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CLINTON V. ECKSTROM

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National Aeronautics and
Space Administration

Langley Research Center
Hampton, Virginia 23665

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ABSTRACT

Results from and details of the procedure used to calibrate strain gage bridges for measurement of wing structural loads, shear (V), bending moment (M), and torque (T), at three semispan stations on both the left and right semispans of the ARW-2 wing are presented. The ARW-2 wing has a reference area of 35-square feet, a span of 19-feet, an aspect ratio of 10.3, a midchord line sweepback angle of 25-degrees, and a taper ratio of 0.4. The ARW-2 wing was fabricated using aluminum spars and ribs covered with a fiberglass/honeycomb sandwich skin material. All strain gage bridges are mounted on the aluminum spars or ribs. The resulting loads equations are presented along with an estimate of their accuracy by means of a comparison of computed loads versus actual loads for three simulated flight conditions.

INTRODUCTION

The second Aeroelastic Research Wing (ARW-2) designed and fabricated as a part of the Drones for Aerodynamic and Structural Testing (DAST) program (ref. 1) is a supercritical wing of energy efficient aerodynamic design that was designed structurally, using an integrated design procedure, to include the benefits of active control systems for Maneuver Load Alleviation (MLA) and Gust Load Alleviation (GLA) to reduce structural strength requirements and an active control Flutter Suppression System (FSS) to reduce structural stiffness requirements. The strain gage bridges, located at three stations on both the left and right semispans, are used to get measurements of structural loads, shear (V), bending moment (M), and torque (T) to: (1) assure that safe loading levels are not exceeded during testing, (2) provide data for evaluation of the active control systems, and (3) provide data for the evaluation of the effects of wing flexibility on aerodynamic loads measurements obtained over a range of Mach number and dynamic pressure test conditions.

The purpose of this paper is to document the procedures used to obtain the equations which define the relationship between structural loads, V, M, and T, and the strain gage bridge outputs and to provide an evaluation of the accuracy of the equations by comparison of computed versus actual loads for three loading conditions.

SYMBOLS

L_i	ith general load (V, M, or T)
M	bending moment, inch-pounds
T	torsion, inch-pounds
V	shear, pounds
β_{ij}	coefficient of jth bridge for ith load equation, load/mV
μ_j	output of jth bridge, mV
X_W, Y_W	axis system oriented perpendicular and parallel to the wing 62-percent chordline (rear spar) with origin at the vehicle centerline
X_{W_I}, Y_{W_I}	inboard strain gage bridge station reference axis system oriented perpendicular and parallel to the wing 62-percent chordline with origin at Y_W = 21.4-inches
X_{W_M}, Y_{W_M}	midwing strain gage bridge station reference axis system oriented perpendicular and parallel to the wing 62-percent chordline with origin at Y_W = 60.4-inches
X_{W_O}, Y_{W_O}	outboard strain gage bridge station reference axis system oriented perpendicular and parallel to the wing 62-percent chordline with origin at Y_W = 96.5-inches

WING AND INSTRUMENTATION

Wing

The ARW-2 is a high aspect ratio, low sweep angle wing designed for energy efficiency at a cruise Mach number of 0.8. The airfoil shapes and wind tunnel test results are presented in references 2 and 3. The general arrangement of the ARW-2 wing mated to a BQM-34F drone aircraft is shown in figure 1.

The wing structure is like that of ARW-1 (ref. 4) in that it consists of a wing center section and right and left wing semispan panels with removable leading and trailing edges and tip sections. The center section mounts on the BQM-34F fuselage at the same position as the standard target drone wing and uses the same attachment bolt locations. The outboard ends of the center section are in a plane normal to the 62-percent chordline of the semispan panels.

The primary structure of the wing semispan panels consists of a front spar at the 25-percent chordline, a rear spar at the 62-percent chordline, and an auxiliary spar located inboard in the trailing edge extension (yehudi) area as a support for the inboard control surfaces. Ribs are located perpendicular to the rear spar every 13.2 inches with the exception of a special streamwise tip rib that also functions as an outboard spar end fitting. The upper and lower skin surfaces located between the front and rear spars are riveted and glued in place except for a section on the upper surface skin located over the first and second inboard cavities between ribs (locations used for mounting wing instrumentation packages) which is held in place with removable screw fasteners. The wing leading and trailing edge panels, the wing tip fairing and the upper and lower skin panels between the rear spar and the auxiliary spar are also held in place with removable screw fasteners. The wing semispans are joined to the wing center section at the front and rear spar inboard end fittings with four tension bolts at each location.

The wing center section was machined from a thick aluminum plate in a configuration to provide a high degree of stiffness without consideration of minimum weight. The spars and ribs were machined from 7075-T73 aluminum alloy. The wing skins are of fiberglass material with honeycomb panels sandwiched between the middle two layers of fiberglass for areas of skin not located over the spars or ribs. The number of layers of fiberglass used to make the skins varied from 36 at the inboard end to 27 at the outboard end with approximately 25-percent of the layers at +/-45 degrees orientation.

Wing Mounting

For the calibration procedure reported on herein the left and right semispans were calibrated separately with the mounting being to a backstop rather than to the wing center section attached to a fuselage as was done for ARW-1 (ref. 4). The left semispan was mounted directly to a backstop using a plate which had a hole pattern similar to that of the wing center section. The right semispan was mounted to the backstop using a half center section fabricated for later use as the wall mounting method for a wind tunnel test (ref. 5) using the right semispan. For both semispans the assembly was mounted upside down so that inert masses (shot bags) would apply forces in the proper direction for most loading conditions as noted on figures 2 and 3. An overhead frame with a cable-pulley arrangement as shown in figures 4 and 5 was used to achieve negative loadings when required.

Strain Gage Bridges

Each semispan was equipped with a primary set of 23 strain gage bridges at 15 locations each as shown on figures 6 and 7 and also with a second identical set of backup bridges on each semispan. The individual strain gages for all bridges were mounted on the vertical web of either the spars or the ribs between front and rear spars. Bridges intended for the measurement of shear loads were mounted with individual gages arranged in an x-pattern about the centerline of the spar vertical web as shown in figure 8 (gages for the backup bridge are mounted directly over the primary bridge). Bridges intended for measurement of bending moment loads were mounted with individual gages located on the spar vertical webs adjacent to the spar caps, two near the upper spar cap and two near the lower spar cap as also shown in figure 8 (gages for the backup bending moment bridge are located side by side with those for the primary bridge). The gages for the bending moment bridges were not mounted on the spar caps because previous experience indicated that installation and removal of screw fasteners used to attach the wing leading and trailing edge skins caused large shifts in the no-load output of the bridges. Also previous experience in working with fiberglass skin materials indicated that, for bridges mounted directly to the fiberglass skins in an arrangement satisfactory for the measurement of torsion loads, the zero or no-load drift was excessive (unsuitable for flight testing). As a result bridges arranged for the measurement of shear and bending moment loads were also used for determining torsion loads with a somewhat less than satisfactory result (ref. 4). In an effort to improve the capability to measure torsion loads on ARW-2, strain gage bridges were mounted in the middle of each rib, as noted in figures 6 and 7, in an x-arrangement as shown in figure 9. All of the strain gage bridges were subjected to an input excitation of 10 volts.

CALIBRATION PROCEDURE

The calibration procedure consisted of: (1) measuring the electrical imbalance of each of the strain gage bridges for a large variety of wing loading conditions, described in terms of shear (V), bending moment (M), and torsion (T) for each wing semispan station of interest, and (2) then using a multiple linear stepwise regression analysis program to establish loads equations for V, M, and T as a function of the electrical imbalance of the selected strain gage bridges. The accuracy of the selected loads equations were checked by performing three additional wing loadings simulating specific flight conditions and using the measured electrical imbalance of the bridges as input to the loads equations and comparing the calculated values of V, M, and T with the magnitudes of V, M, and T loads actually applied.

Input Loading Conditions

A single point and two multipoint loading procedures, each with a large number of individual steps, were performed to obtain strain gage bridge output measurements for the development of loads equations for V, M, and T. Figure 10 shows the locations on the wing right semispan where loads were applied. The locations and numbering system for application of loads to the wing left semispan were similar. Table I presents the X_W and Y_W position of each of the locations shown in figure 10 with respect to the wing reference axis system and also the Y position in the inboard, midwing and outboard strain gage bridge reference axis systems. (The X positions in all axis systems are the same.)

Single Point Loadings.- Single point step loadings were applied individually at each of the loading locations shown in figure 10. The loads applied to the wing were in the form of 25-pound lead shot bags or scale weights hung from the inverted wing by means of cords and special brackets attached to the wing at the appropriate locations as shown in figure 11. Table II(a) through II(f) lists the maximum single point wing loadings in terms of shear (V), bending moment (M), and torsion (T) and the resulting measured electrical imbalance or output of each of the strain gages for each wing station for both the right and left semispans. Influence coefficient plots of the data from Table II are presented as figures 12 and 13 for the right and left semispans respectively.

Bending Moment Multipoint Loadings.- The multipoint loading procedure used to apply large bending moments for calibration purposes is listed in Table III. It is a 48-step procedure that used 18 of the 22 loading points. All chordwise loads at each semispan station were applied or removed before a recording of the strain gage outputs was obtained. The series of eight loading steps were repeated three times with all previous loads remaining in place so that the maximum loading occurred at the 24th step. By following the same sequence during the unloading process an additional 21 distinct loading conditions were achieved along with two repeats and a final zero loading condition. Table IV lists the wing loadings and the measured electrical imbalance or output of the strain gage bridges.

Torsion Multipoint Loadings.- The multipoint loading procedure used to apply large torsion loads to the wing for calibration purposes is listed in Table V. It is also a 48-step procedure similar to that just described. The negative loads needed to achieve a torsion loading were applied using a cable pulley arrangement described earlier (figs. 4 and 5). Table VI lists the wing loadings and the measured output of the strain gage bridges for the torsion multipoint loading conditions.

Loads Equations

Loads equations for calculating wing loadings as a function of the output of selected strain gage bridges were determined by means of the standard regression analysis methods described in reference 6. The load equations have the form:

$$L_i = \begin{bmatrix} \beta_{11} & \beta_{12} & \beta_{13} & - & - & - & \beta_{1j} \\ \beta_{21} & \beta_{22} & \beta_{23} & - & - & - & \beta_{2j} \\ - & - & - & - & - & - & - \\ - & - & - & - & - & - & - \\ \beta_{i1} & \beta_{i2} & \beta_{i3} & - & - & - & \beta_{ij} \end{bmatrix} \begin{Bmatrix} \mu_i \\ \mu_2 \\ - \\ - \\ \mu_j \end{Bmatrix}$$

where L_i is the loading of interest, β is the coefficient of the jth bridge for the ith load, and μ is the output of the jth bridge.

The regression analysis can be performed using one or as many of the strain gage bridges as are available at each wing station. A stepwise regression analysis procedure (ref. 7) was used which selects the best single strain gage bridge, then goes on to select a second bridge that when used with the first bridge selected, gives the best combination of two bridges and continues on in the same manner to include as many bridges as are available at the specified semispan station as long as any of the remaining bridges met the minimum F-value and tolerance level statistical criteria for entry.

For the inboard wing stations (left and right semispans) the loads and strain gage bridge output data from the two multipoint loadings were combined and used as the input to the regression analysis procedures. For the midwing and outboard stations on each semispan the single point loading data as well as the data from the two multipoint loadings were used as the input for the appropriate regression analysis. Table VII indicates which bridges were selected for each load measurement and lists the associated load coefficients (β_{ij}) and probable errors along with the standard error of estimate for the equation and the multiple correlation coefficient which is an indication of how well the calibration data fit the linear regression equation selected. Figures 14 and 15 provide a visual presentation of how well the selected loads equations predict the loads data from which they were derived. These figures present load as calculated using the selected loads equations as a function of the actual applied load for the single point loading and both multipoint loadings. For a perfect correlation coefficient of 1.00 all the data would fall on the straight line with a one to one relationship between applied load and calculated load.

Check Loading Conditions

Three single step distributed loading procedures which simulated design flight test conditions were also performed to obtain data, independent of that used in the regression analysis procedure, for evaluation of the accuracy of the derived loads equations.

Design Cruise Distributed Loading.- The distributed loading that represented the design cruise pressure loading, used to establish the wing construction jig shape, is defined in Table VIII. All 22 loading points were used and all loads were applied before the strain gage bridge outputs were recorded.

Design Bending Moment Distributed Loading.- A distributed loading that represented the spanwise bending moment distribution used for the wing strength design is defined in Table IX. This loading was also the "proof loading" to show that the wing had adequate strength for flight testing.

Torsion Distributed Loading.- In order to provide a check of the torsion equations a distributed torsion loading was also defined, as shown in Table X, which represented straight and level flight at high dynamic pressures where the aircraft angle of attack would be very low. The overhead pulley system was used to achieve the negative loads required.

Check Loading Results

The wing loadings and strain gage bridge outputs for the distributed loadings are presented in Table XI. A comparison of the loads calculated for the distributed loadings compared to the actual applied loads and the percent error in prediction are presented in Table XII. The results indicate that the selected loads equations did quite well for shear and bending moment loads but not so well for torsion loads.

CONCLUDING REMARKS

The ARW-2 Aeroelastic Research Wing consists of conventional spars and ribs covered with fiberglass/honeycomb sandwich skins. Strain gage bridges arranged for measurement of shear and bending moment loads at three semispan stations were installed on both the right and left semispans. Bridges arranged in an x-pattern were also installed on the rib sections between the front and rear spars in an attempt to improve measurement of torsion loads. Both single point and multipoint loadings were used as input to the stepwise regression analysis procedure used to derive loads equations for shear (V), bending moment (M), and torsion (T) at each wing station. Comparison of loads predicted using the derived loads equations with actual applied loads for three simulated flight conditions indicated excellent results for shear and bending moment loads with somewhat less satisfactory results for torsion loads.

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TABLE I.- LOAD APPLICATION LOCATIONS.

Location number	X_W (in)	Y_W (in)	Y_{W_I} (in)	Y_{W_M} (in)	Y_{W_O} (in)
1	-2.55	117.3	95.9	56.9	20.8
2	2.96	119.4	98.0	59.0	22.9
3	-2.74	111.6	90.2	51.2	15.1
4	2.73	111.6	90.2	51.2	15.1
5	-2.94	105.0	83.6	44.6	8.5
6	2.91	105.0	83.6	44.6	8.5
7	-3.09	98.4	77.0	38.0	1.9
8	3.12	98.4	77.0	38.0	1.9
9	-3.31	91.8	70.4	31.4	---
10	3.24	91.8	70.4	31.4	---
11	-3.62	78.6	57.2	18.2	---
12	3.62	78.6	57.2	18.2	---
13	-4.01	65.4	44.0	5.0	---
14	3.99	65.4	44.0	5.0	---
15	-4.33	52.2	30.8	---	---
16	4.34	52.2	30.8	---	---
17	-4.70	39.0	17.6	---	---
18	4.71	39.0	17.6	---	---
19	11.23	39.0	17.6	---	---
20	-5.07	25.8	4.4	---	---
21	5.01	25.8	4.4	---	---
22	14.19	25.8	4.4	---	---

TABLE II.- WING LOADINGS AND STRAIN GAGE BRIDGE OUTPUTS FOR SINGLE POINT APPLIED LOADS.

A.- Right semispan, inboard station.

Loading location	-- Applied Loading -- Shear	Bending	Torque	Strain Gage Bridge Output, mV μ1	μ2	μ3	μ4	μ5	μ6	μ7	μ8	μ17	μ18
1	100	9590	-255	.032	2.765	.241	2.618	-1.267	.517	-.580	1.810	-.125	.018
2	100	9800	296	-.070	2.573	.300	2.549	-1.127	.513	-.459	1.724	-.165	-.052
3	100	9020	-274	.058	2.581	.249	2.431	-1.175	.476	-.568	1.669	-.122	.031
4	100	9020	273	-.048	2.504	.333	2.493	-1.083	.498	-.407	1.640	-.172	-.074
5	100	8360	-294	.083	2.417	.251	2.270	-1.089	.439	-.523	1.525	-.114	.026
6	100	8360	291	-.026	2.317	.334	2.317	-.987	.460	-.350	1.489	-.168	-.077
7	100	7700	-309	.090	1.916	.218	1.793	-.861	.343	-.413	1.189	-.094	.018
8	100	7700	312	-.009	2.129	.342	2.144	-.894	.423	-.286	1.292	-.164	-.100
9	100	7040	-331	.133	2.046	.254	1.917	-.911	.361	-.422	1.231	-.101	.016
10	100	7040	324	.010	1.948	.344	1.974	-.796	.388	-.224	1.191	-.160	-.112
11	100	5720	-361	.180	1.689	.255	1.565	-.731	.285	-.317	.938	-.088	.004
12	100	5720	362	.048	1.571	.354	1.624	-.608	.315	-.096	.890	-.155	-.138
13	150	6600	-602	.351	2.003	.386	1.817	-.837	.318	-.316	.972	-.110	-.016
14	150	6600	599	.129	1.811	.549	1.932	-.630	.363	.063	.897	-.220	-.220
15	150	4620	-650	.423	1.457	.391	1.278	-.572	.201	-.156	.533	-.141	-.162
16	150	4620	651	.187	1.246	.558	1.411	-.347	.253	.261	.466	-.201	-.107
17	150	2640	-705	.512	.905	.376	.741	-.311	.093	-.049	.181	-.172	-.617
18	150	2640	707	.228	.698	.583	.904	.206	.122	.510	-.150	-.071	.526
19	75	1320	842	.027	.300	.355	.472	.008	.139	.860	-.512	-.106	-.099
20	150	660	-760	.709	.272	.278	.281	.131	.024	-.001	.035	-.398	-.126
21	150	660	752	.179	.221	.744	.333	.253	.047	-.004	-.039	.244	.087
22	75	330	1106	-.011	.084	.311	.167	.954	-.323	-.402	.013	-.133	.043

TABLE II.- CONTINUED.

B.- Right semispan, midwing station.

Loading location	-- Applied Loading --			------ Strain Gage Bridge Output, mV ------						
	Shear	Bending	Torque	μ9	μ10	μ11	μ12	μ19	μ20	μ21
1	100	5690	-255	.712	8.042	.722	6.109	-.467	-.100	.030
2	100	5900	296	.357	7.909	1.054	6.095	-.534	-.162	-.068
3	100	5120	-274	.816	7.166	.764	5.472	-.419	-.096	.042
4	100	5120	273	.535	7.172	1.255	5.536	-.512	-.164	-.071
5	100	4460	-294	.930	6.311	.821	4.763	-.373	-.086	.052
6	100	4460	291	.636	6.237	1.341	4.815	-.468	-.157	-.074
7	100	3900	-309	.891	4.376	.770	3.487	-.276	-.072	.043
8	100	3900	312	.732	5.313	1.432	4.106	-.427	-.153	-.058
9	100	3140	-331	1.158	4.419	.946	3.318	-.275	-.066	-.071
10	100	3140	324	.832	4.398	1.522	3.408	-.389	-.149	.097
11	100	1820	-361	1.391	2.599	1.071	1.895	-.183	-.160	-.604
12	100	1820	362	1.027	2.540	1.691	2.002	-.311	.013	.820
13	150	750	-605	2.775	.954	1.512	.910	-.356	-.892	-.134
14	150	750	599	1.507	1.456	3.218	.537	-.092	1.005	.199

C.- Right semispan, outboard station.

Loading location	-- Applied Loading --			--- Strain Gage Bridge Output, mV ---					
	Shear	Bending	Torque	μ13	μ14	μ15	μ16	μ22	μ23
1	100	2080	-255	2.782	5.986	1.207	4.899	-.101	.301
2	100	2290	296	1.949	6.310	1.996	5.659	-.195	.381
3	100	1510	-274	2.786	4.392	1.362	3.417	-.013	-.262
4	100	1510	273	2.006	4.149	2.436	3.774	-.146	.761
5	100	850	-294	2.976	2.570	1.286	1.954	-.090	-.661
6	100	850	291	1.653	2.474	2.991	2.031	.086	.972
7	100	190	-309	2.946	.404	.584	.686	-.377	-.387
8	100	190	312	.894	1.044	4.088	.012	.569	.634

TABLE II.- CONTINUED.

D.- Left semispan, inboard station.

Loading location	-- Applied Loading -- Shear	Bending	Torque	---- Strain Gage Bridge Output, mV ---- μ1	μ2	μ3	μ4	μ5	μ6	μ7	μ8	μ17	μ18
1	100	9590	-255	.251	3.100	.001	2.389	-1.313	.765	.616	1.796	-.165	-.178
2	100	9800	296	.134	3.079	.089	2.518	-1.298	.796	-.499	1.812	-.121	-.096
3	100	9020	-274	.266	2.915	.016	2.236	-1.227	.714	-.567	1.662	-.156	-.165
4	100	9020	273	.141	2.839	.116	2.335	-1.185	.730	-.422	1.657	-.092	-.068
5	100	8360	-294	.278	2.730	.031	2.085	-1.139	.660	-.526	1.530	-.146	-.153
6	100	8360	291	.150	2.610	.138	2.154	-1.074	.667	-.354	1.491	-.079	-.046
7	100	7700	-309	.292	2.516	.049	1.912	-1.039	.599	-.429	1.379	-.135	-.138
8	100	7700	312	.159	2.409	.159	1.995	-.975	.610	-.290	1.348	-.067	-.024
9	100	7040	-331	.304	2.319	.066	1.750	-.944	.542	-.428	1.233	-.126	-.124
10	100	7040	324	.167	2.204	.182	1.835	-.876	.553	-.226	1.201	-.053	-.001
11	100	5720	-361	.332	1.911	.099	1.417	-.754	.426	-.323	.939	-.104	-.098
12	100	5720	362	.181	1.788	.228	1.511	-.678	.438	-.089	.899	-.027	.048
13	150	6600	-602	.536	2.252	.200	1.625	-.831	.467	-.314	.969	-.125	-.101
14	150	6600	599	.290	2.061	.410	1.785	-.714	.492	.084	.897	-.001	.129
15	150	4620	-650	.579	1.662	.251	1.136	-.551	.299	-.150	.537	-.090	.062
16	150	4620	651	.314	1.454	.480	1.311	-.422	.324	.311	.456	.030	.047
17	150	2640	-705	.638	1.052	.290	.639	-.284	.138	-.047	.206	.033	.489
18	150	2640	707	.323	.840	.554	.831	-.074	.125	.518	-.111	-.044	-.500
19	75	1320	842	.059	.369	.362	.445	-.067	.141	.955	-.438	.056	.081
20	150	660	-760	.809	.342	.230	.215	-.114	.041	.000	.030	.270	.087
21	150	660	752	.231	.302	.774	.264	.234	-.087	.000	-.041	-.273	-.090
22	75	330	1106	-.006	.122	.342	.162	.963	-.461	-.431	-.002	.120	.036

TABLE II.- CONCLUDED.

E.- Left semispan, midwing station.

Loading location	-- Applied Loading -- Shear	Bending	Torque	------ Strain Gage Bridge Output, mV ------ μ9	μ10	μ11	μ12	μ19	μ20	μ21
1	100	5690	-255	.592	7.905	.730	6.293	.433	.091	-.041
2	100	5900	296	.289	8.187	1.220	6.657	.574	.184	.097
3	100	5120	-274	.703	7.065	.783	5.614	.392	.077	-.052
4	100	5120	273	.386	7.136	1.351	5.847	.521	.186	.106
5	100	4460	-294	.804	6.208	.859	4.939	.346	.072	-.063
6	100	4460	291	.495	6.110	1.455	4.810	.475	.177	.094
7	100	3900	-309	.912	5.251	.935	4.183	.297	.064	-.057
8	100	3900	312	.592	5.202	1.550	4.321	.434	.169	.075
9	100	3140	-331	1.020	4.344	1.032	3.468	.251	.060	.078
10	100	3140	324	.694	4.286	1.680	3.605	.393	.163	-.090
11	100	1820	-361	1.251	2.506	1.159	1.981	.159	.160	.605
12	100	1820	362	.891	2.418	1.875	2.161	.314	-.016	-.835
13	150	750	-605	2.541	.780	1.584	.986	.306	.881	.015
14	150	750	599	1.311	1.167	3.518	.662	.117	-1.008	-.201

F.- Left semispan, outboard station.

Loading location	-- Applied Loading -- Shear	Bending	Torque	--- Strain Gage Bridge Output, mV --- μ13	μ14	μ15	μ16	μ22	μ23
1	100	2080	-255	2.591	6.217	1.141	5.415	.035	-.330
2	100	2290	296	1.862	6.674	2.110	6.379	.173	-.400
3	100	1510	-274	2.589	4.484	1.348	3.730	-.031	.276
4	100	1510	273	1.767	4.537	2.446	4.411	.102	-.766
5	100	850	-294	2.805	2.582	1.266	2.193	.060	.651
6	100	850	291	1.441	2.574	3.112	2.246	-.147	-.977
7	100	190	-309	3.052	.100	.658	.890	.401	.450
8	100	190	312	.814	1.119	4.160	-.021	-.582	-.656

TABLE III.- BENDING MOMENT MULTIPOINT LOADING PROCEDURE.

Loading Step	Location			Applied Loads			Total Loads (lbs)
	FS	RS	AS	FS (lbs)	RS (lbs)	AS (lbs)	
1	1	2	-	25	25	-	50
2	5	6	-	25	25	-	100
3	9	10	-	50	25	-	175
4	11	12	-	50	25	-	250
5	13	14	-	50	50	-	350
6	15	16	-	50	50	-	450
7	17	18	19	50	25	25	550
8	20	21	22	50	25	25	650
9 to 24				*	*	*	1950
25	1	2	-	-25	-25	-	1900
26	5	6	-	-25	-25	-	1850
27	9	10	-	-50	-25	-	1775
28	11	12	-	-50	-25	-	1700
29	13	14	-	-50	-50	-	1600
30	15	16	-	-50	-50	-	1500
31	17	18	19	-50	-25	-25	1400
32	20	21	22	-50	-25	-25	1300
33 to 48				+	+	+	0

* Repeat steps 1 through 8 two more times.
+ Repeat steps 25 through 32 two more times.

FS = Front Spar
RS = Rear Spar
AS = Auxillary Spar

TABLE IV. - WING LOADINGS AND STRAIN GAGE BRIDGE OUTPUTS FOR BENDING MOMENT MULTIPOINT APPLIED LOADS.

(A) RIGHT WING, INBOARD STATION

WING LOADINGS			STRAIN GAGE BRIDGE OUTPUTS, MILLIVOLTS									
SHEAR, LBS	MOMENT, IN-LBS	TORQUE, IN-LBS	μ1	μ2	μ3	μ4	μ5	μ6	μ7	μ8	μ17	μ18
50.0	4848.0	10.0	-.008	1.391	.148	1.346	-.595	.266	-.267	.920	-.073	-.006
100.0	9028.0	9.0	.007	2.561	.287	2.478	-1.108	.492	-.484	1.664	-.141	-.021
175.0	14308.0	-76.0	.085	4.142	.488	4.013	-1.785	.776	-.724	2.619	-.228	-.048
250.0	18598.0	-167.0	.198	5.460	.698	5.239	-2.328	1.011	-.849	3.344	-.305	-.086
350.0	22999.0	-168.0	.369	6.748	.992	6.497	-2.846	1.264	-.885	3.987	-.413	-.180
450.0	26078.0	-168.0	.583	7.718	1.305	7.438	-3.165	1.431	-.834	4.351	-.508	-.276
550.0	27838.0	-5.0	.809	8.255	1.650	8.047	-3.296	1.533	-.463	4.209	-.617	-.436
650.0	28278.0	222.0	1.077	8.427	1.971	8.268	-2.968	1.418	-.610	4.221	-.749	-.479
700.0	33126.0	232.0	1.080	9.836	2.100	9.602	-3.601	1.701	-.862	5.174	-.824	-.507
750.0	37306.0	231.0	1.105	11.111	2.241	10.816	-4.164	1.951	-1.072	5.974	-.898	-.549
825.0	42586.0	146.0	1.189	12.738	2.443	12.329	-4.880	2.261	-1.340	6.923	-.992	-.611
900.0	46876.0	55.0	1.306	14.046	2.647	13.526	-5.424	2.514	-1.534	7.665	-1.083	-.670
1000.0	51276.0	54.0	1.492	15.423	2.940	14.828	-5.929	2.780	-1.646	8.329	-1.193	-.789
1100.0	54356.0	54.0	1.718	16.439	3.253	15.801	-6.218	2.937	-1.641	8.681	-1.292	-.896
1200.0	56116.0	217.0	1.949	17.028	3.596	16.415	-6.270	3.027	-1.295	8.544	-1.394	-1.055
1300.0	56556.0	444.0	2.232	17.221	3.900	16.655	-5.807	2.858	-1.523	8.560	-1.509	-1.110
1350.0	61404.0	454.0	2.244	18.678	4.044	18.024	-6.387	3.127	-1.827	9.508	-1.596	-1.130
1400.0	65584.0	453.0	2.282	19.924	4.177	19.208	-6.869	3.361	-2.088	10.287	-1.673	-1.162
1475.0	70864.0	368.0	2.407	21.636	4.374	20.717	-7.465	3.654	-2.381	11.261	-1.765	-1.194
1550.0	75154.0	277.0	2.550	23.026	4.580	22.019	-8.004	3.907	-2.573	11.993	-1.845	-1.221
1650.0	79554.0	276.0	2.759	24.400	4.861	23.278	-8.432	4.168	-2.673	12.722	-1.938	-1.292
1750.0	82634.0	276.0	3.019	25.496	5.160	24.312	-8.727	4.347	-2.631	13.096	-2.014	-1.375
1750.0	82634.0	276.0	3.019	25.496	5.160	24.312	-8.727	4.347	-2.631	13.096	-2.014	-1.375
1850.0	84394.0	439.0	3.265	26.075	5.483	24.875	-8.787	4.470	-2.181	12.937	-2.099	-1.516
1950.0	84834.0	666.0	3.557	26.301	5.791	25.128	-8.403	4.342	-2.327	12.933	-2.212	-1.558
1950.0	84834.0	666.0	3.594	26.424	5.786	25.199	-8.345	4.349	-2.320	12.938	-2.200	-1.559
1900.0	79987.0	656.0	3.586	25.018	5.667	23.882	-7.674	4.082	-2.022	12.060	-2.142	-1.576
1850.0	75807.0	657.0	3.566	23.935	5.555	22.847	-7.169	3.832	-1.786	11.256	-2.073	-1.575
1775.0	70527.0	742.0	3.488	22.338	5.348	21.361	-6.489	3.547	-1.539	10.342	-1.979	-1.568
1700.0	66237.0	833.0	3.384	21.049	5.132	20.114	-5.940	3.315	-1.380	9.651	-1.889	-1.554
1600.0	61837.0	834.0	3.224	19.783	4.838	18.891	-5.481	3.064	-1.302	8.951	-1.763	-1.464
1500.0	58757.0	834.0	3.018	18.871	4.522	17.940	-5.162	2.901	-1.351	8.621	-1.659	-1.376
1400.0	56997.0	671.0	2.801	18.319	4.178	17.351	-5.066	2.806	-1.707	8.748	-1.552	-1.222

TABLE IV. - CONTINUED

(A) CONCLUDED

WING LOADINGS			STRAIN GAGE BRIDGE OUTPUTS, MILLIVOLTS									
SHEAR, LBS	MOMENT, IN-LBS	TORQUE, IN-LBS	μ1	μ2	μ3	μ4	μ5	μ6	μ7	μ8	μ17	μ18
1300.0	56557.0	444.0	2.530	18.151	3.862	17.129	-5.419	2.922	-1.542	8.727	-1.418	-1.176
1250.0	51710.0	434.0	2.536	16.759	3.719	15.752	-4.808	2.643	-1.296	7.780	-1.331	-1.171
1200.0	47530.0	435.0	2.514	15.511	3.575	14.537	-4.307	2.410	-1.063	6.957	-1.256	-1.150
1125.0	42250.0	520.0	2.438	13.956	3.375	13.045	-3.705	2.128	-.758	5.975	-1.158	-1.119
1050.0	37960.0	611.0	2.323	12.670	3.171	11.796	-3.235	1.911	-.547	5.232	-1.071	-1.071
950.0	33560.0	612.0	2.164	11.313	2.869	10.462	-2.813	1.692	-.425	4.540	-.964	-.970
850.0	30480.0	612.0	1.930	10.353	2.581	9.509	-2.560	1.550	-.425	4.169	-.869	-.865
750.0	28720.0	449.0	1.703	9.807	2.222	8.914	-2.490	1.459	-.764	4.286	-.767	-.706
650.0	28280.0	222.0	1.430	9.608	1.906	8.659	-2.871	1.598	-.571	4.269	-.645	-.654
600.0	23433.0	212.0	1.421	8.145	1.761	7.284	-2.250	1.319	-.319	3.301	-.563	-.621
550.0	19253.0	213.0	1.389	6.856	1.623	6.063	-1.716	1.072	-.116	2.484	-.502	-.574
475.0	13973.0	298.0	1.291	5.211	1.427	4.558	-1.020	.770	-.109	1.501	-.425	-.508
400.0	9683.0	389.0	1.158	3.866	1.226	2.320	-.467	.522	-.266	.778	-.365	-.436
300.0	5283.0	390.0	.960	2.434	.928	1.989	.041	.265	.318	.103	-.279	-.320
200.0	2203.0	390.0	.724	1.392	.616	1.020	.375	.090	.270	-.265	-.198	-.206
100.0	440.0	227.0	.486	.787	.272	.403	.492	-.030	-.125	-.122	-.101	-.048
.0	.0	.0	.224	.584	-.040	.152	.160	.080	-.005	-.123	.025	.004

TABLE IV. - CONTINUED

(B) RIGHT WING, MIDWING STATION

WING LOADINGS			STRAIN GAGE BRIDGE OUTPUTS, MILLIVOLTS						
SHEAR, LBS	MOMENT, IN-LBS	TORQUE, IN-LBS	μ9	μ10	μ11	μ12	μ19	μ20	μ21
50.0	2898.0	10.0	.296	4.120	.472	3.165	-.255	-.069	-.010
100.0	5128.0	9.0	.690	7.208	.487	5.589	-.466	-.127	-.017
175.0	7483.0	-76.0	1.531	10.680	1.821	8.111	-.725	-.174	-.026
250.0	8848.0	-167.0	2.534	12.784	2.699	9.478	-.909	-.224	-.119
350.0	9348.0	-168.0	4.001	13.482	4.238	10.062	-1.084	-.167	-.100
400.0	12246.0	-158.0	4.342	17.703	4.654	13.217	-1.317	-.206	-.113
450.0	14476.0	-159.0	4.798	21.014	5.152	15.737	-1.525	-.249	-.117
525.0	16831.0	-244.0	5.651	24.459	5.951	18.423	-1.718	-.292	-.129
600.0	18196.0	-335.0	6.663	26.586	6.861	19.896	-1.858	-.355	-.218
700.0	18696.0	-336.0	8.147	27.420	8.402	20.443	-1.972	-.287	-.198
750.0	21594.0	-326.0	8.482	31.800	8.868	23.778	-2.160	-.358	-.210
800.0	23824.0	-327.0	8.914	35.070	9.369	26.267	-2.333	-.416	-.217
875.0	26179.0	-412.0	9.770	38.838	10.275	29.196	-2.508	-.490	-.233
950.0	27544.0	-503.0	10.750	40.831	11.236	30.210	-2.645	-.563	-.320
1050.0	28044.0	-504.0	12.239	41.866	12.833	31.378	-2.805	-.523	-.303
1000.0	25146.0	-514.0	12.005	38.055	12.338	28.377	-2.540	-.416	-.263
950.0	22916.0	-513.0	11.584	34.787	11.830	26.089	-2.350	-.333	-.248
875.0	20561.0	-428.0	10.792	31.391	10.928	23.397	-2.135	-.253	-.228
800.0	19196.0	-337.0	9.842	29.489	9.941	21.831	-1.976	-.178	-.126
700.0	18696.0	-336.0	8.351	28.557	8.403	21.441	-1.823	-.222	-.144
650.0	15798.0	-346.0	8.064	24.445	7.959	18.165	-1.603	-.159	-.126
600.0	13568.0	-345.0	7.637	21.133	7.427	15.612	-1.390	-.104	-.121
525.0	11213.0	-260.0	6.808	17.693	6.606	13.002	-1.157	-.048	-.109
450.0	9848.0	-169.0	5.819	15.670	5.677	11.487	-.977	.010	-.013
350.0	9348.0	-168.0	4.339	14.806	4.123	10.992	-.814	-.056	-.031
300.0	6450.0	-178.0	4.000	10.564	3.721	7.747	-.559	-.028	-.029
250.0	4220.0	-177.0	3.546	7.242	3.249	5.297	-.331	-.009	-.036
175.0	1865.0	-92.0	2.675	3.731	2.482	2.722	-.077	.010	-.036
100.0	500.0	-1.0	1.679	1.672	1.607	1.243	.102	.046	.055
.0	.0	.0	.194	.788	.075	.723	.272	-.026	.035

TABLE IV. - CONTINUED

(C) RIGHT WING, OUTBOARD STATION

WING LOADINGS			STRAIN GAGE BRIDGE OUTPUTS, MILLIVOLTS					
SHEAR, LBS	MOMENT, IN-LBS	TORQUE, IN-LBS	μ13	μ14	μ15	μ16	μ22	μ23
50.0	1093.0	10.0	1.273	3.092	.812	2.660	-.084	.167
100.0	1518.0	9.0	2.426	4.314	1.869	3.711	-.085	.249
150.0	2611.0	19.0	3.665	7.485	2.703	6.384	-.294	.400
200.0	3036.0	18.0	4.844	8.791	3.727	7.457	-.309	.480
250.0	4129.0	28.0	6.047	11.936	4.460	10.188	-.523	.627
300.0	4554.0	27.0	7.180	13.225	5.433	11.247	-.531	.697
250.0	3462.0	17.0	5.840	10.221	4.530	8.681	-.551	.515
200.0	3037.0	18.0	4.740	9.014	3.493	7.624	-.547	.453
150.0	1945.0	8.0	3.503	5.927	2.681	4.992	-.324	.305
100.0	1520.0	9.0	2.316	4.605	1.606	3.933	-.316	.230
50.0	428.0	-1.0	1.093	1.481	.819	1.197	-.101	.088
.0	.0	.0	-.067	.161	-.223	.123	-.088	.004

TABLE IV. - CONTINUED

(D) LEFT WING, INBOARD STATION

WING LOADINGS			STRAIN GAGE BRIDGE OUTPUTS, MILLIVOLTS									
SHEAR, LBS	MOMENT, IN-LBS	TORQUE, IN-LBS	μ1	μ2	μ3	μ4	μ5	μ6	μ7	μ8	μ17	μ18
50.0	4848.0	10.0	.094	1.529	.020	1.218	-.641	.386	-.300	.912	-.067	-.064
100.0	9028.0	9.0	.200	2.863	.066	2.275	-1.180	.730	-.496	1.673	-.122	-.113
175.0	14308.0	-76.0	.387	4.638	.164	3.696	-1.894	1.160	-.680	2.589	-.178	-.156
250.0	18598.0	-167.0	.582	6.116	.291	4.847	-2.421	1.527	-.763	3.284	-.214	-.166
350.0	22999.0	-168.0	.840	7.652	.559	6.171	-2.908	1.895	-.778	3.901	-.209	-.136
450.0	26078.0	-168.0	1.124	8.770	.847	7.105	-3.203	2.136	-.711	4.235	-.192	-.090
550.0	27838.0	-5.0	1.399	9.447	1.193	7.691	-3.298	2.278	-.305	4.115	-.138	.027
650.0	28278.0	222.0	1.701	9.687	1.532	7.917	-2.936	2.117	-.467	4.107	-.035	.058
700.0	33126.0	232.0	1.764	11.286	1.626	9.271	-3.547	2.510	-.616	4.990	-.042	.033
750.0	37306.0	231.0	1.843	12.712	1.740	10.484	-4.028	2.864	-.744	5.783	-.044	.021
825.0	42586.0	146.0	2.015	14.524	1.875	11.999	-4.479	3.291	-.803	6.616	-.062	-.008
900.0	46876.0	55.0	2.213	16.050	2.042	13.265	-4.918	3.642	-.902	7.341	-.068	-.013
1000.0	51276.0	54.0	2.467	17.569	2.305	14.580	-5.304	3.983	-.955	8.031	-.059	.023
1100.0	54356.0	54.0	2.748	18.646	2.588	15.494	-5.513	4.209	-.948	8.419	-.040	.077
1200.0	56116.0	217.0	3.025	19.318	2.920	16.081	-5.527	4.328	-.552	8.224	.012	.189
1300.0	56556.0	444.0	3.328	19.560	3.238	16.309	-5.066	4.117	-.779	8.192	.109	.224
1350.0	61404.0	454.0	3.399	21.153	3.321	17.665	-5.642	4.501	-.909	9.097	.099	.188
1400.0	65584.0	453.0	3.489	22.541	3.408	18.844	-6.048	4.860	-1.041	9.909	.087	.171
1475.0	70864.0	368.0	3.670	24.356	3.539	20.341	-6.532	5.329	-1.252	10.900	.073	.145
1550.0	75154.0	277.0	3.867	25.893	3.691	21.621	-6.924	5.694	-1.430	11.613	.064	.137
1650.0	79554.0	276.0	4.112	27.372	3.944	22.923	-7.316	6.079	-1.507	12.319	.073	.166
1750.0	82634.0	276.0	4.396	28.517	4.221	23.857	-7.480	6.294	-1.542	12.676	.092	.159
1850.0	84394.0	439.0	4.673	29.205	4.555	24.468	-7.488	6.419	-1.157	12.466	.144	.265
1950.0	84834.0	666.0	4.970	29.430	4.866	24.682	-6.998	6.196	-1.415	12.446	.248	.300
1900.0	79987.0	656.0	4.937	28.063	4.793	23.461	-6.305	5.761	-1.127	11.531	.255	.354
1850.0	75807.0	657.0	4.873	26.757	4.704	22.322	-5.720	5.414	-.901	10.800	.259	.389
1775.0	70527.0	742.0	4.741	25.147	4.570	20.939	-5.029	4.963	-.635	9.857	.266	.439
1700.0	66237.0	833.0	4.574	23.773	4.410	19.768	-4.482	4.615	-.469	9.147	.266	.464
1600.0	61837.0	834.0	4.343	22.355	4.150	18.515	-3.966	4.255	-.429	8.496	.248	.441
1500.0	58757.0	834.0	4.076	21.307	3.867	17.635	-3.674	4.026	-.487	8.136	.223	.396
1400.0	56997.0	671.0	3.811	20.715	3.530	17.080	-3.560	3.887	-.874	8.220	.172	.279
1300.0	56557.0	444.0	3.515	20.516	3.201	16.878	-3.895	4.030	-.725	8.215	.071	.249

TABLE IV. - CONTINUED

(D) CONCLUDED

WING LOADINGS			STRAIN GAGE BRIDGE OUTPUTS, MILLIVOLTS									
SHEAR, LBS	MOMENT, IN-LBS	TORQUE, IN-LBS	μ1	μ2	μ3	μ4	μ5	μ6	μ7	μ8	μ17	μ18
1250.0	51710.0	434.0	3.443	18.953	3.119	15.553	-3.261	3.634	-.486	7.283	.082	.312
1200.0	47530.0	435.0	3.359	17.649	3.034	14.413	-2.749	3.261	-.337	6.468	.096	.345
1125.0	42250.0	520.0	3.187	15.899	2.896	12.956	-2.102	2.801	-.133	5.485	.119	.383
1050.0	37960.0	611.0	2.999	14.494	2.743	11.756	-1.589	2.434	-.012	4.761	.136	.399
950.0	33560.0	612.0	2.734	12.966	2.487	10.468	-1.146	2.063	.001	4.070	.137	.367
850.0	30480.0	612.0	2.453	11.909	2.208	9.545	-.856	1.835	-.048	3.720	.124	.319
750.0	28720.0	449.0	2.173	11.261	1.877	8.964	-.781	1.703	-.440	3.836	.081	.207
650.0	28280.0	222.0	1.870	11.042	1.559	8.752	-1.197	1.876	-.236	3.841	-.009	.173
600.0	23433.0	212.0	1.786	9.434	1.487	7.388	-.597	1.479	-.119	2.957	.019	.217
550.0	19253.0	213.0	1.683	8.017	1.407	6.216	-.120	1.112	-.021	2.188	.052	.241
475.0	13973.0	298.0	1.485	6.166	1.286	4.706	.468	.660	.093	1.241	.111	.263
400.0	9683.0	389.0	1.262	4.627	1.148	3.482	.921	.304	.162	.518	.161	.264
300.0	5283.0	390.0	.966	3.027	.920	2.210	1.331	-.029	.173	-.158	.205	.234
200.0	2203.0	390.0	.645	1.839	.664	1.280	1.566	-.243	.131	-.545	.230	.191
100.0	440.0	227.0	.339	1.110	.359	.706	1.581	-.352	-.277	-.383	.211	.084
.0	.0	.0	.024	.848	.049	.491	1.132	-.161	-.053	-.347	.132	.053

TABLE IV. - CONTINUED

(E) LEFT WING, MIDWING STATION

WING LOADINGS			STRAIN GAGE BRIDGE OUTPUTS, MILLIVOLTS						
SHEAR, LBS	MOMENT, IN-LBS	TORQUE, IN-LBS	μ9	μ10	μ11	μ12	μ19	μ20	μ21
50.0	2898.0	10.0	.203	3.989	.513	3.246	.233	.081	.020
100.0	5128.0	9.0	.546	7.076	1.067	5.762	.450	.127	.028
175.0	7483.0	-76.0	1.280	10.510	1.929	8.359	.672	.163	.041
250.0	8848.0	-167.0	2.163	12.467	2.971	9.954	.807	.212	.128
350.0	9348.0	-168.0	3.473	13.173	4.687	10.549	.948	.161	.106
400.0	12246.0	-158.0	3.712	17.346	5.366	14.078	1.110	.250	.102
450.0	14476.0	-159.0	4.045	20.595	6.090	16.824	1.265	.334	.101
525.0	16831.0	-244.0	4.741	24.076	7.187	19.751	1.430	.423	.105
600.0	18196.0	-335.0	5.597	26.094	8.350	21.508	1.542	.505	.197
700.0	18696.0	-336.0	6.869	26.795	10.129	22.177	1.674	.472	.179
750.0	21594.0	-326.0	7.077	31.204	10.879	25.765	1.833	.597	.185
800.0	23824.0	-327.0	7.390	34.586	11.695	28.565	1.952	.696	.194
875.0	26179.0	-412.0	8.068	38.303	12.885	31.633	2.056	.788	.200
950.0	27544.0	-503.0	8.908	40.383	14.045	33.477	2.133	.853	.295
1050.0	28044.0	-504.0	10.186	41.157	15.749	33.993	2.254	.810	.280
1000.0	25146.0	-514.0	9.933	37.411	15.182	31.030	2.003	.724	.251
950.0	22916.0	-513.0	9.599	34.331	14.515	28.401	1.830	.657	.232
875.0	20561.0	-428.0	8.874	30.963	13.575	25.747	1.629	.593	.209
800.0	19196.0	-337.0	8.008	29.039	12.516	24.152	1.480	.526	.122
700.0	18696.0	-336.0	6.708	28.402	10.820	23.549	1.337	.586	.136
650.0	15798.0	-346.0	6.465	24.196	10.323	20.298	1.118	.523	.121
600.0	13568.0	-345.0	6.119	21.036	9.729	17.690	.925	.475	.118
525.0	11213.0	-260.0	5.399	17.593	8.793	14.982	.719	.415	.104
450.0	9848.0	-169.0	4.542	15.668	7.723	13.328	.563	.347	.017
350.0	9348.0	-168.0	3.226	14.868	6.024	12.753	.414	.406	.037
300.0	6450.0	-178.0	3.008	10.649	5.423	9.272	.174	.324	.038
250.0	4220.0	-177.0	2.679	7.427	4.760	6.564	-.018	.256	.047
175.0	1865.0	-92.0	1.960	3.951	3.772	3.674	-.218	.202	.052
100.0	500.0	-1.0	1.076	1.919	2.726	2.008	-.364	.156	-.030
.0	.0	.0	-.233	1.159	1.042	1.401	-.533	.219	-.010

TABLE IV. - CONTINUED

(F) LEFT WING, OUTBOARD STATION

WING LOADINGS			STRAIN GAGE BRIDGE OUTPUTS, MILLIVOLTS					
SHEAR, LBS	MOMENT, IN-LBS	TORQUE, IN-LBS	μ13	μ14	μ15	μ16	μ22	μ23
50.0	1093.0	10.0	1.133	3.206	.783	2.937	.059	-.199
100.0	1518.0	9.0	2.192	4.506	1.867	4.107	.042	-.283
150.0	2611.0	19.0	3.257	7.722	2.696	7.091	.209	-.437
200.0	3036.0	18.0	4.291	9.018	3.798	8.283	.199	-.510
250.0	4129.0	28.0	5.322	12.297	4.670	11.427	.369	-.641
300.0	4554.0	27.0	6.338	13.580	5.772	12.628	.359	-.706
250.0	3462.0	17.0	5.183	10.479	5.024	9.769	.408	-.492
200.0	3037.0	18.0	4.107	9.182	3.935	8.668	.419	-.413
150.0	1945.0	8.0	3.071	6.073	3.151	5.652	.245	-.269
100.0	1520.0	9.0	2.013	4.727	2.033	4.494	.261	-.194
50.0	428.0	-1.0	.962	1.460	1.177	1.420	.104	-.051
.0	.0	.0	-.076	.140	.070	.244	.123	.026

TABLE V.- TORSION MULTIPOINT LOADING PROCEDURE.

