Engineering Services for Engine Performance Development

HERON TECHNIK

GmbH Graz/Austria

Overview 2016

Our History

HERON Technik GmbH

Graz/Austria

Founded in 1990

Combustion Engine Development Support

by means of

Computer Simulation Technology

Technical Director:
Dr. Hans Alten

Tel.: +43 (0)316 384200
Mail: hans.alten@heron.co.at

9 years of experiences in the development of common road engines (AVL List GmbH)
12 years in Formula 1 racing business (ILMOR Engineering and Mercedes Benz High Performance Engines)
10 years CEO of HERON Technik GmbH

Our Services

1D - Engine Simulation

Thermodynamic cycle simulation for revised and new engines
Analysis and optimisation of all main dimensions and components

3D - CFD Flow & Combustion Simulation

Port flow optimisation & cooling system analysis
In-Cylinder flow simulation (tumble & swirl and combustion)
Entire gas exchange process with moving valves and piston

Assistance in the Pressure Indication Technology

High– and low pressure measurements
Specific combustion analysis

Valve Train Analysis

Valve lift and timing optimisation, cam profiles and spring layout

Thermodynamic Training Courses

“The thermodynamics of internal combustion engines”
Theory and praxis - 2 or 3 day courses held on site

Contents

Part 1: 1D – Engine Simulation

Page 9 – 19 : Road Car Engine Applications

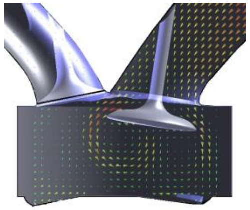
Page 20 – 23 : Race Engine Applications

Part 2: 3D - CFD Flow Simulation

Page 24 – 26 : Generals

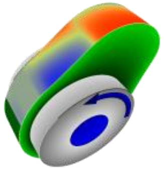
Page 27 – 31 : Steady State Flow

Page 32 – 40 : Transient Flow



Part 3: Software & Valve-Train

Page 41 – 51 : HCS & Valve Train



HERON Contact Details, see Page 52

Previous Projects

1D - Engine Simulation in the automotive industry (overview only)

0.6L Bike engine (Germany, UK)
0.9L HSDI-TCI Diesel engine (India)
1.0L 3C Gasoline DI engine (France)
1.0L R4 Super-Bike race engine (Germany)
1.0L Gasoline engine with HYPREX/COMPREX application
1.3L Gasoline power boat >200kW (Austria)
1.4L Diesel engine with HYPREX/COMPREX application
3.0L HSDI-TCI Diesel marine engine (Japan)
3.5L V6 Gasoline DI (China)
5.0L Gasoline GT2 race engine (Germany)
up to 528L Dual Fuel, Gas & Diesel power plant engine (Austria, Germany, Japan)

3D - CFD Simulation

>4 Year long term contract with gas engine manufacturer (Germany)
Several medium and low speed Gas-, DF and DIESEL engines (USA, Germany, Austria)
New opposite two-stroke Diesel engines concepts (Austria, China)
Emission prediction for new piston bowl shapes (Japan, France)
F1 Engine – Complete new cylinder head (Japan)
Catalyst layout for truck engine (USA)
Coolant flow simulation (Austria, Hungary)

Our Tools

1D – Engine Simulation (AVL-BOOST & CONCERTO, GT - Power)

>30 years of experience
in all kind of engine applications

3D - CFD Flow Simulation (AVL-FIRE)

>20 years of experience
Specialised in IC engine application
(flow, tumble, combustion, coolant flow)

Valve Train Optimisation (CDS and HERON)

Very powerful and long-term proven tool

HERON Software (EXCEL, FORTRAN, BASIC, C++…)

Various tools to assist development issues

Our Approach

1D - Engine Simulation

Step 1: Engine Analysis

Test bed data analysis
High and low pressure measurements
Combustion data evaluation

Step 2: Engine Performance Calculation

Setup of an equivalent computer model of the engine
Correlation to dyno data - comparison to measurements

Step 3: Gas Exchange Optimisation

Review/Optimisation of all geometric data
Optimisation of inlet & exhaust system, specification for TC, charge air cooler CAT/DPF/SCR and EGR strategy

3D - CFD Simulation

Step 1: CFD Mesh generation

Surface preparation, if necessary with CATIA V5
Manual and semi automatic grid generation
Boundary conditions from measurements and/or from 1D engine simulation

Step 2: Multiprocessing for solver solution

State of the art and fast computer system
UNIX and Windows based platforms

Step 3: Postprocessing & Documentation

Static figures and video animation
Local & integral results to understand the results

References

Costumers:

Publications

Haus der Technik Essen/Germany 1997

Indiziersymposium Baden-Baden/Germany 1998

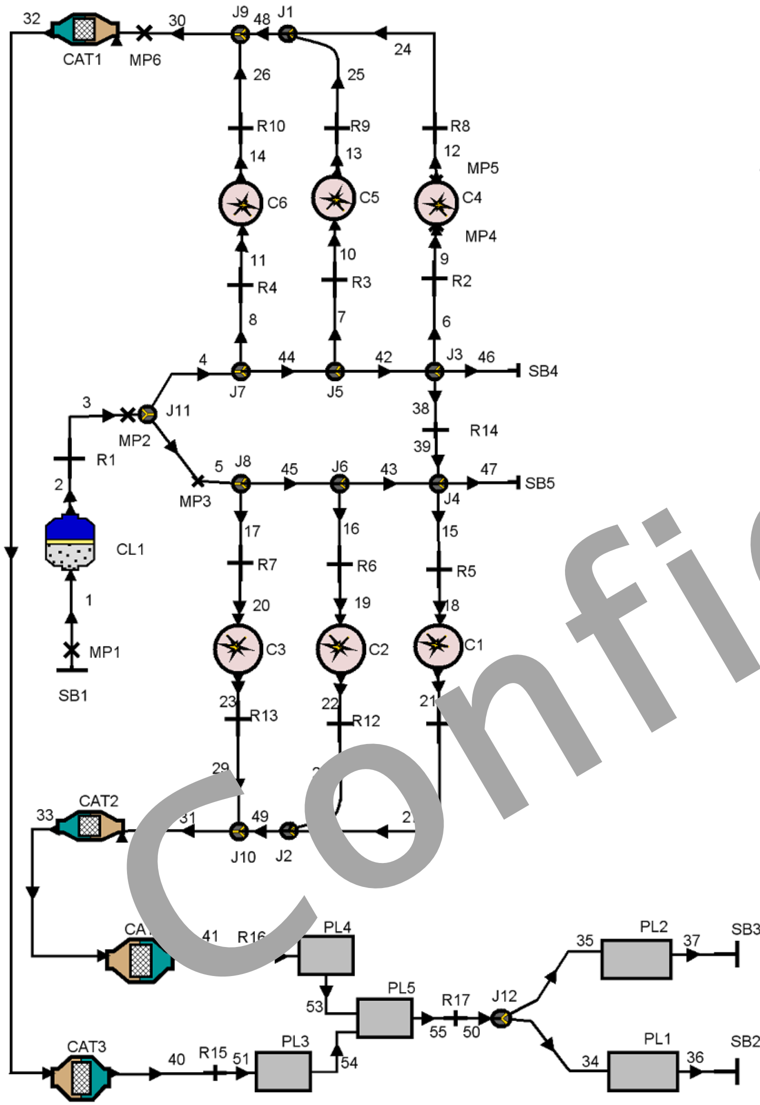
AVL User Conference Graz/Austria 1999

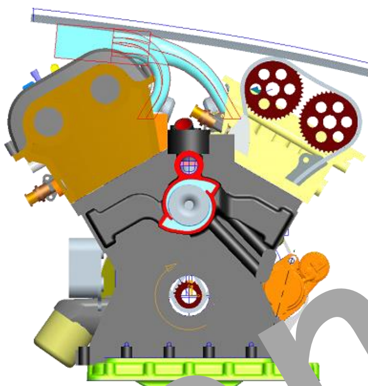
SAE-Paper 2002-01-339 H. Alten, M. Illien:

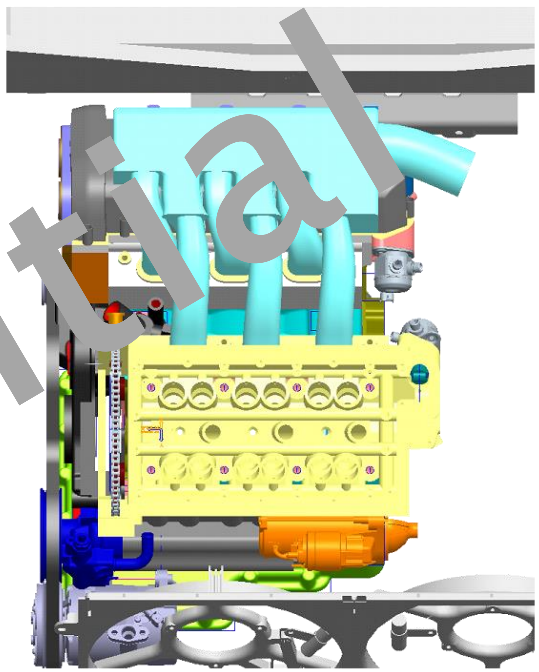
Demands on Formula One Engines and Subsequent Development Strategies

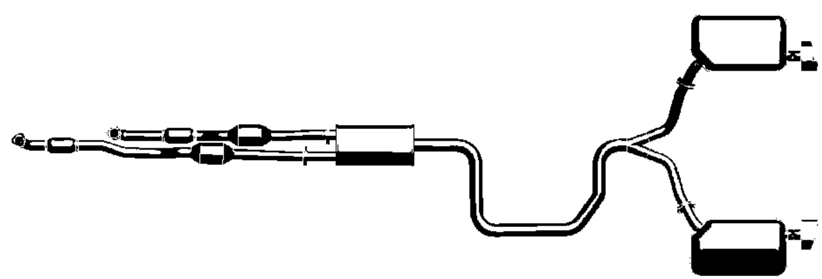
MTZ-Article: *10 Years V10-F1-Engine development - July 2005*

1D - Engine Process Simulation (Gasoline application)

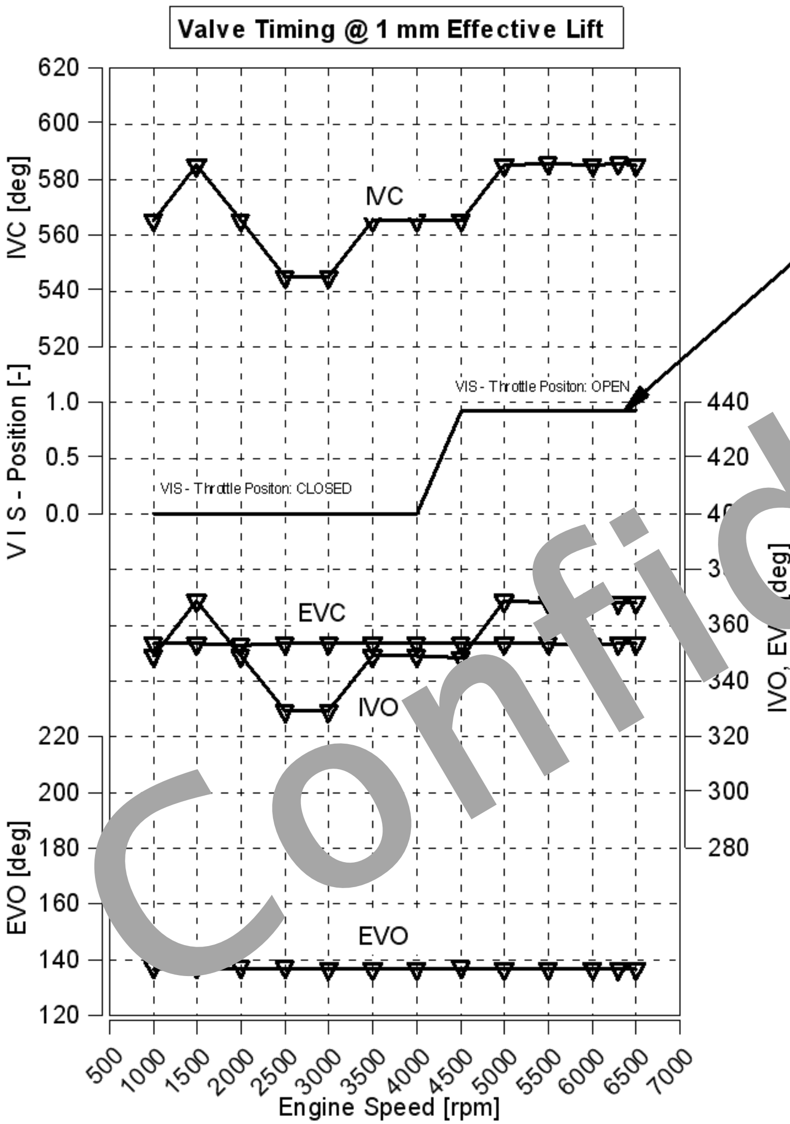


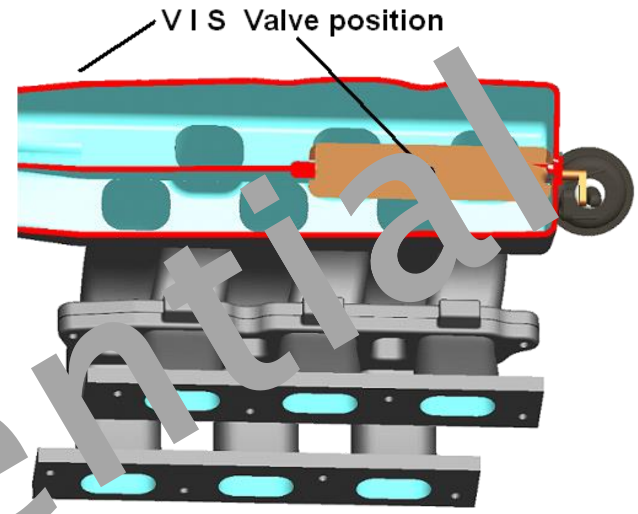


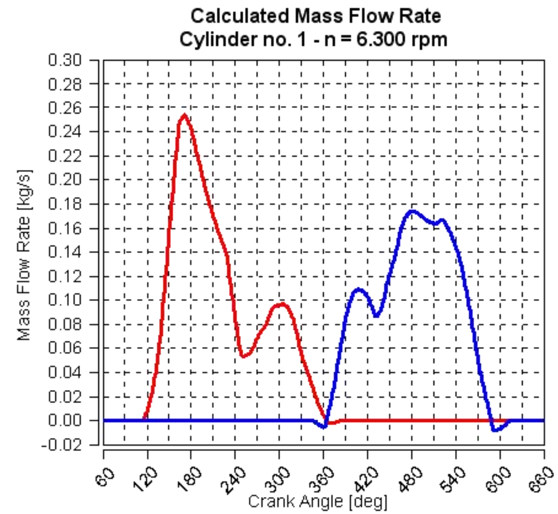




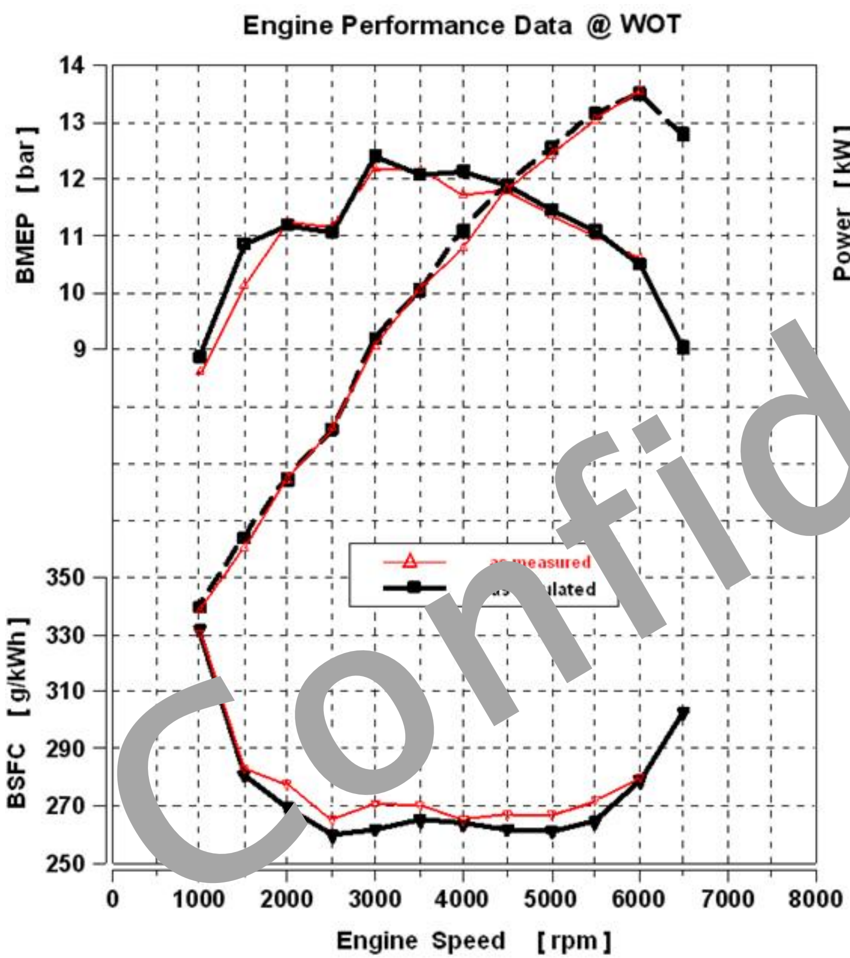
1D - Engine Process Simulation (Gasoline application)

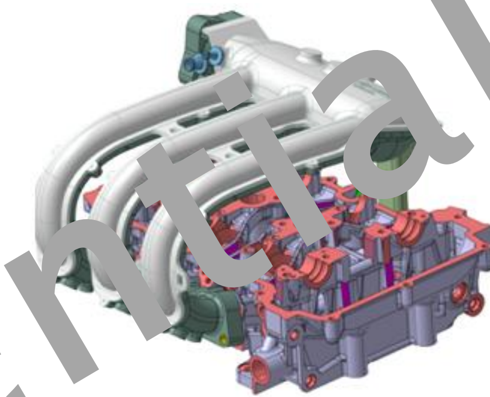


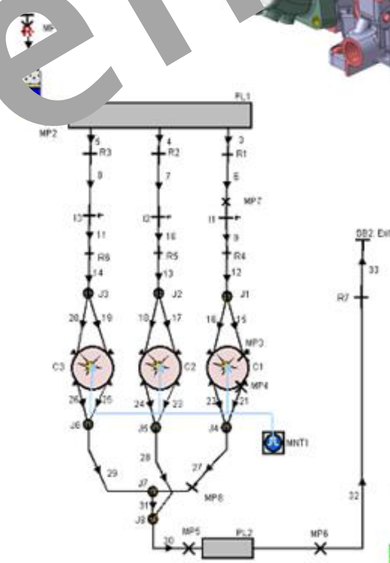


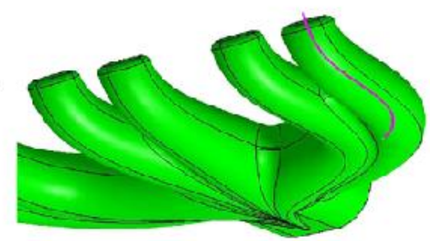


1D - Engine Process Simulation (Gasoline application)



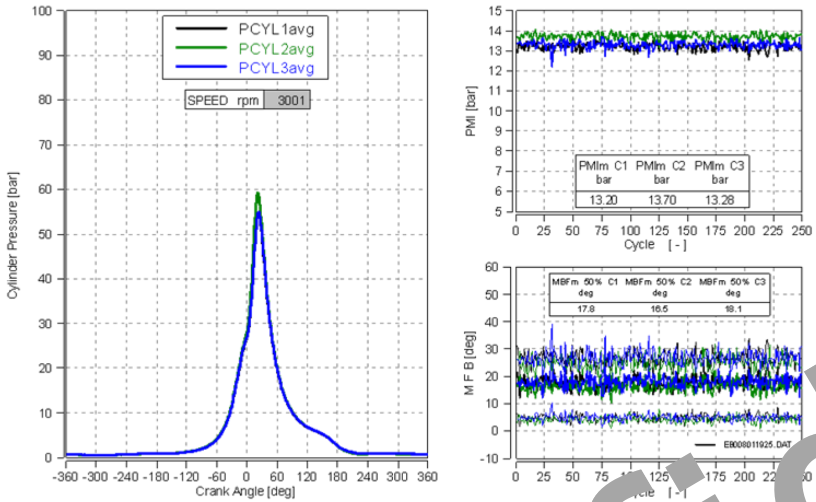


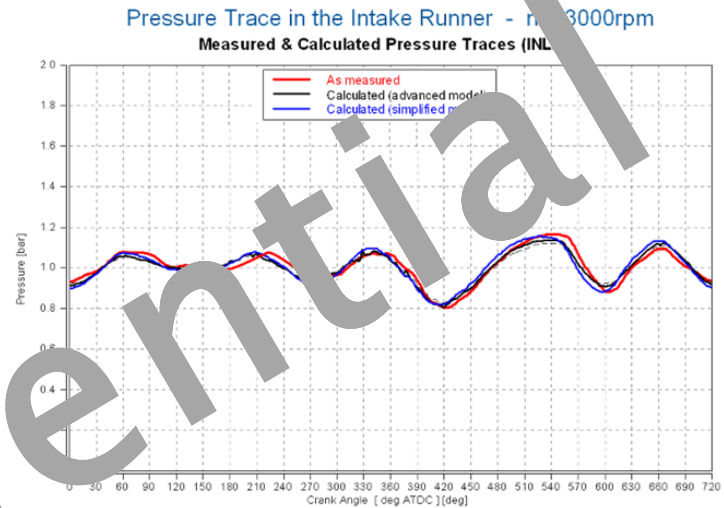




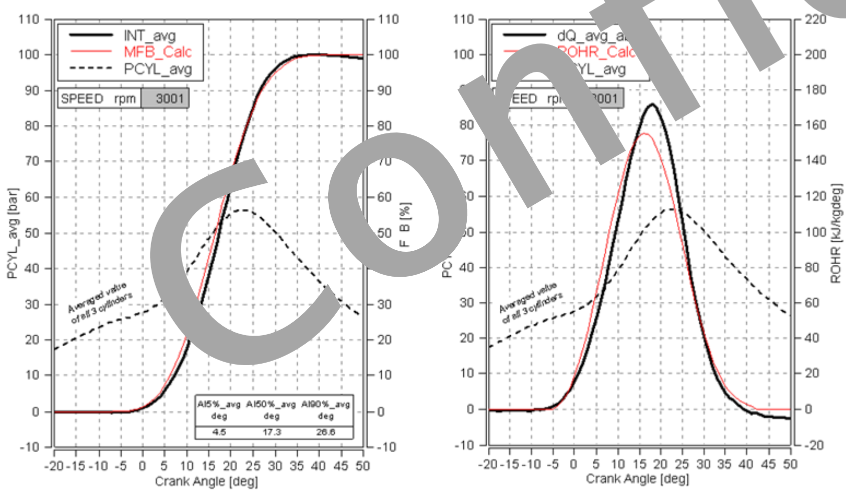
1D - Engine Process Simulation (Gasoline application)

