



# Steady State Model Update for the 10 MWe sCO<sub>2</sub> Test Facility Program

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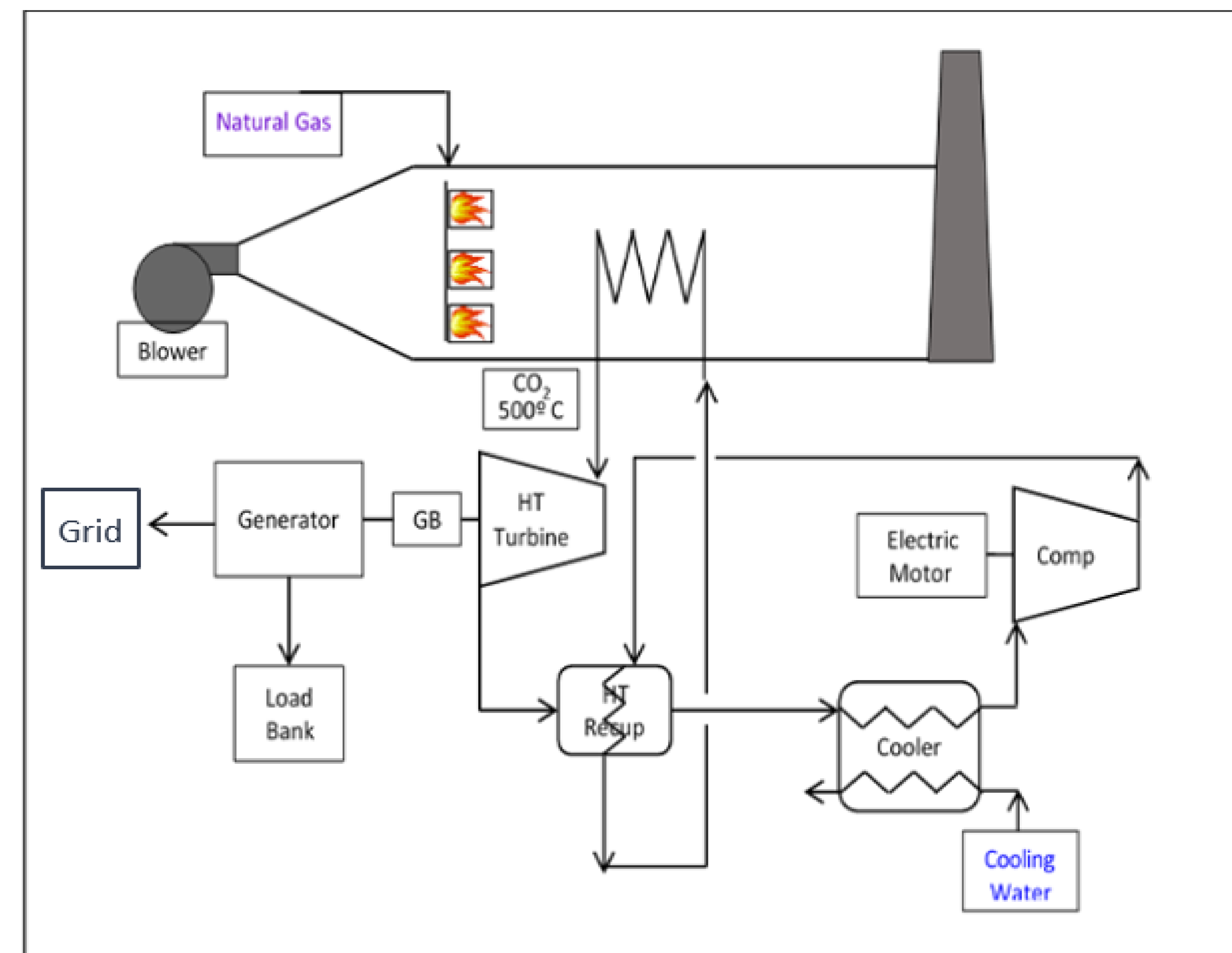
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# Overview

- STEP 10 MWe test facility and simple cycle test campaign
- Steady state Flownex modeling framework
- 2024 test data and Data Acquisition Periods (DAPs)
- Major model improvements
- Validation results across cycle components
- Key conclusions and next steps

# STEP 10 MWe sCO<sub>2</sub> Pilot Facility

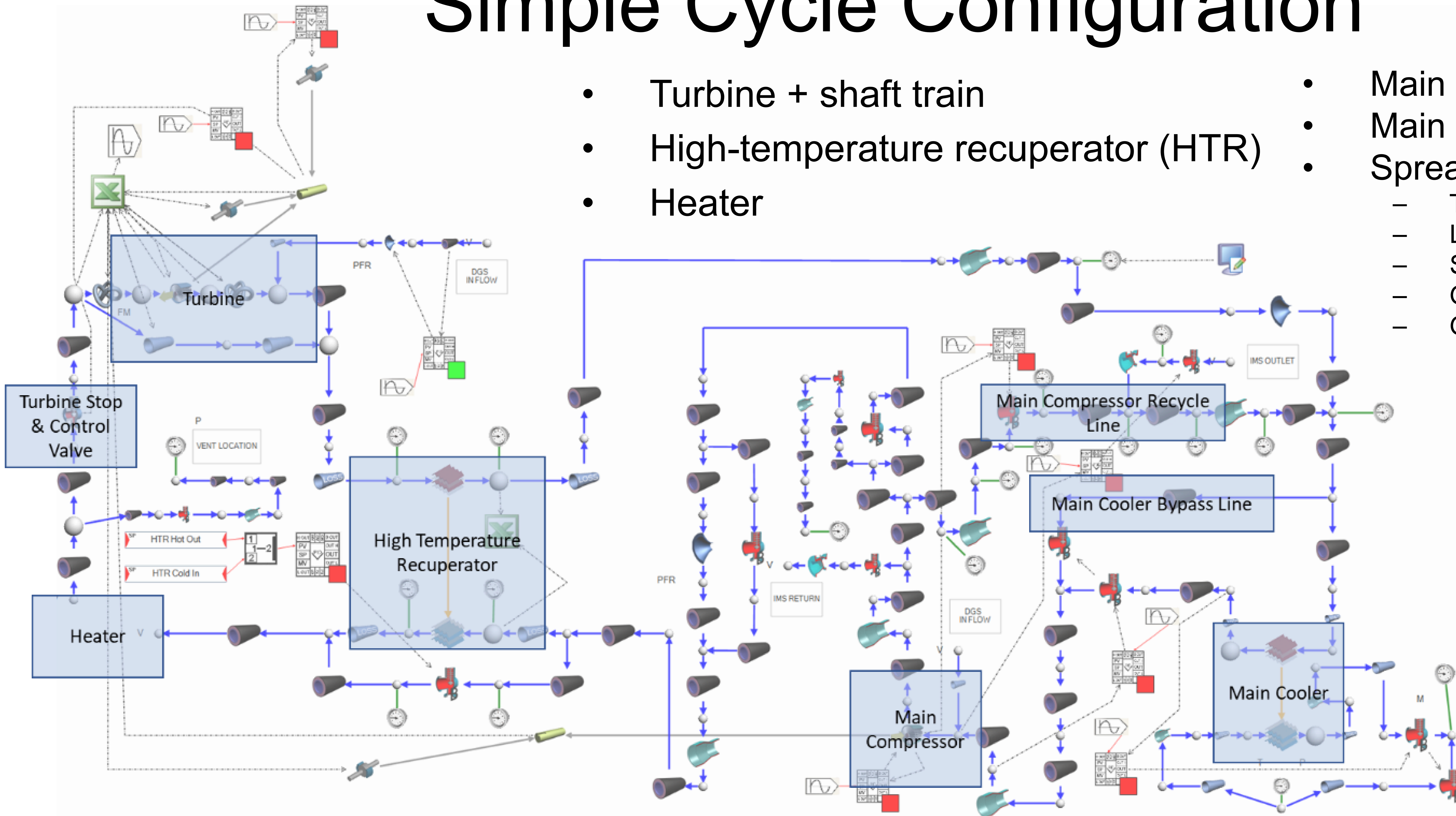
- First integrated multi-MW sCO<sub>2</sub> Brayton cycle demonstration in the U.S.
- Completed simple recuperated cycle testing in 2024
- Achieved:
  - TIT up to 500 °C
  - 8.25 MW<sub>sh</sub> turbine power
  - 3.93 MWe net to grid



