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Test Section Conditions for the Tailored Interface Hypersonic Shock Tunnel

Appendix to H.I.C. No.83 1966

by

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Test Section Conditions for the Tailored Interface Hypersonic Shock Tunnel

Appendix to H.I.C. No.83 1966.

Introduction

This report contains calculated conditions expected in the test section of the Sheffield University Shock Tunnel.

The driver gases used are either cold hydrogen or a mixture of hydrogen oxygen and helium ignited behind the primary diaphragm. Cold hydrogen "Tailors" at a primary shock Mach number of 6 and the helium mixture used at about 12. The report therefore deals with the primary shock Mach number ranges from 5 to 9 and from 9 to 14 to cover both these cases.

The air in the stagnation region is expanded to test section Mach numbers of 3,4 or 5 depending on the nozzle attached.

Symbols used

P	=	pressure	T	=	temperature
h	=	enthalpy	a	=	sound speed
u	=	velocity			
Ms	=	primary shock Mach number.			
Mt	=	test section Mach number.			
Subscript T	=	test section values.			
Subscript 5	=	Stagnation region values			

Method of Calculation

Assumptions made

(i) The expansion through the nozzles from state 5 to state T is assumed isentropic when using Mollier data

(ii) Feldman charts for air were used to obtain values of h_5 P_5 T_5.

(iii) The enthalpy in region 5 appears in region T as

$$h_T + \frac{1}{2} U_T^2 = h_5$$

Method

(i) Find values of h_5 P_5 T_5 using the required conditions P_1 T_1 M_s

(ii) From $h_T + \frac{1}{2} U_T^2 = h_5$

$$h_T = h_5 - \frac{1}{2} (Ma)^2 \qquad \text{......(A)}$$

∴ Assume a value of "a" and substitute this in (A) hence calculate h_T.

(iii) Using P_5T_5 expand isentropicly on a Mollier chart to h_T.

(iv) Check whether the value of "a" assumed equals the value of "a" at h_T.

(v) Repeat the above until the "a" assumed to calculate h_T equals the "a" at h_T on the chart.

When this is so read off values of $h_TP_TT_T$.

Using the above method values of h_TP_T and T_T were obtained for various primary shock Mach numbers using 3 different values of P_1. The primary shock Mach numbers used include the tailoring Mach numbers for hydrogen and hot lhelium as used at Sheffield.

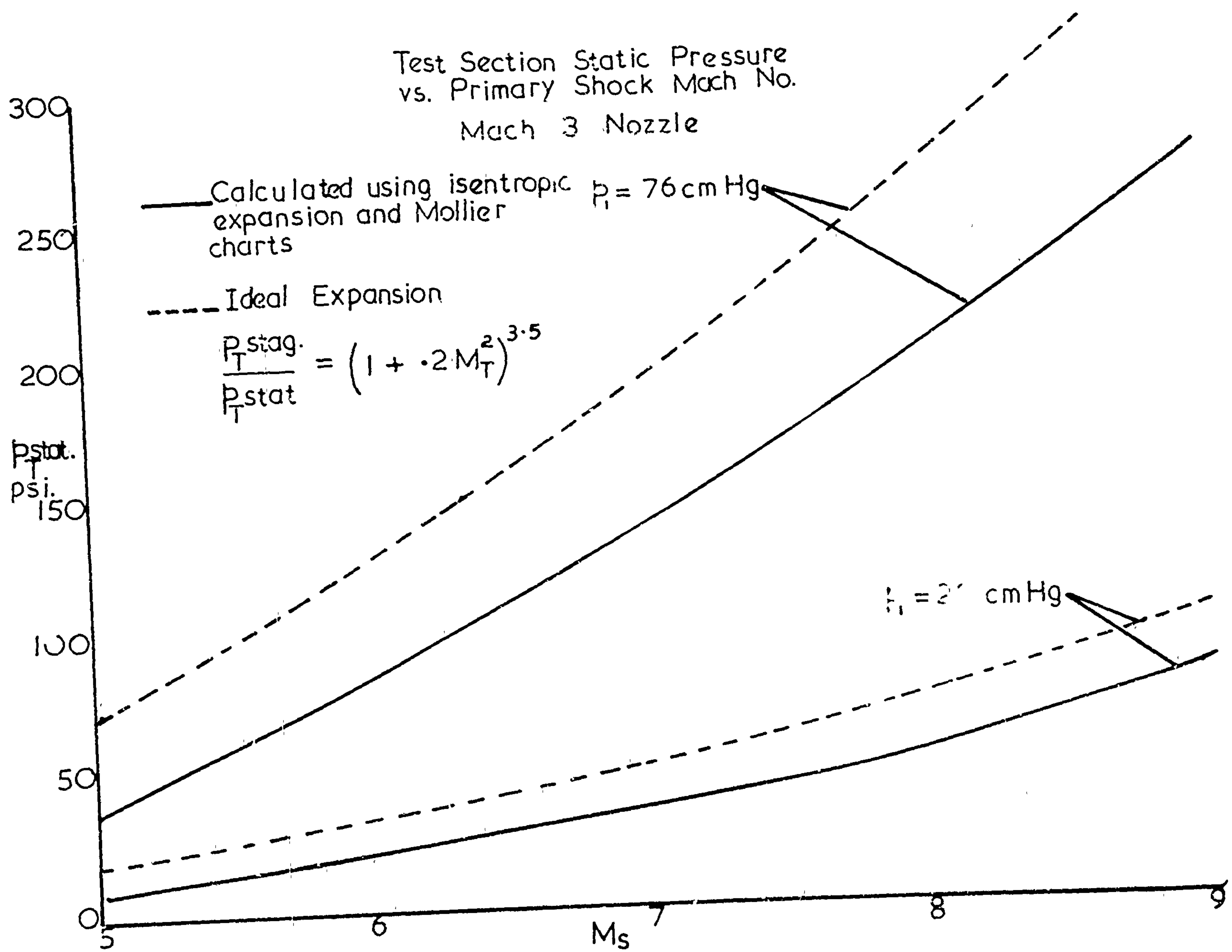
Included on the graphs of P_T and T_T are values calculated assuming ideal gas with $\gamma = 1.4$. Assuming this,

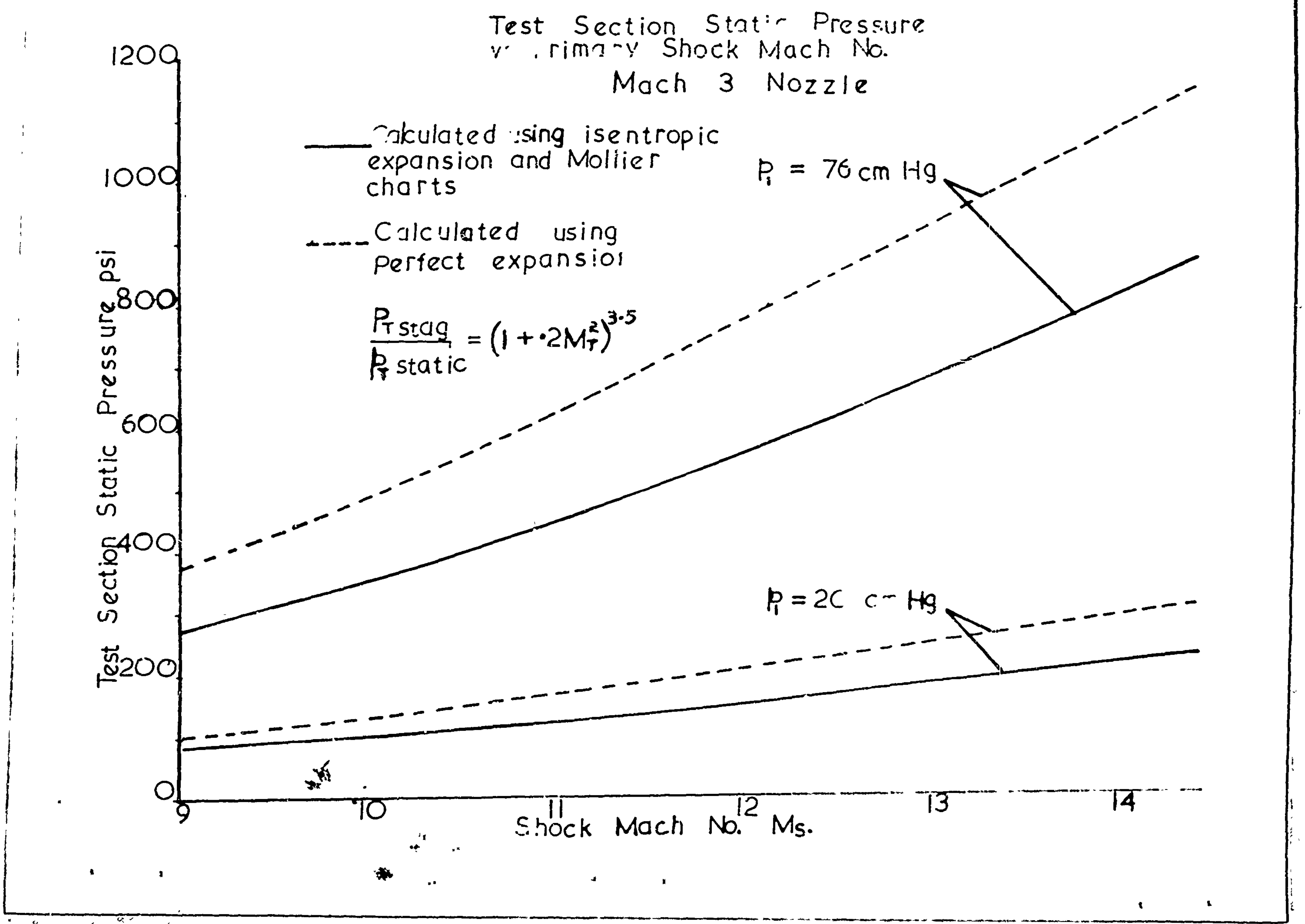
For static temperature $$T_T = \frac{h_5}{RT_o} \quad \frac{1}{3.5(1+0.2M_T^2)} \; T_o$$