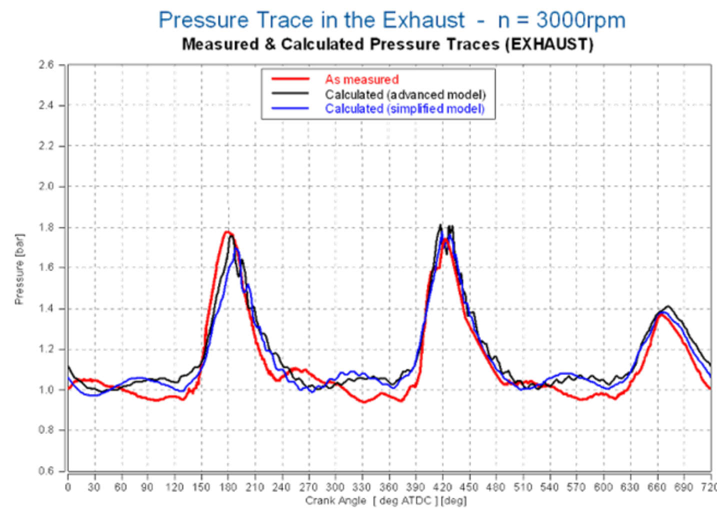
In-Cylinder Data





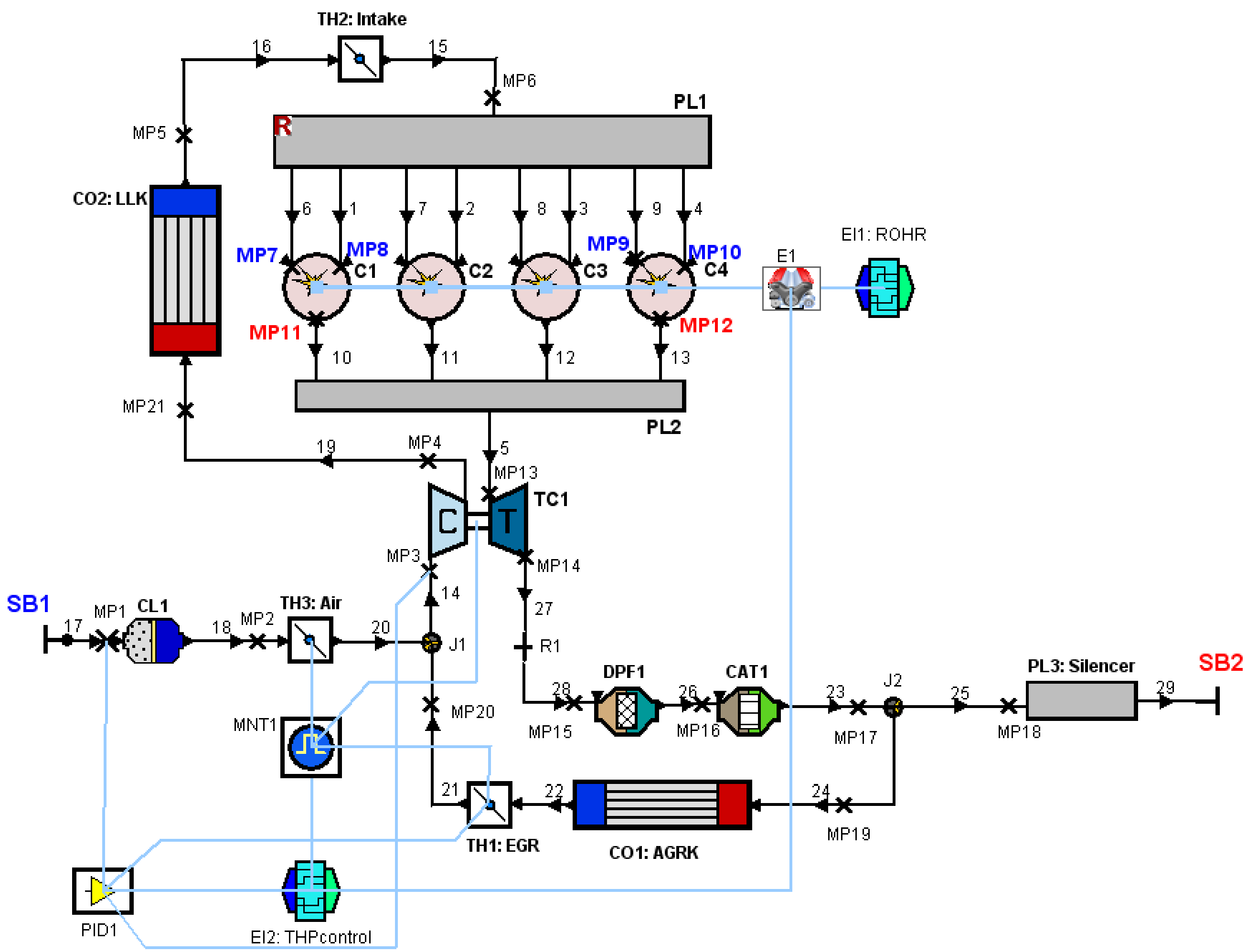
Combustion Data



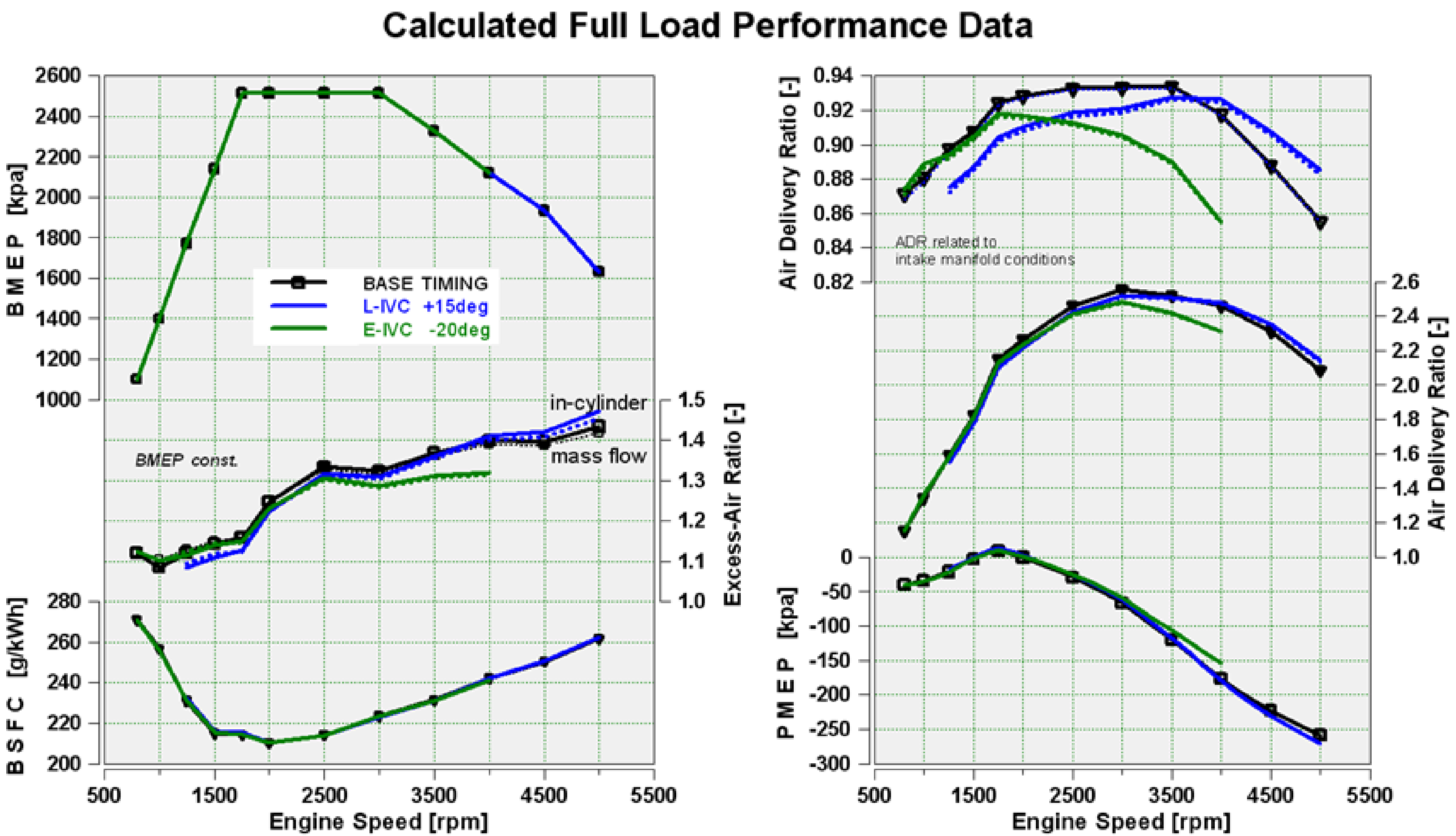


1D - Engine Process Simulation (DIESEL application)

HERON 2.0L 4C HSDI TCI

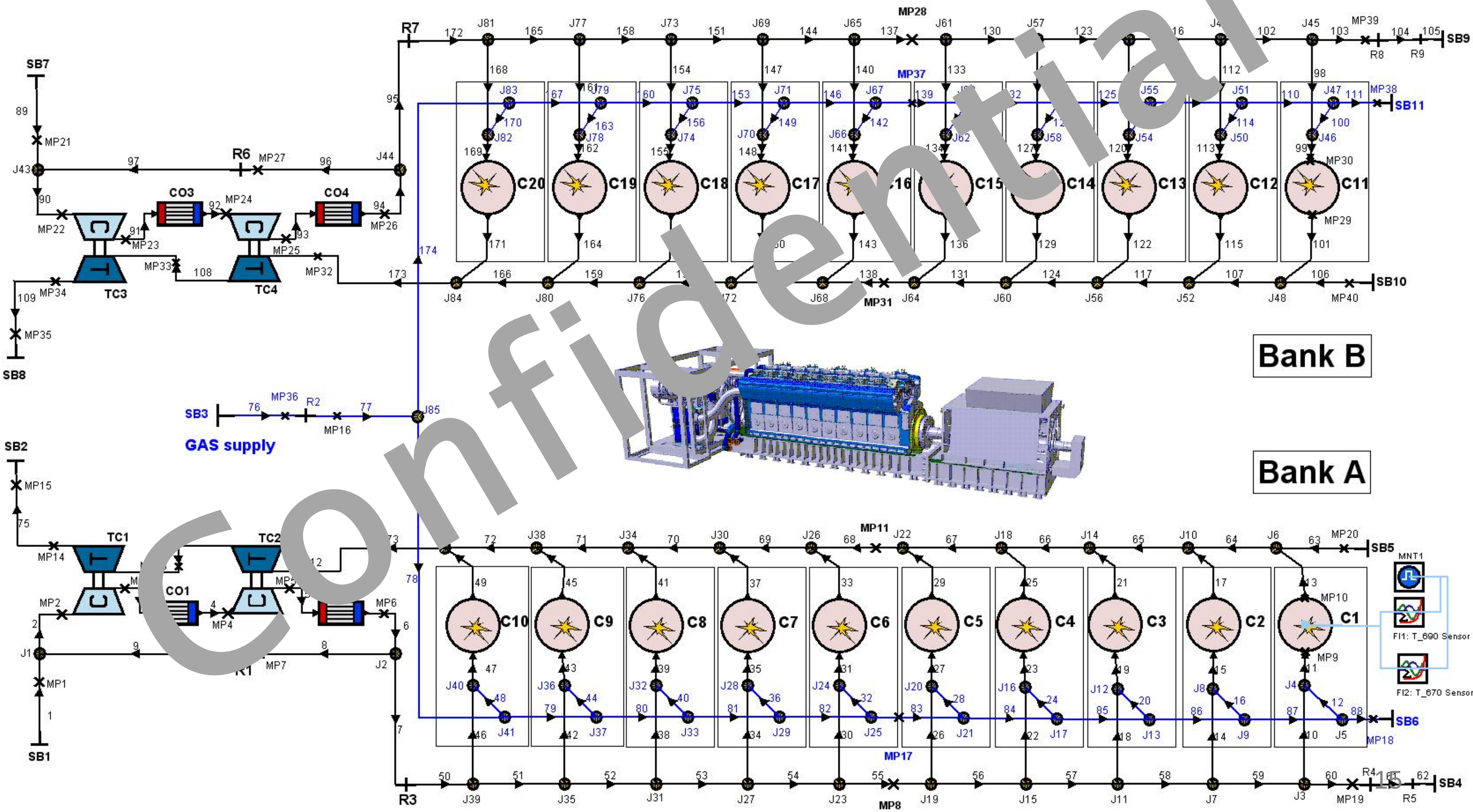


1D - Engine Process Simulation (DIESEL application)



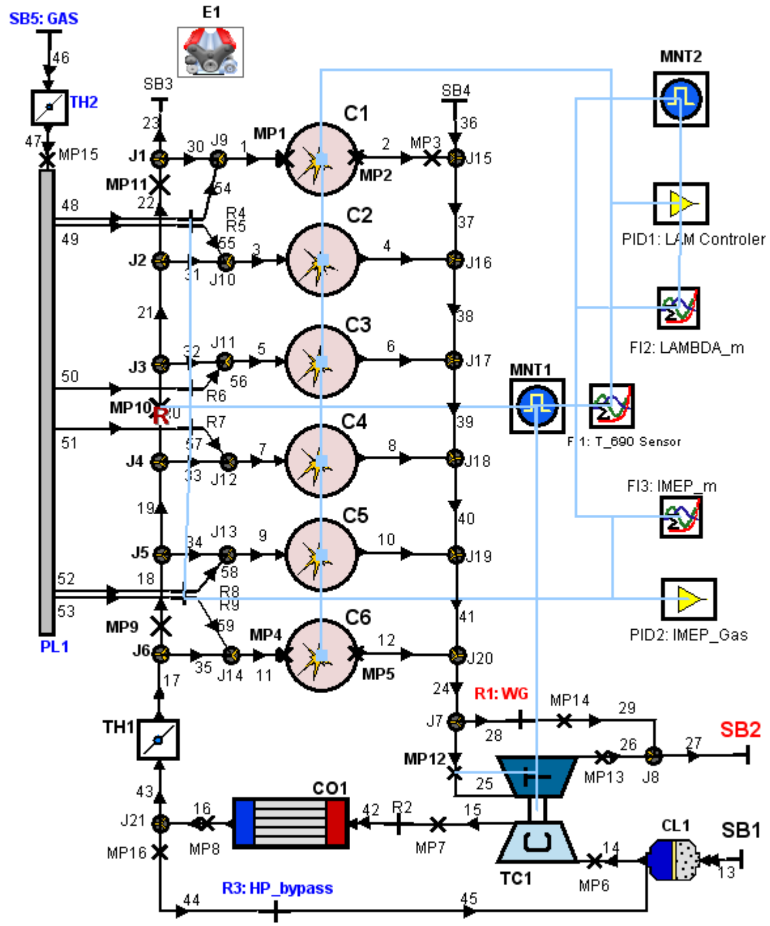
Investigation of EARLY / LATE Intake Valve Closing

1D - Engine Process Simulation for GAS, DF & DIESEL applications



1D - Engine Process Simulation for GAS, DF & DIESEL applications

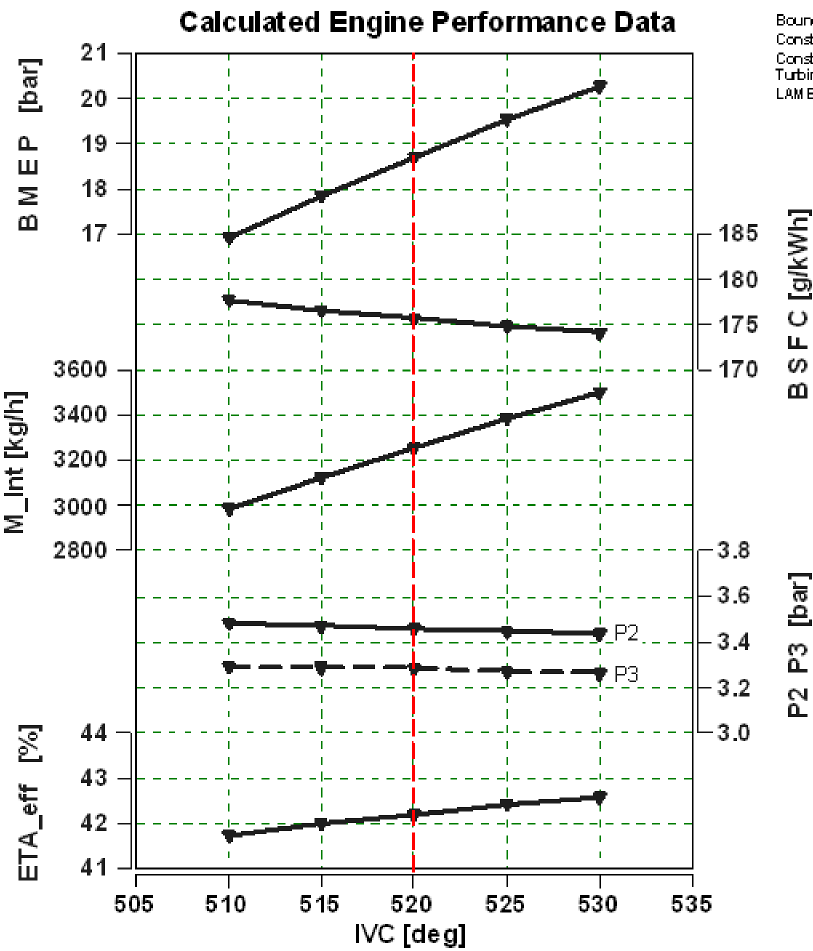
6C TCI Gas & DF Model
B130mm x S157 mm - EPS 12.5



Scope of Work:

- **Analysis of the current DIESEL engine**
- **Conversion into DF application**
- **Valve timings for „MILLER“ process**
- **Grinding coordinates**
- **TC specification**

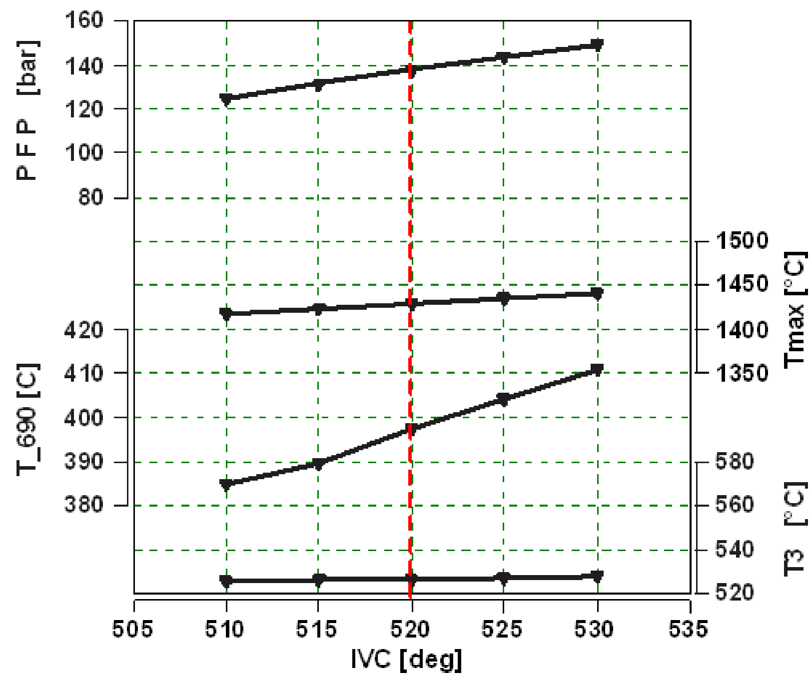
1D - Engine Process Simulation for GAS, DF & DIESEL applications



Boundary conditions:
Constant combustion data
Constant ETA_CO,TU & PI_CO
Turbine size adjusted - no WG flow
LAMBDA = 1.82, CR=13.5:1

Influence of I V C

EVO deg	IVO deg	VOL deg	EVC deg	IVC deg
130	344	36	380	510
130	344	36	380	515
130	344	36	380	520
130	344	36	380	525
130	344	36	380	530



1D - Engine Process Simulation for GAS, DF & DIESEL applications

Influence of IVC @ PI_CO = const.

