Two-Stroke Reed FSI Modeling and Validation

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Agenda

1. Overview
2. Converge CFD Model Setup
3. Experimental Data
4. CFD Results and Validation
5. Future Work

Agenda

1. Overview
   - Background
   - Motivation
   - Approach
2. Converge CFD Model
3. Experimental Validation Data
4. CFD Results
5. Future Work

Background

- Work is Based on 2-stroke DI V6 outboard engine
- Crankcase scavenged with intake reed valves
- Reed motion responds pressure fluctuations which come from many sources in the system
- Gas flow path is very interactive

Motivation

- Accurate in-cylinder gas exchange and trapping predictions
- Current crankcase modeling techniques are dependent on experimental data
  - Opt 1: Pressure boundary condition to model filling of crankcase
  - Opt 2: Reset crankcase pressure at assumed reed closure and drive flow via piston motion
- **Predictive air induction model in Converge that is interactive with entire system**

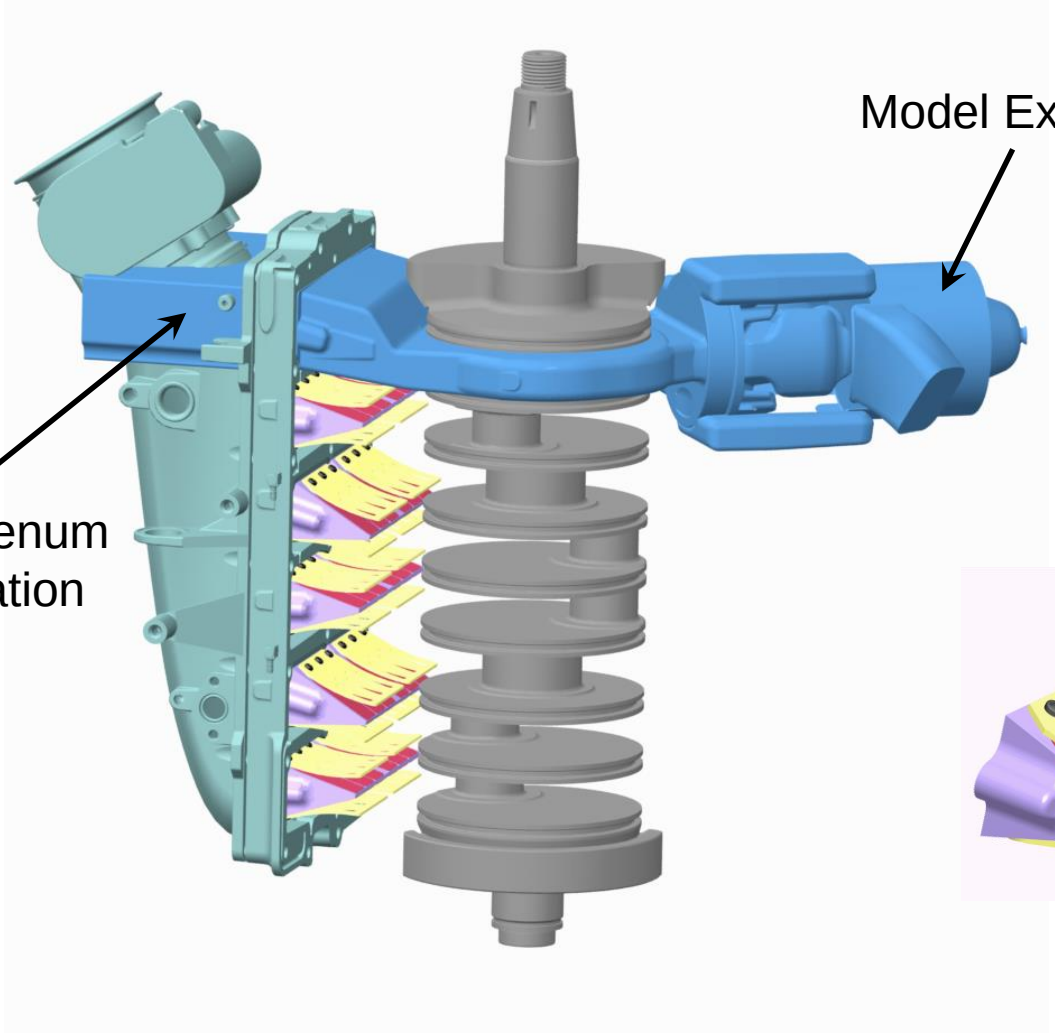
Approach

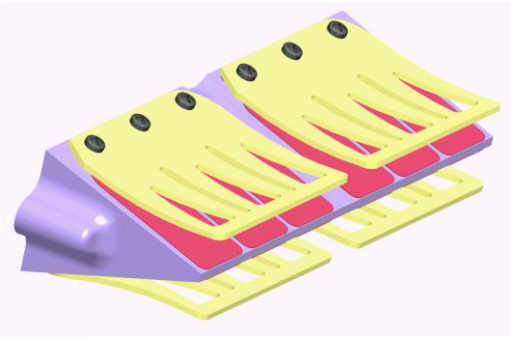
- Model the crankcase filling process
- Implement a reed motion UDF into Converge
- Run model at 3 WOT operating conditions (5500, 3000 and 2000 rpm) - based on reed motion regime
- Obtain experimental validation data from fired engine
- Compare results

Agenda

1. Overview
2. Converge CFD Model
   - Setup
   - UDF
   - Resources
3. Experimental Validation Data
4. CFD Results
5. Future Work

Model Geometry

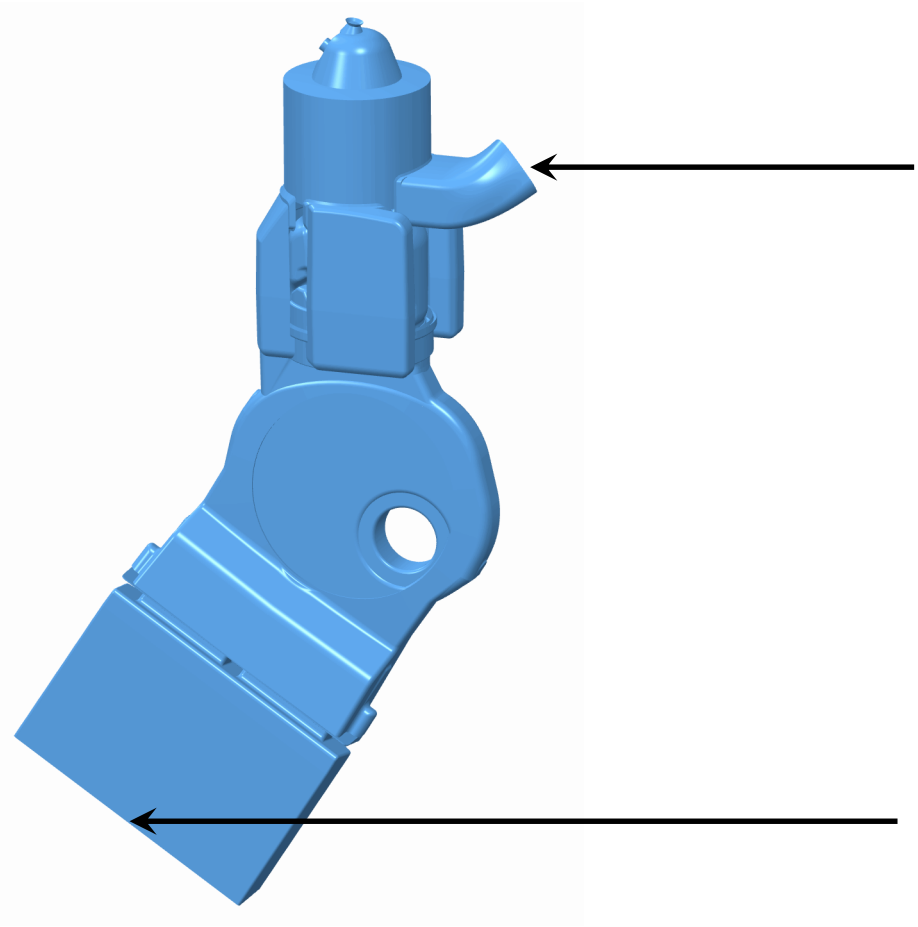


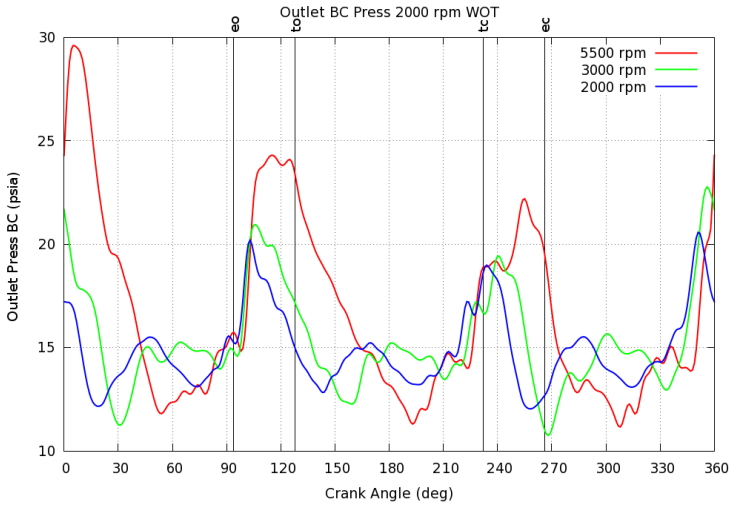


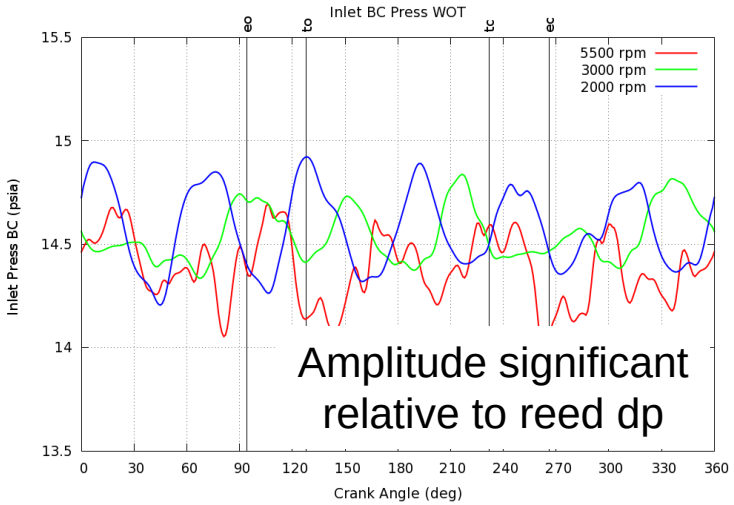
Reed Assembly

Modeling single cylinder of V6 engine

Pressure Boundary Conditions



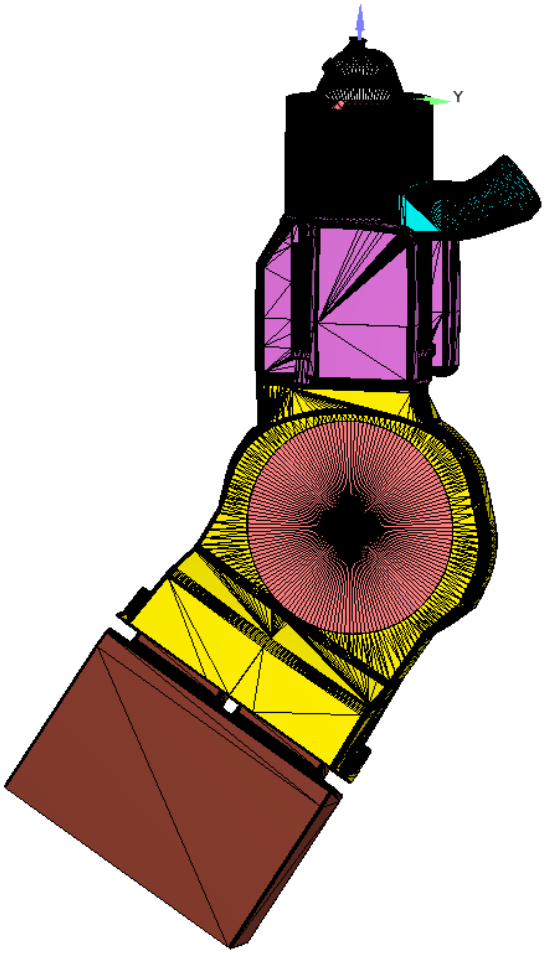




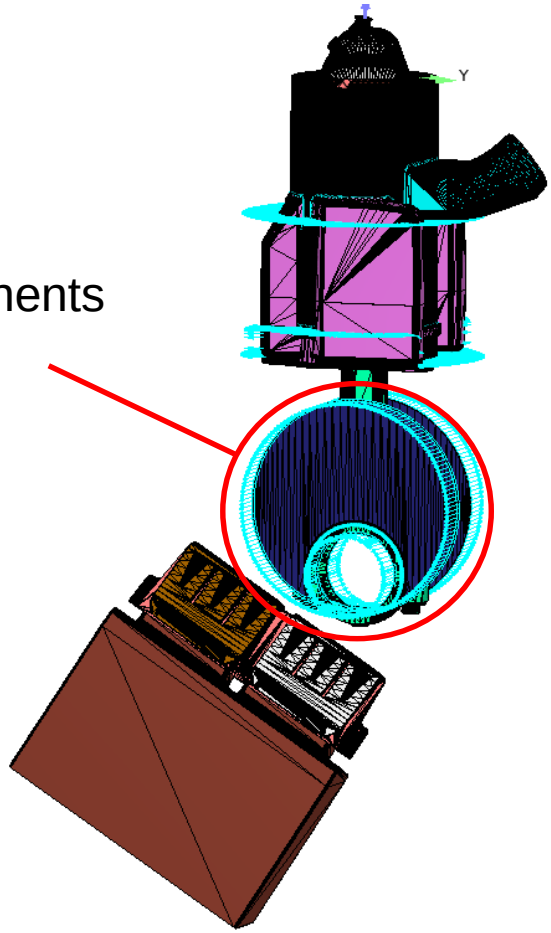
Pressure boundary conditions are still dependent on experimental data

