Cryogenic Hydrogen as a Wind Tunnel Test Gas

Richard C. Haut*
Old Dominion University, Norfolk, Va.
and
Jerry B. Adcock†
NASA Langley Research Center, Hampton, Va.

Nomenclature

A = stream tube area
M = Mach number
P = pressure
R = Reynolds number per meter
T = temperature
X/L = nondimensional nozzle length
ρ = density

Subscripts and Superscripts

t = stagnation condition
1 = upstream of shock
2 = downstream of shock
$*$ = condition at $M = 1$

Theme

THE cryogenic wind tunnel concept has been developed[1,2] and demonstrated[3] at the Langley Research Center as a practical way of increasing the test Reynolds number capability at transonic speeds.[4] During development of the concept, liquid nitrogen was utilized as the coolant with the resultant test gas being nitrogen. Experimental and analytical studies[3,5] have shown cryogenic nitrogen to be an acceptable test gas. Use of another diatomic gas, hydrogen, which has a much lower vapor temperature than nitrogen, would give even higher test Reynolds numbers (Fig. 1) or equivalent Reynolds numbers either at much lower operating pressures or for a much smaller tunnel. A theoretical analysis of the suitability of parahydrogen as a test gas for a cryogenic wind tunnel has been made.[6]

Contents

Hydrogen gas normally exists as a mixture of two molecular types, parahydrogen (opposing nuclear spins) and orthohydrogen (parallel nuclear spins). Pure parahydrogen was chosen for analysis because as liquid hydrogen evaporates it is essentially pure parahydrogen and the self-conversion rate to orthohydrogen is extremely slow compared to the anticipated test times of cryogenic wind tunnels. For parahydrogen to be a suitable test gas, flow solutions must be very nearly the same as those for an ideal diatomic gas, since air at the temperatures and pressures of transonic flight within our atmosphere behaves like such a gas. Various one-dimensional inviscid flow solutions were made for parahydrogen using the thermodynamic characteristics of parahydrogen obtained from a National Bureau of Standards computer program.

Received June 13, 1977; synoptic received Aug. 16, 1977. Full paper available from National Technical Information Service, Springfield, Va. 22151, as N77-24153 at the standard price (available upon request).

Index category: Testing, Flight and Ground; Transonic Flow.

*Graduate Student, Department of Mechanical Engineering and Mechanics; presently Research Engineer, Exxon Production Research, Houston, Texas.

†Aerospace Engineer, Subsonic-Transonic Aerodynamics Division. Member AIAA.

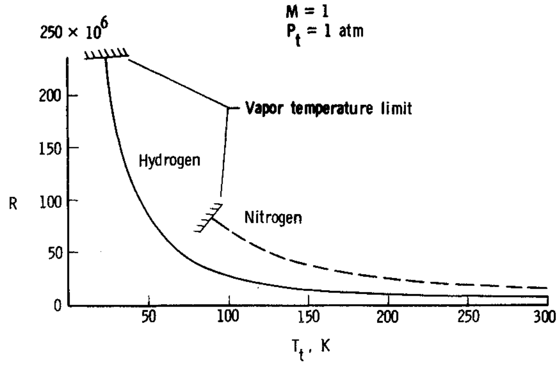

Fig. 1 Reynolds number vs temperature.

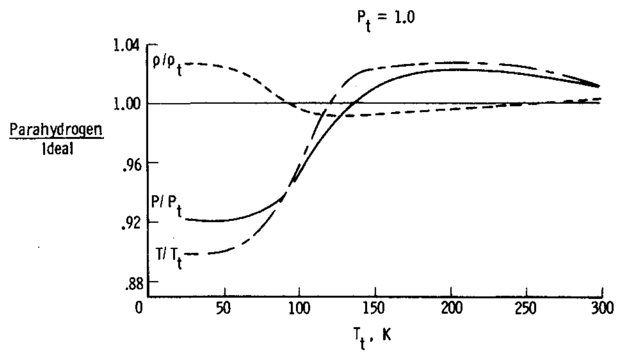

Fig. 2 Flow parameters for isentropic expansions to $M = 1.0$.

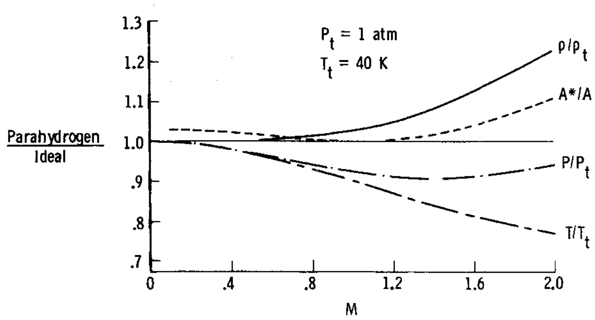

Fig. 3 Isentropic flow parameters for expansions to various Mach numbers.