Loading Step	Location FS	RS	AS	Applied Loads FS (lbs)	RS (lbs)	AS (lbs)	Total (lbs)	Shear Load (lbs)
1	1	2	-	-25	25	-	50	0
2	5	6	-	-25	25	-	100	0
3	9	10	-	-25	25	-	150	0
4	11	12	-	-25	25	-	200	0
5	13	14	-	-25	50	-	275	25
6	15	16	-	-25	50	-	350	50
7	17	18	19	50	50	25	475	175
8	20	21	22	50	50	25	600	300
9 to 24				*	*	*	1800	900
25	1	2	-	25	-25	-	1750	900
26	5	6	-	25	-25	-	1700	900
27	9	10	-	25	-25	-	1650	900
28	11	12	-	25	-25	-	1600	900
29	13	14	-	25	-50	-	1525	875
30	15	16	-	25	-50	-	1450	850
31	17	18	19	-50	-50	-25	1325	725
32	20	21	22	-50	-50	-25	1200	600
33 to 48				+	+	+	0	0

* Repeat steps 1 through 8 two more times.
+ Repeat steps 25 through 32 two more times.

FS = Front Spar
RS = Rear Spar
AS = Auxillary Spar

TABLE VI. - WING LOADINGS AND STRAIN GAGE BRIDGE OUTPUTS FOR TORSION MULTIPOINT APPLIED LOADS.

(A) RIGHT WING, INBOARD STATION

WING LOADINGS			STRAIN GAGE BRIDGE OUTPUTS, MILLIVOLTS									
SHEAR, LBS	MOMENT, IN-LBS	TORQUE, IN-LBS	μ1	μ2	μ3	μ4	μ5	μ6	μ7	μ8	μ17	μ18
.0	51.0	138.0	-.025	-.045	.006	-.016	.028	-.001	.016	-.011	-.013	-.024
.0	51.0	284.0	-.052	-.075	.025	-.007	.051	.004	.065	-.027	-.025	-.051
.0	51.0	448.0	-.084	-.106	.046	.006	.086	.009	.117	-.040	-.040	-.085
.0	51.0	629.0	-.117	-.134	.071	.025	.116	.016	.174	-.052	-.056	-.123
25.0	1152.0	929.0	-.133	.134	.188	.368	.044	.085	.246	.085	-.112	-.201
50.0	1921.0	1254.0	-.141	.304	.314	.625	.017	.132	.358	.146	-.162	-.208
175.0	4121.0	1535.0	.116	.942	.762	1.343	-.098	.248	.800	.012	-.274	-.275
300.0	4671.0	1887.0	.413	1.141	1.216	1.609	.251	.132	.662	.015	-.366	-.303
300.0	4722.0	2025.0	.390	1.153	1.231	1.647	.260	.141	.684	.023	-.378	-.324
300.0	4722.0	2171.0	.364	1.140	1.251	1.673	.284	.148	.734	.020	-.389	-.352
300.0	4722.0	2335.0	.334	1.114	1.275	1.691	.311	.153	.787	.013	-.404	-.385
300.0	4722.0	2516.0	.301	1.091	1.300	1.716	.331	.161	.843	.012	-.420	-.419
325.0	5823.0	2816.0	.284	1.356	1.419	2.056	.270	.227	.915	.163	-.471	-.493
350.0	6592.0	3141.0	.275	1.530	1.547	2.321	.246	.277	1.029	.246	-.516	-.495
475.0	8793.0	3422.0	.534	2.175	2.000	3.048	.126	.400	1.511	.101	-.625	-.563
600.0	9343.0	3774.0	.827	2.374	2.452	3.324	.480	.278	1.369	.112	-.710	-.595
600.0	9393.0	3912.0	.805	2.398	2.472	3.373	.482	.288	1.391	.130	-.720	-.616
600.0	9393.0	4058.0	.779	2.403	2.494	3.422	.498	.298	1.400	.144	-.733	-.642
600.0	9393.0	4222.0	.749	2.343	2.514	3.416	.541	.300	1.486	.125	-.744	-.670
600.0	9393.0	4403.0	.715	2.323	2.538	3.439	.571	.307	1.539	.128	-.758	-.702
625.0	10495.0	4703.0	.698	2.593	2.661	3.789	.498	.376	1.614	.289	-.809	-.771
650.0	11264.0	5028.0	.688	2.767	2.790	4.060	.470	.425	1.715	.388	-.852	-.769
775.0	13464.0	5310.0	.944	3.411	3.247	4.802	.371	.557	2.154	.254	-.954	-.847
900.0	14014.0	5661.0	1.235	3.606	3.704	5.080	.738	.431	1.985	.261	-1.038	-.891
900.0	13964.0	5524.0	1.266	3.689	3.703	5.151	.724	.437	1.956	.293	-1.025	-.871
900.0	13964.0	5377.0	1.293	3.714	3.684	5.140	.706	.433	1.906	.299	-1.012	-.843
900.0	13964.0	5213.0	1.323	3.747	3.663	5.134	.682	.430	1.853	.310	-.998	-.814
900.0	13964.0	5032.0	1.355	3.782	3.639	5.124	.655	.427	1.797	.327	-.982	-.779
875.0	12863.0	4733.0	1.371	3.515	3.520	4.783	.735	.363	1.724	.189	-.924	-.699
850.0	12093.0	4407.0	1.378	3.353	3.399	4.534	.754	.314	1.609	.134	-.875	-.692
725.0	9893.0	4126.0	1.123	2.711	2.958	3.816	.850	.197	1.170	.281	-.763	-.623
600.0	9343.0	3774.0	.833	2.528	2.518	3.563	.468	.314	1.308	.284	-.679	-.597
600.0	9292.0	3636.0	.851	2.498	2.493	3.507	.480	.303	1.284	.269	-.664	-.577

TABLE VI. - CONTINUED

(A) CONCLUDED

WING LOADINGS			STRAIN GAGE BRIDGE OUTPUTS, MILLIVOLTS									
SHEAR, LBS	MOMENT, IN-LBS	TORQUE, IN-LBS	$\mu 1$	$\mu 2$	$\mu 3$	$\mu 4$	$\mu 5$	$\mu 6$	$\mu 7$	$\mu 8$	$\mu 17$	$\mu 18$
600.0	9292.0	3490.0	.879	2.516	2.473	3.487	.461	.298	1.243	.273	-.648	-.545
600.0	9292.0	3326.0	.909	2.538	2.449	3.466	.436	.290	1.991	.282	-.633	-.512
600.0	9292.0	3145.0	.942	2.562	2.423	3.443	.407	.282	1.133	.291	-.621	-.479
575.0	8191.0	2847.0	.956	2.297	2.308	3.104	.481	.217	1.060	.153	-.565	-.403
550.0	7422.0	2620.0	.963	2.126	2.183	2.845	.502	.168	.942	.088	-.513	-.395
425.0	5222.0	2239.0	.707	1.482	1.735	2.121	.601	.052	.482	.242	-.401	-.329
300.0	4671.0	1887.0	.411	1.285	1.288	1.845	.239	.165	.628	.238	-.315	-.299
300.0	4621.0	1749.0	.433	1.285	1.273	1.826	.230	.159	.596	.242	-.304	-.280
300.0	4621.0	1603.0	.459	1.315	1.251	1.817	.201	.155	.549	.256	-.292	-.252
300.0	4621.0	1439.0	.490	1.339	1.226	1.798	.179	.149	.496	.264	-.277	-.219
300.0	4621.0	1258.0	.526	1.357	1.200	1.766	.155	.139	.438	.269	-.259	-.183
275.0	3520.0	958.0	.540	1.082	1.077	1.416	.229	.069	.353	.123	-.206	-.108
250.0	2751.0	633.0	.549	.903	.951	1.146	.253	.018	.233	.051	-.156	-.100
125.0	550.0	352.0	.289	.243	.497	.403	.362	-.104	.220	.199	-.045	-.031
.0	.0	.0	-.007	.031	.045	.118	-.004	.011	-.099	.194	.047	.000

TABLE VI. - CONTINUED

(B) RIGHT WING, MIDWING STATION

WING LOADINGS			STRAIN GAGE BRIDGE OUTPUTS, MILLIVOLTS						
SHEAR, LBS	MOMENT, IN-LBS	TORQUE, IN-LBS	μ9	μ10	μ11	μ12	μ19	μ20	μ21
.0	51.0	138.0	-.077	-.020	.092	.014	-.004	-.017	-.025
.0	51.0	284.0	-.152	-.046	.215	.014	-.029	-.031	-.054
.0	51.0	448.0	-.237	-.077	.354	.015	-.058	-.049	-.010
.0	51.0	629.0	-.328	-.093	.507	.038	-.091	-.004	.351
25.0	177.0	929.0	-.290	.177	1.335	.058	-.066	.479	.438
25.0	228.0	1067.0	-.263	.311	1.305	.074	.507	.542	.412
25.0	228.0	1213.0	-.342	.315	1.438	.093	.480	.524	.384
25.0	228.0	1377.0	-.446	.303	1.588	.100	.449	.503	.425
25.0	228.0	1558.0	-.560	.286	1.756	.118	.418	.544	.778
50.0	354.0	1858.0	-.568	.541	2.599	.118	.432	1.008	.862
50.0	405.0	1996.0	-.599	.688	2.760	.134	.948	1.054	.831
50.0	405.0	2142.0	-.696	.747	2.906	.191	.916	1.032	.798
50.0	405.0	2306.0	-.846	.661	3.082	.135	.890	1.010	.838
50.0	405.0	2487.0	-1.002	.649	3.970	.146	.856	1.045	1.181
75.0	531.0	2787.0	-1.067	.912	3.868	.132	.866	1.510	1.253
75.0	480.0	2158.0	-.758	1.012	3.430	-.022	1.448	1.559	.879
50.0	354.0	1858.0	-.806	.745	2.601	-.043	1.420	1.072	.789
50.0	303.0	1720.0	-.864	.650	2.650	-.034	.844	.999	.811
50.0	303.0	1574.0	-.793	.643	2.525	-.055	.872	1.081	.839
50.0	303.0	1410.0	-.712	.638	2.378	-.079	.903	1.093	.797
50.0	303.0	1229.0	-.621	.644	2.220	-.109	.936	1.039	.438
25.0	177.0	929.0	-.660	.672	1.399	-.129	.913	.548	.352
25.0	126.0	791.0	-.706	.313	1.442	-.081	.344	.470	.375
25.0	126.0	645.0	-.625	.336	1.315	-.076	.369	.479	.402
25.0	126.0	481.0	-.536	.330	1.168	-.094	.402	.493	.361
25.0	126.0	300.0	-.436	.316	.997	-.130	.437	.447	.005
.0	.0	.0	-.459	.019	.150	-.158	.418	-.040	-.081

TABLE VI. - CONTINUED

(C) RIGHT WING, OUTBOARD STATION

WING LOADINGS			STRAIN GAGE BRIDGE OUTPUTS, MILLIVOLTS					
SHEAR, LBS	MOMENT, IN-LBS	TORQUE, IN-LBS	μ13	μ14	μ15	μ16	μ22	μ23
.0	51.0	138.0	-.148	.023	.151	.124	-.040	.021
.0	51.0	284.0	-.493	-.017	.568	.144	.005	.437
.0	101.0	422.0	-.543	.145	.675	.243	.406	.507
.0	101.0	568.0	-.883	.122	1.109	.277	.453	.916
.0	152.0	706.0	-.943	.292	1.234	.378	.841	.984
.0	152.0	852.0	-1.269	.295	1.699	.431	.886	1.393
.0	101.0	714.0	-1.071	.308	1.459	.160	1.329	1.424
.0	101.0	568.0	-.749	.322	1.029	.126	1.281	.994
.0	51.0	430.0	-.691	.173	.929	.033	.881	.918
.0	51.0	284.0	-.365	.186	.502	-.002	.838	.507
.0	.0	146.0	-.290	.075	.407	-.061	.434	.437
.0	.0	.0	.053	.098	-.021	-.093	.385	.029

TABLE VI. - CONTINUED

(D) LEFT WING, INBOARD STATION

WING LOADINGS			STRAIN GAGE BRIDGE OUTPUTS, MILLIVOLTS									
SHEAR, LBS	MOMENT, IN-LBS	TORQUE, IN-LBS	μ1	μ2	μ3	μ4	μ5	μ6	μ7	μ8	μ17	μ18
.0	51.0	138.0	-.036	-.039	.019	.024	.001	.001	-.017	.017	.018	.007
.0	51.0	284.0	-.065	-.042	.045	.054	.019	.007	.038	.025	.030	.032
.0	51.0	448.0	-.101	-.098	.075	.057	.034	.003	.080	.003	.049	.060
.0	51.0	629.0	-.136	-.099	.106	.100	.049	.013	.135	.012	.063	.091
25.0	1152.0	929.0	-.130	.187	.209	.406	-.049	.094	.208	.141	.083	.143
50.0	1921.0	1254.0	-.116	.428	.328	.678	-.106	.162	.320	.226	.102	.137
175.0	4121.0	1535.0	.222	1.167	.734	1.308	-.237	.294	.770	.104	.117	.165
300.0	4671.0	1887.0	.564	1.435	1.196	1.541	.127	.123	.627	.090	.166	.178
300.0	4722.0	2025.0	.536	1.453	1.223	1.591	.130	.130	.632	.114	.182	.166
300.0	4722.0	2171.0	.514	1.481	1.249	1.644	.146	.146	.686	.129	.192	.188
300.0	4722.0	2335.0	.473	1.405	1.280	1.632	.175	.137	.733	.094	.210	.215
300.0	4722.0	2516.0	.443	1.435	1.315	1.701	.173	.158	.781	.120	.224	.243
325.0	5823.0	2816.0	.444	1.707	1.425	2.007	.075	.242	.851	.245	.244	.294
350.0	6592.0	3141.0	.458	1.951	1.547	2.288	.014	.319	.965	.331	.263	.286
475.0	8793.0	3422.0	.787	2.676	1.960	2.926	-.112	.465	1.447	.194	.285	.320
600.0	9343.0	3774.0	1.123	2.937	2.426	3.162	.269	.286	1.283	.174	.342	.339
600.0	9393.0	3912.0	1.097	2.964	2.455	3.226	.267	.301	1.289	.206	.356	.314
600.0	9393.0	4058.0	1.069	2.960	2.482	3.261	.273	.311	1.326	.207	.367	.334
600.0	9393.0	4222.0	1.035	2.920	2.511	3.275	.293	.314	1.374	.193	.379	.362
600.0	9393.0	4403.0	1.000	2.902	2.545	3.312	.302	.325	1.420	.192	.391	.390
625.0	10495.0	4703.0	1.003	3.203	2.657	3.646	.196	.421	1.485	.332	.406	.433
650.0	11264.0	5028.0	1.010	3.413	2.781	3.912	.140	.496	1.602	.396	.425	.422
775.0	13464.0	5310.0	1.335	4.195	3.220	4.635	-.011	.695	2.077	.201	.443	.466
900.0	14014.0	5661.0	1.671	4.444	3.672	4.875	.495	.459	1.843	.172	.490	.491
900.0	13964.0	5524.0	1.708	4.554	3.661	4.925	.461	.472	1.819	.196	.480	.446
900.0	13964.0	5377.0	1.734	4.552	3.638	4.893	.457	.462	1.774	.190	.468	.418
900.0	13964.0	5213.0	1.766	4.585	3.613	4.883	.440	.461	1.718	.203	.453	.387
900.0	13964.0	5032.0	1.801	4.601	3.583	4.856	.424	.456	1.659	.209	.437	.353
875.0	12863.0	4733.0	1.801	4.307	3.478	4.534	.522	.370	1.578	.075	.409	.294
850.0	12093.0	4407.0	1.796	4.095	3.356	4.276	.569	.309	1.454	.010	.382	.291
725.0	9893.0	4126.0	1.473	3.381	2.941	3.640	.693	.177	.972	.143	.349	.260
600.0	9343.0	3774.0	1.132	3.127	2.489	3.408	.323	.340	1.114	.157	.304	.247
600.0	9292.0	3636.0	1.148	3.066	2.464	3.337	.332	.324	1.052	.137	.296	.243

TABLE VI. - CONTINUED

(D) CONCLUDED

WING LOADINGS			STRAIN GAGE BRIDGE OUTPUTS, MILLIVOLTS									
SHEAR, LBS	MOMENT, IN-LBS	TORQUE, IN-LBS	μ1	μ2	μ3	μ4	μ5	μ6	μ7	μ8	μ17	μ18
600.0	9292.0	3490.0	1.180	3.110	2.440	3.332	.316	.326	1.015	.156	.278	.215
600.0	9292.0	3326.0	1.211	3.125	2.410	3.304	.297	.322	.958	.162	.264	.187
600.0	9292.0	3145.0	1.248	3.155	2.380	3.283	.284	.319	.901	.174	.246	.152
575.0	8191.0	2847.0	1.239	2.826	2.271	2.938	.385	.228	.823	.028	.225	.101
550.0	7422.0	2620.0	1.235	2.627	2.150	2.690	.435	.169	.703	-.034	.196	.101
425.0	5222.0	2239.0	.899	1.877	1.740	2.043	.556	.032	.216	.095	.170	.072
300.0	4671.0	1887.0	.553	1.604	1.288	1.802	.165	.204	.377	.111	.127	.057
300.0	4621.0	1749.0	.578	1.586	1.265	1.754	.170	.195	.347	.101	.114	.039
300.0	4621.0	1603.0	.608	1.603	1.238	1.729	.156	.194	.305	.107	.099	.015
300.0	4621.0	1439.0	.642	1.629	1.209	1.709	.138	.193	.254	.119	.084	-.012
300.0	4621.0	1258.0	.676	1.648	1.175	1.682	.119	.189	.197	.126	.066	-.043
275.0	3520.0	958.0	.668	1.325	1.068	1.344	.220	.103	.128	-.024	.049	-.081
250.0	2751.0	633.0	.656	1.100	.948	1.083	.263	.044	.031	-.122	.028	-.073
125.0	550.0	352.0	.309	.298	.547	.414	.328	-.072	-.405	.001	.020	-.104
.0	.0	.0	-.043	.008	.104	.172	-.132	.138	-.185	.011	-.013	-.120

TABLE VI. - CONTINUED

(E) LEFT WING, MIDWING STATION

WING LOADINGS			STRAIN GAGE BRIDGE OUTPUTS, MILLIVOLTS						
SHEAR, LBS	MOMENT, IN-LBS	TORQUE, IN-LBS	μ9	μ10	μ11	μ12	μ19	μ20	μ21
.0	51.0	138.0	-.109	.012	.161	.093	.040	.058	.041
.0	51.0	284.0	-.168	.047	.278	.135	.089	.065	.079
.0	51.0	448.0	-.256	-.023	.428	.124	.139	.094	.037
.0	51.0	629.0	-.335	.013	.595	.199	.196	.043	-.327
25.0	177.0	929.0	-.333	.209	1.494	.202	.211	-.446	-.418
25.0	228.0	1067.0	-.336	.328	1.529	.241	-.124	-.483	-.383
25.0	228.0	1213.0	-.392	.390	1.660	.304	-.060	-.468	-.343
25.0	228.0	1377.0	-.503	.271	1.806	.255	-.010	-.442	-.389
25.0	228.0	1558.0	-.579	.356	1.995	.374	.054	-.488	-.742
50.0	354.0	1858.0	-.605	.530	2.912	.350	.079	-.960	-.837
50.0	405.0	1996.0	-.669	.616	2.992	.378	-.210	-.970	-.797
50.0	405.0	2142.0	-.759	.632	3.138	.424	-.157	-.946	-.759
50.0	405.0	2306.0	-.870	.575	3.290	.423	-.104	-.917	-.801
50.0	405.0	2487.0	-1.000	.562	3.484	.479	-.039	-.953	-1.153
75.0	531.0	2787.0	-1.084	.800	4.446	.513	-.004	-1.409	-1.244
75.0	480.0	2649.0	-1.029	.889	4.316	.442	-.328	-1.453	-1.276
75.0	480.0	2503.0	-.993	.825	4.214	.369	-.364	-1.452	-1.317
75.0	480.0	2339.0	-.917	.851	4.074	.354	-.399	-1.472	-1.274
75.0	480.0	2158.0	-.834	.854	3.913	.304	-.441	-1.424	-.907
50.0	354.0	1858.0	-.829	.594	3.003	.251	-.425	-.939	-.811
50.0	303.0	1720.0	-.874	.441	3.048	.237	-.020	-.862	-.837
50.0	303.0	1574.0	-.773	.493	2.881	.224	-.038	-.902	-.872
50.0	303.0	1410.0	-.700	.484	2.743	.187	-.084	-.921	-.827
50.0	303.0	1229.0	-.603	.501	2.571	.145	-.119	-.877	-.464
25.0	177.0	929.0	-.612	.223	1.641	.084	-.125	-.408	-.371
25.0	126.0	791.0	-.621	.100	1.648	.060	.290	-.357	-.406
25.0	126.0	645.0	-.538	.093	1.504	.020	.251	-.380	-.444
25.0	126.0	481.0	-.444	.105	1.348	-.012	.210	-.407	-.402
25.0	126.0	300.0	-.338	.114	1.163	-.064	.157	-.368	-.045
.0	.0	.0	-.319	-.152	.212	-.124	.115	.096	.047

TABLE VI. - CONTINUED

(F) LEFT WING, OUTBOARD STATION

WING LOADINGS			STRAIN GAGE BRIDGE OUTPUTS, MILLIVOLTS					
SHEAR, LBS	MOMENT, IN-LBS	TORQUE, IN-LBS	μ13	μ14	μ15	μ16	μ22	μ23
.0	51.0	138.0	-.152	.088	.209	.224	.043	-.035
.0	51.0	284.0	-.490	.124	.687	.284	-.012	-.446
.0	101.0	422.0	-.594	.310	.842	.411	-.407	-.526
.0	101.0	568.0	-.932	.354	1.326	.482	-.463	-.924
.0	152.0	706.0	-1.054	.513	1.473	.559	-.858	-1.004
.0	152.0	852.0	-1.397	.536	1.963	.603	-.924	-1.388
.0	101.0	714.0	-1.136	.578	1.692	.292	-1.372	-1.404
.0	101.0	568.0	-.823	.536	1.219	.226	-1.317	-.995
.0	51.0	430.0	-.722	.323	1.057	.059	-.914	-.915
.0	51.0	284.0	-.367	.322	.588	.044	-.853	-.514
.0	.0	146.0	-.279	.115	.437	-.105	-.466	-.433
.0	.0	.0	.074	.093	-.051	-.146	-.404	-.037

TABLE VII.- SUMMARY OF SELECTED STRAIN GAGE BRIDGES, LOAD COEFFICIENTS, PROBABLE ERRORS, AND MULTIPLE CORRELATION COEFFICIENTS.

A. Right Semispan, Inboard Station.

Load Measurement	Selected Bridges	Load Coefficients +/- Probable Error	Range of Wing Calibration Loading	Probable Error of Load Estimate	Multiple Correlation Coefficient
Shear, V (lbs)	1	119.0 +/- 1.7	0 to 1950 lbs	+/- 5 lbs	.99998
	3	179.7 +/- 3.5			
	5	-29.7 +/- 0.8			
	17	-102.7 +/- 11.2			
Bending Moment, M (in-lbs)	4	2882.4 +/- 12.6	0 to 84834 in-lbs.	+/- 401 in-lb s	.99994
	5	-1424.3 +/- 37.9			
Torsion, T (in-lbs)	1	-2771.6 +/- 165.2	0 to +5661 in-lbs	+/- 184 in-lb s	.99699
	2	489.6 +/- 73.3			
	3	1674.3 +/- 53.9			
	5	1433.2 +/- 133.2			

B. Right Semispan, Midwing Station.

Load Measurement	Selected Bridges	Load Coefficients +/- Probable Error	Range of Wing Calibration Loading	Probable Error of Load Estimate	Multiple Correlation Coefficient
Shear, V (lbs)	9	31.9 +/- 0.7	0 to 1050 lbs	+/- 7 lbs	.99983
	10	7.8 +/- 0.3			
	11	25.9 +/- 0.4			
Bending Moment, M (in-lbs)	10	668.4 +/- 2.3	0 to 28044 in-lbs	+/- 307 in-lb s	.99948
Torsion, T (in-lbs)	9	-335.2 +/- 33.4	-514 to +2787 in-lbs	+/- 162 in-lb s	.99121
	11	307.7 +/- 29.7			
	20	188.5 +/- 94.1			
	21	683.3 +/-118.6			

TABLE VII.- CONTINUED.

C. Right Semispan, Outboard Station.

Load Measurement	Selected Bridges	Load Coefficients +/- Probable Error	Range of Wing Calibration Loading	Probable Error of Load Estimate	Multiple Correlation Coefficient
Shear, V (lbs)	13	27.3 +/- 0.4	0 to 300 lbs	+/- 4 lbs	.99958
	15	19.3 +/- 0.5			
Bending Moment, M (in-lbs)	14	171.9 +/- 27.0	0 to 4554 in-lbs	+/- 39 in-lbs	.99978
	16	202.5 +/- 31.8			
Torsion, T (in-lbs)	13	-141.8 +/- 35.8	-309 to 852 in-lbs	+/- 84 in-lb s	.97244
	15	87.6 +/- 30.9			
	16	30.7 +/- 17.5			
	23	312.2 +/- 72.2			

D. Left Semispan, Inboard Station.

Load Measurement	Selected Bridges	Load Coefficients +/- Probable Error	Range of Wing Calibration Loading	Probable Error of Load Estimate	Multiple Correlation Coefficient
Shear, V (lbs)	1	132.4 +/- 2.3	0 to 1950 lbs	+/- 7 lbs	.99997
	3	181.4 +/- 1.2			
	8	32.3 +/- 0.5			
Bending Moment, M (in-lbs)	2	1367.2 +/- 32.3	0 to 84834 in-lbs.	+/- 329 in-lb s	.99996
	3	1314.6 +/- 36.7			
	6	6097.7 +/- 135.2			
Torsion, T (in-lbs)	1	-2207.6 +/- 118.4	-168 to +5661 in-lbs	+/- 171 in -lbs	.99747
	3	2450.0 +/- 92.0			
	7	250.4 +/- 95.6			
	17	-2079.1 +/- 375.6			
	18	2031.3 +/- 371.6			

TABLE VII.- CONCLUDED.

E. Left Semispan, Midwing Station.

Load Measurement	Selected Bridges	Load Coefficients +/- Probable Error	Range of Wing Calibration Loading	Probable Error of Load Estimate	Multiple Correlation Coefficient
Shear, V (lbs)	9	33.8 +/- 0.9	0 to 1050 lbs	+/- 7 lbs	.99986
	11	25.8 +/- 0.5			
	12	6.4 +/- 0.5			
	19	35.2 +/- 4.1			
Bending Moment, M (in-lbs)	10	677.6 +/- 2.8	0 to 28044 in-lbs	+/- 371 in-lb s	.99939
Torsion, T (in-lbs)	9	-452.2 +/- 56.4	-514 to +2787 in-lbs	+/- 194 in-l bs	.98381
	11	277.5 +/- 31.5			
	20	-230.4 +/- 121.5			
	21	-494.7 +/- 144.5			

F. Left Semispan, Outboard Station.

Load Measurement	Selected Bridges	Load Coefficients +/- Probable Error	Range of Wing Calibration Loading	Probable Error of Load Estimate	Multiple Correlation Coefficient
Shear, V (lbs)	13	28.9 +/- 0.3	0 to 300 lbs	+/- 3 lbs	.99976
	15	19.9 +/- 0.3			
Bending Moment, M (in-lbs)	14	333.6 +/- 2.0	0 to 4554 in-lbs	+/- 59 in-lbs	.99946
Torsion, T (in-lbs)	13	-158.8 +/- 25.5	-309 to 852 in-lbs	+/- 62 in-lb s	.98522
	14	-154.2 +/- 39.2			
	15	112.8 +/- 21.2			
	16	182.9 +/- 41.7			
	23	-256.1 +/- 53.4			

TABLE VIII.- CRUISE DESIGN DISTRIBUTED LOADING.

Loading Locations			Loadings		
FS	RS	AS	FS	RS	AS
			----(lbs)-----		
1	2	-	15	25	-
3	4	-	10	25	-
5	6	-	10	25	-
7	8	-	10	50	-
9	10	-	5	75	-
11	12	-	10	100	-
13	14	-	5	125	-
15	16	-	15	150	-
17	18	19	30	100	50
20	21	22	35	125	50

Total Load = 1045 lbs.

FS = Front Spar
RS = Rear Spar
AS = Auxillary Spar

TABLE IX.- DESIGN BENDING MOMENT DISTRIBUTED LOADING.

Loading Locations			Loadings (lbs)		
FS	RS	AS	FS	RS	AS
1	2	-	75	100	-
5	6	-	125	100	-
9	10	-	150	100	-
11	12	-	150	100	-
13	14	-	150	125	-
15	16	-	150	150	-
17	18	19	175	75	50
20	21	22	150	125	25

Total Load = 2075 lbs.

FS = Front Spar
RS = Rear Spar
AS = Auxillary Spar

TABLE X.- TORSION DISTRIBUTED LOADING.

Loading Locations			Loadings		
FS	RS	AS	FS	RS	AS
			----(lbs)-----		
3	4	-	-50	50	-
5	6	-	-50	50	-
7	8	-	-50	50	-
9	10	-	-50	100	-
11	12	-	-25	150	-
13	14	-	-25	150	-
15	16	-	25	150	-
17	18	19	100	125	50
20	21	22	150	100	50

FS = Front Spar
RS = Rear Spar
AS = Auxillary Spar

TABLE XI.- WING LOADS AND STRAIN GAGE BRIDGE OUTPUTS FOR DISTRIBUTED LOADINGS SIMULATING DESIGN CRUISE, DESIGN BENDING MOMENT, AND TORSION FLIGHT TEST CONDITIONS.

Design Flight Condition	Wing Loadings			Strain-gage bridge outputs, millivolts, for-									
	Shear (lbs)	Bending (in-lbs)	Torsion (in-lbs)										
A. Right Semispan, Inboard Station.				μ1	μ2	μ3	μ4	μ5	μ6	μ7μ	μ8	μ17	μ18
Cruise	1035	41064	1925	1.466	12.408	3.506	12.465	-4.103	2.192	-.502	5.985	-.929	-.549
Bending	2075	95642	-114	3.770	29.384	6.058	27.983	-10.464	5.147	-3.110	15.356	-2.126	-1.482
Torsion	1050	27720	4371	1.572	7.893	3.895	9.065	-1.467	1.337	1.263	2.854	-1.308	-1.055
B. Right Semispan, Midwing Station.				μ9	μ10	μ11	μ12	μ19	μ20	μ21			
Cruise	510	13034	464	5.649	19.239	6.856	14.156	-.961	.213	.408			
Bending	1175	33978	-428	3.219	50.447	14.131	38.113	-3.505	-.833	-.077			
Torsion	300	4470	2698	1.911	6.782	7.001	4.594	-.065	1.150	1.472			
C. Right Semispan, Outboard Station.				u13	u14	u15	u16	u22	u23				
Cruise	160	1878	95	3.656	5.581	3.378	4.490	.275	.503				
Bending	400	5762	28	9.738	16.566	7.035	13.838	-.502	.725				
Torsion	0	0	566	2.192	.409	2.844	-.487	1.910	2.086				

TABLE XI.- CONCLUDED.

D. Left Semispan, Inboard Station.

				μ51	μ52	μ53	μ54	μ55	μ56	μ57	μ58	μ67	μ68
Cruise	1045	41410	3912	1.924	13.750	3.333	12.064	-3.257	2.897	.444	5.528	-.056	-.067
Bending	2075	95642	-114	5.391	32.518	4.989	27.293	-9.637	7.637	-1.744	15.148	.000	.163
Torsion	1050	27720	4371	2.243	9.060	3.597	8.412	-1.498	1.661	1.255	2.668	.431	.477

E. Left Semispan, Midwing Station.

				μ59	μ60	μ61	μ62	μ69	μ70	μ71
Cruise	490	13126	1276	4.014	19.106	8.306	15.279	.758	-.678	-.966
Bending	1175	33973	-428	11.078	49.728	16.837	41.086	2.707	.914	.116
Torsion	300	4470	2698	1.512	6.343	7.530	5.082	.494	-1.097	-1.480

F. Left Semispan, Outboard Station.

				μ63	μ64	μ65	μ66	μ72	μ73
Cruise	170	1824	245	3.004	5.860	4.372	4.738	-.926	-.871
Bending	400	5762	28	8.486	17.215	7.605	15.944	.297	-.737
Torsion	0	0	566	-2.000	.781	2.992	-.528	-1.934	-2.027

TABLE XII.- EVALUATION OF PREDICTED LOADS FOR SIMULATIONS OF FLIGHT TEST CONDIT IONS.

A. Right Semispan, Inboard Station.

Flight Condition	Design Cruise			Design Bending			Torsion		
	V	M	T	V	M	T	V	M	T
Calculated loading	1022	41773	2002	2067	95562	-916	1065	28218	3926
Actual loading	1035	41064	1925	2075	95642	-114	1050	27720	4371
Difference	-13	709	77	-8	-80	-802	15	498	445
Error, percent	-1.3	1.7	3.8	-.4	-.1	87.6	1.4	1.8	-11.8

B. Right Semispan, Midwing Station.

Flight Condition	Design Cruise			Design Bending			Torsion		
	V	M	T	V	M	T	V	M	T
Calculated loading	508	12860	535	1180	33720	-293	295	4533	2736
Actual loading	510	13034	464	1175	33978	-428	300	4470	2698
Difference	-2	-174	71	5	-258	135	-5	63	38
Error, percent	-.5	-1.4	13.3	.4	-.8	-46.2	-1.7	1.4	1.4

C. Right Semispan, Outboard Station.

Flight Condition	Design Cruise			Design Bending			Torsion		
	V	M	T	V	M	T	V	M	T
Calculated load	165	1869	72	402	5650	-114	-5	-28	1196
Actual load	160	1878	95	400	5762	28	0	0	566
Difference	5	-9	-23	2	-112	-142	-5	-28	630
Error, percent	3.1	-.5	-32.1	.5	-2.0	124.8	-	-	52.7
.FF									

TABLE XII.- CONCLUDED.

D. Left Semispan, Inboard Station.

Flight Condition	Design Cruise			Design Bending			Torsion		
	V	M	T	V	M	T	V	M	T
Calculated load	1038	40846	4010	2108	97586	216	10 36	27244	4248
Actual load	1045	41410	3912	2075	95642	-114	10 50	27720	4371
Difference	-7	-564	-98	33	1944	330	- 14	-476	-123
Error, percent	-.7	-1.4	2.4	1.6	2.0	152.6	-1 .4	-1.7	-2.9

E. Left Semispan, Midwing Station.

Flight Condition	Design Cruise			Design Bending			Torsion		
	V	M	T	V	M	T	V	M	T
Calculated load	475	12947	1124	1168	33697	-604	2 95	4298	2391
Actual load	490	13126	1276	1175	33978	-428	3 00	4470	2698
Difference	-15	-179	-152	-7	-281	-176	-5	-172	-307
Error, percent	-3.3	-1.4	-13.5	-.6	-.8	29.1	-1 .7	-4.0	-12.8

F. Left Semispan, Outboard Station.

Flight Condition	Design Cruise			Design Bending			Torsion		
	V	M	T	V	M	T	V	M	T
Calculated load	174	1955	202	397	5742	-39	2	260	957
Actual load	170	1824	245	400	5762	28	0	0	566
Difference	4	131	-43	-3	-20	-67	2	260	391
Error, percent	2.2	6.7	-21.1	-.9	-.4	172.5	-	-	40.9

WING

DESIGN C_L - - - - - - - - - - - - 0.53
GROSS AREA - - - - - - - - - - - - 35 SQ. FT
ASPECT RATIO - - - - - - - - - - - 10.3
SPAN - - - - - - - - - - - - - 227.84 IN
TAPER RATIO (BASIC WING) - - - - .4
SWEEP 50% BASIC WING CHORD - 25°

	STREAMWISE TWIST	THICKNESS % CHORD
2y/b = 0.106	+2°	14.4
2y/b = 0.426	-.5°	12.0
2y/b = 1.00	-1.6°	10.6

STREAMWISE INCIDENCE ANGLE - - 0°
DIHEDRAL ANGLE - - - - - - - - - 0°

TAIL - HORIZONTAL

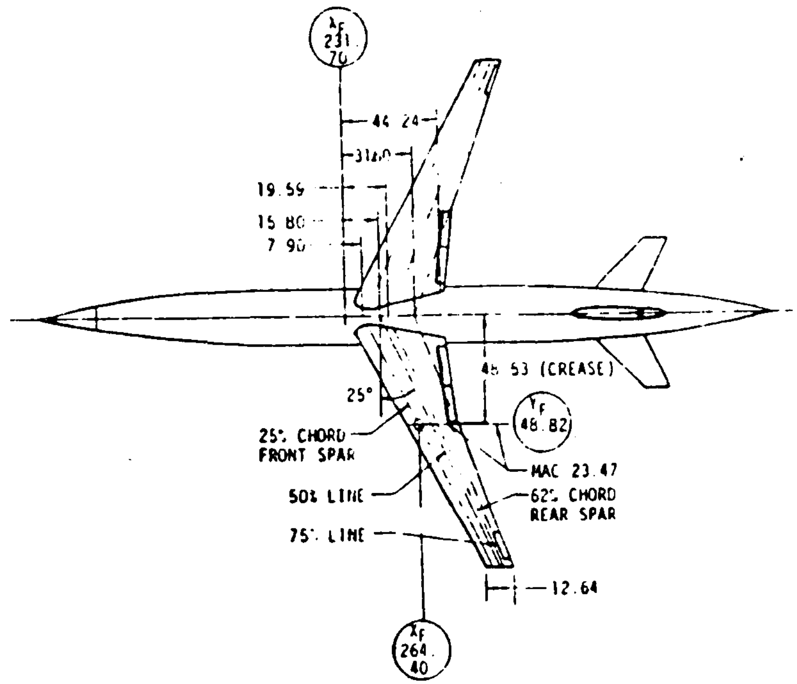
GROSS AREA - - - - - - - - - - - 9.1 SQ. FT.
ASPECT RATIO - - - - - - - - - - 3.5
INCIDENCE - - - - - - - - - - - - ALL MOVABLE
TAPER RATIO - - - - - - - - - - - 0.40
DIHEDRAL - - - - - - - - - - - - 0°

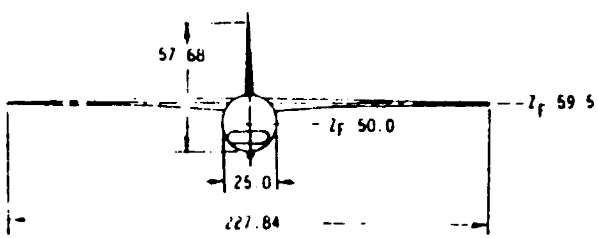
TAIL - VERTICAL

GROSS AREA - - - - - - - - - - - 8.65 SQ. FT.
ASPECT RATIO (GEOMETRIC) - - - 1.2
TAPER RATIO - - - - - - - - - - - 0.30
RUDDER HINGE AXIS - - - - - - - 85% CHORD
RUDDER AREA - - - - - - - - - - 0.61 SQ. FT.

POWER PLANT

CONTINENTAL - - - - - - - - - - - (YJ 69-T406CAE MODEL 356.34)
RATED THRUST - - - - - - - - - - 1840 LB SEA LEVEL STATIC





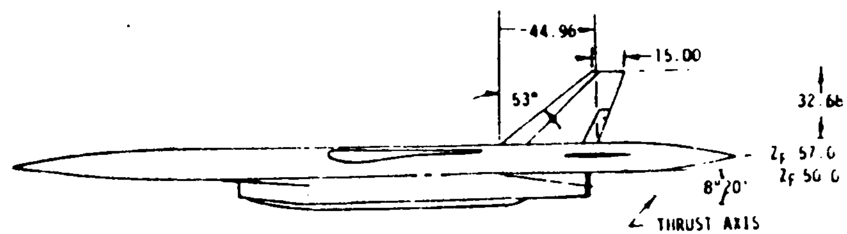


Figure I. - DAST ARW-2 General Arrangement.

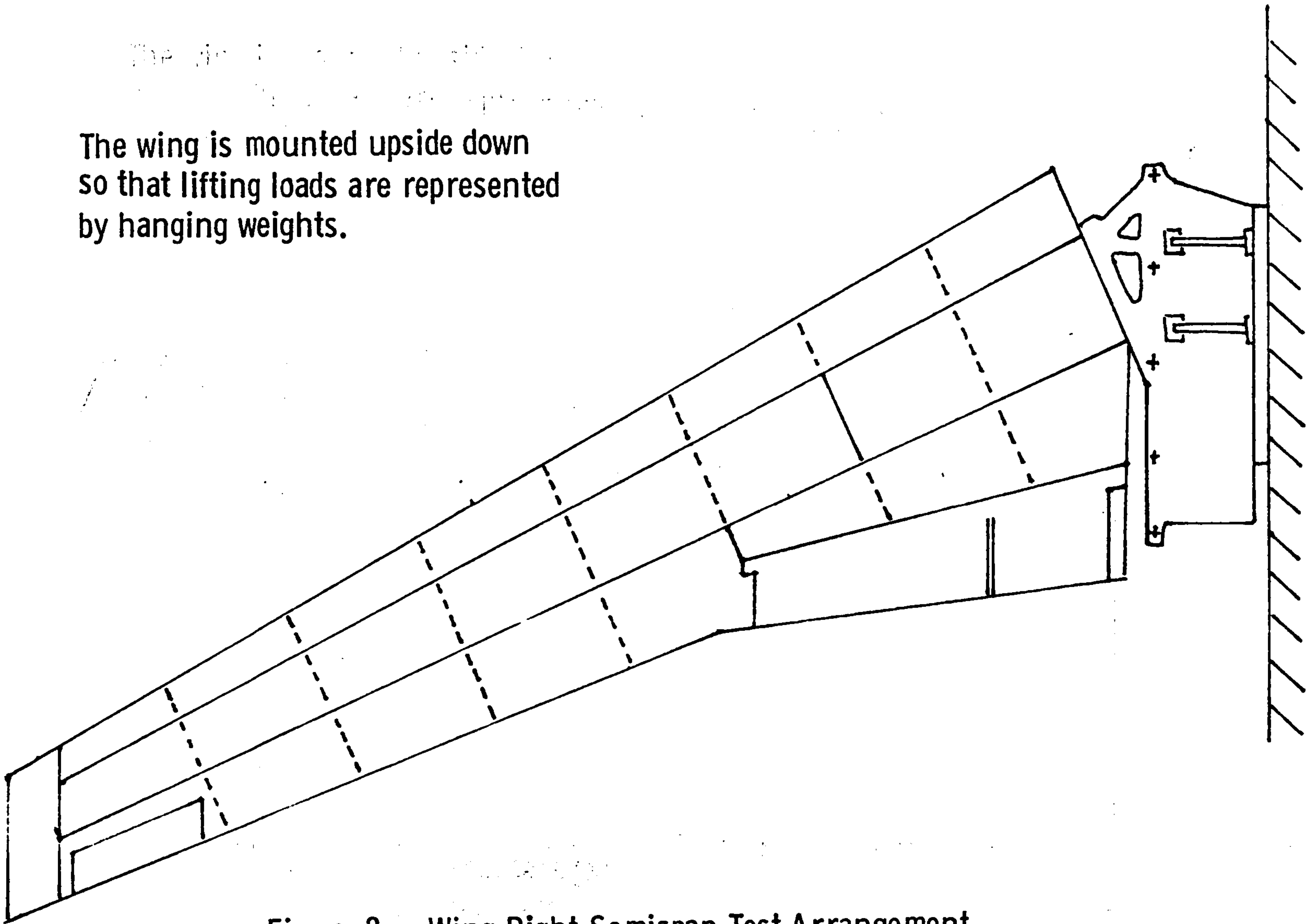


Figure 2.- Wing Right Semispan Test Arrangement.

