MEAN VELOCITY AND STRAIN FIELD

IN AN AXISYMMETRIC FLOW

68

BY

MUTISO MWAKA

A Thesis
submitted to the Faculty of Graduate studies in
partial fulfillment of the requirements for
the degree of

MASTER OF SCIENCE

Department of Mechanical Engineering
University of Manitoba
Winnipeg, Manitoba

ISBN 0-612-13391-5

Name ______________________

Dissertation Abstracts International is arranged by broad, general subject categories. Please select the one subject which most nearly describes the content of your dissertation. Enter the corresponding four-digit code in the spaces provided.

MECHANICAL ENG. — SUBJECT TERM

0548 — SUBJECT CODE

U·M·I

Subject Categories

THE HUMANITIES AND SOCIAL SCIENCES

COMMUNICATIONS AND THE ARTS
Architecture 0729
Art History 0377
Cinema 0900
Dance 0378
Fine Arts 0357
Information Science 0723
Journalism 0391
Library Science 0399
Mass Communications 0708
Music 0413
Speech Communication 0459
Theater 0465

EDUCATION
General 0515
Administration 0514
Adult and Continuing 0516
Agricultural 0517
Art 0273
Bilingual and Multicultural 0282
Business 0688
Community College 0275
Curriculum and Instruction 0727
Early Childhood 0518
Elementary 0524
Finance 0277
Guidance and Counseling 0519
Health 0680
Higher 0745
History of 0520
Home Economics 0278
Industrial 0521
Language and Literature 0279
Mathematics 0280
Music 0522
Philosophy of 0998
Physical 0523
Psychology 0525
Reading 0535
Religious 0527
Sciences 0714
Secondary 0533
Social Sciences 0534
Sociology of 0340
Special 0529
Teacher Training 0530
Technology 0710
Tests and Measurements 0288
Vocational 0747

LANGUAGE, LITERATURE AND LINGUISTICS
Language
- General 0679
- Ancient 0289
- Linguistics 0290
- Modern 0291

Literature
- General 0401
- Classical 0294
- Comparative 0295
- Medieval 0297
- Modern 0298
- African 0316
- American 0591
- Asian 0305
- Canadian (English) 0352
- Canadian (French) 0355
- English 0593
- Germanic 0311
- Latin American 0312
- Middle Eastern 0315
- Romance 0313
- Slavic and East European 0314

PHILOSOPHY, RELIGION AND THEOLOGY
Philosophy 0422
Religion
- General 0318
- Biblical Studies 0321
- Clergy 0319
- History of 0320
- Philosophy of 0322

Theology 0469

SOCIAL SCIENCES
American Studies 0323
Anthropology
- Archaeology 0324
- Cultural 0326
- Physical 0327

Business Administration
- General 0310
- Accounting 0272
- Banking 0770
- Management 0454
- Marketing 0338

Canadian Studies 0385
Economics
- General 0501
- Agricultural 0503
- Commerce-Business 0505
- Finance 0508
- History 0509
- Labor 0510
- Theory 0511

Folklore 0358
Geography 0366
Gerontology 0351
History
- General 0578
- Ancient 0579
- Medieval 0581
- Modern 0582
- Black 0328
- African 0331
- Asia, Australia and Oceania 0332
- Canadian 0334
- European 0335
- Latin American 0336
- Middle Eastern 0333
- United States 0337

History of Science 0585
Law 0398
Political Science
- General 0615
- International Law and Relations 0616
- Public Administration 0617

Recreation 0814
Social Work 0452
Sociology
- General 0626
- Criminology and Penology 0627
- Demography 0938
- Ethnic and Racial Studies 0631
- Individual and Family Studies 0628
- Industrial and Labor Relations 0629
- Public and Social Welfare 0630
- Social Structure and Development 0700
- Theory and Methods 0344

Transportation 0709
Urban and Regional Planning 0999
Women's Studies 0453

THE SCIENCES AND ENGINEERING

BIOLOGICAL SCIENCES
Agriculture
- General 0473
- Agronomy 0285
- Animal Culture and Nutrition 0475
- Animal Pathology 0476
- Food Science and Technology 0359
- Forestry and Wildlife 0478
- Plant Culture 0479
- Plant Pathology 0480
- Plant Physiology 0817
- Range Management 0777
- Wood Technology 0746

Biology
- General 0306
- Anatomy 0287
- Biostatistics 0308
- Botany 0309
- Cell 0379
- Ecology 0329
- Entomology 0353
- Genetics 0369
- Limnology 0793
- Microbiology 0410
- Molecular 0307
- Neuroscience 0317
- Oceanography 0416
- Physiology 0433
- Radiation 0821
- Veterinary Science 0778
- Zoology 0472

Biophysics
- General 0786
- Medical 0760

EARTH SCIENCES
Biogeochemistry 0425
Geochemistry 0996
Geodesy 0370
Geology 0372
Geophysics 0373
Hydrology 0388
Mineralogy 0411
Paleobotany 0345
Paleoecology 0426
Paleontology 0418
Paleozoology 0985
Palynology 0427
Physical Geography 0368
Physical Oceanography 0415

HEALTH AND ENVIRONMENTAL SCIENCES
Environmental Sciences 0768
Health Sciences
- General 0566
- Audiology 0300
- Chemotherapy 0992
- Dentistry 0567
- Education 0350
- Hospital Management 0769
- Human Development 0758
- Immunology 0982
- Medicine and Surgery 0564
- Mental Health 0347
- Nursing 0569
- Nutrition 0570
- Obstetrics and Gynecology 0380
- Occupational Health and Therapy 0354
- Ophthalmology 0381
- Pathology 0571
- Pharmacology 0419
- Pharmacy 0572
- Physical Therapy 0382
- Public Health 0573
- Radiology 0574
- Recreation 0575
- Speech Pathology 0460
- Toxicology 0383

Home Economics 0386

PHYSICAL SCIENCES

Pure Sciences

Chemistry
- General 0485
- Agricultural 0749
- Analytical 0486
- Biochemistry 0487
- Inorganic 0488
- Nuclear 0738
- Organic 0490
- Pharmaceutical 0491
- Physical 0494
- Polymer 0495
- Radiation 0754

Mathematics 0405
Physics
- General 0605
- Acoustics 0986
- Astronomy and Astrophysics 0606
- Atmospheric Science 0608
- Atomic 0748
- Electronics and Electricity 0607
- Elementary Particles and High Energy 0798
- Fluid and Plasma 0759
- Molecular 0609
- Nuclear 0610
- Optics 0752
- Radiation 0756
- Solid State 0611

Statistics 0463

Applied Sciences

Applied Mechanics 0346
Computer Science 0984
Engineering
- General 0537
- Aerospace 0538
- Agricultural 0539
- Automotive 0540
- Biomedical 0541
- Chemical 0542
- Civil 0543
- Electronics and Electrical 0544
- Heat and Thermodynamics 0348
- Hydraulic 0545
- Industrial 0546
- Marine 0547
- Materials Science 0794
- ✓ Mechanical 0548
- Metallurgy 0743
- Mining 0551
- Nuclear 0552
- Packaging 0549
- Petroleum 0765
- Sanitary and Municipal 0554
- System Science 0790

Geotechnology 0428
Operations Research 0796
Plastics Technology 0795
Textile Technology 0994

PSYCHOLOGY
General 0621
Behavioral 0384
Clinical 0622
Developmental 0620
Experimental 0623
Industrial 0624
Personality 0625
Physiological 0989
Psychobiology 0349
Psychometrics 0632
Social 0451

Nom ____

Dissertation Abstracts International est organisé en catégories de sujets. Veuillez s.v.p. choisir le sujet qui décrit le mieux votre thèse et inscrivez le code numérique approprié dans l'espace réservé ci-dessous.

____ ☐☐☐☐ U·M·I

SUJET — CODE DE SUJET

Catégories par sujets

HUMANITÉS ET SCIENCES SOCIALES

COMMUNICATIONS ET LES ARTS
Architecture 0729
Beaux-arts 0357
Bibliothéconomie 0399
Cinéma 0900
Communication verbale 0459
Communications 0708
Danse 0378
Histoire de l'art 0377
Journalisme 0391
Musique 0413
Sciences de l'information 0723
Théâtre 0465

ÉDUCATION
Généralités 515
Administration 0514
Art 0273
Collèges communautaires 0275
Commerce 0688
Économie domestique 0278
Éducation permanente 0516
Éducation préscolaire 0518
Éducation sanitaire 0680
Enseignement agricole 0517
Enseignement bilingue et multiculturel 0282
Enseignement industriel 0521
Enseignement primaire. 0524
Enseignement professionnel 0747
Enseignement religieux 0527
Enseignement secondaire 0533
Enseignement spécial 0529
Enseignement supérieur 0745
Évaluation 0288
Finances 0277
Formation des enseignants 0530
Histoire de l'éducation 0520
Langues et littérature 0279
Lecture 0535
Mathématiques 0280
Musique 0522
Orientation et consultation 0519
Philosophie de l'éducation 0998
Physique 0523
Programmes d'études et enseignement 0727
Psychologie 0525
Sciences 0714
Sciences sociales 0534
Sociologie de l'éducation 0340
Technologie 0710

LANGUE, LITTÉRATURE ET LINGUISTIQUE
Langues
- Généralités 0679
- Anciennes 0289
- Linguistique 0290
- Modernes 0291

Littérature
- Généralités 0401
- Anciennes 0294
- Comparée 0295
- Mediévale 0297
- Moderne 0298
- Africaine 0316
- Américaine 0591
- Anglaise 0593
- Asiatique 0305
- Canadienne (Anglaise) 0352
- Canadienne (Française) 0355
- Germanique 0311
- Latino-américaine 0312
- Moyen-orientale 0315
- Romane 0313
- Slave et est-européenne 0314

PHILOSOPHIE, RELIGION ET THÉOLOGIE
Philosophie 0422
Religion
- Généralités 0318
- Clergé 0319
- Études bibliques 0321
- Histoire des religions 0320
- Philosophie de la religion 0322

Théologie 0469

SCIENCES SOCIALES
Anthropologie
- Archéologie 0324
- Culturelle 0326
- Physique 0327

Droit 0398
Économie
- Généralités 0501
- Commerce-Affaires 0505
- Économie agricole 0503
- Économie du travail 0510
- Finances 0508
- Histoire 0509
- Théorie 0511

Études américaines 0323
Études canadiennes 0385
Études féministes 0453
Folklore 0358
Géographie 0366
Gérontologie 0351
Gestion des affaires
- Généralités 0310
- Administration 0454
- Banques 0770
- Comptabilité 0272
- Marketing 0338

Histoire
- Histoire générale 0578
- Ancienne 0579
- Médiévale 0581
- Moderne 0582
- Histoire des noirs 0328
- Africaine 0331
- Canadienne 0334
- États-Unis 0337
- Européenne 0335
- Moyen-orientale 0333
- Latino-américaine 0336
- Asie, Australie et Océanie 0332

Histoire des sciences 0585
Loisirs 0814
Planification urbaine et régionale 0999
Science politique
- Généralités 0615
- Administration publique 0617
- Droit et relations internationales 0616

Sociologie
- Généralités 0626
- Aide et bien-àtre social 0630
- Criminologie et établissements pénitentiaires 0627
- Démographie 0938
- Études de l' individu et de la famille 0628
- Études des relations interethniques et des relations raciales 0631
- Structure et développement social 0700
- Théorie et méthodes. 0344
- Travail et relations industrielles 0629

Transports 0709
Travail social 0452

SCIENCES ET INGÉNIERIE

SCIENCES BIOLOGIQUES
Agriculture
- Généralités 0473
- Agronomie. 0285
- Alimentation et technologie alimentaire 0359
- Culture 0479
- Élevage et alimentation 0475
- Exploitation des péturages 0777
- Pathologie animale 0476
- Pathologie végétale 0480
- Physiologie végétale 0817
- Sylviculture et faune 0478
- Technologie du bois 0746

Biologie
- Généralités 0306
- Anatomie 0287
- Biologie (Statistiques) 0308
- Biologie moléculaire 0307
- Botanique 0309
- Cellule 0379
- Écologie 0329
- Entomologie 0353
- Génétique 0369
- Limnologie 0793
- Microbiologie 0410
- Neurologie 0317
- Océanographie 0416
- Physiologie 0433
- Radiation 0821
- Science vétérinaire 0778
- Zoologie 0472

Biophysique
- Généralités 0786
- Medicale 0760

SCIENCES DE LA TERRE
Biogéochimie 0425
Géochimie 0996
Géodésie 0370
Géographie physique 0368
Géologie 0372
Géophysique 0373
Hydrologie 0388
Minéralogie 0411
Océanographie physique 0415
Paléobotanique 0345
Paléoécologie 0426
Paléontologie 0418
Paléozoologie 0985
Palynologie 0427

