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SERVICE REPORT

NASA

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Dated **

MEMORANDUM

for the

U. S. Air Force

HEAT-TRANSFER AND PRESSURE MEASUREMENTS FROM A FLIGHT TEST OF THE THIRD 1/18-SCALE MODEL OF THE TITAN INTERCONTINENTAL BALLISTIC MISSILE UP TO A MACH NUMBER OF 3.86 AND REYNOLDS NUMBER PER FOOT OF 23.5×10^6 AND A COMPARISON WITH HEAT TRANSFER OF TWO OTHER MODELS

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COORD. NO. AF-AM-70

[redacted]

By John B. Graham, Jr.

Langley Research Center
Langley Field, Va.

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NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

WASHINGTON

October 1958

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HEAT-TRANSFER AND PRESSURE MEASUREMENTS FROM A FLIGHT TEST OF THE THIRD 1/18-SCALE MODEL OF THE TITAN INTERCONTINENTAL BALLISTIC MISSILE UP TO A MACH NUMBER OF 3.86 AND REYNOLDS NUMBER PER FOOT OF 23.5×10^6 AND A COMPARISON WITH HEAT TRANSFER OF TWO OTHER MODELS*

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ABSTRACT

Heat-transfer and pressure measurements were obtained from a flight test of a 1/18-scale model of the Titan intercontinental ballistic missile up to a Mach number of 3.86 and Reynolds number per foot of 23.5×10^6 and are compared with the data of two previously tested 1/18-scale models. Boundary-layer transition was observed on the nose of the model. Van Driest's theory predicted heat-transfer coefficients reasonably well for the fully laminar flow but predictions made by Van Driest's theory for turbulent flow were considerably higher than the measurements when the skin was being heated. Comparison with the flight test of two similar models shows fair repeatability of the measurements for fully laminar or turbulent flow.

INDEX HEADINGS

Flow, Laminar	1.1.3.1
Flow, Turbulent	1.1.3.2
Heating, Aerodynamic	1.1.4.1
Heat Transfer, Aerodynamic	1.1.4.2
Missiles, Specific Types	1.7.2.2

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NATIONAL AERONAUTICS [redacted]PACE ADMINISTRATION

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U. S. Air Force

HEAT-TRANSFER AND PRESSURE MEASUREMENTS FROM A FLIGHT TEST OF THE THIRD 1/18-SCALE MODEL OF THE TITAN INTERCONTINENTAL BALLISTIC MISSILE UP TO A MACH NUMBER OF 3.86 AND REYNOLDS NUMBER PER FOOT OF 23.5×10^6 AND A COMPARISON WITH HEAT TRANSFER OF TWO OTHER MODELS*

COORD. NO. AF-AM-70

By John B. Graham, Jr.

SUMMARY

Heat-transfer and pressure measurements were obtained from a flight test of the third 1/18-scale model of the Titan intercontinental ballistic missile up to a Mach number of 3.86 and Reynolds number per foot of 23.5×10^6 and compared with the data of two previously tested 1/18-scale models. Boundary-layer transition was observed on the nose of the model. Van Driest's theory predicted heat-transfer coefficients reasonably well for the fully laminar flow, but predictions made by the Van Driest theory for turbulent flow were considerably higher than the measurements when the skin was being heated. Comparison with the flight test of two similar models shows fair repeatability of the measurements for fully laminar or turbulent flow.

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INTRODUCTION

Because of the several geometric transition regions on the first and second stages of the Titan intercontinental ballistic missile, local conditions and, consequently, heating are difficult to estimate. Heating on a vehicle of this type is critical because of the thin metal skin used to keep the weight to a minimum.

From available theories and empirical relationships, the heat transfer was estimated for the existing design. In order to establish the validity of these estimates, the U. S. Air Force has requested the National Advisory Committee for Aeronautics to conduct flight tests of three 1/18-scale models. The first of the series of scale models was a replica of the first and second stages of the full-scale Titan, with a hemispherical nose tip. The second model of the series differed from the first only in that it had a more blunt nose tip. The third model, discussed herein, was identical to the first model. These tests were conducted at the Mach numbers and Reynolds numbers approximately equal to those for which the full-scale Titan experiences maximum heating rates.

The flight models were designed and constructed by the airframe contractor, the Martin Company of Denver, Colorado. They were instrumented at the Langley Laboratory and flight tested at the Langley Pilotless Aircraft Research Station at Wallops Island, Virginia.

The results of the first flight test of the series are presented in reference 1, and the results of the second flight test were presented in reference 2. Presented herein are the results of the third flight test. The heat-transfer data are presented in the form of Stanton numbers reduced from measured wall temperatures and measured flight and wind-tunnel pressures. Comparison is made with the heat-transfer measurements from the first and second models of this series.

The Mach number range for which data were obtained was from 1.09 to 3.86 and the corresponding free-stream Reynolds number per foot ranged from 8.3×10^6 to 23.5×10^6.

SYMBOLS

A area, sq ft

[redacted]

C_f local skin-friction coefficient

[redacted]

[redacted]

c_p	specific heat of air at constant pressure, Btu/slug-$^{\circ}$R
$c_{p,w}$	specific heat of Inconel, Btu/lb-$^{\circ}$R
C_p	pressure coefficient, $\dfrac{p_l - p_\infty}{q_\infty}$
h	heat-transfer coefficient, Btu/sec-ft^2-$^{\circ}$R
H	altitude, ft
K	conductivity of air, Btu/sec-ft-$^{\circ}$R
l	distance along body from stagnation point, in.
M	Mach number
N_{Pr}	Prandtl number, $c_p\mu/K$
N_{St}	Stanton number, $h/c_p\rho V$
$P_1,P_2 \ldots P_7$	pressure stations
p	pressure, lb/sq in.
Q	quantity of heat, Btu
q	dynamic pressure, $0.7p_\infty M^2$, lb/sq in.
R	Reynolds number, $R_{\infty_l} = \rho V l/\mu$ and $R_l = \rho V l/\mu$
T	temperature, $^{\circ}$R
$T_1,T_2 \ldots T_{12}$	temperature stations
t	time, sec
V	velocity, ft/sec
x	distance measured longitudinally along surface from model station 0 (see fig. 2)
η_r	recovery factor, $\dfrac{T_{aw} - T_l}{T_s - T_l}$
ρ	density, slugs/cu ft

τ	thickness, ft
μ	viscosity of air, slugs/ft-sec
Θ	meridian angle, deg

Subscripts:

∞	free stream
l	outside boundary layer
w	pertaining to wall
aw	adiabatic wall
s	stagnation
1	based on length of 1 foot

MODEL

The model used for this test was a 1/18-scale model of the Titan intercontinental ballistic missile. Photographs of the test model are presented in figure 1 and a sketch of the complete model and nose detail, showing pressure pickups and thermocouple locations, is presented in figure 2. The outer skin of the model was constructed of 0.035-inch Inconel and hand polished to a surface roughness of 4 to 12 microinches (measured from peak to valley by interference microscope). The inner shell of the body, which acted as a radiation shield, was constructed of 0.050-inch-thick aluminum alloy. Metal-to-metal contact between the inner and outer bodies was eliminated by using three ceramic rings located at model stations 0, 8, and 17. The ceramic rings were thin and thus conduction was minimized.

The nose shape used in this test was the same as the nose used in reference 1. There were seven thermocouples and four pressure orifices on the nose, the positions being given in figure 2. With the exception of the stagnation pressure orifice, the pressure orifices are located diametrically opposite the corresponding temperature measuring stations. Also given in figure 2 is the skin thickness at each thermocouple location.

The cylinder-flare portion of the model was the same as used in references 1 and 2. There were three thermocouples and one pressure orifice on the cylinder and two thermocouples and two pressure orifices on the flare. The pressure orifices were located diametrically opposite the thermocouples. This portion of the model can also be seen in figure 2.

INSTRUMENTATION AND TEST

The model was instrumented with the NACA 10-channel telemeter. A single channel was used to transmit the skin temperatures from 12 thermocouples on the model. The commutation rate and the electronic system were such that each thermocouple measurement was sampled at about every 0.2 second. Three constant voltages were also commutated on the temperature channel. The constant voltages were chosen to be equivalent to the lowest, middle, and highest temperatures anticipated in flight and provide an in-flight calibration of the thermocouple telemetering system. The thermocouples were No. 30 chromel-alumel and were spot welded to the inner surface of the skin at the stations shown in figure 2(a).

The measured temperatures are believed to be within ±2 percent of the full-scale temperature range and have an accuracy of $\pm 22^{\circ}$ F.

Two telemeter channels were used to transmit normal and transverse accelerations. These measurements were made continuously during flight by a normal and a transverse accelerometer, each being calibrated, before flight, in gravitational units to cover ranges of ±5g. Seven channels were used to transmit continuous absolute pressures along the body. Each pressure channel was calibrated to cover the expected pressure range at that particular orifice. The instrument at pressure station P_1 was calibrated to cover a range from 0 to 265 pounds per square inch. The pressure instruments at stations P_2, P_3, and P_4 were calibrated to cover a range from 0 to 35 pounds per square inch. The pressure instruments on the cylinder and flare (stations P_5, P_6, and P_7) were calibrated to cover ranges from -10 to +10 pounds per square inch (cylinder) and 0 to 35 pounds per square inch (flare). The accuracy of the measured quantities is believed to be within ±2 percent of the full-scale range of the particular channel.

The model was launched at an elevation angle of 67° 17' with respect to the horizontal. The model was boosted by a Cajun rocket motor and was accelerated to a Mach number of 3.86 at an altitude of 4,800 feet. Atmospheric and wind conditions were measured by radiosonde balloons launched near the time of flight and tracked with a rawin set AN/GMD-1A. Velocity data were obtained by means of CW Doppler radar unit and the telemetered stagnation pressure measurements. Altitude and flight-path data were measured with an NACA modified SCR-584 space radar unit. Free-stream temperature, pressure, density, and altitude related to model

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flight time are shown in figure 3, and velocity, free-stream Mach number, and Reynolds number per foot are plotted against time in figure 4.

DATA REDUCTION

From flight records of the model, the following information was obtained: atmospheric properties and altitude (fig. 3); free-stream Mach number, Reynolds number, and velocity (fig. 4); pressure coefficients (fig. 5); and skin-temperature measurements (fig. 6).

The heat-transfer equation given in reference 3 for convection is

$$\frac{dQ}{dt} = h\left(T_{aw} - T_w\right)A$$

The time rate of change of heat contained in the skin is

$$\frac{dQ}{dt} = \left(\rho c_p \tau\right)_w \frac{dT_w}{dt} A$$

Since conduction and radiation heat-transfer rates are low enough to be neglected, the heat transferred to the skin by convection is equal to the quantity of heat contained in the skin

$$h\left(T_{aw} - T_w\right)A = \left(\rho c_p \tau\right)_w \frac{dT_w}{dt} A$$

Therefore

$$h = \frac{\left(\rho c_p \tau\right)_w}{T_{aw} - T_w} \frac{dT_w}{dt}$$

From the local convective heat-transfer coefficient, the Stanton number can be determined by

$$N_{St} = \frac{h}{\left(c_p \rho V\right)_l}$$

From measured wall temperatures, flight conditions and measured pressures, Stanton numbers were obtained by using

$$N_{St} = \frac{\left(c_p \rho \tau\right)_w}{T_{aw} - T_w} \frac{dT_w}{dt} \times \frac{1}{\left(c_p \rho V\right)_l}$$

The skin thickness τ_w was measured and the density ρ_w of Inconel was known. The specific heat of Inconel $c_{p,w}$ is given in reference 4 as a function of temperature.

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Skin temperatures and $\frac{dT_w}{dt}$ were obtained from faired curves of the skin-temperature measurements. The adiabatic wall temperature T_{aw} was computed from the relation

$$T_{aw} = \eta_r\left(T_s - T_l\right) + T_l$$

where the recovery factor η_r was determined from the usual turbulent relation $\eta_r = N_{Pr}^{1/3}$ with the Prandtl number evaluated at the wall temperature. The turbulent value was used since the data indicate that the boundary layer was turbulent over most of the body.

The local conditions for the test model were obtained by using the local pressure measurements and making the assumption that all the flow adjacent to the boundary layer had gone through the normal bow shock. The total-pressure losses for the normal shock were taken from reference 5. It is possible that this assumption is not correct for points on the rear of the body and this may account for some of the differences between the measured and theoretical values shown. The total-pressure losses through the flare shock were neglected.

Tabulated values of the pertinent quantities are given in table I for all thermocouple locations.

RESULTS AND DISCUSSION

Pressure Measurements

The pressure measurements on the body are shown in figure 5 expressed as pressure coefficients and are plotted as a function of free-stream Mach number for both the accelerating and decelerating periods of flight. Also presented in figure 5 are some unpublished wind-tunnel pressure coefficients at various Mach numbers for the same configuration as the free-flight model, and pressure coefficients from references 1 and 2. The wind-tunnel pressure coefficients were obtained from tests conducted in the Langley Unitary Plan wind tunnel for the Martin Company on a 1/25-scale model of the Titan.

In figure 5(a) are shown the pressure coefficients (designated C_{p2}, C_{p3}, and C_{p4}) obtained from measurements made at pressure orifice stations P_2, P_3, and P_4, respectively, located on the nose conical section. The data for stations P_3 and P_4 are in good agreement with both the wind-tunnel data and the data of reference 1 above a Mach number of 2. The data for station P_2 during the deceleration period of flight is in good agreement with wind-tunnel data and reference 1; however, during the acceleration period of flight it is somewhat lower. Pressure lag was computed and was found to be negligible and at the present no reasonable explanation has been determined for this difference. It should

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theory, calculated by using 0.5 instead of 0.6 as the Reynolds analogy constant, shows that the wall-heating data tend toward the 0.5 constant rather than toward the 0.6 constant favored by the wall-cooling data. The differences in the heating and cooling conditions do not offer an explanation as to why the Reynolds analogy factor should change and at this time the reason is not known.

In general, the data of the three models substantiate each other. Where there are apparently large differences, these can be attributed to slightly different time histories of boundary-layer transition. The principal difference in the data of reference 2 and that of reference 1 and the third model which is reported herein is the presence of turbulent flow on the nose of the model of reference 2 under conditions that gave laminar or transitional flow on the other two models. This difference seems to be the result of the blunter nose shape used on the model of reference 2.

CONCLUDING REMARKS

Flight tests have been made of three 1/18-scale models of the Titan intercontinental ballistic missile. In the flight test of the model reported herein and the two models previously tested laminar or transitional boundary-layer heating rates were observed on the model 1 and model 3 nose shape, whereas turbulent flow rates were observed over the model 2 nose shape. The boundary layer over the cylinder and flare portion of all three models appeared to be fully turbulent throughout flight.

During the wall-heating portion of the flights, the heat-transfer data were considerably lower than Van Driest s theory when a Stanton number equal to 0.6 the skin-friction coefficient was used; however, when Stanton number equal to 0.5 the skin-friction coefficient was used, the data were in much better agreement with theory. During the wall-cooling portions of the flights, the data agreed much better with theory when a Stanton number equal to 0.6 the skin-friction coefficient was used. For all flights, Van Driest's laminar theory was in good agreement with the measured data when the flow was fully laminar.

Langley Research Center,
National Aeronautics and Space Administration,
Langley Field, Va., September 12, 1958.

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HEAT-TRANSFER AND PRESSURE MEASUREMENTS FROM

A FLIGHT TEST OF THE THIRD 1/18-SCALE MODEL OF THE TITAN

INTERCONTINENTAL BALLISTIC MISSILE UP TO A MACH NUMBER

OF 3.86 AND REYNOLDS NUMBER PER FOOT OF

23.5×10^6 AND A COMPARISON WITH HEAT

TRANSFER OF TWO OTHER MODELS

COORD. NO. AF-AM-70

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Chief of Pilotless Aircraft Research Division
Langley Research Center

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(9-12-58)

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TABLE I.- TEST DATA

(a) Thermocouple 1

t	M_∞	M_l	T_l	T_w	$\frac{dT_w}{dt}$	h	$\rho c_p V$	N_{St}	R_l
1.0	1.09			521.0	14.95				
1.2	1.32			527.0	31.34				
1.4	1.58			535.0	45.78				
1.6	1.86	1.19	687	546.5	61.04	0.029546	42.027	7.03×10^{-4}	2.242×10^6
1.8	2.18	1.30	753	561.0	71.59	.026198	50.341	5.20	2.504
2.0	2.51	1.37	851	576.5	84.51	.023330	58.344	4.00	2.641
2.1	2.66	1.39	914	585.0	87.50	.020988	61.568	3.41	2.632
2.2	2.81	1.41	983	595.0	90.36	.019017	65.031	2.92	2.619
2.3	2.97	1.44	1,053	604.5	100.50	.018740	69.001	2.72	2.636
2.4	3.15	1.45	1,128	615.0	115.04	.019225	72.058	2.67	2.613
2.5	3.33	1.50	1,188	628.0	127.50	.019352	76.600	2.53	2.670
2.6	3.50	1.52	1,255	642.0	153.99	.021514	79.788	2.70	2.663
2.7	3.65	1.53	1,309	660.0	166.50	.022032	82.929	2.66	2.672
2.8	3.77	1.53	1,376	677.0	197.97	.024698	85.404	2.89	2.645
2.9	3.89	1.53	1,411	700.0	250.00	.030756	87.261	3.52	2.652
3.0	3.86	1.53	1,419	731.0	321.06	.040404	88.168	4.58	2.666
3.1	3.84	1.53	1,396	768.5	457.5	.061515	87.557	7.03	2.684
3.2	3.79	1.53	1,354	829.0	802.85	.121906	86.605	14.08	2.715
3.4	3.67	1.52	1,287	1,000.0	544.86	.114738	84.043	13.65	2.747
3.6	3.52	1.52	1,223	1,076.5	274.75	.074157	81.117	9.14	2.766
3.8	3.36	1.50	1,164	1,111.0	109.90	.037107	78.269	4.74	2.770
4.0	3.22	1.48	1,112	1,123.0	41.63	.017428	75.544	2.31	2.771
4.4	2.96	1.43	1,020	1,130.0	11.75	.007976	69.545	1.15	2.729
4.8	2.74	1.40	932	1,132.5	1.92	.002736	63.957	.43	2.690
5.2	2.55	1.38	858	1,132.5	-2.62	--------	59.406	-----	2.673
5.6	2.38	1.35	800	1,130.5	-6.47	.015108	55.397	2.73	2.628
6.0	2.24	1.32	748	1,127.5	-10.16	.011697	50.963	2.30	2.552
6.4	2.10	1.28	700	1,122.5	-12.99	.010316	49.694	2.08	2.615
6.8	1.98	1.24	666	1,116.0	-17.45	.011199	46.484	2.41	2.538
7.2	1.87	1.19	638	1,110.0	-20.89	.011604	43.972	2.64	2.481
7.6	1.77	1.40	617	1,099.5	-26.61	.013549	41.168	3.29	2.380
8.0	1.68	1.08	603	1,087.5	-34.43	.016508	38.064	4.34	2.243

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TABLE I.- TEST DATA - Continued

(b) Thermocouple 2

t	M_∞	M_l	T_l	T_w	$\frac{dT_w}{dt}$	h	$\rho c_p V$	N_{St}	R_l
1.0	1.09	1.43	458	518.5	13.98	0.02258	17.64	12.77×10^{-4}	1.988×10^6
1.2	1.32	1.48	490	525.5	25.11	.031059	22.08	14.08	2.346
1.4	1.58	1.57	524	534.0	43.13	.037851	26.51	14.28	2.673
1.6	1.86	1.66	569	544.0	62.50	.035637	30.62	11.64	2.901
1.8	2.18	1.76	622	557.0	70.07	.029786	34.41	8.66	3.046
2.0	2.51	1.87	688	569.0	72.12	.023025	37.71	6.11	3.090
2.1	2.66	1.92	730	576.5	72.50	.020071	39.17	5.12	3.065
2.2	2.81	1.96	778	584.0	73.73	.017842	40.69	4.38	3.028
2.3	2.97	2.00	827	591.5	73.90	.015541	42.39	3.74	3.009
2.4	3.15	2.02	881	598.5	76.40	.014619	43.92	3.33	2.967
2.5	3.33	2.05	933	607.0	77.50	.013390	45.92	2.92	2.965
2.6	3.50	2.07	985	616.5	83.41	.013527	48.37	2.80	2.989
2.7	3.65	2.10	1,020	627.0	97.75	.011591	50.43	2.50	3.034
2.8	3.77	2.13	1,059	639.0	112.24	.015721	52.41	3.00	3.061
2.9	3.84	2.14	1,081	655.5	155.50	.021344	54.27	3.93	3.127
3.0	3.86	2.12	1,097	679.0	205.94	.028685	55.21	5.20	3.139
3.1	3.84	2.11	1,084	712.0	275.25	.040805	55.99	7.29	3.215
3.2	3.79	2.10	1,056	727.5	355.20	.062576	55.58	11.26	3.258
3.4	3.67	2.08	1,009	833.5	407.13	.080418	52.74	15.25	3.197
3.6	3.52	2.06	966	907.5	277.76	.067784	48.88	13.87	3.064
3.8	3.36	2.05	919	945.5	83.91	.024543	44.78	5.48	2.922
4.0	3.22	2.04	873	959.5	40.00	.013897	41.93	3.31	2.849
4.4	2.96	2.00	799	970.0	20.89	.010300	37.73	2.73	2.754
4.8	2.74	1.95	738	973.0	17.27	.013193	34.20	3.86	2.653
5.2	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	.032785	30.85	7.59	2.532
5.6	2.38	1.86	644	990.5	12.46	.052438	28.23	18.58	2.429
6.0	2.24	1.81	608	995.0	5.93	--------	26.06	-----	2.336
6.4	2.10	1.77	572	997.0	5.24	--------	24.38	-----	2.297
6.8	1.98	1.73	543	998.0	-1.40	.001606	22.69	.71	2.223
7.2	1.87	1.69	521	997.5	-6.47	.005808	21.24	2.73	2.148
7.6	1.77	1.65	502	994.5	-15.30	.011764	19.83	5.93	2.072
8.0	1.68	1.61	489	990.0	-23.46	.016275	18.38	8.56	1.953
8.5	1.58	1.57	474	980.0	-33.75	.021742	16.82	12.93	1.839
9.0	1.49	1.55	459	967.5	-34.43	.020987	15.50	13.54	1.746
9.5	1.40	1.53	445	882.5	-33.20	.023856	14.26	16.73	1.646
10.0	1.33	1.50	435	851.5	-33.50	.025695	12.99	19.78	1.523
11.0	1.20	1.45	417	827.0	-31.15	.022720	11.15	20.38	1.352
12.0	1.09	1.42	403	819.0	-31.50	.021515	10.09	21.52	1.265
13.0	1.00	1.39	394	814.0	-31.91	.020714	9.23	22.44	1.177
14.0	.93	1.36	387	805.0	-31.50	.020045	8.55	23.44	1.105