and for static pressure $$P_T = \frac{P_5}{(1+0.2M_T^2)^{3.5}}$$

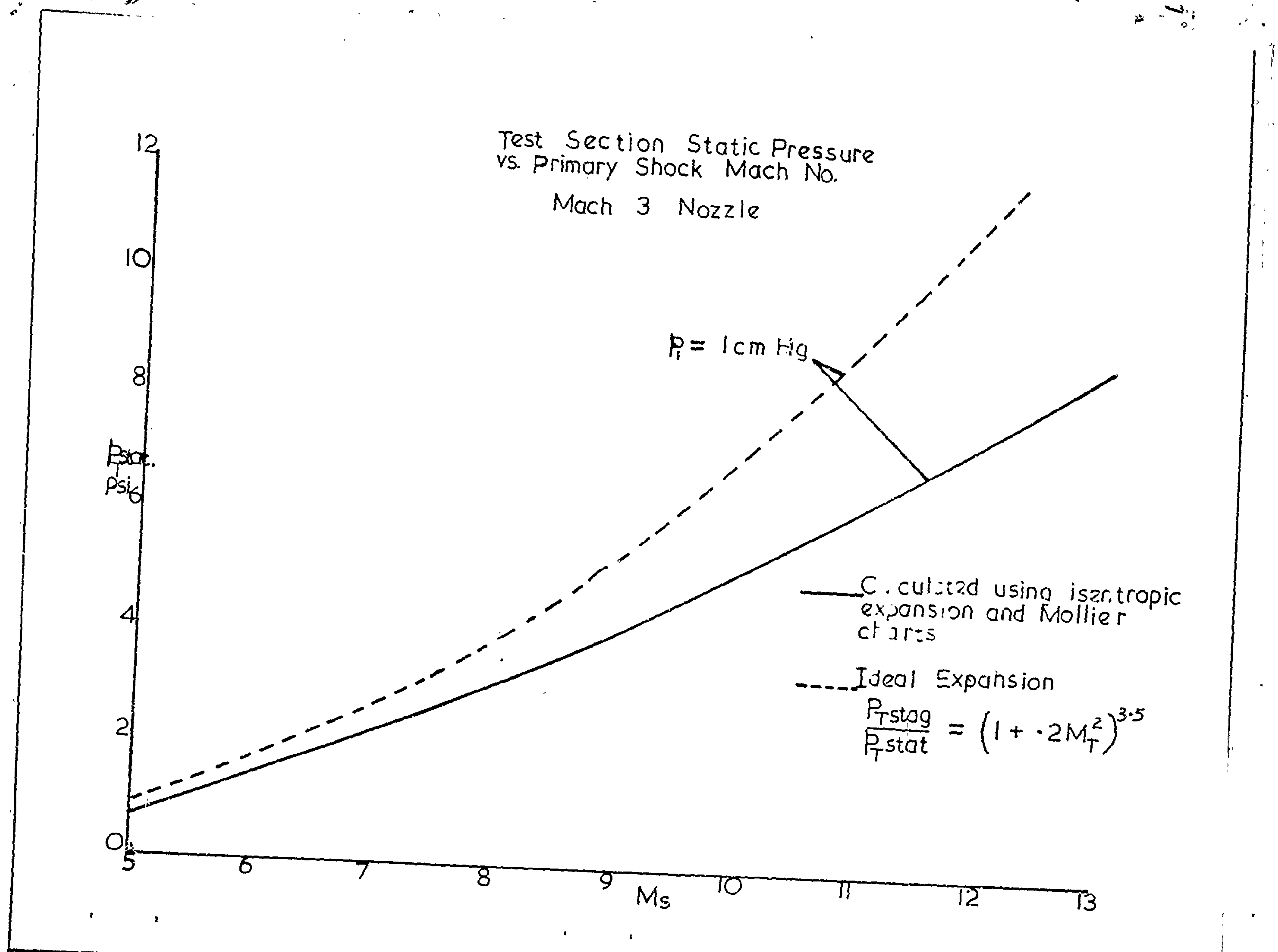
From the graphs it can be seen that these assumptions are only valid at the lower primary shock Mach numbers i.e. when the temperature is less than about 2000°K.

It is proposed to obtain practical values by using static pressure probes and sodium double beam reversal methods.

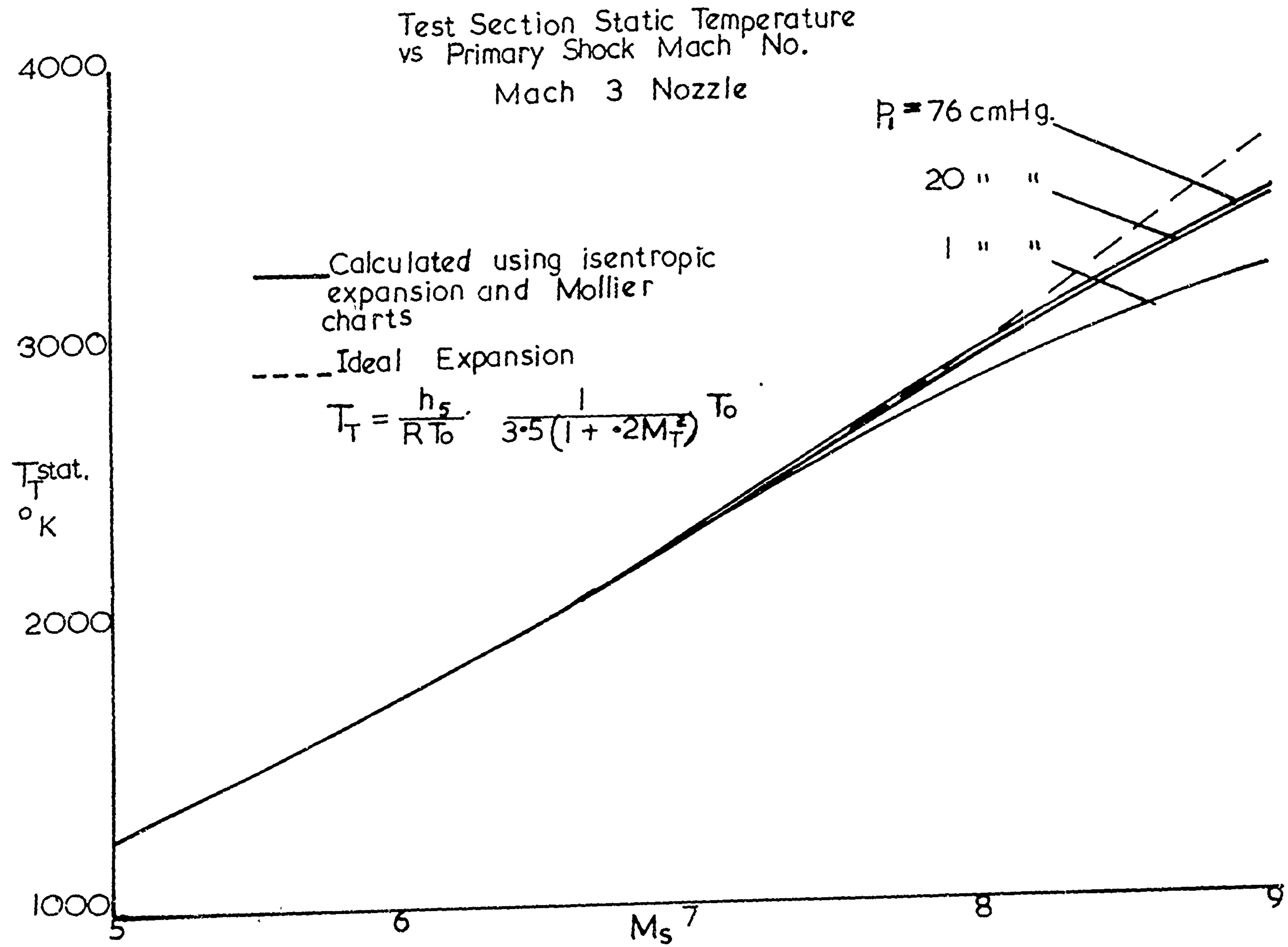

Test Section Static Pressure
vs. Primary Shock Mach No.
Mach 3 Nozzle
Calculated using isentropic expansion and Mollier charts
$p_1 = 76$ cm Hg
Ideal Expansion
$\frac{P_T^{stag.}}{P_T^{stat}} = (1 + \cdot 2 M_T^2)^{3\cdot5}$
cm Hg
$P_T^{stat.}$ psi.
300
250
200
150
100
50
0
5
6
7
8
9
M_s

