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EFFECTS OF WALL COOLING
AND ANGLE OF ATTACK
ON BOUNDARY-LAYER TRANSITION
ON SHARP CONES AT $M_{\infty} = 7.4$

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NOMENCLATURE

k parameter related to circumferential gradient of circumferential velocity on the windward ray of a cone:

$$\frac{2}{3 \sin \Theta_c} \left(\frac{1}{V_e} \frac{\partial w}{\partial \Phi} \right)_{\Phi = 0^\circ}$$

L overall surface length

M Mach number

p pressure

p_t total pressure

Re_θ Reynolds number based on momentum thickness, $\frac{\rho_e V_e \theta}{\mu_e}$

s length along a cone generator

s_t length to transition along a cone generator

T temperature

T_t total temperature

V velocity along a streamline

w circumferential component of velocity

α angle of attack

θ momentum thickness

Θ_c cone half-angle

μ viscosity

ρ density

Φ angular coordinate around the cone ($\Phi = 0^\circ$; windward ray)

Subscripts

<i>B</i>	beginning of transition
<i>E</i>	end of transition
<i>e</i>	boundary-layer-edge condition
<i>w</i>	wall condition
∞	free-stream condition

**EFFECTS OF WALL COOLING AND ANGLE OF ATTACK
ON BOUNDARY-LAYER TRANSITION ON
SHARP CONES AT $M_\infty = 7.4$**

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SUMMARY

The effects of wall cooling and angle of attack on boundary-layer transition have been investigated on 5° and 15° half-angle, sharp cones. An experimental investigation was conducted at a free-stream Mach number of 7.4, wall-to-total-temperature ratios of 0.08 to 0.4, and angles of attack of 0° to 20° . The results indicate that (1) transition Reynolds numbers decrease with decreasing temperature ratio, (2) local transition Reynolds numbers decrease from the windward to the leeward side of the model, and (3) transition data on the windward ray of cones can be correlated in terms of the crossflow velocity gradient, momentum thickness Reynolds number, local Mach number, and cone half-angle.

INTRODUCTION

The effect of wall cooling on transition has been a subject of considerable interest largely because of the observations of transition "reversals" (ref. 1) and "rereversals" (refs. 2 and 3) and their relationships to stability theory (ref. 4). Although there are numerous investigations on the effects of cooling, the observations are inconsistent (e.g., refs. 2 and 5). In contrast, the effect of angle of attack on transition has received relatively little attention until the recently renewed interest in lifting reentry. The angle of attack experiments on cones show a fairly consistent behavior (i.e., transition moves aft on the windward ray and forward on the leeward ray (refs. 5 and 6)). However, the majority of the wind-tunnel angle-of-attack data are limited to the windward and leeward rays and to angles of attack less than the cone half-angle.

The objectives of this investigation were to (1) provide additional data to assess the effects of wall cooling on transition at $\alpha = 0^\circ$, (2) provide a map of the transition zone on a cone at angle of attack, and (3) investigate transition at angles of attack greater than the cone half-angle. The first objective was an attempt to find some consistent observations among results for similar test conditions. The other objectives helped satisfy the need for more transition data on cones.

Tests were conducted on 5° and 15° half-angle cones at wall-to-total-temperature ratios of 0.08 to 0.4 and angles of attack of 0° to 20° . The free-stream Mach number was 7.4. Total temperatures ranged from 768° to 1552° K (1380° - 2800° R) and total pressures from 2.160×10^6 to 1.253×10^7 N/m² (314.0 to 1817 psia). Wall cooling data were compared with results from different investigations, and the transition zone on the 15° cone at angle of attack was mapped for meridians

from 0° to 180° in 30° increments. A correlation of the transition data on the windward ray of cones was developed.

