NASA Technical Memorandum 88312

Supplementary Calibration Test of the Tip-Aerodynamics- and Acoustics-Test Pressure Transducers

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SUMMARY

A calibration test is described that was performed to supplement the normal calibration of the 188 pressure transducers used in the Tip Aerodynamics and Acoustics Test. This calibration led to the identification of 15 transducers which had a slope change of greater than 7% from the initial calibration. The calibration procedure is described and the results presented. The effect of the slope changes on the pressure distributions are described, followed by a method to compensate for these changes.

INTRODUCTION

One of the most important aspects of flight testing is reliable instrumentation. To achieve this reliability, the response characteristics and calibration numbers for the sensors and the instrumentation system are needed. Even such instrumentation as pressure transducers which hold their calibrations well need to be recalibrated periodically. Recalibration is especially important whenever the use of the transducer spans a number of years in a harsh environment.

The standard calibration procedure for pressure transducers is to place them in a small vacuum chamber and measure their responses to known pressures and temperatures. This procedure is difficult whenever the transducer is mounted in such a way that either it or the blade it is mounted on would be damaged if the transducer were removed. However, this problem is slightly alleviated by taking a known pressure point before or after each test flight. While useful, this procedure indicates neither the new calibration values, nor what has changed if a change has occurred. Consequently the calibration of 188 pressure transducers hard mounted in a rotor blade was a problem. In fact, calibration could be done by using a method in which the entire blade is enclosed in a pressure chamber. This report presents the results of this calibration as well as a preliminary method for utilizing the corrected slopes on existing pressure data.

BACKGROUND

The instrumentation system to be calibrated was originally built for a flight test flown in 1976 called the Operational Loads Survey (OLS) (ref. 1) on an AH-1G Cobra helicopter. The OLS test was flown at Bell Helicopter under an Army Research and Technology Laboratories (RTL) contract. An additional test using the OLS blades

was flown during the summer of 1981 with additional pressure instrumentation added in the tip region. This test was called the Tip Aerodynamics and Acoustics Test (TAAT) and was flown at NASA Ames Research Center (ARC). As considerable time passed between the original calibration of the transducers and the TAAT test, a calibration check was needed. The OLS transducers were removed and recalibrated before TAAT, but a post-test calibration was also needed. As the transducers added by TAAT could not be removed without damage to either the transducer or the blade, a facility needed to be located in which the entire blade could be placed.

TEST SETUP AND METHOD

The environmental Chamber located at NASA ARC was found to meet the test calibration requirements. This chamber, which has been operational since 1968, is usually used for studies involving altitude, atmospheric composition, and temperature variations on the human body (fig. 1). Since there would not be any human occupants during the test, the safety and endurance requirements which necessitate the airlock feature could be waived and the inner door left open. With this inner door open, the effective length of the chamber is 23 ft, which is 3 ft longer than the blade. The chamber when fully sealed has a pressure range of 1 to 760 torr and a temperature range of 35° to 160°F.

A difficult part of the test was transferring the voltages from the transducers into and out of the chamber while maintaining a pressure seal. This difficulty was overcome by using ribbon cable to make the wiring harness (fig. 2). The cables were secured to the hinge side of the door jamb in a way that allowed the door to be opened and closed without chafing the wires. The rubber door gasket formed around the ribbon cable to maintain a semi-airtight seal (figs. 3 and 4). Any leakages in pressure caused by this method were compensated for by pumping air out of the chamber at the same rate at which it was leaking in. The use of this method allowed a pressure range of 400 to 760 torr to be maintained during data acquisition. Nominal pressures during the TAAT ranged from 362 to 760 torr with excursions as low as 260 torr.

For accurate calibration, each pressure transducer requires a slope and intercept. The slope is commonly defined as the rate at which the output voltage signal varies with changing pressure. This slope is linear for a properly functioning transducer over its specified range. The intercept is the voltage output for standard atmospheric pressure. To check the intercept of each transducer, 188 balance bridges would have been required. This equipment was not readily available. Instead, the slopes (psia/mV) were obtained with a common multimeter, a rotary switch box, and the laboratory power supply of 6.0 V. This test equipment setup is shown in schematic form in figure 5. Because of the extensive number of transducers involved and the limited funds available to perform the test, only the transducer slopes were calibrated. The environmental chamber was pumped down from a pressure of 760 torr to 400 torr in 50-torr increments. At each pressure step, manually recorded readings from all the transducers were taken by dialing through the rotary

switch and noting the voltage output from the multimeter. A second reading was taken to detect hysteresis after the chamber had returned to 760 torr. After the test was completed, the numbers were input to the computer to be analyzed.

DATA ANALYSIS AND RESULTS

A linear least-squares-curve fit was performed for each transducer with the slope in units of psia/mV. Table 1 compares the curve-fit slopes with the original calibration slopes performed by Bell Helicopter Textron. Individual transducer results are graphically presented in figure 6. For ease of comparison, the y-intercept of the data has been adjusted to highlight differences in the slopes from the original calibration.

The error ranges are shown in figure 7. The absolute value of the errors is used because the sign of an error value is relative and because the use of absolute values gives a better representation of the error grouping. Note that the errors fall in approximately a normal distribution. Because of this grouping, a cutoff of approximately 7% error was used in determining whether the transducer was sufficiently out of calibration to warrant its elimination from use in the data analysis program (DATAMAP, ref. 2) without adjustment for the slope error. There were 15 transducers whose slope error exceeded 7% (shown in Table 2).

It is possible to partially salvage the data from these transducers by correcting the pressure reading for the proper slope. However, this should be done carefully, as the y-intercept could have changed for the calibration and no check was made for this possibility. Figure 8 demonstrates a correction for slope deviation of the transducer at 86.4% radius, upper surface, leading edge (item code P164) for a complete rotor revolution. The flight condition shown in figure 8 was chosen for this correction demonstration as data were available from both the OLS and TAAT to within 5 knots. The use of the OLS and TAAT data allows a direct comparison of pressures from initial tests of the transducers to the more recent test. The differences in pressures remaining after the slope corrections could have been caused by any one or any combination of the following: (1) the points were flown at different static pressures, (2) there were differences in true airspeed, and (3) the y-intercept may have changed.

To demonstrate how the slope error affects the chordwise pressure distributions, an analysis was performed for a radius station. Figure 9 shows the percent of slope errors across the chord for the 86.4% radius station. The pressures for this station (fig. 10) were corrected for 0°, 90°, 180°, and 270° azimuth using both the calculated and original slopes and assuming no change in the y-intercept. Notice that since the errors are relatively small for all the stations except the leading edge station (P164), the correction to the pressure profile is not very large. Despite the small errors, the corrections tend to make the curves smoother. In the case of the upper-surface leading edge, the corrections eliminate the doubling-back of the curve, thereby generating a more logical profile.

CONCLUSIONS

The Supplementary Calibration Test met its original requirements by demonstrating the feasibility of this type of test and by showing that 15 transducers had changed beyond acceptable limits. This test also demonstrated that this post-flight calibration data can be used to correct the TAAT data if the y-intercept values are used with caution. The main data analysis program (DATAMAP) used on the TAAT data is presently undergoing modifications to allow the user to easily perform these corrections. Also, in an extended flighttest program, a method of periodically calibrating even reliable instrumentation such as pressure transducers is necessary to ensure the accuracy of the data.

REFERENCES

1. Shockey, Gerald A.; Cox, Charles R.; and Williamson, Joe W.: AH-1G Helicopter Aerodynamic and Structural Loads Survey. USAAMRDL-TR-76-39, Feb. 1977.

2. Philbrick, Richard B.: The Data From Aeromechanics Test and Analysis--Management and Analysis Package (DATAMAP), Vol. I - User's Manual. USAAVRADCOM-TR-80-D-30A, Dec. 1980.

TABLE 1.- TABULATED SLOPES AND ERRORS

Item code	Radial station, %	Chord, %	Surface	Calculated slope, psia/mV	Original slope, psia/mV	Error, %
P157	40	1	Upper	2.562	2.560	-0.086
P158	↓	3	↓	1.198	1.220	1.786
P159		8		2.348	2.380	1.328
P160		25		2.640	2.610	-1.135
P161		45		1.942	1.960	.911
P162		70		.935	3.370	72.255
163/P167	↓	92		1.653	1.740	4.982
P164	86.4	1		1.483	2.560	42.068
P165	86.4	3		2.739	2.700	-1.451
P166	86.4	8	↓	2.205	2.170	-1.592
P173	40	1	Lower	2.887	2.910	.796
P174	↓	3	↓	2.671	2.660	-.423
P175		8		2.353	2.360	.308
P176		25		1.352	1.430	5.459
P177		45		1.443	1.520	5.035
P178		70		1.878	1.900	1.173
P179	↓	92	↓	1.863	1.990	6.381
P180	86.4	15	Upper	2.222	2.230	.375
P182	86.4	25	↓	1.649	1.740	5.218
P187	60	1		2.943	2.900	-1.481
P188	↓	3		2.887	2.840	-1.660
P189		8		2.283	2.270	-.566
P190		15		2.543	2.550	.276
P191		25		2.523	2.500	-.938
P192		35		2.031	2.010	-1.053
P193	↓	45		2.065	2.070	.257
P194	86.4	35		2.252	2.270	.784
P195	86.4	40		2.743	2.700	-1.578
P196	86.4	45		2.884	2.880	-.154
P601	91	1		1.643	1.640	-.180
P602	↓	3		1.627	1.620	-.411
P603		8		2.041	2.030	-.534
P604		15		1.960	1.970	.531
P605		20		2.084	2.080	-.191
P606		25		2.039	2.060	1.006
P607		35		1.974	1.970	-.225
P608		40		1.830	1.820	-.538
P609		45		2.060	2.030	-1.481
P610	↓	50	↓	2.117	2.050	-3.253

TABLE 1.- CONTINUED

Item code	Radial station, %	Chord, %	Surface	Calculated slope, psia/mV	Original slope, psia/mV	Error, %
P611	91	55	Upper	1.898	1.910	0.616
P612	91	60	↓	2.363	2.390	1.136
P613	91	70	↓	1.552	1.560	.543
P614	97	55	↓	1.919	1.930	.565
P615	91	1	Lower	2.081	2.080	-.070
P616	↓	3	↓	2.184	2.150	-1.601
P617	↓	8	↓	2.044	2.050	.276
P618	↓	15	↓	1.585	1.610	1.542
P619	↓	20	↓	2.143	2.080	-3.025
P620	↓	25	↓	1.706	1.500	-13.726
P621	↓	35	↓	1.511	1.520	.581
P622	↓	40	↓	1.888	1.900	.628
P623	↓	45	↓	1.922	1.910	-.606
P624	↓	50	↓	1.959	1.950	-.472
P625	↓	55	↓	1.378	1.440	4.286
P626	↓	60	↓	1.504	1.490	-.964
P627	↓	70	↓	1.591	1.600	.560
P631	97	1	Upper	1.621	1.720	5.749
P632	↓	3	↓	1.961	2.090	6.153
P633	↓	8	↓	1.861	1.940	4.081
P634	↓	15	↓	1.966	1.980	.729
P635	↓	20	↓	1.978	1.990	.618
P636	↓	25	↓	2.049	2.080	1.468
P637	↓	35	↓	2.054	2.060	.307
P638	↓	40	↓	1.748	1.970	11.273
P639	↓	45	↓	-115.000	1.710	6825.146
P640	↓	50	↓	1.919	1.940	1.075
P642	↓	60	↓	1.935	1.990	2.766
P643	↓	70	↓	1.554	1.580	1.649
P644	↓	92	↓	1.632	1.710	4.590
P645	↓	1	Lower	1.368	1.370	.135
P646	↓	3	↓	1.554	1.570	1.043
P647	↓	8	↓	2.070	2.060	-.465
P648	↓	15	↓	1.830	1.860	1.618
P649	↓	20	↓	1.784	1.800	.871
P650	↓	25	↓	2.108	2.130	1.020
P651	↓	35	↓	2.052	2.050	-.074
P652	↓	40	↓	1.843	1.850	.387
P653	↓	45	↓	2.143	2.280	6.022

TABLE 1.- CONTINUED

Item code	Radial station, %	Chord, %	Surface	Calculated slope, psia/mV	Original slope, psia/mV	Error, %
P654	97	50	Lower	1.769	1.890	6.387
P655	↓	55	↓	-38.444	2.060	1966.235
P656		60		1.429	1.440	.773
P657		70		2.079	2.050	-1.427
P658	↓	92	↓	1.841	1.840	-.073
P661	99	1	Upper	2.016	1.990	-1.323
P662	↓	3	↓	1.905	1.910	.273
P663		8		2.199	2.180	-.867
P664		15		1.961	1.990	1.480
P665		20		2.040	2.050	.482
P666		25		1.775	1.790	.817
P667		35		1.723	1.750	1.528
P668		40		2.024	2.050	1.247
P669		45		2.005	1.990	-.739
P670		50		2.058	2.070	.594
P671		55		2.128	2.080	-2.289
P672		60		2.253	2.280	1.176
P673		70		1.952	1.970	.900
P674		92	↓	1.998	2.100	4.871
P675		1	Lower	1.975	2.050	3.674
P676		3	↓	1.875	1.880	.278
P677		8		2054.785	2.480	-82754.227
P678		15		2.030	2.050	.991
P679		20		1.838	1.830	-.452
P680		25		1.819	1.910	4.778
P681		35		1.945	1.940	-.262
P682		40		1.985	1.980	-.274
P683		45		1.760	1.850	4.888
P684		50		1.618	1.620	.131
P685		55		1.425	1.430	.360
P686		60		2.025	2.040	.721
P687		70		2.060	2.070	.464
P688	↓	92		2.058	2.040	-.879
P738	95.5	50		1.589	1.570	-1.234
P739	↓	55		1.688	1.850	8.745
P740		70		2.120	2.150	1.389
P757	↓	92	↓	1.783	1.770	-.723
P806	60	55	Upper	3.023	3.000	-.762

TABLE 1.- CONTINUED

Item code	Radial station, %	Chord, %	Surface	Calculated slope, psia/mV	Original slope, psia/mV	Error, %
P807	60	70	Upper	1.600	1.610	0.627
P808		92	Upper	1.666	1.660	-.391
P809		1	Lower	2.847	2.830	-.612
P810		3		2.187	2.180	-.307
P811		8		2.032	2.060	1.382
P812		15		2.622	2.620	-.059
P813	86.4	50	Upper	2.388	2.410	.933
P814	86.4	55	Upper	2.873	2.890	.587
P815	86.4	60	Upper	3.000	3.050	1.643
P822	60	25	Lower	1.918	1.940	1.158
P823		35		1.986	1.410	-40.882
P824		45		2.806	2.870	2.216
P825		55		2.730	2.750	.732
P826		70		1.912	1.850	-3.356
P827		92		3.001	3.040	1.276
P828	75	1	Upper	2.064	2.020	-2.198
P829	86.4	70	Upper	1.335	1.420	5.956
P830	86.4	92	Upper	1.907	1.920	.661
P831	86.4	1	Lower	2.190	2.310	5.202
P836	75	3	Upper	2.668	2.650	-.677
P837		8		2.131	2.150	.873
P838		15		2.412	2.420	.312
P840		25		2.870	2.850	-.699
P841		35		2.849	2.830	-.686
P842		40		2.068	2.190	5.587
P843	86.4	3	Lower	2.780	2.780	-.006
P844	86.4	8	Lower	2.375	2.360	-.630
P845	86.4	15	Lower	2.678	2.790	4.007
P852	75	45	Upper	1.822	1.850	1.517
P853		55		2.286	2.280	-.275
P854		70		1.673	1.690	1.010
P855		92		3.176	3.230	1.666
P856		1	Lower	2.773	2.800	.951
P857		3		3.057	2.990	-2.247
P858		8		2.775	2.790	.535
P860	86.4	25		1.768	1.740	-1.586
P861	86.4	35		1.614	1.600	-.851
P868	75	15		1.807	1.810	.161

TABLE 1.- CONCLUDED

Item code	Radial station, %	Chord, %	Surface	Calculated slope, psia/mV	Original slope, psia/mV	Error, %
P869	75	25	Lower	1.655	1.720	3.779
P870	↓	35	↓	1.824	1.890	3.497
P872		40		1.358	1.400	2.990
P873		45		2.077	2.080	.160
P874		55		2.263	2.310	2.036
P875	86.4	40		1.800	1.620	-11.141
P876	86.4	45		1.818	1.860	2.277
P877	86.4	50		1.719	1.820	5.549
P884	75	70		2.698	2.790	3.290
P885	75	92		1.947	1.950	.169
P891	86.4	55		1.841	1.830	-.619
P892	↓	60		2.050	2.150	4.632
P893		70		1.889	1.990	5.086
P907		92	↓	1.908	2.000	4.580
P908	95.5	1	Upper	2.563	2.700	5.085
P909	↓	3	↓	1.511	1.600	5.553
P919		8		2.225	2.290	2.850
P920		15		2.485	2.500	.588
P921		25		2.696	2.840	5.060
P926		35		2.852	2.750	-3.693
P927		40		2.853	2.760	-3.360
P928		45		2.492	3.130	20.384
P941		50		2.995	2.970	-.853
P942		55		2.577	2.560	-.666
P943		70		2.917	2.890	-.919
P957		92	↓	2.314	2.350	1.514
P958		1	Lower	1.384	1.450	4.520
P959		3	↓	2.035	2.140	4.892
P973		8		2.535	2.250	-12.675
P974		15		-1936.672	2.600	74587.375
P975		25		1.691	1.650	-2.494
P989		35		3.347	2.540	-31.757
P990		40		1.981	2.000	.937
P991	↓	45	↓	2.084	1.850	-12.669

