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GEOMETRIC AND STRUCTURAL PROPERTIES OF A RECTANGULAR SUPERCRITICAL WING OSCILLATED IN PITCH FOR MEASUREMENT OF UNSTEADY TRANSONIC PRESSURE DISTRIBUTIONS

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SUMMARY

Wind-tunnel tests to measure unsteady aerodynamic data in the transonic region have been completed on an aspect ratio 2.0 rectangular wing with a supercritical airfoil. In this paper, the geometric and structural properties of the wing are presented. (Other references contain the measured aerodynamic data.) Both measured and design airfoil coordinates are presented and compared. In addition, measured wing bending and torsional stiffness distributions and some trailing-edge flexibility influence coefficients are presented.

INTRODUCTION

In recent years at the NASA Langley Research Center a program has been underway to measure unsteady aerodynamic data in the transonic regime for the purposes of assisting analytical code development and providing a data base for active controls design. Pressure data have been previously reported for two semispan wings which were tested in the Langley Transonic Dynamics Tunnel (TDT)--namely, a clipped delta wing (ref.1) and a high-aspect-ratio transport-type wing (ref.2). The delta wing, which had a circular-arc airfoil, was oscillated in pitch about various mean angles of attack. A partial-span trailing-edge control surface also was oscillated to generate unsteady aerodynamic pressures. The transport-type wing, which had a supercritical airfoil, had five leading-edge and five trailing-edge control surfaces. Some of the surfaces were oscillated independently and in pairs about various mean control surface angles. The static angle of attack of the transport-type wing was varied to allow data acquisition at simulated cruise lift conditions.

Tests have been completed on a third semispan wing--an aspect ratio 2.0 rectangular wing with a 12-percent thick supercritical airfoil. In figure 1 the wing is shown mounted in the TDT. This wing was tested for the purpose of aiding in the development and preliminary assessment of new analytical transonic codes. Some results from this test and their correlation with analytical results are presented in references 3 and 4. The purpose of the present paper is to describe in detail the wing physical properties. The geometric and structural properties of the wing are presented to allow other analysts the opportunity to make calculations for correlation with the experimental data. In particular, the design and measured airfoil coordinates are tabulated and compared. Also presented are measured stiffness distributions and some trailing-edge flexibility coefficients suitable for calculating aeroelastic deformations.

SYMBOLS

c	chord, in (24.0)
EI	bending stiffness, lb in^2
GJ	torsional stiffness, lb in^2
LE	leading edge
P	load, lb
R	radius of wing tip section, in
TE	trailing edge
x	streamwise coordinate measured from LE, in
x/c	fractional chord
y	spanwise coordinate measured from root; span station, in
z	vertical coordinate measured from wing reference plane, in
δ	deflection, in
δ/P	flexibility influence coefficient, in/lb

Subscripts:

u	upper
l	lower

WING DESIGN DETAILS

Geometry and Construction

The wing planform view and the tip shape are shown in figure 2. The planform is rectangular and has a panel aspect ratio of 2.0. The wing was constructed in three sections as defined by the dashed lines in the figure. The wing center box section was made from aluminum halves (upper and lower) that were permanently pinned, bonded and bolted together. The leading- and trailing-edge sections were made of light-weight Kevlar[1] and balsawood sandwich material to minimize the pitch moment of inertia of the wing assembly. The leading- and trailing-edge sections attached to the center box section at 0.23 and 0.69 fractional chord, respectively.

The wing was attached to a shaft that extended through a splitter plate mounted off the wind-tunnel wall (see fig. 1) so that the wing root was outside the wall boundary layer. This shaft was connected to a hydraulic actuator that oscillated the wing in pitch. The wing pitch axis is located at the 0.46 fractional chord to maximize the performance of the actuator by considering both inertia and aerodynamic loads.

Airfoil Coordinates

The airfoil shape is a 12-percent-thick supercritical design and is constant across the wing span. The airfoil shape is shown in figure 3. The

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[1]Kevlar: Registered trademark of E. I. duPont deNemours & Co., Inc. Use of trade names does not constitute an official endorsement, either expressed or implied, by the National Aeronautics and Space Administration.

airfoil has a two-dimensional design Mach number of 0.8 and a design lift coefficient of 0.6. The design was derived from an 11-percent-thick airfoil (ref. 5) by ratioing the thicknesses while maintaining the original mean-chord line. In addition, the wing trailing edge was thickened to 0.7-percent chord by rotating the lower surface cusp area about its inflection point in a manner similar to that outlined in reference 6.

The airfoil coordinates were measured for both the upper and lower surfaces at five span stations using a three-axis coordinate measuring machine which has a measurement accuracy of ±.0004 in. These span stations are located at the following distances in inches from the wing root: 1.000, 14.932, 28.324, 38.932, and 45.948. The four outboard span stations are adjacent to the pressure-measurement locations. The measured coordinates are compared to design values in figure 4 and table I. The maximum deviation from the design values occurs in the lower surface cusp area and does not exceed .021 inches.

Wing-Tip Coordinates

The wing tip (fig.2) was formed with semi-circular arcs joining the upper and lower surfaces of the wing. Coordinates of the wing tip shape are listed in table II.

Instrumentation

The wing instrumentation was designed primarily to measure the unsteady pressure distribution and dynamic deformation shape while the wing was oscillated in pitch. The instrumentation consisted of differential pressure transducers, pressure orifices, accelerometers, and a potentiometer. Locations of the instrumentation items are shown in figure 5 and are tabulated in tables III and IV.

Pressure measurements were made using transducers located along chordwise rows which extended from the leading edge to the trailing edge on the upper and lower surfaces at four spanwise stations. These rows are shown in figure 5. At each spanwise station, there are a total of 29 measurement locations--namely, 14 each along the upper and lower surfaces and one at the leading edge. In the center box section, the transducers were mounted flush to the surface (in situ). For the leading- and trailing-edge sections, the transducers were mounted in the joint area between the sections and were connected to orifices at the section surfaces via tubes that had equal length and diameter. This arrangement alleviated the problems associated with in situ mounting in the thin trailing-edge areas and enabled the transducers to be mounted closer to the pitch axis and thereby reduced the accelerations that they experienced. This tube technique was first introduced by Tijdeman (ref. 7) and is often call the Dutch matched-tubing method. A fifth row of seven matched-tubing orifices were located adjacent to the inboard row of in situ transducers in the center box section. Pressure measurements at these orifices and their corresponding in situ transducers were used to calculate the tube transfer functions at each tunnel condition. The locations for the in situ transducers and matched-tubing orifices are listed in table III.

Eight accelerometers were used to measure wing dynamic motions and were mounted along the front and rear edges of the center box section. The locations of the accelerometers are listed in table IV. A potentiometer connected to the actuator shaft was used to measure both the static angle of attack and dynamic pitching motions of the wing root.

WING STRUCTURAL PROPERTIES

Various structural properties of the wing were measured in the laboratory. The results of these measurements are presented in this section and can be used to calculate wing deformations under specific aerodynamic loadings.

The weight of the wing, including the instrumentation, was 54 lb. The center of gravity was located at 44 percent chord at 41 percent span. The fundamental frequency (wing bending mode) was 34.8 Hz, well above the highest frequency (20 Hz) at which unsteady aerodynamic data was measured during the wind tunnel test.

Bending and torsional stiffnesses were calculated from angular deflection measurements obtained using a laser light source and a set of mirrors mounted to the wing along the pitch axis. The wing stiffness results are shown in figures 6 and 7 for bending and torsion, respectively.

