School of Physics, Engineering and Computer Science

7ENT1134 Flight simulation

Flight simulation of a new high-performance GA aircraft

Problem statement

A new start-up company is hoping to secure a strong position in a new market for high-performance, high-efficiency general aviation (GA) aircraft. A concept for their new aircraft design is shown in Figure 1 below. The company intends to provide the aircraft as a competitor to similar aircraft, but with a greater focus on performance, efficiency and environmental benefits by developing an all-electric version. The aircraft is also being marketed as an air racer as a way to promote its state-of-the art and high-performance design.

One of the company's founders has indicated plans to also offer bespoke training simulators to sell as training tools for pilots. However, there is currently disagreement with the other founders regarding the usefulness of this. The others argue that the investment needed for this will be a waste given the high-performance nature of the aircraft. They believe all pilots will want the training and maintenance of all flying hours to be done in flight.

Figure 1: Concept drawing for the company's new high-performance GA aircraft.

You have been instructed by the company, to work together with a group of other consultants[1], to complete two work packages:

WP1 Assess the viability of developing and offering a flight simulator for the aircraft. You have been asked to consider the following within your group:

- The advantages and disadvantages of providing a bespoke full flight simulator (hardware and software) to pilots and flight companies.
- The design requirements for a simulator for this type of aircraft.
- The potential advantages and disadvantages to leasing hardware instead of developing it in-house.
- If developed in-house or leased, is there a requirement for a motion system for this type of aircraft?
- To what degree do the internals of the aircraft need to be replicated?
- The costs and work required for activities necessary in collecting the data and features to simulate the aircraft (in both hardware and software).

The company has requested that, as a team, you address these issues and produce a realistic specification for a flight simulator appropriate for this type of vehicle, as well as a final, justified, recommendation on what aspects of flight simulation should be invested in by the company.

WP2 The company has already developed a simple model of the aerodynamics of the aircraft to explore its potential performance but does not have a model of the propulsion system. The company is exploring both a traditional high-performance reciprocating engine as well as a new electric motor and would like to develop simulation models of these systems. There is no requirement to model changes in weight due to fuel flow, or to model changes in battery capacity. However, the company also wants a model for the thrust generated by the propeller. Sample test data exists for existing engines, motors, and propellers, but the model of these components has yet to be made.

Your consultancy team is tasked with producing a model of these components, to be added to the company's existing simulation model, written in the Simulink modelling program. You are also required to report on the basic underlying mathematical and modelling principles of the models you create, illustrate that the model is satisfactory in simulating the aircraft, comment on the expected performance of your model and show it satisfactorily compares to the existing test data.

Depending on the size of your team you may choose to develop the reciprocating engine model and/or the electric motor model. However, the propeller model must be included in your simulation.

[1] I.e. other students.

Working method

Both work packages must be addressed in the final group report. However, the elements that each team member looks at must be written in a self-contained subsection(s). The subsections should then be collated and presented as single final report that addressed both work packages.

Each consultancy team will comprise two or three members. You will need to break down the work in each work package to allow an equal distribution of work between each team member. Below are recommendations of how to break the work down for each work package, though you are free to discuss this in your team and approach the distribution of work as you see fit. You are also free to address any other topics, suitably researched, that you feel may be of interest to the company and that strengthens the recommendation you plan to give to the company.

Two-member team:

WP	Activity	Tasks
WP1	1	Address the design requirements of the simulator; Assess the suitability and requirements of a motion system. Determine the appropriate specifications for a simulator for this sort of aircraft.
	2	Address the advantages/disadvantages of the options for the business model (no simulator, in-house simulator, leased hardware). Address the importance or the degree of significance of modelling the internal space of the aircraft for the simulator. Address the issues surrounding generating the data needed to implement the simulator.
WP2	1	Model the reciprocating engine or the electric motor. Describe and explain the underlying mathematical modelling, demonstrate the performance of the model. Provide results or comments on its validation. Comment on the fidelity of the approach and any way it could be improved.
	2	Model the propeller and thrust generation. Describe and explain the underlying mathematical modelling, demonstrate the performance of the model. Provide results or comments on its validation. Comment on the fidelity of the approach and any way it could be improved.

