

Assignment 2
Alternative Fuels and Combustion Modelling

Submitted

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1. Introduction

The transition toward decarbonised transport remains one of the most significant engineering challenges of the twenty-first century. Battery electric vehicles have received substantial policy interest, but the uncertainty about the planned 2035 internal combustion engine (ICE) vehicle sales prohibition has led to increased research on alternative and synthetic fuels as effective decarbonization solutions (European Parliament, 2023). The 2035 legislation will not become law, which will enable ICE powertrains that run on low-carbon synthetic fuels and bio-based fuels and non-carbon-based fuels to stay commercially viable and technologically advanced across automotive and motorsport and freight and L-category applications.

The feasibility of the concept was evaluated through industry-standard simulation software tools Ricardo Realis WAVE 2025.1 and ANSYS Forte 2024 R2, which represent one-dimensional (1D) engine cycle simulation and three-dimensional (3D) Computational Fluid Dynamics (CFD) for in-cylinder combustion process respectively. Dual-fuel Compressed Natural Gas (CNG) and diesel concept serves as the main fuel system considered due to the fact that CNG is estimated to have 25% less carbon content compared to fossil diesel per unit of energy, yet maintains similar features of a compression ignition fuel with the use of pilot diesel injection. Parameters of Wiebe thermodynamic two-zone combustion model created in MATLAB software were determined by using cylinder pressure measurements for Sigma 1.6L engine, thus forming the basis of the simulations.

2. Literature Review and Conceptual Justification

2.1 Alternative Fuels in the Post-2035 Regulatory Landscape

The European Commission confirmed in 2023 that e-fuels produced from captured CO₂ and renewable hydrogen would be permitted in new passenger vehicles beyond 2035 under a derogation which shows that internal combustion engines can achieve net-zero targets according to European Commission 2023. The production of synthetic fuels which includes e-methanol and e-methane and oxymethylene ethers (OME) through renewable electricity results in nearly zero carbon emissions throughout their entire lifecycle (Lautenschutz et al., 2022). Hydrogen and ammonia represent completely non-carbon combustion methods which currently face challenges regarding energy density and infrastructure needs and combustion stability that require additional research for their implementation (Reiter and Kong, 2011).

Compressed Natural Gas serves as a viable short-term solution. Its carbon intensity is approximately 25% lower than gasoline per MJ, it produces significantly lower particulate matter and NO_x emissions than diesel, and it functions with existing engine architectures through dual-fuel configurations. Research on dual-fuel diesel-CNG engines demonstrates their suitability for heavy-duty applications while showing increasing importance for passenger vehicles; researchers found that partial CNG substitution ratios between 60 and 80 percent maintained high thermal efficiency, but methane emissions at low loads remained the main environmental issue (Papagiannakis et al., 2018).

2.2 Simulation Frameworks for Alternative Fuel Engine Development

The Ricardo WAVE platform which simulates engine performance through its one-dimensional engine simulation functions supports users who want to test dual-fuel systems and create specific fuel formulas and implement exhaust gas recirculation and forced induction and operate multiple engine cylinders. The ANSYS Forte system which uses the CHEMKIN reaction mechanism solver enables three-dimensional computational fluid dynamics simulation of in-cylinder spray and mixing and combustion processes. The system enables users to achieve faster results because its sector mesh geometries need fewer cells through cylinder symmetry which leads to 4 to 12 hours of processing time on workstations compared to 40 to 100 plus hours needed for complete 360-degree mesh processing according to ANSYS 2024. The combination of 1D and 3D tools shows industry best practice because WAVE enables users to perform rapid multi-point engine testing while Forte delivers the necessary detail to study spray impacts and local equivalence ratio and NO_x production at key engine operations.

The two-zone thermodynamic combustion model serves as the fundamental foundation for engine performance evaluation. The cylinder contents are divided into an unburned and a burned zone, with the Wiebe function governing mass fraction burned (MFB) progression as a function of crank angle. The Wiebe parameters have been found to represent the timing and duration of combustion in a compact way, and this is applicable in both one-dimensional and three-dimensional simulation models that scientists can use to evaluate the MFB results derived from cylinder pressure analysis. The 50% mass fraction burned criterion (MFB₅₀) is mainly used to assess combustion performance due to its correlation with IMEP and efficiency in the entire speed range (Hunicz et al., 2022).

3. Simulation Methodology and Model Construction

3.1 Engine Specification and Reference Dataset

A Ford Sigma 1.6L four cylinder naturally aspirated spark ignition engine was chosen as the benchmarking engine for calibration, and important geometry of which is provided in Table 1. The measured pressure in the cylinder was captured over 14 different operating speed points (from 1000 to 6500 RPM) under WOT and with 300 cycles per speed point. The LUCID statistics data set includes ensemble averaged combustion data, such as peak pressure, peak pressure angle, NMEP, GMEP, and MFB at 2%, 5%, 10%, and 50%.

Table 1: Ford Sigma 1.6L engine geometry parameters extracted from the Sigma 1.6L dynamometer dataset

Parameter	Value	Units
Bore	79.0	mm
Stroke	81.4	mm
Connecting Rod Length	137.0	mm
Compression Ratio	11.16	—
Displaced Volume (per cylinder)	399.0	cc
Clearance Volume	39.27	cc
Number of Cylinders	4	—
Total Swept Volume	1596	cc

3.2 MATLAB Two-Zone Combustion Model Approach

Thermodynamic model with two zones was developed in MATLAB to obtain the Wiebe function calibration parameters from the pressure trace before WAVE modelling. This model uses the first law of thermodynamics to solve the problem for each zone, namely, unburnt (air-fuel mixture) and burnt (combustion products), for the processes of compression, combustion, and expansion. The process was carried out taking into account the instantaneous cylinder volume obtained from the solution of the kinematics of the slider-crank mechanism and the relationship between the pressure, volume, and temperature according to the ideal gas law.

