HYPERSONIC RESEARCH PROJECT

Memorandum No. 34
October 1, 1956

THE EFFECT OF A SIMPLE THROAT DISTORTION ON THE
DOWNSTREAM FLOW IN A HYPERSONIC WIND TUNNEL NOZZLE

by
R. E. Oliver
B. E. Cummings

ARMY ORDNANCE CONTRACT NO. DA-04-495-Ord-19
THE EFFECT OF A SIMPLE THROAT DISTORTION ON THE DOWNSTREAM FLOW IN A HYPERSONIC WIND TUNNEL NOZZLE

by

R. E. Oliver
B. E. Cummings

Clark B. Millikan, Director
Guggenheim Aeronautical Laboratory

ARMY ORDNANCE CONTRACT NO. DA-04-495-Ord-19
Army Project No. 5B0306004
Ordnance Project No. TB3-0118
OOR Project No. 1600-PE
ABSTRACT

An experimental investigation was conducted in the GALCIT 2¾" Supersonic Wind Tunnel to determine the effect of a known distortion of the throat section of a hypersonic nozzle on the flow in the region downstream from the throat. The flow in the nozzle with a rectangular throat section was compared with the flow in the same nozzle with the throat region distorted to produce a throat height which varied linearly across the throat section. The flow was investigated by means of Pitot pressure surveys in the horizontal plane of symmetry of the undistorted nozzle.

The magnitude of the effect produced by the throat distortion was observed to be approximately that predicted by one-dimensional isentropic flow relations. However, the sign of the effect was reversed in about the distance required for a curved Mach line to cross the channel.
I. INTRODUCTION

Hypersonic wind tunnel nozzles are designed to operate at stagnation temperatures sufficiently high to prevent condensation of air in the test region. The required stagnation temperature $T_0$ increases rapidly with increasing test section Mach number $M_t$. For example, for a test section Mach number of 6 and a reservoir pressure of 100 psia, the stagnation temperature must be at least 300°F, while for a test section Mach number of 9 and a reservoir pressure of 500 psia, the stagnation temperature must be at least 1050°F. For high Mach number nozzles the high heat transfer rates in the throat region can obviously produce large thermal expansions or distortions of the nozzle material unless this region is either cooled or is made from a material with low thermal expansion properties. Either method of avoiding thermal distortions in the throat region presents a difficult design problem. The amount of throat distortion which can be tolerated is, then, of prime importance to the designer of hypersonic wind tunnel nozzles.

This investigation was undertaken to provide some quantitative information about the effect of a known throat distortion on the flow properties in the region downstream from the throat. The scope of the investigation was to determine the streamwise distance-history of the effect of distortion in the region downstream from the throat.

The nozzle and test section used in this investigation were designed and built by the Jet Propulsion Laboratory staff. The distorted throat configuration was proposed by Dr. Joseph Sternberg of the
Ballistic Research Laboratory, Aberdeen Proving Grounds, Maryland. The authors wish to express their appreciation for the many helpful suggestions and the guidance provided by Dr. C. B. Millikan, Professor L. Lees, and Mr. Toshi Kubota of GALCIT and Dr. P. Wegener of JPL.

II. EXPERIMENTAL EQUIPMENT AND PROCEDURE

A. Description of the Wind Tunnel

The experimental investigation was carried out in the GALCIT 2½ by 3 inch Supersonic Wind Tunnel. This facility is described in Reference 1. Both the Supersonic Wind Tunnel compressor plant and the Hypersonic Wind Tunnel compressor plant were used in a parallel arrangement to operate the wind tunnel.

B. Description of the Test Section

A sketch of the test section configuration is shown in Figure 1. This test section is the same as was used in the investigation of Reference 1. Figure 3 shows the nozzle contour and the location of static pressure orifices. The undistorted throat cross section was 2.6 inches wide and nominally 0.084 inch high. The distorted throat cross section was 2.6 inches wide with the height varying linearly from 0.084 inch to 0.088 inch. The method of producing the distorted nozzle shape is shown in Figure 4. Figure 5 shows the measured throat cross sections both before and after the distortion.
C. Instrumentation

Instrumentation included a model support system with an axial drive mechanism, a nine-tube Pitot pressure rake, a multiple tube mercury manometer with a vacuum reference, a carbon dioxide cooled dew point indicator, a mercury-in-glass thermometer for reading the stagnation temperature, and a Tate-Emery indicator for measuring the reservoir pressure.

