UNIVERSITÀ DEL SALENTO | DIPARTIMENTO DI INGEGNERIA DELL'INNOVAZIONE

Centro Ricerca Energia e Ambiente
Dipartimento di Ingegneria dell'Innovazione
Università del Salento

GIORNATA DI STUDIO SUI MOTORI A COMBUSTIONE INTERNA

"I GRUPPI DI RICERCA DELLE UNIVERSITÀ ITALIANE INCONTRANO LE IMPRESE"

MODENA 25 MAGGIO 2016

Studio e potenzialità di architetture ibride alternative per la propulsione terrestre e aeronautica

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Università del Salento – Centro Ricerche Energia e Ambiente (CREA)

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Outline

- **Il gruppo CREA dell'Università del Salento**
- **Studio comparativo di differenti architetture di sovralimentazione – motore GF56**
- **Ottimizzazione motore GF56**
- **Simulazione prestazioni architetture propulsive alternative per impiego terrestre e aeronautico**
- **Attività correnti e future**

Il gruppo CREA dell'Università del Salento

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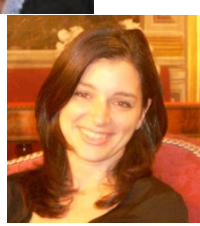
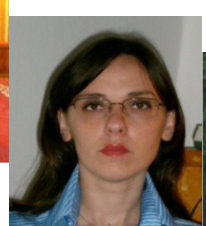
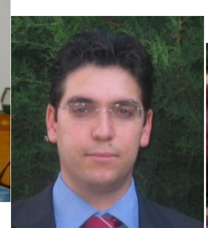


2 Professori Ordinari

Domenico Laforgia (Direttore)
Antonio Ficarella

2 Professori Associati

Arturo de Risi
Teresa Donateo

6 Professori Aggregati

A.P. Carlucci
G. Colangelo
P.M. Congedo
M.G. de Giorgi
M. Milanese
G. Starace

10 Assegnisti di ricerca

10 Dottorandi

Il gruppo CREA - Tematiche MCI

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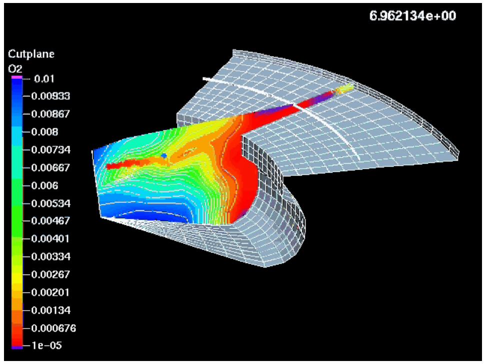
Simulazione e ottimizazione dei MCI

Motori Diesel iniezione diretta
Motori HCCI
Motori dual-fuel CNG/diesel fuel
Combustibili alternativi



Veicoli HEVs e Plug-in

Modellazione del powertrain
Modellazione del motore con finalità di controllo
Modellazione del comportamento termico del motore
Predizione del ciclo guida
Acquisizione del comportamento del pilota

Sistemi motori

Gestione dell'energia
Modellazione e ottimizzazione

Il gruppo CREA – Salento Racing Team

Centro Ricerca Energia e Ambiente
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Dal 2005

250 studenti coinvolti

11 competizioni internazionali

5 prototipi

PON MALET – GF56

Cond. al contorno e target			
Flight Level [kft]	p_amb [bar]	T_amb [°C]	Power % per bank @ 2000 rpm
0	1.01	15	100
10	0.69	-6	100
17	0.53	-18	89
35	0.23	-54	54

PON MALET – GF56

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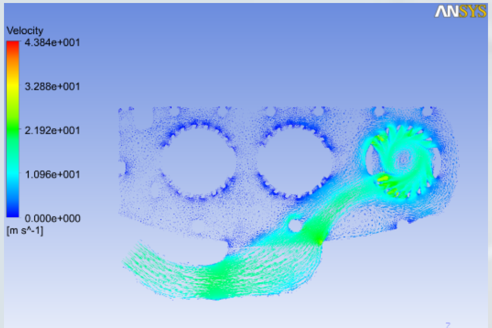
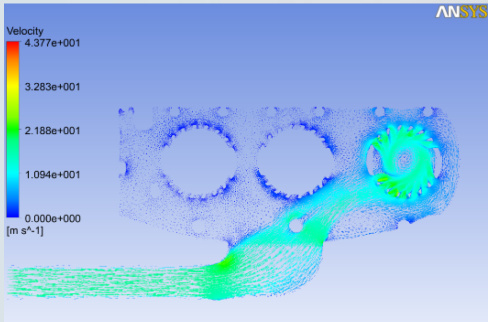
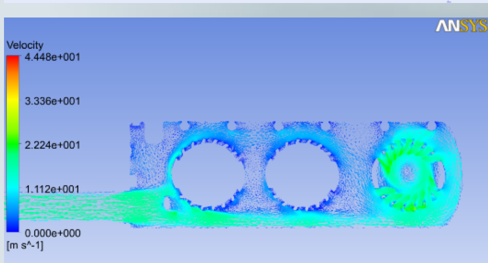
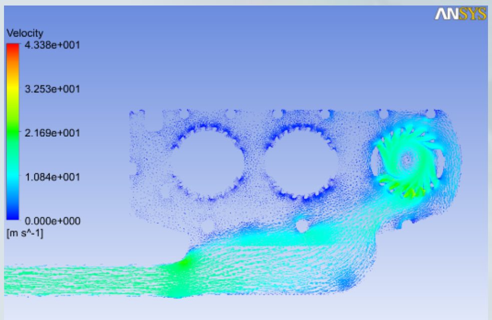
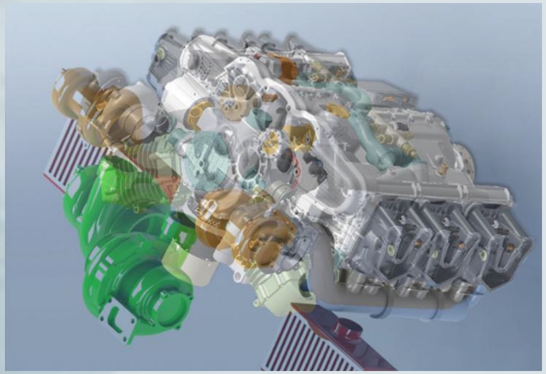
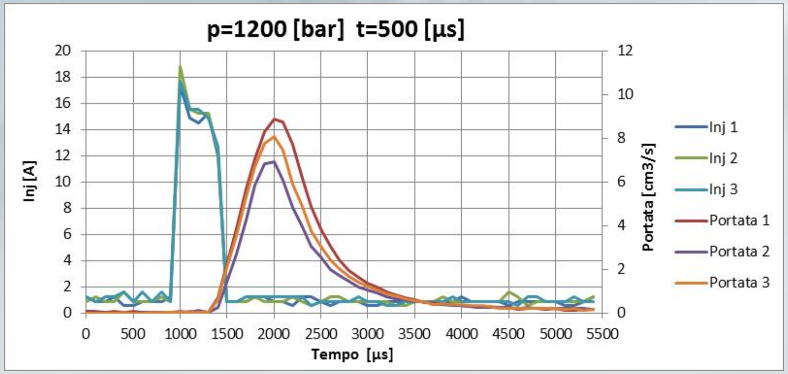


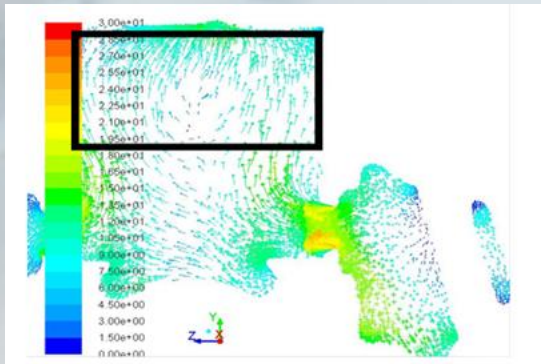




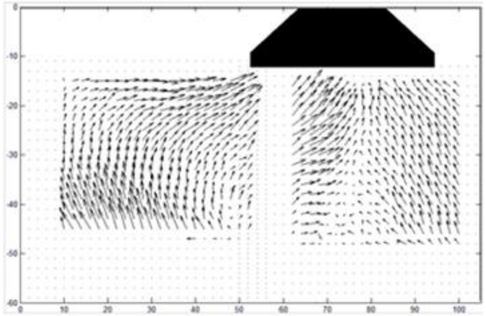








Simulazioni CFD Flussaggio (portata 0,13 kg/s@2,58 kg/mc) - POV



Campo di moto PIV (portata 0,06 kg/s @ 1,2 kg/mc) - POV

Studio comparativo di differenti architetture di sovralimentazione

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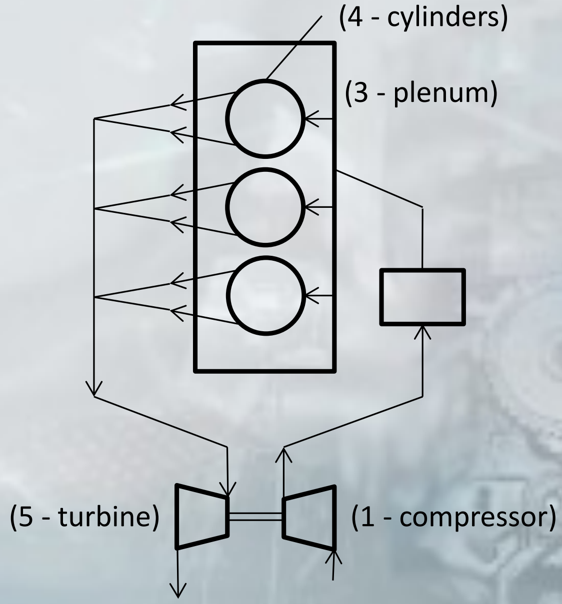
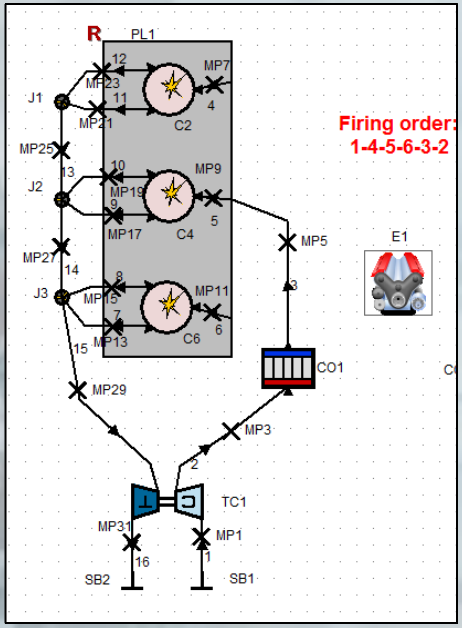
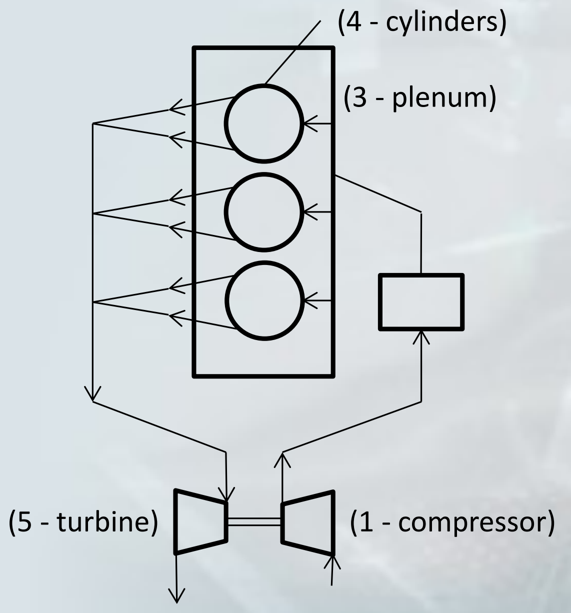


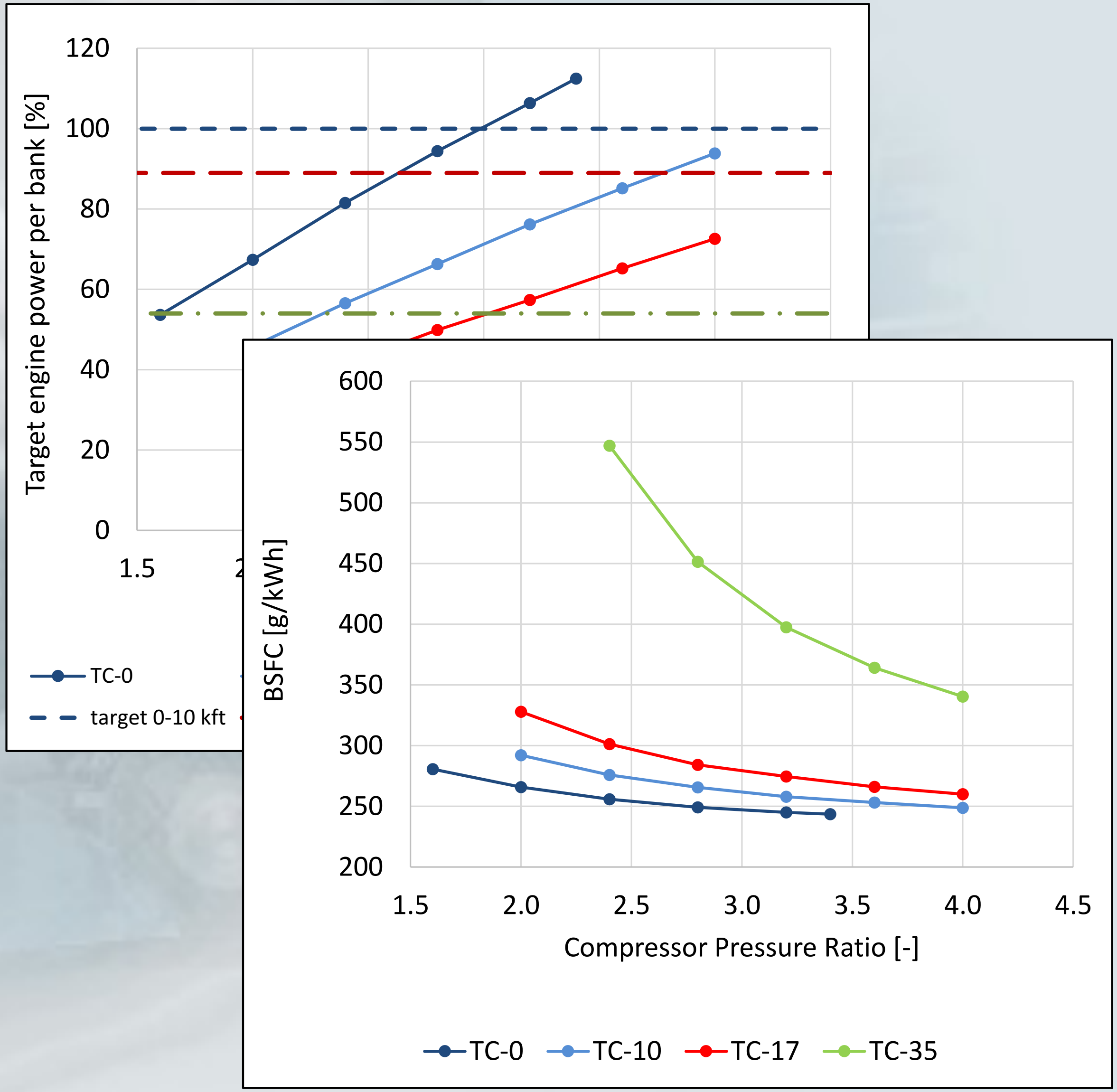


Confronto numerico - sperimentale				
	P_b	BSFC	Air mass flow	PR_TURB
SCOSTAMENTO	-1.8 %	1.9 %	-10.0 %	4.2 %

