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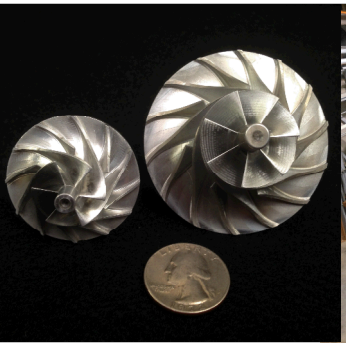


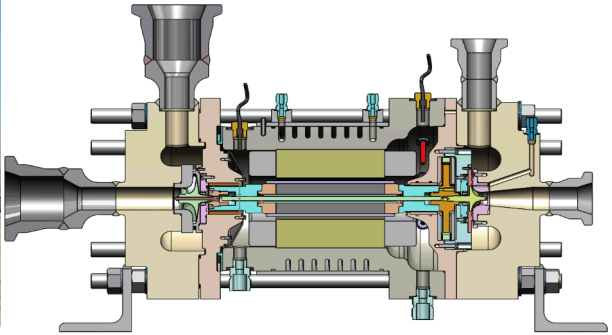

Evaluation of Recent Data from the Sandia National Laboratories Closed Brayton Cycle Testing

J. Pasch, D. Fleming, M. Carlson, G. Rochau

U.S. DEPARTMENT OF ENERGY

National Nuclear Security Administration

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Objectives

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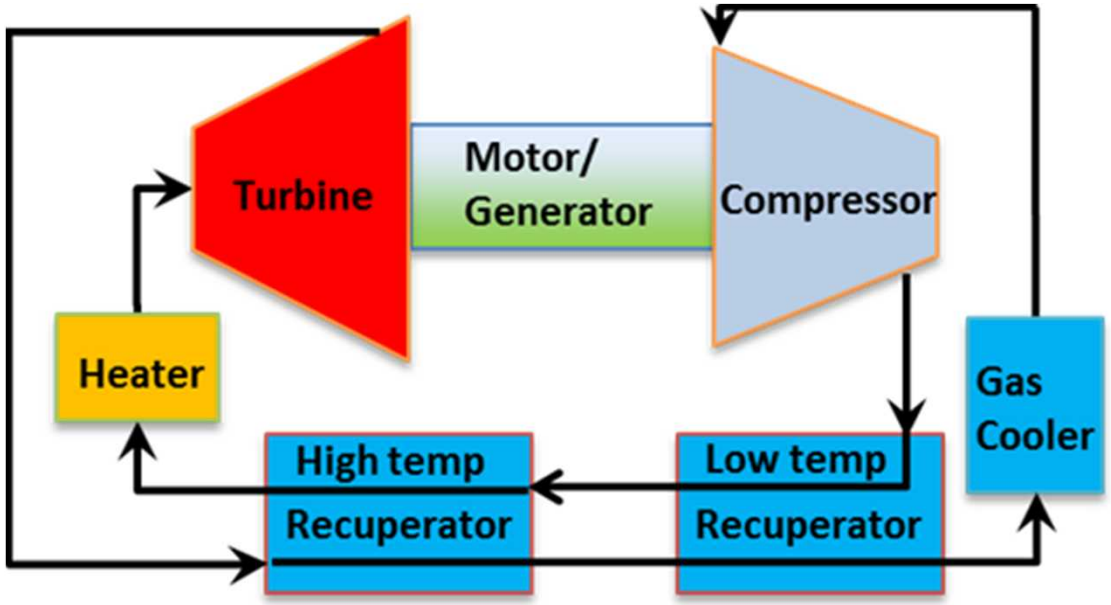
- Test setup and data set
- Present the data for the cooling transient
- Observations
- Present the data for the steady state performance comparisons
- Observations
- conclusions

Test Configuration and Setup

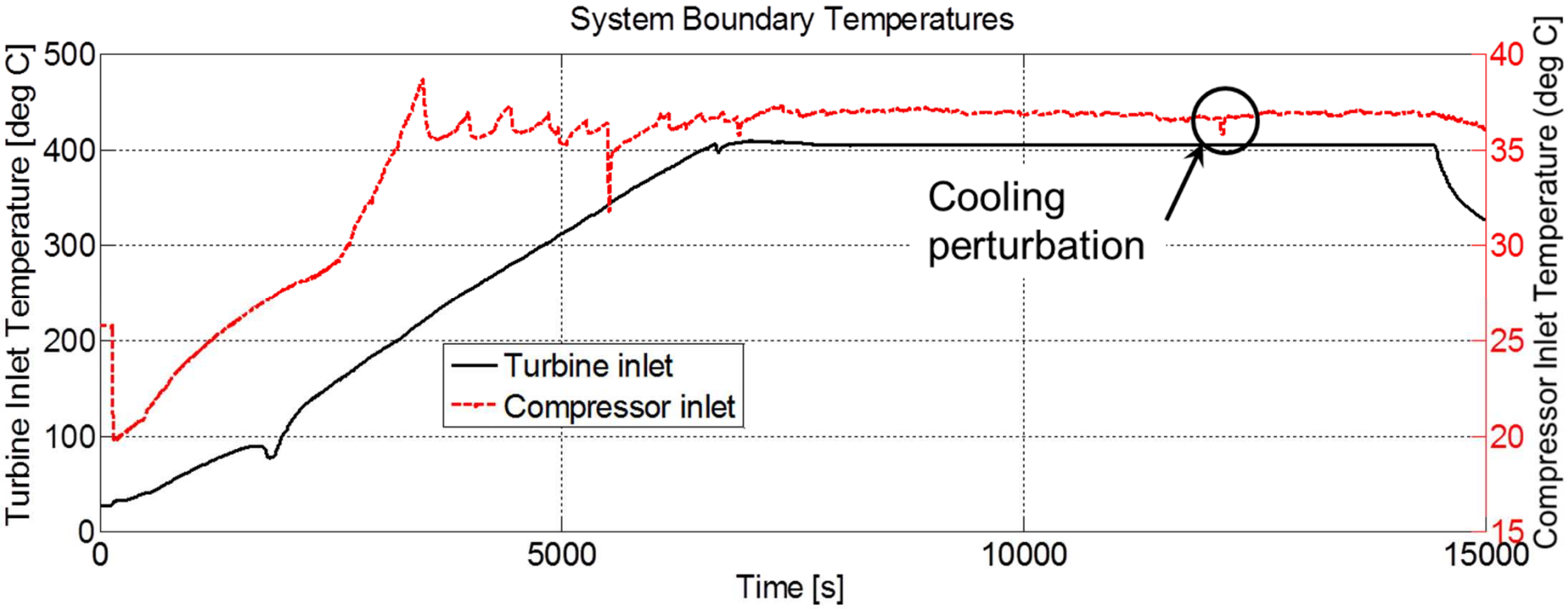
- Development platform configured for simple cycle testing
- Simplified evaluation of recent motor controller software modifications
- Simplified safe and rapid cooling perturbations
- Provided precise knowledge of turbine mass flow rate

