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MOTION SIMULATION AND FINITE ELEMENT ANALYSIS OF A CONROD, USING SOLIDWORKS

Advanced Computational Methods

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1. Introduction

This report investigates the forces acting on a conrod in a Ford 1.6l GTDI engine, a detailed model of the conrod is designed and a motion analysis is done. The motion analysis is cross examined with hand calculations to make sure that the data gathered is correct and accurate. Furthermore, a finite element analysis of the conrod is undertaken and a topology of a simple solid conrod is done and compared with the Ford Standard.

The aims of the study are the following:

- Design engine components for motion analysis:
 - Conrod
 - Engine Block
 - Crank Shaft
 - Piston Head
 - Gudgeon Pin
 - Piston rings
 - Oil ring
- Motion Analysis of engine assembly.
- Gather conrod loading data from motion simulation.
- Compare loading data from simple conrod and detailed conrod.
- FEA conrod and optimisation of conrod.

2. Literature Research

2.1 Motion Simulation and FEA

According to Solidworks, Motion Simulation provides complete, quantitative information about the kinematics, including position, velocity, and acceleration, and the dynamics – including joint reactions, inertial forces, and power requirements, of all the components of a moving mechanism (Solidworks, 2008)

Finite Element Analysis(FEA), is the simulation of any given phenomenon, in this case tensile and compressive load acting on a conrod, using the numerical Finite Element Method (FEM). FEA is used to reduce the number of physical prototypes and to optimize components while they are still in their design stage. (Simscale, 2020)

FEA can tell the user where stress concentrations are happening and where the component can be optimized to get better results. The results are usually depicted via a colour scale, Figure 1, which can show the user, in this case, tensile and compressive displacement of the conrod, as well as stress concentrations. (Simscale, 2020)

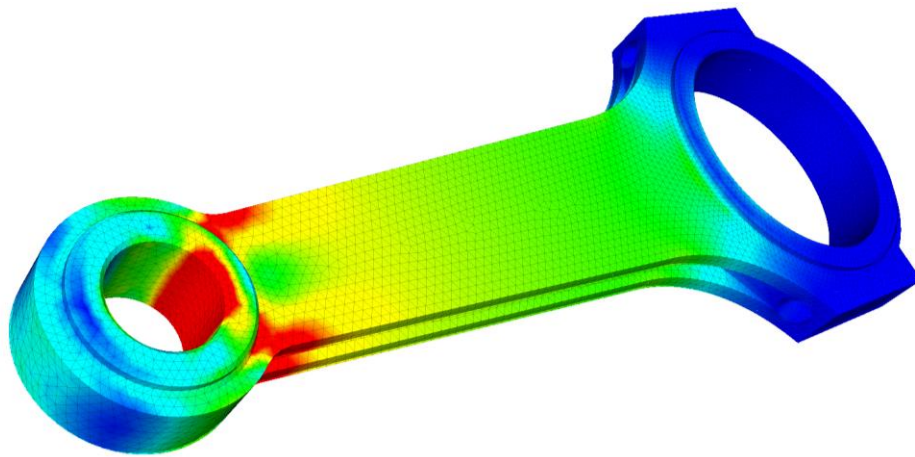


Figure 1 – Colour scale of a conrod (Simscale, 2020)

2.1.1 Motion Analysis and FEA joint use

Motion simulation data can be exported to FEA automatically, this is called “coupled” simulation. This means FEA loads are set up automatically. (Solidworks, 2008)

The procedure for combining both is the following:

- Motion simulation is used to gather data from forces, displacements, joint reactions, acting on all components within the range of motion selected. All the mechanism links are treated as rigid bodies, apart from the conrod. Motion analysis is done for two turns of the crank. (Solidworks, 2008)
- Find the mechanism position where the highest loads are happening on the joints to the connecting rod. Analysis under the maximum loads will show the maximum stresses experienced by the conrod, as seen in Figure 2.

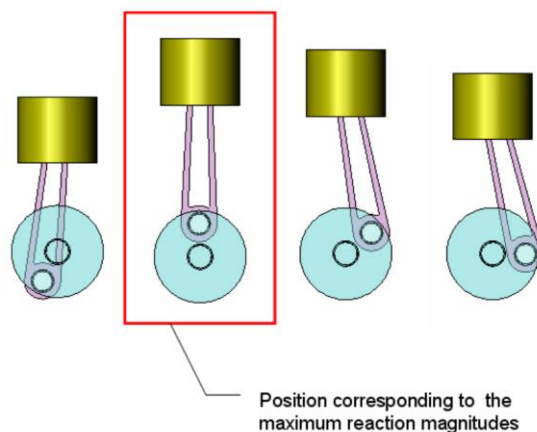


Figure 2 – Forces acting on the conrod at different positions

- The reaction loads and inertial loads are transferred to the conrod CAD model.
- These loads can be treated as a structure under static load.
- This rod is assigned a material, and then submitted to FEA. The FEA will show the user any deformations, strains and stresses.

3. Modelling of engine components

Components were modelled for the Ford 1.6l GTDI engine, the conrod was modelled in detail as it is the component being analysed.

All components were measured using Vernier callipers and engineering rulers, as well as dimensions known by fellow students, lecturers and the Ford data sheet. (McDonald, 2019) (Ford, 2020)

3.1 Equations

Equations were used in such a manner so the user can update the CAD models bore, within the piston head part and the engine block.

Name	Value / Equation	Evaluates to	Comments
Global Variables			
"Bore Size 2"	= 79.5mm	79.5mm	
"Bore Size 3"	= "Bore Size 2" / 2	39.75mm	
Add global variable			
Features			
Add feature suppression			
Equations			
"D7@Sketch3"	= "Bore Size 2"	79.5mm	
"D8@Sketch3"	= "Bore Size 2"	79.5mm	
"D4@Sketch3"	= "Bore Size 3"	39.75mm	
"D3@Sketch3"	= "Bore Size 3"	39.75mm	
Add equation			

Figure 3 – Engine Block Equations

3.2 Piston Head

The piston head was modelled using surfacing techniques initially and followed up by solid features. (Figure 4), the top of the piston was simplified due to time constraints.