APPARATUS AND TESTS

Models

The models used in this investigation were 5° and 15° half-angle cones with surface lengths of 0.711 and 0.508 m (2.33 and 1.67 ft), respectively (fig. 1). They were of thin-walled, 0.838 mm (0.033 in.) thick electroformed nickel construction, instrumented with thermocouples spotwelded to the interior surface. The 5° cone had a single row of 22 thermocouples spaced at 2.54 cm (1 in.) intervals along one conical ray. One quadrant of the 15° cone was instrumented along conical rays having meridian angles of 0° , 30° , 60° , and 90° with 12 thermocouples on each ray. Data on other rays were obtained by rotating the models about the axis of revolution.

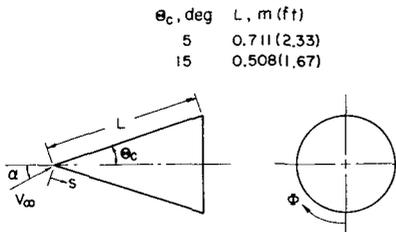


Figure 1. Models

Facility

The tests were conducted in the Ames 3.5-Foot Hypersonic Wind Tunnel (ref. 7), a pebble-bed heated, blowdown facility equipped with interchangeable, contoured nozzles and a mechanism for quickly inserting or retracting the model from the flow at any time during the test. A single nozzle was selected that produced a nominal free-stream Mach number of 7.4. The time required to insert or retract the model was nominally 0.5 sec, and the models remained in the tunnel from 1 to 6 sec.

In the wall-cooling experiments, several tests were conducted by cooling the model with liquid nitrogen. In these instances, a plastic shroud was placed over the model and filled with coolant. When the model was inserted into the tunnel, the shroud blew off and exposed the cooled surface to the flow. The model wall was essentially isothermal before insertion. During the run gradients along the model in the laminar region were less than 17° K/m (10° R/ft).

Test Conditions

The test conditions are listed in tables 1 and 2. For the wall cooling data (table 1), total temperatures ranged from 768° to 1552° K (1380° - 2800° R) and total pressures from 4.178×10^6 to $1.253 \times 10^7 \text{ N/m}^2$ (606 to 1817 psia). Wall-to-total-temperature ratios varied from 0.08 to 0.4. For the angle of attack data (table 2) the wall and total temperatures were nominally constant at 295° and 834° K (530° and 1500° R), respectively, and total pressures ranged from 2.160×10^6 to $1.210 \times 10^7 \text{ N/m}^2$ (314.0 to 1753 psia), angle of attack was varied from 0° to 20° , and free-stream Mach number was 7.4.

RESULTS AND DISCUSSION

Examples of the heat-transfer data obtained from these models were given in reference 8 where it was shown that the heating data agreed well with laminar and turbulent heat-transfer theories and were a well-defined means of detecting boundary-layer transition. The definition of the beginning of transition is the same as in reference 8, that is, the intersection of straight lines faired through the laminar and transitional portions of the heat-transfer data, plotted logarithmically. The end of transition is defined as the intersection of straight lines faired through the transitional and turbulent portions of the heat-transfer data. Although no detailed investigation of unit Reynolds number effect was made for this study, a few check runs were made for both the wall-cooling and angle-of-attack data. These substantiated the conclusion of reference 8 that transition Reynolds numbers are essentially independent of free-stream unit Reynolds number. However, this observation may be related to the method of determining transition or to the definition of the beginning of transition or both. For example, Owen and Horstman (ref. 9) detected some effect of unit Reynolds number on a 5° cone in the same facility when transition was determined from the root mean square voltage fluctuations of a thin-film heat-transfer gage. This slight effect of unit Reynolds number also indicates that any roughness on the model surface did not influence transition.

