Accelerated Test Series to Determine the Extent of Water Swell in Phenolic Pistons

Summary Review April 20, 2009

Background

Recreational vehicles (RVs) were experiencing brake drag and boiling brake fluid after stop-and-go driving. Other vehicles, such as delivery trucks, rollback wreckers, etc equipped with the same hydraulic “ZOHT” brake calipers were not displaying the problem in warranty claims, complaints, or in the Office of Defects Investigations (ODI) Vehicle Owner Questionnaires (VOQs). Complaint RVs inspected in the field were found to have an internal caliper problem, eliminating the external slide pins or trapped brake line pressure events. When the calipers were returned from the field, the phenolic pistons were found to be oversized. Factory records indicated the pistons had originally been manufactured reliably within specification. One theory for this out-of-spec condition was water absorption by the phenolic matrix. RVs were suspected of being susceptible to the phenolic water swell and corresponding brake drag after normal heat shock from stop-and-go driving due to the duty cycle of the RVs. The RVs are typically assumed to be parked for six months then driven for two weeks. The brakes are not regularly exposed to heat to drive the moisture out of the phenolic, like the other medium-duty vehicles using the same brake caliper.

This test was designed to attempt to accelerate the phenolic piston swell observed to occur over two or three years of low usage. A steadily increasing diameter, during bench testing, would confirm the water swell theory and allow appropriate remedies to be evaluated. The testing was designed to accelerate water absorption into the phenolic matrix by exposing the pistons to high humidity, varying low temperatures, and varying atmospheric pressures. These variations were assumed to assist in the transport of the moisture into the phenolic. The moisture was assumed to enter through a groove on the side of the piston that positions the environmental boot. Therefore some of the ZOHT pistons were coated with a polyurethane sealant expecting to reduce moisture transfer, some were machined to remove the entire hard outer sidewall shell expecting to increase moisture transfer, and others were left as originally manufactured. These ZOHT pistons were compared to peer phenolic and steel pistons.

Testing Plan

- **Test Articles**
  - 5 Steel pistons (GM light truck 74.4 mm diameter PN 18060070)
  - 5 Phenolic pistons with machined environmental-boot groove (Ford 55.4 mm PN F1TZ2V121ARM)
  - 5 Phenolic pistons without machined environmental-boot groove (Bosch 66 mm railslide PN 4151728)
  - 5 Phenolic pistons with machined environmental-boot groove (Bosch 66 mm ZOHT PN 4153264)
  - 5 Phenolic pistons with the hard outer shell sidewall removed (Bosch 66 mm ZOHT PN 4153264)
  - 5 Phenolic pistons with polyurethane sealant on boot groove (Bosch 66 mm ZOHT PN 4153264)
- **Pre-Test Setup**
  - Each piston was given an identification number, 12 diameter reference marks were placed on the sidewalls at 45° increments and three heights up the sidewall
  - Prior to testing the 30 pistons were measured (at 12 positions each for 360 readings) and weighed four or more times before the start of testing in the environmental chambers
- **Test Overview**
  - Environmental chambers: two passive chambers that maintain pressure range of +/-7 psig, temperature range of 40 to 170°F, and humidity between 50 to 100%
  - Humidity environment: generated by closed chamber and air pressure supply oiler filled with water
  - Temperature cycles: generated by a refrigerator or oven
  - Pressure/vacuum cycles: generated by external vacuum pump or pressurized shop air line
  - Cycle periods: daily cycles, shown on a following page
  - Measurement periods: monthly after the pistons rested for 24 hours (at room temperature, pressure, and humidity), then record the 12 diameters and the weight of each piston

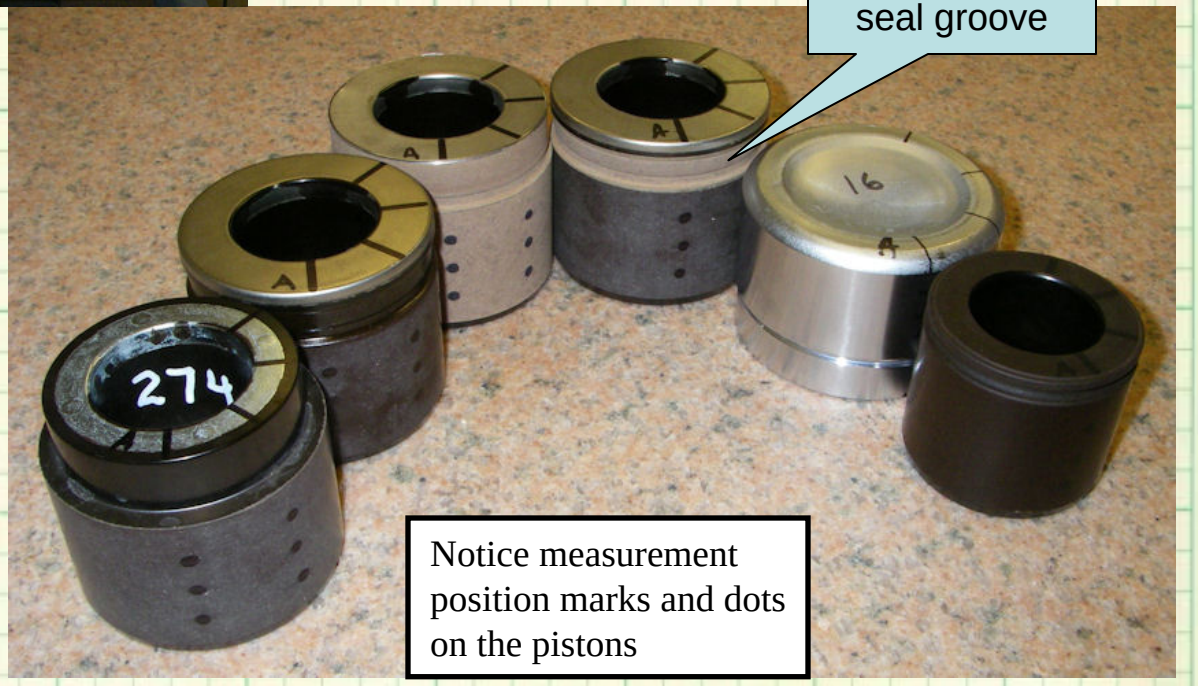
Equipment and Instrumentation

- Presto 16-qt pressure cooker, modified with a Wika pressure gage (-30 inHg to +15 psi) and a Kingston pop-off valve (15 psi) with an additional ring-pull pressure release
- Height measuring gage, Fowler Hi-Cal 300, with a motorized head with 0.3 N measuring force to eliminate operator bias effects
- Starrett Crystal Pink leveled granite table
- Scale, A&D Company Limited, Model FY-2000
- Dickson USB data logger, Model No. TP125, hygrometer and thermometer, records two channels (humidity and temperature) for 32,000 samples (16,000 per channel) recording for 11 days before overwriting
- Vacuum source, Gast Mfg Corp, Model No. 0522-V103-G180X
- Oven, 300°C, by Fisher Scientific Company, IsoTemp Oven Model No. 350
- Refrigerator, Frigidaire, Model FPD12TGL
- Pressure source, shop supply air, filtered and regulated to 7 psi
- Distilled water
- Minwax Helmsman Spar Urethane clear semi-gloss indoor/outdoor, used to seal the environmental-seal groove on five of the ZOHT pistons

Two passive environmental chambers were used to induce pressure/vacuum and heat/cold, the humidity naturally developed in the sealed chambers

Two Sterilite® storage containers with felt lined bottoms and plywood inserts were used anytime the pistons were not in the chambers, the Dickson data logger is at the back of the container

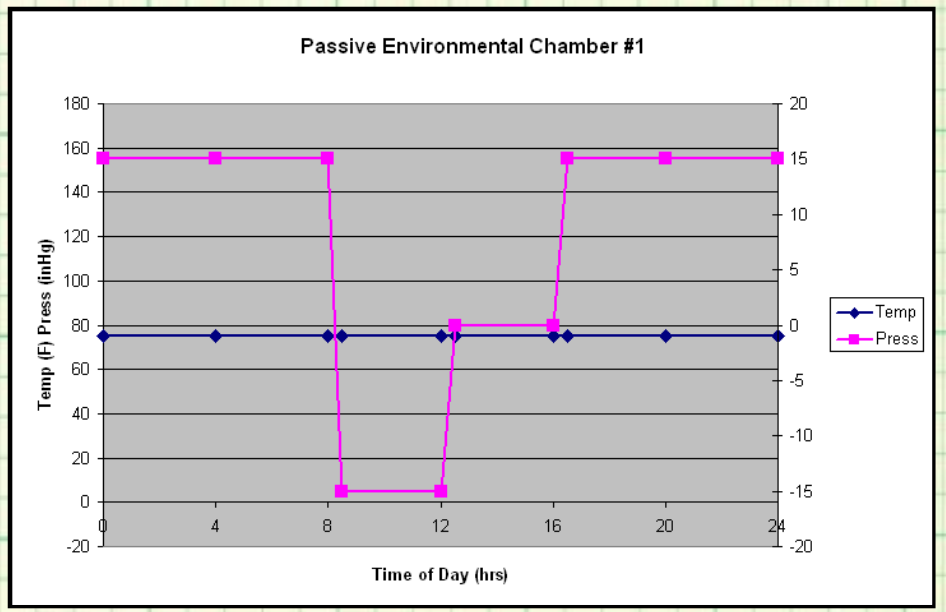
The height sensing gage is accurate to one-half of a ten thousands of an inch (0.00005 inch) and the weigh scale to 0.1 grams