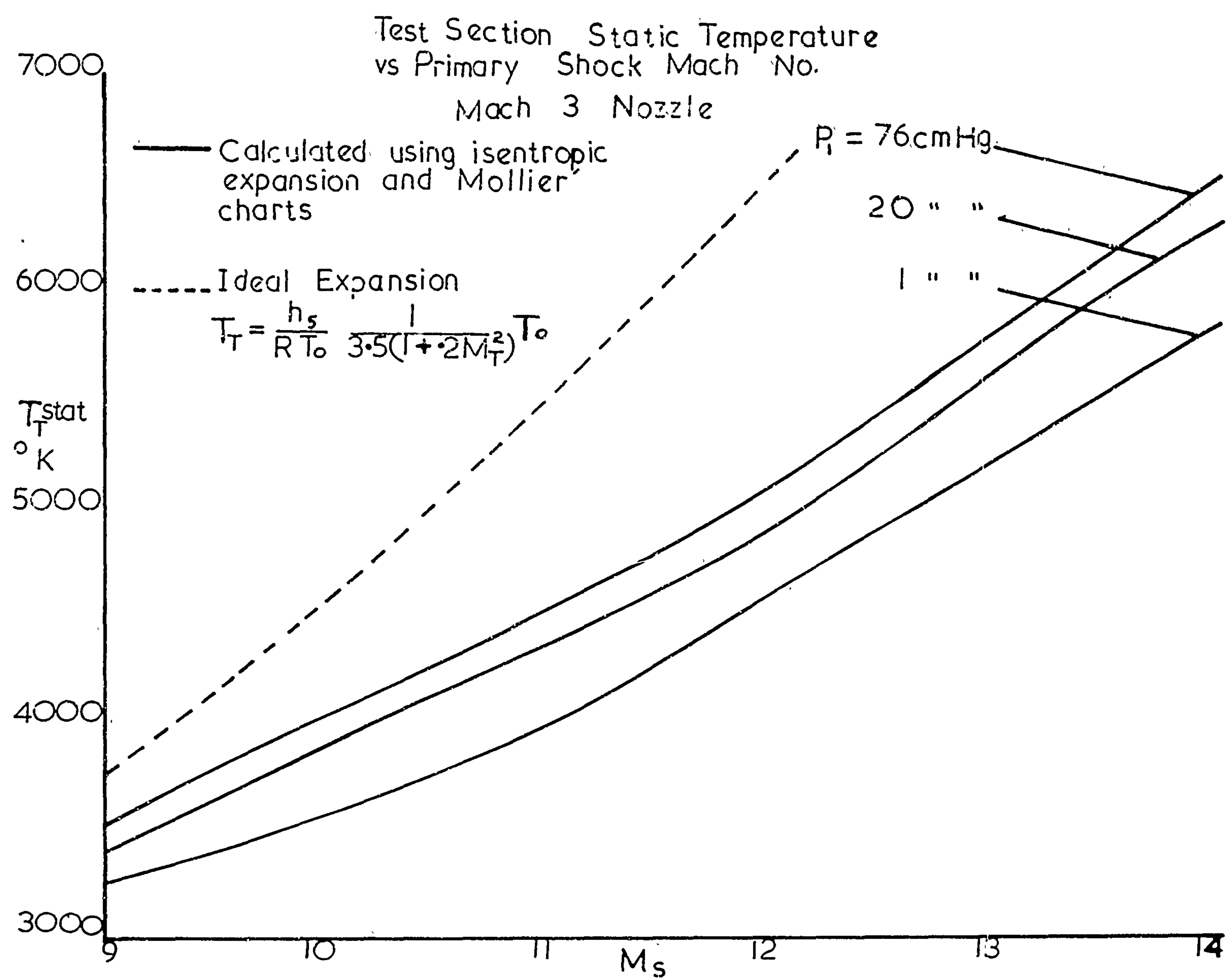


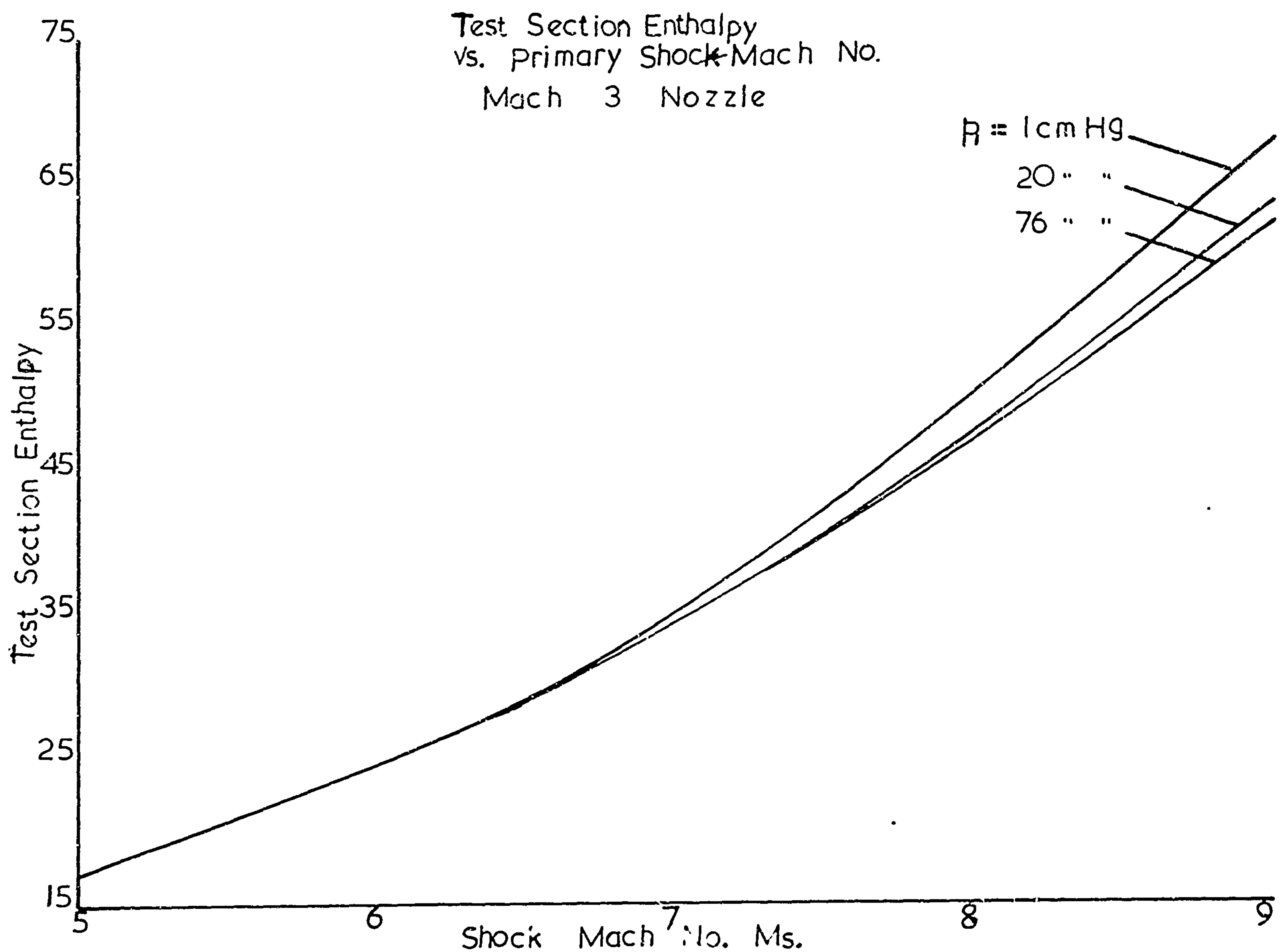
Test Section Static Pressure
vs Primary Shock Mach No.
Mach 3 Nozzle
Calculated using isentropic expansion and Mollier charts
Calculated using perfect expansion
$\frac{P_{T\,stag}}{P_T\,static} = (1 + \cdot 2M_T^2)^{3\cdot 5}$
P_1 = 76 cm Hg
P_1 = 20 cm Hg
Test Section Static Pressure psi
1200
1000
800
600
400
200
0
9
10
11
12
13
14
Shock Mach No. Ms.



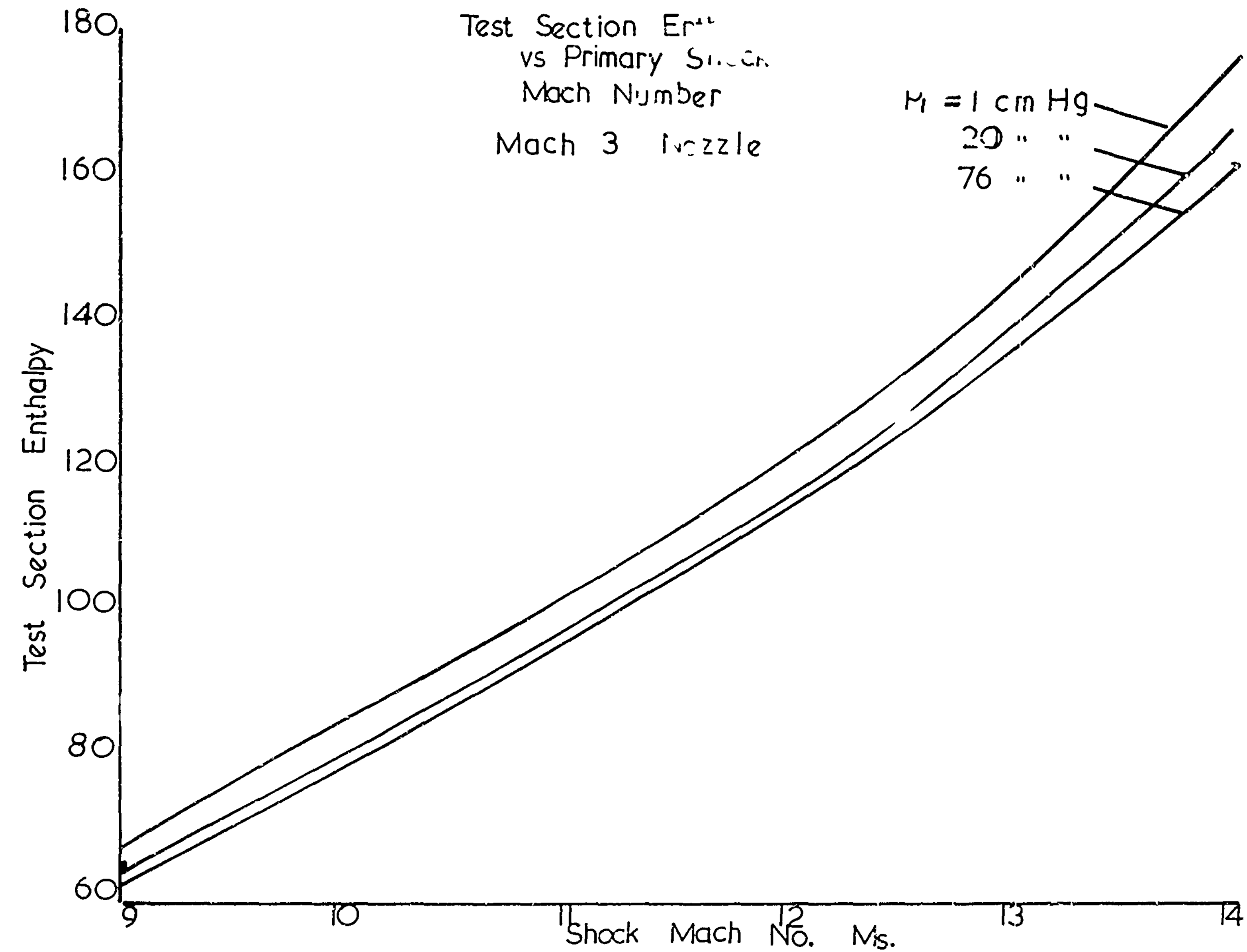
Test Section Static Pressure
vs. Primary Shock Mach No.
Mach 3 Nozzle
P_1 = 1cm Hg
C. culated using isentropic expansion and Mollier charts
Ideal Expansion
$\frac{P_{T stag}}{P_{T stat}} = (1 + .2M_T^2)^{3.5}$
$P_{T stat}$ psi
Ms
0
2
4
6
8
10
12
5
6
7
8
9
10
11
12
13