Wall-Cooling Result

The effect of wall cooling on boundary-layer transition at $\alpha = 0^\circ$ is shown on figure 2. The cooling effect is characterized by presenting transition Reynolds number, based on conditions at

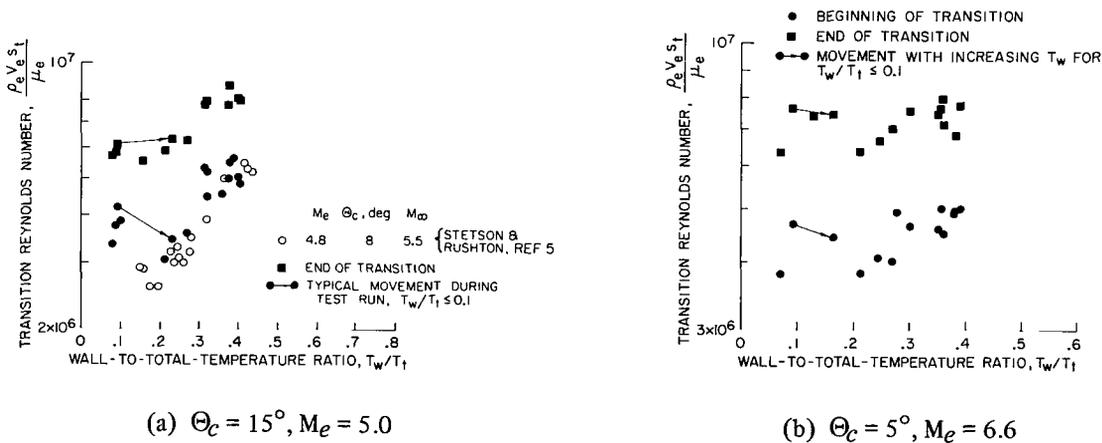


Figure 2. Effect of wall cooling on boundary-layer transition at $\alpha = 0^\circ$

the edge of the boundary layer and surface length to transition, as a function of the wall-to-total-temperature ratio. The 15° cone data of figure 2(a) ($M_e = 5.0$) show that transition Reynolds numbers decrease as the temperature ratio decreases. The same result was observed at the same edge Mach number by Stetson and Rushton (ref. 5) whose measurements agree very well with those of this study. A similar effect was noted by Sheetz (ref. 3) while testing slender cones in a ballistic range at the same edge Mach number. (Sheetz's data were not included on fig. 2 because transition was determined from drag measurements.) Transition Reynolds numbers based on the end of transition also show a similar trend although not as pronounced. Finally, the length of the transition region relative to the length of laminar flow appears to be a weak function of temperature ratio.

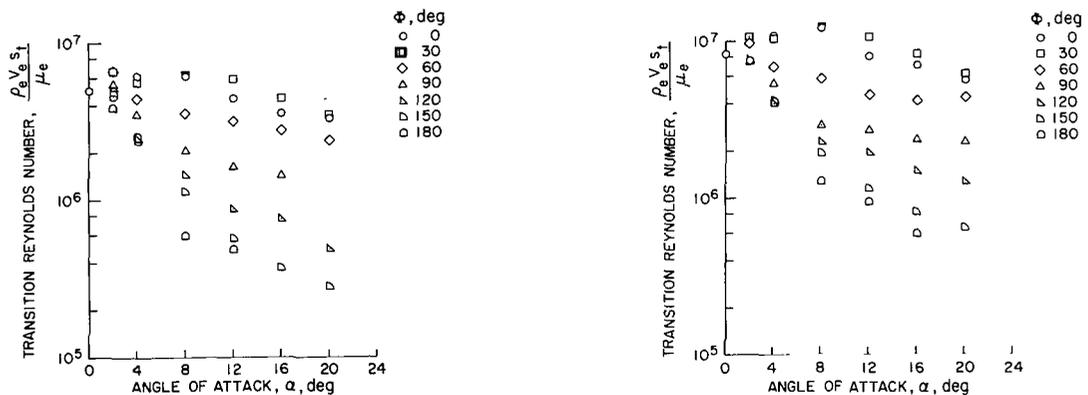
In references 3 and 5 it was suggested that the effect of cooling at $M_e \doteq 5$ (for $T_w/T_t < 0.4$) was initially destabilizing but that below $T_w/T_t \doteq 0.2$ this trend reversed, and continued cooling stabilized the boundary layer (an effect denoted as "rereversal" in ref. 3). A similar conclusion might be made using the present data, although there are no data points in the region $0.1 < T_w/T_t < 0.2$. However, it is possible to get an indication of how transition behaves for $0.1 < T_w/T_t < 0.2$ by observing the movement of transition as the model wall temperature increases during a given test. (This technique is somewhat undesirable because temperature gradients along the model surface are introduced, and it is not known how these gradients would affect transition.) The movement of transition, as the wall temperature increases for a given test, is indicated on the figure by points connected by an arrow. In this situation the beginning of transition moves forward for T_w/T_t increasing from 0.1 to 0.2 while the end of transition remains essentially fixed. This result combined with the initially isothermal wall data suggests that the trend of the beginning of transition with cooling may be changing at $T_w/T_t \doteq 0.2$ although it is not clear that this is a rereversal.

