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RESEARCH MEMORANDUM

INVESTIGATION OF CONTROL SIGNALS FOR VARIABLE RAMPS OF TWIN-DUCT SIDE INLETS

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[redacted]

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

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INVESTIGATION OF CONTROL SIGNALS FOR VARIABLE RAMPS OF TWIN-DUCT SIDE INLETS

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SUMMARY

An investigation was conducted in the NACA Lewis 8- by 6-foot supersonic wind tunnel to determine the effectiveness of experimental control signals which were applied to a theoretical inlet throat Mach number control system and a normal-shock-position control system for varying the inlet geometry of a twin-duct, side-inlet, fuselage forebody model of a prototype aircraft. The inlets were of the double-ramp type with a fixed-angle first ramp and a variable-angle second ramp. The investigation was conducted with various second-ramp angles over a range of angles of attack and yaw at free-stream Mach numbers from 1.5 to 2.0. With some reservations due to twin-duct asymmetry, the theoretical inlet throat Mach number control using the signals investigated appeared to provide satisfactory control performance superior to that for the normal-shock-position control. A constant value of control throat Mach number provided near-optimum performance for all conditions except on a USAF hot day.

INTRODUCTION

Twin-duct side-inlet systems have been used on several fighter- and interceptor-type aircraft. As the flight Mach number of these aircraft is increased in the supersonic range, variable-geometry inlets are employed; and therefore a control system must be selected.

An investigation has been conducted in the Lewis 8- by 6-foot supersonic wind tunnel to determine the effectiveness of experimental control signals applied to two types of theoretical control systems for the variable inlet geometry of the twin-duct, side-inlet, fuselage forebody model of a prototype aircraft reported in reference 1. The inlets were of the double-ramp type with a fixed-angle first ramp and a variable-angle second ramp. The purpose of these theoretical control systems was to vary the second-ramp angle in order to maintain near-optimum inlet-engine performance over the range of flight Mach numbers and temperatures. No variable compressor bypass was incorporated in the design of the aircraft. The test was conducted with several second-ramp angles over a range of angles of attack and yaw at free-stream Mach numbers from 1.5 to 2.0.

The experimental control signals applied to the theoretical inlet throat Mach number control system were the Mach numbers measured just inside the cowling. This was a region where the second-ramp angle theoretically influenced the local Mach number in a unique manner for any given engine corrected airflow. Thus, by controlling this throat Mach number, the ramp angle would be controlled. This theoretical control system was analyzed in detail.

A theoretical normal-shock-position control system was analyzed briefly. For the type inlets investigated at any given engine corrected airflow, normal-shock position theoretically was a unique function of ramp angle. Hence, by controlling normal-shock position, ramp angle would be controlled.

SYMBOLS

A_3 compressor-tip frontal area

D incremental drag

F thrust

m_3/m_0 ratio of inlet mass flow to mass flow at free-stream conditions through inlet capture area

P total pressure

p static pressure

w weight flow

δ ratio of total pressure to NACA standard-day sea-level pressure of 2116 lb/sq ft

θ ratio of total temperature to NACA standard-day sea-level ambient temperature of 519° R

Subscripts:

c control

i ideal

n net

s standard day

0 free-stream conditions

3 compressor-face conditions

APPARATUS

A photograph of the model is presented in figure 1, and a sketch of the inlet appears in figure 2. This model is the same as that investigated in reference 1. The double-ramp twin-duct inlets had a combination scoop and diverter system for fuselage boundary-layer removal. As shown in the sketch in figure 2, the centerline of the initial portion of the duct was canted 5° with respect to the fuselage centerline. The first ramp was fixed at 9°, and the second-ramp angular position was set at several values. The longitudinal position of the second ramp was such that the theoretical second oblique shock was about 0.22 inch upstream of the cowl lip with a second-ramp angle of 19° at a free-stream Mach number of 2.0. Six rows of perforations were located in the surface of the second ramp upstream of the cowl to serve as a ramp boundary-layer-removal system.

To obtain experimental control signals for the theoretical throat Mach number control, a Pitot static tube was located in each of the ducts $1\frac{1}{2}$ inches downstream of the cowl lip. The exact location and details of this tube are indicated in figure 2. This particular location was selected as that at which the local total pressure was closest to the average at this station regardless of angle of attack, angle of yaw, or ramp angle as determined from a total-pressure survey. Cowl coordinates in this region are also shown in figure 2.

The instrumentation providing signals for the theoretical normal-shock-position control consisted of a static-pressure orifice in the ramp surface inside the cowling as shown in figure 2. This instrumentation was located in the left inlet only. Subsonic-diffuser area variations for several second-ramp angles are shown in figure 3. Duct cross sections are also indicated.

PROCEDURE

For a given second-ramp angle, the inlets were investigated over a range of mass-flow ratios, angles of attack and yaw, and Mach numbers from 1.5 to 2.0. The ramp angles selected and the corresponding Mach numbers at which the theoretical second oblique shock was about 0.22 inch upstream of the cowl lip were as follows:

Second-ramp angle, deg	Design Mach number
21	2.1
19	2.0
17	1.9
13	1.7
9	1.5

An individual throat Mach number for each of the two ducts and also an average throat Mach number for both ducts are presented in the figures. The individual throat Mach number was computed from the static- to total-pressure ratio for each Pitot-static tube. The average throat Mach number was computed from the ratio of the average of the two static pressures to the average of the two total pressures. In the figures for the normal-shock-position control system, the ratio of control pressure to free-stream static pressure appears.

Inlet performance characteristics used in the thrust-minus-drag analysis of this report were obtained from reference 1. 4555

RESULTS

Inlet Instability

Before the control problem is considered, the two types of inlet instability encountered with this configuration are discussed. As the mass-flow ratio was reduced from the critical value, the normal shocks of both inlets moved upstream uniformly and in a stable manner until at some mass-flow ratio twin-duct asymmetry began to occur. As the mass flow was reduced further, the normal shock of one inlet continued to move gradually upstream while the other normal shock gradually moved back into the inlet. During operation of this type the normal shocks began to oscillate locally resulting in small variations in diffuser pressures that gradually increased in amplitude. This instability, called flutter, is indicated in the figures by a tail up symbol. Eventually, as the mass flow was decreased further, inlet buzz occurred during which the normal shocks oscillated over large distances with a sharp rise in the amplitude of diffuser pressure variations. This instability is indicated in the figures by a tail down symbol.

Control Requirements

The purpose of any control system for this inlet configuration was to vary the inlet geometry (second-ramp angle) to maintain near optimum inlet-engine performance over the range of flight Mach numbers and temperatures. No variable compressor-bypass system was incorporated in this aircraft.

The chief problems in selecting a control system for a twin-duct configuration are: (1) deciding on a suitable control plan; (2) determining the proper location of the control; (3) obtaining satisfactory control signals to operate the desired controlled parameter; and (4) determining the effect of twin-duct asymmetry on the measured control signals and the subsequent effect on the controlled parameter.

For the twin-duct system investigated the control plan of the inlets can be handled in several ways: (1) sense the conditions in each duct and operate each second ramp separately as required; (2) sense the conditions in each duct, average, and operate both second ramps identically; or (3) sense the conditions in one duct and operate both second ramps identically. The possibilities of method (1) cannot be evaluated in the present report, since data were obtained only for equal ramp angles. It is possible that twin-duct asymmetry could have been prevented with such a control. The practicality of method (2) is investigated in some detail in this report. Operating difficulties may be encountered with method (3) because of twin-duct asymmetrical operation.

A desirable control signal for the configuration investigated would be an inlet parameter that is a unique function of second-ramp angle. At a given corrected airflow, twin-duct asymmetry may cause the signal obtained during unstable operation with a certain ramp angle to be identical to the signal obtained with a different ramp angle operating in a stable manner. (This condition is referred to as signal crossover.) The control system then might set either of two widely different ramp angles, one of which would be undesirable because of poor performance and unstable operation. If the control had the ability to reject the asymmetric condition, it could then seek the stable, symmetric operating conditions.

Some of these problems are analyzed for the theoretical throat Mach number and normal-shock-position control systems.

Individual Throat Mach Number Control Signals

Presented in figure 4 are the individual throat Mach number signals obtained for several second-ramp angles and free-stream Mach numbers at 2° angle of attack. The closed and open symbols indicate the left and right inlets, respectively. During supercritical inlet operation it would be expected that the throat Mach number would be some constant supersonic value depending upon ramp angle and free-stream Mach number. If the inlets were operating symmetrically, the throat Mach numbers would be equal. As critical inlet operation is approached, the throat Mach numbers should suddenly drop to some subsonic value as the normal shocks move upstream of the Pitot-static tubes. The throat Mach numbers should then decrease as the mass flow is further reduced in the subcritical operating range. If the inlets operate symmetrically, this decrease should be continuous and equal for both inlets.

The data in figure 4 indicate that for all ramp angles and free-stream Mach numbers the inlets operated symmetrically from critical operation throughout the subcritical stable range until flutter and buzz occurred. Accompanying flutter and buzz operation was a wide difference in throat Mach numbers indicating severe asymmetric inlet operation.

During the stable subcritical operating range the signal obtained with one ramp angle was distinctly different from that obtained with another ramp angle. Figure 4 shows that in some cases signal crossover occurred during unstable operation.

During supercritical operation the performance of the inlets differed from that expected, particularly at the lower free-stream Mach numbers of 1.6 and 1.5 (figs. 4(e) and (f)), where the throat Mach numbers remained subsonic in both inlets for most ramp angles. In these cases conventional inlet starting did not occur, probably because of the blockage resulting from the Pitot-static control tubes. At Mach numbers of 1.9 and 1.8 (figs. 4(b) and (c)) the right inlet started as expected, but the left inlet did not, causing the throat Mach numbers to be widely asymmetrical.

Average Throat Mach Number Control Signals

The average throat Mach number control signals are presented in figure 5 for the same configurations and operating conditions shown in figure 4. In figure 5 the critical operating points of the inlet are indicated by closed symbols.

The average throat Mach number data follow the same trends as those observed for the individual throat Mach number data presented in figure 4. Averaging the conditions tended to reduce the problem of signal crossover but did not eliminate it completely. In designing a control system serious consideration must be given to this problem.

Theoretical Throat Mach Number Control Analysis

The average throat Mach number data in figure 5 were used in an analysis of a theoretical control system using this signal for ramp actuation. Because of its simplicity, a control designed to maintain a constant value of throat Mach number regardless of operating conditions would be more desirable than one which would have the control value of throat Mach number scheduled with such operating conditions as flight Mach number, altitude, and ambient temperature. The major part of the analysis which follows was made for the constant control Mach number case, but the improvement which could be made by using a variable control Mach number is also indicated.

The analysis was made assuming that a suitable turbojet engine and typical auxiliary airflow requirements were matched to the inlet system. These corrected airflows for NACA standard and USAF hot and cold days are indicated on the abscissas of figures 4 and 5. Inlet performance data were obtained from reference 1. Typical mass-flow pressure-recovery curves used in the analysis are shown in figures 6(a) and (b) for Mach numbers 2.0 and 1.5, respectively. Engine airflow lines are indicated.

The ramp angles, mass-flow ratios, and pressure recoveries which a constant throat Mach number control would set, are shown in figure 7, for a 2° angle of attack over the Mach number range for three ambient temperatures at 35,000 feet altitude. A value of 0.82 for throat Mach number was selected, since this value provided better performance for a larger number of operating conditions than any other value. The figure shows a large effect of ambient temperature, particularly for temperatures higher than the standard day.

Some over-all performance parameters evaluated from the data in figure 7 are shown in figure 8. The effective-thrust ratio is defined as the net thrust of the assumed engine at the measured pressure recovery minus an incremental drag, depending upon mass-flow ratio and ramp angle, divided by the net thrust of the engine with 100-percent pressure recovery. The incremental drag is defined as the difference between the model drag at the operating condition of interest and the minimum model drag attainable at the same Mach number and angle of attack. Thus, with supercritical operation and with a ramp angle less than design, incremental drag would be zero. The performance for a throat Mach number of 0.82 is shown by the curves, and the optimum performance obtainable with a variable throat Mach number is denoted by the symbols.

With this particular match of engine and inlet, the highest values of effective-thrust ratio were obtained on a standard day. The constant throat Mach number control would set operating conditions to within about 1 percent of optimum effective-thrust ratio over the free-stream Mach number range on a standard day. Cold-day performance was somewhat lower than that of the standard day because of reduced pressure recovery, but the constant throat Mach number control would set the optimum condition over the Mach number range. On a hot day the effective-thrust ratio was quite low at the higher free-stream Mach numbers, and for these conditions appreciable improvements could be made by using a variable throat Mach number, as shown on the figure. These improvements, however, required placing the inlet system on the verge of asymmetrical and flutter inlet operation. The 0.82 constant throat Mach number did not operate the inlet system near the range of instability.

As ambient temperature increases, the engine net thrust with 100-percent pressure recovery, $F_{n,i}$, decreases. Hence, the effective-thrust ratio, which is useful as an inlet efficiency parameter, is not an indication of the actual force available to drive the airplane. Therefore, also presented in figure 8 is the ratio of actual thrust minus drag to standard-day ideal net thrust that would be obtained with the constant throat Mach number control. On a standard day the values of this parameter are identical to those of the effective-thrust ratio. The actual thrust minus drag for a cold day is higher than that for the standard day even though the effective-thrust ratio is less. On a hot day the actual thrust minus drag is lowest by large amounts over the Mach number range, and it appears that the problem of obtaining sufficient thrust to drive the airplane is most critical. The figure shows that the improvements obtained by employing a variable throat Mach number control were not large and that greater improvements could be obtained by giving more preference to the hot-day condition in matching the inlet and engine system. The cold-day condition appears to be least critical in matching considerations.

The inlet operating conditions with a constant throat Mach number of 0.82 which were shown in figure 7 at 35,000 feet altitude are also shown in figure 9 for a range of pressure altitude to 65,000 feet. Again the effect of temperature is large over the altitude range. Some of the results for cold-day operation in figure 9 appear to vary somewhat erratically. This is primarily a result of the large variation in ambient temperature with altitude on a cold day.

The same thrust performance parameters discussed previously are also presented in figure 10 for the conditions in figure 9. Effective-thrust ratio remained fairly constant over the altitude range for all flight Mach numbers on standard and cold days. In these cases the constant throat Mach number control maintained near optimum performance. On a hot day the effective-thrust ratio decreases with increasing altitude at the higher Mach numbers and was less than optimum.

The effects of altitude on the thrust minus drag to standard-day ideal net-thrust ratio varied widely depending upon ambient temperature. On a standard day there was little effect; on a cold day the ratio increased with increasing altitude; and on a hot day the ratio decreased with increasing altitude. These trends were similar over the Mach number range. Again, flight on a hot day appears to be the most critical condition, particularly at the higher altitudes.

Effect of Angle of Attack

Airplane angles of attack and yaw greatly influence inlet performance, particularly with a twin-duct system. In the design of a control, therefore, the effect of airplane attitude could be an important factor.

Sufficient data were not obtained to make a complete analysis of the effect of airplane attitude on control performance. However, some trends can be observed from the available data. Individual throat Mach number signals obtained over a range of angles of attack and yaw for a variety of operating conditions are presented in figures 11(a) to (f). Each figure shows a significant effect of attitude over the entire airflow range. For a given ramp angle at a particular free-stream Mach number, increasing model angle of attack increased throat Mach number at any value of corrected airflow. The behavior of the inlets with respect to symmetry was similar at high angles of attack to that discussed previously

for 2° angle of attack, but the range in corrected airflow in which the inlets were symmetric decreased. However, as model yaw angle increased (fig. 11(e)), the inlets became increasingly asymmetric over the airflow range, as would be expected. At ±2.1° yaw the curves for the two inlets did not coincide because of the asymmetry, but both inlets could be operated subcritically and supercritically in the conventional manner. At 6° or 9° yaw this was no longer true; the windward inlet remained subcritical over the airflow range. As seen in the figure, the throat Mach number in this inlet remained constant over the airflow range investi-
 gated, while the signal from the leeward inlet varied in a conventional manner.

For the maneuvers discussed previously, the following alternatives are available: (1) The control could be allowed to operate to maintain either a constant throat Mach number or a Mach number scheduled with ambient temperature, or (2) the controlled value of throat Mach number could be scheduled with model attitude, or (3) the control could be made inoperative during an angle of attack or yaw maneuver. The basic requirement of the control during such maneuvers would be to keep the inlet out of regions either where instability occurs or where inlet performance deteriorates so badly that engine performance is unsatisfactory (e.g.,
 high distortion causing compressor stall). In addition to the structural hazards that instability presents, it might perhaps, with a twin-duct system, cause airplane yaw instability if the two inlets oscillated out of phase. Conceivably, then, by obtaining sufficient data to determine the dangerous operating regions, a control could be scheduled to avoid these regions. Since such a control may be complicated, simpler systems are desirable; however, insufficient data are available to completely resolve this problem. Some trends can be determined, however.

Presented in figures 12(a) and (b) are the average throat Mach number signals for the yaw data of figure 11(e) and the angle of attack data of figure 11(a), respectively. For the yaw maneuver insufficient data are available to determine exactly what the control would do if it were operating to maintain an average throat Mach number of 0.82. However, since the signals increased above 0.82 as yaw angle increased on a standard day, the ramp angles would be lowered below 13° by an unknown amount. Whether or not instability would be encountered is not known. If the control were inoperative during the maneuver, the ramp angle would remain at 13° while the throat Mach number would vary along a line of constant corrected airflow. The figure shows that instability would be approached at 9° yaw, but the performance appears to be satisfactory at lower yaw angles.

A little more information is available for the angle of attack maneuver, since angle of attack performance was obtained for more than one ramp angle at Mach 2.0. Although data were obtained in one inlet only with the 19° ramp angle at Mach 2.0 (fig. 11(b)), the inlets were symmetrical in the operating range of interest. These data and the average Mach number data with the 21° ramp in figure 12(b) were used to obtain the curve in figure 13 of second-ramp angle against angle of attack at Mach number 2.0 with the control maintaining a constant average throat Mach number of 0.82. This analysis was made for some day warmer than the standard day for which the match corrected airflow was 21.8 (lb/sec)/sq ft. This condition was selected since the control would then set the 21° ramp angle at the cruise angle of attack. The figure shows that in the angle of attack range from -2.1° to 5° the ramp angle varied by little more than 1°. However, at angles of attack greater than 5° the ramp angles would be lowered an unknown amount until at 9° angle of attack they would be substantially less than 19°.