SCIENCES DE LA SANTÉ ET DE L'ENVIRONNEMENT
Économie domestique 0386
Sciences de l'environnement 0768
Sciences de la santé
- Généralités 0566
- Administration des hipitaux 0769
- Alimentation et nutrition 0570
- Audiologie 0300
- Chimiothérapie 0992
- Dentisterie 0567
- Développement humain 0758
- Enseignement 0350
- Immunologie 0982
- Loisirs 0575
- Médecine du travail et thérapie 0354
- Médecine et chirurgie 0564
- Obstétrique et gynécologie 0380
- Ophtalmologie 0381
- Orthophonie 0460
- Pathologie 0571
- Pharmacie 0572
- Pharmacologie 0419
- Physiothérapie 0382
- Radiologie 0574
- Santé mentale 0347
- Santé publique 0573
- Soins infirmiers 0569
- Toxicologie 0383

SCIENCES PHYSIQUES
Sciences Pures
Chimie
- Genéralités 0485
- Biochimie 487
- Chimie agricole 0749
- Chimie analytique 0486
- Chimie minérale 0488
- Chimie nucléaire 0738
- Chimie organique 0490
- Chimie pharmaceutique 0491
- Physique 0494
- PolymÇres 0495
- Radiation 0754

Mathématiques 0405
Physique
- Généralités 0605
- Acoustique 0986
- Astronomie et astrophysique 0606
- Electronique et électricité 0607
- Fluides et plasma 0759
- Météorologie 0608
- Optique 0752
- Particules (Physique nucléaire) 0798
- Physique atomique 0748
- Physique de l'état solide 0611
- Physique moléculaire 0609
- Physique nucléoire 0610
- Radiation 0756

Statistiques 0463

Sciences Appliqués Et Technologie
Informatique 0984
Ingénierie
- Généralités 0537
- Agricole 0539
- Automobile 0540
- Biomédicale 0541
- Chaleur et ther modynamique 0348
- Conditionnement (Emballage) 0549
- Génie aérospatial 0538
- Génie chimique 0542
- Génie civil 0543
- Génie électronique et électrique 0544
- Génie industriel 0546
- Génie mécanique 0548
- Génie nucléaire 0552
- Ingénierie des systämes 0790
- Mécanique navale 0547
- Métallurgie 0743
- Science des matériaux 0794
- Technique du pétrole 0765
- Technique minière 0551
- Techniques sanitaires et municipales 0554
- Technologie hydraulique 0545

Mécanique appliquée 0346
Géotechnologie 0428
Matières plastiques (Technologie) 0795
Recherche opérationnelle 0796
Textiles et tissus (Technologie) 0794

PSYCHOLOGIE
Généralités 0621
Personnalité 0625
Psychobiologie 0349
Psychologie clinique 0622
Psychologie du comportement 0384
Psychologie du développement 0620
Psychologie expérimentale 0623
Psychologie industrielle 0624
Psychologie physiologique 0989
Psychologie sociale 0451
Psychométrie 0632

MEAN VELOCITY AND STRAIN FIELD IN AN

AXISYMMETRIC FLOW

BY

MUTISO MWAKA

A Thesis submitted to the Faculty of Graduate Studies of the University of Manitoba in partial fulfillment of the requirements of the degree of

MASTER OF SCIENCE

ABSTRACT

The mean velocity and strain field in an axisymmetric flow with an adverse pressure gradient has been studied in detail through an experimental investigation of an 8° total angle conical diffuser fed with fully developed turbulent pipe flow at its inlet. Air, at ambient conditions, is the test fluid in a low speed wind tunnel.

Pressure probes have been used to determine the local static and total pressures on a horizontal plane of the conical diffuser. Corrections for the wall proximity and high levels of turbulence intensities were done and an empirical method used to obtain the mean velocity. The integral constraint of continuity has been used to check the mass flow rate variation on different axial locations. The symmetry of the flow was checked. Measurements were done both radially and axially at closer intervals to obtain a good velocity distribution.

The mean velocities at the diffuser exit region show an inflectional type of profile different from that at inlet. The empirical method gave mass flow rate variation within 2% that at diffuser inlet, in all cross sections. There is a general increase on the mass flow rate from inlet to exit when the velocity correction is not done. The mean velocity profiles collapse to one asymptotic curve on Perry-Schofield coordinates, in the last one third region of the diffuser. The inlet region of the diffuser was found to be associated with an extra rate of shear strain, high values of mean radial velocity and a high pressure recovery rate. These results corroborate other published work. The r- direction momentum balance showed that radial pressure and normal stress gradient terms dominate the viscous and convective terms at the diffuser exit region unlike the inlet were convective terms have substantial magnitude.

The present results have been compared with results of other researchers where applicable. The results show that pressure measurements are sufficient to correctly obtain the mean velocities and the strain field in this complex turbulent diffuser flow.

ACKNOWLEDGEMENTS

The author would like to express his deep gratitude to Dr. R.S. Azad for his help and guidance during the experimental analysis. I would also like to thank Ken Tarte for the help he provided during the experimental set up. The thoughtful discussions from fellow student R.K. Singh are highly appreciated.

I would also like to thank my parents for their patience and encouragememt during this period.

The Scholarship given by the Kenya Government through the International Development Agency is greatly appreciated.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

NOMENCLATURE

A	Area
A_1	Constant
B	Constant
$C_{0,1,2,3,4,5,6,7}$	Polynomial coefficients
C_f	Skin friction coefficient
D_p	Diameter of pipe
g	Acceleration due to gravity
L	Length of pipe
m	Mass flow rate
P_{atm}	Atmospheric pressure
P_{SC}	Correct static pressure
P_{sw}	Wall static pressure
P_{SL}	Local static pressure
P_T	Total pressure
Q	Volume flow rate
R	Pipe radius
R_G	Universal gas constant
R_L	Local radius of diffuser
Re	Reynolds Number
r	Radial distance from diffuser axis at a given axial location
T	Temperature
U	Mean velocity in x-direction
U_b	Bulk mean velocity in pipe
U_C	Corrected mean velocity
U_{CL}	Centreline velocity
U_L	Mean velocity obtained from local static pressure
U_W	Mean velocity computed from wall static pressure
U_S	Scaling velocity
u	Fluctuating velocity in x-direction
u_r	Mean velocity at a radial distance r in a duct
u'	Root mean square velocity
u^*	Friction velocity
v	Fluctuating velocity in y-direction
V	Mean radial velocity

W	Mean velocity in circumferential direction
w	Fluctuating velocity in circumferential direction
X,Y	Principal mean strain rates
x	Axial distance in streamwise direction
x_w	Distance along diffuser wall
y	Radial distance from the wall perpendicular to diffuser axis
-	Overbar denotes a time average

Greek symbols

δ^*	Displacement thickness
δ	Boundary layer thickness
ϵ	Strain or strain rate, defined by the subscript
μ	Dynamic viscosity
ϱ	Density
π	Constant
θ	Angular direction
τ_w	Wall shear stress

CHAPTER 1

INTRODUCTION

1.1 GENERAL

The flow which occurs in most practical applications is turbulent. It is the most important and complicated kind of fluid motion. The term turbulent denotes a motion in which an irregular fluctuation (mixing, or eddying motion) is superimposed on the main stream. To understand turbulent flow it is important to correctly measure both the fluctuating and mean flow quantities.

A diffuser is a device of engineering importance and finds its use in turbo machinery, mine ventilation and flow deceleration. The catalytic converters in most recent automobiles use diffusers and this device has many practical applications in many fields of modern life and hence the need for a thorough understanding of its flow. One very important quantity to measure in a diffuser is the mean velocity. Various techniques exist for accurately determining mean velocity in ducts especially in pipe flow where there is a favourable pressure gradient, and these techniques have been well established.

Diffuser flow is an axisymmetric wall bounded flow. High turbulent intensities and the adverse pressure gradient in a diffuser makes the flow complex and as such measurements of mean velocity difficult. Researchers have previously attempted to measure the mean velocity in a highly turbulent flow. Previous work on the same diffuser by Okwuobi (1972) showed high turbulent intensities existed especially in the wall region and towards the exit thus making the diffuser an appropriate device for studying turbulence. Previous experimental results on such a diffuser showed that the mass flow rates in the diffuser exit region, calculated from the obtained mean velocity profiles, exceeded the mass flow rate at the diffuser inlet by over 15% when static and total pressure tubes were used. The hot wire measurements were based on this pressure measurements since a pitot tube was used to calibrate the hot wire.

Hot wire and pulse wire are instruments generally used in turbulent measurements however they have some limitations one of which is the non linear character of the heat transfer with respect to velocity and temperature. The hot wire is sensitive to deposition of small particles and this changes the values in the calibration parameters. Due to their construction, there is aerodynamic interference in the flow and measurements can not be taken very close to the wall. Mass flow rates obtained from hot wire mean velocity profiles gave higher mass flow rates especially in diffuser exit region [Figure 3.7(c)]. This meant that the velocities were incorrect since from continuity, for a constant density fluid the mass flow at each cross section of the diffuser should be the same, within experimental uncertainties.

Pressure probes give excellent results in mean velocity measurements in flows which are not highly turbulent. The complete lack of electronic circuitry, minimal effect of slight temperature variations on these probes make them suitable for mean velocity measurements, even in flows with high turbulent intensities once corrections for turbulence are done. In the present study, interest is focussed on the same diffuser studied by Okwuobi (1972) and Kassab(1986) which is of 8^0 total angle and fed with fully developed pipe flow at its inlet. Unlike the hot wire and pulse wire probes, measurements have been taken as close to the wall as possible. The integral constraint of conservation of mass has been used in this study as a control of the measurements taken and also as a justification of the correctness of the method used.

An empirical method developed by Tanjo (1992) has been used to obtain the correct mean velocities which gave within 2% variation of the mass flow rate at diffuser inlet. As much study as has been done on the diffuser, no detailed published work has been found on the mean strain field. In this study, from the experimentally determined results the mean strain rates, the momentum equation balance have been presented in detail. This has been achieved by pressure measurements only.

1.2 LITERATURE REVIEW

An early comprehensive study of diffuser flow was reported by Gibson (1910). Using water as the test fluid, he correlated pressure recovery coefficient with divergence angle for a fixed area ratio. Since then, a lot of experimental and theoretical studies have been devoted to the subject. Sprenger (1959), Sovran and Klomp (1967) studied diffuser flow and to date its known that a diffuser with geometry like the one used in the present study is most efficient.

Axisymmetric turbulent flow subjected to an adverse pressure gradient has been studied for an appreciable length of time at the University of Manitoba and results of this study published periodically. The conical diffuser was found suitable for this kind of study due to its symmetry. Pressure measurements and hot wire anemometry have been used to obtain mean flow and fluctuating quantities in the diffuser. Two diffusers, one made of plexiglas and the other machined from cast aluminium, each of total angle 8^0 have been used for these experimental investigations. The plexiglass diffuser had the advantage over the metal one because of being transparent and this ensured the exact positioning of the probes but not in the wall region. The metal diffuser was more desirable near the wall region because the first contact of the probe at the wall could accurately be established by observing the very initial deflection on an ammeter scale once the circuit was completed at the wall contact.

The development of the boundary layer in the diffuser was studied in detail by Van der Spiegel (1969). The mass flow rate was kept constant and the inlet turbulent boundary layer varied. It was found that the inlet conditions did not affect the diffuser performance and pressure rise. The shear stress at the wall was also obtained by various methods with the cross plot method as described by Azad and Burhanuddin (1983) giving the best results. Diffuser flow is a developing axisymmetric flow and the displacement thickness has been obtained in the present study and the results used in studying the asymptotic velocity profile in the diffuser.

The structure of turbulence was studied in detail by Okwuobi (1972), Kassab (1986) with the diffuser fed with fully developed pipe flow at its inlet. The profiles of mean pressure and mean velocity, turbulent intensities, correlation coefficients and the one dimensional energy spectra were studied by Okwuobi at two Reynolds numbers, viz 152,000 and 293,000. In this study profiles of mean static pressure were determined from measurements of the local static pressures across planes perpendicular to diffuser axis. This pressure was found to vary and not uniform across a section as in pipe flow where the static pressure on a plane perpendicular to the axis is uniform and equal to the static pressure at the wall.

Hummel (1978) investigated the turbulent structure in a straight conical diffuser at a Reynolds number of 137,000. Hot wire anemometry was used and profiles of the mean axial velocity, root mean square in longitudinal direction and moments of the fluctuating longitudinal velocity to the fourth order were presented.

