Model Based Thermotronic Systems

SEDDIT Project workshop 2026-05-20

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The project

Carl Steen

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Main supervisor

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Co-supervisor

The project

TRATON

SCANIA / MAN / INTERNATIONAL / Truck Bus

My Project

Maintain competence in the measuring, modeling, and control of internal combustion engines (ICEs)

ICE modeling

- Turbocharger
  - Compressor modeling
- Bio- and E-fuels
  - RME
  - HVO100
  - Hydrogen

Theory

Compressor Structure

Pressure ratio

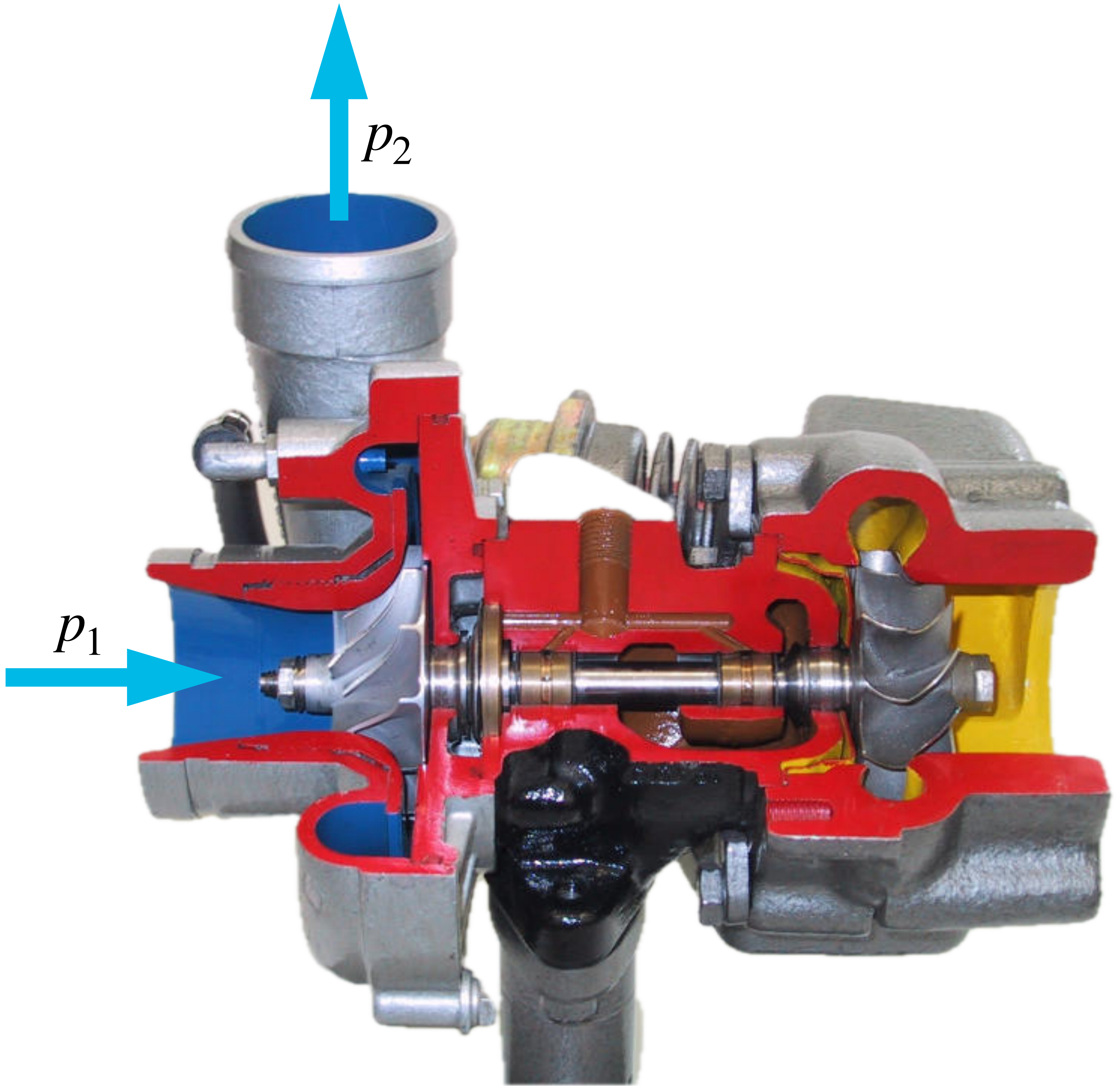
$$\Pi_c = \frac{p_2}{p_1}$$

Corrected mass flow

$$\bar{W}_c = W_c \frac{\sqrt{T_1/T_r}}{p_1/p_r}$$

Corrected rotational speed

$$\bar{N}_c = N_c \frac{1}{\sqrt{T_1/T_r}}$$



$p_r \approx 1$ atm

$T_r \approx 25°C$

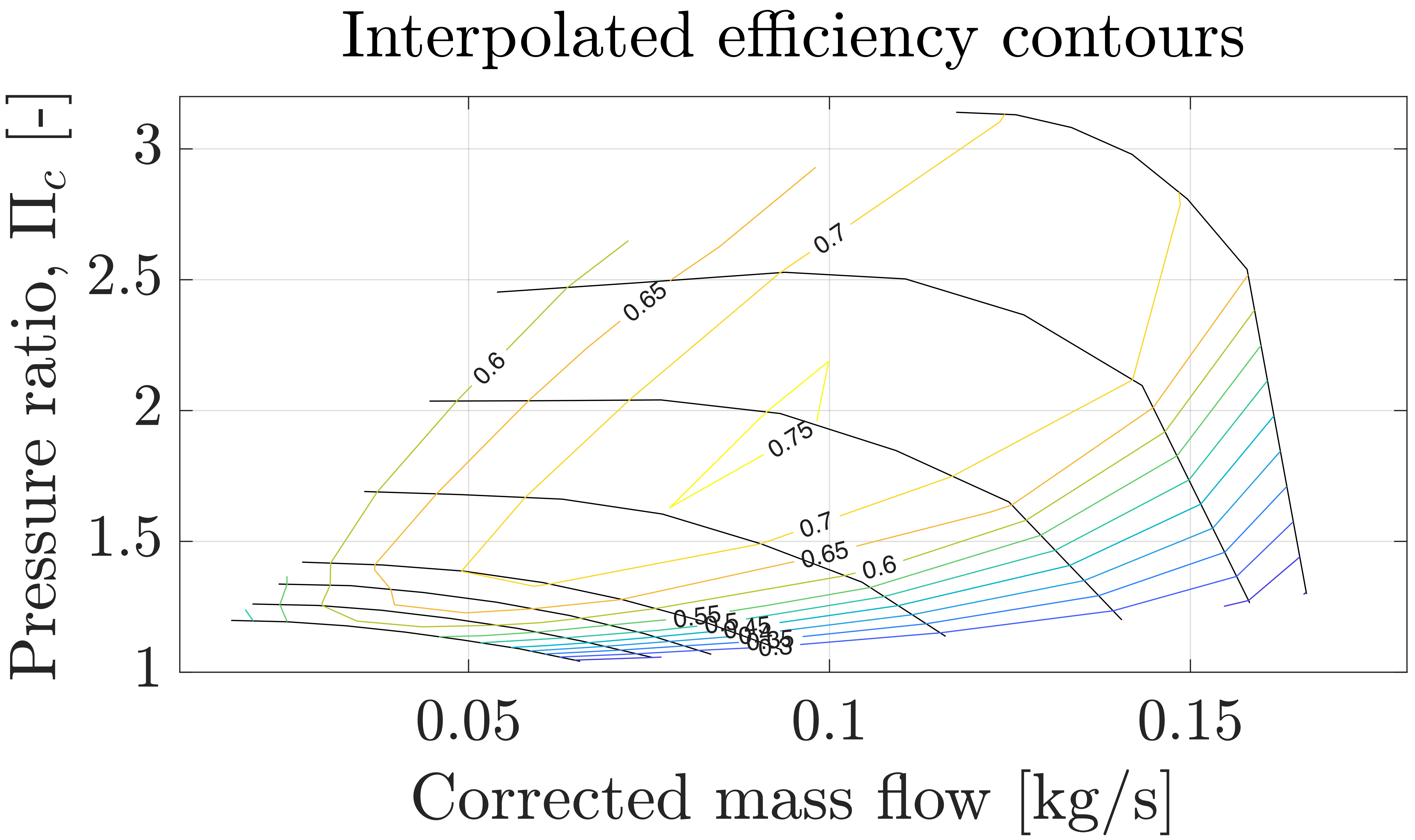
Compressor Map

- Pressure ratio
- Corrected mass flow
- Speedlines

Model structures

$$\bar{W}_c = f\left(\bar{N}_c, \Pi_c\right)$$

$$\Pi_c = f\left(\bar{N}_c, \bar{W}_c\right)$$



Compressor Structure

Dimensionless variable

$$\Psi = \frac{\Delta h_{is}}{\frac{1}{2}U_c^2} = \frac{c_p T_{01}\left(\Pi_c^{\frac{\gamma-1}{\gamma}} - 1\right)}{\frac{1}{2}U_c^2}$$ Energy transfer coefficient

