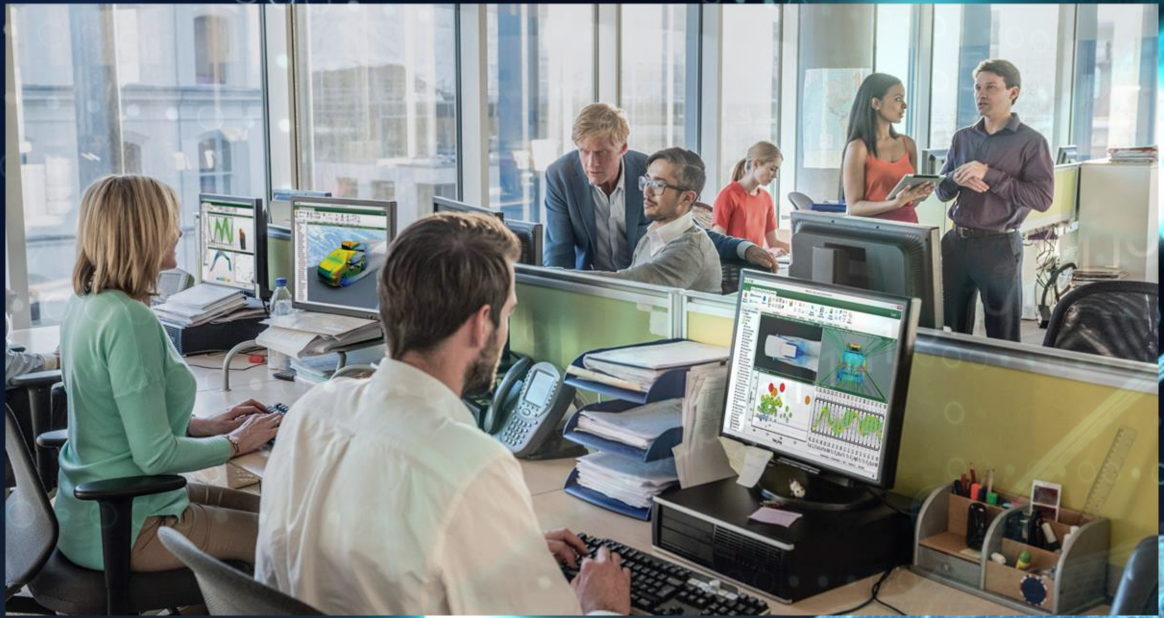

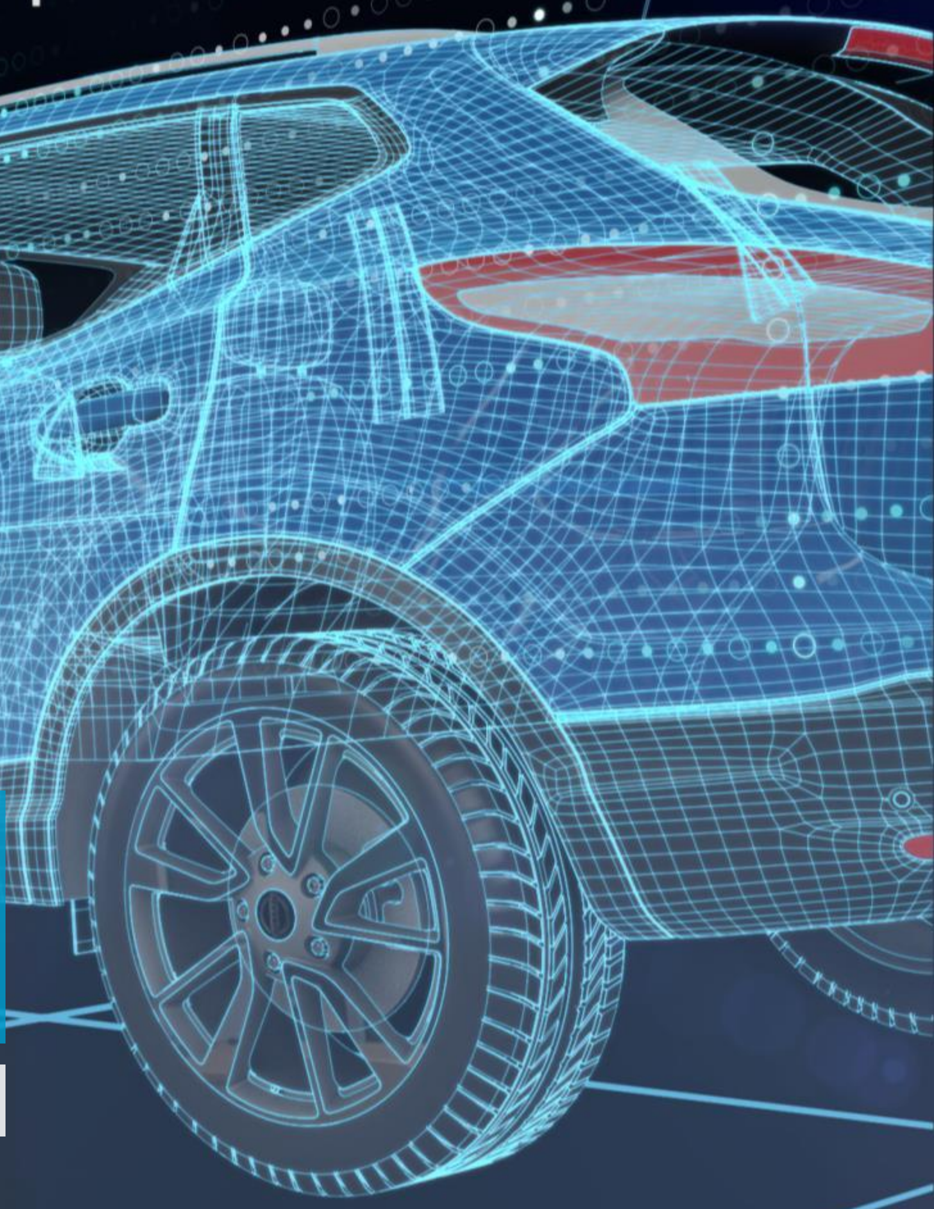

Discover Better Designs, *Faster!*

Driving Product Innovation Through Design Exploration

Realize Innovation.

Executive Summary – Modern Engine Design

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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

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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:

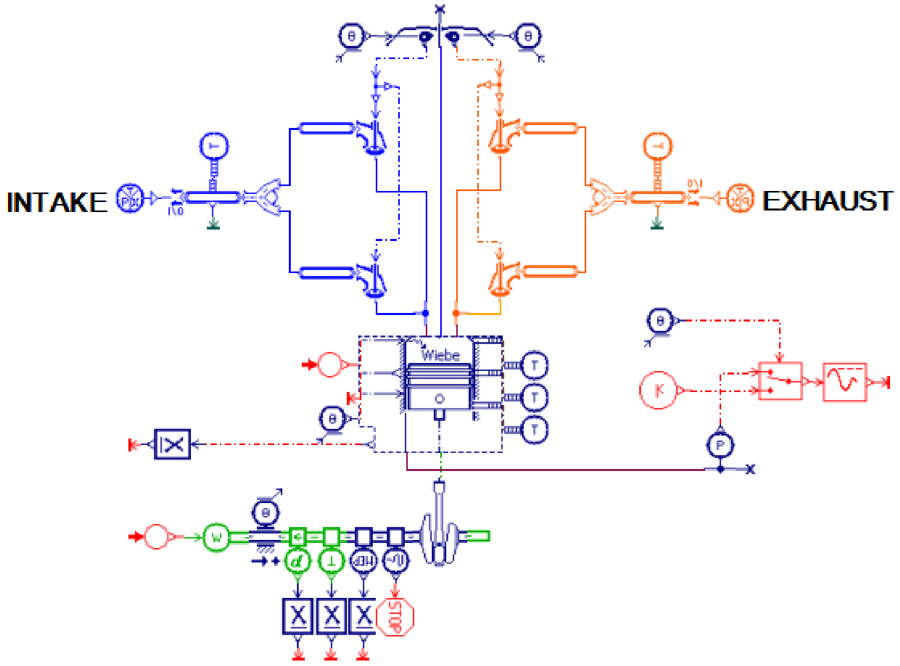
Shape:

- 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

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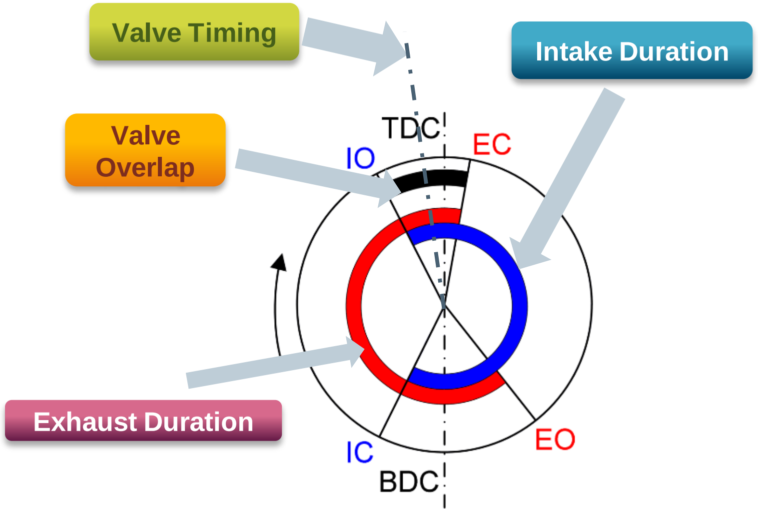
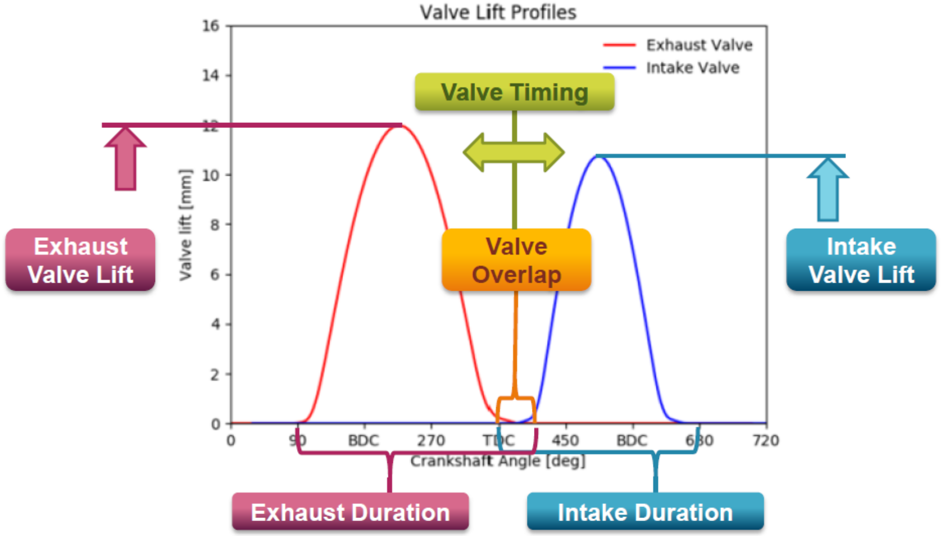
Design Variables:

