

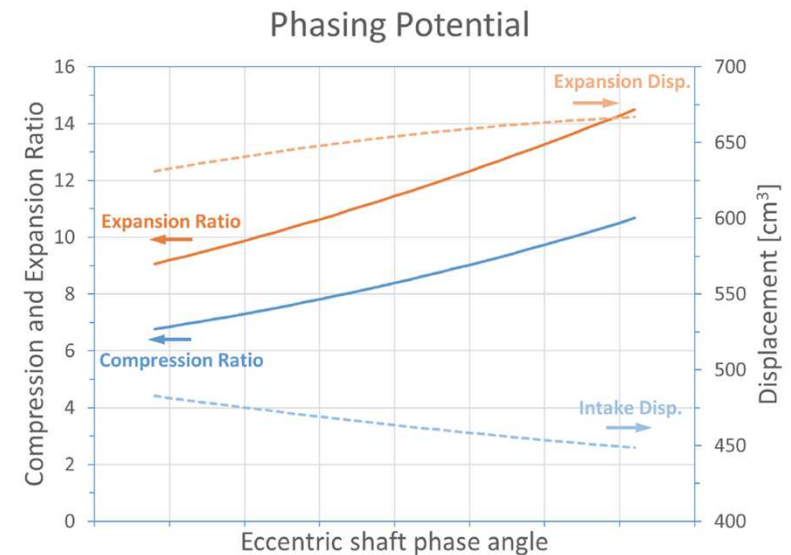
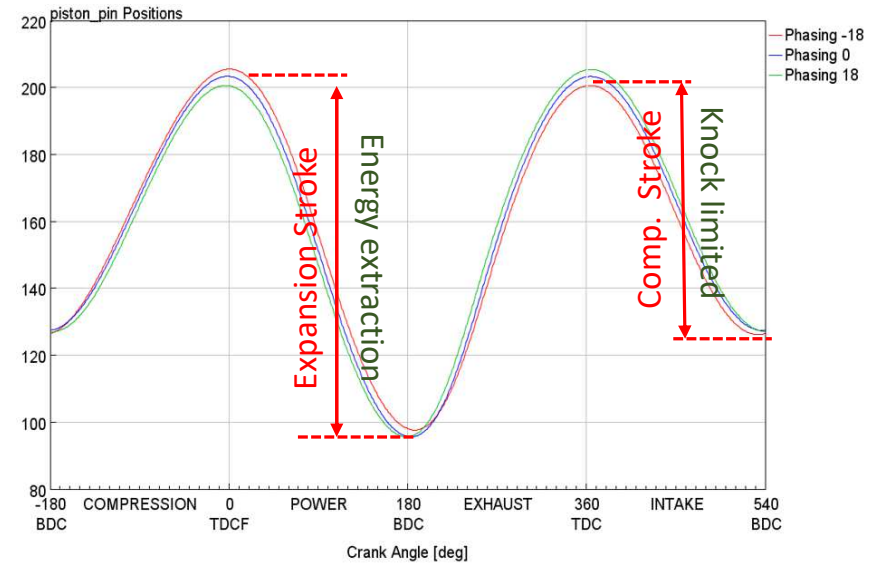
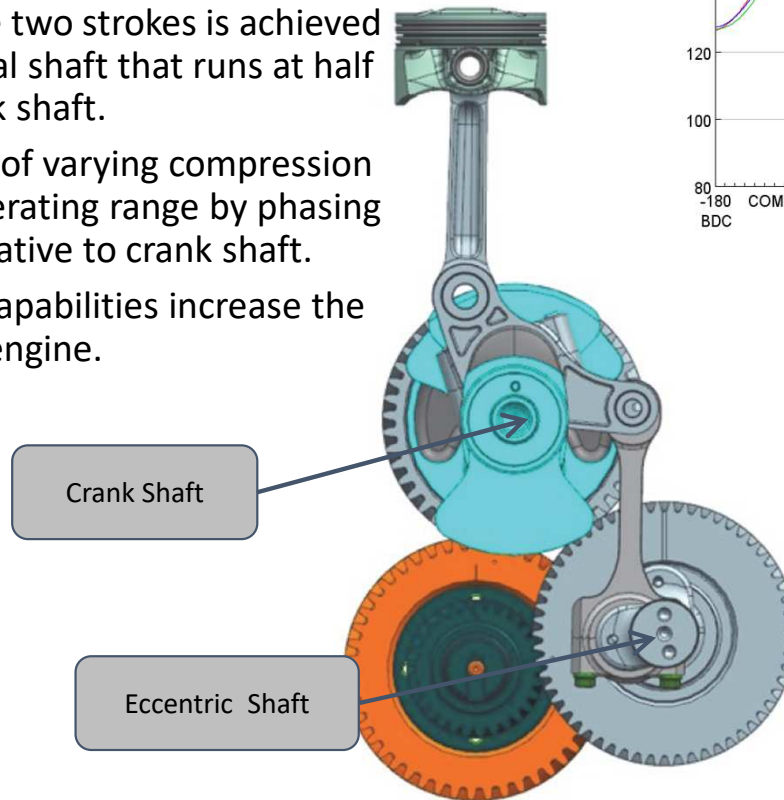
GT-SUITE Role in the Analysis of A Variable Compression Multi-link ICE

- By
- Hatem Orban, Ph.D
- General Motors



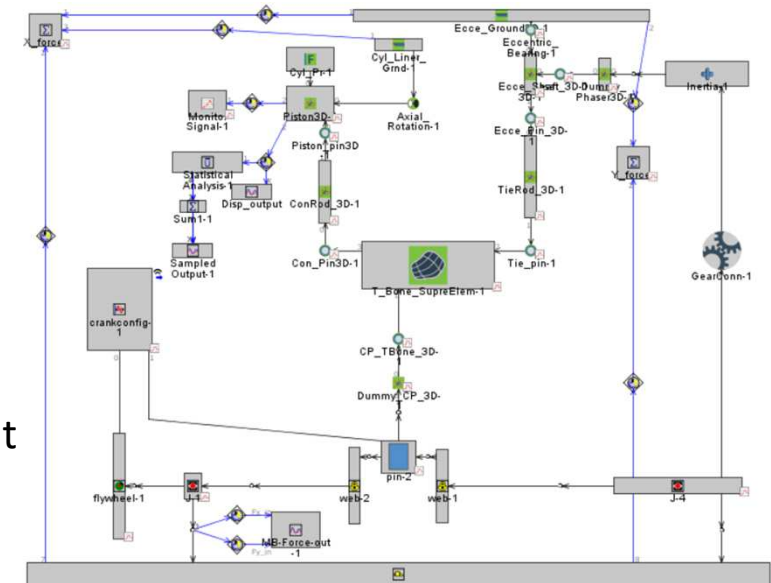
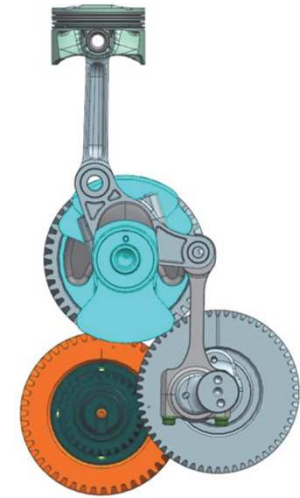
Introduction

- The VCR engine is a multi-link mechanism that runs Atkinson's cycle with different expansion and compression strokes.
- The bias between the two strokes is achieved by having an additional shaft that runs at half the speed of the crank shaft.
- The engine is capable of varying compression ratio along engine operating range by phasing the eccentric shaft relative to crank shaft.
- These added engine capabilities increase the fuel efficiency of the engine.



