



Test Monitoring Center

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MEMORANDUM: 03-002

DATE: February 11, 2003

TO: Sequence IIIF Surveillance Panel

FROM: Michael T. Kasimirsky *Michael T. Kasimirsky*

SUBJECT: Piston Deposit Analysis

At the request of the Sequence IIIF Surveillance Panel, the TMC began an in-depth investigation into Sequence IIIF Piston Deposits, both Weighted Piston Deposits (WPD) and Average Piston Skirt Varnish (APV), to address industry concerns about the performance of the Sequence IIIF test on these parameters. To begin the analysis, the LTMS data set was analyzed for significant differences on overall WPD and APV result for a variety of hardware and operational factors. All analyses were conducted using a 95% confidence level as the threshold for a significant difference.

The TMC analyzed the data for differences in WPD & APV performance due to differences in camshaft pour codes, piston batches, piston size, and ring batches. The data was also examined for correlations between top ring gap or bottom ring gap and the WPD & APV results of the test. In the above analyses, the only significant difference that was noted was that Batch Code 8 pistons were found to be significantly different from Batch Code 11 pistons on APV performance. No other significant differences were found on APV performance and no significant differences in WPD performance was found on any piston batch. In addition, no correlation was found between the measured piston ring gaps and piston deposit performance. The APV differences between the two piston batches identified above are shown in Table 1.

Table 1: APV Differences Due to Piston Batch		
<i>Piston Batch</i>	<i>Least Squares Means of APV Performance by Piston Batch</i>	<i>N size</i>
8	0.402	27
11	-0.720	19

Next, the LTMS data was then analyzed in a similar manner to look for differences in laboratory performance and also for differences in test stand performance. This analysis showed that laboratory A is significantly different from laboratories B and M on WPD performance. No other laboratory or test stand differences were found. However, lab B has recently had problems with their results on piston deposits in Sequence IIIF reference oil testing. Lab M has also had problems with piston deposit results in the past so these results are not entirely unexpected. The laboratory differences found are summarized in Table 2.

Table 2: WPD Differences Due to Laboratory		
<i>Laboratory</i>	<i>Least Squares Means of WPD Performance by Laboratory</i>	<i>N size</i>
A	-0.493	58
B	0.341	35
M	0.341	20

The differences in laboratory performance and piston batch performance were investigated further to see if there was any connection between the two. A review of the data shows that Lab A contributed 44.4% of the Batch Code 8 piston data, while Labs B & M contributed 3.7% and 7.4% of the Batch Code 8 data, respectively. The Batch Code 11 piston data is more uniformly distributed with Labs A, B, and M contributing 27.8%, 33.3%, and 16.7% of the data, respectively, on this hardware. There are a total of 27 tests on Batch Code 8 pistons and 18 tests on Batch Code 11 pistons in the LTMS data set at this time. The data was then reviewed to see if there was any relationship between the laboratory differences found on WPD and the piston batch differences found on APV. Average Δ/s APV & WPD results were calculated by laboratory and piston batch and then plotted. The plots are shown in Figures 1 & 2, shown below:

Figure 1: APV Average Delta/s, by Laboratory & Piston Batch

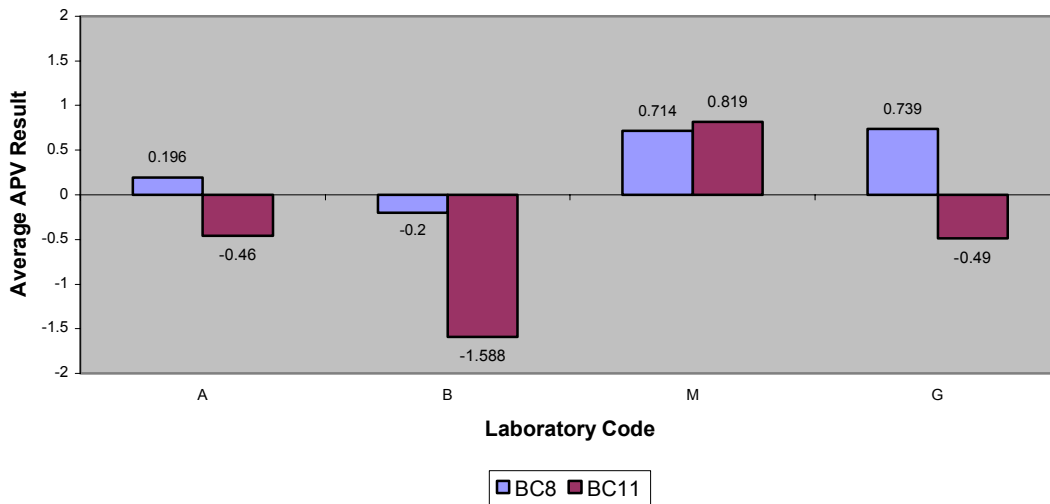
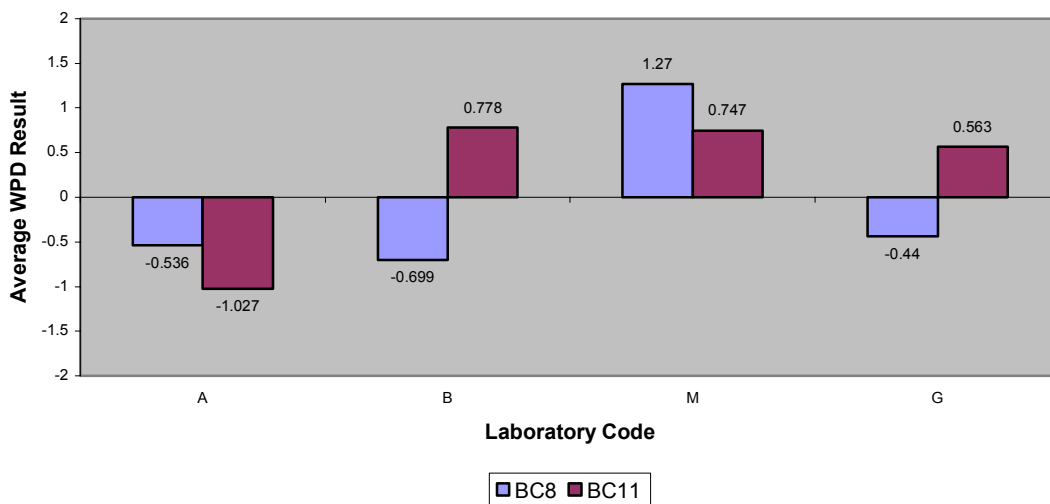


Figure 2: WPD Average Delta/s, by Laboratory & Piston Batch



As you can see from Figure 1, the differences in APV performance between piston batches are not consistent across all laboratories (only laboratories with data on both piston batches are shown in the figure). The WPD results on the two piston batches are also not consistent across all laboratories as well. From this data, it appears that the piston batch differences may be driven by a difference in laboratory performance and not a difference in test hardware performance.

Since WPD and APV are summary parameters, made up of averages of multiple individual ratings, the next step was to break down the summary ratings into their individual components and examine those results. Toward that end, the LTMS data set was reexamined to look at the individual groove, land, under crown, and piston skirt ratings (individual piston average of the thrust and anti-thrust ratings for that piston), by reference oil, since no reference oil targets exist for the individual rated areas. Each test was broken down into six individual observations (i.e. the resultant data set had six times the number of observations as the LTMS data set) and that data set was reexamined for laboratory differences on the individual rated areas, by reference oil.

This analysis yielded quite a few differences in laboratory performance, but the differences were not consistent across all reference oils. For example, two laboratories that were different in the groove 1 ratings on reference oil 1008 were not different in groove 1 ratings on reference oil 1006. Every rated location in the WPD rating showed some laboratory differences, but again they were not consistent across all laboratories or all reference oils. These results did not lend themselves to a concise summary and as such have been omitted from this document. However, the results of the analysis did lend support to the idea that there was more to this story than simple laboratory differences.

Next, some summary statistics on individual position ratings were generated. The mean, standard deviation, minimum, and maximum were calculated (minimum & maximum values listed are the smallest and largest ratings found for that position, rather than a calculation) for each individual rating position (groove 1, groove 2, groove 3, land 3, oil ring land, under crown, and average piston skirt varnish for a single piston), by reference oil, used in the Sequence IIF test. The analysis showed that there are large variations in the rating results obtained in several of the rated positions. The analysis results are shown in Tables 3 through 8, shown below:

<i>Position</i>	<i>Mean</i>	<i>Standard Deviation</i>	<i>Minimum</i>	<i>Maximum</i>
Groove 1	0.788	0.430	0.19	3.78
Groove 2	0.694	0.366	0.00	2.65
Groove 3	6.613	1.250	3.80	9.58
Land 2	0.588	0.220	0.15	8.45
ORLD	2.415	1.531	0.52	8.45
Under Crown	1.136	0.510	0.11	4.22
Piston Skirt	9.251	0.353	8.15	9.85

<i>Position</i>	<i>Mean</i>	<i>Standard Deviation</i>	<i>Minimum</i>	<i>Maximum</i>
Groove 1	0.996	0.706	0.49	4.76
Groove 2	0.883	0.496	0.26	3.26
Groove 3	8.698	0.824	6.32	9.80
Land 2	0.725	0.305	0.21	2.04
ORLD	3.258	2.261	0.71	8.18
Under Crown	1.082	0.627	0.75	6.76
Piston Skirt	9.412	0.326	8.10	9.94

<i>Position</i>	<i>Mean</i>	<i>Standard Deviation</i>	<i>Minimum</i>	<i>Maximum</i>
Groove 1	1.098	0.783	0.28	8.09
Groove 2	1.843	1.590	0.00	9.48
Groove 3	9.128	0.722	5.05	10.00
Land 2	0.634	0.189	0	2.16
ORLD	3.693	2.566	0.56	9.75
Under Crown	1.008	0.374	0.75	3.18
Piston Skirt	9.738	0.197	8.15	10.00

<i>Position</i>	<i>Mean</i>	<i>Standard Deviation</i>	<i>Minimum</i>	<i>Maximum</i>
Groove 1	0.967	0.579	0.08	2.87
Groove 2	2.201	2.509	0.00	8.97
Groove 3	9.188	0.523	7.78	9.92
Land 2	0.705	0.380	0.19	2.59
ORLD	4.275	2.713	0.64	9.41
Under Crown	0.857	0.105	0.75	1.10
Piston Skirt	9.646	0.269	8.94	9.93

<i>Position</i>	<i>Mean</i>	<i>Standard Deviation</i>	<i>Minimum</i>	<i>Maximum</i>
Groove 1	1.102	0.788	0.50	4.82
Groove 2	1.311	1.182	0.42	7.50
Groove 3	9.444	0.496	7.76	10.00
Land 2	0.956	0.452	0.46	3.60
ORLD	4.466	2.669	0.55	9.40
Under Crown	2.484	1.780	0.22	8.91
Piston Skirt	9.346	0.317	8.53	9.94

<i>Position</i>	<i>Mean</i>	<i>Standard Deviation</i>	<i>Minimum</i>	<i>Maximum</i>
Groove 1	1.201	0.843	0.55	5.69
Groove 2	1.094	0.848	0.53	5.56
Groove 3	9.398	0.546	6.69	9.98
Land 2	0.917	0.390	0.31	3.13
ORLD	3.634	2.867	0.73	9.80
Under Crown	2.156	1.767	0.75	8.99
Piston Skirt	9.308	0.314	8.52	9.89

For reference, the weighting factors used in the final WPD calculation for the various positions are shown in the Table 9:

Groove 1	0.05
Groove 2	0.10
Groove 3	0.20

Land 2	0.15
ORLD	0.30
Under Crown	0.10
Piston Skirt	0.10

The data in Tables 2-8 shows several interesting results of the analysis. A review of the Piston Skirt standard deviation data in those tables shows ranges of data only slightly larger than the APV target standard deviation for that reference oil. This larger spread is not unexpected, given that the targets are based upon an average of the average of these ratings (to be specific, APV is calculated from an average of the 12 piston skirt ratings; the WPD result for a piston is calculated from the average of the thrust and anti-thrust ratings for that piston, while the WPD result for the test is the average of the six individual piston WPD ratings) and the results are at least comparable to the APV targets on the oil in question. The groove, land, and under crown data on the other hand, shows large variations in the ranges of reported results. For example, the groove 2 ratings on reference oil 1008 ranged from a low of 0.00 to a maximum of 9.48. Many other of the rated positions show similar variability.

To investigate this variability, the TMC contacted the O&H Panel Chairman to see if this fit with his experiences in the Sequence IIIF test as a test engineer. He confirmed that he had seen large ranges in the reported rating results, sometimes in the rated data of one test. Investigation into those tests confirmed that the rated results are indicative of the test results (i.e. not a rating or data entry error) but no cause for the differences was known.

One possible explanation for the data would be a rating problem. To investigate this, the data from the last Light Duty Rating Workshop as analyzed. This data can be found at the following links:

ftp://ftp.astmtmc.cmu.edu/refdata/gas/rating_workshop_data/2002_fall/Data/20020923_iiif_Apistons_screened.xls

and,

ftp://ftp.astmtmc.cmu.edu/refdata/gas/rating_workshop_data/2002_fall/Data/20020923_iiif_Bpistons_screened.xls

A review of the workshop data showed that the industry raters were fairly consistent in their ratings of the individual locations. That data showed a much less variation in the rated results, leading one to conclude that this is not a rating issue, but rather an actual spread in the test results. To further investigate this issue, a maximum range of the ratings for each rating location within a test was calculated. These ranges were then plotted for all tests in the LTMS data set, by rating location (groove 1, groove 2, etc.) against the overall WPD result generated by the test. The data was plotted with two reference oils per plot to reduce the number of data points per plot and make the plots more readable. These plots are shown in Figures 3 through 23, which are attached. The data was plotted in this manner to see if the spread in the ratings of a particular location on a given test correlated to a particular level of overall WPD severity. It also allowed all the rating range data calculated from the LTMS data set to be reviewed, rather than just the summary information and smallest & largest rating values shown in Tables 3 through 8 above.

A review of the plots shown in Figures 3 through 23 show little in the way of trends in the data. The Groove 1 data shown in Figures 3 through 5 shows no trends in the data. The range of the groove 1 ratings seems to vary regardless of the overall WPD result of the test. The groove 2 data in Figures 6 through 8 shows no relation between overall WPD result and the range of groove 2 ratings on oils 1006 & 1006-2. Oils 1008 & 1008-1, on the other hand, seem to indicate that the groove 2 rating range for a test gets larger as the WPD result gets more mild. Oils 433 & 433-1 seem to fall somewhere between the results shown for the other reference oils, with respect to the range of the groove 2 ratings. The other rating locations show similar scatter in the ranges of the individual ratings.

Another item of note from Figures 3 through 23 is that the largest spread in the piston skirt varnish ratings within a test is less than 1.5 merits (see Figures 28, 19, & 20). However, most of the other rated areas show much larger spreads in the individual ratings on a given test. But even this is not consistent across all locations and reference oils. For example, the under crown ratings on reference oils 1006, 1006-2, 1008, and 1008-1 typically have a range of less than two merits within a given test. However, tests conducted on reference oils 433 & 433-1 have a rating range of less than half a merit to almost seven merits, or anywhere in between.

Next, the six individual ratings within a test, for each rated location on the piston, were plotted against the average of those six ratings. (The average piston skirt varnish for each piston (which is the value used in the WPD calculation) was used for the piston skirt varnish plot.) The average of the six ratings was used to see if the data showed any trends in the data as the overall severity of the test changed. These plots are shown in Figures 24 through 44.

A review of these plots shows several interesting observations. The Groove 1 data (see Figures 24 to 26), the spread of the data increases, as the average groove 1 rating grows larger (milder). The Groove 2 data (see Figures 27 to 29) shows a similar behavior, but with reference oils 1008 & 1008-1 showing much more variability in the ratings than the other four reference oils in the system. The Groove 3 and Land 2 data (see Figures 30 to 35), on the other hand, shows a much more desirable distribution in that the spread of the data does not markedly change with the overall severity of the Groove 3 deposits. The Oil Ring Land data (see Figures 36 to 38) is some of the most bothersome in that the data shows no trends in ring land ratings across any severity level of overall ring land severity. The Piston Skirt Varnish data (see Figures 39 to 41), on the other hand, is very consistent within a test, regardless of the overall severity level of the test. The Under Crown data (see Figures 42 to 44) is similar to the Groove 2 data in that reference oils 433 & 433-1 show much more variability in the individual ratings as the overall Under Crown average increases than the other four reference oils show.

In conclusion, at this time it does not appear that there are any clearly hardware-related problems in the Sequence IIIF piston deposit results. There is, however, a very large spread to the data on several rated position in the WPD rating. No explanation for this spread has been found at this time, but the TMC will continue to investigate this issue in the reference oil data, during upcoming laboratory visits, and at the upcoming Light Duty Rating Workshop on February 17-20, 2003.

