Modeling Lubrication System Oil Flow

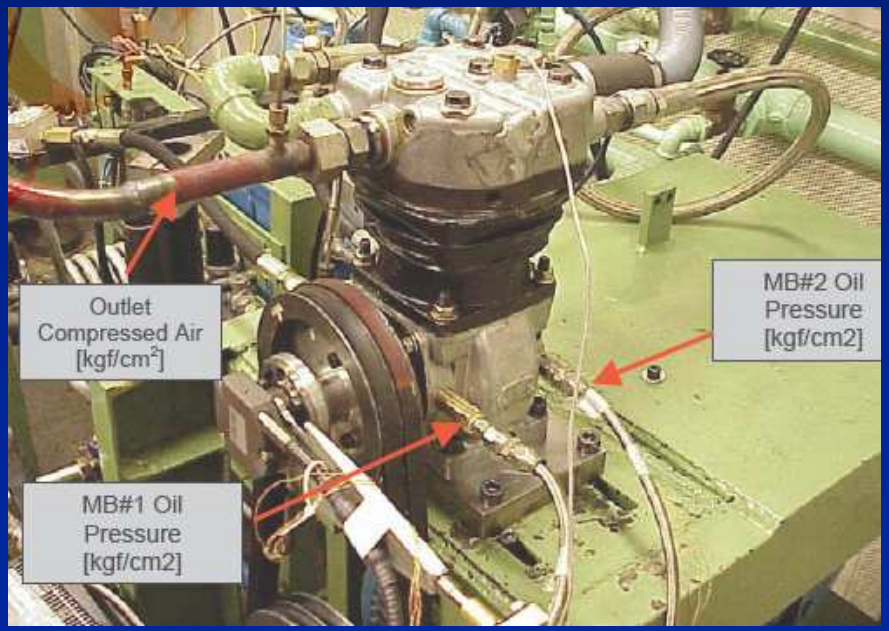
Roberto Pierotti and Walter Zottin,
Mahle Metal Leve S.A.

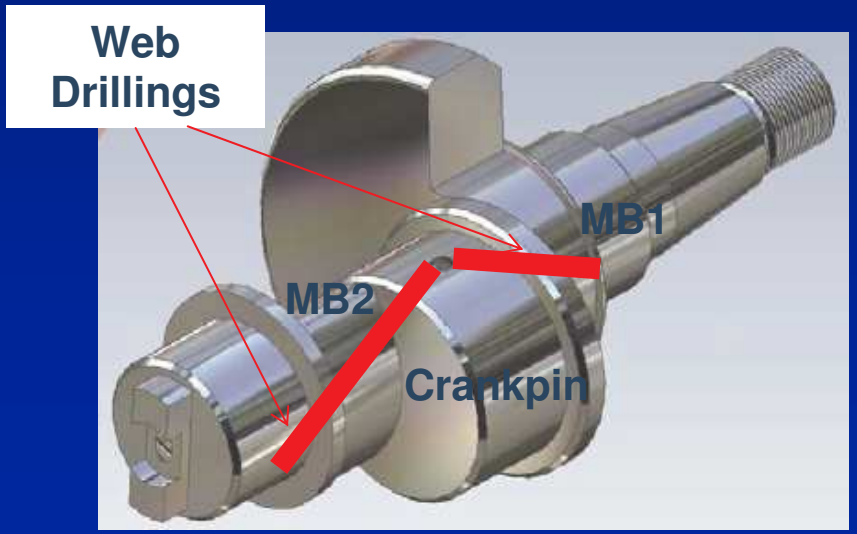
Jon Harrison and Shawn Harnish, GTI

Gamma Technologies

1-Cylinder Engine Lab Setup

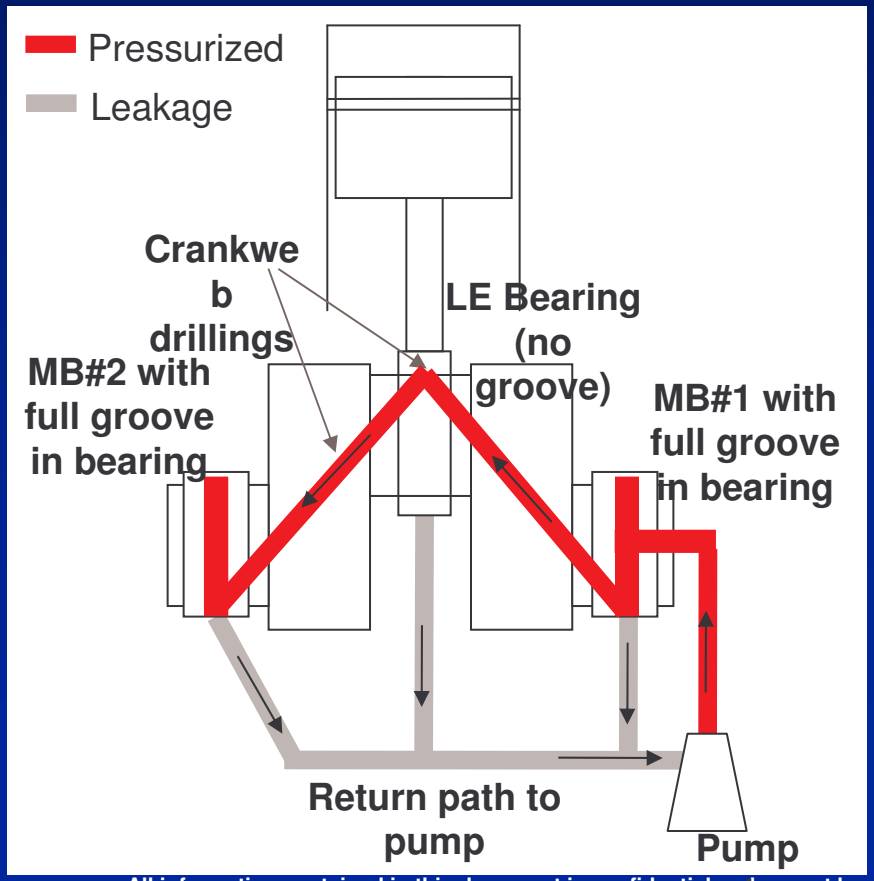
- **Motivation: to calculate flow distribution to each bearing (MB1, CR LEB, MB2) of a KNORR-BREMSE air compressor LK38**
- **3 separate experiments (steps) performed**
  - **1) baseline**
  - **2) MB1 plugged**
  - **3) MB2 plugged**





