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TURBULENCE CHARACTERISTICS OF AN AXISYMMETRIC REACTING FLOW

Richard D. Gould, Warren H. Stevenson
and H. Doyle Thompson

Purdue University School of
Mechanical Engineering

Turbulent sudden expansion flows are of significant theoretical and practical importance. Such flows have been the subject of extensive analytical and experimental study for decades, but many issues are still unresolved. Detailed information on reacting sudden expansion flows is very limited, since suitable measurement techniques have only been available in recent years. The present study of reacting flow in an axisymmetric sudden expansion was initiated under NASA support in December 1983. It is an extension of a reacting flow program which has been carried out with Air Force support under contract F33615-81-K-2003. Since the present effort has just begun, results are not yet available. Therefore a brief overview of results from the Air Force program will be presented to indicate the basis for the work to be carried out. Details may be found in reference 1.

Laser velocimeter measurements of mean streamwise velocity and turbulence intensity were made in the highly turbulent flow field following a sudden pipe expansion. Both isothermal and reacting flows were studied. A fused quartz test section was used to permit laser velocimeter measurements throughout the flow field for x/H values from 0.33 to 15. A lean partially premixed propane-air mixture ($\phi = 0.28$) was used to keep the wall temperature low enough so that steady state operation was possible. The inlet flow condition was that of fully developed turbulent pipe flow with a centerline velocity of 22 m/s. The corresponding Reynold's number based on step height H and inlet centerline velocity U_1 was 5.5×10^4.

Three complete sets of LDV measurements were made. Two were in isothermal flow (biased and unbiased) and one was made in the reacting flow (biased). The biased and unbiased cold flow measurements were compared to determine the effects of velocity bias on the measurements. The hot and cold flow measurements were compared to determine the effect of combustion on the structure of the flow field. (Unbiased hot flow data could not be obtained because of particle seeder limitations.)

The scope of the investigation is outlined in figure 1. The experimental apparatus is shown in figures 2-4 and test parameters are presented in figure 5. Examples of some of the data obtained are given in figures 6-15 and conclusions which can be drawn are given in figure 16. A summary of the further research planned under the present NASA sponsored program is presented in figure 17.

REFERENCES

1. Stevenson, W. H., Thompson, H. D., and Gould, R. D.: Laser Velocimeter Measurements and Analysis in Turbulent Flows with Combustion - Part I, AFWAL-TR-82-2076 Part II, 1983.

2. Stevenson, W. H., Thompson, H. D., and Luchik, T. S.: Laser Velocimeter Measurements and Analysis in Turbulent Flows with Combustion - Part I, AFWAL-TR-82-2076 Part I, 1982.

3. Moon, L. F. and Rudinger, G.: Velocity Distribution in an Abruptly Expanding Circular Duct, ASME Journal of Fluids Engineering, vol. 99, March 1977, pp. 226-230.

4. Freeman, A. R.: Laser Anemometer Measurements in the Recirculating Region Downstream of a Sudden Pipe Expansion, Proceedings of the LDA Symposium, Copenhagen, 1975, pp. 704-709.

SCOPE OF THE STUDY*

1. Measured streamwise mean velocities and turbulence intensities.

2. 3 different measurements were made at each measurement location to form 3 complete data sets. They are identified as:

