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Progress through Research

Assessment of new IC engine concept
M/S KAnalysis /Ibrahim Hanna

Outline

- Objective
- Scope of work and Deliverables
- Reference Engine Simulation
- Floating Piston 3D CFD combustion simulation model build
- Summary

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Objective

3D-Combustion Simulation

- Evaluation of relative motion engine performance at two operating points (rated power and max torque points) w r.t reference SI (Spark Ignited) engine.
- All the simulations carried out in closed cycle.

Scope of work and deliverable

3D-Combustion Simulation

- Base reference SI engine will be selected for comparative study. The same engine will be modelled and simulation results will be validated at rated power and peak torque points.
- M/s. KAnalysis will provide the 3D-models of relative motion engine required for combustion simulation and its displacement volume shall be maintained equivalent to base engine displacement.
- ARAI will prepare the simulation model based on 3D-model & other inputs and boundary conditions provided by M/s KAnalysis.

Scope of work and deliverable

3D-Combustion Simulation

- In case of unavailability of any input or boundary conditions, ARAI will assume after mutual understanding.
- Simulation work will be carried out at max. power and max torque points.
- Relative motion engine simulation results will be analysed and compared with reference SI engine performance such as power, torque, in-cylinder pressure, etc.
- Max. 4 no. of iterations considered for relative motion engine 3D-combustion analysis. Any more iterations may call for price and time implications.

Inputs & Deliverables

Inputs required from KAnalysis

- 2D drawings and 3D models of components and sub-systems, animations of entire new engine concept.
- All inputs and boundary conditions used while conceptualisation.
- Intake & Exhaust valve/port timings.
- Floating piston details like piston motion profile etc.
- Data calculations/literature related to new engine concept.
- Analysis/simulation reports of components/sub-systems of new engine.

Deliverables

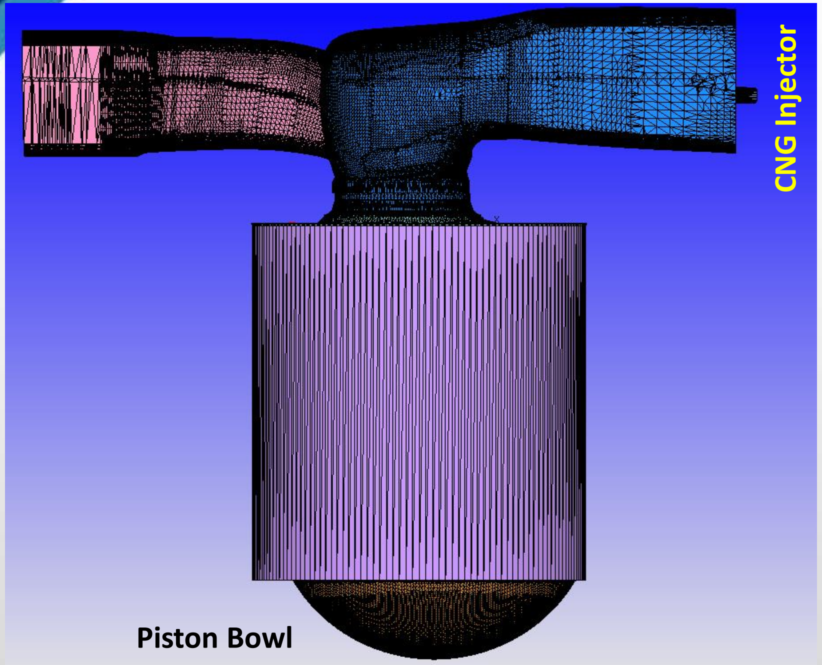
- 3D Combustion Analysis report along with results comparison with base SI engine considered in this analysis

Reference engine specification and Inputs

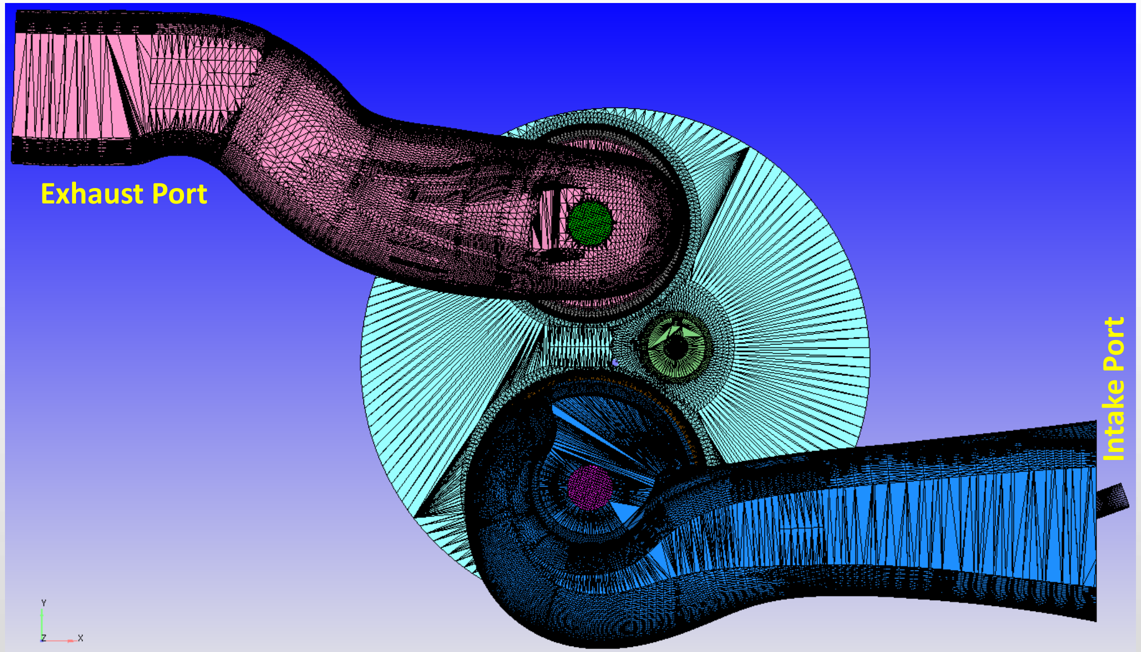
Parameters	Base Engine
Engine Type	Inline, WC
Bore x Stroke (mm)	100 X 112
Connecting Rod Length (mm)	181
Compression Ratio	11.1
No. of cylinders	4
Cubic capacity (litre)	3.52
Valves per Cylinder	2
Aspiration	TCIC
Rated Power	78 kW @ 2800 rpm
Max. torque	306 Nm @ 1400 rpm
Rated BMEP (bar)	9.5
Max. BMEP (bar)	10.93
CNG Fuel System	MPFI
Manifold Pressure, bar	1.61 bar
IVC	52^{o} a BDC
EVO	52^{o} b BDC
IVC Temperature	445 K
Spark Timing	21.4^{0} bTDC
Spark duration	0.53ms
Air flow rate, kg/hr @ 2800rpm	338.6
Fuel flow rate, kg/h @ 2800rpm	19.9
FMEP, bar	1.45
PMEP, bar	0.60
FMEP+PMEP, bar	2.05
A/F ratio (Stoichiometric)	17.0

