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NACA

RESEARCH MEMORANDUM

for the

U. S. Air Force

HEAT-TRANSFER AND PRESSURE MEASUREMENTS FROM A FLIGHT TEST OF THE SECOND 1/18-SCALE MODEL OF THE TITAN INTERCONTINENTAL BALLISTIC MISSILE UP TO A MACH NUMBER OF 3.91 AND REYNOLDS NUMBER PER FOOT OF 23.4×10^6

COORD. NO. AF-AM-70

By John B. Graham, Jr.

Langley Aeronautical Laboratory
Langley Field, Va.

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NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

WASHINGTON

January 29, 1958

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Page 16: In column 9 on this page of table I, under the heading N_{St}, all values are in error and should be corrected by moving the decimal point four places to the right, so that the corrected values will be whole numbers consistent with values in other parts of this table. Thus, the first value should be 17.7×10^{-4} and subsequent values should be 12.6, 12.4 . . . 28.4.

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SUMMARY

Heat-transfer and pressure measurements were obtained from flight test of a 1/18-scale model of the Titan intercontinental ballistic missile up to a Mach number of 3.91 and Reynolds number per foot of 23.4×10^6. With the exception of one station on the nose, turbulent flow was observed over the model throughout flight. Heat-transfer coefficients presented for the accelerating portion of flight were approximately on the order of 20 percent lower than results obtained by available theories; however, during the decelerating portion of the flight, the data were in good agreement with theory. Drag coefficients of the configuration were obtained for a Mach number range of 1.5 to 3.5.

INTRODUCTION

At the request of the U. S. Air Force, the National Advisory Committee for Aeronautics is conducting flight tests of 1/18-scale models of the Titan intercontinental ballistic missile (ICBM). The purpose of these tests is to obtain detailed heat-transfer data to evaluate the calculating procedures used in making temperature estimates for the Titan ICBM design.

[redacted]

The results of the first flight test of the series are presented in reference 1. Results of the second flight test are reported herein. The present model differed from the first in the shape of the reentry nose. The nose design used in this test is designated by the contractor as P-13 whereas the nose used in the first test was designated as P-200.

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

Heat-transfer data in the form of Stanton numbers obtained from the flight measurements are presented herein. These Stanton numbers were reduced from measured wall temperatures and measured flight and wind-tunnel pressures. The Mach number range for which data were obtained was from 1.04 to 3.91 and the corresponding free-stream Reynolds number per foot ranged from 6.1×10^6 to 23.4×10^6.

Also presented herein are drag coefficients for Mach numbers from 1.5 to 3.5.

SYMBOLS

c_p	specific heat of air at constant pressure, Btu/slug-°R
$c_{p,w}$	specific heat of Inconel, Btu/lb-°R
C_p	pressure coefficient, $\dfrac{p_l - p_\infty}{q_\infty}$
h	heat-transfer coefficient, Btu/sec-ft^2-°R
H	altitude, ft
K	conductivity of air, Btu/sec-ft-°R
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 (see fig. 2)
p	pressure, lb/sq in.
q	dynamic pressure, $\rho V^2/2$, lb/sq in.
R	Reynolds number, $R_{\infty,1} = \dfrac{\rho V}{\mu}$ and $R_l = \dfrac{\rho V x}{\mu}$
η_r	recovery factor, $\dfrac{T_{aw} - T_l}{T_s - T_l}$
T	temperature, $^\circ R$
$T_1, T_2, \ldots T_{12}$	thermocouple stations (see fig. 2)
t	time, sec
V	velocity, ft/sec
x	distance along body from stagnation point, in.
ρ	density, slugs/cu ft
τ	thickness, ft
μ	viscosity of air, slugs/ft-sec

Subscripts:

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

MODEL

The model used in this test was a 1/18-scale Inconel model of the Titan ICBM mounted on the forward end of a Cajun rocket motor. Photographs of the model are presented in figure 1. A sketch of the model, with thermocouple locations, pressure pickups, and skin thicknesses, is presented in figure 2. The nose used in this test is designated by the contractor as P-13; a detail of this nose is presented in figure 2(b). The nose was polished to a surface roughness of 4 to 8 microinches (measured from peak to valley by an interference microscope) and had seven thermocouples and four pressure pickups. With the exception of the stagnation pressure pickup, the pressures are located diametrically opposite the corresponding temperature measuring stations.

The cylinder-flare portion of the model was polished to a surface roughness of 8 to 12 microinches. There were three thermocouples and one pressure pickup on the cylinder, and two thermocouples and two pressure pickups on the flare. The flare angle was 7.5°.

INSTRUMENTATION AND TESTS

The model was instrumented with a standard NACA 10-channel telemeter. One channel was used in transmitting measured temperature data, seven channels were used in transmitting pressure data, and two channels were used to transmit longitudinal accelerations. Temperature measurements were made at 12 stations along the body. (See fig. 2.) These measurements were commutated during flight at such a rate that every measurement was sampled at about every 0.2 second. The pressures and accelerations were measured continuously during flight.

The model was launched at an elevation angle of $67^{\circ}42'$ with respect to the horizontal. The Cajun rocket motor accelerated the model to a Mach number of 3.91 at an altitude of 5,450 feet. Velocity data were obtained by means of CW Doppler radar, and altitude and flight path were measured with an NACA modified SCR-584 tracking radar. Atmospheric and wind conditions were measured by radiosonde ballons launched near the time of flight and tracked with a Rawin set AW/GMD-1A. Atmospheric conditions and altitude related to model flight time are shown in figure 3. Free-stream Mach number and free-stream Reynolds number per foot are shown plotted against time in figure 4.

DATA REDUCTION

From flight records of the model, the following information was obtained:

(1) Atmospheric properties and altitude (fig. 3).

(2) Free-stream Mach and Reynolds numbers (fig. 4).

(3) Pressure coefficients (fig. 5).

(4) Skin-temperature measurements (fig. 6).

(5) Stanton numbers (fig. 7).

(6) Drag coefficients (fig. 8).

From measured wall temperatures, flight conditions, and measured pressures, Stanton numbers $(N_{St} = h/c_p \rho V)$ were obtained by using the following relation:

$$N_{St}(c_p \rho V)_l = \frac{(\tau\rho)_w c_{p,w}}{T_{aw} - T_w} \frac{dT_w}{dt}$$

Heat losses due to conduction and radiation were found to be negligible when compared with heat transfer caused by convection. The skin thickness τ_w was measured and the density ρ_w of the Inconel was known. The specific heat of Inconel $c_{p,w}$ is given in reference 2 as a function of temperature. The adiabatic-wall temperature T_{aw} was computed from the relation

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

where the recovery factor η_r was determined from the usual turbulent relation $\eta_r = {N_{Pr}}^{1/3}$ with Prandtl number evaluated at the wall temperature.

A discussion of the accuracy of the heat-transfer coefficients obtained from data measured in free flight is presented in appendix A of reference 3. Measured skin temperatures of the test model have a calculated error of $\pm 22^\circ$.

The local conditions for the test model were obtained by using measured pressures and normal shock relations (ref. 4).

Tabulated data pertinent to the test are given in table I for all thermocouple locations.

RESULTS AND DISCUSSION

Pressure Measurements

The measured pressures on the body are shown in figure 5 and are expressed as pressure coefficients as a function of free-stream Mach number for both the accelerating and decelerating period of flight. Also presented in figure 5, for comparison, are unpublished wind-tunnel pressure coefficients at various Mach numbers, for the same configuration as the free-flight model. These 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), pressure coefficients are presented for the nose conical section having a 9° semiangle, designated C_{p_2}, and for the nose conical section having an 11° semiangle, designated C_{p_3} and C_{p_4}. The pressure coefficients at these stations are in good agreement with the given wind-tunnel data. Also presented in figure 5(a), for stations P_3 and P_4, designated C_{p_3} and C_{p_4} in the figure, are free-flight pressure coefficients on an 11° semiangle conical section described in reference 1.

In figure 5(b), pressure coefficients on the cylinder-flare portion of the model are given. These measurements are in good agreement with the given wind-tunnel data.

Heat Transfer

Figure 6 presents the variation of measured wall temperature with time for all 12 thermocouple stations. In figure 6(c) the measured data points for station T_8 are presented in order to illustrate the fairing accuracy of the temperature curves. Figure 7 presents measured heat-transfer coefficients expressed as local Stanton number N_{St} as a function of distance along the body from the stagnation point to the measurement temperature station. Because no pressure measurements were taken at stations T_2, T_9, and T_{10}, the local Stanton numbers for these stations were calculated by using wind-tunnel pressure measurements. The Stanton numbers for the remaining stations were calculated by using the local measured pressure at these stations. Also presented in figure 7 are the results obtained by the Van Driest theory for laminar and turbulent flow (ref. 5) over both flat and conical regions. Theoretical Stanton number was assumed equal to 0.6 of the skin friction coefficient.

Figures 7(a) to 7(c) present Stanton numbers for the earlier portion of the flight and indicate that the flow over all stations is turbulent. The data presented are approximately 20 percent lower than the results obtained by the Van Driest turbulent theory for both the flat-plate and conical regions where the theory is based on length from the stagnation point and local condition. This same difference on the cylinder flare was also observed in reference 1 for approximately the same flight conditions.

In figures 7(d) to 7(j), all stations appear to be turbulent except for station T_1 $(x = -4.06)$, which is located on the 9° semiangle nose conical section. At Mach number 3.55, during the decelerating portion of flight, station T_1 abruptly turns laminar and remains laminar until the model has decelerated to Mach number 2.26. A short burst of turbulent flow is present until Mach number 1.67. The flow then returns laminar and remains laminar for the remaining time for which data are presented. These sudden changes in flow at station T_1 can also be seen in the temperature time curve of figure 6(a) where the curve for station T_1 suddenly flattens. This curve also shows that the flow after 13.3 seconds might be turbulent.

The data in figures 7(d) to 7(j), for the cylinder flare, agree better with the Van Driest turbulent theory at the latter part of flight. This was also observed in reference 1. The data for the laminar periods of flow agree well with the Van Driest laminar theory of reference 5.

Drag Measurement

Drag coefficients for the complete configuration were measured during the decelerating portion of the flight and are presented in figure 8 as a function of free-stream Mach number. In order to evaluate the drag coefficient of the test model, drag for the Cajun, fins, base, and antenna had to be obtained either experimentally or by calculation. Drag of the Cajun and fins was obtained from reference 6, and the base drag was obtained from reference 7. The fins used in this test were identical to the fins used in reference 6. The drag coefficient for the Titan model shown in the lower part of figure 8 is based on the diameter at the base of the model, 0.2485 square foot, and excludes base drag.

CONCLUDING REMARKS

A flight test has been made of a second 1/18-scale model of the Titan missile up to a Mach number of 3.91 and Reynolds number per foot of 23.4×10^6. With the exception of the foremost measuring station, turbulent heating rates were measured over the model during the flight. The heat-transfer data over the body were approximately 20 percent lower than the results obtained by the Van Driest theory during the accelerating portion of flight, but were in much closer agreement during the decelerating portion of the flight. Drag coefficients were also obtained for a Mach number range of 1.5 to 3.5.

Langley Aeronautical Laboratory,
National Advisory Committee for Aeronautics,
Langley Field, Va., January 20, 1958.

REFERENCES

1. Graham, John B., Jr., Chauvin, Leo T., and Speegle, Katherine C.: Heat-Transfer and Pressure Measurements From a Flight Test of a 1/18-Scale Model of the Titan Intercontinental Ballistic Missile Up to a Mach Number of 3.95 and Reynolds Number Per Foot of 23×10^6. NACA RM SL57L16a, 1957.

2. Ginnings, Defoe C., and Thomas, Eugenia: The Electrical Resistance and Total Radiant Emittance of Inconel in the Range 0° to 1000° C. NBS Rep. 4111 (NACA Contract S54-52), Nat. Bur. Standards, May 1955.

3. Piland, Robert O., Collie, Katherine A., and Stoney, William E.: Turbulent and Laminar Heat-Transfer Measurements on a 1/6-Scale NACA RM-10 Missile in Free Flight to a Mach Number of 4.2 and to a Wall Temperature of 1400° R. NACA RM L56C05, 1956.

4. Ames Research Staff: Equation, Tables, and Charts for Compressible Flow. NACA Rep. 1135, 1953. (Supersedes NACA TN 1428.)

5. Van Driest, E. R.: The Problem of Aerodynamic Heating. Aero. Eng. Rev., vol. 15, no. 10, Oct. 1956, pp. 26-41.

6. Lee, Dorothy B.: Flight Performance of a 2.8 KS 8100 Cajun Solid-Propellant Rocket Motor. NACA RM L56K01, 1957.

7. Love, Eugene S.: Base Pressure at Supersonic Speeds on Two-Dimensional Airfoils and on Bodies of Revolution With and Without Fins Having Turbulent Boundary Layers. NACA TN 3819, 1957. (Supersedes NACA RM L53C02.)

