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***Fatigue Analysis of a Connecting Rod using
ANSYS Mechanical***

Structural Component Analysis (ACHA7030)

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Date (12/2025)

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1. Introduction

This report discusses the fatigue analysis of a connecting rod from a 1.6L Ford Sigma (PNBA) Engine, the methodologies and workflow used to simulate and validate results, as well as considerations of materials, boundary conditions & load cases used.

2. Methodology & Workflow

2.1 Background Research

2.1.1 Engine & Model Specifications

Specifications

Metric	
Bore	79 mm
Stroke	81.4 mm
Compression ratio	11.1
Max power @ RPM	123 hp @ 6,000 rpm
Max torque @ RPM	118 lb-ft @ 4,100 rpm
Cylinder head	Aluminum
Cylinder block	Aluminum
Camshaft drive	Belt

Figure 1 - Engine Specs

Engine specifications were given as part of brief.

Max Pressures			Max Pressure		
RPM	Crank Angle	Pressure (Bar)	RPM	Crank Angle	Pressure (Bar)
1000	-30	9.946	6500	14	72.631
1500	22	55.471			
2500	20	59.357			
3500	17	67.019			
4500	17	69.305			
5500	21	59.715			
6500	14	72.631			

Min Pressure		
RPM	Crank Angle	Pressure (Bar)
6500	-360	0.902

Figure 2 - Calculated Pressures

Max pressure was calculated from the supplied pressure data sheet.

2.1.2 Material Considerations

Research was done into common used materials and ANSYS GRANTA was used to obtain the relevant data.

2.2 Workflow

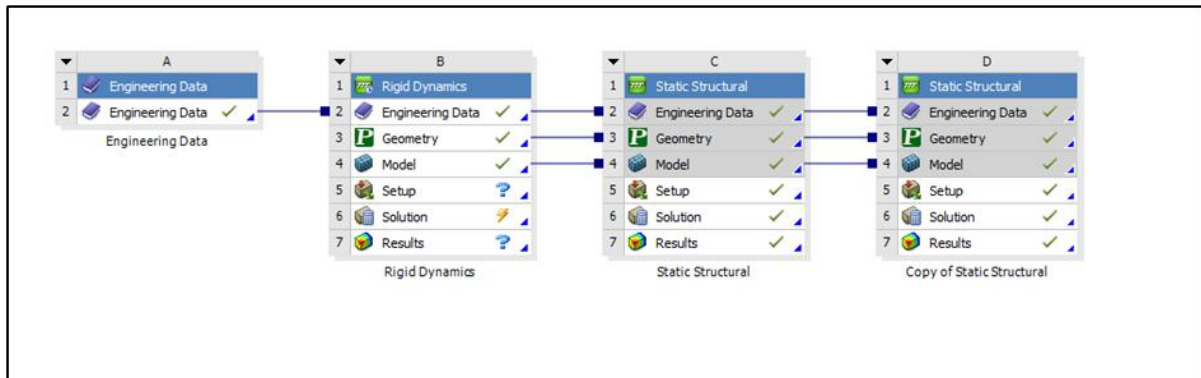


Figure 3 - Workflow Order

The sims were ran in the order:

Rigid Dynamics → Static Structural (Max Inertial) → Static Structural (Max Gas Pressure)
→ Fatigue Study

3. Boundary Conditions & Load Cases

3.1 Rigid Dynamics Simulation

3.1.1 Joints

3.1.1.1 Crankshaft

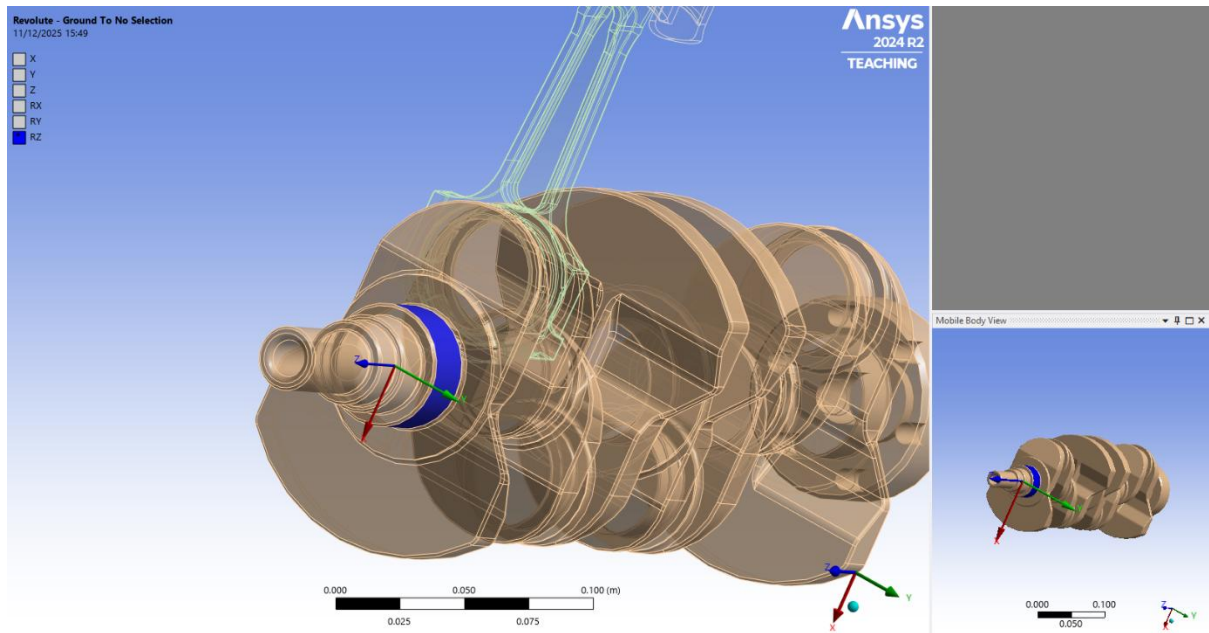


Figure 4 - Crankshaft Joint

A body-ground revolute joint was used on the crankshaft to allow rotation but fix all other movement.