(Wing Mounted Upside Down)

The wing is mounted upside down
so that lifting loads are represented
by hanging weights.

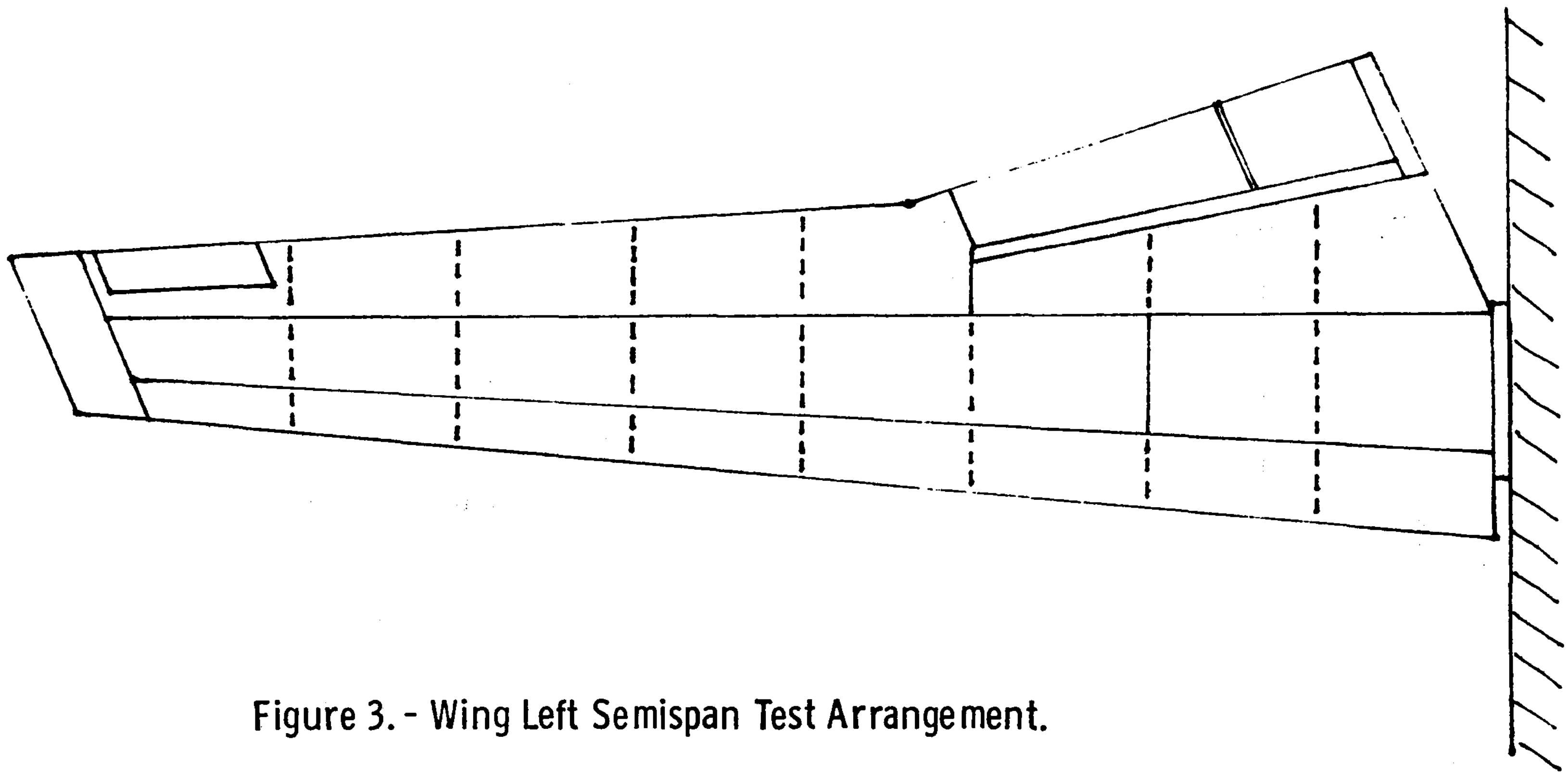


Figure 3. - Wing Left Semispan Test Arrangement.

(Wing Mounted Upside Down)

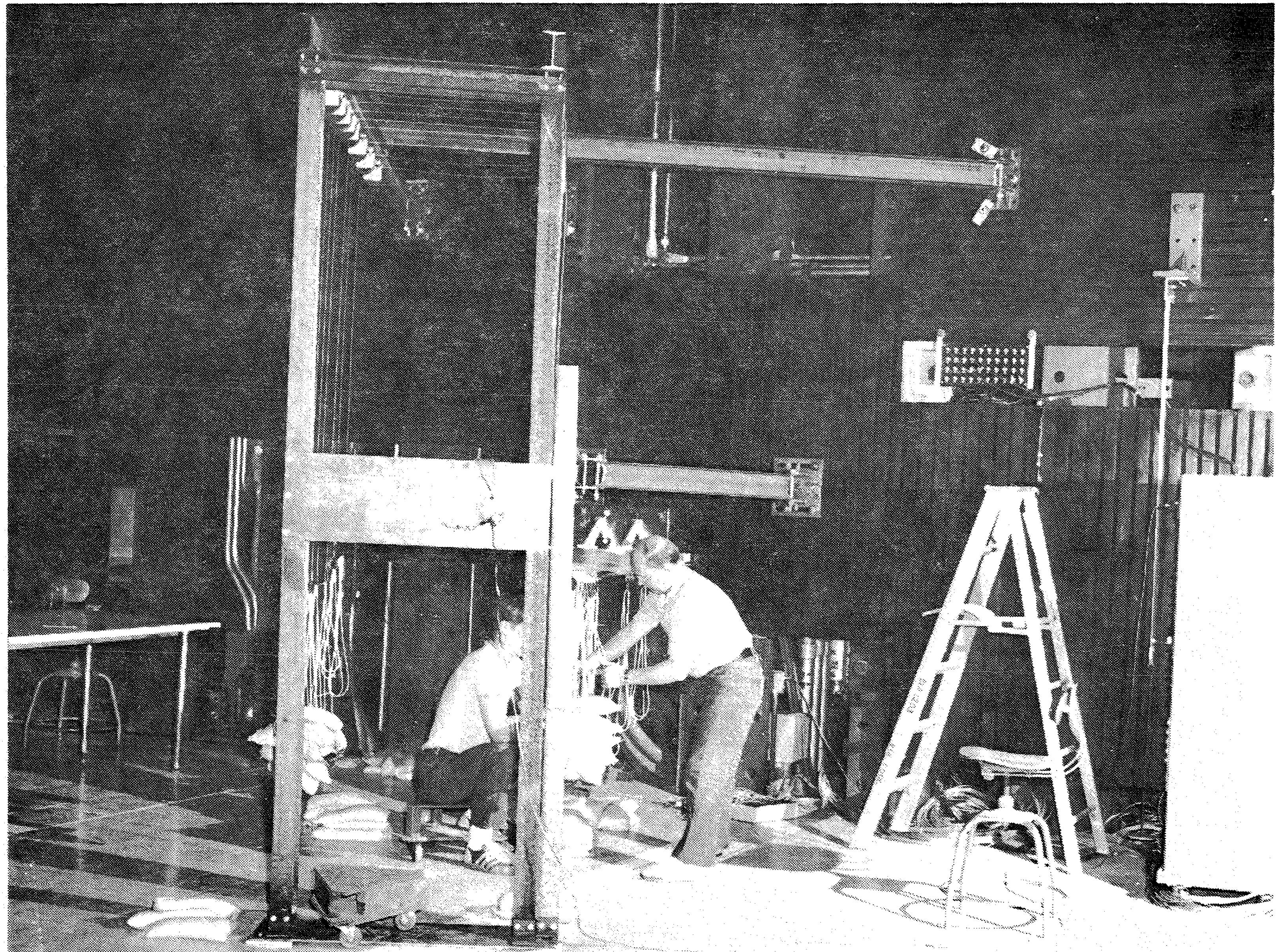


Figure 4.- Overhead frame with pulley arrangement for application of negative loadings.

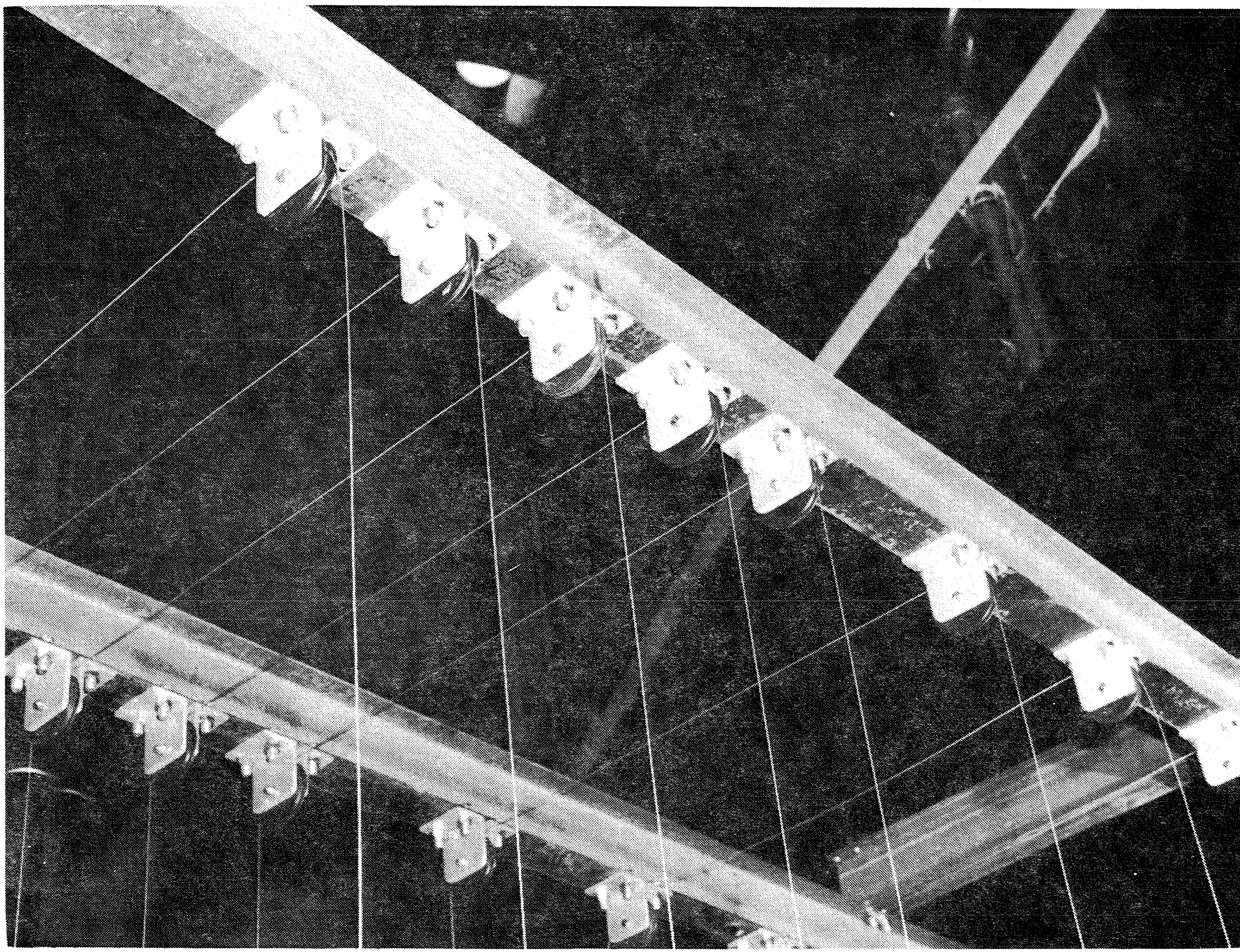


Figure 5.- Closeup of pulley arrangement on overhead frame used for application of negative loadings.

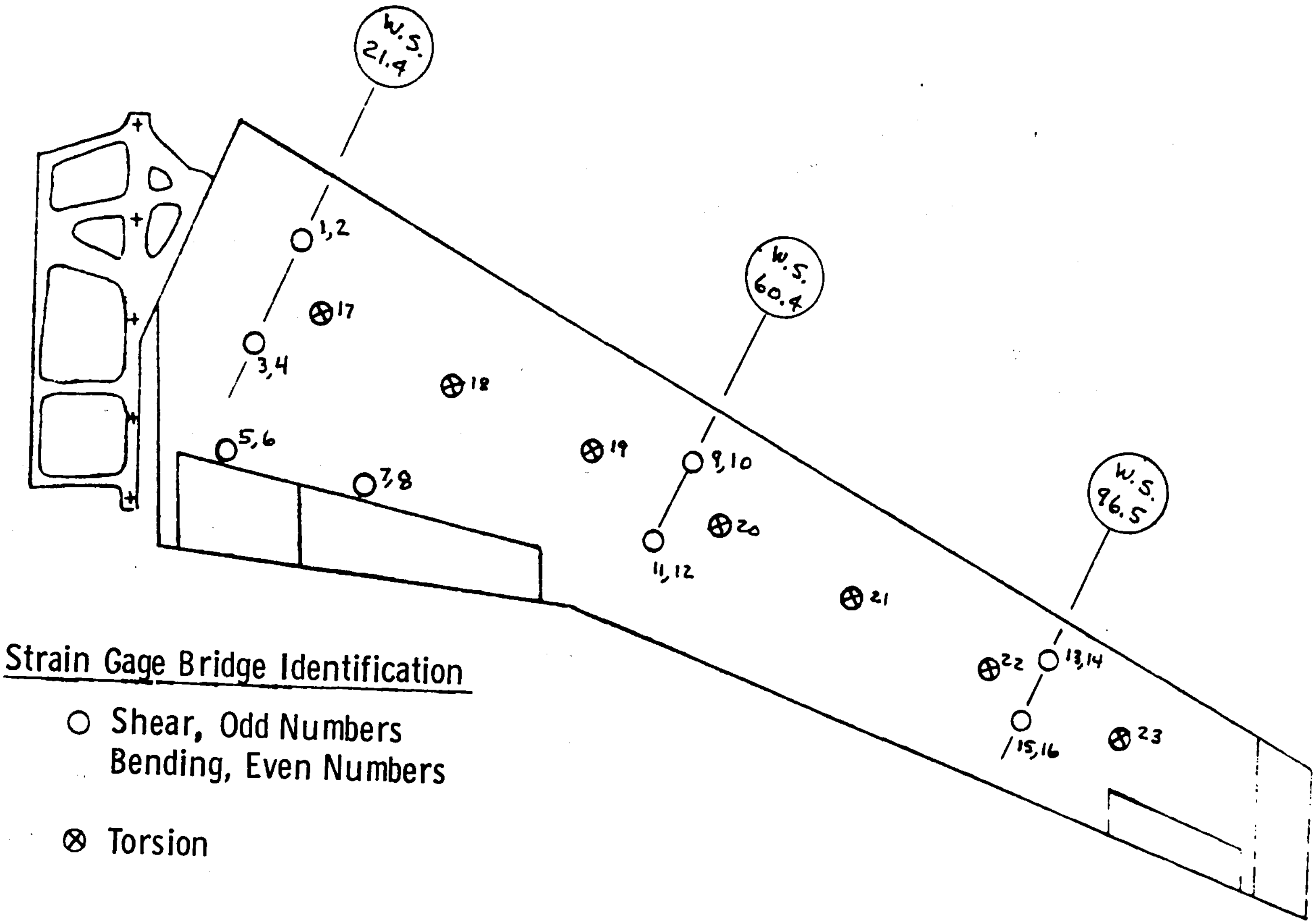


Figure 6.- Right Semispan Strain Gage Bridge Locations.

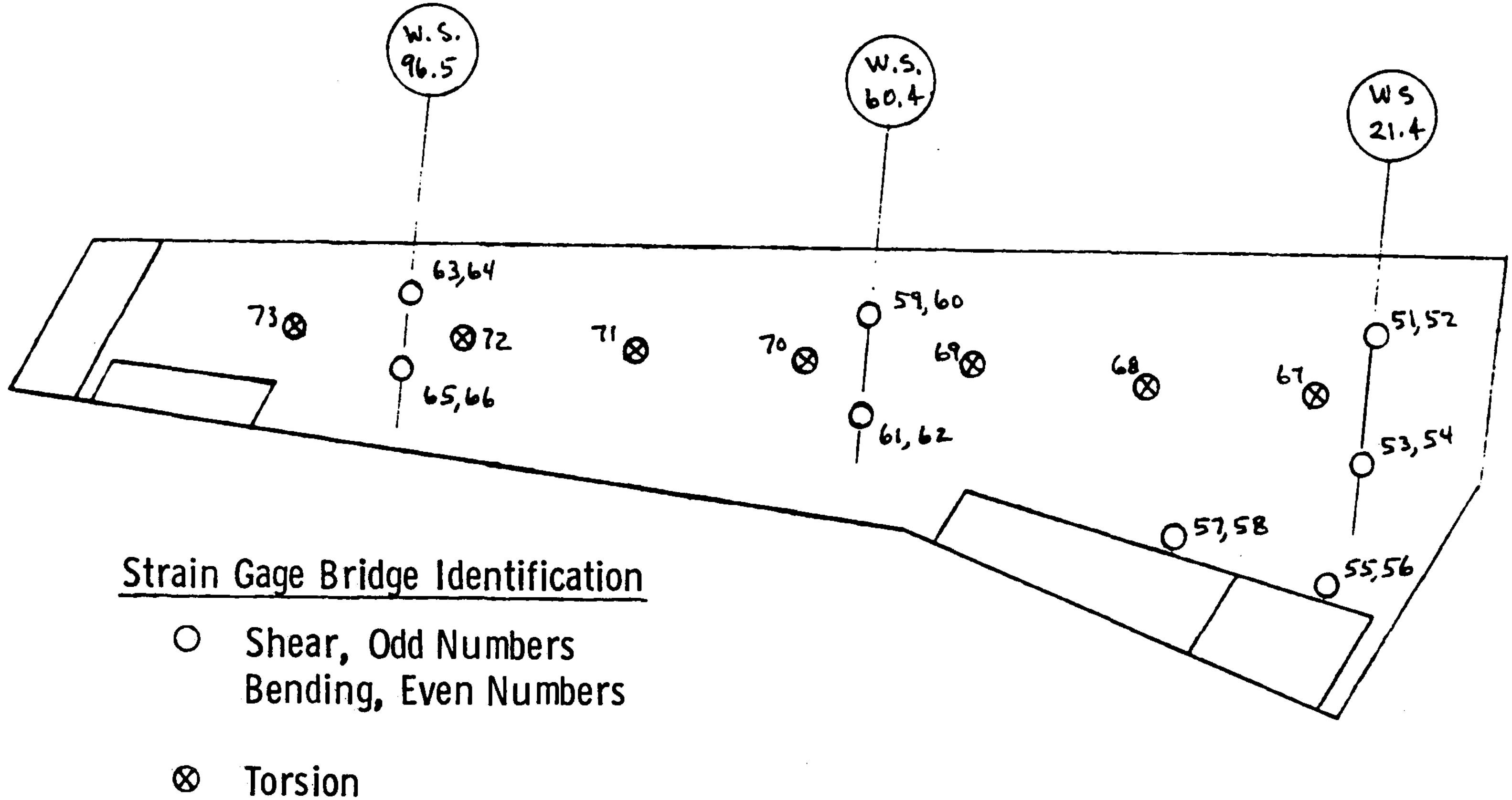


Figure 7.- Left Semispan Strain Gage Bridge Locations.

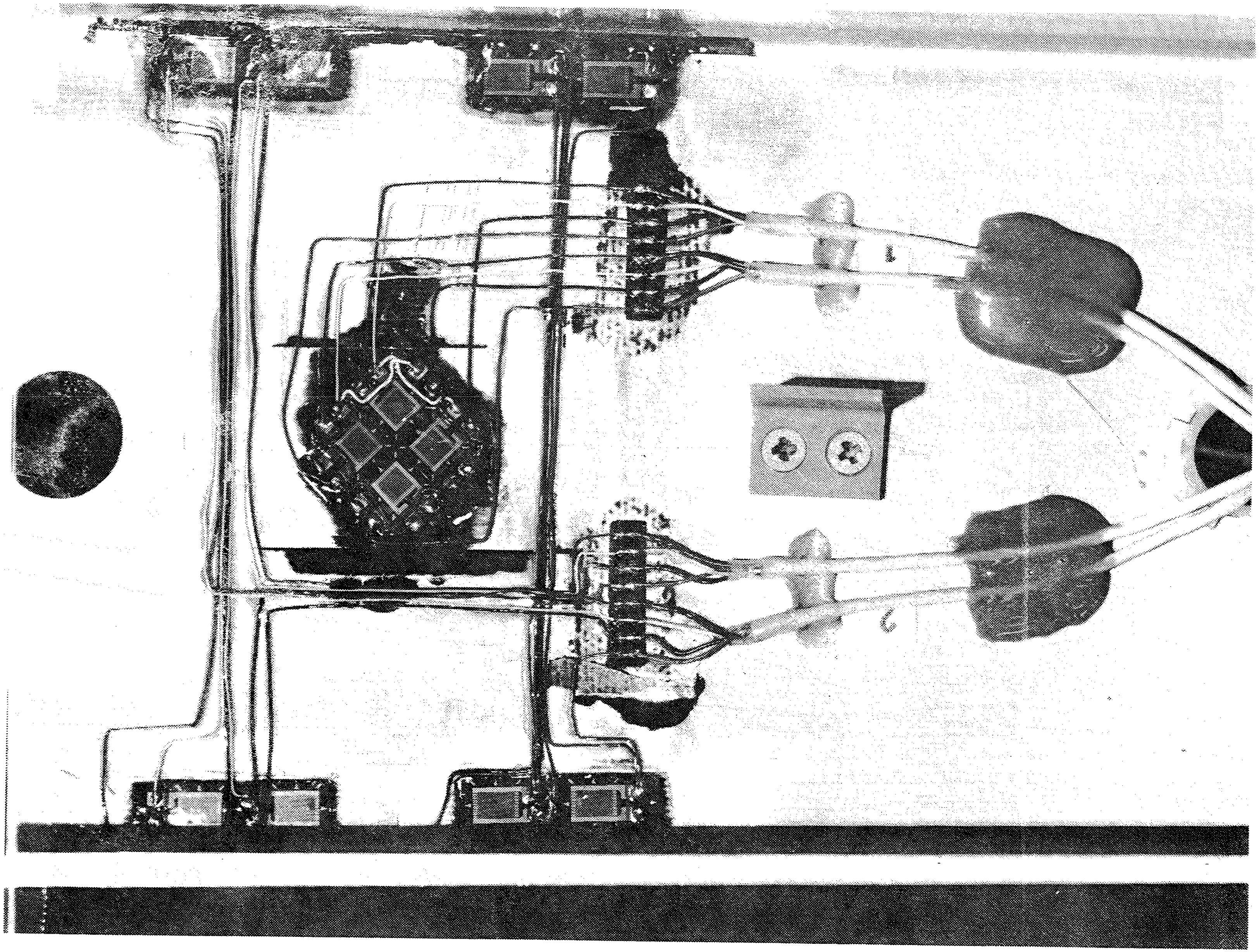


Figure 8.- Typical shear and bending moment strain gage bridge installations on spar vertical webs.

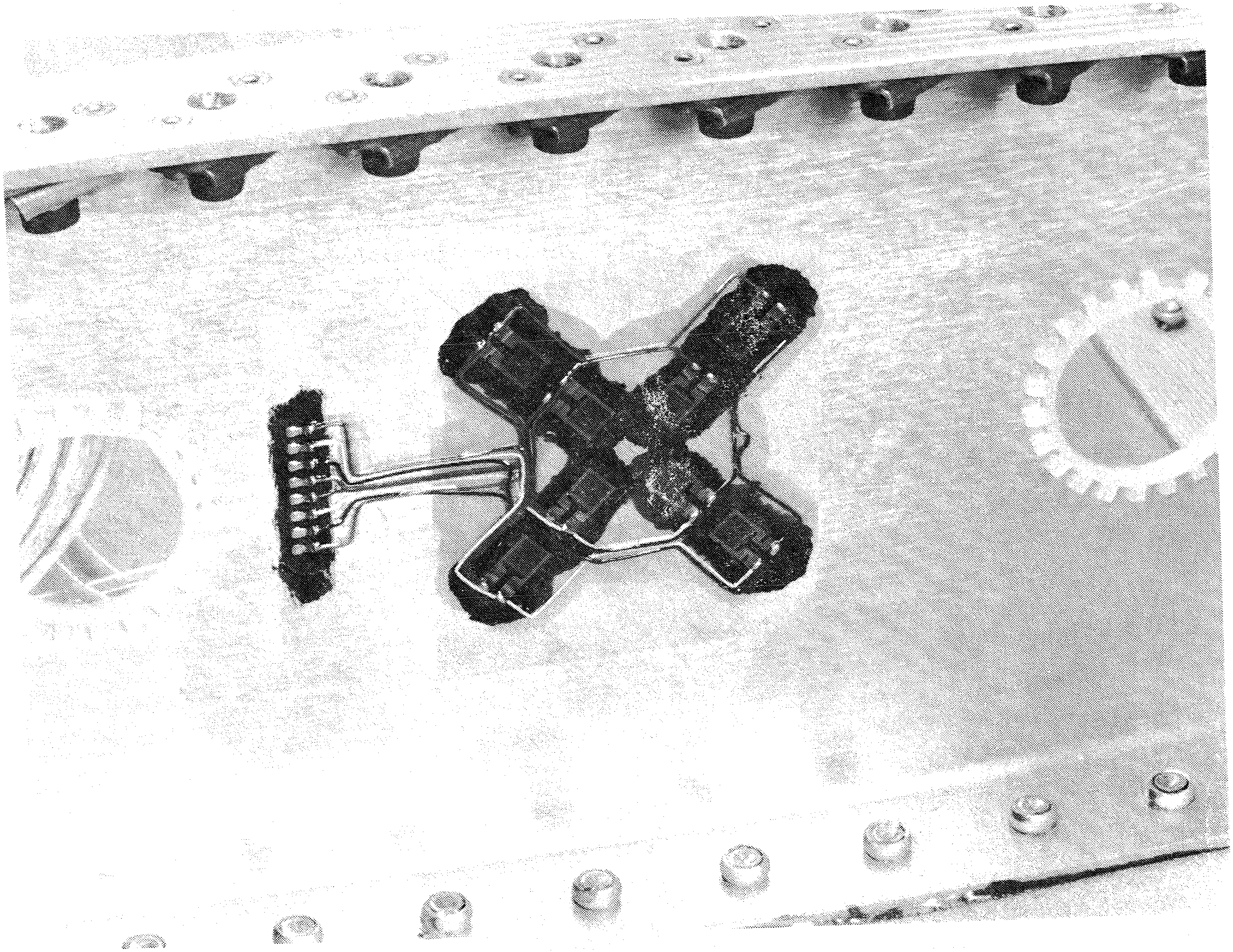


Figure 9.- Typical torsion strain gage bridge installation on ribs between front and rear spars.

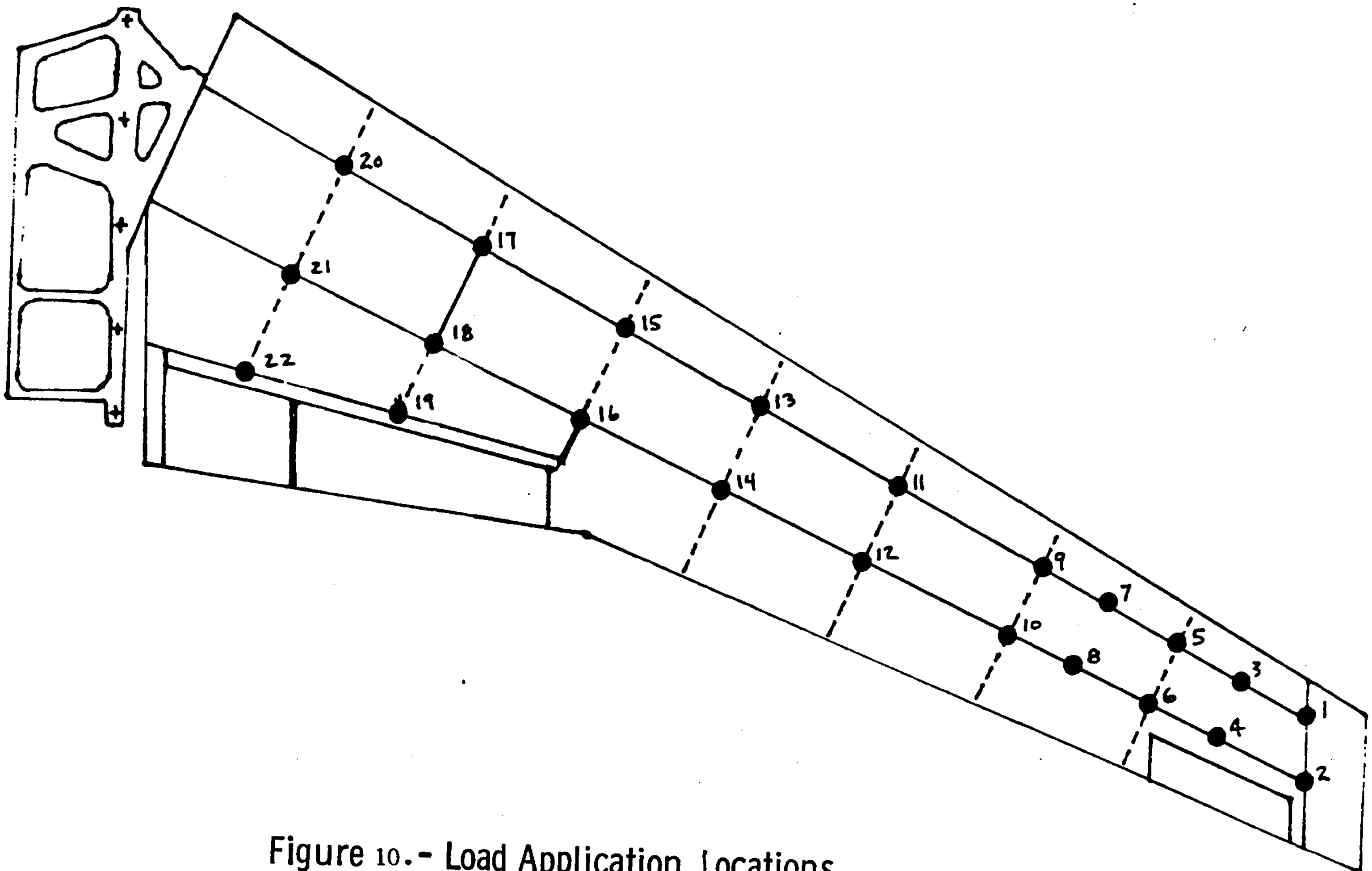


Figure 10.- Load Application Locations.

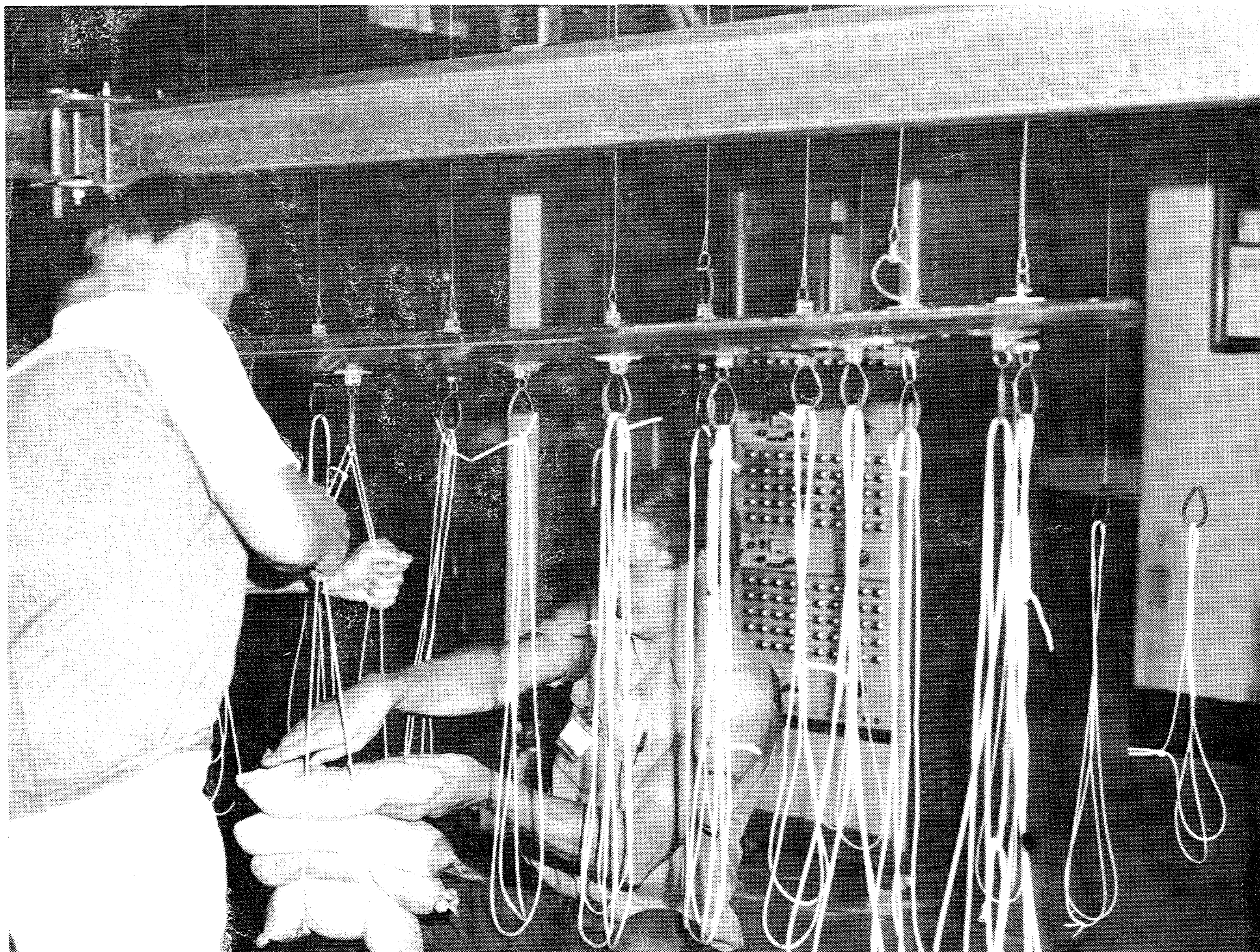
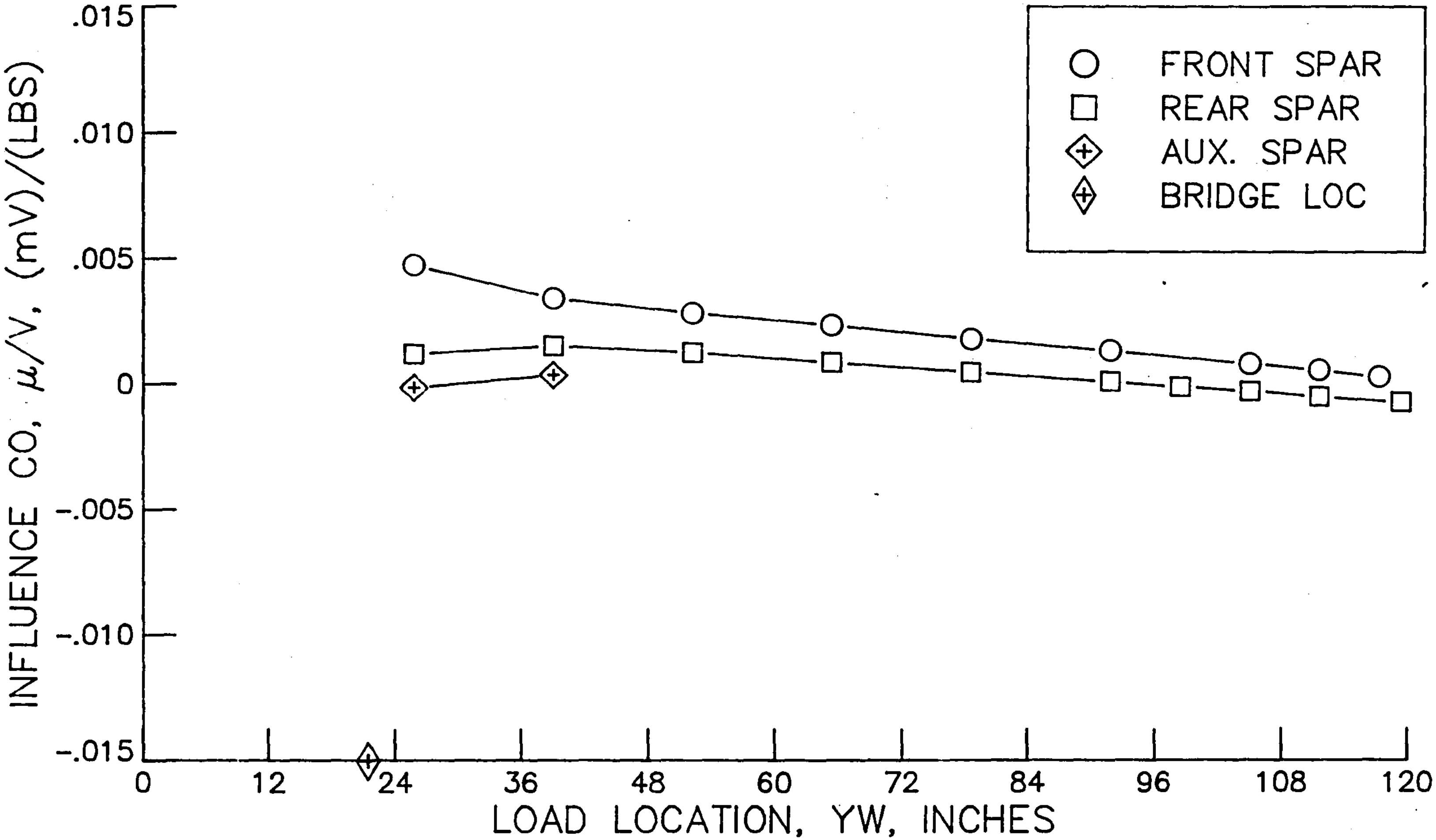
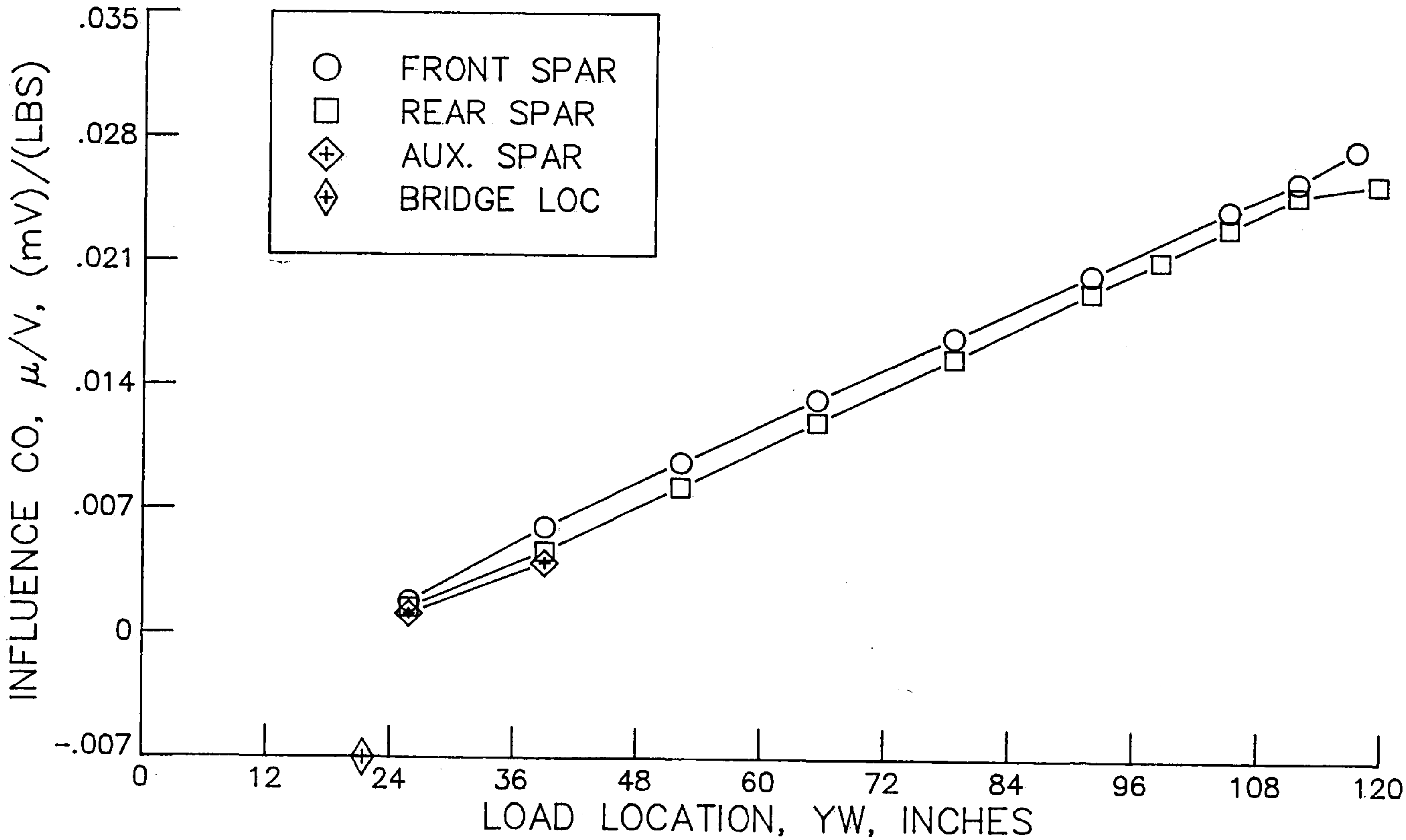


Figure 11.- Load application method.



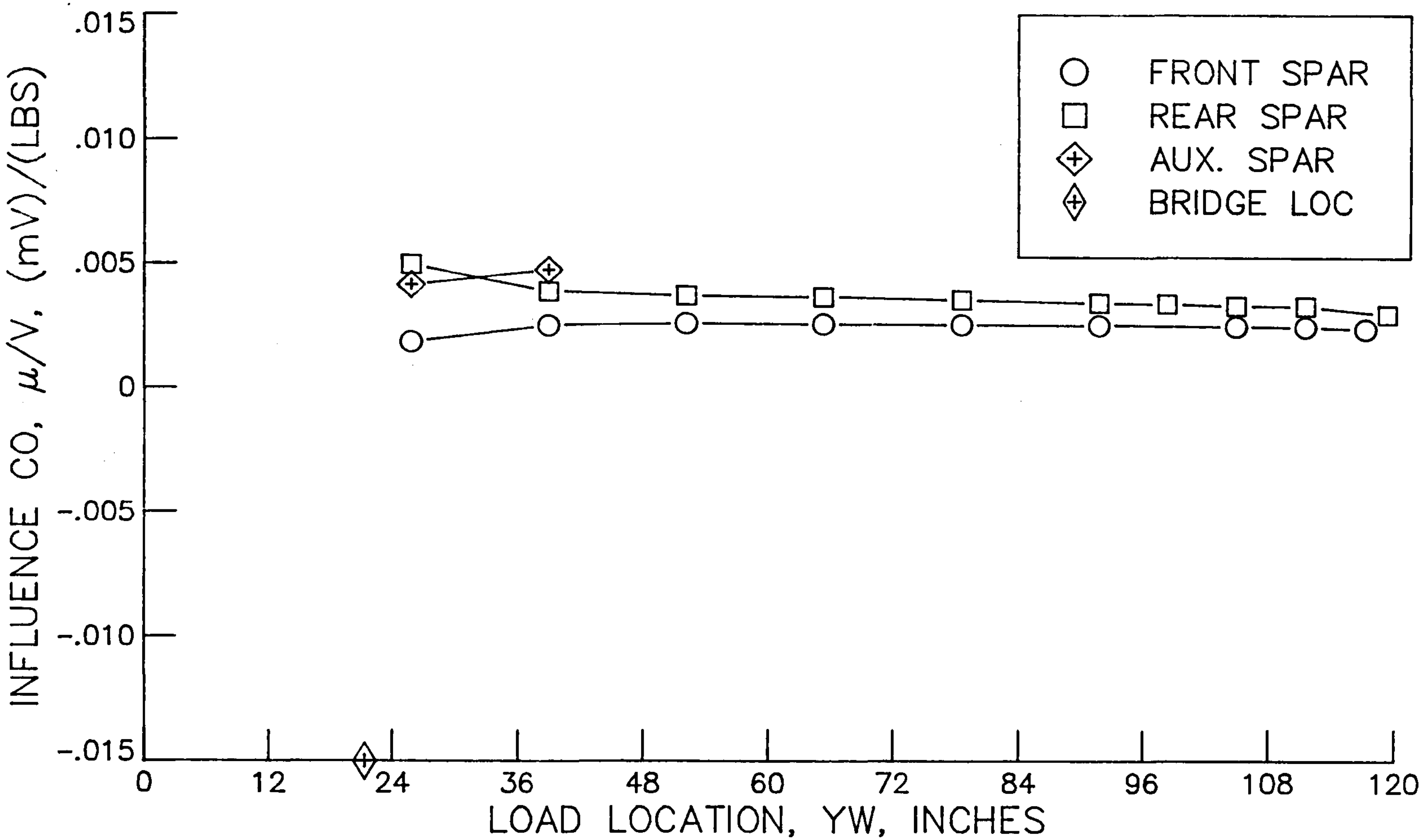
a) - SGB 1, Inboard station, front spar, shear configuration.

Figure 12.- Influence coefficient plots for the right semispan strain gage bridges.