Three-member team:

WP	Activity	Tasks
WP1	1	Address the design requirements of the simulator; Address the importance or the degree of significance of modelling the internal space of the aircraft for the simulator.
	2	Address the advantages/disadvantages of the options for the business model (no simulator, in-house simulator, leased hardware). Address the issues surrounding generating the data needed to implement the simulator.
	3	Assess the suitability and any requirements of a motion system for this aircraft. Discuss the design of the motion system, addressing the advantages and disadvantages of different design options and critical issues that need to be considered.
WP2	1	Model the reciprocating engine. Describe and explain the underlying mathematical modelling, demonstrate the performance of the model. Provide results or comments on its validation. Comment on the fidelity of the approach and any way it could be improved.
	2	Model the electric motor. Describe and explain the underlying mathematical modelling, demonstrate the performance of the model. Provide results or comments on its validation. Comment on the fidelity of the approach and any way it could be improved.
	3	Model the propeller and thrust generation. Describe and explain the underlying mathematical modelling, demonstrate the performance of the model. Provide results or comments on its validation. Comment on the fidelity of the approach and any way it could be improved.

Note: You do not need to do the same activity number for all work packages. For example, if one team member performs activity 1 in WP1, they do not have to perform activity 1 for WP2, they may do 2 or 3. The only requirement is that no activity is replicated in a given work package.

Report format

In addition to the individual subsections written by each team member, an introduction and final conclusion, based on the collated work of all members must be provided at the beginning and end of each work package. The content of these sections will be the result of input from each team member and will therefore have to be written as a team, with a coherent set of recommendations and conclusions derived from discussion and agreement with all team members.

The first section of the group report should address work package 1. It should begin with a short abstract offering a summary of the problem, provide an overview of the approach taken in addressing the problem, and offer the key conclusions and recommendations derived from considering the work by each team member. The end of this section should include an appropriate specification for a potential flight simulator for the aircraft, but also offer the final recommendation based on what approach should be taken to offer it, or not.

The second section of the group report should address work package 2. It should begin with a short description of the content in this section, and an outline of the work in each subsection for this part. The end of this section should include a brief summary on the success in modelling each part of the propulsion system, and if any outstanding work needs to be completed if the modelling was not successful.

The expected outline of your final group report would look something like the structure below, along with recommended page lengths (in parenthesis):

Cover page – including the authors (team members) and their contributions (1)
Section 1: Abstract (1)

- Work for activity WP1-1 (3, max 4)
- Work for activity WP1-2 (3, max 4)
- Work for activity WP1-3 (3, max 4)

Section 1: Conclusion

- Simulator specification (1)
- Recommendation (1)

Section 2: Introduction and outline of work (1)

- Work for activity WP2-1 (4, max 5)
- Work for activity WP2-2 (4, max 5)
- Work for activity WP2-3 (4, max 5)

Section 2: Summary of work done and outstanding work (1)
Appendices (if needed and MUST be cross-referenced to in the text)

The page lengths given above are indicative. However, **the final report must not exceed 35 pages (including appendices and everything else).** It must be written with no smaller than 11 pt font. You must therefore be accurate and concise in your writing.

For ease of assembling the report you may start each team members' contribution on a new page. However, consistency in presentation is important and the report must be presented as a whole coherent document. A template is provided by the company, but you should ensure that as a team you use consistent layout and font of headings, reference formats, and labelling of tables, figures and equations. You are encouraged to cite references, and these should be included at the end of each activity subsection. The name and SRN of each team member must appear at the beginning of each of their contributions. Some pointers on how to prepare your technical work is given in Appendix C.

Simulink model

You will be provided with an existing Simulink model for the aircraft, and the location of the parts for the propulsion model will be indicated. You are only required to model your part for the propulsion system in the appropriate subsection of the model. However, for development and testing purposes you may create a copy of the model and edit it to test your model and generate data to support your WP2 activity. However, the final model must include the elements from each team member in the same format as the original Simulink model provided.

Existing test data for the propulsion systems and propeller to be modelled for the aircraft is included in Appendix A of this briefing. You should make sure you refer to this data to ensure your model represents it appropriately. If you require any further information than is provided you are instructed to estimate it yourselves and provide a clear description and explanation for how you estimated the data.

The mathematical details, and how it represents the physical underpinning of the element you are working on, should be clearly captured in your subsection for WP2. This should also include sample data showing the performance of the model. In particular, you are expected to show the validity of your model against the validation case provided (a simple step climb – discussed in Appendix B) and discuss the fidelity of your modelling approach.

