NASA SP-321

FREE TURBULENT SHEAR FLOWS

Volume II—Summary of Data

A conference held at
LANGLEY RESEARCH CENTER
Hampton, Virginia
July 20–21, 1972

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

NASA SP-321

FREE TURBULENT SHEAR FLOWS

Volume II—Summary of Data

Proceedings of a conference held at
NASA Langley Research Center, Hampton, Virginia, July 20-21, 1972

Prepared by NASA Langley Research Center

Scientific and Technical Information Office 1973
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
Washington, D.C.

THE PROCEEDINGS OF THIS CONFERENCE ARE DEDICATED TO

MITCHEL H. BERTRAM

1924 – 1972

Head, Hypersonic Aircraft Fluid Mechanics Branch
Hypersonic Vehicles Division
NASA Langley Research Center
Hampton, Virginia

PREFACE

The Langley Working Conference on Free Turbulent Shear Flows was held at NASA Langley Research Center July 20-21, 1972. The general format for this conference was based on the 1968 AFOSR-IFP-Stanford Conference on the "Computation of Turbulent Boundary Layers." There were, however, some major differences, primarily in the range and quality of the data used. The objectives of the Langley conference were

(1) To collect and process a set of reliable data for a variety of free mixing problems

(2) To assess the present theoretical capability for predicting mean velocity, concentration, and temperature distributions in free turbulent flows and to identify those methods which hold the most promise for future development

(3) To identify and recommend future experimental studies which might significantly advance the knowledge of free shear flows and, if possible, to assign a priority to these experiments

(4) To increase the understanding of the basic turbulent mixing process for application to free shear flows

In order to accomplish these objectives, the available prediction methods for free shear flows were confronted with a set of standardized data. The resulting computations together with the discussions and the reports of the conference committees constitute Volume I of these proceedings. The standardized data, which were used as test cases, are given in Volume II. A short introductory paper by James M. Eggers and Stanley F. Birch which summarizes the data and outlines the selection procedure used is also included in Volume II.

Virtually all the discussion which followed the papers has been retained with minimal editing. Transcripts of the discussions were sent to the speakers only when the session chairmen or the conference committee believed that this was desirable to improve clarity. The Langley personnel responsible for editing the discussion and prediction papers in Volume I for technical clarity were Stanley F. Birch, David H. Rudy, and Dennis M. Bushnell. Those responsible for compiling the data of Volume II were Stanley F. Birch and James M. Eggers.

CONTENTS

INTRODUCTION

The purpose of this paper is to summarize the data used in the Langley Working Conference on Free Turbulent Shear Flows. The "predictors" were asked to compute flows corresponding to these data and present their results in a specified manner. The results of their computations, together with the invited papers and reports of the evaluation committees, are given in Volume I of this publication. The criteria and procedures used in the data selection will be outlined herein followed by a brief summary of the data. It is hoped that this summary and the test-case data descriptions will be helpful to the reader in deciding for himself the weight that should be given to the agreement, or lack thereof, of a prediction method with a particular set of data. Predictors may find the data discussion helpful, as it is suggested that these data are representative of the range of conditions to which a turbulent mixing model should be applied before concluding that the model is indeed an advance in the state of the art.

DATA SELECTION CRITERIA

The criteria used in the data selection were directly related to the overall conference objective of evaluating the state of the art in the prediction of free turbulent shear flows. One of the basic concepts was that the data selected should be broad in scope and relevant to areas of current research interest. These areas have been outlined by Bushnell in paper no. 1 of Volume I of this publication. Consistent with these broad scope requirements, it was felt that the test cases should include single and compound jets, wakes, and flows with variations in temperature and density at both subsonic and supersonic speeds for planar and axisymmetric geometries. It was obviously not practical to include all possible combinations of these flows over the range of interest. However, every effort was made to insure that the test cases as a whole would provide a critical test of a turbulence model's basic ability to deal with the various types of flows. Other features considered desirable for the test-case data were redundant measurements, clearly specified boundary conditions, measured initial profiles, an analysis of possible errors and tabulated data. (In view of the difficulty encountered in locating data which satisfied these criteria, experimentalists might well take these factors into consideration when planning future experiments.) Where possible, ducted flows were avoided to eliminate possible confinement effects.

Clearly some of these preconceived criteria were too idealistic for much of the available data, and all desired criteria were probably never satisfied in any particular data set. Once into the selection process, it often developed that the strongest factor which influenced the selection of a particular set of data was the favorable experience of the members of the NASA Langley Conference Committee or the Data Selection Committee with that set of data, or in many cases, simply availability. The latter cannot be over-emphasized, for in most cases, the choice of suitable data was very limited.

In the selection of test cases, particular emphasis was given to shear layers in the near-field region of a jet. The primary reason for the emphasis on shear layers was the belief that they would provide a more stringent test of a turbulence model's ability to predict the effect of Mach number, density ratio, and initial conditions on the flow-field development than computations in the far field. A secondary reason for emphasizing the shear layer was to draw attention to the confusion which exists in interpreting experimental results for these flows and to stimulate future work toward a solution of these problems.

DATA SELECTION PROCEDURE

The procedure used in selecting the test cases was briefly as follows. The NASA Langley Conference Committee first formulated a suggested list of experimental references and sent this list to the members of the Data Selection Committee in preparation for a data selection meeting. At a meeting of the two committees a final set of test data was agreed on. Then the Langley Conference Committee, with the help of the Data Selection Committee, obtained the original data for these experiments and prepared brief descriptions of the experiments to accompany the data. Some further checks on the consistency of the data were also performed. After being reviewed by the Data Selection Committee, these test cases were sent to the predictors.

The point to be made from this discussion of the selection procedure is that neither the Data Selection Committee nor the Langley Conference Committee guarantees the absolute accuracy of the data. This is due to the complexity of many of the flows and the difficulty of determining the accuracy of the experimental techniques used to obtain the data. The data selected by the Committees are presented not as the absolute answer to everyone's data needs but as a set of data believed to be reasonably accurate and consistent with the state of the art. Recognizing the uncertainties in the data, the test cases were employed as a basis for discussing prediction methods, rather than an absolute measure of the accuracy of the predictions. Consistent with this view, predictors were encouraged to give constructive criticism of the data and to make suggestions which they believe would help in future experimental work.

DATA SUMMARY

The selected data consist of 17 primary test cases and an additional 7 optional test cases. Some of the optional test cases are simply additional cases, included to broaden the range of the data, whereas others are more difficult flows included to give predictors an opportunity to demonstrate the power of their method.

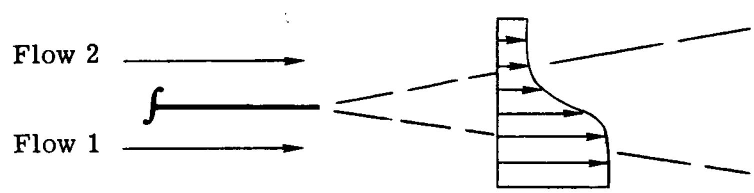
At this point it seems appropriate to note that many turbulence models are still in the development stage or were designed to deal with specific flows. Therefore, it was expected that some models would not be applicable to all the test cases. It was also recognized that prior time commitments might prohibit some predictors from attempting all the flows to which their model was applicable. However, predictors were urged to compute as many of the flows as possible.

For this summary the test cases have been divided into five categories. Certain objectionable features of particular sets of data, which have been noted by the Langley Conference Committee or the Data Selection Committee are given in the data descriptions. However, it is not intended to infer that these data are necessarily worse than others or that other test-case data do not have uncertainties of comparable magnitude.

Two-Dimensional Free Shear Layers

The first category is the two-dimensional free shear layers. The test cases in this category are listed in table 1. Data correlation figures requested from predictors for each test case are given in the section "Specific Figures Requested for Each Test Case."

TABLE 1.- TEST CASES FOR TWO-DIMENSIONAL FREE SHEAR LAYERS



Reference	Test case	Velocity ratio, u_2/u_1	Density ratio, ρ_2/ρ_1	Mach number
----------	1	0, 0.2, 0.4, 0.6, 0.8	Constant density	Incompressible
----------	2	0 (single jet)	$\frac{T_{t,2}}{T_{t,1}} = 1.0$	1, 2, 3, 4, 5
----------	3	0.2 (constant)	14, 1/2, 1/7, 1/14	------------
Lee	4	0.35	1.0	$\frac{M_2}{M_1} = \frac{0.05}{0.14}$
Hill & Page	5	0	----------------	2.09

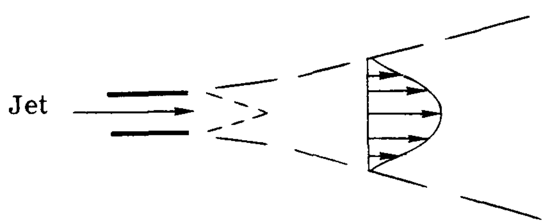
Note that the first three test cases (actually 14 calculations) are purely theoretical and have been specified without reference to any particular experimental data. These three test cases were selected to identify the effects of velocity ratio, Mach number, and density ratio predicted by the various turbulence models, on the mixing in fully developed shear layers. No experimental data were specified for comparison with these predictions because of the general uncertainty which existed in the interpretation of current data. The committees also anticipated that knowledge of these flows would substantially increase before the conference, due in part to experimental studies that were already underway at the time. Because of this uncertainty, a critical review of two-dimensional shear-layer data was undertaken by the present authors. The results of this study are given in paper no. 2 of Volume I of this publication.

Test cases 4 and 5 (complete references for each test case are given in the "Index to Test Cases") were selected as examples of the initial nonsimilar mixing region of free shear layers. Test case 4 is subsonic and test case 5 is a Mach 2.09 supersonic shear layer. Because of the difficulties in formulating boundary conditions for these flows, predictors were asked to concentrate on computing the shape of the velocity profiles.

Axisymmetric Jets Into Still Air

Mach number and temperature ranges for the jets in this second category (axisymmetric jets into still air) are shown in table 2. The Mach numbers range from low speed to Mach 2.22 and the temperature from room temperature to 1222° K. The specific data are the Mach 0.6 jet data of Maestrello and McDaid, test case 6, the Mach 2.22 jet data of Eggers, test case 7, and the Mach 0.7, 667° K jet data of Heck, test case 8.

TABLE 2.- TEST CASES FOR AXISYMMETRIC JETS INTO STILL AIR



Reference	Test case	Mach number	Temperature
Maestrello & McDaid	6	~0.60	Room temp.
Eggers	7	2.22	Room temp.
Heck	8	0.70	667° K
Wygnanski & Fiedler	18	Low speed	Room temp.
Heck	19	1.36	1222° K

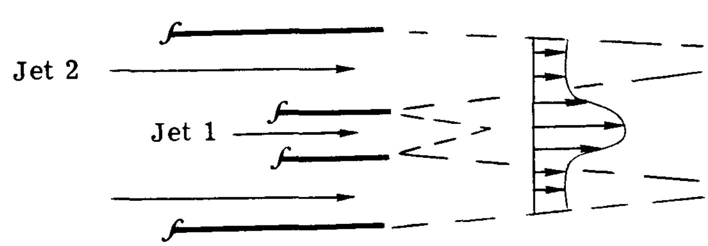
This category also contains two optional test cases; the data used were the low-speed self-preserving jet data of Wygnanski and Fiedler, test case 18, and the Mach 1.36, 1222° K high-temperature jet data of Heck, test case 19.

Jets in Moving Streams

Homogenous flows.- Velocity ratio, temperature ratio, and Mach number for flows in the third category (jets in moving streams (homogenous flows)) are given in table 3. (Mach numbers given in this and the following tables were computed by assuming a temperature of 294° K (70° F) when the reference noted room-temperature flows.) The velocity ratios in these test cases range from 0.25 to 5.05, whereas the bulk of the data is subsonic with a temperature ratio near unity. The data selected consist of the low-speed jet data of Forstall and Shapiro, test case 9, the supersonic nonsimilar jet data of Eggers and Torrence, test case 11, and the two-dimensional jet data of Bradbury, test case 13. Test cases 9 and 13 were chosen because measurements were carried further downstream than in other available experiments and test case 11 was chosen to illustrate the importance of initial conditions.

Two optional test cases were also selected; the data for these two cases were the subsonic data of Chriss and Paulk, test case 20, and the low-speed compound jet data of Champagne and Wygnanski, test case 23. In test cases 9 and 11, trace gases were employed to map the mixing of the jets giving predictors an opportunity to demonstrate

TABLE 3.- TEST CASES FOR JETS IN MOVING STREAMS (HOMOGENOUS FLOWS)



Reference	Test case	Velocity ratio, u_2/u_1	Mach number ratio, M_2/M_1	Temperature ratio, $T_{t,2}/T_{t,1}$
Forstall & Shapiro	9	0.25	0.03/0.10	1.0
Eggers & Torrence	11	1.36	1.30/0.90	1.0
Bradbury	13	0.30	--------	1.0
Chriss & Paulk	20	0.48	0.15/0.34	0.9
Champagne & Wygnanski	23	5.05	0.20/0.04	1.0

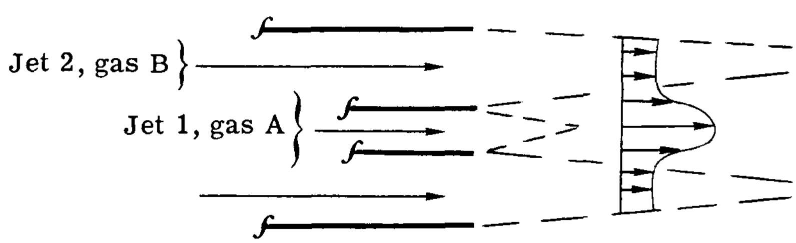
their ability to predict mass as well as momentum transfer. Interestingly, no suitable data were found for the case of a supersonic jet in a supersonic stream.

Heterogenous flows.- The velocity, temperature, and density ratios of the flows for the fourth category (jets in moving streams (heterogenous flows)) are summarized in table 4 and range from 0.16 to 0.55, 1.00 to 1.91, and 7.69 to 25.1, respectively. The Mach numbers range from moderate subsonic to Mach 2.50. All the test cases in this category are nonreactive hydrogen-air mixing studies.

The data for the flows selected include the subsonic hydrogen-air data of Chriss, test case 10, and the Mach 1.32 air, near-sonic hydrogen data of Eggers, test case 12. For the subsonic hydrogen-air test cases, the data of Chriss were considered the best available. The only choice to be made was which set of the data of Chriss to use. For the supersonic test case, the data of Eggers were the only data available.

The data for the optional flows are the subsonic heated air, cold hydrogen data of Chriss, test case 21, and the Mach 2.5 air, near-sonic hydrogen data of Eggers, test case 22.

TABLE 4.- TEST CASES FOR JETS IN MOVING STREAMS (HETEROGENOUS FLOWS)

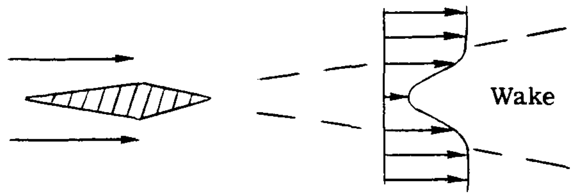


Reference	Test case	Velocity ratio, u_2/u_1	Temperature ratio, $T_{t,2}/T_{t,1}$	Mach number ratio, M_2/M_1	Density ratio, ρ_2/ρ_1
Chriss	10	0.16	1.18	0.42/0.80	11.11
Eggers	12	0.37	1.00	1.32/0.89	15.80
Chriss	21	0.31	1.91	0.47/0.57	7.69
Eggers	22	0.55	1.04	2.50/0.91	25.10

Wake Flows

The wake flows (fifth category), summarized in table 5, include two subsonic and two supersonic flows. In each case one flow was planar and the other was axisymmetric. The wake developing from the turbulent boundary layers on both sides of a flat plate by Chevray and Kovasznay, test case 14, and Chevray's axisymmetric wake, test case 15,

TABLE 5.- TEST CASES FOR WAKES



Reference	Test case	Mach number	Geometry of generator
Chevray & Kovasznay	14	Low speed	Flat plate
Chevray	15	Low speed	Prolate spheroid
Demetriades	16	2.88	Steel ribbon
Demetriades	17	2.93	Rod (parallel to flow)
Demetriades	24	2.85	Heated wedge

were selected for the low-speed flows. The two sets of supersonic wake data were both obtained by Demetriades, test cases 16 and 17.

The one optional test case in this category is also by Demetriades. This flow, test case 24, is similar to the supersonic two-dimensional wake except that transition was moved downstream by heating the wedge. This test case was selected to emphasize the interest in transitional flows, even though the computation of these flows was considered beyond the state of the art.

REMARKS ON USE OF DATA

A final word of caution about the test data seems to be in order here. The data descriptions are of necessity abbreviated discussions. For the purposes of the conference, these descriptions and data were supplied to those actively working on free turbulent shear flow problems and already familiar with a significant portion of the data. It is recommended that researchers initiating efforts into the analysis of turbulent shear flows obtain and study the original references before using the test-case data as given herein.

INDEX TO TEST CASES

Two-Dimensional Shear Layers:

1. Spreading parameter for a fully developed free turbulent shear layer for velocity ratios u_2/u_1 of 0, 0.2, 0.4, 0.6, and 0.8.
2. Spreading parameter for a fully developed free turbulent shear layer with a velocity ratio u_2/u_1 of 0 for Mach numbers of 1.0, 2.0, 3.0, 4.0, and 5.0.
3. Spreading parameter for a fully developed free turbulent shear layer with a velocity ratio u_2/u_1 of 0.2 and density ratios ρ_2/ρ_1 of 14, 1/2, 1/7, and 1/14.
4. Lee, Shen Ching: A Study of the Two-Dimensional Free Turbulent Mixing Between Converging Streams With Initial Boundary Layers. Ph. D. Diss., Univ. of Washington, 1966.
5. Hill, W. G., Jr.; and Page, R. H.: Initial Development of Turbulent, Compressible, Free Shear Layers. Trans. ASME, Ser. D: J. Basic Eng., vol. 91, no. 1, Mar. 1969, pp. 67-73.

Axisymmetric Jets Into Still Air:

6. Maestrello, L.; and McDaid, E.: Acoustic Characteristics of a High-Subsonic Jet. AIAA J., vol. 9, no. 6, June 1971, pp. 1058-1066.
7. Eggers, James M.: Velocity Profiles and Eddy Viscosity Distributions Downstream of a Mach 2.22 Nozzle Exhausting to Quiescent Air. NASA TN D-3601, 1966.
8. Heck, P. H.: Jet Plume Characteristics of 72-Tube and 72-Hole Primary Suppressor Nozzles. T.M. No. 69-457 (FAA Contract FA-SS-67-7), Flight Propulsion Div., Gen. Elec. Co., July 1969.

Jets in Moving Stream:

9. Forstall, Walton, Jr.; and Shapiro, Ascher H.: Momentum and Mass Transfer in Coaxial Gas Jets. J. Appl. Mech., vol. 17, no. 4, Dec. 1950, pp. 399-408.
10. Chriss, D. E.: Experimental Study of the Turbulent Mixing of Subsonic Axisymmetric Gas Streams. AEDC-TR-68-133, U.S. Air Force, Aug. 1968. (Available from DDC as AD 672 975.)
11. Eggers, James M.; and Torrence, Marvin G.: An Experimental Investigation of the Mixing of Compressible-Air Jets in a Coaxial Configuration. NASA TN D-5315, 1969.
12. Eggers, James M.: Turbulent Mixing of Coaxial Compressible Hydrogen-Air Jets. NASA TN D-6487, 1971.
13. Bradbury, L. J. S.: The Structure of a Self-Preserving Turbulent Plane Jet. J. Fluid Mech., vol. 23, pt. 1, Sept. 1965, pp. 31-64.

Wakes:

14. Chevray, René; and Kovasznay, Leslie S. G.: Turbulence Measurements in the Wake of a Thin Flat Plate. AIAA J., vol. 7, no. 8, Aug. 1969, pp. 1641-1643.

15. Chevray, R.: The Turbulent Wake of a Body of Revolution. Trans. ASME, Ser. D: J. Basic Eng., vol. 90, no. 2, June 1968, pp. 275-284.

16. Demetriades, Anthony: Turbulent Mean-Flow Measurements in a Two-Dimensional Supersonic Wake. Phys. Fluids, vol. 12, no. 1, Jan. 1969, pp. 24-32.

17. Demetriades, Anthony: Mean-Flow Measurements in an Axisymmetric Compressible Turbulent Wake. AIAA J., vol. 6, no. 3, Mar. 1968, pp. 432-439.

Optional Test Cases:

18. Wygnanski, I.; and Fiedler, H.: Some Measurements in the Self-Preserving Jet. J. Fluid Mech., vol. 38, pt. 3, Sept. 18, 1969, pp. 577-612.

19. Heck, P. H.: Jet Plume Characteristics of 72-Tube and 72-Hole Primary Suppressor Nozzles. T.M. No. 69-457 (FAA Contract FA-SS-67-7), Flight Propulsion Div., Gen. Elec. Co., July 1969.

20. Chriss, D. E.; and Paulk, R. A.: An Experimental Investigation of Subsonic Coaxial Free Turbulent Mixing. AEDC-TR-71-236, AFOSR-72-0237TR, U.S. Air Force, Feb. 1972. (Available from DDC as AD 737 098.)

21. Chriss, D. E.: Experimental Study of the Turbulent Mixing of Subsonic Axisymmetric Gas Streams. AEDC-TR-68-133, U.S. Air Force, Aug. 1968. (Available from DDC as AD 672 975.)

22. Eggers, James M.: Turbulent Mixing of Coaxial Compressible Hydrogen-Air Jets. NASA TN D-6487, 1971.

23. Champagne, F. H.; and Wygnanski, I. J.: Coaxial Turbulent Jets. D1-82-0958, Flight Sci. Lab., Boeing Sci. Res. Lab., Feb. 1970. (Available from DDC as AD 707 282.)

24. Demetriades, Anthony: Observations on the Transition Process of Two-Dimensional Supersonic Wakes. AIAA J., vol. 9, no. 11, Nov. 1971, pp. 2128-2134.