Isentropic flow solutions are represented in Figs. 2 and 3 relative to the corresponding ideal gas flow solutions. The maximum deviations for isentropic flow are of the order of 10 to 20%. In contrast, for nitrogen these deviations are in the order of 0.5% and of the same order as measuring accuracies in the wind tunnel. These flow results indicate that parahydrogen would not be an acceptable cryogenic test gas except in the incompressible flow regime.

Flow solutions involving normal shocks are represented in Figs. 4 and 5. Again the various normal shock parameters

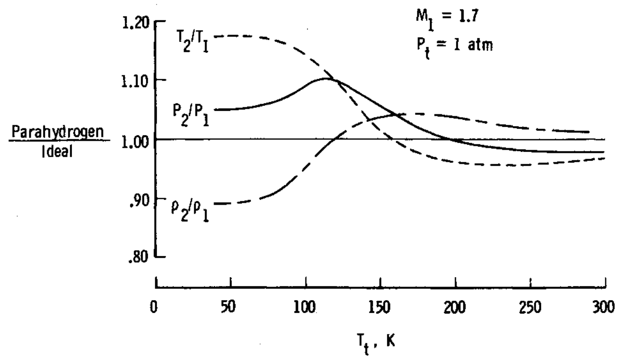

Fig. 4 Normal shock parameters vs temperature.

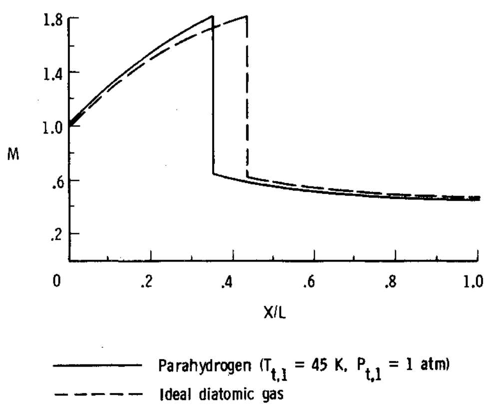

Fig. 5 Mach number distribution for a supersonic nozzle (one-dimensional inviscid flow).

differ from the ideal values by 10 to 20% (Fig. 4). For the case of the supersonic nozzle where the assumption is made that a shock occurs at a Mach number of 1.8 in both parahydrogen and an ideal diatomic gas, a difference in shock position of approximately 7% occurs. This magnitude of experimental error in the shock location on an airfoil would be completely unacceptable.

One of the causes of the much higher deviations in the flow solutions for parahydrogen is the influence of its high characteristic rotational temperature (85K). Below 85K, the rotational mode of the molecule is unexcited and the thermodynamic behavior is more like that of a monatomic gas. Above 85K, the rotational mode begins to be energized and the thermodynamic properties move toward those of a diatomic gas.

References

[1]Goodyer, M. J. and Kilgore, R. A., "High-Reynolds-Number Cryogenic Wind Tunnel," *AIAA Journal*, Vol. 11, May 1973, pp. 613-619.

[2]Kilgore, R. A., "The Cryogenic Wind Tunnel for High Reynolds Number Testing," Ph.D. Thesis, Southampton University, England, Feb. 1974; also available as NASA TM X-70207.

[3]Ray, E. J., Kilgore, R. A., Adcock, J. B., and Davenport, E. E., "Analysis of Validation Tests of the Langley Pilot Transonic Cryogenic Tunnel," NASA TN D-7828, 1975.

[4]Howell, R. R. and McKinney, L. W., "The U.S. 2.5-Meter Cryogenic High Reynolds Number Tunnel," presented at the 10th Congress of the International Council of the Aeronautical Sciences (ICAS), Ottawa, Canada, Oct. 3-9, 1976.

[5]Adcock, J. B., "Real-Gas Effects Associated with One-Dimensional Transonic Flow of Cryogenic Nitrogen," NASA TN D-8274, 1976.

[6]Haut, R. C., "Evaluation of Hydrogen as a Cryogenic Wind Tunnel Test Gas," Ph.D. Dissertation, Old Dominion University, Norfolk, Va., 1977; also available as NASA CR-145186.

Announcement: 1977 Author and Subject Index

The indexes of the five AIAA archive journals (*AIAA Journal, Journal of Aircraft, Journal of Energy, Journal of Hydronautics, Journal of Spacecraft and Rockets*) will be combined and mailed separately early in 1978. In addition, papers appearing in volumes of the *Progress in Astronautics and Aeronautics* book series published in 1977 will be included. Librarians will receive one copy of the index for each subscription which they have. Any AIAA member who subscribes to one or more Journals will receive one index. Additional copies may be purchased by anyone, at $10 per copy, from the Circulation Department, AIAA, Room 730, 1290 Avenue of the Americas, New York, New York 10019. **Remittance must accompany the order.**

Ruth F. Bryans
Director, Scientific Publications