MSc in Advanced Motorsport Engineering / Mechatronics

Motorsport Powertrain Design, 6th October – 10th October 2025

Powertrain simulation assignment

1. Introduction

The method of assessment for the Motorsport Powertrain Design module will be:

- 100% by completion of this assignment. **This must be the student's individual work, it is not a group project**.

2. Assignment brief

The lecture programme includes coverage of the thermo-fluid and electrical principles that govern the operation of complex, modern, motorsport powertrains with internal combustion engines as their prime movers and including different forms of electrification and hybridisation.

This assignment will test the student's ability to apply those principles to assess three gasoline engines and one hybridised powertrain unit using AVL Boost and AVL Cruise-M which are industry-standard powertrain and vehicle performance simulation software.

Each student will undertake a series of tasks for which they can receive marks. The weighting of marks varies between tasks as shown in this assignment brief. The maximum number of marks to be awarded for the assignment will be 100 marks.

Each student must submit a single report document covering all the tasks attempted. Students should be aware from inspection of the maximum marks allocated to each task **that they need to attempt all tasks in order to access sufficient marks to pass the assignment.**

For three of the four tasks, students will receive a fully functioning but not optimised model of the powertrain / vehicle that is the subject of the task. Each student must adapt and extend these models as required by each task and produce their own unique simulations and report document. They may discuss their simulations and results with other students. For one task, students must construct a powertrain model themselves from a donor single cylinder model.

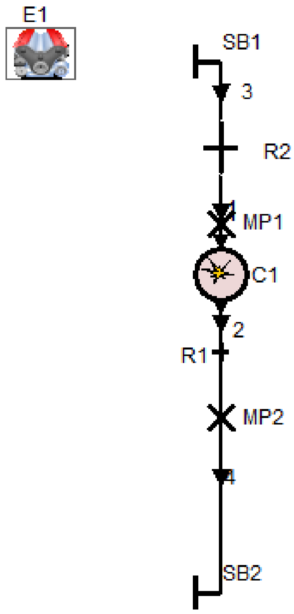
There will be facilitated sessions during the teaching week where the complex powertrain geometry and operation in each task will be inspected and analysed in small groups. **However, students must recognise that they are individually responsible for generating their own simulation results in each task and the reporting and discussion in an individual student's final assignment submission must be unique and entirely their own work.**

The completed report, including Tasks 1-4 must be submitted via Turn It In as a PDF file by 1200 noon on Friday 17th October 2025.

Technical support with the assignment is available from m.f.harrison@cranfield.ac.uk

Task 1 – Intake system optimisation for a single cylinder naturally aspirated engine (maximum 15 marks)

On the first day of the module, each student will be provided with the same AVL Boost model *single500_GDi.bwf.* The intake system for this engine requires optimisation.



Students must run the 0.5 litre single cylinder engine model provided and extract series results. On a **single page**, place **all** of the simulated engine performance indicators required to properly assess the overall performance of the engine. **Those performance indicators will have been discussed in detail in class**. They should be clearly labelled and for the engine speed range 2000-7000 revmin^{-1}.

Students must then optimise the intake geometry and camshaft phasing to improve the performance of the engine across the relevant performance indicators. Results should be overlaid on the same set of graphs used for the baseline performance results for easy comparison.

These graphs must be accompanied by a **full discussion** of the results. To obtain highest marks, the discussion must include comment on the levels of performance achieved, benchmarked for BMEP against relevant published data (including those provided in lecture notes).

Mark scheme (as a guide only):

- Completeness of the data set (5 marks)
- Extent of performance improvement due to intake system optimisation (5 marks)
- Quality and depth of discussion including benchmarking (5 marks)

Task 2 – 2 litre, inline 4-cylinder, naturally aspirated type model (maximum 25 marks)

Students should take **their optimised** 0.5 litre single cylinder AVL Boost model from Task 1 and use it to construct an AVL Boost model of a 2 litre, 4 cylinder in-line naturally aspirated, GDI crate-engine suitable for use in sportscar racing.

The intake system should have an end feed plenum. Four separate intake 'trumpets' are not permitted. Exhaust system design is a free choice but should be compact enough to fit in a rear-engine two-seat sportscar. Variable cam-phasing is allowed but VTEC or VTEC-E type features are not required and should not be included in the modelling. Lean-burn strategies should not be included. Octane number requirement should be considered.

Optimise the intake, exhaust and variable timing camshaft systems in an effort to improve BMEP over engine speed range 2000-8,000 revmin^{-1}.

To obtain highest marks, the discussion should report on:

- Decisions made over intake geometry
- Decisions made over exhaust geometry
- Decisions made on variable cam phasing
- Decisions made over combustion modelling and engine heat loss modelling

and discuss:
- The effects of these decisions on engine performance indicators, including but not limited to BMEP
- Which dimensions have the greatest impact on engine performance
- The levels of performance achieved, benchmarked against relevant published data.

