HERCULES-C logo:

HERCULES-C List of Beneficiaries

No	HERCULES-C BENEFICIARY (LEGAL NAME)	SHORT NAME	COUNTRY
1	National Technical University of Athens	NTUA	Greece
2	Aalto-Korkeakoulusaatio	AALTO	Finland
3	ABB Turbo Systems AG	ABB	Switzerland
4	Bodycote Metallurgical Coating Limited	BODYCOTE	United Kingdom
5	Chalmers Tekniska Hoegskola AB	CHALMERS	Sweden
6	Danfoss IXA AS	DANFOSS	Denmark
7	Danmarks Tekniske Universitet	DTU	Denmark
8	Eidgenössische Technische Hochschule Zürich	ETH Zurich	Switzerland
9	Federal-Mogul Burscheid GmbH	FMO	Germany
10	FEV GmbH	FEV	Germany
11	FOS Faseroptische Systeme Messtechnik GmbH	FOS	Germany
12	Gehring Technologies GmbH	GEHRING	Germany
13	IFP Energies Nouvelles	IFPEN	France
14	M. Jurgensen GmbH & Co KG	MJ	Germany
15	Karlsruher Institut Fuer Technologie	KIT	Germany
16	Man Diesel & Turbo SE	MDT	Germany
17	Paul Scherrer Institut	PSI	Switzerland
18	Pbs Turbo S.R.O. Velka Bites	PBST	Czech Republic
19	Technische Universitaet Graz	TUG	Austria
20	Tehag Engineering AG	TEHAG	Switzerland
21	Wartsila Finland Oy	WFI	Finland
22	Winterthur Gas & Diesel AG	WINGD	Switzerland
23	Flame Spray Technologies Ltd	EPC	United Kingdom

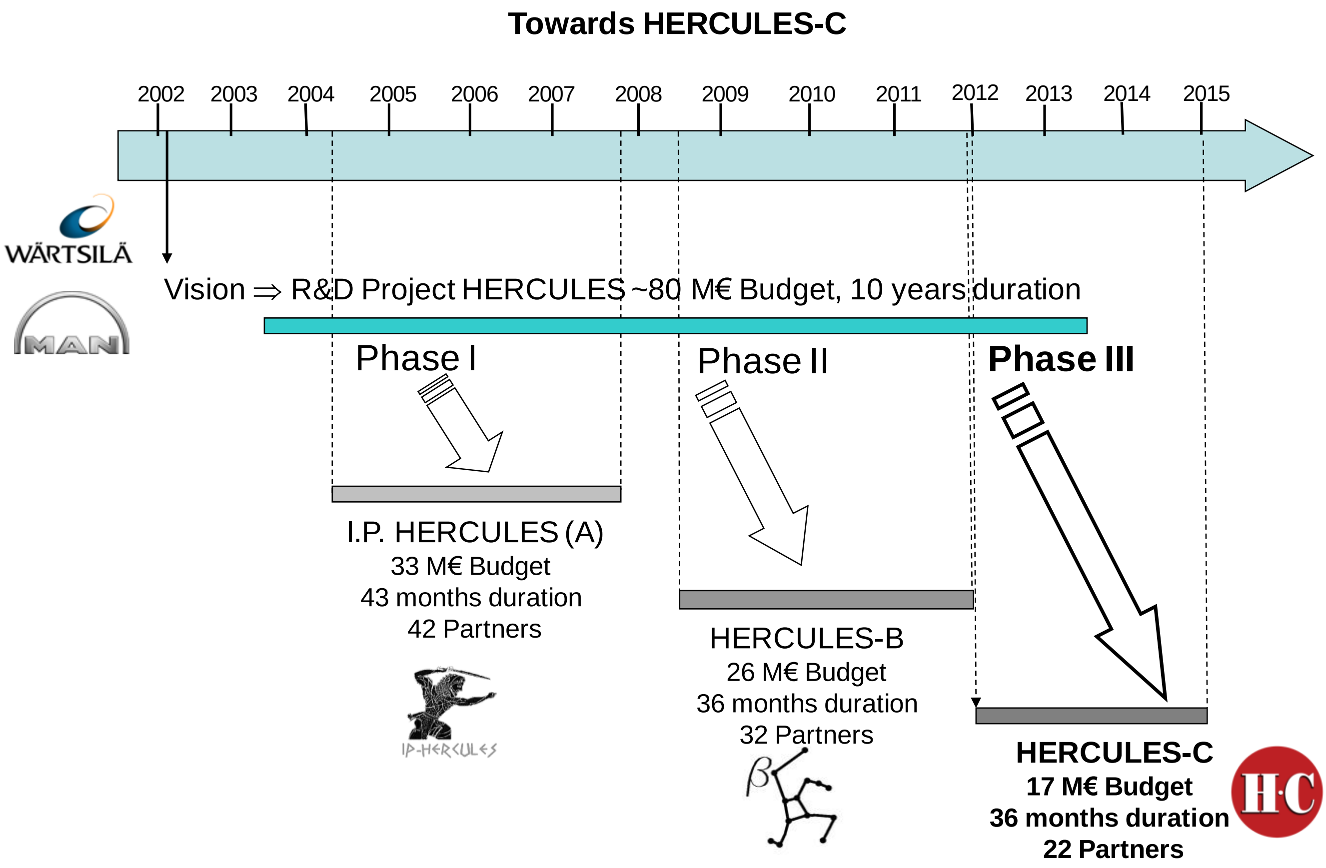


Figure 1: Projects in HERCULES Programme

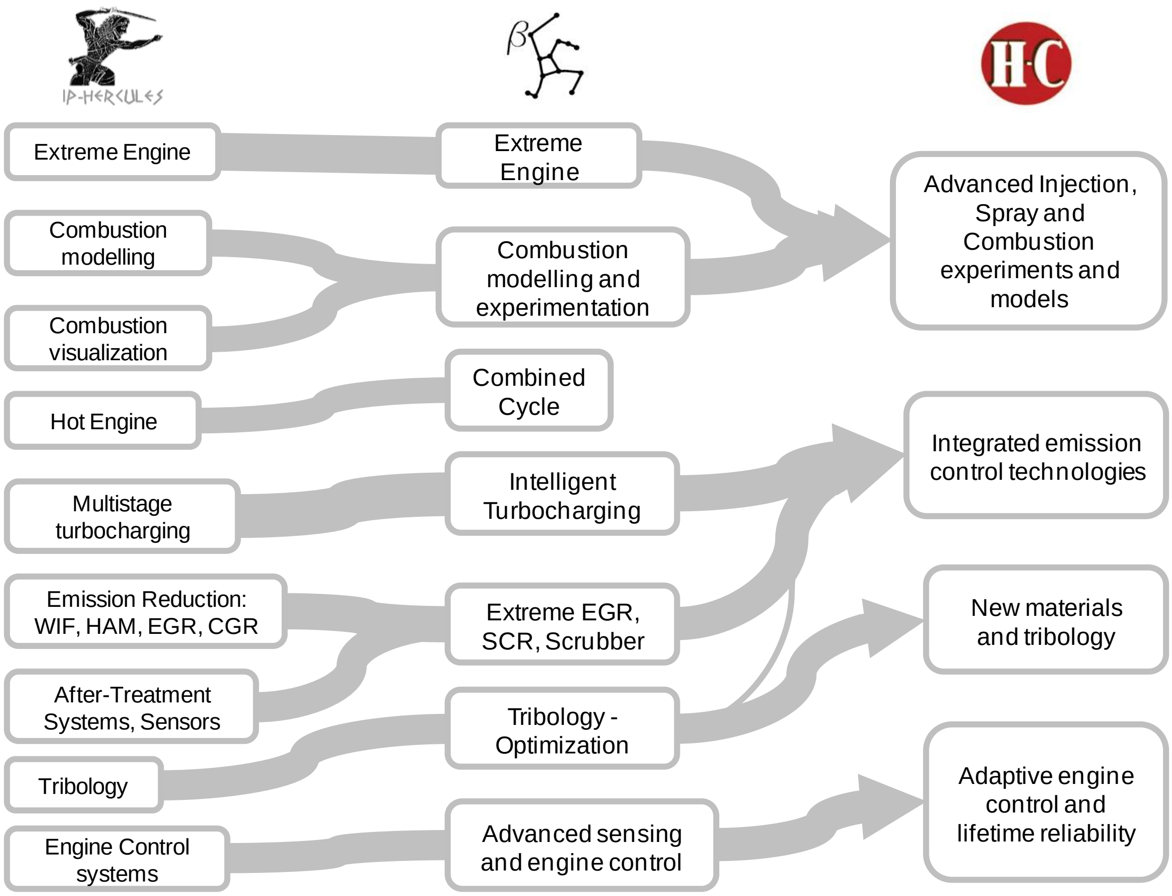


Figure 2: Links from H-A and H-B to H-C.

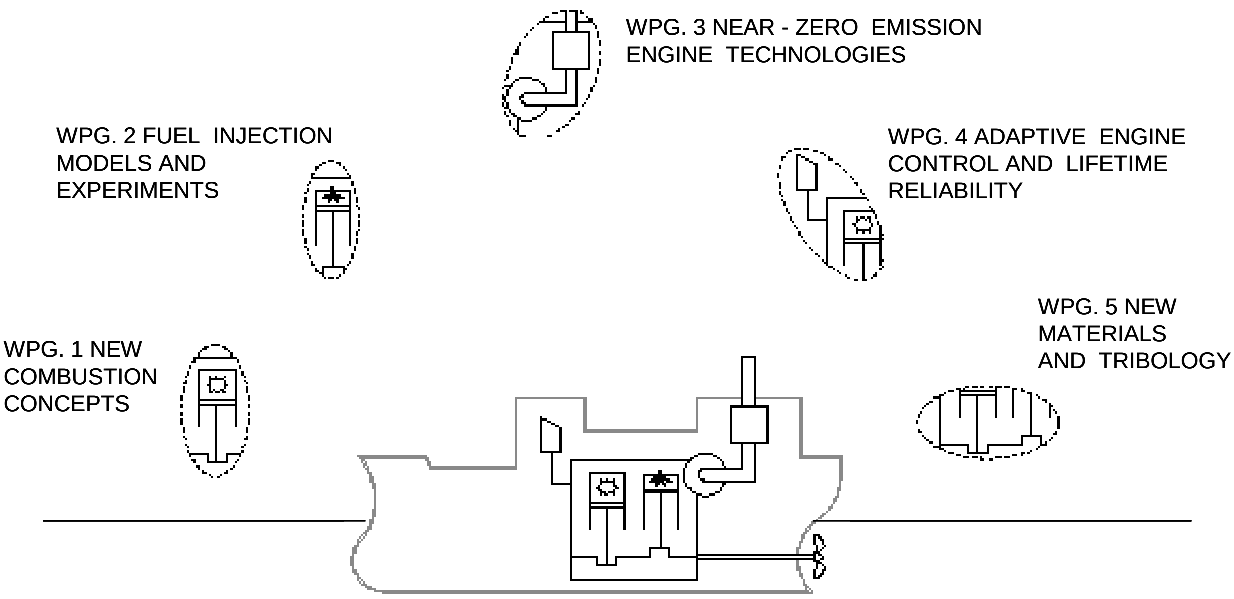


Figure 1: Schematic overview of HERCULES-C Work Package Groups.

HERCULES-C WP’s and Participants

WORK PACKAGE TITLE	PARTICIPANTS LIST
WP 1: Advanced Combustion	AALTO, WFI, WCH
WP 2: Computer Aided Combustion Optimization	KIT, MDT, TUG
WP 3: Injection, Spray Formation and Combustion	ETH Zurich, IFPEN, PSI, WFI, WCH
WP 4: Experimental and modeling studies of fuel injection systems	CHALMERS, MDT
WP 5: Integrated emission control technologies	ABB, PSI, WFI, WCH
WP 6: Near zero emission combustion and DPF technologies	NTUA, DANFOSS, MDT, PBST, TEHAG
WP 7: Advanced system and plant control	NTUA, AALTO, ETH Zurich, PSI, WFI
WP 8: Intelligent engine	NTUA, FEV, MDT, TUG
WP 9: Cylinder lubrication concept for optimized emissions	FOS, WCH
WP 10: Advanced bearing and combustion chamber technology	EPC, DTU, FMO, GEHRING, MJ, MDT
WP 11 Administrative Management	NTUA
WP 12 Technical Management	NTUA, MDT, WFI, WCH
WP 13 Dissemination Activities	NTUA, AALTO, CHALMERS, ETH Zurich, MDT, PSI, WFI

Figure 4: HERCULES-C Work Packages and Participants.

# No.	OBJECTIVE	Target VALUE	Achieved within Project	Related WP
# 1	**Substantial reduction in fuel consumption (and CO_2 production)**	*3% within project*	1% 1 %	• Low temperature Combustion (WP1) • DF-engine optimizations (WP1)
			2%	• Combustion optimization (WP2)
			1.5%	• Intelligent engine / Advanced plant control (WP7) • Pressure based cylinder-individual control, health monitoring technologies (WP8)
# 2	**Substantial reduction of emissions to near - zero**	*80% within project*	PM 50% THC 50% NOx 80%	• DF-engine optimizations (WP1) • EGR - Gas operation on EVE (WP1) • Combustion optimization / multi-fuel (WP2) • Aftertreatment (DPF, EGR) (WP6) • Charging (VGT) (WP6)
# 3	**Retain high performance over plant lifetime**		++	• New turbocharger technologies (WP1)
			++	• Sensors, Monitoring , Adaptive Control (WP7)
			+	• Tribology improvements (WPG5)