# Simple Cycle Configuration

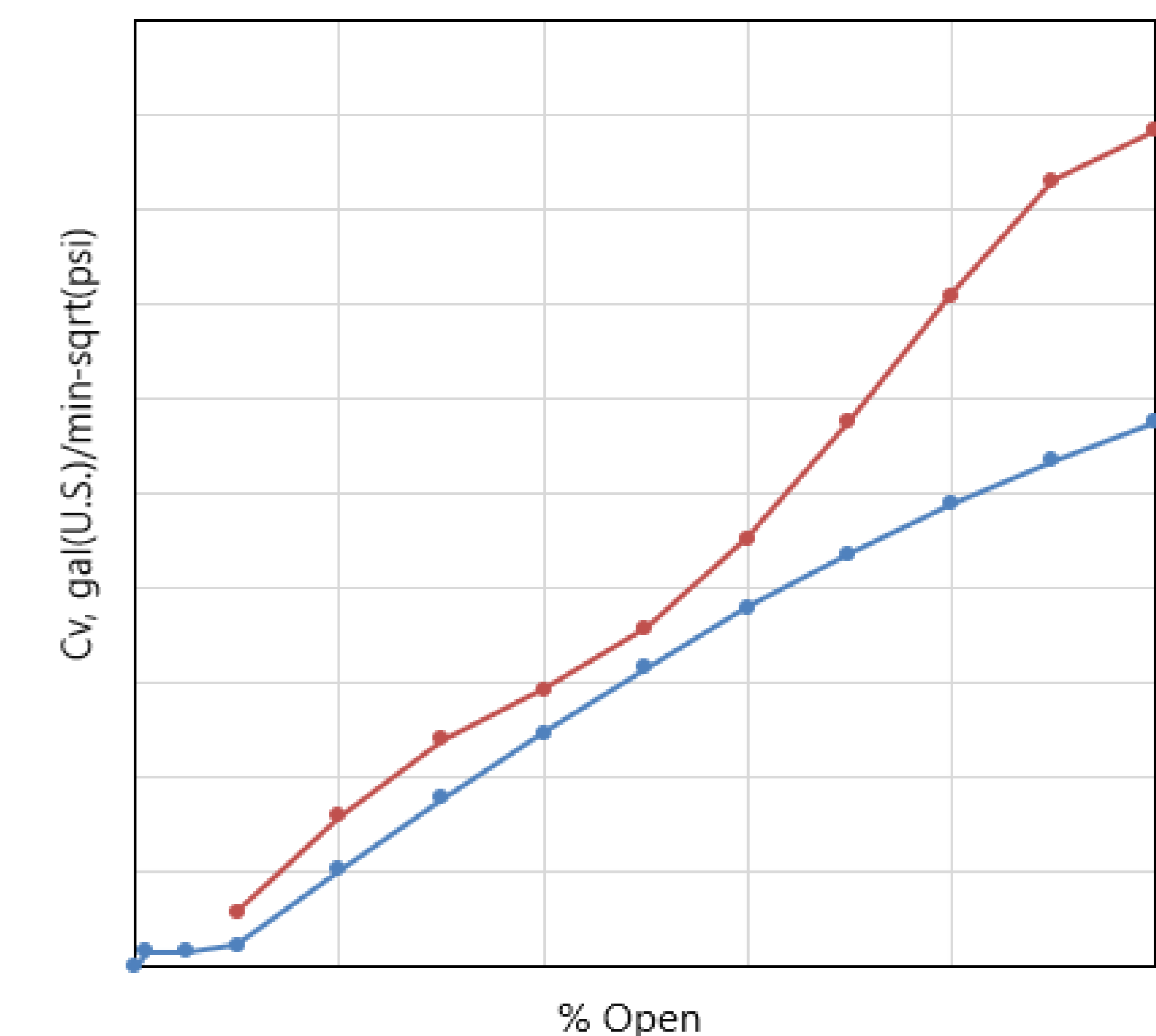
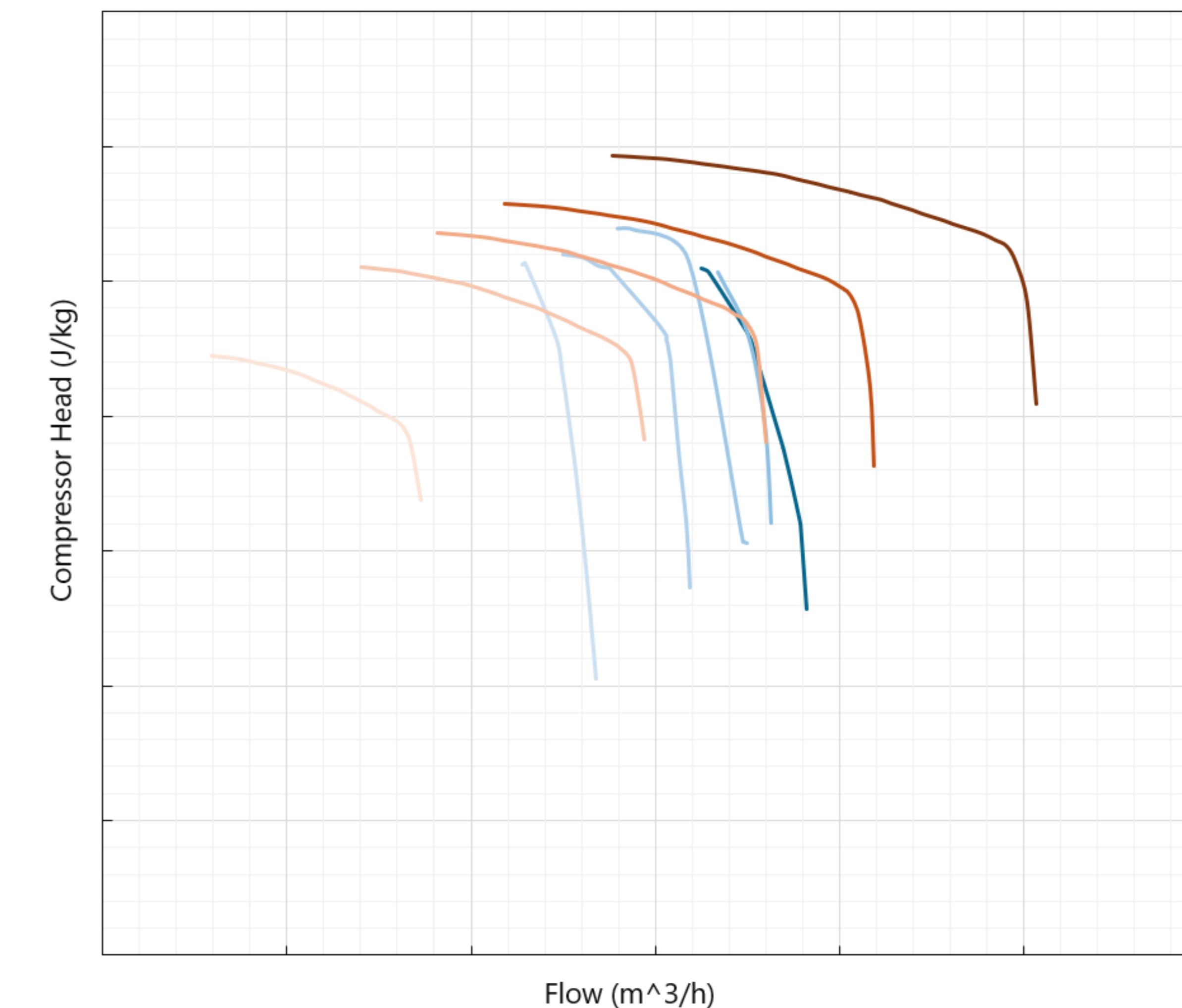
- Turbine + shaft train
- High-temperature recuperator (HTR)
- Heater

- Main Cooler
- Main Compressor
- Spreadsheet captures:
  - Turbine flow function
  - Leakage rates
  - Shaft efficiency
  - Gearbox efficiency
  - Generator efficiency



