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CFD and Emissions Modelling

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Abstract

A study was conducted using Wave and Forte to assess the feasibility of different fuels including E5, E85 and hydrogen for the Ford 1.6L Sigma. Increasing emission reduction legislation threatens the manufacturing of traditional internal combustion engines. Thus, this study aims to assess the characteristics and emissions of alternative fuels. Results from the E5 simulation were used to validate the engine model before alternative fuels were assessed. The simulation had a peak cylinder pressure within 3% of the true value. Thus, the model was deemed valid. The model was then used to assess E85 and hydrogen fuels. E85 showed reduced peak pressure and conflicting peak temperature values between the Wave and Forte simulations. Hydrogen exhibited rapid combustion and eliminated carbon-based emissions, although modelling inconsistencies were observed. The results highlighted the potential of alternative fuels while emphasising the need for further research.

Table of Contents

1.0	Introduction.....	8
2.0	Literature Review.....	9
2.1	Emission Regulations	9
2.2	Four-Stroke Engines	10
2.3	Alternative Fuels	11
2.3.1	E5, E10 and E85.....	11
2.3.1	Hydrogen	14
2.4	Fuel Chemistry Modelling.....	15
2.2	Engine Modelling in Forte and Wave	16
3.0	Methodology	17
3.1	Assumptions	17
3.2	Forte for E5 Validation.....	17
3.3	Wave for E5	18
3.4	Forte for E85.....	18
3.5	Wave for E85	19
3.6	Forte for Hydrogen.....	19
3.7	Wave for Hydrogen	20
4.0	Results	21
4.1	Real-world Engine Dyno Study	21
4.2	Forte for E5.....	24
4.3	Wave for E5	27
4.4	Forte for E85.....	29
4.5	Wave for E85	32
4.6	Forte for Hydrogen.....	35
4.7	Wave for Hydrogen	37

5.0	Analysis	40
5.1	Real-World Engine Dyno Study	40
5.2	Forte for E5	40
5.3	Wave for E5	40
5.4	Forte for E85	41
5.5	Wave for E85	42
5.6	Forte for Hydrogen	42
5.7	Wave for Hydrogen	43
6.0	Discussion & Conclusions	44
6.1	Strengths and Weaknesses	44
6.2	Future Work	44
7.0	References	45
7.1	Work Citations.....	45
7.2	Bibliography	48
8.0	Appendices.....	50
8.1	Engine Specifications.....	50

Table of Figures

Figure 1: Crank Angle against in Cylinder Volume from Engine Dyno Experiment....	21
Figure 2: Crank Angle against in Cylinder Pressure from Engine Dyno Experiment .	22
Figure 3: Cylinder Volume against in Cylinder Pressure from Engine Dyno Experiment	22
Figure 4: Cylinder Volume against in Cylinder Log Pressure from Engine Dyno Experiment	23
Figure 5: RPM against Crank Angle against Cylinder Pressure from Engine Dyno Experiment	23
Figure 6: Crank Angle against in Cylinder Volume from Forte E5 Simulation	24
Figure 7: Crank Angle against in Cylinder Pressure from Forte E5 Simulation	24
Figure 8: Crank Angle against in Cylinder Temperature from Forte E5 Simulation	25
Figure 9: Crank Angle against Unburnt Hydrocarbons Mass Fraction from Forte E5 Simulation	25
Figure 10: Crank Angle against Reactant and Product Mass Fraction from Forte E5 Simulation	26
Figure 11: Crank Angle against Burn Features from Forte E5 Simulation	26
Figure 12: Weibe Function Graph Calculated for Wave from Forte for E5	27
Figure 13: Engine Speed against Maximum Pressure from Wave E5 Simulation	27
Figure 14: Engine Speed against Maximum Temperature from Wave E5 Simulation	28
Figure 15: Engine Speed against Exhaust Air Mass from Wave E5 Simulation	28
Figure 16: Engine Speed against Residual Gas Fraction from Wave E5 Simulation	28
Figure 17: Engine Speed against Fuel Mass and Exhaust Air Mass from Wave E5 Simulation	29
Figure 18: Crank Angle against in Cylinder Volume from Forte E85 Simulation	29
Figure 19: Crank Angle against in Cylinder Pressure from Forte E85 Simulation	30
Figure 20: Crank Angle against in Cylinder Temperature from Forte E85 Simulation	30
Figure 21: Crank Angle against Unburnt Hydrocarbons Mass Fraction from Forte E85 Simulation	31
Figure 22: Crank Angle against Reactant and Product Mass Fraction from Forte E85 Simulation	31

Figure 23: Crank Angle against Burn Features from Forte E85 Simulation	32
Figure 24: Weibe Function Graph Calculated for Wave from Forte for E85	32
Figure 25: Engine Speed against Maximum Pressure from Wave E85 Simulation ..	33
Figure 26: Engine Speed against Maximum Temperature from Wave E85 Simulation	33
Figure 27: Engine Speed against Exhaust Air Mass from Wave E85 Simulation	33
Figure 28: Engine Speed against Residual Gas Fraction from Wave E85 Simulation	34
Figure 29: Engine Speed against Exhaust Air Mass from Wave E85 Simulation	34
Figure 30: Crank Angle against in Cylinder Volume from Forte Hydrogen Simulation	35
Figure 31: Crank Angle against in Cylinder Pressure from Forte Hydrogen Simulation	35
Figure 32: Crank Angle against in Cylinder Temperature from Forte Hydrogen Simulation	36
Figure 33: Crank Angle against Reactant and Product Mass Fraction from Forte Hydrogen Simulation	36
Figure 34: Crank Angle against Burn Features from Forte Hydrogen Simulation	37
Figure 35: Weibe Function Graph Calculated for Wave from Forte for Hydrogen	37
Figure 36: Engine Speed against Maximum Pressure from Wave Hydrogen Simulation	38
Figure 37: Engine Speed against Maximum Temperature from Wave Hydrogen Simulation	38
Figure 38: Engine Speed against Exhaust Air Mass from Wave Hydrogen Simulation	38
Figure 39: Engine Speed against Residual Gas Fraction from Wave Hydrogen Simulation	39
Figure 40: Engine Speed against Fuel Mass and Exhaust Air Mass from Wave Hydrogen Simulation	39

Table of Tables

Table 1: Fuel Chemistry and Information	12
Table 2: Shell V-Power Unleaded Fuel Blend used in Forte Initial Model	18
Table 3: E85 Fuel Blend used in Forte Simulation	19
Table 4: Hydrogen Fuel used in Forte Simulation	19
Table 5: Engine Technical Data for the Ford 1.6L Sigma straight-four engine	50

Table of Equations

Equation 1: Octane Reaction with Oxygen Chemical Equation	13
Equation 2: Ethanol Reaction with Oxygen Chemical Equation	13
Equation 3: Nitrogen Reactions with Oxygen Chemical Equation	14
Equation 4: Hydrogen Reaction with Oxygen Chemical Equation	15
Equation 5: Weibe Function Formula	15

1.0 Introduction

Research into the use of alternate fuels has increased due to emission regulations such as Euro 7. This study aims to evaluate the performance of E5, E85, and hydrogen fuels for a Ford 1.6L Sigma engine using Forte and Wave to create in-cylinder combustion models. A literature review was conducted to examine and gain information regarding emission regulations, alternative fuels and the engine modelling software to be used for this study. The methodology employed along with the results and critical analysis.

2.0 Literature Review

2.1 Emission Regulations

Global emissions regulations have become progressively more stringent in response to concerns surrounding emissions, particularly those caused by road transport driven by internal combustion engines (ICEs). Pollutants from these engines have been proven to cause negative effects on respiratory health, environmental damage and climate change (World Health Organization, 2021)(Choma *et al.*, 2020). Thus, governing bodies are implementing targets with the aim to reduce emissions from road vehicles.

Euro emissions standards are an example of the aforementioned targets. The European Union aimed to reduce harmful exhaust emissions from road vehicles over time; this started with Euro 1 in 1992. Early standards focused primarily on reducing carbon monoxide and hydrocarbon emissions, while later standards increasingly targeted nitrogen oxides (NO_x). Other Euro standards pushed for the use of catalytic converters in vehicles. Euro 7 legislation focuses on battery durability and emissions limits (European Parliament, 2023).

The UK has set a more extreme target that all new vehicles must be '100% zero emission' from the tailpipe. While the European Commission proposed a 90% reduction. Based on previous environmental targets the UK aligns with the European Commission. Therefore, the UK is unlikely to achieve its goal of 0% by 2035 but may aim for the 90% reduction target. Both these targets are pushing to end the manufacturing of petrol and diesel fuelled vehicles (Department for Transport, 2026).

While electric vehicles produce no tailpipe emissions (thus meet the regulations), studies have shown that the manufacturing and raw material extraction result in

significant environmental impacts (Shang *et al.*, 2026) (Grigoratos and Martini, 2015)(Department for Environment, Food & Rural Affairs, 2018)

Thus, research into alternative fuels is in high demand as other solutions (other than electric car vehicles) must be investigated.

2.2 Four-Stroke Engines

The Ford 1.6L Sigma engine used in this study is a naturally aspirated four-stroke spark ignition (SI) petrol engine. Four-stroke engines are a common combustion type used in road vehicle engines due to their efficiency, durability and ability to limit emissions.

A four-stroke engine completes one full power cycle over 720° of crank angle rotation (Heywood, 2018). A power cycle is made up of four strokes: intake, compression, power, and exhaust. During the intake stroke, the intake valve opens while the piston moves from top dead centre (TDC) to bottom dead centre (BDC). This draws the air–fuel mixture into the cylinder. During compression, the intake and exhaust valves remain closed while the piston moves from BDC to TDC. This compresses the air–fuel mixture in the cylinder. Near the end of the compression stroke, the spark plug ignites the compressed air–fuel mixture; this initiates the power stroke. Combustion of the fuel increases cylinder pressure and temperature, forcing the piston to move from TDC to BDC. Accurate simulation of in-cylinder pressure is a key feature of an accurate simulation as it greatly influences the combustion characteristics of the engine. The final stage is when the exhaust valve opens and the piston moves from BDC to TDC.

Irrespective of the advantages of four-stroke spark ignition, this engine type may not be viable with the future emissions legislation without research into alternative fuels. Disadvantages of this engine include (Heywood, 2018):

- Emissions of NO_x particularly when combustion temperatures are high
- Unburnt hydrocarbons and carbon monoxide can be released due to incomplete combustion

The long-term viability of four-stroke petrol engines depends on the development of alternative fuels and improved combustion strategies with respect to emissions. Fuels such as hydrogen offer the potential to eliminate carbon-based exhaust emissions while maintaining the performance characteristics expected from internal combustion engines.

2.3 Alternative Fuels

Alternative fuels is a broad term generally used to refer to any fuel that is not Petrol (pure petrol, E5 and E10) or diesel. In this study on the Ford Sigma engine the fuels simulated were E5, E85 and hydrogen. E5 was selected as it was the fuel used in the real-world dyno experiment (Shell, 2010). Thus, the simulation results from the E5 simulation can be compared with the dynamometer results to assess the accuracy of the model engine. E85 was selected to assess the effect of high ethanol content fuels. Lastly, hydrogen was selected to analyse the behaviour of a non-carbon-based fuel.

2.3.1 E5, E10 and E85

Petrol is a mixture of hydrocarbons (largely alkanes) with a carbon chain length between 4 and 12 (Table 1)(Heywood, 2018). Petrol is often combined with ethanol the two most common blends are E5 and E10. These blends contain a volume percentage of 5% and 10% ethanol respectively (Department for Transport, 2022; Department for Transport, 2024). Using ethanol as an additive has been common practice due to its renewable production potential (fermentation) thus making the fuel

blend more sustainable compared with pure petrol (International Energy Agency, 2023).

To burn fuel with high ethanol percentages the engine requires modification. These modifications include the following:

Increase the injector flow rate as fuel such as E85 have a lower energy density than E5 thus more fuel is required. Engine parts need to be changed if they are not ethanol-safe. Examples of these parts include fuel lines, seals and gaskets. Part changes would be required for real-world modifications but do not affect the simulation (Turns, 2012).

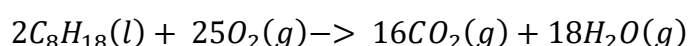
Table 1: Fuel Chemistry and Information

Fuel Name	Chemistry	State
Petrol	C_4H_{10} to $C_{12}H_{26}$	Liquid
Ethanol	C_2H_5OH	Liquid
Petrol E5	C_4H_{10} to $C_{12}H_{26}$ + (5%) C_2H_5OH	Liquid
Petrol E10	C_4H_{10} to $C_{12}H_{26}$ + (10%) C_2H_5OH	Liquid
Petrol E85	C_4H_{10} to $C_{12}H_{26}$ + (85%) C_2H_5OH	Liquid
Iso-Octane	C_8H_{18}	Liquid

Note that Iso-Octane was used to represent petrol. This is a common approximation made in engine simulations (Heywood, 2018)

Equation 1 shows the chemical equations for the reaction between octane and oxygen and Equation 2 shows the chemical equations for the reaction between ethanol and oxygen. From these equations it is known that the burning of petrol and ethanol results in the products carbon dioxide and water. Carbon dioxide is an

undesirable product of combustion as it is known to contribute to climate change. This is one of the gases the emission regulations aim to reduce. Furthermore, these two equations show the theoretical reaction that occurs during combustion. They do not account for other reactions or reactions that do not occur. As stated previously, if the fuel (octane) is not fully burnt -this is often due to limited oxygen- then the hydrocarbon can be released into the atmosphere.



$C_8H_{18}(l)$ =Octane liquid (petrol)

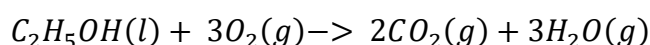
$O_2(g)$ =Diatomic oxygen gas

$CO_2(g)$ =Carbon dioxide gas

$H_2O(g)$ =Dihydrogen monoxide

*Equation 1:Octane
Reaction with
Oxygen Chemical
Equation*

(Heywood,
2018)



$C_2H_5OH(l)$ =Ethanol (alcohol)

$O_2(g)$ =Diatomic oxygen gas

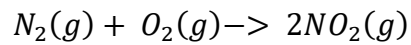
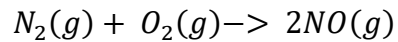
$CO_2(g)$ =Carbon dioxide gas

$H_2O(g)$ =Dihydrogen monoxide

*Equation 2:
Ethanol Reaction
with Oxygen
Chemical Equation*

(Turns, 2012)

Additionally, nitrogen and oxygen (present in the atmosphere) can react when subject to high temperatures. The products shown in Equation 3 can be called NO_x . NO_x gases are known pollutants and are damaging to the environment.