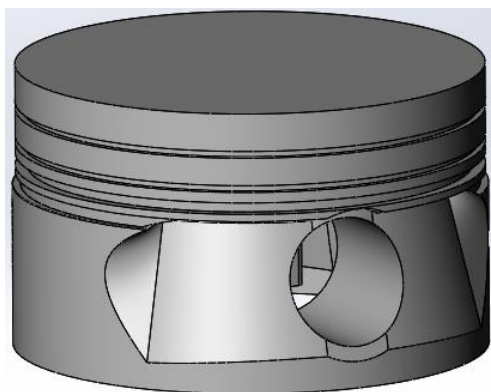


Figure 4 – Piston Head

The material used for the piston head is 34CrNiMo6 (Ovako, 2020)

3.3 Conrod

The conrod was modelled almost entirely with solid features, apart from some surface cuts, the rod is separated into two parts, large top half and small bottom half. (Figure 5)

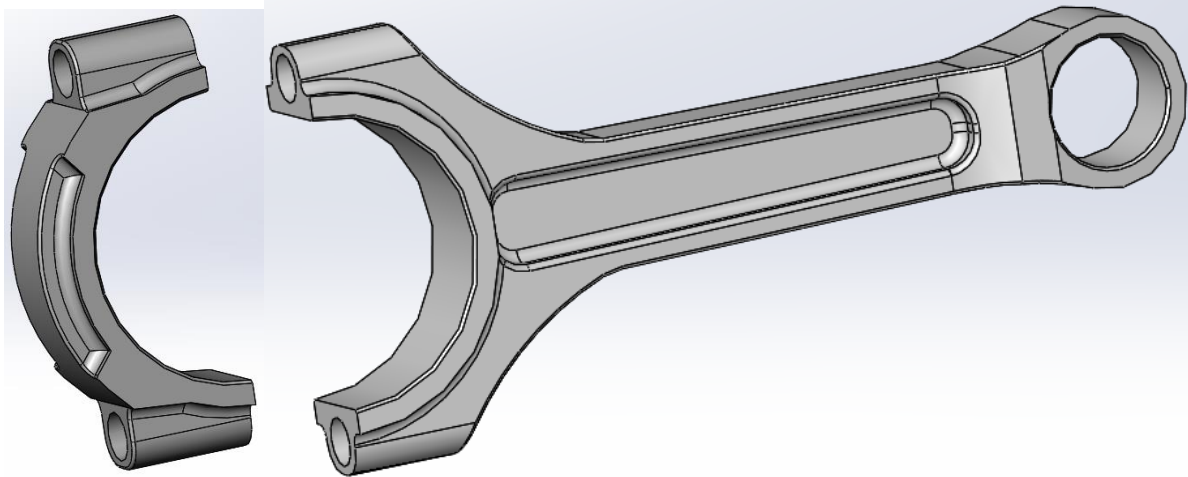


Figure 5 – Small bottom half on the left, large top half on the right

The material used is 34CrNiMo6 (Ovako, 2020)

3.4 Engine Block

The engine block was modelled using solid features, only the important areas for the motion simulation where modelled such as the cylinder walls (Figure 6), the engine block is made entirely out of aluminium (Ford, 2020)

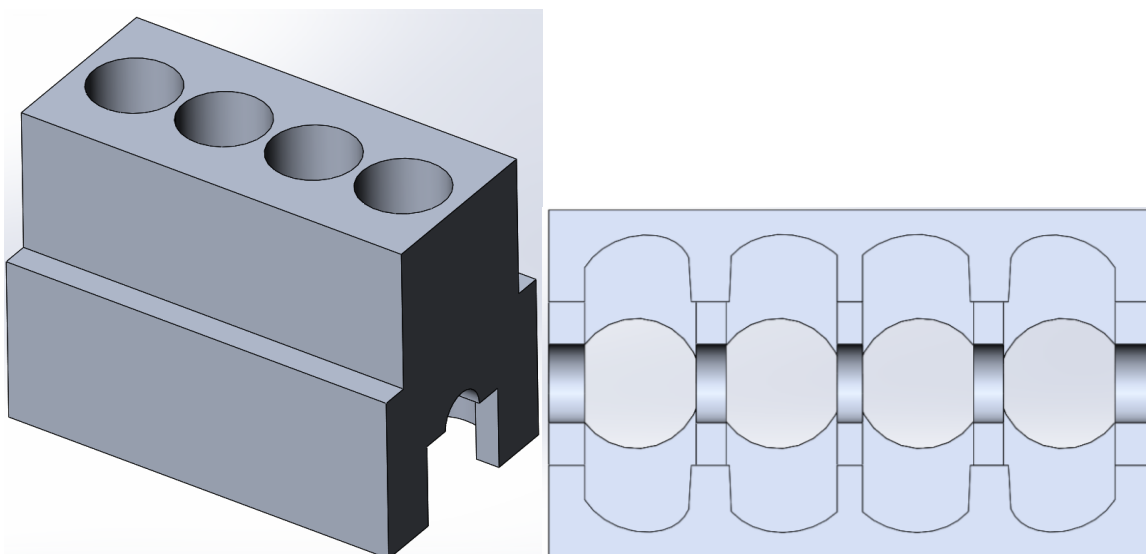


Figure 6 – Engine Block

3.5 Crankshaft

The crankshaft was modelled using solid features and surfaces to cut these solid features. (Figure 7)

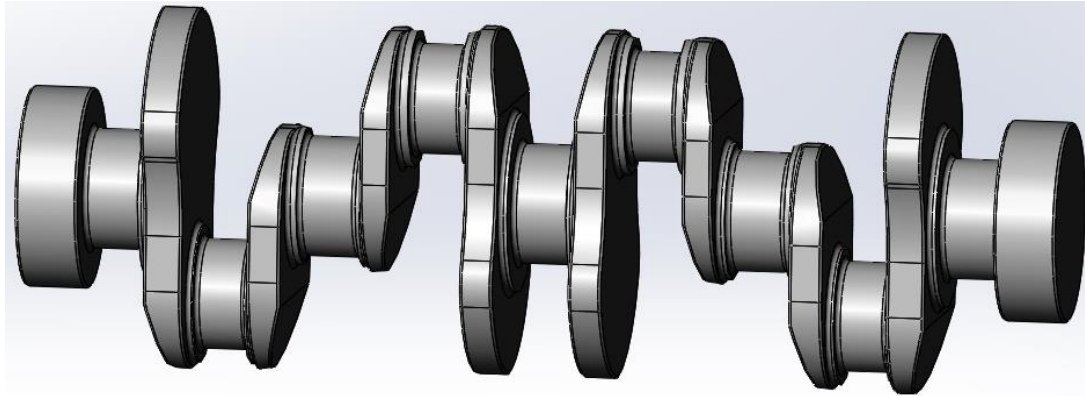


Figure 7 – Crankshaft

The use of planes was used to set the correct dimensions of the crank, thanks to this way of modelling the crank can be modified to any length by simply updating the planes.

