# PERFORMANCE COMPARISION :
# LASER IGNITION VS. CONVENTIONAL IGNITION SYSTEM

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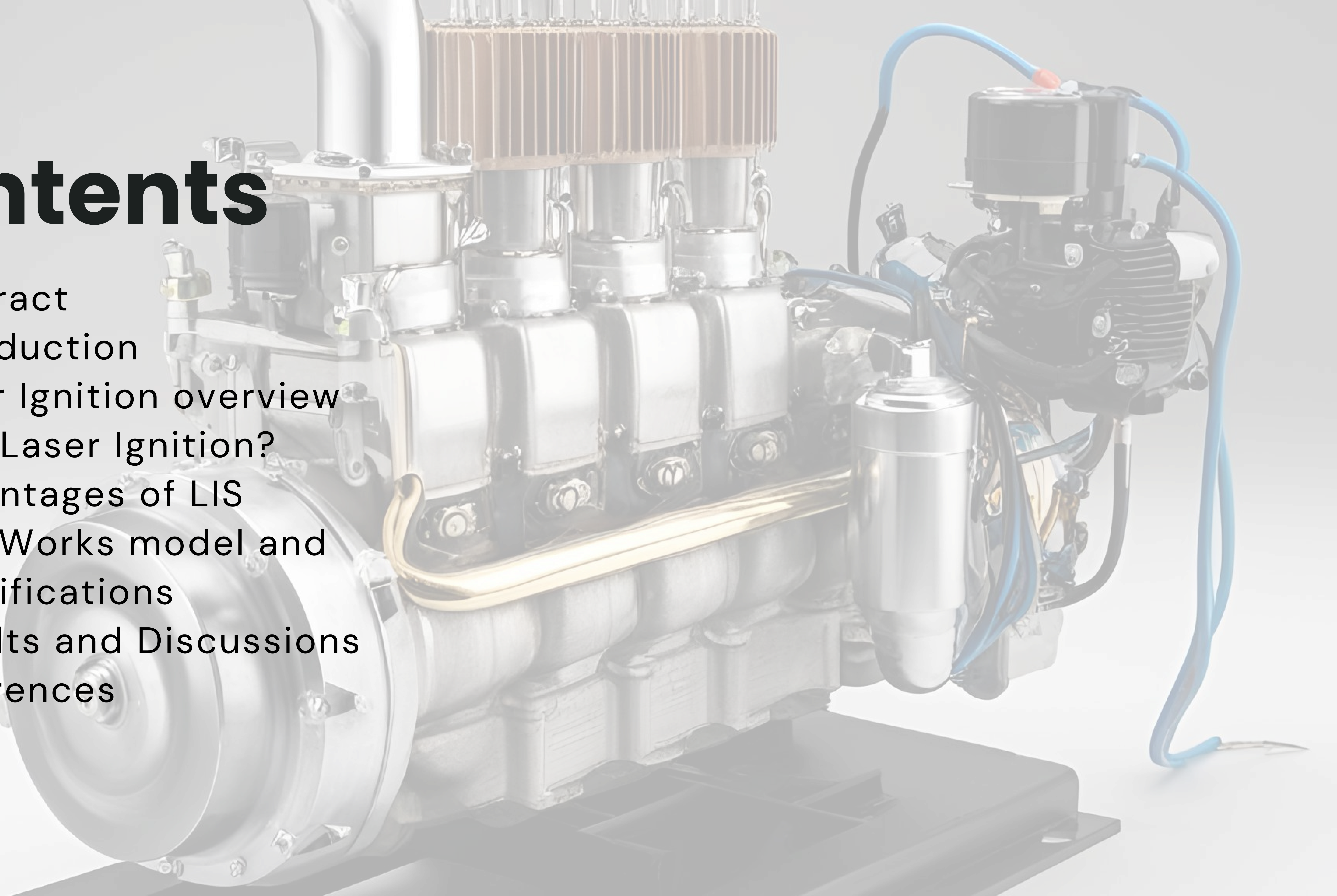
# Contents





# Abstract


- Growing energy demand and emission norms drive new combustion technologies.
- Laser ignition systems (LIS) offers advantages over conventional ignition systems (CIS), especially at high speeds.
- In contrast, the power of the engine is improved and enhanced by the LIS.
- This study simulates and compares engine performance for various combustion initiation angles before TDC in both LIS and CIS.

# Introduction

- Focus: Performance analysis by varying combustion initiation angles in both LIS and CIS systems
- Tools: SOLIDWORKS for designing, MATLAB/Simulink for simulation.
- Motive: Comparative study of pressure and temperature inside the cylinder by varying combustion initiation angles.

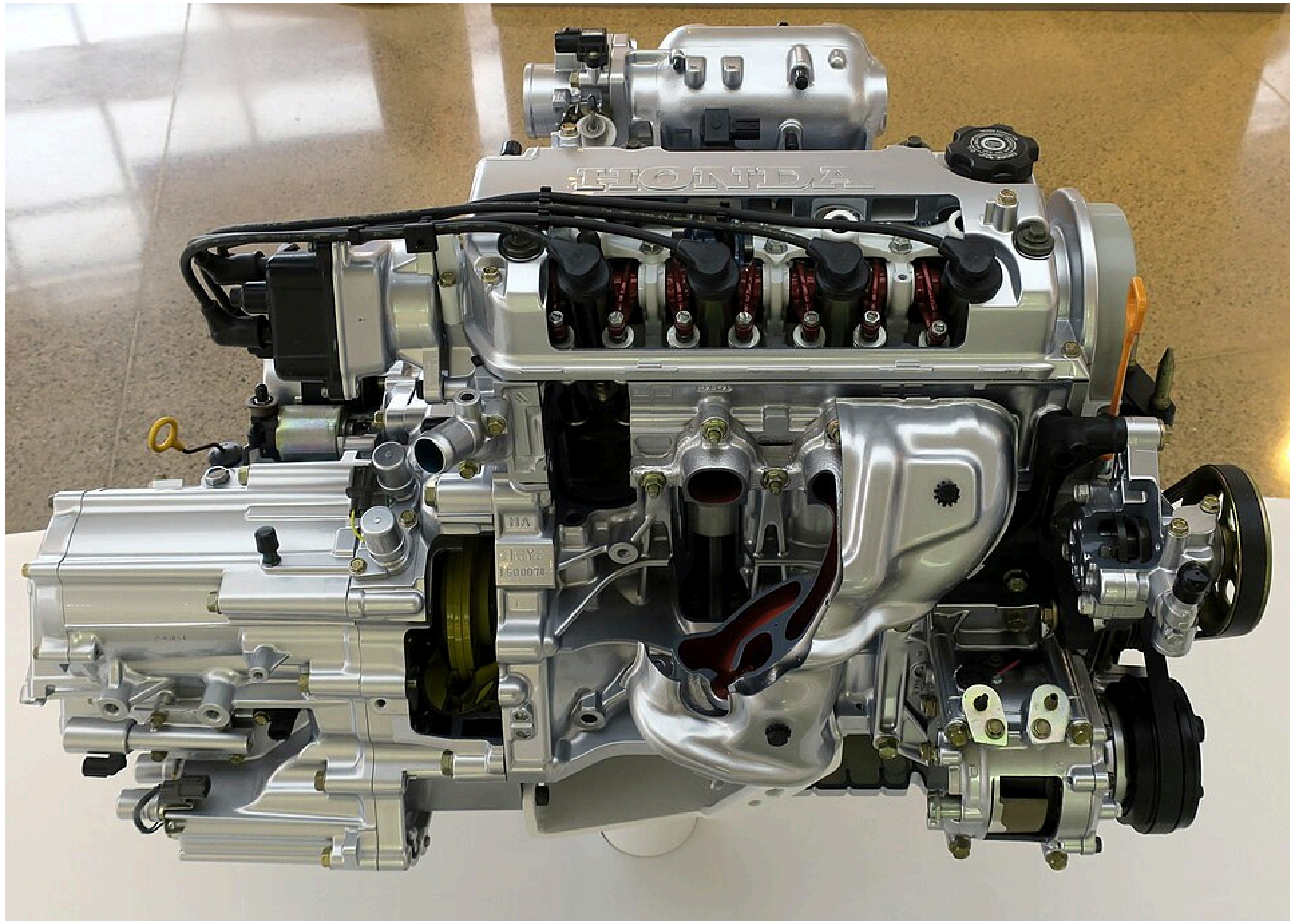



**Fig 1: Honda civic engine**

# LASER IGNITION

- Laser Ignition or Laser Induced Ignition is process of starting combustion by stimulus of laser light source.
- Laser Ignition uses optical breakdown of gas molecules caused by intense laser pulse to ignite gas mixtures.
- Beam of powerful short-pulse laser is focused by a lens into the combustion chamber near the focal spot.
- Due to this, ionization of few gas molecules happens which increase their KE.
- By this means, they collide other gas molecules ionizing them leading to electron avalanche and breakdown of gas.
- This produces plasma which ignites the fuel-air mixture.
- Wavelength and energy depend on gas properties.