MTK/mtk/mem03-002.mtk.doc

c: <ftp://www.astmtmc.cmu.edu/docs/gas/sequenceiii/memos/mem03-002.pdf>
Scott D. Parke, Light Duty Rating Task Force Chairman

Distribution: Electronic Mail

Figure 3: Groove 1 Individual Test Rating Range, Reference Oils 1006 & 1006-2

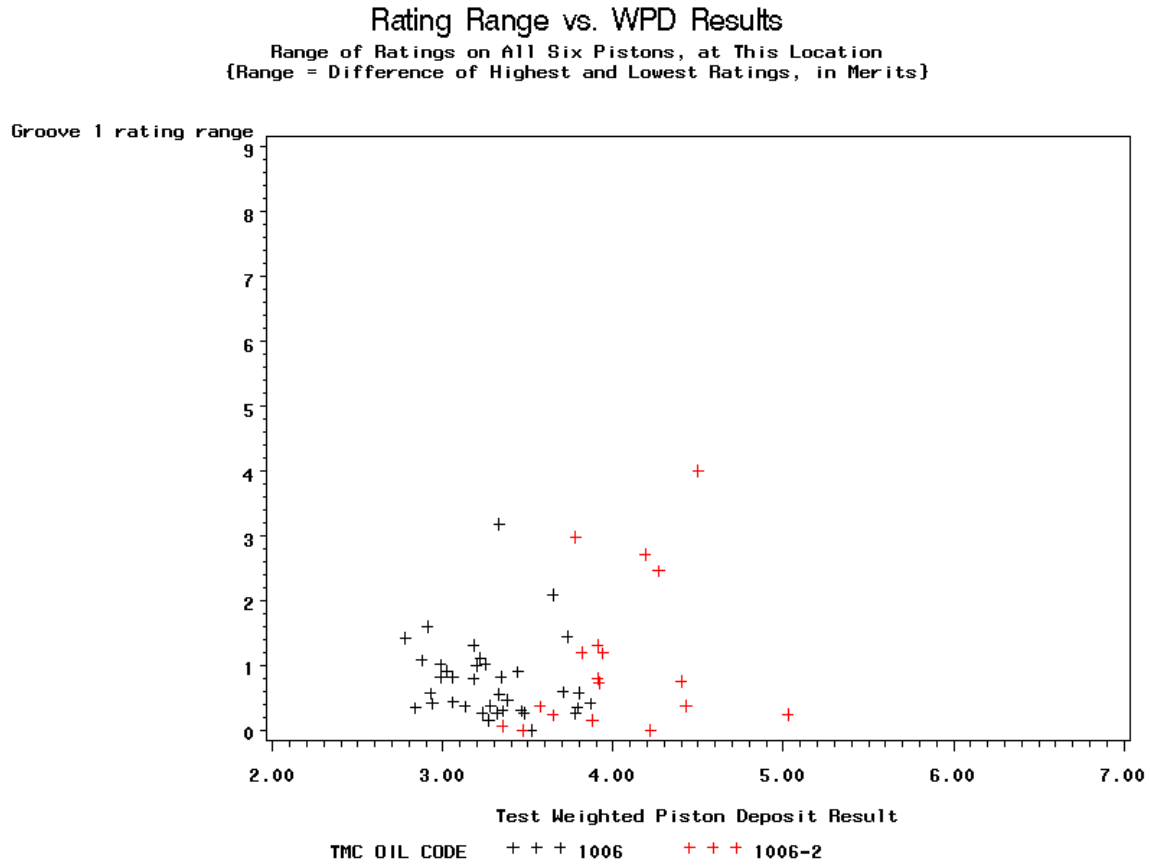


Figure 4: Groove 1 Individual Test Rating Range, Reference Oils 1008 & 1008-1

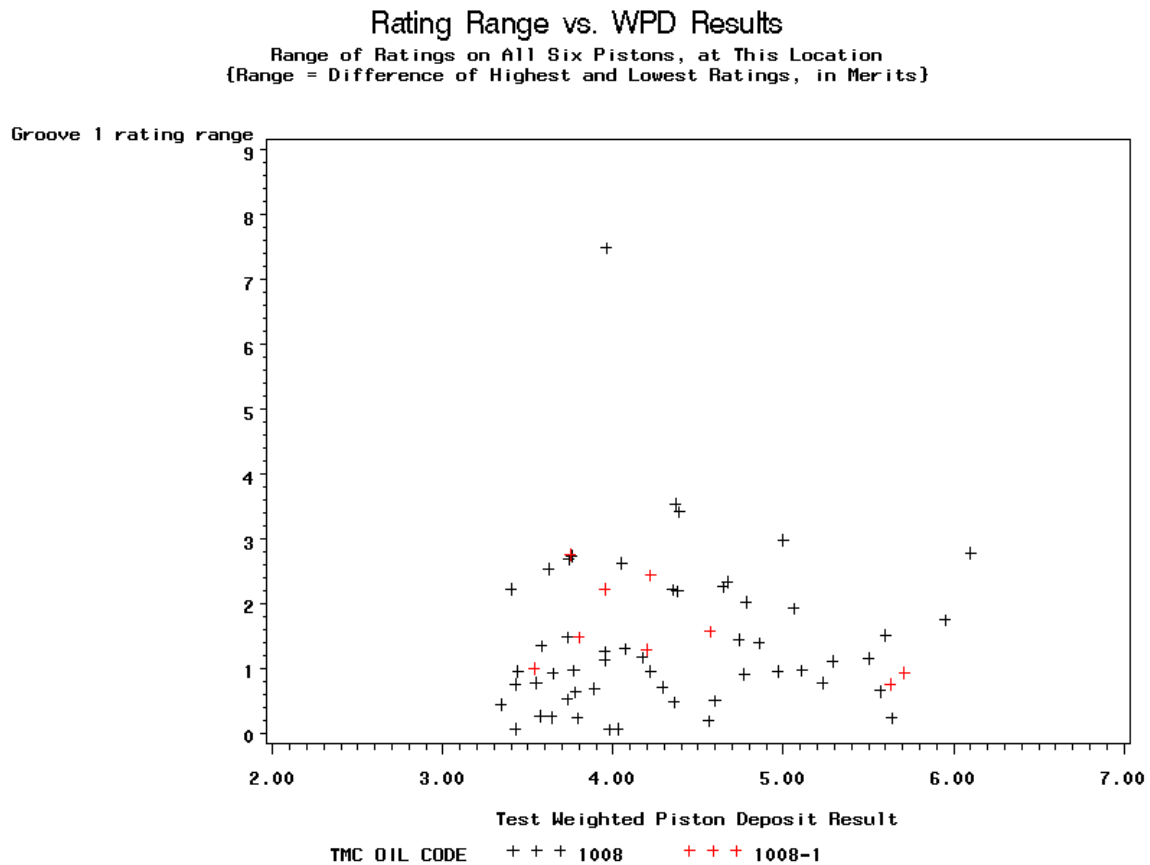


Figure 5: Groove 1 Individual Test Rating Range, Reference Oils 433 & 433-1

Rating Range vs. WPD Results
Range of Ratings on All Six Pistons, at This Location
{Range = Difference of Highest and Lowest Ratings, in Merits}

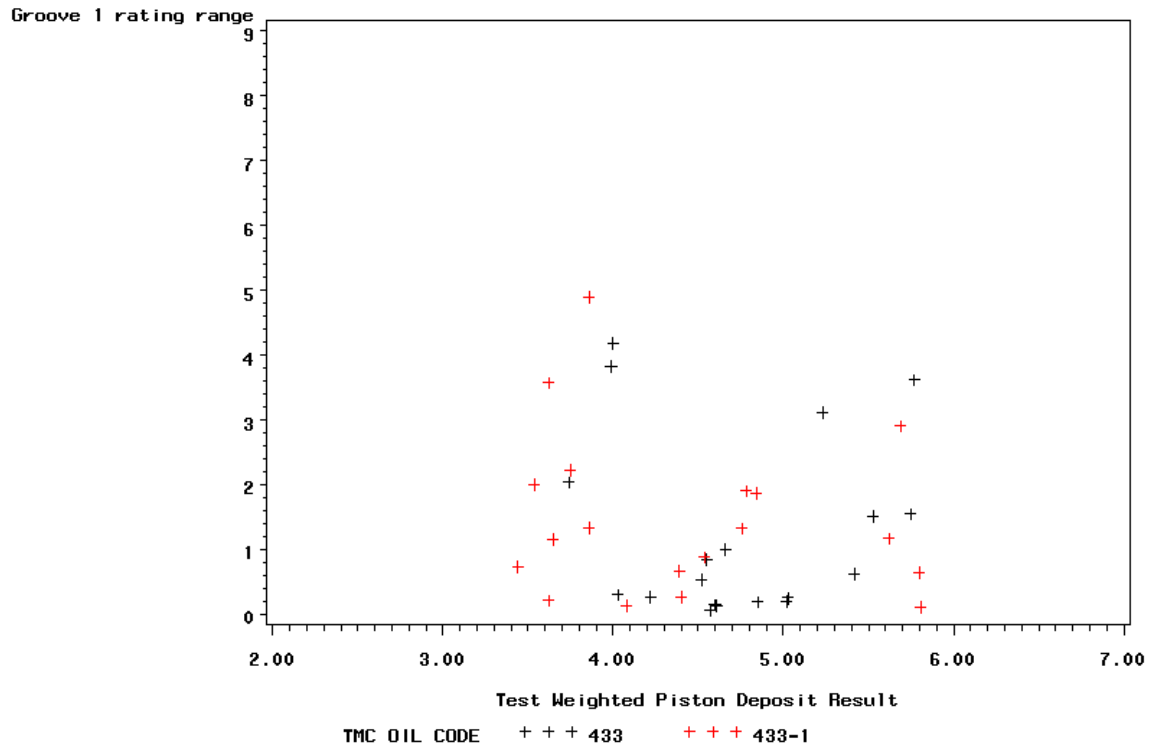


Figure 6: Groove 2 Individual Test Rating Range, Reference Oils 1006 & 1006-2

Rating Range vs. WPD Results
Range of Ratings on All Six Pistons, at This Location
{Range = Difference of Highest and Lowest Ratings, in Merits}