TABLE 2.- ITEM CODES IN EXCESS OF 7% ERROR

Item code	Radial station, %	Chord, %	Surface
P162	40	70	Upper
P163/P167	40	92	Upper
P620	91	25	Lower
P638	97	40	Upper
P639	97	45	Upper
P655	97	55	Lower
P677	99	8	↓
P739	95.5	55	
P823	60	35	
P875	86.4	40	
P928	95.5	45	Upper
P973	↓	8	Lower
P974		15	↓
P989		35	
P991		45	

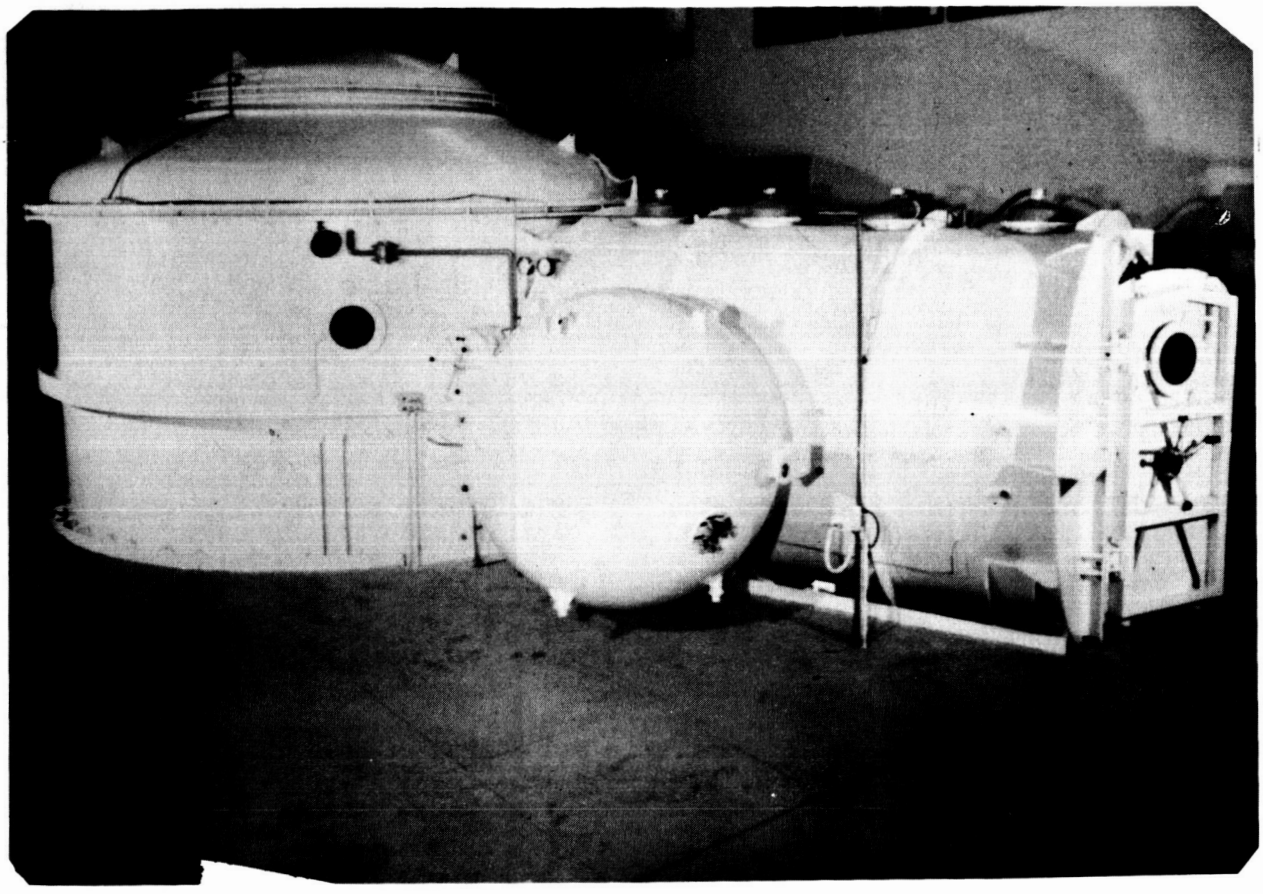


Figure 1.- Environmental chamber.

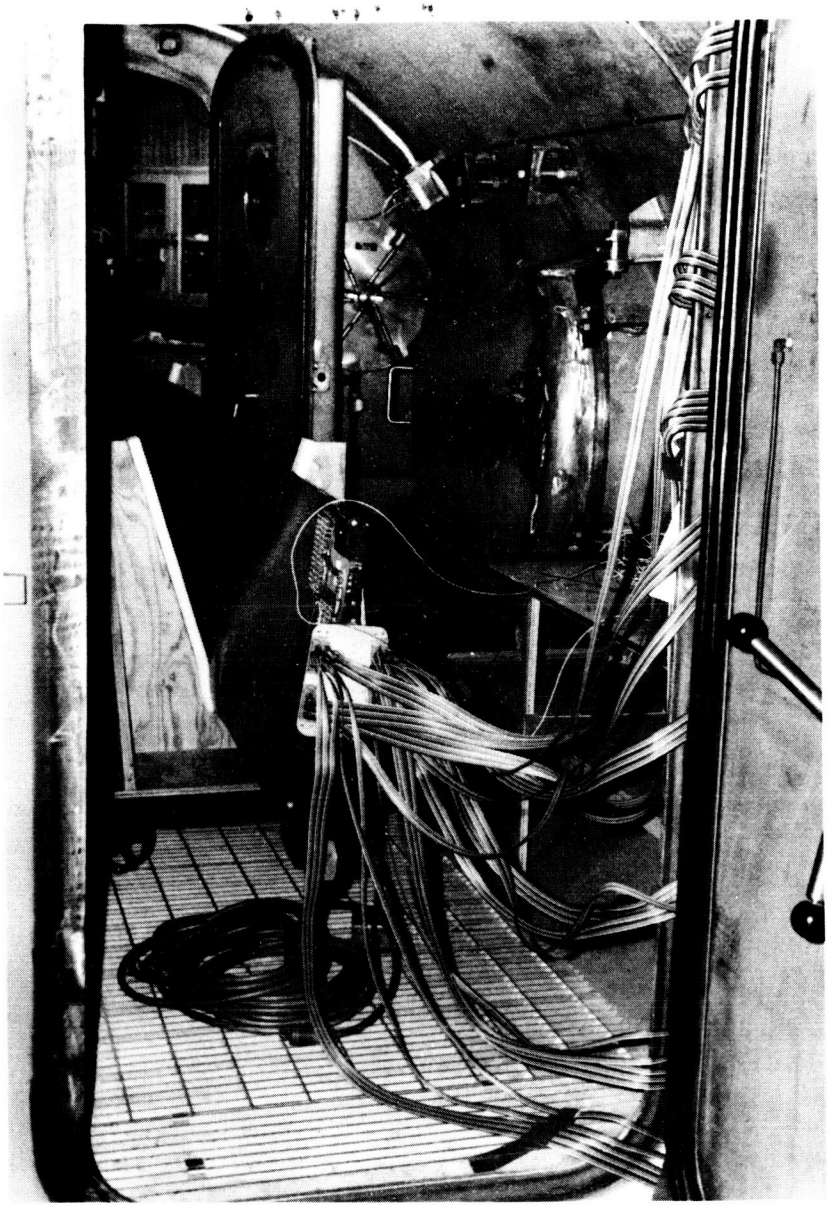


Figure 2.- Wiring harness--attachment to blades.

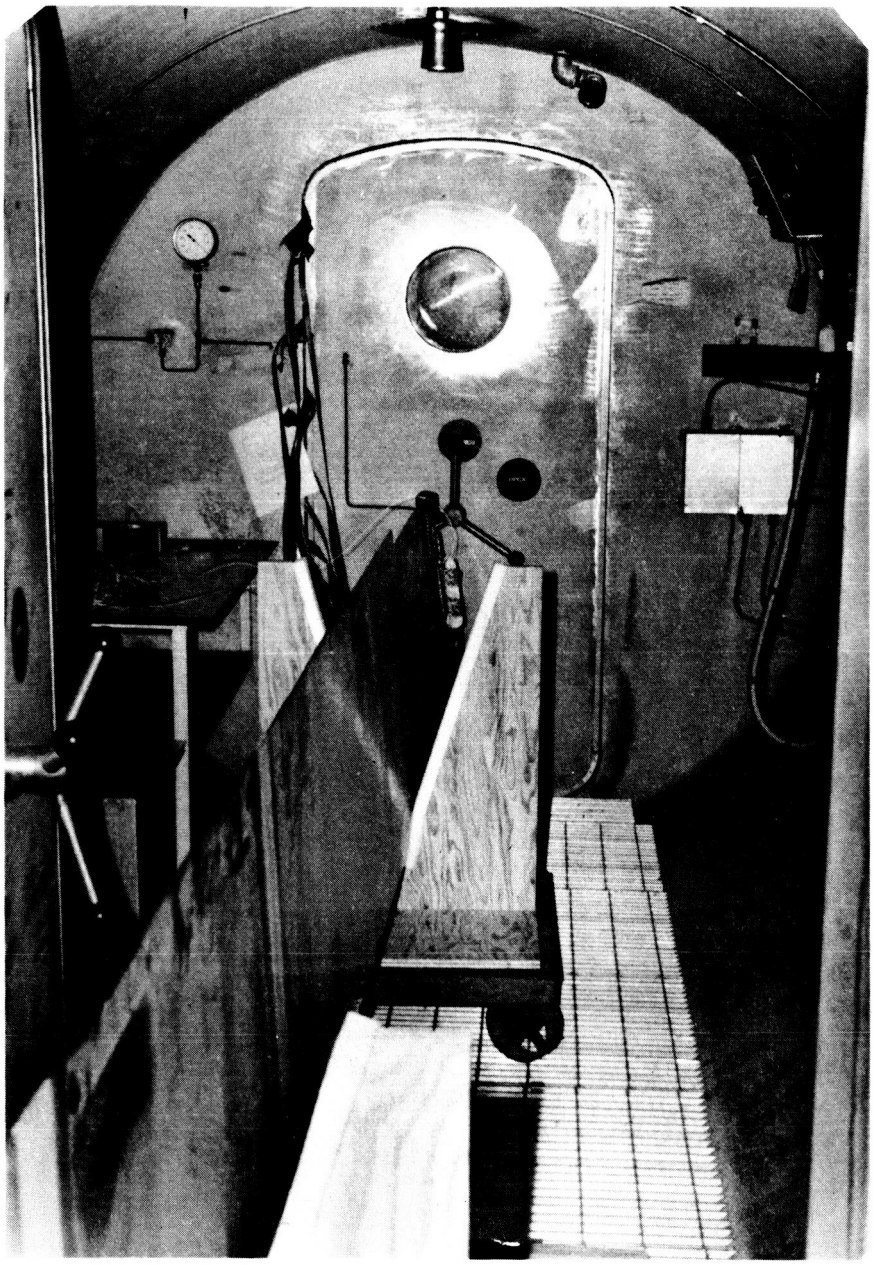


Figure 3.- Inner view of environmental chamber.

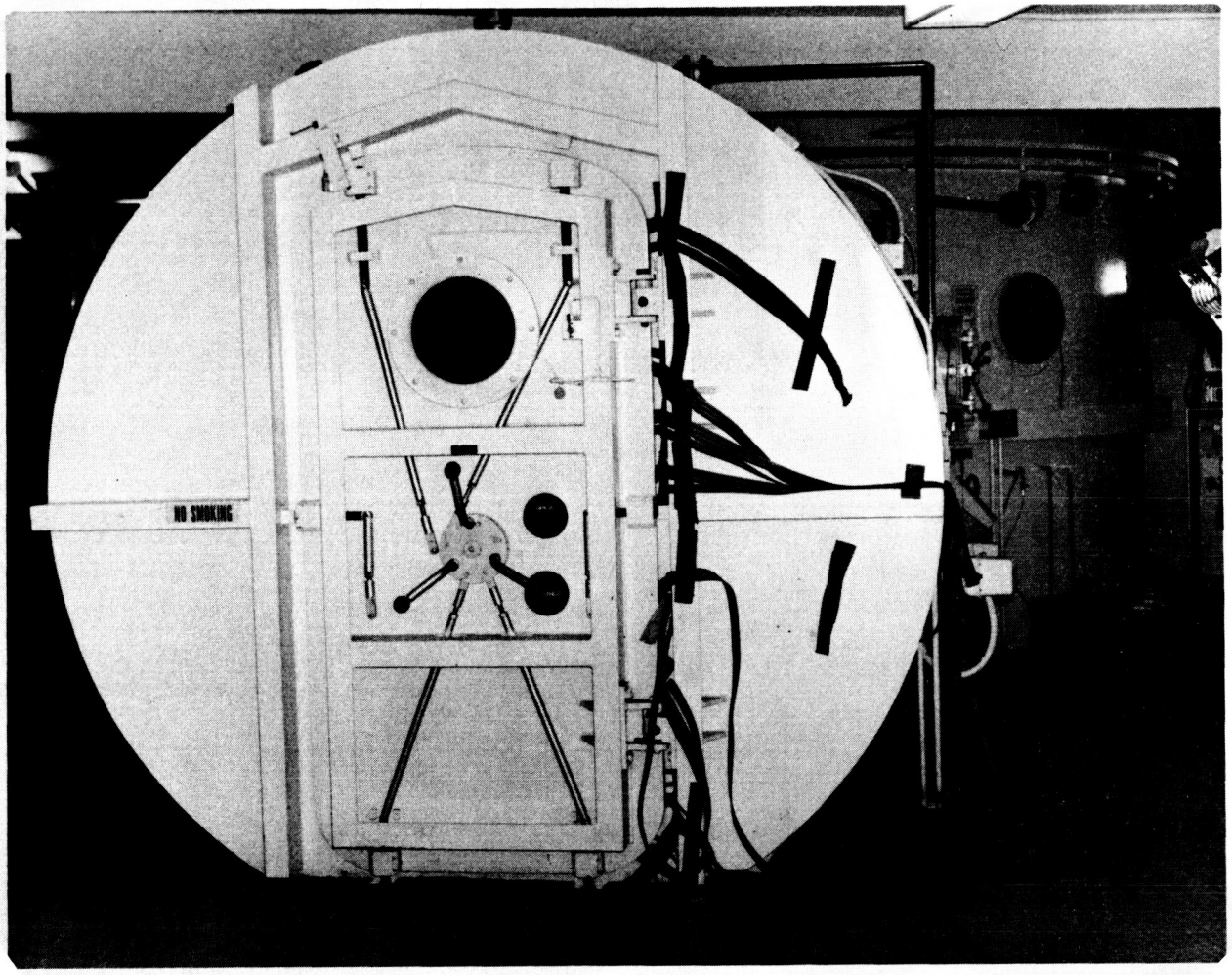


Figure 4.- Outer view of environmental chamber.

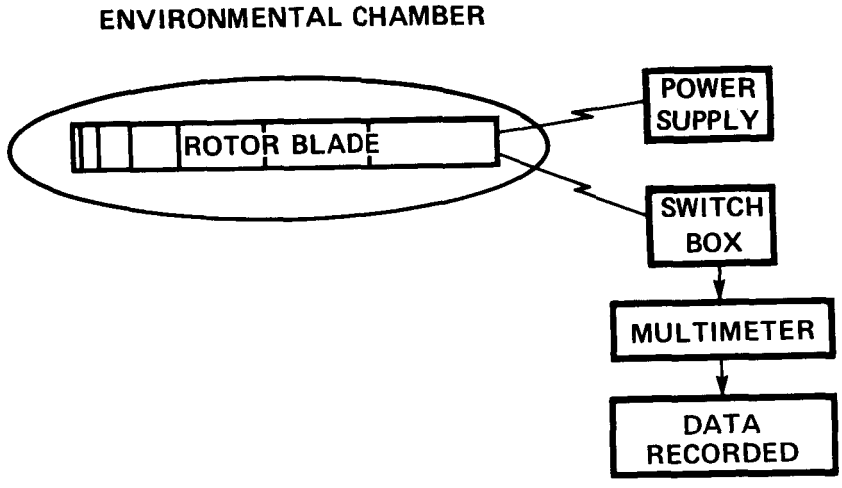


Figure 5.- Schematic of test setup.

