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# TABLES OF PRESSURE RATIOS $P/P_c$ AND $P/P_a$ FOR SUPERSONIC FLOW AROUND A 15° RIGHT CIRCULAR CONE AT ANGLES OF ATTACK

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# LIST OF SYMBOLS

| | |
|---|---|
| $M_1$ | free-stream Mach number |
| $P$ | local yawed pressure |
| $P_a$ | ambient pressure |
| $P_c$ | nonyawed conewall pressure |
| $R$ | gas constant |
| $S$ | entropy |
| $c_p$ | specific heat at constant pressure |
| $c_v$ | specific heat at constant volume |
| $V$ | local velocity referred to limiting velocity |
| $V_1$ | undisturbed velocity referred to limiting velocity |
| $x$ | yaw contribution to the velocity component u |
| $u, v, w$ or $v_r, v_n, w$ | polar velocity components in the radial direction, normal to radial direction, and normal to meridian direction, respectively |
| $\alpha$ | angle of attack |
| $\delta$ | yaw of the axis of the conical shock with respect to the free-stream direction |
| $\gamma$ | ratio of the specific heats |
| $\Theta$ | rotational angle denoting the position on the cross section of the solid cone. |
| $\psi$ | position of the conical body in the $\Theta = \pi$ plane referred to the shock axis |

Subscripts:

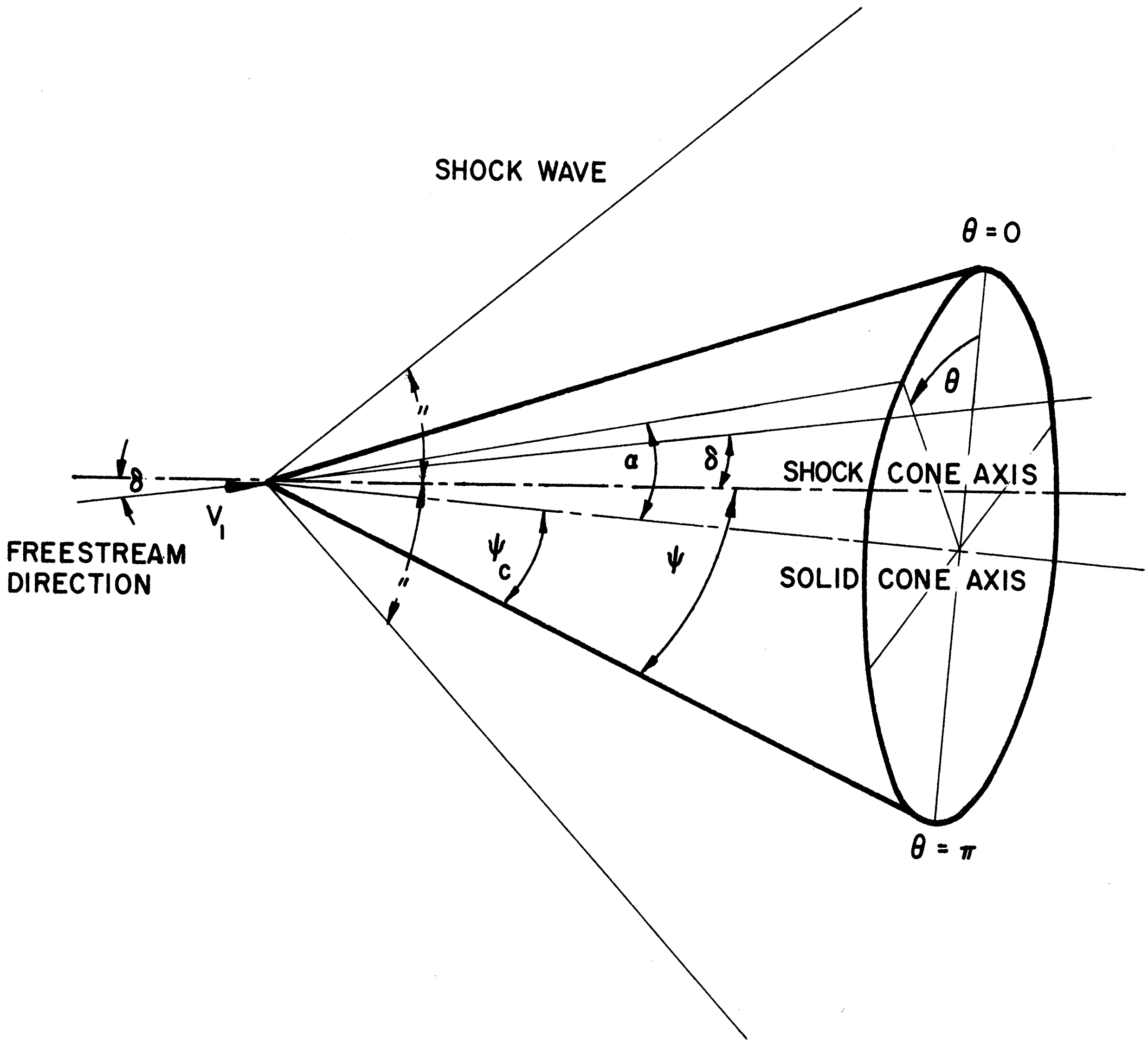
| | |
|---|---|
| a | zero-order terms of Fourier series (part independent of angle of attack); except for $P_a$ above |

| | |
|---|---|
| b | first-order terms of Fourier series (part proportional to angle of attack) |
| c | cone surface values |
| e | quantities at external surface of vortical layer |
| n | referring to direction normal to the direction along a conical ray |
| r | referring to direction along a conical ray |

ABSTRACT

For a right circular cone moving at supersonic velocities at zero angles of attack, measurement of the total head pressure and a conewall pressure enables determination of the ambient pressure and temperature.[1] The analysis is here extended to include corrections for small angles of attack with the use of Ferri's first-order theory.[2]

This report presents a tabulation of the ratio of the yawed conewall pressure to the ambient pressure, and the ratio of the yawed conewall to nonyawed conewall pressure at various rotational points on a 15° right circular cone for Mach numbers ranging from 2.0108 to 8.0589, and at angles of attack from 1 to 10°.




THE SOLID CONE AT SUPERSONIC FLOW
AT AN ANGLE OF ATTACK

## INTRODUCTION

In axially symmetric supersonic flow around a right circular cone, where the direction of the stream is parallel to the axis of the cone, direct measurement of the total head pressure and the conewall pressure enables determination of the free-stream Mach number, the ambient pressure, and the ambient temperature. This technique was employed by this laboratory during the IGY with the use of Aerobee and Nike-Cajun rockets for the measurement of ambient pressure, temperature, and density in the 30- to 80-kilometer range over Fort Churchill, Canada.

Small angles of attack (of the order of 2° to 4°) were observed, and corrections to the nonyawed analysis can be made with the use of Ferri's theory.[2] From this theory, the ratio of the yawed conewall pressure to ambient pressure, and the yawed conewall to nonyawed conewall pressure are computed and tabulated for a 15° right circular cone.

## DISCUSSION

The effect of finite angles of attack can be seen through the ratio of the yawed conewall pressure to the ideal, nonyawed, conewall pressure $P/P_c$. Calculation of $P/P_c$ can be made through the following identity:

$$\frac{P}{P_c} = \frac{P}{P_a} \times \frac{P_a}{P_c}$$

where $P/P_a$ is the ratio of the yawed to the ambient pressure, and $P_a/P_c$ is the ratio of the ambient to the ideal nonyawed conewall pressure.

For the specific case of a 15° right circular cone, the ratio $P_a/P_c$ has been calculated in Ref. 3. The expression for $P/P_a$ is derived by Ferri, and is the basis for the computations in this report.

## FERRI'S ANALYSIS

Ferri's determination for the supersonic flow around a cone at small angles of attack shows the existence of singular points at the surface of the cone in what he terms a "vortical layer." Across this layer the pressure distribution remains constant, but a discontinuity in entropy, density, and velocity occurs. In previous work, as in the Kopal Tables,[4,5] a computation from Stone's Theory, the flow properties were considered continuous. The analysis as developed by Ferri enables use of the Kopal values up to the point of the "vortical layer," after which the previously mentioned discontinuity in entropy is accounted for. The resulting pressure distribution, valid for small but finite angles of attack, is expressed as:

$$\frac{P}{P_a} = \left(\frac{1 - V^2}{1 - V_1^2}\right)^{\frac{\gamma}{\gamma-1}} \exp -\left(\frac{\Delta S}{R}\right) \tag{1}$$

## COMPUTATION OF $P/P_a$

The expression given by $P/P_a$ in Eq. (1) can be expanded, as suggested by Ferri, into a form where Kopal's tables may be used for the evaluation of the shock and conical flow properties, thus facilitating computation.

The steps leading up to the final expanded expression for $P/P_a$ will be given.

(a) For a given Mach number $M_1$, $V_1$ is the undisturbed velocity referred to the limiting velocity, i.e., it is the ratio of the undisturbed velocity to the velocity that the air in front of the shock wave would have after an adiabatic expansion into a vacuum.

$$V_1^2 = \left(1 + \frac{2}{(\gamma - 1)M_1^2}\right)^{-1} \tag{2}$$

(b) $(\Delta S/R)$ is the increase in entropy per gas constant across the shock and is expressed in terms of $S_a$ and $S_b$, the entropy change independent and dependent, respectively, of the angle of attack $\alpha$.

$$\frac{\Delta S}{R} = \frac{S_a}{R} - \frac{\alpha S_b}{(\gamma - 1)c_v} \tag{3}$$

$S_a$ is found in terms of the shock strength $P_w/P_1$ on page 555 of Kopal No. 1, and $S_b/c_v = d$ is tabulated on page 309 of Kopal No. 3.

(c) Corresponding to the yawed pressure P, V, the local velocity referred to the limiting velocity can be expressed in terms of its component polar velocities $v_r$, $v_n$, and w. Using the first-order Fourier series expansion as given by Ferri:

$$v_r = v_{r_a} + \alpha v_{r_b} \cos\Theta$$

$$v_n = v_{n_a} + \alpha v_{n_b} \cos\Theta \qquad (4)$$

$$w = \alpha w_b \sin\Theta$$

where the subscript a refers to the part independent of the angle of attack, and b refers to the part dependent on the angle of attack. Denoting the subscript c as being on the surface of the cone where $v_n$ is zero, $V^2$ becomes:

$$V^2 = (v_{r_{a_c}} + \alpha v_{r_{b_c}} \cos\Theta)^2 + \alpha^2 w_{b_c}^2 \sin^2\Theta \qquad (5)$$

In Ferri's analysis, the properties on the cone (with subscript c) are uniquely related to the quantities at the external surface of the previously mentioned "vortical layer" (denoted by the subscript e). The pressure distribution through the layer remains constant so that the pressure at the external surface of the "vortical layer" is equal to the cone surface pressure. A discontinuity in entropy, density, and velocity exists, but it is shown that the cone surface properties are only affected by the streamlines that cross the shock in the meridian plane $\Theta = \pi$. In this $\Theta = \pi$ plane, $S_e = S_c$, $v_{r_e} = v_{r_c}$ and $w_e = w_c = 0$. It is with these relationships that the terms in Eq. (5) above are established. This is done with the use of Eqs. (32), (34), (35), (37), and (55) of Ferri's report.

Since ultimate computation is with the use of the flow properties as calculated in Kopal's Tables, the terms in the equations referred to above are converted to the notation conforming to Kopal's. The polar velocity components $v_r$, $v_n$, and w used by Ferri correspond to u, v, and w used by Kopal. For example, $v_{r_{a_e}}$ in Ferri's report corresponds to $u_\psi$ in Kopal's notation, and similarly $v_{n_{a_\psi}}$ corresponds to $v_\psi$ where

$$\psi = \psi_c + \alpha - \delta \qquad (6)$$

$\psi$ = position in the $\Theta = \pi$ plane of the conical body referred to the shock axis

$\psi_c$ = half angle of the solid cone

$\alpha$ = angle of attack

$\delta$ = inclination of the conical axis with respect to the free-stream direction.

