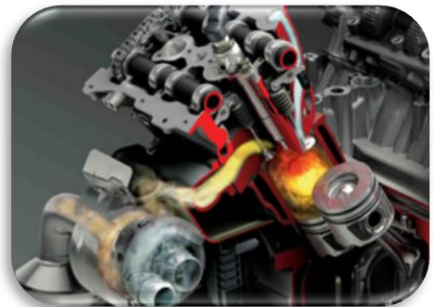


**Discover Better Designs, *Faster!***

Driving Product Innovation Through Design Exploration

Realize Innovation.

# Executive Summary – Modern Engine Design



Automotive engine design is a complex, and often iterative process, aimed at satisfying a multitude of attribute objectives (power, efficiency, durability, emissions, and weight) while minimizing material and manufacturing costs.

Whilst simulation has long played a key role in validating designs, its usage to discover new, higher performing, innovative designs has been previously limited.

This presentation highlights how modern **Process Automation, Simulation** and **Design Space Exploration** using **HEEDS MDO** deployed together with LMS Imagine.Lab can power engineers to **discover better designs, faster**

# Case Study: Engine Performance & Fuel Consumption

## The Challenge (Objectives):

- Minimize Brake Specific Fuel Consumption (BSFC)
- Maximize the Brake Mean Effective Pressure (BMEP)

## System Requirements (Constraints):

- BMEP greater than 10 bar
- Maximum cylinder pressure less than or equal to 75 bar

## Design Variables:

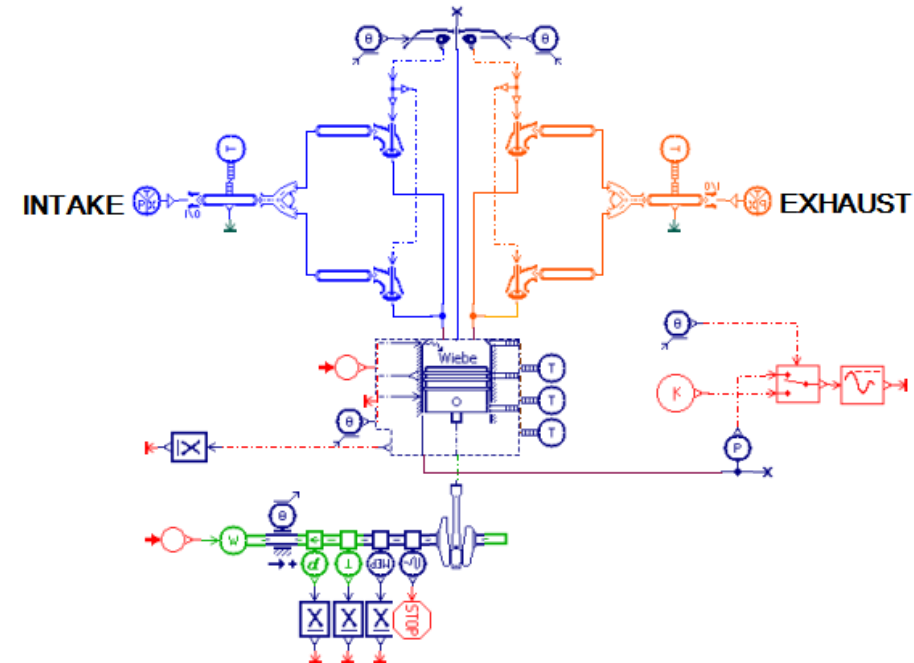
### Shape:

- Intake maximum lift
- Intake open duration
- Exhaust maximum lift
- Exhaust open duration

### Location:

- Valve timing
- Valve overlap

## LMS Amesim Model

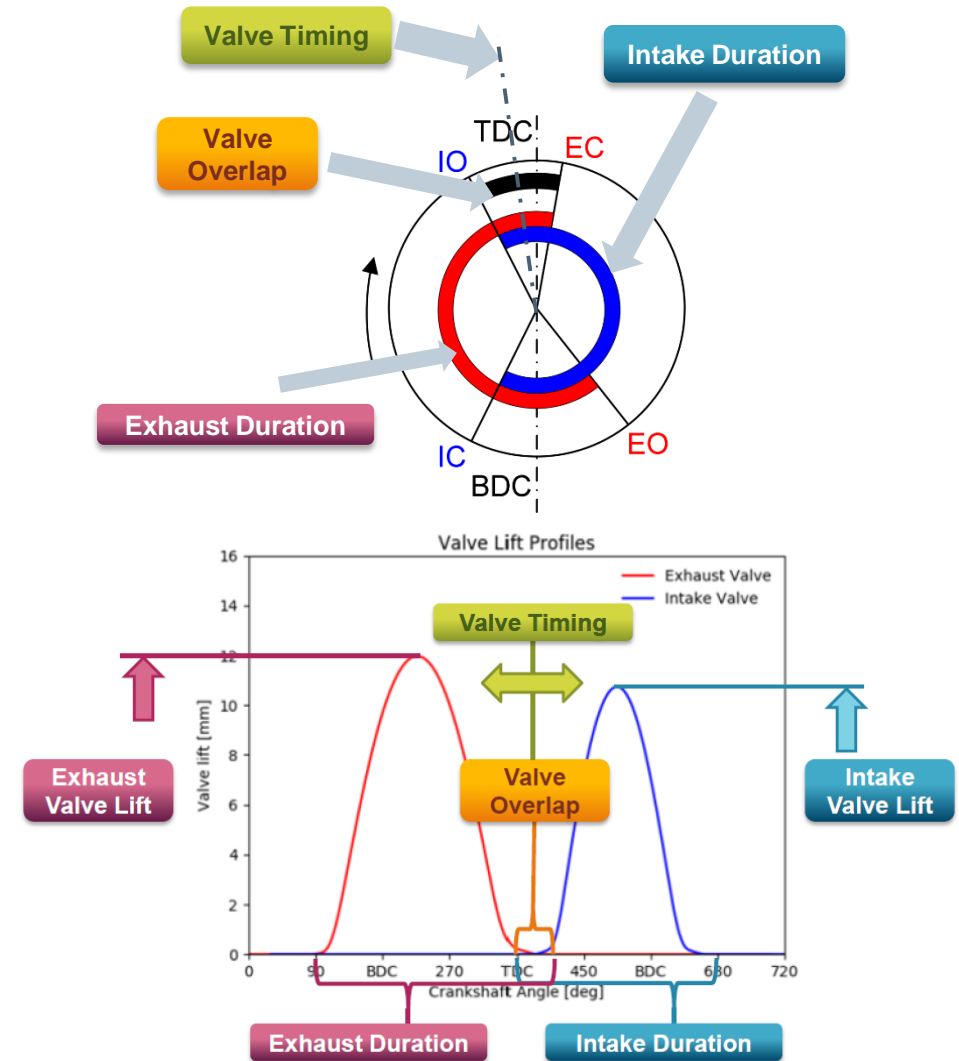


# Case Study: Engine Performance & Fuel Consumption

## Design Variables:

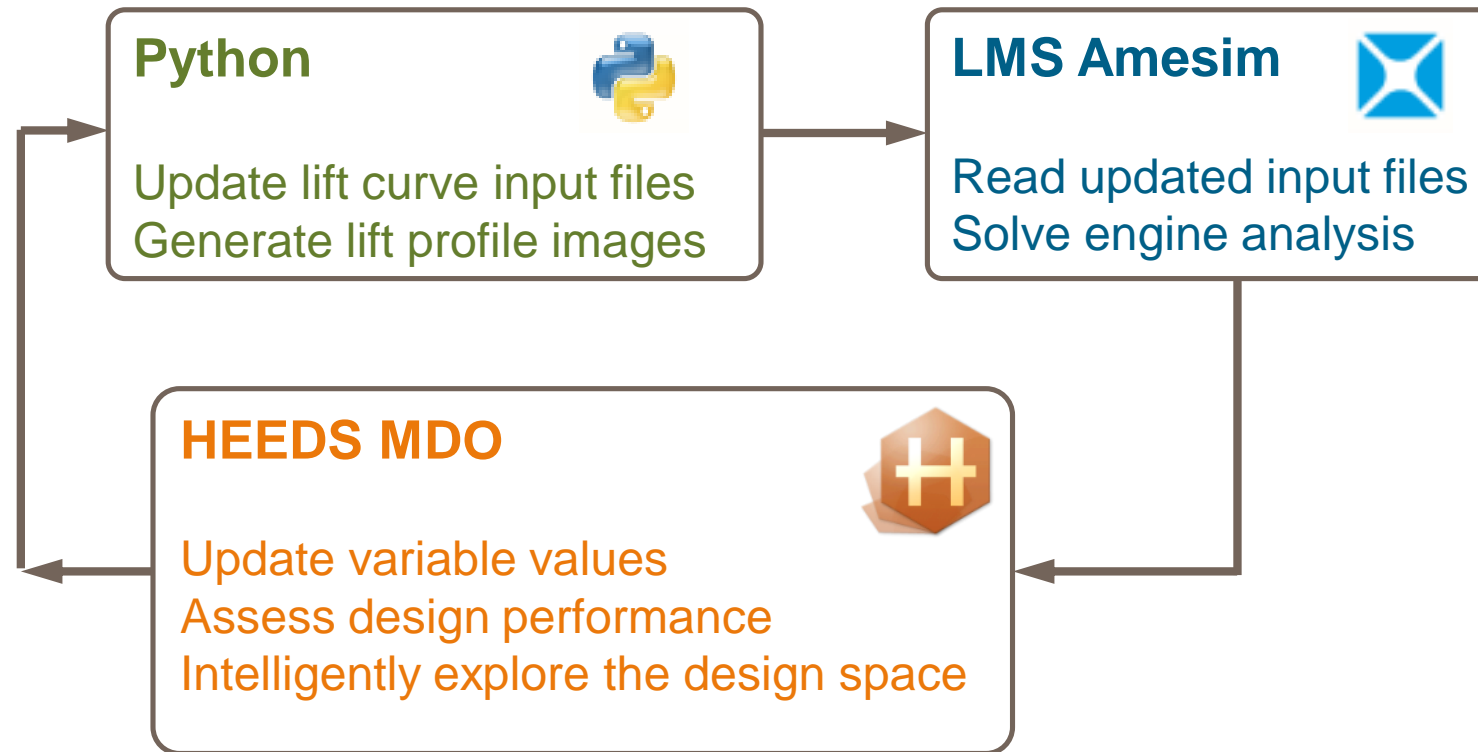
- Six independent variables are used to modify valve lift profiles for cylinder intake and exhaust ports.
- For each design, these variables are used to update the lift curve used directly within the Amesim model