3.6 Small Components

The smaller components such as the piston rings, the oil ring and the gudgeon pin, were modelled using solid features. (Figure 8)

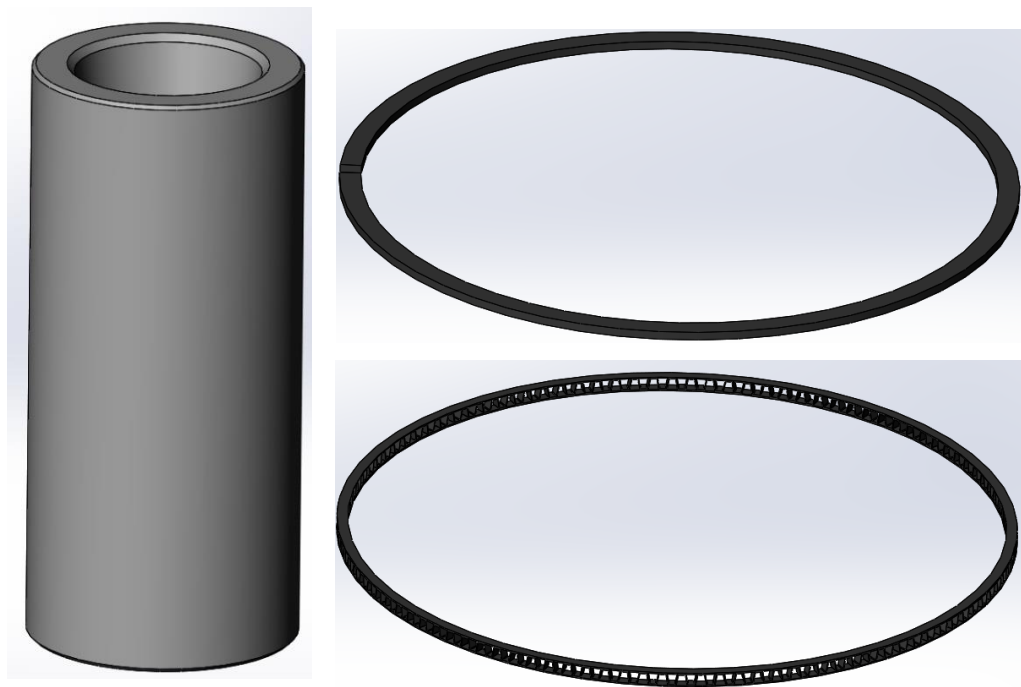


Figure 8 – Left gudgeon pin, Top Right Piston ring, Bottom Right Oil Ring

4. Engine Assembly

4.1 Highlight mates

The Engine Block was used as the fix item in space and the rest of components were floating. The following mates are the most influential ones used in the motion analysis, as they will be involved first hand.

Firstly, the piston rings and oil ring were mated to the piston head using hinged mates, as shown in Figure 9

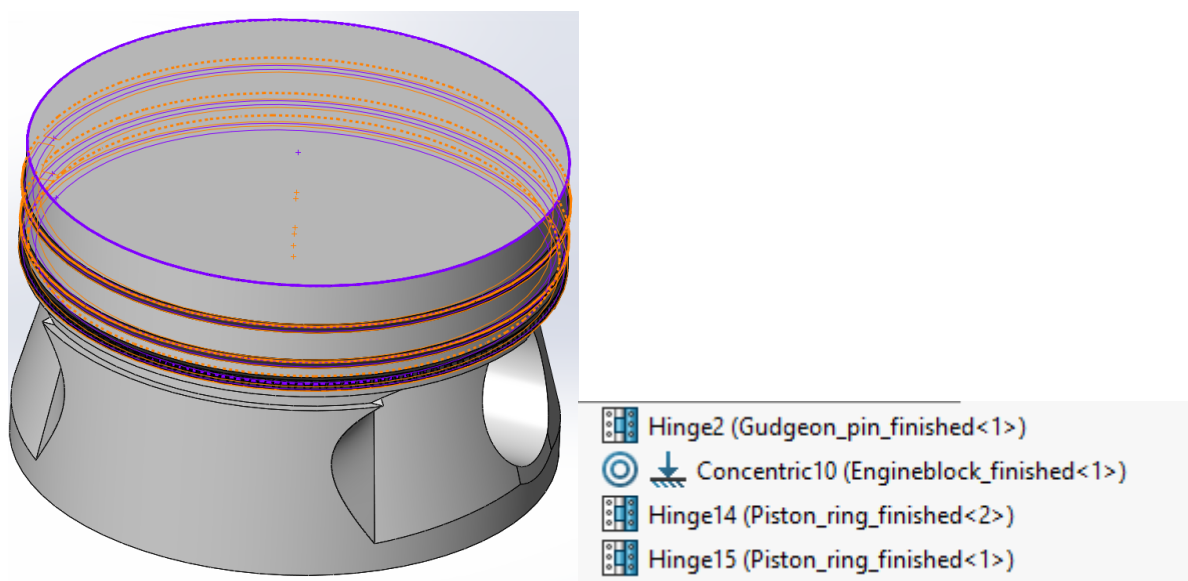


Figure 9 – Piston Head mates with rings

Furthermore, the piston head is mated to the engine block with a concentric mate (Figure 10)

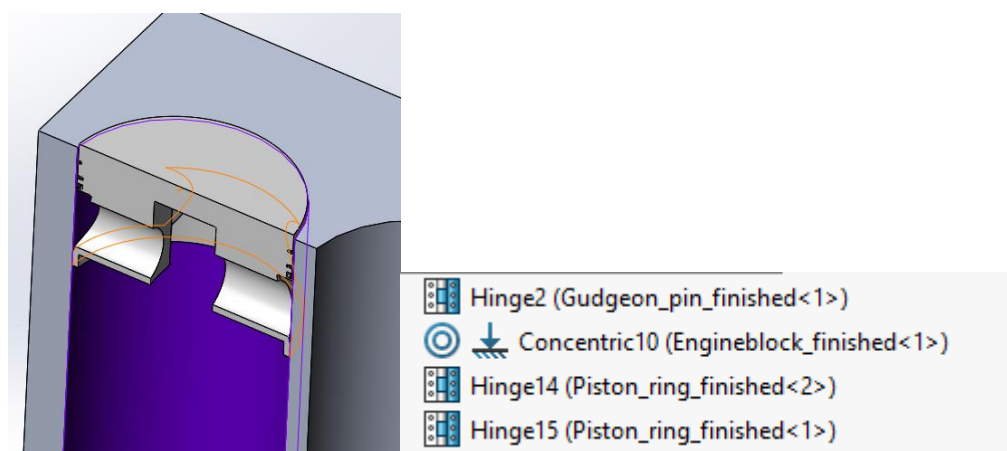


Figure 10 – Piston head mate to engine block

The gudgeon pin is mated to the piston head using a hinge mate, this gives the piston head freedom to move backwards and forwards like a hinge, so it is able to move up and down the cylinder wall, while the conrod is doing a different movement, as seen in figure 11.