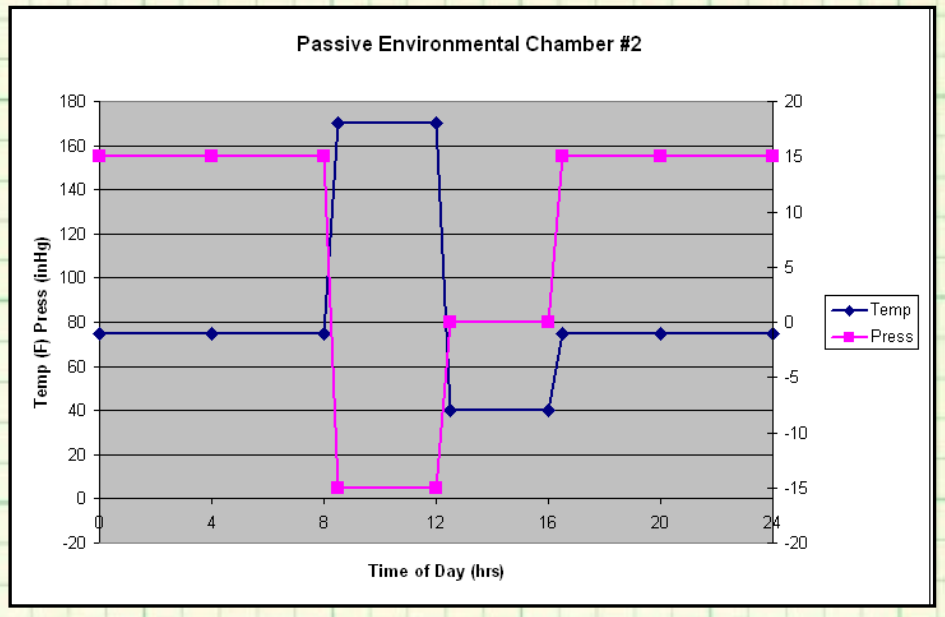


ZOHT Piston environmental seal groove

Notice measurement position marks and dots on the pistons

Six variations of pistons were tested including steel and phenolic



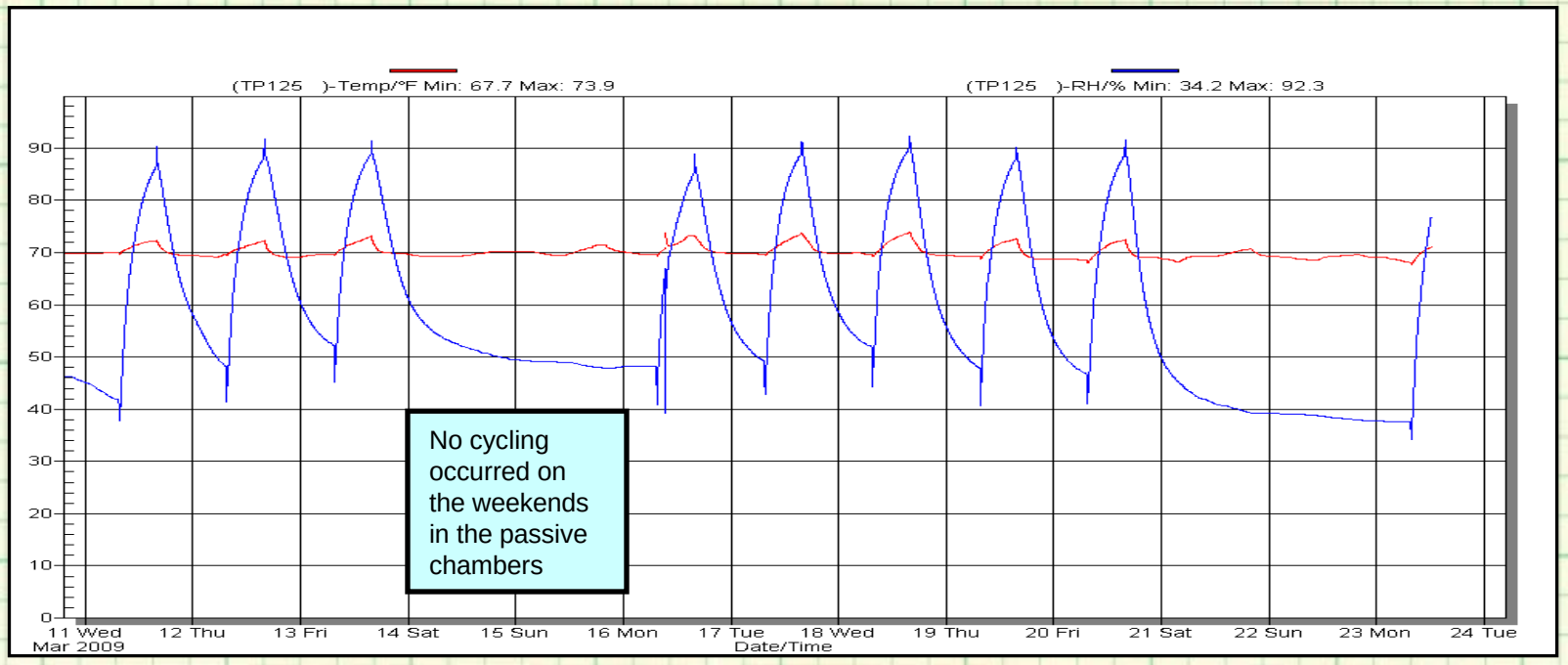


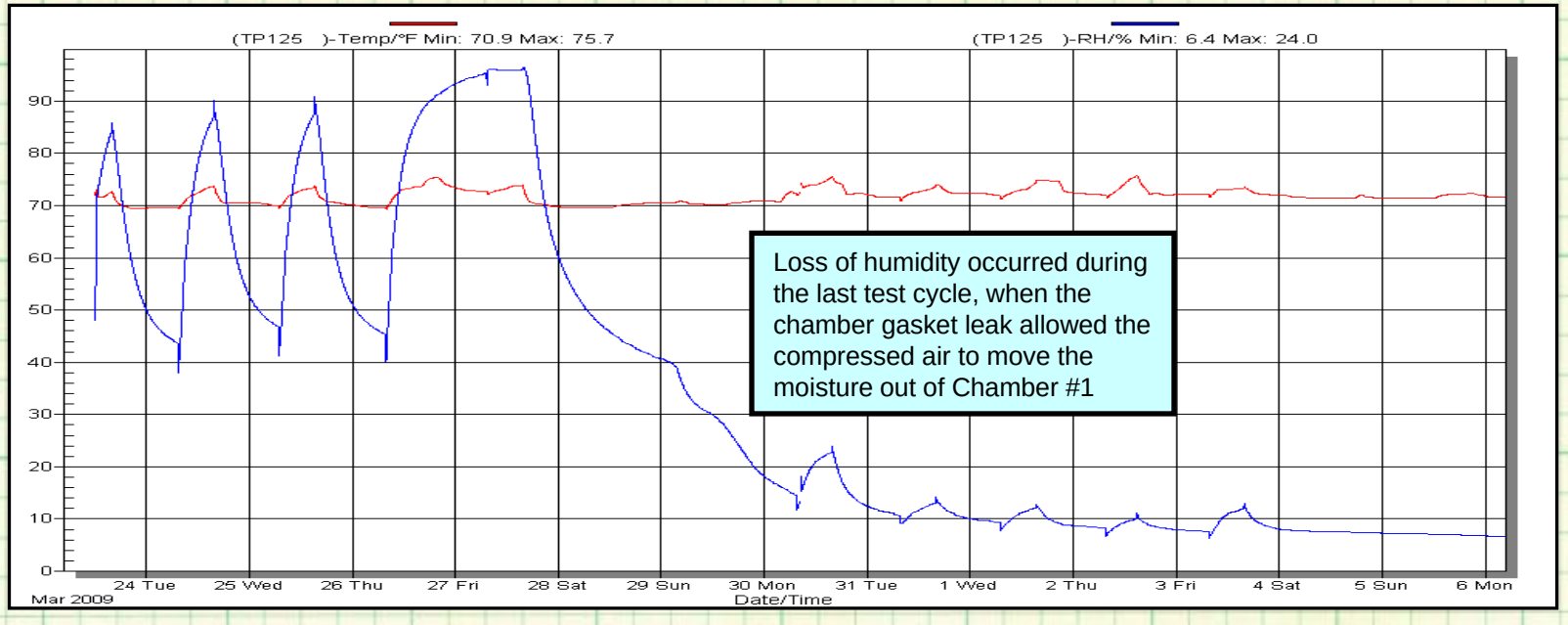
These chambers were always humid and had the same pressure/vacuum changes. Chamber #2 also under went 4 hours in the oven and 4 hours in the refrigerator. Changes in an environmental chamber are usually automated, but these chambers required manual attention three times a day, so they were called “passive chambers”.