Equations (32) and (55) from Ferri's report:

$$v_r' = (v_{r_a} - \alpha v_{r_b})_e = (v_{r_a} - \alpha v_{r_b})_c \tag{7}$$

$$v_{r_{b_e}} = -(x_{\psi_c} + v_{n_{a_\psi}} \frac{\delta}{\alpha}) \tag{8}$$

can be expressed in Kopal's notation as:

$$v_r' = u_\psi + \alpha x_{\psi_c} + \delta v_\psi \tag{9}$$

$$v_{r_{b_e}} = -(x_{\psi_c} + v_\psi \frac{\delta}{\alpha}) \tag{10}$$

Similarly Eqs. (34) and (37) from Ferri's report

$$v_{r_{b_c}} = \frac{a_e^2}{\gamma(\gamma - 1) v_r'} \frac{S_b}{c_v} + v_{r_{b_e}} \tag{11}$$

$$a_e^2 = \frac{\gamma - 1}{2} (1 - v_r'^2) \tag{12}$$

combine, and, in terms of Kopal's notation, with the use of Eqs. (9) and (10) above, $v_{r_{b_c}}$ becomes:

$$v_{r_{b_c}} = \frac{1 - (u_\psi + \alpha x_{\psi_c} + \delta v_\psi)^2}{2\gamma(u_\psi + \alpha x_{\psi_c} + \delta v_\psi)} \frac{S_b}{c_v} - (x_{\psi_c} + v_\psi \frac{\delta}{\alpha}) \tag{13}$$

The term $v_{r_{a_c}}$ from Eq. (7), using (9), (10), and (13), becomes:

$$v_{r_{a_c}} = u_\psi + \alpha \left[\frac{1 - (u_\psi + \alpha x_{\psi_c} + \delta v_\psi)^2}{2\gamma(u_\psi + \alpha x_{\psi_c} + \delta v_\psi)} \frac{S_b}{c_v}\right] \tag{14}$$

Finally, Eq. (35) from Ferri's report:

$$w_{b_c} = \frac{-v_{r_{b_c}}}{\sin \psi_c} \tag{15}$$

and on substitution of Eq. (13):

$$w_{b_c} = \frac{-1}{\sin\psi_c}\;\frac{1-(u_\psi+\alpha x_{\psi_c}+\delta v_\psi)^2}{2\gamma(u_\psi+\alpha x_{\psi_c}+\delta v_\psi)}\frac{S_b}{c_v} - (x_{\psi_c} + v_\psi\frac{\delta}{\alpha}) \tag{16}$$

The above expressions for $v_{r_{a_c}}$, $v_{r_{b_c}}$, and $w_{b_c}$ are substituted into Eq. (5) and give $V^2$ in terms of the quantities $\delta/\alpha$, $u_\psi$, $v_\psi$, $x_{\psi_c}$, and $S_b/c_v$ which are tabulated in Kopal. This expanded expression for $V^2$ is:

$$V^2 = \left\{u_\psi + \alpha(1+\cos\Theta)\frac{1-(u_\psi+\alpha x_{\psi_c}+\delta v_\psi)^2}{2\gamma(u_\psi+\alpha x_{\psi_c}+\delta v_\psi)}\frac{S_b}{c_v} - \alpha\cos\Theta(x_{\psi_c}+v_\psi\frac{\delta}{\alpha})\right\}^2$$
$$+\frac{\alpha^2\sin^2\Theta}{\sin^2\psi_c}\left\{\frac{1-(u_\psi+\alpha x_{\psi_c}+\delta v_\psi)^2}{2\gamma(u_\psi+\alpha x_{\psi_c}+\delta v_\psi)}\frac{S_b}{c_v} - (x_{\psi_c}+v_\psi\frac{\delta}{\alpha})\right\}^2 \tag{17}$$

When substituted into the Ferri expression for the yawed to the ambient pressure ratio $P/P_a$, Eq. (1) becomes:

$$\frac{P}{P_a} = \left\{\frac{1-\left\{u_\psi+\alpha(1+\cos\Theta)\frac{1-(u_\psi+\alpha x_{\psi_c}+\delta v_\psi)^2}{2\gamma(u_\psi+\alpha x_{\psi_c}+\delta v_\psi)}\frac{S_b}{c_v} - (x_{\psi_c}+\frac{\delta}{\alpha}v_\psi)\alpha\cos\Theta\right\}^2}{1-V_1^2}\right.$$
$$\left.-\frac{\frac{\alpha^2\sin^2\Theta}{\sin^2\psi_c}\left\{\frac{1-(u_\psi+\alpha x_{\psi_c}+\delta v_\psi)^2}{2\gamma(u_\psi+\alpha x_{\psi_c}+\delta v_\psi)}\frac{S_b}{c_v} - (x_{\psi_c}+\frac{\delta}{\alpha}v_\psi)\right\}^2}{1-V_1^2}\right\}^{\frac{\gamma}{\gamma-1}} \exp -\left(\frac{\Delta S}{R}\right) \tag{18}$$

This is the final expression used for the computation for the values of $P/P_a$. For a given solid cone (e.g., $\psi_c = 7.5°$), at a given Mach number $M_1$, angle of attack $\alpha$, and rotational angle $\Theta$, the quantities in Eq. (18) are determined as follows:

1. $\delta/\alpha$, $S_b/c_v$ from Kopal No. 3, page 309.

2. $\psi$ from Eq. (6) of this report.

3. $u_\psi$, $v_\psi$ from Kopal No. 1, the values of u and v at the angle $\psi$.

4. $x_{\psi_c}$ from Kopal No. 3, the value of x at the angle $\psi_c$.

5. $V_1$ for various Mach numbers $M_1$ from Eq. (2) of this report.

6. $\Delta S/R$ from Eq. (3) of this report.

These various quantities for the Mach number range 2.0108 to 8.0589 and angle of attack at 1° increments up to 10° were tabulated, and the computation for $P/P_a$ from these quantities, through Eq. (18), was completed through the use of an IBM 704 computer.

## REFERENCES


1. Sicinski, H. S., Spencer, N. W., and Dow, W. G., "Rocket Measurements of the Upper Air," J. Appl. Phys., Dec., 1953.

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3. Spencer, N. W., Table of Pressure Ratios $P_i/P_c$ and $P_c/P_a$ vs. Mach Number for a 15° Right Circular Supersonic Cone ($\gamma = 1.405$), Univ. of Mich. Res. Inst. Scientific Report No. ES-3, Sept., 1958.

4. Staff of the Computing Section, Center of Analysis (under direction of Z. Kopal), Tables of Supersonic Flow around Cones, Tech. Report No. 1, M.I.T., 1947.

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$M = 2.0108$

| $\theta°$ | $\alpha = 1°$ | | $\alpha = 2°$ | | $\alpha = 3°$ | | $\alpha = 4°$ | | $\alpha = 5°$ | |
|---|---|---|---|---|---|---|---|---|---|---|
| | $P/P_a$ | $P/P_c$ | $P/P_a$ | $P/P_c$ | $P/P_a$ | $P/P_c$ | $P/P_a$ | $P/P_c$ | $P/P_a$ | $P/P_c$ |
| 0.0 | 1.16275 | 0.98040 | 1.14220 | 0.96307 | 1.12384 | 0.94759 | 1.10757 | 0.93387 | 1.09320 | 0.92175 |
| 10.0 | 1.16303 | 0.98063 | 1.14259 | 0.96339 | 1.12415 | 0.94785 | 1.10762 | 0.93391 | 1.09280 | 0.92141 |
| 20.0 | 1.16388 | 0.98135 | 1.14377 | 0.96439 | 1.12515 | 0.94869 | 1.10789 | 0.93414 | 1.09181 | 0.92058 |
| 30.0 | 1.16529 | 0.98254 | 1.14580 | 0.96610 | 1.12700 | 0.95025 | 1.10874 | 0.93486 | 1.09083 | 0.91976 |
| 40.0 | 1.16725 | 0.98419 | 1.14876 | 0.96860 | 1.12997 | 0.95276 | 1.11072 | 0.93652 | 1.09079 | 0.91972 |
| 50.0 | 1.16976 | 0.98630 | 1.15274 | 0.97196 | 1.13437 | 0.95646 | 1.11445 | 0.93967 | 1.09276 | 0.92138 |
| 60.0 | 1.17277 | 0.98884 | 1.15781 | 0.97623 | 1.14048 | 0.96162 | 1.12057 | 0.94483 | 1.09785 | 0.92568 |
| 70.0 | 1.17625 | 0.99178 | 1.16399 | 0.98144 | 1.14853 | 0.96840 | 1.12963 | 0.95247 | 1.10703 | 0.93341 |
| 80.0 | 1.18012 | 0.99504 | 1.17124 | 0.98756 | 1.15862 | 0.97691 | 1.14196 | 0.96287 | 1.12099 | 0.94518 |
| 90.0 | 1.18430 | 0.99857 | 1.17946 | 0.99449 | 1.17069 | 0.98709 | 1.15766 | 0.97610 | 1.14001 | 0.96122 |
| 100.0 | 1.18867 | 1.00225 | 1.18844 | 1.00206 | 1.18449 | 0.99873 | 1.17644 | 0.99194 | 1.16390 | 0.98137 |
| 110.0 | 1.19308 | 1.00597 | 1.19788 | 1.01002 | 1.19956 | 1.01143 | 1.19771 | 1.00988 | 1.19191 | 1.00498 |
| 120.0 | 1.19738 | 1.00959 | 1.20740 | 1.01805 | 1.21524 | 1.02466 | 1.22051 | 1.02909 | 1.22273 | 1.03097 |
| 130.0 | 1.20140 | 1.01298 | 1.21657 | 1.02578 | 1.23074 | 1.03773 | 1.24355 | 1.04852 | 1.25455 | 1.05780 |
| 140.0 | 1.20497 | 1.01600 | 1.22493 | 1.03282 | 1.24516 | 1.04988 | 1.26538 | 1.06693 | 1.28520 | 1.08364 |
| 150.0 | 1.20794 | 1.01850 | 1.23201 | 1.03879 | 1.25757 | 1.06035 | 1.28444 | 1.08300 | 1.31232 | 1.10651 |
| 160.0 | 1.21018 | 1.02038 | 1.23740 | 1.04334 | 1.26714 | 1.06841 | 1.29929 | 1.09552 | 1.33365 | 1.12449 |
| 170.0 | 1.21156 | 1.02155 | 1.24078 | 1.04619 | 1.27318 | 1.07350 | 1.30873 | 1.10348 | 1.34729 | 1.13599 |
| 180.0 | 1.21203 | 1.02195 | 1.24193 | 1.04716 | 1.27524 | 1.07524 | 1.31197 | 1.10621 | 1.35198 | 1.13995 |

M = 2.0108

| $\theta^\circ$ | $\alpha = 6^\circ$ $P/P_a$ | $P/P_c$ | $\alpha = 7^\circ$ $P/P_a$ | $P/P_c$ | $\alpha = 8^\circ$ $P/P_a$ | $P/P_c$ | $\alpha = 9^\circ$ $P/P_a$ | $P/P_c$ | $\alpha = 10^\circ$ $P/P_a$ | $P/P_c$ |
|---|---|---|---|---|---|---|---|---|---|---|
| 0.0 | 1.08068 | 0.91120 | 1.06976 | 0.90199 | 1.06067 | 0.89433 | 1.05298 | 0.88784 | 1.04707 | 0.88286 |
| 10.0 | 1.07964 | 0.91032 | 1.06788 | 0.90041 | 1.05775 | 0.89186 | 1.04880 | 0.88432 | 1.04143 | 0.87810 |
| 20.0 | 1.07683 | 0.90795 | 1.06270 | 0.89604 | 1.04962 | 0.88501 | 1.03714 | 0.87449 | 1.02563 | 0.86478 |
| 30.0 | 1.07319 | 0.90489 | 1.05556 | 0.89001 | 1.03810 | 0.87530 | 1.02040 | 0.86037 | 1.00280 | 0.84553 |
| 40.0 | 1.07011 | 0.90229 | 1.04841 | 0.88399 | 1.02589 | 0.86500 | 1.00212 | 0.84496 | 0.97746 | 0.82417 |
| 50.0 | 1.06923 | 0.90155 | 1.04361 | 0.87994 | 1.01610 | 0.85675 | 0.98635 | 0.83166 | 0.95474 | 0.80501 |
| 60.0 | 1.07225 | 0.90409 | 1.04352 | 0.87987 | 1.01193 | 0.85323 | 0.97715 | 0.82391 | 0.93965 | 0.79228 |
| 70.0 | 1.08065 | 0.91118 | 1.05028 | 0.88557 | 1.01618 | 0.85681 | 0.97810 | 0.82471 | 0.93654 | 0.78967 |
| 80.0 | 1.09558 | 0.92376 | 1.06553 | 0.89842 | 1.03108 | 0.86938 | 0.99202 | 0.83644 | 0.94888 | 0.80007 |
| 90.0 | 1.11762 | 0.94234 | 1.09020 | 0.91923 | 1.05801 | 0.89208 | 1.02076 | 0.86068 | 0.97899 | 0.82545 |
| 100.0 | 1.14667 | 0.96684 | 1.12441 | 0.94807 | 1.09730 | 0.92521 | 1.06499 | 0.89797 | 1.02793 | 0.86672 |
| 110.0 | 1.18190 | 0.99654 | 1.16726 | 0.98420 | 1.14810 | 0.96804 | 1.12394 | 0.94768 | 1.09516 | 0.92341 |
| 120.0 | 1.22164 | 1.03005 | 1.21676 | 1.02594 | 1.20814 | 1.01867 | 1.19518 | 1.00774 | 1.17816 | 0.99339 |
| 130.0 | 1.26349 | 1.06534 | 1.26987 | 1.07071 | 1.27371 | 1.07395 | 1.27435 | 1.07449 | 1.27201 | 1.07253 |
| 140.0 | 1.30444 | 1.09986 | 1.32260 | 1.11517 | 1.33977 | 1.12965 | 1.35527 | 1.14272 | 1.36936 | 1.15460 |
| 150.0 | 1.34111 | 1.13078 | 1.37039 | 1.15548 | 1.40036 | 1.18074 | 1.43037 | 1.20604 | 1.46079 | 1.23169 |
| 160.0 | 1.37022 | 1.15533 | 1.40867 | 1.18775 | 1.44931 | 1.22202 | 1.49160 | 1.25767 | 1.53603 | 1.29514 |
| 170.0 | 1.38895 | 1.17112 | 1.43345 | 1.20864 | 1.48120 | 1.24890 | 1.53173 | 1.29151 | 1.58566 | 1.33698 |
| 180.0 | 1.39541 | 1.17657 | 1.44203 | 1.21588 | 1.49227 | 1.25824 | 1.54571 | 1.30330 | 1.60301 | 1.35161 |