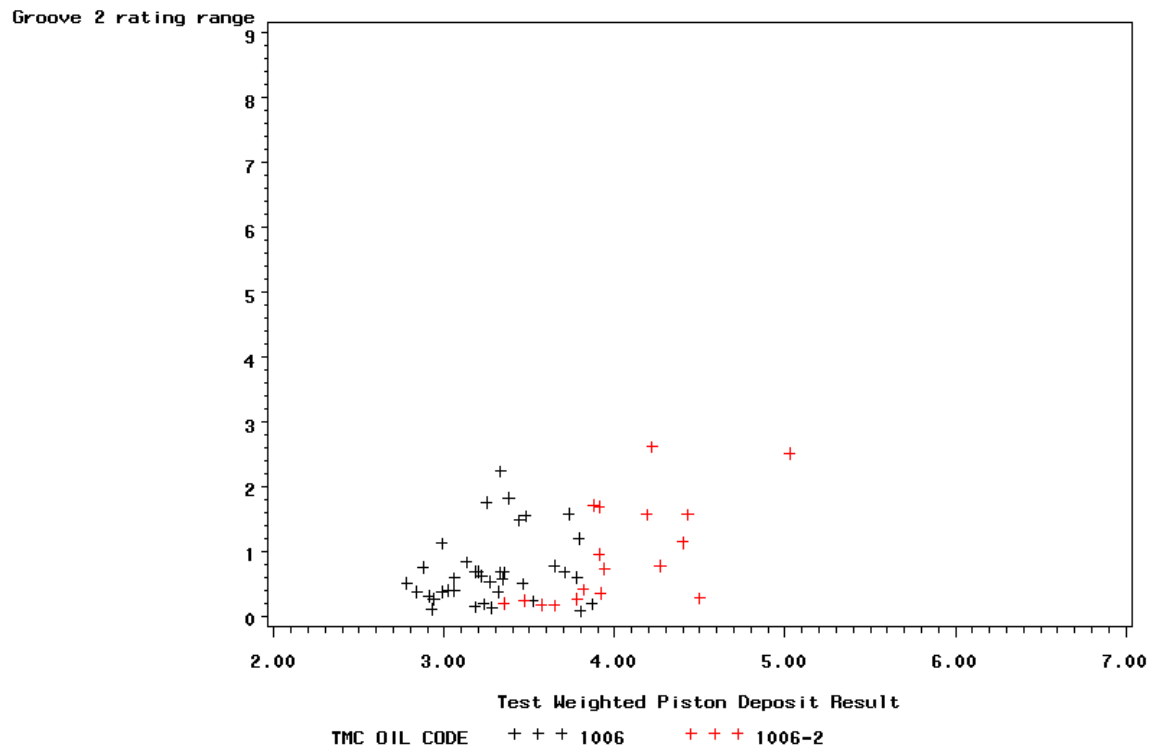


Figure 7: Groove 2 Individual Test Rating Range, Reference Oils 1008 & 1008-1

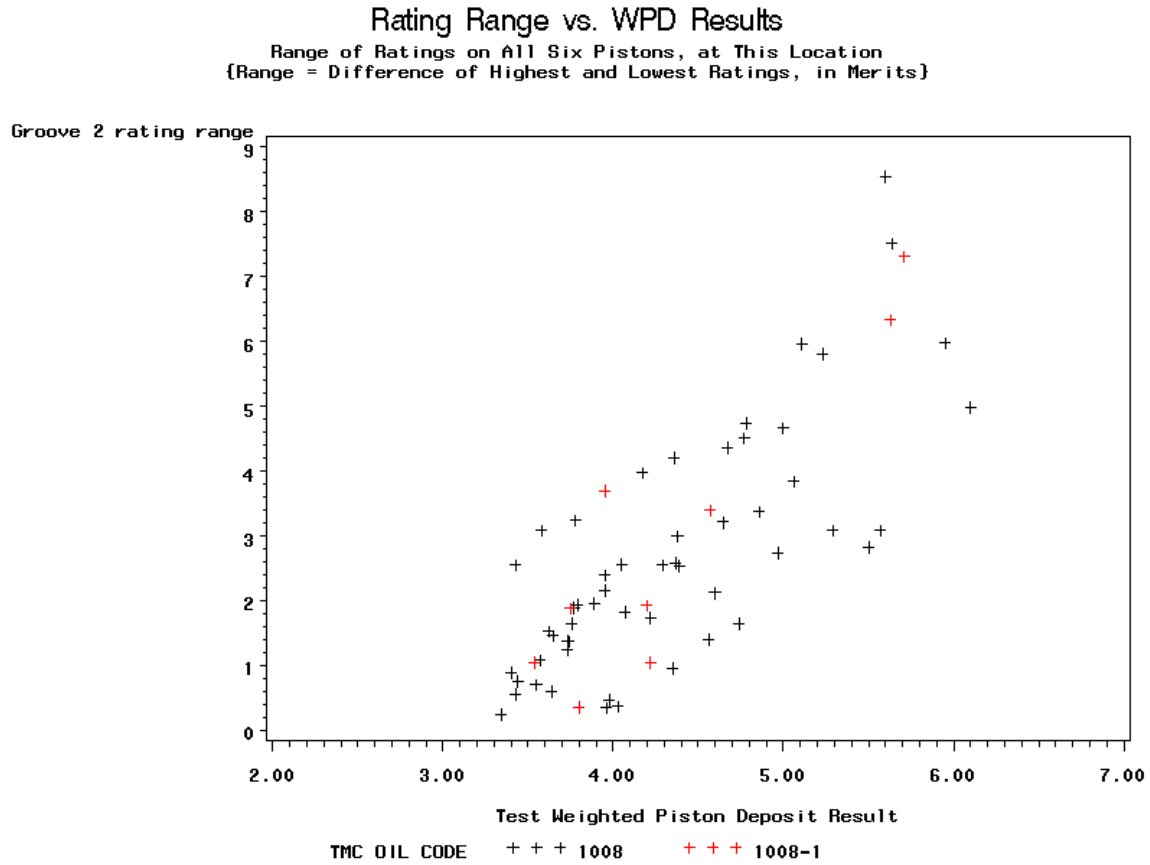


Figure 8: Groove 2 Individual Test Rating Range, Reference Oils 433 & 433-1

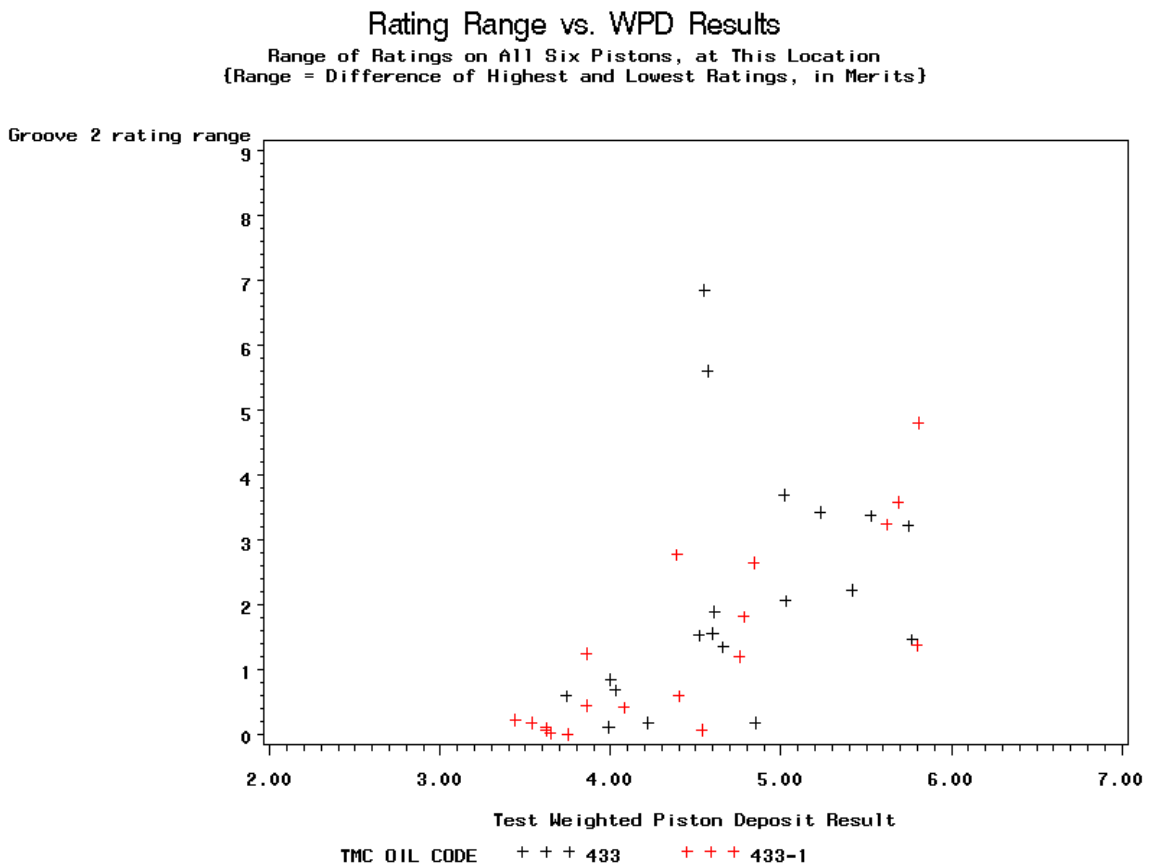


Figure 9: Groove 3 Individual Test Rating Range, Reference Oils 1006 & 1006-2

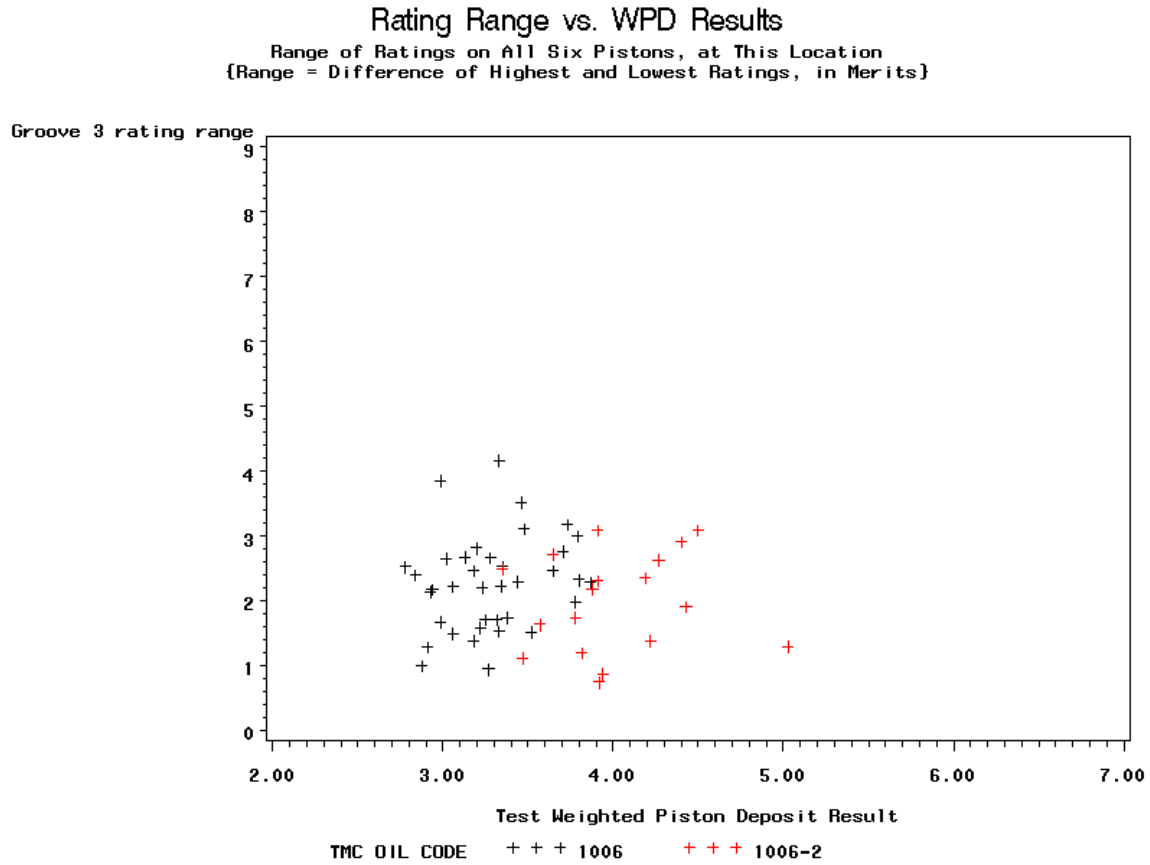


Figure 10: Groove 3 Individual Test Rating Range, Reference Oils 1008 & 1008-1

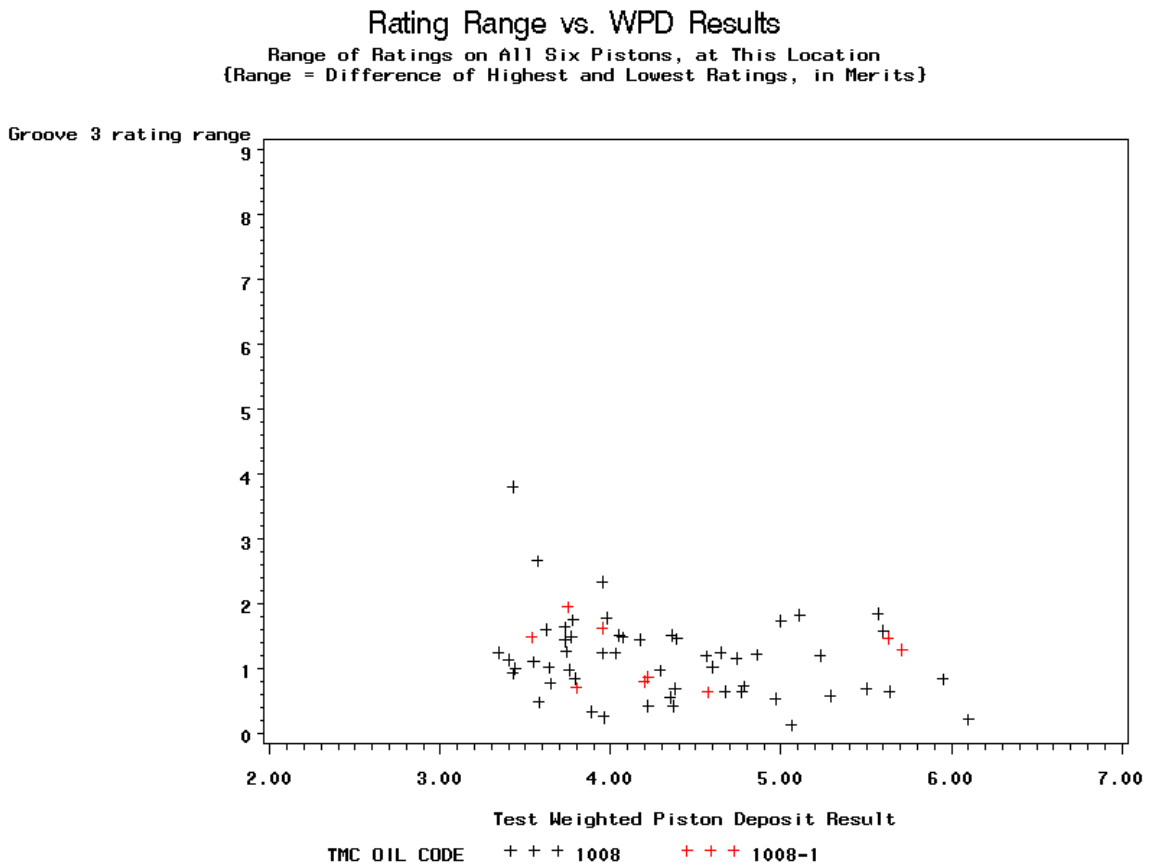


Figure 11: Groove 3 Individual Test Rating Range, Reference Oils 433 & 433-1

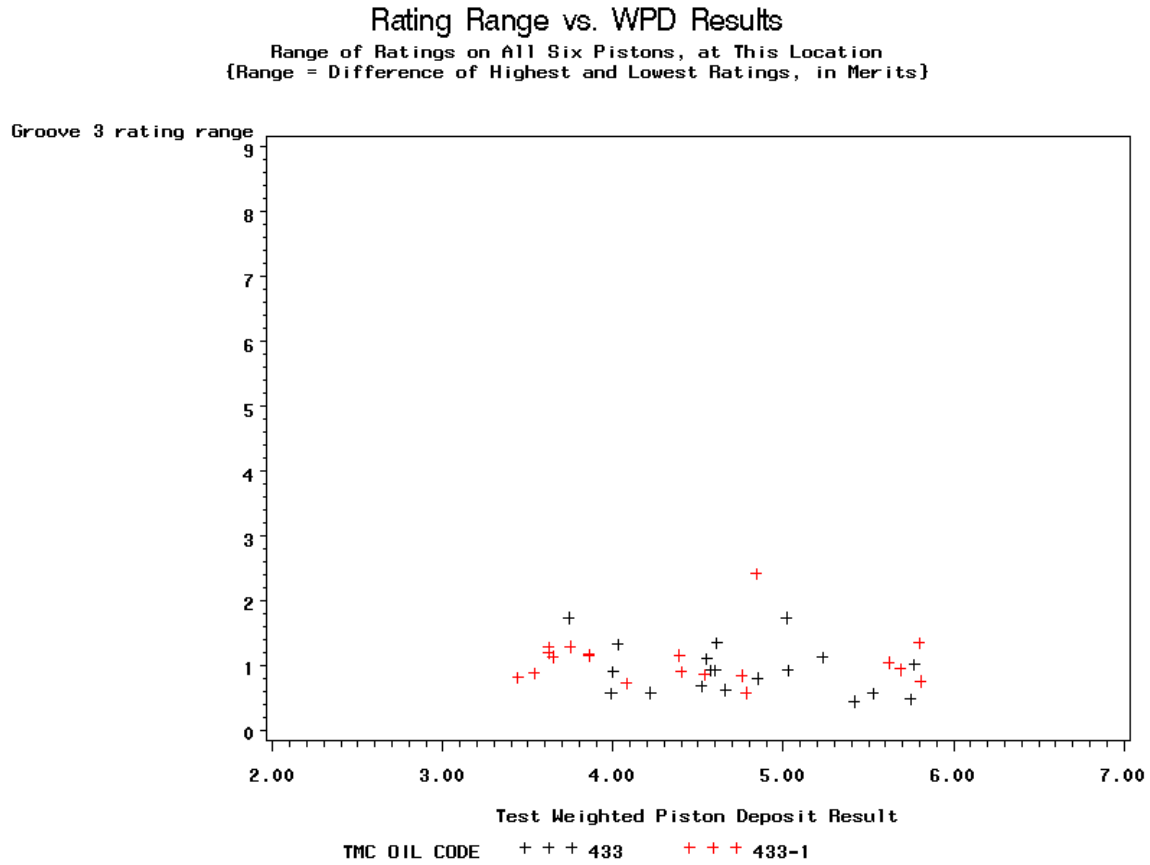


Figure 12: Land 2 Individual Test Rating Range, Reference Oils 1006 & 1006-2

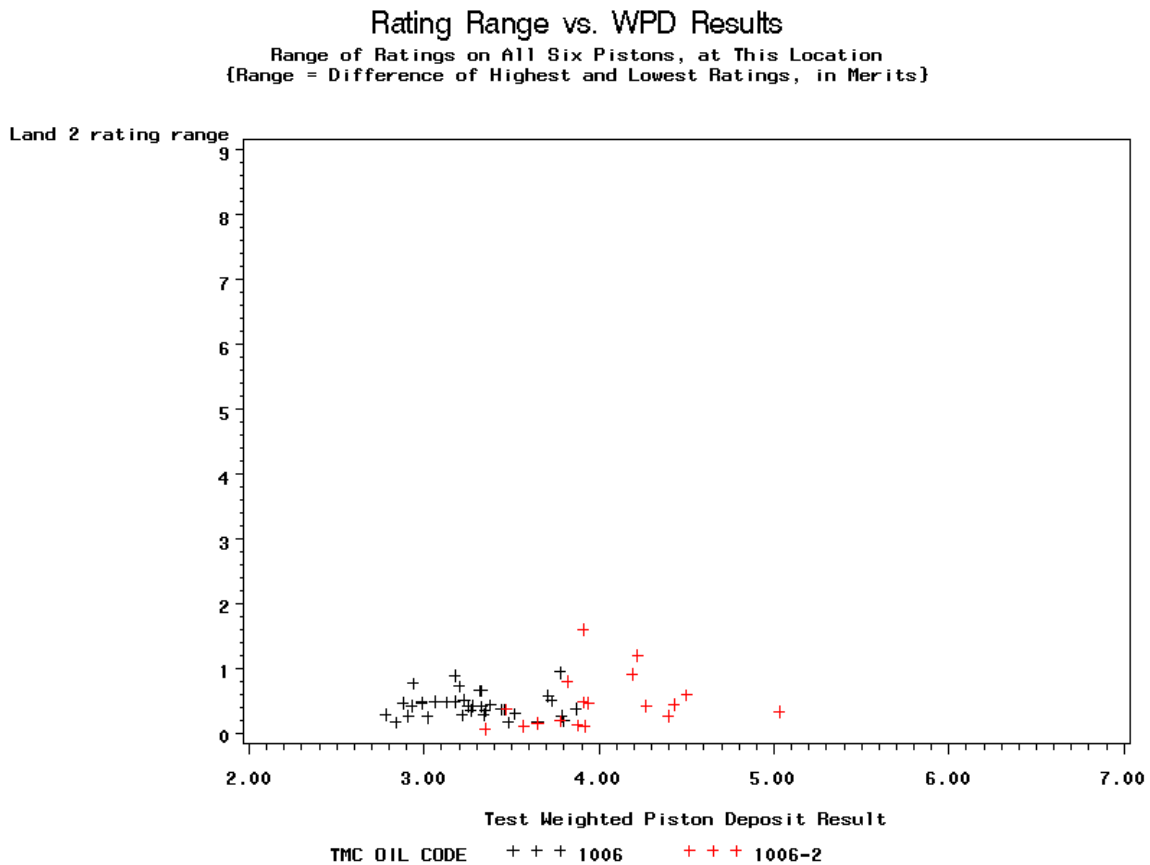


Figure 13: Land 2 Individual Test Rating Range, Reference Oils 1008 & 1008-1

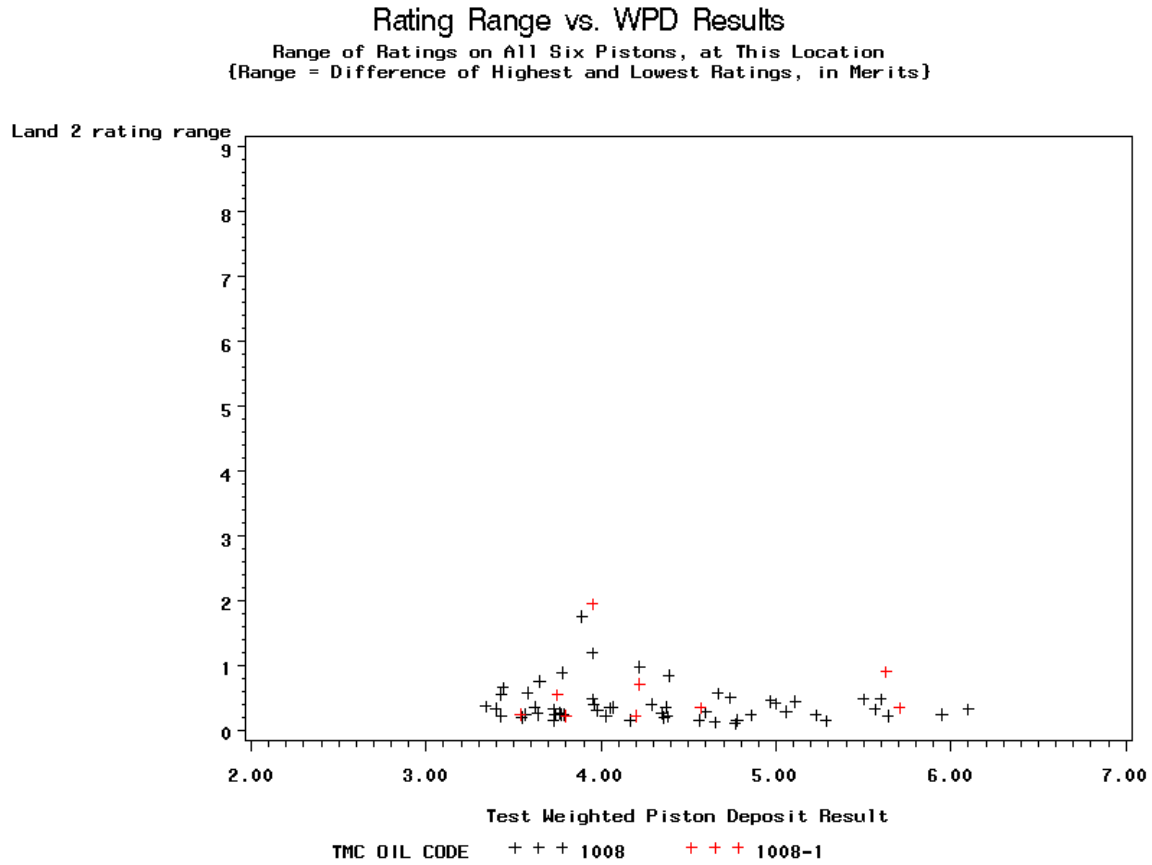


Figure 14: Land 2 Individual Test Rating Range, Reference Oils 433 & 433-1

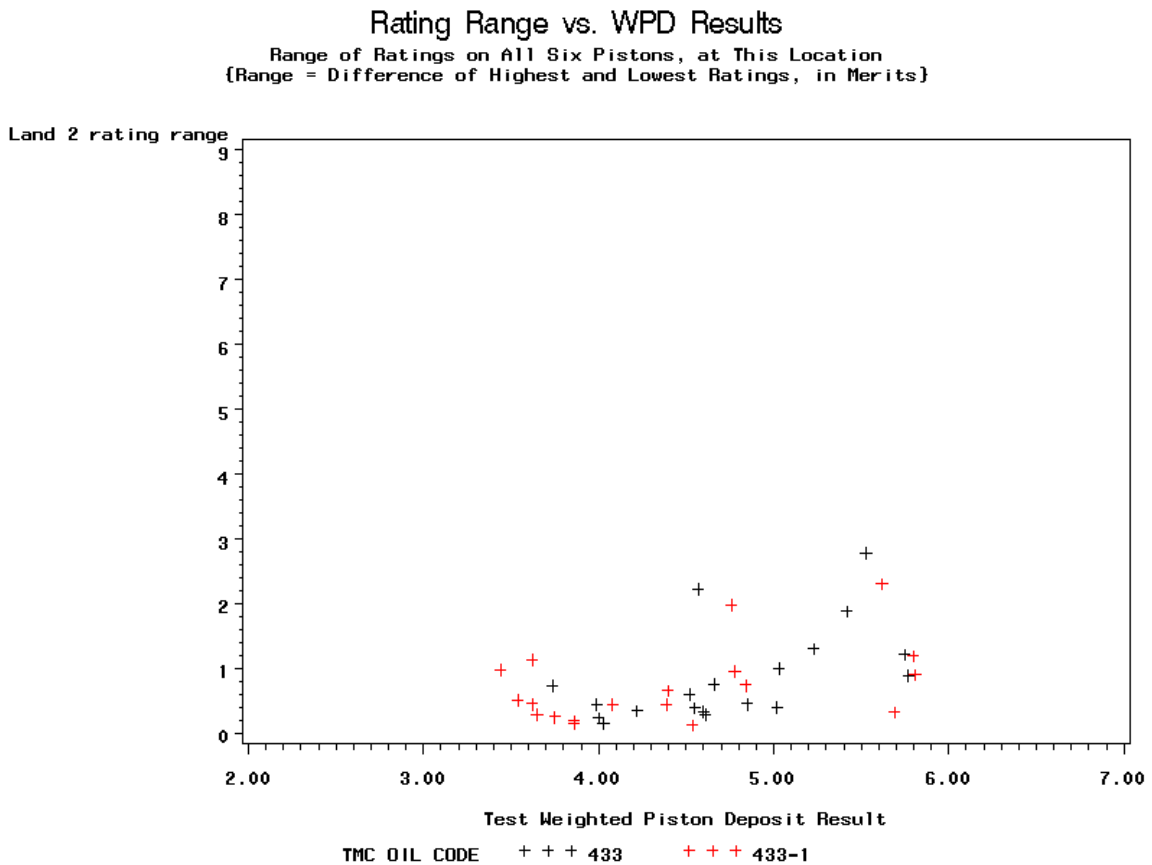


Figure 15: Oil Ring Land Individual Test Rating Range, Reference Oils 1006 & 1006-2

