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Modernizing the Control Systems of Sandia's Hypersonic Wind Tunnel

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Sandia National Laboratories
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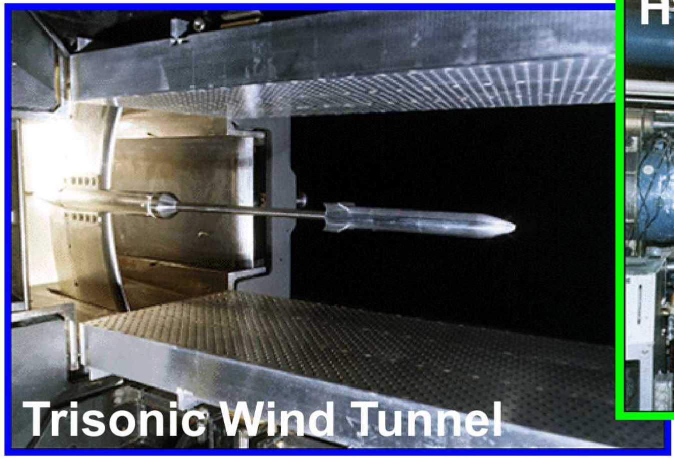
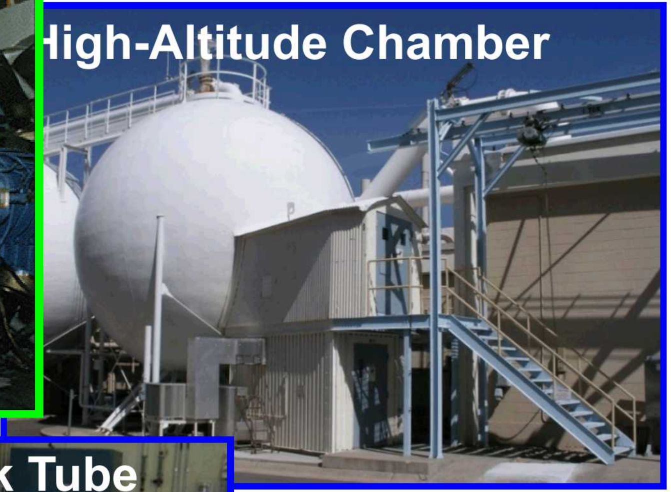
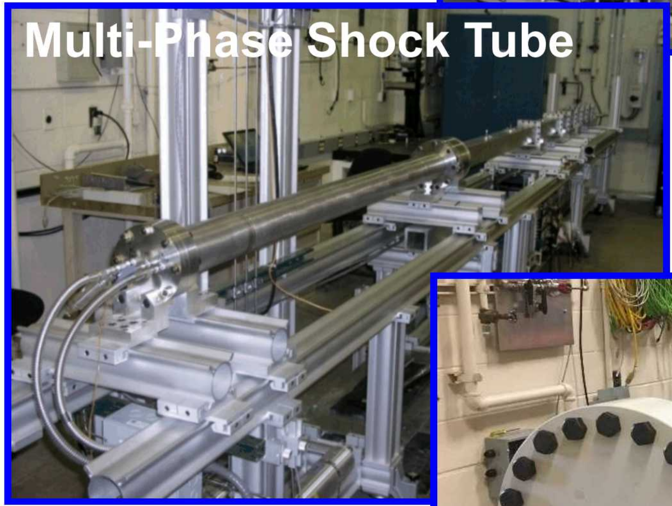
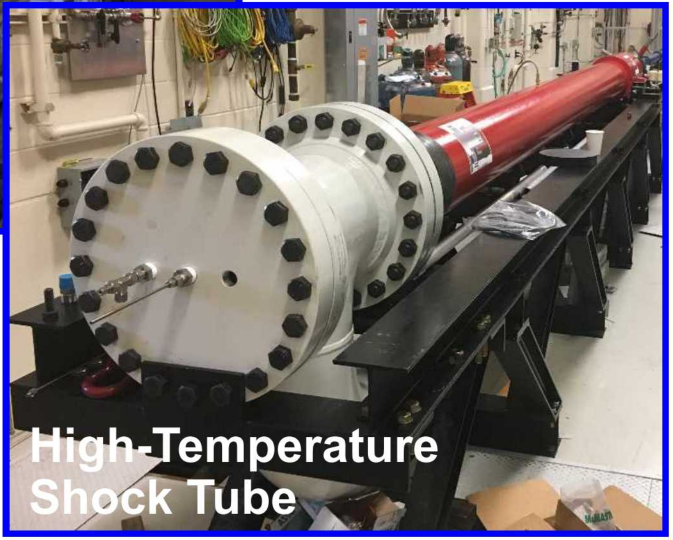
Experimental Aerosciences Facility









Trisonic Wind Tunnel (TWT)
- Mach 0.5 – 3
- Gravity bombs, missiles

Hypersonic Wind Tunnel (HWT)
- Mach 5, 8, 14
- Re-entry vehicles, rockets

High-Altitude Chamber (HAC)
- Satellite components

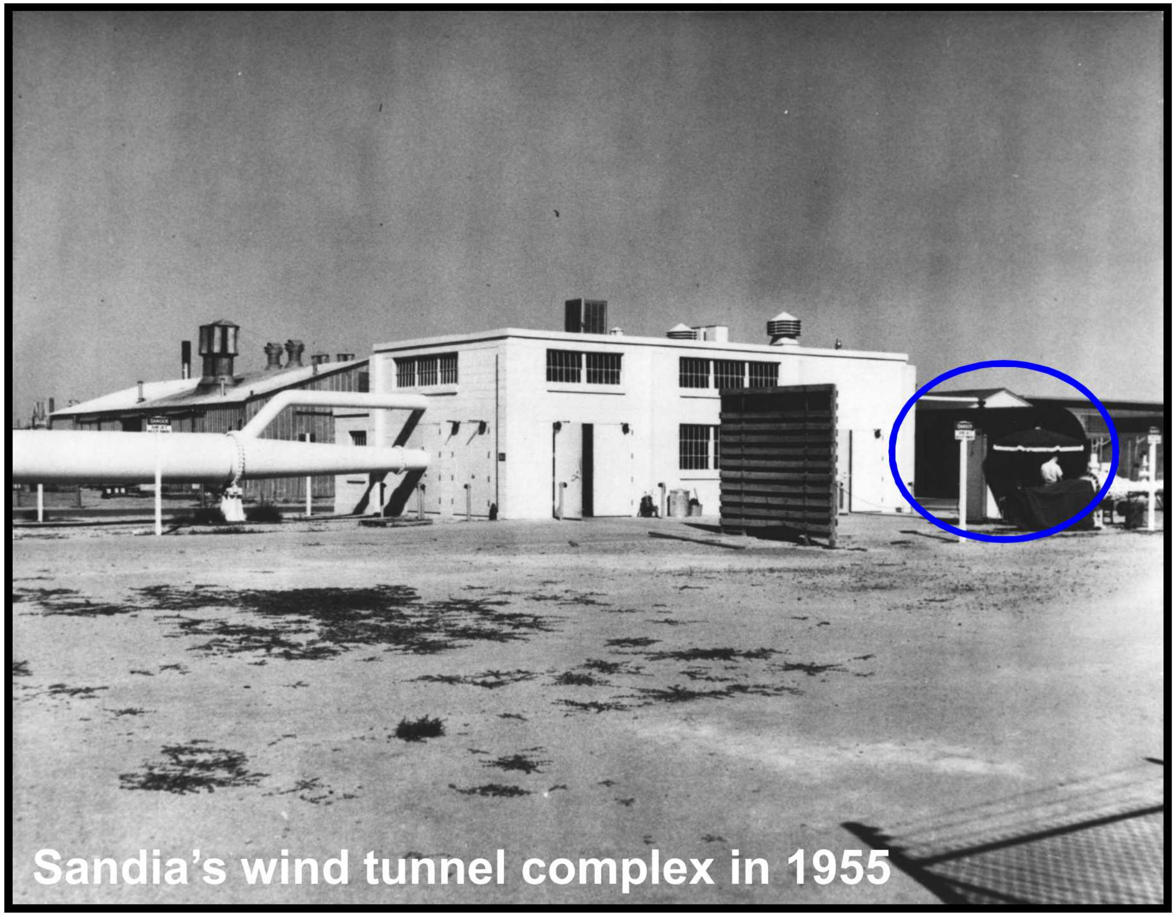
Multi-Phase Shock Tube (MST)
- Explosives research

High-Temperature Shock Tube (HST)
- Soon to be a Mach 8 Shock Tunnel…

A Brief History of the HWT

Sandia began its career in the wind tunnel business in 1955.

Installation of what eventually became the Trisonic Wind Tunnel (TWT).



Initially driven by a single tank of 2600 ft^3 volume, pressurized to 300 psig (74 m^3, 2 MPa).

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A Brief History of the HWT

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Sandia's wind tunnel complex in 1955

Initially driven by a single tank of 2600 ft^3 volume, pressurized to 300 psig (74 m^3, 2 MPa).

In 1958, an identical second tank was added.

Also served the Hypersonic Wind Tunnel.

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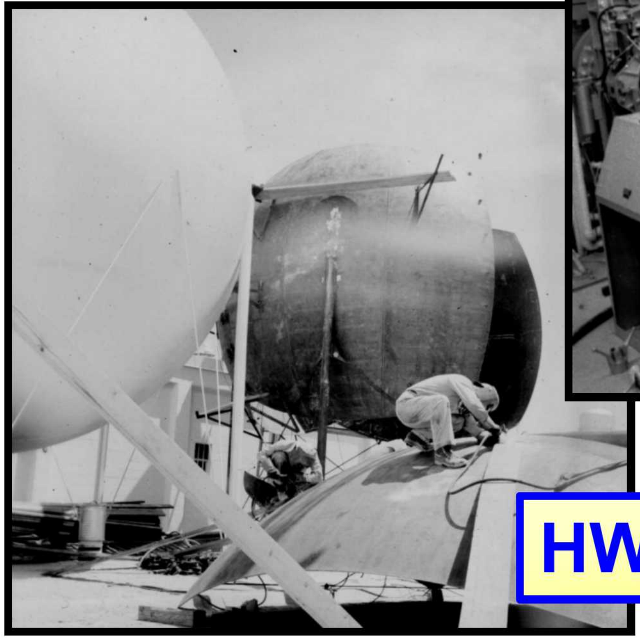
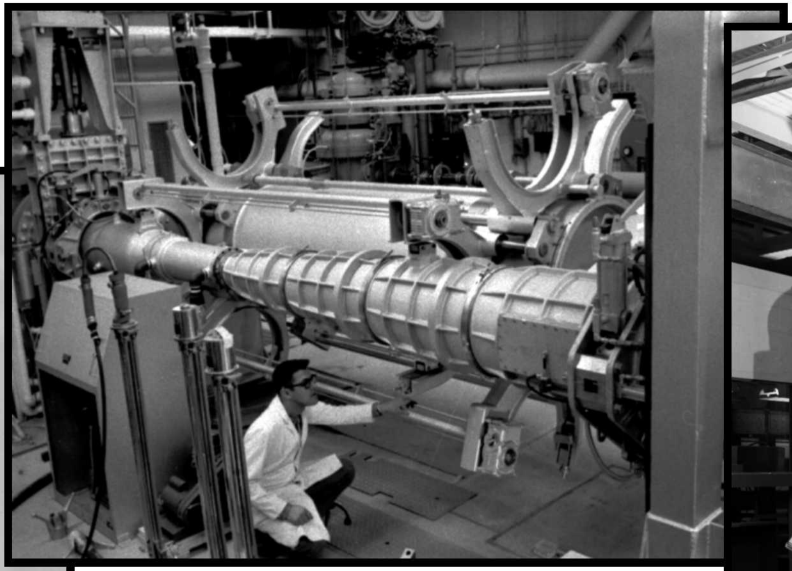
Development of the HWT began in 1958.

Downstream vacuum spheres were added to achieve the necessary pressure ratio.

The HWT mounts interchangeable nozzles on a revolver mechanism.

A pebble-bed heater kept the freestream air above the condensation line.
The nozzle throats were water-jacketed for cooling.