M = 2.3105

| $\theta^\circ$ | $\alpha = 1^\circ$ $P/P_a$ | $P/P_c$ | $\alpha = 2^\circ$ $P/P_a$ | $P/P_c$ | $\alpha = 3^\circ$ $P/P_a$ | $P/P_c$ | $\alpha = 4^\circ$ $P/P_a$ | $P/P_c$ | $\alpha = 5^\circ$ $P/P_a$ | $P/P_c$ |
|---|---|---|---|---|---|---|---|---|---|---|
| 0.0 | 1.19902 | 0.97561 | 1.17129 | 0.95304 | 1.14638 | 0.93277 | 1.12393 | 0.91450 | 1.10359 | 0.89796 |
| 10.0 | 1.19940 | 0.97591 | 1.17181 | 0.95347 | 1.14681 | 0.93313 | 1.12402 | 0.91458 | 1.10311 | 0.89757 |
| 20.0 | 1.20052 | 0.97683 | 1.17340 | 0.95476 | 1.14818 | 0.93424 | 1.12448 | 0.91495 | 1.10193 | 0.89661 |
| 30.0 | 1.20239 | 0.97835 | 1.17613 | 0.95698 | 1.15072 | 0.93631 | 1.12575 | 0.91599 | 1.10084 | 0.89572 |
| 40.0 | 1.20500 | 0.98047 | 1.18010 | 0.96021 | 1.15476 | 0.93960 | 1.12854 | 0.91825 | 1.10102 | 0.89587 |
| 50.0 | 1.20832 | 0.98317 | 1.18542 | 0.96454 | 1.16069 | 0.94442 | 1.13365 | 0.92242 | 1.10387 | 0.89818 |
| 60.0 | 1.21231 | 0.98642 | 1.19217 | 0.97003 | 1.16889 | 0.95109 | 1.14192 | 0.92914 | 1.11082 | 0.90384 |
| 70.0 | 1.21691 | 0.99016 | 1.20039 | 0.97672 | 1.17964 | 0.95984 | 1.15405 | 0.93901 | 1.12313 | 0.91386 |
| 80.0 | 1.22204 | 0.99433 | 1.21002 | 0.98456 | 1.19308 | 0.97077 | 1.17050 | 0.95240 | 1.14173 | 0.92899 |
| 90.0 | 1.22756 | 0.99883 | 1.22092 | 0.99343 | 1.20913 | 0.98383 | 1.19138 | 0.96939 | 1.16704 | 0.94958 |
| 100.0 | 1.23332 | 1.00352 | 1.23282 | 1.00311 | 1.22746 | 0.99875 | 1.21639 | 0.98974 | 1.19885 | 0.97546 |
| 110.0 | 1.23915 | 1.00826 | 1.24533 | 1.01329 | 1.24749 | 1.01505 | 1.24473 | 1.01280 | 1.23623 | 1.00588 |
| 120.0 | 1.24483 | 1.01288 | 1.25795 | 1.02355 | 1.26836 | 1.03203 | 1.27517 | 1.03757 | 1.27750 | 1.03947 |
| 130.0 | 1.25013 | 1.01720 | 1.27011 | 1.03345 | 1.28901 | 1.04883 | 1.30602 | 1.06267 | 1.32031 | 1.07429 |
| 140.0 | 1.25485 | 1.02104 | 1.28119 | 1.04246 | 1.30824 | 1.06448 | 1.33532 | 1.08651 | 1.36170 | 1.10797 |
| 150.0 | 1.25878 | 1.02423 | 1.29058 | 1.05011 | 1.32482 | 1.07797 | 1.36098 | 1.10738 | 1.39847 | 1.13790 |
| 160.0 | 1.26172 | 1.02662 | 1.29774 | 1.05593 | 1.33762 | 1.08838 | 1.38100 | 1.12368 | 1.42748 | 1.16150 |
| 170.0 | 1.26355 | 1.02811 | 1.30222 | 1.05958 | 1.34570 | 1.09496 | 1.39374 | 1.13405 | 1.44608 | 1.17663 |
| 180.0 | 1.26417 | 1.02861 | 1.30375 | 1.06082 | 1.34847 | 1.09721 | 1.39812 | 1.13761 | 1.45249 | 1.18185 |

M = 2.3105

| $\theta^{o}$ | α=6° $P/P_a$ | $P/P_c$ | α=7° $P/P_a$ | $P/P_c$ | α=8° $P/P_a$ | $P/P_c$ | α=9° $P/P_a$ | $P/P_c$ | α=10° $P/P_a$ | $P/P_c$ |
|---|---|---|---|---|---|---|---|---|---|---|
| 0.0 | 1.08553 | 0.88326 | 1.06951 | 0.87023 | 1.05527 | 0.85864 | 1.04263 | 0.84835 | 1.03212 | 0.83980 |
| 10.0 | 1.08421 | 0.88219 | 1.06708 | 0.86825 | 1.05147 | 0.85555 | 1.03717 | 0.84392 | 1.02471 | 0.83378 |
| 20.0 | 1.08066 | 0.87930 | 1.06042 | 0.86283 | 1.04092 | 0.84697 | 1.02196 | 0.83154 | 1.00403 | 0.81695 |
| 30.0 | 1.07609 | 0.87558 | 1.05125 | 0.85537 | 1.02602 | 0.83484 | 1.00020 | 0.81383 | 0.97427 | 0.79274 |
| 40.0 | 1.07231 | 0.87251 | 1.04215 | 0.84797 | 1.01028 | 0.82203 | 0.97654 | 0.79458 | 0.94144 | 0.76602 |
| 50.0 | 1.07144 | 0.87180 | 1.03615 | 0.84308 | 0.99777 | 0.81186 | 0.95626 | 0.77808 | 0.91219 | 0.74222 |
| 60.0 | 1.07568 | 0.87524 | 1.03631 | 0.84321 | 0.99257 | 0.80762 | 0.94452 | 0.76853 | 0.89287 | 0.72650 |
| 70.0 | 1.08697 | 0.88443 | 1.04540 | 0.85061 | 0.99832 | 0.81230 | 0.94589 | 0.76965 | 0.88895 | 0.72331 |
| 80.0 | 1.10683 | 0.90059 | 1.06559 | 0.86704 | 1.01793 | 0.82826 | 0.96404 | 0.78441 | 0.90481 | 0.73622 |
| 90.0 | 1.13608 | 0.92439 | 1.09823 | 0.89360 | 1.05334 | 0.85707 | 1.00153 | 0.81491 | 0.94367 | 0.76784 |
| 100.0 | 1.17473 | 0.95584 | 1.14363 | 0.93053 | 1.10526 | 0.89932 | 1.05961 | 0.86218 | 1.00742 | 0.81971 |
| 110.0 | 1.22177 | 0.99411 | 1.20082 | 0.97707 | 1.17293 | 0.95438 | 1.13785 | 0.92584 | 1.09616 | 0.89191 |
| 120.0 | 1.27513 | 1.03753 | 1.26739 | 1.03124 | 1.25370 | 1.02010 | 1.23359 | 1.00374 | 1.20746 | 0.98247 |
| 130.0 | 1.33166 | 1.08353 | 1.33940 | 1.08983 | 1.34287 | 1.09265 | 1.34146 | 1.09150 | 1.33546 | 1.08663 |
| 140.0 | 1.38730 | 1.12880 | 1.41149 | 1.14849 | 1.43366 | 1.16653 | 1.45319 | 1.18242 | 1.47044 | 1.19645 |
| 150.0 | 1.43741 | 1.16958 | 1.47732 | 1.20205 | 1.51774 | 1.23494 | 1.55815 | 1.26782 | 1.59910 | 1.30114 |
| 160.0 | 1.47736 | 1.20209 | 1.53036 | 1.24521 | 1.58621 | 1.29065 | 1.64456 | 1.33813 | 1.70626 | 1.38833 |
| 170.0 | 1.50316 | 1.22307 | 1.56485 | 1.27327 | 1.63105 | 1.32714 | 1.70159 | 1.38453 | 1.77753 | 1.44633 |
| 180.0 | 1.51208 | 1.23033 | 1.57682 | 1.28301 | 1.64667 | 1.33985 | 1.72153 | 1.40076 | 1.80256 | 1.46669 |

## M = 2.6847

| θ° | α=1° P/Pa | α=1° P/Pc | α=2° P/Pa | α=2° P/Pc | α=3° P/Pa | α=3° P/Pc | α=4° P/Pa | α=4° P/Pc | α=5° P/Pa | α=5° P/Pc |
|---|---|---|---|---|---|---|---|---|---|---|
| 0.0 | 1.24819 | 0.96834 | 1.21009 | 0.93878 | 1.17506 | 0.91160 | 1.14256 | 0.88640 | 1.11271 | 0.86323 |
| 10.0 | 1.24870 | 0.96874 | 1.21081 | 0.93934 | 1.17567 | 0.91208 | 1.14274 | 0.88654 | 1.11211 | 0.86277 |
| 20.0 | 1.25023 | 0.96993 | 1.21300 | 0.94104 | 1.17762 | 0.91359 | 1.14350 | 0.88712 | 1.11070 | 0.86167 |
| 30.0 | 1.25278 | 0.97190 | 1.21676 | 0.94396 | 1.18119 | 0.91636 | 1.14542 | 0.88862 | 1.10950 | 0.86074 |
| 40.0 | 1.25632 | 0.97465 | 1.22221 | 0.94819 | 1.18683 | 0.92073 | 1.14944 | 0.89173 | 1.11006 | 0.86118 |
| 50.0 | 1.26083 | 0.97814 | 1.22950 | 0.95384 | 1.19503 | 0.92710 | 1.15662 | 0.89730 | 1.11423 | 0.86441 |
| 60.0 | 1.26624 | 0.98235 | 1.23873 | 0.96100 | 1.20631 | 0.93585 | 1.16806 | 0.90618 | 1.12392 | 0.87193 |
| 70.0 | 1.27249 | 0.98719 | 1.24994 | 0.96970 | 1.22103 | 0.94727 | 1.18471 | 0.91909 | 1.14081 | 0.88504 |
| 80.0 | 1.27943 | 0.99258 | 1.26307 | 0.97988 | 1.23939 | 0.96151 | 1.20719 | 0.93654 | 1.16620 | 0.90473 |
| 90.0 | 1.28691 | 0.99838 | 1.27790 | 0.99139 | 1.26130 | 0.97851 | 1.23572 | 0.95866 | 1.20071 | 0.93150 |
| 100.0 | 1.29472 | 1.00444 | 1.29409 | 1.00395 | 1.28634 | 0.99793 | 1.26991 | 0.98519 | 1.24419 | 0.96524 |
| 110.0 | 1.30260 | 1.01055 | 1.31110 | 1.01715 | 1.31371 | 1.01917 | 1.30876 | 1.01533 | 1.29552 | 1.00505 |
| 120.0 | 1.31028 | 1.01651 | 1.32828 | 1.03047 | 1.34227 | 1.04133 | 1.35061 | 1.04780 | 1.35251 | 1.04927 |
| 130.0 | 1.31746 | 1.02208 | 1.34484 | 1.04332 | 1.37060 | 1.06330 | 1.39321 | 1.08084 | 1.41197 | 1.09540 |
| 140.0 | 1.32385 | 1.02704 | 1.35994 | 1.05504 | 1.39703 | 1.08381 | 1.43381 | 1.11234 | 1.46983 | 1.14028 |
| 150.0 | 1.32916 | 1.03115 | 1.37276 | 1.06498 | 1.41986 | 1.10152 | 1.46950 | 1.14003 | 1.52151 | 1.18038 |
| 160.0 | 1.33314 | 1.03424 | 1.38252 | 1.07256 | 1.43752 | 1.11522 | 1.49743 | 1.16170 | 1.56247 | 1.21216 |
| 170.0 | 1.33561 | 1.03616 | 1.38865 | 1.07730 | 1.44868 | 1.12388 | 1.51525 | 1.17552 | 1.58881 | 1.23259 |
| 180.0 | 1.33645 | 1.03681 | 1.39073 | 1.07892 | 1.45250 | 1.12684 | 1.52137 | 1.18027 | 1.59791 | 1.23965 |