The Pitot pressure rake (Figure 2) was made from 0.032 inch O.D. stainless steel tubing. The rake was mounted in the test section so that the center tube remained on the test section axis throughout the horizontal traversing. The other tubes were spaced 0.25 inch apart in the horizontal plane through the tunnel axis.

D. Test Procedure

Transverse Pitot pressure profiles were obtained from the nine tube rake at several axial stations between 2\(\frac{1}{2}\) and 11\(\frac{1}{2}\) inches downstream from the throat. These profiles were obtained first for the undistorted throat. The lower nozzle block was then removed without disturbing the rake mounting. Material was removed by hand from the throat region of this block as indicated in Figure 4. The block was mounted in its original position in the test section, and transverse Pitot pressure profiles were then obtained for the distorted nozzle at the same axial stations as for the undistorted nozzle described above.

Before each test the actual throat height was measured at several transverse positions by pulling lead wires through the throat. This was done after the side plates had been fastened securely in position, and care was taken not to disturb the nozzle block positioning.
after this measurement was made. The results of these measurements are shown in Figure 5.

Static pressures on the centerline of the upper nozzle block were measured at the beginning of each test run with the total head rake in its most rearward position. Two static pressure orifices in the north sideplate at the same axial position and equally spaced above and below the horizontal plane of symmetry were used to indicate symmetry of flow conditions during each run.

All test runs were made at a stagnation pressure of 50 psig, stagnation temperatures between 70 and 90 degrees Fahrenheit, and dew points of the reservoir air near -30 degrees Fahrenheit measured at atmospheric pressure.

III. DISCUSSION OF RESULTS

The results of the Pitot pressure measurements are shown in Figures 6 and 7 for the undistorted and distorted throat regions respectively. The general shapes of the profiles are similar in both figures; however, the profiles of Figure 7 appear to be rotated about a point near the centerline as compared to those of Figure 6 for all profiles downstream from $X = 2.86$ inches. A remarkable feature of the distorted throat Pitot pressure profiles is that they indicate higher Mach numbers downstream from the wider portions of the throat, for all profiles downstream from $X = 2.86$ inches.

The cause of the waviness of the profiles of Figures 6 and 7 is unknown; however, since the same profile shapes remained after the
distortion machining, it is assumed that the cause does not lie in the immediate vicinity of the throat. One possible cause is slight leakage around the static pressure orifices in the upper nozzle block. Inaccessibility of the tubes leading to these orifices prevented positive sealing measures.

In order to show the gross effects of the throat distortion without the effects of the extraneous disturbances, the data points of Figures 6 and 7 were replotted as curves of \( p_o'/p_o \) versus \( X \) for each of the nine Pitot pressure tubes. Smooth curves were then faired through these points. The constant Mach number contours of Figures 8 and 9 were derived from these faired curves. The fairing removed much of the effect of the apparently random waviness in the Pitot pressure profiles. The effect due to the throat distortion is obvious in the slopes of the Mach number contours of Figure 9 in contrast to the nearly zero-slope contours of Figure 8.

The magnitude of the effect of the throat distortion is approximately that predicted by one-dimensional isentropic relations. The approximate axial distortion of the Mach number contours as predicted by one-dimensional theory is indicated on Figure 9 for several stations. Note that only the magnitude of the distortion is approximately the one-dimensional value, while the slopes of the contours are reversed.

In attempting to understand the reversal of the pressure profiles, the linearized supersonic wave equation (Reference 2) was applied to the flow in the plane of symmetry with the Mach number distribution as given by one-dimensional theory (Figure 3). Some of the resultant characteristics (Mach lines) are shown in Figure 10. The scale used
in plotting Figure 10 is the same as that used for Figures 8 and 9 in order to facilitate correlation. With such a symmetrical system of Mach lines, one would expect that a pressure profile at any station would be reversed (and possibly distorted) in the distance required for a Mach line to cross the width of the channel. If Figures 9 and 10 are compared, it is seen that this is approximately the case. After the first reversal (in the neighborhood of X = 4 inches), the Mach lines are quite steep, and are becoming steeper (approaching the flow direction) so that the next reversal of the profile would not occur within the region of this investigation.