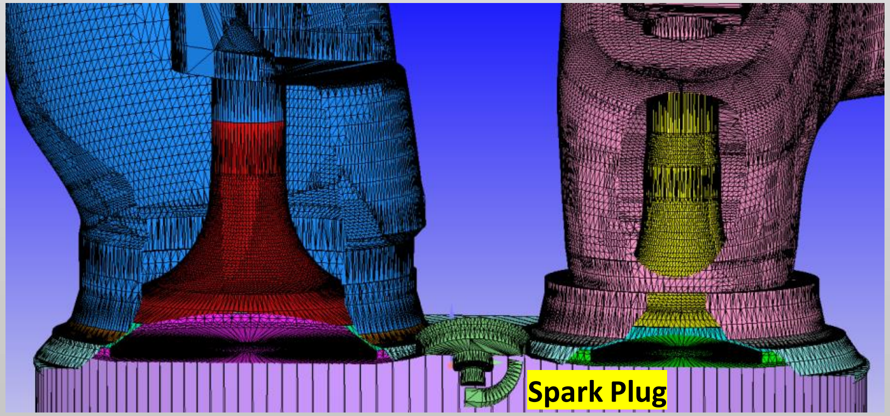
Reference Engine Model

Side View



Top View



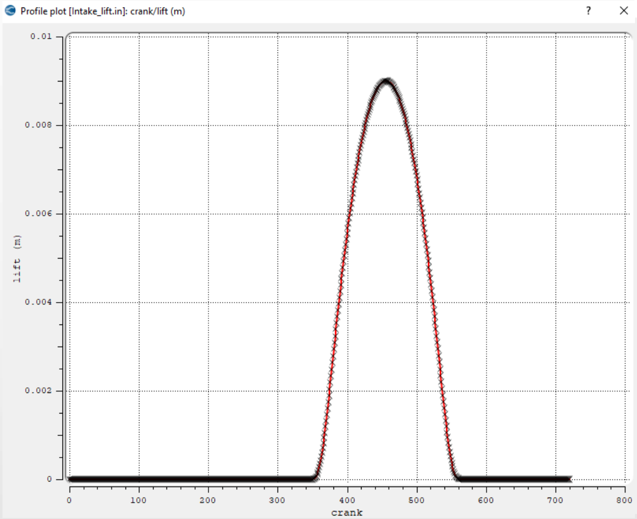


Inputs – Initial & Boundary Conditions

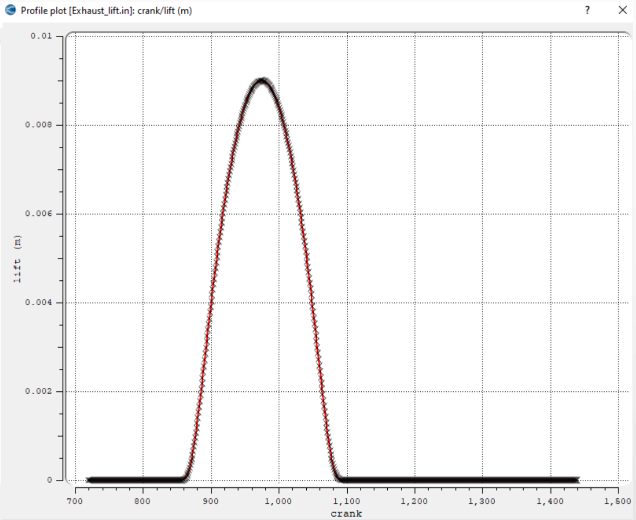
➢ Valve Timings:

- IVO : 336 CAD & IVC : 592 CAD
- EVO : 848 CAD & EVC : 1094 CAD
- Start of Injection : 760 CAD
- End of Injection :1110 CAD
- Duration of Injection : 350 CAD