These pressure variations are approximately +/-50% of nominal atmospheric pressure of 14.7 psi. The record atmospheric variations at sea level are 15.7 psi in the winter of 1968 in Siberia and 13.5 psi is in 2005 in the eye of hurricane Wilma. So extreme natural variations range from +7% to -13%. Note: 14.7 psi equals 29.92 inHg

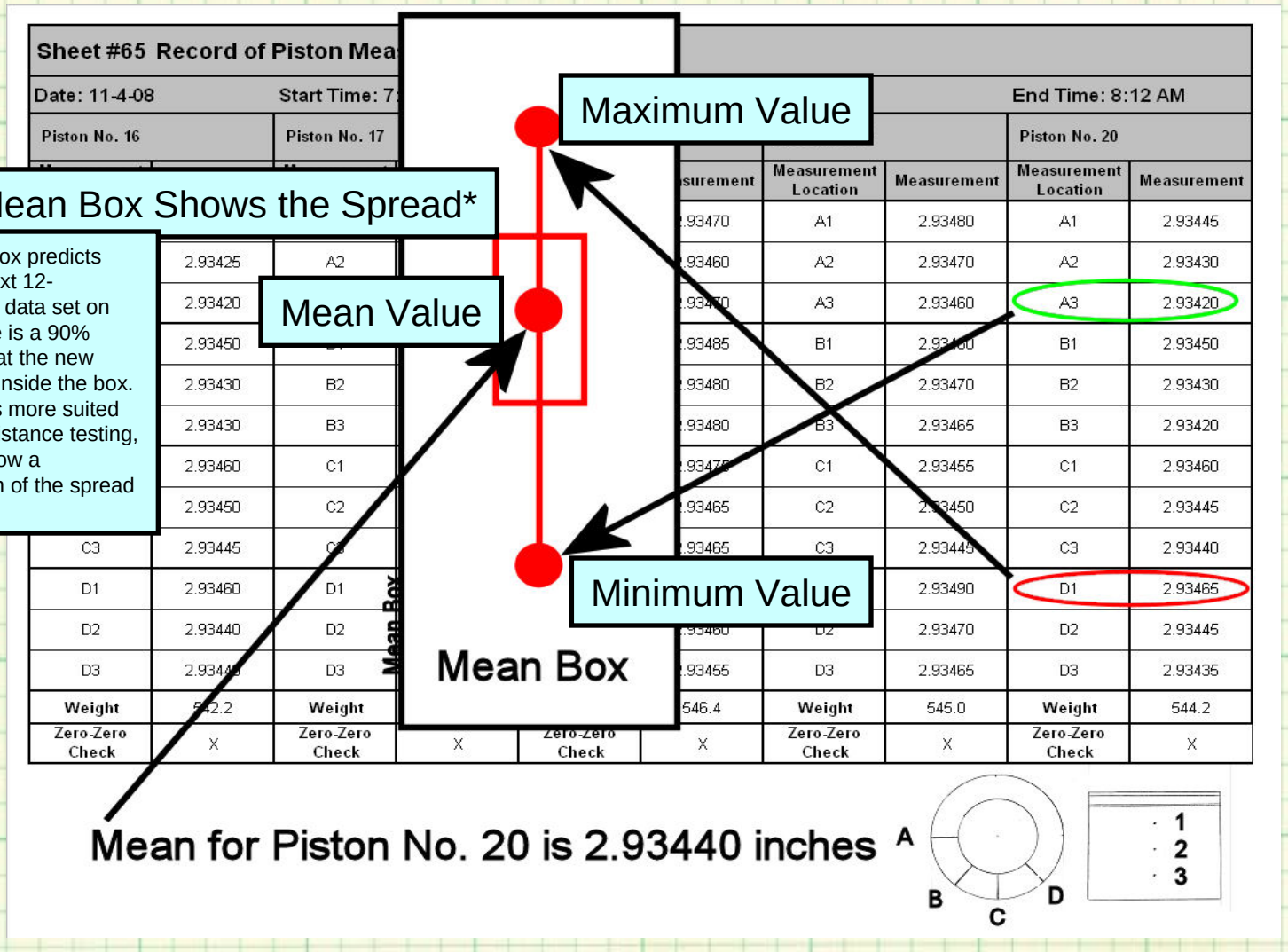
Testing Comments

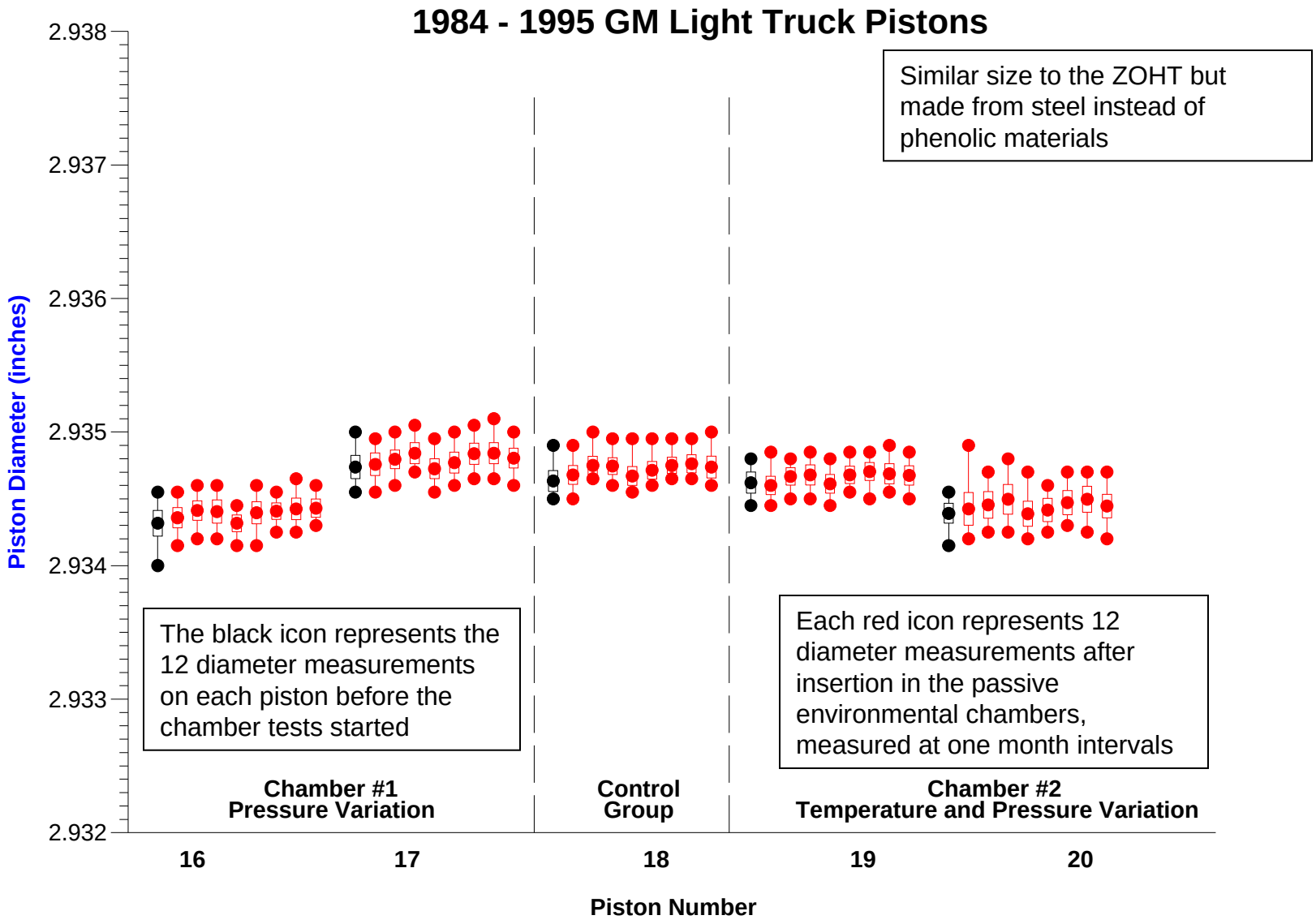
- At the end of the testing period, the test chamber gaskets were leaking and no longer held the full applied vacuum or pressure. The vacuum was applied but leaked off in about one hour. The pressure was maintained by shop air, but the air passing through the chamber reduced the humidity. During the last test period, the non-heated chamber (#1) was found to be dry when opened. A review of the temperature/humidity data logger showed the humidity was approximately 10% for the last 8 days of the test.
- There is a difference in the humidity between the two passive environmental chambers – Chamber #1 averages 65% humidity while the heated and cooled Chamber #2 averages 90% humidity
- The holidays during November, December, and January disrupted our manual cycling of the passive chambers in and out of the heating and cooling devices – leaving the pistons at room temperature in the pressurized (overnight) state for longer periods than desired
- The piston measurements are shown in 4 week increments
- The range of the y-axis scale on the diameter plots is 0.006 inch
- The range of the y-axis scale on the weight plots is 5 grams