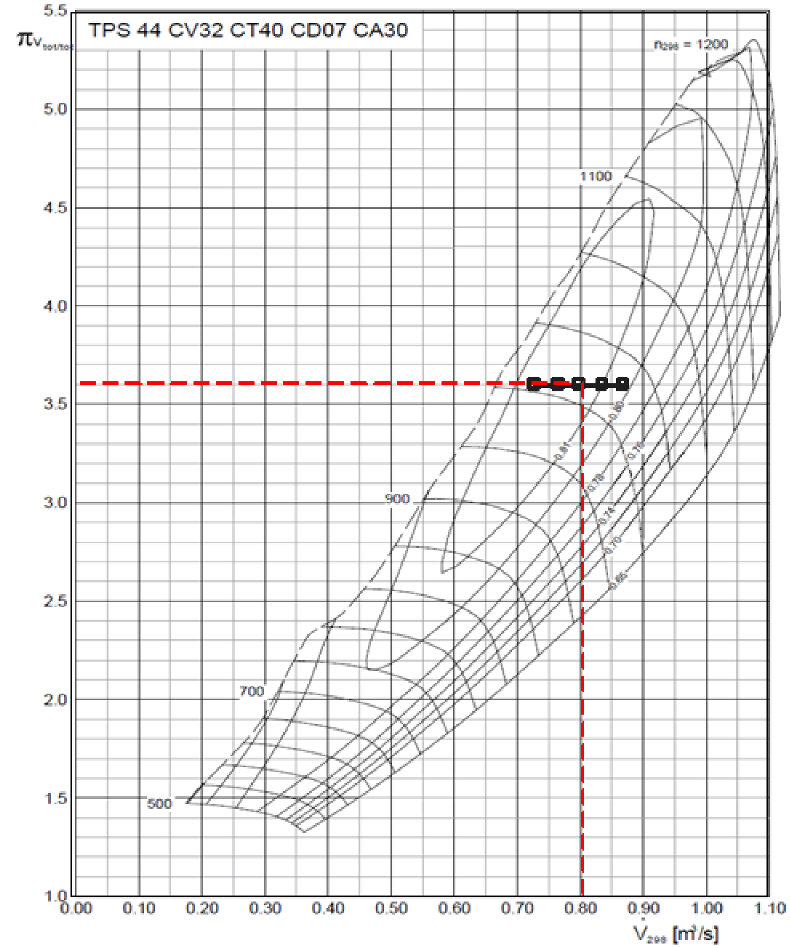
Calculated Engine Performance Data

Constant IGN timing and combustion characteristic

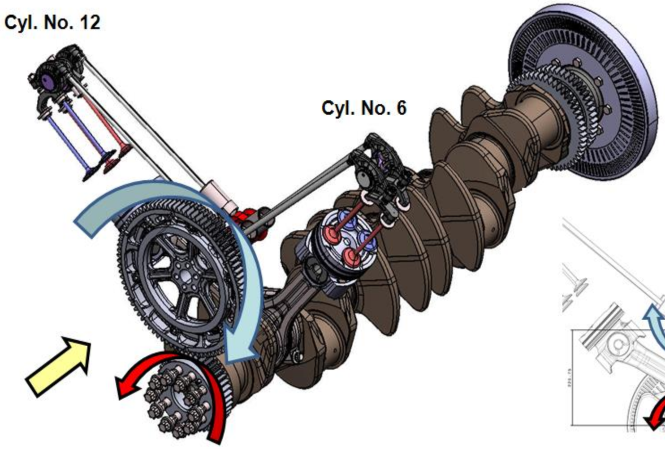
IVC deg	Eta_CO %	Eta_Tu %	Eta_TC %	BMEP bar	PWR_v12 kW	PWR_v12 kW
510	81.0	73.1	58.0	16.9	529	529
515	81.0	73.1	58.0	17.8	557	557
520	81.0	73.1	58.0	18.7	584	584
525	81.0	73.1	58.0	19.5	610	610
530	81.0	73.1	58.0	20.3	634	634

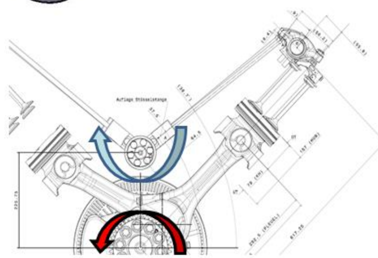
V298_CO m3/s
0.732
0.769
0.804
0.839
0.870

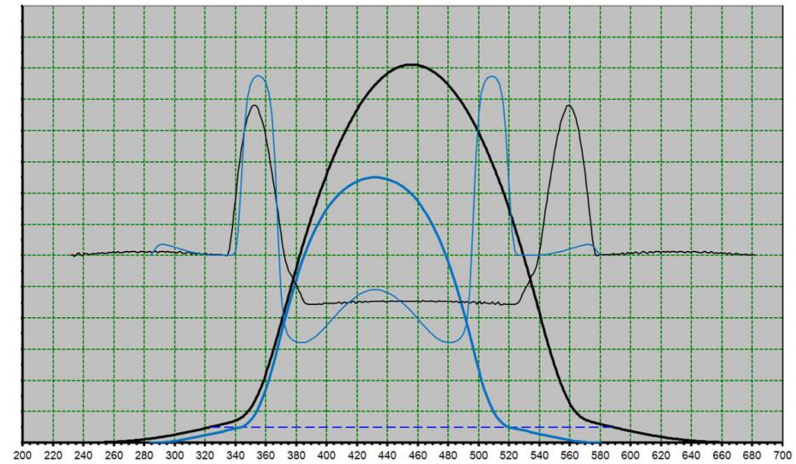
V298_Air m3/s	V298_Gas m3/s
0.709	0.0231
0.745	0.0242
0.779	0.0253
0.813	0.0264
0.843	0.0274

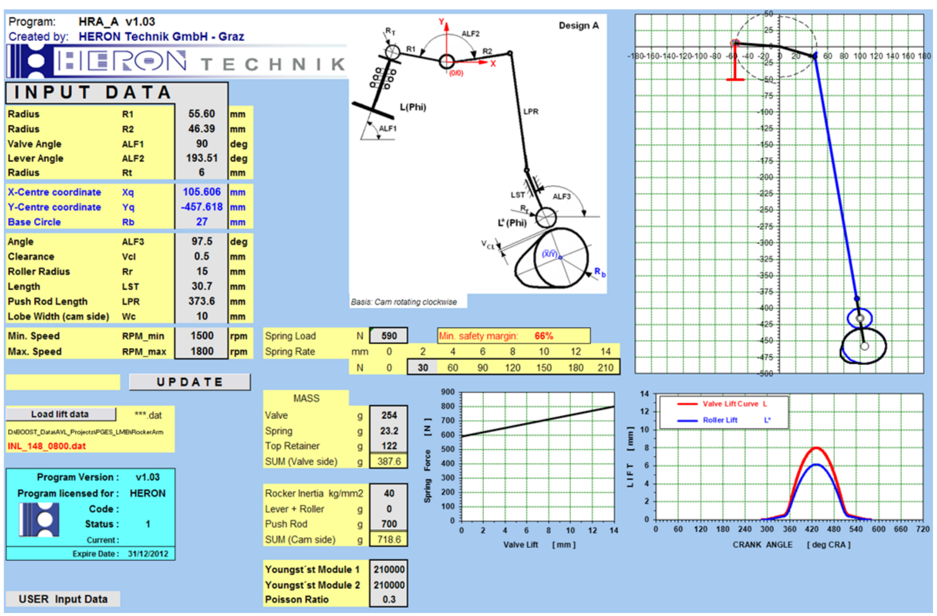


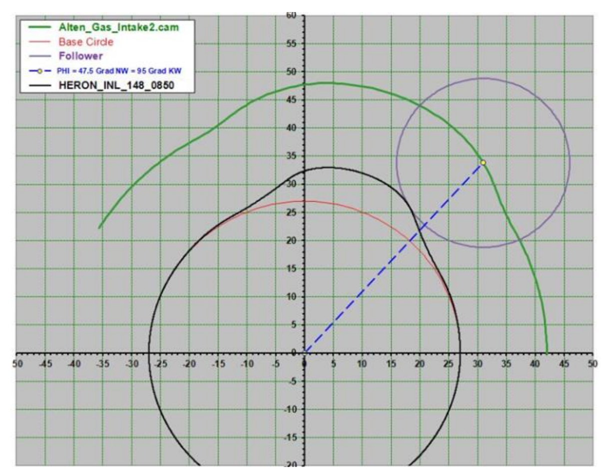
1D - Engine Process Simulation for GAS, DF & DIESEL applications



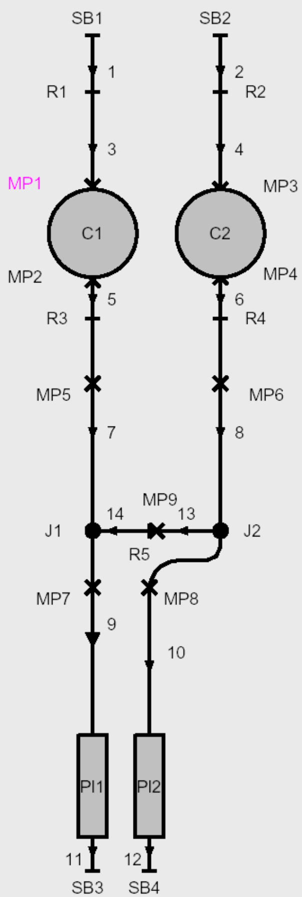








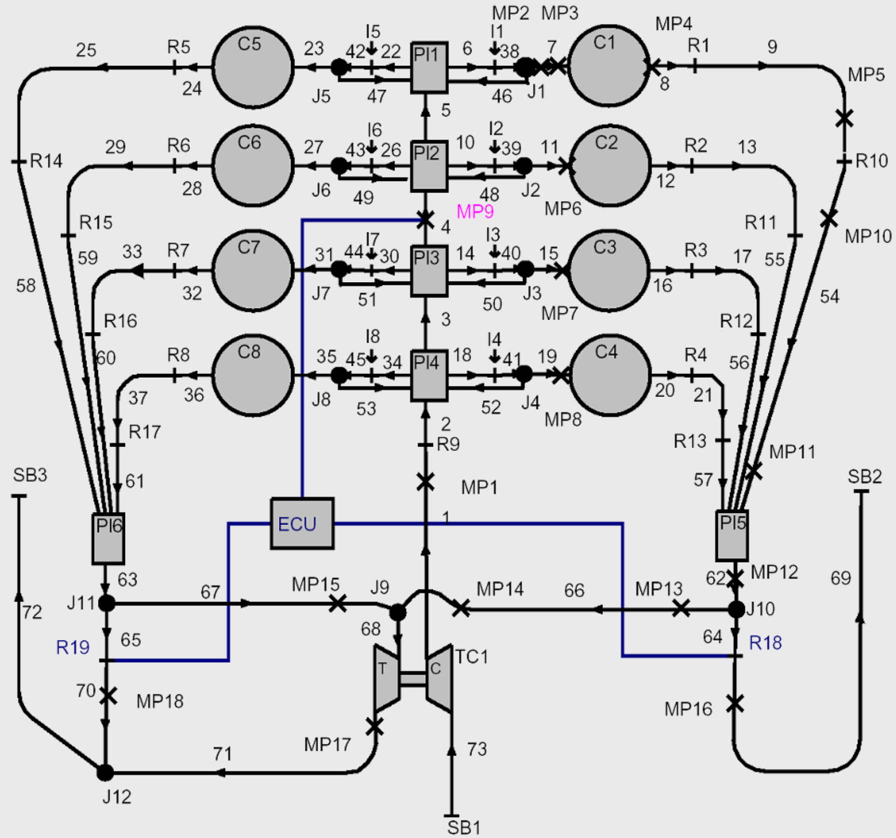
1D - Engine Process Simulation



Simple 2C race bike

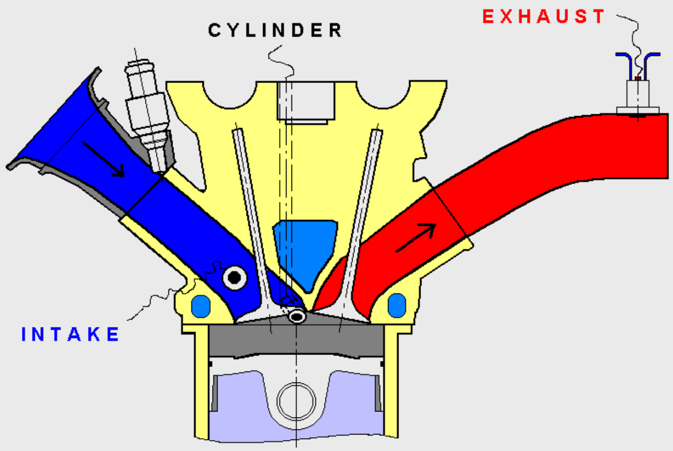
V8 TC Methanol INDY Engine

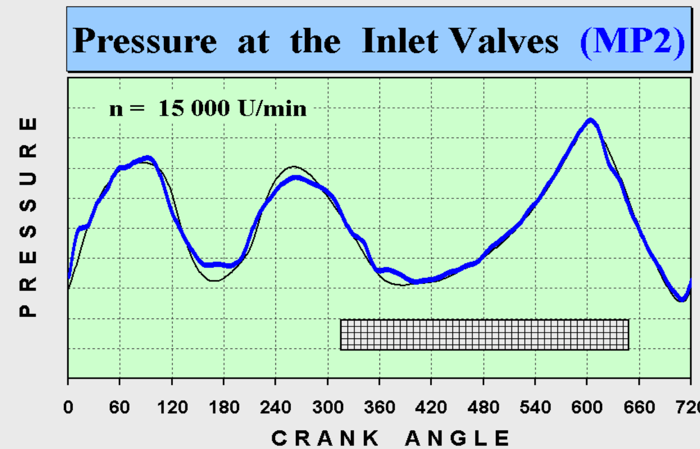
Calculation Model

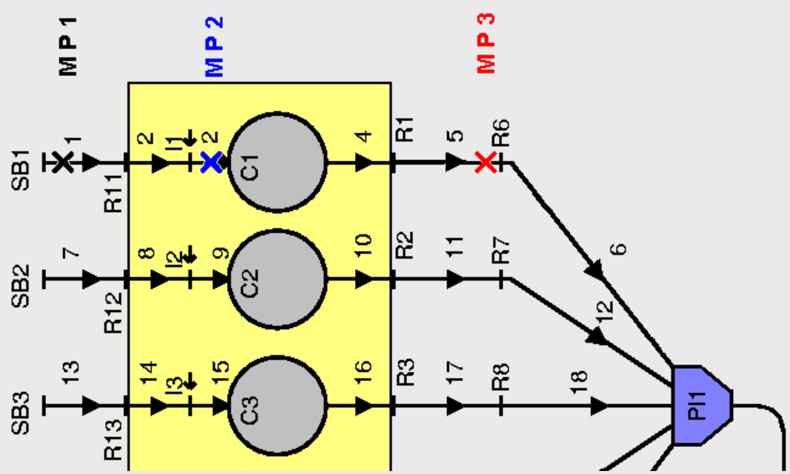


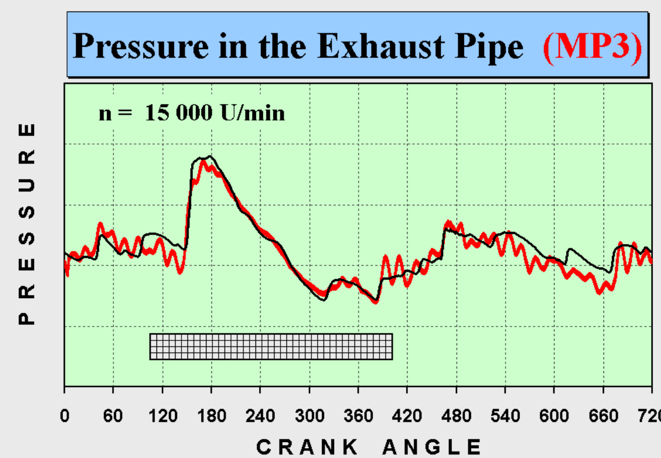
Complex V8 race engine with turbo charger