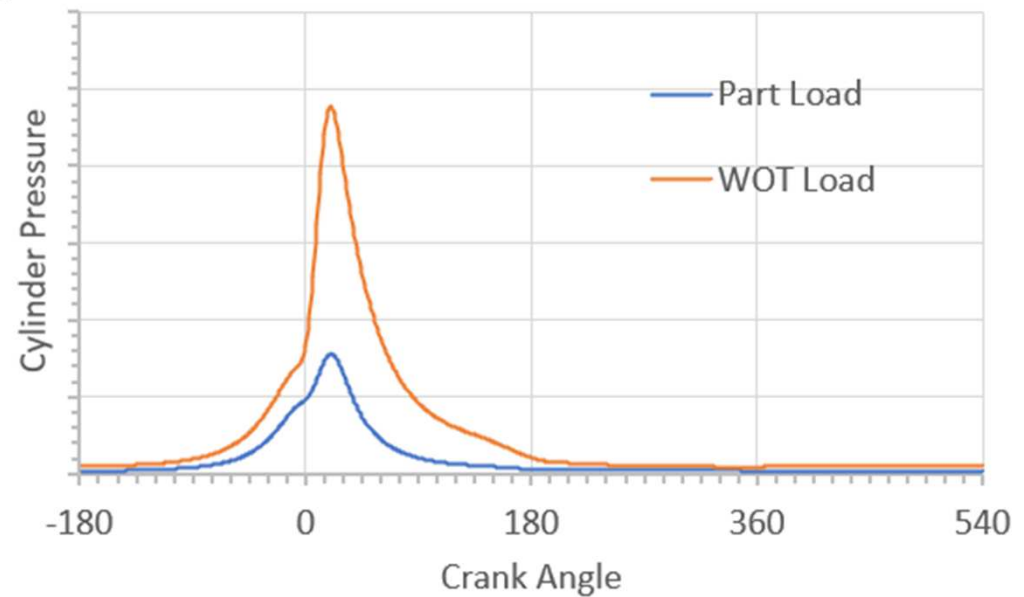
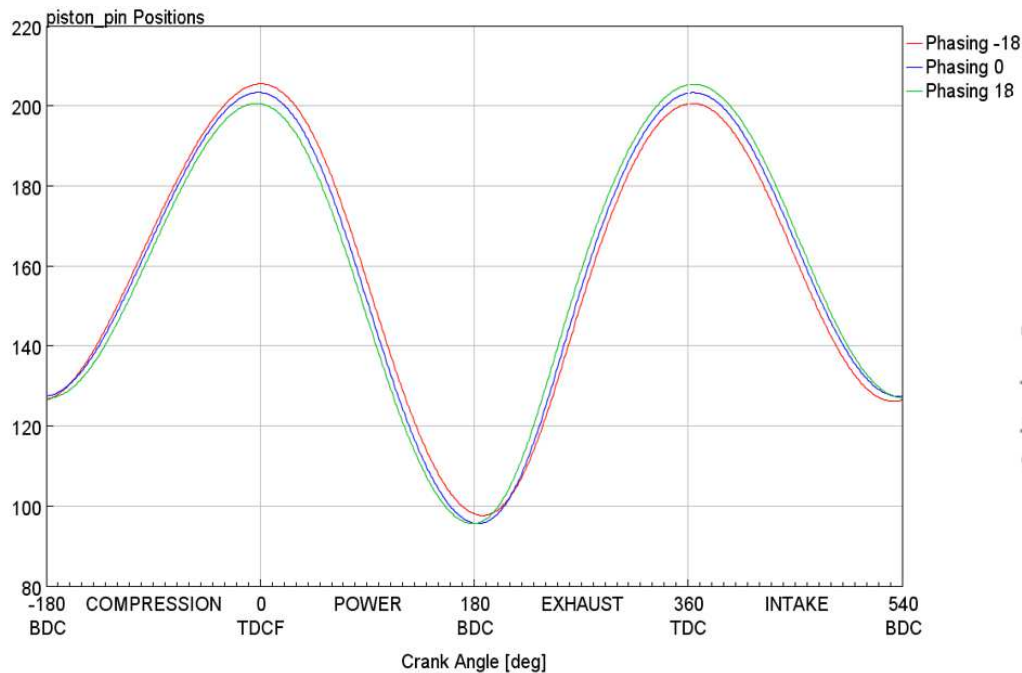
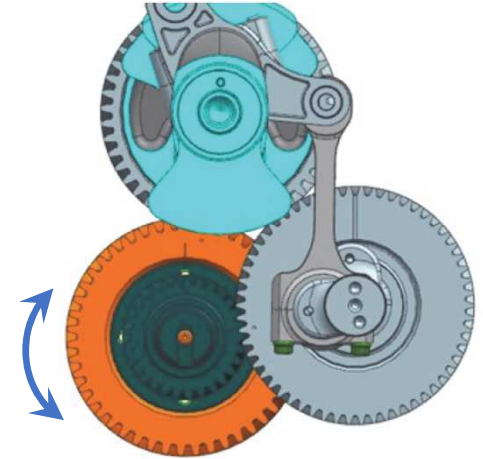
GT-SUITE Role in the Analysis of A Variable Compression Multi-link ICE

- The complexity of the engine along with added components make the analysis of the cranktrain dynamics more challenging.
- These can be characterized as component durability, NVH and Lubrication.
 - Component load calculations
 - Single cylinder engine balancing calculations and durability load calculations
 - Multi-cylinder engine imbalance load calculations (for noise considerations)
 - Main bearing load calculations and crank counter-weight optimization
 - Engine torsional vibration analysis
 - Flexible multibody dynamic analysis of mechanism component

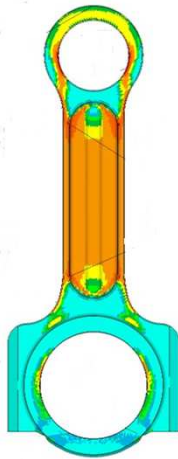
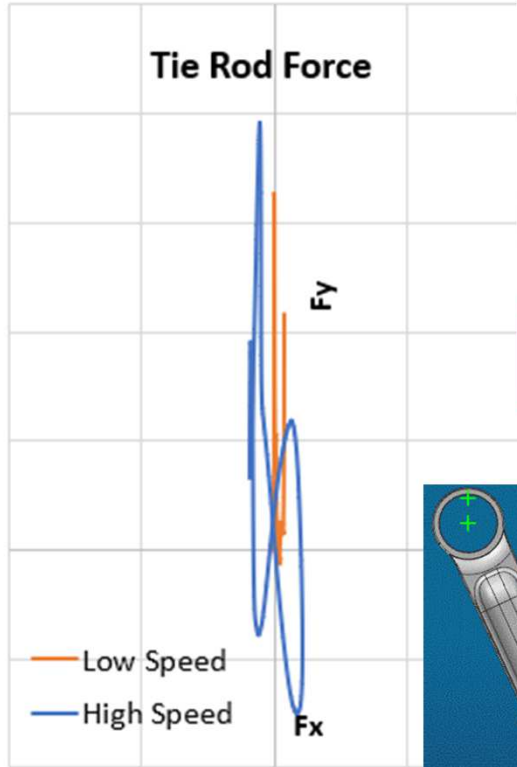


Piston Displacement and Cylinder Pressure Calculations

- Different piston motion is achieved through changing the phase angle between the crank shaft and the Eccentric shaft. The GT-SUITE Model is built with a phase to allow for variable compression conditions.