3.1.1.2 Crankshaft to Connecting Rod

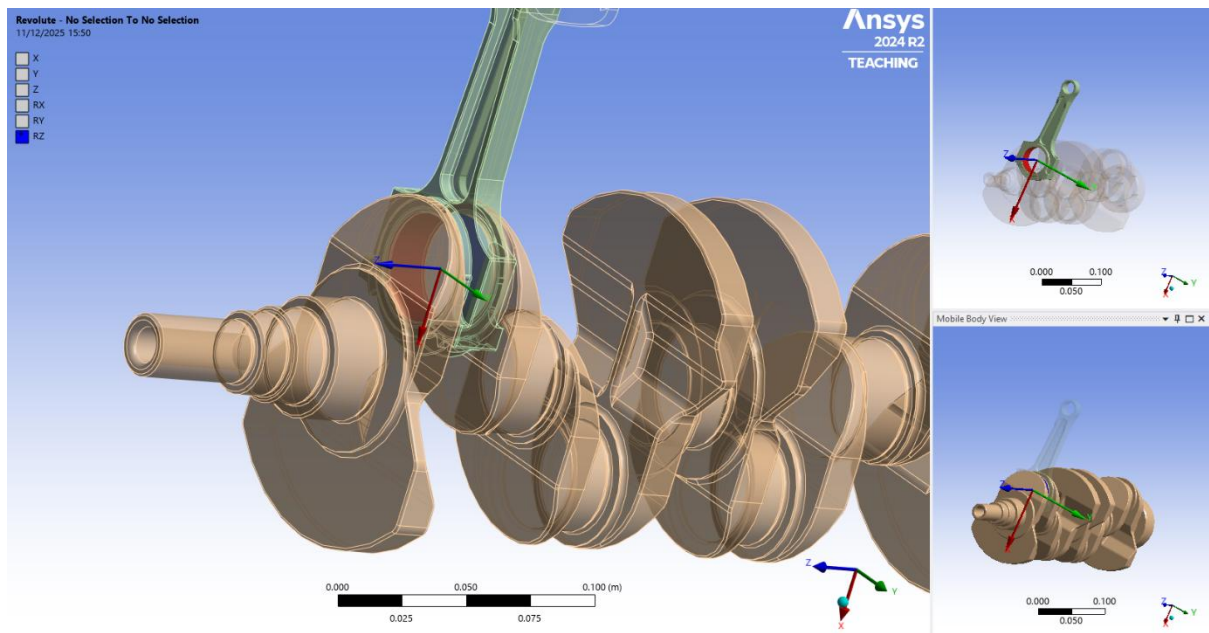


Figure 5 - Crank to Conrod Joint

A body-body revolute joint was used on the crankshaft and connecting rod to allow the connecting rod to rotate around the crankshaft but fix all other movement.

3.1.1.3 Gudgeon Pin to Connecting Rod

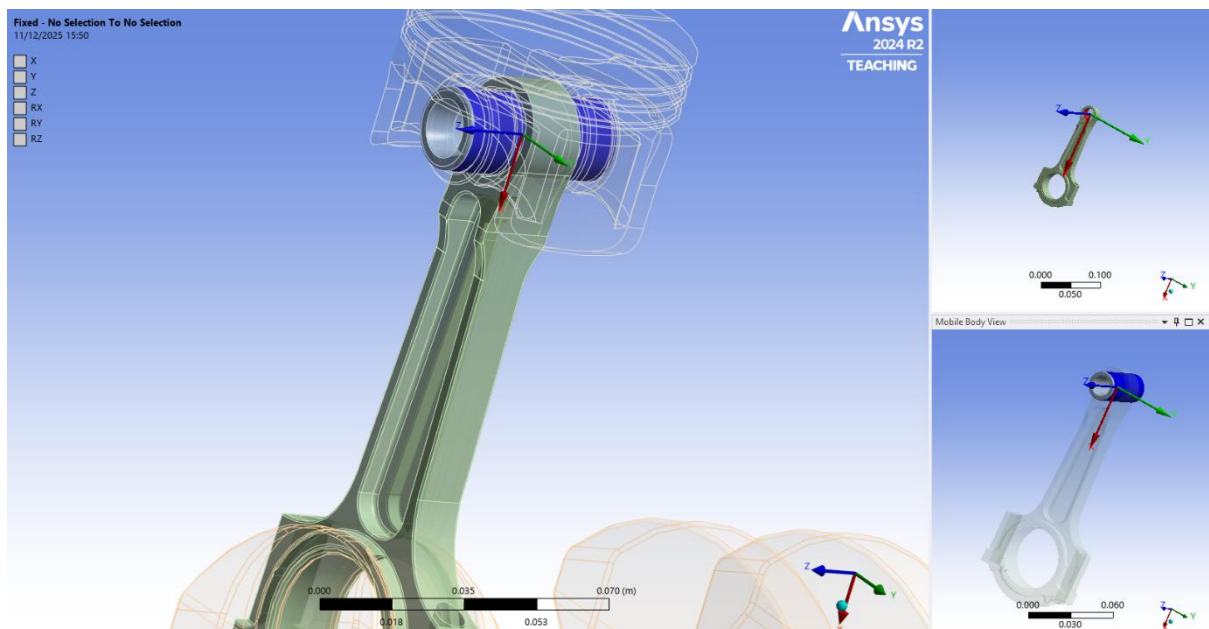


Figure 6 - Gudgeon to Conrod Joint

A body-body fixed joint was used to fix all movement of the gudgeon pin in the connecting rod.

3.1.1.4 Gudgeon Pin to Piston

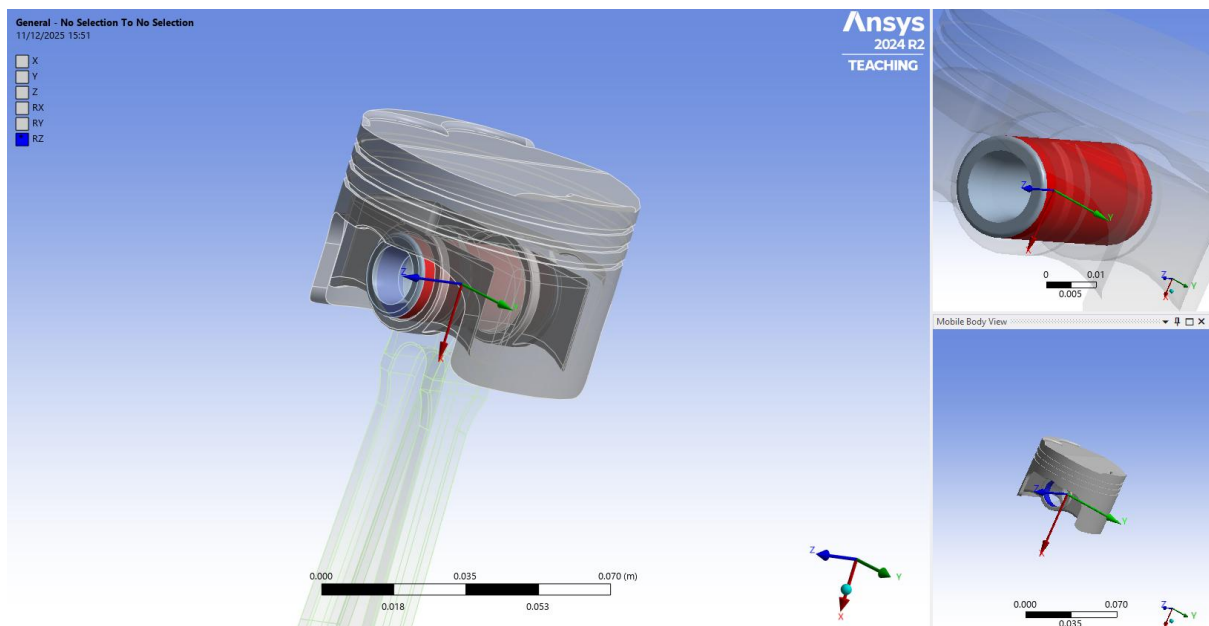


Figure 7 - Piston to Gudgeon Joint

A body-body general joint with free rotation around the Z-axis was used to fix all movement of the gudgeon pin to the piston while allowing for free rotation.