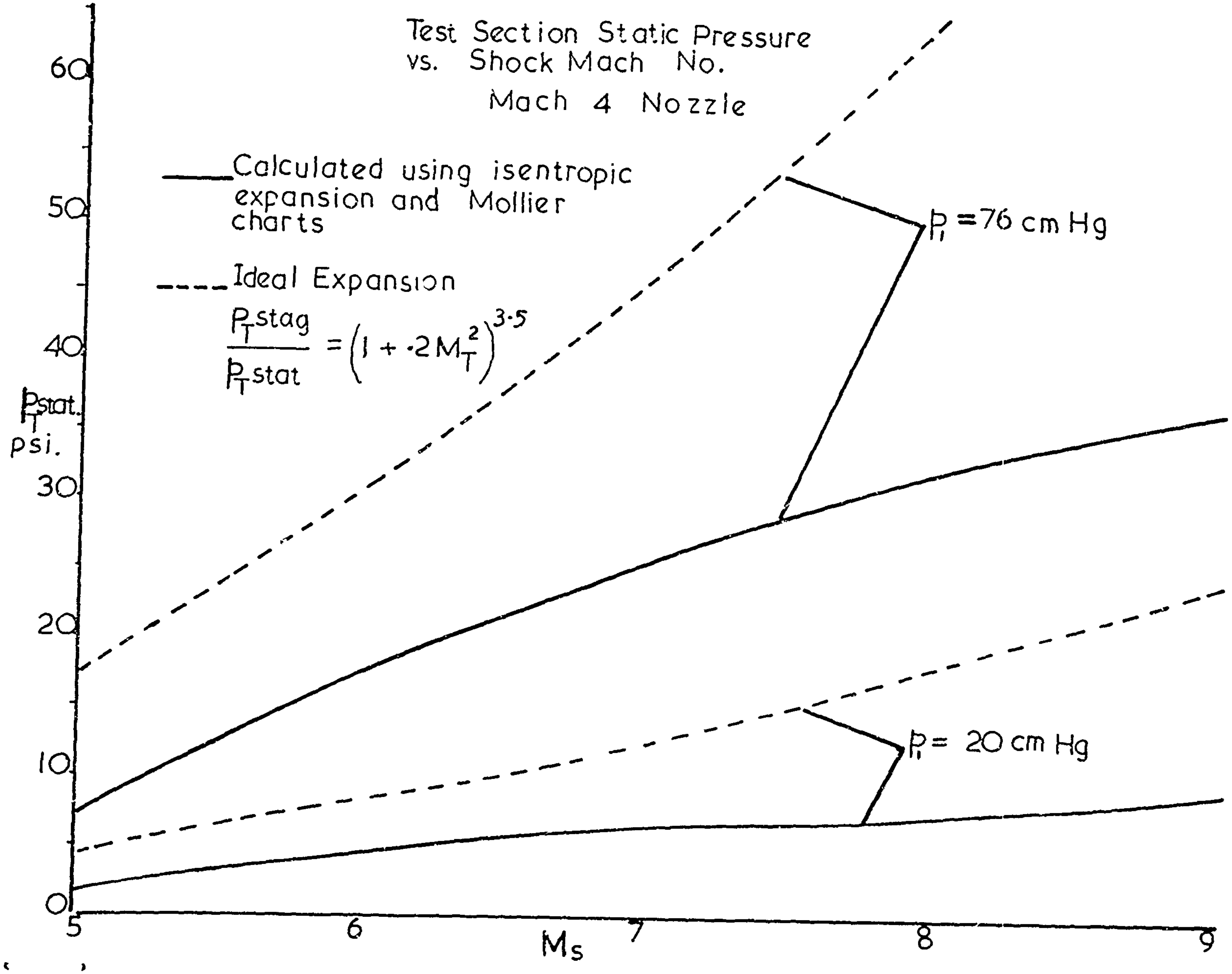

Test Section Static Temperature
vs Primary Shock Mach No.
Mach 3 Nozzle
P_1 = 76 cmHg.
20 " "
1 " "
Calculated using isentropic expansion and Mollier charts
Ideal Expansion
$T_T = \frac{h_s}{R T_o} \cdot \frac{1}{3{\cdot}5(1 + {\cdot}2M_T^2)} T_o$
$T_T^{stat.}$ °K
4000
3000
2000
1000
5
6
7
8
9
M_s


Test Section Static Temperature
vs Primary Shock Mach No.
Mach 3 Nozzle
Calculated using isentropic expansion and Mollier charts
Ideal Expansion
$T_T = \frac{h_s}{R T_o} \frac{1}{3{\cdot}5(1+{\cdot}2M_T^2)} T_o$
P_1 = 76cmHg.
20 " "
1 " "
T_T^{stat} °K
7000
6000
5000
4000
3000
9
10
11
12
13
14
M_s

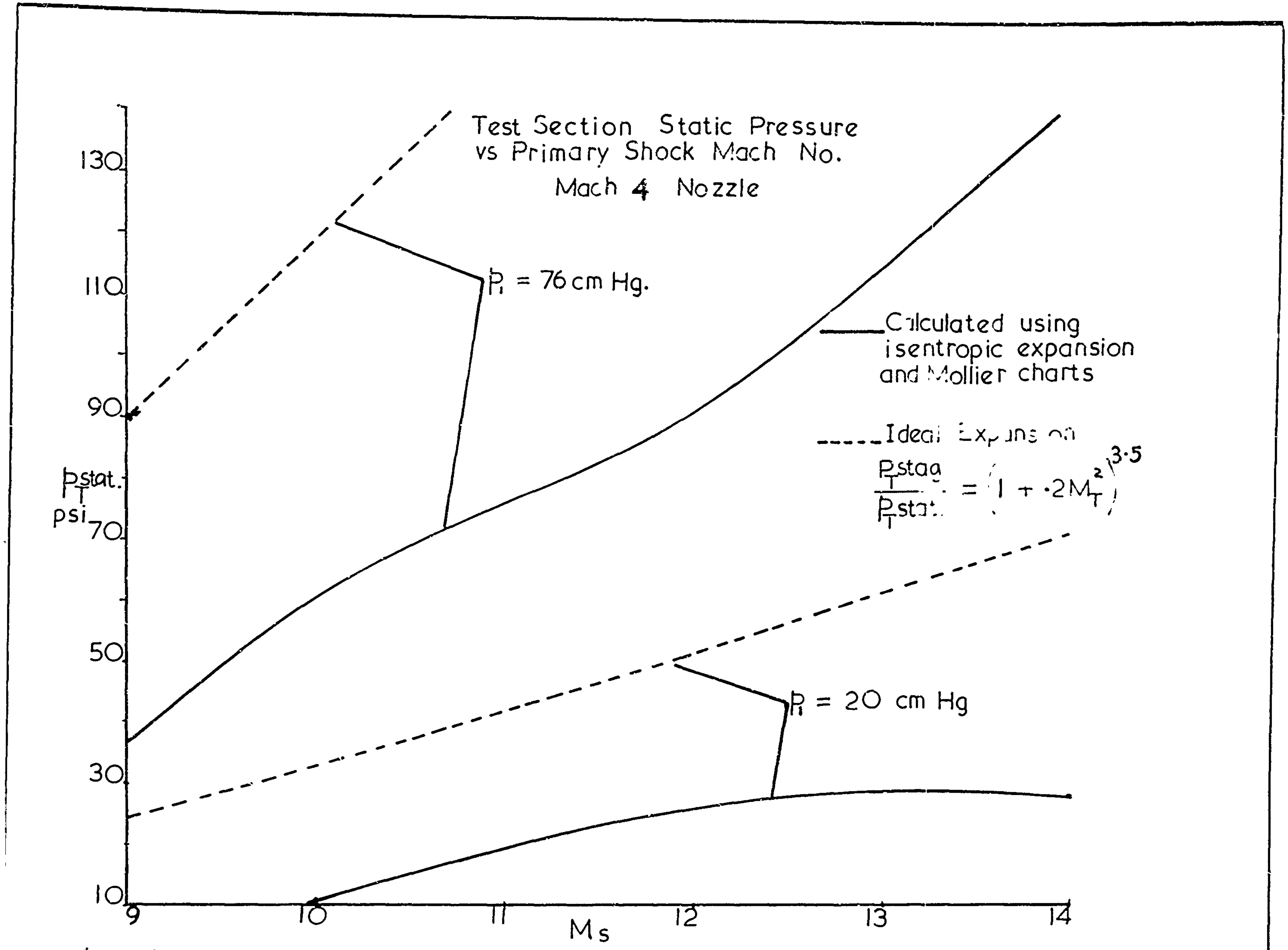


Test Section Enthalpy
vs. Primary Shock Mach No.
Mach 3 Nozzle
P = 1 cm Hg
20 " "
76 " "
75
65
55
45
35
25
15
Test Section Enthalpy
5
6
7
8
9
Shock Mach No. Ms.

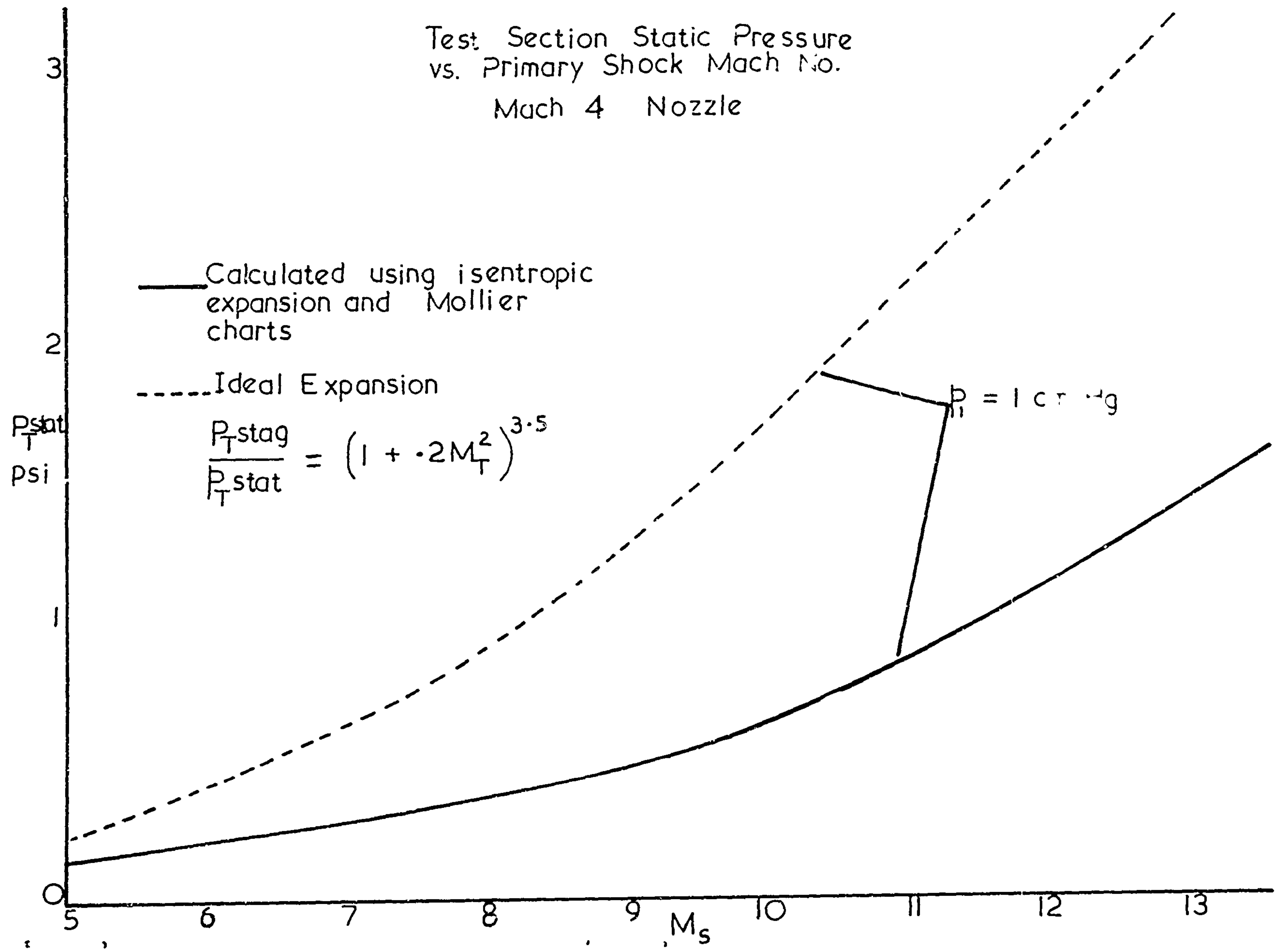

Test Section En
vs Primary Sh
Mach Number
Mach 3 Nozzle
P1 = 1 cm Hg
20 " "
76 " "
180
160
140
120
100
80
60
Test Section Enthalpy
9
10
11
12
13
14
Shock Mach No. Ms.