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Theoretical Normal-Shock-Position Control

The signals obtained for the theoretical normal-shock-position control are presented in figures 14(a) and (b) for flight Mach numbers of 1.98 and 1.49, respectively. The parameter presented is the ratio of the static pressure just inside the cowl on the ramp surface to the free-stream static pressure. Although data were obtained in one inlet only, it is representative of both inlets in the subcritical operating range between critical and the start of instability.

This method of controlling the ramp was not as satisfactory as the throat Mach number control, because the change in corrected airflow with ramp angle at a constant value of static-pressure parameter is relatively small at both Mach 2.0 and 1.5. As a result, the effect of ambient temperature on performance will be larger than it was with the throat Mach number control; and poorer performance would result on the nonstandard days.

Also, at Mach 1.5, if a constant value of static-pressure parameter is selected for operation over the range of ambient temperature, the optimum ramp angle for standard-day operation cannot be obtained. For example, the static-pressure parameter must be greater than about 1.9 if the control is to perform properly on days hotter than the standard day. But with this control value, the ramp angles would be less than 9° on a standard day; and therefore a relatively low pressure recovery would result. This difficulty could be overcome if the static-pressure parameter were scheduled with ambient temperature.

Since the theoretical throat Mach number control appeared to be better than the theoretical normal-shock-position control and less data were available, the latter was not analyzed further.

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SUMMARY OF RESULTS

An investigation was conducted to determine the effectiveness of experimental control signals that were applied to a theoretical inlet throat Mach number control system and a theoretical normal-shock-position control system for varying the inlet geometry of a twin-duct, side-inlet, fuselage forebody model of a prototype aircraft. The inlets were of the double-ramp type with a fixed first ramp and a variable-angle second ramp. The investigation was conducted with various second-ramp angles over a range of angles of attack and yaw at free-stream Mach numbers from 1.5 to 2.0. The following results were observed:

1. If the throat Mach numbers of both ducts are averaged, the resultant control signal when applied to a theoretical control system with a single mechanism actuating both ramps uniformly provides satisfactory performance if the control system disregards signals obtained when the inlets are widely asymmetric.

2. At cruise angle of attack the theoretical constant throat Mach number control system would set near-optimum operating conditions over the Mach number range on either an NACA standard day or a USAF cold day in the altitude range from 35,000 to 65,000 feet. On a USAF hot day, performance could be improved appreciably over the altitude range by scheduling throat Mach number with ambient temperature.

3. The theoretical normal-shock-position control system was not as satisfactory as the throat Mach number control, because changes in ambient temperature produced larger adverse changes in inlet performance.

Lewis Flight Propulsion Laboratory
National Advisory Committee for Aeronautics
Cleveland, Ohio, July 26, 1957

REFERENCE

1. Yeager, Richard A., Beheim, Milton A., and Klann, John L.: Performance of Twin-Duct Variable-Geometry Side Inlets at Mach Numbers of 1.5 to 2.0. NACA RM E56K15, 1957.

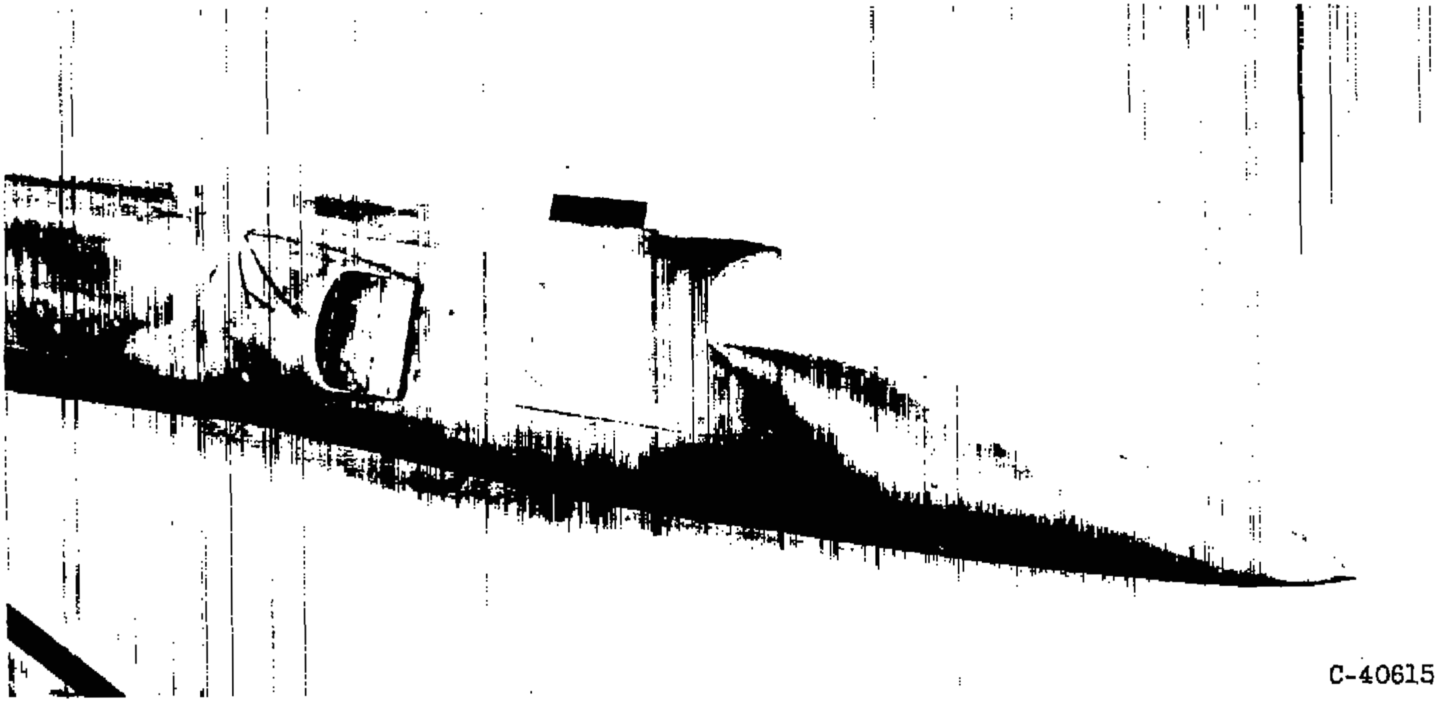

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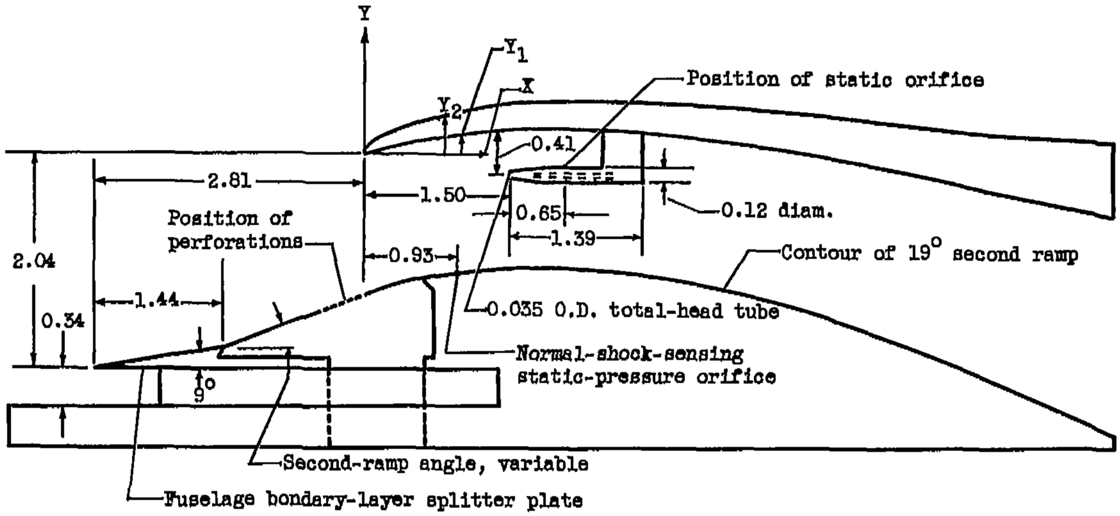
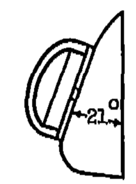
Figure 1. - Fuselage inlet model.

Cowl coordinates, in.

X	Y_1	Y_2
0	0.011	0.016
.1	.014	.086
.2	.037	.122
.3	.061	.172
.4	.083	.208
.5	.103	.240
.6	.122	.268
.7	.138	.296
.8	.153	.318
.9	.165	.339
1.0	.176	.359
1.2	.193	.391
1.4	.203	.417
1.6	.208	.437
1.8	.209	.457





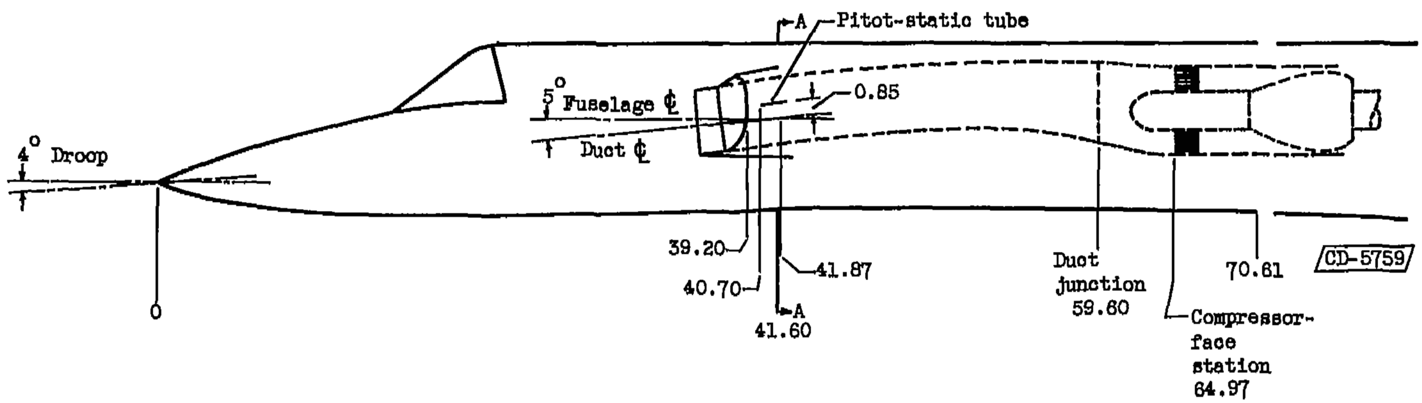


Figure 2. - Diagram of fuselage inlet model showing details of inlet and Mach number sensor. (All dimensions in inches).

[redacted]

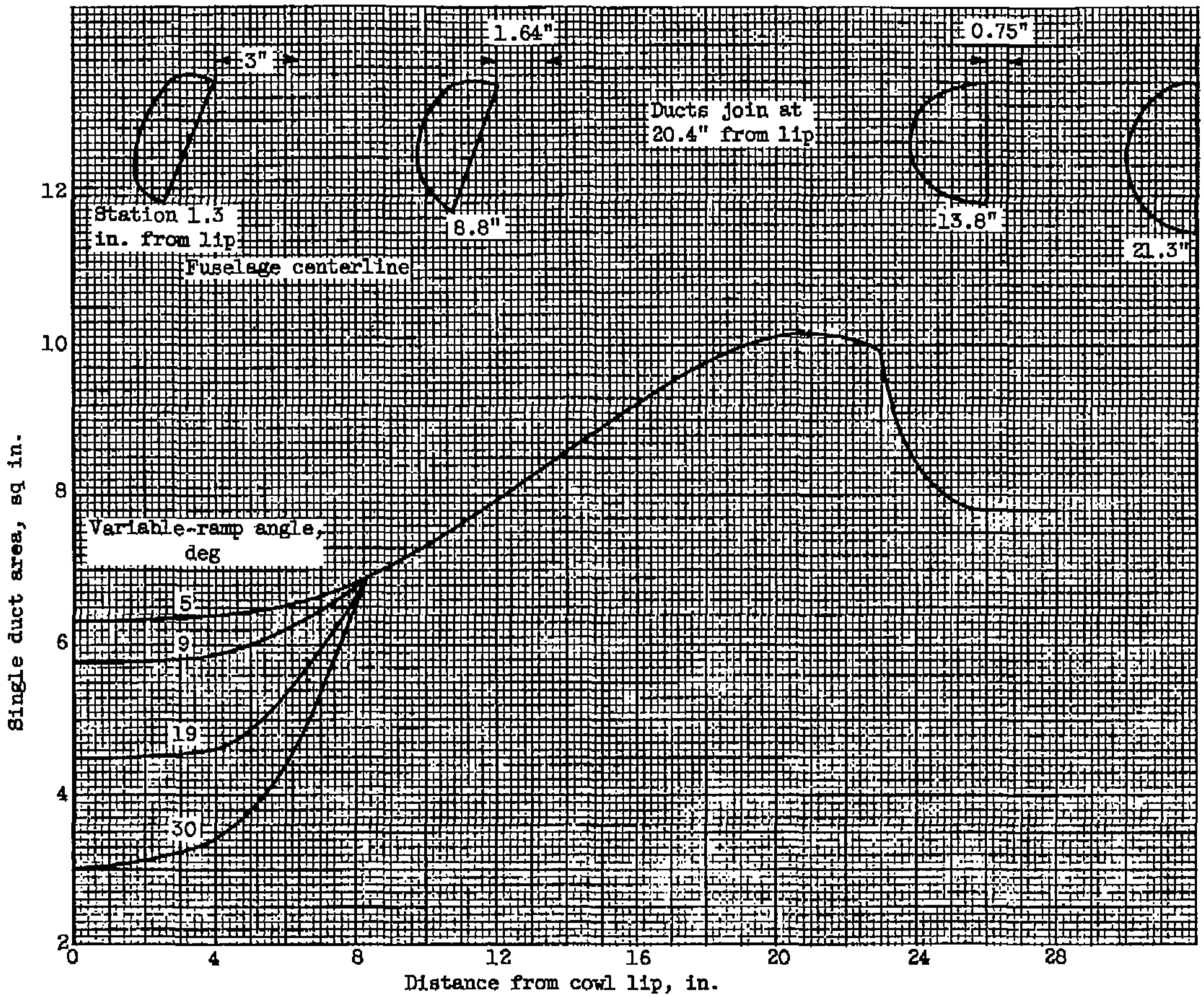


Figure 3. - Subsonic-diffuser area variation.

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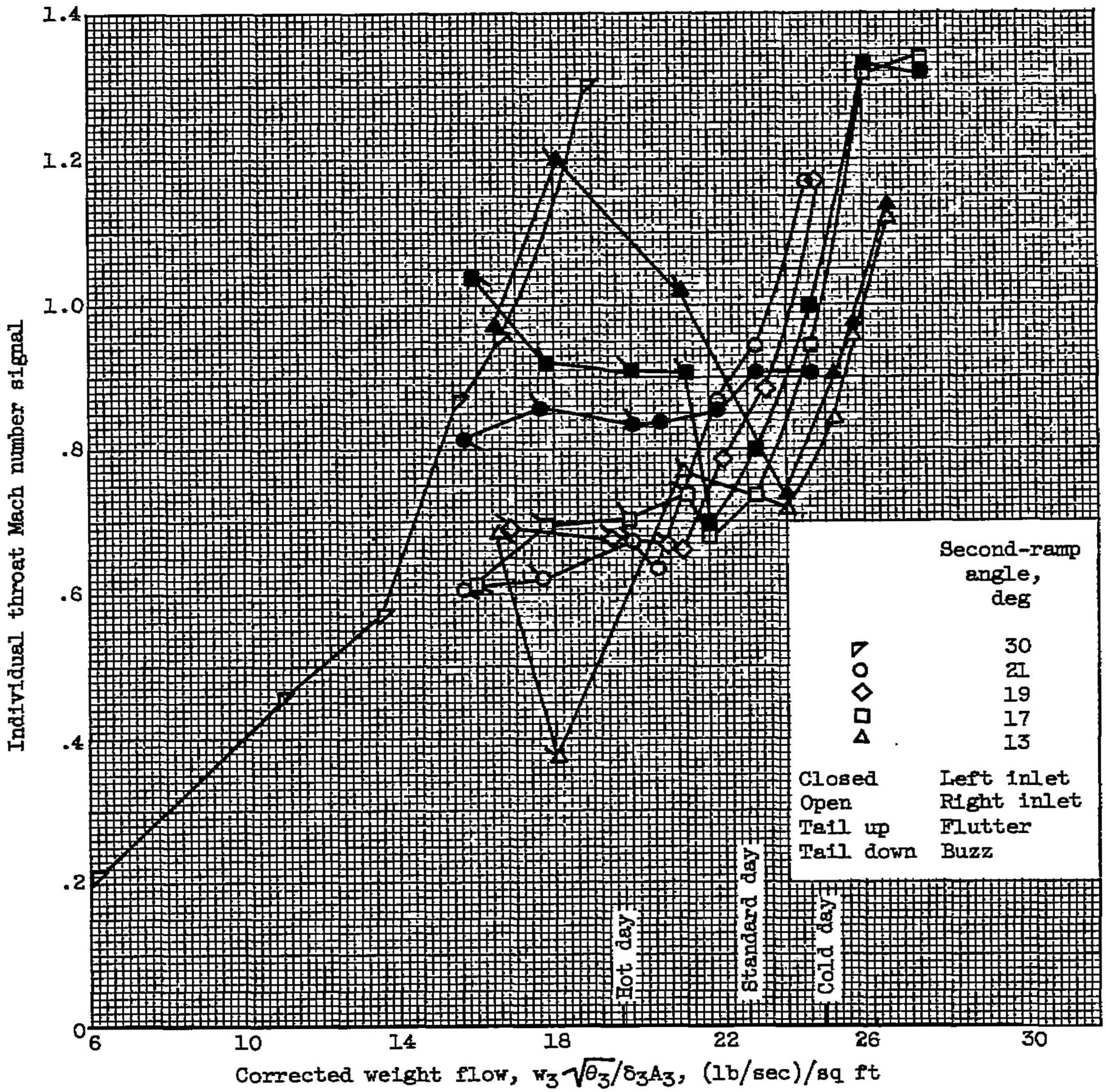

(a) Free-stream Mach number, 1.98.