High- and Low Pressure Indication

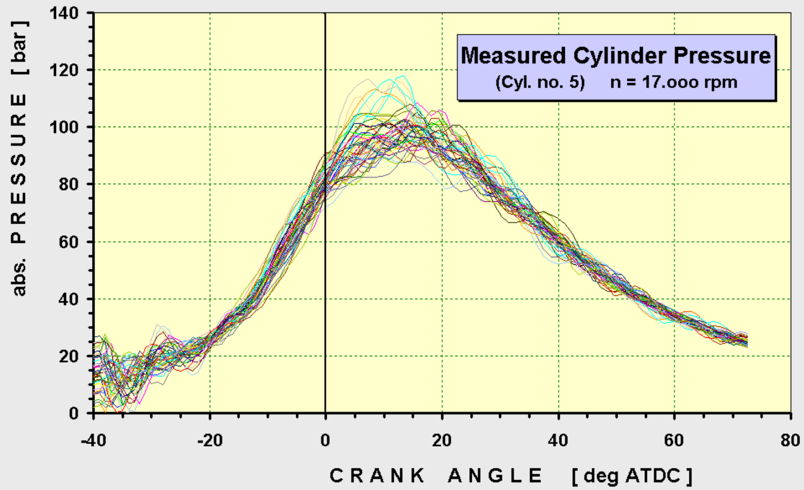


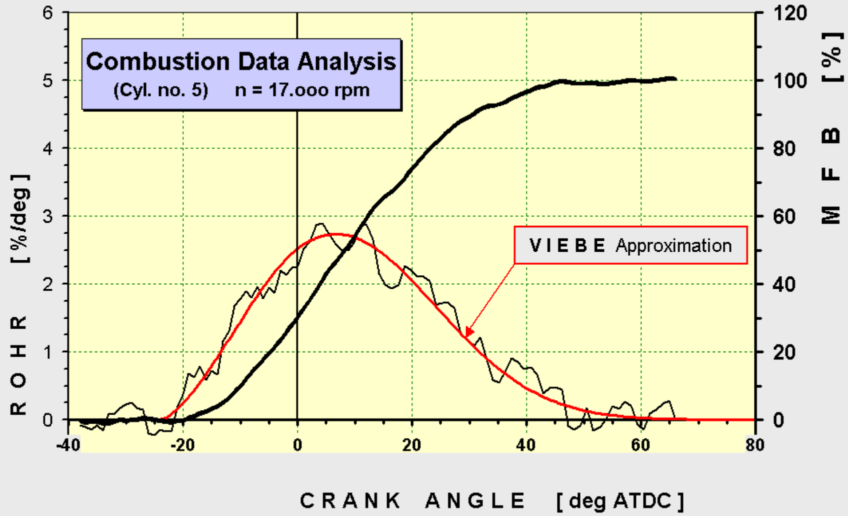


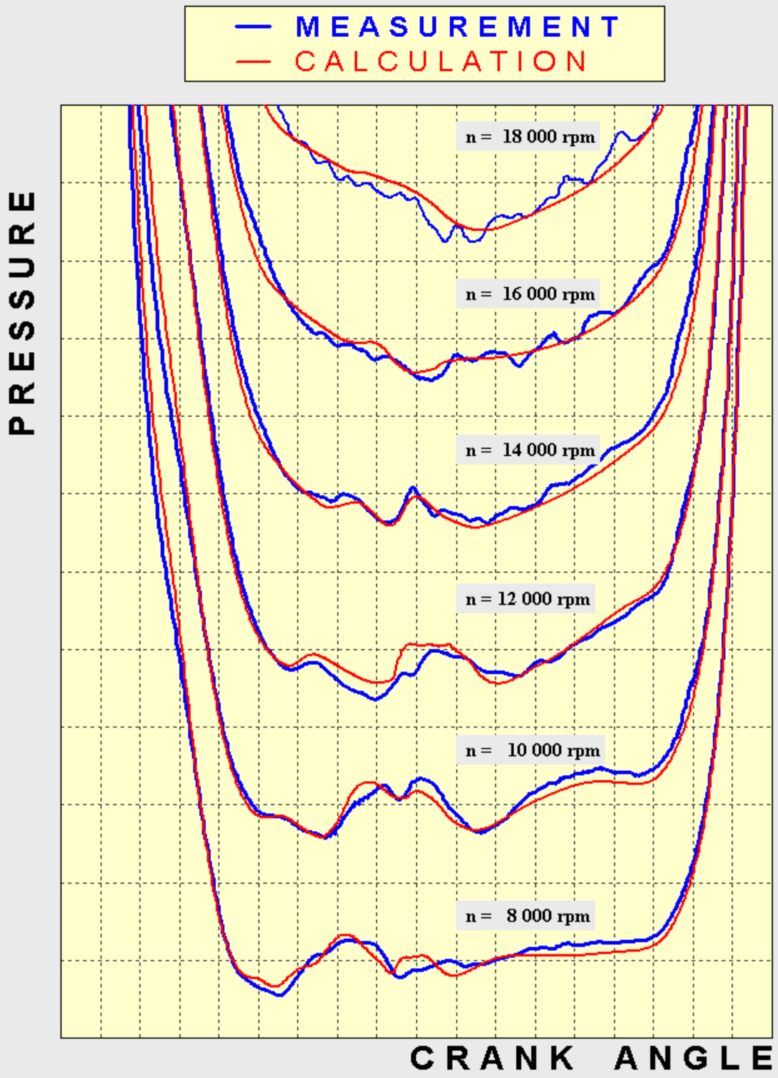




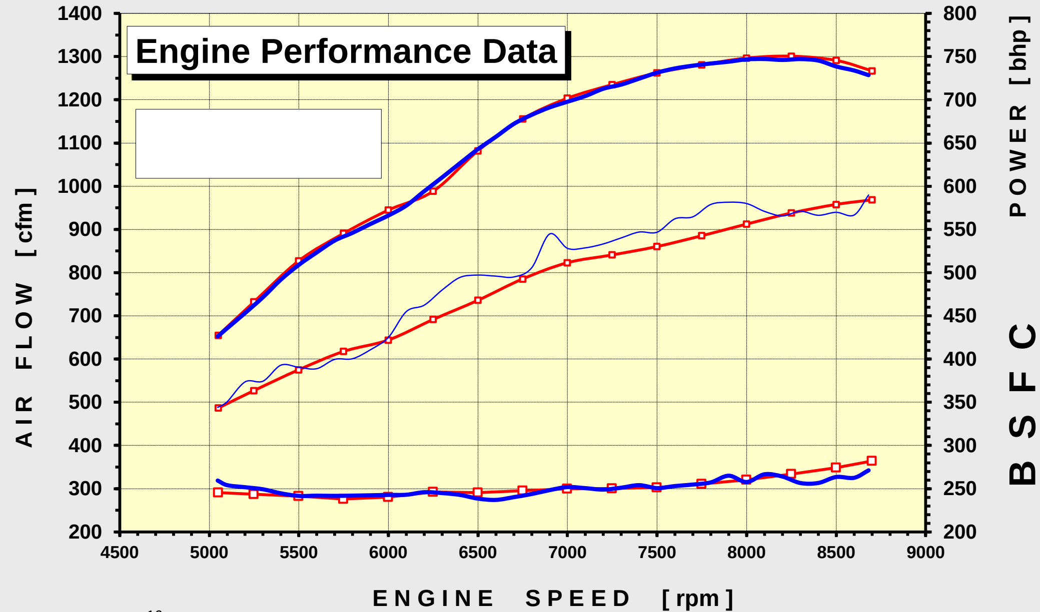
High- and Low Pressure Indication

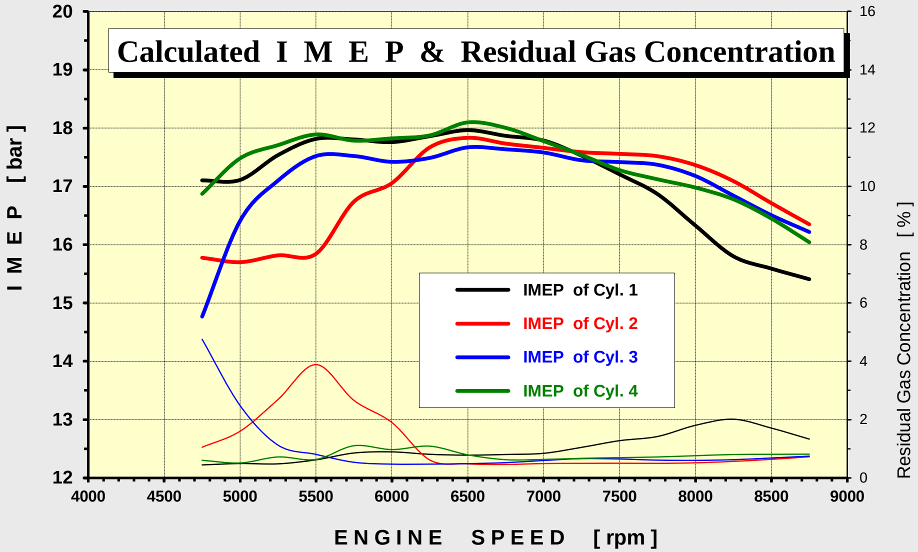


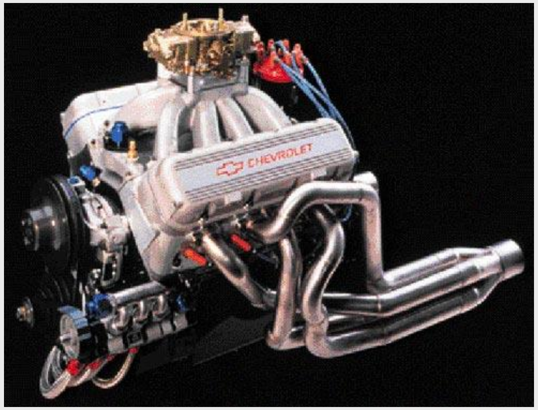




1D – Engine - Analysis







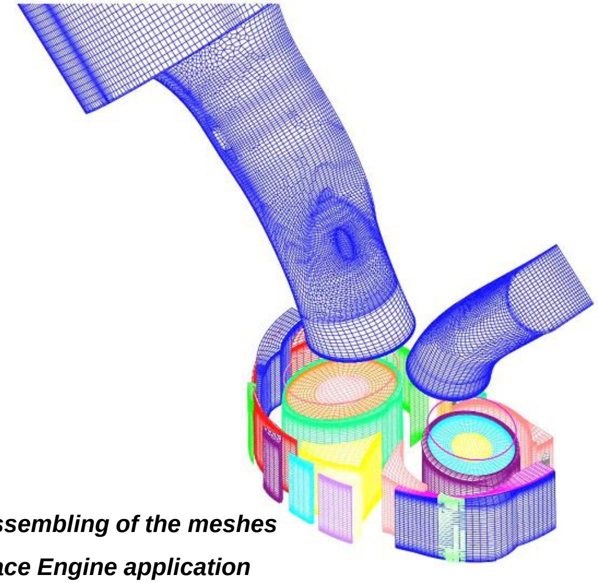
3D - CFD Application in the Engine Development Process

- **Inlet and exhaust port development**
  - Flow bench simulation (flow capacity, tumble & swirl)
  - Layout of ports for 2 - stroke engines (scavenging process)
- **Combustion chamber design**
  - Combustion roof shape and piston bowl layout
  - Pre-chamber design and injector position (Diesel & Gasoline)
- **Combustion analysis**
  - Air/Fuel and residual gas distribution
  - Turbulent kinetic energy distribution
  - Transient swirl/tumble situation
  - Fuel spray propagation
  - Flame front/speed investigation
  - Rate of heat release
  - NOx Emissions
  - .
  - .
- **Coolant flow and catalytic converter simulation**

3D - CFD Application in the Engine Development Process

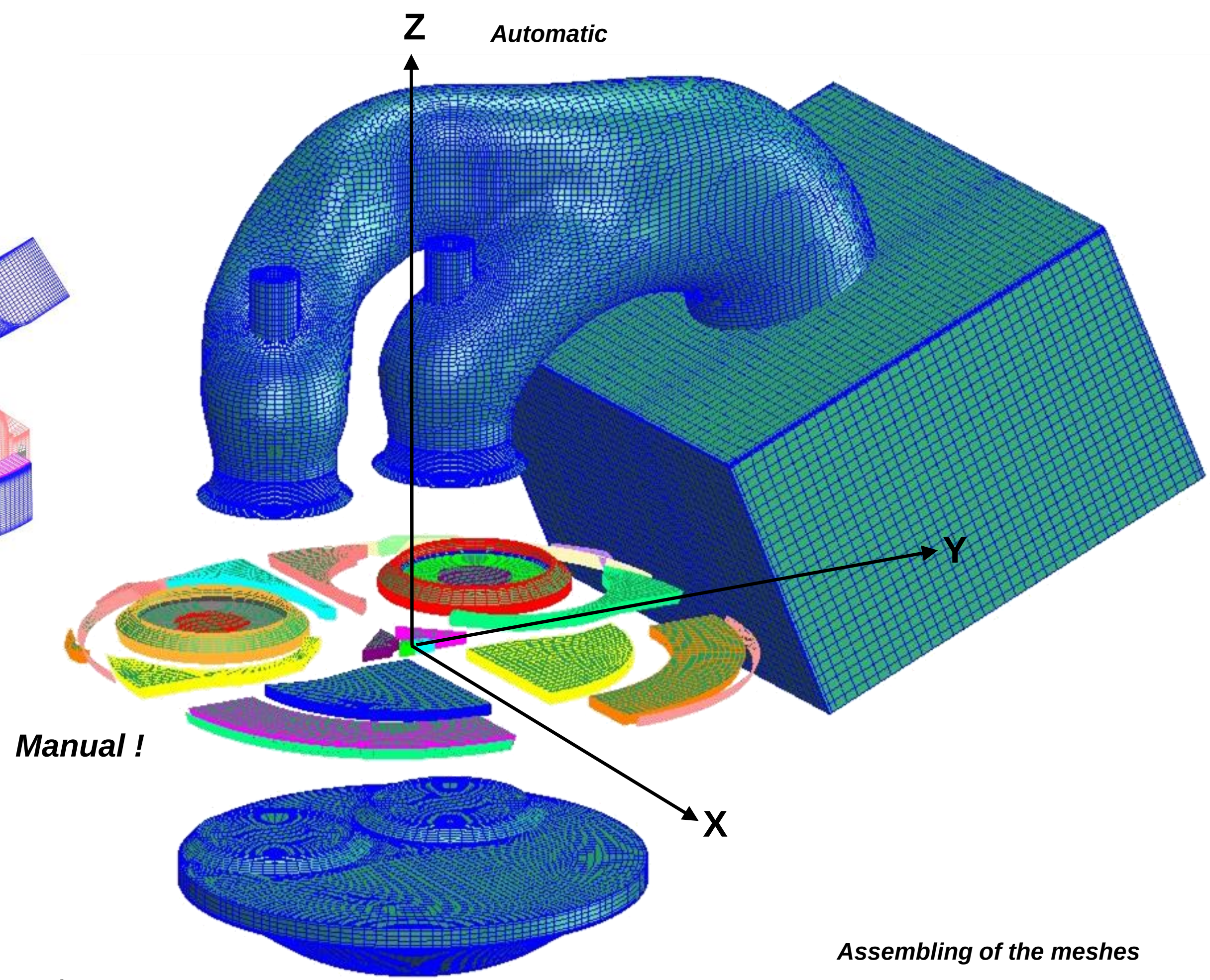
- **Tool to help the design and layout of new and complex systems**
  - Gasoline and Diesel injectors DI
  - Spark plug and spark chamber design for gas engines
- **For understanding and learning the internal flow & combustion process**
  - Transient swirl and tumble before and during the combustion
  - Spray and flame propagation
- **To save time, development and test components costs**
  - Particular for heavy duty engines
- **To reveal information, which can not be measured**
  - Local flow, turbulence, air/fuel concentration, temperature, …

Mesh Generation



Assembling of the meshes

Race Engine application



Assembling of the meshes

Gas Engine application

Remark:

Manually generated meshes are more stable and accurate in critical areas (e.g. valve gap)