A.P. Carlucci, , A. Ficarella, D. Laforgia, A. Renna; *"Supercharging system behavior for high altitude operation of an aircraft 2-stroke Diesel engine"*, **Energy Conversion and Management** 101 (2015) 470-480

Studio comparativo di differenti architetture di sovralimentazione





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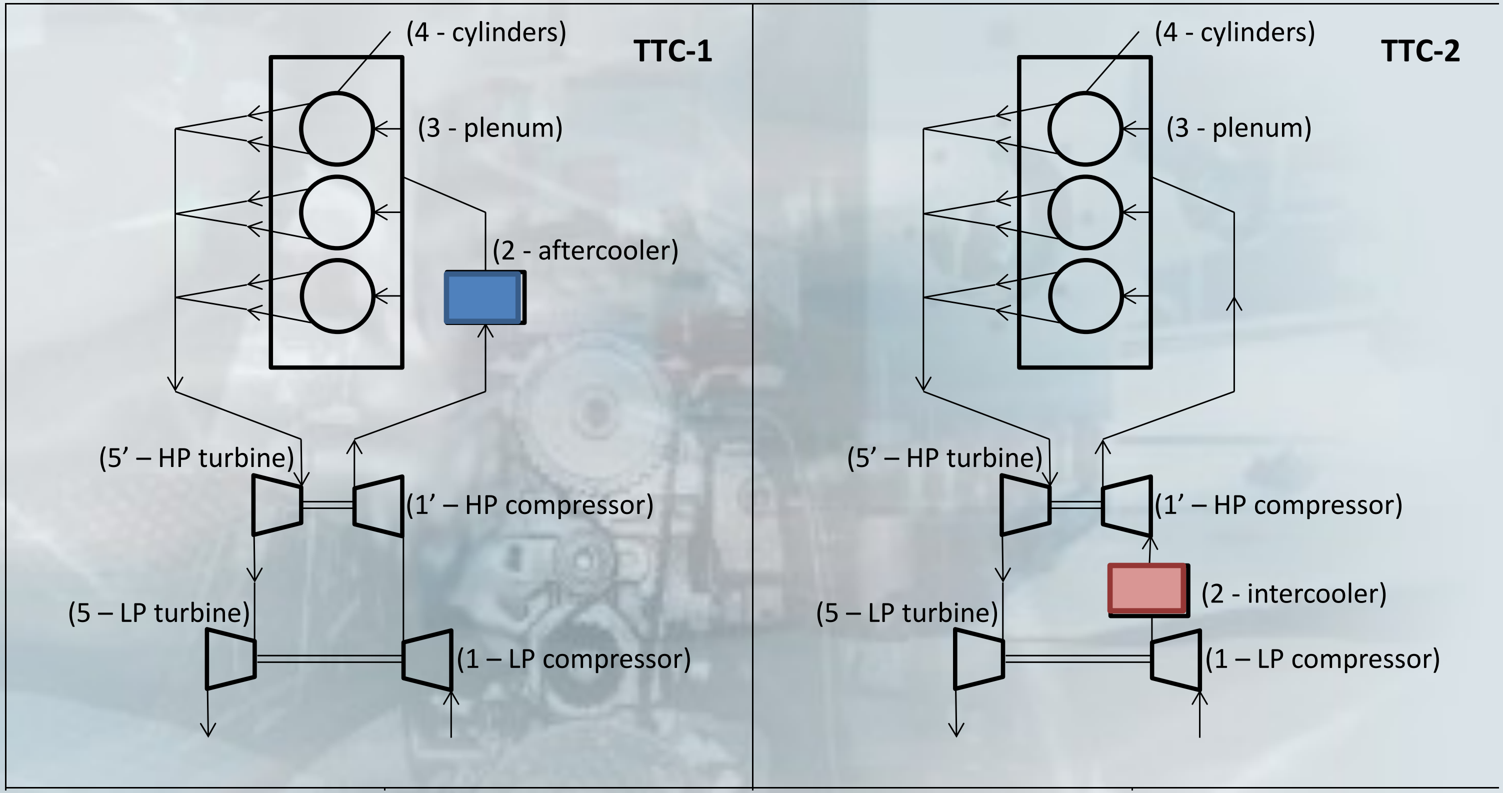

altitude	Low pressure – high pressure	Low pressure – high pressure
0 [m]	1.75-1.70	2.00-1.90
3050 [m]	2.20-1.95	2.50-2.30
5180 [m]	2.30-2.20	2.80-2.50
10670 [m]	3.00-2.30	3.20-3.00

A.P. Carlucci, , A. Ficarella, D. Laforgia, A. Renna; *"Supercharging system behavior for high altitude operation of an aircraft 2-stroke Diesel engine"*, **Energy Conversion and Management** 101 (2015) 470-480

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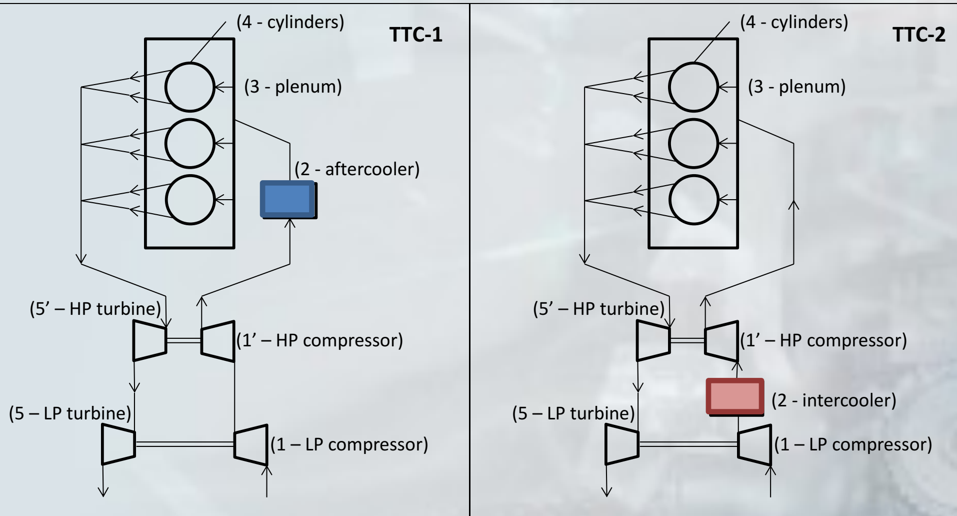

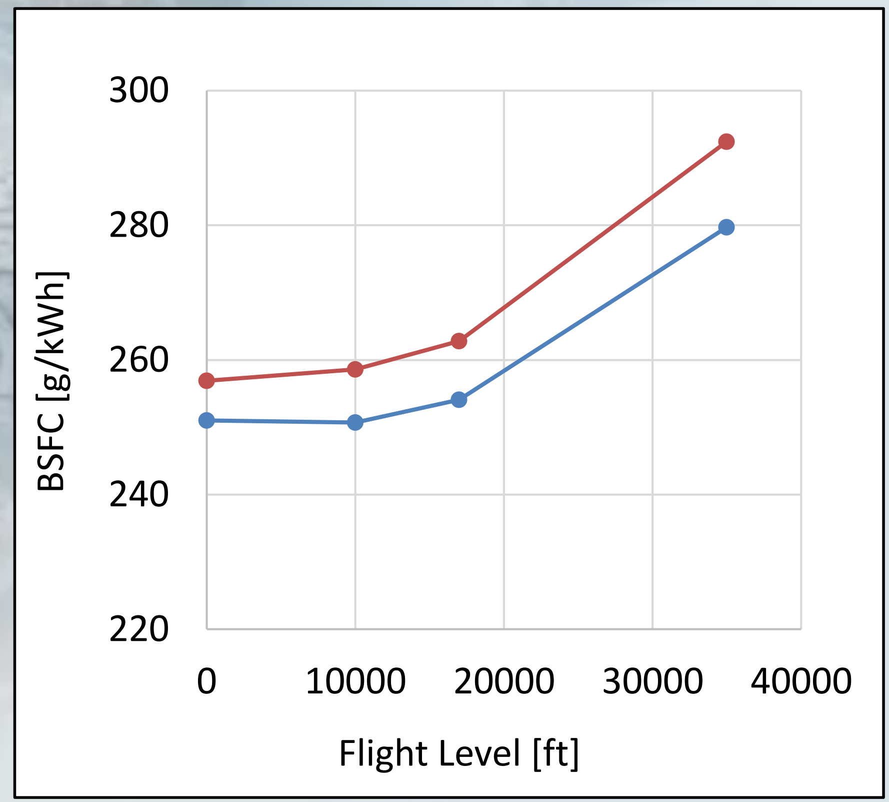

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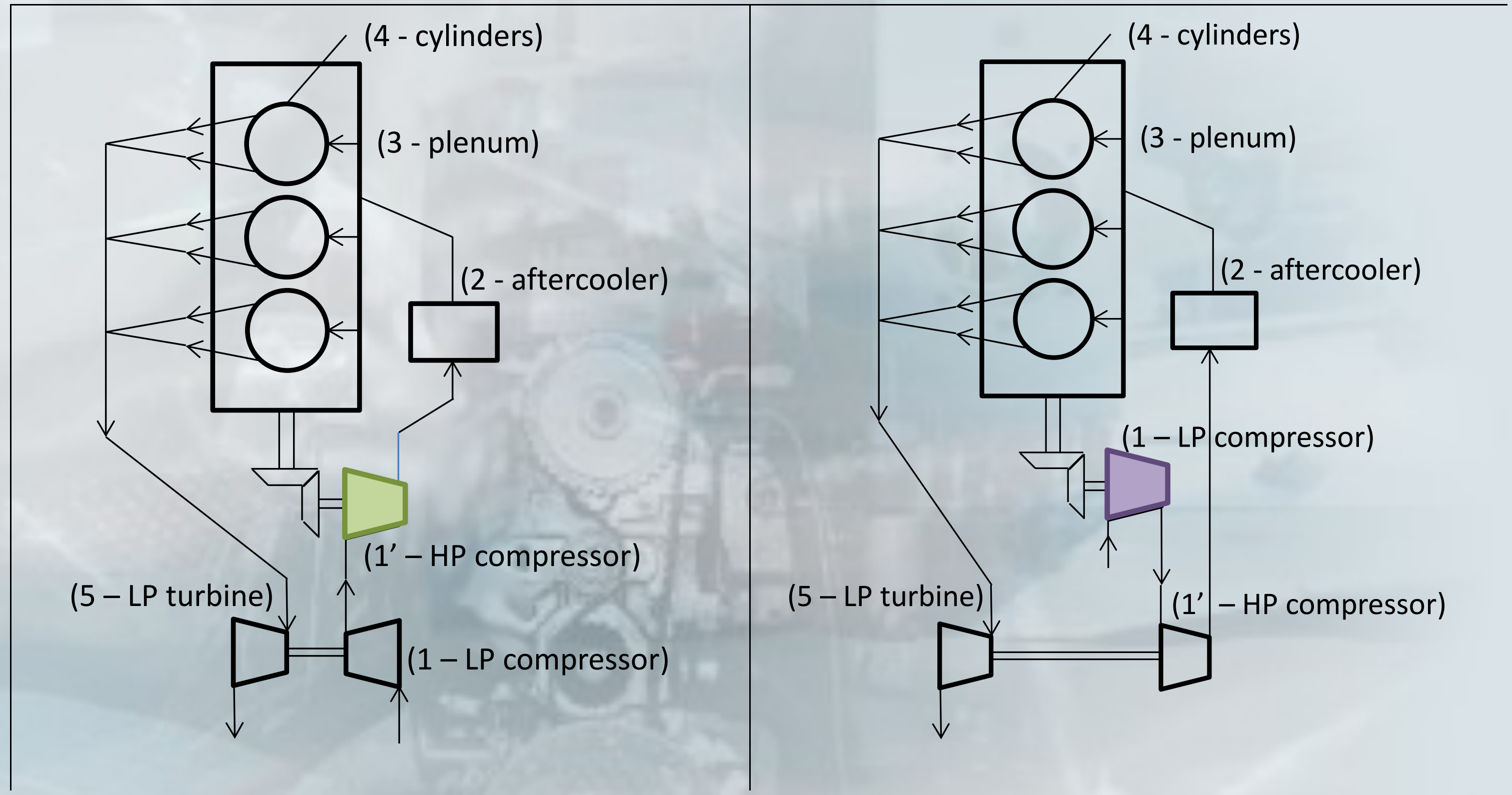

altitude	Turbocharger – mechanical compr.	Turbocharger – mechanical compr.
0 [m]	2.60-1.50	2.30-1.60
3050 [m]	3.60-1.40	3.00-1.70
5180 [m]	4.3-1.70	3.50-1.70
10670 [m]	5.00-1.40	4.00-2.20

A.P. Carlucci, , A. Ficarella, D. Laforgia, A. Renna; *"Supercharging system behavior for high altitude operation of an aircraft 2-stroke Diesel engine"*, **Energy Conversion and Management** 101 (2015) 470-480

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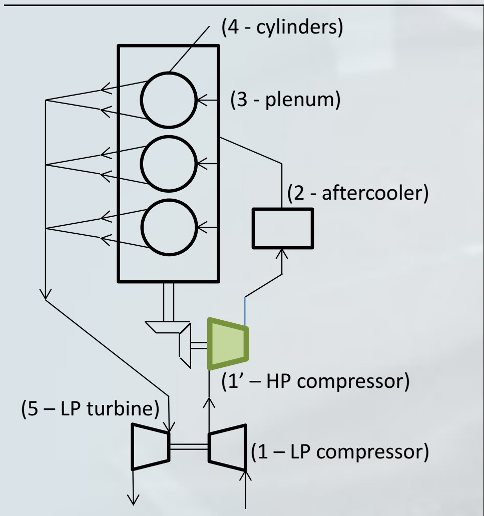