TABLE I.- TEST DATA

(a) Thermocouple 1

t	M_∞	M_l	T_l	T_w	$\frac{dT_w}{dt}$	h	$c_p \rho_l V_l$	N_{St}	R_l
1.0	1.04	1.605	421	528	0.5	0.000915	16.372	0.559×10^{-4}	1.67×10^{6}
1.2	1.31	1.73	440	528	10.5	.011367	19.308	5.887	1.91
1.4	1.61	1.83	476	533	28.4	.020016	22.981	8.710	2.12
1.6	1.88	1.91	514	540	51	.026474	27.306	9.695	2.36
1.8	2.16	1.96	572	555	86	.033795	31.640	10.681	2.53
2.0	2.49	2.005	642	575	141	.043259	36.960	11.704	2.70
2.1	2.66	2.02	685	591	175	.048007	39.137	12.266	2.73
2.2	2.84	2.045	732	613	227.5	.055991	41.688	13.431	2.76
2.3	3.03	2.06	789	638	284	.062686	43.888	14.283	2.74
2.4	3.21	2.08	836	668	340	.069647	46.498	14.978	2.77
2.5	3.40	2.10	893	707	397.5	.075581	48.952	15.440	2.77
2.6	3.59	2.12	944	744	452.5	.080601	51.906	15.582	2.81
2.7	3.75	2.14	1,020	787	510	.082342	54.143	15.208	2.76
2.8	3.87	2.14	1,073	835	522.5	.081838	56.280	14.541	2.76
2.9	3.91	2.135	1,086	891	505	.082832	57.366	14.439	2.79
3.0	3.88	2.125	1,078	940	390	.069425	56.205	12.352	2.75
3.1	3.82	2.11	1,052	980	282.5	.056324	53.673	10.494	2.67
3.2	3.73	2.10	1,016	1,005	182.5	.040929	51.297	7.979	2.62
3.4	3.55	2.10	946	1,030	84	.023348	46.786	4.990	2.53
3.6	3.38	2.08	895	1,043	49	.016611	42.760	3.884	2.42
3.8	3.23	2.07	842	1,050	32	.013595	39.814	3.415	2.36
4.0	3.08	2.06	790	1,054	20.8	.011593	37.231	3.114	2.32
4.4	2.83	2.04	701	1,060	6.5	.007714	32.744	2.356	2.24
4.8	2.62	2.005	647	1,060	-2	.008254	28.782	2.868	2.09
5.2	2.43	1.98	600	1,059	-8.2	.032370	25.762	12.565	1.98
5.6	2.26	1.95	561	1,053	-22	.034060	23.246	14.652	1.88
6.0	2.11	1.93	528	1,041	-31	.033341	21.027	15.856	1.78
6.4	1.98	1.905	500	1,030	-29.5	.025220	19.148	13.171	1.70
6.8	1.87	1.875	480	1,018	-25.4	.018870	17.551	10.752	1.61
7.2	1.77	1.84	469	1,010	-20	.013766	16.061	8.571	1.51
7.6	1.67	1.81	449	1,003	-13	.007897	14.904	5.299	1.45
8.0	1.59	1.81	431	998	-10	.005626	13.963	4.029	1.40
8.5	1.49	1.79	417	993	-10	.005246	12.595	4.165	1.29
9.0	1.41	1.77	401	988	-10	.004897	11.621	4.214	1.23
9.5	1.33	1.76	389	983	-10	.004679	10.683	4.380	1.17
10	1.26	1.75	377	978	-9.9	.004439	9.828	4.512	1.10
11	1.14	1.75	358	969	-9.8	.004170	8.353	4.992	.98
12	1.04	1.74	344	959	-9.7	.003983	7.348	5.421	.89
13	.96	1.72	336	950	-11.4	.004592	6.688	6.866	.83
14	.90	1.25	395	925	-31.5	.013152	7.852	16.750	.85
15	.85								

TABLE I.- TEST DATA - Continued

(b) Thermocouple 2

t	M_∞	M_l	T_l	T_w	$\frac{dT_w}{dt}$	h	$c_p \rho_l V_l$	N_{St}	R_l
1.0	1.04	1.101	512	527	14.2	0.023460	20.435	11.48×10^{-4}	2.169×10^{6}
1.2	1.31	1.322	521	531	24.5	.025855	24.697	10.47	2.578
1.4	1.61	1.516	544	537	38.3	.026904	28.462	9.45	2.862
1.6	1.88	1.738	555	548	62.5	.033025	30.402	10.86	3.018
1.8	2.16	1.770	620	566	101.6	.040998	36.918	11.11	3.364
2.0	2.49	1.870	675	593	171.0	.054688	41.821	13.08	3.575
2.1	2.66	1.902	724	612	203.8	.063367	43.519	14.56	3.530
2.2	2.84	1.934	769	634	237.5	.060859	45.063	13.51	3.489
2.3	3.03	1.973	819	660	268.0	.061638	47.620	12.94	3.493
2.4	3.21	1.999	868	690	302.2	.064247	50.185	12.80	3.532
2.5	3.40	2.033	935	725	336.0	.065598	52.012	12.61	3.450
2.6	3.59	2.064	968	764	368.5	.067804	55.000	12.33	3.542
2.7	3.75	2.086	1,045	808	418.5	.069783	56.575	12.33	3.441
2.8	3.87	2.100	1,092	856	495.9	.080152	57.668	13.90	3.394
2.9	3.91	2.104	1,101	905	489.0	.082121	57.740	14.22	3.373
3.0	3.88	2.105	1,089	954	466.0	.085014	55.777	15.24	3.289
3.1	3.82	2.09	1,059	995	396.5	.081225	54.730	14.84	3.291
3.2	3.73	2.08	1,027	1,030	325	.076253	52.401	14.55	3.231
3.4	3.55	2.06	964	1,083	217.5	.066849	48.600	13.75	3.147
3.6	3.38	2.03	914	1,120	139.0	.056071	45.082	12.44	3.045
3.8	3.23	2.000	870	1,144	92.0	.051056	42.362	12.05	2.976
4.0	3.08	1.98	819	1,160	58.8	.049179	39.943	12.31	2.944
4.4	2.83	1.954	728	1,173	9.2	.039093	35.052	11.15	2.830
4.8	2.62	1.890	680	1,168	-22.3	.069433	31.765	21.86	2.697
5.2	2.43	1.850	634	1,156	-40.5	.054693	28.713	19.05	2.572
5.6	2.26	1.800	600	1,138	-47.5	.044789	26.268	17.05	2.453
6.0	2.11	1.770	567	1,118	-52.1	.040161	24.419	16.45	2.381
6.4	1.98	1.760	533	1,096	-55.4	.037359	21.376	17.48	2.184
6.8	1.87	1.730	511	1,073	-57.0	.035697	19.586	18.23	2.073
7.2	1.77	1.655	509	1,049	-55.6	.034269	18.489	18.53	1.962
7.6	1.67	1.580	496	1,025	-52.6	.030703	17.812	17.24	1.933
8.0	1.59	1.510	490	1,001	-50.8	.029223	17.038	17.15	1.865
8.5	1.49	1.450	480	976	-49.1	.027837	15.847	17.57	1.769
9.0	1.41	1.390	471	960	-48.3	.026296	14.749	17.83	1.670
9.5	1.33	1.335	464	937	-47.4	.025811	13.699	18.84	1.570
10	1.26	1.280	454	914	-46.0	.025117	12.895	19.48	1.505
11	1.14	1.190	448	869	-43.0	.024501	11.319	21.65	1.341
12	1.04	1.100	444	828	-39.0	.023459	10.060	23.32	1.199
13	.96	1.040	438	791	-34.7	.022313	9.042	24.68	1.084
14	.90	.990	434	767	-16.0	.010580	8.209	12.89	.990
15	.85								

[redacted]

TABLE I.- TEST DATA - Continued

(c) Thermocouple 3

t	M_∞	M_l	T_l	T_w	$\frac{dT_w}{dt}$	h	$c_p \rho_l V_l$	N_{St}	R_l
1.0	1.04	0.99	534	531	17.5	0.03218	20.62	15.67×10^{-4}	2.716×10^6
1.2	1.31	1.23	540	536	29.5	.03497	25.60	13.66	3.345
1.4	1.61	1.42	570	544	49.5	.03876	30.02	12.91	3.775
1.6	1.88	1.58	593	557	78	.04632	34.51	13.42	4.204
1.8	2.16	1.71	638	576	120	.05430	38.24	14.20	4.410
2.0	2.49	1.84	691	605	173	.06205	42.40	14.63	4.609
2.1	2.66	1.88	729	624	205	.06568	43.97	14.94	4.589
2.2	2.84	1.93	771	645	238	.06777	45.85	14.78	4.589
2.3	3.03	1.97	821	673	280	.07151	41.70	17.15	4.535
2.4	3.21	2.006	865	701	325	.07646	50.01	15.29	4.531
2.5	3.40	2.05	913	736	365	.07873	52.43	15.02	4.550
2.6	3.59	2.08	961	773	405	.08159	53.95	15.12	4.527
2.7	3.75	2.12	1,030	813	445	.08059	55.10	14.63	4.375
2.8	3.87	2.13	1,077	858	466	.08121	56.60	14.35	4.347
2.9	3.91	2.13	1,089	905	460	.08287	56.75	14.60	4.320
3.0	3.88	2.12	1,081	958	449	.08866	55.73	15.91	4.273
3.1	3.82	2.10	1,056	997	443	.09935	53.97	18.41	4.211
3.2	3.73	2.09	1,020	1,029	440	.11371	52.03	21.86	4.164
3.4	3.55	2.06	963	1,083	211	.07130	48.46	14.71	4.067
3.6	3.38	2.03	915	1,118	144	.06344	45.07	14.08	3.930
3.8	3.23	1.995	870	1,142	101.5	.06148	42.50	14.47	3.853
4.0	3.08	1.97	822	1,158	68	.06178	39.97	15.46	3.792
4.4	2.83	1.92	739	1,174	13	.05923	36.26	16.33	3.735
4.8	2.62	1.86	690	1,173	-18.5	.06020	32.62	18.45	3.546
5.2	2.43	1.80	649	1,161	-35.5	.05114	29.76	17.18	3.383
5.6	2.26	1.75	613	1,143	-47.3	.04828	27.35	17.65	3.246
6.0	2.11	1.70	584	1,123	-53.2	.04453	25.31	17.59	3.110
6.4	1.98	1.64	561	1,101	-56.5	.04164	23.40	17.79	2.971
6.8	1.87	1.58	545	1,078	-57.6	.03956	21.55	18.36	2.803
7.2	1.77	1.53	536	1,056	-57.8	.03892	20.00	19.46	2.635
7.6	1.67	1.49	515	1,033	-57.1	.03613	18.88	19.14	2.562
8.0	1.59	1.44	505	1,010	-56.7	.03504	17.64	19.86	2.440
8.5	1.49	1.38	495	982	-55.7	.03394	16.32	20.80	2.290
9.0	1.41	1.33	482	954	-54	.03228	15.25	21.17	2.188
9.5	1.33	1.27	476	923	-51.2	.03115	14.08	22.12	2.043
10	1.26	1.22	469	903	-47.6	.02889	13.18	21.92	1.935
11	1.14	1.105	464	859	-41.8	.02658	11.47	23.17	1.699
12	1.04	.97	465	820	-57.0	.03831	10.17	37.67	1.507
13	.96	.905	459	785	-52.3	.03738	8.991	41.57	1.344
14	.90	1.03	427	753	-52.4	.03933	8.224	47.82	1.307
15	.85								

TABLE I.- TEST DATA - Continued

(d) Thermocouple 4

t	M_∞	M_l	T_l	T_w	$\frac{dT_w}{dt}$	h	$c_p \rho_l V_l$	N_{St}	R_l
1.0	1.04	0.925	545	532	19.6	0.03531	20.46	17.26×10^{-4}	3.367×10^{6}
1.2	1.31	1.165	553	536	34.6	.03966	26.02	15.24	4.237
1.4	1.61	1.37	577	544	54.8	.04204	30.76	13.67	4.832
1.6	1.88	1.55	600	557	82.2	.04766	35.36	13.48	5.405
1.8	2.16	1.695	642	577	120	.05334	39.98	13.34	5.662
2.0	2.49	1.83	694	606	158	.05556	42.76	12.99	5.858
2.1	2.66	1.88	729	623	185.5	.05808	44.20	13.14	5.827
2.2	2.84	1.94	767	643	220	.06127	45.91	13.35	5.829
2.3	3.03	1.98	817	668	267	.06638	46.95	14.14	5.662
2.4	3.21	2.03	855	700	327	.07524	48.34	15.56	5.674
2.5	3.40	2.075	903	733	367	.07731	50.47	15.32	5.636
2.6	3.59	2.115	935	773	397.5	.08021	52.73	15.21	5.725
2.7	3.75	2.15	1,011	815	415.5	.07400	53.95	13.72	5.509
2.8	3.87	2.16	1,063	860	423	.07249	54.72	13.25	5.368
2.9	3.91	2.154	1,076	900	409.5	.07194	55.31	13.01	5.378
3.0	3.88	2.15	1,061	938	387	.07279	53.98	13.48	5.305
3.1	3.82	2.135	1,040	973	355	.07517	51.97	14.46	5.195
3.2	3.73	2.12	1,007	1,010	310	.07512	50.83	14.78	5.201
3.4	3.55	2.085	952	1,062	207	.06527	47.55	13.73	5.090
3.6	3.38	2.045	910	1,097	146	.05919	44.27	13.37	4.915
3.8	3.23	2.017	863	1,123	99	.05445	41.73	13.05	4.818
4.0	3.08	1.99	815	1,138	62.5	.04972	39.76	12.51	4.807
4.4	2.83	1.92	739	1,153	16.4	.04626	36.18	12.79	4.717
4.8	2.62	1.85	693	1,153	-12	.06324	32.87	19.24	4.512
5.2	2.43	1.784	653	1,144	-30	.05000	30.16	16.58	4.320
5.6	2.26	1.728	620	1,129	-41.5	.04547	27.70	16.42	4.131
6.0	2.11	1.67	591	1,111	-47.8	.04187	25.82	16.22	3.985
6.4	1.98	1.60	571	1,092	-51.5	.03912	23.86	16.40	3.786
6.8	1.87	1.54	554	1,070	-53.6	.03754	22.26	16.86	3.615
7.2	1.77	1.485	546	1,049	-54.8	.03734	20.55	18.17	3.373
7.6	1.67	1.44	526	1,027	-54.3	.03468	19.43	17.85	3.282
8.0	1.59	1.39	515	1,006	-53.4	.03300	18.26	18.07	3.136
8.5	1.49	1.324	506	978	-51.6	.03139	16.87	18.61	2.945
9.0	1.41	1.26	496	954	-49.3	.02923	15.62	18.71	2.773
9.5	1.33	1.20	489	929	-46.8	.02767	14.44	19.16	2.599
10	1.26	1.14	483	907	-44	.02610	13.42	19.45	2.430
11	1.14	1.022	477	864	-38.3	.02371	11.62	20.40	2.121
12	1.04	.95	468	828	-34	.02187	10.13	21.59	1.888
13	.96	.923	456	795	-32.2	.02175	8.80	24.72	1.675
14	.90	.902	446	763	-32.5	.02331	8.14	28.64	1.578
15	.85								

TABLE I.- TEST DATA - Continued

(e) Thermocouple 5

t	M_∞	M_l	T_l	T_w	$\frac{dT_w}{dt}$	h	$c_p \rho_l V_l$	N_{St}	R_l
1.0	1.04	0.925	545	540	15.0	0.026299	20.454	12.86×10^{-4}	3.367×10^{6}
1.2	1.31	1.165	553	544	26	.028079	26.010	10.80	4.237
1.4	1.61	1.37	577	552	55	.039072	30.786	12.69	4.832
1.6	1.88	1.55	600	565	81	.043120	35.344	12.20	5.405
1.8	2.16	1.695	642	585	112	.045473	38.994	11.66	5.662
2.0	2.49	1.83	694	612	159	.050730	42.743	11.87	5.858
2.1	2.66	1.88	729	628	186.0	.052731	44.176	11.94	5.827
2.2	2.84	1.94	767	650	223	.056494	45.876	12.31	5.829
2.3	3.03	1.98	817	674	270	.060928	46.937	12.98	5.662
2.4	3.21	2.03	855	704	333	.069490	48.640	14.29	5.674
2.5	3.40	2.075	903	741	362	.069567	50.409	13.80	5.636
2.6	3.59	2.115	947	777	382	.068699	52.451	13.10	5.725
2.7	3.75	2.15	1,016	818	400	.064781	53.868	12.03	5.509
2.8	3.87	2.16	1,063	857	416	.064659	54.631	11.84	5.368
2.9	3.91	2.154	1,077	900	431	.069169	55.257	12.52	5.378
3.0	3.88	2.15	1,066	944	443	.076623	53.851	14.23	5.305
3.1	3.82	2.135	1,040	985	361	.070130	52.437	13.37	5.195
3.2	3.73	2.12	1,007	1,018	280	.062075	50.810	12.22	5.201
3.4	3.55	2.085	952	1,063	199	.056571	47.525	11.90	5.090
3.6	3.38	2.045	909	1,099	148	.054597	44.285	12.33	4.915
3.8	3.23	2.017	863	1,124	104	.052167	41.743	12.50	4.818
4.0	3.08	1.99	815	1,140	66.5	.048914	39.770	12.30	4.807
4.4	2.83	1.92	739	1,156	18	.051846	36.175	14.33	4.717
4.8	2.62	1.85	693	1,156	-13	.050469	32.847	15.36	4.512
5.2	2.43	1.784	654	1,147	-30	.042116	30.128	13.98	4.320
5.6	2.26	1.728	619	1,134	-41	.038179	27.710	13.78	4.131
6.0	2.11	1.67	591	1,115	-49.5	.037471	25.804	14.52	3.985
6.4	1.98	1.60	571	1,094	-53.2	.035282	23.858	14.79	3.786
6.8	1.87	1.54	554	1,073	-54.5	.033274	22.245	14.96	3.615
7.2	1.77	1.485	546	1,052	-54.5	.032461	20.554	15.79	3.373
7.6	1.67	1.44	526	1,029	-54.3	.030422	19.423	15.66	3.282
8.0	1.59	1.39	515	1,008	-53.8	.029332	18.260	16.06	3.136
8.5	1.49	1.324	506	982	-52.8	.028464	16.859	16.88	2.945
9.0	1.41	1.26	496	954	-51.2	.027439	15.620	17.57	2.773
9.5	1.33	1.20	489	929	-48.4	.026112	14.421	18.11	2.599
10	1.26	1.14	483	907	-44	.023768	13.417	17.71	2.430
11	1.14	1.022	477	865	-38	.021283	11.617	18.32	2.121
12	1.04	.95	468	829	-33.4	.019335	10.126	19.09	1.888
13	.96	.923	456	796	-33	.020126	9.021	22.31	1.675
14	.90	.902	446	763	-33.2	.021433	8.133	26.35	1.578
15	.85								