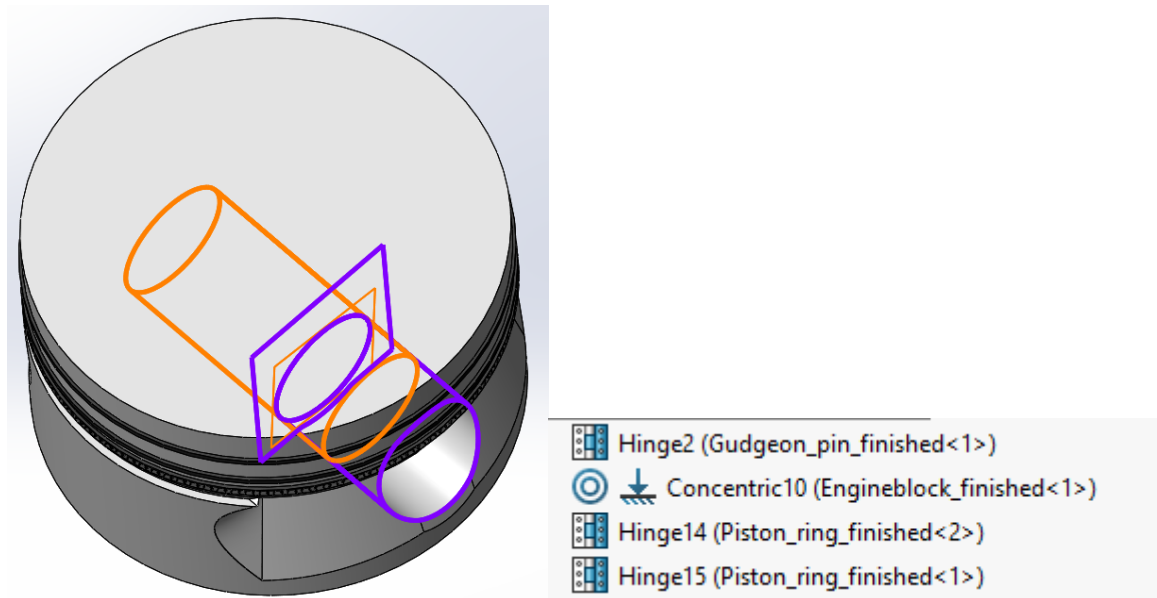


Figure 11 – Piston head hinge mate with gudgeon pin

The gudgeon pin and the conrod are aligned together using a hinge mate used to centre it.

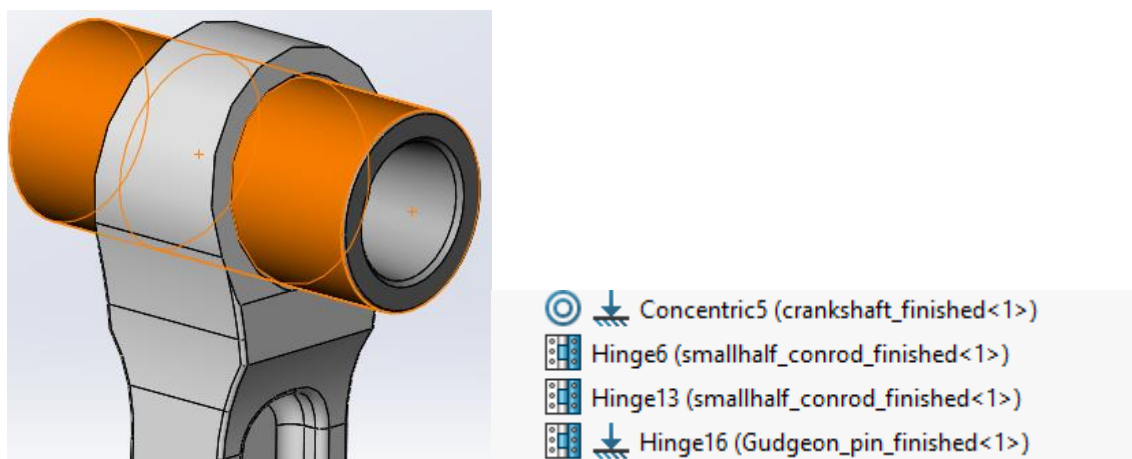


Figure 12 – Gudgeon pin and conrod mate

The Large top half of the con rod and the bottom small half of the con rod where mated together using concentric and coincident mates, taking away the need for using bolts within the assembly as the mates act as them.

The crankshaft was mated to the engine block with a distance and a concentric mate.

While the conrod was mated to the crankshaft by means of a concentric mate, which allows the conrod to follow each crank rotation.

4.2 Rigid body groups

Due to computation power the whole assembly apart from the gudgeon pin and the conrod, have been converted into a rigid body group, this will allow the pc to run the motion analysis more efficiently and avoid crashing, as seen in red box the rigid groups in Figure 13

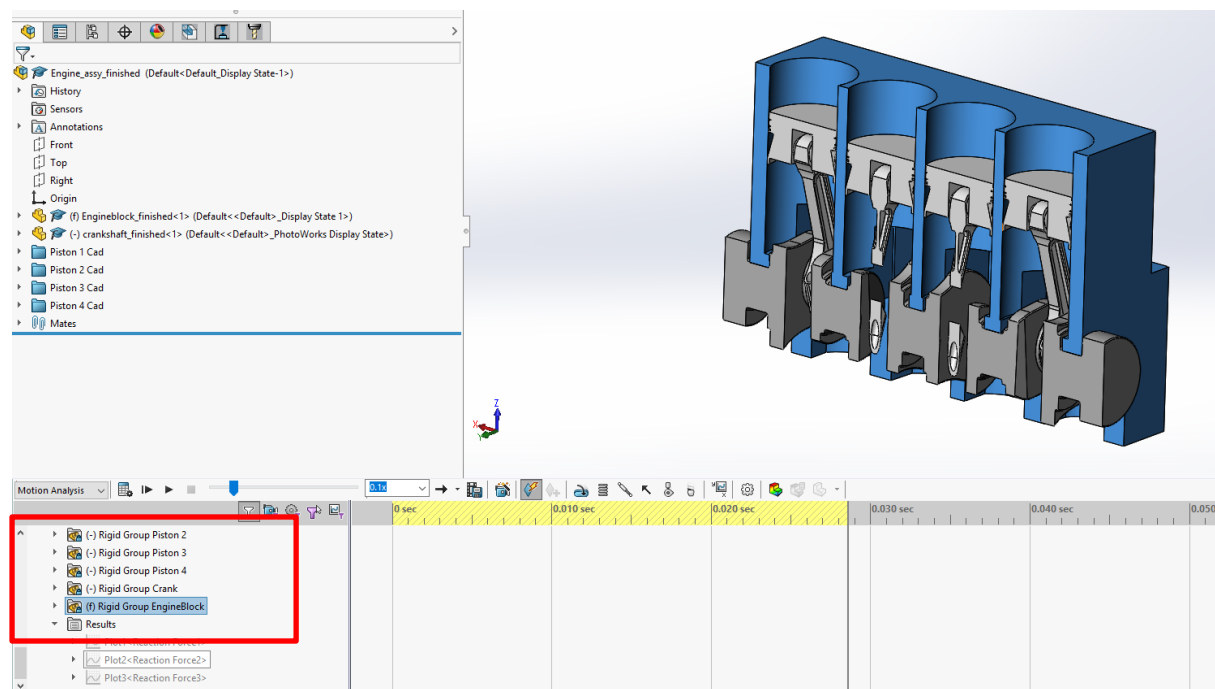


Figure 13 – Rigid Groups

5. Motion Analysis

5.1 Solid Contact Points

Solid contact points are applied on the cylinder walls, the piston head and the piston and oil rings. This will produce contact between the two with a coefficient of friction of value 0.1, this value is used because according to Krzysztof Jan Siczek a boundary friction coefficient such as this is between 0.1 and 0.25, for this motion analysis a boundary friction of 0.1 works best. (Siczek, 2016)