$N_2(g)$ = Diatomic nitrogen gas

$O_2(g)$ = Diatomic oxygen gas

$NO(g)$ = Nitrogen oxide gas

$NO_2(g)$ = Nitrogen dioxide gas

*Equation 3:
Nitrogen Reactions
with Oxygen
Chemical Equation*

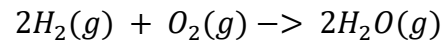
(Heywood,
2018)

2.3.1 Hydrogen

To burn hydrogen in an engine designed for petrol (E5 and E10), modifications are required. Firstly, petrol is liquid when injected while hydrogen is a gas at room temperature thus it is injected into the cylinder in a gaseous state. Furthermore, hydrogen burns faster than petrol (Verhelst and Wallner, 2009) therefore less spark advance is needed.

For real-world applications of hydrogen fuelled vehicles; storage of the fuel within the vehicle is a consideration that must be accounted for. The gaseous hydrogen is held in pressurised tanks. The Toyota Mirai stores hydrogen gas around 700 bar for its fuel cell (Toyota, 2014). This is a more complex and expensive storage method compared with fuel tanks used for petrol and diesel vehicles.

Unlike burning hydrocarbons, burning hydrogen does not directly produce carbon dioxide and if unburnt fuel is released (H_2), it does not negatively affect the environment unlike the release of hydrocarbons. However, nitrogen can still react with oxygen in the atmosphere to produce NO_x (Verhelst and Wallner, 2009).



$H_2(g)$ =Diatomic hydrogen gas

$O_2(g)$ =Diatomic oxygen gas

$H_2O(g)$ =Dihydrogen monoxide

*Equation
4:Hydrogen
Reaction with
Oxygen Chemical
Equation*

Each of the three fuels present advantages and different required engine modifications. E5 offers stable combustion and was used to validate the model. Ethanol improves knock resistance but has a lesser energy density than E5, and hydrogen provides an insight into a non-hydrocarbon-based fuels.

2.4 Fuel Chemistry Modelling

A key equation when considering fuel combustion is the Weibe function (Equation 5). This equation characterises the burn features of the fuel in the chosen engine.

$$x_b(\theta) = 1 - \exp \left[-a \left(\frac{\theta - \theta_{soc}}{\Delta\theta_{dur}} \right)^{m+1} \right]$$

$x_b(\theta)$ =Mass fraction burned

θ =Crankshaft angle (°)

θ_{soc} =Crankshaft angle at start of combustion (°)

$\Delta\theta_{dur}$ =Crankshaft angle range during combustion (°)

a =Efficiency parameter

m =Shape parameter

*Equation 5: Weibe
Function Formula*

(Heywood,
2018)

(Liu and
Dumitrescu,
2019)

2.5 Engine Modelling in Forte and Wave

ANSYS Forte is a three-dimensional computational fluid dynamics (CFD) software that is used to simulate the combustion processes in ICEs. Accurate modelling of in-cylinder pressure, temperature, heat transfer and emissions are all possible information that can be calculated by the software. Due to the high computational cost simulating a full-engine, simplifications are often applied, including modelling only a sector of a single cylinder, assuming constant wall temperatures and using simplified boundary conditions. These assumptions reduce solution time while maintaining sufficient accuracy for combustion validation and fuel comparison studies (Ansys, 2025).

Wave is a one-dimensional engine simulation software used to model gas exchange, combustion, intake and exhaust flow and overall engine behaviour. Unlike Forte, Wave does not model in three-dimensions; instead, mathematical combustion models such as the Wiebe function (Equation 5) are used. This allows a timely simulation of engine performance with lower computational cost (Realis Simulation, 2026).

3.0 Methodology

3.1 Assumptions

Petrol was modelled as iso-octane; this is common practice in engine simulation as simulating the differences in behaviour of all the different carbon chain lengths is a concession made to simplify the simulation without overly compromising the accuracy of the results. Furthermore, the wall temperatures were assumed to be constant at 300K.

3.2 Forte for E5 Validation

A sector of a single cylinder was modelled which represented a cylinder of the Ford 1.6L Sigma straight-four engine. The purpose of this study was to validate the engine and fuel. This engine had a real-world study completed where the crank angle, RPM cylinder volume and cylinder pressure were measured. This information was provided to the author at the start of this project. The results from the real-world study were used to validate this study's engine simulation.

The fuel used in the real-world test was Shell V-Power Unleaded. This fuel was made as a custom fuel blend in Forte based on the specifications given in the product information sheet for this fuel (Shell, 2010). This was not a true representation of the fuel as the information sheet does not state the exact chemical make-up.

Table 2: Shell V-Power Unleaded Fuel Blend used in Forte Initial Model

Chemical Name	Chemistry	Represents
Iso-Octane	C_8H_{18}	95% Petrol in the Fuel
Ethanol	C_2H_5OH	5% Ethanol in the Fuel
Nitrogen	N_2	79% Nitrogen in the atmosphere
Oxygen	O_2	21% Oxygen in the atmosphere

From the information obtained in the Forte simulation the Wiebe function was calculated. This could then be inputted into the Wave simulation.

3.3 Wave for E5

The single cylinder model was made which represented a cylinder of the Ford 1.6L Sigma engine. The Wiebe function values m , θ_{soc} and $\Delta\theta_{dur}$ (shape parameter, crankshaft angle at start of combustion and crankshaft angle range during combustion) were calculated from the Forte simulation and inputted into Wave. A simulation of the cylinders combustion at 1000, 2000, 3000, 4000, 5000 and 6000 revolutions per minute was run.

3.4 Forte for E85

To run the engine on E85 the fuel blend was altered the values seen in Table 3. Additionally, the flow rate was increased due to the lower energy density of E85 compared to E5. If the flow rate had not been increased the engine would have experienced fuel starvation and may have stalled due to the lack of fuel.

Table 3: E85 Fuel Blend used in Forte Simulation

Chemical Name	Chemistry	Represents
Iso-Octane	C ₈ H ₁₈	15% Petrol in the Fuel
Ethanol	C ₂ H ₅ OH	85% Ethanol in the Fuel
Nitrogen	N ₂	79% Nitrogen in the atmosphere
Oxygen	O ₂	21% Oxygen in the atmosphere

3.5 Wave for E85

The Wiebe function values m , θ_{soc} and $\Delta\theta_{dur}$ of E85 combustion were calculated from the Forte simulation and inputted into Wave. A simulation of the cylinder's combustion at 1000, 2000, 3000, 4000, 5000 and 6000 revolutions per minute was run.

3.6 Forte for Hydrogen

To run the engine on hydrogen the fuel combustion physics was changed from a liquid to gaseous and the fuel chemistry was altered the values seen in Table 4. In addition, the spark ignited at -10° (crankshaft angle) opposed to the -50° used for the petrol blend fuels. The spark was active for 10° when burning hydrogen. This was a decrease in duration from the petrol blends which sparked for 20°.

Table 4: Hydrogen Fuel used in Forte Simulation

Chemical Name	Chemistry	Represents
Hydrogen	H ₂	100% of the Fuel
Nitrogen	N ₂	79% Nitrogen in the atmosphere
Oxygen	O ₂	21% Oxygen in the atmosphere

3.7 Wave for Hydrogen

The Wiebe function values m , θ_{soc} and $\Delta\theta_{dur}$ of hydrogen combustion were approximated from other hydrogen combustion studies as the required information to calculate these values was not extracted from the Forte simulation. A simulation of the cylinder's combustion at 1000, 2000, 3000, 4000, 5000 and 6000 revolutions per minute was run.

4.0 Results

4.1 Real-world Engine Dyno Study

Data for the engine dyno study was given to the author at the conception of this project.

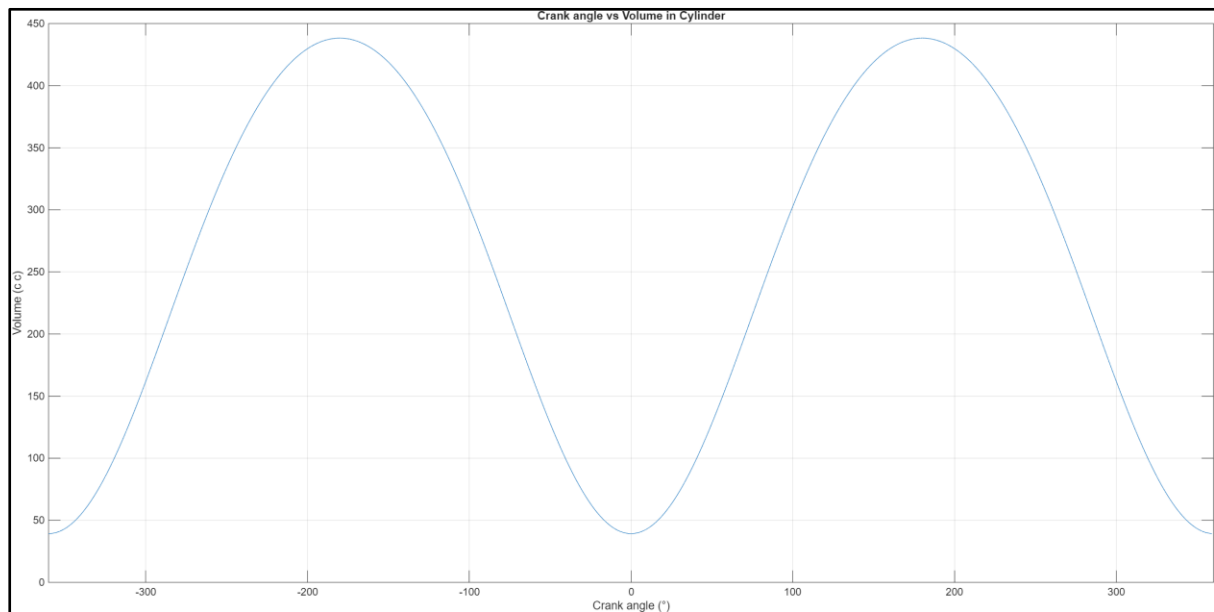


Figure 1: Crank Angle against in Cylinder Volume from Engine Dyno Experiment

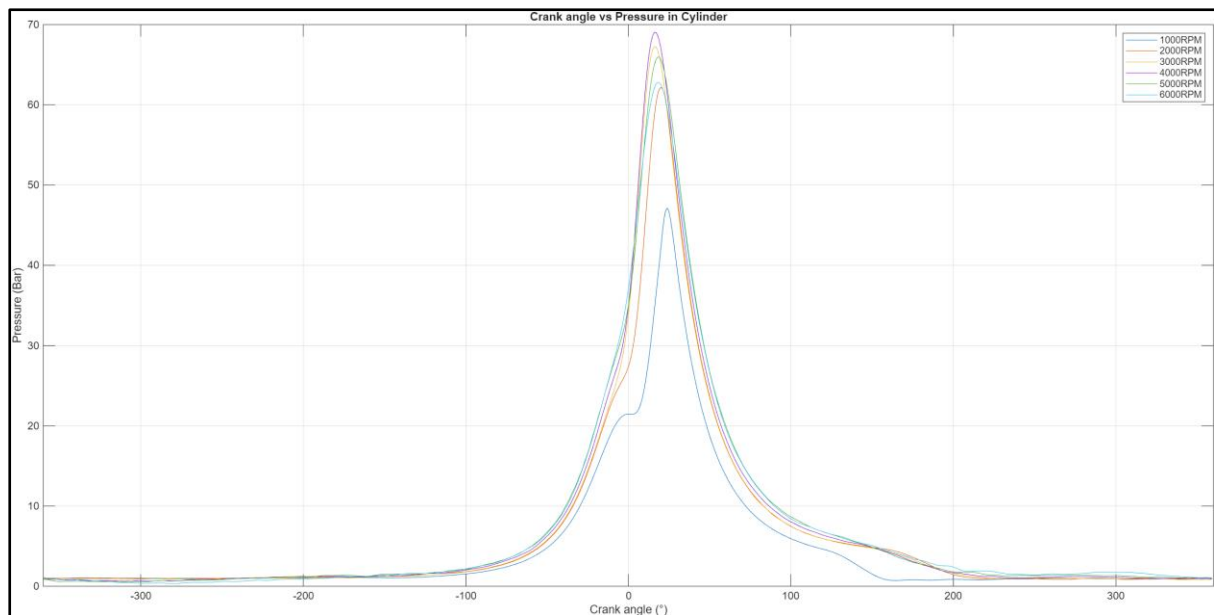


Figure 2: Crank Angle against in Cylinder Pressure from Engine Dyno Experiment

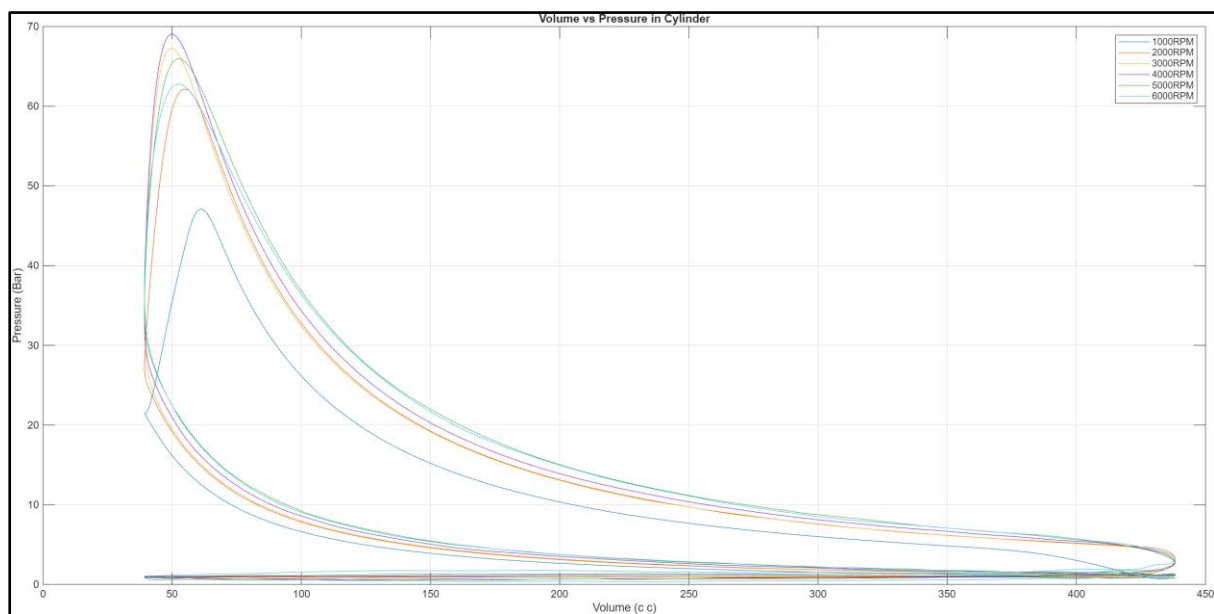


Figure 3: Cylinder Volume against in Cylinder Pressure from Engine Dyno Experiment