For the 5° cone data of figure 2(b) ($M_e = 6.6$) the effect of cooling is not as pronounced nor is there any strong indication of any change in the effect of cooling. This last observation may also be made for the data at $M_e \doteq 6.5$ (ref. 3).

Angle-of -Attack Result

The angle-of-attack transition data are presented in terms of Reynolds numbers that are based on boundary-layer edge conditions calculated by the method of characteristics program described in reference 10. To obtain edge conditions for angles of attack greater than the cone half-angle, the following procedures were employed. (1) The 15° cone edge conditions for $\alpha \leq 15^\circ$ were extrapolated to $\alpha = 20^\circ$. (2) Windward-ray edge conditions on the 5° cone for $\alpha > 5^\circ$ were calculated by replacing the leeward side of the cone with an elliptic cone whose leeward-ray was aligned with the free-stream velocity vector. (3) Leeward-ray edge conditions on the 5° cone for $\alpha = 6^\circ$ were extrapolated from the calculations for $\alpha \leq 5^\circ$. In formulating the transition Reynolds number, the velocity along the streamline was used in conjunction with the distance along conical rays.

The effect of angle of attack on local transition Reynolds number is illustrated in figure 3 for the 15° cone. For transition Reynolds numbers based on either the beginning (fig. 3(a)) or the end (fig. 3(b)) of transition, the influence of angle of attack depends on meridian angle, Φ . For example,



(a) Beginning of transition

(b) End of transition

Figure 3. Effect of angle of attack on transition; $\Theta_c = 15^\circ$, $M_\infty = 7.4$, $T_w/T_t = 0.36$.

on the windward ray, local transition Reynolds numbers show an initial, slight increase with α and then a decrease; whereas, on the leeward ray, transition Reynolds numbers decrease rapidly with α .

On the 5° cone (fig. 4) the effect of α on the beginning and end of transition on the leeward ray is similar to that on the 15° cone; that is, leeward-ray transition Reynolds numbers decrease with increasing angle of attack. In contrast, on the windward ray the effect of α is not similar. For the 5° cone, windward-ray transition Reynolds numbers increase monotonically with angle of attack so at $\alpha = 20^\circ$ the local transition Reynolds number is at least four times the $\alpha = 0^\circ$ value. On the 15° cone the $\alpha = 20^\circ$ value is only 60 percent of the $\alpha = 0^\circ$ value. As will be shown later, the differences between the 5° and 15° cone on the windward ray are related to differences in local conditions, cone angle, and crossflow velocity gradient.

Figures 3 and 4 indicate that the length of the transition region relative to the length of laminar flow is a weak function of both the angle of attack and meridian angle. On the 15° cone, however, these variations are not obvious so figure 5 was prepared. The relative length of the transition region appears to be a minimum at meridian angles from 60° to 90° , although this could be related to the manner in which transition length was defined. For example, if the length of transition had been measured along streamlines instead of along conical rays, the influence of meridian angle might be different. On the 5° cone the relative length of the transition region decreases slightly on the windward and increases on the leeward rays as the angle of attack increases.