Experimental Setup: Step 1

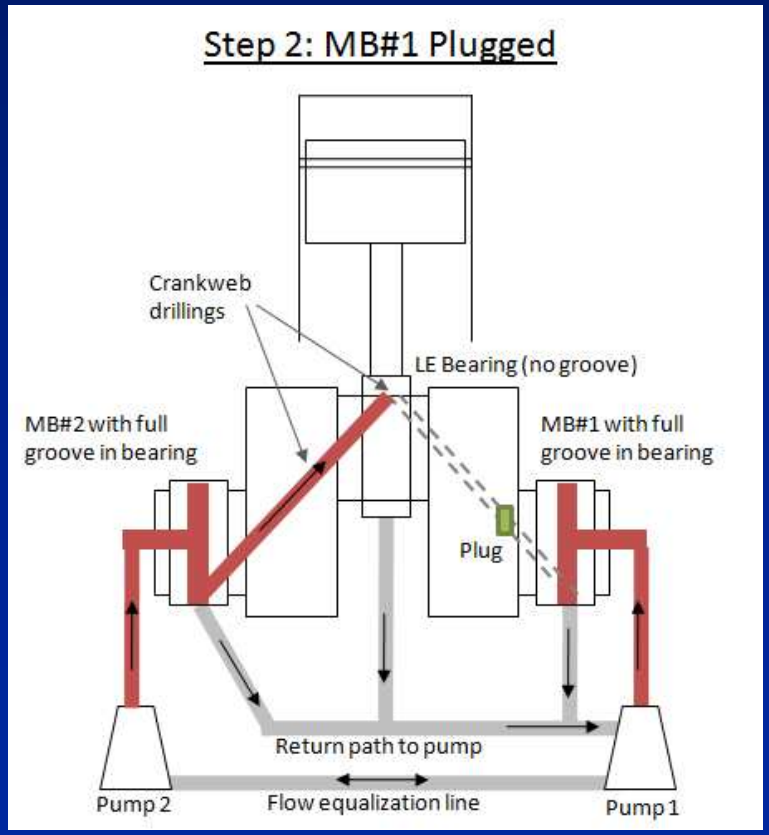
- **Step 1: Baseline Case**
  - **Pump set to a particular flow rate (between 4–14 L/hr)**
    - **Inlet temp., MB1 and MB2 housing temp., and pressure in MB1 and MB2 measured**

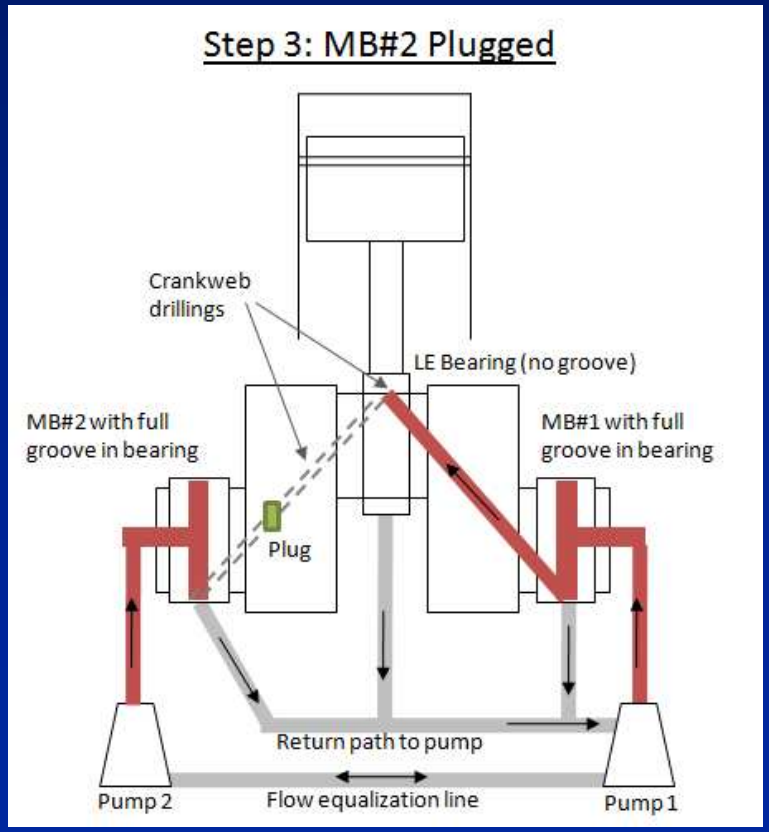


Oil	15W40
Bore	88 mm
Stroke	37 mm
Peak Cylinder Pressure (Abs.)	8.8 bar
MB Dia	30 mm
MB Bearing Width	16 mm
MB1 Radial Clearance	0.0565 mm
MB2 Radial Clearance	0.05 mm
CR LEB Dia	42 mm
CR LEB Radial Clearance	0.017 mm

Experimental Setup: Steps 2 and 3

- **Step 2 and 3:**
  - **Flow rate tuned in pump 1 and pump 2 to match pressure and temperature in each main bearing to baseline case (Step 1)**
    - **Isolating each main bearing allows the con rod large end bearing flow rate to be estimated**

