ANSYS

Engine Expo 2012

Novi, Michigan

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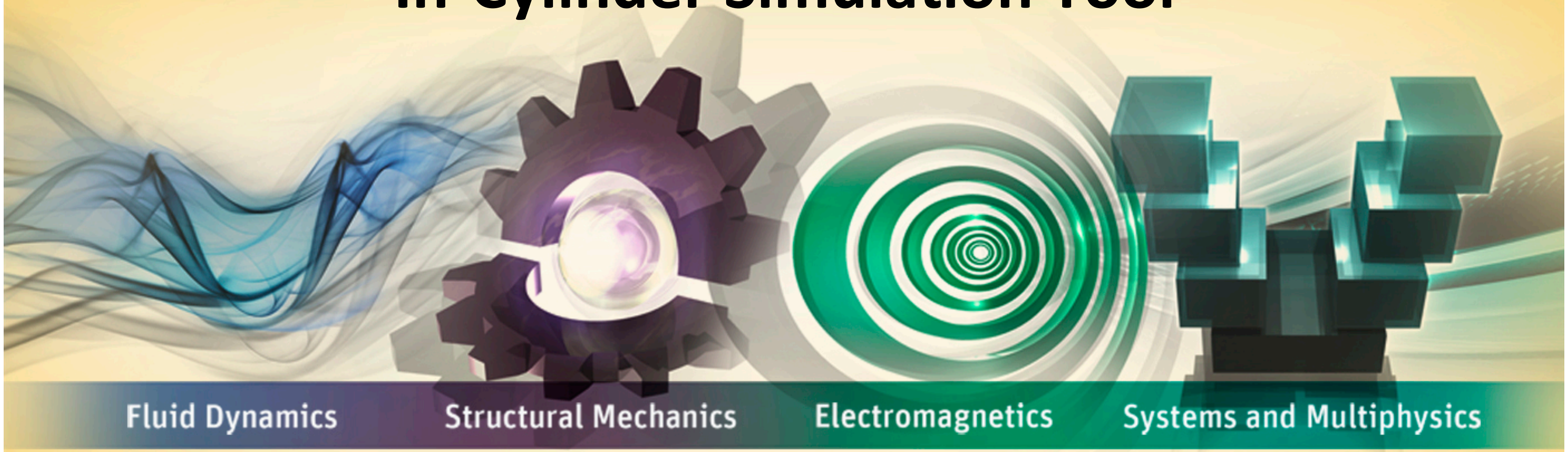
Advancements and Validation of an Automated In-Cylinder Simulation Tool



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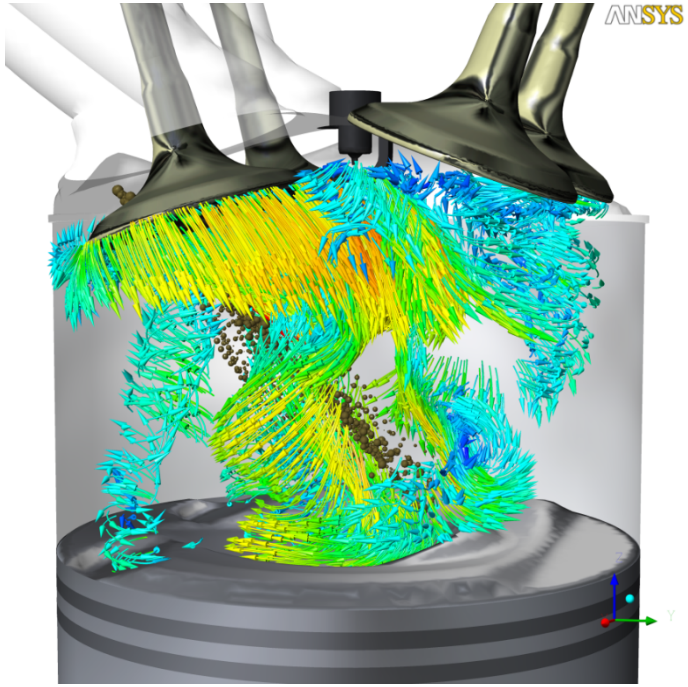
ANSYS, Inc.

Outline

- **IC Engine Simulations**
- **Automated IC Engine Software**
  - Introduction
  - Properties
  - Meshing techniques
  - Additional features
- **Validation Example**
- **Summary**



Market Trend

- Energy Security
- Environment
- Competitiveness
- Global Economy

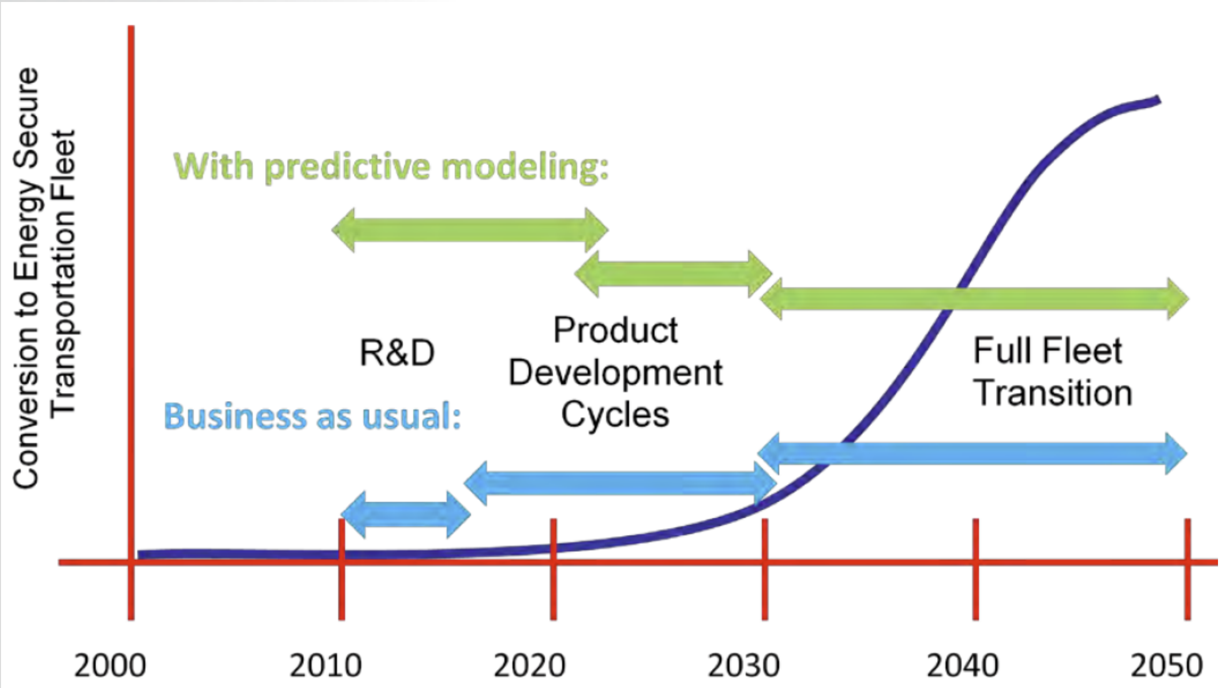
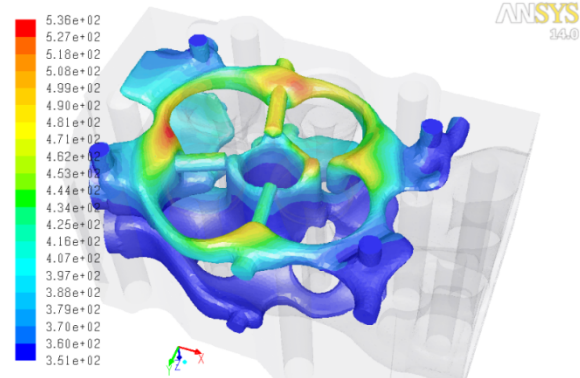


Figure courtesy of PreSICE workshop held by DOE, March 2011

→ Advanced Simulation Technology | Virtual Prototyping | Process Compression

Powertrain Simulation Types

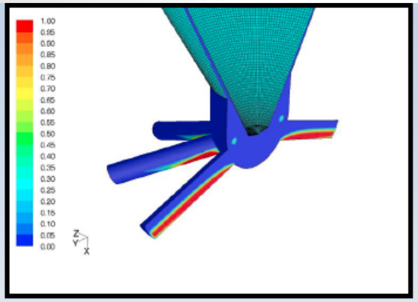


Component simulations

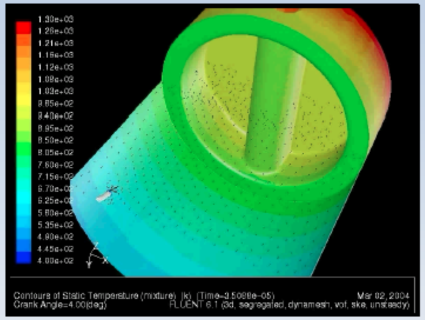
- Intake port, intake manifold, water jackets, fuel injectors
- Spray bomb

IC Engine simulations

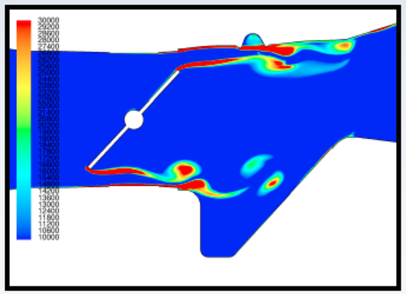
- Cold flow
  - Charge motion
- Combustion
  - Thermal management
  - Emissions



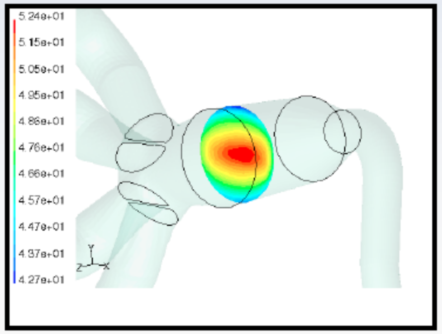
Fuel Injector Cavitation Modeling



Piston Cooling Simulation



Noise generated in throttle body of Air Intake System

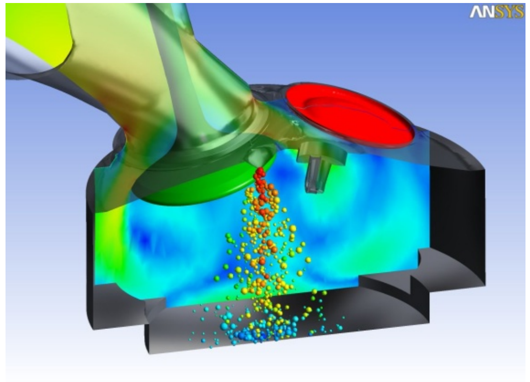


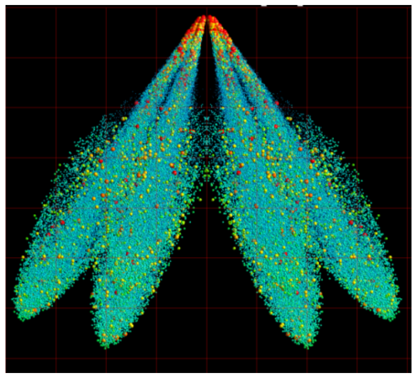
Uniformity calculation in catalytic converter