HWT went online in 1962.

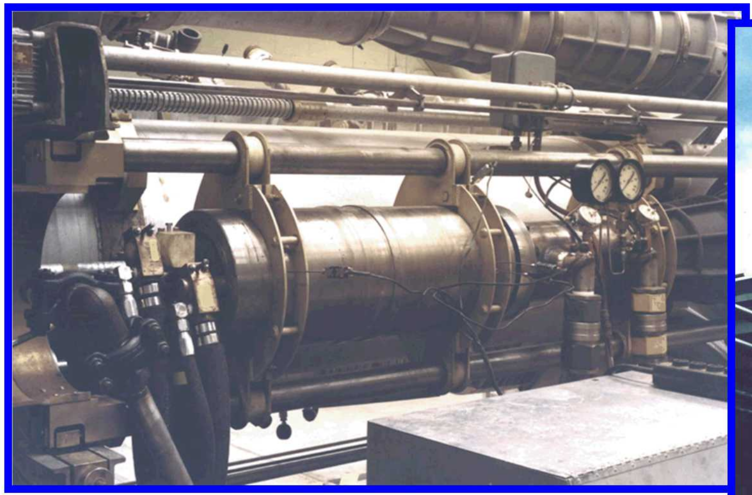
The HWT was upgraded from 1969 to 1977.

Electric-resistance heaters replaced the troublesome pebble-bed, unique for each Mach.

This necessitated pure nitrogen for Mach 8 and 14.

A 10,000-psi cryogenic nitrogen system was added in 1970.

All the gas handling, including valves and regulators and controllers, dates from 1970 or earlier.



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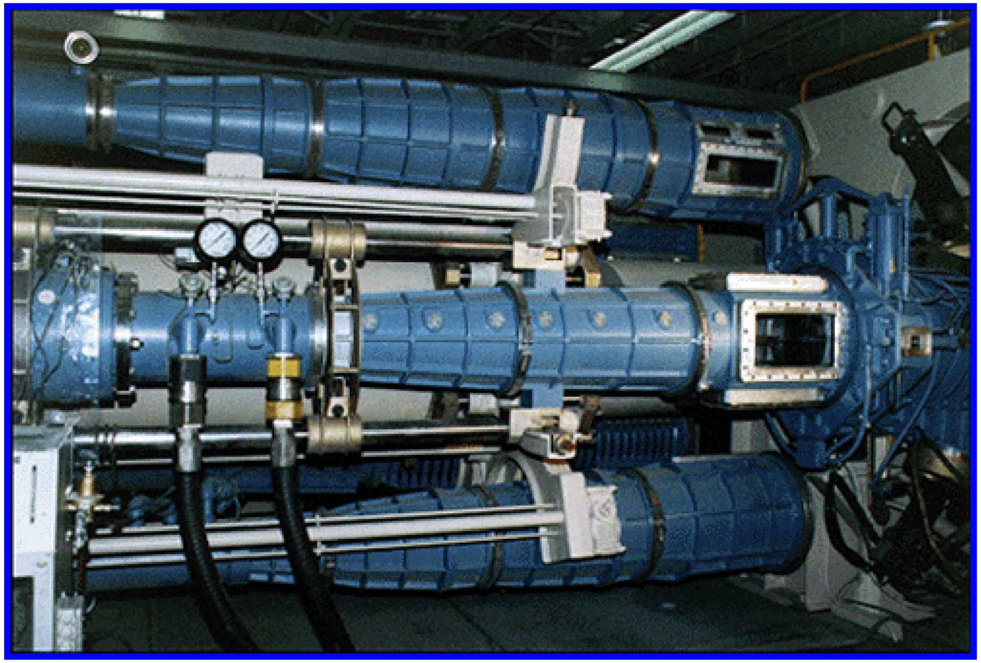
This brought the HWT to essentially the same configuration as today.



- Mach 5, 8, and 14
- Re = 0.2 - 10 x 10^6 /ft
  (0.6 - 32 x 10^6 /m)
- Run times: ~30-60 sec
  at 45-60 minute intervals
- 18" diameter test section
- T_0 to 2500°R (1400 K)

Supported by air, nitrogen, and vacuum.

Sandia recently has invested considerable funds modernizing our tunnel infrastructure.

- **High-pressure air tanks**
- **Compressors, dryers, and filters**
- **Refurbished vacuum tanks**
- **Data acquisition electronics**
- **Refurbished flow heaters**
- **Electrical service for heaters**
- **Pitching strut motor**

…and much more!

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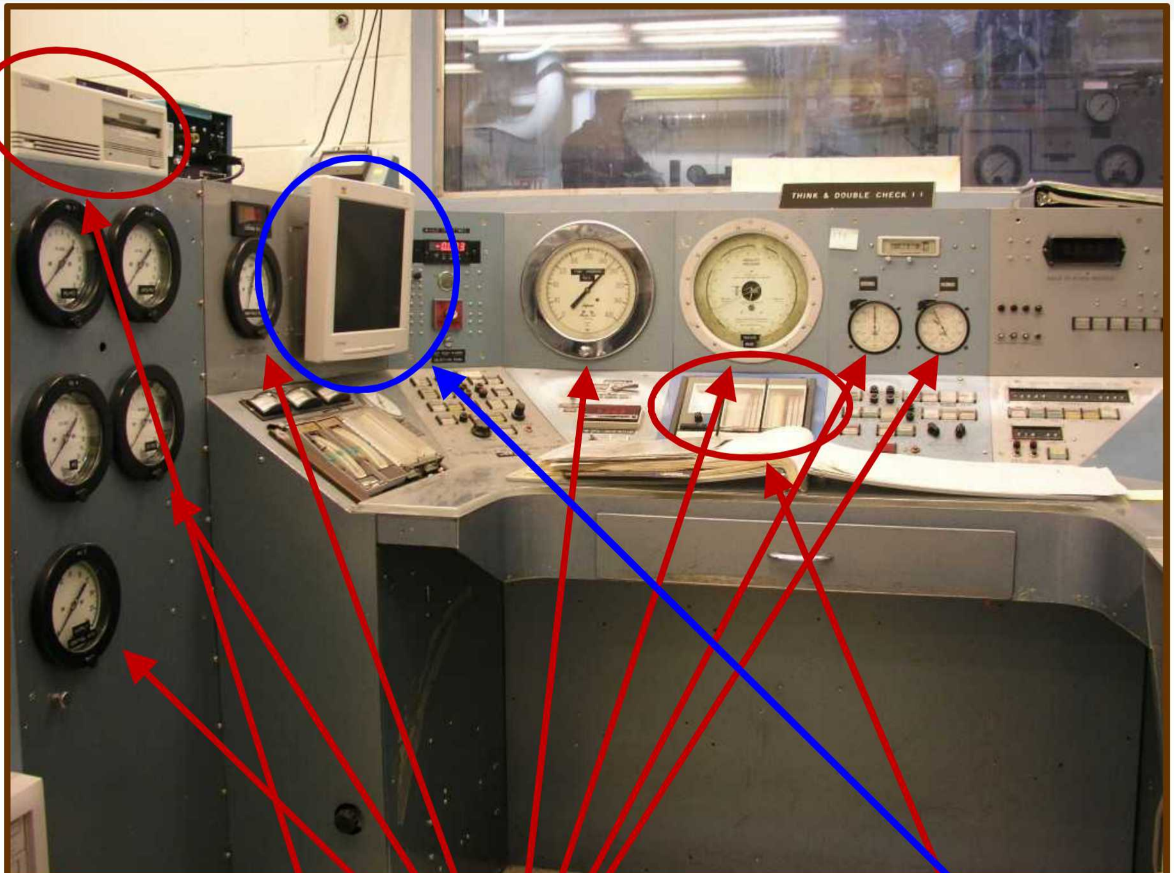
Let's talk about the control console….



The control panel is *embarrassingly* obsolete.

- Pneumatic controls
- Serial interlocks at 120V
- Some controls are manual
- Haphazard user interface
- Confusing to troubleshoot
- Out of electrical code and safety standards

Strip recorders

We grafted LabVIEW control on top of a rickety basis.

Captain Nemo would feel comfortable here.

The modern part of HWT.

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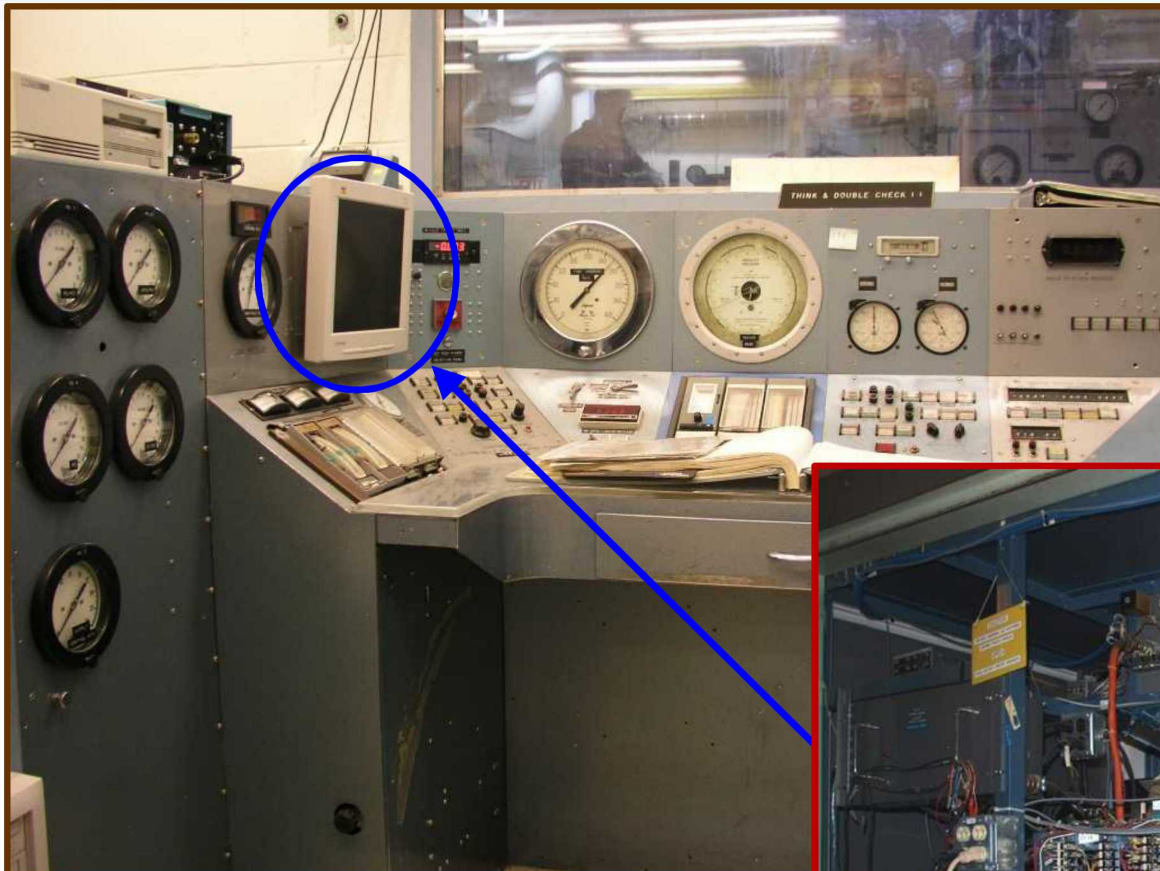
Let's talk about the control console….



