

GT-Suite Users Conference
Frankfurt, Germany, October 10th 2005

***INTEGRATED HYDRO-MECHANICAL SIMULATION OF A
CAM-ROCKER ARM-UNIT INJECTOR SYSTEM TO
ADDRESS NOISE AND VIBRATION ISSUES***



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Presented by:
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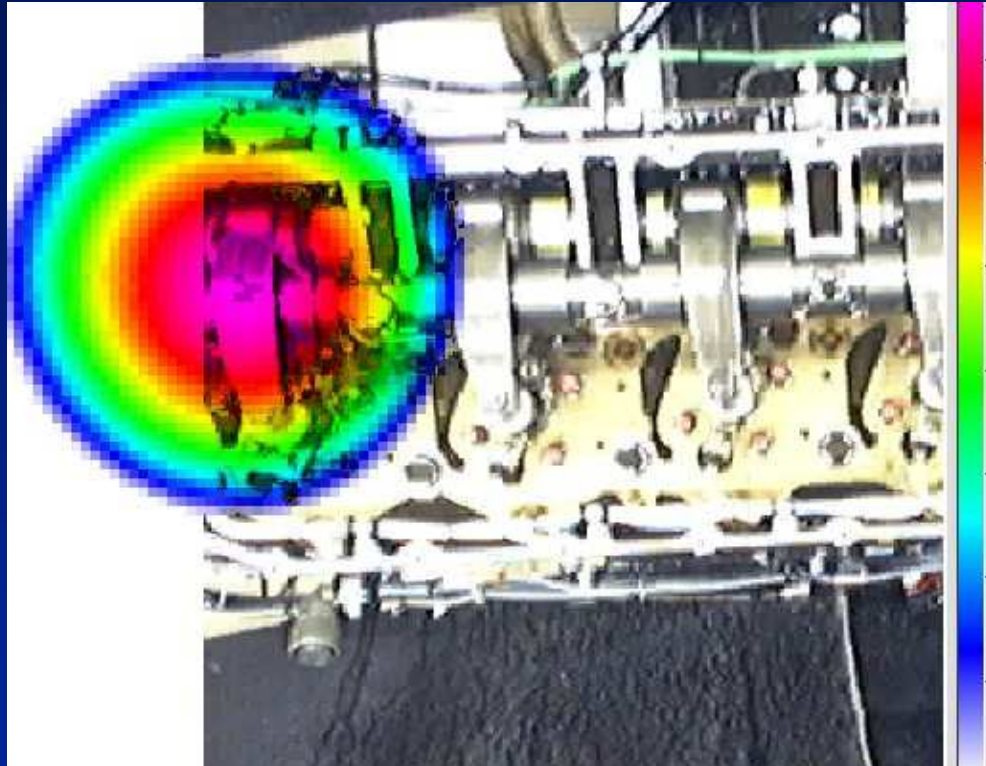
Presentation Overview

- **Introduction**
- **Simulation Model**
 - **Model Construction**
 - **Model Validation**
- **Proposed Improvements/Solutions**
- **Conclusions**
- **Future Work**

Introduction

- **Injection profile modification for increased injection pressure and faster spill times, driven by combustion, emissions and efficiency requirements, made in the new generation of mechanically-driven unit injectors were shown to cause an increase in the level of injector drive-train noise and vibration**
- **The noise was thought to be related to the interactions between the fuel pressure dynamics (i.e. rapid hydraulic pressure fluctuations due to a fast injection cut-off and the correspondingly quicker fall-off in the injector drive force) and the dynamics of the mechanical components in the unit injector and its drive-train (i.e. rocker arm, rocker shaft, overhead camshaft shared with the valve-train)**
- **It occurred across the operating speed range of the engine**

