WYLE LABORATORIES - RESEARCH STAFF

TECHNICAL MEMORANDUM 66-39

DESIGN DETAILS FOR HELIUM HEATER

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FOREWORD

This memorandum contains three informal notes, that were originally issued in 1965 as RCP Notes 65-7, 65-9, and 65-10, and hand carried to the appropriate NASA personnel concerned with the design of the helium heater. They are now issued here for the record.

TABLE OF CONTENTS

LIST OF FIGURES

1.0 STATIC PRESSURES AT STATIC TAPPINGS ON HELIUM NOZZLES (RCP 65-7)

1.1 Introduction

The following calculations are designed to enable the location of the Static Pressure Taps on the helium flow nozzles be located at the best position for checking the nozzle flow. The initial locations given in the preliminary drawings (Reference 1) are midway between the exit and the throat. However, because of the expansion of the nozzle, the pressures here will be near atmospheric. A new location will be determined to allow better analysis of the nozzle flow.

1.2 Critical Dimensions from Drawings (Reference 1)

Mach Number Nozzle	Throat Radius	Exit Radius	Middle Point Radius
		Inches	
3.6	0.3546	0.7500	0.6977
3.0	0.4286	0.7500	0.7076
2.6	0.4960	0.7500	0.7209

Areas are proportional to $(\text{radius})^2$ called A^1

Mach Number	Throat A^1	Exit A^1	Middle A^1
3.6	0.126	0.562	0.486
3.0	0.184	0.562	0.500
2.6	0.246	0.562	0.520

From Reference 2, Page 19.

For isentropic fully expanded helium to 14.7 psi,

Reservoir pressure equals total pressure

$$po = 14.7\left[1 + 0.3\,M^2\right]^{2.667} \qquad (\gamma = 1.6)$$

From Reference 2, Page 18.

Throat static pressure equals the critical pressure

$$p^* = p_0 (0.77)^{2.667} = 0.50\ p_0$$

Nozzle Mach No.		3.6	3.0	2.6
Throat Static Pressure	p^*	487	241	142

1.3 1 Dimensional Flow Reference 2, Page 20

$\rho V a$ = constant mass flow

Put $$\theta = \frac{\rho V}{\rho^* V^*}$$

Then $A\theta$ = constant

$$\theta = M \left[\frac{\gamma + 1}{(\gamma - 1) M^2 + 2} \right]^{\frac{\gamma + 1}{2(\gamma - 1)}}$$

$$= M \left[\frac{2.6}{0.6 M^2 + 2} \right]^{2.16} \quad \text{for helium} \qquad (1.1)$$

At the throat $M = 1$

$$\theta = 1.0 \left[\frac{2.6}{2.6} \right]^{2.16} = 1.00$$ This applies to all Nozzles.

At exit Equation (1.1) gives

M	=	3.6	3.0	2.6
θ	=	0.209	0.315	0.421

		← Throat →			← Exit →			$\frac{\theta A^1 \text{ Exit}}{\theta A^1 \text{ Throat}}$
Nozzle M	θ	A^1	θA^1	θ	A^1	θA^1	
3.6	1.0	0.126	0.126	0.209	0.562	0.117	0.93
3.0	1.0	0.184	0.184	0.315	0.562	0.177	0.962
2.6	1.0	0.246	0.246	0.421	0.562	0.236	0.960

The difference in θA^1 at the exit and throat is because the nozzle flow is not one dimensional in practice. The correct computer calculations for the nozzle allow for two dimensional flow and the boundary layer. However, the above calculations show that the one dimensional approximation is not too great in error.

We guess

M	3.6	3.0	2.6
$\frac{\theta A^1 \text{ mid}}{\theta A^1 \text{ throat}}$	0.97	0.98	0.98

Hence from Figure 1

Nozzle Mach No.	3.6	3.0	2.6
Middle Mach No.	3.3	2.8	2.45

1.4 Static Pressures

$$\frac{p}{p_0} = \left[\frac{2}{(\gamma - 1) M^2 + 2} \right]^{\gamma/\gamma - 1}$$

$$p = \left[p_0 \frac{2}{0.6 M^2 + 2} \right]^{2.667} \qquad (1.2)$$

Which gives the pressures at the proposed ports.

