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2023

Optimization of Engine Water Jacket Performance Using modeFRONTIER

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POLARIS

Polaris Background
Product, Engines & Optimization

Engine Water Jackets
Purpose, Flow Scheme, Role of the Head Gasket

WJ/Head Gasket Optimization
Approach, Inputs, Outputs, Constraints and Objectives

Optimization Results
Key findings and output interactions

Next Steps
Improvements

Polaris Background

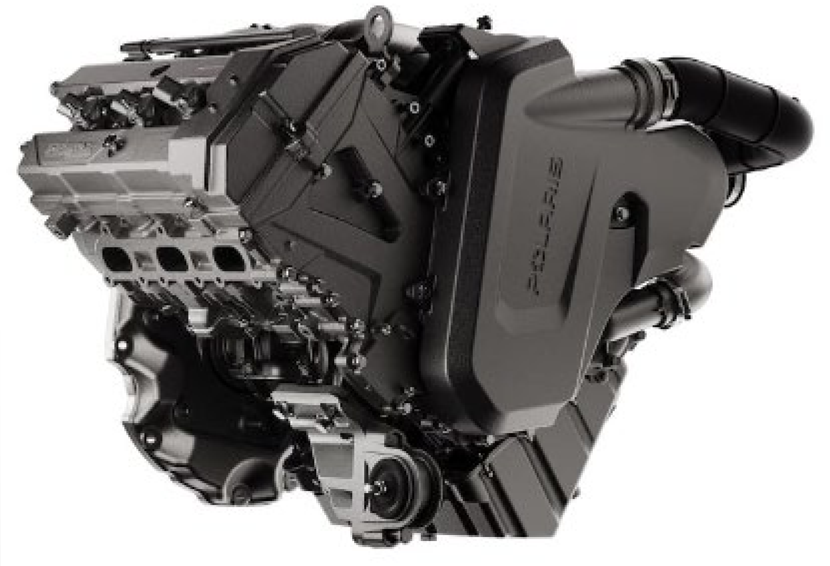
- Founded in 1954 in Roseau, Mn
- Headquarters in Medina, Mn
- Revenue of $8.4B in 2022

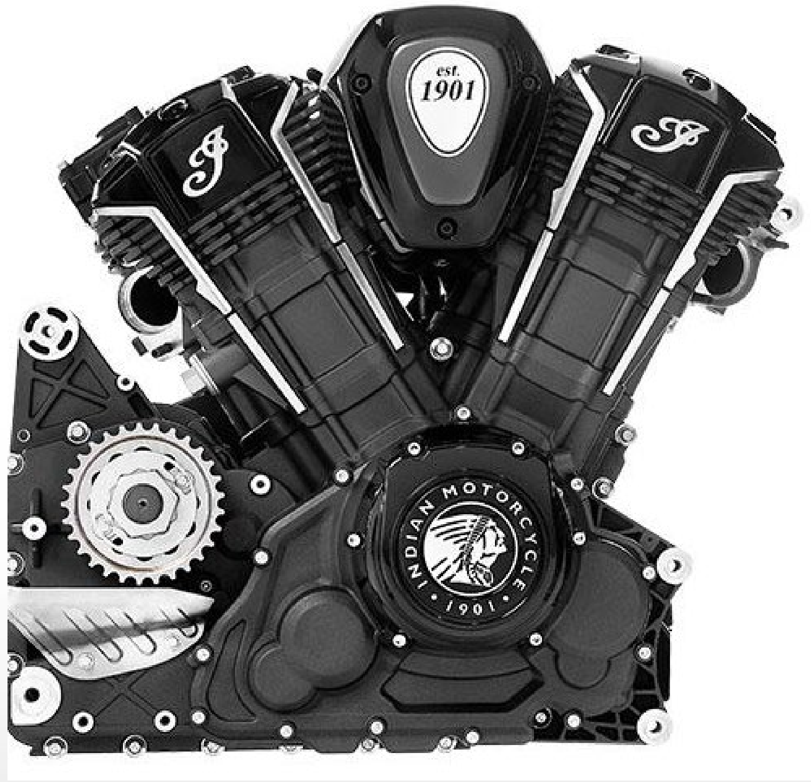
Polaris Background: Product

Industry leading products in the On-Road, Off-Road, Snow, and Marine Power Sports Market.

Polaris Background: Engines

- Started designing and manufacturing engines for our Snow, On-Road and Off-Road products in the late 1990's.
- 2-Stroke and 4-Stroke, naturally aspirated and boosted.
- 1-4 Cylinder Designs.
- Mostly water cooled, some air cooled.





Polaris Optimization Journey

Internal initiative to increase use of Optimization and Multi-Disciplinary Optimization (MDO) started 3 years ago.

2021

- Evaluate optimization tools.
- modeFrontier selected for purchase.
- Pilot Projects.

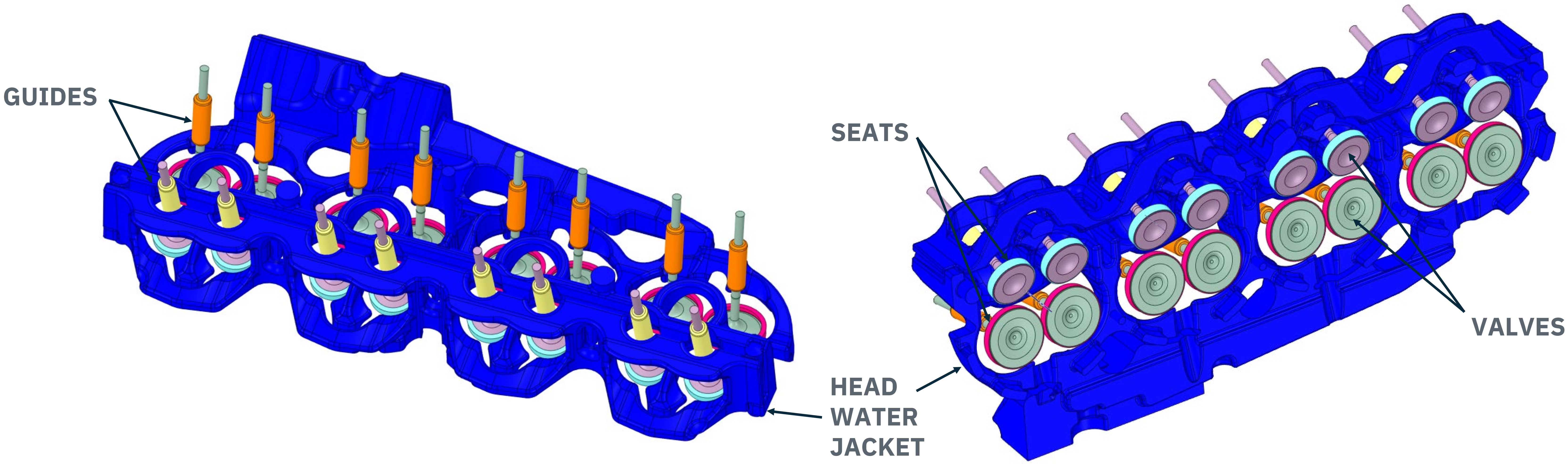
2022

- Develop optimization capabilities.
- Demonstrate value to internal partners.

2023

- Expand deployment of optimization with the analysis team.
- Train new users.