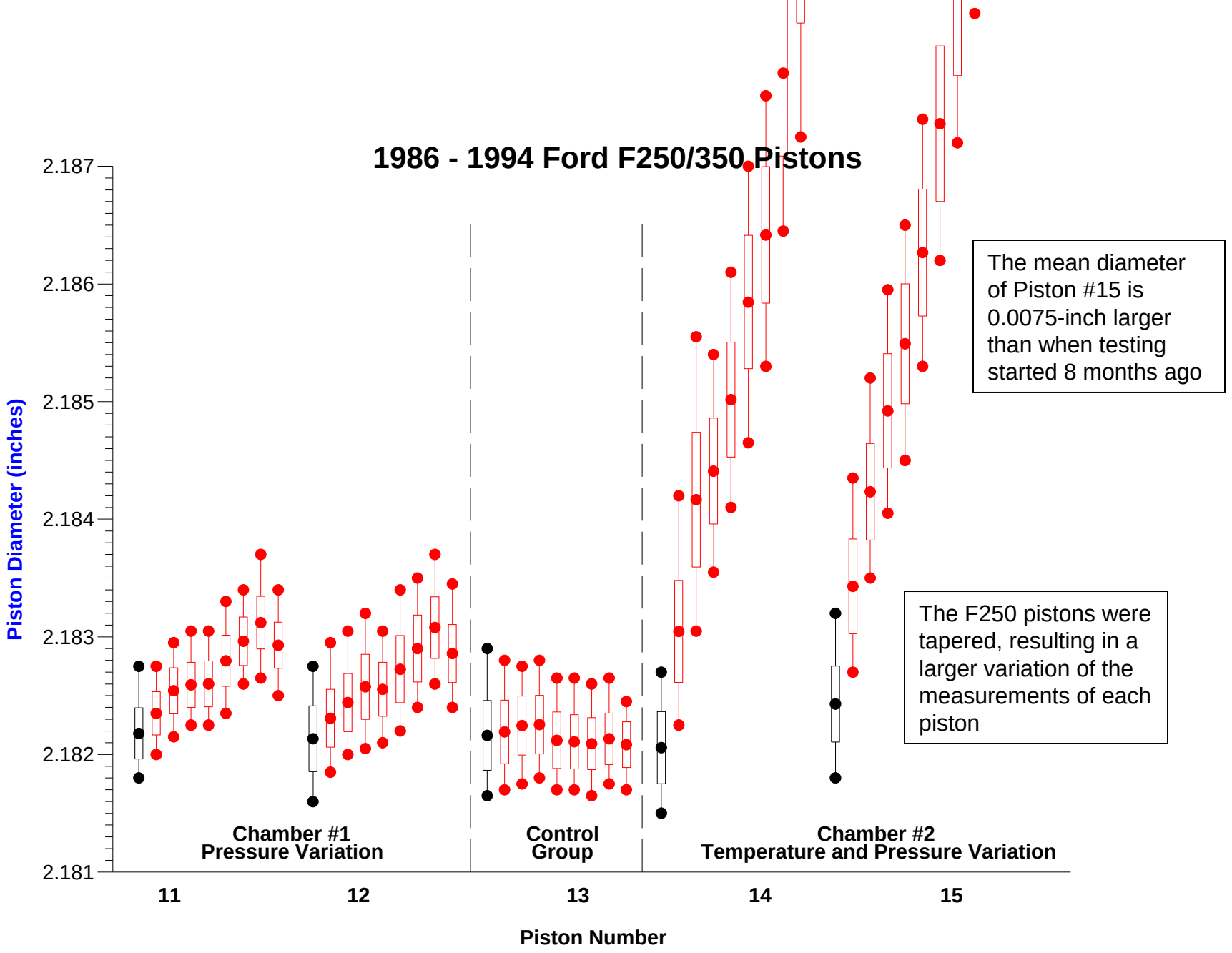

(TP125)-Temp/°F Min: 67.7 Max: 73.9
(TP125)-RH/% Min: 34.2 Max: 92.3
No cycling occurred on the weekends in the passive chambers
11 Wed Mar 2009
12 Thu
13 Fri
14 Sat
15 Sun
16 Mon
17 Tue
18 Wed
19 Thu
20 Fri
21 Sat
22 Sun
23 Mon
24 Tue
Date/Time

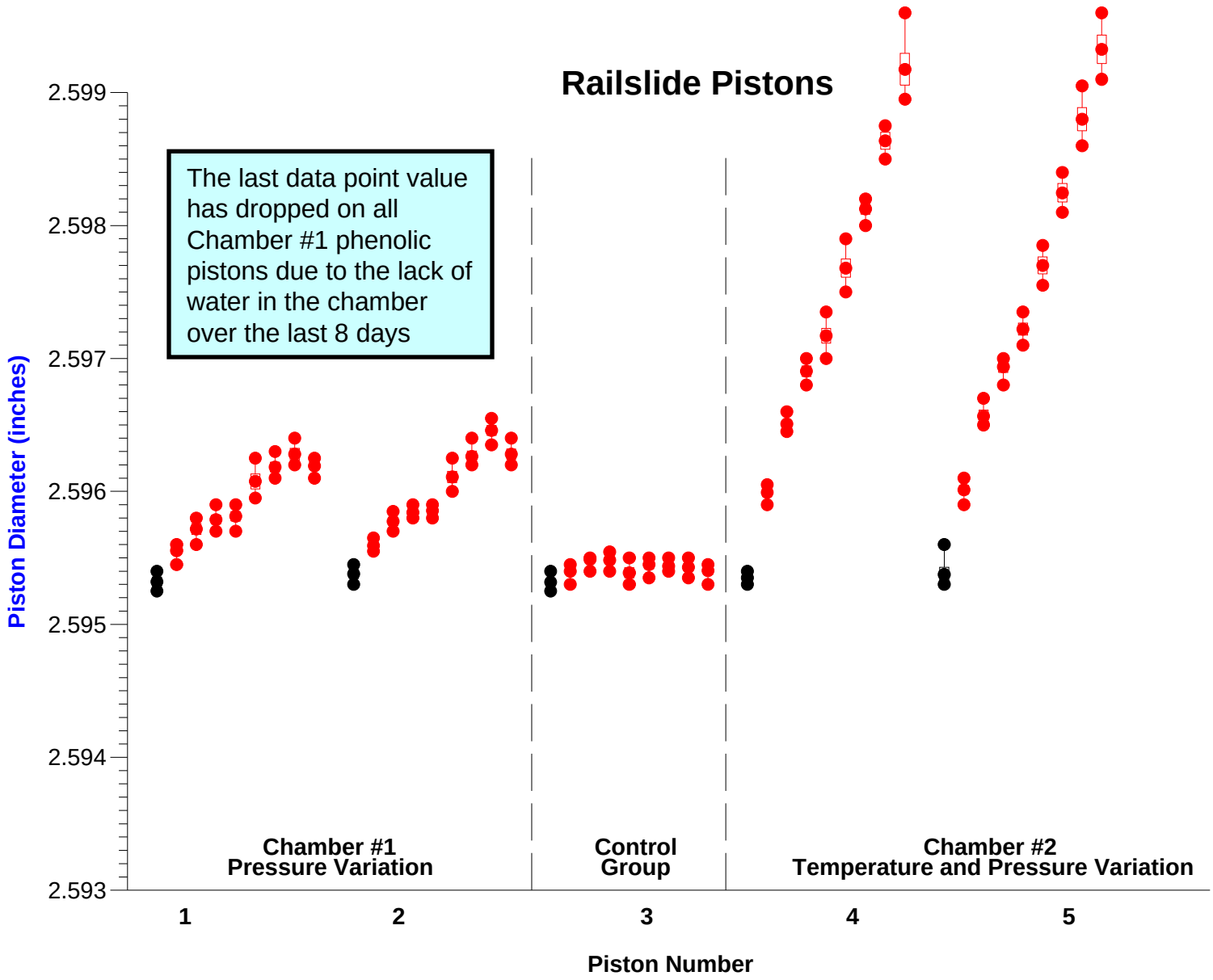

(TP125)-Temp/°F Min: 70.9 Max: 75.7
(TP125)-RH/% Min: 6.4 Max: 24.0
Loss of humidity occurred during the last test cycle, when the chamber gasket leak allowed the compressed air to move the moisture out of Chamber #1
24 Tue Mar 2009
25 Wed
26 Thu
27 Fri
28 Sat
29 Sun
30 Mon
31 Tue
1 Wed
2 Thu
3 Fri
4 Sat
5 Sun
6 Mon
Date/Time

