To fulfil the need, extra instruments need to be provided to passengers. This is being done by accommodating a digital tablet display on the back side of every seat. For the purpose of this simulation, multiple instruments have been positioned in a similar fashion and can be seen in the passenger camera view [figure 8.7].

8.4.1 Data for the instruments

The data from the FDM is first imported into the FlightGear environment and then should be assigned to each and every instrument using the internal properties of the simulation. This can be found under the Debug menu in the simulation window. The list of available systems on this aircraft can be found under the /systems tab.

8.4.2 Instruments for cockpit display & passenger display

The list of instruments included in this simulation are as listed below:

- Airspeed indicator
- Attitude indicator
- Altimeter
- Artificial horizon
- Climb indicator
- Roll and yaw indicator
- Digital flight data management unit

The data to these instruments should be sent by assigning them to the particular property type from the property list available on FlightGear. The property list can be found in the internal properties tab in the simulation debug menu. The list consists of all the properties of the systems running on the aircraft, the velocity data, position data,etc,. In order to send the airspeed data to the airspeed indicator, the ”airspeed-kt” property must be used in the property attributes of that instrument [figure 8.11]. In a similar way, the properties required by other instruments are shown in figures 8.10, 8.12,8.13.

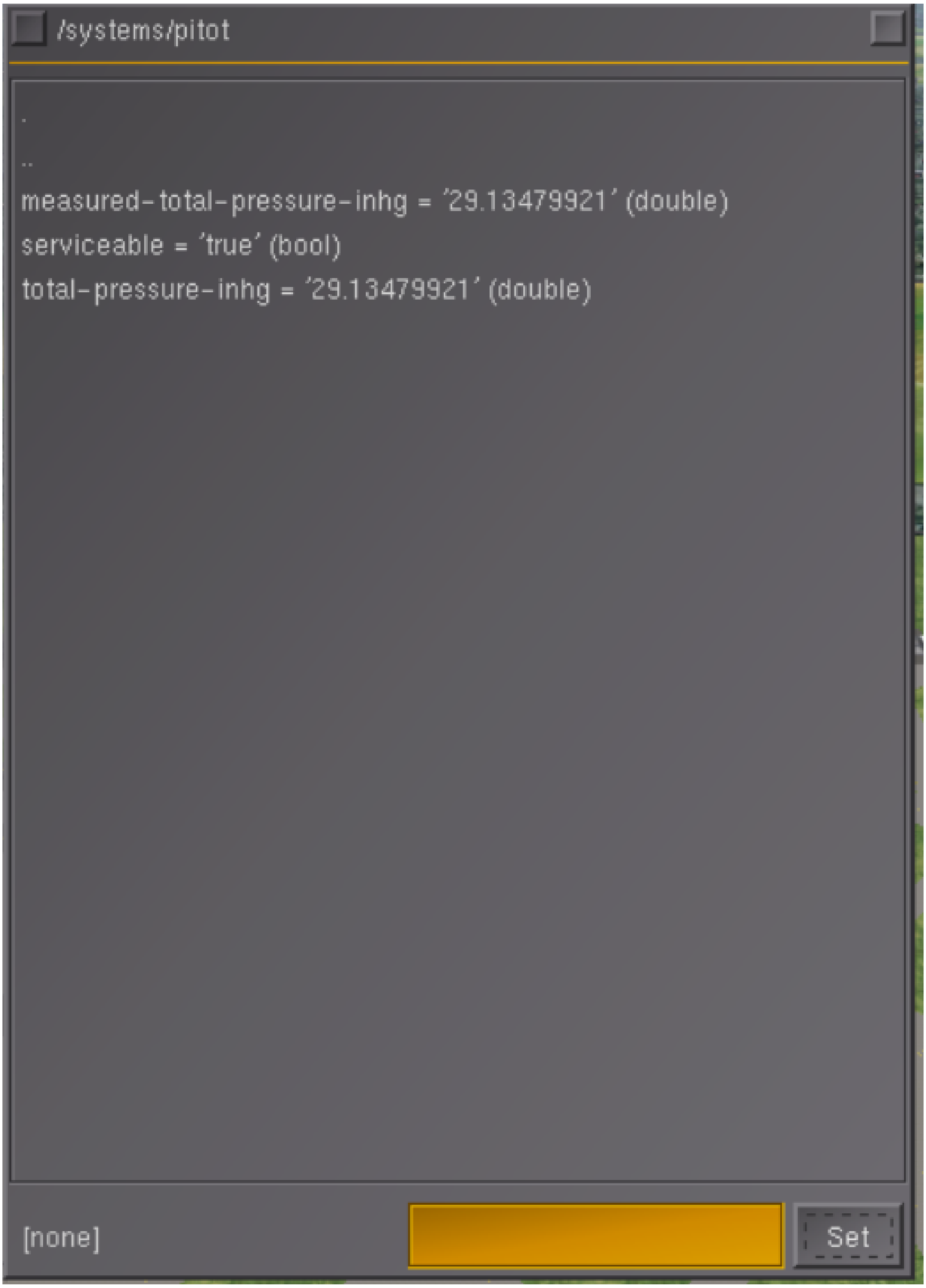


Figure 8.10: Pitot tube system properties

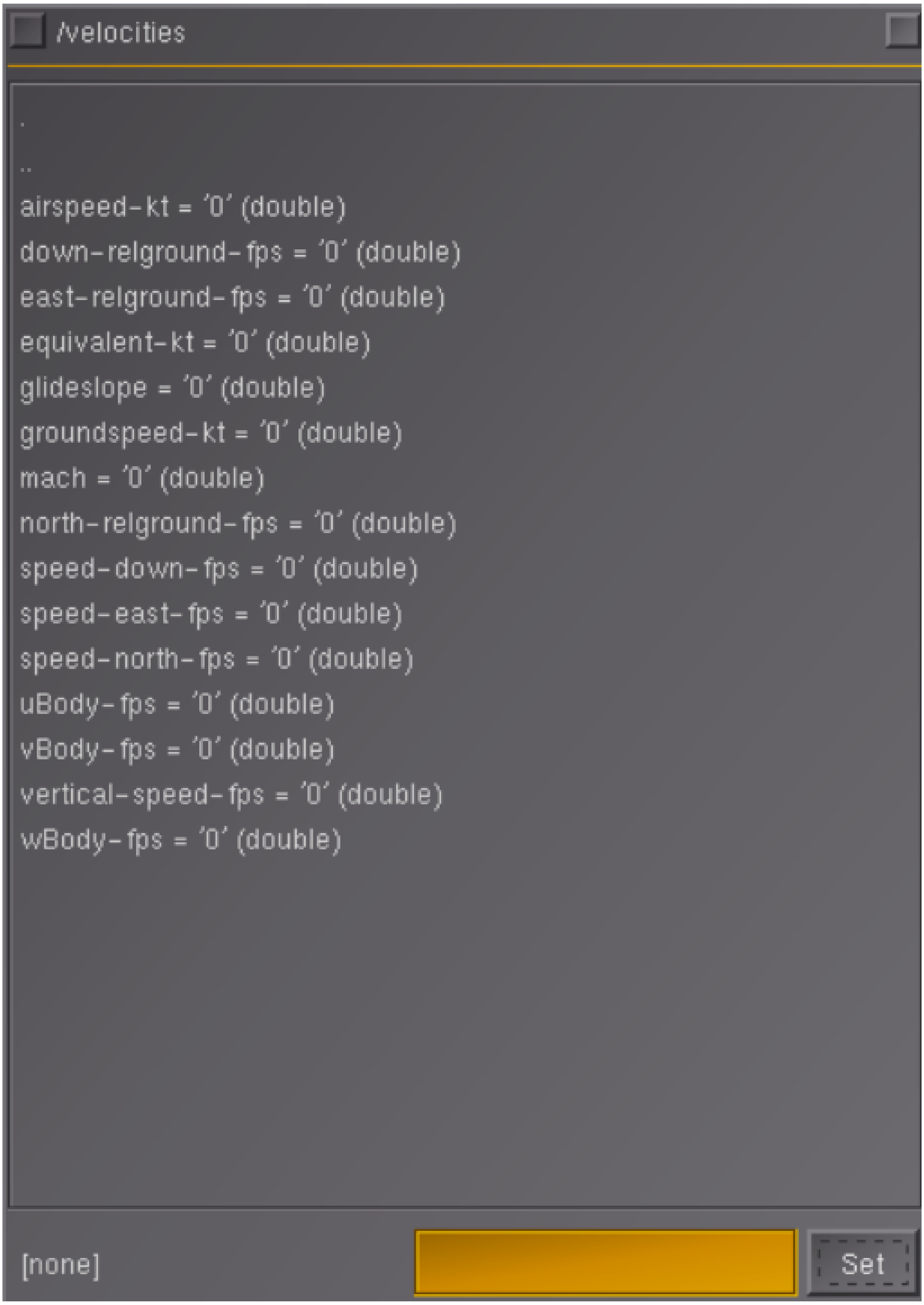


Figure 8.11: Velocity data properties

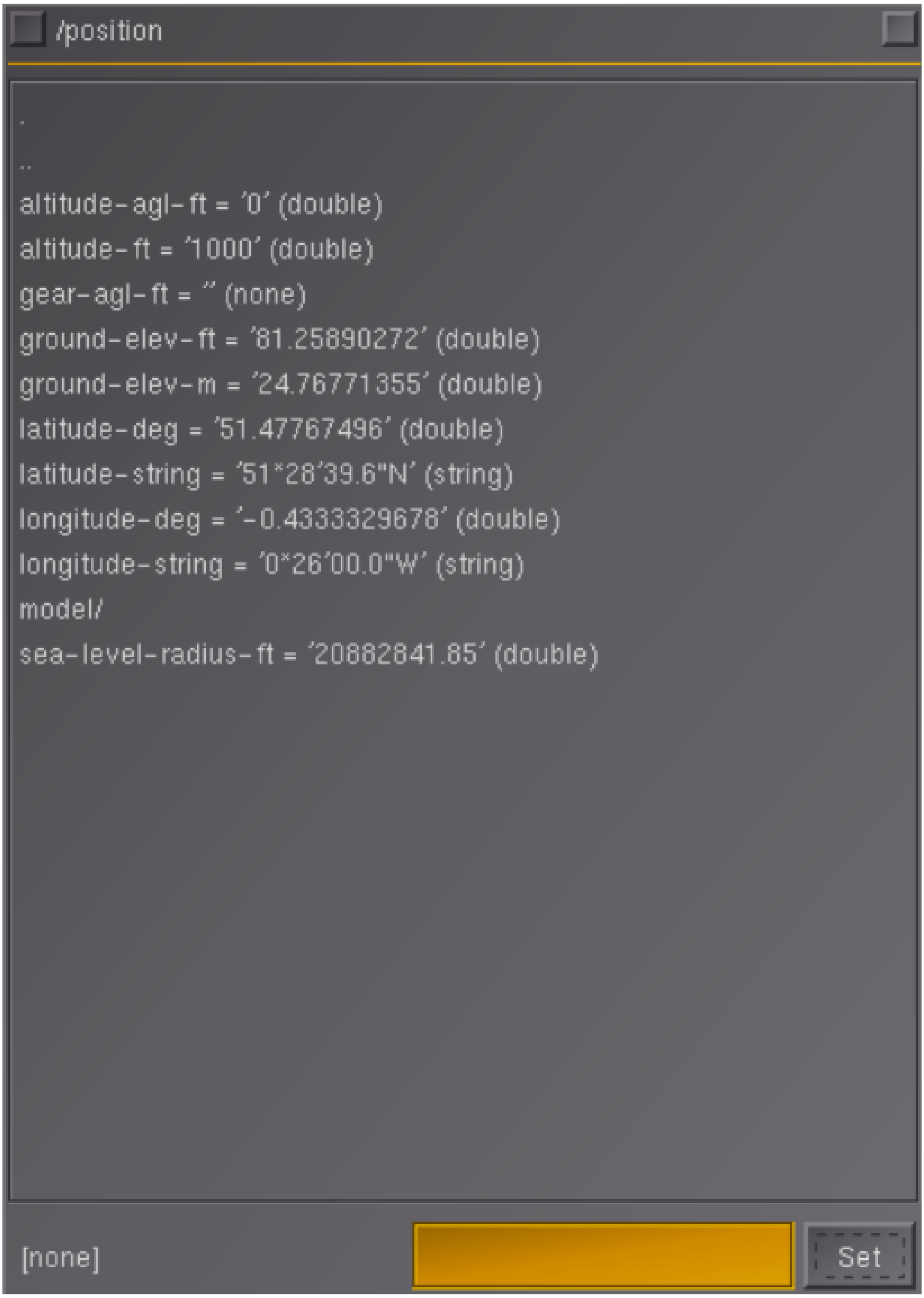


Figure 8.12: Position data properties

Figure 8.13: Static pressure port data properties

8.5 Systems