Mark scheme (as a guide only):

- Quality of the decisions made and the performance achieved (10 marks)
- Quality of the explanation and presentation of the changes made (5 marks)
- Quality and depth of discussion (10 marks)

Task 3 – 1 litre turbocharged 3-cylinder GDi type model (maximum 25 marks)

On the first day of the module, each student will be provided with the same functioning, **but not optimised**, 6 cylinder AVL Boost model approximating that of the Nissan VR38DETT bi-turbo port-injected engine (Nissan_vr38DETT_PFi_biturbo.bwf).

This, along with the Task 1 model which includes GDi, should be used as a guide to constructing an AVL Boost model of a 1.0 litre, 3 cylinder, GDi, single turbocharger with intercooler engine capable of achieving the same maximum torque and maximum power levels of the Task 2 engine whilst restricting the maximum engine speed for Task 3 to 6500 revmin^{-1}. The shape of the two torque curves is expected to be different.

Lean-burn strategies should not be included. Octane number requirement should be considered.

Models must use the 'simplified' turbocharger model in the form shown in the Nissan model BUT demonstrate that the resulting performance line for the compressor is a good fit with an actual turbocharger selected from the Garrett range or similar.

Optimise the intake, exhaust and camshaft systems in an effort to improve BMEP over engine speed range 2000-6500 revmin^{-1}. Variable cam phasing is not permitted. An intercooler and GDi should be included.

To obtain highest marks, the discussion should report on:

- Decisions made over intake geometry
- Decisions made over exhaust geometry
- Decisions made on camshaft selection and timing
- Decisions made on turbocharger selection – including the final compressor performance line super-imposed onto the compressor map
- Decisions made over combustion modelling and engine heat loss modelling
- An assessment of the effectiveness of the intercooler
- An assessment of peak cylinder pressures and octane number requirements

and discuss:

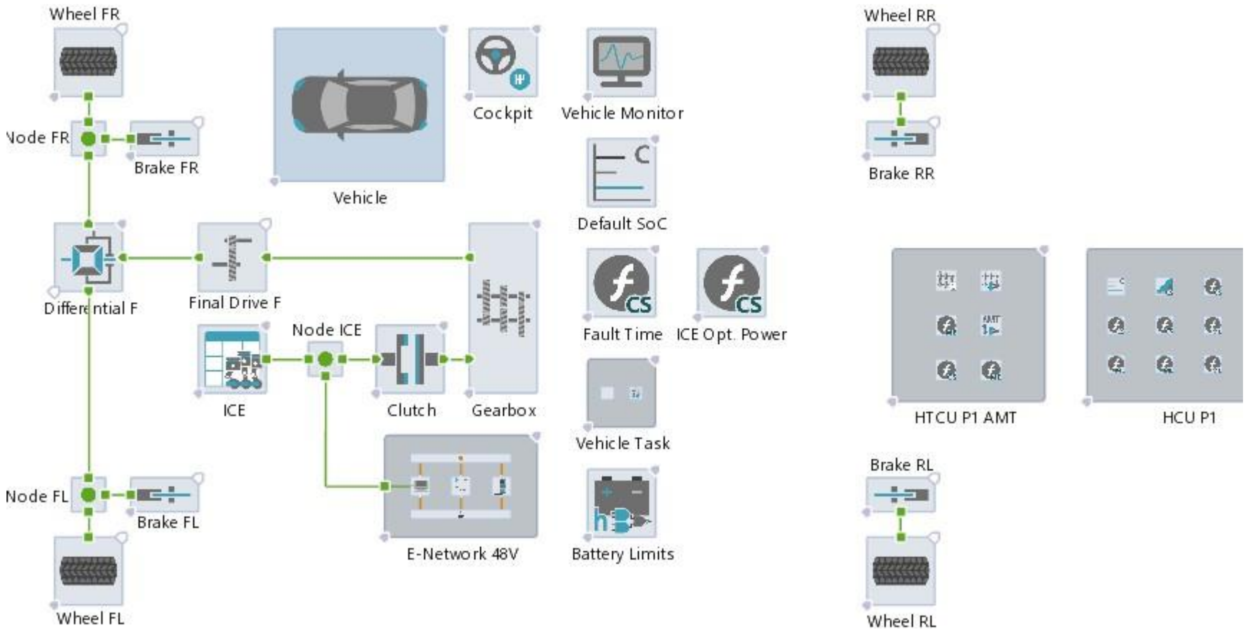
- The effects of these decisions on engine performance indicators, including but not limited to BMEP vs bsfc
- Which dimensions have the greatest impact on engine performance
- The levels of performance achieved, benchmarked for BMEP against relevant published data.