SYMBOLS

D	nozzle diameter
l	parameter used to adjust velocity profiles (see test case 9)
M	Mach number
m	molecular weight
p	pressure
R	Reynolds number
r	nozzle radius
$r_{1/2}$	velocity half-radius
T	temperature
u	velocity in the x-direction
$\overline{u'v'}$	time average velocity fluctuation product
$\sqrt{\overline{u'^2}}, \sqrt{\overline{v'^2}}, \sqrt{\overline{w'^2}}$	root-mean-square velocity fluctuations
w	velocity expressed as $1 - \frac{u_{\mathfrak{c}}}{u_e}$
x_1, x_2	coordinates along X-axis used to define the spreading parameter (see test case 1)
x	longitudinal coordinate
y_1, y_2	coordinates along Y-axis used to define the spreading parameter (see test case 1)
y	transverse coordinate
α	mass concentration

β	survey rake rotation angle (see test cases 8 and 19)
δ	boundary-layer thickness based on velocity
θ	boundary-layer momentum thickness
ν	kinematic viscosity
ρ	local density
σ	spreading parameter (see test case 1)
σ_o	value of σ when $u_2 = 0$

Subscripts:

℄	center-line value
e	free-stream value or value in outer jet for coannular jet mixing
o	value at nozzle
t	stagnation value
1	value on high velocity side of shear layer
2	value on low velocity side of shear layer

SPECIFIC FIGURES REQUESTED FOR EACH TEST CASE

The figures requested from the predictors for each test case are as follows:

Test case	Correlation figures requested
1	Spreading-parameter ratio σ_0/σ plotted against u_2/u_1 for $u_2/u_1 = 0$, 0.2, 0.6, and 0.8
2	Spreading parameter σ plotted against Mach number for $M_1 = 1.0$, 2.0, 3.0, 4.0, and 5.0
3	Spreading parameter σ plotted against density ratio ρ_1/ρ_2 for constant u_2/u_1 of 0.2 and $\rho_1/\rho_2 = 14$, 1/2, 1/7, and 1/14
4	Velocity profiles u/u_1 and shear-stress profiles $\overline{u'v'}/{u_1}^2$ at downstream stations x of 12.7 cm (5 in.) and 76 cm (30 in.)
5	Velocity profiles u/u_1 at downstream stations x of 5.56 cm (2.19 in.) and 20.96 cm (8.25 in.)
6	Center-line velocity distribution $u_{℄}/u_o$ as a function of x/r
7	Center-line velocity distribution $u_{℄}/u_o$ plotted against x/r
	Velocity profiles u/u_e plotted against y/r at x/r = 8.0, 27, and 99
8	Center-line velocity $u_{℄}/u_o$ and total temperature $T_{t,℄}/T_{t,o}$ plotted against x/D
9	Center-line velocity $u_{℄}/u_o$ plotted against x/D
10	Center-line velocity $u_{℄}/u_o$ and center-line concentration $\alpha_{℄}$ plotted against x/D
11	Center-line velocity $u_{℄}/u_e$ plotted against x/D
12	Center-line velocity $u_{℄}/u_o$ and center-line concentration $\alpha_{℄}$ plotted against x/D
13	Center-line velocity $u_{℄}/u_o$ plotted against x/D
14	Center-line velocity distribution $1/w^2$ plotted against x/θ with $\theta = 0.58$ cm
15	Center-line velocity distribution $1/w^{3/2}$ plotted against x/D
16	Center-line velocity distribution $1/w^2$ plotted against x/D with D = 0.00909 cm
17	Center-line velocity distribution $1/w^{3/2}$ plotted against x/D with D = 0.3962 cm
18	Velocity profiles $u/u_{℄}$ plotted against y/x
19	Center-line velocity distribution $u_{℄}/u_o$ plotted against x/D
20	Center-line velocity distribution $(u_{℄} - u_e)/(u_o - u_e)$ and center-line concentration $\alpha_{℄}$ plotted against x/D
21	Center-line velocity distribution $(u_{℄} - u_e)/(u_o - u_e)$ and center-line concentration $\alpha_{℄}$ plotted against x/D
22	Center-line velocity distribution $(u_{℄} - u_e)/(u_o - u_e)$ and center-line concentration $\alpha_{℄}$ plotted against x/D
23	Velocity profiles u/u_e plotted against y/D at downstream stations x/D of 0.124, 2.14, 6.05, and 17.9
24	Center-line velocity distribution $1/w^2$ plotted against x/D with D = 0.00909 cm

TEST CASE DESCRIPTION

AND DATA

Test Case 1

Classification: Two-dimensional shear layer

Description of flow: For test case 1, predictors are asked to compute the spreading parameter σ for a subsonic constant density two-dimensional fully developed free turbulent shear layer for velocity ratios u_2/u_1 of 0, 0.2, 0.4, 0.6, and 0.8. The subscript 2 refers to the low velocity side of the shear layer and the subscript 1 refers to the high velocity side. In order to avoid any possible confusion in the definition of σ, predictors are asked to use the following definition for their computations:

$$\sigma = \frac{1.855(x_2 - x_1)}{y_2 - y_1}$$

where y_1 and y_2 are the distances between the points at which $\frac{u - u_2}{u_1 - u_2}$ is 0.1 and 0.9 at stations x_1 and x_2. Both stations x_1 and x_2 should be in the fully developed self-similar region of the flow and sufficiently separated to insure accuracy in the computation. It is well known that the computed value of σ can vary by as much as 10 percent depending on the matching procedure used. The numerical constant in the above definition is based on the tabulated shear-layer profile reported by Halleen[1] and it gives values of σ comparable with those based on other methods reported in the literature.

[1] Halleen, R. M.: A Literature Review on Subsonic Free Turbulent Shear Flow. AFOSR-TN-5444, U.S. Air Force, Apr. 1964. (Available from DDC as AD 606 758.)

Test Case 2

Classification: Two-dimensional shear layer

Description of flow: For test case 2, predictors are asked to compute the spreading parameter σ for a two-dimensional fully developed free turbulent shear layer with a velocity ratio u_2/u_1 of 0 for Mach numbers of 1.0, 2.0, 3.0, 4.0, and 5.0. The total temperatures on both sides of the shear layer should be assumed to be equal. The spreading parameter σ is defined in the same way as in test case 1.

Test Case 3

Classification: Two-dimensional shear layer

Description of flow: For test case 3, predictors are asked to compute the spreading parameter σ for a subsonic two-dimensional fully developed free turbulent shear layer with a velocity ratio u_2/u_1 of 0.2 for density ratios ρ_2/ρ_1 of 14, 1/2, 1/7, and 1/14. The subscript 2 again refers to conditions on the low velocity side of the shear layer and the spreading parameter σ is defined as in test case 1. Predictors should indicate the differences, if any, predicted by their method between flows in which the density difference in the two streams is a result of a temperature difference and flows in which the density difference is a result of a difference in the molecular weight of the gases.

Test Case 4

Classification: Two-dimensional shear layer

Reference: Lee, Shen Ching: A Study of the Two-Dimensional Free Turbulent Mixing Between Converging Streams With Initial Boundary Layers. Ph. D. Diss., Univ. of Washington, 1966.

Description of flow: This study of two-stream mixing has been chosen as an example of the initial nonsimilar mixing region. The two streams were initially separated by a symmetric airfoil with a 10° trailing edge. Each channel was 25.4 cm (10 in.) high and 17.78 cm (7 in.) wide at the exit where mixing started. Two parallel plates 121.9 cm (48 in.) long were placed on the top and bottom of the two-dimensional airfoil and extended downstream to maintain the two dimensionality of the flow. The mixing region was open on the other two sides. The mean velocities were computed from pitot- and static-pressure measurements. The static pressures for the mixing region were measured by wall static-pressure taps on the top plate. The turbulence measurements were made with a hot-wire anemometer using a commercial x-probe. The data are reproduced here from the original computer printout and there is a small variation in the value of u_1 used to nondimensionalize the velocity at the different x stations. This is apparently due to small experimental variations in the test conditions.

Test case 4 data:

Classification: Two-dimensional shear layer

Source: Childs, M. E.: Univ. of Washington, Private Communication

x = 0.10 cm (0.04 in.)

y		u		u/u_1
cm	in.	m/sec	ft/sec	
-9.1	-3.6	48.8365	160.2248	1.0000
-8.1	-3.2	48.8100	160.1377	.9994
-7.1	-2.8	48.7879	160.0652	.9990
-6.1	-2.4	48.7347	159.8908	.9979
-5.1	-2.0	48.6904	159.7454	.9970
-4.8	-1.9	48.6771	159.7017	.9967
-4.6	-1.8	48.6593	159.6435	.9964
-4.3	-1.7	48.6327	159.5562	.9958
-4.1	-1.6	48.6194	159.5125	.9955
-3.8	-1.5	48.5883	159.4105	.9949
-3.6	-1.4	48.5661	159.3376	.9944
-3.0	-1.2	48.4905	159.0895	.9929
-2.8	-1.1	48.4020	158.7991	.9911
-2.5	-1.0	48.3484	158.6234	.9900
-2.3	-.9	48.0559	157.6636	.9840
-2.0	-.8	47.4217	155.5831	.9710
-1.8	-.7	45.6268	149.6941	.9343
-1.5	-.6	43.0866	141.3604	.8822
-1.3	-.5	39.6422	130.0597	.8117
-1.0	-.4	36.5158	119.8026	.7477
-.8	-.3	32.9927	108.2437	.6756
-.5	-.2	28.8910	94.7866	.5916
-.3	-.1	24.7118	81.0756	.5060
-0.0	-0.0	12.9368	42.4435	.2649
0.0	0.0	11.7282	38.4783	.2401
.3	.1	9.5016	31.1733	.1946
.5	.2	10.9391	35.8895	.2240
.8	.3	12.0328	39.4778	.2464

y		u		u/u_1
cm	in.	m/sec	ft/sec	
1.0	0.4	13.2136	43.3516	0.2706
1.3	.5	14.3120	46.9555	.2931
1.5	.6	15.1925	49.8442	.3111
1.8	.7	15.4841	50.8007	.3171
2.0	.8	15.9448	52.3124	.3265
2.3	.9	16.2360	53.2677	.3324
2.5	1.0	16.4056	53.8243	.3359
2.8	1.1	16.5736	54.3753	.3394
3.0	1.2	16.6121	54.5018	.3402
3.3	1.3	16.6506	54.6280	.3409
3.6	1.4	16.6634	54.6700	.3412
3.8	1.5	16.7018	54.7958	.3420
4.1	1.6	16.7273	54.8796	.3425
4.3	1.7	16.7655	55.0049	.3433
4.6	1.8	16.7909	55.0883	.3438
4.8	1.9	16.8036	55.1300	.3441
5.1	2.0	16.8290	55.2132	.3446
6.1	2.4	16.9048	55.4621	.3461
7.1	2.8	16.9804	55.7100	.3477
8.1	3.2	17.0306	55.8746	.3487
9.1	3.6	17.0806	56.0387	.3497
10.2	4.0	17.1056	56.1206	.3503
11.2	4.4	17.1180	56.1615	.3505
12.2	4.8	17.1429	56.2432	.3510
13.2	5.2	17.1429	56.2432	.3510
14.2	5.6	17.1429	56.2432	.3510
15.2	6.0	17.1429	56.2432	.3510
16.3	6.4	16.6386	54.5886	.3407

x = 1.27 cm (0.50 in.)

y		u		u/u_1
cm	in.	m/sec	ft/sec	
-8.1	-3.2	48.6682	159.6726	1.0001
-7.1	-2.8	48.6505	159.6144	.9997
-6.1	-2.4	48.6061	159.4688	.9988
-5.1	-2.0	48.5350	159.2355	.9974
-4.8	-1.9	48.5261	159.2063	.9972
-4.6	-1.8	48.5038	159.1333	.9967
-4.3	-1.7	48.4816	159.0603	.9963
-4.1	-1.6	48.4593	158.9872	.9958
-3.8	-1.5	48.4370	158.9141	.9954
-3.6	-1.4	46.4014	158.7971	.9946
-3.3	-1.3	48.3791	158.7240	.9942
-3.0	-1.2	48.3478	158.6215	.9935
-2.8	-1.1	48.2680	158.3596	.9919
-2.5	-1.0	48.2233	158.2128	.9910
-2.3	-.9	48.1080	157.8345	.9886
-2.0	-.8	47.5596	156.0355	.9773
-1.8	-.7	45.9605	150.7892	.9445
-1.5	-.6	43.5331	142.8250	.8946
-1.3	-.5	40.8996	134.1849	.8405
-1.0	-.4	37.2879	122.3355	.7662
-.8	-.3	33.6685	110.4608	.6919
-.5	-.2	29.9889	98.3888	.6163
-.3	-.1	26.3049	86.3022	.5406
-0.0	-0.0	20.1127	65.9864	.4133
0.0	0.0	19.6847	64.5822	.4045
.3	.1	9.4787	31.0981	.1948
.5	.2	10.1721	33.3731	.2090
.8	.3	11.6366	38.1777	.2391
1.0	.4	13.0836	42.9251	.2689
1.3	.5	13.9958	45.9179	.2876
1.5	.6	14.9235	48.9616	.3067
1.8	.7	15.5661	51.0698	.3199
2.0	.8	16.0245	52.5737	.3293
2.3	.9	16.2226	53.2239	.3334
2.5	1.0	16.2751	53.3961	.3344
2.8	1.1	16.4574	53.9940	.3382
3.0	1.2	16.4832	54.0789	.3387
3.3	1.3	16.5349	54.2485	.3398
3.6	1.4	16.5736	54.3753	.3406
3.8	1.5	16.5993	54.4596	.3411
4.1	1.6	16.6378	54.5859	.3419
4.3	1.7	16.6634	54.6700	.3424
4.6	1.8	16.6890	54.7539	.3430
4.8	1.9	16.7145	54.8377	.3435
5.1	2.0	16.7528	54.9632	.3443
6.1	2.4	16.8163	55.1716	.3456
7.1	2.8	16.8670	55.3378	.3466
8.1	3.2	16.9048	55.4621	.3474
9.1	3.6	16.9553	55.6275	.3484
10.2	4.0	17.0181	55.8335	.3497
11.2	4.4	17.0431	55.9156	.3502
12.2	4.8	17.0931	56.0797	.3513
13.2	5.2	17.1429	56.2432	.3523
14.2	5.6	17.1429	56.2432	.3523
15.2	6.0	17.1429	56.2432	.3523
16.3	6.4	16.5101	54.1671	.3393

x = 2.54 cm (1.00 in.)

y		u		u/u_1
cm	in.	m/sec	ft/sec	
-8.1	-3.2	48.5382	159.2459	1.0001
-7.1	-2.8	48.5159	159.1729	.9996
-6.1	-2.4	48.4758	159.0414	.9988
-5.1	-2.0	48.1840	158.0840	.9928
-4.8	-1.9	48.3867	158.7490	.9970
-4.6	-1.8	48.3688	158.6904	.9966
-4.3	-1.7	48.3510	158.6318	.9962
-4.1	-1.6	48.3242	158.5439	.9957
-3.8	-1.5	48.2885	158.4267	.9949
-3.6	-1.4	48.2750	158.3827	.9947
-3.3	-1.3	48.2572	158.3240	.9943
-3.0	-1.2	48.1906	158.1057	.9929
-2.8	-1.1	48.1195	157.8723	.9914
-2.5	-1.0	48.0483	157.6387	.9900
-2.3	-.9	47.9680	157.3752	.9883
-2.0	-.8	47.7138	156.5413	.9831
-1.8	-.7	46.6390	153.0150	.9609
-1.5	-.6	44.2051	145.0300	.9108
-1.3	-.5	41.1717	135.0776	.8483
-1.0	-.4	38.0701	124.9019	.7844
-.8	-.3	34.5881	113.4781	.7126
-.5	-.2	31.1818	102.3024	.6425
-.3	-.1	27.5332	90.3319	.5673
-0.0	-0.0	22.1114	72.5440	.4556
0.0	0.0	22.1114	72.5440	.4556
.3	.1	13.7974	45.2672	.2843
.5	.2	10.6635	34.9853	.2197
.8	.3	11.8190	38.7764	.2435
1.0	.4	12.0156	39.4213	.2476
1.3	.5	13.9967	45.9209	.2884
1.5	.6	14.7955	48.5417	.3048
1.8	.7	15.5534	51.0281	.3205
2.0	.8	15.8518	52.0071	.3266
2.3	.9	16.0255	52.5771	.3302
2.5	1.0	16.2237	53.2274	.3343
2.8	1.1	16.3935	53.7845	.3378
3.0	1.2	16.4065	53.8272	.3380
3.3	1.3	16.4584	53.9975	.3391
3.6	1.4	16.4843	54.0825	.3396
3.8	1.5	16.5102	54.1673	.3402
4.1	1.6	16.5360	54.2520	.3407
4.3	1.7	16.5489	54.2943	.3410
4.6	1.8	16.5875	54.4210	.3418
4.8	1.9	16.6004	54.4632	.3420
5.1	2.0	16.6260	54.5474	.3426
6.1	2.4	16.6901	54.7575	.3439
7.1	2.8	16.7539	54.9667	.3452
8.1	3.2	16.8047	55.1336	.3462
9.1	3.6	16.8807	55.3829	.3478
10.2	4.0	16.9186	55.5071	.3486
11.2	4.4	16.9815	55.7136	.3499
12.2	4.8	17.0191	55.8371	.3507
13.2	5.2	17.0567	55.9603	.3514
14.2	5.6	17.1067	56.1242	.3525
15.2	6.0	17.1316	56.2060	.3530
16.3	6.4	16.6397	54.5922	.3428

x = 5.08 cm (2.00 in.)

y		u		u/u1
cm	in.	m/sec	ft/sec	
-9.1	-3.6	48.4274	158.8826	1.0003
-8.1	-3.2	48.4140	158.8387	1.0000
-7.1	-2.8	48.4051	158.8094	.9999
-6.1	-2.4	48.3694	158.6923	.9991
-5.1	-2.0	48.3247	158.5457	.9982
-4.8	-1.9	48.3158	158.5164	.9980
-4.6	-1.8	48.2979	158.4578	.9976
-4.3	-1.7	48.2800	158.3991	.9973
-4.1	-1.6	48.2711	158.3697	.9971
-3.8	-1.5	48.2398	158.2670	.9964
-3.6	-1.4	48.2219	158.2082	.9961
-3.3	-1.3	48.1995	158.1348	.9956
-3.0	-1.2	48.1726	158.0466	.9950
-2.8	-1.1	48.1059	157.8278	.9937
-2.5	-1.0	48.0347	157.5940	.9922
-2.3	-.9	47.9678	157.3746	.9908
-2.0	-.8	47.5885	156.1301	.9830
-1.8	-.7	46.5746	152.8039	.9620
-1.5	-.6	44.7835	146.9275	.9250
-1.3	-.5	42.2624	138.6561	.8730
-1.0	-.4	39.2677	128.8312	.8111
-.8	-.3	36.1432	118.5799	.7466
-.5	-.2	32.9164	107.9933	.6799
-.3	-.1	29.2714	96.0348	.6046
-0.0	-0.0	24.7695	81.2649	.5116
0.0	0.0	24.7695	81.2649	.5116
.3	.1	19.0303	62.4355	.3931
.5	.2	13.9996	45.9305	.2892
.8	.3	12.2290	40.1214	.2526
1.0	.4	13.0873	42.9374	.2703
1.3	.5	14.0907	46.2294	.2911
1.5	.6	14.7265	48.3154	.3042
1.8	.7	15.4605	50.7235	.3194
2.0	.8	15.9222	52.2382	.3289
2.3	.9	16.0820	52.7627	.3322
2.5	1.0	16.2534	53.3247	.3357
2.8	1.1	16.3969	53.7957	.3387
3.0	1.2	16.5522	54.3050	.3419
3.3	1.3	16.5779	54.3895	.3424
3.6	1.4	16.6036	54.4739	.3430
3.8	1.5	16.6293	54.5581	.3435
4.1	1.6	16.6550	54.6423	.3440
4.3	1.7	16.6678	54.6843	.3443
4.6	1.8	16.6933	54.7682	.3448
4.8	1.9	16.7189	54.8521	.3453
5.1	2.0	16.7444	54.9357	.3459
6.1	2.4	16.7953	55.1027	.3469
7.1	2.8	16.8840	55.3938	.3488
8.1	3.2	16.9093	55.4766	.3493
9.1	3.6	16.9848	55.7245	.3508
10.2	4.0	17.0225	55.8481	.3516
11.2	4.4	17.0476	55.9303	.3521
12.2	4.8	17.1100	56.1353	.3534
13.2	5.2	17.1474	56.2579	.3542
14.2	5.6	17.1474	56.2579	.3542
15.2	6.0	17.1474	56.2579	.3542
16.3	6.4	17.1474	56.2579	.3542

x = 12.70 cm (5.00 in.)

y		u		u/u1
cm	in.	m/sec	ft/sec	
-9.1	-3.6	48.1906	158.1057	0.9991
-8.1	-3.2	48.1906	158.1057	.9991
-7.1	-2.8	48.1771	158.0615	.9988
-6.1	-2.4	48.1592	158.0026	.9984
-5.1	-2.0	48.1457	157.9584	.9982
-4.8	-1.9	48.1412	157.9436	.9981
-4.6	-1.8	48.0924	157.7834	.9970
-4.3	-1.7	48.0834	157.7538	.9969
-4.1	-1.6	48.0789	157.7391	.9968
-3.8	-1.5	48.1143	157.8552	.9975
-3.6	-1.4	48.0654	157.6948	.9965
-3.3	-1.3	48.0609	157.6800	.9964
-3.0	-1.2	48.0609	157.6800	.9964
-2.8	-1.1	48.0119	157.5195	.9954
-2.5	-1.0	47.9675	157.3736	.9945
-2.3	-.9	47.9184	157.2127	.9934
-2.0	-.8	47.8694	157.0517	.9924
-1.8	-.7	47.3718	155.4193	.9821
-1.5	-.6	46.0419	151.0562	.9545
-1.3	-.5	44.1922	144.9874	.9162
-1.0	-.4	41.8555	137.3213	.8677
-.8	-.3	38.9993	127.9504	.8085
-.5	-.2	36.2125	118.8075	.7508
-.3	-.1	33.4488	109.7403	.6935
-0.0	-0.0	30.0116	98.4631	.6222
0.0	0.0	29.9788	98.3556	.6215
.3	.1	26.3491	86.4473	.5463
.5	.2	23.0743	75.7030	.4784
.8	.3	19.7955	64.9459	.4104
1.0	.4	17.5121	57.4545	.3631
1.3	.5	15.5815	51.1205	.3230
1.5	.6	15.0249	49.2942	.3115
1.8	.7	15.3057	50.2157	.3173
2.0	.8	15.7176	51.5670	.3259
2.3	.9	15.9863	52.4485	.3314
2.5	1.0	16.1190	52.8838	.3342
2.8	1.1	16.2506	53.3155	.3369
3.0	1.2	16.3941	53.7865	.3399
3.3	1.3	16.5364	54.2533	.3428
3.6	1.4	16.6647	54.6742	.3455
3.8	1.5	16.8047	55.1336	.3484
4.1	1.6	16.8047	55.1336	.3484
4.3	1.7	16.8174	55.1752	.3487
4.6	1.8	16.8301	55.2168	.3489
4.8	1.9	16.8301	55.2168	.3489
5.1	2.0	16.8428	55.2584	.3492
6.1	2.4	16.8807	55.3829	.3500
7.1	2.8	16.9312	55.5485	.3500
8.1	3.2	17.0066	55.7960	.3526
9.1	3.6	17.0817	56.0424	.3541
10.2	4.0	17.1441	56.2469	.3554
11.2	4.4	17.1441	56.2469	.3554
12.2	4.8	17.1441	56.2469	.3554
13.2	5.2	17.1441	56.2469	.3554
14.2	5.6	17.1441	56.2469	.3554
15.2	6.0	17.1441	56.2469	.3554
16.3	6.4	16.1196	52.8858	.3342

x = 25.40 cm (10.00 in.)