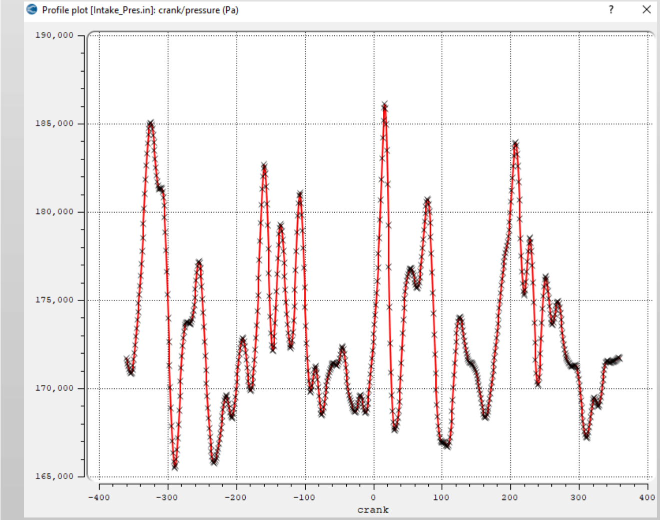
Intake Valve Lift



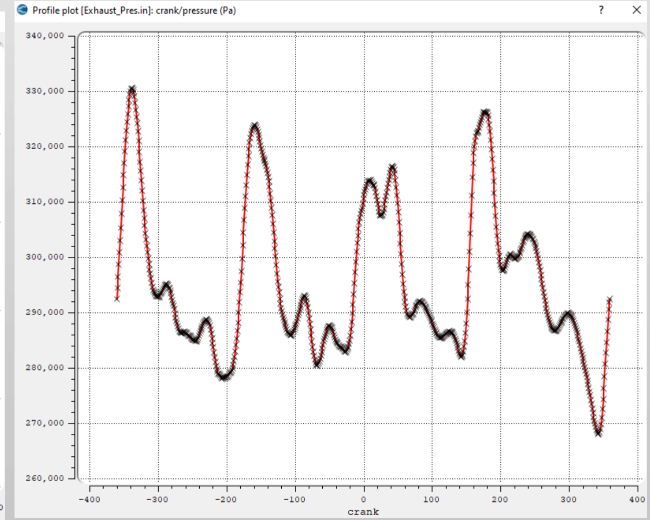
Exhaust Valve Lift



Intake Pressure Condition



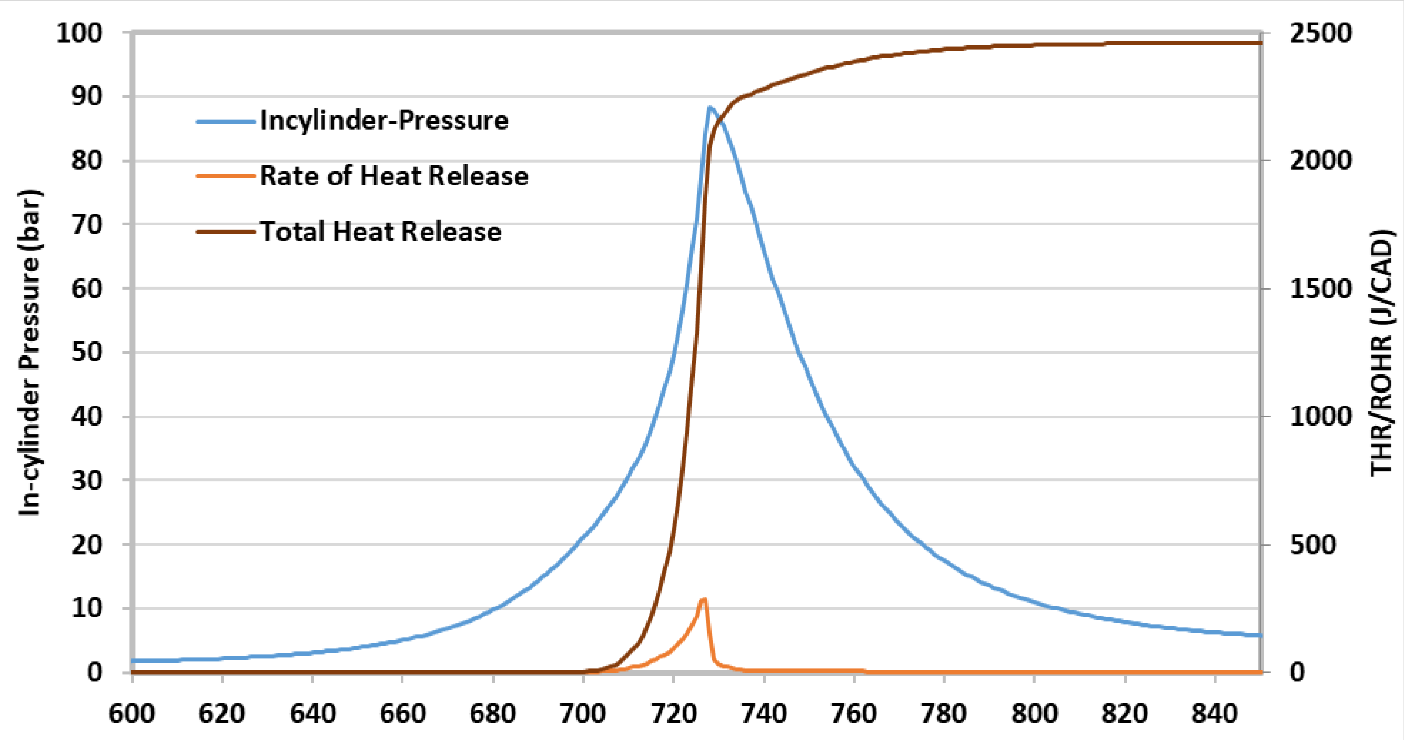
Exhaust Pressure Condition



➢ Initial & boundary condition:

- Intake & exhaust port pressures
- Intake & exhaust valve lift profile & timing
- Air flow rate, fuel flow rate
- Compression ratio: 11.1

Base Engine Performance



Simulation Cases	Engine Speed - 2800 rpm															
	Equivalent Displacement (4-cylinder)	IVC/EVO	Air flow	fuel	Air flow	fuel	A/F	Heat Energy Input	Total Heat Release	Combustion Efficiency based on heat energy release	FMEP	BMEP	Power	Torque	kW/l	Peak Firing Pressure (PFP)
	~cc		mg/st		kg/hr			J	J	%	Bar		kW	Nm		bar
Base Engine test	3520	52 aBDC/52bBDC	949.0	**55.8**	**319.0**	**18.76**	**17.0**	2735.18	**2488**	91.0	**1.45**	**9.492**	**78**	**266.02**	**22.16**	**90.00**
Base Engine simulation	3520	52 aBDC/52bBDC	928.1	54.6	311.8	18.35	17.0	2674.91	2460	92.0	1.45	9.39	77.1	262.84	21.89	88.20
% deviation b/s test & sim	-	-	2.2	2.2	2.2	2.21	-	2.2	1.1	-1.1	-	1.1	1.2	1.2	1.2	2.0

- Reference engine combustion efficiency is only 92%
- Performance is within 3%
- Validated model input conditions considered for floating piston concept analysis

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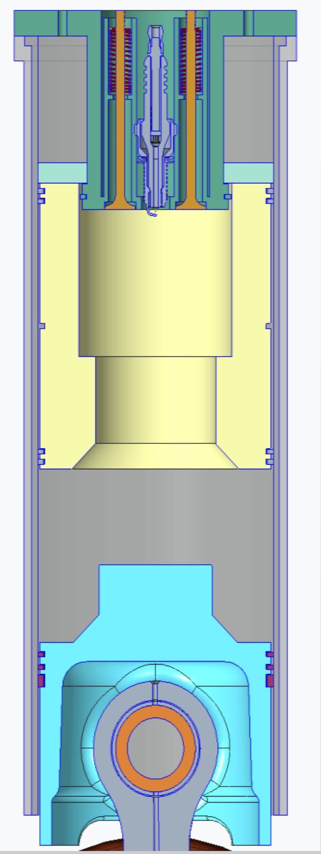
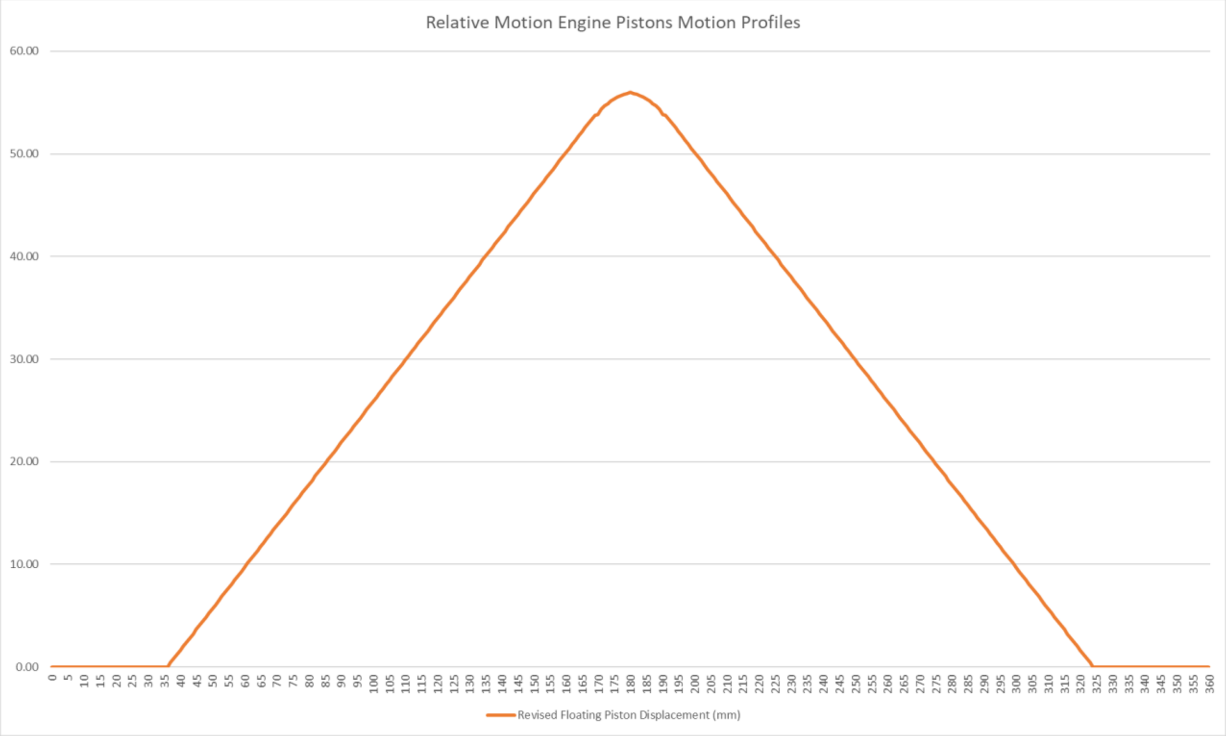
Floating Piston (RM) Model Provided by KAnalysi