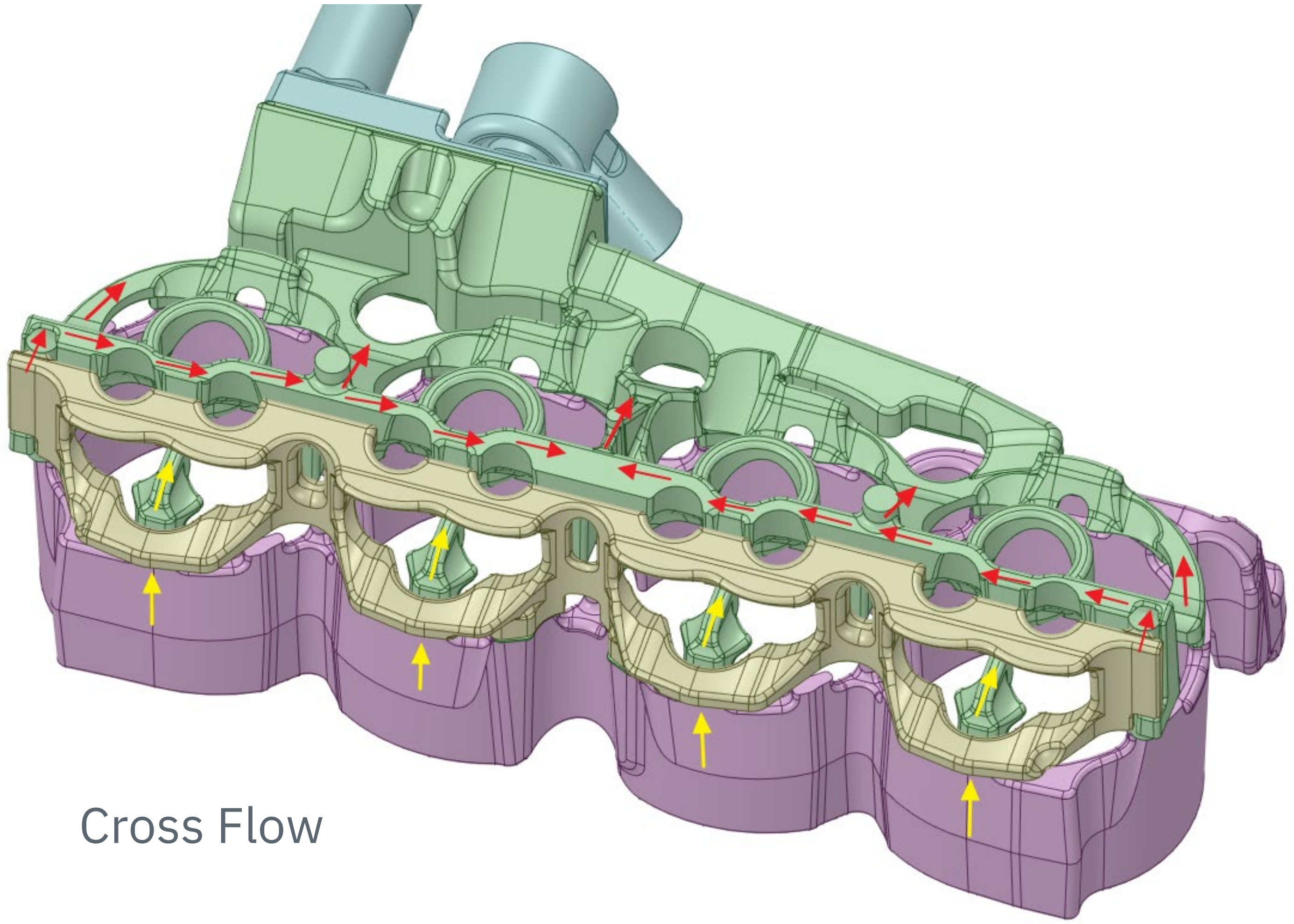
What is an Engine Water Jacket?



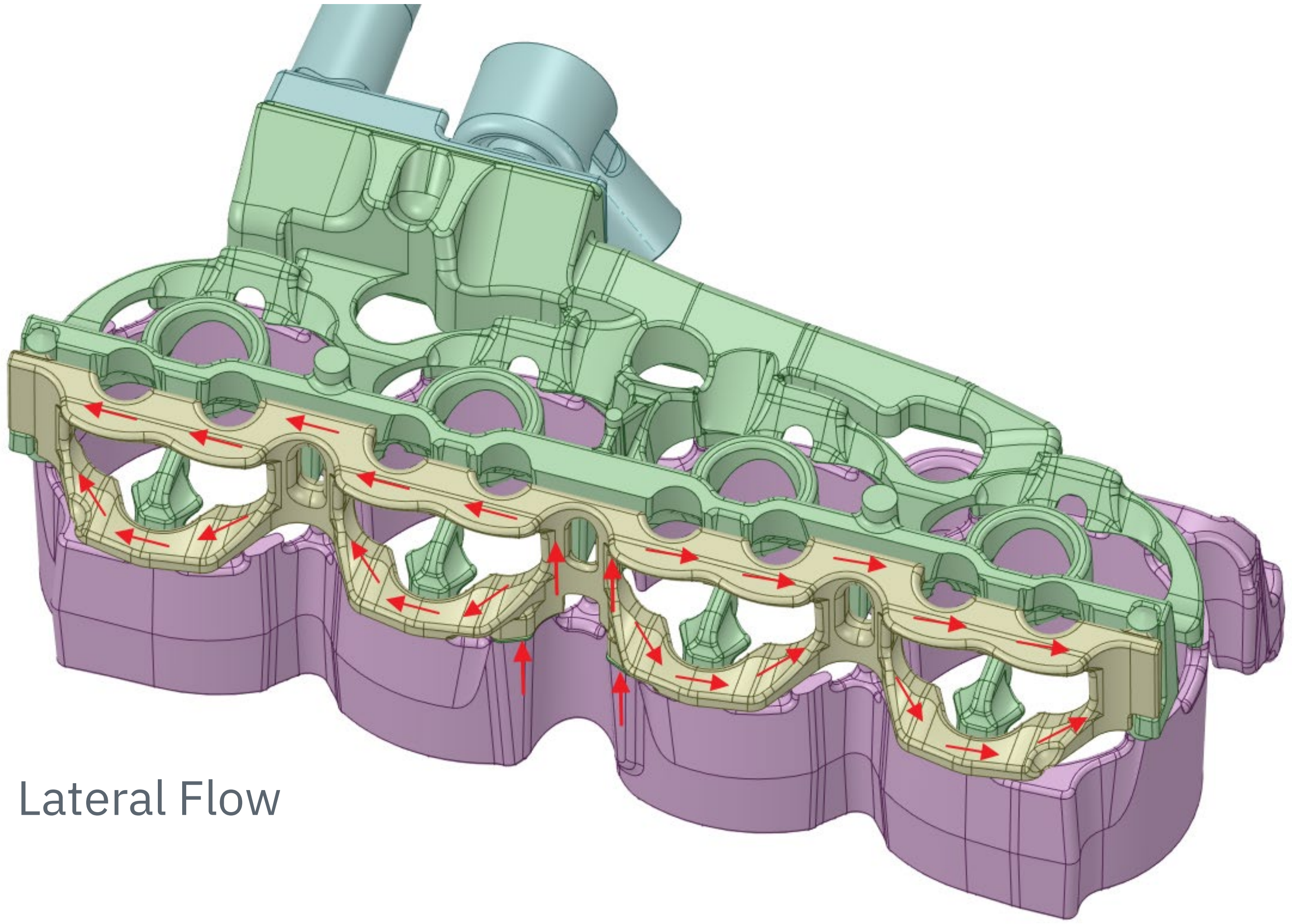
Water Jacket: Voids in the engine where coolant flows.

Objective: Reject waste combustion heat from the engine. Ensure that metal temperatures of the cylinder, cylinder head and valvetrain components remain within acceptable levels for engine performance and durability.

What is an Engine Water Jacket?