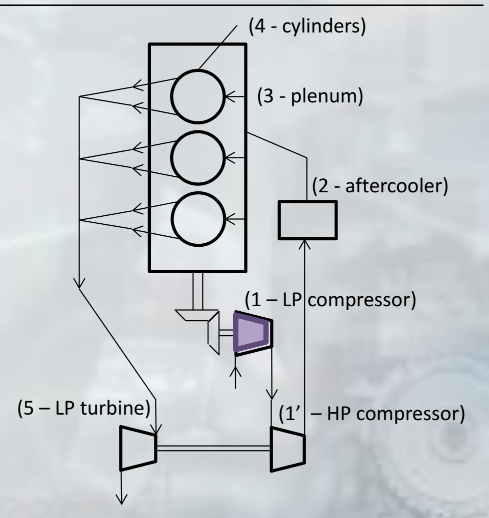

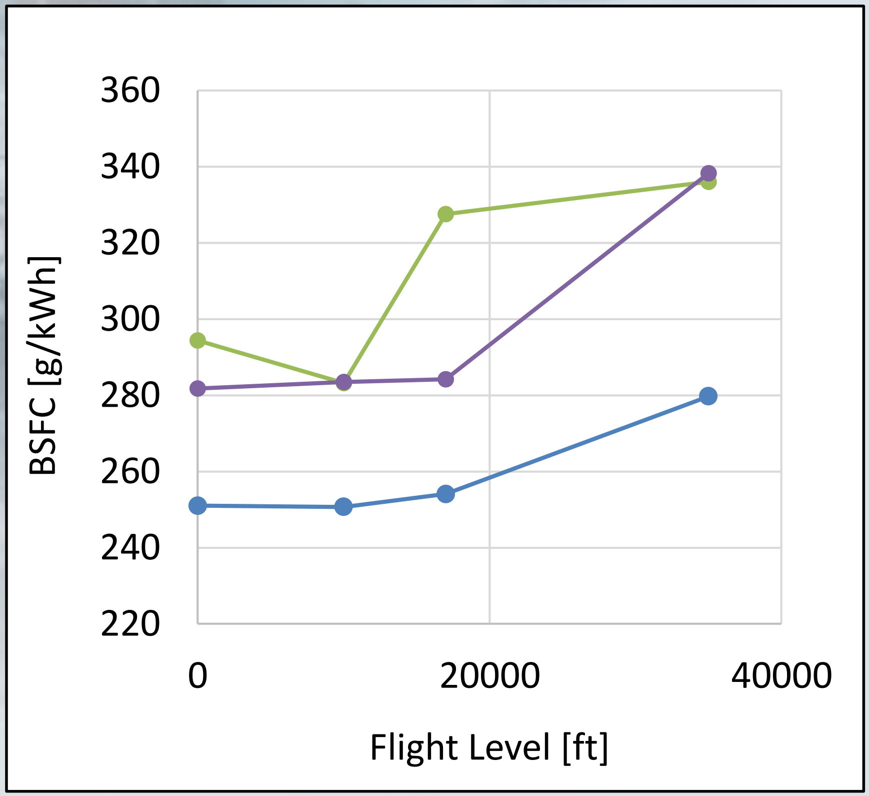

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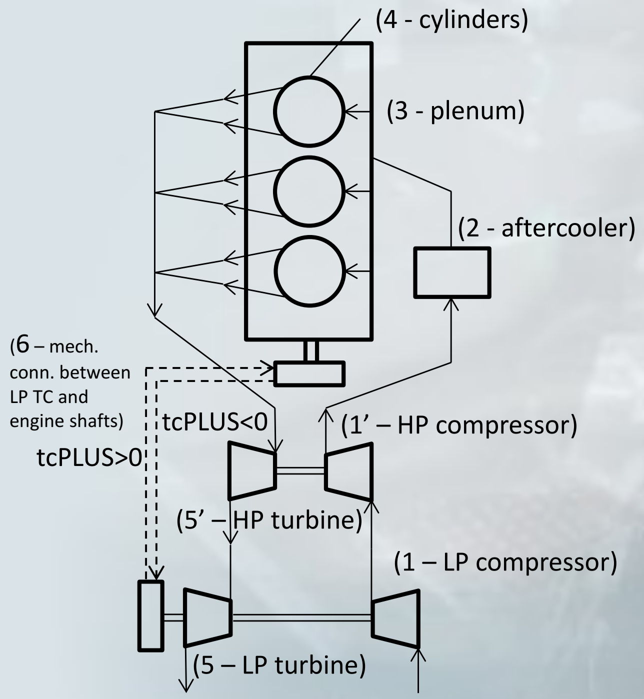
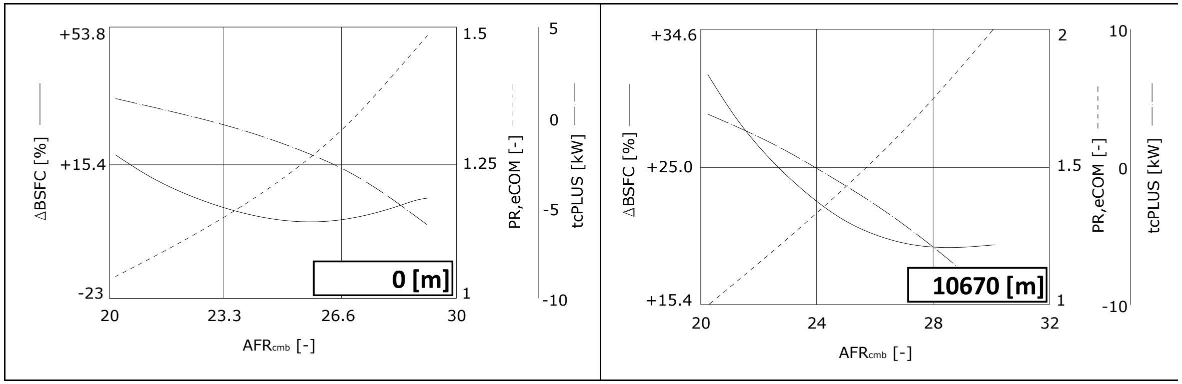
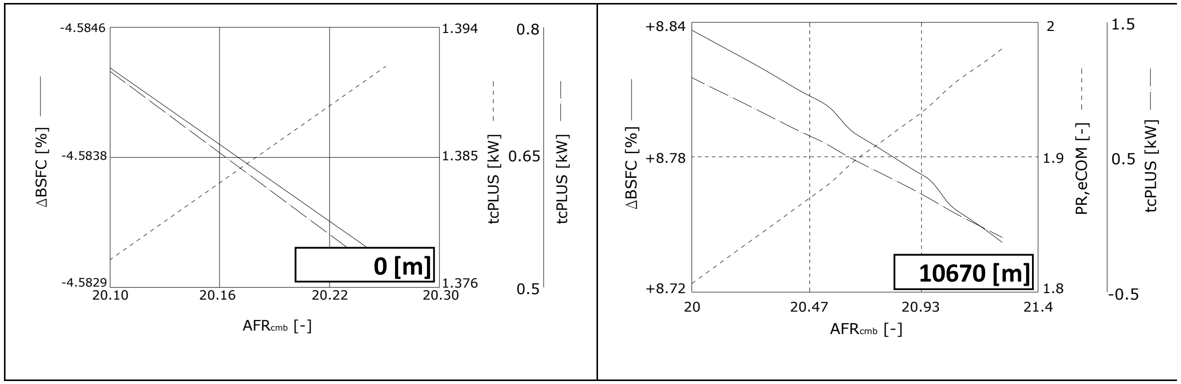




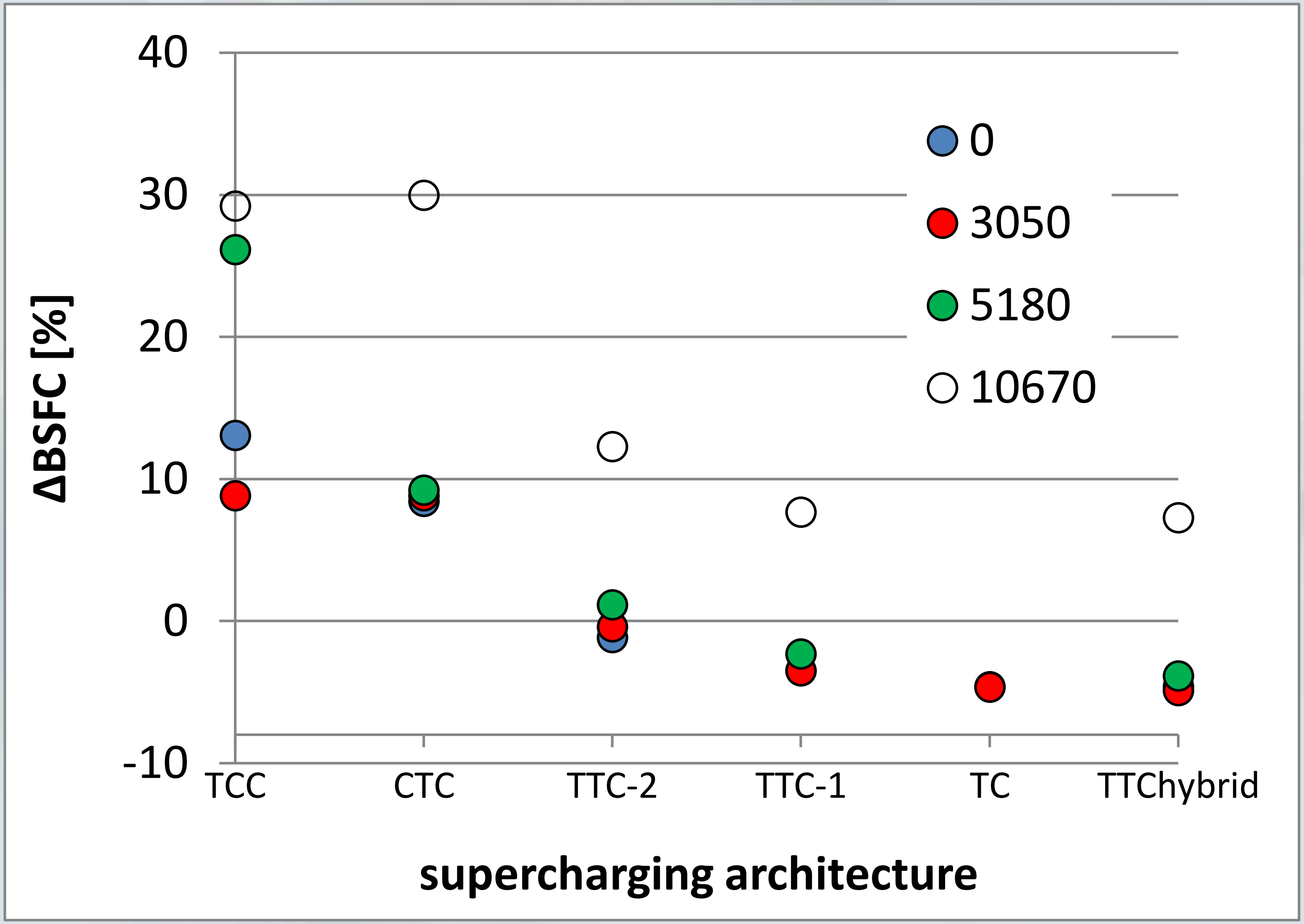
BSFC, tcPLUS and PR,eCOM at different altitudes for a constant output power at 1500 rpm



BSFC, tcPLUS and PR,eCOM at different altitudes for a constant output power at 2000 rpm

A.P. Carlucci, , A. Ficarella, D. Laforgia, A. Renna; *"Supercharging system behavior for high altitude operation of an aircraft 2-stroke Diesel engine"*, **Energy Conversion and Management** 101 (2015) 470-480

Studio comparativo di differenti architetture di sovralimentazione



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Ottimizzazione motore GF56

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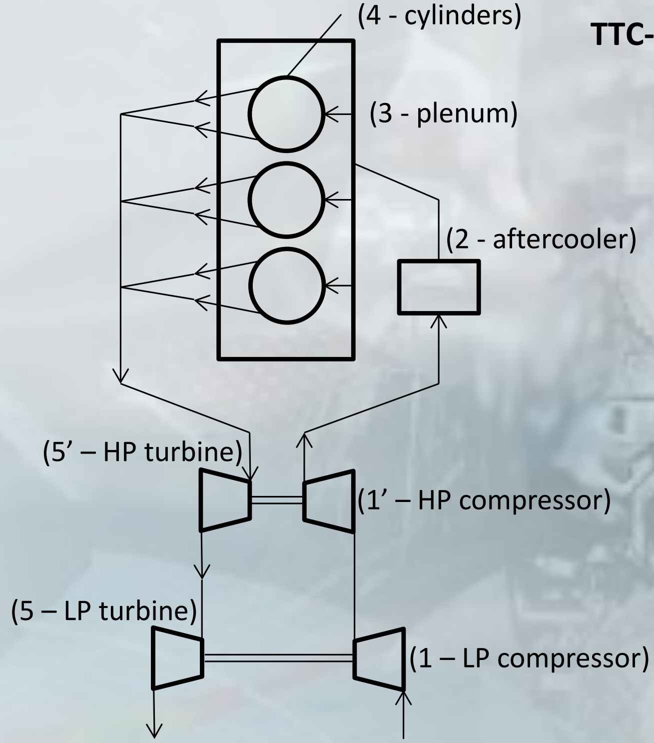
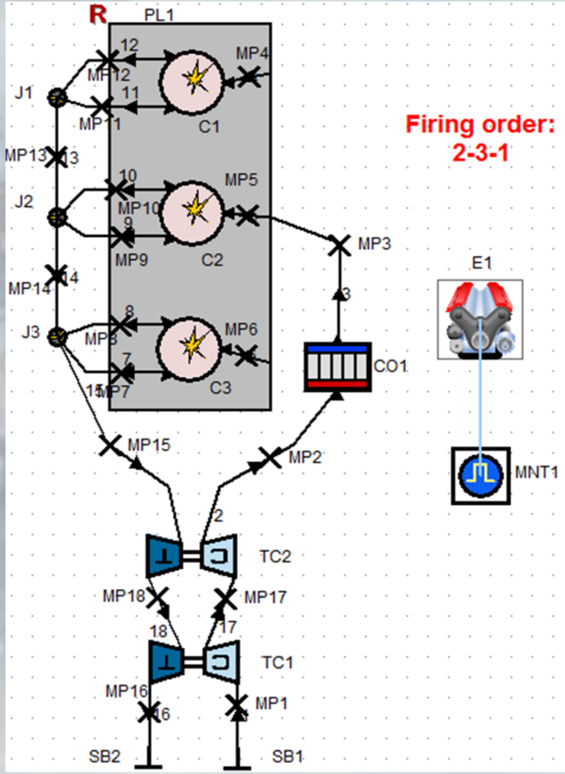
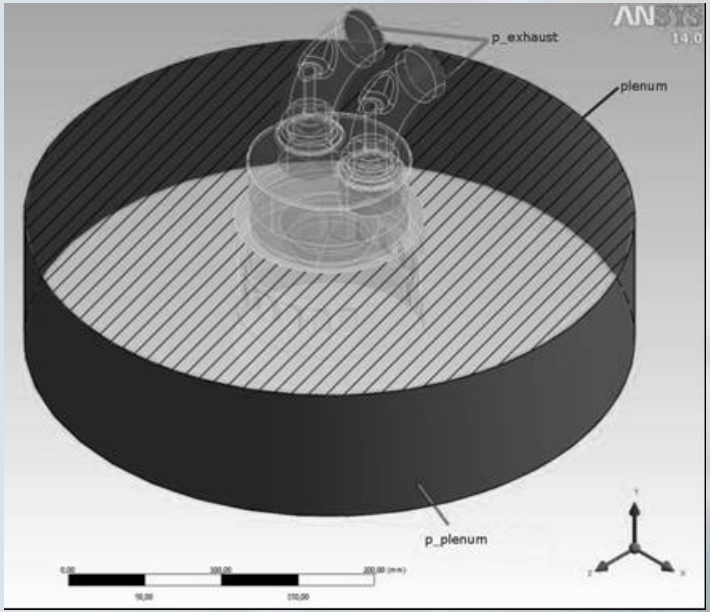