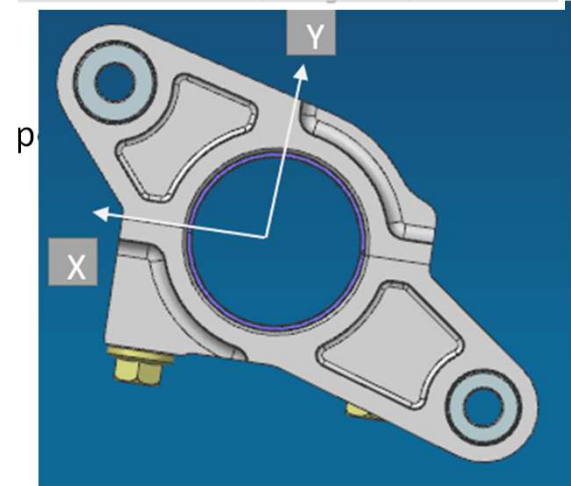
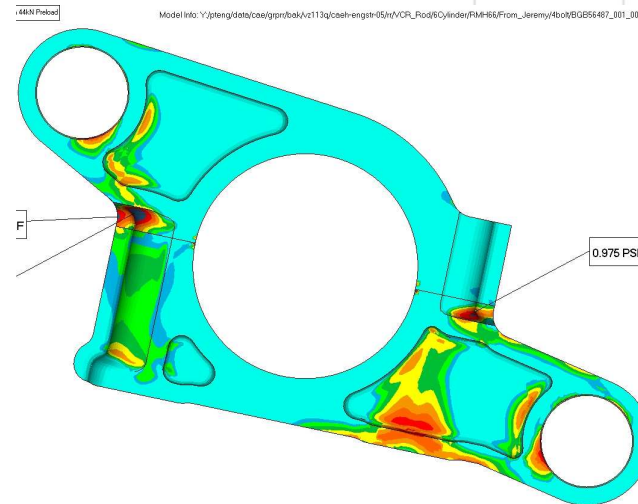
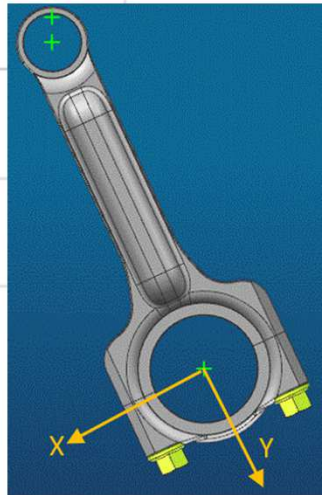
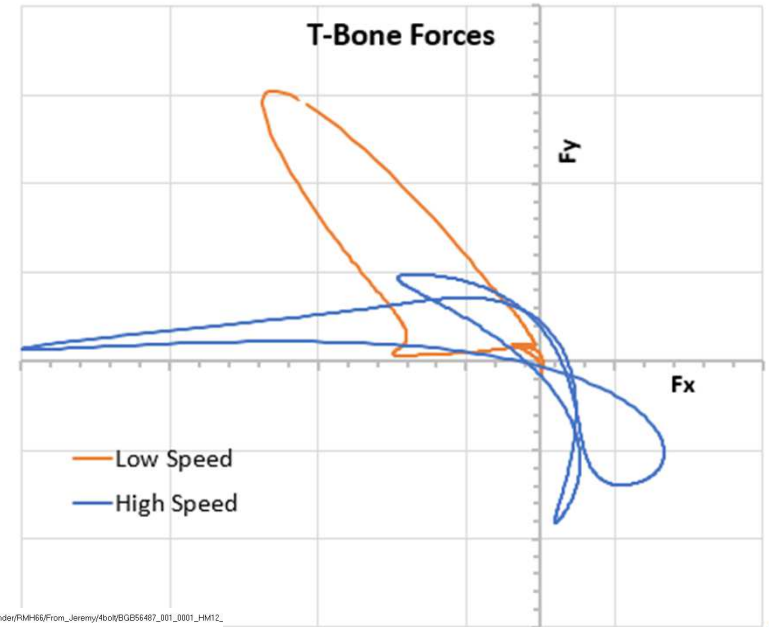
Component Load Calculations and Durability Analysis



Component dimensions,
masses, inertias, and
cylinder pressures

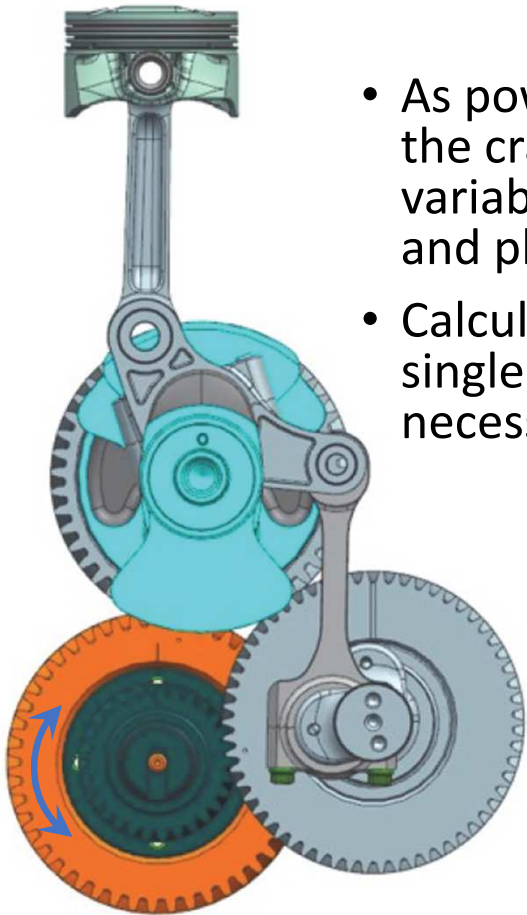
Get component joint loads
from GT model

Component and Joint
Durability analysis

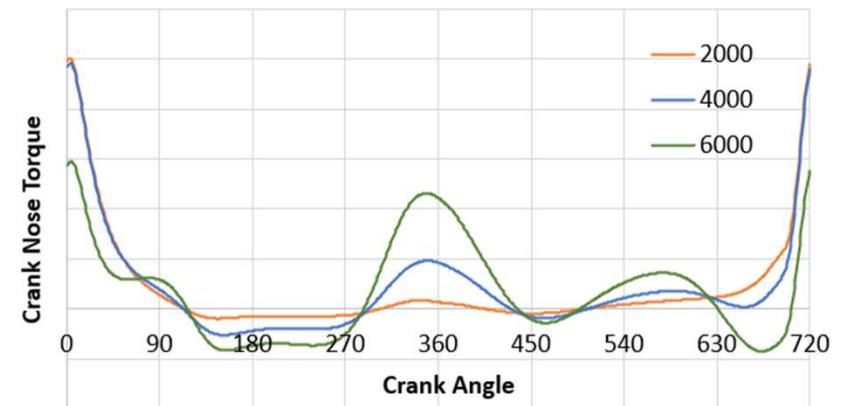


Crank to Eccentric shaft Phaser Torque

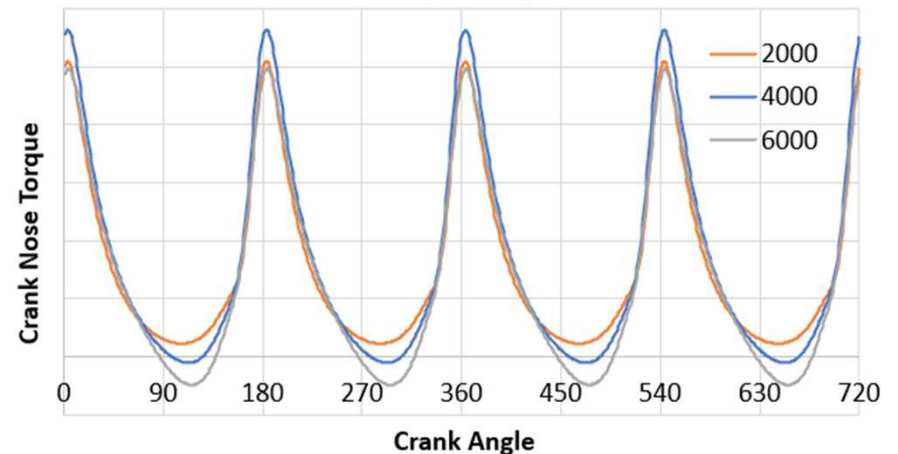
- As power is transmitted between the crankshaft and eccentric shaft, variable torque acts on the gearing and phasing system
- Calculation of such torque for both single and multi cylinder engines is necessary for the phaser design.