   - biased } cold flow
   - unbiased } cold flow
   - biased — hot flow

3. Reattachment point was located.

4. Integrated mass flux at each measurement plane was calculated and was used as a continuity check.

5. Measured temperature at a plane located 17 step heights downstream of the sudden expansion.

6. Comparison of cold flow data with 2/E/FIX.

*AF Contract F33615-81-K-2003

Figure 1

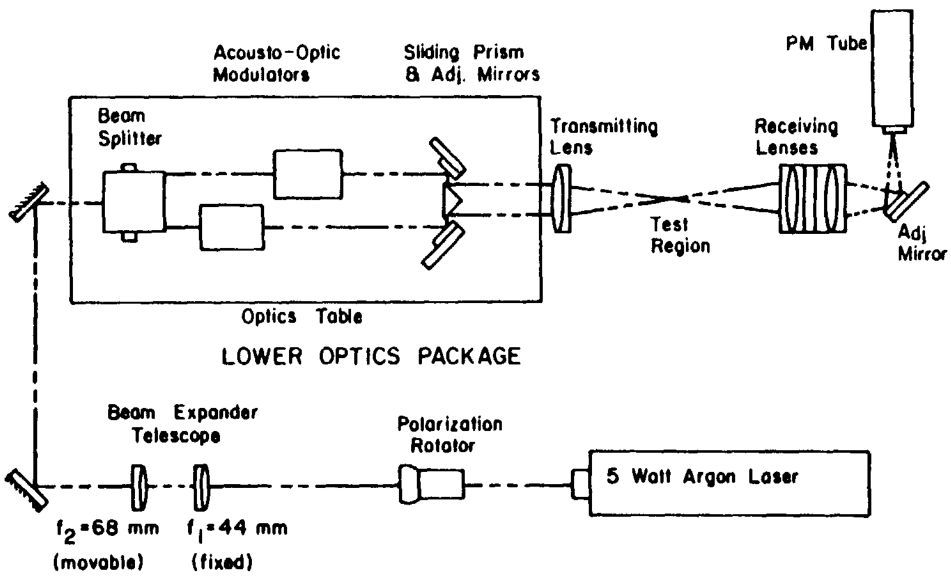

Figure 2 LDV Optics Package

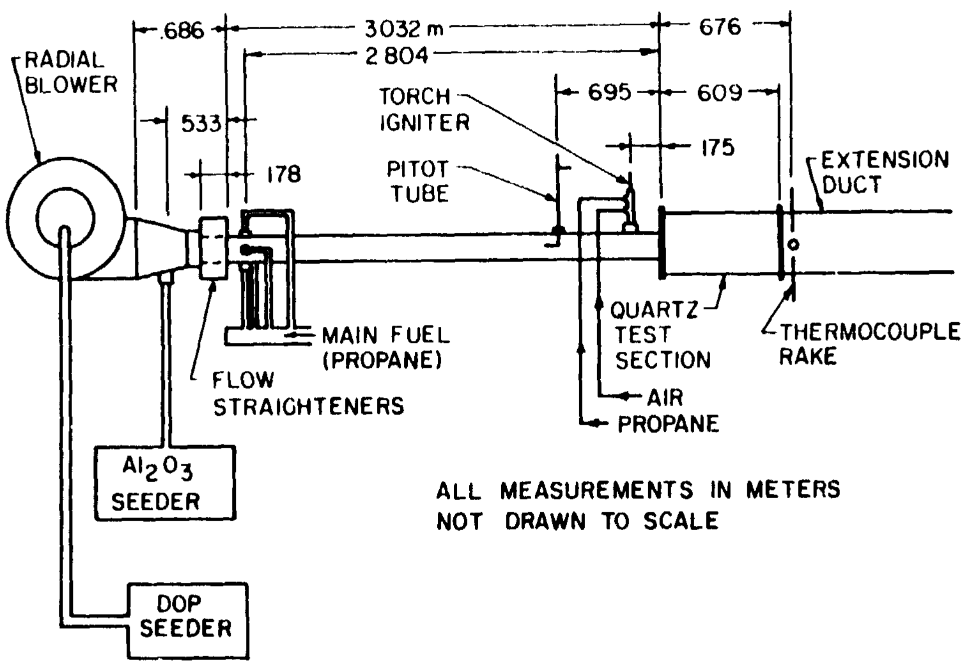

Figure 3. Flow System

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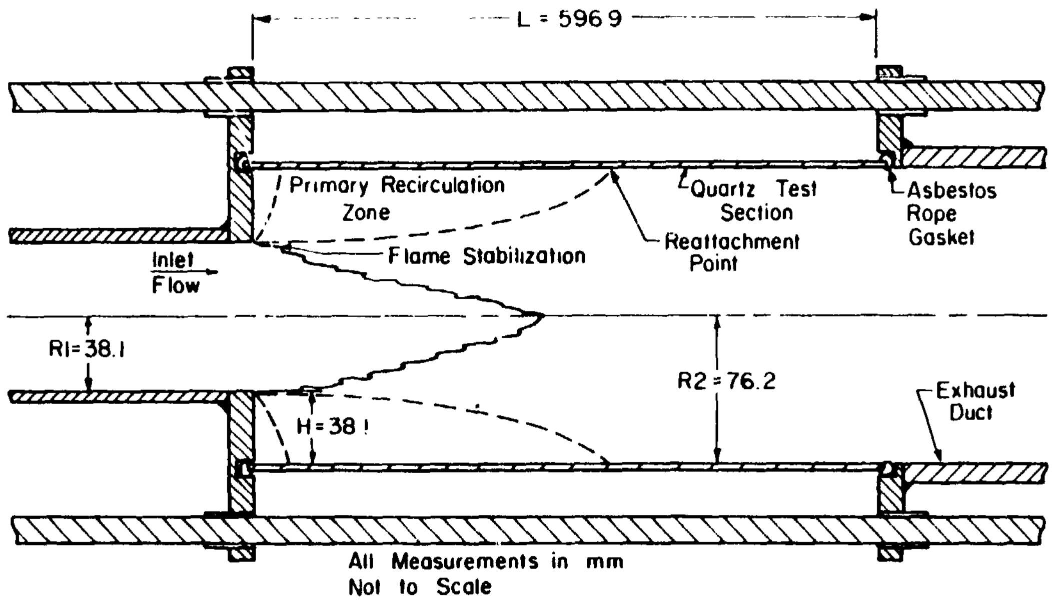

Figure 4. Geometry of Axisymmetric Test Section

TEST PARAMETERS

FLOW PARAMETERS

$U_{\mathfrak{L}}$ = 22.07 m/s (PITOT TUBE MEASUREMENT)

$Re_D = 1.1 \times 10^5$

$Re_H = 5.5 \times 10^4$

OVERALL F/A = 0.0183 (GASEOUS PROPANE)

OVERALL EQUIVALENCE RATIO, ϕ = 0.28

GEOMETRY

D_{IN} = 76.2 mm (3 in)

D_{OUT} = 152.4 mm (6 in)

AREA RATIO, A_R = 4

STEP HEIGHT, H = 38.1 mm (1.5 in)

DATA COLLECTION

	UNBIASED COLD	BIASED COLD	BIASED HOT
PARTICLE ARRIVAL RATE:	> 20,000	500-1500/sec	500-1500/sec
SAMPLE RATE:	50/sec	"FREE" (4700/sec)	"FREE" (4700/sec)
SEED:	DOP	Al_2O_3	Al_2O_3