Figure 5: HERCULES-C Objectives and Achievements

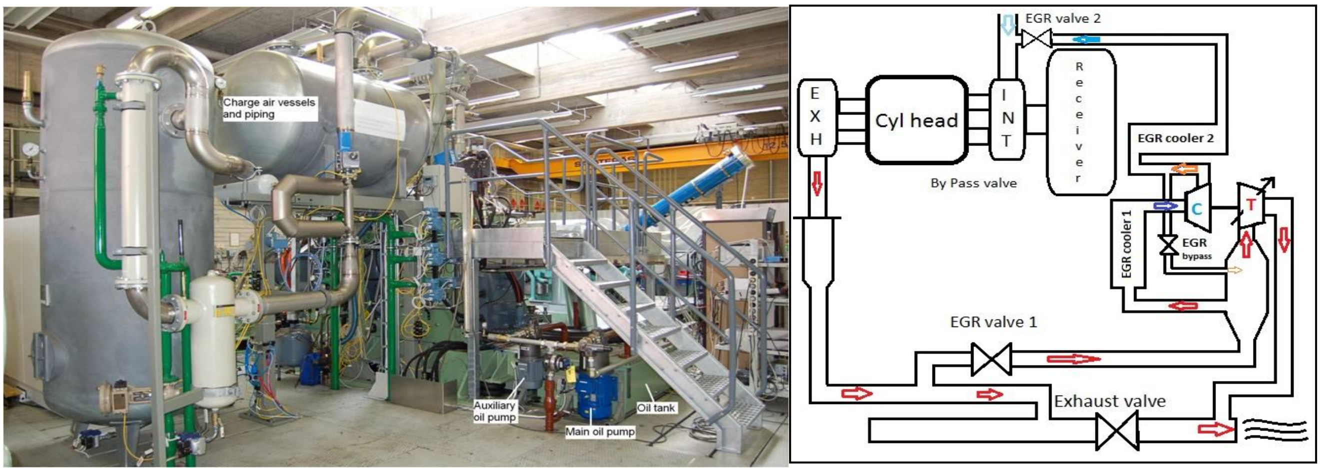


Figure 6: EVE engine and EGR system schematics

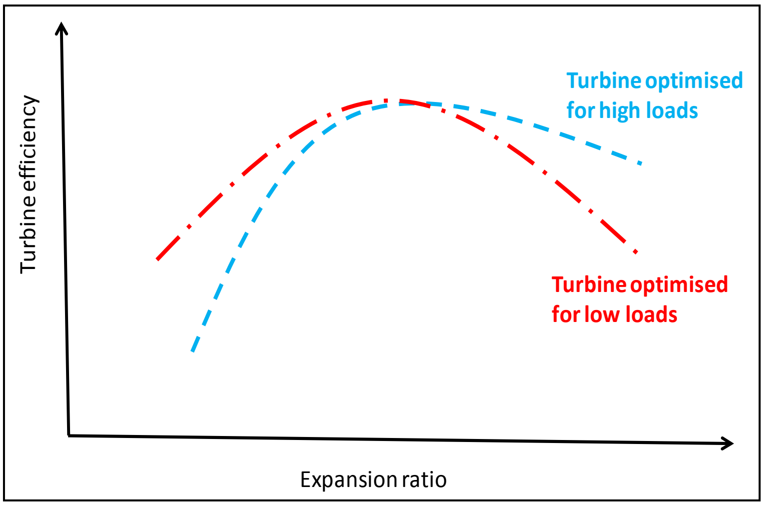


Figure 7 – Difference in turbine efficiencies depending on optimisation

Figure 8: Nephelometer and FTIR emission measurement equipment

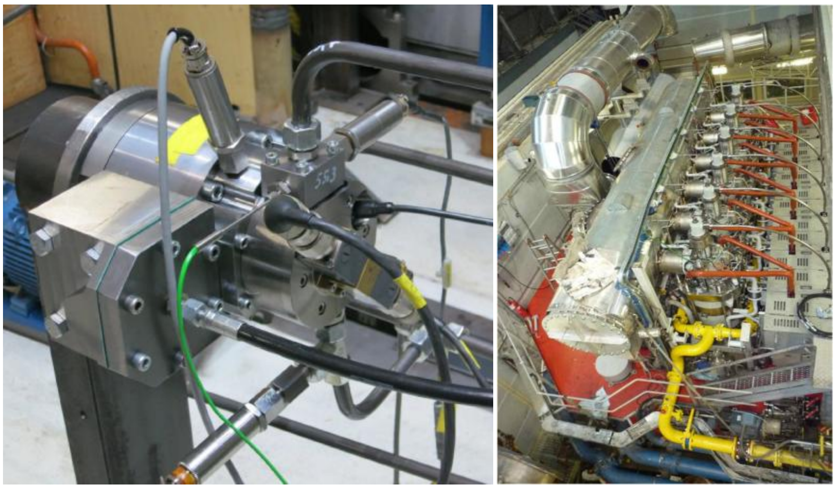


Figure 9: 2-stroke engine direct gas injection investigation test platforms; the hydraulic test rig and RT-flex50D test engine.

Figure 10: 4-stroke engine direct gas injection investigation test platform

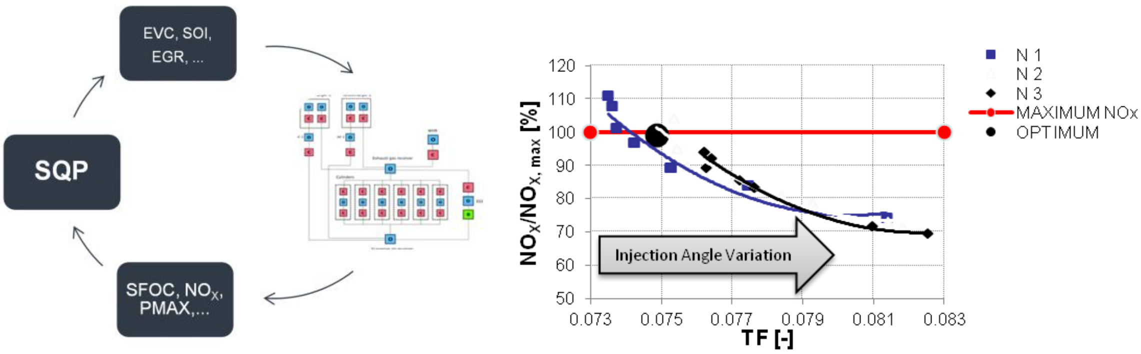


Figure 11: Examples of optimization procedures for engine process (left) and combustion (right)

	ΔSFOC [g/kWh]	
	Predicted	Measured
Atomizer 1	-4.2	-4.5
Atomizer 2	-1.2	-1.2

Figure 12: Engine improvement achieved by the onsite engine optimizer (two-stroke)

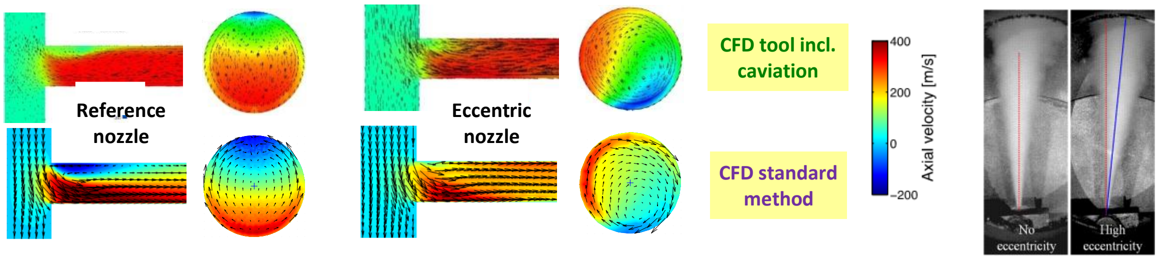


Figure 12: CFD of in-nozzle flow (left) and corresponding spray evolution measurements (right).

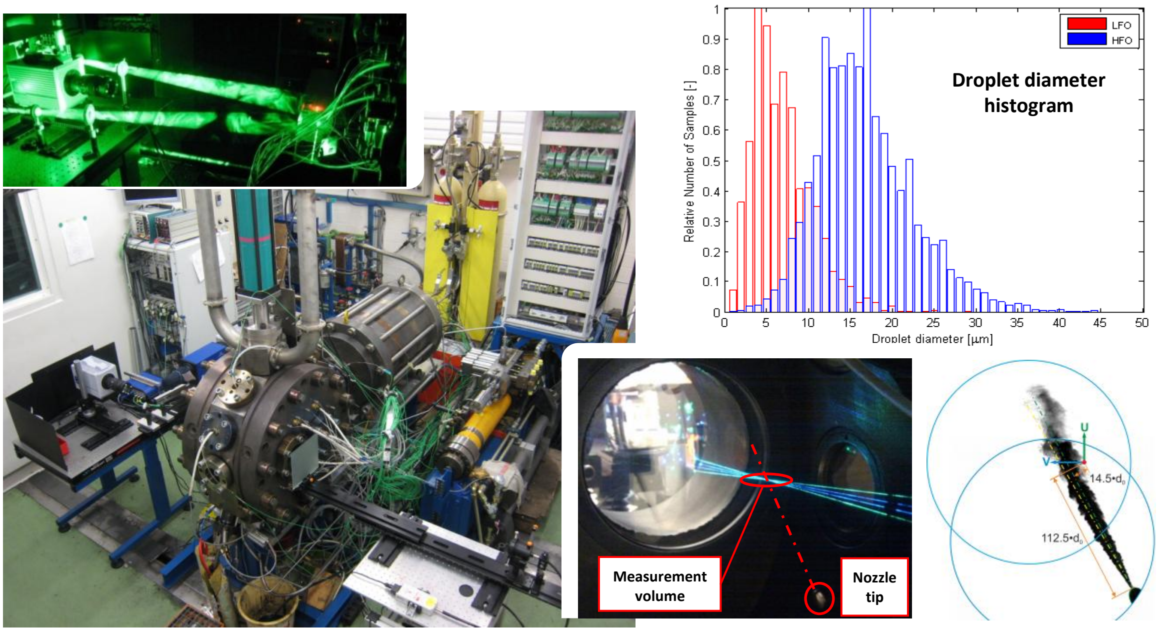


Figure 13: Spray Combustion Chamber test facility: application of Mie-scattering (left) for spray evolution and Phase Doppler Anemometry (PDA) to investigate LFO/HFO droplet size and velocity (right).

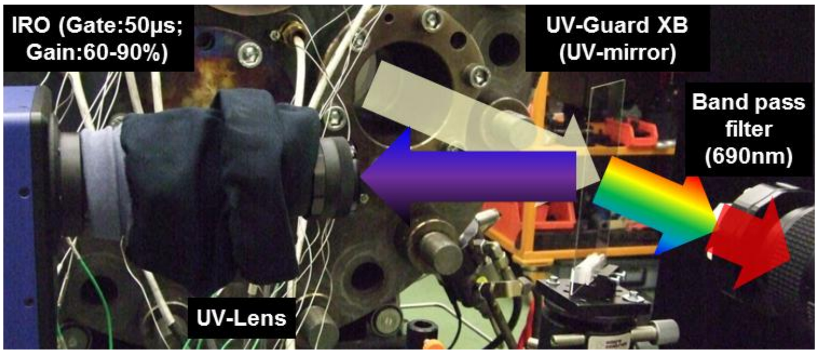


Figure 14: Ignition delay and location of LFO/HFO's by the application of advanced optical diagnostics

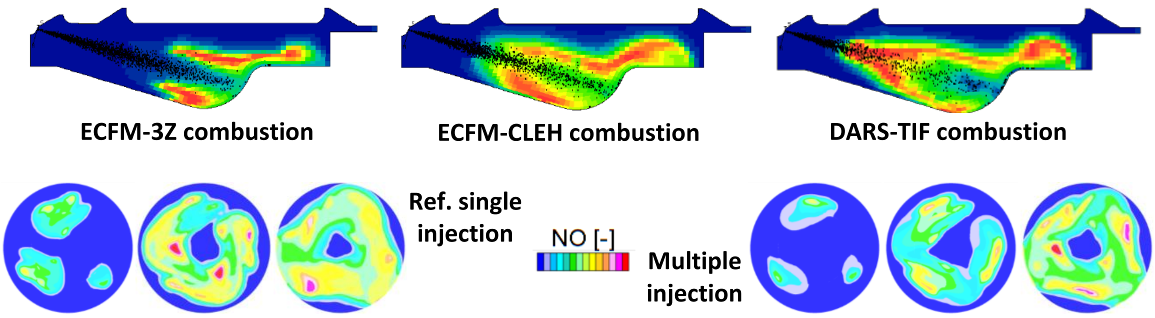


Figure 15: Combustion modeling; comparison different models (4-stroke, upper graph) and NOx distribution for different injection strategies (2-stroke, lower graph).

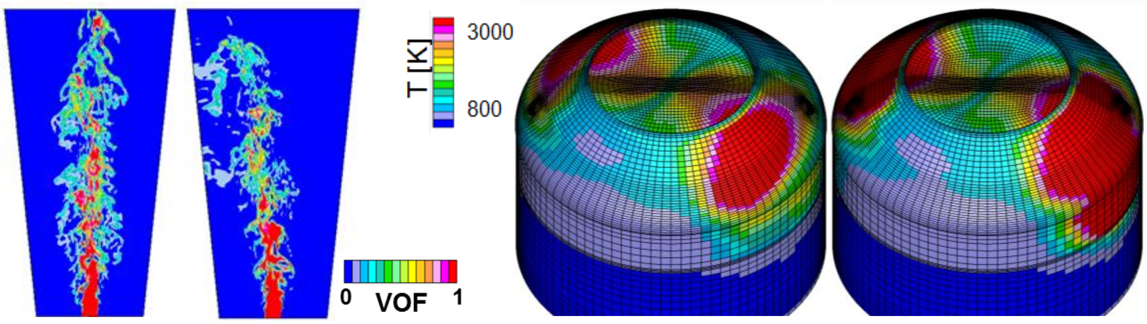


Figure 16: LES spray breakup simulation (fuel concentration, left) and 2-stroke engine process simulation (temperature distribution right) without/with consideration of nozzle eccentricity (left/right image).

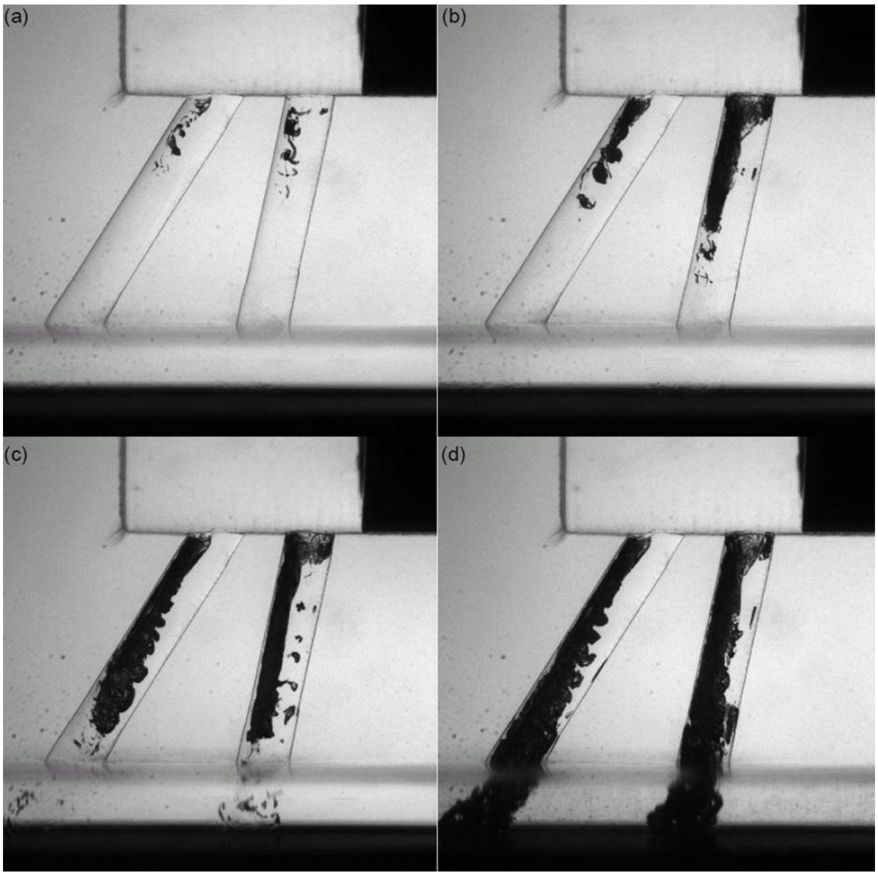


Figure 17: Shadowgrams of cavitation inside an atomizer with two in-line nozzle holes, Pinj~96 bar. Cavitation number (a) 1.5, (b) 2, (c) 4 and (d) 20. Field of view: 6.9 x 6.9 mm

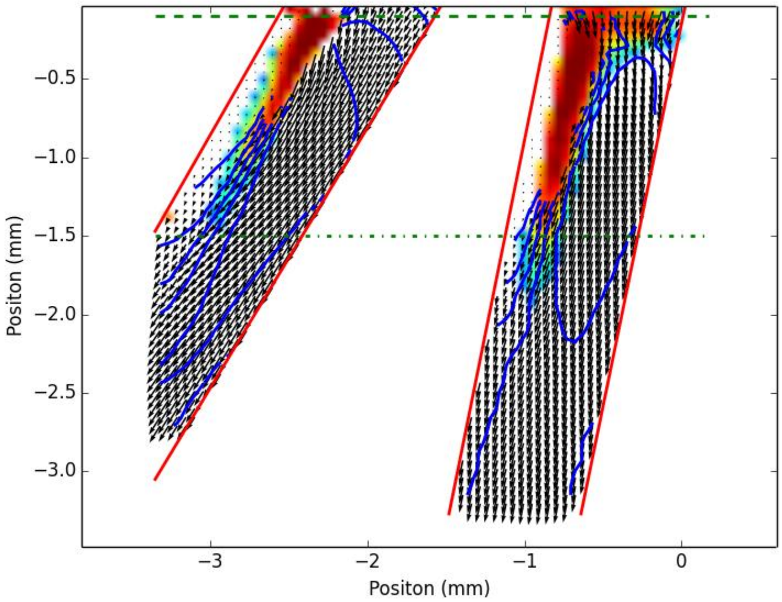


Figure 18: Average velocity field estimated using particle image velocimetry at a cavitation number of 2.1 holes using a sac volume injection pressure of approx. 96 bar. Background color scale indicates the fractions of vectors rejected due to the presence of cavitation. Blue lines correspond to 20 m/s absolute velocity contours.