IC Engine Simulation Workflow

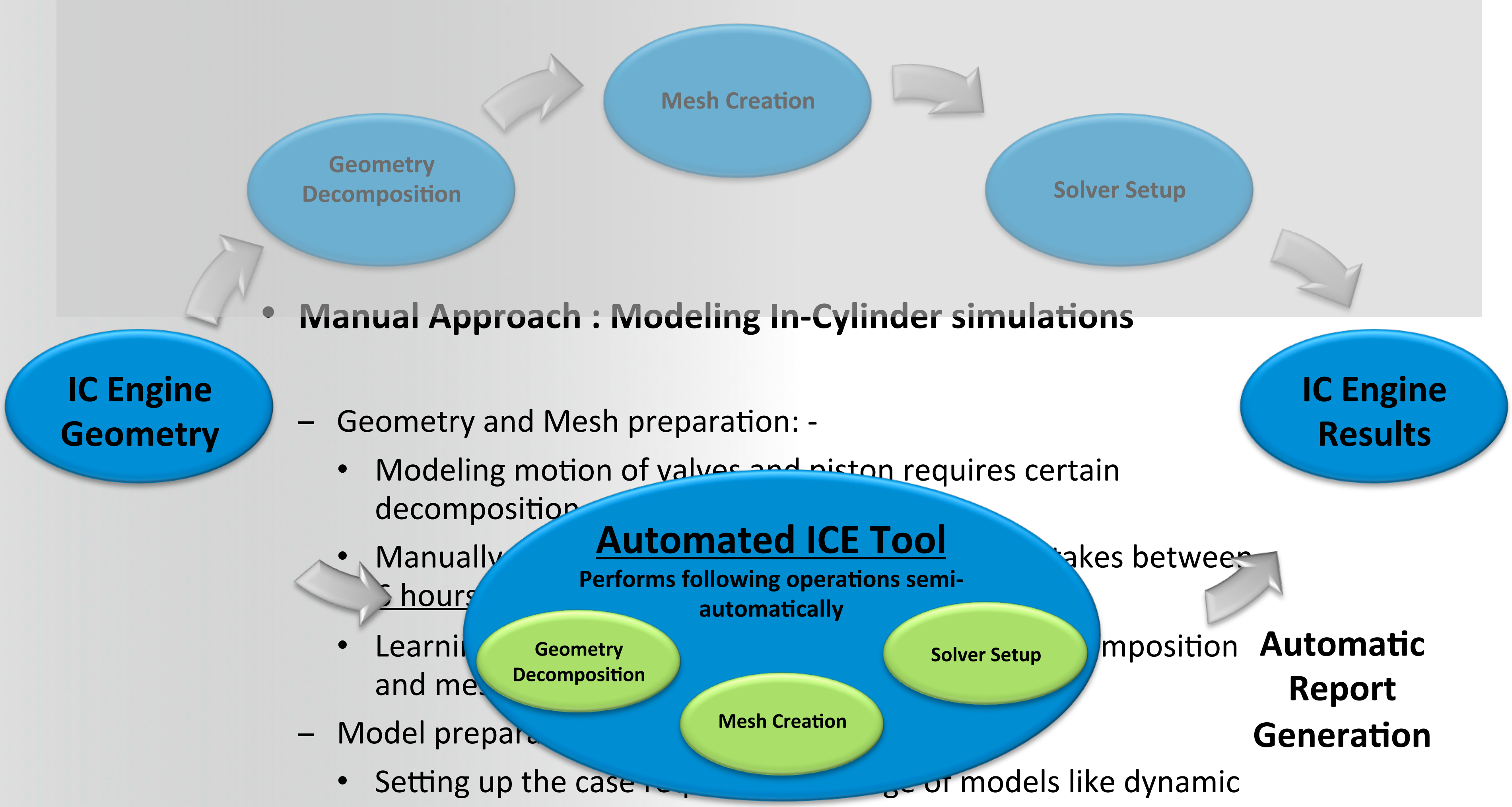
Internal combustion engine simulation components

- Pre-processing
  - Geometry decomposition
  - Initial meshing
  - Simulation parameter definition
- Moving deforming meshes
  - Smoothing, remeshing, layering
- Particle tracking
  - Injection, tracking, evaporation, wall-interaction
- Combustion
  - Ignition, flame front propagation
- Post-processing
  - Automatic processing of monitor and solution data





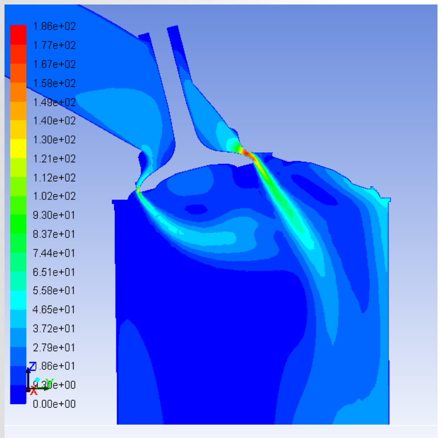
Motivation



- **Manual Approach : Modeling In-Cylinder simulations**
  - Geometry and Mesh preparation: -
    - Modeling motion of valves and piston requires certain decompositio
    - Manually ... takes between ... 5 hours
    - Learni ... mposition and me
  - Model prepar
    - Setting up the case re ... ge of models like dynamic mesh, reacting flows, spray, etc.

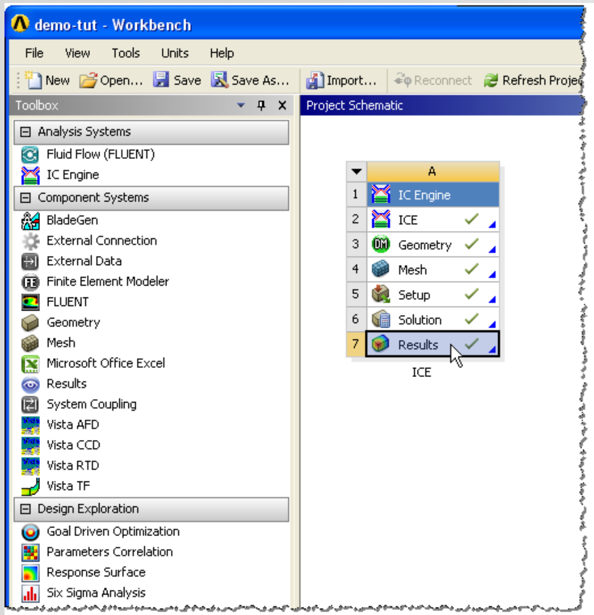
Scope of Automated IC Engine (ICE) Tool

- **Automated mesh generation for all 4 stroke engines**
  - **Any number of valves**
  - **All standard shapes of piston**
- **Automated case setup for “cold-flow” and “gas-exchange” type simulations**
- **User can setup a case for spray and combustion simulation in Fluent**

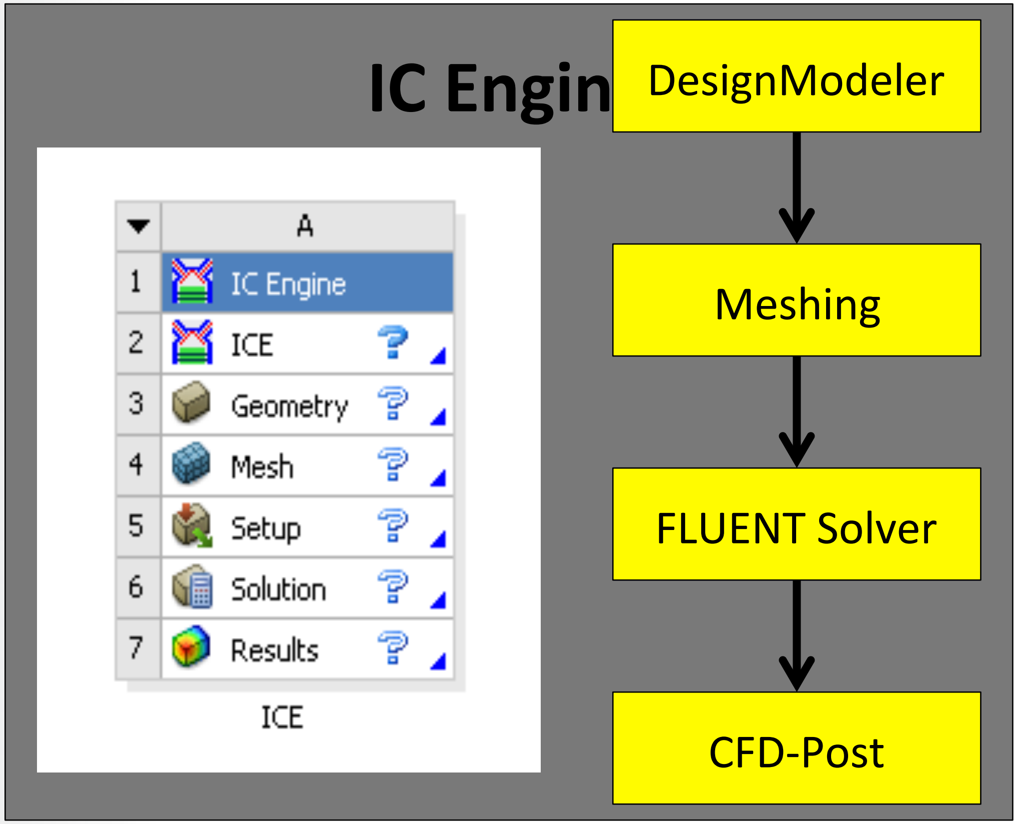


Automated In-Cylinder Simulation Tool: Introduction

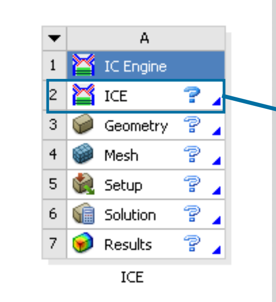
- **Analysis-System similar to Fluid-Flow (FLUENT) or Fluid-Flow (CFX) Analysis-System within Workbench**
- **Supported in Windows only (in R14)**
- **<u>Standard</u> feature along with ANSYS FLUENT license**