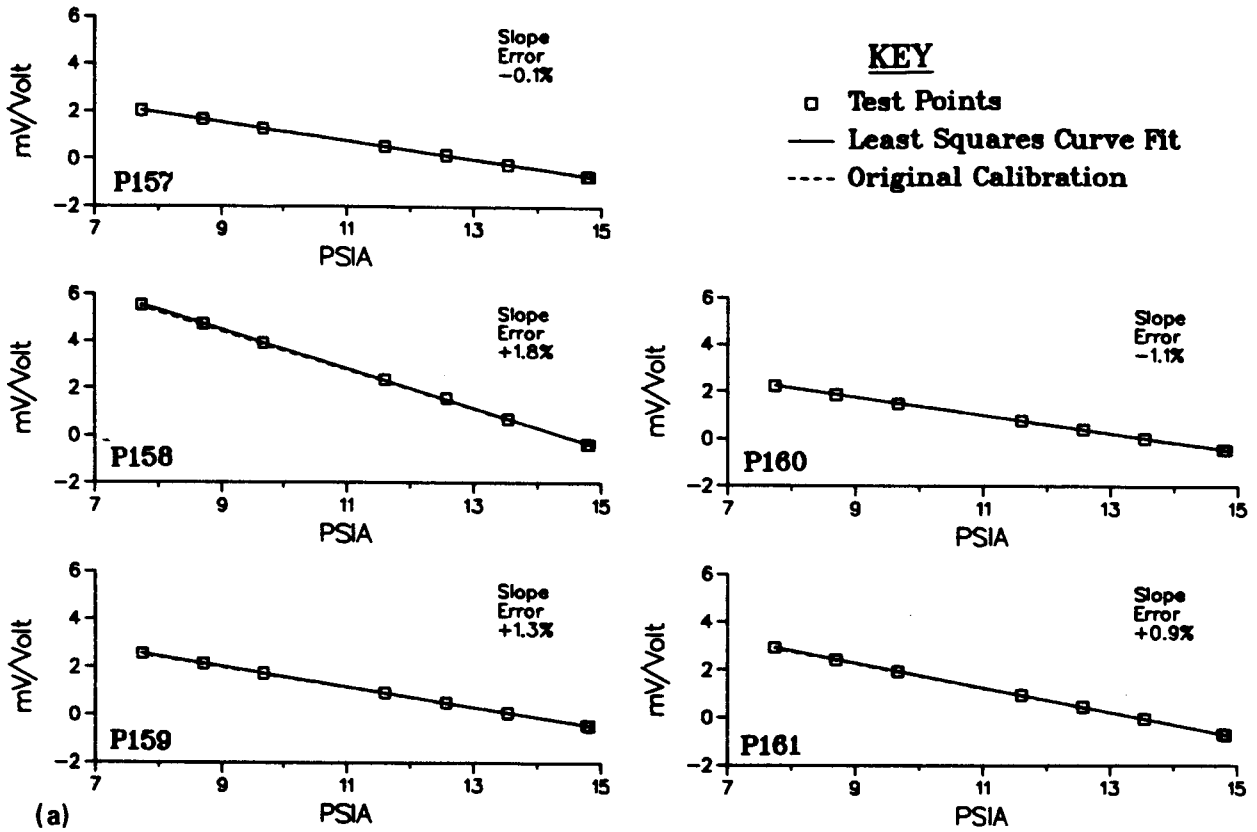


Figure 6.- Comparison of original slopes, test points, and least-square curve fit slopes for pressure transducers used for TAAT.

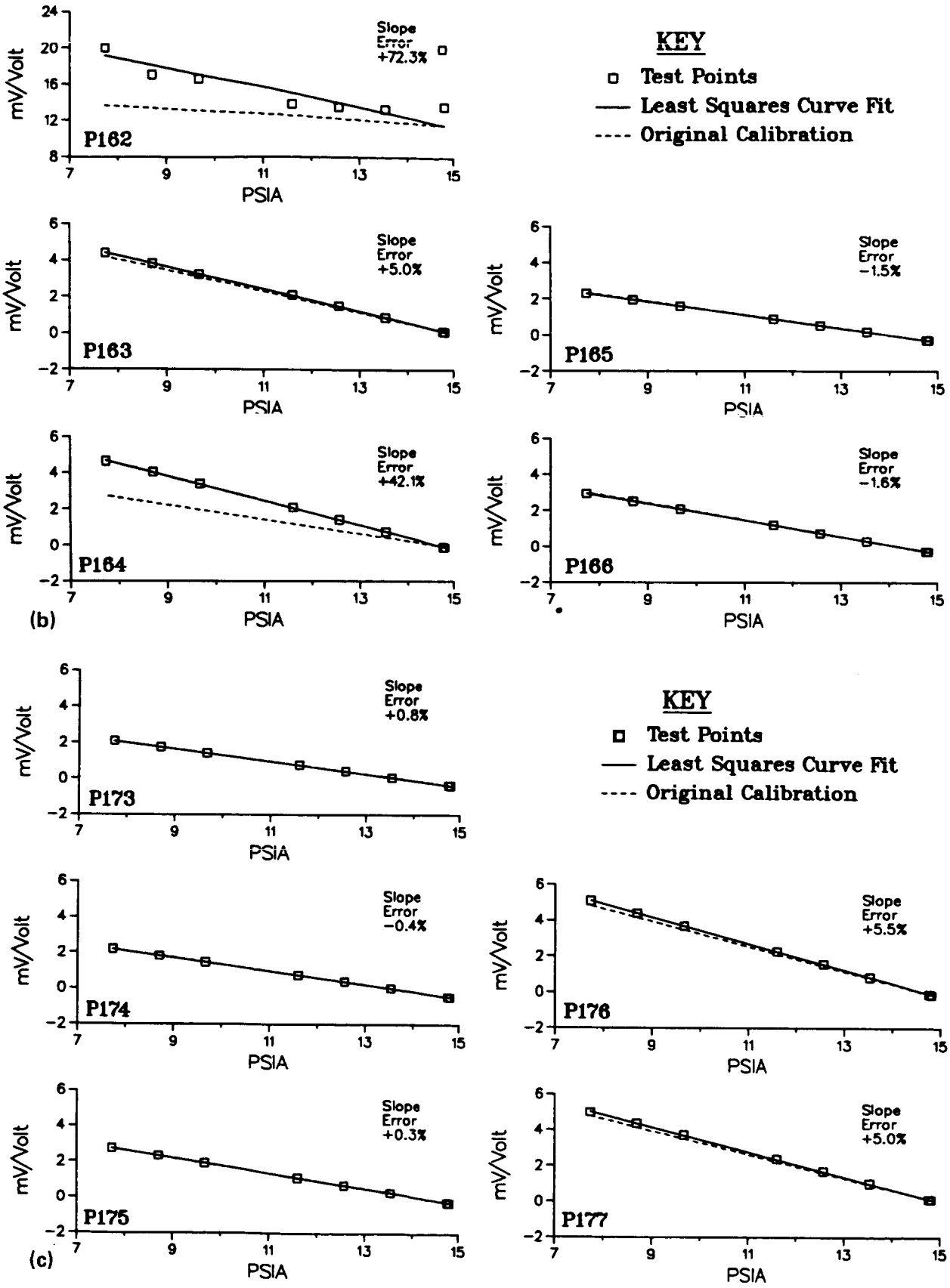


Figure 6.- Continued.

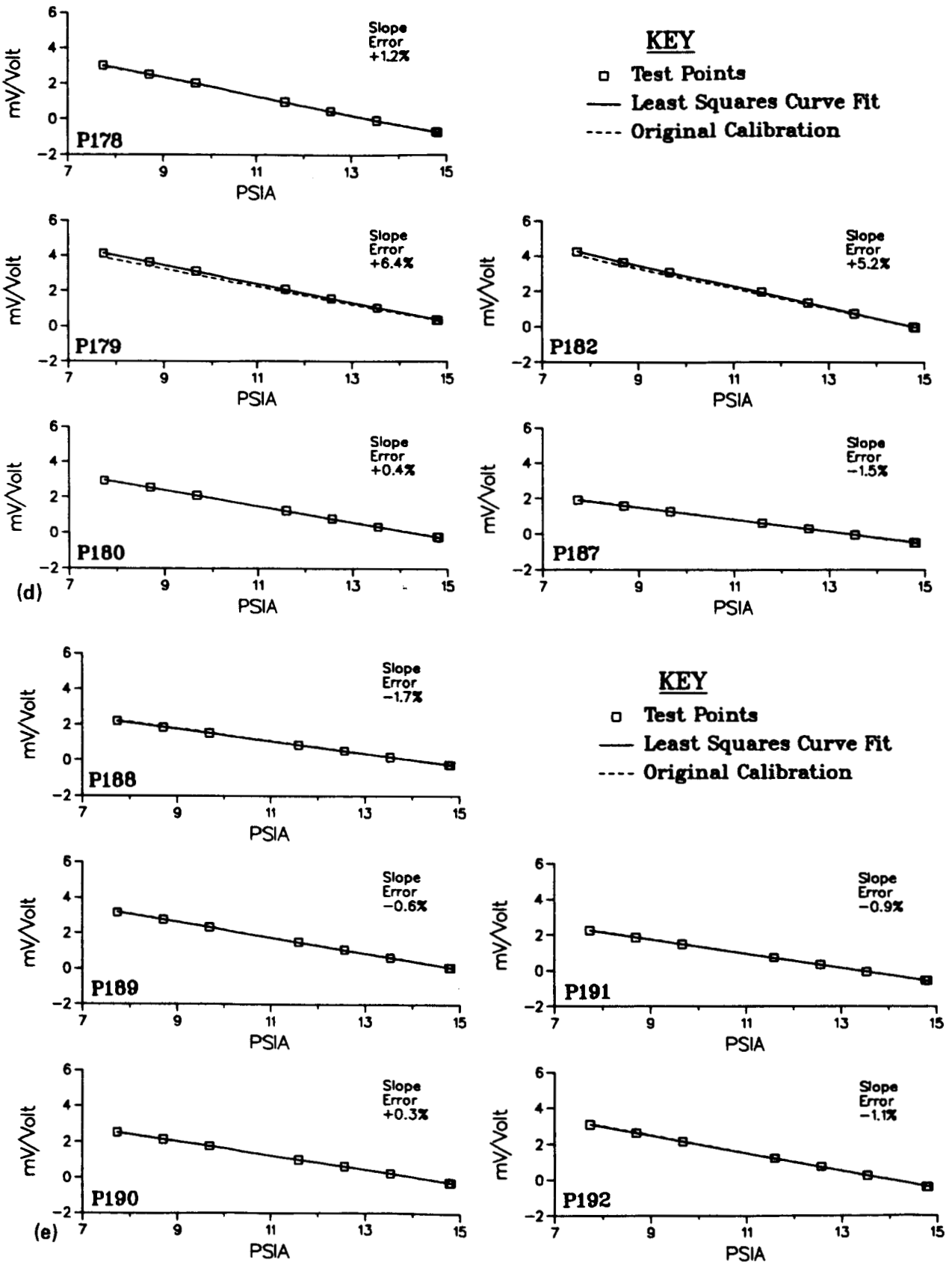


Figure 6.- Continued.

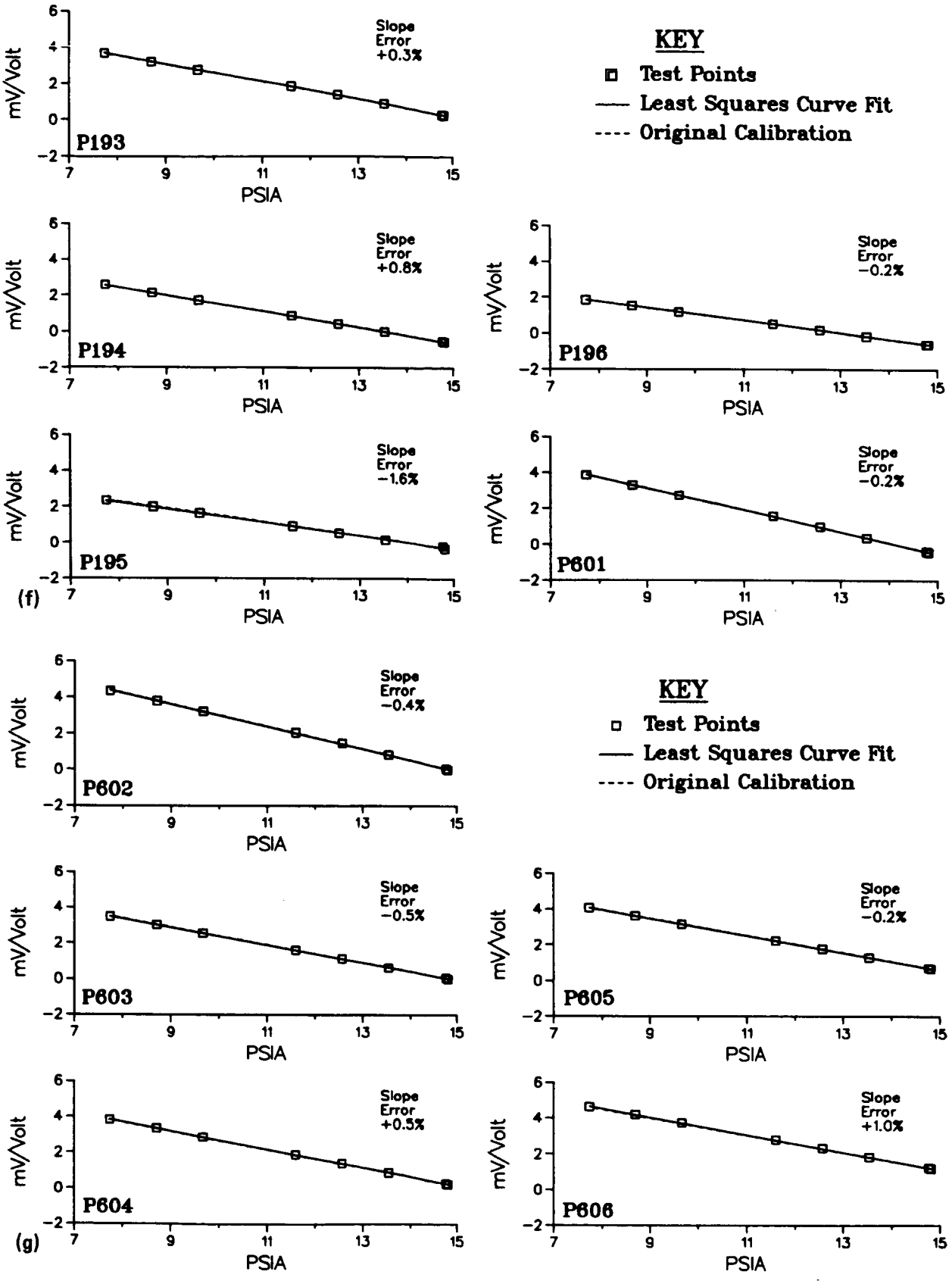


Figure 6.- Continued.