The FlightGear flight simulator has the capability to apply various systems onto the aircraft in operation. For the case of this simulation three basic systems were put to use. The Pitot system, Static pressure port system and the vacuum system. Full realisation of these system requires development of complete powerplant system because many of the properties are interdependent. The definition of the systems must be done in a separate script file ”Systems.XML”. The path to this file should then be defined in the ”Saab340-set.XML” script under the system attribute. These systems help in generating data which are vital to the instruments used on-board the aircraft. The script of the systems file can be found in the Appendix A.4.

8.6 Cockpit configuration

The cockpit of the Saab340 is a 2 seat configuration. The cockpit has four large windscreens for a better visibility. The flight control is done using yoke for roll & pitch, foot pedals for yawing the aircraft and also for nose wheel operation on ground. These are the controls which are defined in this simulation. The movement of the controls are mapped to the joystick to simulate appropriate control column motion and pedal movement. The controls of the aircraft can be visualised in figure 8.6.

8.7 Saab340B Simulation File structure

The main file of the aircraft is the S340b file which need to present in the Aircraft folder of the installation location of FlightGear. The S340b folder contains four folders and 3 files as listed below:

- Liveries folder: Contains the images of the paint job which are assigned to different parts of the aircraft. These are defined in the Liveries attribute section of the S340b.XML file in the models folder.

- Models folder: Contains the Cockpit definition folder, instruments definition folder, S340b.XML file and the S340b aircraft geometry file in AC3D format.

- Previews folder: contains images which need to be displayed during the boot-up of the simulation. These help to provide a big picture idea of the simulation to the user before hand.

- XMLs folder: Contains the XML files which are used to defined functions and attributes of various parts in the geometry assembly.

- instrumentation.XML

- S340b-set.XML

- systems.XML

8.8 Creation of animations