TABLE I.- TEST DATA - Continued

(c) Thermocouple 3

t	M_∞	M_l	T_l	T_w	$\frac{dT_w}{dt}$	h	$\rho c_p V$	N_{St}	R_l
1.0	1.09	1.06	527	521.5	20.5	0.029698	19.94	14.89×10^{-4}	2.73×10^{6}
1.2	1.32	1.26	535	526.0	33.5	.033545	24.48	13.70	3.31
1.4	1.58	1.41	560	534.5	51.0	.036781	28.90	12.73	3.76
1.6	1.86	1.55	596	546.0	65.0	.026628	33.12	8.04	4.11
1.8	2.18	1.67	647	560.5	70.0	.027864	36.61	7.61	4.28
2.0	2.51	1.79	713	573.5	73.0	.021803	40.06	5.44	4.36
2.1	2.66	1.85	753	581.0	73.0	.018938	41.77	4.53	4.37
2.2	2.81	1.89	802	588.0	74.0	.016746	43.06	3.89	4.28
2.3	2.97	1.93	881	596.0	75.5	.015053	44.54	3.38	4.22
2.4	3.15	1.97	901	603.5	78.0	.013958	46.05	3.03	4.17
2.5	3.33	2.01	950	611.0	83.5	.013487	47.78	2.82	4.15
2.6	3.50	2.04	999	619.5	91.0	.013449	49.55	2.71	4.14
2.7	3.65	2.07	1,034	627.5	105.0	.014576	51.57	2.83	4.19
2.8	3.77	2.10	1,073	638.0	130.0	.016931	53.64	3.16	4.24
2.9	3.84	2.11	1,096	652.5	160.0	.020393	54.96	3.71	4.28
3.0	3.86	2.12	1,097	671.5	225.0	.028984	55.66	5.21	4.33
3.1	3.84	2.12	1,080	690.0	325.0	.043823	55.37	7.91	4.36
3.2	3.79	2.11	1,052	732.0	380.0	.056338	54.43	10.35	4.37
3.4	3.67	2.09	1,004	810.0	400.0	.071658	51.89	13.81	4.32
3.6	3.52	2.06	966	885.0	260.0	.057191	48.77	11.73	4.18
3.8	3.36	2.05	919	911.5	77.5	.020032	46.09	4.35	4.11
4.0	3.22	2.01	885	921.5	40.0	.012029	42.91	2.80	3.94
4.4	2.96	1.98	806	931.0	22.5	.009320	38.13	2.44	3.78
4.8	2.74	1.93	745	938.0	18.0	.010907	34.41	3.17	3.62
5.2	2.55	1.87	695	945.0	16.5	.016662	31.49	5.29	3.50
5.6	2.38	1.82	656	950.5	12.5	.025731	29.07	8.85	3.37
6.0	2.24	1.77	618	955.0	10.0	.437163	27.08	-----	3.28
6.4	2.10	1.72	584	956.5	4.0	--------	25.32	-----	3.20
6.8	1.98	1.66	560	956.5	-2.0	.002852	23.64	1.21	3.08
7.2	1.87	1.61	539	955.5	-5.5	.005755	22.25	2.59	2.99
7.6	1.77	1.56	522	951.0	-15.5	.013495	20.98	6.43	2.84
8.0	1.68	1.51	510	942.0	-25.5	.019987	19.57	10.21	2.66
8.5	1.58	1.45	498	927.5	-33.0	.024010	17.99	13.35	2.49
9.0	1.49	1.41	486	909.5	-33.0	.023060	16.75	13.77	2.37
9.5	1.40	1.37	476	892.5	-31.0	.021083	15.57	13.54	2.24
10.0	1.33	1.32	467	876.0	-31.0	.020560	14.34	14.34	2.09
11.0	1.20	1.22	456	845.0	-31.0	.020121	12.40	16.23	1.84
12.0	1.09	1.15	448	812.5	-31.0	.020657	11.07	18.66	1.67
13.0	1.00	.96	461	780.5	-31.0	.021817	10.21	21.37	1.50
14.0	.93	.95	449	748.5	-31.0	.023190	9.21	25.18	1.38

TABLE I.- TEST DATA - Continued

(d) Thermocouple 4

t	M_∞	M_l	T_l	T_w	$\frac{dT_w}{dt}$	h	$\rho c_p V$	N_{St}	R_l
1.0	1.09	1.00	537	523.0	20.50	0.03282	20.015	16.4×10^{-4}	3.41731×10^{6}
1.2	1.32	1.19	549	528.0	31.80	.03505	25.097	14.0	4.20651
1.4	1.58	1.36	571	535.0	45.90	.03621	29.669	12.2	4.84702
1.6	1.86	1.51	606	545.0	57.60	.03322	33.585	9.9	5.22950
1.8	2.18	1.65	653	558.0	66.50	.02874	37.033	7.8	5.47065
2.0	2.51	1.79	713	572.0	70.70	.02309	40.424	5.7	5.62096
2.1	2.66	1.85	753	579.0	72.00	.02043	41.805	4.9	5.54088
2.2	2.81	1.90	798	586.0	73.50	.01827	42.948	4.3	5.40996
2.3	7.97	1.95	843	594.0	75.10	.01644	44.867	3.7	5.34742
2.4	3.15	1.99	893	601.0	77.10	.01512	45.270	3.3	5.20484
2.5	3.33	2.04	937	609.0	80.80	.01432	46.799	3.1	5.20726
2.6	3.50	2.07	985	617.0	86.40	.01402	48.049	2.9	5.18044
2.7	3.65	2.12	1,011	628.0	95.50	.01462	49.923	2.9	5.24459
2.8	3.77	2.15	1,050	638.0	108.00	.01551	51.121	3.0	5.20446
2.9	3.84	2.17	1,067	650.0	122.00	.01709	52.209	3.3	5.23044
3.0	3.86	2.17	1,073	665.0	141.50	.01997	52.567	3.8	5.32144
3.1	3.84	2.17	1,056	682.0	167.00	.02458	52.380	4.7	5.31304
3.2	3.79	2.17	1,024	700.0	225.00	.03545	51.913	6.8	5.38910
3.4	3.67	2.15	978	748.0	310.00	.05664	49.662	11.4	5.33147
3.6	3.52	2.11	945	830.0	450.00	.09966	46.545	21.4	5.15463
3.8	3.36	2.10	899	886.0	152.00	.04153	44.645	9.3	5.12897
4.0	3.22	2.05	869	905.0	48.90	.01561	41.609	3.8	4.91049
4.4	2.96	1.99	802	917.0	24.40	.01063	37.487	2.8	4.73151
4.8	2.74	1.91	752	924.0	15.50	.00963	33.655	2.9	4.47506
5.2	2.55	1.87	695	929.0	9.50	.00963	31.592	3.1	4.36850
5.6	2.38	1.86	644	931.0	6.50	.01196	29.969	4.0	4.46913
6.0	2.24	1.76	621	938.0	4.20	.03820	27.077	14.1	4.14733
6.4	2.10	1.70	589	935.0	.08	-.00032	25.358	----	4.03828
6.8	1.98	1.65	562	934.0	-3.20	.00598	23.918	2.5	3.96648
7.2	1.87	1.60	541	931.0	-7.90	.01046	22.637	4.6	3.85493
7.6	1.77	1.55	524	927.0	-14.80	.01595	21.333	7.5	3.71123
8.0	1.68	1.49	514	917.0	-29.80	.02874	19.887	14.5	3.51585
8.5	1.58	1.42	505	900.0	-32.00	.02824	18.306	15.4	3.29107
9.0	1.49	1.37	494	885.0	-29.20	.02874	17.066	16.8	3.09330
9.5	1.40	1.32	485	870.0	-27.10	.02209	15.939	13.9	5.83135
10.0	1.33	1.26	478	857.0	-26.80	.02107	14.667	14.4	2.74970
11.0	1.20	1.14	470	832.0	-26.00	.01943	12.677	15.3	2.41190
12.0	1.09	1.01	468	806.0	-24.90	.01877	11.379	16.5	2.17798
13.0	1.00	.99	457	783.0	-22.50	.01711	10.281	16.6	2.00360
14.0	.93	.99	443	761.0	-21.00	.01628	9.248	17.6	1.85725
15.0	.88	.98	432	740.0	-22.6	.01794	8.671	20.7	1.77932

[redacted]

TABLE I.- TEST DATA - Continued

(e) Thermocouple 5

t	M_∞	M_l	T_l	T_w	$\frac{dT_w}{dt}$	h	$\rho c_p V$	N_{St}	R_l
1.0	1.09	1.00	537	521.0	20.50	0.03180	20.015	15.9×10^{-4}	3.41731×10^{6}
1.2	1.32	1.19	549	525.0	30.40	.03253	25.097	13.0	4.20651
1.4	1.58	1.36	571	533.0	45.00	.03480	29.669	11.7	4.84702
1.6	1.86	1.51	606	544.0	67.80	.03862	33.585	11.5	5.22950
1.8	2.18	1.65	653	560.0	113.00	.04873	37.033	13.2	5.47065
2.0	2.51	1.79	713	585.0	142.20	.04738	40.424	11.7	5.62096
2.1	2.66	1.85	753	600.0	154.00	.04505	41.805	10.8	5.54088
2.2	2.81	1.90	798	620.0	188.00	.04892	42.948	11.4	5.40996
2.3	2.97	1.95	843	637.0	217.00	.05048	44.867	11.3	5.34742
2.4	3.15	1.99	893	660.0	248.00	.05235	45.270	11.6	5.20484
2.5	3.33	2.04	937	685.0	278.00	.05385	46.799	11.5	5.20726
2.6	3.50	2.07	985	714.0	308.00	.05567	48.049	11.6	5.18044
2.7	3.65	2.12	1,011	743.0	338.00	.05855	49.923	11.7	5.24459
2.8	3.77	2.15	1,050	776.0	367.00	.06074	51.121	11.9	5.20446
2.9	3.84	2.17	1,067	815.0	379.00	.06290	52.209	12.0	5.23044
3.0	3.86	2.17	1,073	855.0	381.00	.06554	52.567	12.5	5.32144
3.1	3.84	2.17	1,056	891.0	360.00	.06659	52.380	12.7	5.31304
3.2	3.79	2.17	1,024	924.0	323.00	.06585	51.913	12.7	5.38910
3.4	3.67	2.15	978	980.0	262.00	.06471	49.662	13.0	5.33147
3.6	3.52	2.11	945	1,027.0	220.00	.06614	46.545	14.2	5.15463
3.8	3.36	2.10	899	1,052.0	64.50	.02354	44.645	5.2	5.12897
4.0	3.22	2.05	869	1,060.0	36.00	.01587	41.609	3.8	4.91049
4.4	2.96	1.99	802	1,069.0	15.50	.01057	37.487	2.8	4.73151
4.8	2.74	1.91	752	1,073.0	8.80	.01091	33.655	3.2	4.47506
5.2	2.55	1.87	695	1,075.0	5.00	.02110	31.392	6.7	4.36850
5.6	2.38	1.86	644	1,075.0	1.20	-.00615	29.969	-2.1	4.46913
6.0	2.24	1.76	621	1,075.0	-3.00	.00518	27.077	1.9	4.14733
6.4	2.10	1.70	589	1,074.0	-9.00	.00969	25.358	3.8	4.03828
6.8	1.98	1.65	562	1,068.0	-17.80	.01496	23.918	6.3	3.96648
7.2	1.87	1.60	541	1,059.0	-29.50	.02139	22.637	9.4	3.85493
7.6	1.77	1.55	524	1,044.0	-42.00	.02792	21.333	13.1	3.71123
8.0	1.68	1.49	514	1,025.0	-48.00	.03053	19.887	15.4	3.51585
8.5	1.58	1.42	505	1,003.0	-45.00	.02768	18.306	15.1	3.29107
9.0	1.49	1.37	494	981.0	-41.00	.02477	17.066	14.5	3.09330
9.5	1.40	1.32	485	961.0	-38.10	.02268	15.939	14.2	5.83135
10.0	1.33	1.26	478	942.0	-37.80	.02223	14.667	15.2	2.74970
11.0	1.20	1.14	470	905.0	-34.90	.02051	12.677	16.2	2.41190
12.0	1.09	1.01	468	872.0	-31.90	.01921	11.379	16.9	2.17798
13.0	1.00	.99	457	843.0	-28.80	.01779	10.281	17.3	2.00360
14.0	.93	.99	443	816.0	-25.40	.01619	9.248	17.5	1.85725
15.0	.88	.98	432	790.0	-22.00	.01449	8.671	16.7	1.77932

[redacted]

TABLE I.- TEST DATA - Continued

(f) Thermocouple 6

t	M_∞	M_l	T_l	T_w	$\frac{dT_w}{dt}$	h	$\rho c_p V$	N_{St}	R_l
1.0	1.09	1.00	537	521.0	19.80	0.03126	20.015	15.6×10^{-4}	3.41731×10^{6}
1.2	1.32	1.19	549	526.0	29.00	.03177	25.097	12.7	4.20651
1.4	1.58	1.36	571	533.0	43.00	.03377	29.669	11.4	4.84702
1.6	1.86	1.51	606	543.0	62.00	.03578	33.585	10.7	5.22950
1.8	2.18	1.65	653	558.0	91.80	.04013	37.033	10.8	5.47065
2.0	2.51	1.79	713	582.0	133.50	.04498	40.424	11.1	5.62096
2.1	2.66	1.85	753	596.0	159.00	.04682	41.805	11.2	5.54088
2.2	2.81	1.90	798	614.0	177.00	.04631	42.948	10.8	5.40996
2.3	2.97	1.95	843	631.0	202.00	.04732	44.867	10.5	5.34742
2.4	3.15	1.99	893	653.0	226.00	.04815	45.270	10.6	5.20484
2.5	3.33	2.04	937	676.0	250.50	.04882	46.799	10.4	5.20726
2.6	3.50	2.07	985	703.0	278.00	.05049	48.049	10.5	5.18044
2.7	3.65	2.12	1,011	733.0	306.00	.05335	49.923	10.7	5.24459
2.8	3.77	2.15	1,050	763.0	332.00	.05335	51.121	10.4	5.20446
2.9	3.84	2.17	1,067	799.0	362.00	.06013	52.209	11.5	5.23044
3.0	3.86	2.17	1,073	838.0	386.00	.06626	52.567	12.6	5.32144
3.1	3.84	2.17	1,056	875.0	343.00	.06347	52.380	12.1	5.31304
3.2	3.79	2.17	1,024	906.0	306.00	.06220	51.913	12.0	5.38910
3.4	3.67	2.15	978	960.0	240.00	.05852	49.662	11.8	5.33147
3.6	3.52	2.11	945	1,005.0	193.00	.05685	46.545	12.2	5.15463
3.8	3.36	2.10	899	1,031.0	160.00	.05702	44.645	12.8	5.12897
4.0	3.22	2.05	869	1,090.0	28.00	.01187	41.609	2.9	4.91049
4.4	2.96	1.99	802	1,097.0	18.50	.01187	37.487	3.2	4.73151
4.8	2.74	1.91	752	1,054.0	12.90	.01438	33.655	4.3	4.47506
5.2	[illegible]	1.87	695	1,059.0	8.60	.02675	31.392	8.5	4.36850
5.6	2.38	1.86	644	1,060.0	5.50	-.04347	29.067	-14.5	4.46913
6.0	2.24	1.76	621	1,063.0	2.80	-.00535	27.077	-2.0	4.14733
6.4	2.10	1.70	589	1,063.0	-3.00	.00334	25.358	1.3	4.03828
6.8	1.98	1.65	562	1,059.0	-13.30	.01170	23.918	4.9	3.96648
7.2	1.87	1.60	541	1,051.0	-26.80	.02023	22.637	8.9	3.85493
7.6	1.77	1.55	524	1,037.0	-35.60	.02458	21.333	11.5	3.71123
8.0	1.68	1.49	514	1,022.0	-38.80	.02541	19.887	12.8	3.51585
8.5	1.58	1.42	505	1,002.0	-38.80	.02424	18.306	13.2	3.29107
8.5	1.58	1.42	505	1,002.0	-38.80	.02424	18.306	13.2	3.29107
9.0	1.49	1.37	494	983.0	-37.70	.02291	17.066	7.2	3.09330
9.5	1.40	1.32	485	964.0	-36.70	.02207	15.939	13.8	5.83135
10.0	1.33	1.26	478	944.0	-35.40	.02107	14.667	14.4	2.74970
11.0	1.20	1.14	470	911.0	-33.00	.01940	12.677	15.3	2.41190
12.0	1.09	1.01	469	879.0	-30.40	.01822	11.379	16.0	2.17798
13.0	1.00	.99	457	849.0	-28.30	.01739	10.281	16.9	2.00360
14.0	.93	.99	443	820.0	-26.70	.01705	9.248	18.4	1.85725
15.0	.88	.98	432	794.0	-25.00	.01655	8.671	19.1	1.77932

TABLE I.- TEST DATA - Continued

(g) Thermocouple 7

t	M_∞	M_l	T_l	T_w	$\frac{dT_w}{dt}$	h	$\rho c_p V$	N_{St}	R_l
1.0	1.09	1.00	537.5	524.0	13.80	0.02201	20.12	10.9×10^{-4}	3.41731×10^{6}
1.2	1.32	1.19	549.4	526.0	22.30	.02401	25.07	9.6	4.20651
1.4	1.58	1.36	570.9	532.0	39.00	.03004	29.71	10.1	4.84702
1.6	1.86	1.51	605.8	541.0	65.80	.03709	33.61	11.0	5.22950
1.8	2.18	1.65	652.7	558.0	96.00	.04117	37.05	11.1	5.47065
2.0	2.51	1.79	712.5	581.0	130.00	.04293	40.50	10.6	5.62096
2.1	2.66	1.85	752.7	595.0	148.00	.04283	41.80	10.2	5.54088
2.2	2.81	1.90	798.5	611.0	175.00	.04481	42.93	10.4	5.40996
2.3	2.97	1.95	843.5	630.0	202.00	.04644	44.38	10.5	5.34742
2.4	3.15	1.99	892.8	650.0	230.00	.04790	45.22	10.6	5.20484
2.5	3.33	2.04	937.1	675.0	260.00	.04970	46.74	10.6	5.20726
2.6	3.50	2.07	985.5	703.0	294.00	.05239	48.14	10.9	5.18044
2.7	3.65	2.12	1,011.1	735.0	331.00	.05672	50.06	11.3	5.24459
2.8	3.77	2.15	1,049.6	768.0	368.00	.06028	51.17	11.8	5.20446
2.9	3.84	2.17	1,067.1	807.0	390.00	.06411	52.15	12.3	5.23044
3.0	3.86	2.17	1,073.3	847.0	398.00	.06769	52.63	12.9	5.32144
3.1	3.84	2.17	1,055.8	885.0	388.00	.07119	52.37	13.6	5.31304
3.2	3.79	2.17	1,023.8	916.0	336.00	.06783	51.93	13.1	5.38910
3.4	3.67	2.15	977.9	966.0	233.00	.05638	49.76	11.3	5.33147
3.6	3.52	2.11	944.8	1,007.0	159.00	.04621	46.57	9.9	5.15463
3.8	3.36	2.10	899.0	1,032.0	75.50	.02647	44.74	5.9	5.12897
4.0	3.22	2.05	869.3	1,041.0	41.70	.01755	41.64	4.2	4.91049
4.4	2.96	1.99	802.4	1,049.0	11.00	.00699	37.49	1.9	4.73151
4.8	2.74	1.91	751.7	1,051.0	6.20	.00673	33.69	2.0	4.47506
5.2	2.55	1.87	694.9	1,054.0	5.40	.01573	31.40	5.0	4.36850
5.6	2.38	1.86	644.2	1,055.0	4.20	-.04360	29.98	-14.5	4.46913
6.0	2.24	1.76	621.2	1,055.0	2.40	-.00499	27.00	-1.8	4.14733
6.4	2.10	1.70	589.3	1,055.0	-3.00	.00358	25.38	1.4	4.03828
6.8	1.98	1.65	562.0	1,050.0	-18.60	.01685	23.88	7.1	3.96648
7.2	1.87	1.60	541.0	1,040.0	-28.00	.02169	22.71	9.6	3.85493
7.6	1.77	1.55	524.1	1,026.0	-36.00	.02534	21.37	11.9	3.71123
8.0	1.68	1.49	513.8	1,010.0	-39.60	.02636	19.83	13.3	3.51585
8.5	1.58	1.42	504.5	989.0	-40.00	.02565	18.36	14.0	3.29107
9.0	1.49	1.37	493.7	970.0	-38.40	.02391	17.06	14.0	3.09330
9.5	1.40	1.32	485.0	952.0	-36.70	.02244	15.97	14.1	5.83135
10.0	1.33	1.26	478.2	934.0	-35.00	.02103	14.71	14.3	2.74970
11.0	1.20	1.14	469.9	899.0	-32.50	.01943	12.72	15.3	2.41190
12.0	1.09	1.01	468.5	868.0	-30.40	.01850	11.33	16.3	2.17798
13.0	1.00	.99	456.5	839.0	-28.60	.01785	10.32	17.3	2.00360
14.0	.93	.99	443.1	812.0	-27.00	.01742	9.23	18.7	1.85725
15.0	.88	.98	432.0	785.0	-25.80	.01727	8.71	19.8	1.77932

TABLE I.- TEST DATA - Continued

(h) Thermocouple 8

t	M_∞	M_l	T_l	T_w	$\frac{dT_w}{dt}$	h	$\rho c_p V$	N_{St}	R_l
1.0	1.09	1.12	516	525.0	17.00	0.023583	16.426	14.36×10^{-4}	5.347×10^{6}
1.2	1.32	1.31	525	528.0	25.30	.023568	20.334	11.59	6.430
1.4	1.58	1.50	539	534.0	35.30	.023447	22.888	10.24	7.246
1.6	1.86	1.68	564	543.0	49.50	.024056	24.746	9.72	7.637
1.8	2.18	1.86	596	554.0	74.00	.026830	26.331	10.19	7.797
2.0	2.51	2.02	644	572.0	107.00	.029575	27.624	10.71	7.685
2.1	2.66	2.10	674	584.0	126.00	.030515	28.181	10.83	7.545
2.2	2.81	2.15	714	596.0	145.00	.030868	28.242	10.93	7.201
2.3	2.97	2.22	748	613.0	162.00	.030986	28.716	10.79	7.050
2.4	3.15	2.29	781	629.0	192.00	.033153	29.260	11.33	6.896
2.5	3.33	2.35	816	652.0	218.00	.034700	29.778	11.65	6.734
2.6	3.50	2.40	850	677.0	253.40	.037040	30.165	12.28	6.576
2.7	3.65	2.46	869	705.0	258.50	.036542	31.015	11.78	6.596
2.8	3.77	2.50	898	730.0	253.50	.034006	31.501	10.80	6.486
2.9	3.84	2.53	909	755.0	241.50	.032046	31.782	10.08	6.489
3.0	3.86	2.54	910	778.0	227.00	.030619	31.782	9.63	6.476
3.1	3.84	2.54	895	800.0	210.00	.029856	31.556	9.46	6.528
3.2	3.79	2.53	872	819.0	188.00	.028866	31.213	9.25	6.616
3.4	3.67	2.50	836	855.0	159.50	.028379	29.981	9.47	6.642
3.6	3.52	2.45	812	884.0	137.50	.028274	28.437	9.94	6.510
3.8	3.36	2.42	779	909.0	116.00	.027989	27.482	10.18	6.536
4.0	3.22	2.36	757	930.0	91.70	.026328	25.974	10.14	6.521
4.4	2.96	2.27	708	958.0	41.00	.017158	23.942	7.17	6.300
4.8	2.74	2.18	667	965.0	8.00	.005099	22.158	2.30	6.187
5.2	2.55	[illegible]	630	965.0	-2.60	-.002870	20.752	-1.38	5.563
5.6	2.38	2.01	603	964.0	-7.00	-.017182	19.503	-8.81	6.010
6.0	2.24	1.93	577	959.0	-11.20	.367446	18.423		5.925
6.4	2.10	1.86	550	954.0	-15.40	.036058	17.446	20.67	5.894
6.8	1.98	1.79	529	948.0	-19.40	.026235	16.240	16.15	5.789
7.2	1.87	1.72	514	939.0	-23.10	.023902	15.197	15.73	5.655
7.6	1.77	1.65	502	929.0	-26.80	.023497	14.308	16.42	5.664
8.0	1.68	1.58	495	917.0	-29.00	.023011	13.497	17.05	5.259
8.5	1.58	1.50	488	902.0	-28.90	.021217	12.672	16.74	4.988
9.0	1.49	1.43	482	888.0	-28.00	.019414	11.841	16.40	4.756
9.5	1.40	1.36	477	874.0	-27.40	.018305	11.067	16.54	4.526
10.0	1.33	1.28	475	861.0	-27.00	.016314	10.116	16.13	4.224
11.0	1.20	1.14	470	834.0	-26.20	.016273	8.559	19.01	3.707
12.0	1.09	1.05	464	807.0	-25.50	.016687	7.455	22.38	3.343
13.0	1.00	1.00	455	783.0	-24.40	.016098	6.692	24.06	3.066
14.0	.93	.97	446	760.0	-21.30	.013921	4.496	24.03	2.401
15.0	.88	.73	465	740.0	-16.00	.010807			