- 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

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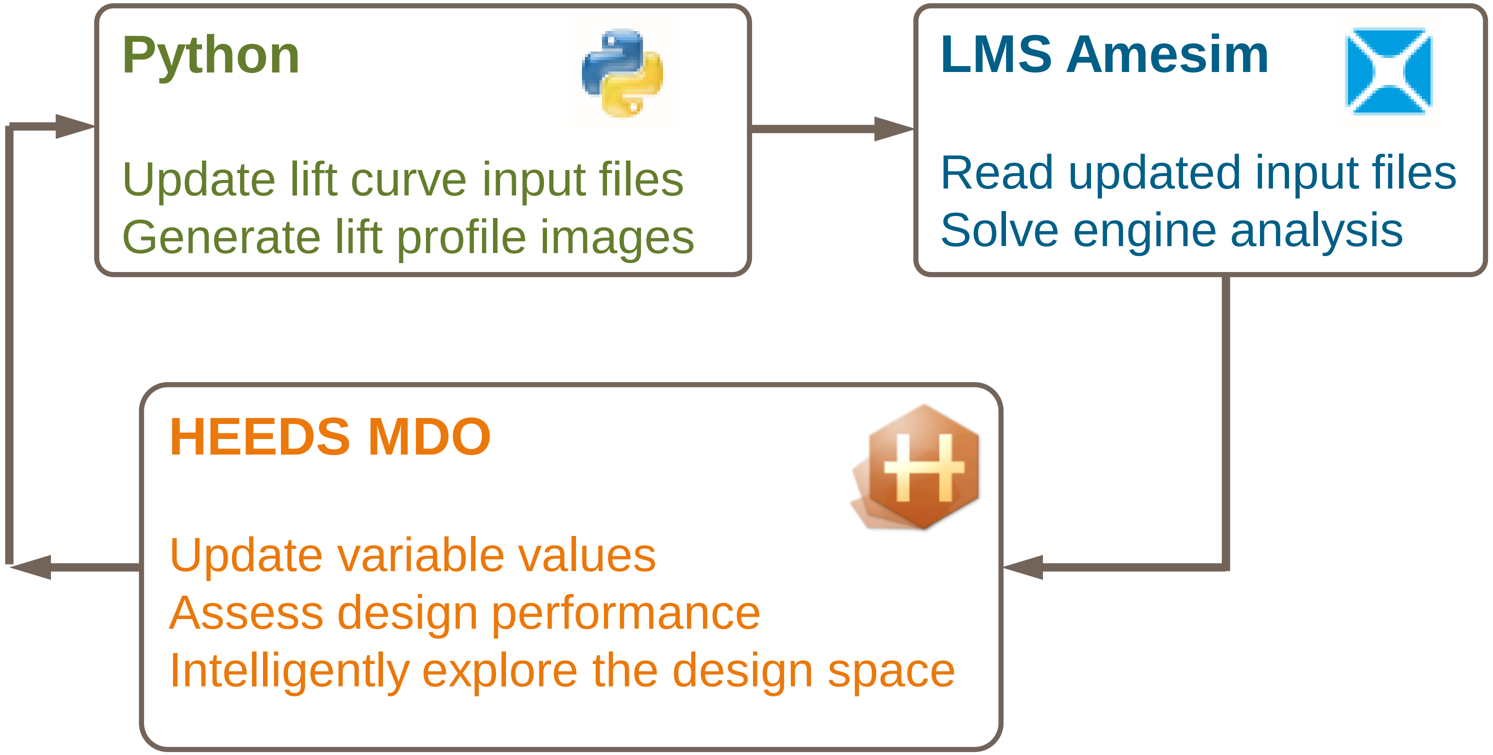
Process Automation:



Process Automation
Python Portal

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

Python
- Update lift curve files
- Generate image

Python

UpdateValveCurves.py

```
import math
import numpy
import sys
import matplotlib.pyplot as plt
#
#
# Variables to modify per design
exhaust_lift = 9
exhaust_opening = 287
exhaust_delay = 50
intake_lift = 9
intake_opening = 287
intake_advance = 50
#
#
#requires: max lift occurs @ 0 degrees
#
def calculateCurveWriteFile(f_old, f_new, new_lift,

    f_in = open(f_old)

    angle_open = 0
```

HEEDS

Tag

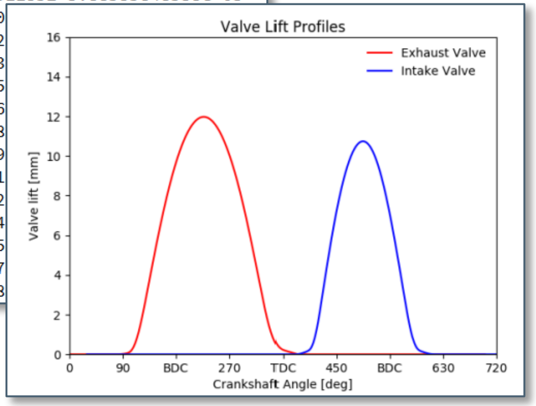
File: C:/working/amesim/SingleCyl_updated/UpdateValveCurves.py

Input Type	Description
Number	
Formula	
All	Name

Name	Value
exhaust_lift	Lift_Exhaust
exhaust_opening	Duration_Exhaust
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

Intake_Lift_cycle.data

```
# Table format: 1D
# table_unit = mm
# axis1_unit = degree
-465.0 0.0
-131.338607595 0.0
-130.485759494 2.80973386271e-06
-129.632911392 5.88939848953e-05
-128.7800
-127.9272
-127.0743
-126.2215
-125.3686
-124.5158
-123.6629
-122.8101
-121.9572
-121.1044
-120.2515
-119.3987
-118.5458
```



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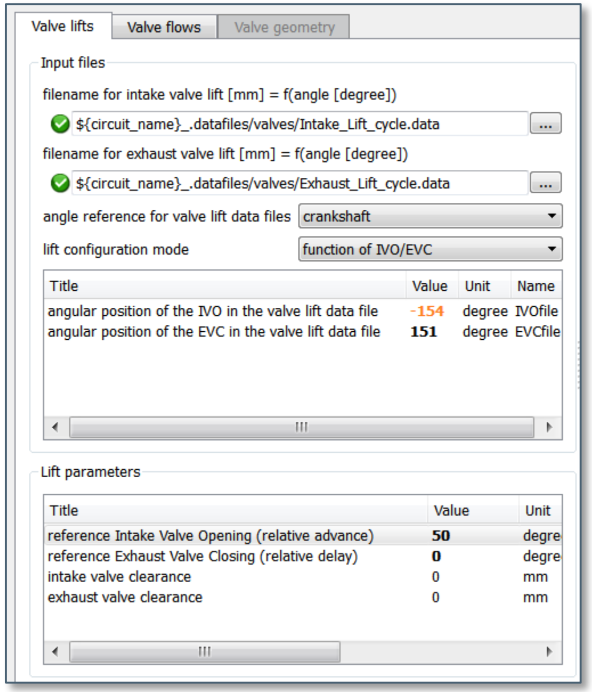
The LMS Amesim Portal is utilized to associate component input and output parameters with variables and responses in HEEDS

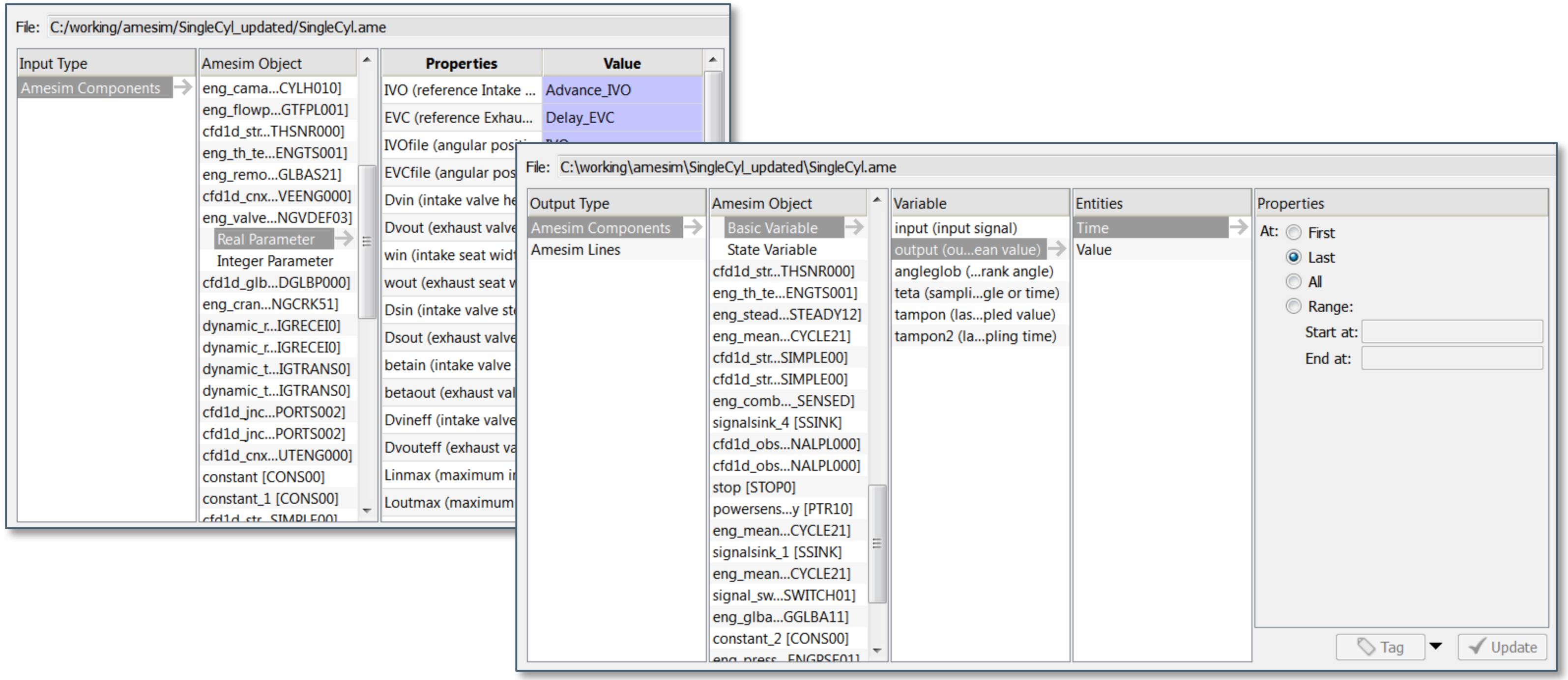
LMS Amesim
Read updated file
Solve engine analysis