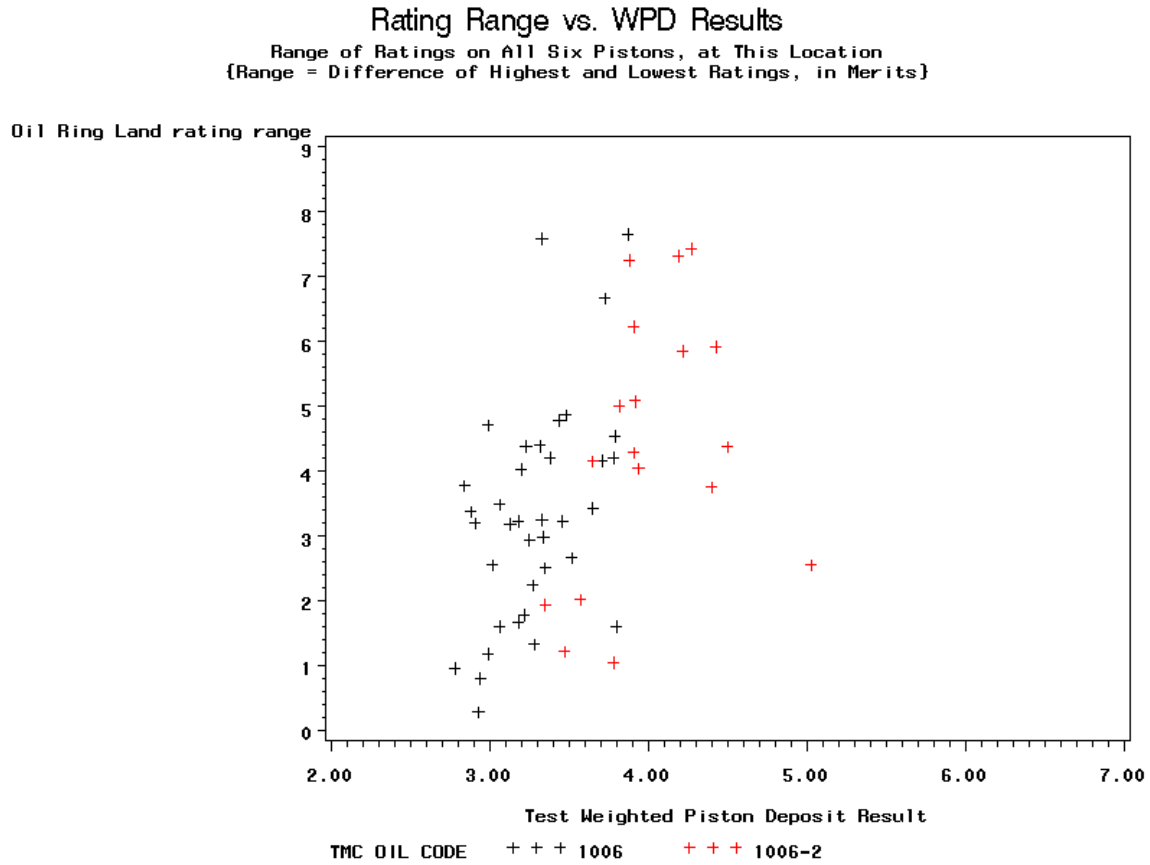


Figure 16: Oil Ring Land Individual Test Rating Range, Reference Oils 1008 & 1008-1

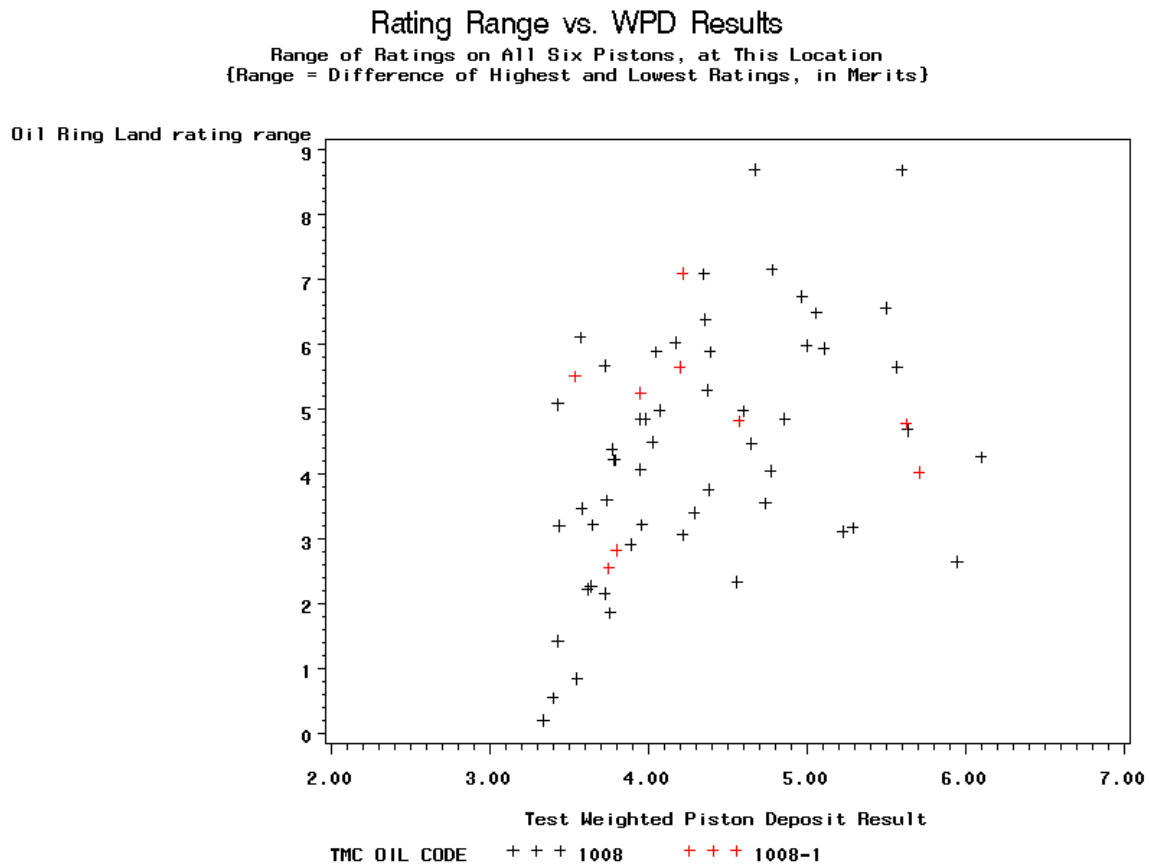


Figure 17: Oil Ring Land Individual Test Rating Range, Reference Oils 433 & 433-1

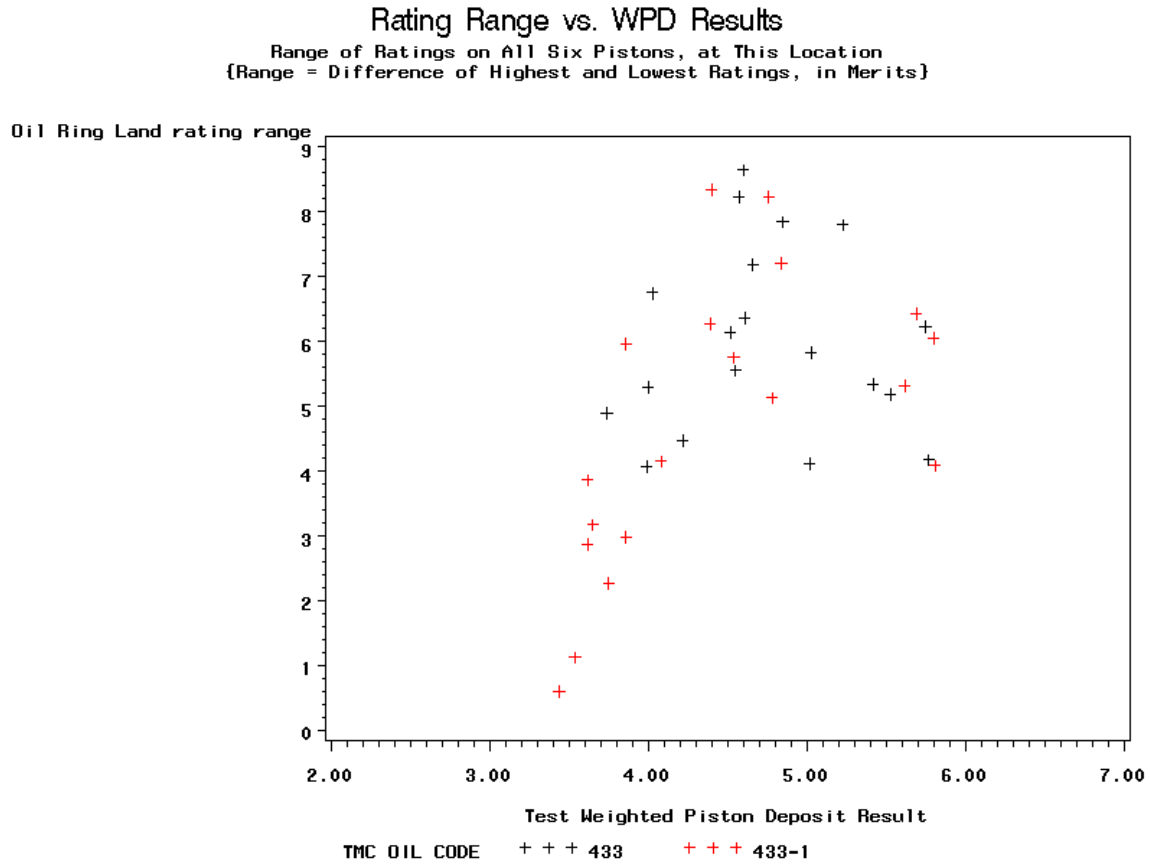


Figure 18: Piston Skirt Individual Test Rating Range, Reference Oils 1006 & 1006-2

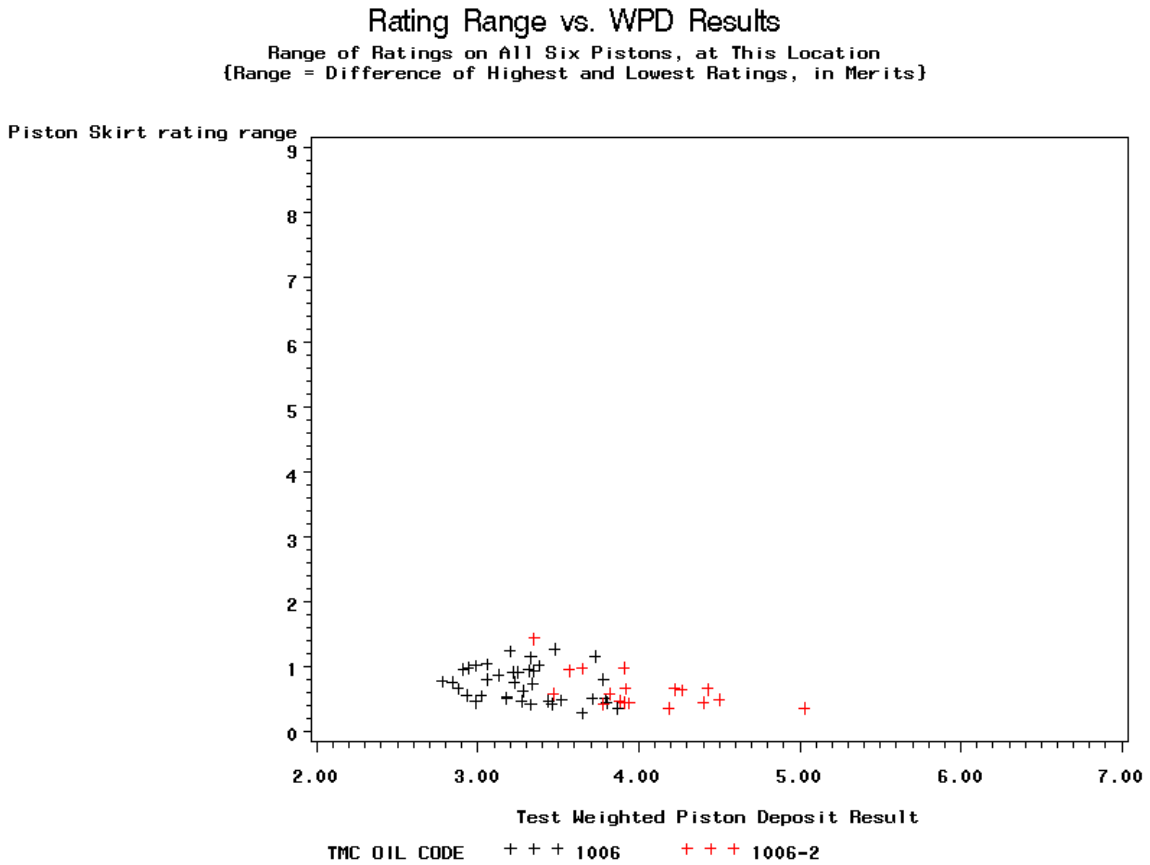


Figure 19: Piston Skirt Individual Test Rating Range, Reference Oils 1008 & 1008-1

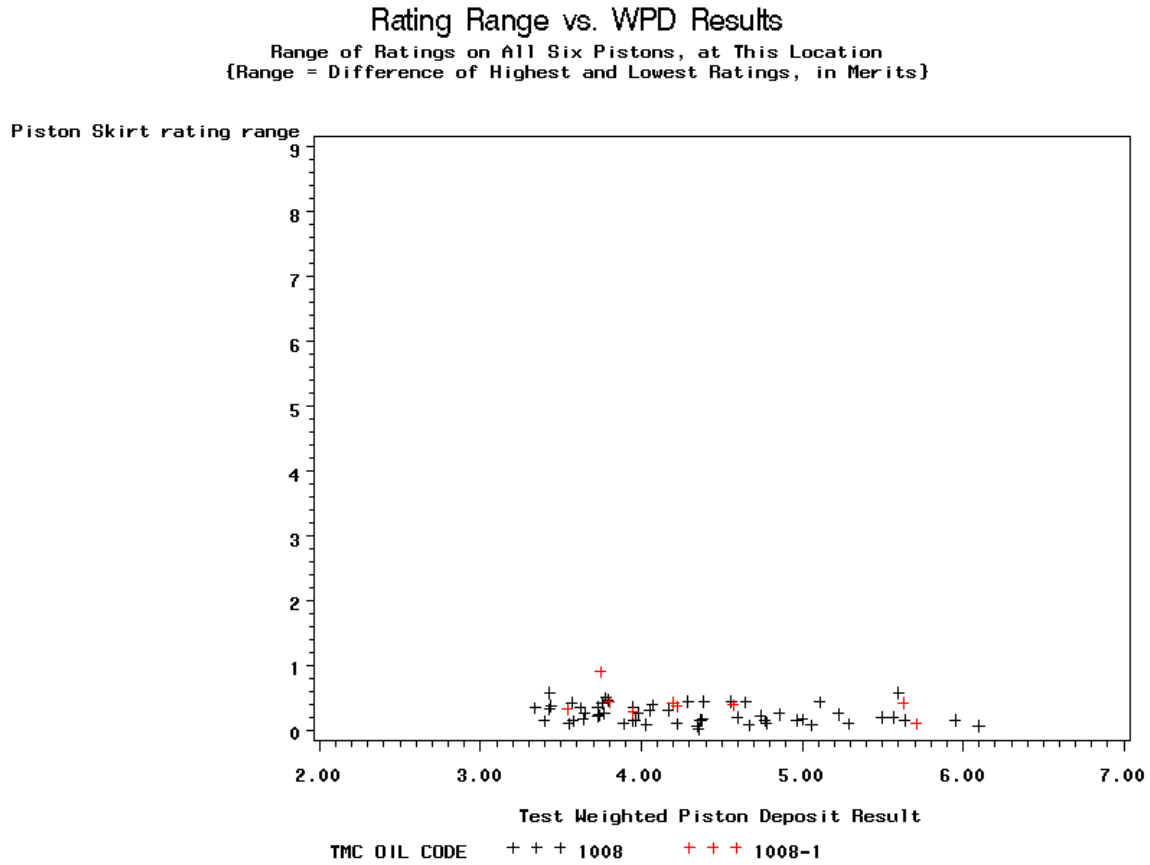


Figure 20: Piston Skirt Individual Test Rating Range, Reference Oils 433 & 433-1

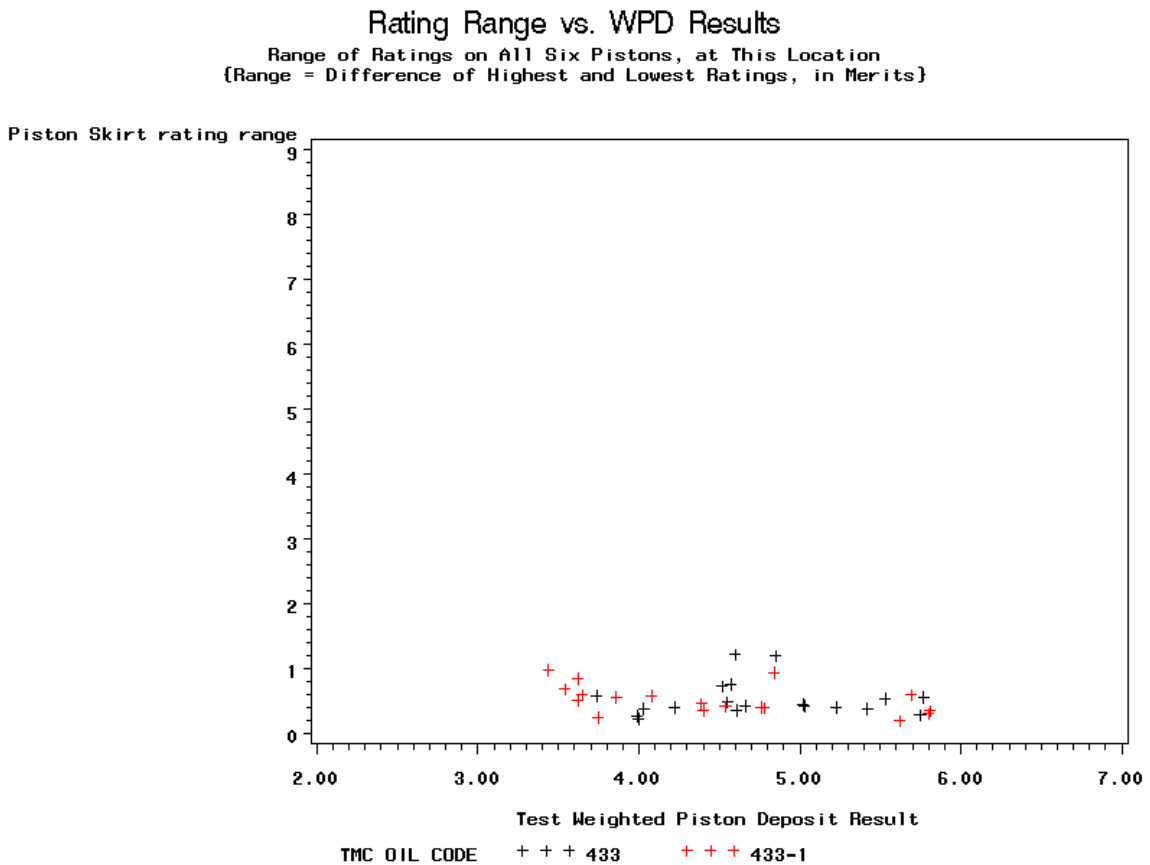


Figure 21: Under Crown Individual Test Rating Range, Reference Oils 1006 & 1006-2