Figure 4. - Effect of second-ramp angle on individual throat Mach number control signal. Angle of attack, 2°.

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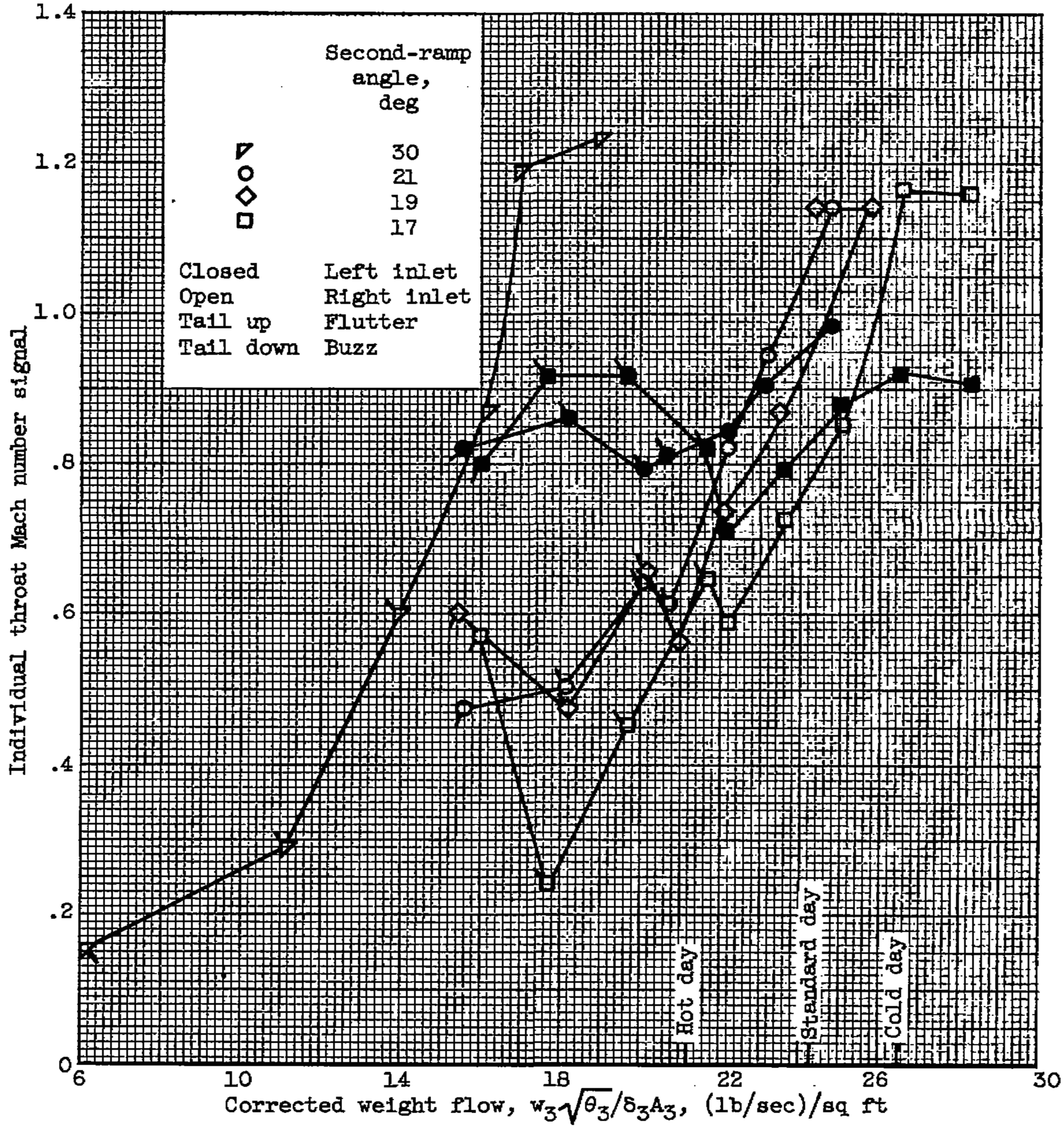

(b) Free-stream Mach number, 1.89.

Figure 4. - Continued. Effect of second-ramp angle on individual throat Mach number control signal. Angle of attack, 2°.

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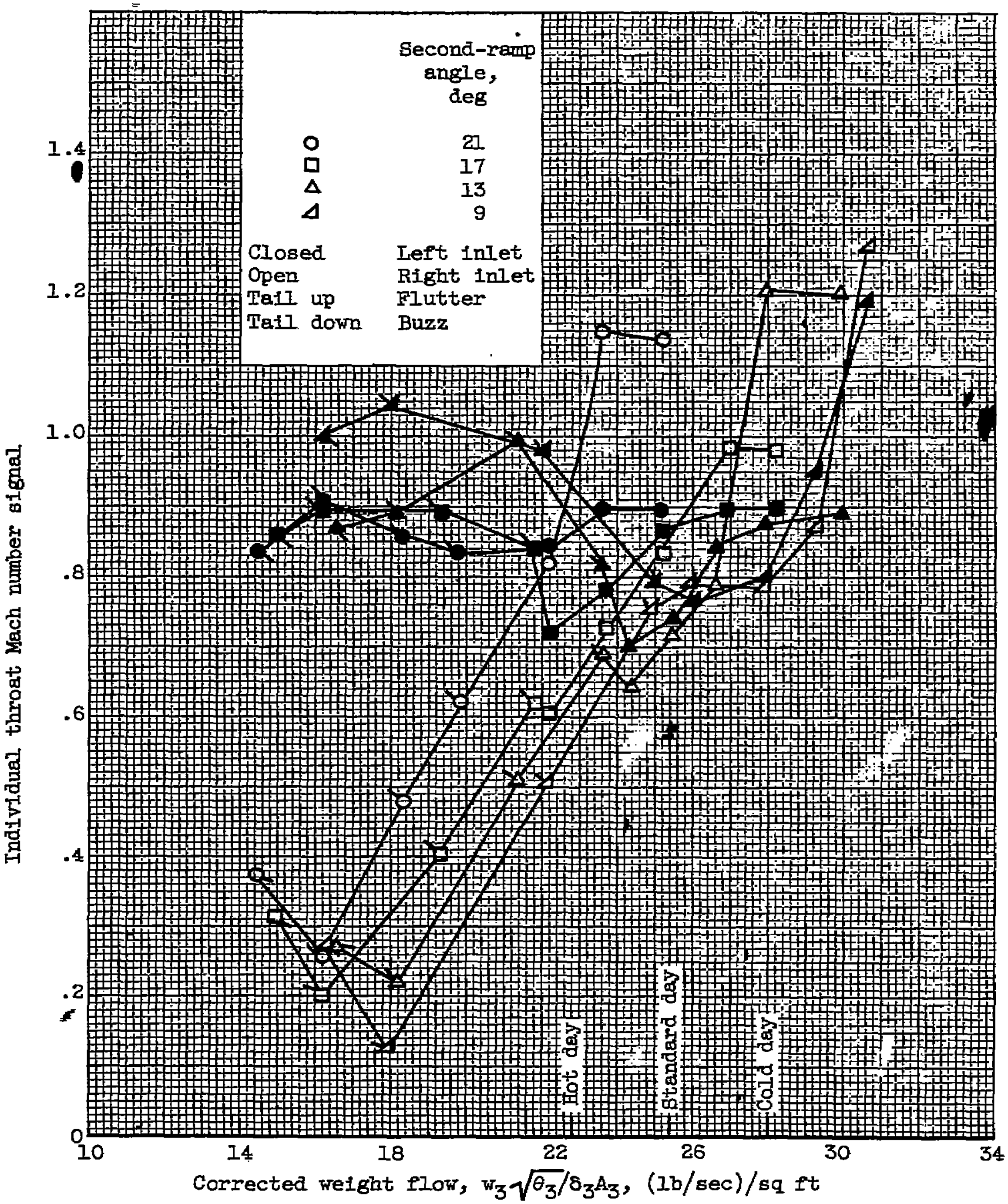

(c) Free-stream Mach number, 1.79.

Figure 4. - Continued. Effect of second-ramp angle on individual throat Mach number control signal. Angle of attack, 2°.

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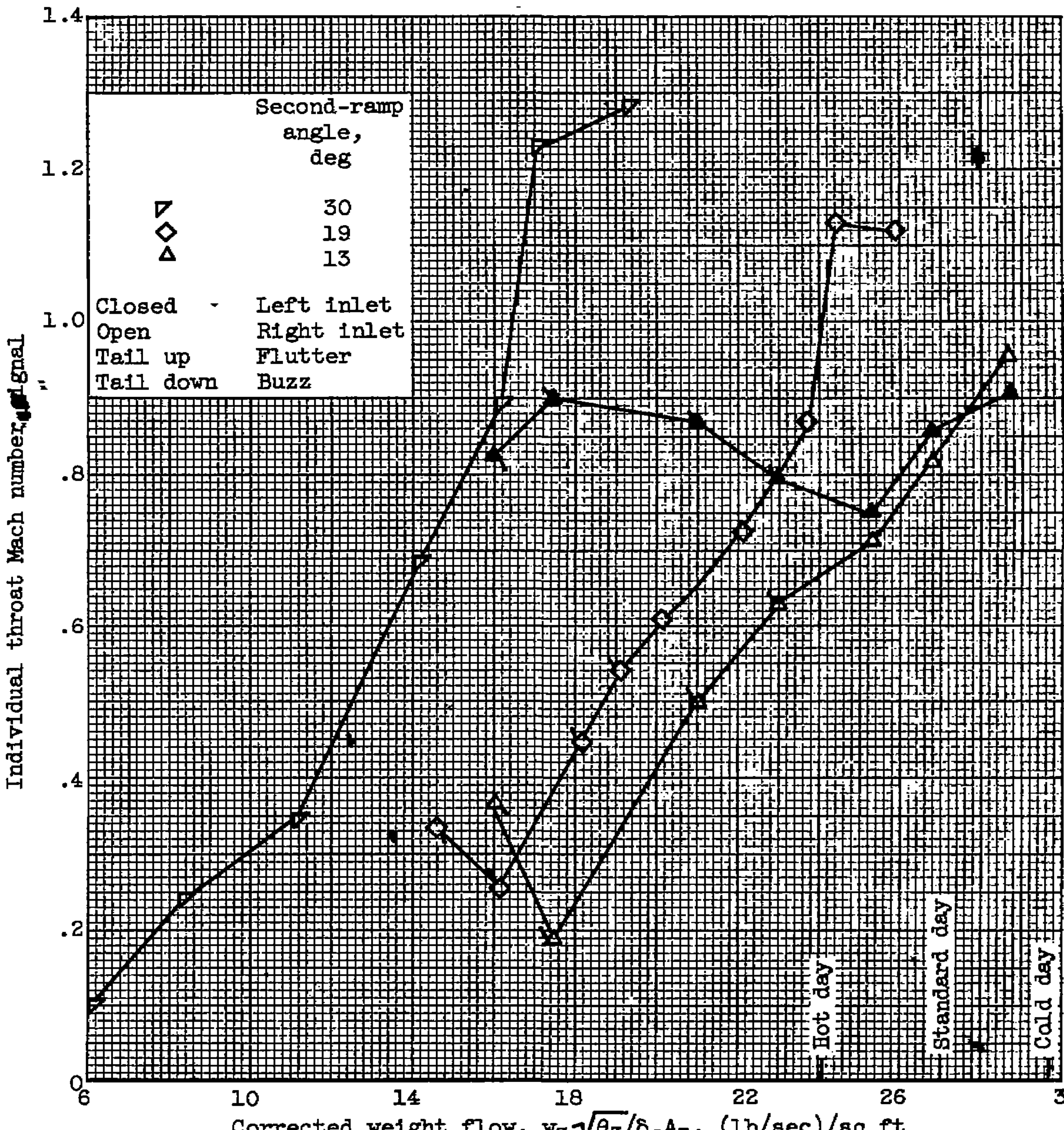

(d) Free-stream Mach number, 1.68.

Figure 4. - Continued. Effect of second-ramp angle on individual throat Mach number control signal. Angle of attack, 2°.

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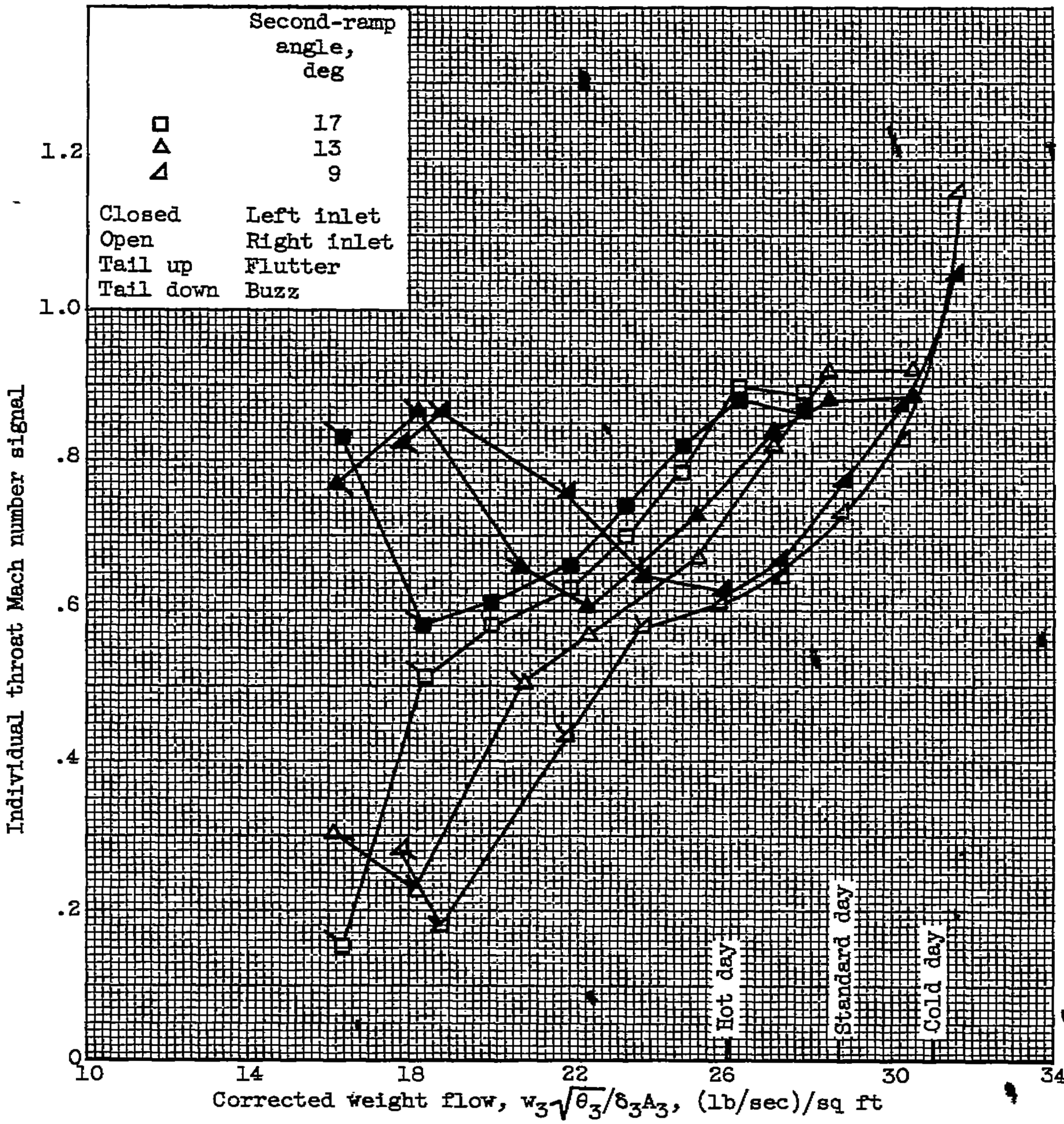

(e) Free-stream Mach number, 1.59.

Figure 4. - Continued. Effect of second-ramp angle on individual throat Mach number control signal. Angle of attack, 2°.

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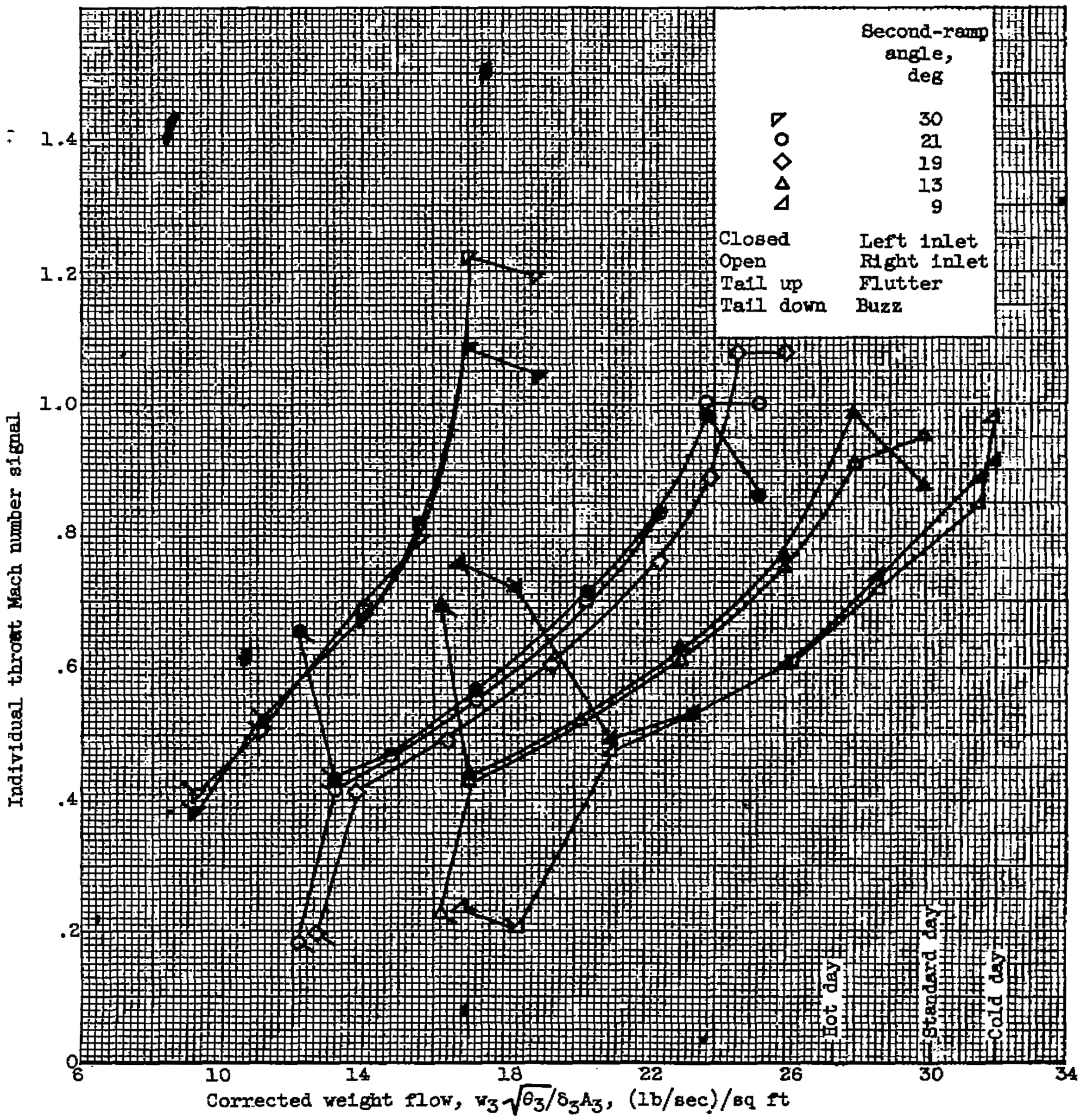

(f) Free-stream Mach number, 1.49.