y		u		u/u_1
cm	in.	m/sec	ft/sec	
-9.1	-3.6	48.0907	157.7780	0.9956
-8.1	-3.2	48.0862	157.7632	.9956
-7.1	-2.8	48.0862	157.7632	.9956
-6.1	-2.4	48.0771	157.7334	.9954
-5.1	-2.0	48.0726	157.7185	.9953
-4.8	-1.9	48.0771	157.7334	.9954
-4.6	-1.8	48.0771	157.7334	.9954
-4.3	-1.7	48.0771	157.7334	.9954
-4.1	-1.6	48.0771	157.7334	.9954
-3.8	-1.5	48.0771	157.7334	.9954
-3.6	-1.4	48.0817	157.7483	.9955
-3.3	-1.3	48.0817	157.7483	.9955
-3.0	-1.2	48.0817	157.7483	.9955
-2.8	-1.1	48.0369	157.6013	.9945
-2.5	-1.0	48.0414	157.6162	.9946
-2.3	-.9	48.0414	157.6162	.9946
-2.0	-.8	47.9966	157.4691	.9937
-1.8	-.7	47.5459	155.9905	.9844
-1.5	-.6	46.9077	153.8965	.9712
-1.3	-.5	45.4626	149.1554	.9412
-1.0	-.4	44.0189	144.4191	.9113
-.8	-.3	41.8115	137.1770	.8656
-.5	-.2	39.7527	130.4222	.8230
-.3	-.1	37.0620	121.5945	.7673
-0.0	-0.0	34.8464	114.3255	.7214
0.0	0.0	34.6857	113.7981	.7181
.3	.1	32.1702	105.5452	.6660
.5	.2	30.1640	98.9633	.6245
.8	.3	27.3919	89.8685	.5671
1.0	.4	25.6942	84.2987	.5320
1.3	.5	23.3188	76.5052	.4828
1.5	.6	21.2887	69.8449	.4408
1.8	.7	19.5022	63.9835	.4038
2.0	.8	18.5967	61.0128	.3850
2.3	.9	16.8958	55.4323	.3498
2.5	1.0	16.3906	53.7748	.3393
2.8	1.1	16.1253	52.9046	.3338
3.0	1.2	15.9910	52.4640	.3311
3.3	1.3	16.2585	53.3414	.3366
3.6	1.4	16.5346	54.2475	.3423
3.8	1.5	16.6645	54.6736	.3450
4.1	1.6	16.6775	54.7161	.3453
4.3	1.7	16.9341	55.5580	.3506
4.6	1.8	16.9341	55.5580	.3506
4.8	1.9	16.9468	55.5998	.3509
5.1	2.0	16.9596	55.6416	.3511
6.1	2.4	16.9723	55.6833	.3514
7.1	2.8	16.9850	55.7251	.3516
8.1	3.2	16.9977	55.7668	.3519
9.1	3.6	16.9977	55.7668	.3519
10.2	4.0	17.0104	55.8085	.3522
11.2	4.4	17.0231	55.8501	.3524
12.2	4.8	17.0358	55.8917	.3527
13.2	5.2	17.0611	55.9748	.3532
14.2	5.6	17.0864	56.0578	.3537
15.2	6.0	16.8450	55.2657	.3487
16.3	6.4	15.9238	52.2434	.3297

x = 45.72 cm (18.00 in.)

y		u		u/u_1
cm	in.	m/sec	ft/sec	
-5.1	-2.0	48.0842	157.7565	1.0000
-4.8	-1.9	48.0842	157.7565	1.0000
-4.6	-1.8	48.0842	157.7565	1.0000
-4.3	-1.7	48.0842	157.7565	1.0000
-4.1	-1.6	48.0842	157.7565	1.0000
-3.8	-1.5	48.0842	157.7565	1.0000
-3.6	-1.4	48.0842	157.7565	1.0000
-3.3	-1.3	48.0842	157.7565	1.0000
-3.0	-1.2	48.0842	157.7565	1.0000
-2.8	-1.1	48.0842	157.7565	1.0000
-2.5	-1.0	48.0842	157.7565	1.0000
-2.3	-.9	48.0842	157.7565	1.0000
-2.0	-.8	48.0395	157.6098	.9991
-1.8	-.7	47.7703	156.7268	.9935
-1.5	-.6	47.2275	154.9458	.9822
-1.3	-.5	46.4938	152.5387	.9669
-1.0	-.4	45.7483	150.0930	.9514
-.8	-.3	44.3169	145.3966	.9217
-.5	-.2	42.5355	139.5523	.8846
-.3	-.1	40.9920	134.4883	.8525
-0.0	-0.0	39.7681	130.4728	.8271
0.0	0.0	39.3549	129.1171	.8185
.3	.1	37.2199	122.1125	.7741
.5	.2	35.8660	117.6706	.7459
.8	.3	34.1454	112.0255	.7101
1.0	.4	33.0571	108.4549	.6875
1.3	.5	31.3881	102.9793	.6528
1.5	.6	29.9861	98.3797	.6236
1.8	.7	28.4398	93.3064	.5915
2.0	.8	26.9644	88.4659	.5608
2.3	.9	25.4035	83.3447	.5283
2.5	1.0	24.2777	79.6513	.5049
2.8	1.1	22.8160	74.8557	.4745
3.0	1.2	21.7542	71.3721	.4524
3.3	1.3	20.5334	67.3667	.4270
3.6	1.4	19.5678	64.1989	.4069
3.8	1.5	18.5521	60.8664	.3858
4.1	1.6	17.9630	58.9336	.3736
4.3	1.7	17.4774	57.3405	.3635
4.6	1.8	17.3539	56.9353	.3609
4.8	1.9	17.2295	56.5271	.3583
5.1	2.0	17.1042	56.1160	.3557
6.1	2.4	17.1042	56.1160	.3557
7.1	2.8	17.1042	56.1160	.3557
8.1	3.2	17.1042	56.1160	.3557
9.1	3.6	17.1042	56.1160	.3557
10.2	4.0	17.1042	56.1160	.3557
11.2	4.4	17.1042	56.1160	.3557
12.2	4.8	17.1042	56.1160	.3557
13.2	5.2	17.1042	56.1160	.3557
14.2	5.6	17.1042	56.1160	.3557
15.2	6.0	16.7226	54.8642	.3478
16.3	6.4	15.1002	49.5416	.3140

x = 76.20 cm (30.00 in.)

y		u		u/u_1
cm	in.	m/sec	ft/sec	
-4.3	-1.7	48.0905	157.7772	1.0000
-4.1	-1.6	48.0905	157.7772	1.0000
-3.8	-1.5	48.0905	157.7772	1.0000
-3.6	-1.4	48.0905	157.7772	1.0000
-3.3	-1.3	48.0905	157.7772	1.0000
-3.0	-1.2	48.0905	157.7772	1.0000
-2.8	-1.1	48.0905	157.7772	1.0000
-2.5	-1.0	48.0010	157.4837	.9981
-2.3	-.9	47.9114	157.1896	.9963
-2.0	-.8	47.8665	157.0423	.9953
-1.8	-.7	47.5511	156.0077	.9888
-1.5	-.6	47.2792	155.1154	.9881
-1.3	-.5	47.0513	154.3678	.9784
-1.0	-.4	46.3610	152.1031	.9640
-.8	-.3	45.9419	150.7280	.9553
-.5	-.2	45.2822	148.5636	.9416
-.3	-.1	44.6127	146.3671	.9277
-0.0	-0.0	43.6877	143.3325	.9084
0.0	0.0	43.5892	143.0093	.9064
.3	.1	42.5411	139.5707	.8846
.5	.2	41.7764	137.0617	.8687
.8	.3	40.7344	133.6432	.8470
1.0	.4	40.0426	131.3734	.8327
1.3	.5	39.0094	127.9837	.8112
1.5	.6	37.9481	124.5018	.7891
1.8	.7	36.9727	121.3016	.7688
2.0	.8	35.8512	117.6220	.7455
2.3	.9	34.6314	113.6201	.7201
2.5	1.0	33.4956	109.8938	.6965
2.8	1.1	32.3864	106.2547	.6734
3.0	1.2	31.5119	103.3854	.6553
3.3	1.3	30.4010	99.7407	.6322
3.6	1.4	29.2479	95.9577	.6082
3.8	1.5	28.2003	92.5207	.5864
4.1	1.6	27.1123	88.9511	.5633
4.3	1.7	26.1437	85.7732	.5436
4.6	1.8	25.2231	82.7530	.5245
4.8	1.9	24.1790	79.3273	.5028
5.1	2.0	23.2731	76.3552	.4839
6.1	2.4	20.2083	66.3002	.4202
7.1	2.8	18.1934	59.6896	.3783
8.1	3.2	17.3467	56.9118	.3607
9.1	3.6	17.2224	56.5038	.3581
10.2	4.0	17.0971	56.0929	.3555
11.2	4.4	17.0971	56.0929	.3555
12.2	4.8	16.8433	55.2618	.3503
13.2	5.2	16.7157	54.8416	.3476
14.2	5.6	16.1932	53.1273	.3367
15.2	6.0	15.2358	49.9862	.3168

x = 0.10 cm (0.04 in.)

y		$\overline{u'v'}/u_1^2$
cm	in.	
-10.2	-4.0	0.0522×10^{-4}
-5.1	-2.0	.0667
-2.5	-1.0	.0577
-2.3	-.9	.1924
-2.0	-.8	1.0856
-1.8	-.7	4.0686
-1.5	-.6	11.5281
-1.3	-.5	16.4211
-1.0	-.4	19.8858
-.8	-.3	24.6271
-.5	-.2	18.8363
-.3	-.1	22.0788
0.0	0.0	5.5860
.3	.1	-5.8592
.5	.2	-6.1423
.8	.3	-5.7456
1.0	.4	-4.1974
1.3	.5	-3.3885
1.5	.6	-2.2581
1.8	.7	-1.4842
2.0	.8	-.6276
2.3	.9	-.3336
2.5	1.0	-.1916
3.8	1.5	-.0297
5.1	2.0	-.0155

x = 12.70 cm (5.00 in.)

y		$\overline{u'v'}/u_1^2$
cm	in.	
-2.5	-1.0	-0.1784×10^{-4}
-2.3	-.9	1.0843
-2.0	-.8	3.1223
-1.8	-.7	8.6221
-1.5	-.6	16.1590
-1.3	-.5	16.5970
-1.0	-.4	15.4946
-.8	-.3	25.6219
-.5	-.2	25.9399
-.3	-.1	25.0691
0.0	0.0	37.5369
.3	.1	26.2337
.5	.2	28.4453
.8	.3	16.2554
1.3	.5	2.2187
1.5	.6	-1.3991
1.8	.7	-1.3250
2.0	.8	-.8865
2.3	.9	-.5038
2.5	1.0	-.1610
3.0	1.2	-.0360
3.8	1.5	-.0179
5.1	2.0	-.0020
10.2	4.0	-.0051

x = 25.40 cm (10.00 in.)

y		$\overline{u'v'}/u_1^2$
cm	in.	
-10.2	-4.0	-0.2240×10^{-4}
-5.1	-2.0	-.0303
-3.8	-1.5	-.0352
-3.0	-1.2	-.1734
-2.5	-1.0	.5267
-2.3	-.9	2.4639
-2.0	-.8	5.4272
-1.8	-.7	9.2653
-1.5	-.6	10.6248
-1.3	-.5	13.5016
-1.0	-.4	15.8129
-.8	-.3	21.4377
-.5	-.2	31.2691
-.3	-.1	13.9765
0.0	0.0	32.6199
.3	.1	32.8538
.5	.2	52.5665
.8	.3	47.0973
1.0	.4	55.1758
1.3	.5	51.0552
2.0	.8	6.7365
2.3	.9	3.5341
2.5	1.0	.7452
3.0	1.2	-.3229
3.8	1.5	-.1815
5.1	2.0	-.1143
10.2	4.0	-.0352
12.7	5.0	-.0834

x = 45.72 cm (18.00 in.)

y		$\overline{u'v'}/u_1^2$
cm	in.	
-10.2	-4.0	-2.7173×10^{-4}
-5.1	-2.0	-.4893
-3.8	-1.5	-.4519
-3.0	-1.2	-.6833
-2.5	-1.0	.1616
-2.3	-.9	1.4867
-2.0	-.8	3.3478
-1.8	-.7	8.2510
-1.5	-.6	10.1943
-1.3	-.5	15.7403
-1.0	-.4	18.0038
-.8	-.3	22.3155
-.5	-.2	21.2161
.3	.1	55.2291
.5	.2	57.3086
1.0	.4	43.3983
1.3	.5	63.8495
1.5	.6	51.3212
1.8	.7	56.0463
2.0	.8	45.9414
2.3	.9	46.9729
2.5	1.0	29.3057
3.0	1.2	19.3897
3.8	1.5	7.4681
4.3	1.7	1.8910
5.1	2.0	-.1828
6.3	2.5	-.5049
7.6	3.0	-.4070
10.2	4.0	-.4383
12.7	5.0	-.7000

x = 76.20 cm (30.00 in.)

y		$\overline{u'v'}/u_1^2$
cm	in.	
-7.6	-3.0	-14.5380×10^{-4}
-5.1	-2.0	-12.4834
-2.5	-1.0	-3.0465
-2.0	-.8	9.4625
-1.5	-.6	18.5304
-1.0	-.4	21.3927
-.5	-.2	28.7125
0.0	0.0	64.2591
.5	.2	56.1521
1.0	.4	70.8934
1.5	.6	82.5230
2.0	.8	112.9559
2.5	1.0	96.6188
3.0	1.2	106.1242
3.8	1.5	95.8463
5.1	2.0	45.4032
6.3	2.5	6.7797
7.6	3.0	.7611
10.2	4.0	-3.7190

Test Case 5

Classification: Two-dimensional shear layer

Reference: Hill, W. G., Jr.; and Page, R. H.: Initial Development of Turbulent, Compressible, Free Shear Layers. Trans. ASME, Ser. D.: J. Basic Eng., vol. 91, no. 1, Mar. 1969, pp. 67-73.

Description of flow: This shear layer was generated in a 10.16- by 10.16-cm (4 by 4 in.) supersonic blowdown tunnel by adjusting the downstream geometry to give a cavity-type flow. The total temperature was $294^{\circ} \pm 6^{\circ}$ K ($530^{\circ} \pm 10^{\circ}$ R) and the total pressure on the high velocity side of the shear layer was 413.7 kN/m^2 (60.0 psia). The upstream boundary layer was turbulent and the separation shock at the edge of the cavity reduced the free-stream Mach number from 2.31 to 2.09. Velocity profiles were computed from pitot- and static-pressure measurements. In the data reproduced herein there are some instances of slightly different velocities given for the same point; this resulted from combining the data from two runs at each x station except the last. For the last station all the data were taken from a single run.

Test case 5 data:

Classification: Two-dimensional shear layer

Reference: Page, R. H.: Rutgers Univ., Private Communication

x = 2.49 cm (0.98 in.)

y, cm	y, in.	u/u_1
-1.02	-0.40	0.071
-.51	-.20	.083
.00	.00	.094
.00	.00	.148
.05	.02	.207
.13	.05	.276
.13	.05	.267
.15	.06	.302
.18	.07	.376
.20	.08	.361
.23	.09	.385
.23	.09	.432
.25	.10	.458
.25	.10	.470
.28	.11	.472
.38	.15	.593
.38	.15	.571
.51	.20	.730
.51	.20	.716
.64	.25	.823
.76	.30	.858
.76	.30	.856
.89	.35	.895
1.02	.40	.935
1.02	.40	.930
1.14	.45	.955
1.27	.50	.966
1.27	.50	.975
1.52	.60	.981
1.52	.60	.995
1.65	.65	.999
1.78	.70	1.000
1.91	.75	.979
2.03	.80	.952

x = 5.56 cm (2.19 in.)

y, cm	y, in.	u/u_1
-0.20	-0.08	0.054
-.20	-.08	.099
-.08	-.03	.126
.05	.02	.205
.18	.07	.273
.18	.07	.277
.20	.08	.326
.23	.09	.338
.25	.10	.350
.28	.11	.388
.30	.12	.429
.30	.12	.378
.33	.13	.427
.36	.14	.455
.38	.15	.467
.41	.16	.474
.43	.17	.485
.43	.17	.485
.56	.22	.575
.56	.22	.602
.69	.27	.661
.81	.32	.742
1.07	.42	.863
1.07	.42	.856
1.32	.52	.925
1.57	.62	.961
1.57	.62	.965
1.83	.72	.984
1.96	.77	.995
2.08	.82	.993
2.21	.87	.994
2.34	.92	1.000
2.34	.92	1.000
2.46	.97	.998

x = 10.11 cm (3.98 in.)

y		u/u_1
cm	in.	
-0.84	-0.33	0.023
-.46	-.18	.000
-.33	-.13	.032
-.33	-.13	.045
-.20	-.08	.063
-.08	-.03	.104
-.08	-.03	.103
-.03	-.01	.136
.05	.02	.170
.05	.02	.171
.05	.02	.163
.13	.05	.211
.18	.07	.203
.18	.07	.221
.23	.09	.242
.30	.12	.271
.30	.12	.302
.43	.17	.342
.43	.17	.340
.56	.22	.441
.69	.27	.480
.69	.27	.465
.94	.37	.601
.94	.37	.610
1.19	.47	.729
1.19	.47	.728
1.19	.47	.731
1.45	.57	.825
1.45	.57	.822
1.70	.67	.907
1.70	.67	.891
1.96	.77	.938
1.96	.77	.956
2.21	.87	.984
2.34	.92	.953
2.46	.97	.997
2.59	1.02	.999
2.72	1.07	.968
2.72	1.07	1.000
2.84	1.12	1.000
2.97	1.17	.980
2.97	1.17	1.000
3.23	1.27	.966

x = 20.96 cm (8.25 in.)

y		u/u_1
cm	in.	
-0.13	-0.05	0.045
.00	.00	.109
.13	.05	.145
.25	.10	.175
.38	.15	.209
.51	.20	.254
.64	.25	.274
.76	.30	.325
.89	.35	.366
1.14	.45	.448
1.52	.60	.588
1.91	.75	.700
2.41	.95	.848
2.79	1.10	.915
2.79	1.10	.920
3.05	1.20	.966
3.30	1.30	.982
3.56	1.40	.991
3.81	1.50	.995
4.06	1.60	.999
4.32	1.70	1.000

Test Case 6

Classification: Axisymmetric jet into still air

Reference: Maestrello, L.; and McDaid, E.: Acoustic Characteristics of a High-Subsonic Jet. AIAA J., vol. 9, no. 6, June 1971, pp. 1058-1066.

Description of flow: The data presented for test case 6 are for an axisymmetric cold jet in still air. The jet exited from a pipe with a partially turbulent shear exit profile. The center-line velocity of the jet was 211 m/sec (693 ft/sec) and the nozzle radius r was 3.1 cm (1.22 in.). The exit velocity profile is not available for this test case and the starting velocity profile is given for $x = 2r$. Due to the relatively high Reynolds number of this jet the mean velocity profile is almost self-similar at this station.

The velocity measurements were made with a constant-temperature hot-wire anemometer and the static pressure was measured with a standard static-pressure tube 0.157 cm (0.062 in.) in diameter. Further details of this experiment are given in the reference document.

Test case 6 data:

Classification: Axisymmetric jet into still air

Source: Maestrello, Lucio: NASA Langley Research Center, Private Communication

$r = 3.1$ cm (1.22 in.); $u_o = 211$ m/sec (693 ft/sec)

Initial profile $x = 2r$

r (cm)	r (in.)	u/u_o
0.254	0.100	1.000
.762	.300	.995
1.524	.600	.982
1.778	.700	.965
2.032	.800	.930
2.286	.900	.860
2.540	1.000	.730
2.794	1.100	.615
3.048	1.200	.465
3.302	1.300	.340
3.556	1.400	.205
3.810	1.500	.085

Center-line value

Velocity

r (cm)	r (in.)	u/u_o
7.75	3.05	1.00
13.61	5.36	1.00
19.81	7.80	.99
24.76	9.75	.98
30.99	12.20	.96
37.46	14.75	.94
43.94	17.30	.85
49.91	19.65	.80
56.01	22.05	.74
63.50	25.00	.64
69.65	27.42	.60
80.52	31.70	.52
94.49	37.20	.44
105.16	41.40	.40
123.70	48.70	.34
137.67	54.20	.30
161.04	63.40	.26
201.17	79.20	.22
244.09	96.10	.18

Static pressure

x (cm)	x (in.)	$\frac{x}{r_o}$	$\frac{\Delta p}{\rho u_o^2}$
18.57	7.31	6.0	0.002
27.94	11.00	9.0	-.003
30.99	12.20	10.0	-.006
37.21	14.65	12.0	-.011
41.78	16.45	13.5	-.018
46.48	18.30	15.0	-.024
54.36	21.40	17.5	-.031
61.98	24.40	20.0	-.036
69.60	27.40	22.5	-.040
78.99	31.10	25.5	-.042
103.63	40.80	33.5	-.043
117.60	46.30	38.0	-.044
131.57	51.80	42.5	-.045
145.54	57.30	47.0	-.046
162.56	64.00	52.5	-.046
193.55	76.20	62.5	-.047
215.14	84.70	69.5	-.047
230.89	90.90	74.5	-.047
261.62	103.00	84.5	-.047

Test Case 7

Classification: Axisymmetric jet into still air

Reference: Eggers, James M.: Velocity Profiles and Eddy Viscosity Distributions Downstream of a Mach 2.22 Nozzle Exhausting to Quiescent Air. NASA TN D-3601, 1966.

Description of flow: The experimental hardware consisted of a circular-cross-section, Mach 2.22 nozzle designed for axial flow at the exit. The nozzle operated at design pressure ratio and exhausted into the quiescent atmosphere with the jet total temperature equal to ambient temperature. Principal measurements consisted of air supply total pressure and total temperature and radial total-pressure surveys. The total-pressure surveys were conducted across the air jet at various axial stations from the nozzle exit plane downstream to 150 nozzle radii. The survey data were reduced to velocity profiles under the assumptions that the total temperature was constant, the profiles were symmetrical, and the static pressure was constant and equal to ambient pressure throughout the flow field. Survey data at the nozzle exit ($x = 0$) and the center-line velocity distribution are given in the following table. In the table, x is the axial coordinate, y is the radial coordinate, u is the local velocity, r is the nozzle radius (1.279 cm), and u_o is the jet exit velocity (538 m/sec). A representative value of the total temperature of the air jet is 292° K.

Test case 7 data:

Classification: Axisymmetric jet into still air

Source: Reference document

Initial profile

x/r = 0.0

y/r	u/u_o
0.0662	1.0020
.1457	1.0010
.2120	1.0030
.2380	1.0030
.3310	1.0030
.4170	1.0030
.5300	.9970
.6420	.9910
.7180	.9910
.7350	.9970
.8610	.9970
.9140	.9970
.9200	.9940
.9269	.9991
.9335	.9698
.9400	.9533
.9434	.9359
.9533	.9169
.9567	.8956
.9599	.8476
.9666	.8200
.9698	.7886
.9732	.7534
.9766	.7336
.9865	.6650
.9897	.6195
.9964	.5278
.9976	.2975
1.0000	0

Center-line velocity distribution

y/r = 0.0

x/r	u/u_o
11.03	1.0068
16.90	.9918
22.92	.9832
24.93	.9577
26.93	.9413
28.93	.9077
30.92	.8800
43.93	.6640
45.94	.6360
47.94	.6083
49.95	.5800
51.96	.5575
61.65	.4525
65.70	.4165
69.73	.3830
73.80	.3568
86.90	.2899
90.86	.2712
94.88	.2569
98.89	.2450
115.3	.1963
121.3	.1857
127.3	.1738
133.6	.1620
149.5	.1454

Test Case 8

Classification: Axisymmetric jet into still air

Reference: Heck, P. H.: Jet Plume Characteristics of 72-Tube and 72-Hole Primary Suppressor Nozzles. T. M. No. 69-457 (FAA Contract FA-SS-67-7), Flight Propulsion Div., Gen. Elec. Co., July 1969.