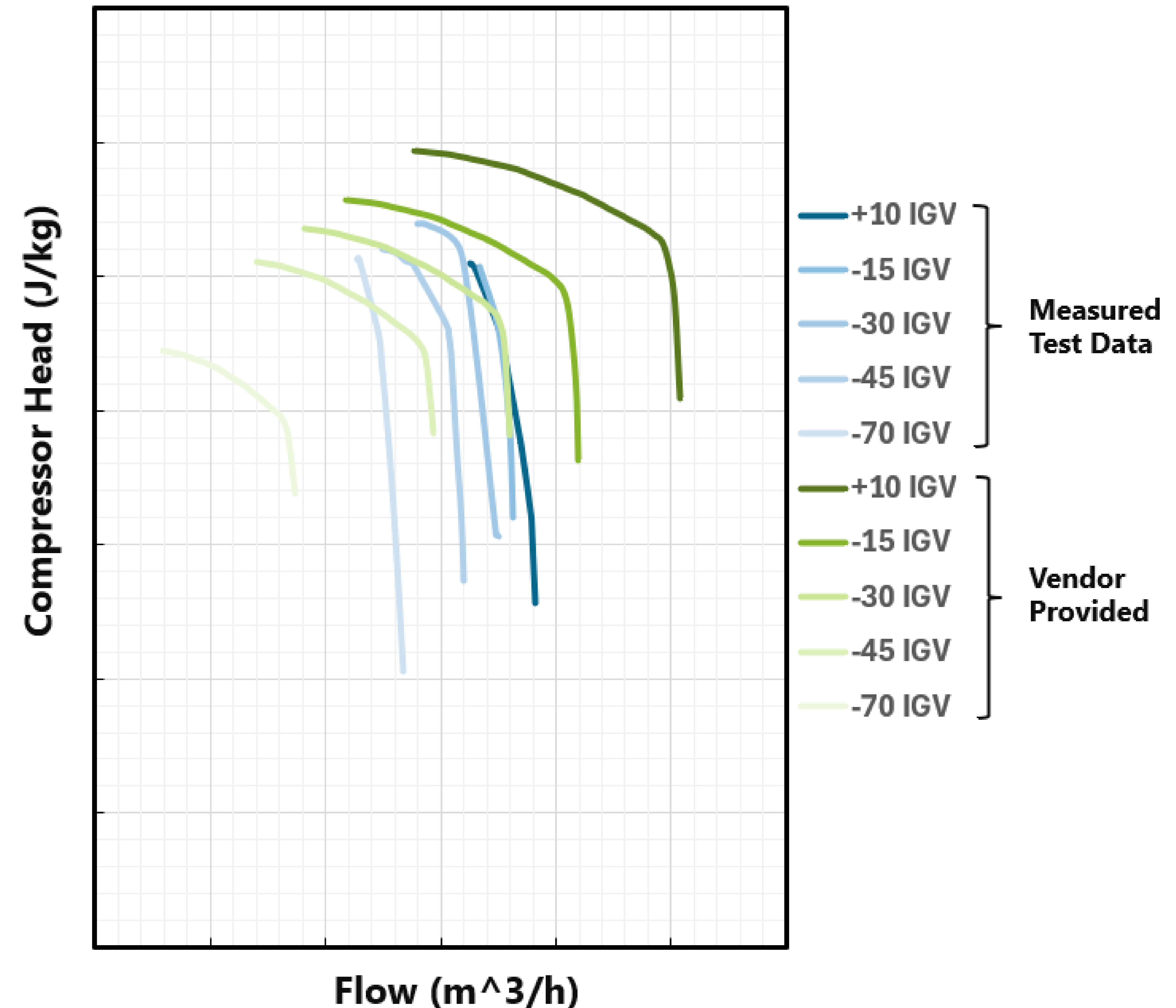
# Summary of Major Model Updates

- Updated main compressor maps from 2024 test data
- Updated TSV Cv curve from latest vendor sheet
- Updated shaft train efficiencies based on commissioning
- Updated as-built piping geometry & insulation
- Added extra thermal loss from lube oil



# Compressor Map Update

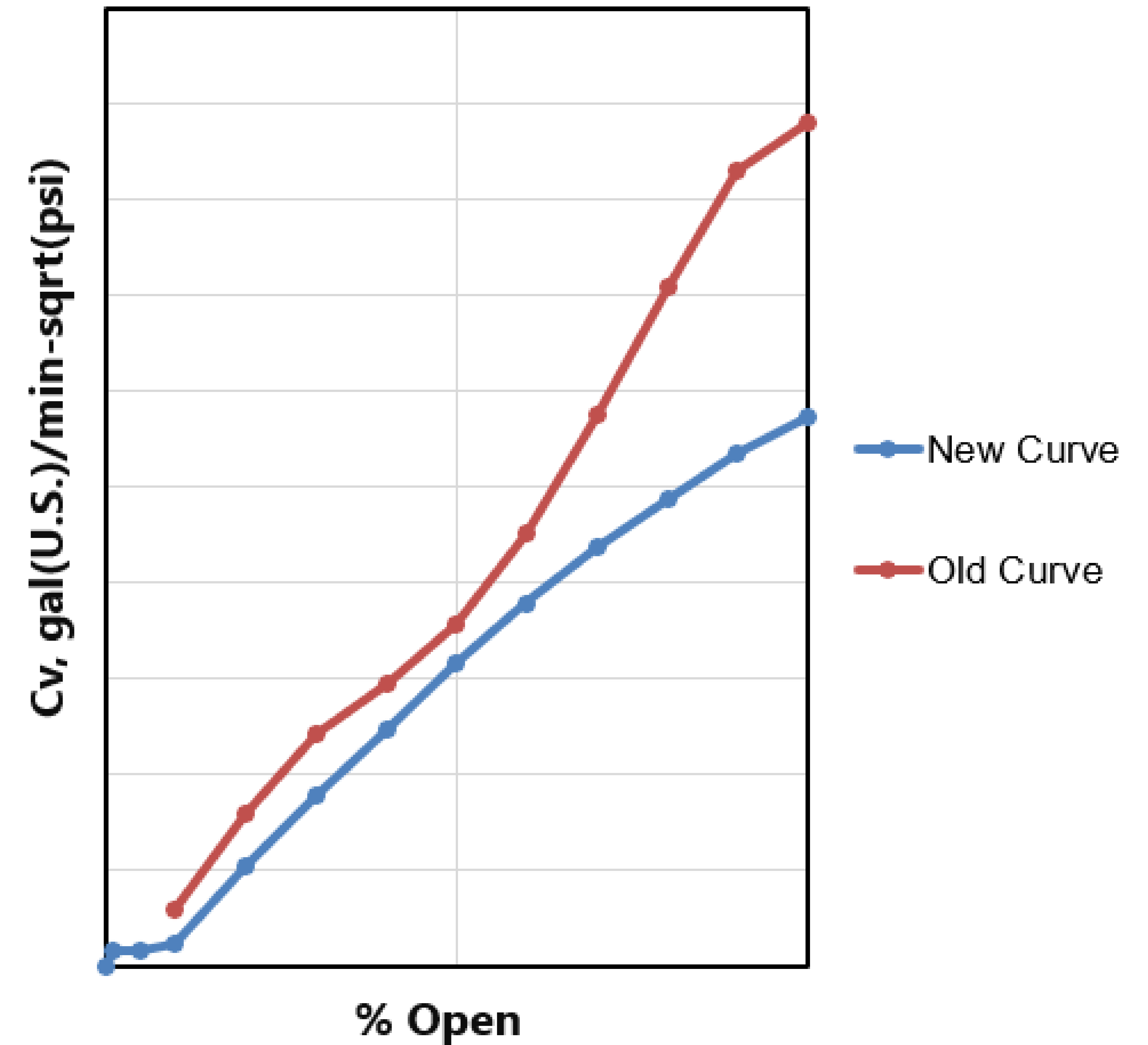
- Vendor map did not align with as-tested performance data
- Updated using test data at nominal condition
  - 84 bar and 35 °C
  - 27,000 rpm
  - -70° to +10° IGV
- CO<sub>2</sub> properties vary sharply near critical point
- Small temperature changes → large density and volume flow changes
- Accurate inlet conditions are essential for map correlation



# Turbine Stop Valve (TSV) Curve Update

- New Cv vs % open data from vendor
- Replaced older approximated curve
- Improved turbine inlet pressure prediction

$$C_v = Q \sqrt{\frac{SG}{\Delta P}}$$

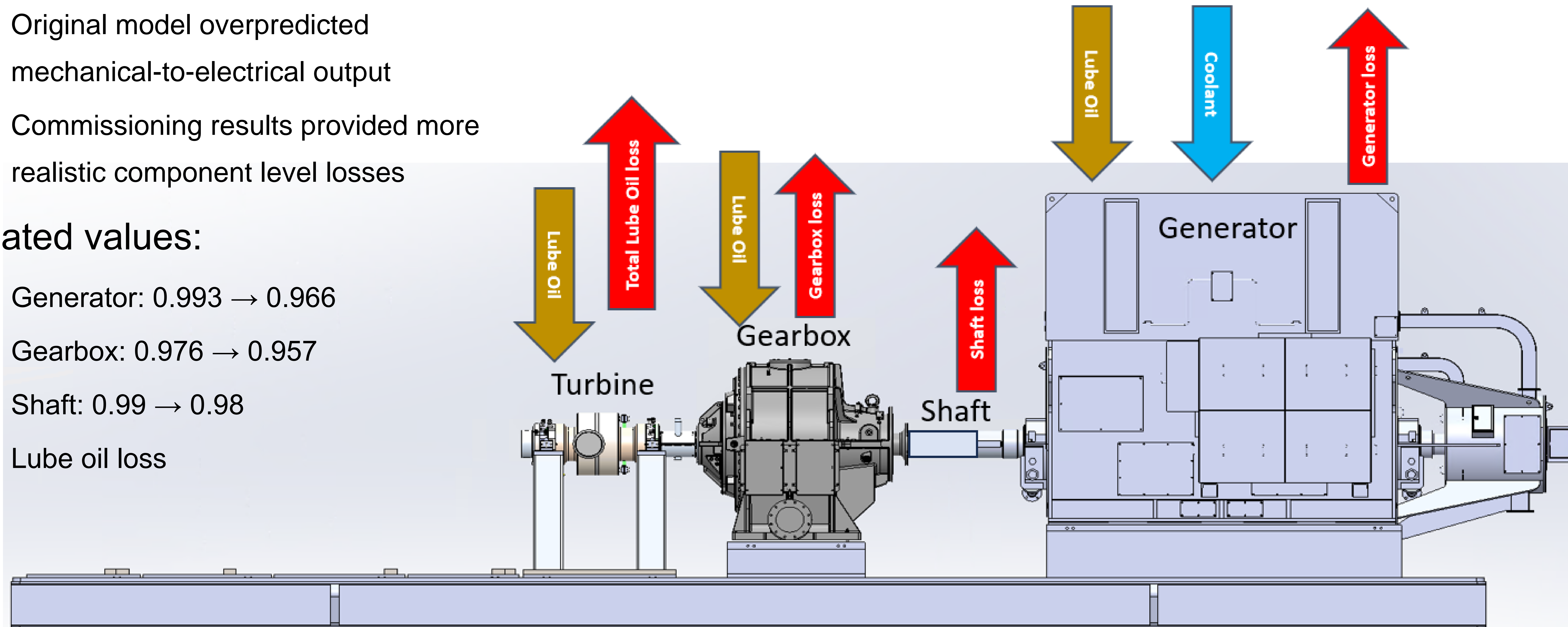


# Updated Turbine Train Efficiencies

- Reason for update:
  - Original model overpredicted mechanical-to-electrical output
  - Commissioning results provided more realistic component level losses