$$\Phi = \frac{W_c}{\frac{\pi}{4}\rho_{01}D_c^2 U_c}$$ Flow coefficient

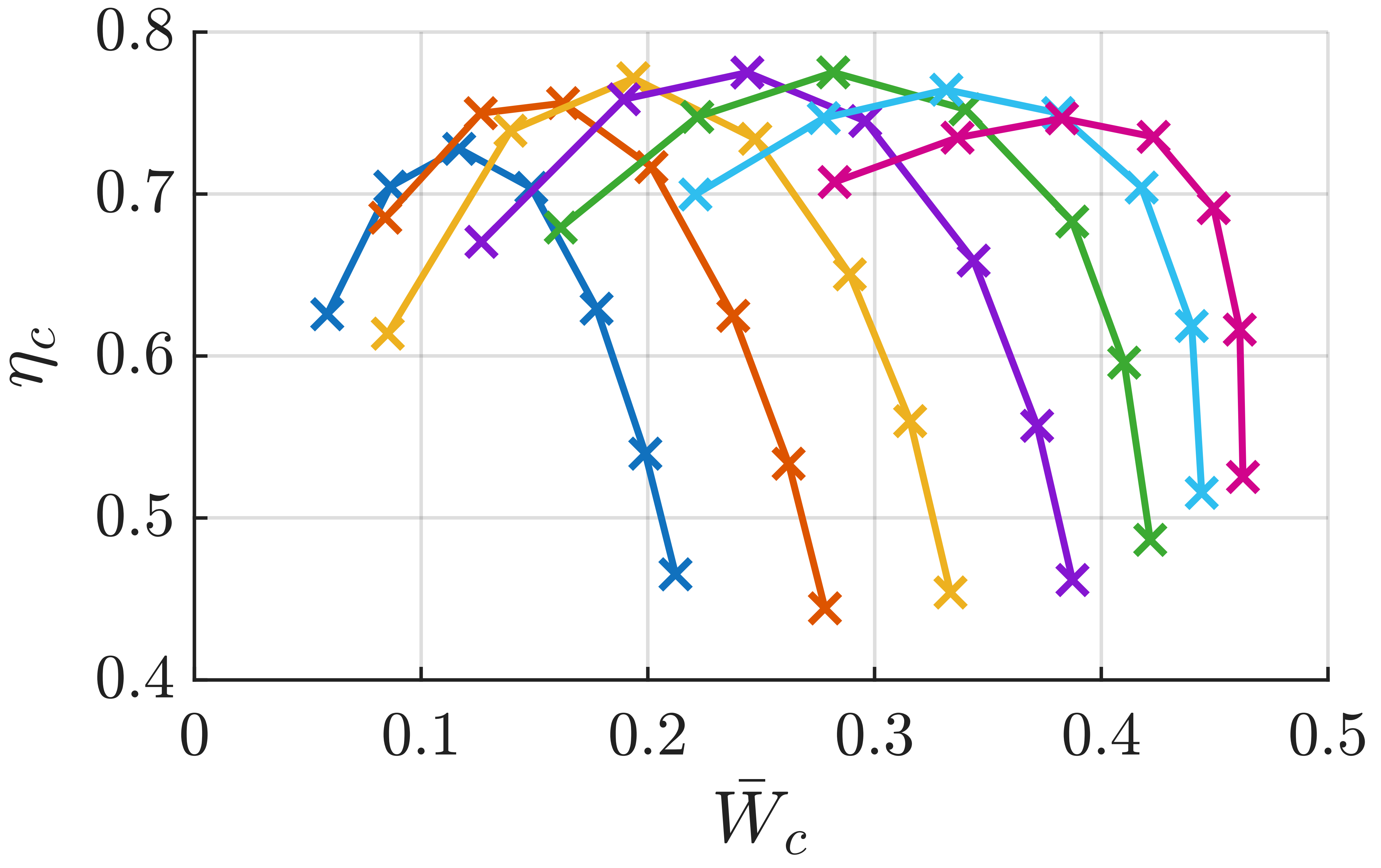
$$M = \frac{U_c}{\sqrt{\gamma R T_{01}}}$$ Mach number

$$U_c = \frac{\pi D_c N_c}{60}$$

Compressor Efficiency

The efficiency is calculated by

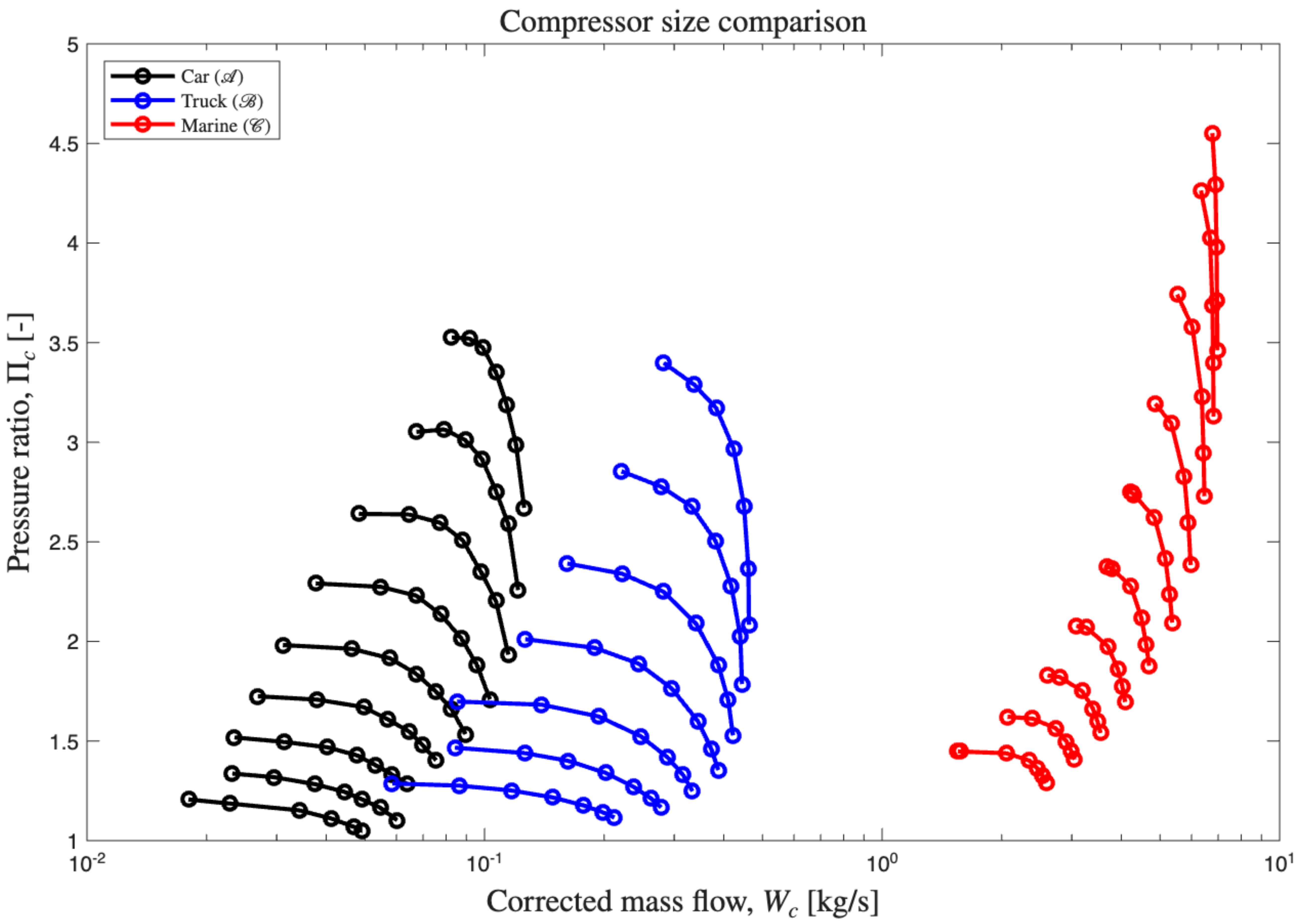
$$\eta_c = \frac{\Delta h_{is}}{\Delta h_{act}} = \frac{\frac{p_{02}}{p_{01}}^{\frac{\gamma-1}{\gamma}} - 1}{\frac{T_{02}}{T_{01}} - 1}$$