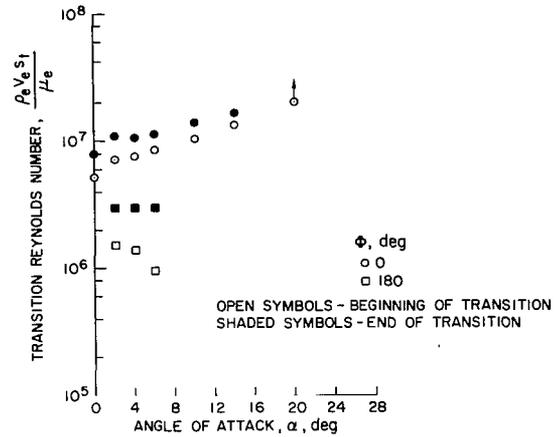


Figure 4. Effect of angle of attack on transition; $\Theta_c = 5^\circ$, $M_\infty = 7.4$, $T_w/T_t = 0.36$

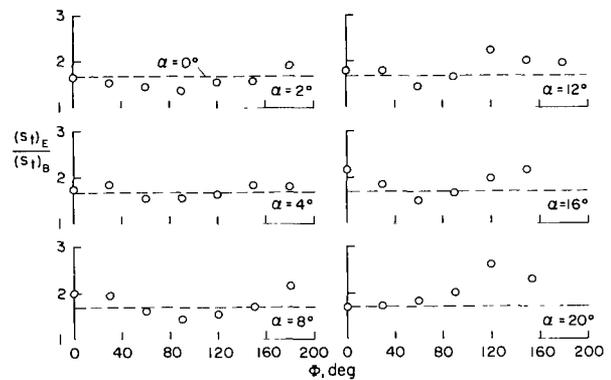


Figure 5. Effect of angle of attack and meridian angle on the length of the transition region; $M_\infty = 7.4$, $\Theta_c = 15^\circ$, $T_w/T_t = 0.36$

Angle-of-Attack Correlation

Transition on cones at angle of attack can, potentially, be affected by such parameters as crossflow velocity, crossflow velocity gradient, pressure gradient along streamlines, and changes in local Mach number. With so many variables to consider, it is desirable to look for situations where some effects can be eliminated so that the influence of one or two parameters can be isolated. The windward centerline affords such a situation. Here, there is no crossflow velocity or pressure gradient along the streamline, and the crossflow velocity gradient (derivative of the circumferential velocity in the circumferential direction) and local conditions can be adequately predicted (ref. 10). Consequently, a correlation based on changes in local conditions and crossflow velocity gradient was attempted for transition data on the windward ray, using the following procedure.

Previous investigations (e.g., ref. 3) have shown that the effects of variation in local conditions on transition on cones at $\alpha = 0^\circ$ can be accounted for by an approximately linear relationship between local momentum thickness Reynolds number (at transition) and local Mach number. In the

present correlation it was assumed that a similar relationship holds at angle of attack. The local conditions were calculated by the previously described characteristics solution, and the momentum thicknesses at transition were calculated from the boundary-layer profiles tabulated in reference 11. The crossflow velocity gradient parameter k of reference 11 was chosen as the independent variable. A satisfactory correlation of windward-ray transition data on cones can be achieved as shown in figure 6.¹ In addition to the present data, those of references 5, 6, and 13 were also correlated. Selection of data from other investigations was contingent on the beginning of transition being defined in the same manner (i.e., from heat-transfer measurements). The results indicate that the linear relationship between local-momentum-thickness Reynolds number and edge Mach number still exists at angle of attack, except that the constant of proportionality is a function of k .

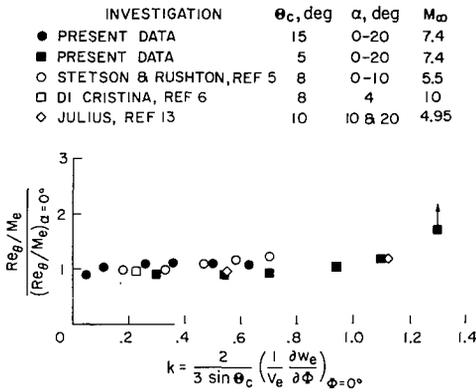


Figure 6. Correlation of the beginning of transition; windward ray of cones.