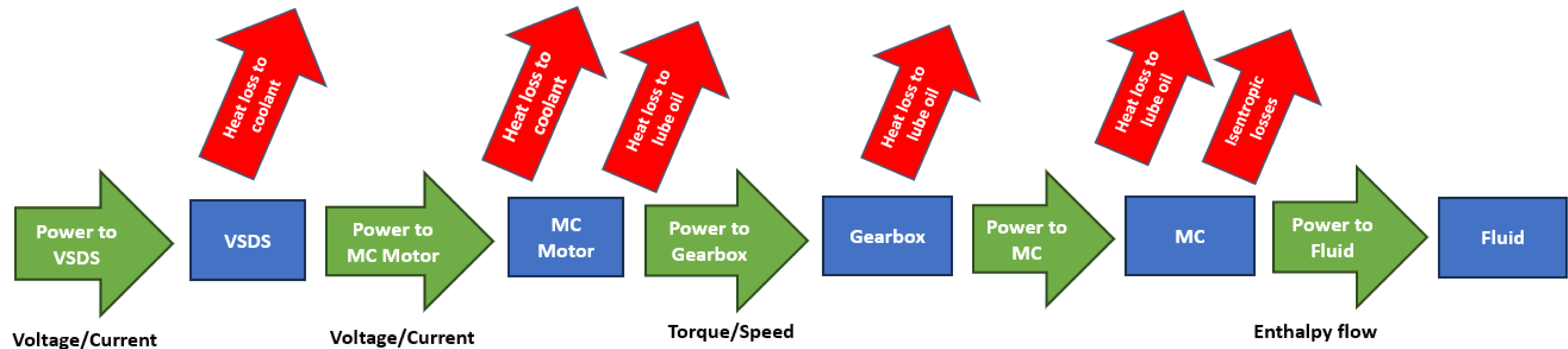
- Updated values:

- Generator: 0.993 → 0.966
- Gearbox: 0.976 → 0.957
- Shaft: 0.99 → 0.98
- Lube oil loss



# Updated Compressor Train Loss

- Added values:
  - MC gearbox efficiency = 0.987
  - MC motor efficiency = 0.968
- Improved the model's agreement with measured electrical power



# Piping & Insulation Geometry Updates

- Updated all pipe lengths, bends, diameters, elevations
- Insulation type & thickness verified against as-built information
- Improved prediction of pressure drop and heat loss



|                                      |                                     |
|--------------------------------------|-------------------------------------|
| <b>Fluids</b>                        |                                     |
| Fluid data reference                 | CO2-GTI  STEP (Two Phase ...        |
| <b>Geometry</b>                      |                                     |
| Geometry option                      | Specify geometry                    |
| Length                               | 58.578 ft                           |
| Diameter                             | 9.564 in                            |
| <b>Losses</b>                        |                                     |
| K value based on minimum area        | No                                  |
| K forward                            | 1.176                               |
| <b>Insulation</b>                    |                                     |
| Layers Click here to edit and rem... |                                     |
| Geometry                             |                                     |
| Thickness in element direction       | 2.5 in                              |
| Number of nodes                      | 2                                   |
| Material Data                        |                                     |
| Material option                      | Select from data reference          |
| Material major conductivity...       | Parallel                            |
| Material                             | Calcium Silicate   Insulation (S... |
| <b>Boundary Conditions</b>           |                                     |
| Elevation                            | 10.23 ft                            |

|    |                |      |
|----|----------------|------|
|    | Smooth Flanged | 1.18 |
|    | r/D=1          | 0.00 |
|    | r/D=1.5        | 1.18 |
| 90 | 6              | 1.18 |

K = specified resistance coefficient

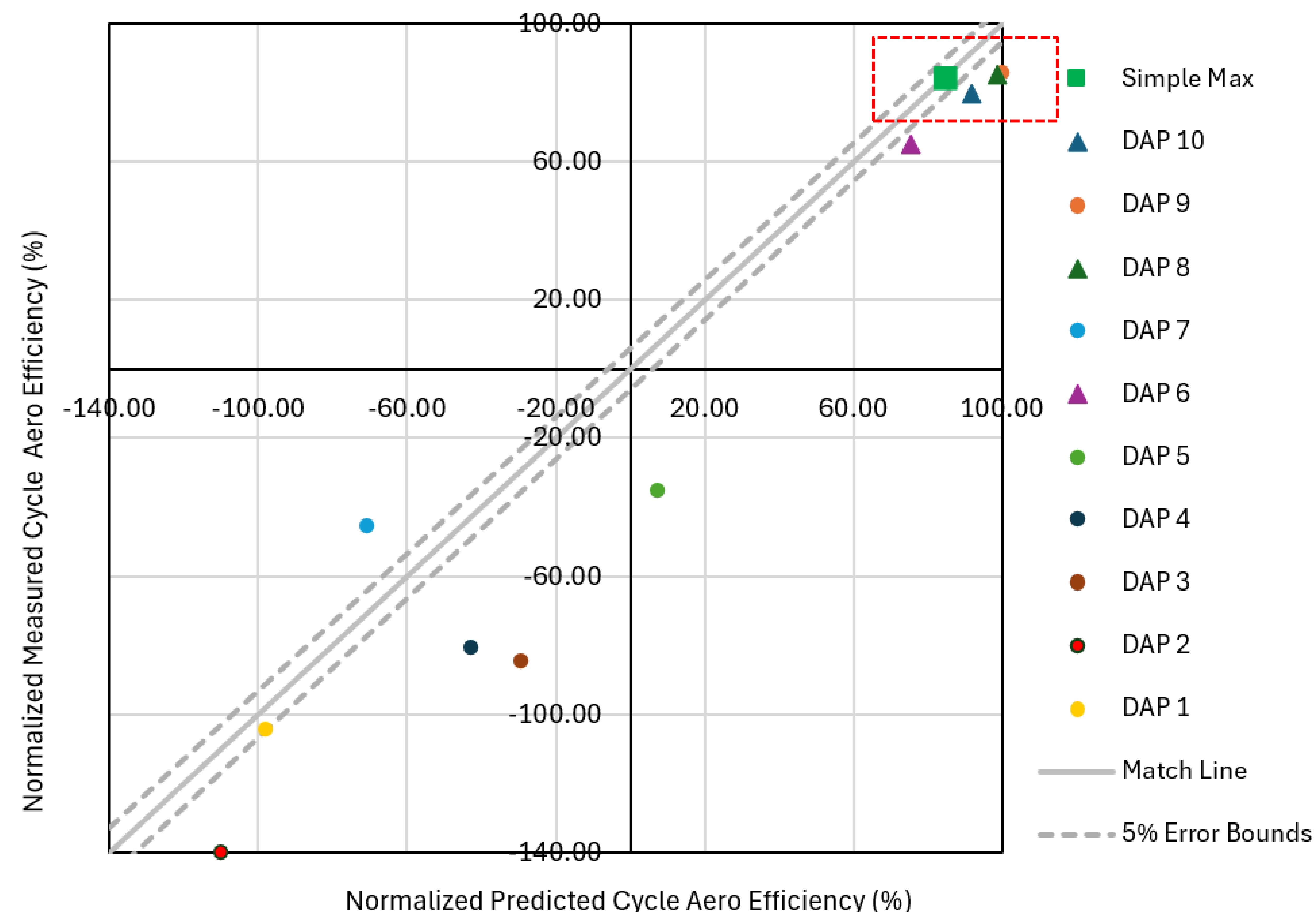
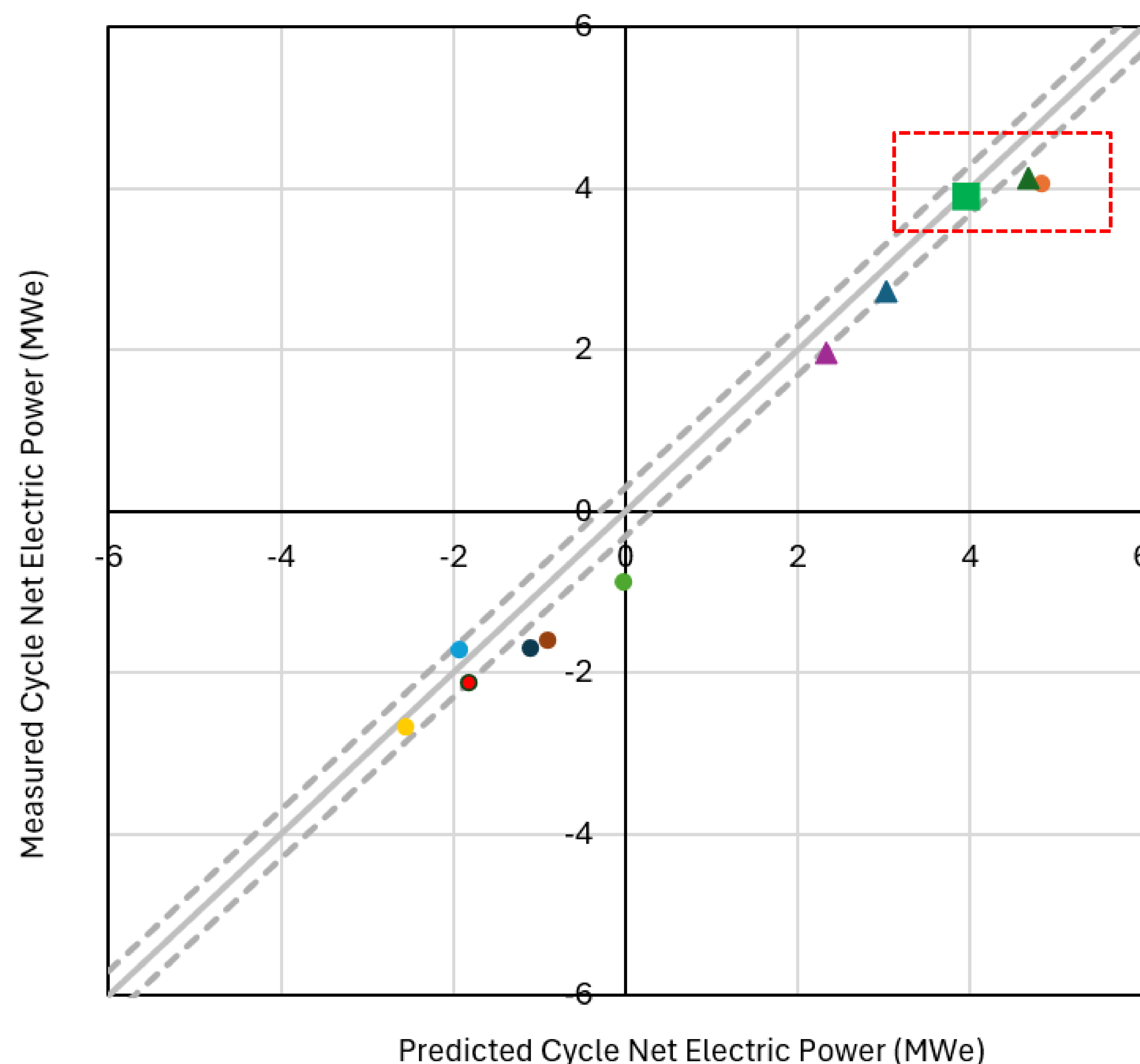
# Data Acquisition Period (DAP) Windows