TABLE I.- TEST DATA - Continued

(f) Thermocouple 6

t	M_∞	M_l	T_l	T_w	$\frac{dT_w}{dt}$	h	$c_p \rho_l V_l$	N_{St}	R_l
1.0	1.04	0.925	544	536	15	0.0283	20.45	13.84×10^{-4}	3.367×10^6
1.2	1.31	1.165	553	541	44	.0523	26.08	20.05	4.237
1.4	1.61	1.37	576	553	62	.0496	31.49	15.75	4.832
1.6	1.88	1.55	600	567	85.2	.0512	35.32	14.50	5.405
1.8	2.16	1.695	643	586	115.5	.0526	38.92	13.51	5.662
2.0	2.49	1.83	692	614	155	.0555	42.81	12.96	5.858
2.1	2.66	1.88	730	630	163	.0518	44.17	11.73	5.827
2.2	2.84	1.94	769	648	180	.0506	45.83	11.04	5.829
2.3	3.03	1.98	798	670	210	.0612	47.43	12.90	5.662
2.4	3.21	2.03	855	696	290	.0683	48.64	14.04	5.674
2.5	3.40	2.075	904	727	388	.0811	50.42	16.08	5.636
2.6	3.59	2.115	947	768	455	.0894	50.82	17.59	5.725
2.7	3.75	2.15	1,015	815	483	.0860	53.87	15.96	5.509
2.8	3.87	2.16	1,062	857	455	.0777	54.69	14.21	5.368
2.9	3.91	2.154	1,081	902	420	.0739	55.18	13.39	5.378
3.0	3.88	2.15	1,065	947	385	.0733	53.83	13.62	5.305
3.1	3.82	2.135	1,038	983	355	.0772	52.45	14.72	5.195
3.2	3.73	2.12	1,009	1,014	322	.0795	50.78	15.66	5.201
3.4	3.55	2.085	953	1,068	262	.0853	47.53	17.95	5.090
3.6	3.38	2.045	908	1,107	142	.0599	44.33	13.51	4.915
3.8	3.23	2.017	865	1,132	113.5	.0654	41.69	15.69	4.818
4.0	3.08	1.99	815	1,148	63.4	.0541	39.76	13.61	4.807
4.4	2.83	1.92	740	1,163	18.0	.0651	36.15	18.01	4.717
4.8	2.62	1.85	691	1,163	-11.5	.0432	32.93	13.12	4.512
5.2	2.43	1.784	655	1,154	-31.5	.0471	30.12	15.64	4.320
5.6	2.26	1.728	619	1,137	-44.1	.0455	27.73	16.41	4.131
6.0	2.11	1.67	591	1,117	-51	.0427	25.82	16.54	3.985
6.4	1.98	1.60	571	1,095	-55.5	.0411	23.86	17.23	3.786
6.8	1.87	1.54	554	1,072	-58	.0412	20.59	20.00	3.615
7.2	1.77	1.485	545	1,047	-58.5	.0398	22.24	17.90	3.373
7.6	1.67	1.44	525	1,025	-57.2	.0364	19.44	18.72	3.282
8.0	1.59	1.39	515	1,003	-55.6	.0344	18.09	19.02	3.136
8.5	1.49	1.324	506	995	-53.1	.0317	16.86	18.80	2.945
9.0	1.41	1.26	495	947	-50.5	.0304	15.65	19.42	2.773
9.5	1.33	1.20	489	923	-47	.0282	14.44	11.54	2.599
10	1.26	1.14	482	900	-44	.0262	13.42	19.52	2.430
11	1.14	1.022	477	857	-39	.0246	11.61	21.19	2.121
12	1.04	.95	468	822	-33	.0223	10.13	22.01	1.888
13	.96	.923	455	789	-33	.0227	9.03	25.14	1.675
14	.90	.902	445	755	-33.5	.0237	8.147	29.09	1.578
15	.85								

TABLE I.- TEST DATA - Continued

(g) Thermocouple 7

t	M_∞	M_l	T_l	T_w	$\frac{dT_w}{dt}$	h	$c_p \rho_l V_l$	N_{St}	R_l
1.0	1.04	0.925	545	534	19.7	0.0362	20.43	0.00177×10^{-4}	3.367×10^6
1.2	1.31	1.165	553	537	28.5	.0329	26.02	.00126	4.237
1.4	1.61	1.37	577	545	49.4	.0381	30.79	.00124	4.832
1.6	1.88	1.55	600	558	79.8	.0464	34.55	.00134	5.405
1.8	2.16	1.695	642	578	111.0	.0494	39.00	.00101	5.662
2.0	2.49	1.83	694	603	155	.0540	42.76	.00126	5.858
2.1	2.66	1.88	729	620	191	.0594	44.19	.00134	5.827
2.2	2.84	1.94	767	643	228	.0635	45.89	.00138	5.829
2.3	3.03	1.98	817	665	274.5	.0679	46.91	.00145	5.662
2.4	3.21	2.03	855	698	317.2	.0727	48.62	.00150	5.674
2.5	3.40	2.075	903	731	353	.0741	50.46	.00147	5.636
2.6	3.59	2.115	947	769	383.5	.0754	52.49	.00144	5.725
2.7	3.75	2.15	1,016	808	403	.0712	53.87	.00132	5.509
2.8	3.87	2.16	1,063	850	410	.0695	54.71	.00127	5.368
2.9	3.91	2.154	1,077	893	410.0	.0714	55.28	.00129	5.378
3.0	3.88	2.15	1,066	935	407.0	.0761	53.88	.00141	5.305
3.1	3.82	2.135	1,040	972	385.0	.0814	52.40	.00155	5.195
3.2	3.73	2.12	1,007	1,005	349.9	.0851	50.84	.00167	5.201
3.4	3.55	2.085	952	1,064	274	.0878	47.56	.00185	5.090
3.6	3.38	2.045	909	1,100	146.0	.0606	44.30	.00137	4.915
3.8	3.23	2.017	863	1,125	108.5	.0612	41.73	.00147	4.818
4.0	3.08	1.99	815	1,145	74.0	.0624	39.76	.00157	4.807
4.4	2.83	1.92	737	1,161	18.0	.0668	36.23	.00184	4.717
4.8	2.62	1.85	692	1,162	-9	.0296	32.89	.00090	4.512
5.2	2.43	1.784	654	1,154	-32.5	.0486	30.12	.00161	4.320
5.6	2.26	1.728	619	1,137	-44.5	.0458	27.72	.00165	4.131
6.0	2.11	1.67	591	1,118	-49.8	.0418	25.82	.00162	3.985
6.4	1.98	1.60	571	1,098	-52.8	.0388	23.85	.00163	3.786
6.8	1.87	1.54	554	1,076	-55.2	.0375	22.26	.00168	3.615
7.2	1.77	1.485	546	1,054	-56.8	.0378	20.55	.00184	3.373
7.6	1.67	1.44	526	1,031	-57.0	.0358	19.43	.00184	3.282
8.0	1.59	1.39	515	1,008	-55.7	.0340	18.26	.00186	3.136
8.5	1.49	1.324	506	981	-52.2	.0313	16.87	.00186	2.945
9.0	1.41	1.26	496	955	-50.0	.0294	15.62	.00188	2.773
9.5	1.33	1.20	489	930	-47.5	.0279	14.44	.00193	2.599
10	1.26	1.14	483	906	-43.8	.0260	13.42	.00194	2.430
11	1.14	1.022	477	864	-35.5	.0184	11.62	.00158	2.121
12	1.04	.95	468	829	-33.0	.0211	10.13	.00208	1.888
13	.96	.923	456	797	-32.2	.0215	9.03	.00238	1.675
14	.90	.902	446	764	-32.5	.0231	8.14	.00284	1.578
15	.85								

TABLE I.- TEST DATA - Continued

(h) Thermocouple 8

t	M_∞	M_l	T_l	T_w	$\frac{dT_w}{dt}$	h	$c_p \rho_l V_l$	N_{St}	R_l
1.0	1.04	1.249	487	535	15.5	0.028393	19.680	14.43×10^{-4}	5.52×10^6
1.2	1.31	1.450	495	538	21.4	.024040	23.174	10.37	6.41
1.4	1.61	1.657	513	543	24.0	.018352	28.964	6.34	7.79
1.6	1.88	1.852	527	550	39.4	.021079	28.391	7.42	7.47
1.8	2.16	2.025	566	560	59	.023565	29.776	7.91	7.42
2.0	2.49	2.190	591	575	87.5	.027118	31.530	8.60	7.58
2.1	2.66	2.257	616	584	107	.029309	31.883	9.19	7.45
2.2	2.84	2.328	645	595	131.2	.031669	32.248	9.82	7.26
2.3	3.03	2.391	680	610	149.5	.032280	32.517	9.93	7.05
2.4	3.21	2.448	709	626	171	.033374	33.264	10.03	6.99
2.5	3.40	2.506	745	644	195	.034519	33.691	10.25	6.82
2.6	3.59	2.561	775	665	221	.036180	34.305	10.55	6.72
2.7	3.75	2.609	828	688	249	.036439	34.405	10.59	6.41
2.8	3.87	2.633	861	712	271	.037688	34.733	10.85	6.26
2.9	3.91	2.633	870	740	255	.035985	34.900	10.31	6.24
3.0	3.88	2.618	866	764	235	.034734	34.339	10.12	6.15
3.1	3.82	2.599	846	788	215.5	.034549	33.518	10.31	6.14
3.2	3.73	2.575	822	808	196	.034512	32.684	10.56	6.12
3.4	3.55	2.533	780	842	157	.033170	31.174	10.64	6.09
3.6	3.38	2.485	747	870	129	.032600	29.464	11.06	5.95
3.8	3.23	2.445	712	892	97.5	.029948	28.156	10.64	5.89
4.0	3.08	2.403	678	910	76	.029341	27.120	10.82	5.90
4.4	2.83	2.319	619	934	48.8	.031911	25.345	12.59	5.89
4.8	2.62	2.232	584	948	24.8	.029661	23.658	12.54	5.75
5.2	2.43	2.157	554	955	7.0	.023398	22.201	10.54	5.62
5.6	2.26	2.078	530	954	-2.8	.022547	20.940	10.77	5.48
6.0	2.11	2.007	510	951	-9.5	.021020	19.860	10.58	5.37
6.4	1.98	1.931	494	946	-14.5	.020035	18.726	10.70	5.19
6.8	1.87	1.861	483	940	-19	.020472	17.721	11.55	5.000
7.2	1.77	1.797	478	932	-22.6	.021906	16.687	13.13	4.75
7.6	1.67	1.737	464	923	-25.8	.021332	15.989	13.34	4.69
8.0	1.59	1.682	456	921	-27.1	.019952	15.290	13.05	4.53
8.5	1.49	1.613	450	897	-27.8	.020194	14.344	14.08	4.31
9.0	1.41	1.547	442	884	-27.4	.018601	13.536	13.74	4.13
9.5	1.33	1.484	437	870	-27.0	.017850	12.744	14.01	3.91
10	1.26	1.427	426	857	-26.5	.016973	12.099	14.03	3.79
11	1.14	1.341	424	830	-25.8	.016410	10.718	15.31	3.37
12	1.04	1.279	416	806	-24.5	.015546	9.609	16.18	3.07
13	.96	1.238	409	782	-24.0	.015539	8.678	17.91	2.82
14	.90	.9812	434	758	-24.0	.016246	8.225	19.75	2.54
15	.85								

TABLE I.- TEST DATA - Continued

(i) Thermocouple 9

t	M_∞	M_l	T_l	T_w	$\frac{dT_w}{dt}$	h	$c_p \rho_l V_l$	N_{St}	R_l
1.0	1.04	1.055	522	535	17.5	0.031249	20.510	15.24×10^{-4}	9.597×10^{6}
1.2	1.31	1.310	523	540	25	.028149	24.785	11.36	11.567
1.4	1.61	1.546	538	545	34.4	.025086	27.940	8.98	12.694
1.6	1.88	1.764	548	553	46	.024864	30.352	8.19	13.612
1.8	2.16	1.970	569	564	66	.026875	31.524	8.53	13.740
2.0	2.49	2.166	597	580	96.5	.030450	30.143	10.10	12.681
2.1	2.66	2.245	620	590	121.5	.034000	32.190	10.56	13.148
2.2	2.84	2.307	652	605	157.5	.039025	32.876	11.87	12.926
2.3	3.03	2.352	692	622	167	.036741	33.679	10.91	12.670
2.4	3.21	2.410	722	638	178.5	.035762	34.453	10.38	12.531
2.5	3.40	2.472	756	658	189	.034342	34.846	9.86	12.255
2.6	3.59	2.533	785	676	201	.033607	32.573	10.32	11.090
2.7	3.75	2.587	836	697	212.5	.031668	35.173	9.00	11.428
2.8	3.87	2.623	864	718	223	.031516	35.165	8.96	11.120
2.9	3.91	2.633	870	742	223	.031817	34.848	9.13	10.972
3.0	3.88	2.625	863	766	216	.032310	34.155	9.46	10.802
3.1	3.82	2.610	842	788	205	.033173	33.180	10.00	10.713
3.2	3.73	2.580	820	808	189	.033620	32.563	10.32	10.735
3.4	3.55	2.520	784	841	156	.033227	31.567	10.53	10.770
3.6	3.38	2.465	754	867	116	.029418	30.420	9.67	10.702
3.8	3.23	5.415	721	888	95.5	.029375	28.998	10.13	10.568
4.0	3.08	2.370	688	903	77	.029349	27.962	10.50	10.566
4.4	2.83	2.315	620	928	46	.029627	25.442	11.64	10.392
4.8	2.62	2.220	588	942	25.2	.028998	23.892	12.14	10.127
5.2	2.43	2.135	560	949	11.0	.033311	22.614	14.73	9.96
5.6	2.26	2.040	539	951	-.10	.001052	21.633	.49	9.805
6.0	2.11	1.935	527	950	-8.2	.019027	21.084	9.02	9.735
6.4	1.98	1.840	515	945	-14.5	.020875	20.106	10.38	9.460
6.8	1.87	1.755	506	938	-18.8	.021072	19.197	10.98	9.208
7.2	1.77	1.695	500	930	-21.8	.021789	17.982	12.12	8.700
7.6	1.67	1.600	492	922	-24	.020493	17.609	11.64	8.639
8.0	1.59	1.525	487	912	-25.2	.019842	16.945	11.71	8.358
8.5	1.49	1.450	482	899	-26	.019223	15.824	12.15	7.872
9.0	1.41	1.390	471	886	-26.6	.018385	14.757	12.46	7.494
9.5	1.33	1.330	465	873	-26.4	.017632	13.767	12.81	7.074
10	1.26	1.265	461	860	-26	.016871	13.250	12.73	6.868
11	1.14	1.185	450	835	-24.4	.015564	11.343	13.72	5.985
12	1.04	1.055	451	812	-22.5	.014317	10.126	14.14	5.337
13	.96	.970	449	789	-21.0	.013644	9.039	15.09	4.792
14	.90	.885	448	770	-19.8	.013054	8.124	16.07	4.315
15	.85								