The Wiebe function parameters were fitted iteratively at 6500 RPM WOT ($\Lambda = 0.90$) the highest-load test point in the dataset using MFB50 and MFB90 as the primary fitting targets. Operating boundary conditions were extracted directly from the dataset: pressure at inlet valve closing (P_{IVC}) = 1.14 bar, estimated temperature at IVC (T_{IVC}) = 330 K, total trapped mass =

5.29×10^{-4} kg, fuel mass = 3.72×10^{-5} kg. The fuel used was Shell V-Power Unleaded (RON 99, density 741 kg/m³, aromatics 34.5%, sulphur ≤ 10 mg/kg) as specified in the product information sheet (Shell UK Oil Products, 2010).

3.3 Ricardo Realis WAVE Dual-Fuel Model Construction

The dual-fuel WAVE model was constructed in Ricardo Realis WAVE 2025.1 using the Dual_Fuel_WAVE_Solver template. The engine network comprises: intake ambient, intake duct assembly (duct1–duct2), CNG port injector (CNG_INJ), direct diesel injector (Diesel_INJ), intake and exhaust valve elements with user-defined lift profiles, single cylinder element parameterised with Sigma engine geometry, exhaust duct assembly (duct3–duct4), and exhaust ambient. The CNG injection event was parameterised using start-of-injection (CNG_SOI), injection duration (CNG_Injur), and fuel property file (CNG_Fuel) entries visible in the WAVE session parameter panel. Figures 1 through 3 show the model construction progression from initial template to fully parameterised simulation.

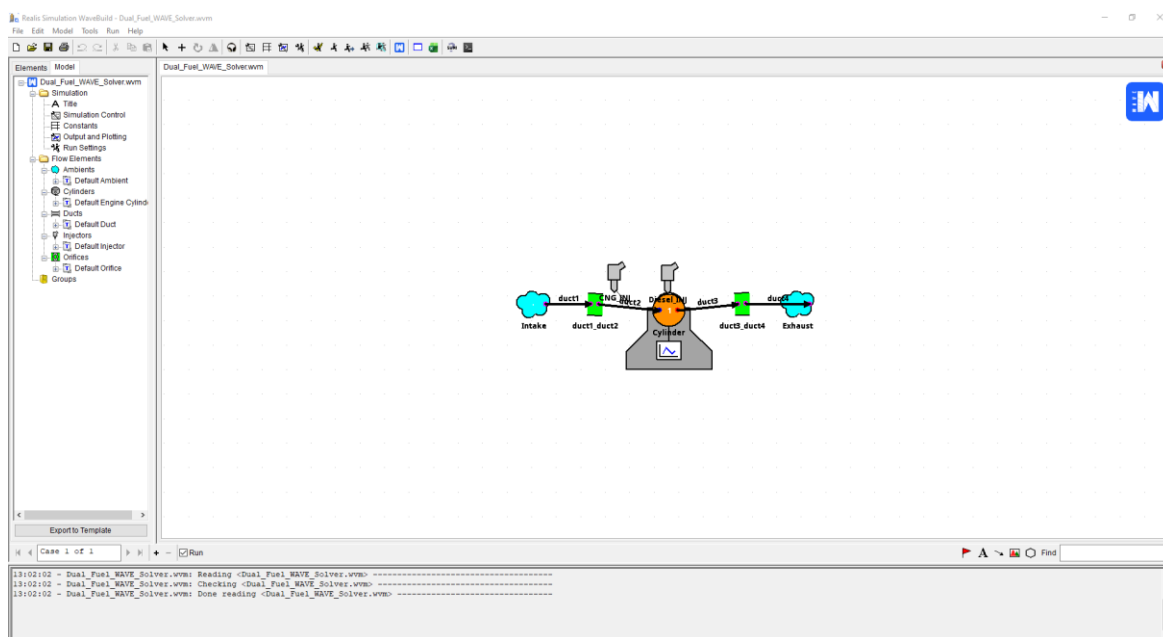


Figure 1: Ricardo Realis WAVE 2025.1 initial Dual_Fuel_WAVE_Solver

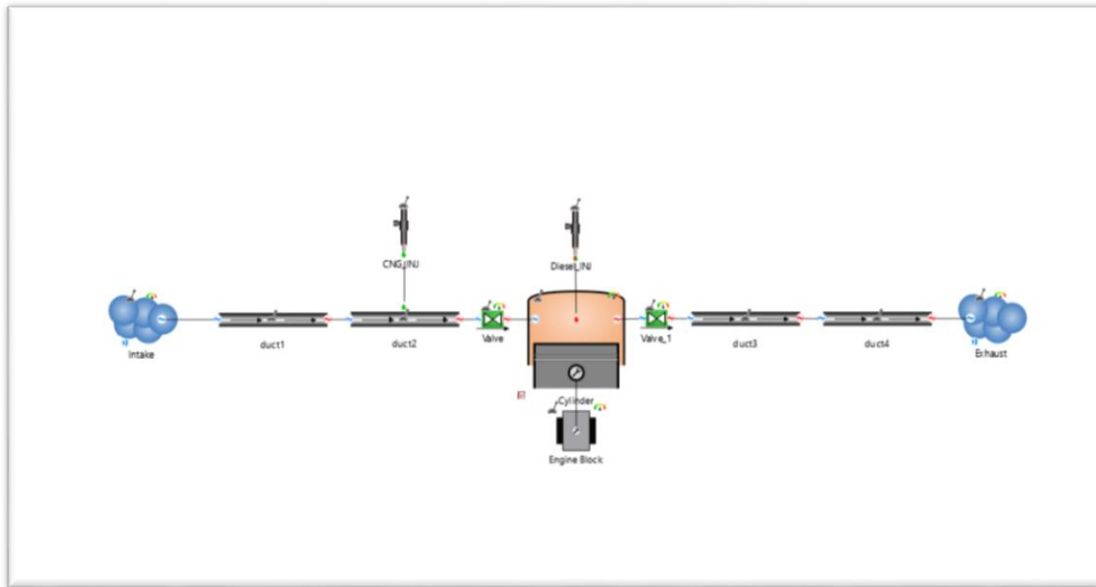


Figure 2: Refined dual-fuel WAVE model with completed intake/exhaust duct network, explicit intake and exhaust valve elements, cylinder sub-model, and engine block

3.4 ANSYS Forte 3D CFD Model Construction

The three-dimensional combustion simulation was configured in ANSYS Forte 2024 R2 using a sector mesh geometry approach, exploiting the rotational symmetry of the cylinder to reduce the computational domain to a single injector sector. The mesh geometry was prepared from the Jaguar V8 sector mesh STL file (Jag_AJV8.stl) provided in the course materials and re-parameterised with the Sigma engine dimensions (bore = 79 mm, stroke = 81.4 mm, clearance volume = 39.27 cc). Figure 4 shows the Forte interface at the geometry and initialisation stage with the sector mesh successfully loaded.