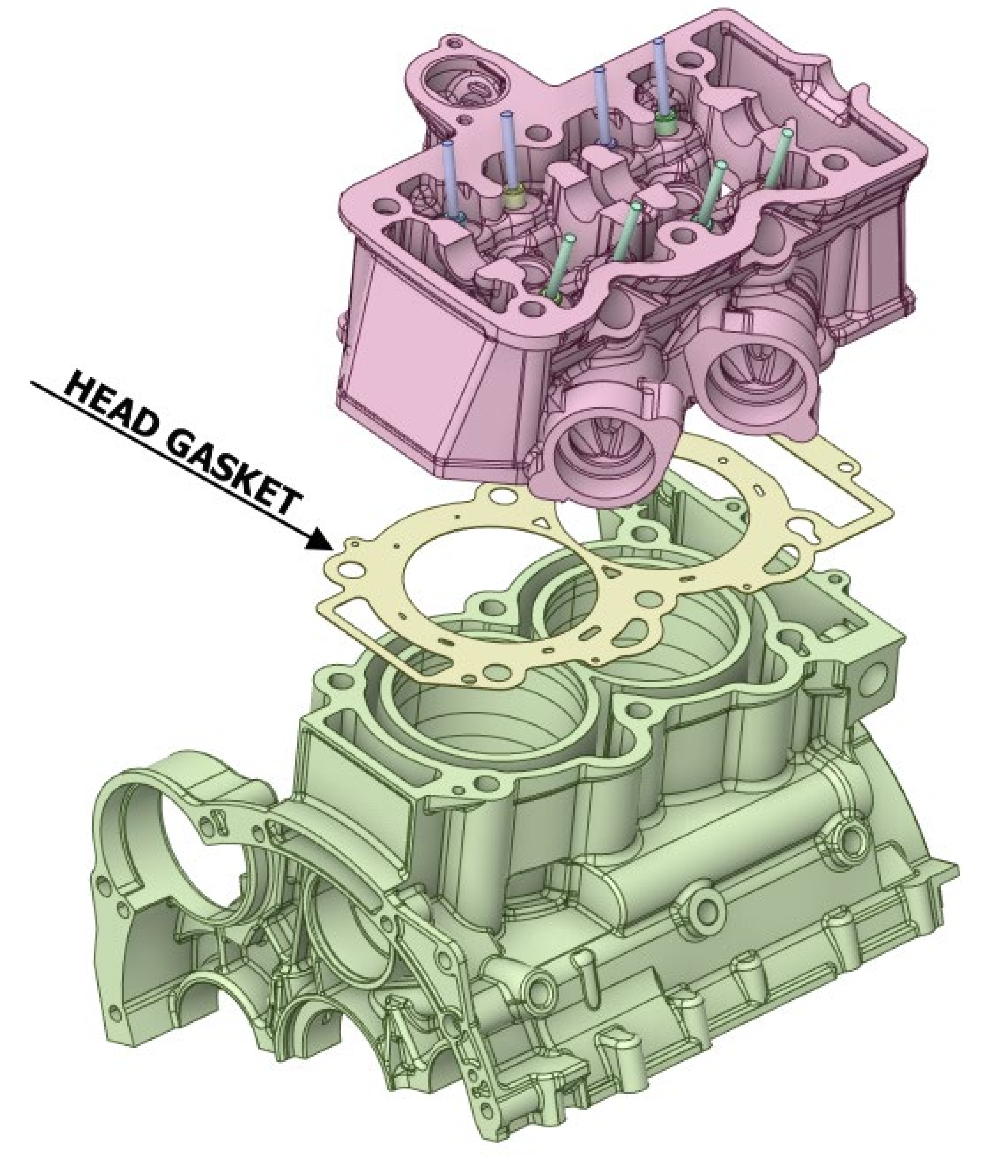
Cross Flow



Lateral Flow

Water Jacket Design: A good flow scheme/plan goes a long way!

Water Jackets: Continued



Head gasket is a critical component in the water jacket design

- Connects the lower (cylinder) and upper (head) sections of the water jacket.
- It supports the overall flow scheme
- It provides flow momentum where it's needed
- It is a significant contributor to overall system restriction (ΔP). Spend your pressure budget wisely!

When to Optimize?

Legacy designs

- Flow scheme may not be as well defined.
- Opportunity to change the gasket.
- Optimize to squeeze additional performance from the design.

New designs

- Flow scheme well defined.
- Gasket's role in the water jacket is clear.
- Still some room for optimization.

Multiple Motivations for Head Gasket / WJ Optimization

Optimization Outline

Inputs
- Gasket opening:
  - Radius
  - Span Angle
  - Location Angle

Models
- Flow (Ansys Fluent)
- Geometry (Creo + SpaceClaim)

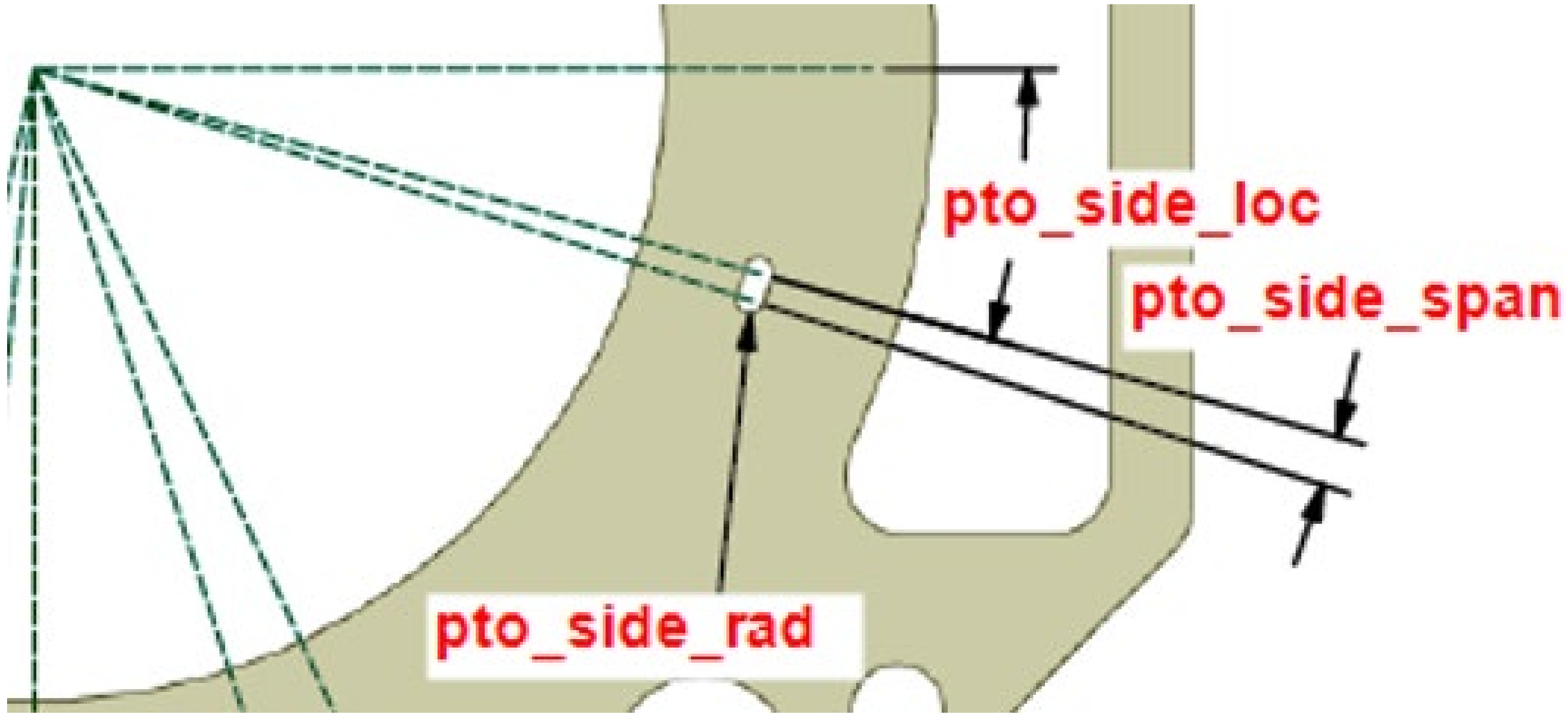
Key Outputs
- Critical Velocities
- Pressure Loss
- Mesh Quality

Constraints
- Pressure at or less than incumbent design.

Objectives
- Maximize Velocity in Exhaust Bridges
- Maximize lowest Recorded Velocity (minimize low flow zones)

DOE of n=75
Total runs = 200
Optimization Approach: pilOPT, all real runs.