REFERENCES


FORWARD MODEL SUPPORT
AND PINION DRIVE

MODEL SUPPORT RACK

REAR MODEL SUPPORT

NOZZLE WIDTH: 2.57"
THROAT RADIUS: 12"
THROAT HEIGHT: 0.084"

SUPPORT BEAM

THROAT HEIGHT: 0.084"
NOZZLE WIDTH: 2.57"
THROAT RADIUS: 12"

FIG. 1
TEST SECTION CONFIGURATION

FORWARD MODEL SUPPORT

THROAT

CUBIC

STRAIGHT LINE

11.695"

3.75"
FIG. 3
ISENTROPIC NOZZLE RELATIONS

MACH NUMBER

STATIC PRESSURE ORIFICES

PRESSURE RATIO

X-INCHES

PRESSURE RATIO

X-INCHES

THROAT

Z-INCHES

PHI
REMOVED IN DISTORTION

TOTAL FAIRING

THROAT $\theta$

SECTION AT THROAT LOOKING UPSTREAM

NOZZLE DISTORTION

FIG 4
FIG. 6

THROAT HEIGHT MEASUREMENTS

- UNDERSTATED
- DISTORTED
APPROX. 2-D IMM Charateristics

\[
\frac{d^2x}{dx^2} = \frac{1}{\sqrt{M_{10} - 1}} \frac{dx}{dx}
\]

For APL-HWT-5W
Distorted Noble
INVESTIGATION

FIG. 10
U. S. Government Agencies

Los Angeles Ordnance District
55 South Grand Avenue
Pasadena, California
Attention: Mr. E. L. Stone
2 copies

Western Division
Office of Scientific Research
Hq., Air Research and Development Command
P. O. Box 2035
Pasadena 2, California
Attention: Dr. Morton Alperin

Office of the Chief of Ordnance
ORDTB - Ballistic Section
The Pentagon
Washington 25, D. C.
Attention: Mr. G. Stetson
2 copies

Office of Ordnance Research
Box CM, Duke Station
Durham, North Carolina
10 copies

Exterior Ballistic Laboratories
Aberdeen Proving Ground
Maryland
Attention: Mr. C. L. Poor

Ballistic Research Laboratories
Aberdeen Proving Ground
Maryland
Attention: Dr. Joseph Sternberg

Commanding General
Headquarters
Air Research and Development Command
P. O. Box 1395
Baltimore 3, Maryland
Attention: RDTRRF

U. S. Naval Ordnance Laboratory
White Oak
Silver Spring 19, Maryland
Attention: Dr. R. K. Lobb

U. S. Naval Ordnance Laboratory
White Oak
Silver Spring 19, Maryland
Attention: Dr. Z. I. Slawsky

Commander
Western Development Division
5760 Arbor Vitae Street
Los Angeles, California
Attention: Brig. Gen. B. A. Schriever

Chief of Ordnance
Department of the Army
Washington 25, D. C.
Attention: ORDTB

For Transmittal To
Department of Commerce
Office of Technical Information

Commanding General
Redstone Arsenal
Huntsville, Alabama
Attention: Technical Library

Commanding General
Redstone Arsenal
Huntsville, Alabama
Attention: Dr. E. Geissler

Air Force Armament Center
Air Research and Development Command
Eglin Air Force Base, Florida
Attention: Technical Library

Navy Department
Bureau of Ordnance
Technical Library
Washington 25, D. C.
Attention: Ad-3
Armed Services Technical Information Agency
Document Service Center
Knott Building
Dayton 2, Ohio
Attention: DSC-SD22
5 copies

Lewis Flight Propulsion Laboratory
National Advisory Committee for Aeronautics
Cleveland Municipal Airport
Cleveland 11, Ohio
Attention: Dr. A. Silverstein

Lewis Flight Propulsion Laboratory
National Advisory Committee for Aeronautics
Cleveland Municipal Airport
Cleveland 11, Ohio
Attention: Dr. J. C. Evvard

Ames Aeronautical Laboratory
National Advisory Committee for Aeronautics
Moffett Field, California
Attention: Mr. H. Julian Allen

Ames Aeronautical Laboratory
National Advisory Committee for Aeronautics
Moffett Field, California
Attention: Dr. D. Chapman

Ames Aeronautical Laboratory
National Advisory Committee for Aeronautics
Moffett Field, California
Attention: Dr. A. C. Charters