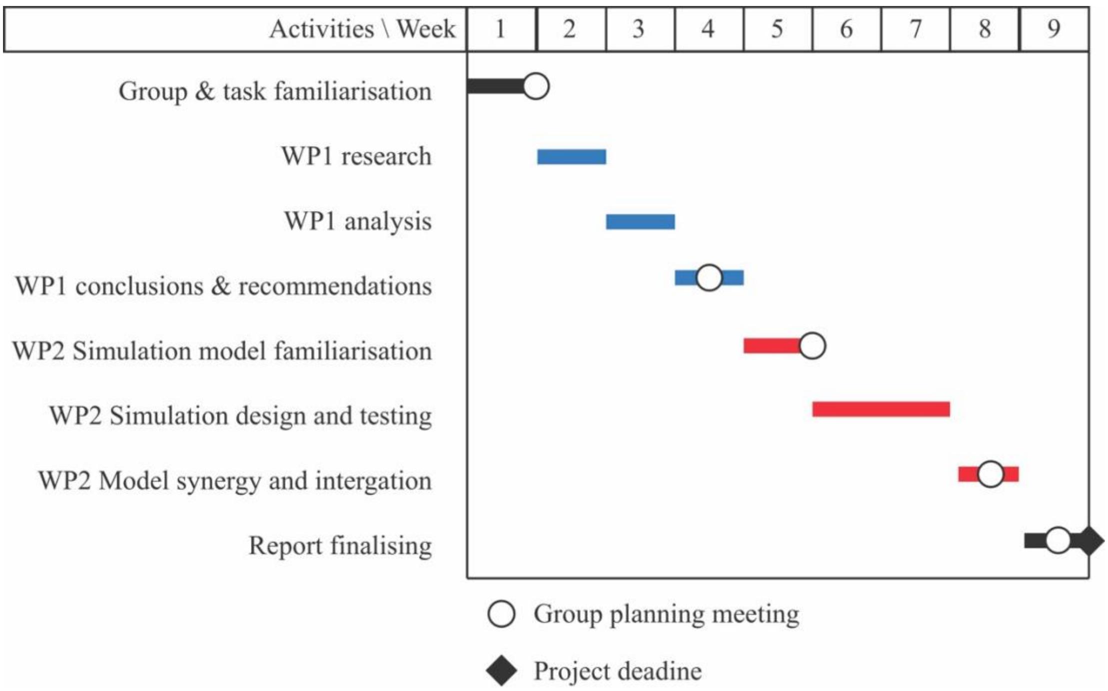
It will be required that the Simulink model run without any setup. Therefore, it is important that, individually and as a team, you ensure the model runs without the need to manually load external data files or setup. If you wish to parametrise data for your model ensure it is embedded in the Simulink file. If you wish to use an external MATLAB file (.mat file) ensure it is called automatically when running the simulation.

Note on student group working

Working in a team or group is a fundamental requirement of most engineering projects. It allows for efficiency and scale in projects. It is important you learn effective team working skills but also that you engage in your group work professionally and courteously.

You will be expected to contribute equally in your team through providing input from the results of your work activities to help your team form coherent conclusions and recommendations. You will also be expected to contribute equally to the writing of the group report, in addition to your individual analysis and writing subsections.

You will be provided with a group area on the StudyNet module site, but you are also recommended to setup meetings on MS Teams (or other remote communication software) when appropriate over the course of this assessment to meet with your fellow team members and organize your work and the group report. Meetings do not need to be frequent (such as every week), but you will need to meet occasionally to organize the collation of your individual parts into a coherent report, and to discuss your individual results to form the overall simulator specifications, recommendations, and Simulink model from your group. You are free to devise your own group project plan, but the plan below is offered as an indicative approach of what you should be aiming for in terms of progress in this work:



Group meeting 1:	Introductions; review of the work; Deciding the distribution of work in WP1 (also WP2 optionally); Devising a project plan; Determining required work for WP1.
Group meeting 2:	Summary of individual wok package results and collating of results to form coherent recommendations and specifications; Decision on report formatting/layout; Collating of material to begin completing the report.
Group meeting 3:	Confirmation of workload distribution for WP2; discussion of integration approach for the simulation model.
Group meeting 4:	Integration meeting for simulation model components.
Group meeting 5:	Collating of all documented material for final report.