Could couple to 1D gas dynamics code in future

Model Setup



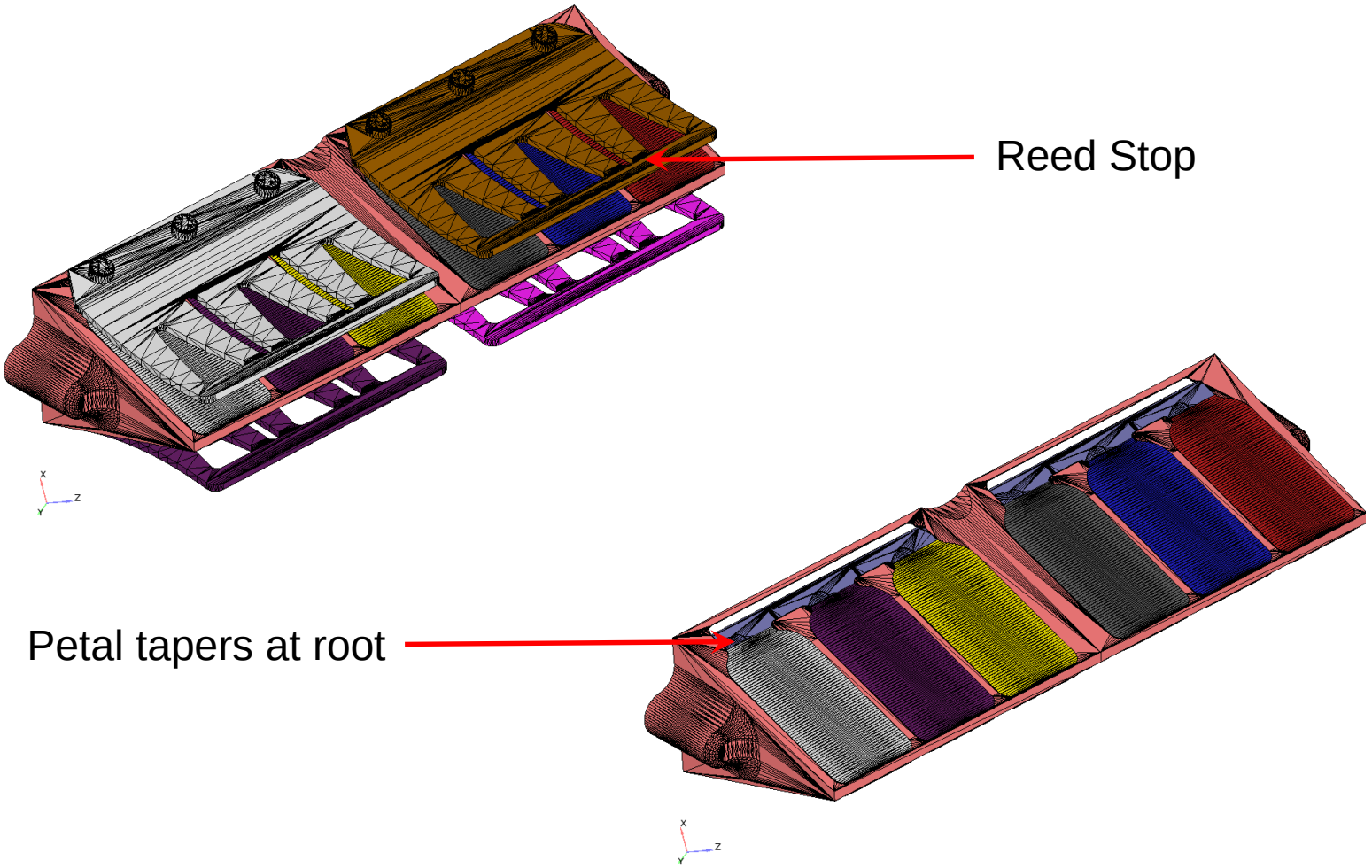
Moving Components
With seals



Full model with moving reeds, piston, conrod, and crankshaft

All runs include spray and combustion

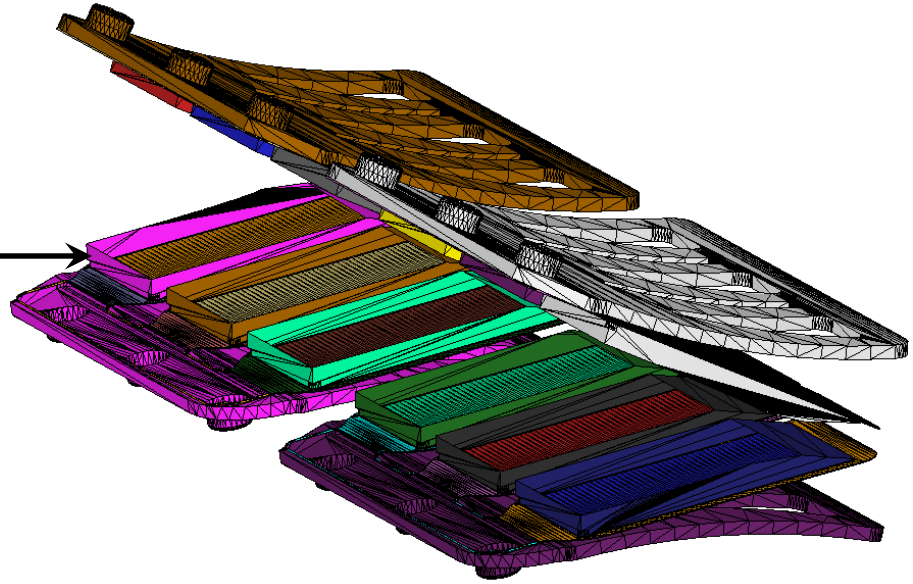
Model Setup

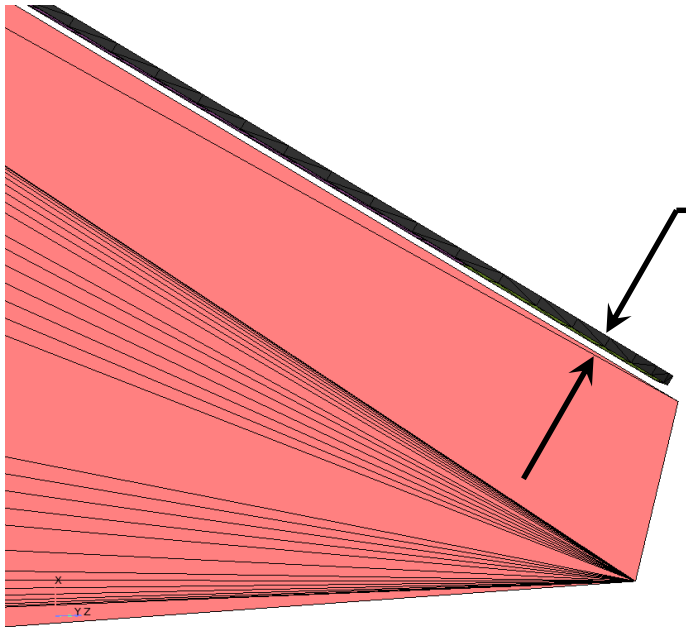


Each petal moves independently

Model Setup

Regions upstream of each reed
Close off based on min lift

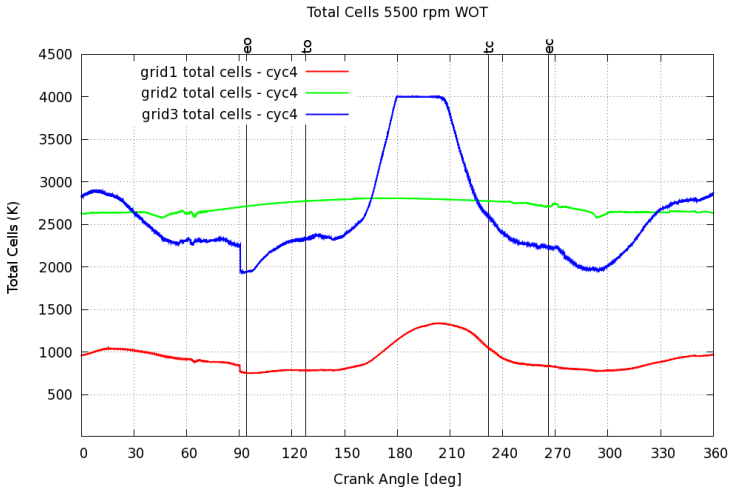


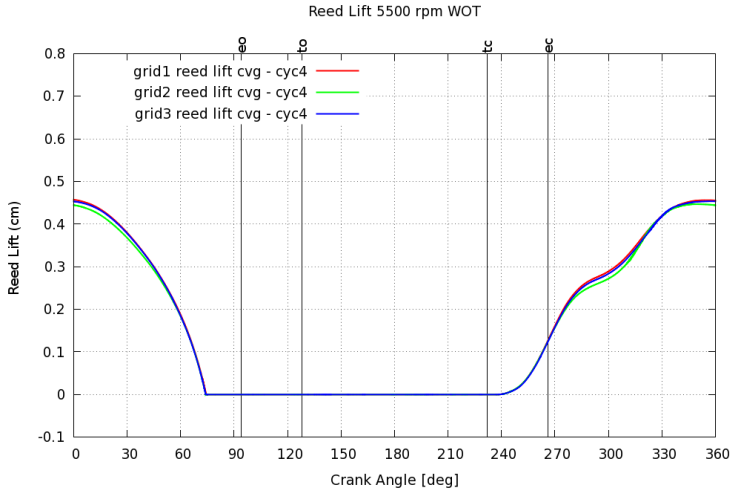


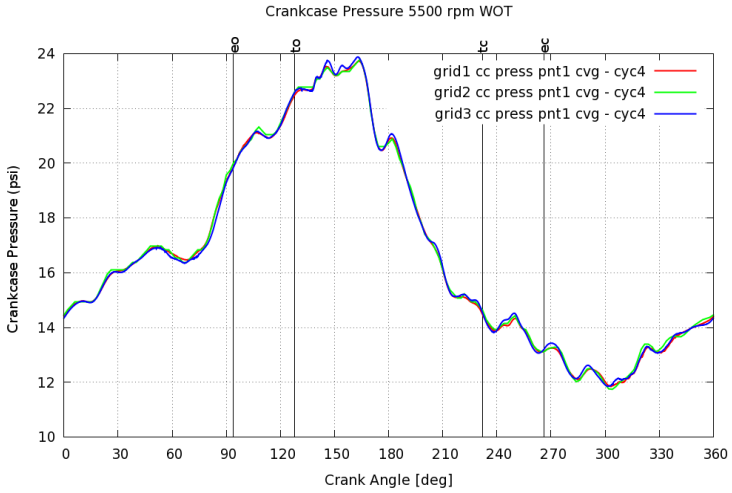
O.12 mm gap reed to block
To minimize cell paring

Mesh Strategy

Grid	Base (mm)	AMR (mm)	Reed (mm)	Max (M)
grid1	4	1	1	2.5
grid2	2	0.5	0.5	2.5
grid3	4	0.5	0.5	4

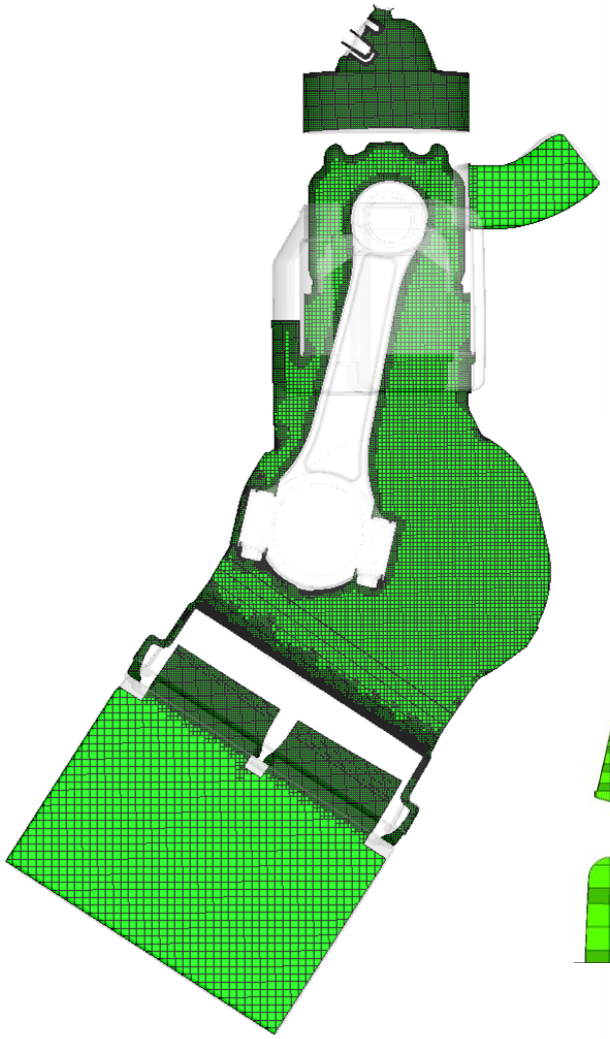




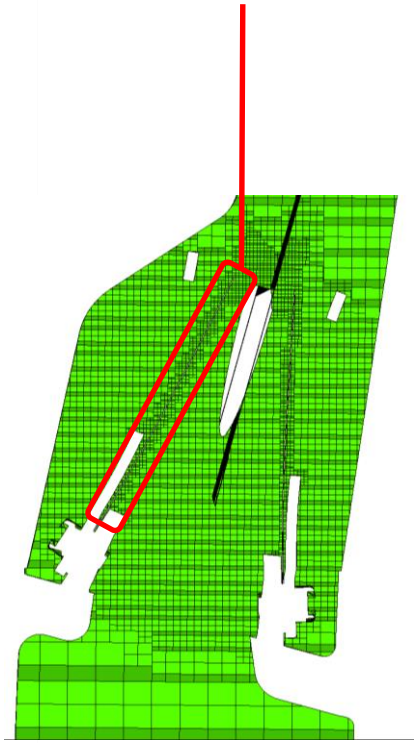


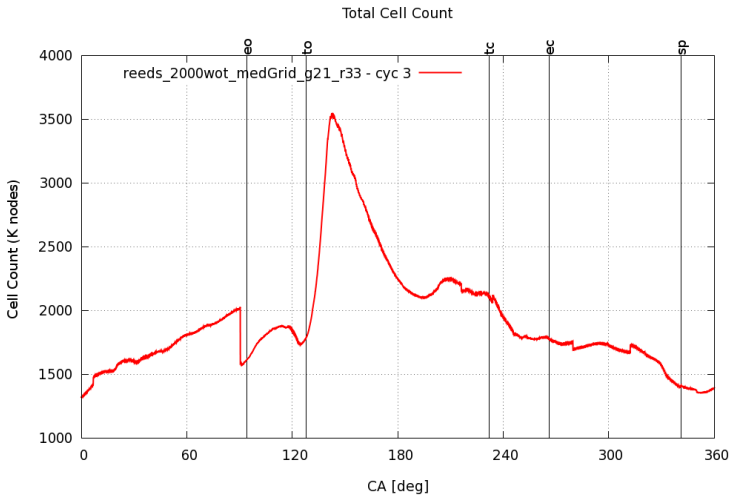
Grid3 used in this study

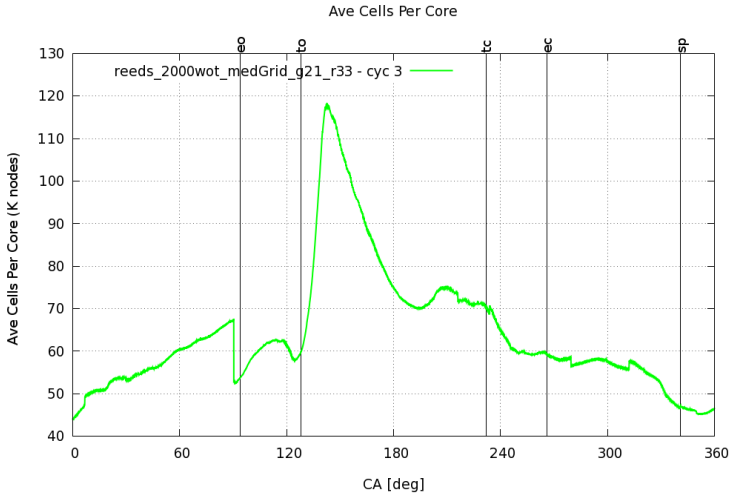
Mesh



0.5mm at reed



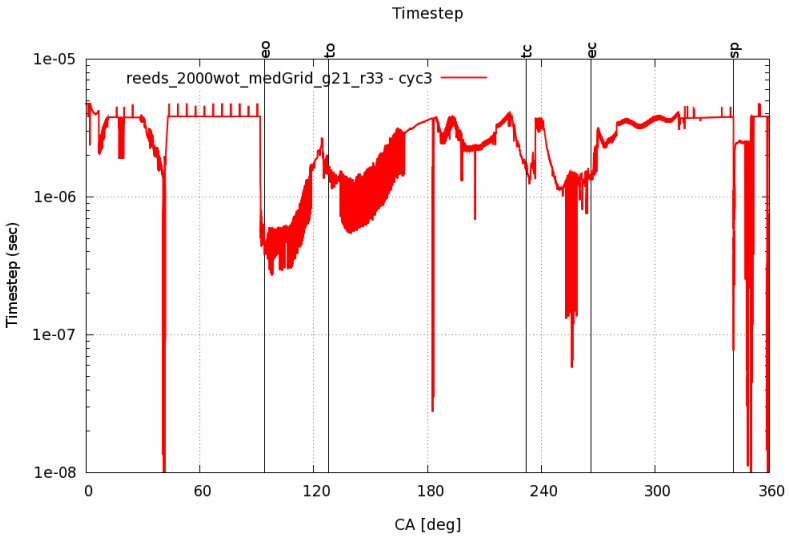




Meshing strategy 3 allowed for head room for AMR

Model Resources

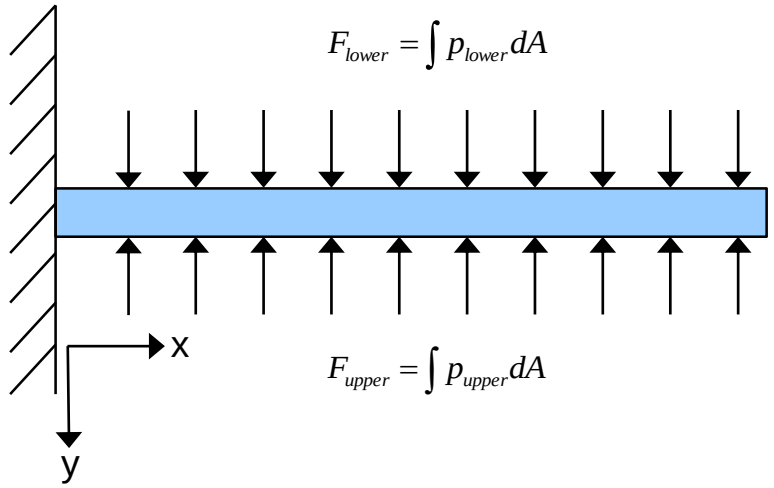
- Run time
  - Run time = 4 days/cycle
  - Min number of cycles = 3
  - 12 days total run time
- Computer Resourses
  - 32 cores (2 nodes x 16 cores)
  - 3.3 GHz Xeon E5-2667v2
  - 128 Gb memory per node
  - 1 GbE interconnect



Significant run time for industry project use

Reed Deflection Model

- Reed Motion is controlled by UDF
- Model is based on original work by G.P. Blair as adapted by Y. Zeng
- Reed is modeled as free vibration of cantilevered beam



$$EI\frac{\partial^4 y}{\partial x^4} + \rho A\frac{\partial^2 y}{\partial t^2} = 0 \qquad y = \phi(x)e^{i\omega t}$$

Zeng, Y., Strauss, S., et al, Predicting and Optimizing Two-Stroke Engine Performance Using Multidimensional CFD, SAE 2004-32-0039
Fleck, R., Blair, G. P., and Houston R. A. R., An Improved Model for Predicting Reed Valve Behavior in Two-Stoke Cycle Engine, SAE 871654
Hinds, E. T., and Blair, G. P. , Unsteady Gas Flow through Reed Valve Induction Systems, SAE 780766

Relatively simple model with proven results

Reed Deflection Model

$$y = \cosh\lambda_i x - \cos\lambda_i x - \frac{\sinh\lambda_i l - \sin\lambda_i l}{\cosh\lambda_i l + \cos\lambda_i l}(\sinh\lambda_i x - \sin\lambda_i x)$$

$$y = \sum_{i=1}^{r} \phi_i(x) \cdot z_i(t)$$

Damping factor – tunable variable

$$\frac{d^2 z_i}{dt^2} + 2\zeta_i \omega_i \frac{dz_i}{dt} + \omega_i^2 z_i = F_i$$

$$\omega_i = (\lambda_i l)^2 \sqrt{\frac{EI}{\rho A l^4}}$$

$\lambda_1 l$	$\lambda_2 l$	$\lambda_3 l$	$\lambda_4 l$	$\lambda_5 l$
1.875	4.694	7.855	10.996	14.137

Opportunities for additional tuning

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   - Reed lift
   - Crankcase pressure
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Validation Data