LMS Amesim

HEEDS

Tag





Efficient Design Exploration

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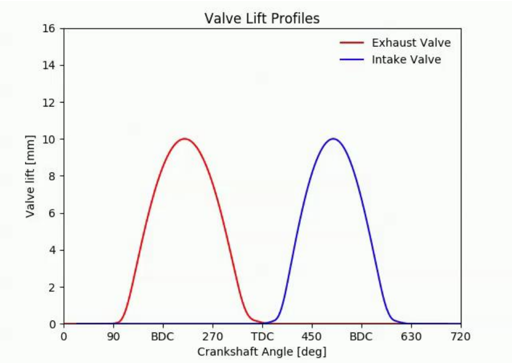
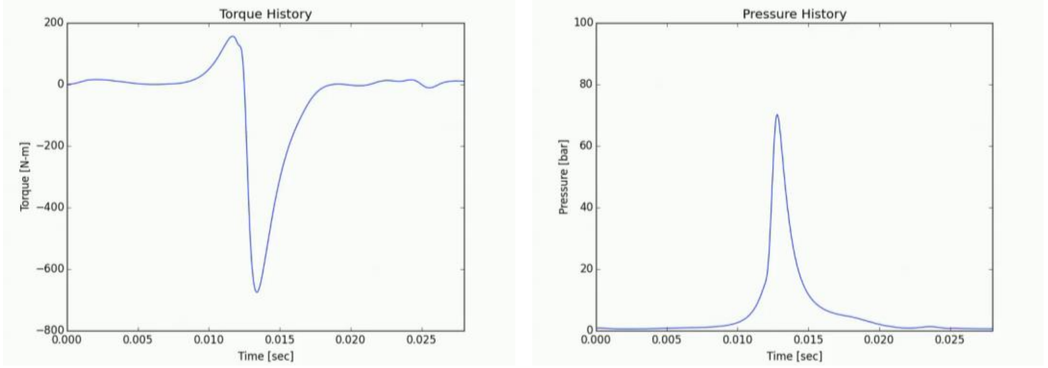
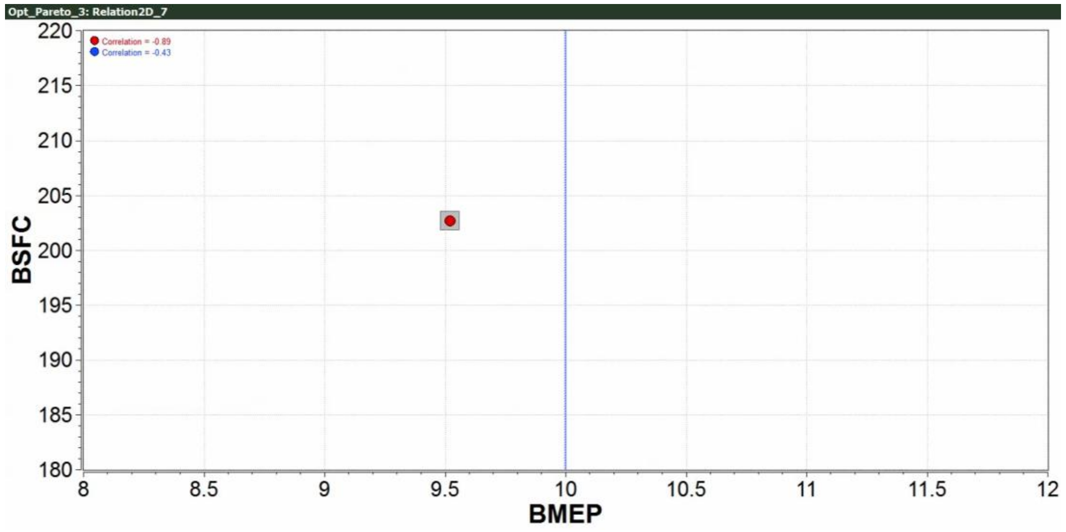
Update Valve Motion



Evaluate Engine Performance



Directed Modification



HEEDS‘ intelligent search algorithm

- **Hybrid & adaptive functionality**
- **No model fitting or surrogates**

Scalable Computation

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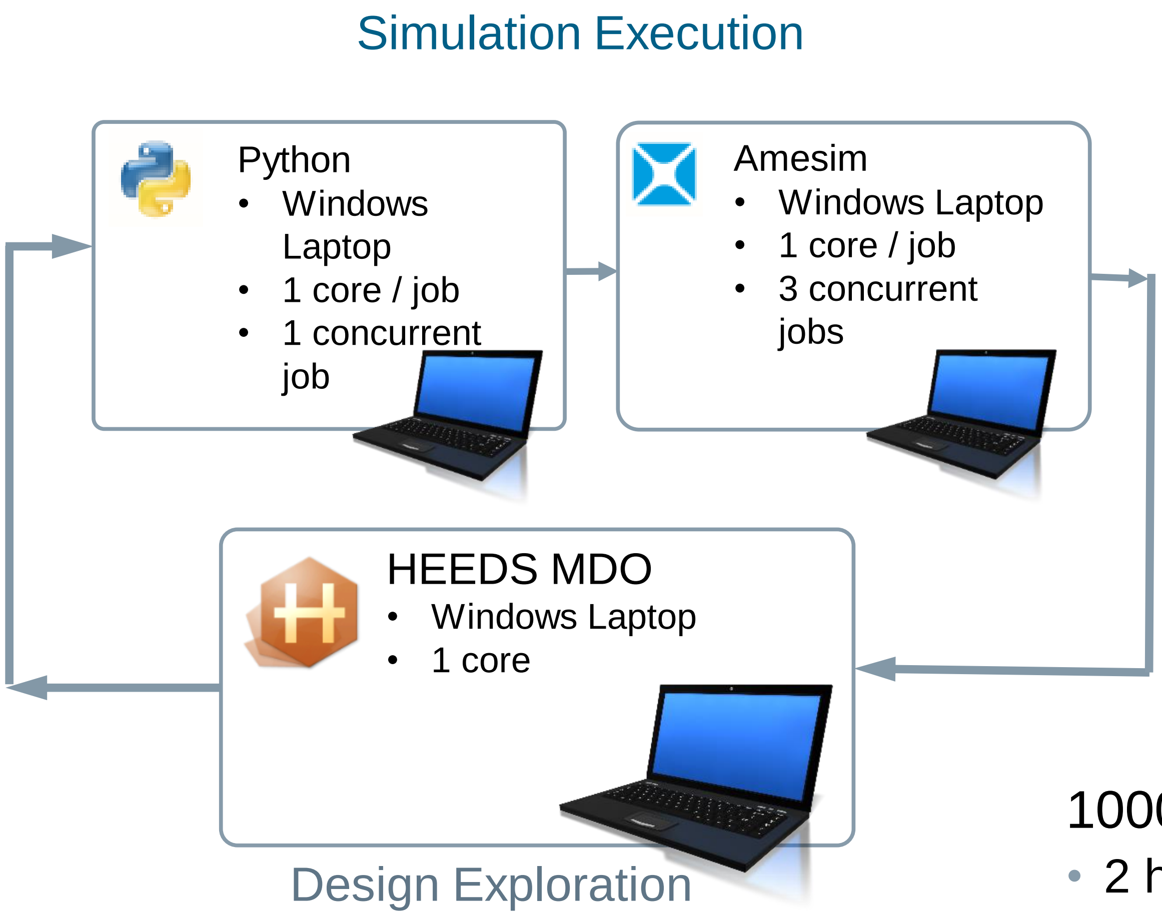

1000 Engine Designs Evaluated

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

Highly Constrained Design Space

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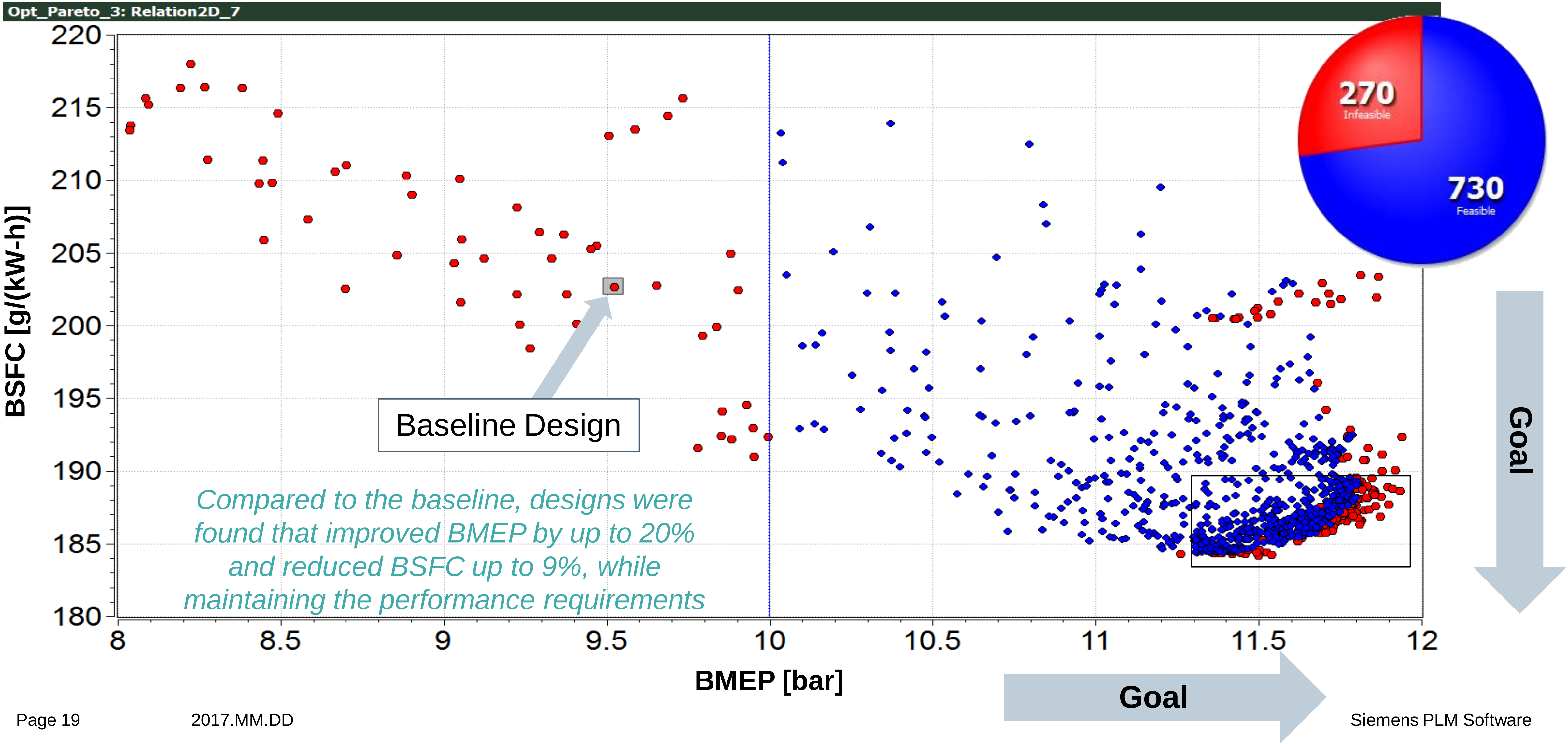

