NASA SP-3020

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GPO PRICE $ ______

CFSTI PRICE(S) $ ______

Hard copy (HC) $1.00

Microfiche (MF) .50¢

ff 653 July 65

FACILITY FORM 602

N65-34243	
(ACCESSION NUMBER)	(THRU)
13	1
(PAGES)	(CODE)
	33
(NASA CR OR TMX OR AD NUMBER)	(CATEGORY)

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

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CHARTS OF ISENTROPIC EXPONENT AS A FUNCTION OF ENTHALPY FOR VARIOUS GASES IN EQUILIBRIUM

By Leland H. Jorgensen

Ames Research Center
Moffett Field, California

Scientific and Technical Information Division 1965
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
Washington, D.C.

For sale by the Clearinghouse for Federal Scientific and Technical Information
Springfield, Virginia 22151 – Price $0.50

SUMMARY

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For enthalpies to 28,000 Btu/lb and pressures from 10^{-3} to 10^{2} atmospheres, curves of isentropic exponent as a function of enthalpy and speed are presented for equilibrium air, nitrogen, carbon dioxide, and a composition of 20-percent CO_2 and 80-percent N_2 (by volume). For a pressure of 1 atmosphere, curves are also presented for compositions of 10-percent CO_2 - 90-percent N_2 and 50-percent CO_2 - 50-percent N_2.

Author

INTRODUCTION

The isentropic exponent or dimensionless speed of sound parameter, $\gamma \equiv a^2\rho/p$, is present in many gasdynamic equations. In the field of planetary entry aerodynamics where real-gas phenomena are important, it is convenient to have plots of γ as a function of enthalpy for specified pressures. This enables the often desired value of γ at the stagnation point to be read directly from the plots after the speed is converted to total enthalpy.

Because of interest in flight within the Martian and Venusian atmospheres which are believed to be primarily nitrogen and carbon dioxide, these gases, as well as air, should be considered. It is the purpose of this report to present curves of isentropic exponent versus enthalpy and speed for air, nitrogen, carbon dioxide, and several mixtures of nitrogen and carbon dioxide. The gases are assumed to be in equilibrium.

NOMENCLATURE

a   isentropic speed of sound

h   enthalpy ($h = 0$ for molecular gas at 0° K)

p   pressure

q   dynamic pressure, $\frac{1}{2}\rho u^2$

u   speed

γ isentropic exponent

ρ density

Subscripts

s constant entropy

st stagnation

∞ free stream

Conversion From Units in Figures 1-6 to "SI Units"
(International System of Units, NASA TT F-200)

Physical quantity	To convert from	Multiply by	To obtain
density	slugs/ft^3	5.154×10^2	kg/m^3
enthalpy	Btu/lb	2.324×10^3	J/kg
speed	ft/sec	0.3048	m/s

METHODS AND RESULTS

For enthalpies to 28,000 Btu/lb and pressures from 10^{-3} to 10^2 atmospheres, values of isentropic exponent were computed from the defining relation

$$\gamma = \left(\frac{\partial \ln p}{\partial \ln \rho}\right)_s = \frac{a^2\rho}{p} \tag{1}$$

All calculations were made on an IBM 7094 system, with the thermodynamic properties having been previously recorded on magnetic tape by Dr. Harry E. Bailey of Ames Research Center. Following the assumptions and approximations made in reference 1, Dr. Bailey recently computed the equilibrium thermodynamic properties of various gases and mixtures. His results for carbon dioxide are reported in reference 2.

In figures 1 through 5, curves of isentropic exponent γ versus enthalpy h are presented for air, nitrogen, carbon dioxide, and a 20-percent CO_2 - 80-percent N_2 composition (by volume). The velocity scale at the top of each figure is applicable only when the values of γ, p, and h are taken at the stagnation point. To obtain γ at the stagnation point, stagnation-point pressure p_{st} and enthalpy h_{st} must be determined. For hypersonic flight,

$$p_{st} \approx \rho_\infty u_\infty^2 = 2q_\infty \tag{2}$$

and

$$h_{st} = \frac{u_\infty^2}{2} + h_\infty \approx \frac{u_\infty^2}{2} \tag{3}$$

The variation of γ with h for low values of h (fig. 5) in air and CO_2 is useful for interpretation of test results from many wind tunnels. In figure 6, the previous curves for the different gases at $p = 1$ atm are compared with each other and with additional curves for compositions of 10-percent CO_2 - 90-percent N_2 and 50-percent CO_2 - 50-percent N_2. The effect of gas composition on γ (fig. 6) appears to be the greatest at enthalpies below about 10,000 Btu/lb.