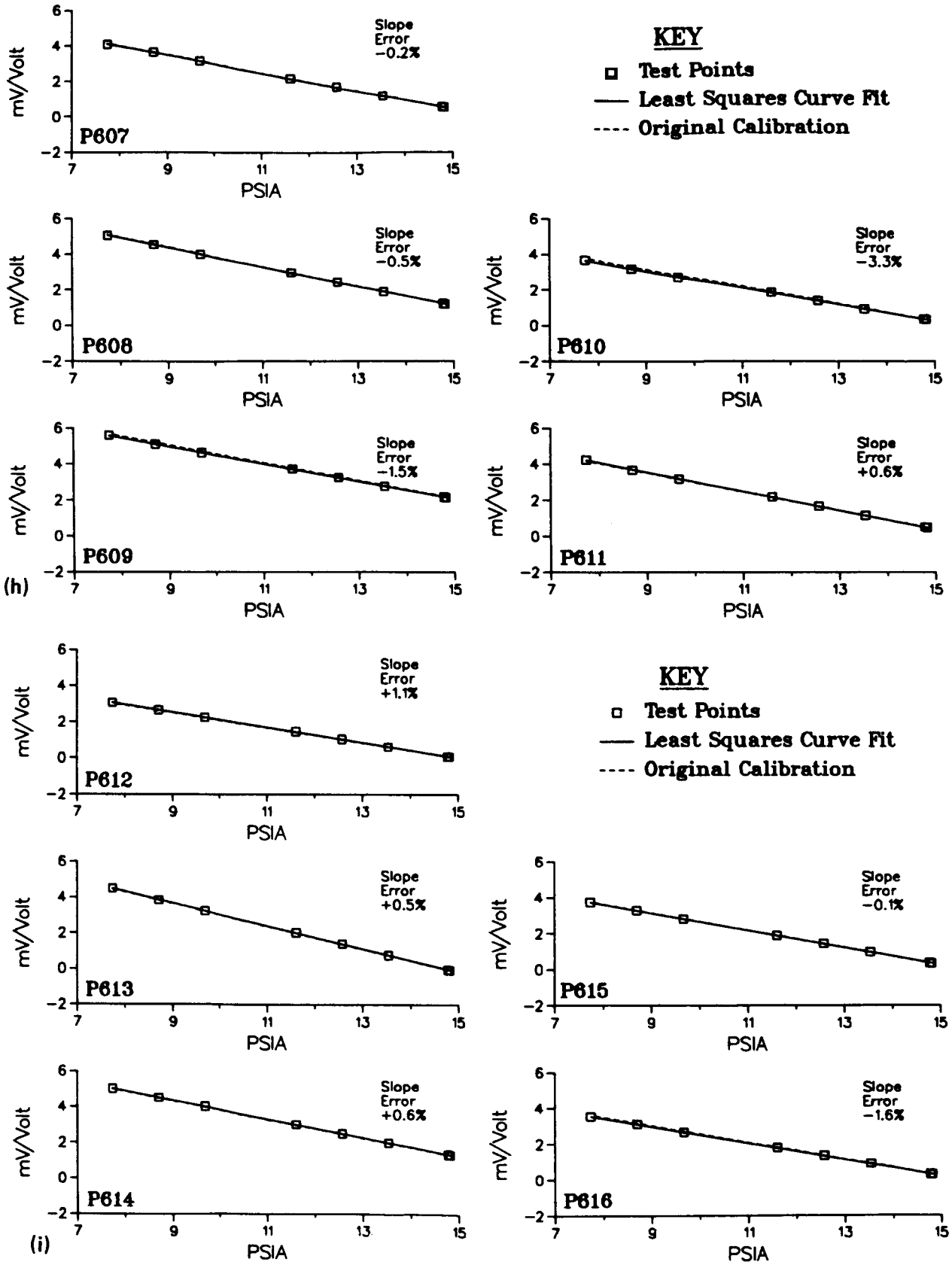
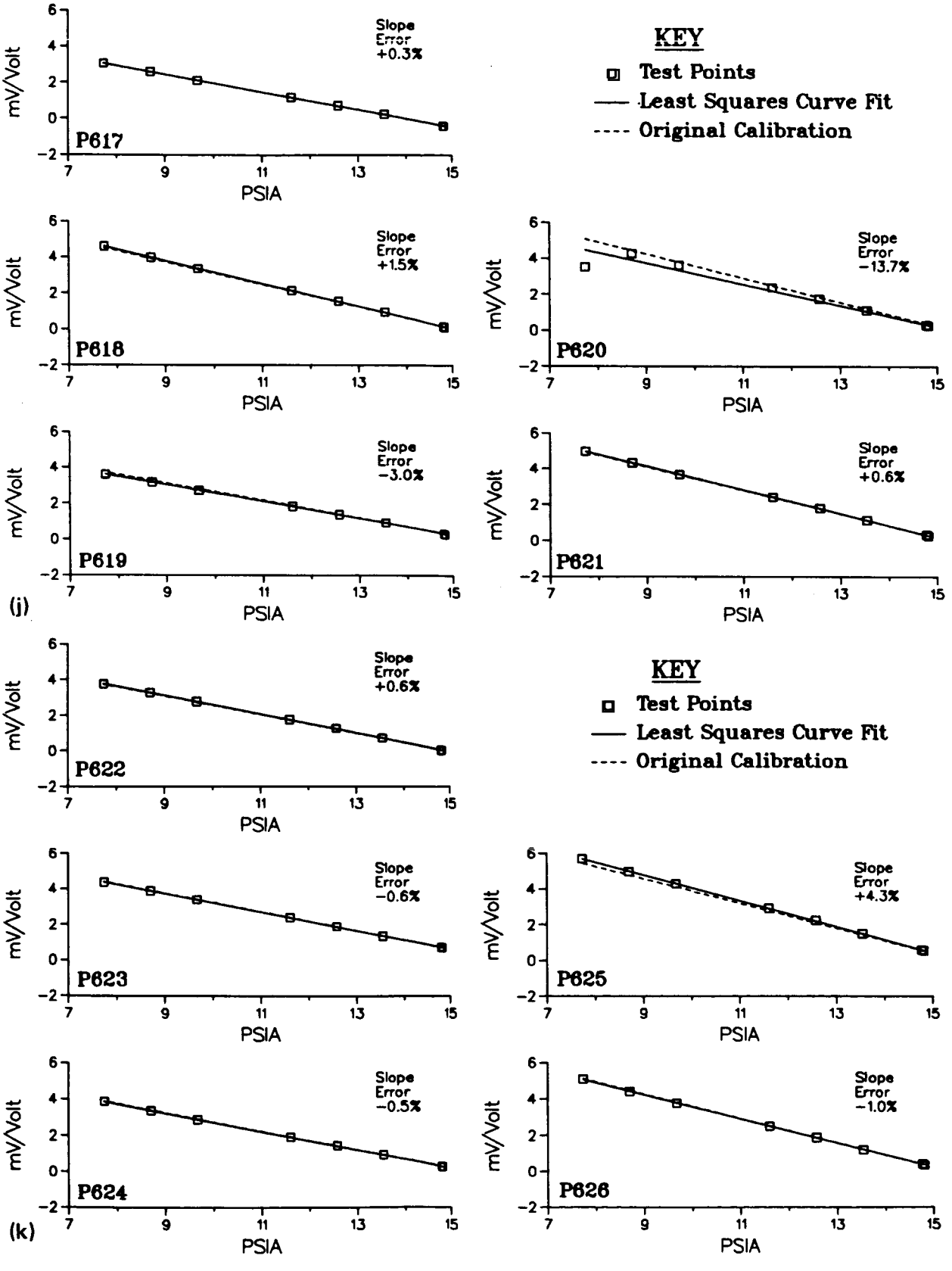


Figure 6.- Continued.



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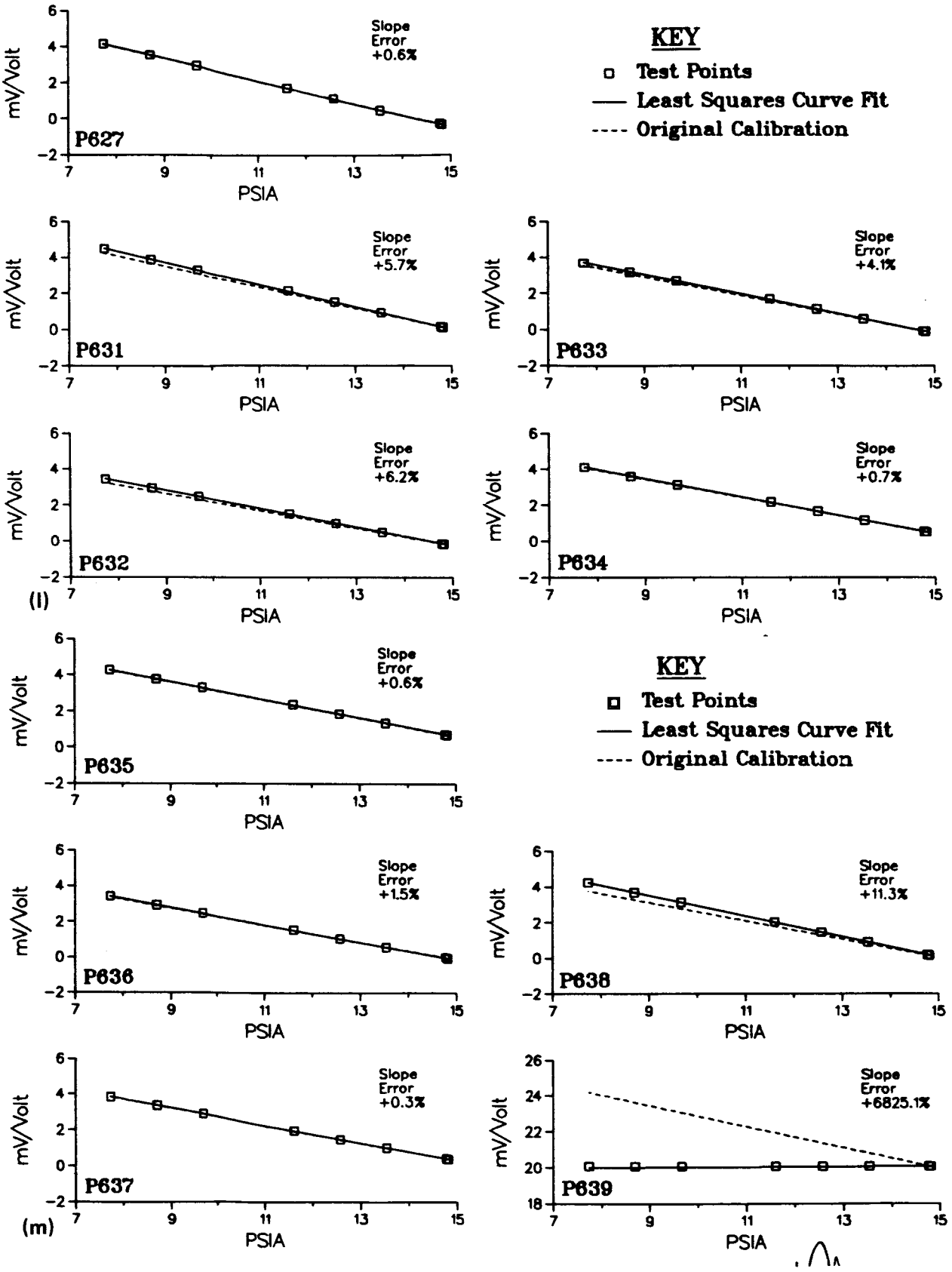

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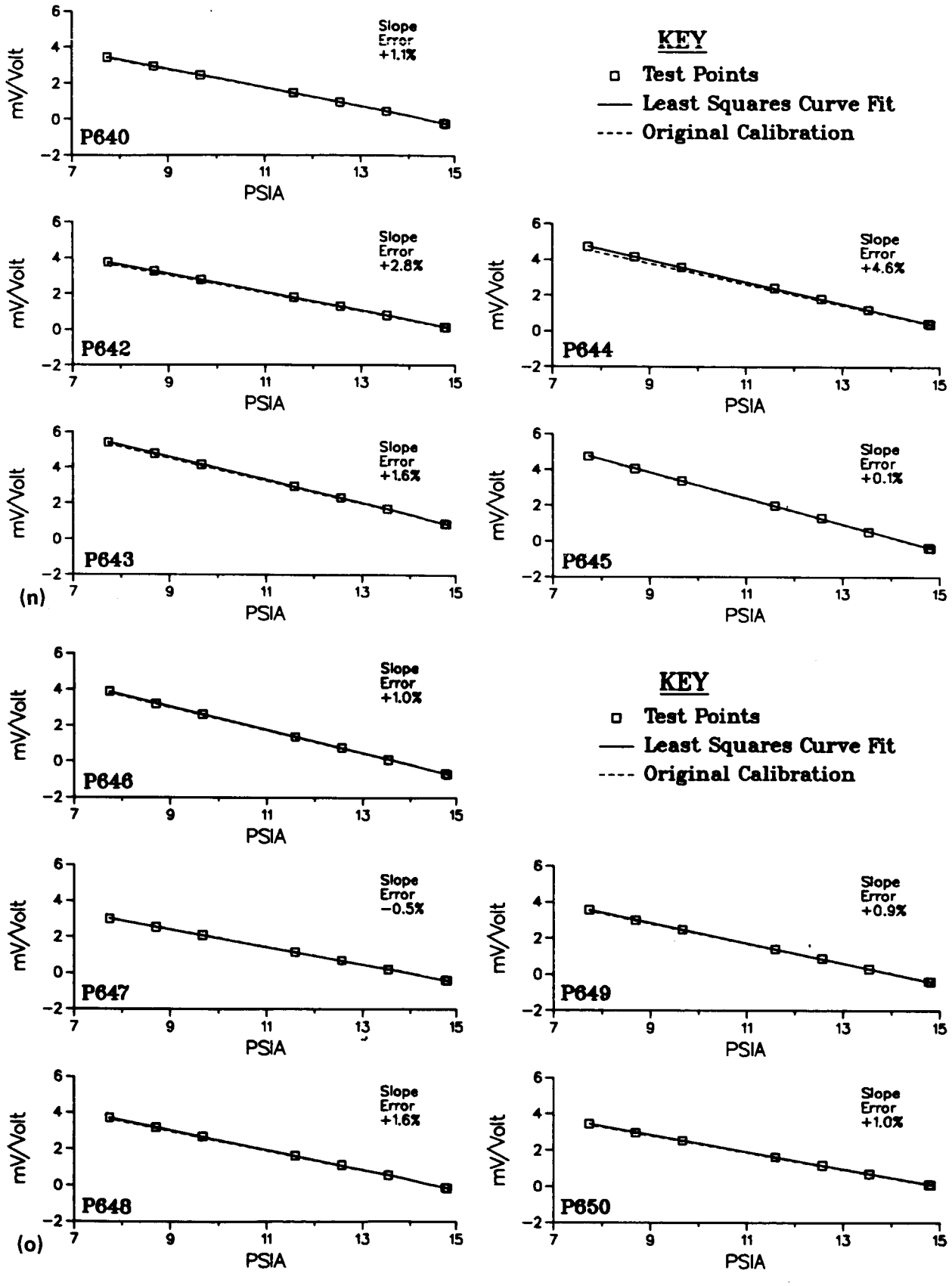

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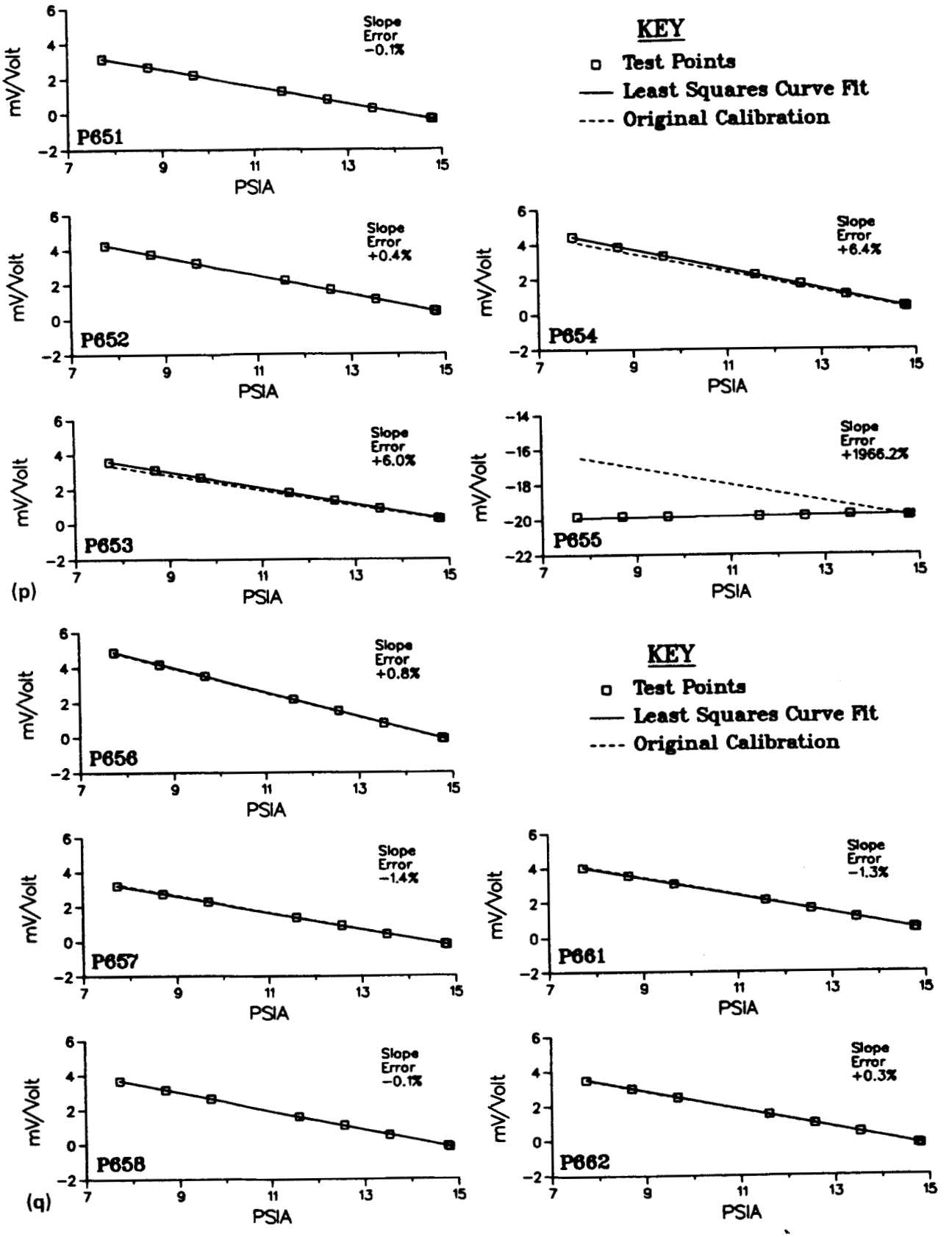