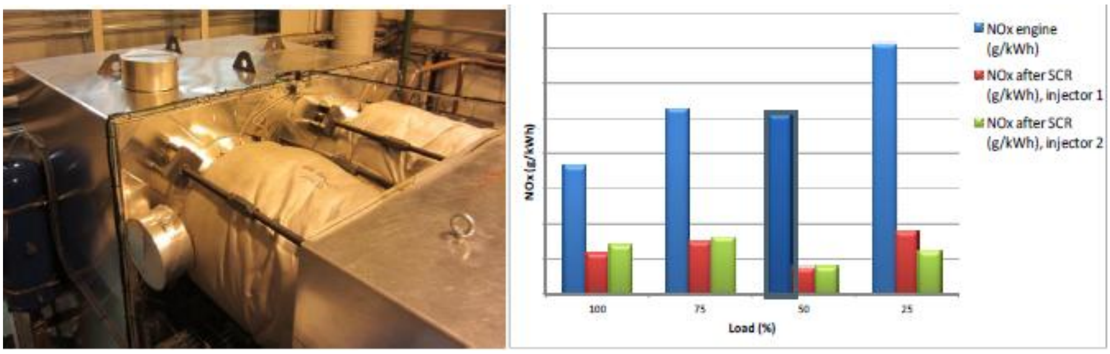


Figure 19: SCR test hardware at Wärtsilä Finland laboratory. NOx reduction with two alternative urea injectors.

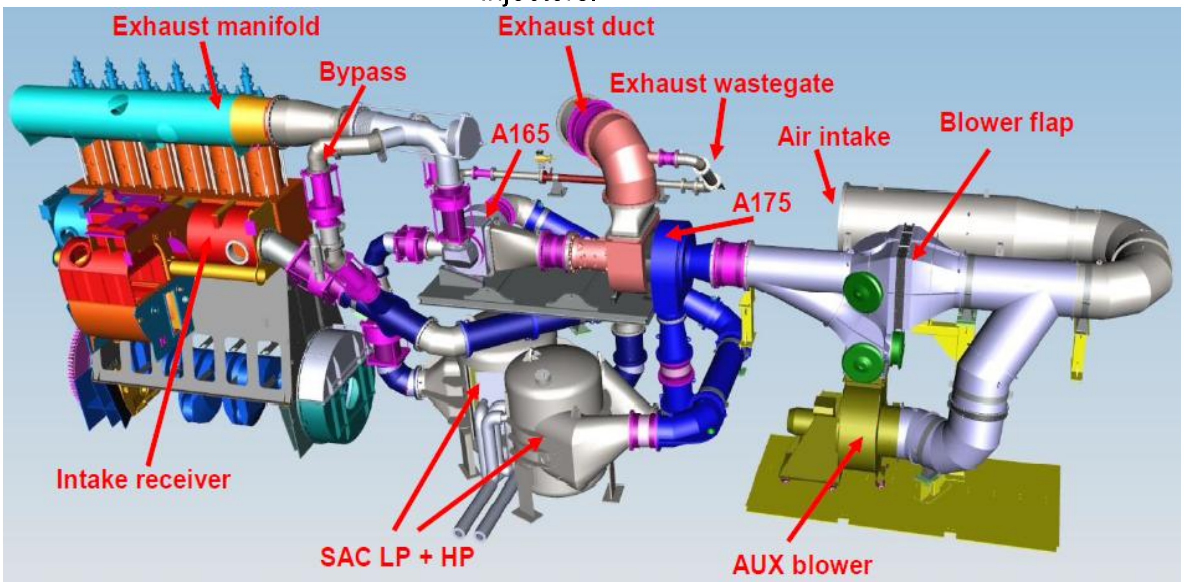


Figure 20: 2-stroke DF-engine with 2-stage turbocharging.

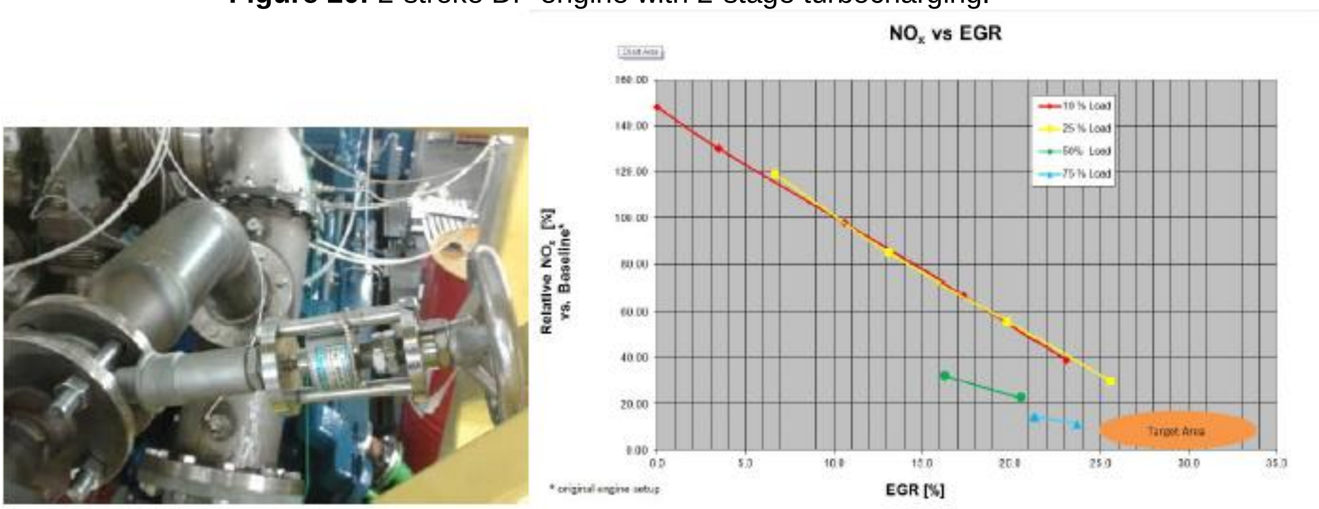


Figure 21: EGR test equipment at PSI. Correlation between EGR rate and NOx emission for semi-short route EGR system.

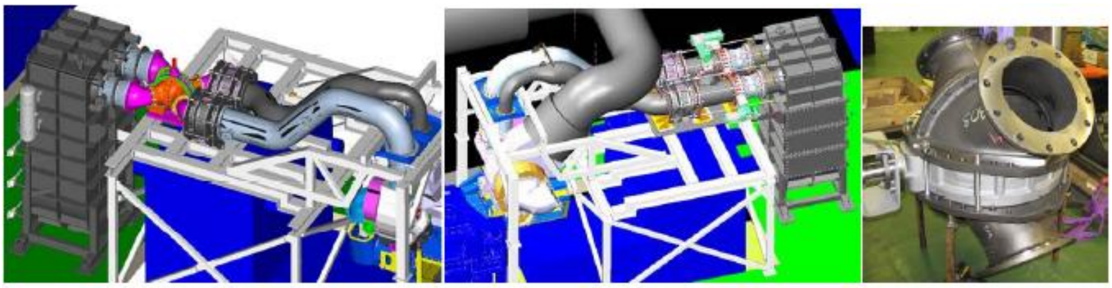


Figure 22: SCR combined with 2-stage turbocharging shown with both conventional valve system (right) and compact control valve (center). Control valve hardware (right).

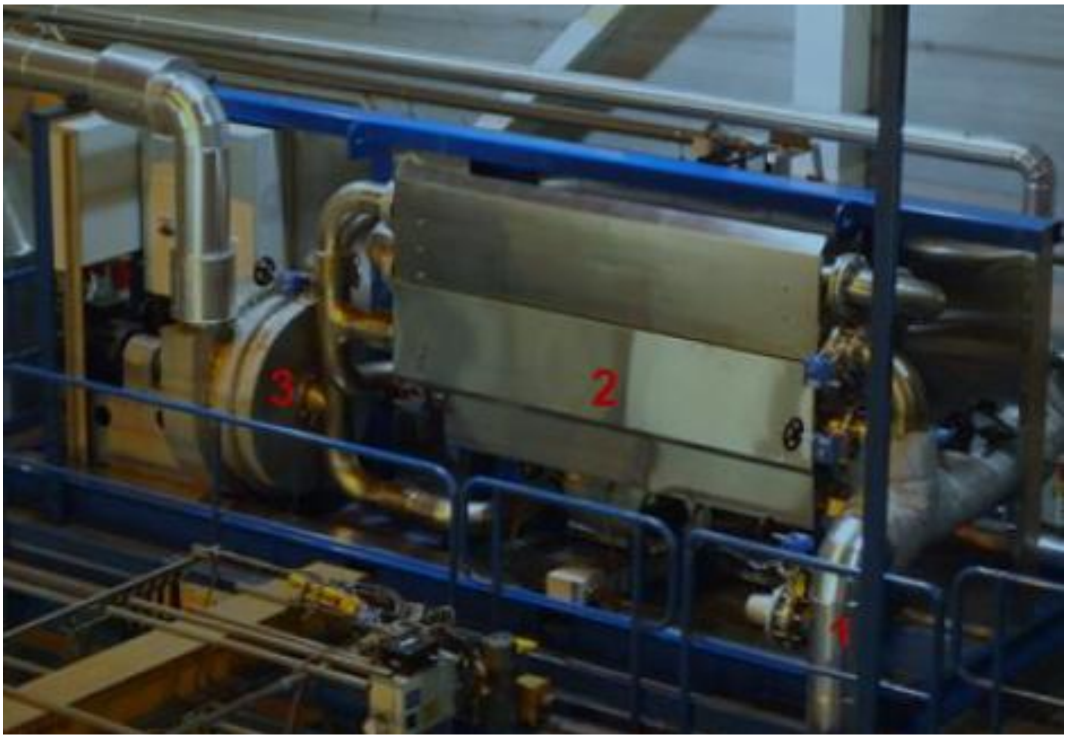


Figure 23: Side view of developed SCR bench, showing inlet (1), heating and cooling (2) and flow producing fan (3).

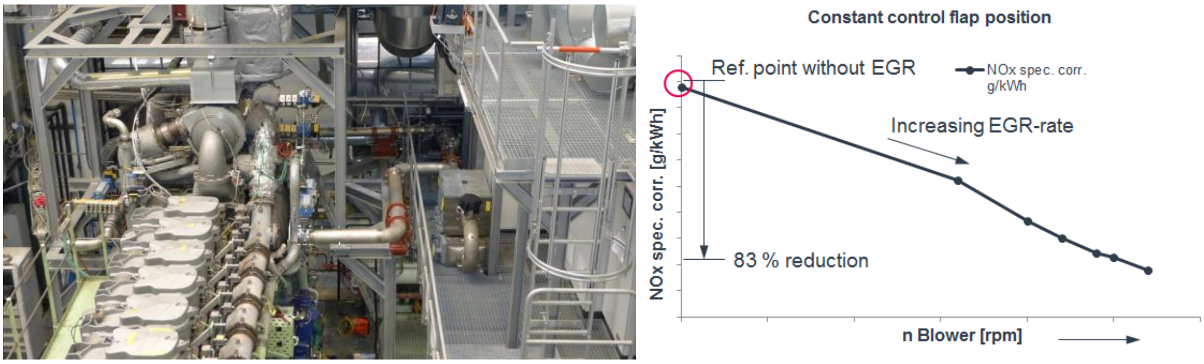


Figure 24: 2-stage turbocharging and ETB12 set-up at 4-stroke test engine 6L32/44-CR (left) & NO_x reduction vs. blower speed at constant flap position (right)

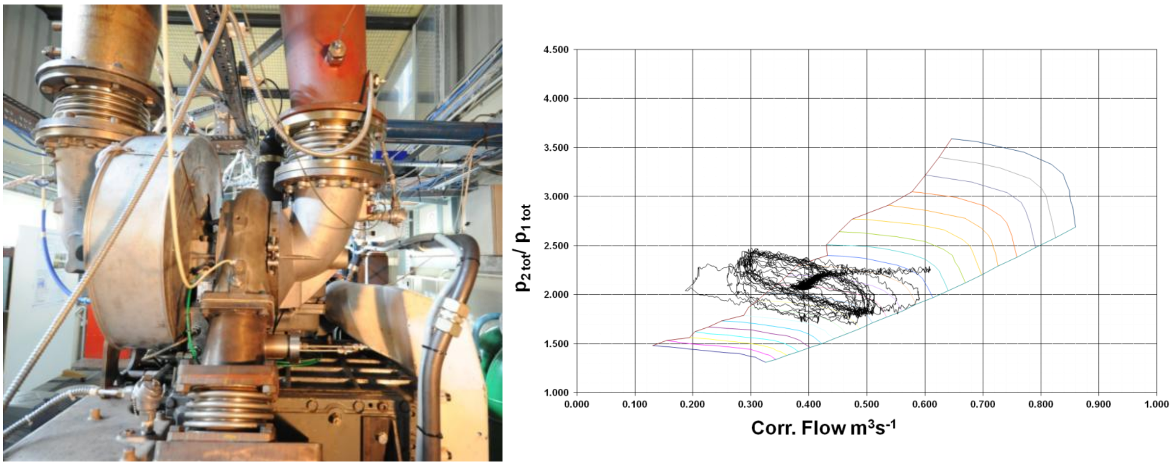


Figure 25: Turbocharger of NTUA-LME research engine (left) & trajectory of measured data during surge cycles (right)

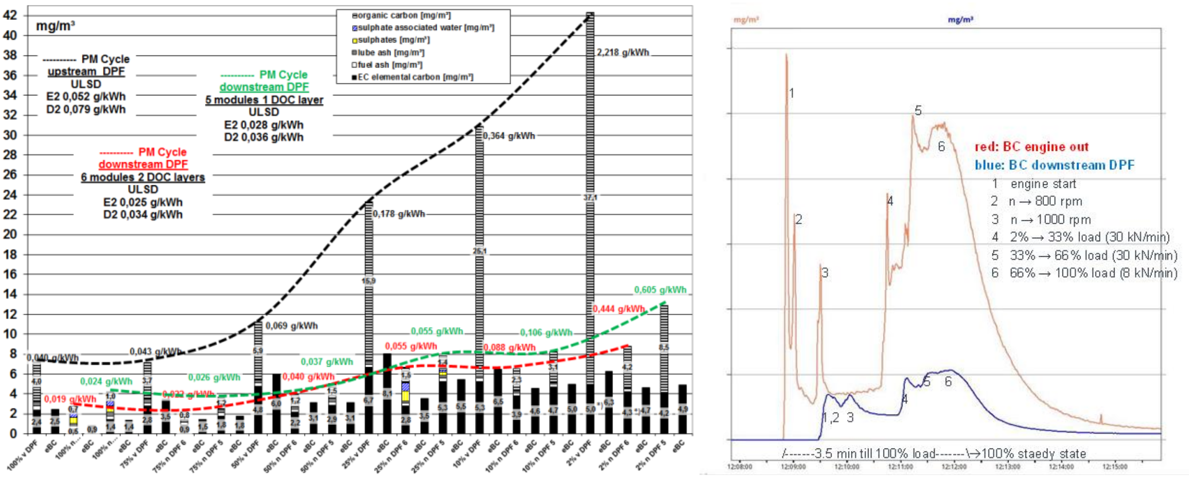


Figure 26: PM emission and composition up- and down-stream of DPF (left) & transient (right) black carbon emission up- (red) and down-stream (blue) of DPF