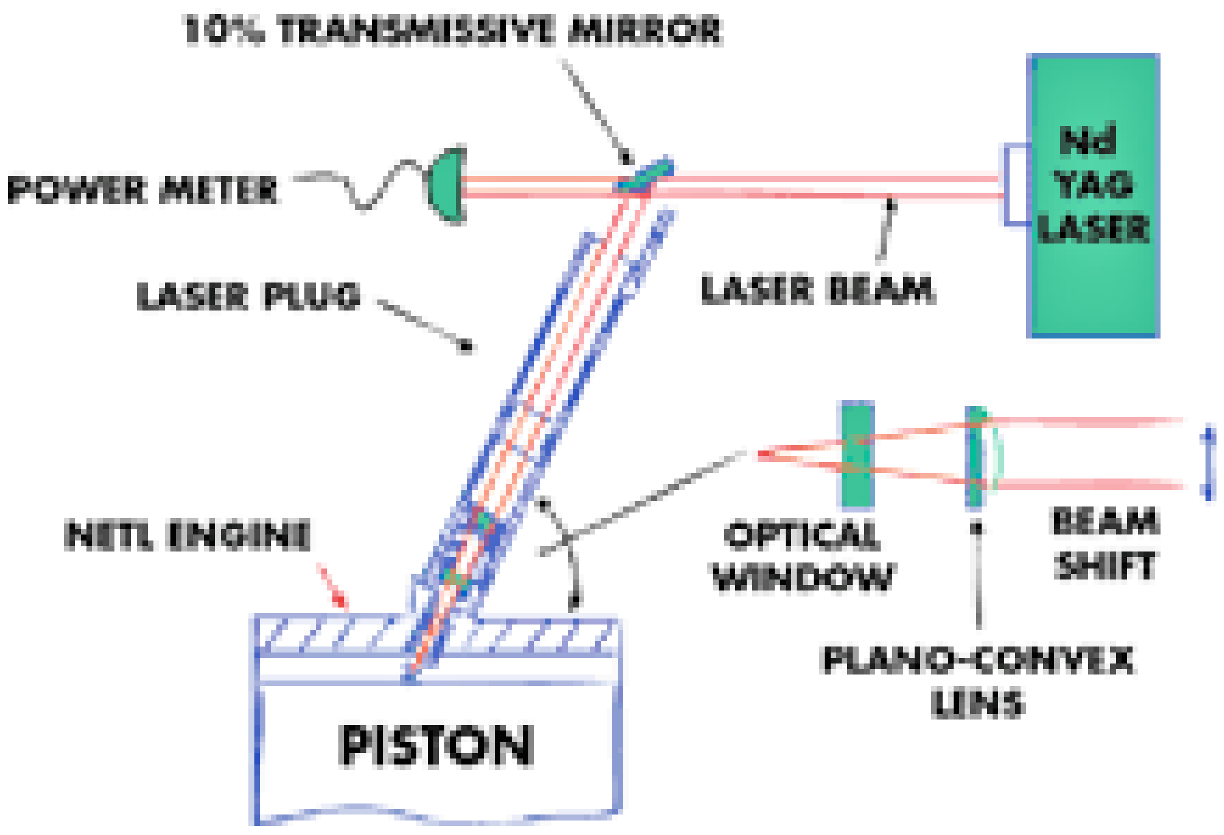



*Diagram of a laser ignition-controlled engine.*

# Advantages of LIS

- Laser ignition can create plasma at the optimal location inside the combustion chamber.
- Unlike spark plugs, lasers don’t have spark plugs so they offer longer life and reduced maintenance.
- High energy of laser induced plasma promotes rapid flame.
- Due to high energy content of laser induced plasma it can ignite very lean air-fuel mixtures.
- Consistent and Reliable in extreme engine conditions.
- Faster ignition timing.
- Laser ignition causes less heat loss to engine components compared to spark plugs.
- High Temperature and Pressure tolerances.

# Workflow adopted

Specifications of Honda Engine was taken from research paper

Back Calculation was done and SOLIDWORKS model of the engine was made

MATLAB/SIMULINK software was employed to model and simulate engine performance between LIS and CIS

Engine performance evaluation and comparison between LIS and CIS

# Specifications of engine

| PARAMETER | DESCRIPTION | VALUE |
|---|---|---|
| Cr | Compression Ratio | 9.3 |
| Dp | Piston diameter (mm) | 52.4 |
| Din | Air intake manifold diameter (mm) | 23.2 |
| L | Connecting rod length (mm) | 101.5 |
| Li | Intake valve opening (mm) | 0.2 |
| Le | Exhaust valve opening (mm) | 0.2 |
| Nv | Number of valves | 2 |
| r | Crankshaft radius (mm) | 28.95 |
| Vd | Displacement volume (cc) | 125 |

# SoildWorks Model

- Our design was based on a specifications of a 4-stroke, 4-cylinder engine.

- Model was done based on the specifications given in paper.