- P/T's at ins/outs of all components
- Pressure: Honeywell model FP2000 FPA1DN-1Y-2Y-5B-6A, output 4—20 mA
- Temperature: Conax RTDs, model MRTD4354
- Flow rate and density: Micro Motion Coriolis flow meters measure both flow rate and fluid density, model DH150S with model 2700 transmitters



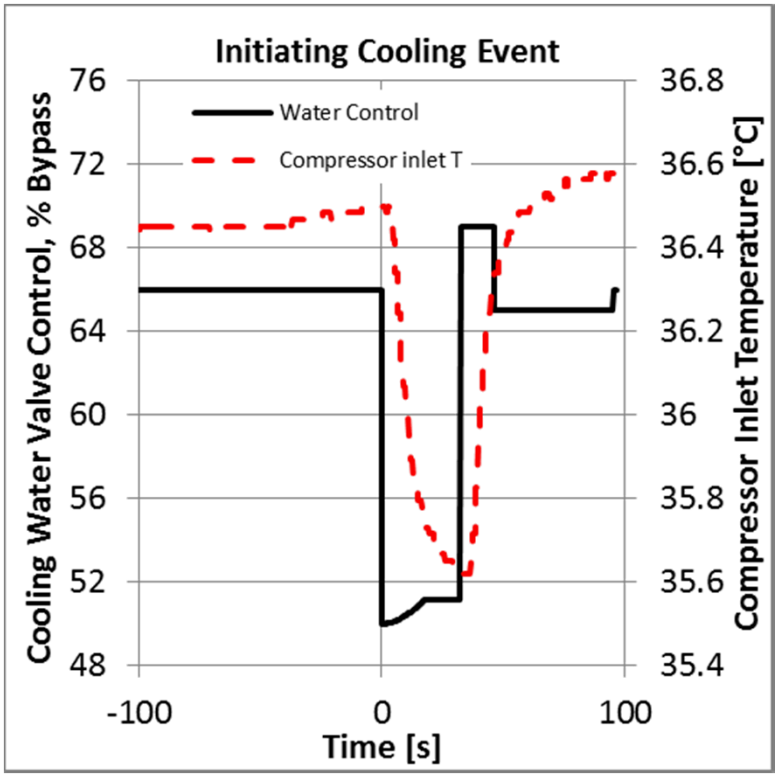
Steady State Established

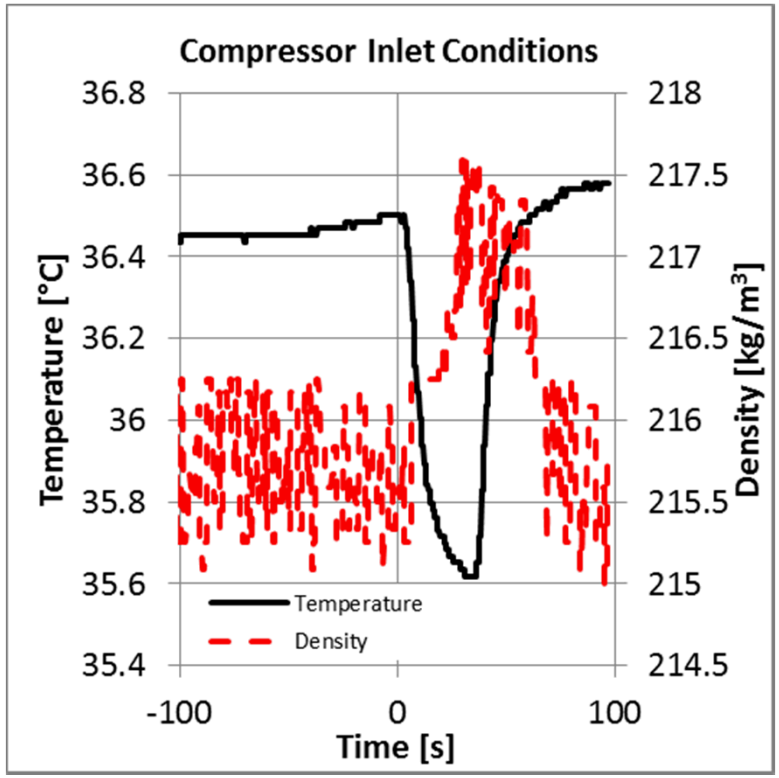
- Over 4000 seconds of steady state conditions, starting around 8000 seconds into the test, established prior to cooling perturbation.
- Compressor inlet temperature during this period ranged from 36.5 °C to 37.2 °C
- Turbine inlet temperature during this period ranged from 404.0 °C to 404.8 °C
- Cooling Perturbation initiated at 12121.5 seconds, and terminated at 12153.0 seconds into test for a duration of 31.5 seconds.