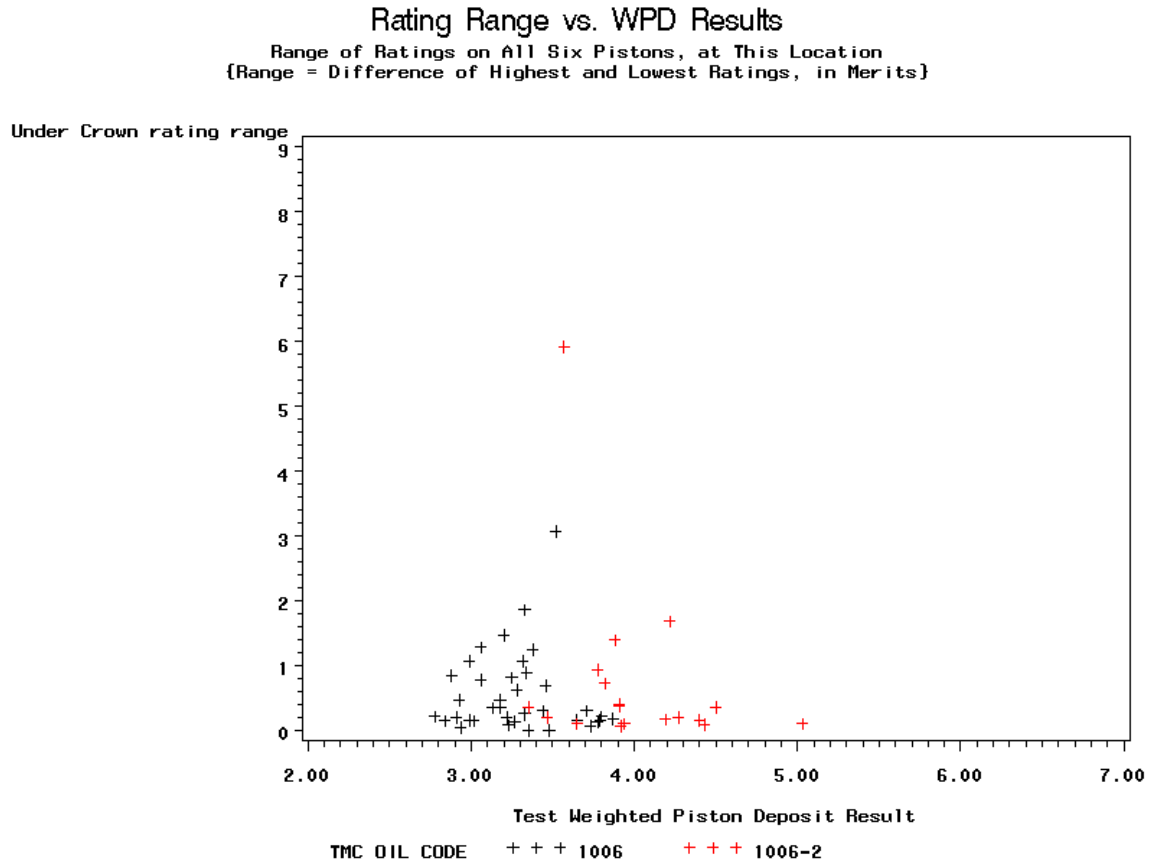


Figure 22: Under Crown Individual Test Rating Range, Reference Oils 1008 & 1008-1