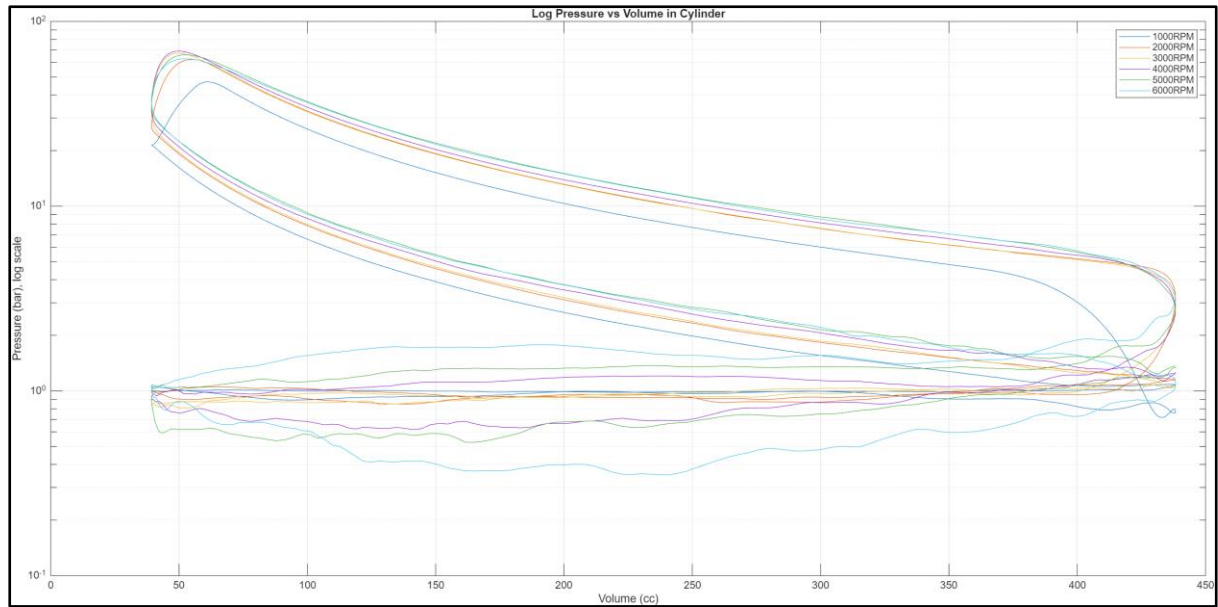


Figure 4: Cylinder Volume against in Cylinder Log Pressure from Engine Dyno Experiment

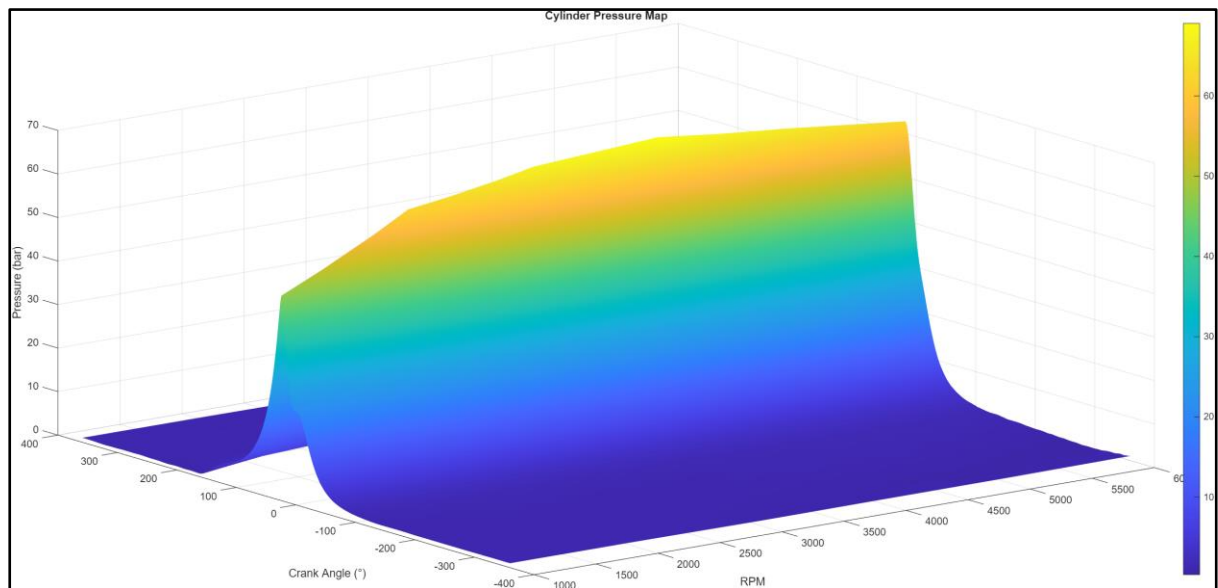


Figure 5: RPM against Crank Angle against Cylinder Pressure from Engine Dyno Experiment

4.2 Forte for E5

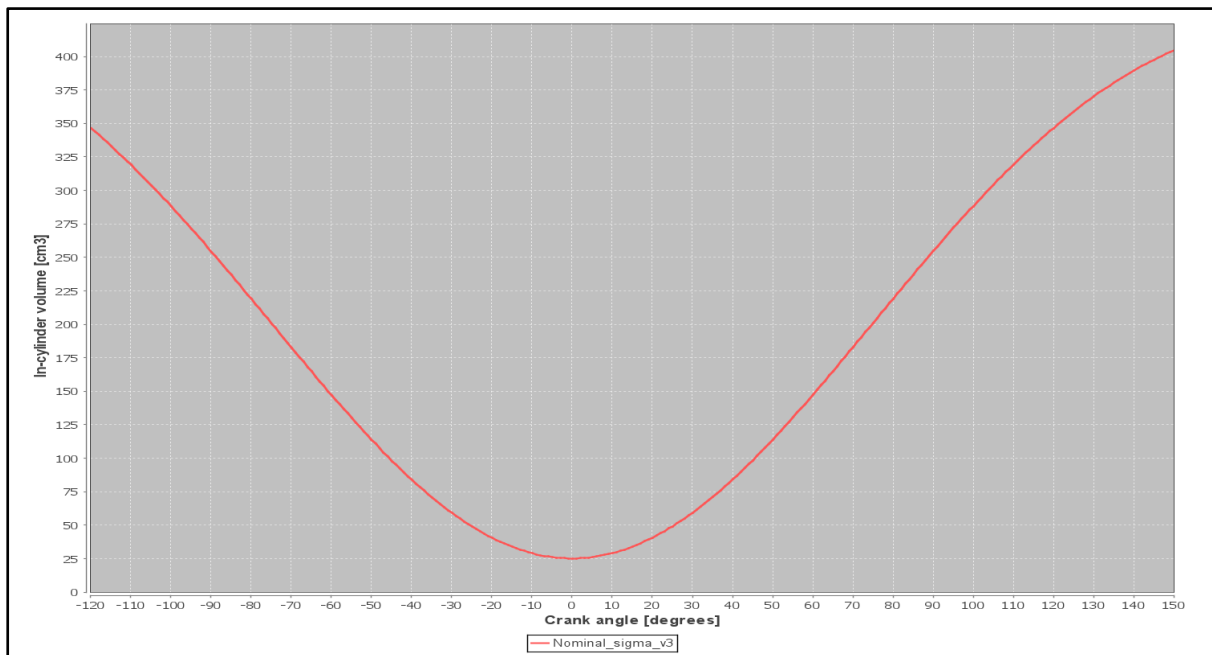


Figure 6: Crank Angle against in Cylinder Volume from Forte E5 Simulation

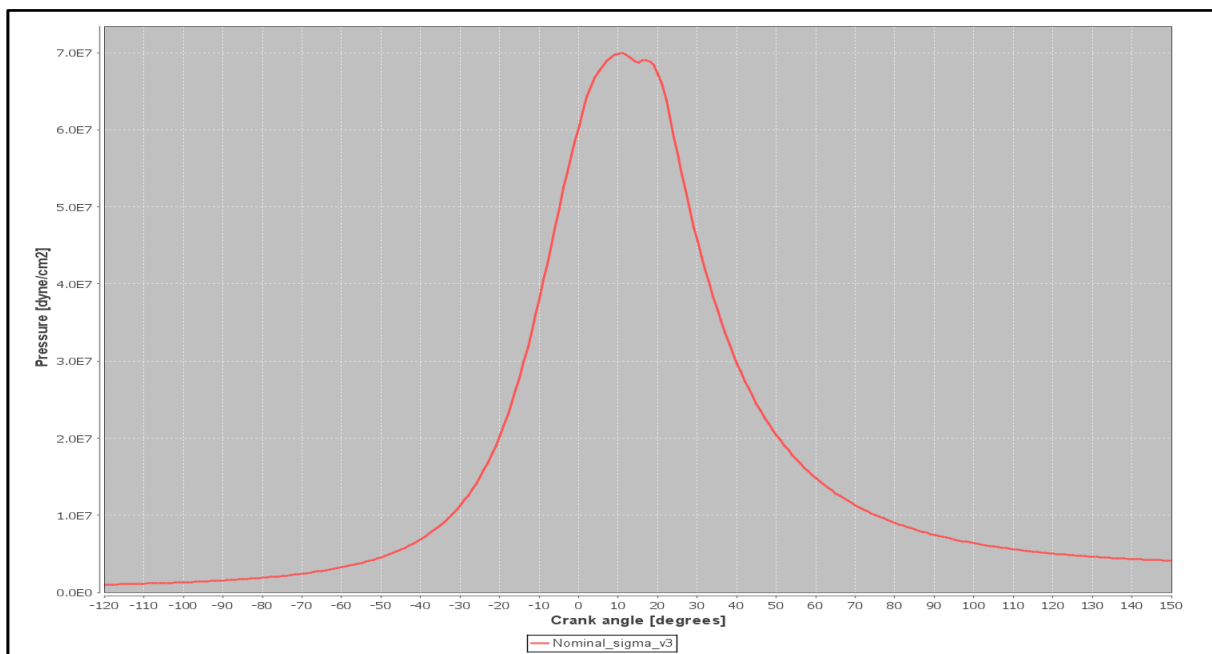


Figure 7: Crank Angle against in Cylinder Pressure from Forte E5 Simulation

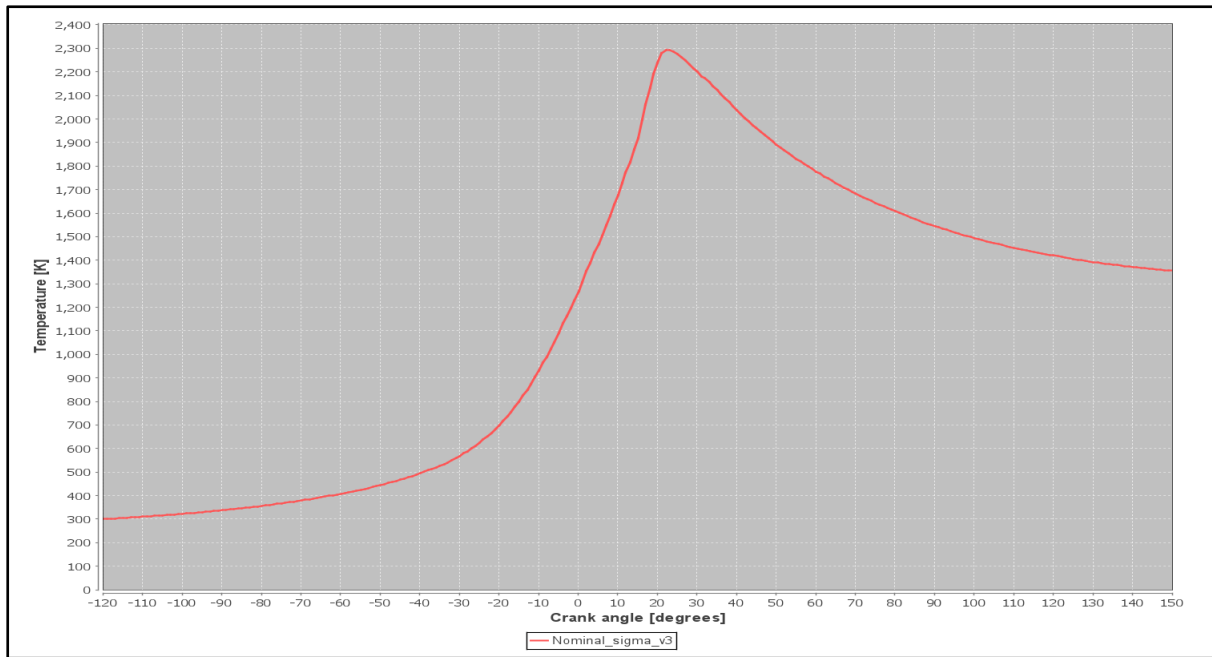


Figure 8: Crank Angle against in Cylinder Temperature from Forte E5 Simulation

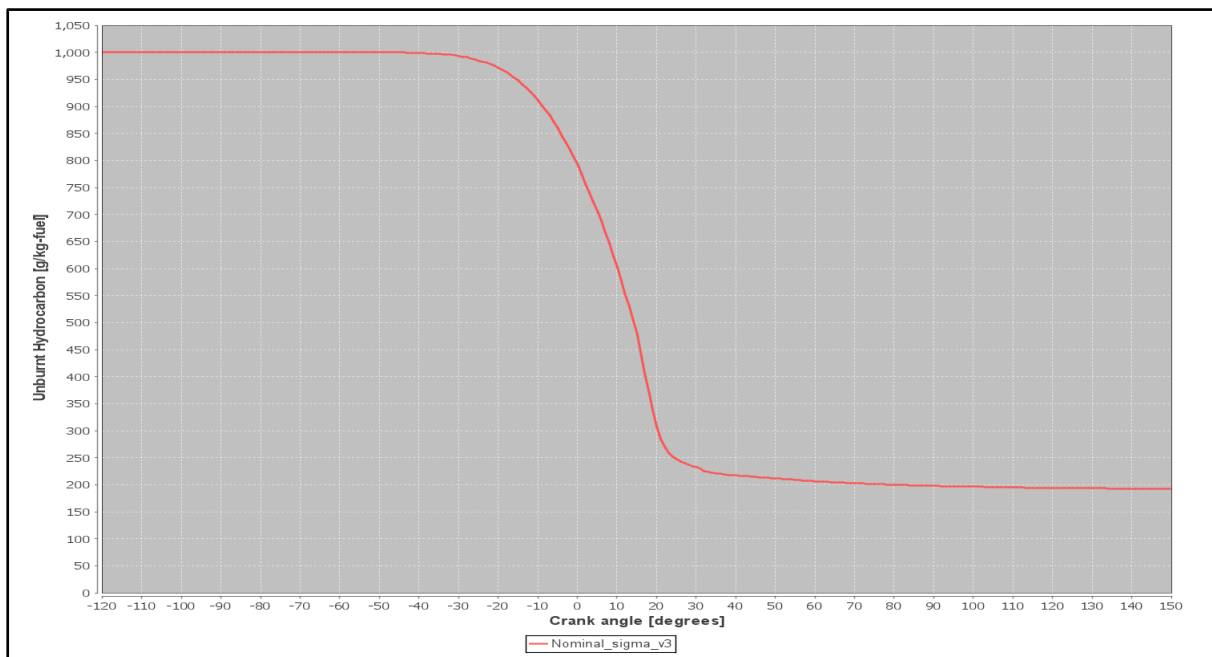


Figure 9: Crank Angle against Unburnt Hydrocarbons Mass Fraction from Forte E5 Simulation