REFERENCES

1. Marrone, Paul V.: Inviscid, Nonequilibrium Flow Behind Bow and Normal Shock Waves. Part I. General Analysis and Numerical Examples. CAL Rep. QM-1626-A-12(I), May 1963.

2. Bailey, Harry E.: Equilibrium Thermodynamic Properties of Carbon Dioxide. NASA SP-3014, 1965.

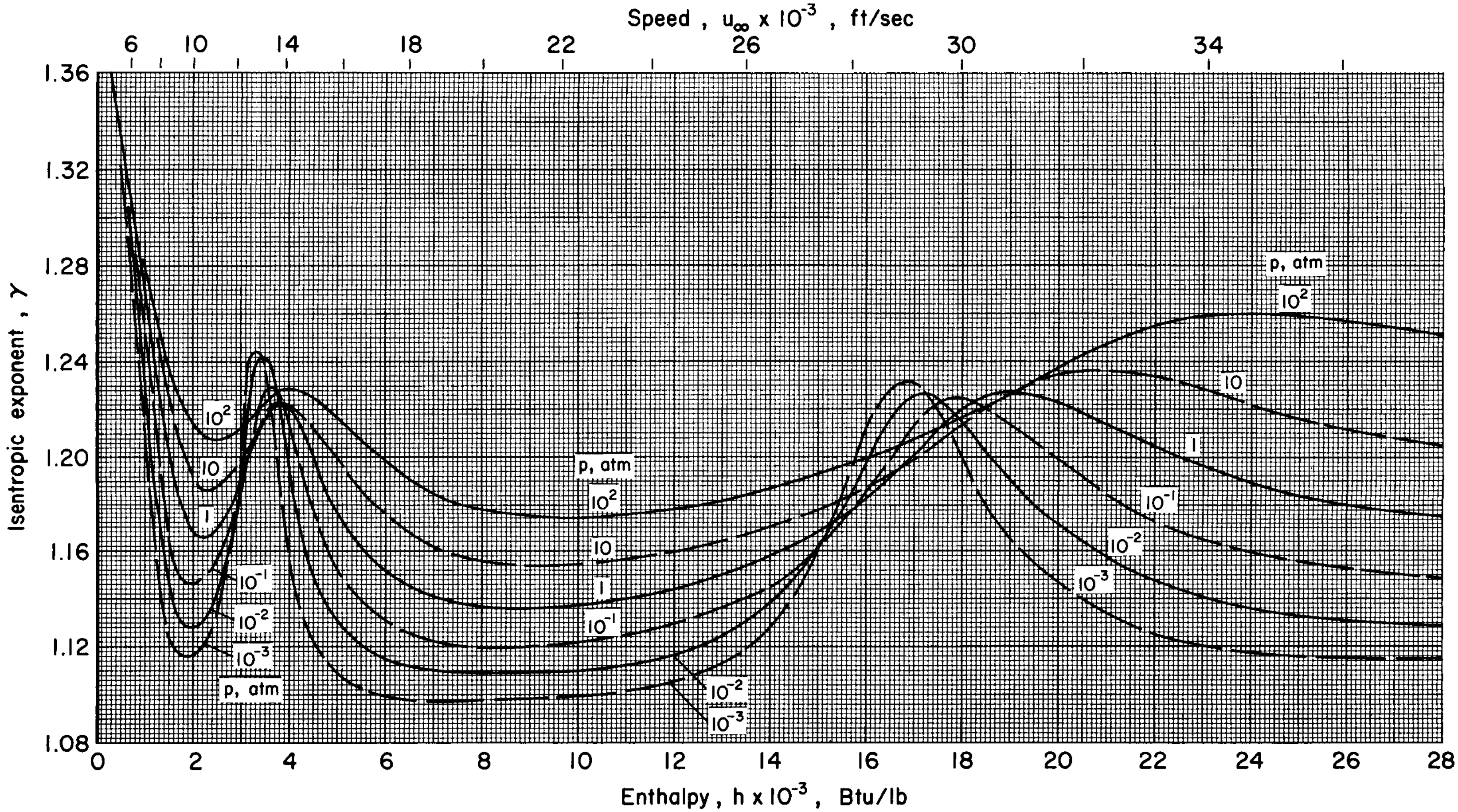


Figure 1. - Variation of isentropic exponent with enthalpy for air at various pressures.