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- Pneumatic controls
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- Some controls are manual
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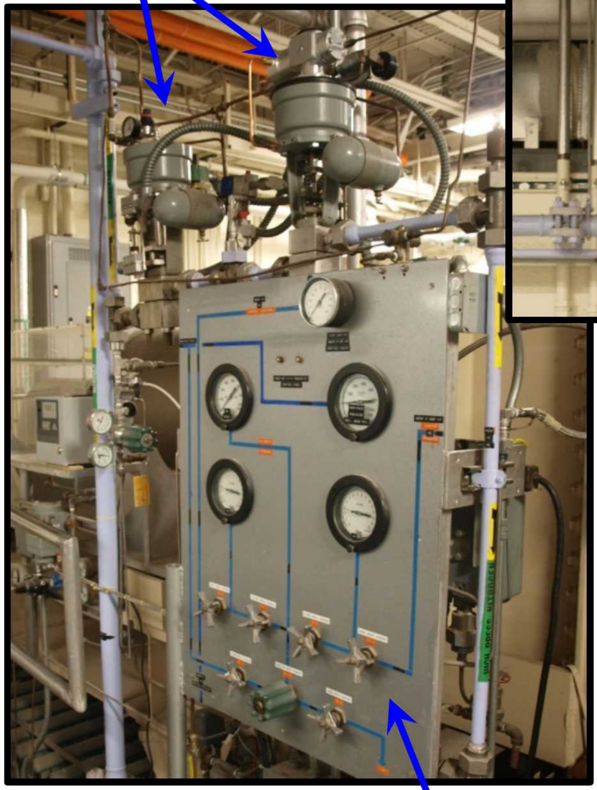
It's even scarier to look behind the HWT control panel!

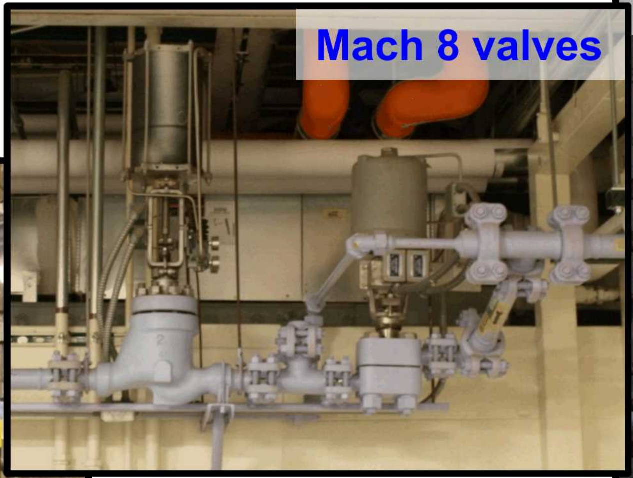
Gas handling systems are aging too.

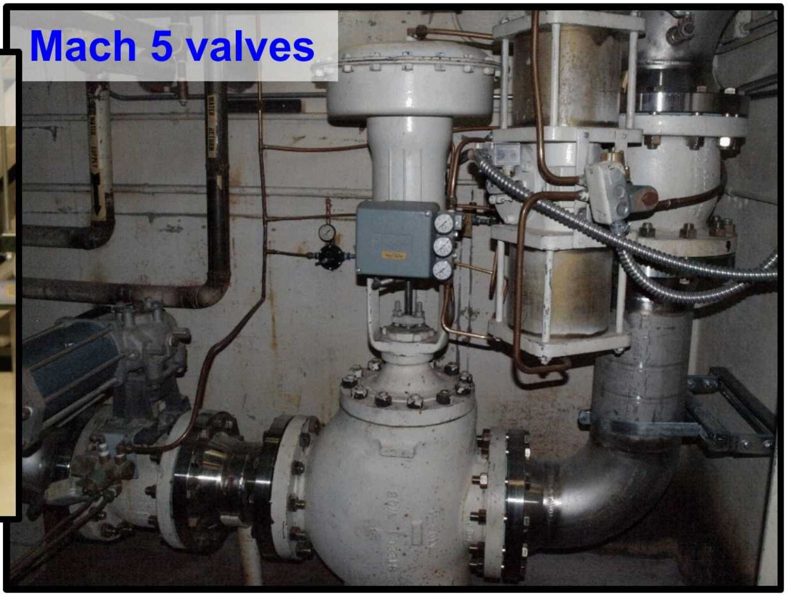
Modernizing the HWT control means not just the control panel, but also the gas handling equipment.

Mach 14 valves



pneumatic controls

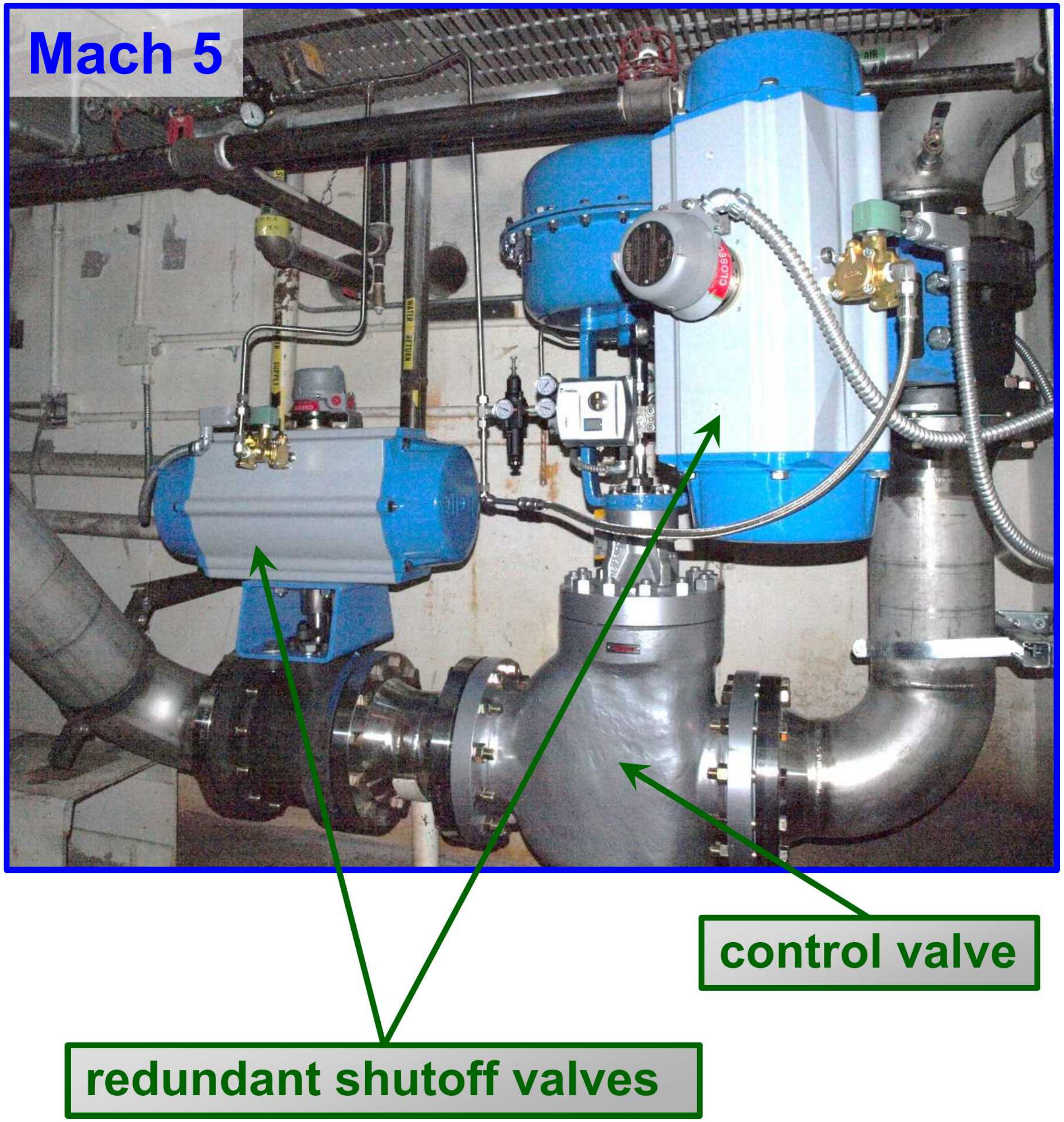




Replace the current control valves.

- From the 1960's and prone to failure.
- Modernize from pneumatic control to electrical.
- Provide valve position feedback; right now, only downstream pressure feedback.
- Currently no valve pre-position; must initiate tunnel flow and then set pressure point.

New valves!



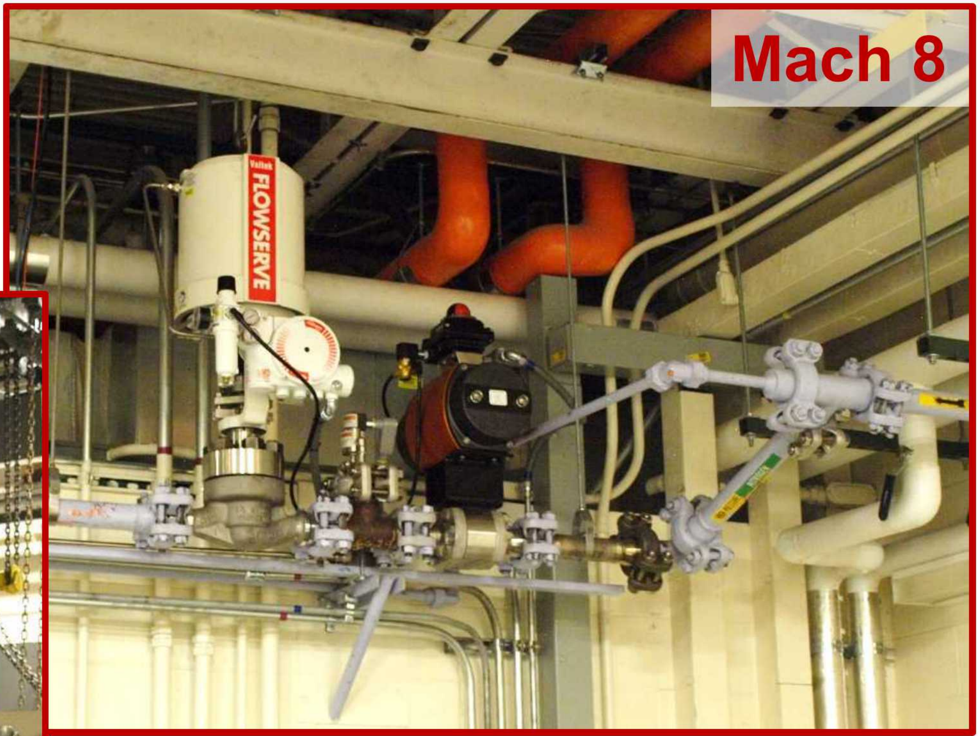
Control Valve: *Metso Flow Control* globe valve

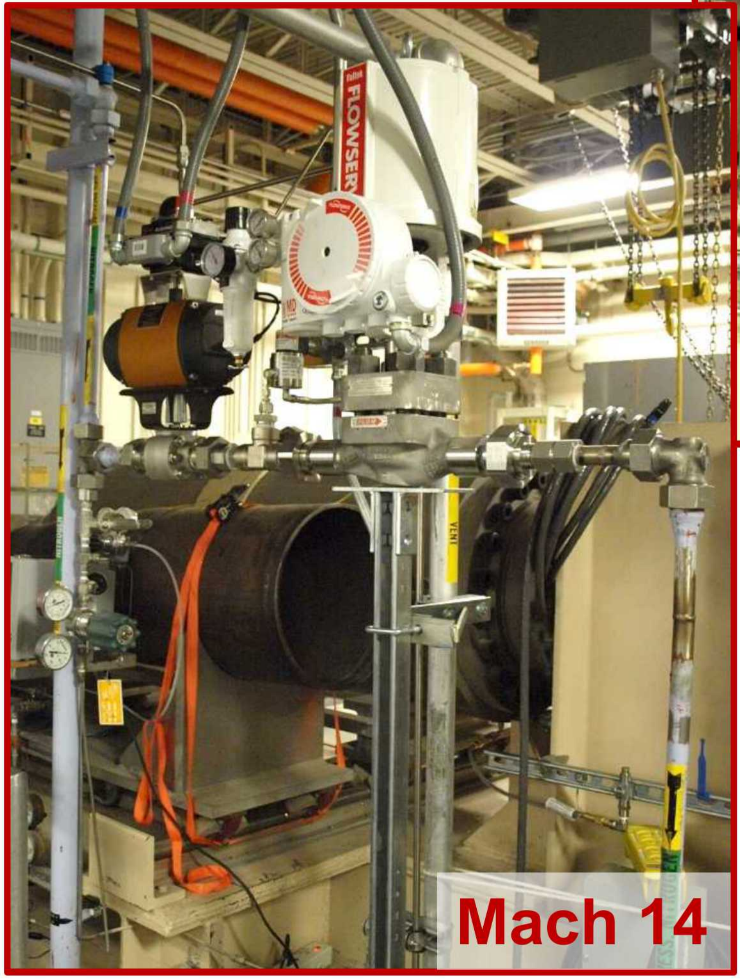
- Double seated
- Spring diaphragm
- Digitally controlled
  - 4-20 mA
  - Position feedback
- Fits in the space available!