Automated IC Engine Workflow



Automated In-Cylinder Simulation Tool Properties



Properties of Schematic A2: ICE

	A	B	C	D
1	Property	Value	Unit	P
2	General			
3	Component ID	ICE		
4	Directory Name	ICE		
5	Notes			
6	Notes			
7	Used Licenses			
8	Last Update Used Licenses			
9	Simulation Type			
10	Simulation Type	Cold Flow Simulation		
11	Engine Inputs			
12	Connecting Rod Length	200	mm	
13	Crank Radius	20	mm	
14	Piston Offset/ Wrench	0	mm	
15	Engine Speed	1800	rev min^-1	
16	Minimum Lift	0.2	mm	
17	Valve Lift And Piston Motion Profile			
18	Solver Setup			
19	Solver Settings File	ICE\ICE\icSolverSettings.txt		
20	Default Boundary Conditions and Monitor Settings	ICE\ICE\icBcSettings.txt		
21	Journal Customization			
22	User Boundary Condition Profiles			
23	User Boundary Conditions and Monitor Settings	ICE\ICE\icUserSettings.txt		
24	Pre Iteration Journal			
25	Post Iteration Journal			

For engines with piston pin offset

For valve profiles

User can hook boundary condition profiles

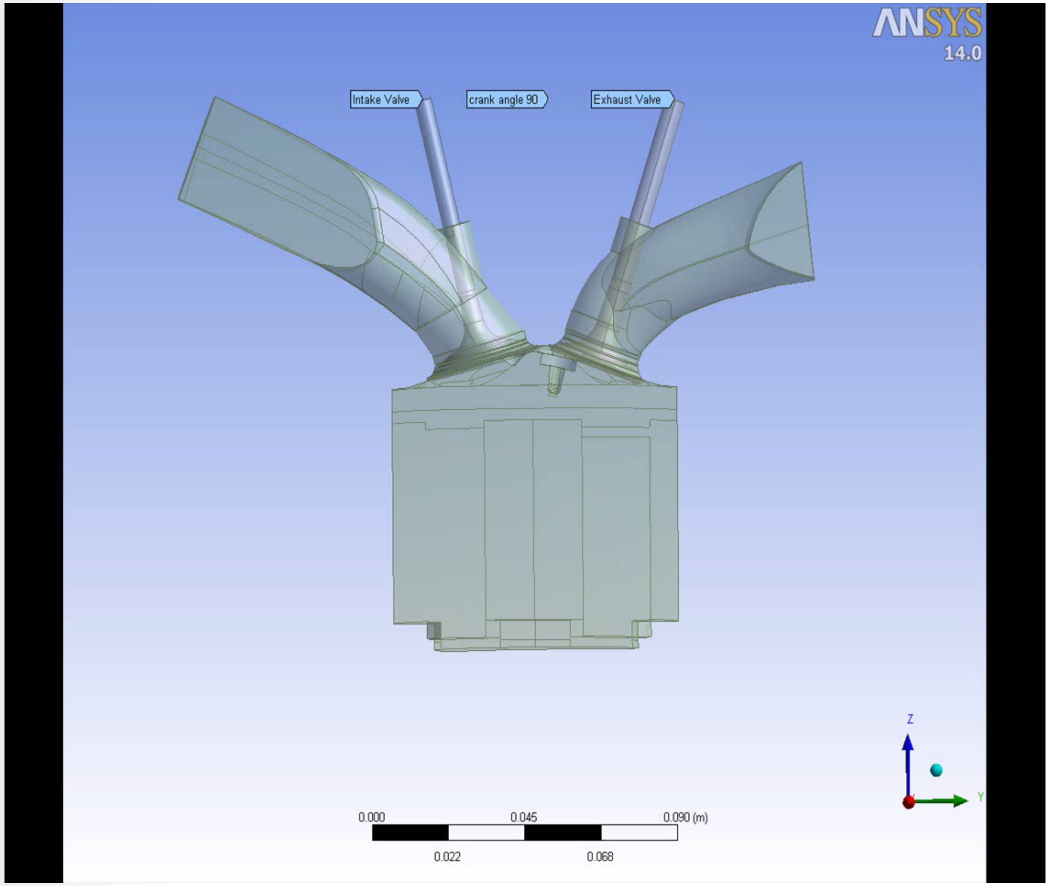
These IC inputs can be defined as Parameters

Can be used to setup a customized case

Can be used to perform custom post-processing

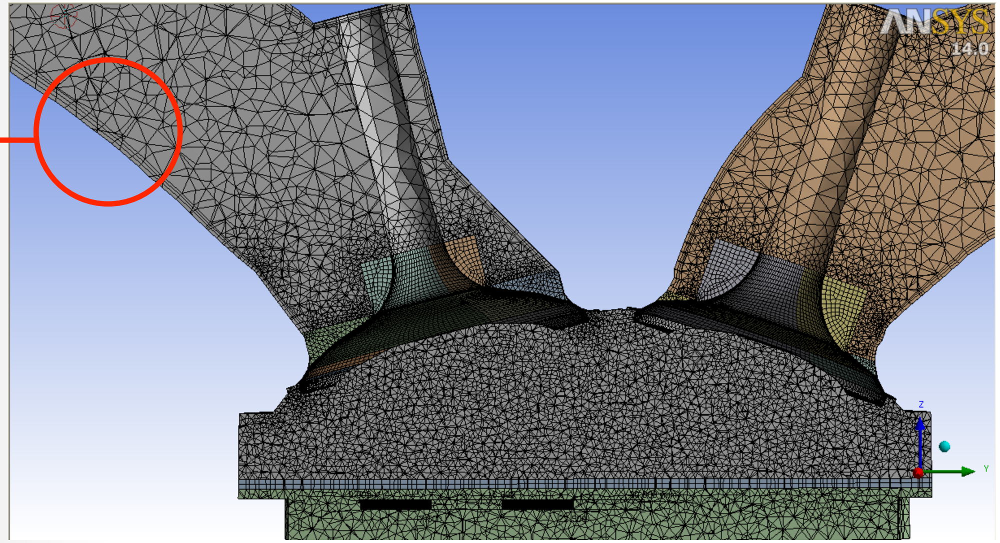
Animation of Piston & Valve Movements

- Ability to animate motion of piston and valves before the mesh creation
  - Up-front identification of any mistakes/errors in valve profile and engine motion inputs
  - Takes just few seconds

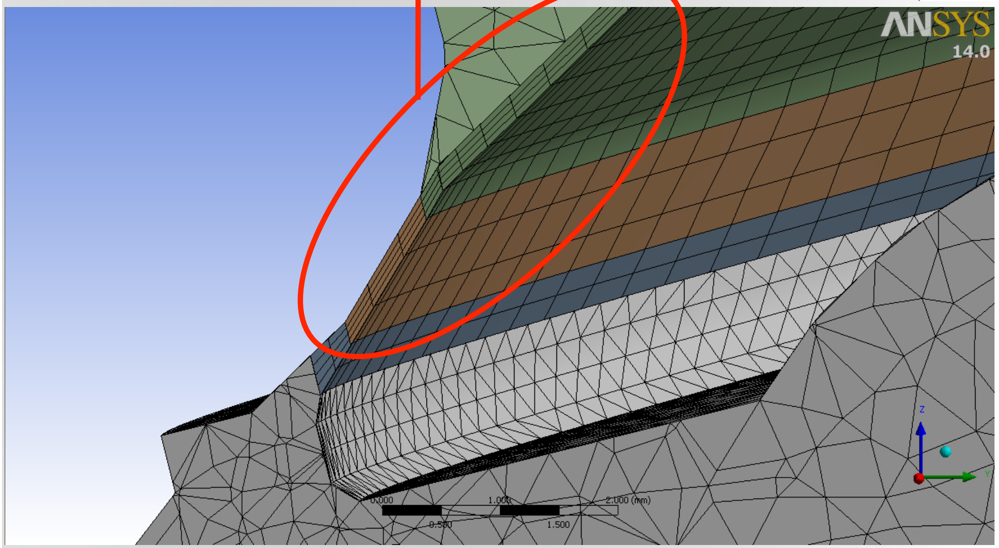


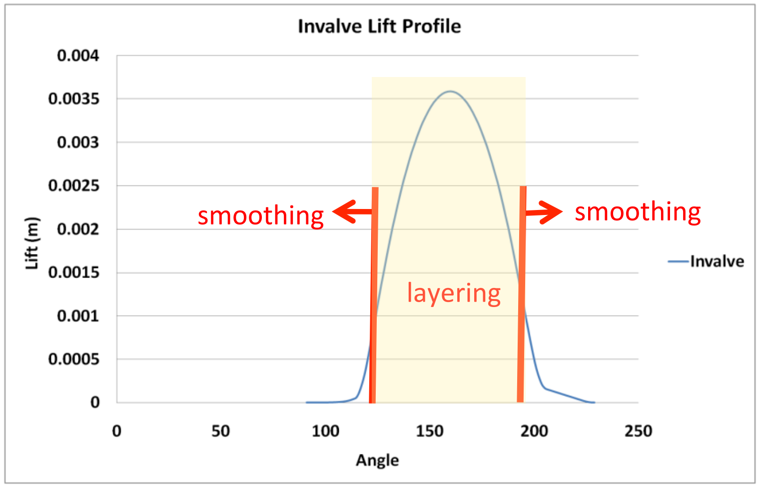
Computational Grids Generated by ICE Tool