Name	Minimum	Baseline	Maximum
Intake Maximum Lift [mm]	8	10	12
Intake Opening Duration [deg]	230	287	345
Exhaust Maximum Lift [mm]	8	10	12
Exhaust Opening Duration [deg]	230	287	345
Timing [deg]	-20	0	20
Overlap [deg]	10	20	60



# Case Study: Engine Performance & Fuel Consumption

## Process Automation:



# Process Automation Python Portal

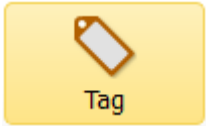
Python is used to modify the baseline valve motion based on the variable values being used

**Python**  
Update lift curve files  
Generate image

Python

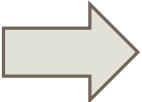


HEEDS



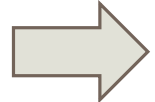
```

1 import math
2 import numpy
3 import sys
4 import matplotlib.pyplot as plt
5 #
6 #
7 # Variables to modify per design
8 exhaust_lift = 9
9 exhaust_opening = 287
10 exhaust_delay = 50
11 intake_lift = 9
12 intake_opening = 287
13 intake_advance = 50
14 #
15 #
16 #requires: max lift occurs @ 0 degrees
17 #
18 def calculateCurveWriteFile(f_old, f_new, new_lift,
19                             f_in = open(f_old)
20
21
22
    
```



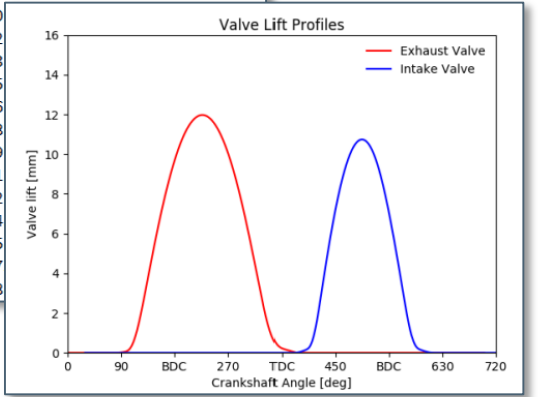
File: C:/working/amesim/SingleCyl\_updated/UpdateValveCurves.py

Input Type	Description	Name	Value
Number		exhaust_lift	Lift_Exhaust
Formula		exhaust_opening	Duration_Exhaust
All	Name	exhaust_delay	Delay_EVC
		intake_lift	Lift_Intake
		intake_opening	Duration_Intake
		intake_advance	Advance_IVO
		angle_open	0
		angle_close	0
		max_lift	0
		total_data_lines	0
		line_num	0



```

1 # Table format: 1D
2 # table_unit = mm
3 # axis1_unit = degree
4 -465.0 0.0
5 -131.338607595 0.0
6 -130.485759494 2.80973386271e-06
7 -129.632911392 5.88939848953e-05
8 -128.7800
9 -127.9272
10 -127.0743
11 -126.2215
12 -125.3686
13 -124.5158
14 -123.6629
15 -122.8101
16 -121.9572
17 -121.1044
18 -120.2515
19 -119.3987
20 -118.5458
    
```



# Process Automation LMS Amesim Portal



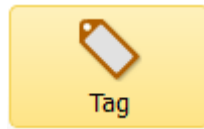
The LMS Amesim Portal is utilized to associate component input and output parameters with variables and responses in HEEDS

**LMS Amesim**  
Read updated file  
Solve engine analysis

LMS Amesim



HEEDS



Valve lifts | Valve flows | Valve geometry

Input files

filename for intake valve lift [mm] = f(angle [degree])  
 \${circuit\_name}.\_datafiles/valves/Intake\_Lift\_cycle.data

filename for exhaust valve lift [mm] = f(angle [degree])  
 \${circuit\_name}.\_datafiles/valves/Exhaust\_Lift\_cycle.data

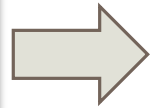
angle reference for valve lift data files: crankshaft

lift configuration mode: function of IVO/EVC

Title	Value	Unit	Name
angular position of the IVO in the valve lift data file	-154	degree	IVOfile
angular position of the EVC in the valve lift data file	151	degree	EVCfile

Lift parameters

Title	Value	Unit
reference Intake Valve Opening (relative advance)	50	degree
reference Exhaust Valve Closing (relative delay)	0	degree
intake valve clearance	0	mm
exhaust valve clearance	0	mm



File: C:\working\amesim\SingleCyl\_Updated\SingleCyl.ame

Input Type	Amesim Object	Properties	Value
Amesim Components	eng_cama...CYLH010]	IVO (reference Intake ...	Advance_IVO
	eng_flowp...GTFPL001]	EVC (reference Exhau...	Delay_EVC
	cfd1d_str...THSNR000]	IVOfile (angular pos...	
	eng_th_te...ENGT001]	EVCfile (angular pos...	
	eng_remo...GLBAS21]	Dvin (intake valve he...	
	cfd1d_cn...VEENG000]	Dvout (exhaust valve...	
	eng_valve...NGVDEF03]	win (intake seat wid...	
	Real Parameter	wout (exhaust seat v...	
	Integer Parameter	Dsin (intake valve st...	
	cfd1d_glb...DGLBP000]	Dsout (exhaust valve...	
	eng_cran...NGCRK51]	betain (intake valve...	
	dynamic_r...IGRECEI0]	betaout (exhaust val...	
	dynamic_r...IGRECEI0]	Dvineff (intake valve...	
	dynamic_t...IGTRANS0]	Dvouteff (exhaust va...	
	dynamic_t...IGTRANS0]	Linmax (maximum in...	
	cfd1d_jnc...PORTS002]	Loutmax (maximum m...	
	cfd1d_jnc...PORTS002]		
	cfd1d_jnc...PORTS002]		
	cfd1d_cn...UTENG000]		
	constant [CONS00]		
	constant_1 [CONS00]		
	cfd1d_str...SIMPLE001]		

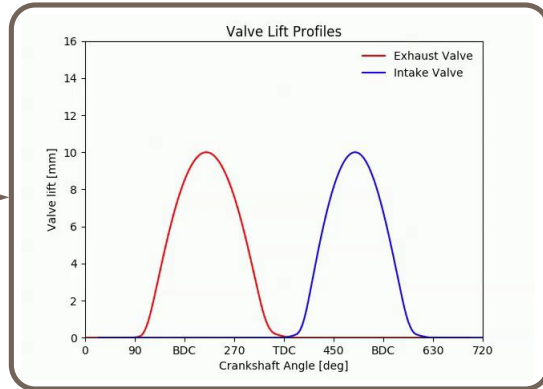
File: C:\working\amesim\SingleCyl\_Updated\SingleCyl.ame

Output Type	Amesim Object	Variable	Entities	Properties
Amesim Components	Basic Variable	input (input signal)	Time	At: <input type="radio"/> First
Amesim Lines	State Variable	output (ou...ean value)	Value	<input checked="" type="radio"/> Last
	cfd1d_str...THSNR000]	angleglob (...rank angle)		<input type="radio"/> All
	eng_th_te...ENGT001]	teta (sampli...gle or time)		Range:
	eng_stead...STEADY12]	tampon (las...pled value)		Start at: <input type="text"/>
	eng_mean...CYCLE21]	tampon2 (la...pling time)		End at: <input type="text"/>
	cfd1d_str...SIMPLE000]			
	cfd1d_str...SIMPLE000]			
	eng_comb...SENSED]			
	signalsink_4 [SSINK]			
	cfd1d_obs...NALPL000]			
	cfd1d_obs...NALPL000]			
	stop [STOP0]			
	powersens...y [PTR10]			
	eng_mean...CYCLE21]			
	signalsink_1 [SSINK]			
	eng_mean...CYCLE21]			
	signal_sw...SWITCH01]			
	eng_glba...GGLBA11]			
	constant_2 [CONS00]			
	eng_press...ENGPRSE011]			