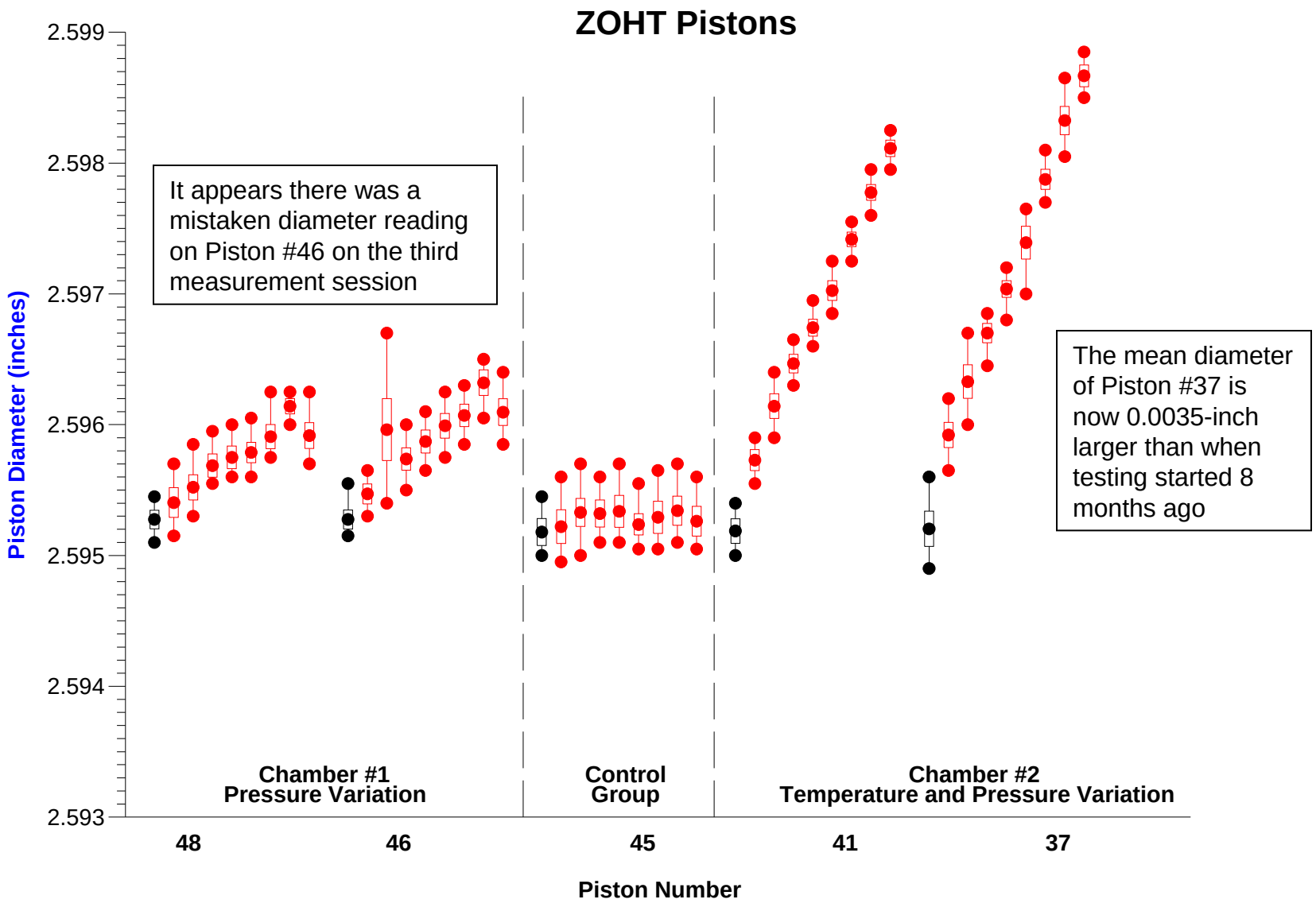
Data Table and How the Mean Box Plot Symbol is Created

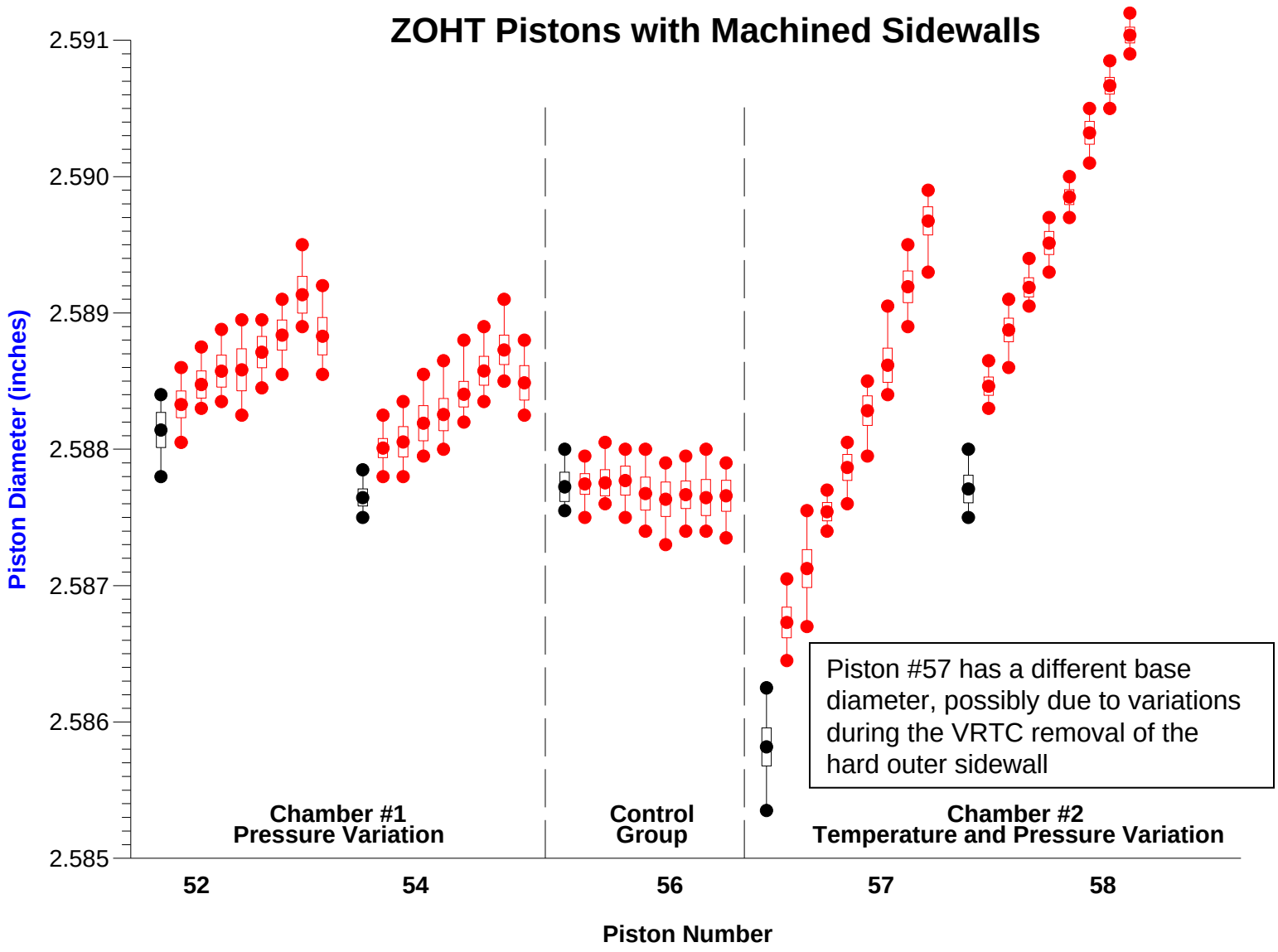


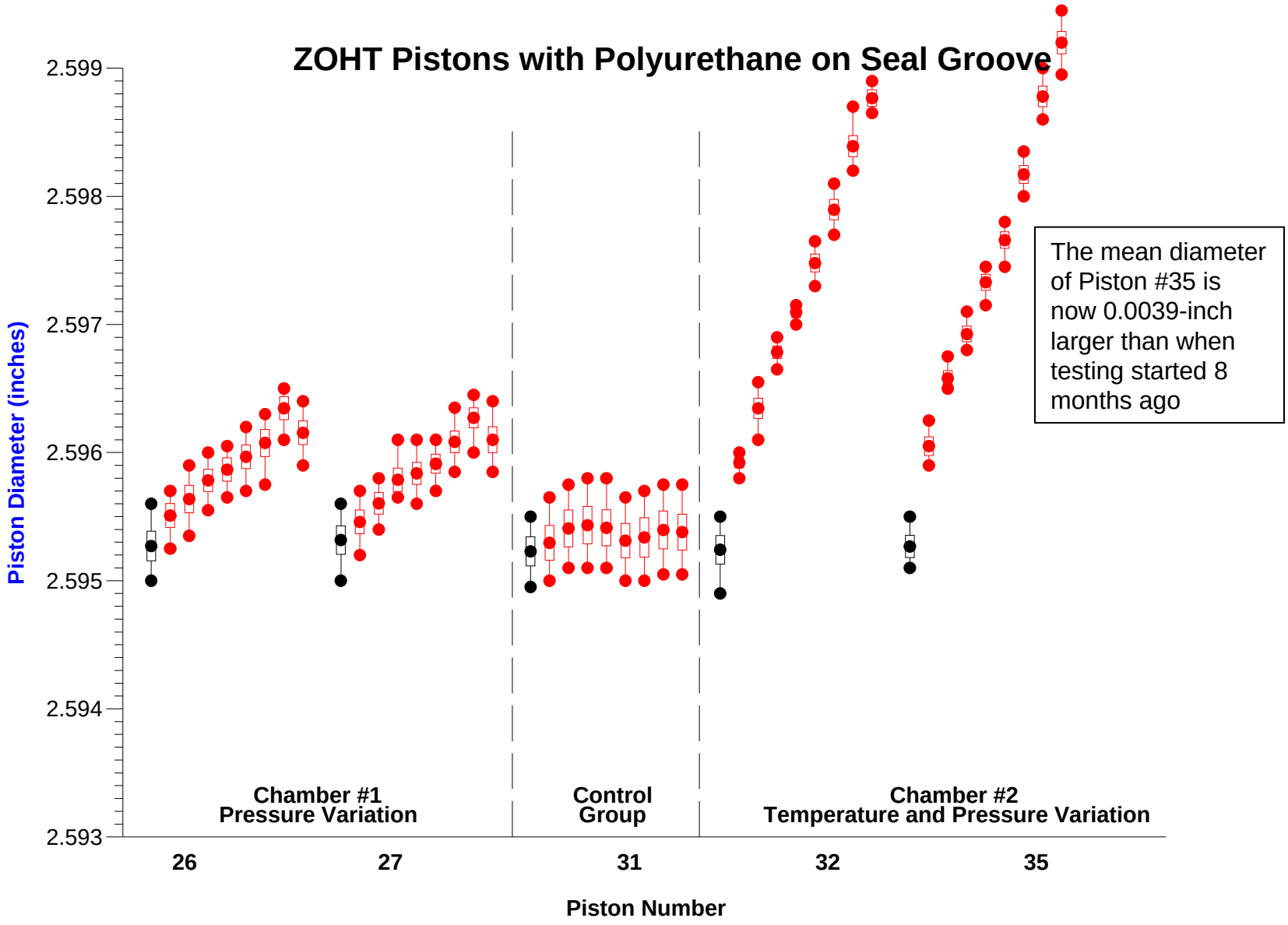

1984 - 1995 GM Light Truck Pistons
Similar size to the ZOHT but made from steel instead of phenolic materials
Piston Diameter (inches)
2.938
2.937
2.936
2.935
2.934
2.933
2.932
The black icon represents the 12 diameter measurements on each piston before the chamber tests started
Each red icon represents 12 diameter measurements after insertion in the passive environmental chambers, measured at one month intervals
Chamber #1
Pressure Variation
Control
Group
Chamber #2
Temperature and Pressure Variation
16
17
18
19
20
Piston Number