Shutoff Valves: *Metso Jamesbury* ball valves with *Valv-Powr* piston actuators

- Pneumatically actuated
- Response time of 1-2 sec
- Safety valve, starting valve (preset control valve)

New valves!





Same design:

- Pneumatically actuated ball valves for shutoff *(Worcester Controls)*.
- Digitally controlled globe valves for flow control *(Valtek Mark 1)*.
- One ball valve for safety; globe valve serves as shutoff valve.

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Criteria for the new control console

Virtual controls are user-friendly, adaptable, and accurate.

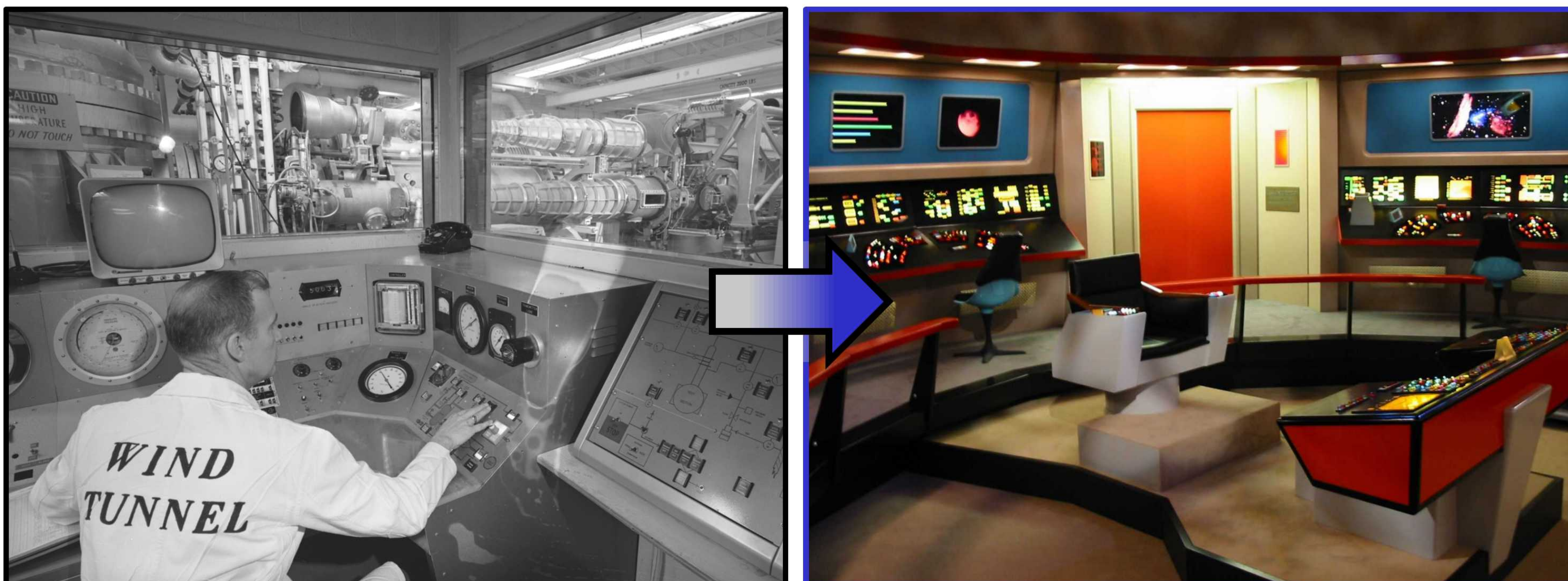
Hard-wired manual console for safety-critical functions.

Three nozzles with a mix of needs:

- Each has unique gas handling and in-line electric heater.
- Common vacuum valve and hydraulic clamps.

Ease of interface with data acquisition.

- Include real-time provision of tunnel conditions.

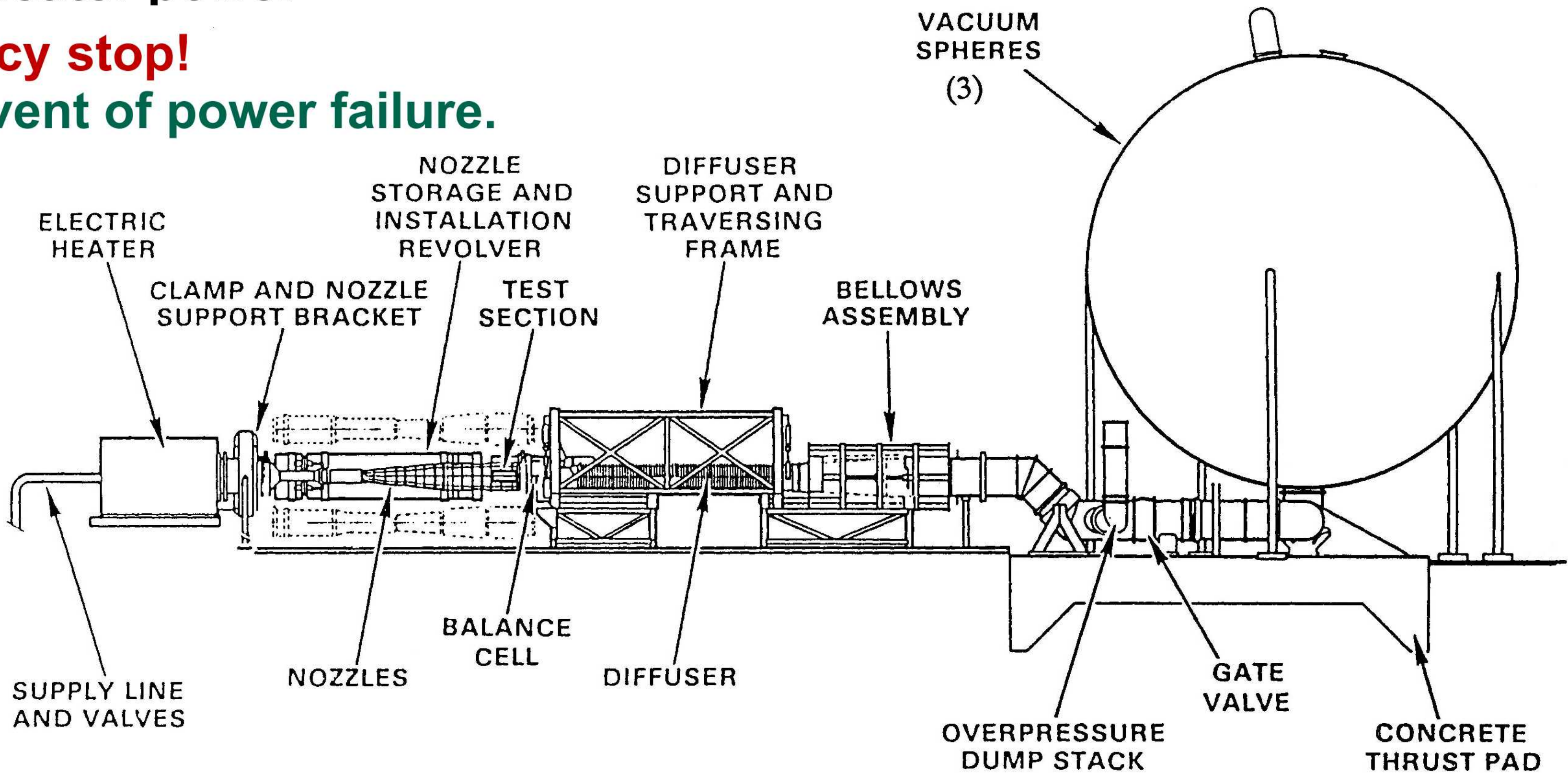


Hard-wired relay logic for safety critical operations

- Single key lockout for 120 V_{AC} power, safety valves, and heater power.
- Tunnel-closed interlocks (24 V_{DC}).
- Heater bus bar interlocks matches Mach selection.
- Sequencing interlocks for:
  - Vacuum valve
  - Safety valves (three in parallel)
  - SCR heater power

Emergency stop!

UPS in event of power failure.



Virtual Controls

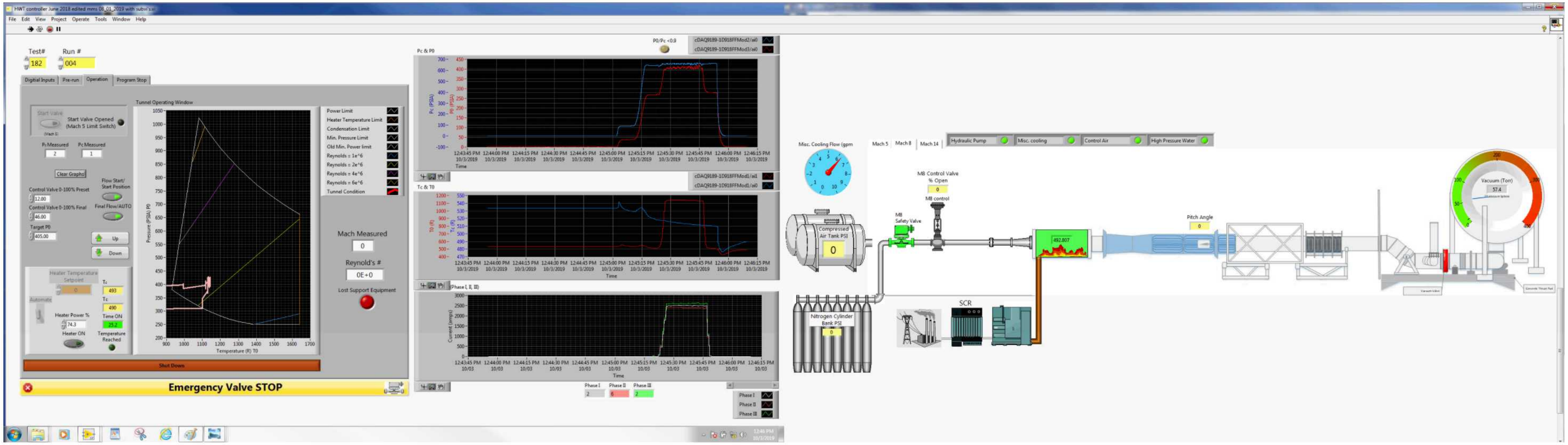
Closed loop feedback for control valves and heater setpoint.

Digital input signals

- Feedback on interlocks and noncritical systems.
- National Instruments Compact DAQ ethernet communication.
- Digitize 4-20 mA pressure sensors, plus thermocouple modules.

LabVIEW user interface

- Disabled and grayed out features to control sequence of operations.
- Real-time operation map for pressure, temperature, and Reynolds number.
- Heater control interlocked until a minimum stagnation pressure is reached (minimum flow rate).



Demolition!

Our control console at the start.

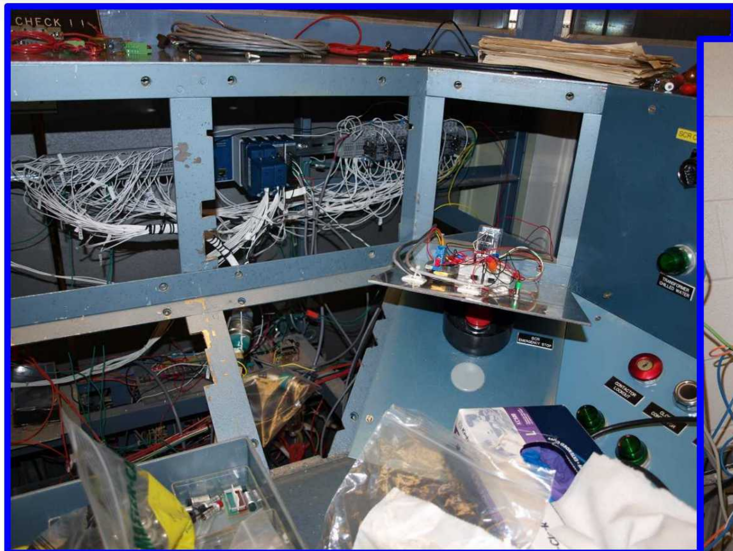
We had been operating with a hybrid than incorporated some new computerized features.