Inflation layers in the port region to capture boundary layers

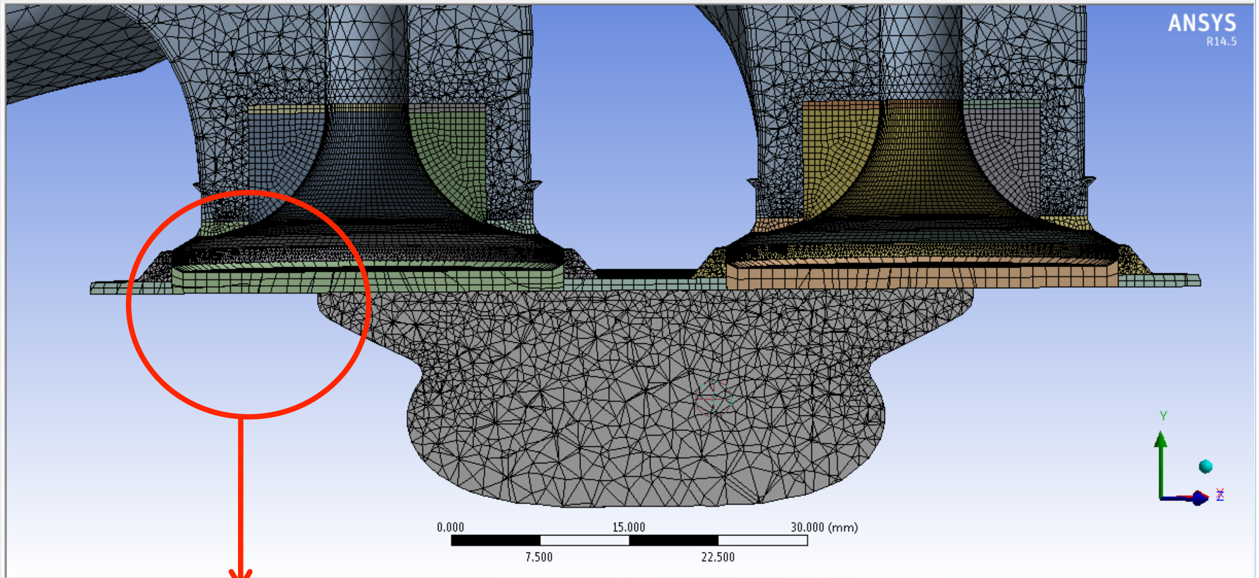


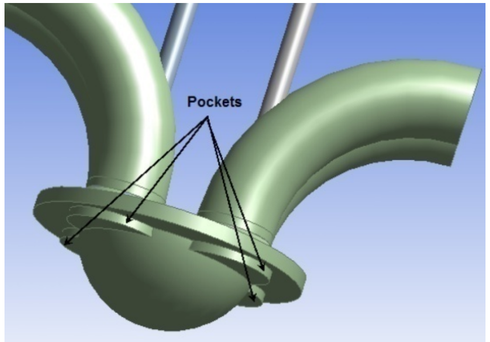
4 layers between valve and valve-seat at fully-closed position of valve (V-layer region)





Meshes for Straight Valve (Diesel) Engines

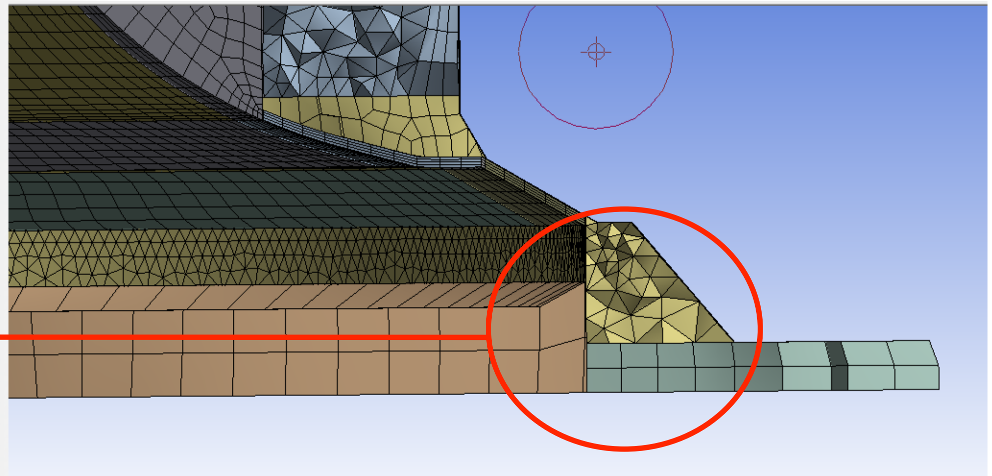




With and without Valve Pockets

Complete layering (hex cells) in the combustion chamber region due to further decomposition and non-conformal interfaces.

Applicable for straight valve engines



IC Engine Reports

1. File Report

Table 1. File Information for bmw aft new

Case	bmw aft new
File Path	G:\sushil-data\BMW_AFT-sep2\bmw-aft_files\dp0\ICE\Fluent\ICE-2-03501.dat.gz
File Date	08 September 2011
File Time	12:20:17 PM
File Type	FLUENT
File Version	14.0.0

2. Mesh Report

Table 2. Mesh Information for bmw aft new

Domain	Nodes	Elements
fluid ch	90064	468437
fluid exvalve 1 port	27805	103552
fluid exvalve1 ib	34104	29792
fluid exvalve1 vlayer	56700	51000
fluid invalve 1 port	37124	138061
fluid invalve1 ib	8136	6480
fluid invalve1 vlayer	21000	16200
fluid piston layer	93680	224544
All Domains	368613	1038066

Chart 1. Monitor: Volume-Average Cell Equivolume Skew (fluid-ch)

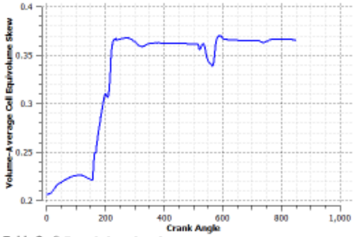


Table 3. Cell count at crank angles

Crank Angle	Cell Count
7.200e+02	7.539e+05
1.800e+02	1.822e+06

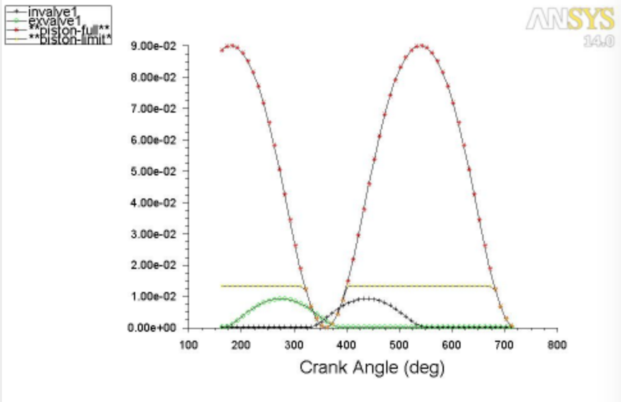
3. Setup

3.1. Physics

Table 4. Boundary Conditions

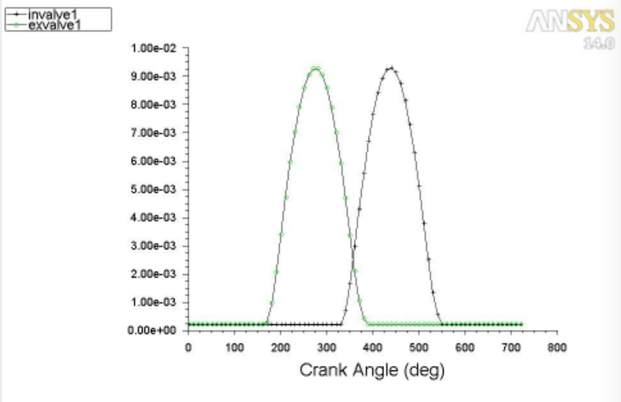
Type	Zones	Values
wall (invalve1)	invalve1-stem	Temperature (k) 551
	invalve1-ob, invalve1-ch, invalve1-ib	Temperature (k) 663
wall (exvalve1)	exvalve1-stem	Temperature (k) 851
	exvalve1-ob, exvalve1-ch, exvalve1-ib	Temperature (k) 812
wall (invalve-port)	invalve-1-port	Temperature (k) 391
wall (exvalve-port)	exvalve-1-port	Temperature (k) 475
pressure-outlet	ice-outlet-exvalve-1-port	Gauge Pressure (profile ex-pres-prof pres)
		Backflow Total Temperature (profile ex-temp-prof temp)
mass-flow-inlet	ice-inlet-invalve-1-port	Mass Flow Rate (profile in-mflow-prof mflow)
		Total Temperature (profile in-temp-prof temp)
wall	invalve1-seat	Temperature (k) 480
wall	exvalve1-seat	Temperature (k) 480
wall	cyl-head	Temperature (k) 300
wall	cyl-quad	Temperature (k) 420
wall	cyl-tri	Temperature (k) 420
wall	ice-user-cyl-piston	Temperature (k) 420
wall	ice-user-spark-plug	Temperature (k) 600
wall	piston	Temperature (k) 520

3.2. Piston and Valves Lift profiles



Valve Lifts (Time=0.0000e+00) Sep 02, 2011
ANSYS FLUENT 14.0 (3d, dp, pbns, dynamesh, ske, transient)

3.3. Valves Lift profiles



Valve Lifts (Time=0.0000e+00) Sep 02, 2011
ANSYS FLUENT 14.0 (3d, dp, pbns, dynamesh, ske, transient)

3.4. Relaxations

Table 5. Relaxations at crank angles

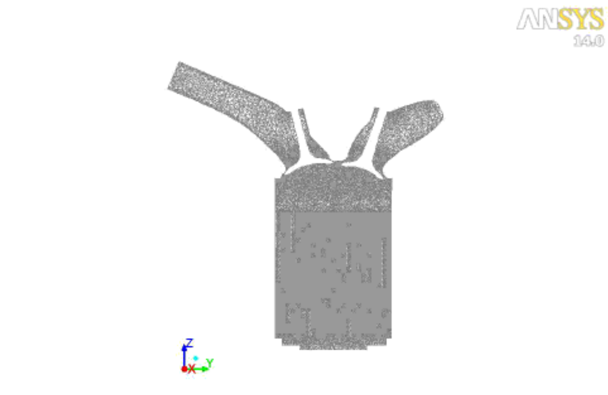
Crank Angle	Pressure	Density	Body Forces	Momentum	Turbulent Kinetic Energy	Turbulent Dissipation Rate	Turbulent
0.000	0.500	1.000	1.000	0.700	0.400	0.400	1.000
162.000	0.300	1.000	1.000	0.500	0.400	0.400	1.000
327.000	0.200	1.000	1.000	0.400	0.200	0.200	1.000
402.000	0.200	1.000	1.000	0.400	0.200	0.200	1.000
560.000	0.200	1.000	1.000	0.400	0.200	0.200	1.000

3.6. IC Engine System Inputs

Engine Inputs
Engine Speed (rev/min) : 2000
Crank Radius (mm) : 45
Piston Pin Offset/Wrench (mm) : 0
Connecting Rod Length (mm) : 144.3
Minimum Lift (mm) : 0.2
-
Journal Customization
Pre Iteration Journal File : N/A
Post Iteration Journal File : N/A