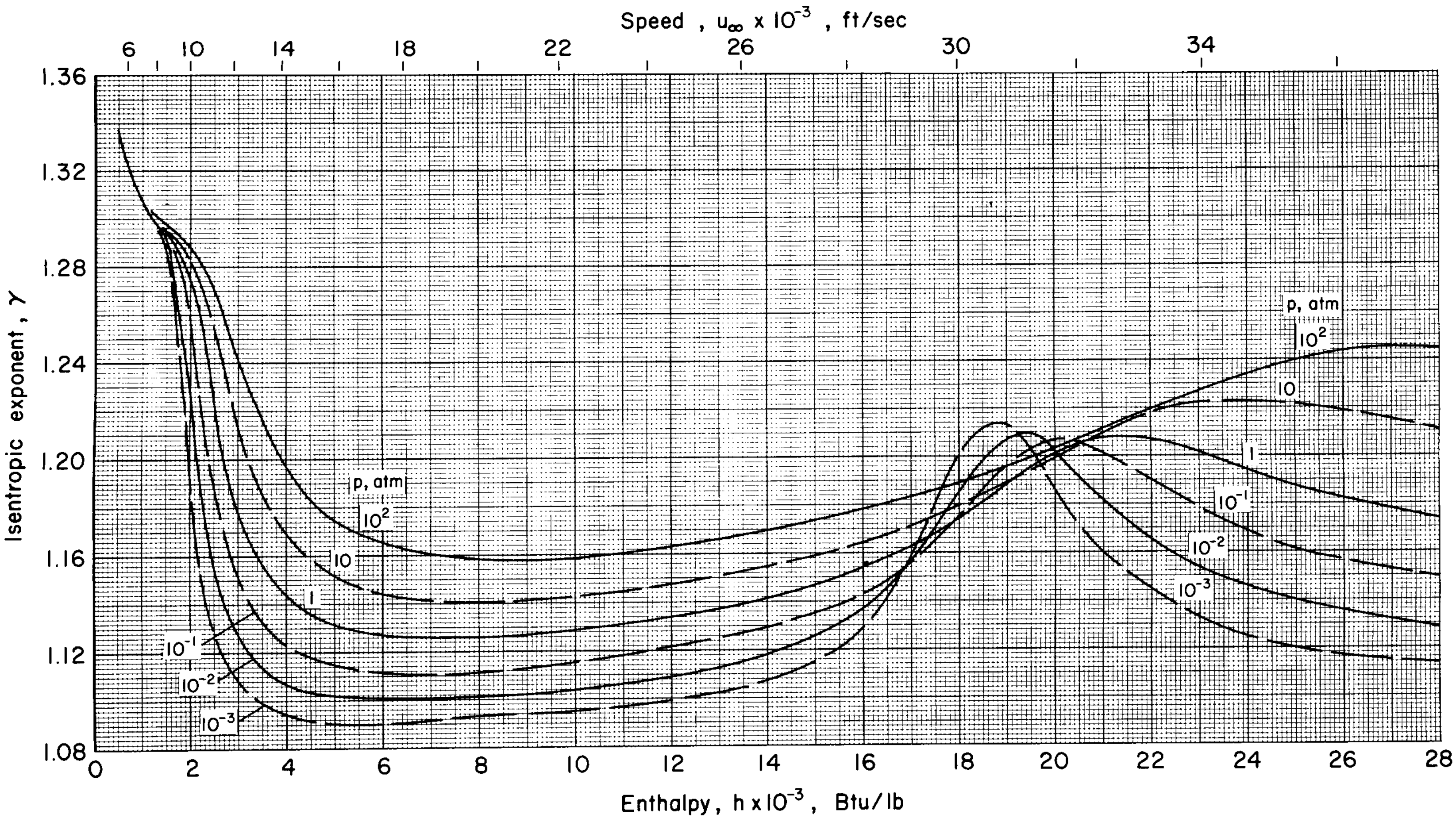


Figure 2. - Variation of isentropic exponent with enthalpy for nitrogen at various pressures.