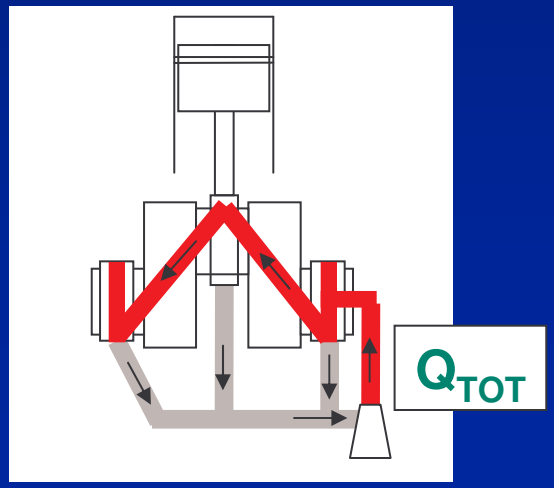




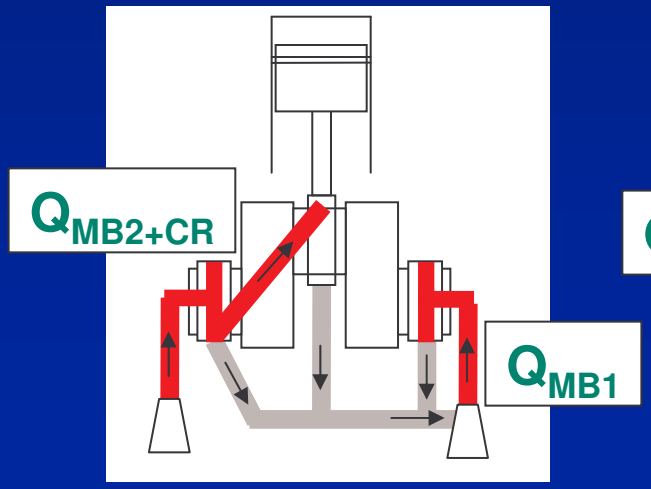
Connecting Rod Large End Bearing Flow Rate Calculation

- Conrod Bearing Flowrate, Q_{CR}, calculated as average of three separate flow rate calculations:
  - $Q_{CR} = (Q_{CR1} + Q_{CR2} + Q_{CR3})/3$
  - $Q_{CR1} = Q_{TOT} - Q_{MB1,Step2} - Q_{MB2,Step3}$
  - $Q_{CR2} = Q_{MB2+CR,Step2} - Q_{MB2,Step3}$
  - $Q_{CR3} = Q_{MB1+CR,Step3} - Q_{MB1,Step2}$