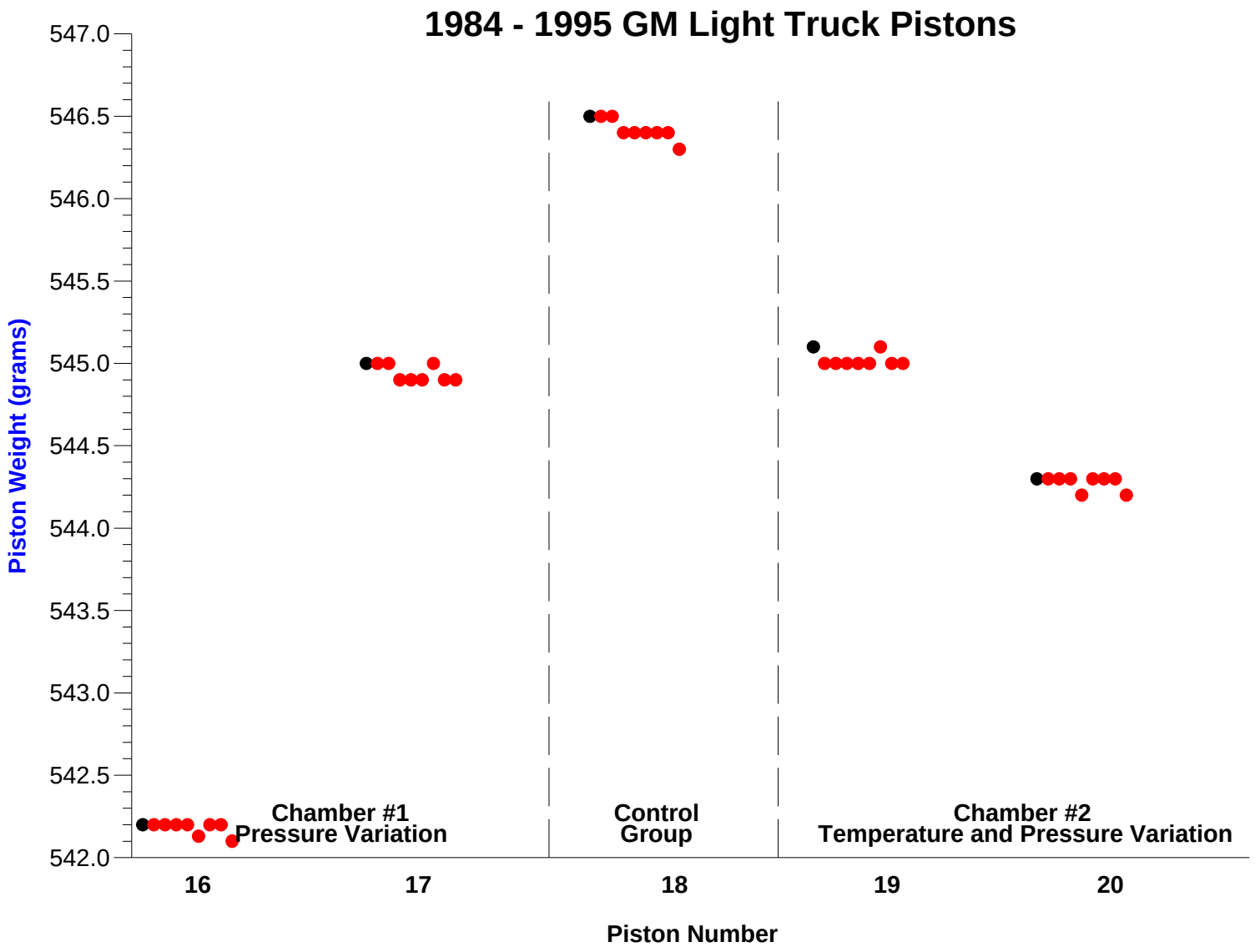

1986 - 1994 Ford F250/350 Pistons
Piston Diameter (inches)
2.187
2.186
2.185
2.184
2.183
2.182
2.181
11
12
13
14
15
Piston Number
Chamber #1
Pressure Variation
Control
Group
Chamber #2
Temperature and Pressure Variation
The mean diameter of Piston #15 is 0.0075-inch larger than when testing started 8 months ago
The F250 pistons were tapered, resulting in a larger variation of the measurements of each piston

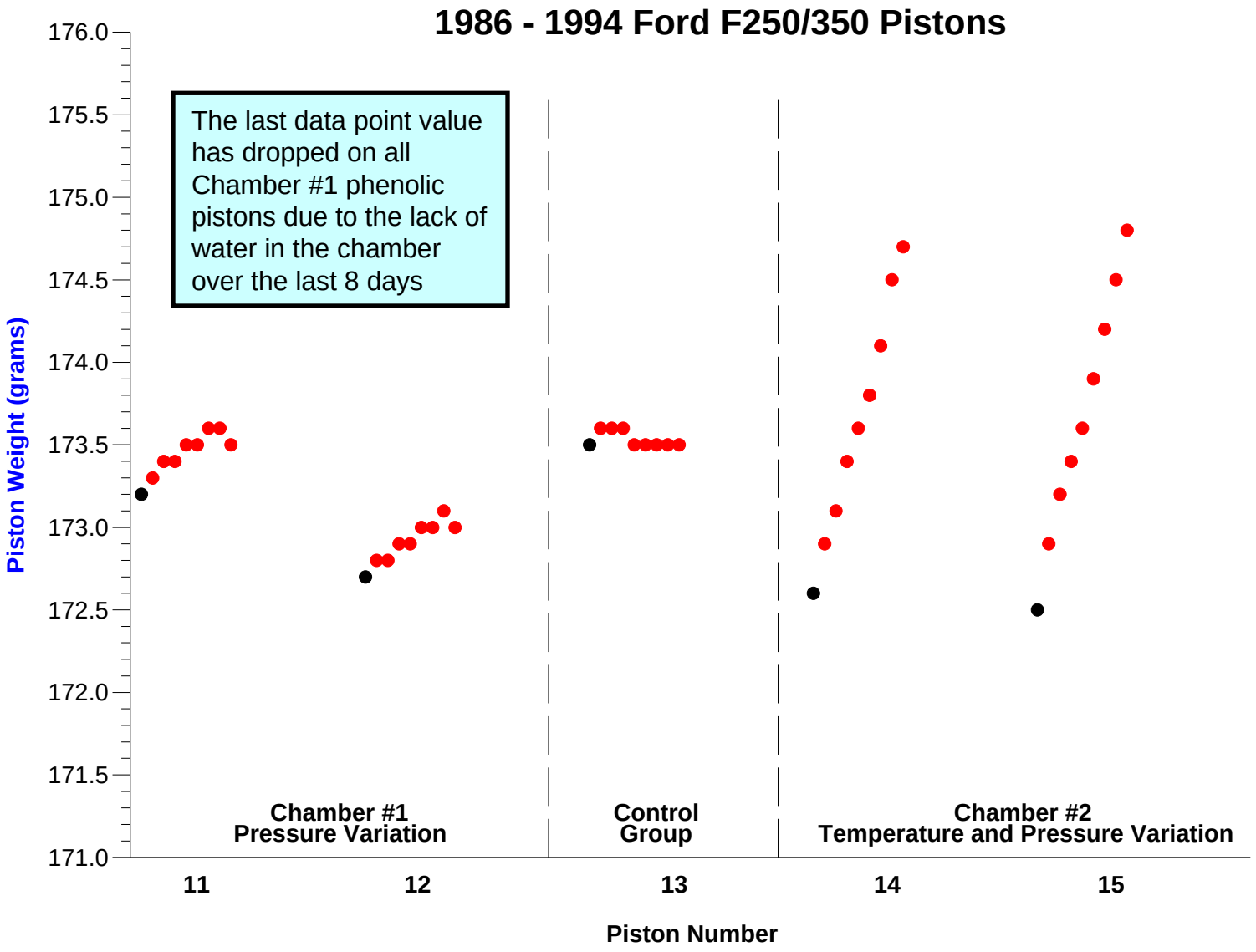

Railslide Pistons
The last data point value has dropped on all Chamber #1 phenolic pistons due to the lack of water in the chamber over the last 8 days
Piston Diameter (inches)
2.599
2.598
2.597
2.596
2.595
2.594
2.593
Chamber #1
Pressure Variation
Control
Group
Chamber #2
Temperature and Pressure Variation
1
2
3
4
5
Piston Number