Design Exploration

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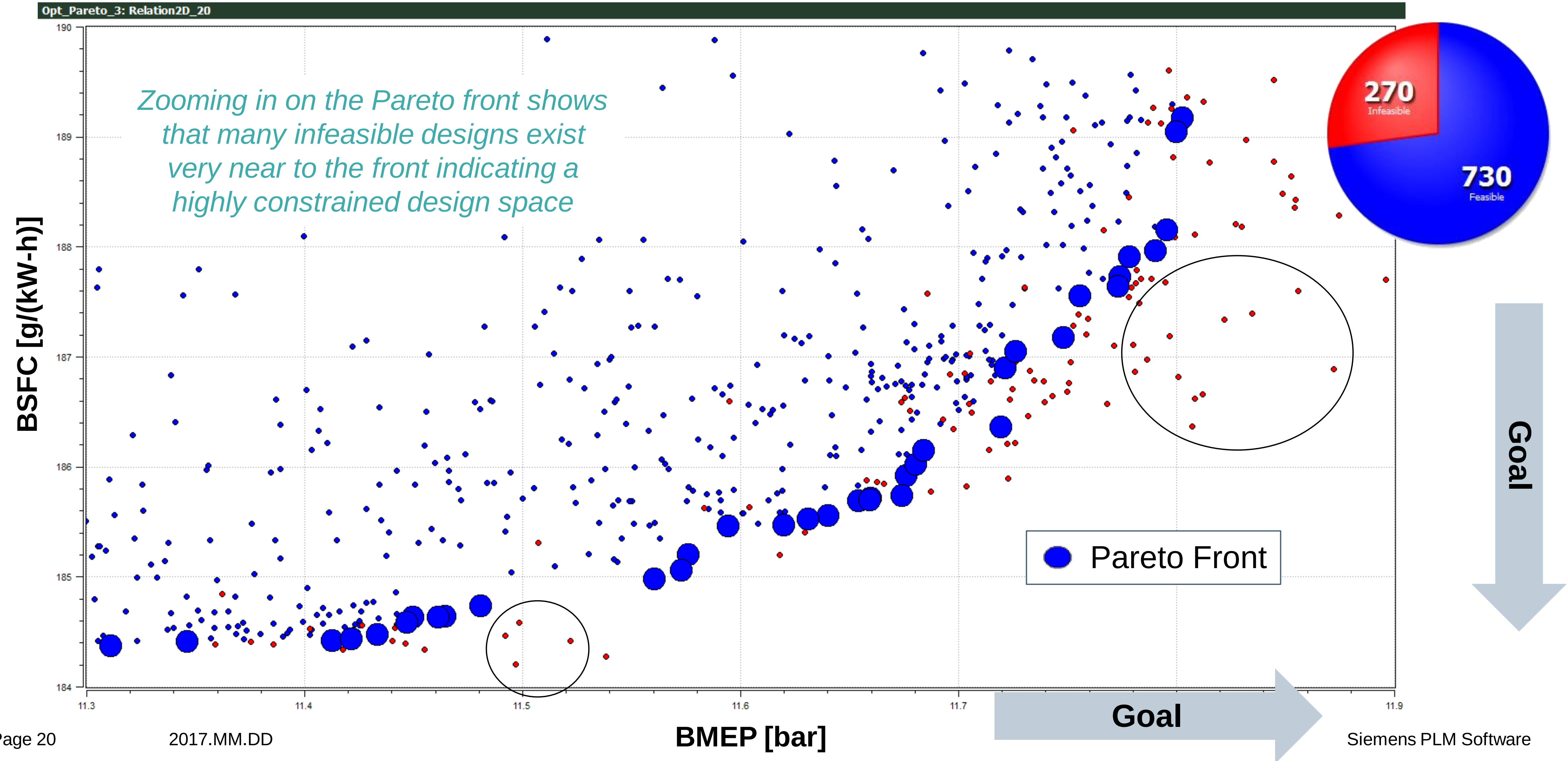

Highly Constrained Design Space

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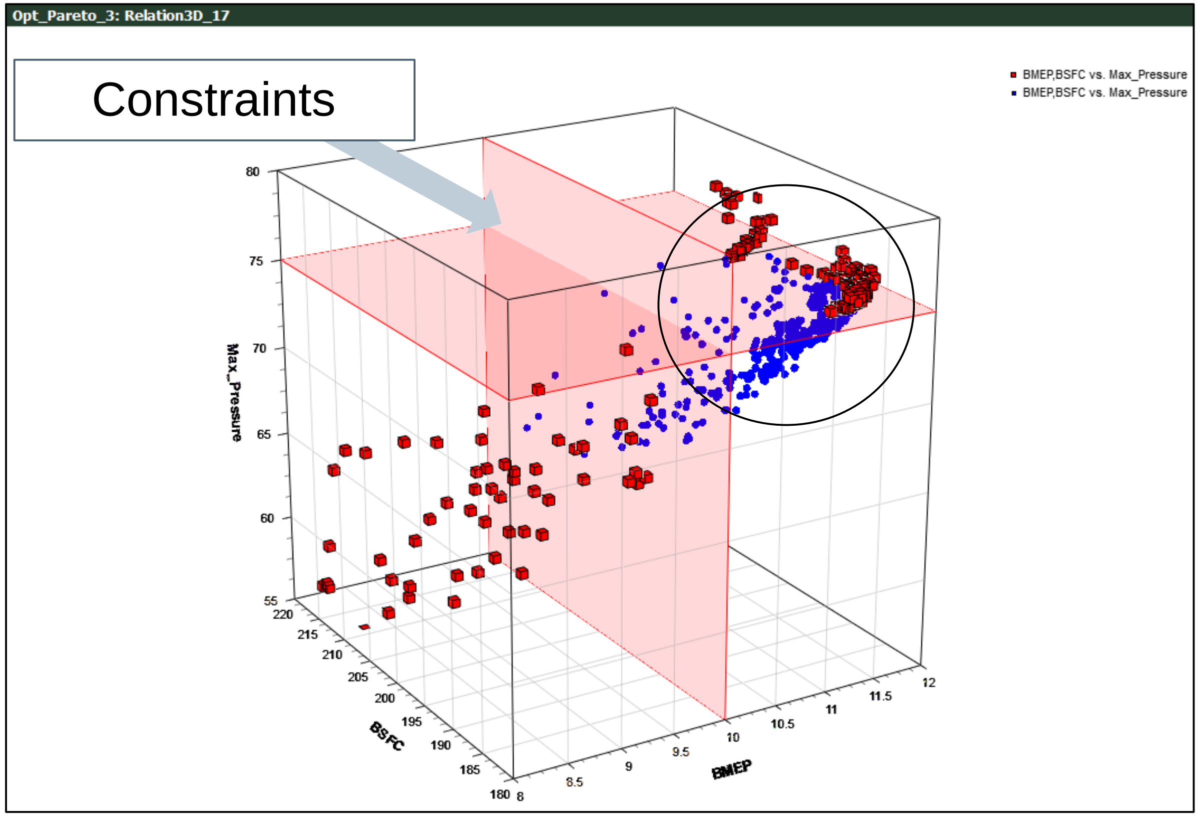
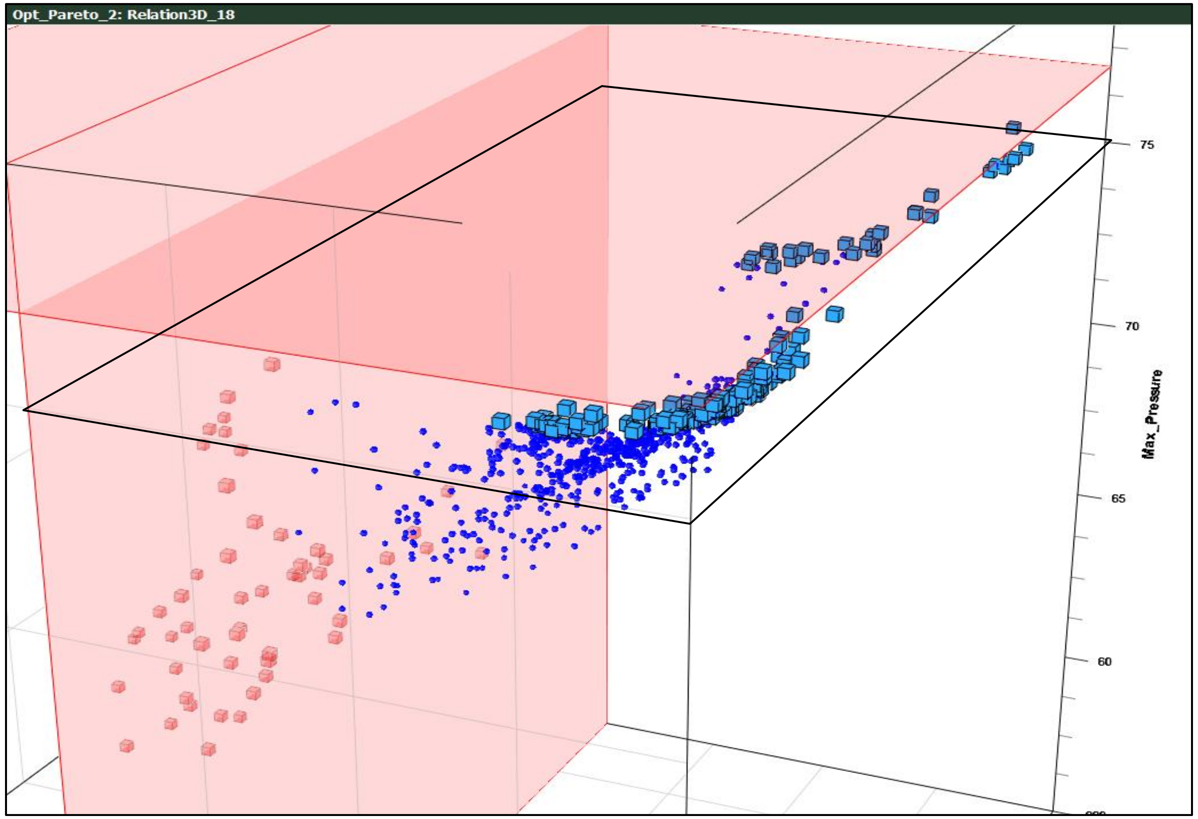
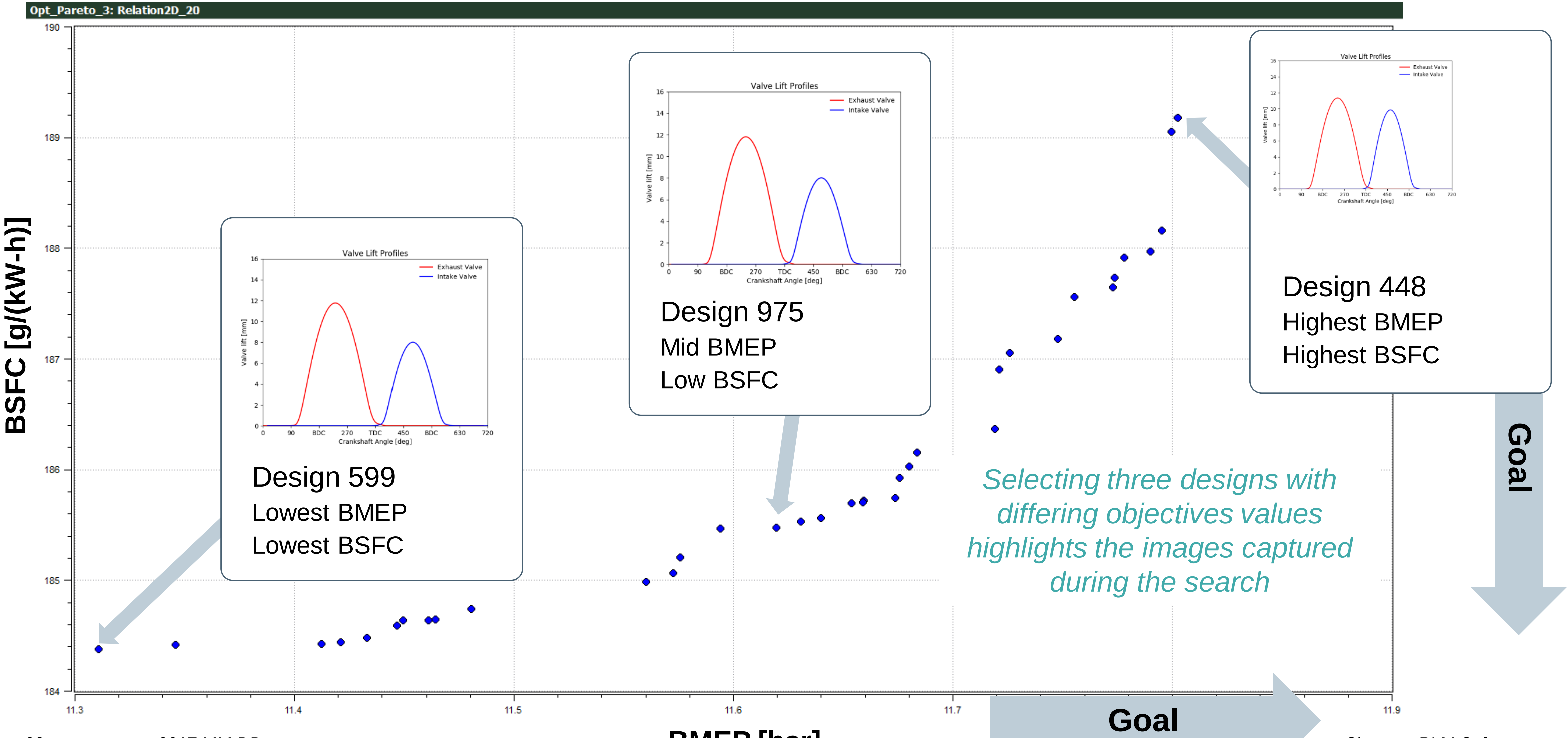