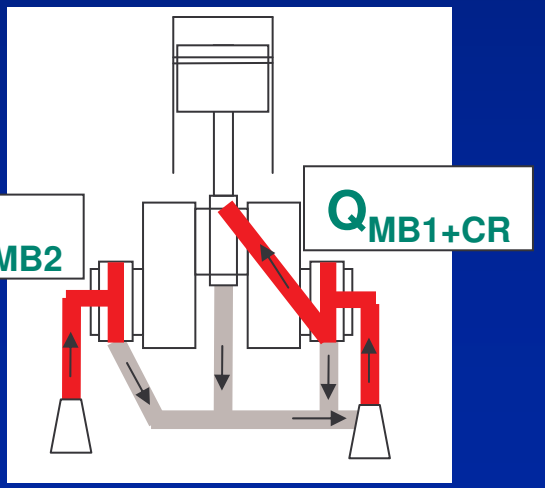
STEP 1



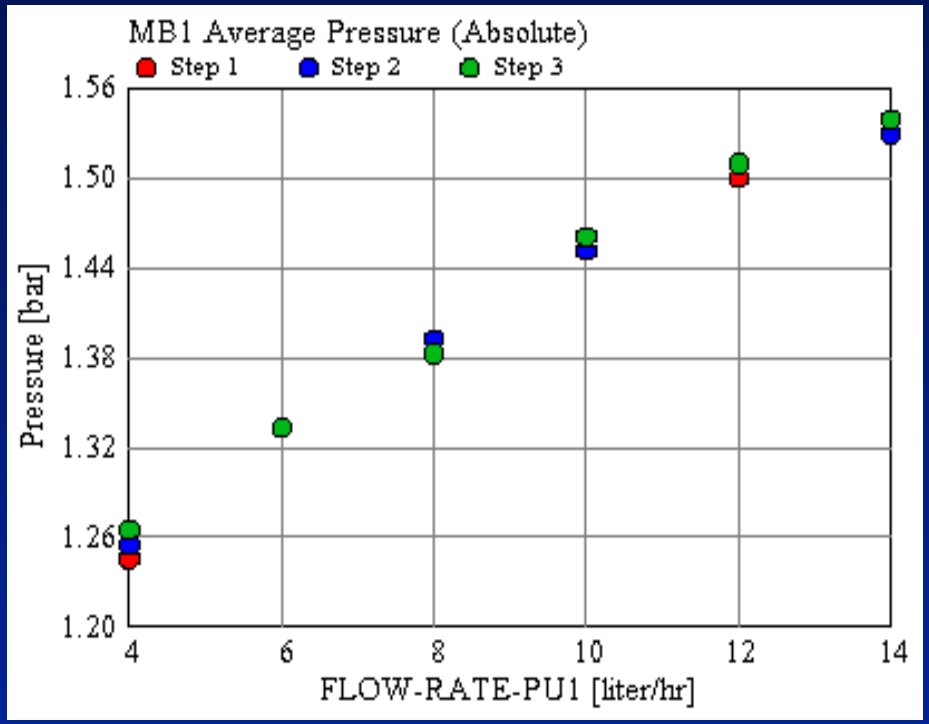
STEP 2



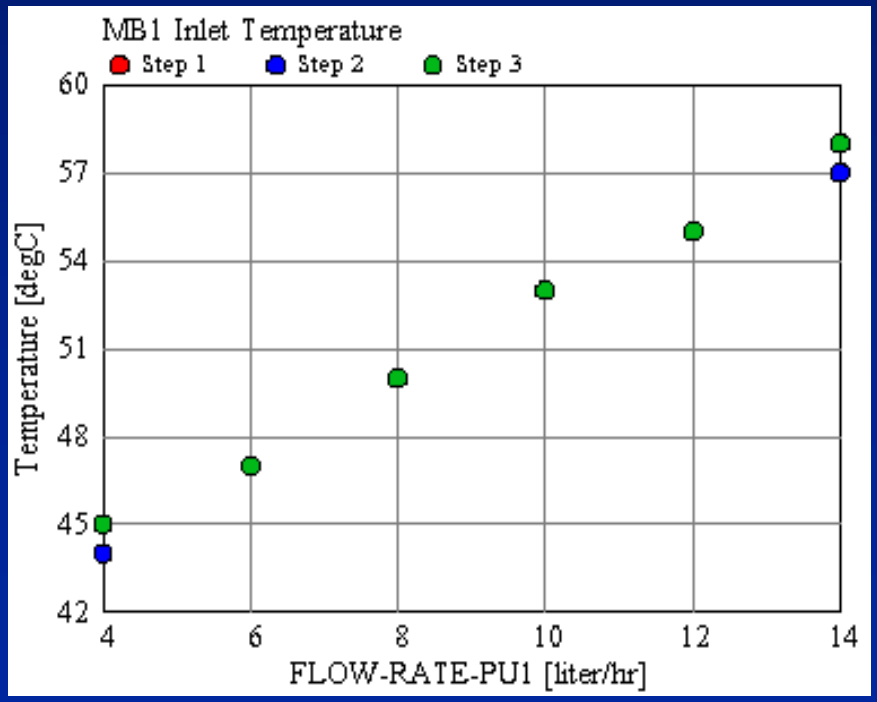
STEP 3



Experimental Results: MB1

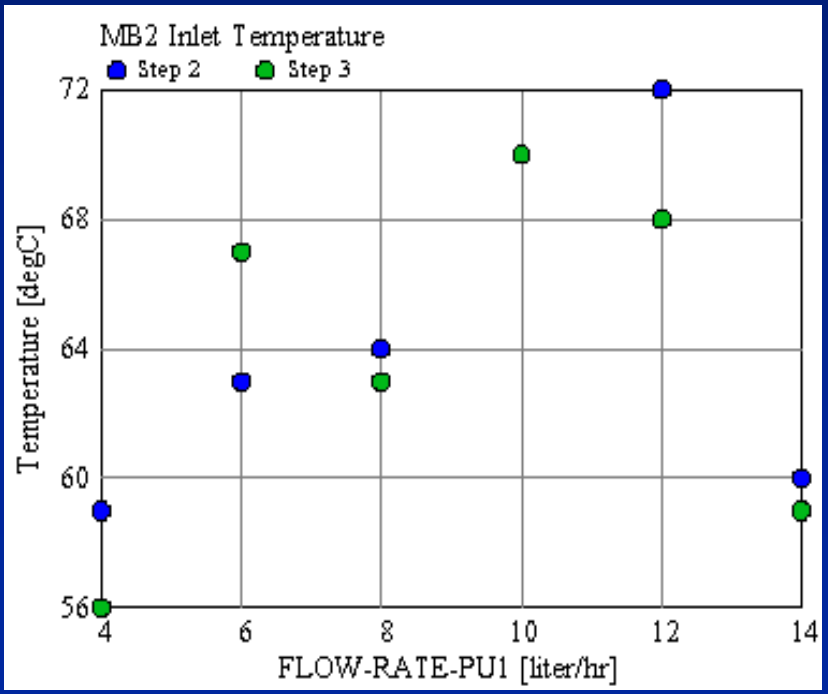


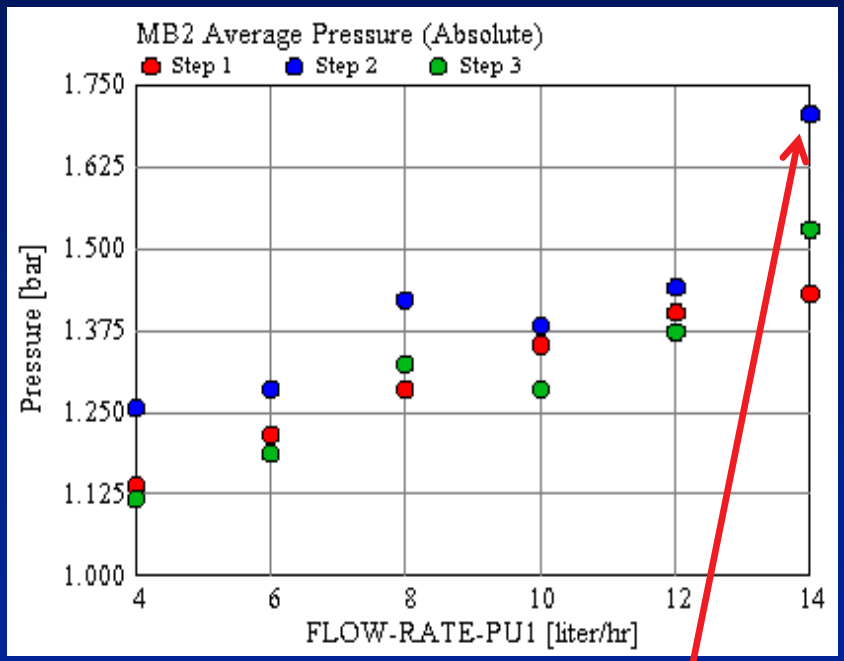
- **MB#1 P and T consistent for all 3 steps**



Experimental Results: MB2

- **MB#2 P and T inconsistent between steps**
  - **Reason: Pump#2 flow rate and heater hard to control**