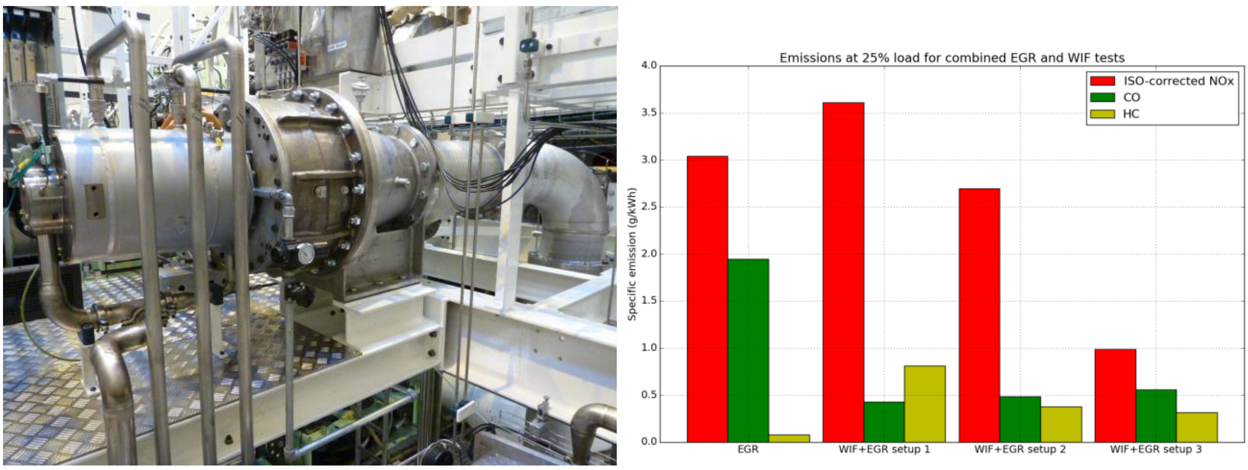


Figure 27: ETB18 set-up at 2-stroke 4T50ME-X test engine (left) & comparison of different WiF + EGR setups (right)

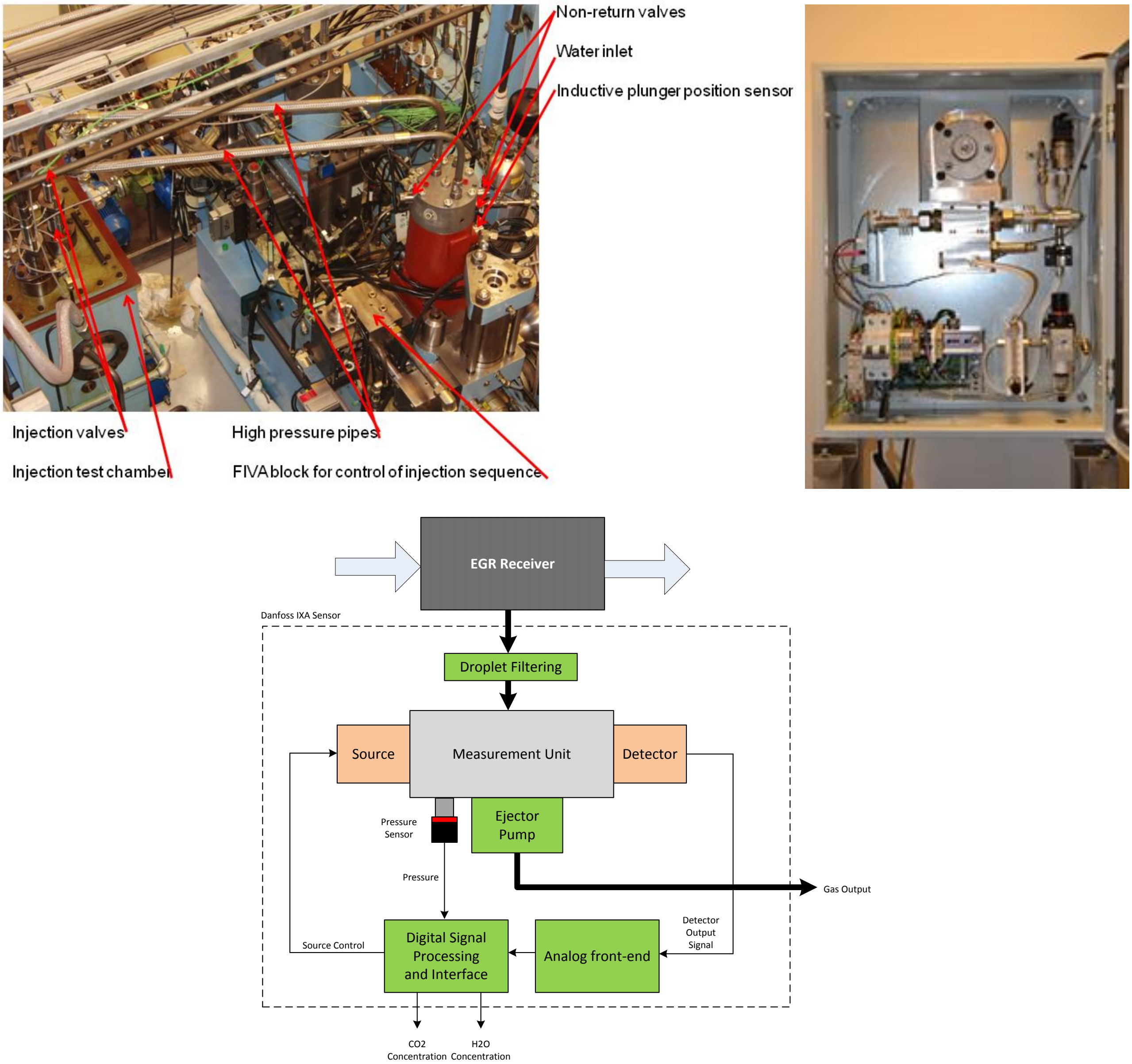


Figure 28: Test of JiT-WiF basic concept at injection test rig (up left), EGR sensor installation (up middle), block diagram (bottom)

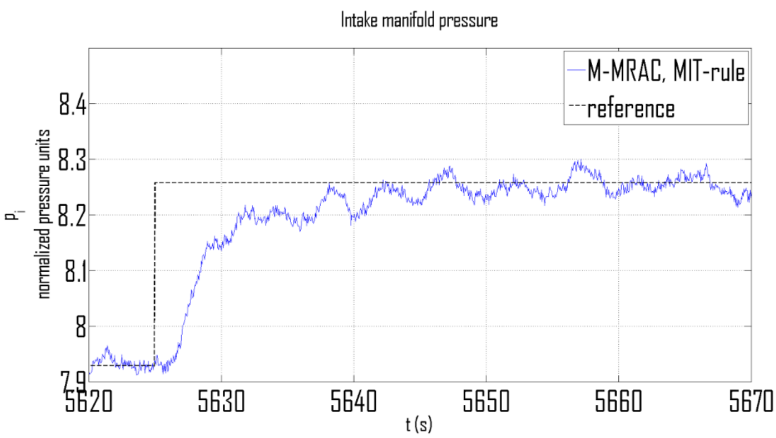


Figure 29: Adaptive (MRAC) manifold air pressure control

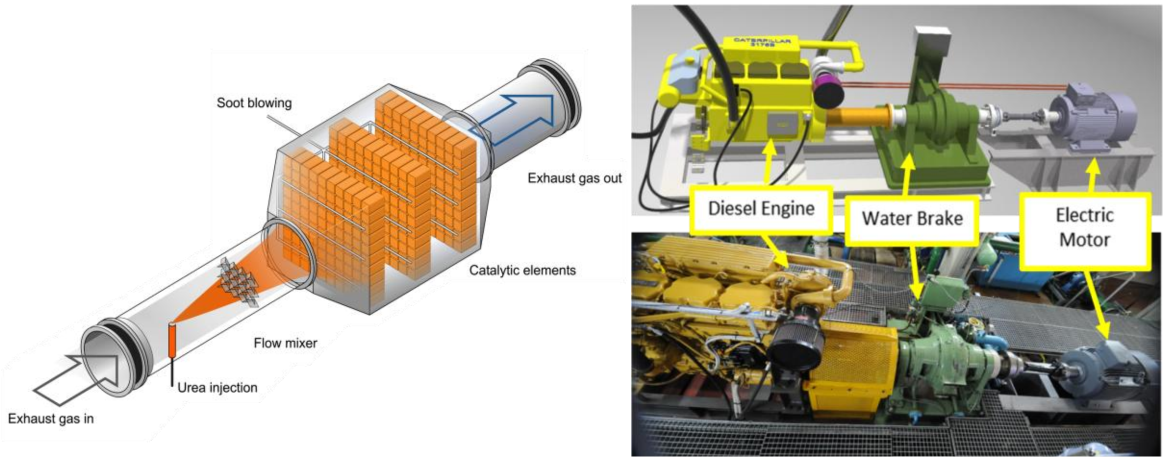


Figure 30: SCR (left) and hybrid engine system (right)

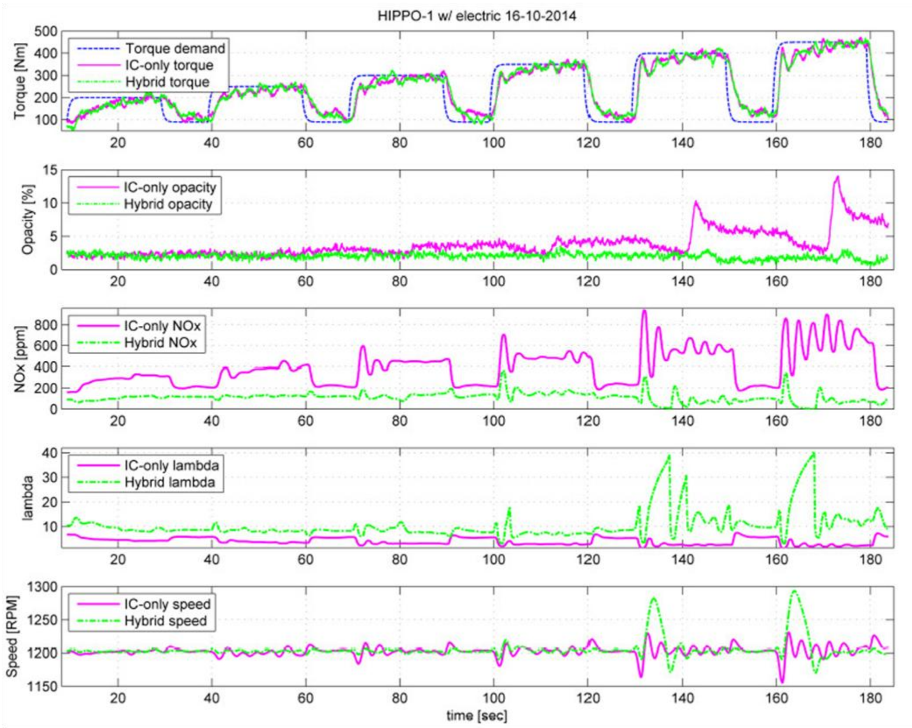


Figure 31: Test results with hybrid engine system

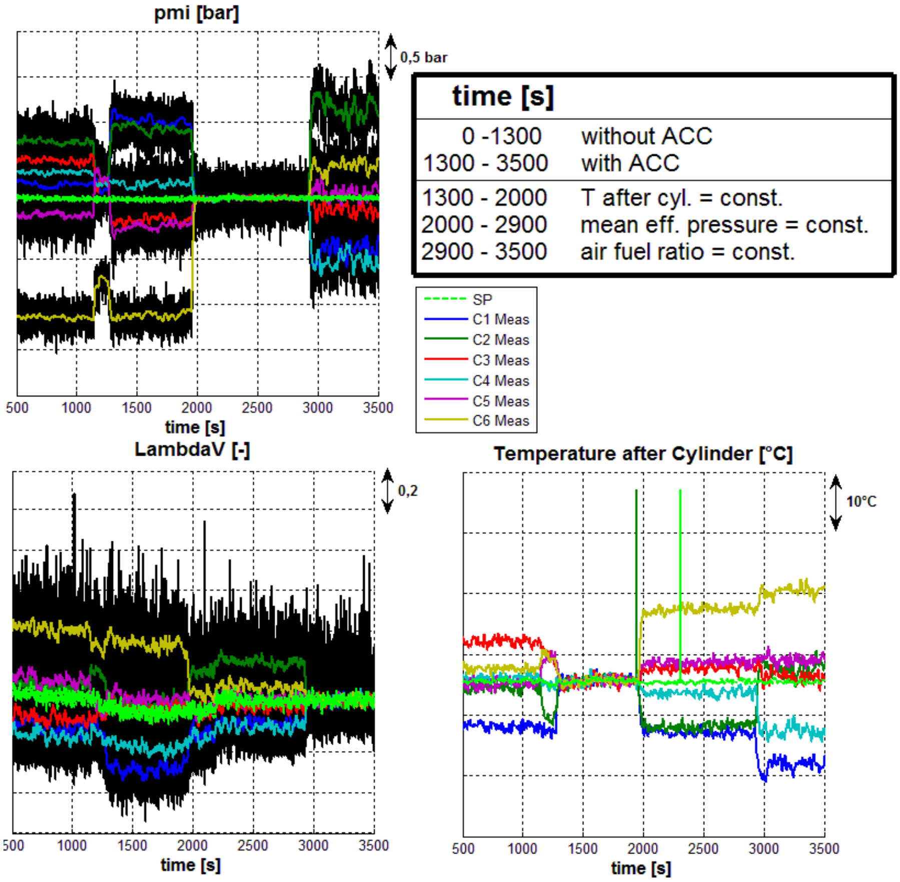


Figure 32: Results of engine test: Influence of adaptive combustion control (with Temperature after cylinder T_{Cyl}, mean effective pressure p_{mi} and air fuel ratio -closed-loop) on engine performance