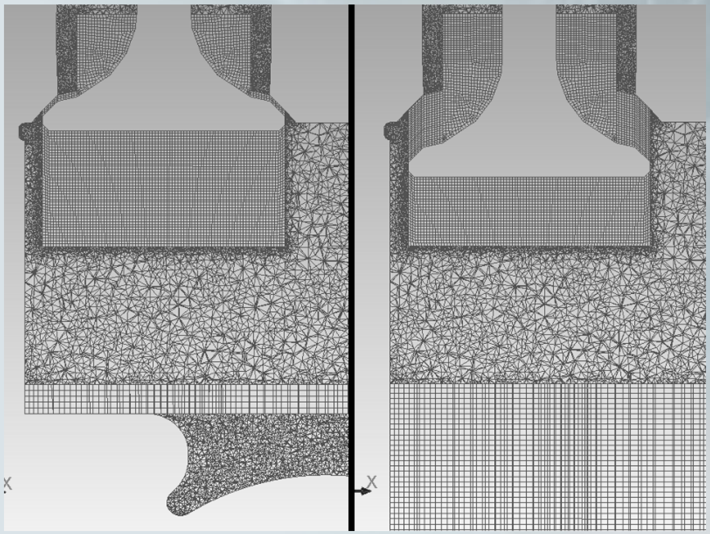
TTC-1

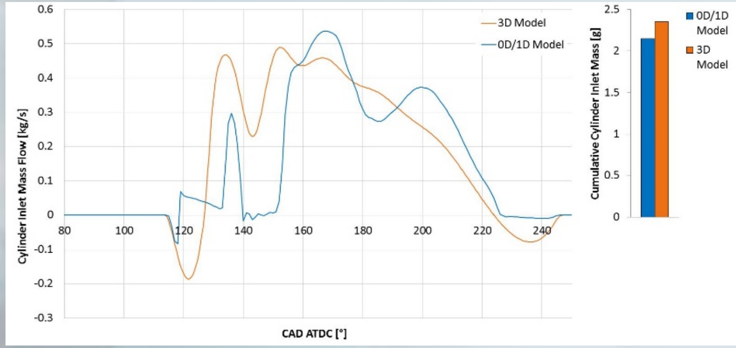


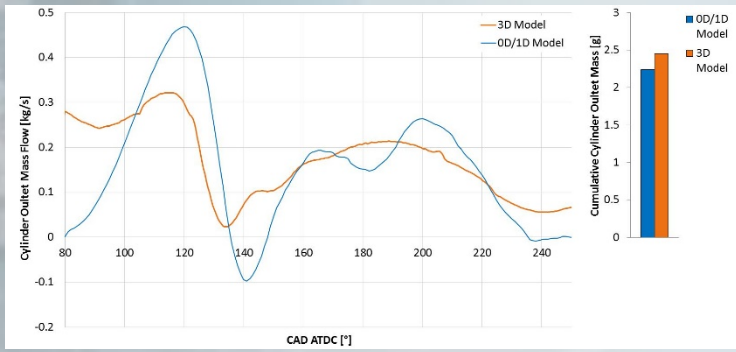
A.P. Carlucci, , A. Ficarella, G. Trullo; *"Performance optimization of a Two-Stroke supercharged diesel engine for aircraft propulsion"*, accepted for publication on **Energy Conversion and Management**

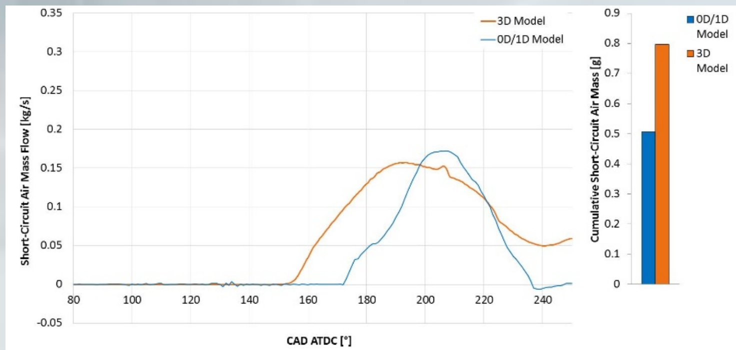
Ottimizzazione motore GF56











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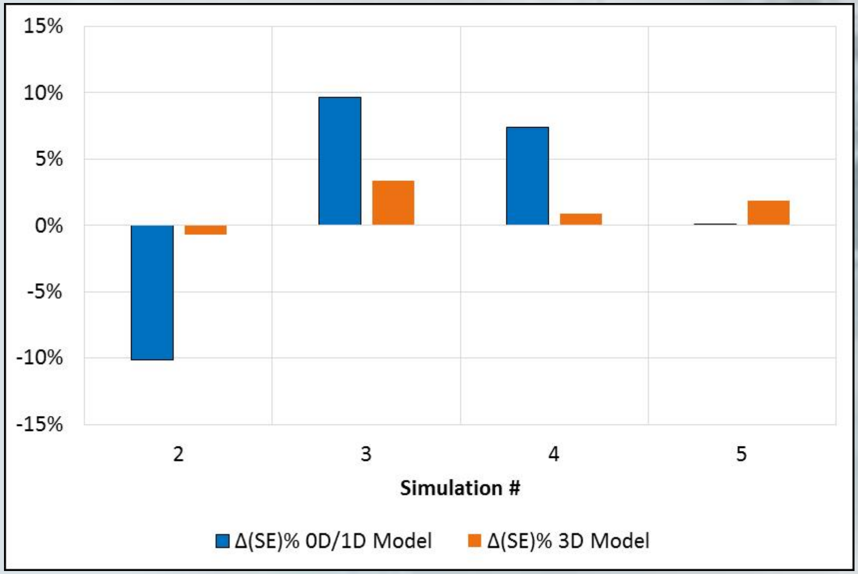

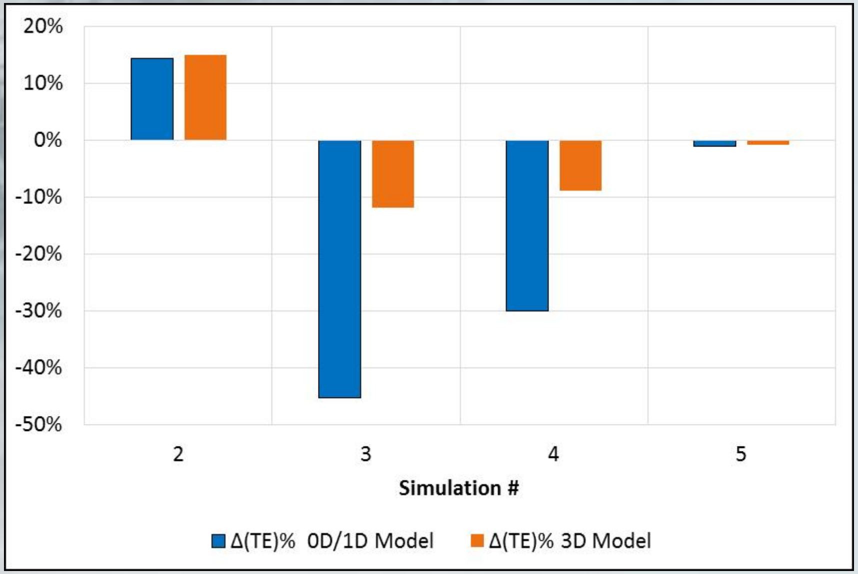

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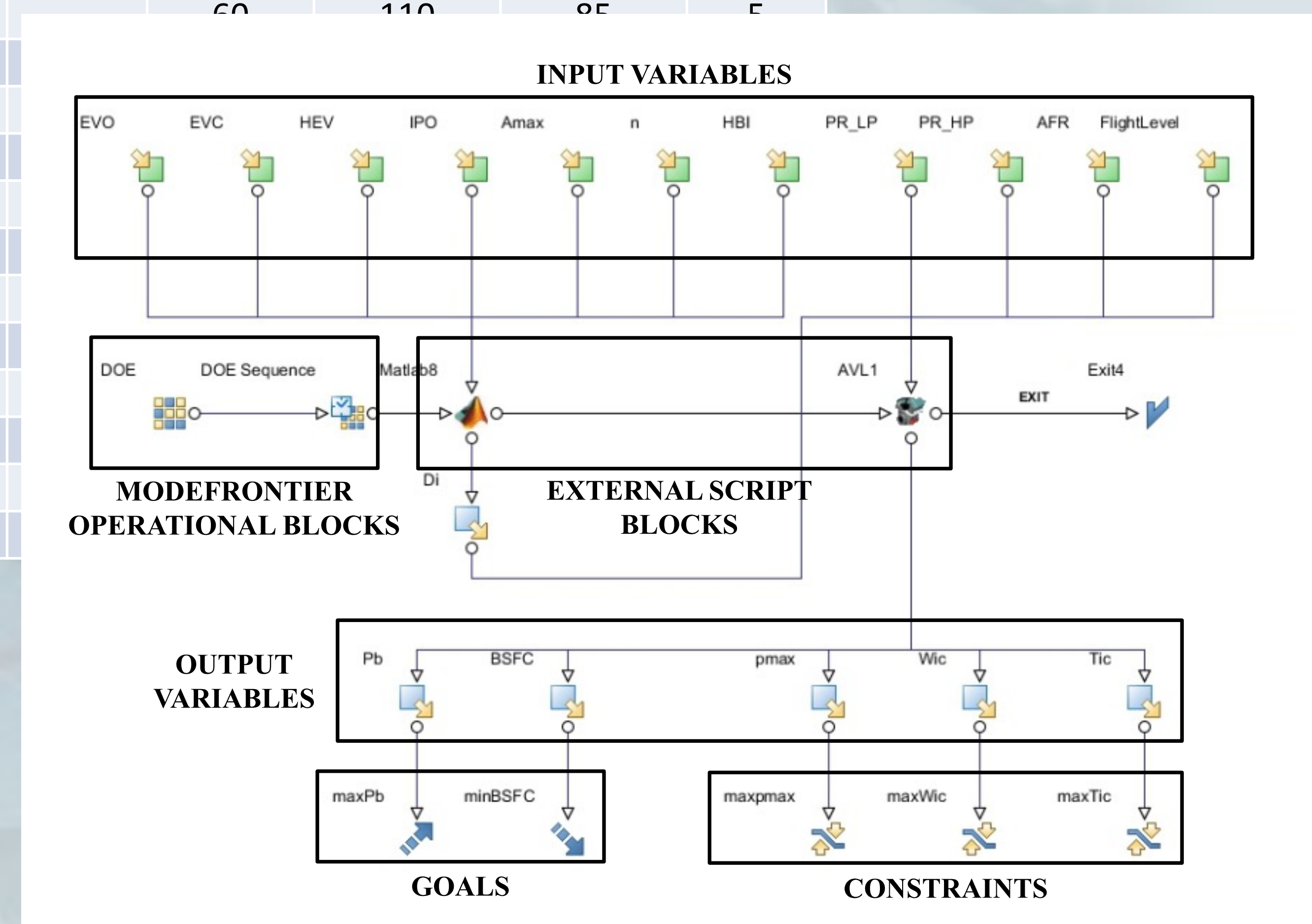
Ottimizzazione motore GF56

Acronym	Unit		Lower Bound	Upper Bound	Central Value	Step
CR	[-]		13	18	15.5	0.2
EVO	[DCA ATDC]		60	110	85	5
EVC	[DCA ATDC]					
HEV	[mm]					
IPO	[DCA ATDC]					
A	[mm^2]					
"n"	[-]					
HBI	[mm]					
AFR	[-]					
PR_{HP} @ SL	[-]					
PR_{LP} @ SL	[-]					
PR_{HP} @ CC	[-]					
PR_{LP} @ CC	[-]					



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Ottimizzazione motore GF56

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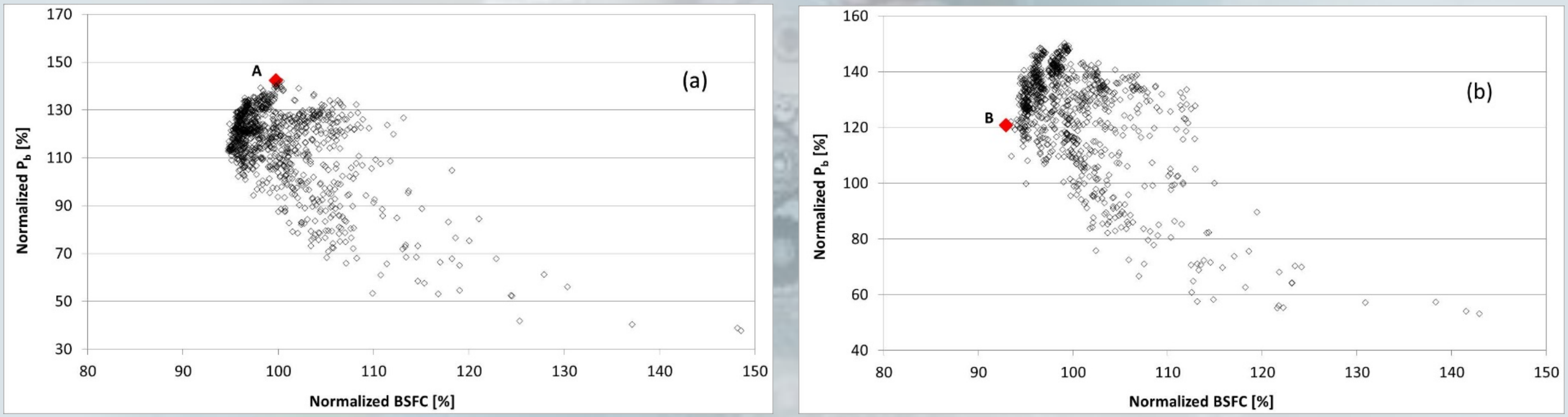
Flight level	P_b [%]	BSFC	A	AFR	CR	EVC	EVO	HBI	IPO	HEV	PR_{LP}	PR_{HP}	n	TE	SE
SL	142	99.75	240	17	16	270	110	1	115	10.5	1.7	2.1	10	0.92	0.69
CC	121	92.92	225	18.5	18	240	95	2	122.5	11	2.7	2.7	17	0.89	0.75