Figure 5

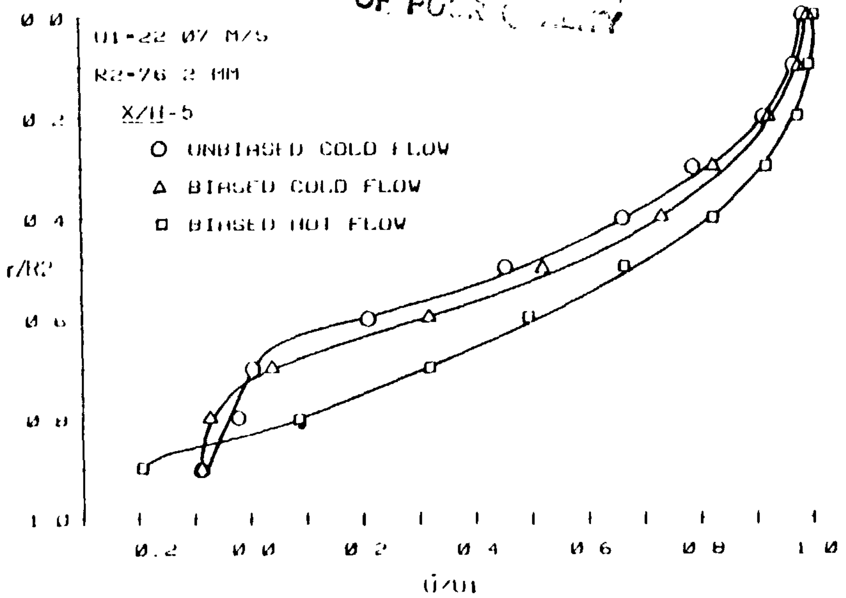

Figure 6. Measured Mean Streamwise Velocity Profiles at x/H = 5

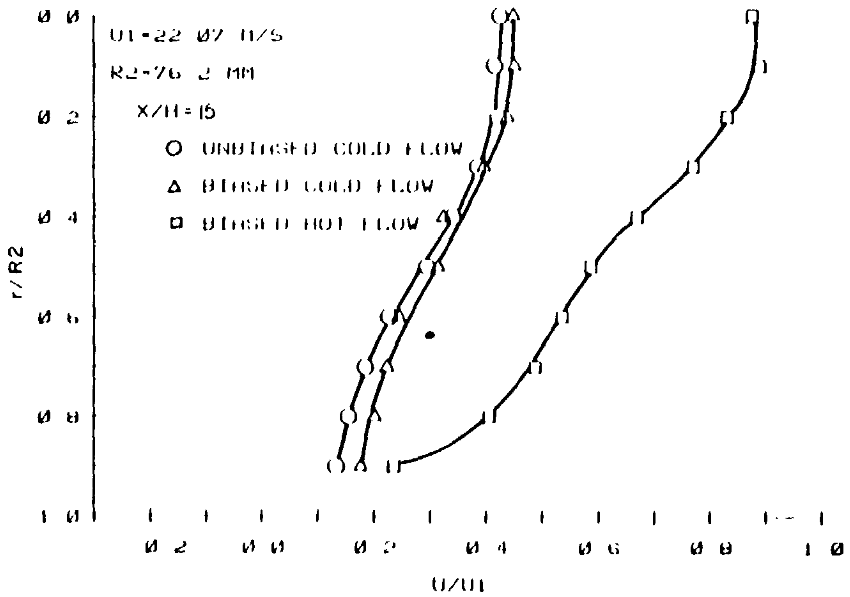

Figure 7. Measured Mean Streamwise Velocity Profiles at x/H = 15

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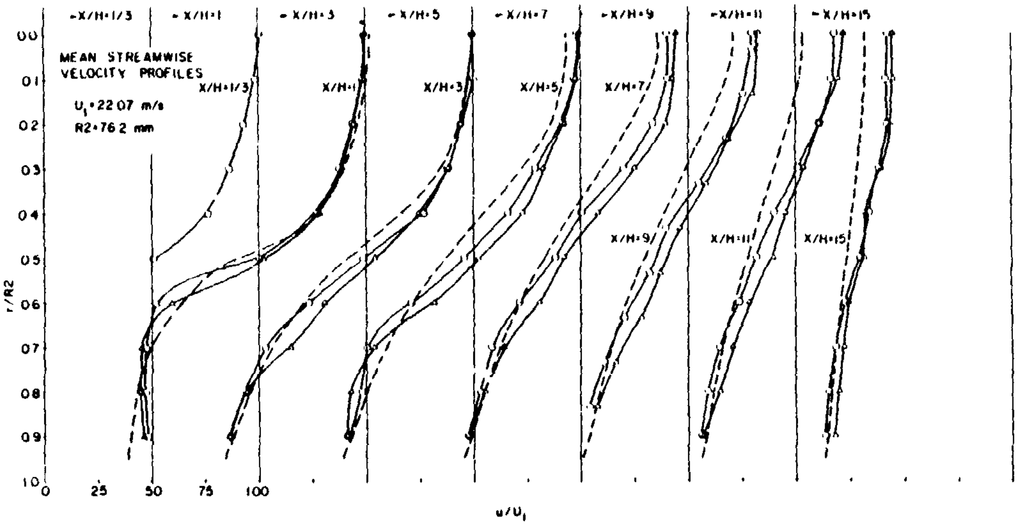

Figure 8. Measured Mean Streamwise Velocity Profiles in Cold Flow
(o - unbiased cold flow, Δ - biased cold flow, --- 2/E/FIX prediction)

NORMALIZED* INTEGRATED MASS FLUX
(COLD FLOW)

x/H	UNBIASED	BIASED
1/3	1.00	---
1	1.044	1.065
3	1.056	1.200
5	1.002	1.129
7	1.012	1.206
9	1.032	1.238
11	1.019	1.212
15	1.031	1.166