Perturbation Event

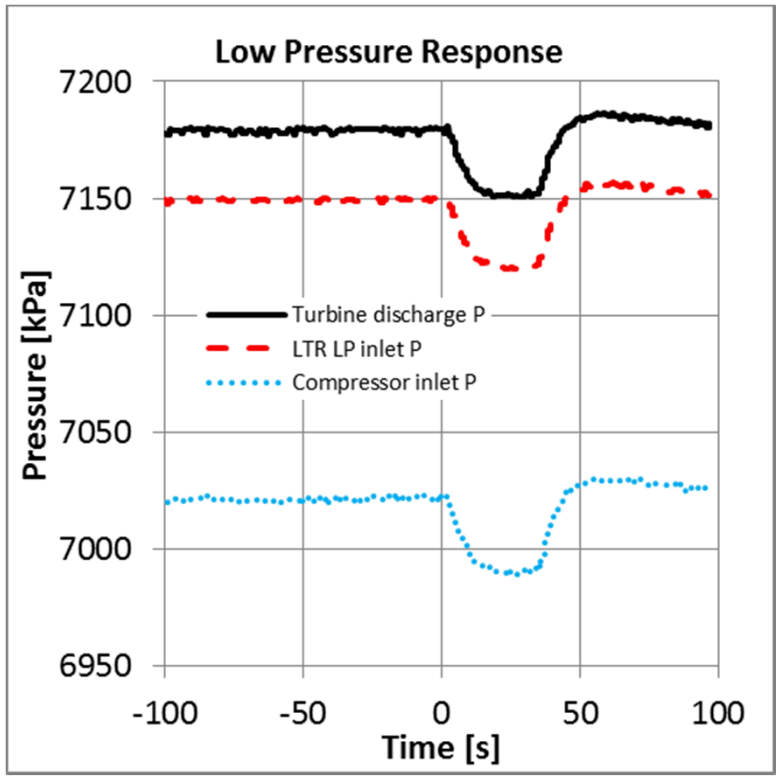
- Cooling perturbation initiated by increase in cooling water flow to the gas cooler.
- Increased heat rejection causes a decrease in CO_2 temperature of 0.9 °C and a resulting increase in CO_2 density of about 1.5 kg/m^3.
- Duration of increased cooling is 31.5 seconds, after which the cooling circuit valves are returned to the original settings.