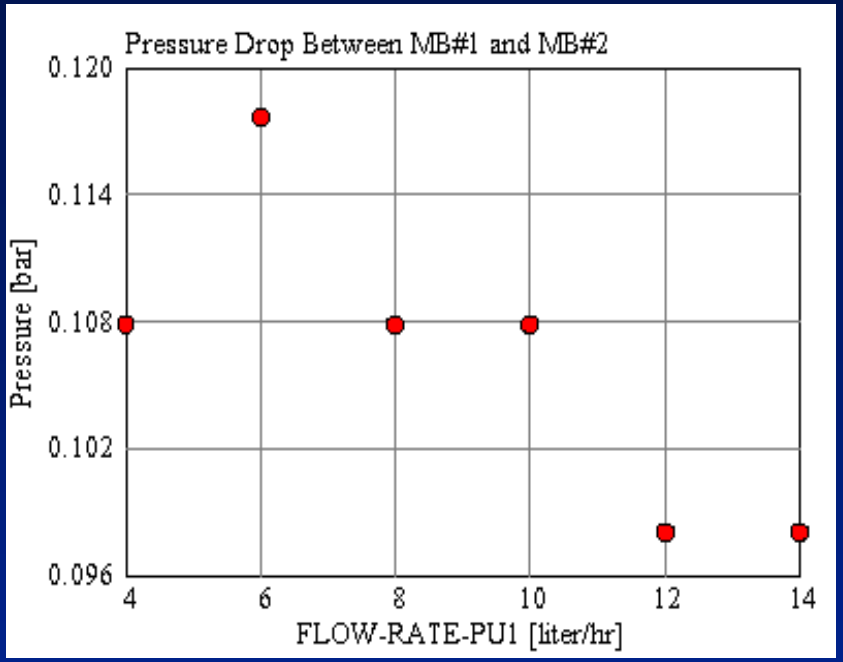


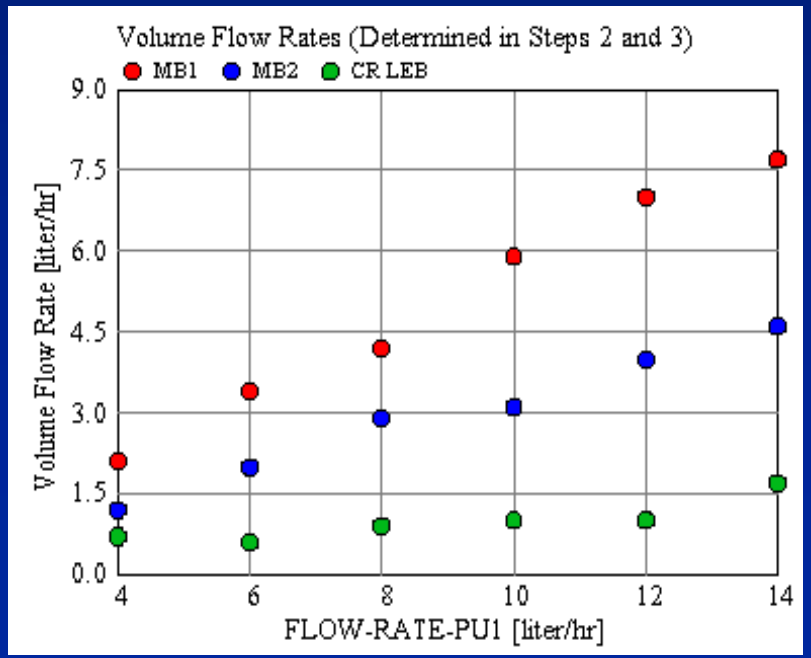


Pressure is high due to low inlet temperature (low temp = higher viscosity = higher pressure for a given flow rate)

Experimental Results

- ΔP ~ constant vs. total pump flow rate for baseline case (Step 1)
  - Theory predicts $\Delta P \sim Q^2$





- Flow rates determined in steps 2 and 3
- $Q_{MB\#1} > Q_{MB\#2}$
  - Reasons:
    - MB#1 clearance > MB#2 clearance
    - MB#1 pressure > MB#2 pressure

General Model Setup: Step 1

Orifice models restriction between web drillings

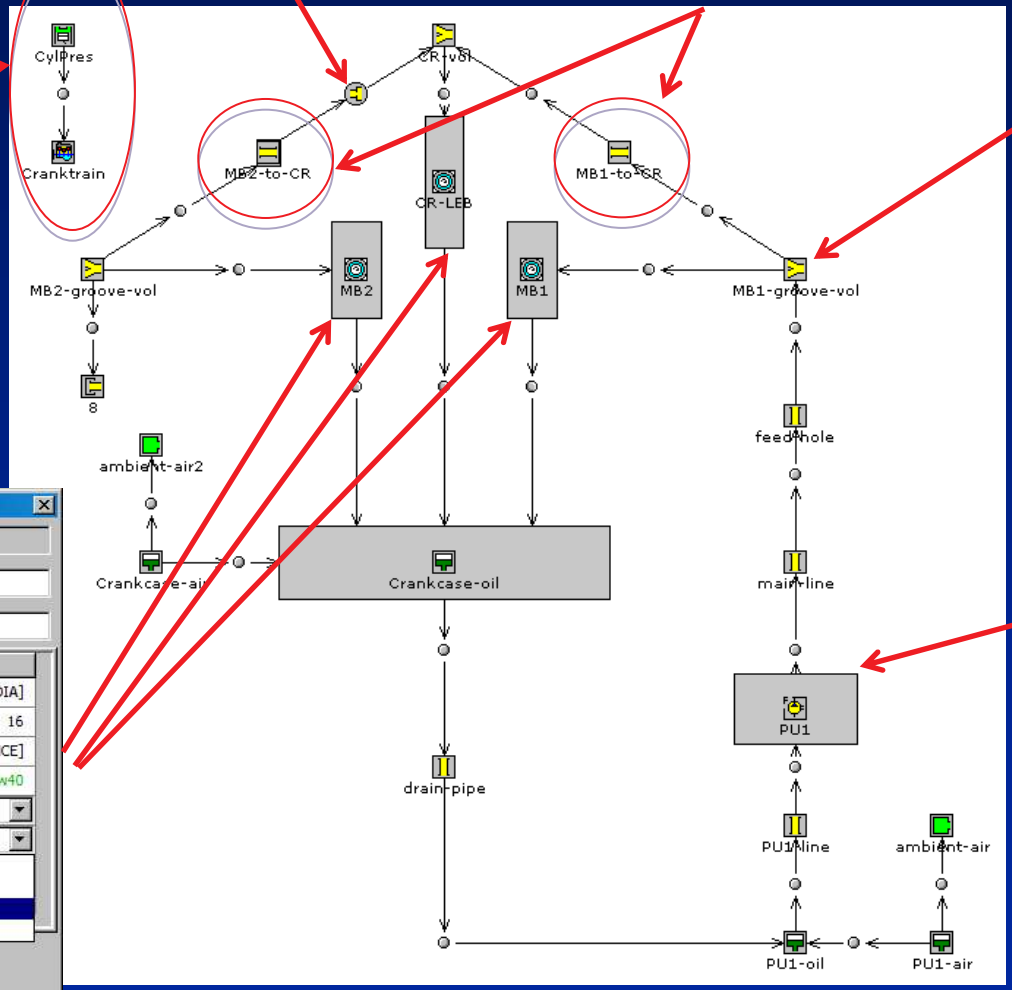
Web drillings account for centrifugal acceleration