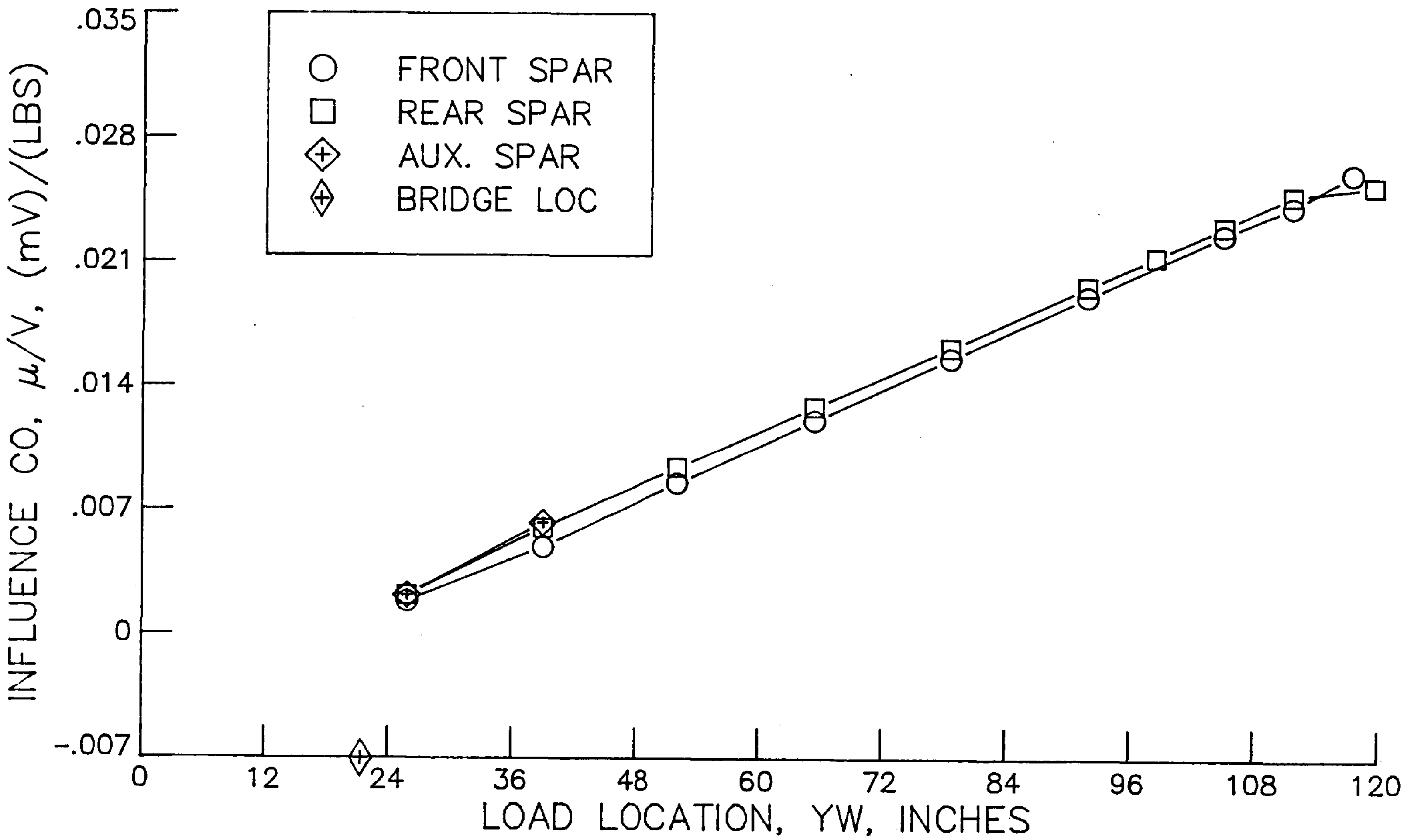
b) - SGB 2, Inboard station, front spar, bending moment configuration.

Figure 12.- Continued.



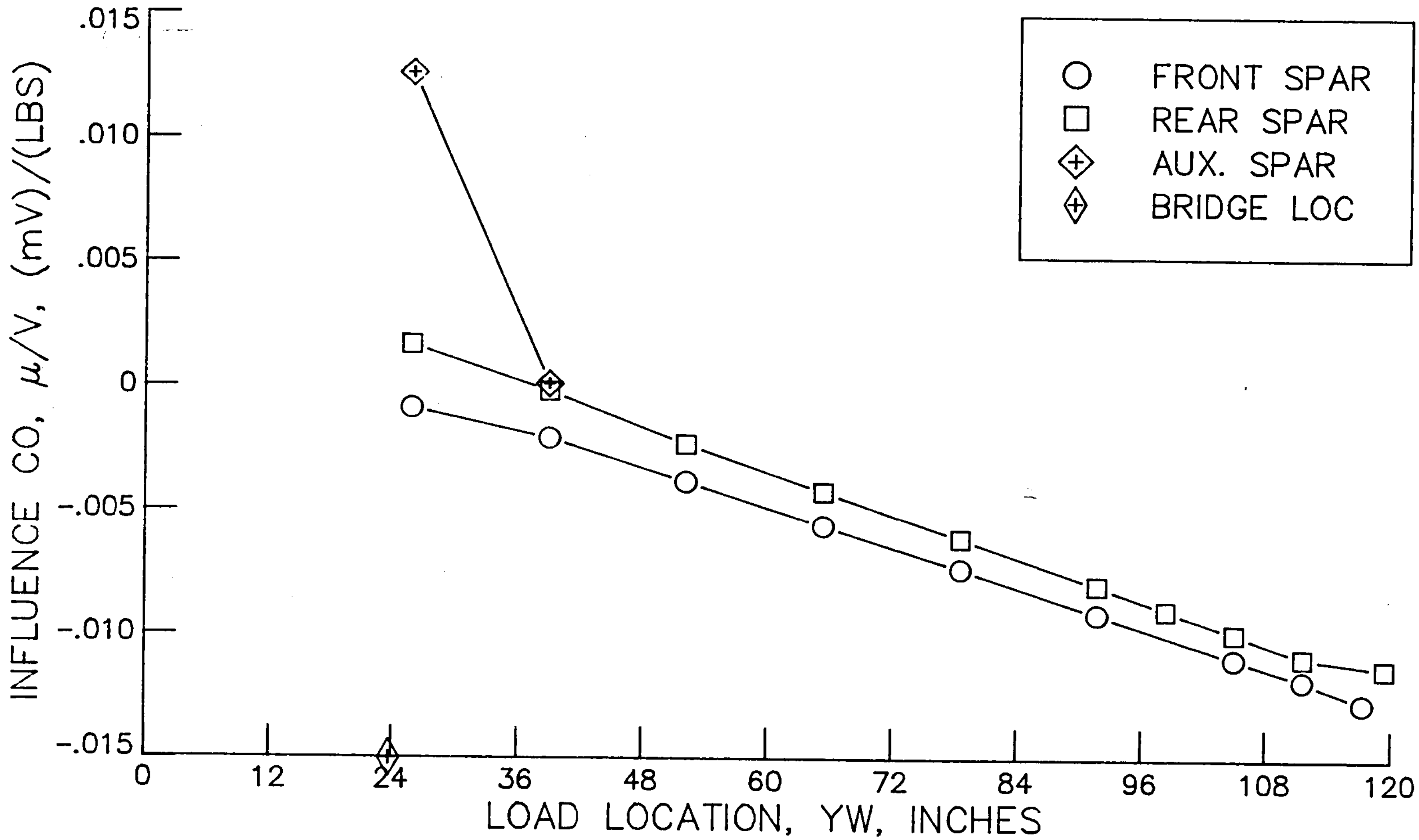
c) – SGB 3, Inboard station, rear spar, shear configuration.

Figure 12.– Continued.



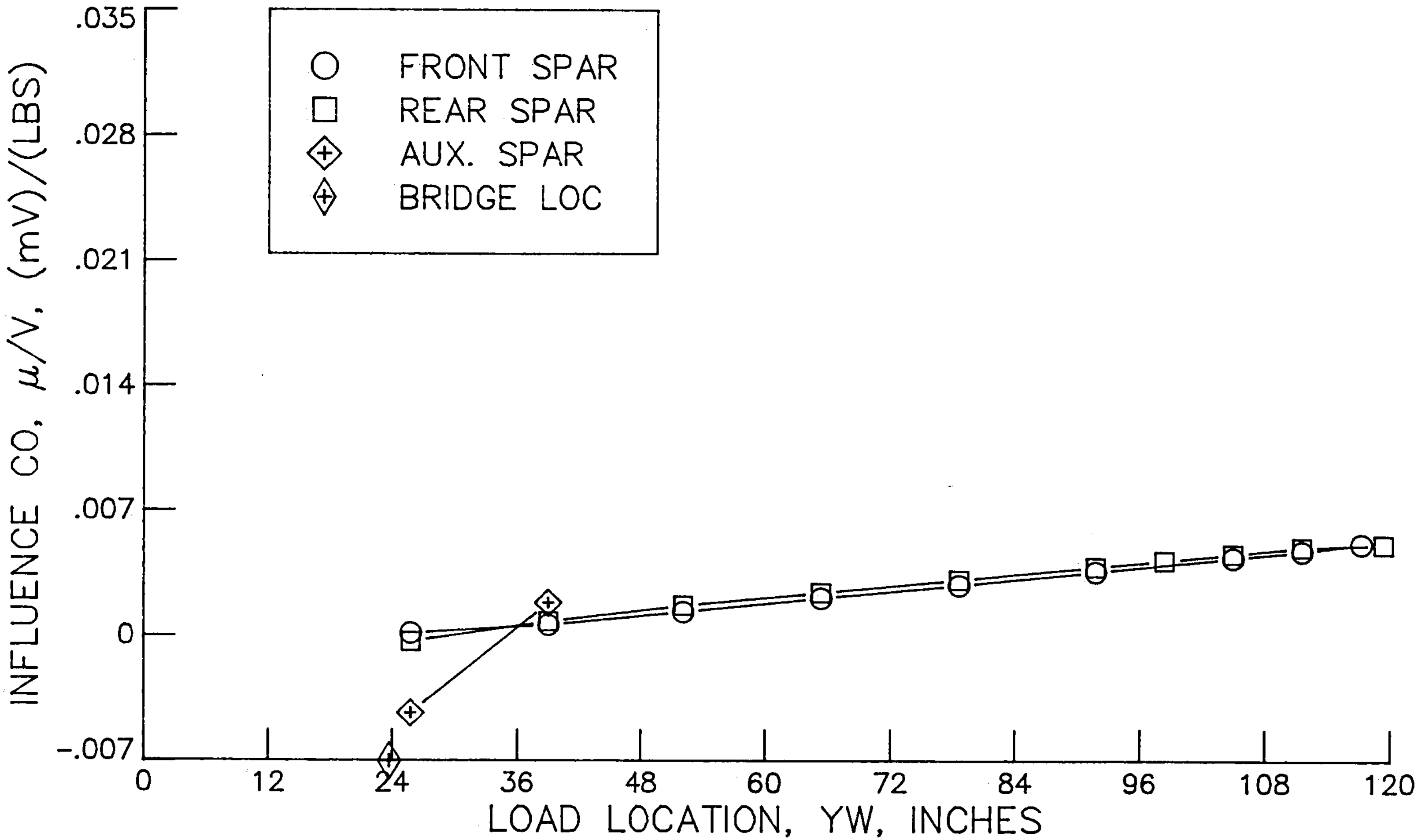
d) - SGB 4, Inboard station, rear spar, bending moment configuration.

Figure 12.- Continued.



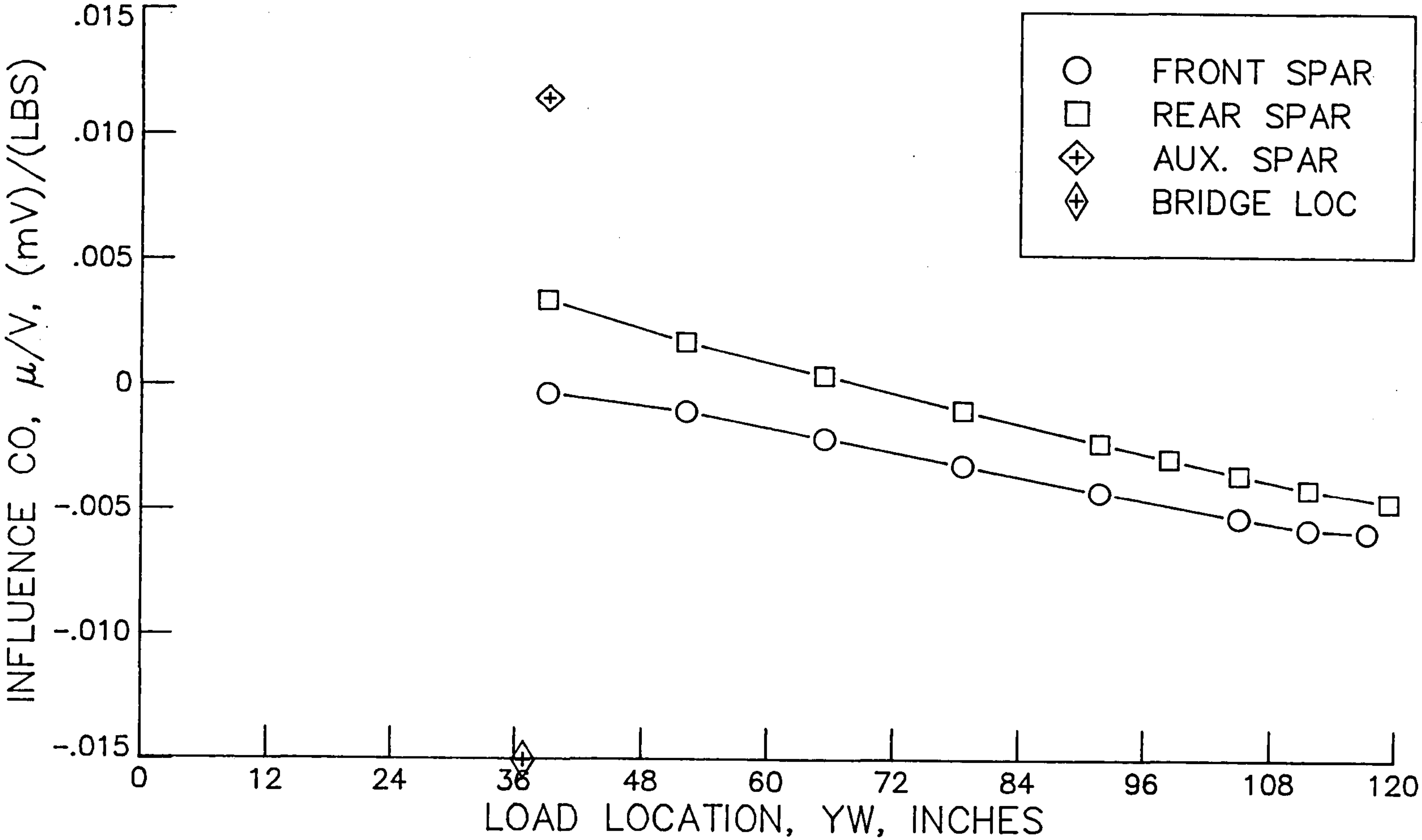
e) - SGB 5, Inboard station, auxillary spar, shear configuration.

Figure 12.- Continued.



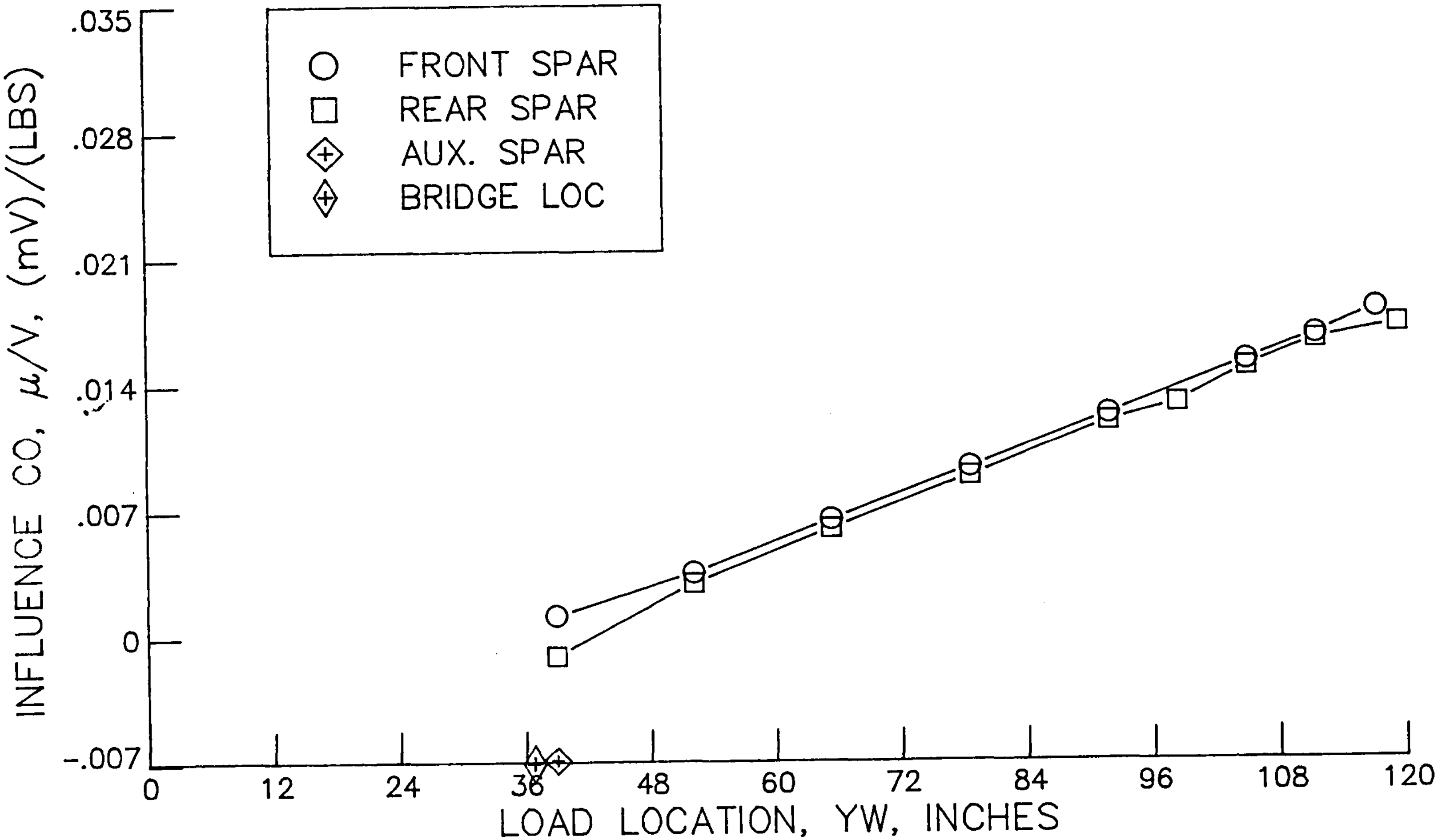
f) - SGB 6, Inboard station, auxillary spar, bending moment configuration.

Figure 12.- Continued.



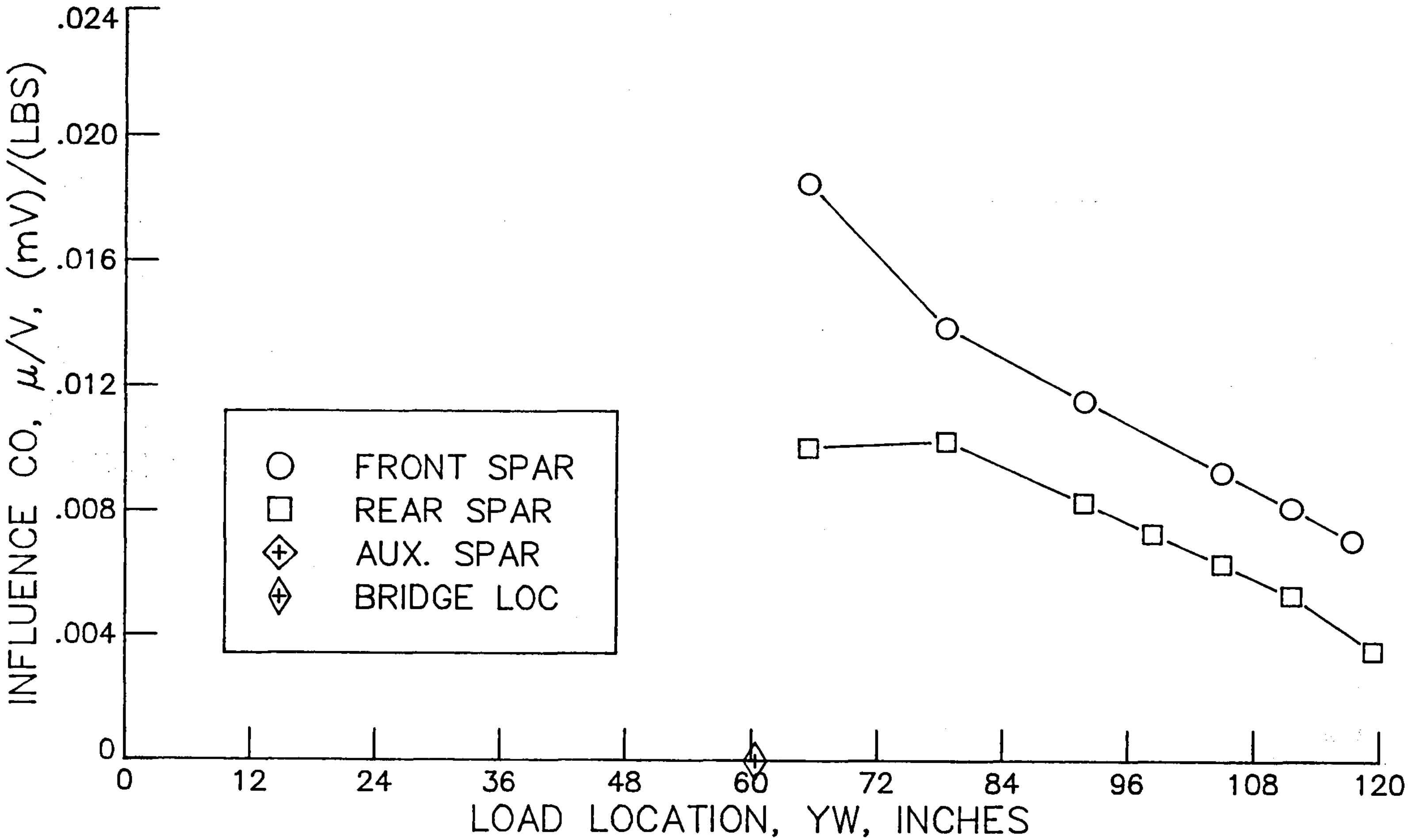
g) - SGB 7, Inboard station, auxillary spar, shear configuration.

Figure 12.- Continued.



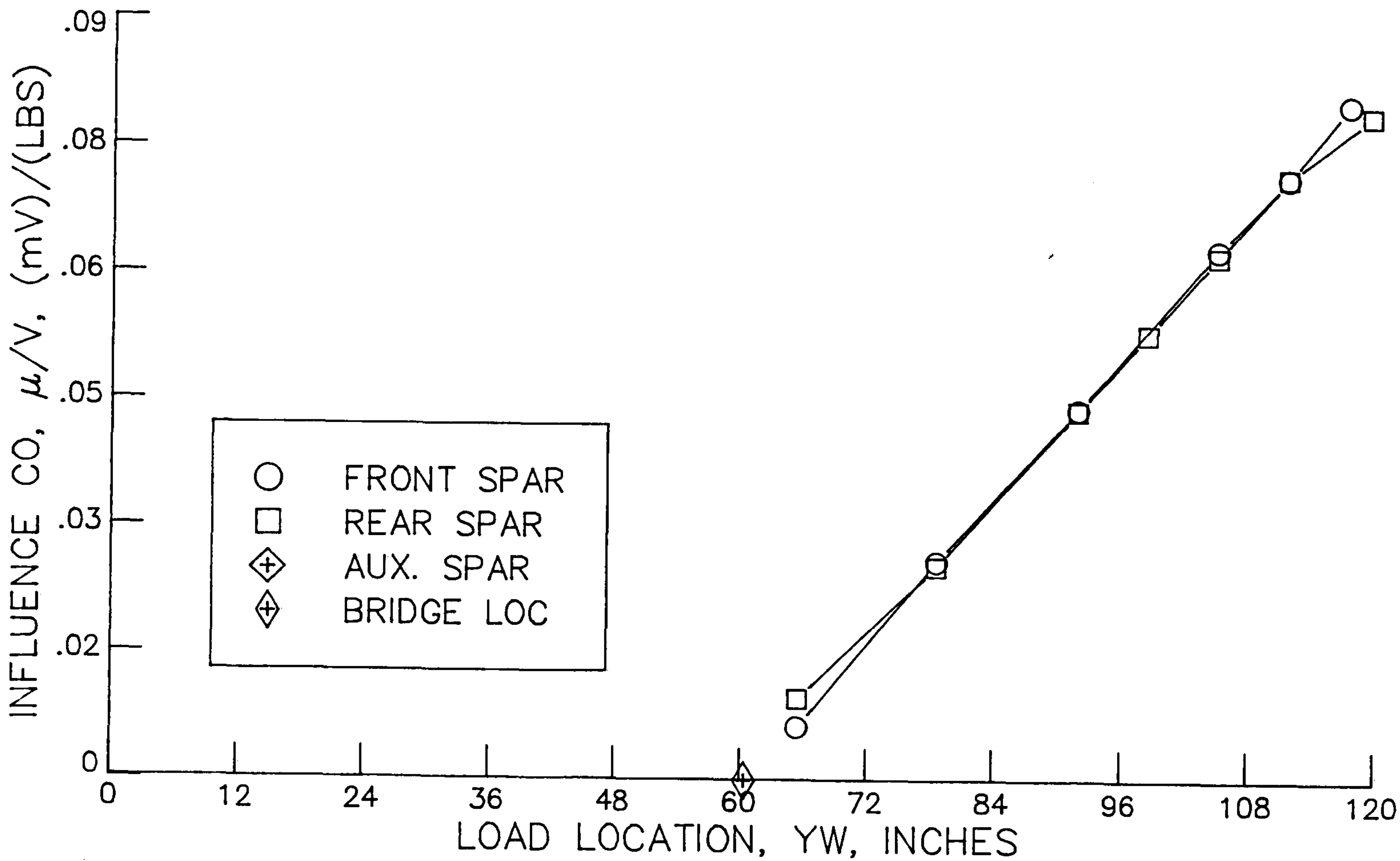
h) - SGB 8, Inboard station, auxillary spar, bending moment configuration.

Figure 12.- Continued.



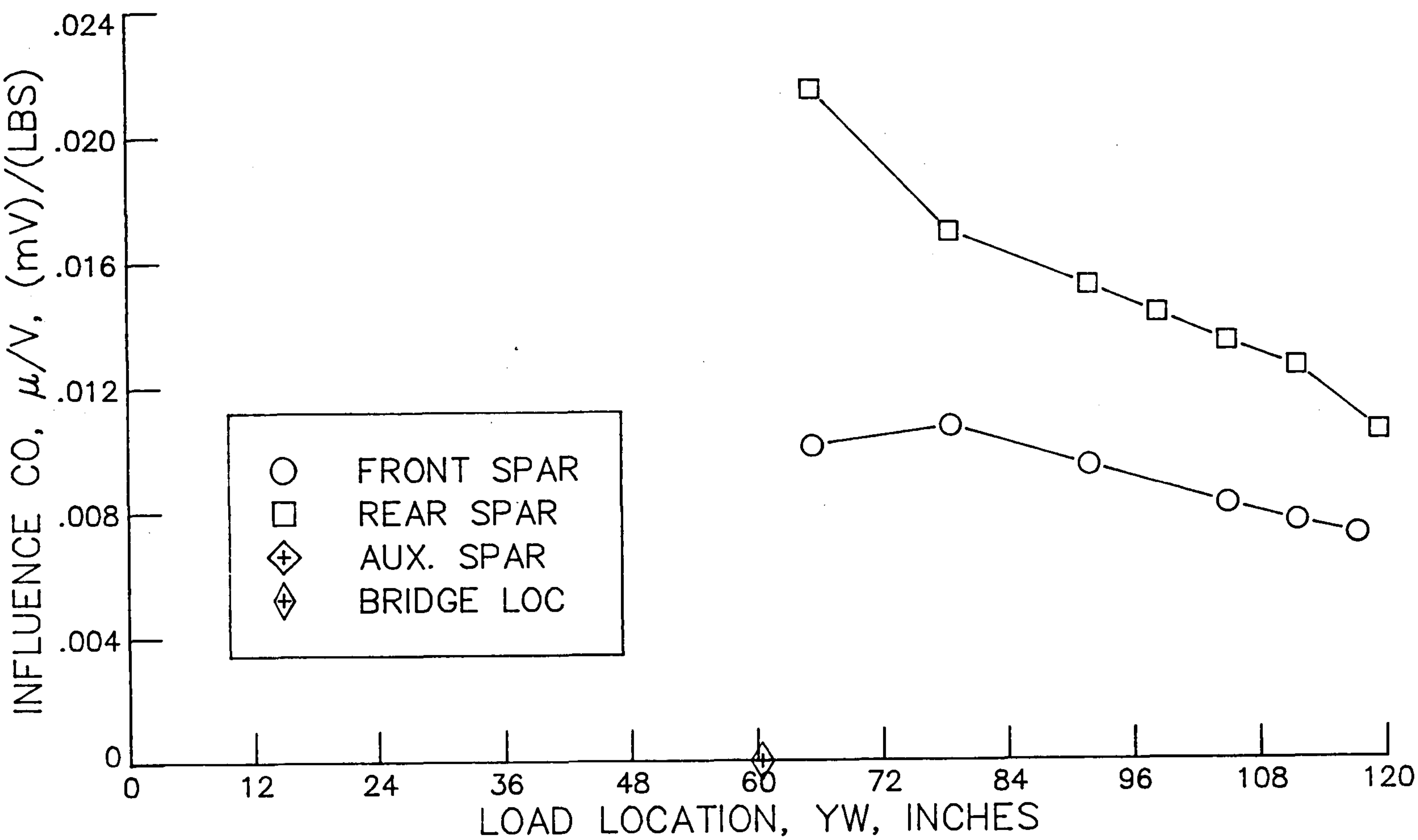
i) - SGB 9, midwing station, front spar, shear configuration.

Figure 12.- Continued.



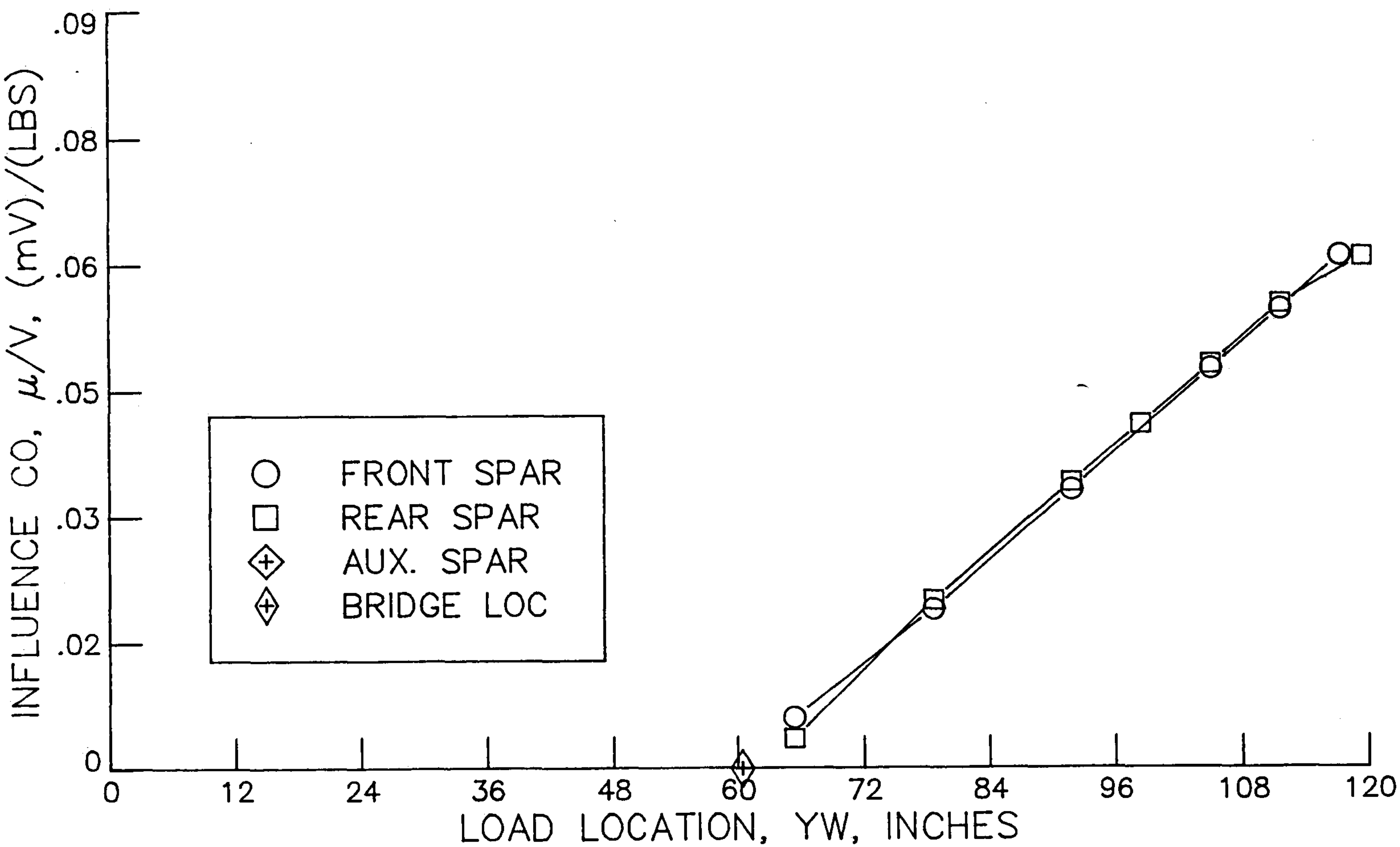
j) - SGB 10, midwing station, front spar, bending moment configuration.

Figure 12.- Continued.



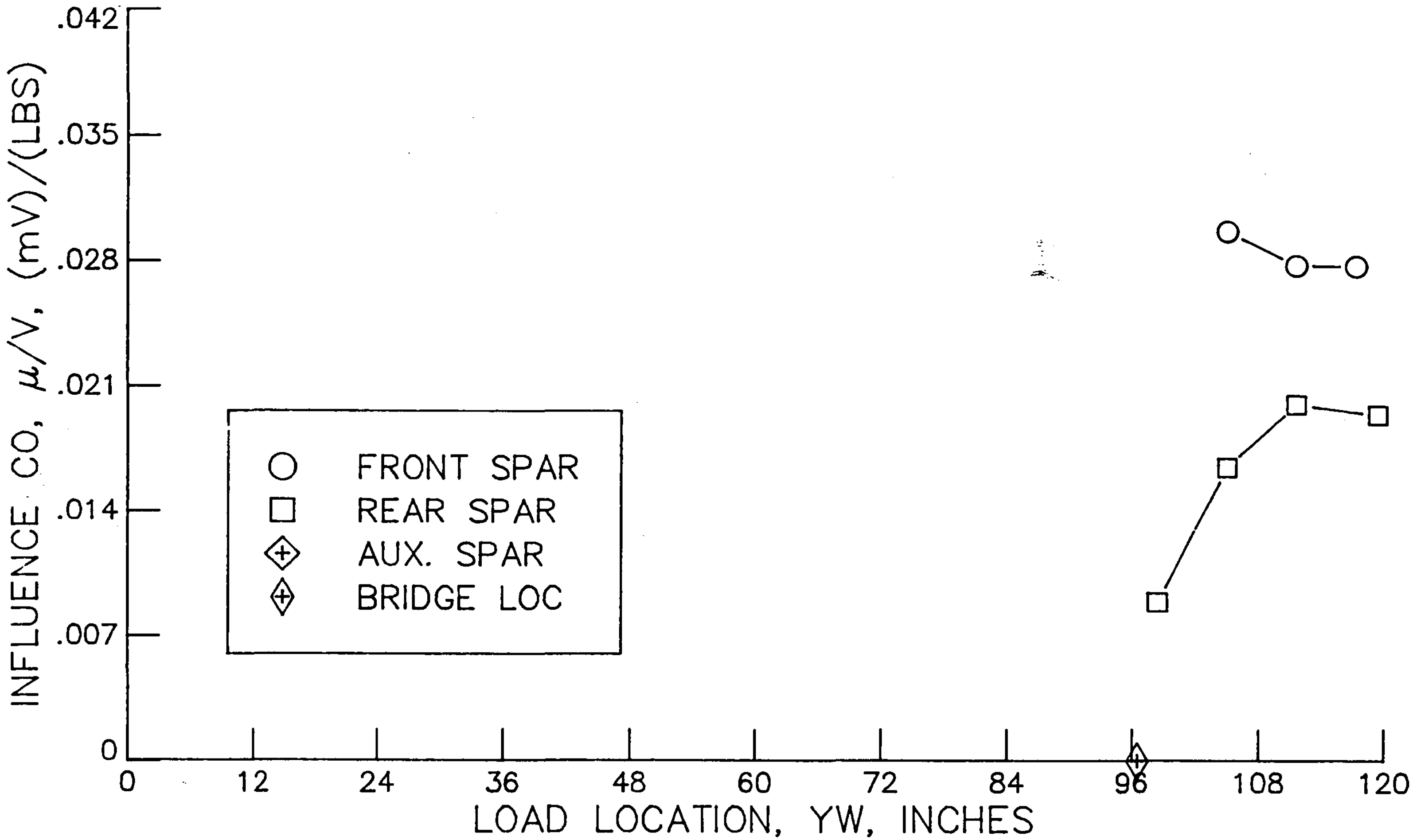
k) - SGB 11, midwing station, rear spar, shear configuration.

Figure 12.- Continued.



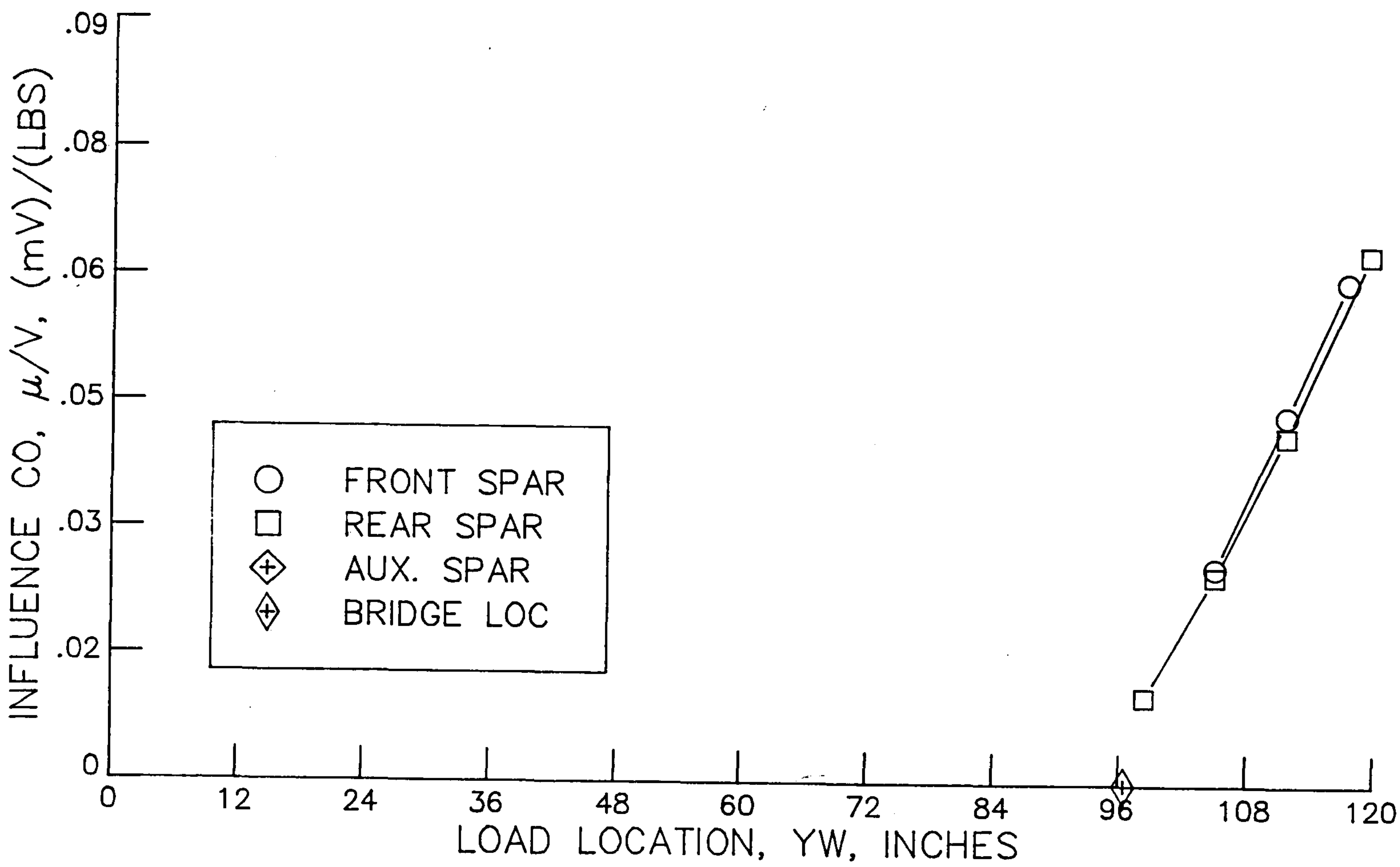
1) - SGB 12, midwing station, rear spar, bending moment configuration.

Figure 12.- Continued.



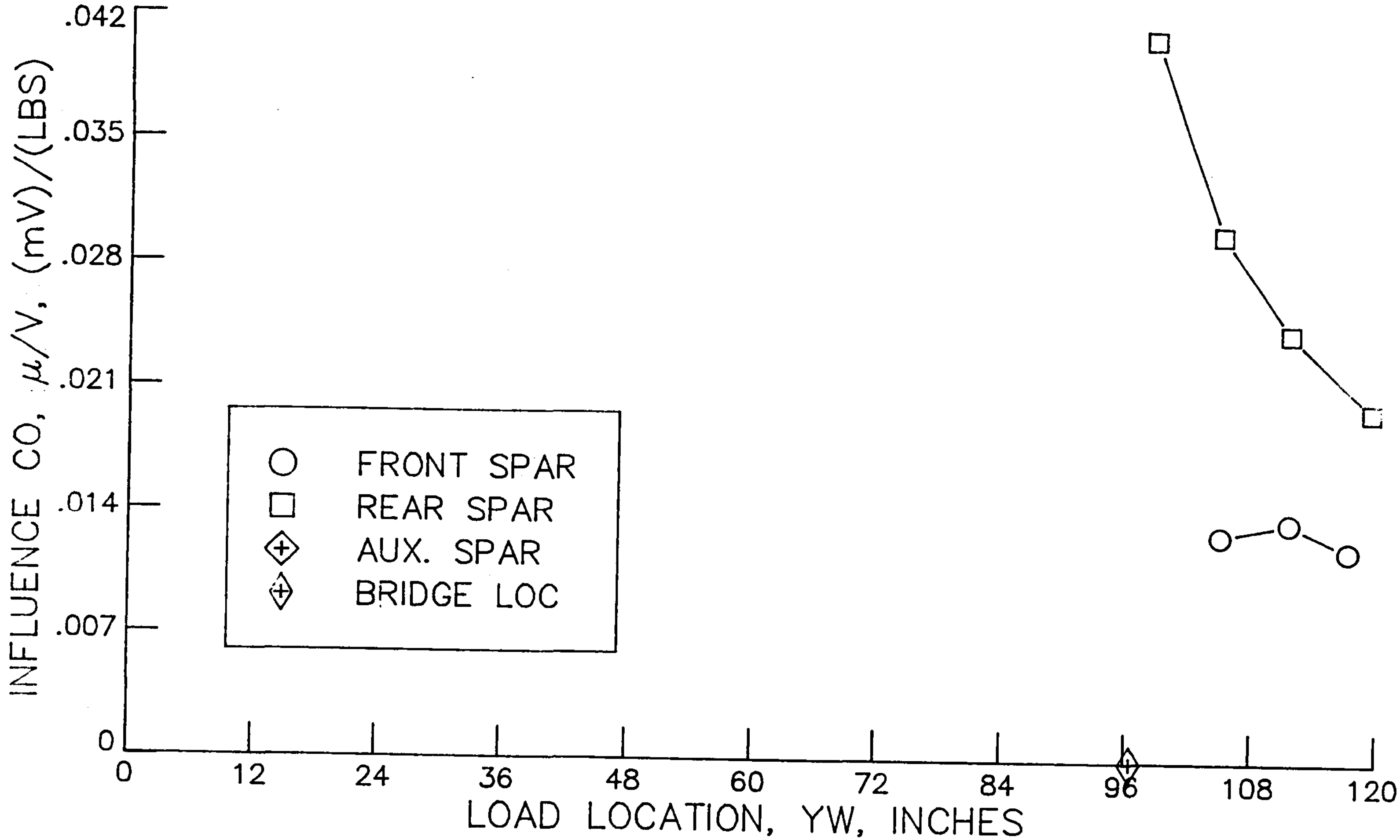
m) - SGB 13, outboard station, front spar, shear configuration.

Figure 12.- Continued.