Ames Aeronautical Laboratory
National Advisory Committee for Aeronautics
Moffett Field, California
Attention: Mr. A. J. Eggers

Ames Aeronautical Laboratory
National Advisory Committee for Aeronautics
Moffett Field, California
Attention: Dr. M. K. Rubesin

Ames Aeronautical Laboratory
National Advisory Committee for Aeronautics
Moffett Field, California
Attention: Mr. J. R. Stalder

Holomann Air Force Base
Alamogordo, New Mexico
Attention: Dr. G. Eber

Langley Aeronautical Laboratory
National Advisory Committee for Aeronautics
Langley Field, Virginia
Attention: Mr. M. Bertram

Langley Aeronautical Laboratory
National Advisory Committee for Aeronautics
Langley Field, Virginia
Attention: Dr. A. Buseman

Langley Aeronautical Laboratory
National Advisory Committee for Aeronautics
Langley Field, Virginia
Attention: Mr. C. McLellan

Langley Aeronautical Laboratory
National Advisory Committee for Aeronautics
Langley Field, Virginia
Attention: Mr. John Stack

National Advisory Committee for Aeronautics
1512 H Street, N. W.
Washington 25, D. C.
Attention: Dr. H. L. Dryden, Director

National Bureau of Standards
Department of Commerce
Washington 25, D. C.
Attention: Dr. G. B. Schubauer

Naval Ordnance Laboratory
White Oak
Silver Spring, Maryland
Attention: Dr. H. Kurzweg

U. S. Naval Air Missile Test Center
Point Mugu, California
Attention: Mr. J. H. Carrington, Chief Engineer

U. S. Naval Ordnance Test Station
China Lake
Inyokern, California
Attention: Mr. Howard R. Kelly, Head Aerodynamics Branch, Code 5032
Universities and Non-Profit Organizations

Brown University
Graduate Division of Applied Mathematics
Providence 12, Rhode Island
Attention: Prof. W. Prager

Brown University
Graduate Division of Applied Mathematics
Providence 12, Rhode Island
Attention: Dr. R. Probstein

University of California at Berkeley
Berkeley, California
Attention: Prof. S. A. Schaaf

University of California at Los Angeles
Department of Engineering
Los Angeles 24, California
Attention: Dr. L. M. K. Boelter

Case Institute of Technology
Cleveland, Ohio
Attention: Dr. G. Kuerti

Catholic University of America
Department of Physics
Washington 17, D. C.
Attention: Prof. K. F. Herzfeld

Cornell Aeronautical Laboratory
Buffalo, New York
Attention: Dr. A. Flax

Cornell Aeronautical Laboratory
Buffalo, New York
Attention: Dr. Ira G. Ross, Director

Cornell University
Graduate School of Aeronautical Engineering
Ithaca, New York
Attention: Dr. W. R. Sears

Harvard University
Department of Applied Physics and Engineering Science
Cambridge 38, Massachusetts
Attention: Dr. A. Bryson

Harvard University
Department of Applied Physics and Engineering Science
Cambridge 38, Massachusetts
Attention: Dr. H. W. Emmons

University of Illinois
Department of Aeronautical Engineering
Urbana, Illinois
Attention: Prof. C. H. Fletcher

Iowa Institute of Hydraulic Research
State University of Iowa
Iowa City, Iowa
Attention: Prof. R. R. Kam

The Johns Hopkins University
Applied Physics Laboratory
8621 Georgia Avenue
Silver Spring, Maryland
Attention: Dr. E. A. Bonney

The Johns Hopkins University
Applied Physics Laboratory
8621 Georgia Avenue
Silver Spring, Maryland
Attention: Dr. F. N. Frenkel

The Johns Hopkins University
Department of Aeronautical Engineering
Baltimore 18, Maryland
Attention: Dr. F. H. Clauser

The Johns Hopkins University
Department of Aeronautical Engineering
Baltimore 18, Maryland
Attention: Dr. L. Kovasznay

The Johns Hopkins University
Department of Mechanical Engineering
Baltimore 18, Maryland
Attention: Dr. S. Corrsin

Lehigh University
Physics Department
Bethlehem, Pennsylvania
Attention: Dr. R. Emrich

University of Maryland
Department of Aeronautical Engineering
College Park, Maryland
Attention: Dr. S. F. Shen

University of Maryland
Institute of Fluid Dynamics and Applied Mathematics
College Park, Maryland
Attention: Director