M = 2.6847

| $\theta°$ | α = 6° P/$P_a$ | α = 6° P/$P_c$ | α = 7° P/$P_a$ | α = 7° P/$P_c$ | α = 8° P/$P_a$ | α = 8° P/$P_c$ | α = 9° P/$P_a$ | α = 9° P/$P_c$ | α = 10° P/$P_a$ | α = 10° P/$P_c$ |
|---|---|---|---|---|---|---|---|---|---|---|
| 0.0 | 1.08515 | 0.84186 | 1.05995 | 0.82230 | 1.03685 | 0.80439 | 1.01552 | 0.78784 | 0.99635 | 0.77296 |
| 10.0 | 1.08344 | 0.84053 | 1.05675 | 0.81982 | 1.03181 | 0.80047 | 1.00825 | 0.78219 | 0.98645 | 0.76528 |
| 20.0 | 1.07886 | 0.83698 | 1.04799 | 0.81302 | 1.01783 | 0.78963 | 0.98801 | 0.76649 | 0.95887 | 0.74389 |
| 30.0 | 1.07302 | 0.83244 | 1.03598 | 0.80371 | 0.99816 | 0.77437 | 0.95921 | 0.74415 | 0.91948 | 0.71333 |
| 40.0 | 1.06829 | 0.82877 | 1.02415 | 0.79453 | 0.97749 | 0.75834 | 0.92808 | 0.72000 | 0.87640 | 0.67991 |
| 50.0 | 1.06749 | 0.82815 | 1.01647 | 0.78857 | 0.96118 | 0.74568 | 0.90156 | 0.69943 | 0.83833 | 0.65038 |
| 60.0 | 1.07351 | 0.83282 | 1.01699 | 0.78897 | 0.95452 | 0.74051 | 0.88630 | 0.68758 | 0.81332 | 0.63097 |
| 70.0 | 1.08896 | 0.84481 | 1.02935 | 0.79857 | 0.96227 | 0.74653 | 0.88810 | 0.68899 | 0.80812 | 0.62694 |
| 80.0 | 1.11592 | 0.86573 | 1.05653 | 0.81965 | 0.98834 | 0.76675 | 0.91179 | 0.70736 | 0.82830 | 0.64259 |
| 90.0 | 1.15565 | 0.89655 | 1.10055 | 0.85380 | 1.03557 | 0.80339 | 0.96108 | 0.74560 | 0.87842 | 0.68148 |
| 100.0 | 1.20834 | 0.93743 | 1.16215 | 0.90159 | 1.10549 | 0.85763 | 1.03841 | 0.80560 | 0.96201 | 0.74632 |
| 110.0 | 1.27292 | 0.98753 | 1.24051 | 0.96238 | 1.19777 | 0.92922 | 1.14434 | 0.88777 | 1.08087 | 0.83854 |
| 120.0 | 1.34678 | 1.04482 | 1.33276 | 1.03395 | 1.30959 | 1.01597 | 1.27648 | 0.99029 | 1.23363 | 0.95705 |
| 130.0 | 1.42572 | 1.10606 | 1.43375 | 1.11230 | 1.43501 | 1.11327 | 1.42842 | 1.10816 | 1.41388 | 1.09688 |
| 140.0 | 1.50408 | 1.16686 | 1.53606 | 1.19167 | 1.56469 | 1.21388 | 1.58892 | 1.23268 | 1.60864 | 1.24798 |
| 150.0 | 1.57523 | 1.22206 | 1.63048 | 1.26492 | 1.68644 | 1.30833 | 1.74231 | 1.35168 | 1.79833 | 1.39514 |
| 160.0 | 1.63232 | 1.26634 | 1.70721 | 1.32445 | 1.78669 | 1.38611 | 1.87038 | 1.45104 | 1.95905 | 1.51982 |
| 170.0 | 1.66934 | 1.29507 | 1.75741 | 1.36339 | 1.85286 | 1.43744 | 1.95573 | 1.51724 | 2.06724 | 1.60375 |
| 180.0 | 1.68218 | 1.30502 | 1.77488 | 1.37694 | 1.87601 | 1.45540 | 1.98572 | 1.54051 | 2.10545 | 1.63340 |

M=3.1795

| $\theta^\circ$ | $\alpha=1^\circ$ $P/P_a$ | $P/P_c$ | $\alpha=2^\circ$ $P/P_a$ | $P/P_c$ | $\alpha=3^\circ$ $P/P_a$ | $P/P_c$ | $\alpha=4^\circ$ $P/P_a$ | $P/P_c$ | $\alpha=5^\circ$ $P/P_a$ | $P/P_c$ |
|---|---|---|---|---|---|---|---|---|---|---|
| 0.0 | 1.31961 | 0.95694 | 1.26437 | 0.91687 | 1.21218 | 0.87903 | 1.16320 | 0.84351 | 1.11673 | 0.80981 |
| 10.0 | 1.32034 | 0.95746 | 1.26540 | 0.91762 | 1.21309 | 0.87969 | 1.16354 | 0.84376 | 1.11602 | 0.80930 |
| 20.0 | 1.32251 | 0.95903 | 1.26857 | 0.91992 | 1.21598 | 0.88179 | 1.16484 | 0.84470 | 1.11437 | 0.80810 |
| 30.0 | 1.32611 | 0.96165 | 1.27397 | 0.92383 | 1.22124 | 0.88560 | 1.16791 | 0.84693 | 1.11318 | 0.80723 |
| 40.0 | 1.33113 | 0.96528 | 1.28178 | 0.92950 | 1.22944 | 0.89155 | 1.17398 | 0.85133 | 1.11454 | 0.80822 |
| 50.0 | 1.33750 | 0.96991 | 1.29219 | 0.93705 | 1.24129 | 0.90014 | 1.18451 | 0.85897 | 1.12095 | 0.81287 |
| 60.0 | 1.34516 | 0.97546 | 1.30534 | 0.94659 | 1.25745 | 0.91186 | 1.20100 | 0.87092 | 1.13500 | 0.82306 |
| 70.0 | 1.35398 | 0.98186 | 1.32128 | 0.95814 | 1.27846 | 0.92709 | 1.22477 | 0.88816 | 1.15906 | 0.84051 |
| 80.0 | 1.36379 | 0.98897 | 1.33991 | 0.97165 | 1.30459 | 0.94604 | 1.25675 | 0.91135 | 1.19498 | 0.86656 |
| 90.0 | 1.37434 | 0.99662 | 1.36095 | 0.98691 | 1.33575 | 0.96863 | 1.29729 | 0.94074 | 1.24383 | 0.90198 |
| 100.0 | 1.38535 | 1.00460 | 1.38391 | 1.00356 | 1.37137 | 0.99447 | 1.34598 | 0.97606 | 1.30564 | 0.94680 |
| 110.0 | 1.39646 | 1.01266 | 1.40805 | 1.02106 | 1.41039 | 1.02276 | 1.40154 | 1.01634 | 1.37909 | 1.00006 |
| 120.0 | 1.40729 | 1.02051 | 1.43244 | 1.03875 | 1.45122 | 1.05237 | 1.46169 | 1.05997 | 1.46134 | 1.05971 |
| 130.0 | 1.41742 | 1.02786 | 1.45598 | 1.05582 | 1.49183 | 1.08182 | 1.52325 | 1.10461 | 1.54792 | 1.12250 |
| 140.0 | 1.42642 | 1.03439 | 1.47747 | 1.07141 | 1.52984 | 1.10938 | 1.58228 | 1.14741 | 1.63292 | 1.18413 |
| 150.0 | 1.43391 | 1.03982 | 1.49573 | 1.08465 | 1.56278 | 1.13327 | 1.63442 | 1.18522 | 1.70945 | 1.23963 |
| 160.0 | 1.43952 | 1.04389 | 1.50966 | 1.09475 | 1.58830 | 1.15178 | 1.67541 | 1.21494 | 1.77051 | 1.28391 |
| 170.0 | 1.44301 | 1.04642 | 1.51840 | 1.10109 | 1.60447 | 1.16350 | 1.70163 | 1.23396 | 1.80995 | 1.31251 |
| 180.0 | 1.44419 | 1.04727 | 1.52138 | 1.10325 | 1.61001 | 1.16752 | 1.71066 | 1.24050 | 1.82360 | 1.32241 |

M = 3.1795

| $\theta^\circ$ | $\alpha = 6^\circ$ $P/P_a$ | $P/P_c$ | $\alpha = 7^\circ$ $P/P_a$ | $P/P_c$ | $\alpha = 8^\circ$ $P/P_a$ | $P/P_c$ | $\alpha = 9$ $P/P_a$ | $P/P_c$ | $\alpha = 10^\circ$ $P/P_a$ | $P/P_c$ |
|---|---|---|---|---|---|---|---|---|---|---|
| 0.0 | 1.07290 | 0.77803 | 1.03147 | 0.74798 | 0.99224 | 0.71954 | 0.95542 | 0.69284 | 0.92032 | 0.66738 |
| 10.0 | 1.07066 | 0.77640 | 1.02720 | 0.74489 | 0.98547 | 0.71462 | 0.94562 | 0.68573 | 0.90701 | 0.65773 |
| 20.0 | 1.06469 | 0.77207 | 1.01553 | 0.73643 | 0.96674 | 0.70105 | 0.91849 | 0.66606 | 0.87019 | 0.63103 |
| 30.0 | 1.05717 | 0.76662 | 0.99964 | 0.72490 | 0.94055 | 0.68205 | 0.88018 | 0.63827 | 0.81819 | 0.59332 |
| 40.0 | 1.05130 | 0.76236 | 0.98412 | 0.71365 | 0.91325 | 0.66225 | 0.83920 | 0.60856 | 0.76216 | 0.55269 |
| 50.0 | 1.05087 | 0.76206 | 0.97433 | 0.70655 | 0.89193 | 0.64679 | 0.80465 | 0.58350 | 0.71340 | 0.51733 |
| 60.0 | 1.05979 | 0.76852 | 0.97561 | 0.70748 | 0.88350 | 0.64068 | 0.78497 | 0.56923 | 0.68172 | 0.49436 |
| 70.0 | 1.08165 | 0.78437 | 0.99291 | 0.72002 | 0.89418 | 0.64843 | 0.78744 | 0.57102 | 0.67507 | 0.48954 |
| 80.0 | 1.11943 | 0.81177 | 1.03041 | 0.74721 | 0.92932 | 0.67391 | 0.81836 | 0.59344 | 0.70028 | 0.50782 |
| 90.0 | 1.17517 | 0.85219 | 1.09132 | 0.79138 | 0.99339 | 0.72037 | 0.88341 | 0.64062 | 0.76402 | 0.55404 |
| 100.0 | 1.24963 | 0.90618 | 1.17746 | 0.85385 | 1.08962 | 0.79015 | 0.98754 | 0.71613 | 0.87316 | 0.63318 |
| 110.0 | 1.34181 | 0.97303 | 1.28865 | 0.93448 | 1.21918 | 0.88410 | 1.13399 | 0.82233 | 1.03380 | 0.74967 |
| 120.0 | 1.44856 | 1.05044 | 1.42182 | 1.03105 | 1.37984 | 1.00061 | 1.32231 | 0.95889 | 1.24849 | 0.90536 |
| 130.0 | 1.56415 | 1.13426 | 1.57027 | 1.13870 | 1.56440 | 1.13444 | 1.54569 | 1.12088 | 1.51213 | 1.09654 |
| 140.0 | 1.68037 | 1.21854 | 1.72326 | 1.24965 | 1.75964 | 1.27603 | 1.78872 | 1.29711 | 1.80781 | 1.31095 |
| 150.0 | 1.78708 | 1.29592 | 1.86665 | 1.35363 | 1.94665 | 1.41164 | 2.02701 | 1.46991 | 2.10516 | 1.52659 |
| 160.0 | 1.87349 | 1.35859 | 1.98463 | 1.43918 | 2.10313 | 1.52511 | 2.23003 | 1.61714 | 2.36352 | 1.71394 |
| 170.0 | 1.92990 | 1.39949 | 2.06247 | 1.49563 | 2.20757 | 1.60085 | 2.36723 | 1.71663 | 2.54044 | 1.84223 |
| 180.0 | 1.94952 | 1.41372 | 2.08969 | 1.51537 | 2.24430 | 1.62748 | 2.41579 | 1.75184 | 2.60348 | 1.88795 |

