Thermal Vacuum Chamber Operation and Testing

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Thermal Vacuum Chamber Operation and Testing

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The purpose of this senior project is to understand the capabilities of the thermal vacuum chamber in the Space Environments Laboratory at California Polytechnic State University and compare the performance to thermal vacuum chambers used in the aerospace industry. The lowest temperature attained inside the chamber during an experiment at ambient pressure was -33°C. The lowest pressure reached by the vacuum chamber at the time of this project was $x10^{-5}$ Torr. This report also yields recommendations for integrating a demonstation of the effects of thermal variation in space on spacecraft components for the class AERO 471. A lit LED can simulate operational spacecraft components, and the LED turns off below a given temperature to simulate component failure due to inadequate thermal regulation. A major element of this project became understanding the operation of the chiller and methods of improving the functionality of the system. This report includes a Chiller Manual compiled from various sources to simplify the steps for future users.

I. Introduction

THIS report encompasses the operational procedures of a thermal vacuum (t-vac) chamber and testing methods used by the aerospace industry for space research and spaceflight preparation. Analyzing the operation of a t-vac chamber is the first step towards understanding the benefits that the system provides in simulating the space environment. Common uses of thermal vacuum chambers include for pre-flight bakeout, thermal cycling, and component testing in the industry.

Thermal bakeout is typically conducted prior to spaceflight to outgass components. Outgassing, the release of gases by a material over time, can be detrimental to spacecraft components. Partcles outgassed from materials due to exposure to the space environment's low pressure can contaminate other parts of a vehicle, ultimately hindering the system's capabilities. ASTM standards require materials to meet a total mass loss (TML) of less than 1.0% and a collected volatile condensable mass (CVCM) of less than 0.10% to be used in spaceflight. The test used to determine the %TML is to be conducted at 125°C and at a pressure less than 5x10-5 Torr for 24 hours. The %CVCM is determined by the percent of mass which condenses into a container maintained at 25°C during the %TML test.[6] By outgassing materials in a thermal vacuum chamber prior to flight, contamination of vehicle components can be significantly reduced. Thermal vacuum chambers are an integral part of preparing a spacecraft for operations.

T-vac chambers are used not only for material preparation, but also for component testing. The thermal subsystem of a spacecraft is critical to the design of a vehicle. Temperature variations in space, as well as heat dissipated and required by components are used along with passive and active thermal systems to prevent a vehicle from freezing or overheating. The design of a spacecraft places components strategically so the vehicle will survive and operate in space. Thermal analysis is conducted on the design using thermal models, which are then verified through testing. Thermal tests can be conducted under vacuum, or a combination of in air and under vacuum.[6]

Thermal cycling tests consist of raising the temperature from ambient to a high temperature, then to a low temperature, and lastly back to ambient to complete the cycle. Thermal tests are typically used to subject objects to nominal or extreme temperatures to be experience in-flight. Thermal testing can also be used to determine thermal deformation of parts.[6]

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Analyzing operating procedures of a thermal vacuum chamber provides insight into spacecraft testing and system verification. The experiments conducted for this report were conducted with local temperatures varying from 60°F to 75°F at California Polytechnic State University from December 2012 through May 2013.

II. Apparatus

Three main apparatuses were used for this project: a vacuum chamber, temperature control system (chiller), and a copper plate. The conjunctive use of these devices functioned as a thermal vacuum chamber. Temperatures inside the chamber were measured using thermocouples and recorded using an Omega HH506 Thermometer. The thermocouples used for this project have the characteristics of an Omega Type K thermocouple. These thermocouples output a voltage difference that can be found in the "Revised Thermocouple Reference Table: Type K", which is converted to a temperature using the thermometer.[7]

Vacuum Chamber

The tests documented in this report were conducted in an HVEC bell jar vacuum chamber which used a Welch Duo-Seal Vacuum Pump Model No. 1374 and a CTI Cryogenics Cryopump Model 8 to reach high-vacuum. The vacuum chamber utilizes both a mechanical pump and a cryogenic pump to decrease the pressure in the chamber. See Appendix A for the DAVE Vacuum Chamber operating procedures.[4]

Temperature Control System (Chiller)

To vary the temperature inside the vacuum chamber, an ATS model 1231-CCN-GL-004 Temperature Control System (1231 TCS) was integrated into the chamber configuration. The 1231 TCS functioned as a chiller with fluid running through lines attached underneath a copper plate situated inside the vacuum chamber. The chilled fluid in the pipes reduces the temperature of the plate, thus controlling the temperature of objects placed on the plate inside the chamber. A schematic of the chiller and plate can be seen in Fig. 1. See Appendix B for the Chiller Manual. The lowest setpoint temperature for the chiller is -38°C to prevent the Galden fluid from freezing.

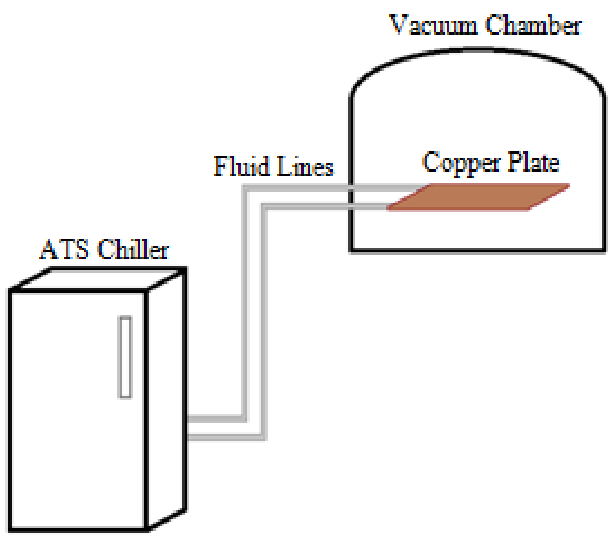


Figure 1. Schematic of the thermal vacuum chamber.
System consists of the chiller, the chamber, and the plate.

Copper Plate

Figure 2 shows an image of the copper plate used for this project. A schematic of the plate is shown in Fig. 3. The image on the left shows the top side of the copper plate and the image on the right shows the underside of the plate. The pipe that runs the fluid under the plate is represented in gray. The strip heater underneath the copper plate (shown on the right image of Fig. 2) was not used for this project.

Figure 2. Copper Plate. Left image is the top of the plate and faces the ceiling when in use. Right image is the underside of the plate. The gray pipe runs fluid under the plate.