University of Maryland
Institute of Fluid Dynamics and Applied Mathematics
College Park, Maryland
Attention: Dr. H. T. Yang
Massachusetts Institute of Technology
Cambridge 39, Massachusetts
Attention: Dr. Z. Kopal

Massachusetts Institute of Technology
Cambridge 39, Massachusetts
Attention: Dr. A. H. Shapiro

Massachusetts Institute of Technology
Department of Aeronautical Engineering
Cambridge 39, Massachusetts
Attention: Prof. J. R. Markham

Massachusetts Institute of Technology
Department of Aeronautical Engineering
Cambridge 39, Massachusetts
Attention: Prof. G. Stever

University of Michigan
Ann Arbor, Michigan
Attention: H. P. Liepmann

University of Michigan
Department of Aeronautical Engineering
East Engineering Building
Ann Arbor, Michigan
Attention: Dr. Arnold Kuethe

University of Michigan
Department of Aeronautical Engineering
East Engineering Building
Ann Arbor, Michigan
Attention: Prof. W. C. Nelson

University of Michigan
Department of Physics
Ann Arbor, Michigan
Attention: Dr. O. Laporte

University of Minnesota
Department of Aeronautical Engineering
Minneapolis 14, Minnesota
Attention: Prof. J. D. Akerman

University of Minnesota
Department of Aeronautical Engineering
Minneapolis 14, Minnesota
Attention: Dr. C. C. Chang

University of Minnesota
Department of Aeronautical Engineering
Minneapolis 14, Minnesota
Attention: Dr. F. Hermann

University of Minnesota
Department of Mechanical Engineering
Division of Thermodynamics
Minneapolis, Minnesota
Attention: Dr. E. R. G. Eckert

New York University
Department of Aeronautics
University Heights
New York 53, New York
Attention: Dr. J. F. Ludloff

New York University
Institute of Mathematics and Mechanics
45 Fourth Street
New York 53, New York
Attention: Dr. R. W. Courant

North Carolina State College
Department of Engineering
Raleigh, North Carolina
Attention: Prof. R. M. Pinkerton

Ohio State University
Aeronautical Engineering Department
Columbus, Ohio
Attention: Prof. A. Tifford

Ohio State University
Aeronautical Engineering Department
Columbus, Ohio
Attention: Prof. G. L. von Eschen

Pennsylvania State College
Department of Aeronautical Engineering
State College, Pennsylvania
Attention: Prof. M. Lessen

Polytechnic Institute of Brooklyn
Aerodynamic Laboratory
527 Atlantic Avenue
Freeport, New York
Attention: Dr. A. Ferri

Polytechnic Institute of Brooklyn
Aerodynamic Laboratory
527 Atlantic Avenue
Freeport, New York
Attention: Dr. P. Libby

Princeton University
Forrestal Research Center
Princeton, New Jersey
Attention: Library
Princeton University
Institute for Advanced Study
Princeton, New Jersey
Attention: Dr. John von Neumann

Princeton University
Aeronautics Department
Forrestal Research Center
Princeton, New Jersey
Attention: Prof. S. Bogdonoff

Princeton University
Aeronautics Department
Forrestal Research Center
Princeton, New Jersey
Attention: Dr. L. Crocco

Princeton University
Aeronautics Department
Forrestal Research Center
Princeton, New Jersey
Attention: Prof. Wallace Hayes

Princeton University
Palmer Physical Laboratory
Princeton, New Jersey
Attention: Dr. W. Bleakney

Princeton University
Palmer Physical Laboratory
Princeton, New Jersey
Attention: Dr. W. Griffith

Purdue University
School of Aeronautical Engineering
Lafayette, Indiana
Attention: Librarian

Rensselaer Polytechnic Institute
Aeronautics Department
Troy, New York
Attention: Dr. R. P. Harrington

Rensselaer Polytechnic Institute
Aeronautics Department
Troy, New York
Attention: Dr. T. Y. Li

Rouss Physical Laboratory
University of Virginia
Charlottesville, Virginia
Attention: Dr. J. W. Beams

Stanford University
Department of Mechanical Engineering
Palo Alto, California
Attention: Dr. D. Bershader

University of Texas
Defense Research Laboratory
500 East 24th Street
Austin, Texas
Attention: Prof. M. J. Thompson