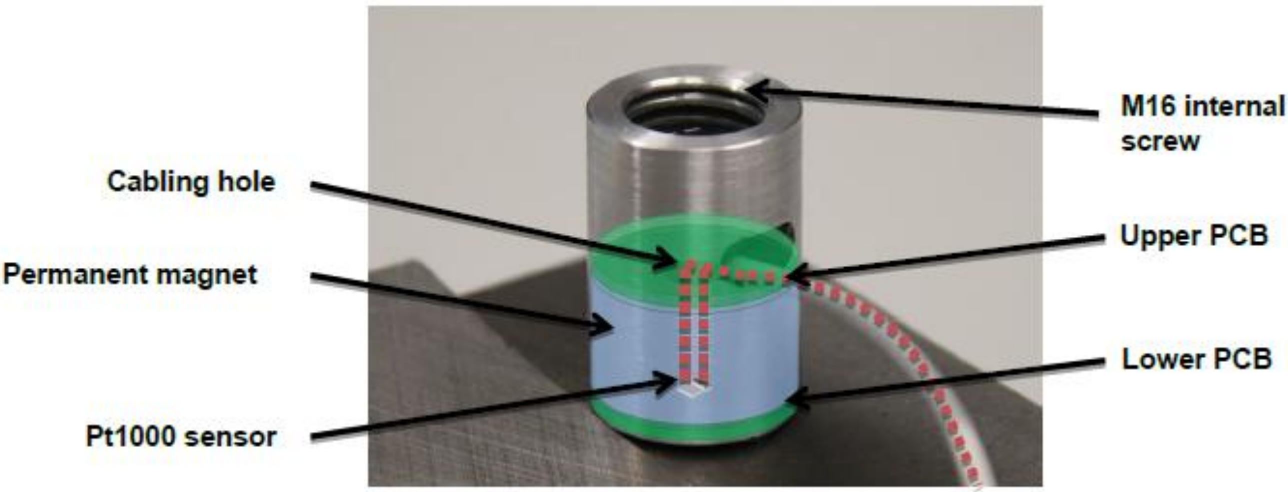


Figure 33: Image of the wear sensor head with overlaid sketch of major internal components

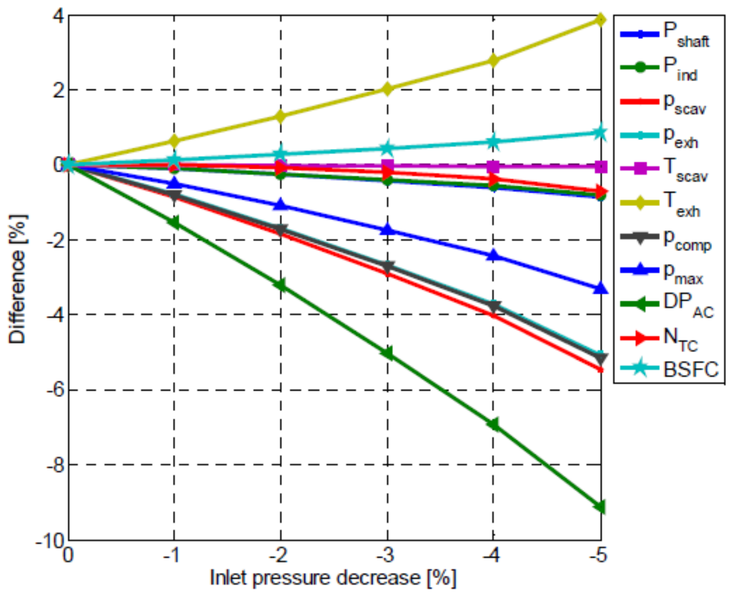


Figure 34: Simulated effect of inlet filter fouling on various engine parameters.

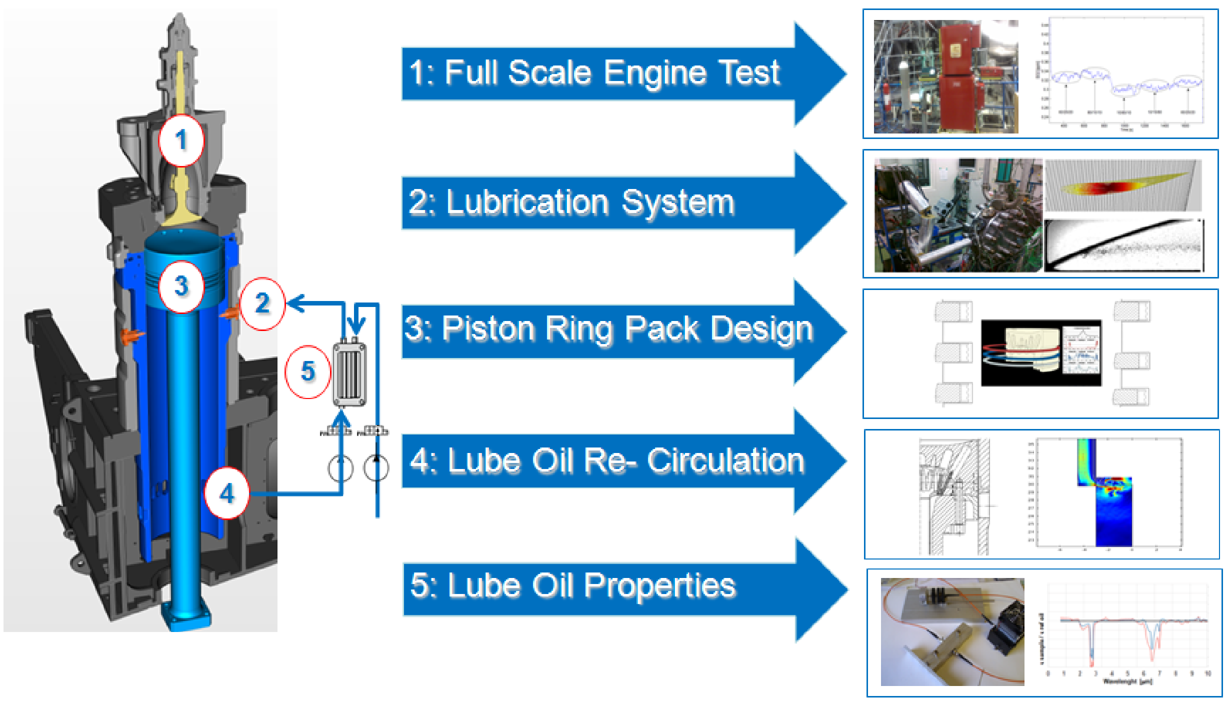


Figure 35: Overview of performed work

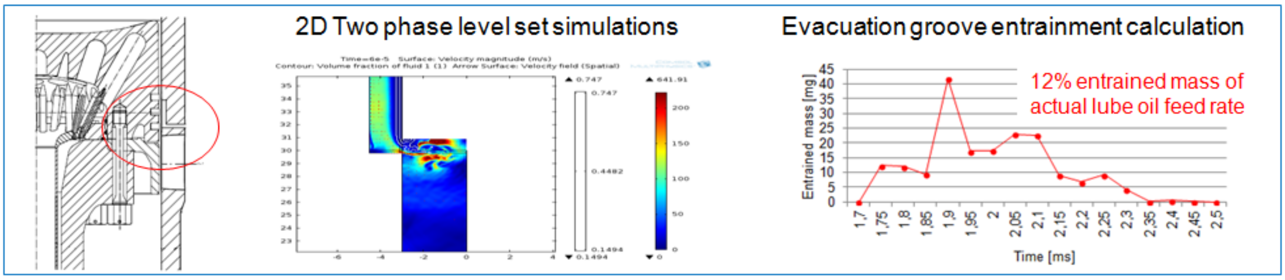


Figure 36: Lube oil evacuation groove performance simulation result

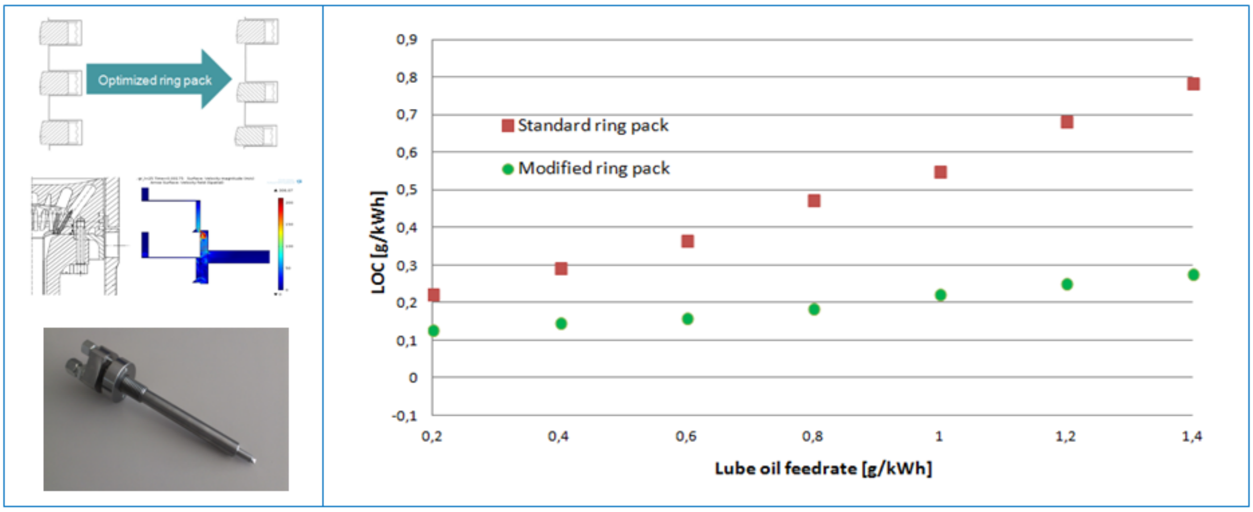


Figure 37: Performance evaluation of the new lubrication concept

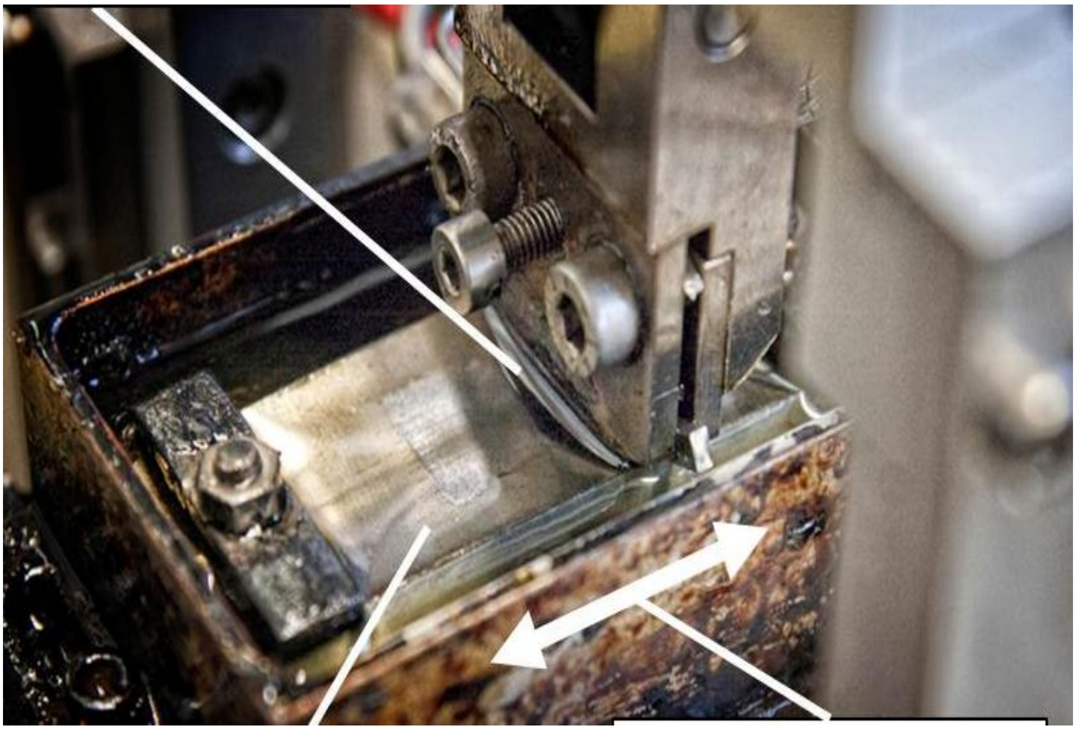


Figure 38: Test rig for pre-validation of the selected combinations

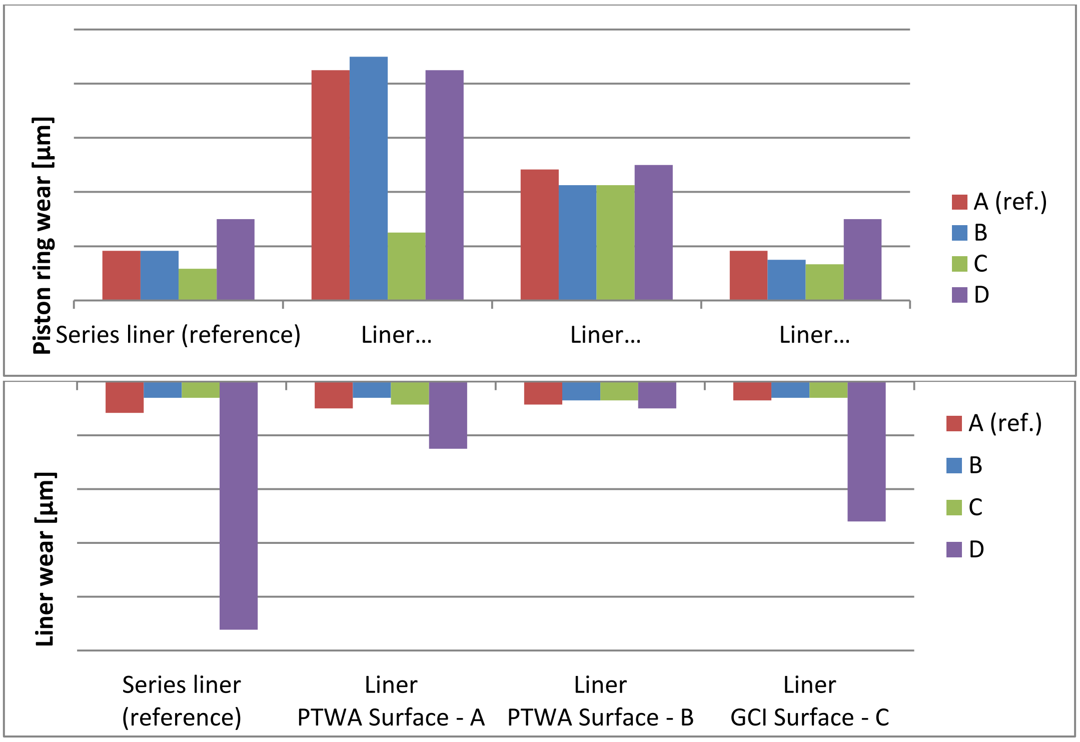


Figure 39: Overview of averaged wear of piston ring and cylinder liner of reciprocating test rig

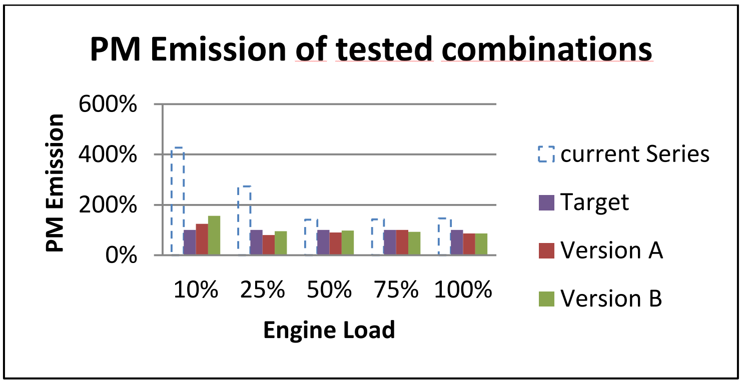


Figure 40: Result of the Particulate Matter measurements of new developed combinations of piston ring cylinder liner for 4-stroke