Description of flow: The primary purpose of the test facility used to generate this data was noise measurement, but capabilities for nozzle and flow-field temperature and pressure measurements were incorporated. The hardware used to generate this data consisted of a conical convergent nozzle 10.92 cm (4.3 in.) in diameter. Gas was supplied to the nozzle from a subscale jet engine simulator capable of producing hot exhaust gases at temperatures up to 1778° K (3200° R). Air was preheated in a burner can and then brought to test conditions in an afterburner section utilizing JP-4 as fuel. Test conditions for the present data correspond to a jet total temperature of 667° K (1200° R) and a pressure ratio of 1.4, which gave a nozzle exit Mach number of 0.7. Measurements of total pressure, total temperature, and static pressure were made by means of a survey rake which could be translated and/or rotated. Temperatures in the outer region of the flow were measured by using chromel-alumel thermocouples, and temperatures in the hot inner core were measured with iridium/iridium-rhodium thermocouples. The latter thermocouples were flame sprayed to eliminate the tendency for the material to act as a catalyst. Pitot-static probes were used in the outer portion of the flow, but only pitot measurements and temperature measurements were made in the innermost area which had a radius of 13.46 cm (5.3 in.). The static pressure in the center portion of the rake was assumed to be the average of the two innermost static probe readings. The resultant velocities are reported to be accurate within ±15 m/sec (±50 ft/sec) and the total temperatures to be no better than ±5 percent with 10 percent error probable. The profile data at 2.79 diameters from the nozzle exit and the center-line values at downstream stations are given in the following table. For analysis, the properties of the jet gas may be approximated by those of air and the static pressure may be assumed constant. In the table, x and y are the axial and radial coordinates, respectively, D is the nozzle diameter, T_t is the measured total temperature, M is the local Mach number, u is the local velocity, and p_t is the local stagnation pressure. Data for only one angular position, β of the survey rake were available for this test condition. The center line (y/D = 0.0) of the source data has been shifted $+0.2 \frac{y}{D}$ to more nearly allow $\frac{y}{D} = 0.0$ to correspond to the center line of the profiles.

Test case 8 data:

Classification: Axisymmetric jet into still air

Source: The data have been read from plots supplied by P. H. Heck, General Electric Co.

Initial profile

x/D = 2.79

y/D	T_t		M	u		P_t	
	°K	°R		m/sec	ft/sec	kN/m^2	psia
-3.590	275	495	0.020	7.0	23.0	100.0	14.50
-3.350	276	497	0.000	0.0	0.0	98.6	14.30
-3.075	272	490	.020	7.0	23.0	98.3	14.25
-2.800	272	490	0.000	0.0	0.0	100.0	14.50
-2.520	272	490	0.000	0.0	0.0	101.4	14.70
-2.150	277	498	0.000	0.0	0.0	102.0	14.80
-1.680	282	508	.028	7.6	25.0	100.0	14.50
-1.350	289	520	.015	4.0	13.0	100.0	14.50
-1.230	297	535	.015	4.6	15.0	99.3	14.40
-1.050	312	562	----	0.0	0.0	98.6	14.30
-.860	367	660	.040	17.7	58.0	97.9	14.20
-.650	433	780	.175	73.2	240.0	102.0	14.80
-.400	561	1010	.523	237.7	780.0	113.2	16.42
0.000	577	1038	.700	318.5	1045.0	138.0	20.02
.230	---	----	.605	298.7	980.0	127.2	18.45
.450	500	900	.390	170.7	560.0	111.0	16.10
.660	431	775	.190	78.6	258.0	102.9	14.93
.825	375	675	.093	36.0	118.0	100.8	14.62
1.275	298	537	.014	5.5	18.0	100.3	14.55
1.740	276	497	0.000	0.0	0.0	100.2	14.53
2.100	272	490	0.000	0.0	0.0	100.1	14.52
2.410	272	490	0.000	0.0	0.0	100.0	14.50
2.675	272	490	0.000	0.0	0.0	100.0	14.50
2.950	272	490	.022	6.7	22.0	99.8	14.48
3.175	278	500	0.000	----	-----	100.0	14.50

x/D = 5.58

y/D	T_t		M	u		p_t	
	°K	°R		m/sec	ft/sec	kN/m²	psia
-3.590	275	495	0.030	12.2	40.0	99.6	14.45
-3.350	275	495	0.000	0.0	0.0	100.3	14.55
-3.075	272	490	.040	12.8	42.0	99.6	14.45
-2.800	272	490	0.000	0.0	0.0	100.0	14.50
-2.520	275	495	0.000	0.0	0.0	100.0	14.50
-2.150	272	490	0.000	0.0	0.0	100.0	14.50
-1.680	289	520	0.000	0.0	0.0	100.0	14.50
-1.350	311	560	0.000	0.0	0.0	100.0	14.50
-1.230	328	590	.065	12.8	42.0	100.0	14.50
-1.050	352	633	.078	29.9	98.0	100.5	14.57
-.860	397	715	.167	67.1	220.0	102.0	14.80
-.650	448	807	.290	121.3	398.0	106.0	15.38
-.400	525	945	.475	212.8	698.0	116.5	16.90
0.000	528	950	.603	267.6	878.0	127.6	18.50
.230	---	---	.500	232.3	762.0	118.5	17.18
.450	479	863	.388	167.6	550.0	110.9	16.08
.660	431	775	.265	109.7	360.0	111.9	16.23
.825	389	700	.182	72.2	237.0	108.9	15.80
1.275	321	578	.025	6.1	20.0	100.0	14.50
1.740	278	500	0.000	0.0	0.0	99.6	14.45
2.100	275	495	0.000	0.0	0.0	99.8	14.47
2.410	272	490	0.000	0.0	0.0	99.8	14.47
2.675	272	490	.020	7.0	23.0	99.8	14.47
2.950	272	490	0.000	0.0	0.0	99.8	14.47
3.175	281	505	0.000	0.0	0.0	100.0	14.50

x/D = 8.38

y/D	T_t		M	u		p_t	
	°K	°R		m/sec	ft/sec	kN/m²	psia
-3.590	272	490	0.020	6.7	22.0	100.0	14.50
-3.350	272	490	0.000	0.0	0.0	100.0	14.50
-3.075	275	495	.040	6.7	22.0	99.6	14.45
-2.800	275	495	0.000	0.0	0.0	100.0	14.50
-2.520	272	490	0.000	0.0	0.0	100.0	14.50
-2.150	281	505	0.000	0.0	0.0	100.0	14.50
-1.680	314	565	0.000	0.0	0.0	100.1	14.52
-1.350	339	610	.070	25.9	85.0	100.5	14.58
-1.230	358	645	.107	37.5	123.0	100.8	14.62
-1.050	377	678	.150	60.4	198.0	101.7	14.75
-.860	411	740	.225	91.4	300.0	103.4	15.00
-.650	439	790	.315	131.1	430.0	106.9	15.50
-.400	478	860	.420	181.4	595.0	112.9	16.38
0.000	472	850	.478	201.2	660.0	117.1	16.98
.230	---	---	.420	182.3	598.0	108.9	15.80
.450	450	810	.355	147.8	485.0	107.2	15.55
.660	422	760	.278	114.3	375.0	104.8	15.20
.825	394	710	.228	89.9	295.0	103.8	15.05
1.275	344	620	.090	31.4	103.0	101.4	14.70
1.740	300	540	.023	7.6	25.0	99.6	14.45
2.100	281	505	0.000	0.0	0.0	100.3	14.55
2.410	278	500	0.000	0.0	0.0	100.0	14.50
2.675	276	497	.020	6.1	20.0	100.0	14.50
2.950	274	493	0.000	0.0	0.0	99.6	14.45
3.175	278	500	0.000	0.0	0.0	100.0	14.50

x/D = 11.17

y/D	T_t		M	u		p_t	
	°K	°R		m/sec	ft/sec	kN/m²	psia
-3.590	275	495	0.033	11.6	38.0	100.3	14.55
-3.350	275	495	0.000	0.0	0.0	100.0	14.50
-3.075	275	495	.023	6.1	20.0	100.0	14.50
-2.800	278	500	0.000	0.0	0.0	99.6	14.45
-2.520	278	500	0.000	0.0	0.0	100.0	14.50
-2.150	289	520	0.000	1.5	5.0	100.0	14.50
-1.680	331	595	.060	22.9	75.0	99.6	14.45
-1.350	350	630	.120	47.2	155.0	100.7	14.60
-1.230	361	650	.150	54.9	180.0	101.4	14.70
-1.050	378	680	.180	68.6	225.0	102.0	14.80
-.860	392	705	.230	91.4	300.0	103.8	15.05
-.650	417	750	.290	120.4	395.0	106.2	15.40
-.400	432	778	.353	145.4	477.0	108.9	15.80
0.000	431	775	.382	157.0	515.0	110.7	16.05
.230	---	---	.358	147.2	483.0	108.9	15.80
.450	411	740	.318	128.0	420.0	107.2	15.55
.660	400	720	.270	108.2	355.0	105.1	15.25
.825	384	692	.238	91.4	300.0	103.4	15.00
1.275	353	635	.130	48.8	160.0	101.4	14.70
1.740	317	570	.060	21.3	70.0	100.1	14.52
2.100	294	530	.025	6.1	20.0	100.0	14.50
2.410	281	505	.025	6.7	22.0	99.6	14.45
2.675	278	500	0.000	0.0	0.0	100.0	14.50
2.950	275	495	.020	6.7	22.0	100.0	14.50
3.175	278	500	0.000	0.0	0.0	100.2	14.53

x/D = 13.95

y/D	T_t		M	u		p_t	
	°K	°R		m/sec	ft/sec	kN/m²	psia
-3.590	272	490	0.000	0.0	0.0	100.3	14.55
-3.350	272	490	0.000	0.0	0.0	100.0	14.50
-3.075	278	500	0.000	0.0	0.0	100.2	14.53
-2.800	281	505	0.000	0.0	0.0	100.2	14.53
-2.520	294	530	.025	6.1	20.0	100.0	14.50
-2.150	311	560	.050	18.3	60.0	100.0	14.50
-1.680	328	590	.108	39.6	130.0	100.7	14.60
-1.350	342	615	.155	57.9	190.0	101.4	14.70
-1.230	350	630	.178	66.1	217.0	101.4	14.70
-1.050	361	650	.200	74.7	245.0	102.4	14.85
-.860	372	670	.232	86.9	285.0	103.4	15.00
-.650	383	690	.267	102.1	335.0	104.8	15.20
-.400	394	710	.300	117.3	385.0	106.2	15.40
0.000	400	720	.313	123.4	405.0	106.9	15.50
.230	---	---	.300	117.3	385.0	106.2	15.40
.450	394	710	.275	108.2	355.0	105.1	15.25
.660	389	700	.245	96.9	318.0	104.7	15.18
.825	378	680	.220	85.3	280.0	103.4	15.00
1.275	354	637	.150	57.9	190.0	101.4	14.70
1.740	322	580	.080	29.9	98.0	100.0	14.50
2.100	303	545	.040	13.7	45.0	100.0	14.50
2.410	296	533	.020	6.1	20.0	100.3	14.55
2.675	281	505	0.000	0.0	0.0	99.6	14.45
2.950	278	500	0.000	0.0	0.0	100.0	14.50
3.175	278	500	0.000	0.0	0.0	100.0	14.50

x/D = 16.74

y/D	T_t		M	u		p_t	
	^oK	^oR		m/sec	ft/sec	kN/m^2	psia
-3.590	278	500	0.000	0.0	0.0	100.0	14.50
-3.350	281	505	0.000	0.0	0.0	100.0	14.50
-3.075	288	518	0.000	0.0	0.0	99.6	14.45
-2.800	294	530	0.000	0.0	0.0	99.6	14.45
-2.520	300	540	.033	10.1	33.0	100.0	14.50
-2.150	311	560	.065	19.8	65.0	100.0	14.50
-1.680	336	605	.110	39.6	130.0	100.3	14.55
-1.350	344	620	.150	54.9	180.0	101.0	14.65
-1.230	354	638	.160	59.4	195.0	102.0	14.80
-1.050	354	638	.173	64.6	212.0	101.9	14.78
-.860	364	655	.195	73.2	240.0	102.4	14.85
-.650	367	660	.225	85.3	280.0	103.4	15.00
-.400	372	670	.250	92.4	303.0	104.1	15.10
0.000	372	670	.265	100.6	330.0	104.6	15.17
.230	---	---	.258	99.1	325.0	104.6	15.17
.450	364	655	.242	90.5	297.0	103.8	15.05
.660	358	645	.223	83.8	275.0	103.3	14.98
.825	356	640	.205	74.7	245.0	102.7	14.90
1.275	339	610	.160	56.4	185.0	101.4	14.70
1.740	325	585	.110	38.1	125.0	99.8	14.47
2.100	311	560	.070	24.4	80.0	100.3	14.55
2.410	300	540	.055	19.8	65.0	100.3	14.55
2.675	292	525	.047	13.7	45.0	100.0	14.50
2.950	289	520	0.000	0.0	0.0	100.0	14.50
3.175	281	505	0.000	0.0	0.0	99.6	14.45

x/D = 19.53

y/D	T_t		M	u		p_t	
	^oK	^oR		m/sec	ft/sec	kN/m^2	psia
-3.590	283	510	0.030	5.5	18.0	99.6	14.45
-3.350	288	518	.031	6.1	20.0	99.6	14.45
-3.075	290	522	.043	15.2	50.0	99.3	14.40
-2.800	294	530	.043	14.3	47.0	99.3	14.40
-2.520	306	550	.059	21.3	70.0	99.6	14.45
-2.150	333	600	.085	30.5	100.0	99.6	14.45
-1.680	334	602	.118	42.7	140.0	100.5	14.58
-1.350	---	---	.155	55.5	182.0	100.7	14.60
-1.230	343	618	.160	61.0	200.0	----	----
-1.050	343	618	.177	64.0	210.0	102.0	14.80
-.860	344	620	.187	68.6	225.0	101.4	14.70
-.650	350	630	.209	77.7	255.0	102.2	14.82
-.400	354	638	.220	80.8	265.0	102.7	14.90
0.000	356	640	.220	82.9	272.0	103.2	14.97
.230	---	---	.217	80.8	265.0	103.2	14.97
.450	352	633	.202	77.7	255.0	102.4	14.85
.660	350	630	.189	69.2	227.0	101.2	14.68
.825	344	620	.172	63.4	208.0	101.7	14.75
1.275	333	600	.140	49.7	163.0	100.7	14.60
1.740	317	570	.096	33.5	110.0	100.3	14.55
2.100	306	550	.068	25.0	82.0	100.3	14.55
2.410	300	540	.054	19.2	63.0	100.0	14.50
2.675	293	528	.048	17.4	57.0	100.3	14.55
2.950	289	520	.020	8.2	27.0	100.7	14.60
3.175	283	510	0.000	0.0	0.0	100.0	14.50

Test Case 9

Classification: Axisymmetric jet in moving stream

Reference: Forstall, Walton, Jr.: Material and Momentum Transfer in Coaxial Gas Streams. Sc. D. Thesis, Massachusetts Inst. Technol., June 1949.

Description of flow: In this study of mass and momentum transfer, mixing took place in a 10.2-cm-diameter (4 in.) copper tube. The tube contained a baffle and rounded entrance to provide a flat uniform velocity profile for the outer flow which streamed in from the room. The outer flow surrounded a center jet flow consisting of room temperature air with about 10 percent by volume of helium added as a tracer. Interchangeable nozzles of either 0.635 cm (1/4 in.) diameter or 2.54 cm (1 in.) diameter were used for the center jet. A pitot-static tube was used for velocity and concentration surveys. Data presented herein correspond to Forstall's Series E experiment with a velocity ratio, outer jet to center jet, u_e/u_o of 0.25. In table I of test case 9 data, the initial velocity profile from figure 28 of the reference corresponding to $x = 0$ (x is the axial coordinate) and the 0.635-cm-diameter (1/4 in.) nozzle is given. In table I, y is the radial coordinate and r is the nozzle radius. The values of u/u_o have been computed from the values of $(u - u_e)/(u_o - u_e)$. It is noted that the minimum velocity occurs at $y/r = 1.1$ on the right side of the nozzle and at $y/r = 1.25$ on the left side of the nozzle. As it was adjudged inconceivable that the minimum velocity could occur at other than $y/r = 1.0$, the initial profiles were shifted such that $u = 0$ at $y = r$. In table I, y_l/r is the position of the minimum velocity point. It is noted that the data from both sides of the nozzle fall reasonably close together on a plot of $(y - y_l)/r$ against u/u_o. Therefore, an adjusted average profile is given in table II, and it is suggested that this latter profile be used for initiating calculations. Also given in table II are the test conditions of the Series E experiment. Center-line velocity and concentration values taken from figure 70 of the reference are given in table III, where D is the center nozzle diameter, $u_{\mathrm{ȼ}}$ is the center-line velocity, $\alpha_{\mathrm{ȼ}}$ is the center-line concentration of helium by volume, and α_o is the concentration of helium supplied in the center jet. Values of the velocity half-radius $r_{1/2}$ are given in table IV. These values were taken from figure 65 of the reference. It should be noted that Forstall made his measurements at $x/D = 2$, 6, and 10 with the 2.54-cm-diameter (1 in.) nozzle and at $x/D = 8$, 24, 40, 56, and 80 with the 0.635-cm-diameter (1/4 in.) nozzle. As the data at $x/D = 8$ correspond to the flow field for which the initial profile is given, these data should be weighted more than the data at $x/D = 10$.

Test case 9 data:

Classification: Axisymmetric jet in moving stream

Source: Peters, C. E.: ARO, Inc., Arnold Eng. Develop. Center, Private Communication

TABLE I.- INITIAL PROFILE DATA FROM FORSTALL's FIGURE 28
[Series E, 0.635 cm (1/4 in.) nozzle]

Right side

y/r	$\frac{u - u_e}{u_o - u_e}$	u/u_o	$\frac{y - y_l}{r}$
0.65	1.00	1.00	-0.45
.70	.99	.993	-.40
.80	.963	.972	-.30
.85	.950	.962	-.25
.90	.92	.94	-.20
.95	.88	.91	-.15
1.00	.50	.63	-.10
1.05	.15	.363	-.05
1.10	-.29	.032	0
1.20	-.17	.122	.10
1.30	-.13	.153	.20
1.50	-.09	.182	.40
1.60	-.077	.192	.50
1.70	-.067	.20	.60
2.00	-.046	.215	.90
2.25	-.032	.226	1.15
2.50	-.022	.234	1.40
2.75	-.012	.241	1.65
3.00	-.005	.246	1.90

Left side

y/r	$\frac{u - u_e}{u_o - u_e}$	u/u_o	$\frac{y - y_l}{r}$
0.80	1.00	1.00	-0.45
.90	.995	.995	-.35
1.00	.90	.925	-.25
1.10	.72	.79	-.15
1.20	0	.25	-.05
1.25	-.27	.048	0
1.30	-.14	.135	.05
1.40	-.108	.169	.15
1.50	-.09	.182	.25
1.75	-.06	.205	.50
2.00	-.041	.219	.75
2.25	-.028	.229	1.00
2.50	-.017	.237	1.25
2.75	-.006	.246	1.50

TABLE II.- CONDITIONS FOR FORSTALL SERIES E EXPERIMENT AND SUGGESTED INITIAL BOUNDARY-LAYER PROFILE

$u_e/u_o = 0.25$

$u_e = 9.14$ m/sec (30 ft/sec)

$u_o = 36.58$ m/sec (120 ft/sec)

Nozzle diameter = 0.635 cm (1/4 in.)

$T_e = T_o$ = Room temperature

Central stream 10% He by volume, $\rho_o/\rho_e = 0.92$

y/r	u/u_o
0	1.00
.5	1.00
.6	.993
.7	.978
.8	.938
.9	.63
1.0	0
1.1	.135
1.2	.165
1.3	.180
1.4	.190
1.5	.199
1.6	.205
1.7	.211
1.8	.217
1.9	.221
2.0	.225
2.2	.232
2.4	.238
2.6	.243
2.8	.248
3.0	.250

TABLE III.- CENTER-LINE DECAY

x/D	$\frac{u_{\mathfrak{c}} - u_e}{u_o - u_e}$	$\alpha_{\mathfrak{c}}/\alpha_o$
2	1.00	1.00
6	.99	.96
8.2	.80	.76
* 10	.82	.73
24	.30	.285
41	.18	.167
56	.129	.120
80	.089	.079

* Suggest omitting.

TABLE IV.- VELOCITY HALF-RADIUS

x/D	$\frac{r_{1/2}}{r}$
2	1.04
6	1.05
8.1	1.16
10	1.24
24	2.30
40	3.50
56	4.15
80	5.35

Test Case 10

Classification: Axisymmetric jet in moving stream

Reference: Chriss, D. E.: Experimental Study of the Turbulent Mixing of Subsonic Axisymmetric Gas Streams. AEDC-TR-68-133, U.S. Air Force, Aug. 1968. (Available from DDC as AD 672 975.)

Description of flow: The apparatus used to generate the flow field corresponding to the data consisted of a 8.89-cm-diameter (3.5 in.) subsonic air nozzle which formed an annulus around an inner subsonic hydrogen nozzle. The inner nozzle had an exit inside diameter of 1.27 cm (0.5 in.) and a nozzle lip thickness of 0.127 mm (0.005 in.). The nozzles were alined to give flow with center lines which are parallel within less than 0.5°. The test section was open to the atmosphere.

A dual-probe arrangement was used to measure total pressure, total temperature, gas composition, and static pressure at various stations in the flow field. For test IA of the reference, for which data are tabulated in the following table, surveys were made at seven locations from 2.96 to 14.59 diameters from the nozzle exit (1 diameter equals 1.27 cm). A nozzle exit survey was not performed; however, the data and table I of the reference give representative velocity values of 1005 m/sec (3300 ft/sec) for the hydrogen jet and a hydrogen jet to air jet velocity ratio of 6.3. Representative temperatures of the hydrogen jet and air jet are reported as 305° K (550° R) and 361° K (650° R), respectively. Representative boundary-layer thicknesses including the air jet and hydrogen jet boundary layers and the nozzle lip thickness were reported as approximately 14 percent of the inner nozzle radius. The ratio of hydrogen jet flow rate deduced from the data to the metered hydrogen flow rate ranged from 9.0 percent high to 1.0 percent low. (Values were taken from fig. V-1 of the reference report; a value for the data corresponding to $x/D = 14.59$ was not reported.) In the table, x is the axial coordinate, y is the radial coordinate, D is the nozzle diameter, α is the mass fraction of hydrogen, u is the axial velocity component, and T is the static temperature.