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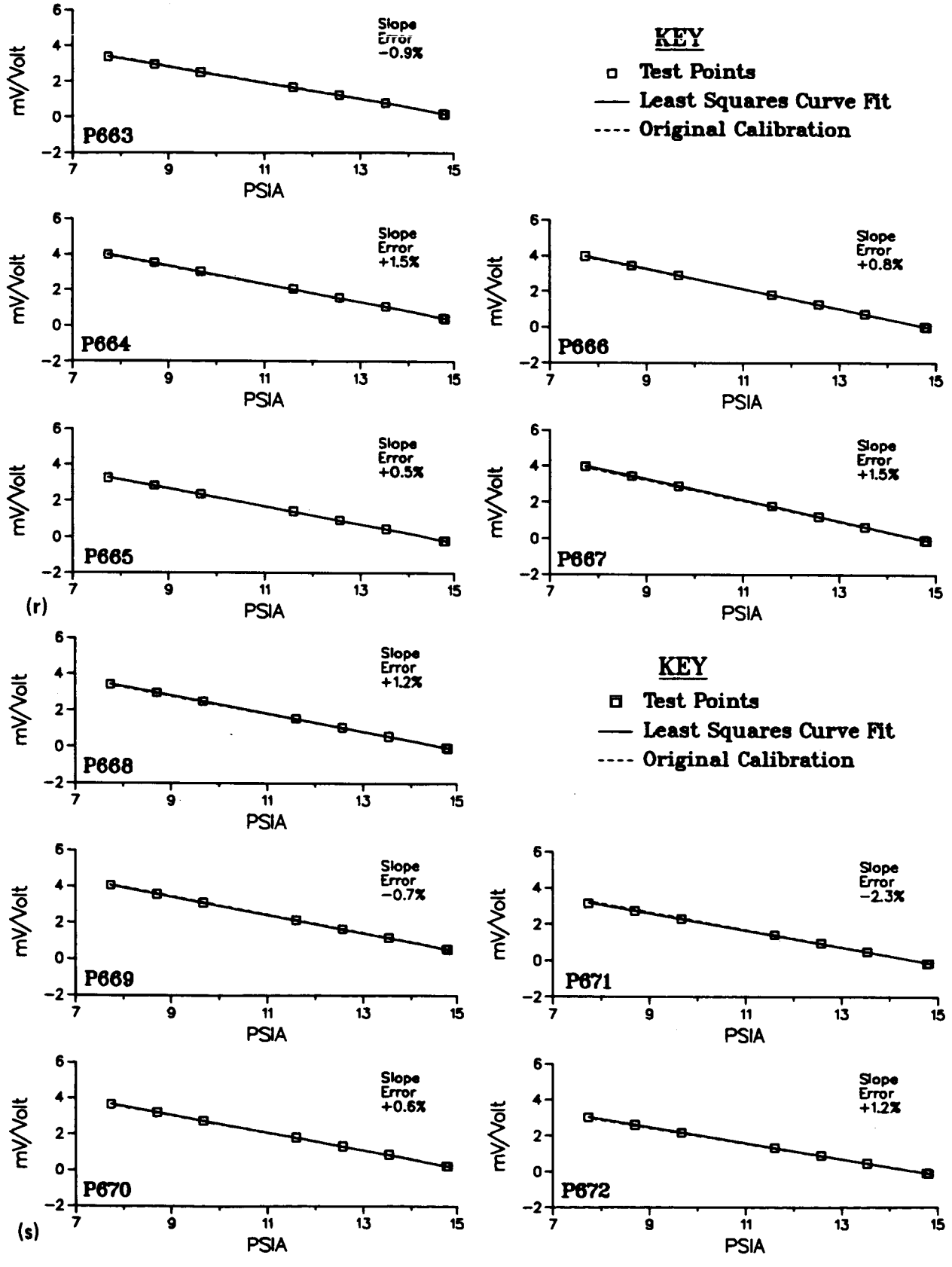

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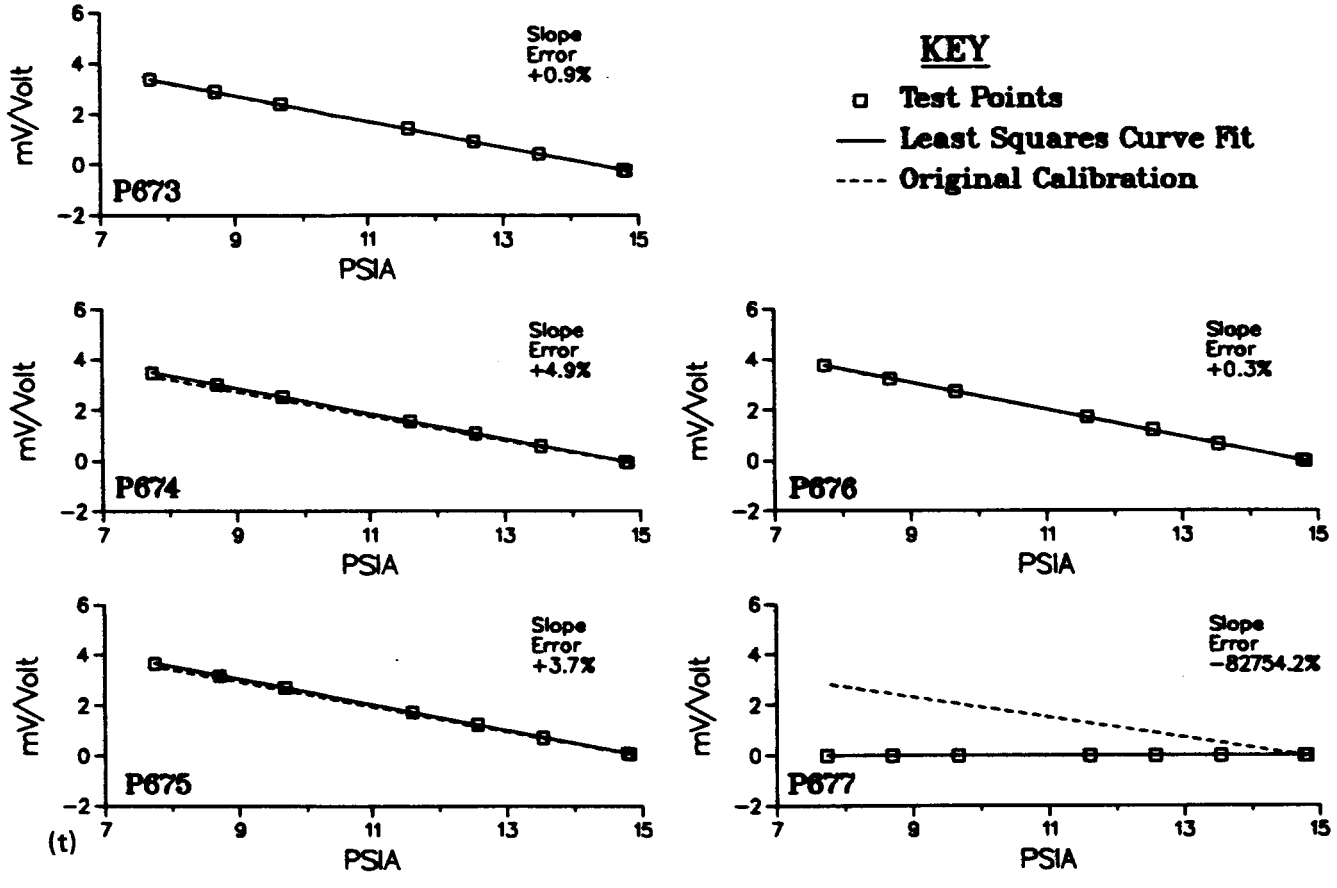

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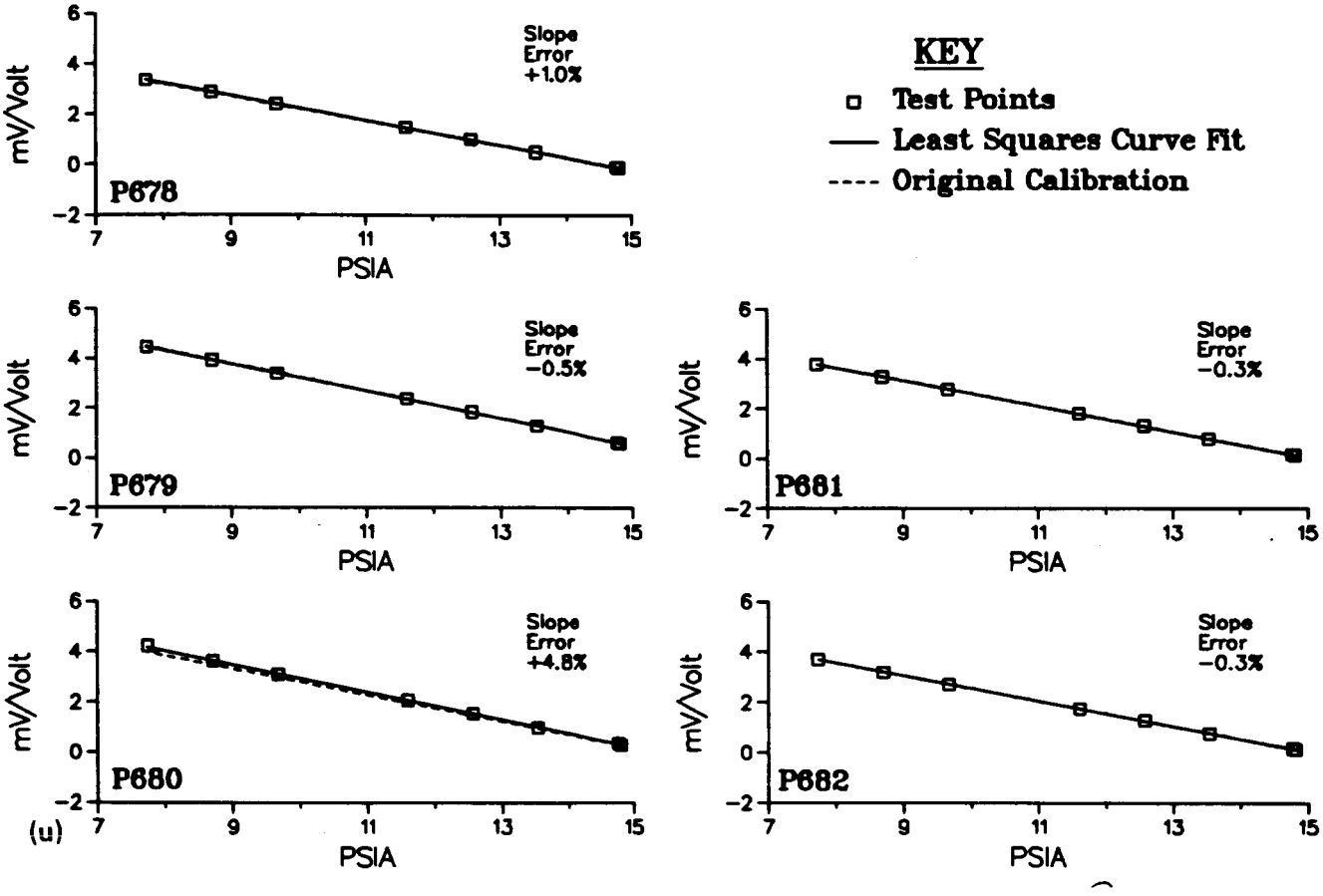

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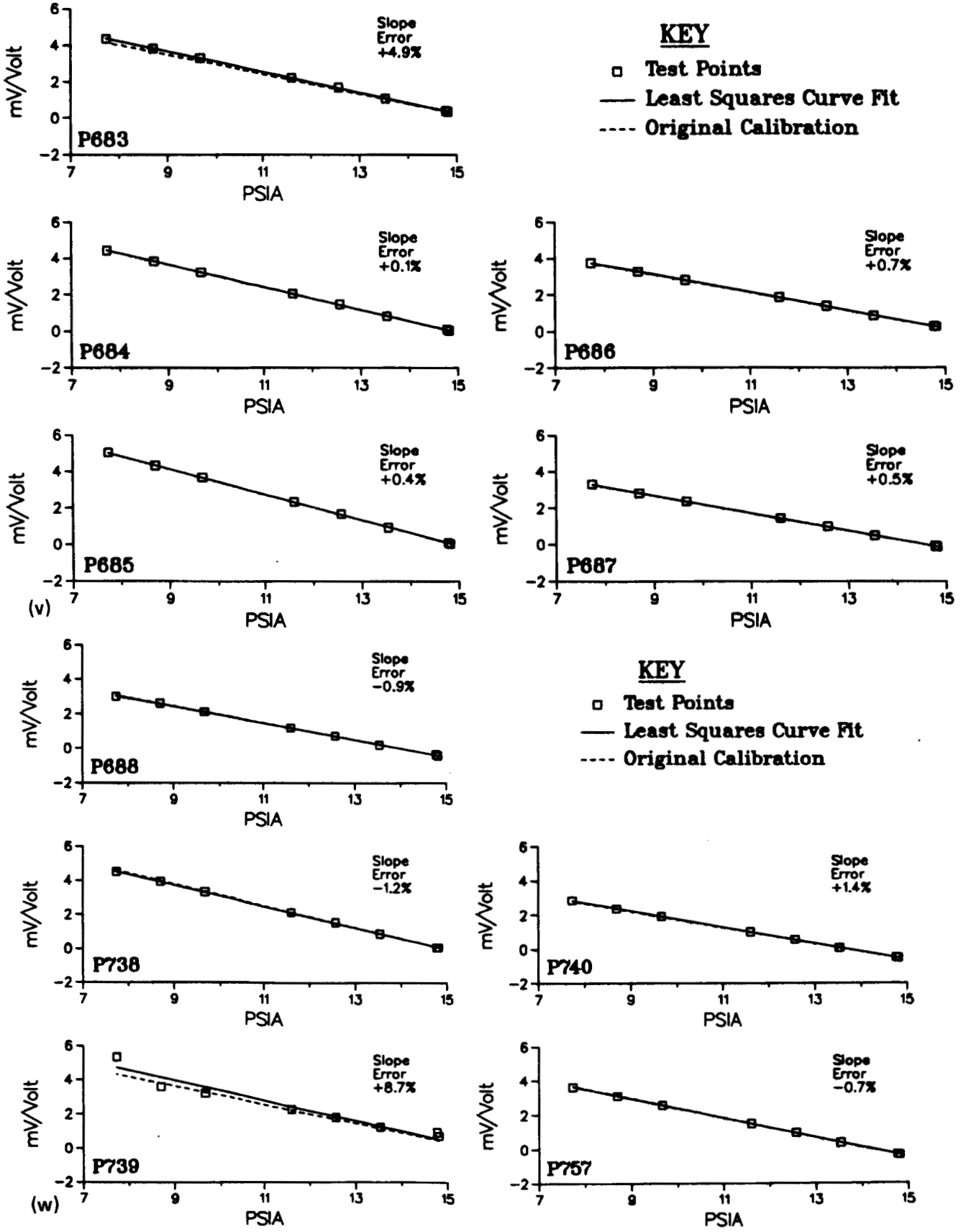

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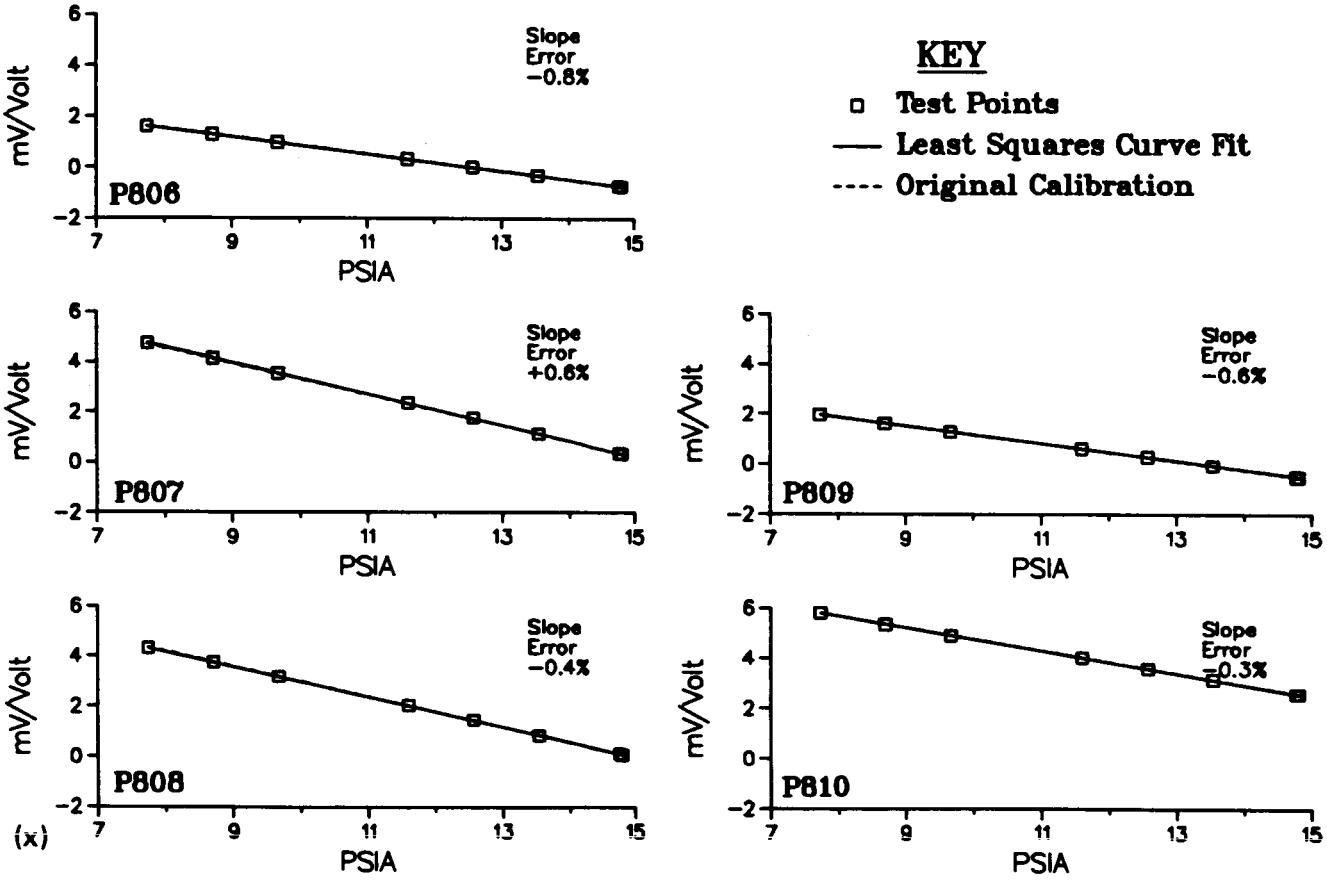