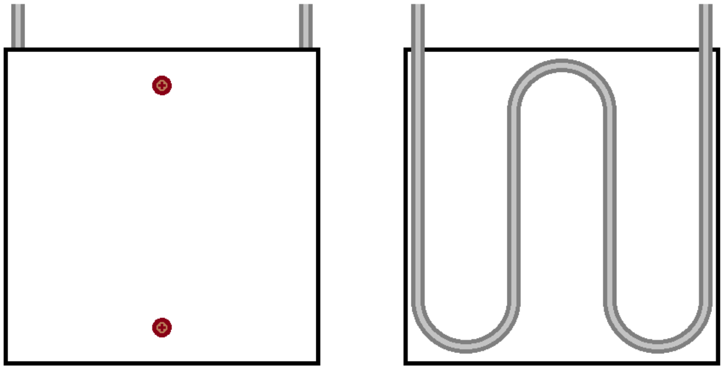


Figure 3. Copper Plate Schematic. Left image is the top of the plate and faces the ceiling when in use. Right image is the underside of the plate. The gray curve is the pipe that runs fluid under the plate.

III. Procedures

Thermocouples that were already set up in the vacuum chamber were used to measure the temperature at different locations of the copper plate while operating the chiller. To ensure the metal tips of the thermocouples were actually touching the plate, the section of copper to be used was first cleaned with IPA. Next, the thermocouple was held in place and the wire was taped with kapton tape approximately one, two and three inches from the tip, as well as at the contact point. Kapton tape was used generously to ensure the thermocouples stayed in contact with the plate, as shown in Fig. 4. The location of each thermocouple number used for this project is shown in Fig. 5. Please note that thermocouple #21 was on the solder and thermocouple #5 was on the underside of the copper plate.

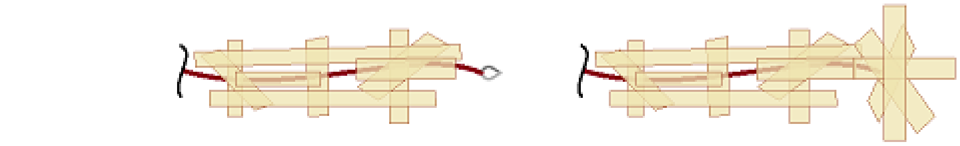


Figure 4. Typical thermocouple taping procedure. Kapton tape was pressed to help avoid air bubbles.

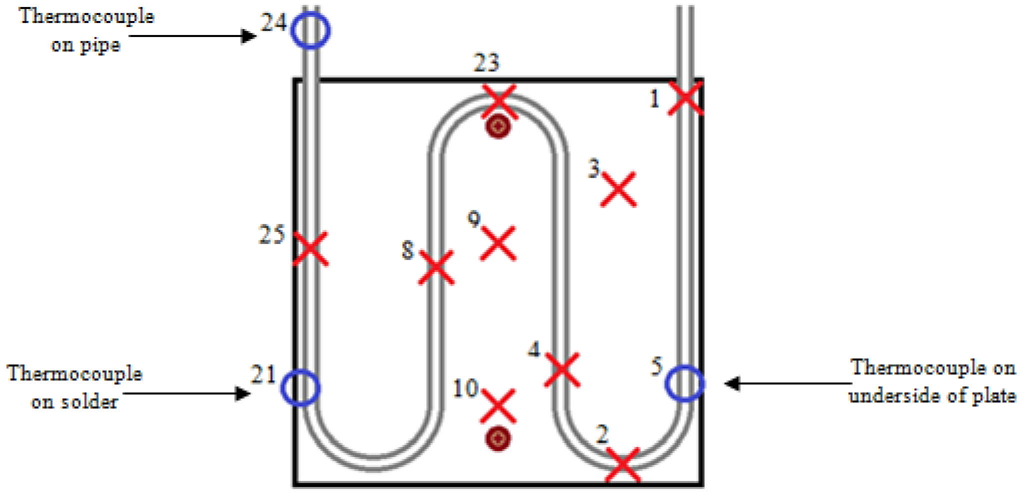


Figure 5. Thermocouple locations. The red crosses are where thermocouples were on the top side of the plate and the blue circles are where thermocouples were not on the top side of the plate. The outline of the pipe is shown in this image solely for reference purposes. The numbers correspond to the number of the thermocouple used at that location.

After the thermocouples were in place, the vacuum chamber pressure was lowered to approximately 4×10^{-5} Torr. Next, the chiller was used to lower the temperature of the plate. Due to the limited supply of Galden fluid, the data and results shown in this report were obtained at ambient pressure (~760 Torr). Once the chiller setpoint was set to -38°C, temperatures were recorded.

The next step in understanding operations of a thermal vacuum chamber would be to compare the recorded temperatures at ambient pressure to temperatures under vacuum.

To demonstrate component survival temperatures in space, an electrical circuit was constructed. The description of this part of the project, the circuit, and the expected results are shown in Section VI of this report, titled Course Implementation. When conducting the Course Implementation experiment, the circuit should be set up prior decreasing the pressure and temperature in the vacuum chamber. The experimental observations can be made as the temperature decreases towards the setpoint thermal value.

IV. Results and Discussion

The vacuum chamber reached a pressure of 4×10^{-5} Torr during testing, which simulates an environment slightly lower than low earth orbit (LEO). The altitude for low earth orbit ranges from ~200km to ~2000km.

As the temperature decreased towards the setpoint of -38°C, the thermocouple readings were recorded over time, as shown in Fig. 6. Four measurements were taken at each location, as shown on the x-axis of the plot.

The best case recorded plate temperature was -33°C, obtained by thermocouple #21. The worst case recorded plate temperature was -13.6°C, obtained by thermocouple #2. See Fig. 5 for thermocouple numbers and locations. Best case is defined as the closest temperature to the Chiller setpoint and the worst case is defined as the furthest temperature from the Chiller setpoint. These values were obtained when the chiller was steadily operating at -38°C. The average temperature of the plate was -21.5°C with the Chiller at -38°C setpoint. All recorded values reached temperatures lower than -13°C. This observation was used to determine the cut-off value for the component survival demonstration in the Course Implementation section of this report.