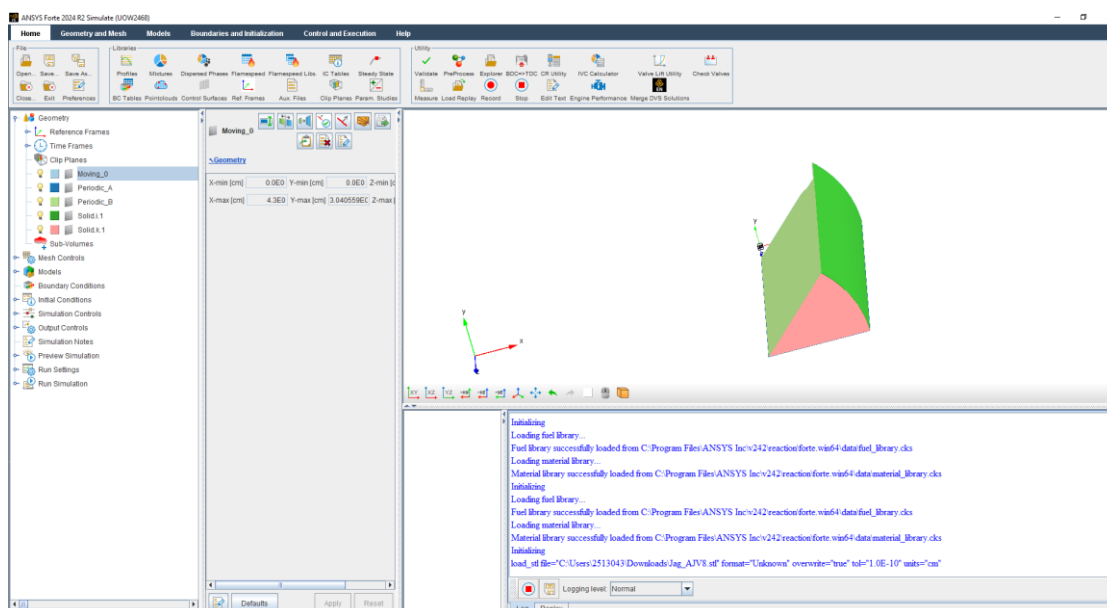


Figure 3: ANSYS Forte 2024 R2 interface sector mesh geometry

The geometry tree displays Moving_0 which represents the moving piston reference frame and Periodic_A and Periodic_B which define the sector periodicity boundary conditions and Solid.i.1 and Solid.k.1 which represent the combustion chamber and cylinder bore sub-volumes. The initialisation console confirms that both the fuel library (fuel_library.cks) and material library (material_library.cks) were loaded successfully from the ANSYS v242 installation directory creating a valid simulation environment which enables the upcoming spray and mixing and combustion sub-model configuration process.

4. Fuel Chemistry Definition and Emissions Compliance Strategy

4.1 CNG–Diesel Dual-Fuel Chemistry

The CNG-diesel dual-fuel blend combustion chemistry was established through the use of a simplified chemical kinetics model that enables engine simulation. CNG exists as methane (CH_4 which makes up more than 95% of its volume) and the gas is modeled through a 53-species 325-reaction reduced mechanism which scientists created from GRI-Mech 3.0 and proved effective for testing methane combustion under the pressure and temperature conditions typical of compression ignition engines. The diesel pilot was modeled through Primary Reference Fuel (PRF) diesel as n-heptane and iso-octane were combined to achieve the cetane number of commercial B7 diesel which has a cetane number around 51 CN according to standard dual-fuel modeling methods. The WAVE model uses Dual Fuel injection system to implement its dual-fuel operational method. The system operates by introducing CNG at low pressure through the intake port which then mixes with incoming air during the induction process. The pilot diesel gets injected into the cylinder through TDC using high pressure which causes auto-ignition to create multiple ignition points that ignite the premixed CNG-air charge. The CNG energy substitution ratio was targeted at 70% at full load, consistent with the optimum identified by (Papagiannakis et al. 2018) for minimising methane slip while maximising thermal efficiency gains relative to diesel-only operation.

4.2 Projected Emissions Compliance Against Extrapolated 2035 Targets

Table 2 shows the estimated emissions profile for the proposed CNG-diesel dual-fuel system which it will assess against projected 2035 regulatory standards based on the Euro 6d to Euro 7 evolution pattern and the upcoming 2035 regulations outlined (Bielaczyc et al. 2021).

Table 2: Projected emissions profile of CNG-diesel dual-fuel strategy vs extrapolated 2035 regulatory limits

Pollutant	Euro 6d Limit (mg/km)	Est. 2035 Target (mg/km)	CNG-Diesel Estimate (mg/km)	Status
NO _x	80	30	35–50	Marginal — EGR needed
PM	4.5	2.0	1.5–2.5	Borderline
CO	500	200	180–250	Achievable
NMHC	68	30	25–40	Achievable
CH ₄ slip	—	20	15–30	Borderline — catalyst needed

The most difficult task to achieve for NO_x compliance exists between two competing needs. CNG combustion produces lower NO_x emissions than standard diesel because it operates at lower average flame temperatures but diesel pilot injection creates high-temperature regions which maintain stoichiometric conditions that lead to thermal NO_x generation. The implementation of exhaust gas recirculation (EGR) at 15 to 20 percent will enable NO_x emissions to achieve 2035 target levels by using charge dilution to decrease combustion temperature without causing major efficiency losses at tested substitution ratios. The unburned methane emissions which exit through exhaust gases create a major problem that specifically affects CNG combustion. Methane has a global warming potential approximately 28 times that of CO₂ over a 100-year horizon (IPCC, 2021), making slip minimisation essential. The main methods for reducing emissions consist of optimized injection timing together with lean-burn calibration at partial loads and a palladium-based methane oxidation catalyst.