Compressor Modeling

Compressor Modeling

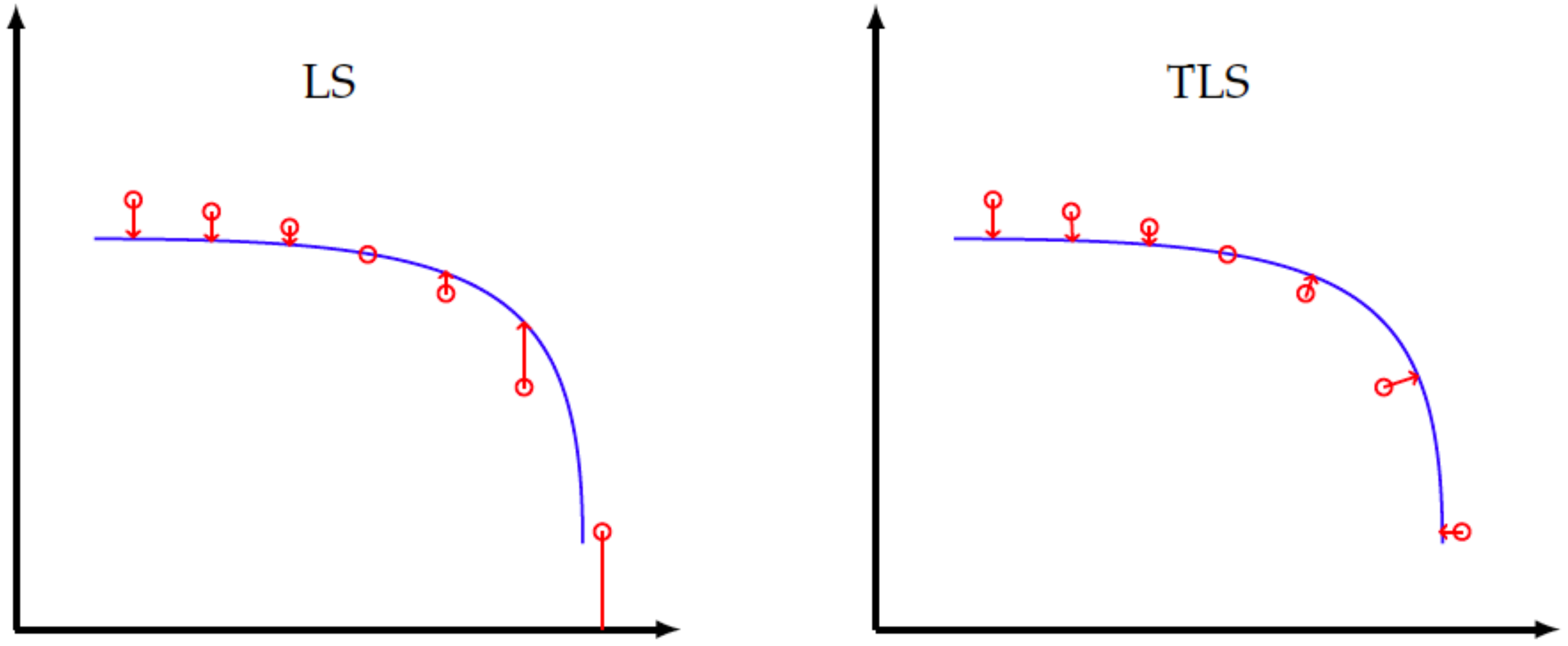
- Six compressor models
- Compressors of three different sizes
- Evaluate the models using Total Least Squares (TLS)



Total Least Squares (TLS)

- Assumes errors in both quantities

$$TLS = \min \left[\sum_{i=1}^{N} \left(\left[\frac{y_i - f(\hat{x}_i | \theta)}{\max(y)} \right]^2 + \left[\frac{x_i - \hat{x}_i}{\max(x)} \right]^2 \right) \right]$$



Compressor Models

Guan Cong

$$\Phi = \frac{k_1 + k_2 M + k_3 \Psi + k_4 M \Psi}{k_5 + k_6 M + \Psi}$$

Karlsen I

$$\Phi = a(M) + \left(1 - e^{\Psi^{c(M)} + b(M)}\right)$$

Melkhede

$$W_{c,corr} = a_1 + a_2 N_{c,corr} + a_3 N_{c,corr}^2 + a_4 N_{c,corr}^3$$

$$+ \frac{a_5}{\Pi_c} + \frac{a_6}{\Pi_c^2} + \frac{a_7}{\Pi_c^3} + a_8 \frac{N_{c,corr}}{\Pi_c} + a_9 \frac{N_{c,corr}}{\Pi_c^2} + a_{10} \frac{N_{c,corr}^2}{\Pi_c}$$

Müller I & II

$$\Pi_c = \left(\frac{\Delta h_{is}(W_c, U_c)}{c_p T_{in}} + 1 \right)^{\frac{k}{k-1}}$$