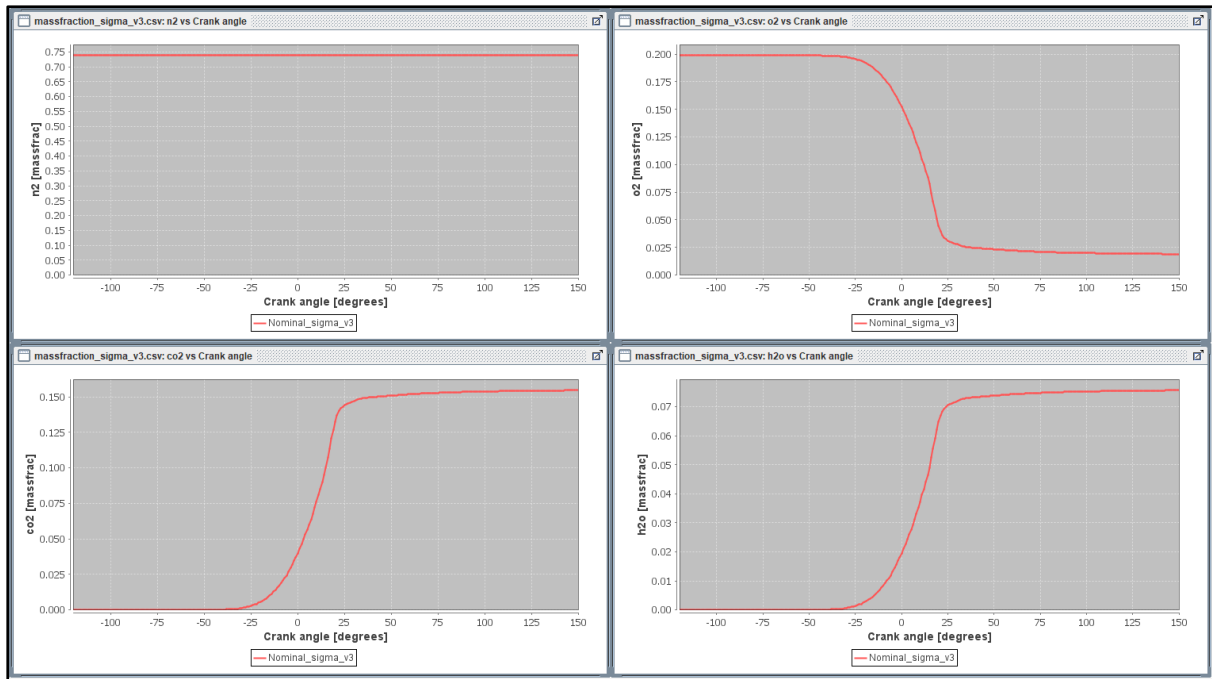


Figure 10: Crank Angle against Reactant and Product Mass Fraction from Forte E5 Simulation