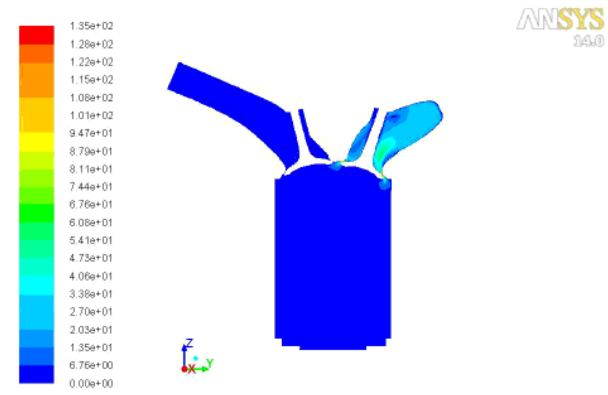
4. Solution Data

4.1. Animation: mesh-on-plane1



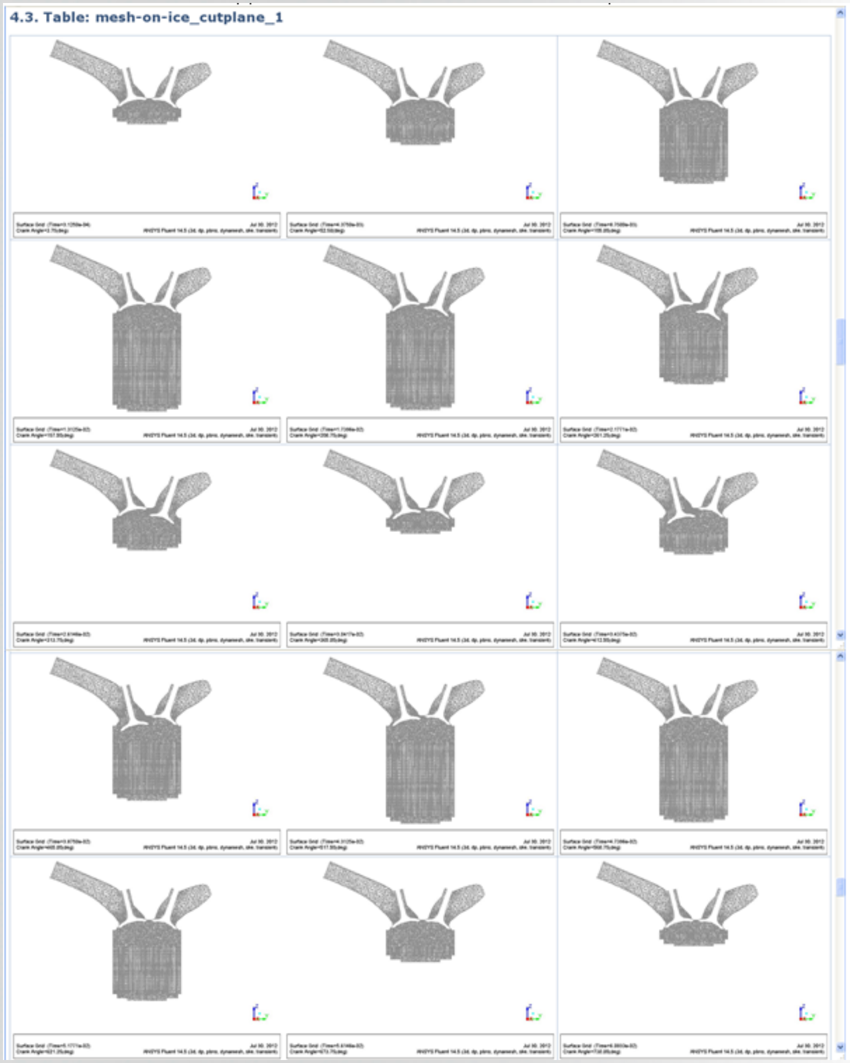
Surface Grid (Time=6.1979e-02) Sep 02, 2011
Crank Angle=905.75(deg) ANSYS FLUENT 14.0 (3d, dp, pbns, dynamesh, ske, transient)

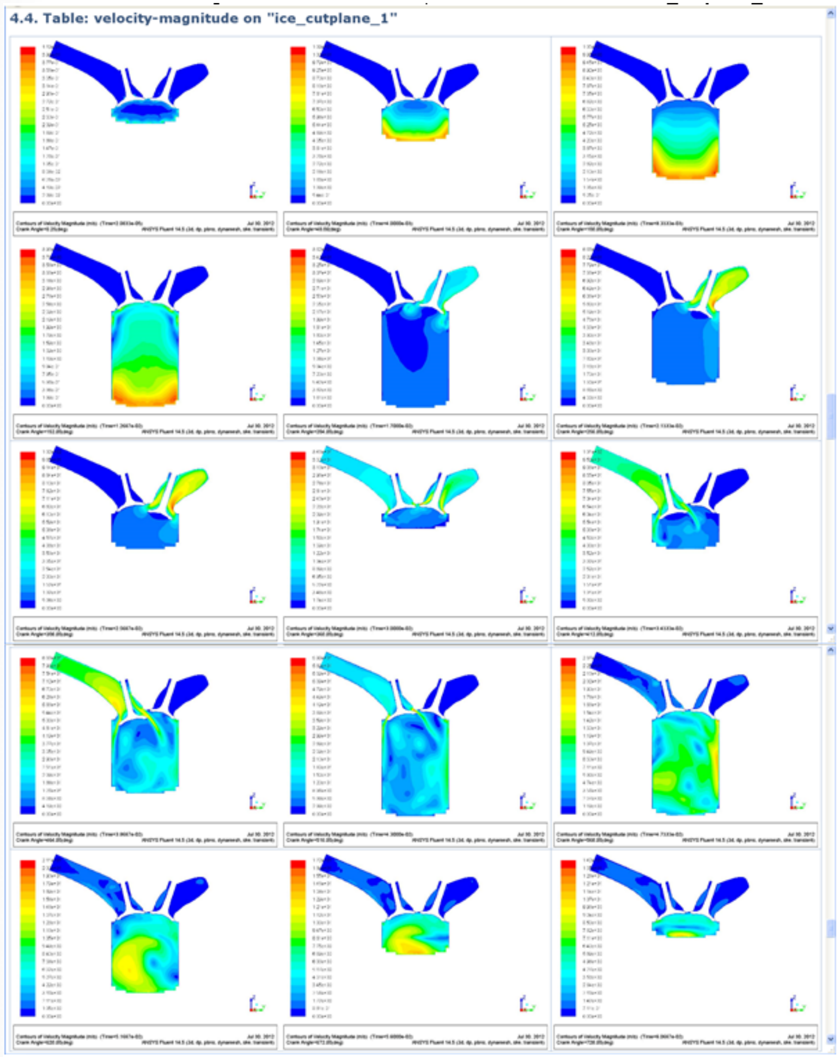
4.2. Animation: vel-mag-on-plane1



Contours of Velocity Magnitude (m/s) (Time=6.1667e-02) Sep 02, 2011
Crank Angle=902.00(deg) ANSYS FLUENT 14.0 (3d, dp, pbns, dynamesh, ske, transient)

IC Engine Reports

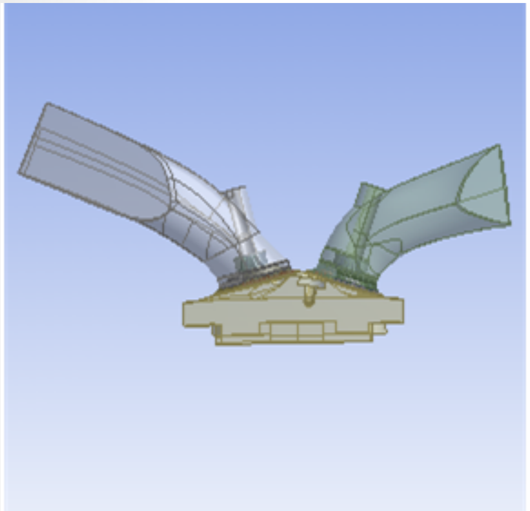




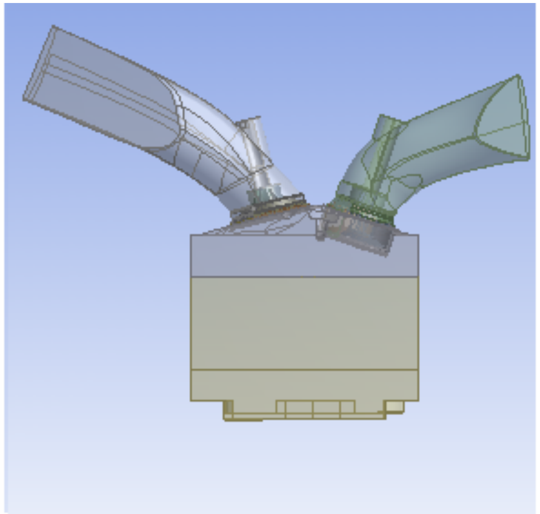
Automatic Decomposition at Different Crank Angles

- ICE tool can decompose IC engine model for any specific crank angle
- This allows:
  - Simulation to start from any specific crank angle in FLUENT without any need to perform mesh preview from TDC to particular crank angle.
  - Simulation using KeyGrids mesh. This feature provides better control on mesh size and quality throughout the simulation.

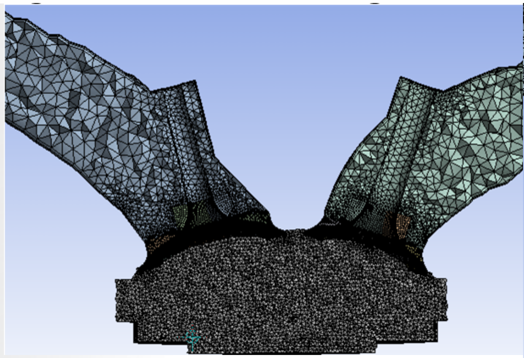
IC Advanced Options (RMB)	
V Layer Slice	Yes
V Layer Slice Angle	15 °
V Layer Approach	4 Layers
FD1, Decomposition Crank Angle	0 °