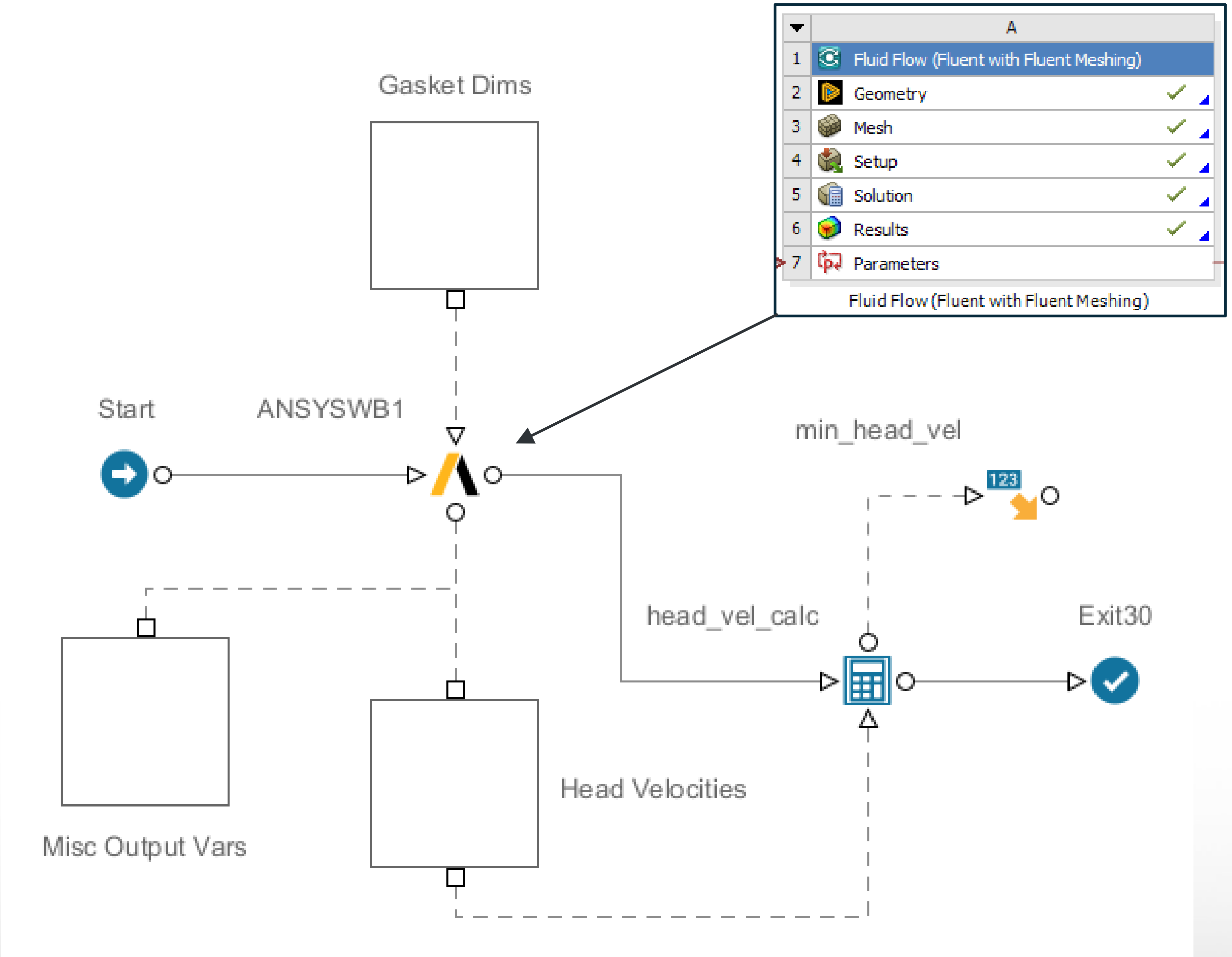
Inputs



Name	Type	Unit of measure	Lower bound	Upper bound
mag_main_span	Scalar	degree	0.5	14
pto_main_span	Scalar	degree	0.5	14
mag_main_rad	Scalar	mm	0.5	2.5
pto_main_rad	Scalar	mm	0.5	2.5
mag_main_loc	Scalar	degree	3	12
pto_main_loc	Scalar	degree	3	12
mag_side_span	Scalar	degree	0.5	7
pto_side_span	Scalar	degree	0.5	7
mag_side_rad	Scalar	mm	0.5	2.5
pto_side_rad	Scalar	mm	0.5	2.5
mag_side_loc	Scalar	degree	15	18
pto_side_loc	Scalar	degree	15	18
pto_aux_rad	Scalar	mm	0.5	2
mag_aux_span	Scalar	degree	0.5	7
mag_aux_rad	Scalar	mm	0.5	2
pto_aux_span	Scalar	degree	0.5	7

Gasket openings modeled as slots with 3 input variables. A locating angle, a span angle and a slot radius. Design space is bounded by the mating head and cylinder water jacket geometries.

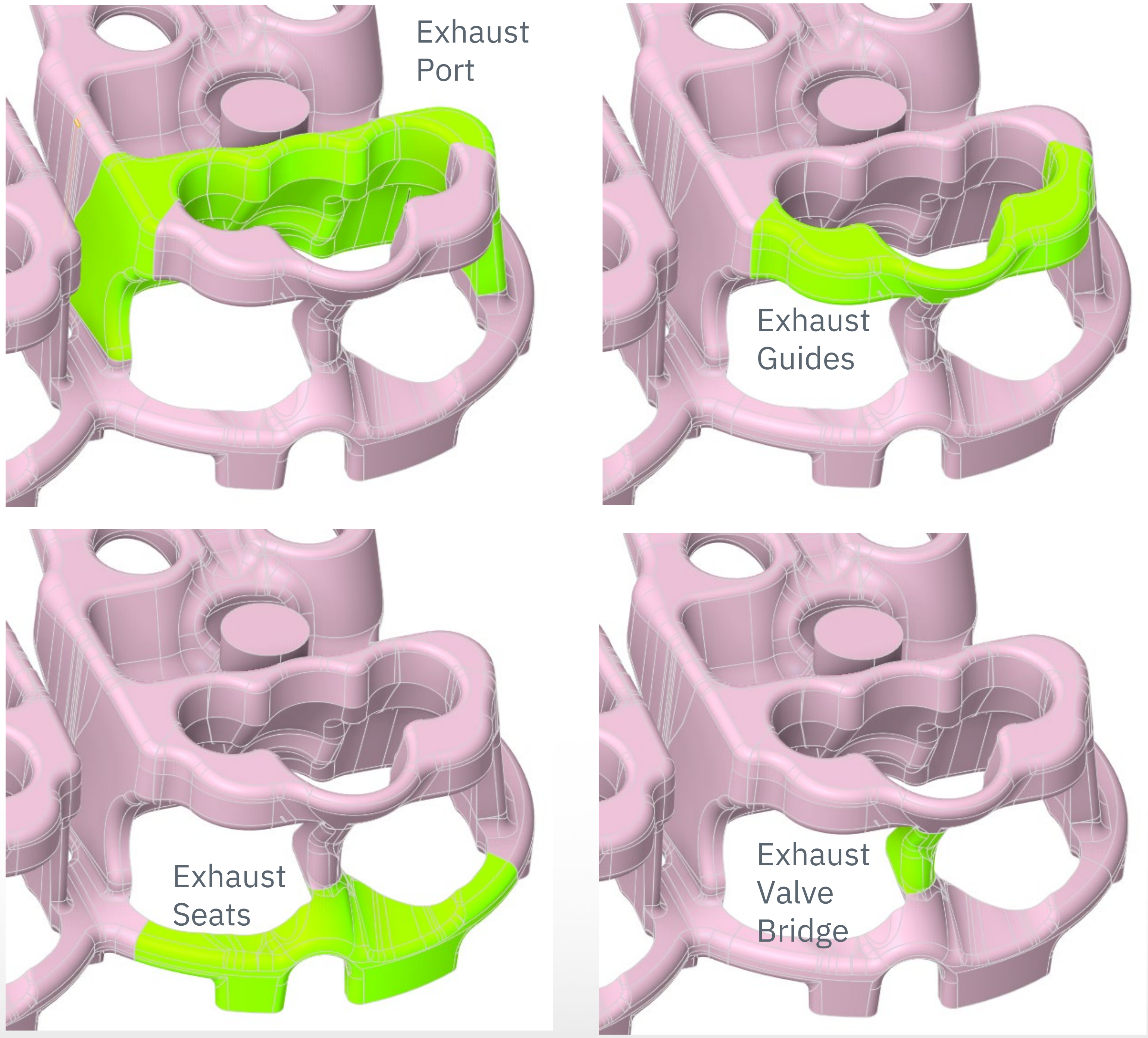
Modeling Approach and Workflow



Notes:

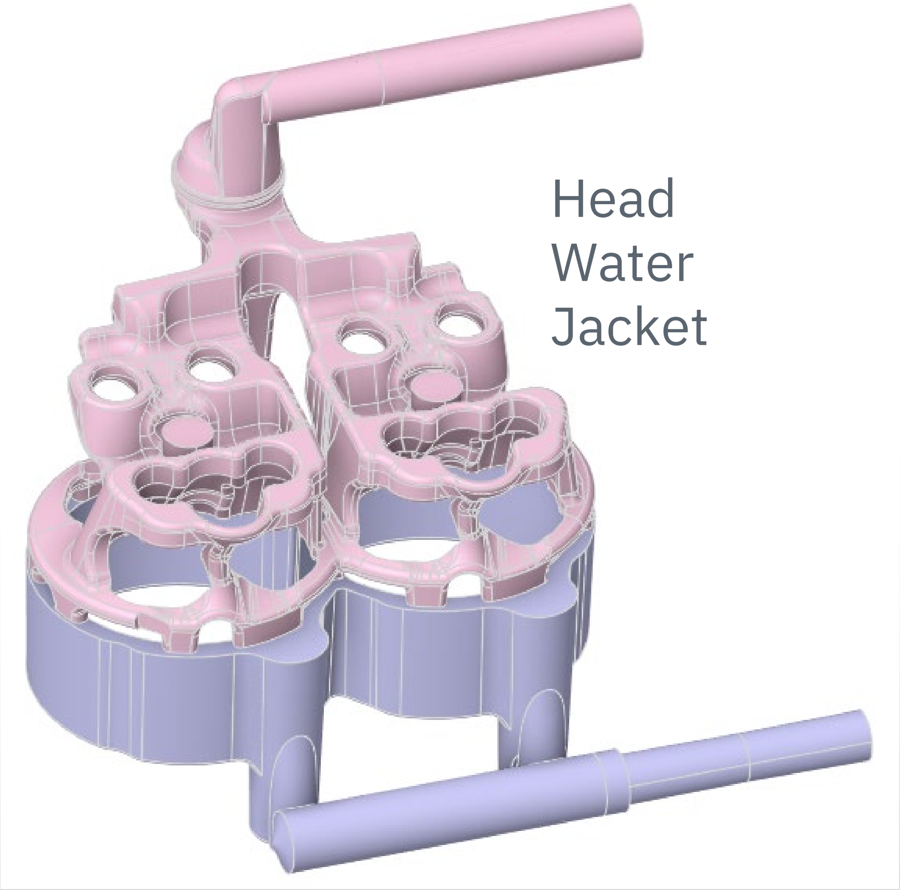
- Ansys Workbench handles the Creo geometry import along with the Fluent meshing and Fluent flow solver.
- Calculator node performs a simple min( ) function on all monitored velocities to extract the lowest velocity.
- One iteration takes about 35 minutes from start to finish.
- Ability to run up to 2 designs concurrently.