TABLE I.- TEST DATA - Continued

(i) Thermocouple 9

t	M_∞	M_l	T_l	T_w	$\frac{dT_w}{dt}$	h	$\rho c_p V$	N_{St}	R_l
1.0	1.09			525.0	16.70				
1.2	1.32			529.0	26.00				
1.4	1.58	1.51	537	535.0	37.60	0.026789	27.473	9.75×10^{-4}	12.315×10^6
1.6	1.86	1.76	545	543.0	55.00	.028626	30.495	9.38	13.880
1.8	2.18	1.98	565	556.0	74.50	.029139	34.135	8.53	14.209
2.0	2.51	2.15	608	575.0	106.00	.031611	32.049	9.86	13.413
2.1	2.66	2.21	642	585.0	122.00	.031663	31.893	9.92	12.811
2.2	2.81	2.27	677	598.0	137.00	.031296	32.242	9.70	12.445
2.3	2.97	2.36	702	612.0	151.00	.030857	33.604	9.18	12.618
2.4	3.15	2.40	742	628.0	166.00	.030544	33.936	9.00	12.238
2.5	3.33	2.47	776	645.0	180.50	.030252	34.172	8.85	11.874
2.6	3.50	2.53	805	664.0	196.50	.030463	34.204	8.90	11.556
2.7	3.65	2.58	824	686.0	205.60	.030312	34.061	8.89	11.312
2.8	3.77	2.63	549	704.0	212.00	.029506	33.568	8.78	10.871
2.9	3.84	2.65	863	728.0	217.00	.029810	32.932	9.05	10.533
3.0	3.86	2.65	867	750.0	219.40	.030606	32.799	9.33	10.446
3.1	3.84	2.65	853	772.0	203.50	.029920	33.100	9.03	10.676
3.2	3.79	2.63	835	790.0	193.10	.030559	33.671	9.07	11.064
3.4	3.67	2.59	805	826.0	170.00	.031061	34.440	9.01	11.635
3.6	3.52	2.54	782	858.0	146.00	.030856	34.706	8.89	12.005
3.8	3.36	2.98	760	884.0	124.60	.030761	34.617	8.88	12.239
4.0	3.22	2.43	735	907.0	103.00	.030210	34.453	8.76	12.509
4.4	2.96	2.34	689	940.0	63.70	.027176	33.694	8.06	12.826
4.8	2.74	2.24	647	960.0	38.00	.025409	32.297	7.86	12.912
5.2	2.55	2.16	611	970.0	17.50	.021562	32.108	6.71	13.373
5.6	2.38	2.08	584	974.0	5.30	.016874	32.152	5.24	13.896
6.0	2.24	2.01	557	974.0	-4.50	.035817	32.455	11.03	14.540
6.4	2.10	1.93	533	970.0	-11.40	.022665	32.604	6.95	15.077
6.8	1.98	1.85	516	965.0	-17.20	.021459	32.348	6.63	15.368
7.2	1.87	1.77	503	957.0	-21.80	.021476	31.838	6.74	15.504
7.6	1.77	1.69	494	947.0	-25.20	.021381	31.154	6.86	15.300
8.0	1.68	1.61	489	936.0	-26.80	.020682	30.147	6.86	14.973
8.5	1.58	1.51	486	923.0	-27.00	.019323	28.857	6.69	14.414

TABLE I.- TEST DATA - Continued

(j) Thermocouple 10

t	M_∞	M_l	T_l	T_w	$\frac{dT_w}{dt}$	h	$\rho c_p V$	N_{St}	R_l
1.0	1.09			526.0	19.50				
1.2	1.32			531.0	27.20				
1.4	1.58	1.48	544	537.0	38.50	0.026	28.116	9.25×10^{-4}	17.90×10^{6}
1.6	1.86	1.73	552	545.0	53.00	.026	31.586	8.23	19.88
1.8	2.18	1.92	580	559.0	74.50	.028	32.153	8.71	19.84
2.0	2.51	2.09	624	576.0	106.40	.030	33.554	8.94	19.15
2.1	2.66	2.16	656	588.0	122.00	.030	34.119	8.79	18.76
2.2	2.81	2.22	692	600.0	139.00	.030	34.381	8.72	18.16
2.3	2.97	2.29	725	616.0	155.00	.030	34.632	8.66	18.18
2.4	3.15	2.37	753	631.0	171.00	.030	34.939	8.59	17.35
2.5	3.33	2.44	784	651.0	186.00	.030	34.694	8.65	16.67
2.6	3.50	2.50	810	669.0	198.50	.029	34.208	8.48	16.18
2.7	3.65	2.57	827	690.0	206.00	.029	33.811	8.58	15.60
2.8	3.77	2.62	841	711.0	212.00	.028	33.386	8.39	15.05
2.9	3.84	2.65	862	733.0	217.00	.028	33.313	8.40	14.87
3.0	3.86	2.66	863	754.0	219.00	.029	33.332	8.70	14.88
3.1	3.84	2.65	853	776.0	213.00	.030	32.708	9.17	14.73
3.2	3.79	2.63	834	797.0	202.00	.030	32.453	9.24	14.88
3.4	3.67	2.58	807	836.0	179.00	.031	31.743	9.78	14.90
3.6	3.52	2.52	787	868.0	150.00	.030	30.815	9.74	14.78
3.8	3.36	2.46	765	896.0	122.00	.029	29.150	9.68	14.55
4.0	3.22	2.40	744	917.0	91.00	.027	29.063	9.29	14.58
4.4	2.96	2.29	702	948.0	58.30	.024	27.470	8.73	14.32
4.8	2.74	2.19	664	966.0	34.00	.022	25.940	8.48	14.12
5.2	2.55	2.11	625	976.0	18.50	.022	24.754	9.28	14.12
5.6	2.38	2.02	600	980.0	4.50	.015	23.211	6.46	13.62
6.0	2.24	1.95	571	980.0	-6.10	.037	22.020	16.80	13.51
6.4	2.10	1.88	545	975.0	-14.40	.026	21.179	12.28	13.47
6.8	1.98	1.81	524	968.0	-20.10	.023	20.399	11.28	13.37
7.2	1.87	1.74	510	959.0	-24.10	.022	19.531	11.27	13.07
7.6	1.77	1.67	498	948.0	-26.90	.021	18.717	11.21	12.77
8.0	1.68	1.59	493	937.0	-28.00	.020	17.638	11.33	12.11
8.5	1.58	1.48	492	923.0	27.70	.019	16.269	11.69	11.30

TABLE I.- TEST DATA - Continued

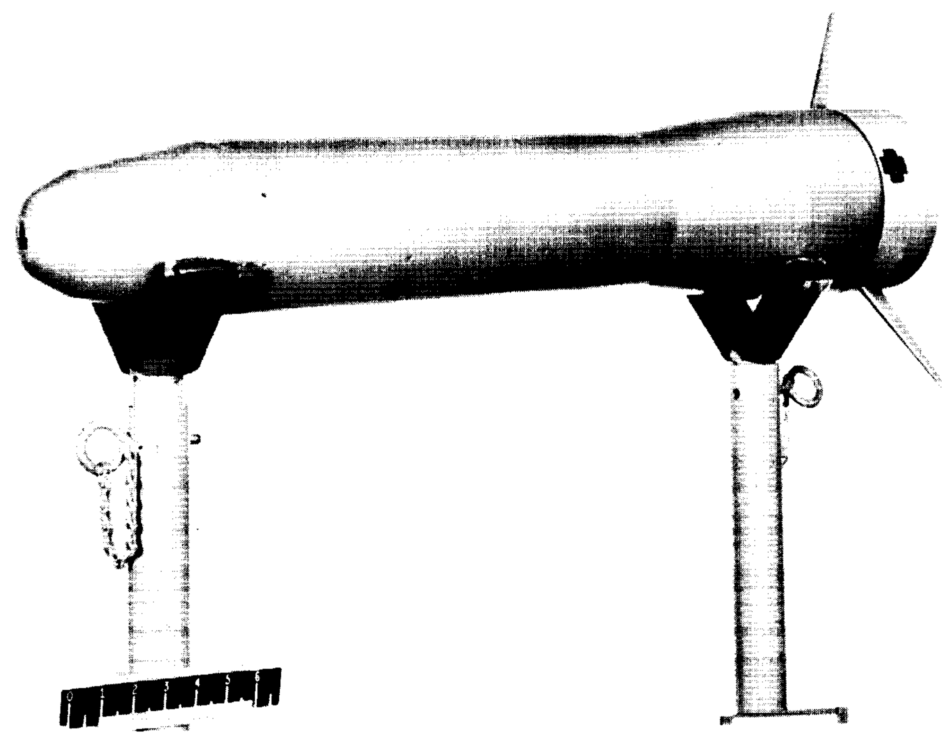
(k) Thermocouple 11

t	M_∞	M_l	T_l	T_w	$\frac{dT_w}{dt}$	h	$\rho c_p V$	N_{St}	R_l
1.0	1.09	0.78	620	525.0	20.00	0.02628	17.16	15.32×10^{-4}	11.22×10^{6}
1.2	1.32	1.07	574	530.0	29.00	.02775	25.78	10.76	17.90
1.4	1.58	1.27	591	536.0	39.50	.02707	30.87	8.77	20.95
1.6	1.86	1.45	621	541.0	57.00	.02813	35.04	8.03	22.91
1.8	2.18	1.61	664	558.0	86.00	.03242	38.11	8.51	23.65
2.0	2.51	1.77	719	580.0	113.60	.03295	40.46	8.14	23.61
2.1	2.66	1.86	749	594.0	126.40	.03217	41.73	7.71	23.65
2.2	2.81	1.93	788	610.0	197.00	.04443	42.25	10.52	22.98
2.3	2.97	1.99	829	634.0	227.00	.04635	42.49	10.91	22.23
2.4	3.15	2.05	869	660.0	247.60	.04619	42.68	10.82	21.48
2.5	3.33	2.12	904	685.0	262.50	.04497	43.13	10.43	21.08
2.6	3.50	2.18	938	711.0	274.00	.04369	43.44	10.06	20.60
2.7	3.65	2.25	954	741.0	284.00	.04342	44.14	9.84	20.68
2.8	3.77	2.31	977	769.0	287.00	.04177	44.05	9.48	20.22
2.9	3.34	2.34	989	798.0	285.50	.04125	44.24	9.32	20.11
3.0	3.86	2.36	986	827.0	280.50	.04147	44.08	9.41	21.12
3.1	3.84	2.36	973	854.0	272.50	.04281	43.65	9.81	20.13
3.2	3.79	2.35	945	879.0	260.00	.04460	43.44	10.27	20.48
3.4	3.67	2.31	909	925.0	210.00	.04264	42.13	10.12	20.51
3.6	3.52	2.26	884	962.0	165.00	.03962	40.48	9.79	20.16
3.8	3.36	2.23	848	990.0	140.20	.04038	39.55	10.21	20.32
4.0	3.22	2.16	828	1,016.0	103.50	.03661	37.72	9.71	19.78
4.4	2.96	2.06	778	1,047.0	55.00	.03092	35.16	8.79	19.33
4.8	2.74	1.98	729	1,060.0	24.50	.02509	33.18	7.56	19.19
5.2	2.55	1.89	689	1,060.0	-3.30	.00947	31.08	3.05	18.75
5.6	2.38	1.82	656	1,057.0	-15.00	.13161	29.27	44.96	18.33
6.0	2.24	1.75	624	1,050.0	-24.00	.04663	27.69	16.84	18.02
6.4	2.10	1.67	597	1,038.0	-31.40	.03700	25.89	14.29	17.40
6.8	1.98	1.61	572	1,024.0	-36.60	.03316	24.55	13.51	17.09
7.2	1.87	1.55	552	1,010.0	-39.10	.03027	23.19	13.05	16.60
7.6	1.77	1.49	537	993.0	-41.00	.02880	21.80	13.21	15.90
8.0	1.68	1.43	527	976.0	-41.00	.02716	20.38	13.33	15.06
8.5	1.58	1.36	517	956.0	-40.00	.02530	18.80	13.46	14.12
9.0	1.99	1.30	507	938.0	-38.40	.02340	17.58	13.31	13.42
9.5	1.40	1.24	500	921.0	-36.60	.02178	16.34	13.33	12.65
10.0	1.33	1.17	495	903.0	-34.30	.02013	15.03	13.39	11.70
11.0	1.20	1.04	487	870.0	-29.00	.01678	12.75	13.16	10.04
12.0	1.09	.94	481	845.0	-23.70	.01372	11.12	12.33	8.88
13.0	1.00	.92	467	824.0	-20.20	.01172	10.20	11.49	8.34
14.0	.93	.92	453	805.0	-18.00	.01050	9.41	11.16	7.91
15.0	.88	.88	446	787.0	-17.00	.01002	8.60	11.65	7.31

TABLE I.- TEST DATA - Concluded

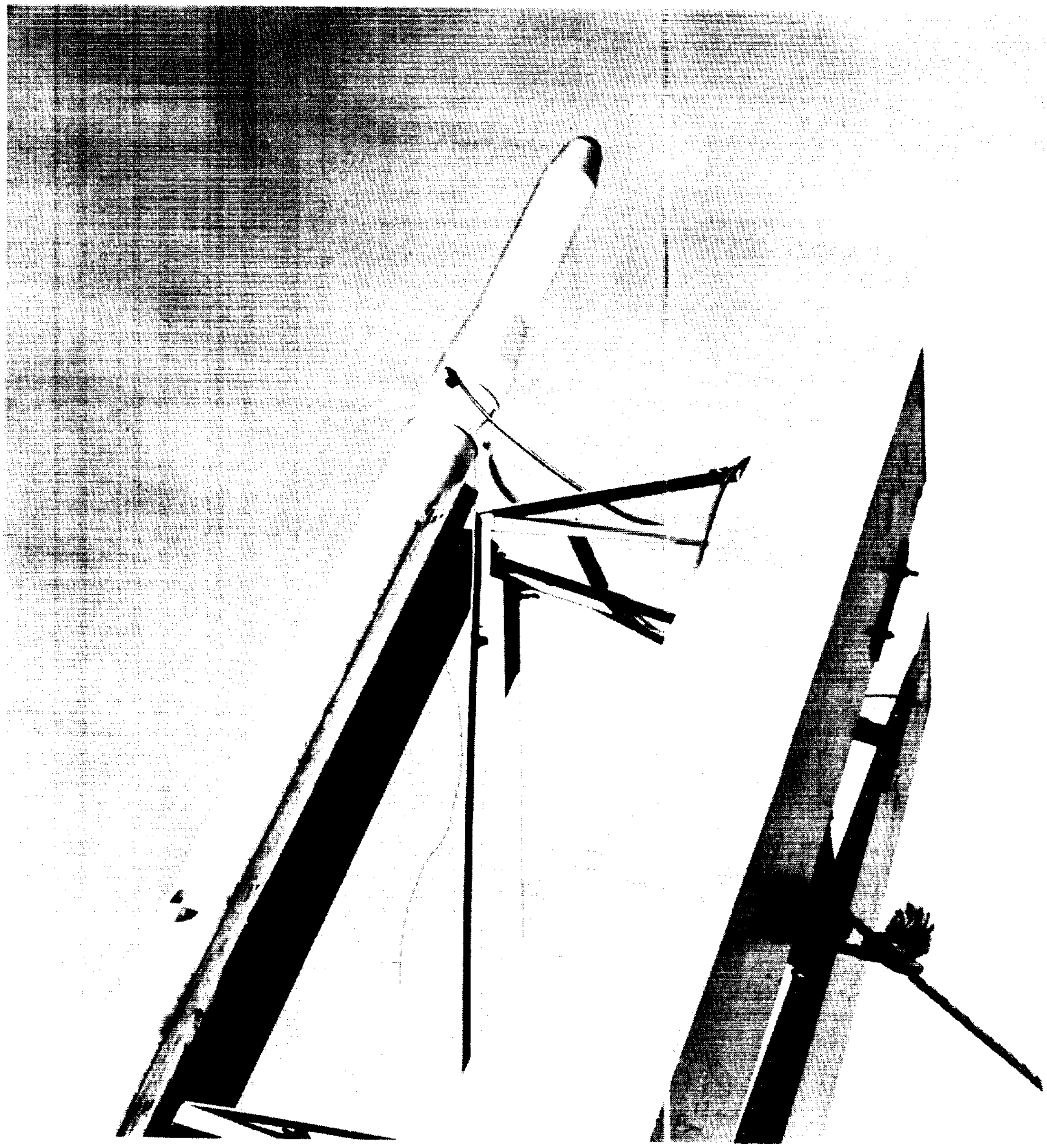
(l) Thermocouple 12

t	M_∞	M_l	T_l	T_w	$\frac{dT_w}{dt}$	h	$\rho c_p V$	N_{St}	R_l
1.0	1.09	0.98	541	526.0	18.40	0.026194	19.941	13.14×10^{-4}	15.811×10^{6}
1.2	1.32	1.14	560	531.0	28.20	.027467	25.188	10.90	19.458
1.4	1.58	1.34	575	537.0	41.00	.028347	30.008	9.45	22.768
1.6	1.86	1.51	606	546.0	57.50	.029053	33.699	8.62	24.563
1.8	2.18	1.67	647	560.0	83.50	.031790	36.973	8.60	25.678
2.0	2.51	1.82	703	581.0	119.00	.034679	39.504	8.78	25.718
2.1	2.66	1.89	740	595.0	140.00	.039161	40.326	9.71	25.271
2.2	2.81	1.96	778	610.0	163.00	.036814	41.152	8.95	24.786
2.3	2.97	2.02	818	628.0	193.90	.039268	41.610	9.44	24.256
2.4	3.15	2.08	858	650.0	230.00	.042456	42.001	10.11	23.487
2.5	3.33	2.14	896	676.0	263.00	.044544	42.459	10.49	22.884
2.6	3.50	2.20	930	704.0	290.80	.049826	42.884	11.62	22.464
2.7	3.65	2.26	892	736.0	307.00	.046945	44.647	10.51	24.157
2.8	3.77	2.32	973	767.0	318.50	.046308	44.021	10.52	22.244
2.9	3.84	2.35	985	799.0	328.50	.047509	44.001	10.80	22.091
3.0	3.86	2.36	986	833.0	331.00	.049367	43.719	11.29	21.909
3.1	3.84	2.37	965	866.0	324.20	.051740	43.703	11.84	22.254
3.2	3.79	2.36	941	893.0	284.00	.049550	43.386	11.42	22.503
3.4	3.67	2.32	906	946.0	219.00	.045804	42.119	10.87	22.513
3.6	3.52	2.27	880	984.0	172.00	.042883	40.521	10.58	22.193
3.8	3.36	2.23	848	1,014.0	131.50	.039619	39.314	10.08	22.166
4.0	3.22	2.17	824	1,036.0	101.00	.037449	37.597	9.96	21.694
4.4	2.96	2.08	771	1,070.0	48.60	.029729	34.980	8.50	21.295
4.8	2.74	1.95	738	1,079.0	13.00	.014941	33.959	4.40	21.367
5.2	2.55	1.87	695	1,080.0	-3.80	-.015909	31.812	-----	20.944
5.6	2.38	1.84	650	1,077.0	-14.80	.065067	28.556	22.79	19.742
6.0	2.24	1.78	616	1,070.0	-24.00	.037960	27.040	14.04	19.469
6.4	2.10	1.70	589	1,058.0	-30.80	.031917	25.228	12.65	18.760
6.8	1.98	1.65	562	1,045.0	-37.00	.030205	23.960	12.61	18.504
7.2	1.87	1.59	543	1,030.0	-41.50	.029494	22.572	13.07	17.848
7.6	1.77	1.54	526	1,011.0	-45.00	.029469	21.370	13.79	17.400
8.0	1.68	1.48	516	994.0	-44.00	.027277	20.075	13.59	16.568
8.5	1.58	1.41	507	973.0	40.80	.024296	18.497	13.14	15.559
9.0	1.49	1.35	498	954.0	-38.00	.021926	17.166	12.77	14.563
9.5	1.40	1.29	491	936.0	-35.00	.019778	15.944	12.40	13.681
10.0	1.33	1.22	485	919.0	-33.00	.018281	14.730	12.41	12.822
11.0	1.20	1.11	475	887.0	-30.00	.016385	12.636	12.97	11.154
12.0	1.09	1.05	464	860.0	-24.50	.013443	11.276	11.92	10.128
13.0	1.00	1.03	450	837.0	-22.00	.012118	10.201	11.88	9.442
14.0	.93	1.02	439	816.0	-20.50	.011469	9.320	12.31	8.791
15.0	.88	1.00	429	796.0	-19.00	.010801	8.717	12.39	8.373



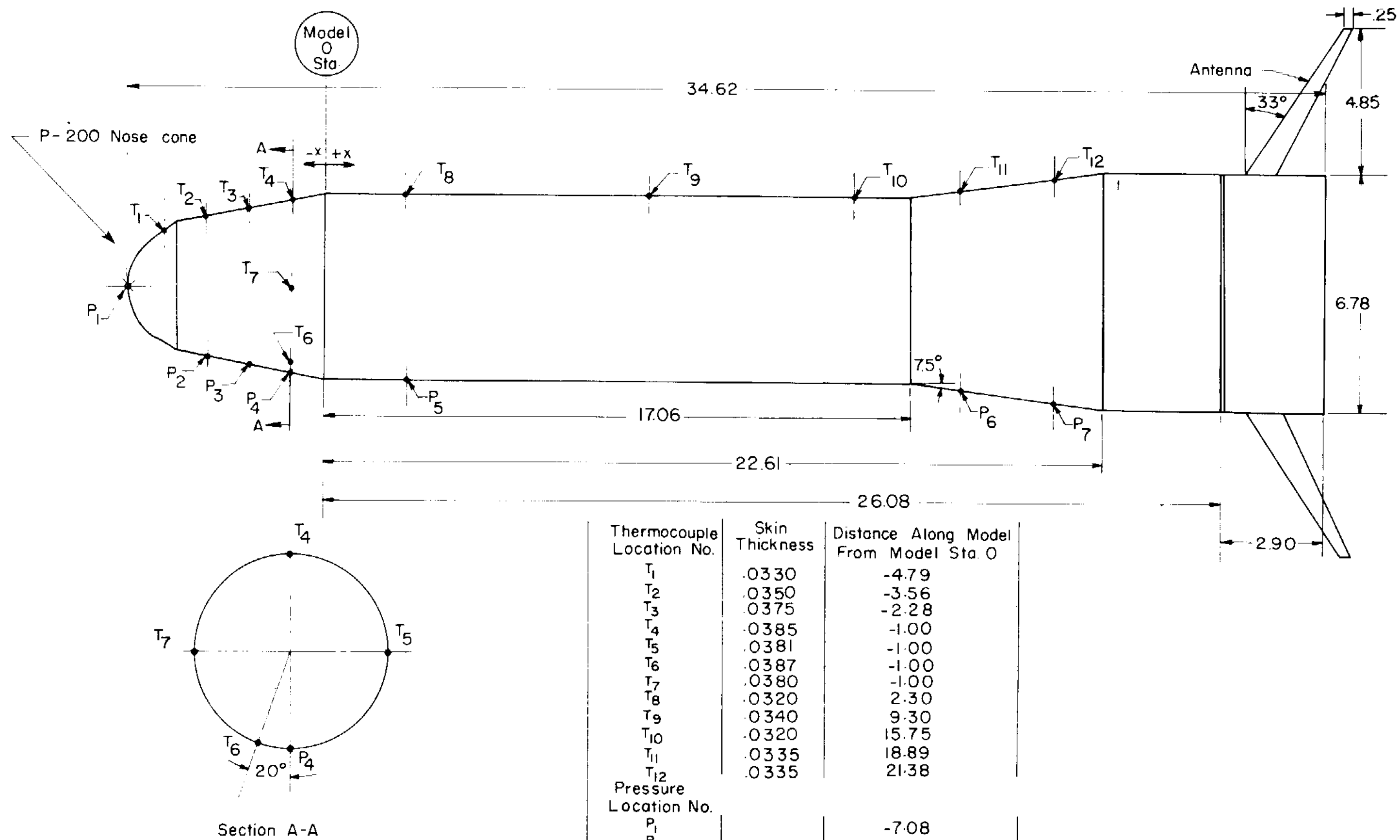
(a) Test portion of model. L-57-4655

Figure 1.- Photograph of model.