Figure 4. - Concluded. Effect of second-ramp angle on individual throat Mach number control signal. Angle of attack, 2°.

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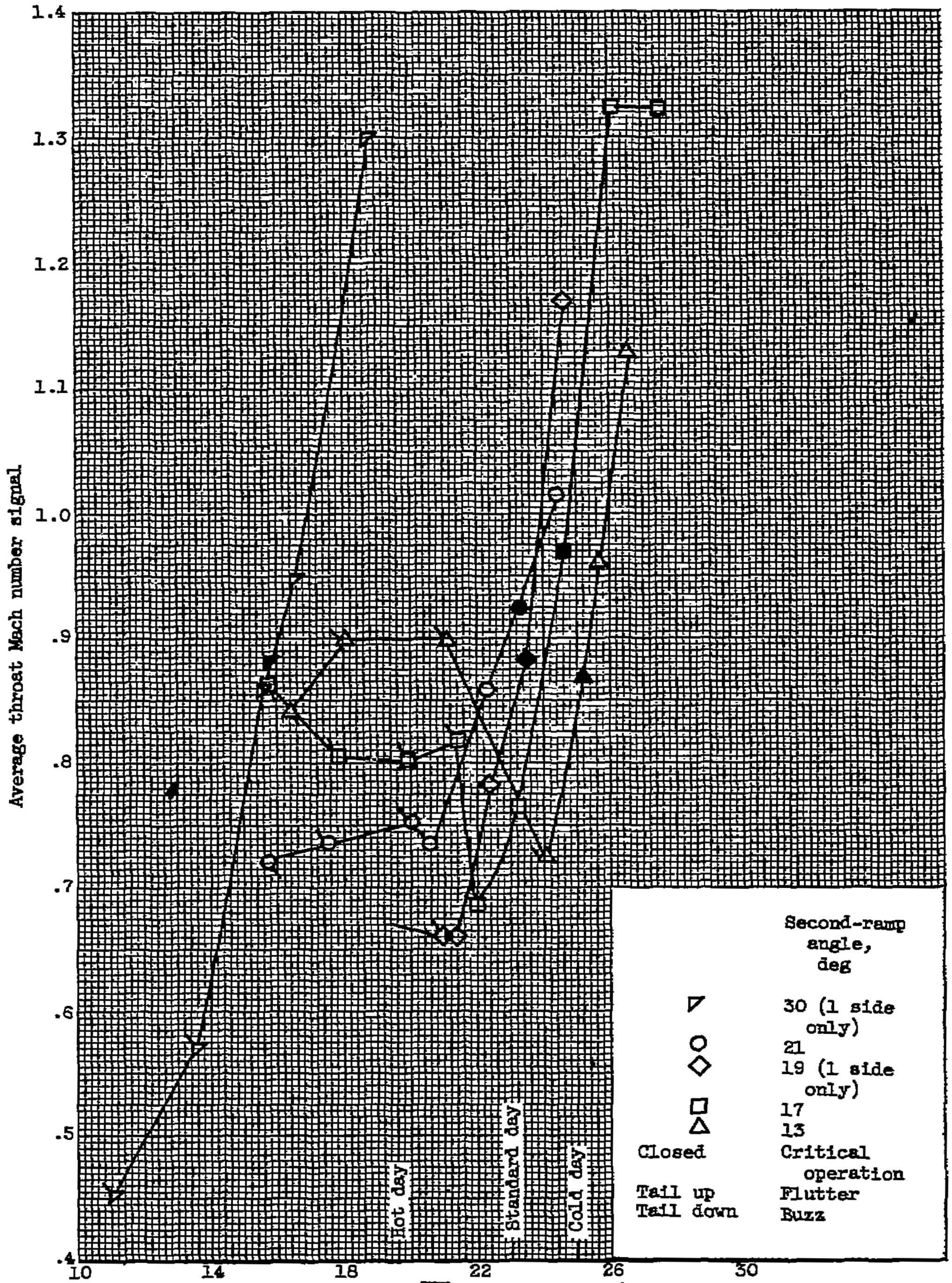

(a) Free-stream Mach number, 1.98.

Figure 5. - Effect of second-ramp angle on the average throat Mach number control signal. Angle of attack, 2°.

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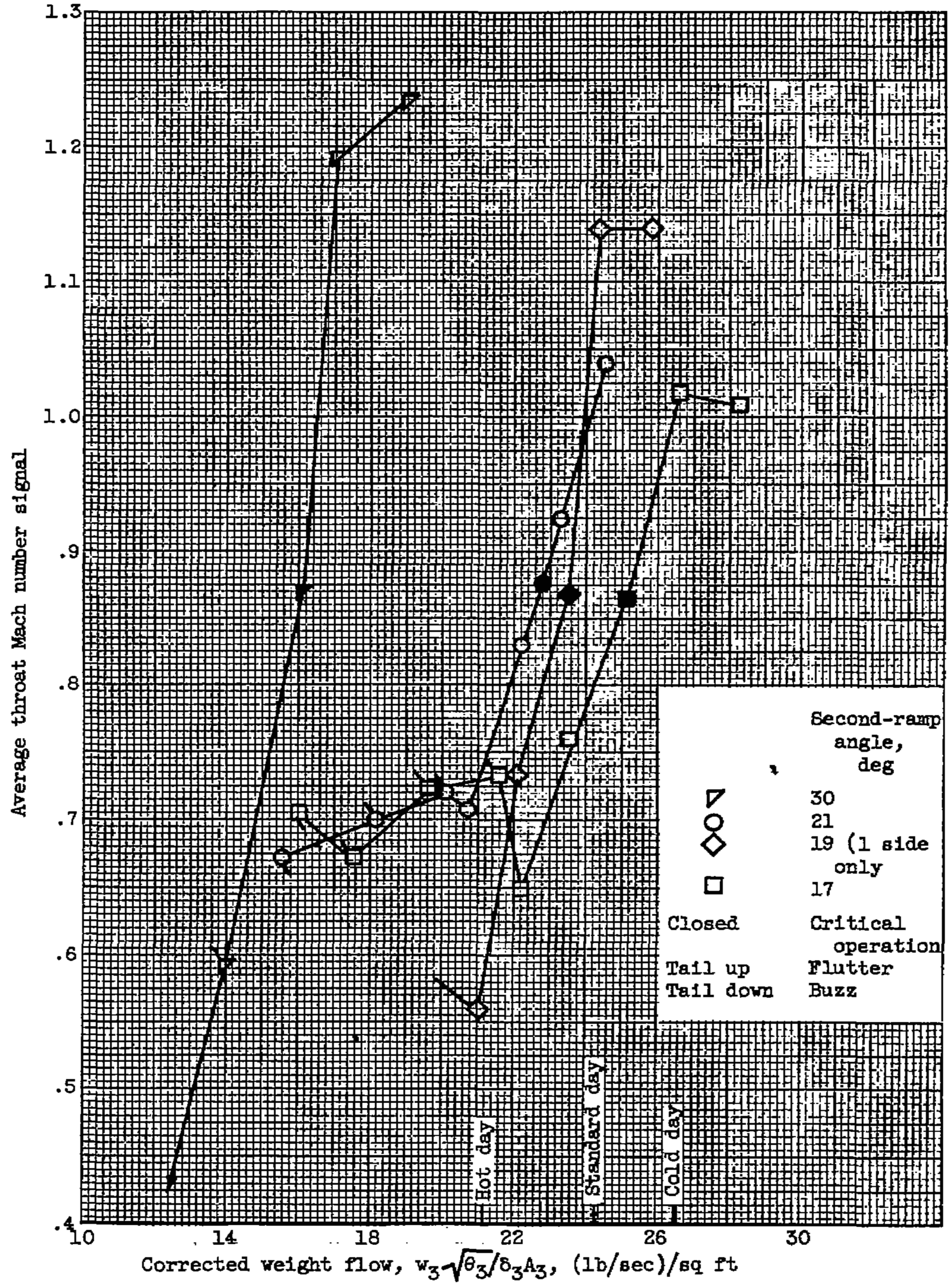

(b) Free-stream Mach number, 1.89.

Figure 5. - Continued. Effect of second-ramp angle on the average throat Mach number control signal. Angle of attack, 2°.

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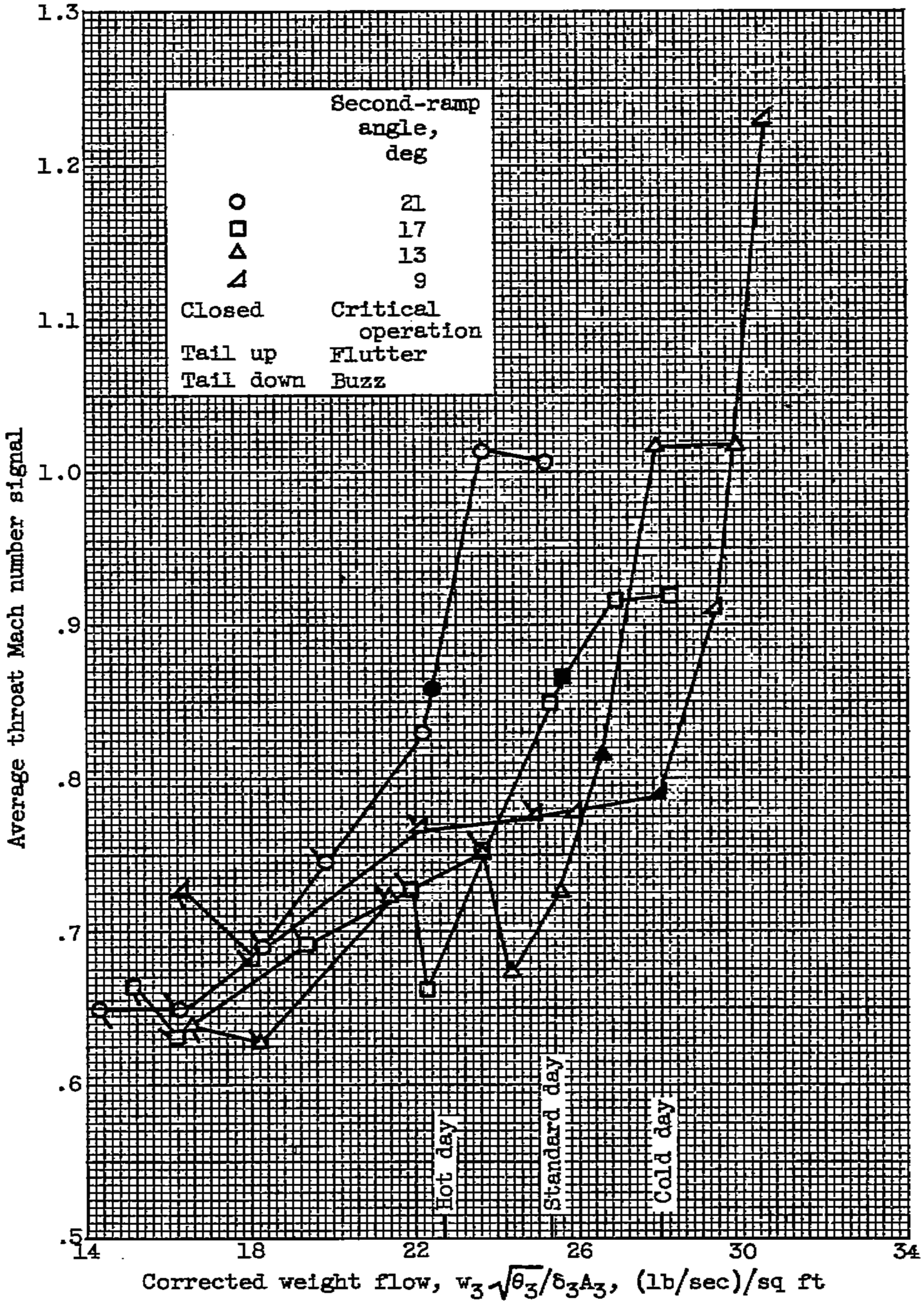

(c) Free-stream Mach number, 1.79.

Figure 5. - Continued. Effect of second-ramp angle on the average throat Mach number control signal. Angle of attack, 2°.

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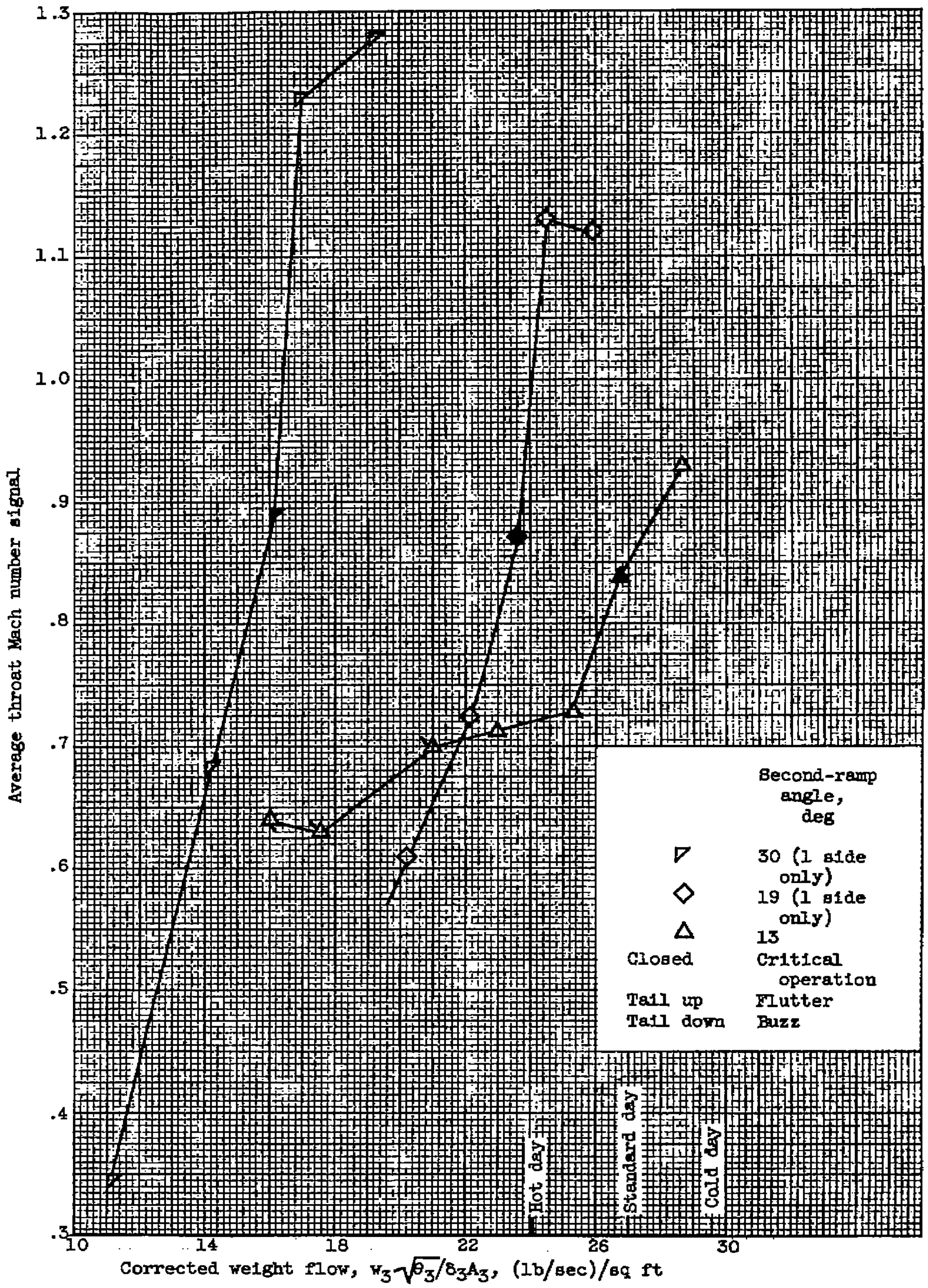

(d) Free-stream Mach number, 1.68.

Figure 5. - Continued. Effect of second-ramp angle on the average throat Mach number control signal. Angle of attack, 2°.