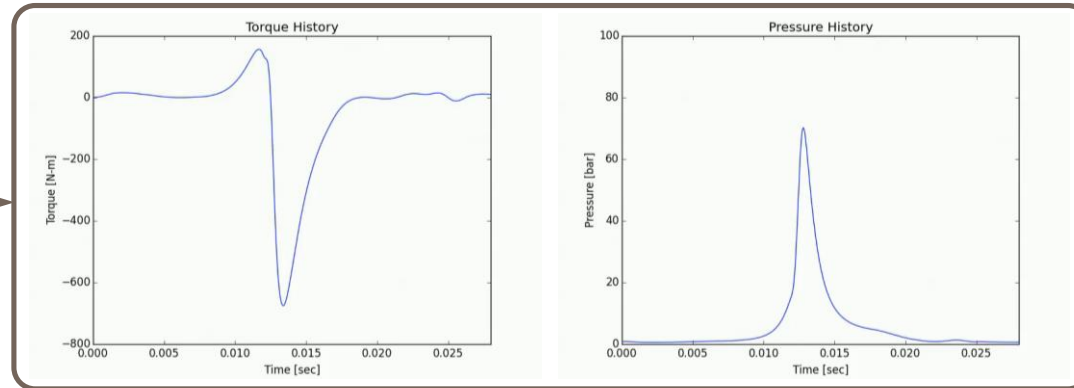
Tag Update

# Efficient Design Exploration

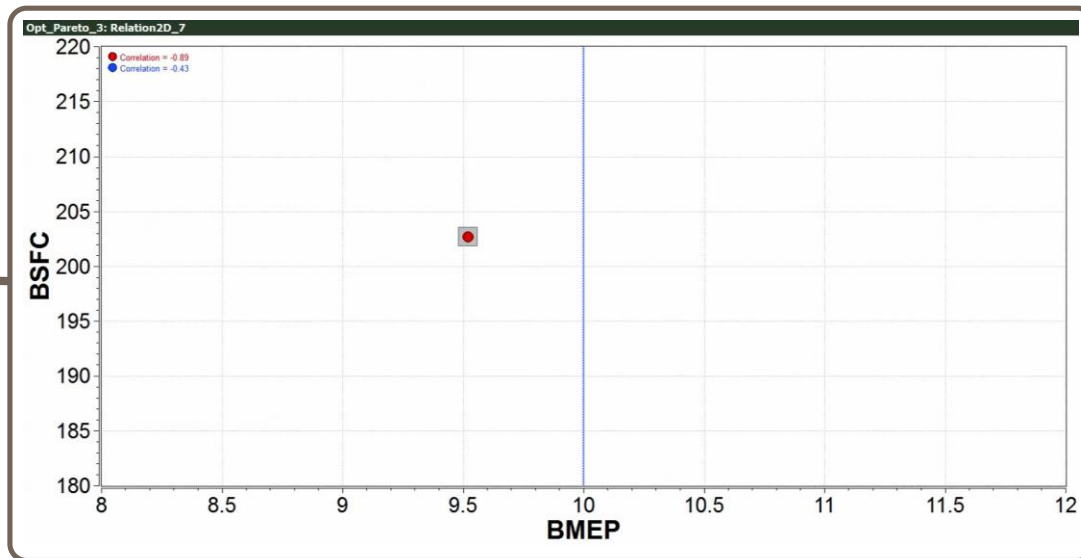
Update Valve Motion



Evaluate Engine Performance



Directed Modification

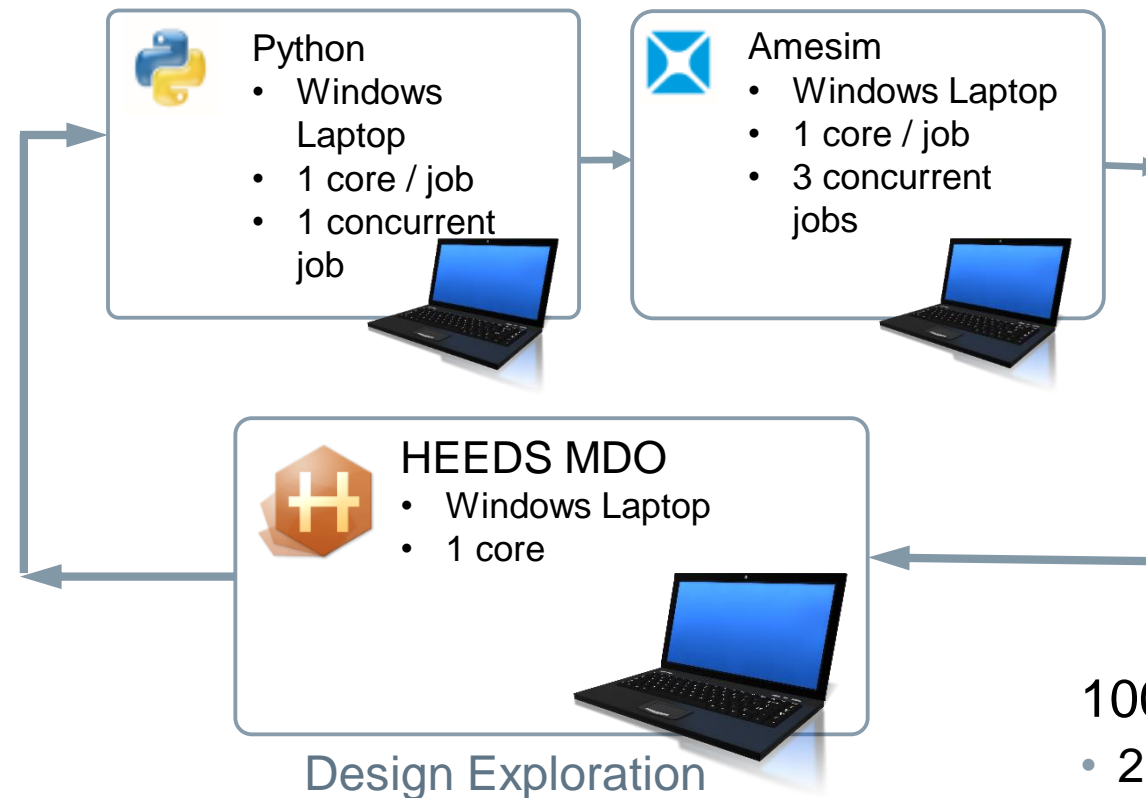


HEEDS' intelligent search algorithm

- Hybrid & adaptive functionality