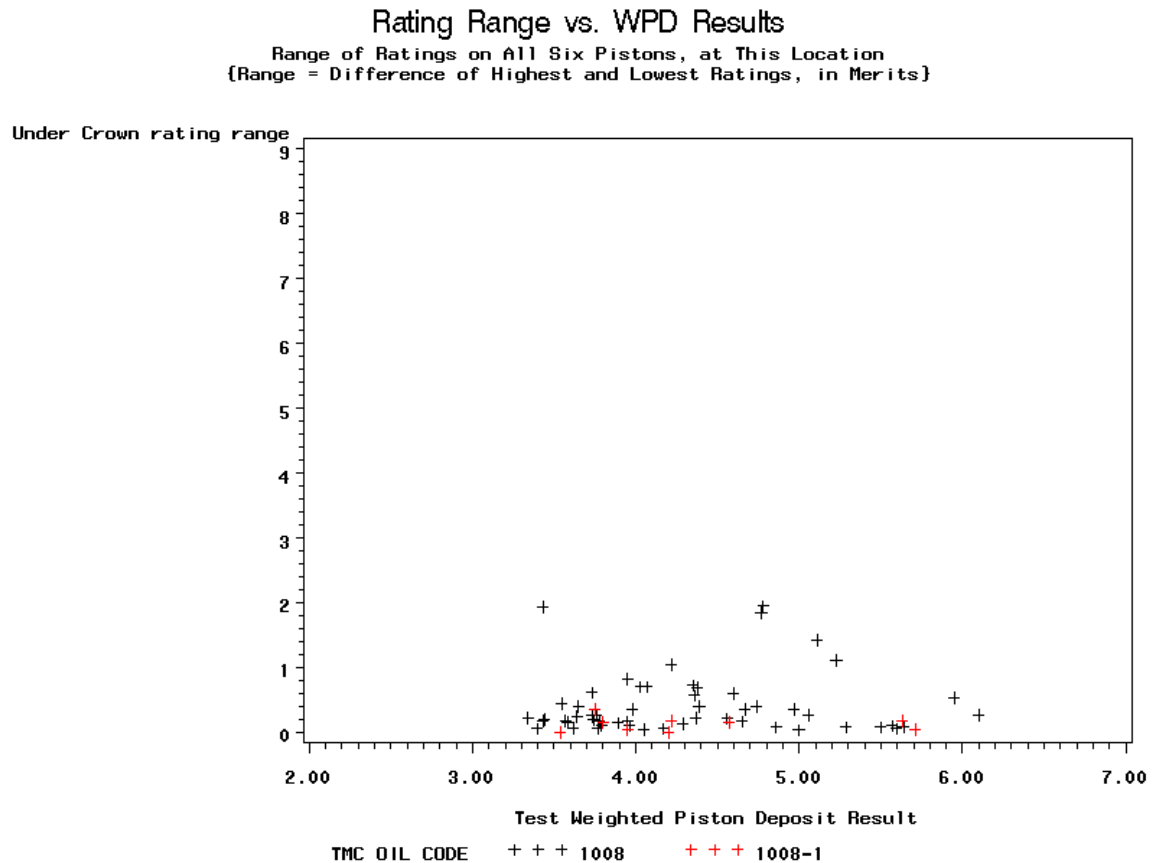


Figure 23: Under Crown Individual Test Rating Range, Reference Oils 433 & 433-1

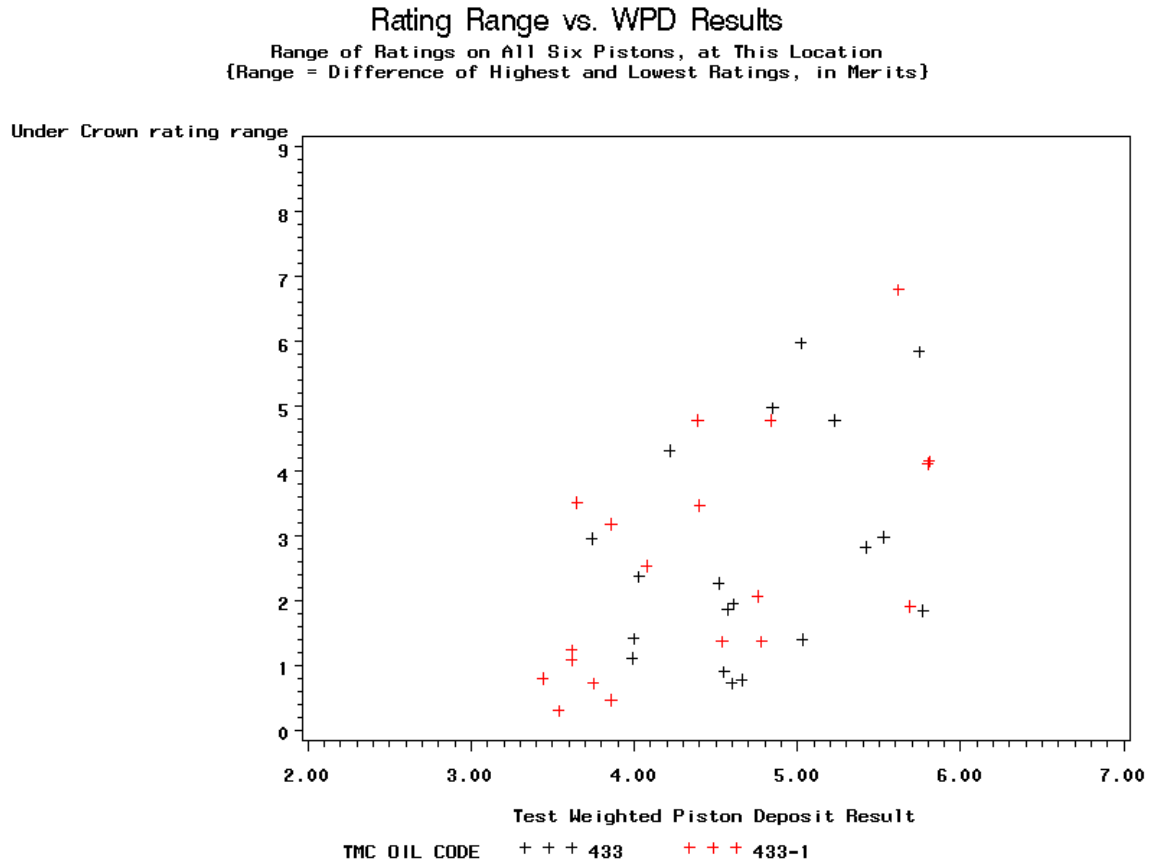


Figure 24: Groove 1 Ratings for all Positions, Reference Oils 1006 & 1006-2

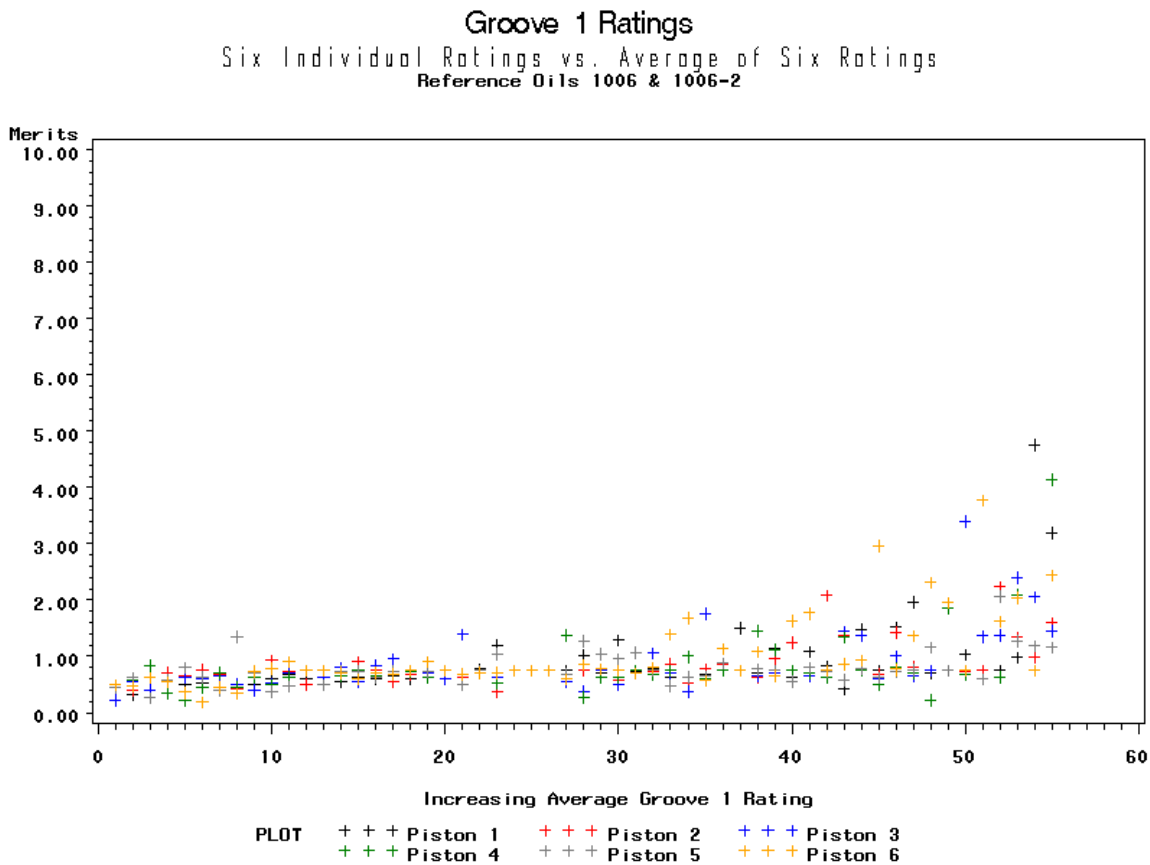


Figure 25: Groove 1 Ratings for all Positions, Reference Oils 1008 & 1008-1

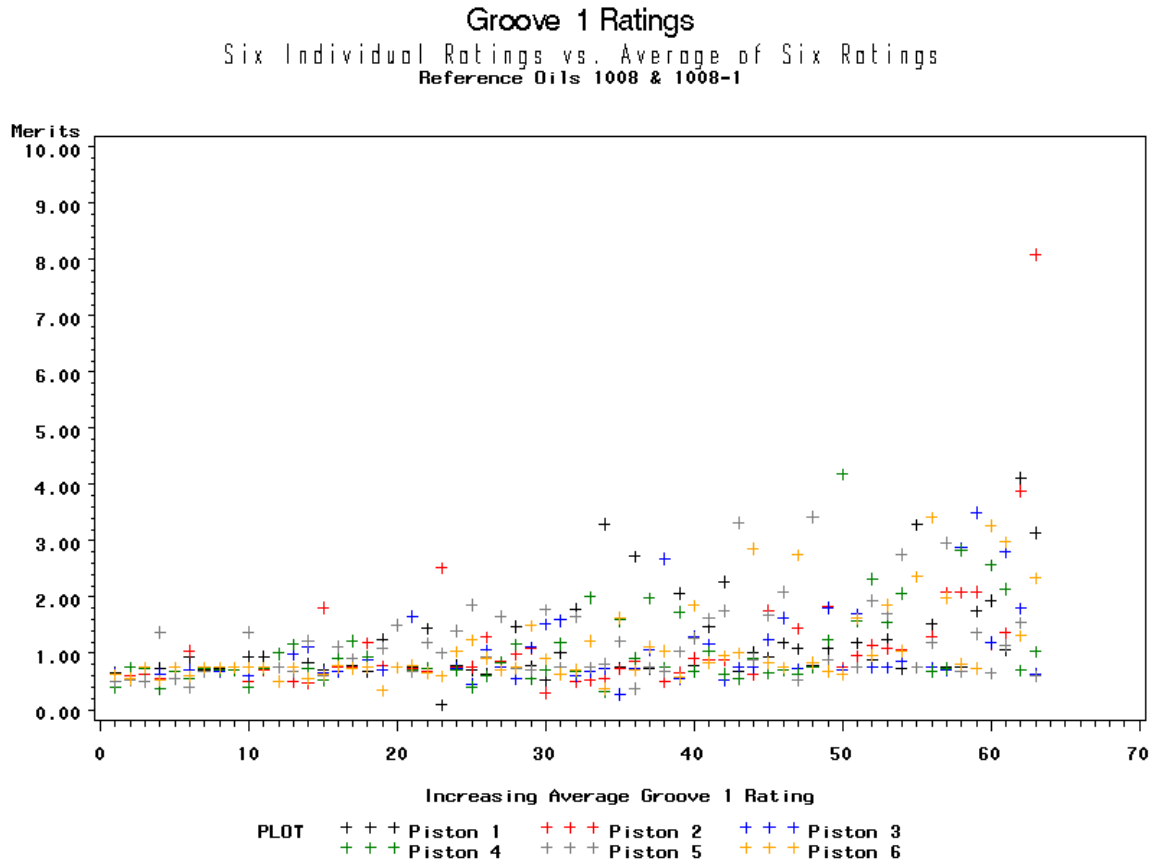


Figure 26: Groove 1 Ratings for all Positions, Reference Oils 433 & 433-1

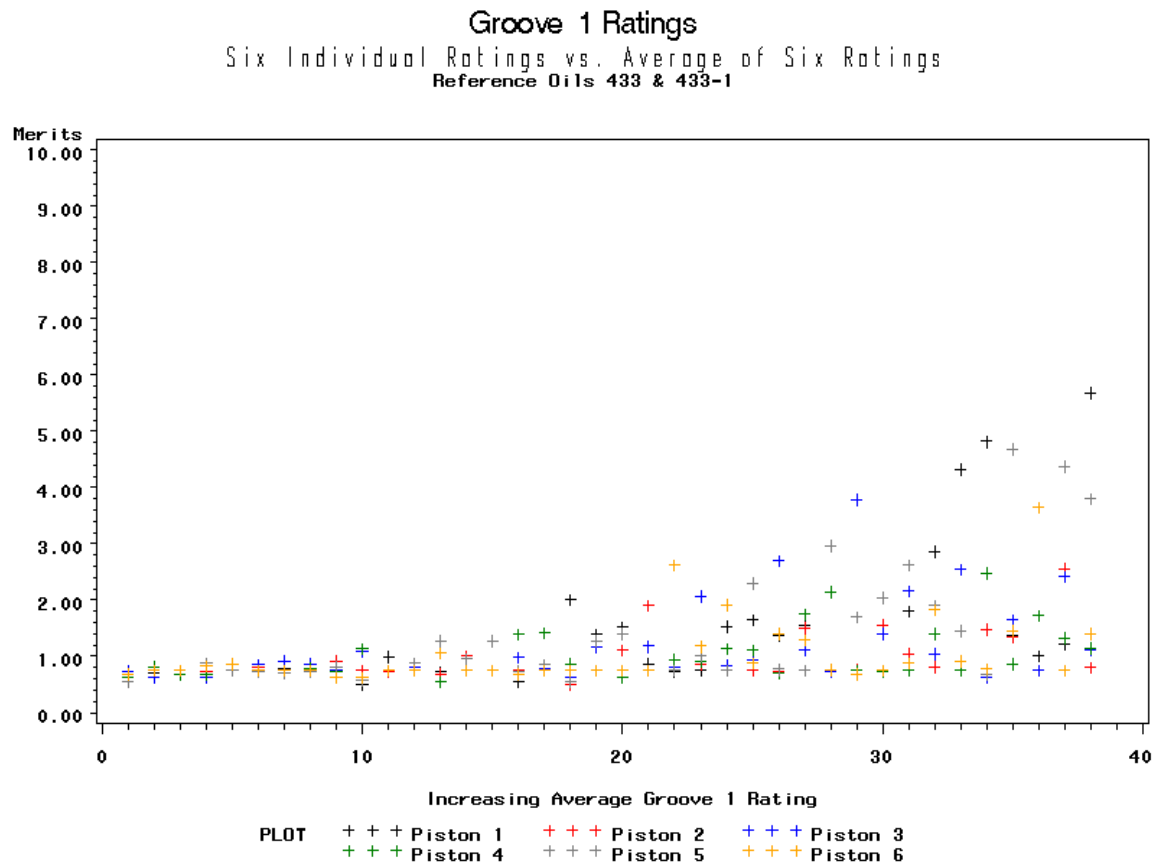


Figure 27: Groove 2 Ratings for all Positions, Reference Oils 1006 & 1006-2

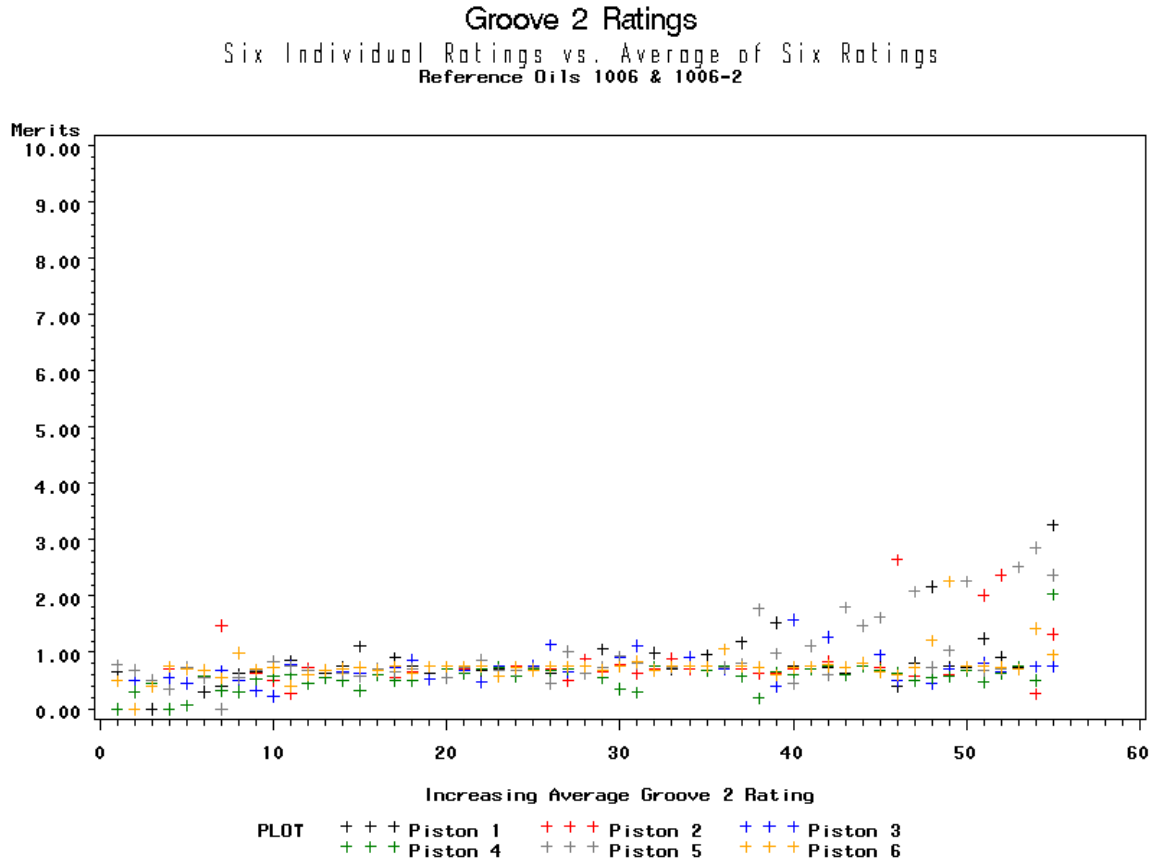


Figure 28: Groove 2 Ratings for all Positions, Reference Oils 1008 & 1008-1

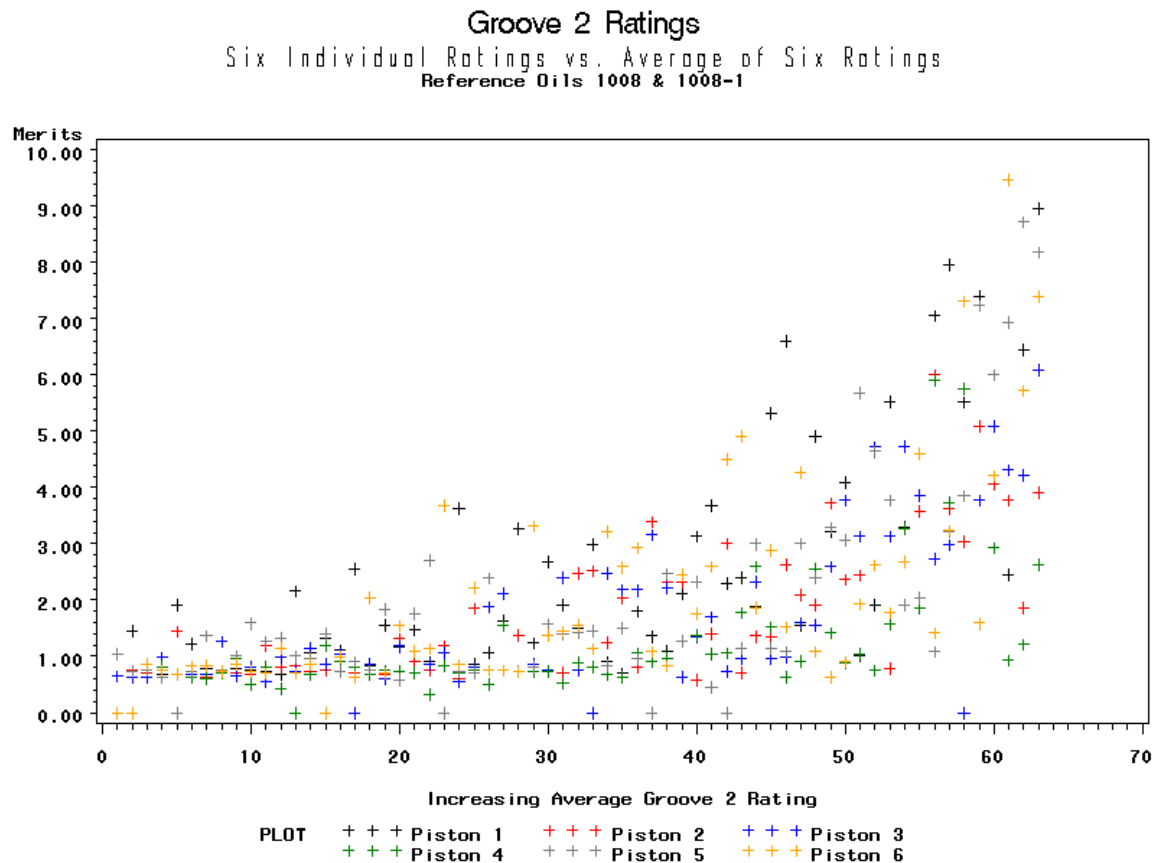


Figure 29: Groove 2 Ratings for all Positions, Reference Oils 433 & 433-1

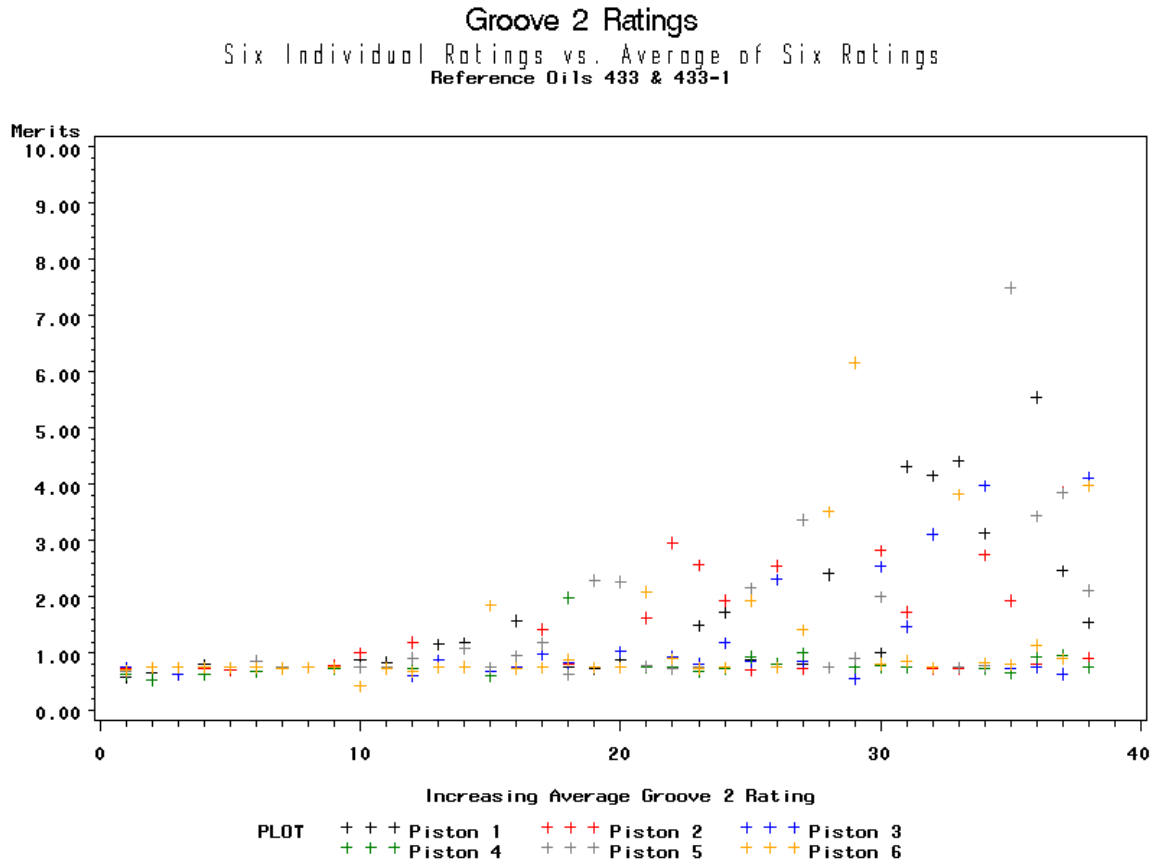


Figure 30: Groove 3 Ratings for all Positions. Reference Oils 1006 & 1006-2

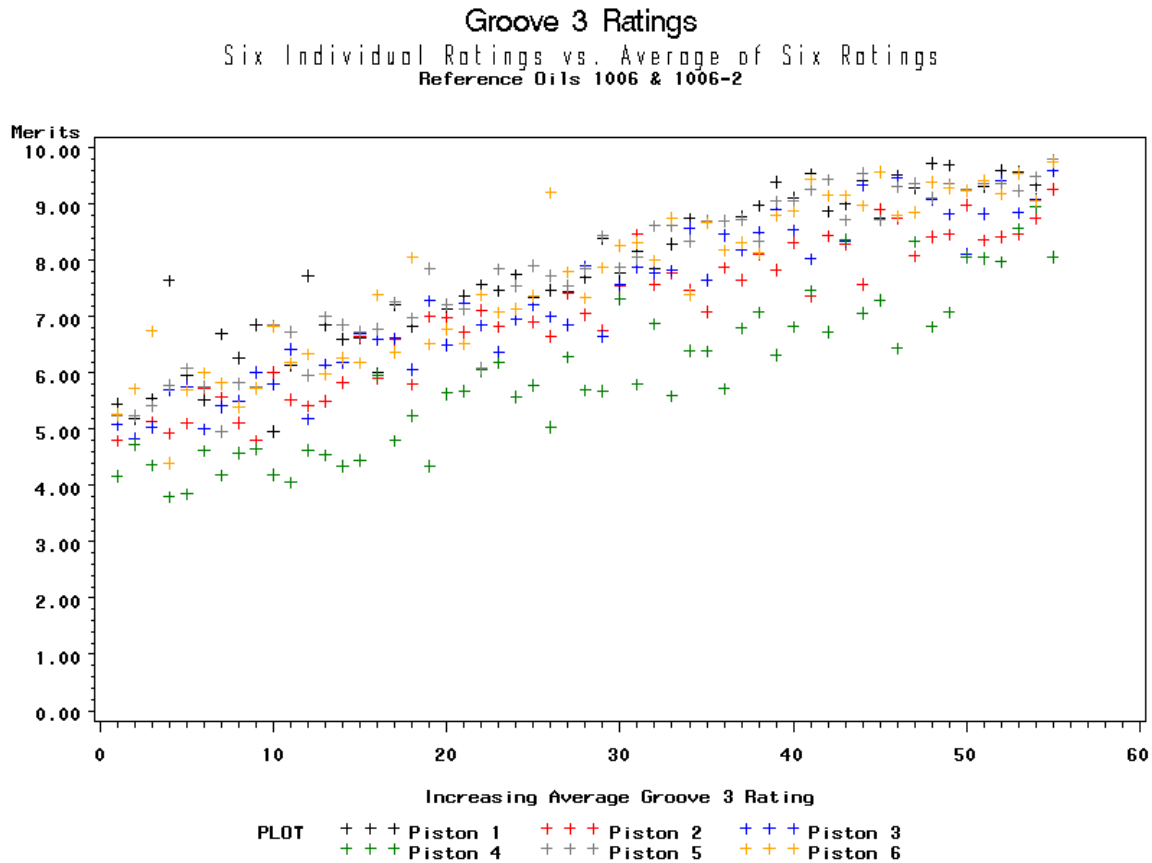