<u>Crank Piston at BDC</u>



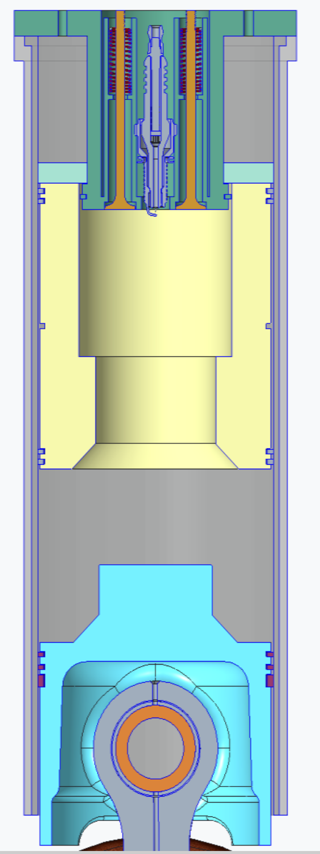
CP stroke= 112
FP stroke= 56
RM engine volume= 687.8 cc
ARAI engine volume= 966.7 cc



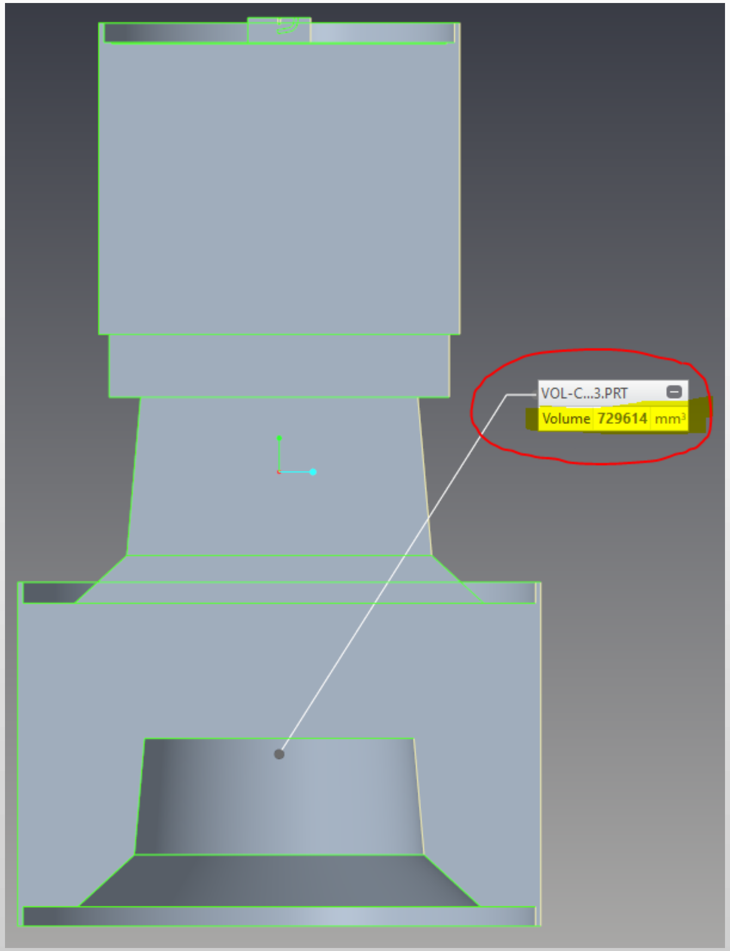
- 3D-model for RM piston concept and floating piston motion data provided by Analysis
- Final model considered for closed cycle combustion simulation
- Equivalent 4-cylinder engine displacement will be 2.47 ltr and the same considered for calculations

Floating Piston (RM) Model Provided by KAnalysi

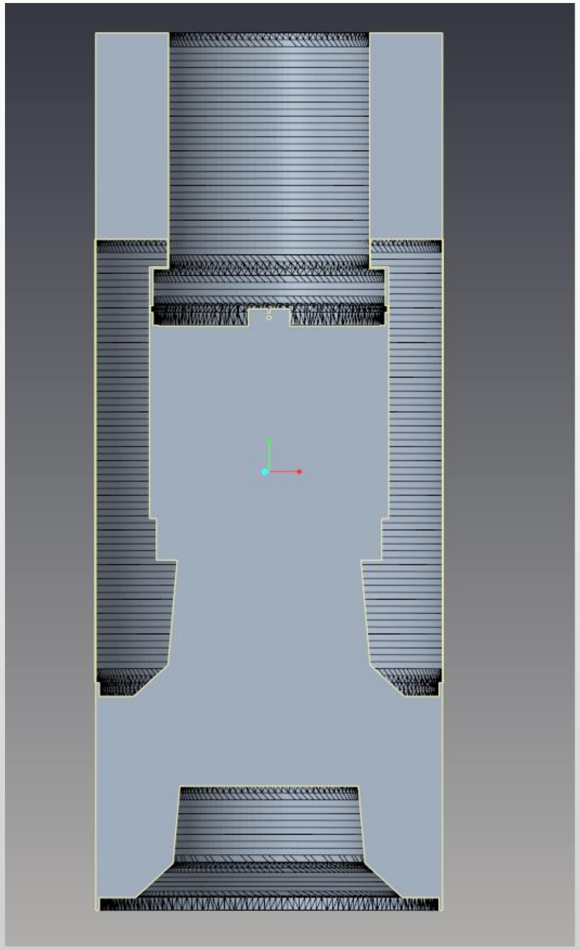
Crank Piston at BDC



CP stroke= 112
FP stroke= 56
RM engine volume= 687.8 cc
ARAI engine volume= 966.7 cc
From KAnalysis