Steady State Application

Flow Bench Simulation

Boundary Conditions

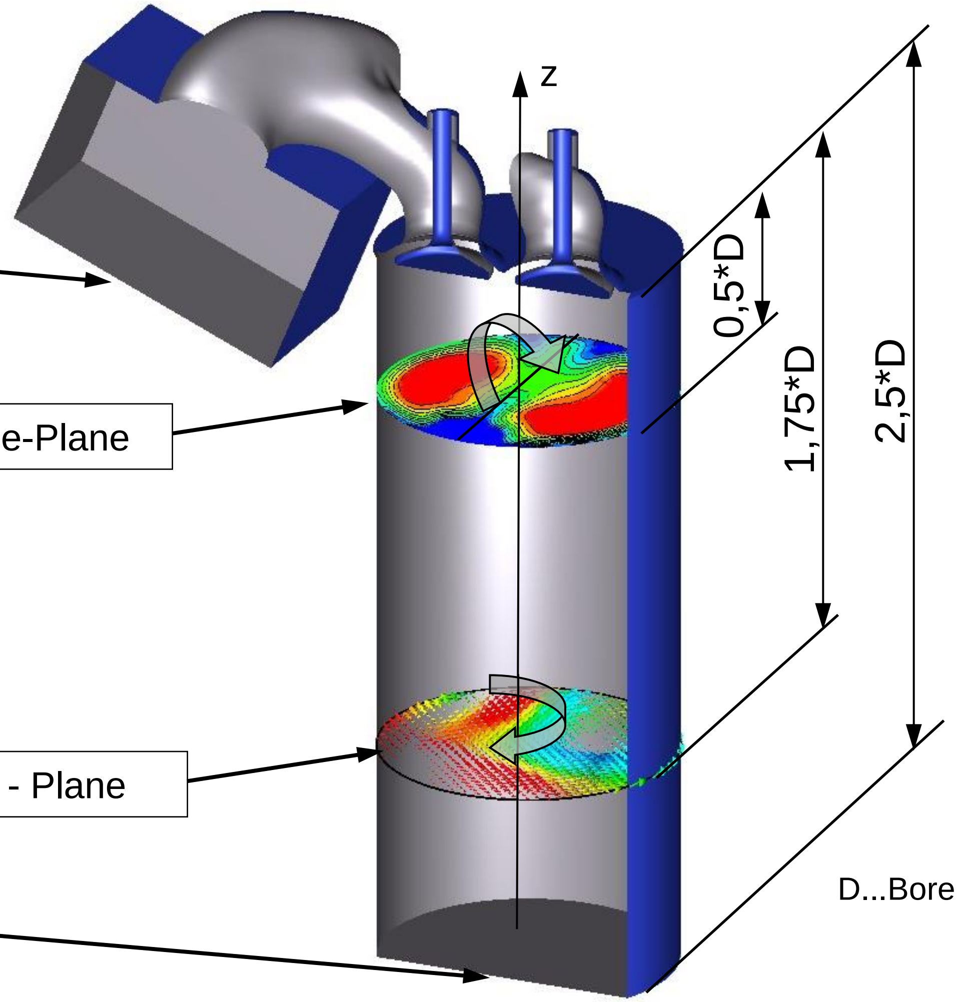
Intake: p_E = 100000 Pa

Δp = 2500 Pa

Exit: p_A = 97500 Pa

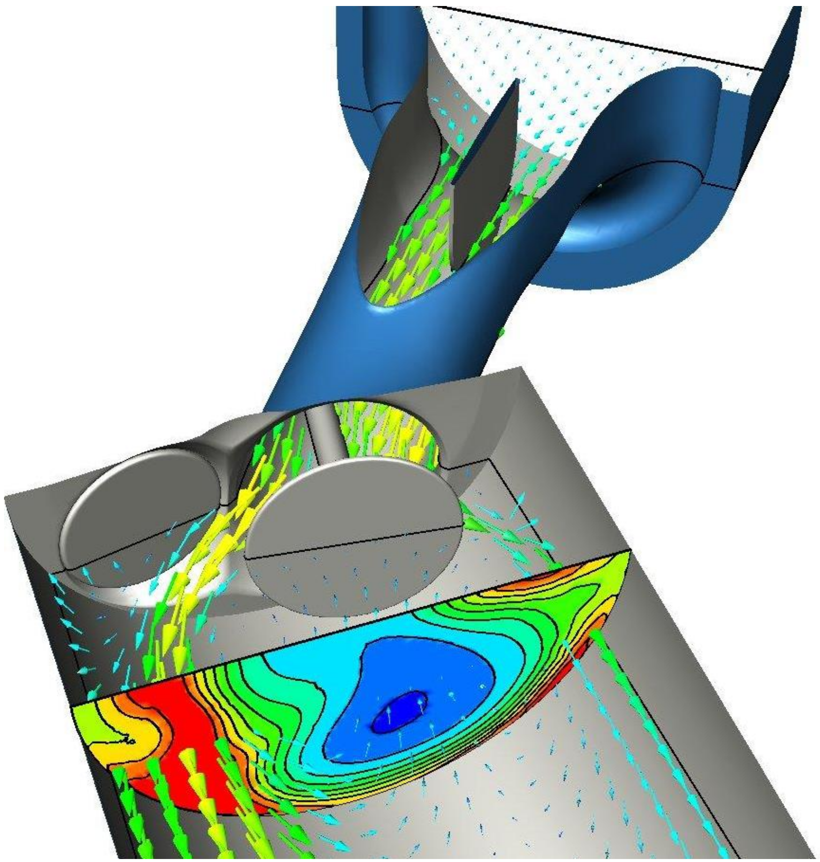
Tumble-Plane

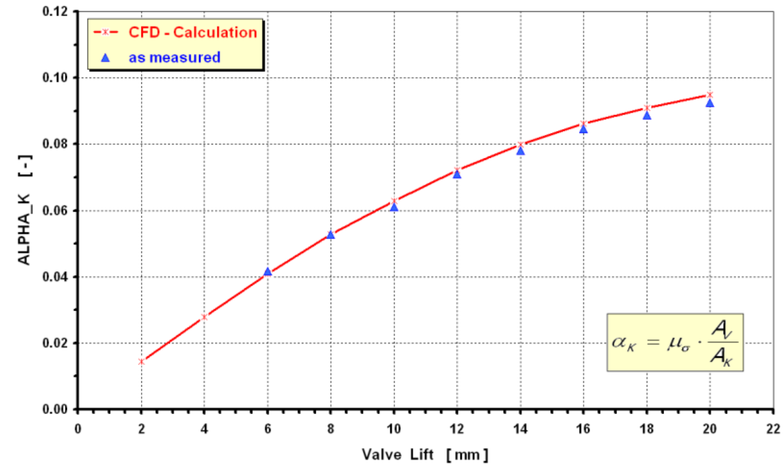
Swirl - Plane

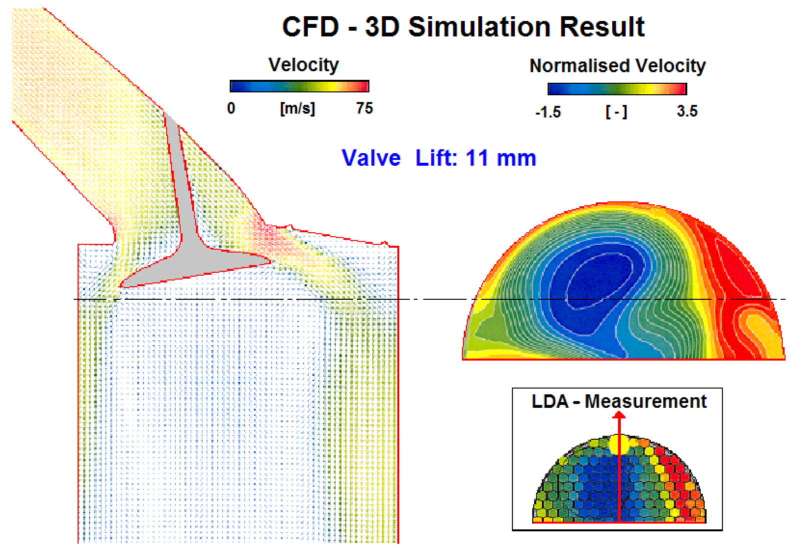


Steady State Application

Flow Bench Simulation

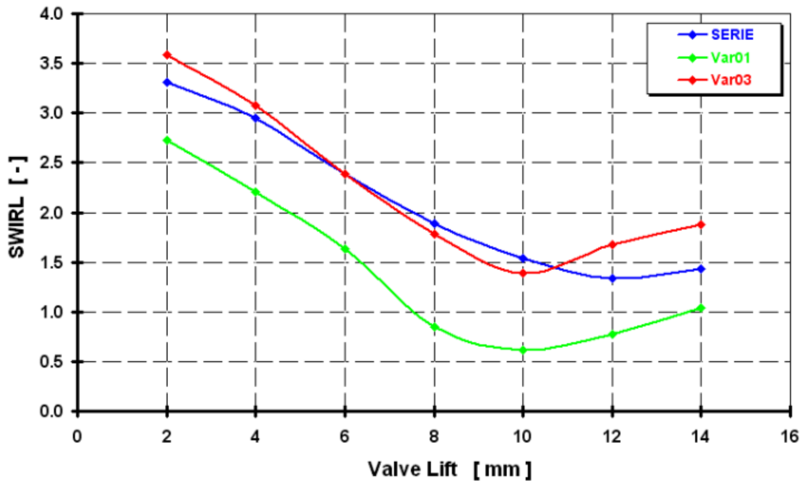


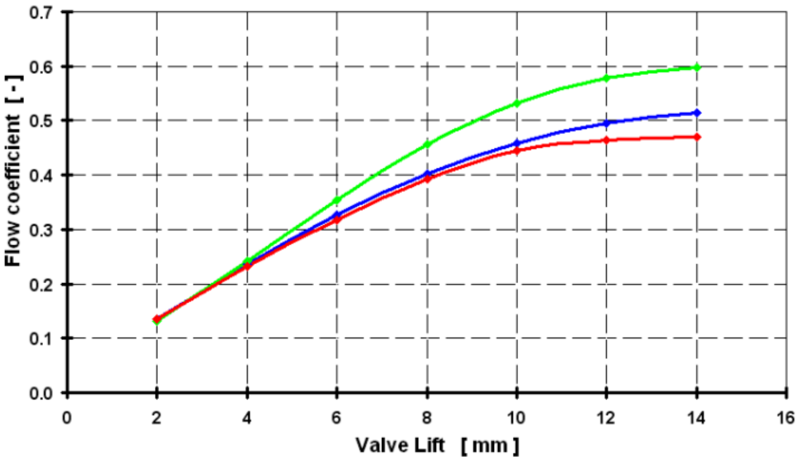


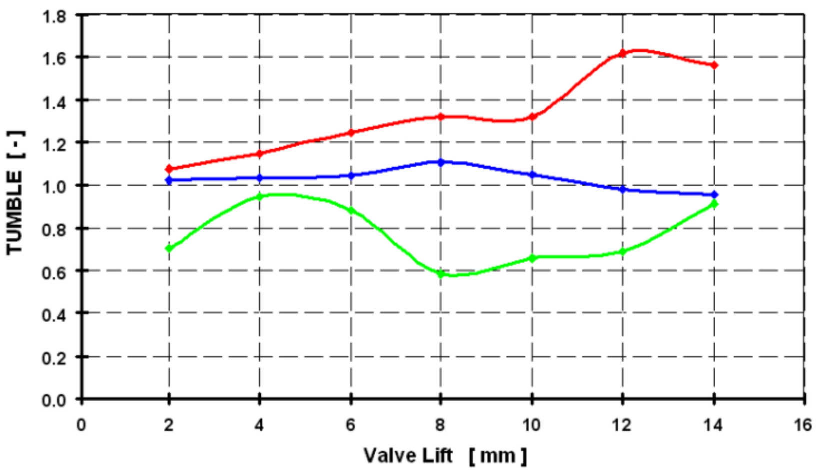


Steady State Application

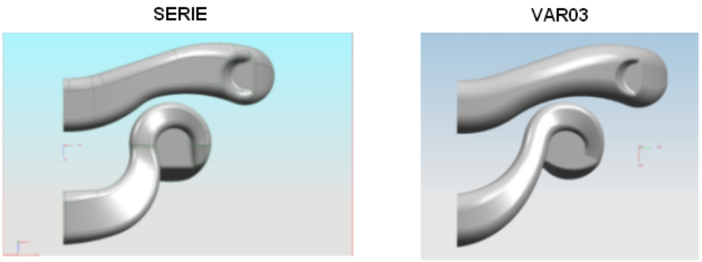
Flow Bench Simulation





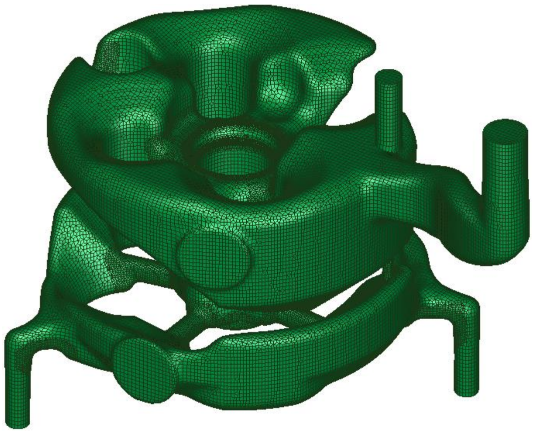


Intake Port Designs

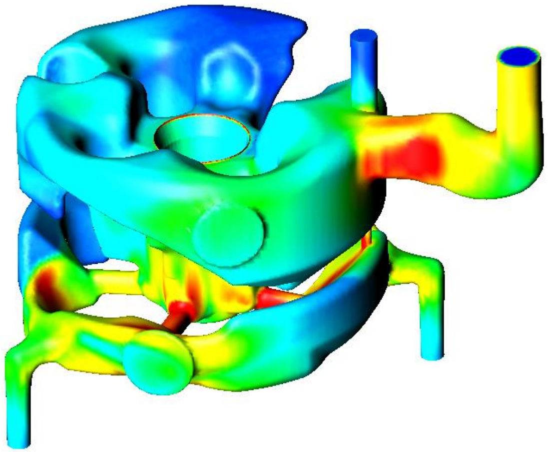


Steady State Application

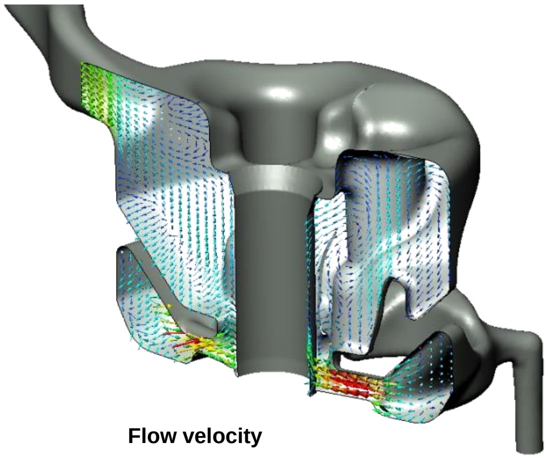
Coolant flow



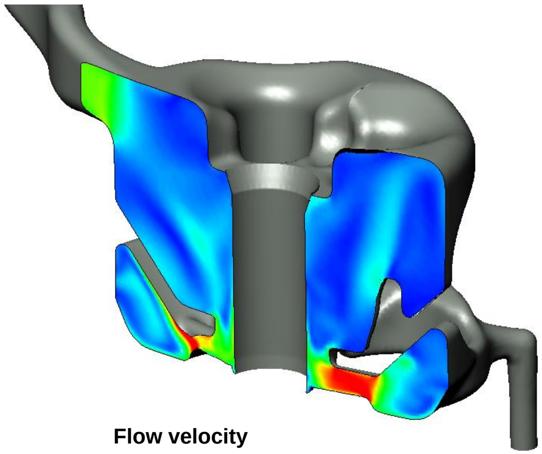
The grid



Heat transfer coefficients on the surface



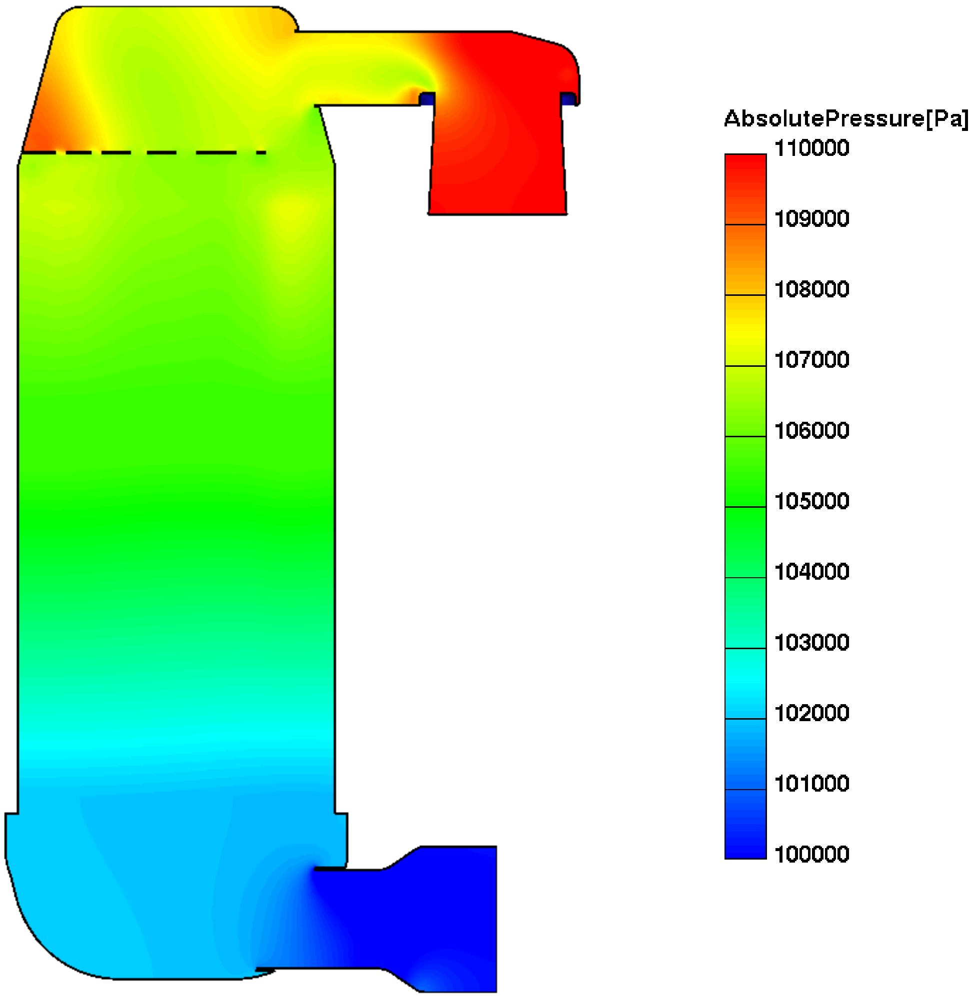
Flow velocity

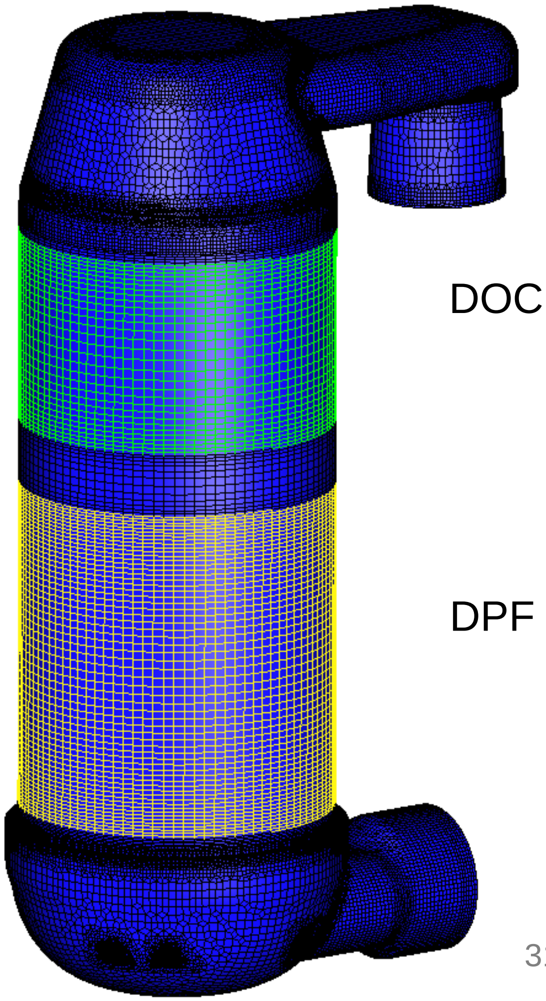


Flow velocity

Steady State Application

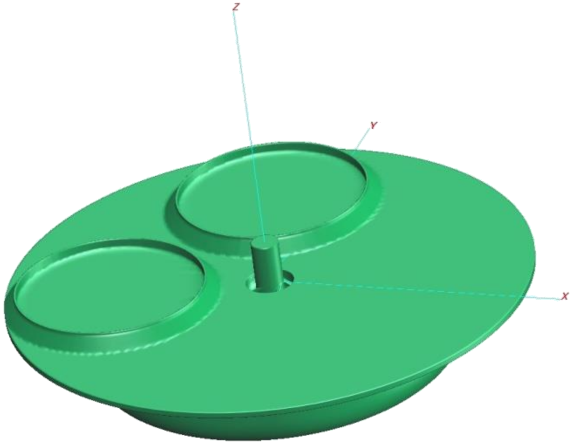
Catalytic Converter and Particle Filter

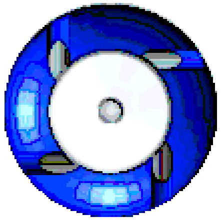


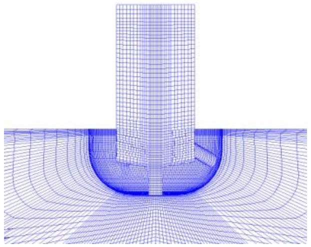


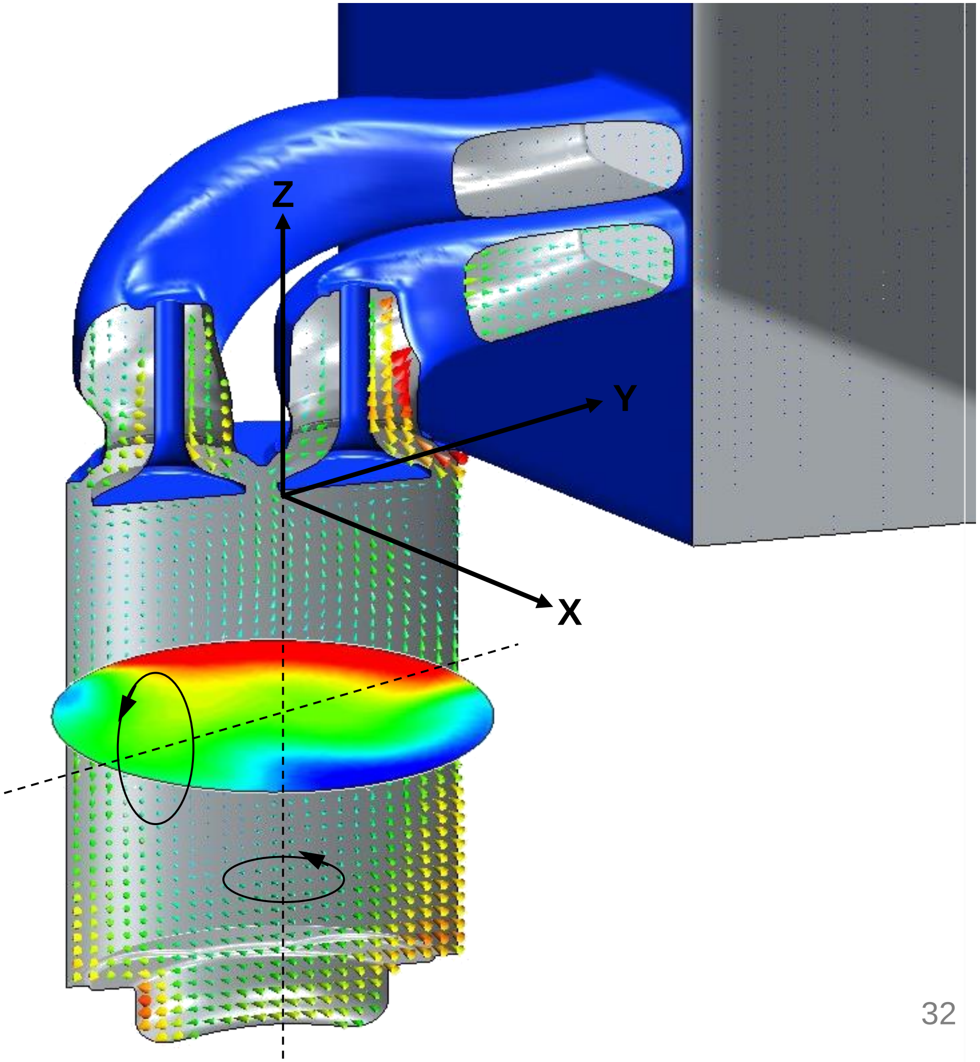
Transient Application

Gas Exchange Process and Combustion Simulation



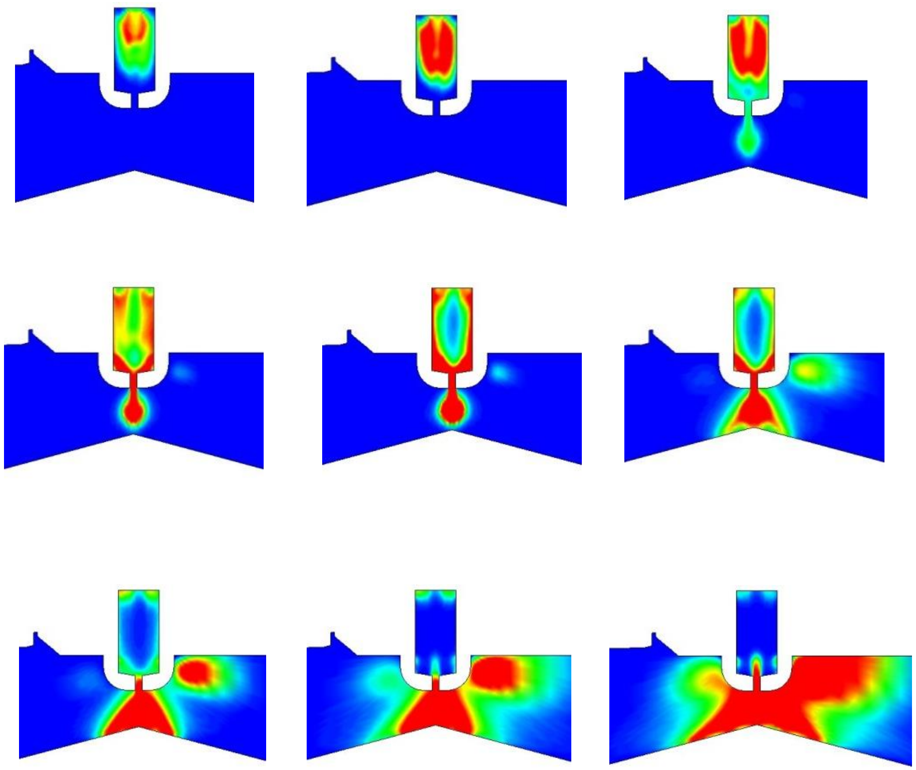


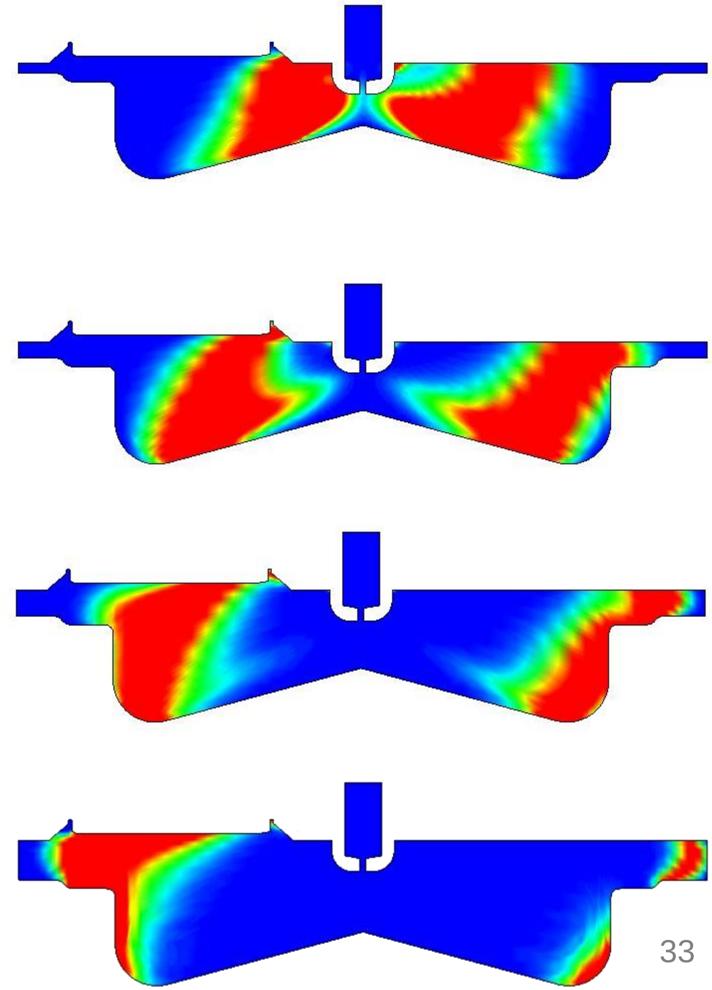




Transient Application

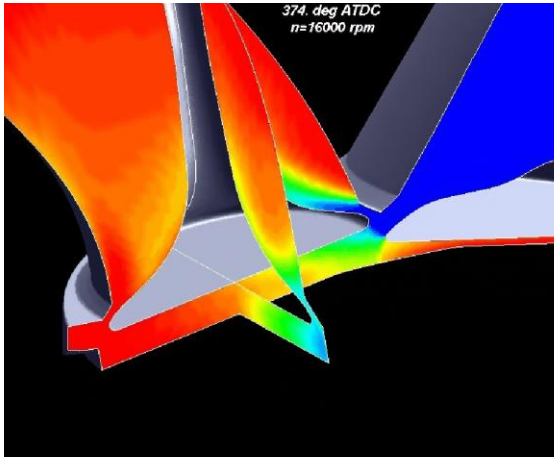
Gas Exchange Process and Combustion Simulation



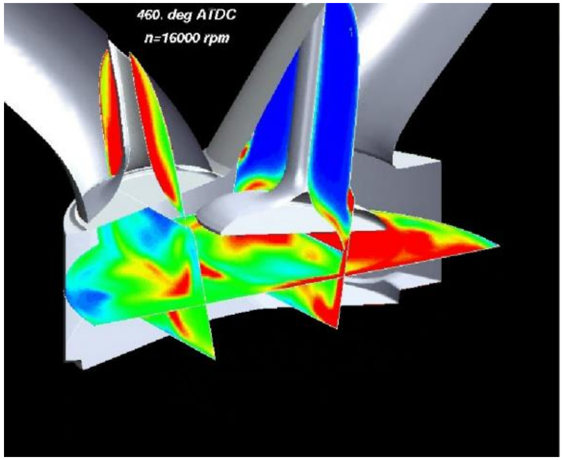


Flame propagation inside the spark plug and combustion chamber by visualisation of the gas temperature distribution

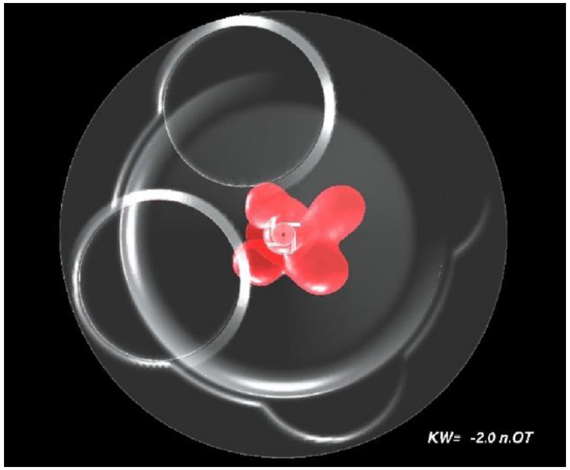
Transient Application



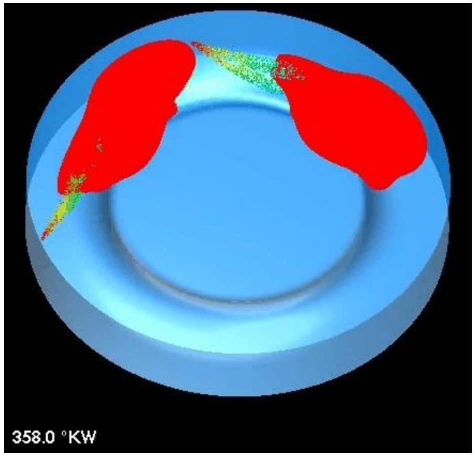
Air and residual gas distribution during the gas exchange process
Capture from Video: Heron_EGR_16000_FR20_04.avi



Turbulent kinetic energy in the combustion chamber
Capture from Video: Heron_Whole_Cycle_TKE_16000_FR20_02.avi



Flame front propagation in a gas engine
Capture from Video: FLA_FRO_3D_A_00.avi

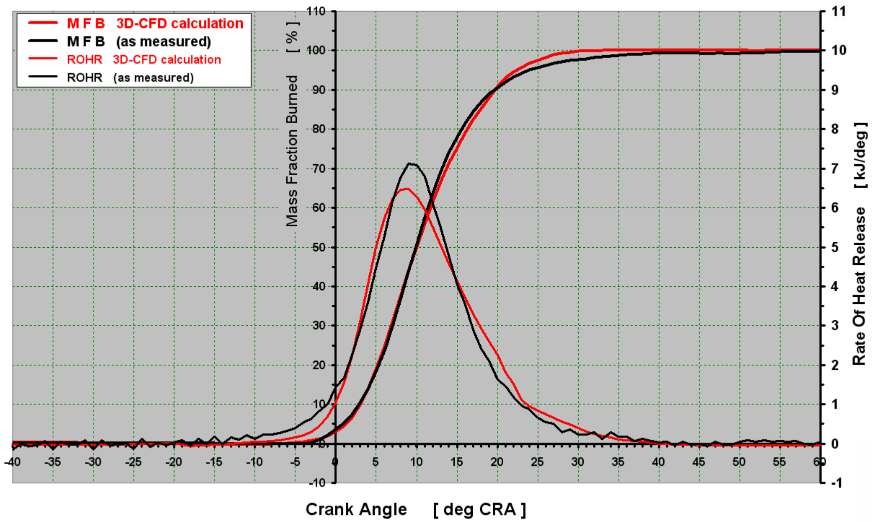


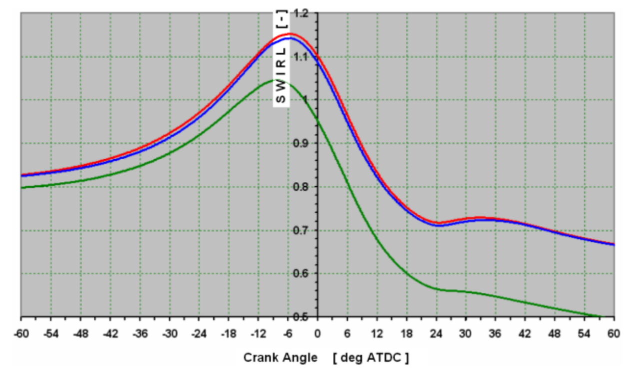
Flame front propagation in a 2 stroke opposite piston DIESEL engine
Capture from Video: V9-Flamefront_isoTemp.avi

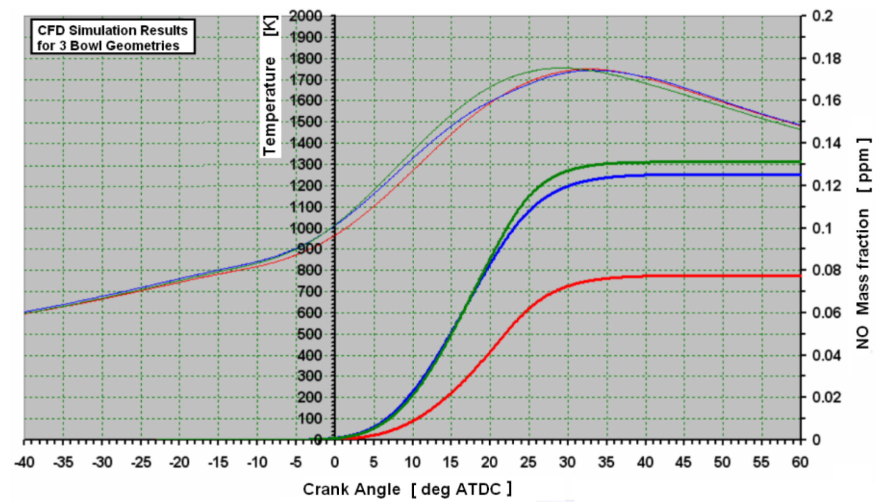
Transient Application

3D - CFD Combustion Simulation and Emission Prediction

3D-CFD Combustion Simulation







Integral Values:

In-Cylinder Pressure & Temperature

ROHR & MBF, Swirl

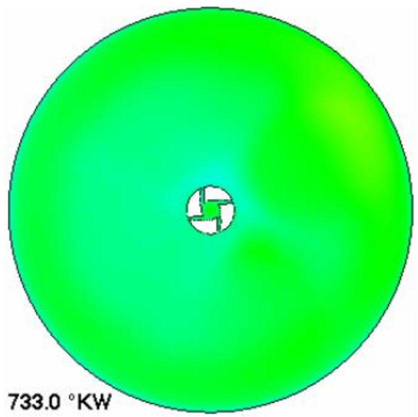
Mean and local T.K.E.