Introduction



Noise camera picture showing the noise source at the injector rocker arm

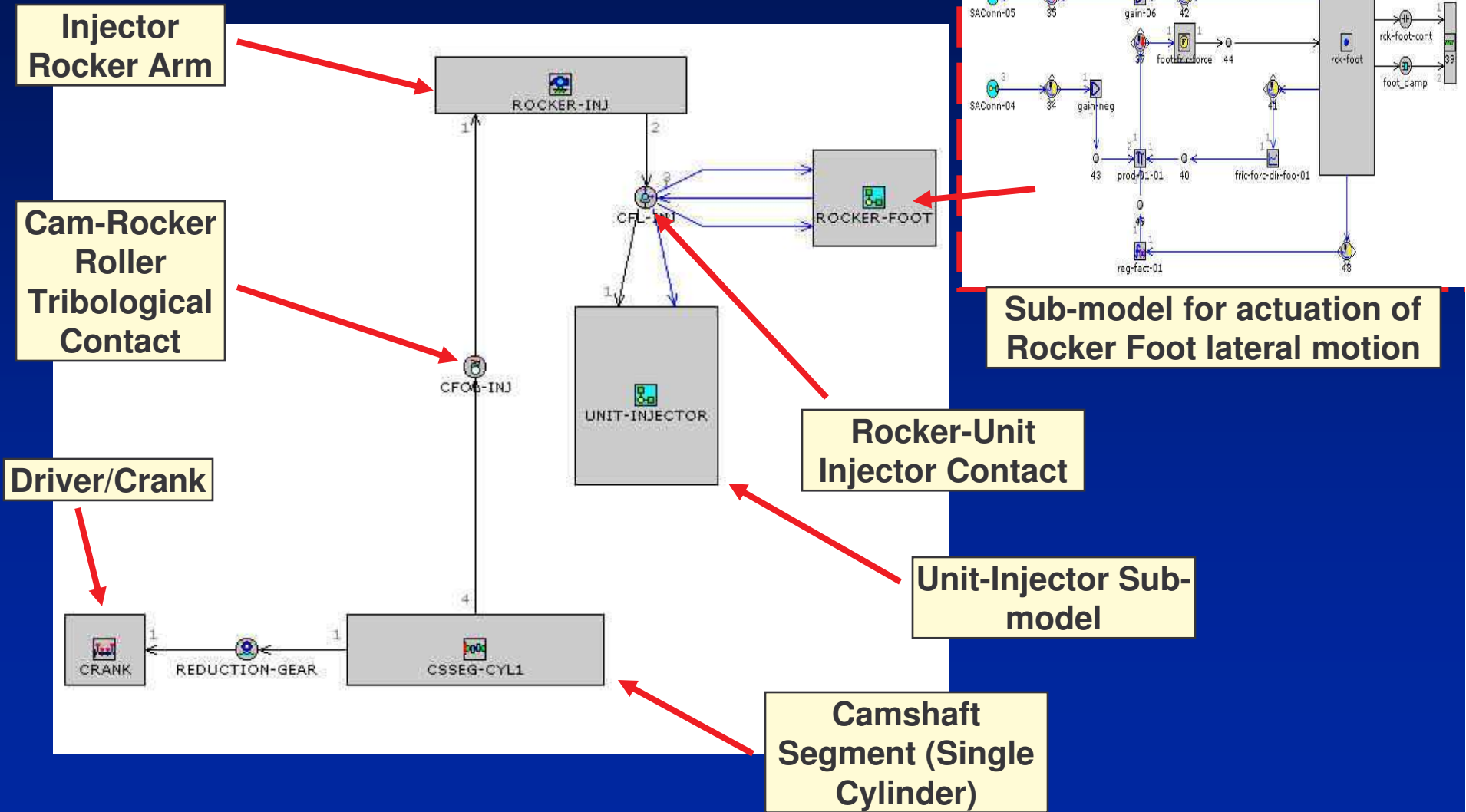
Simulation Model

Model Construction

- **A model of a single unit injector and its drive set-up (rigid camshaft segment, cam lobe, flexible rocker arm) was developed and studied in GT-SUITE (GT-VTRAIN+GT-FUEL)**
- **It represented the geometry, masses, inertias, stiffness values, flow path lengths and areas, volumes, etc. of the injector and its drive system**