Design Exploration

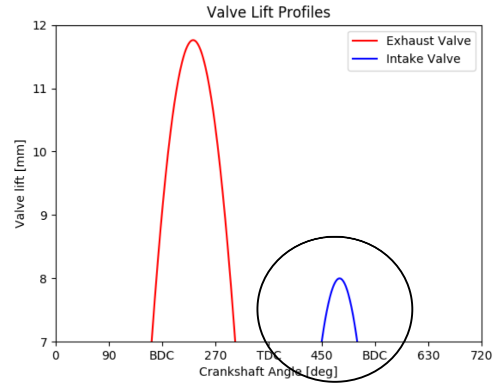
SIEMENS
Ingenuity for life



Design Exploration

SIEMENS

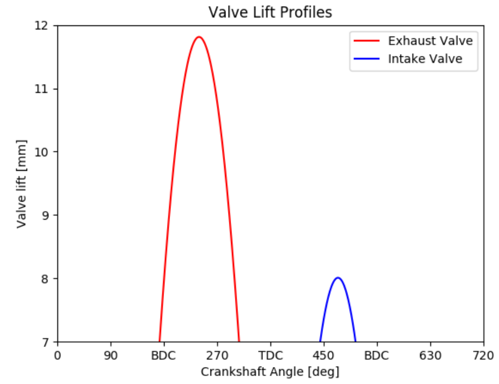
Ingenuity for life



Design 599

Lowest BMEP

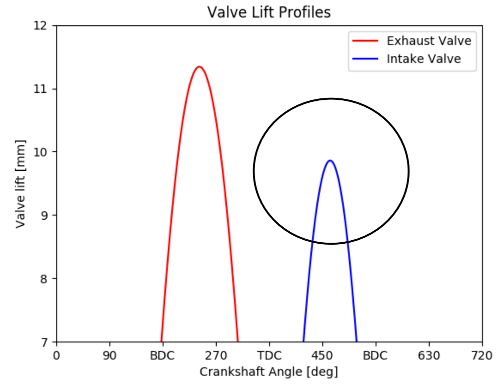
Lowest BSFC



Design 975

Mid BMEP

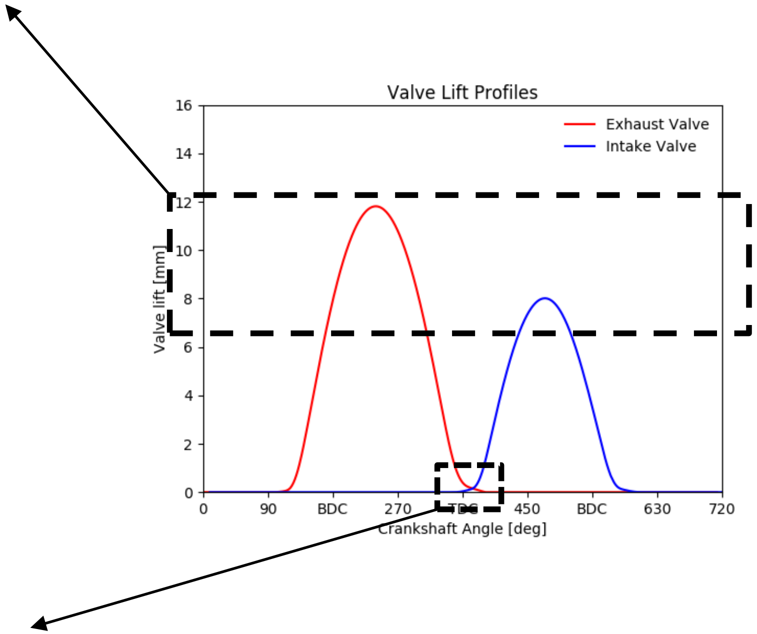
Low BSFC

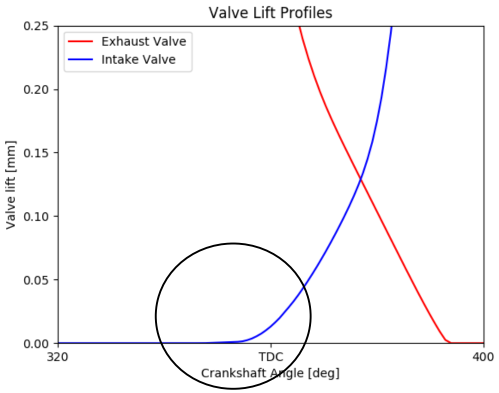


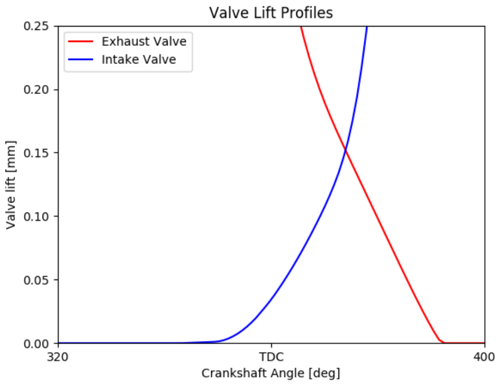
Design 448

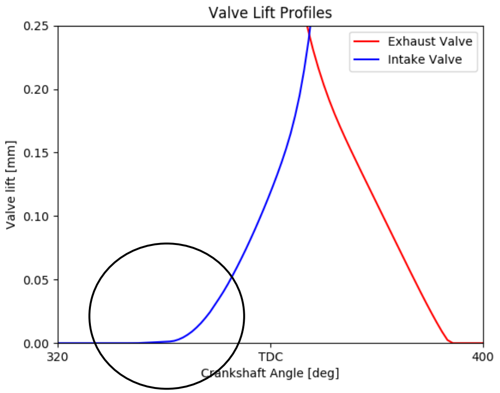
Highest BMEP

Highest BSFC









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

Design Trends

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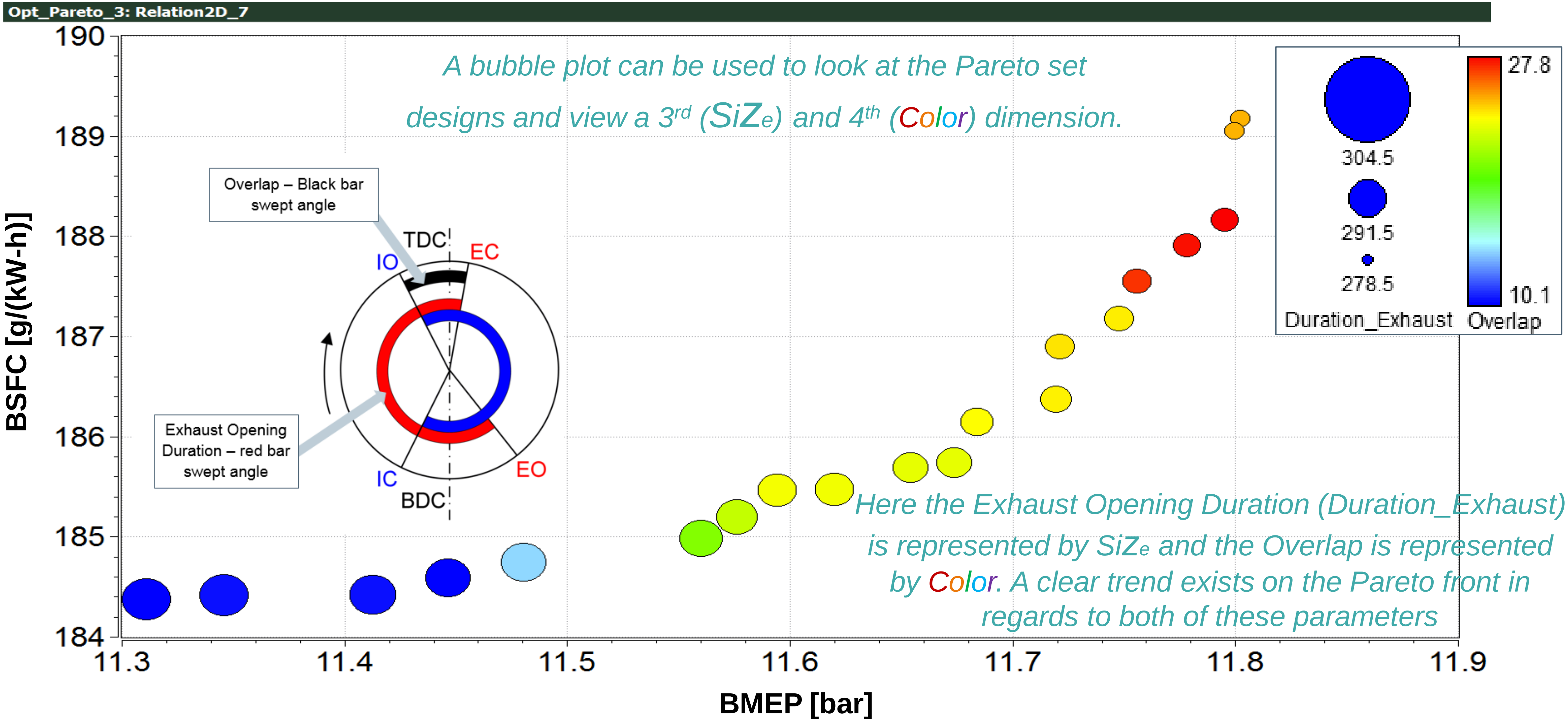