Mach Number of Nozzle	Throat	Middle psi	Exit
3.6	487	20.9	14.7
3.0	241	19.3	14.7
2.6	142	18.2	14.7

1.5 New Location of Ports

These pressures at the middle ports are low. Let us try and reposition these middle ports to give the following higher pressures

Mach Number of Nozzle	Required Middle Port Pressure psi
3.6	70
3.0	50
2.6	40

$$\frac{p}{p_0} = \left[\frac{2}{0.6\,M^2 + 2}\right]^{2.667} \tag{1.3}$$

$$\left(\frac{p}{p_0}\right)^{1/2.667} = \frac{2}{0.6\,M^2 + 2}$$

$$M^2 = \left[\frac{2}{\left(\frac{p}{p_0}\right)^{0.375}} - 1\right] \times 1.667 \tag{1.4}$$

which gives the following results for the location of the taps.

Nozzle Mach Number	Mach Number at Intermediate	A^1 Intermediate	Distance from Exit x inches
3.6	2.71	0.317	3.545
3.0	2.48	0.394	2.174
2.6	2.29	0.422	2.480

1.6 Concluding Remark

It is recommended that the static pressure ports be placed at the distances given in the above table. This will allow higher pressures than for the proposed tips, and enable better control of the nozzle flow to be attained.

2.0 POSITIONING OF TOTAL HEAD PROBES IN RAKE (RCP 65-9)

2.1 Background

In order to measure the total pressure and the composition of the helium jet, it will be necessary to use fixed rakes of pitot tubes. These will be operated in conjunction with a single transducer using a scanner valve. The tubes will have to be positioned very close together, because of the narrow mixing regions and the limiting sizes of the tubes. Thus, a neighboring tube will probably affect the flow to a given tube, and will reduce the accuracy of the measurements. This note is a short study of this problem.

2.2 Results in Reference 3

In Reference 3, a rake of pitot tubes were operated in a wind tunnel flow at $M = 1.60$.

The conclusions of the experiment were:

a) At Mach 1.60, the tube gap should be at least 1 diameter or more, for near interference - free conditions.

b) If the rake is operated with the tubes touching, then the readings of the two end tubes must be ignored. The errors in the pressure readings of the other tubes will be small, but difficult to assess.

c) The ratio of the tube external diameter to the orifice diameter, N, has a definite effect on the pressure readings of the end tube. Sharp edged tubes ($N \rightarrow 1.0$) appear to give the best results. (Least error.)

2.3 Reasons for Inaccuracies

This point is not brought out by Reference 3. However, examination of the Schlieren pictures presented shows that the irregularities caused in the bow shock wave appear to be the main reason for errors. When the tubes are together, one large wave, which bows from the center of the rake, is formed. When the tubes are spaced out, with 1 diameter between them, then the bow shock wave is wavy, but apparently is normal to the flow immediately in front of all the tubes. See Figure 2.

2.4 Recommended Action

It appears that the tubes should be spaced out and the walls made as thin as possible. One such design for thin walls at the entrance is shown in Figure 3a. It is not possible to position sufficient tubes in the required distance for positions near the nozzle exit, then the tubes should be placed together, such as shown in Figure 3b. The results of Reference 3 indicate that the regions between the tubes should not be filled to make a solid slab, since this increases the possible error. The readings from the end tubes must be ignored in this case, and the results from the other tubes cannot be considered as too reliable.

This analysis was for supersonic flow, but the same considerations will exist in the subsonic parts of the flow.

3.0 USE OF THE HELIUM NOZZLESTO FLOW AIR (RCP 65-10)

3.1 Objective

To examine existing helium nozzles, to determine if one is suitable for flowing air through. The airflow will be used to check out the facility and the instrumentation. It is required to produce a steady uniform flow, and since the contours of the nozzle are changing very slowly, it should be possible to operate the nozzles with air.

3.2 Critical Dimensions (Reference 1)

Helium Nozzle Mach Number	Exit Dia. (in.)	Throat Dia. (in.)	Exit Area ($in.^2$)	Throat Area ($in.^2$)
2.6	1.5	0.9920	1.718	0.773
3.0	1.5	0.8572	1.718	0.577
3.6	1.5	0.7092	1.718	0.395

3.3 One Dimensional Flow (Reference 2, Page 20)

$$\rho V A = \text{constant mass flow}$$

Put $\frac{\rho V}{\rho^* V^*}$ where $*$ refers to a critical conditions, which occur at throat.