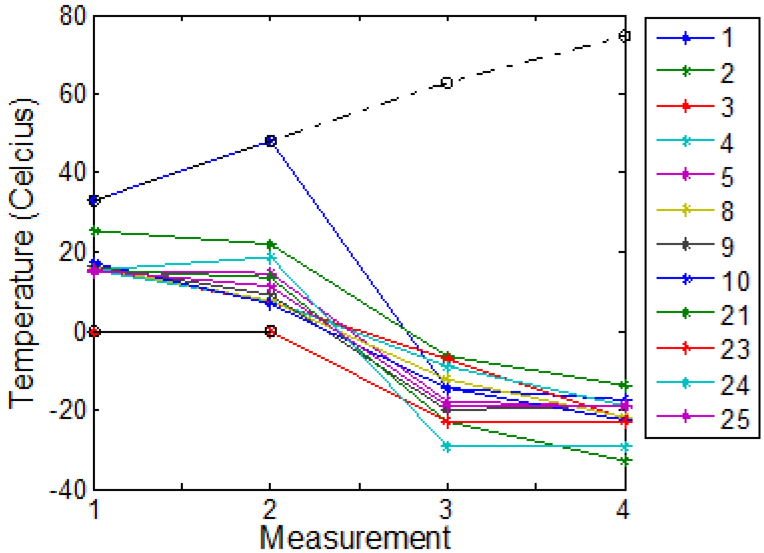


Figure 6. Temperatures recorded as the chiller approached the setpoint temperature.
Four measurements were taken at each location. See Appendix C for Matlab code.

The plot it Fig. 6 contains a black dotted line that shows increasing temperature for thermocouple #1 and an odd starting temperature for thermocouple #23. These errors indicate a problem with the equipment. When the temperature reading for thermocouple #1 increased while the rest of the plate temperature values decreased, it was evident that thermocouple #1 was outputting incorrect values. This can possibly be attributed to a flawed internal control or it is possible that the voltage polarity is internally flipped, causing the thermometer to read an incorrect temperature. It was also observed that thermocouple #23 lacked the interface to the thermometer, and thus could not be used. Once flaws were detected in thermocouples #1 and #23, a different thermocouple was used to record the temperatures at those respective locations.

The lowest recorded temperatures for each thermocouple are shown in Fig. 7 below.

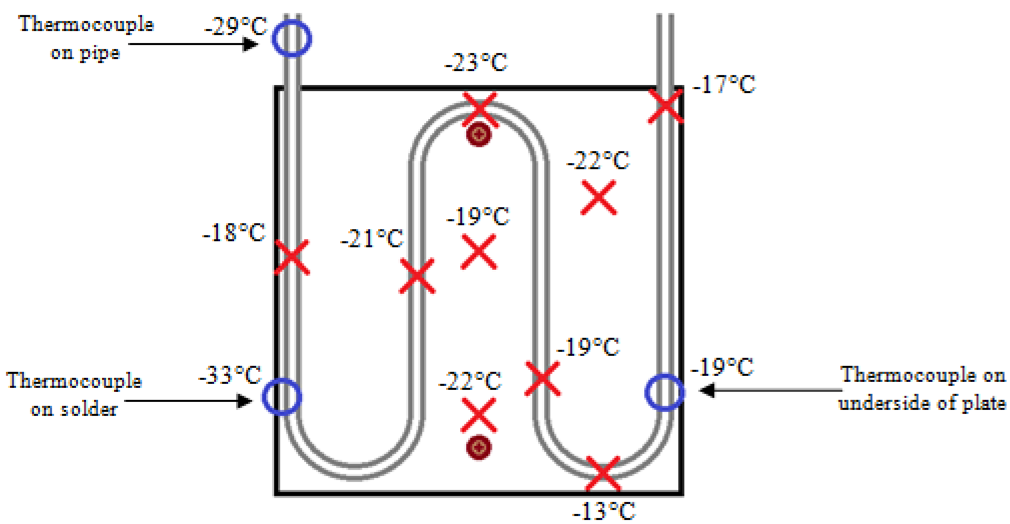


Figure 6. Lowest Recorded Temperatures at Each Thermocouple Location.
The red crosses depict thermocouples on top of the copper plate.

The data recorded demonstrates that the lowest temperature value was measured on the solder (thermocouple #21) that holds the pipe and the plate together. The temperature of the pipe that feeds fluid under the plate, measured by thermocouple #24, displayed a value of -29°C, which was lower than average. However, none of the temperatures on the copper plate measured below -25°C. This indicates that the solder currently holding the system together is a cause of losses, and a better soldering job will improve the conductance between the pipe and the plate, thus allowing the entire plate to reach lower temperatures.

The thermal vacuum chamber was capable of reaching approximately 5×10^{-5} Torr and the plate currently reaches an average low temperature of -21.5°C or about -6.7°F.

An example of a thermal vacuum chamber used in industry is The Thermal Vacuum Chamber A at the NASA Johnson Space Center. It simulates and environment of -253°C (20K) at 1×10^{-6} Torr. This NASA chamber takes about 24 hours to pump down to test conditions.[5] The Cal Poly thermal vacuum chamber is capable of operating approximately 230°C higher at a pressure about 50 times greater than that of this NASA chamber.

Demonstrations of thermal cycling can be performed using the equipment in the Space Environments Lab by lowering the setpoint on the chiller until the desired value is acquired, and then raising the setpoint to ambient. The strip heater underneath the plate can also be used for thermal cycling, but only up to approximately 40°C to avoid boiling the Galden fluid in the lines. By repeating this process, one can observe how the aerospace industry tests components to ensure survival during exposure to space temperatures.

Although the results obtained using the thermal vacuum chamber in the Space Environments Laboratory at Cal Poly are far from the specifications used in industry, the concepts demonstrated with the use of the chamber, chiller, and plate can be applied to better understand how such systems operate, as well as gain knowledge of spacecraft thermal ranges. Use of the system ultimately yields an understanding of how spacecraft components are tested and how materials and parts are affected by temperatures in space.

V. Course Implementation

Spacecraft components must be kept in certain temperature ranges for both operation and survival. The comparator circuit in Fig. 8 can demonstrate this concept. An LED remains ON above -5°C, and will turn OFF below -5°C, showing that components will fail if they fall below a certain temperature. Since the temperatures at all points measured on the plate were less than -13°C, the temperature which triggers the switch from ON to OFF for the LED was chosen to be -5°C. This value allows for some margin of error, either from variations of plate temperatures or from flaws of the equipment.