University of Washington
Department of Aeronautical Engineering
Seattle 5, Washington
Attention: Prof. F. S. Eastman

University of Washington
Department of Aeronautical Engineering
Seattle 5, Washington
Attention: Prof. R. E. Street

University of Wisconsin
Department of Chemistry
Madison, Wisconsin
Attention: Dr. J. O. Hirschfelder

Institute of the Aeronautical Sciences
2 East 64th Street
New York 21, New York
Attention: Library

Midwest Research Institute
4049 Pennsylvania
Kansas City, Missouri
Attention: Mr. M. Goland, Director for Engineering Sciences

National Science Foundation
Washington 25, D. C.
Attention: Dr. J. McMillan

National Science Foundation
Washington 25, D. C.
Attention: Dr. R. Seeger
Industrial Companies

Aeronutronic Systems, Inc.
1234 Air Way
Glendale, California
Attention: Dr. J. Charyk

Aeronutronic Systems, Inc.
1234 Air Way
Glendale, California
Attention: Dr. L. Kovana

Aerophysics Development Corp.
P. O. Box 949
Santa Monica, California
Attention: Librarian

ARO, Inc.
P. O. Box 162
Tullahoma, Tennessee
Attention: Mr. R. Smelt

ARO, Inc.
Tullahoma, Tennessee
Attention: Dr. B. Goethert

AVCO Manufacturing Corp.
2385 Revere Beach Parkway
Everett 49, Massachusetts
Attention: Library

AVCO Manufacturing Corp.
2385 Revere Beach Parkway
Everett 49, Massachusetts
Attention: Dr. A. Kantrowitz

Bell Aircraft Corp.
Aerodynamics Section
P. O. Box 1
Buffalo 5, New York
Attention: Dr. Joel S. Isenberg

Bell Aircraft Corp.
P. O. Box 1
Buffalo 5, New York
Attention: Mr. R. J. Woods

Boeing Airplane Company
P. O. Box 3107
Seattle 14, Washington
Attention: Mr. G. Snyder

Chance Vought Aircraft, Inc.
P. O. Box 5907
Dallas, Texas
Attention: Mr. J. R. Clark

Chance Vought Aircraft, Inc.
P. O. Box 5907
Dallas, Texas
Attention: Dr. R. Wilson

CONVAIR
Division of General Dynamics Corp.
San Diego 12, California
Attention: Mr. C. Bossart

CONVAIR
Division of General Dynamics Corp.
San Diego 12, California
Attention: Mr. W. H. Dorrance
Dept. 1-16

CONVAIR
Division of General Dynamics Corp.
San Diego 12, California
Attention: Mr. W. B. Mitchell

CONVAIR
Division of General Dynamics Corp.
Fort Worth 1, Texas
Attention: Mr. W. B. Fallis

CONVAIR
Division of General Dynamics Corp.
Fort Worth 1, Texas
Attention: Mr. E. B. Maske

CONVAIR
Division of General Dynamics Corp.
Fort Worth 1, Texas
Attention: Mr. W. G. McMullen

CONVAIR
Division of General Dynamics Corp.
Fort Worth 1, Texas
Attention: Mr. R. H. Widmer

Cooperative Wind Tunnel
950 South Raymond Avenue
Pasadena, California
Attention: Mr. F. Felberg

Cooperative Wind Tunnel
950 South Raymond Avenue
Pasadena, California
Attention: Mr. E. I. Pritchard

Douglas Aircraft Company
Santa Monica, California
Attention: Mr. J. Gunkel

Douglas Aircraft Company
Santa Monica, California
Attention: Mr. Ellis Lapin
Douglas Aircraft Company
Santa Monica, California
Attention: Mr. H. Luskin

Douglas Aircraft Company
Santa Monica, California
Attention: Dr. W. B. Oswald

General Electric Company
Research Laboratory
Schenectady, New York
Attention: Dr. H. T. Nagamatsu

General Electric Company
Campbell Avenue Plant
Schenectady, New York
Attention: Mr. G. Metcalf

The Glenn L. Martin Company
Baltimore 3, Maryland
Attention: Mr. G. S. Trimble, Jr.

Grumman Aircraft Engineering Corp.
Bethpage, New York
Attention: Mr. C. Tilgner, Jr.