Simulation Model

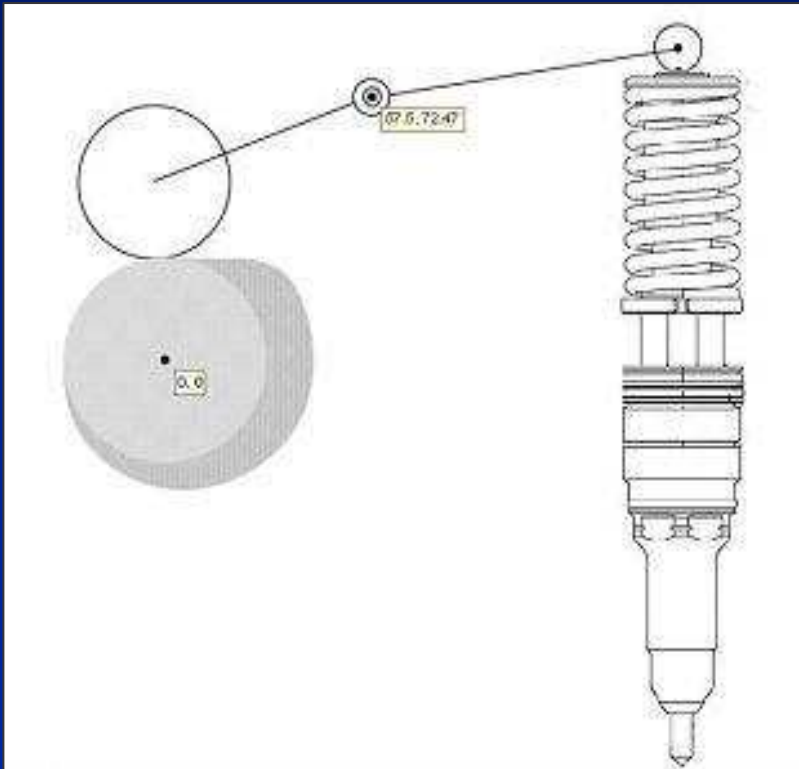
Model Construction



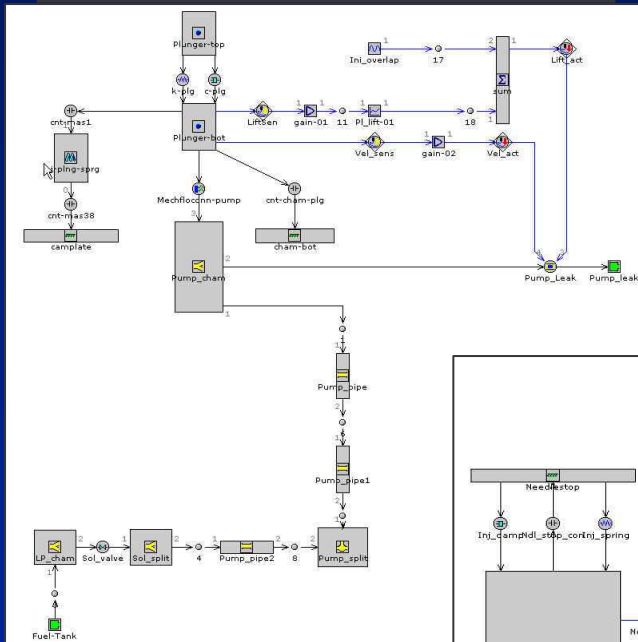
Simulation Model

Model Construction

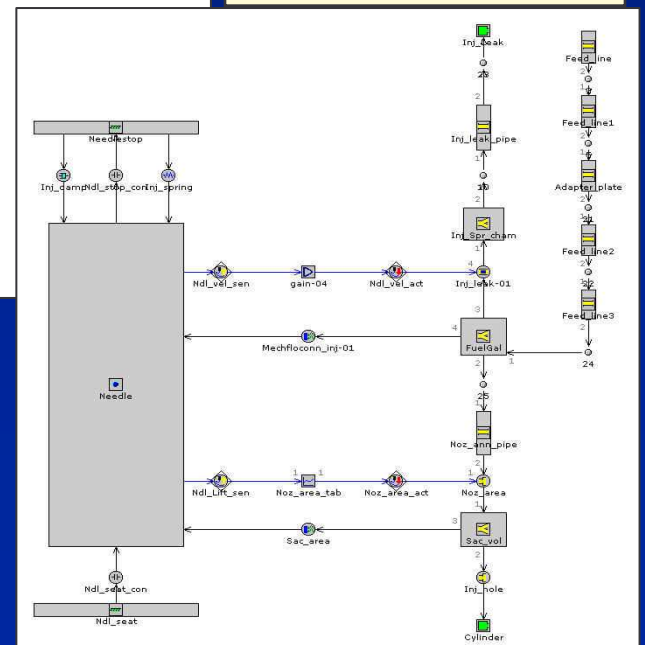
Unit injector drive-train geometry



Unit injector pump and solenoid valve sub-model



Unit injector feed path and injection nozzle sub-model



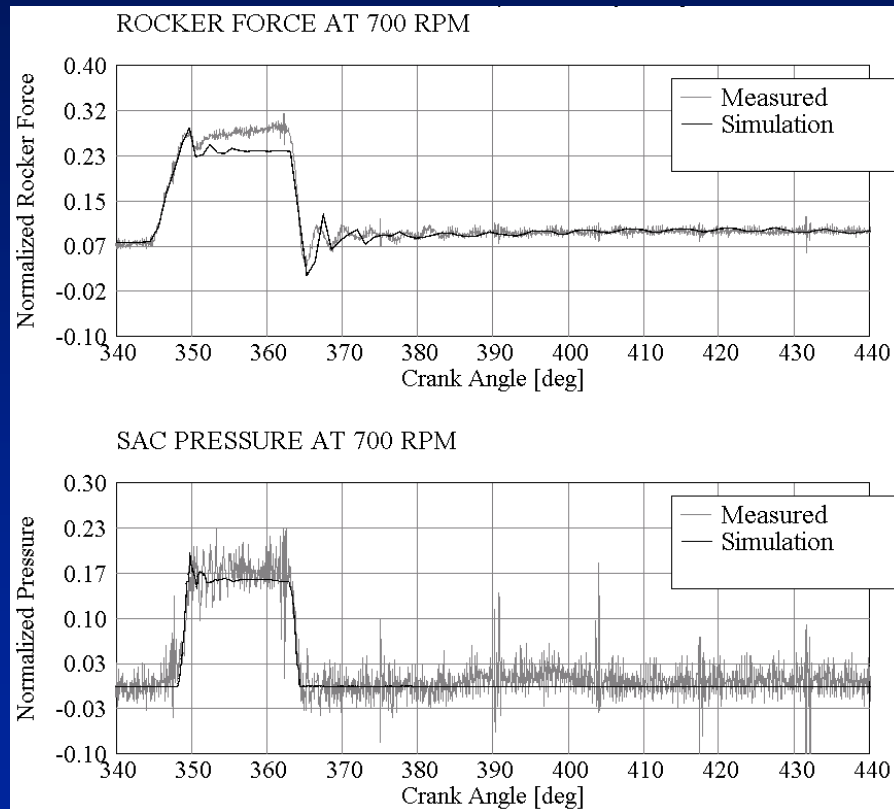
Simulation Model

Model Validation

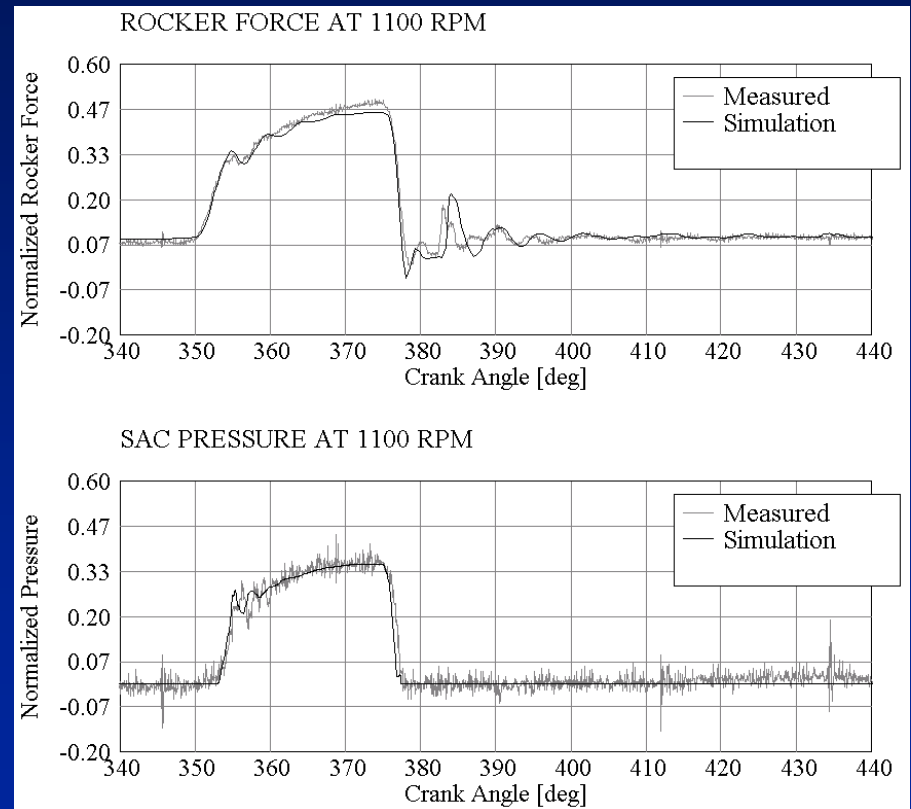
- **Model was exercised and carefully tuned to match the behavior of the unit-injector and its drive-train**
- **Simulation was carried out at multiple speed increments at which measured data was available**
- **Experimental, test rig measurements (rocker arm force on injector pump plunger, injector sac pressure and total injected mass of fuel per injector per stroke) at 353kW were used for tuning purposes**

Simulation Model

Model Validation



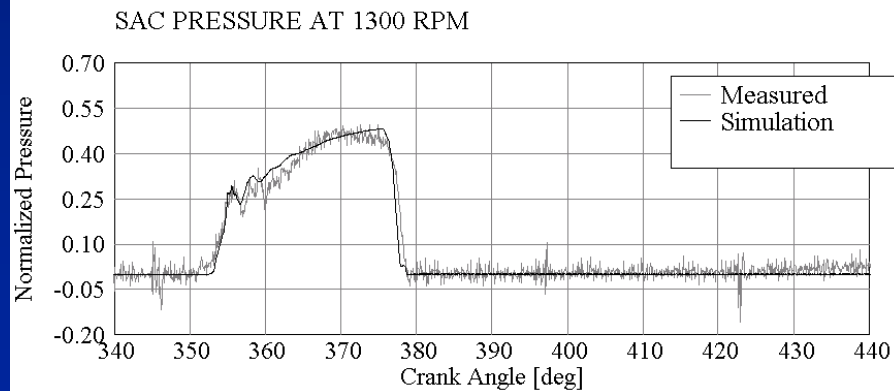
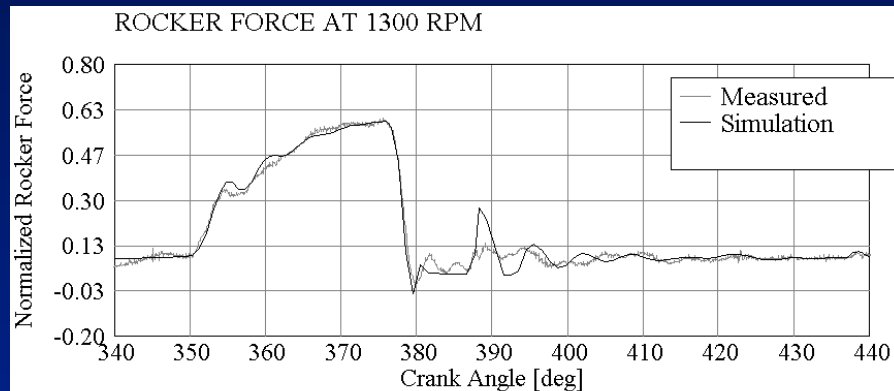
Comparison between experimental and simulation results at 700 RPM