(b) Model on launcher. L-57-4877

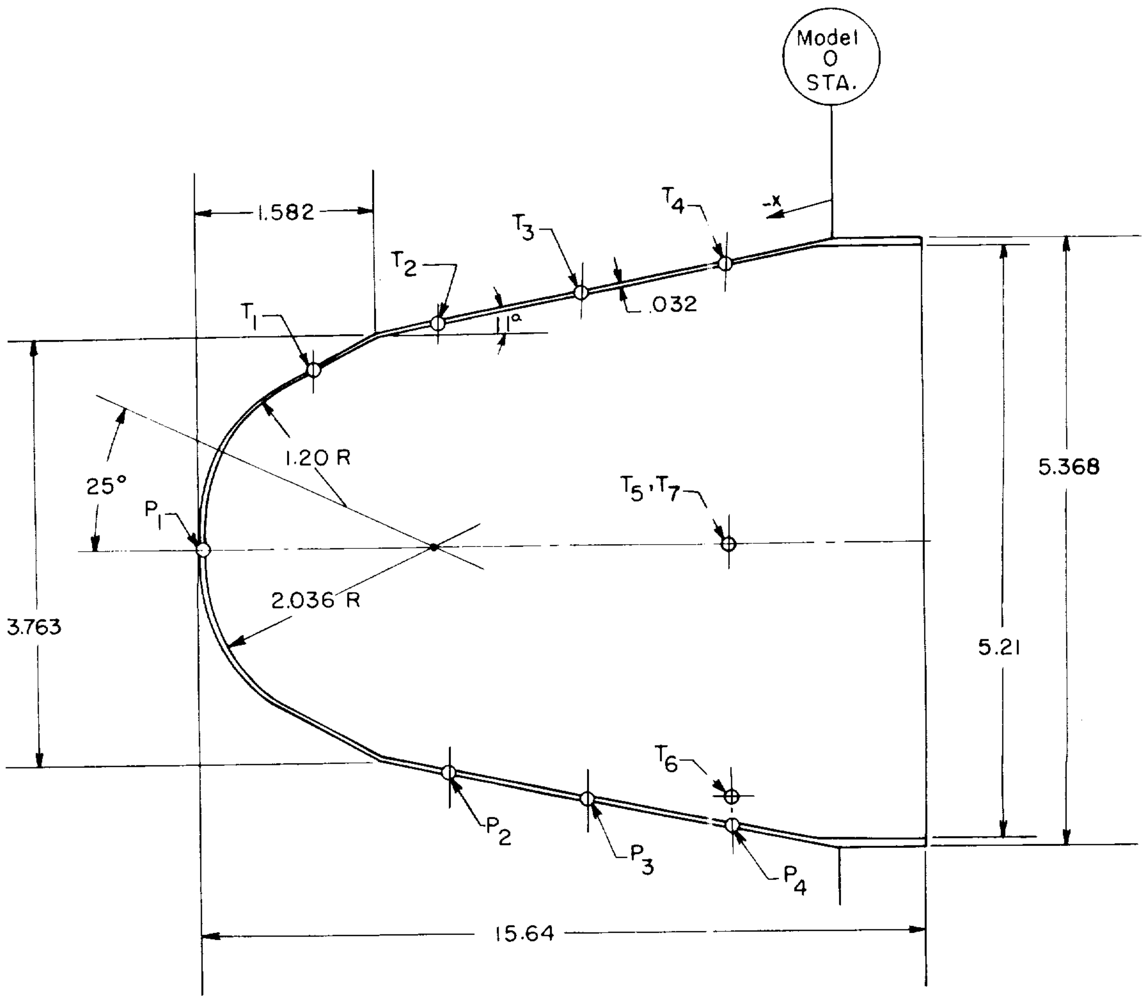
Figure 1.- Concluded.



Thermocouple Location No.	Skin Thickness	Distance Along Model From Model Sta. 0
T_1	.0330	-4.79
T_2	.0350	-3.56
T_3	.0375	-2.28
T_4	.0385	-1.00
T_5	.0381	-1.00
T_6	.0387	-1.00
T_7	.0380	-1.00
T_8	.0320	2.30
T_9	.0340	9.30
T_{10}	.0320	15.75
T_{11}	.0335	18.89
T_{12}	.0335	21.38
Pressure Location No.		
P_1		-7.08
P_2		-3.56
P_3		-2.28
P_4		-1.00
P_5		2.30
P_6		18.89
P_7		21.38

(a) Complete configuration.

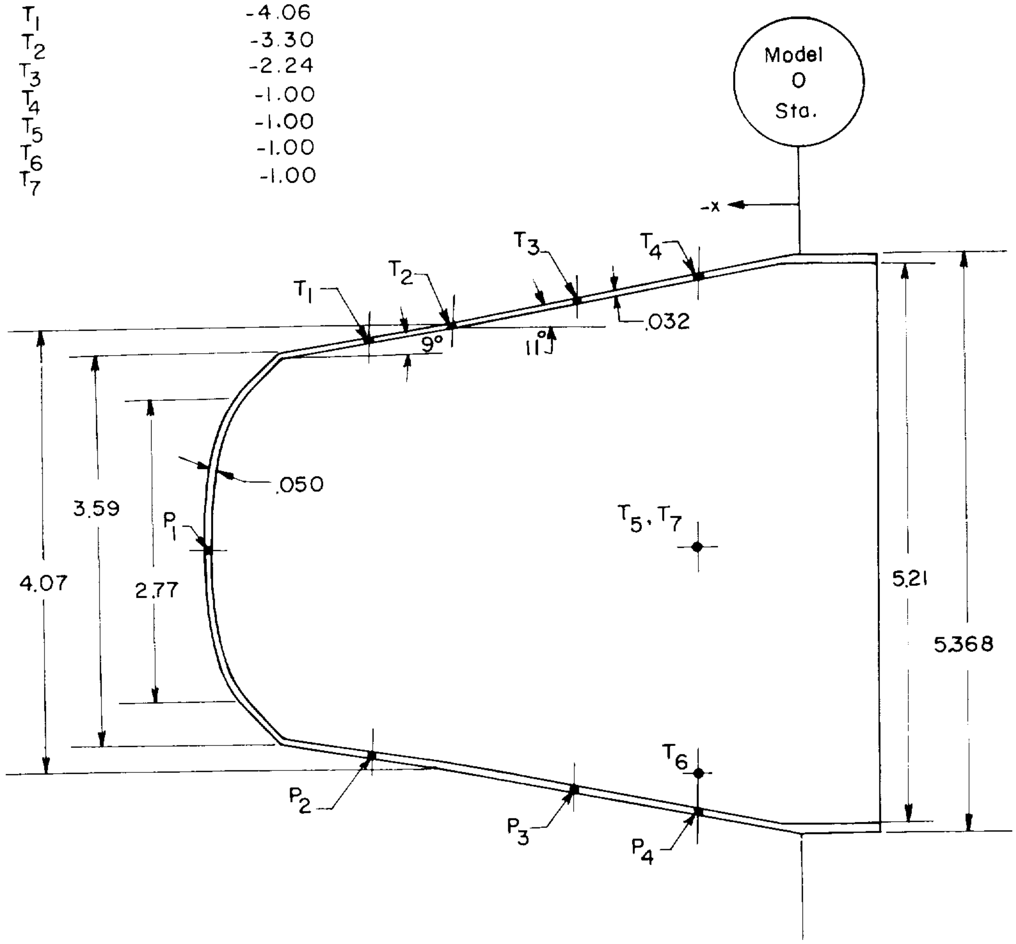
Figure 2.- Sketch of model showing pressure pickups and thermocouple locations. All dimensions are in inches.



(b) Models 1 and 3 nose detail.

Figure 2.- Continued.

Thermocouple location no.	Distance along model from model sta. 0
T_1	-4.06
T_2	-3.30
T_3	-2.24
T_4	-1.00
T_5	-1.00
T_6	-1.00
T_7	-1.00



(c) Model 2 nose detail.

Figure 2.- Concluded.

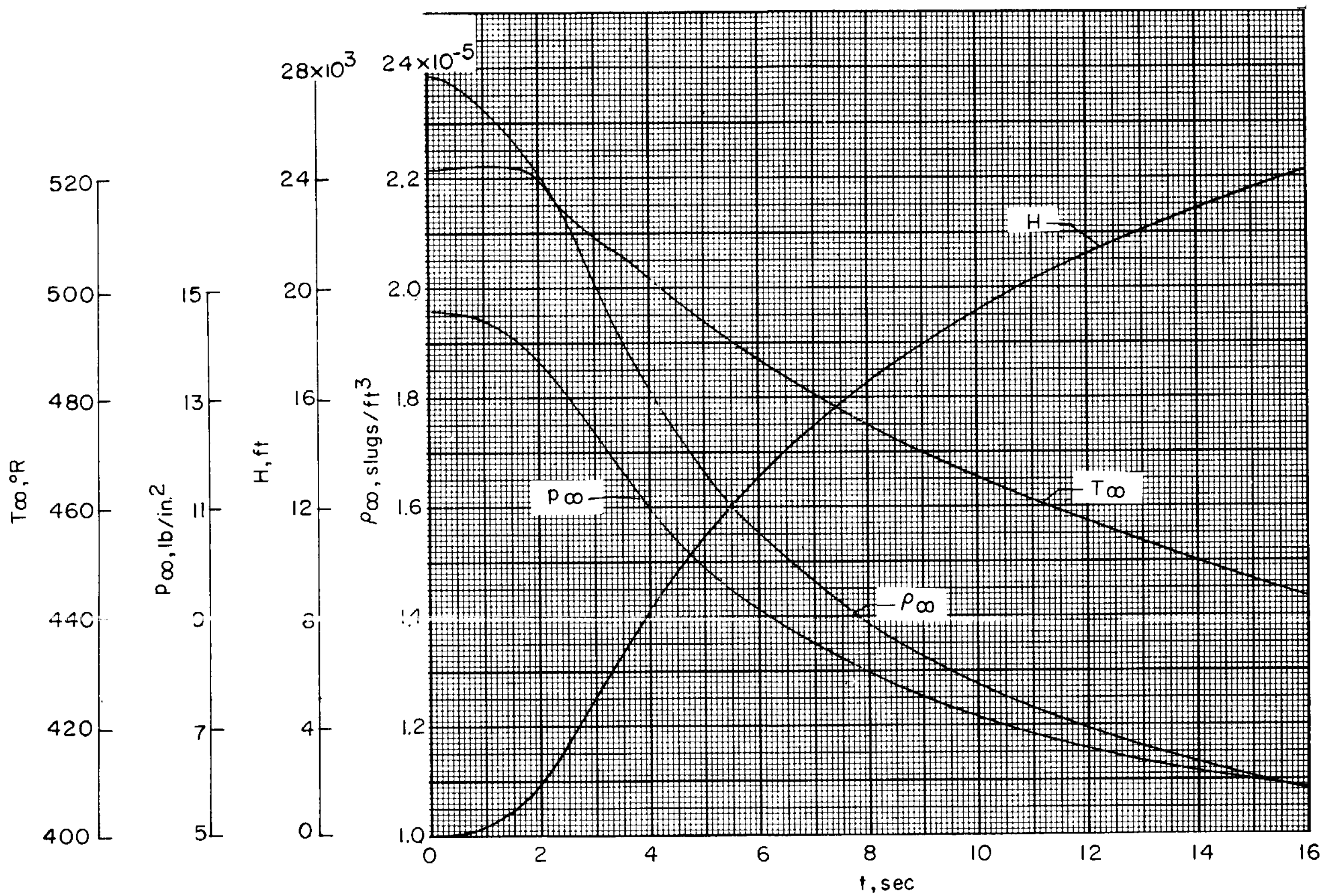
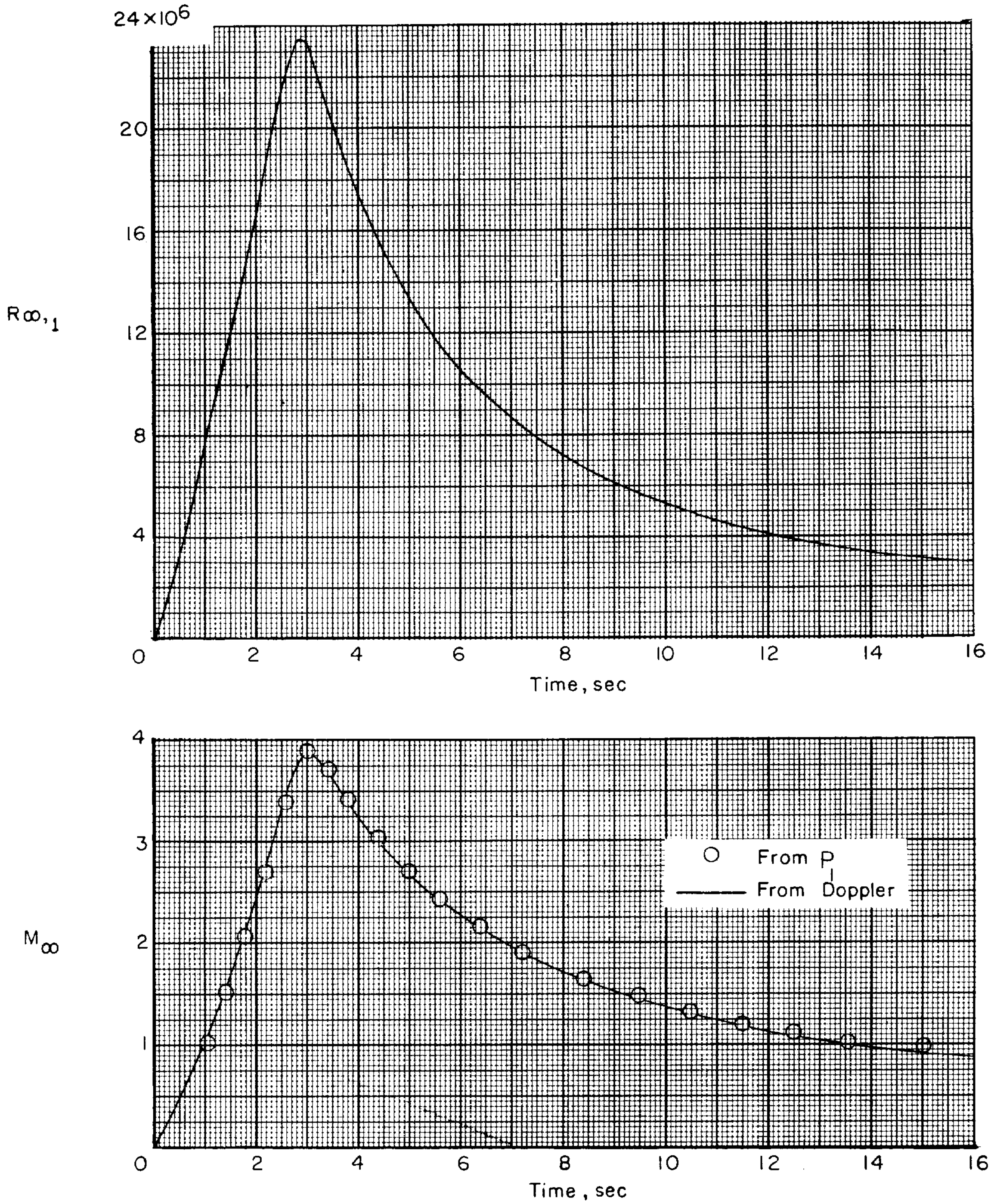


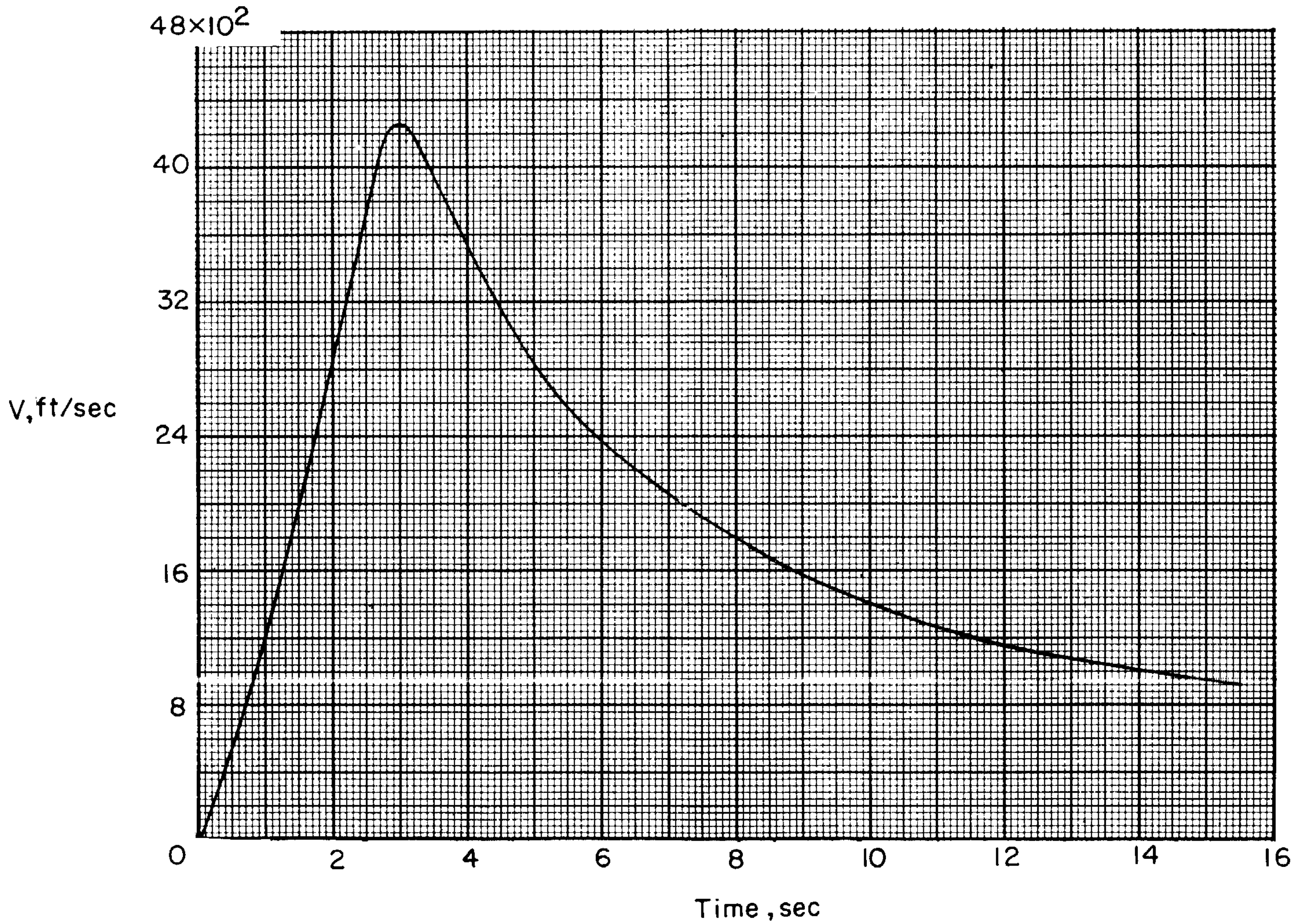
Figure 3.- Time histories of atmospheric conditions and altitude.



(a) Mach number and free-stream Reynolds number per foot.