Reed Lift

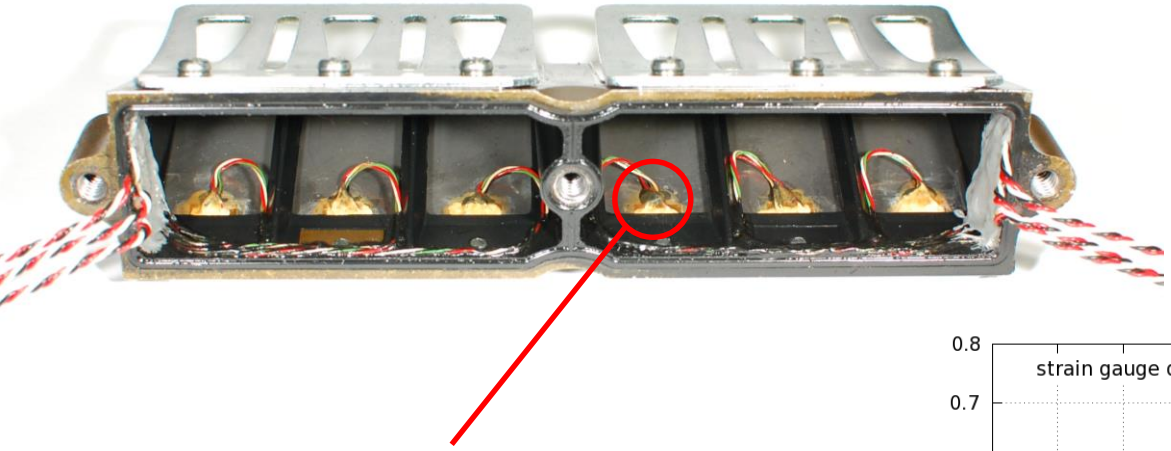
Strain Gauged Reeds

Optical Measurement

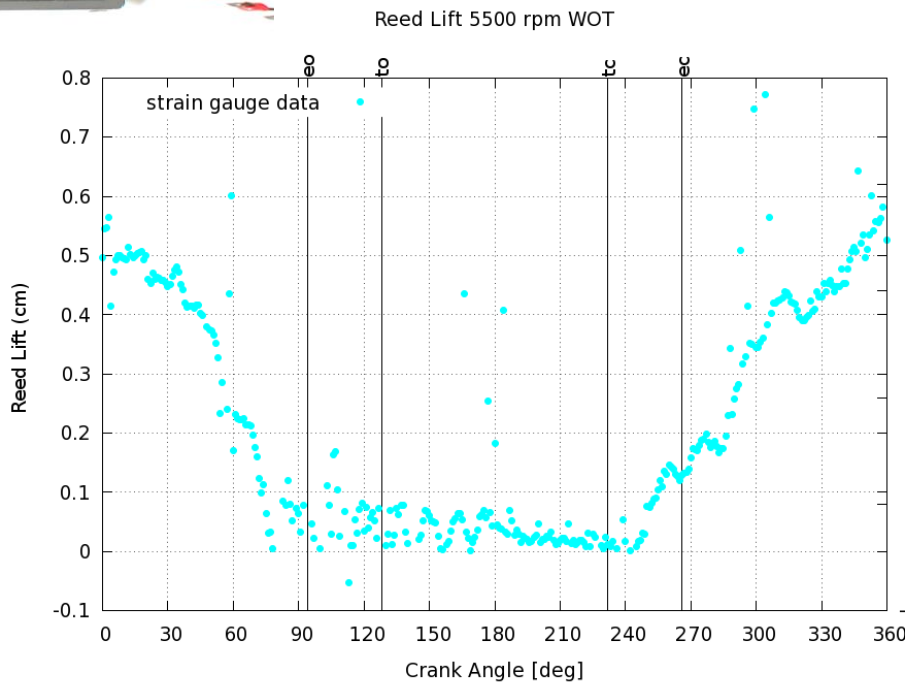
Crankcase Pressure

Reed lift measured by two techniques

Strain Gauged Reed Petals – Reed Lift Validation



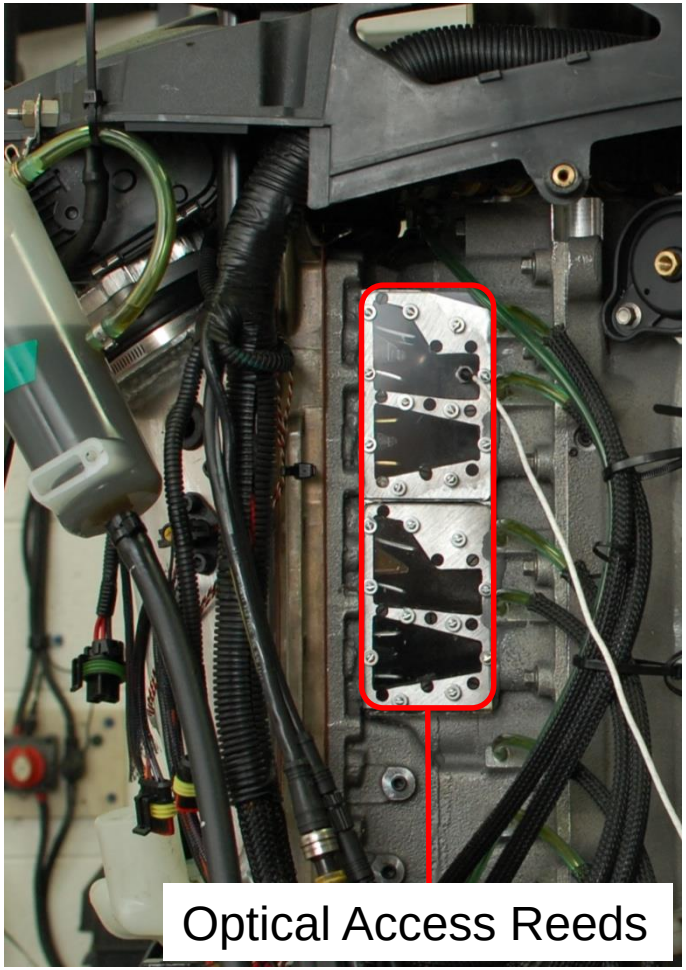
Strain gauge at root of petal

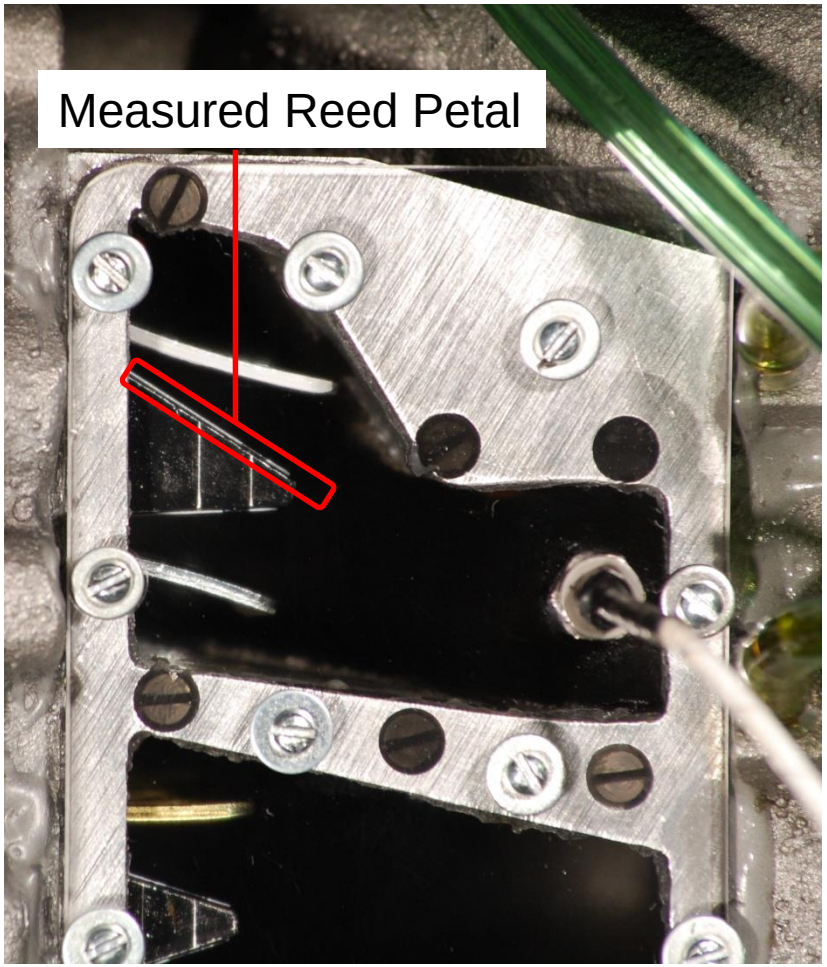


Each reed petal calibrated for static tip deflection

Higher order bending modes give false reading

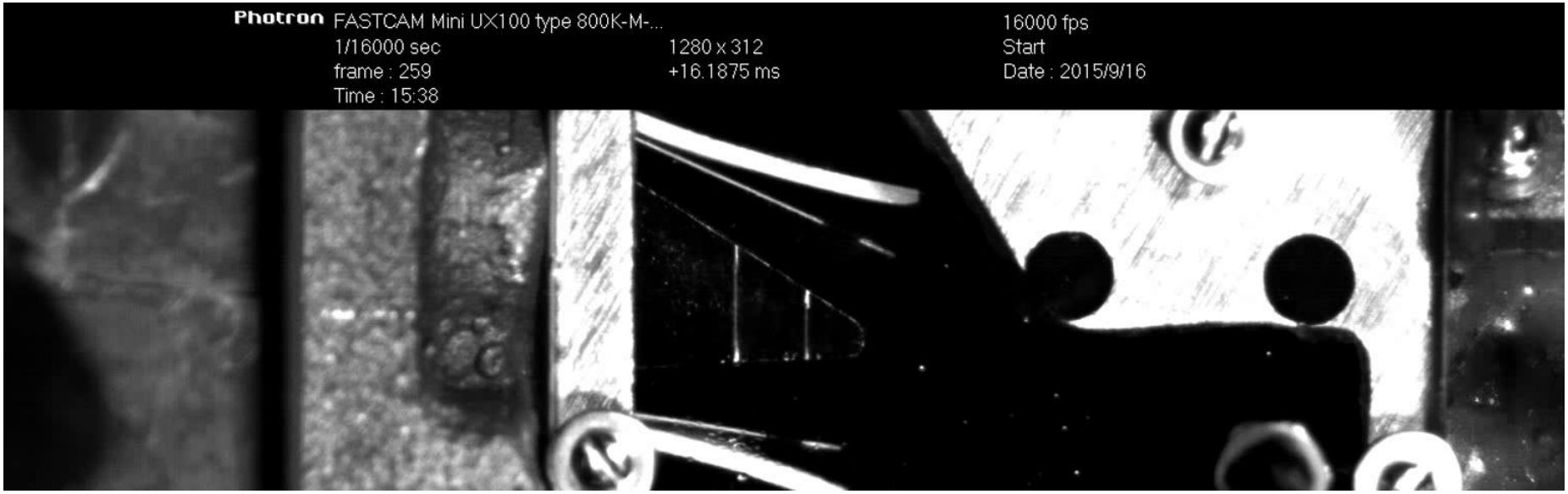
Experimental Setup – High Speed Reed Video





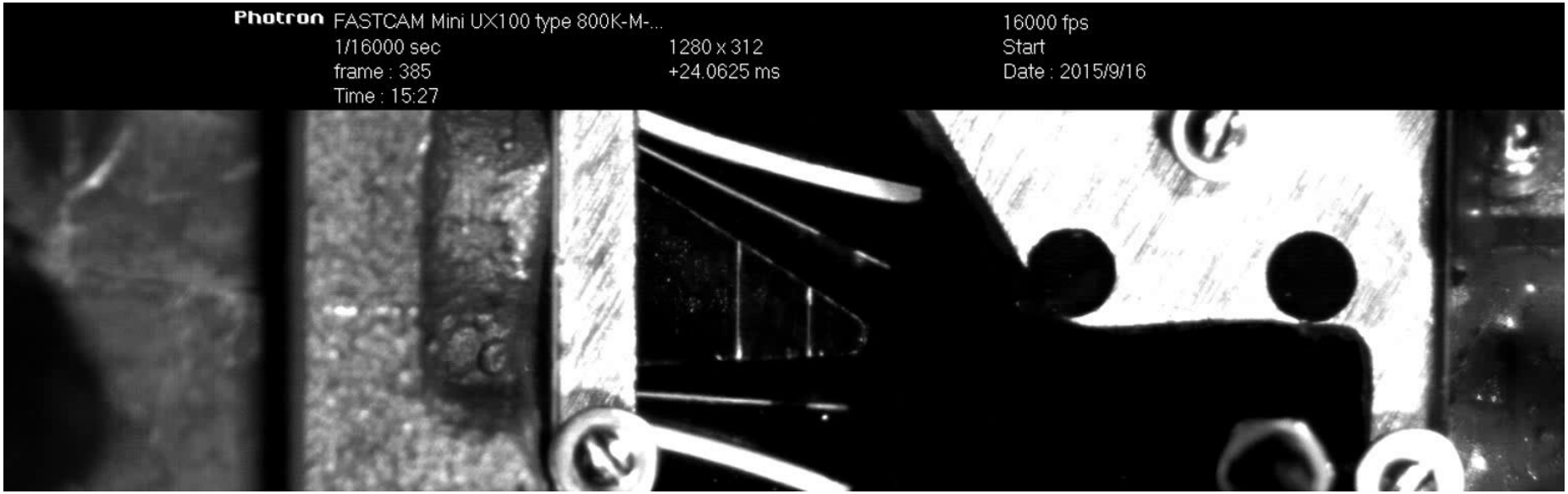
Challenging operating environment to make video

Reed Video – 5500 rpm



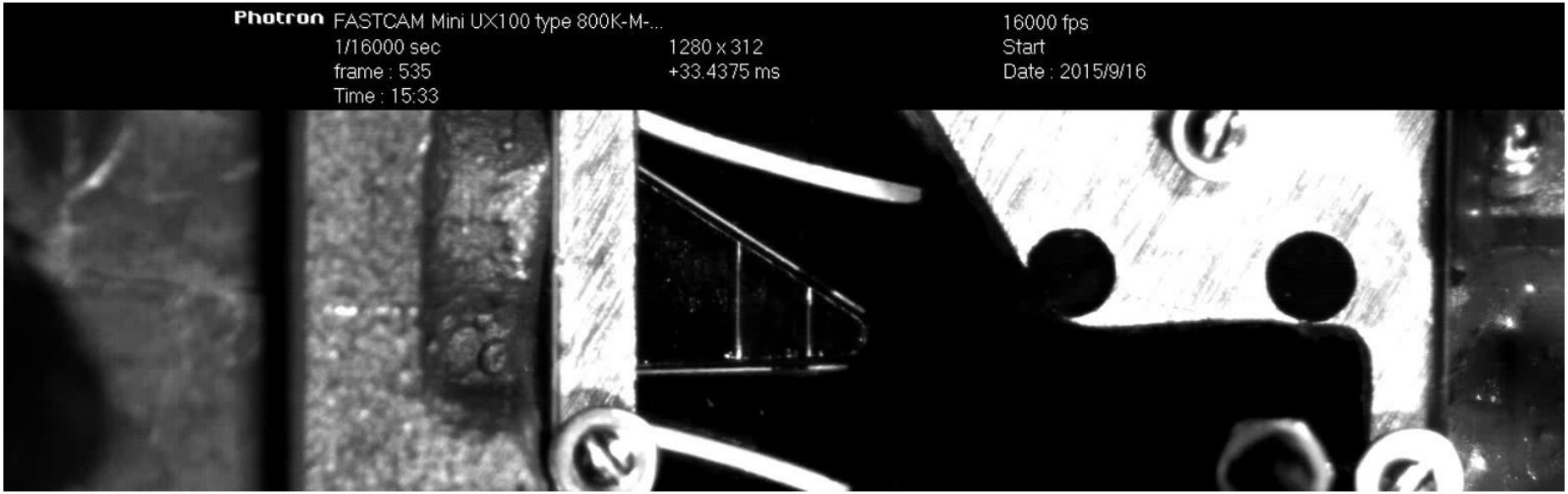
1 opening and close event per cycle

Reed Video – 3000 rpm



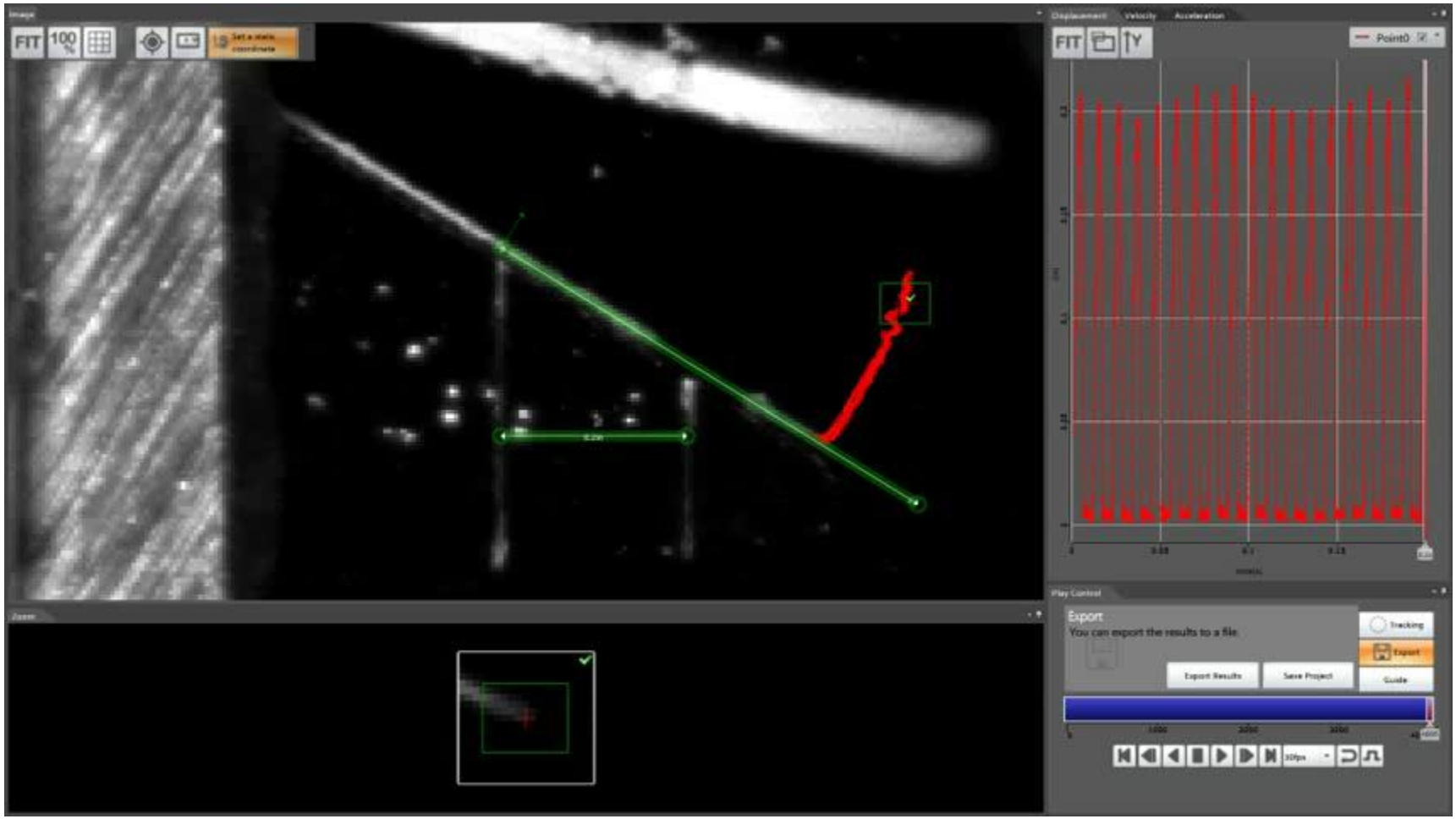
2 opening per cycle – partial close between