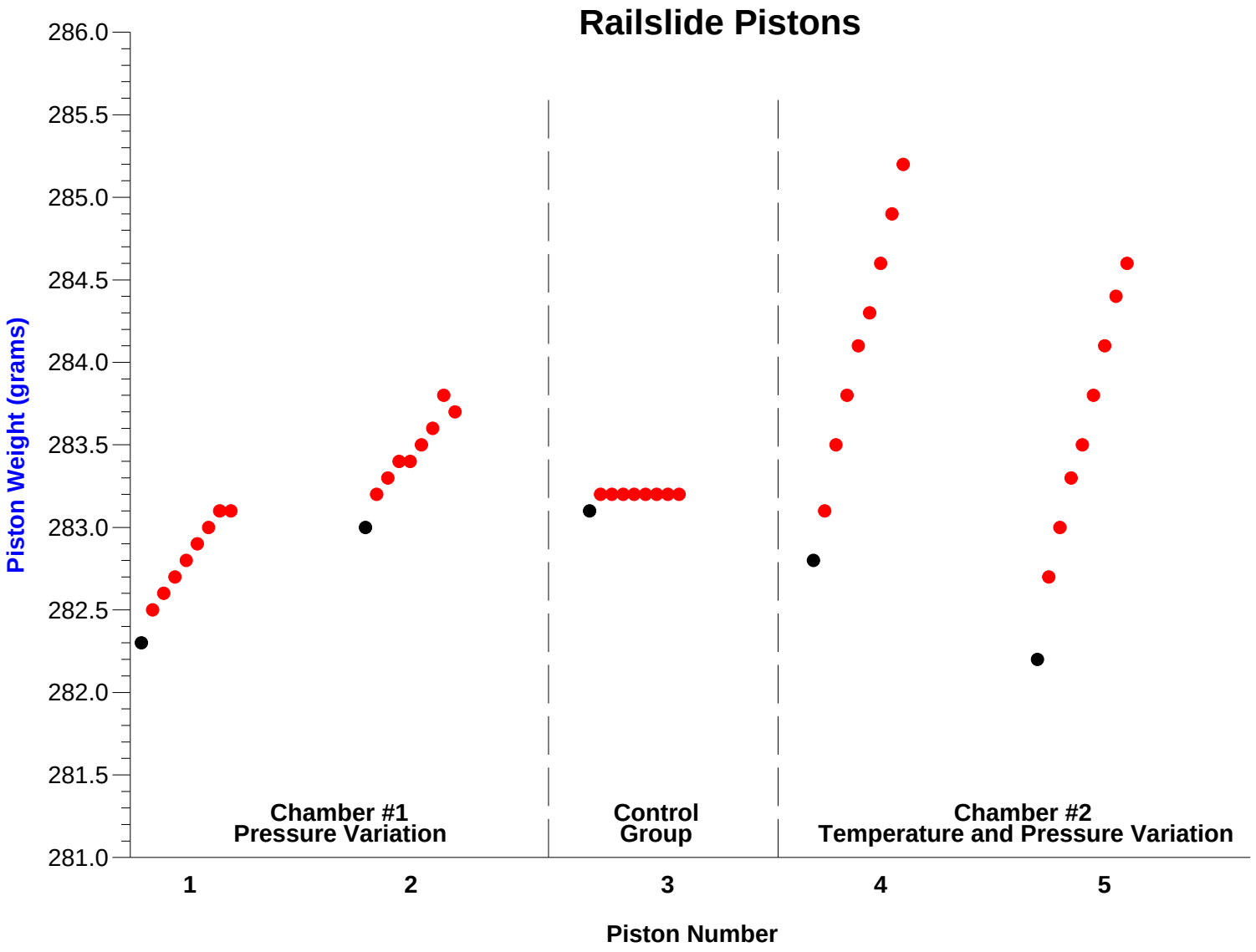

ZOHT Pistons
It appears there was a mistaken diameter reading on Piston #46 on the third measurement session
The mean diameter of Piston #37 is now 0.0035-inch larger than when testing started 8 months ago
Piston Diameter (inches)
2.599
2.598
2.597
2.596
2.595
2.594
2.593
Chamber #1
Pressure Variation
Control
Group
Chamber #2
Temperature and Pressure Variation
48
46
45
41
37
Piston Number

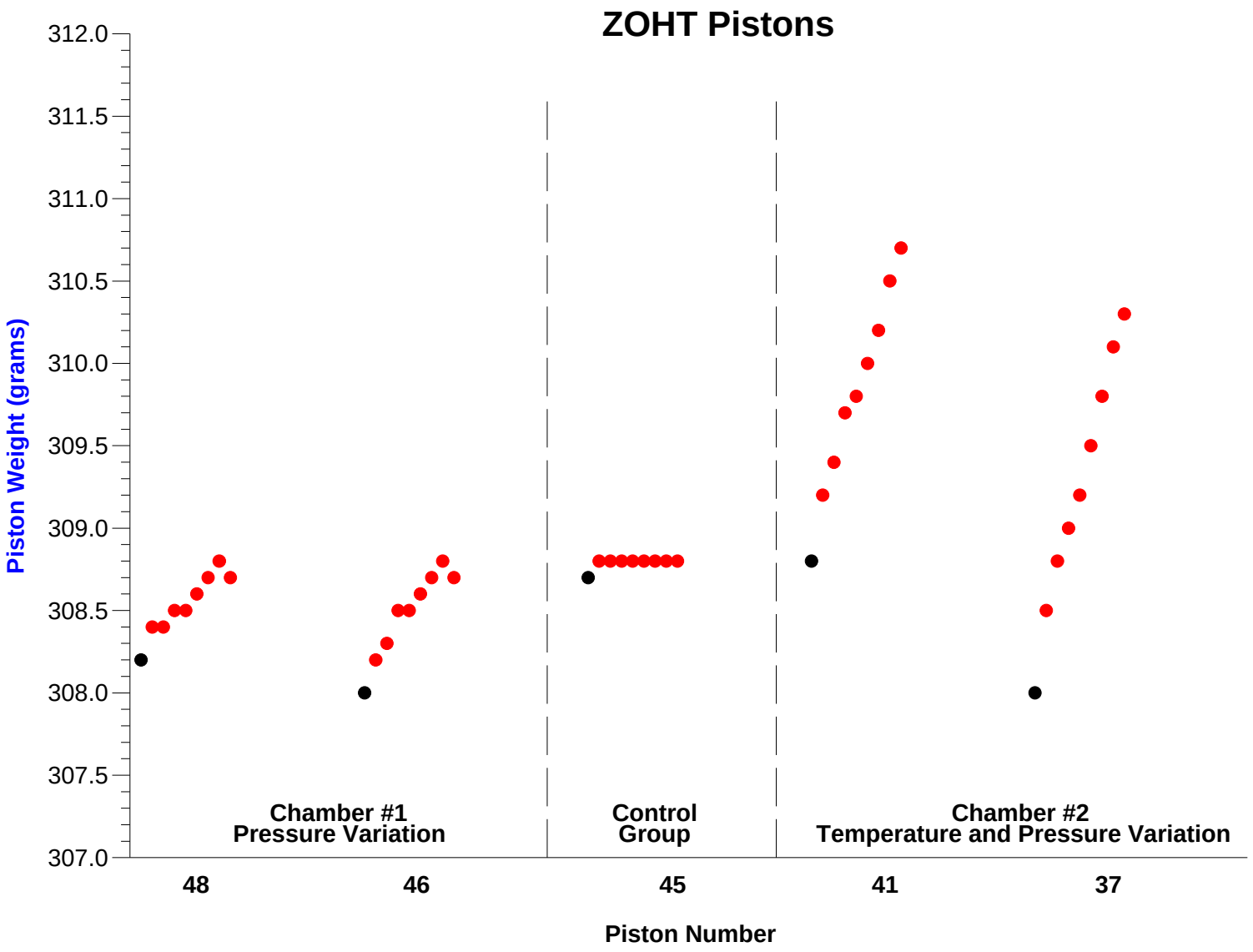

ZOHT Pistons with Machined Sidewalls
Piston Diameter (inches)
2.591
2.590
2.589
2.588
2.587
2.586
2.585
52
54
56
57
58
Piston Number
Chamber #1
Pressure Variation
Control
Group
Chamber #2
Temperature and Pressure Variation
Piston #57 has a different base diameter, possibly due to variations during the VRTC removal of the hard outer sidewall