- 10 DAP windows selected ( $\approx 1000$  s each)
- Only highlighted DAPs represent true steady state
- Others are ramp-up transitional periods where mismatch is expected in steady state model
- Model updated and anchored using DAP 8 & 9 corresponding to Simple Max conditions
  - TIT = 500 °C
  - Compressor speed = 27,000 RPM

| DAP # | Test ID | Day       | Turbine Inlet Temp TC-325avg [C] | Turbine Speed N-550 [rpm] | Compressor Inlet Temp TC-473avg [C] | Compressor Speed KT-3351 [rpm] | Time Slice Start [GMT] | Time Slice [sec] |
|-------|---------|-----------|----------------------------------|---------------------------|-------------------------------------|--------------------------------|------------------------|------------------|
| 1     | T-8     | 9/10/2024 | 286                              | 19998                     | 49                                  | 27026                          | 254/17:46:43           | 64000-65000      |
| 2     | T-11    | 9/11/2024 | 389.6                            | 19999                     | 49.5                                | 27022                          | 255/12:26:47           | 44800-45800      |
| 3     | T-12    | 9/11/2024 | 394.4                            | 26612                     | 49.5                                | 27025                          | 255/15:00:07           | 54000-55000      |
| 4     | T-12    | 9/11/2024 | 492.1                            | 26616                     | 49.6                                | 27027                          | 255/16:36:57           | 59810-60810      |
| 5     | T-13    | 9/12/2024 | 496.4                            | 26615                     | 34                                  | 20729                          | 256/17:51:19           | 64275-65275      |
| 6     | T-17    | 9/13/2024 | 502                              | 26602                     | 35.3                                | 20728                          | 257/15:22:00           | 55320-56320      |
| 7*    | T-15    | 9/26/2024 | 319                              | 26614                     | 49                                  | 27024                          | 270/19:53:25           | 71600-72400*     |
| 8     | T-16    | 9/27/2024 | 500.5                            | 26622                     | 36.7                                | 27026                          | 271/20:25:04           | 73500-74500      |
| 9     | T-19    | 10/2/2024 | 500.7                            | 26617                     | 37.3                                | 27025                          | 276/13:03:21           | 47000-48000      |
| 10    | T-19    | 10/2/2024 | 498.8                            | 26620                     | 35                                  | 20727                          | 276/14:10:01           | 51000-52000      |

\* 800 sec avg. All others 1000 sec

# Cycle Level Validation



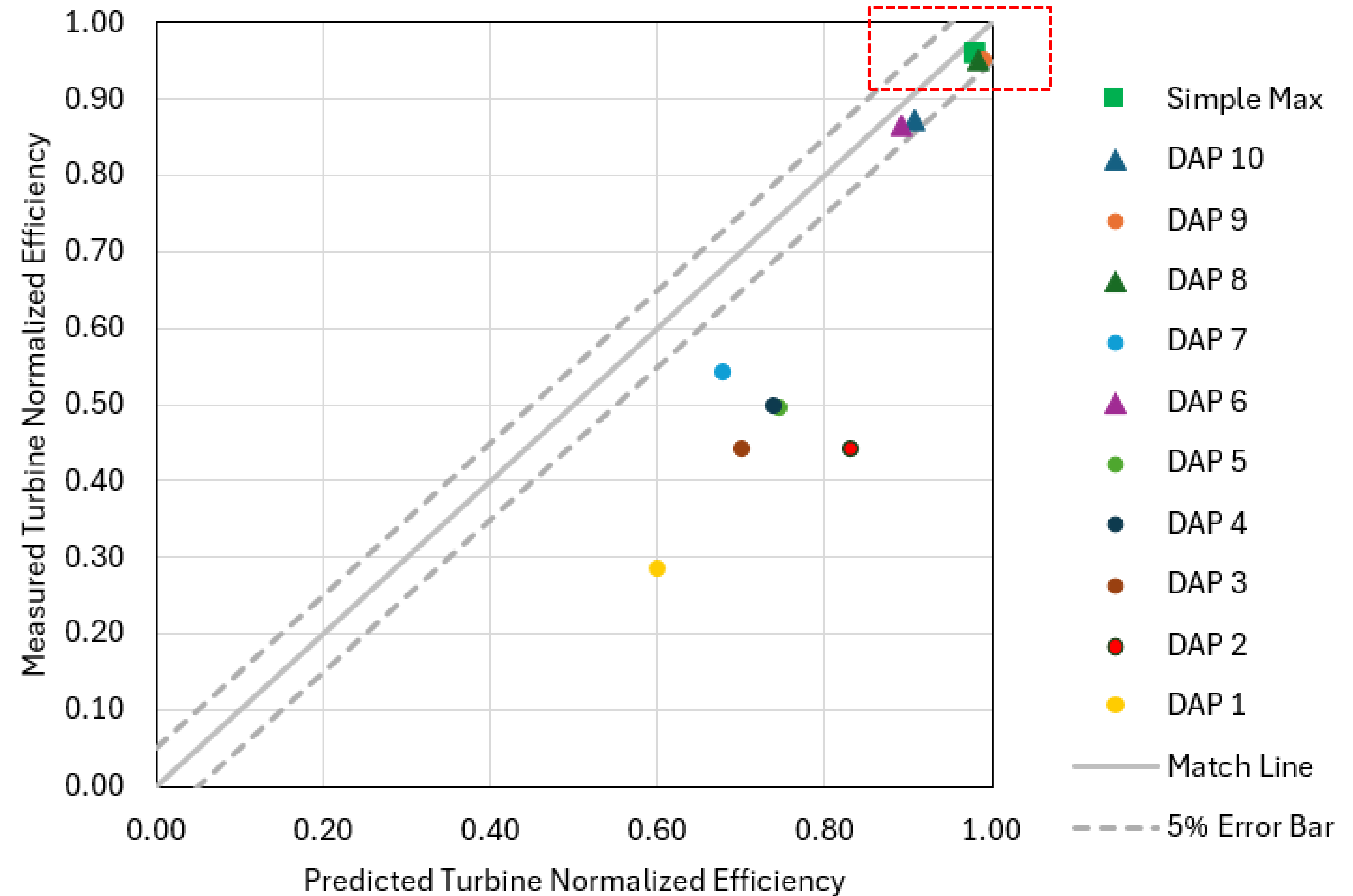
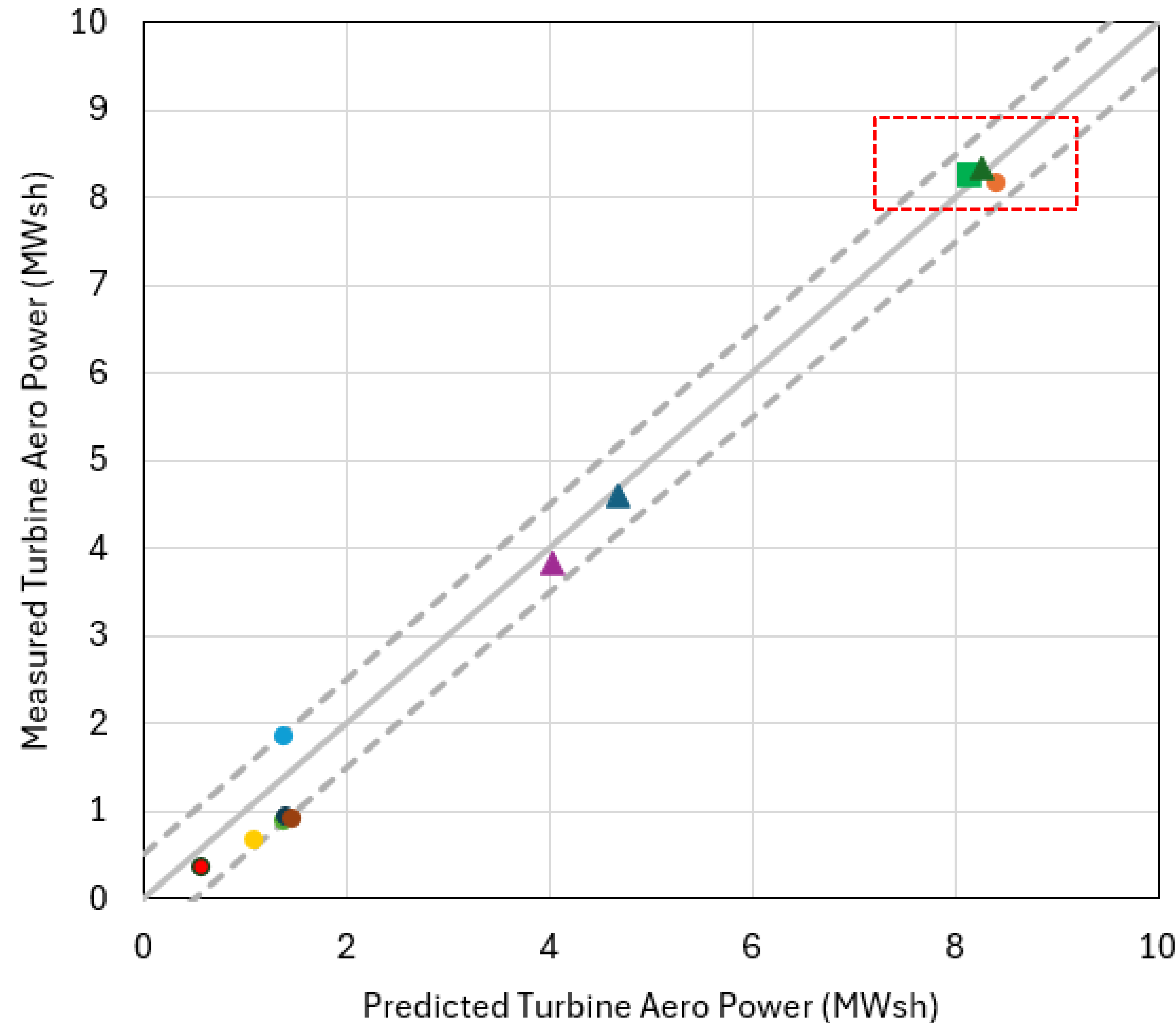
## Net Electric Power (Measured vs Predicted)