*VALUES NORMALIZE WITH ASSUMED 1/7 POWER LAW INLET VELOCITY PROFILE

Figure 9

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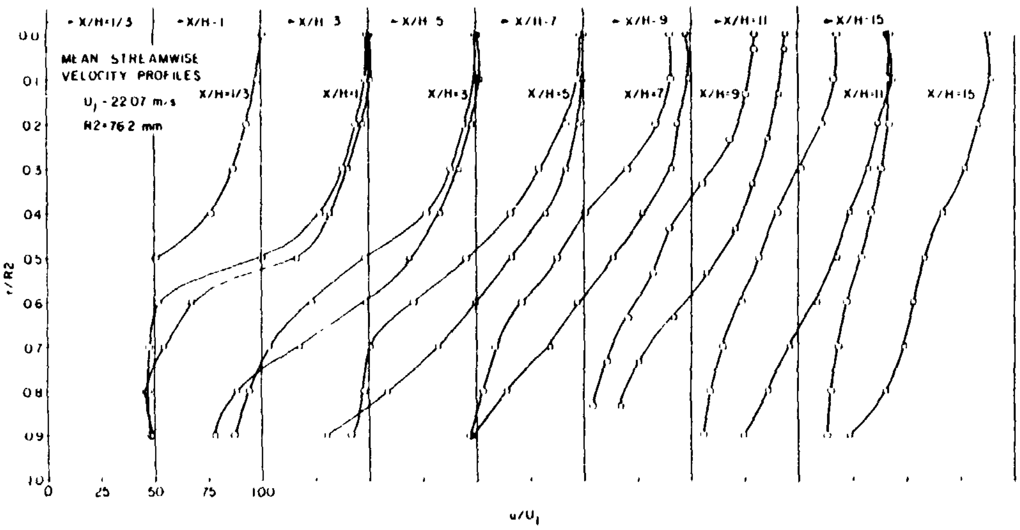

Figure 10. Measured Mean Streamwise Velocity Profiles in Cold Flow and in Reacting Flow

(o - unbiased cold flow, □- biased hot flow)