M = 3.8946

| θ° | α = 1° P/$P_a$ | α = 1° P/$P_c$ | α = 2° P/$P_a$ | α = 2° P/$P_c$ | α = 3° P/$P_a$ | α = 3° P/$P_c$ | α = 4° P/$P_a$ | α = 4° P/$P_c$ | α = 5° P/$P_a$ | α = 5° P/$P_c$ |
|---|---|---|---|---|---|---|---|---|---|---|
| 0.0 | 1.43616 | 0.94113 | 1.35038 | 0.88492 | 1.26752 | 0.83061 | 1.18795 | 0.77848 | 1.11171 | 0.72851 |
| 10.0 | 1.43727 | 0.94185 | 1.35200 | 0.88598 | 1.26900 | 0.83159 | 1.18866 | 0.77894 | 1.11095 | 0.72802 |
| 20.0 | 1.44057 | 0.94402 | 1.35691 | 0.88919 | 1.27366 | 0.83464 | 1.19115 | 0.78057 | 1.10936 | 0.72697 |
| 30.0 | 1.44606 | 0.94761 | 1.36527 | 0.89467 | 1.28204 | 0.84013 | 1.19657 | 0.78412 | 1.10885 | 0.72664 |
| 40.0 | 1.45368 | 0.95261 | 1.37732 | 0.90257 | 1.29496 | 0.84860 | 1.20662 | 0.79071 | 1.11232 | 0.72891 |
| 50.0 | 1.46337 | 0.95896 | 1.39332 | 0.91305 | 1.31338 | 0.86067 | 1.22335 | 0.80167 | 1.12324 | 0.73607 |
| 60.0 | 1.47500 | 0.96658 | 1.41345 | 0.92625 | 1.33829 | 0.87699 | 1.24892 | 0.81843 | 1.14526 | 0.75050 |
| 70.0 | 1.48838 | 0.97535 | 1.43779 | 0.94220 | 1.37045 | 0.89807 | 1.28526 | 0.84224 | 1.18185 | 0.77448 |
| 80.0 | 1.50324 | 0.98508 | 1.46620 | 0.96081 | 1.41032 | 0.92420 | 1.33387 | 0.87410 | 1.23590 | 0.80990 |
| 90.0 | 1.51922 | 0.99556 | 1.49826 | 0.98182 | 1.45782 | 0.95532 | 1.39545 | 0.91445 | 1.30940 | 0.85806 |
| 100.0 | 1.53589 | 1.00648 | 1.53323 | 1.00474 | 1.51220 | 0.99095 | 1.46967 | 0.96309 | 1.40295 | 0.91937 |
| 110.0 | 1.55272 | 1.01751 | 1.57005 | 1.02887 | 1.57193 | 1.03010 | 1.55485 | 1.01891 | 1.51526 | 0.99296 |
| 120.0 | 1.56912 | 1.02826 | 1.60730 | 1.05328 | 1.63468 | 1.07122 | 1.64778 | 1.07980 | 1.64259 | 1.07641 |
| 130.0 | 1.58446 | 1.03831 | 1.64332 | 1.07688 | 1.69737 | 1.11230 | 1.74368 | 1.14265 | 1.77842 | 1.16541 |
| 140.0 | 1.59810 | 1.04725 | 1.67627 | 1.09848 | 1.75632 | 1.15093 | 1.83639 | 1.20340 | 1.91349 | 1.25393 |
| 150.0 | 1.60944 | 1.05468 | 1.70432 | 1.11685 | 1.80762 | 1.18455 | 1.91889 | 1.25747 | 2.03652 | 1.33455 |
| 160.0 | 1.61796 | 1.06026 | 1.72575 | 1.13090 | 1.84750 | 1.21068 | 1.98415 | 1.30023 | 2.13557 | 1.39946 |
| 170.0 | 1.62325 | 1.06373 | 1.73921 | 1.13971 | 1.87283 | 1.22728 | 2.02607 | 1.32770 | 2.19999 | 1.44167 |
| 180.0 | 1.62504 | 1.06490 | 1.74379 | 1.14272 | 1.88152 | 1.23297 | 2.04054 | 1.33718 | 2.22235 | 1.45633 |

M = 3.8946

| $\theta^\circ$ | $\alpha=6^\circ$ $P/P_a$ | $P/P_c$ | $\alpha=7^\circ$ $P/P_a$ | $P/P_c$ | $\alpha=8^\circ$ $P/P_a$ | $P/P_c$ | $\alpha=9^\circ$ $P/P_a$ | $P/P_c$ | $\alpha=10^\circ$ $P/P_a$ | $P/P_c$ |
|---|---|---|---|---|---|---|---|---|---|---|
| 0.0 | 1.03863 | 0.68062 | 0.96876 | 0.63484 | 0.90212 | 0.59117 | 0.83843 | 0.54943 | 0.77776 | 0.50967 |
| 10.0 | 1.03576 | 0.67874 | 0.96313 | 0.63115 | 0.89315 | 0.58529 | 0.82554 | 0.54099 | 0.76045 | 0.49833 |
| 20.0 | 1.02819 | 0.67378 | 0.94782 | 0.62112 | 0.86850 | 0.56914 | 0.79013 | 0.51778 | 0.71309 | 0.46729 |
| 30.0 | 1.01892 | 0.66771 | 0.92721 | 0.60761 | 0.83440 | 0.54679 | 0.74085 | 0.48549 | 0.64762 | 0.42439 |
| 40.0 | 1.01234 | 0.66339 | 0.90757 | 0.59474 | 0.79945 | 0.52388 | 0.68919 | 0.45163 | 0.57904 | 0.37945 |
| 50.0 | 1.01362 | 0.66424 | 0.89603 | 0.58717 | 0.77290 | 0.50649 | 0.64669 | 0.42378 | 0.52126 | 0.34159 |
| 60.0 | 1.02815 | 0.67376 | 0.89974 | 0.58960 | 0.76356 | 0.50036 | 0.62341 | 0.40853 | 0.48495 | 0.31779 |
| 70.0 | 1.06106 | 0.69532 | 0.92545 | 0.60645 | 0.77941 | 0.51075 | 0.62790 | 0.41147 | 0.47817 | 0.31335 |
| 80.0 | 1.11691 | 0.73192 | 0.97940 | 0.64181 | 0.82801 | 0.54260 | 0.66835 | 0.43798 | 0.50865 | 0.33332 |
| 90.0 | 1.19937 | 0.78596 | 1.06716 | 0.69932 | 0.91690 | 0.60085 | 0.75391 | 0.49404 | 0.58649 | 0.38433 |
| 100.0 | 1.31062 | 0.85886 | 1.19318 | 0.78190 | 1.05334 | 0.69026 | 0.89514 | 0.58659 | 0.72566 | 0.47553 |
| 110.0 | 1.45053 | 0.95054 | 1.35954 | 0.89092 | 1.24293 | 0.81450 | 1.10256 | 0.72252 | 0.94304 | 0.61798 |
| 120.0 | 1.61556 | 1.05869 | 1.56411 | 1.02498 | 1.48670 | 0.97424 | 1.38270 | 0.90609 | 1.25342 | 0.82137 |
| 130.0 | 1.79778 | 1.17810 | 1.79845 | 1.17854 | 1.77726 | 1.16465 | 1.73173 | 1.13482 | 1.66013 | 1.08789 |
| 140.0 | 1.98445 | 1.30043 | 2.04627 | 1.34094 | 2.09540 | 1.37313 | 2.12898 | 1.39514 | 2.14368 | 1.40477 |
| 150.0 | 2.15871 | 1.41462 | 2.28381 | 1.49660 | 2.40927 | 1.57882 | 2.53362 | 1.66030 | 2.65412 | 1.73927 |
| 160.0 | 2.30170 | 1.50832 | 2.48276 | 1.62697 | 2.67806 | 1.75495 | 2.88870 | 1.89299 | 3.11428 | 2.04081 |
| 170.0 | 2.39589 | 1.57005 | 2.61566 | 1.71406 | 2.86034 | 1.87440 | 3.13349 | 2.05340 | 3.43726 | 2.25247 |
| 180.0 | 2.42881 | 1.59162 | 2.66243 | 1.74471 | 2.92497 | 1.91675 | 3.22101 | 2.11075 | 3.55377 | 2.32882 |

$M = 5.1033$

| $\theta^\circ$ | $\alpha = 1°$ | | $\alpha = 2°$ | | $\alpha = 3°$ | | $\alpha = 4°$ | | $\alpha = 5°$ | |
|---|---|---|---|---|---|---|---|---|---|---|
| | $P/P_a$ | $P/P_c$ | $P/P_a$ | $P/P_c$ | $P/P_a$ | $P/P_c$ | $P/P_a$ | $P/P_c$ | $P/P_a$ | $P/P_c$ |
| 0.0 | 1.67141 | 0.91484 | 1.51911 | 0.83148 | 1.37247 | 0.75122 | 1.23209 | 0.67438 | 1.09867 | 0.60135 |
| 10.0 | 1.67335 | 0.91590 | 1.52201 | 0.83307 | 1.37533 | 0.75278 | 1.23389 | 0.67536 | 1.09847 | 0.60124 |
| 20.0 | 1.67914 | 0.91907 | 1.53081 | 0.83788 | 1.38417 | 0.75762 | 1.23984 | 0.67862 | 1.09880 | 0.60142 |
| 30.0 | 1.68876 | 0.92433 | 1.54575 | 0.84606 | 1.39980 | 0.76618 | 1.25156 | 0.68504 | 1.10232 | 0.60335 |
| 40.0 | 1.70210 | 0.93164 | 1.56716 | 0.85778 | 1.42344 | 0.77911 | 1.27152 | 0.69596 | 1.11308 | 0.60924 |
| 50.0 | 1.71904 | 0.94091 | 1.59543 | 0.87325 | 1.45656 | 0.79724 | 1.30274 | 0.71305 | 1.13601 | 0.62179 |
| 60.0 | 1.73934 | 0.95202 | 1.63083 | 0.89263 | 1.50065 | 0.82137 | 1.34852 | 0.73811 | 1.17652 | 0.64396 |
| 70.0 | 1.76267 | 0.96479 | 1.67345 | 0.91595 | 1.55701 | 0.85222 | 1.41204 | 0.77287 | 1.24008 | 0.67875 |
| 80.0 | 1.78856 | 0.97896 | 1.72306 | 0.94311 | 1.62645 | 0.89023 | 1.49595 | 0.81880 | 1.33182 | 0.72897 |
| 90.0 | 1.81640 | 0.99420 | 1.77898 | 0.97372 | 1.70899 | 0.93541 | 1.60191 | 0.87680 | 1.45596 | 0.79692 |
| 100.0 | 1.84542 | 1.01008 | 1.83999 | 1.00711 | 1.80360 | 0.98719 | 1.73002 | 0.94692 | 1.61499 | 0.88396 |
| 110.0 | 1.87472 | 1.02612 | 1.90430 | 1.04231 | 1.90792 | 1.04429 | 1.87817 | 1.02801 | 1.80845 | 0.98985 |
| 120.0 | 1.90328 | 1.04175 | 1.96949 | 1.07799 | 2.01809 | 1.10459 | 2.04147 | 1.11739 | 2.03153 | 1.11195 |
| 130.0 | 1.93001 | 1.05638 | 2.03269 | 1.11258 | 2.12882 | 1.16520 | 2.21190 | 1.21067 | 2.27388 | 1.24460 |
| 140.0 | 1.95378 | 1.06940 | 2.09066 | 1.14431 | 2.23361 | 1.22256 | 2.37852 | 1.30187 | 2.51914 | 1.37884 |
| 150.0 | 1.97357 | 1.08022 | 2.14012 | 1.17138 | 2.32532 | 1.27275 | 2.52830 | 1.38385 | 2.74605 | 1.50304 |
| 160.0 | 1.98843 | 1.08836 | 2.17800 | 1.19212 | 2.39696 | 1.31196 | 2.64775 | 1.44923 | 2.93103 | 1.60429 |
| 170.0 | 1.99765 | 1.09341 | 2.20182 | 1.20516 | 2.44261 | 1.33695 | 2.72494 | 1.49148 | 3.05238 | 1.67071 |
| 180.0 | 2.00078 | 1.09512 | 2.20995 | 1.20961 | 2.45829 | 1.34554 | 2.75165 | 1.50610 | 3.09469 | 1.69387 |