The simulation can be brought to life with the development of full scale animations of each and every moving part in the aircraft. The animations can be mapped to the basic flight control signals. The FlightGear flight simulator allows to animate models in response to property changes: for example, the propellers can spin at various speeds with change in engine RPM and the control surfaces can move up and down with the control inputs. There is no limitation to the number or types of parts which can be animated. The only requirement is that the part has been assigned a name in the geometry file and can be identified by FlightGear. Also, the user must be able to extract a property from the main tree which can be used to get the positioning information. In order to explain the animation function, Rudder control surface has been used as an example.

8.8.1 Object name

These names are set in the 3D model. Each single object has a unique name; for easy identification it is advised to use descriptive names (S340b_Rudder, S340b_prop_PS etc.). Animations are only applied to those objects that are mentioned in an object-name line (one object per line!). Animations lacking those, will be applied to the entire model as described in the FlightGear manual [9].

<object-name >S340b_rudder </object-name >

8.8.2 Property

Each animation must be associated with exactly one property from the main FlightGear property tree, using ¡property¿ to provide the property path as described below:

<property >/surface-positions/rudder-pos-norm </property >

Omission of the leading slash '/' when referring to the property assures that when the model is used for AI or multiplayer traffic the animations will follow that of the AI controller instead of that of the user [9].

8.8.3 Axis

An axis part is required in every animation that involves a rotating or moving thing. The definition of axis can be done in numerous ways. two points can be defined, between which FlightGear will calculate the correct axis. Such coordinates are extremely useful for animating control surfaces (rudder, elevators etc.). This method is shown in the example below: the two points are defined using X,Y,Z co-ordinates which can be obtained from a 3D modelling software similar to the ones used to create the geometry. This method of axis definition makes the use of a <center >tag redundant [9].