Then $A\theta$ = constant

At throat $M = 1.0, \quad \theta = 1.0$

$$\theta = M\left[\frac{\gamma + 1}{(\gamma - 1)M^2 + 2}\right]^{\gamma + 1/2(\gamma - 1)}$$

$$= M\left[\frac{2.4}{0.4M^2 + 2}\right]^3$$

for air, since $\gamma = 1.4$

This function is plotted in Figure 4.

At the throat	$A\theta$	Helium Nozzle Mach Number
	0.773	3.6
	0.577	3.0
	0.395	2.6

At the exit the same value of $A\theta$ applies for 1 dimensional isentropic flow. (Expansion). This flow will approximate to the actual three-dimensional flow of the real nozzle, but calculations in Section 1.0 show that the error is only slight for these Helium nozzles.

Helium Nozzle Mach Number	$A\theta$	A	θ	Mach Number With Air
3.6	0.395	1.718	0.229	3.02
3.0	0.577	1.718	0.336	2.63
2.6	0.776	1.718	0.452	2.32

3.4 Total Pressure Required, (Reservoir Pressure)

$$p_0 = 14.7 \left[\frac{0.4\,M^2 + 2}{2}\right]^{3.5}$$

$$= 14.7 \left[1 + 0.2\,M^2\right]^{3.5}$$

Helium Nozzle Mach Number	Mach Number With Air	Reservoir Pressure psi
3.6	3.02	554
3.0	2.63	308
2.6	2.32	187

3.5 Concluding Remarks

In view of the heater requirement to operate at reasonable high pressures to get the best control, it is recommended that the Helium Mach 3.6 nozzle be used with a hot air flow to check instruments. A reservoir pressure of 554 psi is needed for a complete expansion to the atmospheric pressure, and this produces an exit Mach number of 3.02.

Because of the gradual change in cross-sectional area of the Helium nozzle, (the nozzle is very long), it is concluded that a clean shock free flow should be created.