**Parts Designed:**

- Piston
- Connecting Rod
- Crank Shaft
- Engine Block

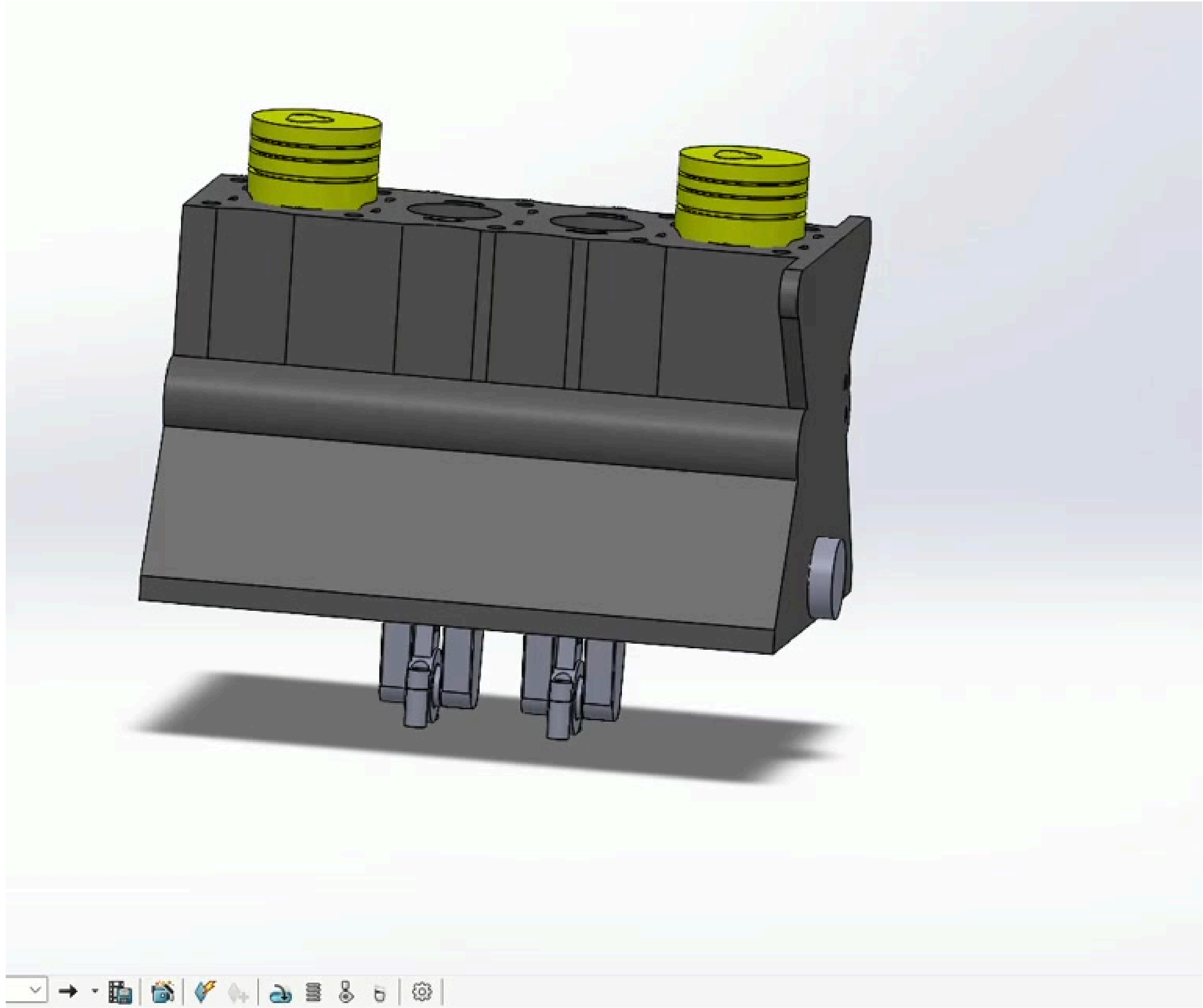


Fig 2: Motion study of SOLIDWORKS model

# SIMULINK model of Intake manifold

- First SIMULINK model gives an overview of the intake manifold with input parameter being the throttle angle and engine speed and the output being  mass flow rate of air entering the cylinder.
- Second SIMULINK model gives subsytem description at throttle valve. It primarily consists of two blocks operating in a closed-loop feedback system, which regulate the throttle flow into the intake manifold. This flow is influenced by input parameters such as throttle angle, intake manifold pressure, and ambient pressure. The resulting output is the air mass flow rate entering the cylinder.
- Third SIMULINK model models the air flow rate through the component valve and the same output is fed into the intake manifold

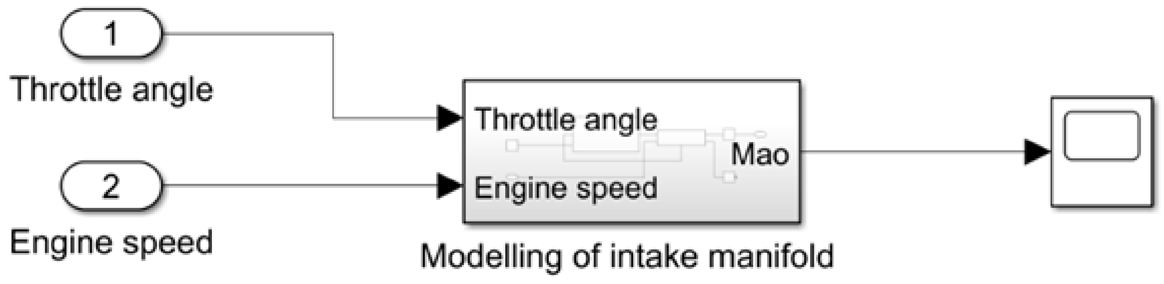



Fig 1) SIMULINK model of Intake Manifold1

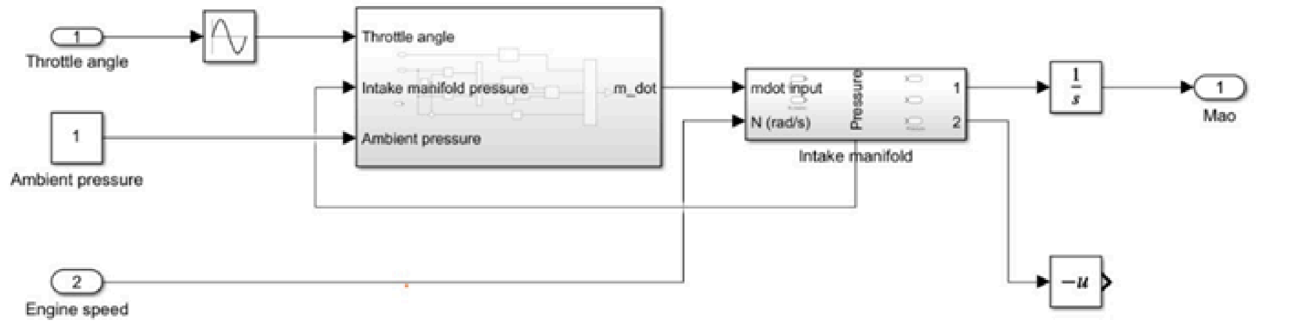



Fig 2) Subsystem block in intake manifold model for Honda Future 125cc engine

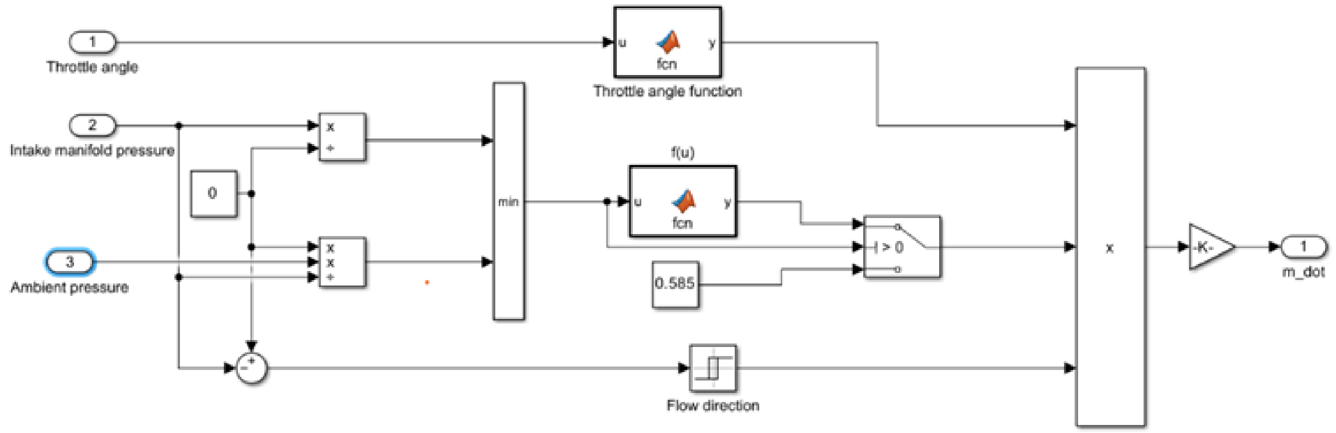
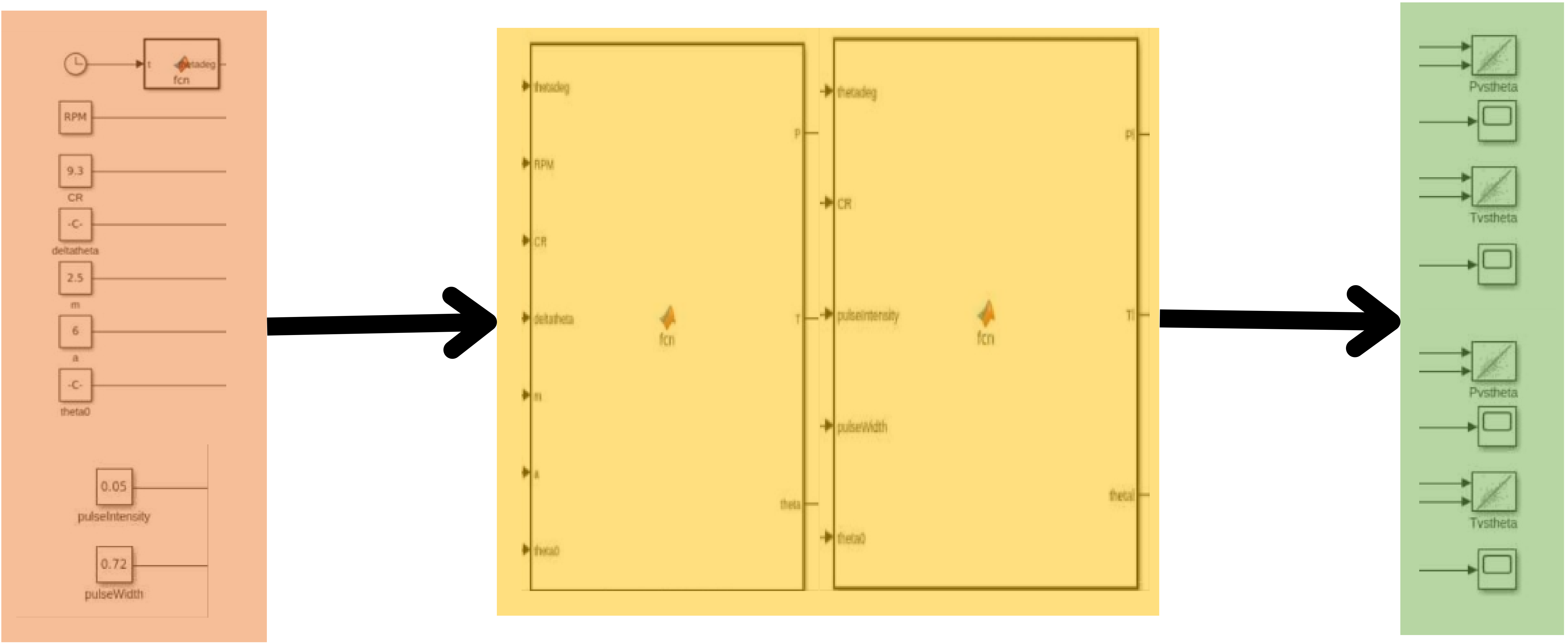