3.1.1.5 Piston

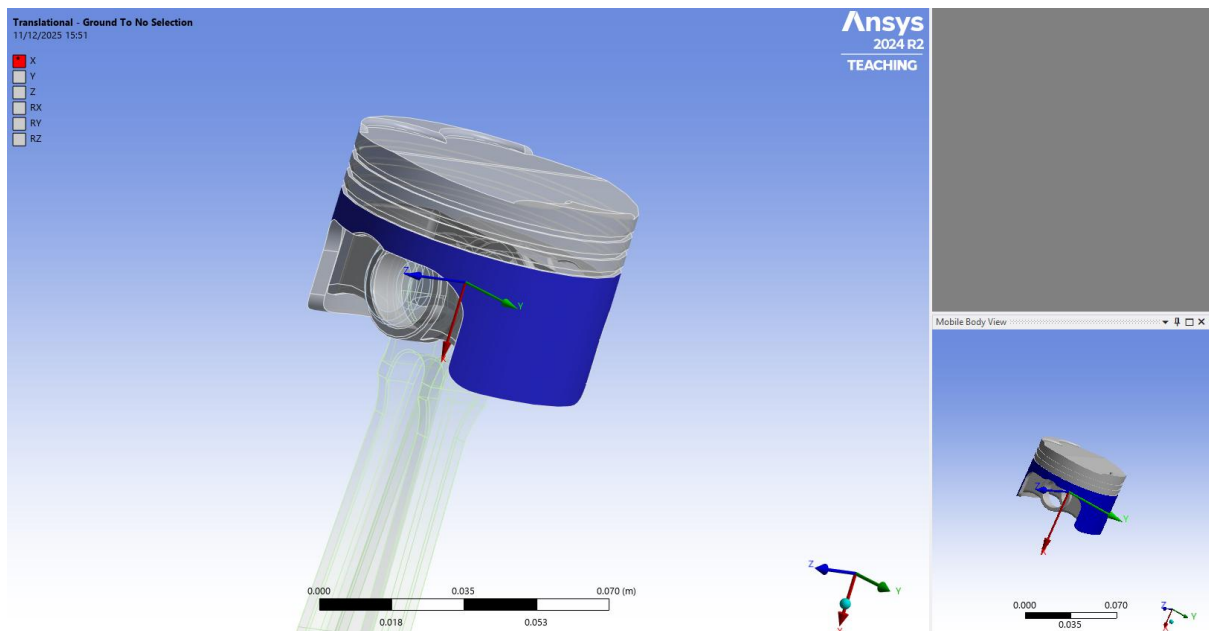


Figure 8 - Piston Joint

A body-ground translational joint was used to fix all movement of the piston while allowing it to travel along the X-axis.

3.1.2 Running

The speed chosen for the rigid dynamics simulation was 6500RPM, this was due to the max gas pressure appearing within the 6500RPM range.

3.2 Static Structural Simulations

3.2.1 Meshing



Figure 9 - Mesh

A uniform mesh of 1mm element size was chosen, this reduced complexity and simulation run time, however is also less accurate. Results may have differed if edges and/or specific parts of the geometry were edited via the sizing tool, making certain, high stress areas more detailed could provide more realistic results, however for the purpose of this report and due to time constraints, these were not implemented.

3.2.2 Max Inertia Simulation

3.2.2.1 Motion Loads

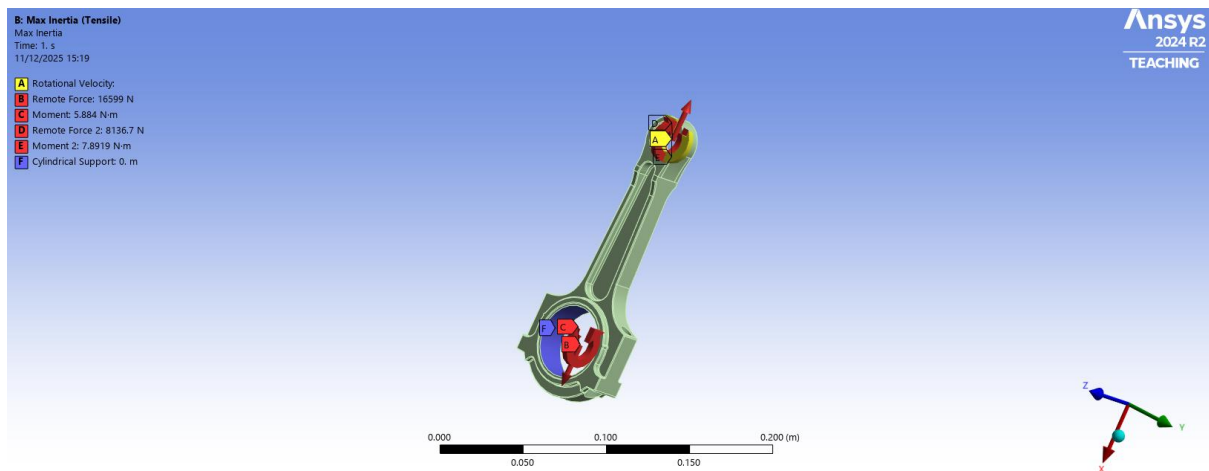


Figure 10 - Inertia Loads

Exported motion loads from the rigid dynamics simulation at TDC were used as the forces for the inertia simulation.

3.2.2.2 Cylindrical support

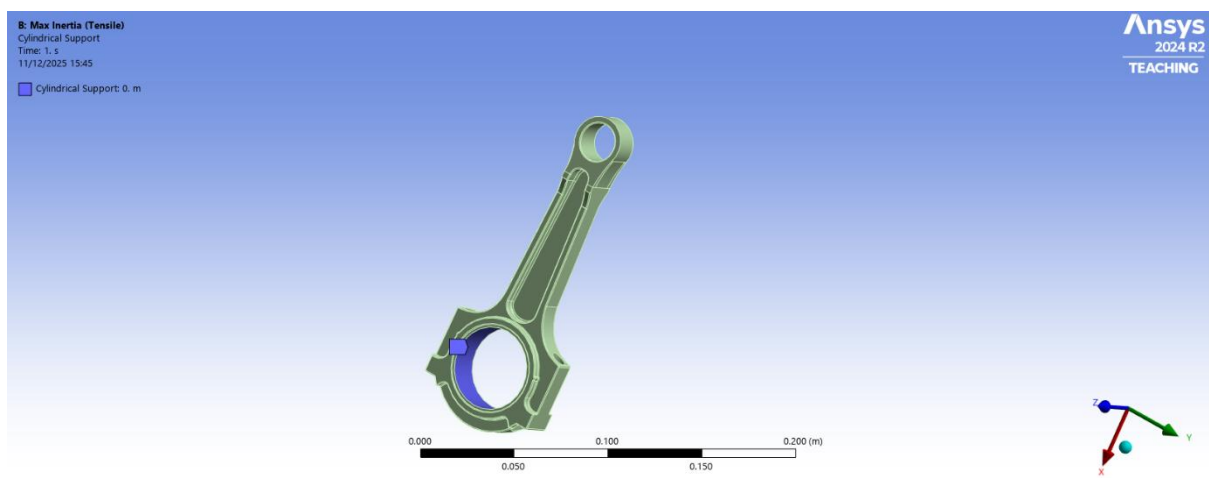


Figure 11 - Cylindrical Support

A basic cylindrical support, placed at the crankshaft end of the connecting rod was used for both the inertial and max gas simulations.