The extension of this correlation to the case of an arbitrary streamline is certainly an attractive possibility. In the general case, however, the velocity gradient may not be the correlating parameter. In this instance a parameter related to streamline spreading may be more appropriate. For example, for the specific case of the windward ray of a cone, Vaglio-Laurin (ref. 14) has shown that the variable k is related to streamline spreading.

CONCLUSIONS

The effects of wall cooling and angle of attack on boundary-layer transition have been investigated on 5° and 15° half-angle cones. Wall-to-total-temperature ratios (T_w/T_t) varied from 0.08 to 0.4 and angles of attack ranged from 0° to 20° . The tests were conducted at a free-stream Mach number of 7.4, total temperatures from 768° to 1552° K (1380° to 2800° R) and total pressures of 2.160×10^6 to 1.210×10^7 N/m² (314.0 to 1817 psia). The following is concluded from this investigation.

1. In general, transition Reynolds numbers decrease with decreasing T_w/T_t . On the 15° cone, however, there are indications that this trend does not continue for $T_w/T_t < 0.2$.
2. Local transition Reynolds numbers are a function of both angle of attack and cone half-angle. On the lee side of both models transition Reynolds numbers decreased with increasing α while on the windward side an increase was observed on the 5° cone, and a slight increase was followed by a decrease on the 15° cone.

¹This figure replaces figure 6 of reference 12.

3. Transition data on the windward ray of cones can be correlated by accounting for variations in crossflow velocity gradient, momentum thickness Reynolds number, local Mach number, and cone half-angle.

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National Aeronautics and Space Administration