<axis >

<x1-m >1075.3 </x1-m >

<y1-m>0 </y1-m >

<z1-m >267.5 </z1-m >

<x2-m >1048.6 </x2-m >

<y2-m >0 </y2-m >

<z2-m >157.0 </z2-m >

</axis >

The axis are similar to the ones of the 3D model. There is a difference between rotation and translation [9] :

- In rotation animations, the axis part defines around what axis the object rotates. Negative/positive values make the difference between counterclockwise and clockwise rotations.

- In translate animations, the part defines along what axis the object moves. If the x-axis is pointing backwards, an x-value of -1 will result in forward motion.

8.8.4 Center

Various animations (rotate, spin, scale) move around a center point. The axis are similar to the ones of the 3D model, so finding coordinates is easily done in 3D modeling software. The Center tag is not used in the current simulation because all the animations are defined using the two point axis definition method. But the definition of center is also done by using the X,Y,Z co-ordinates of the point which can be easily obtained from a 3D modelling software similar to the ones used to create the geometry. For example:

<center >

<x-m >-1.50 </x-m >

<y-m >1 </y-m >

<z-m >0.25 </z-m >

</center >

8.8.5 Animation of the undercarriage

The animation of the undercarriage requires a combination of kinematic movements. The detail in which the landing gear is modelled determines the level of animation which can be imparted to the part. Two major movements can be used to define the landing gear animation in the basic form. They are translation and rotational movements. The landing gear as a complete part should rotate about an axis for deployment and stowage. Based on the complexity of the landing gear geometry, this motion may involve multiple rotating objects to complete the extension and retraction of the landing gear. In the case of Oleo strut landing gear design, translation of the strut on touch down can be modelled to simulate the contraction of the strut due to the weight of the aircraft. Finer details such as relating the length of contraction to the landing weight of the aircraft can also be modelled.
To add to the visual effects of the landing scenario, smoke generation can be created at the point of touch down. For the purpose of this simulation, only rotation of the landing gear for deployment and stowage are created. The details of the animation can be found in S340b.XML file in the appendix A.2.

8.8.6 Animation of the Control surfaces

The animation of the control surfaces provide the most important visual when flying the aircraft from an external view. The control surfaces in this aircraft include the Ailerons on the outboard position of the wing, Elevators on the Horizontal tail-plane and Rudder on the vertical tail-plane. Similar method can be used to build animations to simulate the other prominent flight control surfaces such as the the trim tabs, air brakes, flaps and slats. The flap and slats may involve a combination of translation and rotational motions.

The undercarriage doors are similar in geometry to the control surfaces, therefore, same method can be applied. For the simplicity of the this simulation, the control surfaces are modelled with rotation about an axis which is defined by X,Y,Z co-ordinates. The property related to the control surfaces is used as shown below:

<property >/surface-positions/rudder-pos-norm </property >
<property >/surface-positions/right-aileron-pos-norm </property >
<property >/surface-positions/left-elevator-pos-norm </property >

Complete definition of the control surface animation is included in the file S340b.XML and can be found in the appendix A.2.

Chapter 9

Conclusions & Future Work

9.1 Conclusion

The development of the Saab 340 flight simulator was done to create a platform to simulate and predict the real-life behaviour of the aircraft. While no formal validation of the simulation environment was performed, informal comparison of the handling qualities of the aircraft and simulated data have shown that the Flight dynamics model and the Simulation accurately predict the behaviour of the aircraft in the current form of the model. Several flight tests produced results that, initially appeared to contradict the simulated behaviour. After corrections to the initial conditions to the Flight dynamics model and the simulator, the simulator behaved in a manner similar to behaviour observed in normal flights of the aircraft. Once the problem was corrected in the simulator, the problem was also corrected in the flight. This was observed several times during the development of the simulator.

The combination of FlightGear and Matlab/Simulink provide a solid base for building the simulation environment. Problems found during the development were easily corrected, typically by consulting the source code and the FlightGear manual. Development of the 3D model took most of the effort, primarily in the measurement and validation of accuracy of the aircraft geometry. Also, a major part of the effort was put in integration with the Simulink FDM and visualising the aircraft model in FligthGear environment.

9.2 Future work

This is the first effort at the development of a simulation environment for Saab340 aircraft at Cranfield University. This project aimed at developing a basic form of the simulator. There is a large scope of future work which can be carried out in order to bring this project to maturity. The development of the simulation environment should go hand-in-hand with the development of the FDM. The addition of systems into the FDM can aid the development of many functions in the simulator. The possible work which can be carried out on the simulator is listed below:

- Integration of the movement of the control surfaces to the deflection inputs from the FDM.

- Development of the animations of the undercarriage by incorporating combination of kinematic movements in the deployment and stowage actions.

- Development of definition in 3D geometry and detailed animations of flaps, slats and trim tabs.

- Detailed development of cockpit environment with interactive switches and display units.

- Detailed development of the aircraft powerplant by integrating the throttle with sound of the engine and propeller RPM.

- Development of handling qualities of the aircraft to observe the effects of change in Center of gravity while performing manoeuvres.

- Development of the interiors of the aircraft to simulate the add-on data instruments present on G-NFLB.

- Integration of the simulator of the large scale flight simulator facility available at Aerospace Integration Research Centre (AIRC), Cranfield University.
- Detailed development of the aircraft livery.

Appendix A

Simulation environment files

A.1 S340b.xml

The script of the XML file S340b.XML is described in the pictures A.1, A.2,A.3,A.4, A.5,A.6.