3.2.3 Max Gas Pressure Simulation

3.2.3.1 Motion Loads

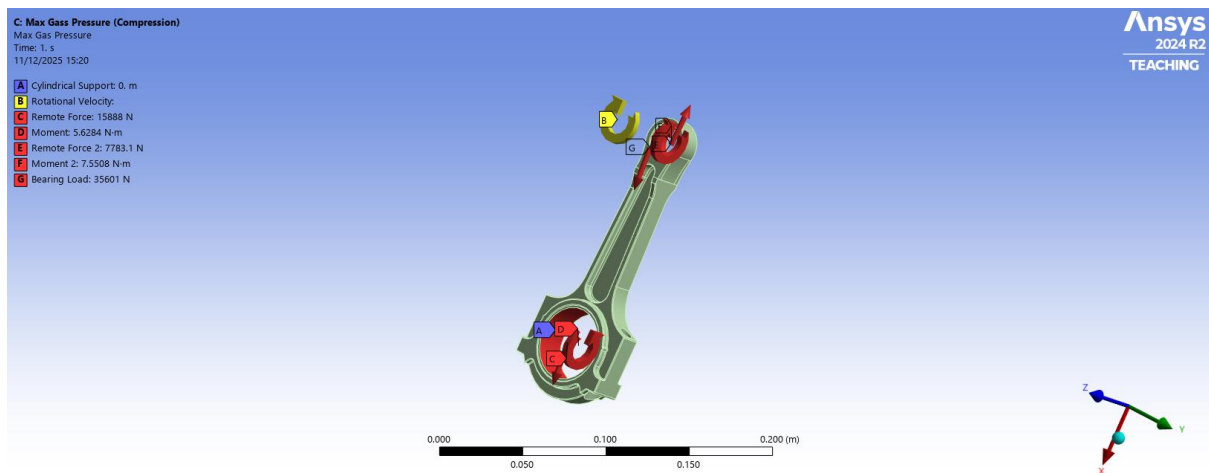


Figure 12 - Gas Pressure Loads

Exported motion loads from the rigid dynamics simulation at 14° crank angle which translates to 4.177929459° Connecting rod angle were used as the forces for the max gas pressure simulation.

3.2.3.2 Custom Co-ordinate System

A custom system was made to translate the 14° crank angle to the 4.177929459° Connecting rod angle, this increases accuracy of the force applied.

3.2.3.3 Bearing Load

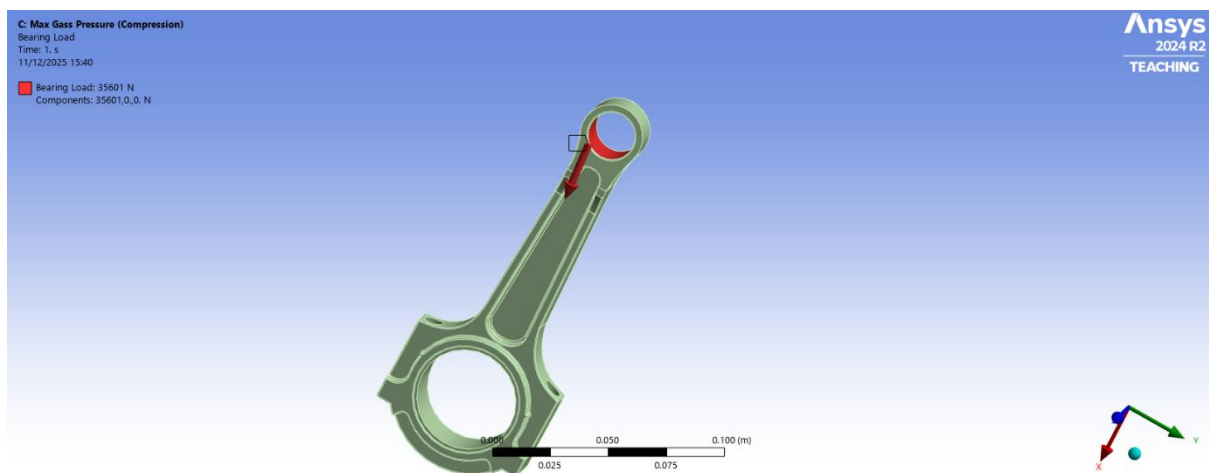


Figure 13 - Gas Pressure Bearing Load

A bearing load was used to apply a force to the connecting rod at the offset angle of the custom coordinate system, this force was calculated using the max cylinder gas pressure over the area of the bore.

3.3 Fatigue Tool Simulation

3.3.1 Solution Combination

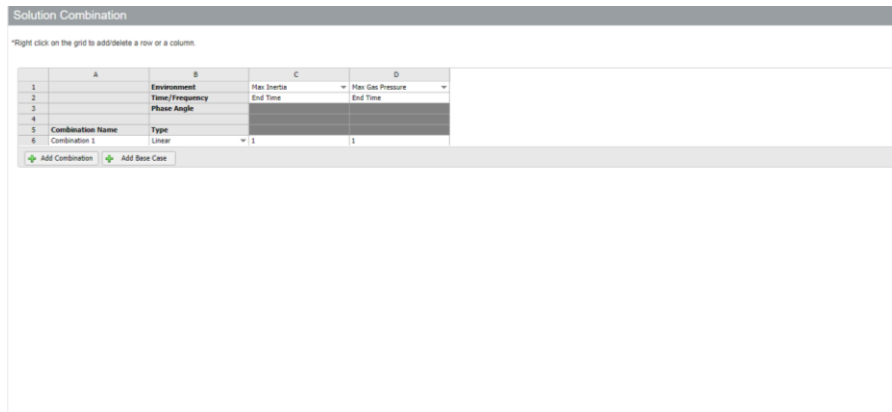


Figure 14 - Solution Combination

The solution combination tool was first ran to combine the static structural of max inertia and max gas pressure into one result, this then allowed for the use of the fatigue tool, the desired results chosen where fatigue life and fatigue safety factor (FSF), with these it is possible to estimate the possibility of infinite life.

3.3.2 Goodman Method

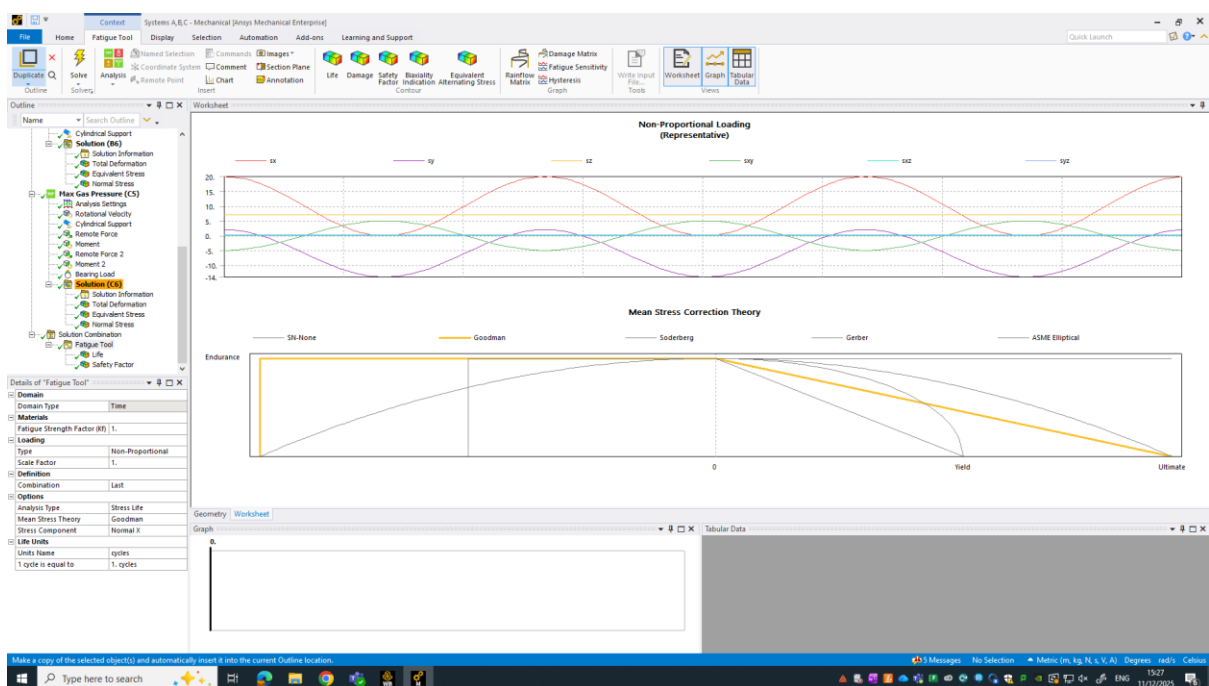


Figure 15 - Goodman Method

The Goodman method was chosen as it is conservative which increases safety, works well with mean stresses and works with fully reversed loads.