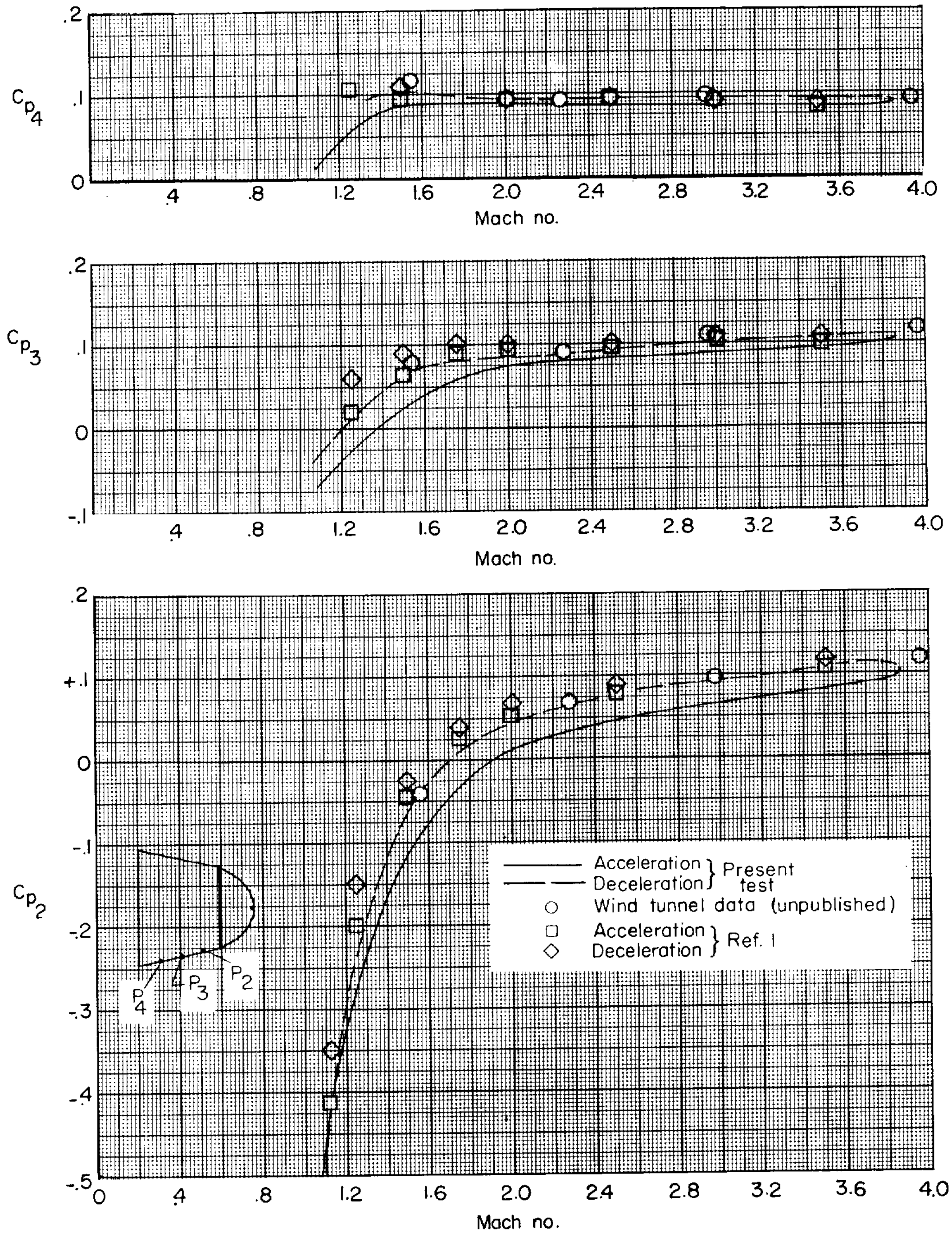
Figure 4.- Time histories.

[redacted]



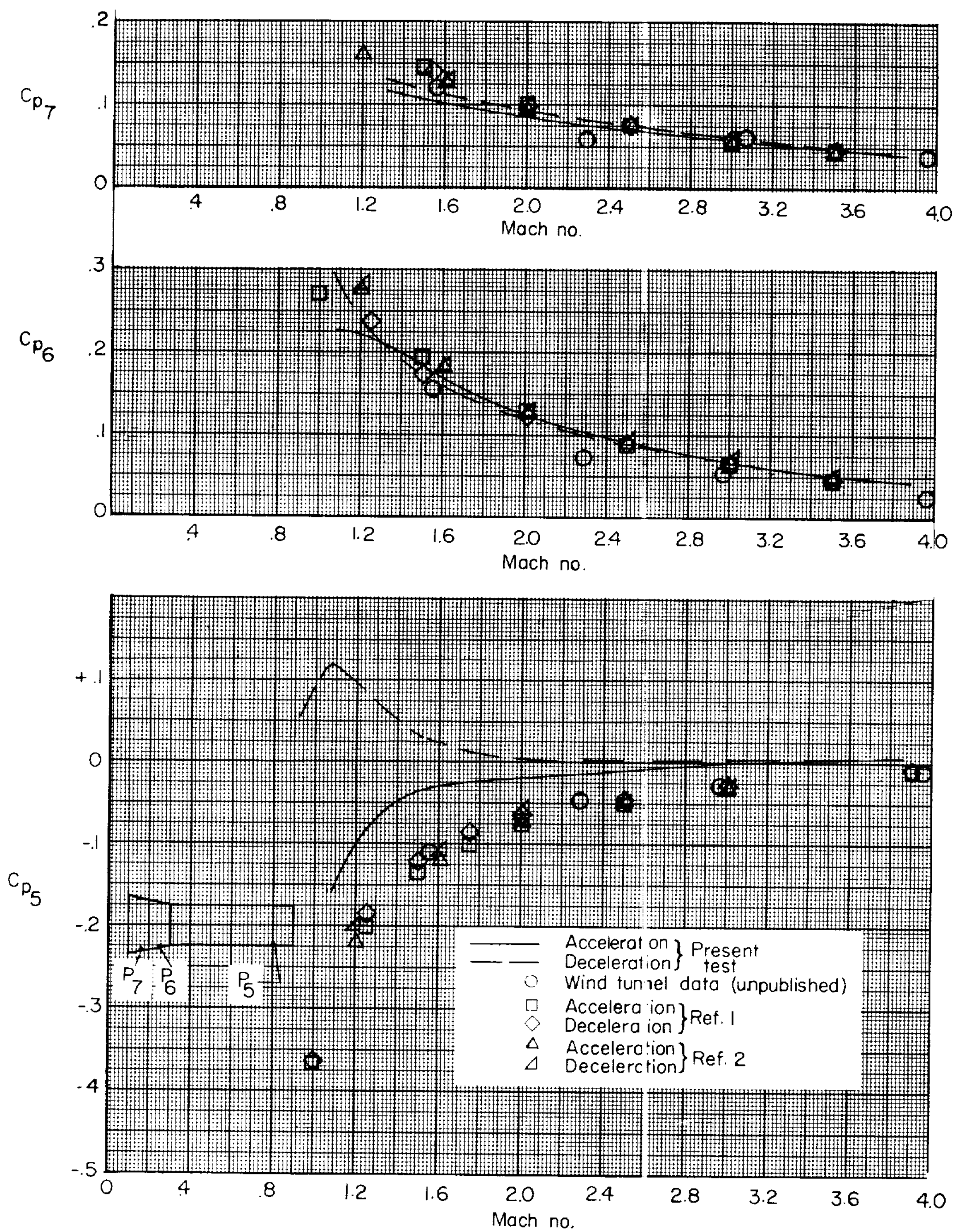
(b) Velocity.

Figure 4.- Concluded.



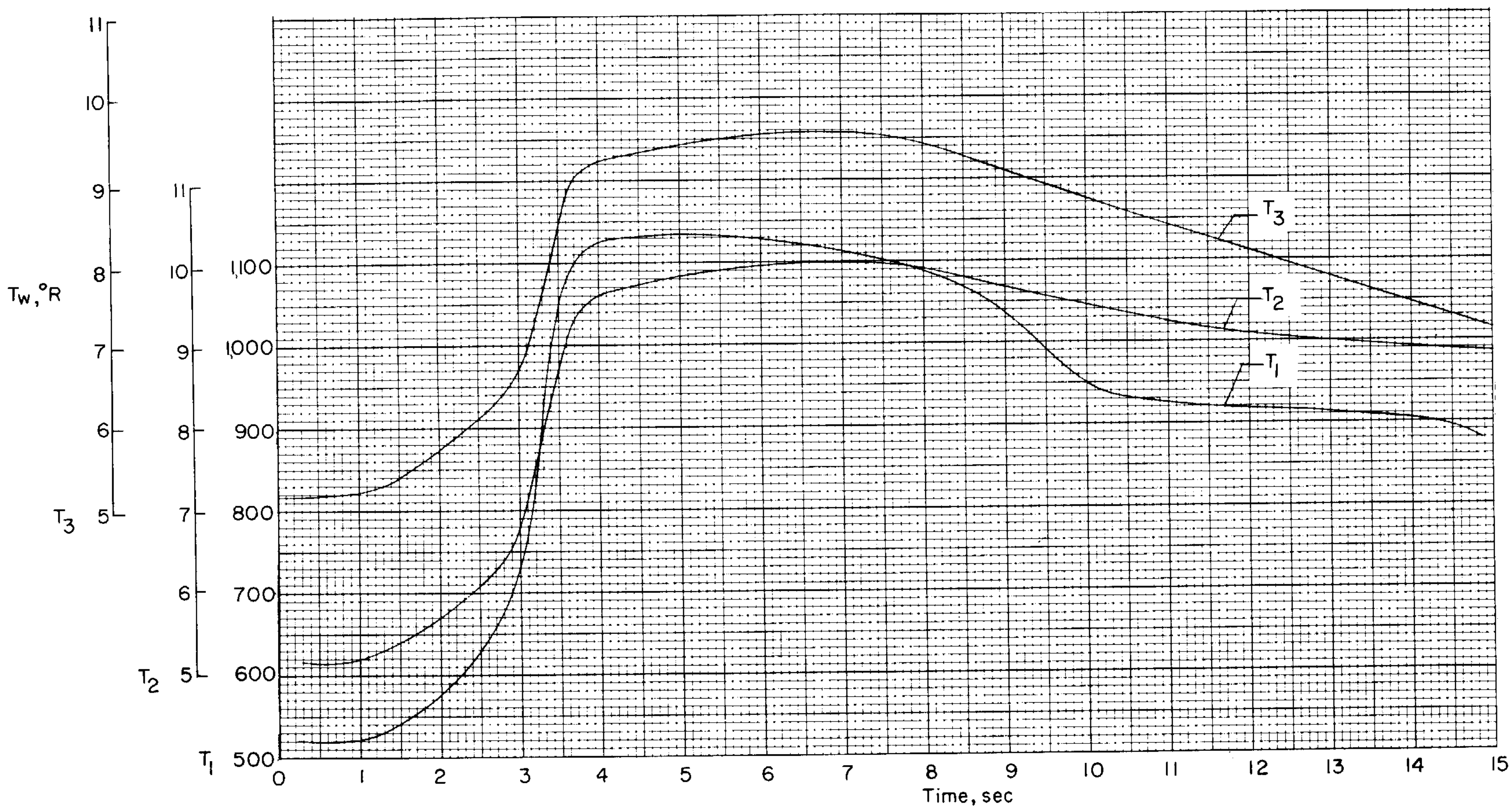
(a) Pressures 2 to 4.

Figure 5.- Pressure coefficient.



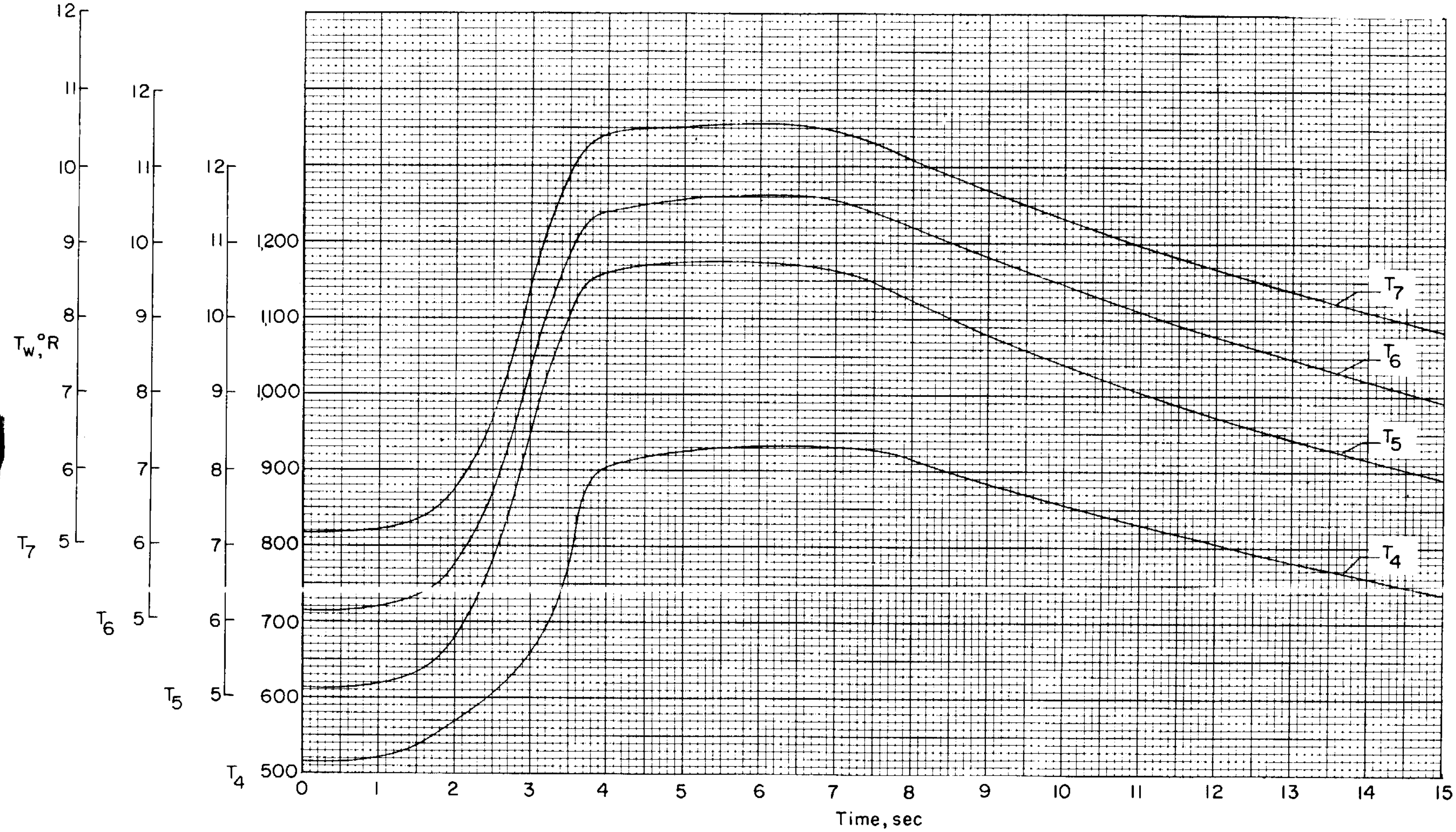
(b) Pressures 5 to 7.

Figure 5.- Concluded.



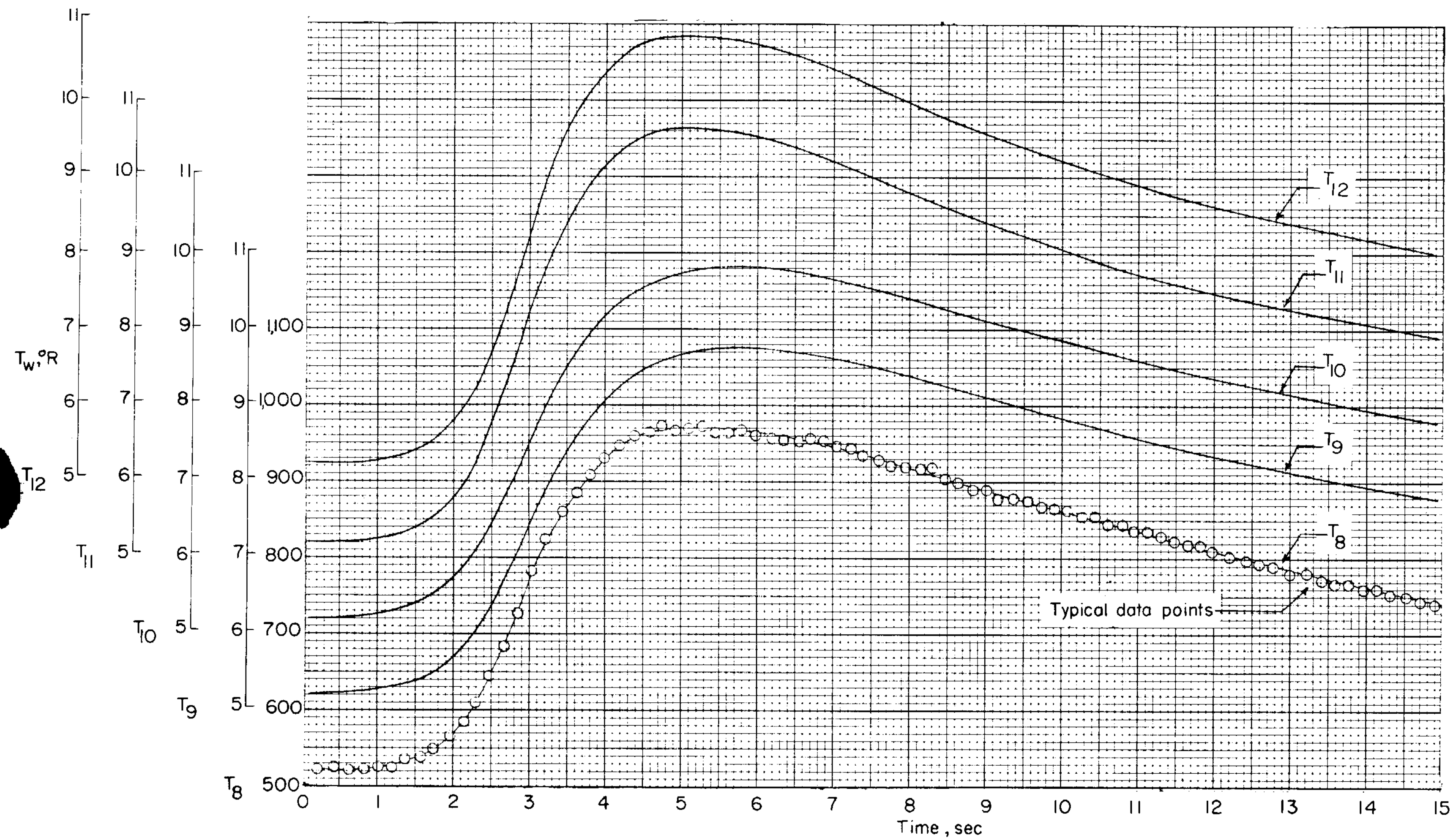
(a) Stations T_1 to T_3.

Figure 6.- Skin-temperature time histories.



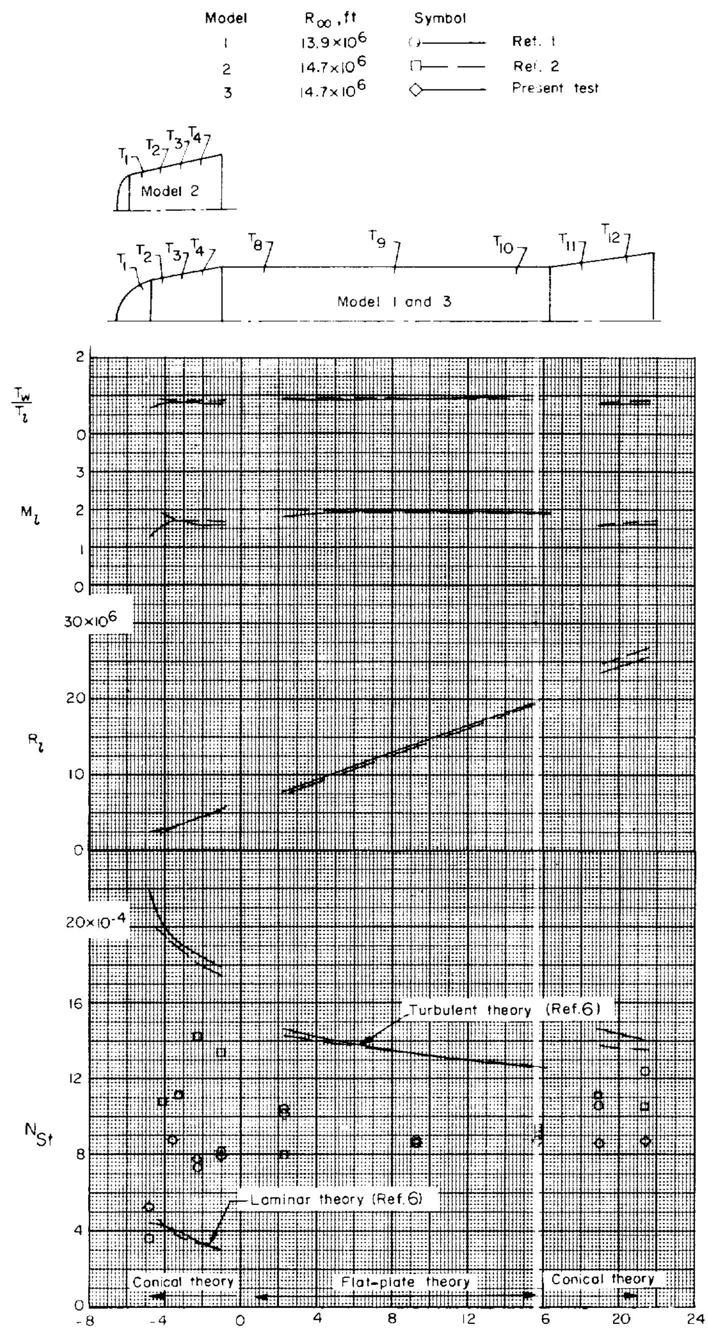
(b) Stations T_4 to T_7.

Figure 6.- Continued.



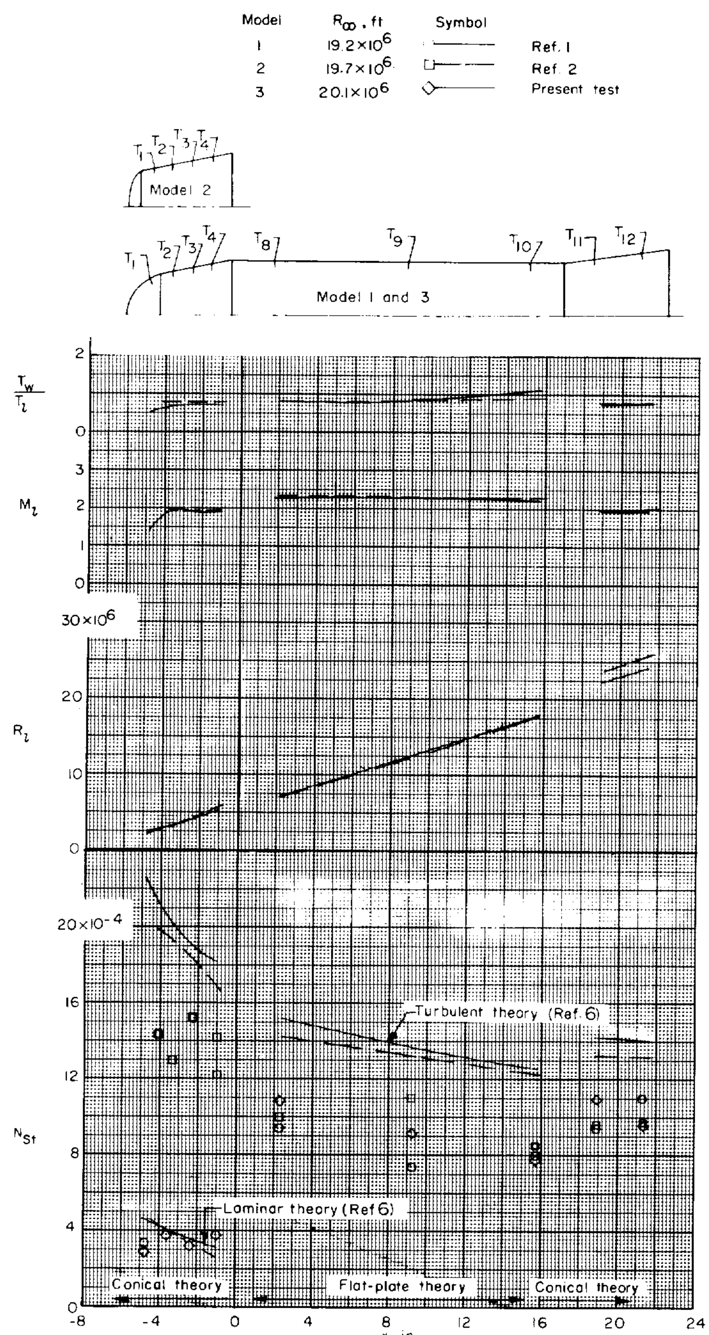
(c) Stations T_8 to T_{12}.