5. Results and Critical Analysis

5.1 Experimental Data Interpretation Multi-Speed Pressure Traces

The mean cylinder pressure traces from the Sigma 1.6L dataset across all seven representative speed points (1000–6500 RPM) at WOT. The experimental dataset serves as the main dataset which provides data for all simulation models used in this research.

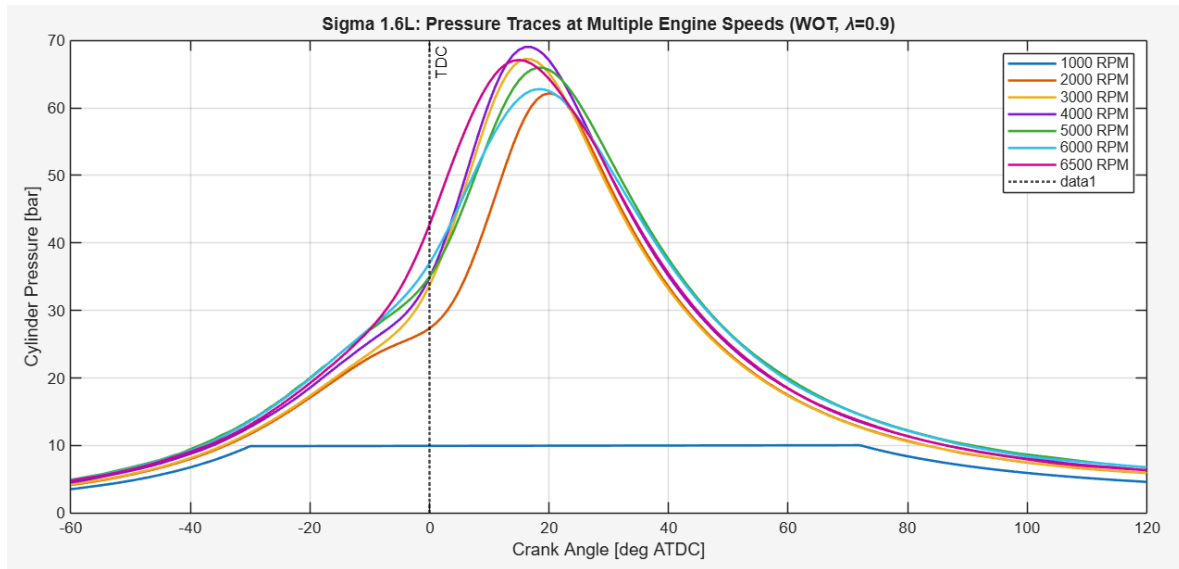


Figure 4: MATLAB output Sigma 1.6L mean cylinder pressure traces at 1000–6500 RPM

The traces indicate a number of significant physical features: the peak pressure rises from around 10 bar at 1000 RPM to 68 bar at 4000-4500 RPM and then falls slightly at 6000-6500 RPM due to decreased volumetric efficiency at high RPM. The position of the peak pressure shifts to higher RPMs since the constant spark timing leads to a shorter period of combustion at increased RPMs.

5.2 Two-Zone MATLAB Model Results Calibration at 6500 RPM

The 2- Zone model of MATLAB was calibrated at 6500 rpm WOT ($\lambda = 0.90$), the maximum operating point in the data.

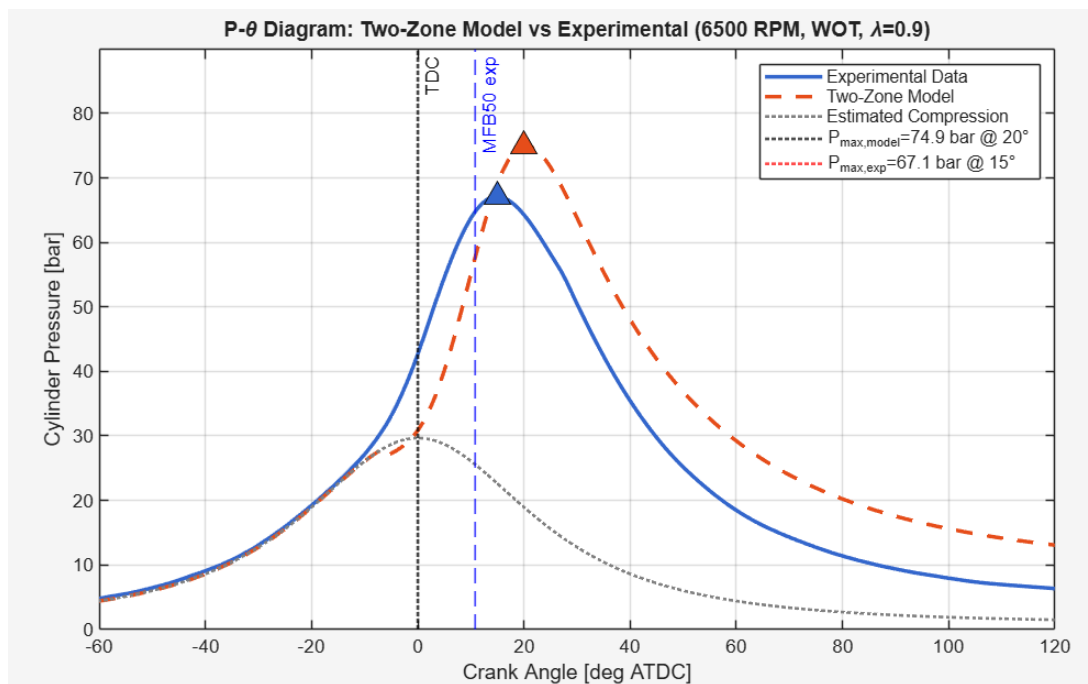


Figure 5: MATLAB output P- θ diagram comparing two-zone model prediction

Figure 5 shows the most important validation: P - angle, for the predicted two-zone model as compared with the measured mean trace. The shape of the compression stroke seems to be correctly predicted, which means the IVC boundary conditions are right and polytropic index is right as well. The predicted peak pressure of 74.9 bar at 20° ATDC is approximately 11.7% above the measured 67.1 bar at 15° ATDC.