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PLA.N.E.S.: A platform for new environmental friendly solutions

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Aircraft specification

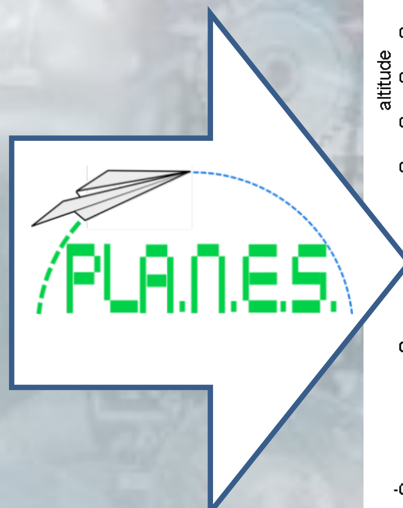
- Wing span and area;
- Drag versus lift
- Take-off weight
- Auxiliaries power request
- Available Fuel

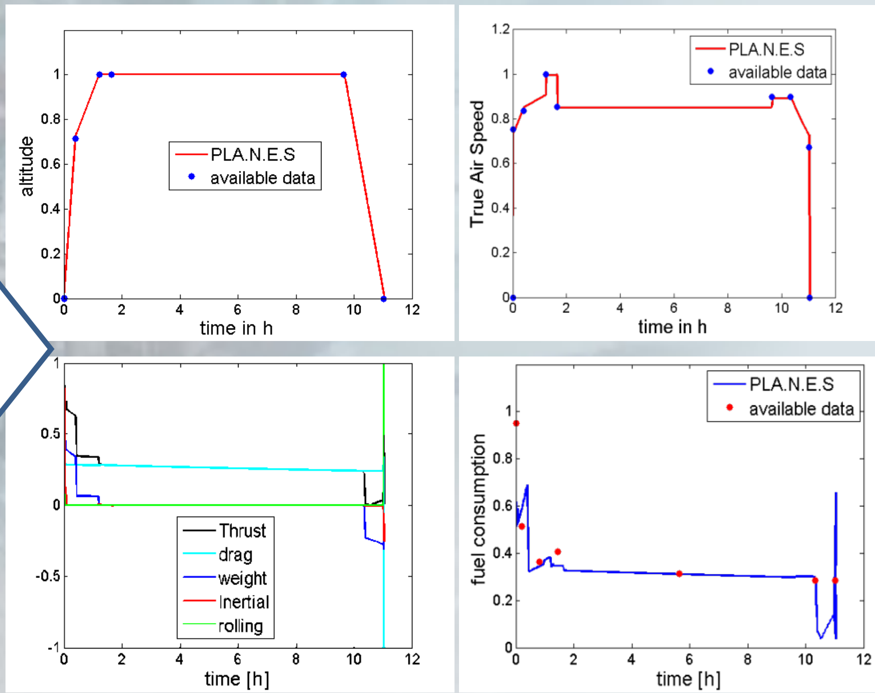
SIZING - MISSION BASED ANALYSIS

Takeoff, cruise, climb analysis

Powertrain details

- Conventional and advanced powertrains
- Supervisory control strategies





Scalable models

- Constant speed and constant pitch propellers
- Scalable performance maps for piston, Wankel and turbine engines
- Quasi-static models for energy storage systems
- Power-to-mass and power-to volume correlations

OPTIMIZATION

Donateo, T., Ficarella, A., Spedicato, L., Development and validation of a software tool for complex aircraft powertrains (2016) **Advances in Engineering Software**, 96, pp. 1-13. DOI: 10.1016/j.advengsoft.2016.01.001

PLA.N.E.S. - Powertrains

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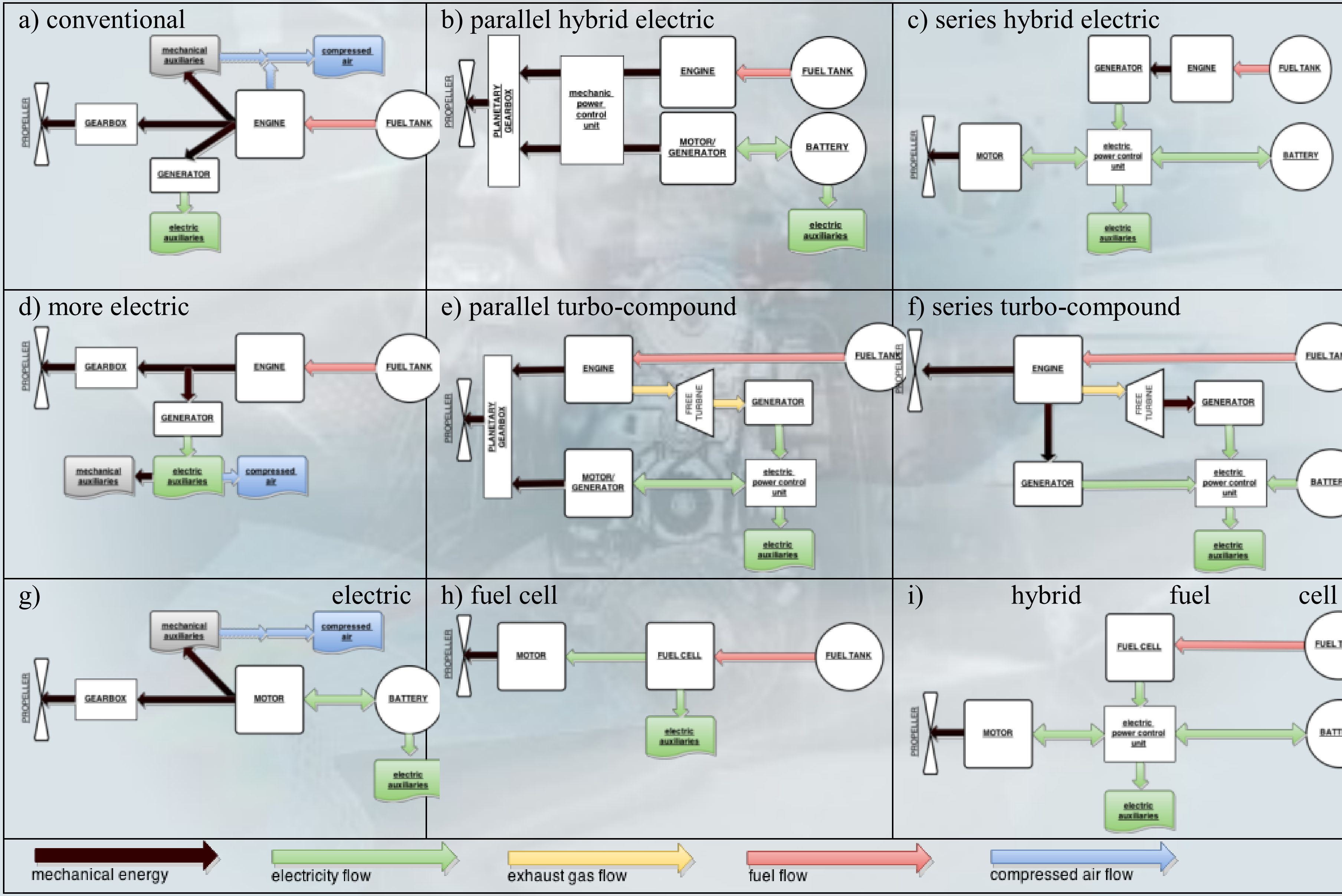

PLA.N.E.S. – Engine scaling model

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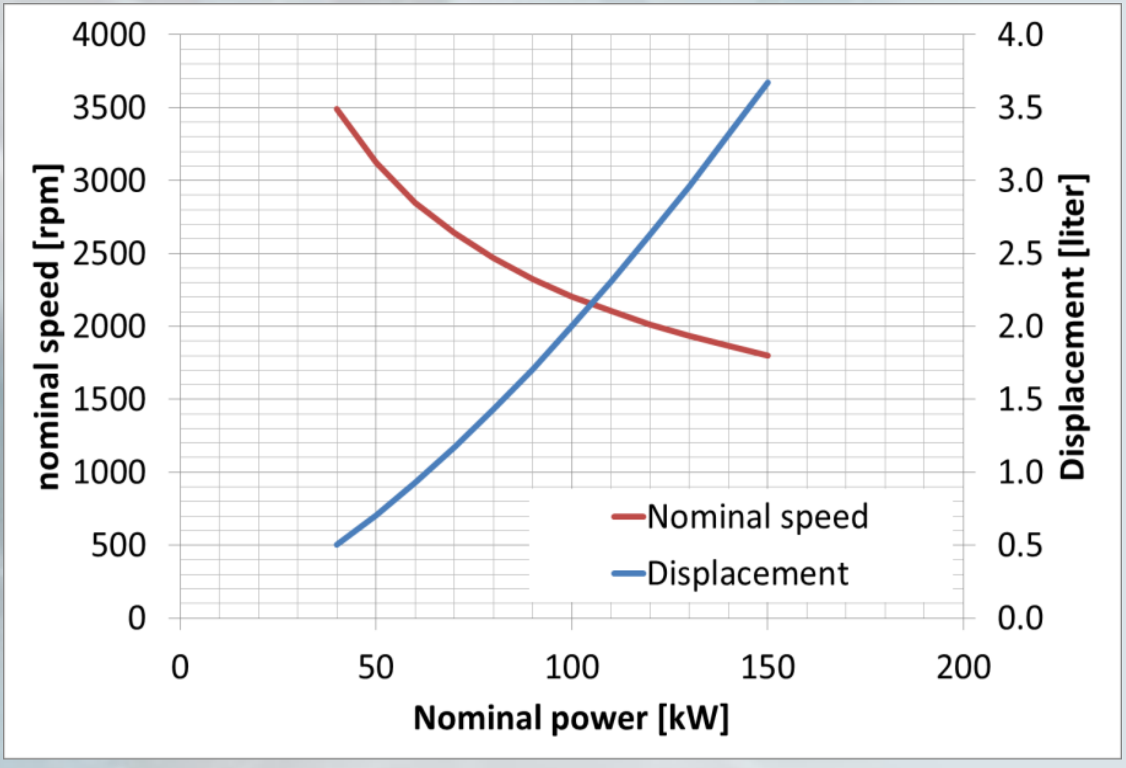
The scaling parameter of the engine is assumed to be its nominal power.

According to the nominal power, the model calculates the displacement, the nominal speed, the mass, the volume and the efficiency map of the engine.

$$M_{\mathrm{ICE}} = 6.88 \left(HP_{ICE}\right)^{0.61} \qquad [kg]$$



T. Donateo, L. Spedicato, G. Trullo, A.P. Carlucci, A. Ficarella, "Sizing and Simulation of a Piston-prop UAV", **Energy Procedia**, Volume 82,pp 119-124, 2015, ISSN: 1876-6102, doi:10.1016/j.egypro.2015.12.003

PLA.N.E.S. – Engine scaling model

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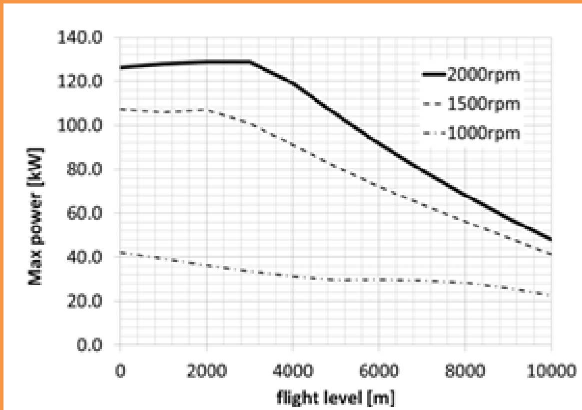
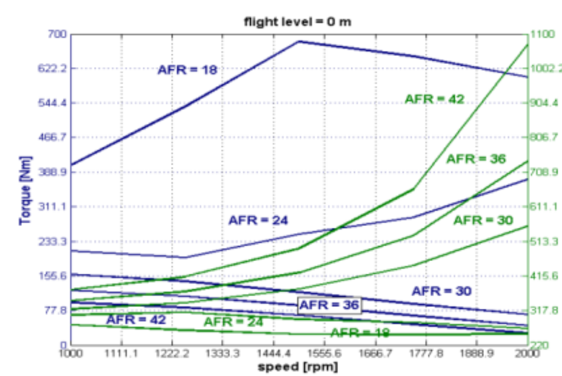
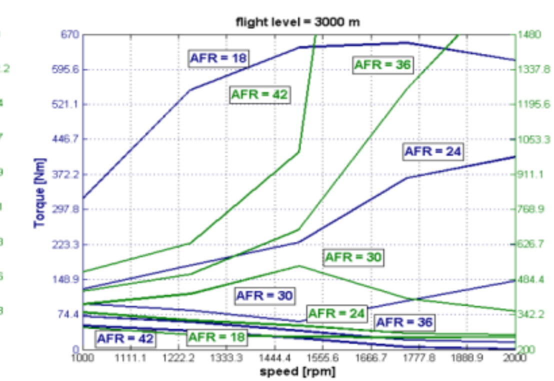
Reference engine: 128 kW two-stroke diesel (nominal speed 2000rpm)

Sea-level and altitude perfs maps from 1-D sims (AVL-Boost)





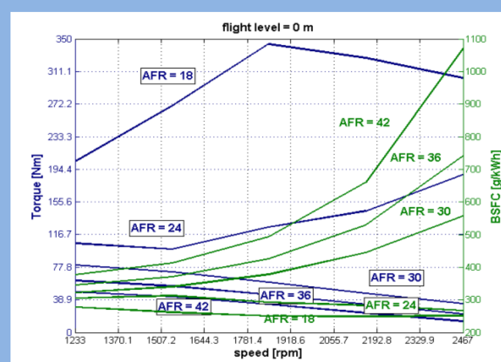


HYPOTHESIS

Engines with the same technology have a different torque-speed map but the same BMEP-piston mean speed map

Scaled engine: 80 kW two-stroke diesel (nominal speed 2500rpm)

Sea-level and altitude performance maps from scaling procedure



A possible correction (from literature data)

$$\frac{bsfc}{bsfc_0} = \left(\frac{HP_{ICE}}{HP_{ICE,0}}\right)^{-0.062}$$

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Many-objective optimization of a hybrid electric aircraft