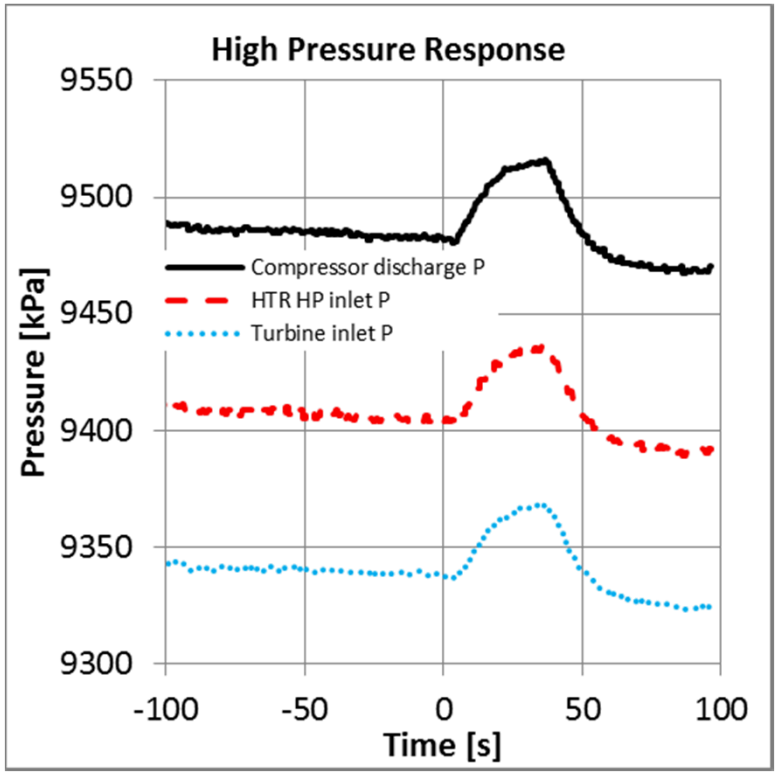




Pressure Response

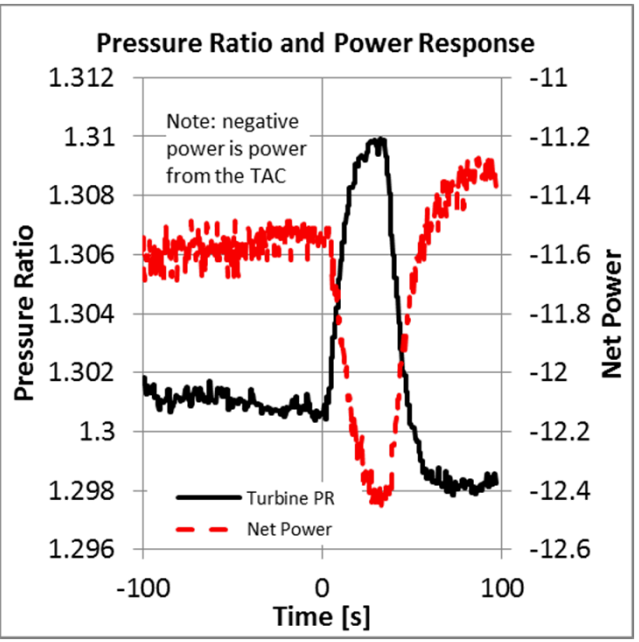
- Low pressure leg responds with decreased pressure.
- Low pressure response appears to achieve new, quasi-steady state about 15 seconds after initiation.
- High pressure leg responds with increased pressure, caused by control scheme allowing increased rotor speed.
- High pressure response approaches new, quasi-steady state about 30 seconds after initiation.

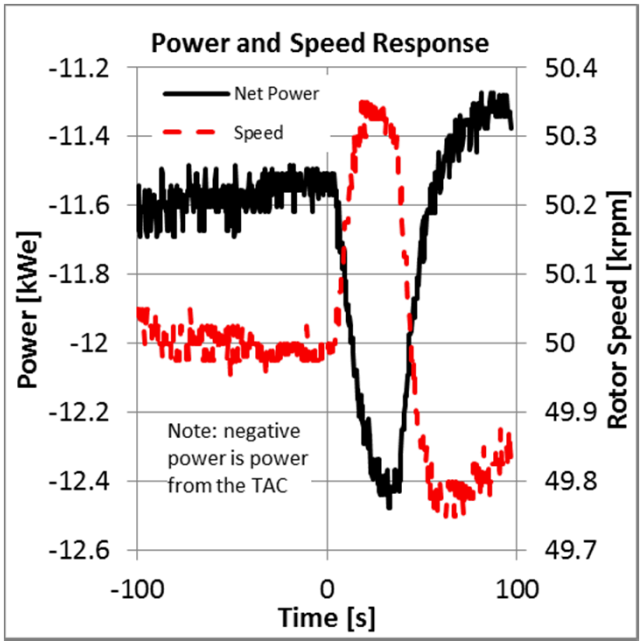


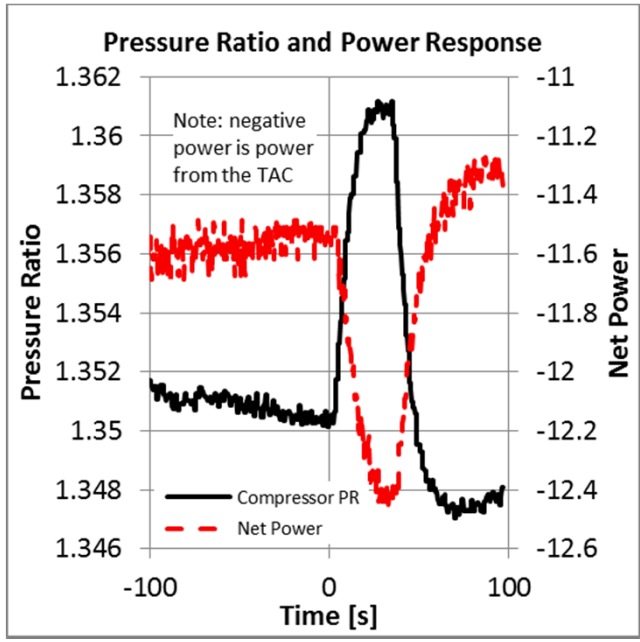


Power Changes and Distribution

- Increased turbine pressure ratio leads directly to increased power and shaft speed.
- Increased shaft speed leads directly to increased compressor pressure ratio.
- Increased compressor power subtracts from net power, but the net effect is an increase in generated power.
- Power distribution is an increase in turbine power of 2.0 kW, compressor power increase of 1.0, with the remaining 0.1 kW attributed to increased windage.