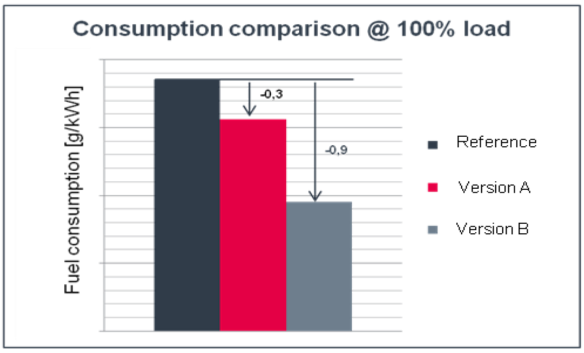


Figure 41: Influence on fuel consumption by the different tested versions

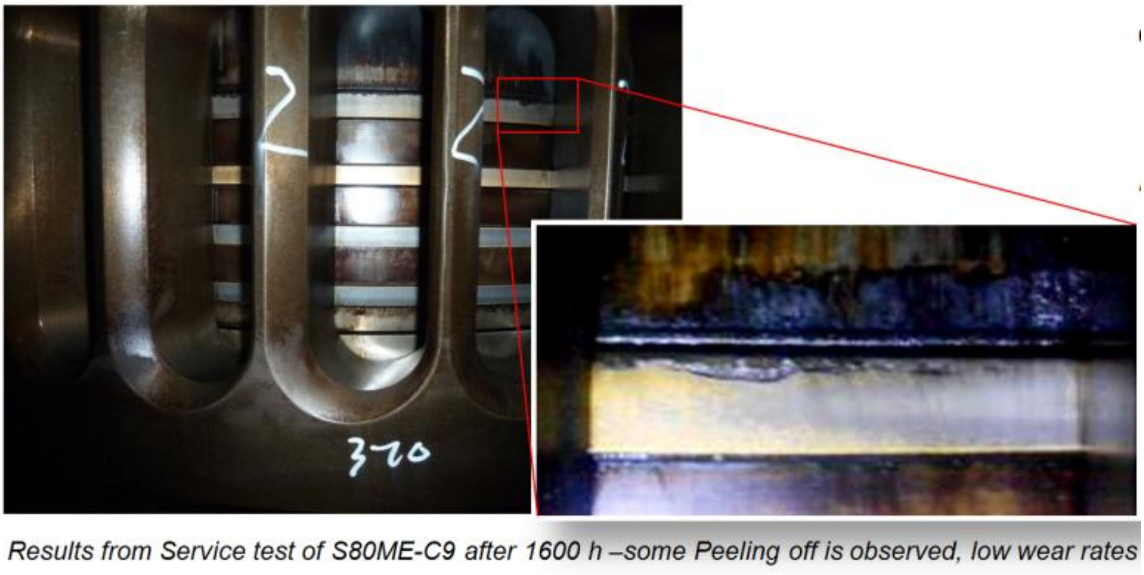


Figure 42: Test of candidate no. 1 from the 2-stroke survey

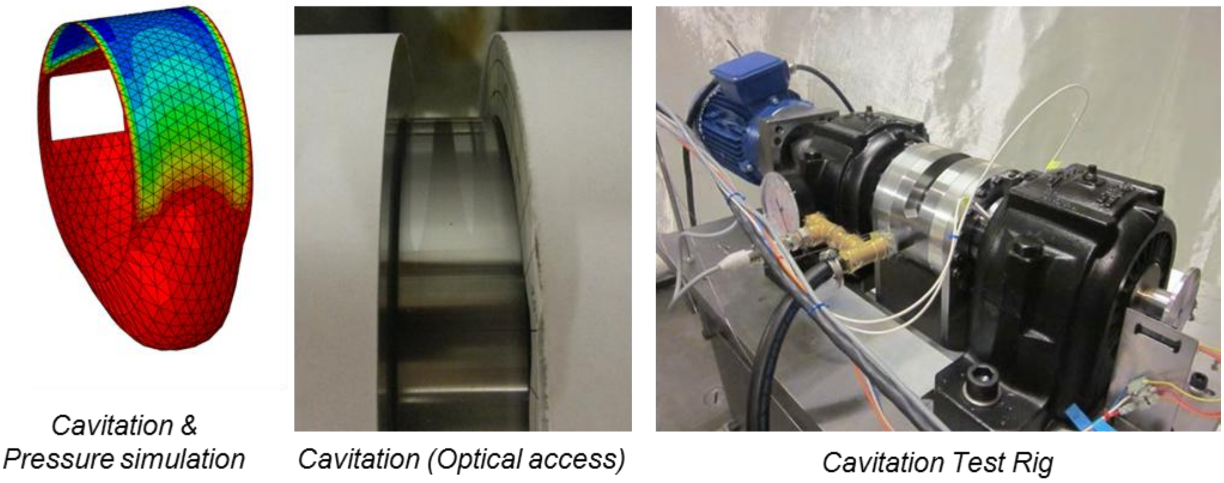
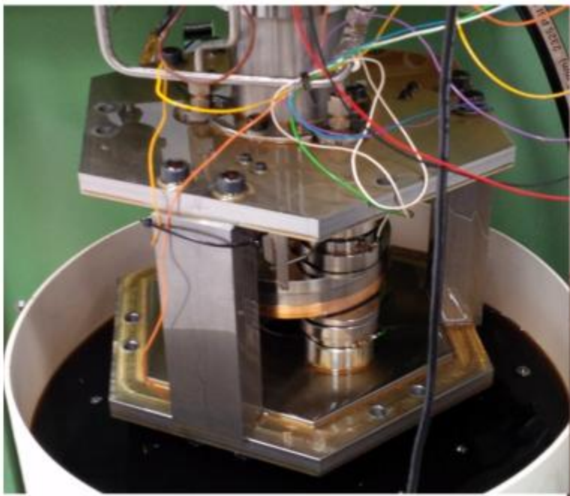
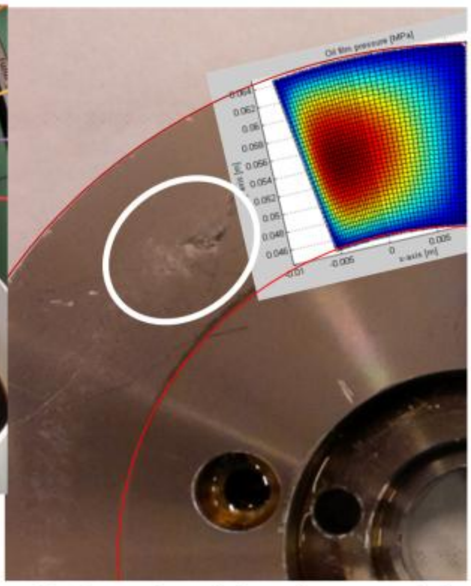


Figure 43: Simulation and validation of cavitation in a lightly loaded journal bearing on the Cavitation Tets Rig (CTR)

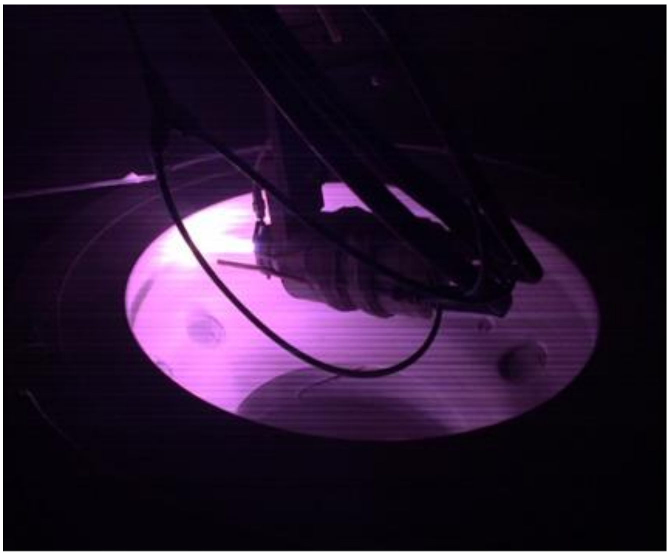


Disc Fatigue Test Rig used for fatigue evaluation of bearing materials and validation of TEHD



Fatigue Crack bearing material & TEHD result

Figure 44: Disc Fatigue Test Rig (DFTR) showing results of fatigue crack of a standard white metal compared to a simulation carried out utilizing TEHD



Thermal Coating in progress

TBC coated Cover for 4T50MX

Figure 45: Application of Thermal Barrier Coating (TBC) on a cylinder cover for the T50ME-X research engine

Del. #	Deliverable Title	WP #	Delivery Date (Month)
D2.1	Literature review of state-of-the-art in numerical optimisation	2	6
D13.1	Public section of Project Website complete and operational	13	6
D12.1	Progress Review of all Work Packages	12	12
D12.2	Interim presentation of overall project results	12	18
D13.2	Report on Dissemination Activities at Mid-Term	13	18
D12.3	Progress review and results update of all Work packages	12	24
D13.3	Compendium of scientific papers published by the Consortium	13	36
D13.5	Report on Dissemination Activities at End of Project	13	36

Figure 46: HERCULES-C Public Deliverables uploaded ion the Project web-site

Table of HERCULES-C Scientific Publications				
No.	Title	Authors	Date Approved	Conference / Journal
1	Influence of in-nozzle flow on spray morphology	Schmid, A., Habchi, C., Bohbot, J., Rotz, B., Herrmann, K., Bombach, R., Weisser, G.	2/9/2014	ILASS - Europe 2014, 26th Annual Conference on Liquid Atomization and Spray Systems, Bremen, September 2014,
2	Ignition behaviour of marine diesel fuels under engine like conditions	Schmid, A., Rotz., B., Weisser, G., Herrmann, K.	2/9/2014	SAE 2014 International, Birmingham, October 2014
3	Optimization of Tribodynamic Effects to improve the Reduction Potential of Particulate Matter Concentrations in the Exhaust Gas of Large Two Stroke Marine Diesel Engines	Stark, M., Mittler, R.	1/9/2014	SAE 2014 International, USA, October 2014
4	On the role of Cavitation in Marine Large Diesel injector: Numerical investigation of nozzle orifices eccentricity	Habchi, C., Gillet, N., Velghe, A., Bohbot, J., Schmid, A., Rotz, B., Hermmann, K.	1/9/2014	ILASS – Europe 26th Annual Conference on Liquid Atomization and Spray Systems, September 2014, Bremen
5	CMC model applied to marine diesel spray combustion: Influence of fuel evaporation terms	Srna, A., Bolla, M., Boulouchos, K., Wright, Y.M.	1/9/2014	SAE 2014 International, USA, October 2014
6	Methodology for Analysis and Simulation of Dual Fuel Combustion in Large Engines	Krenn, M., Pirker, G., Wimmer, A., Djuranec, S., Meier, M., Wladenmaier, U., Zhu, J.	18/8/2014	THIESEL 2014 Conference on Thermo- and Fluid Dynamic Processes in Direct Injection Engines, Valencia, September 2014
7	Evaluation of PDA Applicability in Regard to Heavy Fuel Oil Spray Investigations	Rotz, B., Kammermann, T., Schneider, B., Schmid, A., Herrmann, K., Weisser, G., 8Boulouchos, K.	20/6/2014	17th International Symposium on Applications of Laser Techniques to Fluid Mechanics, Lisbon, July 2014
8	Tribologische Optimierung von Großmotoren, Geringere Emissionen und längere Wartungsintervalle	Flores, G., Bugsch, M., Bastuck, T., Brauns, S.	19/6/2014	Symposium "Zylinderlaubahn, Kolben, Pleuel", VDI-Wissensforum, Baden-Baden, June 2014.
9	HERCULES-1: The long term (2004-2014) R&D programme on large engine technologies for ships	Nikolaos P. Kyrtatos	16/5/2014	Transport Research Arena, Paris, April 2014
10	Robust and Adaptive Wastegate Control of Turbocharged Internal Combustion Engines	Samokhin, S., Zenger, K.	4/2/2014	American Control Conference, Portland, June 2014

Table of HERCULES-C Scientific Publications				
11	Optical Diagnostics of Fuel Injection and Ignition in a Marine Twostroke Diesel Engine	Hult, S., Matlok S., Mayer, S.	6/2/2014	SAE World Congress 2014, USA, April 2014
12	Influence of Injector Diameter (0.2-1.2 mm range) on Diesel Spray Combustion: Measurements and CFD Simulations	Bolla, M., Srna, A., Wright, Y. Rotz, B., Herrmann, K., Boulouchos, K.	11/2/2014	SAE World Congress 2014, USA, April 2014
13	Modeling and Control of Diesel Engines with a High-Pressure Exhaust Gas Recirculation System	Samokhin, S., Sarjovaara, T., Zenger, K.	6/12/2013	IFAC World Congress 2014, Cape Town, August 2014
14	Untersuchungen zur Strahlausbreitung und Verbrennung unter typischen Bedingungen für Grossdieselmotoren anhand eines speziell dafür entwickelten Versuchsträgers	Weisser, G., Rotz, B., Schmid, A., Schulz,R., Herrmann, K.	19/9/2013	14. Tagung "der arbeitsprozess des verbrennungsmotors", Graz, September 2013.
15	Influence of nozzle hole eccentricity on spray morphology	Schmid, A., Rotz, B., Schulz,R., Herrmann, K., Weisser, G., Bombach, R.	18/9/2013	25th European Conference on Liquid Atomization and Spray Systems, Chania, September 2013
16	Diesel Spray Breakup at Pressure	Falgout, Z., Rahm, M., Wang, Z., Sienes, E., Linne, M., Paciaroni, M., Hult, J., Matlok, S.	18/9/2013	25th European Conference on Liquid Atomization and Spray Systems, Chania, September 2013
17	Testing of Bearing Materials for Large Two-stroke Marine Diesel Engines	Klit, P., Persson, S., Voelund, A.	17/9/2013	12th EDF / Prime Workshop, France, September 2014
18	Advanced optical development tools for two-stroke marine diesel engines	Mayer, S., Hult, J., Nogenmyr, K., Clausen, S.	14/5/2013	27th CIMAC Congress, Shanghai, May 2013
19	30 Mpa Mixing Controlled Combustion	Larmi, M., Kallio, I., Elonheimo, A., Sarjovaara, T., Imperato, M.	13/5/2013	27th CIMAC Congress, Shanghai, May 2013
20	Partially Premixed Combustion (PPC) for low load conditions in marine engine using computational and experimental techniques	Shrestha, K., Imperato, M., Kaario, O., Larmi, M., Sarjovaara, T.	19/4/2013	Finnish – Swedish Flame Days, Finland, April 2013
21	Optimization of Mixture Formation in Medium Speed Dual-Fuel and Gas Engines with Support of Advanced Optimization Techniques and Optical Measurements	Waldenmaier, U., Djuranec, S., Stiesch, G., Unfug, F., Wagner, U.	19/3/2013	27th CIMAC Congress, Shanghai, May 2013
22	Correlation of Internal Flow and Spray Breakup for a Fuel Injector Used in Ship Engines	Linne, M., Falgout, Z., Rahm, M., Wang, Z., Paciaroni, M., Matlok, S., Hult, J.	19/3/2013	8th US National Combustion Meeting, Utah, May 2013
23	Ten Years After: Results from the Major Programme HERCULES A-B-C on Marine Engine R&D	Kyrtatos, N., Hellberg, L., Poensgen, C.	27/2/2013	27th CIMAC Congress, Shanghai, May 2013