- No model fitting or surrogates



## Simulation Execution

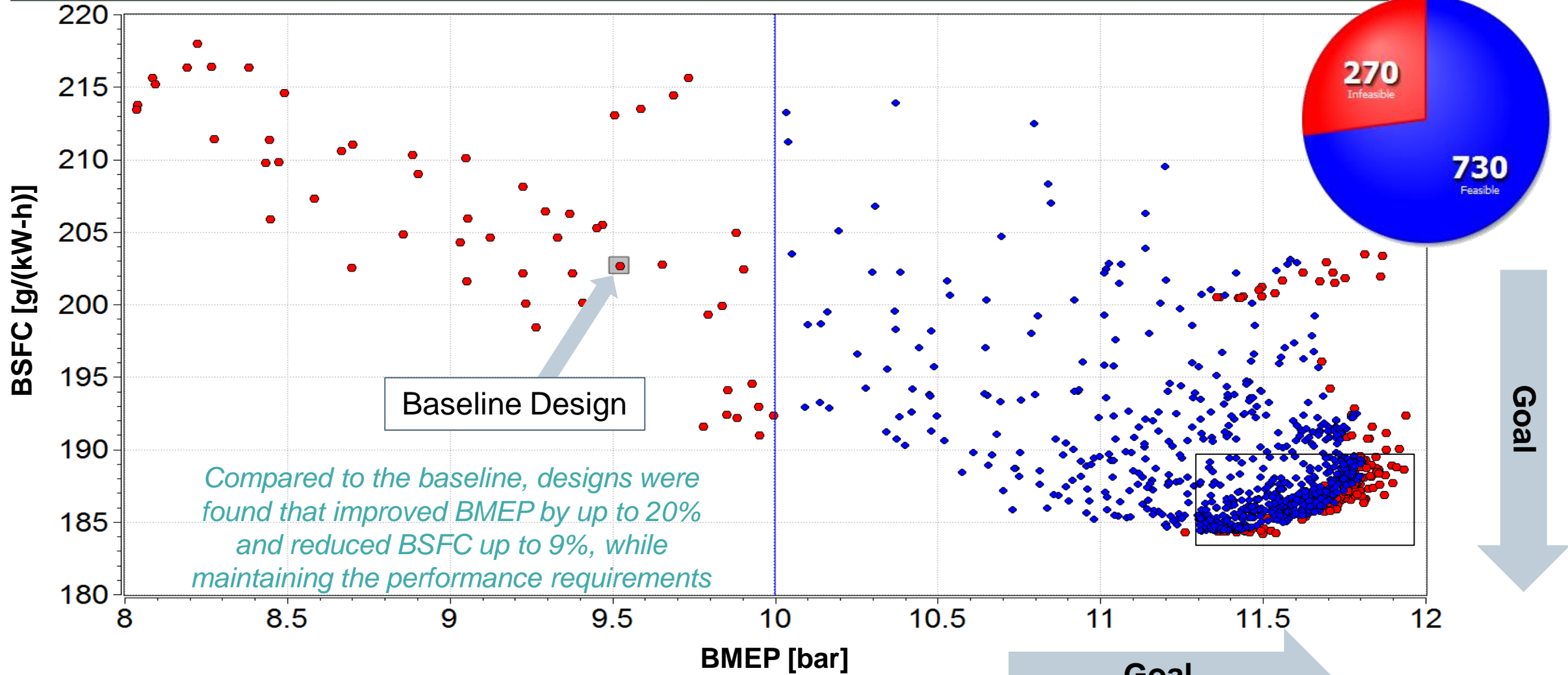


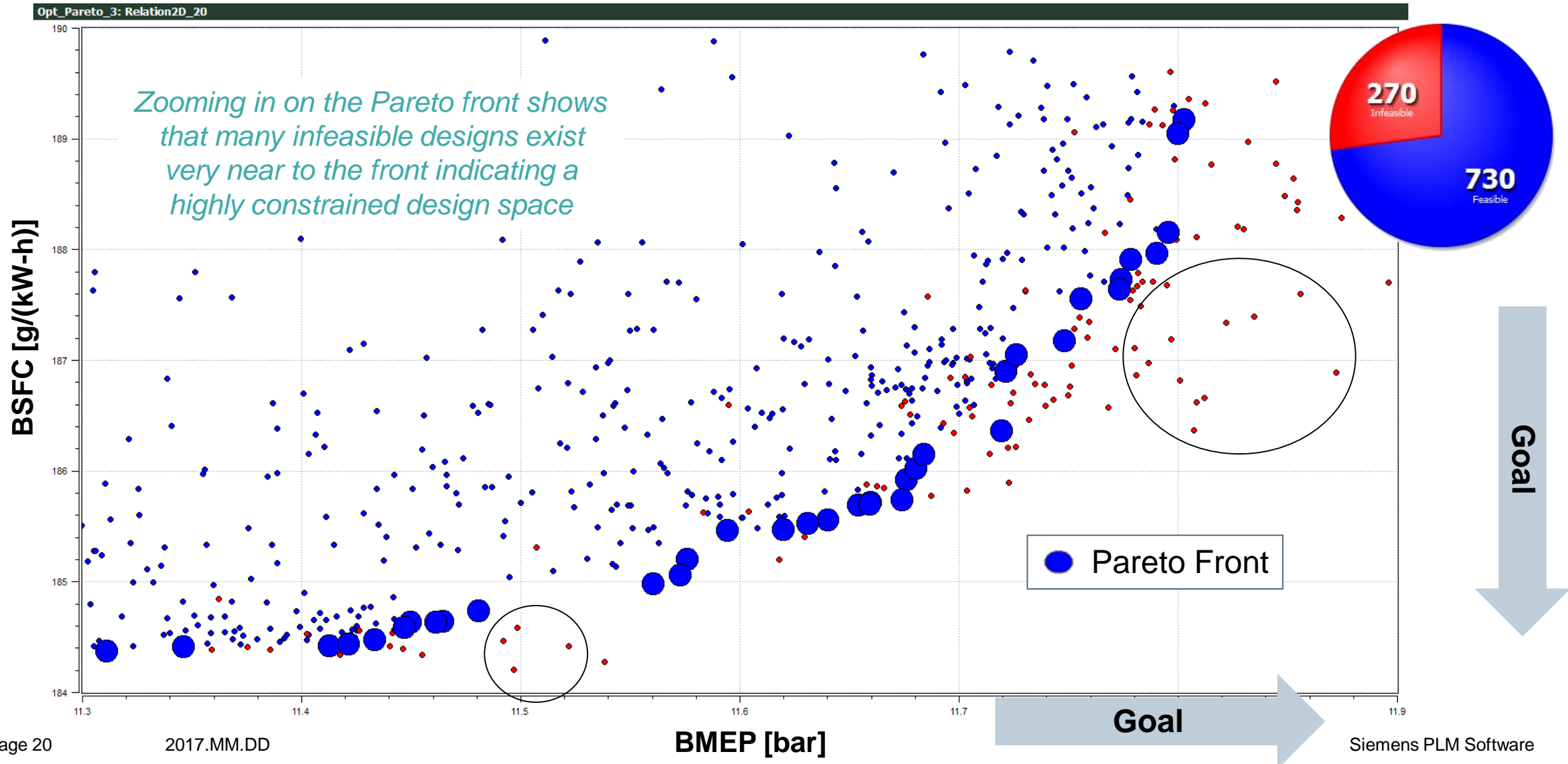
1000 Engine Designs Evaluated

- 2 hours of wall time
- ~30 seconds per design

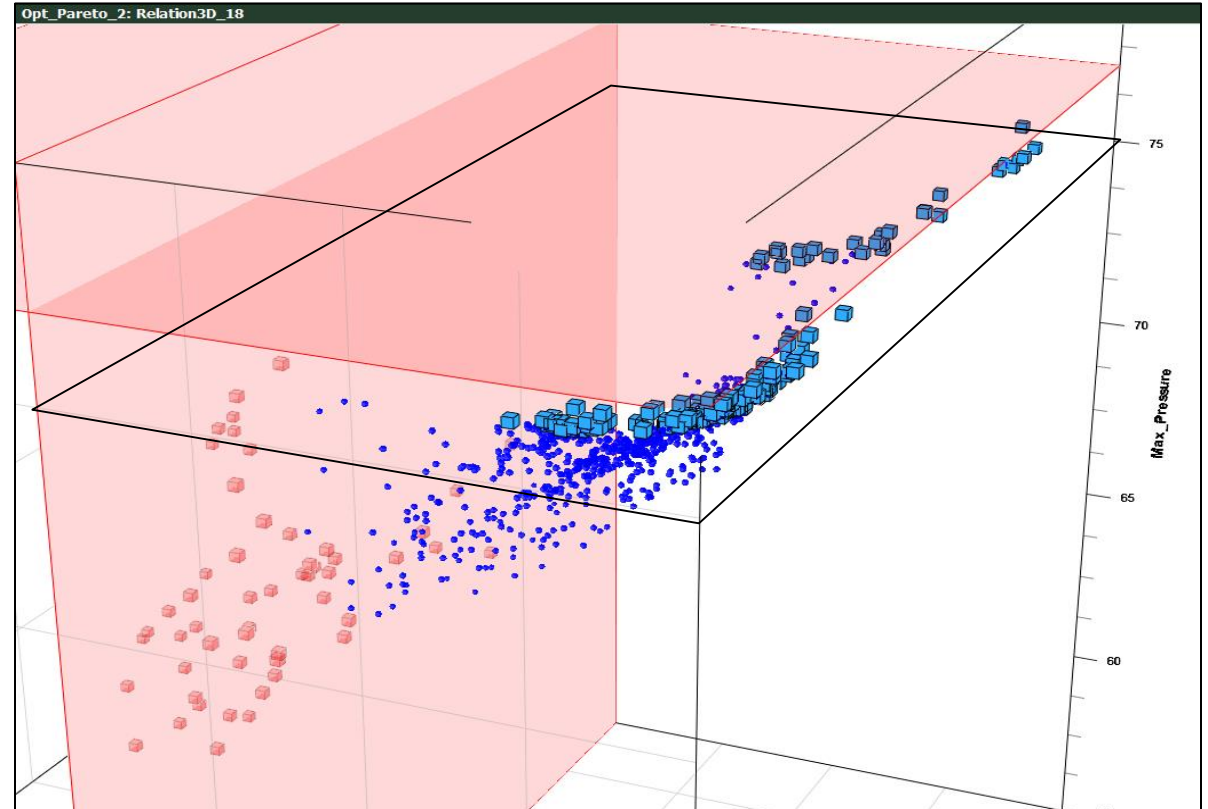
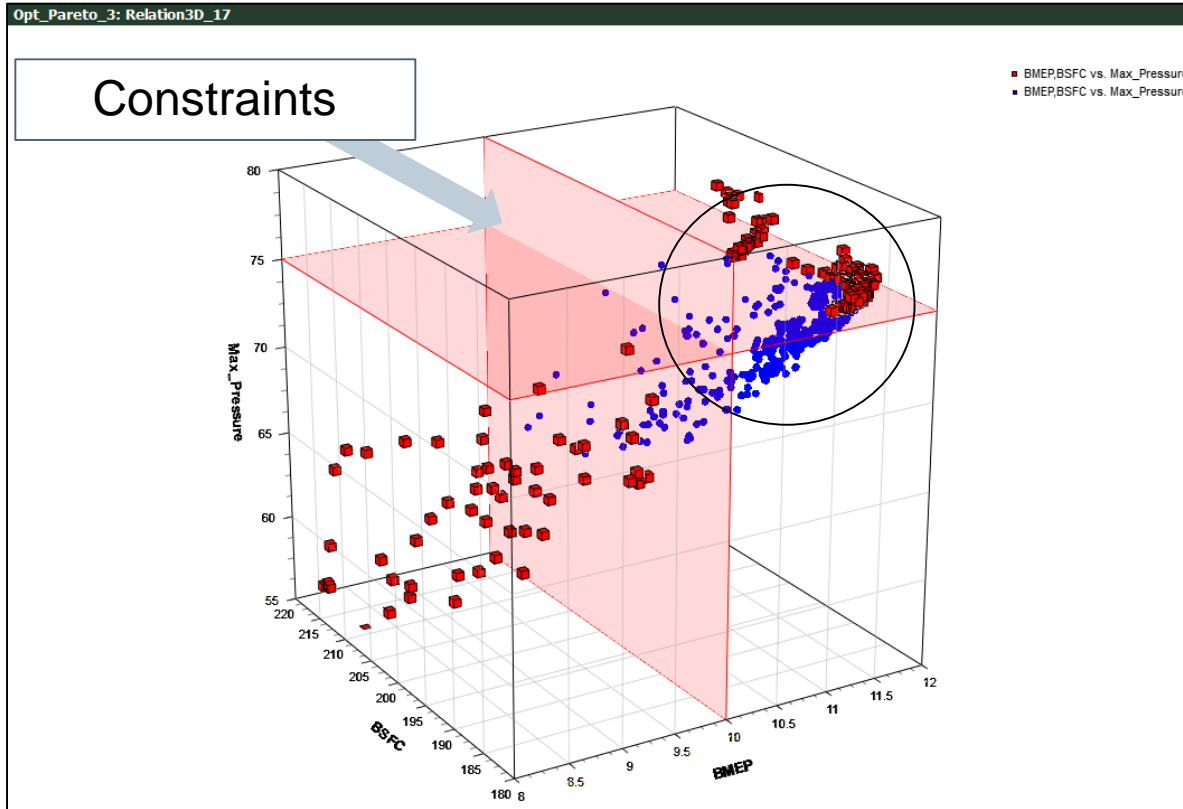
# Highly Constrained Design Space