Key Velocity Outputs

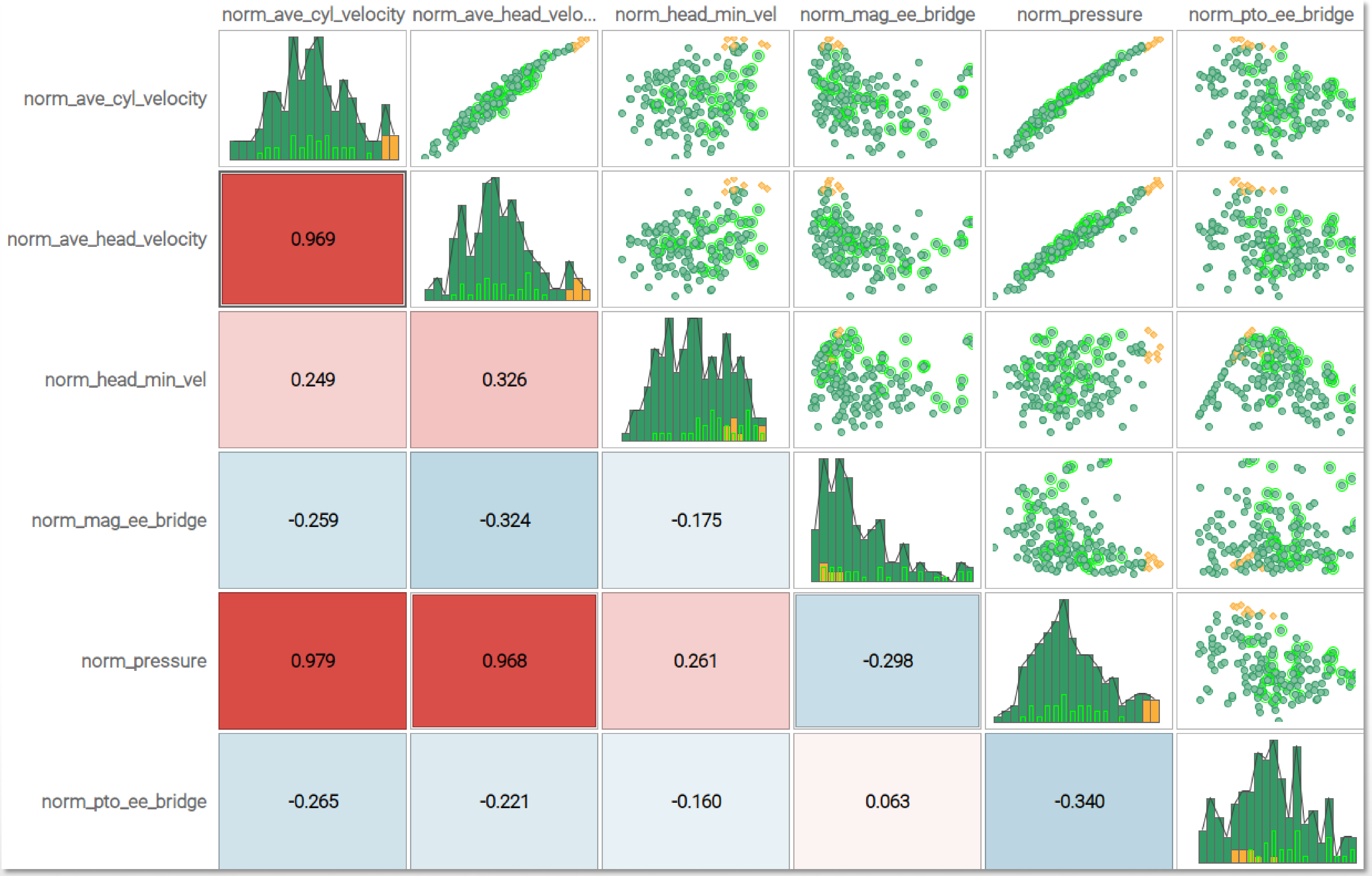


Regions of the Water Jacket Where Velocity is Monitored

- 40 Velocity monitor points are placed in key regions of the water jacket so that flow performance can be tracked by zone.
- Volume based average velocity is calculated for head and cylinder jacket zones as well.