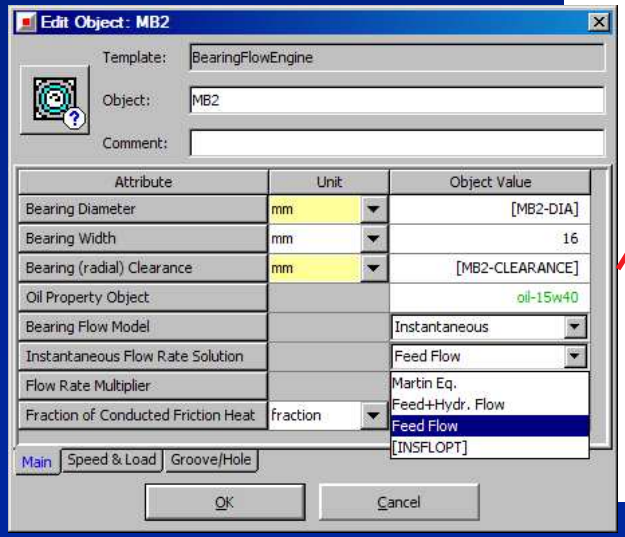
Bearing loads automatically calculated from cylinder pressure and engine geometry/inertia

Main bearing groove volume

Bearing info defined in the BearingFlowEngine object

Pump imposes flow rate





Model Setup: Steps 2 and 3

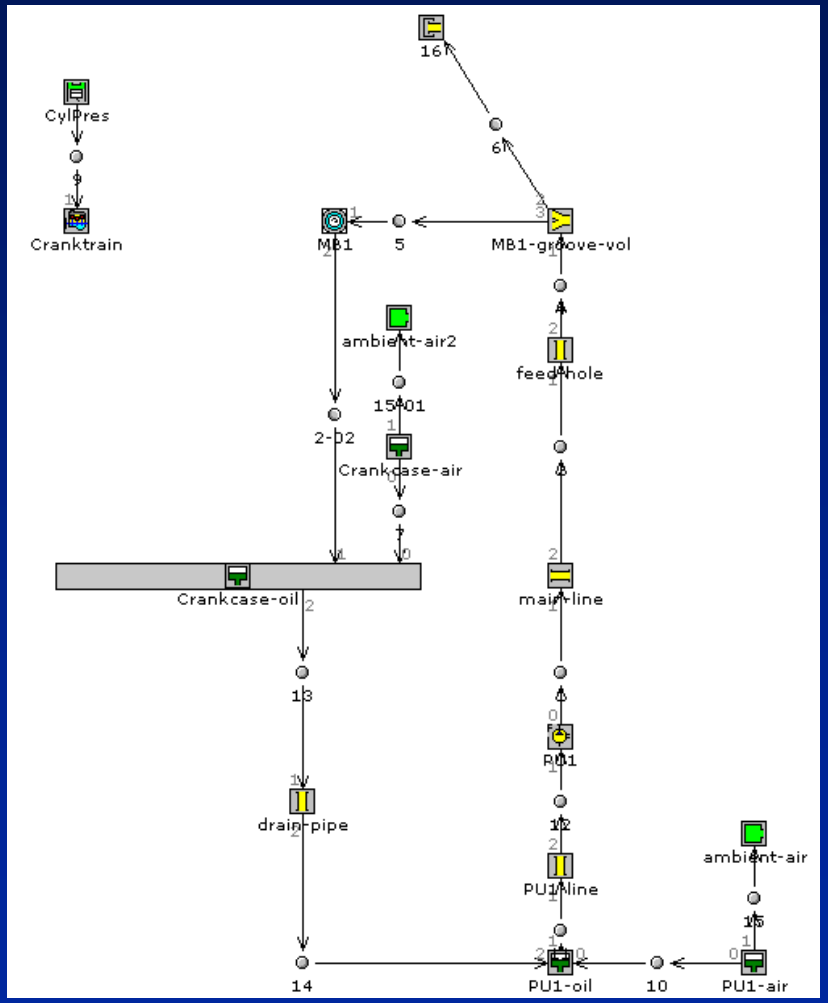
Experiment:

- Flow rate was tuned to match pressure in MB1 of baseline case
- Temperature of fluid was tuned to match baseline case

Model:

- Pump flow rate and temperature of MB1 are imposed based on experiment
  - Pressure in MB1 predicted