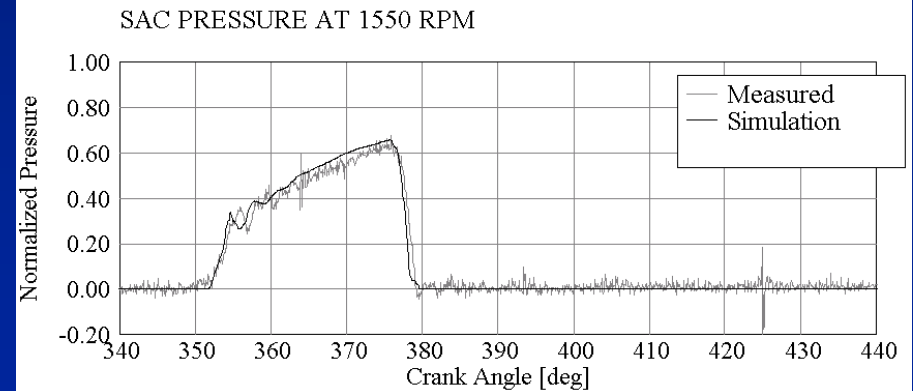
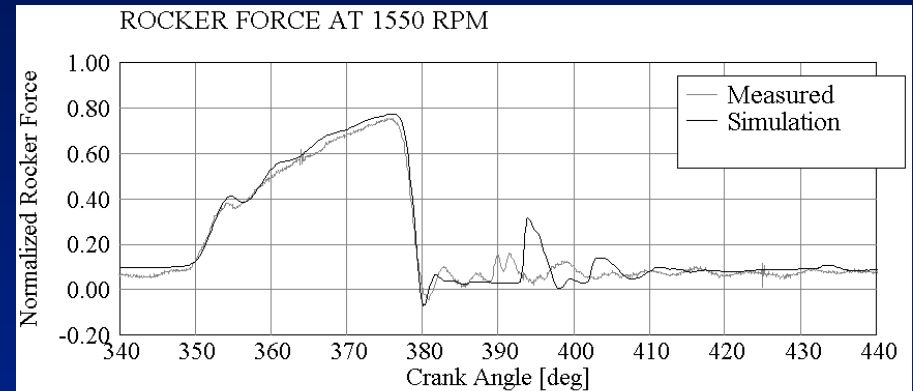
Comparison between experimental and simulation results at 1100 RPM

Simulation Model

Model Validation



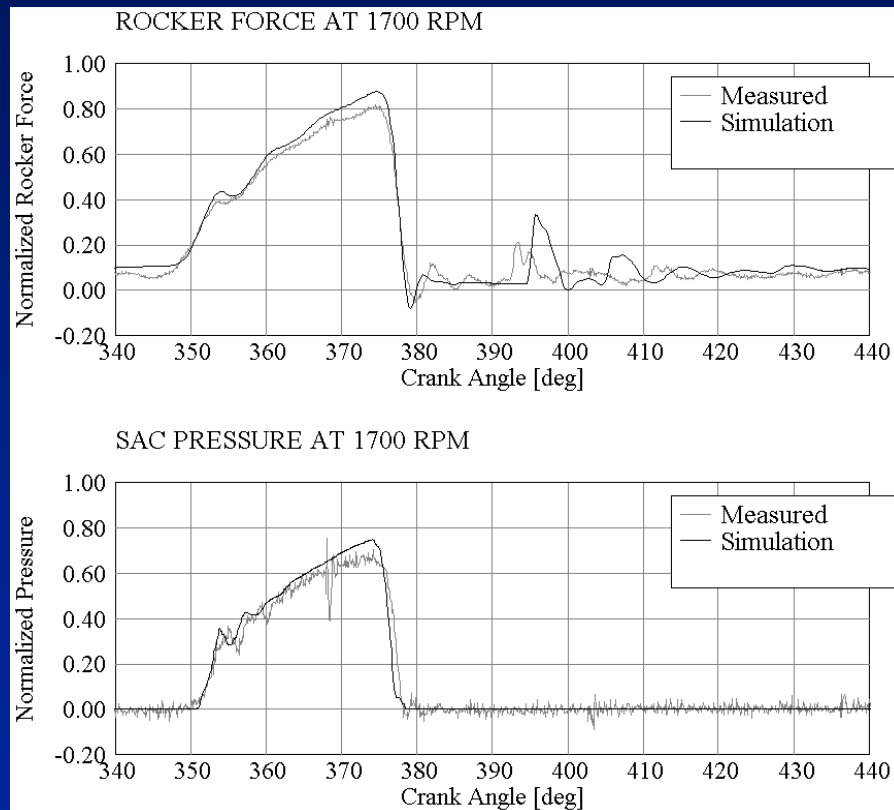
Comparison between experimental and simulation results at 1300 RPM



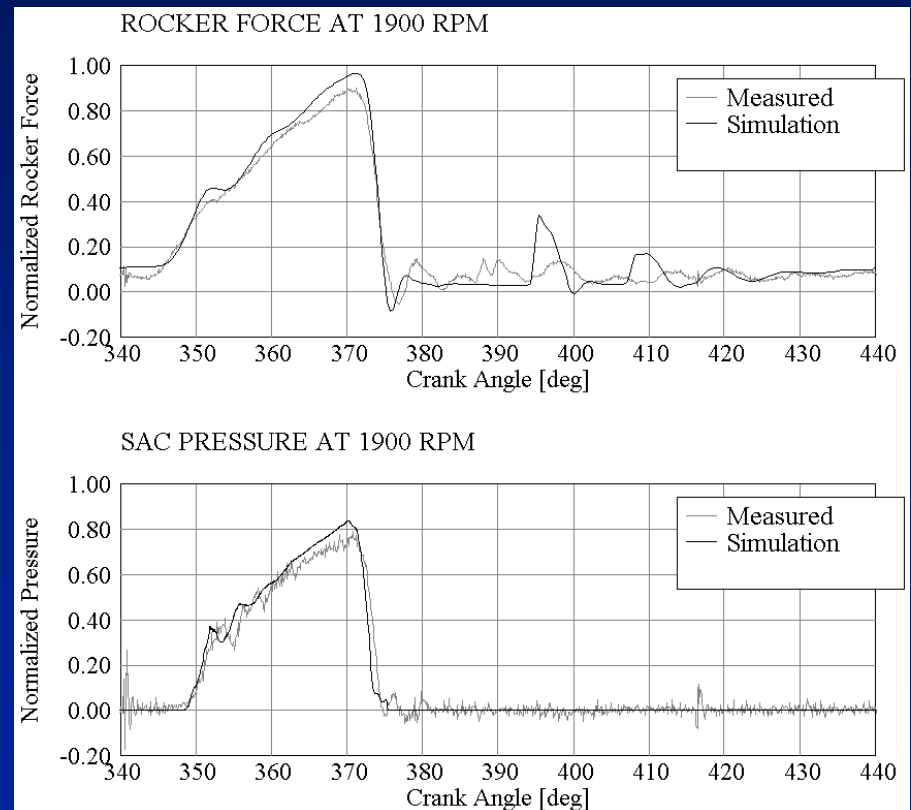
Comparison between experimental and simulation results at 1550 RPM