Test case 10 data:

Classification: Axisymmetric jet in a moving stream

Source: The reference document and Chriss, D. E.; and Paulk, R. A.: An Experimental Investigation of Subsonic Coaxial Free Turbulent Mixing. AEDC-TR-71-236, AFOSR-72-0237TR, U.S. Air Force, Feb. 1972. (Available from DDC as AD 737 098.)

Initial profile

x/D = 2.966

y/D	α	u		T	
		m/sec	ft/sec	°K	°R
1.6635	0.000010	158.4	519.6	346.6	623.9
1.2947	.000010	157.6	517.1	346.4	623.6
1.0239	.000010	157.6	517.0	345.8	622.5
.9095	.001199	159.0	521.8	343.1	617.6
.7675	.031540	180.0	590.7	318.9	574.1
.6539	.124700	271.5	890.7	299.9	539.8
.5810	.230300	384.0	1260.0	292.1	525.7
.5133	.370600	530.7	1741.0	285.9	514.7
.4435	.541700	698.6	2292.0	280.1	504.1
.3729	.733600	852.2	2796.0	275.3	495.6
.3036	.889400	950.4	3118.0	271.7	489.0
.2298	.968800	985.1	3232.0	269.8	485.6
.1575	.992200	987.6	3240.0	269.4	485.0
.0890	.999500	989.1	3245.0	269.3	484.8
.0133	.991900	983.6	3227.0	269.3	484.8
-.0532	.992100	983.9	3228.0	269.3	484.7
-.1239	.996500	986.9	3238.0	269.2	484.6
-.3621	.742500	853.7	2801.0	274.5	494.1
-.5397	.298300	458.4	1504.0	287.8	518.1
-.6835	.084430	237.2	778.2	305.6	550.0
-.8075	.015300	173.6	569.4	329.2	592.5
-.8711	.003904	167.3	548.8	340.2	612.3
-1.0960	.000642	164.1	538.4	344.3	619.7
-1.5856	.000188	158.0	518.5	346.0	622.8
-2.4382	.000137	158.5	519.9	344.8	620.6

Center-line values

x/D	$\alpha_{℄}$ (a)	$u_{℄}$	
		m/sec (a)	ft/sec (a)
5.3396	0.826	936	3072
6.9618	.562	760	2494
8.5337	.404	612	2009
10.3024	.277	479	1570
12.4142	.194	386	1268
14.5956	.142	328	1076

[a] Center-line values are estimates taken from plots of the data in the source document.

Test Case 11

Classification: Axisymmetric jet in moving stream

Reference: Eggers, James M.; and Torrence, Marvin G.: An Experimental Investigation of the Mixing of Compressible-Air Jets in a Coaxial Configuration. NASA TN D-5315, 1969.

Description of flow: The following data are the result of a study of the turbulent mixing of parallel, circular air jets. An annular Mach 1.30 nozzle which surrounded a Mach 0.90 subsonic inner nozzle was used to generate the flow field. (Note that the inner nozzle Mach number has been incorrectly reported in the reference as 0.942.) The internal diameter of the inner nozzle was 2.443 cm with a lip thickness of 0.559 mm. The outer nozzle had an exit diameter of 17.8 cm. The jets exhausted into a quiescent atmosphere and mixed in an unconfined region. The total temperature of both jets was 296° K ± 2 percent. Principal measurements consisted of surveys of pitot pressure, static pressure, and central gas concentration, the latter by use of a 1 percent ethlene tracer gas in the center jet. Center jet mass-flow rates deduced from survey data agreed within ± 5 percent to the metered center jet mass-flow rate. Nonuniformity of static pressure in both the axial and radial directions was noted in the raw data. In order to facilitate analytical correlation of the data, a data reduction method was employed which crudely eliminated the nonuniformity in static pressure from the reduced data and which allowed analytical computations to be made at a constant static pressure of 1 atmosphere. Although noticeable uncertainties exist in the data, the data illustrate the importance of initial conditions, particularly as in this air-air data where the jet flows consist of a large percentage of boundary layer. The radial distributions of velocity u and static temperature T are given in the following table for the jet exit. Center-line values of velocity and mass fraction are also given for the downstream stations. It is suggested that all predictors use 390 m/sec and 220° K as the values of velocity and static temperature in the region of uniform external stream conditions. In the table, x is the axial coordinate, y is the radial coordinate, and D is the jet diameter (2.443 cm).

Test case 11 data:

Classification: Axisymmetric jet in moving stream

Source: Reference document and data tabulation supplied by James M. Eggers, NASA Langley Research Center

x/D = 0.0

y/D	u, m/sec	T, °K	y/D	u, m/sec	T, °K	y/D	u, m/sec	T, °K
2.794	390.4	220.3	0.471	207.1	274.8	-0.722	368.5	228.6
2.581	390.8	220.1	.431	241.5	267.1	-.755	371.8	227.3
2.329	390.8	220.1	.393	257.1	263.2	-.818	373.6	226.7
2.172	390.4	220.3	.343	268.5	260.2	-.875	374.2	226.4
2.078	390.4	220.3	.243	281.5	256.7	-.933	375.7	225.9
1.789	390.1	220.4	.223	282.0	256.6	-.995	376.1	225.7
1.679	390.1	220.4	.166	284.2	255.9	-1.053	377.0	225.4
1.477	390.4	220.3	.076	286.8	255.2	-1.107	376.8	225.5
1.287	390.1	220.3	-.009	287.0	255.2	-1.241	378.0	225.0
1.225	389.5	220.6	-.085	286.3	255.3	-1.437	378.7	224.8
1.101	388.9	220.9	-.159	285.4	255.6	-1.644	378.5	224.8
.916	385.3	222.2	-.200	283.8	256.0	-1.707	378.0	225.0
.818	380.1	224.2	-.207	284.3	255.9	-1.808	381.3	223.8
.734	373.4	226.7	-.303	277.6	257.8	-1.925	378.8	224.7
.693	368.8	228.4	-.351	272.0	259.3	-2.007	378.8	224.7
.668	365.5	229.7	-.388	263.4	261.6	-2.064	383.0	223.1
.641	359.1	231.9	-.425	252.3	264.4	-2.116	385.0	222.4
.621	350.8	234.8	-.460	239.6	267.6	-2.172	381.5	223.7
.605	343.5	237.4	-.496	176.8	280.6	-2.224	383.5	222.9
.570	326.7	243.0	-.507	161.5	283.1	-2.274	379.8	224.4
.558	306.6	249.3	-.516	164.3	282.7	-2.314	380.8	223.9
.535	284.8	255.8	-.531	256.4	263.4	-2.377	387.6	221.3
.531	266.9	260.7	-.546	280.4	257.0	-2.391	379.3	224.6
.521	239.4	267.6	-.559	312.8	247.4	-2.426	389.5	220.6
.497	136.6	286.8	-.583	328.3	242.5	-2.454	389.5	220.6
.490	157.3	283.8	-.622	345.5	236.7	-2.522	379.8	224.3
.502	130.6	287.6	-.655	359.0	232.0	-2.677	389.4	220.7
.486	177.7	280.4	-.695	364.8	229.9			

Center-line values

x/D	$u_{℄}$, m/sec	$\alpha_{℄}$
0.0	286.8	1.000
11.0	280.4	1.000
17.2	276.1	.898
25.0	288.3	.548
30.0	306.9	.352
36.0	321.0	.250
49.0	352.3	.107

Test Case 12

Classification: Axisymmetric jet in moving stream

Reference: Eggers, James M.: Turbulent Mixing of Coaxial Compressible Hydrogen-Air Jets. NASA TN D-6487, 1971.

Description of flow: The interest in the mixing of hydrogen-air jets is related to the problem of fuel injector design for supersonic-combustion-ramjet engines. The hardware employed to generate these data consisted of a Mach 1.32 circular outer air nozzle which surrounded a circular parallel subsonic inner hydrogen nozzle of Mach 0.89. The outer nozzle had an exit diameter of 15.2 cm. The hydrogen nozzle had an exit inside diameter of 11.6 mm and a nozzle lip thickness of 0.55 mm. The jets mixed in an unconfined region at a static pressure of 1 atmosphere. Both jets had total temperatures of approximately 300° K. Surveys of pitot pressure and hydrogen concentration were made at seven axial stations, including the nozzle exit station, to 63.6 diameters downstream of the nozzle exit (1 diameter equals 11.6 mm). The static pressure was assumed to be uniform and equal to atmospheric pressure for data reduction. Attempts to obtain representative gas samples from the flow field by use of an internally expanded pitot probe were unsuccessful, even though the flow through the probe was strongly aspirated. Therefore, gas samples were extracted from the flow by use of a conventional static probe. This technique resulted in some uncertainty as to whether the gas samples obtained were representative of the location of the static probe tip or the location of the static orifices. It was assumed that the gas samples were representative of the location of the static probe tip which was positioned at the same axial location as the pitot probe tip. Hydrogen mass-flow rates deduced from the data ranged from 6 percent low to 4 percent high (with the exception of the data at $x/D = 5.51$ where large fluctuations and gradients existed and the deduced flow rate was 16 percent low) relative to the metered hydrogen flow rate. The agreement between the deduced and metered flow rates is considered to give a reasonable degree of confidence in the data. The concentration profiles were found to be self-similar and exhibit a high degree of self-consistency. A similarity plot of the velocity profiles indicated less self-consistency and significantly more scatter than in the concentration profiles. The scatter is related to some asymmetry of the velocity profiles, and uncertainties in the pitot pressure related to large fluctuations noted in the turbulent mixing zone. The radial distribution of Mach number M and velocity u for $x/D = 0.0$ are given in the following table. Center-line values of Mach number, velocity, and hydrogen mass fraction α, are also given for the downstream stations. In the table, y/D is the nondimensional radial coordinate, and x/D is the nondimensional axial coordinate ($D = 11.6$ mm). The total temperature of the hydrogen jet and air jet may be taken as 295° K.

Test case 12 data:

Classification: Axisymmetric jet in moving stream

Source: Reference document

x/D = 0.0

y/D	M	u, m/sec
-6.595	0.368	126
-6.565	.897	289
-6.538	1.055	331
-6.476	1.218	371
-6.437	1.284	386
-6.317	1.318	394
-6.203	1.324	395
-5.965	1.326	395
-5.612	1.324	395
-5.193	1.322	394
-4.729	1.322	394
-4.262	1.322	394
-3.790	1.317	394
-3.357	1.328	396
-2.881	1.326	395
-2.471	1.324	395
-2.029	1.320	394
-1.628	1.320	394
-1.244	1.309	392
-.975	1.294	388
-.843	1.271	383
-.776	1.245	377
-.697	1.204	368
-.649	1.153	355
-.591	1.079	337

y/D	M	u, m/sec
-0.565	1.023	323
-.543	.961	306
-.538	.823	268
-.490	.621	781
-.472	.735	911
-.459	.772	952
-.432	.817	1001
-.384	.852	1039
-.340	.862	1049
-.274	.872	1060
-.199	.878	1066
-.154	.882	1070
-.097	.884	1072
-.018	.886	1074
.119	.886	1074
.251	.876	1064
.322	.868	1056
.393	.846	1032
.463	.760	938
.485	.615	773
.525	.374	128
.534	.823	268
.543	.996	315
.565	1.046	329

y/D	M	u, m/sec
0.604	1.138	352
.631	1.182	362
.675	1.227	373
.724	1.251	379
.803	1.280	385
.949	1.297	389
1.050	1.303	390
1.174	1.308	391
1.381	1.315	393
1.654	1.320	394
2.025	1.322	394
2.462	1.326	395
2.956	1.328	396
3.428	1.328	396
3.829	1.326	395
4.301	1.324	395
4.835	1.324	395
5.157	1.324	395
5.629	1.326	395
6.079	1.327	396
6.481	1.305	391
6.525	1.196	366
6.587	.968	308
6.617	.520	176

Center-line values

x/D	$M_{℄}$	$u_{℄}$, m/sec	$\alpha_{℄}$
0.00	0.890	1074	1.000
5.51	.860	1061	1.000
9.58	.820	740	.504
15.44	.825	553	.232
25.20	.920	445	.103
42.80	1.067	415	.042
63.60	1.182	403	.017

Test Case 13

Classification: Two-dimensional jet in moving stream

Reference: Bradbury, L. J. S.: The Structure of a Self-Preserving Turbulent Plane Jet. J. Fluid Mech., vol. 23, pt. 1, Sept. 1965, pp. 31-64.

Description of flow: Although it was originally intended that data from the reference document be used for this test case, the data actually given are those of K. W. Everitt and L. J. S. Bradbury, Aeronautics Department, Imperial College of Science and Technology. This substitution was made on the advice of Dr. Bradbury who considers these data to be more satisfactory. However, the original reference has been retained as a useful general description of this flow since details of the more recent experiments are not at present available.

Test case 13 data:

Classification: Two-dimensional jet in a moving stream

Source: Bradbury, L. J. S.: Univ. of Surrey, England, Private Communication

Nozzle width D = 0.476 cm (3/16 in.); initial velocity ratio $\frac{u_o}{u_e} = 3.29$;

momentum thickness $\int_{-\infty}^{\infty} \frac{u}{u_e}\left(\frac{u}{u_e} - 1\right) dy = 2.24$ cm (0.882 in.)

Center-line values

x/D	$u_{℄}/u_e$
9.1	2.910
13.6	2.520
18.3	2.234
23.2	2.037
30.0	1.905
35.0	1.827
40.0	1.758
46.0	1.701
52.3	1.653
58.6	1.627
64.0	1.585
69.3	1.559
163.9	1.353
174.6	1.342
185.3	1.335
196.0	1.320
206.6	1.311
217.3	1.300
228.0	1.293
238.6	1.287
249.3	1.277
259.9	1.271
270.6	1.264
291.9	1.256
302.6	1.252

Test Case 14

Classification: Wake

Reference: Chevray, René; and Kovasznay, Leslie S. G.: Turbulence Measurements in the Wake of a Thin Flat Plate. AIAA J., vol. 7, no. 8, Aug. 1969.

Description of flow: This wake was generated with a flat aluminum plate 240 cm long, 50 cm wide, and 0.160 cm thick. The last 60 cm of the plate were uniformly tapered to a trailing-edge thickness of 0.025 cm. The boundary layer was turbulent and its characteristics at the trailing edge were as follows:

Boundary-layer thickness ($u/u_e = 0.99$), δ . . . . 5.50 cm
Momentum thickness, θ . . . . 0.58 cm
Reynolds number (based on boundary-layer thickness δ),
$\delta u_e/\nu$ . . . . 1.5×10^4

Further details of the apparatus and the experimental techniques are given in the reference document.

Test case 14 data:

Classification: Wake

Source: Kovasznay, Leslie S. G.: Johns Hopkins Univ., Private Communication

y, cm	u/u_e for –					
	x = 0 cm	x = 5 cm	x = 20 cm	x = 50 cm	x = 150 cm	x = 240 cm
0	0	0.525	0.645	0.725	0.81	0.864
.1	.3	.540	.647	.727	.81	.864
.2	.525	.575	.650	.729	.81	.864
.3	.585	.605	.654	.731	.81	.864
.4	.625	.625	.66	.734	.811	.864
.5	.645	.645	.667	.737	.812	.865
.6	.66	.6625	.68	.740	.8125	.866
.7	.68	.675	.69	.745	.815	.867
.8	.695	.69	.7	.750	.815	.868
.9	.705	.705	.71	.756	.8175	.868
1.0	.725	.72	.722	.761	.82	.869
1.5	.775	.78	.77	.793	.8325	.874
2.0	.83	.825	.82	.825	.85	.88
2.5	.87	.87	.86	.858	.8675	.89
3.0	.91	.905	.9	.892	.885	.9
3.5	.945	.9375	.932	.922	.905	.91
4.0	.97	.965	.96	.950	.9225	.92
4.5	.9825	.985	.975	.974	.9375	.934
5.0	.9937	.995	.986	.9875	.952	.945
5.5	.9975	.998	.999	.995	.9675	.957
6.0	1.0	1.0	1.0	.996	.98	.97
6.5		1.0	1.0	.999	.99	.975
7.0			1.0	1.0	.995	.9825
7.5				1.0	.998	.9875
8.0					1.0	.99
8.5					1.0	.994
9.0						.995
9.5						.996
10.0						.9975
10.5						.999
11.0						1.0
11.5						1.0
12.0						1.0

y, cm	$\overline{u'v'}/u_e^2$					
	x = 0 cm	x = 5 cm	x = 20 cm	x = 50 cm	x = 150 cm	x = 240 cm
0	0	0	0	0	0	0
.1	14×10^{-4}	5.4×10^{-4}	3.1×10^{-4}	$.65 \times 10^{-4}$	$.75 \times 10^{-4}$	$.7 \times 10^{-4}$
.2	22.2	12.0	5.4	1.6	1.3	1.0
.3	22.1	18.2	7.3	2.6	1.8	1.35
.4	21.8	19.7	8.8	3.55	2.25	1.6
.5	21.4	20.2	10.3	4.5	2.75	1.95
.6	21.1	20.3	11.7	5.45	3.25	2.25
.7	20.7	20.2	13.0	6.45	3.7	2.5
.8	20.2	20.0	14.0	7.4	4.15	2.75
.9	19.8	19.6	14.6	8.35	4.6	3.0
1.0	19.4	19.2	15.1	9.3	5.0	3.20
1.5	16.8	17.0	15.6	12.7	6.7	4.3
2.0	14.4	14.4	14.5	13.2	8.2	5.25
2.5	11.8	12.0	12.0	11.75	9.4	6.05
3.0	9.2	9.5	9.3	9.85	10.0	6.6
3.5	6.6	7.4	6.7	7.9	9.7	7.0
4.0	4.4	5.4	4.4	5.90	8.7	7.12
4.5	2.6	3.7	2.7	3.9	7.35	6.95
5.0	1.5	2.4	1.5	2.0	6.0	6.4
5.5	.7	1.3	.9	1.0	4.55	5.5
6.0	.2	.6	.5	.35	3.1	4.52
6.5	0	.1	.2	.12	1.95	3.52
7.0		0	0	.02	1.0	2.65
7.5			0	0	.45	1.9
8.0				0	.15	1.35
8.5					0	.95
9.0						.65
9.5						.4
10.0						.25
10.5						.13
11.0						.07
11.5						.02
12.0						0

Test Case 15

Classification: Axisymmetric wake

Reference: Chevray, R.: The Turbulent Wake of a Body of Revolution. Trans. ASME, Ser. D.: J. Basic Eng., vol. 90, no. 2, June 1968, pp. 275-284.

Description of flow: A six-to-one prolate spheroid, 1.52 m (5 ft) long, was used to generate this axisymmetric wake. The model was suspended with 0.051-cm-diameter (0.020 in.) spring steel wires in the test section of a low-speed closed-loop wind tunnel. This test section was 7.32 m (24 ft) long with a 1.52 m (5 ft) octagonal cross section. The Reynolds number, based on the model length, for these tests was 2.75×10^6 with a corresponding velocity of approximately 27.4 m/sec (90 ft/sec). A constant-temperature hot-wire anemometer, in conjunction with single and crossed wire probes, was used to measure the mean and the fluctuating velocity components. The resulting data for mean velocity and shear stress are given in the following tables. Further information on the individual turbulence components can be found in the reference document. The constant r and D used to nondimensionalize the axial and radial coordinates are the maximum radius and diameter, respectively, of the spheroid. The downstream end of the spheroid was taken as the origin for the X-axis.

Test case 15 data:

Classification: Axisymmetric wake

Source: Data were taken from large-scale plots supplied by R. Chevray.

x/D = 0

y/r	u/u_e
0.098	0.053
.144	.100
.194	.186
.242	.313
.290	.427
.339	.542
.386	.642
.437	.726
.482	.796
.531	.854
.578	.902
.627	.945
.677	.967
.722	.971
.774	.976
.819	.972
.867	.975
.915	.976
.964	.976

x/D = 0.25

y/r	u/u_e
0.024	0.270
.074	.277
.124	.316
.170	.400
.221	.496
.267	.566
.315	.633
.364	.715
.412	.781
.463	.838
.506	.878
.567	.923
.629	.956

x/D = 0.5

y/r	u/u_e
0.017	0.425
.053	.431
.091	.453
.128	.482
.165	.539
.199	.590
.237	.637
.272	.681
.310	.722
.347	.758
.382	.805
.418	.844
.453	.884
.486	.904
.526	.929
.561	.953
.597	.961
.634	.975
.673	.979
.703	.981
.741	.981
.849	.980
.992	.986

x/D = 1.0

y/r	u/u_e
0.041	0.514
.113	.553
.183	.621
.254	.701
.329	.774
.402	.856
.471	.910
.617	.984
.761	.991

x/D = 2.0

y/r	u/u_e
0.027	0.621
.075	.640
.123	.666
.171	.698
.220	.737
.265	.781
.315	.822
.367	.866
.412	.897
.460	.931
.507	.959
.556	.979
.601	.989
.649	.997
.702	.998
.743	1.000

x/D = 3.0

y/r	u/u_e
0.002	0.636
.025	.639
.072	.650
.124	.682
.169	.712
.219	.753
.268	.782
.316	.819
.365	.865
.412	.896
.507	.955
.555	.975
.604	.990
.651	.996
.699	.997
.746	.999

x/D = 6.0

y/r	u/u_e
0.001	0.720
.024	.730
.074	.736
.121	.754
.170	.778
.220	.806
.264	.825
.314	.853
.368	.879
.409	.904
.459	.926
.506	.949
.554	.965
.601	.981
.651	.991
.797	.997

x/D = 9.0

y/r	u/u_e
0.005	0.805
.050	.808
.101	.817
.148	.823
.196	.836
.245	.856
.291	.870
.341	.890
.391	.907
.437	.927
.485	.944
.582	.973
.676	.990
.725	.994
.770	.995
.823	.998

x/D = 12.0

y/r	u/u_e
0.005	0.850
.048	.849
.100	.856
.146	.865
.195	.869
.242	.876
.294	.893
.341	.902
.390	.918
.439	.934
.580	.965
.628	.973
.678	.982
.723	.990

x/D = 15.0

y/r	u/u_e
0.004	0.887
.025	.889
.073	.890
.123	.895
.171	.901
.219	.907
.267	.912
.316	.920
.365	.929
.410	.935
.458	.942
.604	.966
.654	.973
.703	.981
.749	.987
.795	.990
.845	.992
.882	.996
.938	.997
.984	.999

x/D = 18.0

y/r	u/u_e
0.005	0.908
.049	.910
.098	.911
.146	.912
.195	.916
.245	.920
.291	.925
.341	.931
.389	.938
.436	.942
.492	.950
.530	.952
.580	.961
.628	.967
.675	.972
.724	.978
.771	.982
.8188	.987
.866	.990
.917	.992
.963	.995

x/D = 0

y/r	$\overline{u'v'}/u_e^2$
0.0	0.17×10^{-4}
.094	9.41
.145	11.45
.195	11.91
.239	12.27
.285	11.62
.337	9.99
.381	8.27
.428	6.30
.479	4.14
.526	1.77
.574	.33
.623	.01
.673	.02

x/D = 0.25

y/r	$\overline{u'v'}/u_e^2$
0.025	2.90×10^{-4}
.068	5.70
.122	8.05
.167	9.10
.215	9.59
.263	9.24
.313	8.62
.362	8.11
.411	7.00
.456	5.74
.504	4.08
.553	2.27
.598	.76
.647	.14

x/D = 0.5

y/r	$\overline{u'v'}/u_e^2$
0.0	1.21×10^{-4}
.043	3.42
.096	5.72
.142	6.50
.189	6.85
.239	7.00
.284	6.73
.340	6.10
.385	5.25
.432	4.08
.477	2.70
.529	1.58
.575	.93
.623	.37
.720	.02