* Same procedure done for MB2

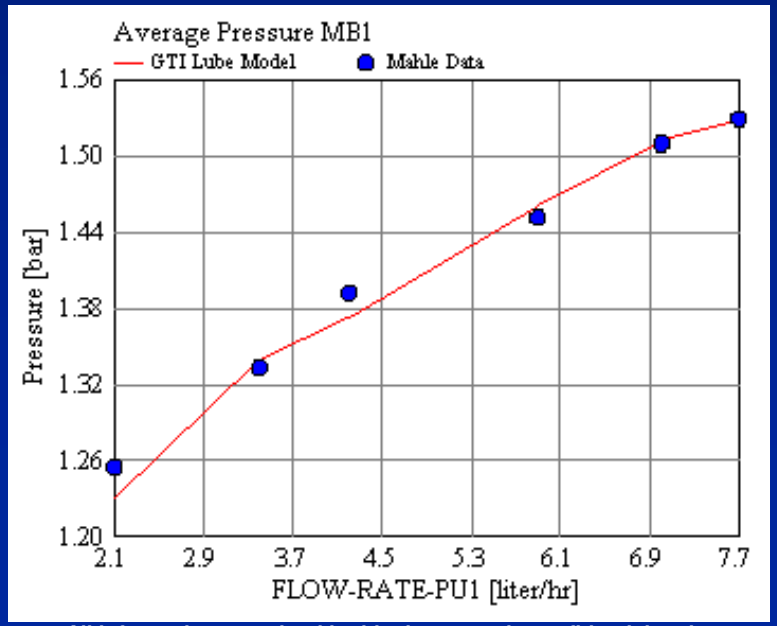


Model Results: Steps 2 and 3

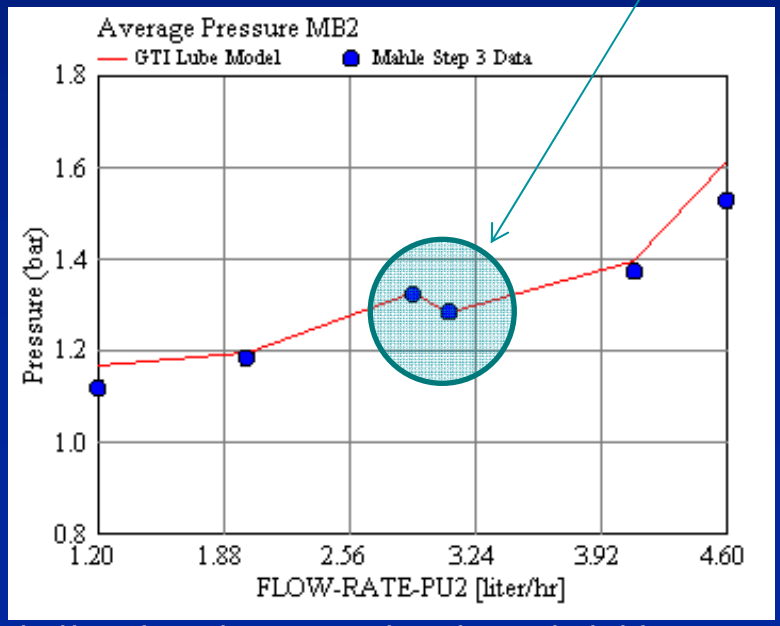
- Cycle averaged pressure in main bearings vs. flow rate provided by the pump
- Pressure in both bearings by themselves matches well to experimental data
- No tuning of the model required
  - bearing clearances within limits

Model captures experimental pressure drop due to temperature increase (see temp data from previous slide)