Moffett Field, California 94035, April 7, 1972

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TABLE 1.—TEST CONDITIONS FOR WALL-COOLING DATA

θ_c , deg	p_t , N/m ²	p_t , psia	T_t , °K	T_t , °R	T_w , °K	T_w , °R	$\left(\frac{\rho V}{\mu}\right)_\infty$, m ⁻¹	$\left(\frac{\rho V}{\mu}\right)_\infty$, ft ⁻¹	$(s_t)_B$, m	$(s_t)_B$, ft	$(s_t)_E$, m	$(s_t)_E$, ft
15	1.248×10 ⁷	1810	1519	2735	119.4	215	8.035×10 ⁶	2.449×10 ⁶	0.2210	0.7250	0.3758	1.233
	7.584×10 ⁶	1100	1161	2089	101.1	182	8.219×10 ⁶	2.505	.2514	.8250	.3962	1.300
	1.246×10 ⁷	1807	1181	2126	108.3	195	1.307×10 ⁷	3.983	.1829	.6000	.2642	.8667
	4.178×10 ⁶	606	876.7	1578	87.22	157	7.490×10 ⁶	2.283	.3099	1.017	O.M. ^a	O.M.
	1.240×10 ⁷	1798	903.9	1627	142.8	257	2.108×10 ⁷	6.424	A.T. ^b	A.T.	.1880	.6167
	1.253×10 ⁷	1817	1498	2697	320.6	577	8.294×10 ⁶	2.528	.2006	.6583	.3785	1.242
	7.667×10 ⁶	1112	1143	2057	305.6	550	8.554×10 ⁶	2.607	.2514	.8250	.4139	1.358
	1.230×10 ⁷	1784	1042	1876	314.4	566	1.624×10 ⁷	4.951	.1956	.6417	.2819	.9250
	1.211×10 ⁷	1757	1028	1850	327.8	590	1.640×10 ⁷	5.000	.1854	.6083	.2819	.9250
	5.698×10 ⁶	826.4	963.3	1734	314.4	566	8.662×10 ⁶	2.640	.2794	.9167	O.M.	O.M.
	4.178×10 ⁶	606.0	861.7	1551	303.9	547	7.717×10 ⁶	2.352	.3022	.9917	O.M.	O.M.
	6.164×10 ⁶	894.0	815.6	1468	305.6	550	1.250×10 ⁷	3.811	.2387	.7833	.3758	1.233
	1.091×10 ⁷	1582	837.2	1507	313.9	565	2.116×10 ⁷	6.450	.1600	.5250	.2489	.8167
	7.350×10 ⁶	1066	790.0	1422	307.8	554	1.574×10 ⁷	4.796	.2108	.6917	.2794	.9167
	6.191×10 ⁶	898.0	790.6	1423	316.7	570	1.324×10 ⁷	4.035	.2311	.7583	.3682	1.208
5.840×10 ⁶	847.0	781.1	1406	316.7	570	1.274×10 ⁷	3.884	.2260	.7417	.3709	1.217	
5	1.247×10 ⁷	1809	1552	2794	110.6	199	7.694×10 ⁶	2.345	.3557	1.167	.5891	1.933
	6.054×10 ⁶	878	833.3	1500	77.78	140	1.184×10 ⁷	3.608	.2997	.9833	.4901	1.608
	1.211×10 ⁷	1757	828.9	1492	107.8	194	2.391×10 ⁷	7.287	A.T.	A.T.	.2349	.7708
	1.251×10 ⁷	1815	1532	2758	325.6	586	7.924×10 ⁶	2.415	.3453	1.133	.5843	1.917
	9.398×10 ⁶	1363	1313	2364	320.6	577	8.058×10 ⁶	2.456	.3758	1.233	.6120	2.008
	8.143×10 ⁶	1181	1195	2152	323.9	583	8.347×10 ⁶	2.544	.3557	1.167	.6248	2.050
	1.139×10 ⁷	1652	1108	1994	306.7	552	1.346×10 ⁷	4.102	.2844	.9333	.4572	1.500
	8.281×10 ⁶	1201	1010	1819	305.6	550	1.156×10 ⁷	3.523	.3048	1.000	.4953	1.625
	6.019×10 ⁶	873	852.2	1534	300.0	540	1.133×10 ⁷	3.453	.3072	1.008	.5004	1.642
	1.177×10 ⁷	1707	875.0	1575	311.1	560	2.117×10 ⁷	6.452	A.T.	A.T.	.2730	.8958
	6.054×10 ⁶	875	850.0	1530	305.6	550	1.140×10 ⁷	6.054	.3328	1.092	.5309	1.742
	5.950×10 ⁶	863	851.7	1533	307.8	554	1.121×10 ⁷	3.417	.3048	1.000	.4825	1.583
	4.344×10 ⁶	630	807.2	1453	305.6	550	8.967×10 ⁶	2.733	.4114	1.350	O.M.	O.M.
	8.039×10 ⁶	1166	796.7	1434	304.4	548	1.697×10 ⁷	5.172	.2110	.7250	.3022	.9917
	5.874×10 ⁶	852	768.3	1383	302.2	544	1.318×10 ⁷	4.016	.2921	.9583	.4496	1.475