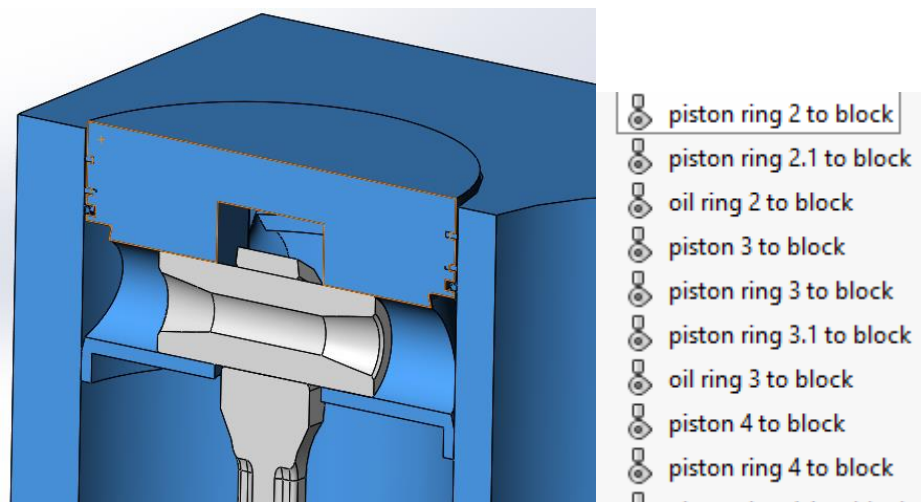


Figure 14 – Solid contact points

5.2 Rotary motor, gravity and gas force

A rotary motor is set on the crank to turn at 6000RPM, it is set at 6000RPM so the data gathered reflects the engine at its max stress levels.

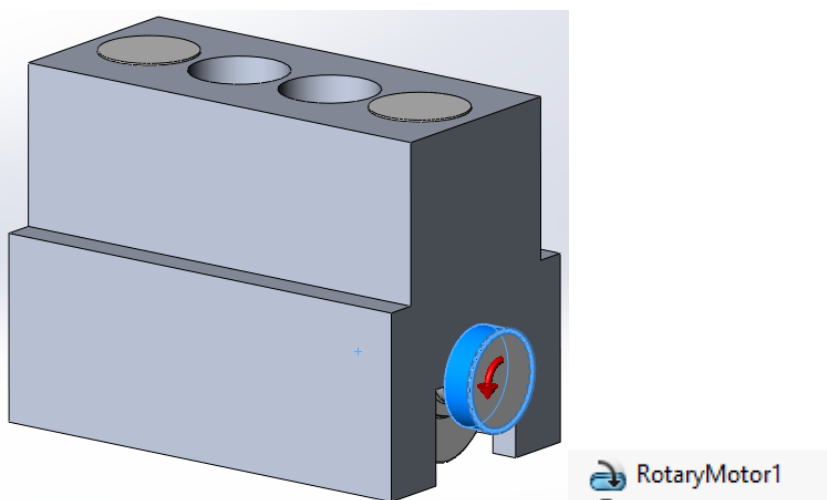


Figure 15 – Rotary motor

A gravity load was applied for the inertia force of the engine.

A gas force was applied to the top of the piston by means of data points, the cylinder pressures were given to the author by Malcolm McDonald and from that data the gas force above the piston could be calculated for 720° of crank or 0.02 seconds.

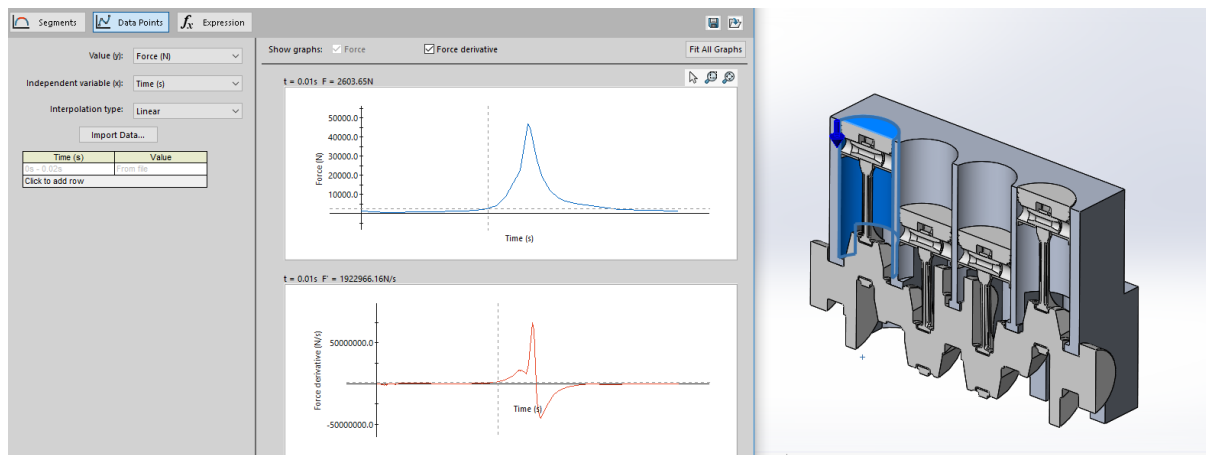
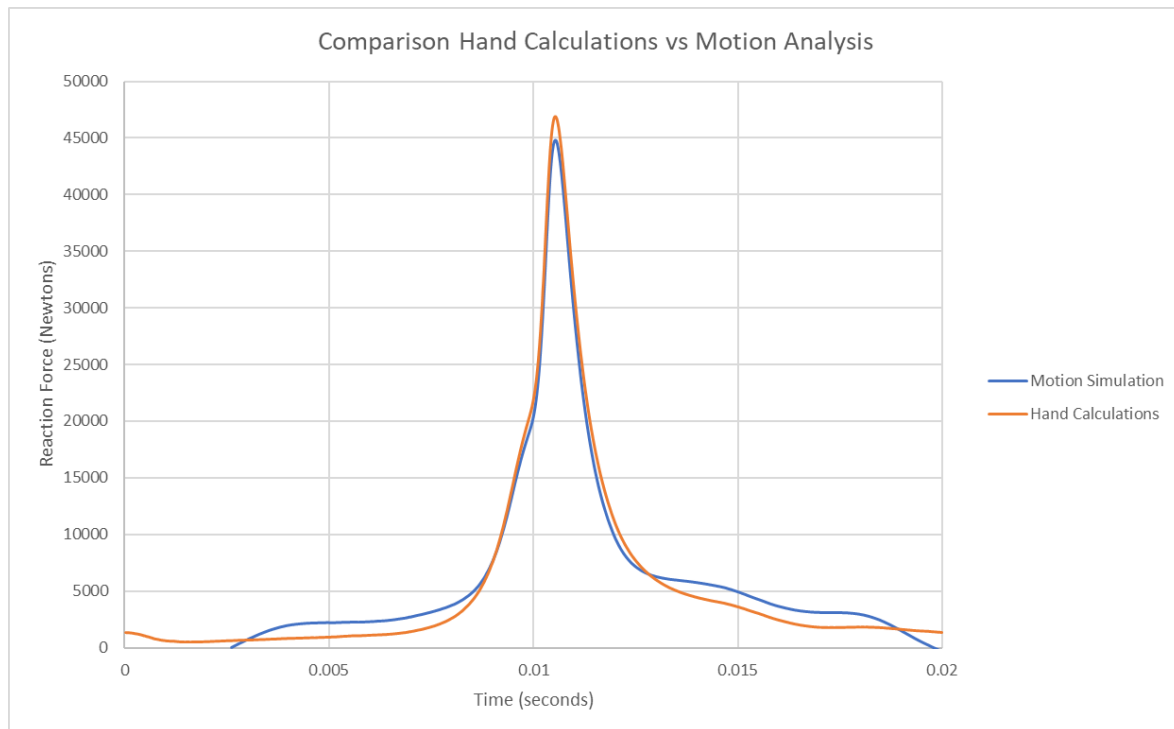


Figure 16 – Force Data Points

Looking at graph 1 it is seen that the motion analysis correlates with the hand calculations for one of the studs.