M = 5.1033

| $\theta^\circ$ | $\alpha = 6^\circ$ $P/P_a$ | $P/P_c$ | $\alpha = 7^\circ$ $P/P_a$ | $P/P_c$ | $\alpha = 8^\circ$ $P/P_a$ | $P/P_c$ | $\alpha = 9^\circ$ $P/P_a$ | $P/P_c$ | $\alpha = 10^\circ$ $P/P_a$ | $P/P_c$ |
|---|---|---|---|---|---|---|---|---|---|---|
| 0.0 | 0.97289 | 0.53251 | 0.85494 | 0.46795 | 0.74483 | 0.40768 | 0.64344 | 0.35218 | 0.54972 | 0.30089 |
| 10.0 | 0.96986 | 0.53085 | 0.84841 | 0.46438 | 0.73430 | 0.40191 | 0.62860 | 0.34406 | 0.53049 | 0.29036 |
| 20.0 | 0.96219 | 0.52665 | 0.83093 | 0.45481 | 0.70572 | 0.38627 | 0.58840 | 0.32206 | 0.47896 | 0.26216 |
| 30.0 | 0.95390 | 0.52211 | 0.80823 | 0.44238 | 0.66717 | 0.36517 | 0.53402 | 0.29230 | 0.41048 | 0.22467 |
| 40.0 | 0.95089 | 0.52047 | 0.78844 | 0.43155 | 0.62939 | 0.34449 | 0.47940 | 0.26240 | 0.34270 | 0.18757 |
| 50.0 | 0.96020 | 0.52556 | 0.78069 | 0.42731 | 0.60351 | 0.33033 | 0.43733 | 0.23937 | 0.28954 | 0.15848 |
| 60.0 | 0.98938 | 0.54153 | 0.79432 | 0.43477 | 0.59989 | 0.32835 | 0.41806 | 0.22882 | 0.25958 | 0.14208 |
| 70.0 | 1.04619 | 0.57263 | 0.83882 | 0.45913 | 0.62866 | 0.34409 | 0.43061 | 0.23569 | 0.25873 | 0.14161 |
| 80.0 | 1.13844 | 0.62312 | 0.92436 | 0.50594 | 0.70121 | 0.38381 | 0.48594 | 0.26598 | 0.29531 | 0.16164 |
| 90.0 | 1.27367 | 0.69714 | 1.06202 | 0.58129 | 0.83190 | 0.45534 | 0.60044 | 0.32865 | 0.38575 | 0.21114 |
| 100.0 | 1.45817 | 0.79812 | 1.26327 | 0.69145 | 1.03835 | 0.56834 | 0.79812 | 0.43685 | 0.55945 | 0.30621 |
| 110.0 | 1.69514 | 0.92782 | 1.53752 | 0.84155 | 1.33906 | 0.73293 | 1.10925 | 0.60714 | 0.86010 | 0.47077 |
| 120.0 | 1.98200 | 1.08484 | 1.88769 | 1.03322 | 1.74703 | 0.95623 | 1.56251 | 0.85523 | 1.33807 | 0.73239 |
| 130.0 | 2.30744 | 1.26296 | 2.30443 | 1.26132 | 2.25976 | 1.23687 | 2.16953 | 1.18748 | 2.02906 | 1.11060 |
| 140.0 | 2.64944 | 1.45016 | 2.76097 | 1.51120 | 2.84851 | 1.55912 | 2.90522 | 1.59016 | 2.92120 | 1.59890 |
| 150.0 | 2.97586 | 1.62882 | 3.21189 | 1.75801 | 3.45277 | 1.88986 | 3.69371 | 2.02173 | 3.92583 | 2.14879 |
| 160.0 | 3.24843 | 1.77801 | 3.59843 | 1.96958 | 3.98604 | 2.18174 | 4.41239 | 2.41510 | 4.87515 | 2.66839 |
| 170.0 | 3.43017 | 1.87749 | 3.86076 | 2.11317 | 4.35506 | 2.38372 | 4.92042 | 2.69317 | 5.56212 | 3.04440 |
| 180.0 | 3.49406 | 1.91246 | 3.95381 | 2.16410 | 4.48723 | 2.45606 | 5.10432 | 2.79383 | 5.81367 | 3.18209 |