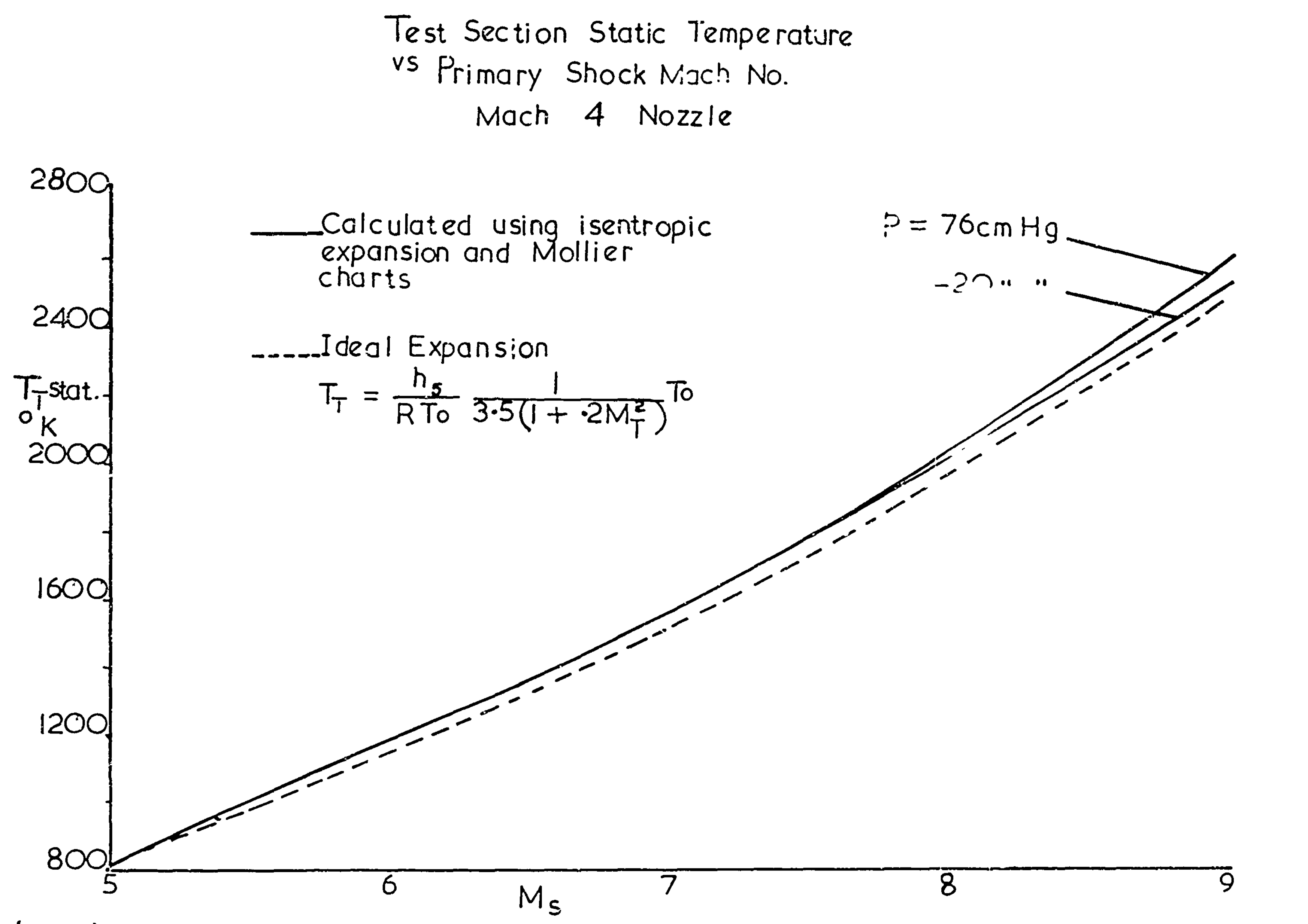
Test Section Static Pressure
vs. Shock Mach No.
Mach 4 Nozzle
Calculated using isentropic expansion and Mollier charts
Ideal Expansion
$\frac{P_T stag}{P_T stat} = \left(1 + \cdot 2 M_T^2\right)^{3\cdot 5}$
P_T stat. psi.
60
50
40
30
20
10
0
5
6
7
8
9
M_s
P_1 = 76 cm Hg
P_1 = 20 cm Hg



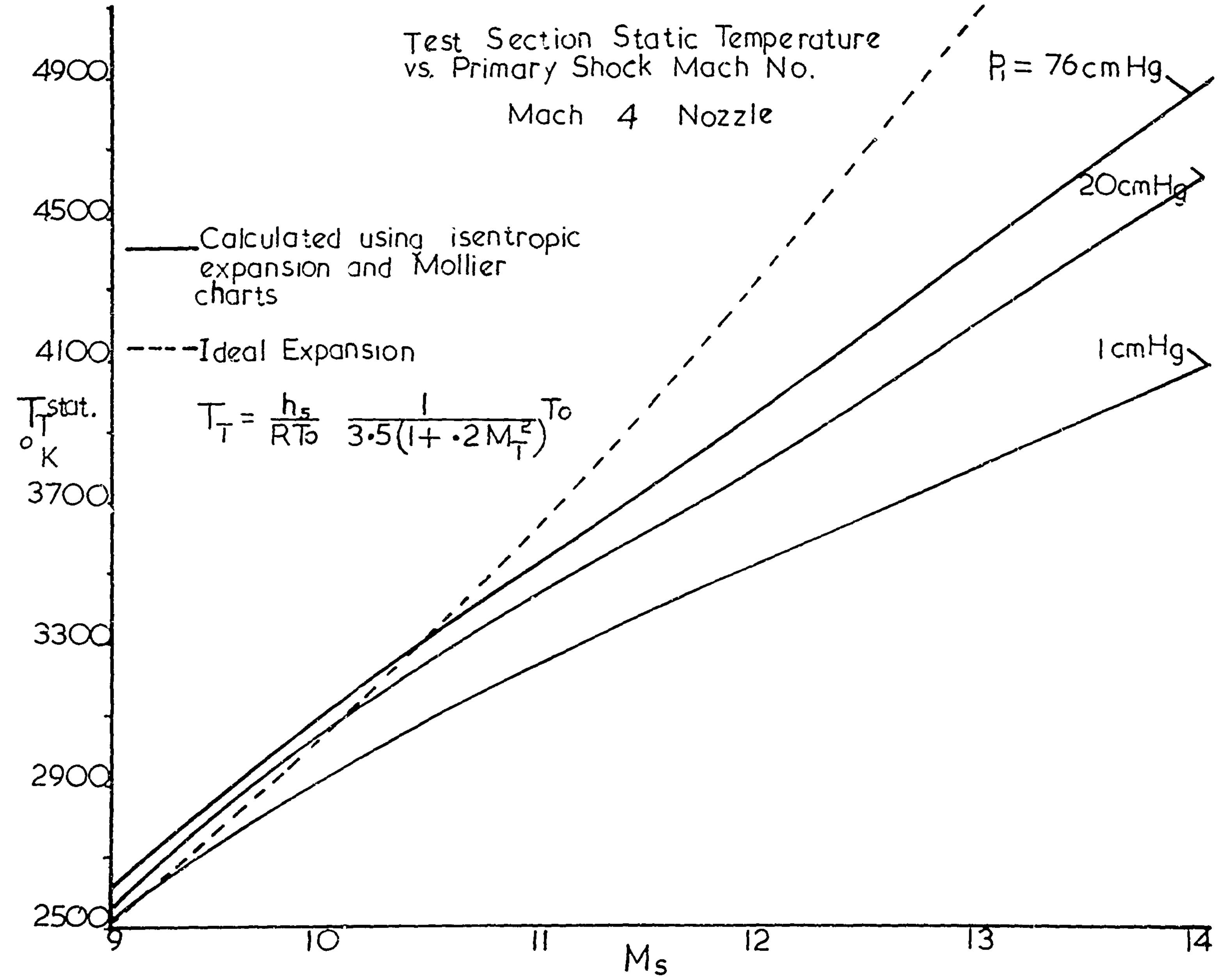
Test Section Static Pressure
vs Primary Shock Mach No.
Mach 4 Nozzle
P_1 = 76 cm Hg.
P_1 = 20 cm Hg
Calculated using
isentropic expansion
and Mollier charts
Ideal Expansion
$\frac{P_{T}stag}{P_{T}stat} = (1 + \cdot 2M_T^2)^{3\cdot 5}$
$P_T$stat. psi
130
110
90
70
50
30
10
9
10
11
12
13
14
Ms



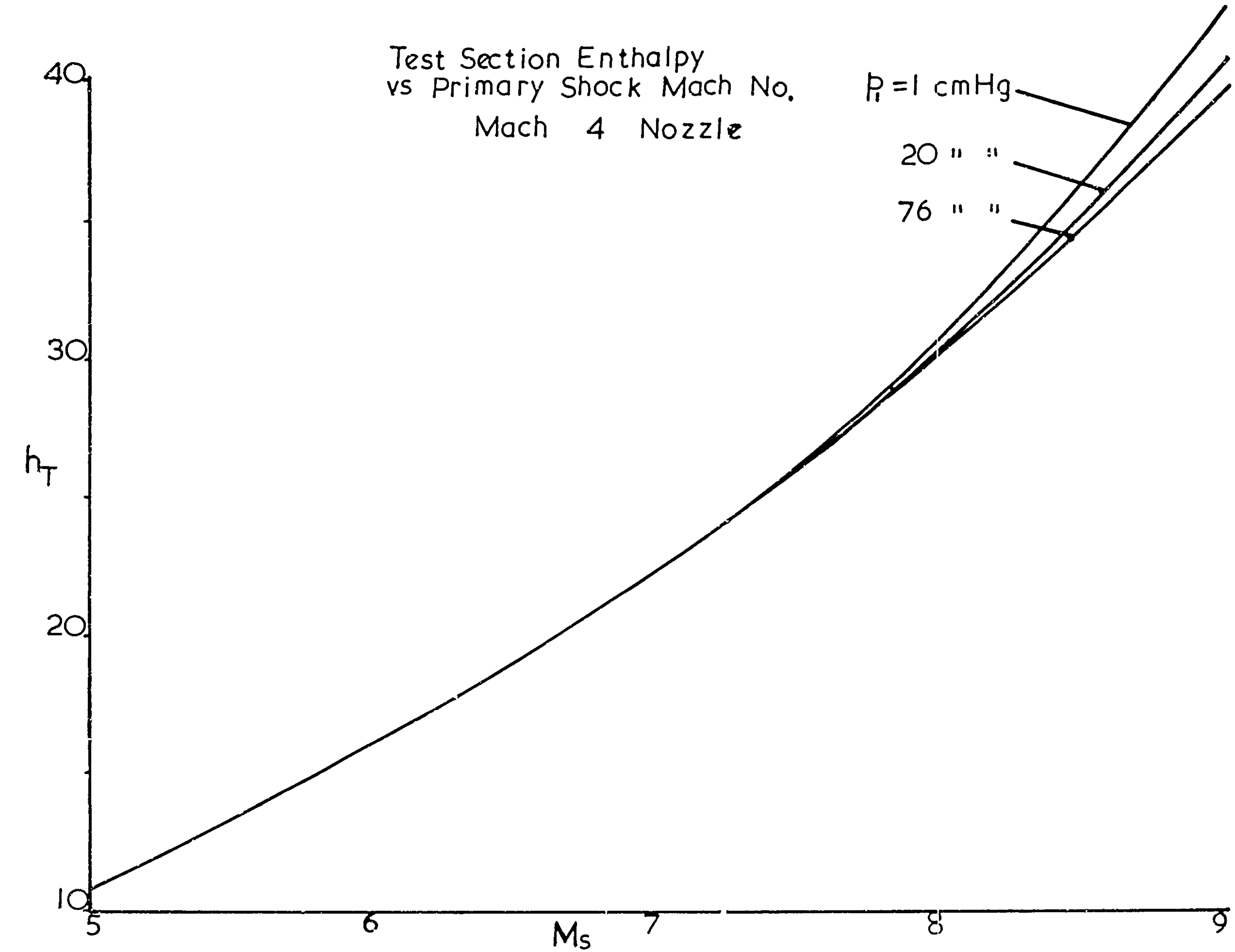
Test Section Static Pressure
vs. Primary Shock Mach No.
Mach 4 Nozzle
Calculated using isentropic expansion and Mollier charts
Ideal Expansion
$\frac{P_T stag}{P_T stat} = (1 + \cdot 2M_T^2)^{3\cdot 5}$
P_T stat
psi
3
2
1
0
5
6
7
8
9
10
11
12
13
M_s