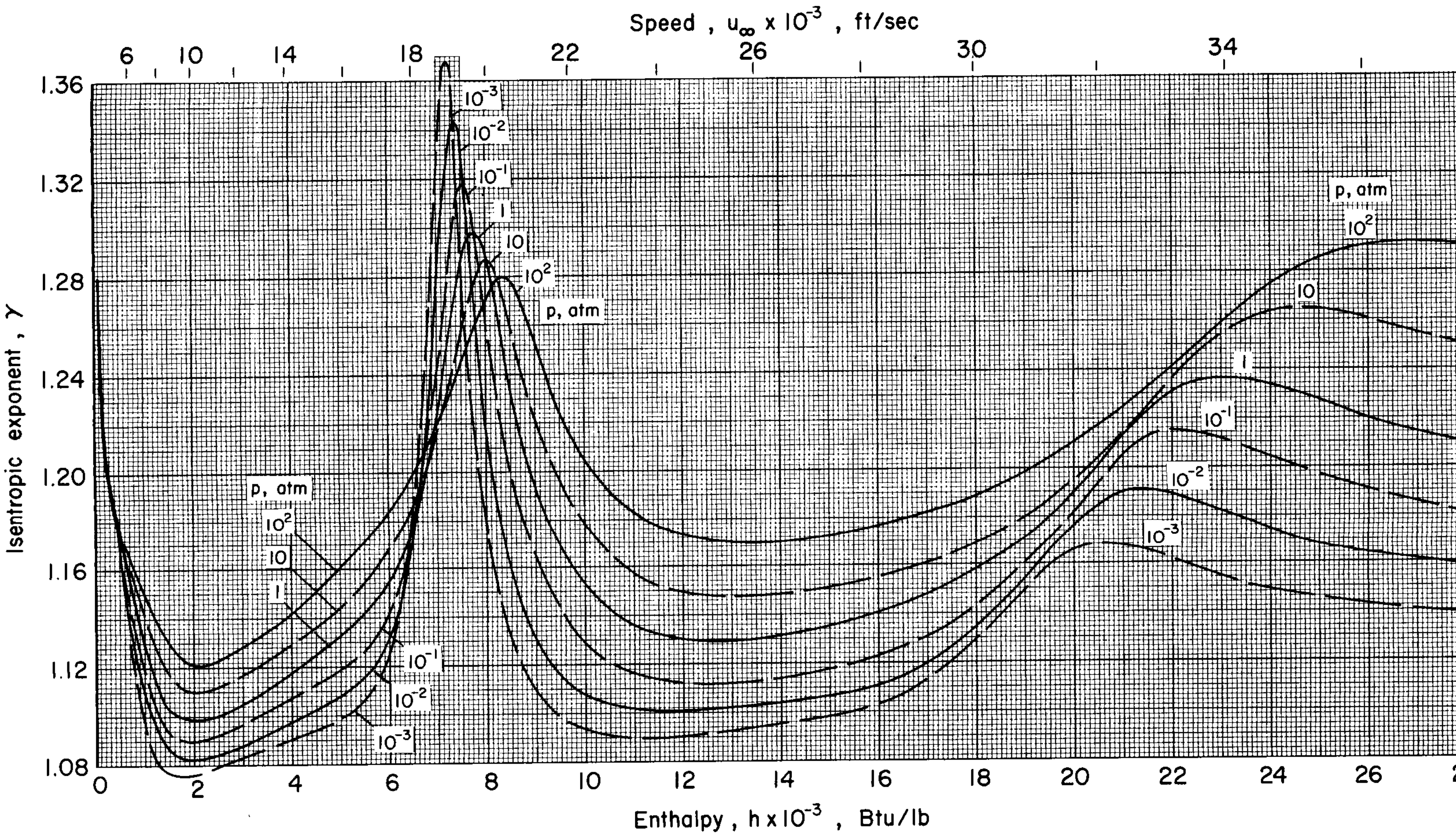


Figure 3. - Variation of isentropic exponent with enthalpy for carbon dioxide at various pressures.