$x/D = 1.0$

y/r	$\overline{u'v'}/u_e^2$
0.02	0.96×10^{-4}
.071	2.88
.118	4.41
.168	5.44
.218	5.63
.262	5.55
.313	5.21
.357	4.85
.409	4.31
.458	3.44
.504	2.34
.552	1.13
.598	.32
.645	.05
.695	0.0
.745	0.0

$x/D = 2.0$

y/r	$\overline{u'v'}/u_e^2$
0.046	2.28×10^{-4}
.094	4.18
.141	5.35
.190	6.00
.240	5.97
.287	5.39
.334	4.90
.384	4.13
.431	3.19
.477	2.35
.528	1.26
.577	.70

$x/D = 3.0$

y/r	$\overline{u'v'}/u_e^2$
0.046	2.17×10^{-4}
.095	4.96
.143	6.38
.191	6.84
.240	7.08
.286	6.56
.334	6.11
.384	5.01
.431	3.94
.479	2.80
.527	1.66
.576	.82
.623	.26
.672	.07
.722	.01

x/D = 6.0

y/r	$\overline{u'v'}/u_e^2$
0.024	1.0 $\times 10^{-4}$
.071	3.35
.121	5.28
.170	7.25
.217	7.34
.268	8.01
.314	7.46
.362	7.05
.408	6.55
.453	5.26
.506	3.70
.551	2.38
.604	1.25
.646	.48
.695	.17
.747	0.0

x/D = 9.0

y/r	$\overline{u'v'}/u_e^2$
0.024	1.66 $\times 10^{-4}$
.084	3.37
.120	5.26
.168	7.22
.262	8.00
.286	7.98
.316	7.49
.360	7.00
.454	5.22
.506	3.68
.553	2.38
.600	1.27
.648	.48
.696	.15
.747	0.0

x/D = 12.0

y/r	$\overline{u'v'}/u_e^2$
0.022	1.14 $\times 10^{-4}$
.071	2.75
.121	4.31
.169	5.56
.217	6.30
.265	6.85
.312	7.29
.362	7.60
.409	7.15
.454	6.72
.505	6.08
.551	5.03
.600	4.24
.651	3.13
.699	1.98
.744	1.18
.792	.64
.841	.30
.890	.17
.937	.01
.986	.02

x/D = 15.0

y/r	$\overline{u'v'}/u_e^2$
0.047	1.28×10^{-4}
.095	2.53
.141	3.37
.193	3.86
.239	4.48
.287	5.15
.335	5.20
.383	5.48
.431	5.35
.480	5.16
.528	4.81
.575	4.23
.623	3.69
.672	3.19
.721	2.27
.816	1.08
.867	.68
.911	.45
.960	.22
1.007	.11
1.056	.07
1.104	.01

x/D = 18.0

y/r	$\overline{u'v'}/u_e^2$
0.047	0.72×10^{-4}
.140	1.85
.242	2.65
.337	3.14
.432	3.47
.528	3.23
.624	2.67
.725	2.00
.768	1.65
.818	1.19
.916	.68
1.008	.30
1.104	.11
1.202	.06

Test Case 16

Classification: Wake

Reference: Demetriades, A.: Compilation of Numerical Data on the Mean Flow From Compressible Turbulent Wake Experiments. Publ. No. U-4970, Aeronutronic Div., Philco-Ford Corp., Oct. 1, 1971.

Description of flow: This wake was two-dimensional and was generated with a stainless-steel ribbon stretched across the test section of a Mach 3 continuous supersonic wind tunnel. The ribbon was 0.0102 cm thick, 0.294 cm wide, and 7.88 cm long. It had a 25° half-angle on the leading edge and the trailing edge was square. The stagnation pressure was 97 kN/m^2 (730 mm Hg) and the stagnation temperature was 311° K (38° C) giving a unit Reynolds number per centimeter of 66 500 in the test section. Although the momentum thickness, calculated from the measured profiles, was constant over most of the wake, it did increase about 19 percent between $x = 0.91$ cm, the first x-station surveyed, and $x = 4.72$ cm. A more detailed discussion of the experiment together with a complete tabulation of the experimental data may be found in the reference document. For the data given, the temperatures, densities, and velocities have been nondimensionalized with respect to the local free-stream values.

Test case 16 data:

Classification: Wake

Source: Reference document

Profiles at x = 0.91 cm

u_e = 62 593.8 cm/sec T_e = 116.896° K

ρ_e = 0.000079 g/cm^3 M_e = 2.882

Lateral distance, y, cm	Nondimensional velocity, u/u_e	Nondimensional density, ρ/ρ_e	Nondimensional static temperature, T/T_e
0.0	0.7196	0.5785	1.7177
.010	.8282	.6684	1.4877
.020	.9643	.8696	1.1441
.030	.9921	.9646	1.0316
.041	.9979	.9899	1.0057
.051	1.0008	.9987	.9964
.061	1.0009	.9987	.9966
.071	1.0009	.9987	.9970
.081	1.0008	.9987	.9973

x, cm	Nondimensional center-line values		
	$u_{\mathfrak{c}}/u_e$	$\rho_{\mathfrak{c}}/\rho_e$	$T_{\mathfrak{c}}/T_e$
0.91	0.7196	0.5785	1.7177
1.67	.7960	.6410	1.5489
2.43	.8487	.7035	1.4127
3.96	.9265	.8393	1.1813
4.72	.9381	.8777	1.1442
5.48	.9452	.8869	1.1276
6.24	.9496	.8901	1.1232
7.01	.9541	.8902	1.1231
7.77	.9568	.8943	1.1191
8.53	.9590	.8980	1.1141
9.29	.9595	.9011	1.1092
10.05	.9624	.9050	1.1054
10.82	.9638	.9079	1.1012
11.58	.9658	.9118	1.0971
12.34	.9658	.9126	1.0963
13.10	.9673	.9153	1.0928
13.86	.9686	.9117	1.0895
14.63	.9699	.9197	1.0875
15.39	.9707	.9224	1.0836
16.15	.9715	.9178	1.0814
16.91	.9720	.9261	1.0792
17.67	.9727	.9287	1.0773
18.44	.9724	.9317	1.0787

Test Case 17

Classification: Axisymmetric wake

Reference: Demetriades, A.: Compilation of Numerical Data on the Mean Flow From Compressible Turbulent Wake Experiments. Publ. No. U-4970, Aeronutronic Div., Philco-Ford Corp., Oct. 1, 1971.

Description of flow: This axisymmetric wake was produced by the boundary layer of a rod, 0.3962 cm in diameter, suspended in a Mach 3.0 continuous supersonic wind tunnel. The supports of the rod were upstream of the nozzle throat and appear to have had little or no effect on the flow in the test section. Test conditions were adjusted to give a laminar boundary layer on the rod with transition occurring in the wake close to the base of the rod. No measurements were made in the near field of the wake. The first survey was made at 6.74 cm (2.652 in.) or 17 rod diameters downstream of the base. The stagnation pressure was 68 kN/m^2 (508 mm Hg abs) and the total temperature was 300° K (27° C) giving a Reynolds number per centimeter of 50 000 in the test section. Free-stream conditions over the region of the wake surveyed are constant within about ±3 percent. The wake drag, computed from the experimental profile is also approximately constant but shows a larger scatter. A complete tabulation of these results can be found in the reference document.

Test case 17 data:

Classification: Axisymmetric wake

Source: Reference document

Initial profile at x = 6.736 cm

u_e = 61 807.7 cm/sec T_e = 109.893° K

ρ_e = 0.0000597 g/cm^3 M_e = 2.9352 D = 0.3962 cm

Nondimensional radial stations, y/D	Nondimensional velocity, u/u_e	Nondimensional density, ρ/ρ_e	Nondimensional static temperature, T/T_e
0	0.7236	0.5678	1.7543
.1282	.7336	.5729	1.7330
.2564	.7527	.5846	1.6936
.3846	.7910	.6147	1.6113
.5128	.8594	.6834	1.4474
.6410	.9390	.8191	1.2095
.7692	.9792	.9263	1.0728
.8974	.9904	.9581	1.0380
1.0256	.9947	.9732	1.0223
1.1538	.9969	.9849	1.0151
1.2820	.9983	.9883	1.0088
1.4102	.9997	.9916	1.0037
1.5384	1.0004	.9933	.9994
1.6667	1.0007	.9950	.9982
1.7948	1.0004	.9966	.9988
1.9230	1.0004	.9983	.9986
2.0512	1.0004	.9983	.9985
2.1794	1.0004	1.0	.9984
2.3076	1.0003	1.0	.9990
2.4358	1.0000	1.0	1.0
2.5641	1.0000	1.0	1.0
4.4871	1.0000	1.0	1.0

x station		Nondimensional center-line values		
x, cm	x/D	$u_{\mathrm{¢}}/u_e$	$\rho_{\mathrm{¢}}/\rho_e$	$T_{\mathrm{¢}}/T_e$
6.736	17.0	0.7236	0.5678	1.7543
8.006	20.21	.7780	.6205	1.6217
9.276	23.41	.8189	.6655	1.5221
10.546	26.62	.8503	.6974	1.4354
11.816	29.82	.8633	.7463	1.3274
13.086	33.03	.8927	.7527	1.3129
14.356	36.23	.9049	.7750	1.2828
15.626	39.44	.9269	.8133	1.2309
16.896	42.64	.9312	.8313	1.2113
18.166	45.85	.9385	.8356	1.1814
19.436	49.05	.9405	.8319	1.1709
20.706	52.26	.9436	.8676	1.1734
21.976	55.46	.9441	.8847	1.1676
23.246	58.68	.9510	.8621	1.1488

Test Case 18 (Optional)

Classification: Axisymmetric jet into still air

Reference: Wygnanski, I.; and Fiedler, H.: Some Measurements in the Self-Preserving Jet. J. Fluid Mech., vol. 38, pt. 3, Sept. 18, 1969, pp. 577-612.

Description of flow: These data for the mean and fluctuating velocity components in the self-preserving region of a jet are given, as an optional test case, to allow predictors to check the behavior of their models in the far field of a jet without the complication of having to deal with the transition between the near and far fields. In this study, the jet was found to be truly self-preserving only for distances greater than 60 diameters downstream of the nozzle. Note that the data given for test case 6 extend only to a little over 40 diameters downstream.

The jet emerged from a nozzle 2.64 cm (1.04 in.) in diameter and was laminar at the exit plane. The nozzle was set in the middle of a wall 2.29 m $\left(7\frac{1}{2}\text{ ft}\right)$ high and 2.44 m (8 ft) wide and the entire jet was enclosed in a double walled cage formed from two 0.16-cm (1/16 in.) mesh screens placed 6.35 cm $\left(2\frac{1}{2}\text{ in.}\right)$ apart. This cage was 2.29 m $\left(7\frac{1}{2}\text{ ft}\right)$ high, 2.44 m (8 ft) wide, and 5.18 m (17 ft) long and was open at the downstream end.

The mean and fluctuating velocity measurements were made by using linearized constant-temperature hot-wire anemometers. Further details of the equipment together with a detailed discussion of the experimental results are given in the reference document.

Test case 18 data:

Classification: Axisymmetric jet into still air

Source: Wygnanski, I. J.: Univ. of Tel Aviv, Private Communication

SELF-PRESERVING AXISYMMETRIC JET

y/x	$u/u_{\not{c}}$	$\frac{\sqrt{\overline{u'^2}}}{u_{\not{c}}}$	$\frac{\sqrt{\overline{v'^2}}}{u_{\not{c}}}$	$\frac{\sqrt{\overline{w'^2}}}{u_{\not{c}}}$
0.00	1.000	0.284	0.238	0.238
.01	.983	.284	.238	.238
.02	.955	.284	.236	.237
.03	.900	.284	.231	.233
.04	.833	.282	.225	.229
.05	.760	.280	.216	.222
.06	.685	.275	.206	.212
.07	.606	.268	.195	.200
.08	.540	.254	.184	.187
.09	.470	.240	.170	.172
.10	.415	.226	.156	.156
.11	.350	.210	.142	.140
.12	.300	.190	.126	.124
.13	.250	.175	.111	.108
.14	.200	.156	.097	.092
.15	.150	.137	.082	.077
.16	.110	.117	.068	.063
.17	.090	.098	.057	.051
.18	.070	.080	.046	.040
.19	.050	.061	.036	.032
.20	.035	.047	.026	.024

Data applies for $x/D \geqq 60$, although mean velocity profiles are similar from $x/D = 30$.

x is distance from nozzle.

D is diameter of nozzle.

$u_{\not{c}}$ is local velocity on center line and is given by

$$u_o/u_{\not{c}} = -1.37 + 0.196\ x/D$$

where u_o is the velocity at the nozzle.

The data were taken at $R = 10^5$ (R is based on the diameter of the nozzle and u_o).

Test Case 19 (Optional)

Classification: Axisymmetric jet into still air

Reference: Heck, P. H.: Jet Plume Characteristics of 72-Tube and 72-Hole Primary Suppressor Nozzles. T.M. No. 69-457 (FAA Contract FA-SS-67-7), Flight Propulsion Div., Gen. Elec. Co., July 1969.

Description of flow: The primary purpose of the test facility used to generate these data was noise measurement, but capabilities for nozzle and flow-field temperature and pressure measurement were incorporated. The hardware used to generate these data consisted of a conical convergent nozzle 10.92 cm (4.3 in.) in diameter. Gas was supplied to the nozzle from a subscale jet engine simulator capable of producing hot exhaust gases at temperatures up to 1778° K (3200° R). Air was preheated in a burner can and then brought to test conditions in an afterburner section utilizing JP-4 as the fuel. Test conditions for the present data correspond to a jet total temperature of 1222° K (2200° R) and a pressure ratio of 3.0, which gave a nozzle exit Mach number of 1.36 (assuming full expansion). Measurements of total pressure, total temperature, and static pressure were made by means of a survey rake which could be translated and/or rotated. Temperatures in the outer region of the flow were measured by using chromel-alumel thermocouples, and temperatures in the hot inner core were measured with iridium/iridium-rhodium thermocouples. The latter thermocouples were flame sprayed to eliminate the tendency for the material to act as a catalyst. Pitot static probes were used in the outer portion of the flow, but only pitot measurements and temperature measurements were made in the innermost area, which had a radius of 13.46 cm (5.3 in.). The static pressure in the center portion of the rake was assumed to be the average of the two innermost static probe readings. The resultant velocities are reported to be accurate within ±15 m/sec (±50 ft/sec) and the total temperatures to no better than ±5 percent with 10 percent error probable. The profile data at 2.79 diameters from the nozzle exit and the center-line values at downstream stations are given in the following table.[1] For analysis, the properties of the jet gas may be approximated by those of air and the static pressure may be assumed constant. In the table, x and y are the axial and radial coordinates, respectively, D is the nozzle diameter, T_t is the measured total temperature, M is the local Mach number, u is the local velocity, p_t is the local stagnation pressure, and β is the rake rotation angle. The center line ($y/D = 0.0$) of the source data has been shifted $+0.15$ y/D to more nearly allow $y/D = 0.0$ to correspond to the center line of the profiles.

[1] For each axial location, data are presented which correspond to two angular positions β of the survey rake 90° apart.

Test case 19 data:

Classification: Axisymmetric jet into still air

Source: The data have been read from plots supplied by P. H. Heck, General Electric Co.

x/D = 2.79, $\beta = 0^{o}$

y/D	T_t		M	u		p_t	
	°K	°R		m/sec	ft/sec	kN/m²	psia
-3.520	277	498	0.155	52	170	100.7	14.60
-3.290	277	498	.125	37	120	101.0	14.65
-3.025	278	500	0.000	0	0	99.8	14.47
-2.750	278	500	0.000	0	0	99.3	14.40
-2.500	277	499	.192	61	200	100.7	14.60
-2.100	278	500	.125	38	125	101.0	14.65
-1.625	293	527	.045	14	45	100.3	14.55
-1.300	----	----	0.000	0	0	98.6	14.30
-1.170	306	550	.088	30	100	100.5	14.57
-1.000	358	645	.153	58	190	101.4	14.70
-.800	483	870	.082	37	120	100.0	14.50
-.600	700	1260	.370	192	630	109.3	15.85
-.350	1167	2100	1.188	712	2335	229.8	33.33
-.150	----	----	----	---	----	295.4	42.85
.050	1244	2240	1.410	842	2762	295.1	42.80
.300	1281	2305	1.378	840	2755	285.1	41.35
.500	975	1755	.940	533	1750	171.3	24.85
.700	639	1150	.370	183	600	115.8	16.80
.875	307	553	.090	30	100	99.6	14.45
1.000	----	----	----	---	----	99.4	14.42
1.325	306	550	.090	30	100	100.7	14.60
1.800	278	500	.188	61	200	101.0	14.65
2.150	278	500	0.000	0	0	100.0	14.50
2.450	278	500	0.000	0	0	98.9	14.35
2.725	278	500	0.000	0	0	100.0	14.50
3.000	278	500	.220	6	20	101.0	14.65
3.225	278	500	0.000	2	5	100.1	14.52

x/D = 2.79, $\beta = 90^{o}$

y/D	T_t		M	u		p_t	
	°K	°R		m/sec	ft/sec	kN/m²	psia
-3.520	277	498	0.155	52	170	100.7	14.60
-3.290	277	498	.125	38	125	101.0	14.65
-3.025	278	500	0.000	0	0	99.8	14.47
-2.750	278	500	0.000	0	0	99.3	14.40
-2.500	277	499	.192	63	207	100.7	14.60
-2.100	278	500	.125	40	130	101.0	14.65
-1.625	293	527	.040	14	45	100.3	14.55
-1.300	----	----	0.000	0	0	98.6	14.30
-1.170	306	550	.088	30	100	100.5	14.57
-1.000	353	635	.153	58	190	101.4	14.70
-.800	478	860	.110	43	140	100.0	14.50
-.600	700	1260	.468	244	800	115.5	16.75
-.350	1228	2210	1.353	811	2660	277.2	40.20
-.150	----	----	----	---	----	295.1	42.80
.050	1258	2265	1.415	842	2762	295.1	42.80
.300	1339	2410	1.265	802	2630	249.2	36.15
.500	867	1560	.713	360	1180	130.5	18.93
.700	550	990	.650	119	390	110.7	16.05
.875	----	----	.055	30	100	99.6	14.45
1.000	----	----	----	---	----	98.3	14.25
1.325	292	525	.090	32	105	100.5	14.57
1.800	278	500	.188	61	200	101.0	14.65
2.150	278	500	0.000	0	0	100.0	14.50
2.450	278	500	0.000	0	0	98.9	14.35
2.725	278	500	0.000	0	0	100.0	14.50
3.000	278	500	0.000	6	20	101.0	14.65
3.225	278	500	0.000	2	5	100.1	14.52

x/D = 5.58, $\beta = 0^{o}$

y/D	T_t		M	u		p_t	
	°K	°R		m/sec	ft/sec	kN/m²	psia
-3.520	278	500	0.155	49	160	100.0	14.50
-3.290	278	500	.125	41	135	101.4	14.70
-3.025	278	500	0.000	0	0	99.6	14.45
-2.750	277	498	0.000	0	0	98.3	14.25
-2.500	278	500	.192	64	210	100.3	14.55
-2.100	278	500	.125	43	140	101.4	14.70
-1.625	293	527	.040	12	40	99.6	14.45
-1.300	----	----	0.000	0	0	98.6	14.30
-1.170	361	650	.110	35	115	100.0	14.50
-1.000	450	810	.213	91	300	102.0	14.80
-.800	586	1055	.330	157	515	106.0	15.37
-.600	756	1360	.573	297	975	123.1	17.85
-.350	1094	1970	1.055	617	2025	195.5	28.35
-.150	----	----	----	---	----	272.3	39.50
.050	1178	2120	1.335	762	2500	269.6	39.10
.300	1314	2365	1.218	756	2480	235.8	34.20
.500	922	1660	.925	512	1680	169.3	24.55
.700	722	1300	.620	317	1040	128.2	18.60
.875	314	565	.382	136	445	110.0	15.95
1.000	----	----	----	---	----	99.3	14.40
1.325	358	645	.090	34	110	100.3	14.55
1.800	278	500	.188	61	200	100.7	14.60
2.150	277	499	0.000	0	0	100.0	14.50
2.450	277	499	0.000	0	0	98.3	14.25
2.725	278	500	0.000	0	0	100.3	14.55
3.000	278	500	.220	6	20	100.7	14.60
3.225	278	500	0.000	0	0	100.0	14.50

x/D = 5.58, $\beta = 90^{o}$

y/D	T_t		M	u		p_t	
	°K	°R		m/sec	ft/sec	kN/m²	psia
-3.520	278	500	0.155	49	160	100.0	14.50
-3.290	278	500	.125	41	135	101.4	14.70
-3.025	278	500	0.000	0	0	99.6	14.45
-2.750	277	498	0.000	0	0	98.3	14.25
-2.500	278	500	.192	64	210	100.3	14.55
-2.100	278	500	.125	43	140	101.4	14.70
-1.625	293	527	.040	12	40	99.6	14.45
-1.300	----	----	0.000	0	0	98.6	14.30
-1.170	361	650	.095	35	115	100.0	14.50
-1.000	425	765	.193	79	260	102.0	14.80
-.800	556	1000	.303	140	460	106.0	15.37
-.600	731	1315	.573	297	975	123.1	17.85
-.350	1094	1970	1.128	660	2165	213.4	30.95
-.150	----	----	----	---	----	273.7	39.70
.050	1078	1940	1.328	751	2465	271.7	39.40
.300	1322	2380	1.055	686	2250	194.4	28.20
.500	836	1505	.713	387	1270	137.9	20.00
.700	625	1125	.428	209	685	112.7	16.35
.875	314	565	.220	79	260	110.0	15.95
1.000	----	----	----	---	----	99.3	14.40
1.325	328	590	.090	34	110	100.3	14.55
1.800	278	500	.188	61	200	100.7	14.60
2.150	277	499	0.000	0	0	100.0	14.50
2.450	277	499	0.000	0	0	98.3	14.25
2.725	278	500	0.000	0	0	100.3	14.55
3.000	278	500	0.000	0	0	100.7	14.60
3.225	278	500	0.000	0	0	100.0	14.50