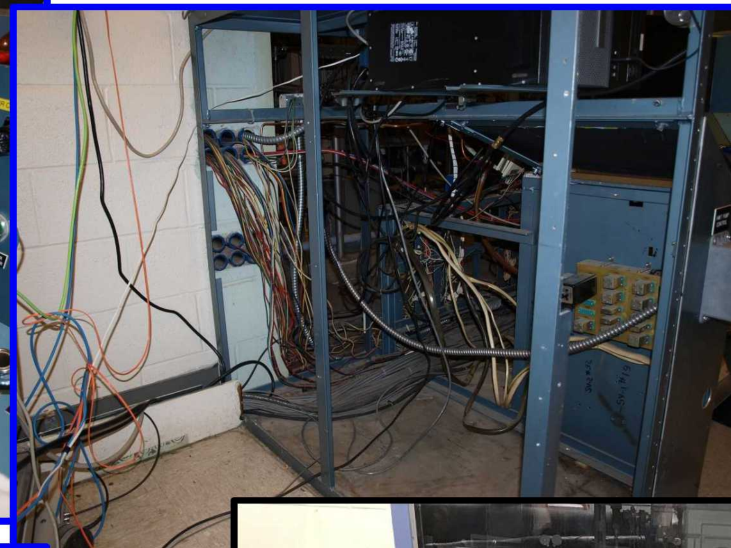
Convert pneumatic controls to voltage or mA controls.

We found 120 VAC powering motors and hydraulics routed through control console.

Unnecessary!

Tear it down piece by piece.



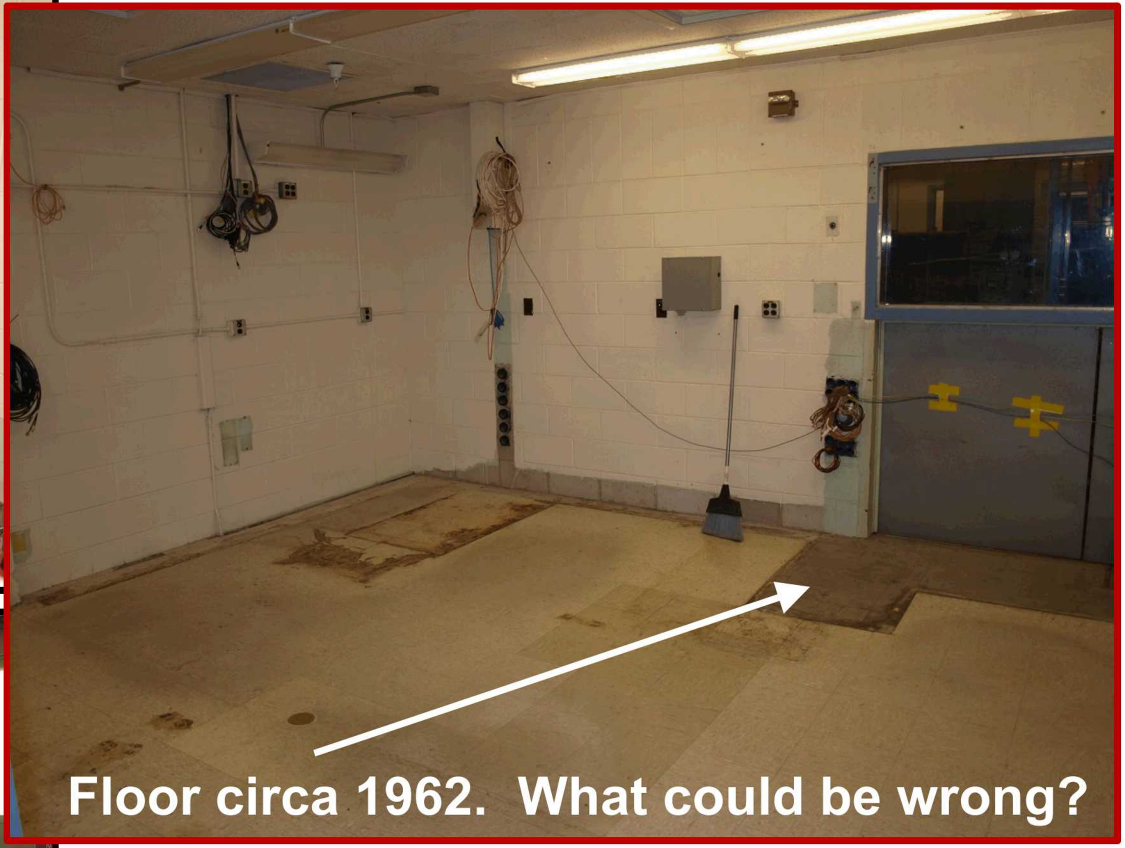


Some reverse engineering during demo.

Preserve some cables to pull new wire later.

Most of these physical controls will be replaced with virtual controls.

Empty the control room.



Remove all the old instrumentation electronics as well.

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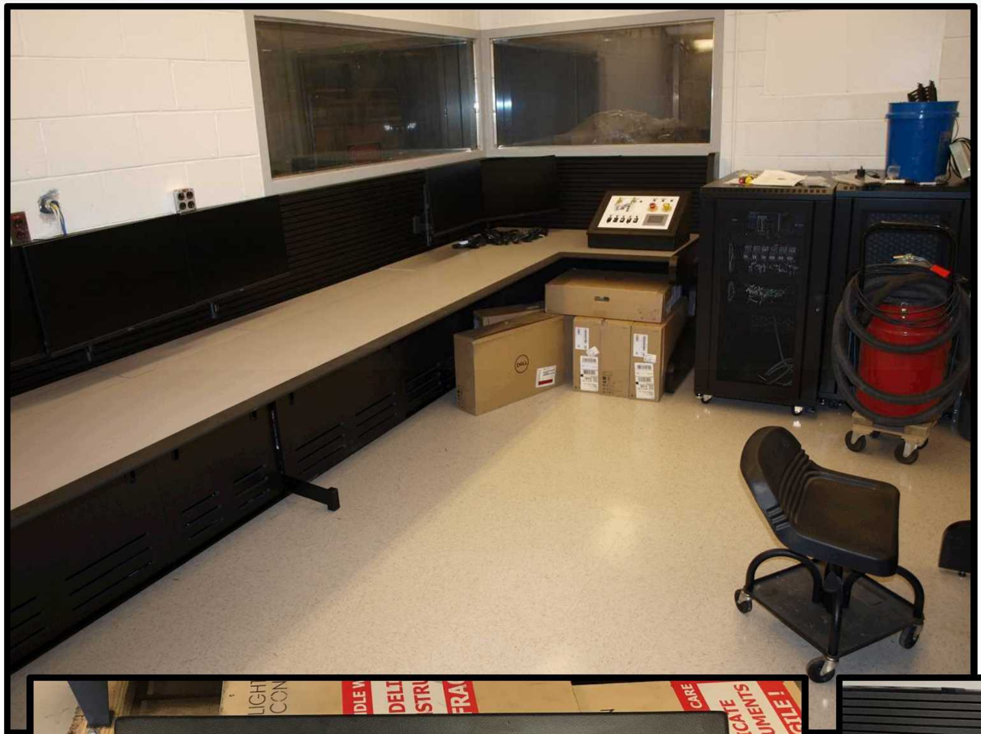
Build it back up shiny and new!



All new furnishings.

(Plus a chemically acceptable floor.)

Safety critical functions have manual control.

Standard racks for:

- Compact DAQ
- Hardwired relay logic
- Breakout panel for easy troubleshooting

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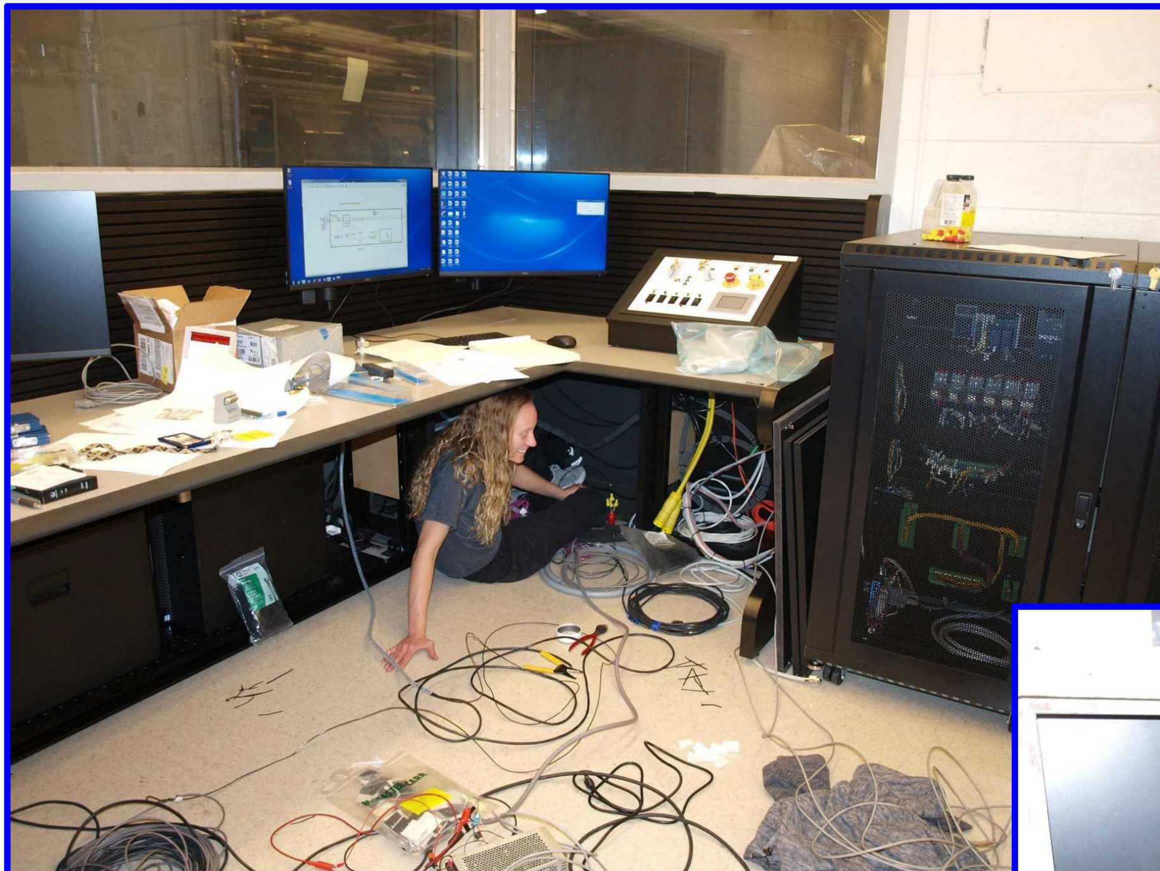
A whole lot of rewiring…



Reroute all voltages above 24V to avoid control room.

New conduit replaces corroded conduit.

No longer a horror show behind the console.