Opt\_Pareto\_3: Relation2D\_7



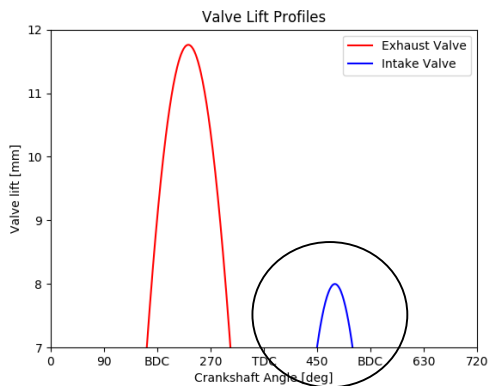


# Highly Constrained Design Space

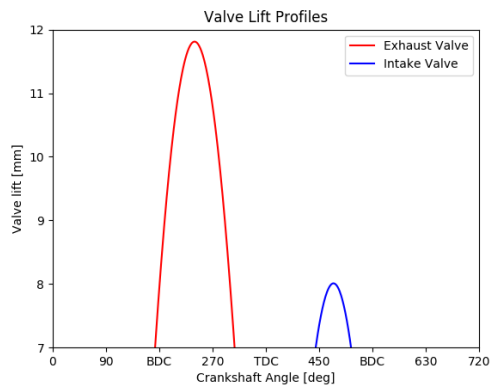




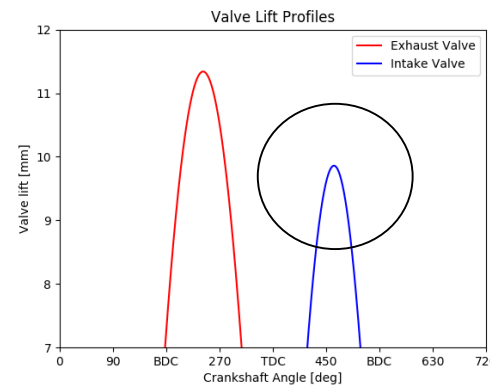
# Design Exploration



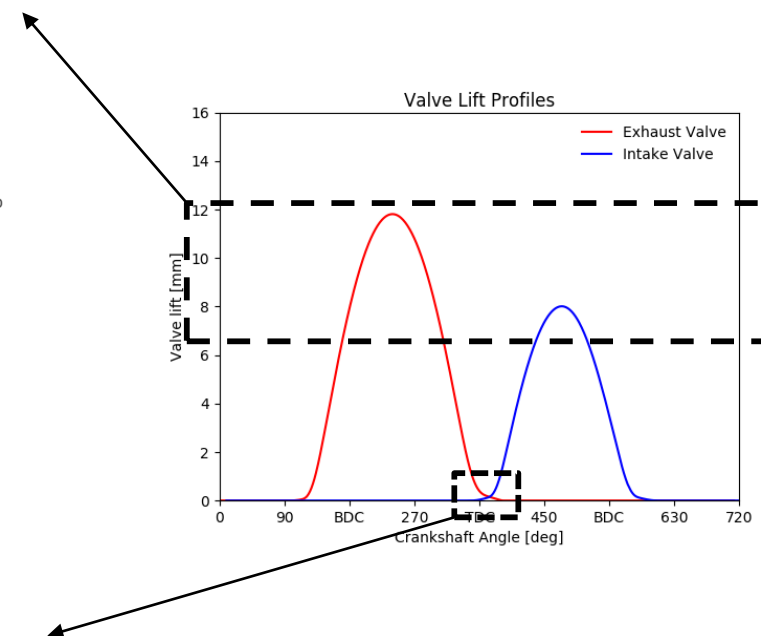
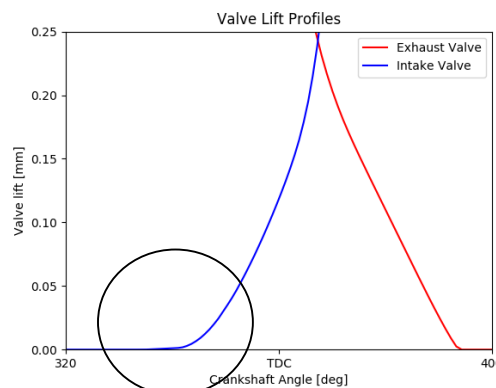
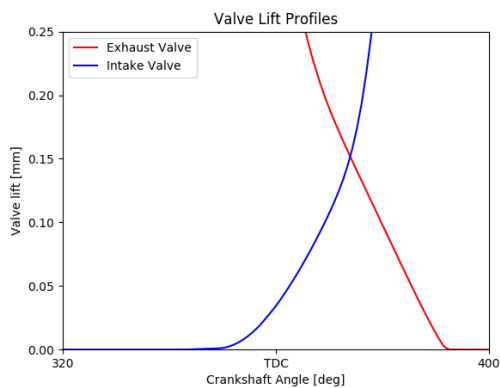
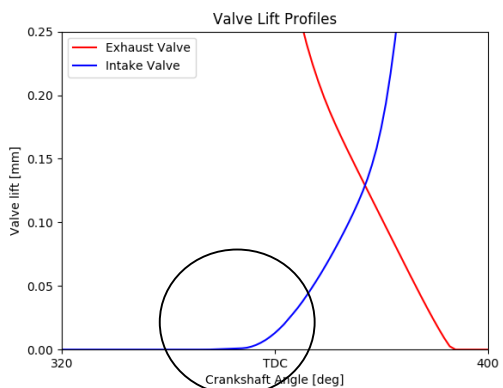
**Design 599**  
Lowest BMEP  
Lowest BSFC



