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**EXPERIMENTAL STUDIES OF A LUDWIG TUBE
HIGH REYNOLDS NUMBER TRANSONIC TUNNEL**

R. F. Starr and C. J. Schueler

ARO, Inc.

December 1973

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**VON KÁRMÁN GAS DYNAMICS FACILITY
ARNOLD ENGINEERING DEVELOPMENT CENTER
AIR FORCE SYSTEMS COMMAND
ARNOLD AIR FORCE STATION, TENNESSEE**

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FOREWORD

The study reported herein was conducted by the Arnold Engineering Development Center (AEDC), Air Force Systems Command (AFSC), under Program Element 65802F.

This work was done by ARO, Inc. (a subsidiary of Sverdrup & Parcel and Associates, Inc.), contract operator of AEDC, Arnold Air Force Station, Tennessee. The research covered the period from July 1972 to February 1973, and the manuscript was submitted for publication on July 2, 1973. The ARO Project No. was VD209.

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This technical report has been reviewed and is approved.

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ABSTRACT

A significant justification for a much higher Reynolds number ground test capability in the transonic regime has developed in the past few years. An extensive experimental investigation of a high Reynolds number transonic wind tunnel employing a Ludwieg tube air storage system has been undertaken at the Arnold Engineering Development Center to assess the utility of such a device. The transonic starting process and starting time of this impulse facility have been carefully evaluated, and the spatial and timewise quality of the test section flow has been analyzed. Results from studies of the aerodynamic flow response time at transonic speeds and measurement of the pressure distribution and forces on selected models are presented. Also included are the results from associated studies of the influence of plenum volume on test section flow quality and the acoustic environment of the tunnel exhaust.

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NOMENCLATURE

. 48	A	Cross-sectional area
. 48	A*	Cross-sectional area at sonic point
	A _M	Main starting device effective open area
. 49	A _{PE}	Plenum exhaust effective open area
. 49	A _W	Porous wall effective open area
	a	Speed of sound
. 50	a _{4a}	Speed of sound behind unsteady wave in charge tube
. 51	b	Vehicle wing span
	C _D	Total drag coefficient, drag/q _∞ S _b
. 52	C _{DB}	Base drag coefficient, (p _∞ - p _B)/q _∞
	C _{DF}	Forebody drag coefficient, C _D - C _{DB}
. 52	C _p *	Sonic pressure coefficient
	C _{p_u}	Pressure coefficient on upper surface, (p _L - p _∞)/q _∞
. 53	c	Chord length
	D	Characteristic dimension - hole diameter or model base diameter
. 55	d _s	Sting diameter near the base of the model
	f	Frequency
. 56	h	Height above ground
	h _{HIRT}	Characteristic dimension of full-scale tunnel - test section height
. 57	h _{Pilot}	Characteristic dimension of HIRT Pilot tunnel - test section height

l	Characteristic dimension over which flow must respond
M	Mach number
\bar{M}_p	Average plenum chamber Mach number (from plenum pressures)
\bar{M}_{TS}	Average test section Mach number (from centerline static pipe)
p	Static pressure
\bar{p}	Root-mean-square fluctuating pressure
p_B	Model base pressure
p_L	Local pressure
p_o	Stagnation pressure
p_p	Plenum chamber static pressure
q	Dynamic pressure
Re_c	Length Reynolds number based on chord length, $Re/ft \times c$
Re_D	Length Reynolds number based on model base diameter, $Re/ft \times D$
Re/ft	Unit Reynolds number, $\rho_\infty U_\infty / \mu_\infty$
$Re_{\Delta x}$	Length Reynolds number based on distance to head of unsteady wave, $Re/ft \times \Delta x$
r	Radial distance from exhaust stack
S_b	Model base area
T	Nondimensional flow response time, Thompson number, $t_r U / l$
t	Time
t_r	Flow response time
U	Local flow velocity
U_{4a}	Local flow velocity behind unsteady wave
U_e	Local flow velocity at boundary-layer edge
U_w	Velocity through the porous wall
V_p	Plenum chamber volume
V_T	Test section volume

\dot{W}_{1a}	Flow rate through porous test section wall
\dot{W}_{1b}	Flow rate through plenum exhaust system
\dot{W}_2	Flow rate out of charge tube
\dot{W}_T	Flow rate through main starting device
x	Axial dimension on body or in test section
Y	Vertical height from wall
Z	Spanwise dimension
α	Angle of attack
ΔC_D	Difference between total drag coefficient at any Mach number and coefficient at some reference Mach number
ΔC_{DF}	Difference between forebody drag coefficient at any Mach number and coefficient at some reference Mach number
ΔC_p	Fluctuating pressure coefficient, \bar{p}/q_m
Δt_p	Time between opening of main starting device and opening of plenum exhaust diaphragm
ΔW	Length between head and tail of unsteady wave
Δx	Length from measurement station to head of unsteady wave
δ	Boundary-layer total thickness
δ^*	Boundary-layer displacement thickness
η	Nondimensional semispan location, $Z/(b/2)$
θ	Angular position relative to tunnel axis in the ground plane
μ	Viscosity
ρ	Density
$\sigma \Delta M$	Standard deviation in test section axial Mach number distribution
τ	Time during run, since passage of the head of the unsteady wave, at which thickness measured
τ_w	Test section wall porosity

SUBSCRIPTS

- 4 Charge tube storage condition
- ° Free-stream conditions