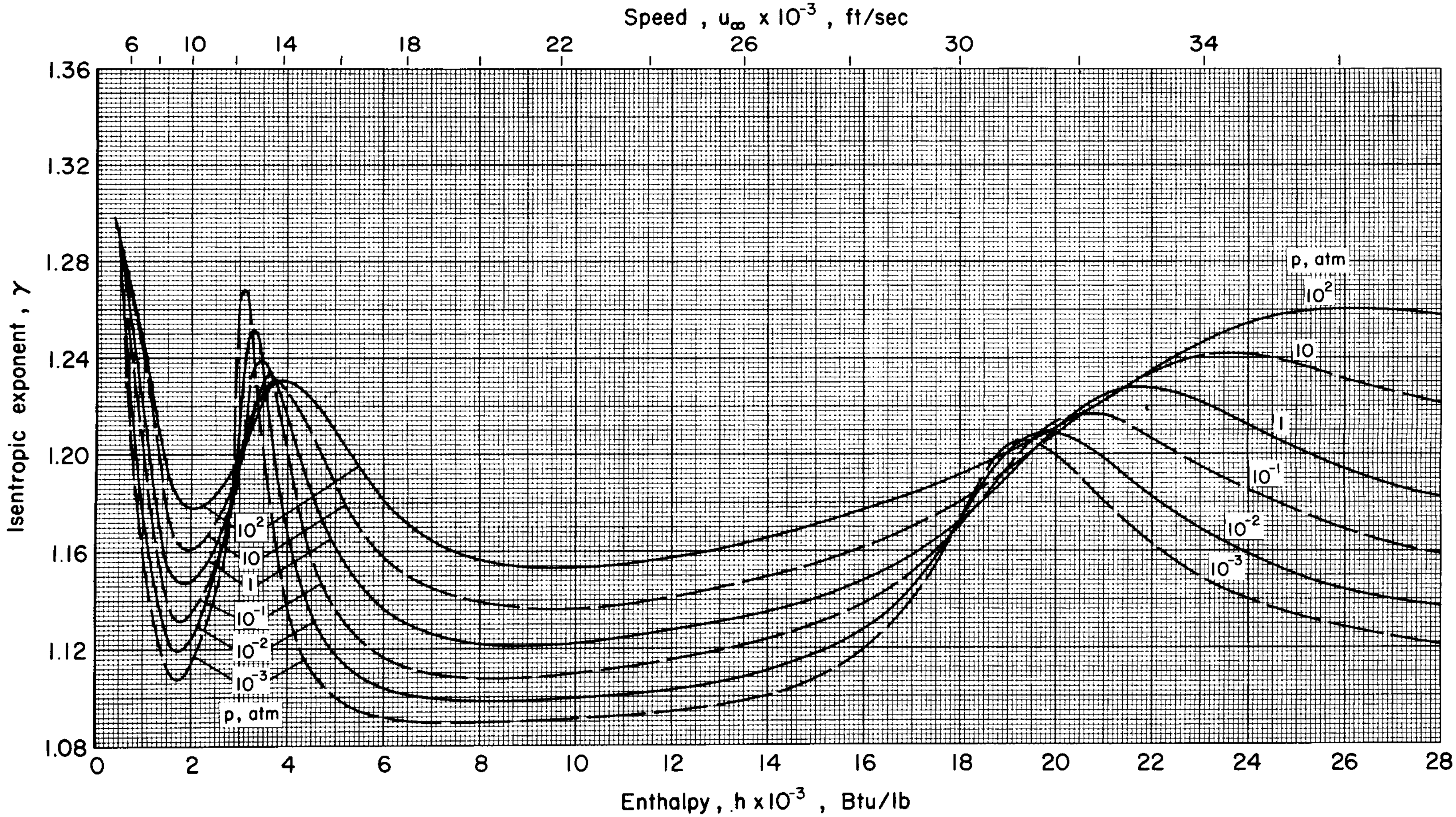
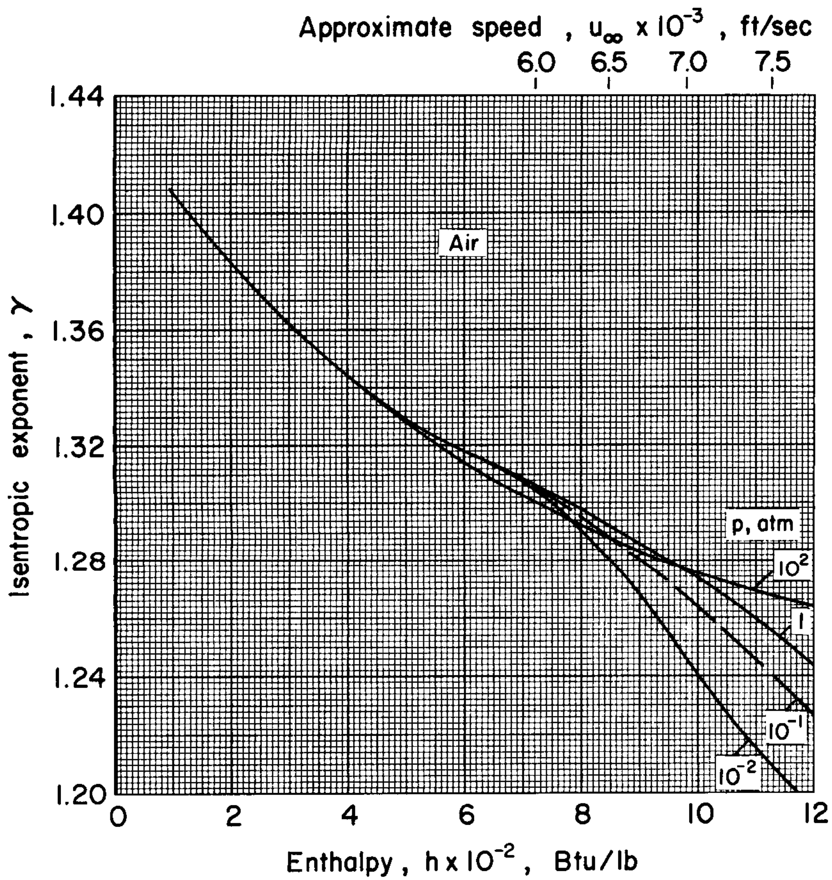