Model corrected by ARAI after discussions with KAnalyis and RM engine total volume (displacement + clearance volumes = 729.6 cc
Engine cylinder displacement : 663.3cc

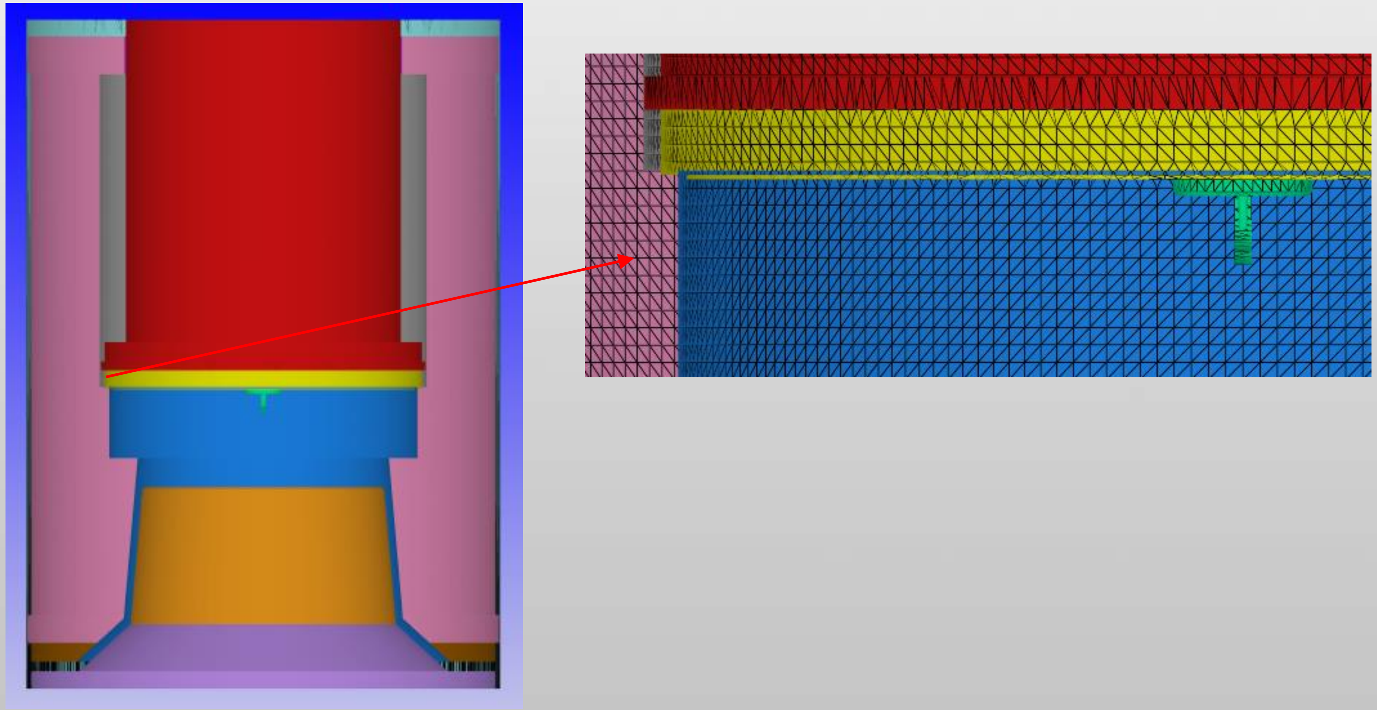


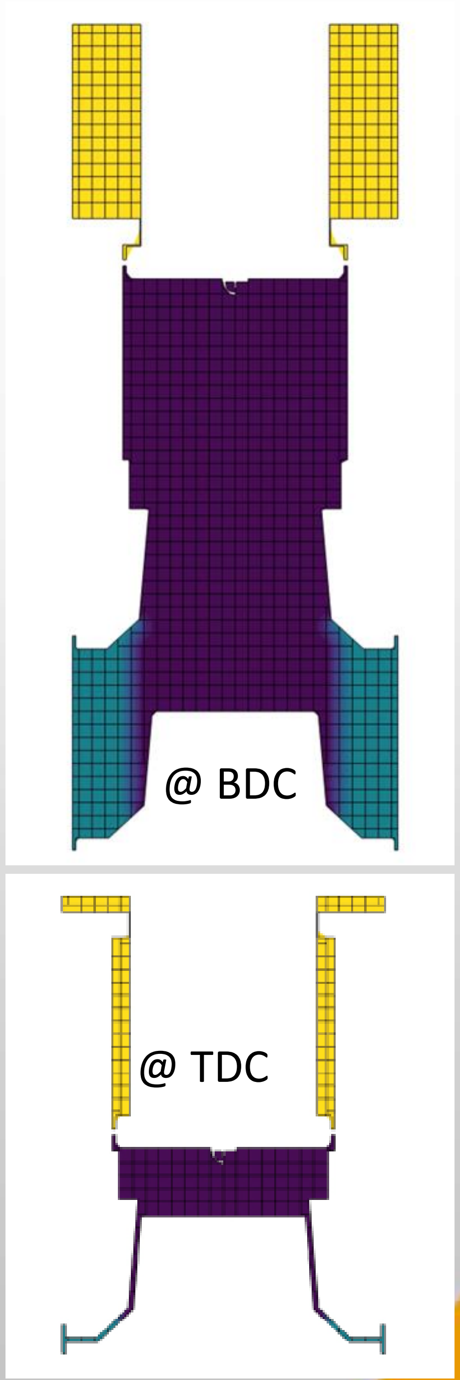
Model prepared by ARAI for simulation with CR: 11.1

Equivalent 4-cylinder engine displacement will be 2.63 ltr

Floating Piston (RM) Meshing

- Final 3D model provided by KAnalysis used for meshing
- During meshing few inter sections observed and resolved to complete the floating piston concept engine meshing