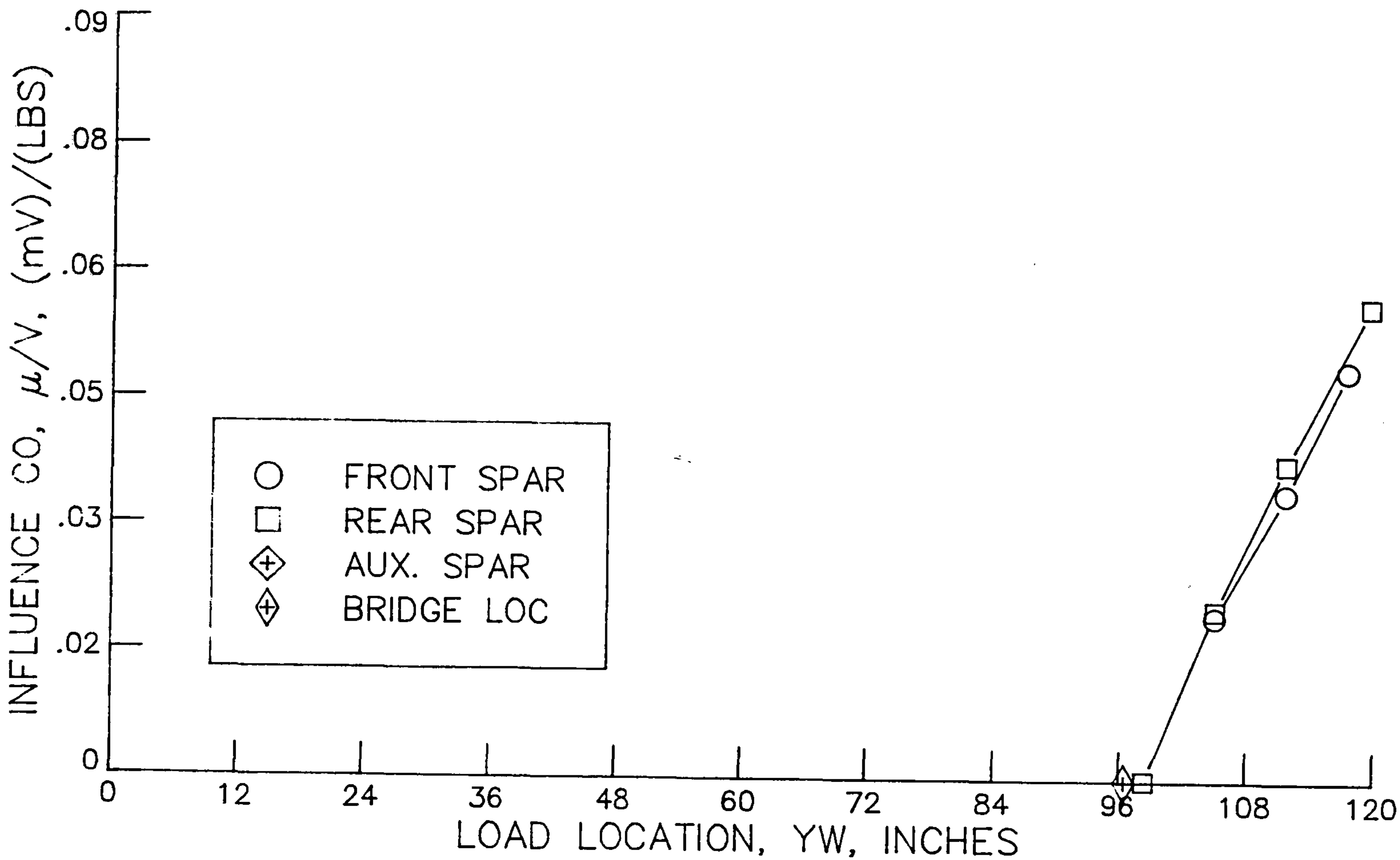
n) - SGB 14, outboard station, front spar, bending moment configuration.

Figure 12.- Continued.



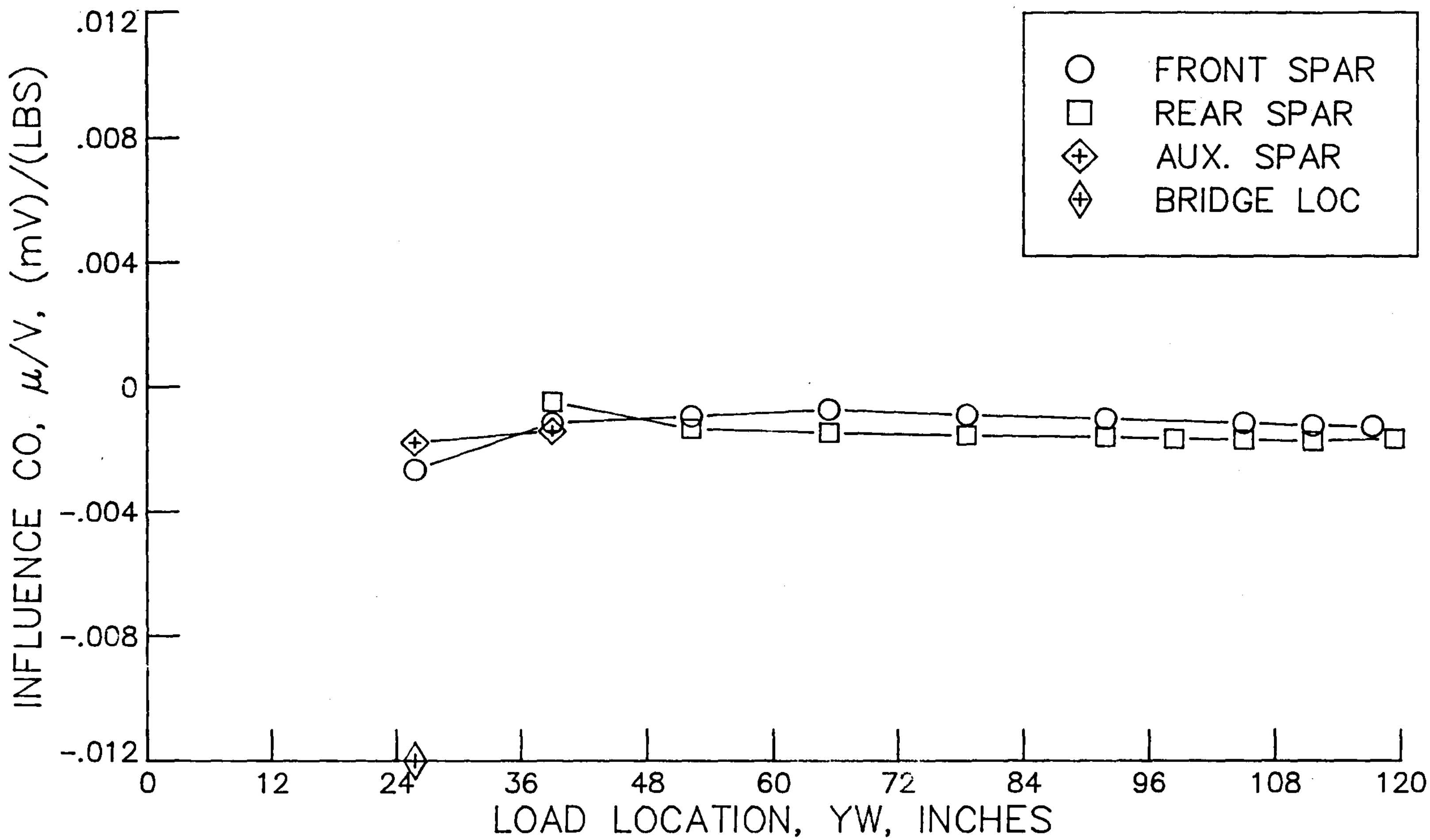
o) - SGB 15, outboard station, rear spar, shear configuration.

Figure 12.- Continued.



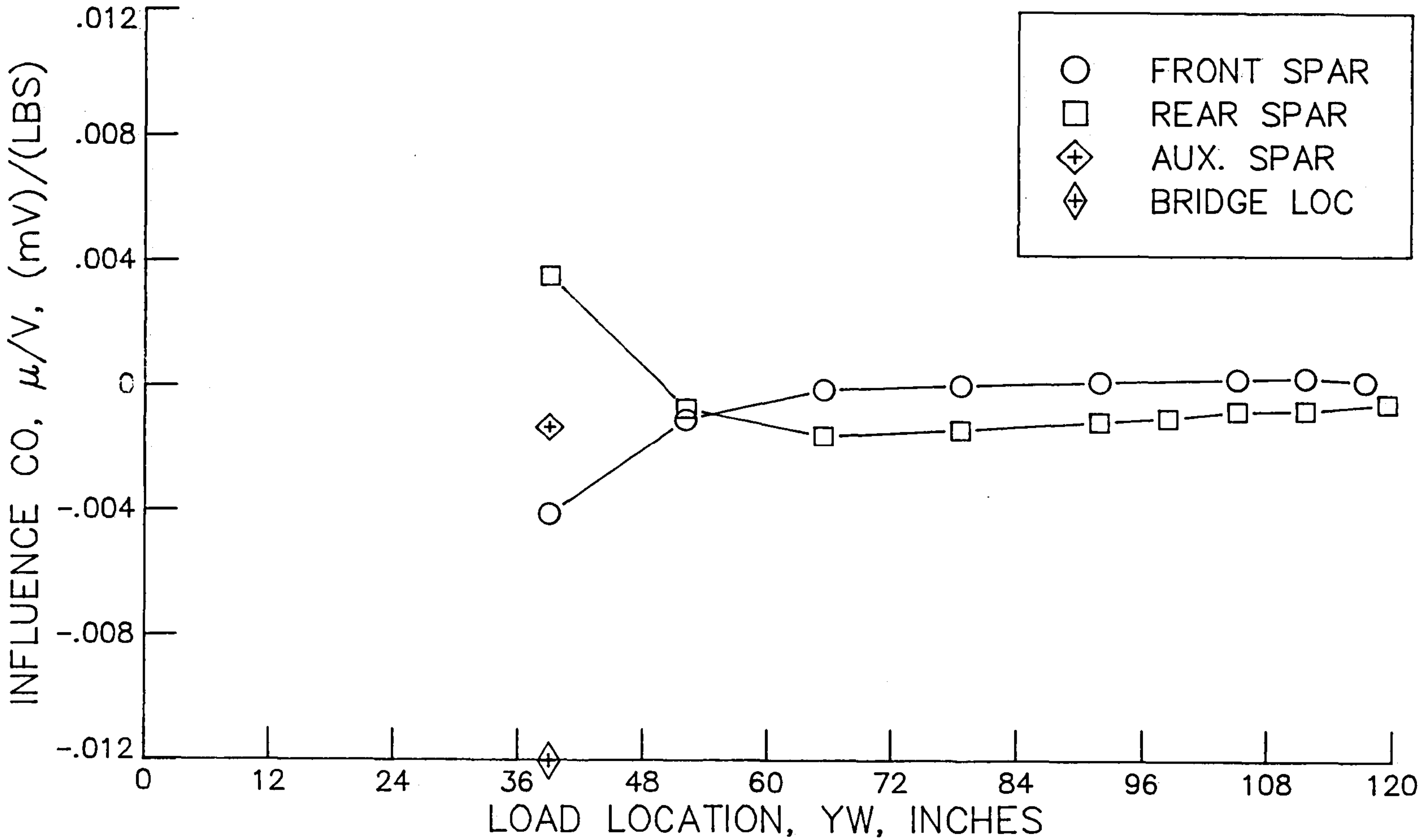
r) - SGR 16, outboard station, rear spar, bending moment configuration.

Figure 12.- Continued.



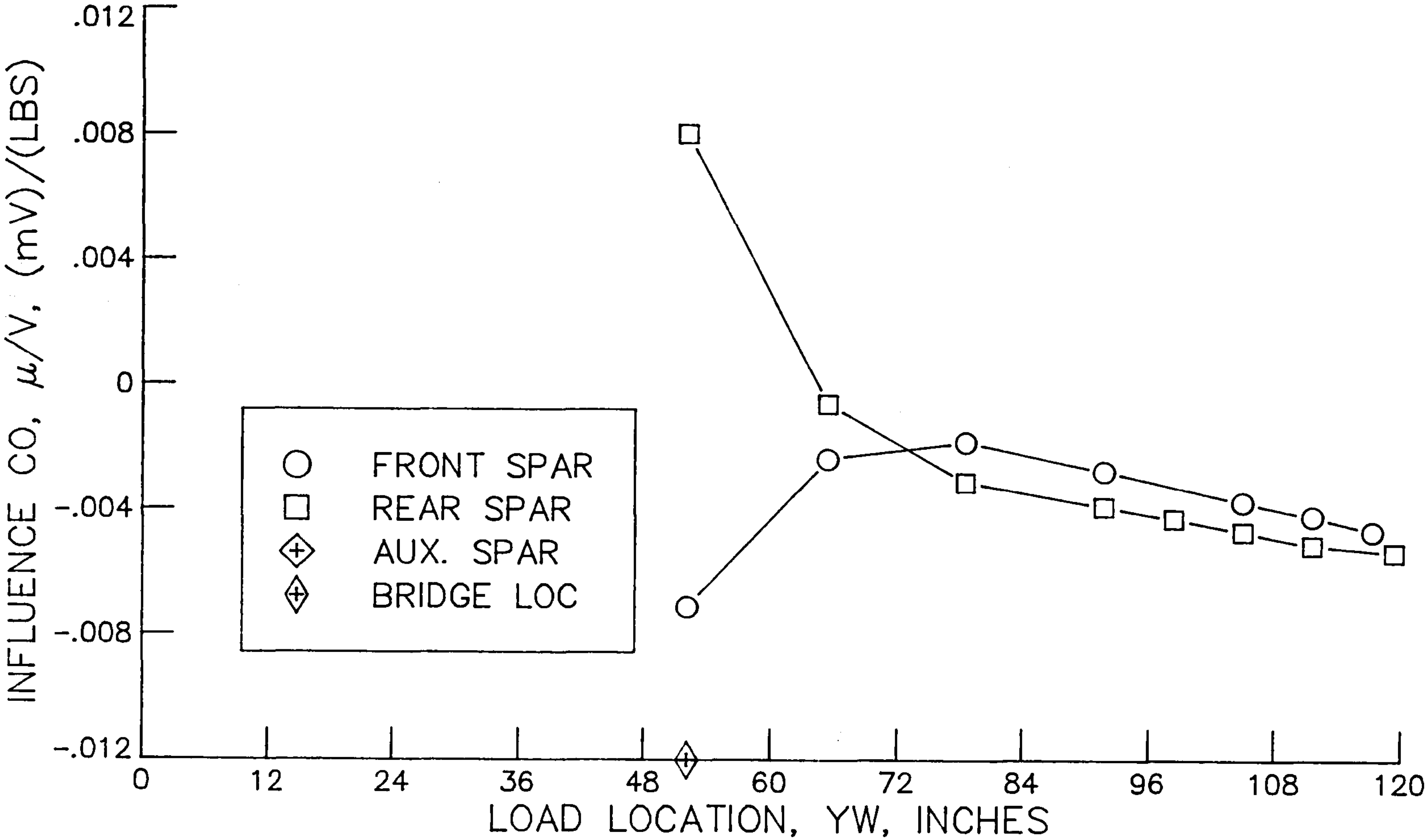
q) - SGB 17, inboard station, rib mounting, torque configuration.

Figure 12.- Continued.



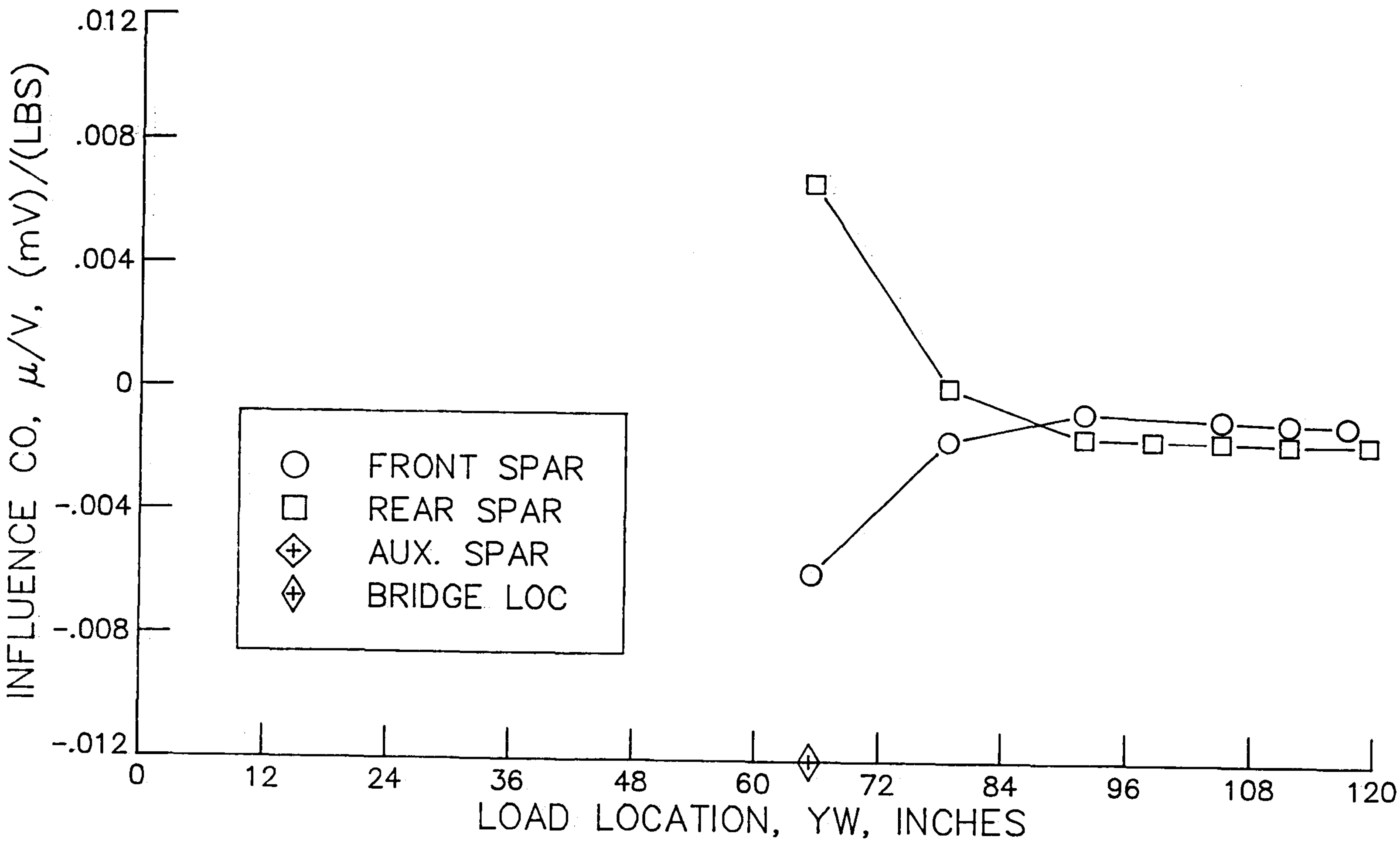
r) - SGB 18, inboard station, rib mounting, torque configuration.

Figure 12.- Continued.



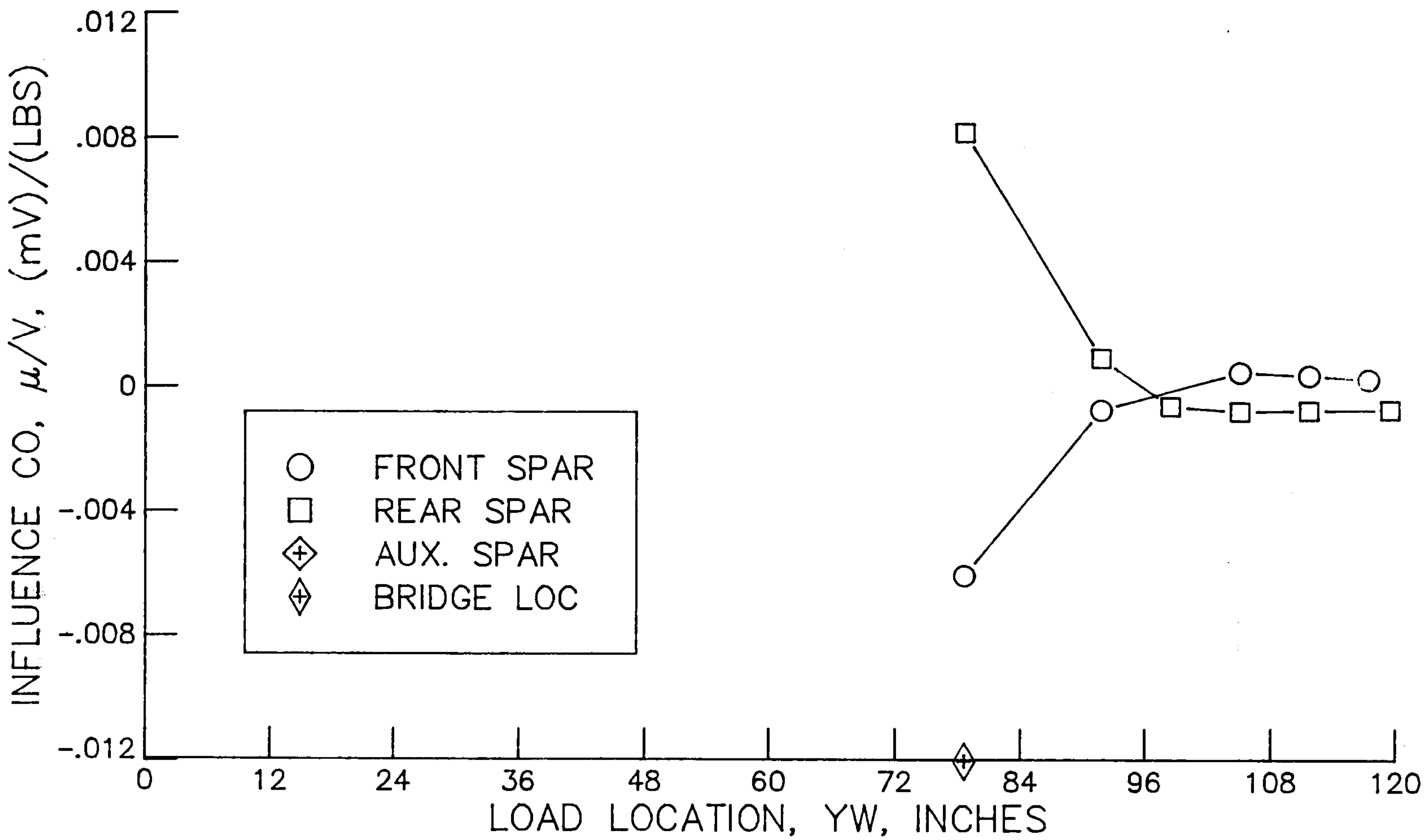
s) - SGB 19, midwing station, rib mounting, torque configuration.

Figure 12.- Continued.



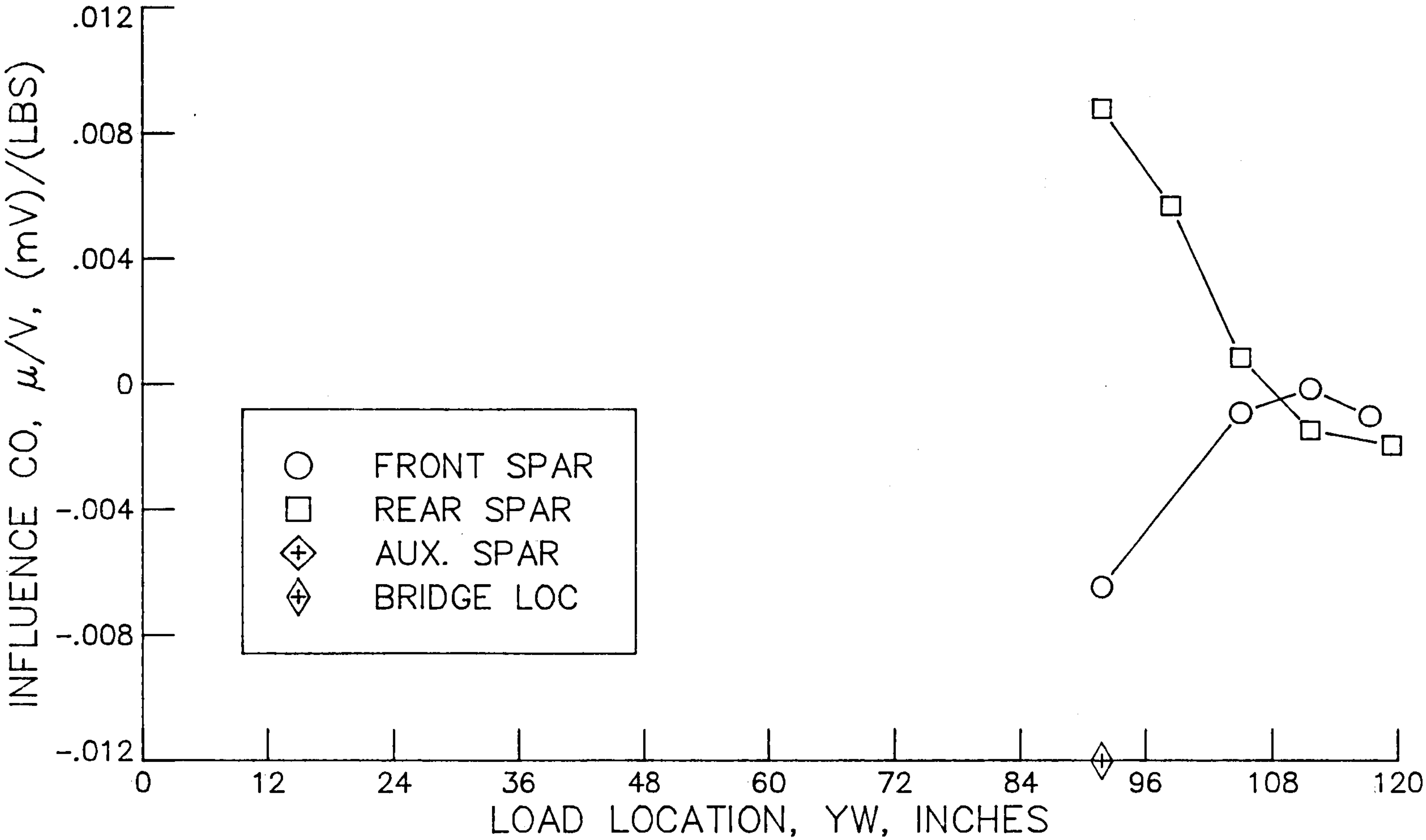
t) - SGB 20, midwing station, rib mounting, torque configuration.

Figure 12.- Continued.



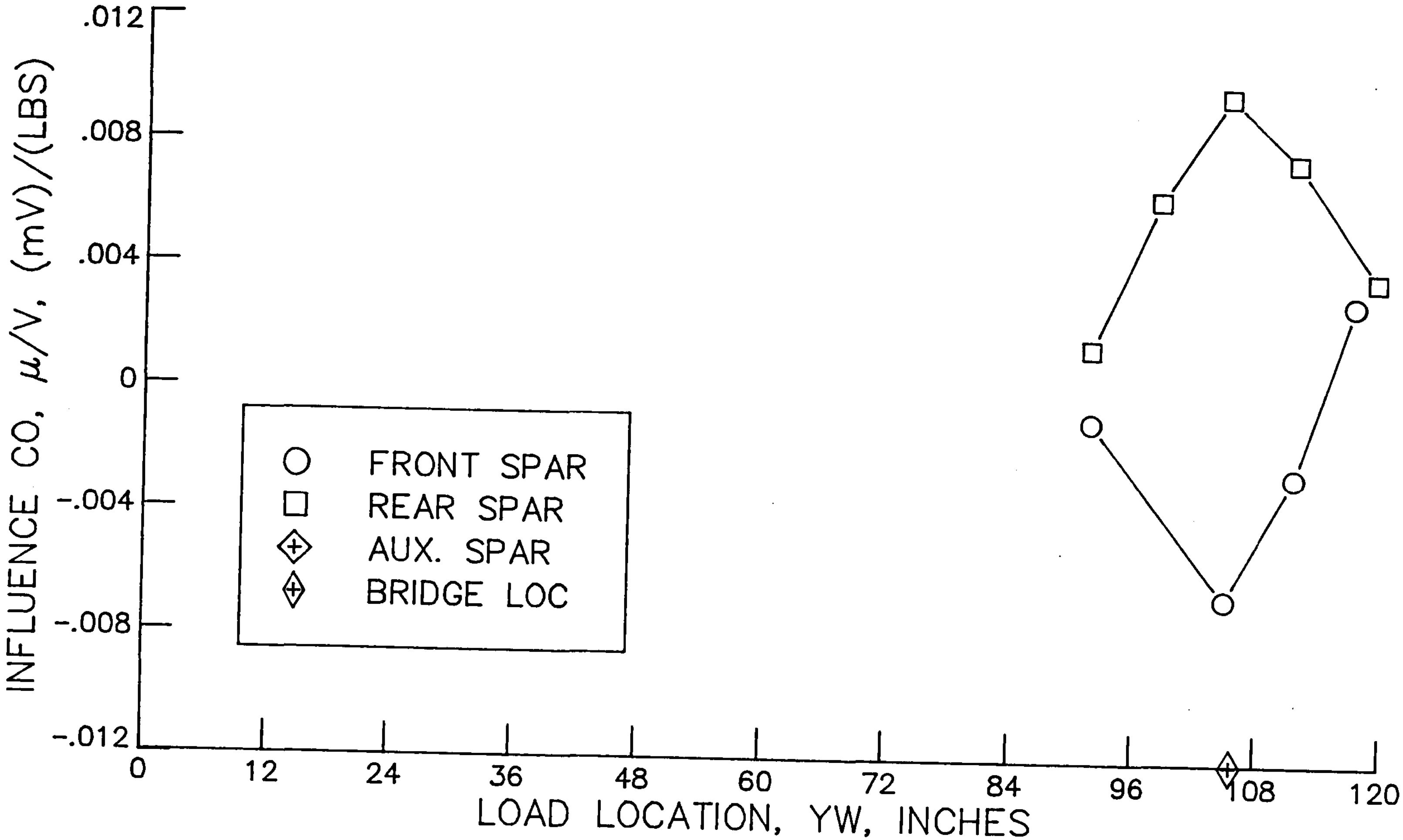
u) - SGB 21, midwing station, rib mounting, torque configuration.

Figure 12.- Continued.



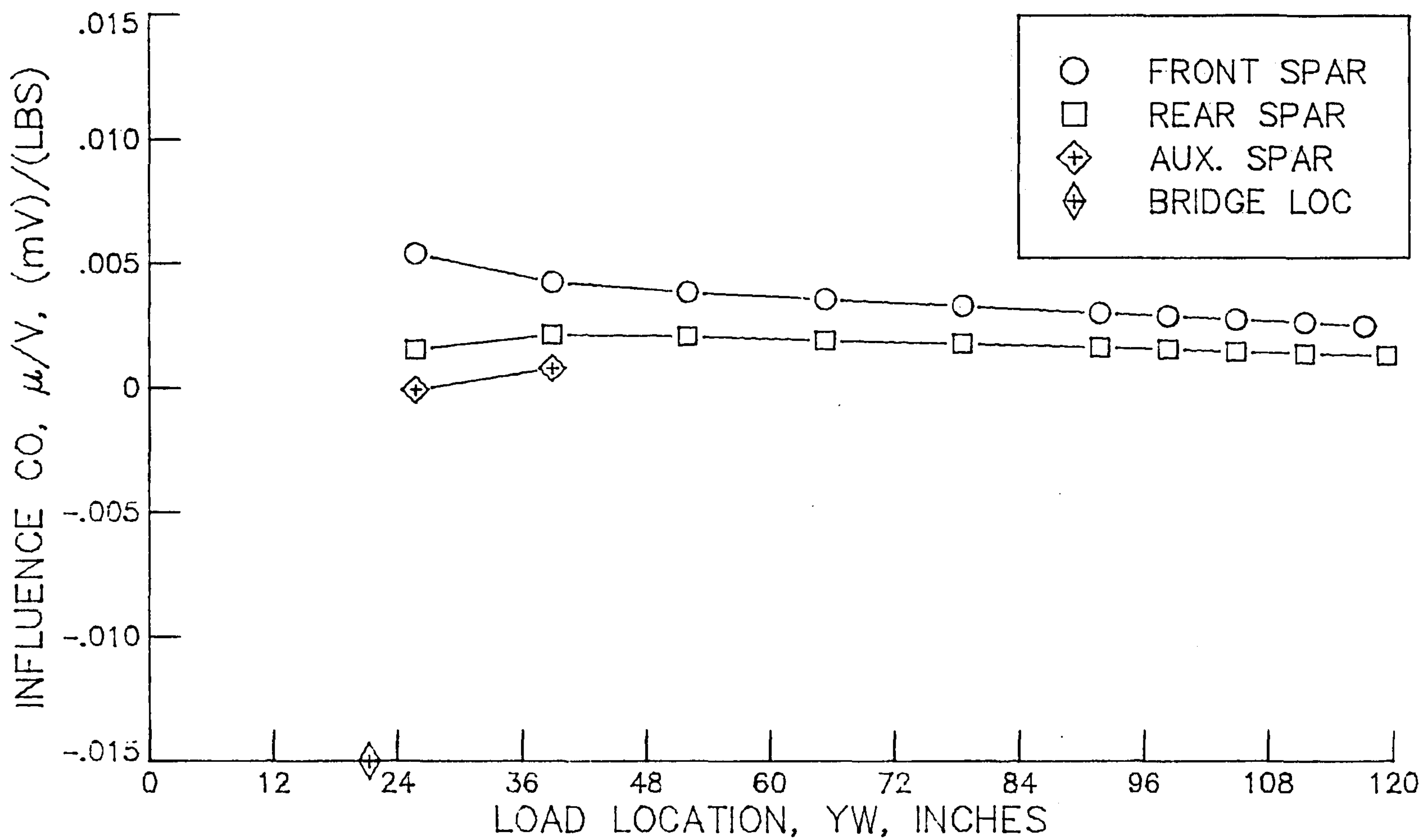
v) - SGB 22, outboard station, rib mounting, torque configuration.

Figure 12.- Continued.



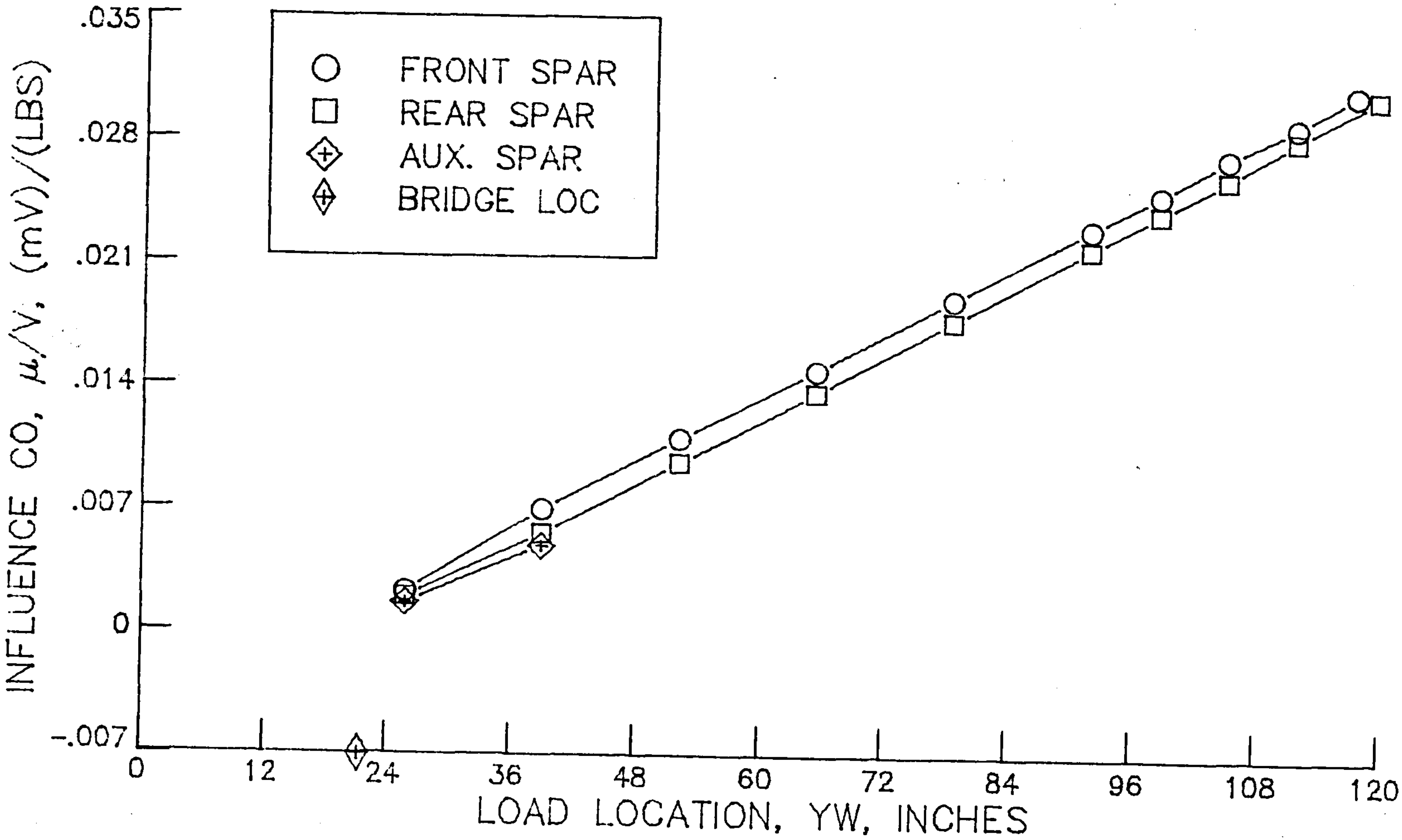
w) - SGB 23, outboard station, rib mounting, torque configuration.

Figure 12.- Concluded.



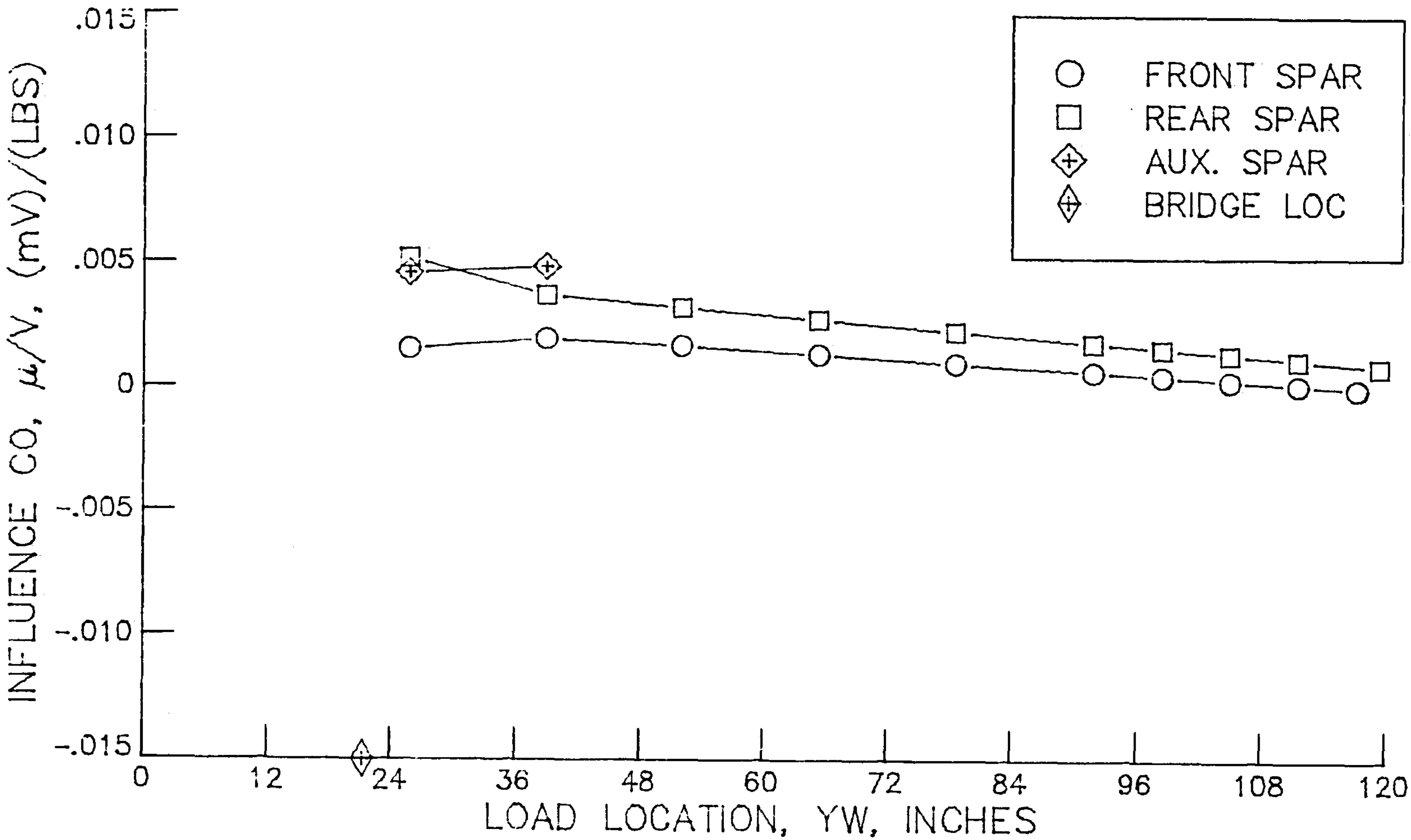
a) - SGB 1, Inboard station, front spar, shear configuration.

Figure 13.- Influence coefficient plots for the left semispan strain gage bridges.



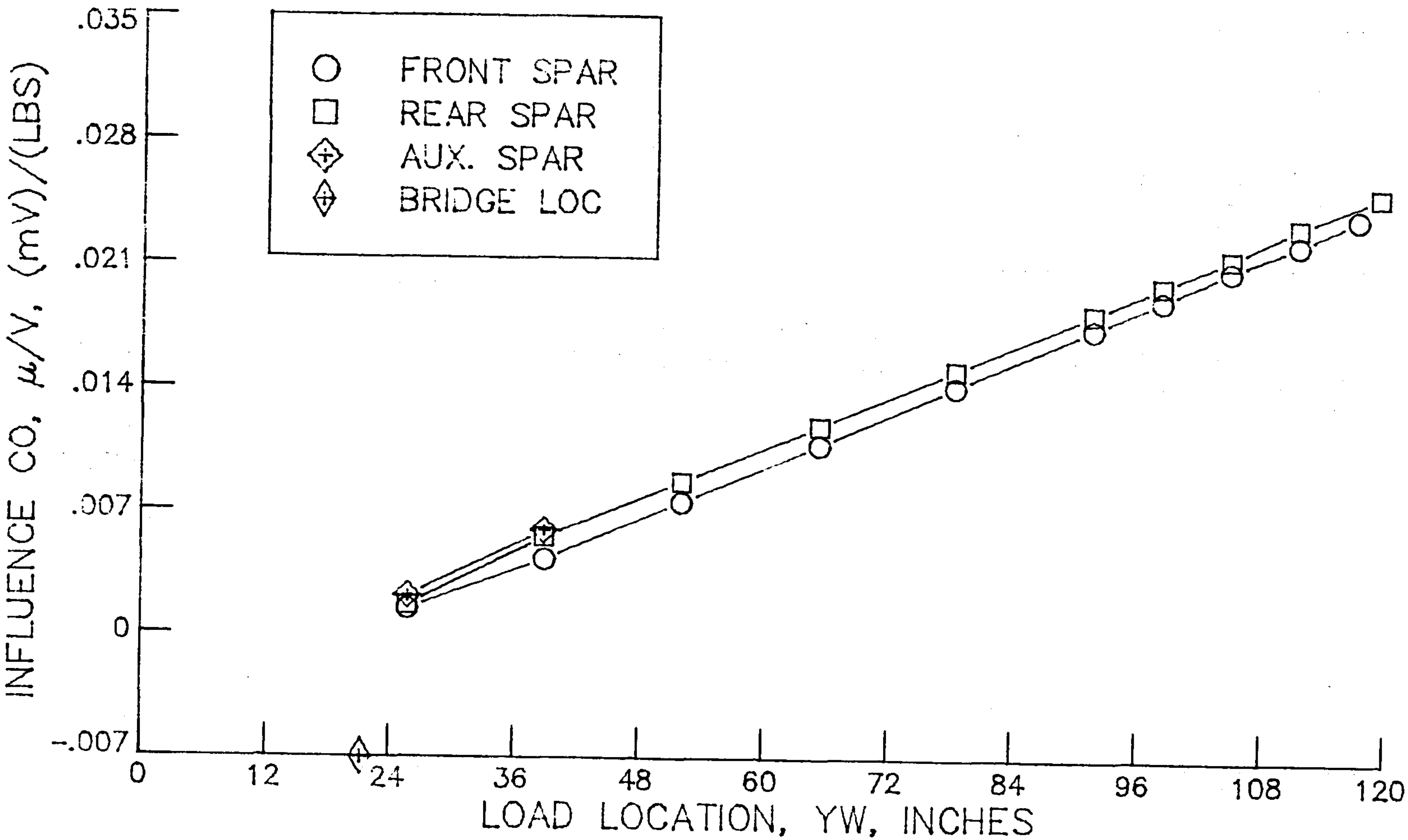
b) - SGB 2, Inboard station, front spar, bending moment configuration.

Figure 13.- Continued.