S340b.xml 18/04/2021

```
<?xml version="1.0"?>
<!--
**************************************************************************
 Flight Gear config file for CRANFIELD UNIVERSITY SAAB340 simulation

 D. Shashidhara
 2021-JAN-10
**************************************************************************
-->

<PropertyList>

<path>S340b.ac</path>
<model>
        <name>Flightdeck</name>
        <path>Aircraft/S340b/Models/Cockpit/cockpit.xml</path>
        <offsets>
                <x-m>0.000</x-m>
                <y-m>0.000</y-m>
                <z-m>0.000</z-m>
        </offsets>
</model>

<!-- ANIMATIONS -->

<!--NOSE LANDING GEAR-->

<animation>
  <type>rotate</type>
  <object-name>S340b_NLG</object-name>
  <property>gear/gear[0]/position-norm</property>
  <factor>0</factor>
  <offset-deg>100</offset-deg>
        <axis>
                <x>0</x>
                <y>1</y>
                <z>0</z>
        </axis>
        <center>
                <x-m>137.0</x-m>
                <y-m>0.0</y-m>
                <z-m>-20.0</z-m>
        </center>
</animation>

<!--MAIN LANDING GEAR-->

<animation>
  <type>rotate</type>
  <object-name>S340b_MLG_SB</object-name>
  <property>gear/gear[1]/position-norm</property>
  <factor>0</factor>
  <offset-deg>100</offset-deg>
        <axis>
                <x>0</x>
                <y>1</y>
                <z>0</z>
        </axis>
        <center>
                <x-m>539.5</x-m>
                <y-m>0</y-m>
                <z-m>-33.3</z-m>
        </center>
</animation>

<animation>
  <type>rotate</type>
  <object-name>S340b_MLG_PS</object-name>
```

1

Figure A.1: S340b.XML page1

S340b.xml 18/04/2021

```
  <property>gear/gear[2]/position-norm</property>
  <factor>0</factor>
  <offset-deg>100</offset-deg>
        <axis>
                <x></x>
                <y>1</y>
                <z>0</z>
        </axis>
        <center>
                <x-m>539.5</x-m>
                <y-m>0</y-m>
                <z-m>-33.3</z-m>
        </center>
 </animation>

   <!--CONTROL SURFACES-->

    <animation>
     <type>rotate</type>
     <object-name>S340b_rudder</object-name>
     <property>/surface-positions/rudder-pos-norm</property>
     <factor>0</factor>
     <offset-deg>0</offset-deg>
        <axis>
                <x1-m>1075.3</x1-m>
                <y1-m>0</y1-m>
                <z1-m>267.5</z1-m>
                <x2-m>1048.6</x2-m>
                <y2-m>0</y2-m>
                <z2-m>157.0</z2-m>
        </axis>
    </animation>

    <animation>
     <type>rotate</type>
     <object-name>S340b_aileron_SB</object-name>
     <property>/surface-positions/right-aileron-pos-norm</property>
     <factor>30</factor>
     <offset-deg>0</offset-deg>
        <axis>
                <x1-m>560.8</x1-m>
                <y1-m>477.0</y1-m>
                <z1-m>20.0</z1-m>
                <x2-m>559.5</x2-m>
                <y2-m>608.2</y2-m>
                <z2-m>32.9</z2-m>

        </axis>
    </animation>

    <animation>
     <type>rotate</type>
     <object-name>S340b_aileron_PS</object-name>
     <property>/surface-positions/left-aileron-pos-norm</property>
     <factor>30</factor>
     <offset-deg>0</offset-deg>
        <axis>
                <x1-m>560.8</x1-m>
                <y1-m>-477.0</y1-m>
                <z1-m>19.8</z1-m>
                <x2-m>559.5</x2-m>
                <y2-m>-608.2</y2-m>
                <z2-m>32.9</z2-m>
        </axis>
    </animation>

     <animation>
      <type>rotate</type>
```

2

Figure A.2: S340b.XML page2

S340b.xml 18/04/2021


```
      <object-name>S340b_elevator_SB</object-name>
      <property>/surface-positions/left-elevator-pos-norm</property>
      <factor>30</factor>
      <offset-deg>0</offset-deg>
        <axis>
                <x1-m>1041.0</x1-m>
                <y1-m>65.4</y1-m>
                <z1-m>57.0</z1-m>
                <x2-m>1057.0</x2-m>
                <y2-m>261.4</y2-m>
                <z2-m>100.4</z2-m>
        </axis>
    </animation>

     <animation>
      <type>rotate</type>
      <object-name>S340b elevator PS</object-name>
      <property>/surface-positions/left-elevator-pos-norm</property>
      <factor>30</factor>
      <offset-deg>0</offset-deg>
        <axis>
                <x1-m>1041.0</x1-m>
                <y1-m>-65.4</y1-m>
                <z1-m>57.0</z1-m>
                <x2-m>1060.3</x2-m>
                <y2-m>-213.2</y2-m>
                <z2-m>100.4</z2-m>
        </axis>
 </animation>

 <!--COCKPIT INSTRUMENTS-->

 <model>
         <name>Pilot Alt</name>
         <path>Aircraft/S340b/Models/Instruments/alt/alt.xml</path>
         <offsets>
             <x-m>118.00</x-m>
             <y-m>-15.0</y-m>
             <z-m>59.2</z-m>
             <pitch-deg>-15.0</pitch-deg>
             <heading-deg>0</heading-deg>
         </offsets>
     </model>

 <model>
        <name>Pilot asi</name>
        <path>Aircraft/S340b/Models/Instruments/asi300/asi300-3d.xml</path>
         <offsets>
             <x-m>118.0</x-m>
             <y-m>-15.1</y-m>
             <z-m>59.2</z-m>
             <pitch-deg>-15.0</pitch-deg>
             <heading-deg>0</heading-deg>
         </offsets>
     </model>

 <model>
        <name>Pilot vsi</name>
        <path>Aircraft/S340b/Models/Instruments/vsi/vsi.xml</path>
         <offsets>
             <x-m>118.0</x-m>
             <y-m>-15.2</y-m>
             <z-m>59.2</z-m>
             <pitch-deg>-15.0</pitch-deg>
             <heading-deg>0</heading-deg>
         </offsets>
     </model>
```