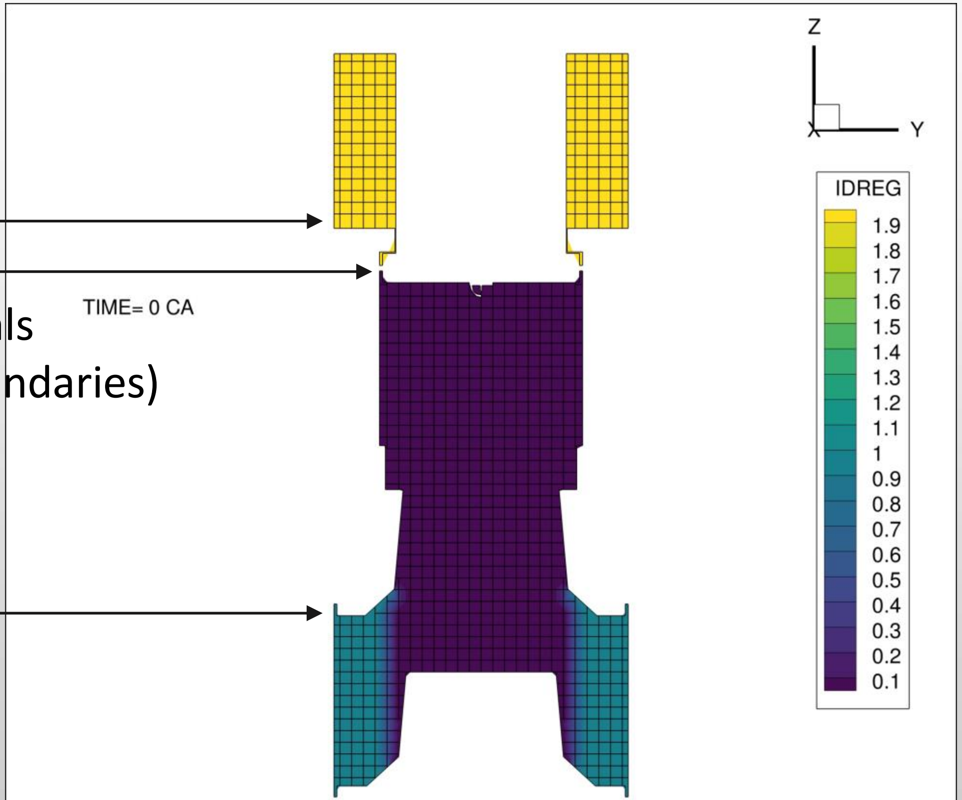




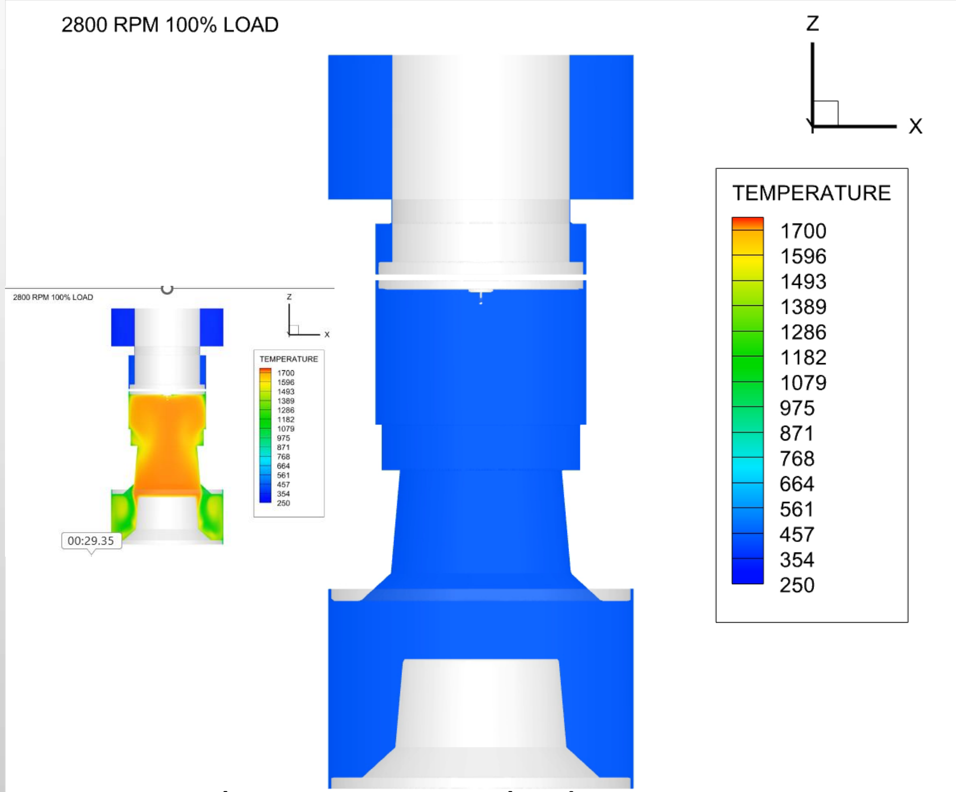
3D CFD cold flow simulation

- Close cycle cold flow simulation for full load point at 2800rpm carried out.

Intersection seals
(Between Moving Boundaries)



- Motion check with cold flow.



- Combustion – in-cylinder temperature

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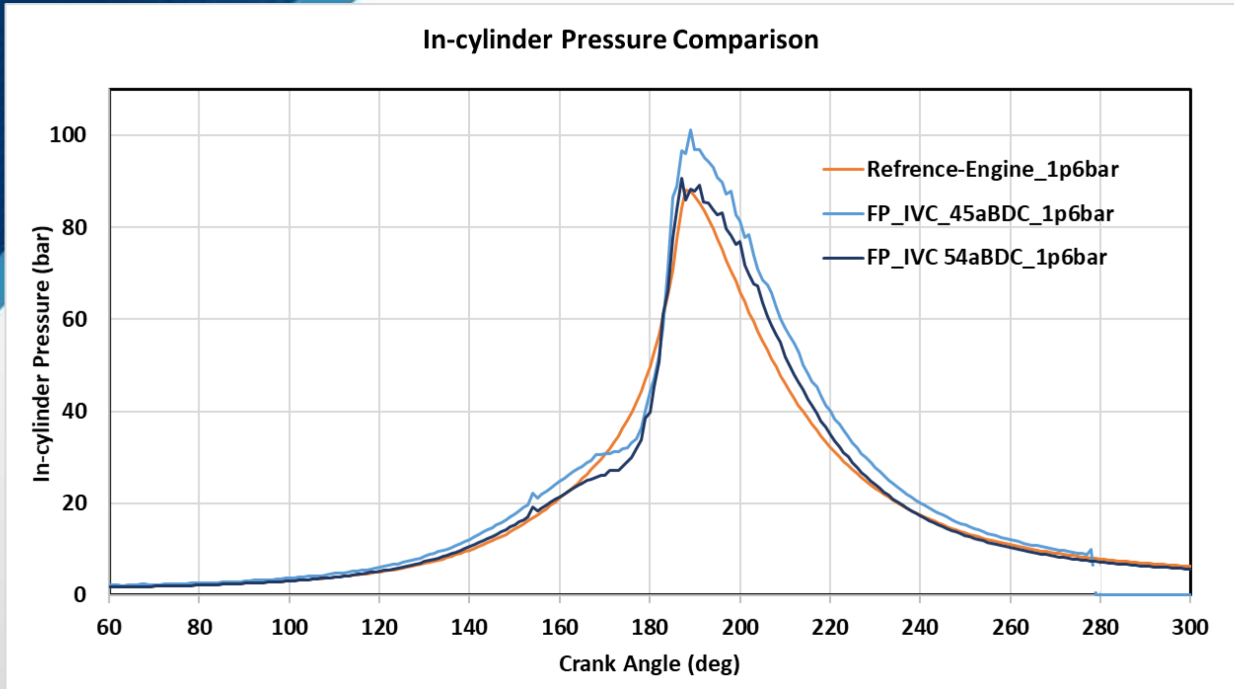
3D CFD Combustion Simulation – Relative Motion