Flexibility measurements were made in two regions on the trailing-edge section--one near the wing tip and the other at mid span. These two regions were chosen to be representative of the entire trailing-edge section with respect to edge constraints. The wing-tip region is similar to the root region, and the mid-span region is similar to the region between the root and tip. Locations of the load/deflection measurement points are given in figure 8. The loads were applied to the wing lower surface. The deflections were measured using a set of dial gages which also touched the lower surface. The resulting flexibility influence coefficients measurements, δ/P (deflection per unit load), are presented in figure 9. Measurements are presented both in the chordwise direction (fig. 9a and 9c) and in the spanwise direction (fig. 9b and 9d).

CONCLUDING REMARKS

Geometric and structural properties were presented herein for a rectangular wing that was tested to measure unsteady aerodynamic pressures due to pitch oscillations. These properties are presented to allow other analysts the opportunity to make calculations for comparison with experimental data. The measured coordinates of the supercritical airfoil at several span stations compared very well with the design values. Measured wing bending and torsional stiffness distributions and some trailing-edge flexibility influence coefficients are presented to allow calculations of wing aeroelastic deformations.

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November 30, 1983

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TABLE I.- DESIGN AND MEASURED AIRFOIL COORDINATES.

		DESIGN VALUES		MEASURED VALUES			
				y = 1.000 in		y = 14.932 in	
x, in	x/c	z_u, in	z_ℓ, in	z_u, in	z_ℓ, in	z_u, in	z_ℓ, in
.000	.000	.000	.000	.000	.000	.000	.000
.180	.008	.461	-.461	.457	-.473	.453	-.470
.300	.012	.563	-.565	.560	-.575	.556	-.572
.600	.025	.723	-.735	.719	-.743	.716	-.738
.900	.037	.828	-.847	.823	-.857	.823	-.850
1.200	.050	.910	-.936	.905	-.944	.905	-.938
1.800	.075	1.033	-1.067	1.029	-1.072	1.029	-1.069
2.400	.100	1.122	-1.161	1.119	-1.164	1.118	-1.162
3.000	.125	1.193	-1.234	1.190	-1.237	1.189	-1.234
3.600	.150	1.248	-1.289	1.247	-1.293	1.246	-1.290
4.200	.175	1.293	-1.333	1.294	-1.338	1.292	-1.335
4.800	.200	1.329	-1.365	1.333	-1.369	1.329	-1.367
6.000	.250	1.384	-1.413	1.388	-1.415	1.385	-1.412
7.200	.300	1.415	-1.434	1.418	-1.434	1.415	-1.432
8.400	.350	1.432	-1.437	1.434	-1.437	1.433	-1.434
9.600	.400	1.439	-1.417	1.442	-1.415	1.440	-1.413
10.800	.450	1.432	-1.375	1.435	-1.374	1.434	-1.372
12.000	.500	1.417	-1.306	1.419	-1.307	1.418	-1.304
13.200	.550	1.387	-1.200	—	-1.201	1.389	-1.197
13.800	.575	1.369	-1.126	1.371	-1.127	1.370	-1.122
14.400	.600	1.345	-1.033	1.349	-1.033	1.349	-1.028
15.000	.625	1.320	-.914	1.323	-.913	1.323	-.908
15.600	.650	1.288	-.762	1.292	-.761	1.291	-.757
16.200	.675	1.250	-.594	1.255	-.594	1.254	-.590
16.800	.700	1.211	-.439	1.209	-.442	1.217	-.437
17.400	.725	1.164	-.301	1.162	-.307	1.174	-.299
18.000	.750	1.113	-.175	1.113	-.180	1.123	-.170
18.600	.775	1.058	-.065	1.059	-.067	1.068	-.061
19.200	.800	.993	.029	.995	.028	1.003	.035
19.800	.825	.919	.108	.922	.109	.928	.124
20.400	.850	.833	.165	.839	.169	.845	.177
21.000	.875	.738	.203	.744	.206	.749	.215
21.600	.900	.625	.211	.632	.215	.637	.221
22.200	.925	.498	.187	.505	.192	.508	.200
22.800	.950	.350	.119	.357	.126	.358	.131
23.400	.975	.179	-.001	.186	.005	.183	.010
24.000	1.000	-.019	-.187	-.008	-.177	-.022	-.180

TABLE I.- CONCLUDED.

		MEASURED VALUES					
		y = 28.324 in		y = 38.932 in		y = 45.948 in	
x, in	x/c	z_u, in	z_ℓ, in	z_u, in	z_ℓ, in	z_u, in	z_ℓ, in
.000	.000	.000	.000	.000	.000	.000	.000
.180	.008	.451	-.462	.458	-.458	.465	-.459
.300	.012	.557	-.567	.563	-.564	.568	-.561
.600	.025	.720	-.738	.725	-.732	.725	-.727
.900	.037	.824	-.849	.830	-.845	.832	-.840
1.200	.050	.906	-.937	.910	-.932	.911	-.927
1.800	.075	1.030	-1.068	1.033	-1.064	1.030	-1.055
2.400	.100	1.118	-1.160	1.120	-1.156	1.116	-1.148
3.000	.125	1.191	-1.235	1.190	-1.228	1.184	-1.221
3.600	.150	1.247	-1.290	1.245	-1.284	1.242	-1.278
4.200	.175	1.292	-1.333	1.293	-1.328	1.289	-1.327
4.800	.200	1.330	-1.366	1.332	-1.363	1.331	-1.363
6.000	.250	1.384	-1.412	1.383	-1.412	1.388	-1.414
7.200	.300	1.415	-1.431	1.414	-1.431	1.417	-1.436
8.400	.350	1.433	-1.433	1.431	-1.428	1.434	-1.439
9.600	.400	1.440	-1.413	1.437	-1.407	1.440	-1.418
10.800	.450	1.435	-1.372	1.433	-1.367	1.436	-1.374
12.000	.500	1.419	-1.304	1.417	-1.300	1.421	-1.305
13.200	.550	1.389	-1.198	1.388	-1.196	1.391	-1.199
13.800	.575	1.370	-1.123	1.369	-1.122	1.371	-1.125
14.400	.600	1.347	-1.029	1.346	-1.029	1.348	-1.031
15.000	.625	1.322	-.910	1.320	-.909	1.321	-.913
15.600	.650	1.290	-.756	1.289	-.756	1.289	-.760
16.200	.675	1.253	-.589	1.252	-.589	1.251	-.593
16.800	.700	1.216	-.435	1.213	-.434	1.214	-.438
17.400	.725	1.174	-.300	1.170	-.297	1.169	-.302
18.000	.750	1.124	-.173	1.123	-.171	1.121	-.176
18.600	.775	1.070	-.060	1.069	-.058	1.066	-.060
19.200	.800	1.007	.037	1.005	.040	1.000	.036
19.800	.825	.933	.117	.932	.120	.928	.117
20.400	.850	.847	.175	.849	.181	.845	.175
21.000	.875	.752	.215	.755	.219	.751	.213
21.600	.900	.641	.223	.645	.228	.639	.218
22.200	.925	.514	.199	.515	.206	.508	.200
22.800	.950	.363	.133	.366	.140	.359	.131
23.400	.975	.189	.013	.189	.017	.181	.009
24.000	1.000	-.018	-.173	-.006	-.167	-.014	-.176

TABLE II.- WING-TIP GEOMETRY.