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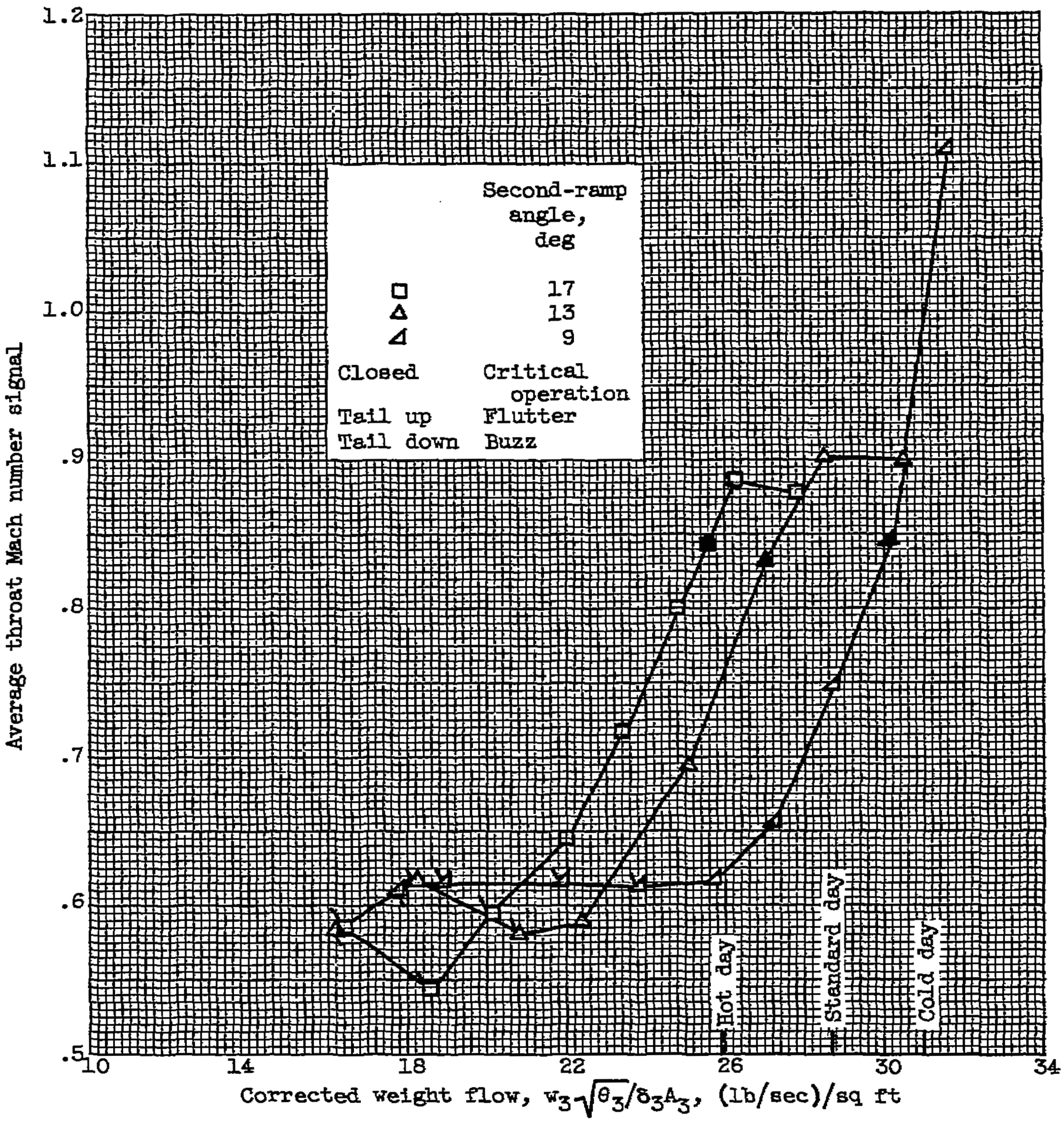
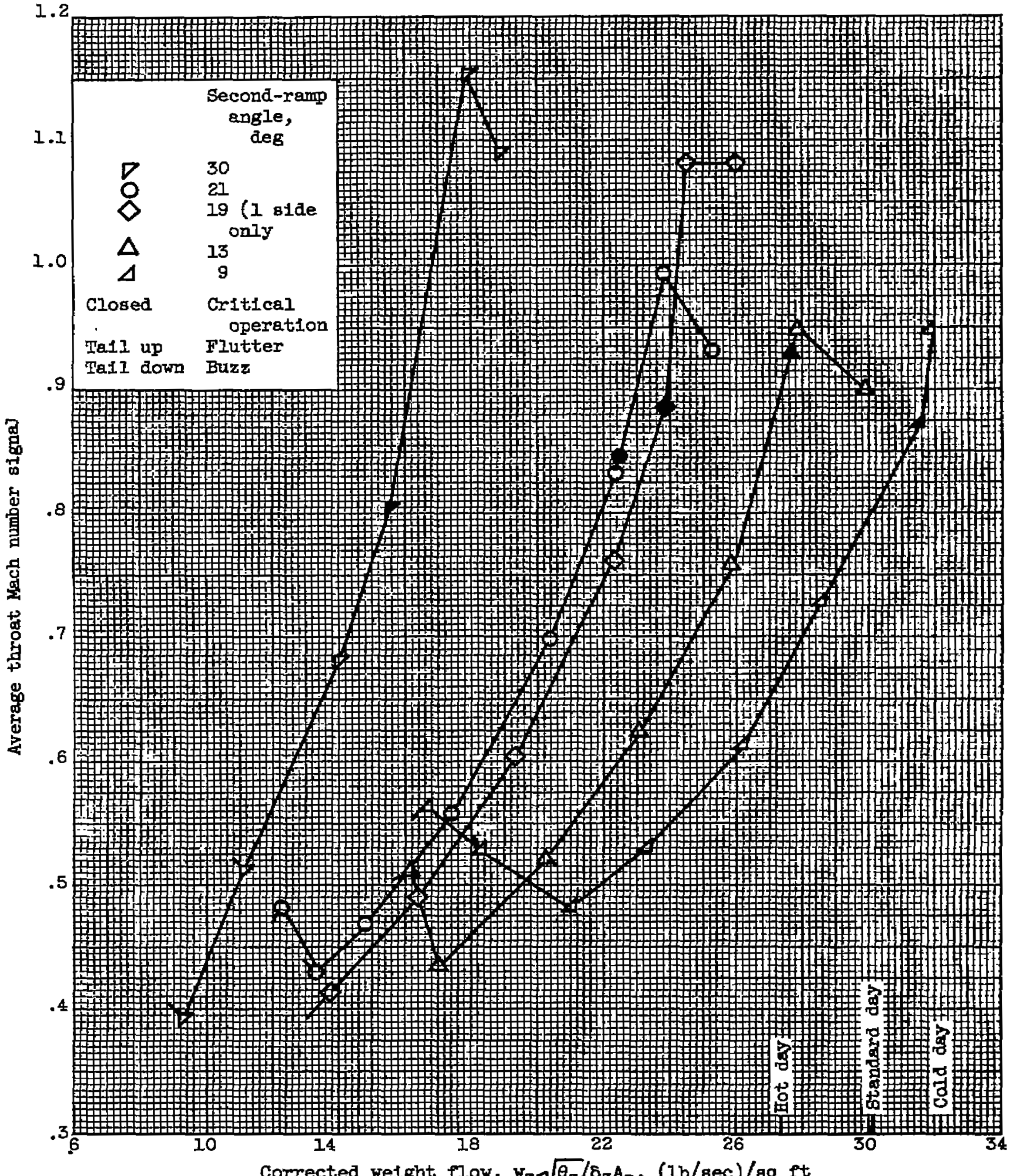


(e) Free-stream Mach number, 1.59.

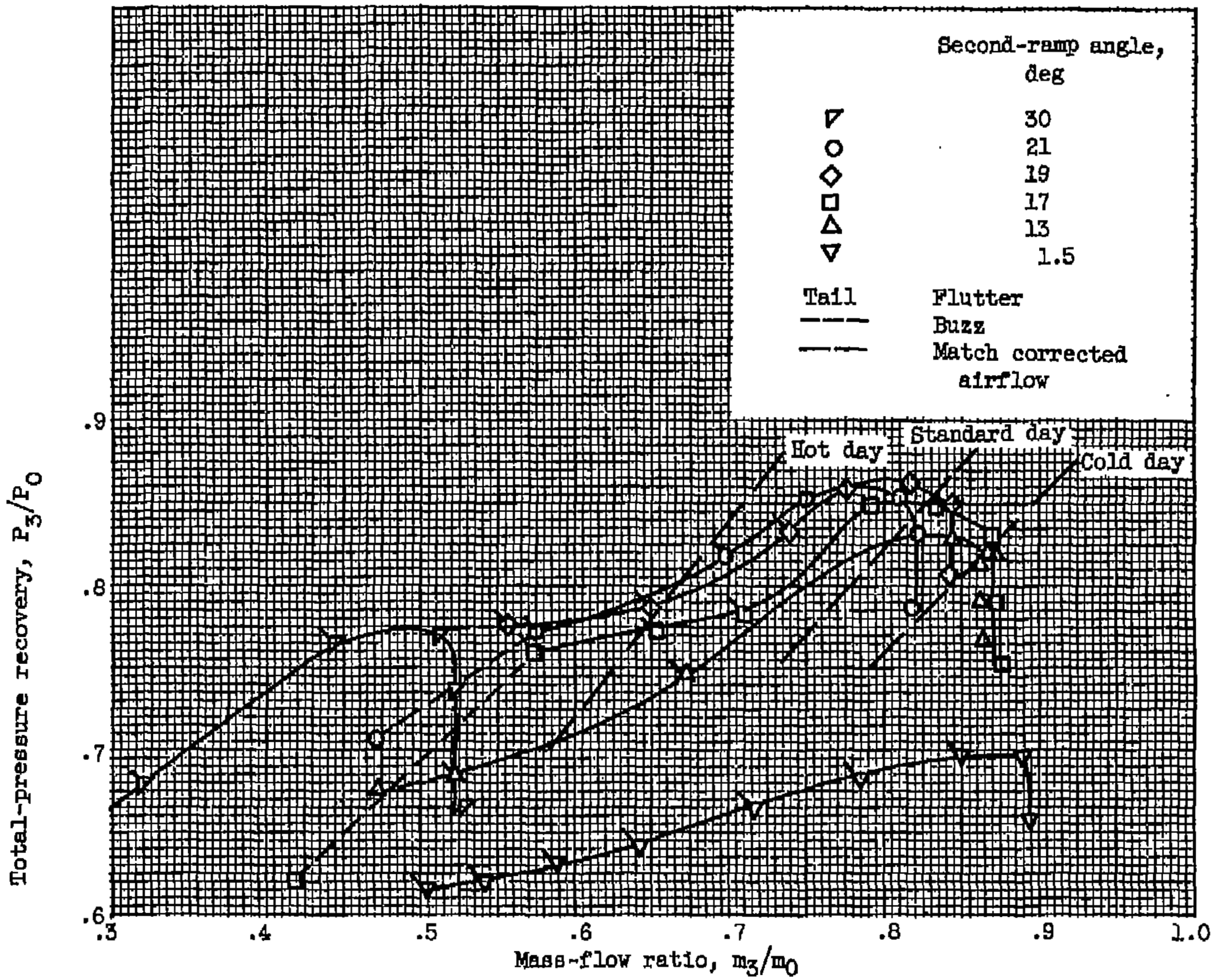
Figure 5. - Continued. Effect of second-ramp angle on the average throat Mach number control signal. Angle of attack, 2°.

[redacted]



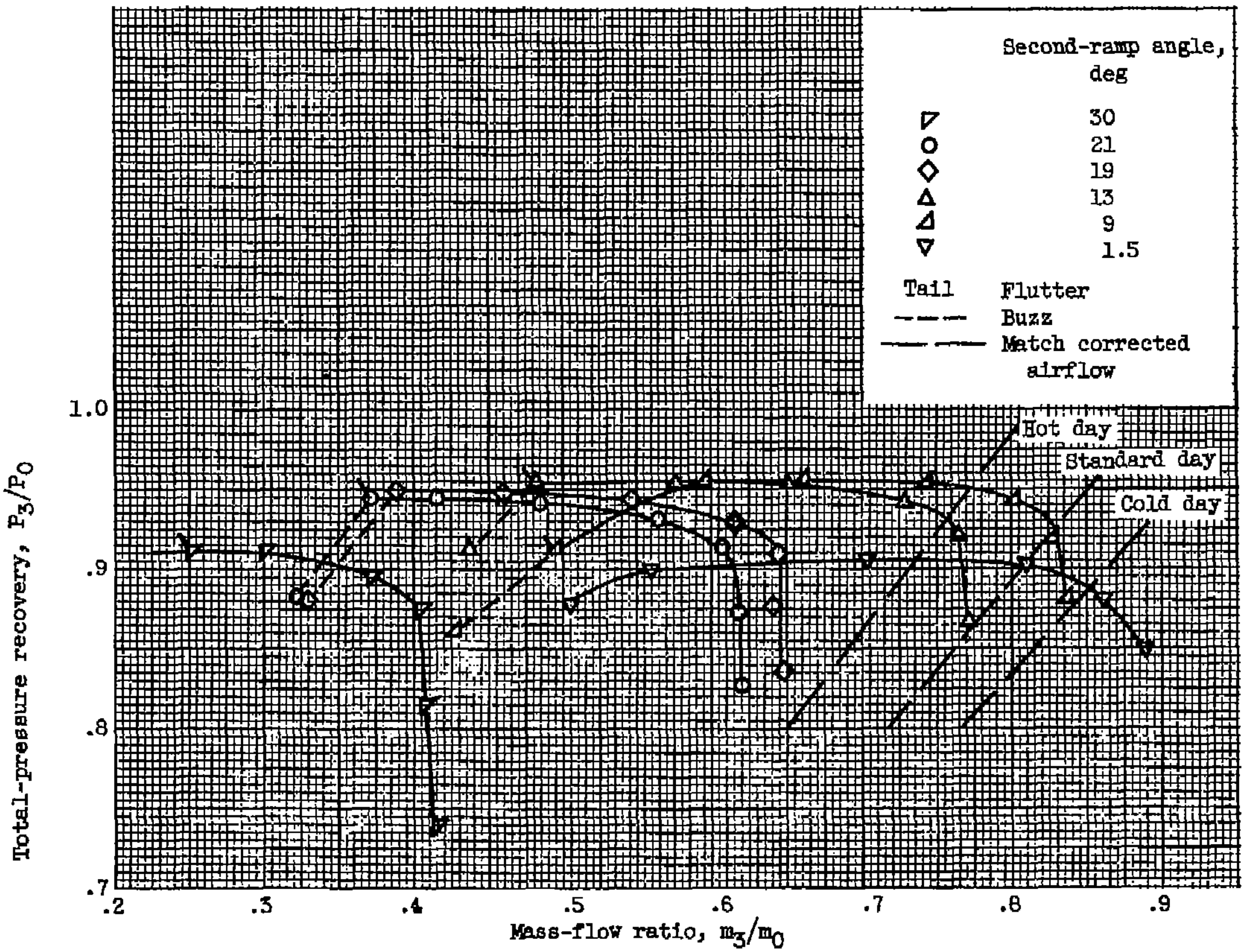
(f) Free-stream Mach number, 1.49.

Figure 5. - Concluded. Effect of second-ramp angle on the average throat Mach number control signal. Angle of attack, 2°.



(a) Free-stream Mach number, 1.98.

Figure 6. - Effect of second-ramp angle on inlet performance. Angle of attack, 2°.



(b) Free-stream Mach number, 1.49.

Figure 6. - Concluded. Effect of second-ramp angle on inlet performance. Angle of attack, 2°.

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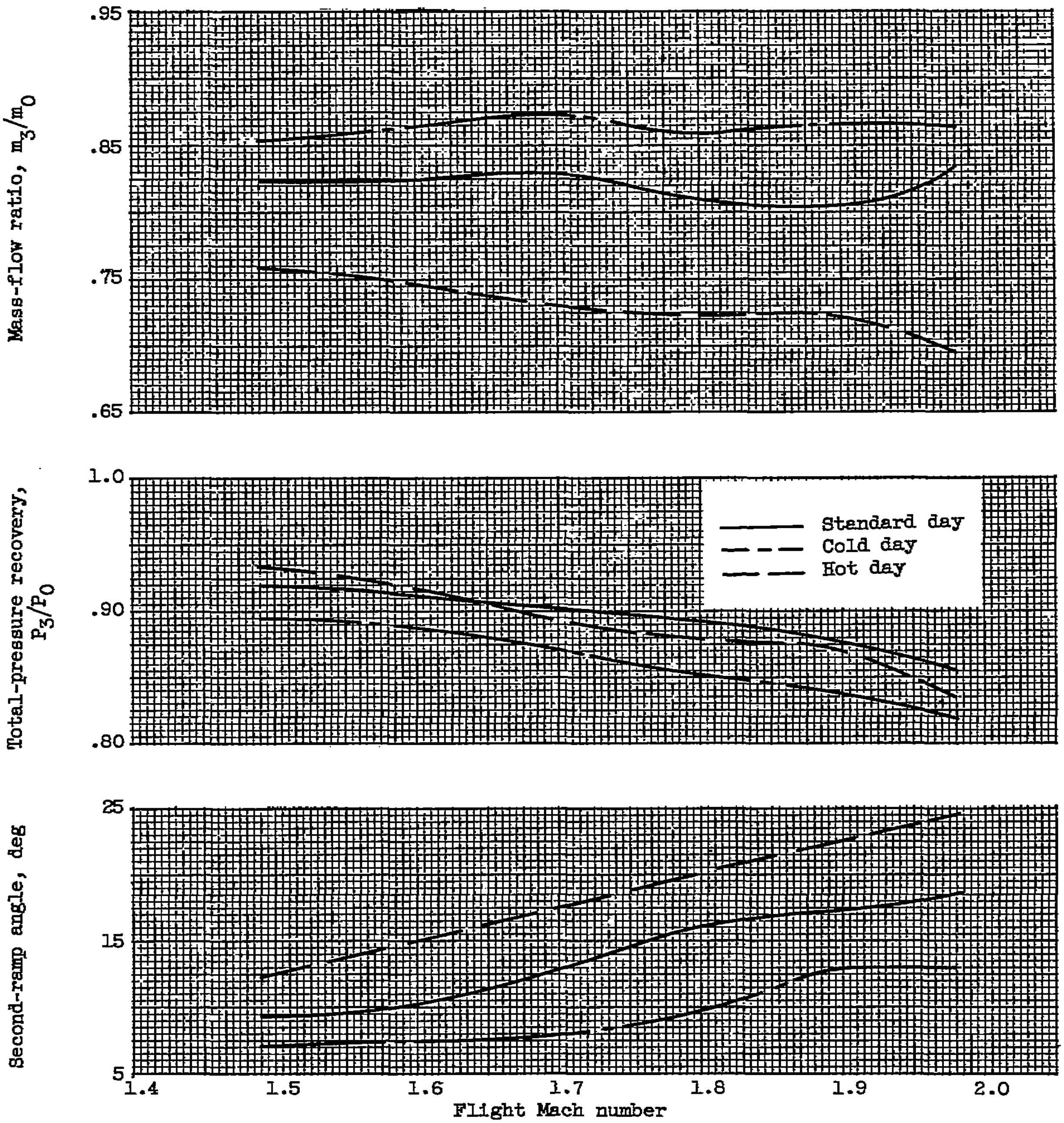


Figure 7. - Effect of operation of constant throat Mach number control system on inlet performance over a range of free-stream Mach numbers. Angle of attack, 2°; altitude, 35,000 feet; throat Mach number, 0.82.