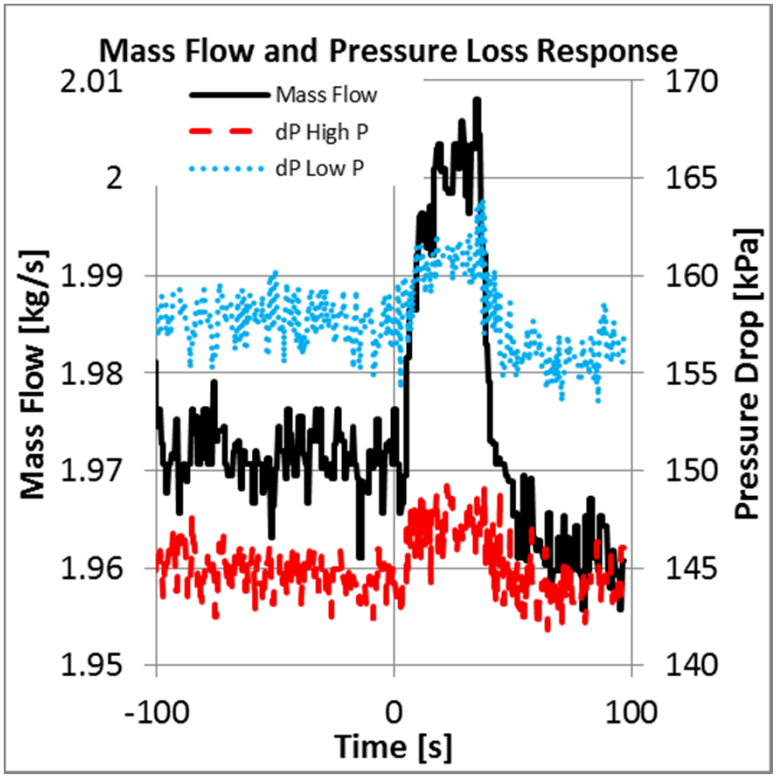






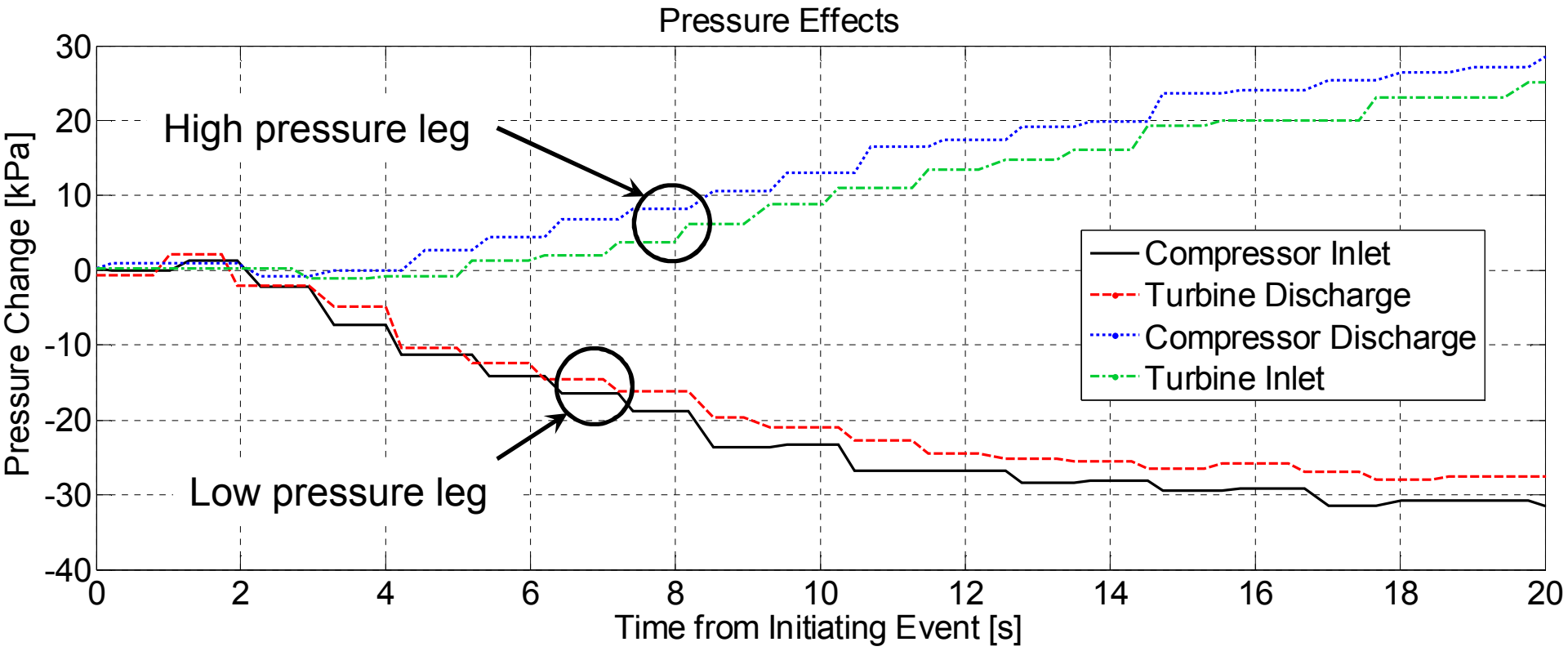
Momentum Effects

- Note that because pressure ratio increases, mass flow rate also increases by 0.03 kg/s, which causes an increase in momentum loss of about 5 kPa in both low and high pressure legs