Note that 10% of the marks for this assignment are based on your work you submit as a group. Each student will receive the same group mark from your submission. There is no peer assessment so marks will not be weighted based on perceived levels of contribution. If, for example, a particular student feels they have put more work into the group submission, there is no mechanism for them to be awarded more. You are therefore encouraged not to take on all the editing and formatting work for the group report unless you are happy to accept the extra work to ensure you achieve a good group mark. However, those students who are not contributing will also receive those marks. It is each student's responsibility to contribute equally to the team's effort in producing the group report and thus share the possible 10%.

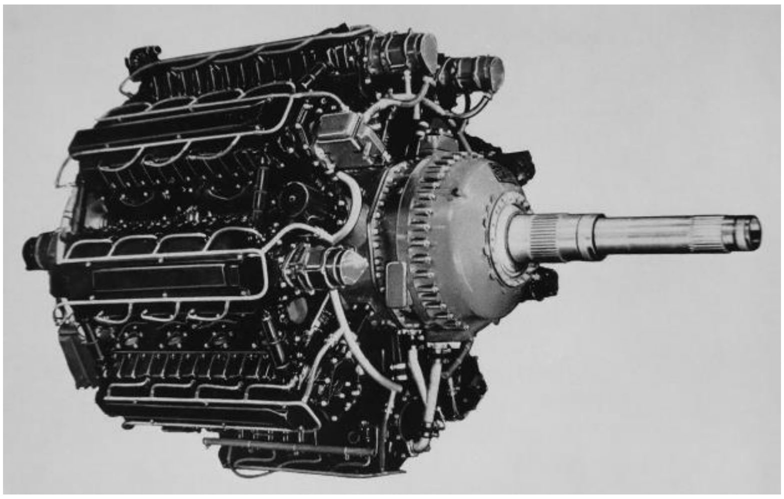
Students who do not contribute and are hoping to receive sufficient marks will not successfully pass the assessment. Only 10% of the marks for this assignment are obtained through the quality of the group work. The bulk of work is still based on your individual contributions (90% of the marks for this assignment).

Some students find group work anxious and uncomfortable, whilst other students become disgruntled when their grade is affected by the performance of other students. Group work is a fundamental skill and you cannot avoid it if you wish to have an exciting and fulfilling career in most fields, especially engineering. Students who are not happy with the idea they will lose marks if the performance of other students is not satisfactory are reminded that the significant bulk of marks for this assignment (90%) are still from your individual work. Requests for extra marks based on perceived levels of extra contribution will not be considered.

More importantly, **bullying of other students or other forms of unprofessional group behaviour will absolutely not be tolerated**. Students who undertake such behaviour will be investigated and, where appropriate, reported for severe disciplinary action.