Design Trends

SIEMENS
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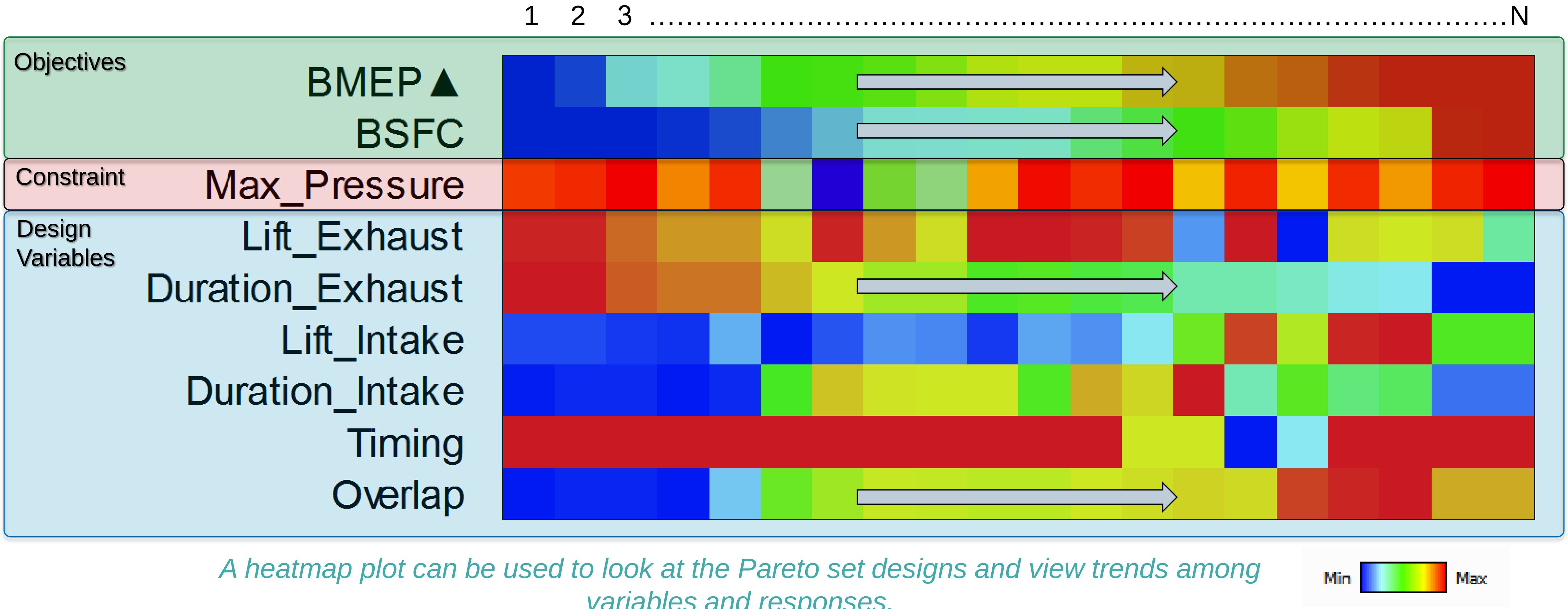

A heatmap plot can be used to look at the Pareto set designs and view trends among variables and responses.

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

Insight and Discovery

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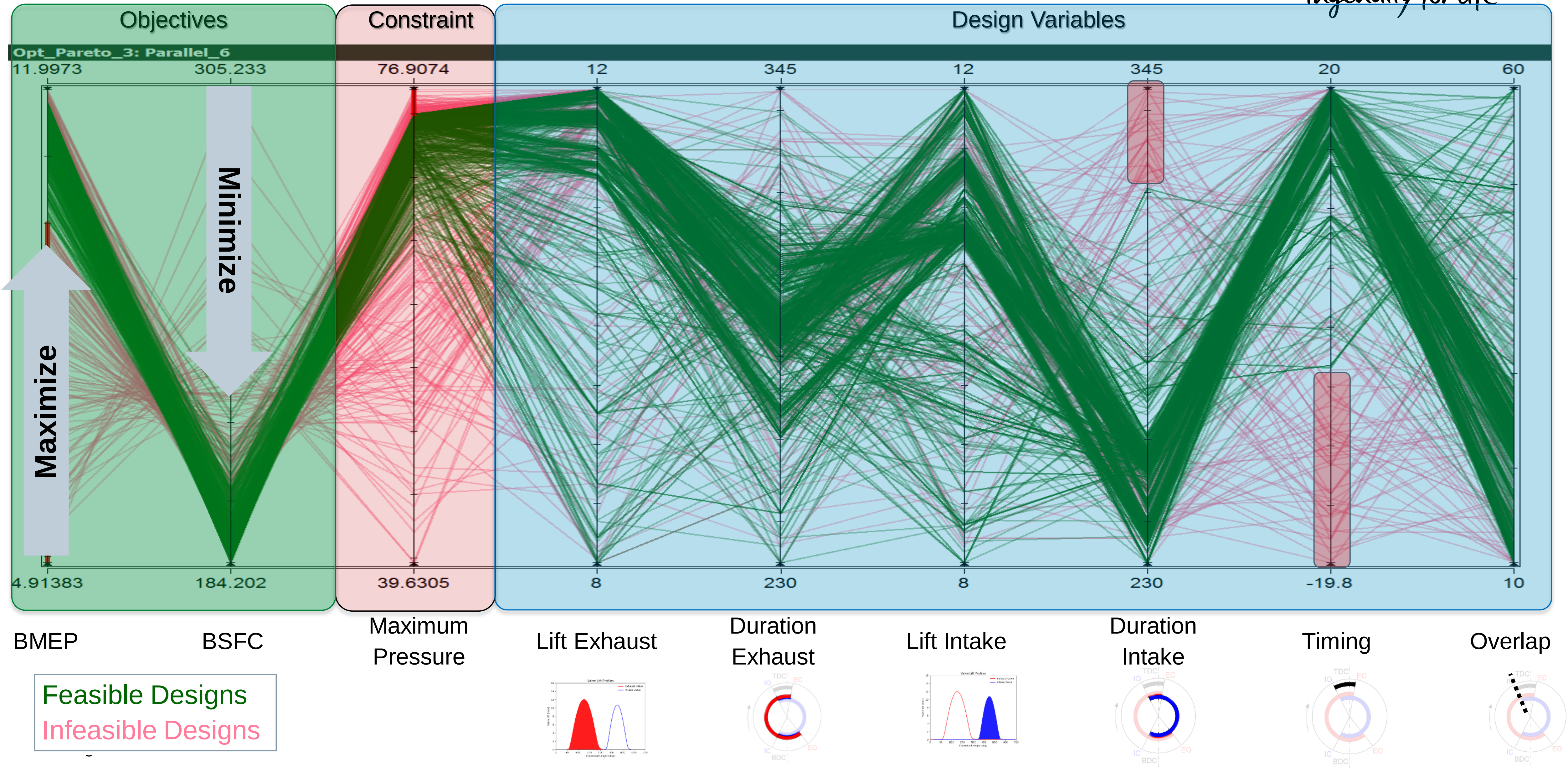
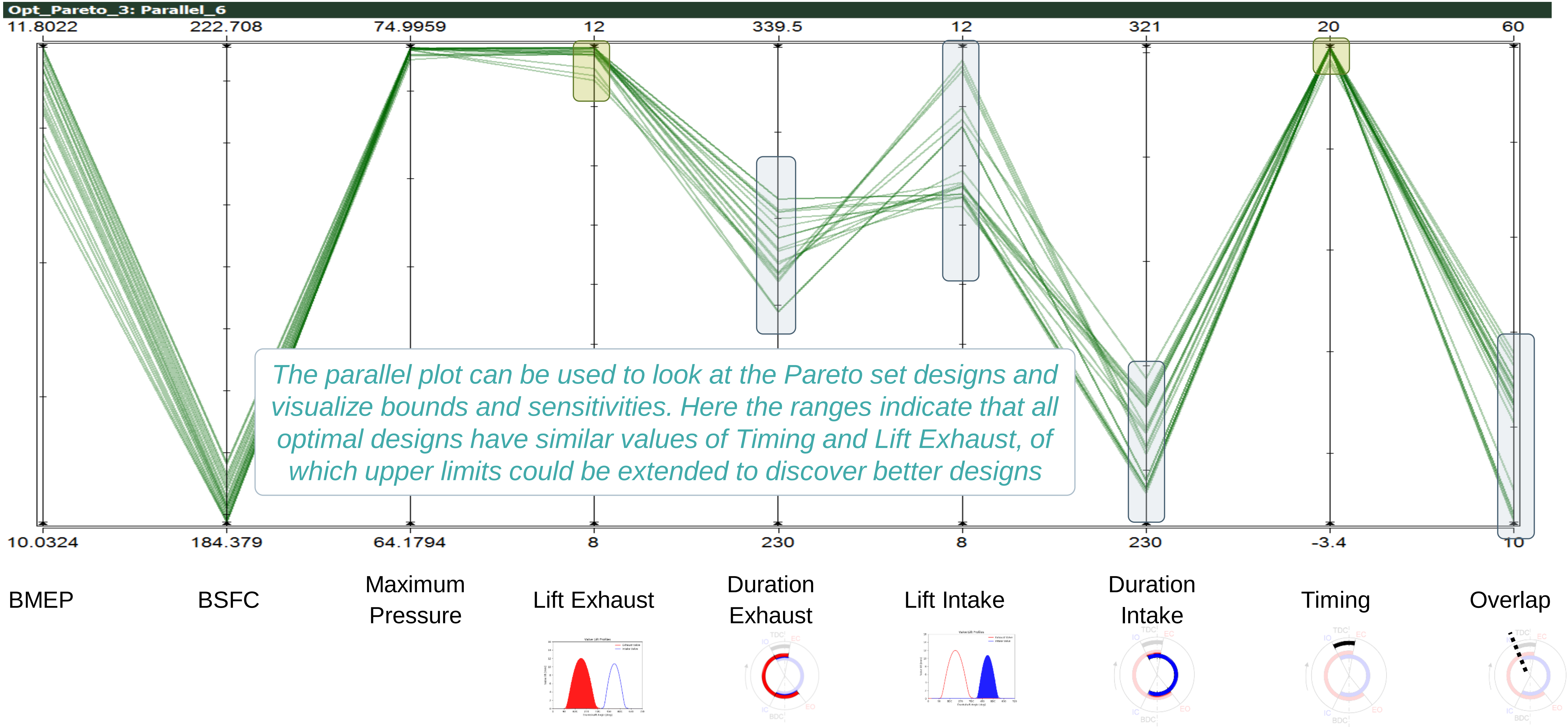