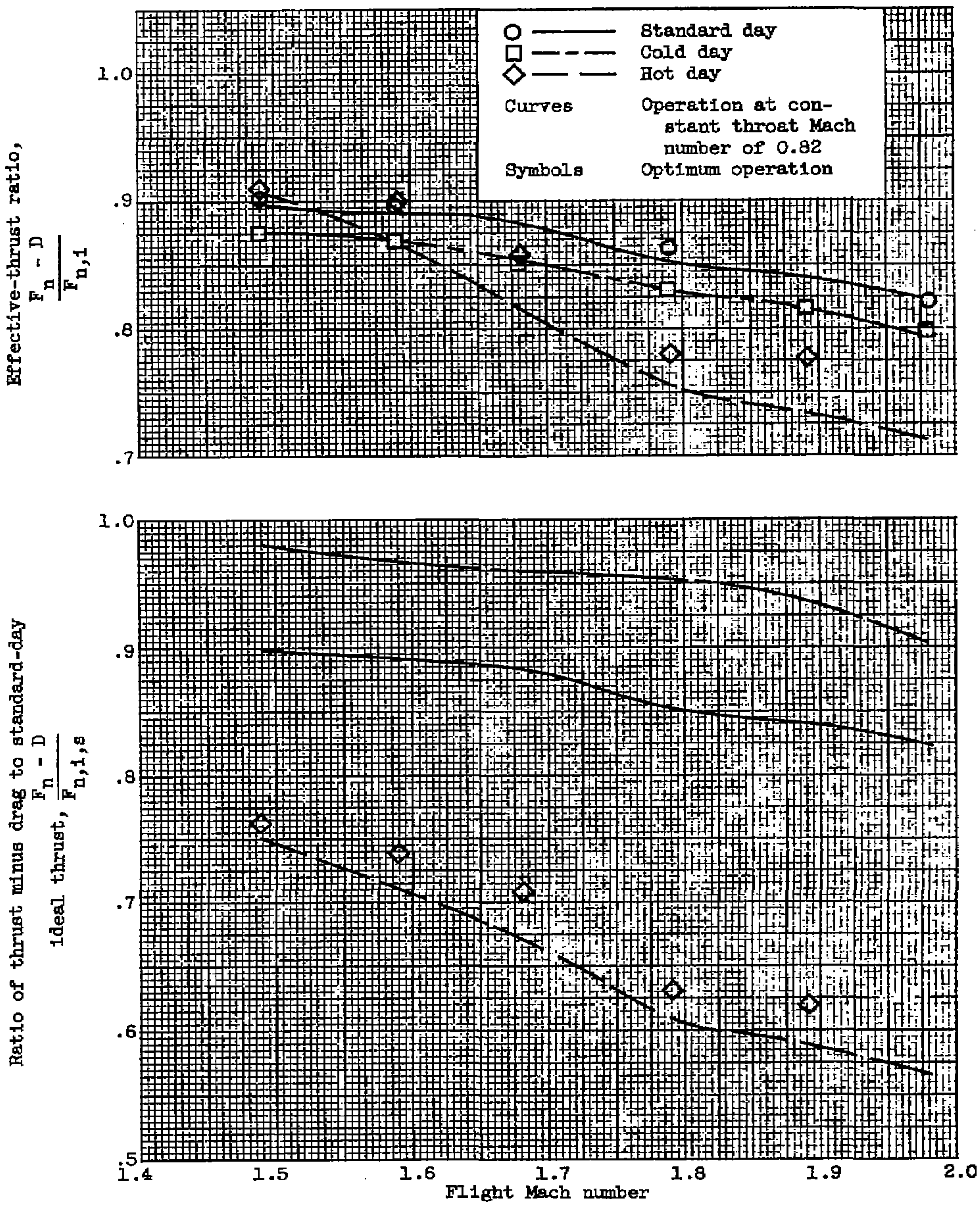
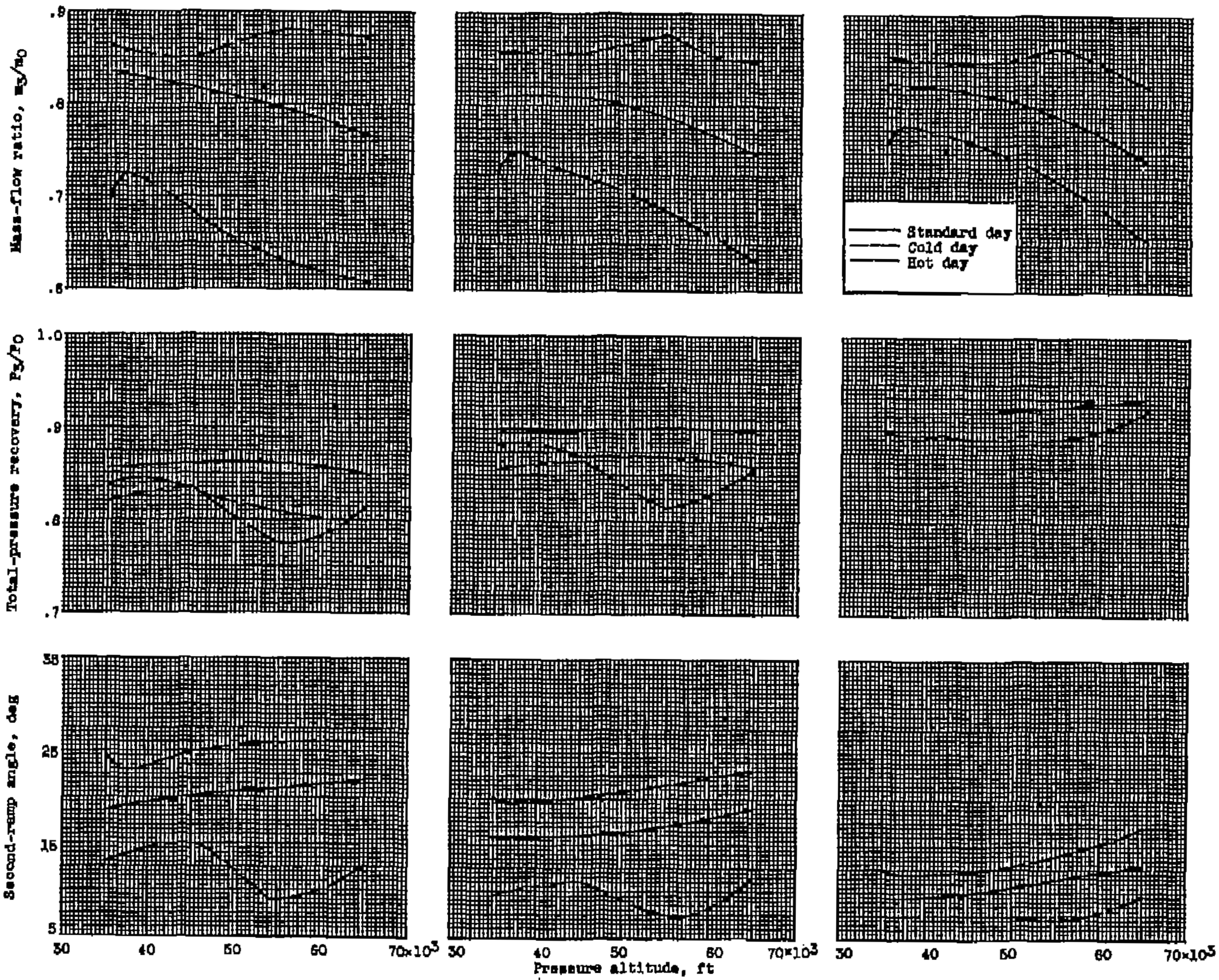


Figure 8. - Effect of operation of throat Mach number control system on thrust parameters over a range of free-stream Mach numbers. Angle of attack, 2°; altitude, 35,000 feet.



(a) Flight Mach number, 1.98.

(b) Flight Mach number, 1.79.

(c) Flight Mach number, 1.49.

Figure 9. - Effect of operation of constant throat Mach number control system on inlet performance over a range of altitudes. Angle of attack, 2°; throat Mach number, 0.82.

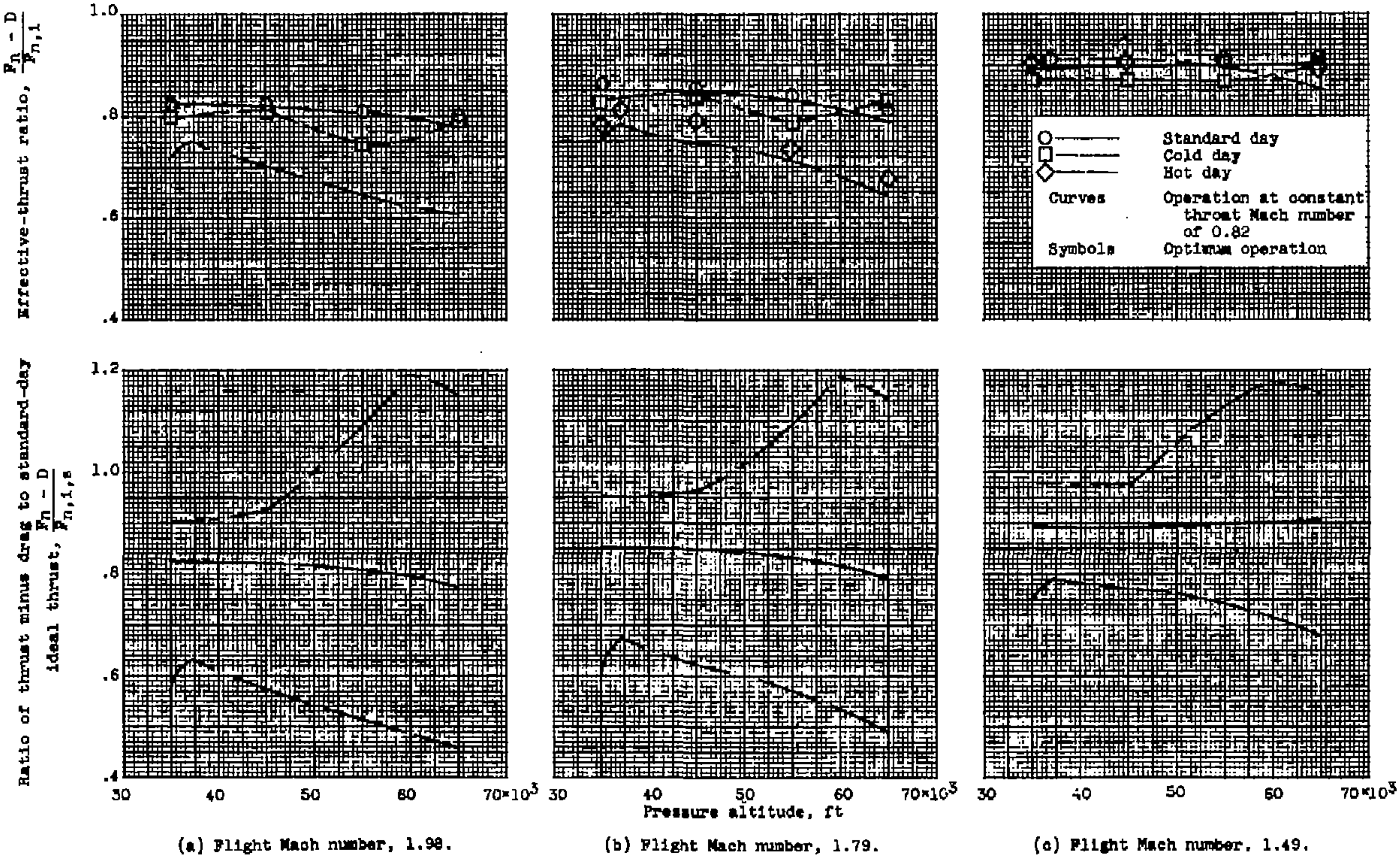


Figure 10. - Effect of operation of throat Mach number control system on thrust parameters over a range of altitudes. Angle of attack, 2°.

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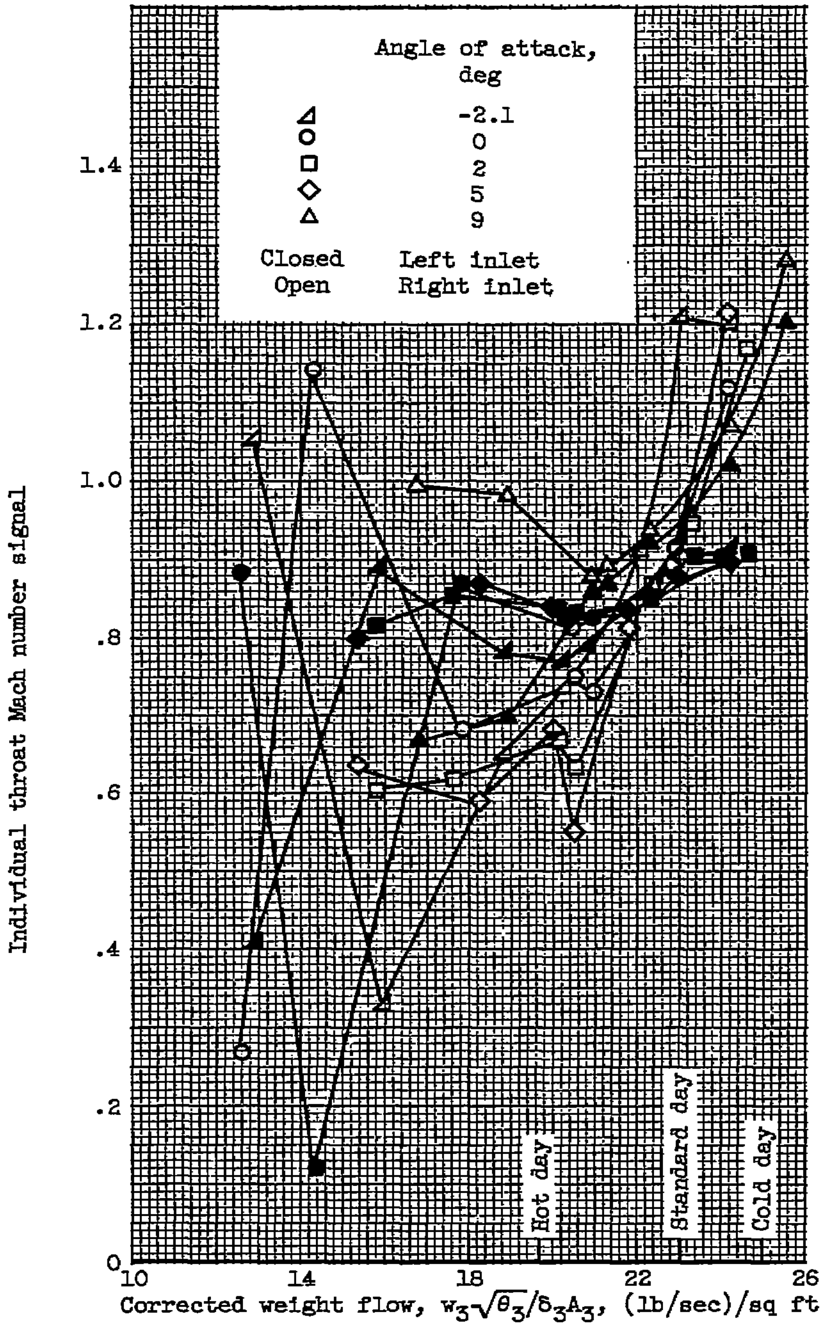
CM-5



(a) Second-ramp angle, 21°; free-stream Mach number, 1.98.

Figure 11. - Effect of angles of attack and yaw on individual throat Mach number control signal with fixed second-ramp angles.