Fig 3) Calculation of air flow rate passing through the component of throttle valve

# SIMULINK MODEL OF COMBUSTION PROCESS




INPUT

CIS AND LIS

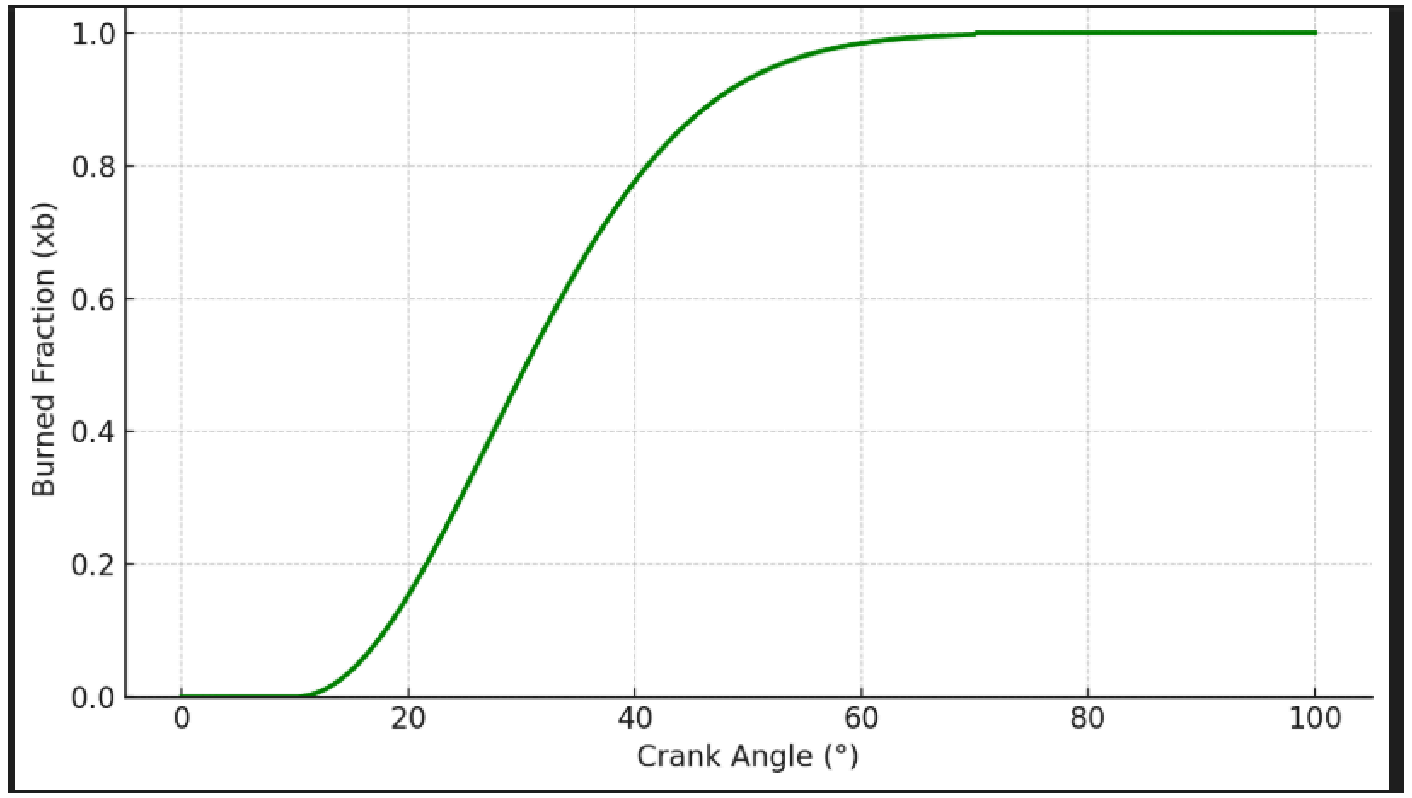
OUTPUT

# WIEBE FUNCTION

The Wiebe function is math formula used to show **how fuel burns** inside the engine cylinder with time or crank angle

Think of it like this;

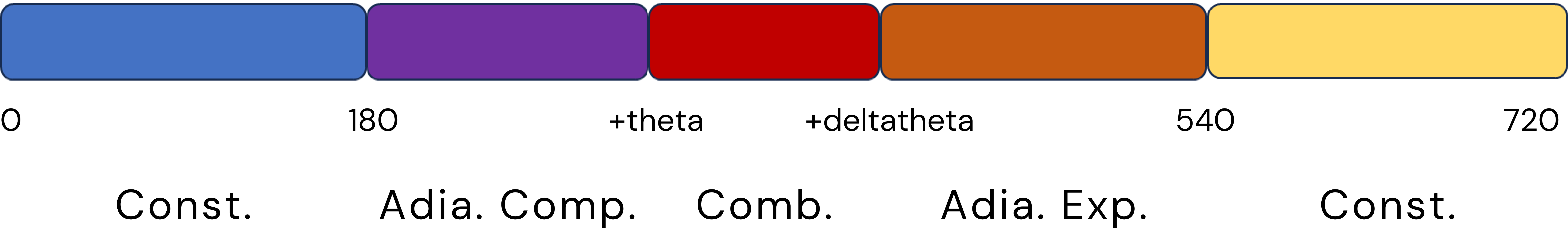
- When fuel starts burning, it burns slowly at first.
- Then it speeds up.
- And finally, it slows down again as it finishes.




**General form of wiebe function;**

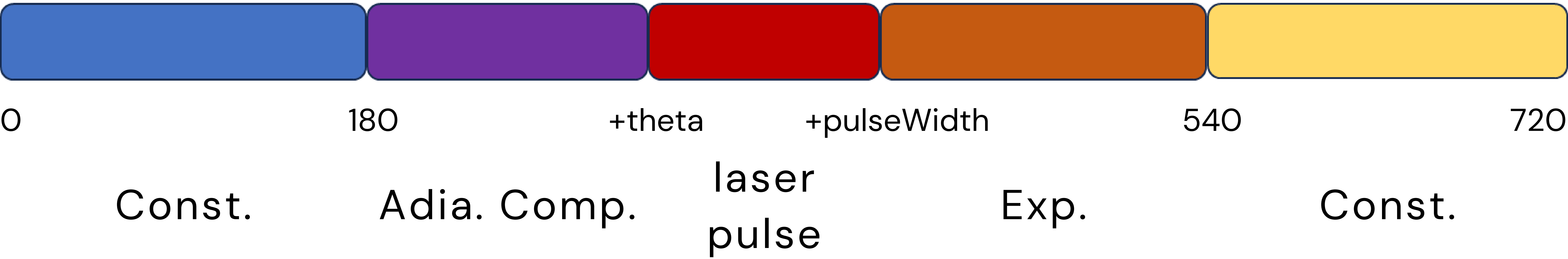
$$x_b(\theta) = 1 - \exp\left(-a\left(\frac{\theta - \theta_0}{\Delta\theta}\right)^m\right)$$

# DIVISION OF CYCLE INTO PHASES




CONVENTIONAL IGNITION ENGINE

# DIVISION OF CYCLE INTO PHASES




LASER IGNITION ENGINE

# Code:

```
% Constants
CR = 9.3;
theta0 = 330;
m = 2.5;
a = 6;
deltatheta = 60;
R = 287;
gamma = 1.35;
Vd = 500e-6;
Vc = (Vd / (CR - 1));
T0 = 300;
P0 = 1e5;

% Initialize arrays
thetadeg_all = 0:2.5:720;
T_all = zeros(size(thetadeg_all));
P_all = zeros(size(thetadeg_all));

% Loop through crank angles
for i = 1:length(thetadeg_all)
thetadeg = thetadeg_all(i);

if thetadeg < 720
theta = thetadeg;
else
theta = mod(thetadeg, 720);
end

if theta < theta0
xb = 0;
elseif theta > (theta0 + deltatheta)
xb = 1;
else
xb = 1 - exp(-a * ((theta - theta0) / deltatheta)^m);
end
```