x, in	x/c	z, in	R, in
.000	.000	.000	.000
.180	.008	.000	.461
.300	.012	-.001	.564
.600	.025	-.006	.729
.900	.037	-.009	.837
1.200	.050	-.013	.923
1.800	.075	-.017	1.050
2.400	.100	-.020	1.141
3.000	.125	-.021	1.214
3.600	.150	-.020	1.268
4.200	.175	-.020	1.313
4.800	.200	-.018	1.347
6.000	.250	-.015	1.398
7.200	.300	-.010	1.424
8.400	.350	-.003	1.434
9.600	.400	.011	1.428
10.800	.450	.029	1.403
12.000	.500	.056	1.361
13.200	.550	.094	1.293
13.800	.575	.122	1.248
14.400	.600	.156	1.189
15.000	.625	.203	1.117
15.600	.650	.263	1.025
16.200	.675	.328	.922
16.800	.700	.386	.825
17.400	.725	.431	.732
18.000	.750	.469	.644
18.600	.775	.496	.561
19.200	.800	.511	.482
19.800	.825	.513	.405
20.400	.850	.499	.334
21.000	.875	.470	.267
21.600	.900	.418	.207
22.200	.925	.342	.155
22.800	.950	.234	.115
23.400	.975	.089	.090
24.000	1.000	-.103	.084

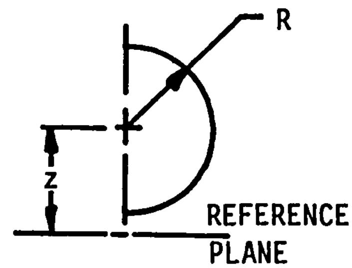


TABLE III.- LOCATIONS OF TRANSDUCERS AND ORIFICES.

x, in	x/c	Type (I = In situ 0 = orifice)
At span stations 14.832, 28.224, 38.832, and 45.648 in		
0.	0.	0
.06	.003	0
1.20	.050	0
2.40	.100	0
4.80	.200	0
6.24	.260	I
7.68	.320	I
9.12	.380	I
10.56	.440	I
12.00	.500	I
13.44	.560	I
14.88	.620	I
16.80	.700	0
19.20	.800	0
21.60	.900	0
At span station 15.216 in		
6.24	.260	0
7.68	.320	0
9.12	.380	0
10.56	.440	0
12.00	.500	0
13.44	.560	0
14.88	.620	0

TABLE IV.- LOCATIONS OF ACCELEROMETERS.

	x, in	x/c	y,in
1	5.57	0.23	46.56
2	5.57	0.23	35.62
3	5.57	0.23	24.44
4	5.57	0.23	14.88
5	16.51	0.69	47.47
6	16.51	0.69	35.16
7	16.51	0.69	24.25
8	16.51	0.69	13.03

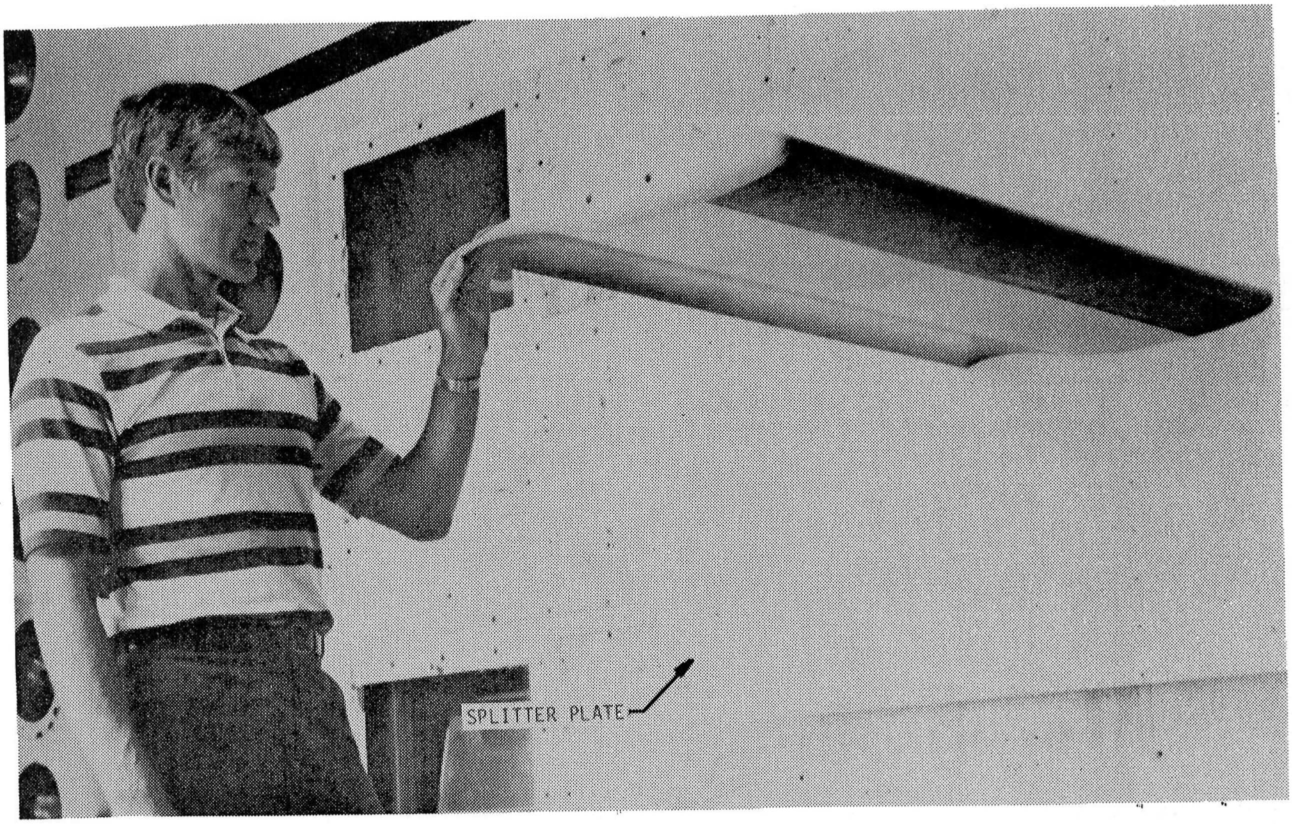


Figure 1.- Wing mounted in TDT test section.