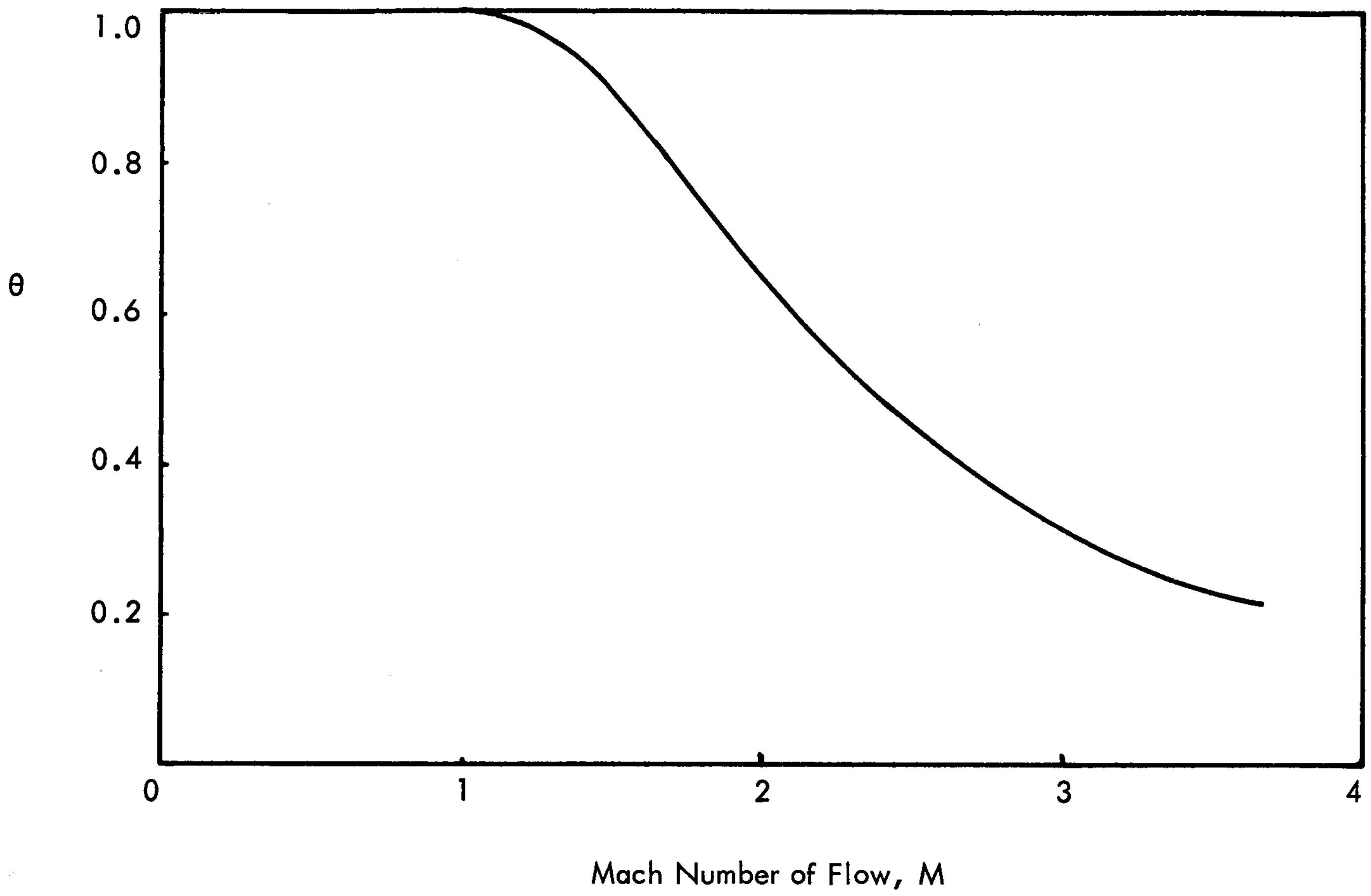
REFERENCES

1. Marshall Space Flight Center Preliminary Drawings of Helium Nozzles.

   80 M 50763
   80 M 50759
   80 M 50762

2. Miles, E.R.C., "Supersonic Aerodynamics", Dover Publ., 1961.

3. Quincy, U.G. and Cullinan, J., "Experiments with a Pitot Rake at M = 1.5", Jour. Roy. Aero. Soc., Vol. 67, p. 793, 1963.



Plot of $\theta = \frac{\rho V}{\rho^* V^*}$ against M,

$$\theta = M\left[\frac{2.6}{0.6M^2 + 2}\right]^{2.16}$$

for Helium, $\gamma = 1.6$

Figure 1. Function θ .