Appendix A: Propulsion data

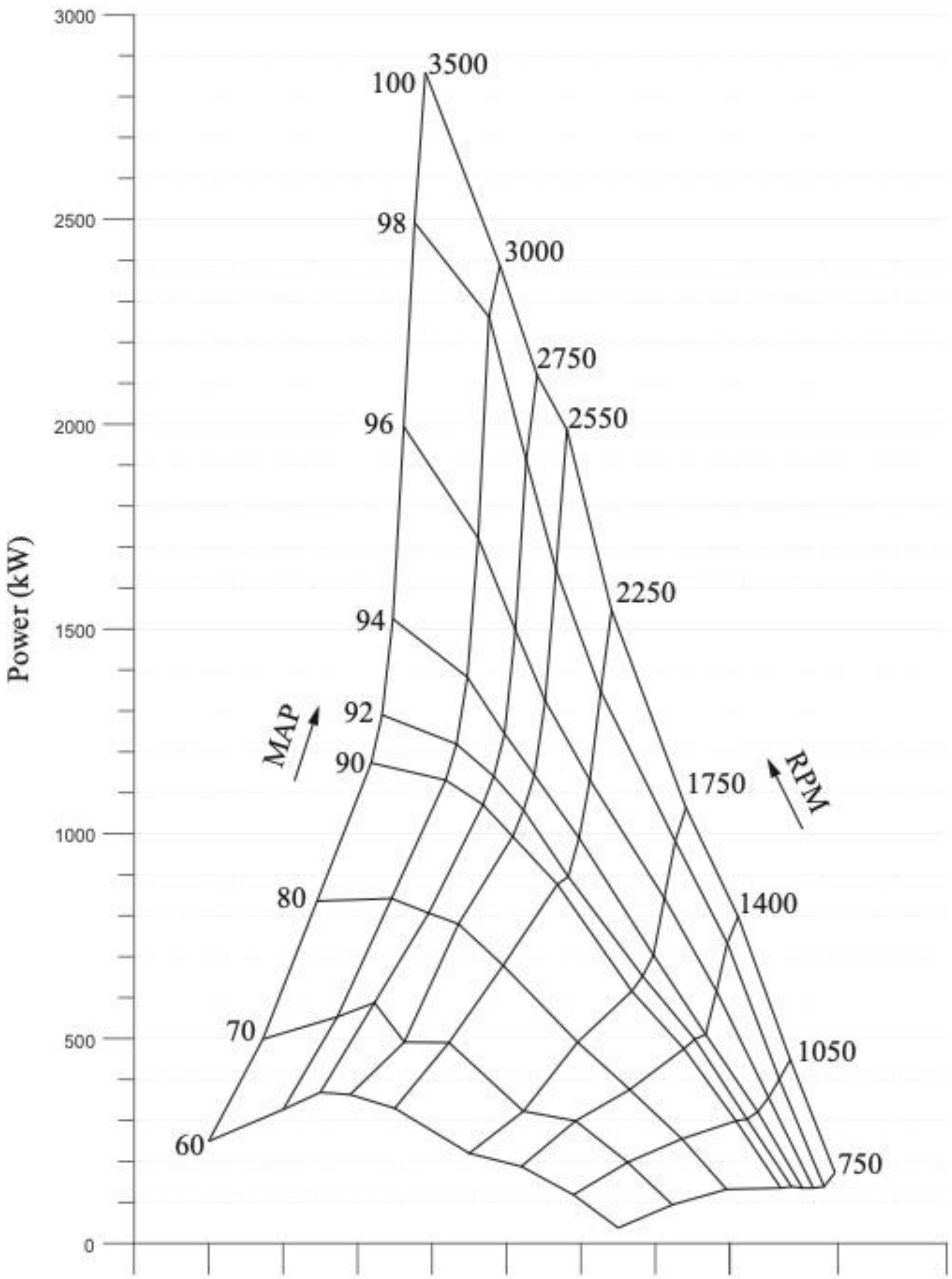
High-performance reciprocating engine



Note: Illustrative example

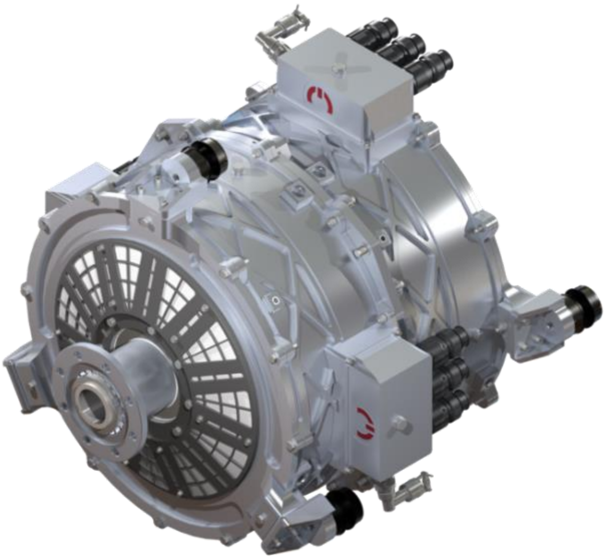
Modelling data		
Dry weight*	2.4	tonnes
Minimum manifold pressure	60	kPa
Power output (SL @ 3000 rpm)	~2400	kW

*You may neglect the engine moment of inertia.



Engine power map for engine RPM (revs/min) and manifold pressure (kPa).

High-performance DC electric motor



Note: Illustrative example

Modelling data		
Dry weight*	75	kg
Maximum supply voltage**	1.26	kV
Power output (SL @ 3000 rpm)	~1100	kW
Motor current (SL @ 3000 rpm)	~900	A
Motor inductance	500	mH
Motor resistance	1	Ω
Motor armature constant, K_m	4.0	N-m/A
Motor back EMF constant, K_e	1.2	V/rad/s
Motor viscous friction constant, K_b	0.6	N-m/rad/s