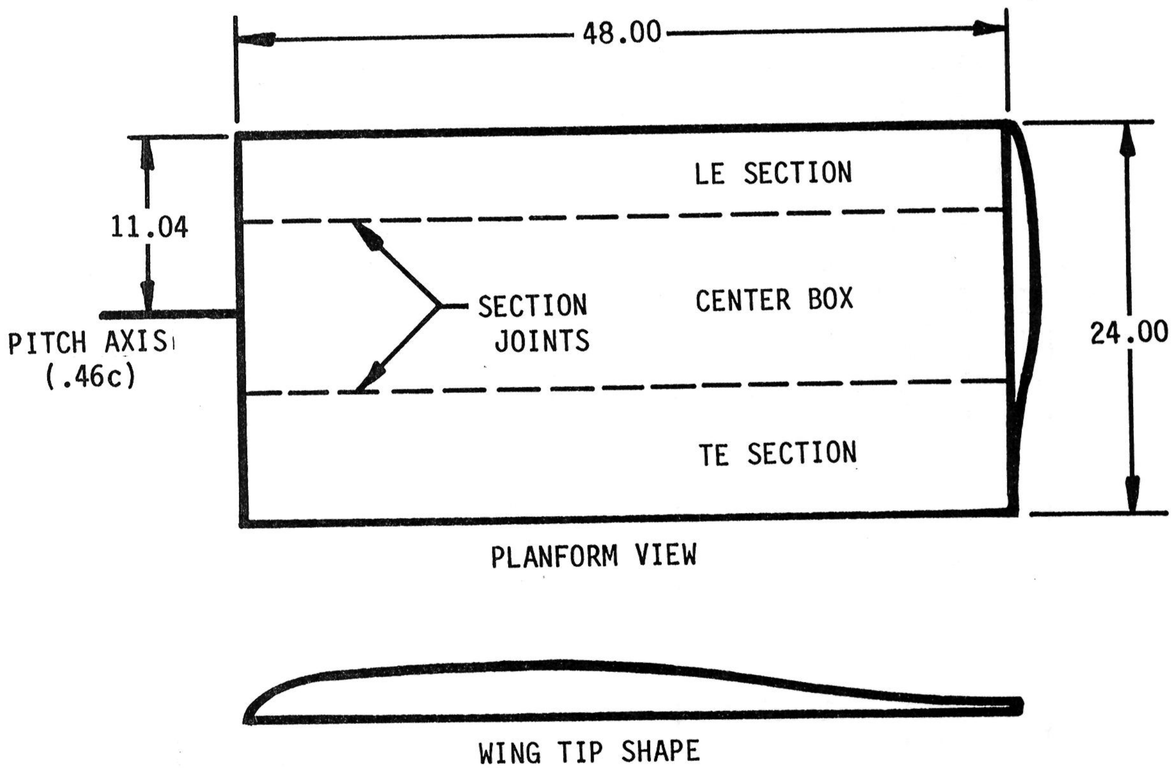


Figure 2.- Planform view of wing. Dimensions in inches.

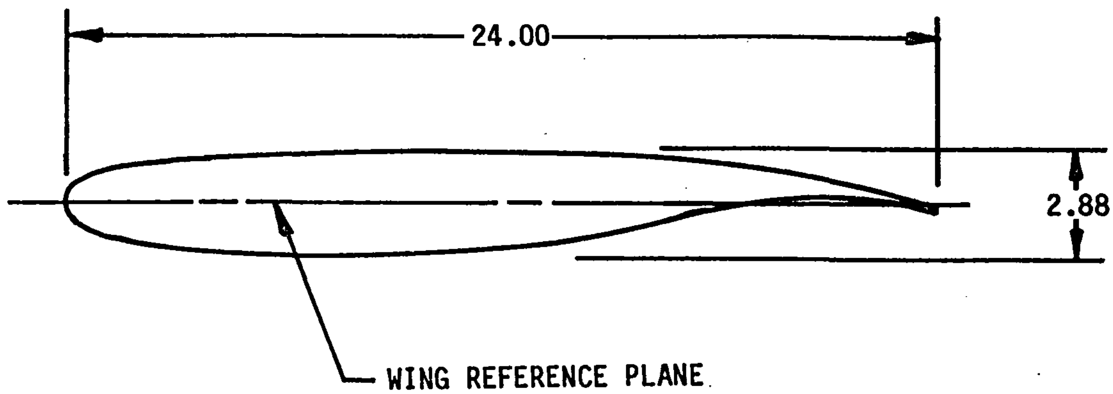
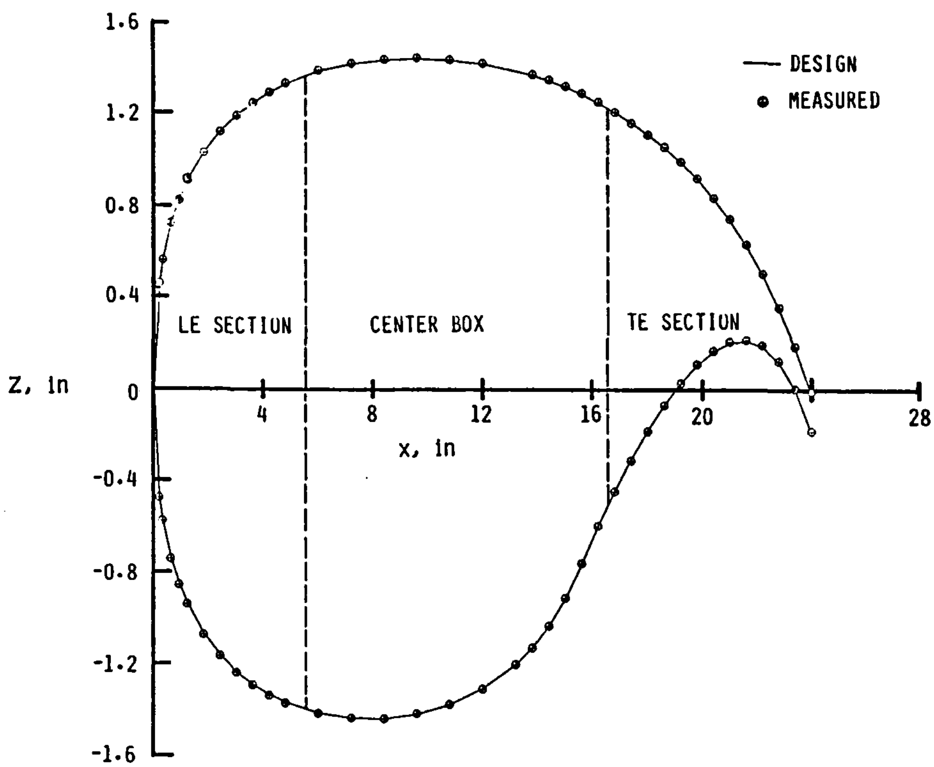
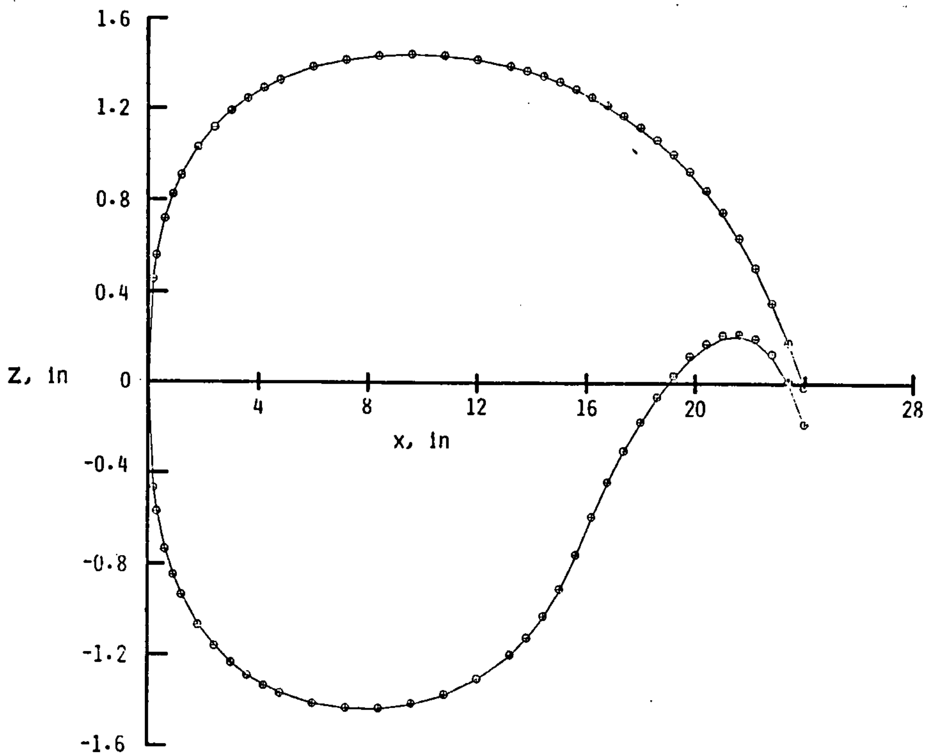


Figure 3.- Airfoil shape. Dimensions in inches.