- After updates, designed point matches exactly: 3.93 MW

## Normalized Aero Efficiency (Measured vs Predicted)

- Discrepancy falls within 1%
- Larger deviations only in ramp-up DAPs

# Turbine Validation



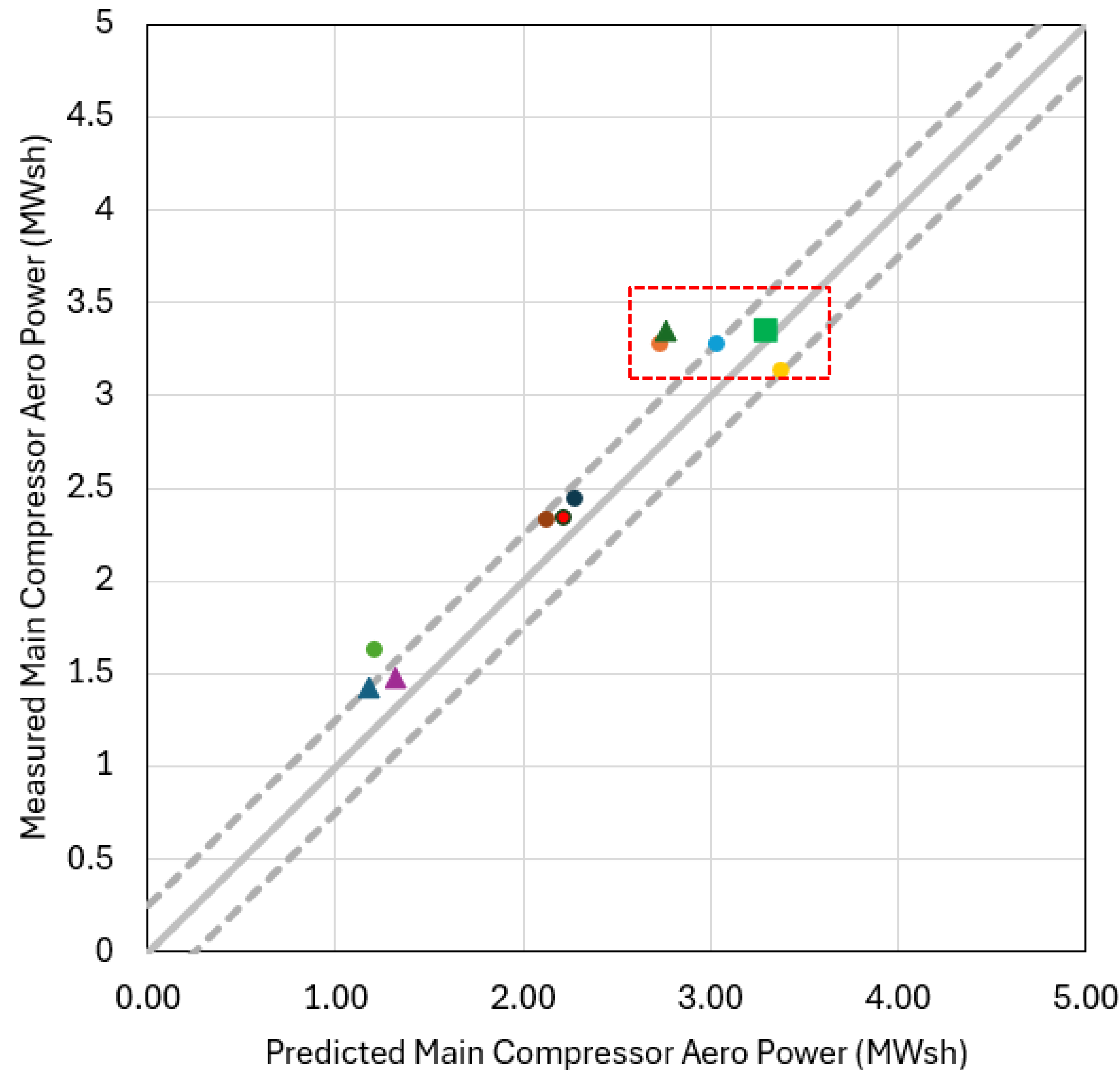
## Turbine Aero Power (Measured vs Predicted)

- Steady-state DAPs within 1–5% of measured values

## Turbine Normalized Efficiency (Measured vs Predicted)

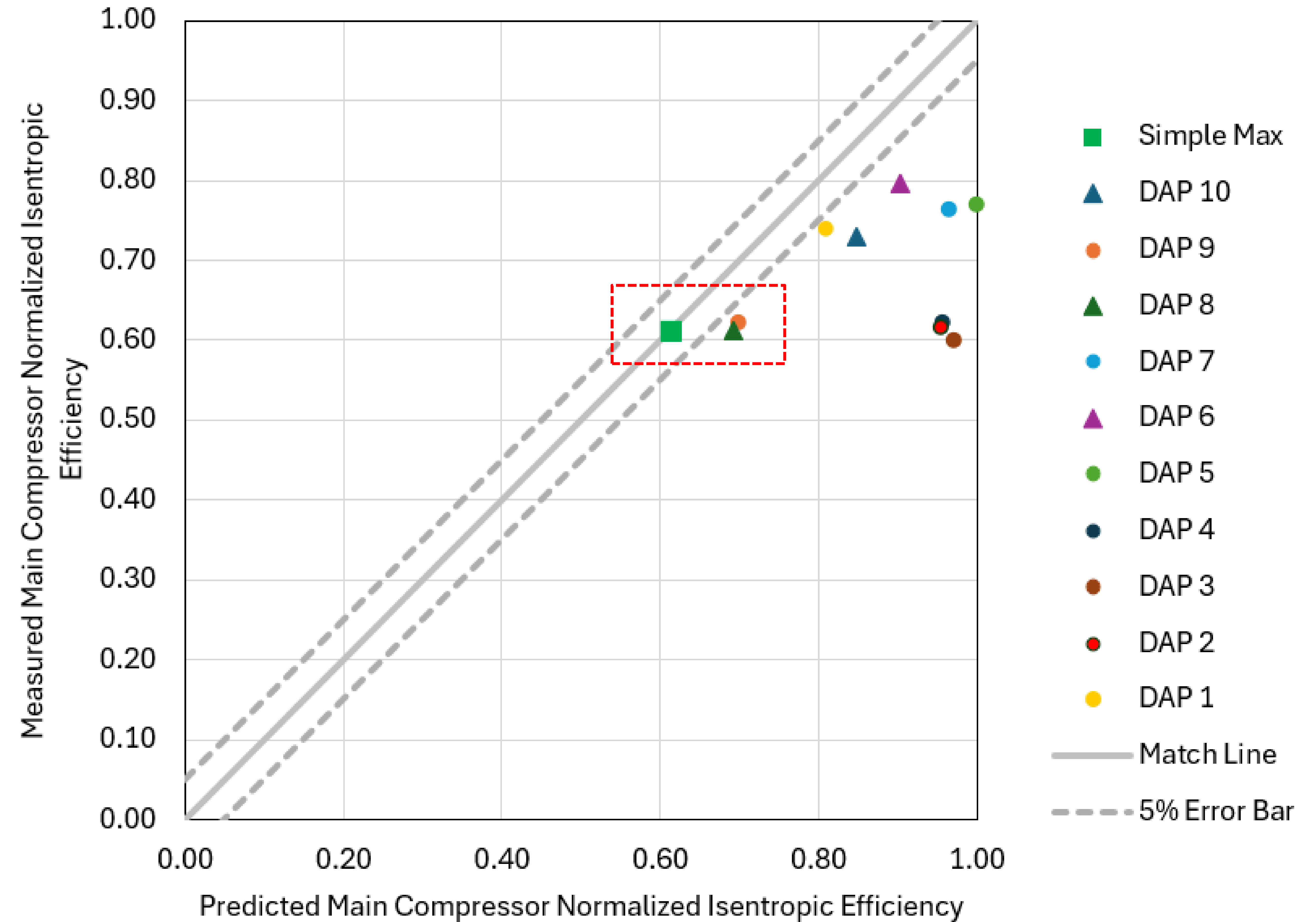
- Consistent prediction accuracy after updates
- Larger deviations only in transient DAPs