Simulation Model

Model Validation



Comparison between experimental and simulation results at 1700 RPM



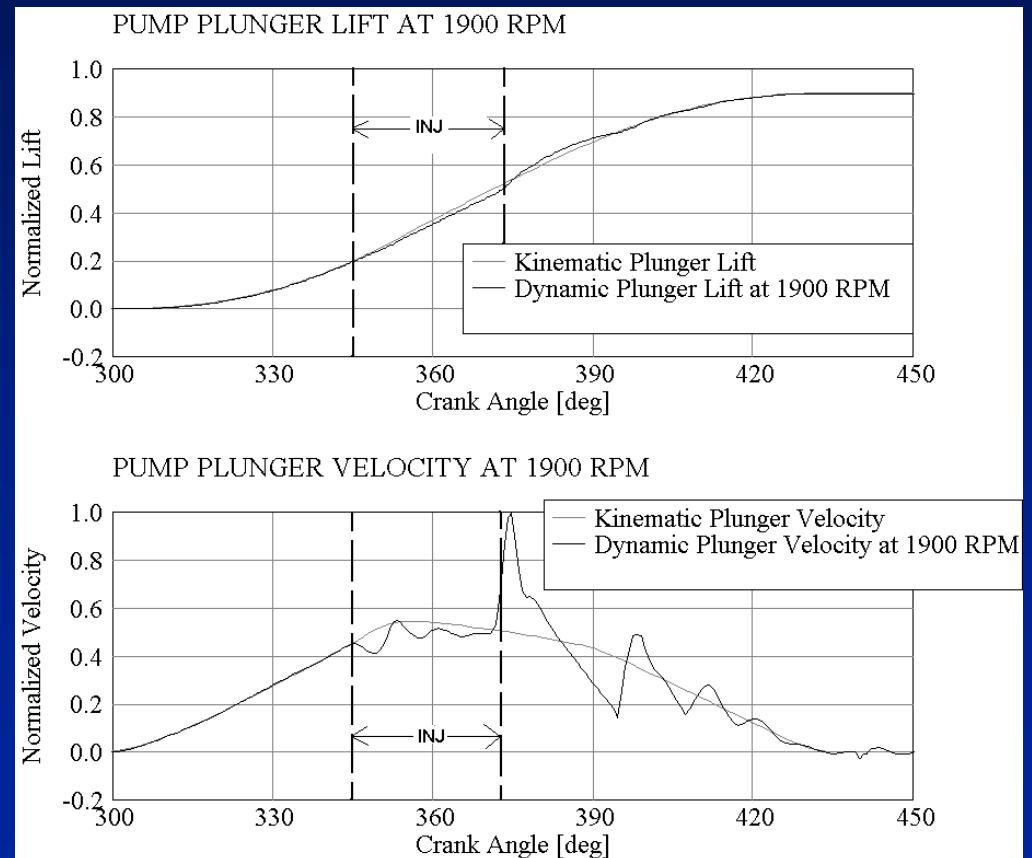
Comparison between experimental and simulation results at 1900 RPM

Simulation Model

Model Validation

	Engine Speed	% Diff. Injected Mass
	RPM	%
1	700	0.09
2	1100	0.04
3	1300	0.13
4	1550	0.08
5	1700	0.10
6	1900	0.14

Comparison between experimental and simulation results for total injected mass quantity per stroke



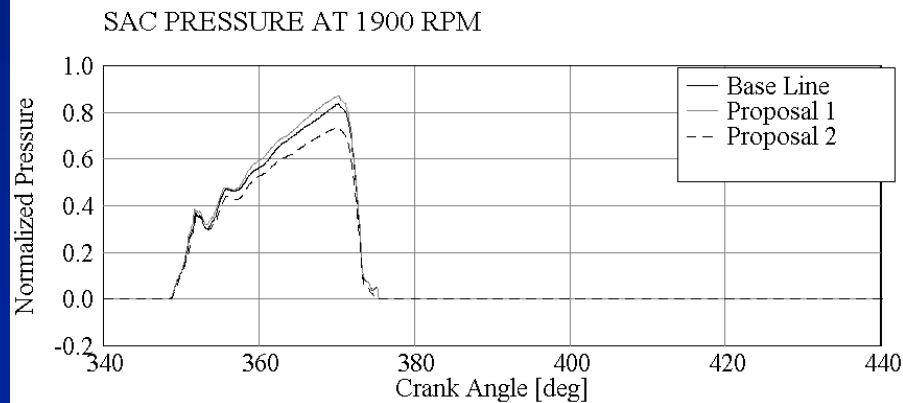
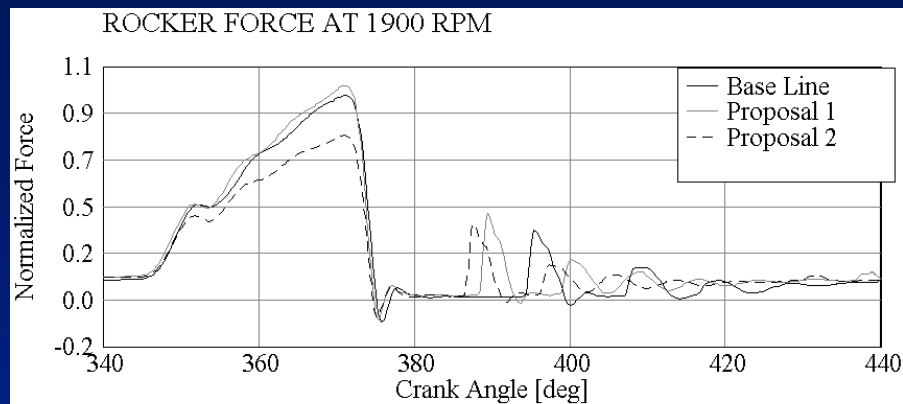
Injector pump plunger normalized lift and velocity at 1900 RPM