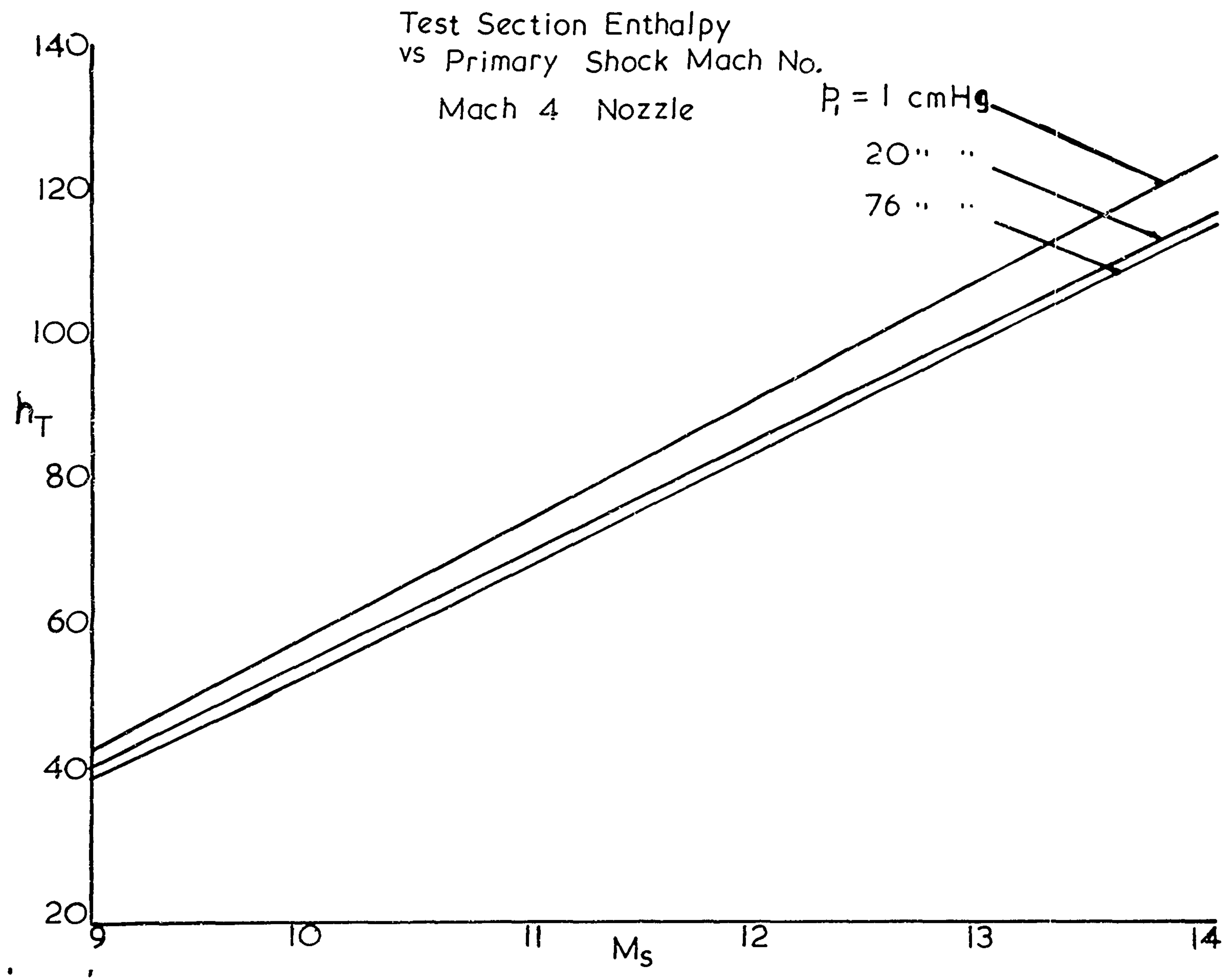


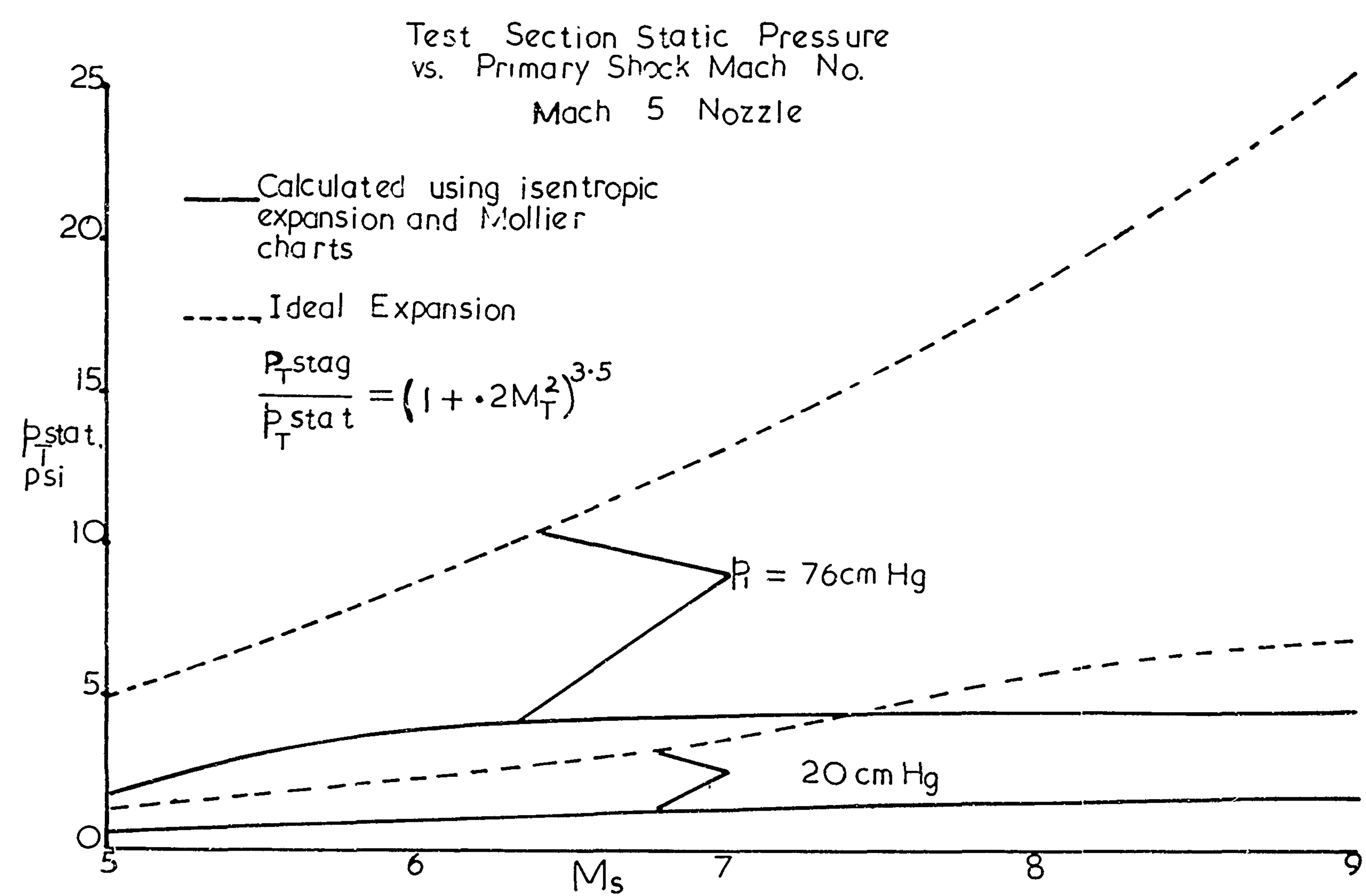
Test Section Static Temperature
vs Primary Shock Mach No.
Mach 4 Nozzle
Calculated using isentropic expansion and Mollier charts
Ideal Expansion
$T_T = \frac{h_5}{R T_o} \frac{1}{3 \cdot 5(1 + \cdot 2 M_T^2)} T_o$
P = 76cm Hg
T_T stat. °K
2800
2400
2000
1600
1200
800
5
6
7
8
9
M_s