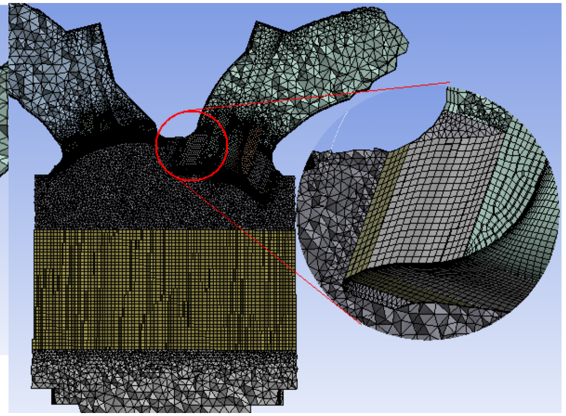


At 0 Degrees



At 270 Degrees





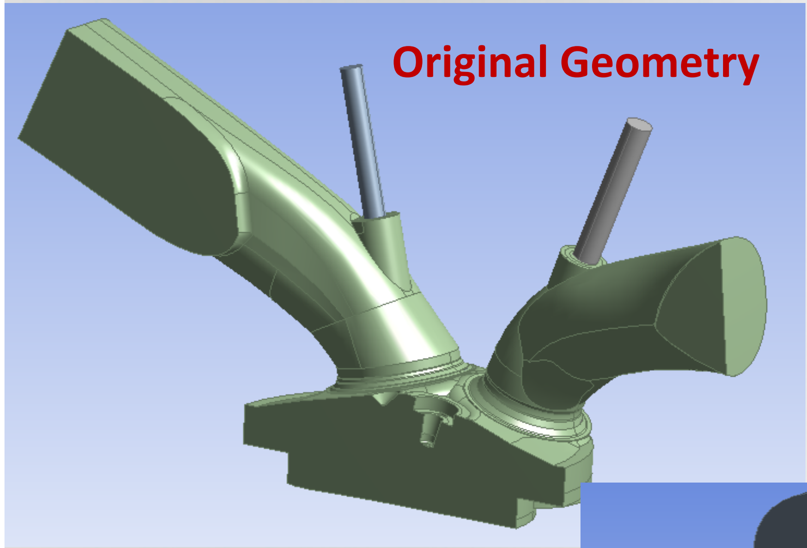
Linux Support & Port Flow Analysis

Linux Support

Port-flow support

- Automatic preparation of Geometry for port flow
  - Moving the valve to appropriate given distance
  - Deactivate the closed valve
  - Remove the piston-bowl (if needed) and extend the cylinder to appropriate length
  - Create different types of inlet/outlet plenum
  - Automatic creation of swirl/tumble planes
- Automatic meshing
  - Cartesian (Cutcell) and Hybrid meshing support
  - Create proper mesh controls and sizing to get better mesh in the chamber and valve gap
  - Proper boundary layers in both hybrid and cutcell meshing

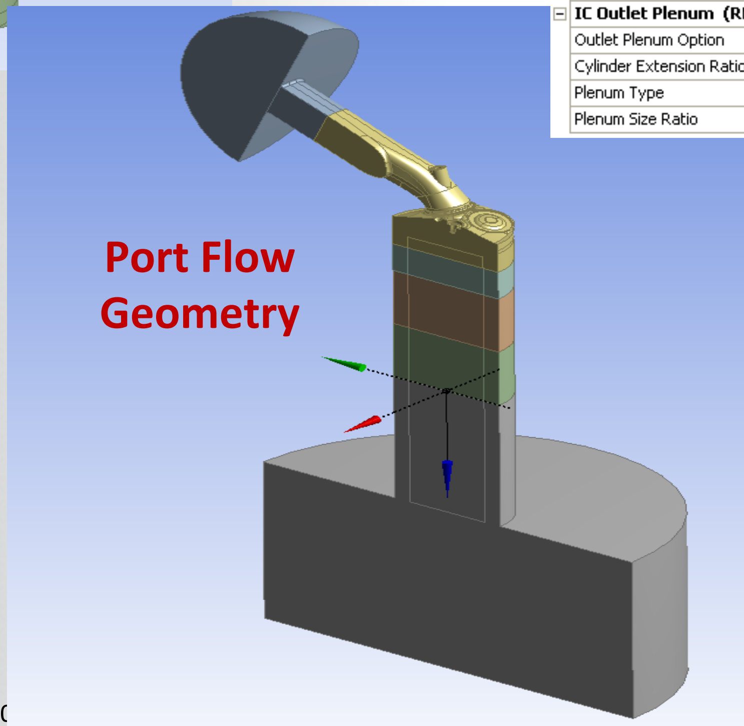
Workflow of Port Flow Analysis



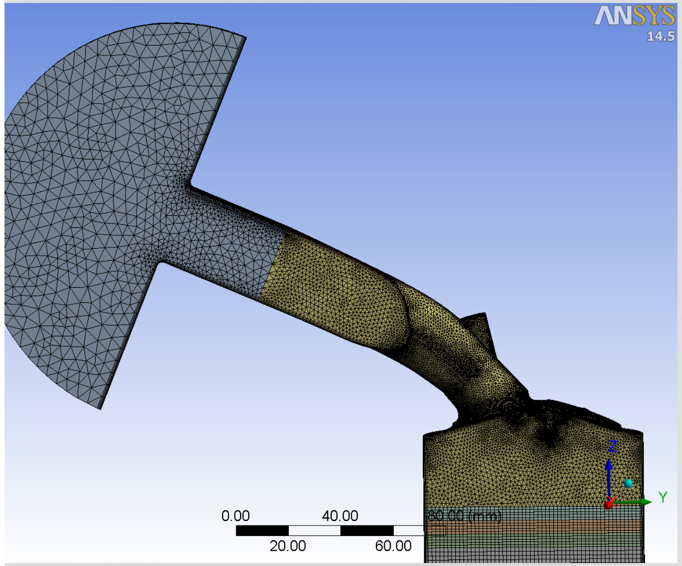
Details of InputManager1	
Name	InputManager1
Cylinder Faces	1 Face
Symmetry Face Option	Yes
Symmetry Faces	2 Faces
Post Planes Dist. From Ref.	None
IC Valves Data 1 (RMB)	
Valve Type	InValve
Valve	2 Bodies
Valve Seat	2 Faces
Valve Lift	5 mm
IC Inlet Plenum 1 (RMB)	
Inlet/(Plenum Inlet) Faces	1 Face
Inlet Extension Ratio(L/D)	1.5 Hyd Dia
Plenum Type	Hemisphere
Plenum Size Ratio	5.5 Hyd Dia
Plenum Blend Rad	2 mm
IC Inlet Plenum 2 (RMB)	
IC Outlet Plenum (RMB)	
Outlet Plenum Option	Yes
Cylinder Extension Ratio(…	3.0 Cyl Dia
Plenum Type	Cylinder
Plenum Size Ratio	3.5 Cyl Dia

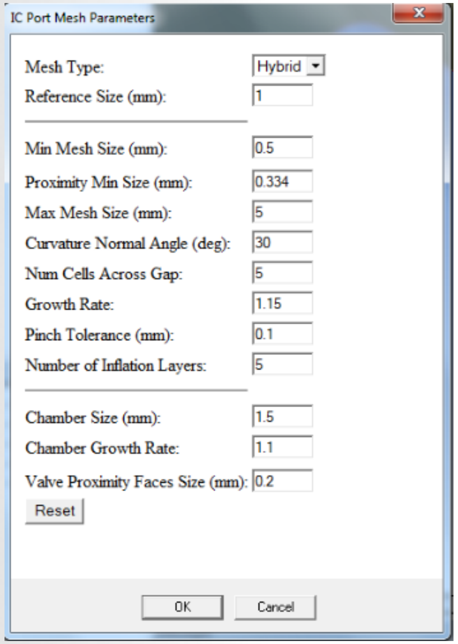
Input Manager for Port Flow

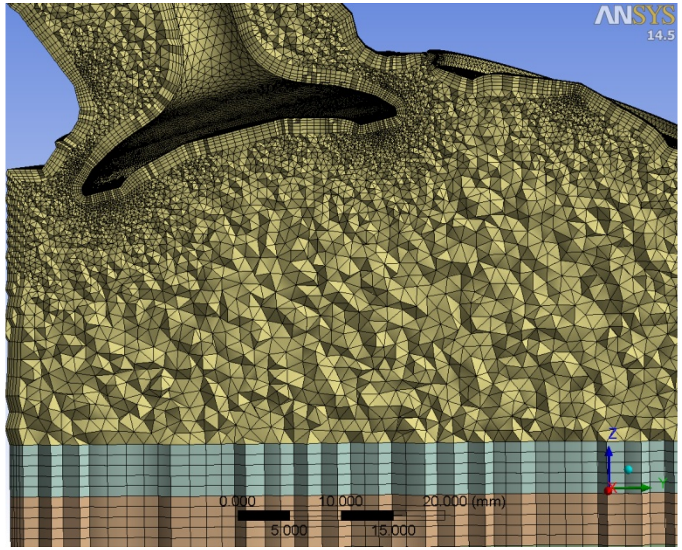
Final geometry with Inlet and Outlet Plenums, and port deactivated