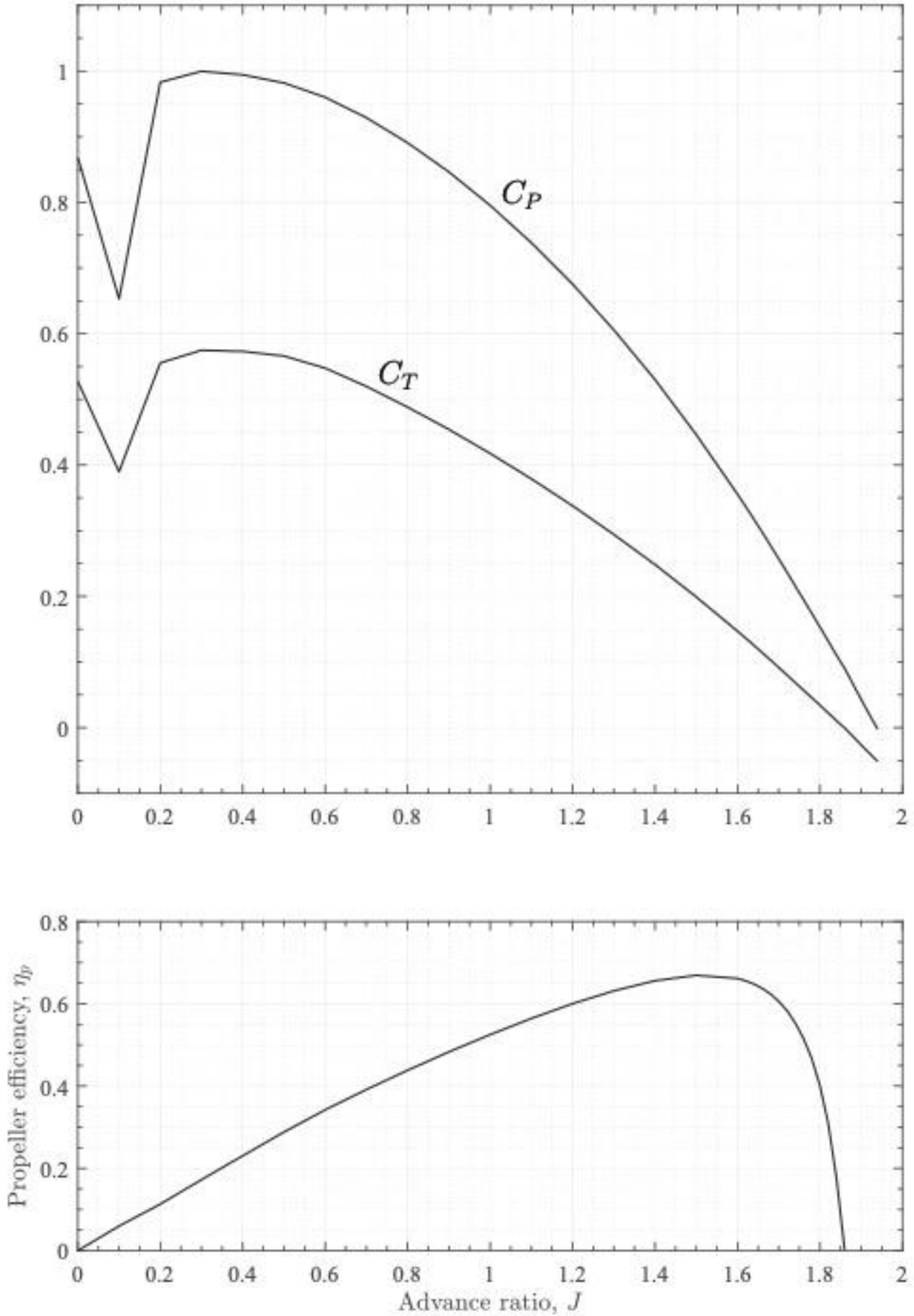
*You may neglect the motor moment of inertia.
*You may assume the voltage supply to the motor is proportional to the throttle command.

High-performance propeller

Note: Illustrative example

Modelling data		
Dry weight	2	kg
Diameter	1.8	M
Number of blades	2	

You are only required to model the thrust generated by the propeller. You do not need to consider any rotational-induced or interference effects (e.g. gyroscopic or slipstream effects).



Propeller thrust (C_T) and power coefficients (C_P), and propeller efficiency for advance ratio, J.