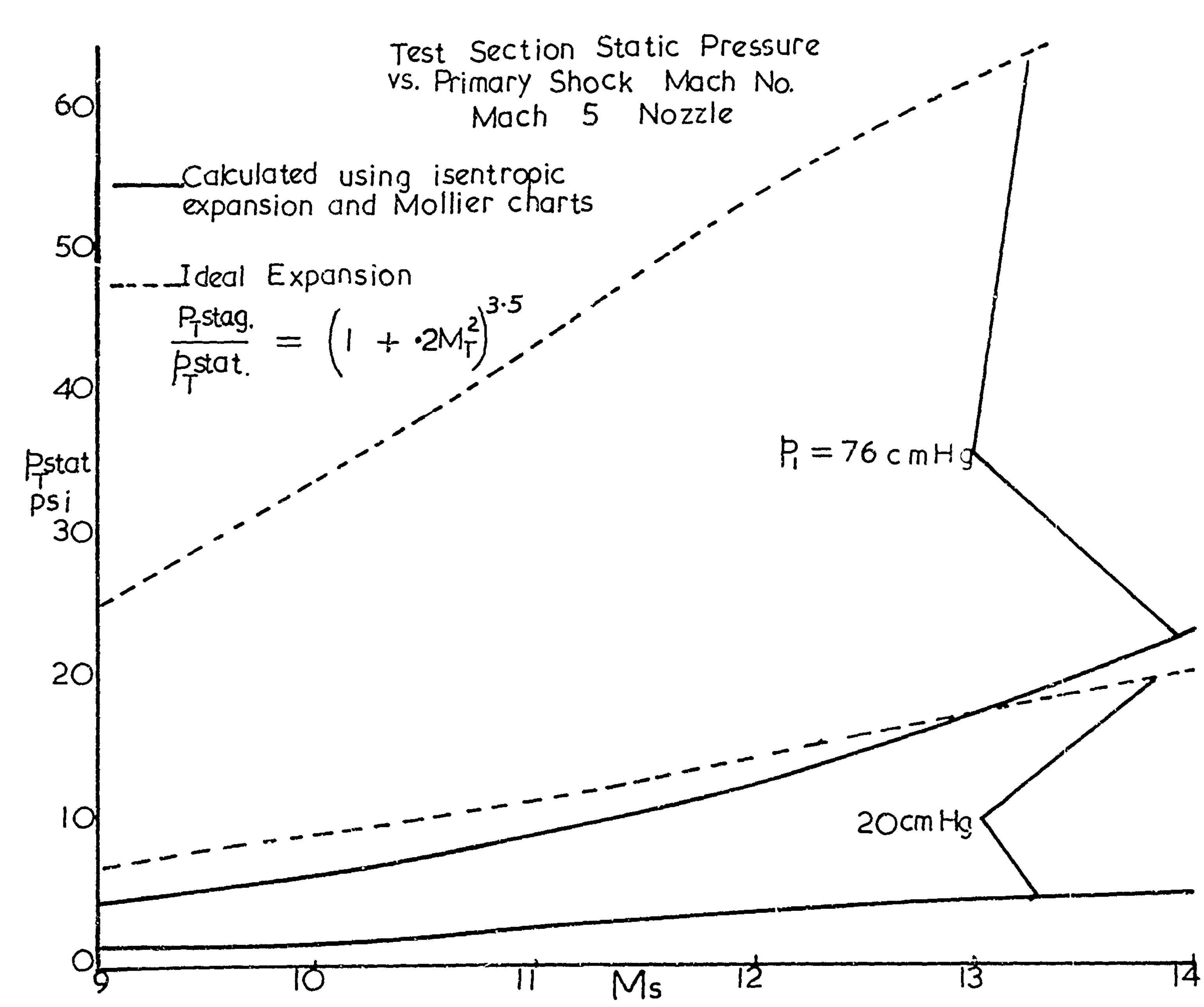


Test Section Static Temperature
vs. Primary Shock Mach No.
Mach 4 Nozzle
Calculated using isentropic expansion and Mollier charts
Ideal Expansion
$T_T = \frac{h_s}{RT_0} \frac{1}{3.5(1+.2M_T^2)} T_0$
P_1 = 76cmHg
20cmHg
1cmHg
$T_T^{stat.}$ °K
4900
4500
4100
3700
3300
2900
2500
9
10
11
12
13
14
M_s

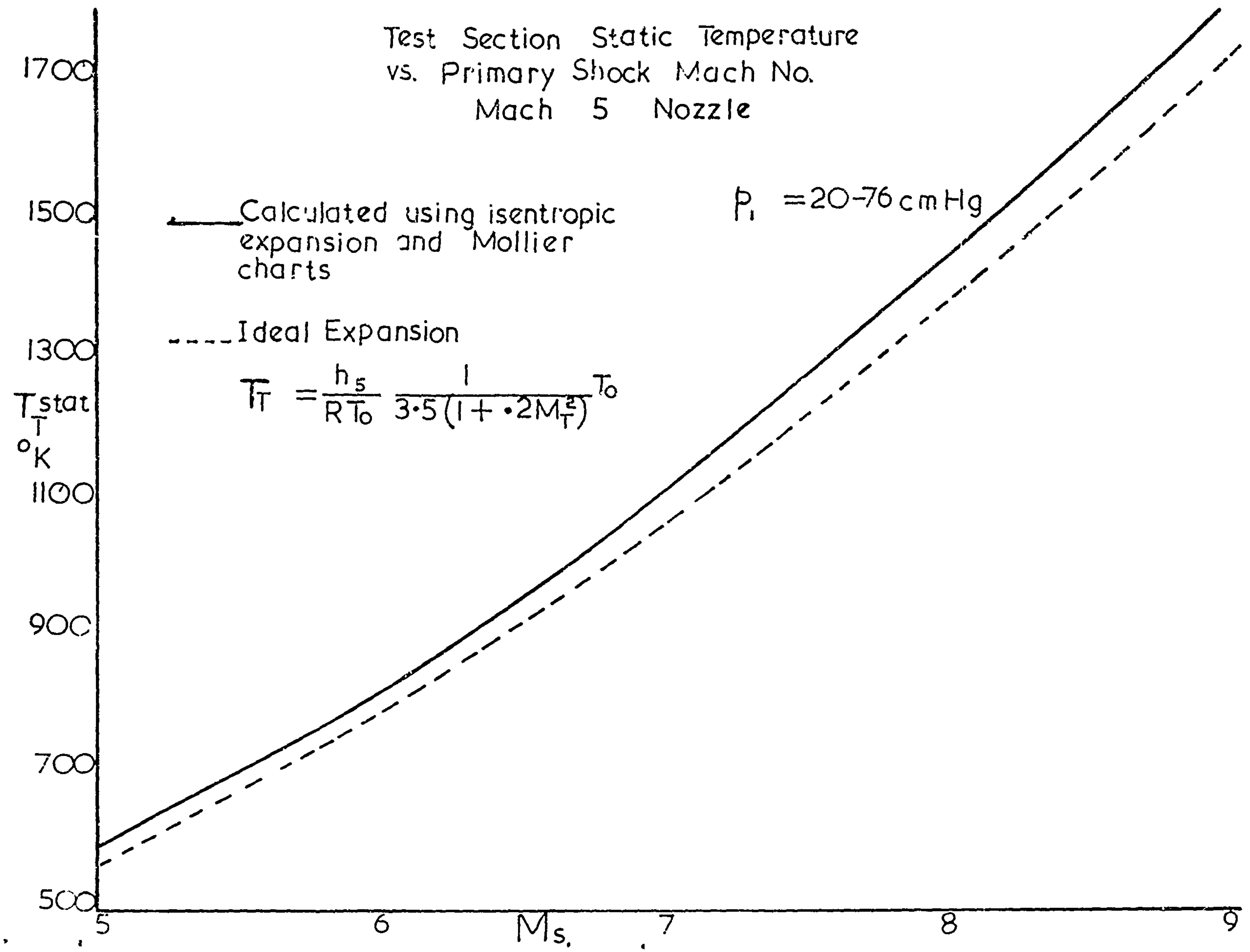

Test Section Enthalpy
vs Primary Shock Mach No.
Mach 4 Nozzle
P1 =1 cmHg
20 " "
76 " "
hT
Ms
40
30
20
10
5
6
7
8
9


Test Section Enthalpy
vs Primary Shock Mach No.
Mach 4 Nozzle
p_1 = 1 cmHg
20 " "
76 " "
140
120
100
h_T
80
60
40
20
9
10
11
12
13
14
M_s

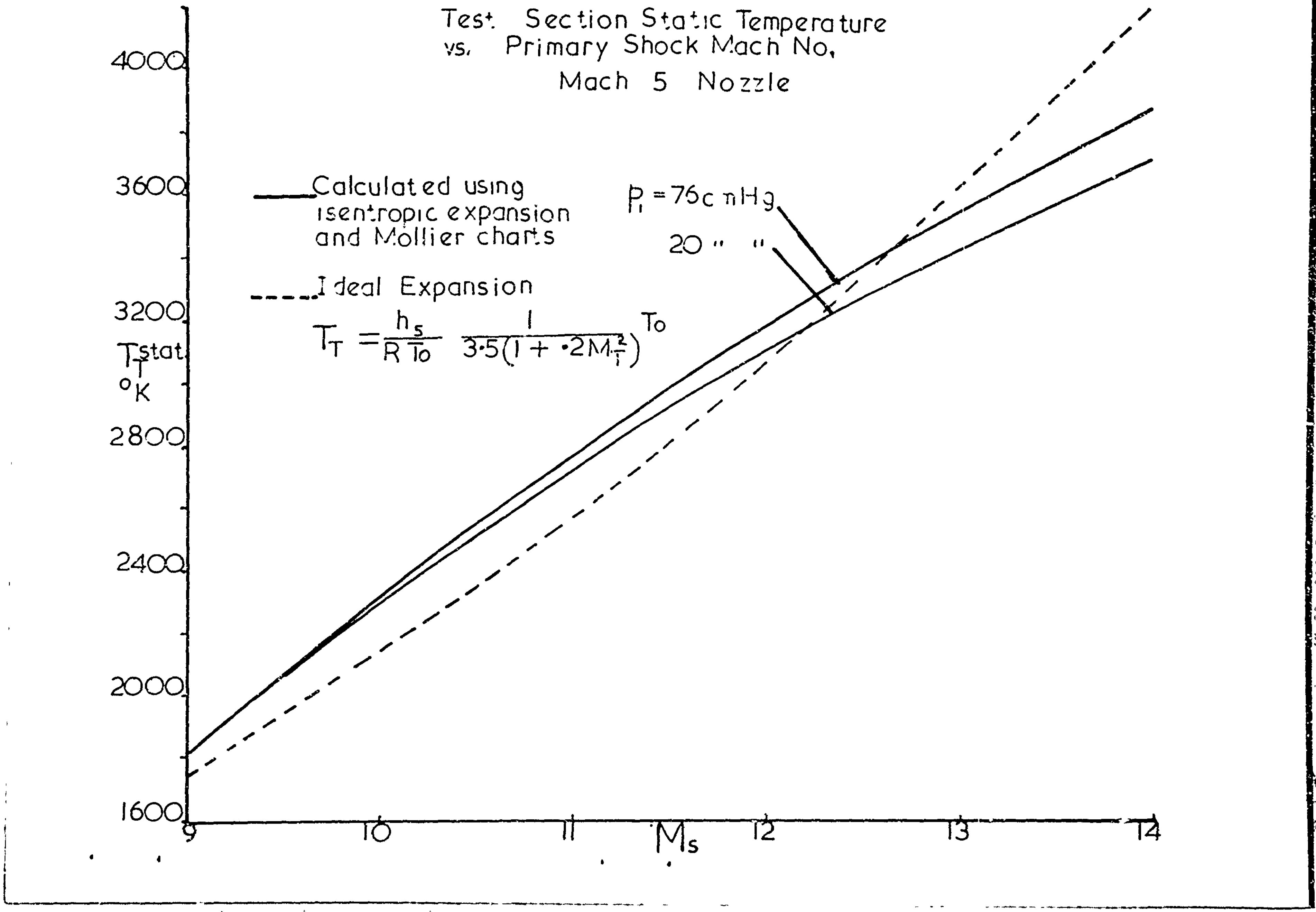

Test Section Static Pressure
vs. Primary Shock Mach No.
Mach 5 Nozzle
Calculated using isentropic expansion and Mollier charts
Ideal Expansion
$\frac{p_T stag}{p_T stat} = (1 + .2M_T^2)^{3.5}$
p_T stat. psi
p_1 = 76cm Hg
20 cm Hg
25
20
15
10
5
0
5
6
7
8
9
M_s