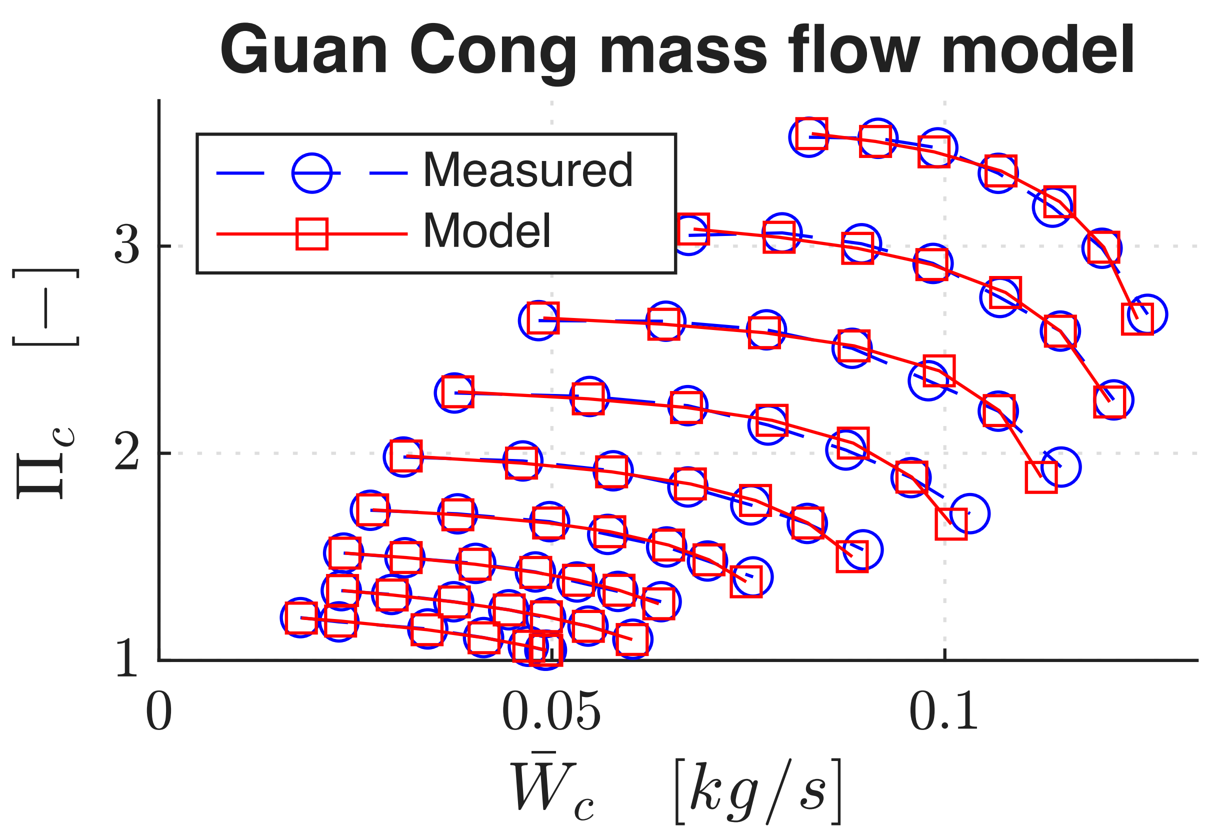
Ellipse

$$1 = \left(\frac{W_c - W_{zs}}{W_{ch} - W_{zs}} \right)^{CUR} + \left(\frac{\Pi_c - \Pi_{ch}}{\Pi_{zs} - \Pi_{ch}} \right)^{CUR}$$

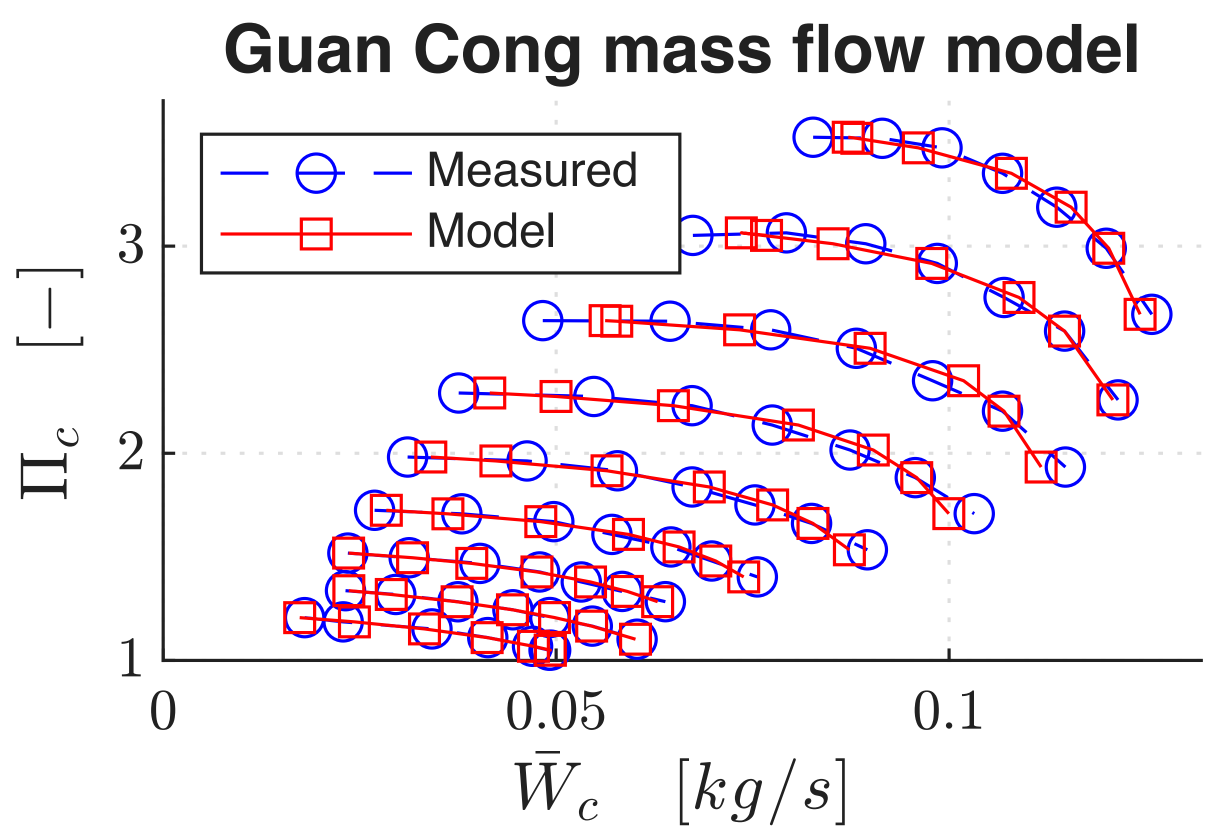
Results

Table 3. Error evaluation results of each compressor mass flow rate model in the design operating area for Compressor $\mathcal{A}$.

Model	# parameters	TLS [–]	LS [–]	R_c^2 [–]	MAPE [%]
Guan Cong	56	0.0030	0.0305	0.9951	0.5361
Karlsen I	10	0.0043	0.0586	0.9994	0.6814
Malkhede	10	0.0134	0.0918	0.9978	1.1981
Müller I	9	0.0024	0.0033	0.9993	0.6177
Müller II	4	0.0267	0.0267	0.9890	2.5341
Ellipse	14	0.0014	$8.268{\cdot}10^{-4}$	0.9996	0.6250