Reed Video – 2000 rpm



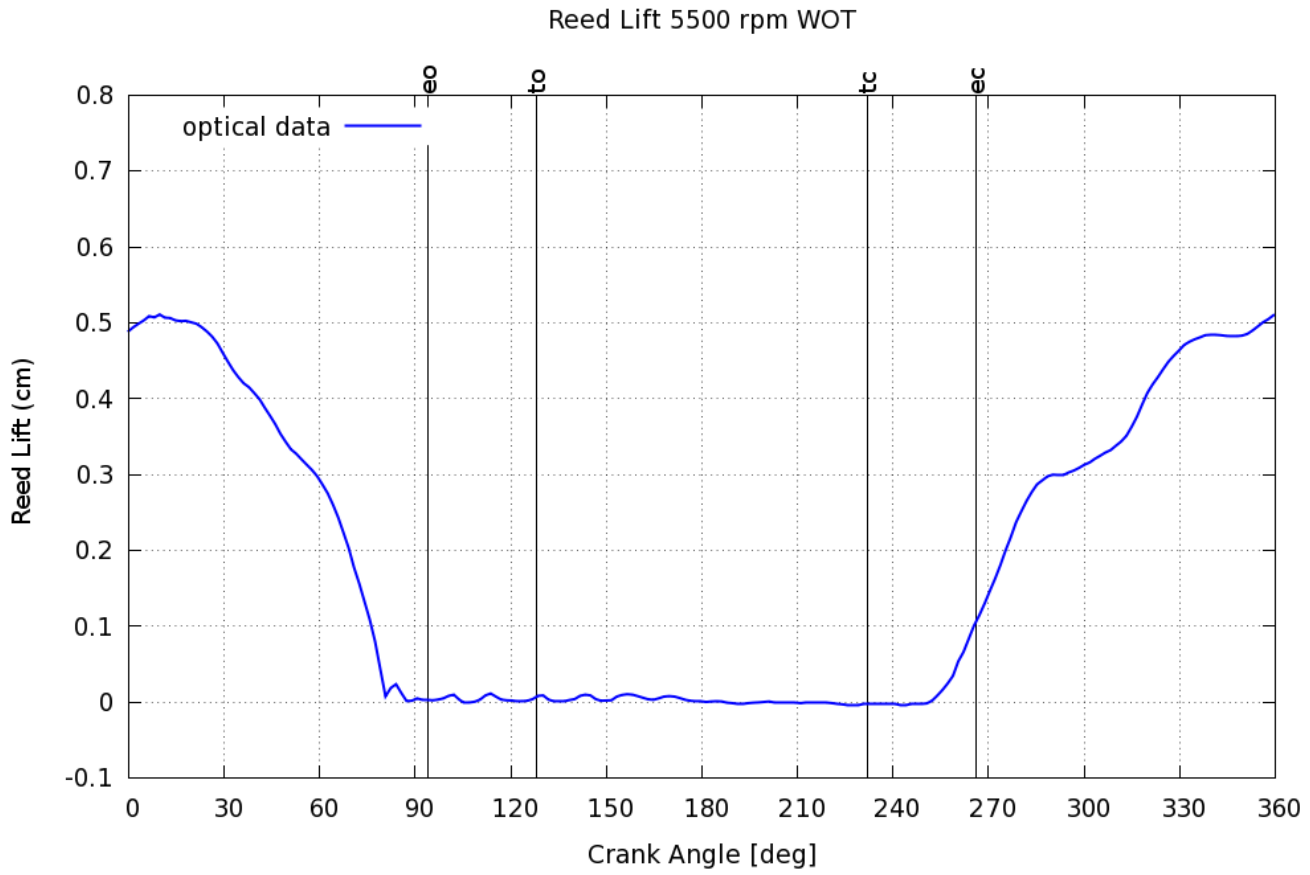
3 open and close events per cycle

Reed Tip Motion Tracking – 5500 rpm



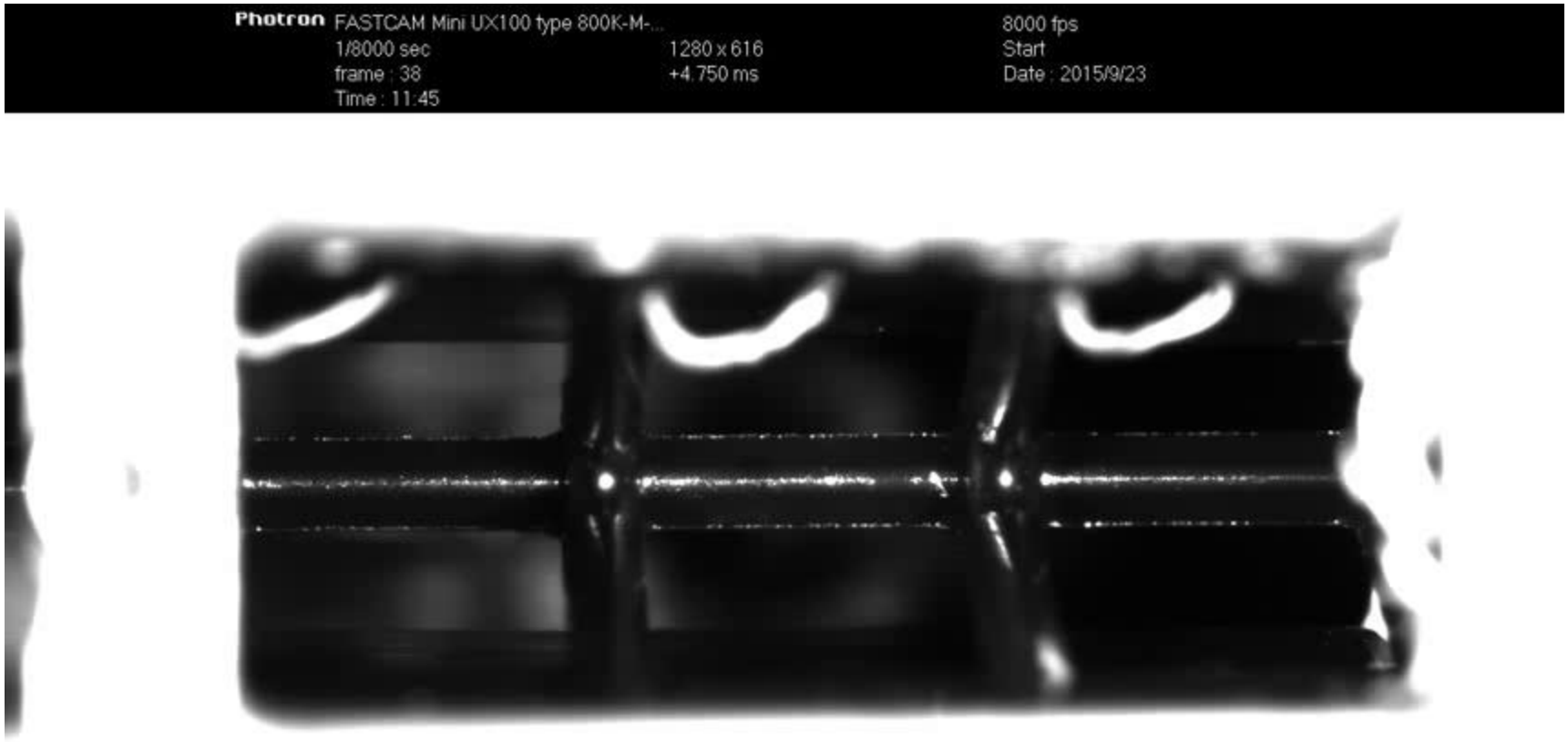
Good repeatability cycle to cycle

Reed Tip Motion Tracking – 5500 rpm



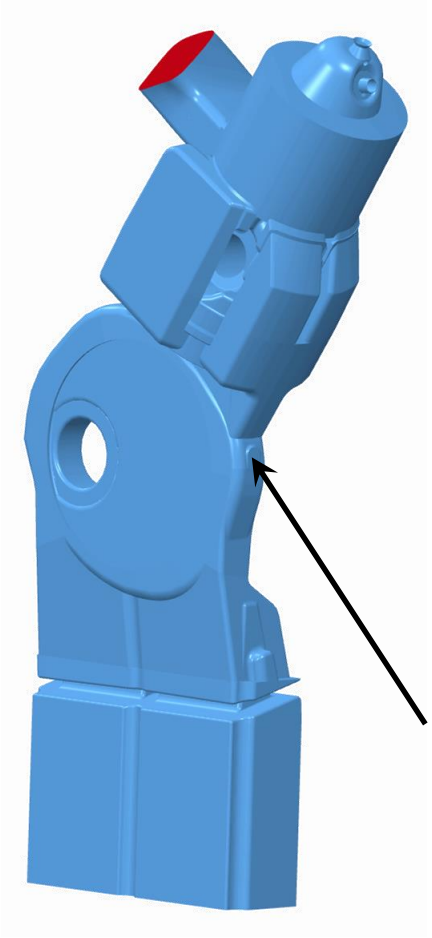
Low noise reed lift signal

Reed Video from Intake Side

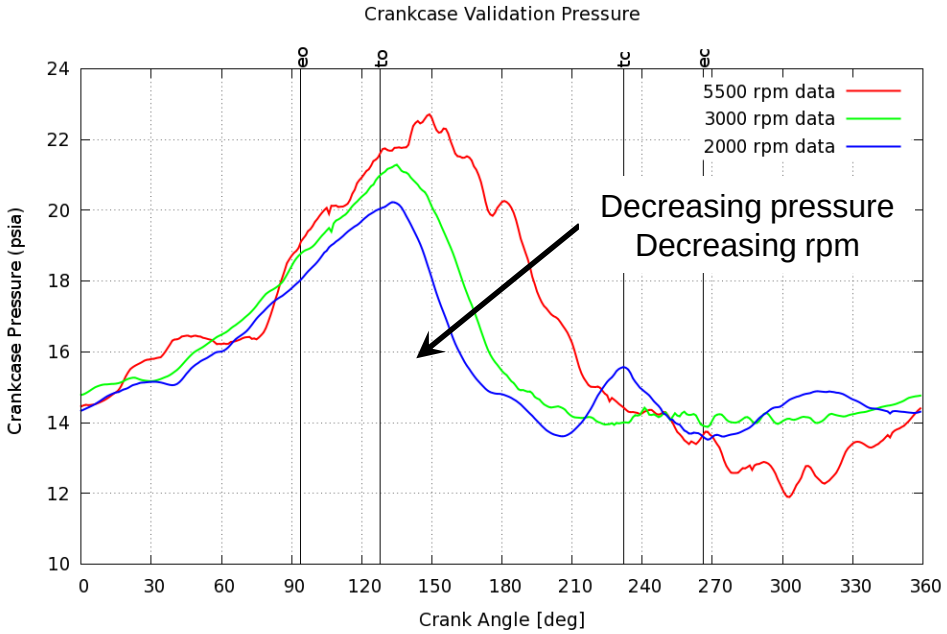


Strain gauges on top reed petals

Crankcase Validation Pressure



Crankcase Pressure
Measurement Location



Lower CC pressure at lower rpm = earlier reed opening

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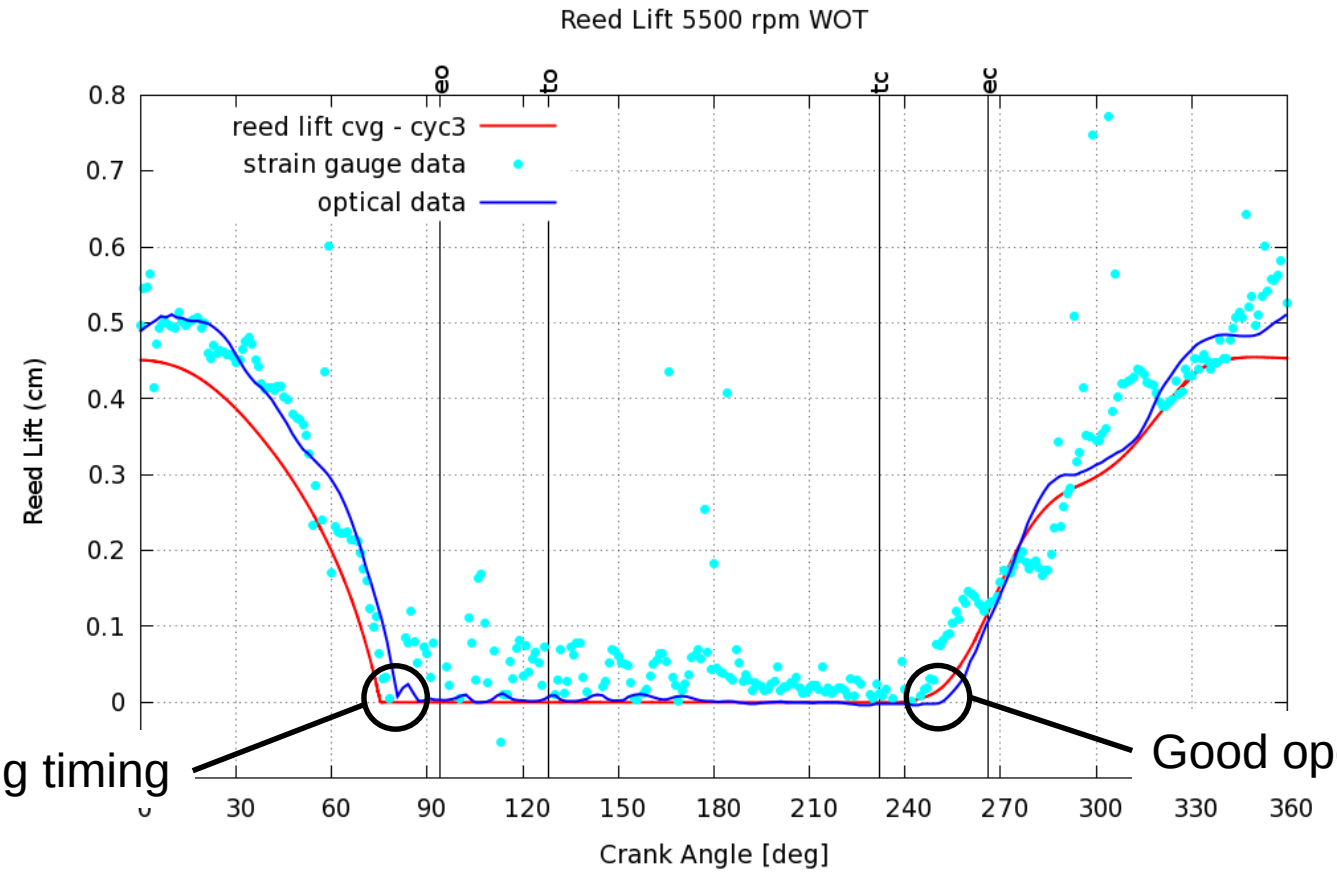
Reed Lift Validation – 5500 rpm

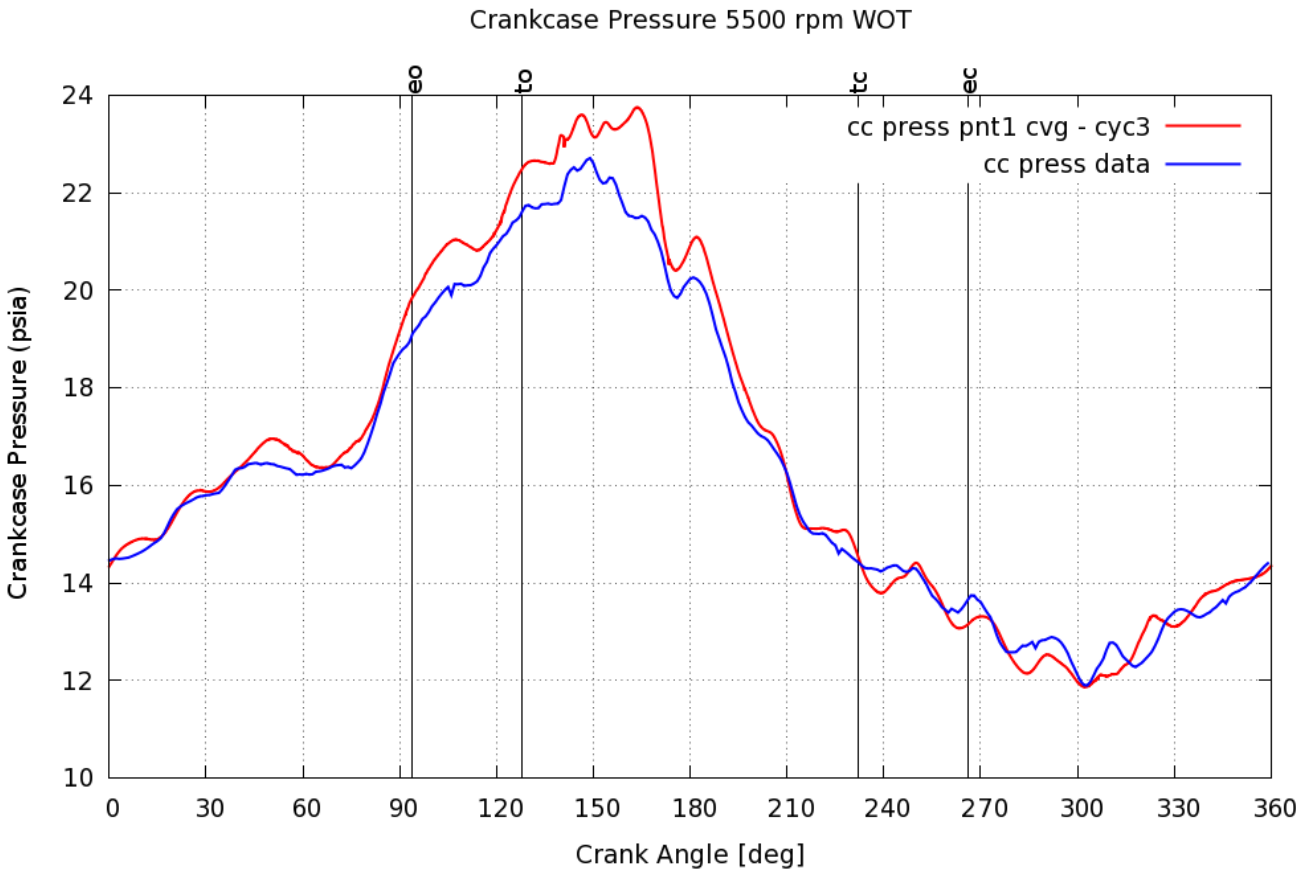


Good closing timing

Good opening timing

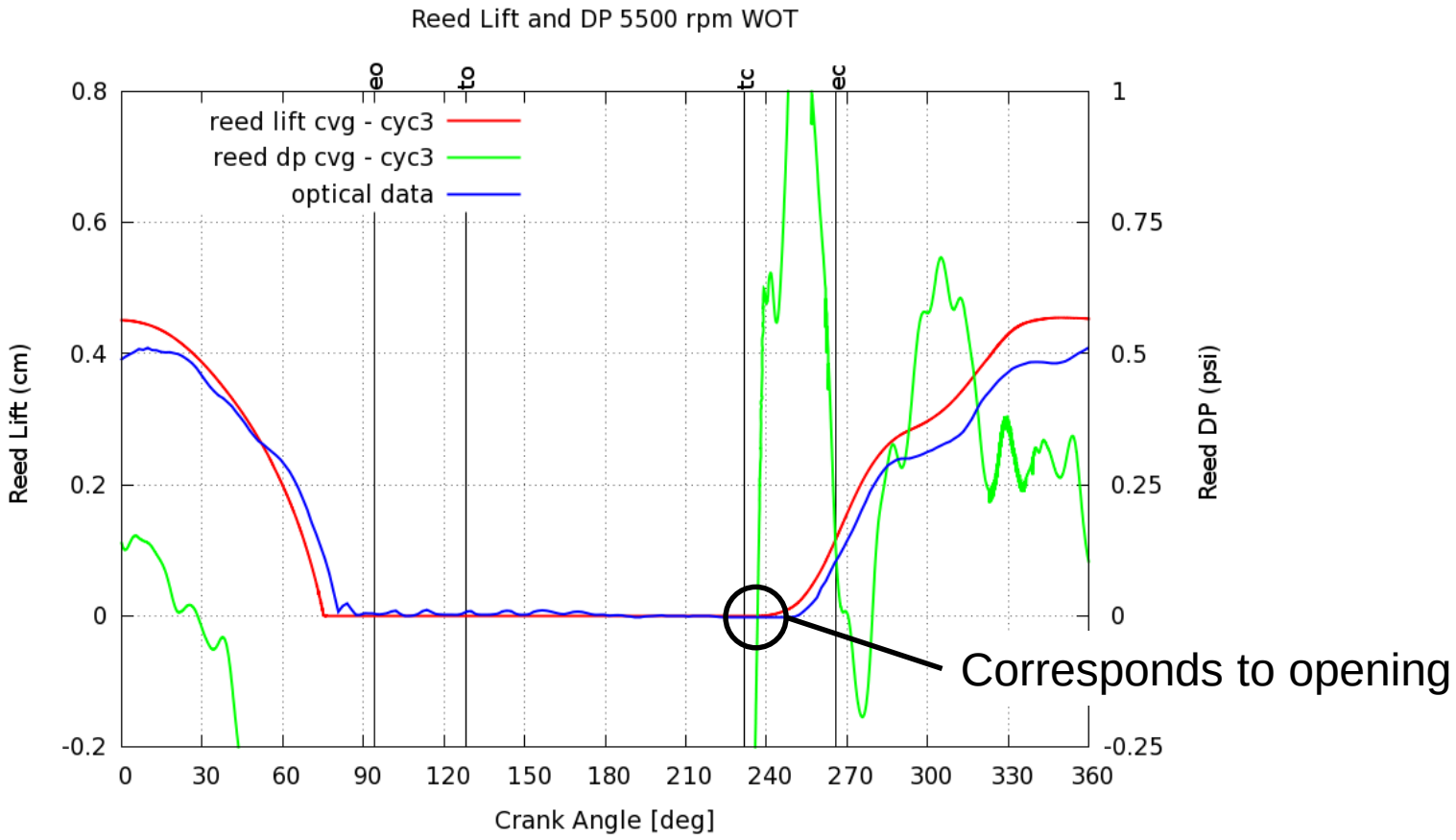
Good correlation in timing and magnitude to experimental data