MB1 Pressure

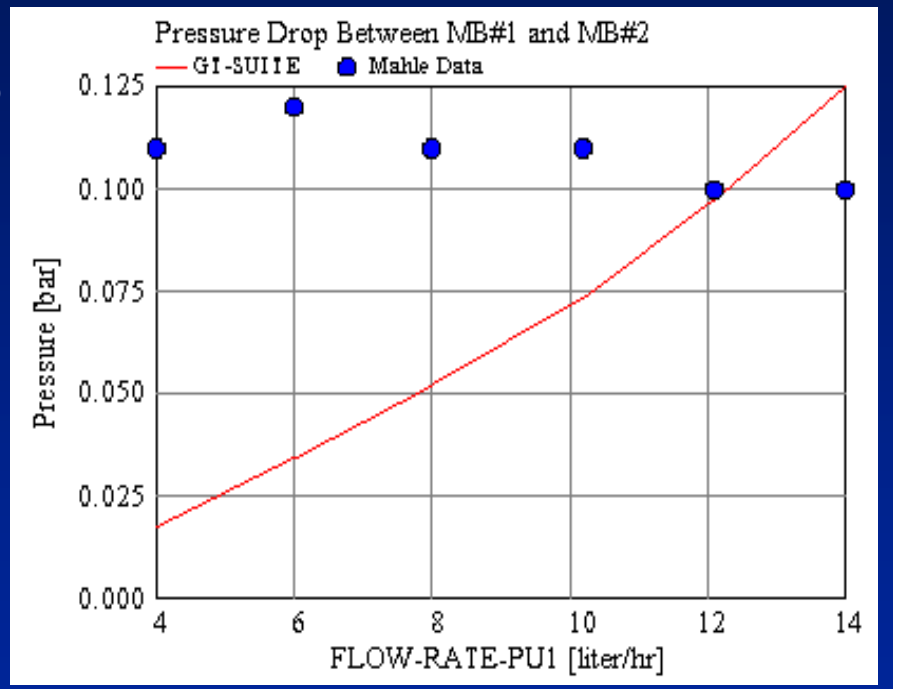


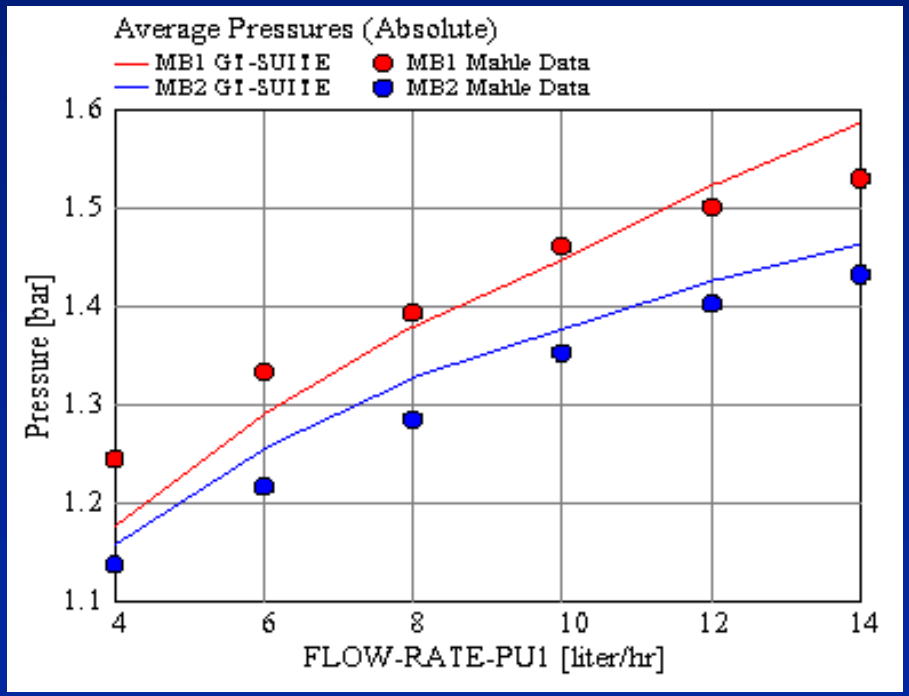
MB2 Pressure



Model Results: Step 1

- **Model does not predict a constant ΔP vs. Q relationship as seen in experiment**
  - **Is experimental data flawed?**
  - **Not modeling unknown phenomena?**

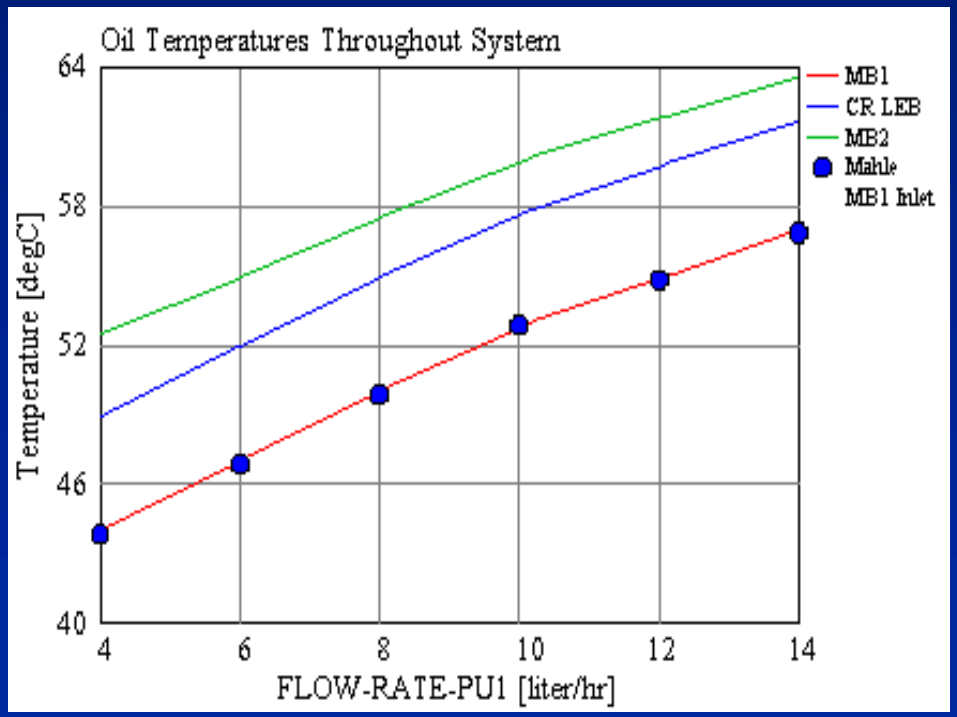


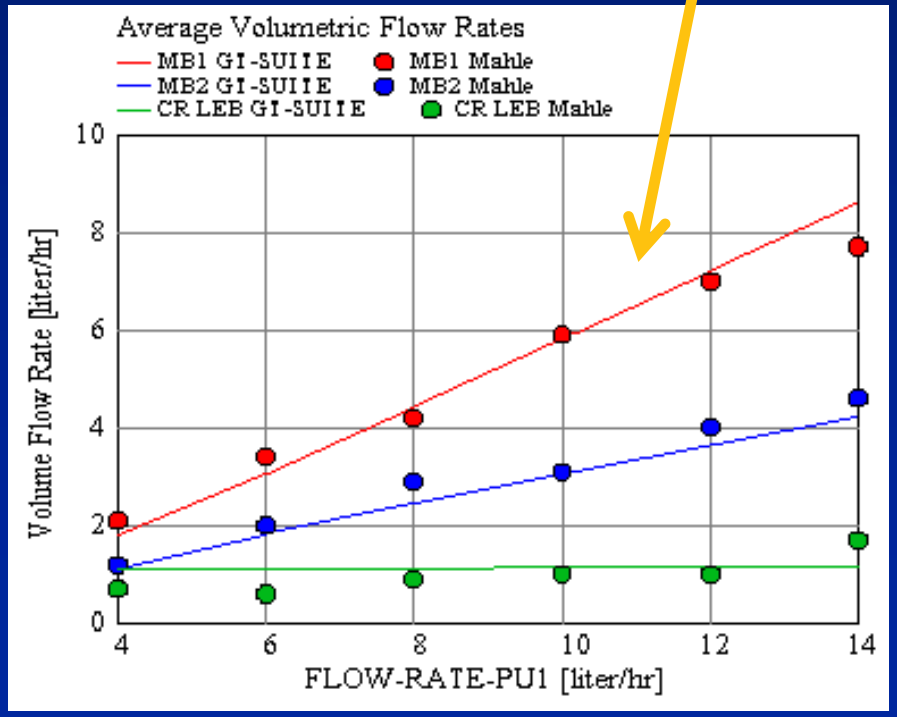


Model Results: Step 1

- Oil temp. at MB#2 and CR LEB not known experimentally in Step 1
  - estimated in model based on bearing wall temps ($T_{MB2} > T_{MB1}$)
- Only tuning parameters were:
  - Temp. at MB#2 and CR LEB (see chart)
  - Restriction dia. between web drillings (0.7mm)

Flow rate distribution matches well





Summary

Main Findings

- Main bearing pressure vs. flow rate through each bearing by itself correlates well to experimental data
- Model does not predict constant ΔP vs. Q
  - Either flawed data or not modeling certain physics

Future Work

- Investigate system instantaneous pressure pulsations
- Further validation through projects with Mahle and other customers