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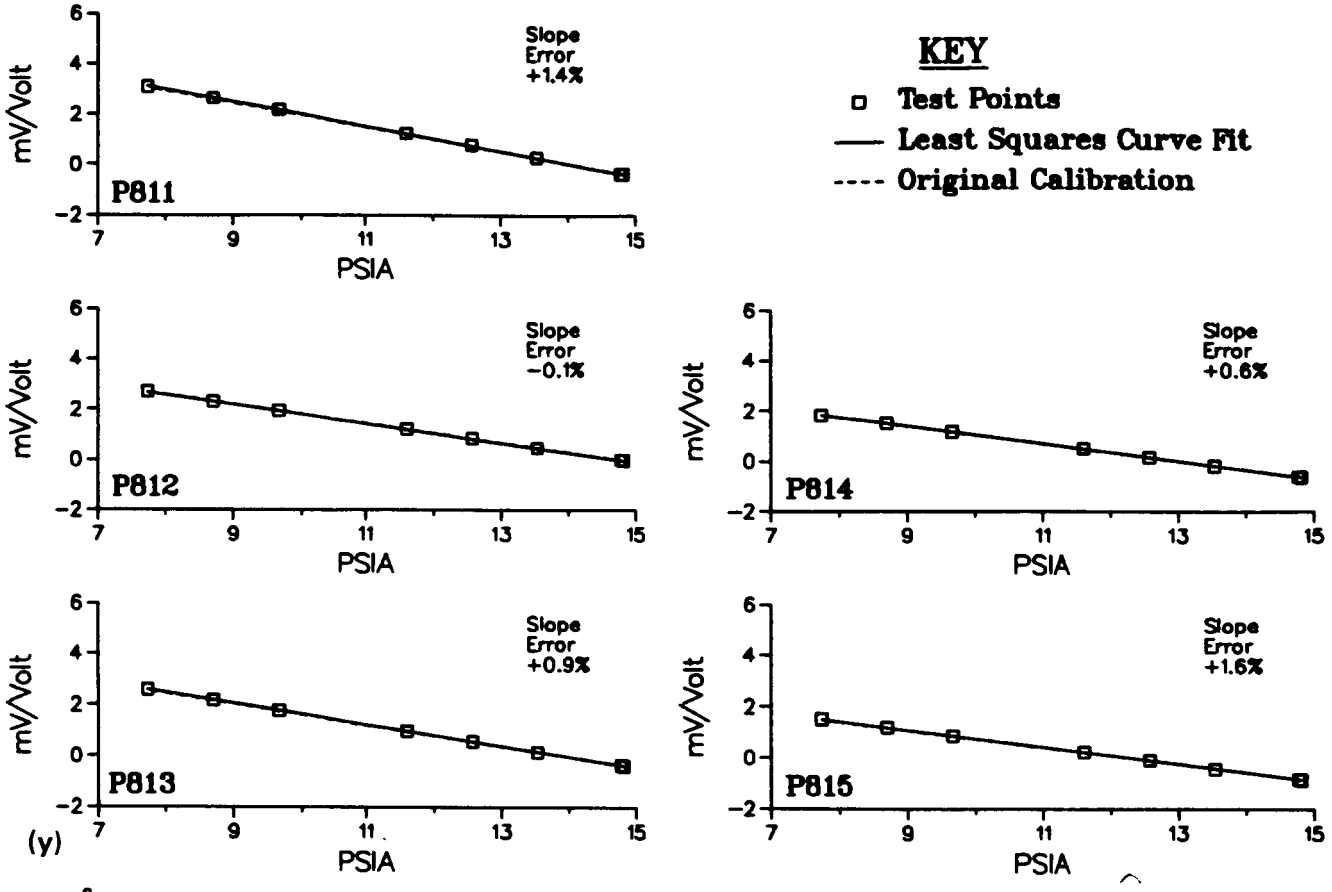

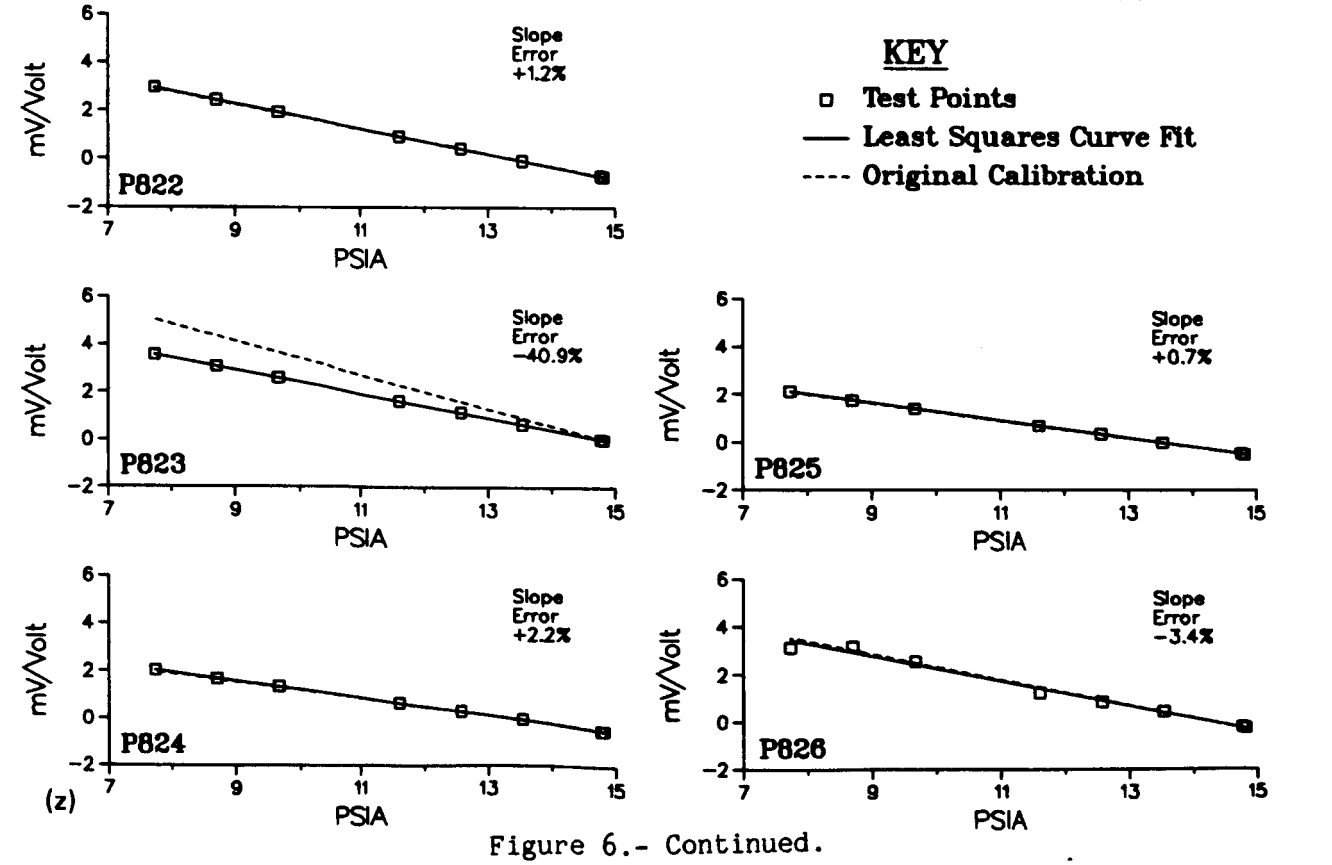

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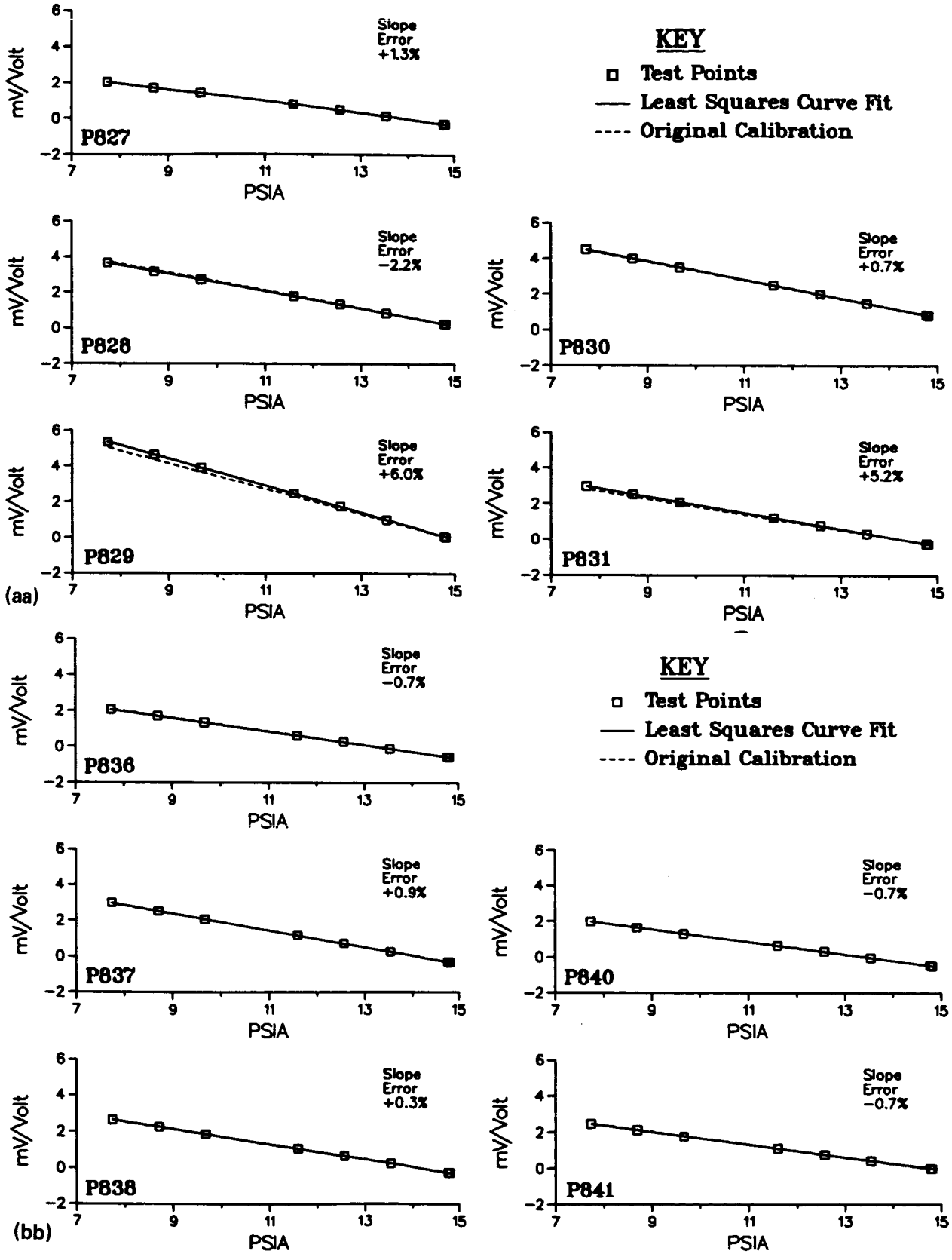

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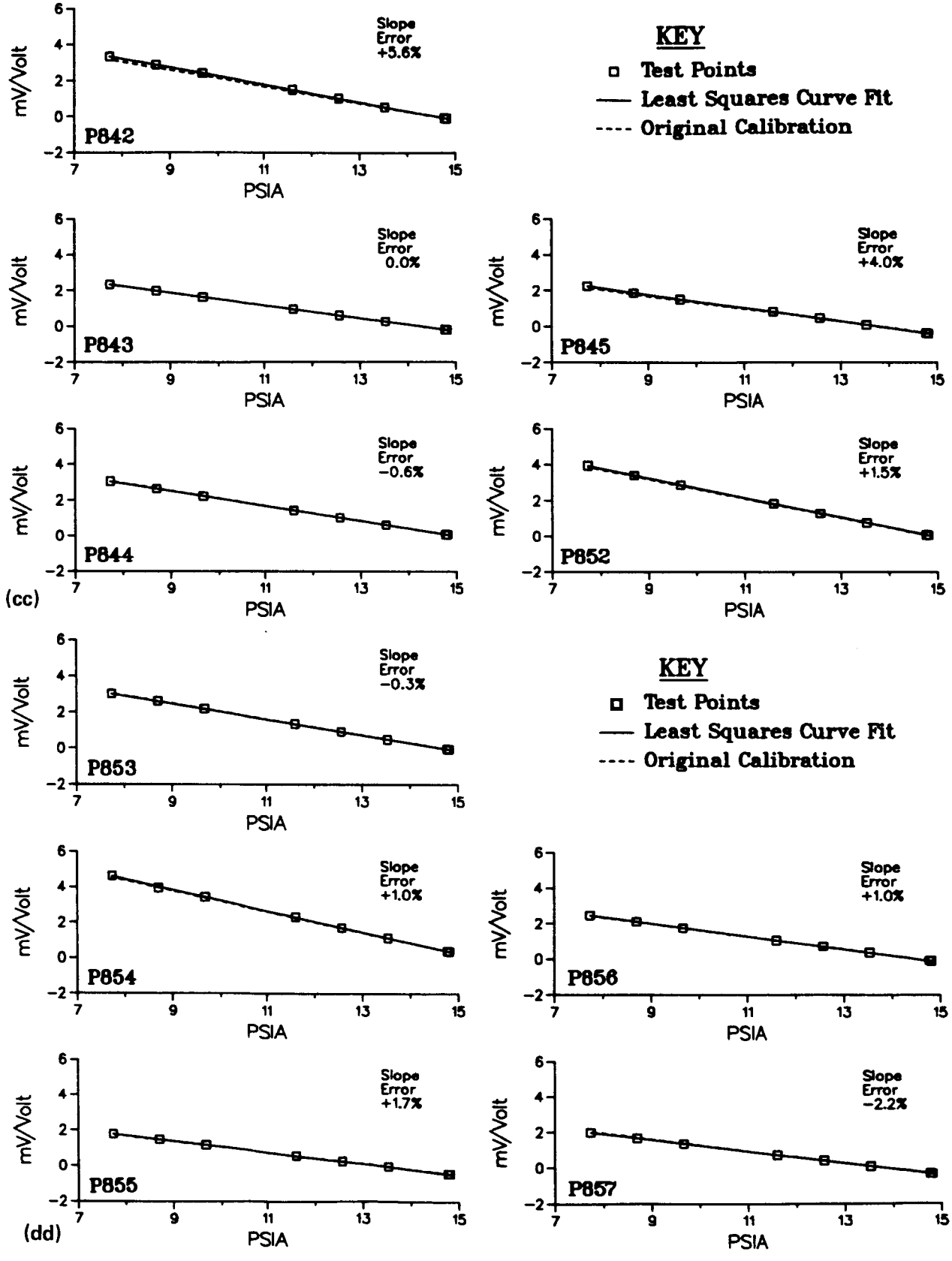