Proposed Improvements/Solutions

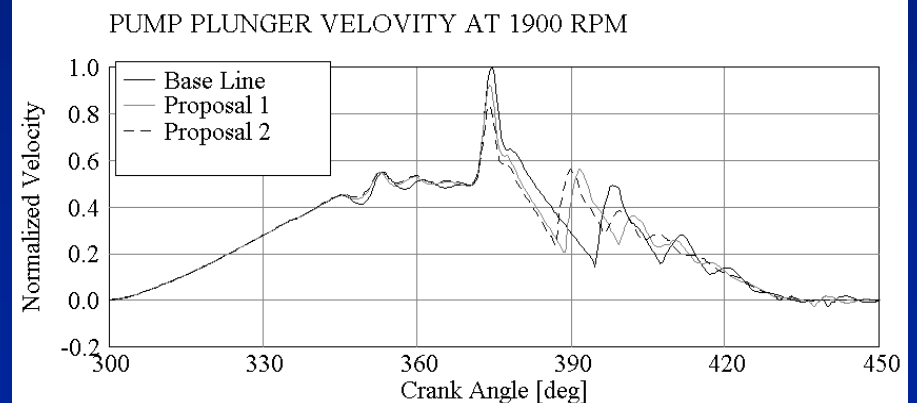
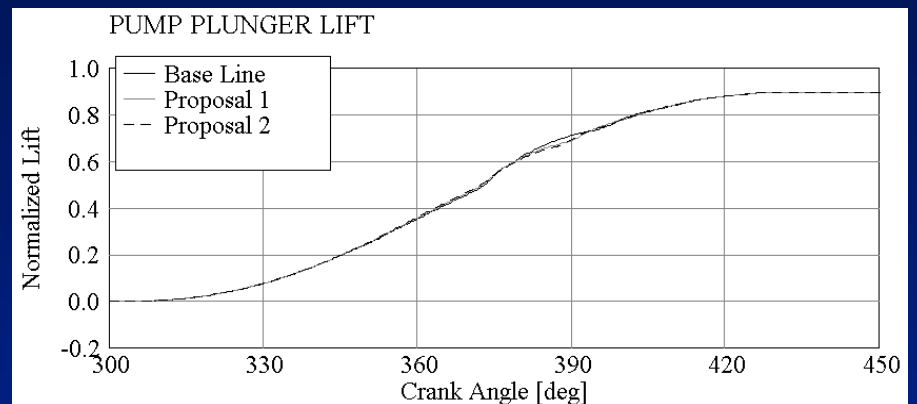
- **After the assessment of the accuracy and reliability of the unit injector drive-train model, the numerical simulation could be used to point out the possible solutions for elimination or amelioration of the “noise” problem**
- **Four design proposals were studied:**
 1. **Rocker arm stiffness and rocker shaft stiffness increased by 50%, unit injector pump spring stiffness and pretension increased by 25%**
 2. **Same as proposal 1 but the unit injector pump plunger diameter was reduced from 9.5 mm to 9.0 mm**
 3. **Diameter of the flow path just outside the pump chamber reduced by 45%**
 4. **Diameter of the flow path just outside the pump chamber reduced by 60%**

Proposed Improvements/Solutions

Results from Proposals 1 and 2



Predicted rocker force and sac pressure comparison between baseline and proposals 1 & 2 at 1900 RPM



Predicted dynamic pump plunger lift and velocity comparison between baseline and proposals 1 & 2 at 1900 RPM