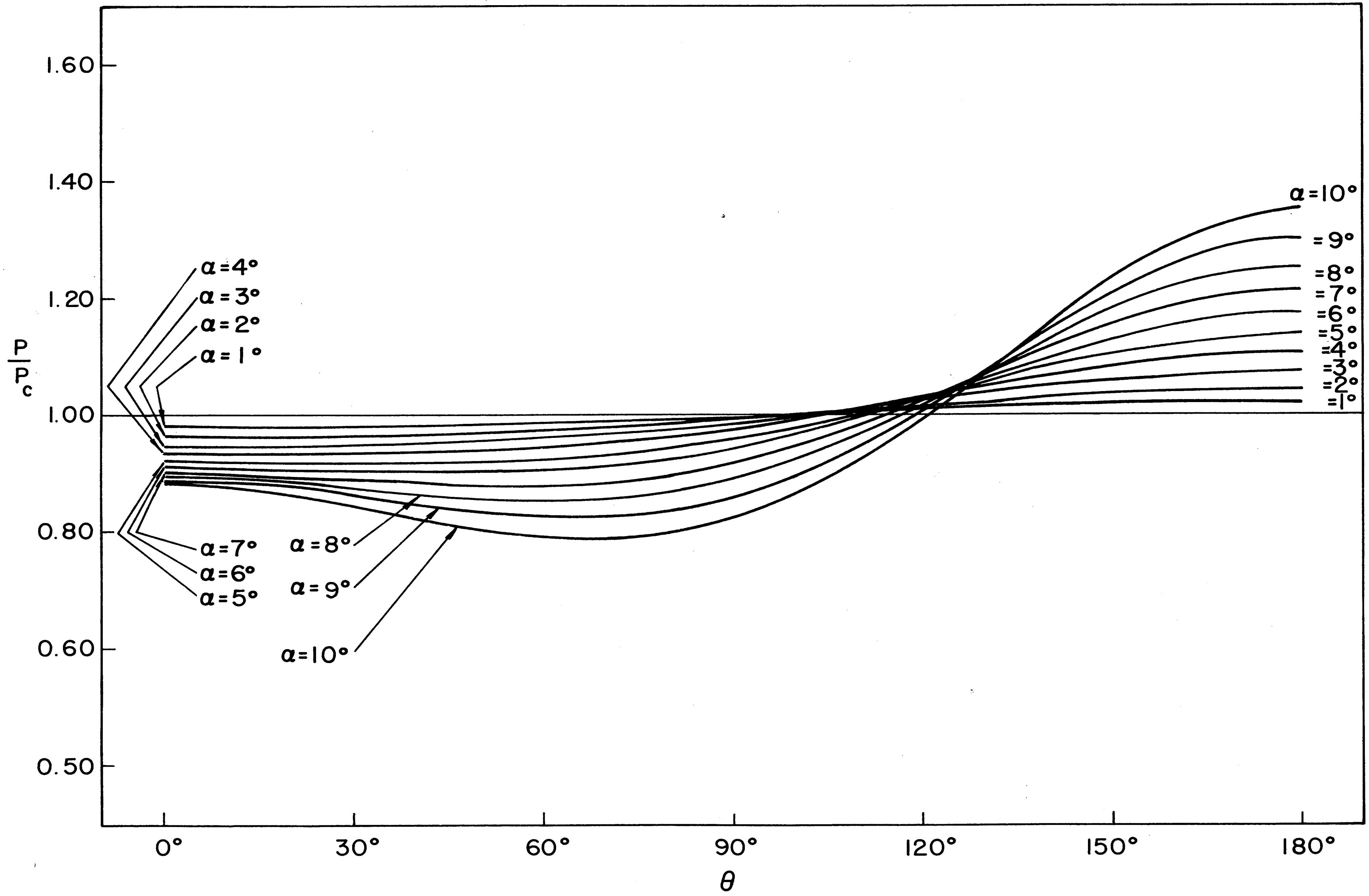
## M = 8.0589

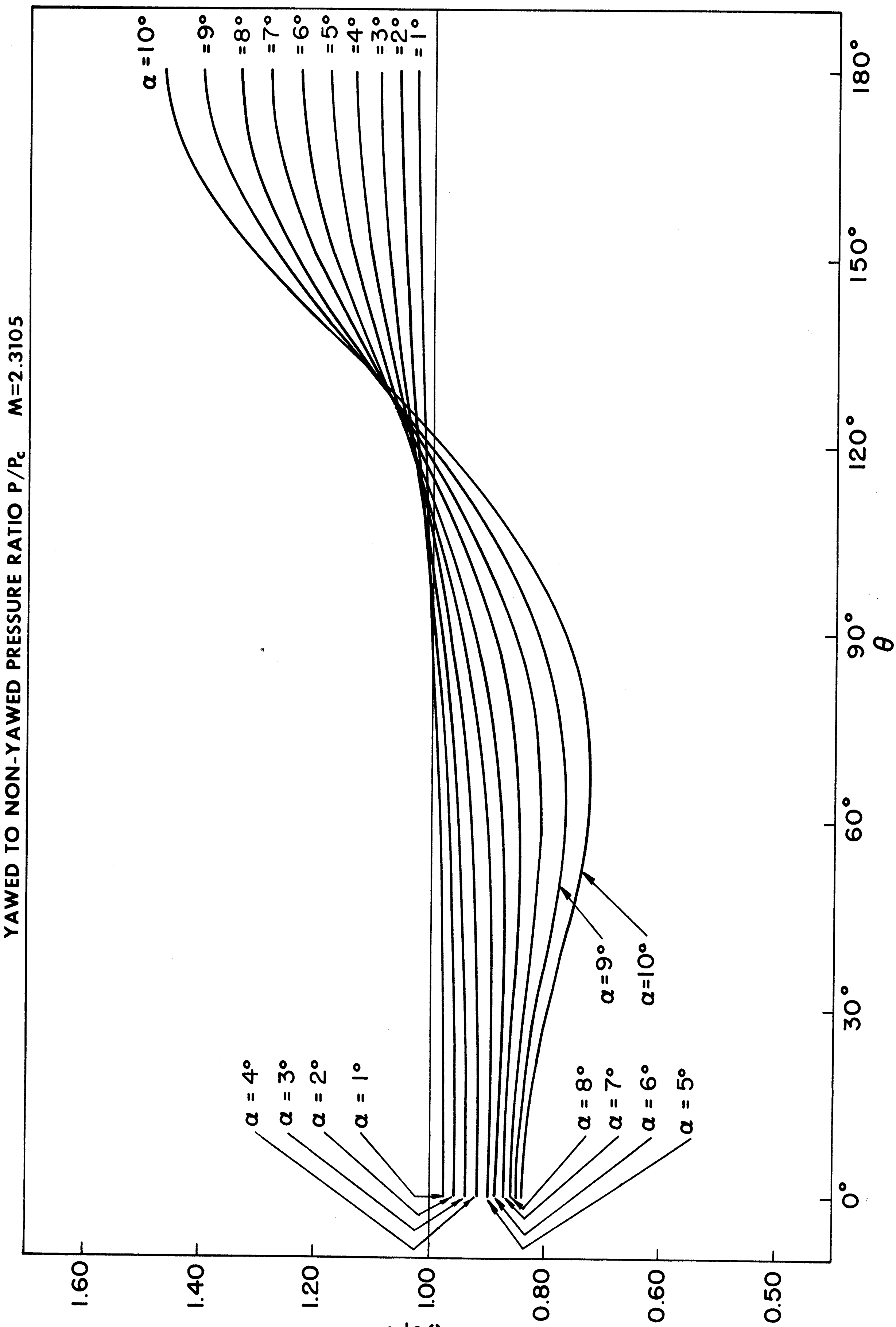
| $\theta^{\circ}$ | α = 1° P/Pa | α = 1° P/Pc | α = 2° P/Pa | α = 2° P/Pc | α = 3° P/Pa | α = 3° P/Pc | α = 4° P/Pa | α = 4° P/Pc | α = 5° P/Pa | α = 5° P/Pc |
|---|---|---|---|---|---|---|---|---|---|---|
| 0.0 | 2.46313 | 0.86607 | 2.11520 | 0.74373 | 1.80582 | 0.63495 | 1.53219 | 0.53874 | 1.29375 | 0.45490 |
| 10.0 | 2.46803 | 0.86779 | 2.12278 | 0.74640 | 1.81409 | 0.63786 | 1.53949 | 0.54131 | 1.29882 | 0.45668 |
| 20.0 | 2.48270 | 0.87295 | 2.14565 | 0.75444 | 1.83933 | 0.64673 | 1.56222 | 0.54930 | 1.31525 | 0.46246 |
| 30.0 | 2.50699 | 0.88149 | 2.18420 | 0.76799 | 1.88285 | 0.66204 | 1.60280 | 0.56357 | 1.34664 | 0.47350 |
| 40.0 | 2.54067 | 0.89333 | 2.23898 | 0.78726 | 1.94668 | 0.68448 | 1.66507 | 0.58546 | 1.39872 | 0.49181 |
| 50.0 | 2.58331 | 0.90833 | 2.31058 | 0.81243 | 2.03334 | 0.71495 | 1.75405 | 0.61675 | 1.47906 | 0.52006 |
| 60.0 | 2.63432 | 0.92626 | 2.39939 | 0.84366 | 2.14556 | 0.75441 | 1.87556 | 0.65947 | 1.59684 | 0.56147 |
| 70.0 | 2.69282 | 0.94683 | 2.50542 | 0.88094 | 2.28578 | 0.80371 | 2.03577 | 0.71580 | 1.76249 | 0.61972 |
| 80.0 | 2.75762 | 0.96962 | 2.62800 | 0.92404 | 2.45570 | 0.86346 | 2.24038 | 0.78775 | 1.98700 | 0.69866 |
| 90.0 | 2.82720 | 0.99408 | 2.76550 | 0.97239 | 2.65547 | 0.93370 | 2.49362 | 0.87679 | 2.28071 | 0.80193 |
| 100.0 | 2.89966 | 1.01956 | 2.91506 | 1.02498 | 2.88304 | 1.01372 | 2.79666 | 0.98334 | 2.65107 | 0.93215 |
| 110.0 | 2.97278 | 1.04527 | 3.07246 | 1.08032 | 3.13335 | 1.10173 | 3.14591 | 1.10614 | 3.09942 | 1.08980 |
| 120.0 | 3.04402 | 1.07032 | 3.23203 | 1.13643 | 3.39777 | 1.19470 | 3.53121 | 1.24162 | 3.61704 | 1.27180 |
| 130.0 | 3.11069 | 1.09376 | 3.38682 | 1.19085 | 3.66403 | 1.28832 | 3.93468 | 1.38349 | 4.18174 | 1.47036 |
| 140.0 | 3.17002 | 1.11462 | 3.52900 | 1.24084 | 3.91669 | 1.37716 | 4.33083 | 1.52278 | 4.75626 | 1.67237 |
| 150.0 | 3.21938 | 1.13198 | 3.65046 | 1.28355 | 4.13847 | 1.45514 | 4.68851 | 1.64855 | 5.29045 | 1.86019 |
| 160.0 | 3.25649 | 1.14503 | 3.74362 | 1.31631 | 4.31216 | 1.51622 | 4.97480 | 1.74921 | 5.72775 | 2.01396 |
| 170.0 | 3.27952 | 1.15313 | 3.80226 | 1.33693 | 4.42305 | 1.55521 | 5.16031 | 1.81443 | 6.01546 | 2.11512 |
| 180.0 | 3.28733 | 1.15587 | 3.82228 | 1.34397 | 4.46119 | 1.56862 | 5.22459 | 1.83704 | 6.11592 | 2.15044 |

## M = 8.0589

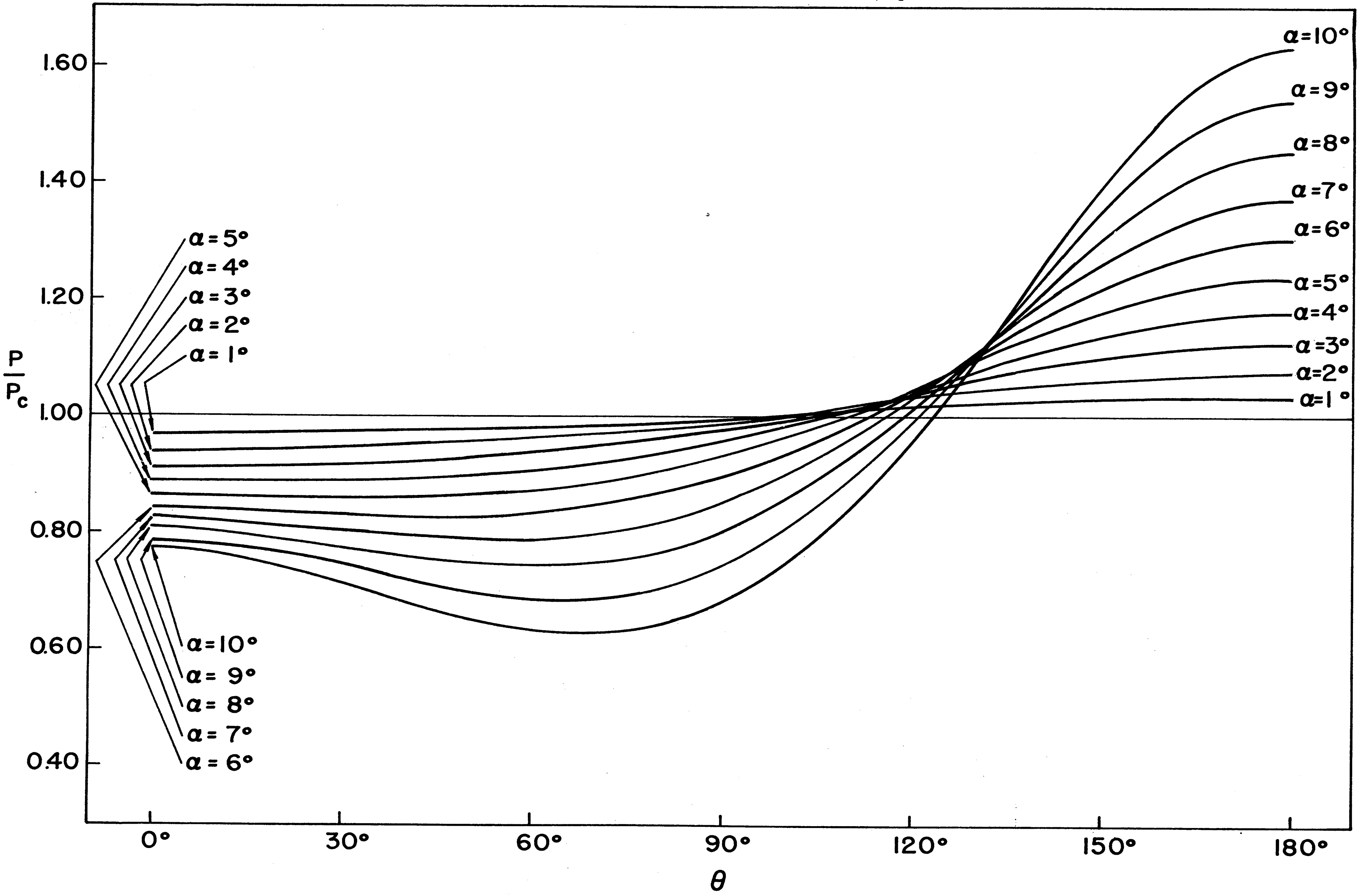
| $\theta^\circ$ | $\alpha = 6°$ $P/P_a$ | $\alpha = 6°$ $P/P_c$ | $\alpha = 7°$ $P/P_a$ | $\alpha = 7°$ $P/P_c$ | $\alpha = 8°$ $P/P_a$ | $\alpha = 8°$ $P/P_c$ | $\alpha = 9°$ $P/P_a$ | $\alpha = 9°$ $P/P_c$ | $\alpha = 10°$ $P/P_a$ | $\alpha = 10°$ $P/P_c$ |
|---|---|---|---|---|---|---|---|---|---|---|
| 0.0 | 1.08842 | 0.38270 | 0.91492 | 0.32170 | 0.76819 | 0.27011 | 0.64600 | 0.22714 | 0.54500 | 0.19163 |
| 10.0 | 1.09033 | 0.38338 | 0.91313 | 0.32107 | 0.76237 | 0.26806 | 0.63609 | 0.22366 | 0.53108 | 0.18673 |
| 20.0 | 1.09774 | 0.38598 | 0.90993 | 0.31994 | 0.74771 | 0.26291 | 0.61007 | 0.21451 | 0.49423 | 0.17378 |
| 30.0 | 1.11546 | 0.39221 | 0.91147 | 0.32048 | 0.73199 | 0.25738 | 0.57775 | 0.20315 | 0.44699 | 0.15717 |
| 40.0 | 1.15105 | 0.40473 | 0.92706 | 0.32597 | 0.72630 | 0.25538 | 0.55215 | 0.19414 | 0.40458 | 0.14226 |
| 50.0 | 1.21448 | 0.42703 | 0.96856 | 0.34056 | 0.74384 | 0.26154 | 0.54719 | 0.19240 | 0.38110 | 0.13400 |
| 60.0 | 1.31795 | 0.46341 | 1.05038 | 0.36933 | 0.80003 | 0.28130 | 0.57784 | 0.20318 | 0.38954 | 0.13697 |
| 70.0 | 1.47604 | 0.51900 | 1.19032 | 0.41853 | 0.91432 | 0.32149 | 0.66307 | 0.23314 | 0.44611 | 0.15686 |
| 80.0 | 1.70560 | 0.59971 | 1.41063 | 0.49600 | 1.11305 | 0.39136 | 0.83099 | 0.29219 | 0.57787 | 0.20319 |
| 90.0 | 2.02488 | 0.71197 | 1.73833 | 0.61122 | 1.43193 | 0.50349 | 1.12449 | 0.39539 | 0.83215 | 0.29260 |
| 100.0 | 2.45088 | 0.86176 | 2.20299 | 0.77460 | 1.91551 | 0.67352 | 1.60402 | 0.56400 | 1.28462 | 0.45169 |
| 110.0 | 2.99452 | 1.05291 | 2.83038 | 0.99520 | 2.61042 | 0.91786 | 2.34231 | 0.82359 | 2.03836 | 0.71671 |
| 120.0 | 3.65346 | 1.28461 | 3.63136 | 1.27684 | 3.54965 | 1.24811 | 3.40467 | 1.19713 | 3.20232 | 1.12598 |
| 130.0 | 4.40439 | 1.54864 | 4.58746 | 1.61301 | 4.72878 | 1.66271 | 4.81332 | 1.69243 | 4.84172 | 1.70242 |
| 140.0 | 5.19774 | 1.82760 | 5.63850 | 1.98257 | 6.08162 | 2.13838 | 6.50479 | 2.28717 | 6.90959 | 2.42951 |
| 150.0 | 5.95860 | 2.09513 | 6.67961 | 2.34864 | 7.46850 | 2.62603 | 8.30250 | 2.91927 | 9.19284 | 3.23233 |
| 160.0 | 6.59637 | 2.31937 | 7.57391 | 2.66309 | 8.69089 | 3.05584 | 9.92973 | 3.49143 | 11.31771 | 3.97946 |
| 170.0 | 7.02269 | 2.46928 | 8.18160 | 2.87676 | 9.53583 | 3.35293 | 11.07435 | 3.89389 | 12.83956 | 4.51456 |
| 180.0 | 7.17276 | 2.52204 | 8.39727 | 2.95260 | 9.83827 | 3.45927 | 11.48763 | 4.03921 | 13.39392 | 4.70949 |