TABLE I.- TEST DATA - Continued

(j) Thermocouple 10

t	M_∞	M_l	T_l	T_w	$\frac{dT_w}{dt}$	h	$c_p \rho_l V_l$	N_{St}	R_l
1.0	1.04	1.039	524.7	536	13.8	0.0230	20.54	11.20×10^{-4}	13.32×10^{6}
1.2	1.31	1.288	527.8	540	21.8	.0227	25.03	9.07	16.15
1.4	1.61	1.514	544.4	545	34	.0229	28.49	8.04	17.96
1.6	1.88	1.722	558.1	556	56.5	.0287	31.33	9.16	19.39
1.8	2.16	1.915	583.2	570	81.5	.0306	32.96	9.28	19.67
2.0	2.49	2.110	612.6	589	108	.0322	33.81	9.52	19.45
2.1	2.66	2.196	633.2	600	122.5	.0327	33.66	9.72	18.90
2.2	2.84	2.281	659.2	614	137	.0321	33.63	9.55	18.31
2.3	3.03	2.352	692.3	628	153.8	.0318	33.69	9.44	17.71
2.4	3.21	2.410	721.7	644	170	.0320	34.44	9.29	17.51
2.5	3.40	2.472	756.0	663	186.5	.0318	34.70	9.16	17.16
2.6	3.59	2.533	784.9	681	203	.0318	34.61	9.19	16.51
2.7	3.75	2.587	836.0	703	223	.0312	35.19	8.87	16.02
2.8	3.87	2.623	864.9	725	250	.0331	35.15	9.42	15.51
2.9	3.91	2.633	870.3	753	230.5	.0311	34.81	8.93	15.30
3.0	3.88	2.625	862.9	774	214	.0301	34.16	8.81	15.10
3.1	3.82	2.610	841.5	795	200	.0278	33.20	8.37	14.99
3.2	3.73	2.575	822.0	815	187.5	.0313	32.72	9.57	15.05
3.4	3.55	2.515	785.9	850	165	.0331	31.75	10.43	15.14
3.6	3.38	2.460	755.5	878	132	.0317	30.19	10.50	14.84
3.8	3.23	2.410	723.0	902	106.5	.0313	29.06	10.77	14.78
4.0	3.08	2.370	687.5	921	82.5	.0307	27.97	10.98	14.77
4.4	2.83	2.290	626.7	945	44	.0282	26.05	10.83	14.76
4.8	2.62	2.190	595.6	958	20.5	.0246	24.55	10.02	14.45
5.2	2.43	2.080	573.6	963	9.3	.0330	23.68	13.94	14.36
5.6	2.26	1.980	553.8	963	-3	.0182	22.74	8.00	14.14
6.0	2.11	1.88	539.6	960	-9.1	.0178	22.05	8.07	13.97
6.4	1.98	1.800	523.7	955	-14.6	.0182	19.20	9.48	12.49
6.8	1.87	1.720	513.3	948	-20	.0198	19.71	10.05	13.00
7.2	1.77	1.635	512.8	938	-24.1	.0217	18.74	11.58	12.39
7.6	1.67	1.570	498.3	928	-26.5	.0205	17.97	11.41	12.18
8.0	1.59	1.490	494.4	918	-27.4	.0196	17.30	11.33	11.76
8.5	1.49	1.420	487.4	904	-27.5	.0186	16.08	11.57	11.09
9.0	1.41	1.385	471.8	890	-27.6	.0175	14.84	11.79	10.50
9.5	1.33	1.295	478.0	876	-27.4	.0170	13.86	12.27	9.69
10	1.26	1.240	465.0	862	-27	.0168	13.02	12.90	9.35
11	1.14	1.140	458.0	836	-25.4	.0161	11.92	13.51	8.67
12	1.04	1.040	453.9	812	-22	.0139	10.14	13.71	7.44
13	.96	.970	449.5	790	-20	.0121	9.05	13.37	6.68
14	.90	.905	450.2	769	-19.5	.0120	8.116	14.79	5.99
15	.85								

TABLE I.- TEST DATA - Continued

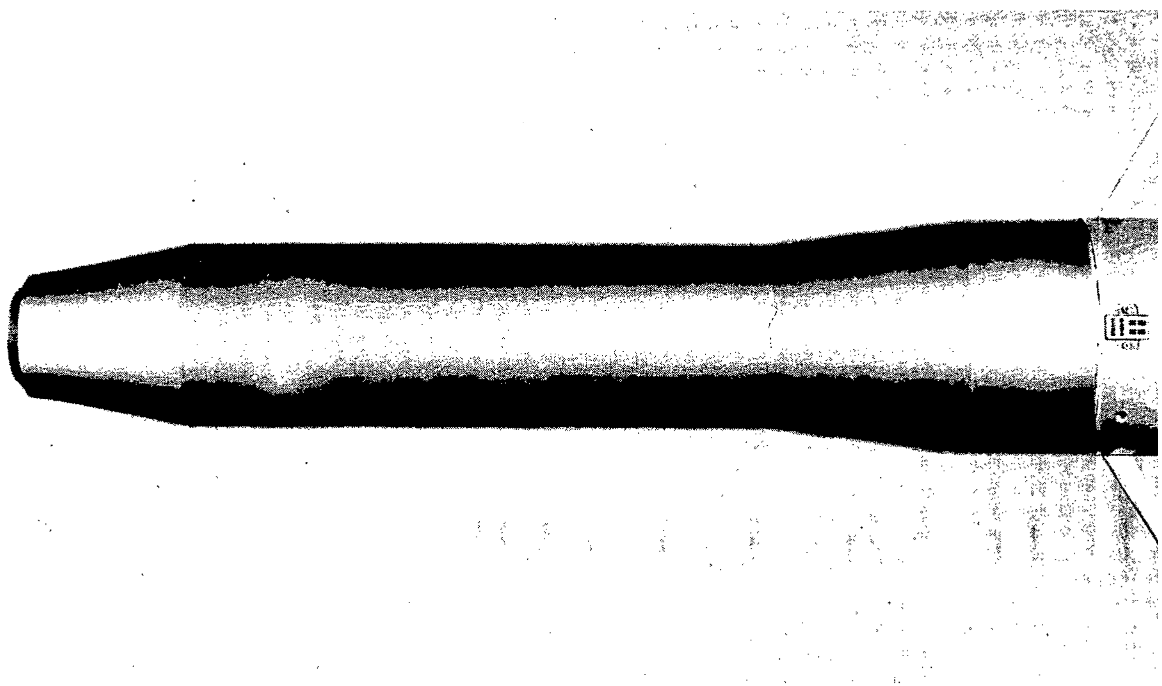
(k) Thermocouple 11

t	M_∞	M_l	T_l	T_w	$\frac{dT_w}{dt}$	h	$c_p \rho_l V_l$	N_{St}	R_l
1.0	1.04	0.862	555	534	23.5	0.033595	20.24	16.60×10^{-4}	14.35×10^{6}
1.2	1.31	1.077	571	540	38	.034701	26.42	13.13	18.31
1.4	1.61	1.295	596	550	58	.035615	31.77	11.21	21.31
1.6	1.88	1.489	616	565	85	.039633	36.47	10.87	23.87
1.8	2.16	1.663	651	585	123	.043885	39.82	11.02	24.96
2.0	2.49	1.835	692	613	153	.043057	42.48	10.14	25.47
2.1	2.66	1.908	721	628	173.5	.043454	43.15	10.07	25.07
2.2	2.84	1.987	751	646	193	.042864	43.81	9.78	24.67
2.3	3.03	2.052	791	665	213.5	.042015	43.88	9.57	23.76
2.4	3.21	2.131	817	688	233.5	.042086	44.60	9.44	23.49
2.5	3.40	2.203	852	711	256.5	.041972	44.88	9.35	22.91
2.6	3.59	2.272	882	740	281.5	.042808	45.22	9.47	22.47
2.7	3.75	2.335	935	773	311	.042422	44.93	9.44	21.30
2.8	3.87	2.377	985	807	341	.044452	44.27	10.04	20.13
2.9	3.91	2.389	970	843	373	.049358	44.22	11.16	20.35
3.0	3.88	2.375	985	882	404	.057600	43.22	13.33	19.64
3.1	3.82	2.349	945	917	278	.044037	42.71	10.31	20.05
3.2	3.73	2.318	922	942	225	.039895	41.88	9.53	20.06
3.4	3.55	2.261	880	980	167	.036517	40.37	9.05	20.10
3.6	3.38	2.195	867	1,012	143.5	.039106	38.37	10.19	19.26
3.8	3.23	2.140	816	1,037	104	.036649	37.35	9.81	19.72
4.0	3.08	2.088	780	1,053	72.5	.034388	36.18	9.50	19.80
4.4	2.83	1.988	717	1,071	27.5	.029561	34.05	8.68	19.83
4.8	2.62	1.892	680	1,075	-.5	.002345	31.71	.74	19.28
5.2	2.43	1.806	648	1,072	-19.5	.056951	29.65	19.21	18.67
5.6	2.26	1.727	619	1,061	-32.8	.042956	27.78	15.46	18.09
6.0	2.11	1.652	596	1,045	-38.8	.036634	26.02	14.08	17.45
6.4	1.98	1.576	577	1,030	-42	.031919	24.26	13.16	16.64
6.8	1.87	1.507	562	1,013	-43.8	.029498	22.66	13.02	15.90
7.2	1.77	1.443	556	995	-44.9	.028965	21.05	13.76	14.89
7.6	1.67	1.385	538	976	-45	.026546	19.91	13.33	14.42
8.0	1.59	1.330	527	958	-44.5	.025162	18.73	13.44	13.78
8.5	1.49	1.2606	519	937	-43	.023679	17.28	13.70	12.88
9.0	1.41	1.194	508	916	-40.8	.021791	15.95	13.66	12.12
9.5	1.33	1.128	502	895	-38.4	.020442	14.67	13.93	11.28
10	1.26	1.068	495	878	-36	.018814	13.54	13.90	10.50
11	1.14	.960	487	844	-30.5	.016144	11.61	13.91	9.10
12	1.04	.883	477	816	-26	.013953	10.05	13.88	8.01
13	.96	.8465	467	792	-23	.012580	8.87	14.18	7.22
14	.90	.8123	458	769	-21.8	.012218	7.96	15.35	6.59
15	.85								

TABLE I.- TEST DATA - Concluded

(l) Thermocouple 12

t	M_∞	M_l	T_l	T_w	$\frac{dT_w}{dt}$	h	$c_p \rho_l V_l$	N_{St}	R_l
1.0	1.04	0.9667	537	533	18.5	0.025775	20.492	12.58×10^{-4}	16.31×10^{6}
1.2	1.31	1.150	556	539	33.5	.029702	26.063	11.40	20.21
1.4	1.61	1.352	581	547	54.5	.032020	30.973	10.34	23.64
1.6	1.88	1.539	603	561	81	.036066	35.433	10.18	25.74
1.8	2.16	1.705	639	580	110	.037586	36.094	10.41	25.11
2.0	2.49	1.867	694	607	148	.041111	41.115	10.00	26.91
2.1	2.66	1.935	711	622	166.5	.041254	42.250	9.76	27.16
2.2	2.84	2.009	744	641	189	.041635	42.988	9.69	26.67
2.3	3.03	2.077	783	661	210.6	.041177	43.376	9.49	25.86
2.4	3.21	2.147	812	682	247	.044142	43.995	10.03	25.52
2.5	3.40	2.215	848	711	283	.062671	44.412	14.11	24.90
2.6	3.59	2.282	878	738	322	.049184	44.863	10.96	24.49
2.7	3.75	2.343	932	773	355	.048467	44.649	10.86	23.21
2.8	3.87	2.381	963	810	381	.049932	44.474	11.23	22.53
2.9	3.91	2.392	969	850	341	.046263	44.141	10.48	22.23
3.0	3.88	2.378	963	883	305	.044290	43.507	10.18	22.04
3.1	3.82	2.349	945	914	273	.043145	42.743	10.09	21.95
3.2	3.73	2.318	922	937	245	.043114	41.952	10.28	21.99
3.4	3.55	2.261	880	988	191	.042539	40.373	10.54	21.99
3.6	3.38	2.199	849	1,017	146	.040424	38.580	10.48	21.79
3.8	3.23	2.1475	813	1,043	104	.037309	37.124	10.05	21.49
4.0	3.08	2.099	776	1,061	75.5	.036892	35.818	10.30	21.50
4.4	2.83	2.007	711	1,080	31.5	.036177	33.498	10.80	21.63
4.8	2.62	1.916	673	1,086	1.5	.011084	31.092	3.56	20.83
5.2	2.43	1.836	639	1,082	-18.5	.044818	28.972	15.47	20.15
5.6	2.26	1.761	610	1,070	-31.5	.038093	27.050	14.08	19.46
6.0	2.11	1.694	585	1,058	-38.5	.033370	25.393	13.14	18.87
6.4	1.98	1.619	566	1,040	-43.5	.031404	23.624	13.29	18.05
6.8	1.87	1.554	551	1,022	-46	.029747	22.046	13.49	17.20
7.2	1.77	1.492	545	1,005	-45.9	.028362	20.486	13.84	16.11
7.6	1.67	1.446	525	983	-45.5	.025998	19.314	13.46	15.63
8.0	1.59	1.388	515	968	-45	.024520	18.225	13.45	14.95
8.5	1.49	1.322	507	948	-43.7	.023048	16.861	13.67	14.06
9.0	1.41	1.259	496	926	-42	.021586	15.597	13.84	13.23
9.5	1.33	1.199	489	906	-39.8	.020299	14.415	14.08	12.36
10	1.26	1.144	482	886	-37.4	.018978	13.375	14.19	11.60
11	1.14	1.054	472	853	-32.2	.016452	11.590	14.19	10.23
12	1.04	.9986	460	822	-27.9	.014559	10.162	14.33	9.19
13	.96	.9834	447	797	-25.4	.013548	9.058	14.96	8.39
14	.90	.9511	439	772	-24.7	.013592	8.201	16.57	7.69
15	.85								