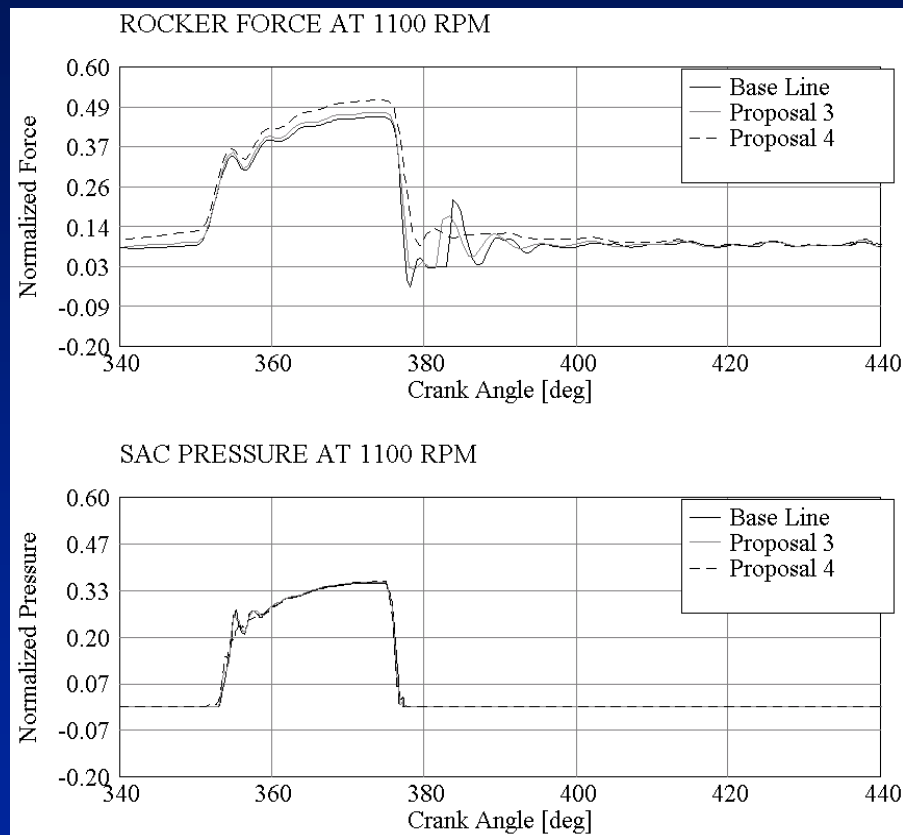
Proposed Improvements/Solutions

Results from Proposals 1 and 2

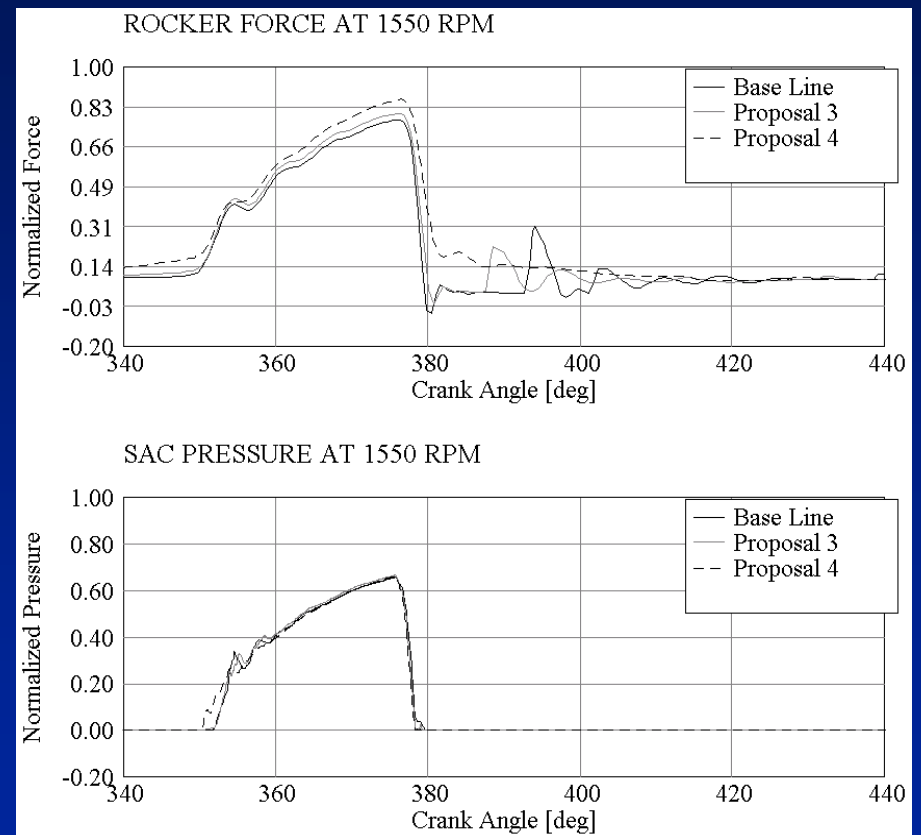
- Approximately 40% reduction in the plunger vibration level achieved with proposal 2 (decrease in vibration is quantified by calculating the % reduction of magnitude of the max. pump plunger velocity peak)
- Proposals 1 and 2 are costly and difficult for implementation as both these proposals require a substantial modification in the unit injector drive-train components
- Proposals 1 and 2 have significant influence on the injection characteristics and may call for the re-optimization of the fuel system

Proposed Improvements/Solutions

Results from Proposals 3 and 4



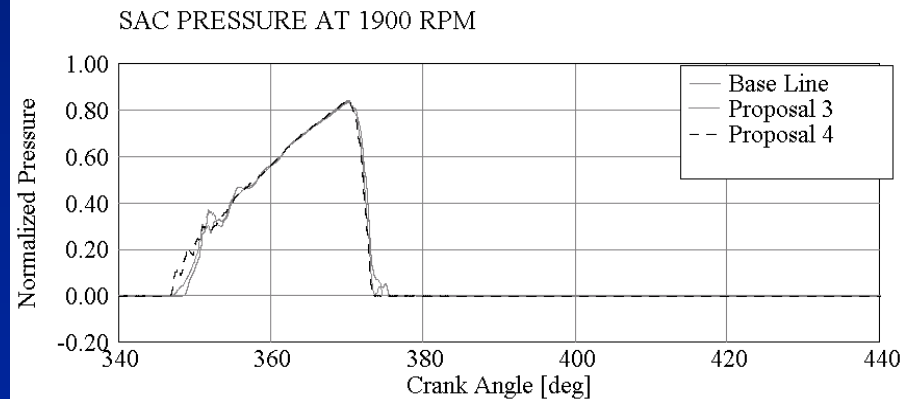
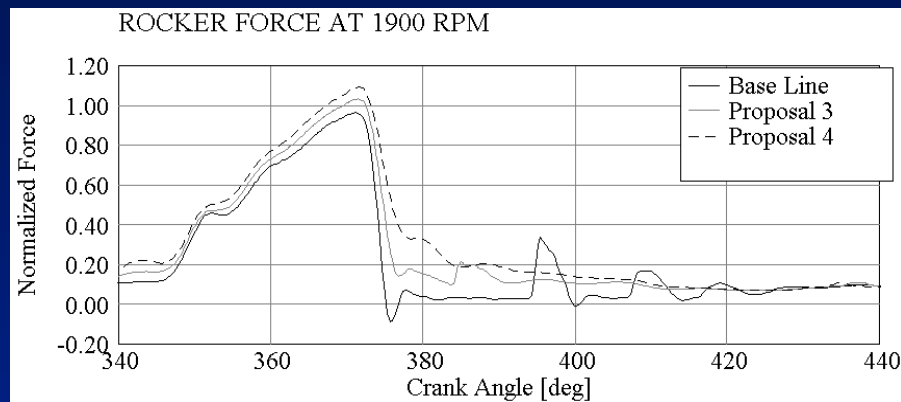
Predicted rocker force and sac pressure comparison between baseline and proposals 3 & 4 at 1100 RPM



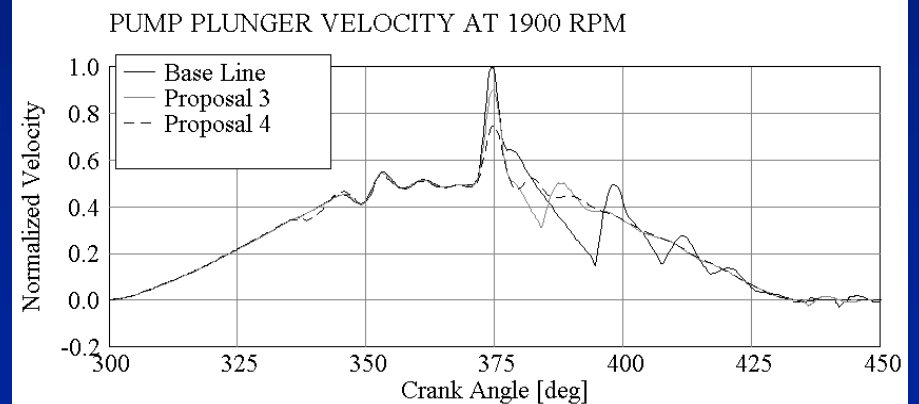
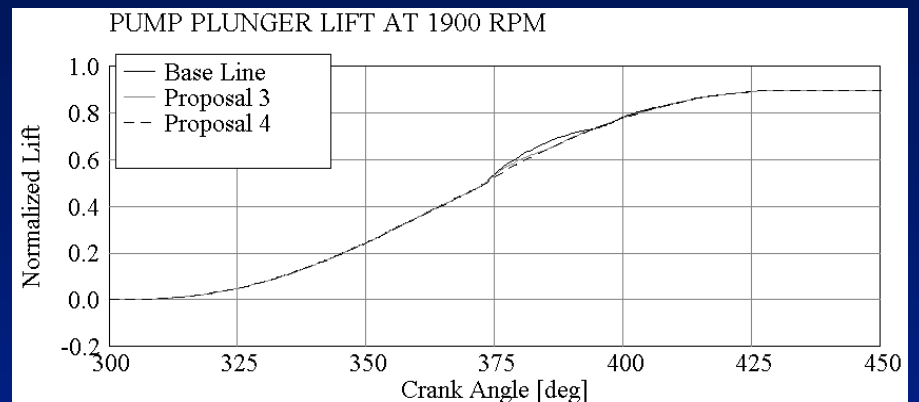
Predicted rocker force and sac pressure comparison between baseline and proposals 3 & 4 at 1550 RPM