Turbulent parameters in a conical diffuser were examined for a flow of Reynolds number 130,000 based on pipe inlet diameter and bulk mean velocity by Ozimek, Azad, and Derksen (1989). They used hot wire anemometry to obtain various moments of velocity and velocity time derivative and found that the diffuser has two distinct regions, namely, wall and core. The flow is different from pipe flow where the pipe displays constant shear layers in the wall region and the diffuser does not. These researchers also found that towards the exit of the diffuser the axial mean velocity profiles exhibit distinct points of inflection near the wall. The same behaviour was observed in this study (Figure 3.4. c-d).

Turbulent structure in shear flows with low Reynolds number turbulent boundary layer and fully developed pipe flow have been studied by Kassab (1986) and particularly the turbulent structure in a conical diffuser. This was done by measurements of mean velocities, determination of strain rates, shear stresses, triple products and length scales. In the present work much attention has been focussed on the mean velocity and strain rates in the same diffuser with rigorous determination of mean velocity profiles after applying a correction method which produced reliable results. The perturbations caused by an adverse pressure gradient, divergence and streamwise curvature on turbulence was studied by Azad and Kassab (1989).

Much has been studied on turbulent boundary layers in adverse pressure gradient and in the vicinity of separation. Perry and Schofield (1973) studied the mean velocity and shear stress distribution in turbulent boundary layers. Schofield (1981) studied the equilibrium boundary layers in moderate to strong adverse pressure gradients. For turbulent boundary layers in the vicinity of separation Dengel (1990) showed that there is an asymptotic velocity defect law near separation. In an optimum geometry diffuser flow, Singh and Azad (1993) have shown that the flow does not separate but towards the exit region there is appreciable incipient separation. With that understanding of the present kind of flow it was desired to study the development of asymptotic velocity profile in the diffuser. Mean velocity profiles were plotted on Perry and Schofield coordinates for various locations of the diffuser.

Simpson *et al.* (1981) have reported results on the momentum and energy balances in the streamwise and cross stream directions of a separating turbulent layer. A momentum balance on a fully separated turbulent layer was also given by Thompson and Whitelaw (1985) for a trailing edge flow with turbulent boundary layer separation. The momentum and turbulence energy balance in an incipient separating turbulent flow is rare in the literature. The normal or r-momentum balance has therefore been presented in this study in regions of varying turbulent intensity.

Further details of study by the aforementioned researchers will be given as they relate to the present findings in a later chapter.

1.3 DESCRIPTION OF PRESENT EXPERIMENT

It was desired to study and perform measurements in an axisymmetric wall bounded flow subjected to an adverse pressure gradient. This made a conical diffuser an excellent choice of apparatus and its description is given in a following chapter. A traversing mechanism, was used to move the probes to the desired locations. Mean static, total pressures, and mean velocities were obtained for the whole diffuser at selected points in the horizontal plane of the diffuser. From the velocity profiles the strain rates were obtained. The section following from this gives a detailed description of the apparatus and the experimental procedure, results, analysis and discussion of the obtained results. The results have been put in a tabular form and illustrated graphically. The concluding remarks and recommendations for further work are presented in the last chapter.

CHAPTER 2

2.0 EXPERIMENTAL APPARATUS, SET UP AND PROCEDURE

2.1 APPARATUS

2.1.1 Wind tunnel equipment

The apparatus used in this experimental investigation has been described by Okwuobi and Azad (1973). The plan view of the wind tunnel is shown in figure 2.1. Briefly the wind tunnel consists of a fan of fixed blade angle driven by a 25 h.p. direct current motor. The fan draws air at its inlet which is fitted with variable guide vanes. The air exits radially without swirl to a rectangular-to-circular duct. This is connected, through a flexible canvas coupling, to a settling chamber of 0.914m diameter and 2.2m length. The canvas coupling reduces the transmission of vibrations from the running motor to the test section. The settling chamber is equipped with three pairs of fine mesh screens. The contraction cone of area ratio 89:1 has two static pressure rings to measure the pressure drop across the cone. A No. 16 floor sanding paper is pasted on the first 8cm. of the 0.106m internal diameter steel pipe to initiate turbulent flow.

The total length of the steel pipe is 8.2m and this corresponds to about 78 pipe diameters. In the last portion of the steel pipe four sets of static holes of 1mm diameter were drilled at the pipe wall at intervals of 1m. The exit of this pipe was connected to the inlet of the conical diffuser.

The diffuser is shown in figure 2.2. It is machined from cast aluminium with an 8^0 total included angle and an area ratio of 4:1 over its length of 72cm. Sovran and Klomp (1967) have shown a diffuser of this type to be of optimum geometry. The length of the diffuser is divided into axial locations 6cm. apart and these are termed as stations. Station 0 corresponds to diffuser inlet while station 12 the exit. Each of the stations (1 to 11) has four equiangle (90^0) drilled holes for static pressure measurement.

A traversing mechanism is mounted on the exit end of the diffuser to facilitate the movement of the probes both in the axial and radial directions of the diffuser. This consists of a coordinate table(Model FB102, M.S Tool supplies) with an axial feed of 37cm. and a cross feed of 15cm. and attached to a rotating table for the angle setting. A travel microstage made from aluminium alloy was mounted on the coordinate table by four pins on the coordinate table. Accurate determination of the probe radial positions was achieved by a digit micrometer head of 0.01mm graduation and of 0-25mm range which could traverse in the horizontal plane of the diffuser. A vertical slide attached to the micro-stage was used to traverse/secure the probes as required.

2.1.2 Instruments

The pressures were measured by a Betz projection manometer graduated at 0.1mm of water and a range of -17mm to 400mm of water. This manometer could measure both pressures above and below the atmosphere depending on the connection. The static pressure tube (United sensor, USC-E-120-04) of 1.2mm external diameter and having very small holes drilled 14mm from its tip was used to determine the local static pressures [Figure 2.3(a)]. A pitot tube (United sensor, USC-E-120-03) of 0.6mm internal diameter was used for recording the total pressures and is shown in Figure 2.3(b). A mercury thermometer mounted on the traversing mechanism and placed at the stream of exiting air at exit of the diffuser was used to determine the air temperature. The atmospheric pressure was measured by a Fortin type "princo" standard mercurial barometer and the observed pressure corrected for temperature and altitude. An inclined manometer filled with coloured alcohol of specific gravity 0.827 was used to determine the pressure drop at the contraction cone which gave the magnitude of the air speed. Probe contact with the wall at locations inside the diffuser was noted when a deflection occurred on a sensitive resistance meter (HONAR KRT 101 or ELCO 68).

2.2 EXPERIMENTAL PROCEDURE

To study the flow in the diffuser it was necessary to perform some measurements at the exit of the pipe before the diffuser was connected to clearly understand the type of flow fed to the diffuser. A static pressure tube was used to obtain the static pressure distribution across the exit face of the 78 diameter length steel pipe. This was done along a horizontal diameter and at a quarter pipe diameter inside the pipe from the exit face. A pitot tube was then traversed to obtain the total pressures and thus the axial mean velocity profile. Based on these results the mass flow rate and bulk mean velocity for the fully developed pipe flow were obtained. The mass flow rate was used as reference when comparing mass flow rates in different axial locations of the diffuser. The pipe mean bulk velocity and diameter were used to non dimensionalize relevant quantities whenever necessary.

The diffuser was securely connected to the pipe after cleaning the inside and outside to ensure that none of the holes in the diffuser wall were blocked by dust or any other particles. The diffuser axis was aligned with the pipe axis to ensure symmetric flow. The pressure probes were attached to the sliding mechanism and the initial setting was done to locate the probes at the centre of the diffuser exit face. A tracing paper with a circle drawn having the same diameter as the diffuser exit face and with two perpendicular diameters drawn was used to locate the probes at the exact centre at the exit face of the diffuser.

The traversing mechanism was cross fed to check if the tip of the probe followed the horizontal diameter drawn on the tracing paper which coincided with the diffuser diameter. A sensitive resistance meter earlier described was used to indicate when the probe just touched the diffuser wall from the first deflection noted once contact occurred. The ambient or room temperature was taken and the atmospheric pressure noted from which the air density was obtained. The betz projection manometer was zeroed. It was also found necessary to ensure that no leakage occurred in the hoses connecting the probe to the manometer by ensuring all connections were tight. Traverse angle with respect to diffuser axis was set by using the graduated milling table. This ensured that the pressure probes were traversed either parallel or perpendicular to the diffuser axis.

A spirit level was used to ensure that the table was horizontal. The axial traverse distance was accurately obtained by attaching a half metre-rule on the sliding mechanism and a pointer secured by a magnet on the non sliding part of the table. The traversed distance was then obtained by noting the distance moved by the metre rule (indicated on its scale of 1mm divisions) relative to the stationary pointer. The same traverse distance was then counter checked with the one from the coordinate table. A 'Mitutoyo' dial gauge was used to determine the radial positions. A micrometer attached to the travel microstage was used to measure traverses near the wall. It was observed that the probe tended to sag downwards when extended to locations near the diffuser inlet due to the cantilever effect.

Anytime this was done a fine adjustment on the table was used to raise the probe tip to its original horizontal position. The correction for this cantilever effect was determined before the experiment was started. A spirit level was used to ensure the probes were horizontal.

The fan motor was then started. The fan was left to run for a certain period of time for the temperature of various sections in the wind tunnel to stabilize. The inclined manometer indicating the pressure drop across the contraction cone was used to adjust the air speed. Initially the cone pressure had a tendency to increase even when the motor speed was kept constant but after running the tunnel for sometime this behaviour stopped. Once these settings were done the required measurements could then be taken.

2.2.1 Static pressures

The static pressures were obtained by using a static pressure tube described earlier and the gauge pressure recorded by the Betz manometer. The manometer was zeroed before the start of each experiment. For the axial wall static pressure distribution, the piezometric rings on the diffuser wall were used to measure the static pressure at the wall. For all other locations the static pressure tube was used, radial intervals being 5mm and axial intervals being 30mm.

2.2.2 Total pressures

A pitot tube (United sensor, USC-E-120-03) described earlier was used for the acquisition of the total pressures and the measurements were done in the same way and at the same locations as the local static pressures. Measurements were taken radially from left wall to the right wall of the diffuser at a particular axial location or station. At a different day measurements would be done axially (From inlet towards exit) and the value of one point obtained from a radial traverse would be compared to the value obtained from an axial traverse as shown in Figure 3.3(d). This showed the dependability of the measurements.

CHAPTER 3

3.0 ANALYSIS AND DISCUSSION OF RESULTS

The preceding chapter gave a description of the apparatus and the experimental procedure. The basic process of the present experimental investigation was to obtain correct mean velocity profiles for the whole diffuser i.e from inlet to exit. The other required quantities could then be derived from the these mean velocities . The mean strain rates were obtained by differentiating the velocity with respect to either axial or radial distances depending on the strain rate sought. The mass flow rates were obtained by integrating the velocity profiles with respect to radius. The continuity equation in cylindrical coordinates has been used to obtain the mean radial velocity, V, for the whole diffuser. An asymptotic velocity profile in the last third region of the diffuser has also been obtained in the Perry-Schofield coordinates. The terms in the r-momentum equation have been evaluated and compared. The upcoming section gives a detailed analysis of the obtained results and a discussion of the same.

3.1 SPECIFICATION OF THE FLOW

The flow in this study was turbulent axisymetric diffuser flow subjected to an adverse pressure gradient. A brief description of the flow fed at the diffuser inlet will be given. The diffuser was fed with fully developed turbulent pipe flow at a Reynolds number of 120,000 based on the pipe diameter and mean bulk velocity. Arora (1978), Okwuobi (1972), Ozimek, Azad and Derksen (1989) have shown that when the static pressures are non dimensionlized with the average velocity head ($1/2\rho U^2$) at the inlet of the diffuser the profiles collapse to one single curve. Most measured quantities in diffuser once properly normalized are Reynolds number independent and for this reason only one Reynolds number was used. The inlet of the diffuser which corresponded to the exit of the pipe was used as the reference station. The maximum velocity occurred at the centre of the pipe. The mean bulk velocity was the ratio of the volumetric flow rate to the cross sectional area of the pipe. The ratio of the mean bulk velocity to the centreline mean velocity (U_b/U_C) in this study was 0.827. Much experimental work has been done to study fully developed pipe flow. For flow to be termed fully developed turbulent flow certain conditions are required. A minimum Reynolds number is required to ensure fully turbulent flow. When fully developed, the velocity profile ceases to change in the flow direction. In a pipe, the flow develops from inlet and after a certain distance becomes fully developed. Nikuradse (referenced in Schlichting 1979, p596) determined that the fully formed velocity profile exists already after an inlet length of 25 to 40 pipe diameters. Values of U_b/U_C in the range of 0.806-0.833 were obtained by Lawn at a

Reynolds number in the range $3.5x10^4$ to $2.5x10^5$ for $L/D_P=59$ and the fact that $L/D_P=78$ in the present experiment indicated the flow at diffuser entry was fully developed. The mass flow rate was 0.1743Kg/s, mean bulk velocity 18.3m/s and experiments performed at temperatures ranging from 21^0 to 23^0 C. The air viscosity and density were $1.82*10^{-5}$ Ns/m^2 and 1.18 Kg/m^3 respectively. The centre of the diffuser inlet was the origin of the coordinate system and axial distances, x, were measured positive in the downstream direction. Radial distances were measured from the diffuser axis and positive towards the wall.