EGR distribution ...

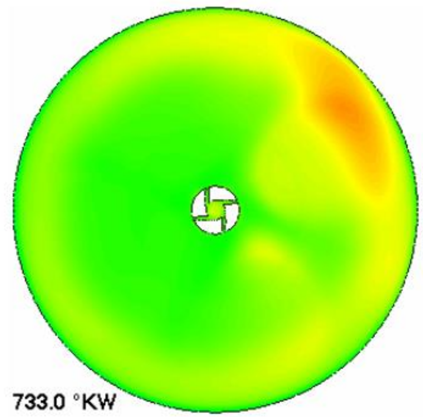
Transient Application

Probability of Nocking

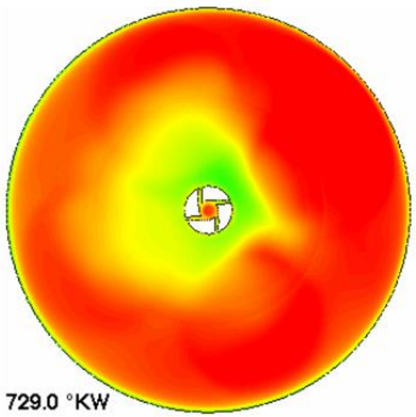
Bowl Geo 1



Bowl Geo 2



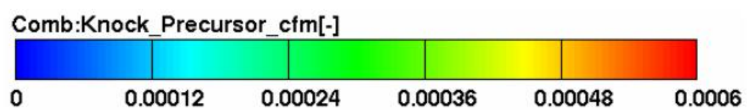
Bowl Geo 3

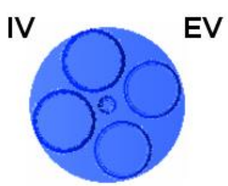


C U T

z = - 1,5 mm

Remark: Figures are shown at highest in-Cyinder temperature

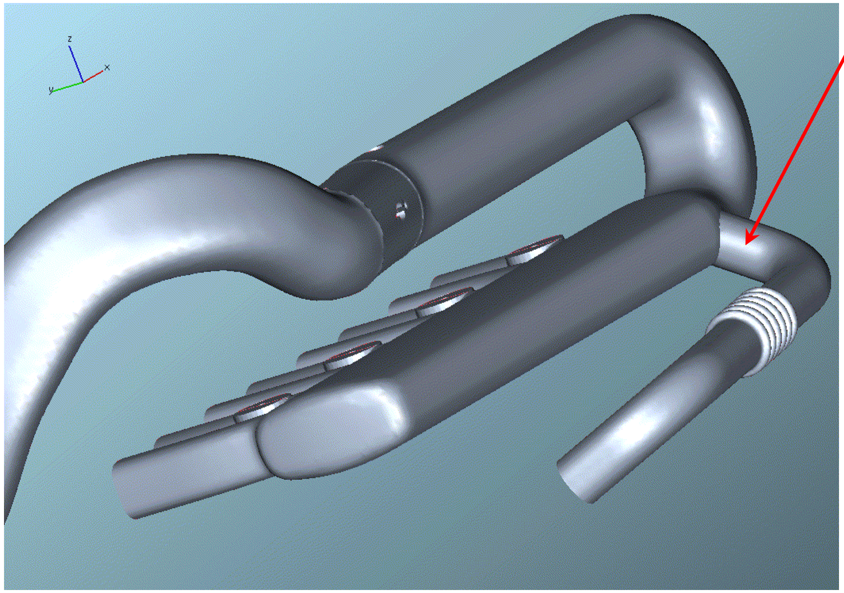




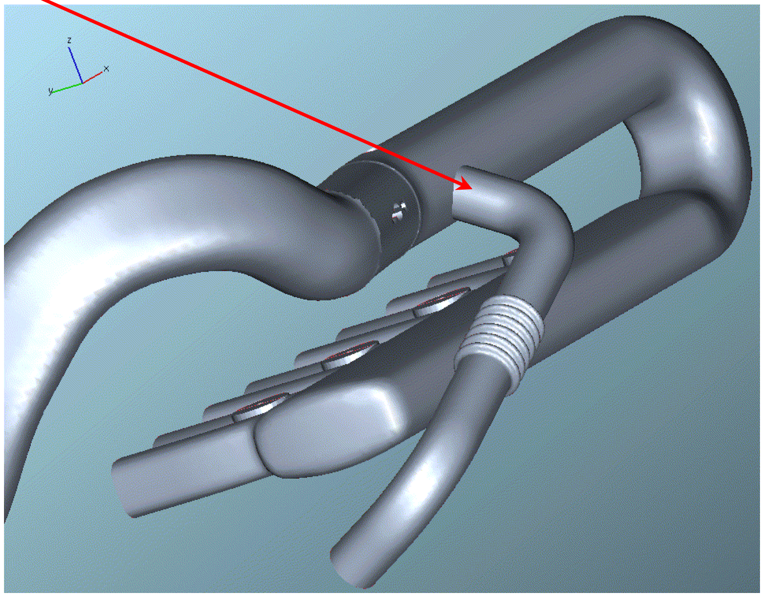
Transient Application

E G R - Distribution in the inlet manifold

E G – Inlet position



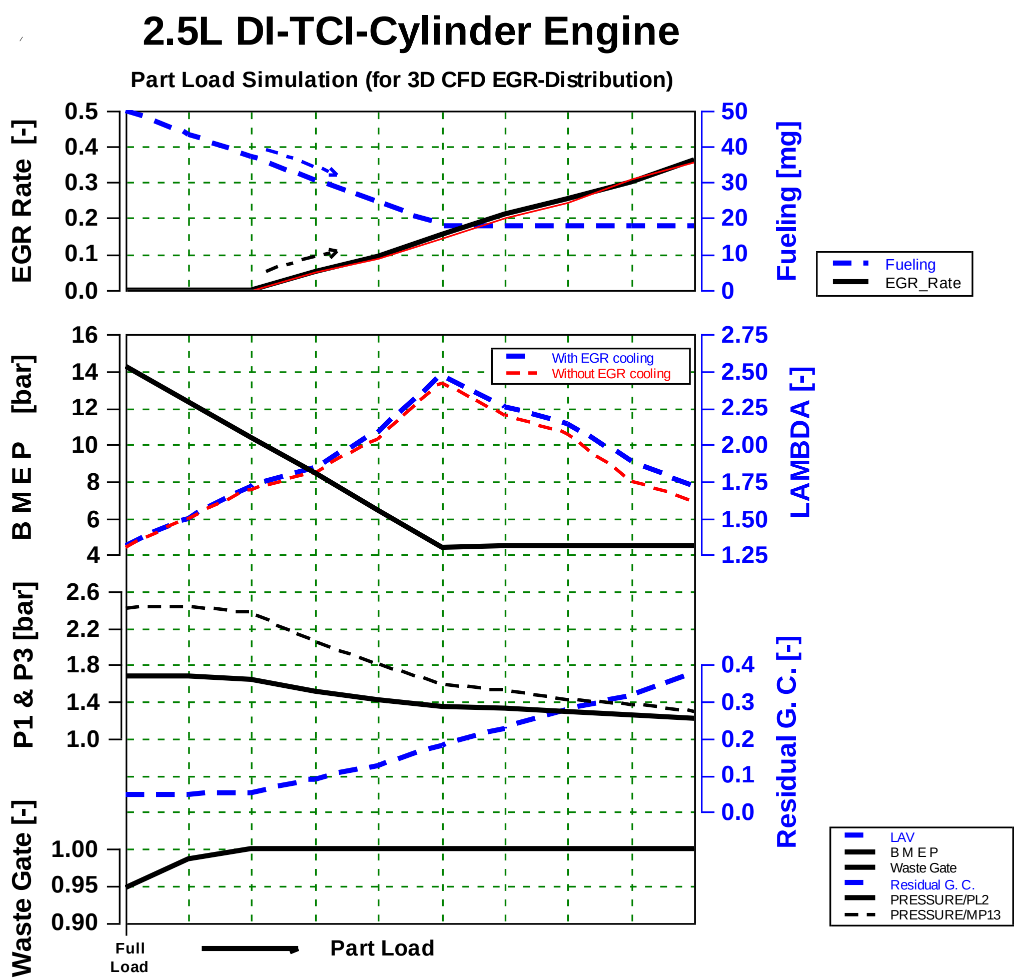
Design A

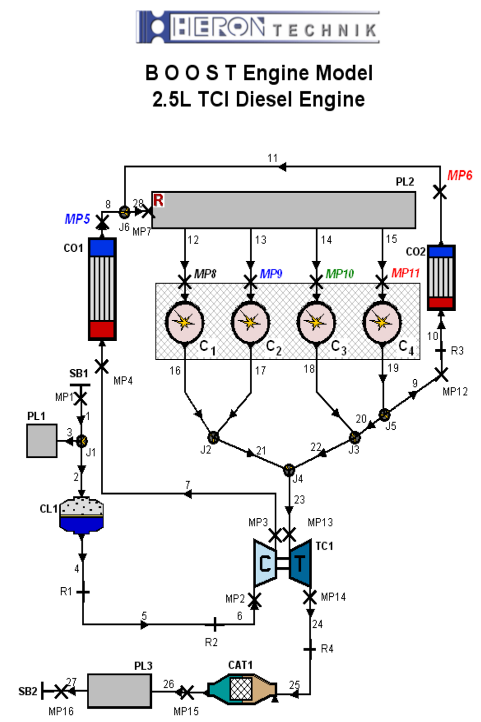


Design B

Transient Application

E G R - Distribution in the inlet manifold



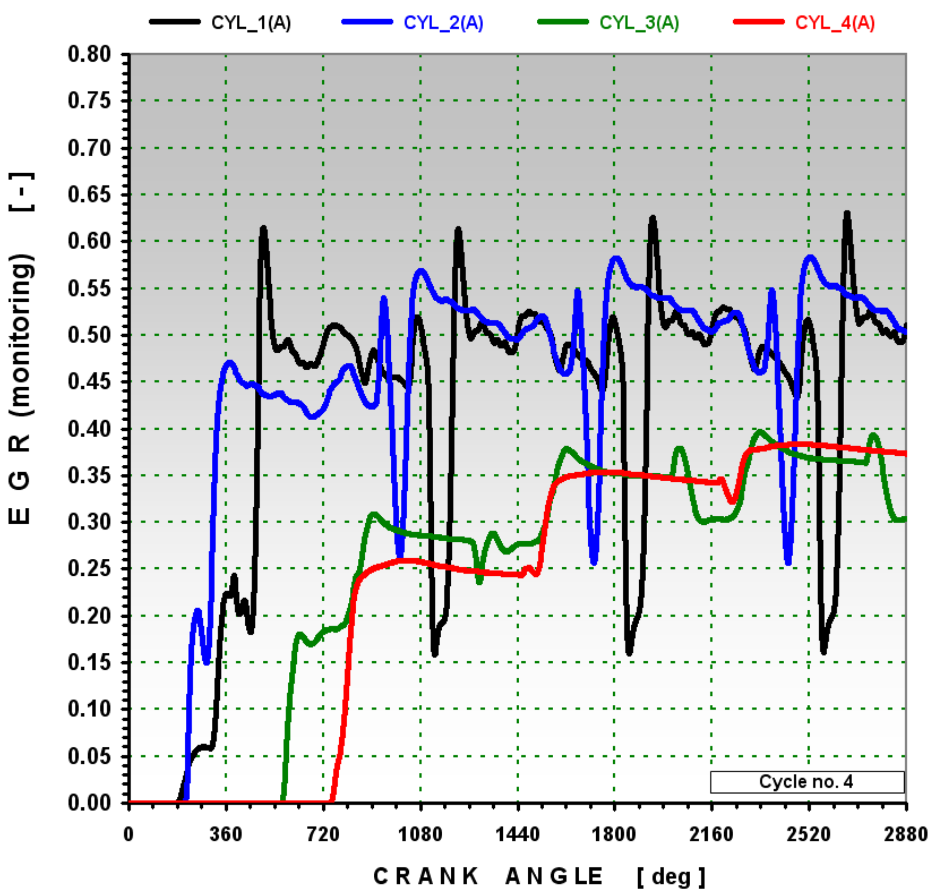


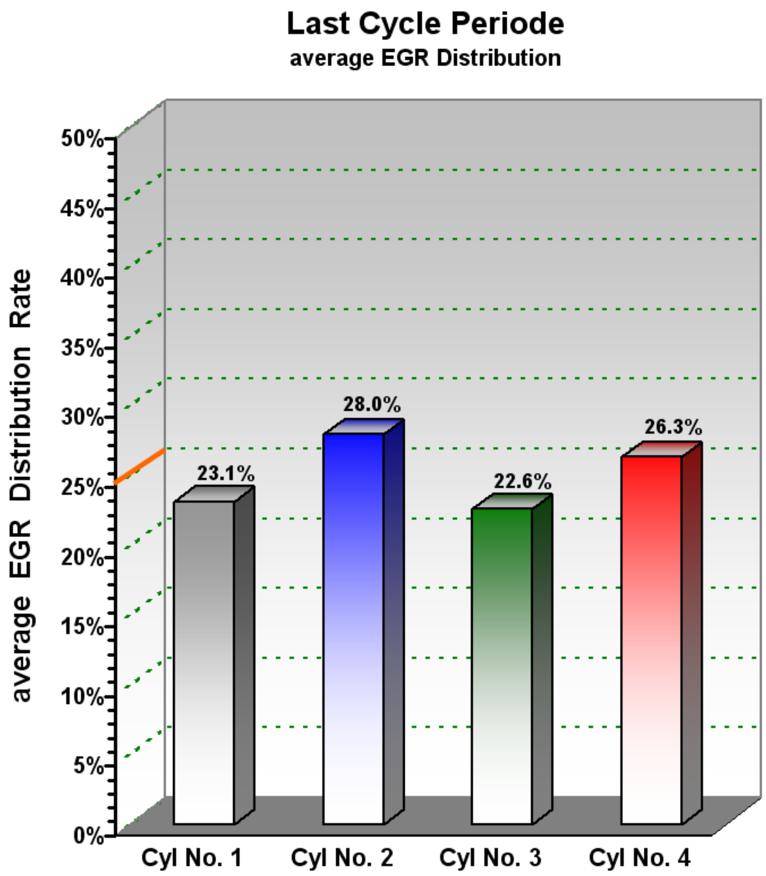
Engine Speed n = 1800 rpm

Transient Application

Calculated E G R Distribution - Design A

4C-TCI Diesel Engine n = 2800 rpm / 4.2 bar - Part Load with EGR 36%

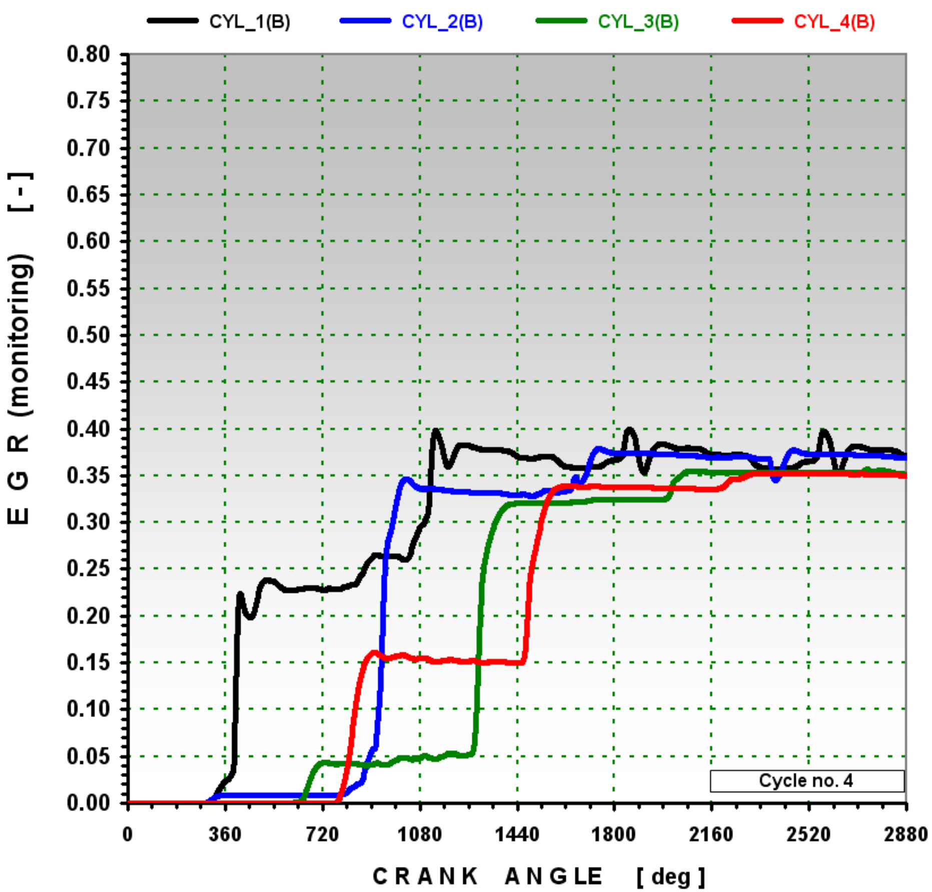


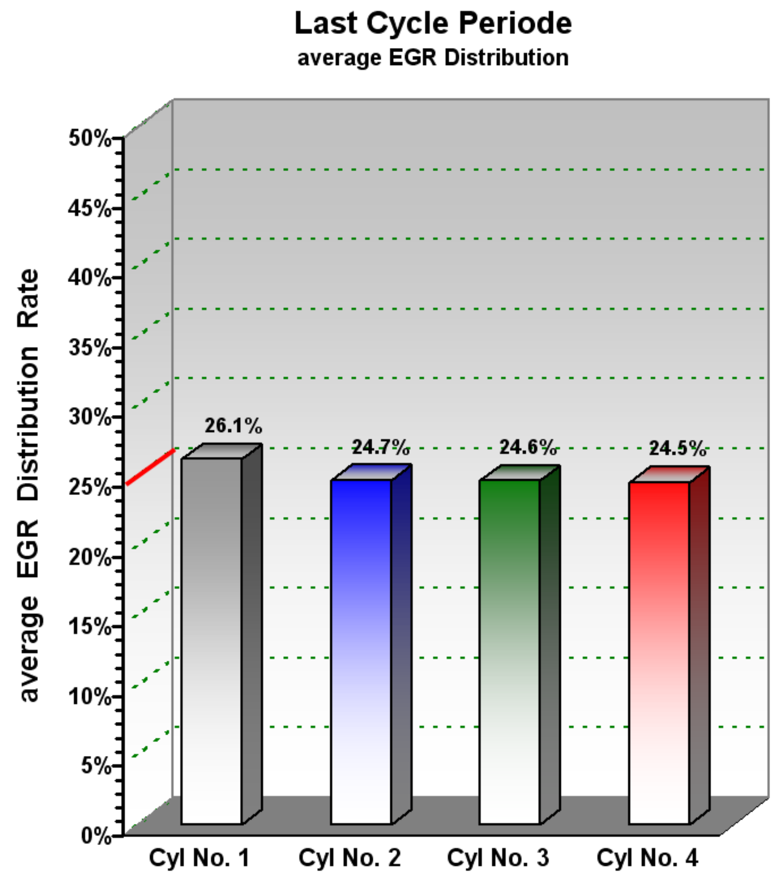


Transient Application

Calculated E G R Distribution - Design B

4C-TCI Diesel Engine n = 2800 rpm / 4.2 bar - Part Load with EGR 36%





HERON Software - Commercially available

Specialized in the development of user-friendly EXCEL based programs

H C S Gas Exchange Program for TC/TCI DIESEL Engines

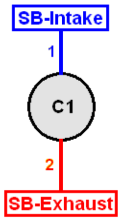
- Easy to use - Simple to embed into existing data acquisition systems
- Very accurate engine simulation program
- Created for designers, application and test bed engineers
- No modelling required – No simulation experiences required
- No annual license fees