Mark scheme (as a guide only):

- Quality of the decisions made (10 marks)
- Quality of the explanation and presentation of the changes made (5 marks)
- Quality and depth of discussion (10 marks)

Task 4 – Comparison of the transient 0-100 mph performance of a two seat FWD sportscar fitted with the Task 2 and Task 3 engines with added P1 electric motor (maximum 35 marks)

On the first day of the module, each student will be provided with the same functioning AVL Cruise-M transient simulation of a P1 hybridised vehicle (C04023_HEV_P1_AMT_FWD.proj). This is a Cruise-M example model that students will need to interrogate and adapt to the geometry given for a notional two-seater FWD sportscar in Appendix A.



Students should adapt the ICE components of the Cruise-M model to reflect the full load performance of **their own final** Task 2 and Task 3 engines using results from their AVL Boost models. This will also mean adapting the maximum performance envelope of the electric motor for each Task 2 and Task 3 variant to ensure the acceleration performance remains within the reasonable traction-limit expectations of a light FWD sportscar. Tyre data is given in Appendix A for this purpose. The gear ratios should be re-optimised for the Task 2 and Task 3 engines with their respective electric motors.

The principal output is to compare the 0-100 mph performance of the two-seater sportscar fitted with the Task 2 and Task 3 ICE, each with specially adapted P1 electric motors. Altering the hybrid control units to further enhance performance is not expected and is outside the scope of this assignment.

To obtain highest marks, the discussion should report on:

- The influence that the difference in torque curves between the Task 2 and Task 3 engines has of the time taken for the manoeuvre
- The impact of re-optimising gear ratios on the time taken for the manoeuvre
- Comparison of the power deployed by the electric motors versus the ICE in both cases

In order to provide these comparisons, students should be anticipating the need to compare the time histories of different performance parameters for the different ICE and EM combinations.

Students are required to report the input data they modify in each model case.

Mark scheme (as a guide only):

- Quality of the optimisation decisions made in constructing the two model variants including a critical assessment of the transient simulation with verification of tyre friction limits and gear ratios (10 marks)
- Reporting on how the ICE and EM characteristics put into the model determine the deployment of ICE and EM during each manoeuvre (10 marks).
- Quality and depth of discussion (15 marks)

Appendix A

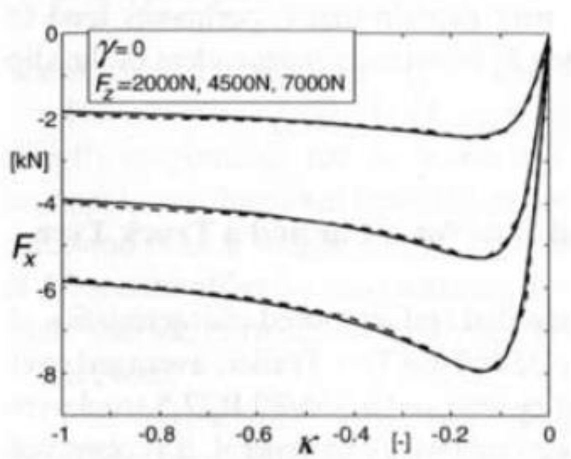
Vehicle data for a two-seat FWD sportscar

Item	Value
Total vehicle mass (full tank)	720kg
Volume of fuel tank	36.4 litres
Volume of oil	7.4 litres
Wheel base	2300mm
Front track	1440mm
Rear track	1453mm
Tyre size front	195/65 R15
Tyre size rear	195/65 R15
Rolling radius front	284mm
Rolling radius rear	297mm
Height of centre of gravity	470mm
Height of roll centre front	30mm
Height of roll centre rear	75mm
Height of roll centre at C.of.G	58 mm
Rolling stiffness front	15 kN/rad
Rolling stiffness rear	15 kN/rad
Lateral tyre stiffness front	23,000 N/rad (static) per tyre
Lateral tyre stiffness rear	36,000 N/rad (static) per tyre
Drag coefficient	0.418
Frontal area	1.62 m^2
Lift coefficient front	-0.02
Lift coefficient rear	-0.04
Steering ratio	15.8 : 1

Weight distribution 50% Front, 50% Rear

Gear	Ratio	% difference between ratios
1^{st}	2.583	24.7% (1^{st} to 2^{nd})
2^{nd}	2.071	22.7% (2^{nd} to 3^{rd})
3^{rd}	1.688	19.5% (3^{rd} to 4^{th})
4^{th}	1.412	17.7 % (4^{th} to 5^{th})
5^{th}	1.200	14.5% (5^{th} to 6^{th})
6^{th}	1.048	
Final drive	3.938	

When considering maximum permissible longitudinal tyre forces, student should make use of these relationships:



Load sensitivity on lateral and longitudinal tyre force, zero camber. 195/65 R15 tyre (Pacejka, 2006, p210)