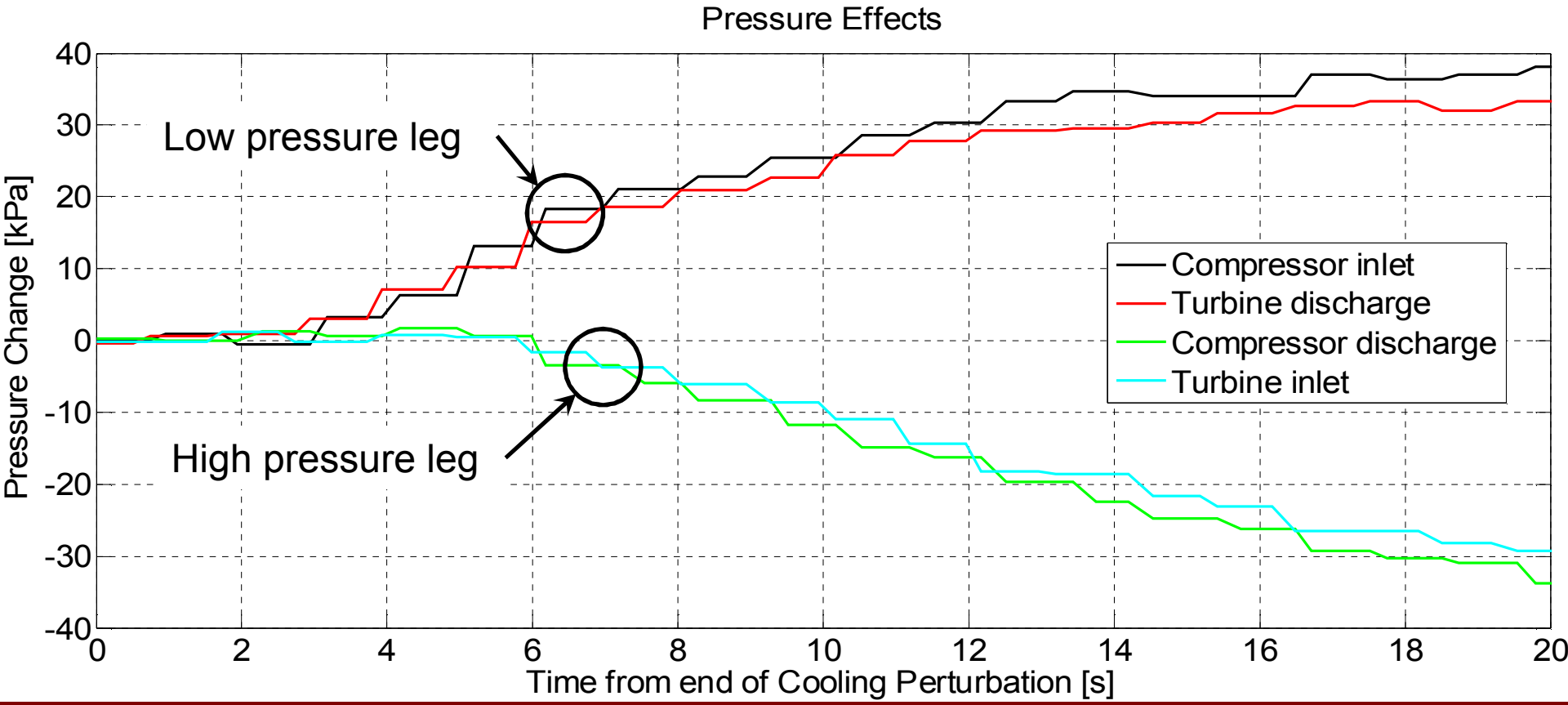
Pressure Response

- Low pressure leg reacts first with decreasing pressure
- High pressure leg response delayed about 2 seconds with an increase in pressure
- High pressure response caused by increase in speed