Single Cyl. Torque

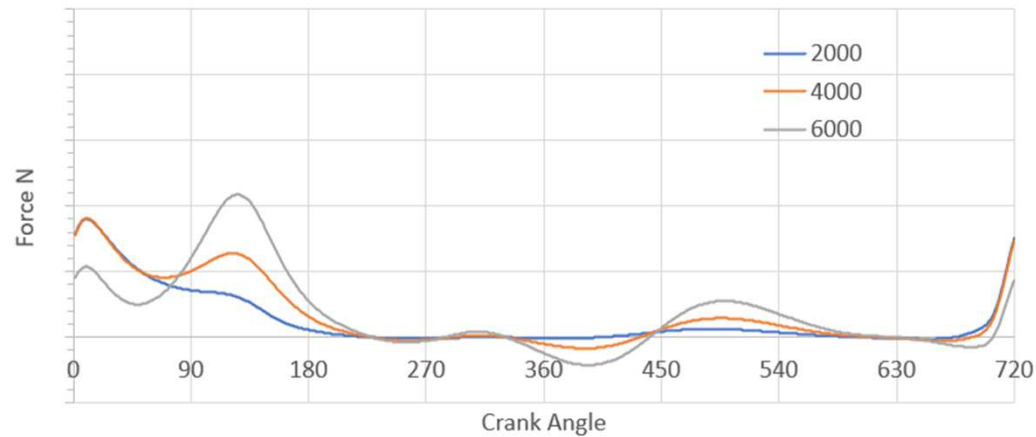


Multi Cyl. Torque

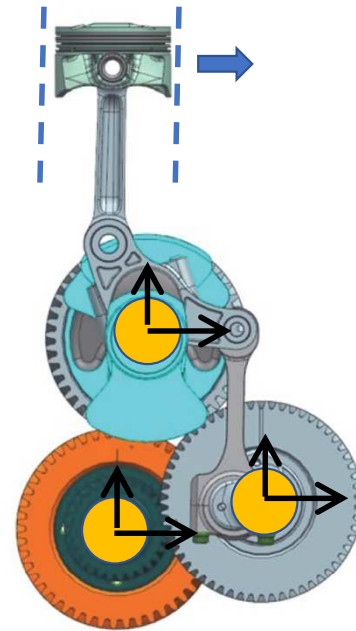
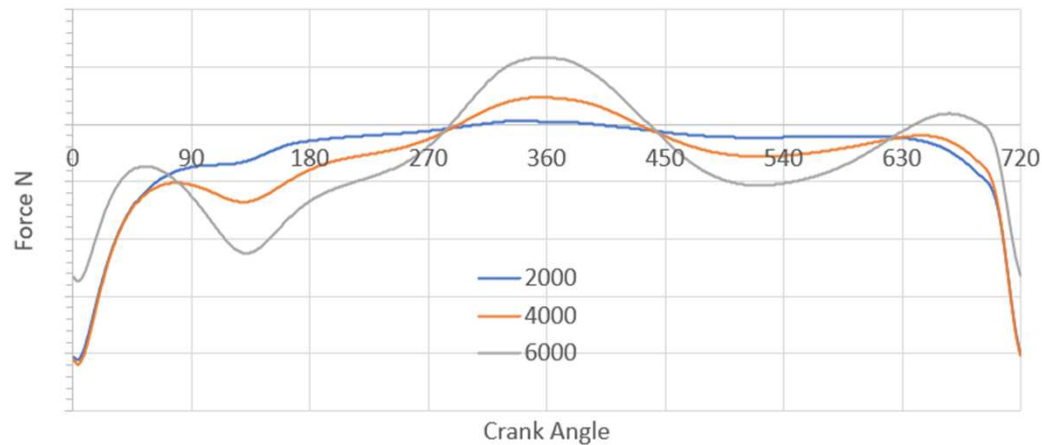


Load Calculations on Engine Block

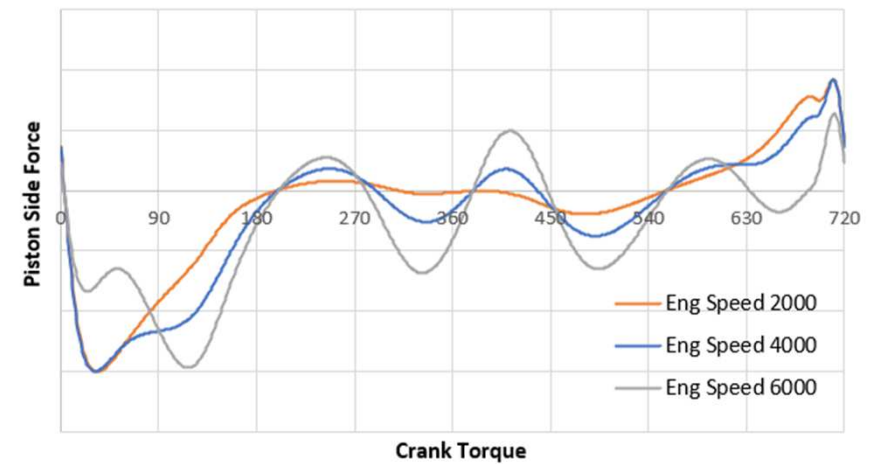
MB Fx



MB Fy

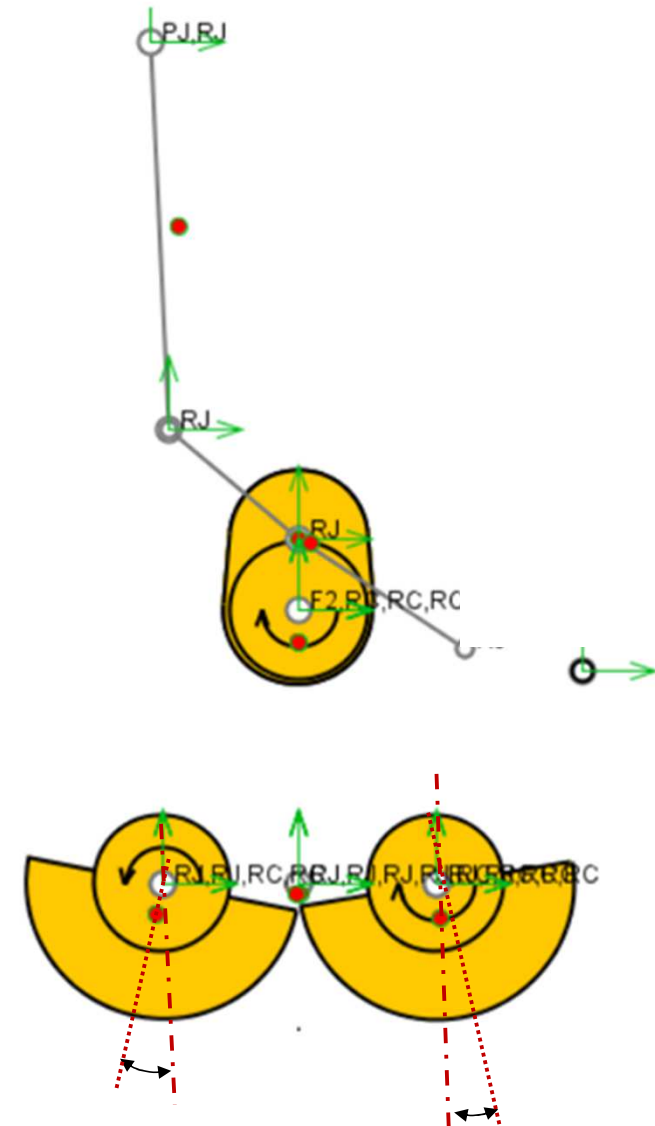


Piston Side Force

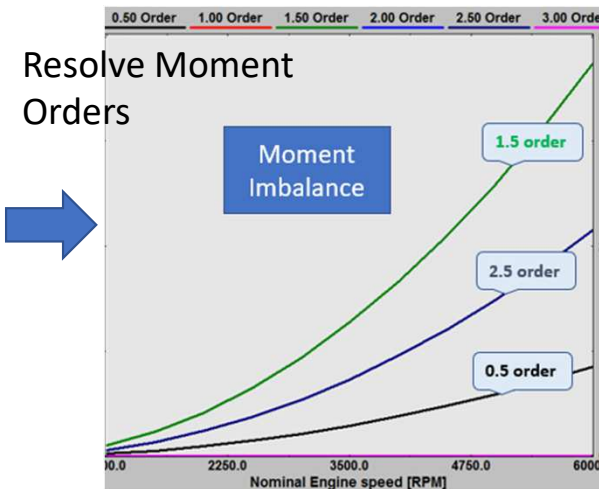
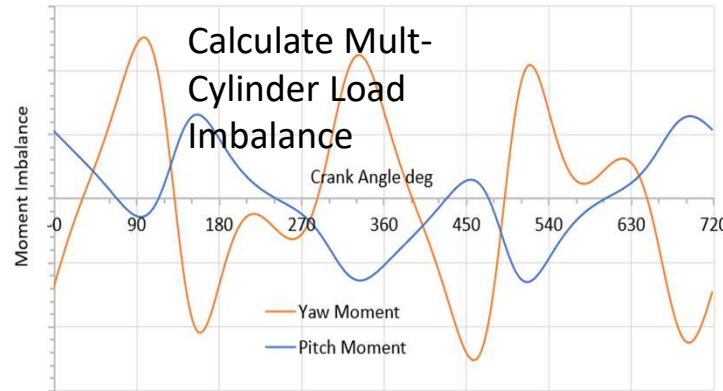
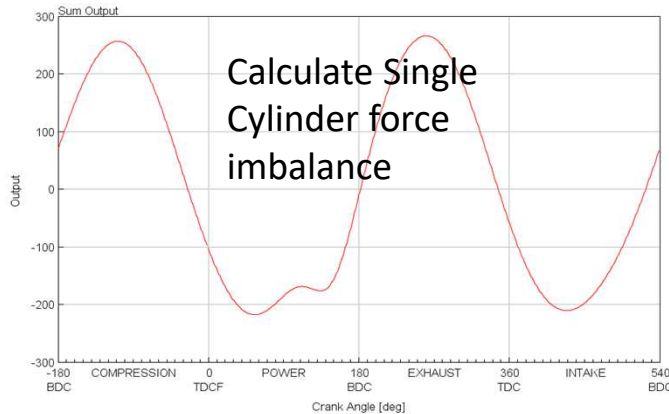