Appendix B: Simulink model

The top level of the Simulink model (shown in the diagrams below) comprises three blocks:

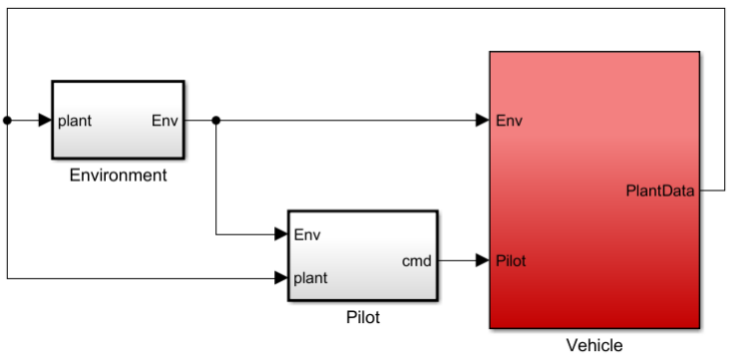
- A block to calculate the environmental and atmospheric properties.
- A block to implement a piloted manoeuvre.
- The vehicle aerodynamics, propulsion system, and equations of motion.

Inside the vehicle subsystem you will note the propulsion subsystem (coloured red). You should only edit inside this subsystem block by adding your models for the propulsion units and propeller model. The torque from one or more propulsion units should be connected to the *Torque select* multiport switch block so that the output from either propulsion unit can be selected. The output torque from the multiport switch should be connected to the torque output from your propeller model so that the total torque can be found.

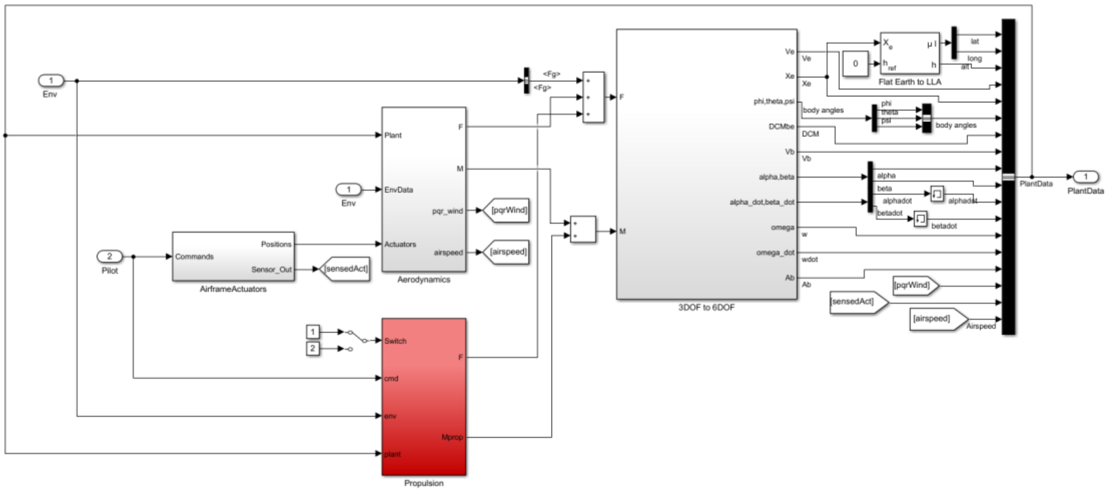
The final output of your model should be the total thrust computed, which should be connected to the single unconnected input to the *Mux* block that connects to the first output port 'F'.

Ensure that your model is sensibly laid out and commented as necessary. Consider how easy it will be for somebody receiving this model to understand how it works. This model and your report should be sufficient information for the company receiving both to comprehend what you have done.

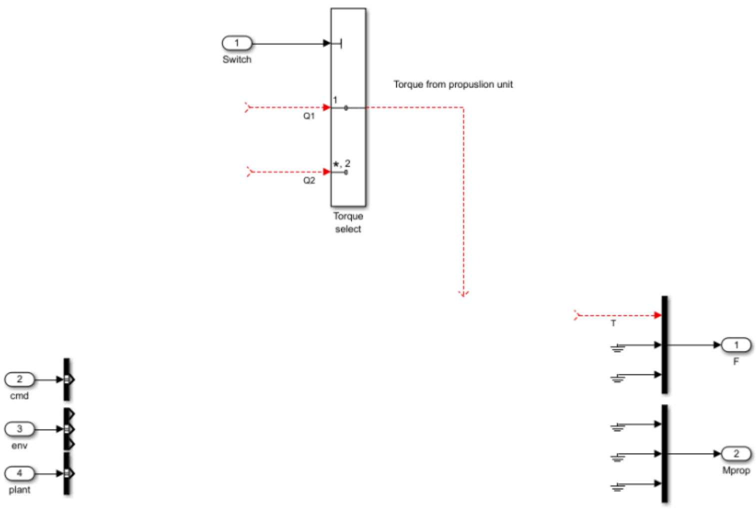
It is important that your simulation runs without any further setup or needing to load any external files or data tables. Therefore, ensure any parametrised variables are self-contained in the Simulink model file.