Crankcase Pressure Validation – 5500 rpm



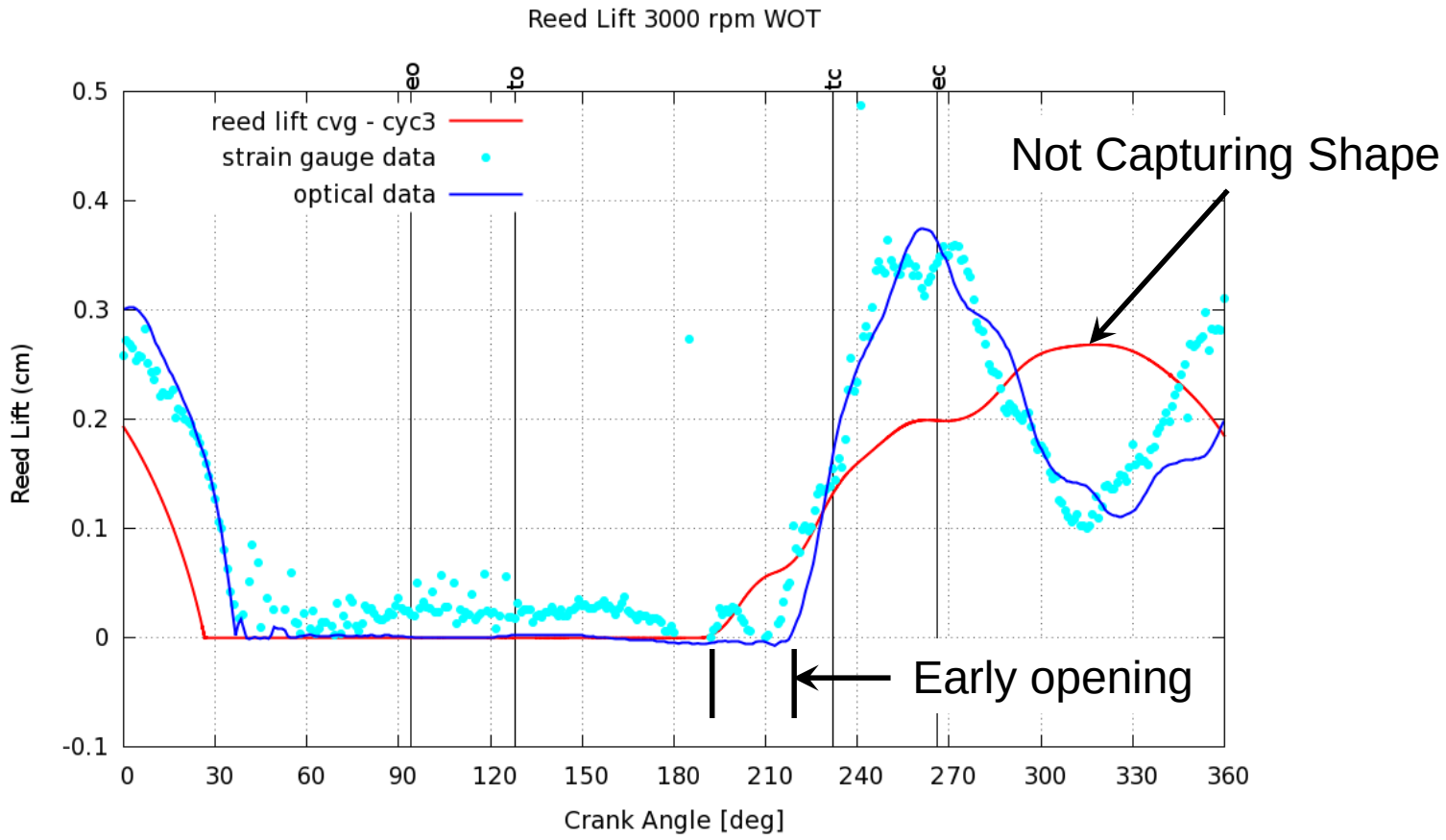
Good correlation to experimental data

Reed DP and Lift – 5500 rpm



Reed motion responds to DP sign change but not every inflection in curve

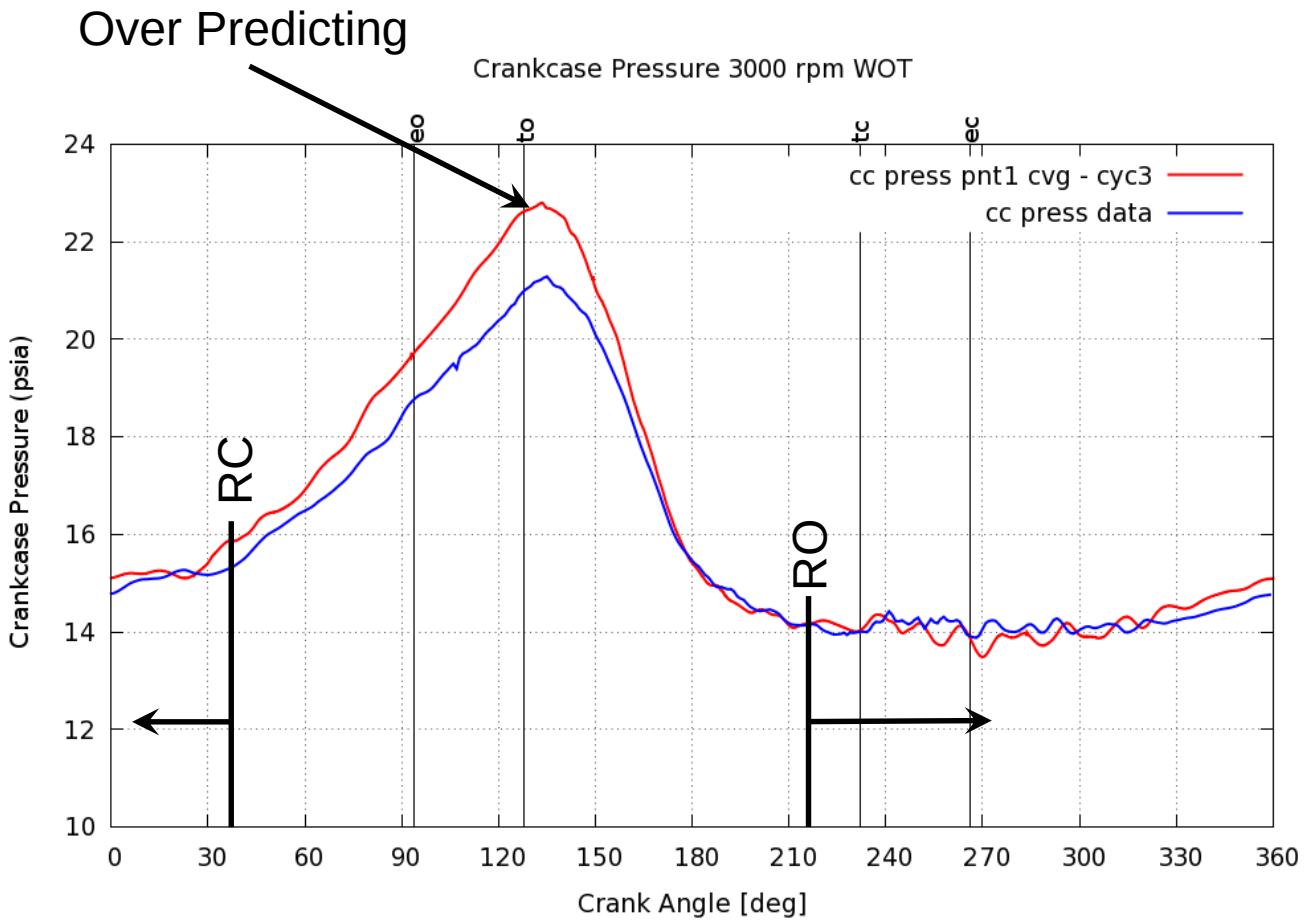
Reed Lift Validation – 3000 rpm



Relatively poor correlation with experiment

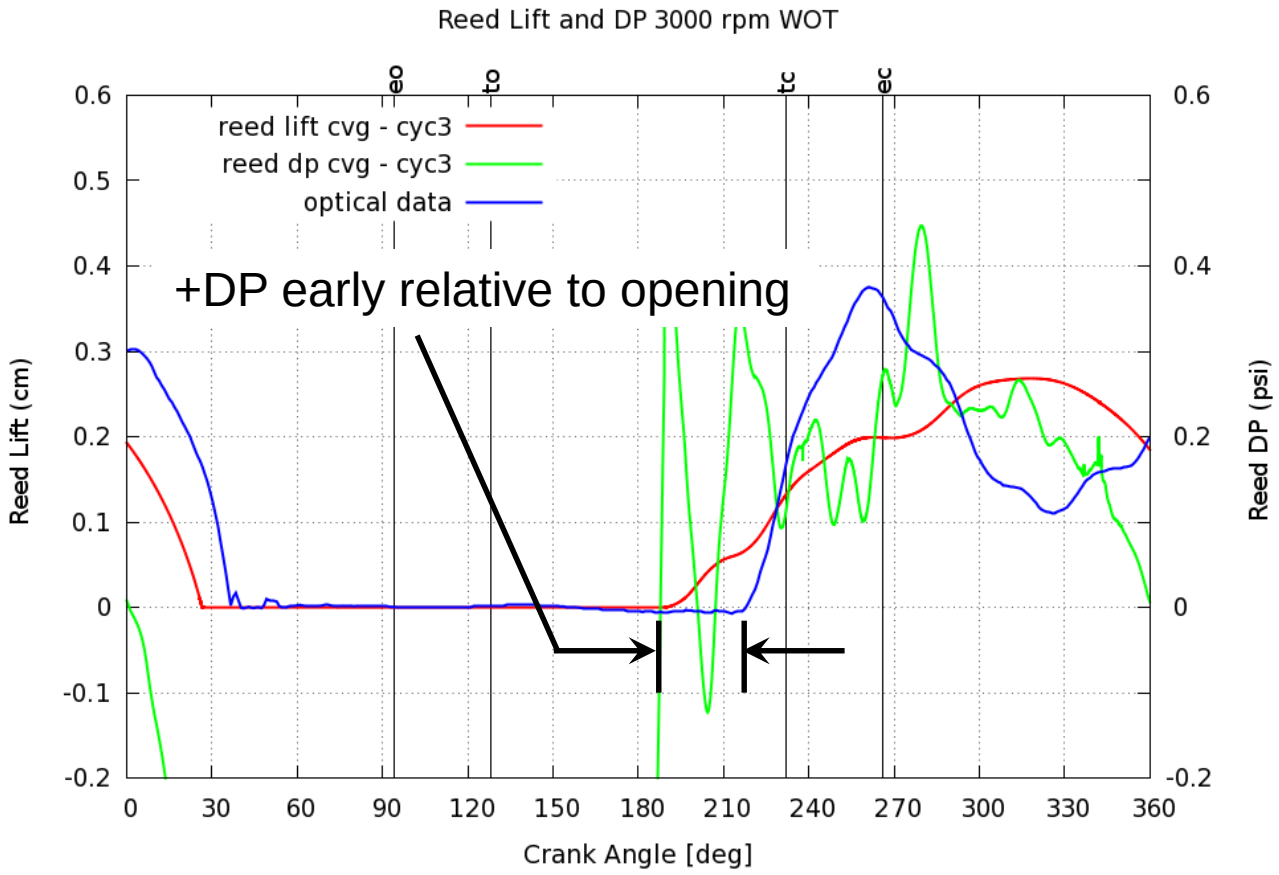
CFD opening is early and missing partial close

Crankcase Pressure Validation – 3000 rpm



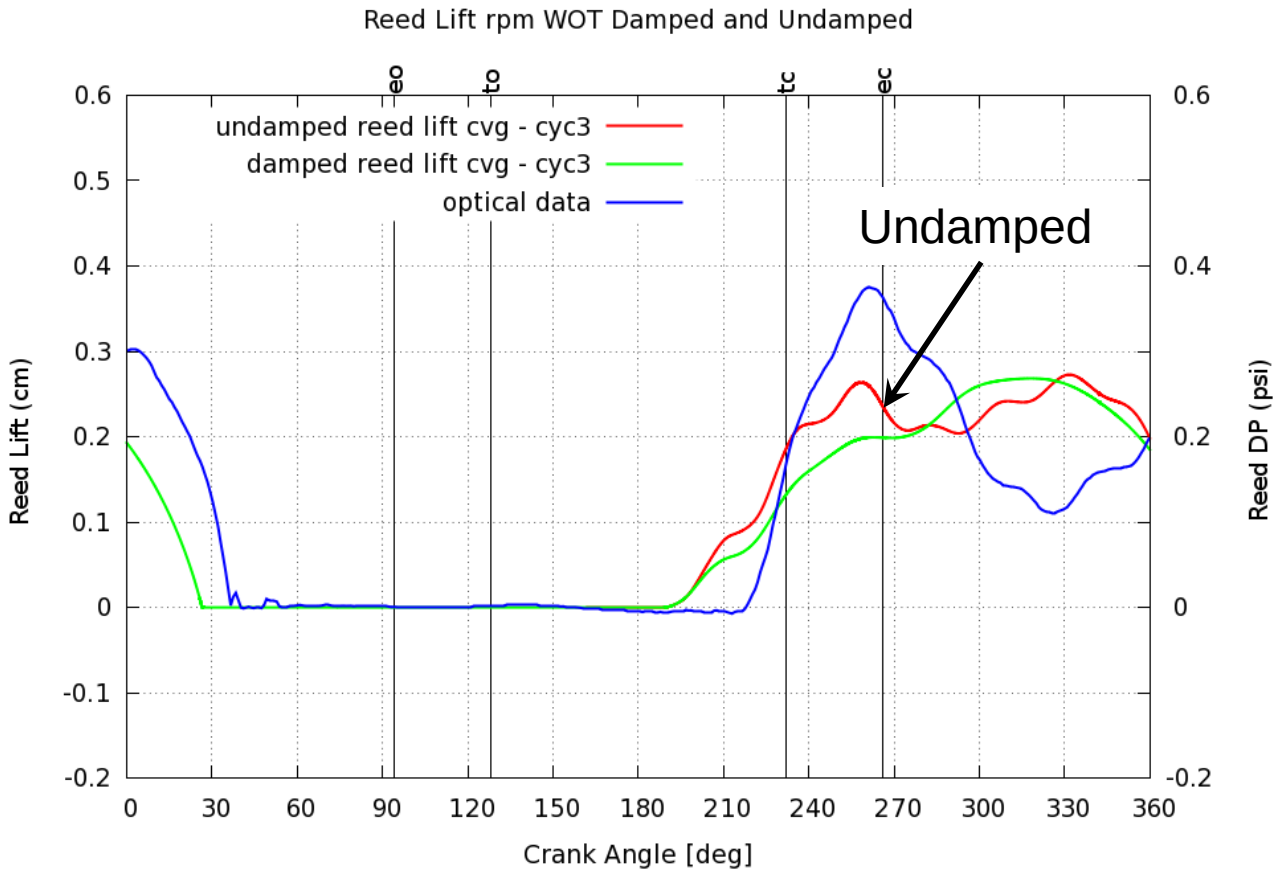
Over predicting peak crankcase pressure

Reed DP and Lift – 3000 rpm



Reed +DP is too early relative to experimental opening time

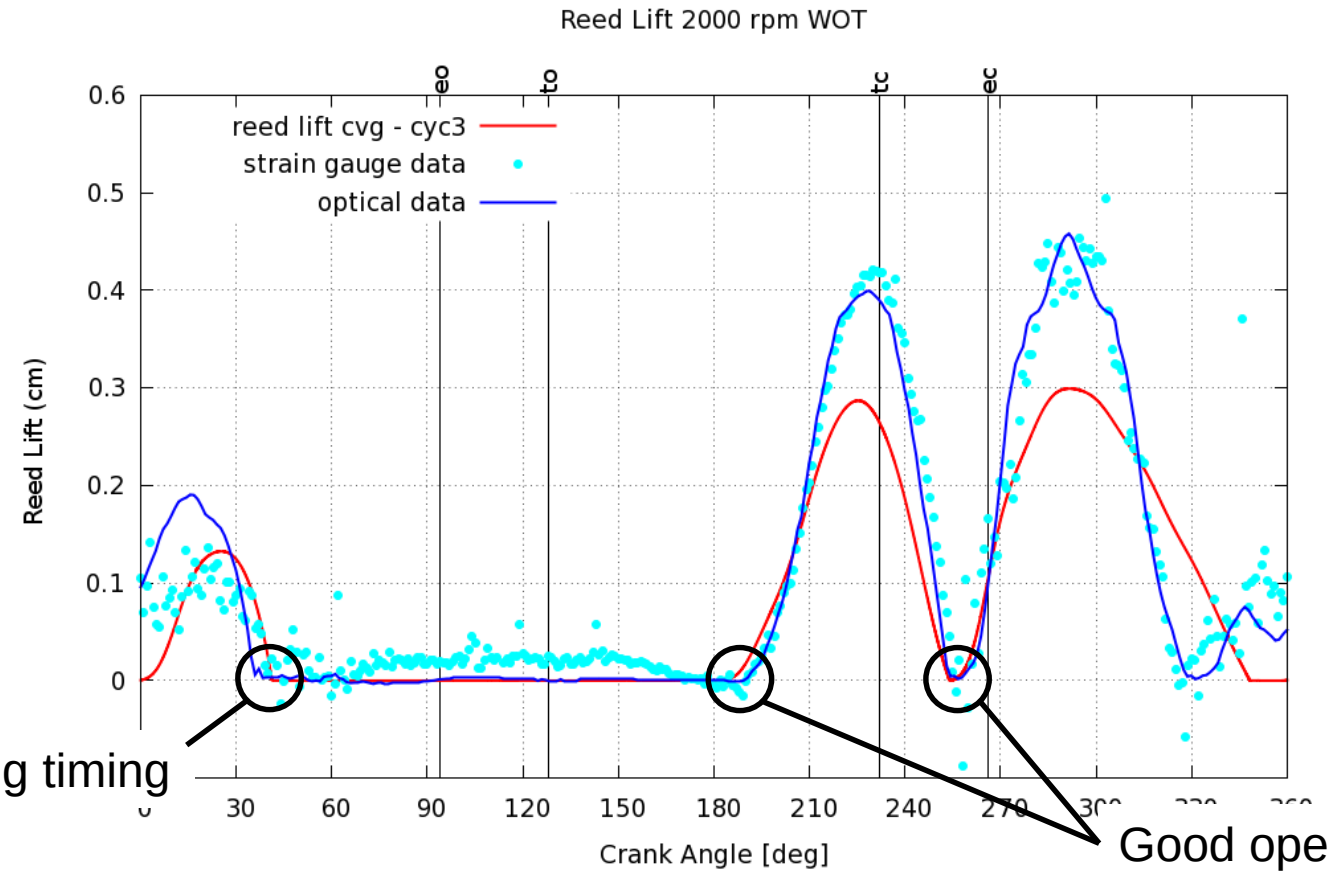
Reed Lift Damped and Undamped – 3000 rpm