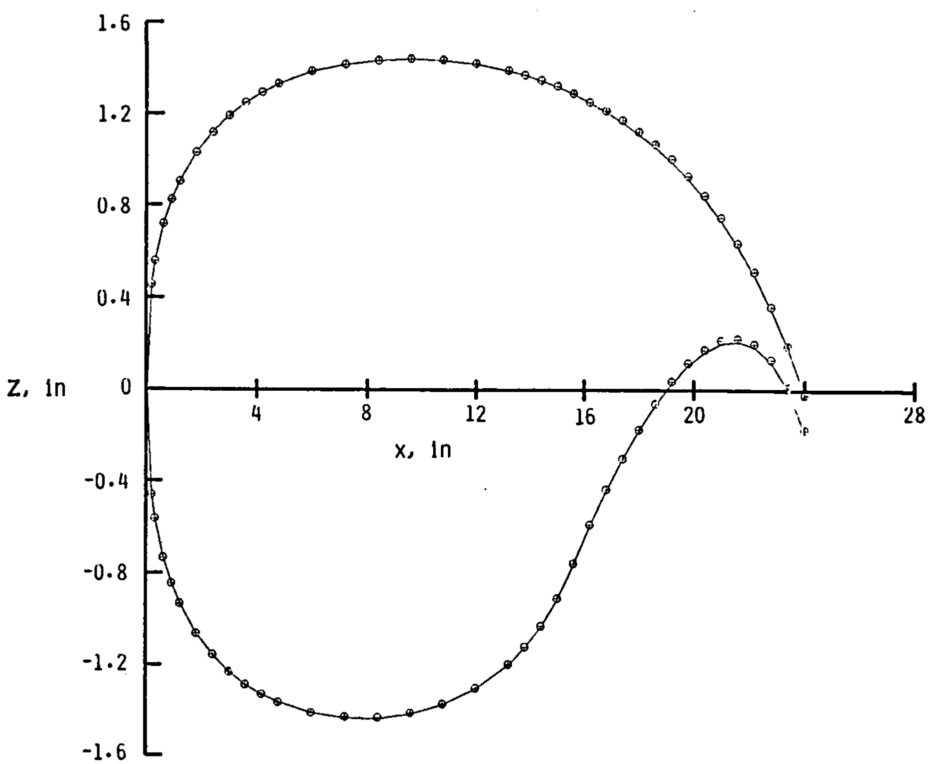


(a) Span station 1.000 in.

Figure 4.- Comparison of measured and design airfoil coordinates.

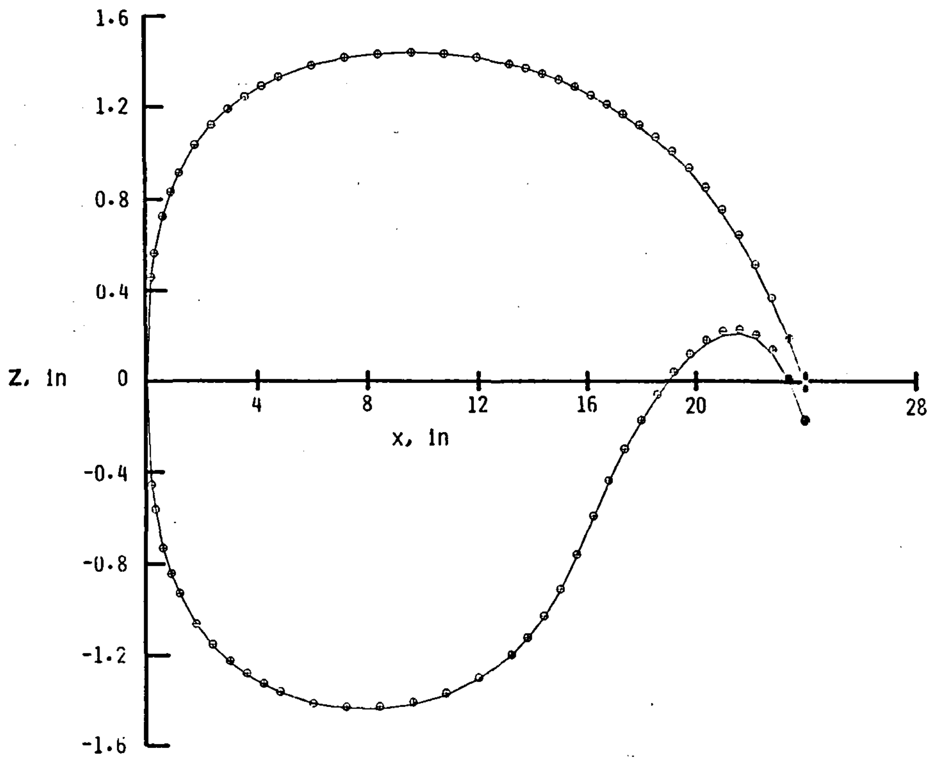


(b) Span station 14.932 in.

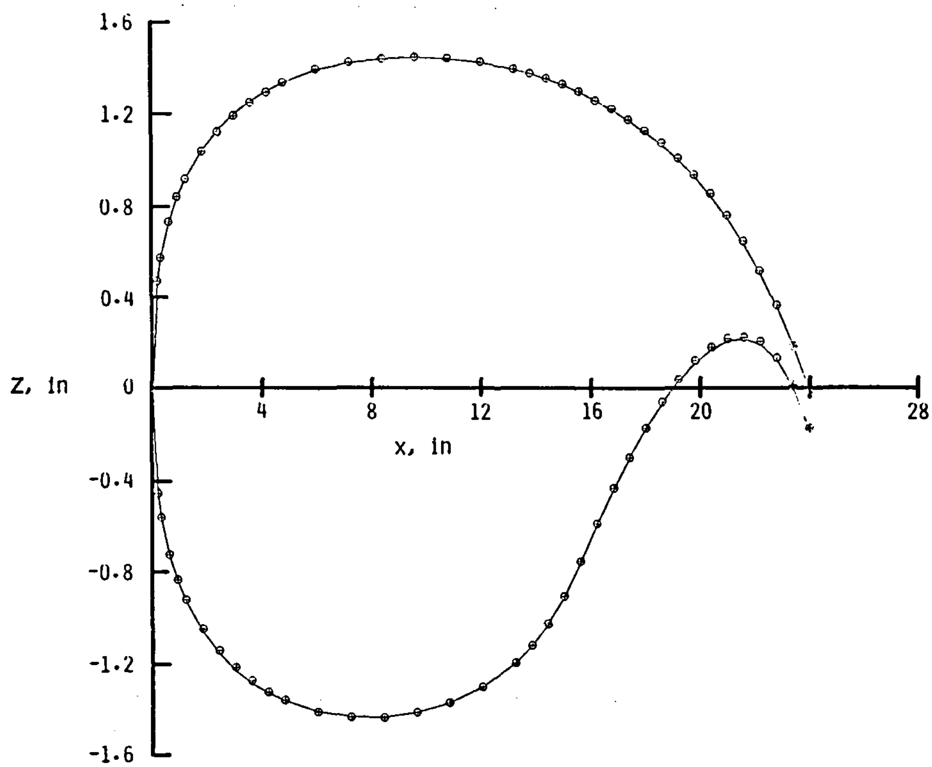


(c) Span station 28.324 in.

Figure 4.- Continued.



(d) Span station 38.932 in.



(e) Span station 45.948 in.