VALVE TRAIN SYSTEMS

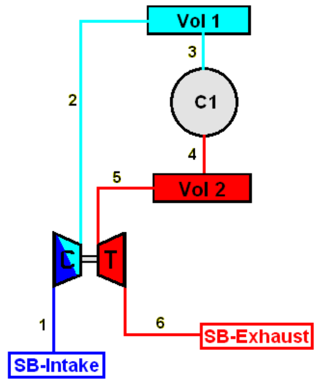
- Smooth and jerk-free cam profiles based on specified valve lift demands
- User specified layout (lift height, ramps, asymmetric characteristics)
- Spring and pneumatic valve layout
- Forces and stress calculation
- Grinding coordinates

H C S - Models (Examples)

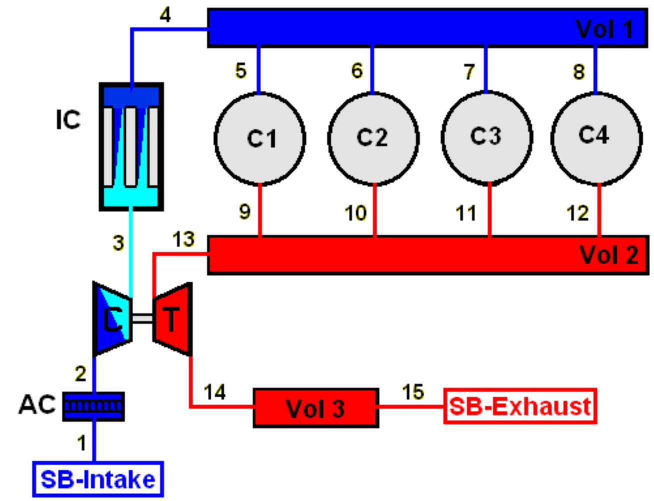
1C NA-Model



1C-TC Model



4C-TCI DIESEL Engine Model



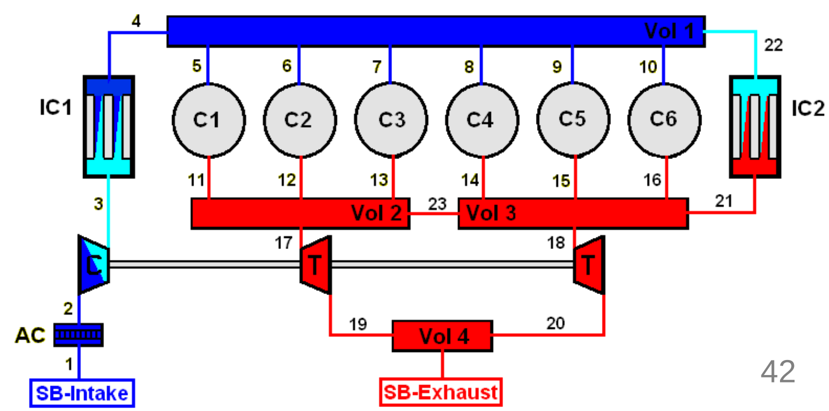
HERON delivers the individual

engine models -

The costumer only changes the

required input data

6C-TCI Diesel Engine with externally cooled EGR



H C S - Example for the Pre- & Post Processing

Program:	HCS_4C_TCI_v1.15
Created by:	HERON TECHNIK
Project ID:	4C - 5.1L (Example VE)

INPUT DATA		
BORE	110	mm
STROKE	135	mm
CONROD LENGTH	221	mm
Crankshaft-Offset	0	mm
COMPRESSION RATIO	17.5	-
Total Displacement	5.132	L
Number of INTAKE Valves	2	-
Dvi - INTAKE	32.70	mm
Intake Valve Clearance	0.4	mm
LIFT_intake.dat	Load INLET Valve	
Number of EXHAUST Valves	2	-
Dvi - EXHAUST	30.70	mm
Exhaust Valve Clearance	0.5	mm
LIFT_exhaust.dat	Load EXHAUST Valve	

D:\HCS_Data\Projects\HCS_Examples amples

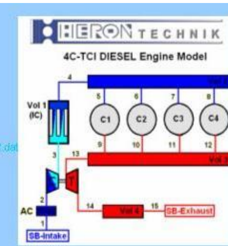
Engine Speed		2200	rpm
Timestep		1	deg
Number of Cycles		12	-
Number of Cylinders		4	
SB1 - INTAKE	Po1	1	bar
Ambient Conditions	To1	25	°C
= Ref. Condition	Pur1	1	-
SB2 - EXHAUST	Po2	1	bar
Ambient Conditions	To2	550	°C
	Pur2	0.1	-

INTAKE Timings	orig.	shift	new
IVO	355.0	deg	
max. Lift	459.4	0	
IVC	571.3		

EXHAUST Timings	orig	shift	new
EVO	142.4	deg	
max. Lift	254.4	0	
EVC	372.0		

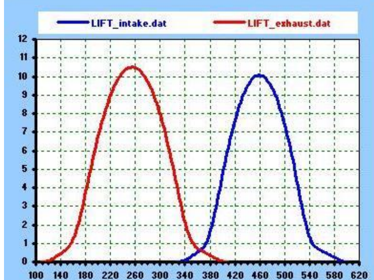
FUEL DATA			
Stoichiometric A/F		14.7	kg/kg
Net Calorific Value		42700	kJ/kg
Friction Loss FMEP		1.65	bar
Fuelling	Mass	125	mg
Combustion		Vibe	Load ROHR
CombStart		-12	deg.CRA
CombDuration		64	deg.CRA
Vibe m		1.9	-
Vibe a		6.9	-
Heat Transfer		Woschni	
Head to Bore Area		1.03	-
Piston to Bore Area		1.4	-
Piston to Head Distance		1	mm
Head Temperature		291	°C
Piston Temperature		320	°C
Liner Temperature		230	°C
cu/cm		2	-
DI/IDI		DI	

HCS_ROHR.dat



Air Cleaner AC		
Pressure loss	27	mbar
TC-Modus:	Wastegate Flow	
Compr. Eff.	72	%
P2 / P1	2.8	-
Turbine Eff.	71	%
Turbine Size Ø	24	mm
calc. Turbine Size Ø		mm
W.G. Flow Rate	18.8	%

CALCULATION			Save last results	DIFF
Summary				
SPEED	2200 rpm		2200	100.0%
IMEP	18.37 bar		18.78	97.8%
BMEP	16.72 bar		17.13	97.6%
Power	157.3 kW		161.2	97.6%
Torque	683.0 Nm		699.5	97.6%
BSFC	209.7 g/kWh		204.8	102.4%
LAMBDA	1.75 -		1.75	100.1%
Fuelling	125.00 mg		125.00	100.0%
RGC	3.90 %		4.01	97.4%
P F P	163 bar		172	94.5%
PFP Position	7.0 deg		11.0	63.6%
MFB 5%	-0.2 deg		-0.2	80.1%
MFB 50%	17.0 deg		13.9	122.3%
MFB 90%	31.8 deg		27.2	117.1%
PMEP	-1.32 bar		-1.33	99.3%
PMEP Intake	2.25 bar		2.25	99.9%
PMEP Exhaust	-3.57 bar		-3.58	99.7%
ADR_SB1	214.4 %		214.2	100.1%
ADR_Vol2	85.4 %		85.4	100.1%
ETA_vol	82.1 %		81.9	100.2%
Air mass flow	850 kg/h		849	100.1%
Fuel mass flow	33.0 kg/h		33.0	100.0%
Exhaust flow	883 kg/h		882	100.1%
Piston Heat Flow	5.68 kW		6.07	93.5%
Head Heat Flow	4.43 kW		4.73	93.8%
Liner Heat Flow	4.64 kW		4.50	103.2%
P_Vol 2	2.680 bar		2.680	100.0%
T_Vol 2	45 °C		45	99.9%
P_Vol 3	3.333 bar		3.346	99.6%
T_Vol 3	624 °C		607	102.8%
P_Vol 4	1.150 bar		1.146	100.3%
W.G. Flow Rate	18.8 %		17.6	106.9%
M-Balance error	0.0 %		0.0	-58.9%
TC-Balance error	0.1 %		0.1	107.1%



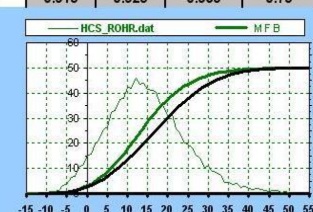
INLET Flow Coeff.		EXH. Flow Coeff.	
Lift	forward	Lift	forward
Lift/Diameter	-	Lift/Diameter	-
0	0	0	0
0.04	0.084	0.04	0.097
0.08	0.151	0.08	0.231
0.12	0.229	0.12	0.399
0.16	0.324	0.16	0.516
0.20	0.415	0.20	0.578
0.24	0.502	0.24	0.615
0.28	0.575	0.28	0.643
0.32	0.629	0.32	0.659
0.36	0.665	0.36	0.673
0.40	0.690	0.40	0.681

	AREA		TEMP.	
INLET Port	13075	mm²	80	°C
EXHAUST Port	9548	mm²	220	°C

		I C	Vol 2	Vol 3	Vol 4
Volume	L	3	3.5	2	10
Surface	m²	5	0	0	0
Wall Temperature	°C	25	25	680	340
Diameter DIA	mm	40	90	80	100
ALFA IN	-	0.91	0.92	0.93	0.75
ALFA OUT	-	0.915	0.925	0.935	0.75

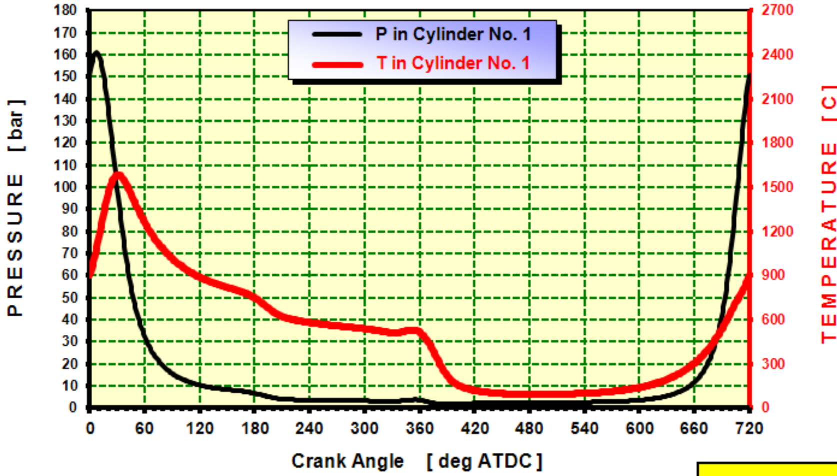
Program Version :	v1.15		
Licensed for :	HERON_02		
Code :	0851-DAC1	16:47:36	Start
Status :	44	16:48:07	End
Error :	-	31	dT [s]
Expire Date :	30/05/2011	16/04/2011	Date

... User INPUT data
... Calculation RESULTS

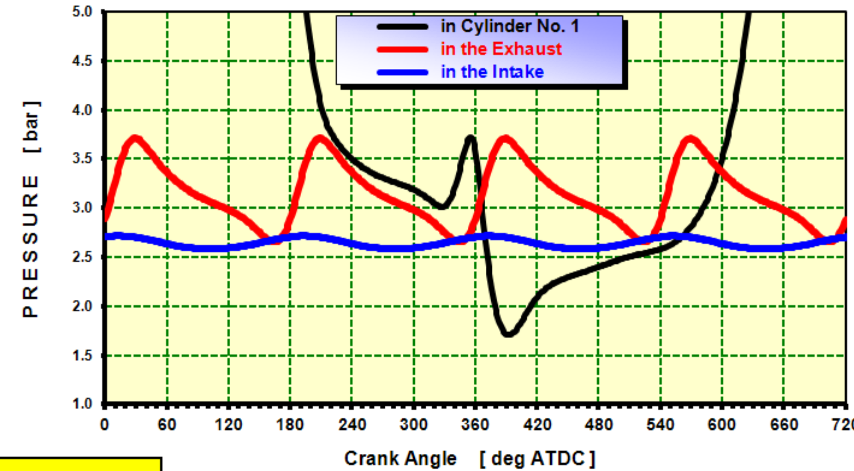


H C S - Example for the Pre- & Post Processing

Calculated Cylinder Pressure & Temperature

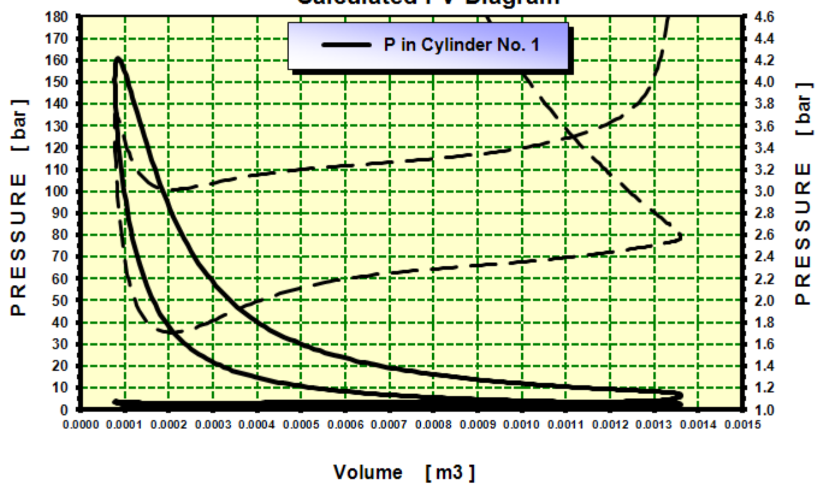


Calculated Pressure Traces

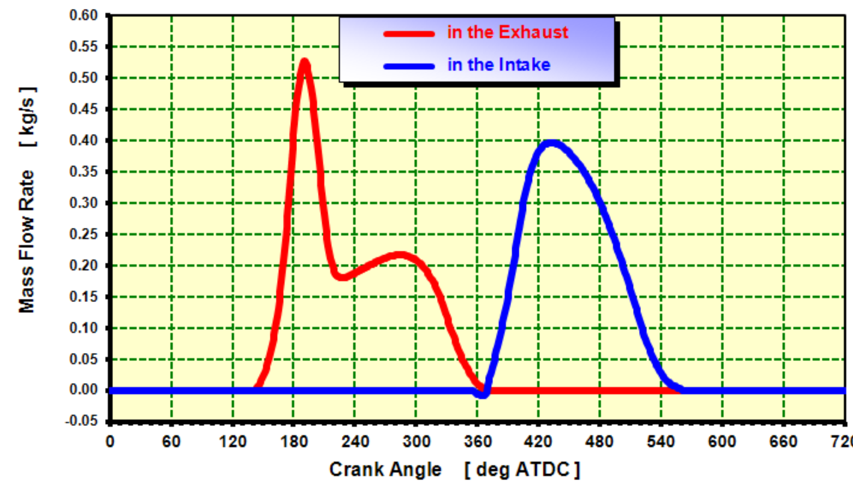


4C - 5.1L (Example VE)

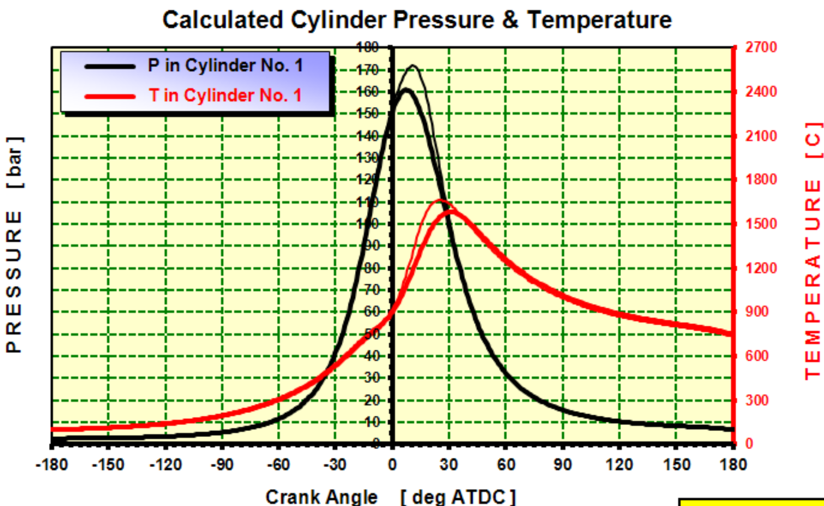
Calculated PV-Diagram

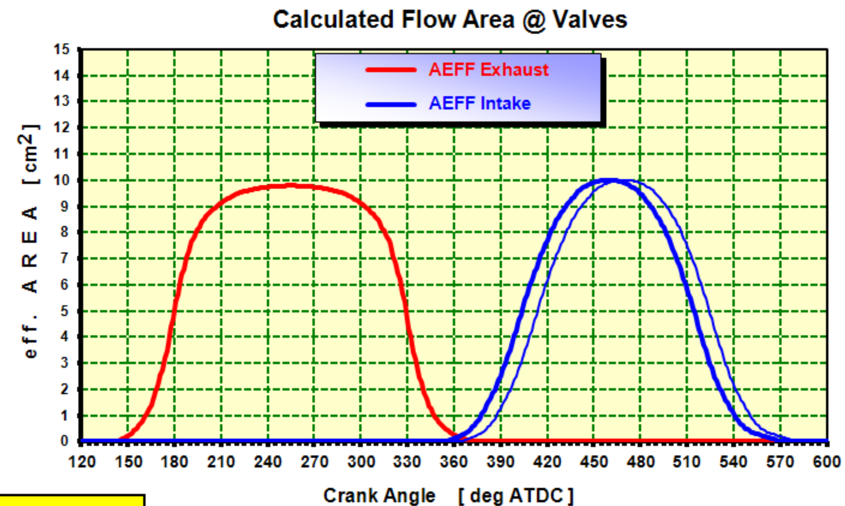


Calculated Mass Flow Rate

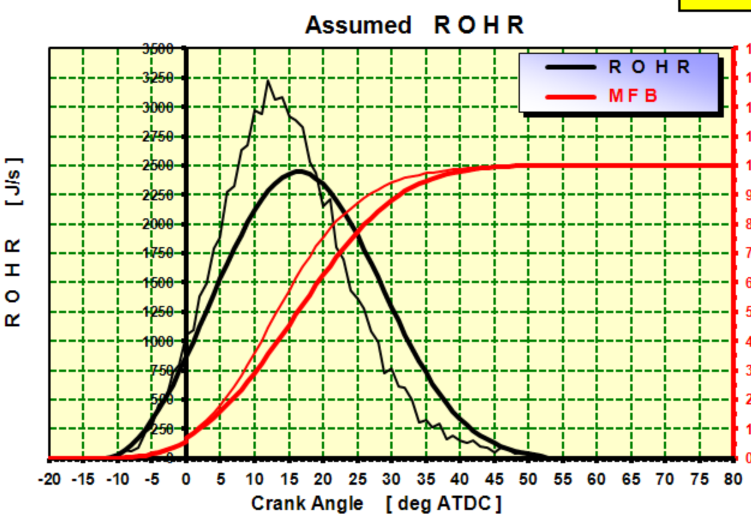


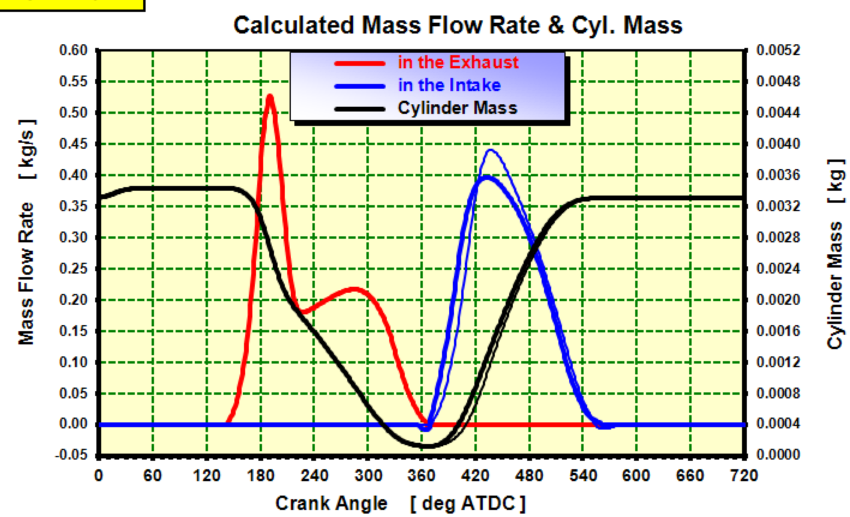
H C S - Example for the Pre- & Post Processing





4C - 5.1L (Example VE)



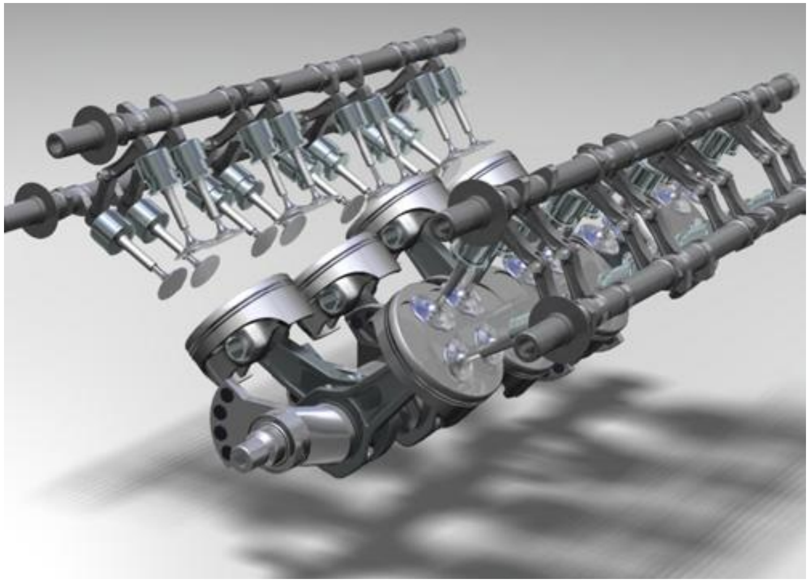


Valve Train Systems

Valve lift and cam shaft design is a major part for the engine performance development

Optimised inlet and exhaust systems – together with the valve timings and lift characteristics – are key parameters for volumetric efficiency, power output and low fuel consumption. These targets require a close link between gas exchange optimisation and valve train calculations as well as good experiences

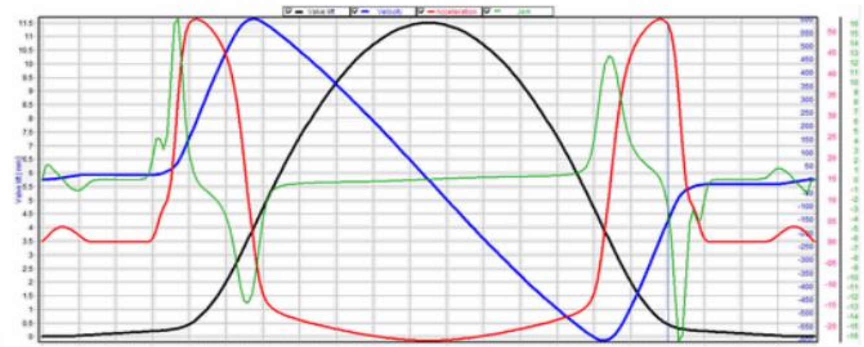
HERON Technik GmbH has <u>both</u>, the tools and long term experience!