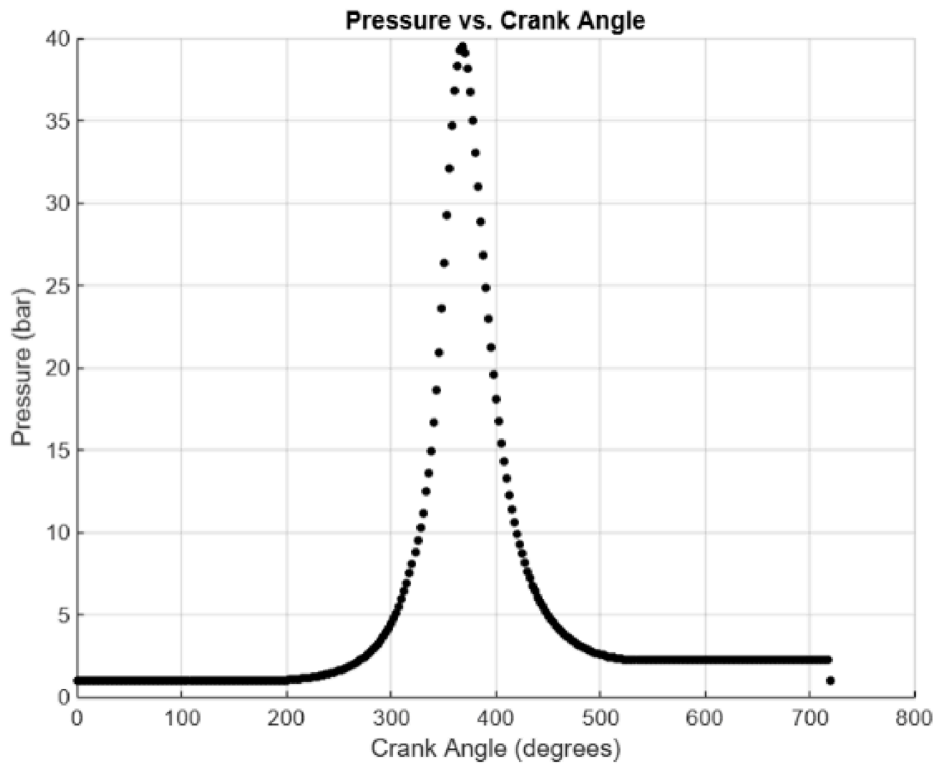
```
% Constants
CR = 9.3;

Qtotal = 300;
Q = Qtotal * xb;
Vi = Vc + 0.5 * Vd * (1 - cosd(theta0));
Ti = T0 * (((Vc + Vd) / Vi)^(gamma - 1));
Pi = P0 * (((Vc + Vd) / Vi)^gamma);
Vj = Vc + 0.5 * Vd * (1 - cosd(theta0 + deltatheta));
Tj = Ti + (((gamma - 1) * 300) / ((Vc + Vd) * R));
Pj = Pi * (Tj / T0) * ((Vc / Vj)^gamma);
Vk = Vc + 0.5 * Vd * (1 - cosd(540));

if theta <= 180
T = T0;
P = P0;
V = Vc + 0.5 * Vd * (1 - cosd(theta));

elseif (theta > 180 && theta <= theta0)
V = Vc + 0.5 * Vd * (1 - cosd(theta));
T = T0 * (((Vc + Vd) / V)^(gamma - 1));
P = P0 * (((Vc + Vd) / V)^gamma);

elseif (theta > theta0 && theta <= theta0 + deltatheta)
V = Vc + 0.5 * Vd * (1 - cosd(theta));
T = Ti + (((gamma - 1) * Q) / ((Vc+Vd) * R));
P = Pi * (T / T0) * ((Vc / V)^gamma);

elseif (theta0 + deltatheta < theta && theta <= 540)
V = Vc + 0.5 * Vd * (1 - cosd(theta));
T = Tj * ((Vj / V)^(gamma - 1));
P = Pj * ((Vj / V)^gamma);

elseif (theta > 540 && theta <= 720)
T = Tj * ((Vj / Vk)^(gamma - 1));
P = Pj * ((Vj / Vk)^gamma);
V = Vc + 0.5 * Vd * (1 - cosd(theta));
end

% Store the values
T_all(i) = T;
P_all(i) = P;
end
```