Instrumentation Improvements

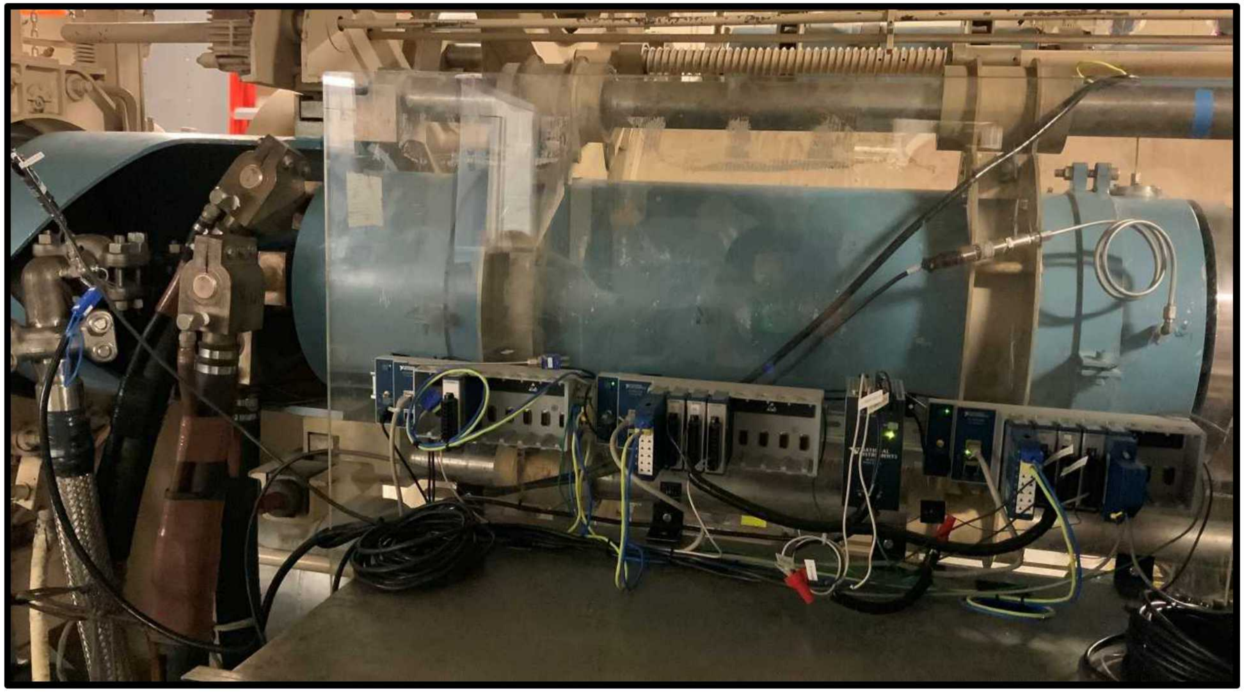
Pressure sensors changed from mV signals to 4-20 mA to reduce EMI.

Tunnel condition pressure/temperature signals routed to multiple compact DAQs.

- **Simultaneously read by control computer and data acquisition.**

Compact DAQs relocated by the equipment and sensors:

- **Shortened cable lengths prior to signal conditioning for lower noise.**
- **Data to control room via ethernet improving signal-to-noise.**



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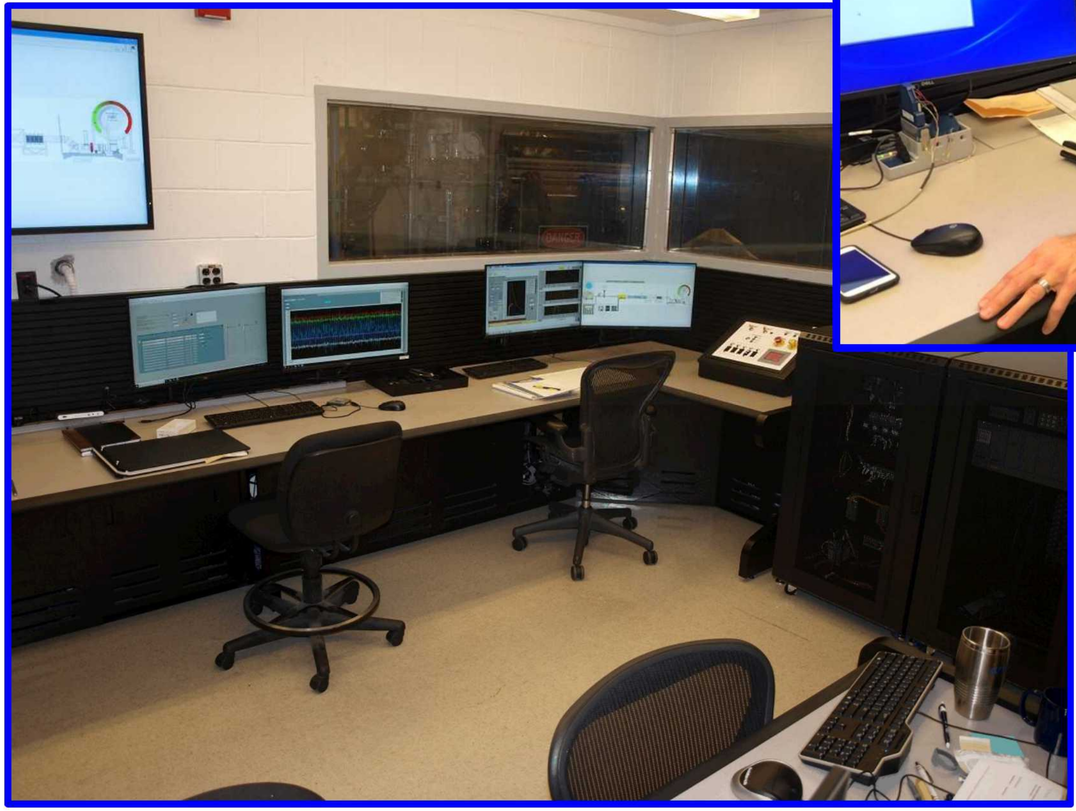
Ready to resume testing!

Tunnel operator and data acquisition operator now sit side by side for better communication.

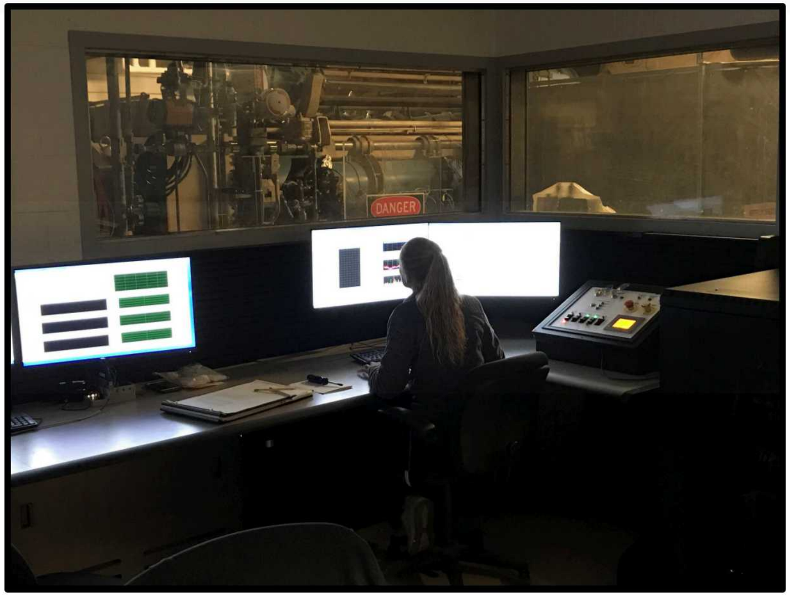


More open floor plan for engineers and customers to watch or participate.

Testing our new operations

Run HWT in a safe mode:
- Upstream pressure lockouts.
- Heat lamps stand-in for flow heaters.

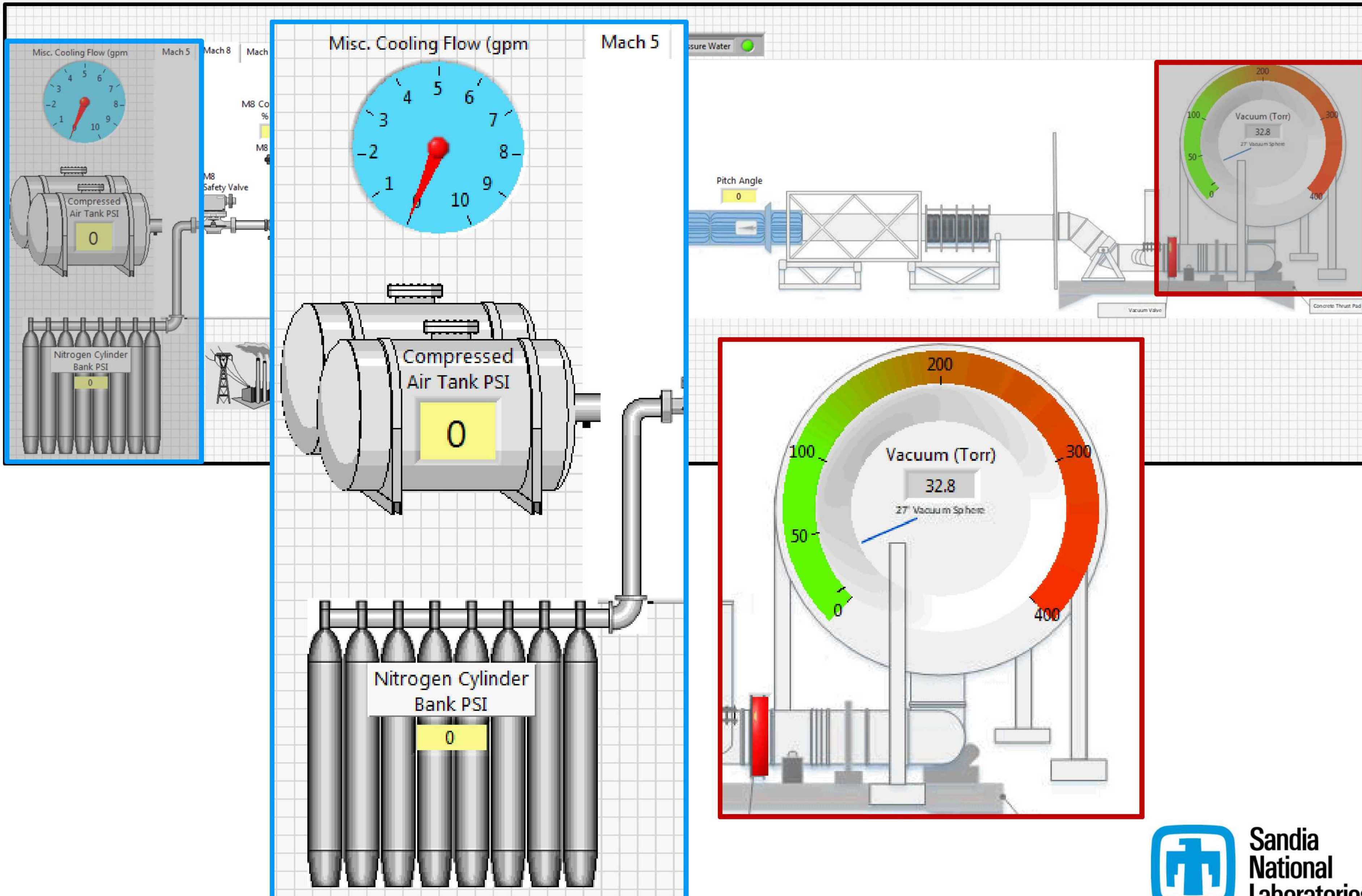
Operational verification:
- Test interlocks and sequencing.
- Test software protections.
- Cold runs replacing heater to test heater controls and interlocks.



Virtual controls permit less training for routine tunnel operation.
- Focus on non-standard shutdown procedures.
- Better operator awareness of sounds and indicators rather than focus on controlling the tunnel conditions.

We are building a new data base of valve and heater settings.
- Tunnel operates differently now.
- New setpoints to get on condition faster and more consistently.