Undamped beam vibration model gave more pronounced double peak

Still off in timing

Reed Lift Validation - 2000 rpm



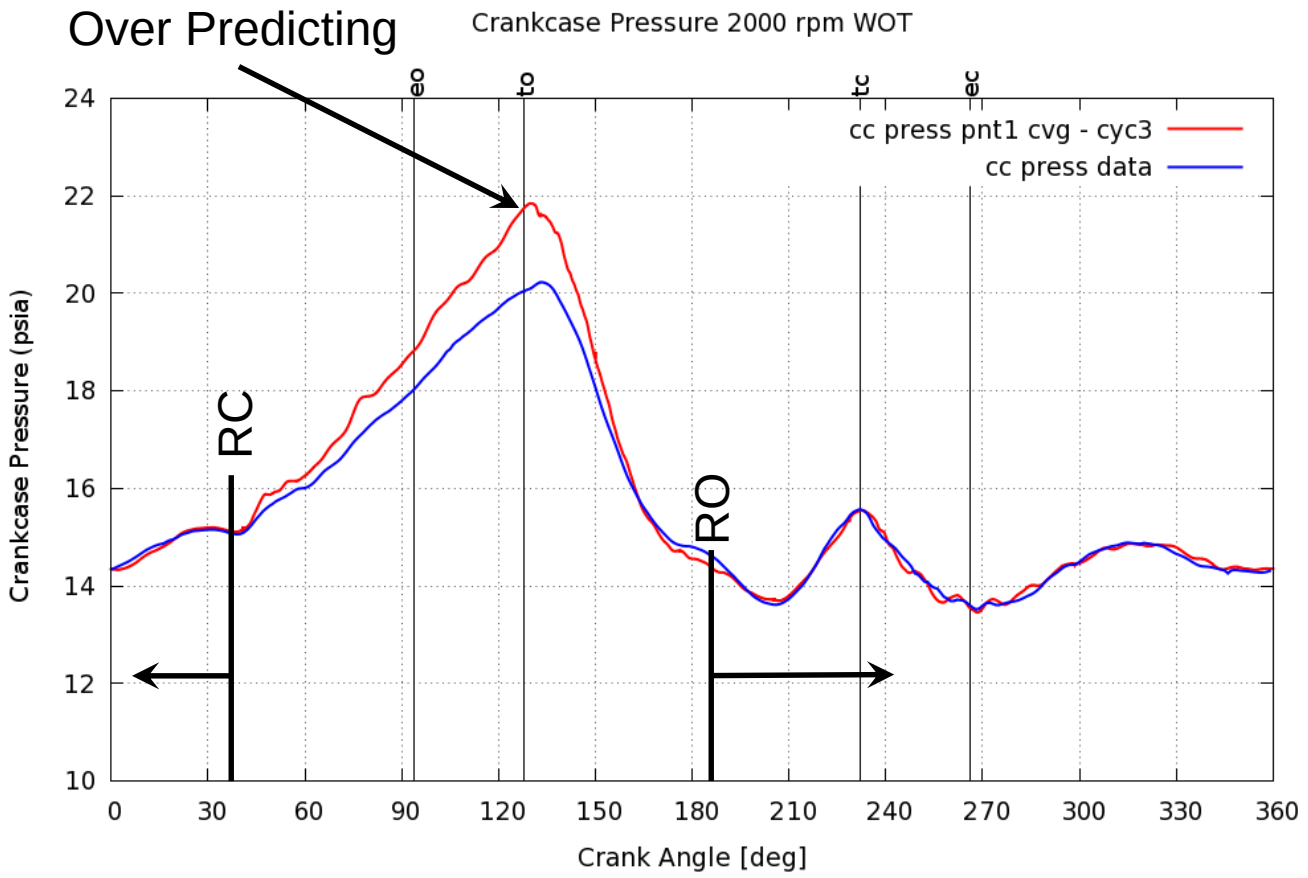
Good closing timing

Good opening timing

Captured 3 opening events

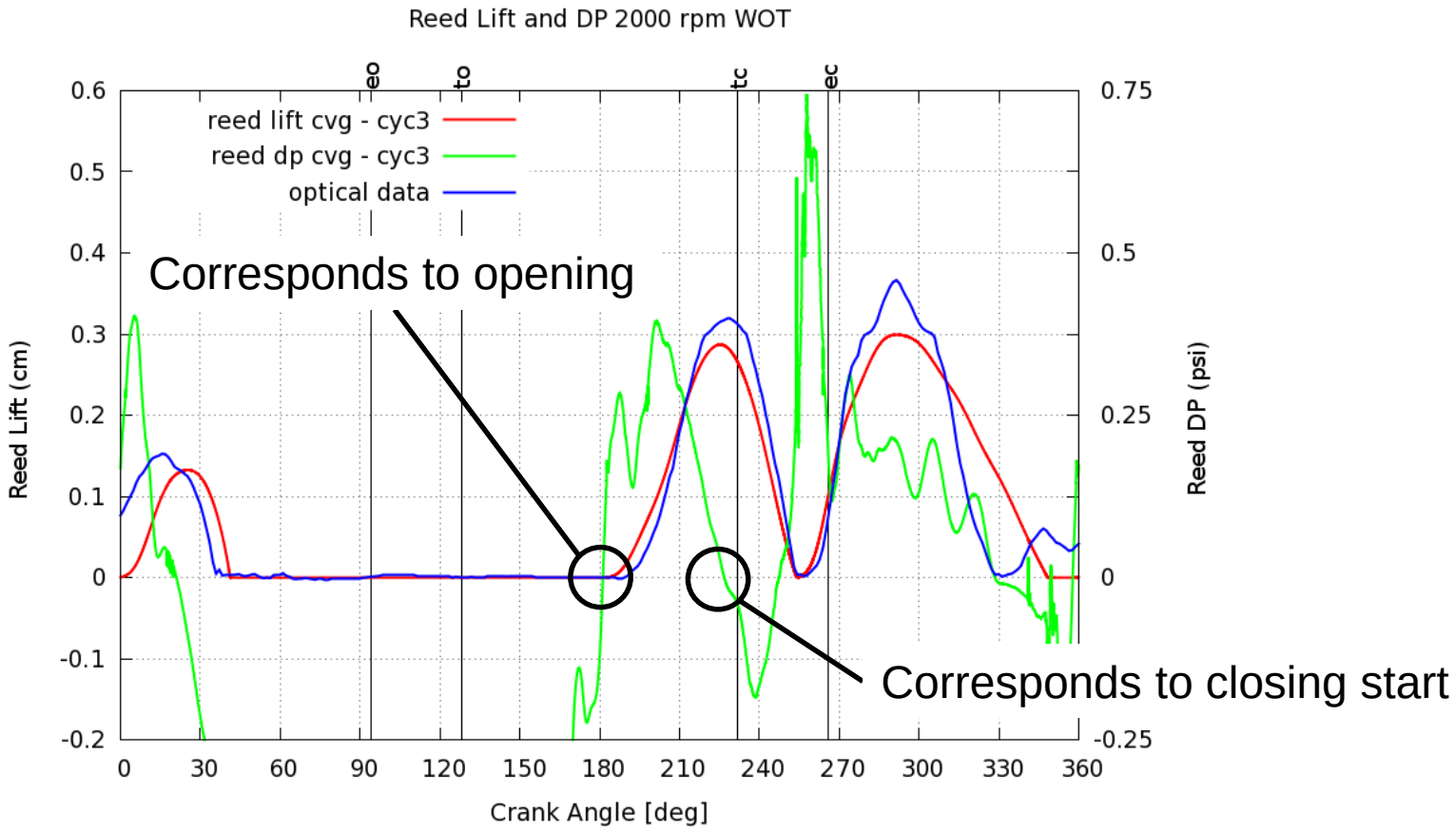
Low in peak magnitude

Crankcase Pressure Validation – 2000 rpm



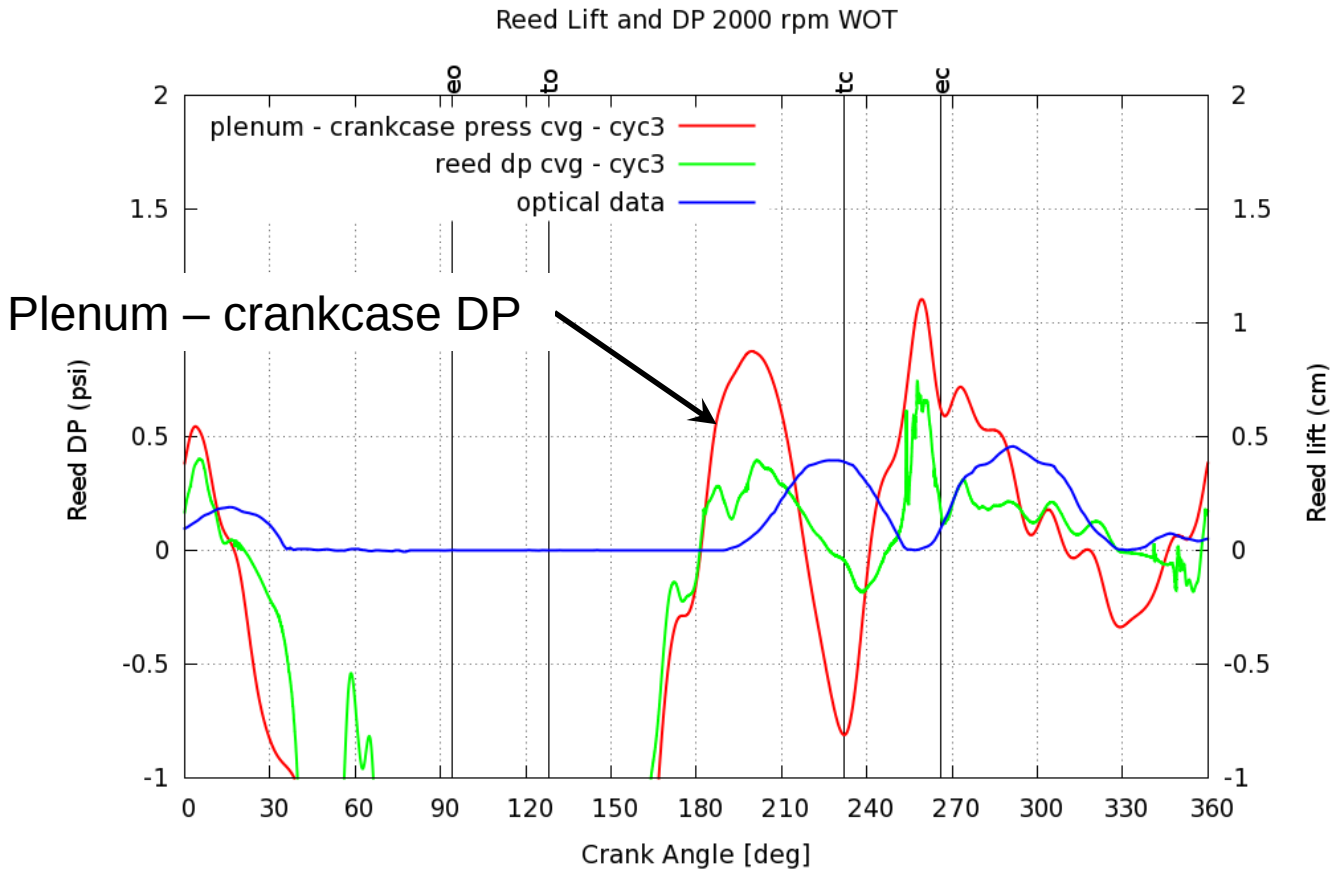
Over predicting peak crankcase pressure

Reed DP and Lift – 2000 rpm



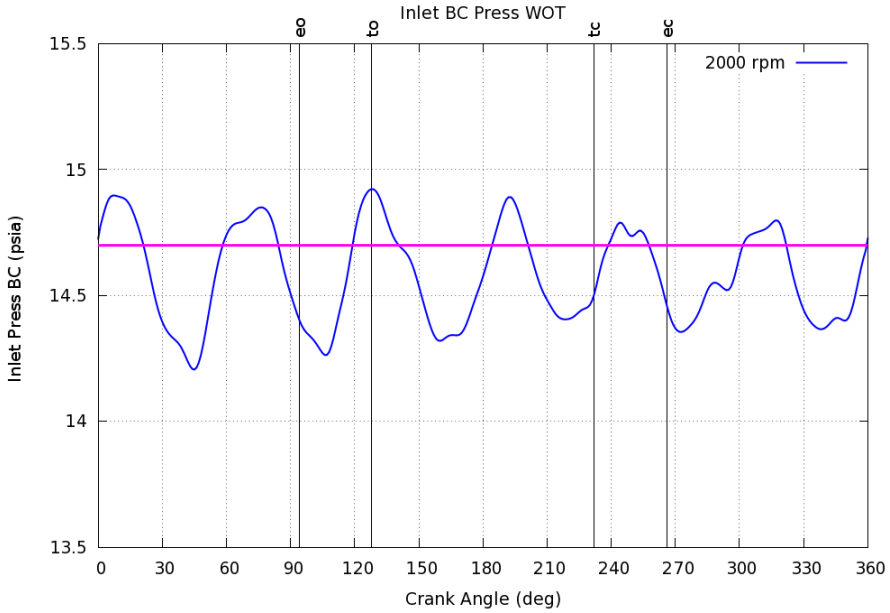
Good correlation between +DP and –DP with opening and closing