# Compressor Validation



Main Compressor Power (Measured vs Predicted)

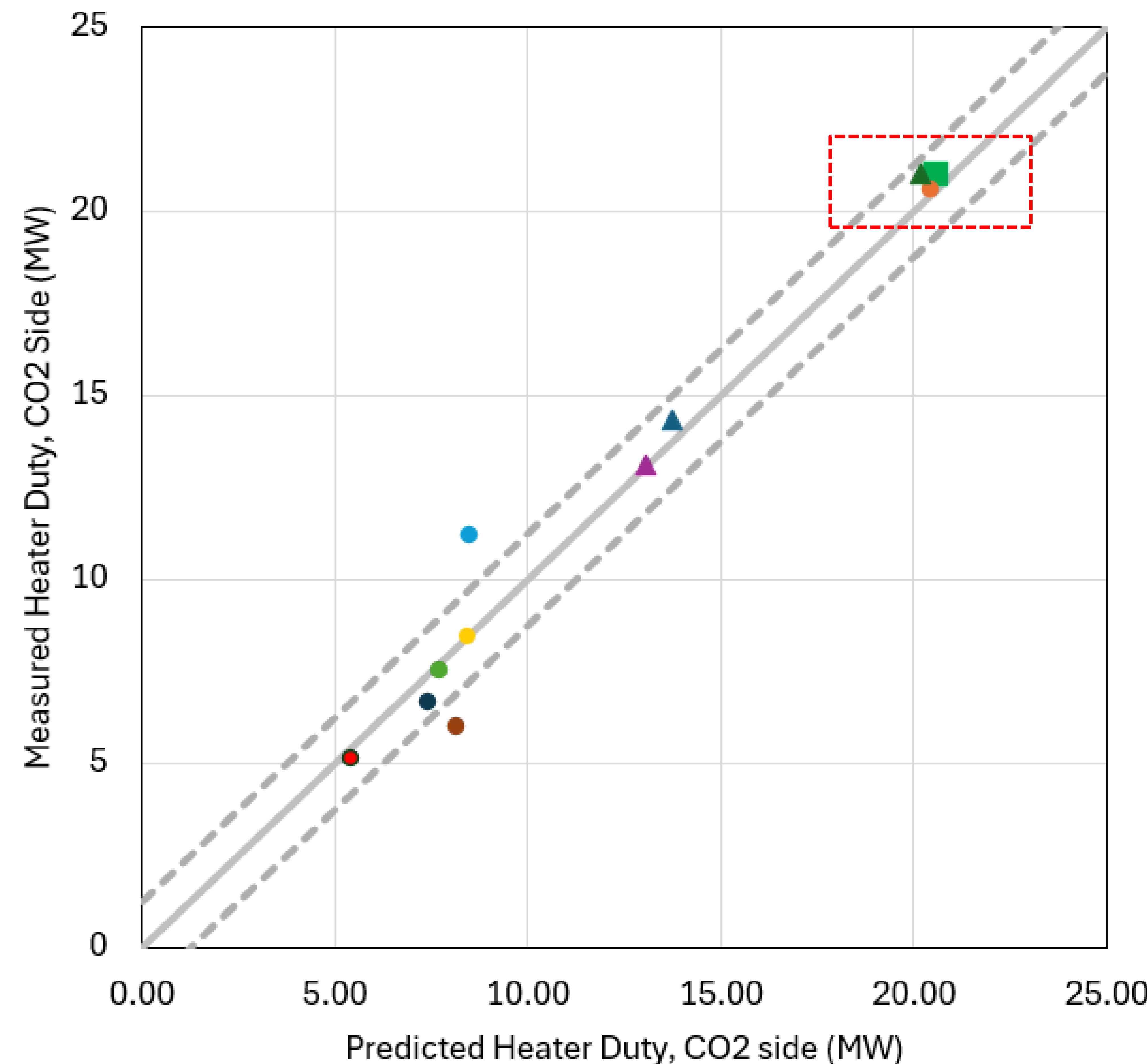
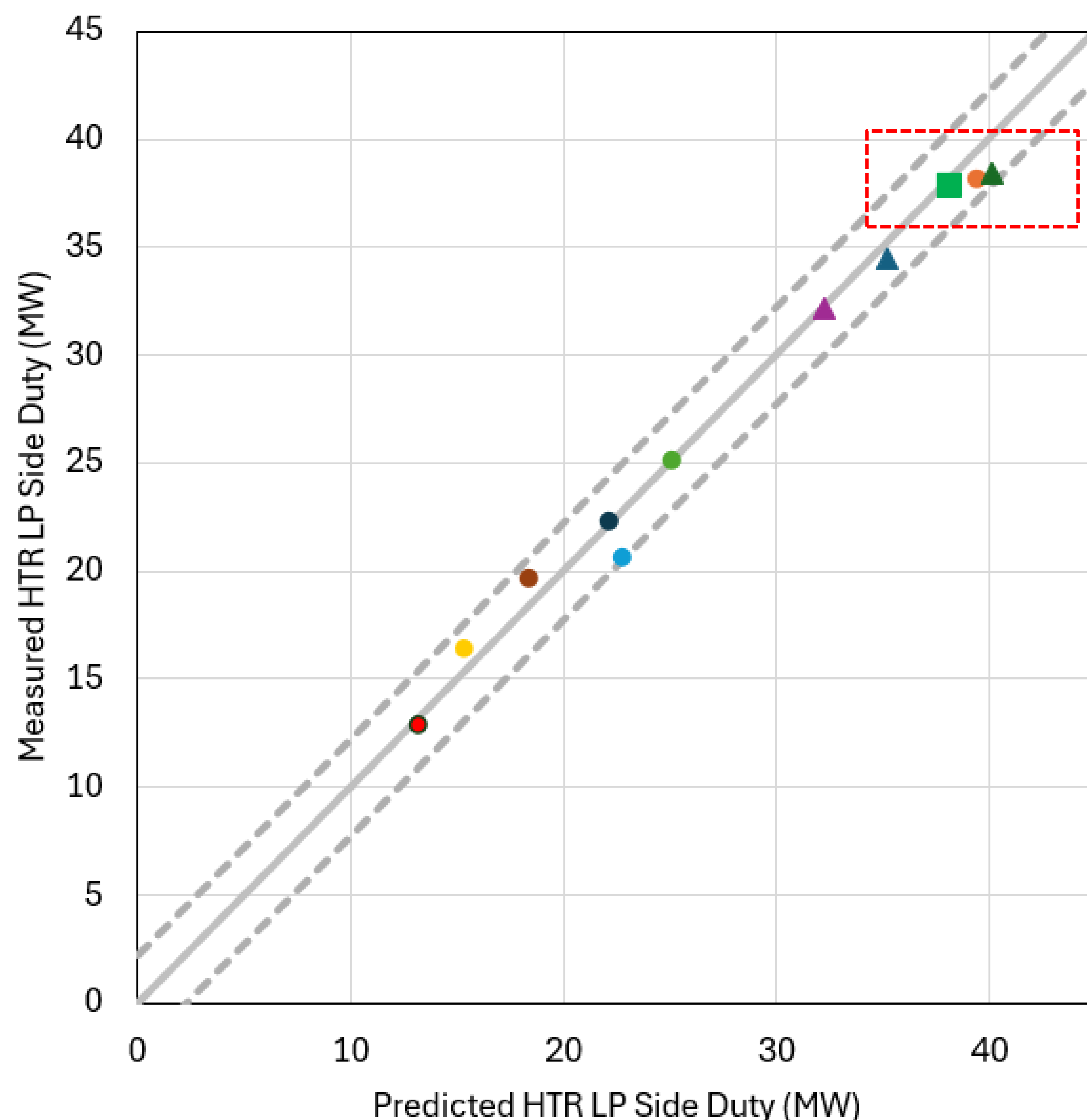
- Before update: large underprediction
- After update: within ~2%