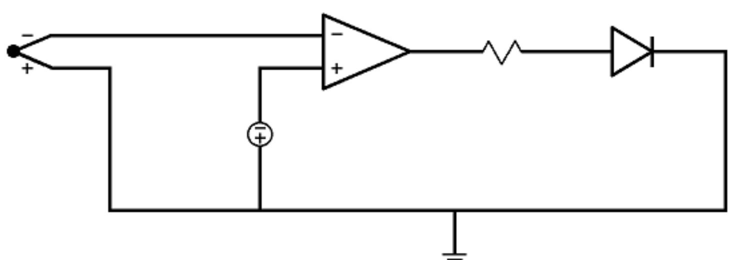
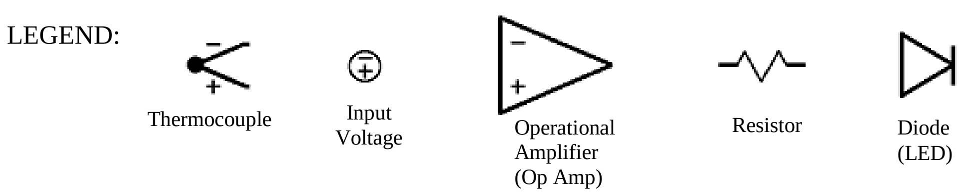


Figure 8. Circuit consisting of thermocouple and LED. LED will remain lit while temperature is above a given value.



Thermocouples output a voltage difference, which are converted into a temperature using the Omega HH506 Thermometer. The thermocouples in the vacuum chamber are characterized by the Revised Thermocouple Reference Table: Type K specifications sheet, but the output voltages are actually 1mV less than the guide states.[7] The source of this 1mV error is unknown, but has been consistent across all tested thermocouples. The focal range of temperatures is shown in Table 1 below. These values are from the characteristics of an Omega Type K thermocouple.

Table 1. Relationship between thermocouple output and temperature reading.[7]
The values inside the table are in millivolts (mV).

0	-0.692	-0.671	-0.650	-0.628	-0.607	-0.586	-0.564	-0.543	-0.521	-0.500	-0.478	0
10	-0.478	-0.457	-0.435	-0.413	-0.392	-0.370	-0.349	-0.327	-0.305	-0.284	-0.262	10
20	-0.262	-0.240	-0.218	-0.197	-0.175	-0.153	-0.131	-0.109	-0.088	-0.066	-0.044	20
30	-0.044	-0.022	0.000	0.022	0.044	0.066	0.088	0.110	0.132	0.154	0.176	30
40	0.176	0.198	0.220	0.242	0.264	0.286	0.308	0.330	0.353	0.375	0.397	40
50	0.397	0.419	0.441	0.463	0.486	0.508	0.530	0.552	0.575	0.597	0.619	50
60	0.619	0.642	0.664	0.686	0.709	0.731	0.753	0.776	0.798	0.821	0.843	60
70	0.843	0.865	0.888	0.910	0.933	0.955	0.978	1.000	1.023	1.045	1.068	70
80	1.068	1.090	1.113	1.136	1.158	1.181	1.203	1.226	1.249	1.271	1.294	80
90	1.294	1.316	1.339	1.362	1.384	1.407	1.430	1.453	1.475	1.498	1.521	90
°F	0	1	2	3	4	5	6	7	8	9	10	°F

The selected value of -5°C converts to 23°F. Table 1 shows that the thermocouple will output -0.197mV when the temperature reading is 23°F. However, the thermocouple will actually output -1.197mV due to the 1mV error discussed above. This value of -1.197mV will be used as the input voltage.

As long as the temperature from the thermocouple is greater than -5°C, the op amp will output a voltage, which will light the LED. If the temperature from the thermocouple is less than -5°C, the op amp will output negative voltage and the LED will be off. Some examples of different scenarios for the circuit are shown in Table 2 below.

Table 2. Examples of circuit outputs. The initial values for each scenario are close estimates to realistic values.

Scenario	°Farenheit	°Celcius	Voltage Difference from Data Sheet	Actual Voltage Difference	Negative Side of Op Amp	Positive Side of Op Amp	LED
Body Temp	~93°F	33.8°C	1.362 mV	0.362 mV	-0.362 mV	-1.197 mV	ON
Room Temp	~73°F	22.7°C	0.910 mV	-0.085 mV	0.085 mV	-1.197 mV	ON
Ice Temp (Assume -15°C)	5°F	-15°C	-0.586mV	-1.586 mV	1.586 mV	-1.197 mV	OFF

To construct the circuit, use

- Thermocouples inside the vacuum chamber
- Operational Amplifier: 741 Op Amp
  - Power the op amp using +15V and -15V with a current limit of 0.5Amps on the power supply
- Input Voltage: 1.197mV with a current limit of 0.5Amps on the power supply
- Resistor: 1kΩ
- Diode: red LED

Using this circuit, the LED remains ON while the thermocouple reads above a certain temperature, and the LED turns OFF once the thermocouple reads below that temperature. The temperature that triggers the ON/OFF function can be changed to any desired value. To do this, choose the trigger temperature, find the corresponding voltage difference on the Omega Type K thermocouple specifications sheet, subtract 1mV from that value, and use that voltage as the input voltage for the circuit.

To perform this experiment, at least two thermocouples should be used: one in direct contact with the copper plate and one on top of layers of MLI. Other thermocouples can be used to explore how different layers of MLI affect temperatures. As the temperature decreases, the LED connected to the thermocouple with the MLI should remain lit longer than the LED connected to the circuit without MLI. This demonstates the benefits of MLI on spacecraft to regulate component temperature.

VI. Future Considerations

Sources of error encountered throughout this project included insufficient contact between the copper plate and the chiller fluid pipe line, as well as inconsistent timing between temperature measurements. Resoldering the underside of the plate will provide a better contact surface, allowing the temperature of the entire plate to decrease further. Finding a more effective way of recording temperatures would assist in understanding the rates at which the temperature of certain points of the plate decrease. This could be done using a DAQ linked to a computer in order to match temperatures to the times which they were recorded. This would be an improvement to the method used in this report, which was to use one thermometer with two input slots, where only two temperatures could be recorded simultaneously and thermocouples were constantly switched in and out, without knowledge of how much time has passes between recordings. Additionally, Galden leaks behind the chiller need to be patched to reduce fluid loss. The leaks occur on the exterior pipe lines close to the *Channel 1 Supply* and *Channel 1 Return* ports behind the chiller. Throughout the course of this project, leaked Galden was captured in red SOLO cups, and then reintroduced into the system via the "Step II: Add more Galden fluid to the reservoir" in the procedures of Appendix B. The leaked Galden fluid sometimes mixed with the water which condensed from the frost on the lines, so patching the leaks in the future will prevent waste of the costly fluid.