3.2 CORRECTNESS OF THE OBTAINED RESULTS

All experimentally determined results are subject to errors, however much effort has been put to present accurate results. To check the reliability of the results, the mass flow rates at all the cross sections were calculated from the mean velocity profiles. From continuity the mass flow at all the cross sections should be the same. All the mass flow rates obtained were found to be within 2% the mass flow rate at diffuser inlet. This meant that the velocities were correctly measured to within the allowable deviation. The test for axisymmetry was done by comparing measured values at equidistant positions from the axis. A diffuser is very sensitive to inflow velocity distribution (Yuan *et al* ,1991 and thus symmetry tests were done at the exit region since any non uniformities in the inlet profiles would be magnified at the exit Goenka(1990). If these differed by more than

1.5% the measurements were repeated, otherwise the average was taken. Intersecting points from axial and radial traverses were also compared and performance of these tasks ensured production of reliable results.

3.3 STATIC PRESSURE PROFILES

3.3.1 Wall static pressure distribution

The four circular holes (spaced 90°) drilled on the diffuser wall at a particular axial distance enabled the pressure taps to be connected to a piezometric ring which could then register the average wall static pressure on the manometer. The wall static pressure was determined from these piezometer rings. The last 4m. of the pipe had four sets of piezometric rings spaced 1m apart and from these the static pressure at the wall of the pipe could be obtained. In the static pressure distribution curve shown in Figure 3.3(a) the local static pressure tube was used to determine the wall static pressures at the inlet region of the diffuser and last 20cm. of the pipe because this region did not have piezometric rings. The values obtained from the piezometric rings and those from the static tube were very close to each other in this inlet region. Measurement of static pressure by wall static taps in highly turbulent regions is subjected to error due to turbulent velocity fluctuations both normal and tangential to the tap hole. The errors can however be reduced if the tap hole is small and the wall is smooth. From the pressure curve it can be seen that the maximum pressure recovery occurs at the inlet region and the axial pressure gradient is maximum. The exit region the static pressure slowly increases until it is equal to the atmospheric pressure at the diffuser exit. The axial pressure gradient at this exit region is minimum.

3.3.2 Local static pressure distribution

From the measurements obtained from the static tube, graphs of local static pressure (normalized with the wall static pressure at a given cross section so as to show the relative variation, in that cross section, of the local static pressure to wall static pressure) versus the non dimensional radius are given in Figure 3.3(b). Due to the angle between the diffuser wall and the probe (this angle is half the diffuser total angle i.e 4^0) it was not possible to obtain the static pressure at the wall by the probe since the static holes are 14mm from the tip of the probe [Figure 2.3(a)]. The value so obtained was however found to be very close to that obtained from the four piezometric rings placed at equiangular positions on the circumference of that particular axial location. A static pressure tube has small holes drilled on its sides to register the static pressure but when it is used to measure mean static pressure in turbulent flow, errors arise due to turbulent velocities affecting the static pressure. The lateral velocities perpendicular to the tube result in the measured value by the tube being low. The low value results to high computed velocities as shown in Figures 3.3(c). In isotropic turbulence it can be shown that

$$P_{SC}=P_{SL}+\frac{1}{2}\rho A_1(u')^2........3.3.2.1$$

where P_{SC} , P_{SL} are the true and measured pressures respectively and

$$(u')^2=\overline{v^2}=\overline{w^2}$$

where u' is the root mean square value.

The constant A_1 is approximately 1 from static flow measurements and the last quantity in the above relation is positive indicating the low measured static pressure.

The results show that the pressure profiles give a similar trend in shape from inlet to exit with variations being higher at the exit region [figure 3.3(b)]. It was found that the minimum static pressure (The minimum pressure, which is negative with reference to the atmospheric pressure, would correspond to the peaks or maximums in figure 3.3(b) since this graph gives the distribution of the ratio of a negative local static pressure to a negative wall static pressure which turns out being positive) occurs at a radial distance somewhere between the diffuser axis and the wall. This behaviour was also noted by Okwuobi (1972) in the same diffuser in which he plotted the pressure difference (P_{SL}-P_{SW}) versus y, the distance from the wall. The figure shows that at the wall region the pressure changes at a faster rate than at the core region and as such large values of the radial pressure gradient (dP/dr) near the wall especially towards the exit. From Figure 3.3(a) it can be seen the pressure rises gradually therefore this region has low values of the axial pressure gradient (dP/dx). In regions of high turbulent intensities like in the exit region of the conical diffuser published work (Hinze, 1975) has shown that the measured pressure is in fact lower than the actual (see equation 3.1). This was found to be true in the present study as is evident from the computed velocities based on this measured static pressure (Figure 3.3c-d). Various researchers (e.g Bradshaw, 1975) have noted the difficulties involved in the measurement of static pressure in turbulent flow and for this reason it is worthwhile to make attempts to do corrections in order to make the difference between the measured and the true static pressure as small as possible.

3.4 MEAN VELOCITY PROFILES

3.4.1 Mean velocity profiles obtained from wall static pressure

The static pressure distribution along the diffuser wall was obtained from the readings obtained from the piezometric rings axially spaced 6 cm apart. Static pressures at intermediate positions could then be obtained from the graph of static pressure distribution [Figure 3.3(a)] . Assuming viscous effects are negligible and the static pressure across a section is constant and equal to the static pressure at the wall, Bernoulli's equation can be used to obtain the velocity U of a moving fluid in which the relation between the total pressure P_T, wall static pressure P_W , and the velocity pressure is given by the relation

$$P_T=P_{SW}+\frac{1}{2}\rho U^2 \ldots\ldots 3.4.1.1$$

This relation can be used to obtain the total pressure at various locations by traversing a total pressure tube across a given cross-section. From the above equation the velocity is then obtained from

$$U=\sqrt{\frac{2}{\varrho_{air}}(P_T-P_W)} \ldots\ldots 3.4.1.2$$

which can be expressed in easily measurable quantities as

$$U=\sqrt{2g\frac{\varrho_{water}}{\varrho_{air}}(h_T-h_w)} \ldots\ldots 3.4.1.3$$

where h_T is the manometer reading for the total pressure tube, m.

h_W is the manometer reading for the wall static pressure, m.

ϱ_{water} and ϱ_{air} are respectively water and air densities, Kg/ m^3.

The density of the air is obtained by measuring the atmospheric pressure of the experimental day by a barometer and recording the air temperature by a thermometer placed at the diffuser exit, this ensures that only the temperature of the fluid in the tunnel is taken. The gas equation is then used to compute the density from the expression

$$\varrho_{air}=\frac{P_{atm}}{R_G T} \ldots\ldots 3.4.1.4$$

where P_{atm} = Atmospheric pressure, N/ m^2

T = Air temperature, ^{0} K

R_G = Gas constant, Nm/(Kg. K) .

The velocity so obtained is then plotted against the radius for a particular cross section and hereafter termed as U_W i.e velocity obtained by assuming uniform static pressure in duct cross-section and equal to the wall static pressure.

3.4.2 Velocity profiles obtained from local static pressures

These are obtained in the same way as the wall static profiles (U_W) only that a static pressure tube is traversed the same way and in the same locations as the total pressure tube to obtain the local static pressures. The velocity is obtained from equation 3.4.1.3 with h_w being replaced by the manometer reading for the local static tube. These velocities are hereafter termed as U_L i.e velocities obtained from total pressure and local static pressure.

3.4.3 Corrected mean velocity profiles

This correction was found necessary because previous results of Kassab (1986) showed up to 15% mass flow rate increase towards the diffuser exit as compared to the mass flow rate at the diffuser inlet (pipe exit). Previous results have been used to obtain the mass flow rates at various locations of the diffuser and these are compared and shown in figure 3.7(c). Okwuobi (1972) has shown that turbulent intensities in this kind of flow increased towards the exit and the wall region. According to Bradbury and Castro (1971) in a highly turbulent flow, instruments such as hot-wire anemometers and pitot-static tubes used for velocity measurements are subject to serious errors. This is due to not only the non-linear response of these instruments but also due to their ambiguous response to variations in the flow direction. Incorrect velocity measurements lead to incorrect mass flow rates. Several researchers have come up with various methods of correction and approximations in measurement of the static pressures and total pressures in high turbulent intensity flow. Bradshaw (1975) reckoned that the total pressures which are used to evaluate the mean velocities could be measured with acceptable accuracy if the size of the measuring tube is small compared to the energy containing eddies. Goldstein (referenced in Hinze) found that the pitot tube measured the total head of the total velocity vector, since he assumed that the frontal part of the tube might be considered a point of stagnation. In that case we would have

$$P_T=P_{SW}+\frac{1}{2}\rho\,[\overline{(U+u)^2}+\overline{w^2}+\overline{v^2}]\;.....3.4.3.1$$

This assumption could only be true if the tube was infinitely small in diameter so that the frontal area of the tube might be considered a true point. The lateral velocity fluctuations would not produce an impact pressure and instead might even produce a suction pressure. Hinze and van der Hegge Zijnen, Alexander, Baron and Comings (referenced in Hinze, 1975) only considered the axial velocity fluctuations. The latter three researchers observed that the total pressure increased with increase in turbulence intensities contrary to the expected. It was earlier shown that the static pressure is measured too low and these two produce a combined effect tending to produce high calculated velocities. In such a case they neglected all the effects of turbulence. This present study shows that neglecting the effects of turbulence produces wrong results as regards velocity measurements. Correction due to presence of the wall was done according to Macmillan (1957). A detailed description of an empirical method for turbulent corrections is given by Tanjo (1992) and will only be described briefly. The empirical relation used greatly eliminates the errors because these cancel out and give velocities which give mass flow rates to within 2% of the mass flow at inlet of diffuser. Due to high turbulent intensities the amount of error in the velocity obtained from total and local pressure, U_L, is almost double that obtained in U_W (described in 3.4.1). From figure 3.3c(i-ii) U_L is higher than U_W and these are combined to obtain an empirical method where the corrected mean velocity, U_C is obtained from the relation $U_C=U_W-(U_L-U_W)$

i.e $U_C=2U_W-U_L$

This relation was used to obtain the velocities in all measured cross sections of the diffuser. The velocities obtained from this method agreed closely to the results from pulse wire measurements [Figure 3.4 (f)]. When U_C was used to obtain the mass flow rates, these varied to within 2% of the mass flow rate at diffuser inlet for all the axial locations. The obtained mean velocities were used to obtain mean strain rates. Many algebraic combinations can be used to give a certain expected mass flow deviation from the mass flow at inlet (region of low turbulent intensities) but this empirical method was sufficient and applicable for the whole region of the diffuser and acceptable for most engineering purposes.

3.4.4 Mean axial velocity distribution

3.4.4(i) Mean velocity profiles in radial direction

The variation of the mean axial velocity in the diffuser is shown in figures 3.4(a-d) for various axial locations of the diffuser. Figure 3.4(a-b) show the velocity distribution for the fully developed pipe flow (corresponding to diffuser inlet) and the first half of the diffuser. From these profiles it is clear that the maximum velocity occurs at the centre (r=0cm. or at the diffuser axis). The centreline velocity is highest at the inlet and consistently reduces in a streamwise direction. This is expected from the diffuser's conversion of kinetic energy to pressure head. The profiles in this region of diffuser are similar in shape to that of the fully developed pipe flow. Figures 3.4(c-d) give the profiles for the last half of the diffuser. These figures show that the centreline velocity continuously decreases in the positive x direction as in the first half however in the last stages of the diffuser the velocity profiles exhibit an inflectional behaviour in the wall region, as has been reported by other researchers.

3.4.4(ii) Mean axial velocity in axial direction.