Figure 6.- Concluded.



(a) $M_\infty = 2.15$.

Figure 7.- Variation of local Stanton number, Reynolds number, Mach number, and ratio of wall temperature to local temperature along the body for several Mach numbers.

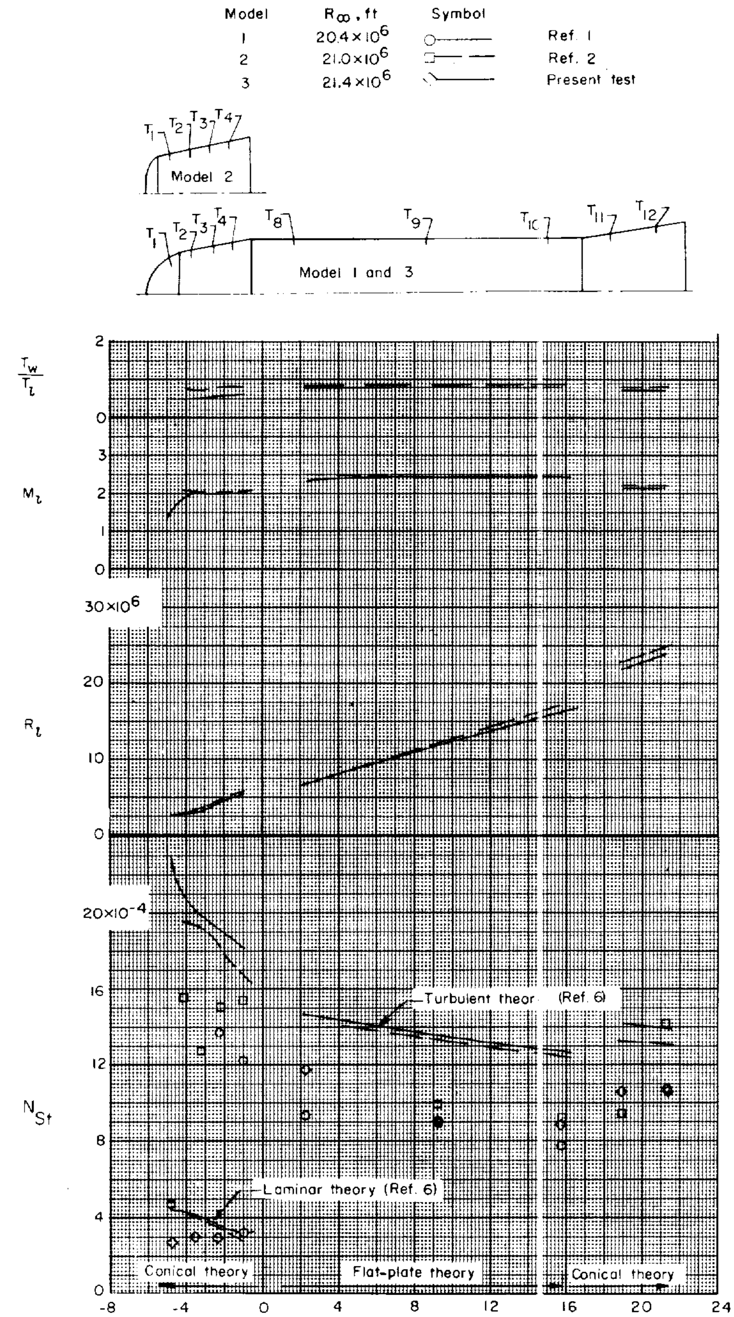


(b) $M_\infty = 3.0$.

Figure 7.- Continued.

[redacted]

[redacted]

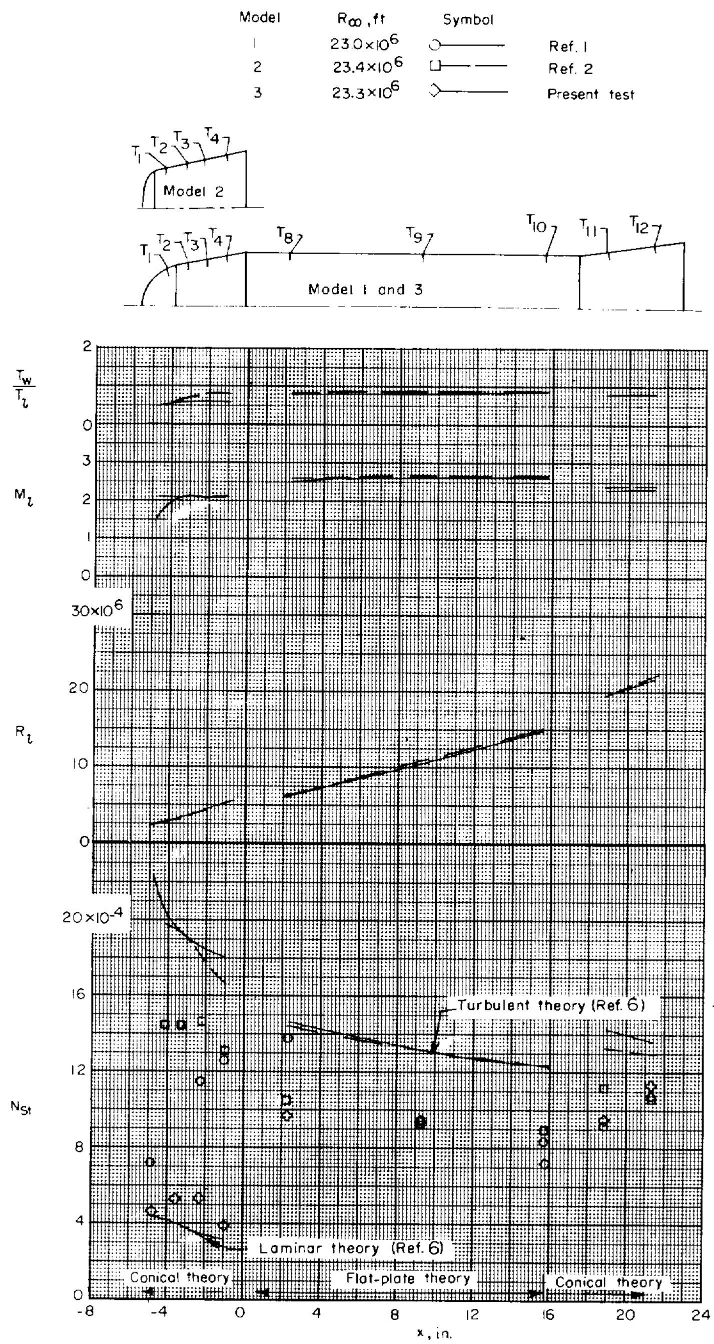


(c) $M_\infty = 3.35$.

Figure 7.- Continued.

[redacted]

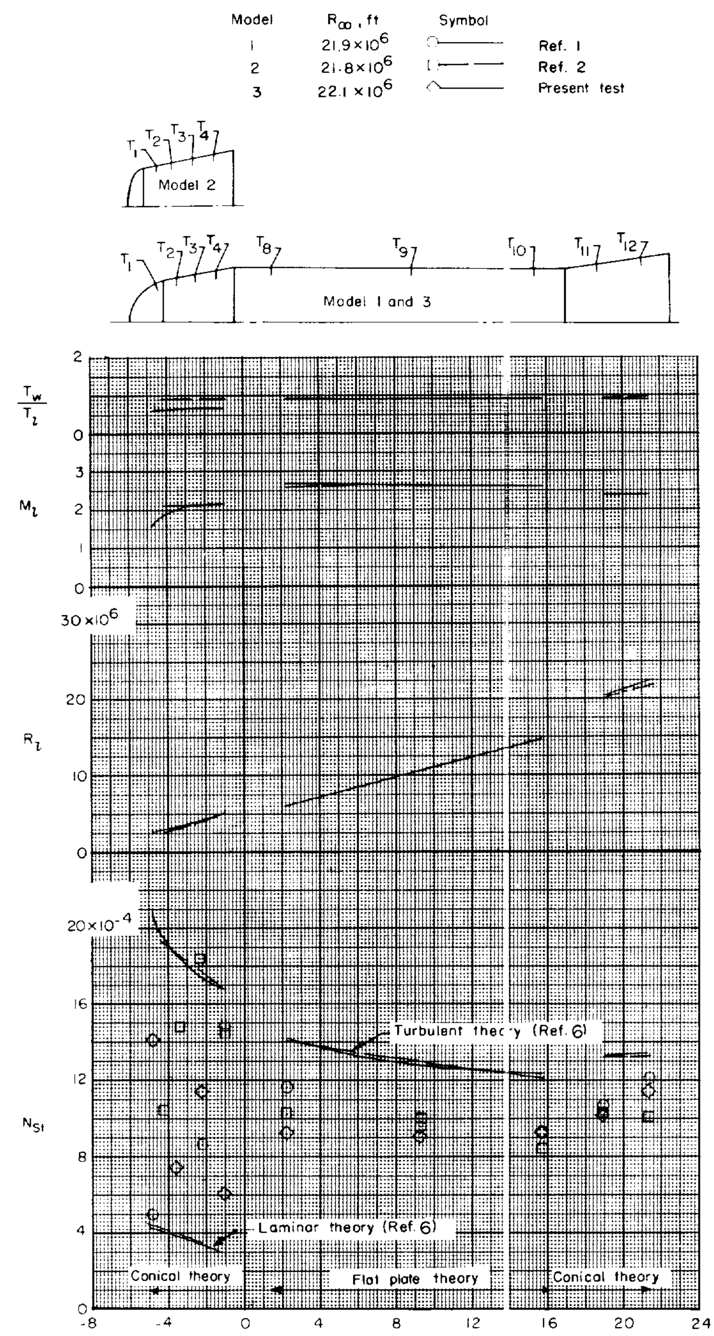
[redacted]



(d) $M_\infty = 3.88$.

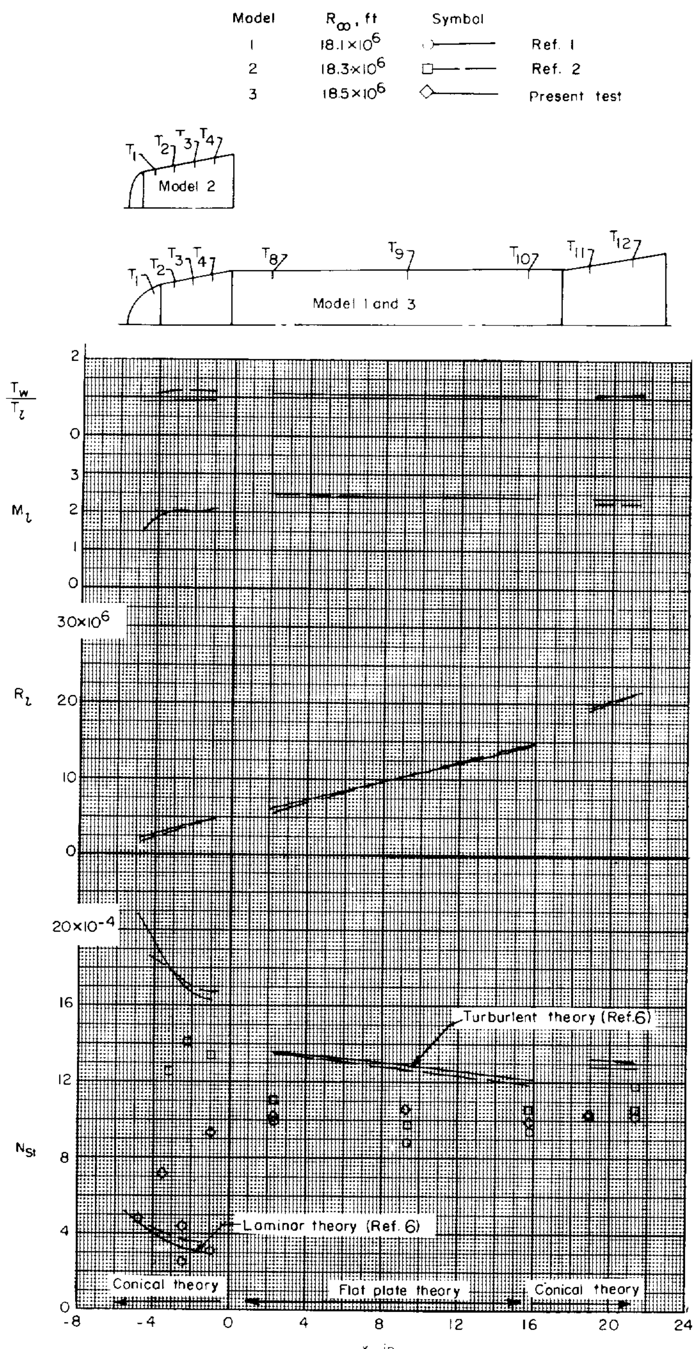
Figure 7.- Continued.

[redacted]



(e) $M_\infty = 3.80$.

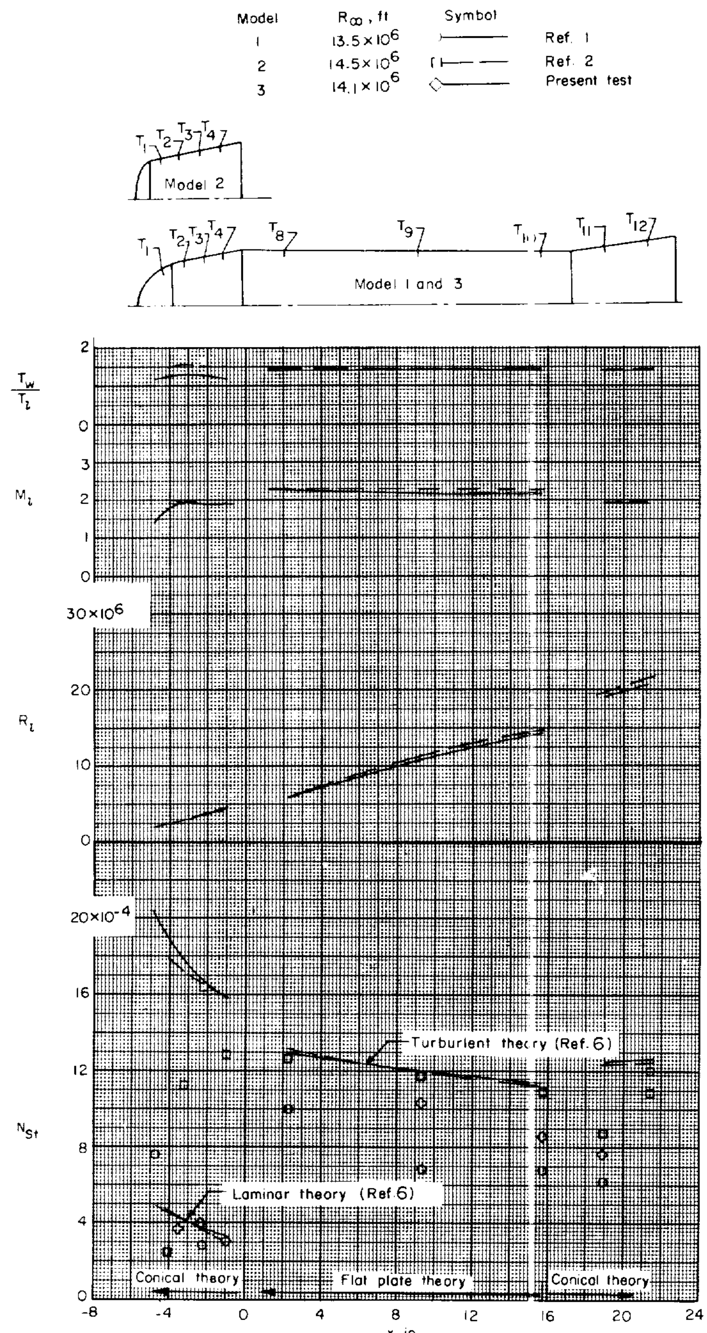
Figure 7.- Continued.



(f) $M_\infty = 3.36$.

Figure 7.- Continued.

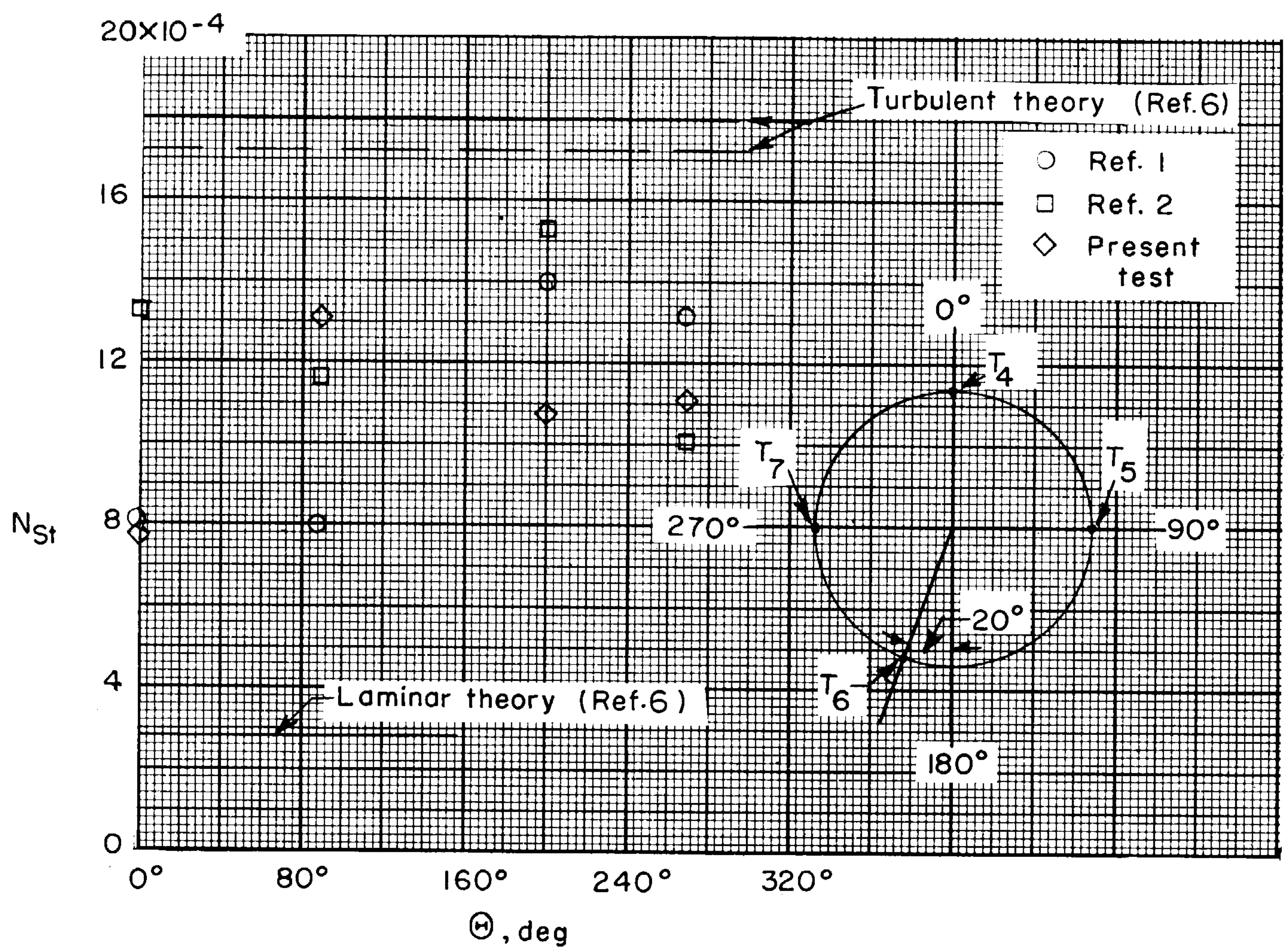
[redacted]



(g) $M_\infty = 2.80$.

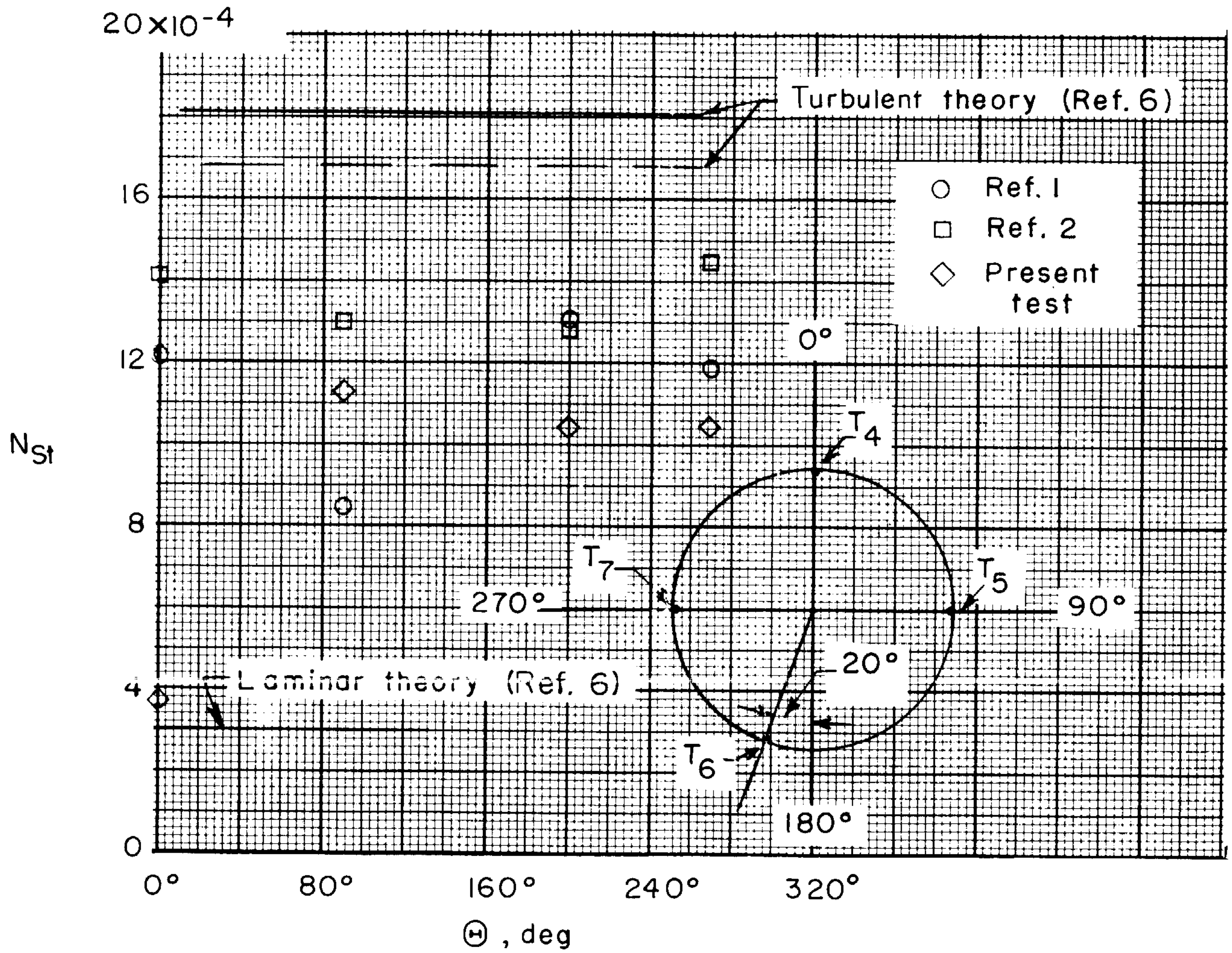
Figure 7.- Concluded.