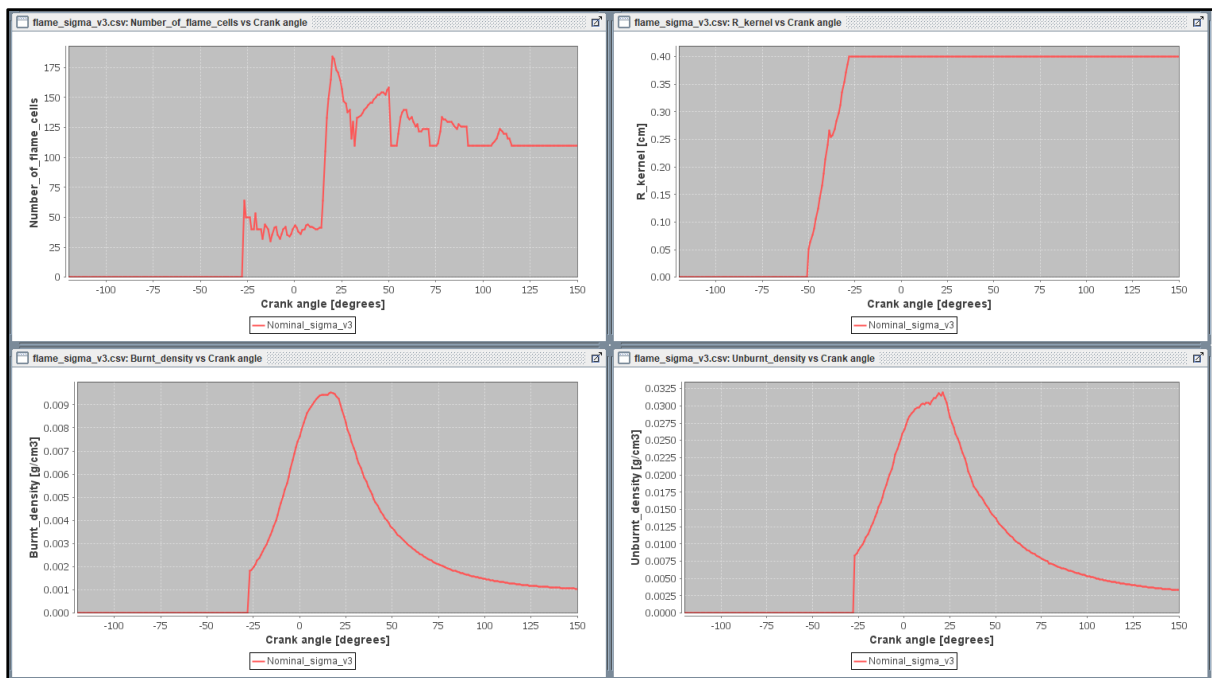


Figure 11: Crank Angle against Burn Features from Forte E5 Simulation

4.3 Wave for E5

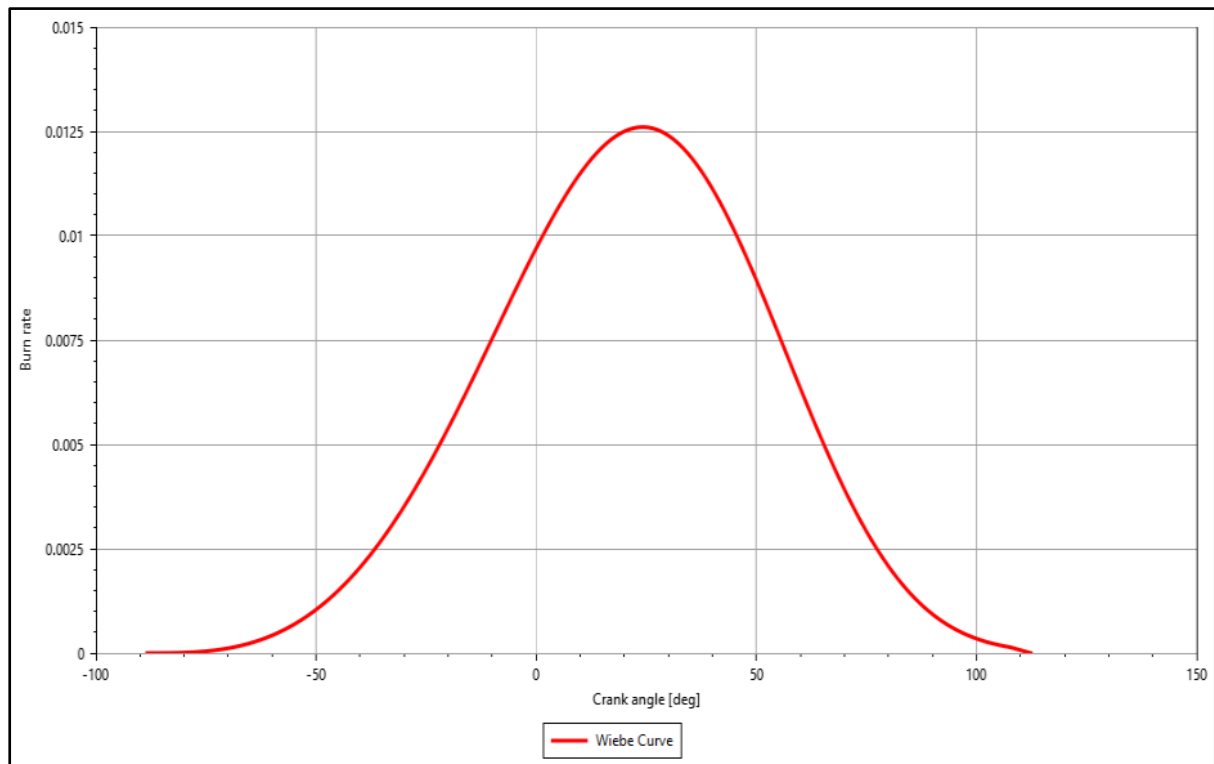


Figure 12: Weibe Function Graph Calculated for Wave from Forte for E5

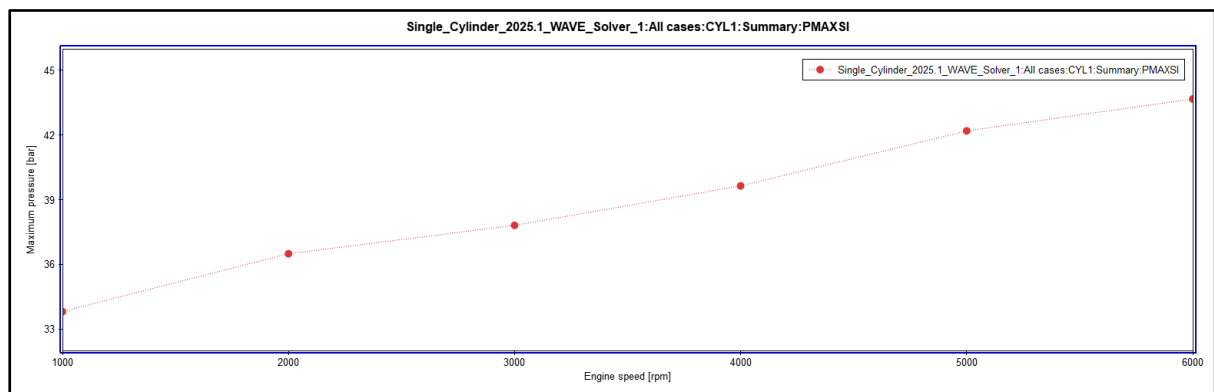


Figure 13: Engine Speed against Maximum Pressure from Wave E5 Simulation

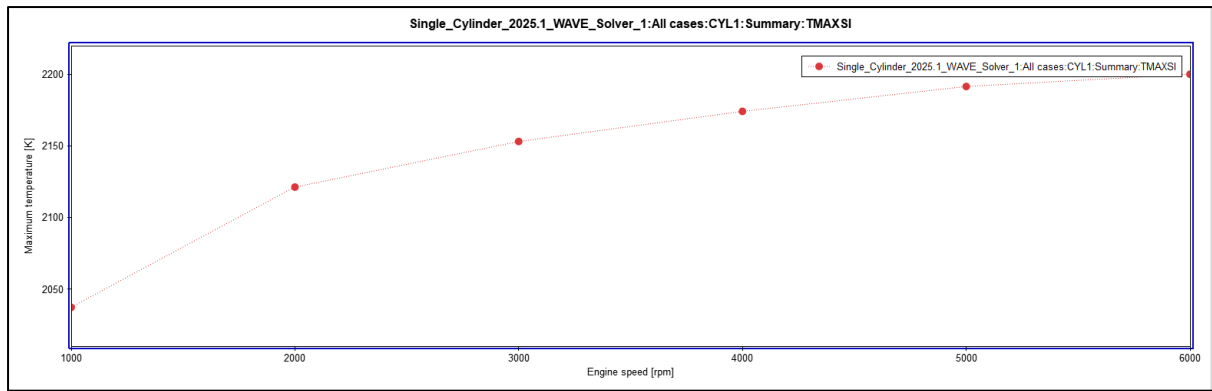


Figure 14: Engine Speed against Maximum Temperature from Wave E5 Simulation

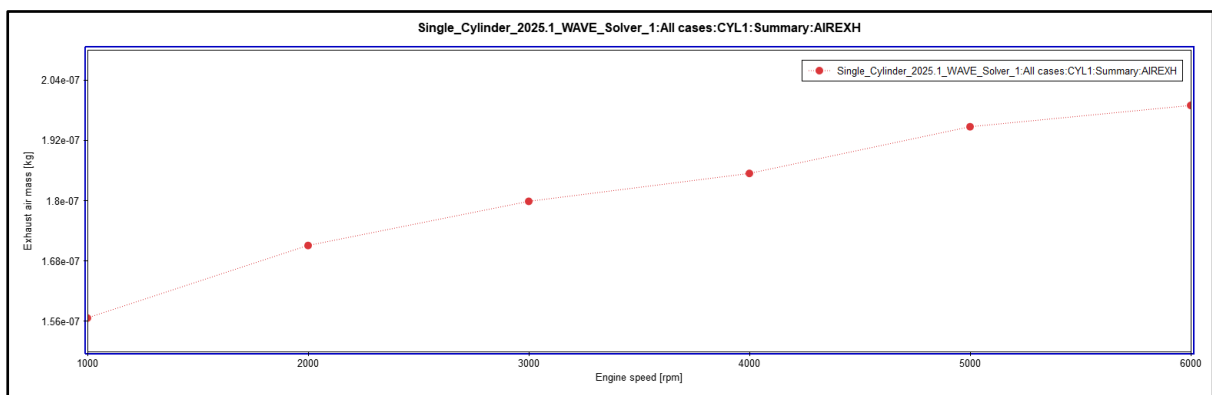


Figure 15: Engine Speed against Exhaust Air Mass from Wave E5 Simulation

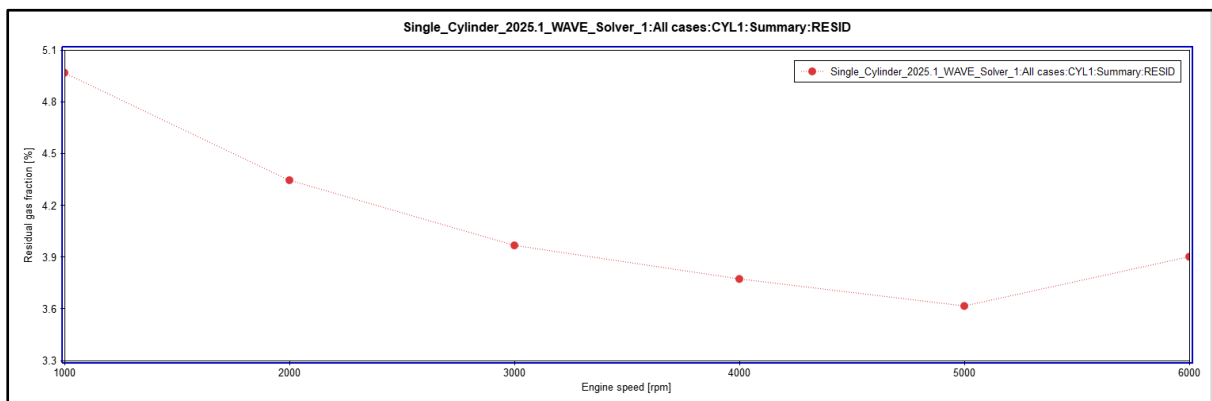


Figure 16: Engine Speed against Residual Gas Fraction from Wave E5 Simulation

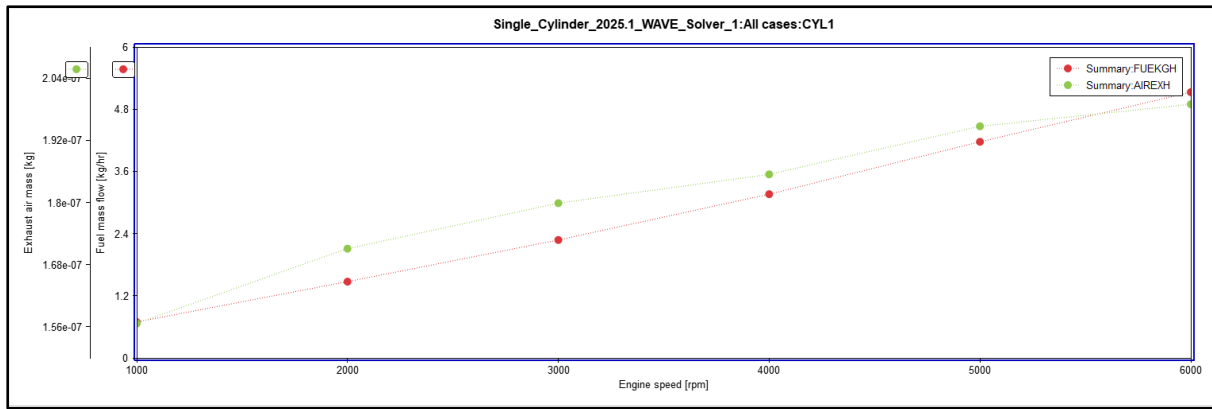