TLS



LS

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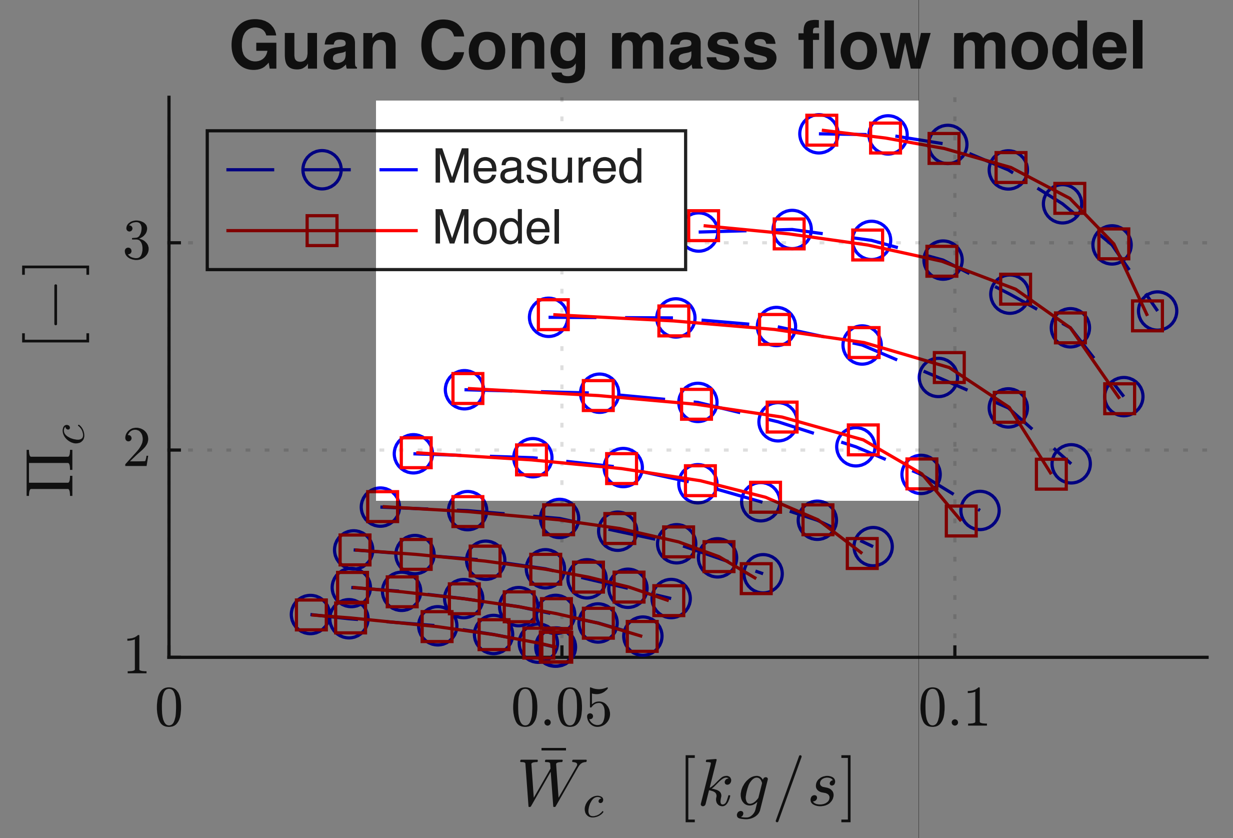
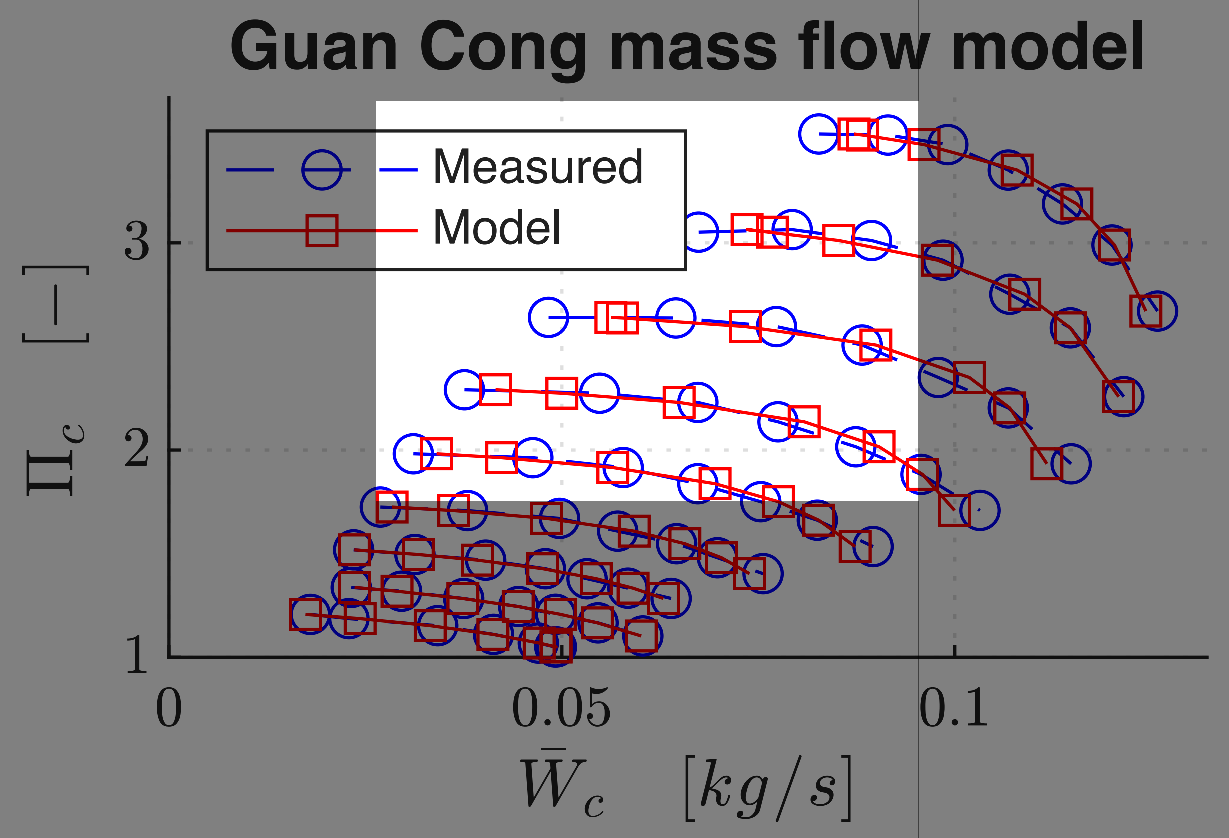