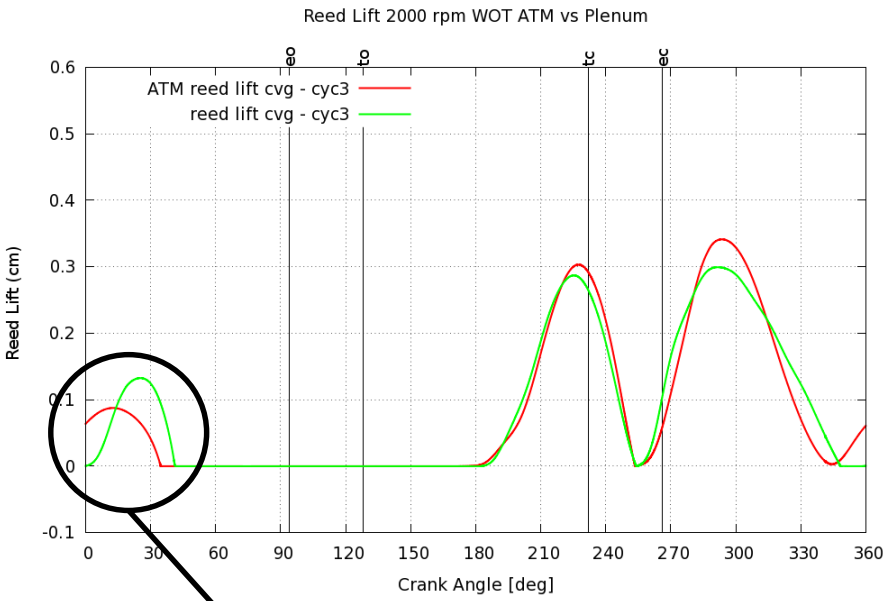
Plenum – Crankcase Press 2000 rpm



Reed DP is much different than average plenum – crankcase pressure

ATM vs Plenum BC – 2000 rpm

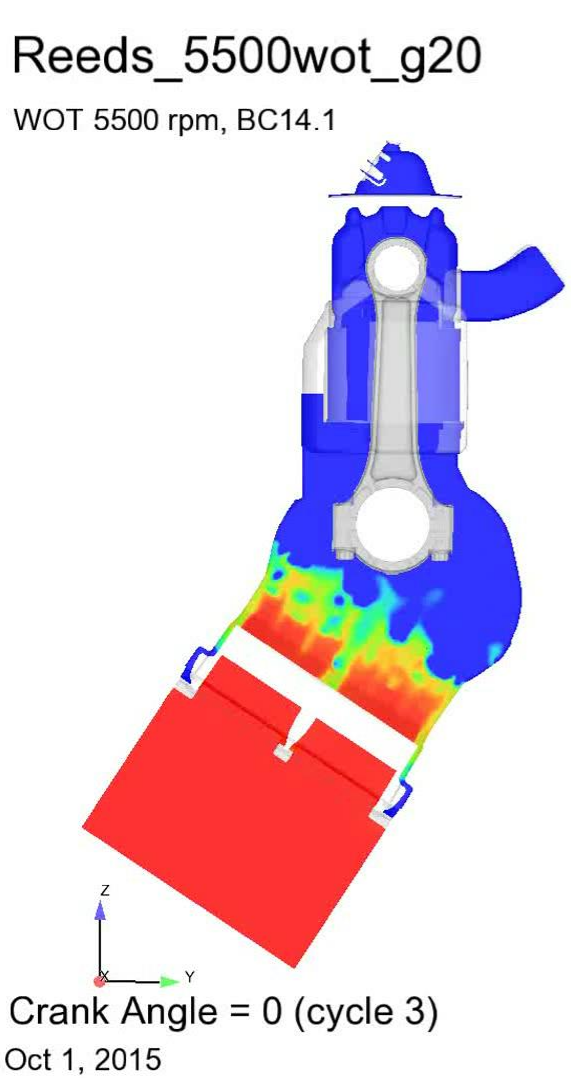


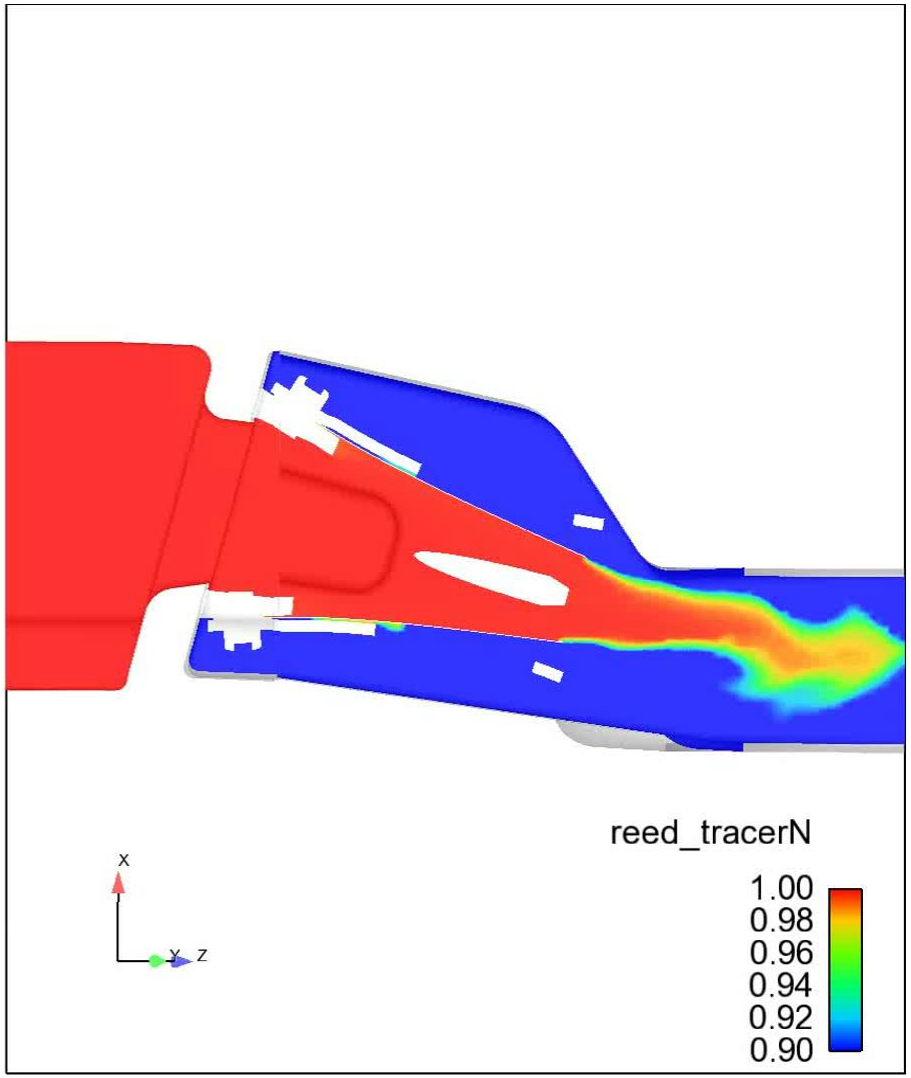


ATM BC closer to data

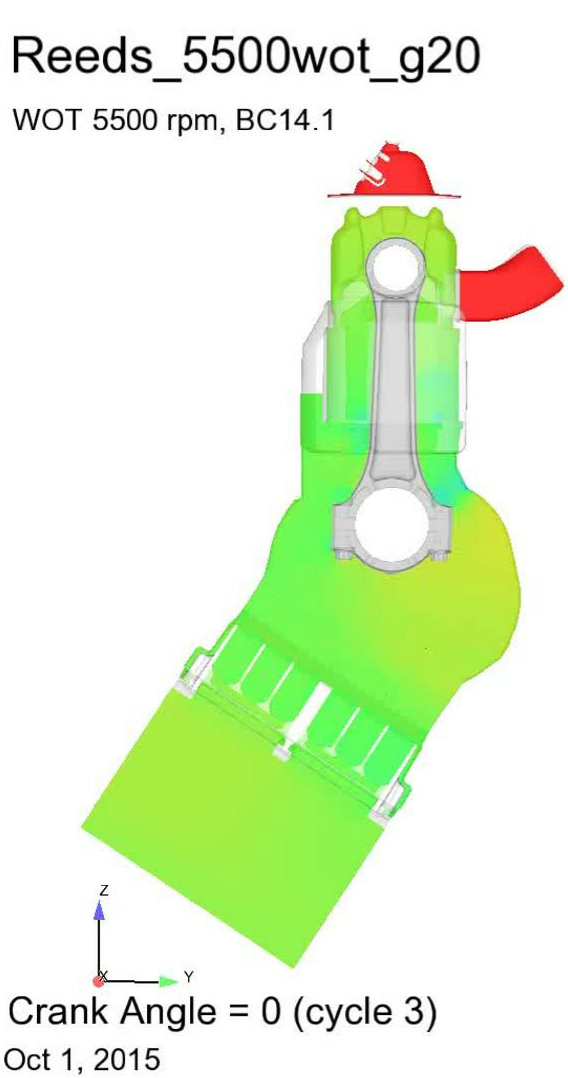
Sensitivity to intake plenum pressure BC is modest

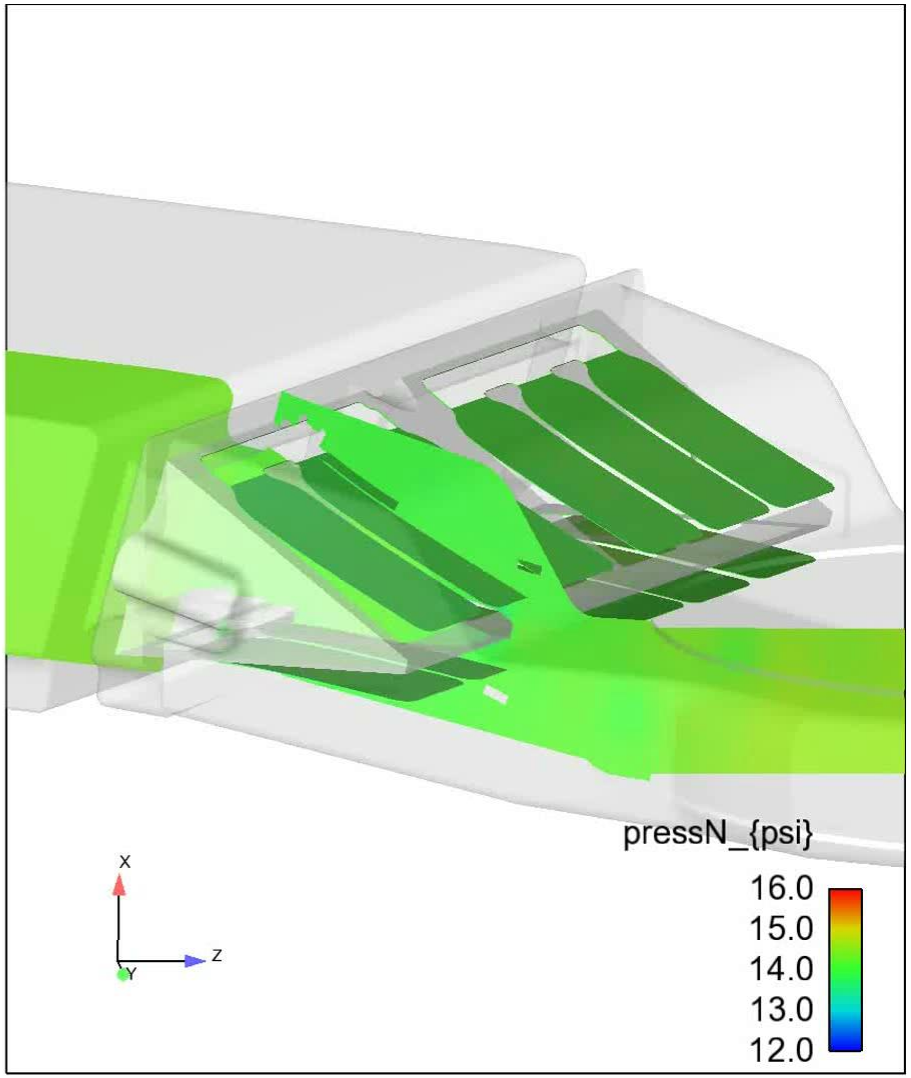
Intake Tracer – 5500 rpm



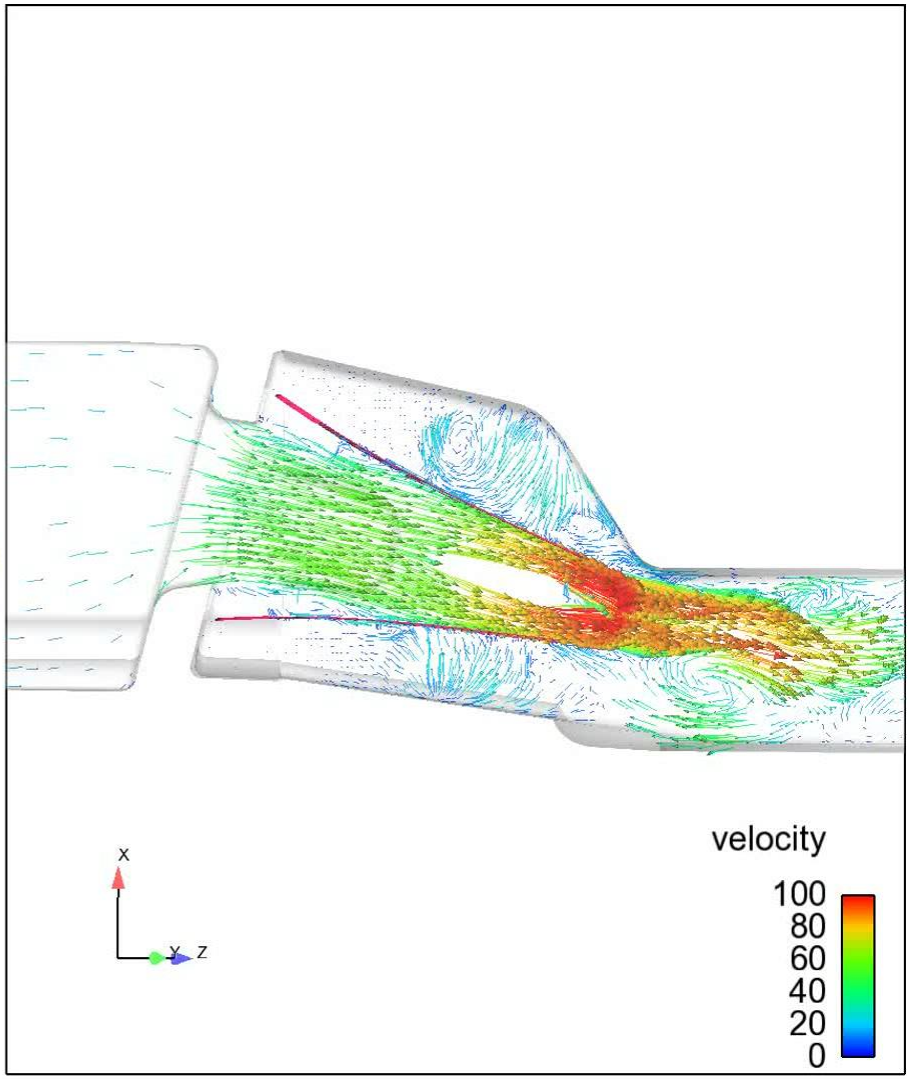


Pressure – 5500 rpm

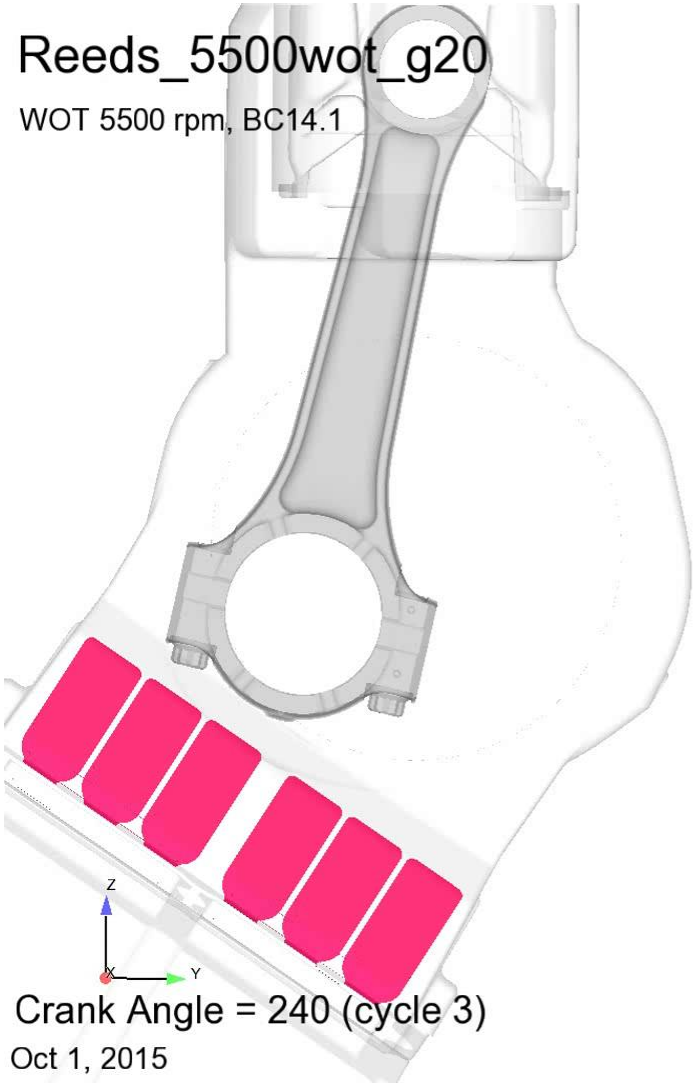


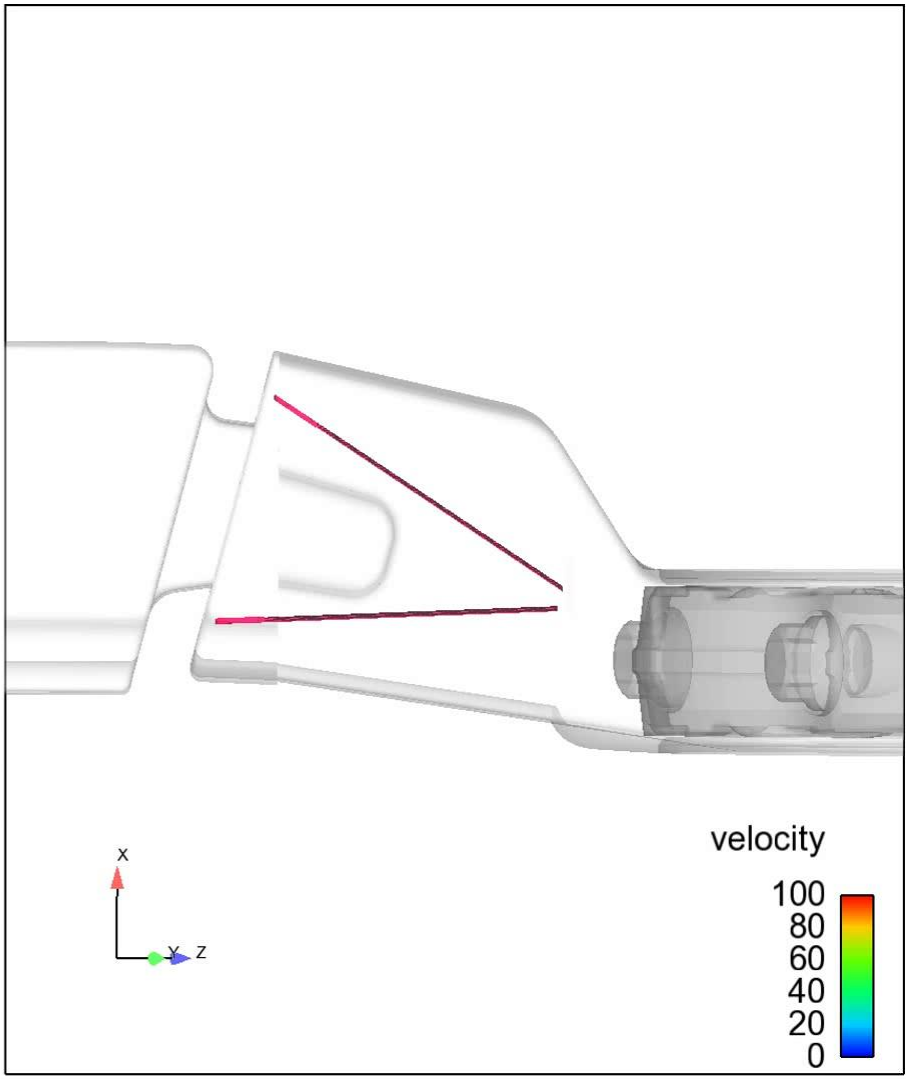


Velocity - 5500 rpm



Pathlines – 5500 rpm

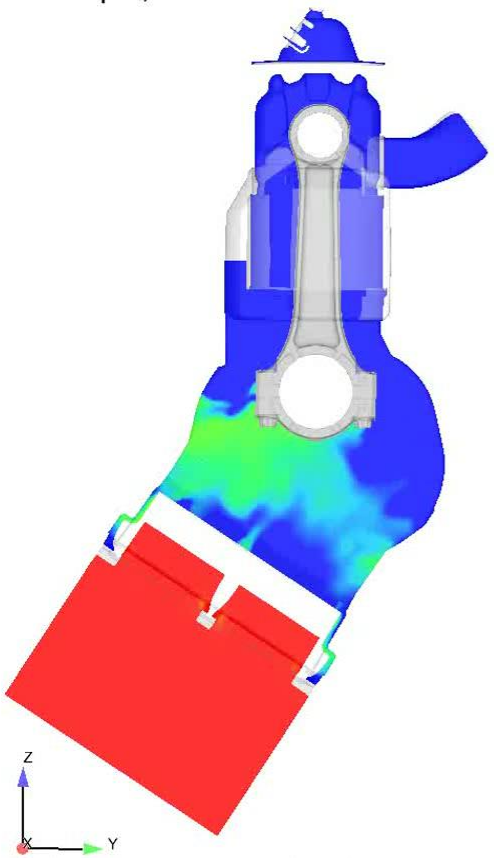




Intake Tracer - 2000 rpm

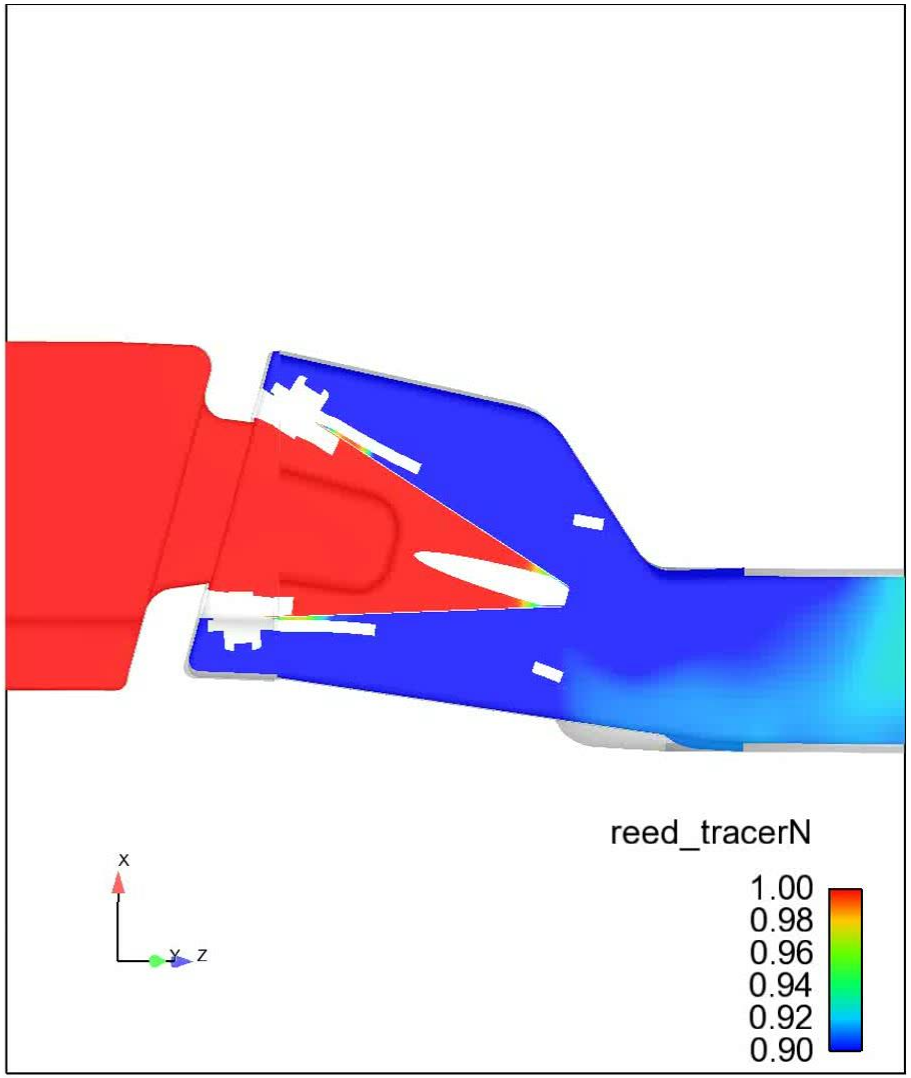
Reeds_2000wot_g20_r32

WOT 2000 rpm, BC16.1



Crank Angle = 0 (cycle 3)