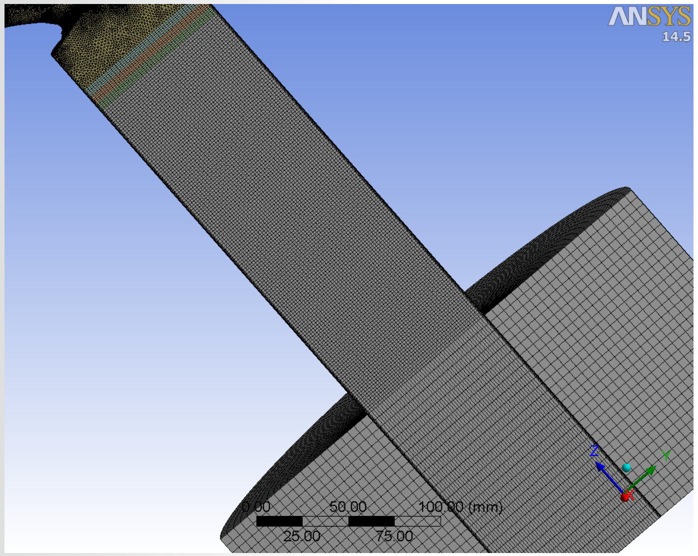


Meshed Generated for Port Flow Analysis

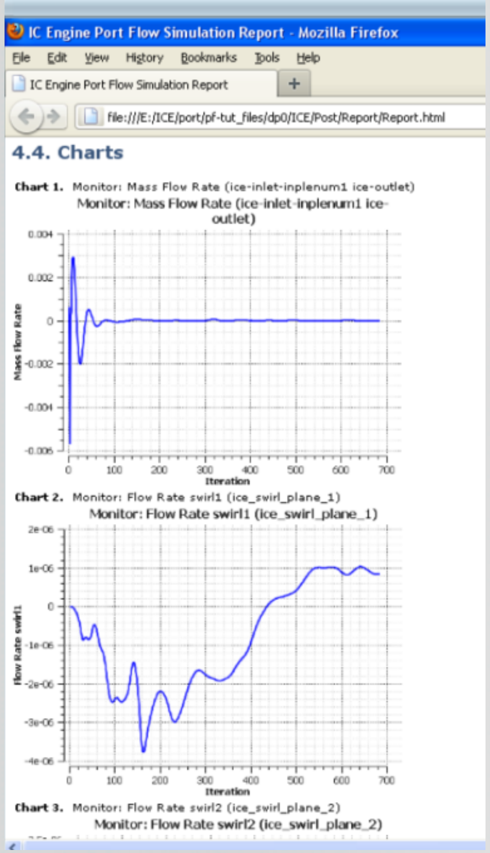




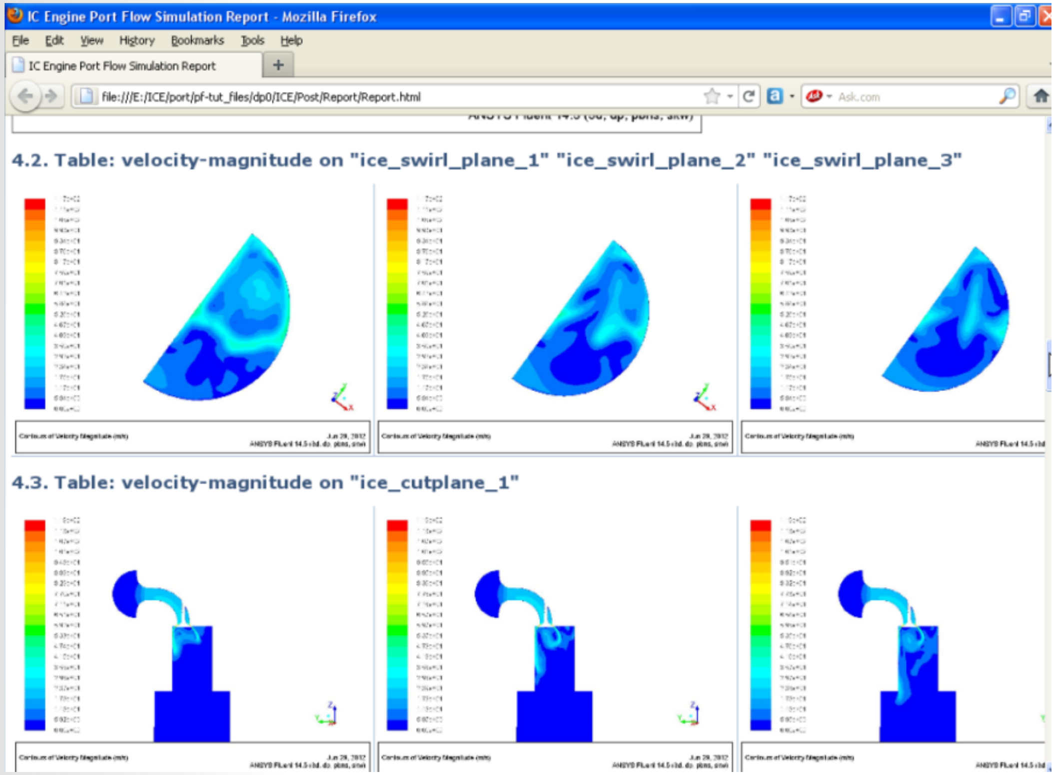




Automatic CFD Setup, Solver and Report Creation



Solution Monitors

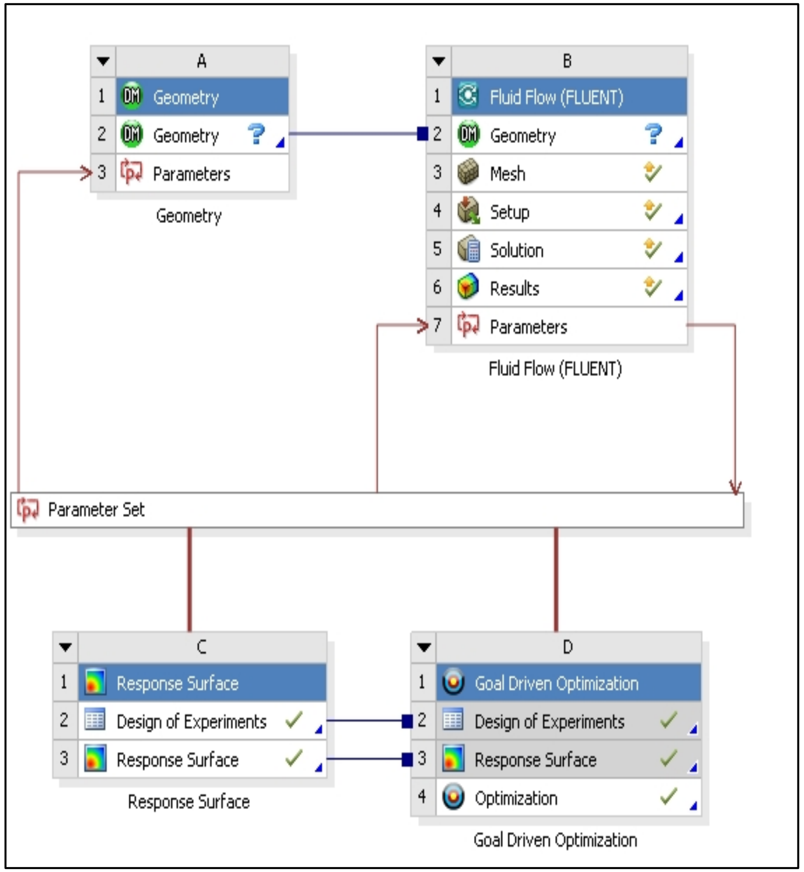


Flow Visualization

Parametric Design Optimization

Goal: Maximize Effective Flow Area of a gasoline engine within a specified range of input design parameters

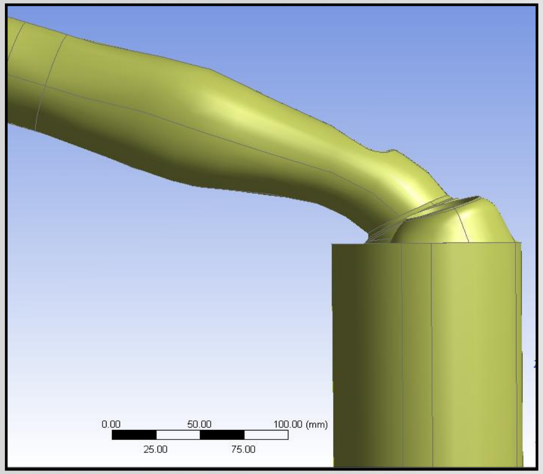
- Effective Flow Area
  - EFA = $\dfrac{\dot{m}}{\sqrt{2\rho\Delta P}}$
  - m = Mass flow rate through the intake port
  - ρ = Density of the incoming fuel-air mixture
  - ΔP = Pressure drop across the intake duct



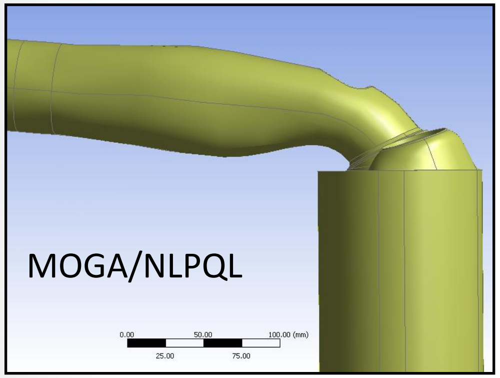
Input Parameter	Value at baseline design
guide-curve-angle	63 Deg
guide-curve-radius	41 mm
section-1-length-1	51 mm

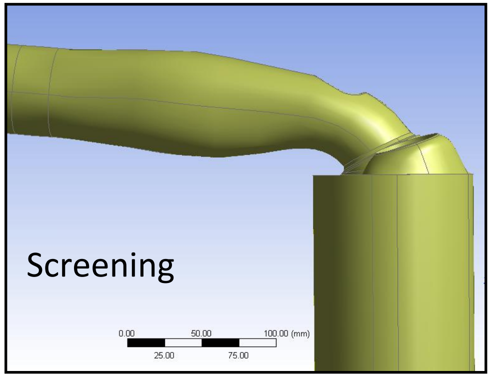
Parametric Design Optimization

Baseline Design



Optimized Designs





Guide Curve Angle (Deg)	Guide Curve radius (mm)	Section-1-Length (mm)	EFA (mm^2)
63	41	51	1100.2

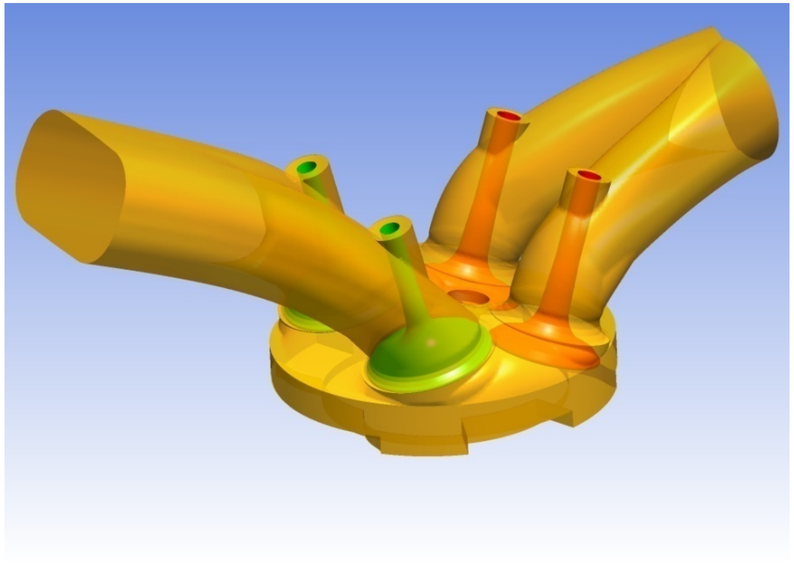
Method	Guide Curve Angle (Deg)	Guide Curve radius (mm)	Section-1-Length (mm)	EFA (mm^2)
MOGA/NLPQL	50	30	60.499	1180.4
Screening	50.069	35.314	58.519	1153.8

Validation: Direct Injection Gasoline Engine

Complete cycle setup

- **Initial conditions and boundary conditions provided by 1D simulation**
- **Fuel: Iso-octane**
- **6-hole injector**
  - **Double injection**
  - **Transient mass flow**
  - **Prescribed diameter distribution**
- **Spark ignition**
- **G equation combustion model**

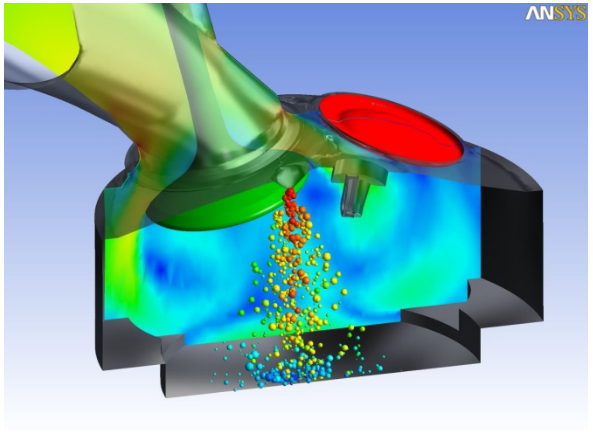
Test case provided by BMW



Validation: Direct Injection Gasoline Engine

Simulations

- Cold flow simulation (no spray or combustion)
- Charge motion
  - Plus spray injection
  - Plus particle tracking
- Combustion
  - Plus ignition
  - Plus flame front propagation