Figure 4.- Concluded.

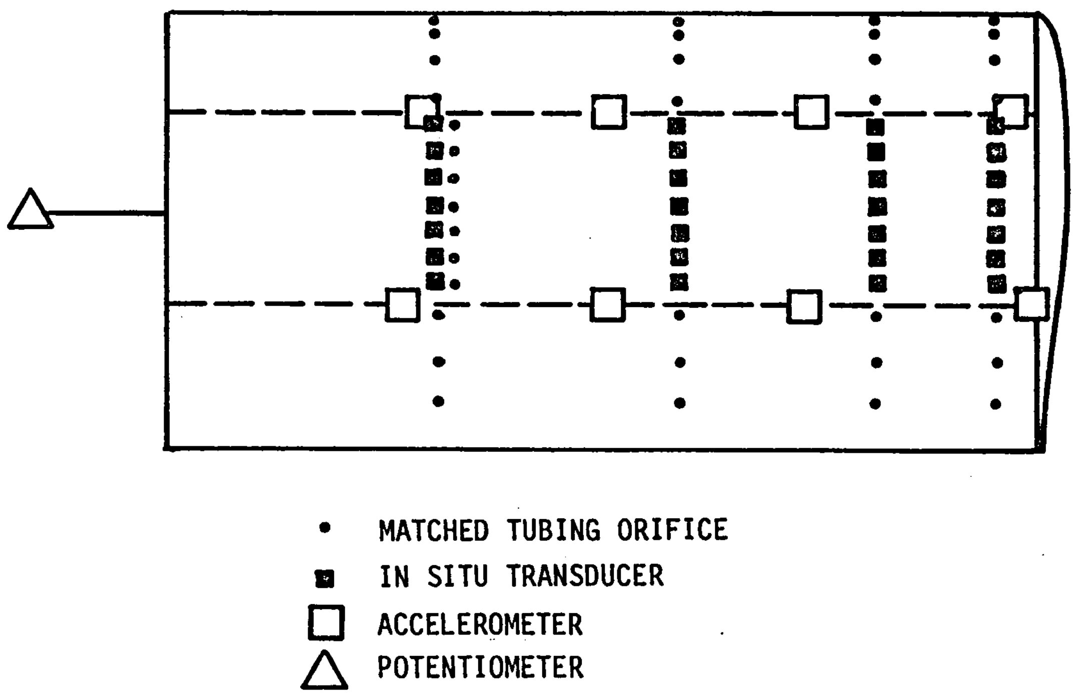


Figure 5.- Locations of instrumentation.

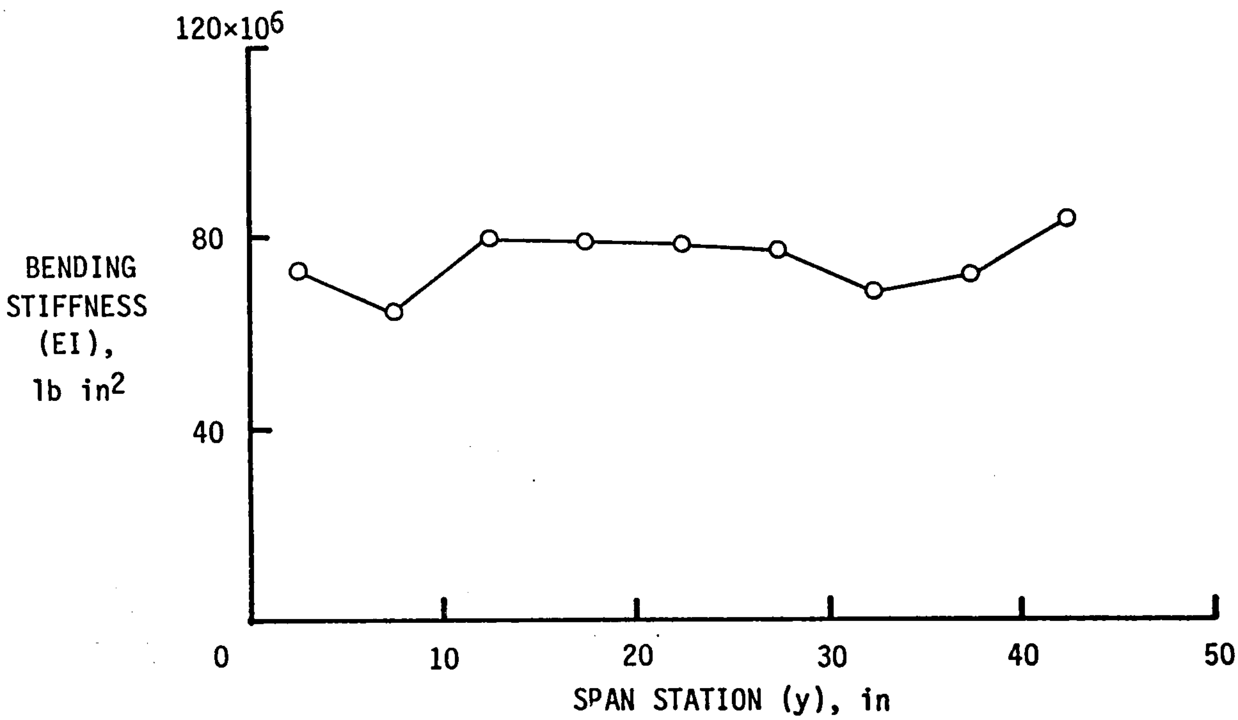


Figure 6.- Bending stiffness of wing.

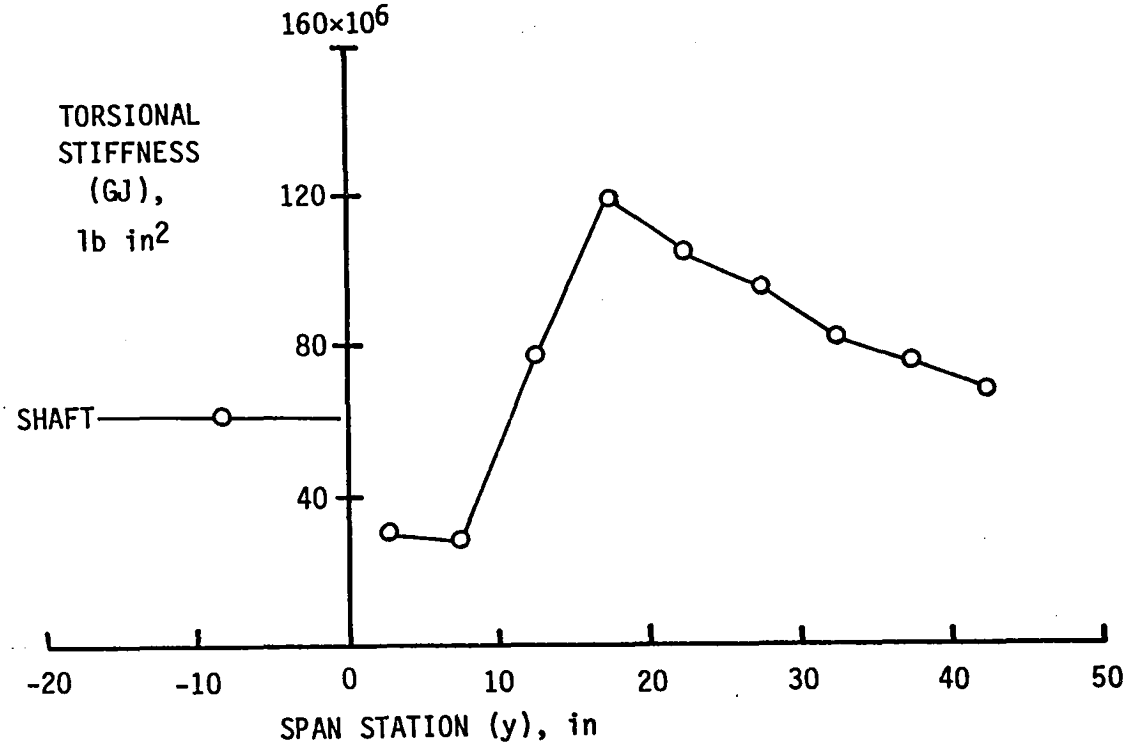


Figure 7.- Torsional stiffness of wing.