3.4 Analytical

A program was made inside MATLAB (found in appendices) to calculate the analytical result for σ_{Min} , σ_{Max} , σ_{Mean} , σ_{Range} , and FSF, this was useful as a validation to the simulations ran through ANSYS.

```
% Variables
RPM = 6500;
L = 0.13515; % Rod length (centre of bearings) in m
R = 0.0407; % Crank radius in m
BoreD = 0.079; % Bore diameter in m
ThetaMin = 14; % Crank angle minimum (Angle at max gas pressure)
ThetaMax = -360; % Crank angle maximum (TDC, max inertial force)
PMax = 90200; % Pressure at minimum crank angle (Max Inertia)
PMin = 7263100; % Max pressure (Max gas pressure) in N/m^2
mRec = 0.470965249; % Reciprocating mass in kg (piston+gudgeon+1/3*conrod, using avg densities of each material via GRANTA)
CSA = 0.00015407; % Cross-sectional area of the Conrod in m^2 (Found from a section view of the conrod at the edge of reciprocating mass)
UTSAvg = 1.0225e+9; % Average ultimate tensile strength in N/m^2 (Pulled from material data sheet)
```

Figure 16 - MATLAB 1

```
% Max Gass Pressure Calculations
A = pi*BoreD^2/4; % Area of piston in m (based on bore)
PhiMin = asind(R*sind(ThetaMin)/L); % Conrod angle in degrees
w = RPM*2*pi/60; % Engine speed in rad/s
a = R*w^2*cosd(ThetaMin)+R^2/L*w^2*cosd(2*ThetaMin); % Accelration in m/s^2
FInertia = mRec*a; % Inertia force in N
FGas = PMin*A; % Gas pressure force in N
Fnet = FInertia-FGas; % Net force in N
FRodMin = Fnet/cosd(PhiMin); % Rod force in N
SigmaMin = FRodMin/CSA; % Min stress in N/m^2 (Max Compression, remember -ve force is compression, +ve is tensile)

% Max Inertia Calculations
PhiMax = asind(R*sind(ThetaMax)/L); % Conrod angle in degrees
a = R*w^2*cosd(ThetaMax)+R^2/L*w^2*cosd(2*ThetaMax); % Accelration in m/s^2
FInertia = mRec*a; % Inertia force in N
FGas = PMax*A; % Gas pressure force in N
Fnet = FInertia-FGas; % Net force in N
FRodMax = Fnet/cosd(PhiMax); % Rod force in N
SigmaMax = FRodMax/CSA; % Max stress in N/m^2 (Max Tensile, remember -ve force is compression, +ve is tensile)

% Fatigue FOS Calculations
SigmaMean = (SigmaMin+SigmaMax)/2; % Average stress in N/m^2
SigmaRange = SigmaMax-SigmaMin; % Stress Range in N/m^2
EndLim = UTSAvg*0.45; % Endurance Limit in N/m^2 (For steels with UTS<1100 Endurance limit is typically given as 45% of the UTS)
SigmaAllowable = 2*EndLim*(1-(SigmaMean/UTSAvg)); % Allowable Stress in N/m^2
FSF = SigmaAllowable/SigmaRange;
```

Figure 17 - MATLAB 2

Figures 16 & 17 show the MATLAB code created, first variables and values from material data sheets, then sections for max inertia and max gas pressure, followed by a section calculating the FSF.

3.5 Temperature Simulation Consideration

Within the research conducted, it was deemed unnecessary to include a thermal study as the connecting rod has negligible changes in young's modulus over the small range of temps it experiences.

4. Fatigue Life & Safety Factor Comparisons

4.1 ANSYS Results

4.1.1 Rigid Dynamics Simulation

4.1.1.1 Gudgeon Pin Side Probe Forces (Max Inertia)

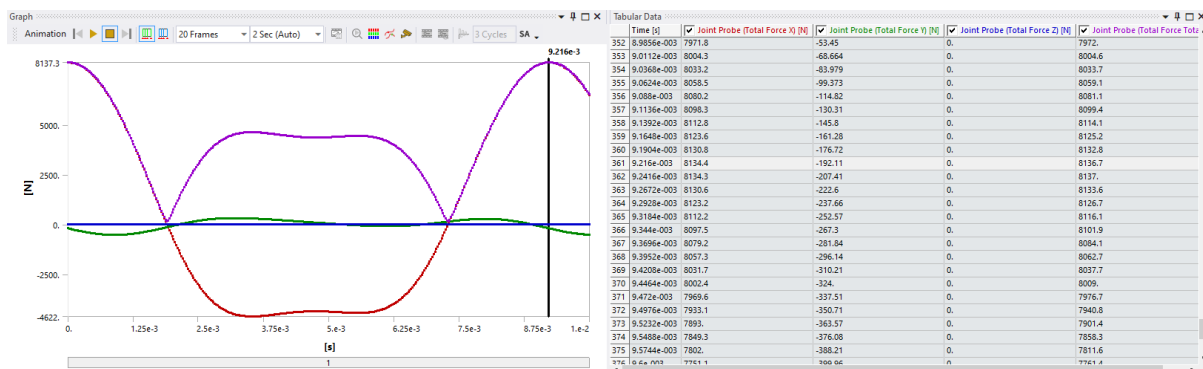


Figure 18 - Joint Load 1

As seen in figure 18, the forces experienced at the gudgeon pin / connecting rod joint at 360° crank angle, top dead centre (TDC) where the max inertial force is experienced. The predominant being 8134.4N along the X-axis. (Table shows 361° since sim is offset by 1)

4.1.1.2 Crankshaft Side Probe Forces (Max Inertia)

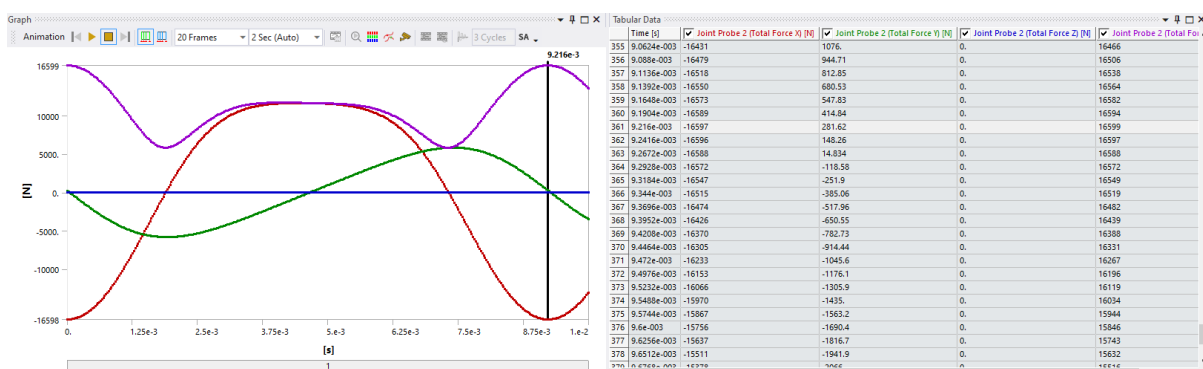


Figure 19 - Joint Load 2

As seen in figure 19, the forces experienced at the crankshaft / connecting rod joint at 360° crank angle, top dead centre (TDC) where the max inertial force is experienced. The predominant being -16,597N along the X-axis.