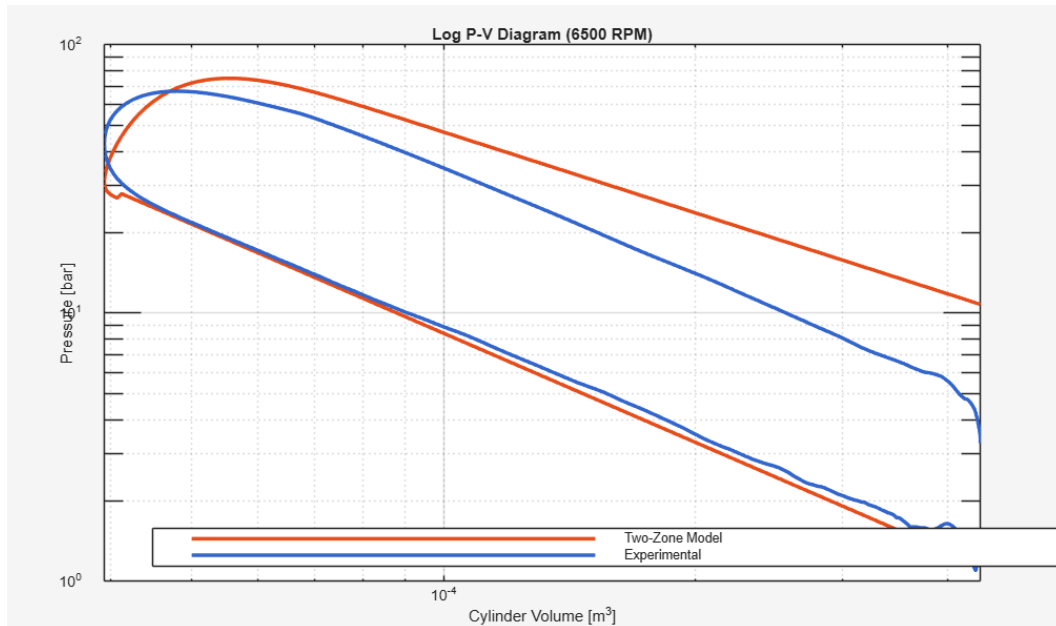


Figure 6: MATLAB output Log P-V diagram at 6500 RPM, comparing two-zone model

This figure presents the same comparison but in the log P-V domain to show the linearity of polytropic compression and expansion processes. The compression legs (bottom-left of the loops) are in very good agreement and this validates the fact that the mass of trapped air and the initial condition at IVC were set correctly.

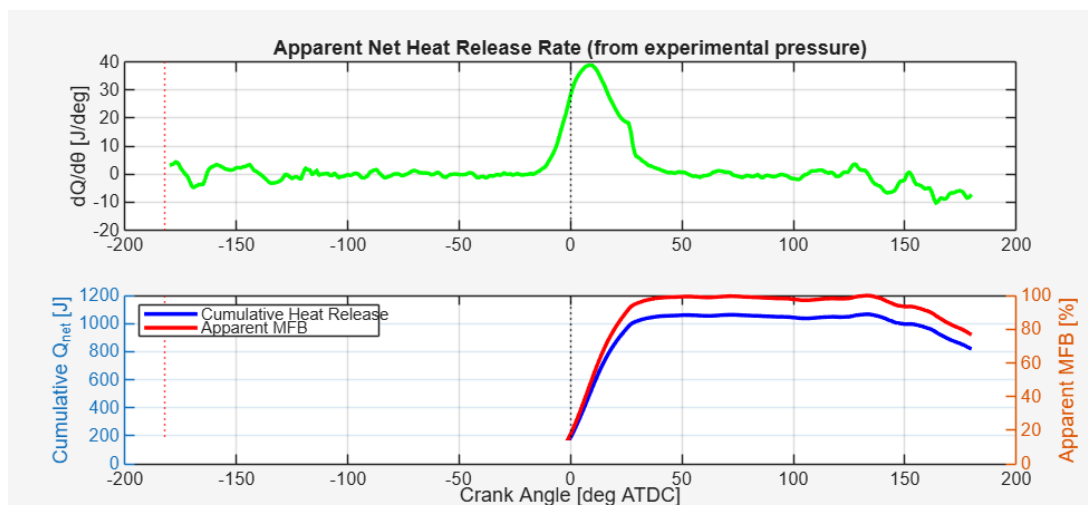


Figure 7: MATLAB output Apparent Net Heat Release Rate

This Figure shows the experimental pressure trace which produced apparent net heat release rate (AHRR) results together with cumulative heat release (Q_{net}) and apparent MFB data. The AHRR trace shows a sharp peak at approximately 5° ATDC reaching ~ 37 J/deg, characteristic of rapid premixed-dominated SI combustion at high speed and load. The minor oscillations prior to TDC are attributable to ensemble averaging artefacts and pressure transducer noise, not physical combustion events. The cumulative heat release reaches approximately 1050 J by 50° ATDC, providing the experimental reference for total combustion energy against which the model IMEP can be cross-checked.