Figure 31: Groove 3 Ratings for all Positions, Reference Oils 1008 & 1008-1

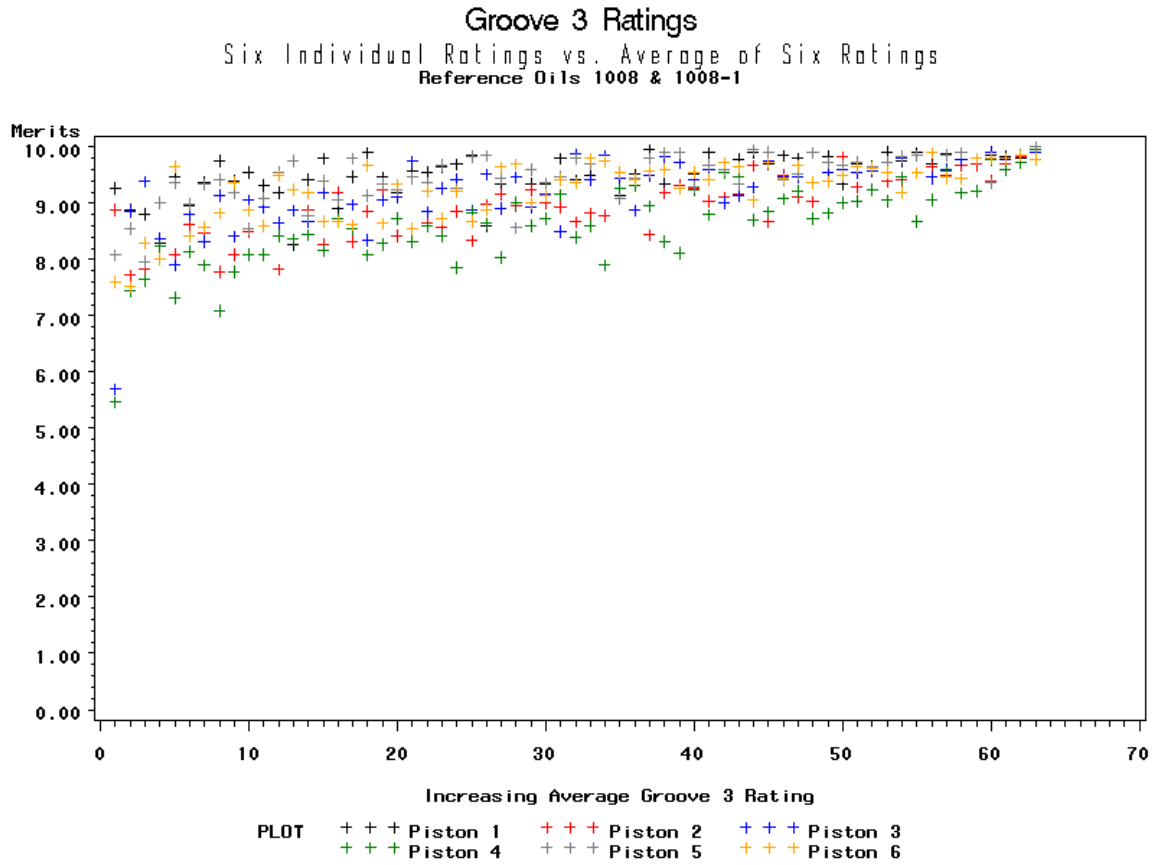


Figure 32: Groove 3 Ratings for all Positions, Reference Oils 433 & 433-1

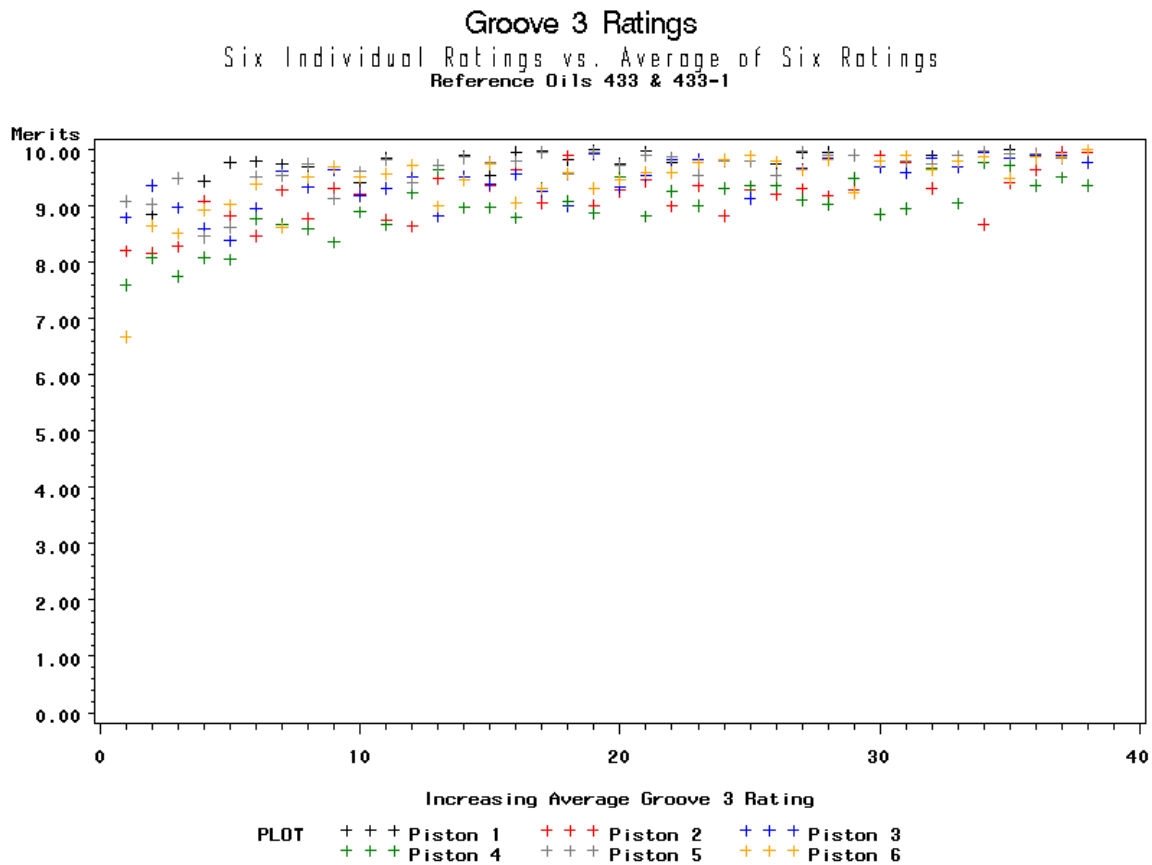


Figure 33: Land 2 Ratings for all Positions, Reference Oils 1006 & 1006-2

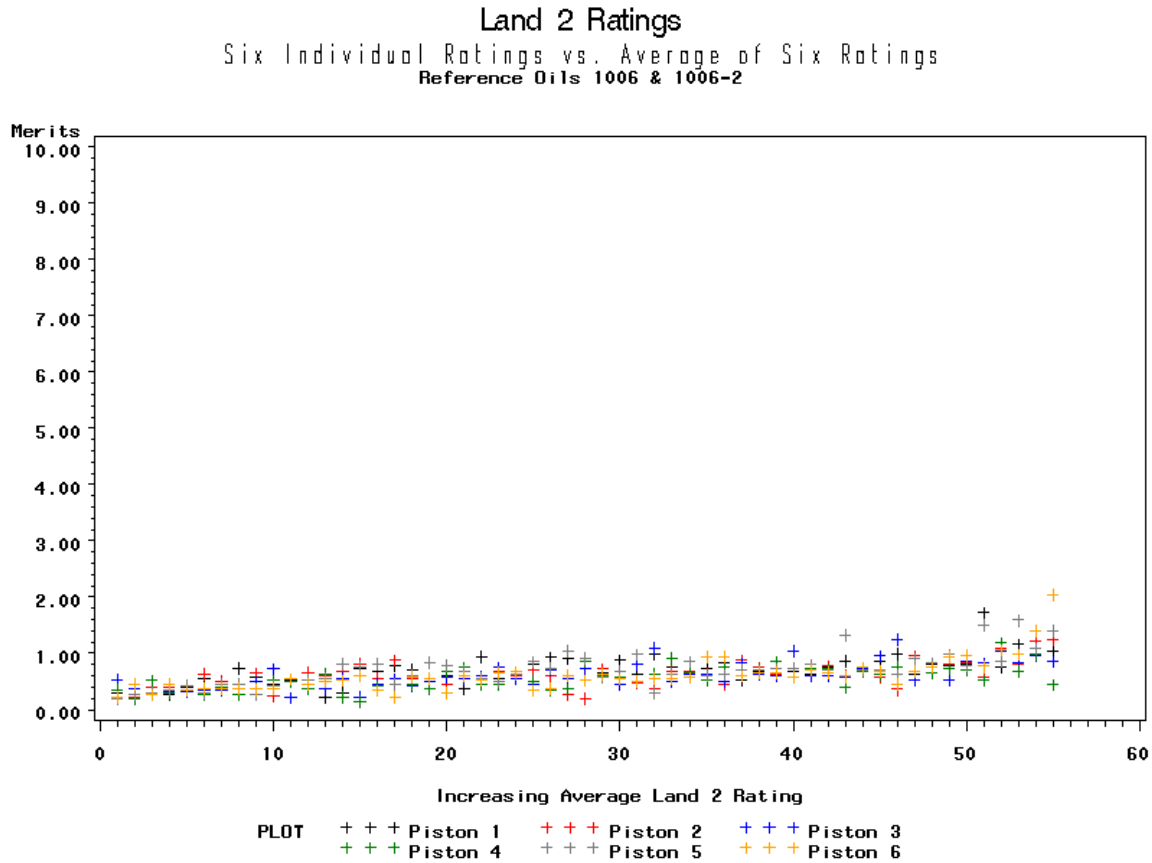


Figure 34: Land 2 Ratings for all Positions. Reference Oils 1008 & 1008-1

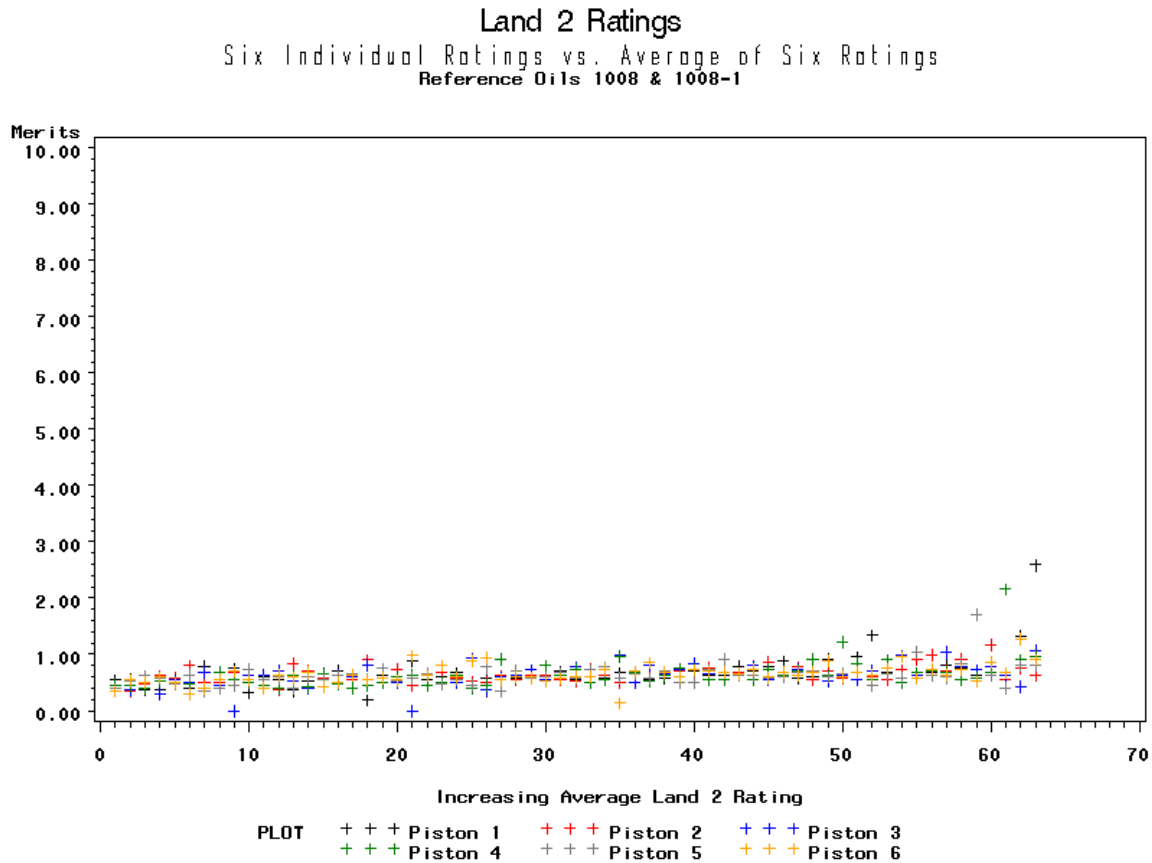


Figure 35: Land 2 Ratings for all Positions, Reference Oils 433 & 433-1

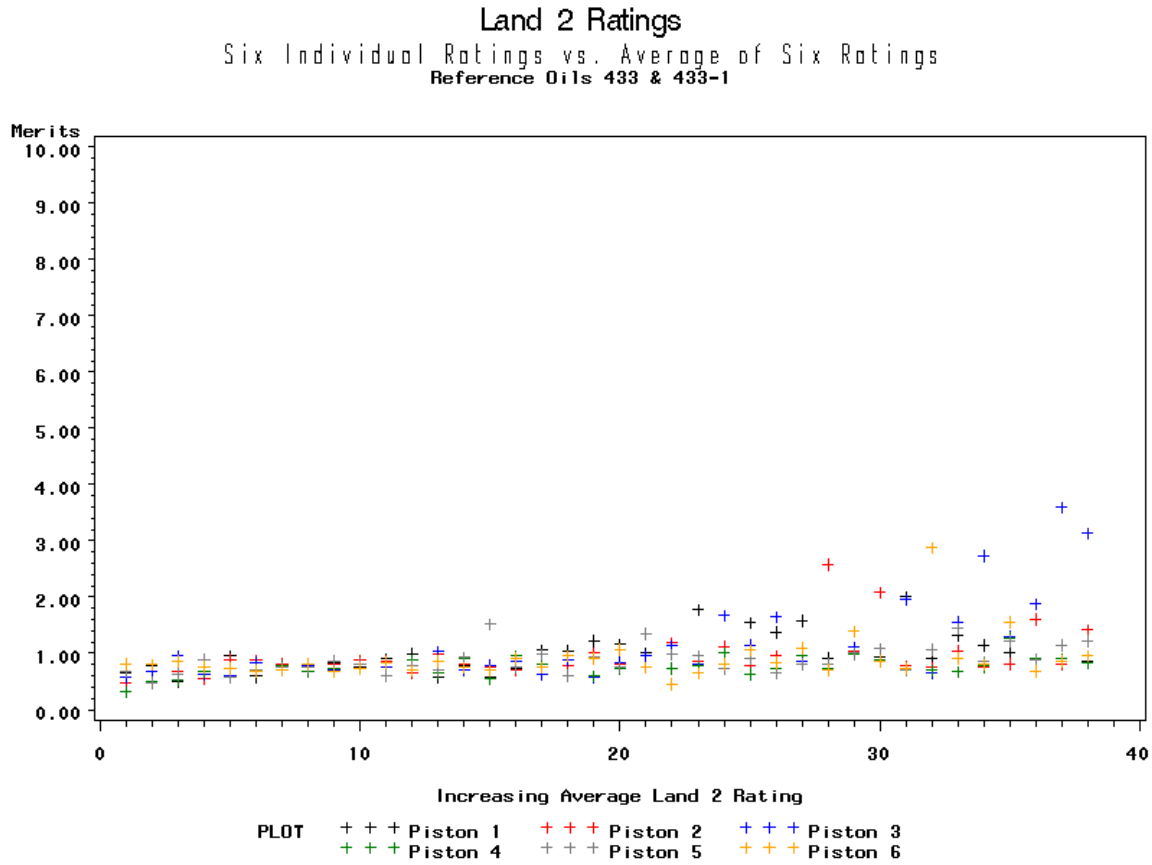


Figure 36: Oil Ring Land Ratings for all Positions, Reference Oils 1006 & 1006-2

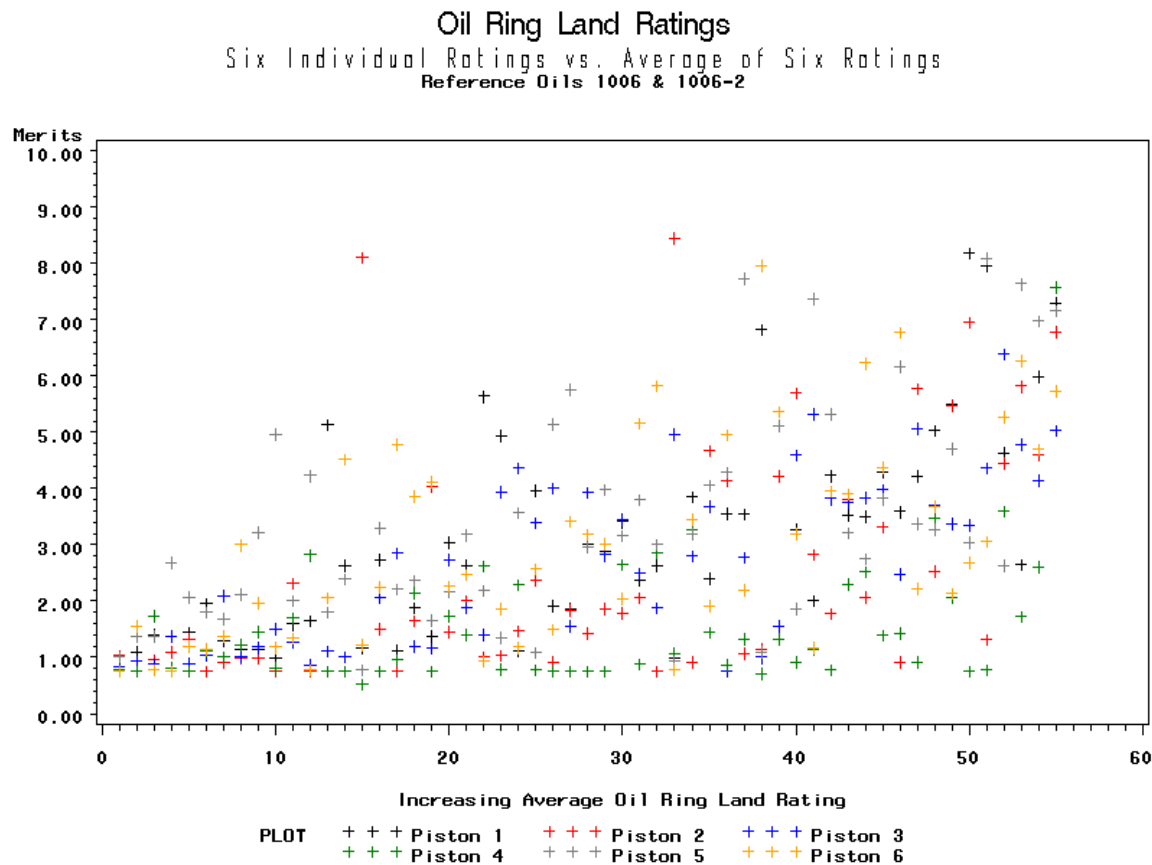


Figure 37: Oil Ring Land Ratings for all Positions, Reference Oils 1008 & 1008-1

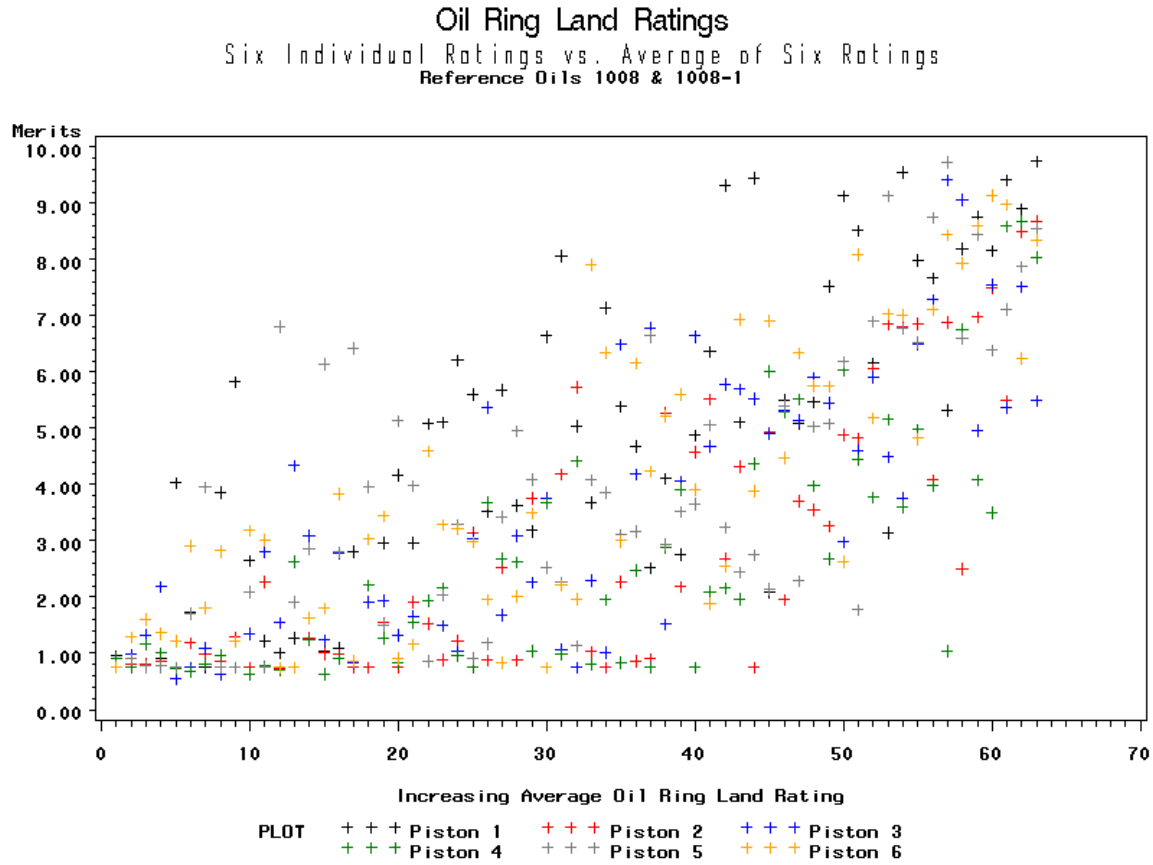


Figure 38: Oil Ring Land Ratings for all Positions, Reference Oils 433 & 433-1

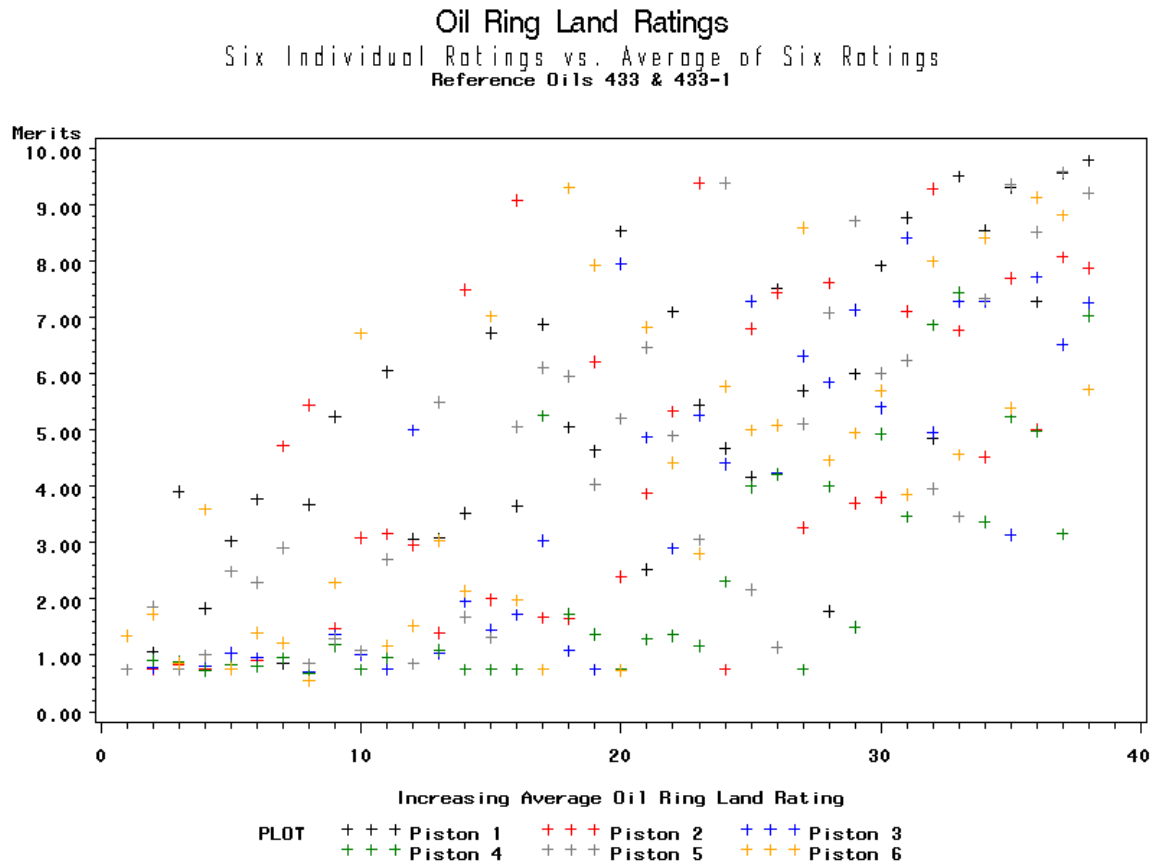