Table of HERCULES-C Scientific Publications				
24	Development of Spray and Combustion Simulation Tools and Application to Large Two-Stroke Diesel Engine Combustion Systems	Schulz, R., Hensel, S., Herrmann, K., Schmid, A., Rotz, B., Weisser, G.	27/2/2013	27th CIMAC Congress, Shanghai, May 2013
25	Simulations of Diesel Sprays Using the Conditional Moment Closure Model	Bolla, M., Gudmundsson, T., Wright, Y., Boulouchos, K.	25/2/2013	SAE World Congress 2013, USA, April 2013
26	Partially Premixed Combustion (PPC) for low load conditions in a marine engine using computational and experimental technique	Shrestha, K., Imperato, M., Kaario, O., Larmi, M., Sarjovaara, T.	1/2/2013	27th CIMAC Congress, Shanghai, May 2013
27	Model Reference Adaptive Control of a Marine Diesel Engine Combined with Electric PTI/PTO Motor	Papalambrou, G., Glaros, S., Topaloglou, S., Kyrtatos, N.	27/8/2012	International Conference on Powertrain Modelling and Control, Bradford, September 2012
28	HERCULES A-B-C, A 10-Year Major R&D Effort Towards the Next Generation Large Marine Diesel Engines	Nikolaos P. Kyrtatos		Transport Research Arena, Athens, April 2012

Figure 47: List of HERCULES-C scientific publications

Title	Date	Source
Land ahoy for cleaner, greener ship engines	January 2014	Horizon 2020 Project Stories
Fathom Spotlight: All Hail Hercules!	December 2013	Ship & Bunker
Results-driven Hercules research project in third phase	October 2013	The Motorship
Is Europe's mutli-forked fightback winning?	May 2013	Lloyd's list
HERCULES-C	June 2012	Naftiliaki – The Greek Shipping Review
Wärtsilä and MAN Diesel & Turbo to continue comprehensive HERCULES Research Project	May 2012	Marine-Diesels.net News
HERCULES-C	May 2012	Transport Research & Innovation Portal
Productive outcome from Pan-European engine research project	April 2012	The Motorship
Herculean effort to raise emission standards	March 2012	The Naval Architect
Hercules engines project enters next phase	February 2012	Bairdmaritime.com
Hercules Project aims to develop zero-emission engine	February 2012	Lloyd’s list
Wärtsilä y MAN Diesel & Turbo avanzan en el proyecto Hércules-C	February 2012	Máquinas de Barcos
Next Phase Begins In Hercules Research Program	February 2012	Diesel & Gas Turbine Worldwide
Wärtsilä and MAN Diesel & Turbo enter...	February 2012	Financial Express
Wärtsilä and MAN Diesel & Turbo enter Next Phase of HERCULES Research Project	February 2012	Marine Insight news
Wärtsilä, Man Diesel Continue Research	February 2012	MarineLink.com
Wärtsilä and MAN Diesel & Turbo enter next phase of HERCULES research project	February 2012	Micportal
MAN Diesel & Turbo and Wärtsilä enter next phase of HERCULES research project	February 2012	Metal Supply

Title	Date	Source
Wärtsilä and MAN Diesel & Turbo enter next phase of HERCULES research project	February 2012	Reuters
Wärtsilä and MAN Diesel & Turbo Continue HERCULES	February 2012	MAN Diesel & Turbo, Press Release
Wärtsilä and MAN Diesel & Turbo enter next phase of HERCULES research project	February 2012	Wärtsilä Corporation, Trade & Technical Press release
Next phase of Hercules project begins	February 2012	The Motorship
Wärtsilä and MAN Diesel & Turbo enter next phase of HERCULES research project	February 2012	Wärtsilä Corporation, Trade & Technical Press release
Wärtsilä and MAN Diesel & Turbo enter next phase of HERCULES research project on marine engines	February 2012	Green Car Congress
Wärtsilä and MAN enter Phase III of HERCULES project	February 2012	DieselNet
Wärtsilä & MAN into HERCULES-C	February 2012	Korea Marine Equipment
Hercules-B Completed	February 2012	Diesel & Gas Turbine Worldwide
2012 Maritime Environmentally and Economically Optimized Solutions	January 2012	World Maritime News Staff
Hercules-Forschungsprogramm verlägert	March 2011	Schiff&Hafen
Europe's Hercules project enters third phase with new partners	January 2011	Lloyd’s List
Wärtsilä and MAN Diesel & Turbo to Continue Comprehensive HERCULES Research Project	December 2010	MAN
European engine makers to continue joint research project	December 2010	MarineLog
Wärtsilä and MAN Diesel & Turbo to continue comprehensive HERCULES Research Project	December 2010	Ship Management
Wärtsilä and MAN Diesel & Turbo to continue comprehensive HERCULES Research Project	December 2010	Wärtsilä Corporation, Trade & Technical Press release

Figure 48: HERCULES - C in Press and Media

(TIMESPAN: SHORT=S, MEDIUM=M, LONG=L)

WORK PACKAGE GROUP	ITEM	TIME
WPG1 New Combustion Concepts	Advanced dual fuel gas engines with low temperature and partially premixed combustion and valving strategies for IMO Tier III	S
	Combustion strategies compatible with aftertreatment methods (SCR, DPF)	M
WPG2 Fuel Injection Models & Experiments	Models for flow and cavitation applicable to large engine injectors	M
WPG3 Near–Zero Emission engine technologies	Combined SCR and Scrubber units	S
	Complete variability of turbocharging system combined with EGR equipment	M
	Particulate Filters (DPF) and regeneration techniques for marine fuel including desulfurization & ash handling	M
	Combined WIF (water-in-fuel) and EGR	L
WPG4 Adaptive engine control & lifetime reliability	Combination of individual engine subsystem controllers to overall adaptive control	M
	Self diagnostic algorithms and techniques for control system	M
	Sensors for wear detection integrated in health monitoring system	S
WPG5 New Materials & Tribology	Low friction and wear engine piston rings	S
	Increased performance main engine bearings	M
	Thermal Barrier Coatings for piston crowns	M

Figure 49: Table of HERCULES-C Exploitable results

Figure 50: EVE engine “cool combustion”