Variable	Unit	Min	Max	Step
Nominal Engine power	kW	90	150	2
Motor cooling ID: **1: free cooling;** **2: forced air cooling** **3: forced liquid cooling**		1	3	1
Battery ID		1	2	1
Battery nominal capacity C_{nom}	Ah	10	100	5
Battery elements in series	-	C_{nom}	5 C_{nom}	0.1 C_{nom}
Discharge current	A	0.5 C_{nom}	2.5C_{nom}	0.1C_{nom}
Recharge current	A	C_{nom}	5 C_{nom}	0.1 C_{nom}

Parameter	Battery 1	Battery 2
Rated Voltage [V]	3.7	3.6
Max Voltage [V]	4.2	4
Cut-off Voltage [V]	2.7	2.8
Max continuous current in discharge [A]	5C_{nom}	2.2C_{nom}
Peak current [A]	10C_{nom}	5C_{nom}
Max continuous current in charge [A]	3C_{nom}	1C_{nom}
Energy density [Wh/kg]	134.5	149
Energy volumetric density [kWh/m3]	140	172
Power density [kW/kg]	0.67	0.33

PLA.N.E.S. modeFRONTIER

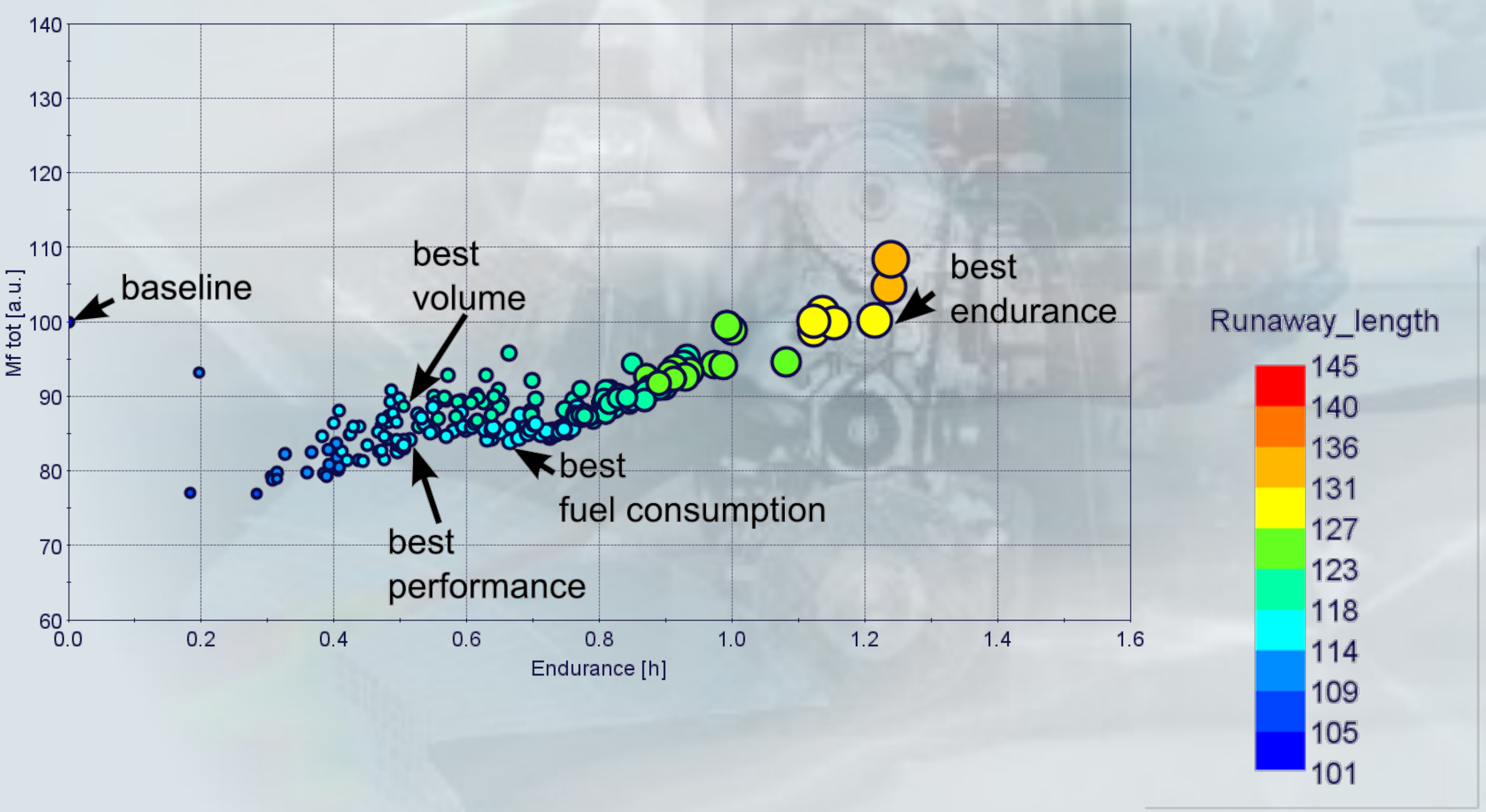
DISTRETTO TECNOLOGICO AEROSPAZIALE

- Electric Endurance ↑
- Fuel consumption ↓
- Take-off performance ↑
- Powertrain volume ↓

T. Donateo, "Sizing and Simulation of a Piston-prop UAV", Submitted to IEEE Transaction on Evolutionary Computation

PLA.N.E.S.

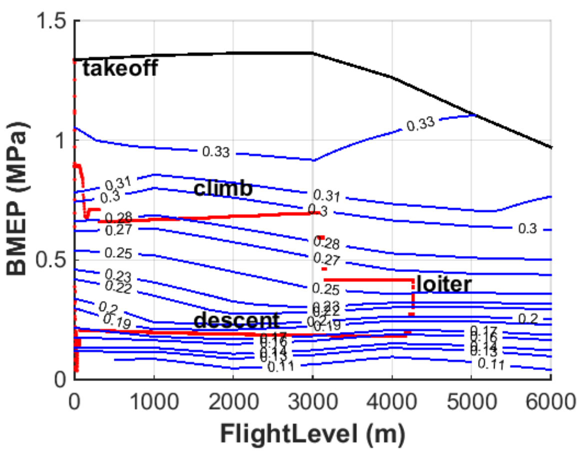
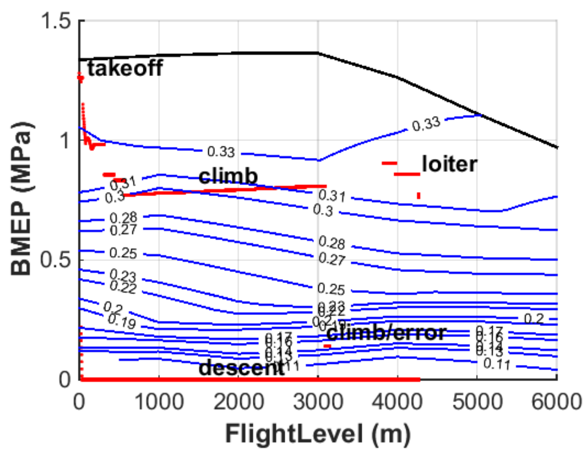
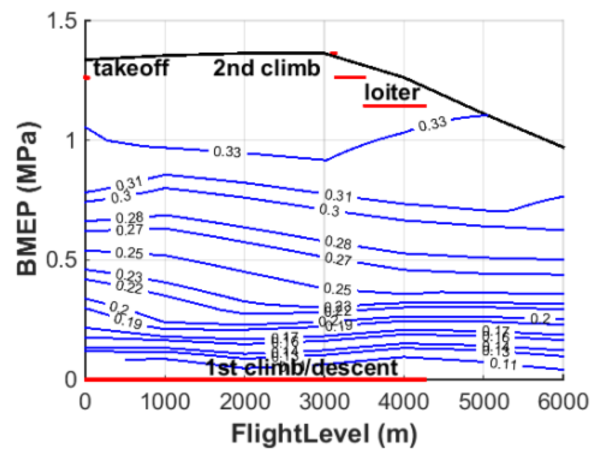
Many-objective optimization of a hybrid electric aircraft



Additional volume (diameter of the bubbles)

Min=30a.u.
Max=640 a.u.

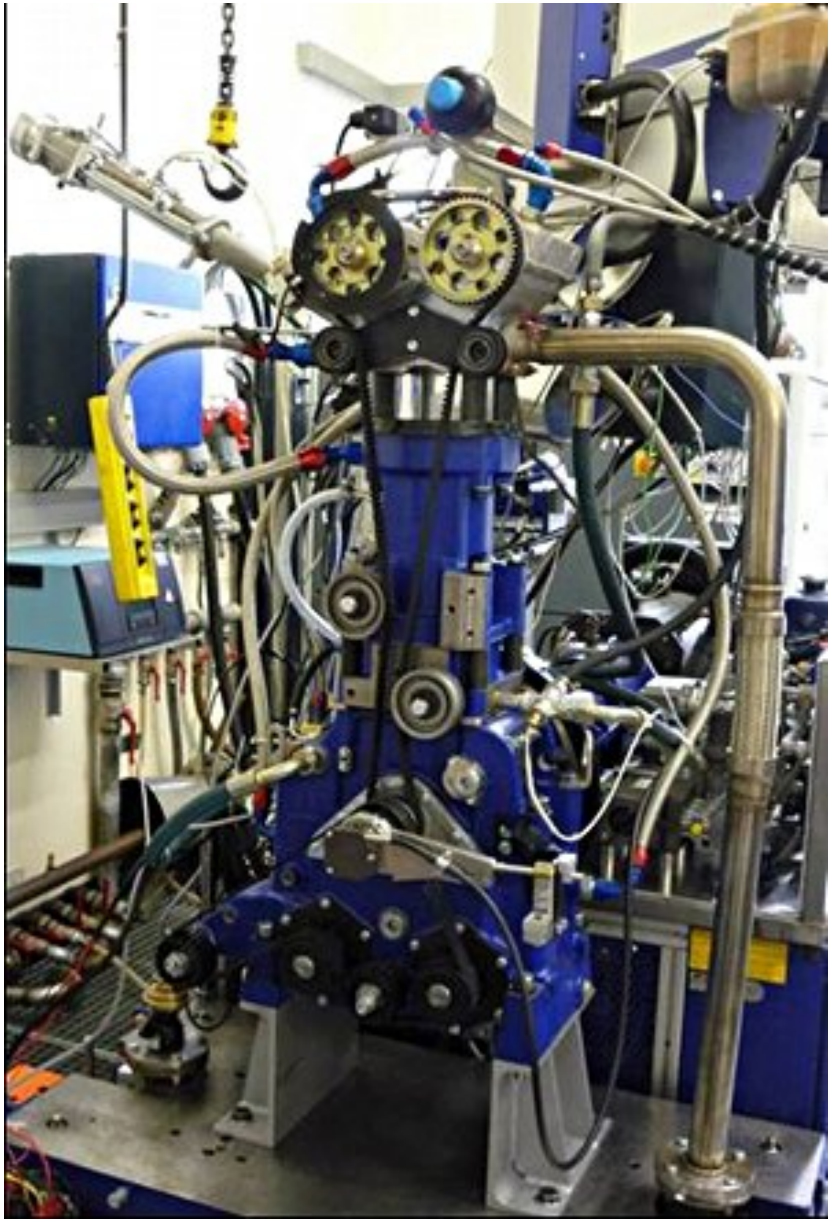
Engine working points

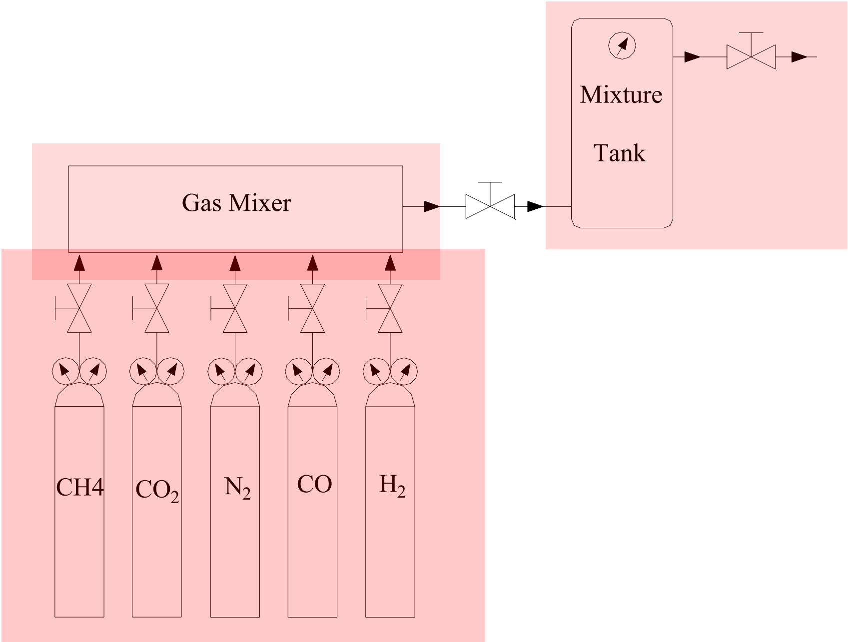
Baseline (non hybrid)	Non - optimized hybrid	Optimized hybrid
		

Future developments

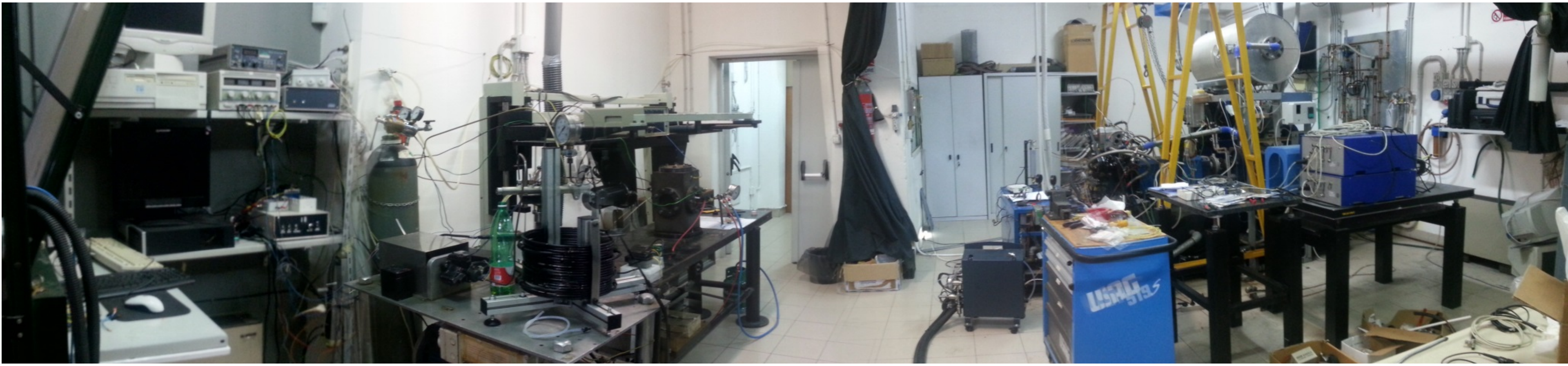
- Advanced supervisory control strategies
- Optimization of the combustion process in the engine working points