x/D = 8.37, $\beta = 0^o$

y/D	T_t °K	T_t °R	M	u m/sec	u ft/sec	p_t kN/m^2	p_t psia
-3.520	278	500	0.155	50	165	100.0	14.50
-3.290	278	500	.125	40	130	101.0	14.65
-3.025	278	500	0.000	0	0	100.3	14.55
-2.750	277	498	0.000	0	0	98.6	14.30
-2.500	278	500	.193	64	210	100.0	14.50
-2.100	281	505	.128	43	140	101.0	14.65
-1.625	344	620	.053	21	70	100.3	14.55
-1.300	----	----	.058	46	150	100.0	14.50
-1.170	447	805	.230	94	310	103.4	15.00
-1.000	514	925	.335	152	498	104.8	15.20
-.800	577	1038	.455	221	725	110.7	16.05
-.600	756	1360	.630	332	1090	124.1	18.00
-.350	967	1740	.953	539	1770	175.5	25.45
-.150	----	----	----	---	----	237.5	34.45
.050	1000	1800	1.202	669	2195	237.9	34.50
.300	1111	2000	1.053	629	2065	165.5	24.00
.500	881	1585	.877	480	1575	134.8	19.55
.700	741	1333	.678	349	1145	115.8	16.80
.875	319	575	.507	177	580	106.2	15.40
1.000	----	----	----	---	----	----	----
1.325	433	780	.208	85	280	102.7	14.90
1.800	328	590	.190	69	225	101.4	14.70
2.150	286	515	0.000	0	0	99.6	14.45
2.450	277	498	0.000	0	0	98.6	14.30
2.725	277	498	0.000	0	0	100.3	14.55
3.000	277	498	0.000	0	0	100.7	14.60
3.225	278	500	0.000	0	0	100.0	14.50

x/D = 8.37, $\beta = 90^o$

y/D	T_t °K	T_t °R	M	u m/sec	u ft/sec	p_t kN/m^2	p_t psia
-3.520	278	500	0.155	50	165	100.0	14.50
-3.290	278	500	.125	40	130	101.0	14.65
-3.025	278	500	0.000	0	0	100.3	14.55
-2.750	277	498	0.000	0	0	98.6	14.30
-2.500	278	500	.193	64	210	100.0	14.50
-2.100	281	505	.128	43	140	101.0	14.65
-1.625	344	620	.030	21	70	100.3	14.55
-1.300	----	----	0.000	0	0	100.0	14.50
-1.170	414	745	.168	70	230	103.4	15.00
-1.000	482	868	.280	122	400	100.7	14.60
-.800	589	1060	.397	187	615	107.6	15.60
-.600	719	1295	.587	302	990	128.9	18.70
-.350	953	1715	.958	539	1770	175.5	25.45
-.150	----	----	----	---	----	225.5	32.70
.050	944	1700	1.217	658	2160	233.4	33.85
.300	1142	2055	.905	558	1830	195.7	28.38
.500	789	1420	.683	363	1190	160.0	23.20
.700	644	1160	.483	238	780	134.1	19.45
.875	319	575	.318	113	370	118.9	17.25
1.000	----	----	----	---	----	108.9	15.80
1.325	378	680	.108	43	140	102.7	14.90
1.800	289	520	.190	66	215	101.4	14.70
2.150	286	515	0.000	0	0	99.6	14.45
2.450	277	498	0.000	0	0	98.6	14.30
2.725	277	498	0.000	0	0	100.3	14.55
3.000	277	498	0.000	0	0	100.7	14.60
3.225	278	500	0.000	0	0	100.0	14.50

x/D = 11.16, $\beta = 0^o$

y/D	T_t °K	T_t °R	M	u m/sec	u ft/sec	p_t kN/m^2	p_t psia
-3.520	277	498	0.155	52	170	99.6	14.45
-3.290	277	498	.125	40	130	101.0	14.65
-3.025	277	498	0.000	0	0	99.6	14.45
-2.750	277	498	0.000	0	0	98.3	14.25
-2.500	278	500	.190	62	205	100.3	14.55
-2.100	294	530	.125	41	135	101.0	14.65
-1.625	383	690	.130	49	160	100.0	14.50
-1.300	---	----	.220	87	285	100.3	14.55
-1.170	492	885	.330	142	465	103.4	15.00
-1.000	550	990	.420	190	625	107.2	15.55
-.800	639	1150	.520	255	835	118.2	17.15
-.600	721	1297	.650	332	1090	131.0	19.00
-.350	836	1505	.850	454	1490	155.8	22.60
-.150	---	----	----	---	----	179.3	26.00
.050	867	1560	----	527	1730	182.4	26.45
.300	911	1640	.905	500	1640	165.5	24.00
.500	800	1440	.815	428	1405	151.5	21.97
.700	714	1285	.700	354	1160	136.7	19.83
.875	317	570	.583	203	665	124.8	18.10
1.000	---	----	----	---	----	116.2	16.85
1.325	492	885	.340	148	485	106.2	15.40
1.800	378	680	.223	85	280	101.0	14.65
2.150	325	585	.040	14	45	99.6	14.45
2.450	300	540	.020	6	20	98.6	14.30
2.725	283	510	0.000	0	0	100.3	14.55
3.000	278	500	0.000	0	0	101.4	14.70
3.225	278	500	0.000	0	0	100.0	14.50

x/D = 11.16, $\beta = 90^o$

y/D	T_t °K	T_t °R	M	u m/sec	u ft/sec	p_t kN/m^2	p_t psia
-3.520	277	498	0.155	52	170	99.6	14.45
-3.290	277	498	.125	40	130	101.0	14.65
-3.025	277	498	0.000	0	0	99.6	14.45
-2.750	277	498	0.000	0	0	98.3	14.25
-2.500	278	500	.190	64	210	100.3	14.55
-2.100	294	530	.125	41	135	101.0	14.65
-1.625	361	650	.075	27	90	100.0	14.50
-1.300	---	----	.108	87	285	100.3	14.55
-1.170	456	820	.250	105	345	103.4	15.00
-1.000	508	915	.338	152	500	107.2	15.55
-.800	600	1080	.433	207	680	113.1	16.40
-.600	692	1245	.577	293	960	123.8	17.95
-.350	847	1525	.840	457	1500	157.2	22.80
-.150	---	----	----	---	----	184.8	26.80
.050	828	1490	.988	517	1695	182.4	26.45
.300	922	1660	.775	500	1640	146.5	21.25
.500	722	1300	.630	428	1405	128.2	18.60
.700	622	1120	.482	354	1160	115.8	16.80
.875	322	580	.353	201	660	108.1	15.68
1.000	---	----	----	---	----	103.4	15.00
1.325	406	730	.163	66	215	101.0	14.65
1.800	328	590	.190	70	230	101.0	14.65
2.150	289	520	0.000	0	0	99.6	14.45
2.450	0	0	.020	6	20	98.6	14.30
2.725	0	0	0.000	0	0	100.3	14.55
3.000	0	0	0.000	0	0	101.4	14.70
3.225	0	0	0.000	0	0	100.0	14.50

x/D = 13.95, $\beta = 0^{o}$

y/D	T_t		M	u		p_t	
	°K	°R		m/sec	ft/sec	kN/m²	psia
-3.520	277	498	0.155	49	160	100.3	14.55
-3.290	277	498	.120	43	140	101.4	14.70
-3.025	278	500	0.000	0	0	100.0	14.50
-2.750	294	530	0.000	0	0	98.6	14.30
-2.500	311	560	.193	67	220	100.7	14.60
-2.100	344	620	.145	54	177	101.4	14.70
-1.625	422	760	.197	81	265	101.4	14.70
-1.300	---	----	.290	226	740	104.1	15.10
-1.170	508	915	.375	165	540	108.9	15.80
-1.000	547	985	.450	206	675	112.9	16.37
-.800	611	1100	.520	250	820	117.9	17.10
-.600	656	1180	.608	297	975	125.5	18.20
-.350	722	1300	.735	376	1233	141.0	20.45
-.150	---	----	----	---	----	153.4	22.25
.050	722	1300	.822	413	1355	152.0	22.05
.300	756	1360	.770	395	1295	144.8	21.00
.500	689	1240	.715	354	1160	137.9	20.00
.700	644	1160	.640	311	1020	129.3	18.75
.875	469	845	.560	235	770	121.7	17.65
1.000	---	----	----	---	----	115.8	16.80
1.325	499	898	.383	169	555	109.3	15.85
1.800	411	740	.275	110	360	102.4	14.85
2.150	361	650	.090	34	110	100.0	14.50
2.450	333	600	.050	18	60	99.6	14.45
2.725	306	550	0.000	0	0	100.0	14.50
3.000	292	525	0.000	0	0	101.4	14.70
3.225	289	520	0.000	0	0	100.0	14.50

x/D = 13.95, $\beta = 90^{o}$

y/D	T_t		M	u		p_t	
	°K	°R		m/sec	ft/sec	kN/m²	psia
-3.520	277	498	0.155	49	160	100.3	14.55
-3.290	277	498	.120	43	140	101.4	14.70
-3.025	278	500	0.000	0	0	100.0	14.50
-2.750	281	505	0.000	0	0	98.6	14.30
-2.500	294	530	.193	67	220	100.7	14.60
-2.100	319	575	.145	46	150	101.4	14.70
-1.625	386	695	.120	47	155	100.0	14.50
-1.300	---	----	.180	137	450	102.0	14.80
-1.170	475	855	.282	122	400	104.8	15.20
-1.000	519	935	.365	166	545	108.6	15.75
-.800	581	1045	.440	207	680	112.9	16.38
-.600	644	1160	.543	258	845	121.0	17.55
-.350	722	1300	.743	371	1218	141.0	20.45
-.150	---	----	----	---	----	152.0	22.05
.050	706	1270	.805	396	1300	150.3	21.80
.300	750	1350	.675	349	1145	133.6	19.38
.500	647	1165	.570	277	910	123.4	17.90
.700	589	1060	.465	219	718	114.5	16.60
.875	322	580	.355	125	410	108.2	15.70
1.000	---	----	----	---	----	104.1	15.10
1.325	433	780	.202	84	275	102.0	14.80
1.800	354	638	.202	76	250	101.0	14.65
2.150	314	565	.022	7	23	98.3	14.25
2.450	289	520	0.000	0	0	98.3	14.25
2.725	279	503	0.000	0	0	98.3	14.25
3.000	274	493	.020	9	30	99.6	14.45
3.225	278	500	0.000	0	0	98.3	14.25

x/D = 16.74, $\beta = 0^{o}$

y/d	T_t		M	u		p_t	
	°K	°R		m/sec	ft/sec	kN/m²	psia
-3.520	283	510	0.155	50	165	100.7	14.60
-3.290	289	520	.130	42	138	101.4	14.70
-3.025	297	535	0.000	0	0	99.3	14.40
-2.750	317	570	0.000	0	0	98.3	14.25
-2.500	339	610	.210	70	230	99.8	14.47
-2.100	378	680	.178	70	230	101.0	14.65
-1.625	406	730	.260	183	600	100.7	14.60
-1.300	444	800	.322	134	440	104.1	15.10
-1.170	472	850	.418	323	1060	110.1	15.97
-1.000	506	910	.463	204	670	109.6	15.90
-.800	528	950	.503	226	740	112.6	16.33
-.600	567	1020	.555	256	840	117.2	17.00
-.350	592	1065	.630	299	980	128.2	18.60
-.150	---	----	----	---	----	134.4	19.50
.050	611	1100	----	---	----	132.4	19.20
.300	639	1150	.635	305	1000	127.9	18.55
.500	636	1145	.618	299	980	127.1	18.43
.700	606	1090	.578	273	895	123.1	17.85
.875	589	1060	.517	244	800	117.6	17.05
1.000	---	----	----	---	----	113.4	16.45
1.325	517	930	.400	177	580	110.0	15.95
1.800	422	760	.318	128	420	104.8	15.20
2.150	383	690	.140	55	180	100.0	14.50
2.450	350	630	.110	43	140	98.6	14.30
2.725	331	595	.058	21	70	100.0	14.50
3.000	314	565	.040	15	50	101.4	14.70
3.225	297	535	0.000	---	----	99.6	14.45

x/D = 16.74, $\beta = 90^{o}$

y/D	T_t		M	u		p_t	
	°K	°R		m/sec	ft/sec	kN/m²	psia
-3.520	277	498	0.155	50	165	100.7	14.60
-3.290	278	500	.130	42	138	101.4	14.70
-3.025	289	520	0.000	0	0	99.3	14.40
-2.750	302	543	0.000	0	0	98.3	14.25
-2.500	322	580	.200	70	230	99.8	14.47
-2.100	356	640	.143	55	180	101.0	14.65
-1.625	406	730	.165	67	220	100.7	14.60
-1.300	---	----	.230	183	600	102.0	14.80
-1.170	472	850	.308	136	445	106.2	15.40
-1.000	497	895	.380	168	550	108.7	15.77
-.800	542	975	.435	198	650	112.6	16.33
-.600	578	1040	.503	233	765	117.2	17.00
-.350	622	1120	.630	299	980	128.2	18.60
-.150	---	----	----	---	----	134.4	19.50
.050	610	1098	.665	311	1020	132.4	19.20
.300	639	1150	.580	282	925	123.4	17.90
.500	581	1045	.520	244	800	119.3	17.30
.700	544	980	.450	204	670	113.8	16.50
.875	322	580	.360	126	415	107.9	15.65
1.000	---	----	----	---	----	104.6	15.17
1.325	433	780	.240	98	320	102.4	14.85
1.800	378	680	.220	85	280	102.0	14.80
2.150	336	605	.060	21	70	99.6	14.45
2.450	314	565	.040	12	40	98.6	14.30
2.725	300	540	.020	6	20	100.0	14.50
3.000	288	518	.023	6	20	101.4	14.70
3.225	283	510	0.000	0	0	99.6	14.45

x/D = 19.53, $\beta = 0^{o}$

y/D	T_t		M	u		p_t	
	°K	°R		m/sec	ft/sec	kN/m^2	psia
-3.520	300	540	0.155	49	160	100.3	14.55
-3.290	311	560	.130	42	138	101.4	14.70
-3.025	322	580	0.000	0	0	100.0	14.50
-2.750	336	605	0.000	0	0	98.6	14.30
-2.500	361	650	.230	74	243	100.7	14.60
-2.100	389	700	.215	62	205	102.7	14.90
-1.625	439	790	.275	110	360	103.8	15.05
-1.300	---	----	.340	195	640	105.8	15.35
-1.170	483	870	.395	135	443	109.6	15.90
-1.000	494	890	.445	164	538	113.1	16.40
-.800	522	940	.463	181	593	113.8	16.50
-.600	536	965	.490	201	660	115.1	16.70
-.350	553	995	.550	244	800	120.7	17.50
-.150	---	----	----	---	---	123.4	17.90
.050	556	1000	.560	253	830	122.7	17.80
.300	567	1020	.540	235	770	119.3	17.30
.500	550	990	.530	213	700	118.9	17.25
.700	536	965	.513	192	630	117.2	17.00
.875	517	930	.460	126	415	113.8	16.50
1.000	---	----	----	---	---	110.7	16.05
1.325	483	870	.380	108	353	108.6	15.75
1.800	422	760	.332	94	310	105.1	15.25
2.150	389	700	.180	35	115	100.7	14.60
2.450	367	660	.160	26	85	99.3	14.40
2.725	347	625	.100	14	45	100.5	14.58
3.000	333	600	.080	6	20	101.0	14.65
3.225	311	560	0.000	0	0	99.6	14.45

x/D = 19.53, $\beta = 90^{o}$

y/D	T_t		M	u		p_t	
	°K	°R		m/sec	ft/sec	kN/m^2	psia
-3.520	300	540	0.155	55	180	100.3	14.55
-3.290	311	560	.130	46	150	101.4	14.70
-3.025	322	580	0.000	0	0	100.0	14.50
-2.750	336	605	0.000	0	0	98.6	14.30
-2.500	336	605	.210	85	280	100.7	14.60
-2.100	365	657	.170	85	278	101.4	14.70
-1.625	411	740	.200	122	400	103.8	15.05
-1.300	---	----	.250	259	850	105.8	15.35
-1.170	465	837	.320	170	558	106.2	15.40
-1.000	478	860	.380	193	633	108.9	15.80
-.800	511	920	.408	206	675	111.4	16.15
-.600	528	950	.450	219	720	113.1	16.40
-.350	553	995	.540	250	820	120.7	17.50
-.150	---	----	----	---	---	123.4	17.90
.050	550	990	.565	256	840	122.7	17.80
.300	567	1020	.507	247	810	119.3	17.30
.500	550	990	.477	242	793	118.9	17.25
.700	536	965	.430	229	750	112.4	16.30
.875	517	930	.358	204	670	107.9	15.65
1.000	---	----	----	---	---	104.8	15.20
1.325	439	790	.258	163	535	103.4	15.00
1.800	389	700	.242	136	445	101.8	14.77
2.150	353	635	.090	67	220	100.7	14.60
2.450	333	600	.070	61	200	99.3	14.40
2.725	311	560	.040	37	120	100.5	14.58
3.000	297	535	.022	30	97	101.0	14.65
3.225	286	515	0.000	0	0	99.6	14.45

Test Case 20 (Optional)

Classification: Axisymmetric jet in moving stream

Reference: Chriss, D. E.; and Paulk, R. A.: An Experimental Investigation of Subsonic Coaxial Free Turbulent Mixing. AEDC-TR-71-236, AFOSR-72-0237TR, U.S. Air Force, Feb. 1972. (Available from DDC as AD 737 098.)

Description of flow: The apparatus used to generate the flow field corresponding to the data consisted of a 8.9-cm-diameter (3.5 in.) subsonic air nozzle which formed an annulus around an inner subsonic nozzle. The inner nozzle had an exit diameter of 1.27 cm (0.5 in.) and a lip thickness of 0.0127 cm (0.005 in.). The nozzles were alined to give flow with center lines which were parallel within less than 0.5°. The test area was open to the atmosphere.

A dual probe arrangement was used to measure total pressure, total temperature, static pressure, and gas concentration. The center jet flow contained approximately 2 percent by volume of hydrogen which allowed measurements of concentration to be made with a thermal conductivity meter. Data tabulated herein are for a ratio of outer jet to inner jet velocity of 0.48. The total temperatures of the inner and outer jet were 314° K (565° R) and 283.2° K (510° R), respectively. Static-pressure variation in this flow field was not significant. The initial measured profile at $x = 0.29$ cm (0.009516 ft) from the nozzle exit and downstream center-line values are given in the following table. In the table, x is the axial coordinate, y is the radial coordinate, α is the mass fraction of inner jet gas, u is the local velocity, T is the local static temperature, and m is the local molecular weight.

Test case 20 data:

Classification: Axisymmetric jet in moving stream

Source: Reference document

Initial profile

x = 0.29 cm (0.009516 ft)

y/D	α	u		T		m
		m/sec	ft/sec	°K	°R	
1.1704	0.0155	53.6	176.0	286.7	516.0	28.96
.9921	.0166	53.8	176.6	286.5	515.7	28.96
.8584	.0165	53.0	174.0	286.6	515.9	28.96
.7442	.0184	52.9	173.6	286.5	515.7	28.95
.6628	.0180	52.9	173.7	286.7	516.1	28.95
.5760	.0183	52.3	171.7	288.4	519.1	28.95
.5205	.3660	72.3	237.3	297.3	535.2	28.65
.4838	.9150	82.7	271.2	303.3	545.9	28.18
.4389	1.0030	117.5	385.6	304.7	548.4	28.11
.3432	1.0030	117.4	385.3	304.9	548.8	28.11
.2201	1.0040	117.5	385.6	305.0	549.0	28.11
.1409	1.0050	117.6	385.8	305.1	549.2	28.11
.0391	1.0030	117.6	385.9	305.1	549.1	28.11
-.0617	1.0050	117.6	385.7	304.9	548.8	28.11
-.1363	1.0070	117.5	385.6	304.7	548.5	28.11
-.2174	1.0080	117.5	385.5	304.7	548.4	28.11
-.3153	1.0060	117.5	385.6	304.9	548.8	28.11
-.4092	1.0050	117.6	385.7	305.2	549.4	28.11
-.4776	.9833	116.4	381.8	303.6	546.5	28.13
-.5232	.4280	75.7	248.2	289.8	521.7	28.60
-.5712	.0176	51.7	169.6	288.4	519.2	28.95
-.6520	.0183	52.1	171.0	287.2	517.0	28.95
-.7543	.0216	52.5	172.1	286.5	515.7	28.95
-.8457	.0215	52.5	172.1	286.3	515.3	28.95
-1.0252	.0228	52.6	172.7	285.8	514.5	28.95

Center-line values

x/D	$\alpha_{\mathbb{C}}$*	$u_{\mathbb{C}}$*	
		m/sec	ft/sec
1.9196	1.000	118.5	388.8
3.4980	.996	119.1	390.8
5.1286	.995	119.0	390.5
6.5236	.965	118.3	388.0
8.5260	.895	115.8	380.0
10.4039	.793	112.5	369.0
12.2191	.702	108.2	355.0
14.2685	.604	100.9	331.0
16.1903	.526	96.3	316.0
18.1027	.450	90.5	297.0

* Center-line values have been estimated from plots of tabulated data from source document.

Test Case 21 (Optional)

Classification: Axisymmetric jet in moving stream

Reference: Chriss, D. E.: Experimental Study of the Turbulent Mixing of Subsonic Axisymmetric Gas Streams. AEDC-TR-68-133, U.S. Air Force, Aug. 1968. (Available from DDC as AD 672 975.)

Description of flow: The apparatus used to generate the flow field corresponding to the data consisted of a 8.89-cm-diameter (3.5 in.) subsonic air nozzle which formed an annulus around an inner subsonic hydrogen nozzle. The inner nozzle had an exit inside diameter of 1.27 cm (0.5 in.) and a nozzle lip thickness of 0.127 mm (0.005 in.). The nozzles were alined to give flow with center lines which are parallel within less than 0.5°. The test section was open to the atmosphere. A dual probe arrangement was used to measure total pressure, total temperature, gas composition, and static pressure at various stations in the flow field. For test IIB of the reference for which a portion of the data is tabulated in the following table, surveys were made at 12 locations from 0.50 to 16.32 diameters from the nozzle exit (1 diameter equals 1.27 cm). Insufficient data were obtained at $x/D = 0.50$ to adequately define the profiles; thus, the data tabulated herein for the initial station are for $x/D = 2.575$. A nozzle exit survey was not performed for this specific test condition; however, representative boundary-layer thicknesses including the air jet and hydrogen jet boundary layers and the nozzle lip thickness are reported as approximately 14 percent of the inner nozzle radius. Table I of the reference document lists representative velocity values of 747 m/sec (2450 ft/sec) for the hydrogen jet and a hydrogen jet to air jet velocity ratio of 3.2. Representative temperatures of the hydrogen jet and air jet are reported as 306° K (550° R) and 583° K (1050° R), respectively. The ratio of hydrogen jet flow rate deduced from the data to the metered hydrogen flow rate ranged from 47 percent high at $x/D = 2.575$ to 2 percent low at $x/D = 10.06$. (Values were taken from figure V-1 of the reference report; a value for x/D of 16.32 was not given.) The percent uncertainty in the hydrogen flow rate ratio generally decreased with x/D leaving the average uncertainty substantially less than the quoted 47 percent. Static-pressure variation over the range of x/D of 2.575 to 16.32 is estimated to be less than ± 1 percent (values taken from fig. 20 of the reference) and, thus, is not significant.

In the following table, x is the axial coordinate, y is the radial coordinate, D is the hydrogen nozzle diameter, α is the local mass fraction of hydrogen, u is the local velocity, and T is the local static temperature.