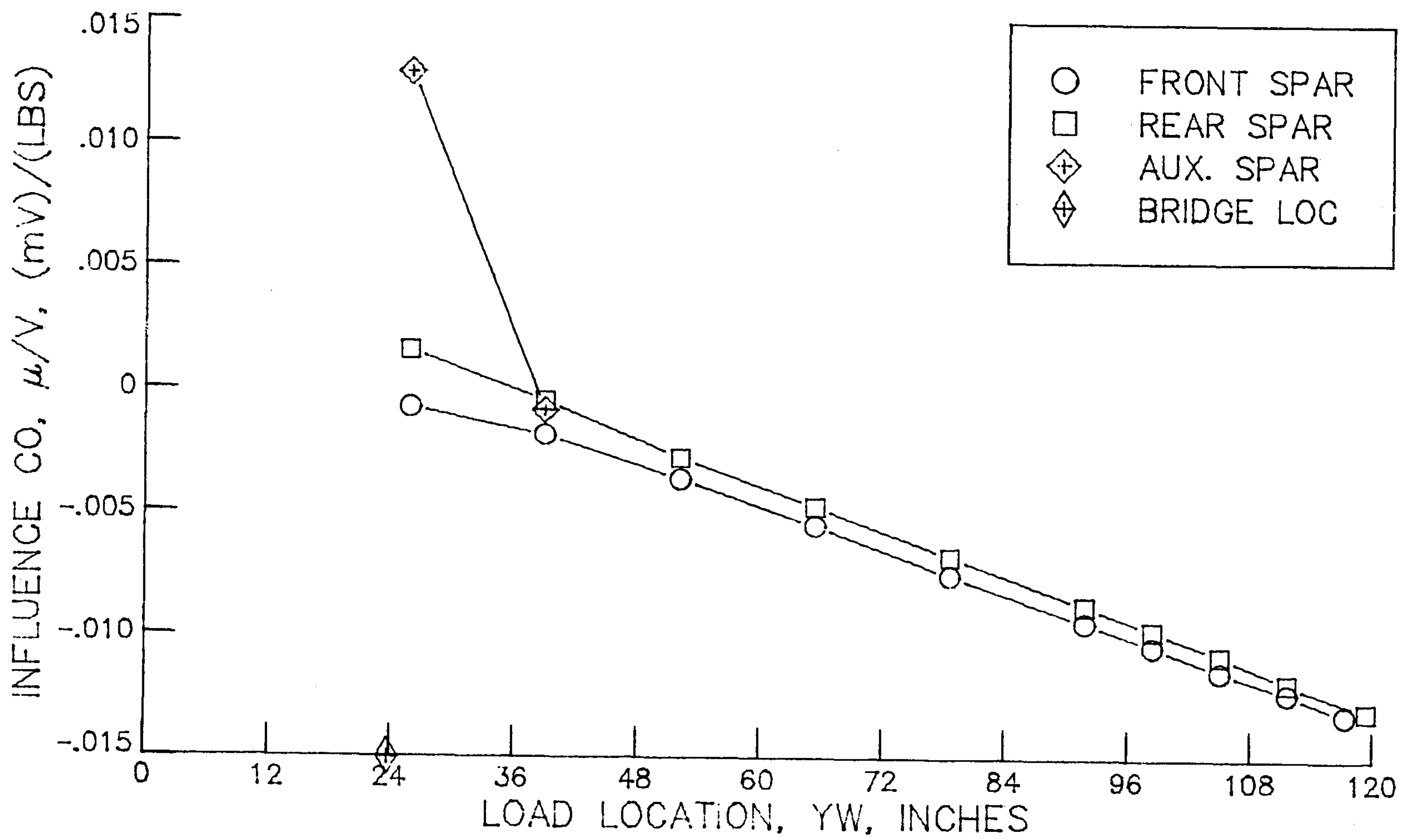
c) - SGB 3, Inboard station, rear spar, shear configuration.

Figure 13.- Continued.



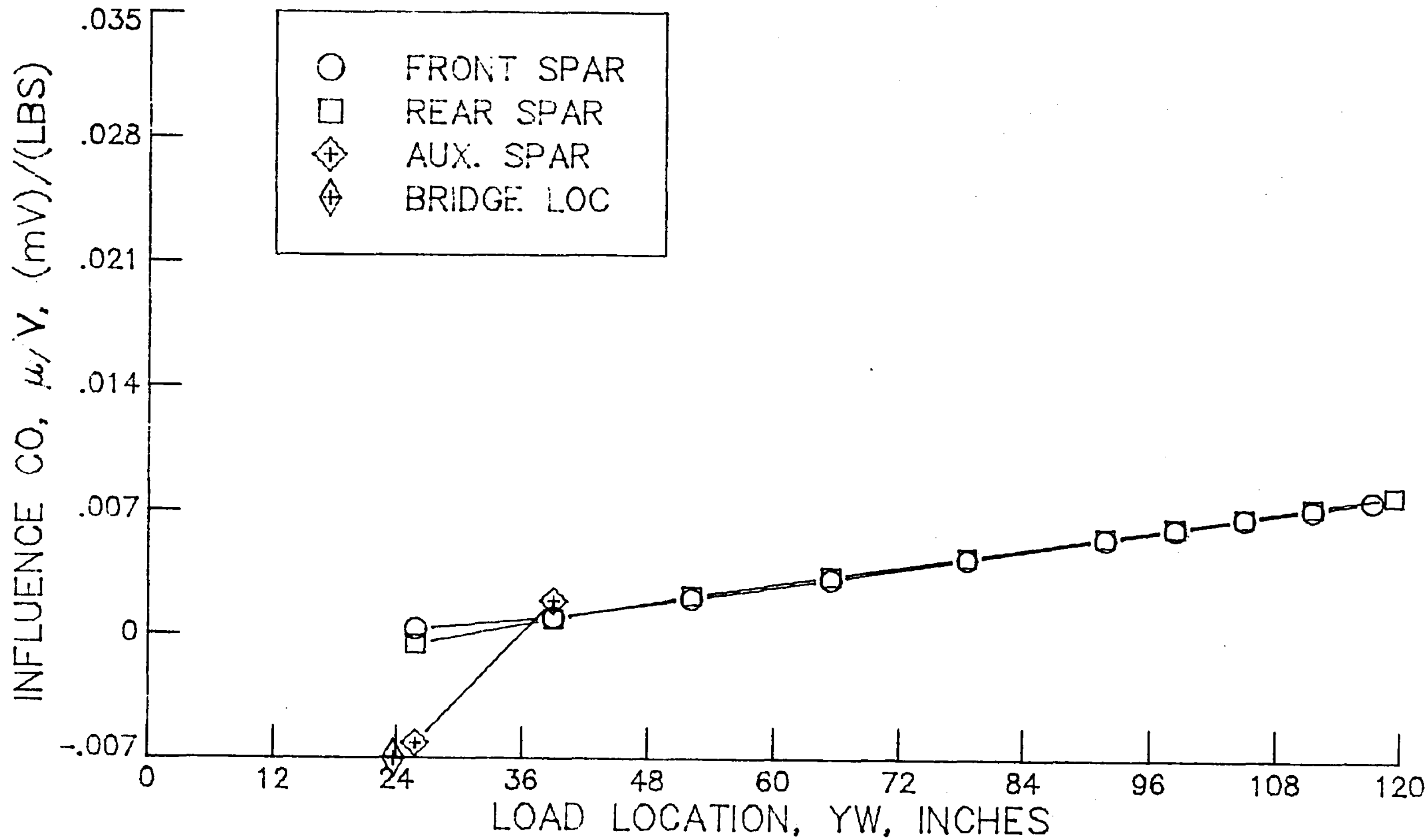
d) - SGB 4, Inboard station, rear spar, bending moment configuration.

Figure 13.- Continued.



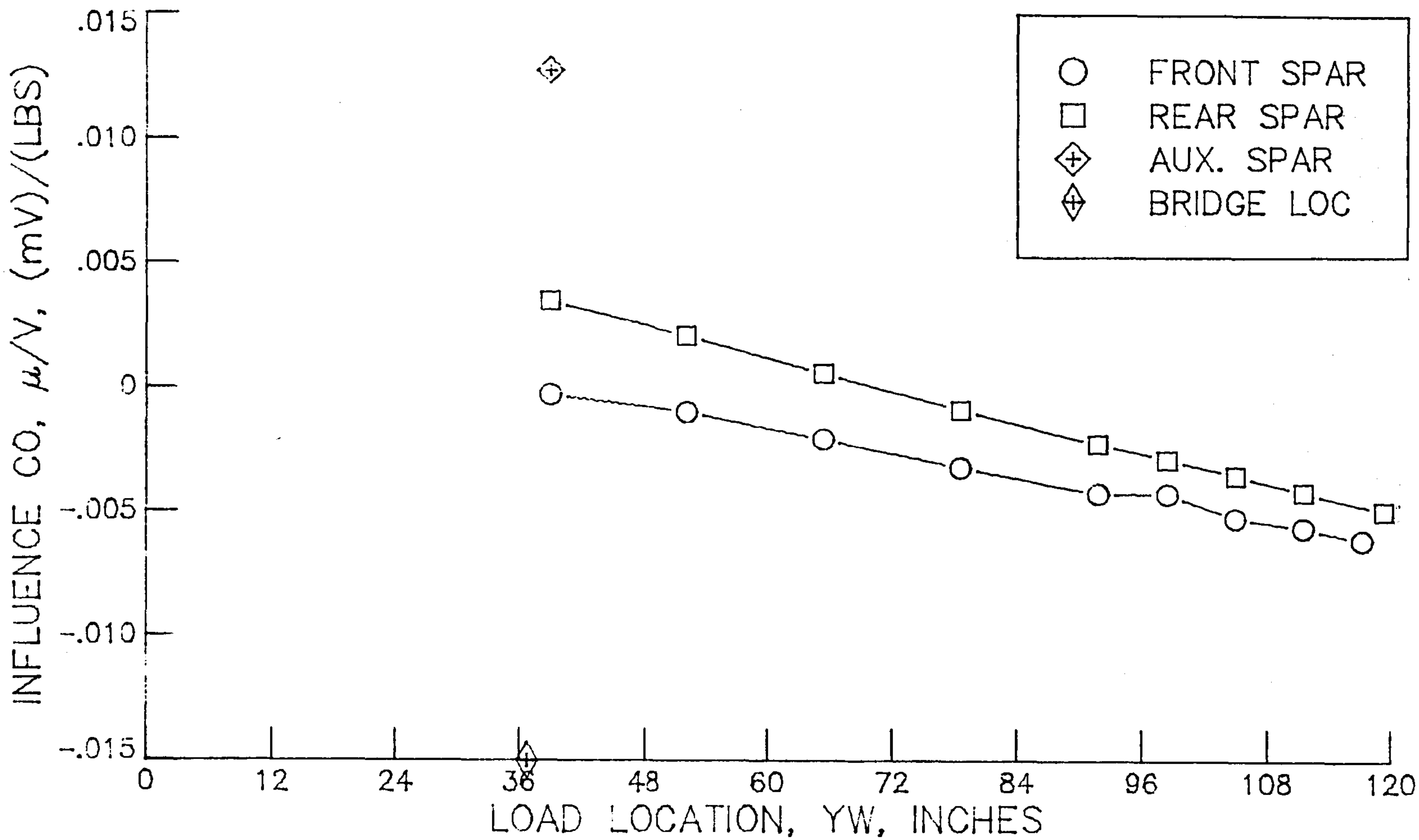
e) - SGB 5, Inboard station, auxillary spar, shear configuration.

Figure 13.- Continued.



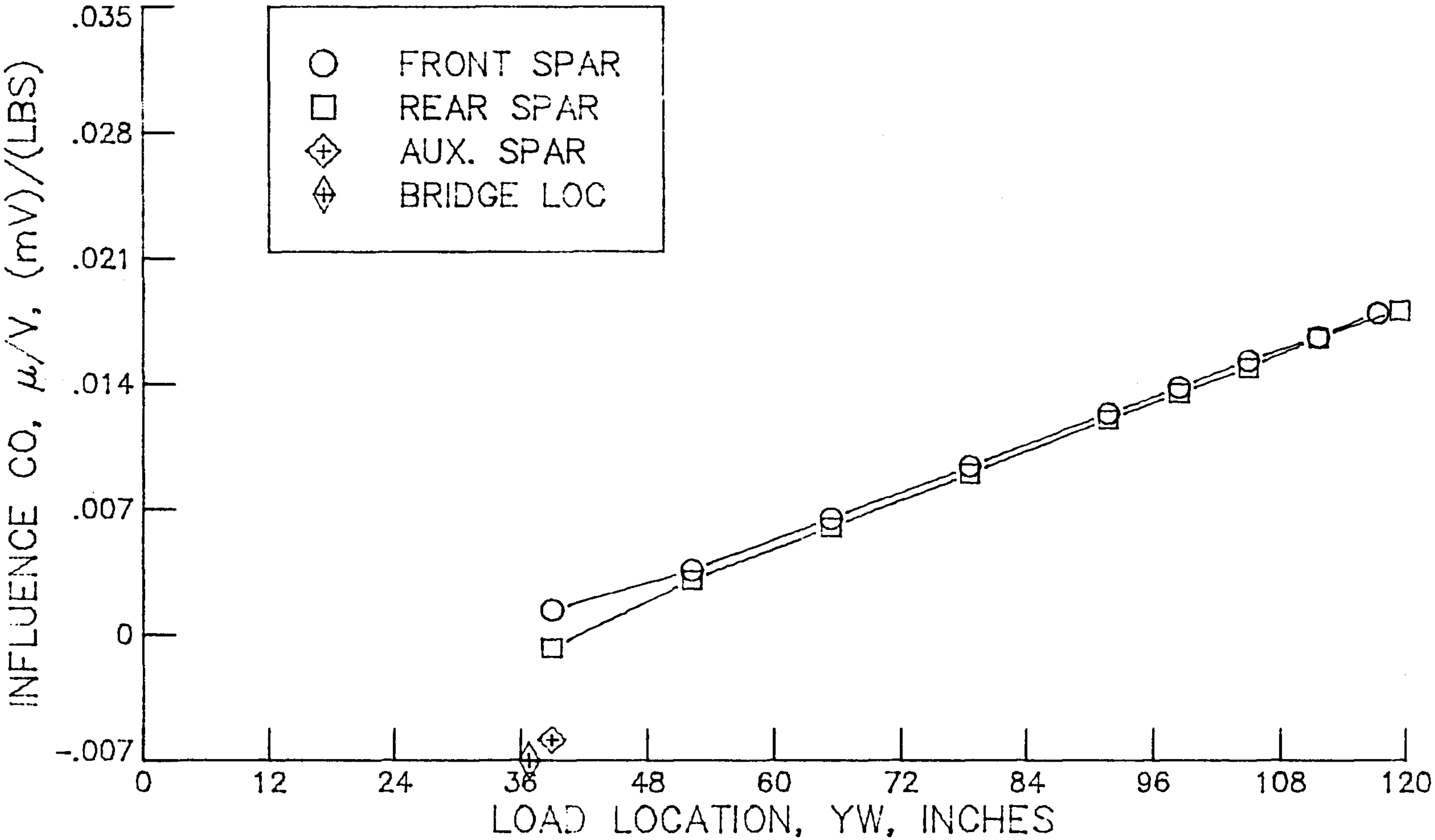
f) - SGB 6, Inboard station, auxillary spar, bending moment configuration.

Figure 13.- Continued.



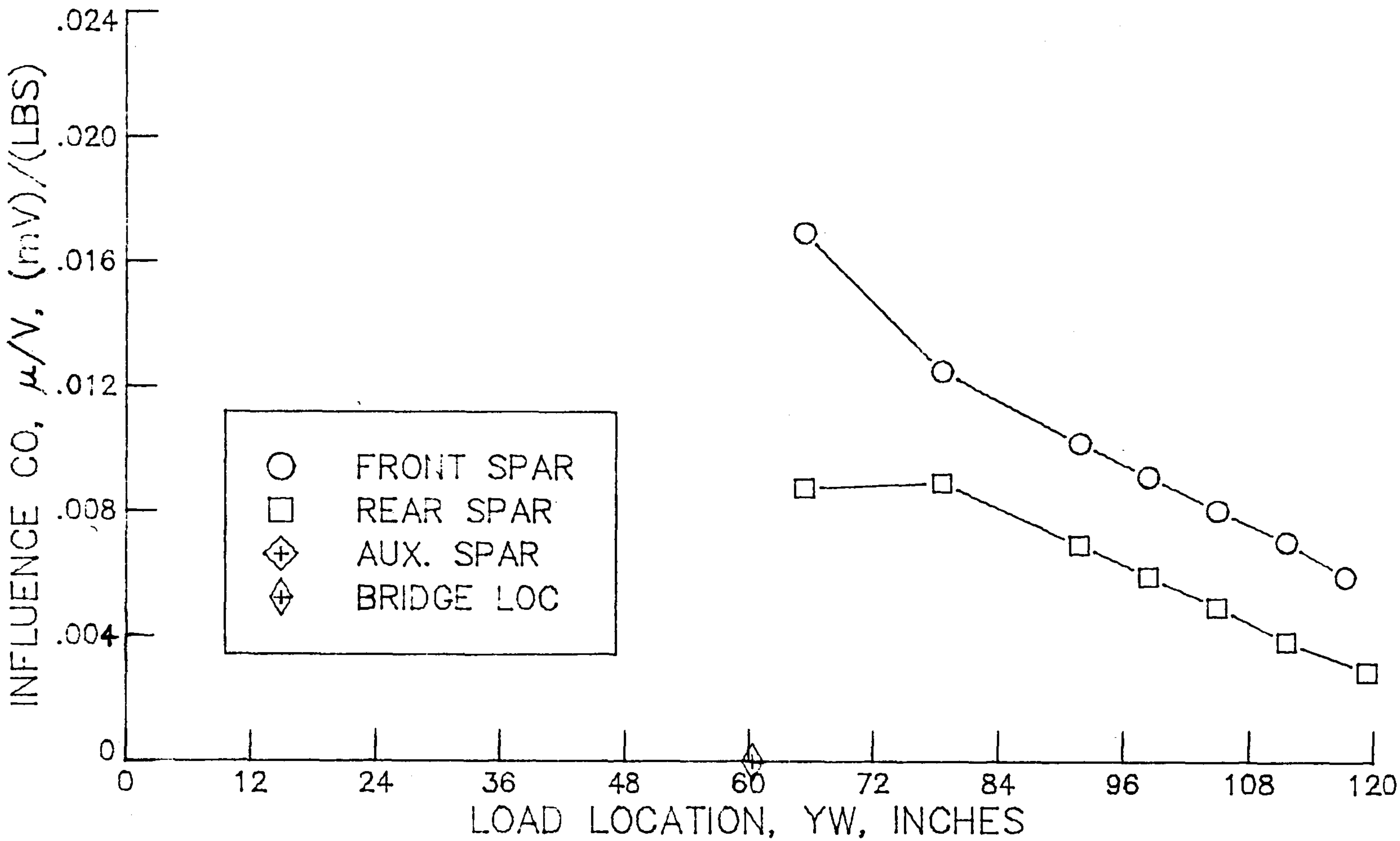
g) - SGB 7, Inboard station, auxillary spar, shear configuration.

Figure 13.- Continued.



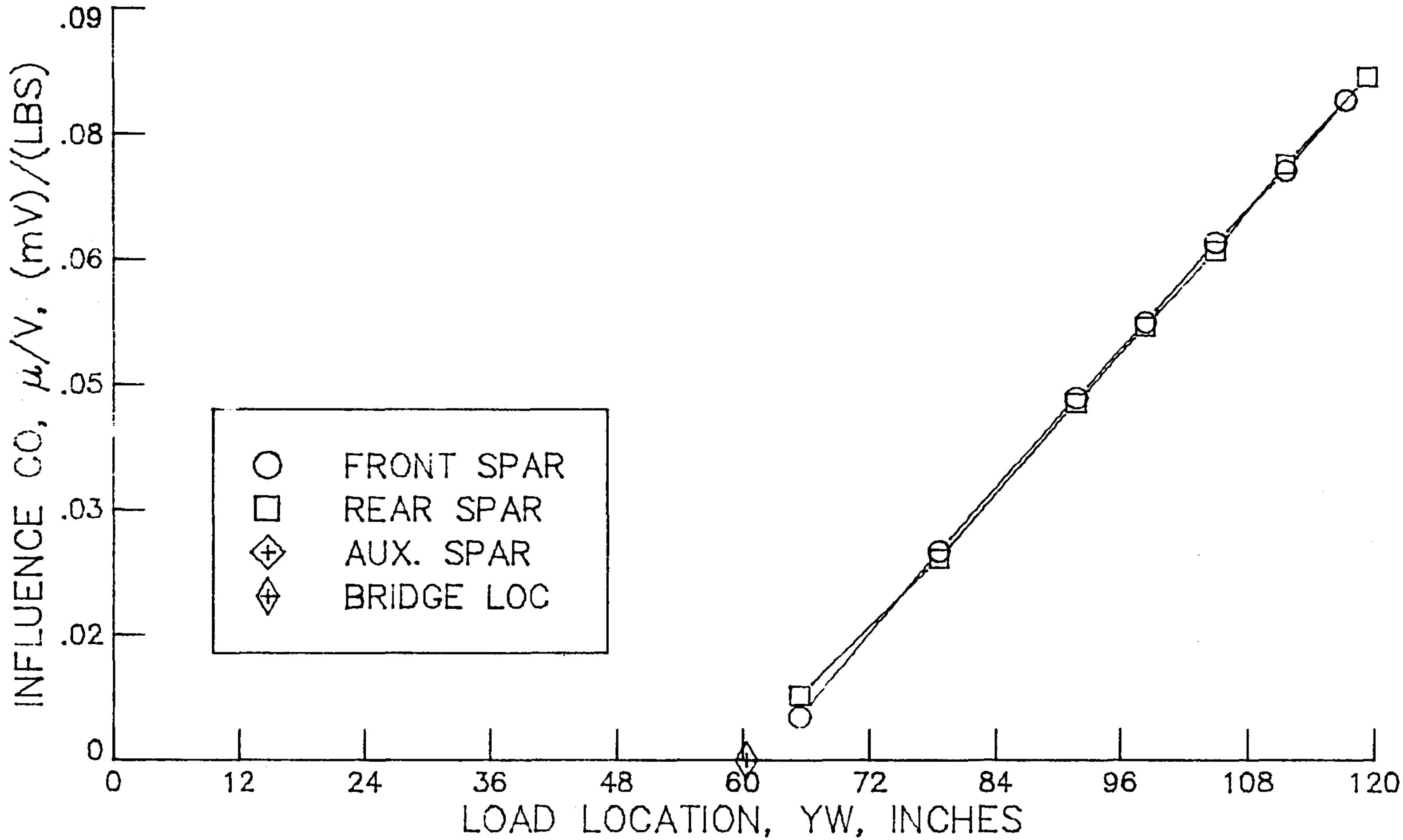
h) - SGB 8, Inboard station, auxillary spar, bending moment configuration.

Figure 13.- Continued.



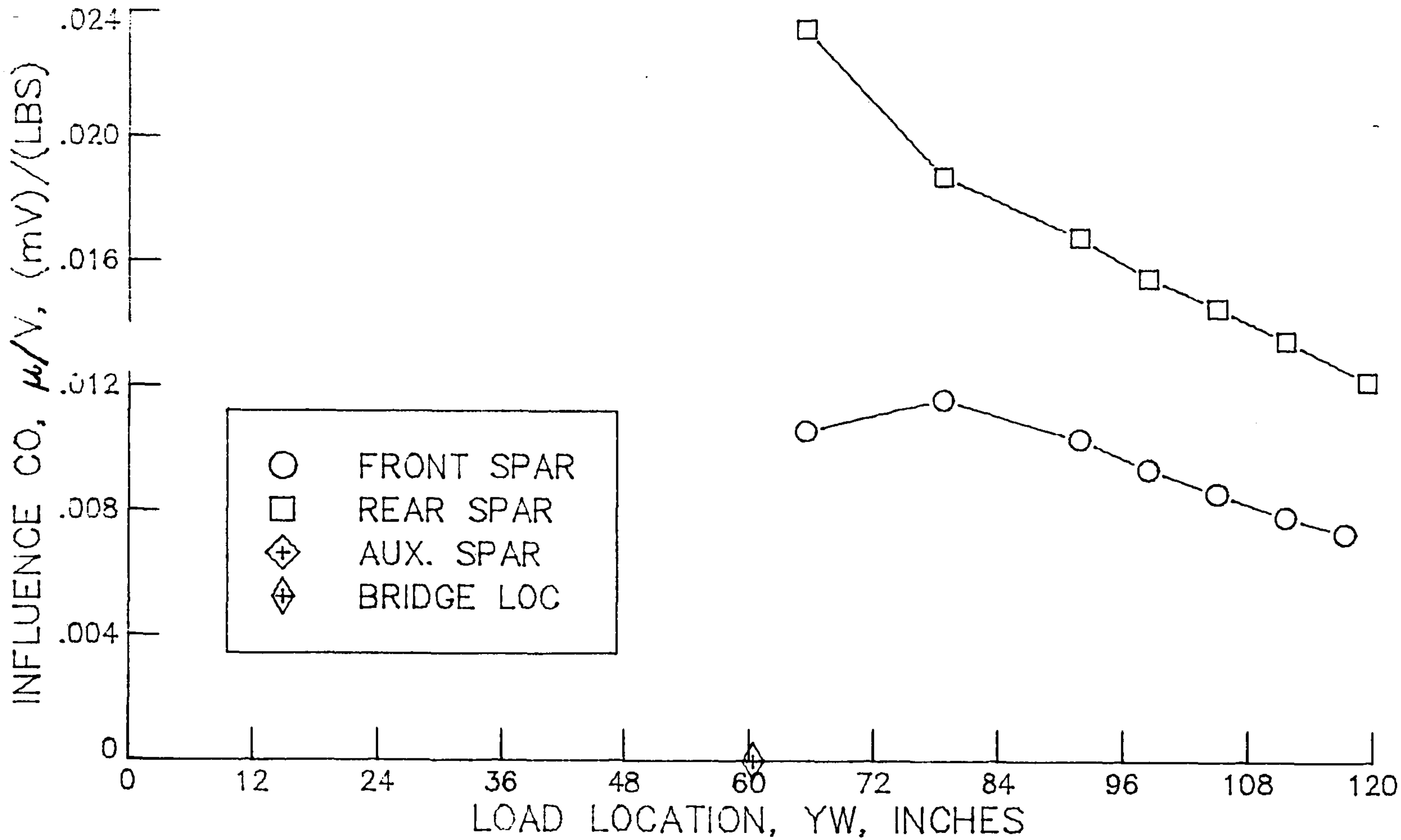
i) - SGB 9, midwing station, front spar, shear configuration.

Figure 13.- Continued.



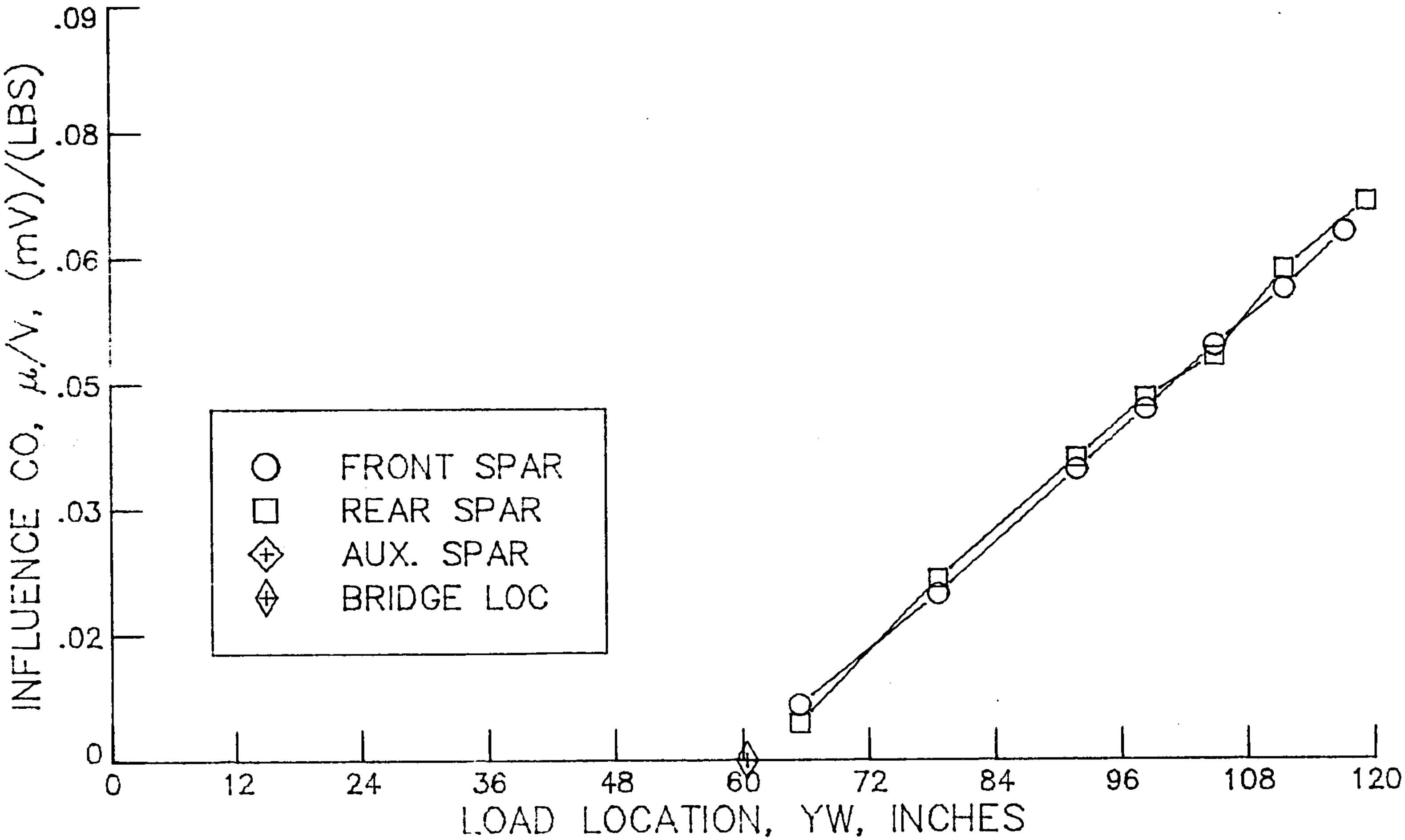
j) - SGB 10, midwing station, front spar, bending moment configuration.

Figure 13.- Continued.



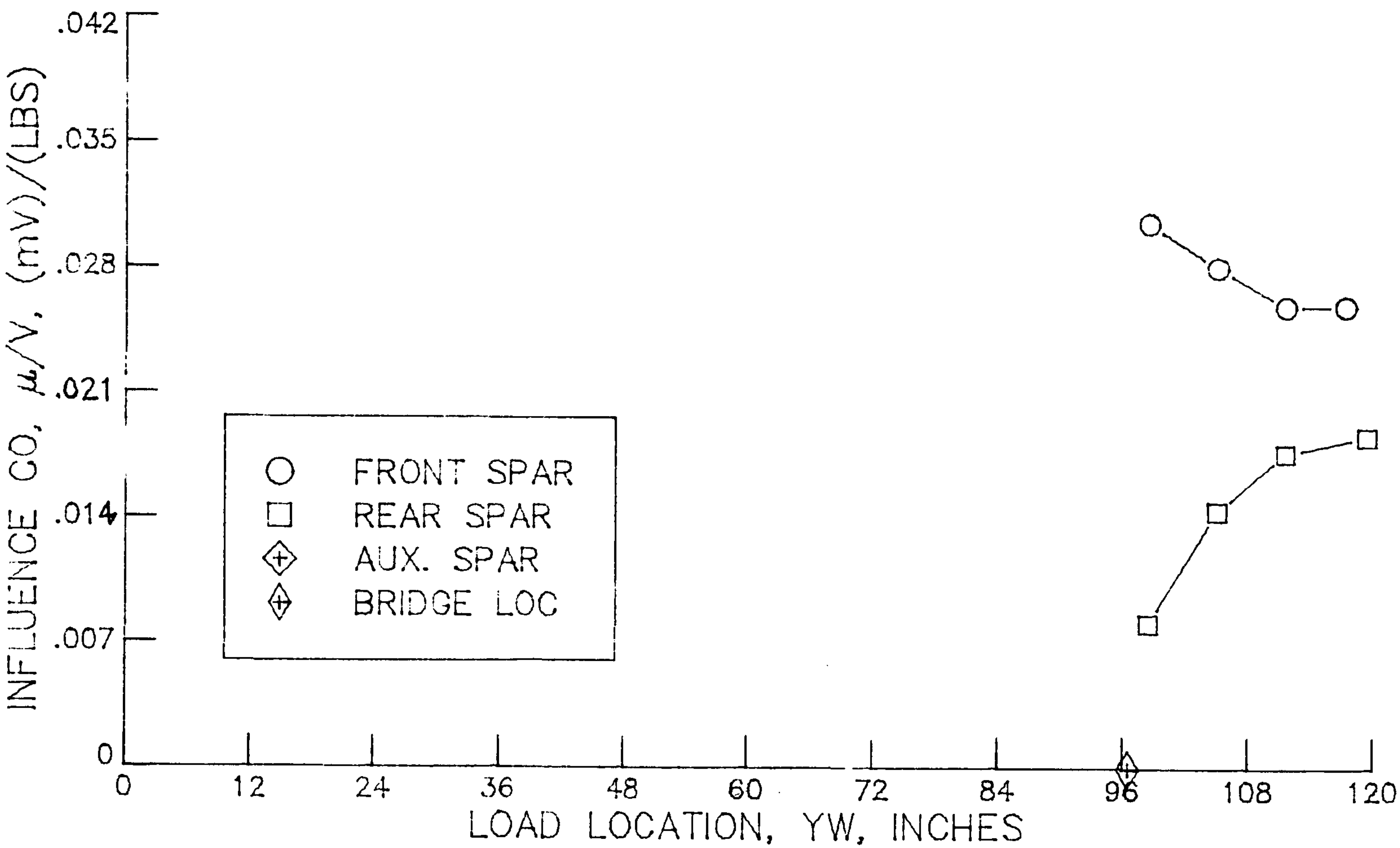
k) - SGB 11, midwing station, rear spar, shear configuration.

Figure 13.- Continued.



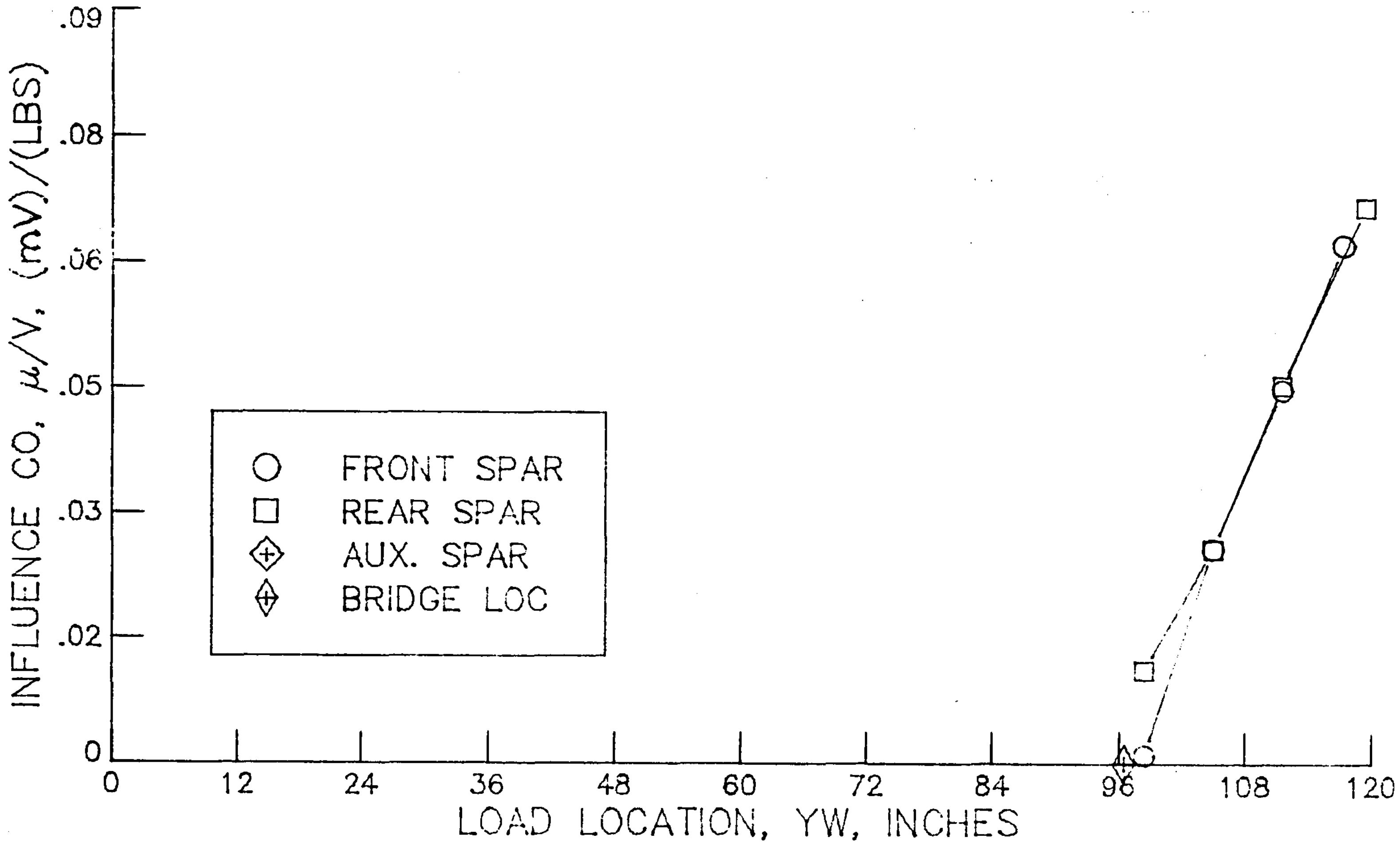
1) - SGB 12, midwing station, rear spar, bending moment configuration.

Figure 13.- Continued.



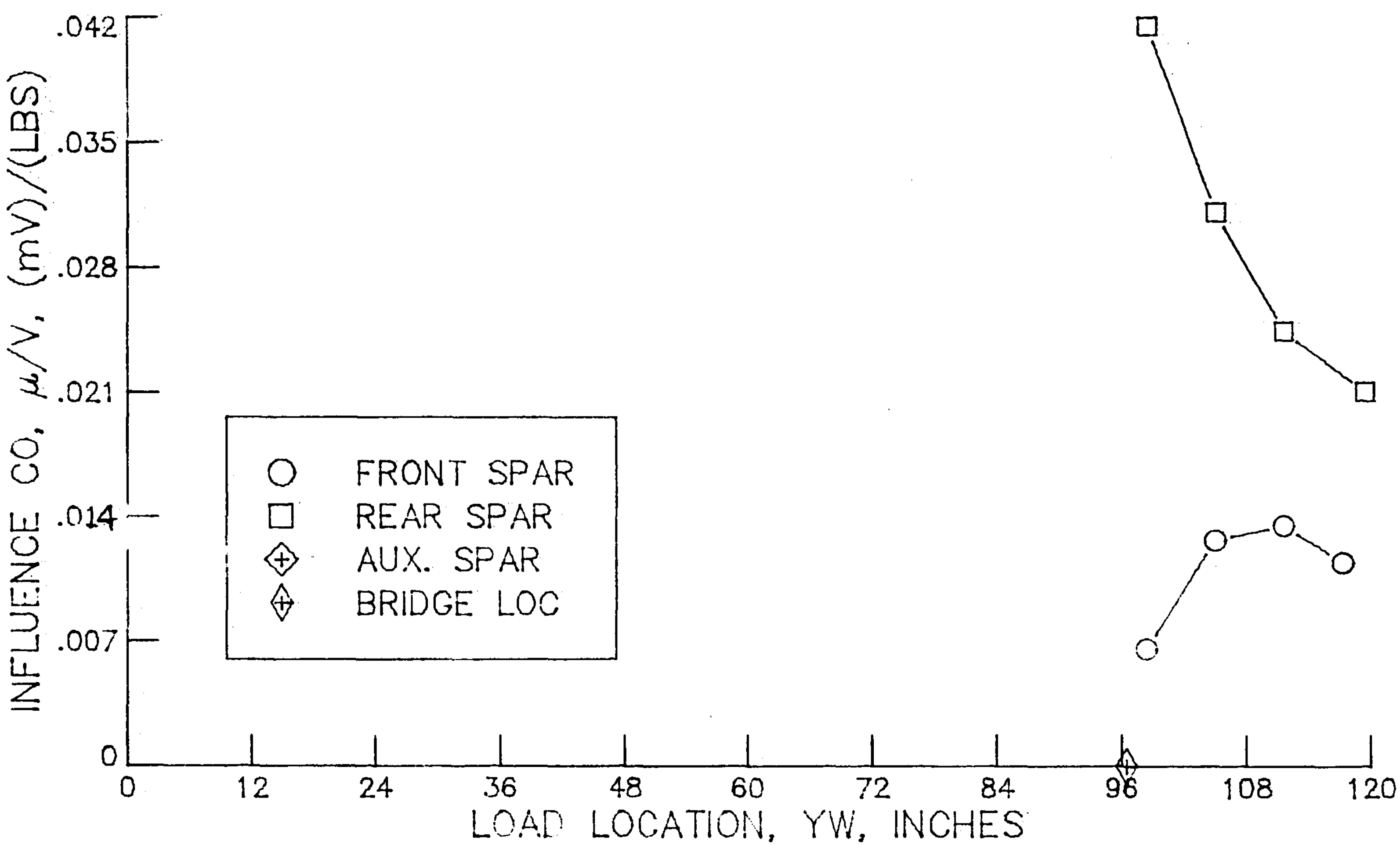
m) - SGB 13, outboard station, front spar, shear configuration.

Figure 13.- Continued.



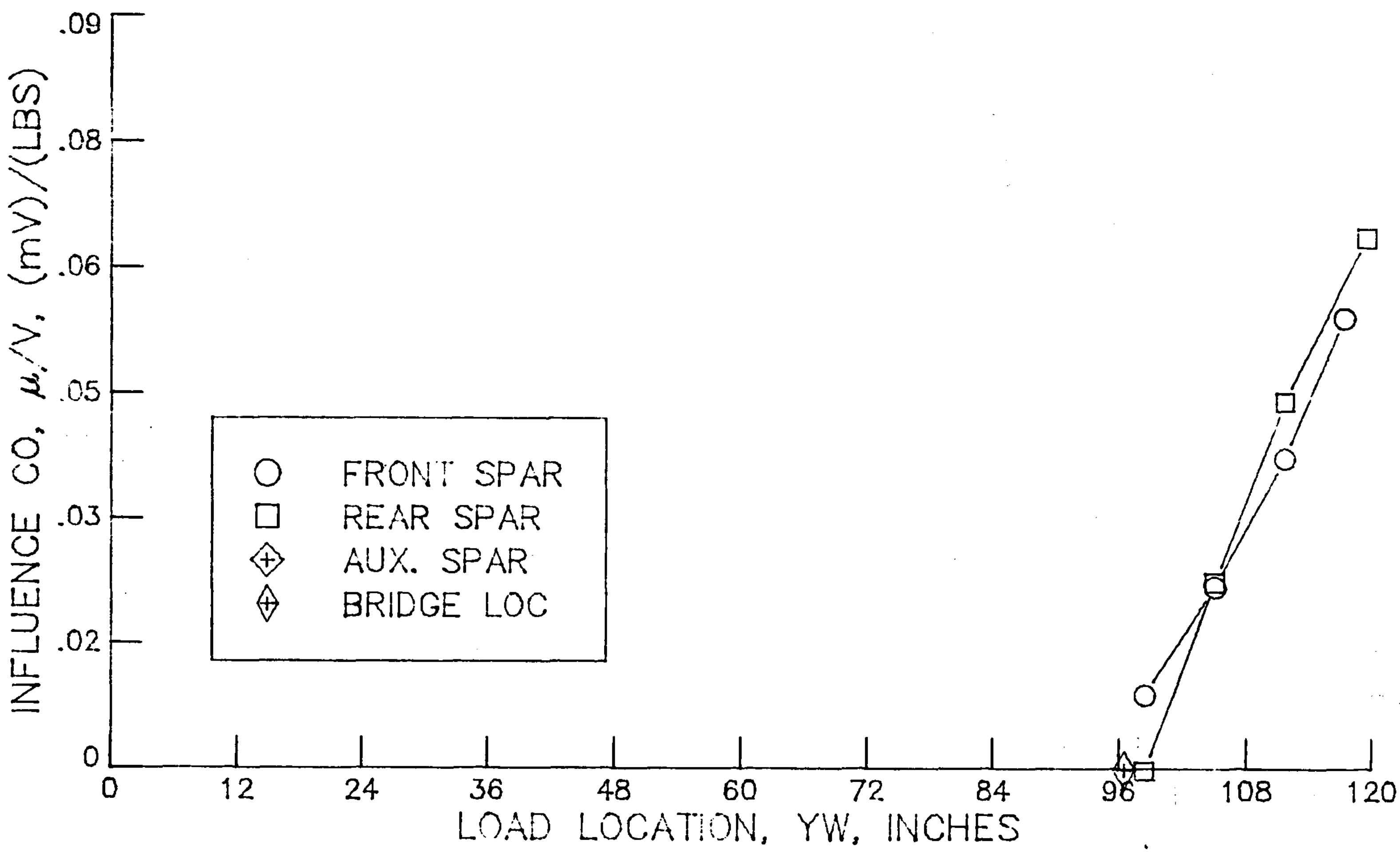
n) - SGB 14, outboard station, front spar, bending moment configuration.

Figure 13.- Continued.



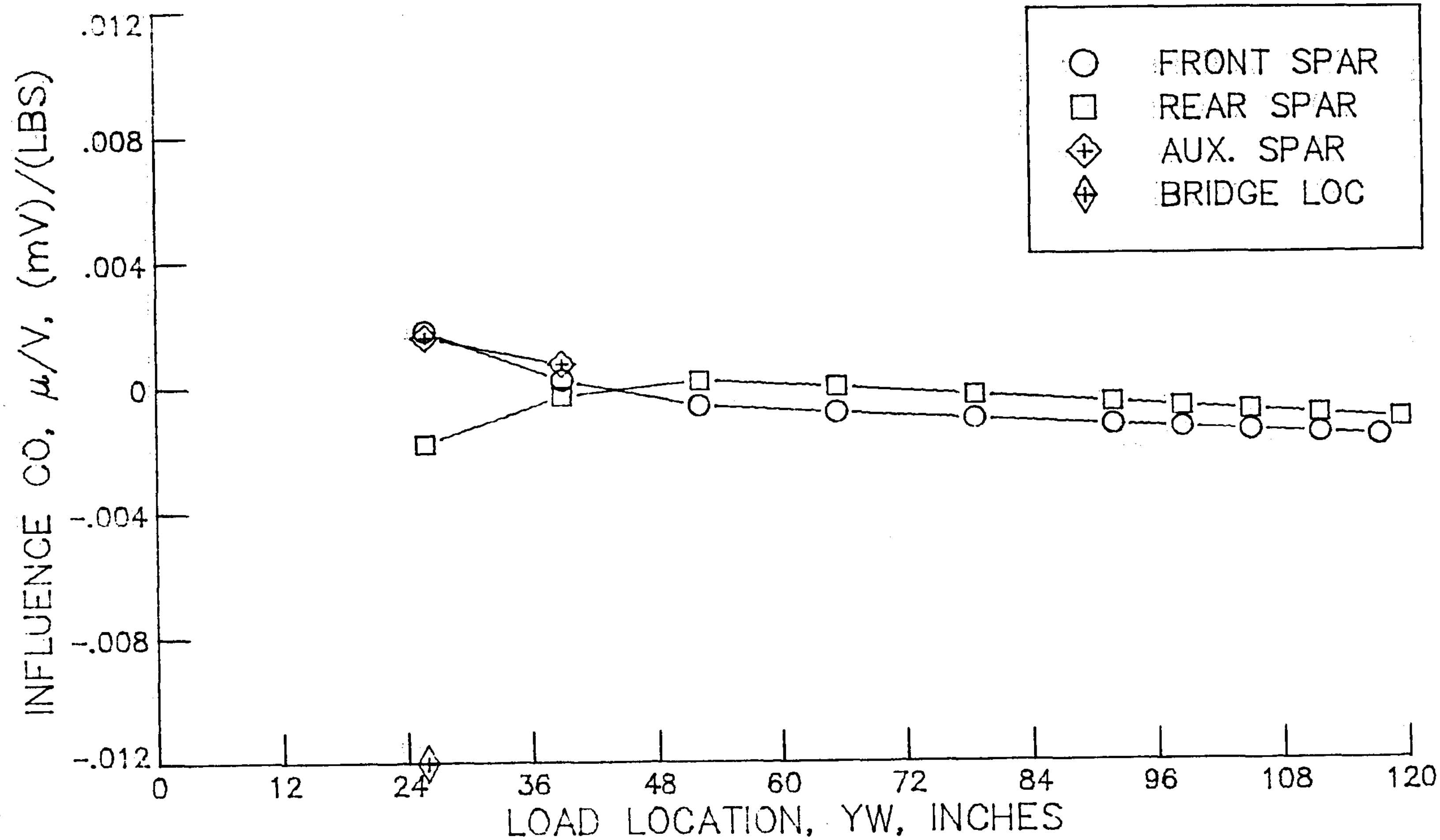
o) - SGB 15, outboard station, rear spar, shear configuration.