Virtual Controls



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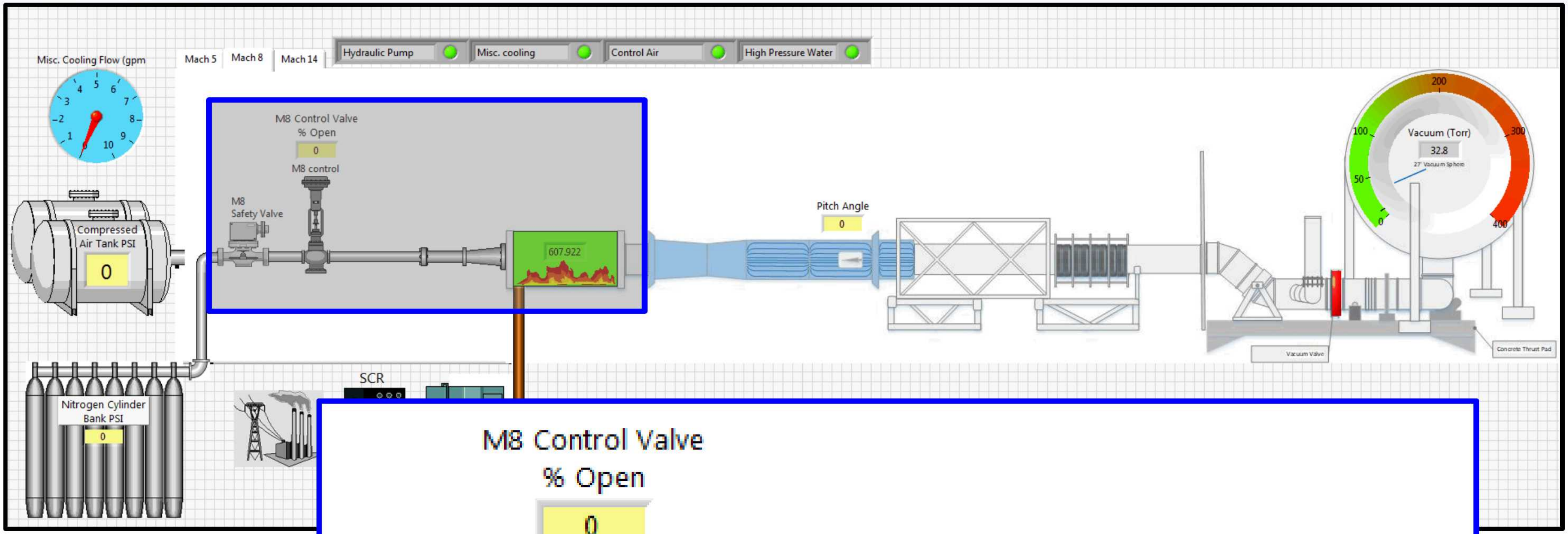

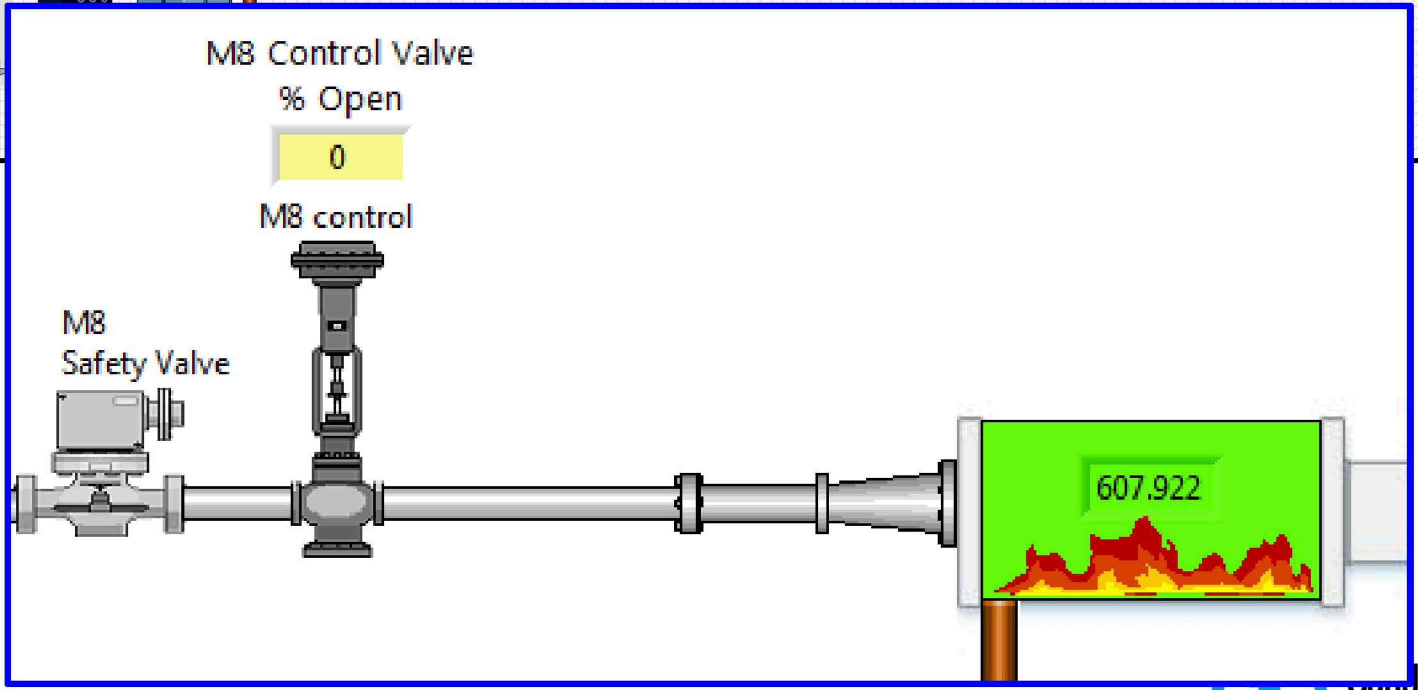

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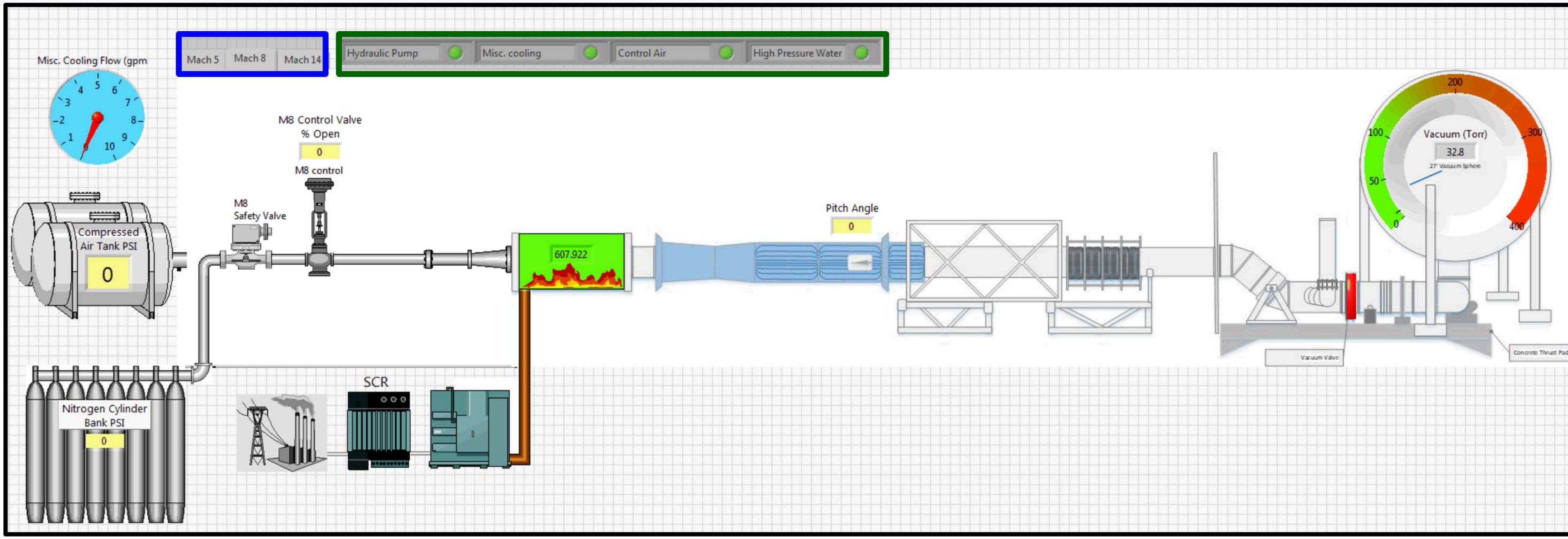
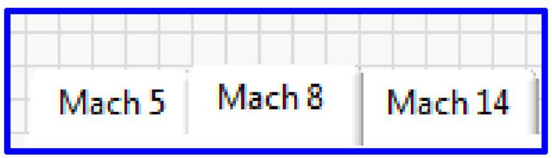
Virtual Controls





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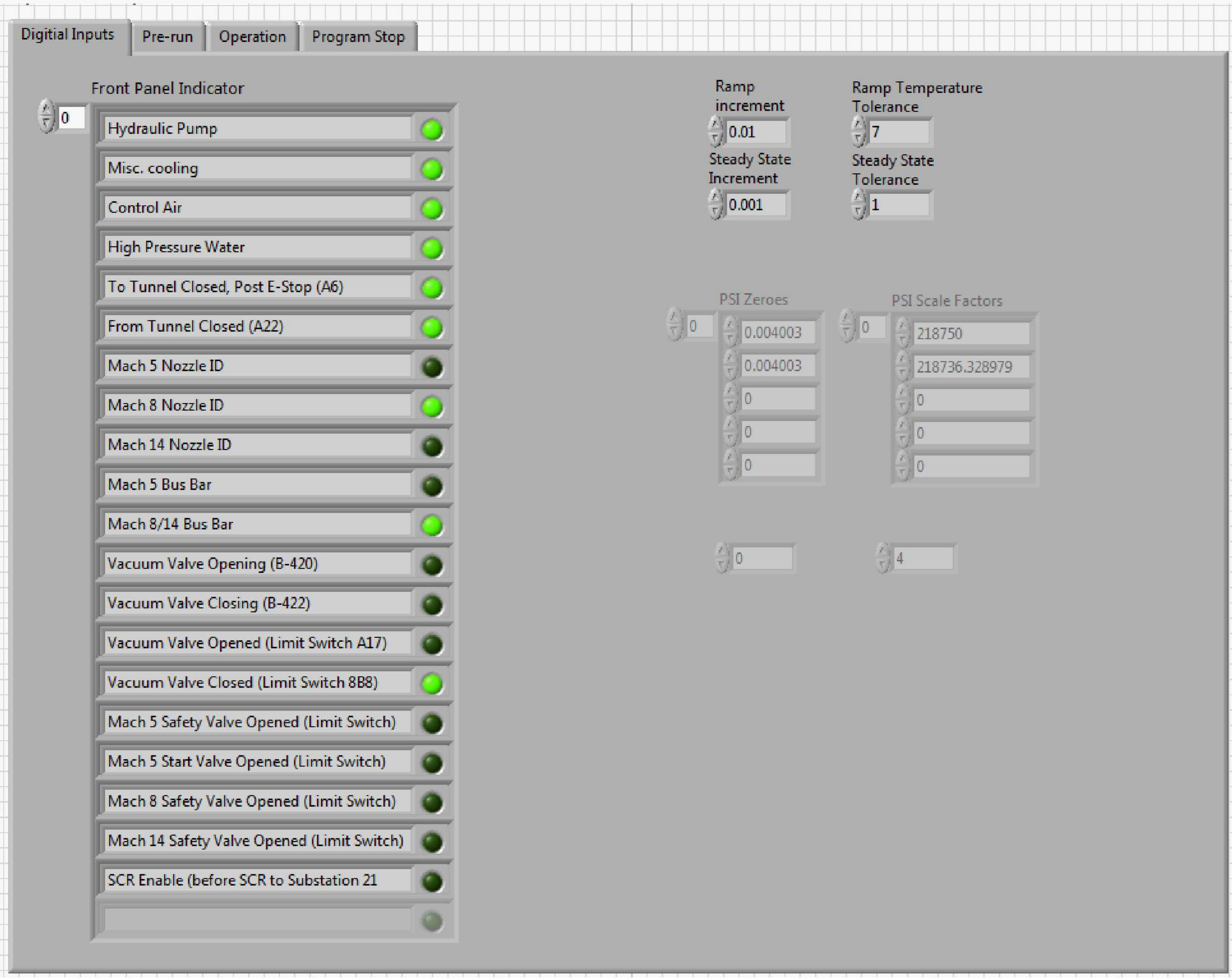
Virtual Controls