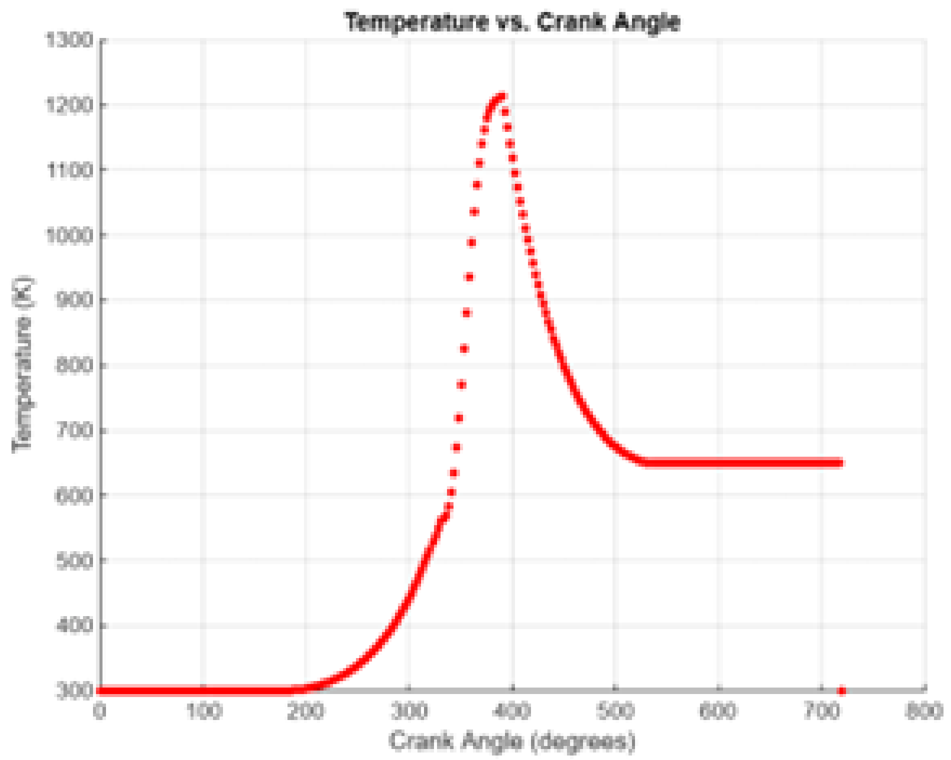
```
% PLOT TEMPERATURE VS. CRANK ANGLE
FIGURE;
SCATTER(THETADEG_ALL, T_ALL, 15, 'R', 'FILLED');
XLABEL('CRANK ANGLE (DEGREES)');
YLABEL('TEMPERATURE (K)');
TITLE('TEMPERATURE VS. CRANK ANGLE');
GRID ON;

% PLOT PRESSURE VS. CRANK ANGLE
FIGURE;
SCATTER(THETADEG_ALL, P_ALL / 1E5, 15, 'K', 'FILLED'); % CONVERTED TO BAR
XLABEL('CRANK ANGLE (DEGREES)');
YLABEL('PRESSURE (BAR)');
TITLE('PRESSURE VS. CRANK ANGLE');
GRID ON;

%%
% ENGINE AND COMBUSTION CONSTANTS
CR = 9.3;                % COMPRESSION RATIO
PULSEWIDTH = 0.72;       % DURATION OF LASER PULSE IN DEGREES
PULSEINTENSITY = 0.1;    % LASER FRACTION OF TOTAL HEAT
THETA0 = 330;            % START OF COMBUSTION
A = 6;                   % WIEBE PARAMETER (SHAPE)
M = 2.5;                 % WIEBE EXPONENT
DELTATHETA = 60;         % DURATION OF COMBUSTION
R = 287;                 % SPECIFIC GAS CONSTANT FOR AIR (J/KG·K)
GAMMA = 1.32;            % SPECIFIC HEAT RATIO (TYPICAL FOR COMBUSTION GASES)
VD = 500E-6;             % DISPLACEMENT VOLUME (M^3)
VC = VD / (CR - 1);      % CLEARANCE VOLUME (M^3)
T0 = 300;                % INITIAL TEMPERATURE (K)
P0 = 1E5;                % INITIAL PRESSURE (PA)
QTOTAL = 300;            % TOTAL HEAT RELEASED (J)
EFFICIENCY = 0.5;        % EFFECTIVE CONVERSION TO THERMAL ENERGY

% EXHAUST CONDITIONS (POST 540 DEGREES)
T_EXHAUST = 500;         % EXHAUST TEMPERATURE (K)
P_EXHAUST = 1E5;         % EXHAUST PRESSURE (PA) ~ 1 BAR

% ARRAYS FOR RESULTS
THETADEG_ALL = 0:2.5:720;
T_ALL = ZEROS(SIZE(THETADEG_ALL));
P_ALL = ZEROS(SIZE(THETADEG_ALL));

% VARIABLES TO TRACK THE PRESSURE AND TEMPERATURE IN EXHAUST PHASE
T_EXHAUST_VALUE = NAN; % INITIALIZE A VARIABLE FOR THE EXHAUST TEMPERATURE
P_EXHAUST_VALUE = NAN; % INITIALIZE A VARIABLE FOR THE EXHAUST PRESSURE

% MAIN LOOP OVER CRANK ANGLES
FOR I = 1:LENGTH(THETADEG_ALL)
THETADEG = THETADEG_ALL(I);
THETA = MOD(THETADEG, 720);  % ENSURE THETA IS WITHIN 0-720 DEGREES

% INSTANTANEOUS VOLUME CALCULATION
V = VC + 0.5 * VD * (1 - COSD(THETA));

% INITIAL CONDITIONS
VI = VC + 0.5 * VD * (1 - COSD(THETA0));
TI = T0 * (((VC + VD) / VI)^(GAMMA - 1));
PI = P0 * (((VC + VD) / VI)^GAMMA);

IF THETA <= 180
T = T0;
P = P0;

ELSEIF THETA > 180 && THETA < THETA0
T = T0 * (((VC + VD) / V)^(GAMMA - 1));
P = P0 * (((VC + VD) / V)^GAMMA);

ELSEIF THETA >= THETA0 && THETA <= THETA0 + PULSEWIDTH
% LASER-ASSISTED RAPID COMBUSTION
Q = PULSEINTENSITY * QTOTAL * ((THETA - THETA0) / PULSEWIDTH);
T = TI + (EFFICIENCY * (GAMMA - 1) * Q) / (V * R);
P = PI * (T / T0) * ((VC / V)^GAMMA);

ELSE
% GRADUAL COMBUSTION VIA WIEBE FUNCTION
XB = 1 - EXP(-A * ((THETA - (THETA0 + PULSEWIDTH)) / DELTATHETA)^M);
XB = MIN(MAX(XB, 0), 1);
Q = PULSEINTENSITY * QTOTAL + (1 - PULSEINTENSITY) * QTOTAL * XB;
T = TI + (EFFICIENCY * (GAMMA - 1) * Q) / (V * R);
P = PI * (T / T0) * ((VC / V)^GAMMA);
END

% AFTER 540 DEGREES (EXHAUST PHASE)
IF THETA > 540
% IF T_EXHAUST_VALUE AND P_EXHAUST_VALUE ARE NOT INITIALIZED YET, STORE THEM
IF ISNAN(T_EXHAUST_VALUE)
T_EXHAUST_VALUE = T;
END
IF ISNAN(P_EXHAUST_VALUE)
P_EXHAUST_VALUE = P;
END
% KEEP TEMPERATURE AND PRESSURE CONSTANT IN EXHAUST PHASE
T = T_EXHAUST_VALUE;
P = P_EXHAUST_VALUE;
END

% STORE RESULTS
T_ALL(I) = T;
P_ALL(I) = P;
END

% PLOT TEMPERATURE
FIGURE;
SCATTER(THETADEG_ALL, T_ALL, 15, 'R', 'FILLED');
XLABEL('CRANK ANGLE (DEGREES)');
YLABEL('TEMPERATURE (K)');
TITLE('TEMPERATURE VS. CRANK ANGLE');
GRID ON;

% PLOT PRESSURE
FIGURE;
SCATTER(THETADEG_ALL, P_ALL / 1E5, 15, 'K', 'FILLED'); % CONVERT FROM PA TO BAR
XLABEL('CRANK ANGLE (DEGREES)');
YLABEL('PRESSURE (BAR)');
TITLE('PRESSURE VS. CRANK ANGLE');
GRID ON;
```

# CIS VS LIS ( 30 DEGREE BTDC)

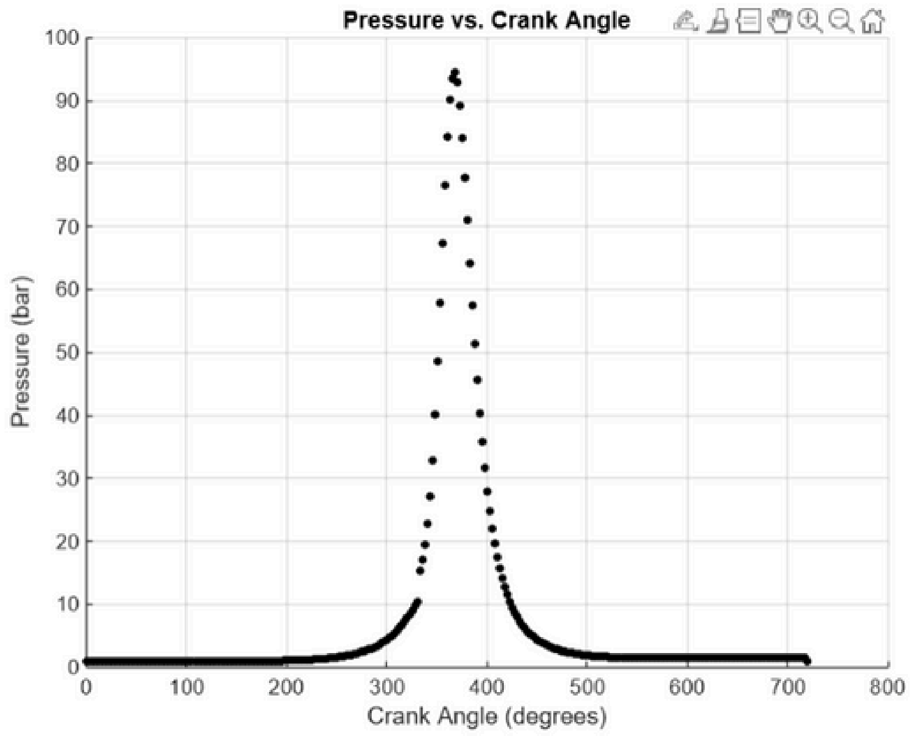
- For the CIS engine, advancing combustion by 30° BTDC results in a peak pressure of 39.3 bar and a peak temperature of 1227 K.
- For the LIS engine, under the same 30° combustion advancement, the peak pressure and temperature increase significantly to 95.2 bar and 2789 K, respectively.
- Conclusion: The LIS engine exhibits markedly better performance compared to the CIS engine for a 30° combustion advancement, as evidenced by the higher peak pressure and temperature values.