Single Cylinder Engine Balancing

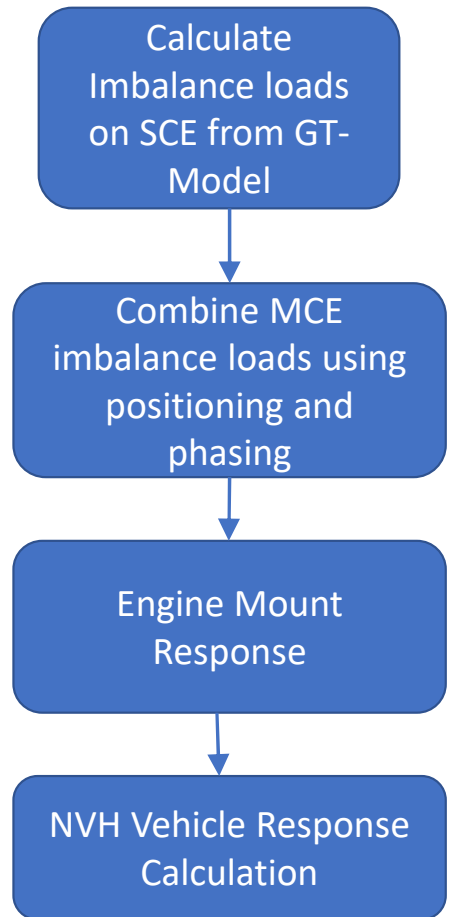
- Balance the first order forces of the single cylinder engine using two counter rotating balance shafts. Otherwise, excessive vibration can hinder the SCE testing.
- Balancing provides both mass radius and angle of both shafts.
- GT-model provides imbalance loads and is used to validate balancing while masses and angles are calculated using internally developed tools.



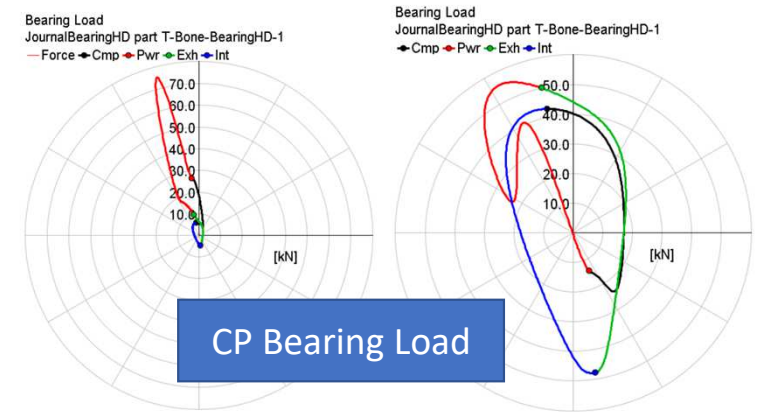
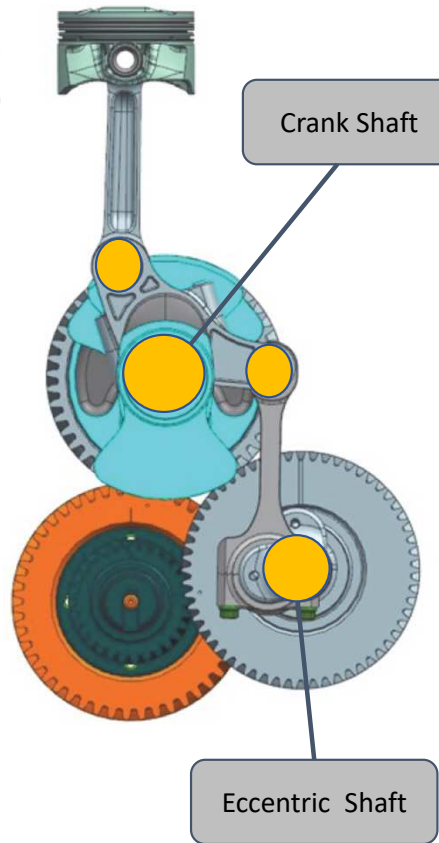
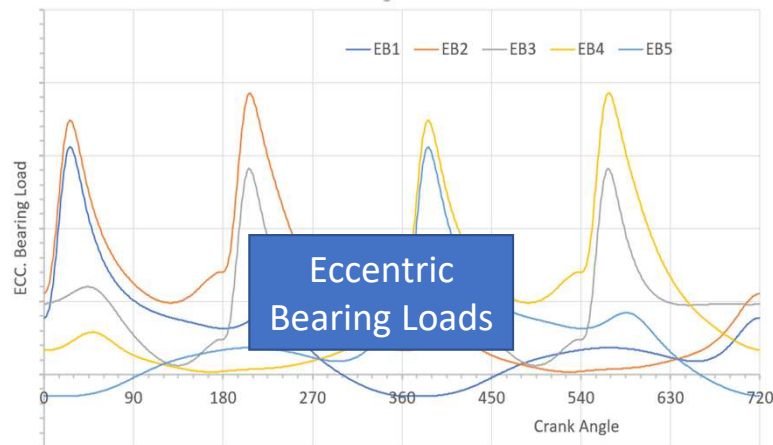
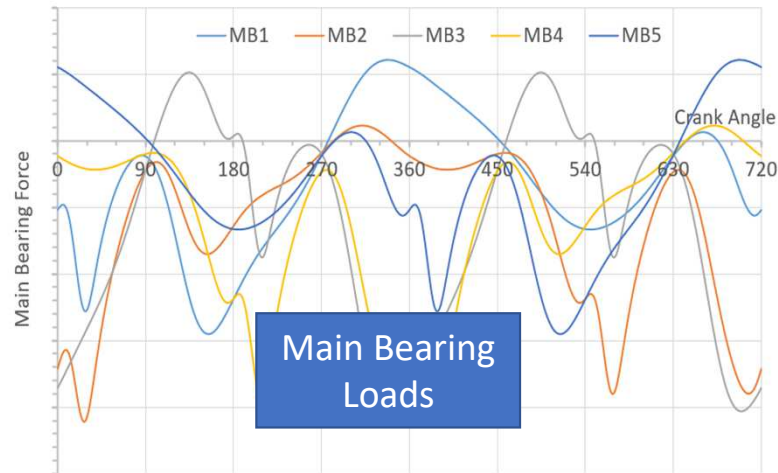
Imbalance Load Calculations and Engine Configuration



- The differential expansion and compression strokes of the engine results in a $\frac{1}{2}$ order inertia imbalance in a single cylinder arrangement .
- The magnitude and phases of these imbalance loads depends on engine configuration and firing order