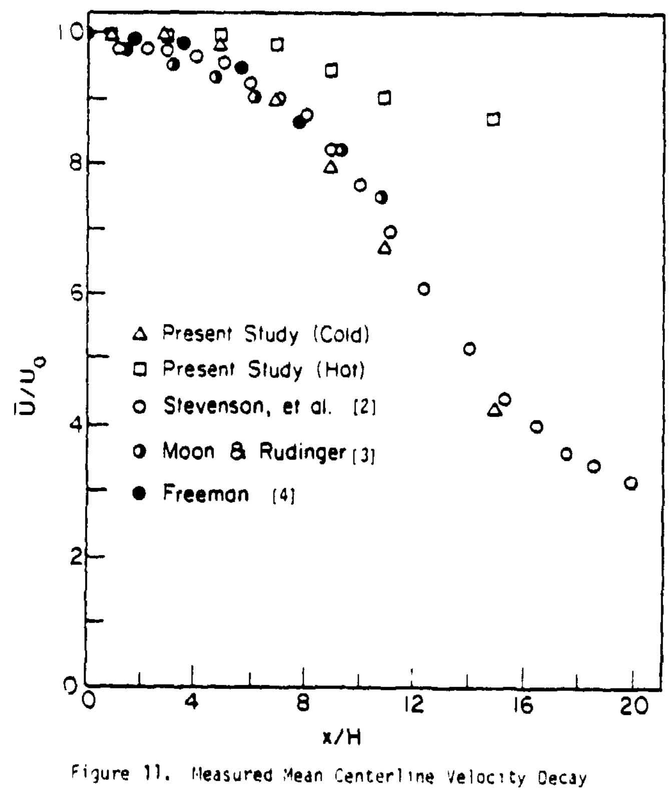

Figure 11. Measured Mean Centerline Velocity Decay

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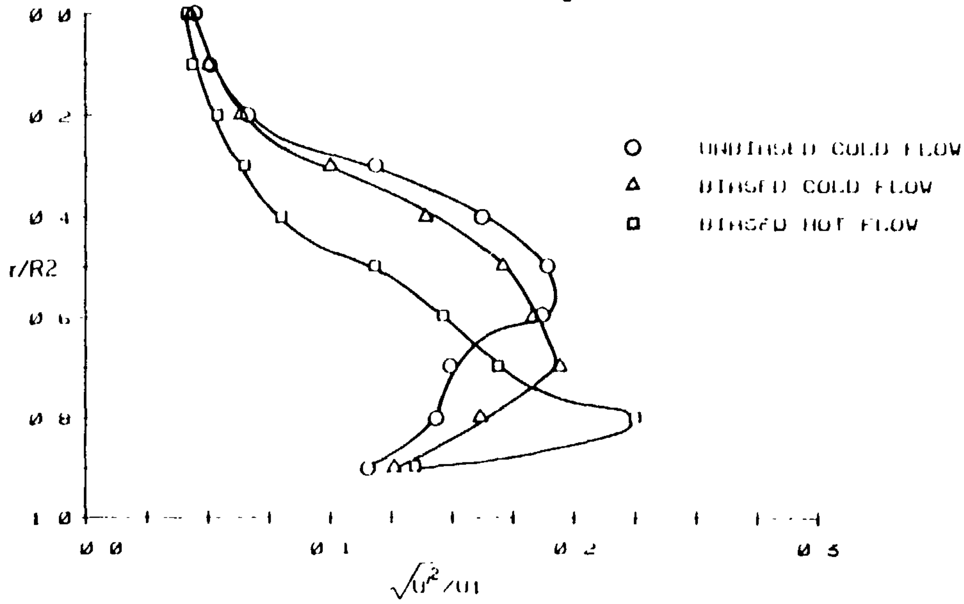

Figure 12. Measured Normalized Streamwise Turbulence Intensity Profiles at x/H = 5

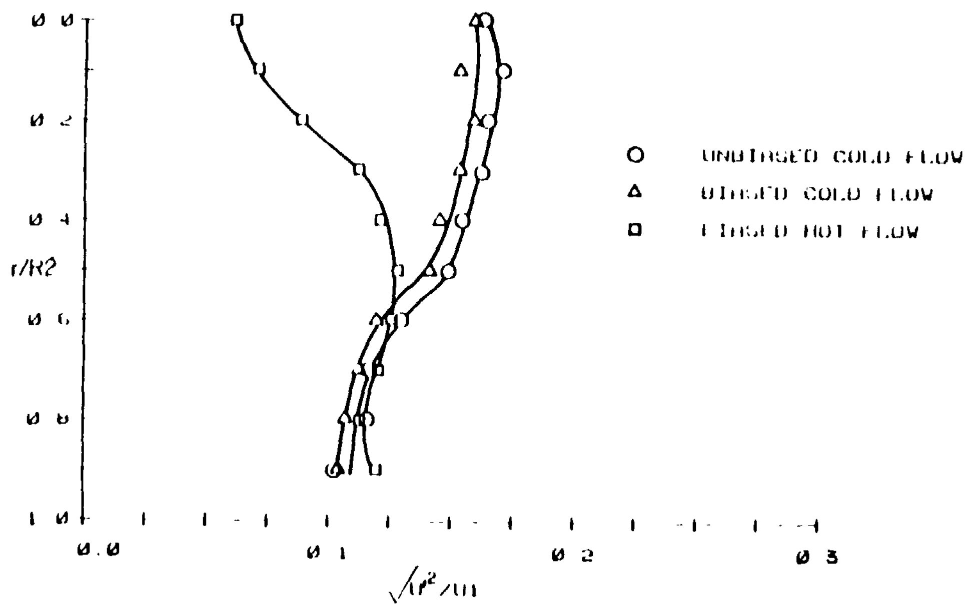

Figure 13. Measured Normalized Streamwise Turbulence Intensity Profiles at x/H = 15