4.1.1.3 Gudgeon Pin Side Probe Forces (Max Gas Pressure)

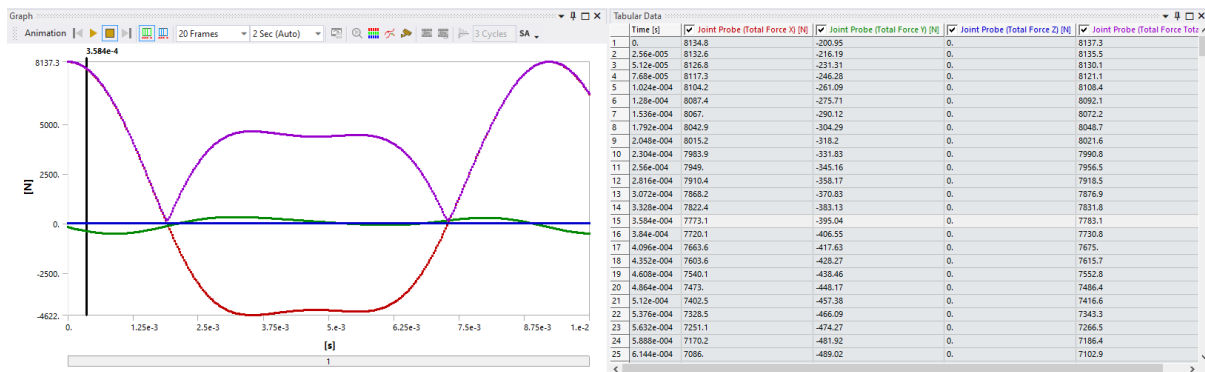


Figure 20 - Joint Load 3

As seen in figure 20, the forces experienced at the gudgeon pin / connecting rod joint at 14° crank angle where max gas pressure acts. The predominant being 7773.1N along the X-axis. (Table shows 15° since sim is offset by 1)

4.1.1.4 Crankshaft Side Probe Forces (Max Gas Pressure)

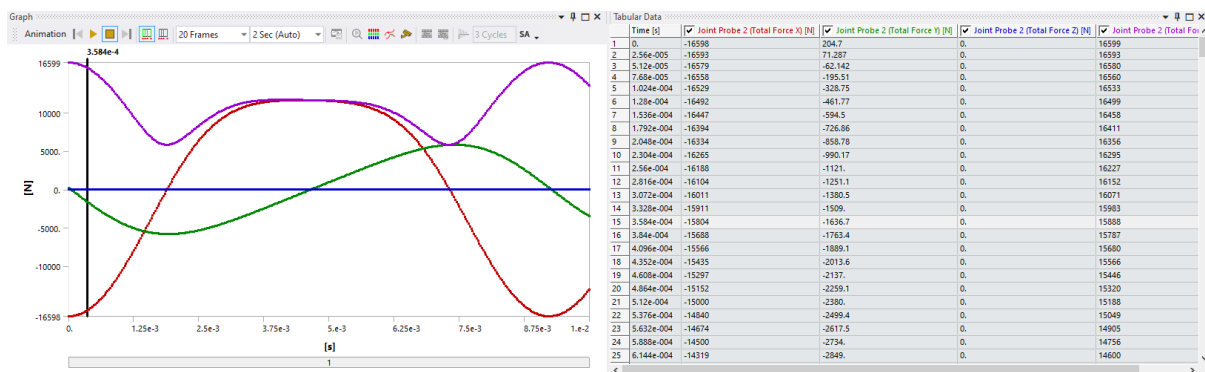


Figure 21 - Joint Load 4

As seen in figure 21, the forces experienced at the crankshaft / connecting rod joint at 14° crank angle where max gas pressure acts. The predominant being -15804N along the X-axis.

4.1.2 Static Structural – Max Inertia Simulation

4.1.2.1 Total Deformation

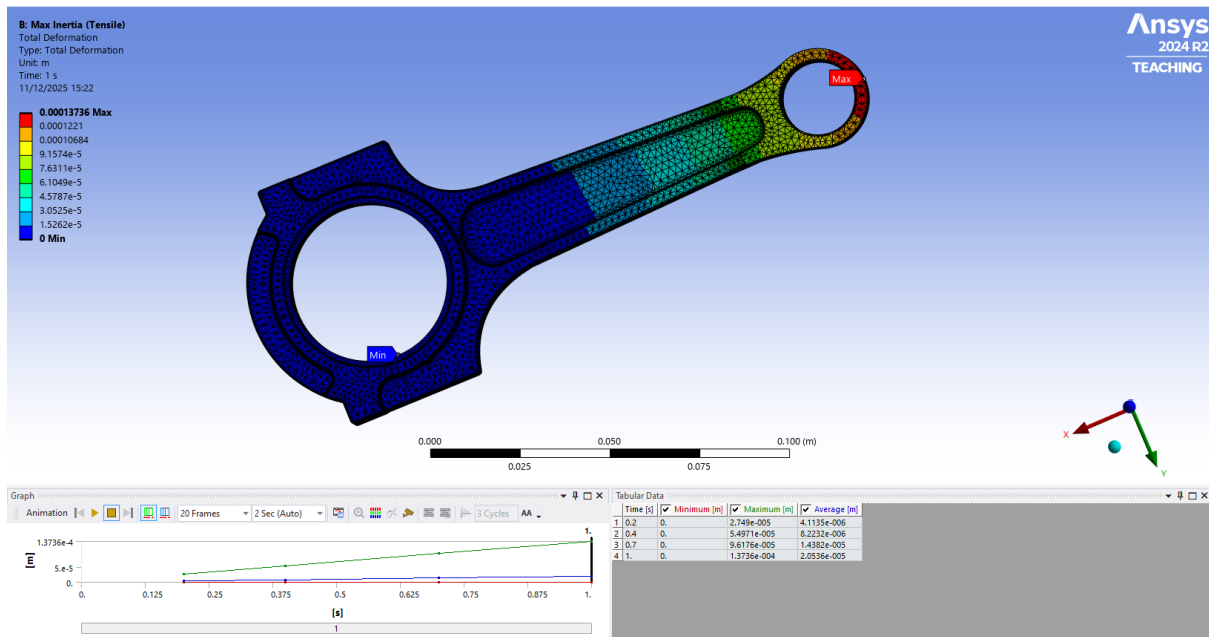
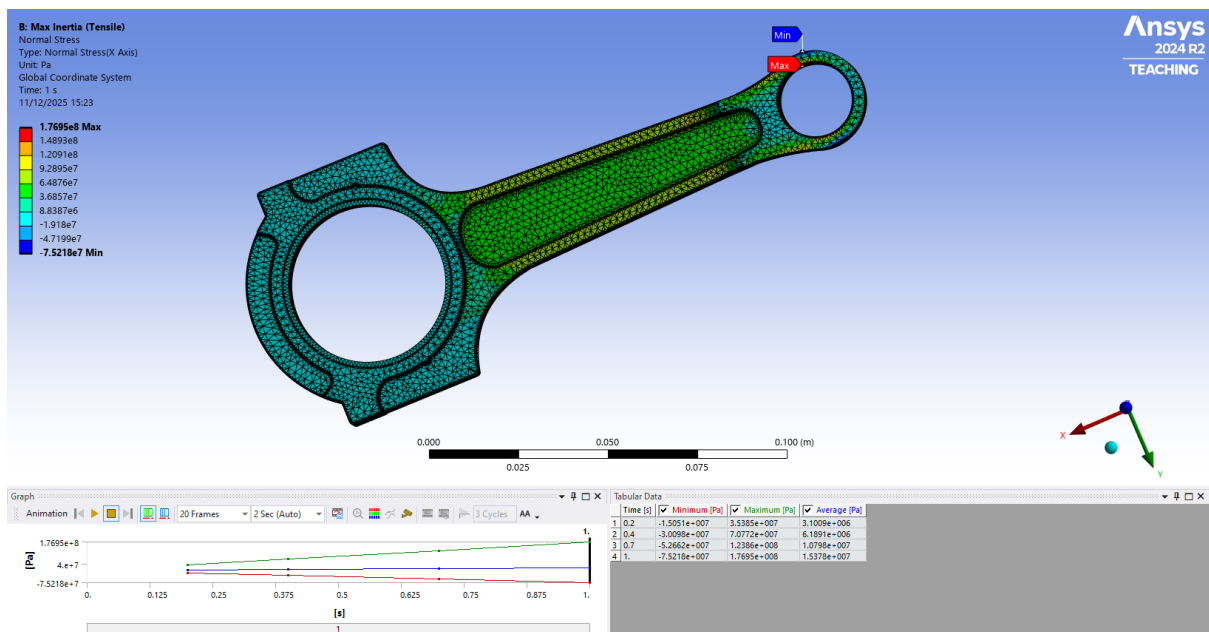