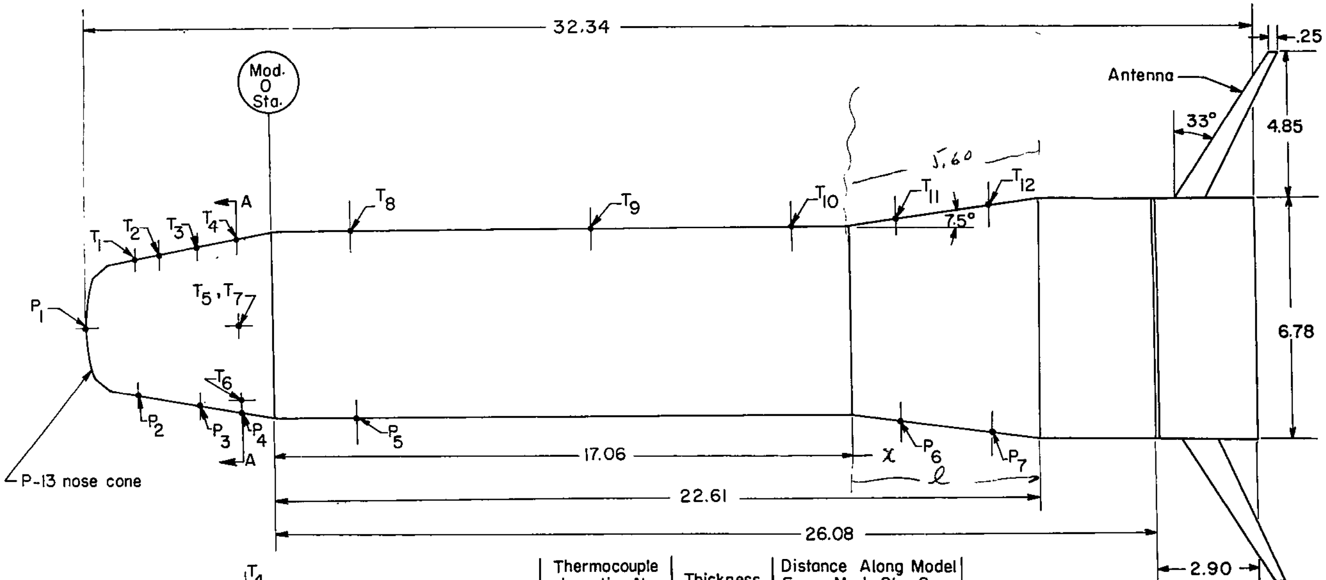


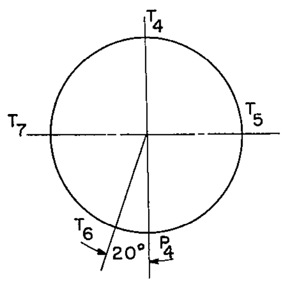
(a) Test portion of model. L-57-3916

Figure 1.- Photograph of model.

(b) Model and booster. L-57-3915

Figure 1.- Concluded.



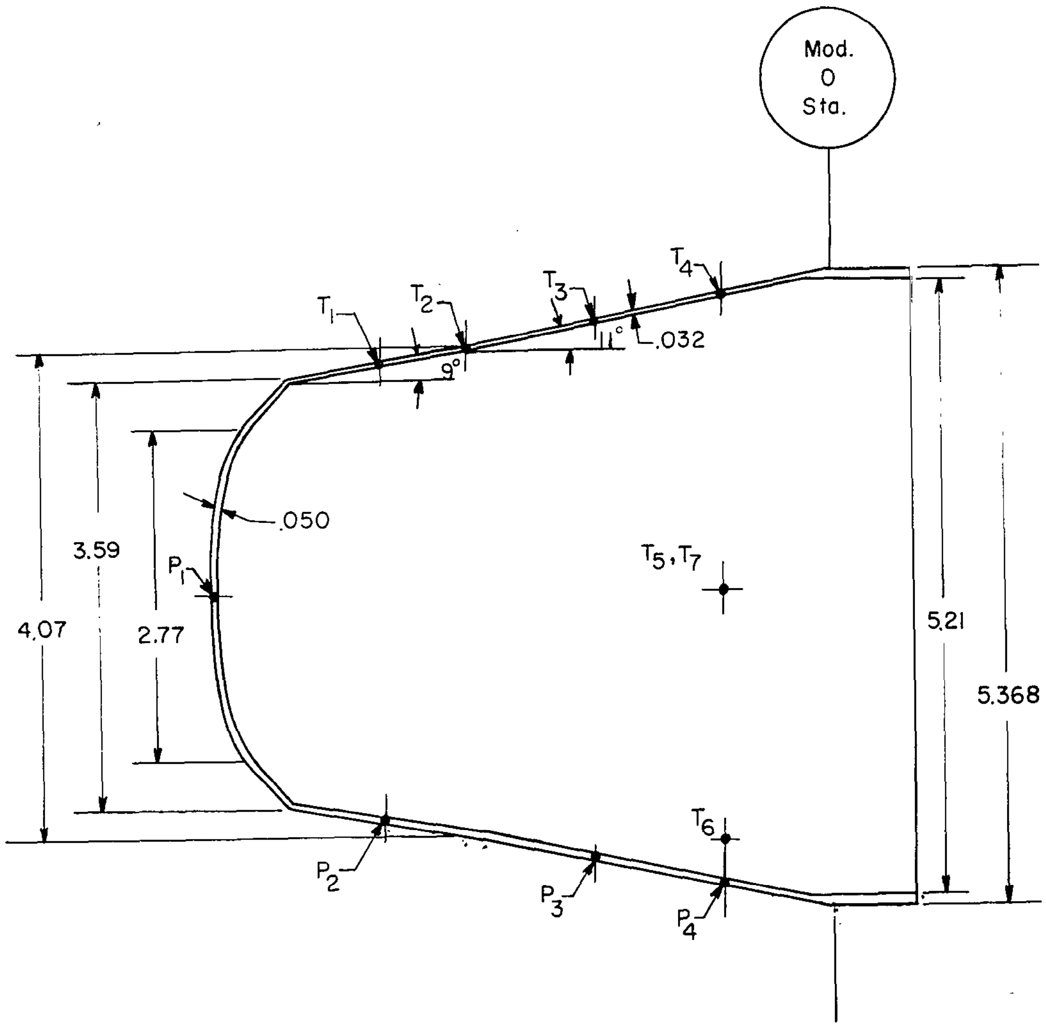


Section A-A

Thermocouple Location No.	Thickness	Distance Along Model From Mod. Sta. 0	
T_1	.0347	-4.06	
T_2	.035	-3.30	
T_3	.0342	-2.24	
T_4	.0335	-1.00	
T_5	.0335	-1.00	
T_6	.0335	-1.00	
T_7	.0335	-1.00	
T_8	.0346	2.30	
T_9	.035	9.30	
T_{10}	.0325	15.75	
T_{11}	.0295	18.89	
T_{12}	.0295	21.38	
Pressure Location No.			x/ℓ
P_1		-6.92	
P_2		-4.06	
P_3		-2.24	
P_4		-1.00	
P_5		2.30	
P_6		18.89	.436
P_7		21.38	.777

(a) Complete configuration.

Figure 2.- Sketch of model showing pressure pickups and thermocouple locations.



(b) Nose detail.

Figure 2.- Concluded.

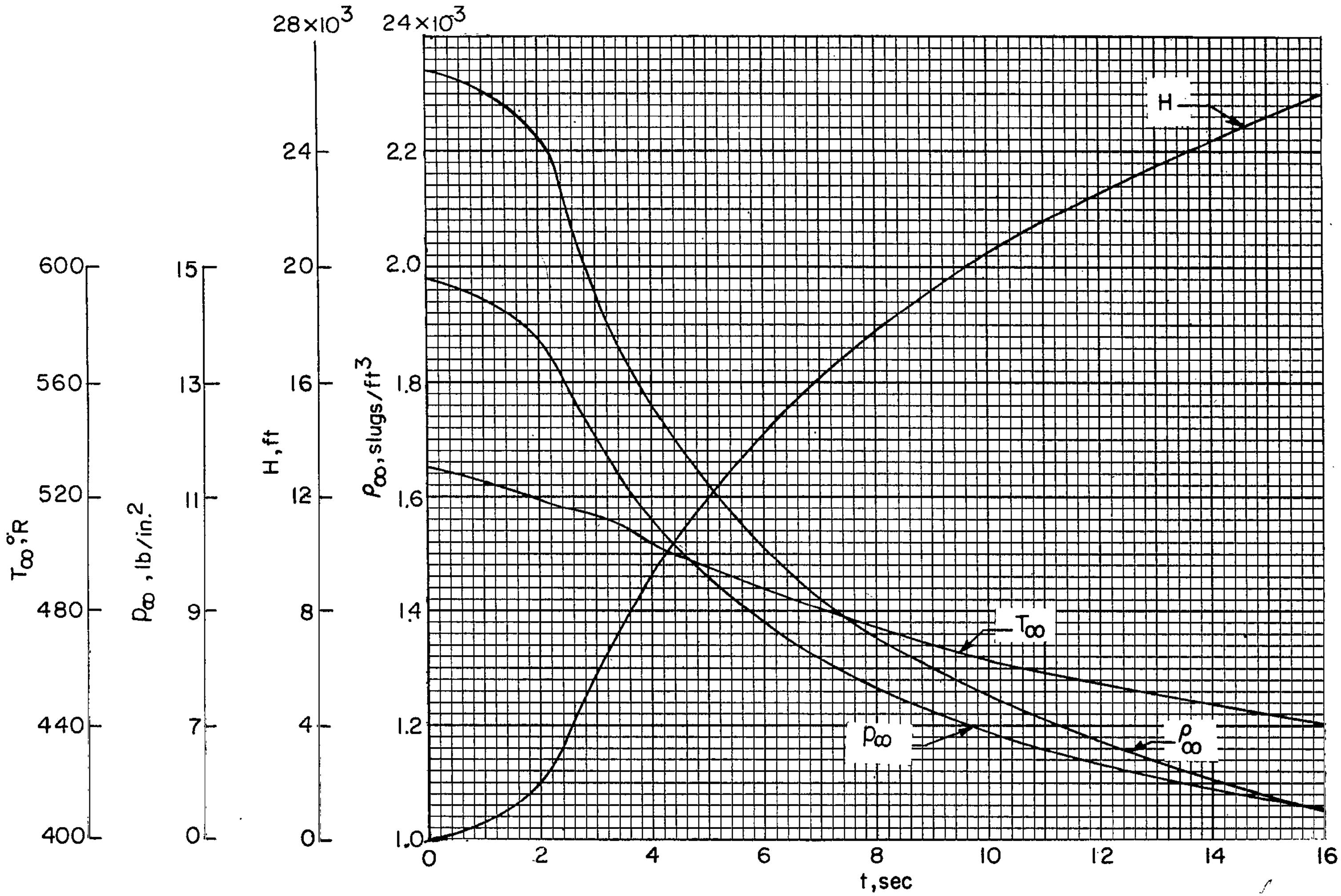


Figure 3.- Time histories of atmospheric conditions and altitude.