Figure 17: Engine Speed against Fuel Mass and Exhaust Air Mass from Wave E5 Simulation

4.4 Forte for E85

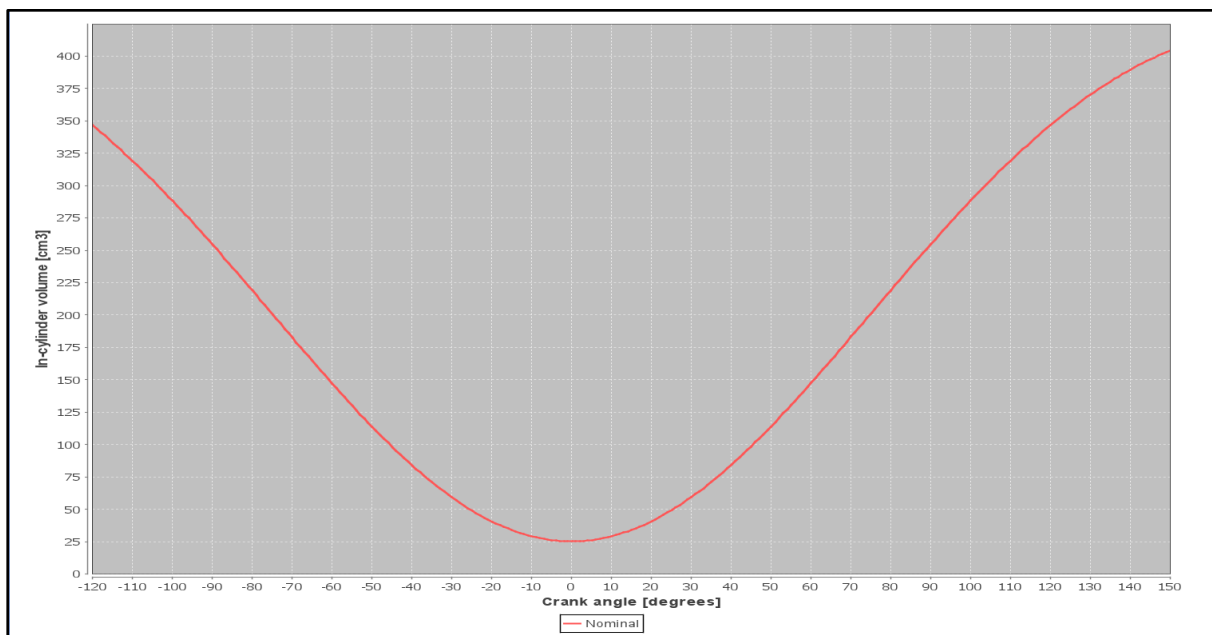


Figure 18: Crank Angle against in Cylinder Volume from Forte E85 Simulation

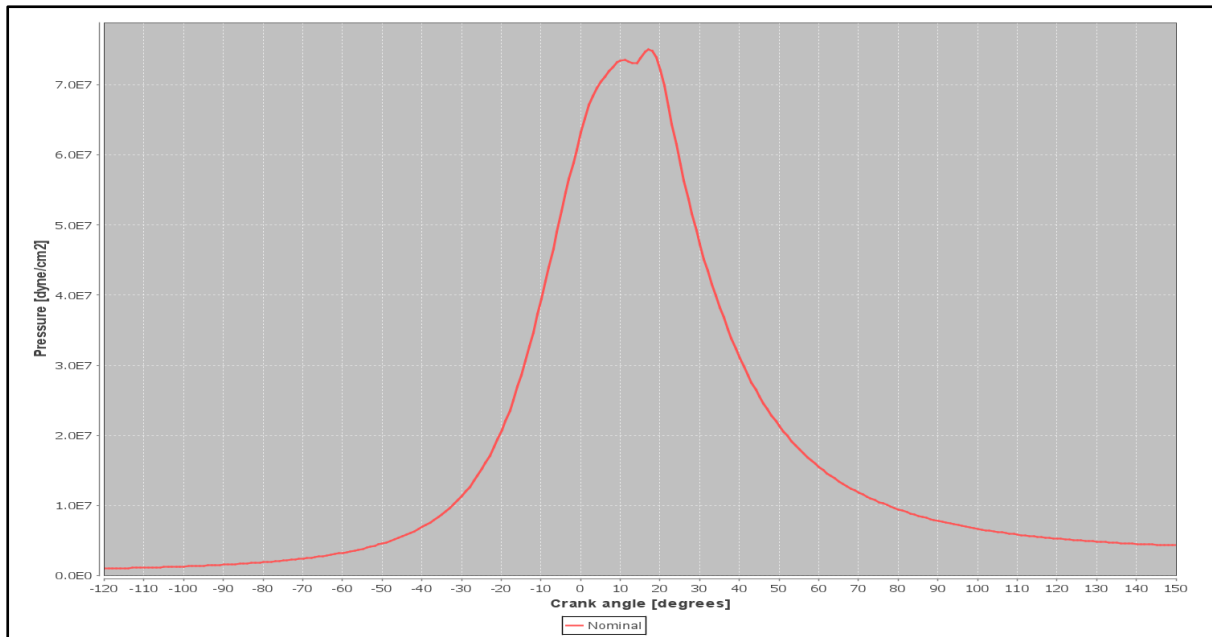


Figure 19: Crank Angle against in Cylinder Pressure from Forte E85 Simulation

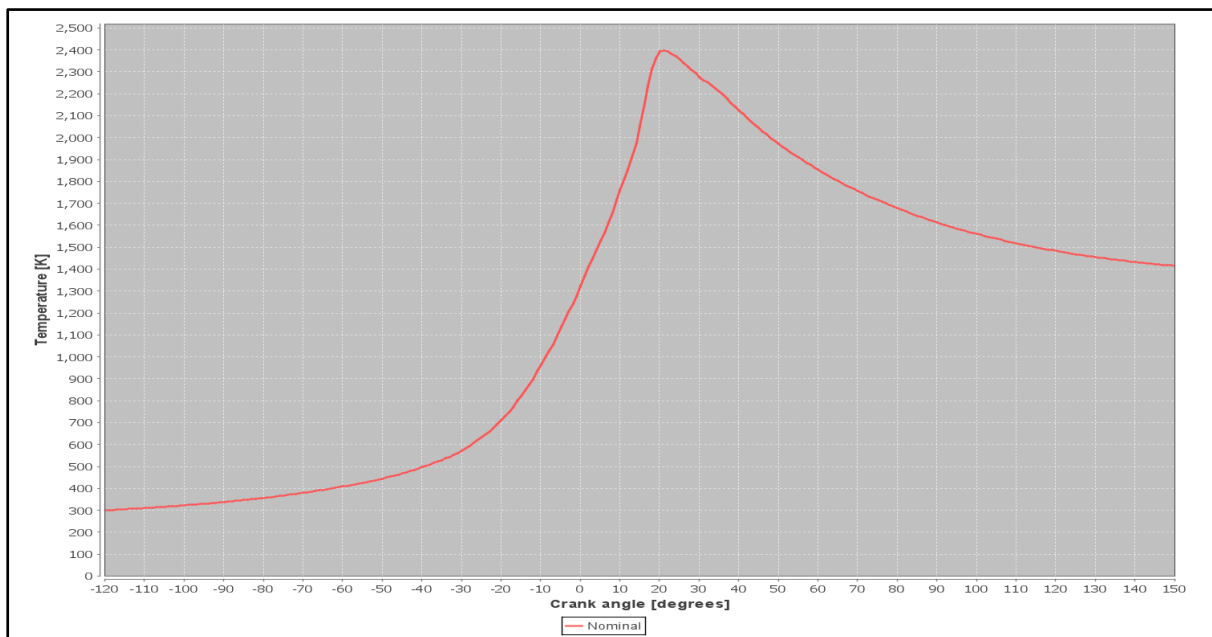


Figure 20: Crank Angle against in Cylinder Temperature from Forte E85 Simulation

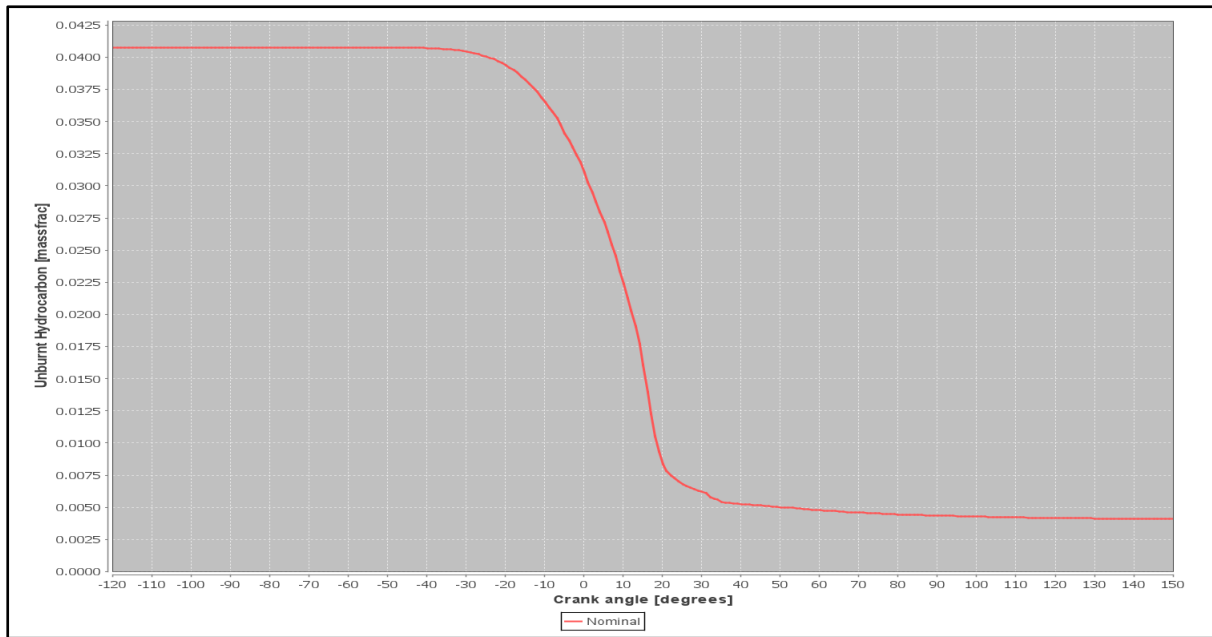


Figure 21: Crank Angle against Unburnt Hydrocarbons Mass Fraction from Forte E85 Simulation

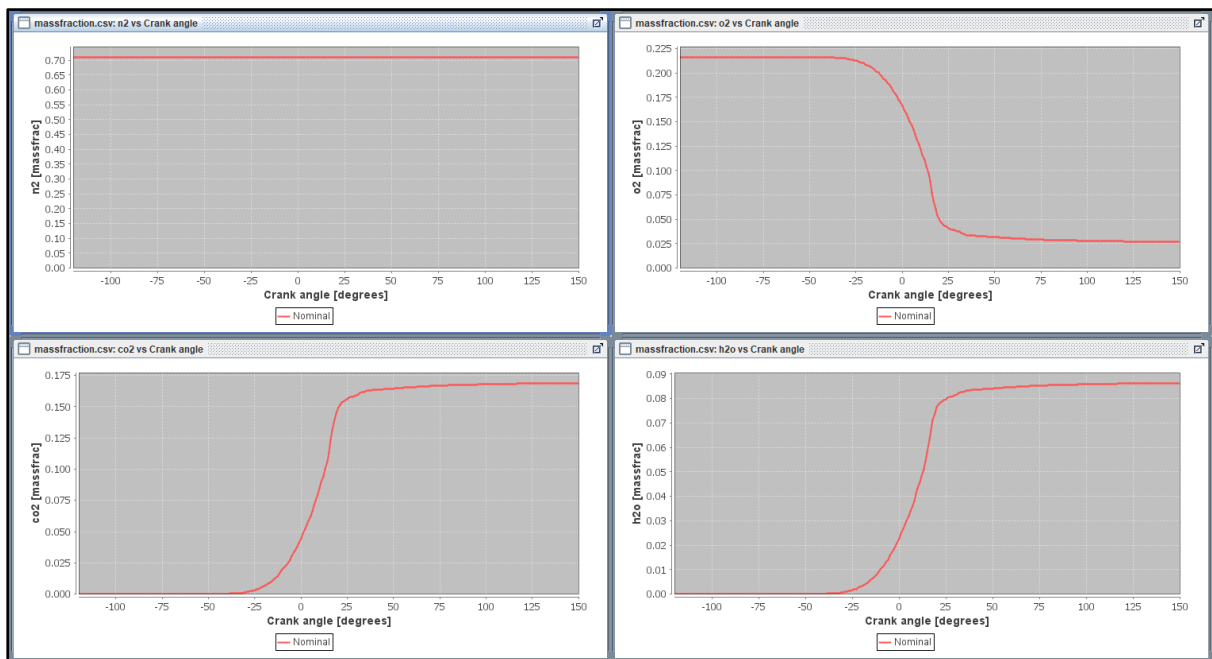


Figure 22: Crank Angle against Reactant and Product Mass Fraction from Forte E85 Simulation