Insight and Discovery

SIEMENS
Ingenuity for life



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

Design Trends – Pareto Set

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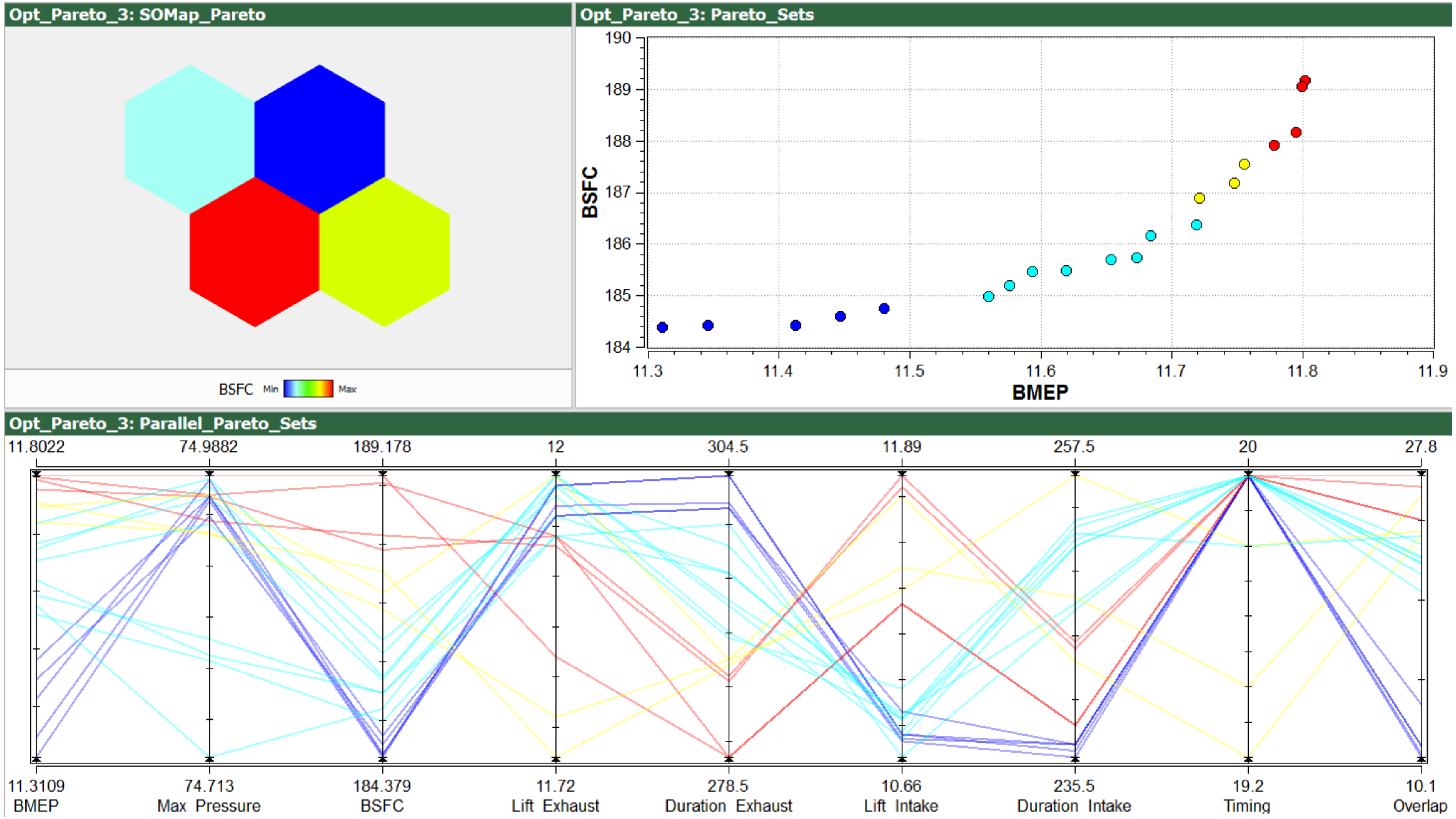
A self-organizing map is used to group designs based on similarities in particular design parameters.

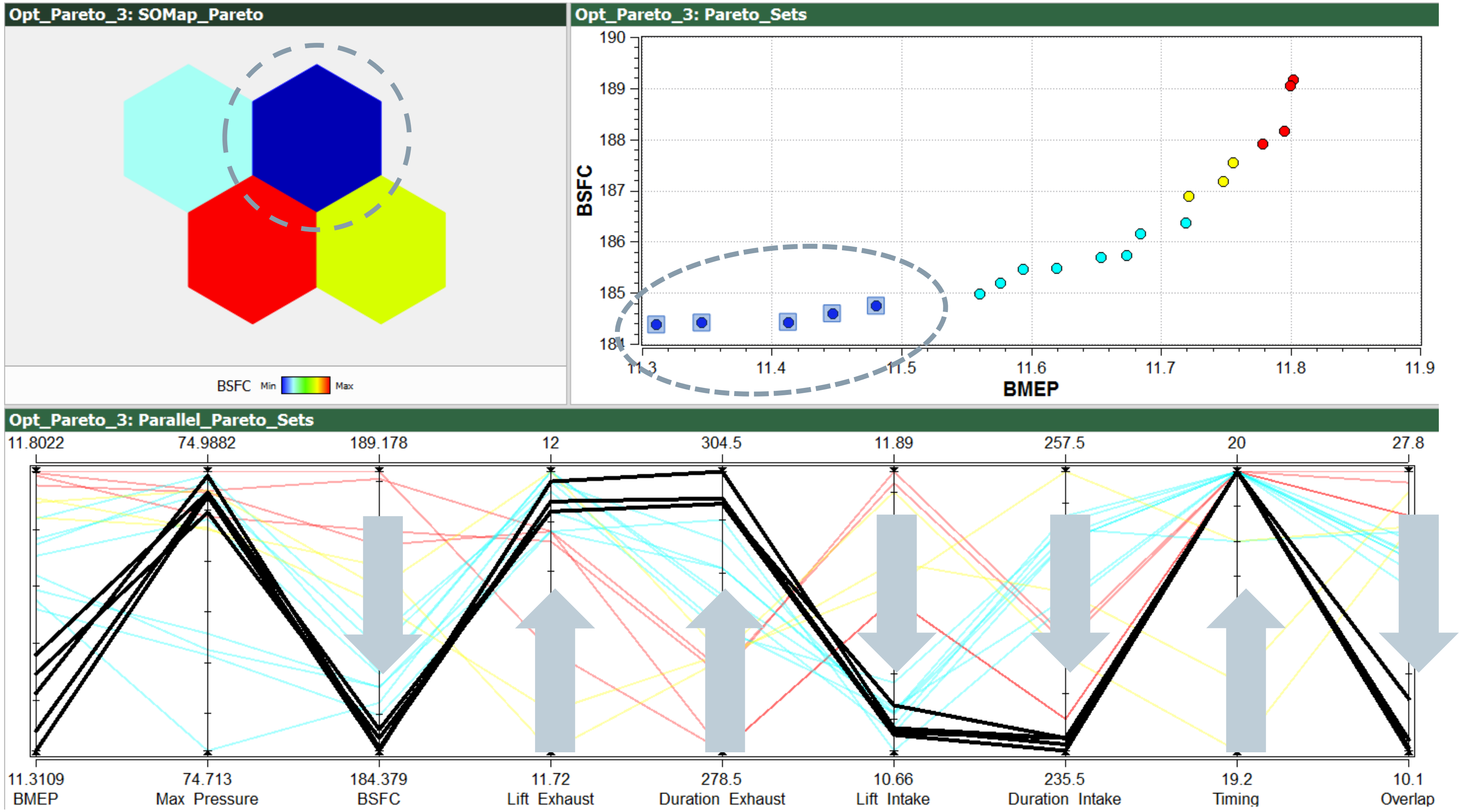
Here designs in the Pareto set have been broken into four groups.