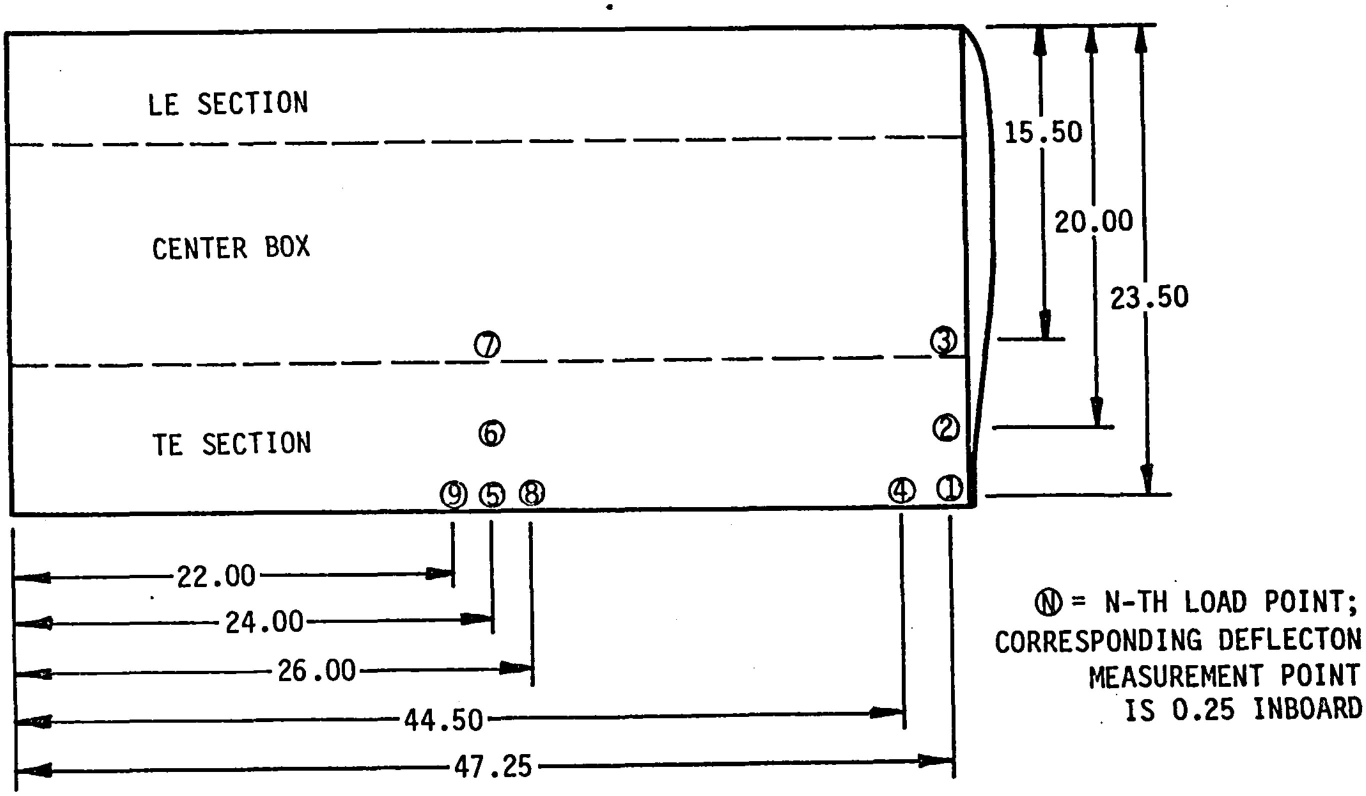
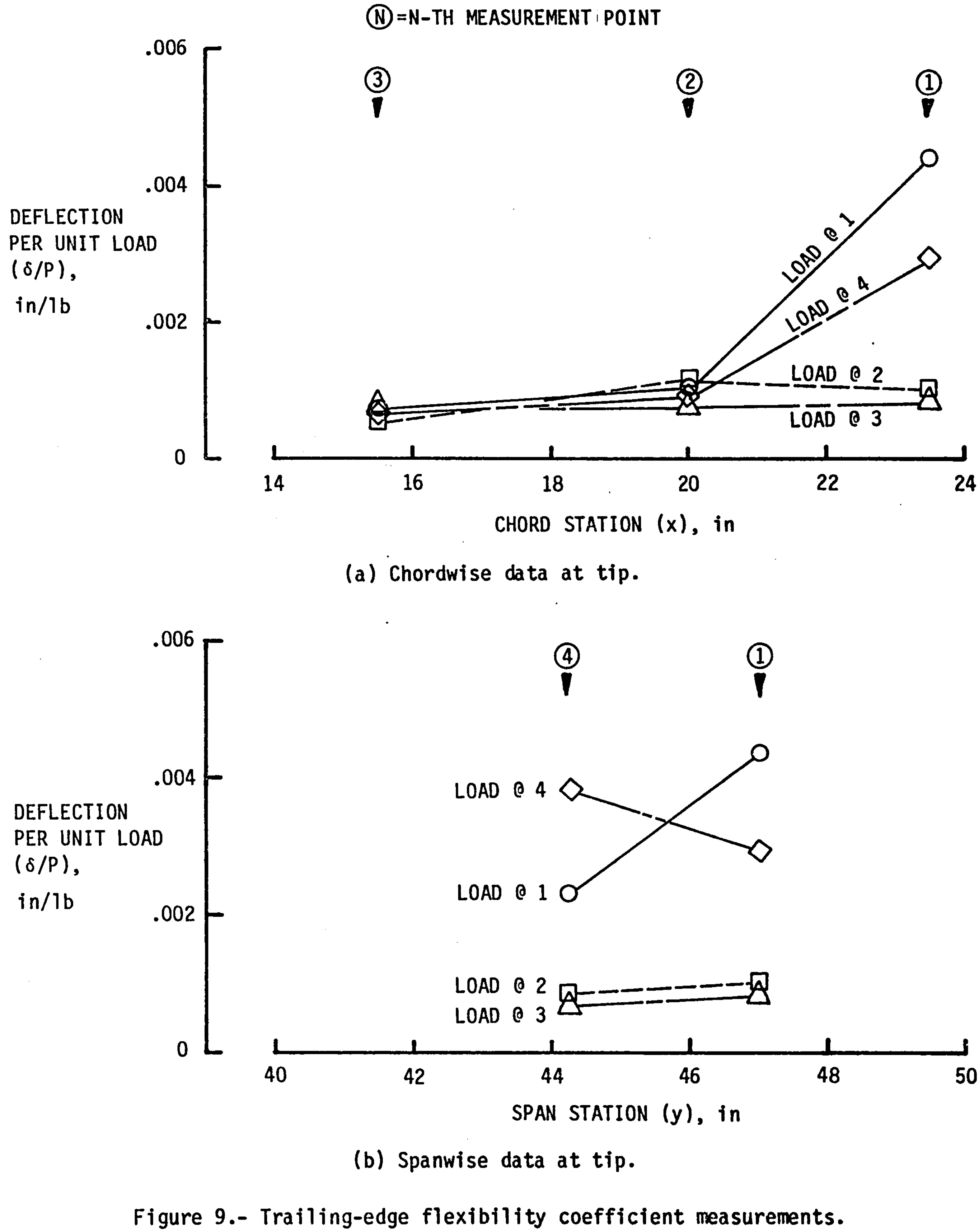