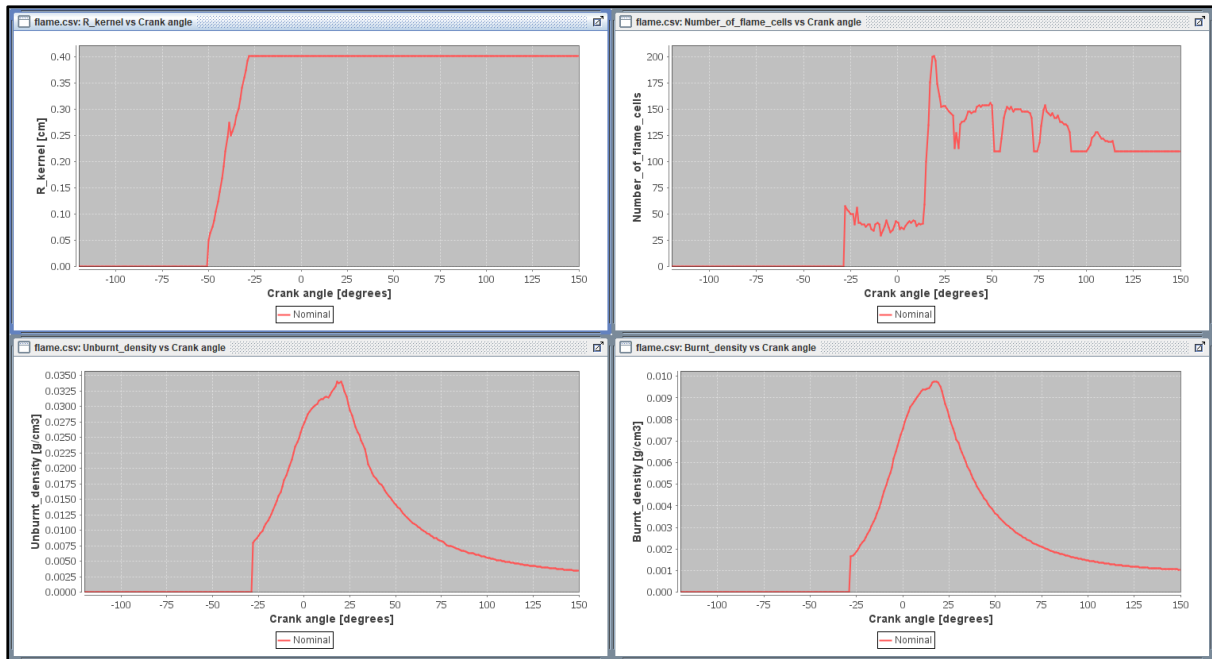


Figure 23: Crank Angle against Burn Features from Forte E85 Simulation

4.5 Wave for E85

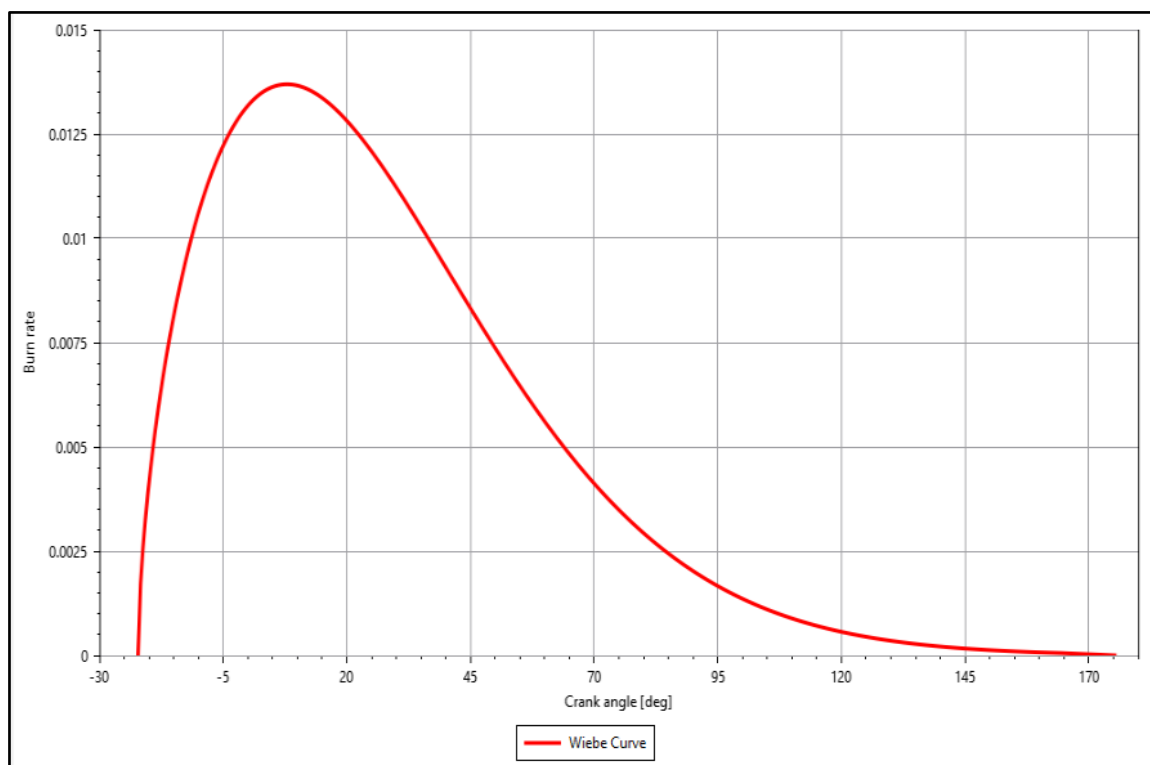


Figure 24: Weibe Function Graph Calculated for Wave from Forte for E85

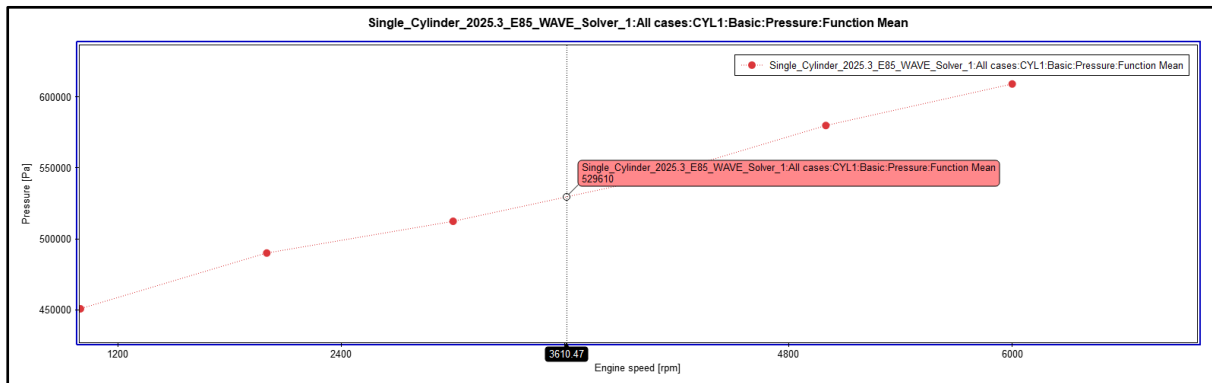


Figure 25: Engine Speed against Maximum Pressure from Wave E85 Simulation

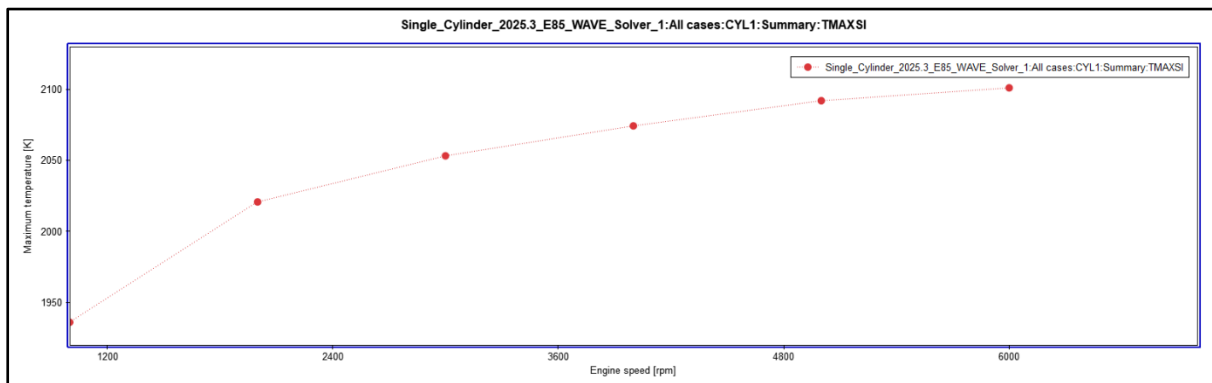


Figure 26: Engine Speed against Maximum Temperature from Wave E85 Simulation

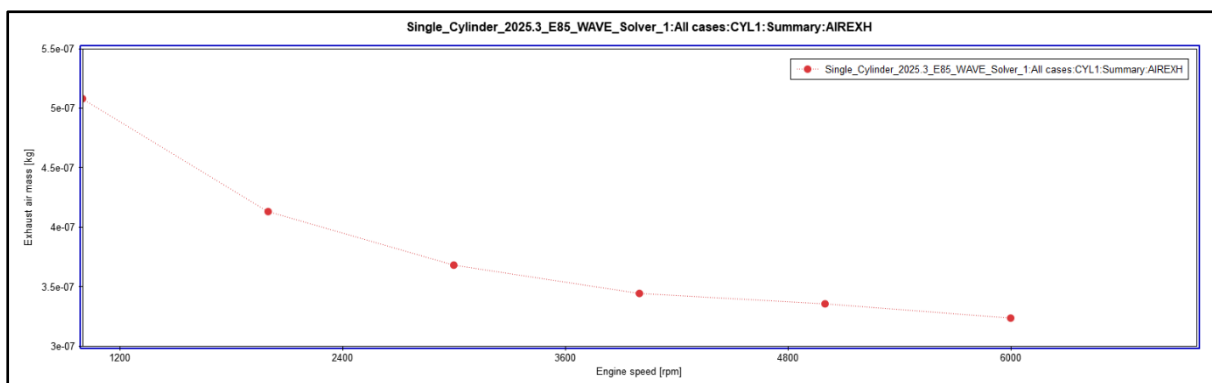


Figure 27: Engine Speed against Exhaust Air Mass from Wave E85 Simulation

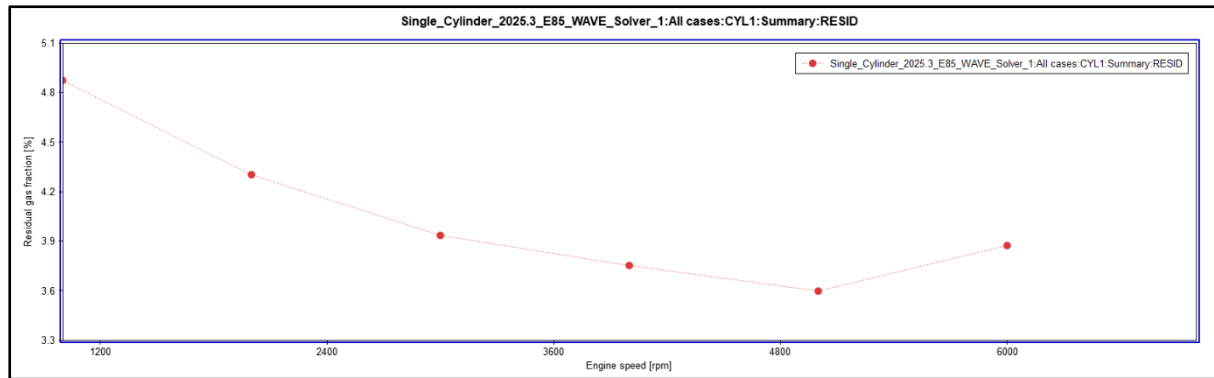


Figure 28: Engine Speed against Residual Gas Fraction from Wave E85 Simulation

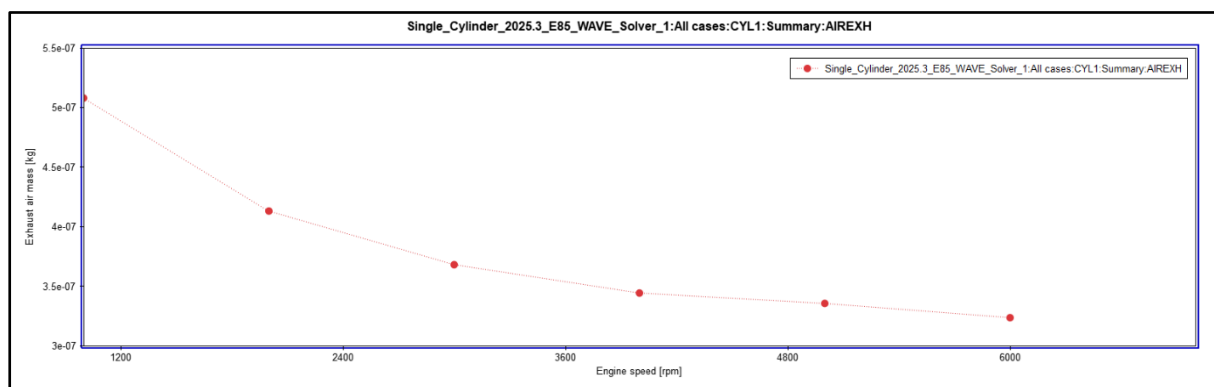


Figure 29: Engine Speed against Exhaust Air Mass from Wave E85 Simulation

4.6 Forte for Hydrogen

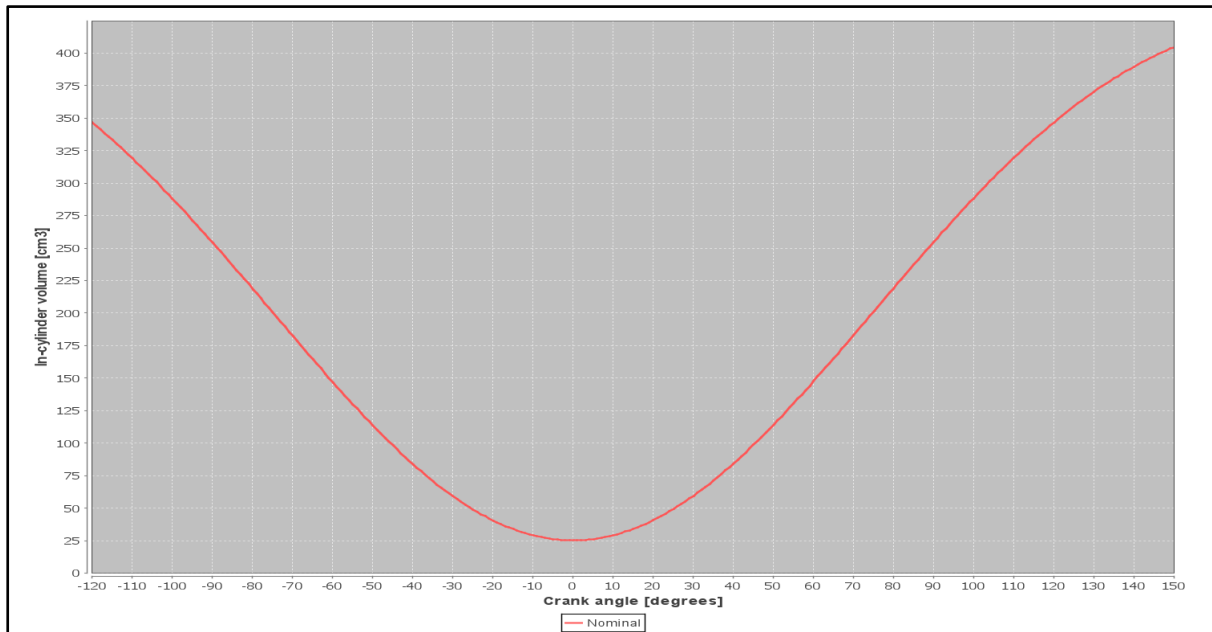


Figure 30: Crank Angle against in Cylinder Volume from Forte Hydrogen Simulation

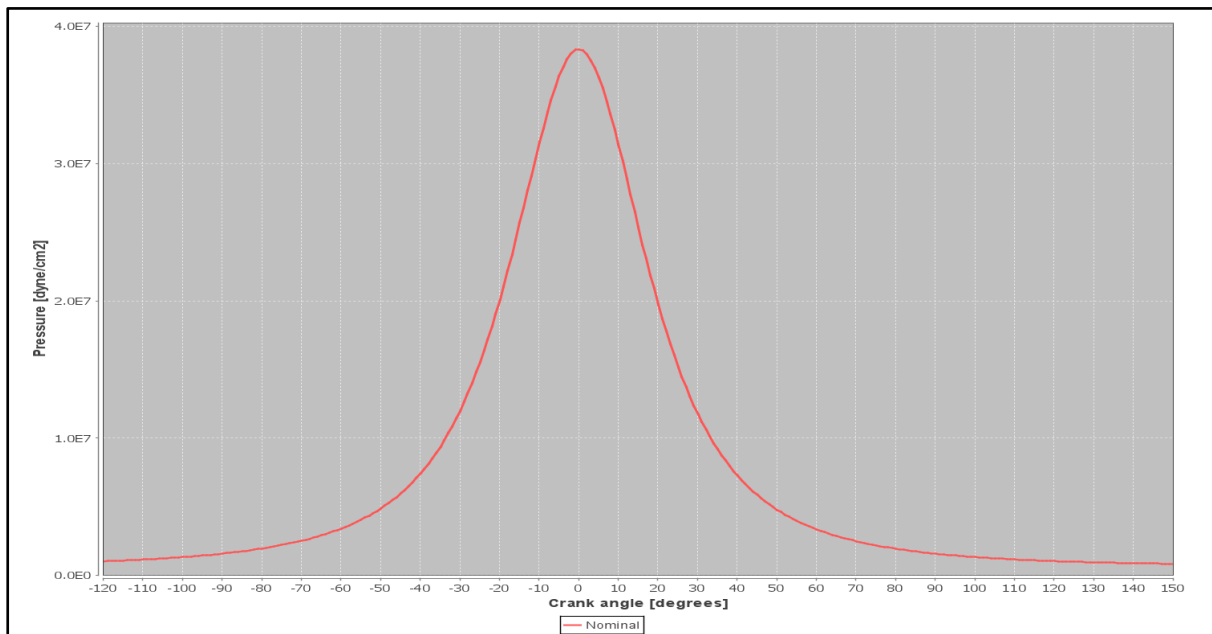


Figure 31: Crank Angle against in Cylinder Pressure from Forte Hydrogen Simulation

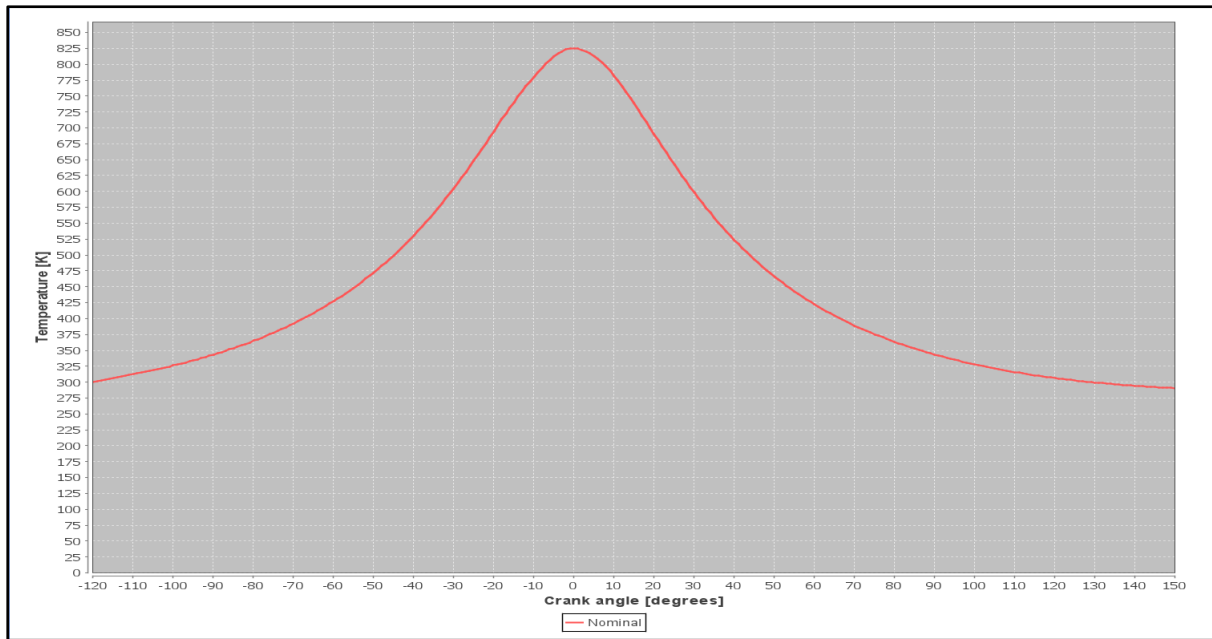


Figure 32: Crank Angle against in Cylinder Temperature from Forte Hydrogen Simulation

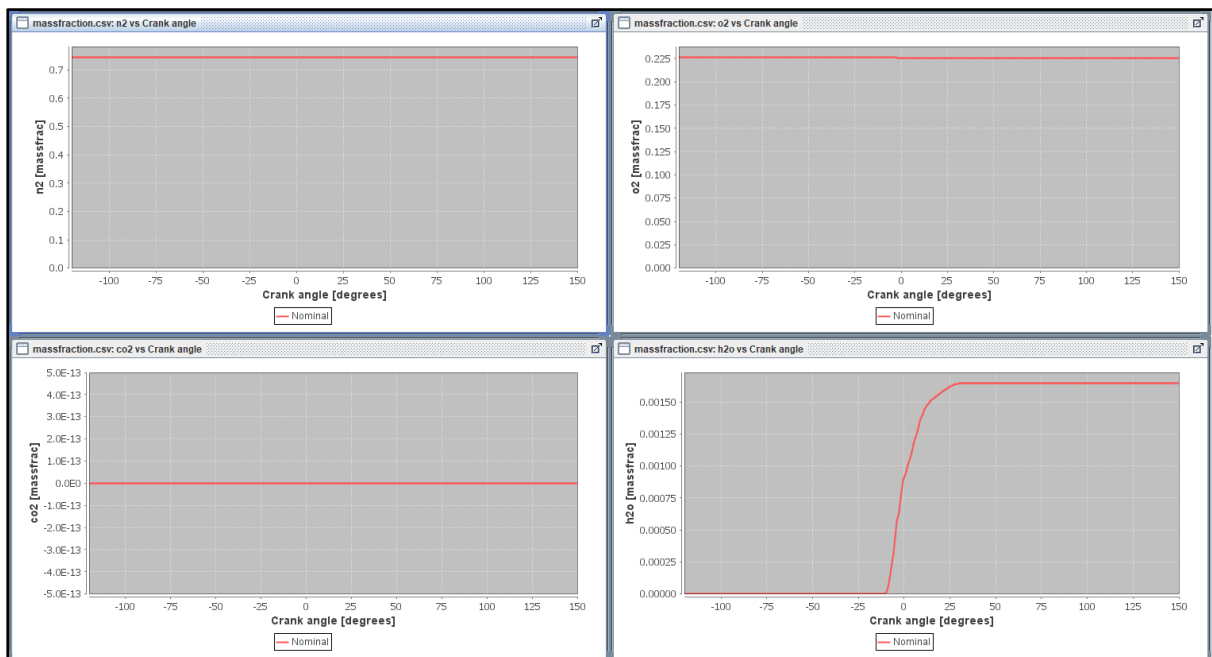


Figure 33: Crank Angle against Reactant and Product Mass Fraction from Forte Hydrogen Simulation