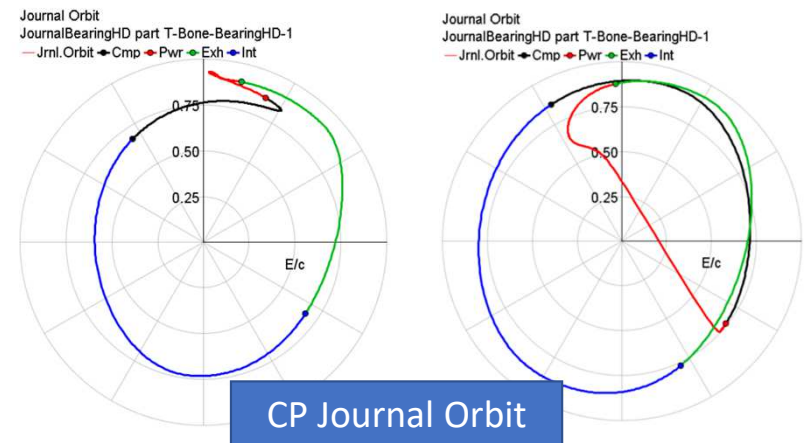


Main Bearing and Eccentric Bearing Load Calculation and Oil Film analysis



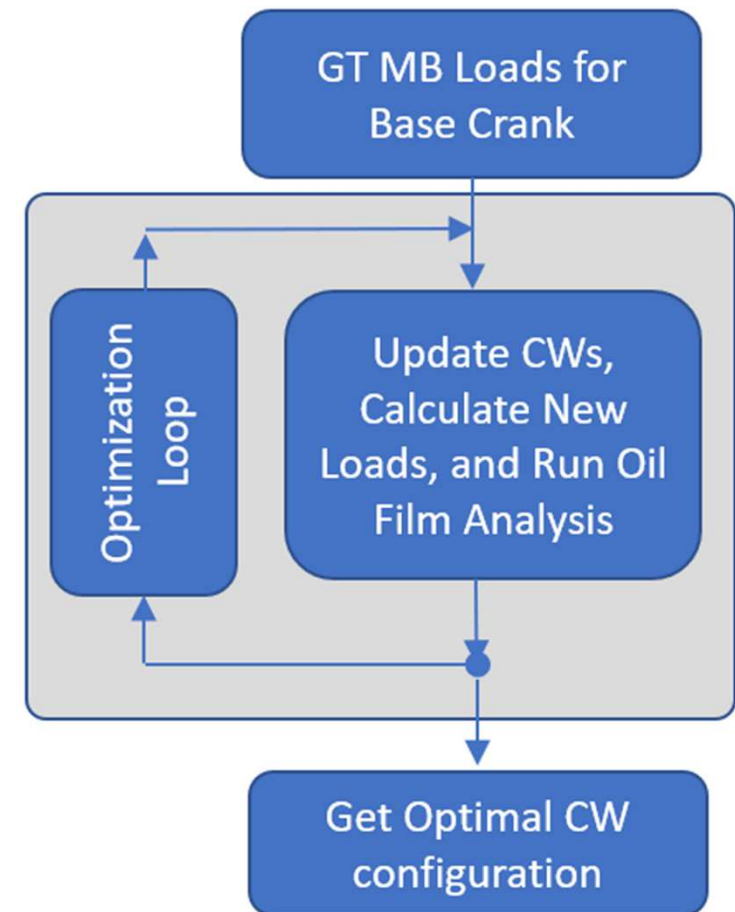
• 2000 RPM

• 6000 RPM

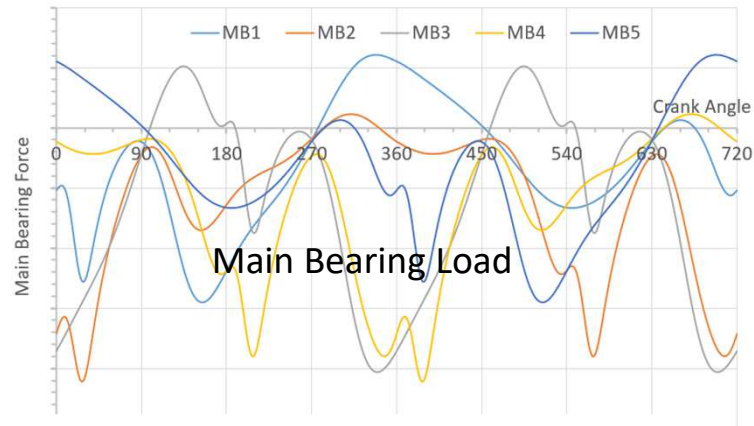


Crank Counter-Weight Calculation for the VCR Engine

- An optimization workflow that calculates counter-weight configurations for balance, with minimum total mass ratio, while meeting lubrication requirement (target Minimum Oil Film Thickness “MOFT”).
- Calculation of main bearing loads from GT-SUITE modeling simulation for a multilink engine.
- Optimization for both CW mass ratios and angle.
- Considers packaging constraints on the maximum CW on each crank web.
- Crankshaft global crank force and moment balance is maintained
- CWs can be easily recalculated as the Main bearing configurations change (i.e. length, grooves, feeding holes, etc.)

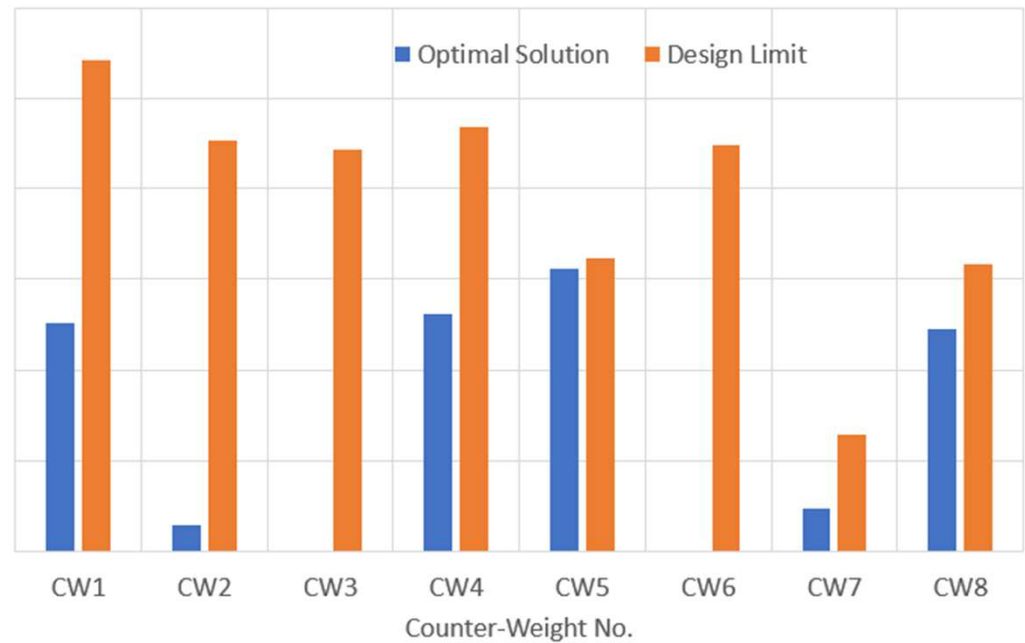
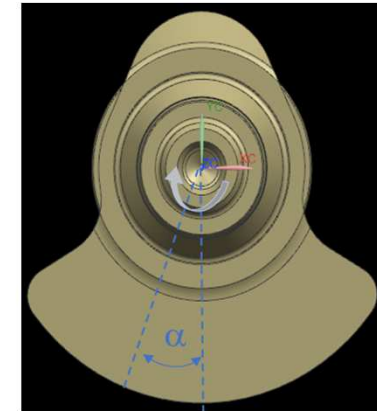
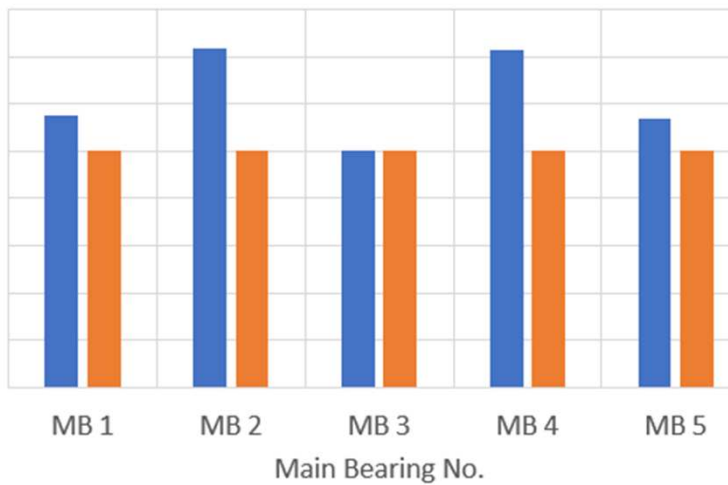