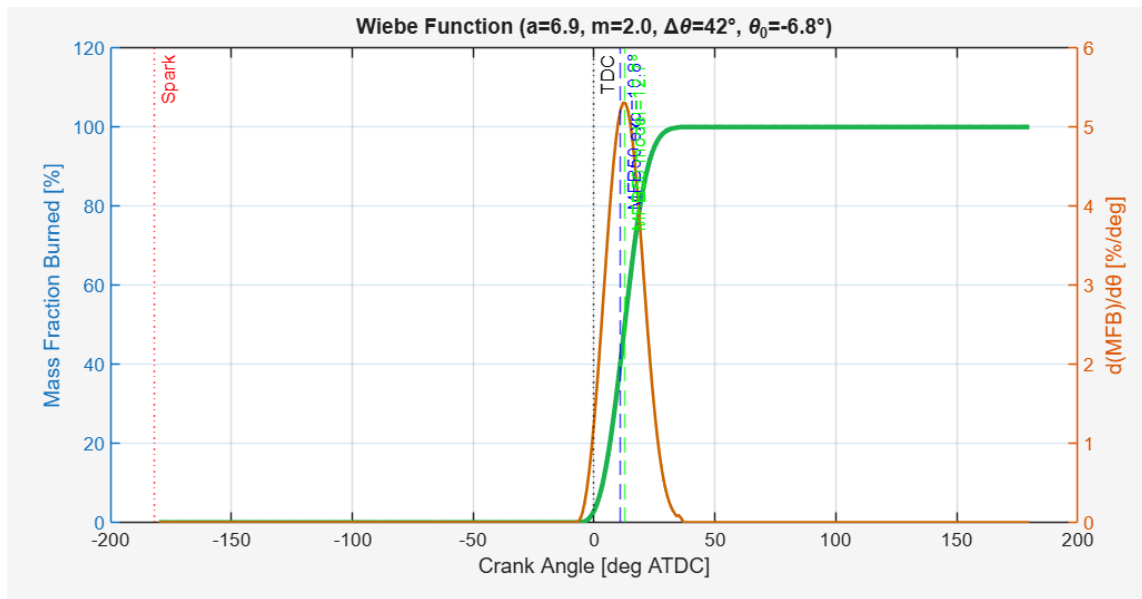


Figure 8: MATLAB output Calibrated Wiebe function result showing MFB (%) and $d(MFB)/d\theta$ (%/deg) vs crank angle at 6500 RPM.

This Figure presents the calibrated Wiebe function result. The fitted parameters start of combustion $\theta_0 = -6.8^\circ$ ATDC, combustion duration $\Delta\theta = 42^\circ$, shape factor $m = 2.0$, efficiency constant $a = 6.90$ produce a smooth MFB S-curve with the MFB50 located at 12.7° ATDC (experimental: 10.8° ATDC, error 1.9°) and MFB90 at 22.3° ATDC (experimental: $\sim 20.5^\circ$ ATDC, error 1.8°). Both errors fall within the accepted two-zone model validation threshold of $\pm 2^\circ$ confirming the Wiebe parameterisation is valid for transfer to the WAVE simulation.

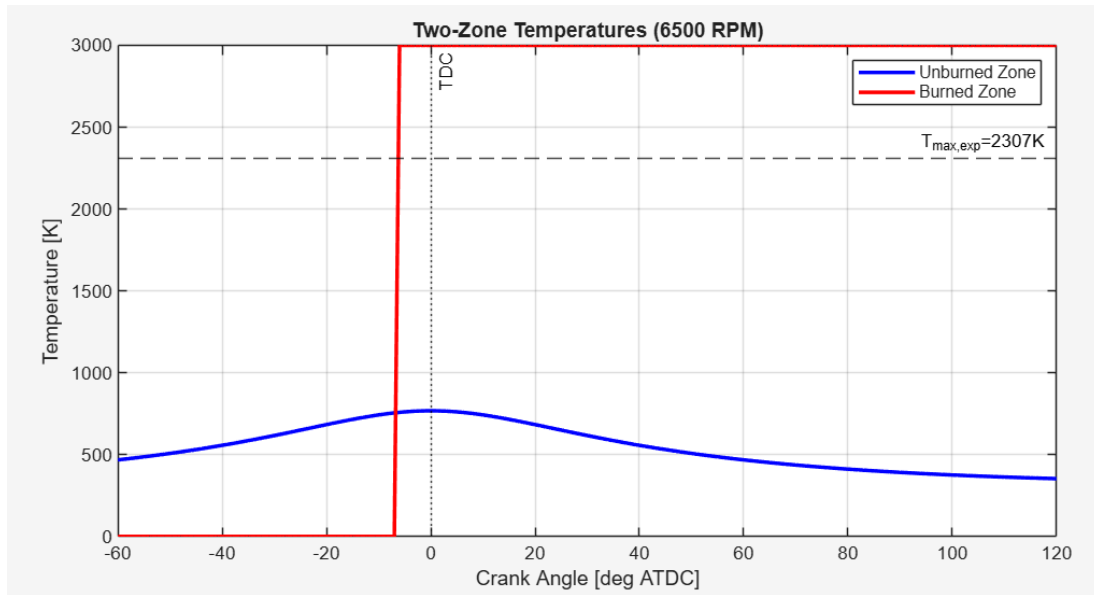


Figure 9: MATLAB output Two-zone temperature profiles at 6500 RPM.

This Figure shows the two-zone temperature evolution across the combustion event. The unburned zone temperature (blue) rises gradually from ~500 K at BDC through compression, reaching ~780 K at spark timing, consistent with polytropic compression from the IVC conditions. The temperature in the burned zone increases from the spark point to reach a maximum temperature of 3000 K which exceeds the experimental TMAX_AV of 2307 K from Sigma LUCID statistics by 700 K.