Figure 51: 2-stroke engine “low temperature combustion” with DWI

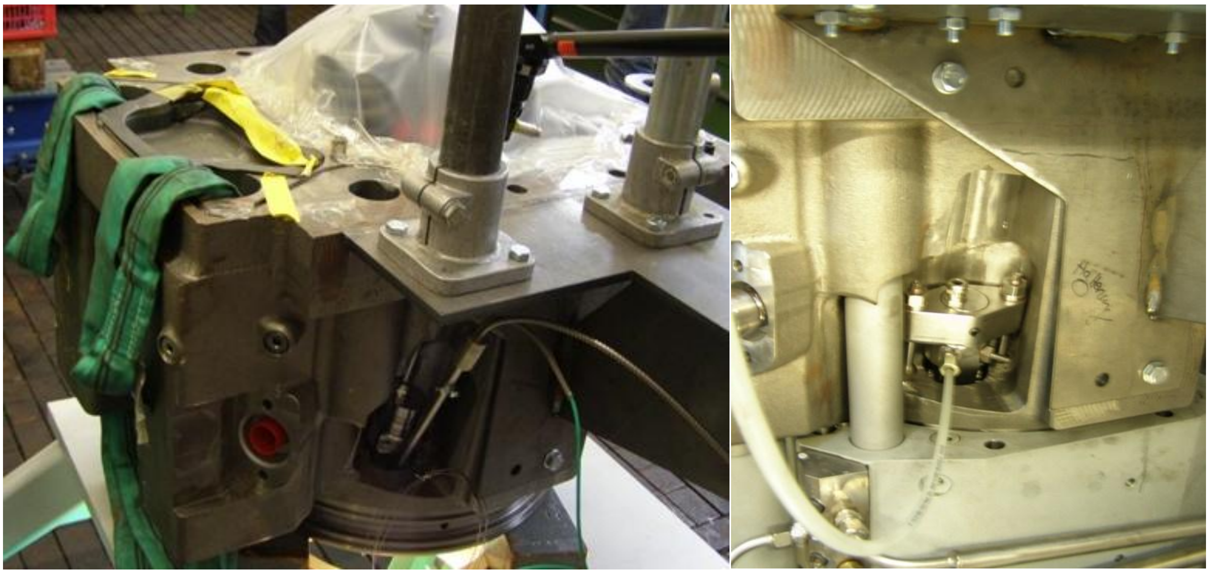


Figure 52: Optical probes in a multi-fuel single-cylinder engine

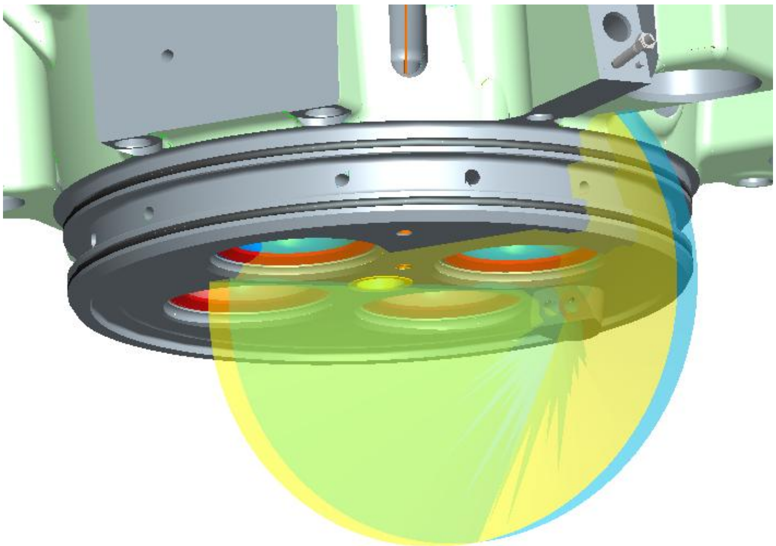


Figure 53: Optical cylinder head with optical access and viewing range

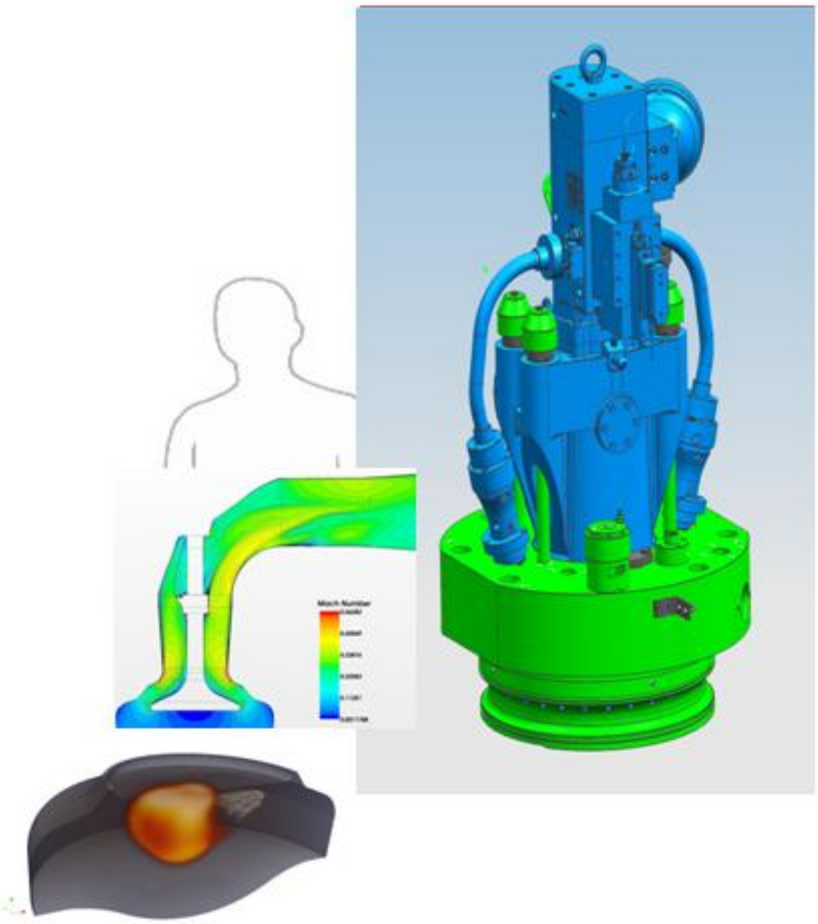


Figure 54: Model based combustion optimization

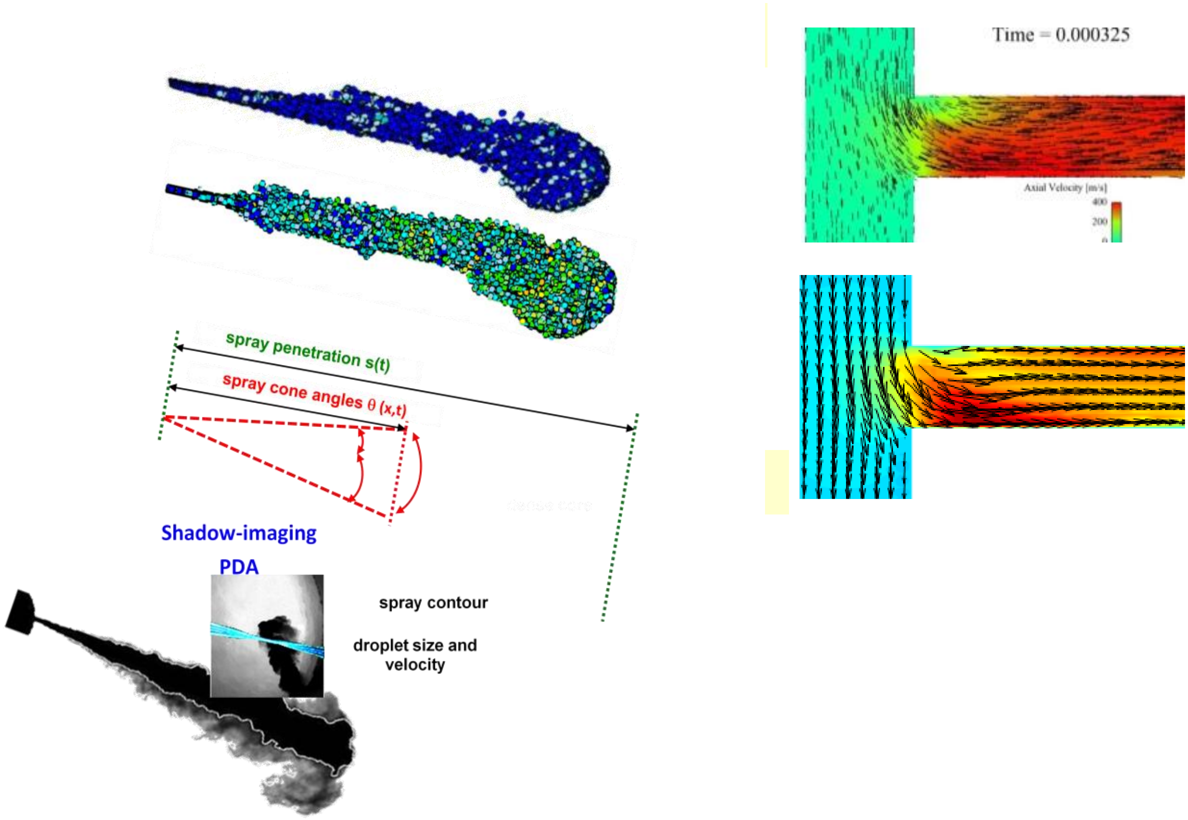


Figure 55: CFD investigations of the nozzle internal flow

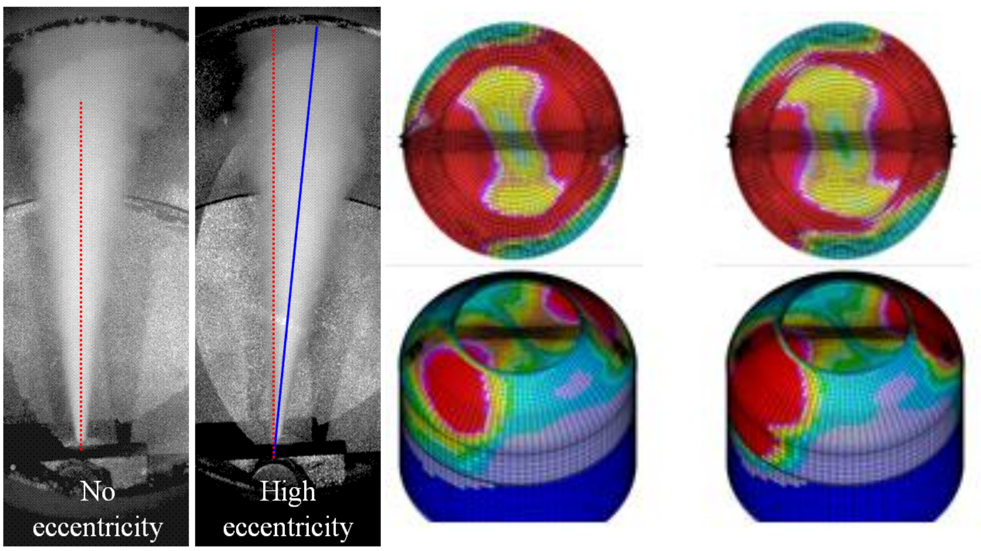


Figure 56: Nozzle bore eccentricity investigation

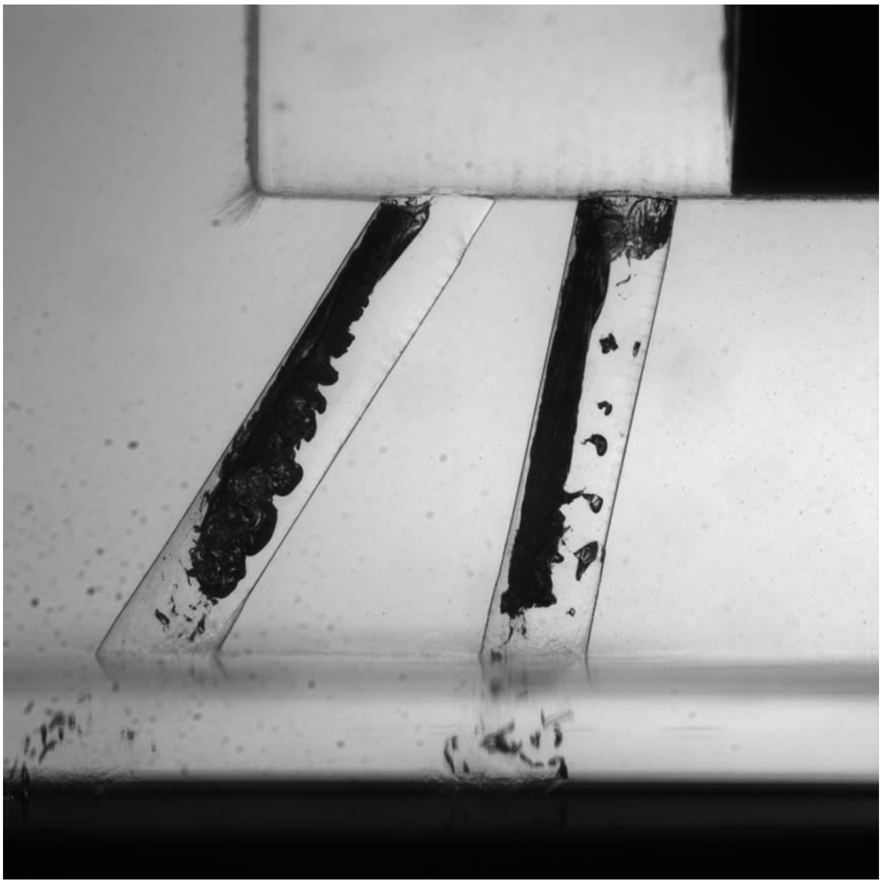


Figure 57: Instantaneous in-nozzle cavitation pattern for a two hole nozzle layout

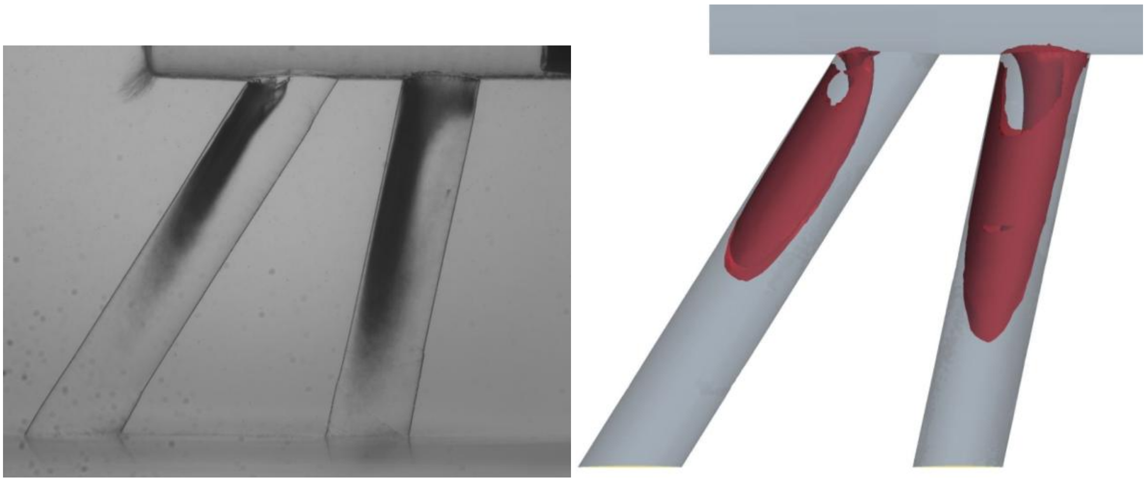


Figure 58: CFD tool for evaluation of flow coefficients and for describing in-nozzle flow and cavitation

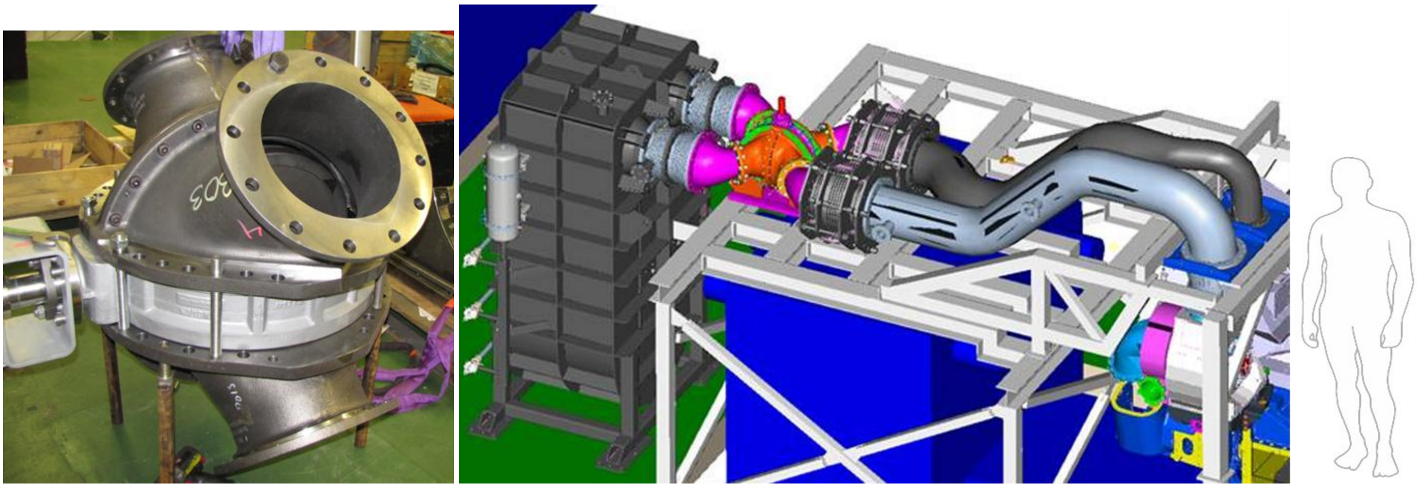


Figure 59: Sequential SCR concept with 2-stage turbocharging

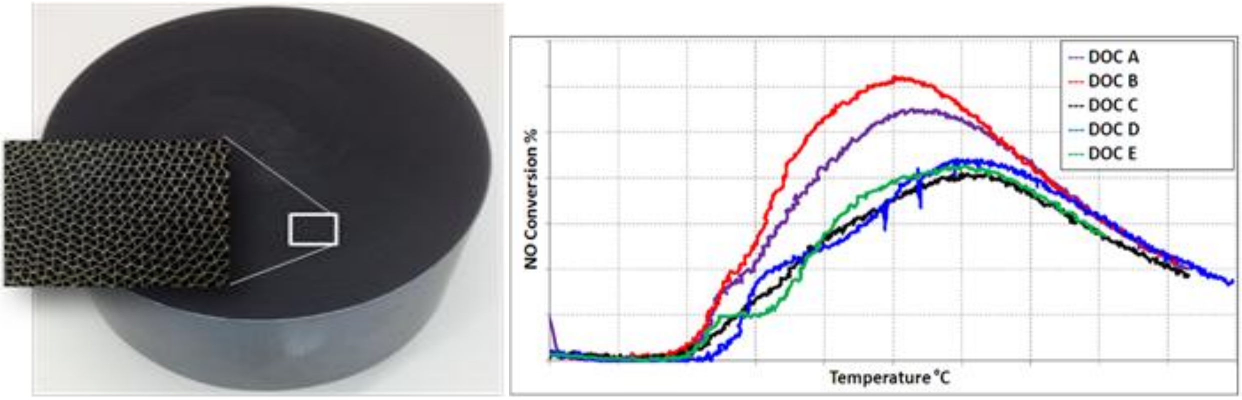


Figure 60: DPF Substrate variant (left), coating performance (right)

Figure 61: DPF installation(left) and transient (right) black carbon emission up- (red) & down-stream (blue) of DPF

Figure 62: Test of JiT-WiF basic concept at injection test rig

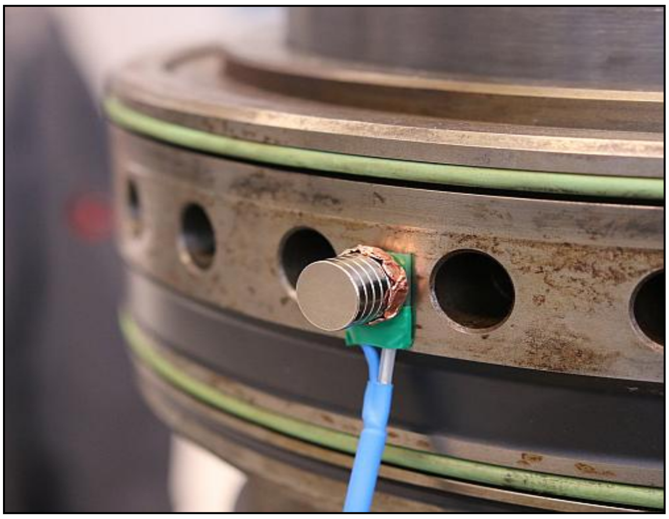


Figure 63: Wear sensor prototype installed externally on cylinder liner

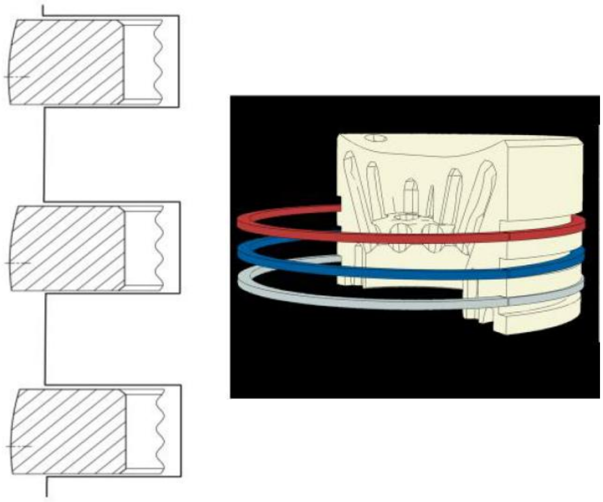


Figure64: Modified ring pack

Figure 65: New lube oil injectors

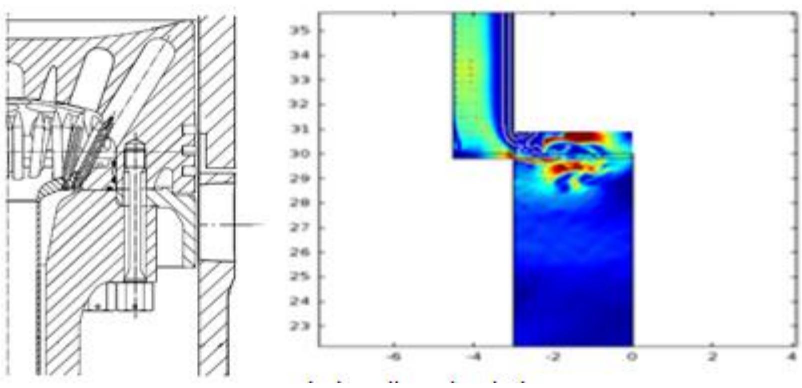


Figure 66: Lube oil re-circulation grooves

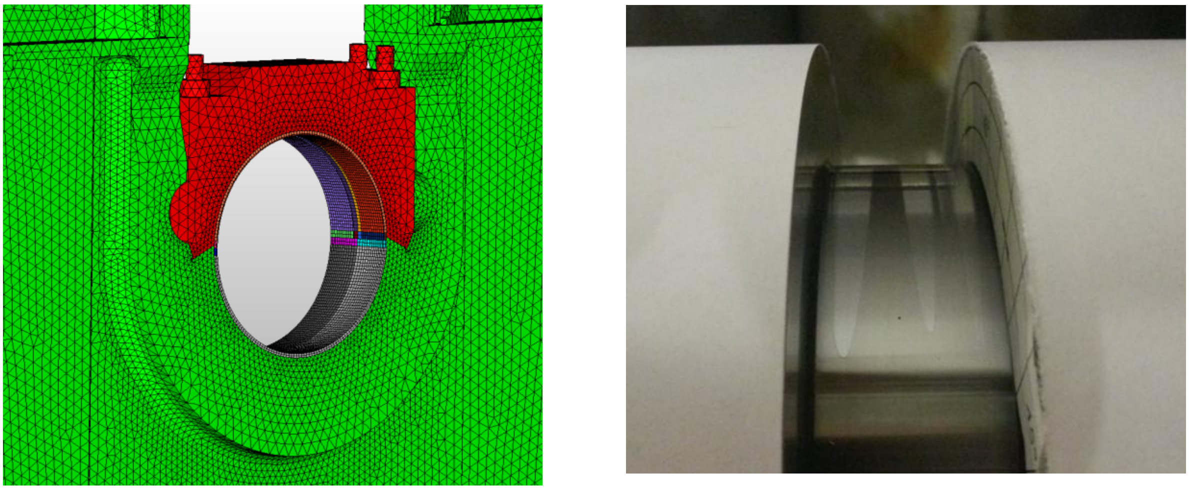


Figure 67: New Increased performance main engine bearings