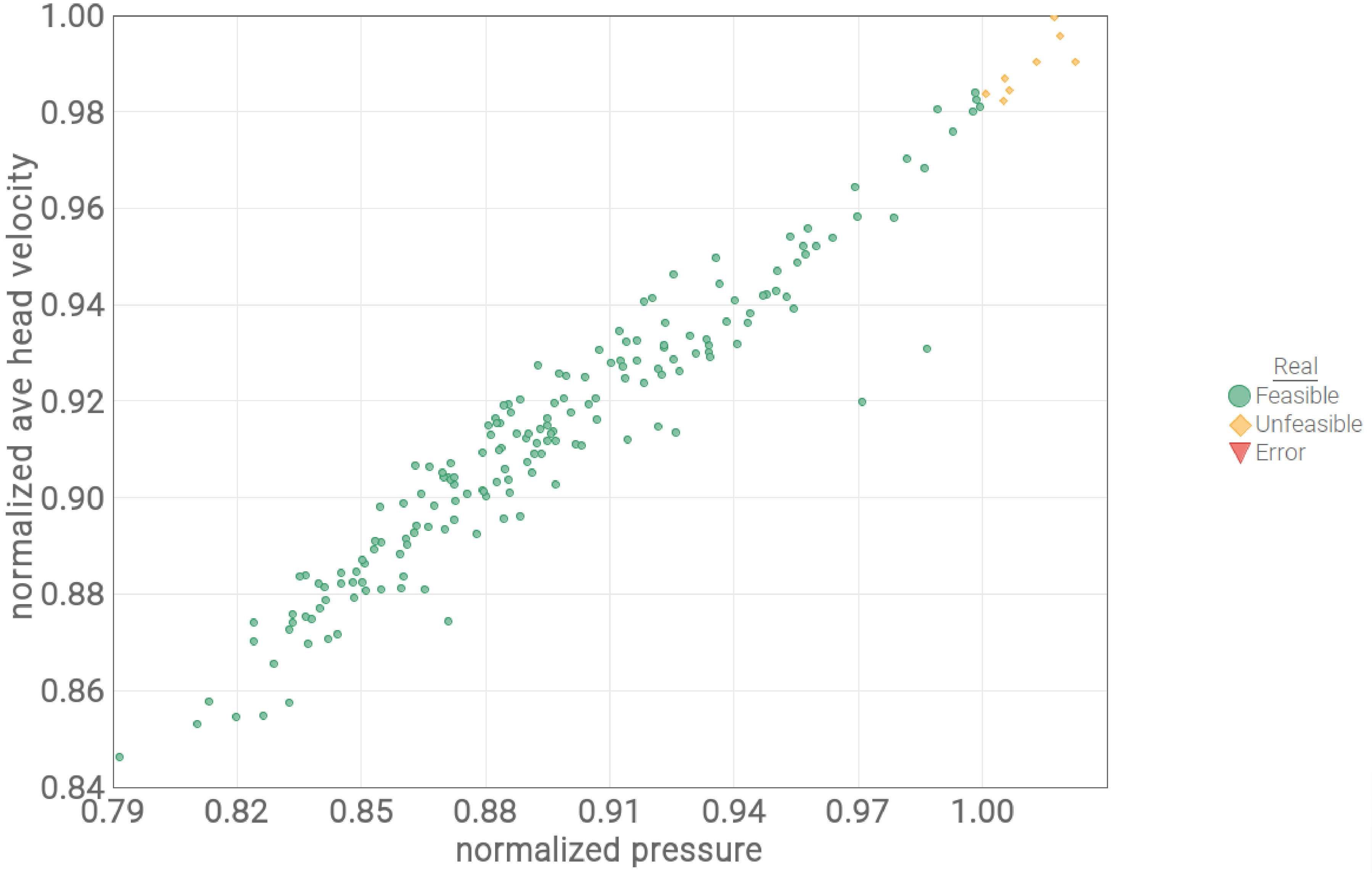


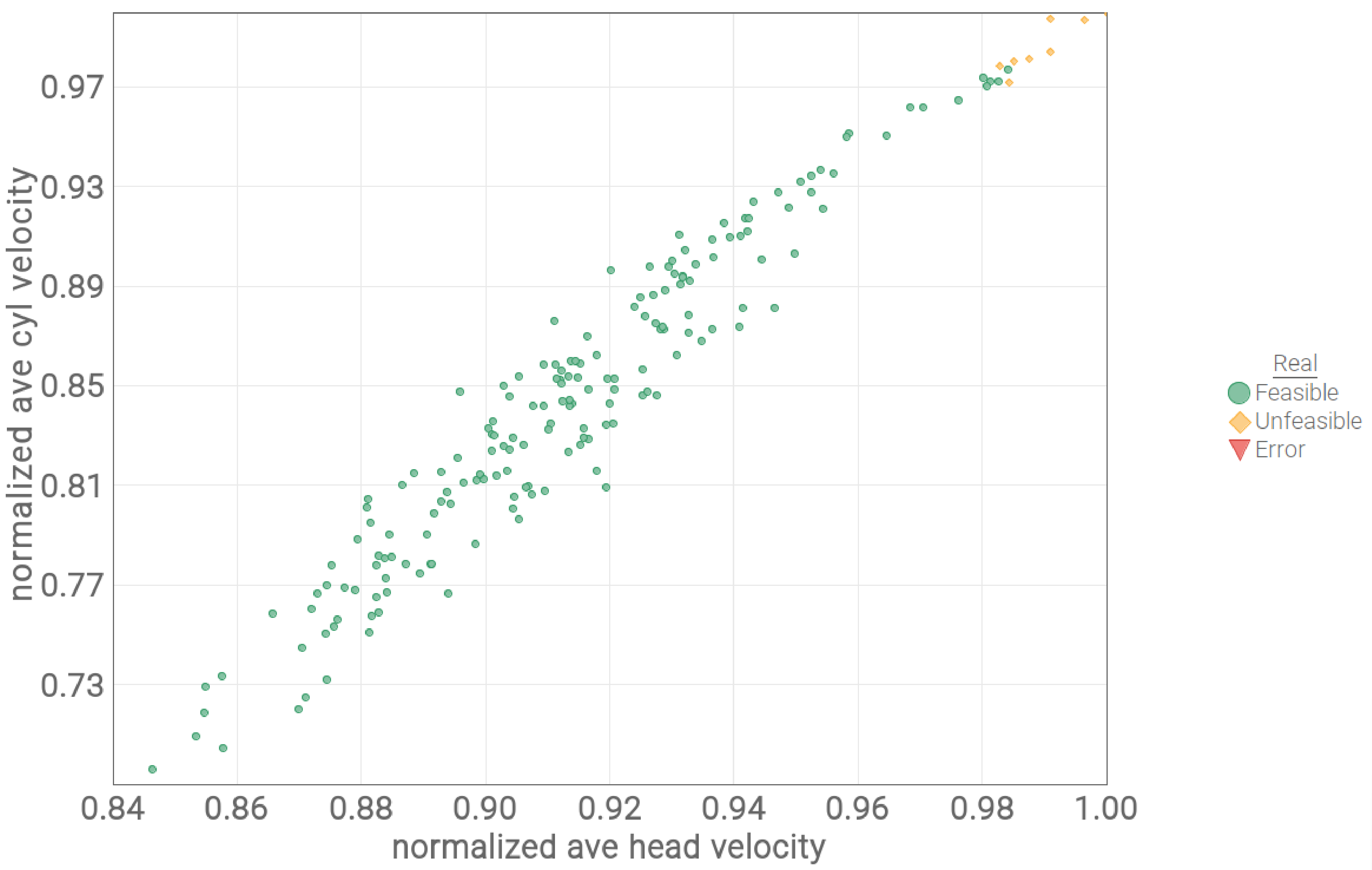
Results: Output Correlations



The relations between outputs can tell us a lot about the quality of the water jacket.

Results: Key Output Trends





Pressure drop and average head/cylinder velocities have a strong positive correlation.

Average head and cylinder velocities have a strong positive correlation.

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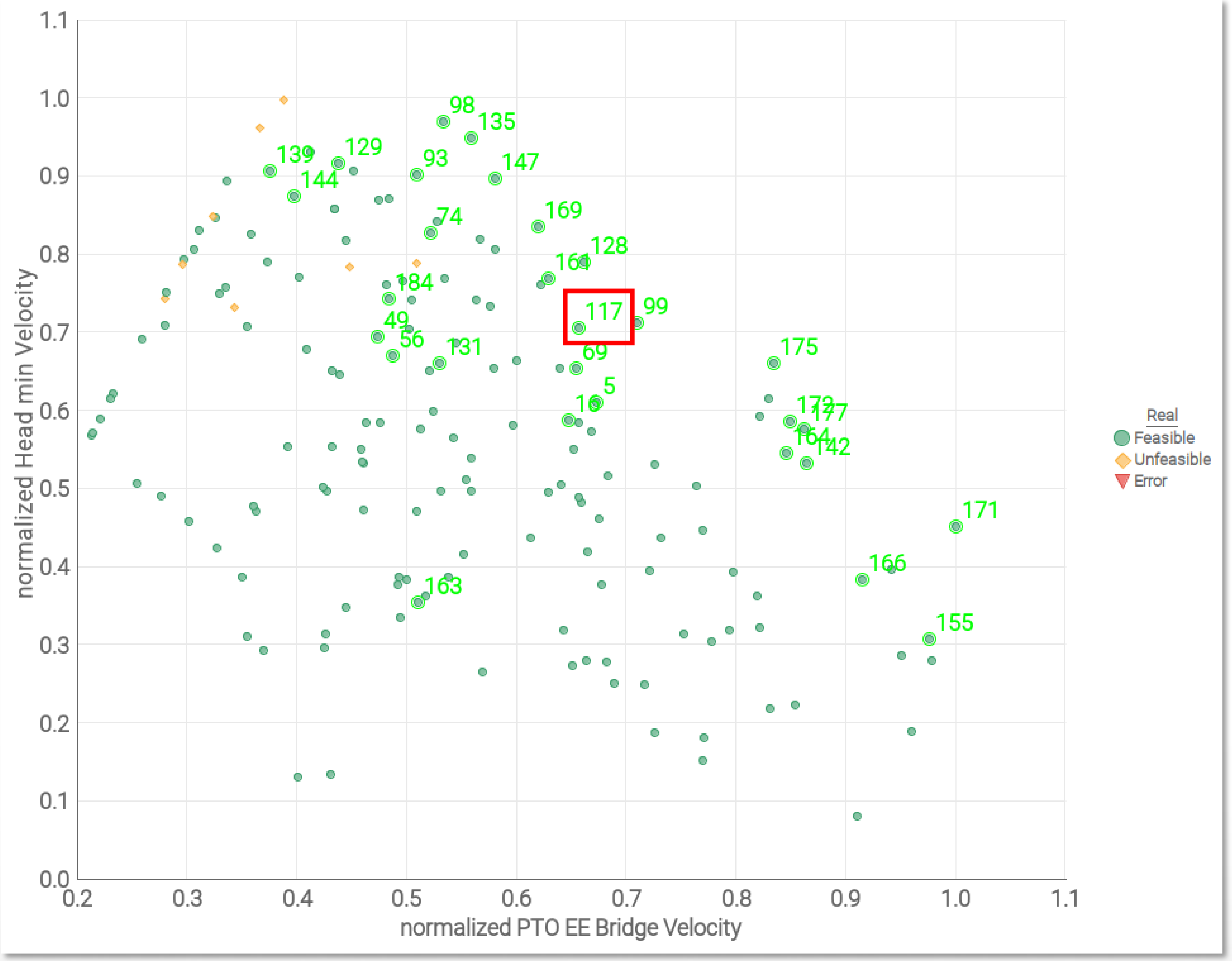
Results: Objectives



Objective Scatter Plots with Pareto Designs Marked. Chosen Design Highlighted.