Additional recommendations include recording operational plate temperatures with the chamber at high vacuum, as well as using the strip heater to warm up the plate for further testing. Thermal cycling and actual component testing would yield interesting insight into spacecraft testing and operations.

VII. Conclusion

The vacuum chamber, chiller, and copper plate in the Space Environments Laboratory at Cal Poly function as a thermal vacuum chamber to simulate conditions experienced in space. Understanding the space environment is crucial in the preparation of spacecraft to ensure component vehicle survival. This project determined the capabilities of the chiller operating at ambient pressure. With the chiller setpoint at -38°C, the copper plate temperature varies from -13°C to -33°C, depending on the location on the plate. At that same setpoint, the average plate temperature is -21.5°C. This average temperature is about 230°C greater than the Thermal Vacuum Chamber A at NASA Johnson Space Center.[5] The lowest pressure reached in the chamber during this project was 5×10^{-5} Torr, which is 50 times greater than the capabilities of the Thermal Vacuum Chamber A at NASA Johnson Space Center.[5] This project provided insight into the operation of a chiller and a vacuum chamber. Due to the various manuals and phone calls which were required to understand how to operate the chiller, this project includes a Chiller Manual in Appendix B which has compiled procedures from different sources into one document. Lastly, an experiment was created to demonstrate the importance of shielding to protect spacecraft components. This experiment consists of a comparator circuit with an LED that turns off below a given temperature, simulating component failure in space due to temperatures lower than required for survival. The understanding of the chiller operations, comparison to an actual thermal vacuum chamber, and creation of an experiment ultimately yielded further knowledge of how and why thermal vacuum chambers are utilized in the aerospace industry.

Appendix A. HVEC High Vacuum Procedure[4]

Cryo Procedure (Complete First)

1. System Power – ON
2. Compressed Air Supply at wall - ON
3. Mechanical Pump – ON
4. Rough Interlock – ON
5. Cryo Rough – ON
6. Let the pressure in the cryo get to < 150 mTorr
7. Compressor – ON
8. Let the temperature drop to ~15 K (this can take several hours)
9. Cryo Rough – OFF
10. Rough Interlock – OFF
11. Mechanical Pump – OFF

Roughing the Chamber (Complete Second)

1. Mechanical Pump – ON
2. Chamber Rough – ON
3. Let the pressure in the chamber get to ~50 mTorr
4. Chamber Rough – OFF
5. Mechanical Pump – OFF

High Vaccum (After Completing the first two sections)

1. Pressure Interlock – ON
2. Gate Valve – ON
3. When the convectron gage in the chamber zeros, Ion Gage 1 – ON

Shut Down from High Vacuum

1. Turn Ion Gage 1 – OFF
2. Gate Valve – OFF
3. Pressure Interlock – OFF
4. Compressor – OFF
5. Vent Valve – ON
6. Let the chamber vent to ambient pressure
7. Vent Valve – OFF
8. Compressed Air Supply – OFF
9. System power – OFF

Appendix B. Chiller Manual

The following steps are a guideline to using the Advances Thermal Sciences (ATS) model 1231-CCN-GL-004 Temperature Control System (TCS) in the Space Environments Laboratory at Cal Poly, San Luis Obispo. Details for each step are discussed in this document.

- **I. Fill the cooling loops of the chiller**
- **II. Add more Galden fluid to the reservoir**
  - **a. Pressurize the Fill/Drain Tank**
  - **b. Add Galden fluid to the chiller**
- **III. Prepare the Chiller**
  - **a. Plug in the Chiller**
  - **b. Run water**
  - **c. Pressurize the Reservoir**
  - **d. Turn on Circuit Breakers**
- **IV. Operate the Chiller**
  - **a. Start the Pump**
  - **b. Change the Setpoint temperature**
- **V. Shut Down the Chiller**
- **VI. Drain the Chiller**

<u>Where to Begin?</u>

- Begin with **Step I: Fill the cooling loops of the chiller** if there is no fluid in the entire system.
- Begin with **Step II: Add more Galden fluid to the reservoir** if fluid in the sightglass is lower than the halfway level.
- Begin with **Step III: Preparing the Chiller** if fluid in the sightglass is at least at the halfway level.

The italicized items in this report are pictured at the end of this document.

This manual was adapted from the ATS 1231-CCN-GL-004 Operating Manual.

I. <u>Fill the cooling loops of the chiller</u>

This process consists of three parts: filling the lines between the chiller and the plate, filling the internal loops, and filling the reservoir and sightglass.

A) Pressurize the Fill/Drain Tank:

1) Attach hose to *pressure regulator* on *nitrogen supply* and *Drain Port* of *Fill/Drain Tank*. To do this, make sure that:
    a. the *pressure regulator* is closed (loose knob)
    b. the valve on *hose* is closed
2) Open *nitrogen source*
3) Open *pressure regulator* (tighten knob) to 80psi
4) Open valve on *hose* to pressurize *Fill/Drain Tank* to 60psi
5) Close valve on *hose*
6) Close *nitrogen source*
7) Close (loosen) *pressure regulator* valve
8) Detach hose from *Fill/Drain Tank*
9) Open valve on *hose*
10) Open (tighten) *pressure regulator*
11) Close (loosen) *pressure regulator*
12) Close valve on *hose*
13) Detach *hose* from *nitrogen source*

B) Filling the Lines Between the Chiller and the Plate

1) Close *Channel 1 Supply* valve at the back of the chiller
2) Attach hose to *Fill Port* of *Fill/Drain Tank* and *Fill/Drain connection* at the front of the chiller. To do this, make sure that the valve on the hose is closed.
3) Open *hose* valve and introduce fluid to the system. The pressure in the tank should drop slowly. Use a flashlight to look for bubbles in the *sightglass*.
    a. Press the *Pressurize 80psi Max* fitting to maintain the *Reservoir* gage pressure at zero.
    b. Continue until liquid is seen filling the *sightglass* without bubbles.
4) Close *hose* valve