Crank Counter-Weight Optimization

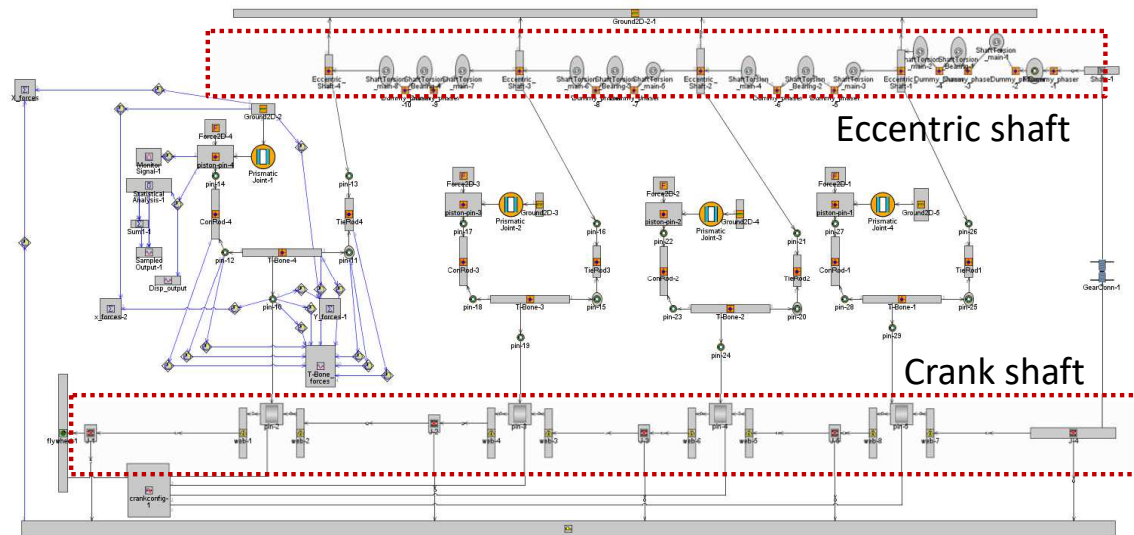
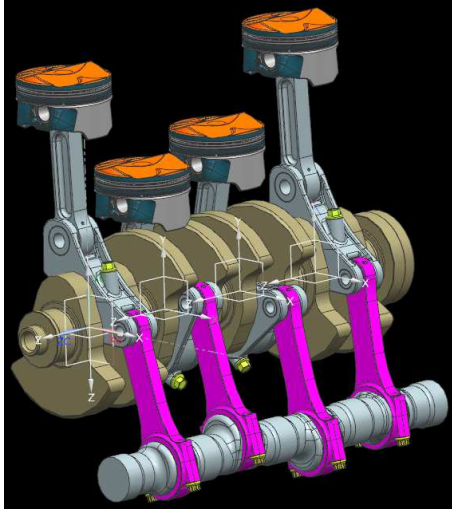


Min. Oil Film Thickness

■ Optimum Solution ■ MOFT Limit



Engine Torsional Vibration Analysis

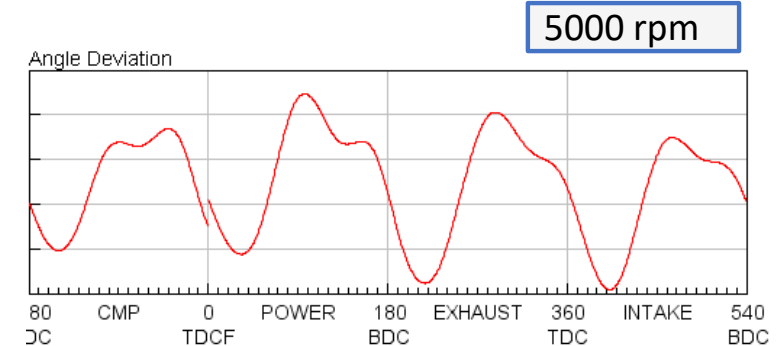
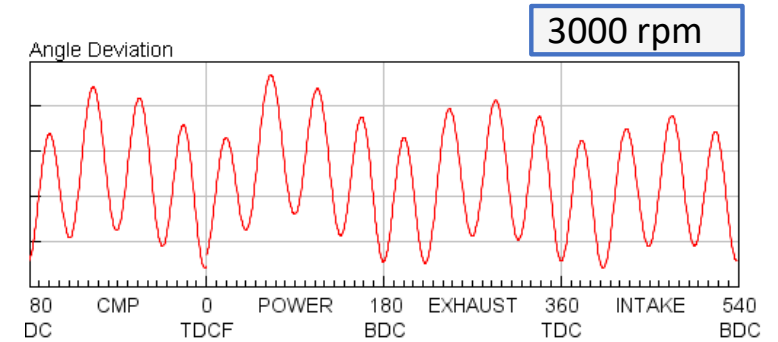
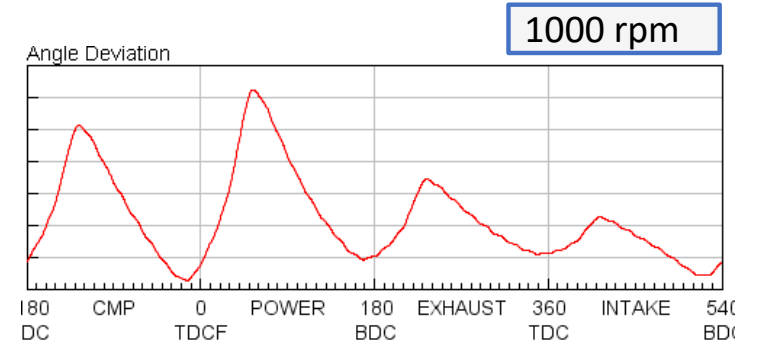
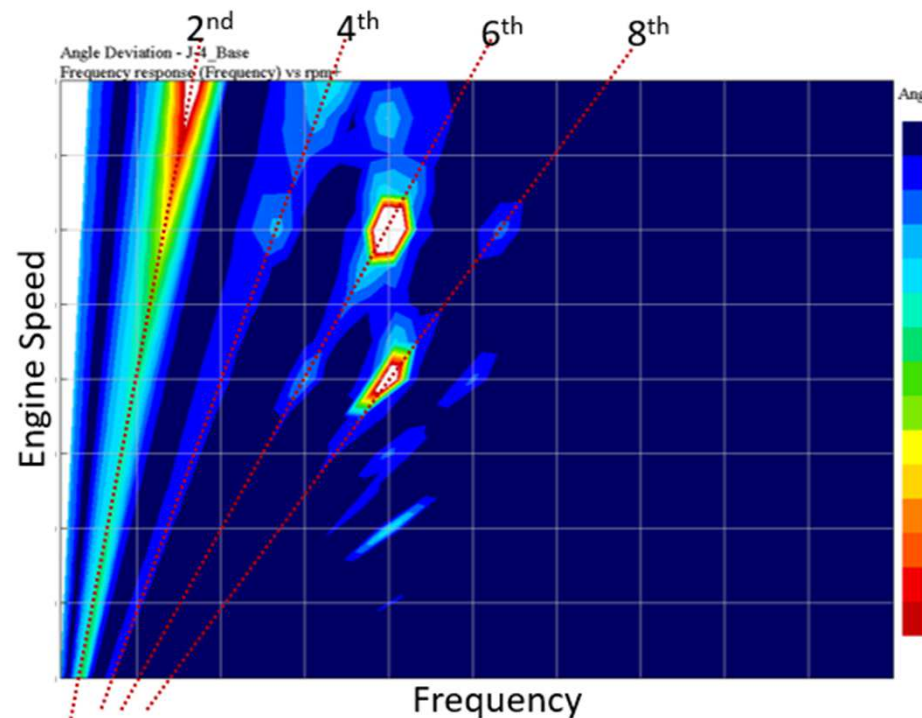
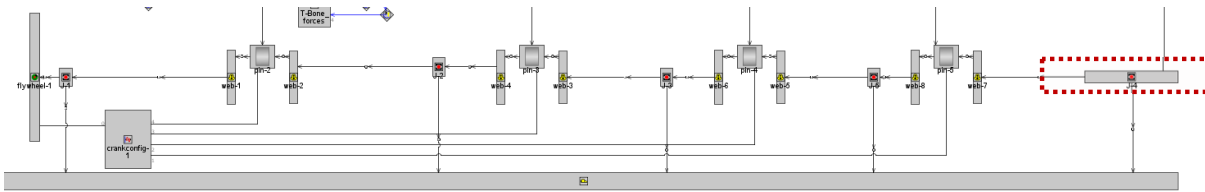


The main challenge for the analysis is to capture the torsional effects of both the crank shaft and the parallel eccentric shaft.