Cam Shaft Design

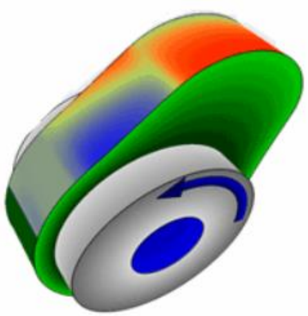
Using state-of-the-art technology that has been proven in the common road industry as well as applied in several high performance race series like F1, touring cars and race bikes.

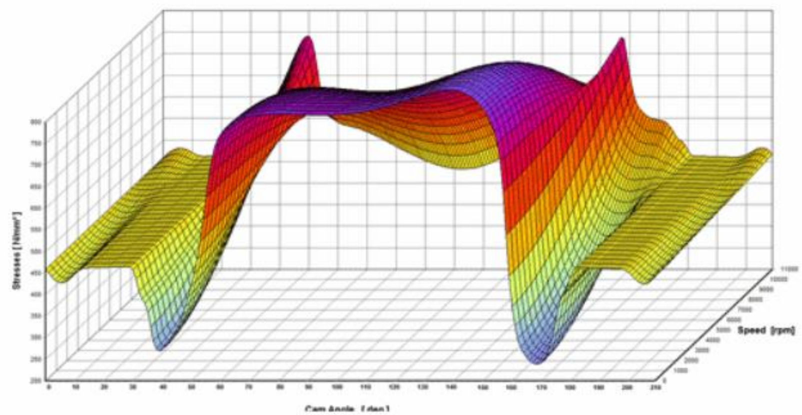
- Timing & Valve Lift Curve
- Valve Velocity, Acceleration and Jerk
- Entire Geometry for all kinds of VT Design
- Stress Calculation
- Spring and Pneumatic Layout
- Grinding Coordinates



Applied for

- Flat tapped design
- Roller follower
- Finger follower
- Rocker arm design
- Push rod design





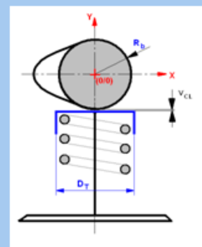
Additionally, HERON Technik GmbH offers costumer-tailored programs based on EXCEL, which complies to all requests for a sucsessful valve train layout

Program: **HERON-FT v1.02**
Created by: **HERON Technik GmbH - Graz**

HERON TECHNIK

INPUT DATA

Base Circle	Rb	18	mm
Tappet Diameter	DT	26	mm
Clearance	Vcl	0.25	mm
Distance to centre line	dX	0.2	mm
Lobe Width	Wl	8.7	mm
Min. Speed	RPM_min	1500	rpm
Max. Speed	RPM_max	13500	rpm
Valve Mass	Mv	23.4	g
Total Spring Mass	Msp	18.4	g
Top Retainer Mass	Mtr	21.6	g
SUM (Valve side)		54.2	g
Youngst´st Module 1		210000	
Youngst´st Module 2		210000	
Poisson Ratio		0.3	



CLOCKWISE

SWITCH

UPDATE

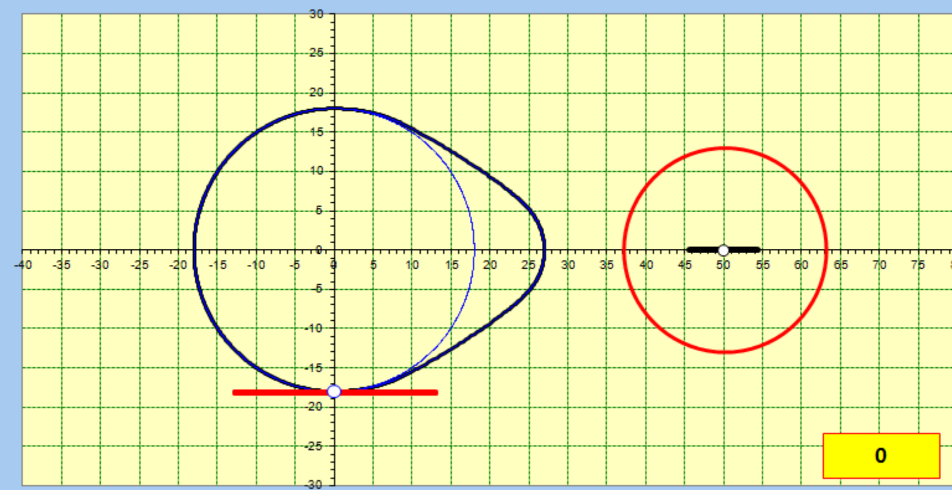
Load lift data ***.dat

C:\HERON-Technik\Lift_POOL

WMB_inl_050.dat

Program Version : v1.02
Program licensed for : HERON
Code :
Status : 0
Current :
Expire Date : 20/12/2012

CAM ROTATION

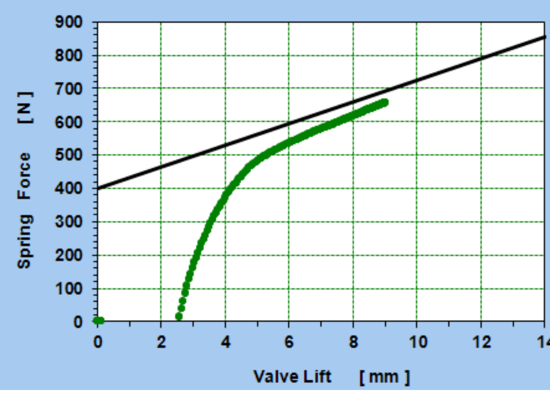


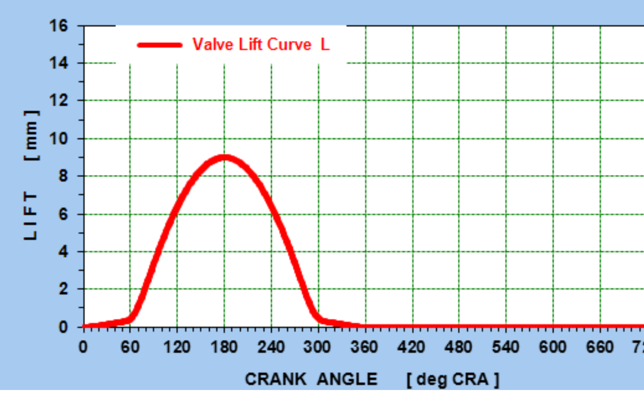
PHI: 720 deg CA
LIFT 0.000 mm

Animation

Aimed spring cover	[%]	20
Calculated spring cover	[%]	24.0

Spring Load	N	400							
Spring Rate	mm	0	1	4	6	8	10	12	14
	N/mm	0	32.5	130	195	260	325	390	455





Program: **HERON-RockerArm_A v1.03**
Created by: **HERON Technik GmbH - Graz**

HERON TECHNIK

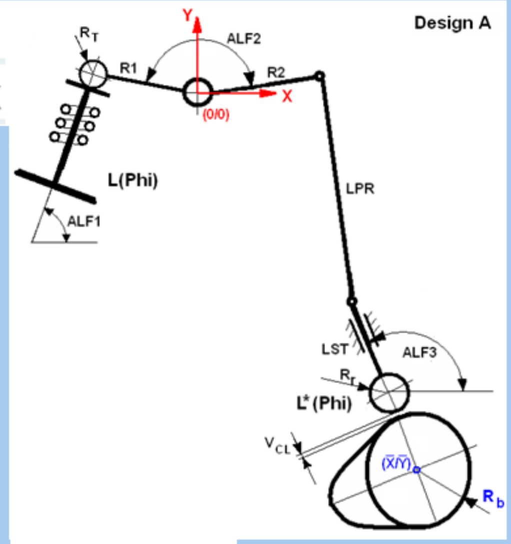
INPUT DATA

Radius	R1	30	mm
Radius	R2	30	mm
Valve Angle	ALF1	75	deg
Lever Angle	ALF2	180	deg
Radius	Rt	5	mm
X-Centre coordinate	Xq	45	mm
Y-Centre coordinate	Yq	-215	mm
Base Circle	Rb	15	mm
Angle	ALF3	95	deg
Clearance	Vcl	0.25	mm
Roller Radius	Rr	15	mm
Length	LST	25	mm
Push Rod Length	LPR	160	mm
Lobe Width (cam side)	Wc	10	mm
Min. Speed	RPM_min	1000	rpm
Max. Speed	RPM_max	4000	rpm

UPDATE

Load lift data ***.dat
C:\HERON-Technik\HERON-Create_Lift
EXACT_05.dat

Program Version :	v1.03
Program licensed for :	HERON
Code :	
Status :	0
Current :	
Expire Date :	20/06/2012



Basis: Cam rotating clockwise

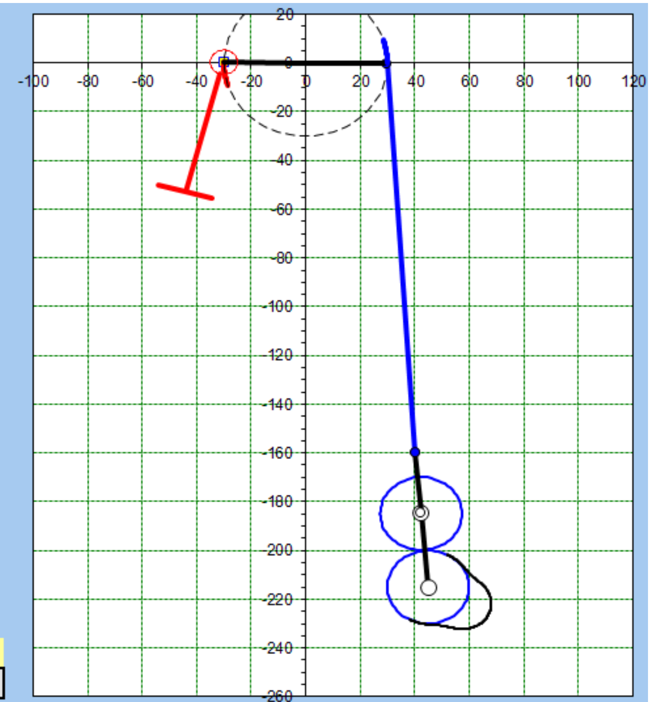
Aimed spring cover	[%] :	20
Calc. Spring cover	[%] :	24

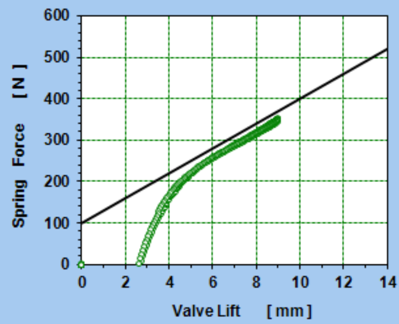
Spring Load	N	100							
Spring Rate	mm	0	2	4	6	8	10	12	14
	N	0	60	120	180	240	300	360	420

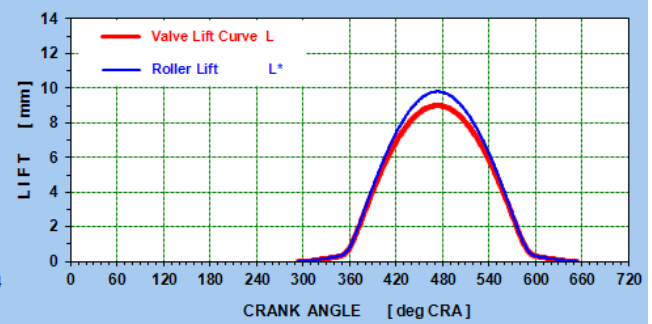
MASS		
Valve	g	40
Spring	g	80
Top Retainer	g	40
SUM (Valve side)	g	120

Rocker Inertia	kg/mm2	40
Lever + Roller	g	80
Push Rod	g	40
SUM (Cam side)	g	164.44

Youngst´st Module 1	210000
Youngst´st Module 2	210000
Poisson Ratio	0.3

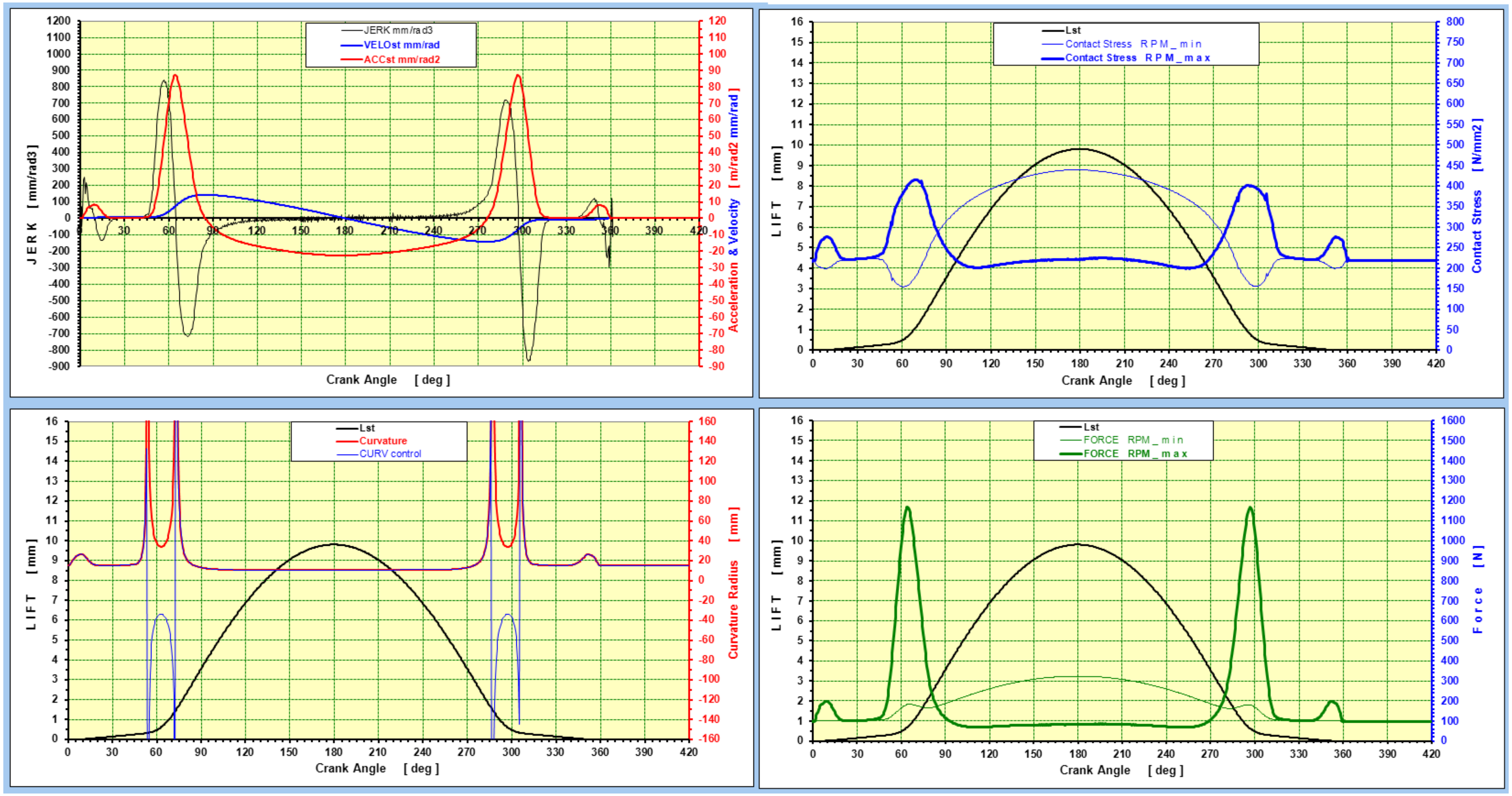




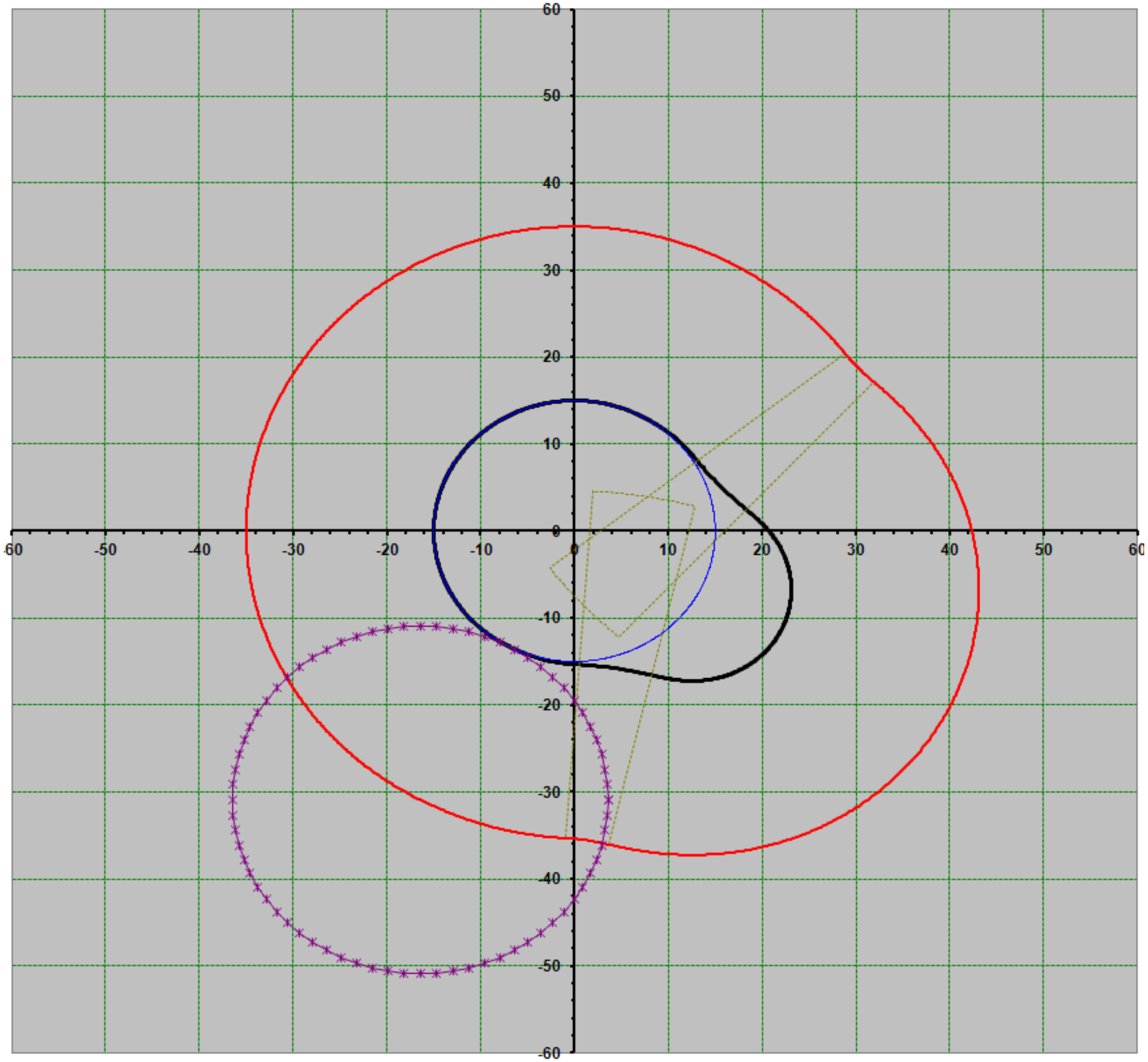


Calculated kinematic data, forces and cam stress

Applying high sophisticated SPLINE algorithm for jerk free valve movement



Path of the Grinding Wheel



HERON Technik GmbH

Technikerstrasse 3

8010 Graz

Austria

Tel. **+43 (0)316 384200-11**
Fax. **+43 (0)316 384200-20**
Mobile **+43 (0)664 526 7009**

Email: **hans.alten@heron.co.at**
Web : **www.heron.co.at**