C) Filling the Internal Loops

1) Open *Channel 1 Supply* valve at the back of the chiller
2) Hose should be connected to *Fill Port* of *Fill/Drain Tank* and *Fill/Drain* connection at the front of the chiller
3) Open hose valve and the tank and introduce more fluid to the system. The pressure in the tank should drop slowly. Look for bubbles in the *sightglass*.
    a. **Maintain a liquid level above the standpipe opening of the *Fill Port* INSIDE the *Fill/Drain Tank* to prevent the rist of introducing air back into the internal loop**
    b. Press the *Pressurize 80psi Max* fitting to maintain the *Reservoir* gage pressure at zero.

    c. Continue until liquid is seen filling the sightglass without bubbles. Bubbles in the sightglass signify that the air is being purged from channel 1 internal loop to the reservoir.
4) Close *hose* valve
5) Detach hose from *Fill/Drain connection* at the back to the chiller. Have a cup ready to catch fluid leaks.
6) Pull on *Pressure Release* ring on the *Fill/Drain Tank* until back at ambient pressure
7) Open the *Fill/Drain Tank*
    a. Dump fluid caught from leak into the *Fill/Drain Tank*
    b. Dump fluid from the hose back into the *Fill/Drain Tank* by opening valve on hose
8) Detach hose from *Fill/Drain Tank*
9) Detach *hose* from *Fill Port* of *Fill/Drain Tank*

D) Filling the Reservoir and Sightglass
1) Attach hose to *Reservoir Drain* port (below *sightglass*) and *Fill Port* of the *Fill/Drain Tank*
    c. Make sure valve on hose is closed
2) Press on *Pressurize 80psi Max* (above *sightglass*) while filling the reservoir
3) Slightly open valve on hose
    d. Bubbles may appear in *sightglass*
    <u>NOTE: If the ball in the *sightglass* drops out of sight, close hose valve and continue pressing on *Pressurize 80psi Max* nozzle to depressurize reservoir</u>
4) Once fluid has been transferred, close valve on hose
    e. Detach hose from *Reservoir Drain* port while holding cup ready for fluid leak
5) Pull on *pressure Release* ring on *Fill/Drain Tank* until back to ambient pressure
6) Open the *Fill/Drain Tank*
    f. Dump fluid caught from leak into the *Fill/Drain Tank*
    g. Dump fluid from the hose back into the *Fill/Drain Tank* by opening valve on hose
7) Detach hose from *Fill/Drain Tank*

At this point, it is recommended to pressurize the reservoir to 20psi. If the chiller is not being operated, depressurize the system by compressing the *Pressurize 80psi Max port.* If the chiller is to be operated, proceed with **Step III: Preparing the Chiller.**

II. <u>Add more Galden fluid to the reservoir</u>

A) Pressurize the Fill/Drain Tank:

1) Attach hose to *pressure regulator* on *nitrogen supply* and *Drain Port* of *Fill/Drain Tank*. To do this, make sure that:
    a. the *pressure regulator* is closed (loose knob)
    b. the valve on *hose* is closed
2) Open *nitrogen source*
3) Open *pressure regulator* (tighten knob) to 80psi
4) Open valve on *hose* to pressurize *Fill/Drain Tank* to 60psi
5) Close valve on *hose*
6) Close *nitrogen source*
7) Close (loosen) *pressure regulator* valve
8) Detach hose from *Fill/Drain Tank*
9) Open valve on *hose*
10) Open (tighten) *pressure regulator*
11) Close (loosen) *pressure regulator*
12) Close valve on *hose*
13) Detach *hose* from *nitrogen source*

B) Add Galden fluid to the chiller:

1) Attach hose to *Reservoir Drain* port (below *sightglass*) and *Fill Port* of the *Fill/Drain Tank*
    h. Make sure valve on hose is closed
2) Press on *Pressurize 80psi Max* (above *sightglass*) while filling the reservoir
3) Slightly open valve on hose
    i. Bubbles may appear in *sightglass*

    <u>NOTE: If the ball in the *sightglass* drops out of sight, close hose valve and continue pressing on *Pressurize 80psi Max* nozzle to depressurize reservoir</u>
4) Once fluid has been transferred, close valve on hose
    j. Detach hose from *Reservoir Drain* port while holding cup ready for fluid leak
5) Pull on *Pressure Release* ring on *Fill/Drain Tank* until back to ambient pressure
6) Open the *Fill/Drain Tank*
    k. Dump fluid caught from leak into the *Fill/Drain Tank*
    l. Dump fluid from the hose back into the *Fill/Drain Tank* by opening valve on hose
7) Detach hose from *Fill/Drain Tank*

III. Preparing the Chiller

A) Plug in the Chiller

For this step, make sure all *circuit breakers* are OFF.

1) Turn off *Power Box* (flip switch down)
2) Unplug other equipment from *three-phase outlet*
3) Plug in Chiller *three-phase plug*
4) Turn on *Power Box* (flip switch up)

B) Run Water

1) Yellow water hose should be attached to the *water faucet with a green knob* and to the *water filter*
2) The *water filter* should be attached to the *Facilities H2O Inlet*
3) Green water hose should be attached to the *Facilities H2O Outlet*
4) Insert other end of green water hose into floor drain hole
5) Open *water supply valve* (blue valve in line with pipe)
6) Open *water faucet with green knob*
7) Ensure flow out of green water hose is greater than 10 gpm
    a. Test by filling a 5-gallon bucket HALFWAY in 15 seconds

C) Pressurize the Reservoir:

1) Place cups in the back of chamber, under *Channel 1 Supply* in the back of the chiller
2) Attach *hose* to *pressure regulator* on *nitrogen supply* and *Pressurize 80psi Max* port of the chiller. To do this, make sure that:
    a. the *pressure regulator* is closed (loose knob)
    b. the valve on *hose* is closed
3) Open *nitrogen source*
4) Open *pressure regulator* (tighten knob) to 80psi
5) Open valve on *hose* to pressurize to 40psi on the *Reservoir* gage below *sightglass*.
6) Close valve on *hose*
7) Close *nitrogen source*
8) Close (loosen) *pressure regulator* valve
9) Detach *hose* from chiller
10) Open valve on *hose*
11) Open (tighten) *pressure regulator*
12) Close (loosen) *pressure regulator*
13) Close valve on *hose*
14) Detach hose from *pressure regulator*

D) Turn on Circuit Breakers

1) Flip on the *main circuit breaker* on the back of the chiller
2) Flip on *Pump 1* and *Pump 2 circuit breakers* on the back of the chiller
3) Flip on *Heater/Chiller* and *Compressor circuit breakers* on the back of the chiller

IV. Operate the Chiller

A) Start the pump

1) Turn on *Pump 1* (front of chiller)
2) Purge for ~3 min by opening the *Channel 1 Purge* valve on front of the chiller
3) Turn on *Heat/Chill* AND *Compressor* by pressing their green buttons on front of chiller

B) Change the Setpoint temperature

1) Press *CHNG SP*
2) Press *Yes* (up arrow)
3) Press down arrow until desired temperature is displayed

NOTE: (Min Setpoint = -38°C)

4) Press *Enter*

CAUTION: Frost may appear on exposed areas of the lines: Do not touch frost.