Test case 21 data:

Classification: Axisymmetric jet in a moving stream

Source: Reference document

Initial profile

x/D = 2.575

y/D	α	u		T	
		m/sec	ft/sec	°K	°R
2.0528	0.0004	234.5	769.5	554.6	998.2
1.8601	.0003	235.9	774.0	557.2	1003.0
1.6515	.0003	234.4	769.0	557.2	1003.0
1.4363	.0003	235.5	772.8	556.7	1002.0
1.2453	.0003	233.7	766.8	554.9	998.8
1.0497	.0003	234.4	769.0	552.9	995.3
.8522	.0079	227.5	746.4	504.7	908.4
.7766	.0446	232.8	763.9	416.3	749.4
.7015	.1165	276.0	905.5	370.4	666.8
.6290	.2102	346.9	1138.0	347.3	625.1
.5572	.3237	438.6	1439.0	333.9	601.1
.4764	.4647	535.8	1758.0	324.2	583.5
.4022	.6258	621.8	2040.0	317.3	571.2
.3302	.7691	677.9	2224.0	312.6	562.6
.2546	.8600	705.9	2316.0	311.4	560.5
.1781	.8951	715.1	2346.0	312.1	561.7
.1077	.9210	722.4	2370.0	313.8	564.8
.0312	.8973	712.3	2337.0	314.7	566.4
-.0437	.9127	717.8	2355.0	316.1	569.0
-.1174	.9141	717.2	2353.0	315.9	568.7
-.2357	.8925	711.7	2335.0	314.7	566.5
-.4024	.6587	636.4	2088.0	317.9	572.3
-.4980	.4299	524.9	1722.0	325.8	586.4
-.6105	.2307	379.2	1244.0	344.8	620.6
-.7449	.0689	249.8	819.7	407.4	733.3
-.8625	.0118	229.6	753.3	499.1	898.4
-1.0324	.0008	231.8	760.6	548.9	988.0
-1.1490	.0005	233.1	764.8	550.7	991.2
-1.2645	.0004	232.5	762.7	551.6	992.8
-1.3768	.0006	233.8	767.2	552.4	994.4
-1.4958	.0005	234.4	768.9	553.6	996.5
-1.6172	.0006	234.5	769.3	554.3	997.8
-1.7557	.0005	235.5	772.5	553.9	997.0
-1.9446	.0002	235.2	771.5	552.8	995.0
-2.2697	.0005	236.3	775.3	550.3	990.5
-2.6566	.0004	232.7	763.5	549.0	988.2

Center-line values

x/D	α_{CL}*	u_{CL}*	
		m/sec	ft/sec
4.0930	0.813	706.8	2319.0
4.5380	.677	666.6	2187.0
5.1860	.561	628.2	2061.0
5.8830	.447	571.5	1875.0
6.5620	.387	539.2	1769.0
7.5080	.317	482.5	1583.0
8.8660	.238	423.1	1388.0
10.0590	.190	383.7	1259.0
12.4270	.142	341.4	1120.0
16.3210	.095	303.0	994.0

* Center-line values have been estimated from plots of tabulated data from source document.

Test Case 22 (Optional)

Classification: Axisymmetric jet in moving stream

Reference: Eggers, James M.: Turbulent Mixing of Coaxial Compressible Hydrogen-Air Jets. NASA TN D-6487, 1971.

Description of flow: The interest in the mixing of hydrogen-air jets is related to the problem of fuel injector design for supersonic-combustion-ramjet engines. The hardware employed to generate these data consisted of a Mach 2.50 circular outer air nozzle which surrounded a circular parallel subsonic inner hydrogen nozzle of Mach 0.91. The outer nozzle had an exit diameter of 15.2 cm. The hydrogen nozzle had an exit inside diameter of 11.6 mm and a nozzle lip thickness of 0.55 mm. The jets mixed in an unconfined region at a static pressure of 1 atmosphere. Both jets had total temperatures of approximately 300° K. Surveys of pitot pressure and hydrogen concentration were made at seven axial stations, including the nozzle exit station, to 58.0 diameters downstream of the nozzle exit (1 diameter equals 11.6 mm). The static pressure was assumed to be uniform and equal to atmospheric pressure for data reduction. Gas samples were extracted from the flow by use of a conventional static probe. (Sampling attempts with an internally expanded pitot probe were unsatisfactory even though the flow through the probe was strongly aspirated.) The static probe sampling technique resulted in some uncertainty as to whether the gas samples obtained were representative of the location of the static probe tip or the location of the static orifices. It was assumed that the gas samples were representative of the location of the static probe tip, which was positioned at the same axial location as the pitot probe tip. Hydrogen mass-flow rates deduced from the data ranged from 12 percent low to 29 percent high relative to the metered hydrogen flow rate. A plot of concentration profiles were reasonably self-similar. A plot of the velocity data indicated significant asymmetry and scatter in the similarity plot. A significant fraction of the scatter in the velocity similarity plot is due to asymmetry of the profiles and uncertainties in the pitot pressure data related to large pressure fluctuations noted in the turbulent mixing zone. A decrease of the center-line velocity (initially $u_o/u_e = 1.823$) to values below the free-stream velocity u_e for values of x/D greater than approximately 18 is evident in the data. This decrease in center-line velocity below the free-stream value is not necessarily due to pressure gradients but may be attributed to the wake-like nature of the flow. The radial distribution of Mach number M and velocity u are given in the following table for $x/D = 0.0$. Also tabulated are the center-line values of M, u, and α (where α is the local mass fraction of hydrogen) at the downstream locations. In the table, y/D is the nondimensional radial coordinate and x/D is the nondimensional axial coordinate ($D = 11.6$ mm). The total temperatures of the hydrogen jet and air jet may be taken as 300° K and 313° K, respectively.

Test case 22 data:

Classification: Axisymmetric jet in moving stream

Source: Reference document

x/D = 0.0

y/D	M	u, m/sec	y/D	M	u, m/sec
-6.666	0.432	153	0.154	0.907	1107
-6.591	.932	311	.251	.907	1107
-6.512	1.548	461	.353	.871	1068
-6.437	2.105	555	.366	.865	1062
-6.159	2.499	603	.384	.845	1040
-6.026	2.502	603	.406	.815	1008
-5.572	2.494	603	.424	.769	957
-5.325	2.531	606	.446	.668	843
-4.862	2.538	607	.459	.598	761
-4.412	2.531	606	.472	.432	558
-3.922	2.538	607	.485	.309	403
-3.468	2.565	610	.503	1.098	357
-3.168	2.586	612	.516	1.278	401
-2.943	2.511	604	.543	1.522	455
-2.493	2.520	605	.569	1.673	485
-2.215	2.545	608	.596	1.760	500
-1.990	2.524	606	.622	1.834	513
-1.562	2.503	603	.688	1.975	536
-1.394	2.461	599	.768	2.092	553
-1.284	2.423	595	.860	2.204	568
-1.134	2.363	588	.962	2.287	579
-.904	2.240	573	1.054	2.333	584
-.746	2.067	549	1.147	2.379	590
-.578	1.732	496	1.253	2.434	596
-.547	1.600	471	1.368	2.472	600
-.499	.718	248	1.522	2.507	604
-.485	.309	403	1.703	2.527	606
-.468	.507	651	1.932	2.531	606
-.454	.644	815	2.126	2.519	605
-.446	.662	836	2.303	2.496	603
-.432	.718	901	2.625	2.481	601
-.415	.783	973	2.912	2.472	600
-.397	.819	1013	3.238	2.575	611
-.379	.857	1054	3.684	2.541	607
-.344	.877	1075	4.147	2.506	604
-.300	.896	1095	4.663	2.514	605
-.053	.907	1107	5.237	2.493	602

Center-line values

x/D	$M_{℄}$	$u_{℄}$, m/sec	$\alpha_{℄}$
0.00	0.907	1108	1.000
4.31	.897	1094	1.000
8.75	.918	928	.698
15.36	.995	656	.260
19.80	1.035	537	.122
37.30	1.340	540	.059
58.00	1.560	549	.035

Test Case 23 (Optional)

Classification: Coaxial jets

Reference: Champagne, F. H.; and Wygnanski, I. J.: Coaxial Turbulent Jets. D1-82-0958, Flight Sci. Lab., Boeing Sci. Res. Lab., Feb. 1970. (Available from DDC as AD 707 282.)

Description of flow: This coaxial jet mixing experiment has been chosen to give predictors an opportunity to demonstrate the applicability of their models to a flow which is more complex than most of the other test cases. While this jet approaches self-preservation far downstream, both the mean and fluctuating velocity components are non-similar over most of the region considered herein.

This flow was generated from a pair of coaxial nozzles set flush in the center of a plane vertical wall which extended about 1.219 m (4 ft) in any radial direction. The inner nozzle was 2.64 cm (1.04 in.) in diameter with a contraction ratio of 144 to 1. The outer nozzle had a contraction ratio of about 100 to 1 and the area ratio of the nozzles at the exit was 2.94. The larger initial velocity was approximately 60 m/sec.

Mean and fluctuating velocity measurements were made with two linearized, constant temperature, hot-wire anemometers. Further details of the experimental apparatus together with a detailed discussion of the results are given in the reference document.

Test case 23 data:

Classification: Coaxial jets

Source: Wygnanski, I. J.: Univ. of Tel Aviv, Private Communication

Diameter: $D_e = 5.13$ cm (2.02 in.) $D_o = 2.64$ cm (1.04 in.)

Area ratio: $\frac{A_e}{A_o} = 2.94$

Velocity ratio: $\frac{u_e}{u_o} = 5.05$

Reynolds number: $R_o = \frac{u_o D_o}{\nu} = 0.2 \times 10^5$ $R_e = \frac{u_e (D_e - D_o)}{\nu} = 0.96 \times 10^5$

Subscript e denotes outer nozzle; subscript o denotes inner nozzle.

Thickness of wall separating the two nozzles is 0.183 cm (0.072 in.).

$x/D_e = 0.124$

y, cm	y, in.	u/u_e
0.000	0.000	0.217
.318	.125	.217
.572	.225	.217
.825	.325	.222
.889	.350	.223
.953	.375	.223
1.016	.400	.223
1.080	.425	.223
1.143	.450	.219
1.206	.475	.155
1.270	.500	.110
1.308	.515	.710
1.333	.525	1.000
1.587	.625	1.000
1.842	.725	1.000
2.096	.825	1.000
2.350	.925	1.000
2.540	1.000	.800
2.553	1.005	.690
2.565	1.010	.360
2.578	1.015	.210
2.591	1.020	.020

$x/D_e = 0.606$

y, cm	y, in.	u/u_e
0.000	0.000	0.179
.318	.125	.179
.572	.225	.179
.698	.275	.181
.825	.325	.208
.889	.350	.267
.953	.375	.341
1.016	.400	.424
1.080	.425	.546
1.143	.450	.612
1.206	.475	.768
1.270	.500	.837
1.333	.525	.934
1.397	.550	.983
1.460	.575	1.010
1.587	.625	1.010
1.715	.675	.997
1.842	.725	.996
2.096	.825	.996
2.350	.925	.974
2.477	.975	.829
2.603	1.025	.629
2.731	1.075	.405
2.858	1.125	.231
2.984	1.175	.106
3.112	1.225	.053
3.239	1.275	.036

$x/D_e = 1.16$

y, cm	y, in.	u/u_e
0.000	0.000	0.176
.063	.025	.175
.318	.125	.187
.572	.225	.299
.698	.275	.397
.825	.325	.509
.953	.375	.616
1.080	.425	.708
1.206	.475	.792
1.333	.525	.899
1.460	.575	.961
1.587	.625	.990
1.715	.675	.995
1.842	.725	.995
1.968	.775	.995
2.096	.825	.991
2.222	.875	.955
2.350	.925	.888
2.477	.975	.762
2.603	1.025	.691
2.858	1.125	.401
3.112	1.225	.196
3.366	1.325	.072
3.619	1.425	.031

$x/D_e = 2.14$

y (cm)	y (in.)	u/u_e
0.000	0.000	0.461
.063	.025	.452
.318	.125	.478
.572	.225	.574
.825	.325	.691
1.080	.425	.789
1.333	.525	.896
1.587	.625	.958
1.842	.725	.988
2.096	.825	.922
2.350	.925	.827
2.603	1.025	.678
2.858	1.125	.531
3.112	1.225	.377
3.366	1.325	.263
3.619	1.425	.161
3.873	1.525	.872
4.127	1.625	.461

$x/D_e = 3.09$

y (cm)	y (in.)	u/u_e
0.000	0.000	0.676
.572	.225	.708
1.080	.425	.807
1.587	.625	.911
2.096	.825	.890
2.603	1.025	.685
3.112	1.225	.468
3.619	1.425	.288
4.127	1.625	.147
4.636	1.825	.059
5.144	2.025	.026

$x/D_e = 4.07$

y (cm)	y (in.)	u/u_e
0.000	0.000	0.770
.698	.275	.782
1.333	.525	.842
1.968	.775	.848
2.603	1.025	.704
3.239	1.275	.512
3.873	1.525	.319
4.508	1.775	.182
5.144	2.025	.078
5.779	2.275	.036

$x/D_e = 6.05$

y (cm)	y (in.)	u/u_e
0.000	0.000	0.797
.698	.275	.808
1.333	.525	.800
1.968	.775	.757
2.603	1.025	.662
3.873	1.525	.426
5.144	2.025	.211
6.414	2.525	.079
7.684	3.025	.021

$x/D_e = 8.02$

y (cm)	y (in.)	u/u_e
0.000	0.000	0.738
.698	.275	.745
1.333	.525	.726
1.968	.775	.676
2.603	1.025	.606
3.873	1.525	.449
5.144	2.025	.299
6.414	2.525	.162
7.684	3.025	.078
8.954	3.525	.029

$x/D_e = 10.0$

y (cm)	y (in.)	u/u_e
0.000	0.000	0.646
1.333	.525	.637
2.603	1.025	.547
3.873	1.525	.426
5.144	2.025	.317
6.414	2.525	.214
7.684	3.025	.130
8.954	3.525	.072
10.224	4.025	.035

$x/D_e = 17.9$

y (cm)	y (in.)	u/u_e
0.000	0.000	0.365
2.603	1.025	.357
5.144	2.025	.294
7.684	3.025	.215
10.224	4.025	.144
12.764	5.025	.084
15.304	6.025	.044

$x/D_e = 0.606$

y (cm)	y (in.)	$\frac{\sqrt{\overline{u'^2}}}{u_e}$	$\frac{\sqrt{\overline{v'^2}}}{u_e}$
0.000	0.000	0.00565	0.00535
.381	.150	.00660	.00635
.635	.250	.01120	.01160
.762	.300	.01900	.02150
.889	.350	.03700	.03500
1.016	.400	.08750	.06100
1.270	.500	.10750	.08450
1.524	.600	.02050	.02350
1.651	.650	.01110	.01160
1.778	.700	.00860	.00860
1.905	.750	.00910	.00975
2.032	.800	.01000	.01520
2.159	.850	.02000	.02570
2.286	.900	.03700	.04750
2.413	.950	.09250	.07450
2.477	.975	.12300	.09400
2.540	1.000	.13400	.10000
2.667	1.050	.14400	.09900
2.731	1.075	.13700	.09000
2.794	1.100	.13100	.08100
3.048	1.200	.06300	.03100
3.302	1.300	.01220	.01000
3.556	1.400	.00580	.00450
3.810	1.500	.00320	.00230

$x/D_e = 1.16$

y (cm)	y (in.)	$\frac{\sqrt{\overline{u'^2}}}{u_e}$	$\frac{\sqrt{\overline{v'^2}}}{u_e}$
0.000	0.000	0.0240	0.0250
.254	.100	.0230	.0230
.508	.200	.0402	.0358
.762	.300	.0900	.0605
.889	.350	.1095	.0720
1.016	.400	.1150	.0775
1.143	.450	.1130	.0790
1.270	.500	.1000	.0720
1.524	.600	.0350	.0360
1.651	.650	.0200	.0230
1.778	.700	.0182	.0200
1.905	.750	.0202	.0237
2.032	.800	.0265	.0322
2.286	.900	.0900	.0670
2.413	.950	.1170	.0810
2.477	.975	.1190	.0820
2.540	1.000	.1300	.0880
2.667	1.050	.1370	.0910
2.794	1.100	.1350	.0850
2.921	1.150	.1250	.0760
3.048	1.200	.1090	.0610
3.302	1.300	.0660	.0320
3.556	1.400	.0221	.0120
3.810	1.500	.0080	.0060
3.937	1.550	.0060	.0050
4.064	1.600	.0050	.0040

$x/D_e = 2.14$

y, cm	y, in.	$\frac{\sqrt{\overline{u'^2}}}{u_e}$	$\frac{\sqrt{\overline{v'^2}}}{u_e}$
0.000	0.000	0.096	0.072
.254	.100	.088	.068
.508	.200	.098	.071
.635	.250	.105	.074
.762	.300	.109	.076
.889	.350	.115	.079
1.143	.450	.114	.077
1.397	.550	.102	.069
1.651	.650	.066	.056
1.778	.700	.058	.055
1.905	.750	.054	.057
2.096	.825	.074	.064
2.222	.875	.100	.074
2.413	.950	.126	.087
2.540	1.000	.134	.091
2.667	1.050	.140	.095
2.794	1.100	.141	.094
2.921	1.150	.140	.090
3.175	1.250	.131	.080
3.429	1.350	.109	.062
3.937	1.550	.056	.027
4.445	1.750	.013	.009
4.953	1.950	.006	.003

$x/D_e = 3.09$

y, cm	y, in.	$\frac{\sqrt{\overline{u'^2}}}{u_e}$	$\frac{\sqrt{\overline{v'^2}}}{u_e}$
0.000	0.000	0.091	0.075
.635	.250	.096	.075
.953	.375	.106	.075
1.270	.500	.110	.075
1.333	.525	.100	.075
1.905	.750	.093	.080
2.159	.850	.114	.089
2.413	.950	.134	.095
2.540	1.000	.135	.096
2.667	1.050	.141	.097
2.921	1.150	.143	.096
3.175	1.250	.140	.090
3.429	1.350	.130	.080
3.683	1.450	.117	.067
3.810	1.500	.108	.063
3.937	1.550	.100	.055
1.651	1.650	.081	.042
4.445	1.750	.063	.030
5.080	2.000	.022	.008
5.715	2.250	.008	.003

$x/D_e = 4.07$

y (cm)	y (in.)	$\frac{\sqrt{\overline{u'^2}}}{u_e}$	$\frac{\sqrt{\overline{v'^2}}}{u_e}$
0.000	0.000	0.086	0.069
.635	.250	.087	.070
1.270	.500	.097	.074
1.905	.750	.102	.085
2.222	.875	.115	.093
2.540	1.000	.132	.098
2.858	1.125	.138	.099
3.175	1.250	.143	.098
3.493	1.375	.136	.090
3.810	1.500	.129	.080
4.445	1.750	.098	.054
5.080	2.000	.063	.031
5.715	2.250	.030	.014
6.350	2.500	.012	.005
6.985	2.750	.007	.002
7.620	3.000	.004	.001

$x/D_e = 6.05$

y (cm)	y (in.)	$\frac{\sqrt{\overline{u'^2}}}{u_e}$	$\frac{\sqrt{\overline{v'^2}}}{u_e}$
0.000	0.000	0.079	0.068
.635	.250	.077	.068
1.270	.500	.083	.074
1.905	.750	.098	.084
2.540	1.000	.121	.092
3.175	1.250	.131	.095
3.810	1.500	.131	.088
4.445	1.750	.120	.078
5.080	2.000	.102	.060
5.715	2.250	.085	.046
6.350	2.500	.060	.029
6.985	2.750	.038	.017
7.620	3.000	.022	.009
8.255	3.250	.012	.005
8.890	3.500	.007	.003
9.525	3.750	.003	.002

$x/D_e = 8.02$

y (cm)	y (in.)	$\frac{\sqrt{\overline{u'^2}}}{u_e}$	$\frac{\sqrt{\overline{v'^2}}}{u_e}$
0.000	0.000	0.094	0.079
.635	.250	.090	.079
1.270	.500	.090	.080
1.905	.750	.107	.086
2.540	1.000	.117	.089
3.810	1.500	.125	.087
5.080	2.000	.114	.073
6.350	2.500	.091	.053
7.620	3.000	.067	.032
8.890	3.500	.037	.015
10.160	4.000	.013	.005
11.430	4.500	.006	.002
12.700	5.000	.004	.001

$x/D_e = 10.00$

y (cm)	y (in.)	$\frac{\sqrt{\overline{u'^2}}}{u_e}$	$\frac{\sqrt{\overline{v'^2}}}{u_e}$
0.000	0.000	0.107	0.085
1.270	.500	.105	.085
2.540	1.000	.114	.086
3.810	1.500	.116	.084
5.080	2.000	.120	.076
6.350	2.500	.098	.063
7.620	3.000	.081	.047
8.890	3.500	.064	.032
10.160	4.000	.040	.017
11.430	4.500	.024	.010
12.700	5.000	.011	.004
13.970	5.500	.005	.002
15.240	6.000	.003	.001

Test Case 24 (Optional)

Classification: Wake

Reference: Demetriades, A.: Compilation of Numerical Data on the Mean Flow From Compressible Turbulent Wake Experiments. Publ. No. U-4970, Aeronutronic Div., Philco-Ford Corp., Oct. 1, 1971.

Description of flow: This wake flow was two-dimensional and differed from that described in test case 16 in that the wedge was heated so that transition in this flow did not occur until about 9.0 cm downstream of the model. Note that the momentum thickness, calculated from the experimental data, again increased by about 20 percent between the first x-station (x = 1.67 cm) surveyed and the transition point. It did, however, remain approximately constant over the rest of the flow. The data given below has been nondimensionalized with respect to the local free-stream values. Complete tabulations of the data are given in the reference document.

Test case 24 data:

Classification: Wake

Source: Reference document

Initial profile at $x = 1.67$ cm

$u_e = 62\,083.1$ cm/sec $\quad T_e = 117.2473^o$ K

$\rho_e = 0.00008161$ g/cm^3 $\quad M_e = 2.8543$

y, cm	u/u_e	ρ/ρ_e	T/T_e
0	0.7718	0.4412	2.2671
.004	.8050	.4681	2.1376
.008	.8931	.5662	1.7669
.012	.9665	.7402	1.3509
.016	.9912	.9020	1.1095
.020	.9934	.9694	1.0322
.024	.9949	.9841	1.0166
.028	.9972	.9914	1.0092

x, cm	Nondimensional center-line values		
	$u_{\mathbb{C}}/u_e$	$\rho_{\mathbb{C}}/\rho_e$	$T_{\mathbb{C}}/T_e$
1.64	0.7718	0.4412	2.2671
2.43	.8277	.4588	2.1259
3.20	.8466	.4893	2.0199
3.96	.8592	.5238	1.8815
4.72	.8738	.5506	1.805
5.48	.8866	.5774	1.7177
6.24	.8955	.5923	1.6518
7.01	.9010	.6333	1.5580
7.77	.9218	.6606	1.4692
8.53	.9312	.6963	1.4077
9.29	.9377	.7124	1.3682
10.05	.9442	.7376	1.3278
10.82	.9468	.7576	1.3072
11.58	.9511	.7718	1.2826
12.34	.9550	.7758	1.2524
13.10	.9562	.7841	1.2544
13.86	.9585	.7919	1.2320
14.63	.9616	.8054	1.2201
15.39	.9651	.8171	1.2048
16.15	.9682	.7964	1.1936
16.91	.9663	.8122	1.1925
17.67	.9630	.8266	1.2086

NASA-Langley, 1973 —— 12