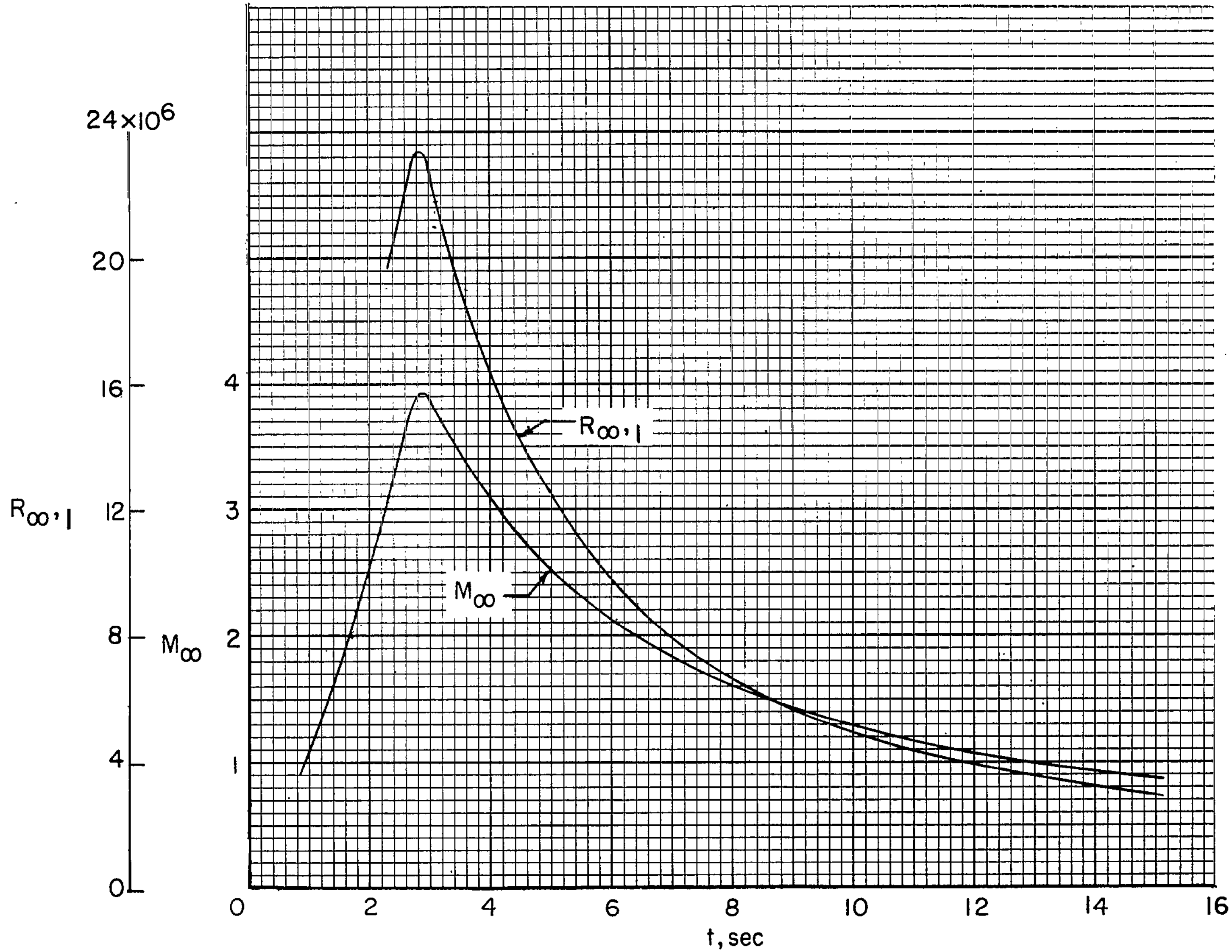
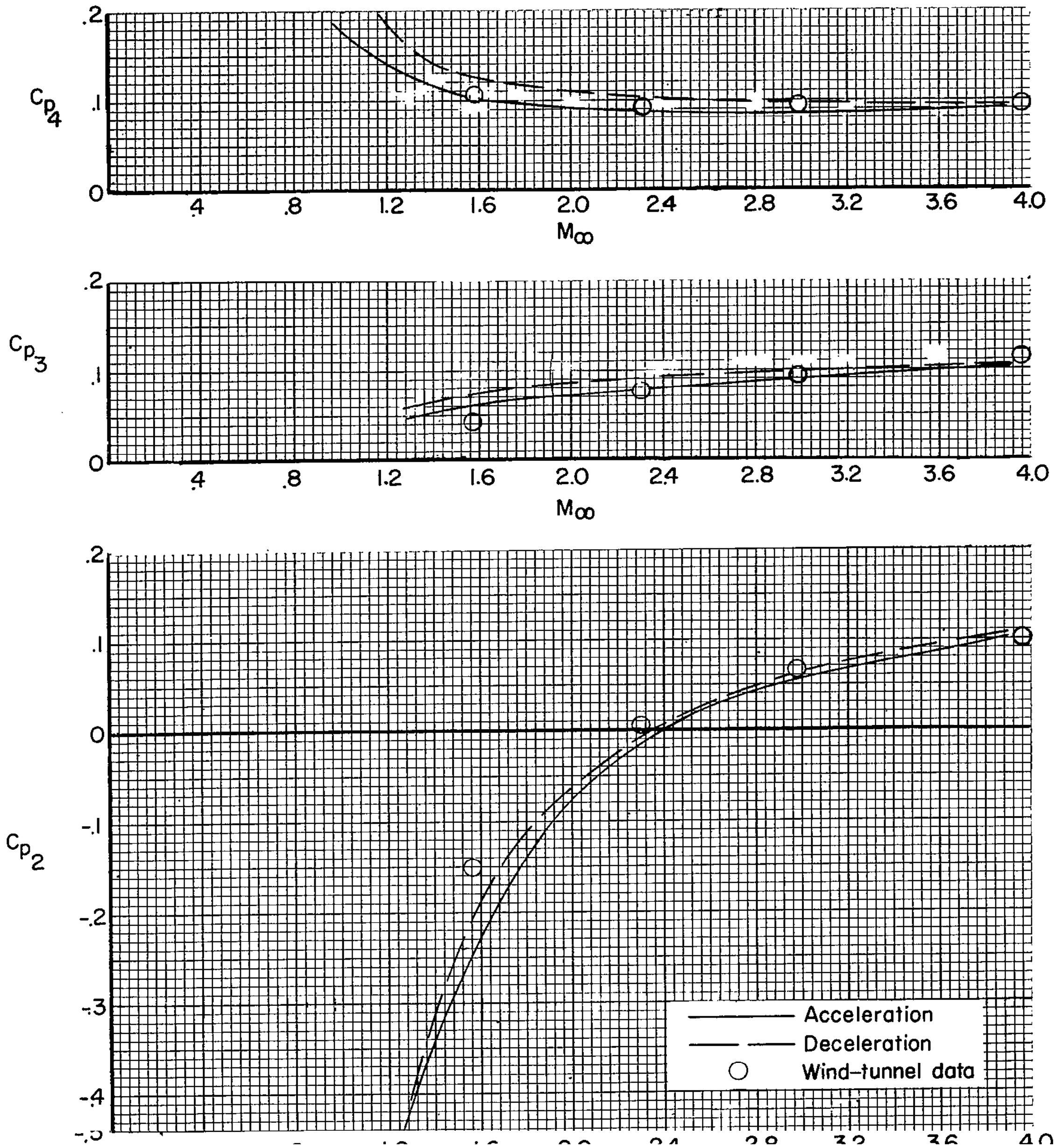
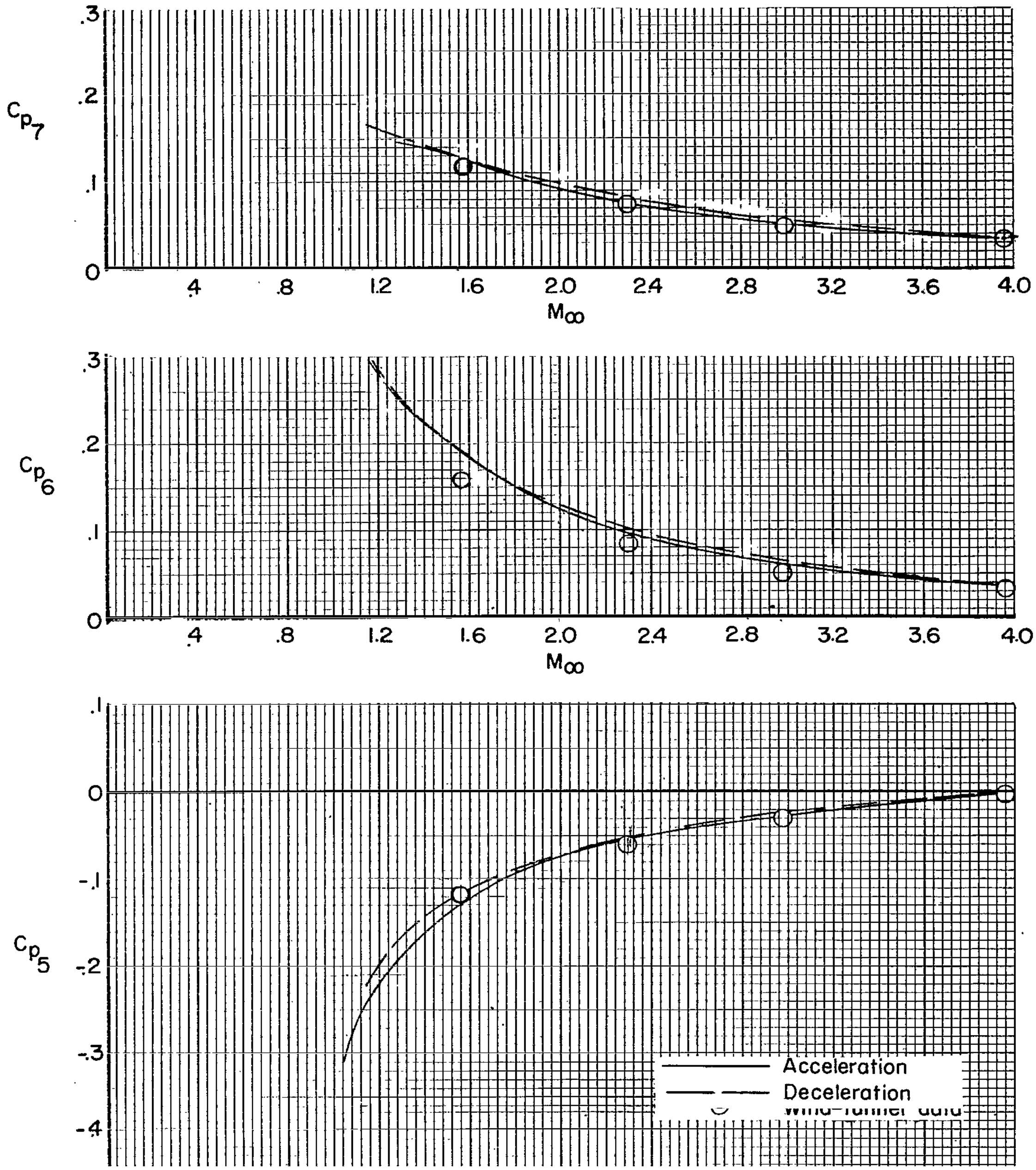
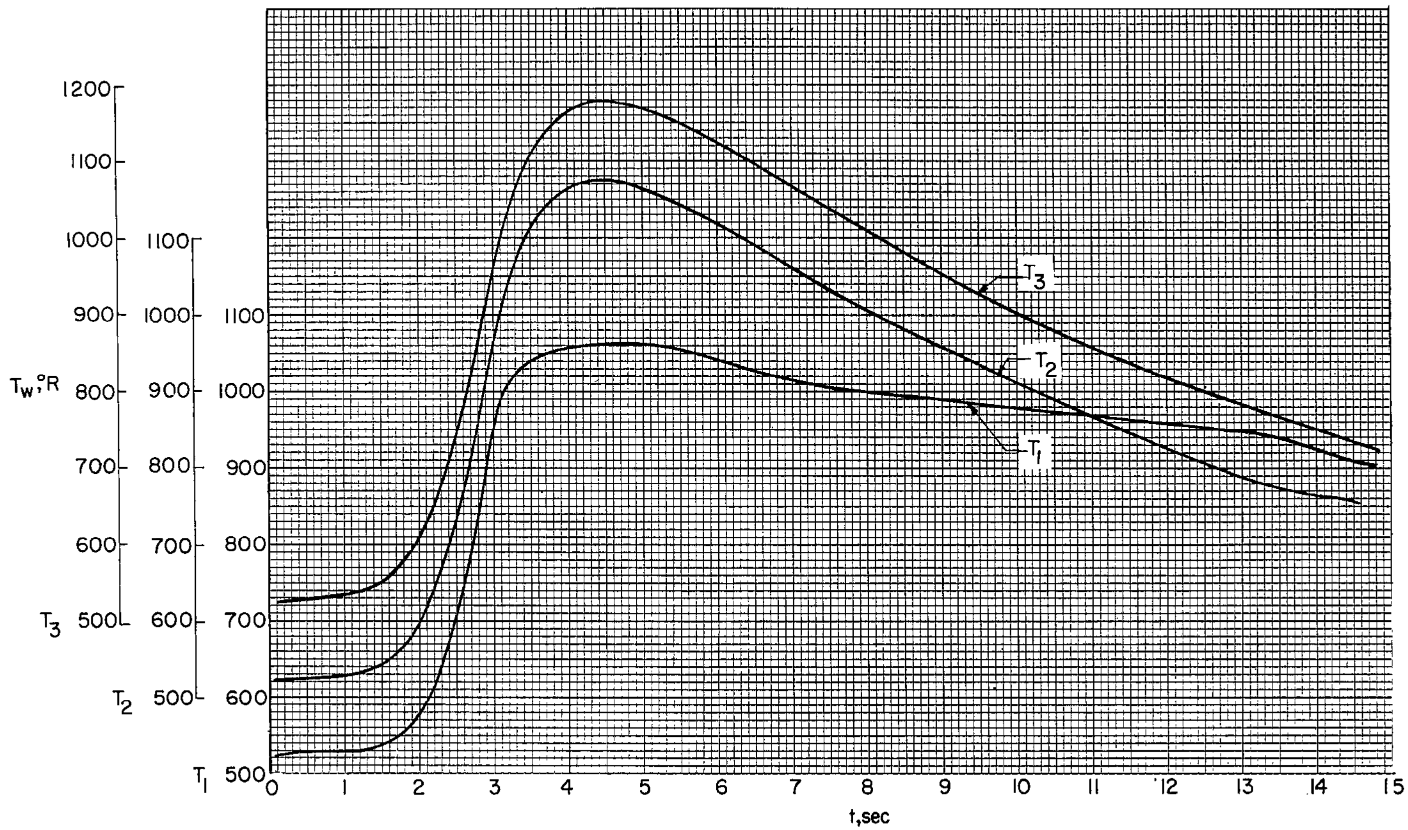


Figure 4.- Time histories of free-stream Mach number and free-stream Reynolds number per foot.