[redacted]



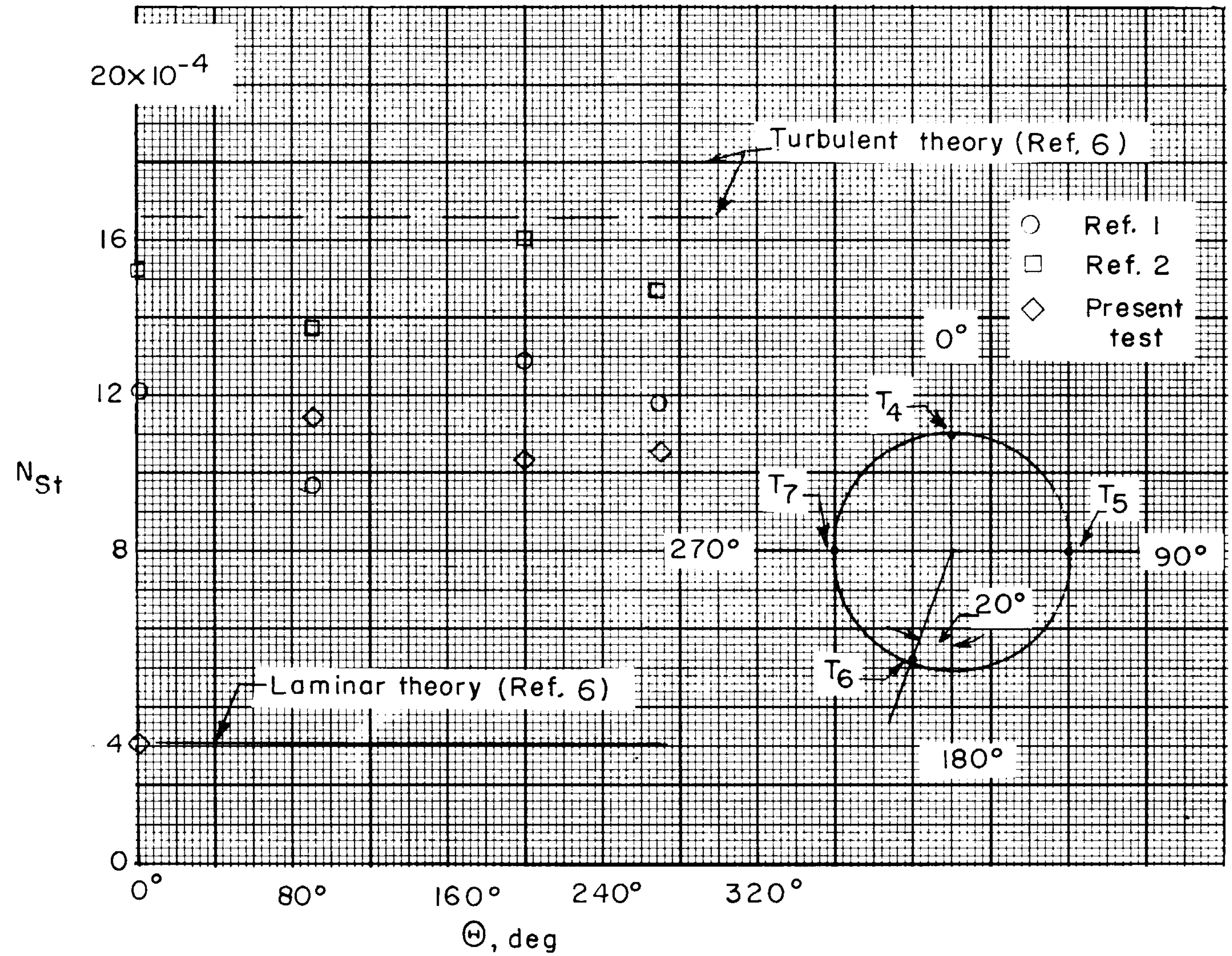
(a) $M_\infty = 2.15$.

Figure 8.- Variation of Stanton number around the body for model station, 1.00 inch.



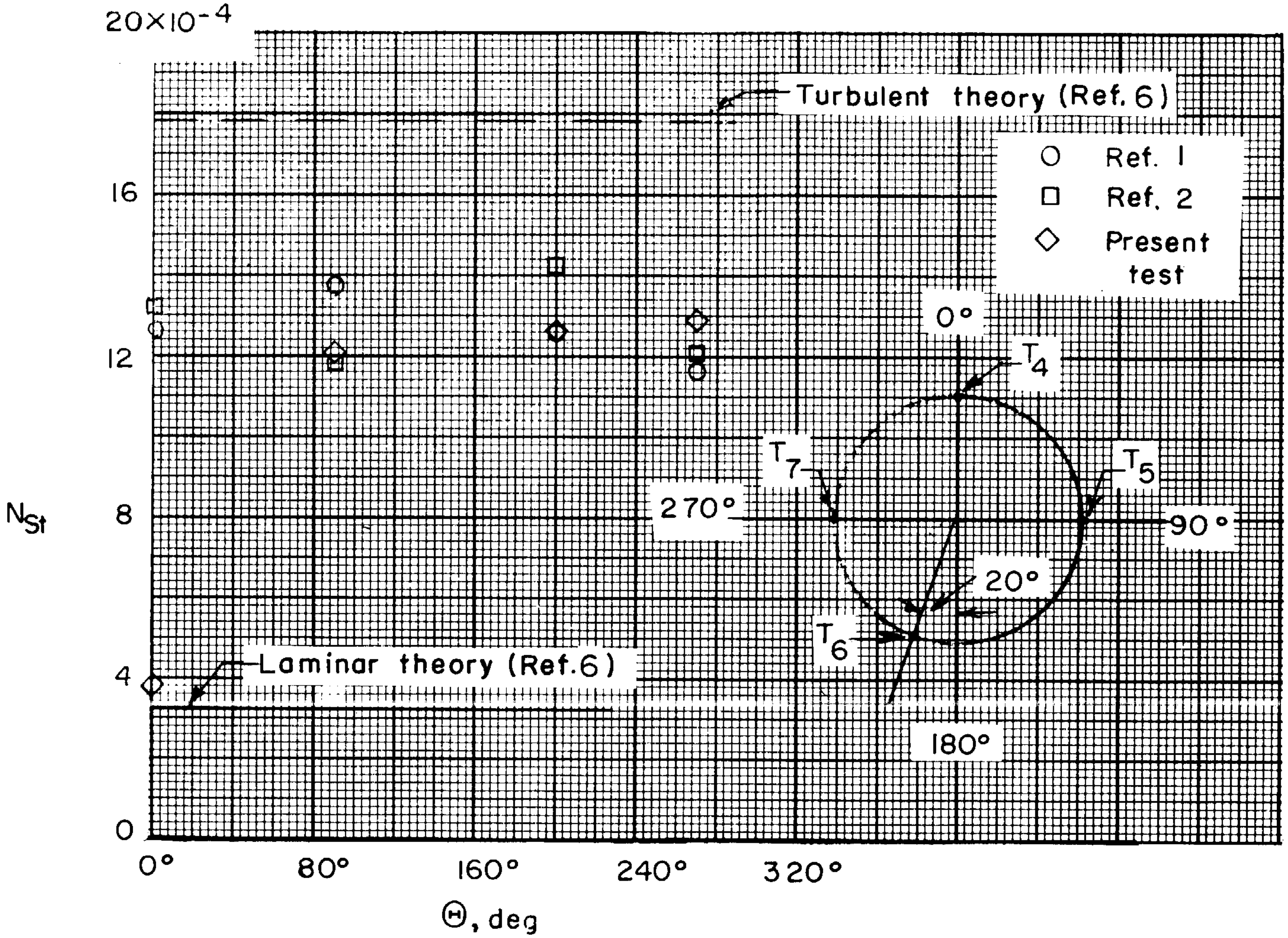
(b) $M_\infty = 3.0$.

Figure 8.- Continued.



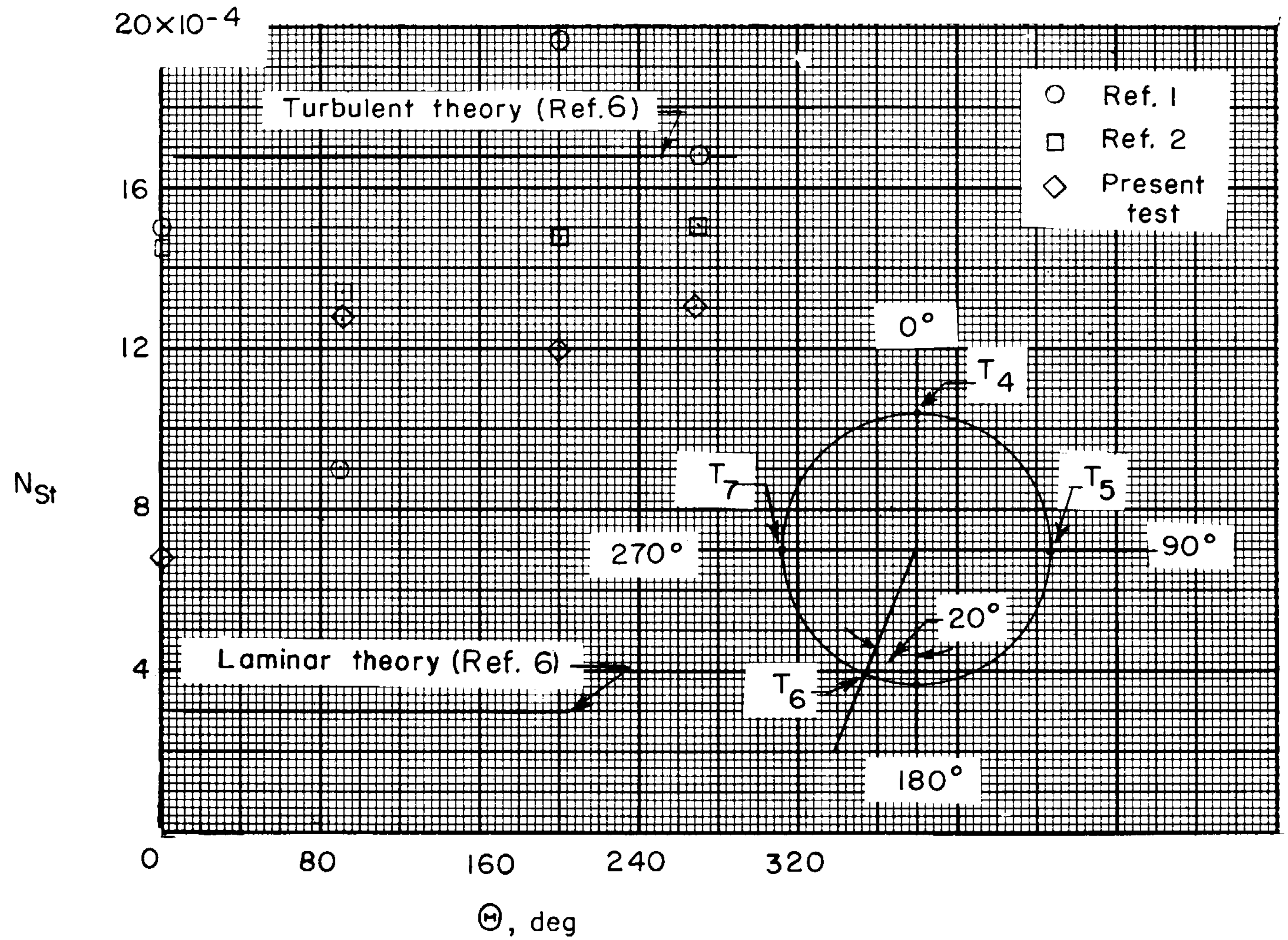
(c) $M_\infty = 3.35$.

Figure 8.- Continued.



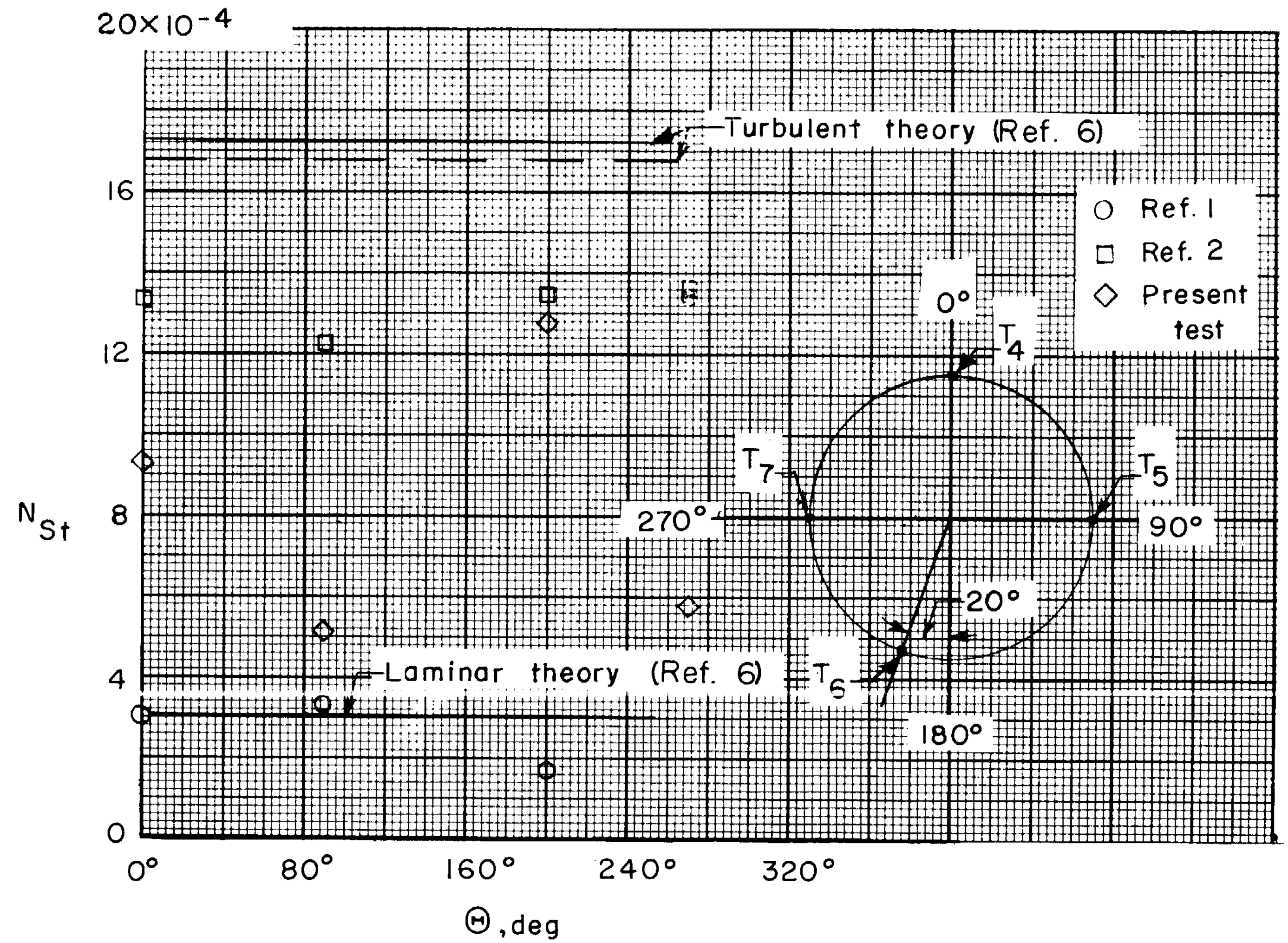
(d) $M_\infty = 3.88$.

Figure 8.- Continued.



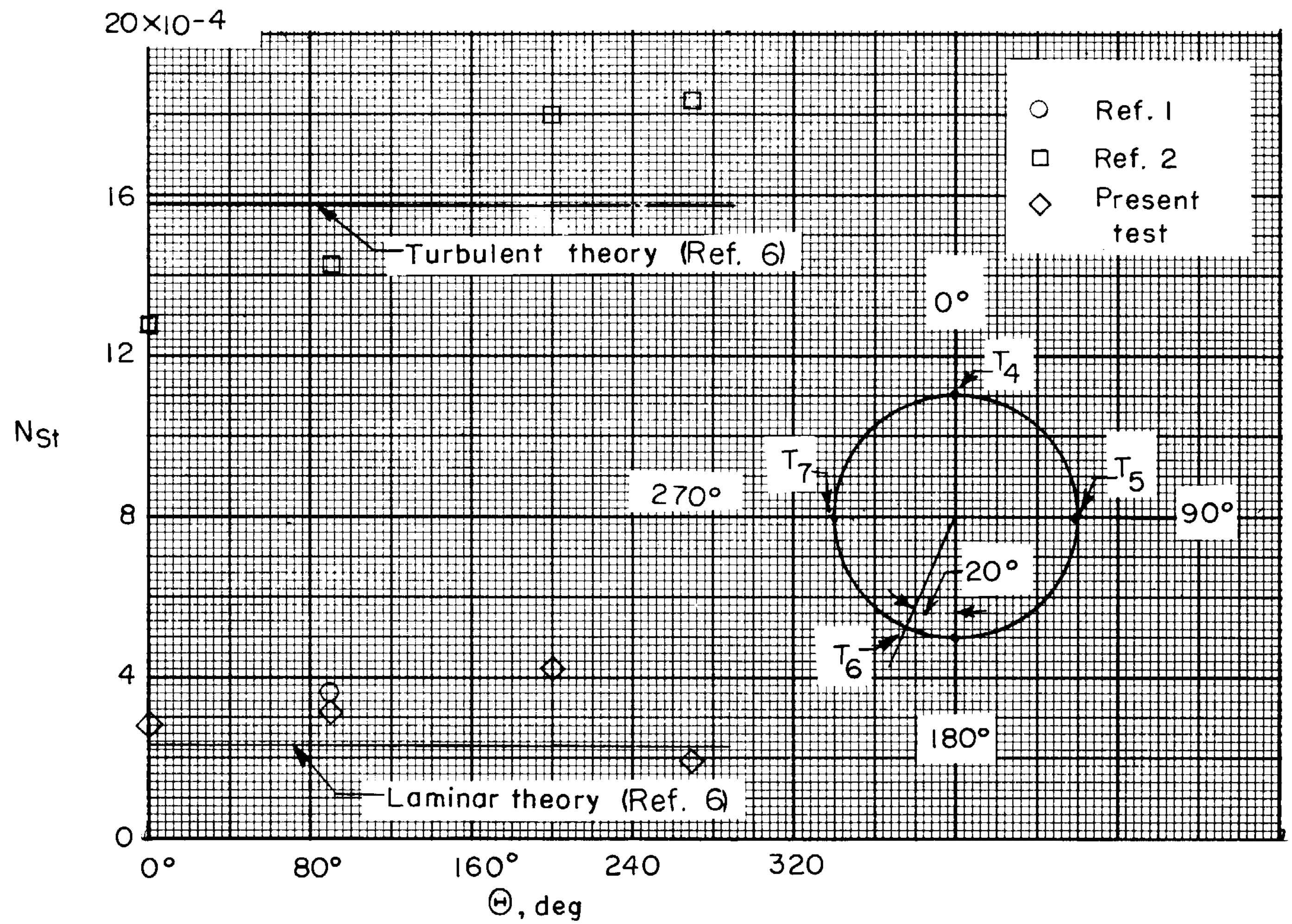
(e) $M_\infty = 3.80$.

Figure 8.- Continued.



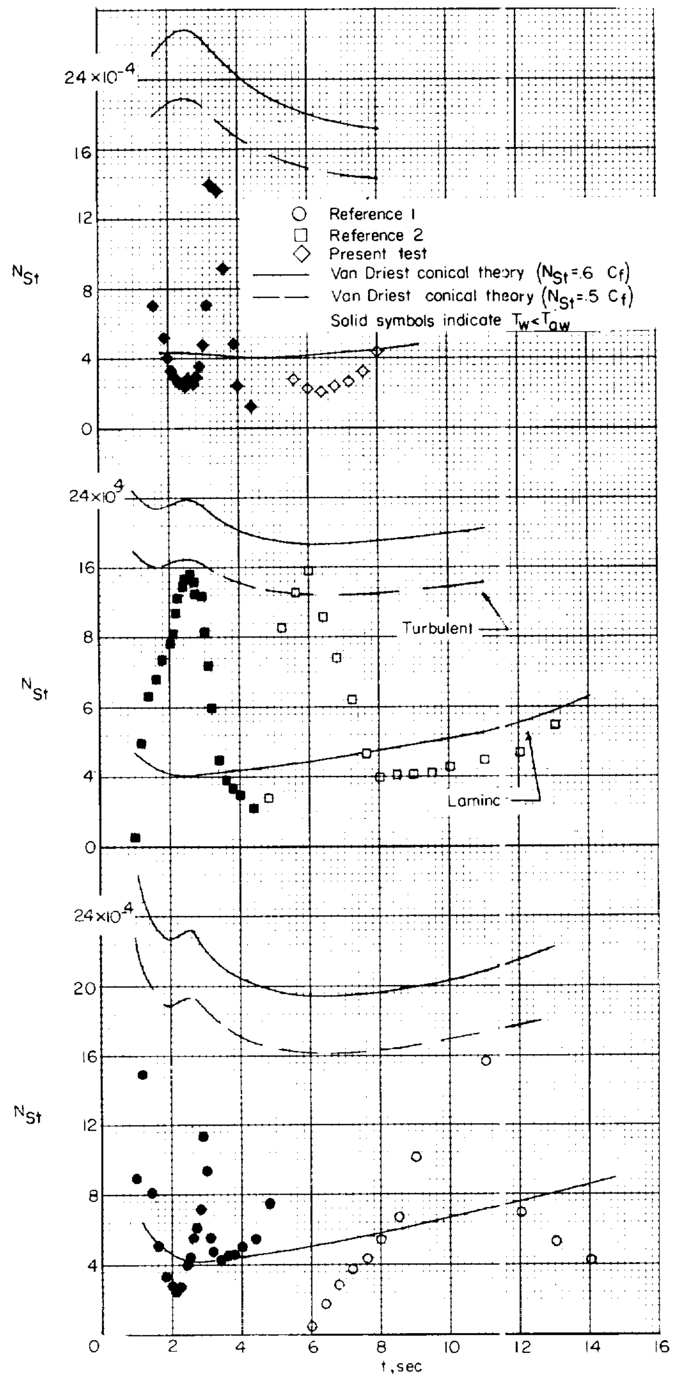
(f) $M_\infty = 3.36$.