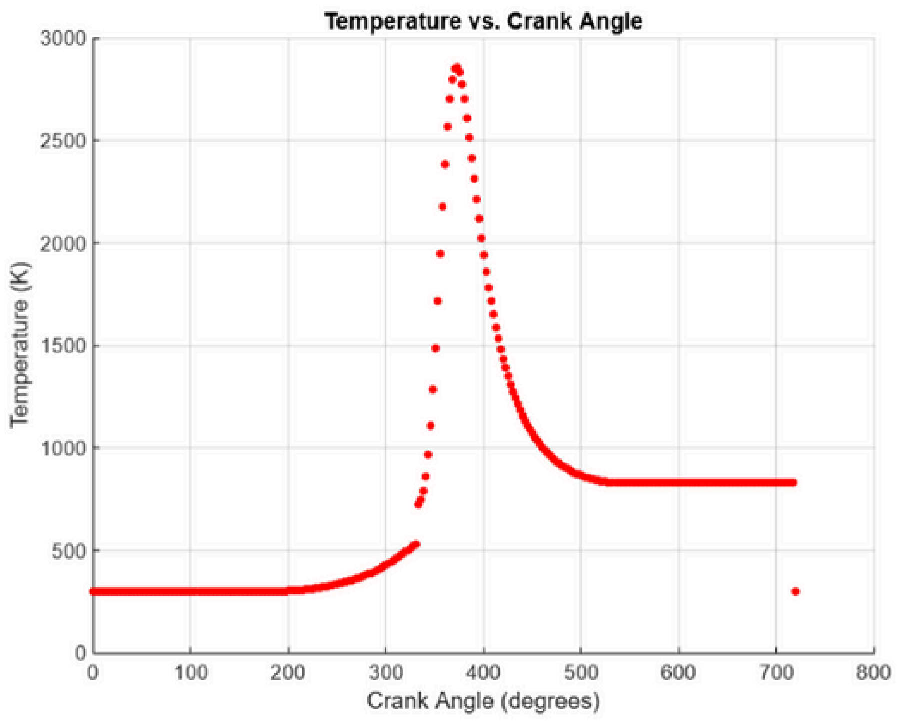
## CIS




## LIS



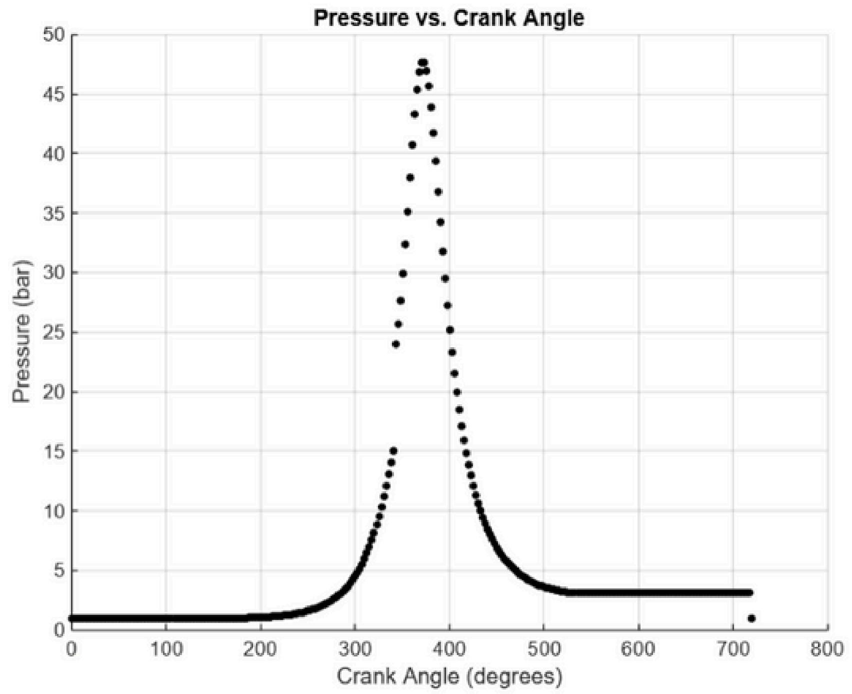
# CIS VS LIS (20 DEGREE BTDC)

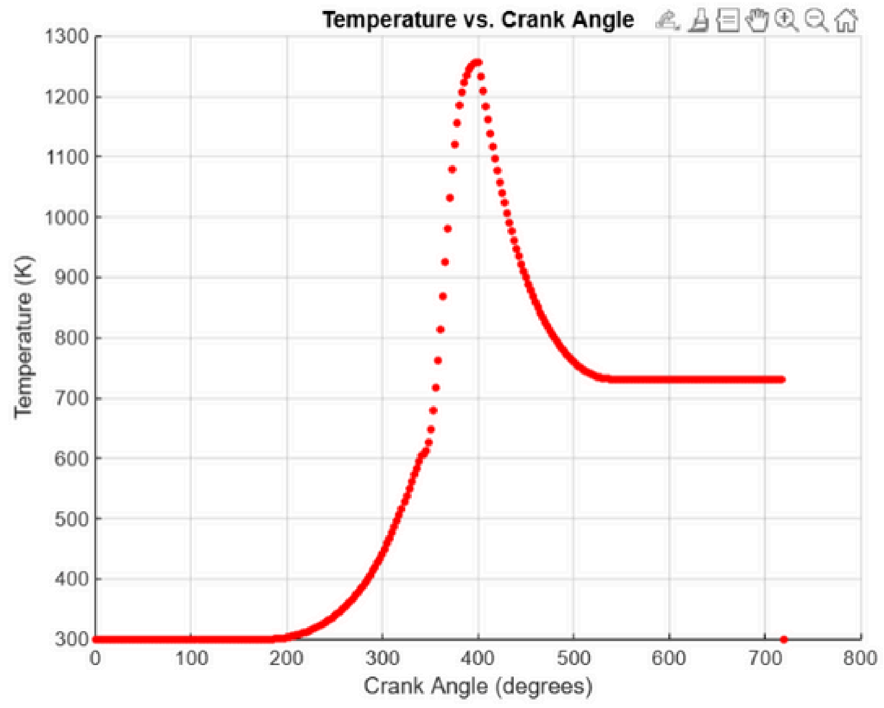
- For the CIS engine, advancing combustion by 20° BTDC results in a peak pressure of 47.1 bar and a peak temperature of 1265 K.

- For the LIS engine, under the same 20° combustion advancement, the peak pressure and temperature increase significantly to 100.1 bar and 2590 K, respectively.

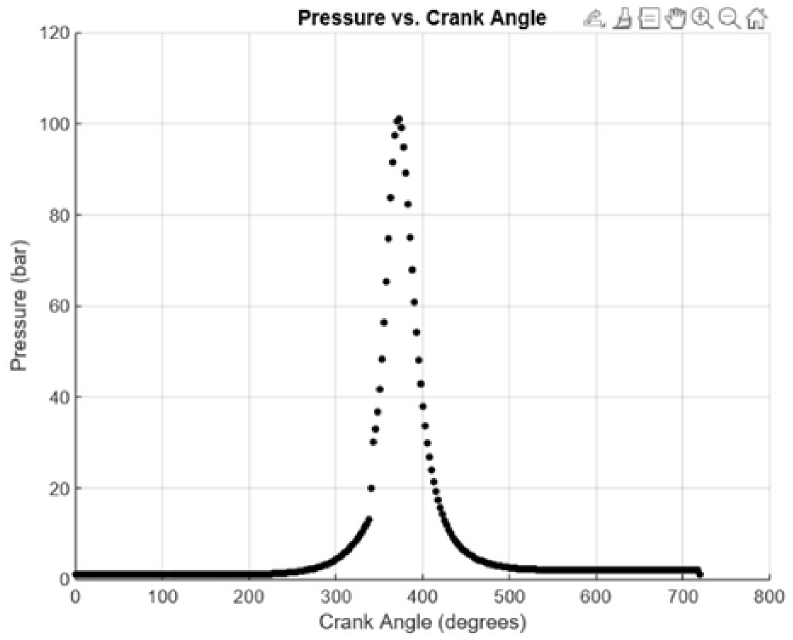
- Conclusion: The LIS engine exhibits markedly better performance compared to the CIS engine for a 20° combustion advancement, as evidenced by the higher peak pressure and temperature values.