Graph 1 – Hand calculations and motion analysis

It can be seen in graph how the piston is at peak compressive force 0.01s when the gas force is at its max level. When it is negative it means the tensile loads, by the inertia force, are greater than the gas force.

It is important that for achieving the correct data a high frame rate is used, the ideal frame rate found was 29000 fps, as it gives a nice smooth graph with less spikes. However, for importing loads it is found that 1000fps is the best computing time to results average.

6. Finite Element Analysis

6.1 Mesh

A point of interest for this conrod is the small end, for this reason a finer mesh is used in that area to save computing power and get more accurate results, as seen in Figure 19. The Mesh Control option was used for undergoing the procedure.

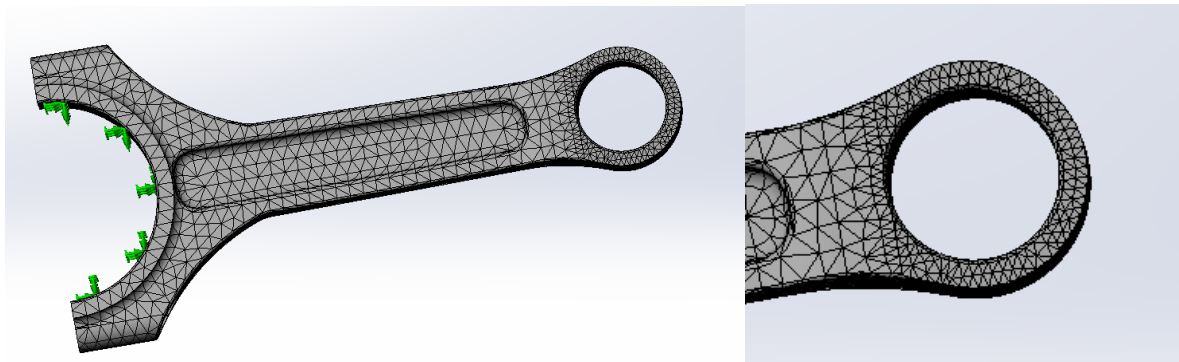


Figure 17 – Fine mesh on small end of conrod

6.2 Ford Conrod

At a first glance of the conrod, inertial relief on the conrod makes the crank end of it to move in an outwards motion, Figure 18, which isn't realistic, a fixed fixture is hence placed on the crank end, Figure 17. The deformation in the models are exaggerated, looking at Figure 17 the deformed end is not near its yield point.

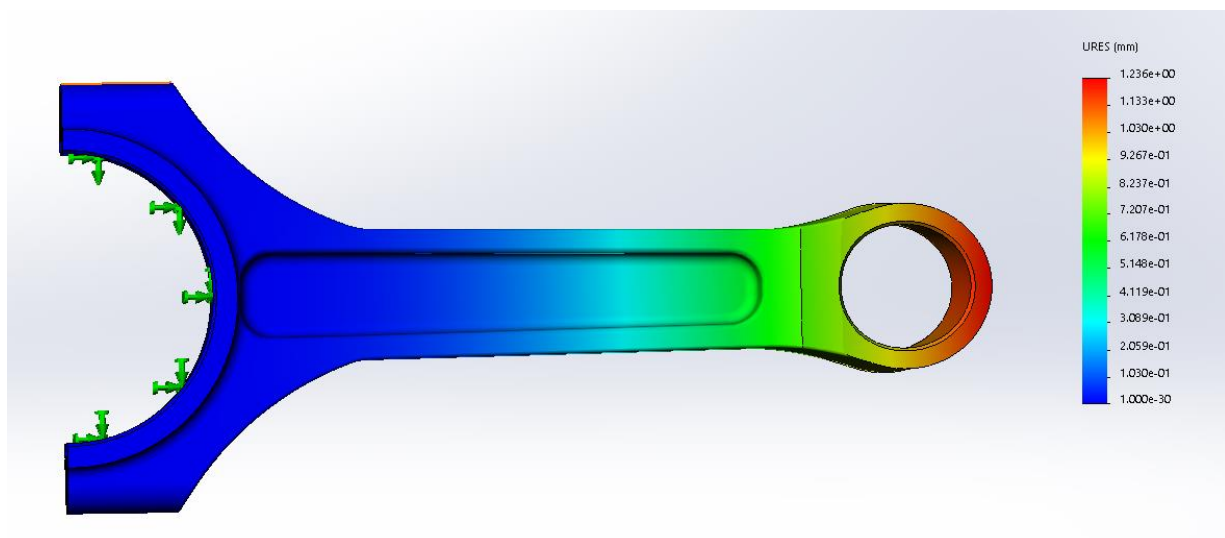


Figure 18 – Fixed Conrod with displacement

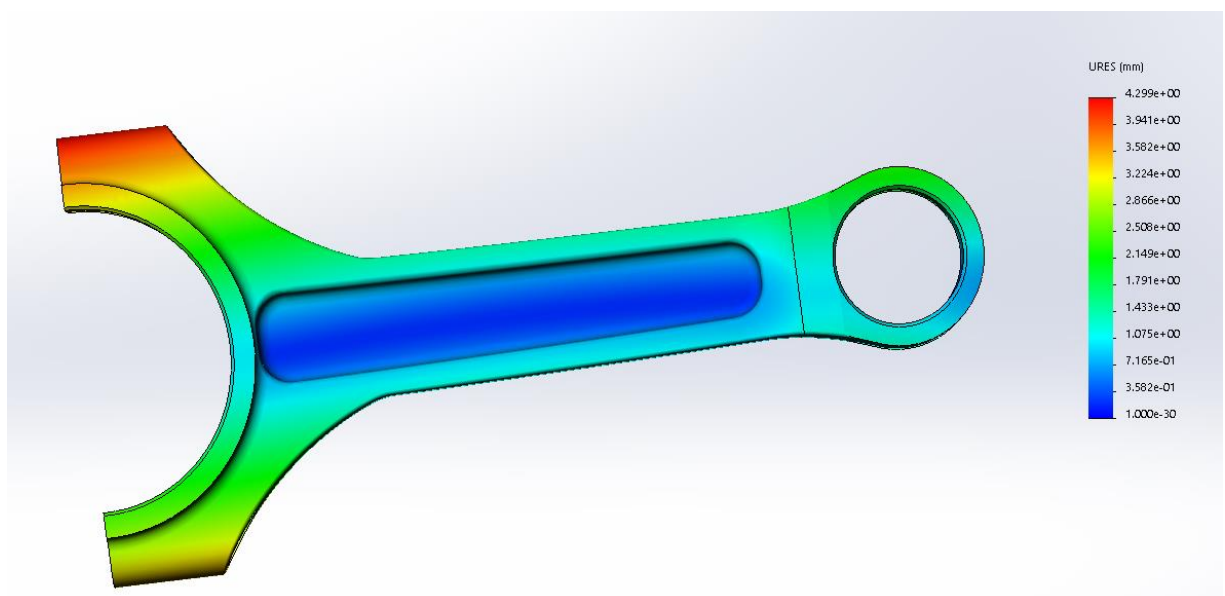


Figure 19 – Inertial relief conrod, without fixed constraints.