Figures 3.4g(i-ii) show how the mean axial velocity varies in axial direction. In the core region of the conical diffuser, for a given radius, the velocity continuously reduces from the inlet towards the exit and the rate of reduction being higher at the inlet (figure 3.4g(i). In the wall region a completely different behaviour is observed. For the radial distances shown in Figure 3.4g(ii) the velocity rises steeply to a maximum and then starts reducing gradually towards the exit. These graphs are important since from the distribution of the mean axial velocity in axial (x) direction the derivative, $\partial U/\partial x$, can be obtained. This derivative is a normal strain rate (discussed in section 3.8) and is also used to obtain the mean radial velocity, V, described in the next section.

3.5 MEAN RADIAL VELOCITY, V

In order to obtain the extra strain rates $\partial V/\partial x$ and $\partial V/\partial r$, it was necessary to obtain the mean radial velocity V first. This velocity is also important because in conical diffuser flow the mean radial velocity plays an important role in the accurate prediction of downstream mean velocity field (Cho & Fletcher, 1991). The continuity equation in cylindrical polar coordinates for this flow can be written as

$$\frac{1}{r}\frac{\partial}{\partial r}(rV)+\frac{\partial U}{\partial X}=0 \ldots\ldots 3.5.1$$

Since the W component of velocity is zero, the velocity V can be obtained by integration, i.e.,

$$V = -\frac{1}{r}\int \frac{\partial}{\partial}\,\frac{U}{x}\,dr \ldots 3.5.2$$

3.5 (i) Variation of mean radial velocity in the diffuser in radial direction.

In order to study the strain rates in the diffuser its worthwhile knowing how the mean quantity itself is distributed in the flow field.

The variation of V in the radial direction is illustrated in Figures 3.5(a-d). The first 48cm. from the diffuser inlet, there is a general increase of V from the axis towards the wall and then a sudden reduction to zero at the wall. The value of V at the wall has to be zero at the wall since the wall is non porous. Towards the diffuser exit the rise in V at a given axial location is gradual, where V increases to a maximum and then reduces gradually to zero at the wall as seen in Figure 3.5 (d).

3.5 (ii) Distribution of mean radial velocity in axial direction.

The variation of V in the axial direction is summarized in figure 3.5(e-g). The first two graphs give the variation of V with axial distance in the core region. At the diffuser inlet the value is zero and sharply rises in the first few centimetres, reaches a maximum value and reduces sharply up to midway of the diffuser after which it remains almost constant up to the diffuser exit. Figure 3.5(g) gives the variation of V in the wall region and it is evident for radial distances above 75mm. the trend is different and the quantity increases through out towards the diffuser exit.

3.6 ASYMPTOTIC VELOCITY PROFILES

The use of pulse wire anemometry has shown that the last one third of the diffuser has appreciable incipient separation (Singh and Azad, 1995). In the present study the values of displacement thickness, δ^*, have been obtained and it was found that it increased consistently from diffuser inlet to exit and earlier work by the above authors has shown that the incipient separation follows the same trend. From the definition of the displacement thickness, for diffuser flow this could be obtained by calculating the area under the curve of $(1-U/U_{cL})$ versus the square of the radius(Van der Spiegel, 1969) and if the area under the curve is A, then

$$\delta^*=R-\sqrt{(R^2-A)} \quad \ldots\ldots 3.6.1$$

The variation of the displacement thickness along the diffuser wall is given in Figure 3.6(a). Its distribution is important since a rapid increase of this quantity is a characteristic of flows approaching separation (Cutler 1989, Dengel & Fernholz, 1990). Perry and Schofield (1973), Schofield (1981) and Schofield (1986) studied boundary layers in adverse pressure gradient near separation and reported a general defect law for the mean velocity profile given by the relation

$$(U_{cL}-U)/U_s=1-0.4\ (y/B)^{1/2}-0.6\sin\ (\pi y/2B) \quad \ldots\ldots\ldots 3.6.2$$

and in the wall region the above equation can be represented by the half power form as shown below

$$U/U_{cL}=0.47\ (U_s/U_{cL})^{3/2}\ (y/\delta^*)^{1/2}+1-(U_s/U_{cL}) \quad \ldots\ldots\ldots 3.6.3$$

where for the above two equations

U_{cL} is centreline velocity

U_s is a scaling velocity based on half power profile

B is the integral layer thickness defined by $B=2.86\delta^* U_{cL}/U_s$

U is the mean axial velocity.

The Perry schofield coordinates were used for plotting the velocity defect law in the last region of the diffuser and it was found the curves collapsed to one asymptotic curve as shown in figure 3.6. A seventh order polynomial was fitted to this curve and taking $(U_{CL}-U)/U_S$ as f(y/B) and y/B as z then the equation took the following form

$$f(z)=C_7z^7+C_6z^6+C_5z^5+C_4z^4+C_3z^3+C_2z^2+C_1z+C_0$$

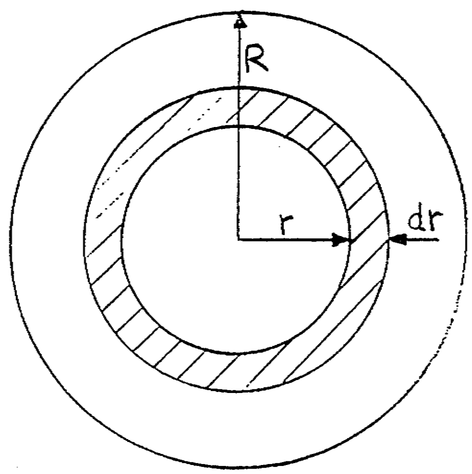
Where

$C_0= 0.83$	$C_1=-1.47$	$C_2= 12.29$	$C_3=-69.49$
$C_4=182.05$	$C_5=-250.11$	$C_6=174.22$	$C_7=-48.38$

A seventh order polynomial was fitted for the asymptotic velocity profiles in a similar diffuser by Singh and Azad (1995) but the values obtained for the constants were different. This is because the diffuser was of different geometry as compared to the present one. The velocity profiles obtained for this diffuser by pulse wire anemometry did not exactly match the present ones for the same axial distances from the inlet since these stations did not have the same local radii [(See Figure 3.4(f)]. A slight change in the value of the velocity produced different polynomial constants. The polynomial fit from the results of the above authors is also given in Figure 3.6(b).

3.7 MASS FLOW RATES

The mean velocity profiles were used to obtain the mass flow rates by integrating the profiles across a given radius of a cross section. Consider a fluid of density ρ flowing in a circular duct of radius R.



Taking an element (shown hatched) at a radius r where the velocity is u_r and thickness dr the elemental volume flow rate is $Q=2\pi r.dr.u_r$ and the elemental mass flow rate is

$$d\dot{m} = 2\pi\rho r\,dr\,u_r$$

and the total flow for the whole cross section can be obtained by integration and thus the total mass flow is given by

$$\dot{m} = 2\pi\rho\int_0^R u_r\, r(dr)$$

which can be rewritten as

$$\dot{m} = \pi\rho\int_0^R u_r (dr^2)$$

Therefore a plot of u_r versus r^2 gives the area A under the curve thus

$$\dot{m} = \pi\rho A$$

A compensating planimeter was used to obtain the area under the curves and then using the above expression, the mass flow rate was obtained. This procedure was repeated for all stations. The mass flow rate were obtained from the velocity profiles based on U_W, U_L and the empirically corrected velocity U_C and one of the graphs is given in Figure 3.7(a) for x=9cm.

The mass flow rates obtained by different methods using pressure probes are shown in Figure 3.7(b). This figure shows that the mass flow rates obtained by using U_L are higher than those obtained by using U_W for all the stations. This is expected from the consistent higher value of the velocity U_L. When compared to the mass flow rate at the diffuser inlet values of mass flow rates 15% higher than at diffuser inlet were observed. The mass flow rates from the empirically obtained velocity were within 2% that at inlet for the whole diffuser region.

Comparative results of other experimenters with different measurement techniques are given in Figure 3.7(c). It can be seen that the values of the mass flow rates obtained by hot wire measurements of Kassab (1986) lie between the values of those of present study (empirical) and those of velocities obtained by using total and local static pressures by Okwuobi (1972). The hot wire results give higher mass flow rates than the pressure probes because a comparison of the velocity profiles obtained from the empirical method and the hot wire showed higher velocities obtained from the latter especially in the later stages of the diffuser. See Figure 3.4.(e).

3.8 MEAN STRAIN RATES

The strain rate in a conical diffuser can be divided into two. These are the normal and shear strain rates. They are usually expressed in matrix form and referred to as the rate of deformation tensor. In this matrix the leading diagonal gives the normal strain rates($\partial U/\partial x$, $\partial V/\partial r$, V/r) and the other non zero terms give the shear strain rates ($\partial U/\partial r$, $\partial V/\partial x$). The distribution of these strain rates in axial and radial directions in the diffuser is given in the following section. A knowledge of the distribution of the strain rates gives an indication of how the fluid is stretched or compressed in the flow field.

3.8.1 Basic rate of shear strain, $\partial U/\partial r$

From the velocity profiles (U versus r) obtained using the empirical method a polynomial fit was done on the experimental data to obtain the polynomial coefficients of the equation of the velocity curve. Sometimes it was necessary to fit the data in sections so as to have a close curve fit. The equation of the curve was differentiated with respect to r to obtain the basic rate of shear strain, $\partial U/\partial r$. The derivative was also obtained numerically and compared with the results from the polynomial fit. The polynomial gave better results than the numerical method since the latter gave rapid oscillations (Turan & Azad, 1988) and so most of the results given here are based on the polynomial fit. In the core region of the diffuser the polynomial fit was very exact and the fitted curve passed through almost all data points. To obtain more accurate results, in the wall proximity, the derivative was obtained by drawing tangents on the profiles and getting the slope on the tangents. The strain rate was non dimensionalized with the pipe radius and pipe bulk mean velocity. The results were then put in form of tables as shown in the Tables A.1-A.1.25 and presented in form of graphs.

The variation of this strain rate in radial direction is given in figure 3.8(a). From the graph the shear strain rate at all stations is zero at the diffuser axis as expected from symmetry. At the diffuser inlet region the results show that the strain rate increases continuously in magnitude and attains the maximum at the wall. The last half of the diffuser the shear strain rate increases in magnitude from the axis to a maximum then reduces and then rises sharply near the wall. This behaviour can be seen on the figure 3.8(a) and is due to the inflectional behaviour of the mean velocity profiles especially in the exit region of the diffuser. A similar distribution was reported by Kassab (1986). Some oscillatory behaviour is evident in some stations and this might be due to slight errors in the derivatives obtained from the polynomial curve fitting.

Figure 3.8(b) shows how this main strain rate varies in the streamwise direction. It can be seen that this quantity remains fairly constant in the core region (r=0 to 40mm.) from inlet to exit of the diffuser. In the wall region (large values of r, e.g r greater than 50mm.) the shear strain rate has a high magnitude at the diffuser inlet region and approaches a more or less constant value as the exit is approached.

3.8.2 Normal strain rate, $\partial U/\partial x$

This is a normal strain rate in the diffuser flow and was obtained by taking velocity measurements axially from the diffuser inlet to the exit for a given radius and then getting the derivative of the mean velocity U with respect to the axial distance x. This axial traverse was compared with the radial traverse for coinciding points. These were found close to each other. Measurements were done on equidistant positions from diffuser centreline on the left and right and these too compared and their difference found negligible. The results are presented in tables A.2.1-A.2.18

Figure 3.8(c) shows the radial distribution of this normal strain rate which remains fairly uniform as can be seen in the figure.

Figure 3.8(d) shows the axial distribution of the normal strain rate. In the core region, (e.g r=0, 10 and 20mm.) the value has a high negative value at the diffuser inlet and this reduces in magnitude in the streamwise direction. For radial distances larger than 60mm. the strain rate has high positive values at the diffuser inlet which reduces and approaches zero towards the diffuser exit. The high positive normal strain rates obtained initially (for values of r larger than the pipe radius) is due to the no slip condition at the wall where the velocity is zero and a short distance downstream the velocity has a finite magnitude and hence the high positive derivative.

3.8.3 Normal strain rate, $\partial V/\partial r$

The results of this quantity have been presented in form of tables A3.1-A3.21 and Figure 3.8(e) gives the variation of this quantity in radial direction at some selected axial locations. At the diffuser entry this quantity is zero across the cross section. This strain rate is positive in the inner core region. As the wall is approached the quantity reduces in magnitude and changes sign and attains very high negative values at the wall due to the sudden reduction of the mean velocity to zero at the wall.

The axial variation is given in Figure 3.8(f). In this graph at the core region there is a general reduction from inlet to exit where as for the wall region (r greater than 50mm) the strain rate has high negative values and approach zero towards the exit.