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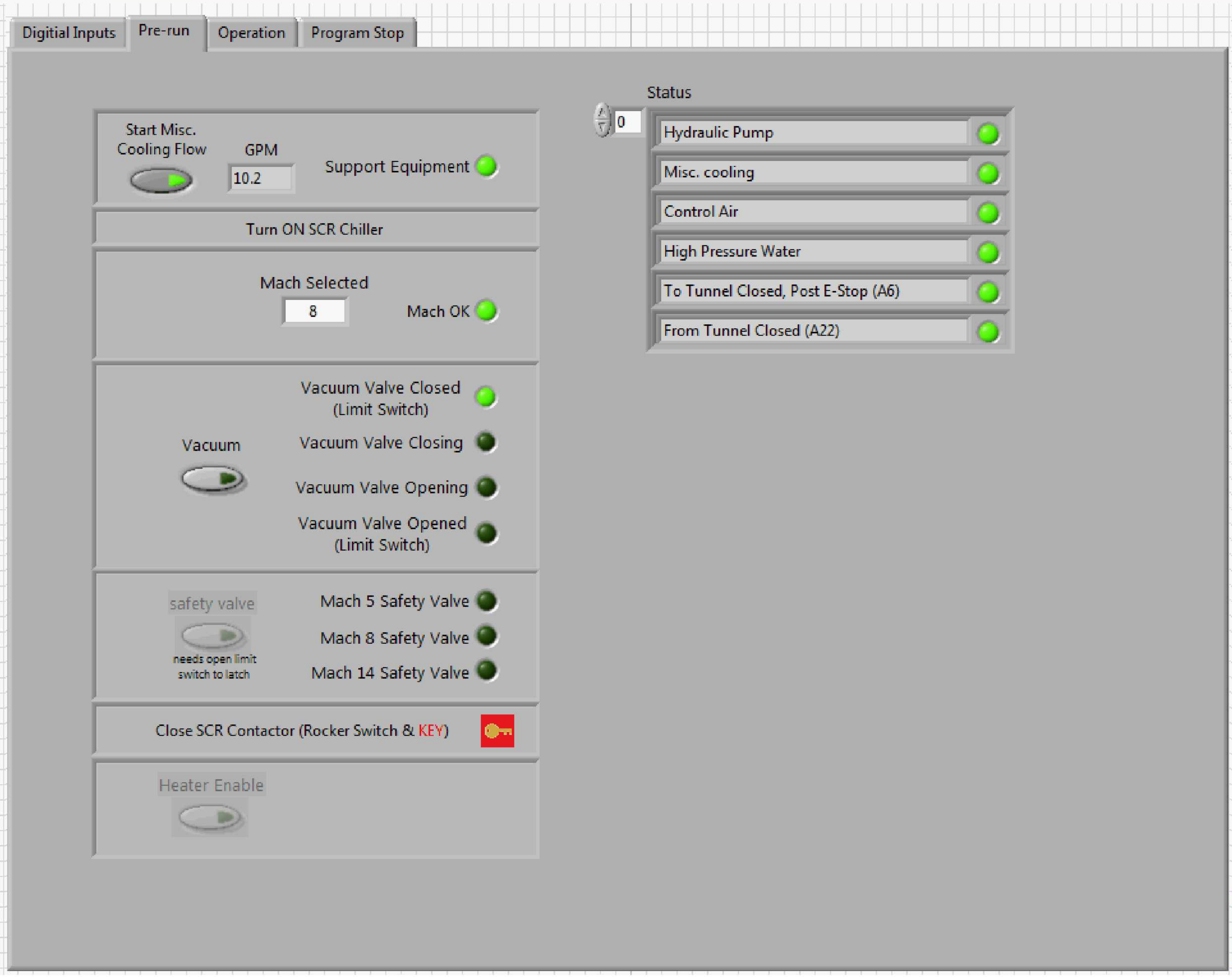

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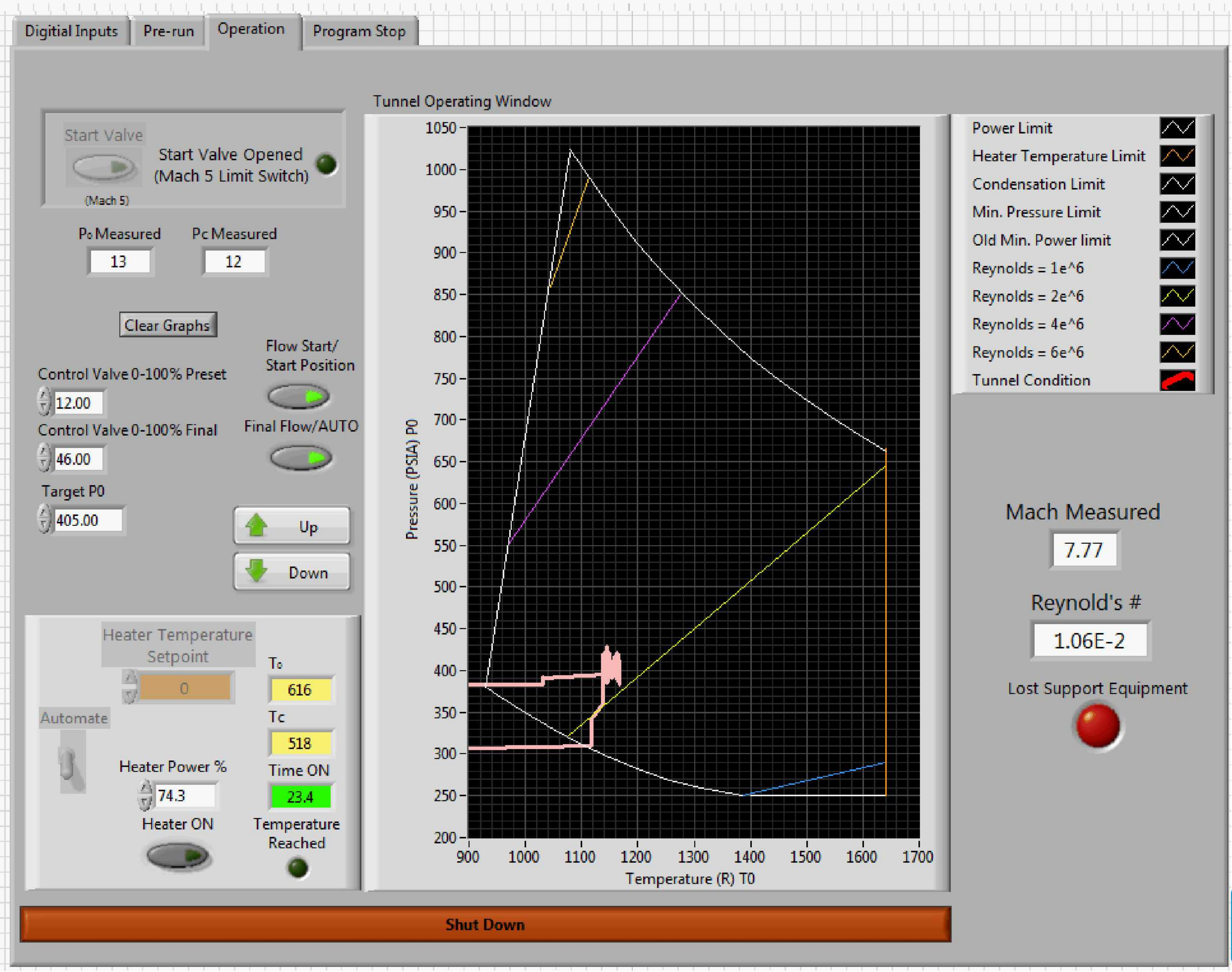

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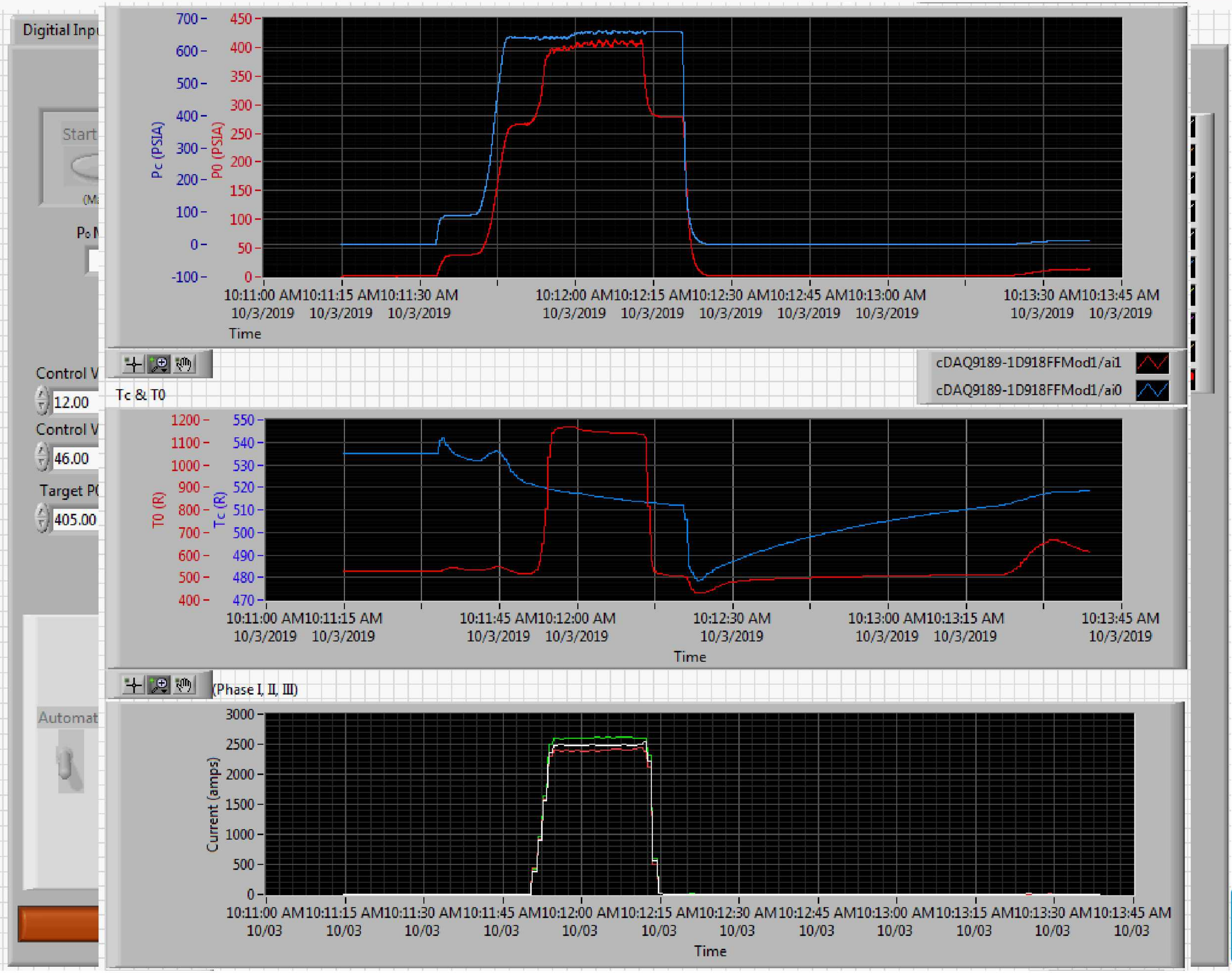
Virtual Controls



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Status

The wind tunnel is fully operational again.

We are building a new database of setpoints for tunnel conditions.

- Active feedback is being incorporated for setting and maintaining conditions.
- We will assess tunnel stability and repeatability then.

We now have a system that we understand, trust, and has been shown to be reliable.

- We also have documentation and better feedback for troubleshooting.

And we now have LOTS of hypersonic work for our fully modernized wind tunnel!

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How well does HWT function now?

?