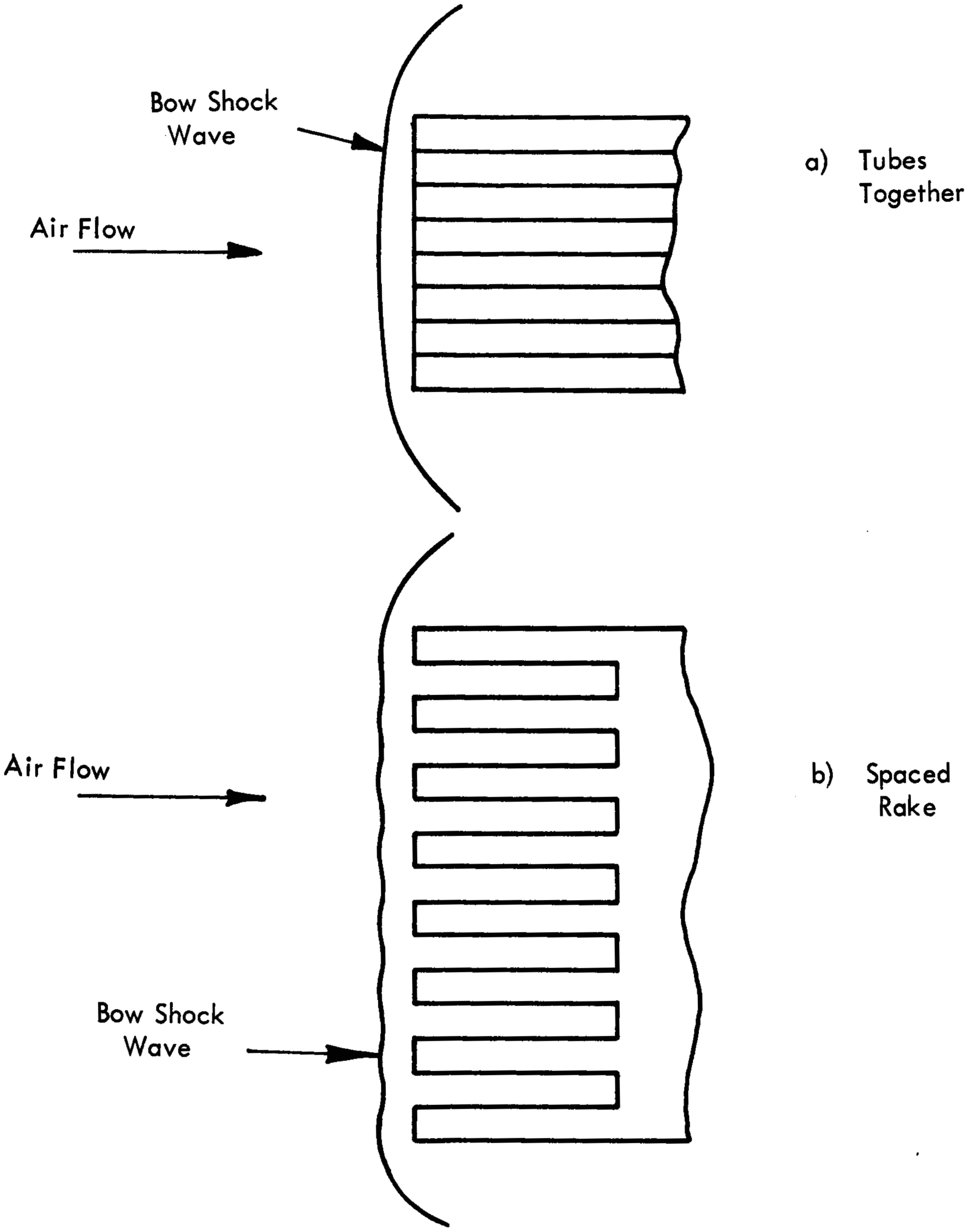


Figure 2. Shock Waves for Spaced and Unspaced Rakes, from Reference 3.

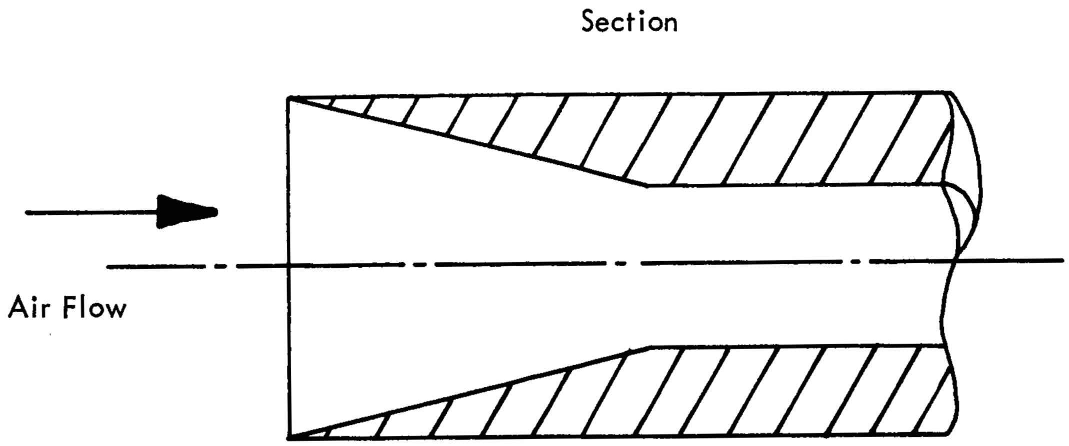


Figure 3a. Pitot Tube with Sharp Inlet.