3.8.4 Extra shear strain rate, $\partial V/\partial x$

These quantities are obtained after the mean radial velocity V is differentiated with respect to x. The results are presented in tables A.4.1-A.4.18. At the inlet region due to the sudden expanding of the fluid high values of mean radial velocity are obtained as shown in figure 3.5(a). Due to increase in flow area there is circumferential straining of the fluid and as at this region, according to Clausen (1993) the flow is complex due to high axial pressure gradient, stabilizing effect of streamwise curvature and lateral divergence. The present study has confirmed this to be true where at the inlet there is an extra rate of strain and V was found to increase and attain a maximum value 7cm from diffuser inlet and the value of the maximum velocity gradually reducing towards the exit.

The radial variation of this strain rate is illustrated in Figure 3.8(g). For the first 10cm. at the diffuser inlet, high magnitudes of this quantity are evident and increase from a value of zero to a maximum at the wall. For values of x larger than 18cm. the shear strain rate is nearly zero but slightly negative and the attains high positive values at the wall. A similar behaviour of this strain rate was observed by Kassab(1986).

The axial distribution of this strain rate is shown in Figure 3.8(h) for the core region and Figure 3.8(j) for the wall region. No noticeable axial variation for this shear strain rate is seen for the inner core region (r less than 40mm.) For larger values of the radius, high positive values are observed and this gradually reduces and approaches zero towards the exit [Figure 3.8(j)].

3.9 MOMENTUM EQUATION

The x and r-momentum equations in three dimensional turbulent flow are given by Hinze (1975). In order to understand more of the radial mean static pressure gradient variation, only the r-momentum equation will be considered. For axisymmetric flow, due to lack of circumferential variations, the momentum equation in r-direction in polar cylindrical coordinates can be written as in equation 3.9.1.

$$V\frac{\partial V}{\partial r}+U\frac{\partial V}{\partial x}=-\frac{1}{\rho}\frac{\partial P}{\partial r}+\frac{1}{\rho}\mu\left(\nabla^2 V-\frac{V}{r^2}\right)-\frac{\partial}{\partial x}(\overline{uv})-\frac{1}{r}\frac{\partial}{\partial r}(r\overline{v^2})+\frac{\overline{w^2}}{r} \quad (3.9.1)$$

where

$$\nabla^2 V=\frac{\partial^2 V}{\partial r^2}+\frac{1}{r}\frac{\partial V}{\partial r}+\frac{\partial^2 V}{\partial x^2}$$

since the terms in W and axial derivatives of fluctuating quantities reduce to zero. The relevant terms in the momentum equation in radial direction for diffuser flow shown in equation 3.9.1 were evaluated from the obtained results. The fluctuating quantities were obtained from the work of Kassab (1986).

All the quantities in the equation were obtained and their orders of magnitude compared as shown in figures 3.9(a-c). The terms in the left hand side of equation 3.9.1 are the inertia or convective terms. On the right side are the pressure gradient, viscous, shear stress gradient, normal stress gradient, and normal stress terms respectively. Simpson et al (1981) have reported results of momentum balance in various separating flows. In this study, results are given for three axial locations. It can be seen that a the diffuser inlet , convective terms are dominating and the radial pressure gradient is not high. The reason for this is due to the high values of extra strain rates ∂V/∂r and ∂V/∂x. It is also in this region the value of the mean radial velocity attains a maximum value. No detailed comparative results were found for this region. Further downstream (18cm.) from the inlet it can be seen that the convective term become comparatively less in magnitude while the pressure gradient terms become more important [Figure 3.9(b)]. At the diffuser exit region it was found that the viscous and convective terms were negligible compared to the pressure gradient term and the normal stress terms. The shear stress term was also neglible and so the pressure gradient terms almost balanced by the normal stress gradient terms [Figure 3.9(c)]. This behaviour was also observed by simpson *et al* (1981) when the shear stress gradient term was positive. At this region the radial pressure gradient term is of high values and the same was found by Thompson and Whitelaw (1985) for trailing edge flow with turbulent boundary layer separation. Theoretically the left hand side of the momentum equation should exactly equal the right hand side but this was not the case. The equation almost entirely consists of derivatives of experimentally measured mean and fluctuating velocities. The errors of these measured quantities and any errors associated with evaluating the derivatives results to the left hand side of equation 3.9.1 not equal to the right hand side of the same equation.

CHAPTER 4

MEAN STRAIN RATE IN CONICAL DIFFUSER

4.1 Introduction

In many problems of continuum Mechanics the kinematic property of greatest importance is not the change of shape of a body but the rate at which this change is taking place. In Fluid mechanics, this is especially the case were it is required to find the fluid flow in a particular region of space and the shape of the body of fluid is rarely relevant at a reference time. When a continuous body of fluid is made to flow every element is displaced to a new position in the course of time and this causes elements of the fluid to be strained. The rate at which an element of fluid is strained is dependent on the relative motion of two points within it. Schlichting (1979) has shown that the relative motion of a certain point with respective to another neighbourhood point can be described by the nine partial derivatives of the local velocity field. For three dimensional flow in cartesian coordinates this is given in matrix form as shown below

$$\begin{pmatrix} \frac{\partial U}{\partial x} & \frac{\partial U}{\partial y} & \frac{\partial U}{\partial z} \\ \frac{\partial V}{\partial x} & \frac{\partial V}{\partial y} & \frac{\partial V}{\partial z} \\ \frac{\partial W}{\partial x} & \frac{\partial W}{\partial y} & \frac{\partial W}{\partial z} \end{pmatrix} \qquad \text{M 4.1}$$

The rate of strain tensor (sometimes referred to the rate of deformation tensor) is given by half the sum of matrix M4.1 and its transpose while half the difference gives the vorticity.

4.2 Rate of strain in conical diffuser

The rate of strain in a conical diffuser is obtained similar to the preceding section but in cylindrical polar coordinates. The derivation of the rate of strain in polar Cylindrical coordinates from first principles is given in appendix A. For conical diffuser flow the rate of deformation tensor can be written as shown below. Since there is no circumferential variation then all derivatives in θ and V_θ are zero.

$$\begin{pmatrix} \frac{\partial U}{\partial x} & \frac{1}{2}\left(\frac{\partial U}{\partial r} + \frac{\partial V}{\partial x}\right) & 0 \\ \frac{1}{2}\left(\frac{\partial U}{\partial r} + \frac{\partial V}{\partial x}\right) & \frac{\partial V}{\partial r} & 0 \\ 0 & 0 & \frac{V}{r} \end{pmatrix} \qquad \text{M4.2}$$

The matrix M4.2 is a symmetric matrix and the diagonal elements are the normal strain rates and the other non zero terms give the shear strain rate.

4.3 Principal mean rate of strain and direction of principal mean rate of strain.

The principal mean rate of strain occurs when there are no shear strain rates and the direction at which this occurs is termed as the principal direction. The rate of deformation tensor is a symmetric second order tensor and by application of the properties of symmetric second order tensors and matrix algebra (Hunter 1976), the principal mean strain rates and principal directions can be obtained. Unpublished work of Professor Azad has shown that in a conical diffuser, Starting from the rate of strain tensor and by use of tensor algebra the principal rates of strain in conical diffuser are given by

$$X = \mathrm{Cos}2\theta\ \partial U/\partial x + 1/2(\partial U/\partial r + \partial V/\partial x)\mathrm{Sin}2\theta - V/r\mathrm{Sin}^2\theta \quad ......4.1$$

$$Y = -\mathrm{Cos}2\theta\ \partial U/\partial x - 1/2(\partial U/\partial r + \partial V/\partial x)\mathrm{Sin}2\theta - V/r\mathrm{Sin}^2\theta \quad ....4.2$$

and the principal directions given by

$$\theta_P = 1/2\tan^{-1}[0.5(\partial U/\partial r + \partial V/\partial x)/(\partial U/\partial x + V/2r)] \quad ....4.3$$

The principal directions have been plotted on figures 4.1 and the value of the principal mean strain rate obtained from equation 4.1 above is shown in figure (4.2). In the core region, the principal strain rate is linear for all the stations. Comparing the figures for the radial variation of the basic strain rate ($\partial U/\partial r$ versus r, in Figure 3.8a) and the graph of the principal rate of strain it can be seen that the two graphs have a similar shape. These is due to the large values of the main shear strain rate, $\partial U/\partial r$, which is the dominant quantity if compared to the other strains which are neglible in comparison.

CHAPTER 5

CONCLUSION

The results show that the effects of turbulence cannot be ignored if reliable results are to be obtained on the mean flow field of a conical diffuser fed with fully developed turbulent pipe flow. Pressure measurements with turbulent and wall proximity corrections are adequate for obtaining correct mean velocities which give mass flow rates to within 2% of the mass flow rate at inlet of diffuser. The empirical relation given for the turbulent correction is applicable in the whole region of the diffuser.

The diffuser inlet region the sudden increase in flow area causes the circumferential straining of the fluid and this results to maximum value of the mean radial velocity which occurs at 7cm. from diffuser inlet and then gradually reduces towards the exit.

At the diffuser inlet region, x<20cm. , the mass flow rates obtained from hot wire measurements, pulsed wire and pressure probes with correction are close to each other to within experimental uncertainties and give mass flow rates within 2% of that at diffuser inlet. At the exit region the results show that pressure probes (Without corrections for turbulent and wall proximity) and hot wire can not provide reliable results since mass flow rates 15% higher than that at inlet were observed.

The strain field has been studied from the velocity derivatives. It was found that the basic shear strain rate, $\partial U/\partial r$, has a similar radial distribution to that of fully developed pipe flow at the diffuser inlet region(x=0 to 6cm.). In the core region, $\partial U/\partial r$, does not vary appreciably in the streamwise direction.

The normal strain rate, $\partial U/\partial x$, in the core region has high negative value at the diffuser inlet due to the sudden retardation of the flow and reduces in magnitude towards the exit and is always negative in the core region(r<40mm.). For axial locations with radii larger than the feed pipe radius(r>50mm.), the radial distribution of the normal strain rate is that it remains fairly constant and negative in all axial location but increases and changes sign very close to the wall.

The radial distribution of the normal strain rate, $\partial V/\partial r$, is nearly constant from the axis and attains high negative magnitudes close to the wall. The axial variation shows that it gradually reduces in the core region and in the wall region the quantity has high negative magnitudes and approach zero towards the exit.

The shear strain rate, $\partial V/\partial x$, generally increases towards the wall and is positive for the first 10cm. from diffuser inlet. For the diffuser core region (up to r=50mm.), this quantity does not show any streamwise variation.

It was also found that the last one third of the diffuser, which is the region associated with appreciable incipient separation, the mean velocity profiles collapse to one asymptotic curve in Perry and Schofield coordinates which can be fitted by a polynomial of seventh order. Distinct points of inflection are also evident in the mean velocity profiles for this region.

The mean static axial pressure gradient asymptotically approaches zero towards the exit while the maximum pressure recovery is at the inlet region where the pressure gradient is high. On the contrast, the r-direction momentum equation balance revealed high radial pressure gradients at the exit region especially in the wall proximity. In this region the radial pressure gradient and the derivatives of the fluctuating quantities dominate the viscous and inertial terms (Figure 3.9c).

Conclusively, static and total pressure measurements can be effectively used to increase our understanding on the mean flow and strain field in an axisymmetric turbulent incipient separating flow with an adverse pressure gradient.

RECOMMENDATIONS

With correct calibration from the pitot tube other techniques should be used to correctly obtain the mean and turbulent fluctuating quantities for the whole diffuser and the radial pressure gradient obtained from balancing the r-momentum equation. The knowledge of the distribution of the pressure gradient can be used to obtain the mean static pressure by integration.

A better curve fitting and method of acquiring the velocity derivatives should extensively be used and the results used for the momentum equation balance.

In Tennekes and Lumley (1972), evidence suggests that the eddies most effective in maintaining a correlation between the fluctuating velocities and in extracting energy from the mean flow are vortices whose principal axes are approximately aligned with those of the mean strain rate. This energy transfer is linked with vortex stretching and a thorough study on the principal strain rates in the diffuser and the vorticity field would give more understanding on the turbulence mechanism in this flow.

REFERENCES

Arora, S.C., An Experimental Study of The Turbulent Kinetic Energy and Vorticity in a Conical Diffuser, Ph.D Thesis, The University of Manitoba, Winnipeg, Canada, 1978.

Azad, R.S., and Kassab, S.Z., Turbulence Structure in a Conical Diffuser: Overview and Implications, *Physics of Fluids A*,1, 564-573, 1989.

Azad, R.S., and Burhanuddin, S., Measurement of Some Features of Turbulence in Wall Proximity, *Experiments in fluids*, 1, 149-160, 1983.