Figure 39: Piston Skirt Average Ratings for all Positions, Reference Oils 1006 & 1006-2

Average Piston Skirt Ratings (Thrust & Anti-Thrust Average)
Six Individual Piston Averages vs. Average of Six Piston Averages
Reference Oils 1006 & 1006-2

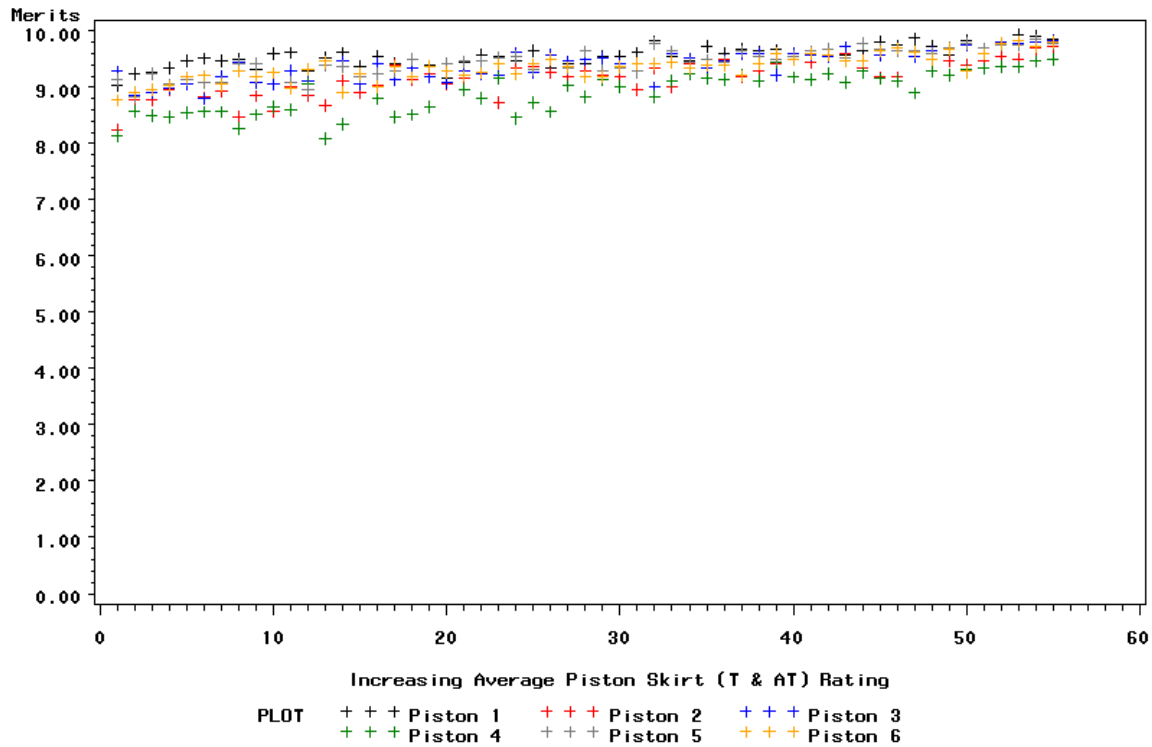


Figure 40: Piston Skirt Average Ratings for all Positions, Reference Oils 1008 & 1008-1

Average Piston Skirt Ratings (Thrust & Anti-Thrust Average)
Six Individual Piston Averages vs. Average of Six Piston Averages
Reference Oils 1008 & 1008-1

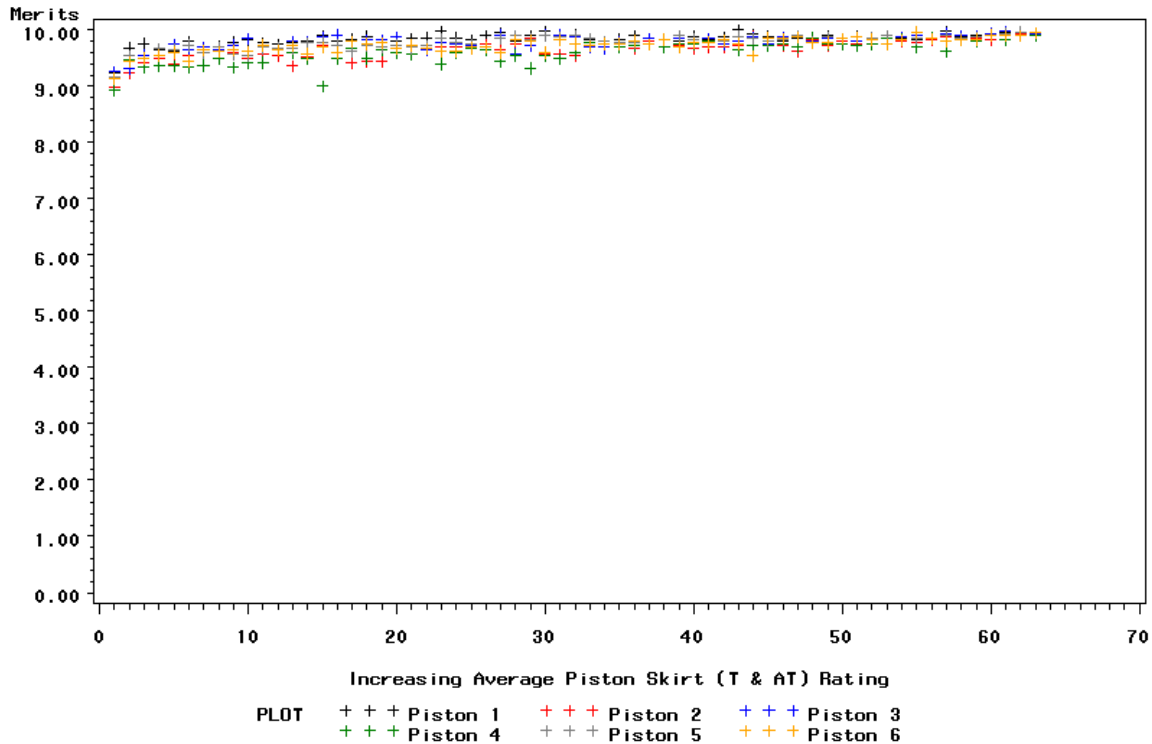


Figure 41: Piston Skirt Average Ratings for all Positions, Reference Oils 433 & 433-1

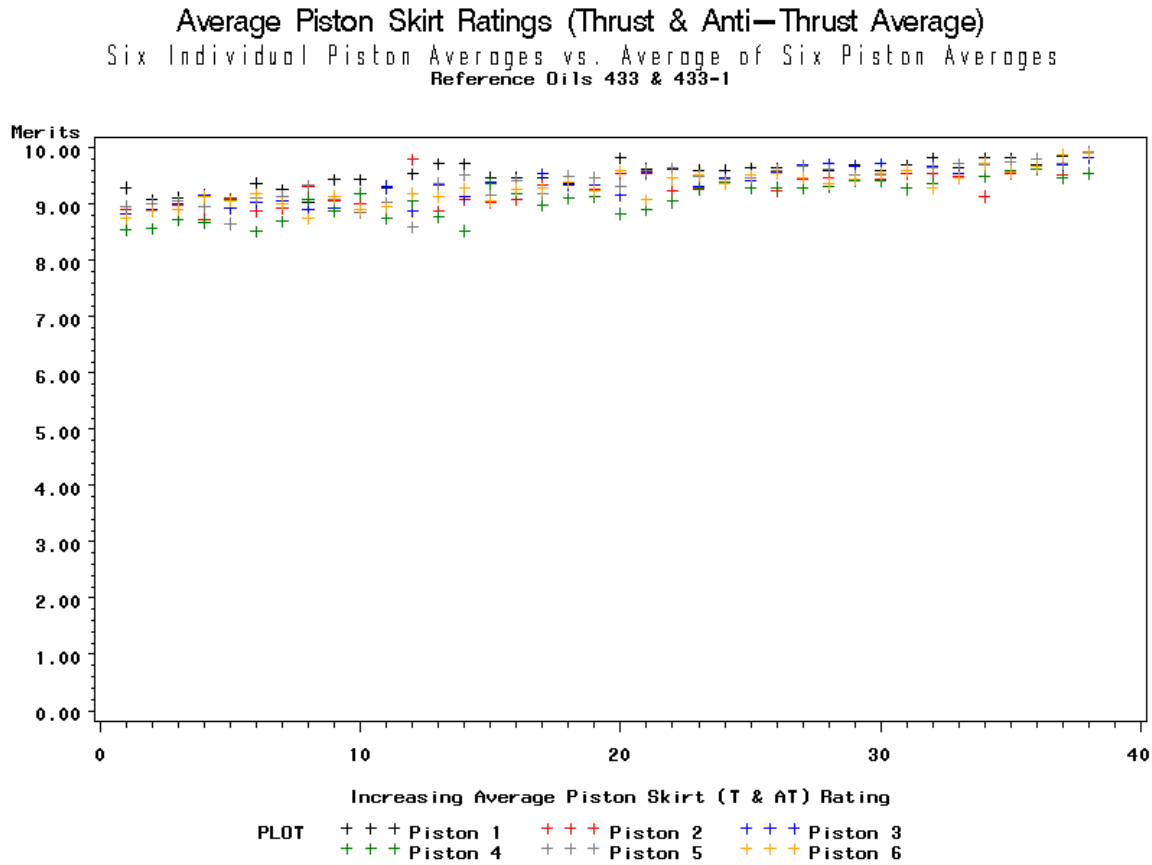


Figure 42: Under Crown Ratings for all Positions, Reference Oils 1006 & 1006-2

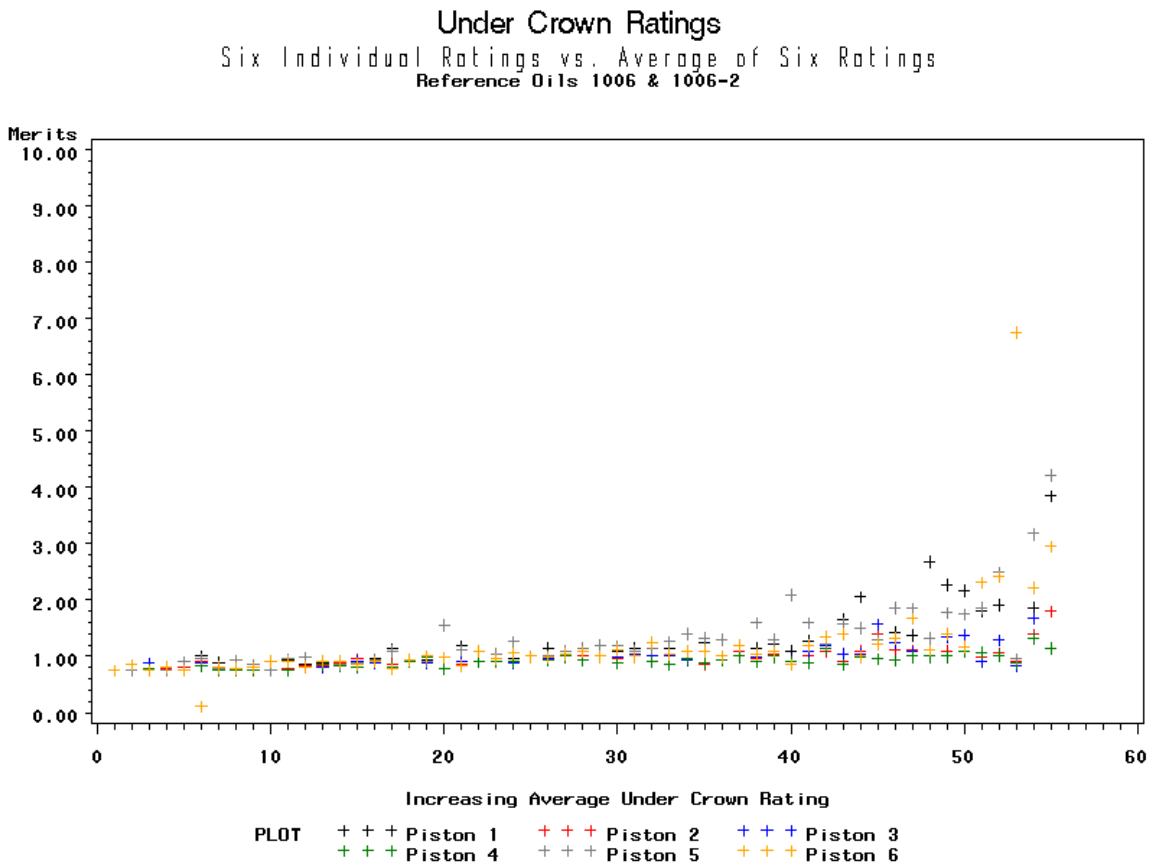


Figure 43: Under Crown Ratings for all Positions, Reference Oils 1008 & 1008-1

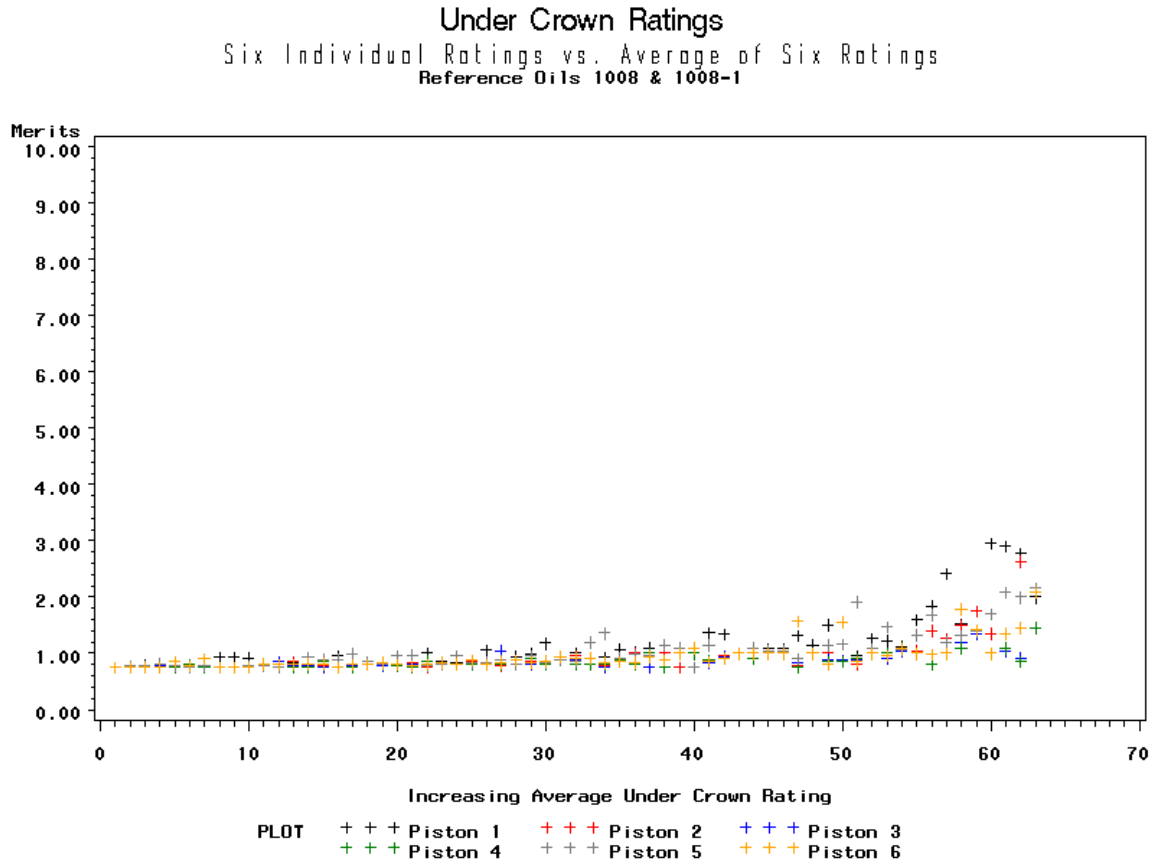


Figure 44: Under Crown Ratings for all Positions, Reference Oils 433 & 433-1