^aO.M. — off model; ^bA.T. — ahead of thermocouples

TABLE 2.—TEST CONDITIONS FOR ANGLE-OF-ATTACK DATA

θ_c , deg	α , deg	P_T , N/m ²	P_T , psia	T_t , °K	T_t , °R	$(\frac{\rho V}{\mu})_\infty$, m ⁻¹	$(\frac{\rho V}{\mu})_\infty$, ft ⁻¹	Φ , deg	$(s_t)_B$, m	$(s_t)_B$, ft	$(s_t)_E$, m	$(s_t)_E$, ft	
15	2	1.209×10 ⁷	1753	820.0	1476	2.43×10 ⁷	7.41×10 ⁶	0	0.123	0.403	0.203	0.666	
								30	.179	.587	.282	.926	
								60	.183	.602	.267	.875	
		4	1.126×10 ⁷	1633	803.9	1447	2.34×10 ⁷	7.13×10 ⁶	90	.155	.510	.213	.698
								120	.159	.522	.244	.799	
								150	.156	.513	.239	.785	
		8	6.943×10 ⁶	1007	827.2	1489	1.38×10 ⁷	4.19×10 ⁶	180	.127	.418	.245	.803
								0	.303	.993	.522	1.713	
								30	.282	.925	.520	1.705	
		12	5.523×10 ⁶	801.0	851.7	1533	1.04×10 ⁷	3.17×10 ⁶	60	.237	.778	.364	1.193
								90	.199	.653	.314	1.03	
								120	.200	.655	.326	1.07	
		16	1.093×10 ⁷	1585	827.8	1490	2.16×10 ⁷	6.59×10 ⁶	150	.205	.674	.375	1.23
								180	.216	.708	.373	1.225	
								0	.208	.682	.405	1.33	
		20	4.309×10 ⁶	625.0	838.9	1510	8.33×10 ⁶	2.54×10 ⁶	30	.221	.725	.430	1.41
								60	.141	.463	.227	.746	
								90	.095	.311	.136	.448	
		5	1.091×10 ⁷	1582	812.2	1462	2.23×10 ⁷	6.79×10 ⁶	120	.207	.680	.320	1.05
								150	.190	.625	.323	1.06	
								180	.102	.335	.219	.720	
		10	9.660×10 ⁶	1401	830.6	1495	1.90×10 ⁷	5.79×10 ⁶	0	.190	.622	.338	1.11
								30	.263	.864	.472	1.55	
								60	.168	.553	.242	.794	
	14	2.751×10 ⁶	399.0	832.8	1499	5.38×10 ⁶	1.64×10 ⁶	90	.113	.370	.188	.617	
							120	.277	.910	.616	2.02 ^a		
							150	.229	.752	.460	1.51		
	20	1.087×10 ⁷	1576	822.8	1481	2.17×10 ⁷	6.62×10 ⁶	180	.190	.623	.369	1.21	
							0	.132	.433	.285	.934		
							30	.192	.631	.354	1.16		
	5	1.083×10 ⁷	1572	868.9	1564	1.97×10 ⁷	6.01×10 ⁶	60	.148	.485	.222	.728	
							90	.107	.350	.176	.579		
							120	.083	.273	.164	.540		
	10	1.096×10 ⁷	1589	840.0	1512	2.11×10 ⁷	6.44×10 ⁶	150	.016	.199	.130	.427	
							180	—	—	.090	.297		
							0	.175	.574	.295	.968		
	14	1.095×10 ⁷	1588	820.6	1477	2.20×10 ⁷	6.70×10 ⁶	30	.203	.666	.350	1.15	
			2.165×10 ⁶	314.0	783.9	1411	4.69×10 ⁶	1.43×10 ⁶	60	.167	.549	.305	1.00
			1.099×10 ⁷	1594	830.0	1494	2.16×10 ⁷	6.60×10 ⁶	90	.112	.368	.224	.736
	20	2.220×10 ⁶	322.0	792.2	1426	4.72×10 ⁶	1.44×10 ⁶	120	.076	.249	.198	.651	
			1.097×10 ⁷	1591	872.2	1570	1.98×10 ⁷	6.05×10 ⁶	150	.079	.260	.181	.594
			1.100×10 ⁷	1595	862.8	1553	2.03×10 ⁷	6.18×10 ⁶	0	.234	.768	.357	1.17
	5	1.097×10 ⁷	1591	842.8	1517	2.10×10 ⁷	6.41×10 ⁶	180	.287	.941	.567	1.86	
			1.093×10 ⁷	1585	808.9	1456	2.25×10 ⁷	6.85×10 ⁶	0	.234	.768	.332	1.09
			1.100×10 ⁷	1596	833.9	1501	2.15×10 ⁷	6.55×10 ⁶	180	.288	.946	.622	2.04
	10							0	.280	.917	.369	1.21	
								0	.280	.917	.369	1.21	
								0	.280	.917	.369	1.21	
	14							0	.280	.917	.369	1.21	
								0	.280	.917	.369	1.21	
								0	.280	.917	.369	1.21	
	20							0	.280	.917	.369	1.21	
								0	.280	.917	.369	1.21	
								0	.280	.917	.369	1.21	

^aEstimated

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