TLS



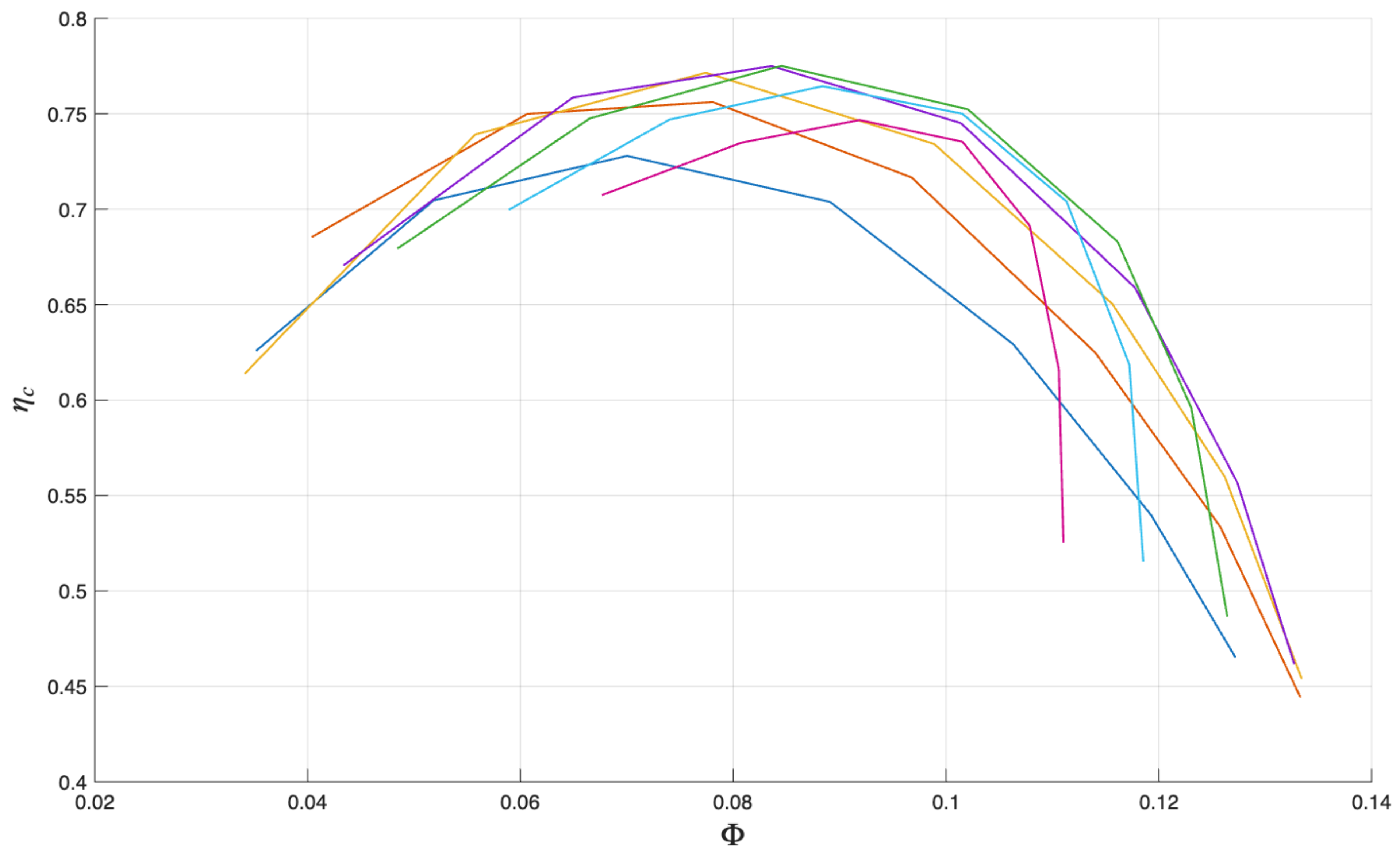
LS

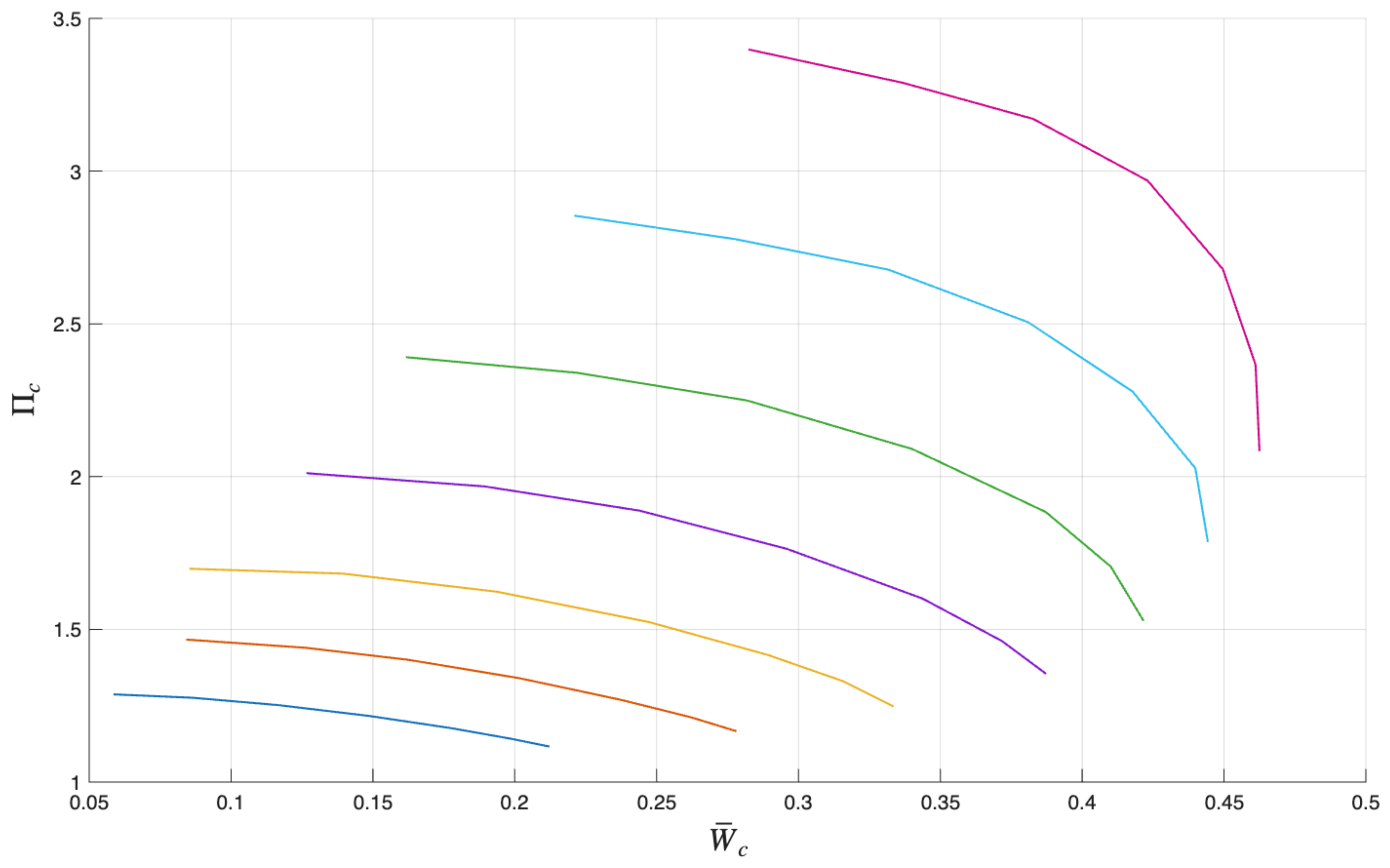
Ongoing Work

Dimensionless Efficiency Modeling

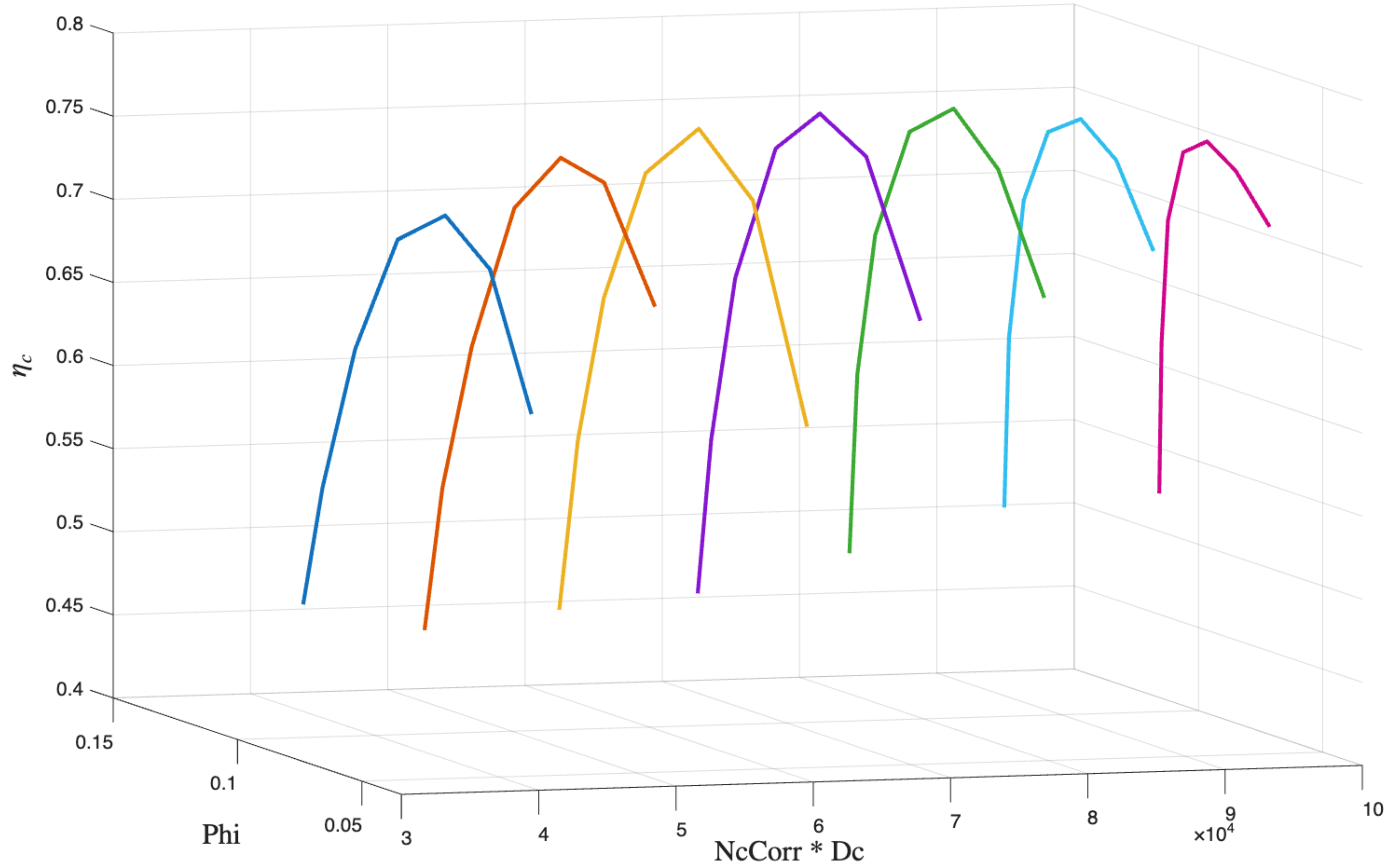
Create a model that can go from efficiency to mass flow

- Model the efficiency and, via the dimensionless variables, model the mass flow
- Want to decrease the number of parameters needed.