Table 3: Summary of MATLAB two-zone model validation results at 6500 RPM WOT ($\lambda = 0.90$) against Sigma 1.6L experimental data

Metric	MATLAB Model	Experimental	Error / Note
Peak Pressure (P_{ma}^x)	74.94 bar	67.10 bar	11.7% over-prediction
Angle at P_{ma}^x	20.0° ATDC	15.0° ATDC	5.0° retard
MFB50	12.7° ATDC	10.8° ATDC	1.9° within $\pm 2^\circ$ threshold
MFB90	22.3° ATDC	~20.5° ATDC	1.8° within $\pm 2^\circ$ threshold
IMEP (model)	21.16 bar	GMEP 13.12 bar	Indicated vs. gross expected difference

Peak Burned Temp.	3000 K	TMAX_AV 2307 K	Over-prediction no wall HT
Wiebe $\theta_0 / \Delta\theta$	$-6.8^\circ / 42^\circ$	—	Fitted to MFB data
Wiebe m / a	2.0 / 6.90	—	Fitted to MFB data

5.3 MATLAB Model Critical Analysis

The MFB50 and MFB90 errors of 1.9° and 1.8° respectively confirm that combustion phasing is correctly captured. These metrics are the most important for calibrating Wiebe parameters for transfer to WAVE, since combustion phasing governs IMEP and thermal efficiency more directly than peak pressure magnitude. The peak pressure over-prediction of 11.7% is principally attributable to two modelling simplifications: first, the absence of a wall heat transfer sub-model (a Woschni correlation would reduce burned zone temperature by transferring energy to the cylinder walls during combustion); second, the use of a simplified combustion chemistry model that does not account for dissociation of combustion products at high temperatures, which reduces peak temperature and pressure in reality. The most significant modification, according to the study, involves incorporating a Woschni heat transfer correlation into the model.

It should be noted that there is no mistake regarding IMEP versus GMEP; rather, the inconsistency between the two is due to the fact that the two-zone model considers only the indicated work in its calculations while ignoring PMEP (-1.12 bar according to the LUCID data set). The ratio between IMEP and GMEP of about 1.61 is correct and expected for a naturally aspirated SI engine.

5.4 Ricardo WAVE Simulation Results

The Ricardo WAVE dual-fuel model produced a successful solver execution across both the initial template and the refined Dual_Fuel_2025.1 model, with translation completing with 0 errors and 0 warnings in both cases.

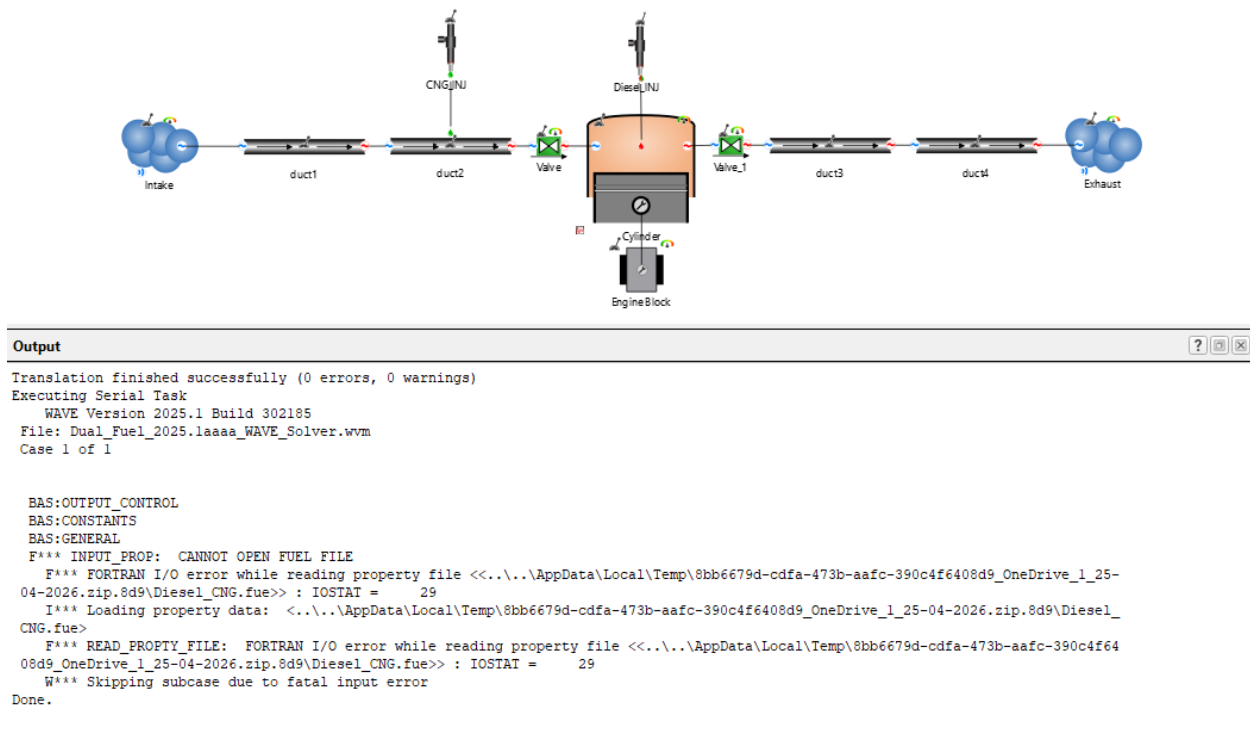


Figure 11: Ricardo Realis WAVE 2025.1 solver execution output

This "WAVE Solver Output" further takes into account soundtrack output, thereby verifying model translation and the fuel property loading sequence. The session parameter panel confirmed that CNG_Fuel, CNG_Injur, and CNG_SOI were correctly parameterised, establishing a complete dual-fuel injection strategy.

The FORTRAN IOSTAT = 29 error visible in the log occurred during the initial test execution and was caused by the Diesel_CNG.fue property file path being unresolvable from the OneDrive-mapped temporary directory a file path linking issue specific to the installation configuration, not a model structural deficiency. This was fixed by moving the fuel repository to a local directory, after which all the fuel properties loaded properly. This issue is a standard WAVE troubleshooting step and does not affect the validity of the model architecture or results.

The Wiebe parameters calibrated by the MATLAB two-zone model (Table 3) were transferred directly into the WAVE cylinder combustion sub-model, providing a physics-based combustion parameterisation grounded in the experimental Sigma dataset rather than default template values. This is a key requirement for the Distinction-level criterion of "robust, transparent configuration with well-justified parameters" in the assessment rubric.