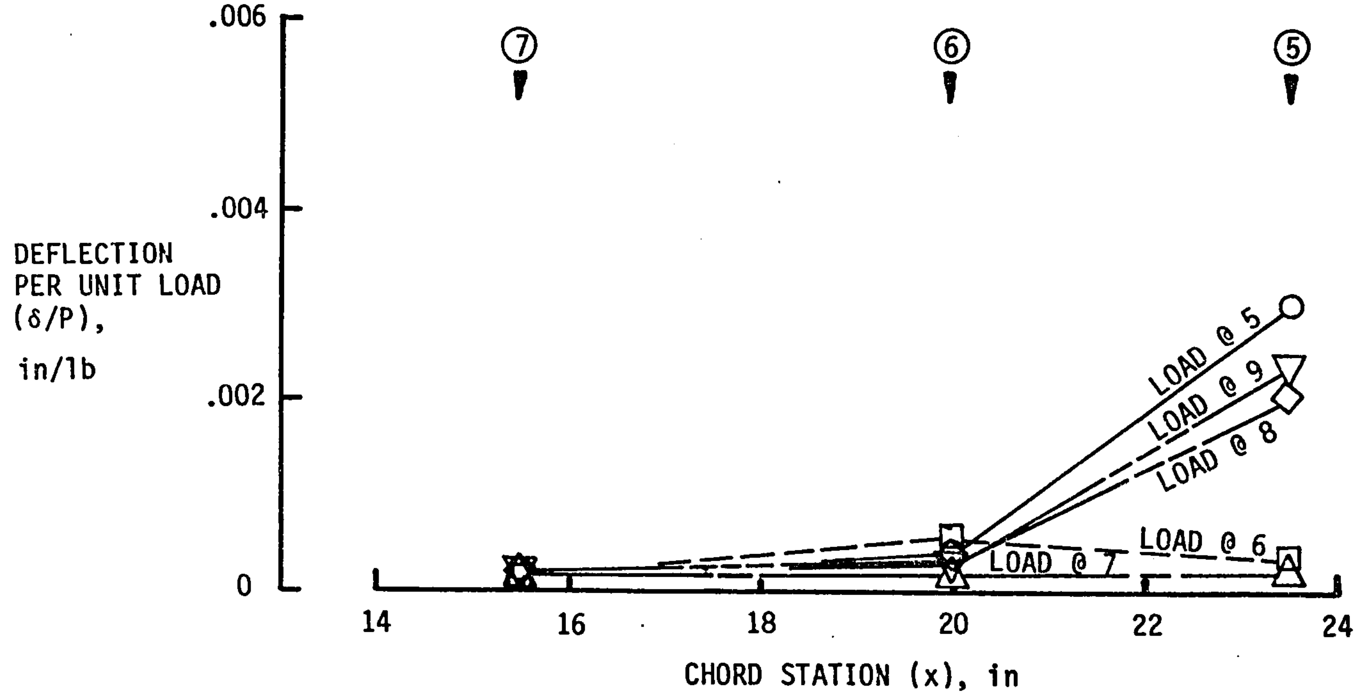
Figure 8.- Load/measurement locations for determination of trailing-edge flexibility. Dimensions in inches.



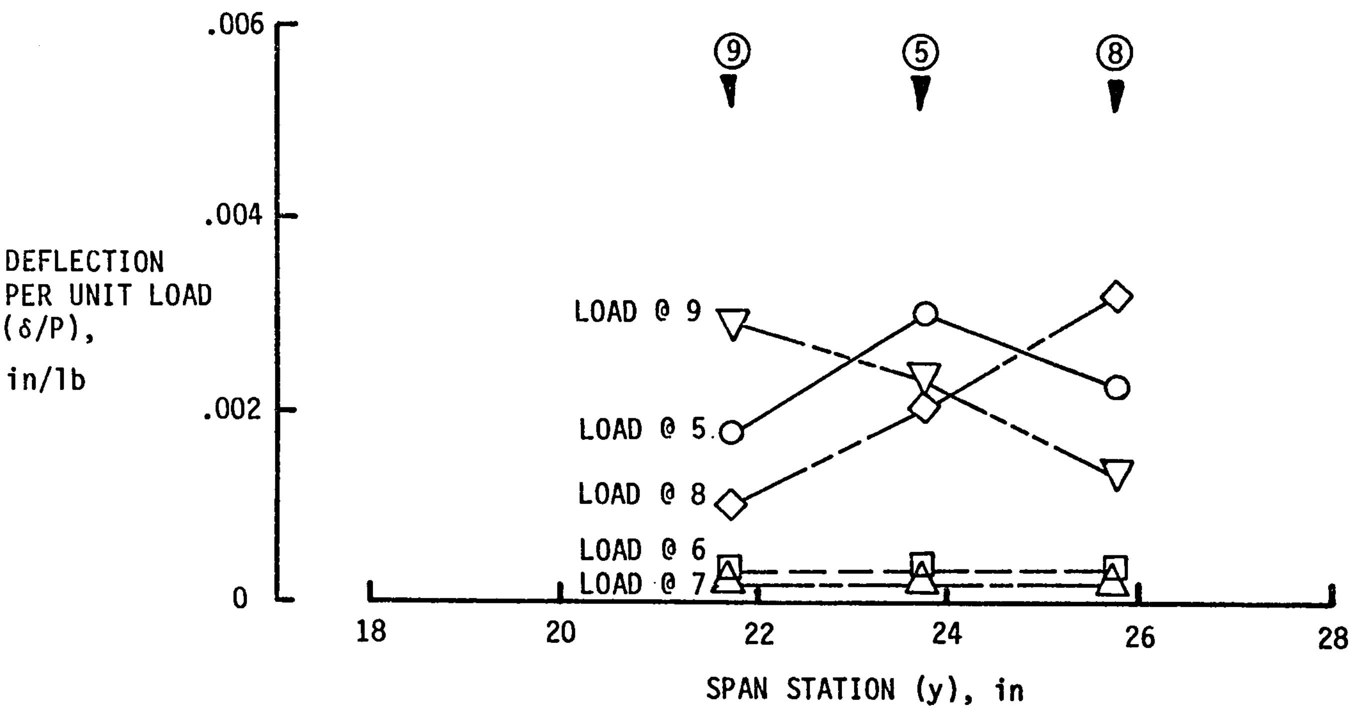
(a) Chordwise data at tip.

(b) Spanwise data at tip.

Figure 9.- Trailing-edge flexibility coefficient measurements.



(c) Chordwise data at mid span.



(d) Spanwise data at mid span.

Figure 9.- Concluded.

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15. Supplementary Notes

16. Abstract Wind-tunnel tests to measure unsteady aerodynamic data in the transonic region have been completed on an aspect ratio 2.0 rectangular wing with a supercritical airfoil. In this paper, the geometric and structural propertiesof the wing are presented. (Other references contain the measured aerodynamic data.) Both measured and design airfoil coordinates are presented and compared. In addition, measured wing bending and torsional stiffness distributions and some trailing-edge flexibility influence coefficients are presented.

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