Looking at the safety factors of the conrod in comparison to the yield strength of the material, tells the user that there is material that could be taken away, but it might be there for fatigue reasons, which means that over time that area will begin fatiguing and losing its material properties.

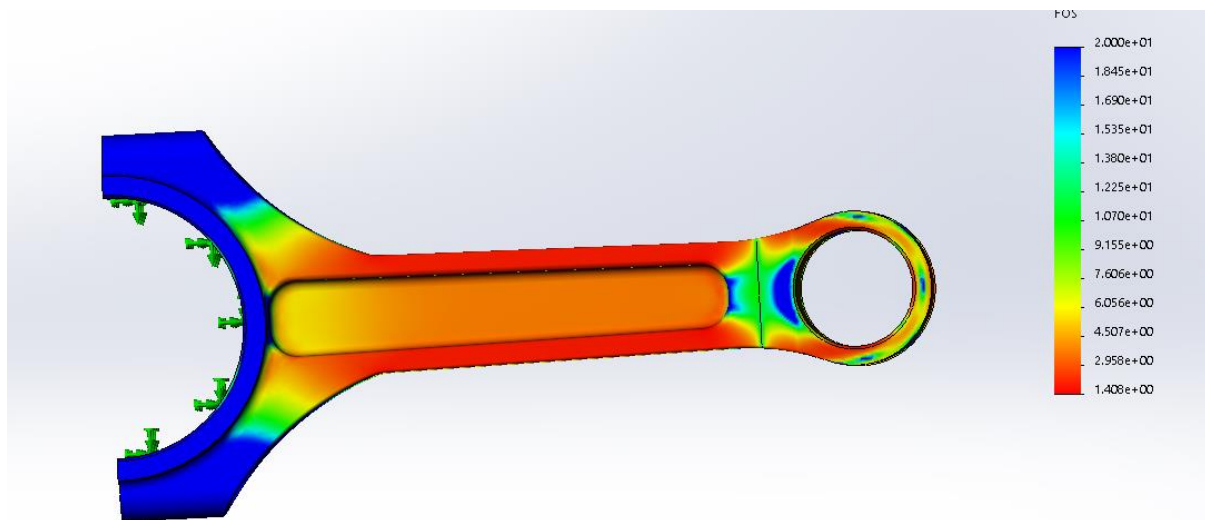


Figure 20 – Safety factor

In Figure 20, some material can be taken away in the green areas of the little end of the conrod and material can be taken away from the crank end of the conrod.

Another factor to consider when removing material, is that it might affect the displacement of the conrod within the engine, which in turn will change the clearances of the engine and parts colliding within the engine. Looking at Figure 18, the displacement is larger at the little end of the conrod, if material was taken away from that end of the conrod then the conrod would be weaker and therefore displacement would go up.

The wise move would be to only take material away from the crank end of the conrod.

6.3 Optimised Ford Conrod

Material has been taken away from the Crank end of the conrod as seen in Figure 21.

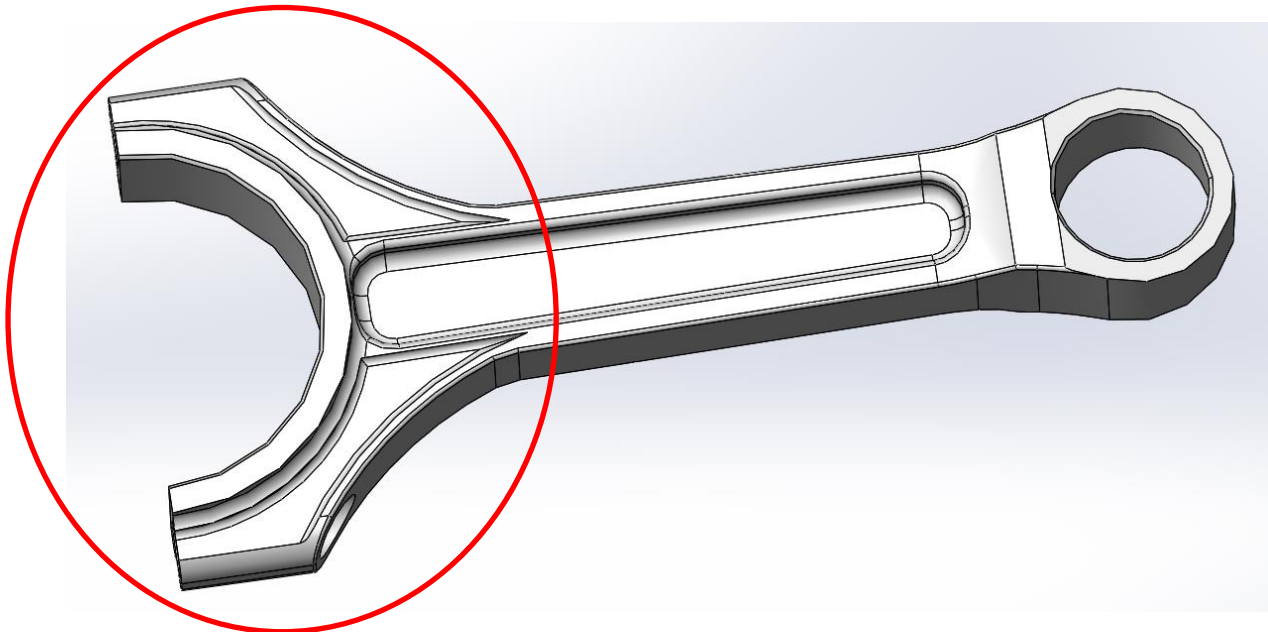


Figure 21 – Optimised Ford Conrod

Another motion simulation was undertaken with the optimised design, the displacement of the rod has increased in comparison with the original Ford Conrod with a percentage of 4.9%, this increase in displacement may affect the engine clearances. Figure 22