Bradbury, L.J.S., and Castro, I.P., A pulsed-wire Technique for Velocity Measurements in Highly Turbulent Flows, *Journal of Fluid Mechanics*, **49**, 657-691, 1971.

Bradshaw, P., An introduction to Turbulence and its Measurements, Aeronautic Department, Imperial College of Science and technology, 1975.

Cho N.H., and Fletcher, C.A.J., Computation of Turbulent Conical Diffuser Flows Using a Non-Orthogonal Grid System, *Computers and Fluids*, **19**, No. 3/4, 347-361, 1991.

Clausen, P.D., Koh, S.G., and Wood, D.H., Measurements of a Swirling Turbulent Boundary Layer Developing in a Conical Diffuser, *Experimental Thermal and Fluid Science*, **6**, 39-48, 1993.

Dengel, P., and Fernholz, H.H., An Experimental Investigation of an Incompressible Turbulent Boundary Layer in the Vicinity of Separation, *Journal of Fluid Mechanics*, **212**, 615-636, 1990.

Eck, Dr.-Ing. Bruno, Fans, Design and Operation of centrifugal, Axial-flow & Cross-Flow Fans, Translated and Edited by R.S. Azad and D.R. Scott, 1973.

Fung, Y.C., A First Course in Continuum Mechanics, Prentice-Hall, Inc., Englewood, N.J., 1969.

Gibson, A.H., On The Flow of Water Through Pipes Having Converging or Diverging Boundaries, *Proc. Roy. Soc London*, **83**, 366, 1910.

Goenka, L.N., Panton, R.L., and Bogard, D.G., Pressure and Three Component Velocity Measurements on a Diffuser That Generates Longitudinal Vortices, *ASME Journal of Fluids Engineering*, **112**, 281-288, 1990.

Hinze, J.O., Turbulence, 2nd Ed. McGraw-Hill, New York, 1975.

Hummel, R.H., Turbulence Structure in a Conical Diffuser, Ph.D Thesis, The University of Manitoba, Winnipeg, Canada, 1978.

Hunter,S.C., Mechanics of Continuous Media, Ellis Horwood ltd., 1976.

Kassab, S.Z., Turbulence Structure in Axisymmetric Wall-bounded Shear Flow, Ph.D Thesis, The university of Manitoba, Winnipeg, Canada, 1986.

MacMillan, F.A., Experiments on Pitot-Tubes in Shear flow, Ministry of Supply, Aeronautical Research council, Reports and memoranda, 1957.

Okwuobi, P.A.C, Turbulence in a Conical Diffuser with Fully Developed Flow at Entry, Ph. D Thesis, The University of Manitoba, Winnipeg, Canada, 1972.

Okwuobi, P.A.C, and Azad, R.S., Turbulence in a Conical Diffuser with Fully Developed Flow at Entry, *Journal of Fluid Mechanics*, **57**, 603-622, 1973.

Ozimek, L.G., Azad, R.S., Derksen, R.W., An Experimental Investigation of Turbulence Parameters in an Eight Degree Conical Diffuser, in Sym*posium in Thermal Anemometry*, D.E. Stock, Ed., ASME FED, **53**, 93-102, 1987.

Perry, A.E., and Schofield, W.H., Mean Velocity and Shear Stress Distributions in Turbulent Boundary Layers, *Physics of Fluids*, **16**, No.12, 2068-2074, 1973.

Schlichting, H., Boundary Layer Theory, 6th ed., New York: McGraw-Hill, 1979.

Schofield, W.H., Equilibrium Boundary Layers in Moderate to Strong Adverse Pressure Gradients, *Journal of Fluid Mechanics*, **113**, 91-122, 1981.

Schofield, W.H., Two Dimensional Separating Turbulent Boundary Layers, *AIAA Journal*, **24**, 1611-1620, 1986.

Simpson, R.L., Chew, Y.-T., and Shivaprasad, B.G., Structure of a Separating Turbulent Boundary Layer, Part 2, *Journal of Fluids Mechanics*, **113**, 53-73, 1981.

Singh, R.K., and Azad, R.S., Effects of incipient separation on mean and fluctuating velocities in a conical diffuser flow, in *Proceedings of the third world conference on experimental heat transfer, Fluid Mechanics and Thermodynamics*; M.D.Kelleher, R.K. Shah, K.R. Sreenivasan, and Y. Joshi, Eds., 977-984, Elsevier, New York, 1993.

Singh, R.K, and Azad, R.S., Asymptotic Velocity Profile in an Incipient Separating Axisymmetric Flow, *AIAA Journal,* **33**, No. 1, 95-103, 1995.

Sovran, G. and Klomp, E., Experimentally Determined Optimum Geometries for Rectlinear Diffusers with Rectangular, Conical or Annular Cross Sections, in *Fluid Mechanics of internal flows* , G. Sovran, Ed., Elsevier, N.Y., 270-319, 1967.

Spencer, A.J.M., Continuum Mechanics, Longman Inc., New York, 1980.

Sprenger, H., Experimentelle untersuchugen an geraden und gekrummten diffusoren, Mitteilung aus dem Institute fur Aerodynamik an der ETH, Zurich No.27 (Translation: Experimental research on straight and curved diffusers, obtained from ministry of aviation, GB), 1959.

Tanjo, A.E., A Study of Coherent Motions in a Turbulent Flow Subjected to an Adverse Pressure Gradient, Ph. D Thesis, The University of Manitoba, Winnipeg, Canada, 1992.

Tennekes, H., and Lumley, J.L., A first course in turbulence, MIT press, Cambridge, Massachussets, 1985.

Thompson, B.E., and Whitelaw, J.H., Trailing Edge Flow with Turbulent Boundary Layer Separation, *Journal of Fluid Mechanics,* **157**, 305-326, 1985.

Turan, O., and Azad, R.S., Representation of Experimental Data by Fourier Functions for Differentiation, *AIAA Journal*, Inc., **26** , No.8 , 903-904, 1988.

Van der Spiegel, P.J.A., An Experimental Investigation of The Turbulent Boundary Layer in a Straight Conical Diffuser, Msc. Thesis, The University of Manitoba, Winnipeg, Canada, 1969.

Wiggert, D.C and Potter, M.C., Mechanics of Fluids, Prentice Hall, Englewood Cliffs, NJ 07632, 1991.

Yuan M., Song, C.C.S., and He, J., Numerical Analysis of Turbulent Flow in a Two-Dimensional Non-Symmetric plane wall Diffuser, *Journal of Fluids Engineering*, **113**, 210-215, 1991.

Appendix A

DERIVATION OF STRAIN RATE FOR A CONICAL DIFFUSER IN CYLINDRICAL POLAR COORDINATES

In cylindrical coordinates with the axial direction denoted by the z-axis, radial direction by r and azimuthal direction by θ,

Let the velocities be defined as follows

U_r= Velocity in radial direction.

U_z= Velocity in the z-axis (streamwise direction).

U_θ= velocity in the θ- direction.

let the strain rates be defined as follows,

ε_{rr}= Normal strain rate in radial direction.

$\varepsilon_{\theta\theta}$=Total tangential strain.

ε_{zz}= Normal strain in the axial direction.

$\varepsilon_{r\theta}, \varepsilon_{zr}, \varepsilon_{z\theta}$ = Shear strain rates.

(see Figure shown in the next page).

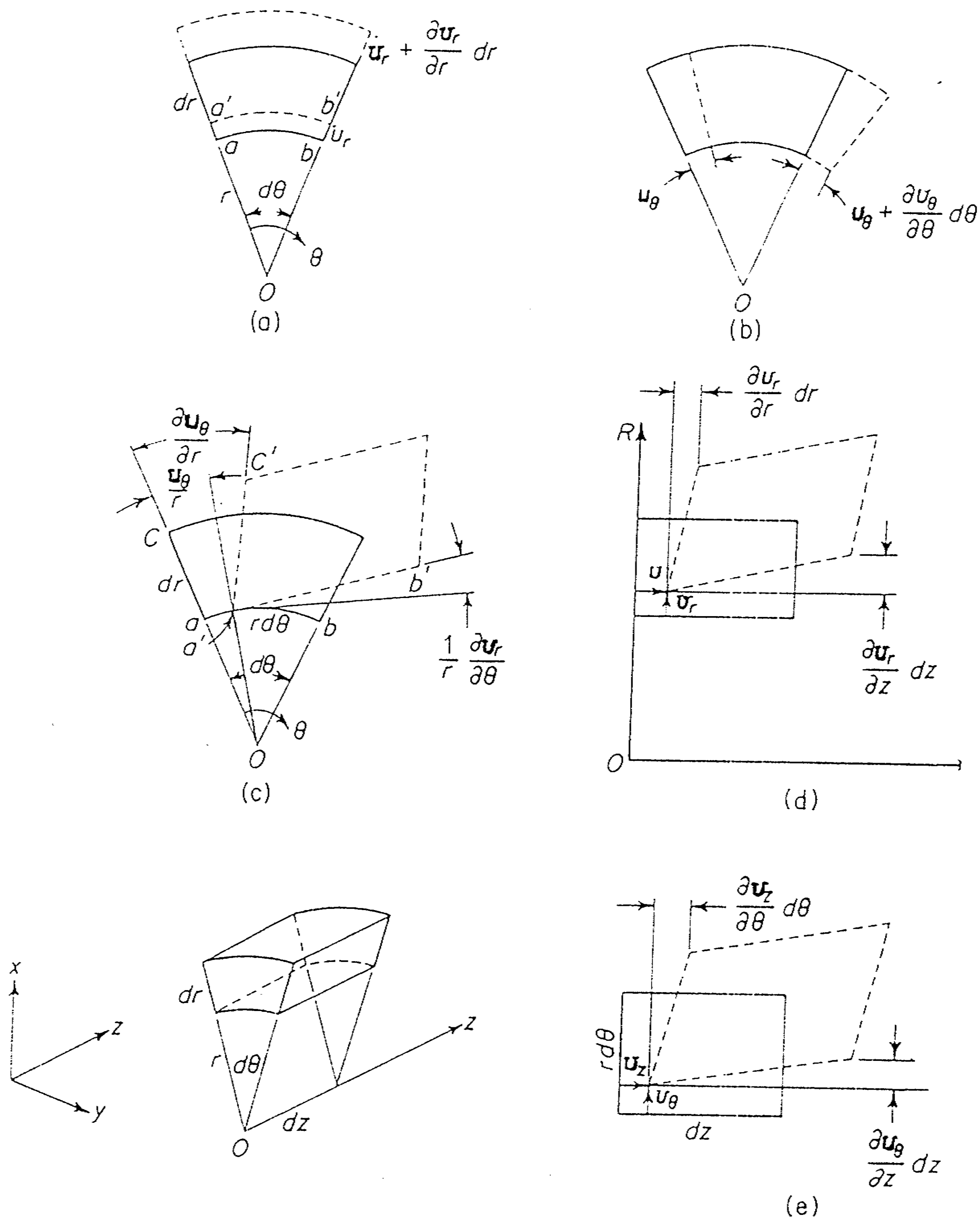


Figure A.1 Displacement in cylindrical coordinates.

Strain rate and strain are related in the sense that strain is defined as the change of distance per unit length and strain rate is the change of distance per unit length per unit time. The normal strain components mean the ratio of change of length per unit length and the shearing strain components mean one-half of the change of a right angle, the same can be applied to strain rates with the change of length being replaced by change of velocity.

From the figure given the normal strain in the radial direction will be given by the change of radial distance to the original length. Consider the element shown were the velocity at a or b is U_r, it follows that the velocity at a point at a distance (r+dr) from the origin O is $U_r+(\partial U_r/\partial r)dr$. In a small time dt the point b moves to the point b′ and the distance moved is $U_r dt$ and point d moves to d′ and the distance moved is $[U_r+(\partial U_r/\partial r)dr]dt$. The radial strain is therefore given by the radial stretching divided by the original radial length of the element, dr. This strain is equal to

$$\frac{dr+[U_r+(\partial U_r/\partial r)\,dr]\,dt-U_r dt-dr}{dr}=\frac{\partial U_r}{\partial r}dt$$

The rate at which this straining occurs is therefore given by

$$\epsilon_{rr}=\frac{\partial U_r}{\partial r}\frac{dt}{dt}=\frac{\partial U_r}{\partial r}\ldots\ldots\ldots\ldots A.1$$

If this was not a velocity field but instead displacement with U_r being the distance from the origin O, then the strain would be obtained from

$$\frac{U_r + (\partial U_r/\partial r)\,dr - U_r}{dr} = \frac{\partial U_r}{\partial r}$$

which is the same as equation A.1.