Dimensionless Efficiency Modeling

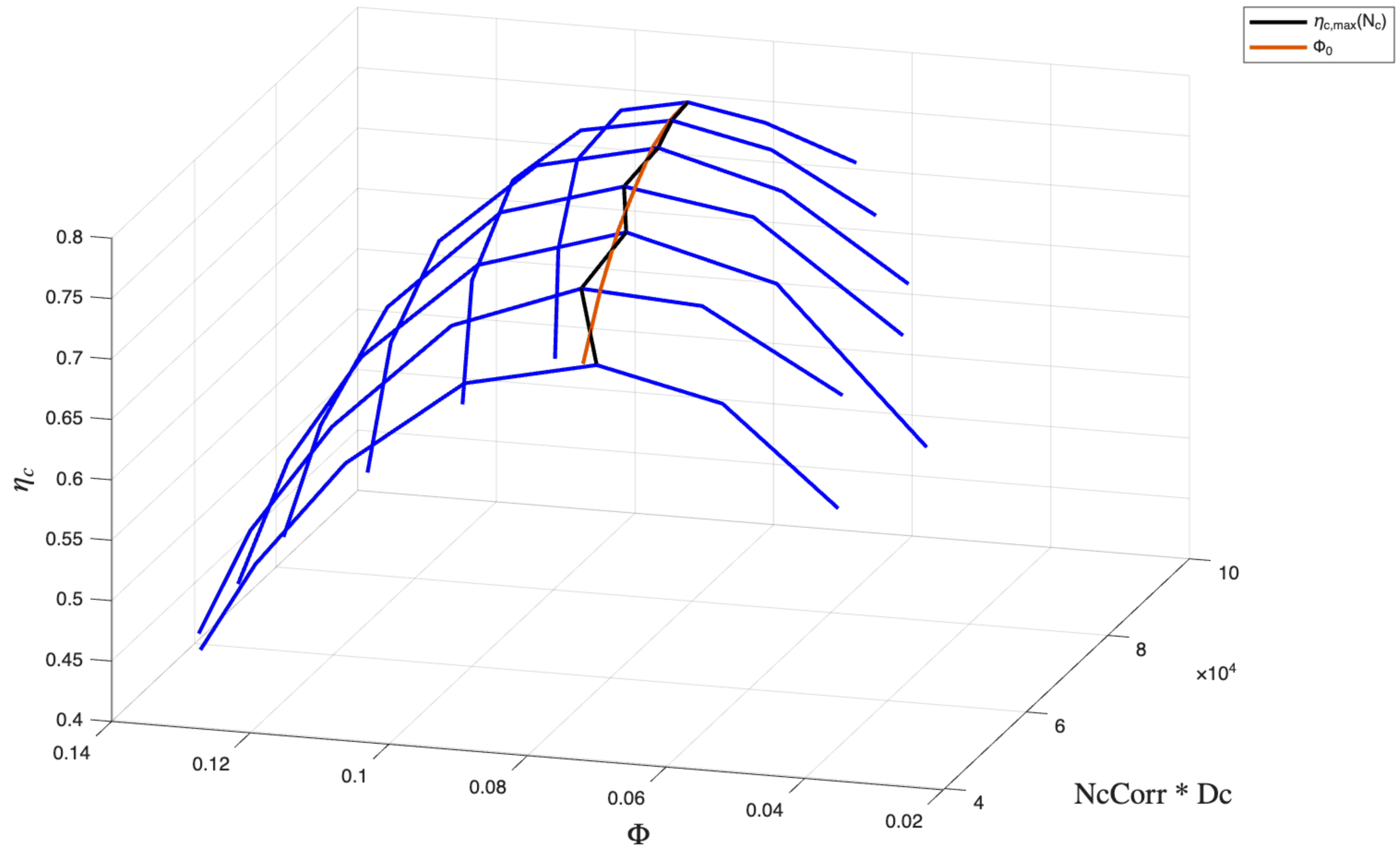


Dimensionless Efficiency Modeling

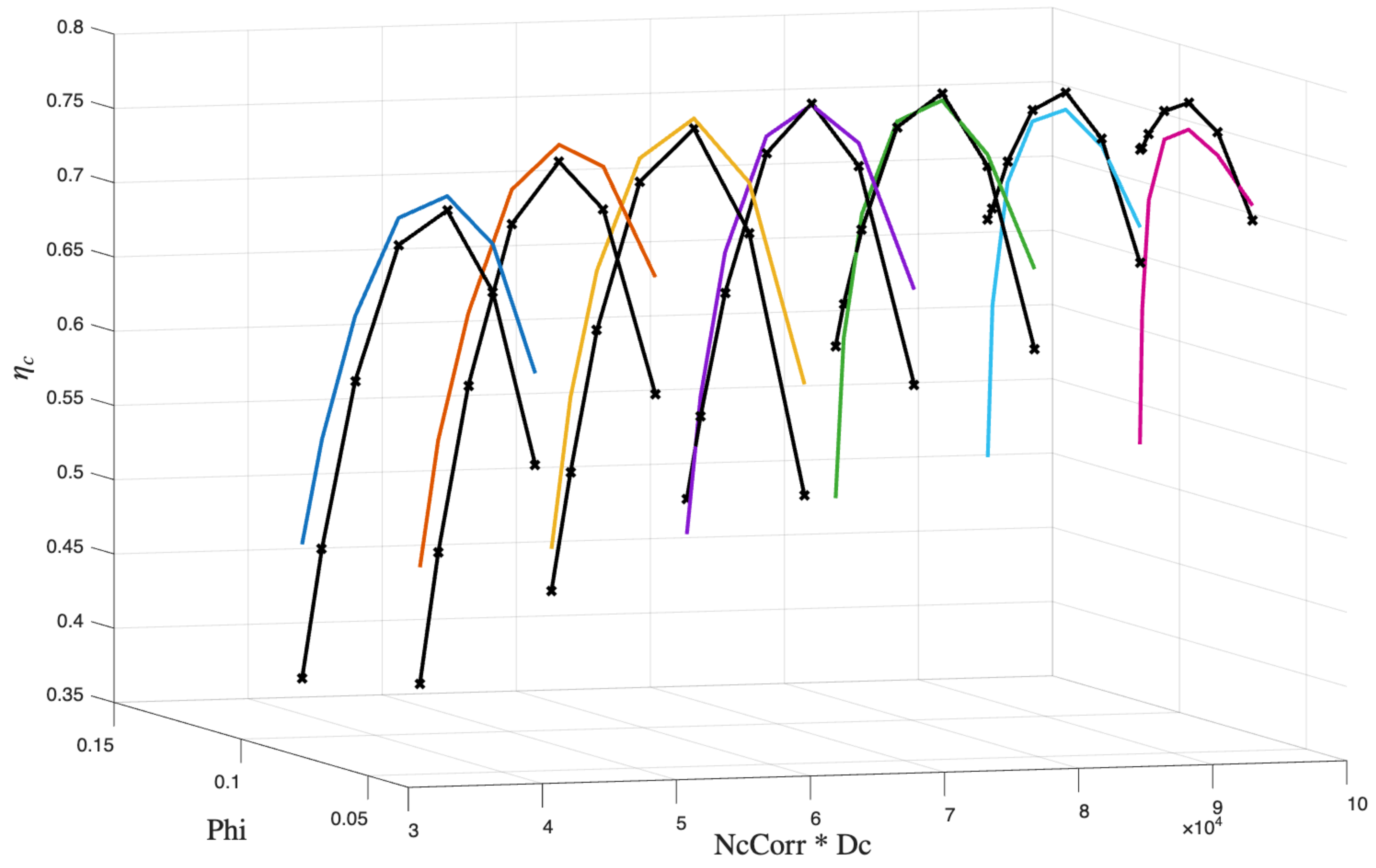
Model the efficiency curves by

$$\eta_c = -k_1 \left(\Phi - \Phi_{\eta_{c,max}}(N_c)\right)^2 - k_2 \left(\Phi - \Phi_{\eta_{c,max}}(N_c)\right)^3 - k_3 \left(N_c - N_{c,\eta_{c,max}}\right)^2 + \eta_{c,max}$$