Figure 22 - Deform Inertia

As seen in figure, max deformation = 0.13mm, min deformation = 0mm for max inertia.

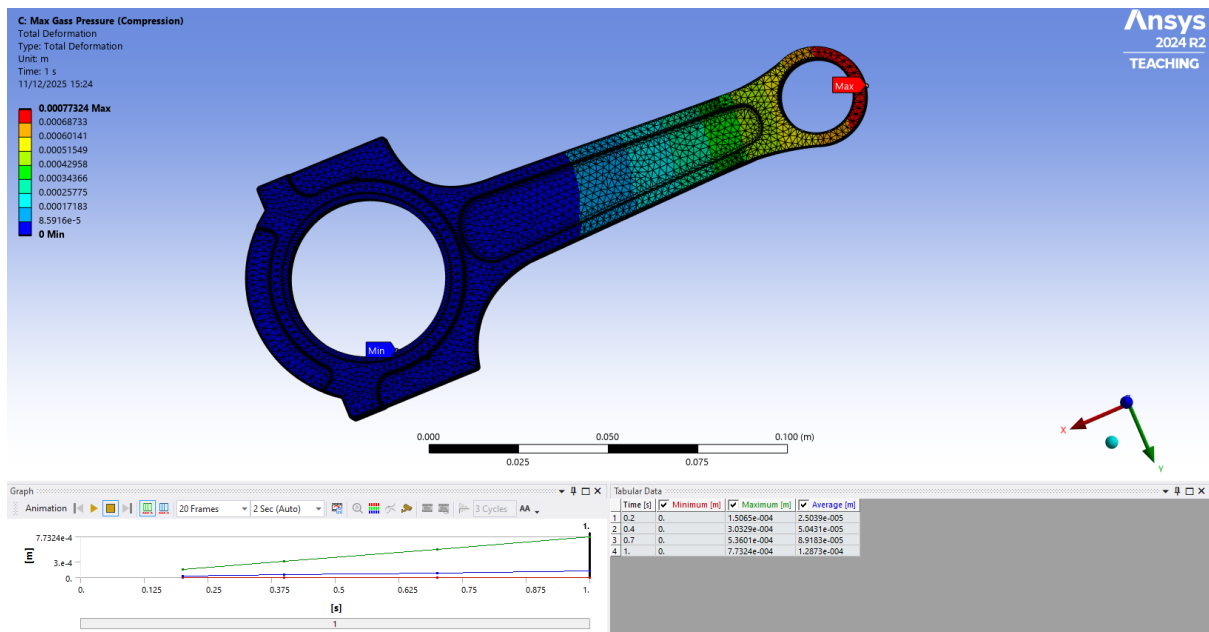
4.1.2.2 Normal Force



As seen in figure, max normal stress = 176.95MPa, min normal stress = -75.218MPa along the X-axis for max inertia.

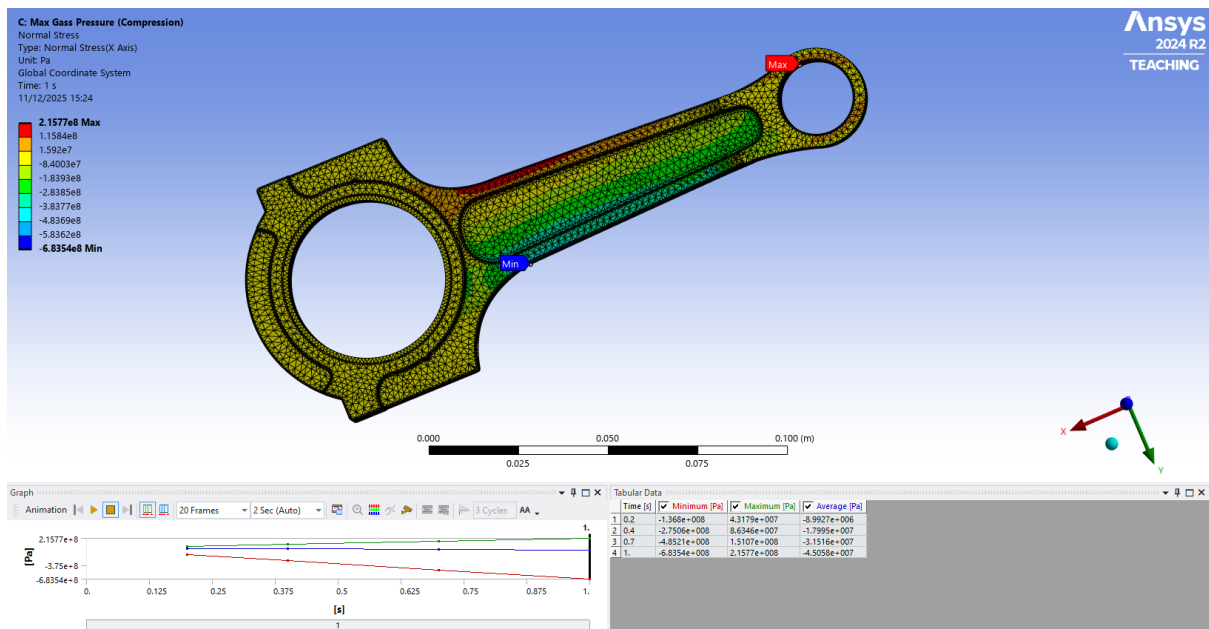
4.1.3 Static Structural – Max Gas Pressure Simulation

4.1.3.1 Total Deformation



As seen in figure ##, max deformation = 0.77mm, min deformation = 0mm for max gas pressure.