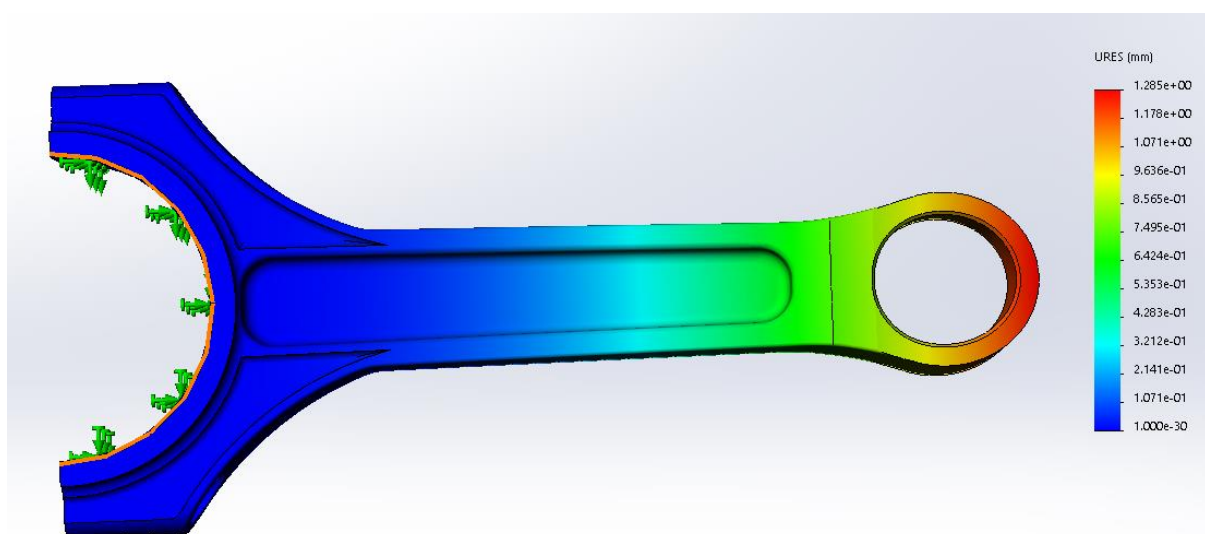


Figure 22 – Optimised conrod displacements

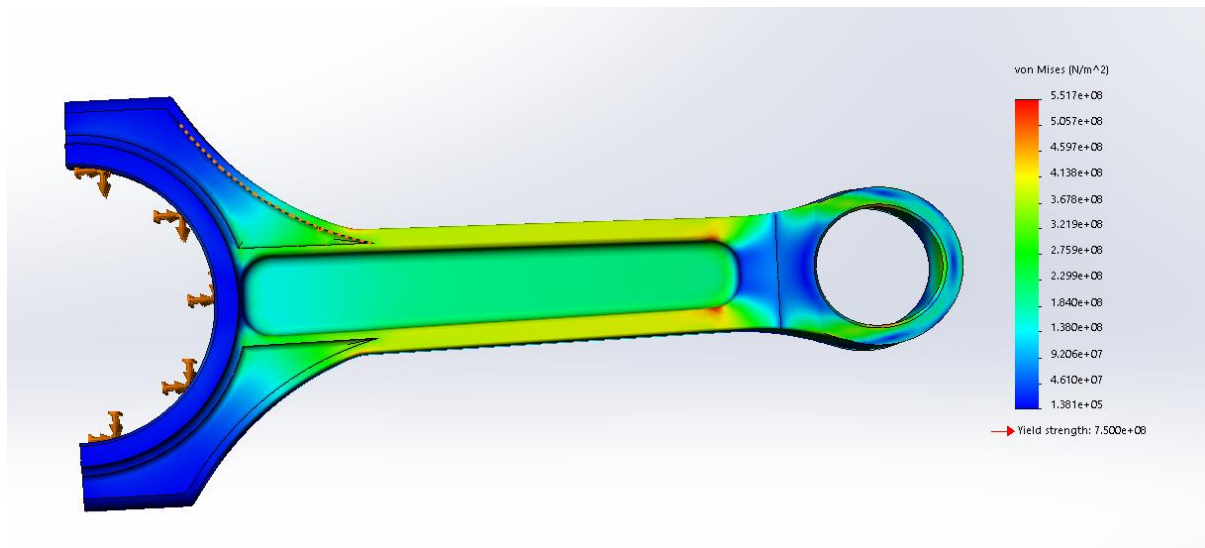


Figure 23 – Optimised Conrod Stresses

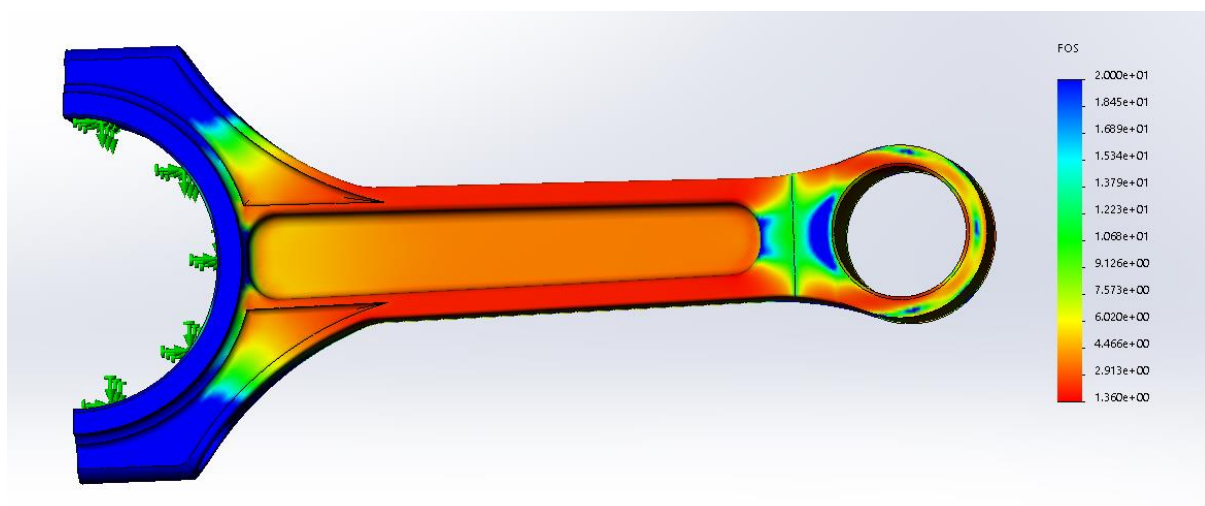


Figure 24 – Optimised Conrod Safety Factors

Further material can be removed, but the increase in displacement would be too high for the reliability of the engine.

7. Conclusion

Motion Simulation can give the user the necessary tools to achieve any kind of analysis, and in cooperation with FEA they can both work with each other very efficiently.

In terms of this reports analysis, the conrod can loose some of its weight but in doing so it is opening avenues for reliability problems within the engine due to clearances issues, which in turn could mean the engine block would have to be modified.

Further research can be done into how to use topology with the import simulation feature.

Other work can be done onto what external factors would affect the conrod such as heat and engine friction.

For a detailed design of the conrod a 3D scanner can be used, as the most detailed features of the conrod could not be achieved due to measuring restrictions.

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9. Link

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