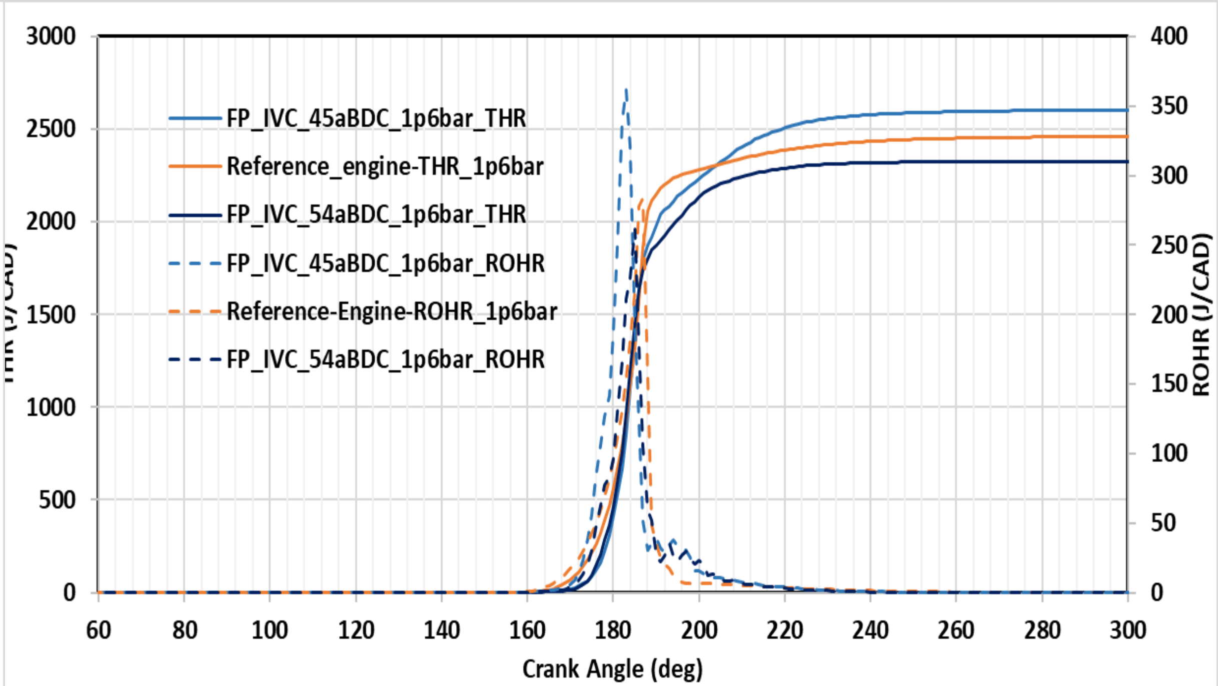
- Following two cases performed for performance evaluation of floating piston and compared with base engine performance

Parameters	Case 1	Case 1
Displacement/cly, cc	619	
Connecting Rod Length (mm)	181	
Compression Ratio	11.1	
No. of cylinders	4	
Cubic capacity (litre)	2.47	
Manifold Pressure, bar	1.61 bar	1.61 bar
IVC	52^o a BDC	45^o a BDC
EVO	52^o b BDC	
IVC Temperature	422.5 K	
Spark Timing	21.4^0 bTDC	
Spark duration	0.53ms	
Air flow rate, kg/hr @ 2800rpm	287.2	314.8
Fuel flow rate, kg/h @ 2800rpm	15.83	18.52
FMEP, bar	1.45	1.45
PMEP, bar	0.60	0.60
FMEP+PMEP, bar	2.05	2.05
A/F ratio (Stoichiometric)	17.0	17.0

- Case 1: IVC pressure is same as base and accordingly fuel quantity calculated based on stoichiometric a/f
- Case 2: IVC conditions changed to get tapped mass equivalent to base engine. This case performed to check the response of floating piston

Performance Comparison – Relative Motion





Simulation Cases	Engine Speed - 2800 rpm															
	Equivalent Displacement (4-cylinder)	IVC/EVO	Air flow	fuel	Air flow	fuel	A/F	Heat Energy Input	Total Heat Release	Combustion Efficiency based on heat energy release	FMEP	BMEP	Power	Torque	kW/l	Peak Firing Pressure (PFP)
	~cc		mg/st		kg/hr			J	J	%	Bar		kW	Nm		bar
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Base Engine simulation	3520	52 aBDC/52bBDC	928.1	54.6	311.8	18.35	17.0	2674.91	2460	92.0	1.45	9.39	77.1	262.84	21.89	88.20
% deviation b/s test & sim	-	-	2.2	2.2	2.2	2.21	-	2.2	1.1	-1.1	-	1.1	1.2	1.2	1.2	2.0
Floating Piston Case1	2653	45 aBDC/52bBDC	936.9	55.1	314.8	18.52	17.0	2700.39	2611	96.7	1.45	13.19	81.7	278.69	30.80	108.50
Floating Piston Case2	2653	52 aBDC/52bBDC	801.0	47.1	287.2	15.83	17.0	2307.9	2262	98.0	1.45	11.71	72.5	247.35	27.34	90.57

Note: RM piston engine friction considered equivalent to base engine and above calculations done for comparison

Relative Motion Friction – Simulation Results

- RM piston is having additional two relative motions and additional piston rings, these may contribute to additional friction.
- Assuming about 50% additional friction, total engine friction estimated to up to 2.17 bar.

With revised friction, engine performance is as below

Simulation Cases	Engine Speed - 2800 rpm																
	Equivalent Displacement (4-cylinder)	IVC/EVO	Air flow	fuel	Air flow	fuel	A/F	Heat Energy Input	Total Heat Release	Combustion Efficiency based on heat energy release	FMEP	BMEP	Power	Torque	kW/l	Peak Firing Pressure (PFP)
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Floating Piston Case2	2653	52 aBDC/52bBDC	801.0	47.1	287.2	15.83	17.0	2307.9	2262	98.0	2.17	10.99	68.0	232.03	25.64	90.57