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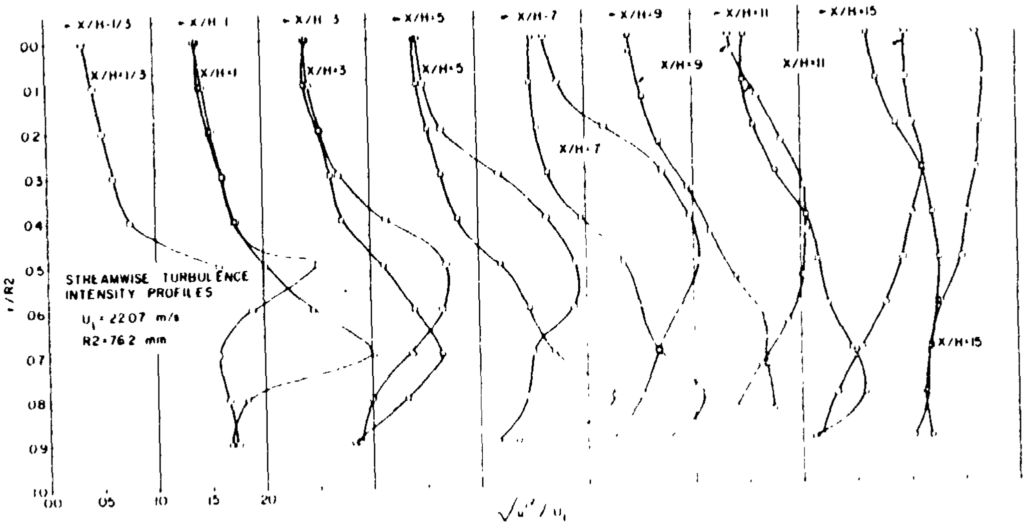

Figure 14. Measured Normalized Streamwise Turbulence Intensity Profiles

(o unbiased cold flow, □- biased hot flow)

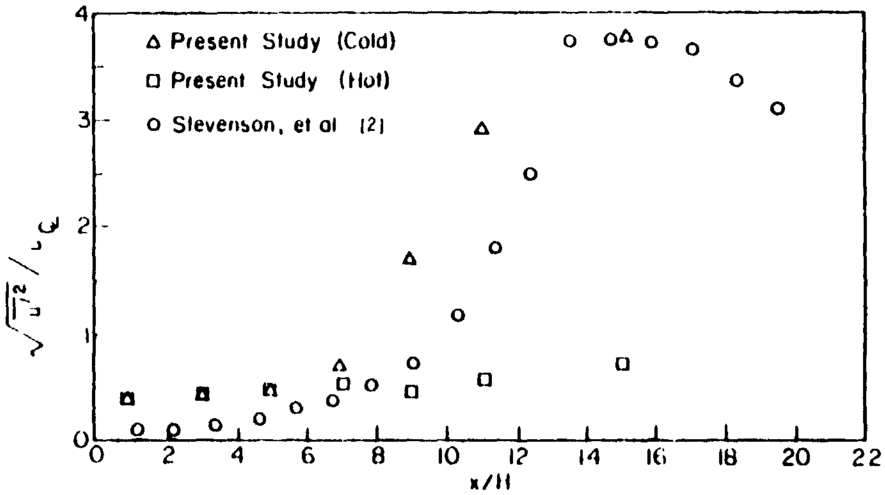

Figure 15. Measured Local Centerline Turbulence Intensity Profiles

CONCLUSIONS

1. Velocity measurements were made in a sudden expansion turbulent reacting flow at atmospheric pressure. Few difficulties were encountered in making these measurements.

2. The reacting flow exhibited several structural differences relative to the cold flow:

   a) The recirculation zone was smaller and more intense in the reacting flow. Reattachment occurred at X/H = 7.4 for the hot flow as compared to 8.6 for the cold flow.

   b) The position of peak turbulence intensity was different in the reacting flow, although the maximum normalized turbulence intensity was approximately the same in both cases.

   c) Local turbulence intensity was reduced by up to 60 percent in the reacting flow due to the higher local velocities resulting from the heat release.

3. Velocity bias had the expected effect on the mean velocity data. A significant shift in the normalized turbulence distribution in the shear layer was found to exist due to bias.

Figure 16

FUTURE WORK*

1. Develop 2 color - 2 component LDV system
   - Measure mean and fluctuating velocity simultaneously for two components
   - Measure Reynolds stress correlation
   - Obtain power spectrum and length scales.

2. Utilize correction lens system to make radial velocity measurements
   - Allows $\overline{uv_R}$ Reynolds stress correlation measurement
   - Important if studying effects of swirl

3. Utilize high frequency response thermocouple to make dynamic temperature measurements in reacting flow
   - Balance te'ms in the turbulent kinetic energy conservation equation in both hot and cold flow
   - Identify regions where the various turbulence mechanisms dominate in the hot and cold flow

     Production

     Advection

     Diffusion

     Dissipation

*NASA Grant NAG 3-502

Figure 17

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