3

Figure A.3: S340b.XML page3

S340b.xml 18/04/2021

```
 <model>
        <name>Pilot turn-indicator</name>
        <path>Aircraft/S340b/Models/Instruments/tc/tc.xml</path>
         <offsets>
             <x-m>118.0</x-m>
             <y-m>-15.3</y-m>
             <z-m>59.2</z-m>
             <pitch-deg>-15.0</pitch-deg>
             <heading-deg>0</heading-deg>
         </offsets>
     </model>

<model>
        <name>Pilot heading indicator</name>
        <path>Aircraft/S340b/Models/Instruments/hi/hi.xml</path>
         <offsets>
             <x-m>118.0</x-m>
             <y-m>-15.4</y-m>
             <z-m>59.2</z-m>
             <pitch-deg>-15.0</pitch-deg>
             <heading-deg>0</heading-deg>
         </offsets>
     </model>

<model>
        <name>Pilot AI</name>
        <path>Aircraft/S340b/Models/Instruments/ai/ai.xml</path>
         <offsets>
             <x-m>118.0</x-m>
             <y-m>-14.9</y-m>
             <z-m>59.2</z-m>
             <pitch-deg>-15.0</pitch-deg>
             <heading-deg>0</heading-deg>
         </offsets>
     </model>

<model>
        <name>Pilot clock</name>
        <path>Aircraft/S340b/Models/Instruments/clock/clock.xml</path>
         <offsets>
             <x-m>118.0</x-m>
             <y-m>-14.9</y-m>
             <z-m>59.1</z-m>
             <pitch-deg>-15.0</pitch-deg>
             <heading-deg>0</heading-deg>
         </offsets>
     </model>

<model>
        <path>Aircraft/S340b/Models/Instruments/MFD/MFD.xml</path>
         <offsets>
             <x-m>118.0</x-m>
             <y-m>-15.2</y-m>
             <z-m>59.0</z-m>
        <pitch-deg>-15.0</pitch-deg>
        <heading-deg>0</heading-deg>
        </offsets>
     </model>

<model>
        <name>Pilot pfd</name>
        <path>Aircraft/S340b/Models/Instruments/pfd/pfd.xml</path>
         <offsets>
             <x-m>118.0</x-m>
             <y-m>-15.0</y-m>
             <z-m>59.0</z-m>
             <pitch-deg>-15.0</pitch-deg>
             <heading-deg>0</heading-deg>
```

4

Figure A.4: S340b.XML page4

S340b.xml 18/04/2021

```
        </offsets>
    </model>

 <!--PAX INSTRUMENTS-->

<model>
        <path>Aircraft/S340b/Models/Instruments/ai/ai.xml</path>
         <offsets>
             <x-m>479.5</x-m>
             <y-m>14.85</y-m>
             <z-m>59.88</z-m>
             <pitch-deg>-15</pitch-deg>
             <heading-deg>0</heading-deg>
         </offsets>
    </model>

 <model>
         <path>Aircraft/S340b/Models/Instruments/alt/alt.xml</path>
         <offsets>
             <x-m>479.5</x-m>
             <y-m>14.95</y-m>
             <z-m>59.88</z-m>
             <pitch-deg>-15</pitch-deg>
             <heading-deg>0</heading-deg>
         </offsets>
    </model>

 <model>
        <path>Aircraft/S340b/Models/Instruments/asi300/asi300-3d.xml</path>
         <offsets>
             <x-m>479.5</x-m>
             <y-m>15.05</y-m>
             <z-m>59.88</z-m>
             <pitch-deg>-15</pitch-deg>
             <heading-deg>0</heading-deg>
         </offsets>
    </model>

 <model>
        <path>Aircraft/S340b/Models/Instruments/tc/tc.xml</path>
         <offsets>
             <x-m>479.5</x-m>
             <y-m>14.85</y-m>
             <z-m>59.78</z-m>
             <pitch-deg>0</pitch-deg>
             <heading-deg>0</heading-deg>
         </offsets>
    </model>

 <model>
        <path>Aircraft/S340b/Models/Instruments/vsi/vsi.xml</path>
         <offsets>
             <x-m>479.5</x-m>
             <y-m>14.95</y-m>
             <z-m>59.78</z-m>
             <pitch-deg>-15</pitch-deg>
             <heading-deg>0</heading-deg>
         </offsets>
    </model>

<model>
        <path>Aircraft/S340b/Models/Instruments/hi/hi.xml</path>
         <offsets>
             <x-m>479.5</x-m>
             <y-m>15.05</y-m>
             <z-m>59.78</z-m>
             <pitch-deg>-15</pitch-deg>
             <heading-deg>0</heading-deg>
```

5

Figure A.5: S340b.XML page5

```
S340b.xml                                                      18/04/2021

        </offsets>
    </model>

</PropertyList>
```