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



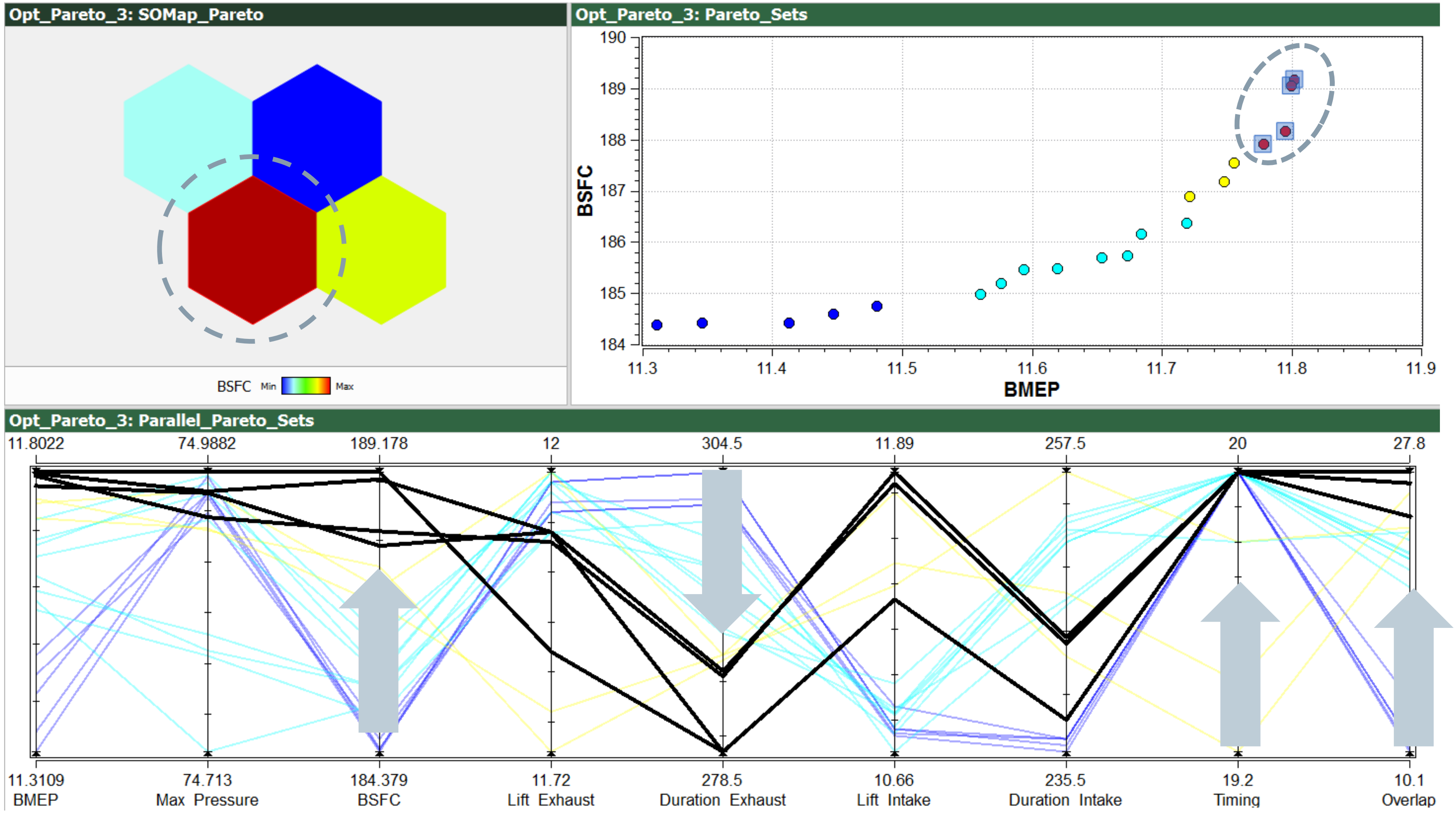
Design Trends – Pareto Set

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

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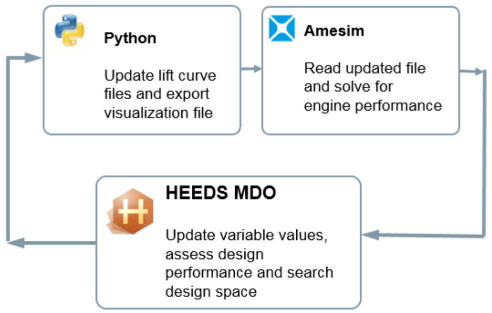
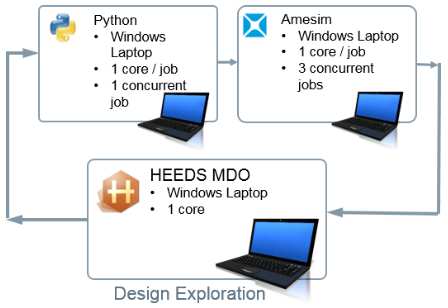
- Demonstrated process automation to simplify virtual prototype construction
  - ✓ Python: Pre-processing and visualization
  - ✓ Amesim: Engine performance prediction
- Demonstrated that scalable computation hardware and software can be effectively used to accelerate virtual prototype testing
  - ✓ 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

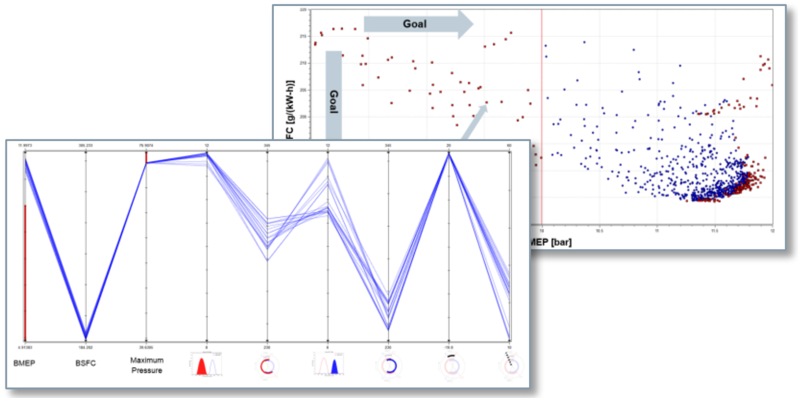
Process Automation



Scalable Computation

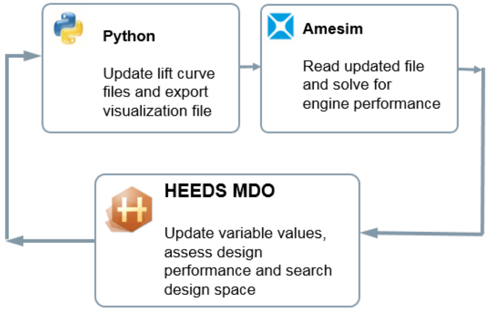


Efficient Exploration

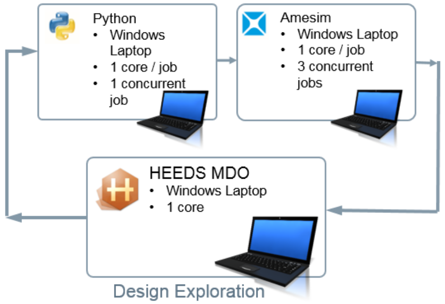


Summary

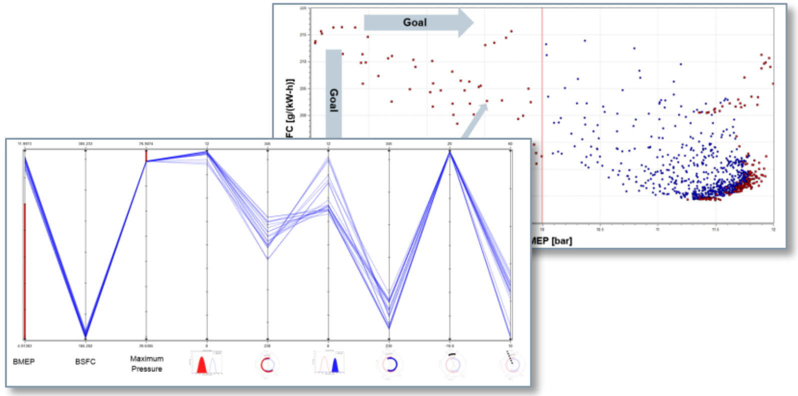
Process Automation



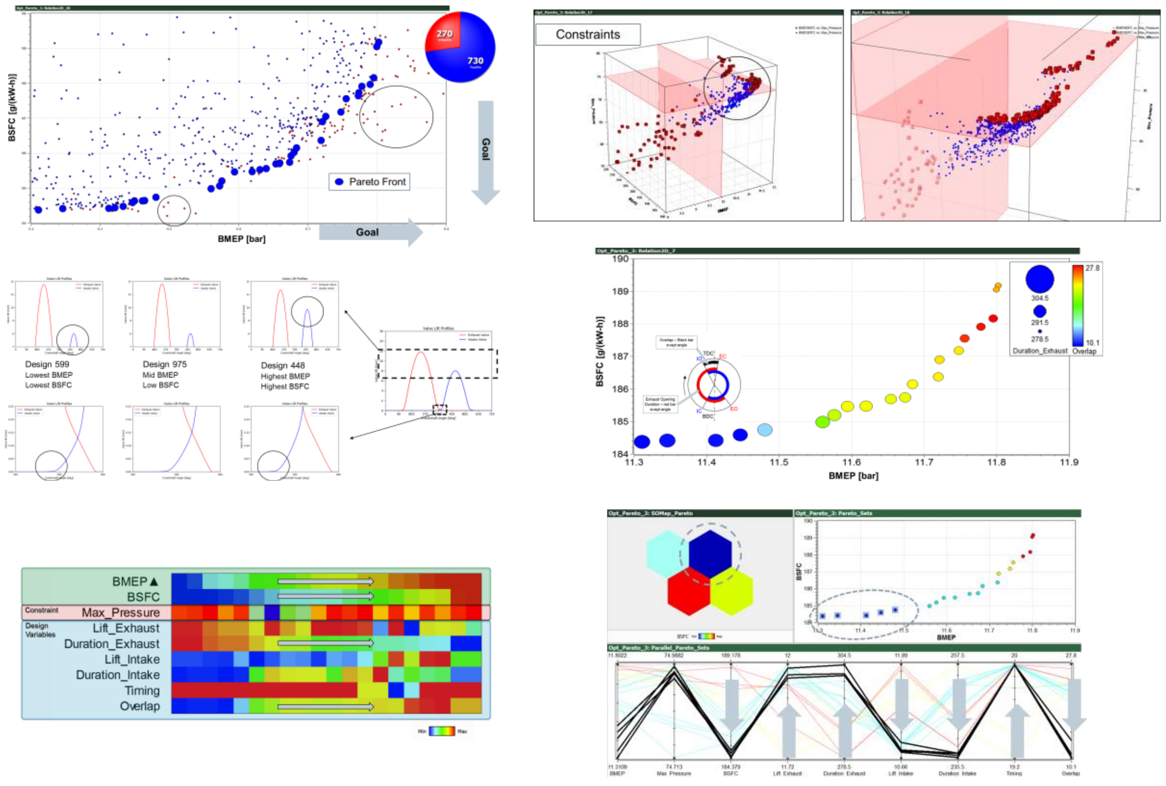
Scalable Computation



Efficient Exploration



Insight & Discovery



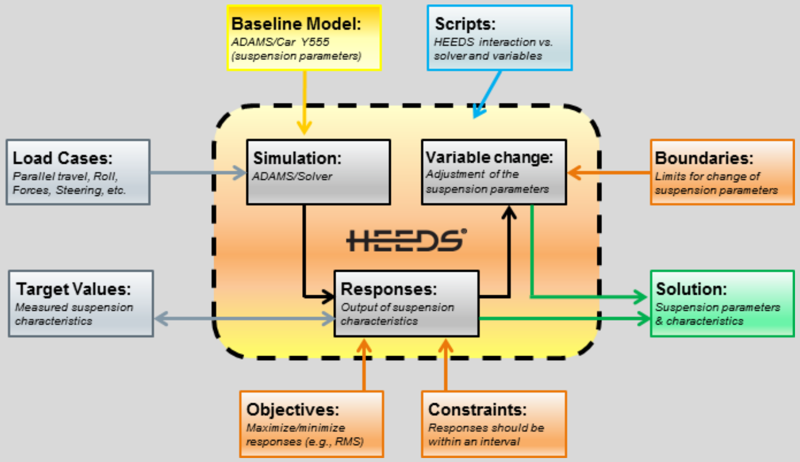
Discover Better Designs, *Faster!*
HEEDS

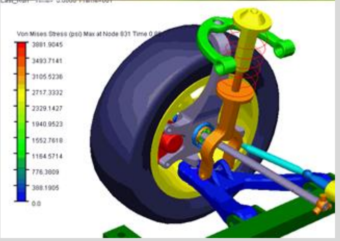
Multidisciplinary Design Exploration Platform

- 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**

Process Automation | Distributed Execution | Efficient Search | Insight & Discovery





Suspension Auto-Correlation reduced time from months to under 1 week
"HEEDS drastically reduces correlation time." — Erik Wendeberg, Chalmers