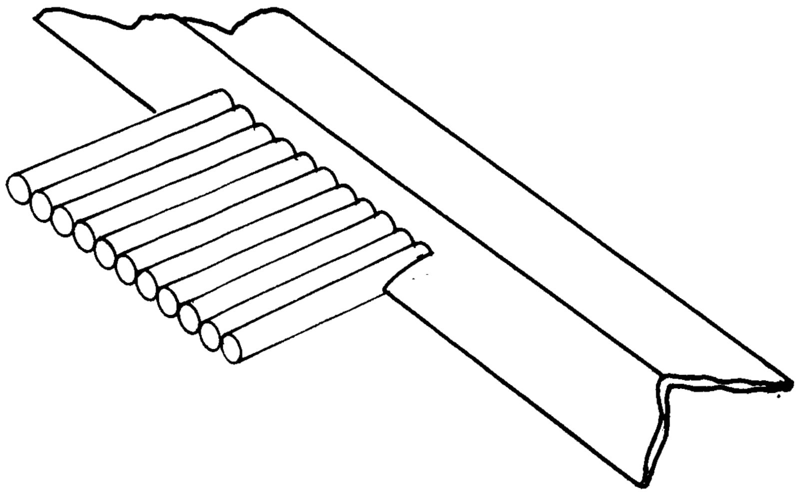
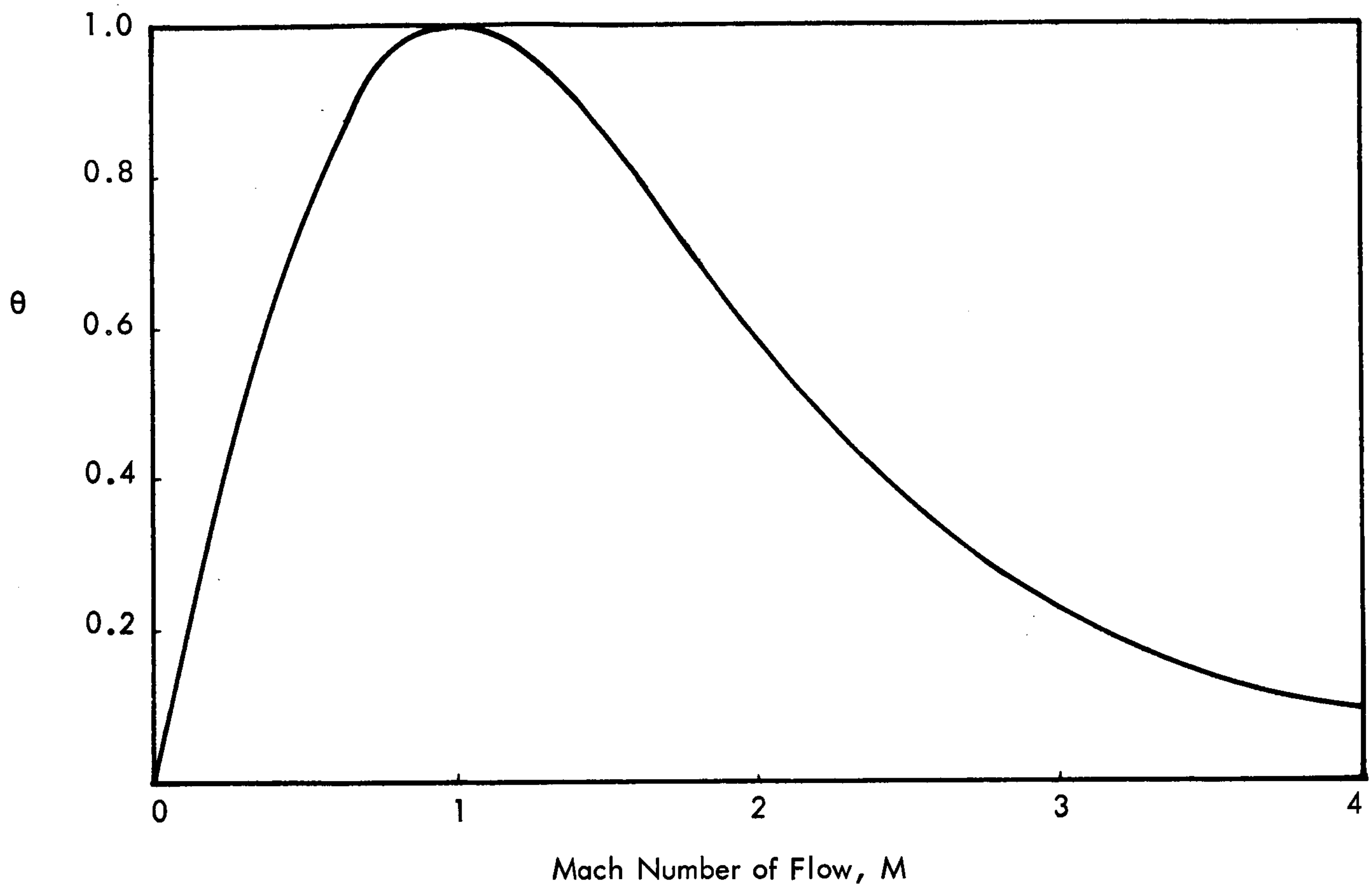


Figure 3b. Close Spacing Rake



Plot of $\theta = \frac{\rho V}{\rho^* V^*}$ against M

$$\theta = M\left[\frac{2.4}{0.4\,M^2 + 2}\right]^3$$

For Air, $\gamma = 1.4$

Figure 4. Function θ, Values from Reference 2, Page 21.