CREA facilities





CREA facilities



Vessel for spray w/wo combustion characterization

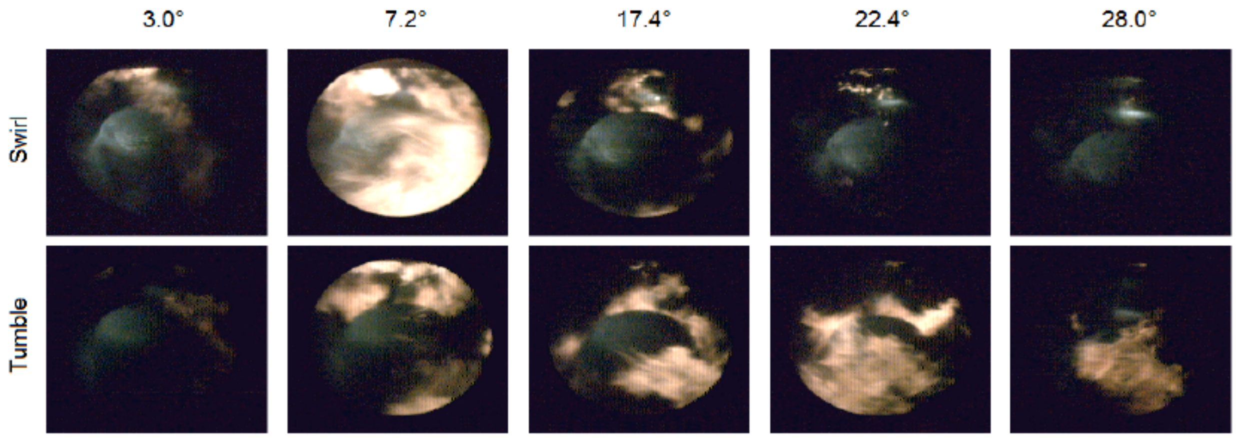
Optical single cylinder Diesel engine on active test bench

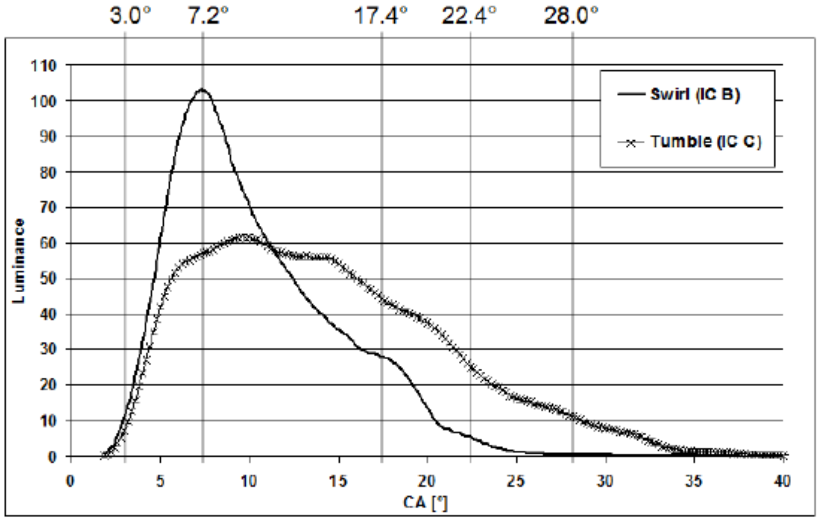
Average fuel consumption (AVL 733 Fuel Balance)
and emission measurements (AVL AMA i60)

PM at tailpipe measurement (AVL Micro Soot sensor, AVL Smoke Meter)

Imaging and optical characterization of sprays and combustion

Methane DF - Power mode – Effect of gas motion

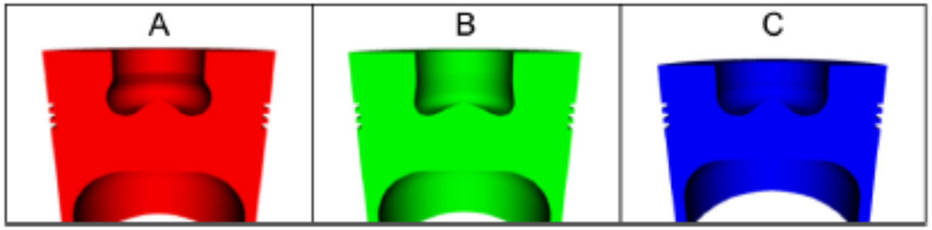


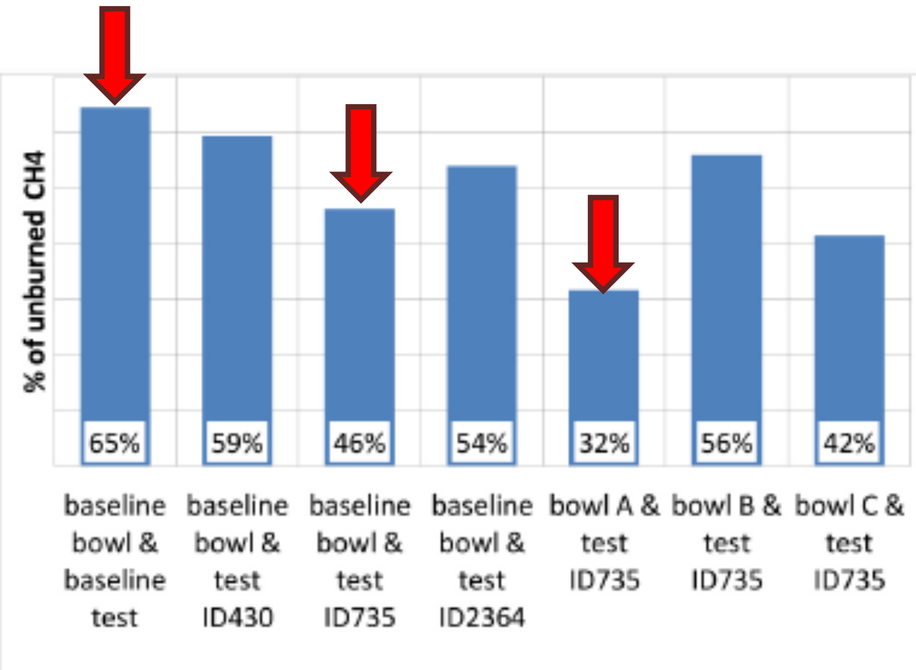


P. Carlucci, D. Laforgia, R. Saracino, G. Toto: "*Study of combustion development in methane-diesel dual fuel engines, based on the analysis of in cylinder luminance*", SAE World Congress 2010, April 13-15, 2010; SAE Paper 2010-01-1297

A.P. Carlucci, D. Laforgia, R. Saracino, G. Toto: "*Combustion and emissions control in diesel-methane dual fuel engines: the effects of methane supply method combined with variable in-cylinder charge bulk motion*", **Energy Conversion and Management** 52 (2011) 3004–3017

Methane DF - Power mode





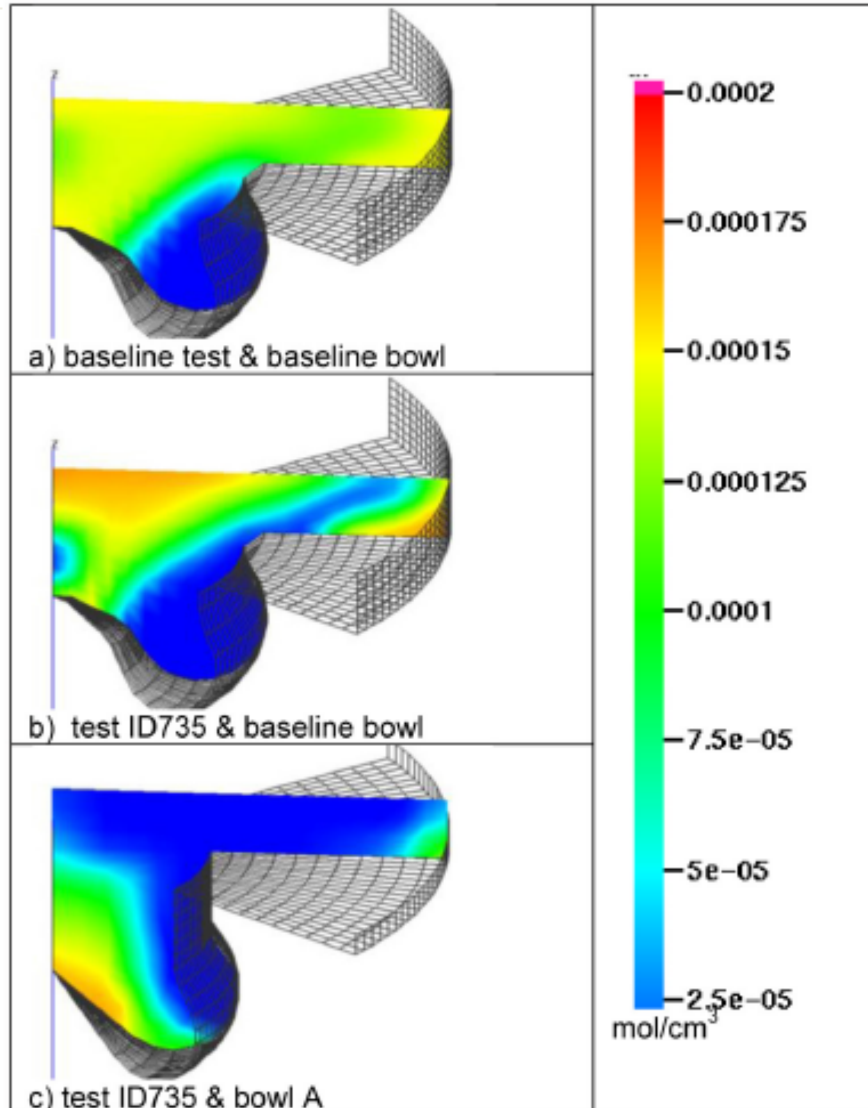
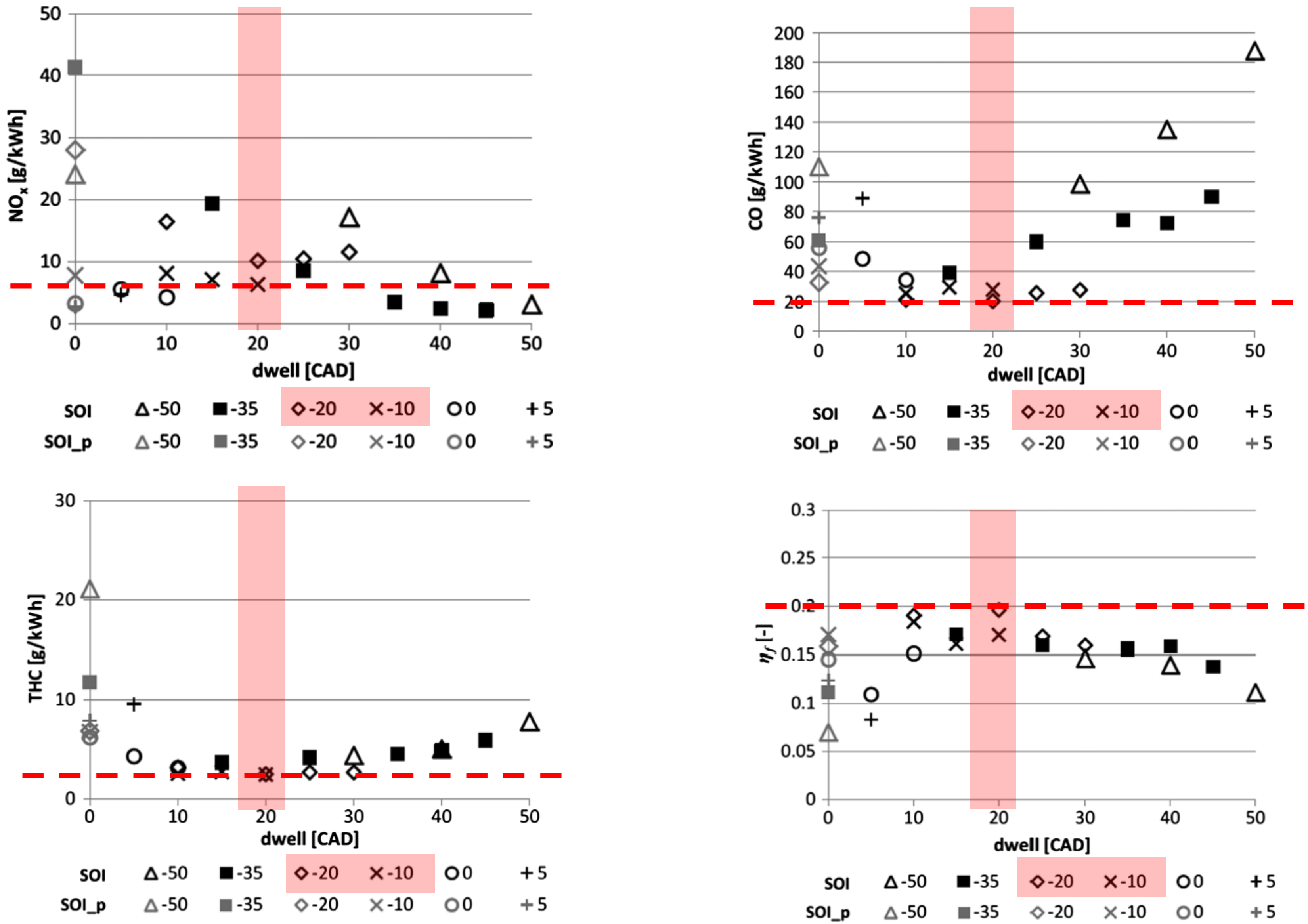


Figure 26. Methane distribution at 25 deg ATDC

Donateo, T., Carlucci, A., Strafella, L., and Laforgia, D.: "*Experimental Validation of a CFD Model and an Optimization Procedure for Dual Fuel Engines*" SAE Technical Paper 2014-01-1314, 2014

Syngas DF – Splitting of diesel fuel injection



A.P. Carlucci, G. Colangelo, A. Ficarella, D. Laforgia, L. Strafella: "*Improvements in dual-fuel biodiesel-producer gas combustion at low load through pilot injection splitting*", **Journal of Energy Engineering** Volume 141, Issue 2 (2015)