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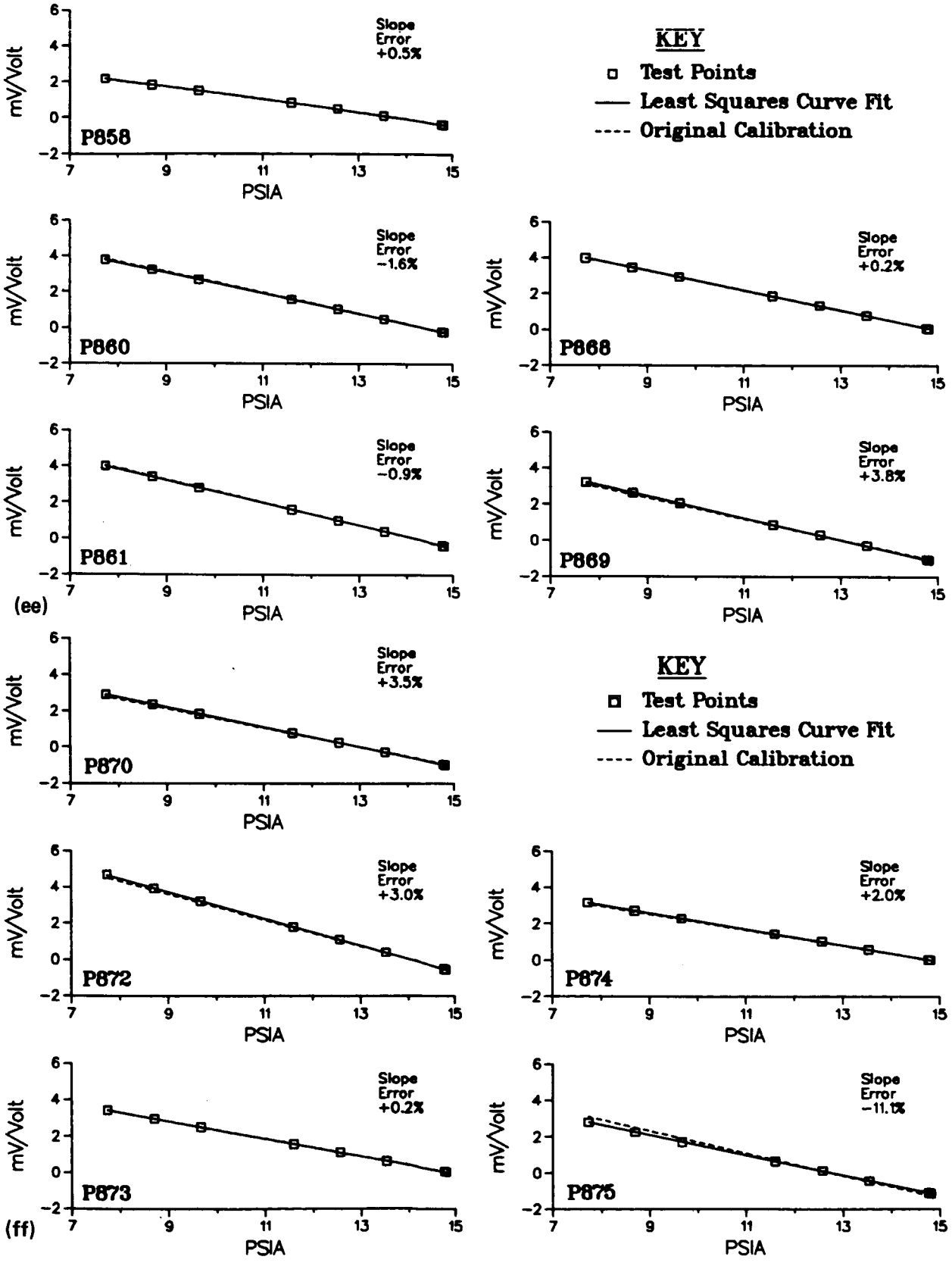

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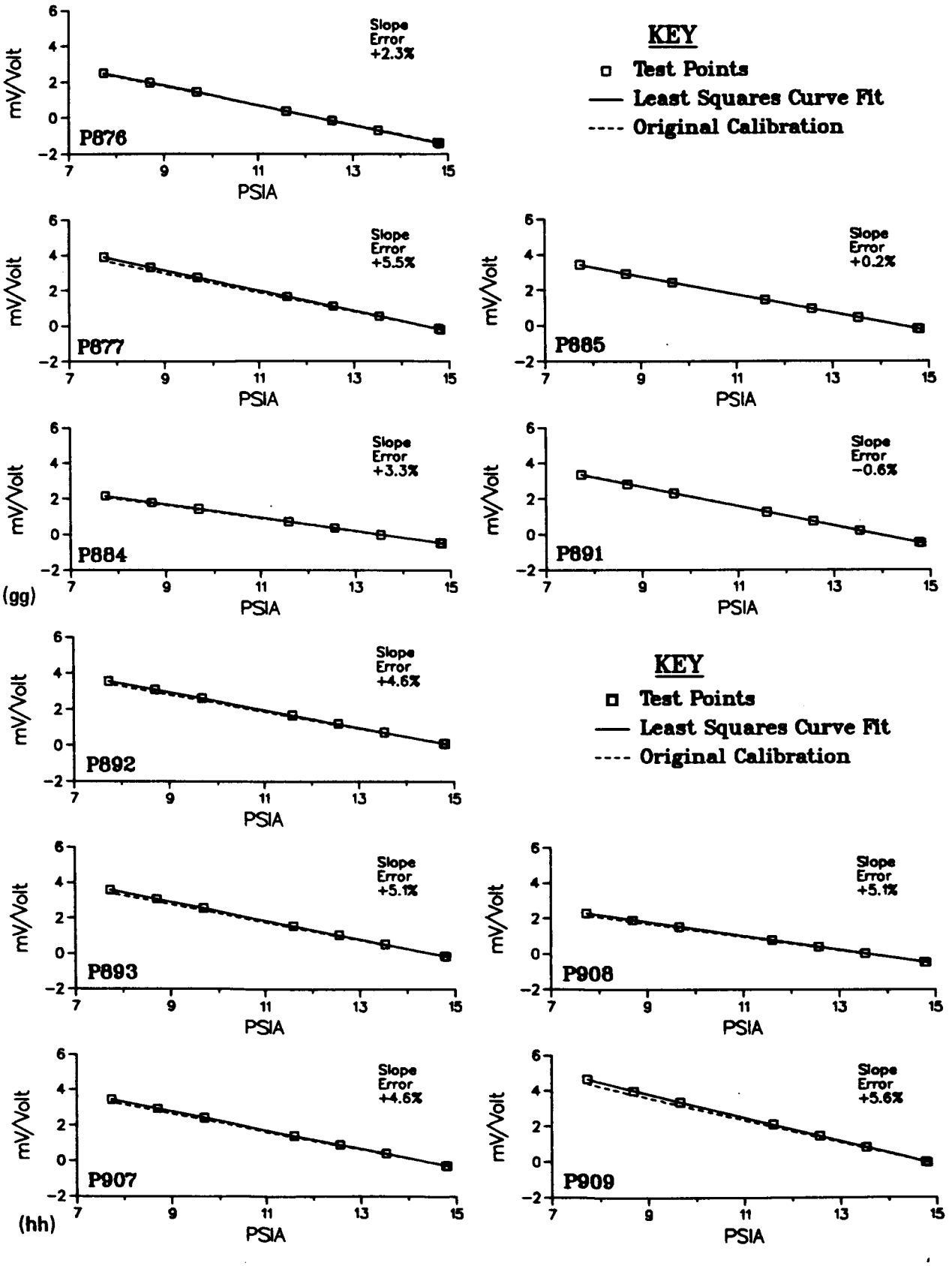

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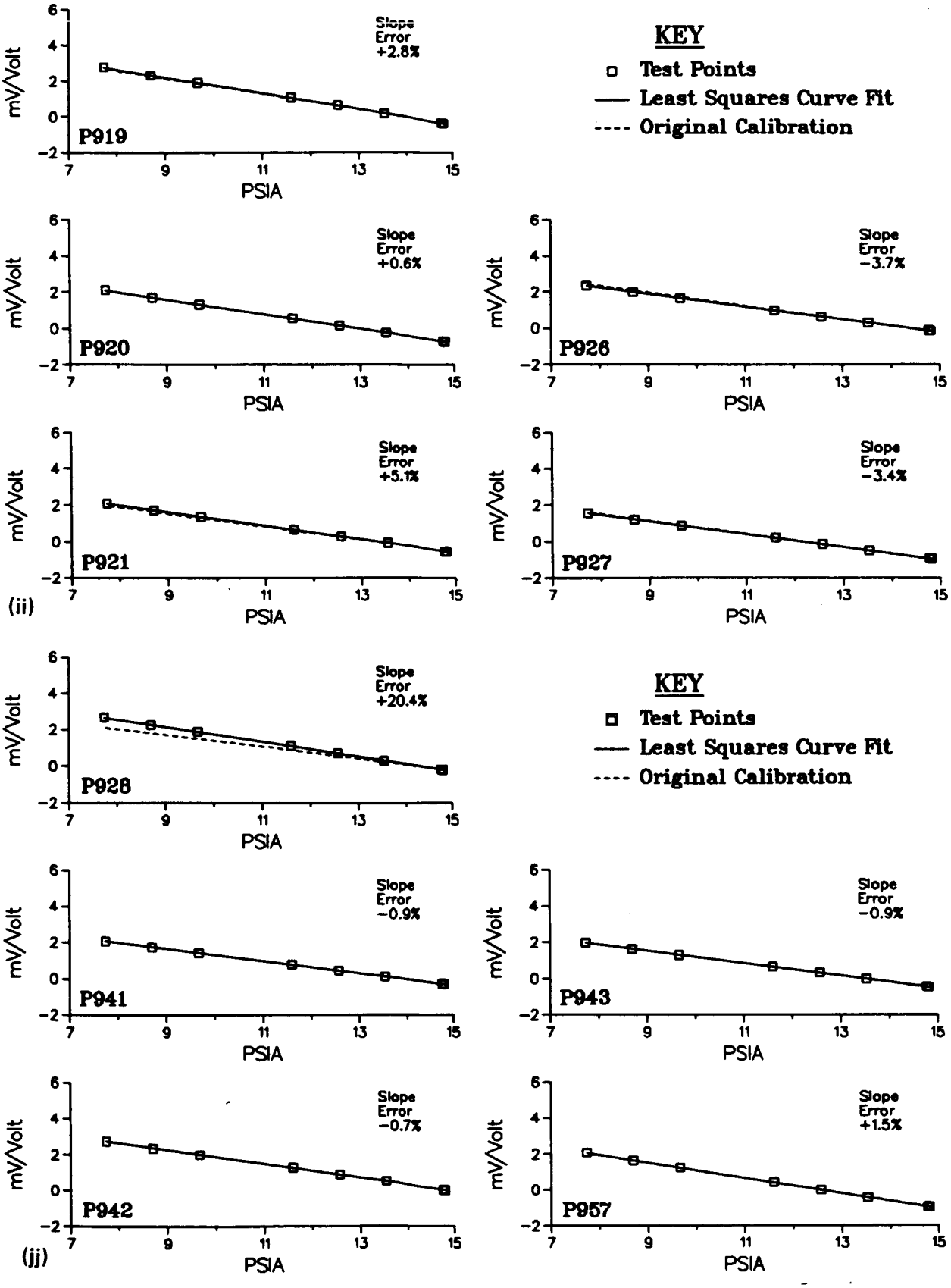

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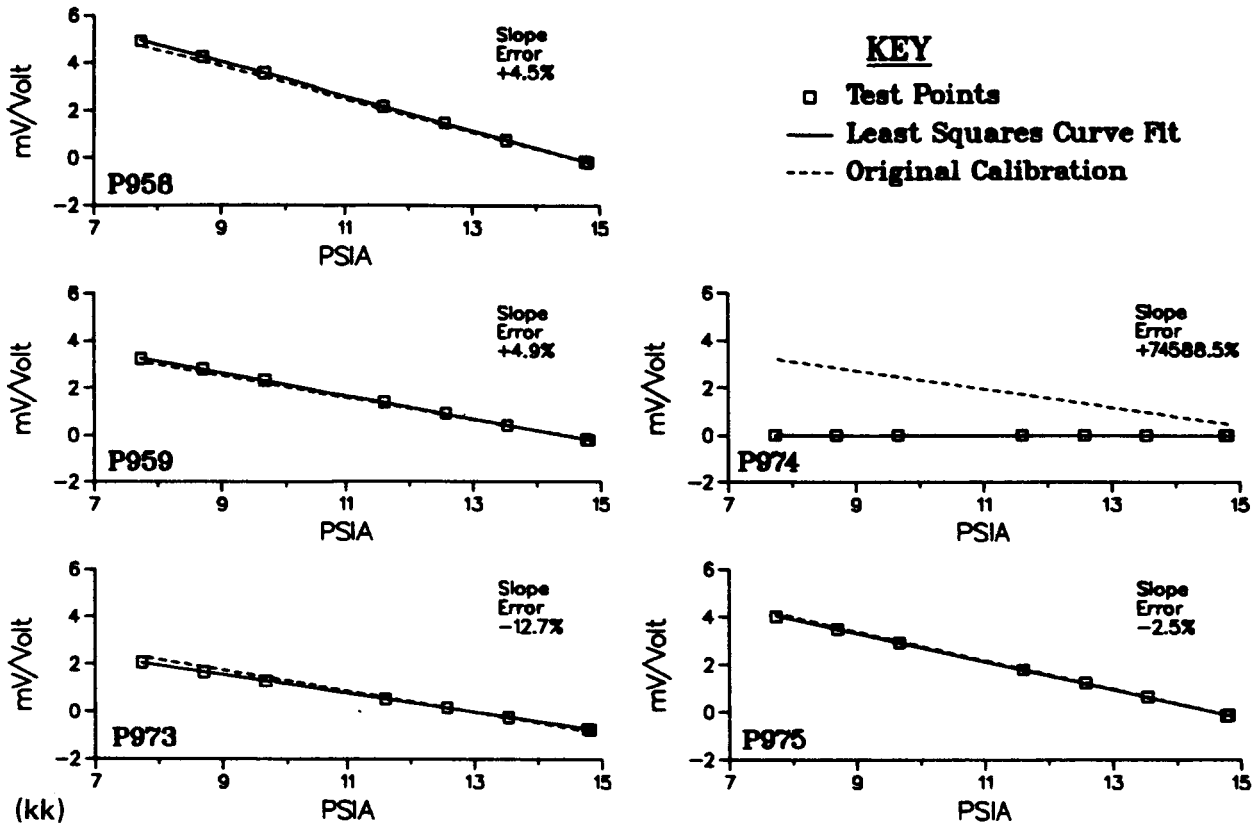