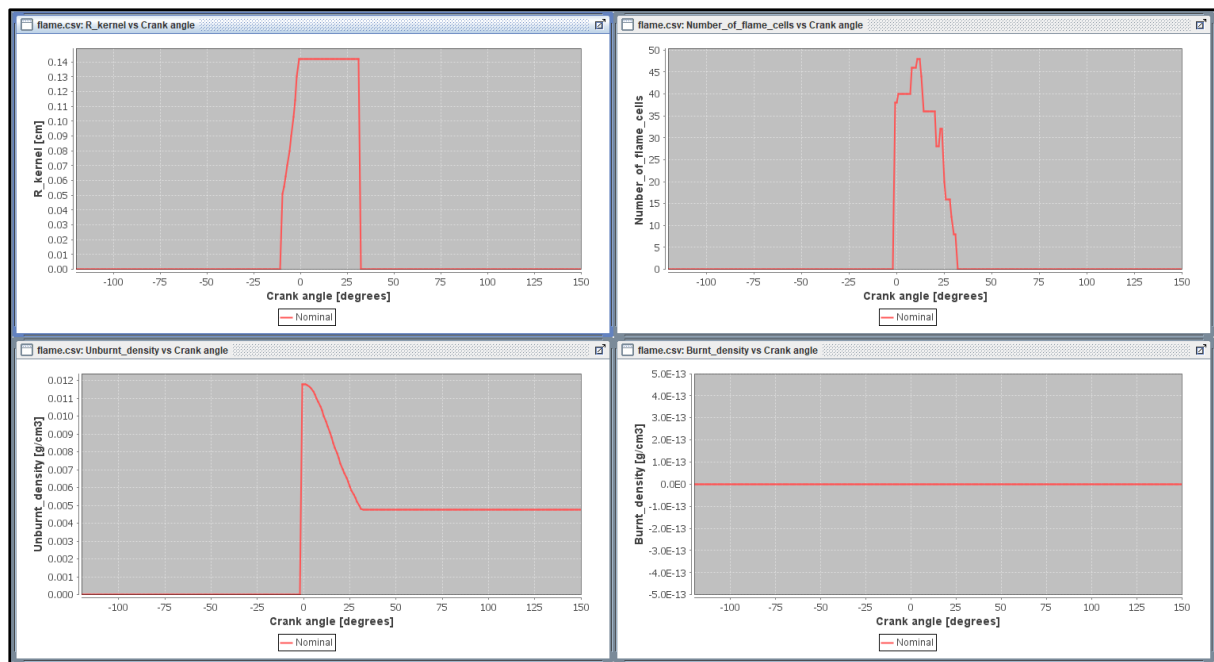


Figure 34: Crank Angle against Burn Features from Forte Hydrogen Simulation

4.7 Wave for Hydrogen

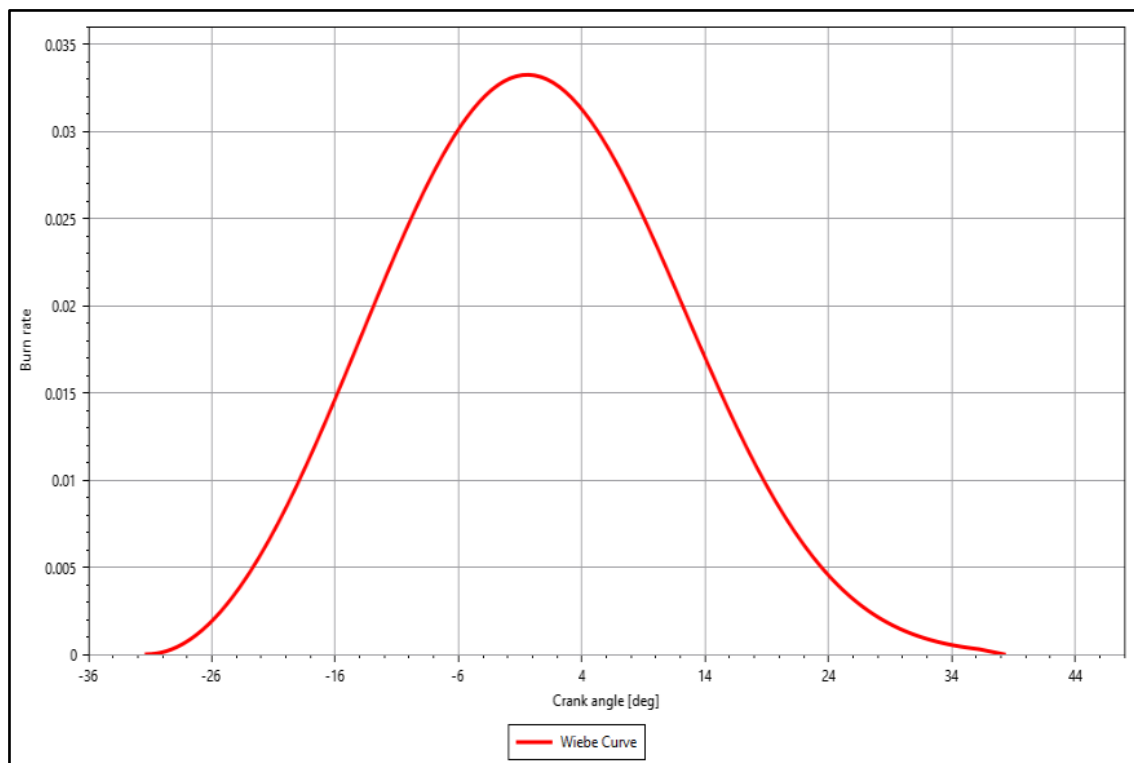


Figure 35: Weibe Function Graph Calculated for Wave from Forte for Hydrogen

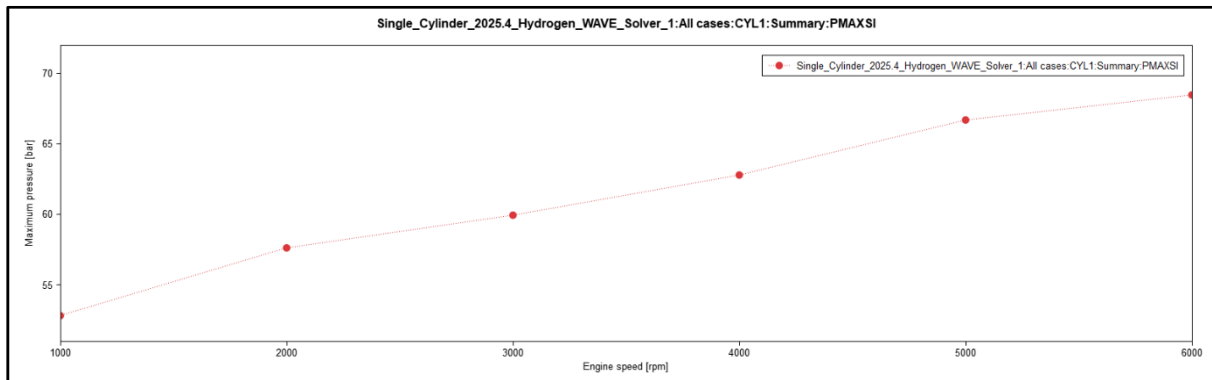


Figure 36: Engine Speed against Maximum Pressure from Wave Hydrogen Simulation

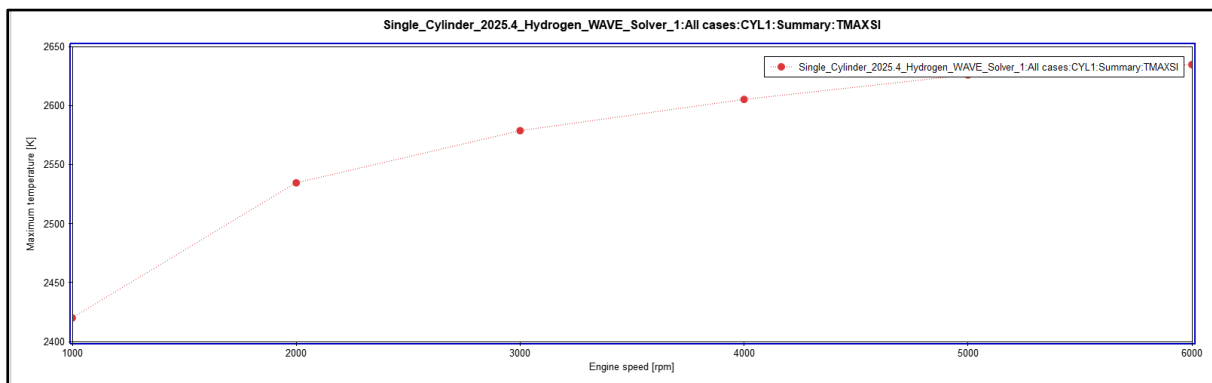


Figure 37: Engine Speed against Maximum Temperature from Wave Hydrogen Simulation

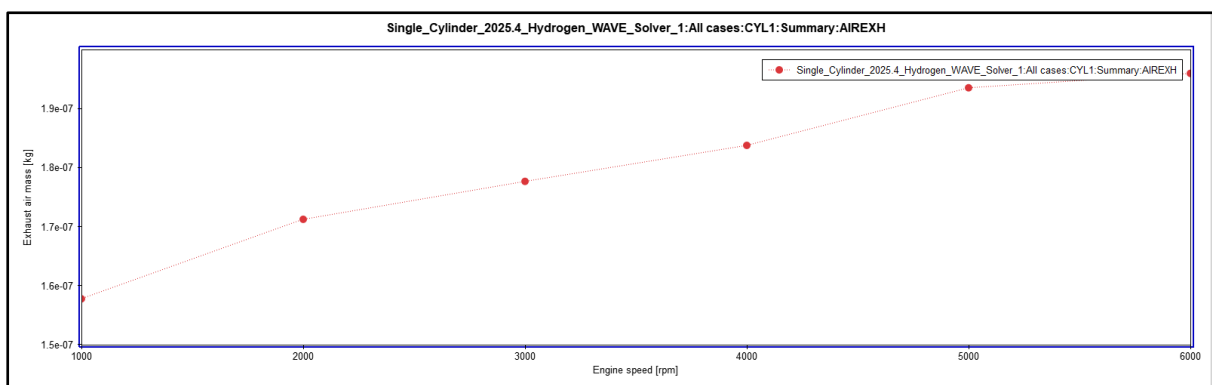


Figure 38: Engine Speed against Exhaust Air Mass from Wave Hydrogen Simulation

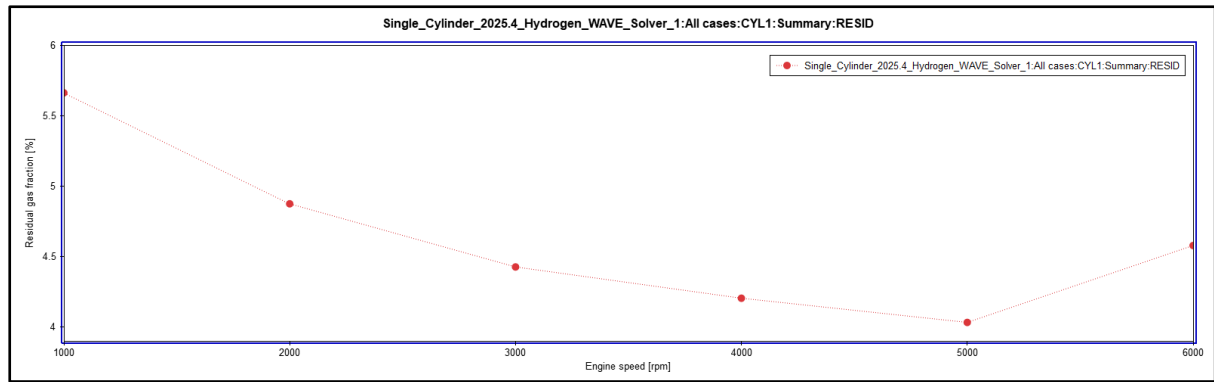


Figure 39: Engine Speed against Residual Gas Fraction from Wave Hydrogen Simulation

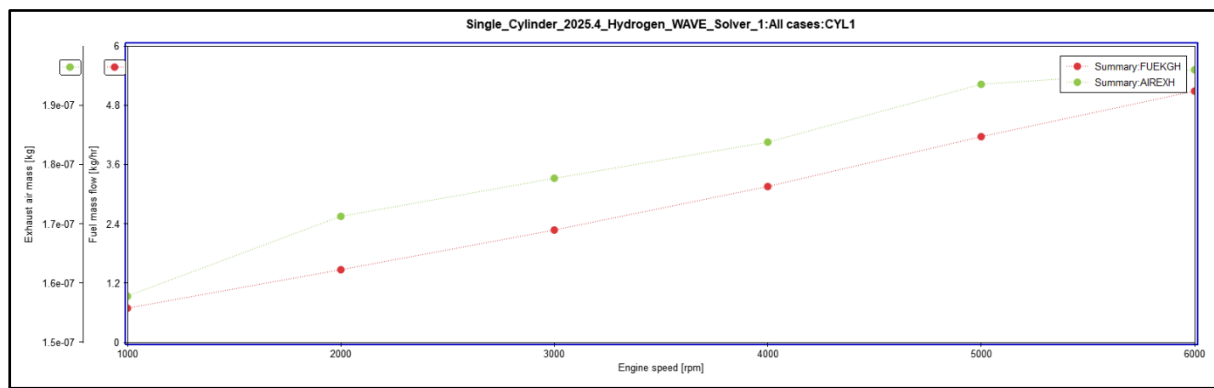


Figure 40: Engine Speed against Fuel Mass and Exhaust Air Mass from Wave Hydrogen Simulation

5.0 Analysis

5.1 Real-World Engine Dyno Study

The engine dyno data provided was used to validate the models made in Forte and Wave.

5.2 Forte for E5

The Forte simulation for E5 aligns with the engine dyno data provided. The in-cylinder volumes and in-cylinder pressures graphs show similar values. Peak pressure from the simulated engine was 70 bar ($7 \times 10^7 \text{ dyne/cm}^2$) and the dyno study produced a result of 68 bar. As in-cylinder pressure strongly influences combustion characteristics it was essential that the simulations peak pressure was similar to the real-world value. There was an error of less than 3% between the peak pressures.

$$100 - \left(\frac{68}{70} \times 100 \right) = 2.857$$

2.857% error

*Equation 6: Peak
Pressure Error
Calculation*

Minor discrepancies between the simulation and experimental data may be attributed to simplifications in the model, such as assumed wall temperatures. Overall, the Forte E5 simulation demonstrates that the model is capable of accurately representing the combustion behaviour of E5 in the Ford Sigma engine.

5.3 Wave for E5

The Wave simulation was completed over a range of engine speeds. This gave a broader view of the engine's behaviour compared to the Forte simulation which was conducted at 6000 RPM. The results show a general increase in maximum cylinder pressure and temperature as engine speed increased. This is expected due to the decrease in time between each combustion in the engine.

The exhaust air mass increased with engine speed. Further research should be undertaken to determine the chemical makeup of the exhaust gas and whether the increase in mass is due solely to the increase in engine speed.

Compared to the Forte simulation, Wave produced a less detailed combustion data but allowed for analysis across the engine's rev range.

5.4 Forte for E85

The Forte simulation for E85 showed noticeable differences compared to the E5 simulation. The peak cylinder pressure is slightly reduced, which could be attributed to the lower energy density of ethanol compared to iso-octane. To achieve the same in-cylinder pressure as E5 the fuel flow rate of the E85 should be increased further.

The temperature profile between E5 and E85 was very similar. Peak temperature of E85 was 100K greater than E5, which is consistent with the findings of other studies. However, higher burn temperatures can increase NO_x formation. While NO_x mass fraction was unknown CO₂ emissions were plotted and analysed. The CO₂ mass fraction of E85 was greater than the mass fraction produced by the E5 simulation. However, the molecular mass of octane plus ethanol in a 95% to 5% blend can be approximated as double that of E85 (Equation 7). Therefore, E85 produces less CO₂ with respect to its mass.

Atomic Mass of Carbon, Hydrogen and Oxygen Atoms

C=6, H=1, O=8

C₈H₁₈ Molecular mass

$$6 \times 8 + 1 \times 18 = 66$$

C₂H₅OH Molecular mass

$$6 \times 2 + 1 \times 5 + 8 \times 1 + 1 \times 1 = 26$$

E5 Molecular mass

$$66 \times 0.95 + 26 \times 0.05 = 64$$

E85 Molecular mass

$$66 \times 0.15 + 26 \times 0.85 = 32$$

*Equation 7:
Molecular Mass
Calculation of E5
and E85*

5.5 Wave for E85

The Wave simulation for E85 disagrees with the Forte simulation regarding peak temperature. The Wave simulations assessed the peak temperature at 6000 RPM to be lower than the temperature calculated by the Forte simulations for both E5 and E85. Additionally, Forte assessed peak temperature to be near 2300K for E5 and 2400K for E10. Conversely Wave calculated the E5 peak temperature as 2200K and the E10 as 2100K. This would require further study to assess reasoning for this discrepancy.

5.6 Forte for Hydrogen

The Forte simulation for hydrogen showed significantly different combustion characteristics compared to E5 and E85. The in-cylinder pressure increase and decreases at a greater rate. This is likely a result of hydrogen's low burn time and low ignition energy.

The peak temperature was significantly less (825K) than the peak temperatures of the petrol blend fuels (low 2000K). Low combustion temperatures may aid in a reduction of NO_x emissions. Moreover, the absence of unburnt hydrocarbons and carbon dioxide as combustion products suggests that hydrogen releases less harmful combustion products compared to E5 and E85. These results demonstrate that hydrogen fuelled engines could offer significant emissions benefits

5.7 Wave for Hydrogen

Wave calculated the peak temperature at 6000 RPM of hydrogen to be 2650K. This once again disagreed with the Forte assessment. As stated above further research should be completed to understand the divergence of results in the two softwares.

Due to temperature differences and the use of approximated Wiebe parameters; the Wave simulation of hydrogen is unlikely to be a fair representation of true hydrogen combustion within the Ford Sigma engine.

6.0 Discussion & Conclusions

6.1 Strengths and Weaknesses

The initial simulation was an accurate representation of the Ford Sigma 1.6L engine. The in-cylinder pressure aligned with the known cylinder values and the in-cylinder volumes were similar between the engine dyno study and simulation. The combustion behaviour of E5 strongly correlated with expected results. The E85 simulations contained some errors but can be regarded as a reasonable assessment of the fuel. Further research is required to prove or disprove the findings. The hydrogen results displayed significant inconsistencies between the simulation softwares with much conflicting information.

6.2 Future Work

For this simulation to become a valid study further work is required to improve the accuracy of the simulated engine particularly with respect to simulating alternative fuels. Moreover, if the fuel simulated is not carbon-based (such as hydrogen) significantly more research would be required as the modifications required to burn non-carbon-based fuels are extensive and can be difficult to simulate well.

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8.0 Appendices

8.1 Engine Specifications

The engine used was a Ford 1.6L Sigma four stroke straight-four engine.

(Ford Authority, 2010)

Table 5: Engine Technical Data for the Ford 1.6L Sigma straight-four engine

Name	Value	Unit
Bore	79	mm
Stroke	81.4	mm
Connecting Rod Length	138	mm
Engine displacement	1596	cc
Compression Ratio	11.1:1	N/A
Power	120	hp