Dimensionless Efficiency Modeling



Dimensionless Efficiency Modeling



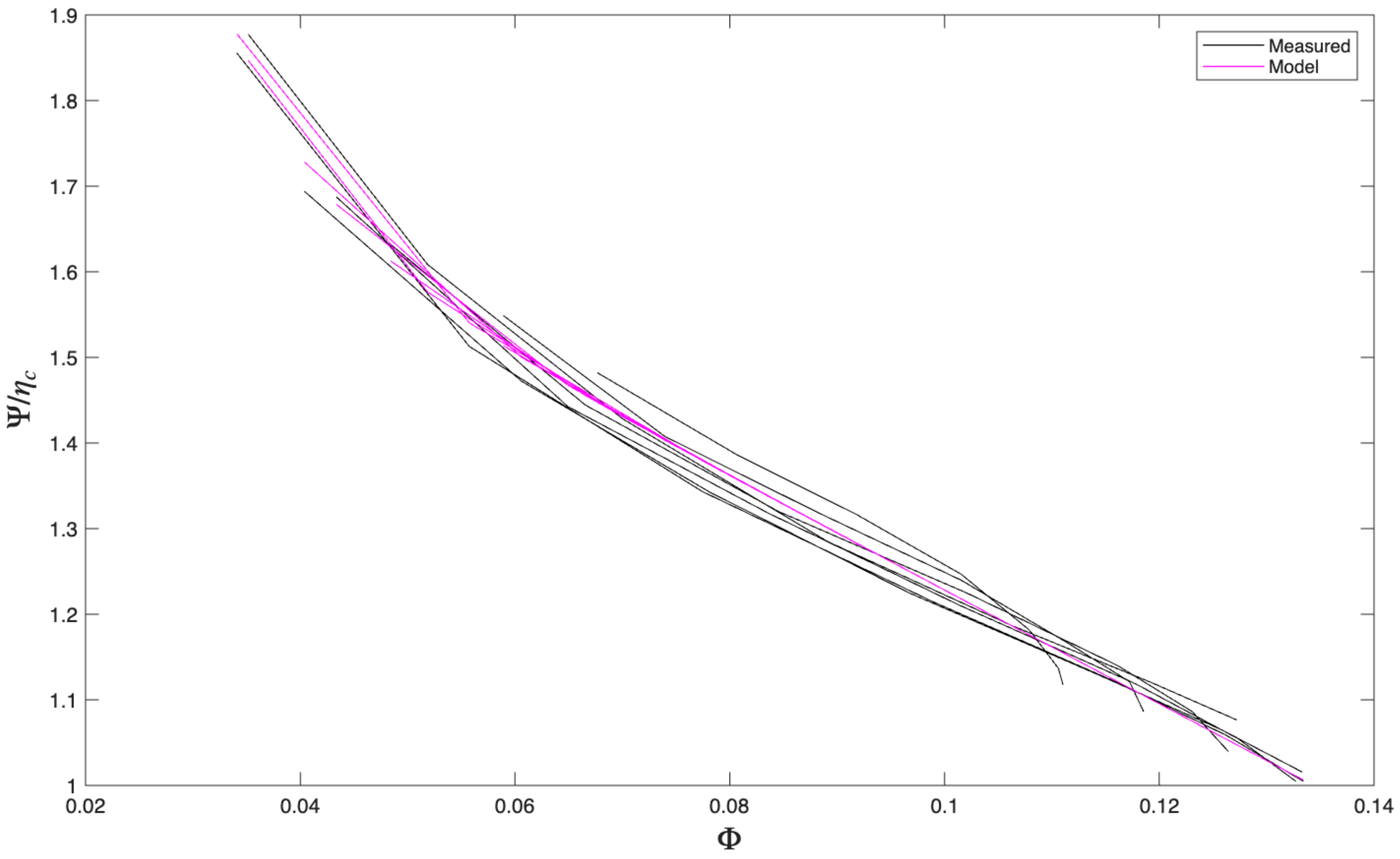
Dimensionless Efficiency Modeling

Power coefficient

$$\hat{P} = \Phi\Psi/\eta_c$$

Approximation

$$H = \Psi/\eta_{c,est} = k_5 + k_6\Phi + k_7 e^{-k_8\Phi}$$

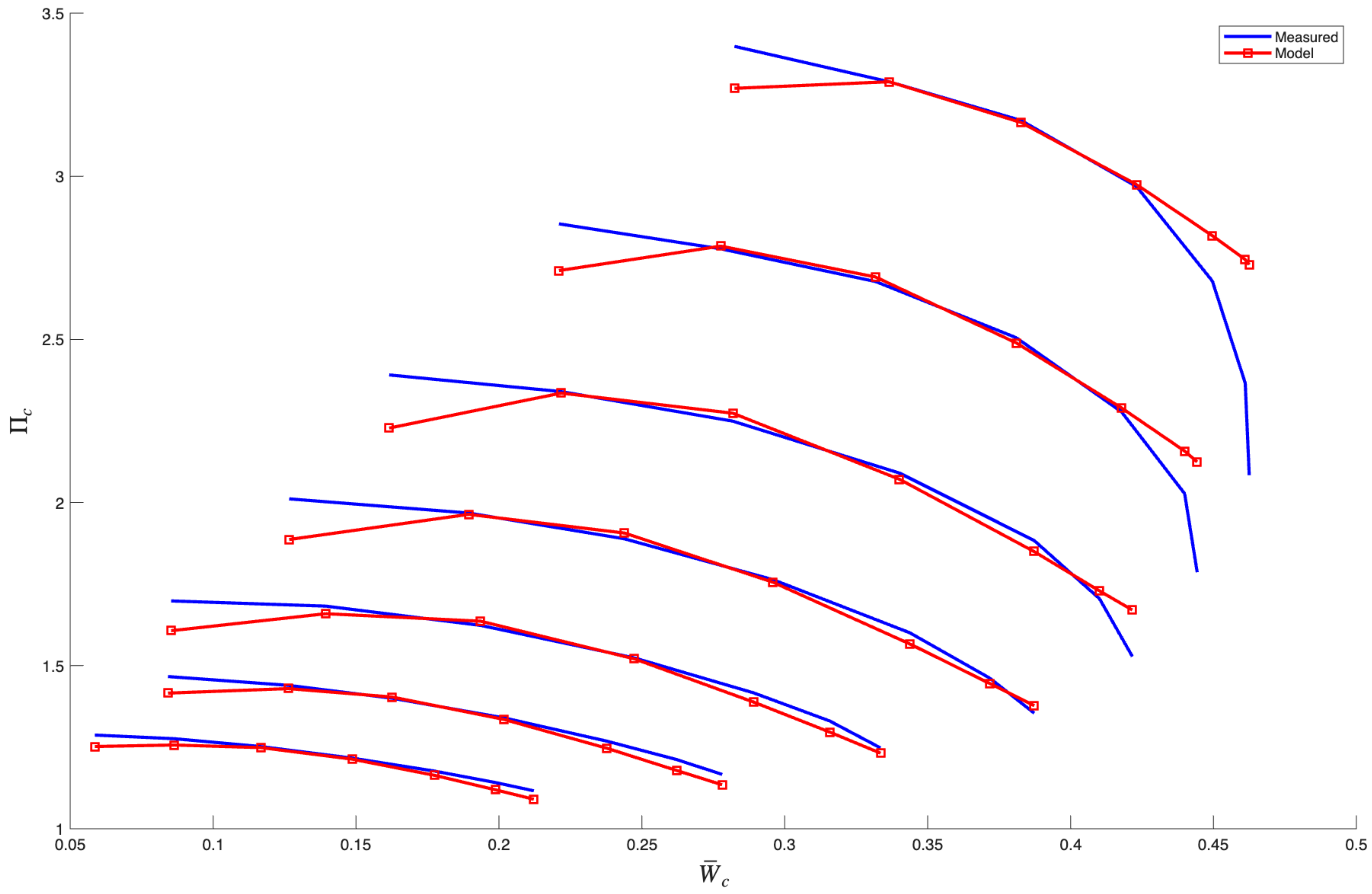


Dimensionless Efficiency Modeling

Multiplying

$$H \cdot \eta_{c,est} = \Psi$$

As of now, the model is using 8 parameters



Future Work

Future work

Wishlist from Traton/Scania

- HIL implementation of LiU Genie

Working with the test engine in the engine lab

- Testing bio-fuels

Thank you!

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Questions?