**Design 975**  
Mid BMEP  
Low BSFC

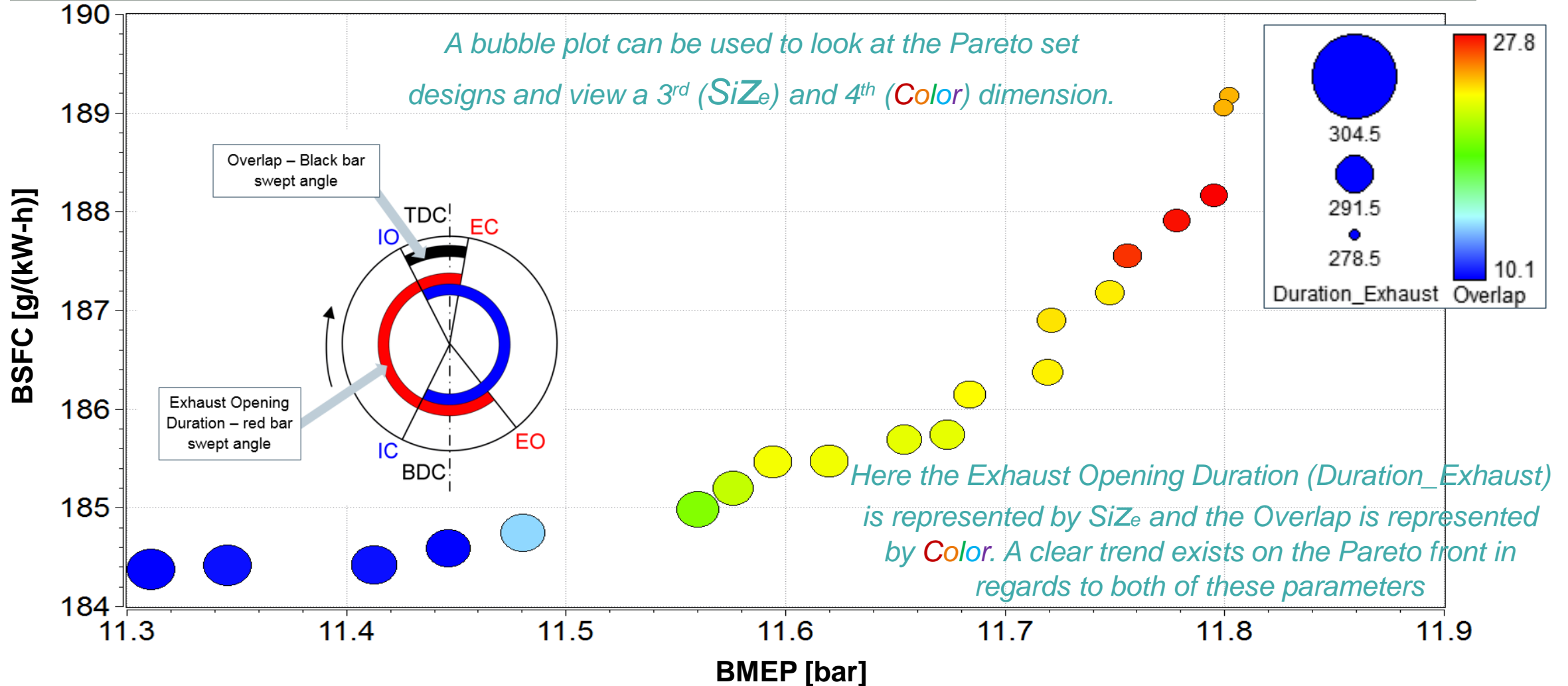


**Design 448**  
Highest BMEP  
Highest BSFC

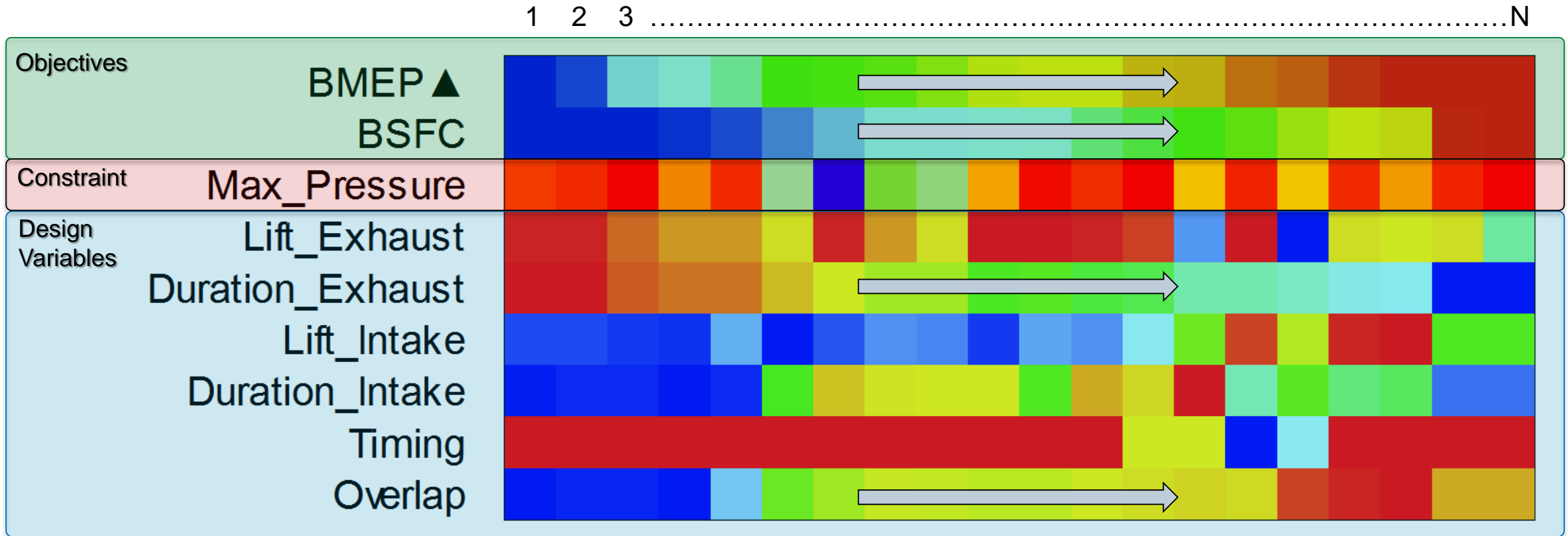


*Zooming in on the images shows the differences between the three selected designs*

Opt\_Pareto\_3: Relation2D\_7



# Design Trends



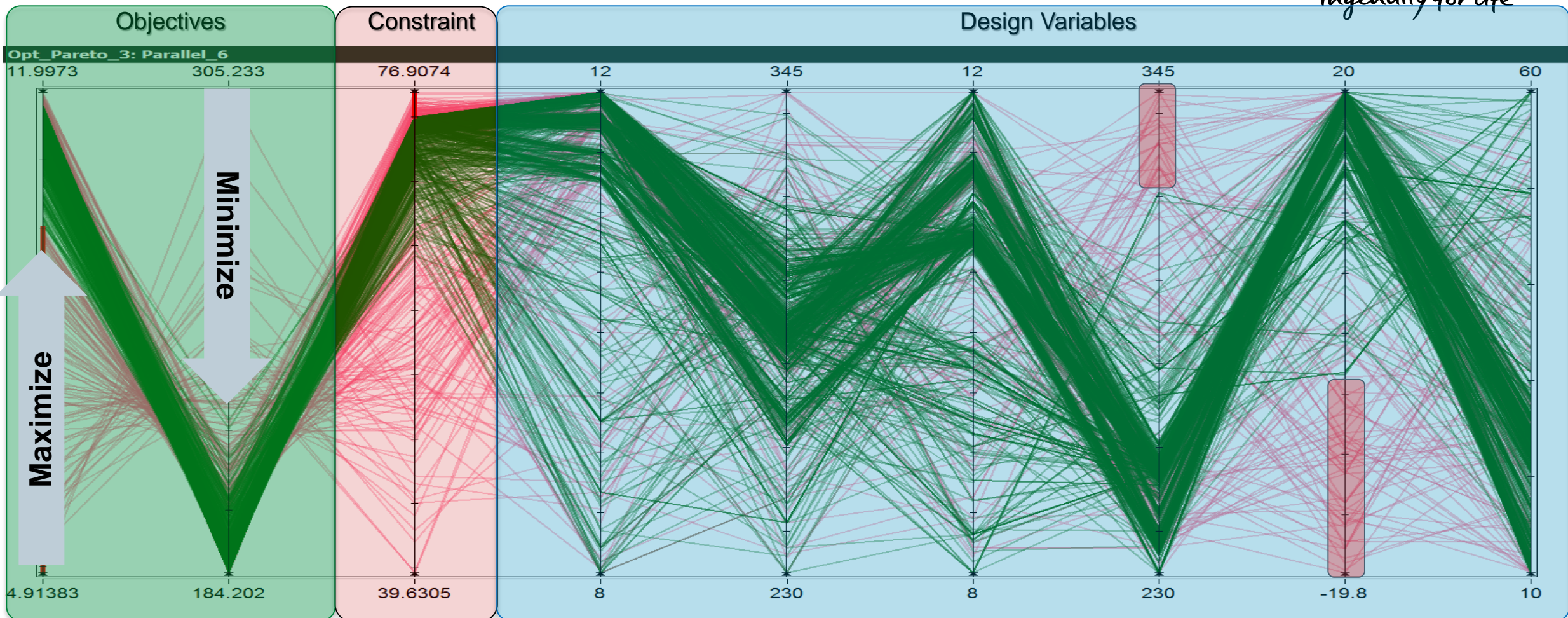
*A heatmap plot can be used to look at the Pareto set designs and view trends among variables and responses.*



*The coloring confirms that as BMEP increases, BSFC increases, Duration Exhaust decreases, and Overlap increases.*



# Insight and Discovery



BMEP

BSFC

Maximum Pressure

Lift Exhaust

Duration Exhaust

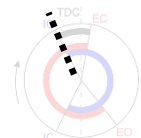
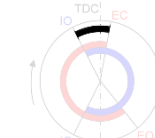
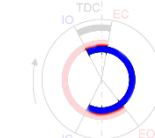
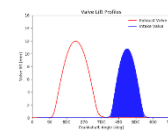
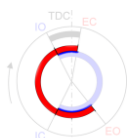
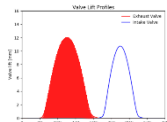
Lift Intake

Duration Intake

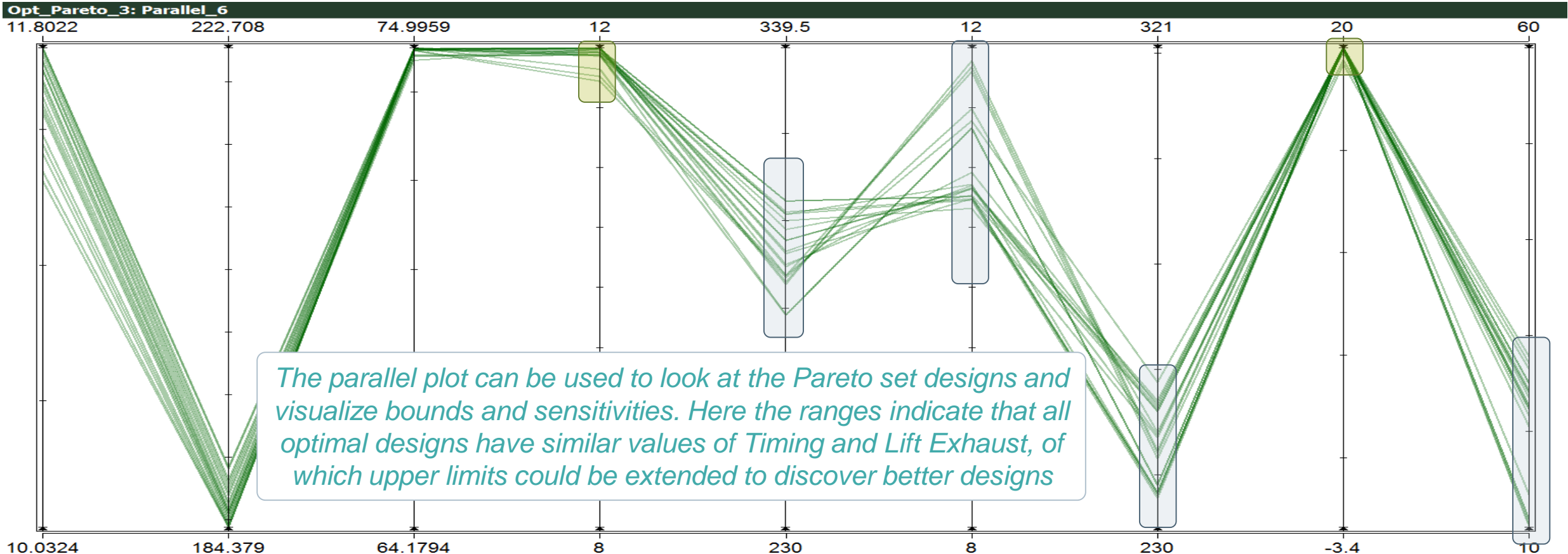
Timing

Overlap

Feasible Designs  
Infeasible Designs



# Insight and Discovery



*The parallel plot can be used to look at the Pareto set designs and visualize bounds and sensitivities. Here the ranges indicate that all optimal designs have similar values of Timing and Lift Exhaust, of which upper limits could be extended to discover better designs*