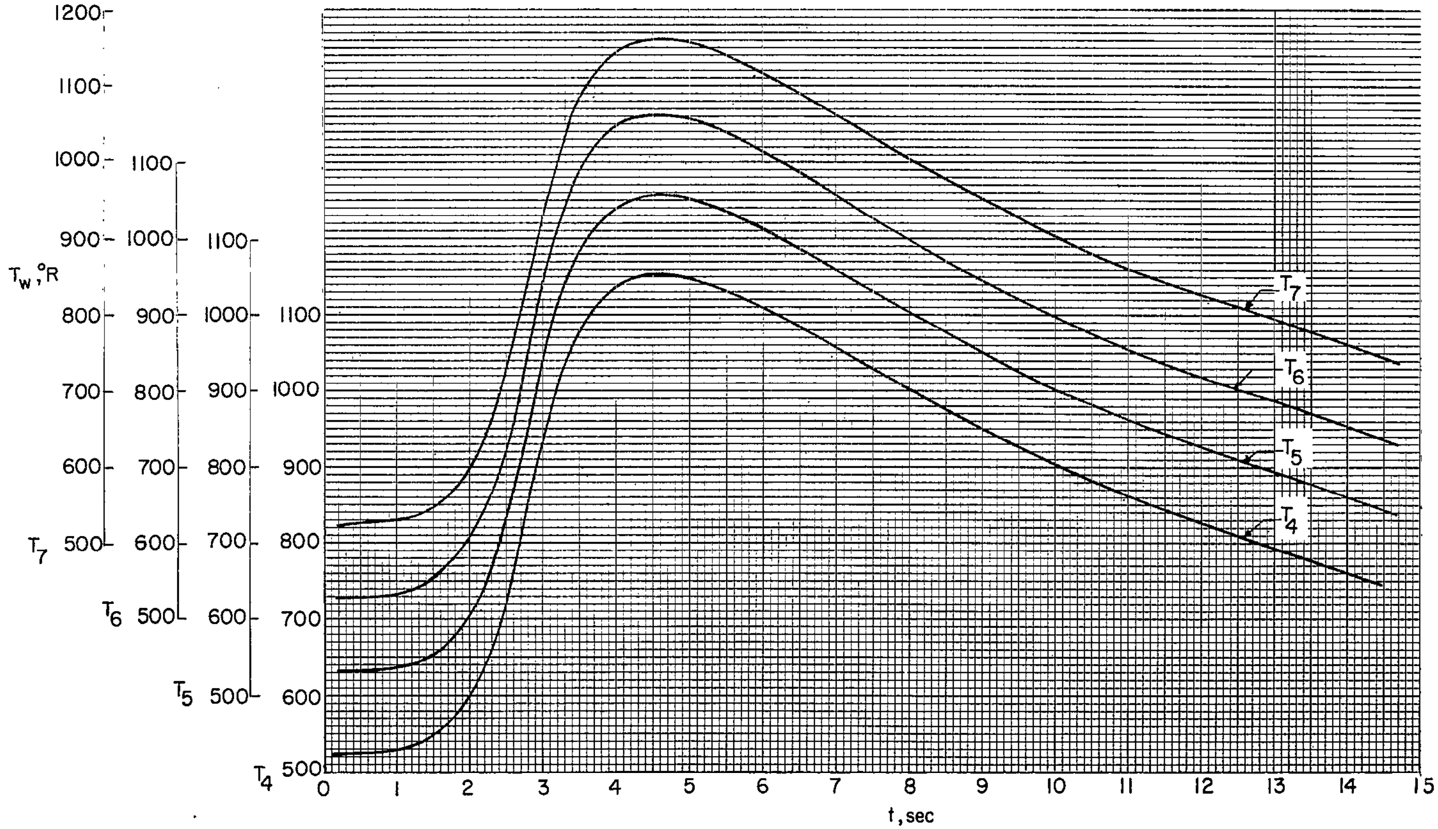

C_{p_4}
C_{p_3}
C_{p_2}
M_∞
M_∞
Acceleration
Deceleration
Wind-tunnel data


C_{p_7}
M_∞
C_{p_6}
M_∞
C_{p_5}
Acceleration
Deceleration



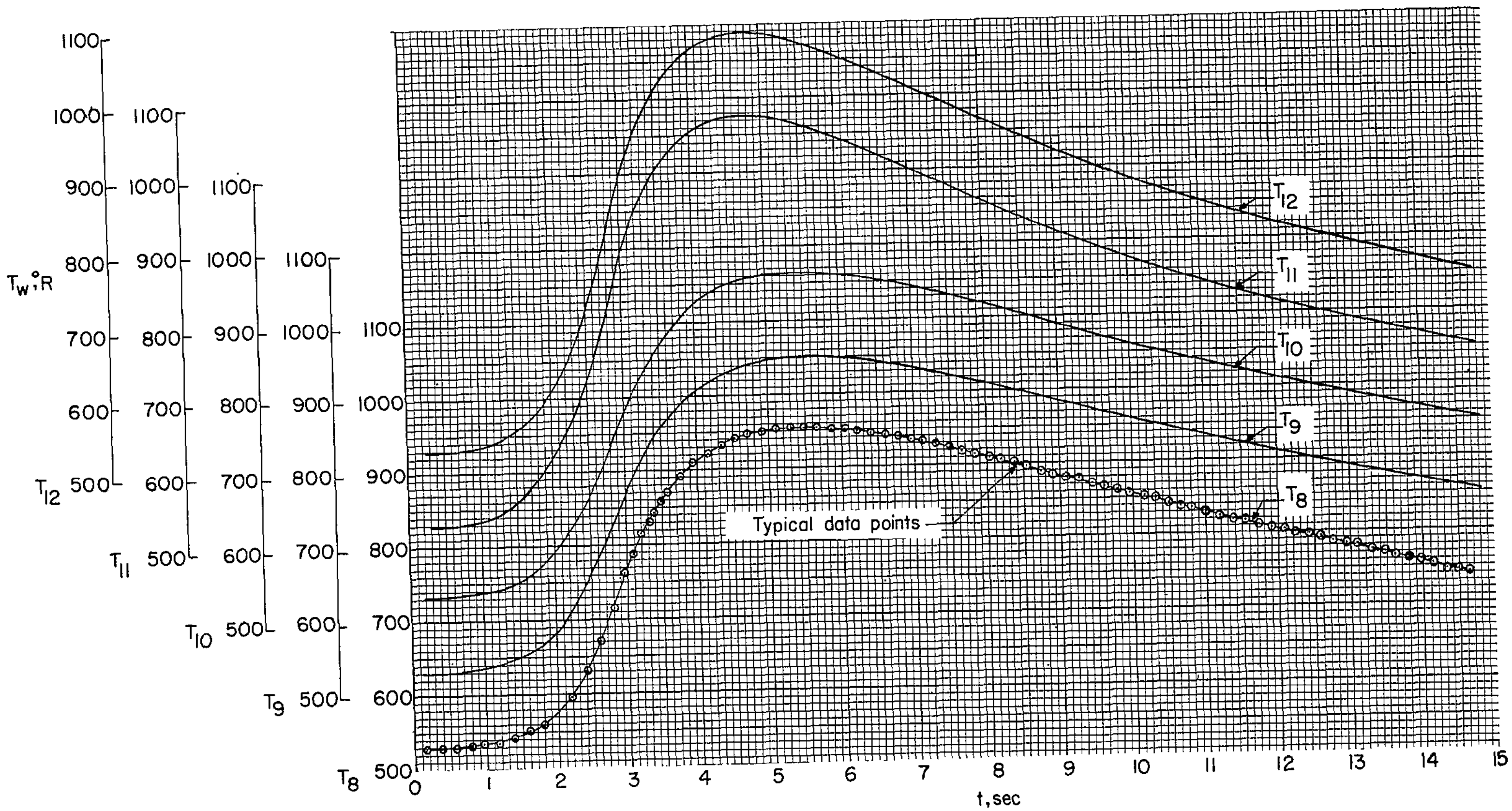
(a) Thermocouple stations T_1 to T_3.

Figure 6.- Skin-temperature time histories.



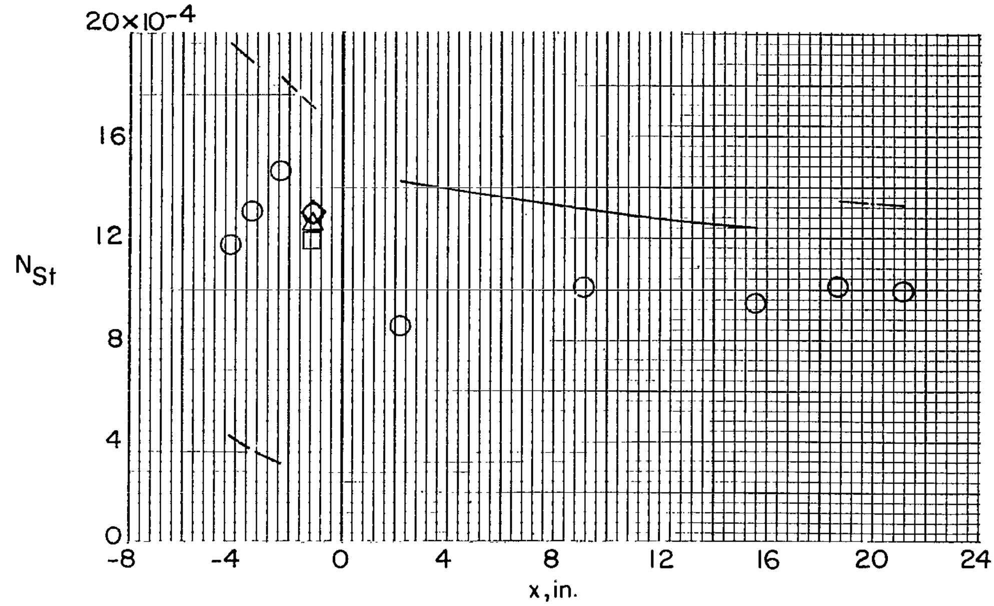
(b) Thermocouple stations T_4 to T_7.

Figure 6.- Continued.

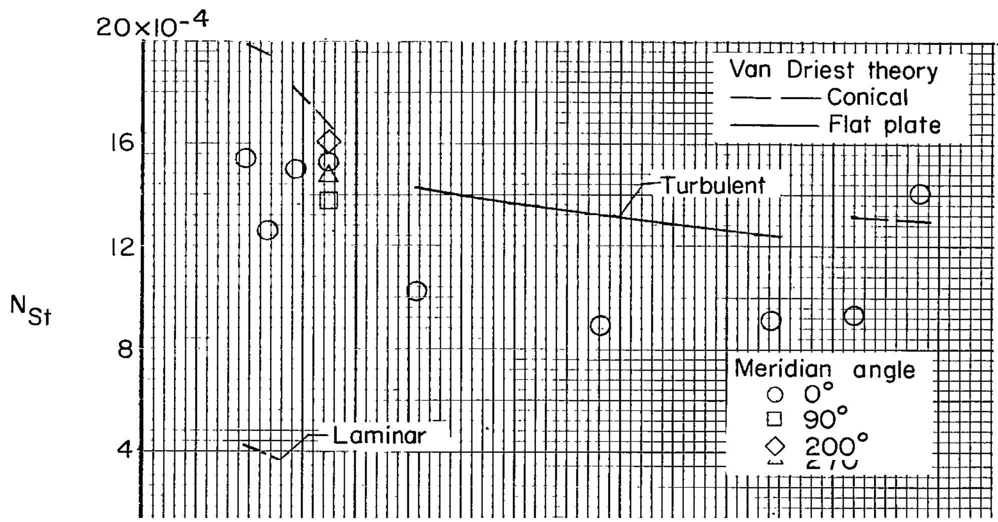


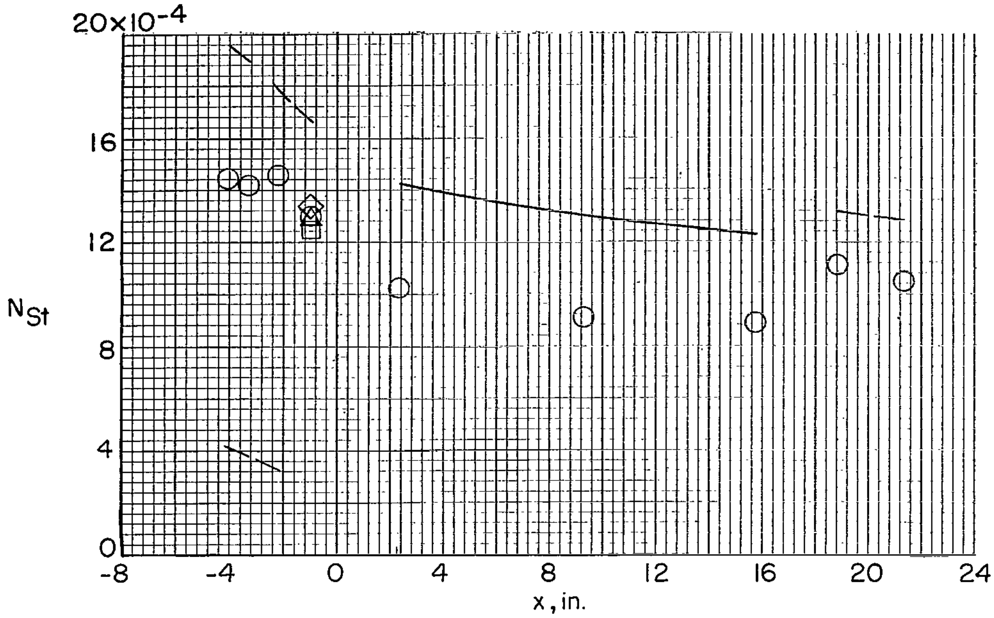
(c) Thermocouple stations T_8 to T_{12}.

Figure 6.- Concluded.

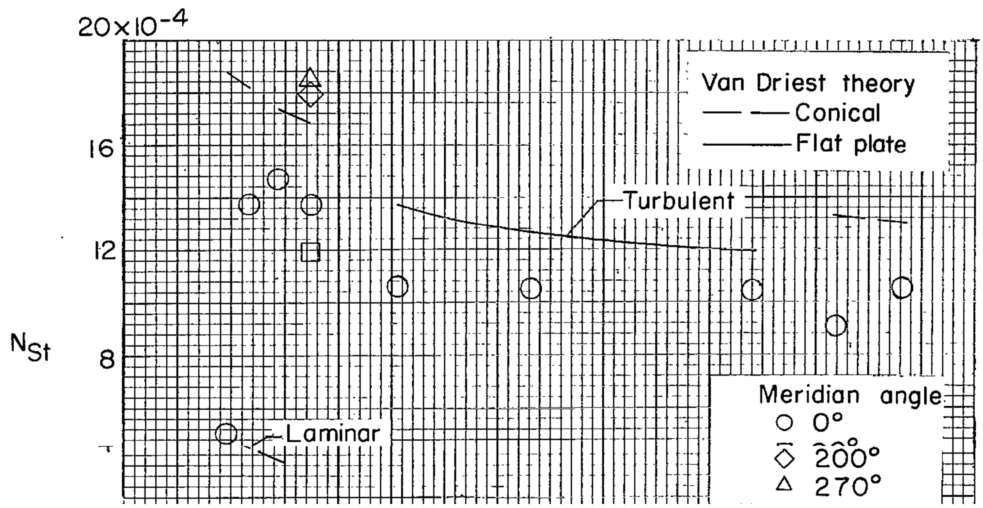


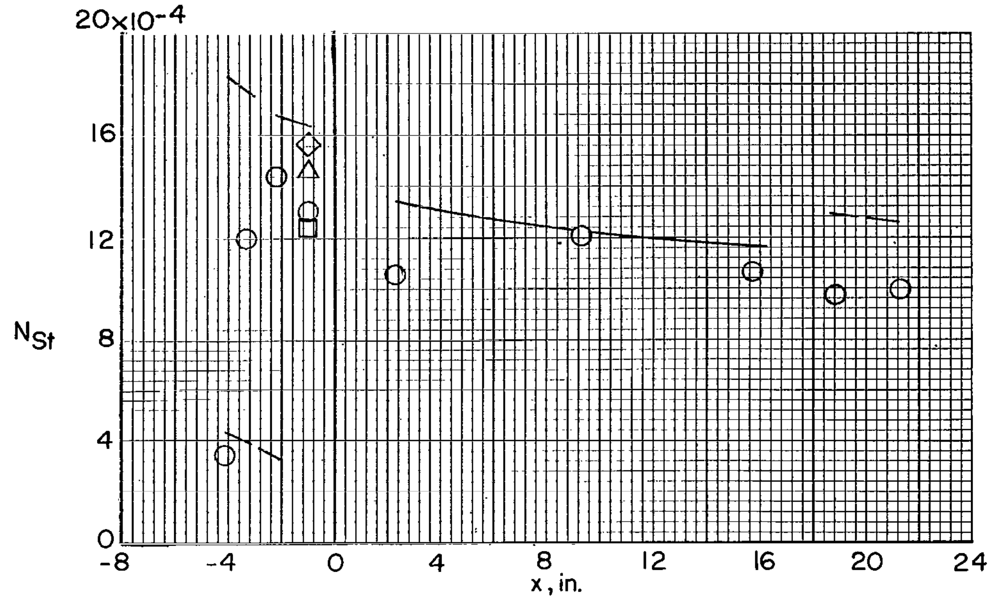
(a) T = 2.0 seconds; $M_\infty = 2.48$; $R_{\infty,1} = 16.7 \times 10^6$.