YAWED TO NON-YAWED PRESSURE RATIO $P/P_c$ M=2.0108

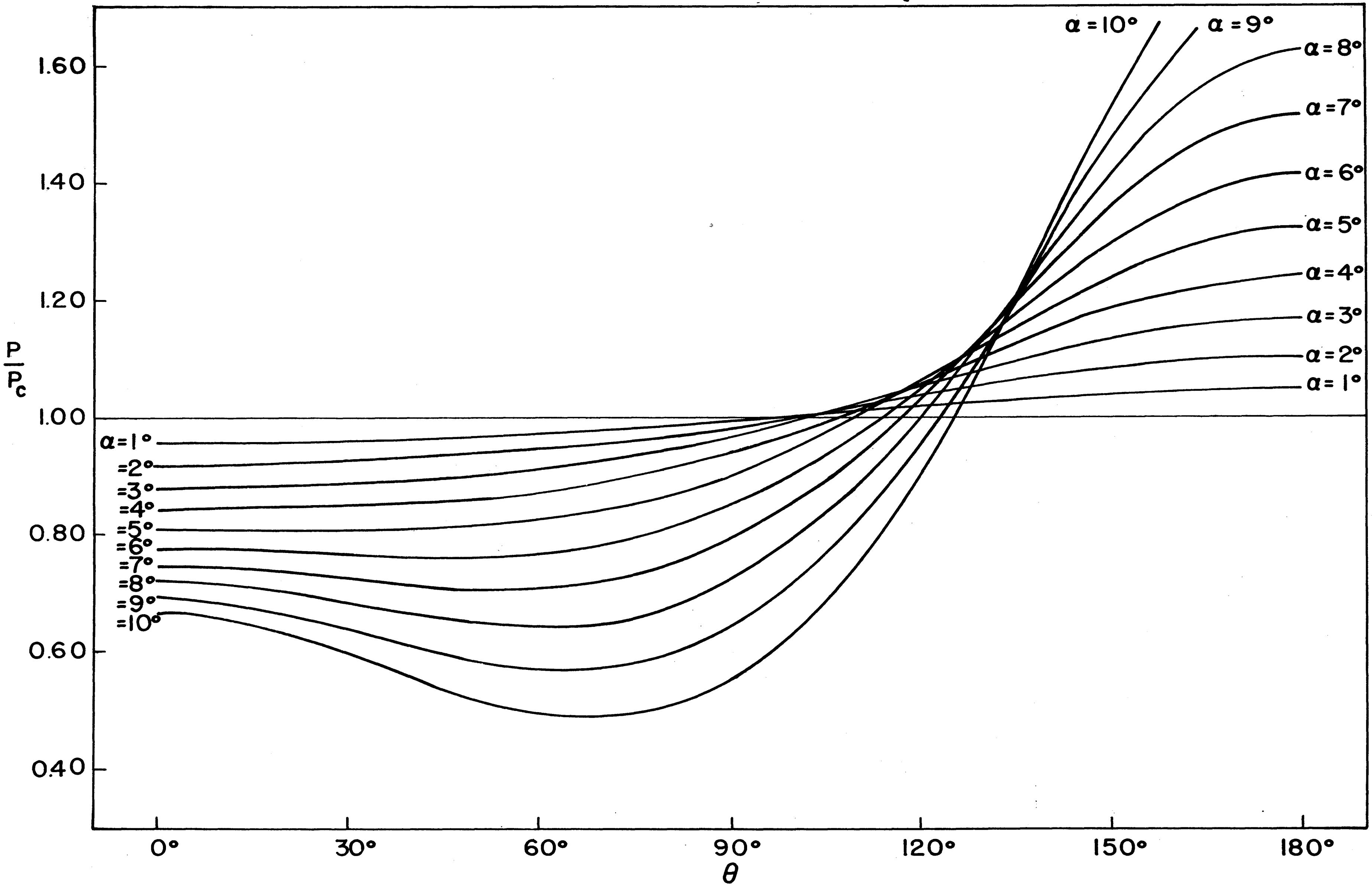



YAWED TO NON-YAWED PRESSURE RATIO P/P$_c$  M=2.3105
α = 10°
= 9°
= 8°
= 7°
= 6°
= 5°
= 4°
= 3°
= 2°
= 1°
α = 4°
α = 3°
α = 2°
α = 1°
α = 8°
α = 7°
α = 6°
α = 5°
α = 9°
α = 10°
P/P$_c$
1.60
1.40
1.20
1.00
0.80
0.60
0.50
0°
30°
60°
90°
θ
120°
150°
180°

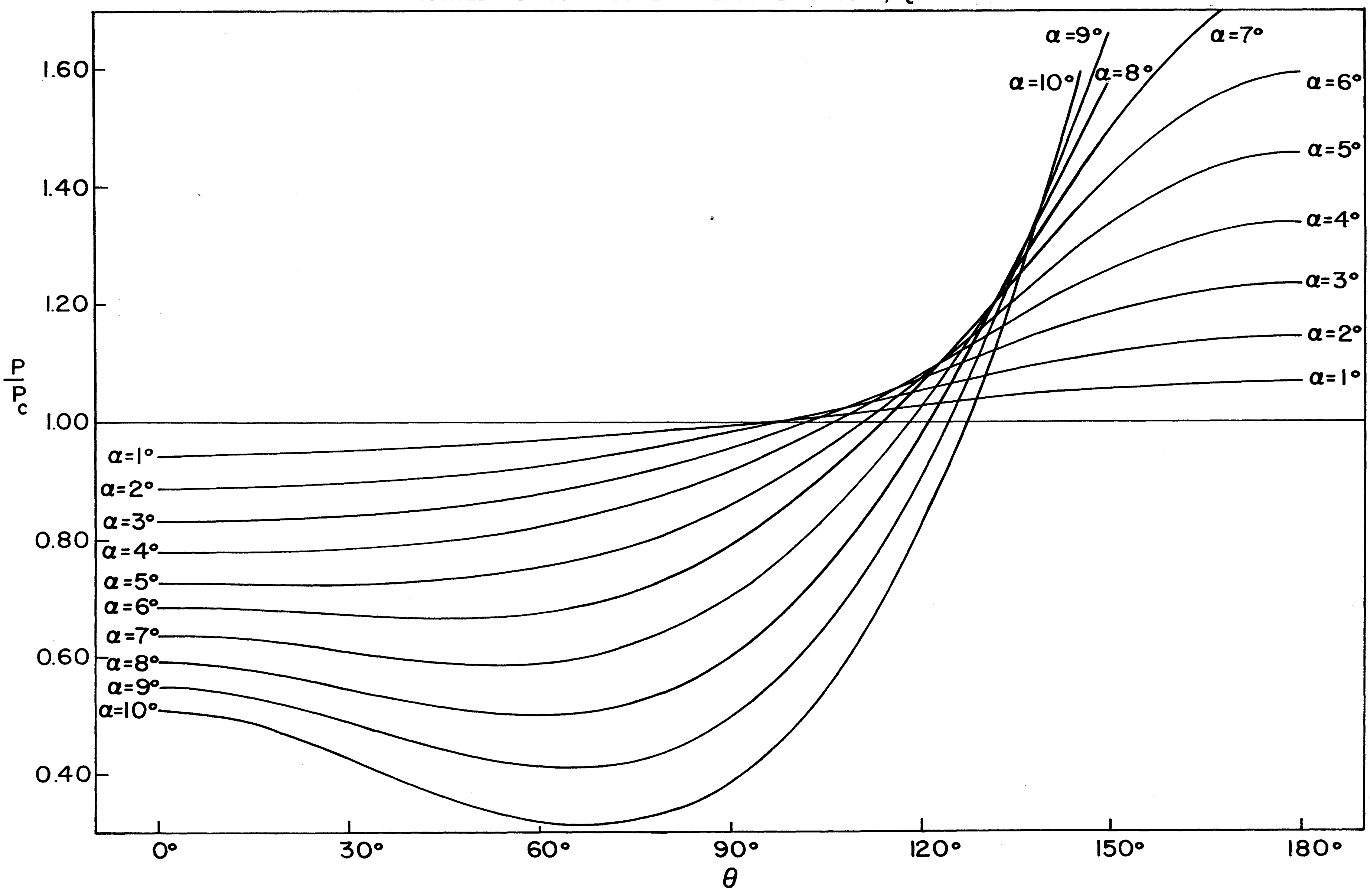
YAWED TO NON-YAWED PRESSURE RATIO $P/P_c$ M= 2.6847

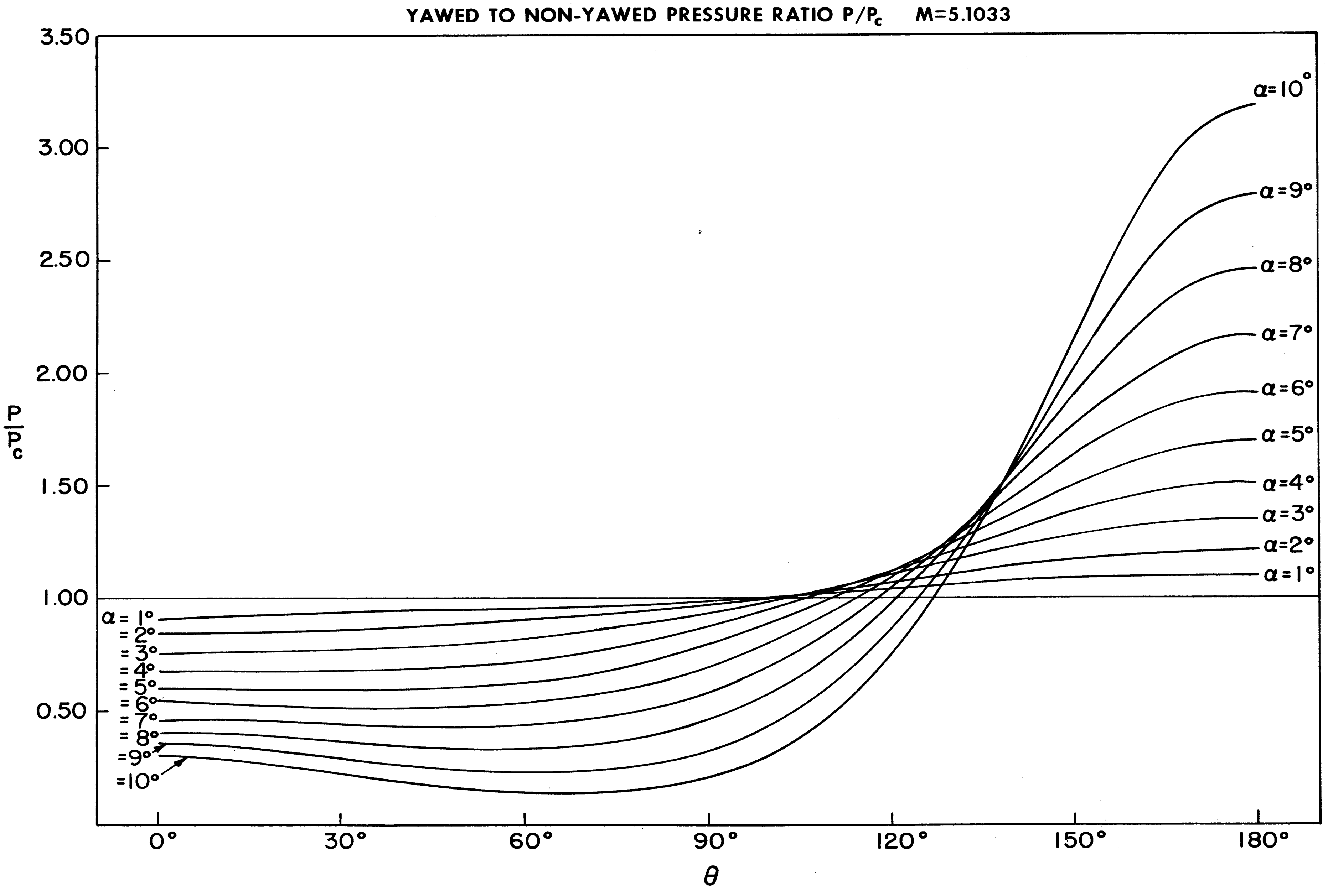


YAWED TO NON-YAWED PRESSURE RATIO $P/P_c$ $M=3.1795$



YAWED TO NON-YAWED PRESSURE RATIO $P/P_c$ $M = 3.8946$





YAWED TO NON-YAWED PRESSURE RATIO P/Pc M=5.1033
3.50
3.00
2.50
2.00
1.50
1.00
0.50
P/Pc
0°
30°
60°
90°
120°
150°
180°
θ
α=10°
α=9°
α=8°
α=7°
α=6°
α=5°
α=4°
α=3°
α=2°
α=1°
α= 1°
=2°
=3°
=4°
=5°
=6°
=7°
=8°
=9°
=10°

YAWED TO NON-YAWED PRESSURE RATIO $P/P_c$ M=8.0589