- Ability to run dynamic analysis for the whole system including secondary shaft drive mechanism
- Eccentric shaft phasing is a parameter that can be modified at running
- Objective of analysis is to position, tune and size a damper to overcome excessive vibrations

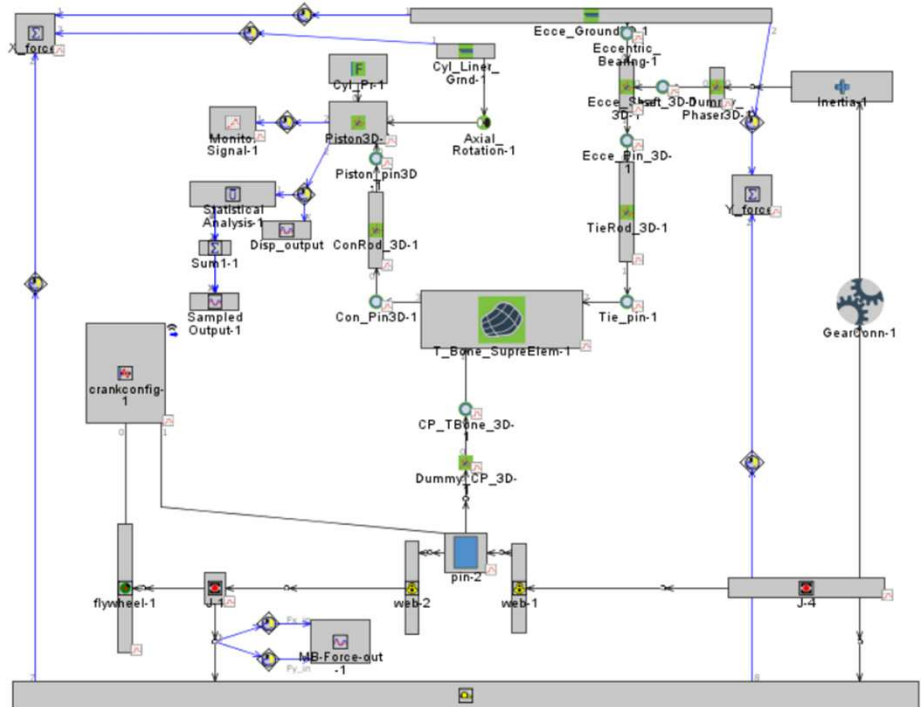
Torsional Vibration Analysis Results

- Angle Deviation at Crank nose

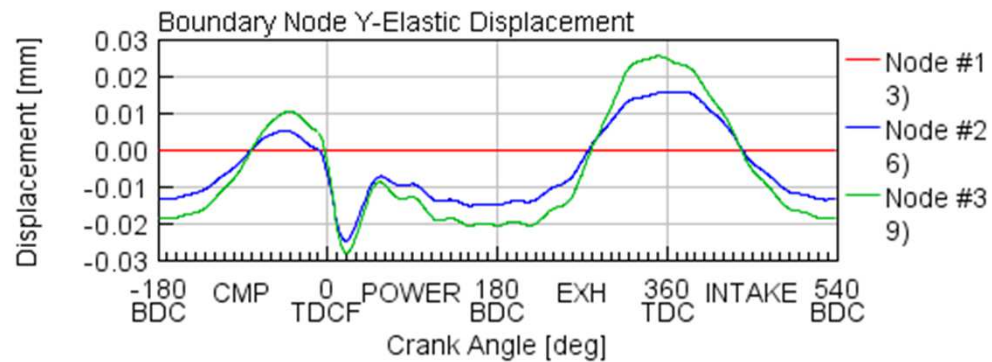
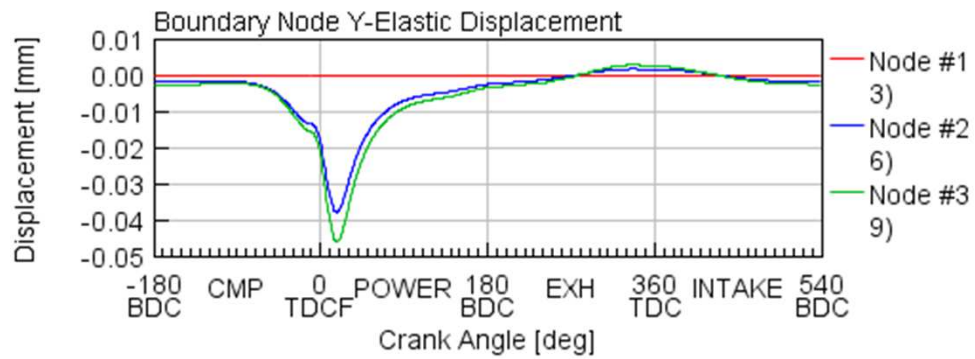


Flexible Multibody Dynamic Analysis

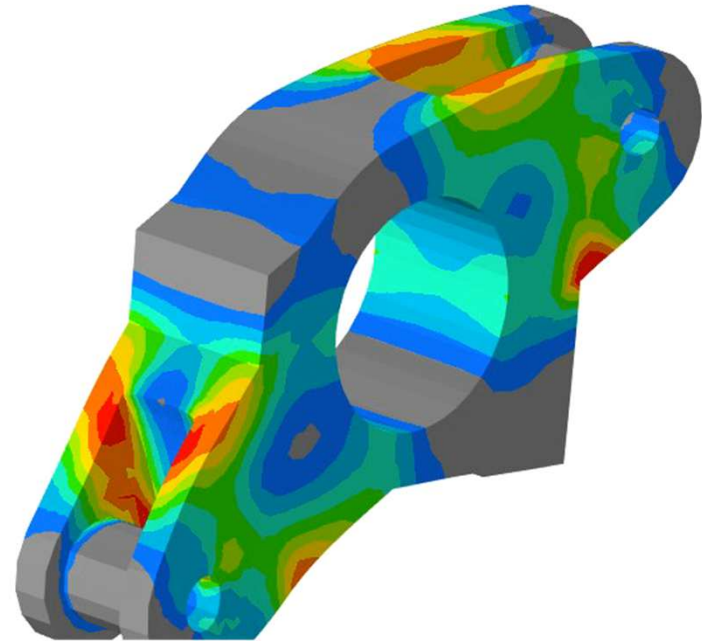
- GT-SUITE super-element was used to model the T-bone linkage utilizing the CBM dynamic reduction.
- The multi-link model needed to be updated from 2D to 3D components.
- Appropriate constraints needs to be defined not to over constraint or under-constraint the model.



Flexible Multibody Dynamic Analysis



Loadcase 1 : SUB10 - T=2.80000E+01 : Frame 29



Conclusions

- The inline variable compression ratio engine is a multi-link mechanism that has more dynamic challenges than conventional engines.
- GT-SUITE analysis modeling done using both 2D rigid dynamics, and 3D flexible body Dynamics.
- GT-SUITE has been successfully used in addressing some of the engine dynamic aspects.
 - Load calculations for component and joints durability
 - Single cylinder engine balancing calculations and load calculations
 - Multi cylinder engine imbalance load calculations
 - Main bearing load calculations and crank counter-weight optimization
 - Engine torsional vibration analysis
 - Flexible multibody dynamic analysis of mechanism components