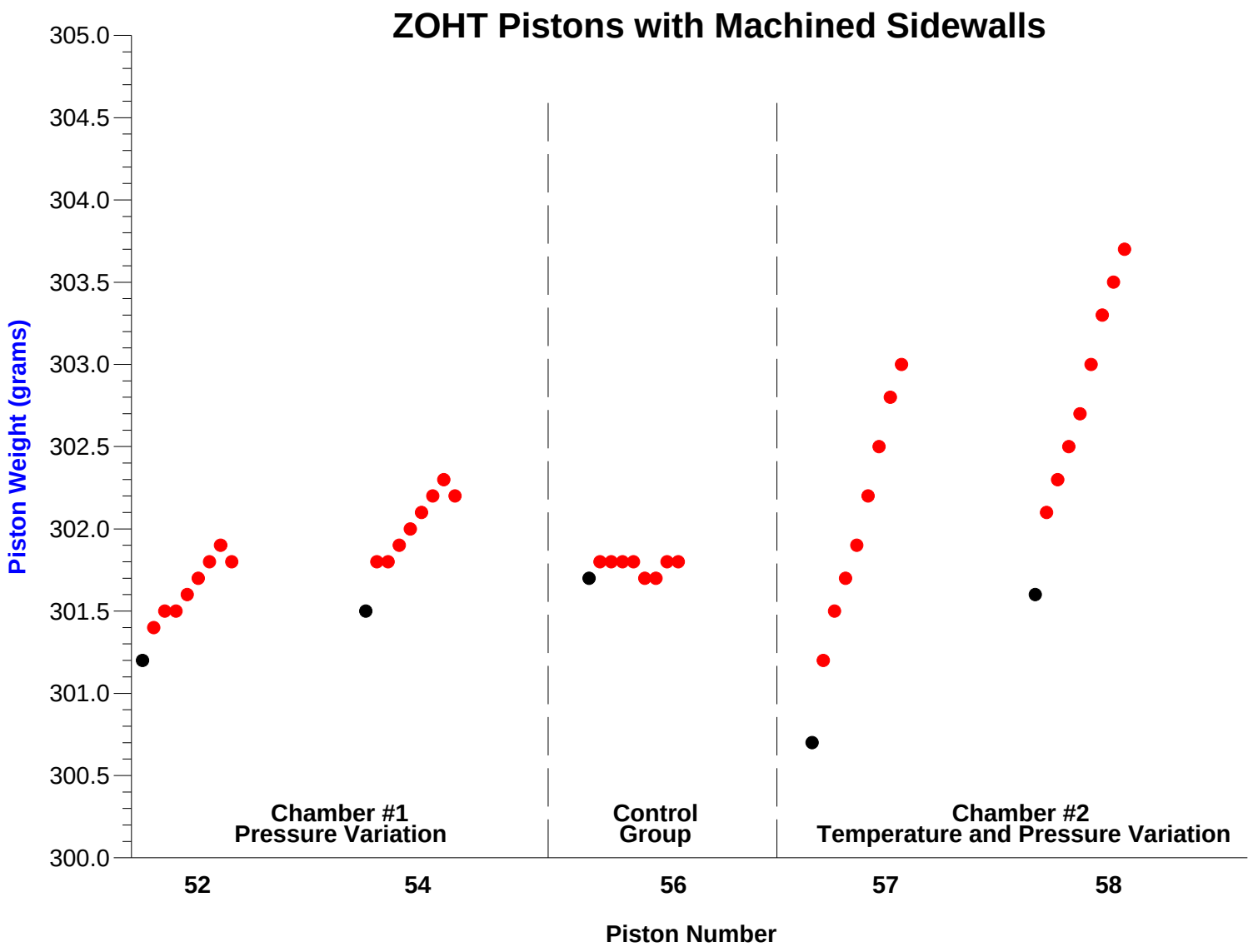

ZOHT Pistons with Polyurethane on Seal Groove
Piston Diameter (inches)
2.599
2.598
2.597
2.596
2.595
2.594
2.593
Chamber #1
Pressure Variation
Control
Group
Chamber #2
Temperature and Pressure Variation
26
27
31
32
35
Piston Number
The mean diameter of Piston #35 is now 0.0039-inch larger than when testing started 8 months ago

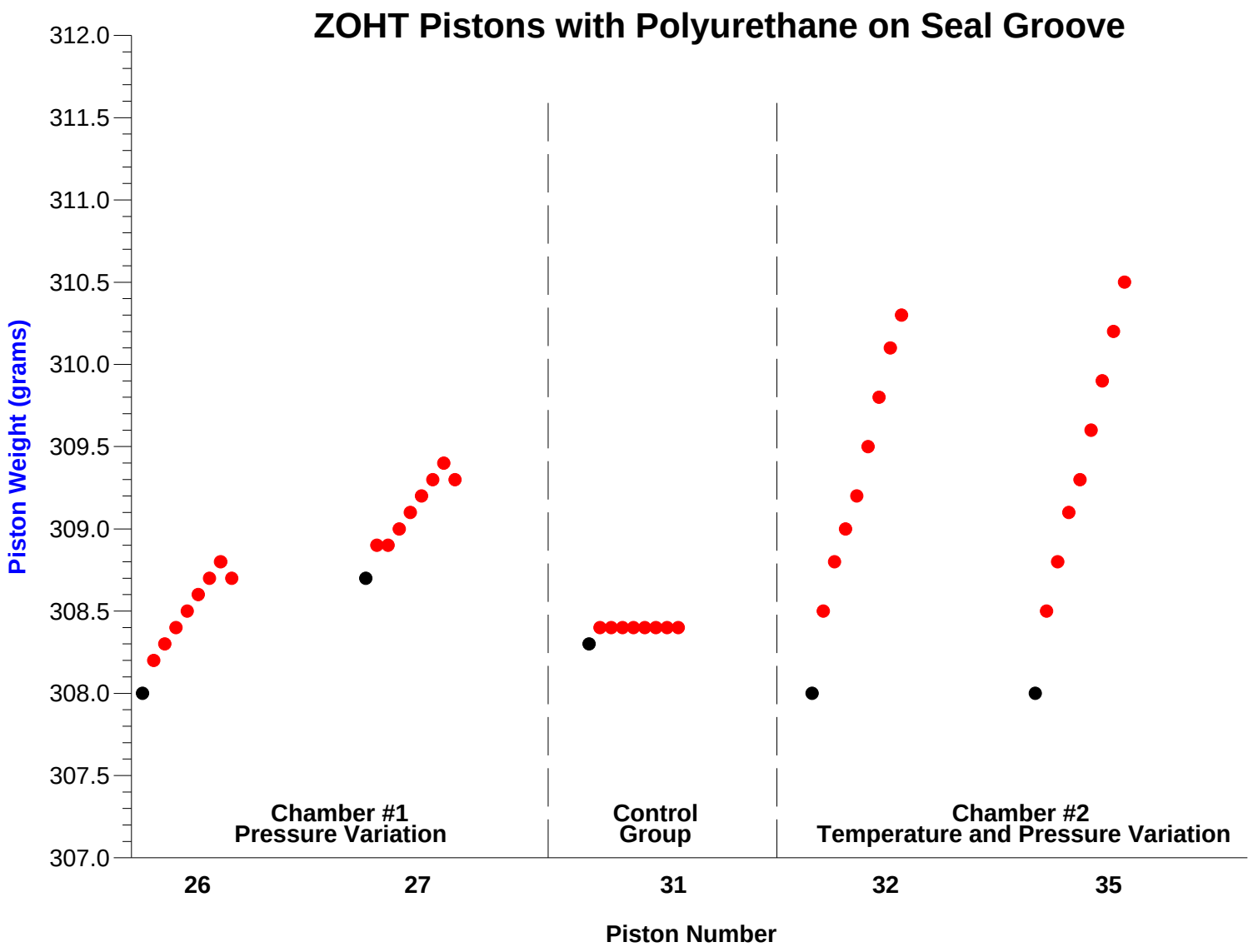

1984 - 1995 GM Light Truck Pistons
Piston Weight (grams)
547.0
546.5
546.0
545.5
545.0
544.5
544.0
543.5
543.0
542.5
542.0
Chamber #1
Pressure Variation
Control
Group
Chamber #2
Temperature and Pressure Variation
16
17
18
19
20
Piston Number


1986 - 1994 Ford F250/350 Pistons
The last data point value has dropped on all Chamber #1 phenolic pistons due to the lack of water in the chamber over the last 8 days
Piston Weight (grams)
176.0
175.5
175.0
174.5
174.0
173.5
173.0
172.5
172.0
171.5
171.0
Chamber #1
Pressure Variation
Control
Group
Chamber #2
Temperature and Pressure Variation
11
12
13
14
15
Piston Number


Railslide Pistons
Piston Weight (grams)
286.0
285.5
285.0
284.5
284.0
283.5
283.0
282.5
282.0
281.5
281.0
Chamber #1
Pressure Variation
Control
Group
Chamber #2
Temperature and Pressure Variation
1
2
3
4
5
Piston Number


ZOHT Pistons
Piston Weight (grams)
312.0
311.5
311.0
310.5
310.0
309.5
309.0
308.5
308.0
307.5
307.0
Chamber #1
Pressure Variation
Control
Group
Chamber #2
Temperature and Pressure Variation
48
46
45
41
37
Piston Number


ZOHT Pistons with Machined Sidewalls
Piston Weight (grams)
305.0
304.5
304.0
303.5
303.0
302.5
302.0
301.5
301.0
300.5
300.0
Chamber #1
Pressure Variation
Control
Group
Chamber #2
Temperature and Pressure Variation
52
54
56
57
58
Piston Number


ZOHT Pistons with Polyurethane on Seal Groove
Piston Weight (grams)
312.0
311.5
311.0
310.5
310.0
309.5
309.0
308.5
308.0
307.5
307.0
Chamber #1
Pressure Variation
Control
Group
Chamber #2
Temperature and Pressure Variation
26
27
31
32
35
Piston Number