Test Section Static Pressure
vs. Primary Shock Mach No.
Mach 5 Nozzle
Calculated using isentropic expansion and Mollier charts
Ideal Expansion
$\frac{P_T stag.}{P_T stat.} = \left(1 + \cdot 2 M_T^2\right)^{3.5}$
$P_1 = 76$ cmHg
20cmHg
$P_T$stat psi
0
10
20
30
40
50
60
9
10
11
12
13
14
Ms



Test Section Static Temperature
vs. Primary Shock Mach No.
Mach 5 Nozzle
Calculated using isentropic expansion and Mollier charts
Ideal Expansion
$T_T = \frac{h_5}{RT_0} \frac{1}{3 \cdot 5(1 + \cdot 2M_T^2)} T_0$
P_1 = 20-76 cm Hg
T_T^{stat} °K
1700
1500
1300
1100
900
700
500
5
6
7
8
9
Ms.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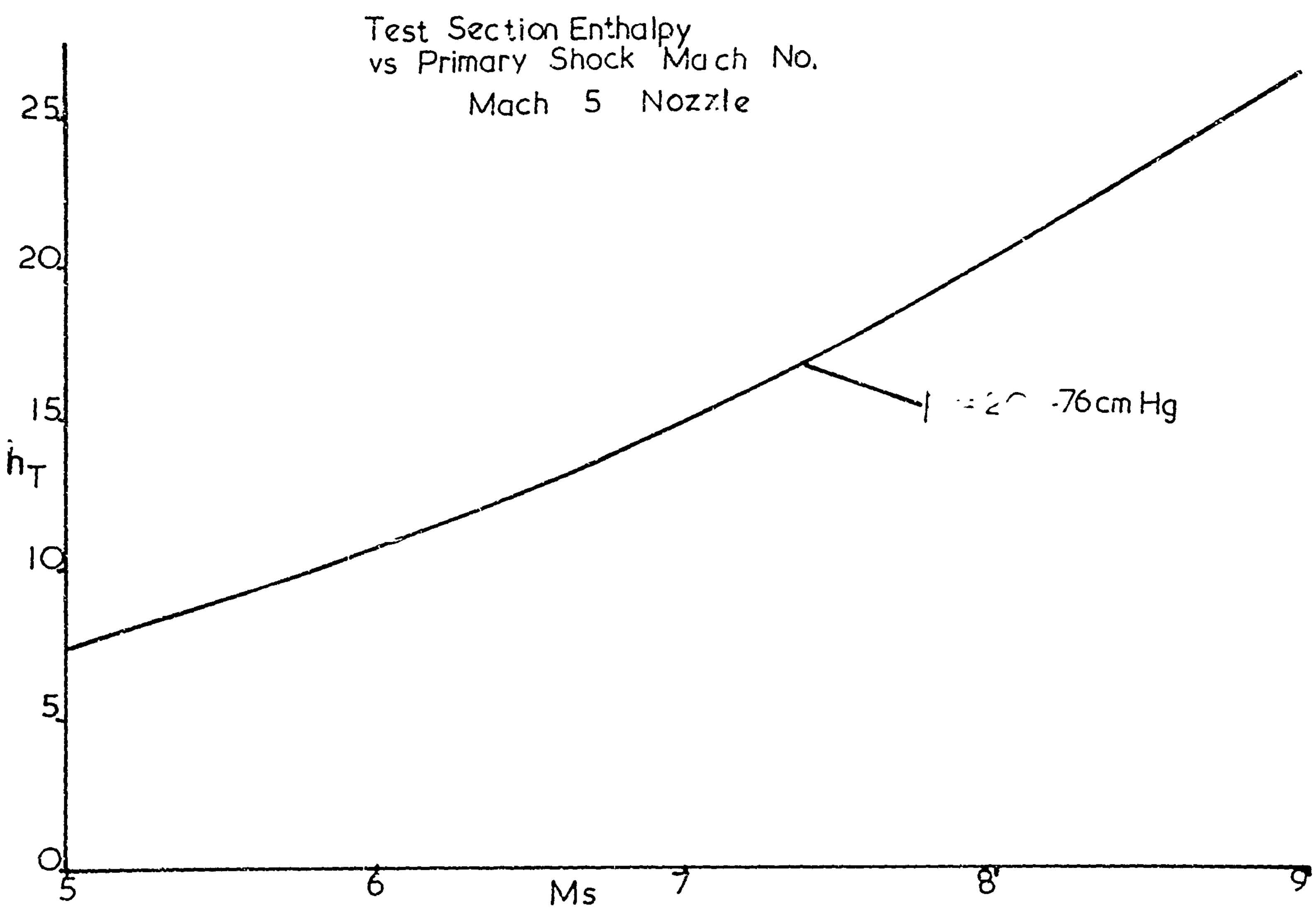
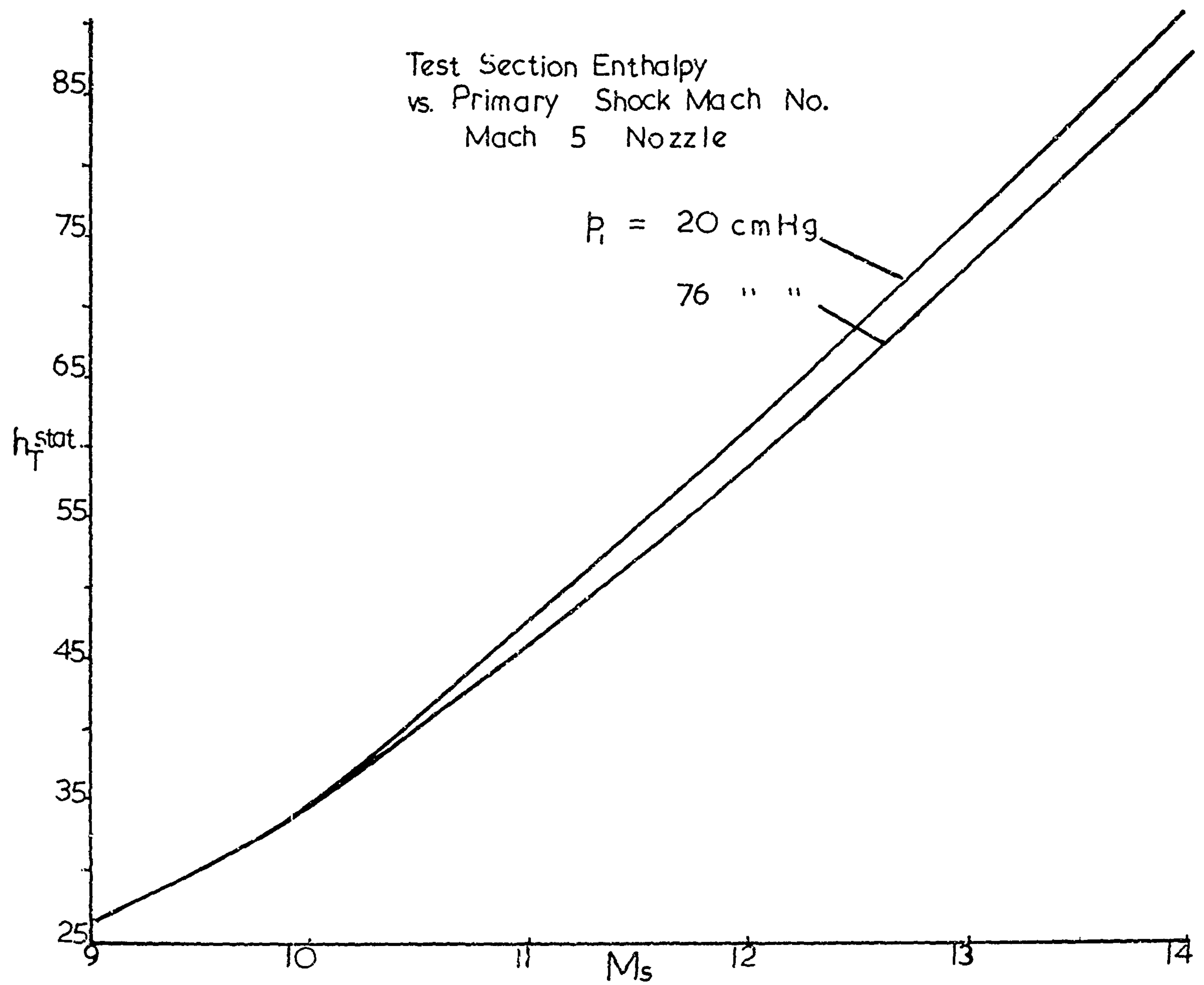
vs. Primary Shock Mach No.
Mach 5 Nozzle
Calculated using isentropic expansion and Mollier charts
Ideal Expansion
$T_T = \frac{h_s}{R T_0} \frac{1}{3.5(1 + .2 M_T^2)} T_0$
P_1 = 76 cm Hg
20 " "
T_T^{stat} °K
4000
3600
3200
2800
2400
2000
1600
9
10
11
12
13
14
M_s


Test Section Enthalpy
vs Primary Shock Mach No.
Mach 5 Nozzle
76cm Hg
h_T
0
5
10
15
20
25
Ms
5
6
7
8
9


Test Section Enthalpy
vs. Primary Shock Mach No.
Mach 5 Nozzle
P1 = 20 cmHg
76 " "
85
75
65
55
45
35
25
h T stat.
9
10
11
12
13
14
Ms

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Security Classification

DOCUMENT CONTROL DATA - R & D

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1. ORIGINATING ACTIVITY (Corporate author)
University of Sheffield
Fuel Technology and Chemical Engineering Department
Sheffield, England

2a. REPORT SECURITY CLASSIFICATION: UNCLASSIFIED

2b. GROUP

3. REPORT TITLE
TEST SECTION CONDITIONS FOR THE TAILORED INTERFACE HYPERSONIC SHOCK TUNNEL

4. DESCRIPTIVE NOTES (Type of report and inclusive dates)
Scientific Interim

5. AUTHOR(S) (First name, middle initial, last name)
M P Wood

6. REPORT DATE: 1966

7a. TOTAL NO. OF PAGES: 24

7b. NO. OF REFS

8a. CONTRACT OR GRANT NO. AF EOAR 66-11

b. PROJECT NO. 9711-01

c. 61445014

d. 681308

9a. ORIGINATOR'S REPORT NUMBER(S): Appendix to H.I.C. No. 83

9b. OTHER REPORT NO(S) (Any other numbers that may be assigned this report): AFOSR 67-2026

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13. ABSTRACT

This report contains calculated conditions expected in the test section of the Sheffield University Shock Tunnel.

The driver gases used are either cold hydrogen or a mixture of hydrogen oxygen and helium ignited behind the primary diaphragm. Cold hydrogen "Tailors" at a primary shock March number of 6 and the helium mixture used at about 12. The report therefore deals with the primary shock Mach number ranges from 5 to 9 and from 9 to 14 to cover both these cases.

The air in the stagnation region is expanded to test section Mach numbers of 3,4 and 5 depending on the nozzle attached.

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Hypersonic Shock Tunnel						
Hypersonic Flight						
SCRAMJET						

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