BMEP

BSFC

Maximum Pressure

Lift Exhaust

Duration Exhaust

Lift Intake

Duration Intake

Timing

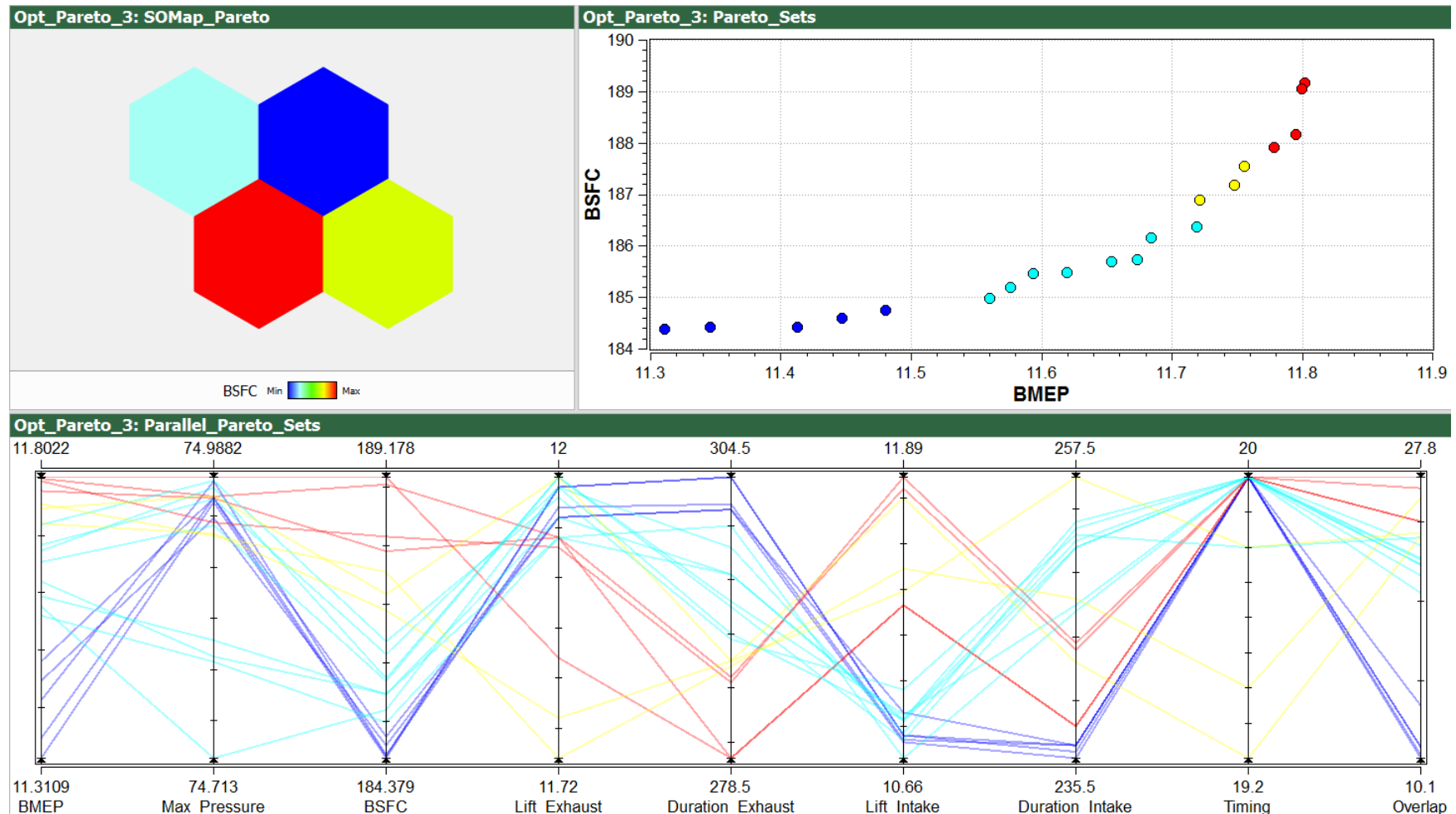
Overlap

# Design Trends – Pareto Set

A self-organizing map is used to group designs based on similarities in particular design parameters.

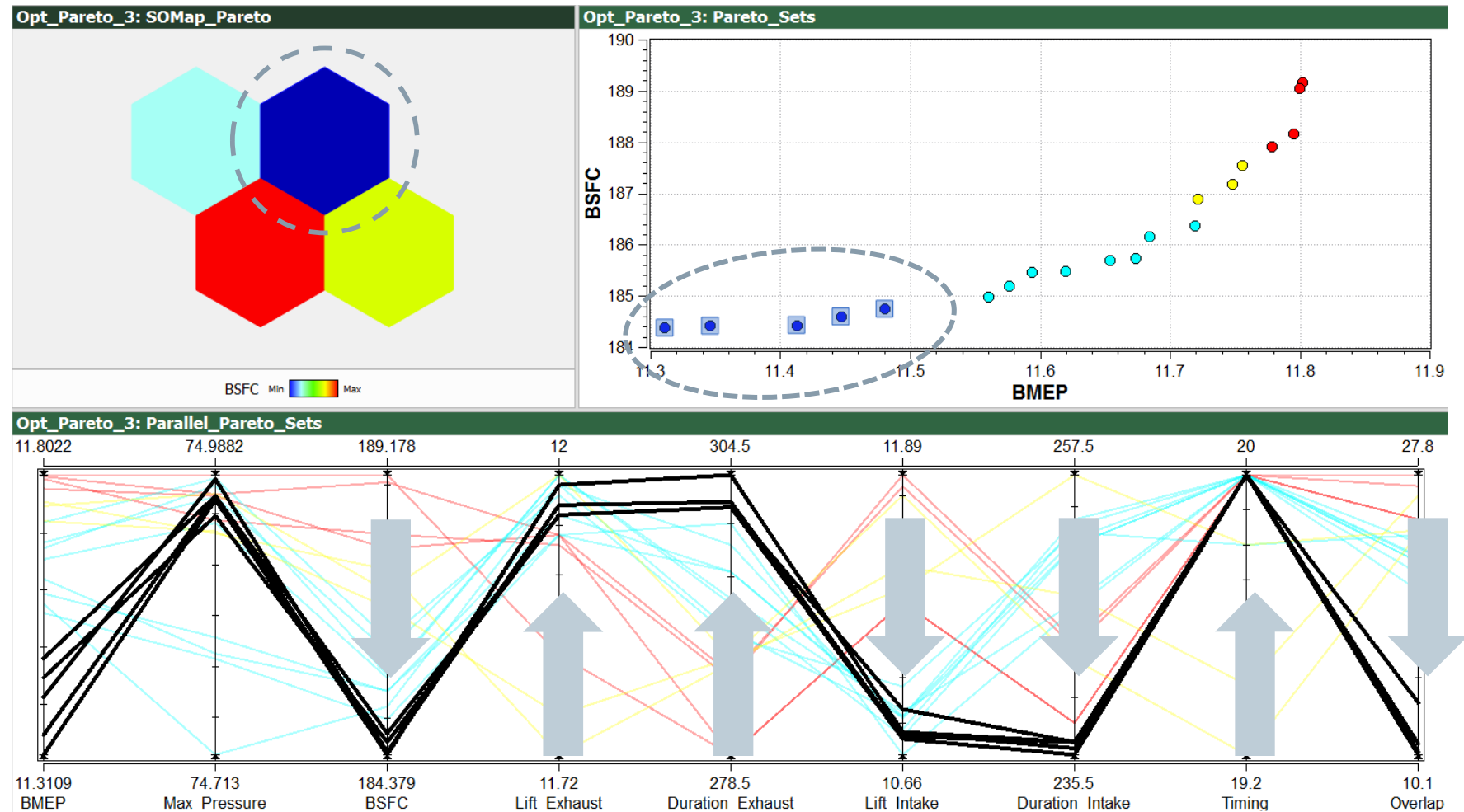
Here designs in the Pareto set have been broken into four groups.

These four groups are color coded and linked with other plots to help us in visualizing the trends.



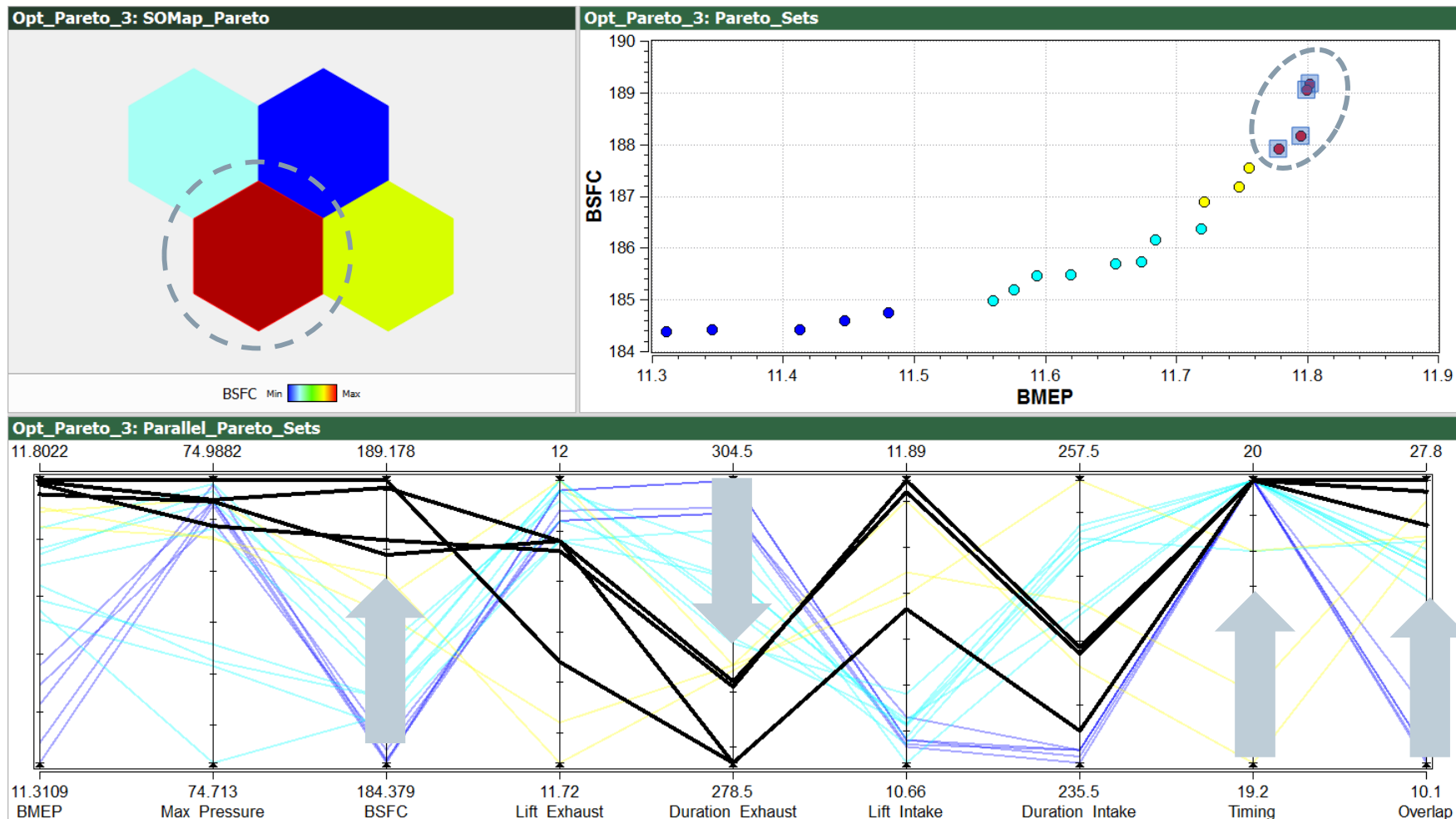
# Design Trends – Pareto Set

Here the group of designs with the lowest values of BSFC are select in all three plots. The parallel plot shows the values the variables take for the designs in this group.