Figure A.6: S340b.XML page6

A.2 S340b-set.xml

The script of the XML file S340b-set.XML is described in the pictures A.7, A.8, A.9.

```
S340b-set.xml                                                              18/04/2021

<?xml version="1.0"?>
<!--
**********************************************************************
 Flight Gear config file for CRANFIELD UNIVERSITY SAAB340 simulation

 D. Shashidhara
 2021-JAN-10
**********************************************************************
-->

<PropertyList>

 <sim>
  <description>Cranfield University SAAB340 simulation</description>

  <flight-model>external</flight-model>

  <startup>
    <splash-texture>Aircraft\S340b\Previews\saab340_1.jpg</splash-texture>
    <splash-title><font color="#F0FFFF">Cranfield University SAAB340
    simulation</font></splash-title>
  </startup>

  <systems>
  <path>Aircraft/S340b/systems.xml</path>
  </systems>

  <model>
      <path>Aircraft/S340b/Models/S340b.xml</path>
  </model>

  <!--CAMERA SETTINGS-->

        <view n="0">
            <internal archive="y">true</internal>
            <name>Nose Camera</name>
            <config>
                <x-offset-m archive="y">0.0</x-offset-m>
                <y-offset-m archive="y">90.0</y-offset-m>
                <z-offset-m archive="y">0.0</z-offset-m>
                <pitch-offset-deg>-20</pitch-offset-deg>
                <heading-offset-deg>0</heading-offset-deg>
                <default-field-of-view-deg type="double">60</default-field-
                of-view-deg>
            </config>
        </view>

        <view n="100">
          <name>Tail Camera</name>
          <type>lookfrom</type>
          <internal archive="y">true</internal>
          <config>
            <from-model type="bool">true</from-model>
            <from-model-idx type="int">0</from-model-idx>
            <default-field-of-view-deg type="double">100</default-field-of-
            view-deg>
            <pitch-offset-deg>-30</pitch-offset-deg>
            <heading-offset-deg>0</heading-offset-deg>
            <x-offset-m archive="y">0.0</x-offset-m>
            <y-offset-m archive="y">300.0</y-offset-m>
            <z-offset-m archive="y">1500.0</z-offset-m>
          </config>
        </view>
        <chase-distance-m>-7</chase-distance-m>

        <view>
          <name>Model view-PS</name>
          <type>lookfrom</type>
```

Figure A.7: S340b-set.XML page1

S340b-set.xml 18/04/2021


```
        <internal archive="y">true</internal>
        <config>
          <from-model type="bool">true</from-model>
          <from-model-idx type="int">0</from-model-idx>
          <default-field-of-view-deg type="double">100</default-field-of-
          view-deg>
          <pitch-offset-deg>-30</pitch-offset-deg>
          <heading-offset-deg>-90</heading-offset-deg>
          <x-offset-m archive="y">-1500.0</x-offset-m>
          <y-offset-m archive="y">500.0</y-offset-m>
          <z-offset-m archive="y">-500.0</z-offset-m>
        </config>
      </view>

      <view>
        <name>Model view-SB</name>
        <type>lookfrom</type>
        <internal archive="y">true</internal>
        <config>
          <from-model type="bool">true</from-model>
          <from-model-idx type="int">0</from-model-idx>
          <default-field-of-view-deg type="double">100</default-field-of-
          view-deg>
          <pitch-offset-deg>-30</pitch-offset-deg>
          <heading-offset-deg>90</heading-offset-deg>
          <x-offset-m archive="y">1500.0</x-offset-m>
          <y-offset-m archive="y">500.0</y-offset-m>
          <z-offset-m archive="y">-500.0</z-offset-m>
        </config>
      </view>

       <view>
         <name>Cockpit</name>
         <type>lookfrom</type>
         <internal archive="y">true</internal>
         <config>
           <from-model type="bool">true</from-model>
           <from-model-idx type="int">0</from-model-idx>
           <default-field-of-view-deg type="double">60</default-field-of-
           view-deg>
           <pitch-offset-deg>0</pitch-offset-deg>
           <heading-offset-deg>0</heading-offset-deg>
           <x-offset-m type="double">0.0</x-offset-m>
           <y-offset-m type="double">60.0</y-offset-m>
           <z-offset-m type="double">180.0</z-offset-m>
         </config>
       </view>

       <view>
         <name>Pilot view</name>
         <type>lookfrom</type>
         <internal archive="y">true</internal>
         <config>
           <from-model type="bool">true</from-model>
           <from-model-idx type="int">0</from-model-idx>
           <default-field-of-view-deg type="double">60</default-field-of-
           view-deg>
           <pitch-offset-deg>-10</pitch-offset-deg>
           <heading-offset-deg>0</heading-offset-deg>
           <x-offset-m type="double">-15.0</x-offset-m>
           <y-offset-m type="double">60.0</y-offset-m>
           <z-offset-m type="double">120.0</z-offset-m>
         </config>
       </view>

       <view>
         <name>Passenger view</name>
         <type>lookfrom</type>
```