Figure 13.- Continued.



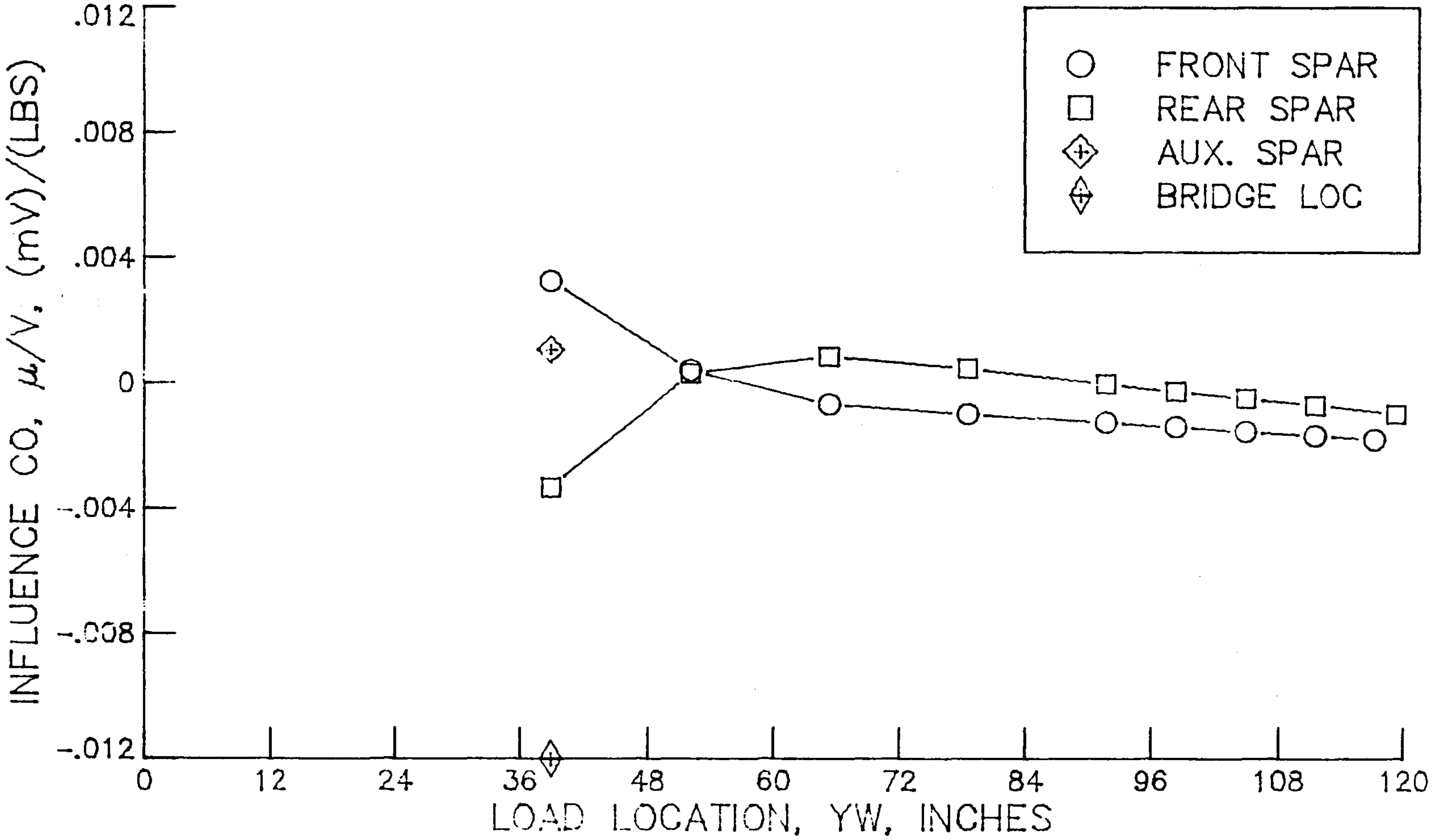
p) - SGB 16, outboard station, rear spar, bending moment configuration.

Figure 13.- Continued.



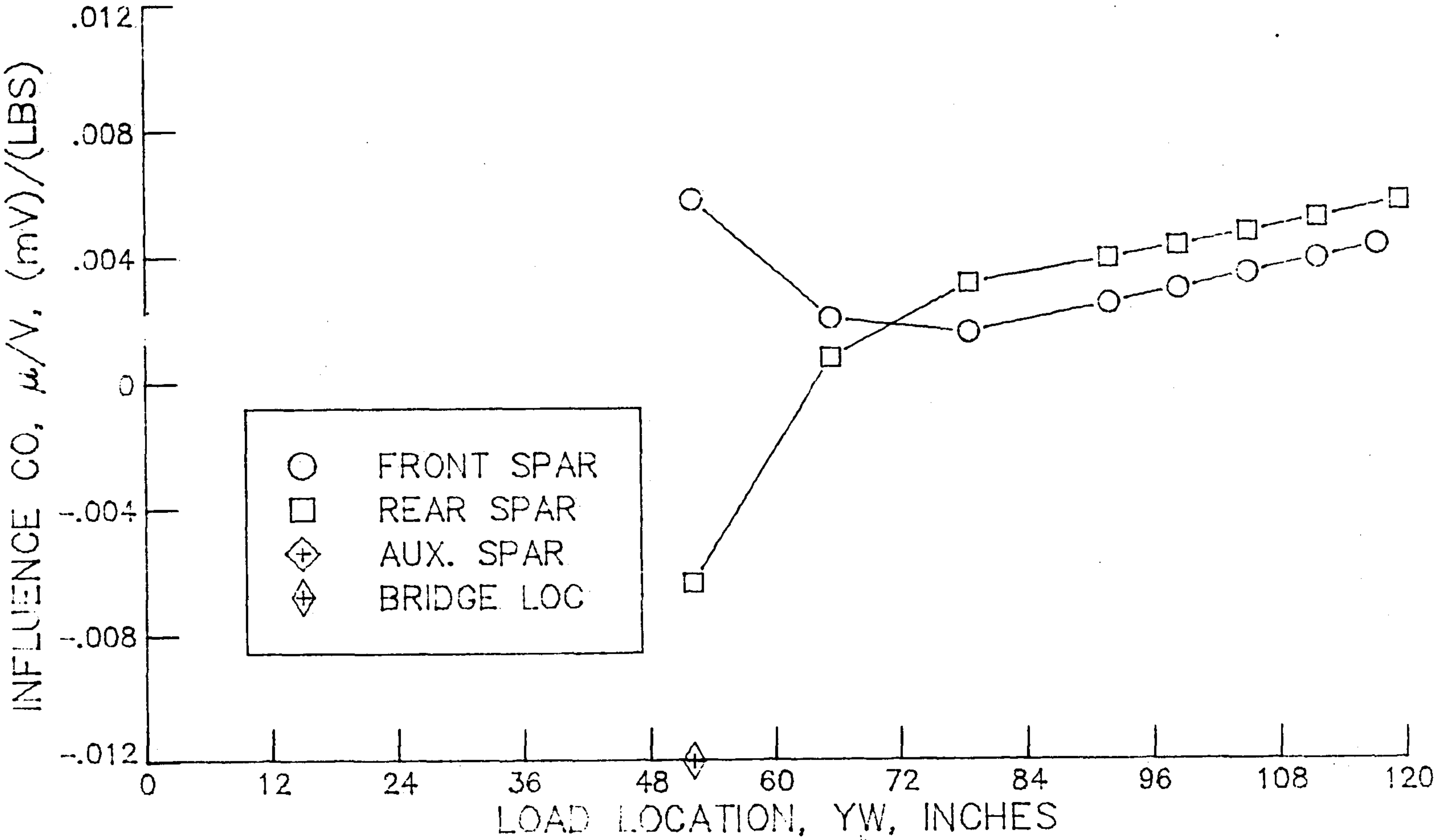
q) - SGB 17, inboard station, rib mounting, torque configuration.

Figure 13.- Continued.



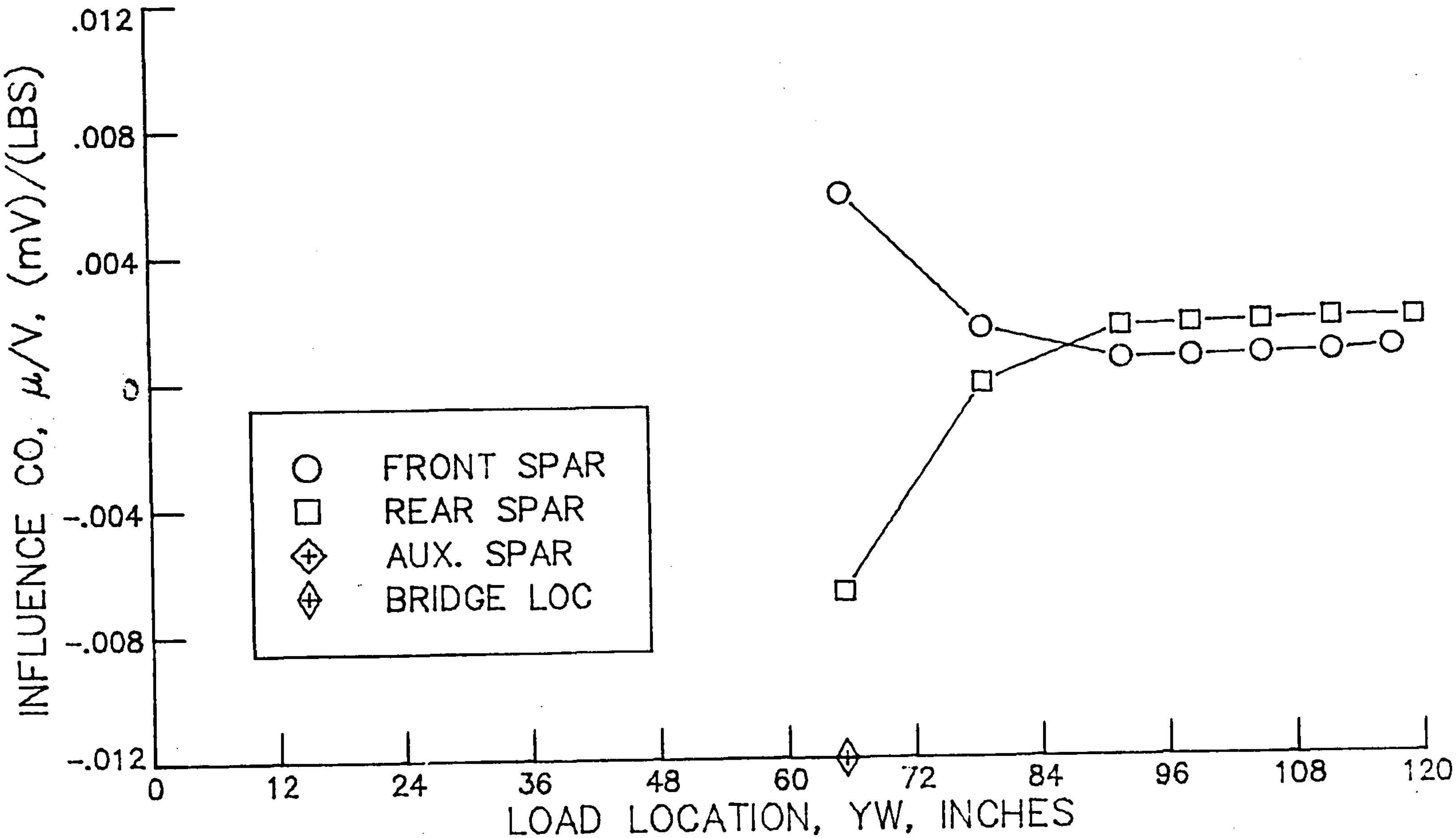
r) - SGB 18, inboard station, rib mounting, torque configuration.

Figure 13.- Continued.



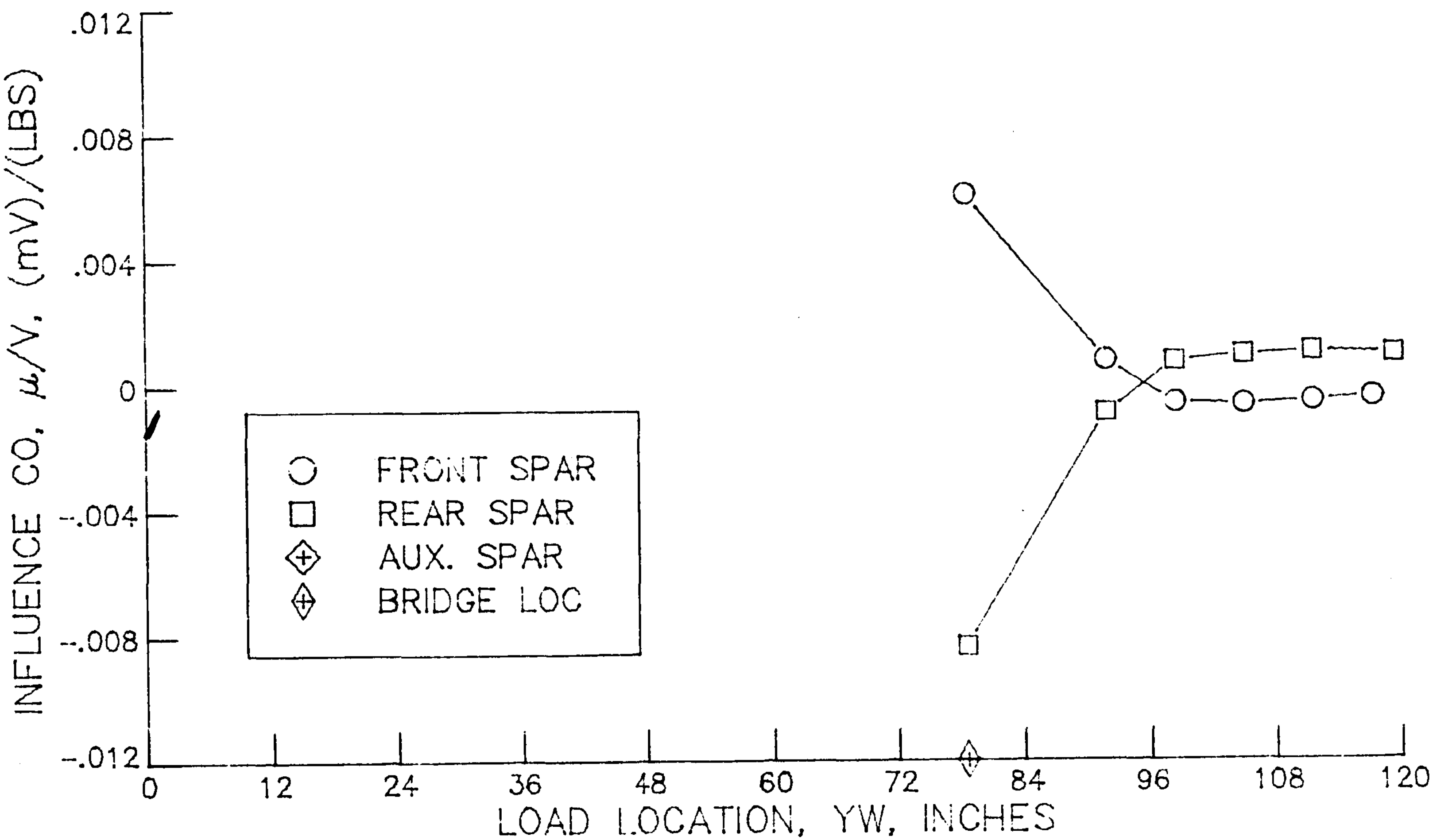
s) - SGB 19, midwing station, rib mounting, torque configuration.

Figure 13.- Continued.



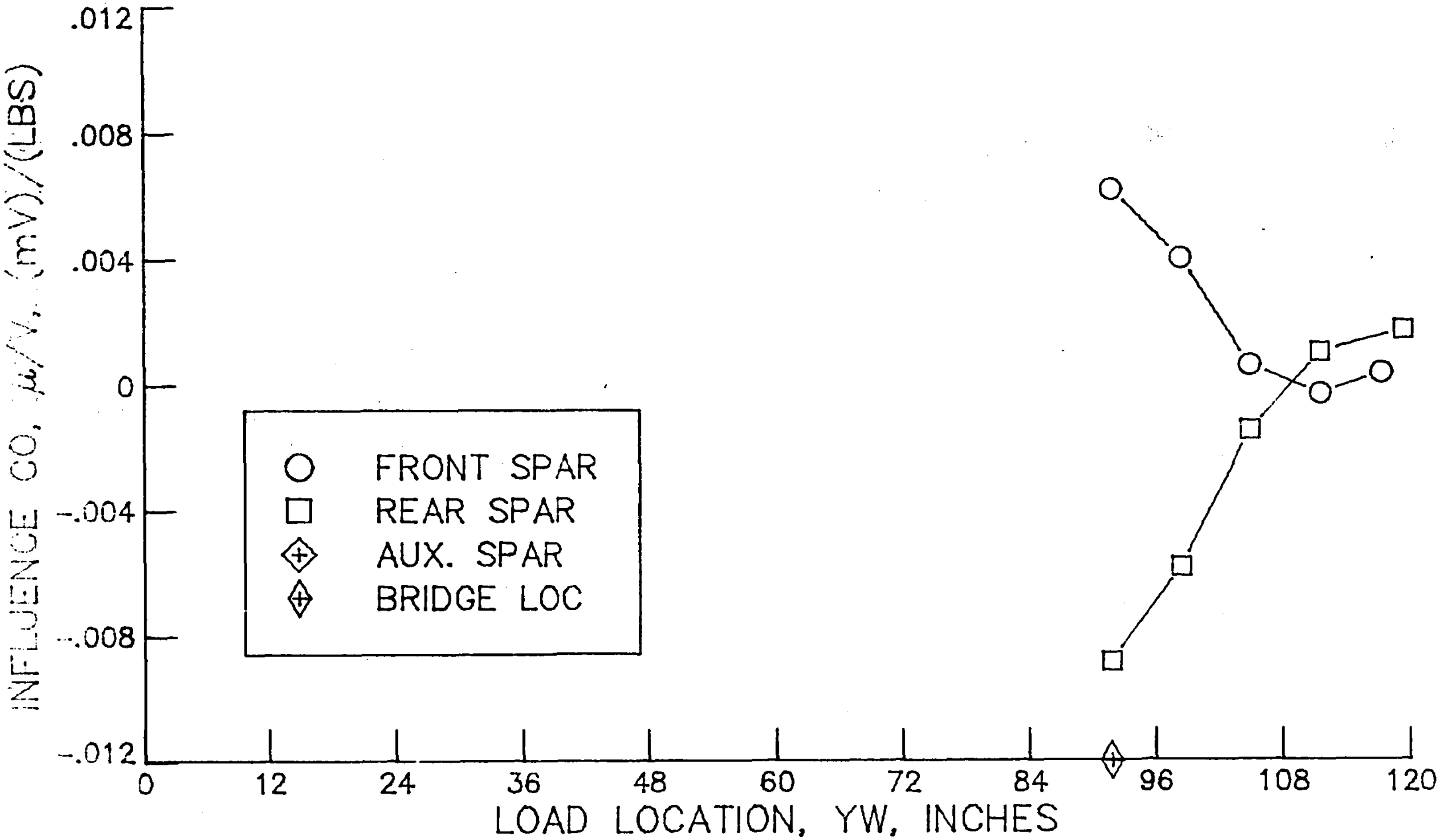
t) - SGB 20, midwing station, rib mounting, torque configuration.

Figure 13.- Continued.



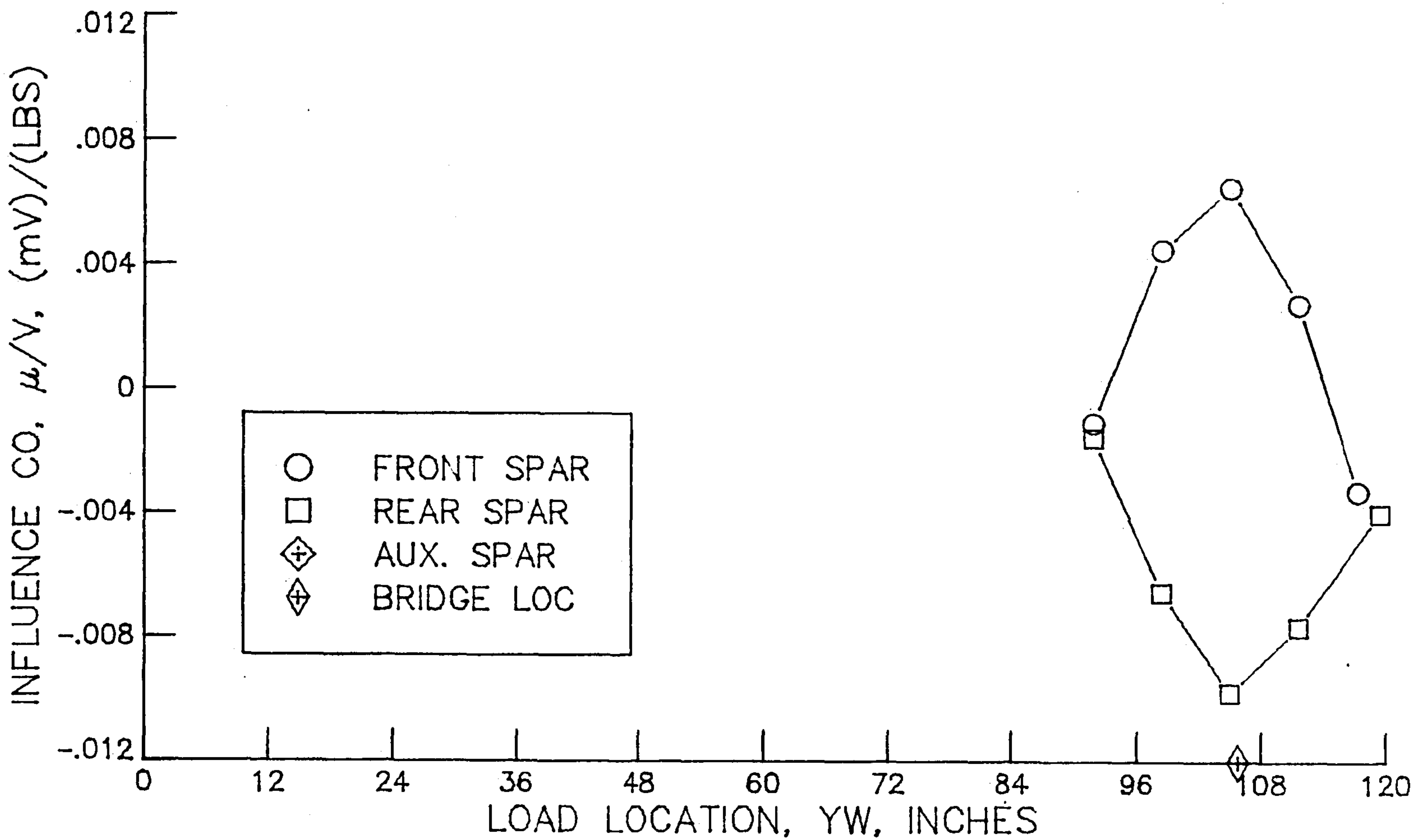
u) - SGB 21, midwing station, rib mounting, torque configuration.

Figure 13.- Continued.



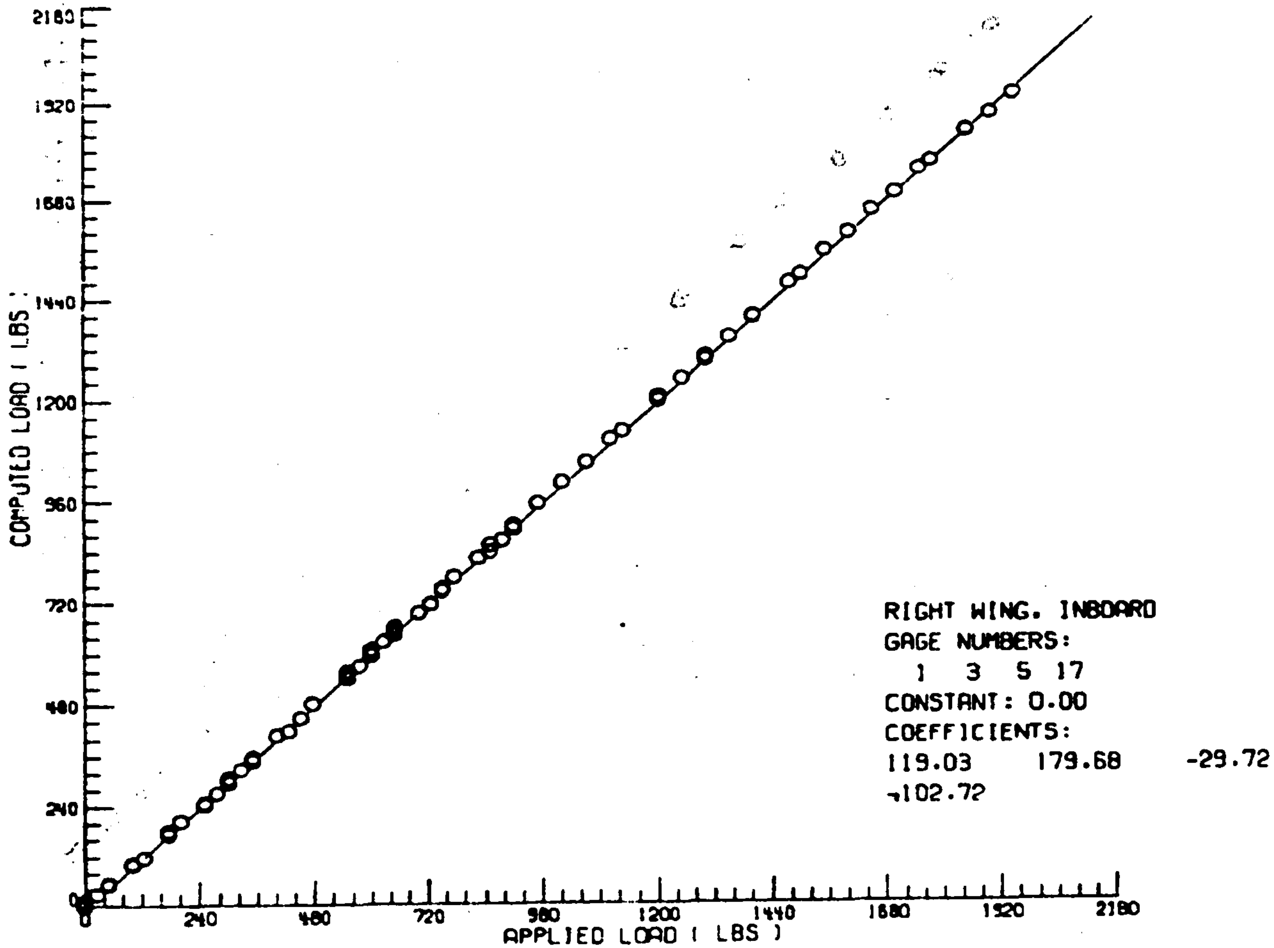
v) - SGB 22, outboard station, rib mounting, torque configuration.

Figure 13.- Continued.



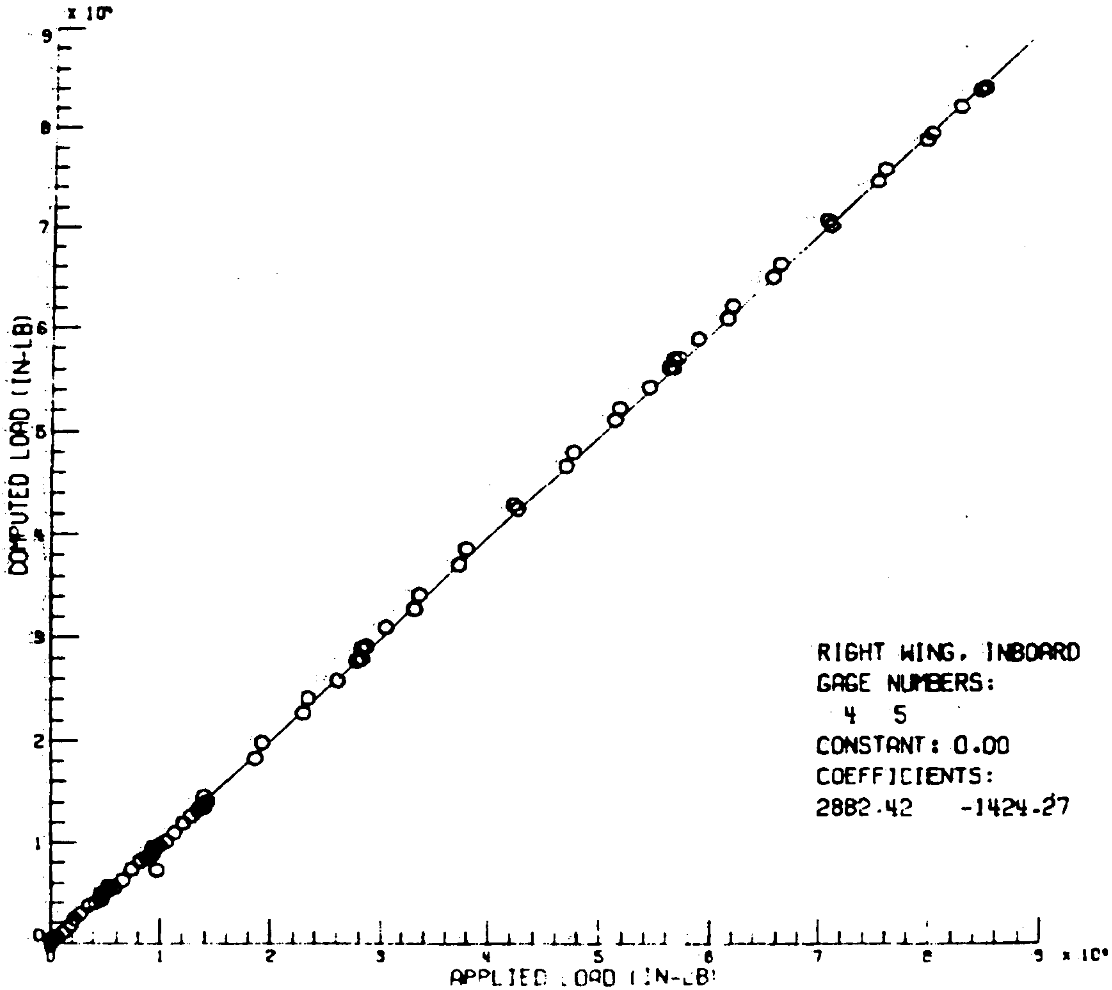
w) - SGB 23, outboard station, rib mounting, torque configuration.

Figure 13.- Concluded.



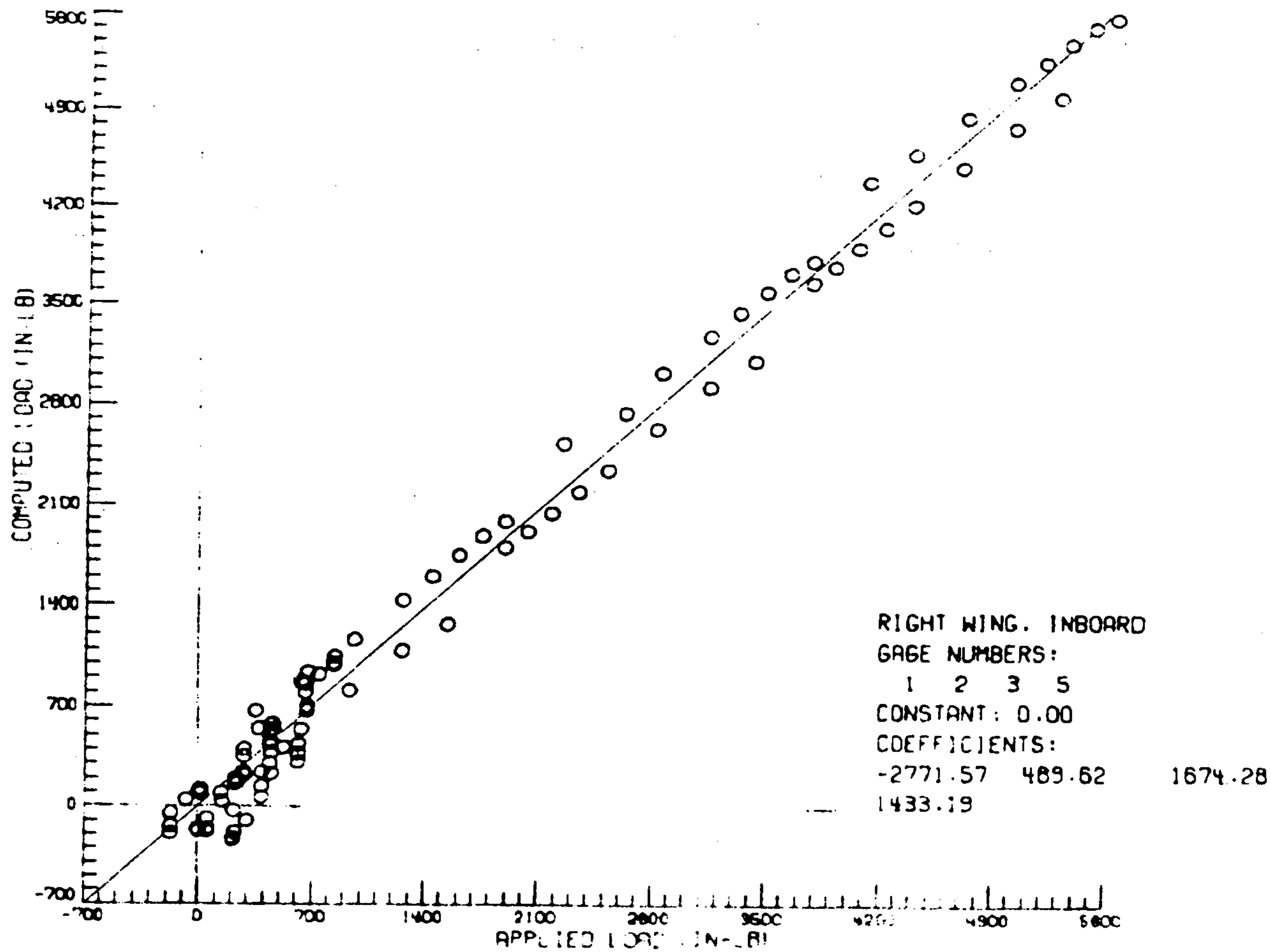
a) - Inboard station shear loads.

Figure 14.- Calculated versus applied loads for the right semispan loads.



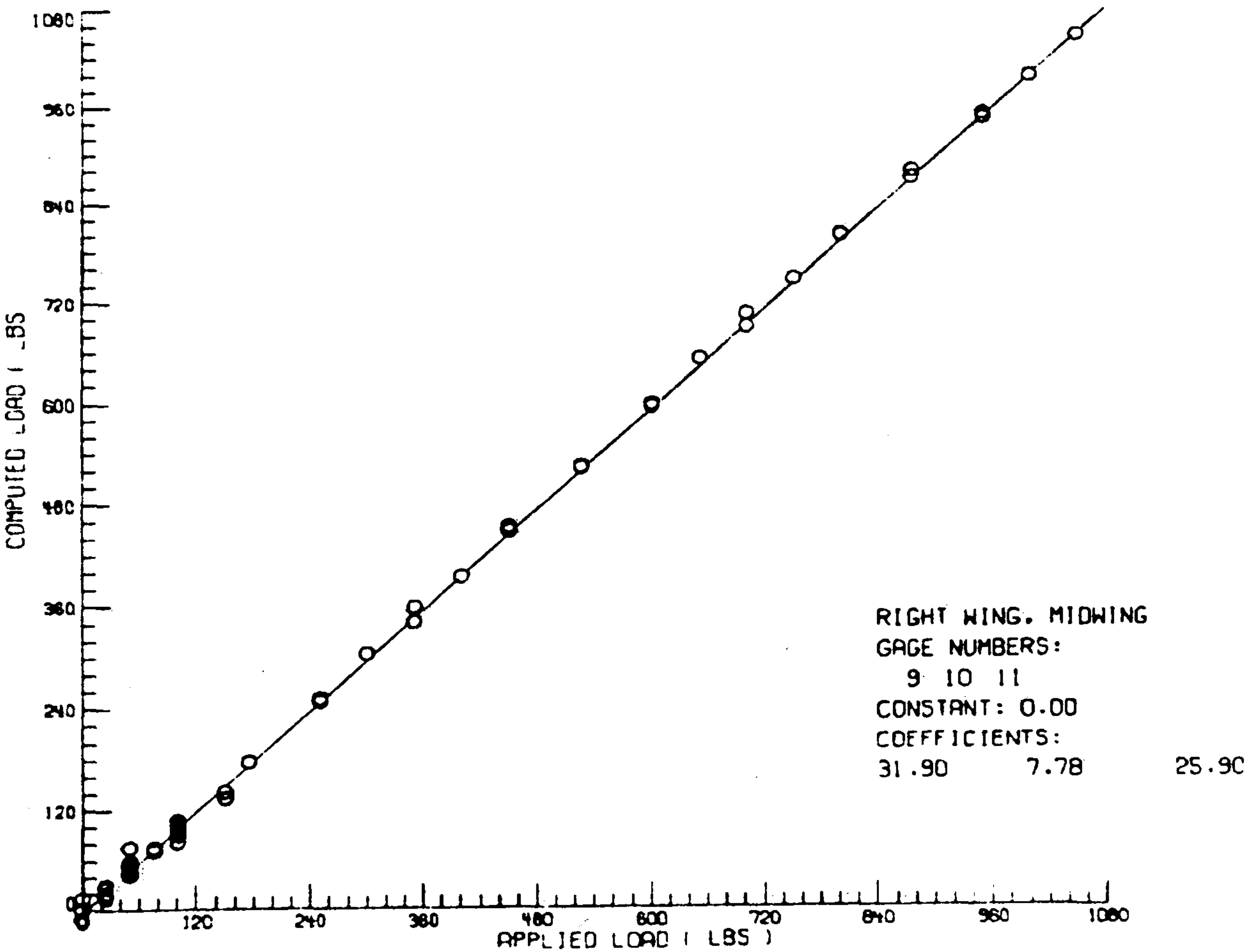
b) - Inboard station bending moment loads.

Figure 14.- Continued.



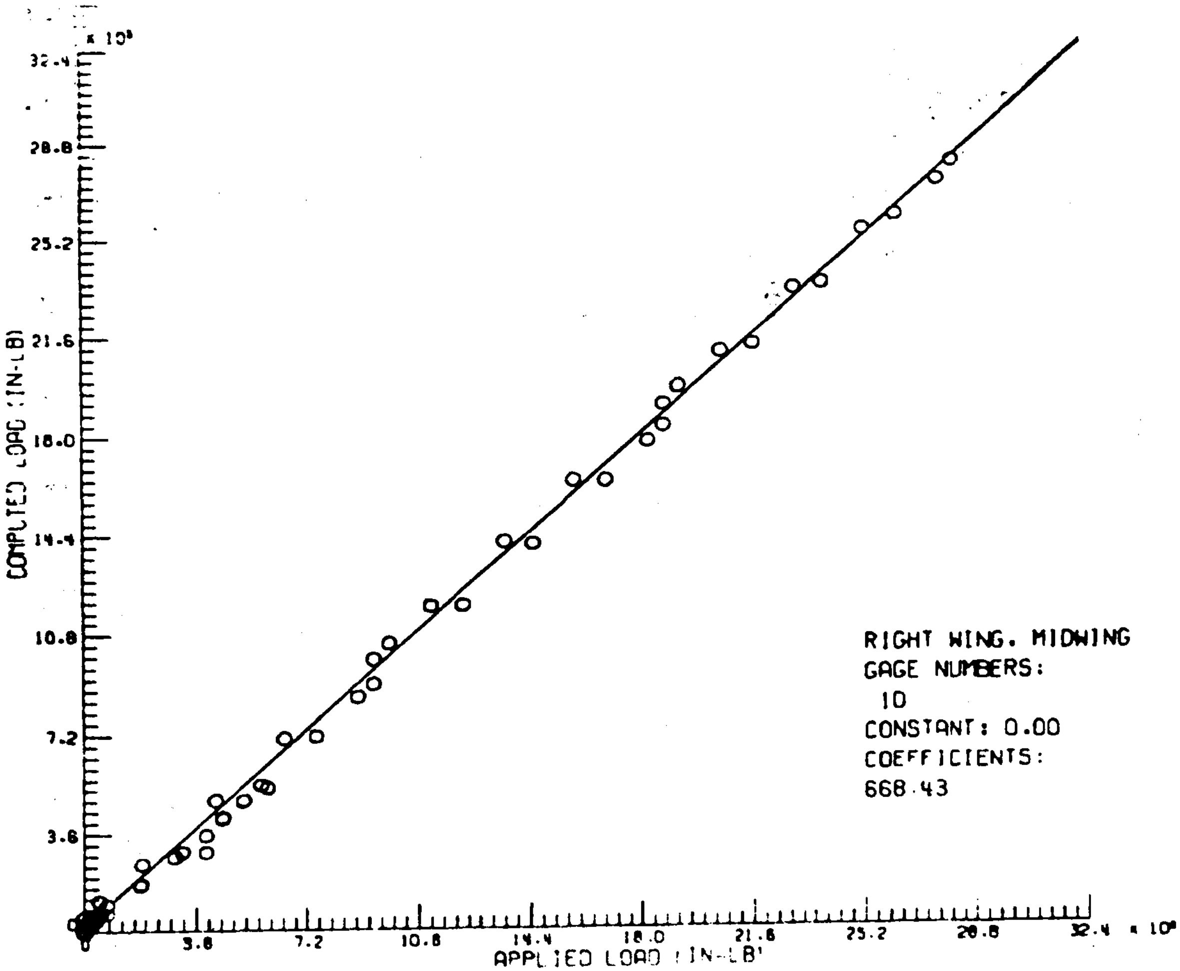
c) - Inboard station torque loads.

Figure 14.- Continued.



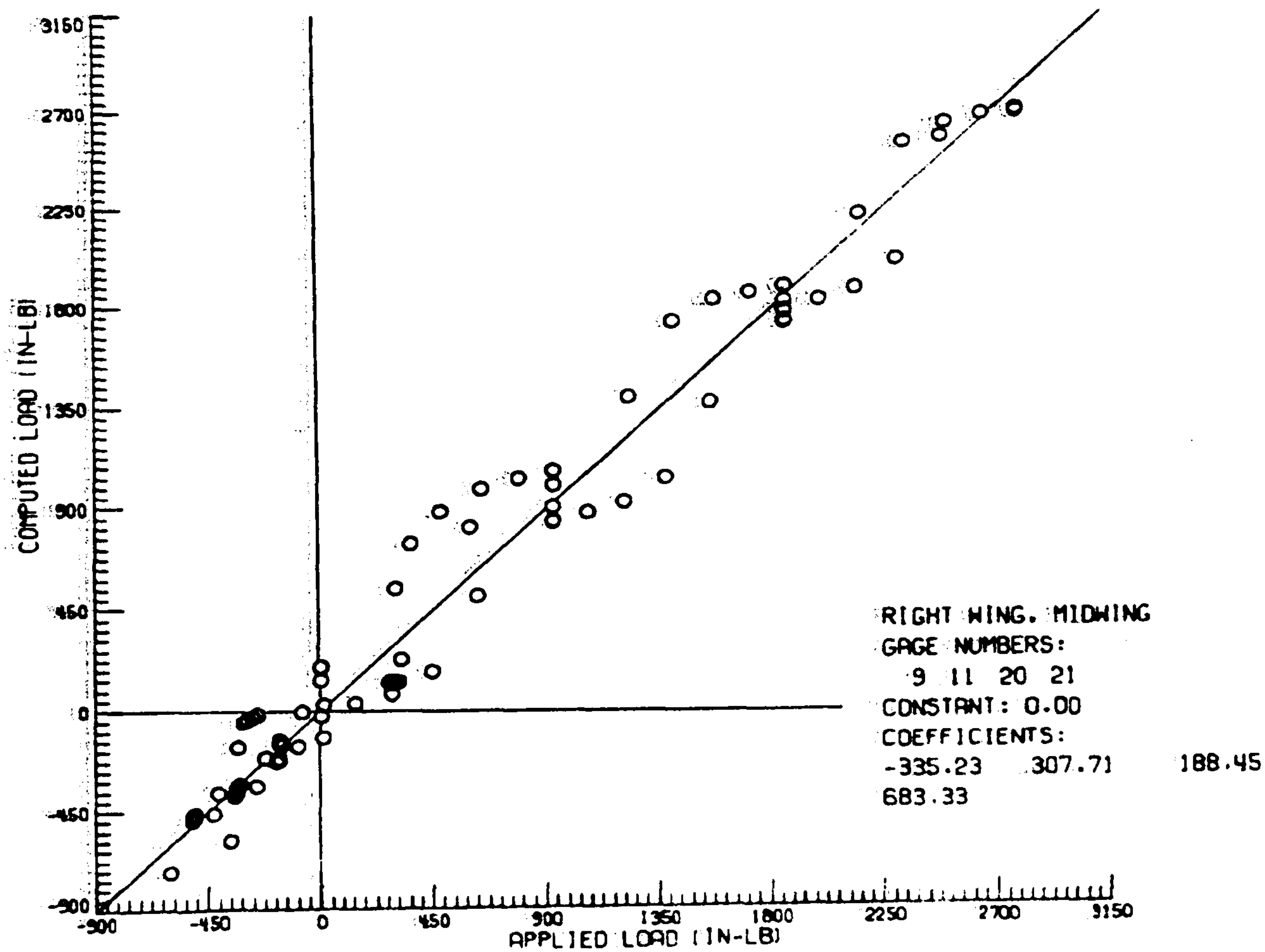
d) - Midwing station shear loads.