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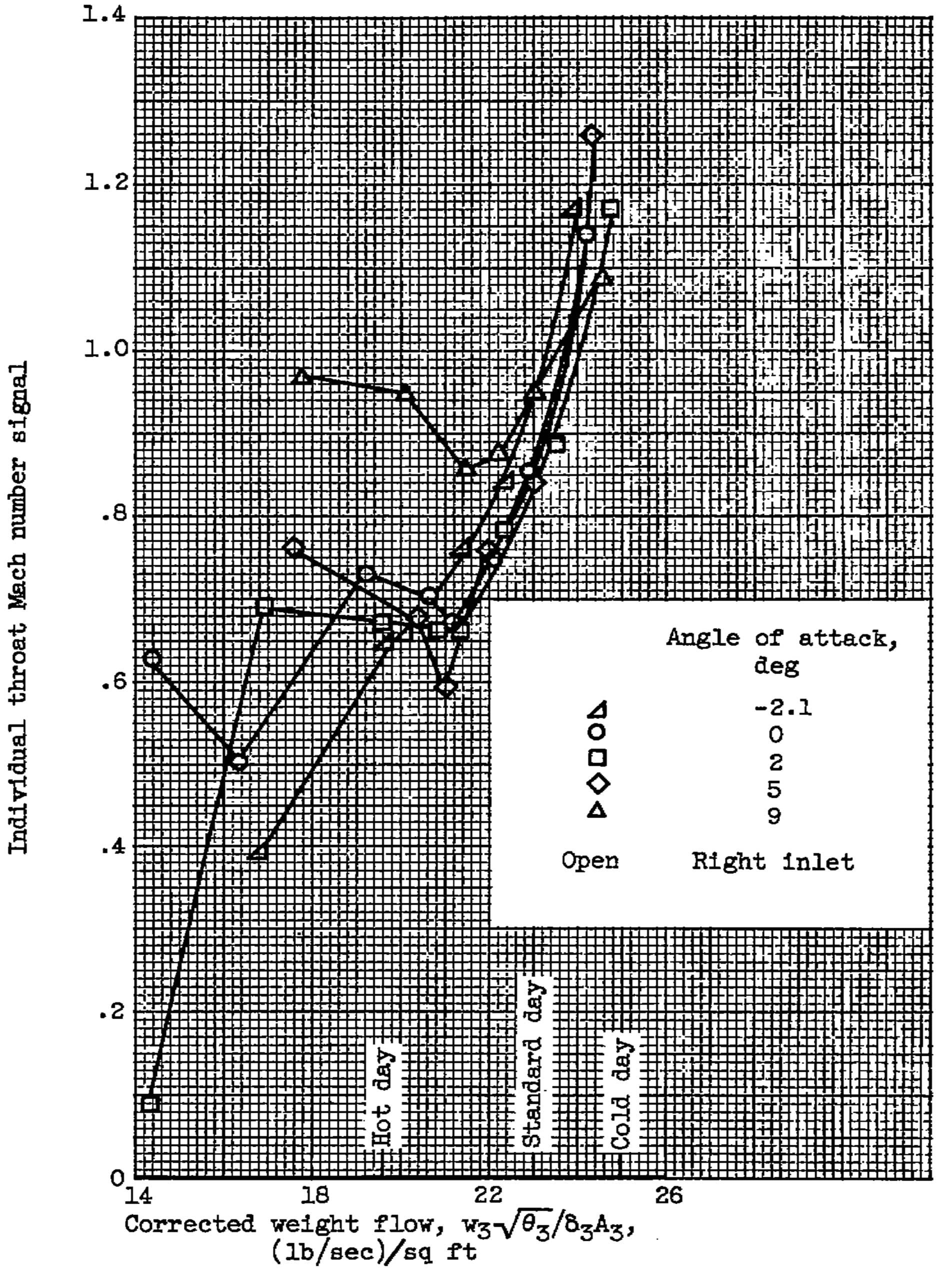

(b) Second-ramp angle, 19°; free-stream Mach number, 1.98.

Figure 11. - Continued. Effect of angles of attack and yaw on individual throat Mach number control signal with fixed second-ramp angles.

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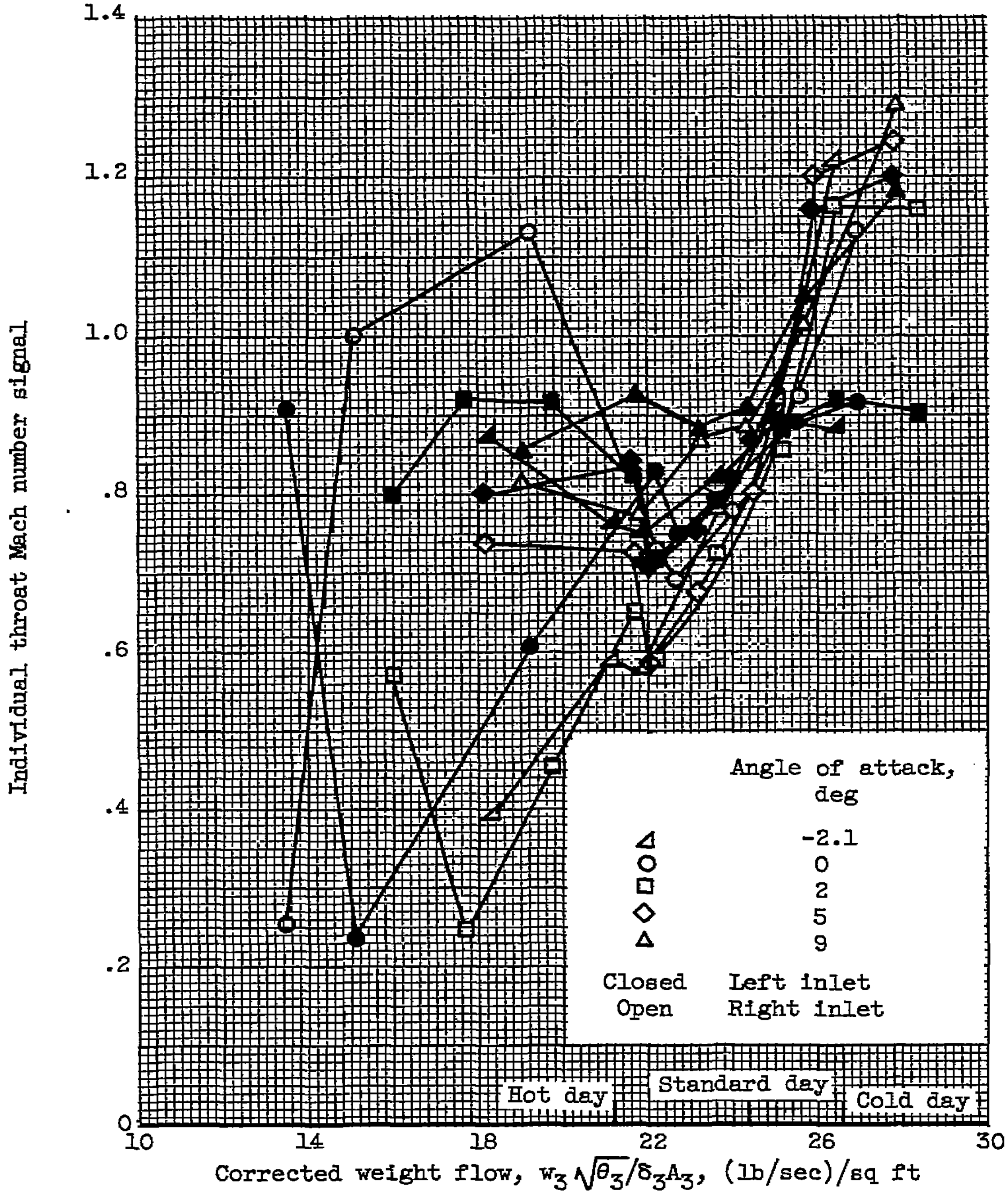
CM-5 back



(c) Second-ramp angle, 17°; free-stream Mach number, 1.89.

Figure 11. - Continued. Effect of angles of attack and yaw on individual throat Mach number control signal with fixed second-ramp angles.

[redacted]

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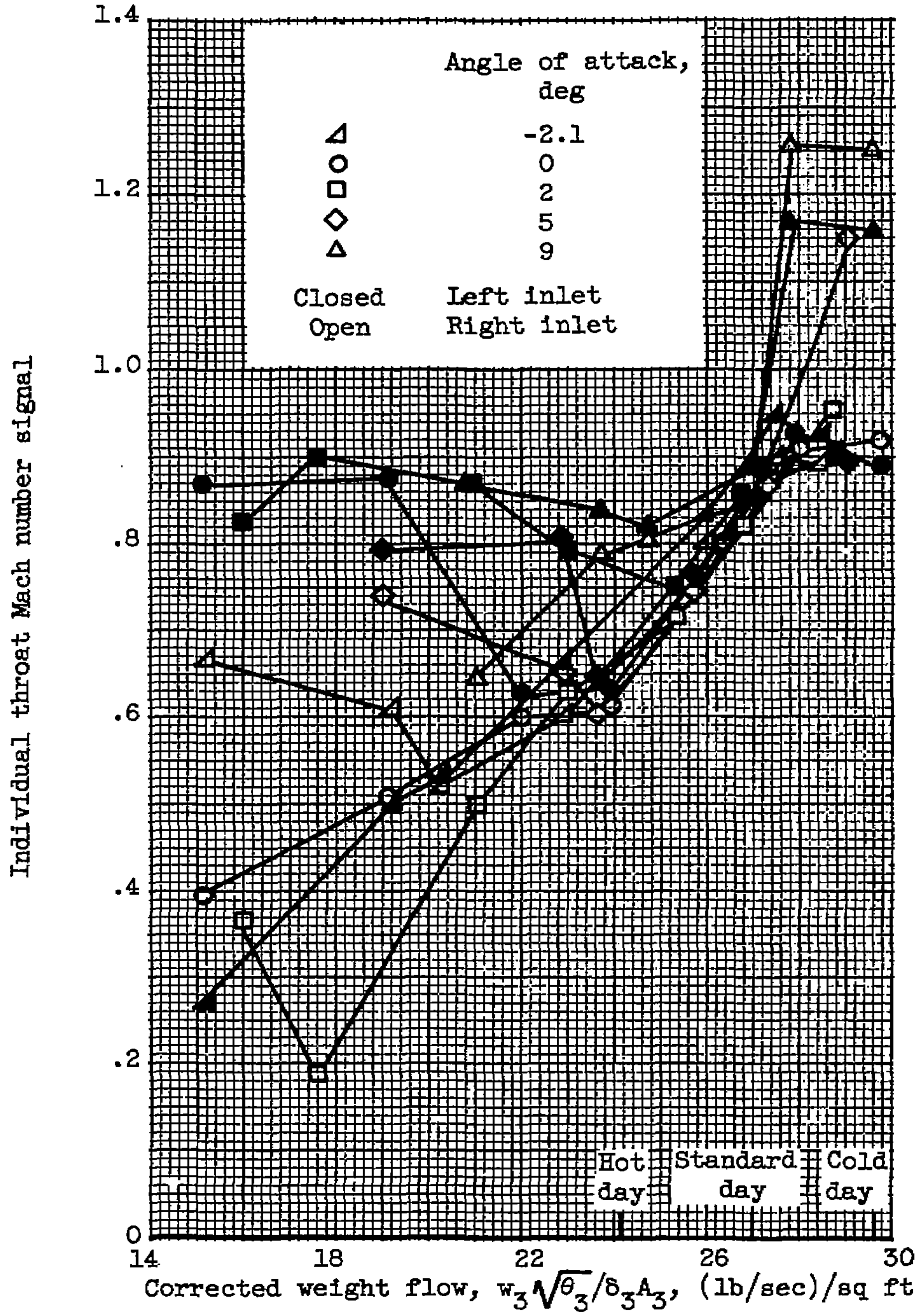

(d) Second-ramp angle, 13°; free-stream Mach number, 1.68.

Figure 11. - Continued. Effect of angles of attack and yaw on individual throat Mach number control signal with fixed second-ramp angles.

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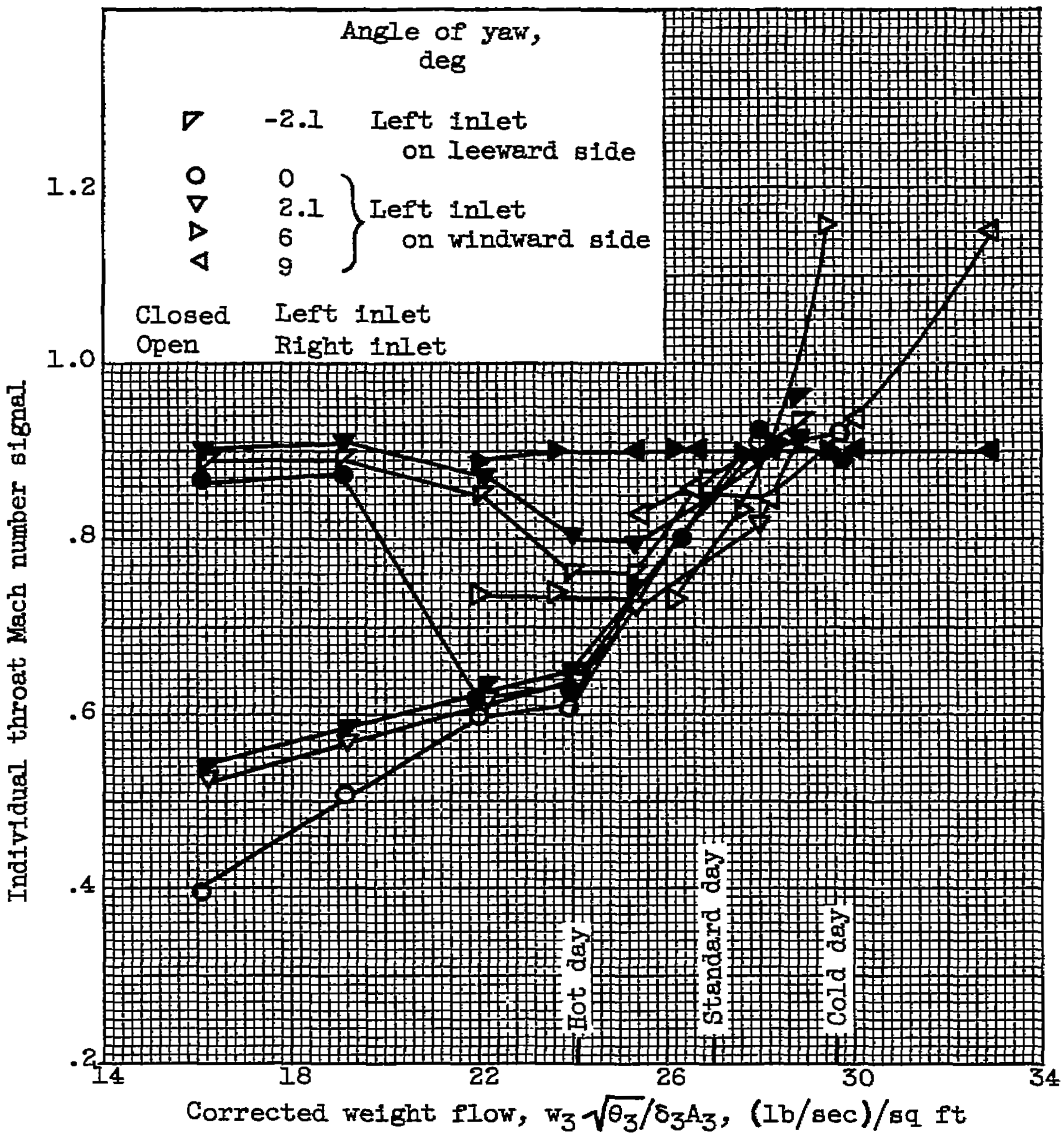

(e) Second-ramp angle, 13°; free-stream Mach number, 1.68.

Figure 11. - Continued. Effect of angles of attack and yaw on individual throat Mach number control signal with fixed second-ramp angles.

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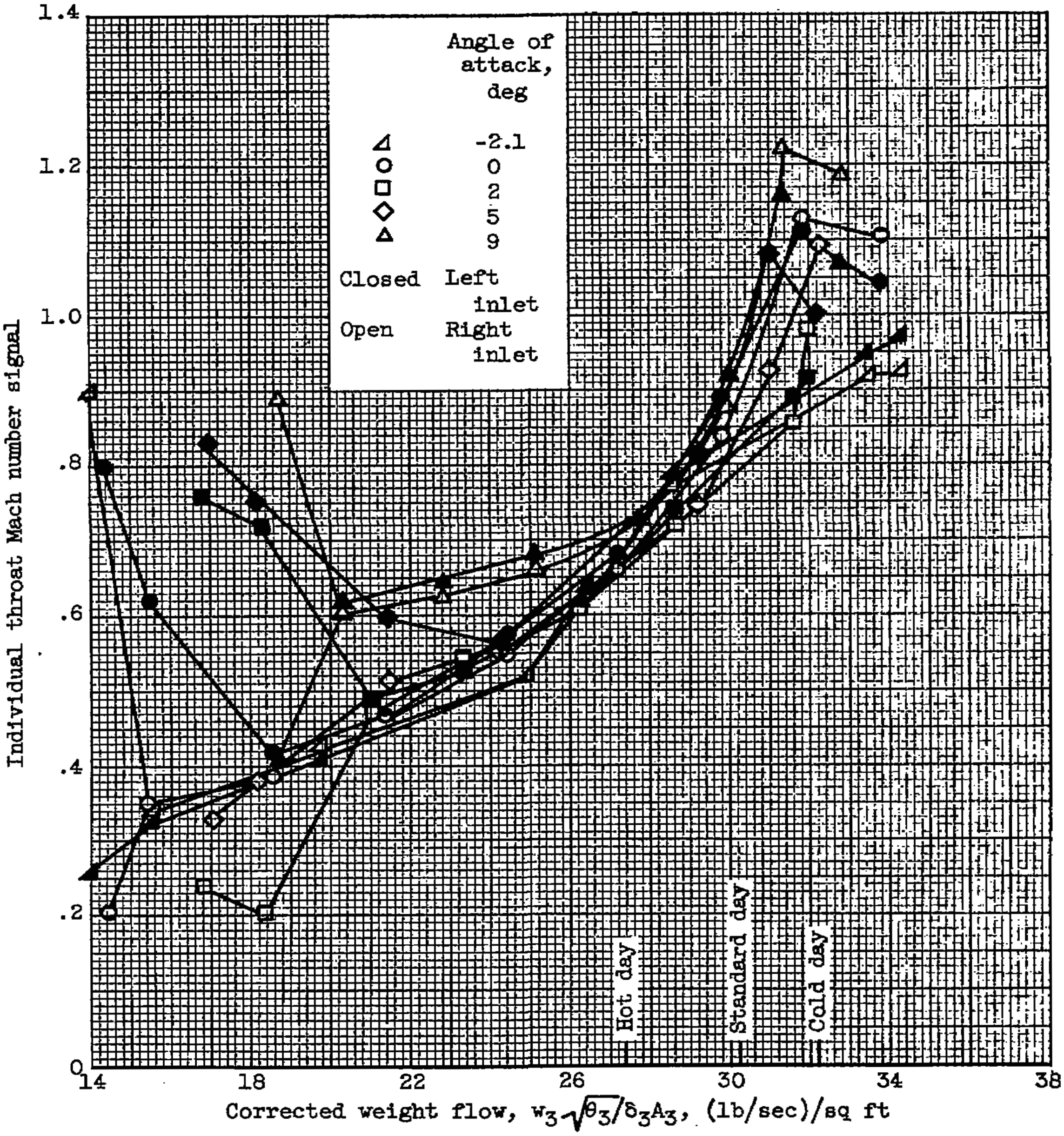

(f) Second-ramp angle, 9°; free-stream Mach number, 1.49.

Figure 11. - Concluded. Effect of angles of attack and yaw on individual throat Mach number control signal with fixed second ramp angles.