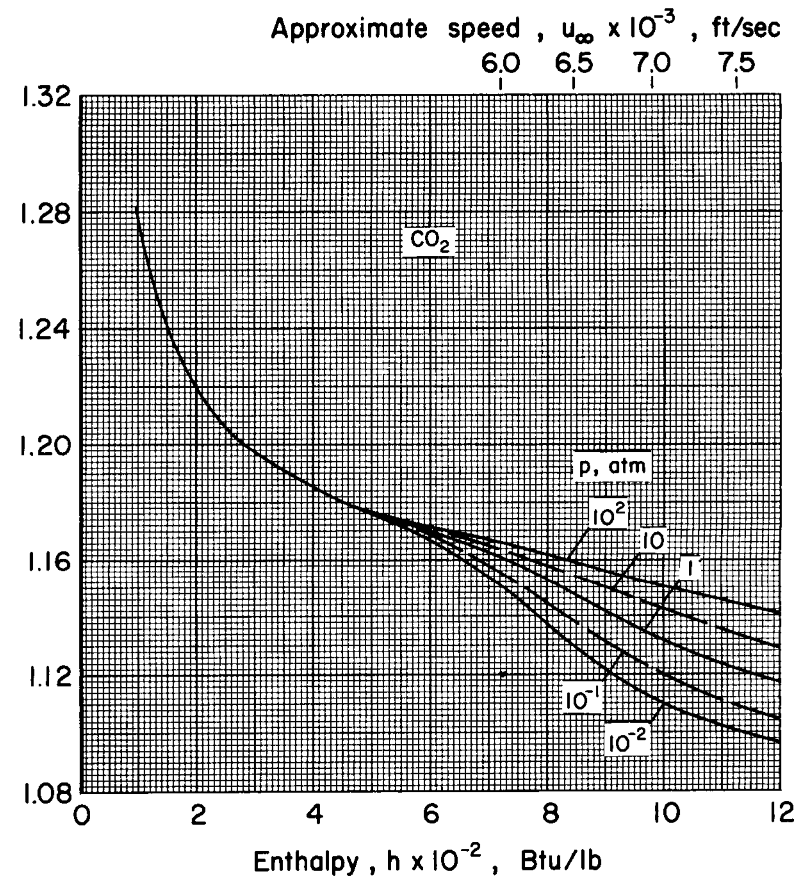