2

Figure A.8: S340b-set.XML page2

S340b-set.xml 18/04/2021


```xml
            <internal archive="y">true</internal>
            <config>
              <from-model type="bool">true</from-model>
              <from-model-idx type="int">0</from-model-idx>
              <default-field-of-view-deg type="double">85</default-field-of-
              view-deg>
              <pitch-offset-deg>-10</pitch-offset-deg>
              <heading-offset-deg>0</heading-offset-deg>
              <x-offset-m type="double">15.0</x-offset-m>
              <y-offset-m type="double">60.0</y-offset-m>
              <z-offset-m type="double">480.0</z-offset-m>
            </config>
          </view>

          <view>
            <name>Aisle view</name>
            <type>lookfrom</type>
            <internal archive="y">true</internal>
            <config>
              <from-model type="bool">true</from-model>
              <from-model-idx type="int">0</from-model-idx>
              <default-field-of-view-deg type="double">85</default-field-of-
              view-deg>
              <pitch-offset-deg>-10</pitch-offset-deg>
              <heading-offset-deg>0</heading-offset-deg>
              <x-offset-m type="double">0.0</x-offset-m>
              <y-offset-m type="double">60.0</y-offset-m>
              <z-offset-m type="double">480.0</z-offset-m>
            </config>
          </view>


        <help>
            <title>Cranfield University SAAB 340</title>
            <line>- Speeds
            ---------------------------------------------------------------
            -</line>
            <line>Cruise speed (Vc):-----252.16 kts</line>
            <line>Never-exceed (Vne):-----281.85 kts</line>
            <line>Stall speed (Vs):-----088.55 kts</line>

            <line>---------------------------------------------------------
            </line>
        </help>

<!--INSTRUMENTATION-->

        <instrumentation>
                <path>Aircraft/S340b/instrumentation.xml</path>
        </instrumentation>

 </sim>


</PropertyList>
```


3

Figure A.9: S340b-set.XML page3

A.3 instrumentation.xml

The script of the XML file instrumentation.XML is described in the pictures A.10,A.11.

instrumentation.xml 07/02/2021

```
<?xml version="1.0"?>

<!--
**********************************************************************
This file selects the instrumentation modules that should be available.
**********************************************************************
-->

<PropertyList>

    <adf>
        <name>adf</name>
        <number>0</number>
    </adf>

    <airspeed-indicator>
        <name>airspeed-indicator</name>
        <number>0</number>
        <indicated-speed-kt>/velocities/airspeed-kt</indicated-speed-kt>
        <total-pressure>/systems/pitot/total-pressure-inhg</total-pressure>
        <static-pressure>/systems/static/pressure-inhg</static-pressure>
    </airspeed-indicator>

    <altimeter>
        <name>altimeter</name>
        <number>0</number>
        <static-pressure>/systems/static/pressure-inhg</static-pressure>
    </altimeter>

    <attitude-indicator>
        <name>attitude-indicator</name>
        <number>0</number>
        <suction>/systems/vacuum/suction-inhg</suction>
    </attitude-indicator>

    <clock>
        <name>clock</name>
        <number>0</number>
    </clock>

    <heading-indicator>
        <name>heading-indicator</name>
        <number>0</number>
        <suction>/systems/vacuum/suction-inhg</suction>
    </heading-indicator>

    <heading-indicator-dg>
        <name>heading-indicator-dg</name>
        <number>0</number>
    </heading-indicator-dg>

    <magnetic-compass>
        <name>magnetic-compass</name>
        <number>0</number>
    </magnetic-compass>

    <nav-radio>
        <name>nav</name>
        <number>0</number>
    </nav-radio>

    <slip-skid-ball>
        <name>slip-skid-ball</name>
        <number>0</number>
    </slip-skid-ball>

    <transponder>
        <name>transponder</name>
```

1

Figure A.10: instrumentation.XML page1

```
instrumentation.xml                                                07/02/2

        <number>0</number>
        <mode-c-altitude>/instrumentation/encoder/mode-c-alt-ft</mode-c-
        altitude>
    </transponder>

    <turn-indicator>
        <name>turn-indicator</name>
        <number>0</number>
    </turn-indicator>

    <vertical-speed-indicator>
        <name>vertical-speed-indicator</name>
        <number>0</number>
        <static-pressure>/systems/static/pressure-inhg</static-pressure>
    </vertical-speed-indicator>

    <gps>
        <name>gps</name>
        <number>0</number>
    </gps>

    <mk-viii>
        <name>mk-viii</name>
        <number>0</number>
        <serviceable>true</serviceable>
    </mk-viii>

    <encoder>
        <name>encoder</name>
        <number>0</number>
    </encoder>

</PropertyList>
```

Figure A.11: instrumentation.XML page2

A.4 systems.xml

The script of the XML file systems.XML is described in the picture A.12.

```
systems.xml                                                        06/03/2021

<?xml version="1.0" encoding="UTF-8"?>
<!--
**************************************************************************

Cranfield University SAAB340 Systems

Adapted from Aircraft/Generic/generic-systems.xml

**************************************************************************
-->

<PropertyList>

  <pitot>
    <name>pitot</name>
    <number>0</number>
  </pitot>

  <static>
    <name>static</name>
    <number>0</number>
    <tau>1</tau>
  </static>

  <vacuum>
    <name>vacuum</name>
    <number>0</number>
    <rpm>/engines/engine[0]/rpm</rpm>
    <scale>1.0</scale>
  </vacuum>

</PropertyList>
```

Figure A.12: systems.XML page1

A.5 runfg_340.bat

The windows batch file script generated using the generate bat file block available in the Simulink library.

```
runfg_340.bat                                                      26/03/2021

C:
cd C:\Program Files\FlightGear 2018.3.6

SET FG_ROOT=C:\Program Files\FlightGear 2018.3.6\data
.\\bin\fgfs --aircraft=S340b --fdm=network,localhost,5501,5502,5503 --fog-
fastest --disable-clouds --start-date-lat=2004:06:01:09:00:00 --disable-
sound --in-air --enable-freeze --airport=EGLL --runway=27R --altitude=1000
--heading=0 --offset-distance=0 --offset-azimuth=0
```

Figure A.13: runfg_340.bat page1

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