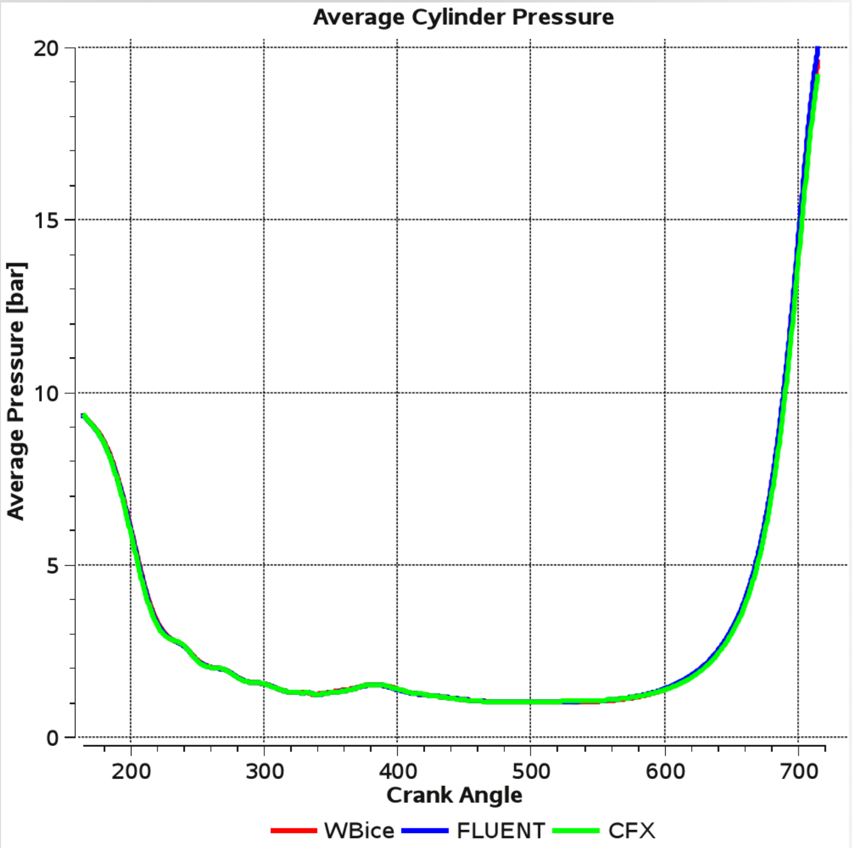
Compare cycle simulation using different workflows

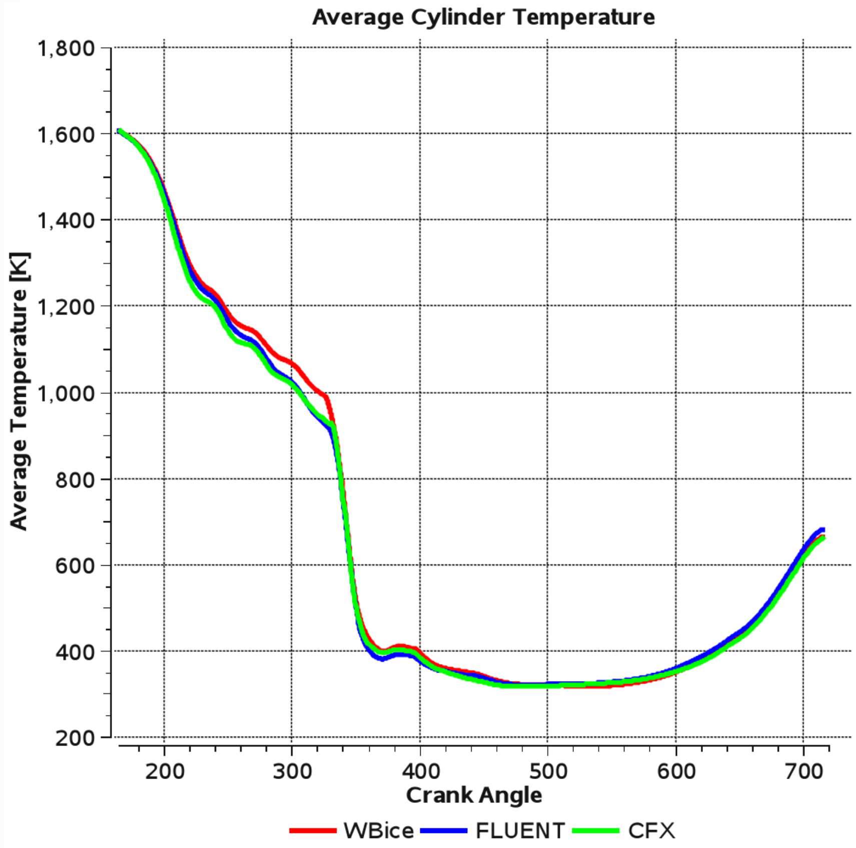
- WB-ICE with ANSYS Meshing & FLUENT
- ICEM CFD key grids & FLUENT
- ICEM CFD key grids & CFX

Validation: Direct Injection Gasoline Engine

Cold flow simulation

- **Comparison WB-ICE, FLUENT, CFX**
- **Cylinder averaged values of pressure and temperature**





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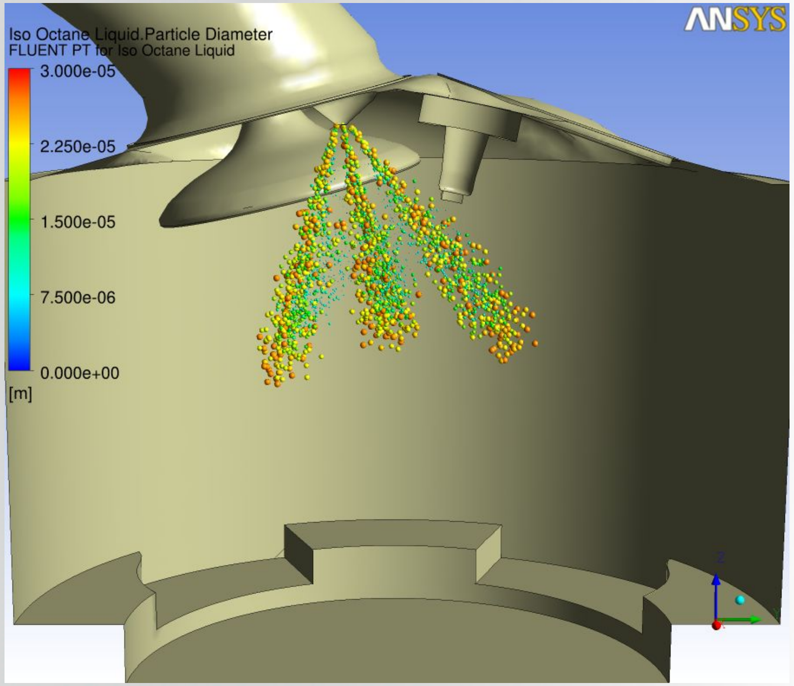
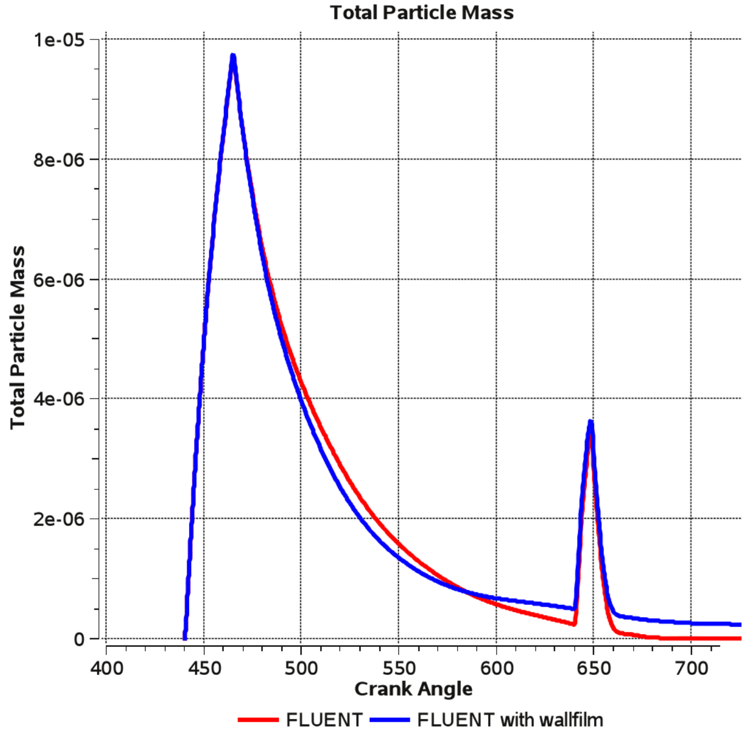
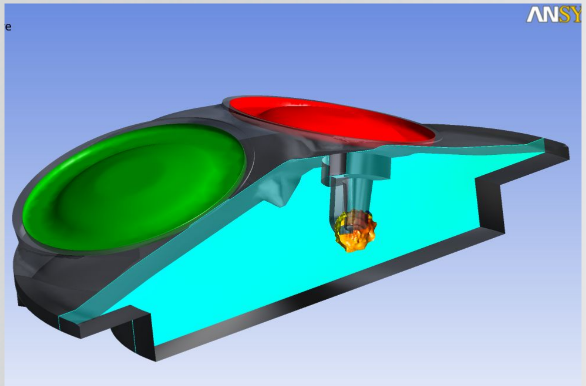
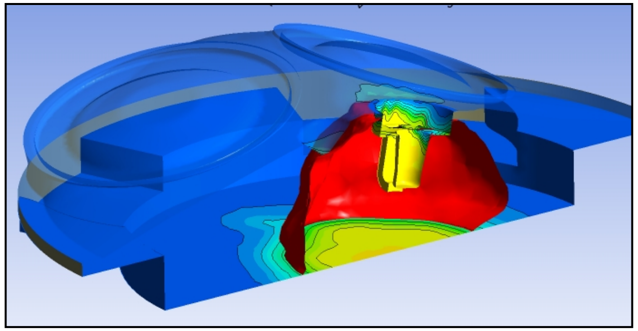
Particle Tracking and Flame Propagation







G-equation combustion



Summary

- A new "standard" feature in ANSYS-FLUENT for In-Cylinder simulations was presented.
- The ICE Tool automates In-Cylinder model creation and simulation.
- The ICE Tool provides ease of use and accurate analysis of In-Cylinder flows and heat transfer.
- A validation study on a GDI engine was utilized to test and improve the performance.
- Combustion and spray analysis can be conducted in Fluent, but automation of combustion is a future plan.