Figure 4. - Variation of isentropic exponent with enthalpy for composition of 20-percent carbon dioxide - 80-percent nitrogen (by volume) at various pressures.



(a) Air.



(b) Carbon dioxide.

Figure 5. - Variation of isentropic exponent with low values of enthalpy for air and carbon dioxide at various pressures.

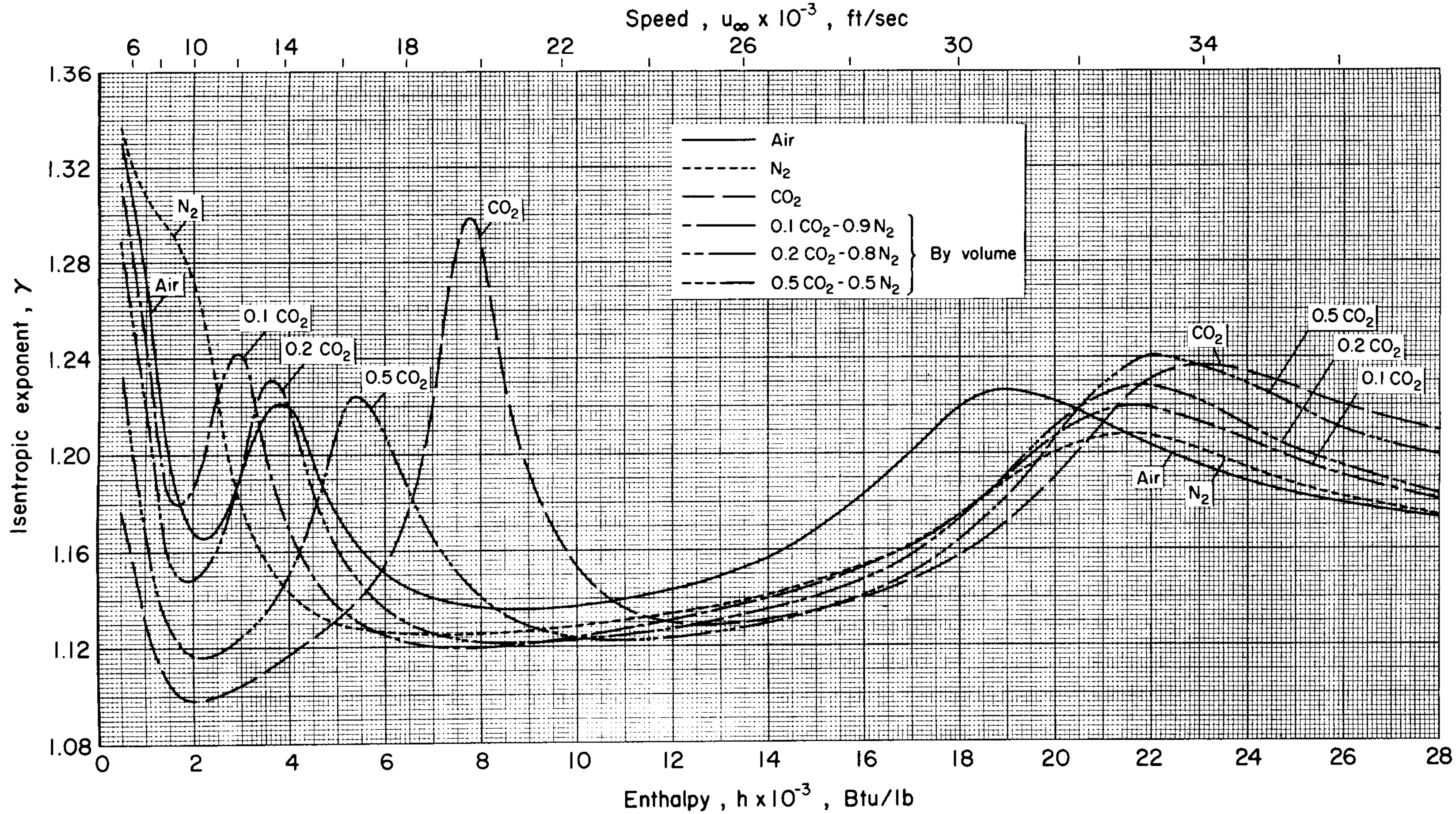


Figure 6. - Comparisons of values of isentropic exponent for air, nitrogen, carbon dioxide, and carbon dioxide-nitrogen mixtures; p = 1 atm.

NASA-Langley, 1965 A-2153