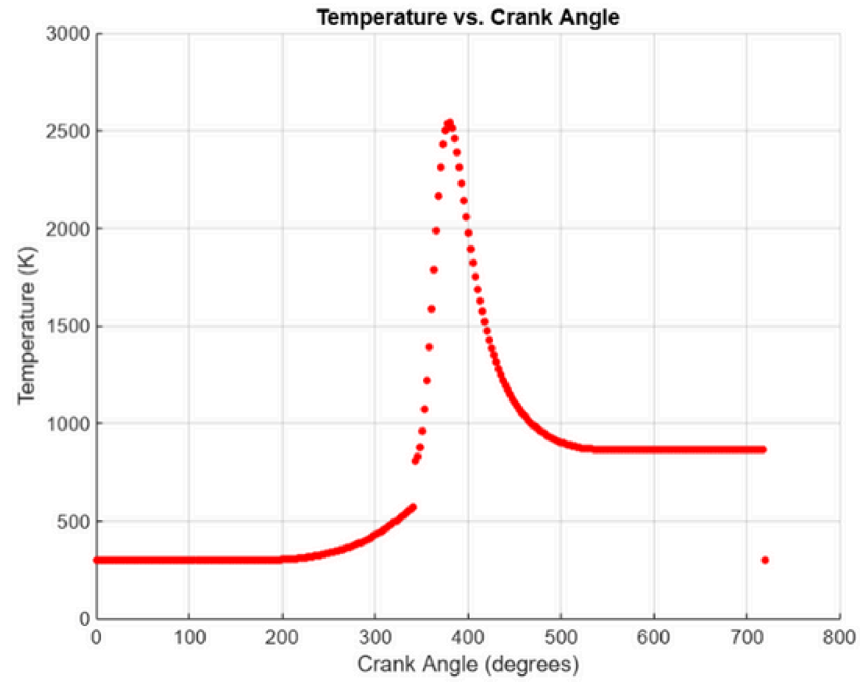
## CIS




## LIS

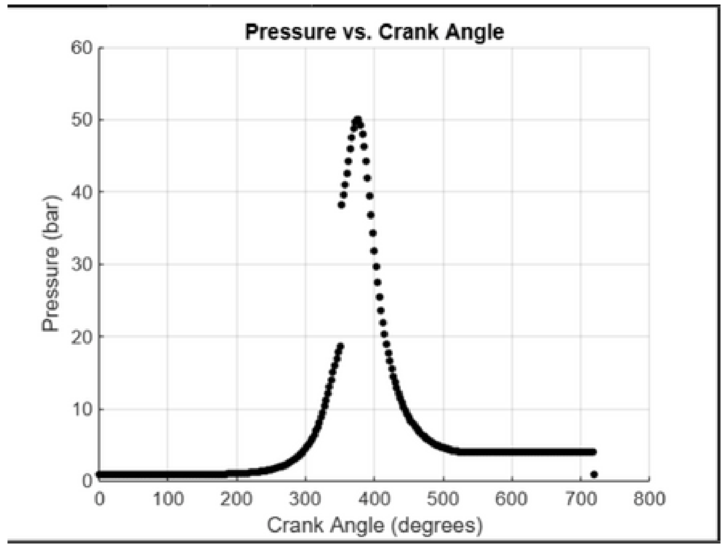


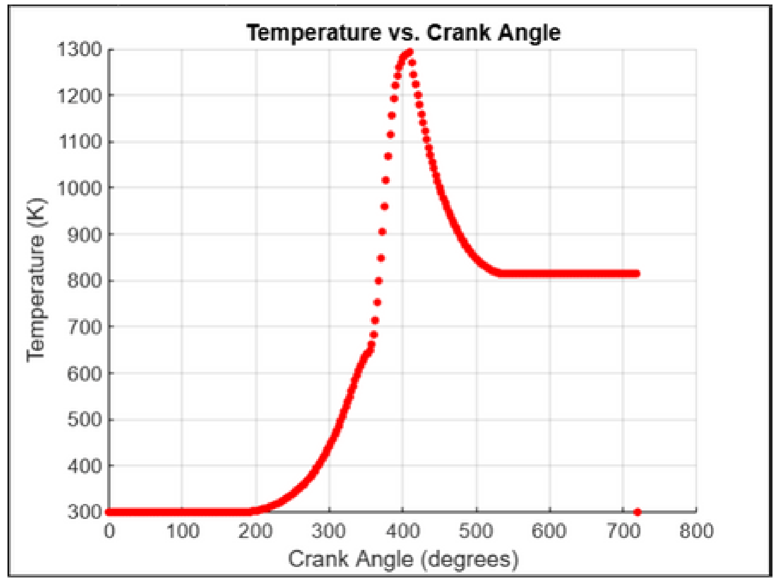



# CIS VS LIS ( 10 DEGREE BTDC)

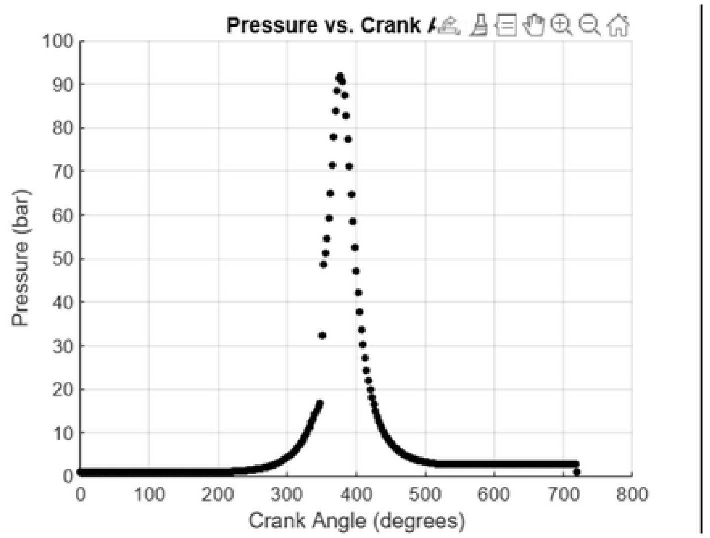
- For the CIS engine, advancing combustion by 10° BTDC results in a peak pressure of 51 bar and a peak temperature of 1304 K.
- For the LIS engine, under the same 10° combustion advancement, the peak pressure and temperature increase significantly to 92.9 bar and 2234 K, respectively.
- Conclusion: The LIS engine exhibits markedly better performance compared to the CIS engine for a 10° combustion advancement, as evidenced by the higher peak pressure and temperature values.

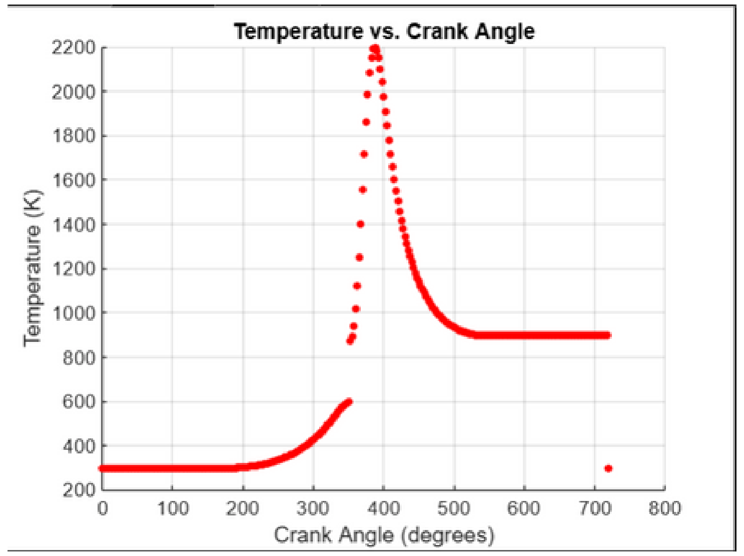
## CIS




## LIS



# RESULTS

with varying combustion initiation angles

Comparative study of various engine parameters with varying combustion angles

| Combustion Angle | Conventional | | | Laser | | |
|---|---|---|---|---|---|---|
| | Pmax (bar) | Tmax (K) | Texhaust (K) | Pmax (bar) | Tmax (K) | Texhaust (K) |
| 330 | 39.3 | 1227 | 654 | 95.2 | 2789 | 854 |
| 340 | 47.1 | 1265 | 732 | 100.1 | 2590 | 890 |
| 350 | 51 | 1304 | 815 | 92.9 | 2234 | 955 |

# CONCLUSIONS

## DISCUSSIONS

**Peak Pressure and Temperature:**
- The laser ignition system achieves higher maximum cylinder pressure and temperature compared to the conventional ignition engine.

**Rate of Pressure and Temperature Rise:**
- The rate of increase of pressure and temperature after ignition is steeper in the laser ignition engine.

**Mean Effective Pressure (MEP):**
- The MEP is higher for the laser ignition system than for the conventional system.

**Exhaust Temperature:**
- The laser ignition engine shows a higher exhaust temperature compared to the conventional engine.

**Effect of Ignition Timing on Peak Pressure and Temperature:**
- In the conventional ignition engine, as the combustion initiation angle moves closer to 360° (TDC), both Pmax and Tmax increase steadily.

# SCOPES OF IMPROVEMENTS

- IMEP, THERMAL EFFICIENCY, AND VOLUMETRIC EFFICIENCY CALCULATIONS WERE NOT INCLUDED.
- HEAT LOSSES TO THE COOLANT WERE IGNORED.
- LINEAR HEAT RELEASE WAS ASSUMED FOR LASER IGNITION INSTEAD OF A MORE REALISTIC FUNCTION.
- MOTION STUDY AND ADDITIONAL ENGINE COMPONENTS WERE NOT ADDED.
- SIMULATIONS WERE NOT RUN FOR DIFFERENT ENGINE SIZES.
- IGNITION DURATION AND WIEBE FUNCTION CONSTANTS WERE ASSUMED THE SAME FOR BOTH ENGINES.
- INTAKE AND EXHAUST PROCESSES WERE NOT MODELED.
- AIR WAS TREATED AS AN IDEAL GAS, LEADING TO DEVIATIONS.

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# Thank you very much!