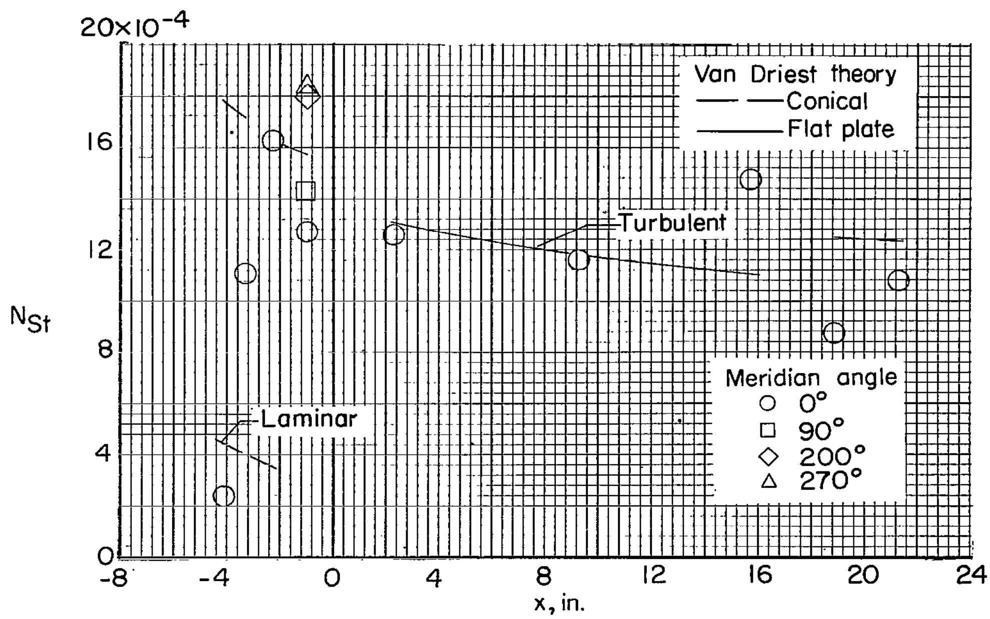


(c) $T = 2.9$ seconds; $M_\infty = 3.91$; $R_{\infty,1} = 23.30 \times 10^6$.



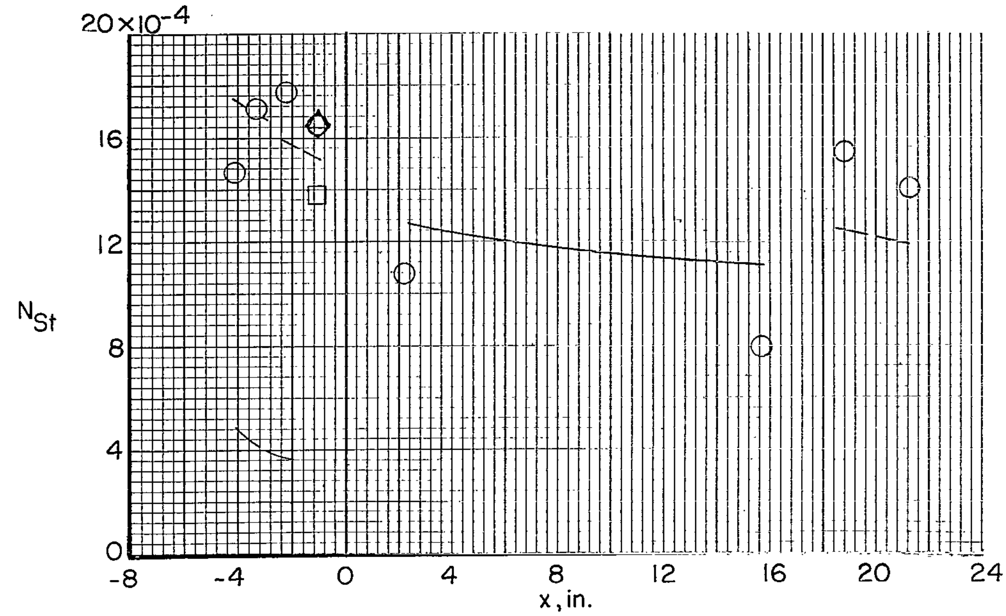


(e) T = 3.8 seconds; $M_\infty = 3.23$; $R_{\infty,1} = 17.47 \times 10^6$.

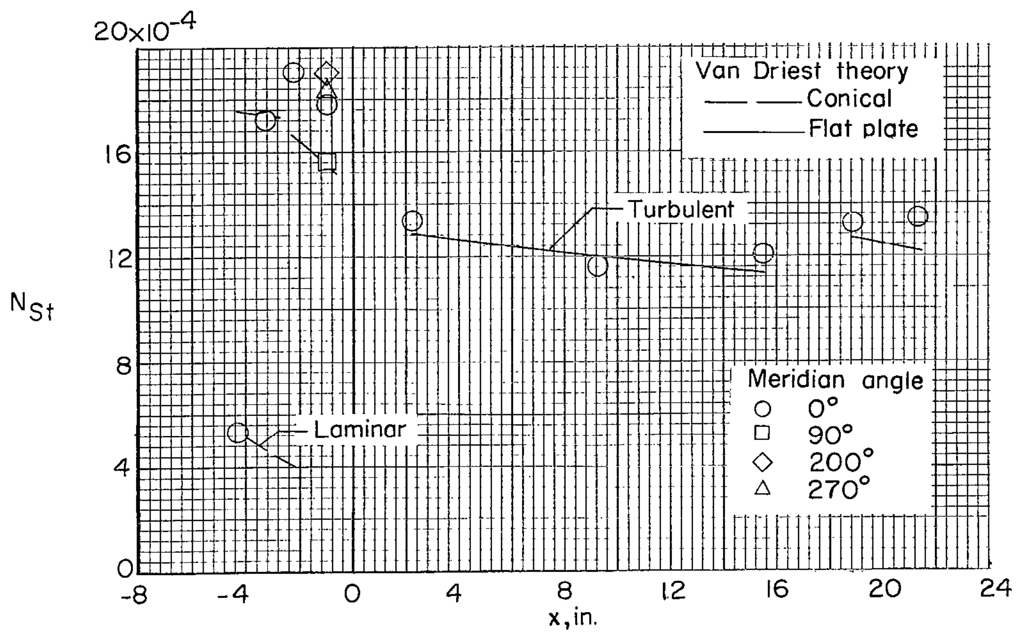


(f) T = 4.4 seconds; $M_\infty = 2.83$; $R_{\infty,1} = 14.59 \times 10^6$.

Figure 7.- Continued.

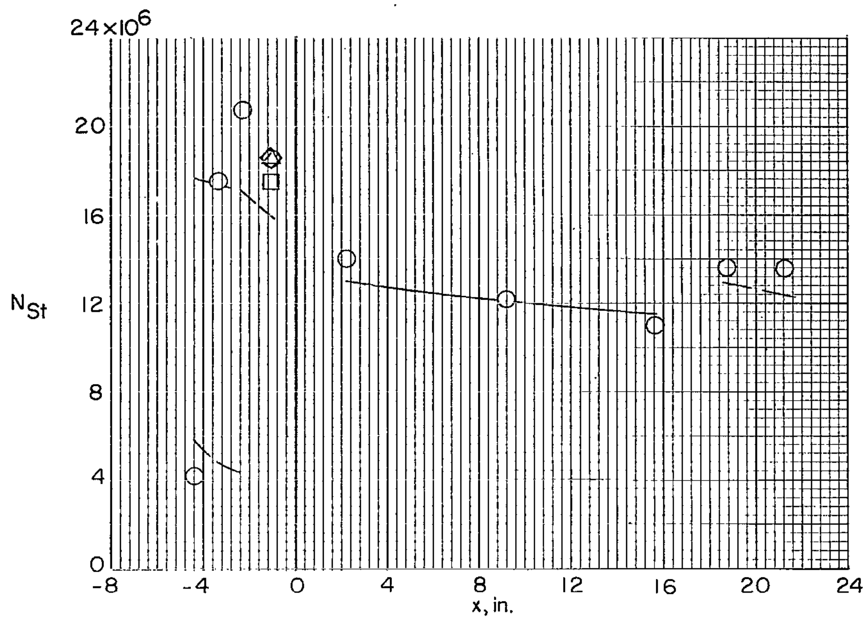


(g) T = 5.6 seconds; M_∞ = 2.26; $R_{\infty,1}$ = 10.69 × 10^6.

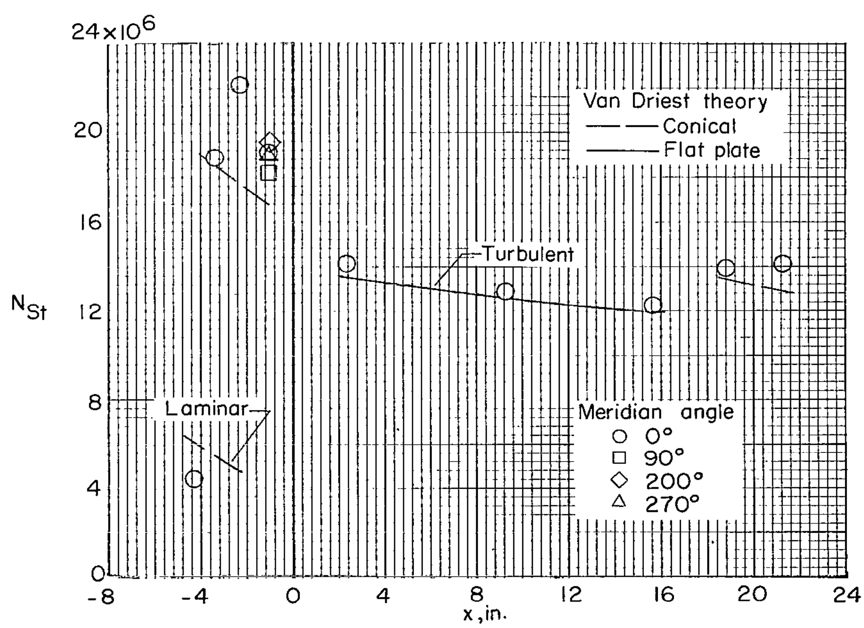


(h) T = 7.6 seconds; M_∞ = 1.67; $R_{\infty,1}$ = 7.11 × 10^6.

Figure 7.- Continued.



(i) T = 8.5 seconds; $M_\infty = 1.49$; $R_{\infty,1} = 6.12 \times 10^6$.



(j) T = 9.5 seconds; $M_\infty = 1.33$; $R_{\infty,1} = 5.27 \times 10^6$.

Figure 7.- Concluded.

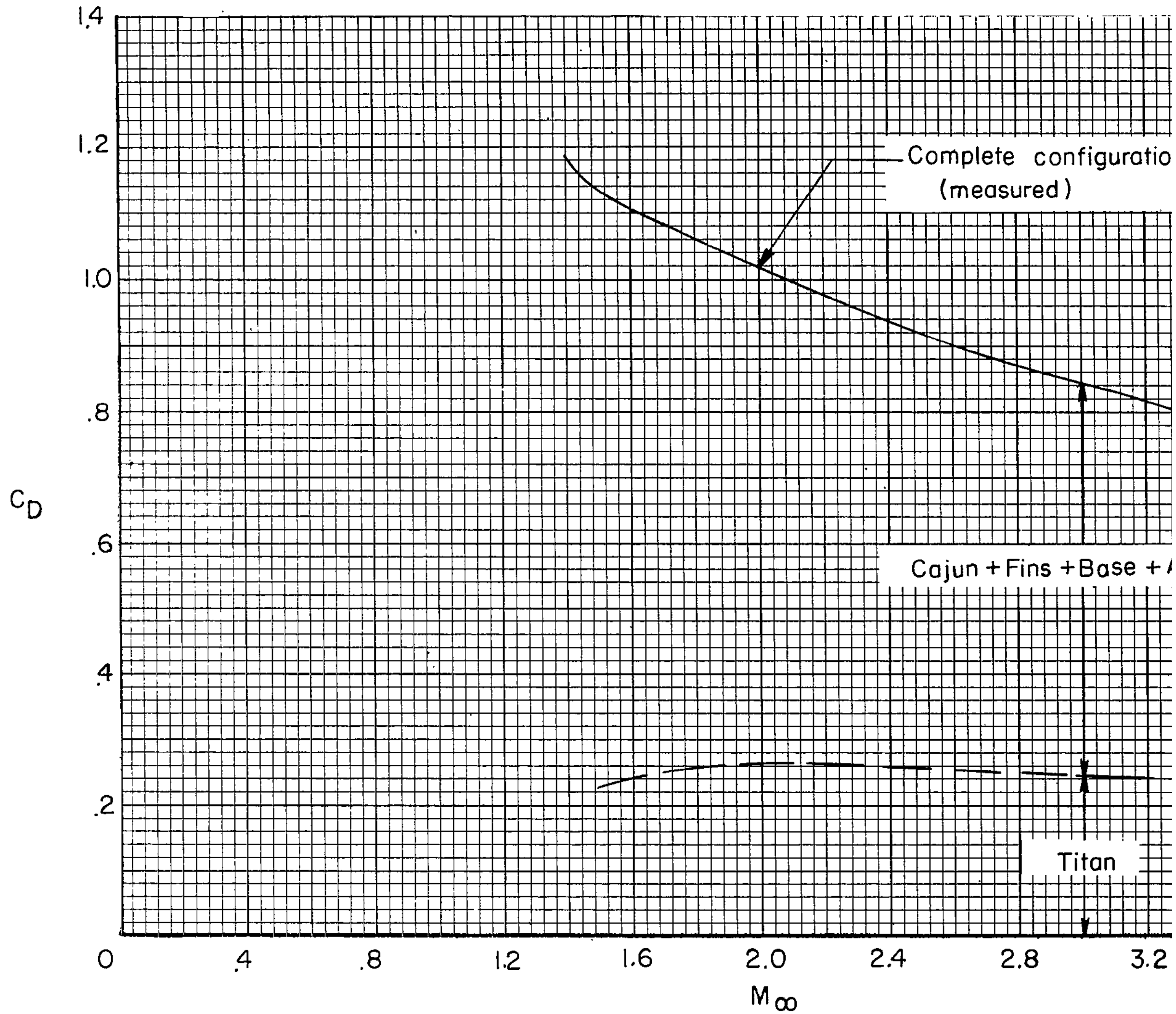


Figure 8.- Drag coefficients for complete configuration and Titan base 0.2485 square foot.

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HEAT-TRANSFER AND PRESSURE MEASUREMENTS FROM A FLIGHT TEST OF THE SECOND 1/18-SCALE MODEL OF THE TITAN INTERCONTINENTAL BALLISTIC MISSILE UP TO A MACH NUMBER OF 3.91 AND REYNOLDS NUMBER PER FOOT OF 23.4×10^6

COORD. NO. AF-AM-70

By John B. Graham, Jr.

ABSTRACT

Turbulent flow was observed over the model throughout flight, with the exception of one station on the nose. Heat-transfer coefficients presented for the accelerating portion of flight were approximately on the order of 20 percent lower than results obtained by available theories; however, during the decelerating portion of the flight, the data were in good agreement with theory. Drag coefficients of the configuration were obtained for a Mach number range of 1.5 to 3.5.

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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HEAT-TRANSFER AND PRESSURE MEASUREMENTS FROM A FLIGHT TEST OF THE SECOND 1/18-SCALE MODEL OF THE TITAN INTERCONTINENTAL BALLISTIC MISSILE UP TO A MACH NUMBER OF 3.91 AND REYNOLDS NUMBER PER FOOT OF 23.4×10^6

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John B. Graham Jr.

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Approved: Joseph A. Shortal

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Chief of Pilotless Aircraft Research Division

Langley Aeronautical Laboratory

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