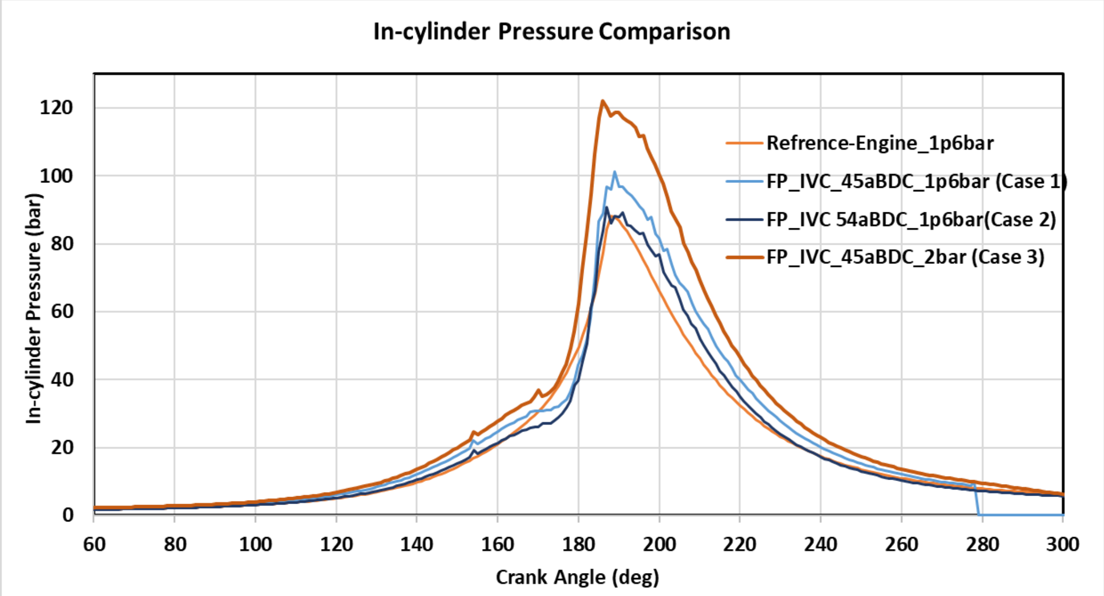
RM engine performance is also depending on engine friction level

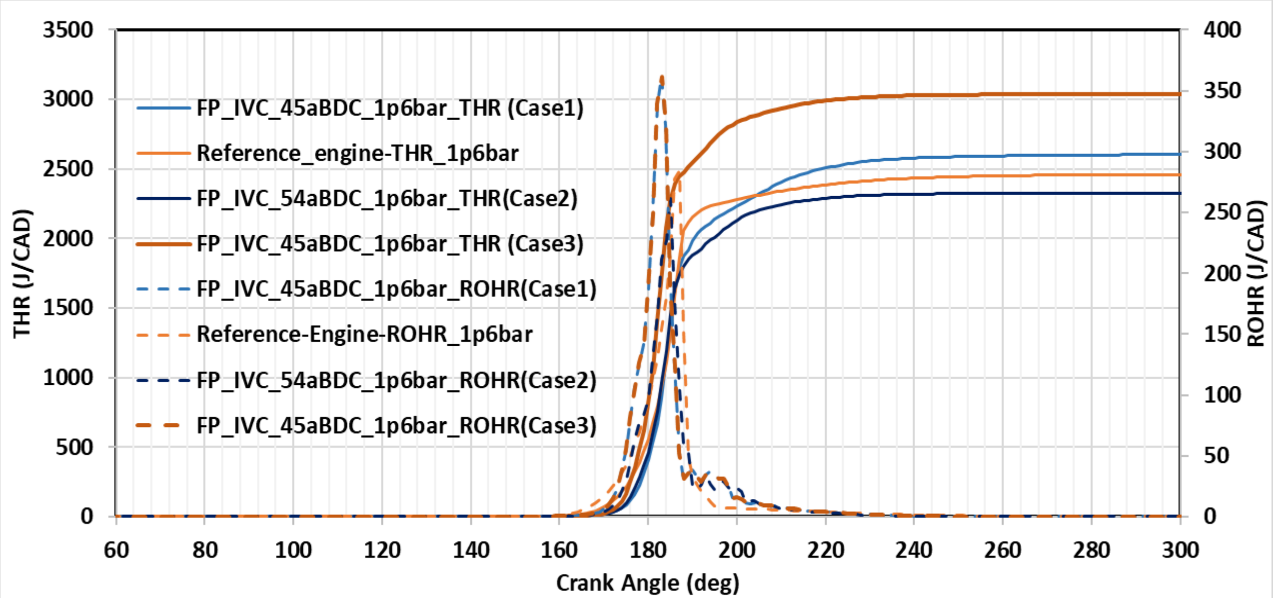
Relative Motion Friction – Simulation Results

Parameters	Case 3
Displacement/cly, cc	663.3
Connecting Rod Length (mm)	181
Compression Ratio	11.1
No. of cylinders	4
Cubic capacity (litre)	2.65
Manifold Pressure, bar	2.0 bar
IVC	52^o a BDC
EVO	52^o b BDC
IVC Temperature	422.5 K
Spark Timing	21.4^0 bTDC
Spark duration	0.53ms
Air flow rate, kg/hr @ 2800rpm	358.9
Fuel flow rate, kg/h @ 2800rpm	21.1
FMEP, bar	2.17
PMEP, bar	0.60
FMEP+PMEP, bar	2.77
A/F ratio (Stoichiometric)	17.0

Case 3 simulation run performed with higher intake mass flow about 12.5% as compared to case 1 to understand the engine combustion performance.

Relative Motion Friction – Simulation Results





Simulation Cases	Engine Speed - 2800 rpm															
	Equivalent Displacement (4-cylinder)	IVC/EVO	Air flow	fuel	Air flow	fuel	A/F	Heat Energy Input	Total Heat Release	Combustion Efficiency based on heat energy release	FMEP	BMEP	Power	Torque	kW/l	Peak Firing Pressure (PFP)
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Floating Piston Case2	2653	52 aBDC/52bBDC	801.0	47.1	287.2	15.83	17.0	2307.9	2262	98.0	2.17	10.99	68.0	232.03	25.64	90.57
Floating Piston Case3	2653	45 aBDC/52bBDC	1054.0	62.1	358.9	21.11	17.0	3040.45	3036	99.9	2.17	16.06	99.5	339.23	37.49	126.00

Summary of Results

- Base engine simulation model validated within 3%
- RM piston engine model and floating piston motion profile shared by Kanalysis
- Model shared by KAnalysis corrected by ARAI and total clearance volume 729.6cc and compression ratio 11.1
- 50% higher friction considered for RM piston friction and calculations done with both base and revised friction for comparison
- Base model IVC conditions considered for RM piston model and two case studies simulation performed with IVC 45 deg aTDC and 52 deg aTDC
- Results shows that combustion efficiency improvement with RM piston concept
- Flat peak pressure observed with RM piston as compared to base which is unique feature of this concept
-

Summary of Results

- 40% higher Power/ltr with RM piston concept for the same fuel and air mass conditions
- About 25% higher Power/ltr with RM piston concept for RM piston conditions where air+fuel mass fuel is as per actual engine size and conditions
- Improved combustion efficiency is good sign of this concept

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