Figure 14.- Continued.



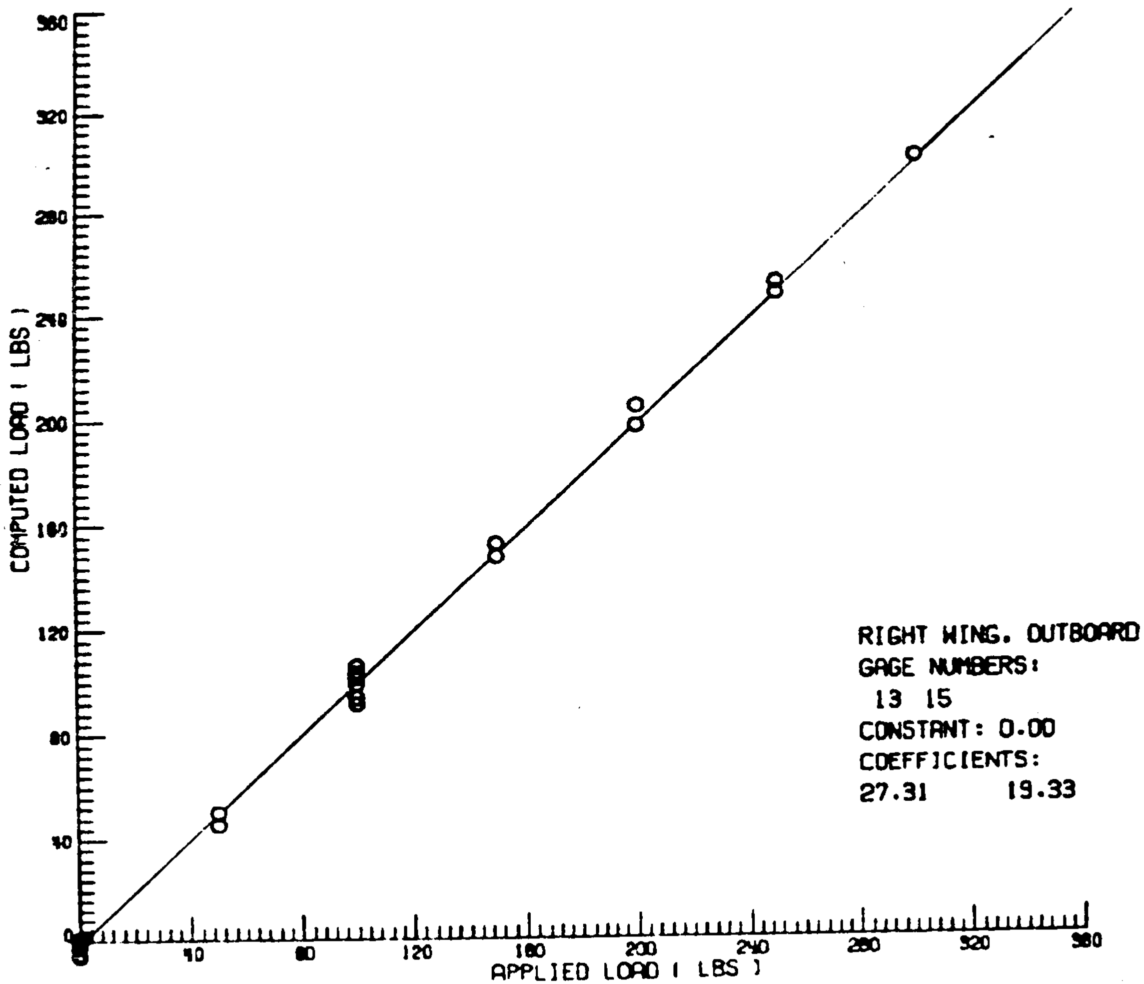
e) - Midwing station bending moment loads.

Figure 14.- Continued.



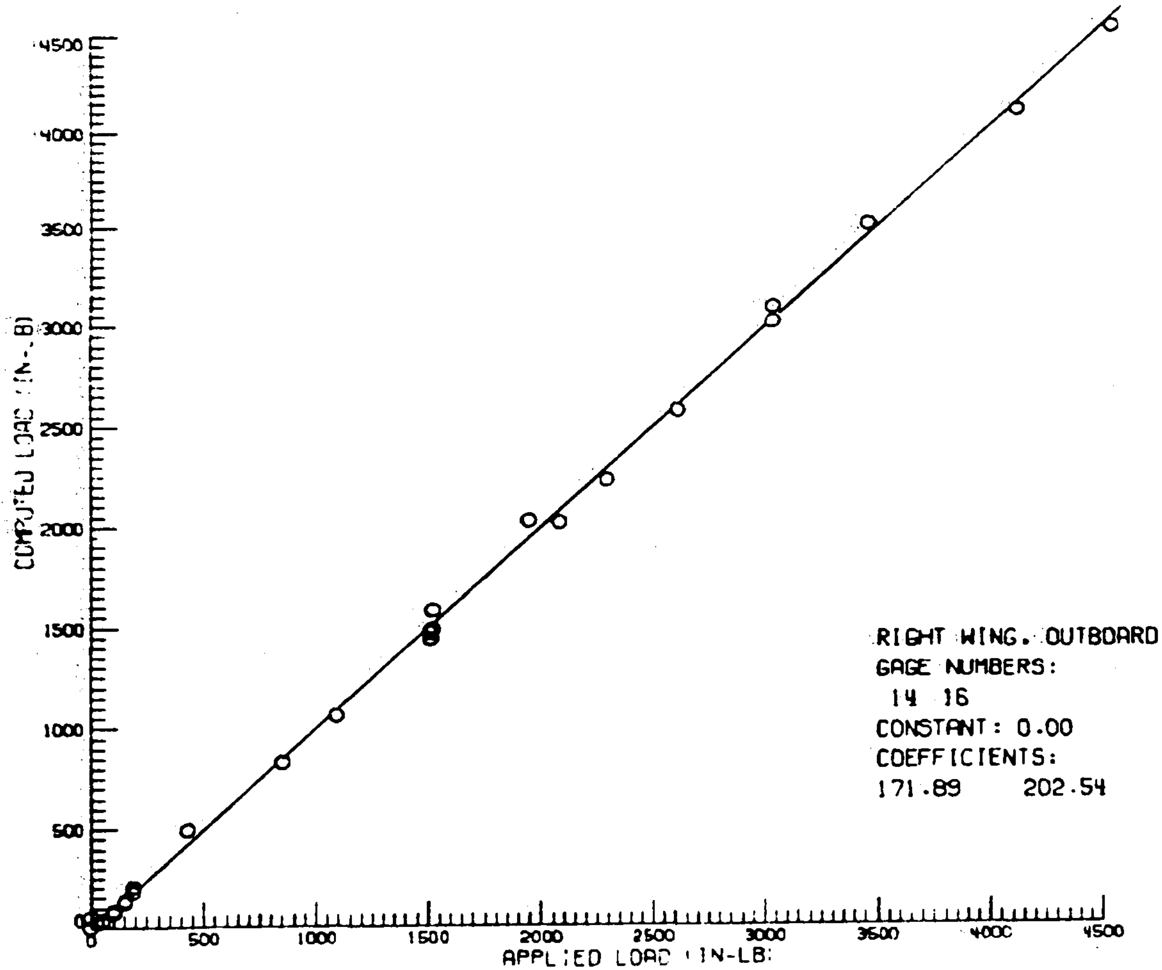
f) - Midwing station torque loads.

Figure 14.- Continued.



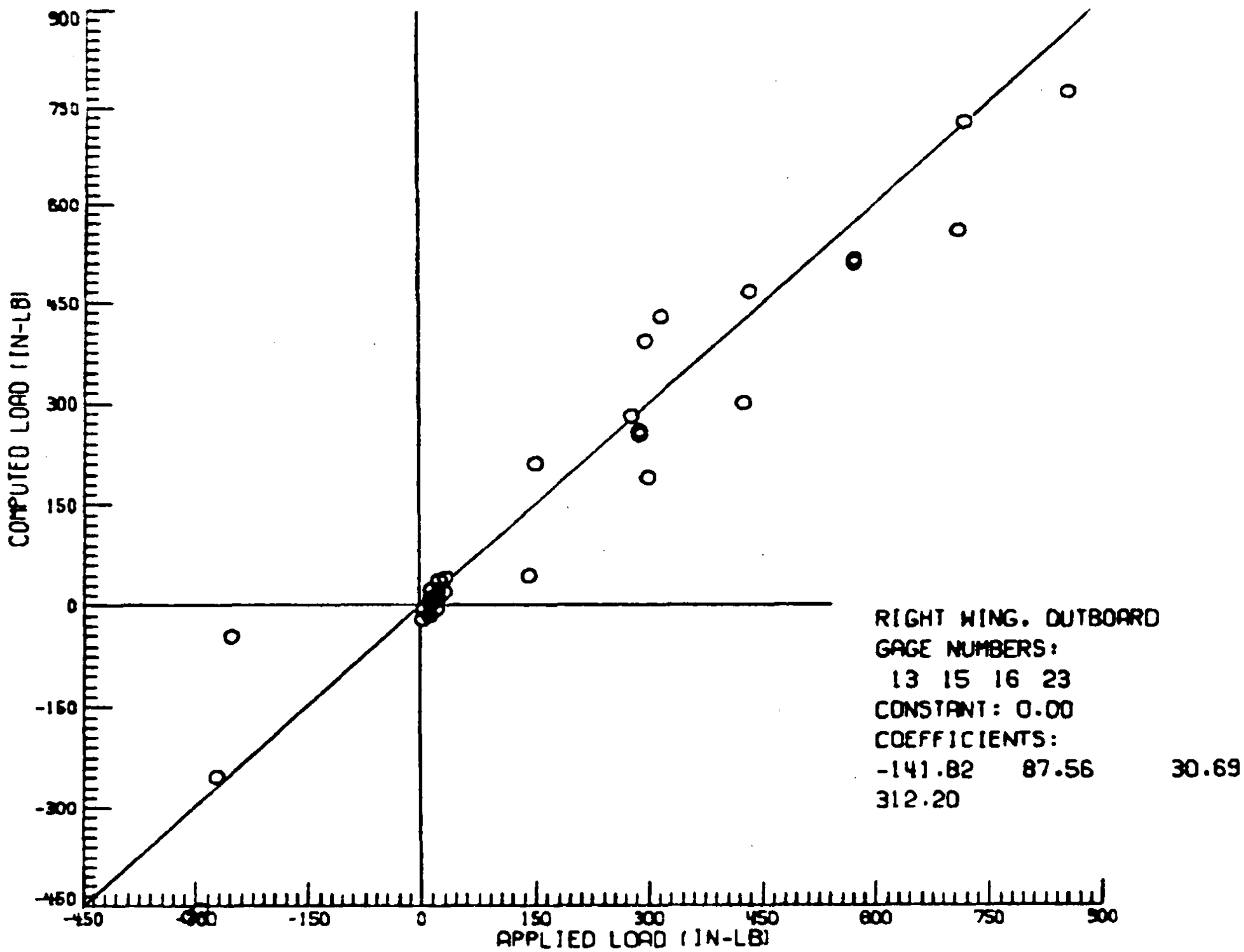
g) - Outboard station shear loads.

Figure 14.- Continued.



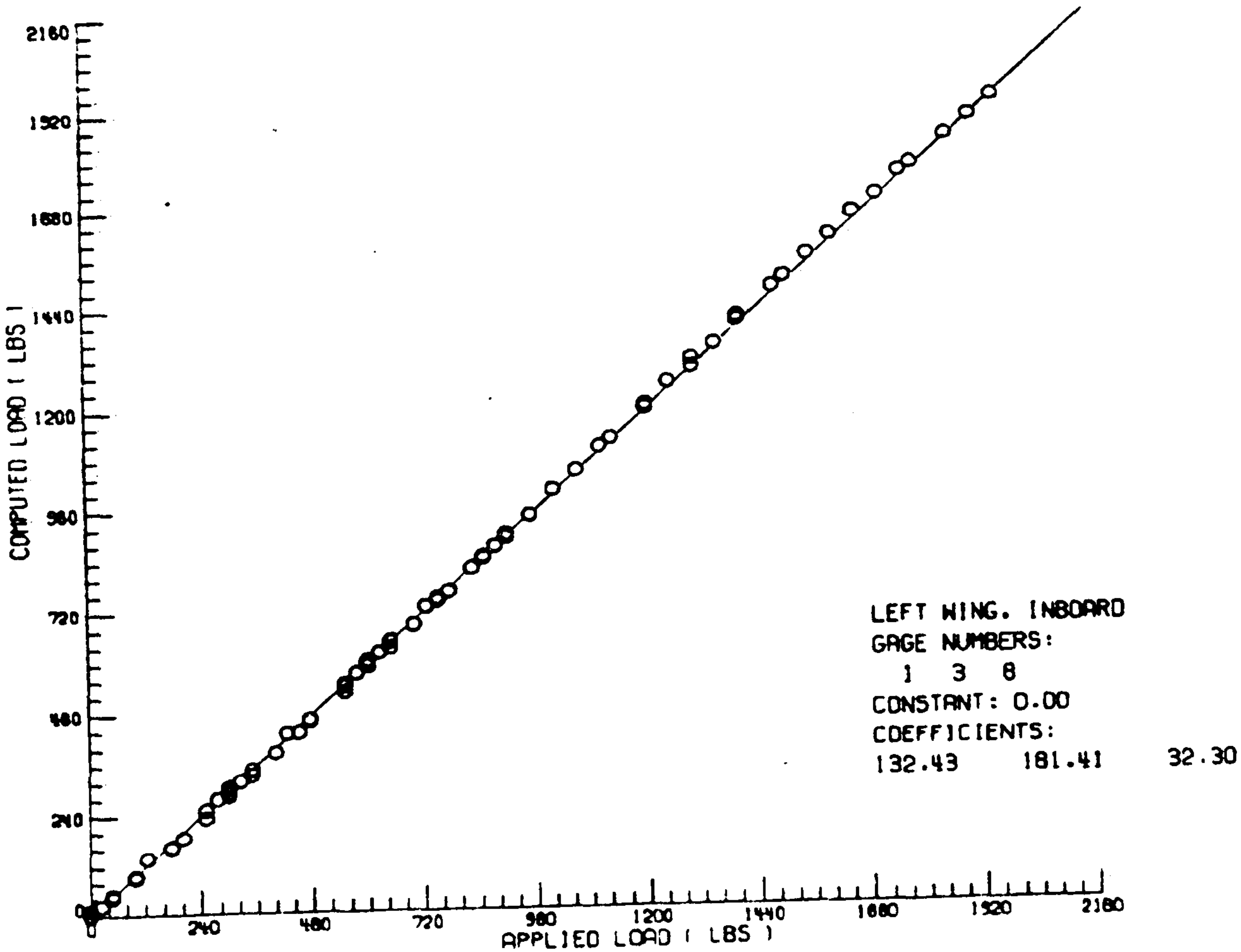
h) - Outboard station bending moment loads.

Figure 14.- Continued.



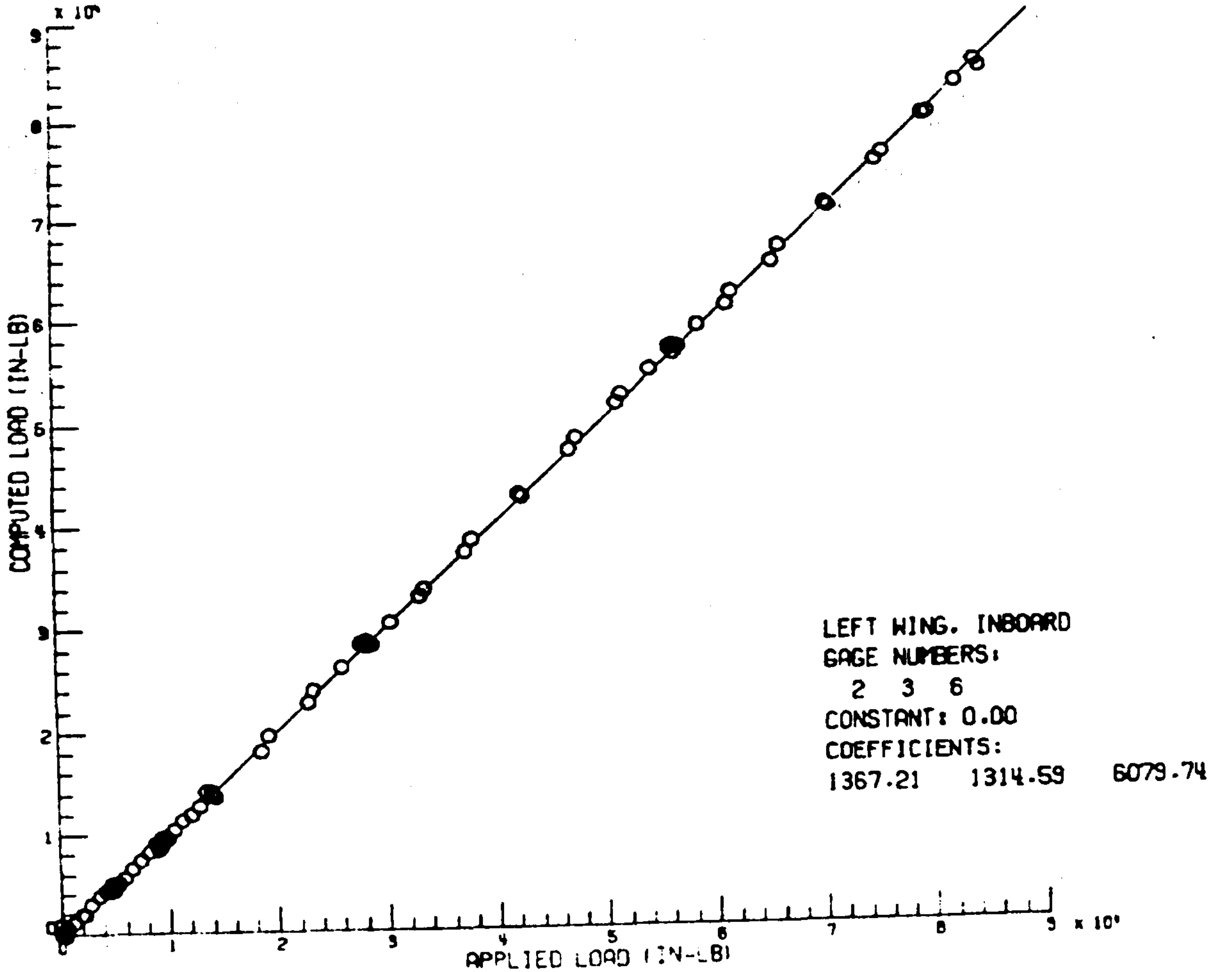
i) - Outboard station torque loads.

Figure 14.- Concluded.



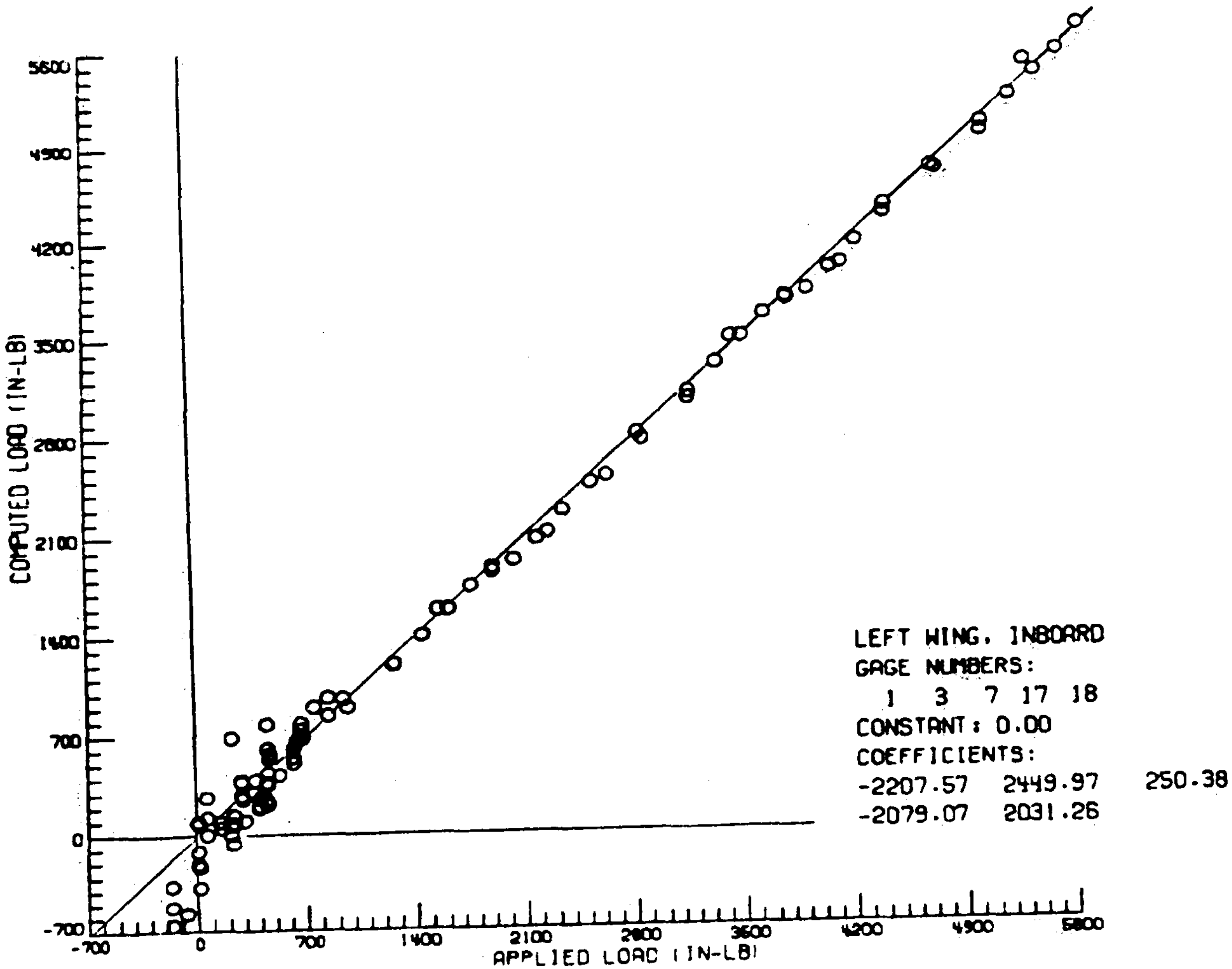
a) - Inboard station shear loads.

Figure 15.- Calculated versus applied loads for the left semispan.



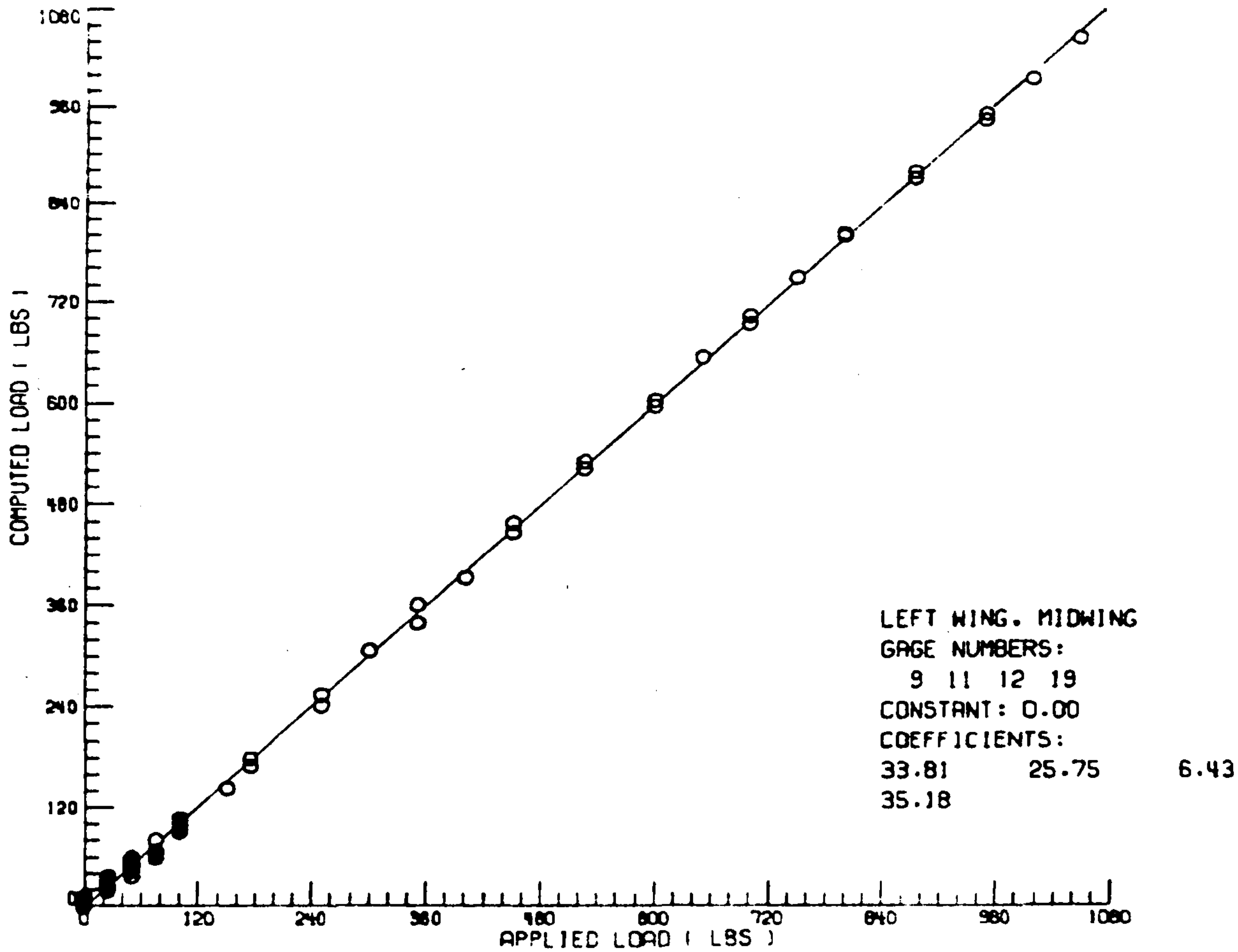
b) - Inboard station bending moment loads.

Figure 15.- Continued.



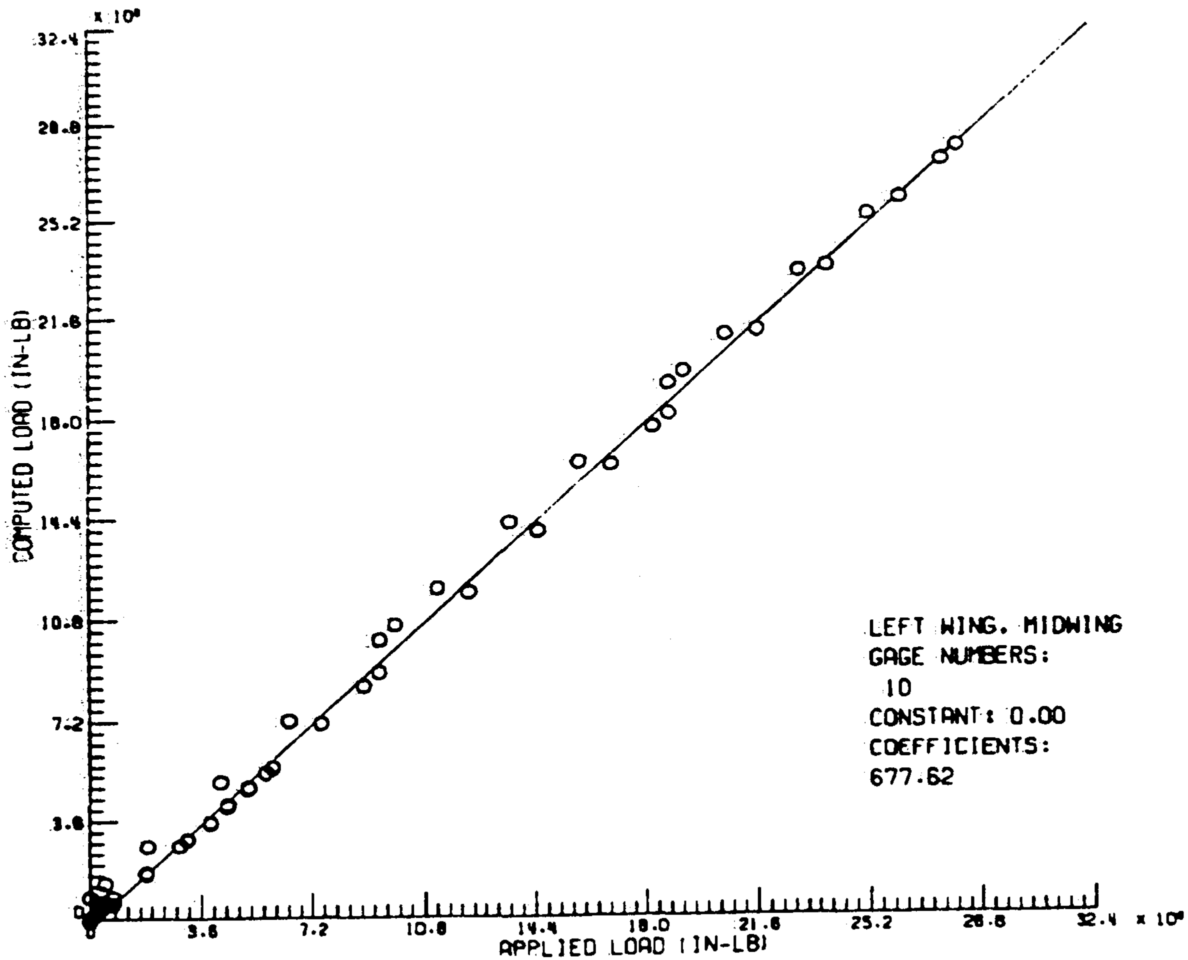
c) - Inboard station torque loads.

Figure 15.- Continued.



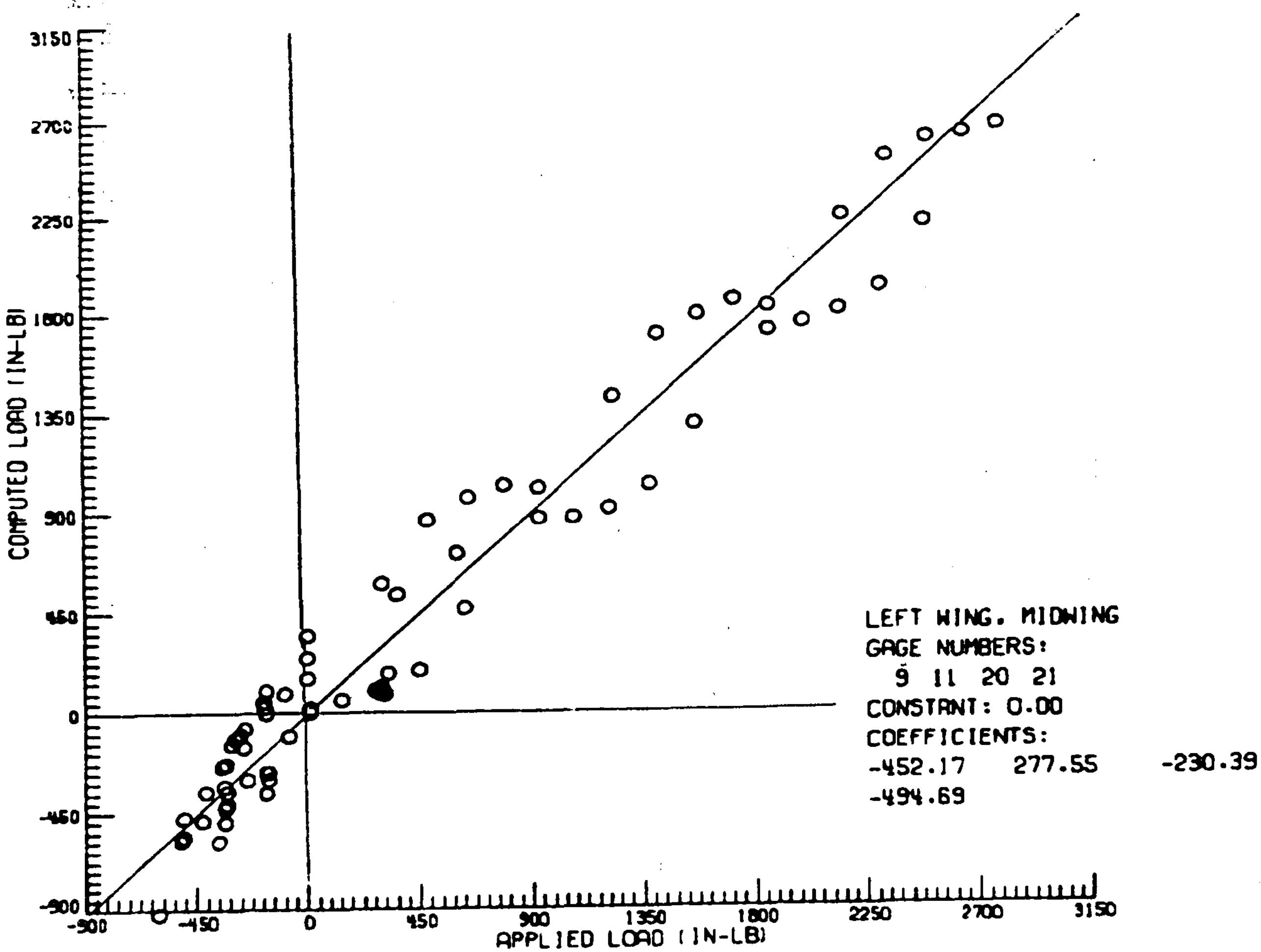
d) - Midwing station shear loads.

Figure 15.- Continued.



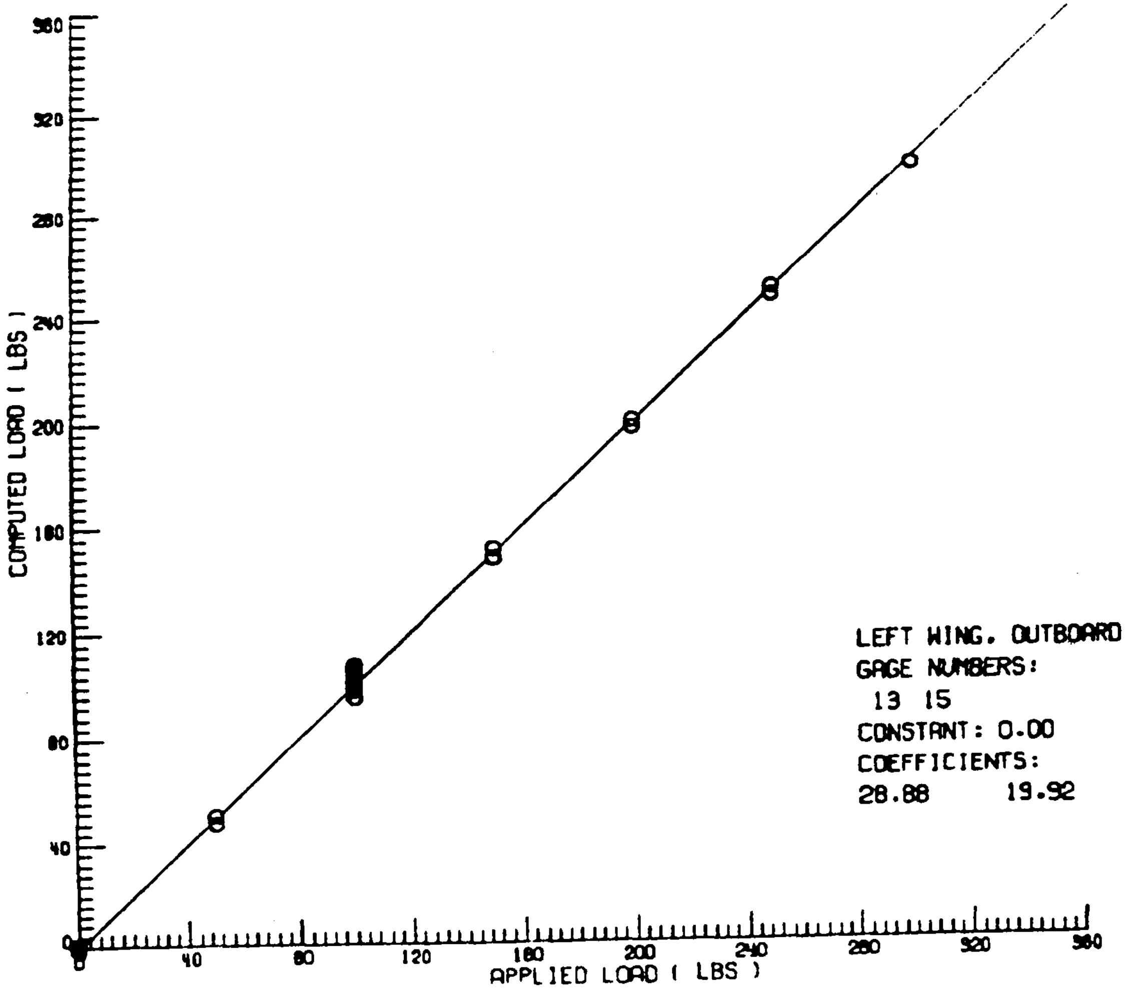
e) - Midwing station bending moment loads.

Figure 15.- Continued.



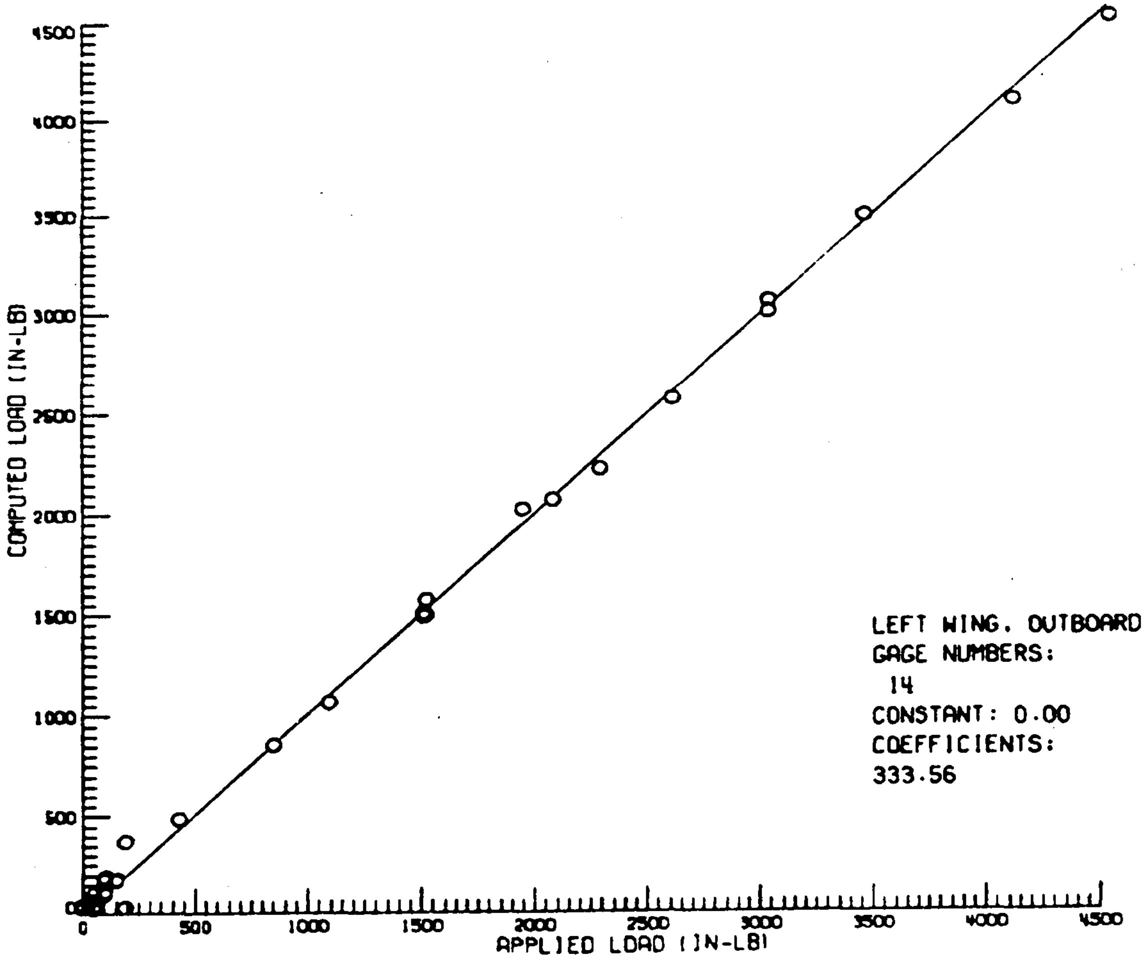
f) - Midwing station torque loads.

Figure 15.- Continued.



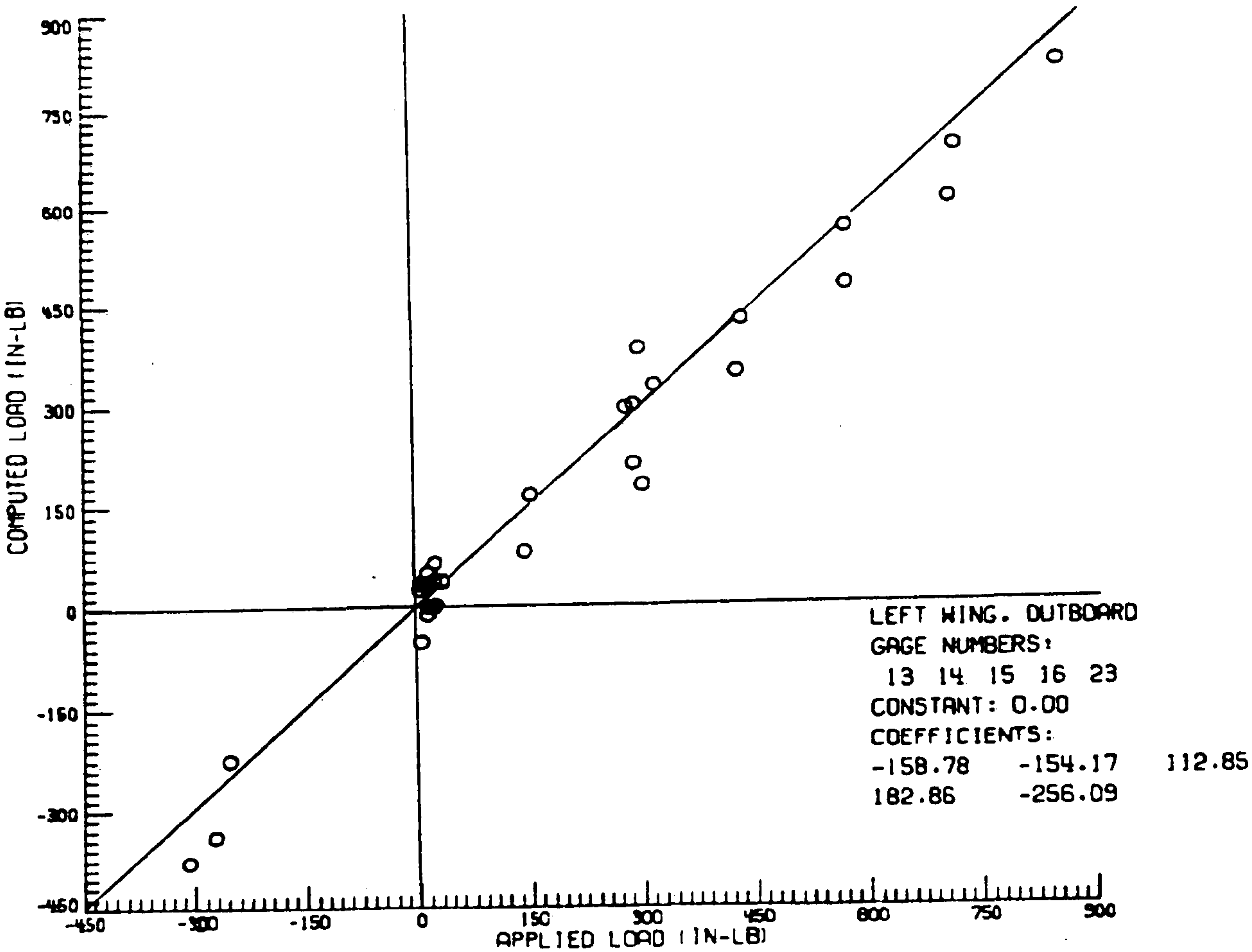
g).- Outboard station shear loads.

Figure 15.- Continued.



h) - Outboard station bending moment loads.

Figure 15.- Continued.



i) - Outboard station torque loads.

Figure 15.- Concluded.

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16. Abstract

Results from and details of the procedure used to calibrate strain gage bridges for measurement of wing structural loads, shear (V), bending moment (M), and torque (T), at three semispan stations on both the left and right semispans of the ARW-2 wing are presented. The ARW-2 wing has a reference area of 35-square feet, a span of 19-feet, an aspect ratio of 10.3, a midchord line sweepback angle of 25-degrees, and a taper ratio of 0.4. The ARW-2 wing was fabricated using aluminum spars and ribs covered with a fiberglass/honeycomb sandwich skin material. All strain gage bridges are mounted on the aluminum spars or ribs. The resulting loads equations are presented along with an estimate of their accuracy by means of a comparison of computed loads versus actual loads for three simulated flight conditions.

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