Hughes Aircraft Company
Culver City, California
Attention: Dr. A. E. Puckett

Lockheed Aircraft Corp.
Missiles Division
Van Nuys, California
Attention: Library

Marquardt Aircraft Company
P. O. Box 2013 - South Annex
Van Nuys, California
Attention: Dr. P. D. Arthur

McDonnell Aircraft Corp.
Lambert-St. Louis Municipal Airport
P. O. Box 516
St. Louis 3, Missouri
Attention: Mr. K. Perkins

North American Aviation, Inc.
Aeronautical Laboratory
Downey, California
Attention: Dr. E. R. Van Driest

Northrop Aircraft, Inc.
1001 East Broadway
Hawthorne, California
Attention: Mr. E. Schmued

Ramo-Wooldridge Corporation
409 East Manchester Blvd.
Inglewood, California
Attention: Dr. M. U. Clauser

Ramo-Wooldridge Corporation
409 East Manchester Blvd.
Inglewood, California
Attention: Dr. Louis G. Dunn

The RAND Corporation
1700 Main Street
Santa Monica, California
Attention: Librarian

The RAND Corporation
1700 Main Street
Santa Monica, California
Attention: Dr. C. Gazley

The RAND Corporation
1700 Main Street
Santa Monica, California
Attention: Mr. E. P. Williams

Republic Aviation Corporation
Conklin Street
Farmingdale, L. I., New York
Attention: Dr. W. J. O'Donnell

United Aircraft Corporation
East Hartford, Connecticut
Attention: Mr. J. G. Lee
Douglas Aircraft Company
Santa Monica, California
Attention: Mr. H. Luskin

Douglas Aircraft Company
Santa Monica, California
Attention: Dr. W. B. Oswald

General Electric Company
Research Laboratory
Schenectady, New York
Attention: Dr. H. T. Nagamatsu

General Electric Company
Campbell Avenue Plant
Schenectady, New York
Attention: Mr. G. Metcalf

The Glenn L. Martin Company
Baltimore 3, Maryland
Attention: Mr. G. S. Trimble, Jr.

Grumman Aircraft Engineering Corp.
Bethpage, New York
Attention: Mr. C. Tilgner, Jr.

Hughes Aircraft Company
Culver City, California
Attention: Dr. A. E. Puckett

Lockheed Aircraft Corp.
Missiles Division
Van Nuys, California
Attention: Library

Marquhardt Aircraft Company
P. O. Box 2013 - South Annex
Van Nuys, California
Attention: Dr. P. D. Arthur

McDonnell Aircraft Corp.
Lambert-St. Louis Municipal Airport
P. O. Box 516
St. Louis 3, Missouri
Attention: Mr. K. Perkins

North American Aviation, Inc.
Aeronautical Laboratory
Downey, California
Attention: Dr. E. R. Van Driest

Northrop Aircraft, Inc.
1001 East Broadway
Hawthorne, California
Attention: Mr. E. Schmued

Ramo-Wooldridge Corporation
409 East Manchester Blvd.
Inglewood, California
Attention: Dr. M. U. Clauser

Ramo-Wooldridge Corporation
409 East Manchester Blvd.
Inglewood, California
Attention: Dr. Louis G. Dunn

The RAND Corporation
1700 Main Street
Santa Monica, California
Attention: Librarian

The RAND Corporation
1700 Main Street
Santa Monica, California
Attention: Dr. C. Gazley

The RAND Corporation
1700 Main Street
Santa Monica, California
Attention: Mr. E. P. Williams

Republic Aviation Corporation
Conklin Street
Farmingdale, L. I., New York
Attention: Dr. W. J. O'Donnell

United Aircraft Corporation
East Hartford, Connecticut
Attention: Mr. J. G. Lee
Internal

Jet Propulsion Laboratory
4800 Oak Grove Drive
Pasadena 2, California
Attention: Reports Group

Mr. Frank Goddard
Dr. John Laufer
Dr. Peter P. Wegener
Jet Propulsion Laboratory

Dr. W. D. Rannie,
Goddard Professor
Jet Propulsion Center
California Institute of Technology

Dr. Julian D. Cole
Dr. Donald E. Coles
Dr. P. A. Lagerstrom
Prof. Lester Lees
Dr. H. W. Liepmann
Dr. Clark B. Millikan
Dr. Anatol Roshko

Foreign Distribution

via AGARD Distribution Centers

Aeronautics Library
Hypersonic Staff and Research Workers (20)
Hypersonic Files (3)