V. Shut Down the Chiller

1) Bring back to ambient temp
    a. *CHNG SP*; *Yes*; up until ~21°C
2) Turn off *Heat/Chill* and *Compressor* and *Pump1*by pressing green buttons on front of chiller
3) Turn off *all circuit breakers*
4) Depressurize reservoir by pressing on *Pressurize 80psi Max* (above *sightglass*)
    a. Have cup ready, fluid may spray.
5) Run air through water supply lines
    a. Detach black hoses on *Facilities H2O Inlet* and *Facilities H2O Outlet*
    b. Pressurize Fill/Drain Tank using the nitrogen supply; close nitrogen supply; use hose attached to Drain port of Fill/Drain Tank to run the pressurized nitrogen through the *Facilities H2O Outlet* hole on back of chiller. A lot of water will come out of the *Facilities H2O Inlet* hole. Have one or two red SOLO cups ready to catch the water. Close *hose* valve and depressurize *Fill/Drain Tank*.
6) Return any leaked Galden fluid to *Fill/Drain Tank*
    a. This fluid may mix with water from melted frost. Do not return water to the Fill/Drain Tank
7) Leave cup under to collect leaking Galden

Note: Any hose used with fluid should be purged after use to prevent damage to the equipment. Run nitrogen at low pressure through the hose to ensure there is no liquid residue inside the hose.

VI. Drain the Chiller

Note: ONLY perform this step if you require removing all the fluid from the system

This step requires two hoses. It does not matter which hose is used for which function.

1) Attach one hose to *Pressurize 80psi Max* on front of the chiller and to the *pressure regulator* on the *nitrogen supply*.
2) Open *nitrogen source*
3) Open *pressure regulator* (tighten knob) between 40psi and 60psi
4) Attach second hose to *Channel 1 Fill/Drain* on front of chiller and to the *Drain* port of the *Fill/Drain Tank*. *Fill/Drain Tank* should be kept open to observe the fluid.
5) Perform Step 4 simultaneously with Step 3. Open first hose valve to introduce nitrogen into the system at 40psi – 60psi.
6) Open second hose valve to drain the fluid from the chiller into the Fill/Drain Tank. Continue until it seems that all the fluid has been removed.
7) Close both hose valves.
8) Detach hose from *Channel 1 Fill/Drain* on front of chiller and from the *Drain* port
9) Close *nitrogen source*
10) Close (loosen) *pressure regulator* valve
11) Detach *hose* from chiller
12) Open valve on *hose*
13) Open (tighten) *pressure regulator*
14) Close (loosen) *pressure regulator*
15) Close valve on *hose*
16) Detach hose from *pressure regulator*

CAUTION: If removing the plate from the chamber, be prepared to capture Galden fluid leaks where the plate is attached to the pipe lines.

The following figures depict the items italicized throughout the manual which are used to operate the chiller in the Space Environments Laboratory.

Figure 9. Hose
There is a blue hose and a yellow hose. It does not matter which is used for which function.