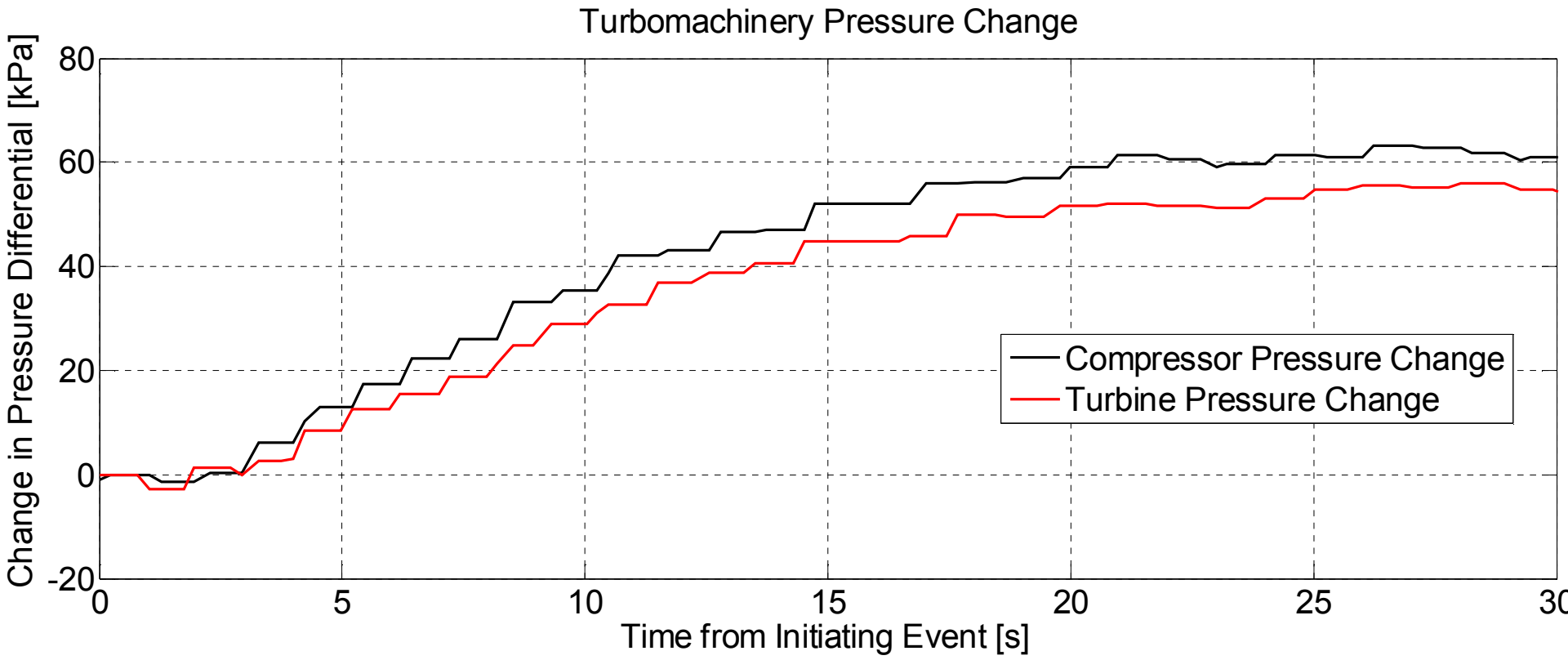
Pressure Response

- Return to previous cooling conditions caused system return to near-previous conditions. Order of events consistent with initiating event.
- Low pressure leg reacts first with increasing pressure
- High pressure leg response delayed about 2-3 seconds with a decrease in pressure
- High pressure response caused by decrease in speed



Change in Delta P's

- Compressor pressure rise increases by 63 kPa, consuming an additional 1.0 kW of power
- Turbine pressure drop increases by 55 kPa, generating an additional 2.0 kW of power



Detailed Prediction Performance

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Operating characteristic	Units	Measured	Predicted	Difference
Compressor ΔP change	kPa	+ 62	+47	- 15
Compressor power change	kW	+ 0.9	+ 1.2	+0.3
Turbine mass flow rate change	Kg/s	+ 2.0	+ 2.0	0
Turbine power change	kW	+ 2.0	+ 2.0	0

Turbomachinery Performance Predictions

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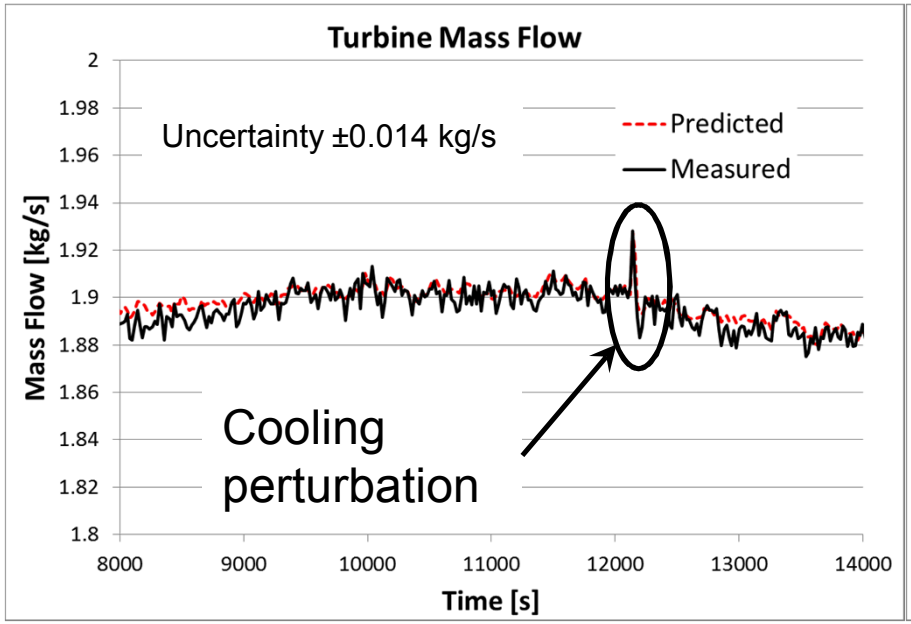
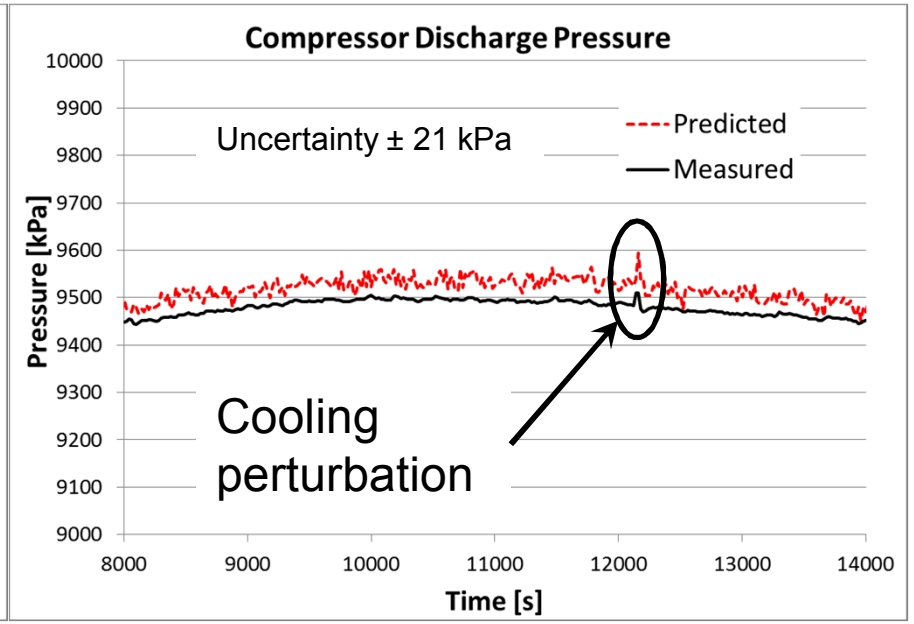
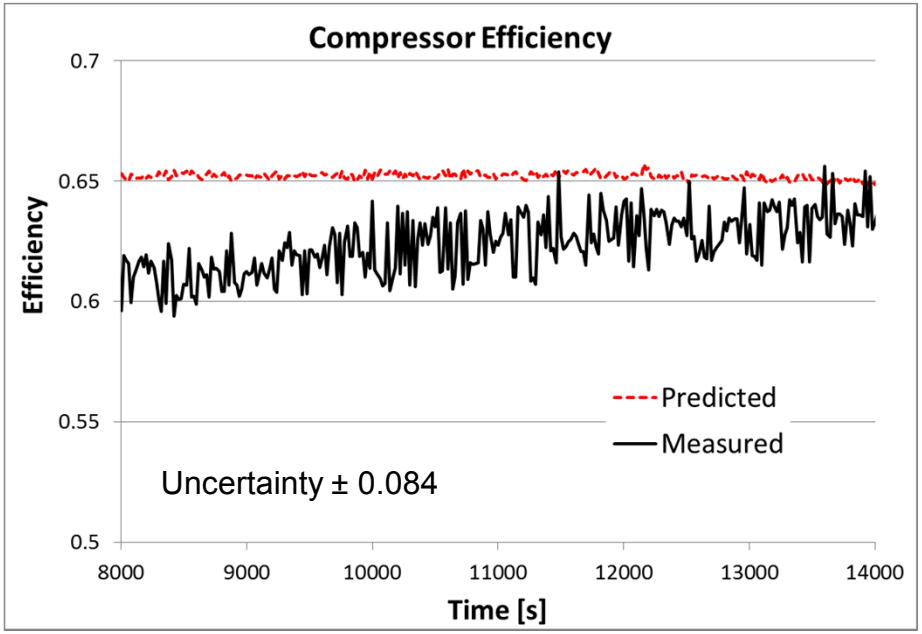
- Testing in simple cycle configuration allows for accurate measurement of turbine flow rate.
  - Is the difference between measured compressor flow and measured leakage flow.
- Measured and predicted turbine mass flow rates are almost equal for majority of the steady state period.
- Measured compressor discharge pressure is consistently lower than predicted by 30 kPa.