Main Compressor Efficiency (Measured vs Predicted)

- Major improvement from original >16% deviation
- Updated maps align well with operational data

# Heat Exchanger Validation (HTR & Heater)



- Simple Max
- ▲ DAP 10
- DAP 9
- ▲ DAP 8
- DAP 7
- ▲ DAP 6
- DAP 5
- DAP 4
- DAP 3
- DAP 2
- DAP 1
- Match Line
- - - 5% Error Bar

## HTR Duty (Measured vs Predicted)

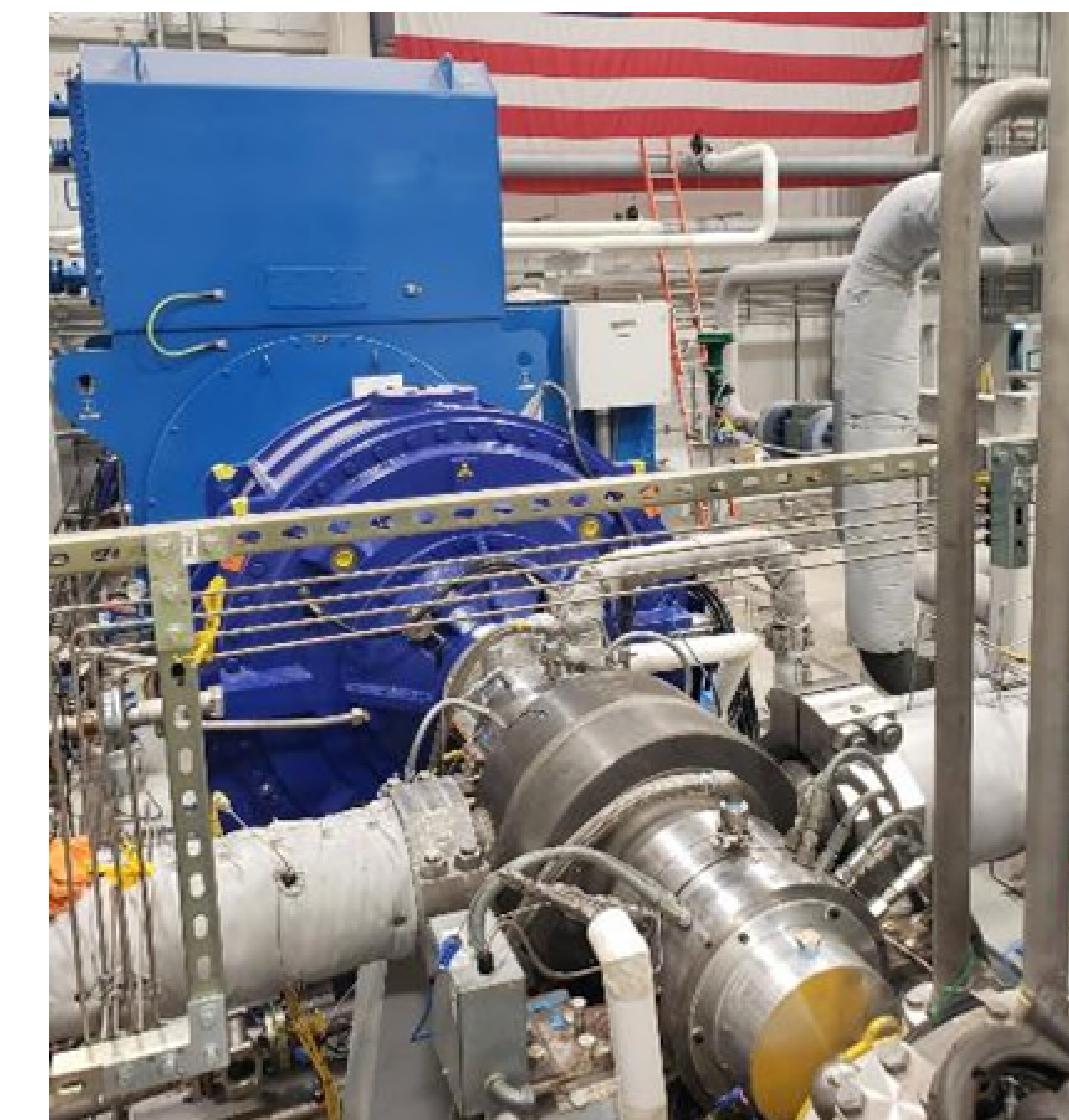
- Within 2% across steady state DAPs
- Same before and after results

## Heater Duty (Measured vs Predicted)

- Very strong agreement
- Heater model requires no updates

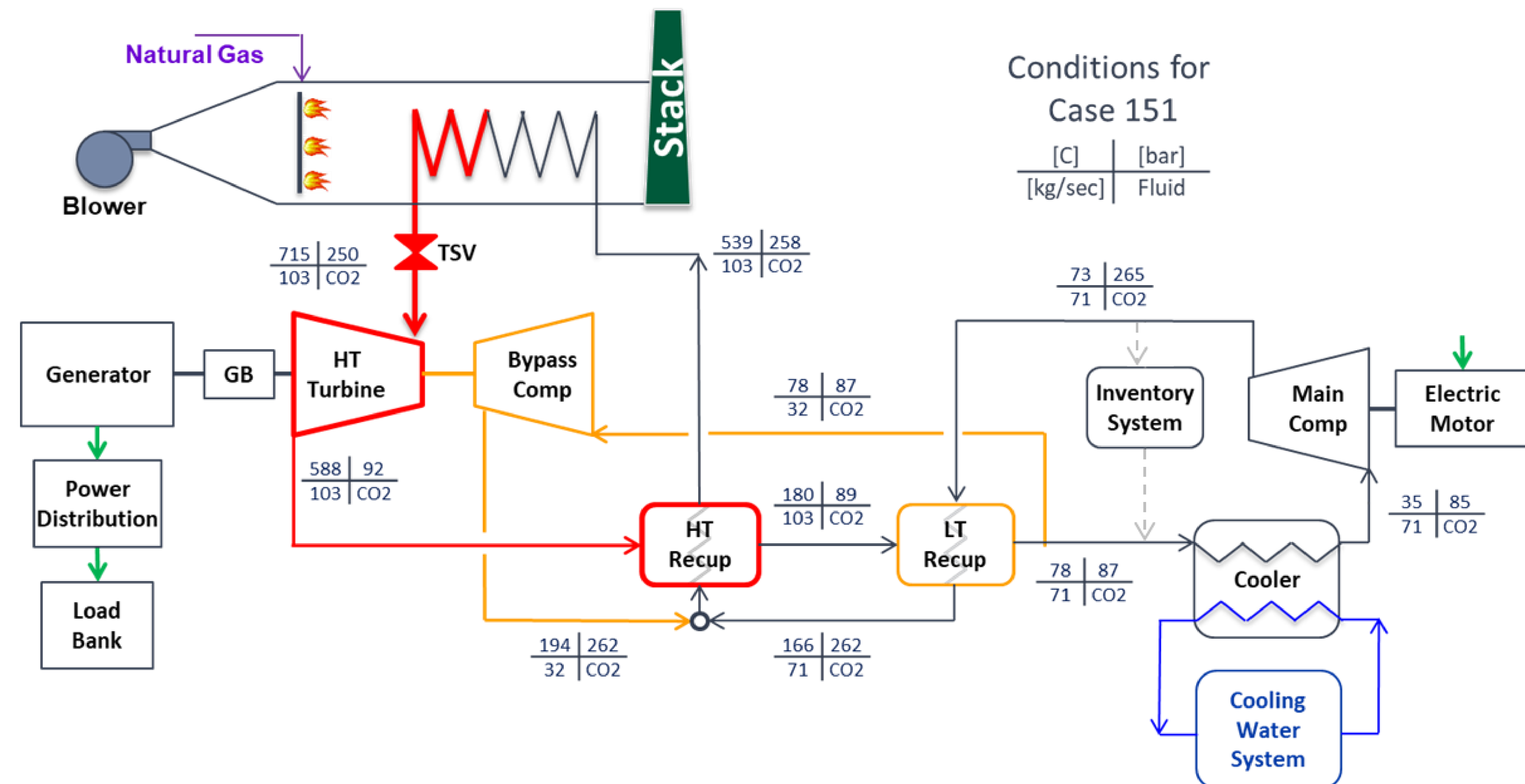
# Summary of Key Improvements

- Model updated using actual 2024 test data
- Compressor map corrections: biggest reduction in error
- Turbine & shaft efficiency updates improved power prediction
- As-built piping + heat losses significantly enhanced accuracy
- Final model matches steady state data within:
  - Cycle-level: ~1–5%
  - Turbine: 1–5%
  - Compressor: ~2%
  - HTR & Heater: ~2%



# Path Forward

- Incorporate new turbomachinery test data during RCBC commissioning
- Implement updated HTR model from Carleton University
- Integrate cooling tower model (NRCAN support)
- Begin RCBC steady state validation and future transient modeling



# Gratefully Acknowledging the Support from U.S. DOE-NETL and Project Partners



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# Questions?

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# Backup

# DAQ Network from C.J.