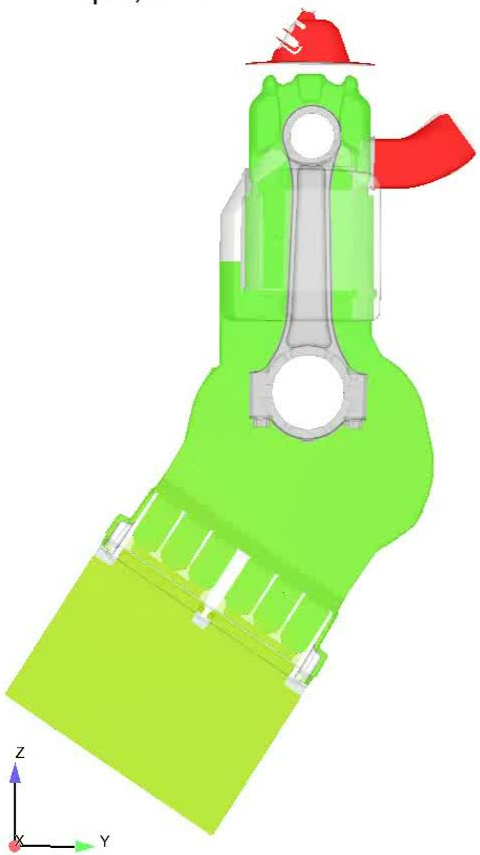
Sept 29, 2015



Pressure - 2000 rpm

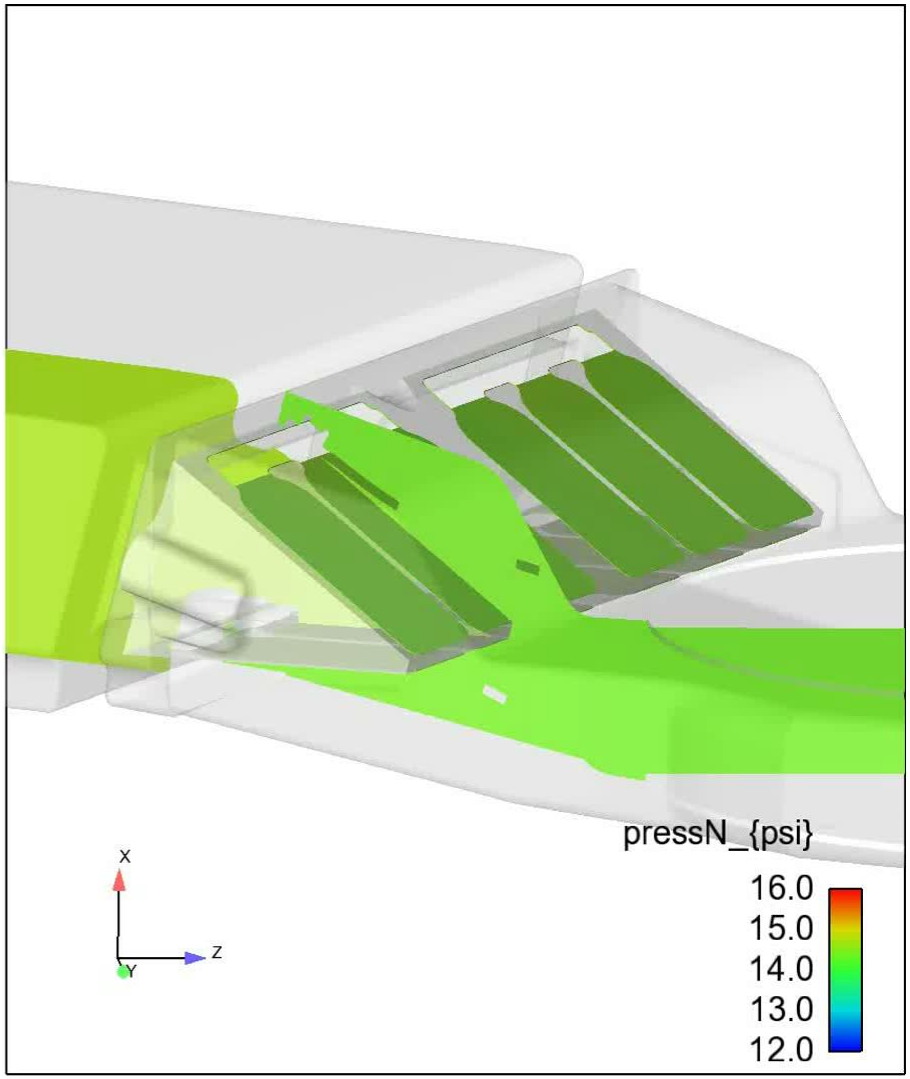
Reeds_2000wot_g20_r32

WOT 2000 rpm, BC16.1

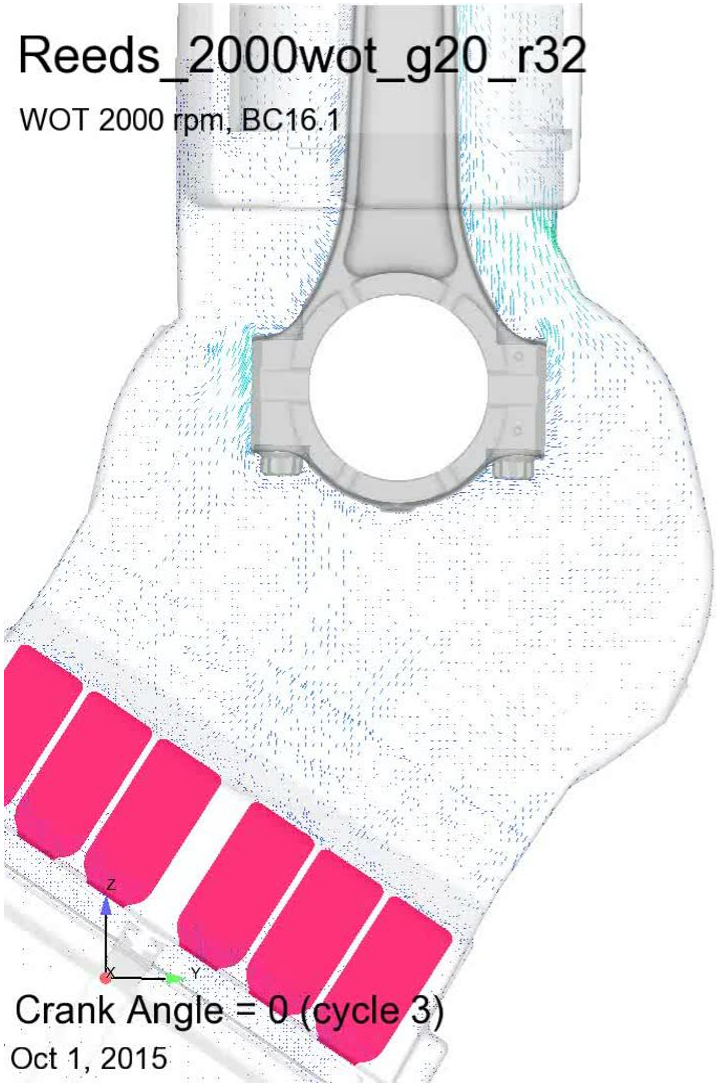


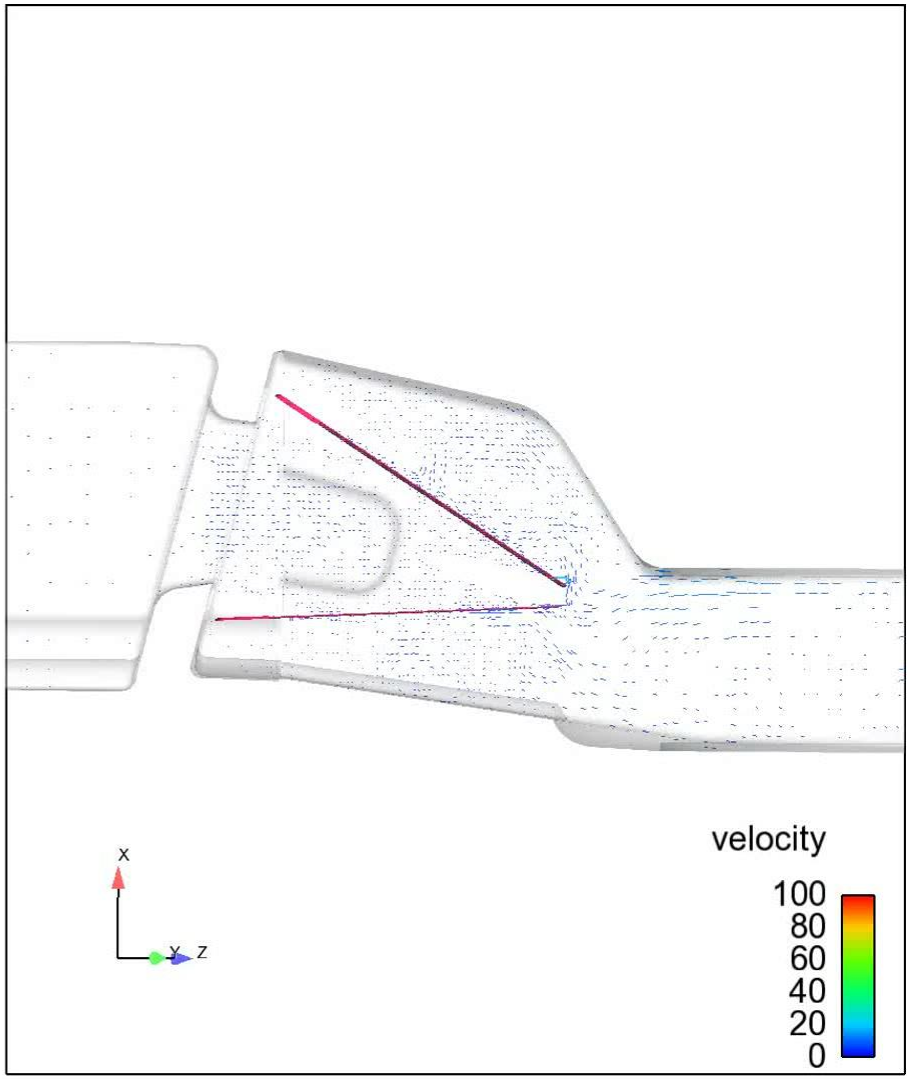
Crank Angle = 0 (cycle 3)

Oct 2, 2015

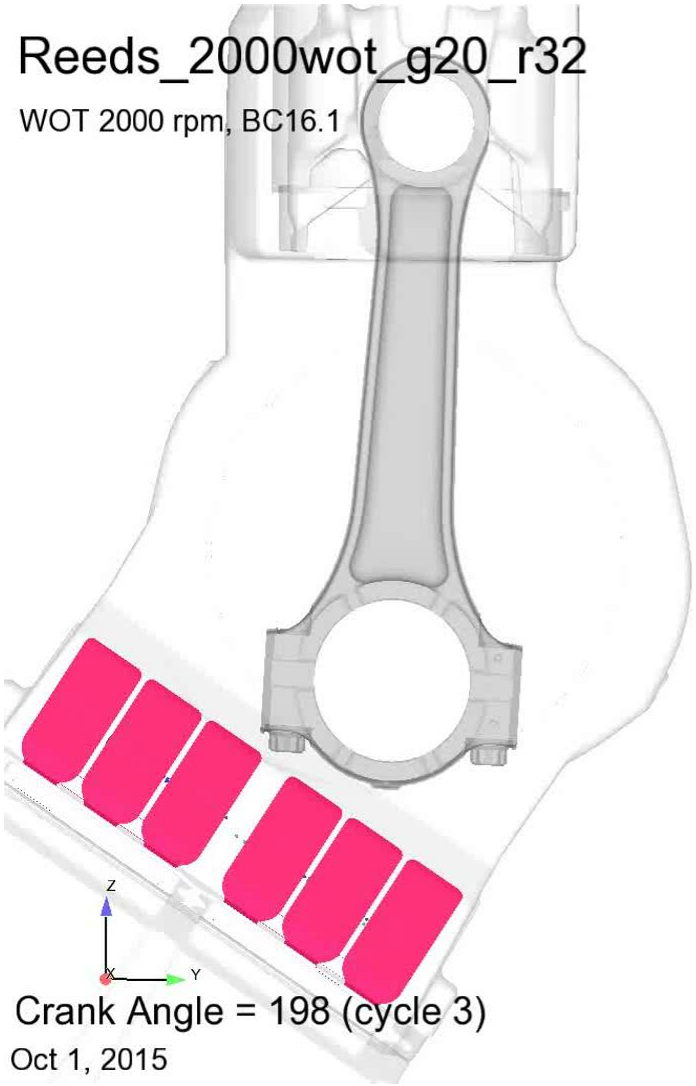


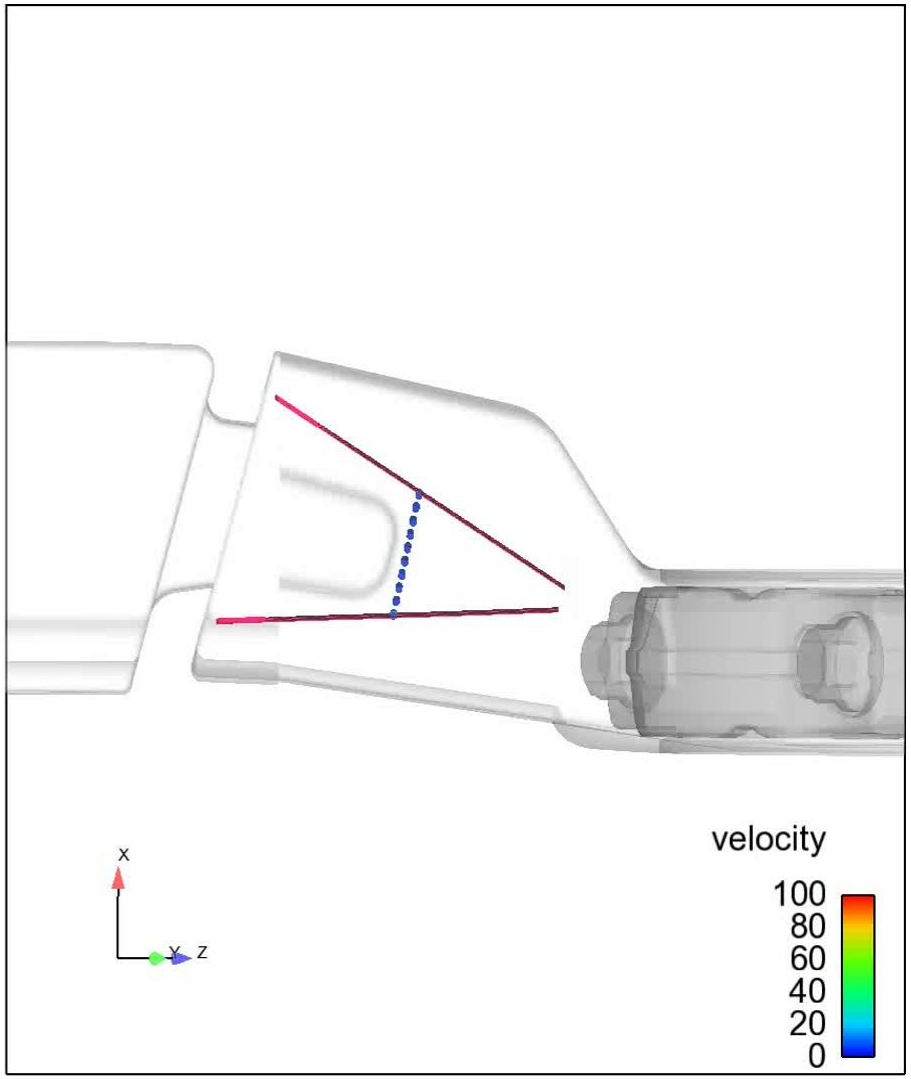
Velocity - 2000 rpm





Pathlines – 2000 rpm





Agenda

1. Overview
2. Converge CFD Model
3. Experimental Validation Data
4. CFD Results
5. Future Work

Future Work

- Improve correlation at 3000 rpm
- Reed UDF tuning – damping factor, correction for neck down, reed stop
- Correlate to no plenum, no reed stop and motored data sets
- 1-D coupling to plenum, exhaust
- Reed design optimization

Thanks for Your Attention