Figure 10. Hose valve
The blue valve is the hose valve

Figure 11. Fill/Drain Tank

Figure 12. Nitrogen Supply

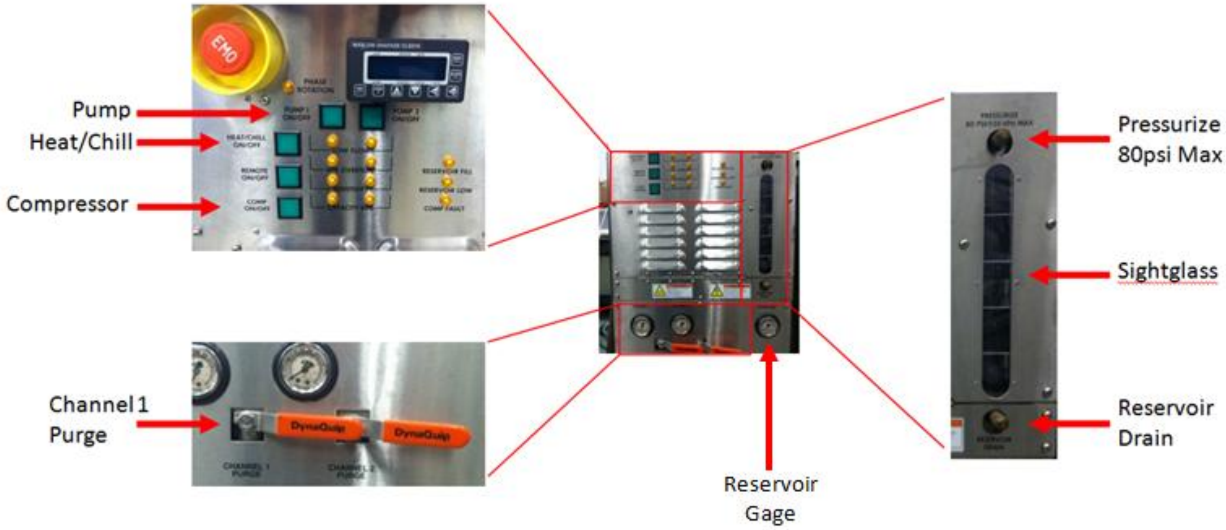


Figure 13. Front of Chiller

Figure 14. Power Box

Figure 15. Three-Phase Outlet

Figure 16. Three-Phase Plug

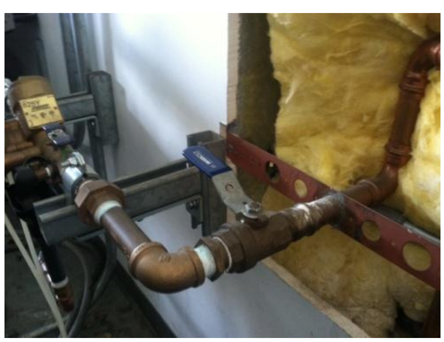


Figure 17. Water Supply Valve

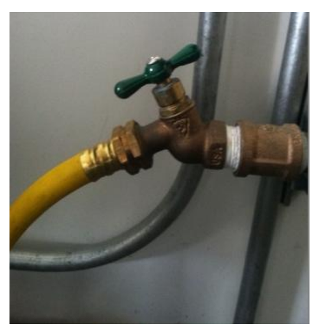


Figure 18. Water Faucet with Green Knob

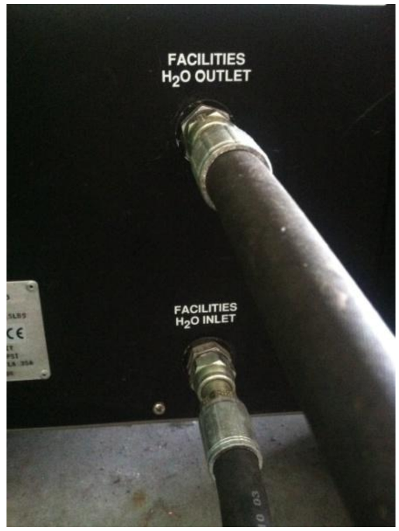


Figure 19. Facilities H2O Outlet and Facilities H2O inlet

Figure 20. Main Circuit Breaker

Figure 21. Circuit Breakers for Pump 1, Pump 2, Compressor (Comp), Heater 1, and Heater 2

Figure 22. Channel 1 Supply and Return

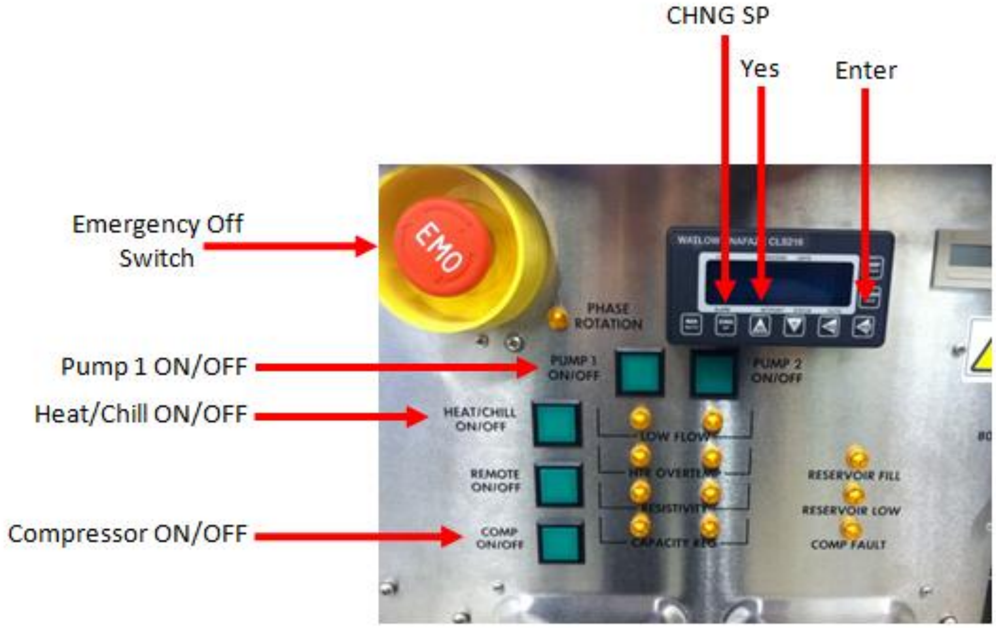


Figure 23. Chiller Controls

Figure 24. Fill/Drain Connection
on Front of Chiller

Appendix C. Matlab code

```
%% Experiment at Patm
close all
clear all
clc

tcouple = [1 2 3 4 5 8 9 10 21 23 24 25];
temp1 = [33.0 25.5 15.6 15.3 15.2 16.1 16.5 17.1 15.5 0 15.4 15.5];
temp2 = [48.0 22.1 7.2 7.6 14.5 7.7 9.2 6.8 13.7 0 18.8 11.4];
temp3 = [-14.3 -6.5 -7.1 -8.8 -17.7 -12.2 -20.1 -14.5 -22.7 -23 -29 -18.8];
temp4 = [-17.3, -13.6, -22.2, -18.9, -19.3,-21.8 -19.0, -22.6, -33, -23.0, -
29.0, -18.8];
for a = 1:12
temp(:,a) = [temp1(a),temp2(a),temp3(a),temp4(a)];
end
b = [1,2,3,4];
figure
plot([1:4], [temp1(1), temp2(1), temp3(1), temp4(1)],'-*')
hold all
plot([1:4], [temp1(2), temp2(2), temp3(2), temp4(2)],'-*')
plot([1:4], [temp1(3), temp2(3), temp3(3), temp4(3)],'-*')
plot([1:4], [temp1(4), temp2(4), temp3(4), temp4(4)],'-*')
plot([1:4], [temp1(5), temp2(5), temp3(5), temp4(5)],'-*')
plot([1:4], [temp1(6), temp2(6), temp3(6), temp4(6)],'-*')
plot([1:4], [temp1(7), temp2(7), temp3(7), temp4(7)],'-*')
plot([1:4], [temp1(8), temp2(8), temp3(8), temp4(8)],'-*')
plot([1:4], [temp1(9), temp2(9), temp3(9), temp4(9)],'-*')
plot([1:4], [temp1(10), temp2(10), temp3(10), temp4(10)],'-*')
plot([1:4], [temp1(11), temp2(11), temp3(11), temp4(11)],'-*')
plot([1:4], [temp1(12), temp2(12), temp3(12), temp4(12)],'-*')

legend('1','2','3','4','5','8','9','10','21','23','24','25','Location','EastO
utside')
title('Temperature Over Time')
xlabel('Measurement')
ylabel('Temperature (Celcius)')
   plot(a, temp2)
   plot(a, temp3)
plot(b, [temp(1,1), temp(2,1),63.0, 74.6],'-.ok')
plot([1,2],[temp(1,10),temp(2,10)],'-ok')
```

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