# Design Trends – Pareto Set

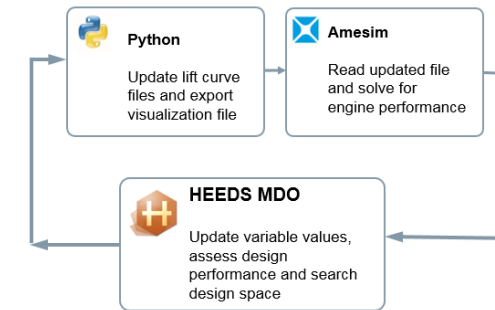
Here the group of designs with the highest values of BSFC are select in all three plots. The parallel plot shows the values the variables take for the designs in this group.



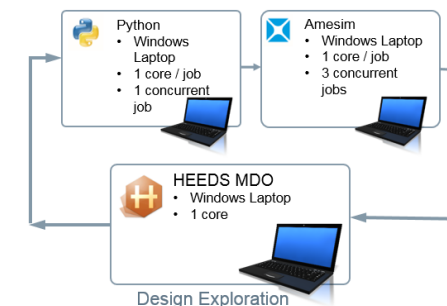
# Summary

- ▶ Demonstrated process automation to simplify virtual prototype construction
  - ✓ Python: Pre-processing and visualization
  - ✓ Amesim: Engine performance prediction
- ▶ Demonstrated that scalable computation hardware and software can be effectively used to accelerate virtual prototype testing
  - ✓ 1000 designs successfully evaluated in 2 hours
- ▶ Proved that intelligent search can help engineers to discover better designs, faster
  - ✓ Discovered family of designs that demonstrate tradeoff between fuel consumption and power generation
  - ✓ Identified critical design variables and relationship between design variables, fuel consumption, and power generation

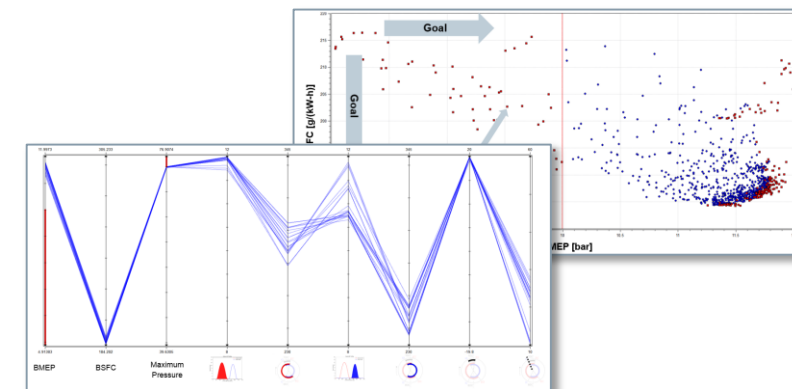
Process Automation



Scalable Computation

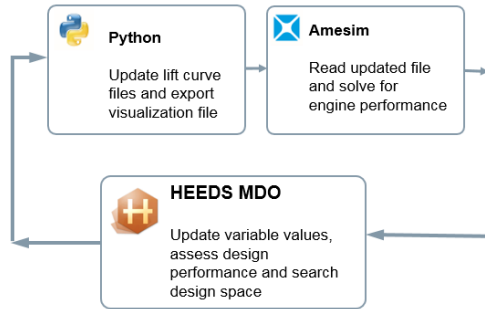


Efficient Exploration

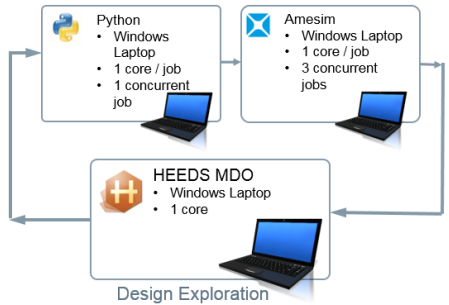


# Summary

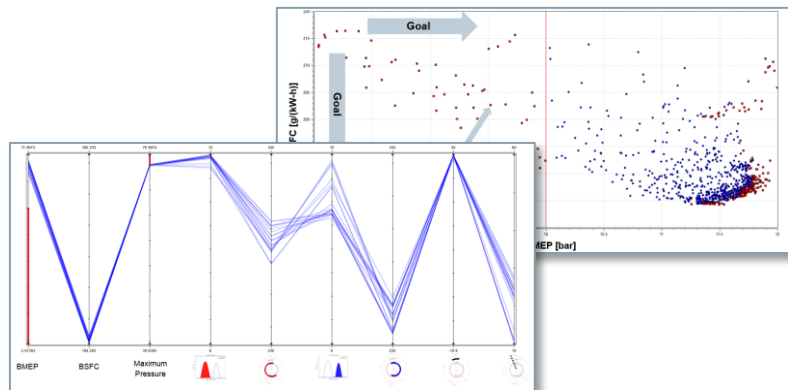
Process Automation



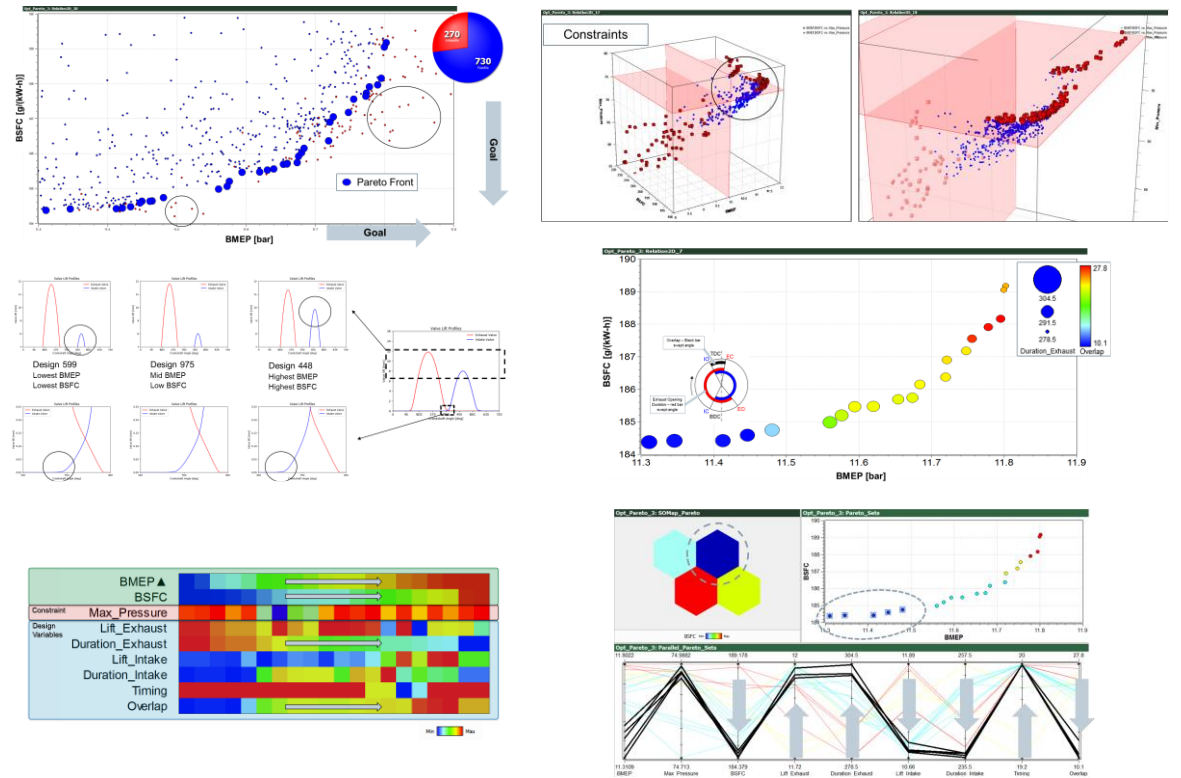
Scalable Computation



Efficient Exploration



Insight & Discovery



# Discover Better Designs, *Faster!* HEEDS

**SIEMENS**  
*Ingenuity for life*

## Multidisciplinary Design Exploration Platform

- Accelerate design process with automated workflow
- Explore early & often with a streamlined process
- Increase product knowledge with multi-variant analysis
- Discover better designs faster with automated intelligent search
- Assess design robustness
- In PLM context, configurations are stored, managed and can be reused
- **Easy to use – no need to be an optimization specialist**
- **Easy to deploy across organizations**