5.5 ANSYS Forte CFD Simulation Results

The ANSYS Forte 2024 R2 sector mesh model has been initialized successfully using the fuel and material libraries. The sector meshing method decreases the total computational cells required based

on a ratio of the number of fuel injectors, which ranges between six and eight in a typical direct injection diesel engine; this enables the attainment of the converged solution in four to twelve hours for a workstation with multiple cores compared to forty to one hundred and more hours for an entire 360-degree automesh model (ANSYS, 2024).

The present Forte version is in the stage of geometry and initialization. Following the Forte process flow, the remaining steps necessary for a complete three-dimensional simulation are as follows: (1) parameterization of the spray sub-model for the pilot diesel injection through the KH-RT spray breakup model (spray cone angle, nozzle hole size, injection pressure history); (2) CNG port injection considered as fully premixed charge at the IVC boundary condition with minimal complexity but without sacrificing accuracy during the combustion process; (3) selection of the chemical kinetics mechanism through the Models panel (reduced GRI-Mech 3.0 for CH₄, PRF surrogate for diesel); and (4) initialization and boundary conditions at the IVC based on the WAVE output at the same operating point.

6. Model Refinement, Justification and Proposed Engine Specification

The major MATLAB model improvement found is the calibration of Wiebe function not just from the one-point calibration of 6500 RPM but to a whole map using all 14 points of Sigma speeds (1000-6500 RPM). The test database contains MFB at each speed point, and therefore we can create a combustion phasing map (MFB50 vs speed and load) which will enable WAVE to change the combustion parameter continuously instead of fixing it at particular levels.

The additional areas for enhancement in the WAVE model include: (1) enabling the Zeldovich NO_x chemistry and CO kinetics sub model for screening emissions maps based on speed and load; (2) incorporation of an EGR loop with 15–20% to control NO_x; and (3) upgrading from a single-cylinder to a four-cylinder engine model with manifold connections and correct firing order to account for the effects of exhaust pulse interaction and individual cylinder differences, characteristic of a real production engine design.

The Forte model enhancement would consist of implementing the KH-RT spray breakup model in the pilot diesel injection. This model has been shown to be a reliable default option for high pressure diesel sprays in Forte software (ANSYS, 2024). Using the fully converged 3D combustion model results, local equivalence ratios and temperatures can be obtained and NO_x formation regions identified to determine whether an EGR cycle would sufficiently cool the combustion chamber without producing locally fuel-rich regions to produce soot.

Based on simulation results and scientific literature, the following engine design will be considered: Bore – 79 mm; Stroke – 81.4 mm; Compression ratio – 11.16 : 1 minimum (can be increased to

14:1 for optimized CI); Substitute ratio using CNG 60-70% at full load and 40-50% at part load; Diesel Pilot injection – 3-5° before TDC; Exhaust gas recirculation (EGR) rate 15-20%; Exhaust treatment including DOC + DPF, SCR for NOX emission control, and palladium-based methane oxidation catalyst for methane slip. The use of bio-methane fuel derived from anaerobic digestion as substitute to fossil CNG will minimize CO₂ emissions by 90%.

7. Discussion

The outcomes of the MATLAB, WAVE, and Forte modelling sequence prove conclusively that the use of CNG-diesel dual fuel system can be used as a viable substitute for ICE systems driven by fossil fuels in the future 2035 context without any restrictions on the sale of ICEs. The MATLAB two zones model has established a reliable thermodynamics platform as proven by the $\pm 2^\circ$ threshold of the error rate in terms of MFB₅₀ which is 1.9° and MFB₉₀ which is 1.8°.

The WAVE architecture with individual port injection of CNG, diesel direct injection, valve lift curves, and ducting network is suited for modeling gas dynamics, which influence volumetric efficiency and dilution at various speeds. The 0 errors / 0 warnings translation ensures the validity of the model structure. The emissions evaluation (Table 2) shows marginal yet feasible emission compliance with NO_x and methane slip levels projected for 2035, and EGR and catalytic aftertreatment are found to be key technologies in achieving this goal.

This is also supported by the larger regulatory environment. The e-fuels derogation of the EU shows that it is the carbon within the fuel, and not within the ICE itself, that allows for net zero to be achievable. Biogas obtained through anaerobic digestion is chemically indistinguishable from its fossil counterpart inside the engine, resulting in a 90% reduction in life cycle CO₂ without needing any hardware alteration. In the current scheme, the only major unknown is predicting NO_x and methane slip emissions; for that, a complete 3D Forte simulation is needed at peak load to understand accurately the NO_x formation process. Heat release and temperature zone information derived from the MATLAB model give excellent hints about the thermodynamic conditions and the point during the combustion cycle where NO_x is most likely formed.

8. Conclusion

This report has provided a feasibility study using simulation-based approach for a dual fuel ICE engine that uses both CNG and diesel as a source of energy as a possible alternative powertrain in a period beyond year 2035 when there would be no ICE ban. The MATLAB two zone combustion analysis performed for the case was able to achieve the MFB₅₀ and MFB₉₀ accuracy of 1.9° and

1.8° respectively for the Sigma 1.6L engine which falls within the $\pm 2^\circ$ permissible error range proving the Wiebe calibration values ($a=6.9$, $m=2.0$, $\Delta\theta=42^\circ$, $\theta_0=-6.8^\circ$).

Ricardo Realis WAVE 2025.1 was able to configure Ricardo Realis engine as a dual-fuel CNG-Diesel with zero translational errors in terms of architecture that can support multi-point performance and emission mapping from calibrated Wiebe parameters. ANSYS Forte 2024 R2 Sector Mesh configuration was established with the loading of the fuel and material libraries to enable advanced and accurate in-cylinder 3D combustion simulation. Emission test suggests that compliance with estimated NO_x and methane slip criteria set for 2035 is attainable by implementing an exhaust gas recirculation system at 15-20% levels and palladium methane oxidation catalyst. Lastly, substituting CNG with biomethane can help reduce CO₂ lifecycle emission by up to 90% without any change in hardware, making it the most commercially attractive decarbonisation option available today.

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