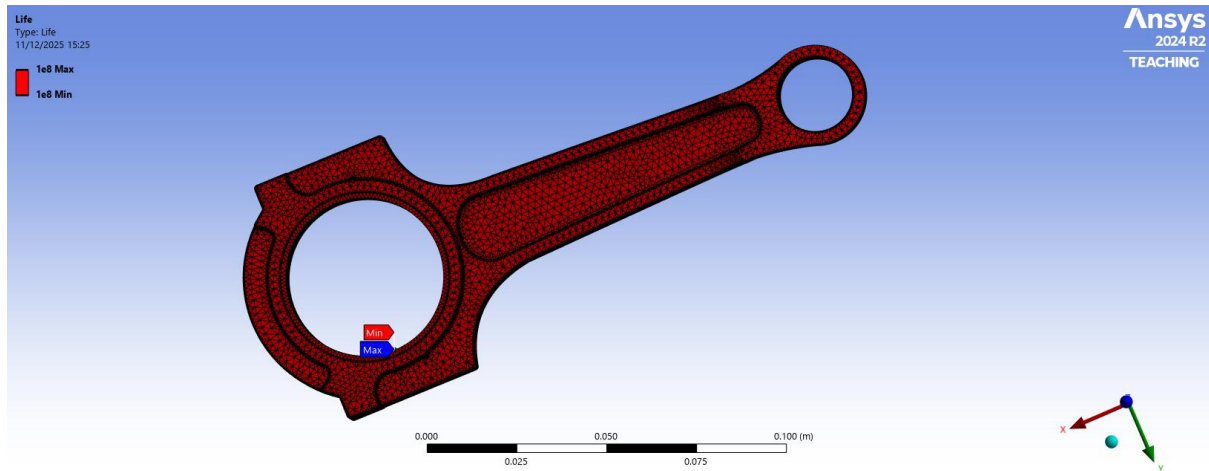
4.1.3.2 Normal Force



As seen in figure ##, max normal stress = 215.77MPa, min normal stress = -683.54MPa along the X-axis for max gas pressure.

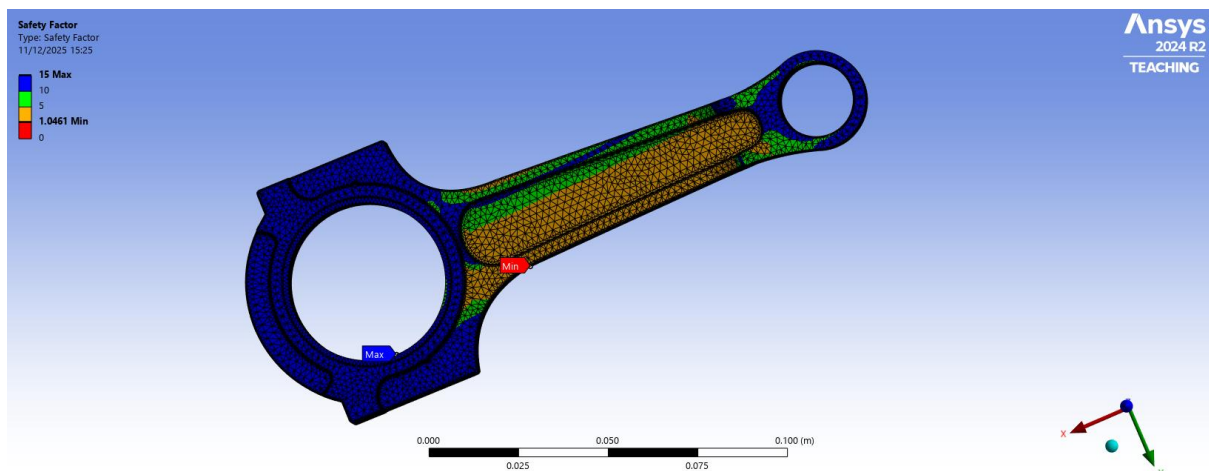
4.1.4 Fatigue Tool Simulation

4.1.4.1 Fatigue Life



As seen in figure ##, fatigue life = 100MPa.

4.1.4.2 Fatigue Safety Factor (FSF)



As seen in figure ##, fatigue safety factor max = 15, fatigue safety factor min = 1.0461.

4.2 Analytical Method Validation

σ_{Min}	σ_{Max}	σ_{Mean}	σ_{Range}	FSF
-1.6024e+08	7.2133e+07	-4.4054e+07	2.3237e+08	4.1309

σ Is in Pa

5. Discussion & Critical Evaluation

5.1 Simplifications

5.2 Possible Improvements

5.3 Analytical Result Comparison

While the ANSYS simulation for fatigue safety factor returned a max of 15 and a min of 1.0461, the analytical method done via MATLAB returned a FSF of 4.1309, the majority of the reciprocating mass sits at around 5, taking into consideration the use of a basic cylindrical support for the static simulations, which would not allow for deformation around that area, it is visible that the areas with an FSF of around 15 are the areas situated around the cylindrical support. This would also skew results in other parts of the connecting rod. However both the ANSYS and analytical show minimum FSF of above 1, with the ANSYS also showing a fatigue life of 100MPa, this meets most industries criteria for infinite life.

6. Bibliography

7. Appendices

7.1 MATLAB Analytical Code

%% Analytical Validation

clc; clear;

% Variables

RPM = 6500;

L = 0.13515; % Rod length (centre of bearings) in m

R = 0.0407; % Crank radius in m

BoreD = 0.079; % Bore diameter in m

ThetaMin = 14; % Crank angle minimum (Angle at max gas pressure)

ThetaMax = -360; % Crank angle maximum (TDC, max inertial force)

PMax = 90200; % Pressure at minimum crank angle (Max Inertia)

PMin = 7263100; % Max pressure (Max gas pressure) in N/m²

mRec = 0.470965249; % Reciprocating mass in kg (piston+gudgeon+1/3*conrod, using avg densities of each material via GRANTA)

CSA = 0.00015407; % Cross-sectional area of the Conrod in m² (Found from a section view of the conrod at the edge of reciprocating mass)

UTSAvg = 1.0225e+9; % Average ultimate tensile strength in N/m² (Pulled from material data sheet)

% Max Gass Pressure Calculations

A = pi*BoreD²/4; % Area of piston in m (based on bore)

PhiMin = asind(R*sind(ThetaMin)/L); % Conrod angle in degrees

w = RPM*2*pi/60; % Engine speed in rad/s

a = R*w^2*cosd(ThetaMin)+R^2/L*w^2*cosd(2*ThetaMin); % Accelration in m/s^2

FIertia = mRec*a; % Inertia force in N

FGas = PMin*A; % Gas pressure force in N

Fnet = FIertia-FGas; % Net force in N

FRodMin = Fnet/cosd(PhiMin); % Rod force in N

SigmaMin = FRodMin/CSA; % Min stress in N/m^2 (Max Compression, remember -ve force is compression, +ve is tensile)

% Max Inertia Calculations

PhiMax = asind(R*sind(ThetaMax)/L); % Conrod angle in degrees

a = R*w^2*cosd(ThetaMax)+R^2/L*w^2*cosd(2*ThetaMax); % Accelration in m/s^2

FIertia = mRec*a; % Inertia force in N

FGas = PMax*A; % Gas pressure force in N

Fnet = FIertia-FGas; % Net force in N

FRodMax = Fnet/cos(PhiMax); % Rod force in N

SigmaMax = FRodMax/CSA; % Max stress in N/m^2 (Max Tensile, remember -ve force is compression, +ve is tensile)

% Fatigue FOS Calculations

SigmaMean = (SigmaMin+SigmaMax)/2; % Average stress in N/m^2

SigmaRange = SigmaMax-SigmaMin; % Stress Range in N/m^2

```

EndLim = UTSAvg*0.45; % Endurance Limit in N/m^2 (For steels with UTS<1100
Endurance limit is typically given as 45% of the UTS)

SigmaAllowable = 2*EndLim*(1-(SigmaMean/UTSAvg)); % Allowable Stress in N/m^2

FSF = SigmaAllowable/SigmaRange;

% Display Results

Results = table(FSF, SigmaRange, SigmaMean, SigmaMax, SigmaMin, ...
    'VariableNames', {'FSF','Stress Range','Mean Stress','Max Stress','Min Stress'});

disp(Results)

```