Top level of Simulink model exp_ac_m1.slx



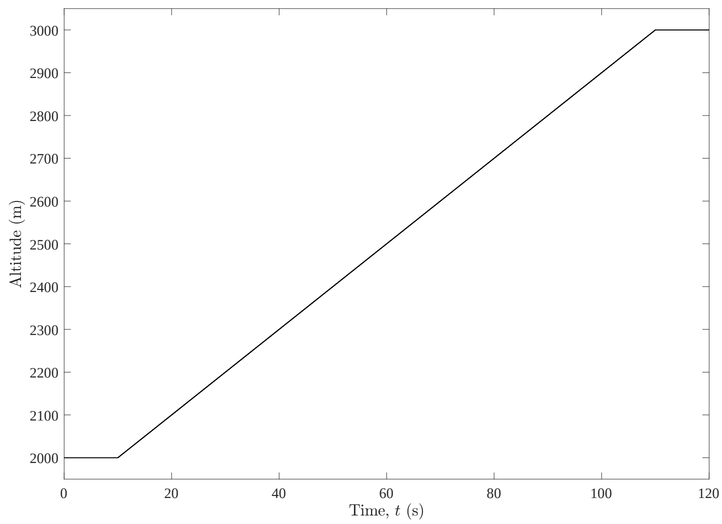
Content of Vehicle subsystem, with propulsion subsystem highlighted.



Content of Propulsion subsystem block.

In order to develop your model, you have been provided with the following validation case:

When running the simulation, after 10 seconds the pilot will initiate a 1km climb at a rate of approximately 2000 fpm (~10 m/s). The propulsion system you model should be able to provide sufficient thrust to support the 1 km climb at the required rate. The typical flight profile command is shown below:



The performance of the aircraft should be sufficient to follow this altitude command and then stabilise at the final altitude.

An indication of expected thrust ranges required is given below:

Cruising: 2000 – 3000 N
Climbing: 4000 – 6000 N

Appendix C: General technical report writing considerations

Note the following in preparing a technical report:

- You have a restrictive page limit but you must put in as much detail as possible for the reader to understand and replicate your results – you must therefore be concise. **Concise does not mean arrange your content haphazardly without any explanation for what it is, where it comes, or without any logical flow/progression in your derivation or analysis!**
- Use references to refer readers to well established theory / derivations in order for you to concentrate on the specifics of your work. However, there is a balance – ensure you adequately explain (or at least introduce) the principles of the theory or method such that the reader has some understanding of your approach but can look it up for more details if required.
- Explain your methodology and all decisions made in performing your analysis. You must present enough detail for the reader to be able to follow your work clearly from the start of the problem to the results and final conclusions with no uncertainty in your method or origin of your results so that they have a reasonable chance of replicating your work.
- Report on the results of all pertinent calculations you perform. This includes not just showing them but discussing what the implications are for the physical objects/conditions they represent.
- Justify your analysis, statements, discussions, and conclusions either with the results you have obtained or suitably reliable references (webpages and lecture notes are generally not preferred – you should refer to textbooks, peer-reviewed articles, and/or published technical reports).
- Provide a citation to a reference for any significant point, image, or data that you have not produced yourself (this includes images/tables taken from lecture slides or course material). If referencing a text, use the reference appropriately and specifically in context with what you are writing about. You may include references for general issues in the introduction of a topic, but your references should increasingly become more specific and should always be relevant to your specific work. Ensure you reference work correctly using a standard technique (e.g. Harvard or Vancouver).
- All figures and tables in your report must be referred to in the main text. Much like references if they are not referred to then they should not appear in the report.

If you are unsure of how to prepare a technical report, or how to undertake technical writing, you are encouraged to look at the variety of NASA / NACA / ARC or other technical institute reports that are freely available over the internet to see how a technical report is arranged and written.