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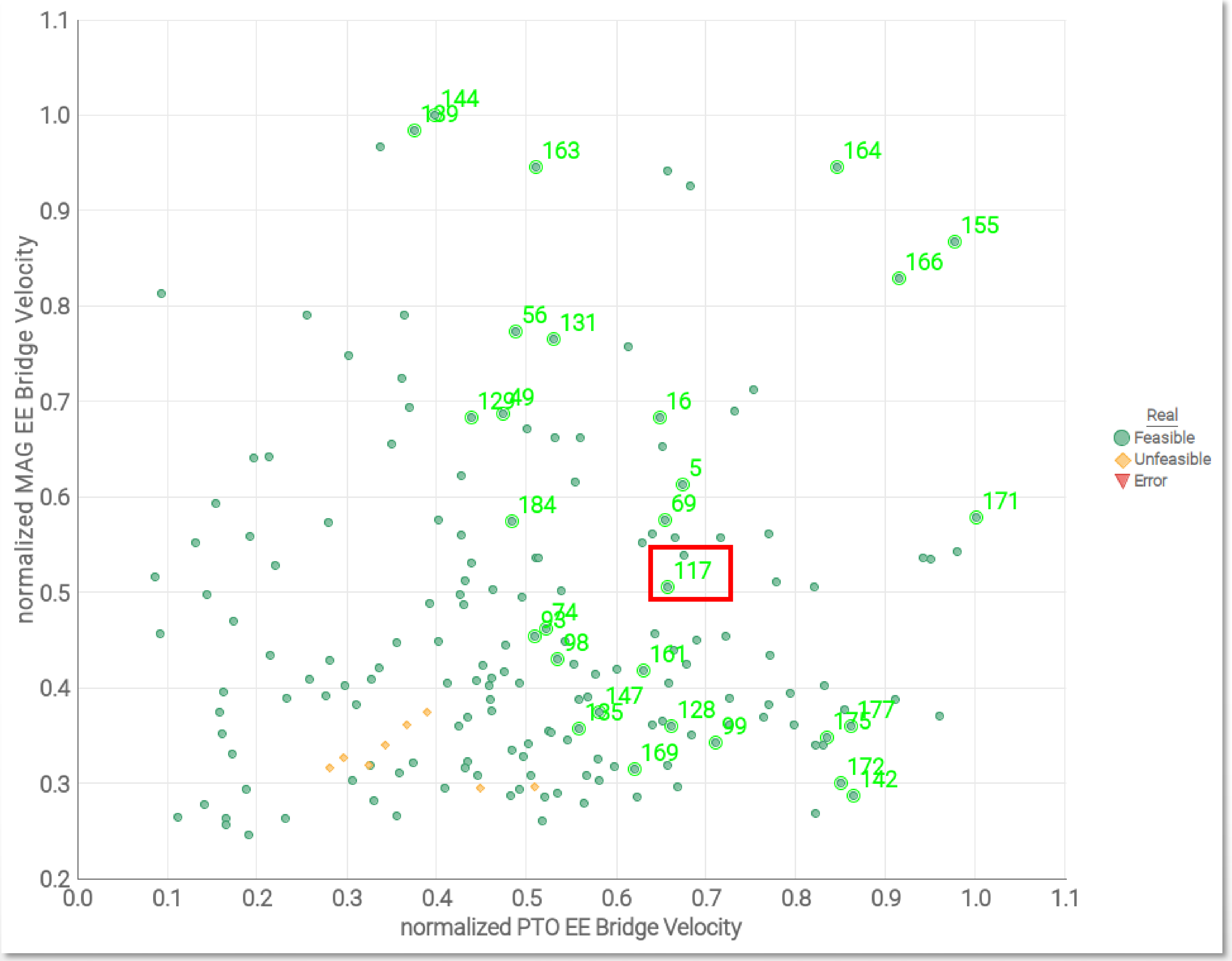
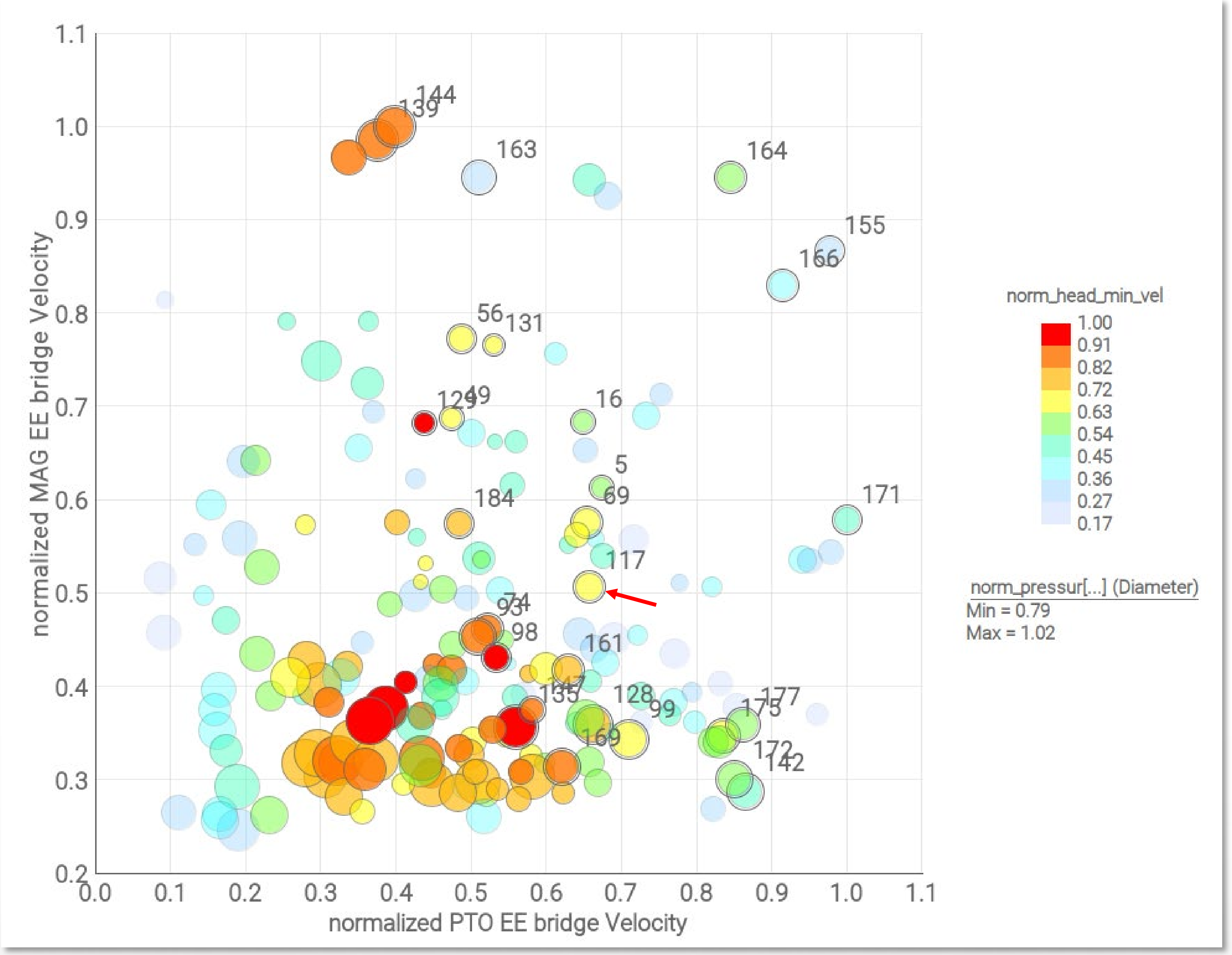
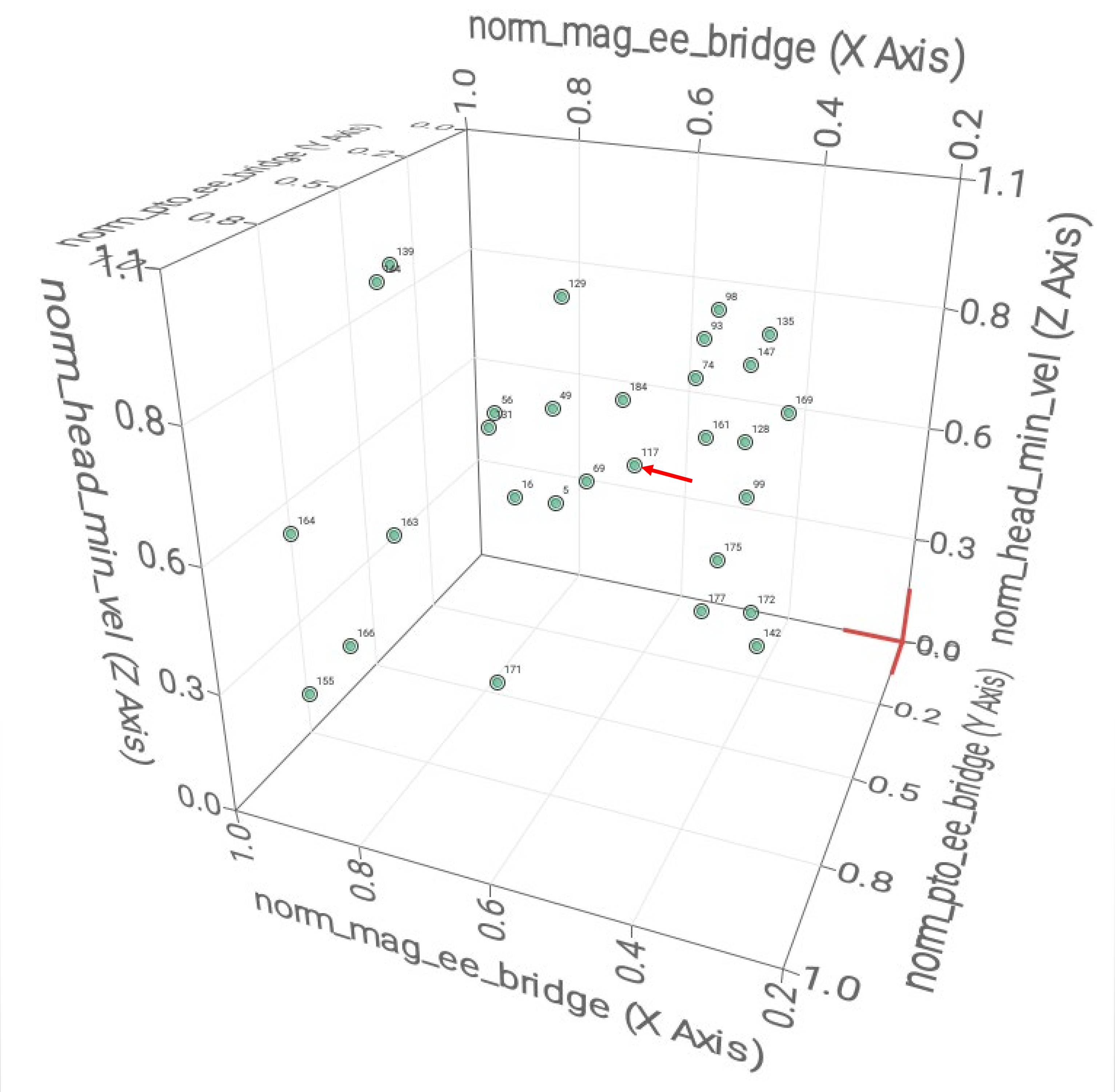
Results: Objectives