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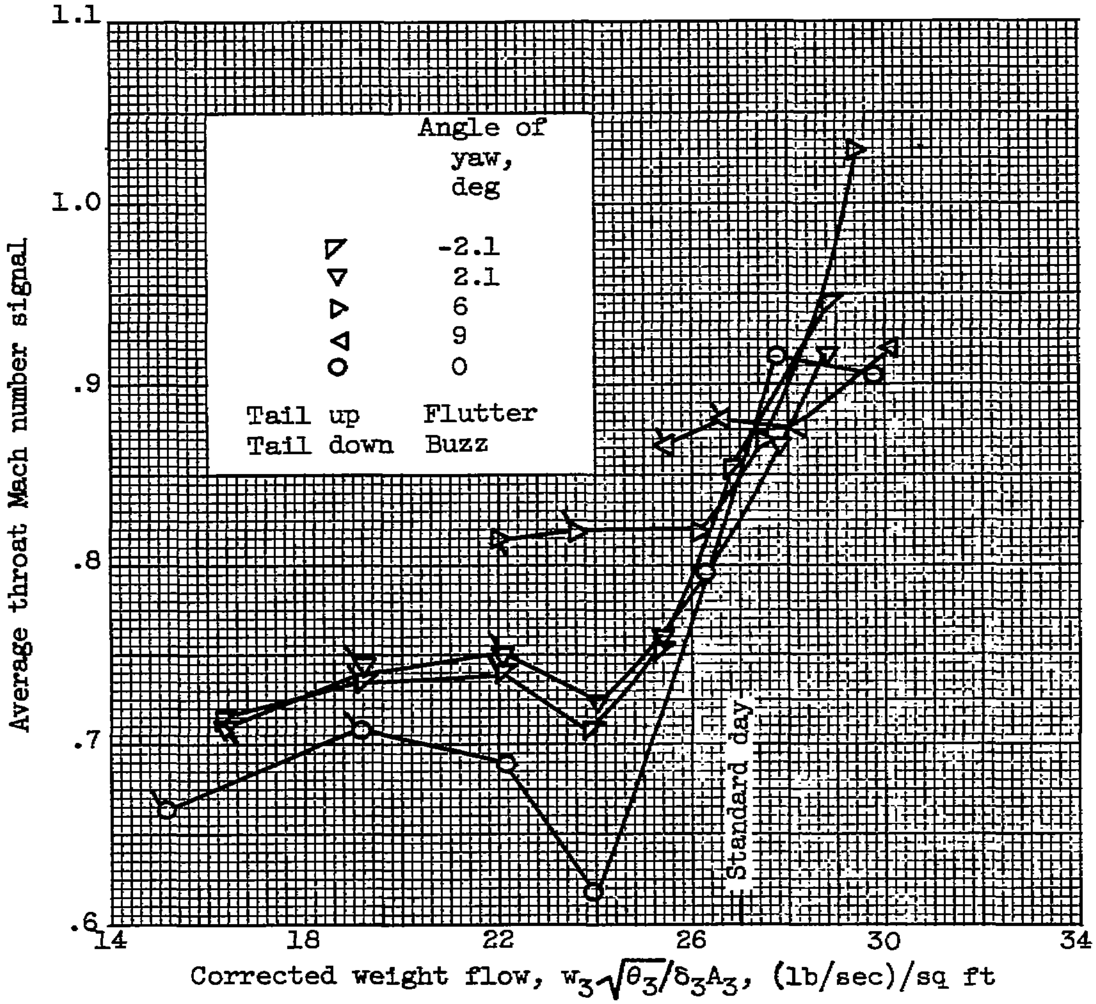

(a) Variable angle of yaw; second-ramp angle, 13°; free-stream Mach number, 1.68.

Figure 12. - Effect of angles of attack and yaw on average throat Mach number control signal with fixed second-ramp angles.

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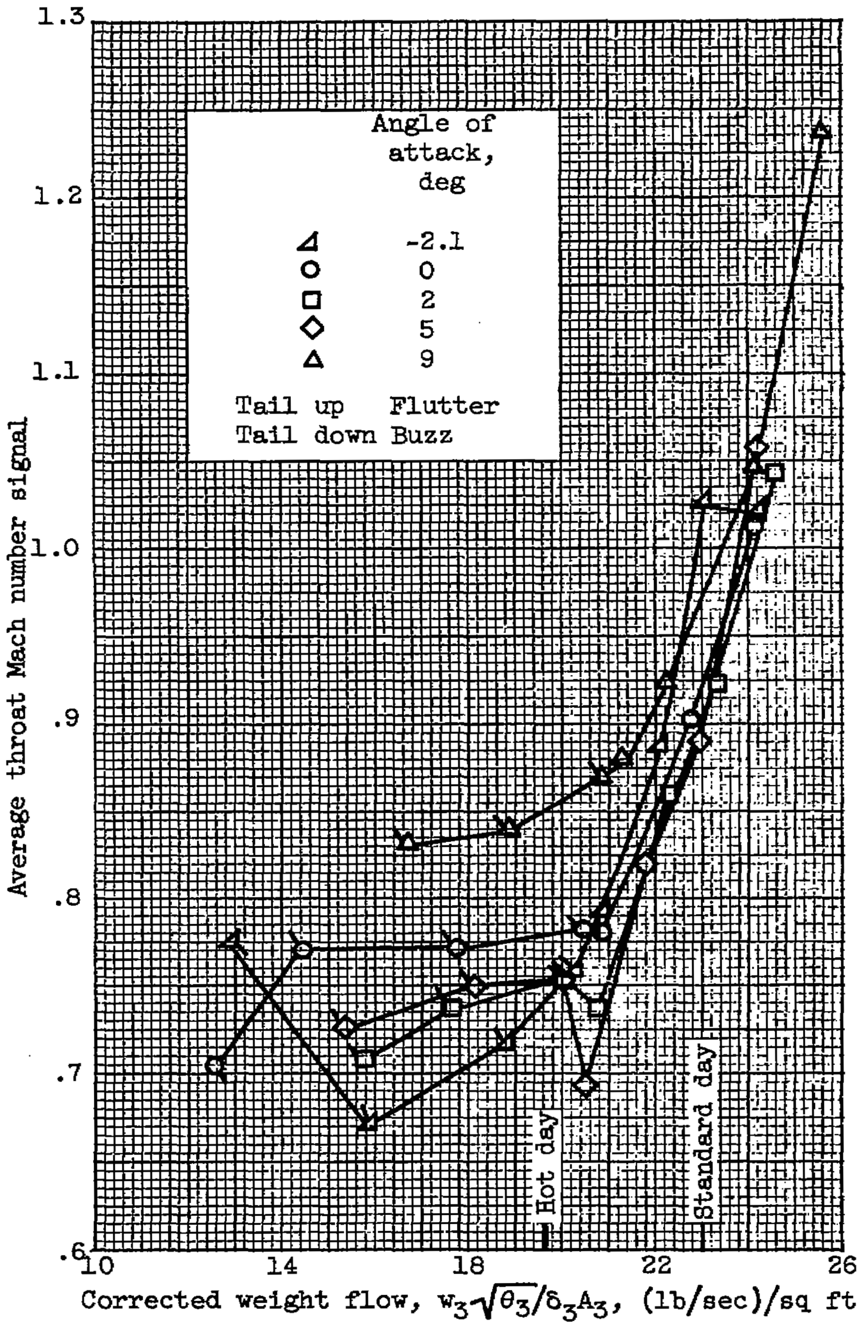


(b) Variable angle of attack; second-ramp angle, 21°; free-stream Mach number, 1.98.

Figure 12. - Concluded. Effect of angles of attack and yaw on the average throat Mach number control signal with fixed second-ramp angles.

[redacted]

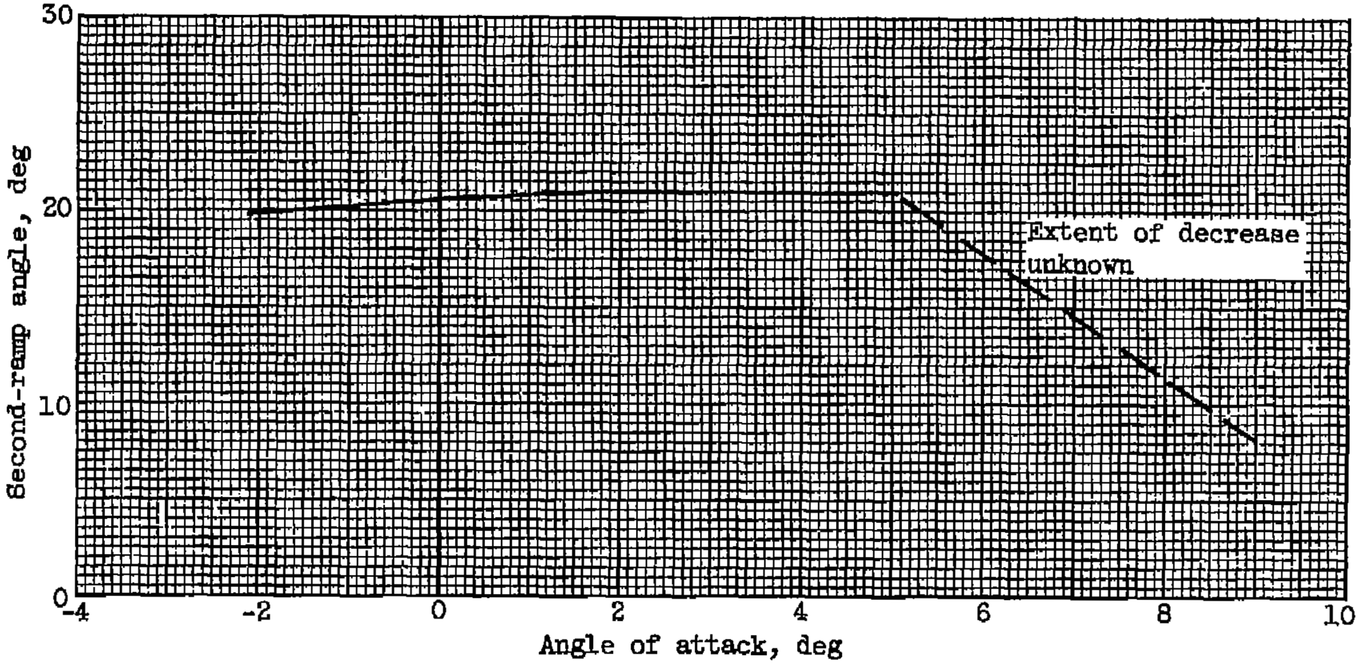
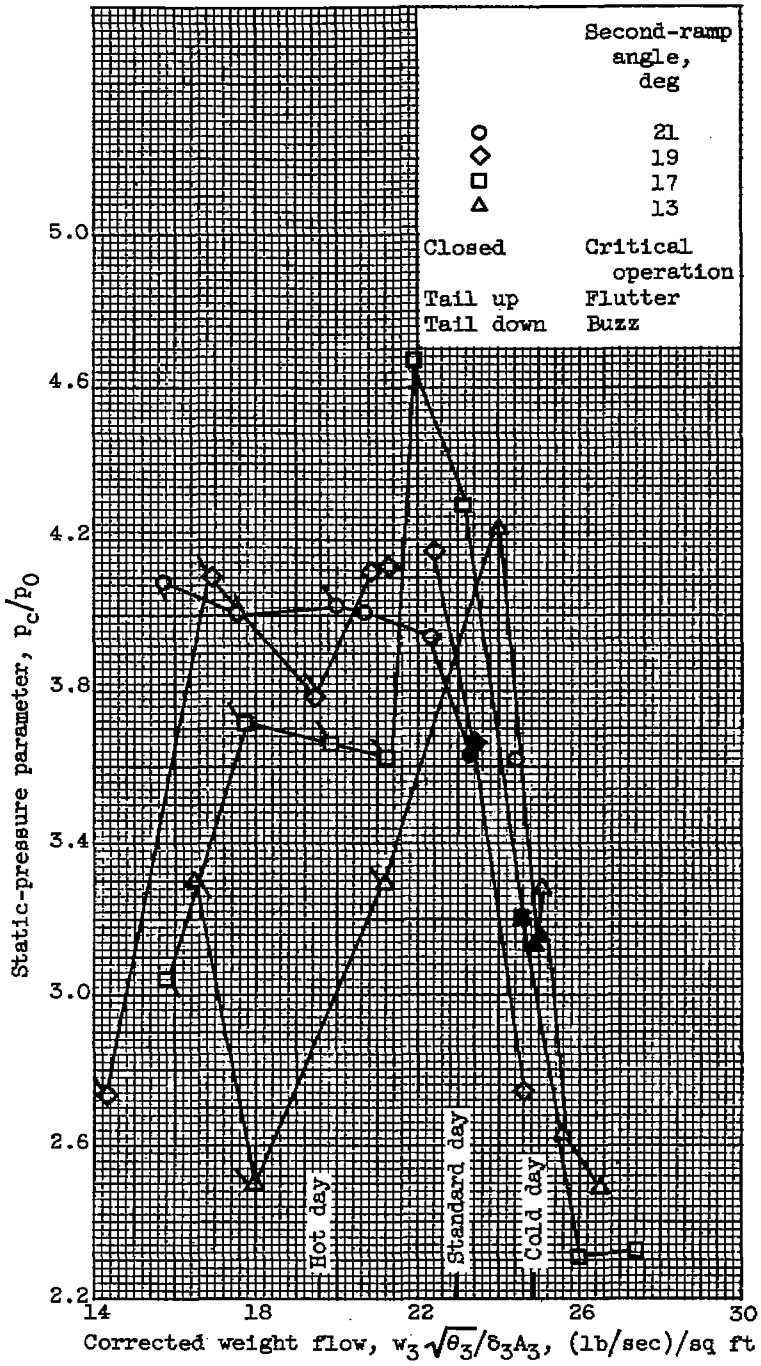
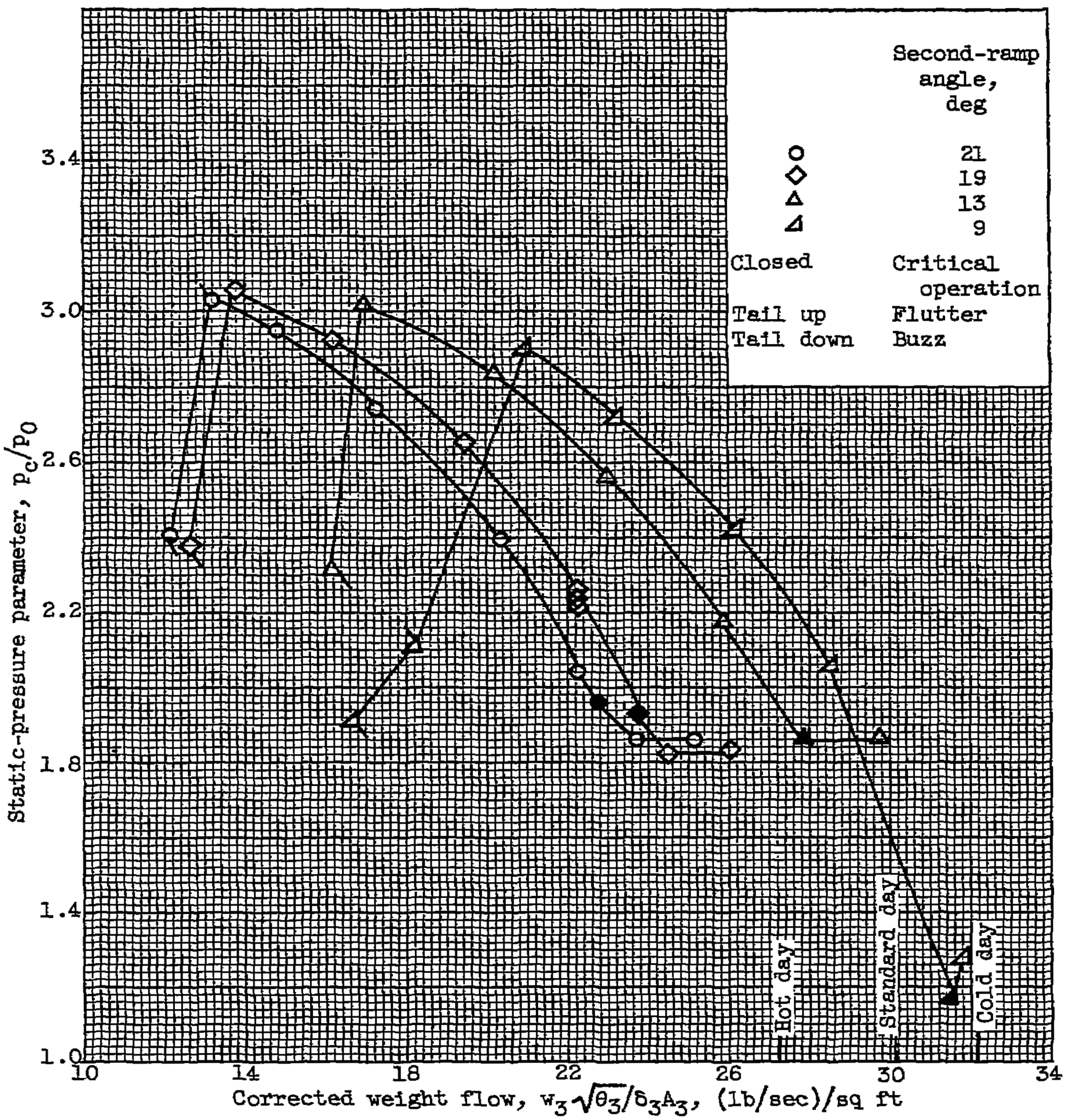


Figure 13. - Effect of angle of attack on ramp angle set by constant throat Mach number control system at flight Mach number 2.0. Altitude, 35,000 feet; corrected airflow, 21.8 (lb/sec)/sq ft; throat Mach number, 0.82.



(a) Free-stream Mach number, 1.98.

Figure 14. - Control signal from normal-shock-sensing static-pressure orifice in second-ramp surface. Angle of attack, 2°; left inlet.



(b) Free-stream Mach number, 1.49.

Figure 14. - Concluded. Control signal from normal-shock-sensing static-pressure orifice in second-ramp surface. Angle of attack, 2°; left inlet.

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