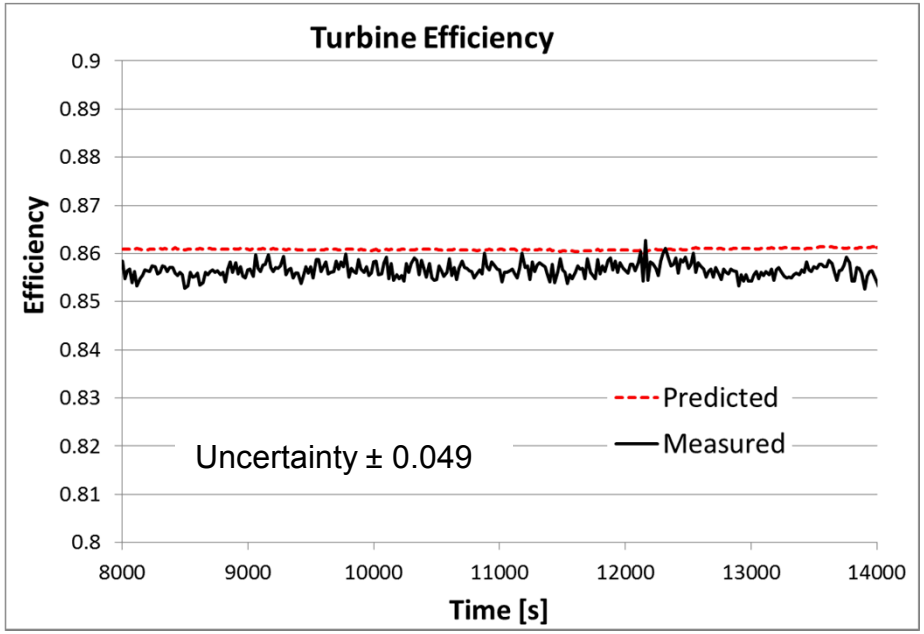




Turbomachinery Performance Predictions

- Results of turbine performance are the best yet obtained. Isentropic efficiency calculated from measurements is consistently 0.5 percentage points below predicted.
- Results of compressor performance similar to previous tests. Isentropic efficiency calculated from measurements is between 2-4 percentage points below predicted.
- Relatively large difference is attributed to operating the recompressor far from its design inlet temperature of 59.4 °C.





Conclusions

- A closed simple Brayton sCO_2 cycle was operated at steady state boundary conditions for about 6000 seconds.
- At about 4000 seconds into steady state, the system was subjected to a rapid heat rejection transient for 32 seconds that affected primarily pressures and net power.
- A series of effects result from the cooling event and speed control function that contribute to increased net power
  - Initiating cooling event decreases pressure in low pressure leg, establishing increased pressure ratio across the turbine, and therefore greater net power.
  - Increased turbine power increases rotor speed, which increases compressor pressure ratio, which increases both compressor power and turbine power.
- The closed volume design of the CBC causes pressure changes at 1 location to affect conditions throughout the circuit.
- The simple cycle remained stable during the transient.
- Steady state measured turbine performance is the best yet obtained with this system. Agreement to with 0.5 percentage points validates turbine design predictions.
- Steady state measured compressor performance is similar to history. Agreement to with 2-4 percentage points of design predictions is good, and attributed to off-design operation.