Proposed Improvements/Solutions

Results from Proposals 3 and 4



Predicted rocker force and sac pressure comparison between baseline and proposals 3 & 4 at 1900 RPM



Predicted dynamic pump plunger lift and velocity comparison between baseline and proposals 3 & 4 at 1550 RPM

Proposed Improvements/Solutions

Results from Proposals 3 and 4

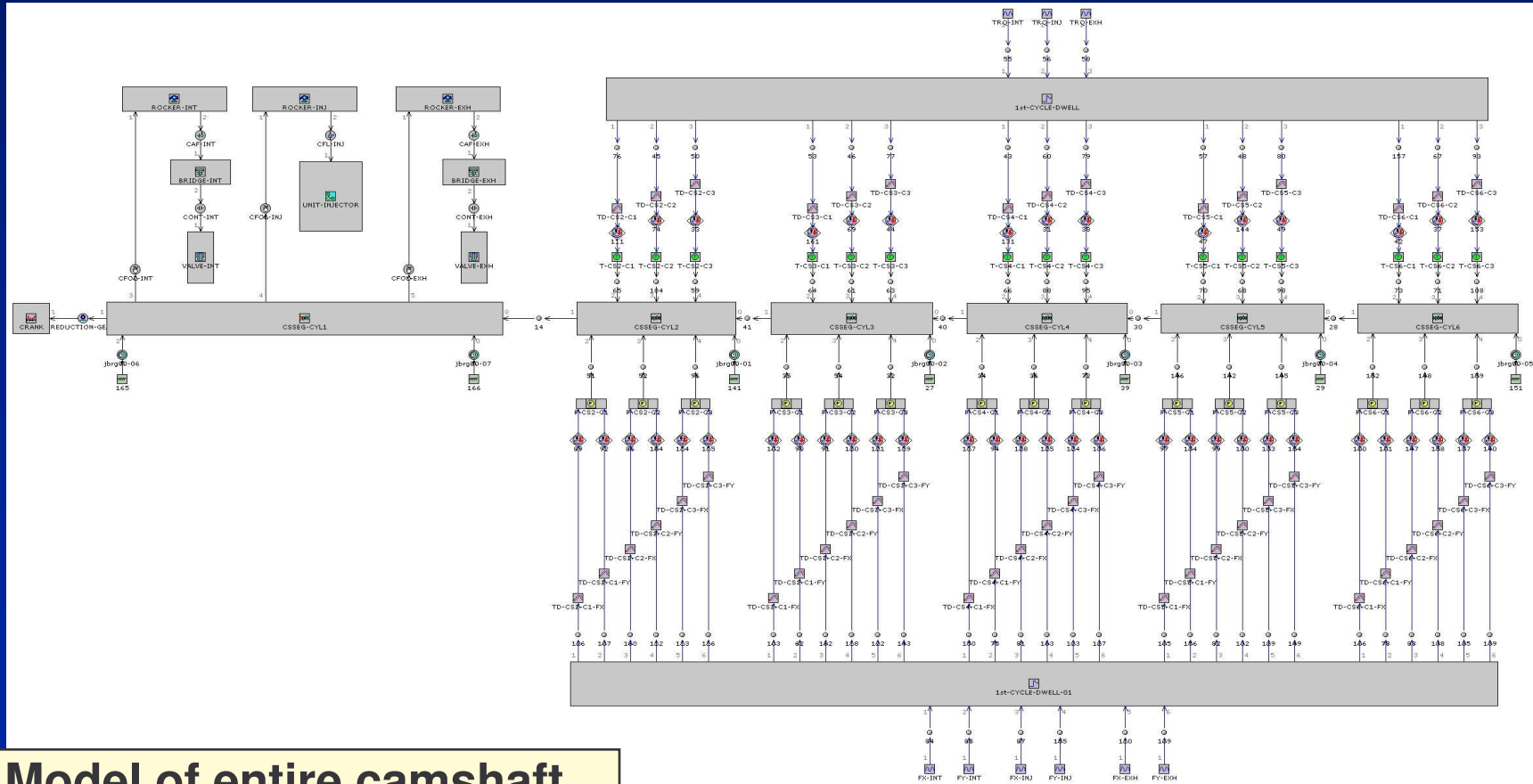
- **Substantial reduction in the level of plunger vibration with proposals 3 and 4 (approximately 50% with proposal 4)**
- **Injection characteristics practically unaltered with proposals 3 and 4**
- **Proposals 3 and 4 show an increase in the rocker forces (about 14% at 1900 RPM with proposal 4)**
- **Based on improvement in the noise level, cost efficiency and the ease of implementation, proposals 3 and 4 were found to be more suitable for implementation as compared to proposals 1 and 2**

Conclusions

- **An integrated hydro-mechanical model of the unit injector and its drive-train was created and analyzed in GT-SUITE**
- **Through a detailed validation process, the model was shown to correlate well with the actual system**
- **The “noise” phenomenon was recognized to be related to the rapid pressure decay in the hydraulic system of the emission-optimized unit injector at the end of injection, which caused a high level of vibration of the mechanical components in the injector drive-train**
- **Several key parameters were selected and investigated in search of the solution to the noise/vibration issue**

Future Work

The single camshaft segment model can be extended to a full valvetrain model in order to account for the effects of torsional and bending vibrations of the camshaft as well as for the dynamics of the intake and exhaust valvetrain branches



Model of entire camshaft

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