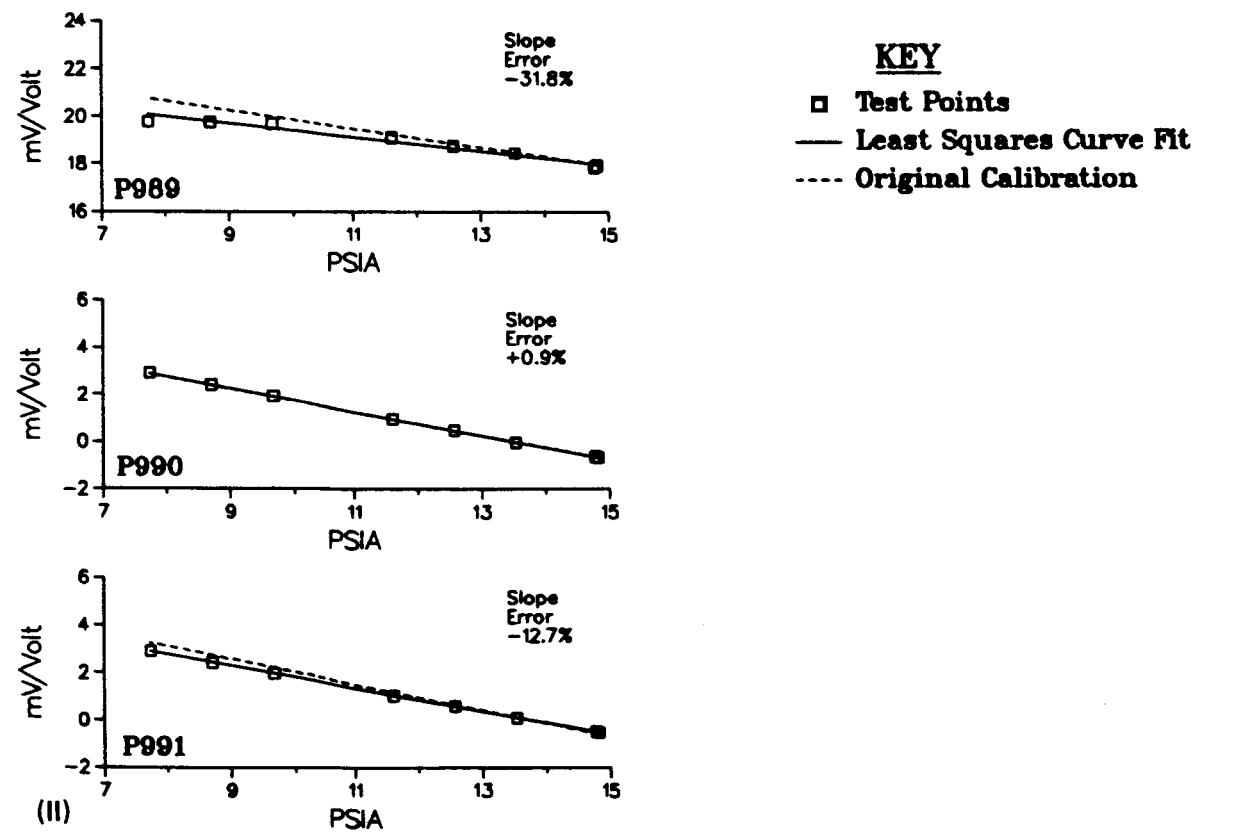

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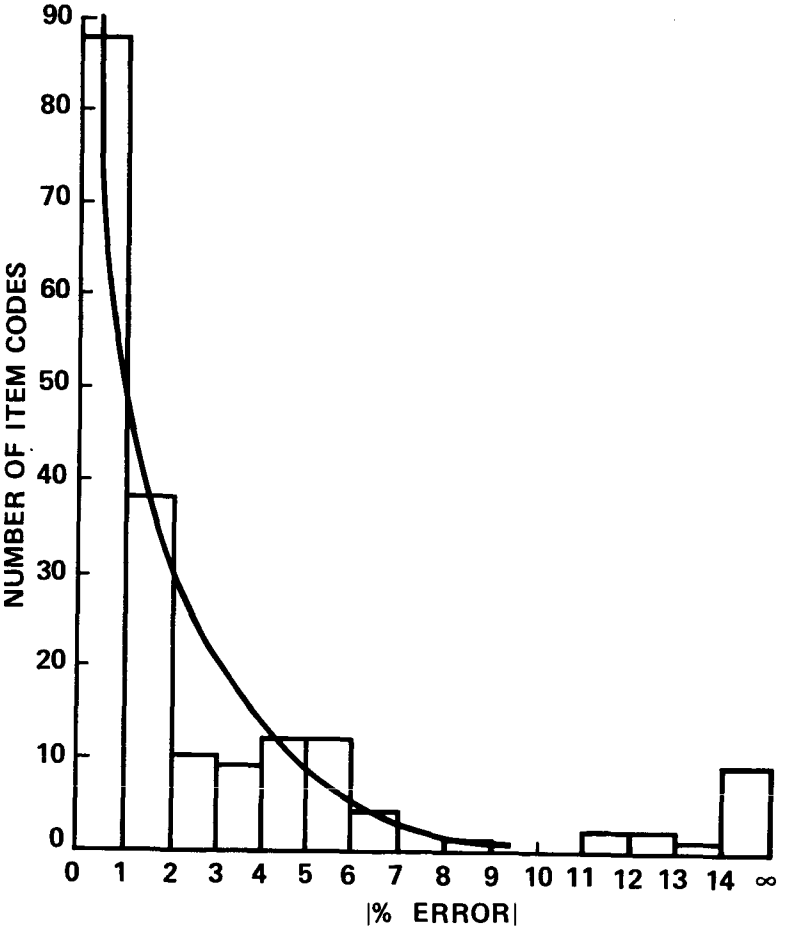


Figure 7.- Absolute percent error distribution.

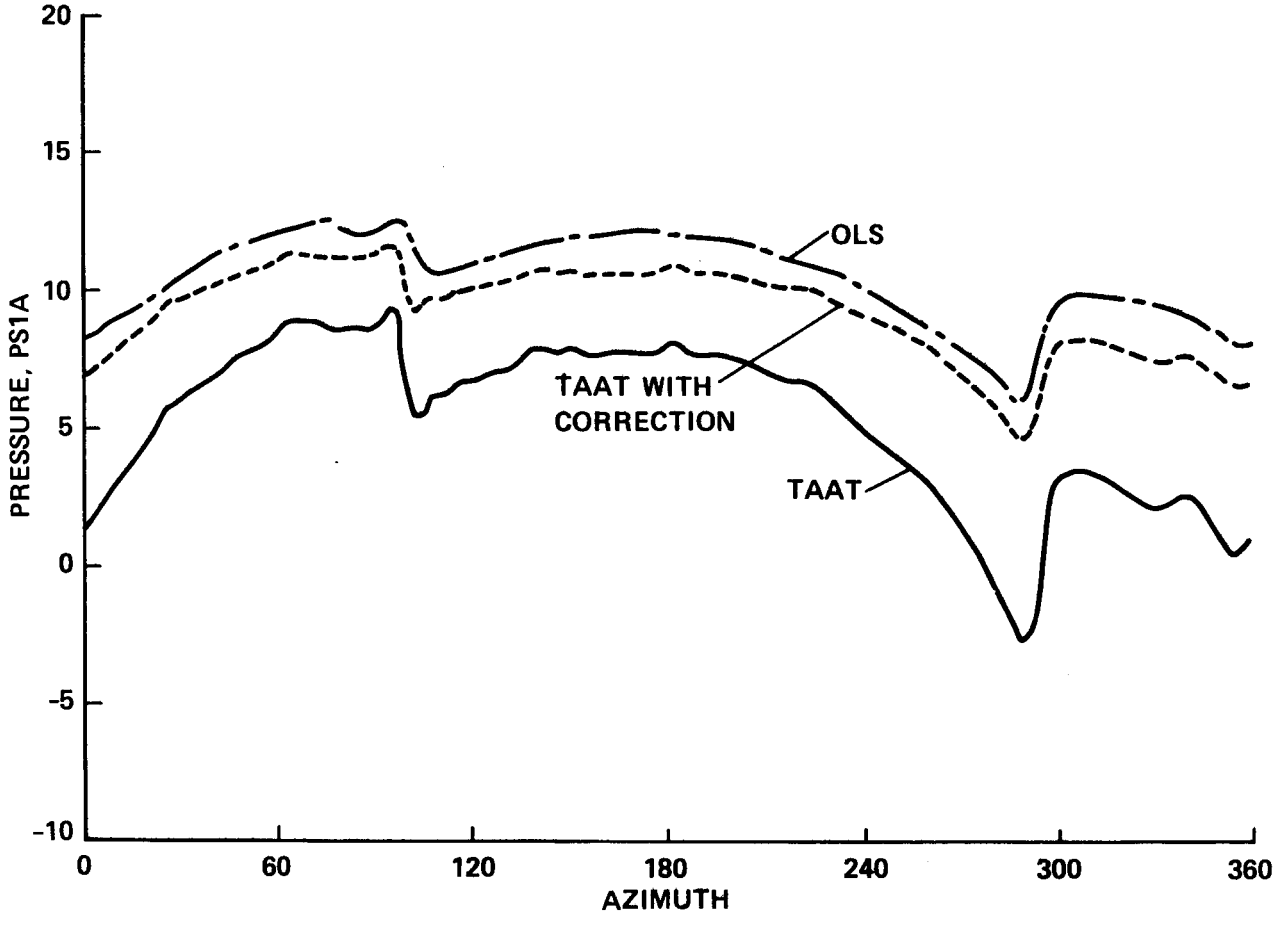


Figure 8.- Measured blade pressure comparison for OLS, TAAT and corrected TAAT for one transducer location and one flight condition (127 knots level flight).

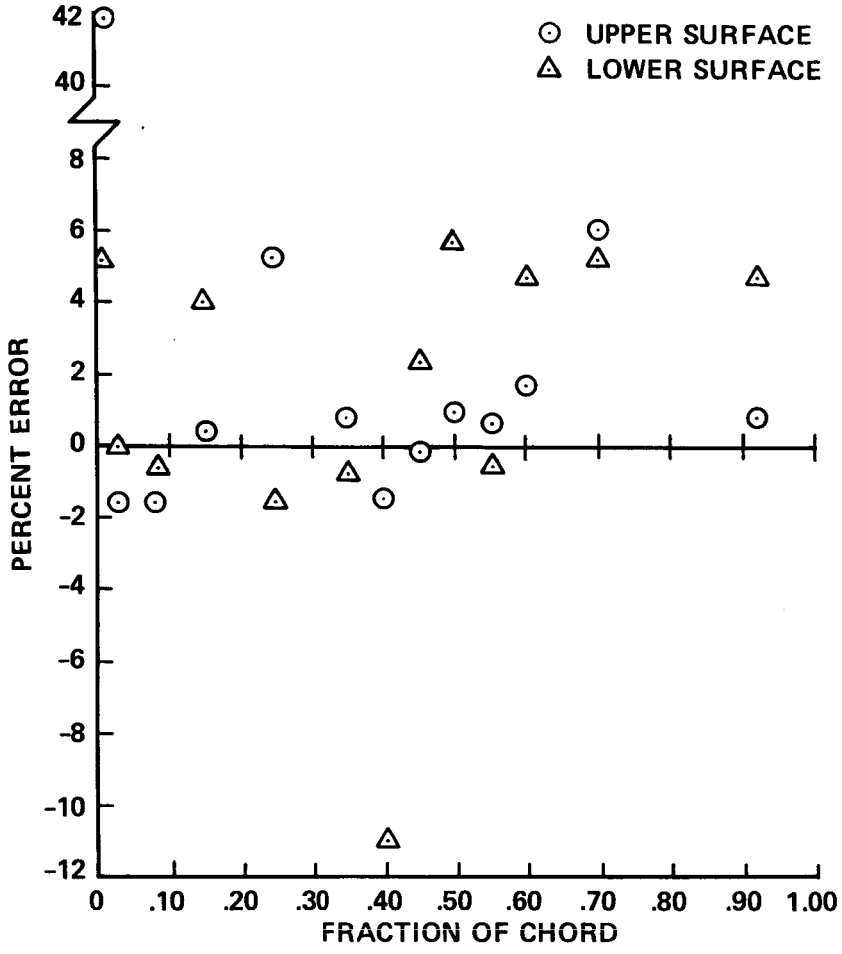
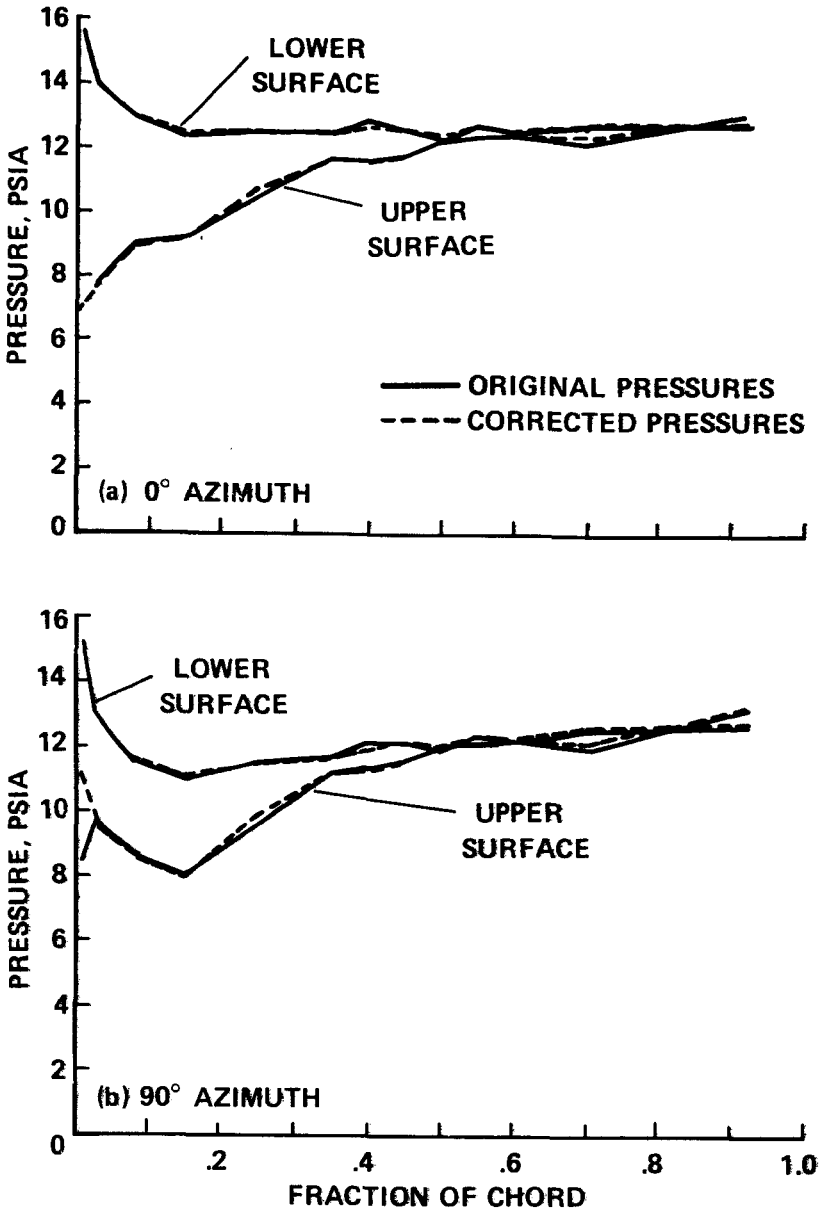


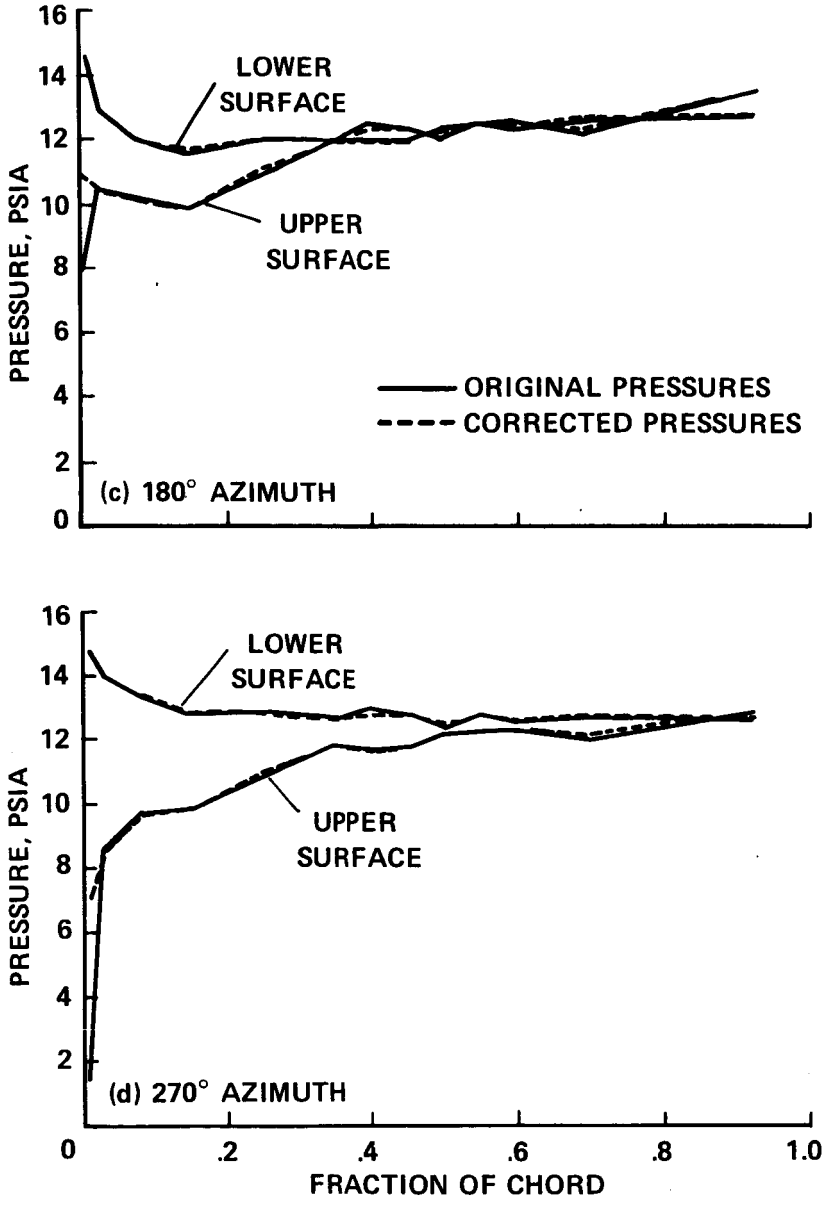
Figure 9.- Pressure transducer errors for 86.4% radius.



(a) 0° azimuth.

(b) 90° azimuth.

Figure 10.- Corrected and uncorrected chordwise pressures for 0.864 r/R.



(c) 180° azimuth.

(d) 270° azimuth.

Figure 10.- Concluded.

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15. Supplementary Notes

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16. Abstract

A calibration test is described that was performed to supplement the normal calibration of the 188 pressure transducers used in the Tip Aerodynamics and Acoustics Test. This calibration led to the identification of 15 transducers which had a slope change of greater than 7% from the initial calibration. The calibration procedure is described and the results presented. The effect of the slope changes on the pressure distributions are described, followed by a method to compensate for these changes.

17. Key Words (Suggested by Author(s))	18. Distribution Statement
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