CREA facilities

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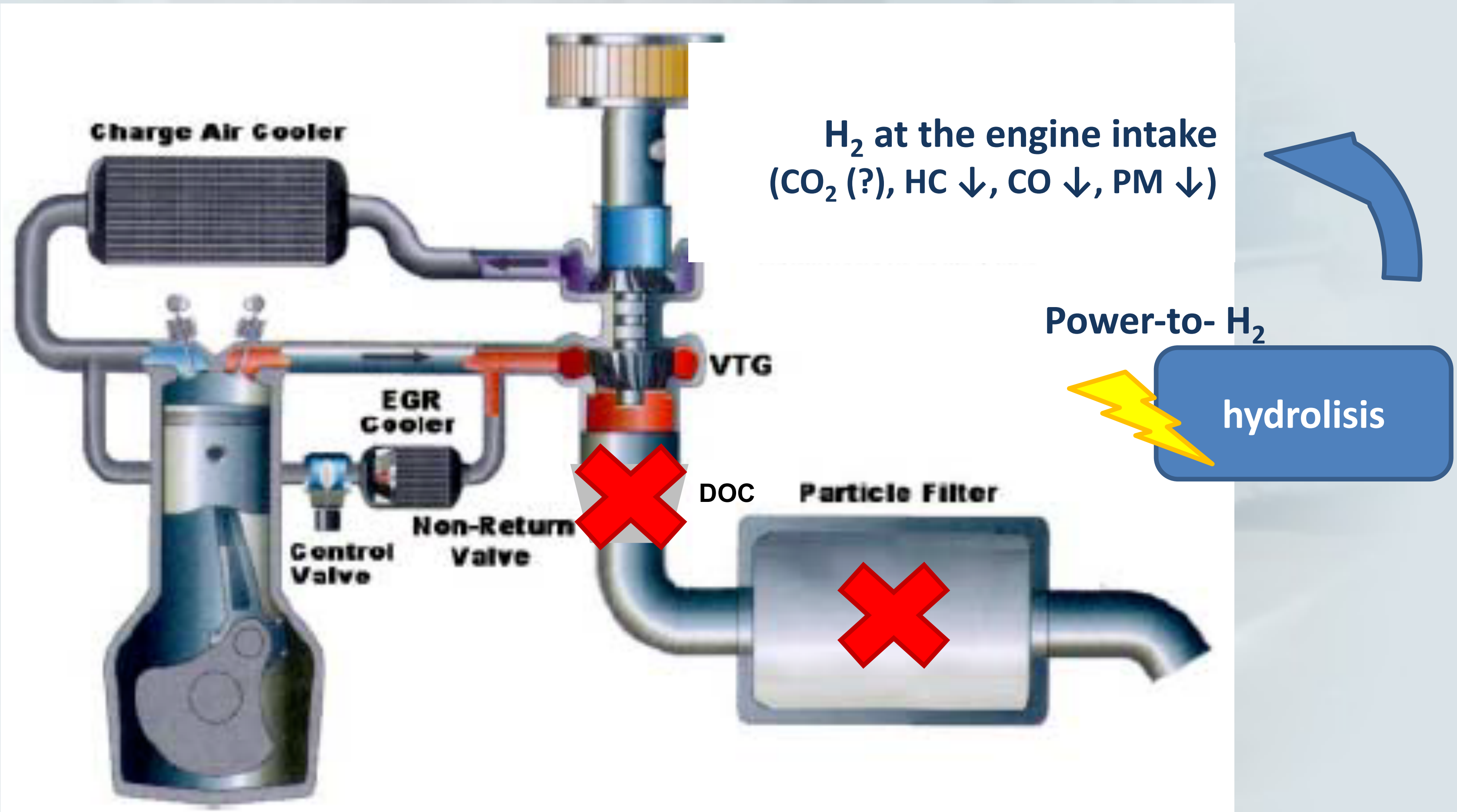
2 engine test benches (160 kW, 400 Nm, 10000 rpm; 240 kW, 600 Nm, 10000 rpm

Average fuel consumption (AVL 733 Fuel Balance) and emission (AVL AMA i60) measurement

PM at tailpipe measurement (AVL Micro Soot sensor, AVL Smoke Meter)

Dilution tunnel

Future activities – “dual-fuel powertrains”



DOC – CO and HC oxydation

DPF – particle filtration

Current activities - Alternative ignition technologies

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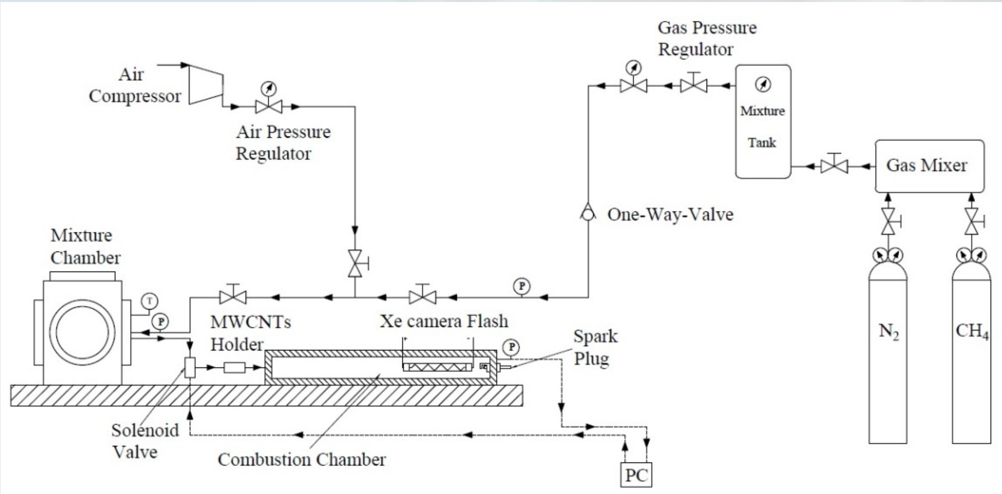
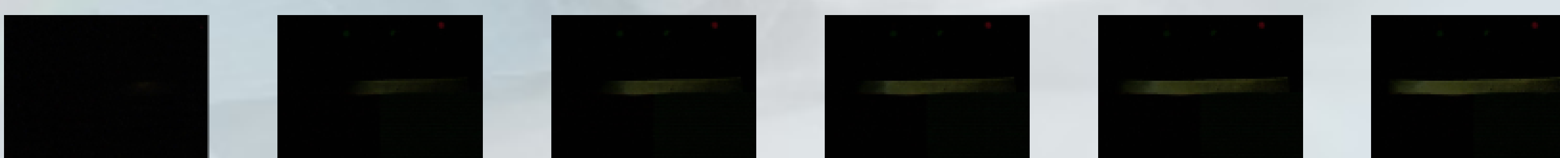


λ=1.35 MWCNTs

λ=1.35 spark



Current activities - Alternative ignition technologies

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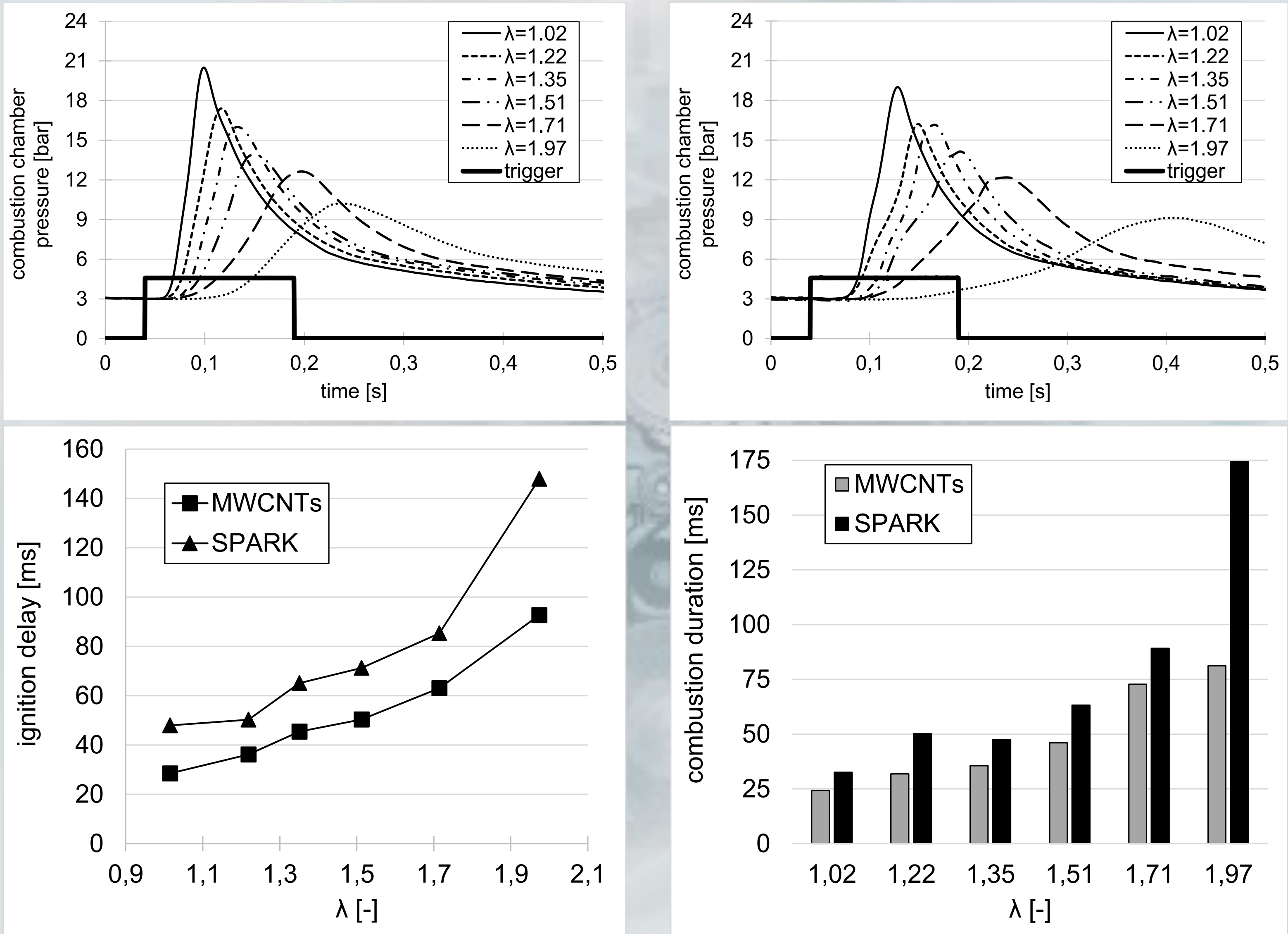

A.P. Carlucci, F. Carnevale, G. Ciccarella, A. Ficarella, D. Laforgia, F. Mussardo, L. Strafella: "*Air/methane mixture ignition with Multi-Walled Carbon Nanotubes (MWCNTs) and comparison with spark ignition*", Transactions of Nanofim 2015 (Nanotechnology for Instrumentation and Measurement Workshop), July 24-25, 2015 – Lecce (Italy).

Current activities - Alternative ignition technologies

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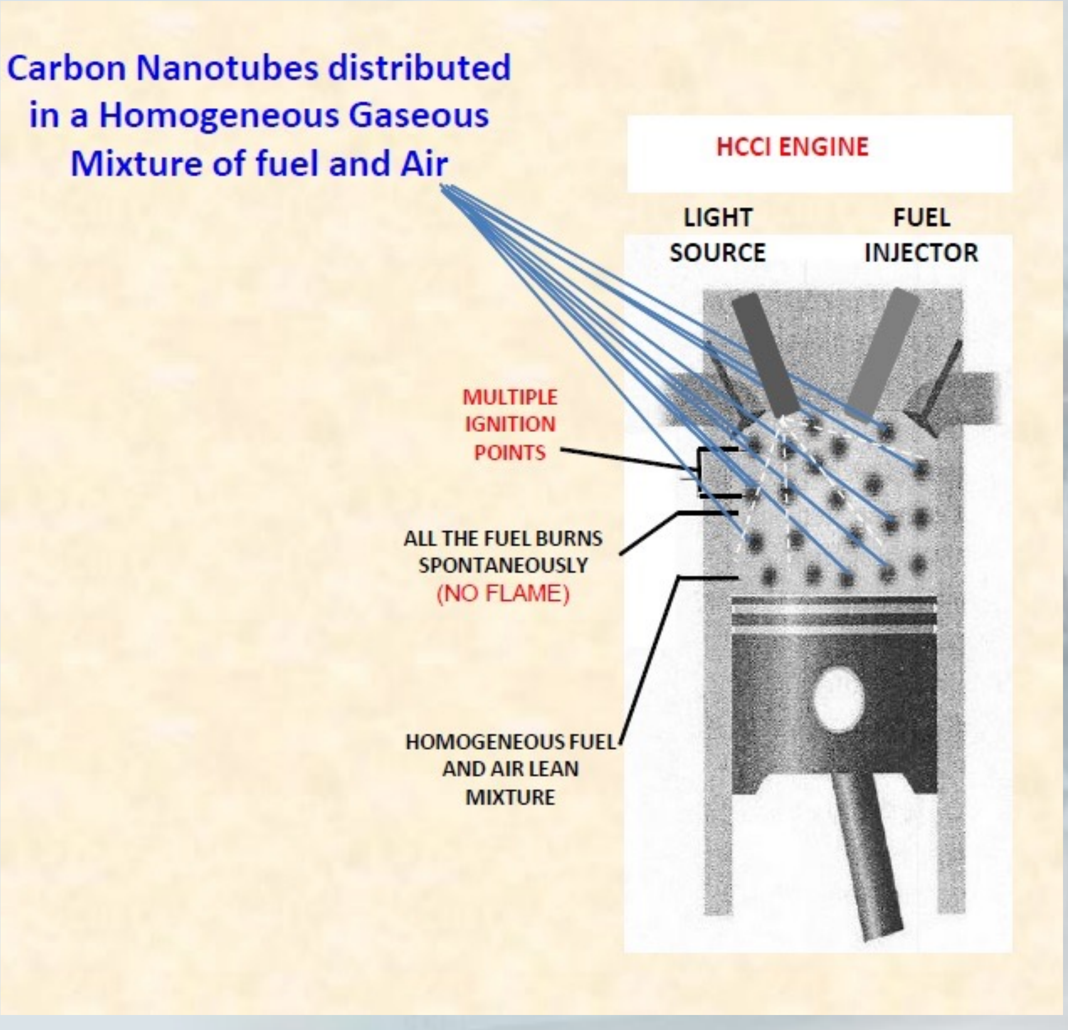

Chehroudi B, Vaghjiani GL, Ketsdever A.
Method for distributed ignition of fuels by light sources.
US Patent 7,517,215 B1;April 14,2009.

- Photo-ignition of CNT can be used to:
  - manages the HCCI combustion process
  - On-demand autoignition of homogeneous gaseouse air-fuel mixture
- **Photo-ignition of CNT is a new technology for a precise control/initiation of autoignition process in HCCI engines**
- **Other possible applications: DPF more uniform regeneration**

Grazie!