Objective Scatter Plots with Pareto Designs Marked. Chosen Design Highlighted.

Results: Selected Design



- The selected design was chosen for its balance of EE bridge velocities values and relative lack of low velocity regions.
- The design is in the middle of the Pareto front.

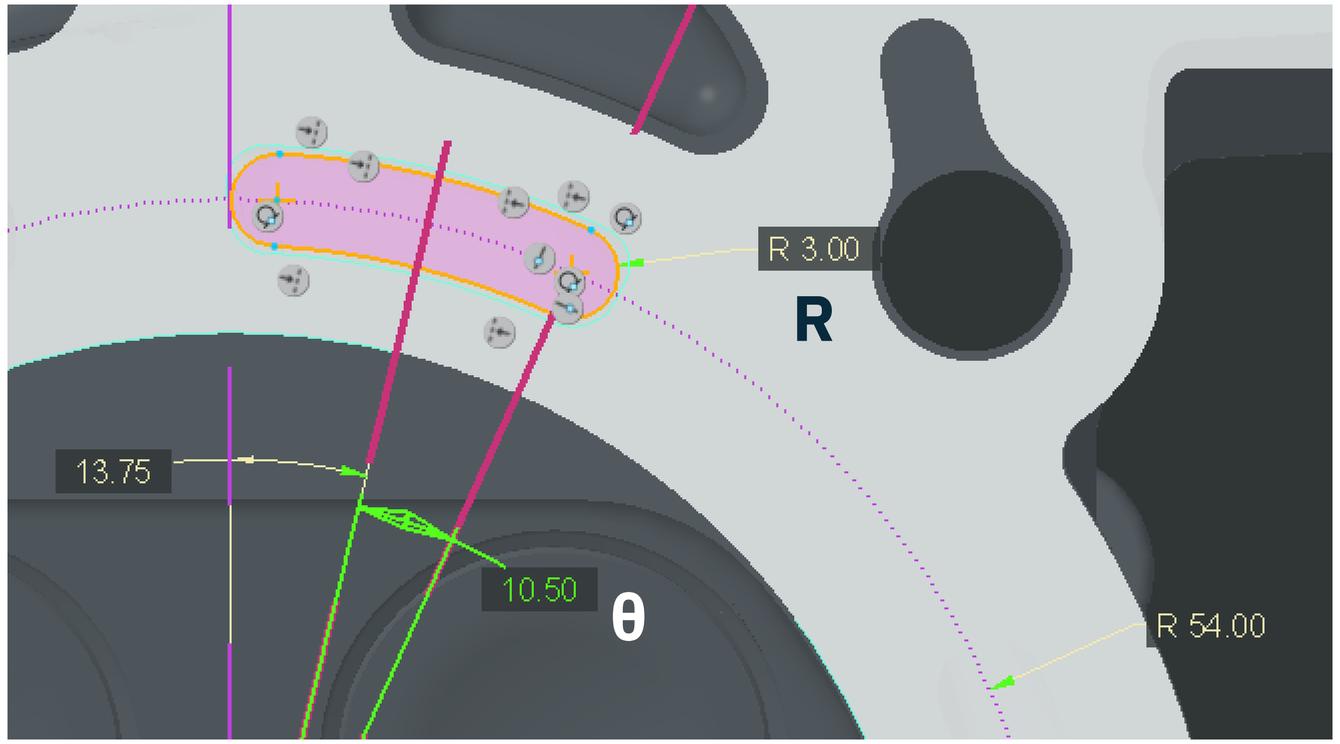
Next Steps / Improvements

Input Reduction

- The number of input variables in these optimizations can get very high (location angle, span angle and radius vars for each opening).

To reduce inputs:

- Fix location angle (tends to be a less influential input).
- Calculate radius and span angle as a function of the design space min/max and a scalar variable φ.
- This reduces 3 input variables into 1.
- Can be valuable for a first pass exercise when you are trying to find which locations are the most important.



$$R = R_{min} + \varphi(R_{max} - R_{min})$$

$$\theta = \theta_{min} + \varphi(\theta_{max} - \theta_{min})$$

$$0 \leq \varphi \leq 1$$

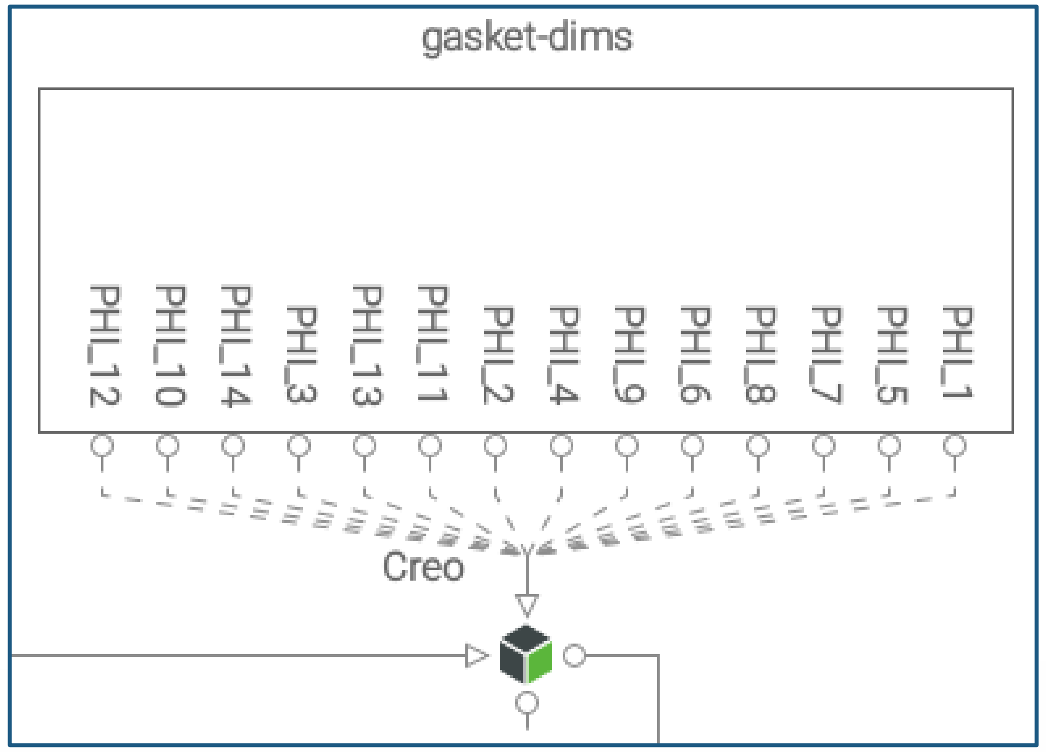
Next Steps / Improvements

Optimize a flow + thermal model. Use temperatures as the output variables instead of velocity monitors.

- A more direct approach (temperature is what we care about).
- Easier to correlate (measuring velocities inside a water jacket is difficult).
- Reduced number of output variables.
- Solve times can be a concern but are manageable.

Create a test DOE with the Creo node to validate parametric geometry.

- Allows you to test many points in the design space quickly so that corner cases can be found upfront.



Questions?

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