Figure 8.- Continued.



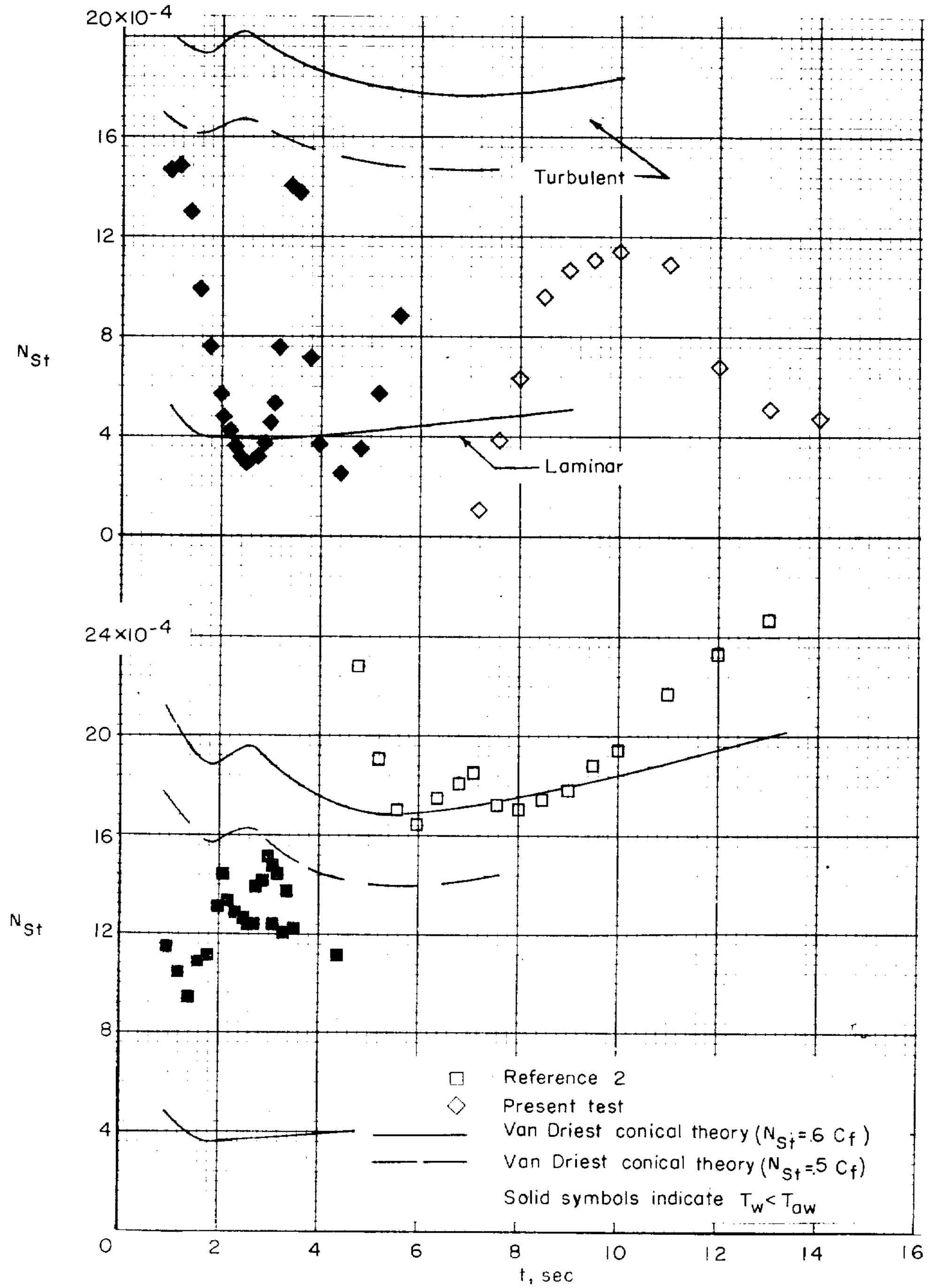
(g) $M_\infty = 2.80$.

Figure 8.- Concluded.



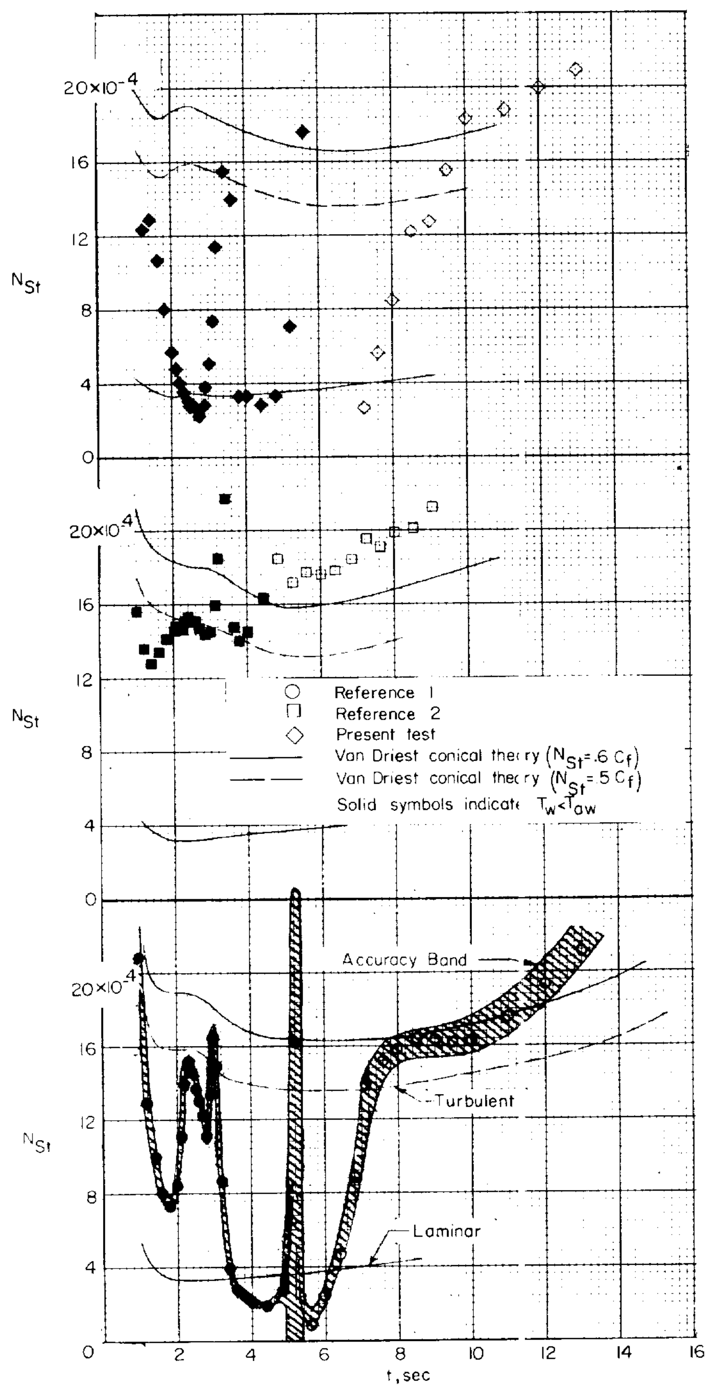
(a) Station T_1 (nose).

Figure 9.- Stanton number time histories for models 1, 2, and 3.



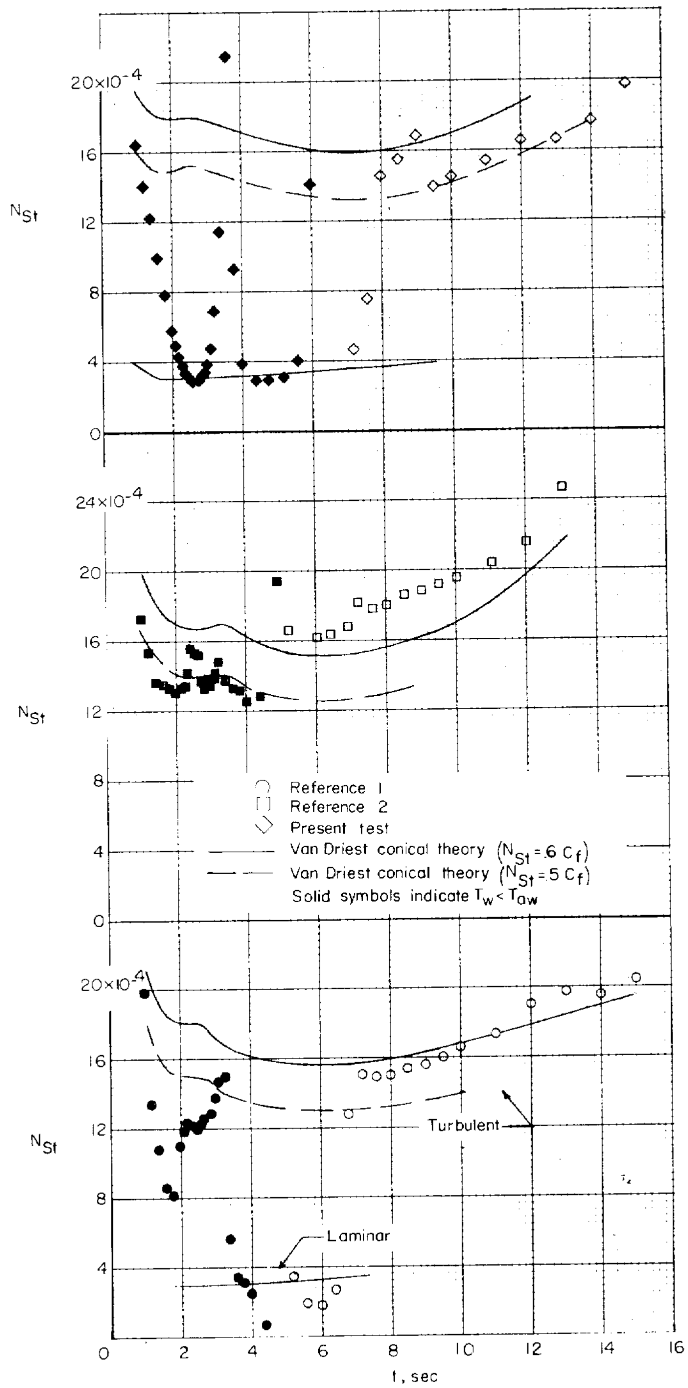
(b) Station T_2 (nose).

Figure 9.- Continued.



(c) Station T_3 (nose).

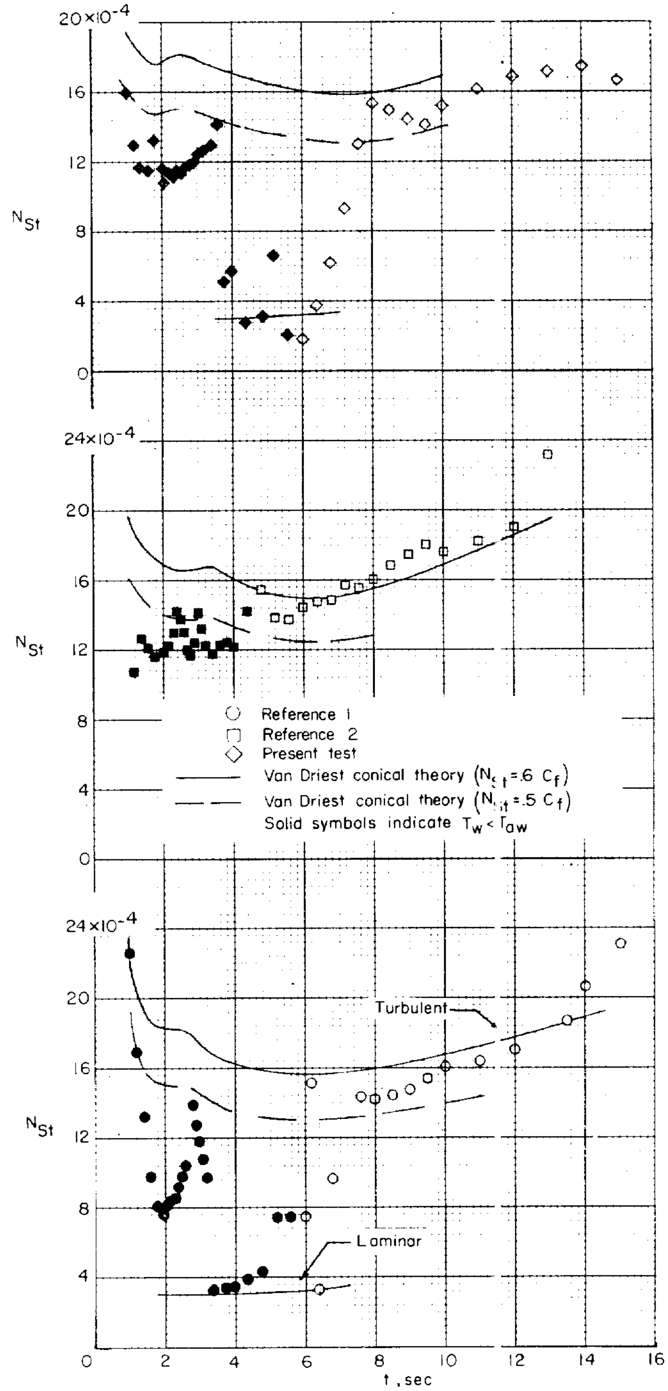
Figure 9.- Continued.



(d) Station T_4 (nose).

Figure 9.- Continued.

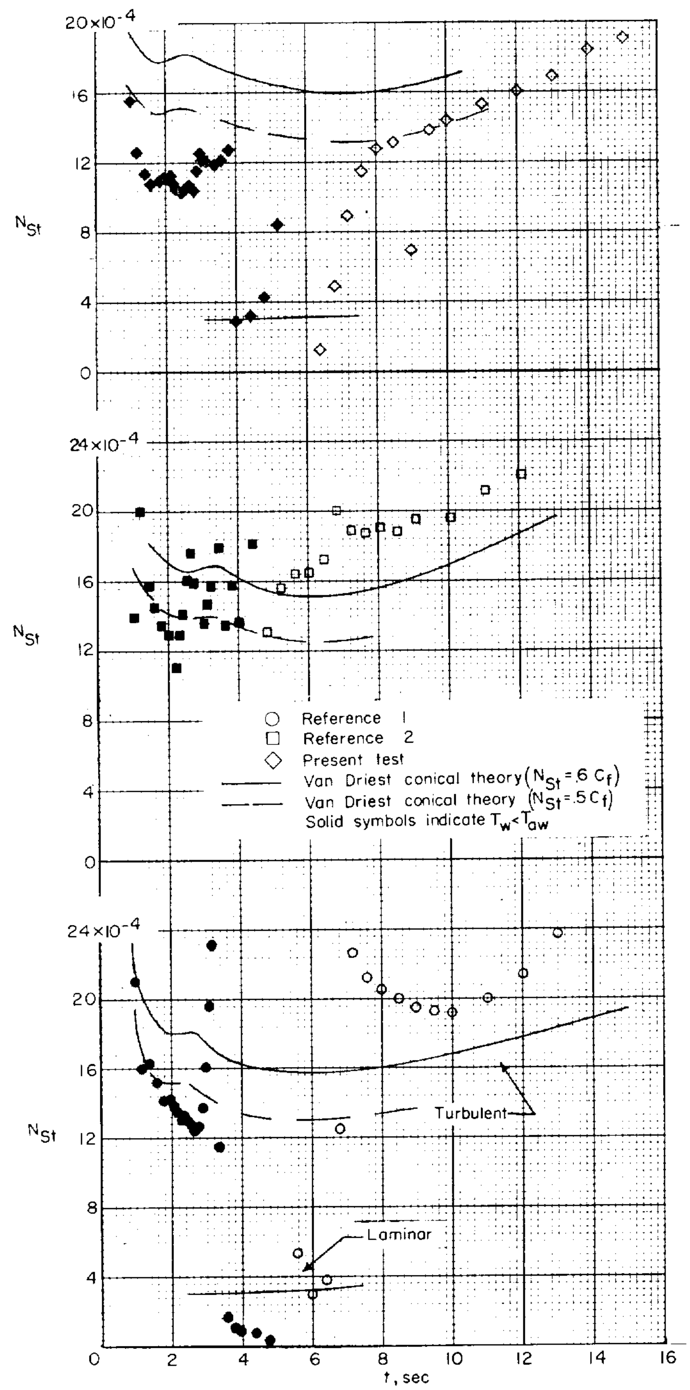
[redacted]



(e) Station T_5 (nose).

Figure 9.- Continued.

[redacted]

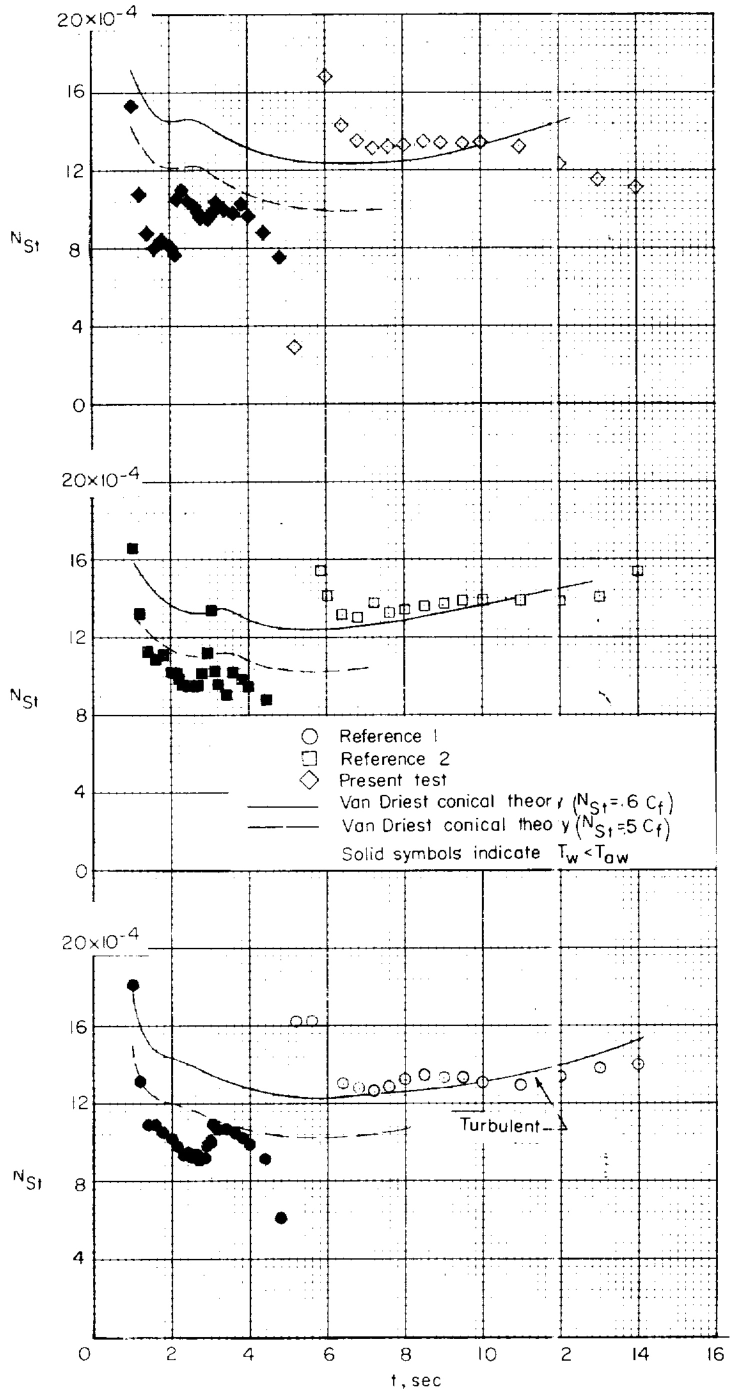


(f) Station T_6 (nose).

Figure 9.- Continued.

[redacted]

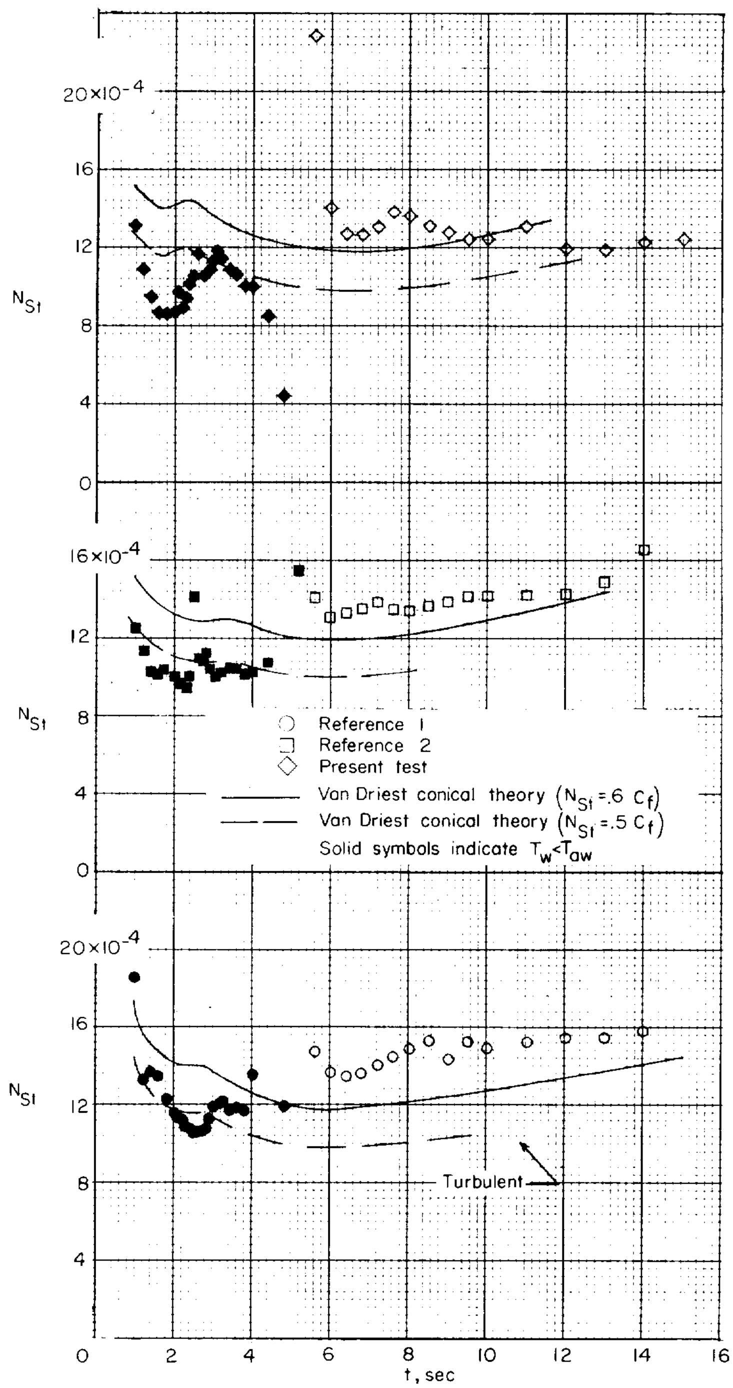
[redacted]



(k) Station T_{11} (flare).

Figure 9.- Continued.

[redacted]



(*l*) Station T_{12} (flare).

Figure 9.- Concluded.

[redacted]

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