The radial displacement of a circumferential element causes a strain in the θ-direction since the length which was originally rdθ becomes ($r+U_r dt$) dθ. This radial displacement causes a tangential strain, $\varepsilon_{\theta\theta}^{(1)}$, given by

$$\epsilon_{\theta\theta}^{(1)} = \frac{(r+U_r dt)\,d\theta - r\,d\theta}{r\,d\theta} = \frac{U_r}{r}dt \quad \text{..........} A.2$$

Similarly, from Figure A.1(b) the tangential displacement U_θ dt, gives rise to a tangential strain equal to

$$\varepsilon_{\theta\theta}^{(2)} = \frac{U_\theta dt + (\partial U_\theta/\partial\theta)\,d\theta dt - U_\theta dt}{r\,d\theta} = \frac{1}{r}\frac{\partial U_\theta}{\partial\theta}dt \quad \text{..........} A.3$$

The total tangential strain is the sum

$$\varepsilon_{\theta\theta}=\frac{U_r}{r}dt+\frac{1}{r}\frac{\partial U_\theta}{\partial\theta}dt \quad \ldots\ldots\ldots\ldots A.4$$

and therefore the total strain rate is

$$\varepsilon_{\theta\theta}=\frac{U_r}{r}+\frac{1}{r}\frac{\partial U_\theta}{\partial\theta} \quad \ldots\ldots\ldots\ldots A.5$$

If U_θ is the displacement in the θ-direction and U_r the radial displacement instead of velocities, using the same procedure as described above the radial displacement of a circumferential element would cause an elongation of that element and hence a strain in the θ-direction. The element ab, originally of length rdθ would have a length a′b′ equal to $(r+U_r)\,d\theta$ and the tangential strain due to this radial displacement is

$$\frac{(r+U_r)\,d\theta-r\,d\theta}{r\,d\theta}=\frac{U_r}{r}$$

and the tangential displacement U_θ gives rise to a tangential strain equal to

$$\frac{U_\theta+(\partial U_\theta/\partial\theta)\,d\theta-U_\theta}{r\,d\theta}=\frac{1}{r}\frac{\partial U_\theta}{\partial\theta}$$

The total tangential strain is the sum of the above two strains and is therefore equal to

$$\frac{U_r}{r}+\frac{1}{r}\frac{\partial U_\theta}{\partial \theta}$$

which is the same as the total strain rate given in equation A.5.

Since the strain rate and strain result to the same expressions when either velocity or displacement are respectively used, for simplicity the remaining strain rates will be obtained by considering displacements and therefore the time dt will not be taken into account. (A detailed analysis of strain displacement -relations is given by Y.C.Fung, A First Course in Continuum Mechanics, Prentice-Hall, INC., ENGLEWOOD CLIFFS, N.J.,page 105-111)

The normal strain in the axial direction is the ratio of the elongation in the axial direction to the original length, thus

$$\varepsilon_{zz}=\frac{\partial U_z}{\partial z}\ldots\ldots\ldots\ldots A.6$$

The shear strain will be half the angle $\angle c'a'b'$-$\angle cab$ as shown in the Figure A.1(c).

$$\varepsilon_{r\theta}=\frac{1}{2}\left(\frac{1}{r}\frac{\partial U_r}{\partial \theta}+\frac{\partial U_r}{\partial \theta}-\frac{U_\theta}{r}\right)\ldots\ldots\ldots\ldots A.7$$

The first term comes from the change in the radial displacement in the θ-direction; the second term from the change in tangential displacement in the r-direction; the last term appears since part of the slope change of the line a′c′ comes from the rotation of the element as a solid body about the axis through O.

The remaining strain components can be derived with reference to Figures A.1(d) and A.1(e) thus

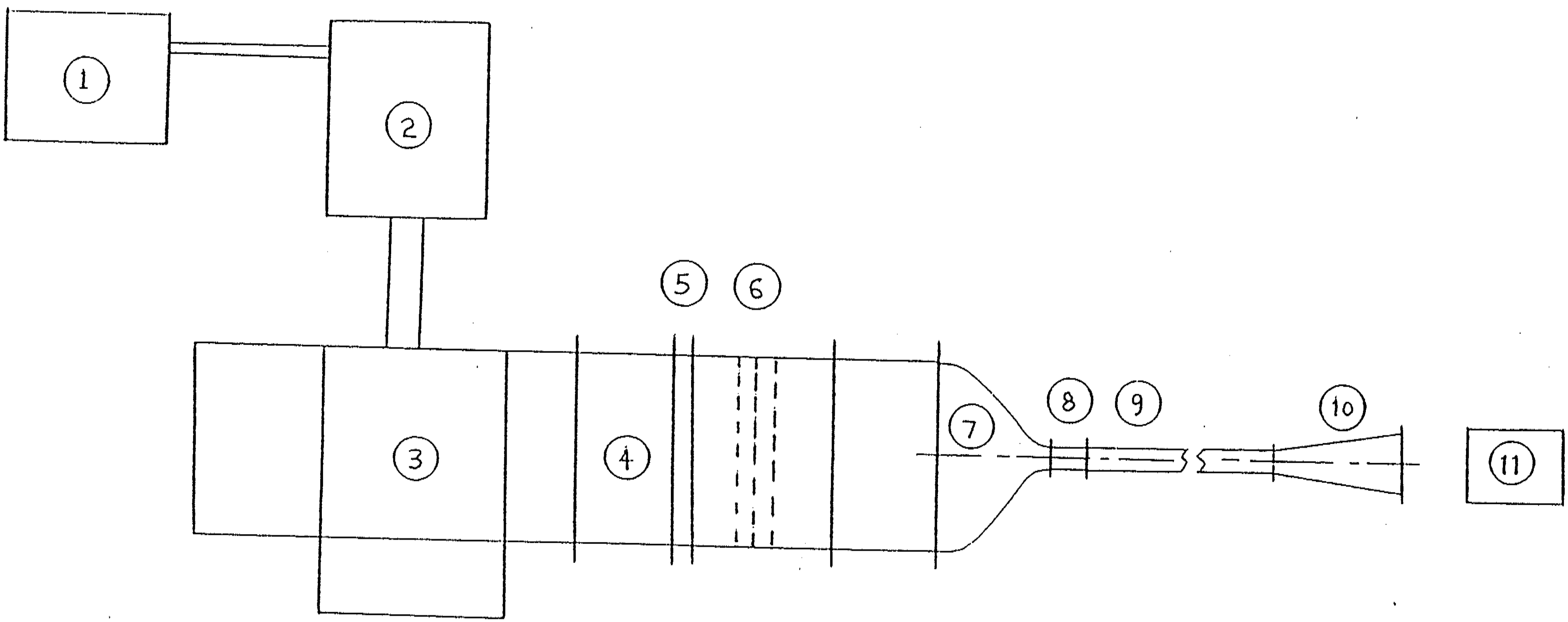
$$\varepsilon_{z\theta}=\frac{1}{2}\left[\frac{(\partial U_z/\partial\theta)\,d\theta}{r\,d\theta}+\frac{(\partial U_\theta/\partial z)\,dz}{dz}\right]=\frac{1}{2}\left[\frac{1}{r}\frac{\partial U_z}{\partial\theta}+\frac{\partial U_\theta}{\partial z}\right].....A.8$$

and

$$\varepsilon_{zr}=\frac{1}{2}\left[\frac{(\partial U_r/\partial z)\,dz}{dz}+\frac{(\partial U_z/\partial r)\,dr}{dr}\right]=\frac{1}{2}\left[\frac{\partial U_r}{\partial z}+\frac{\partial U_z}{\partial r}\right]..........A.9$$

these strain components can then be written in matrix form as the rate of deformation tensor as given in chapter 4 where U_z , U_r , U_θ represent the streamwise velocity U, the radial mean velocity V and W respectively.

PLAN VIEW OF THE WIND TUNNEL



DESCRIPTION

1. Electrical Supply.
2. D.C.Motor.
3. Fan.
4. Rectangular to circular section.
5. Flexible Coupling.
6. Settling chamber.
7. Contraction cone.
8. No. 16 Floor sanding.
9. Steel pipe.
10. Diffuser.
11. Traversing mechanism.

Figure 2.1. Tunnel for the studies of diffuser flow.

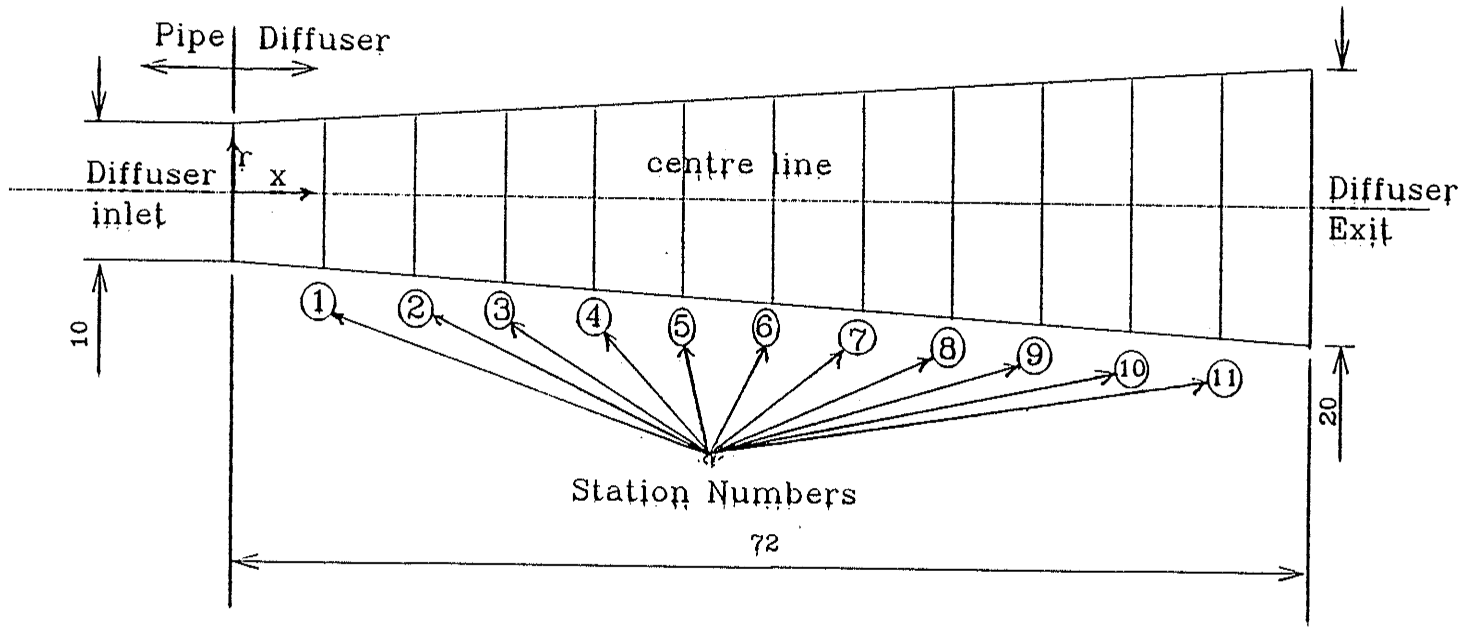
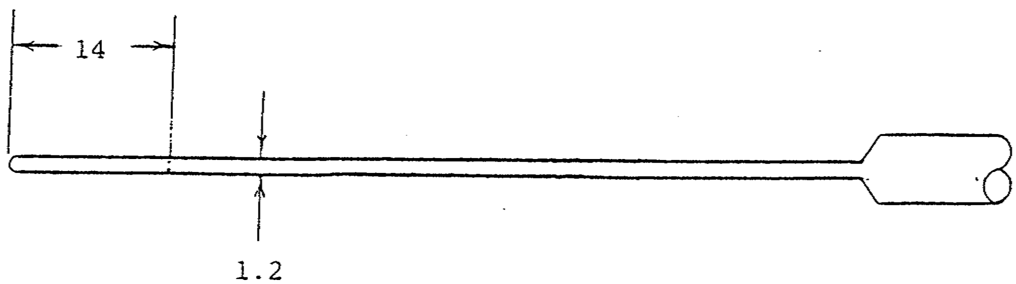
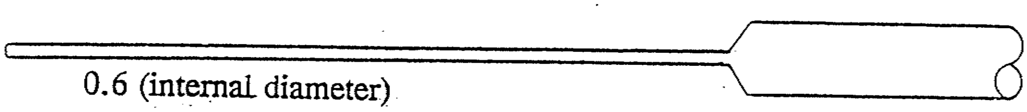


Figure 2.2 Geometry and dimensions of the conical diffuser. Dimensions in cm. Stations are 6cm. apart.



(a) Static Probe.



(b) Pitot Probe.

Figure 2.3 Pressure Probes (all dimensions in mm).

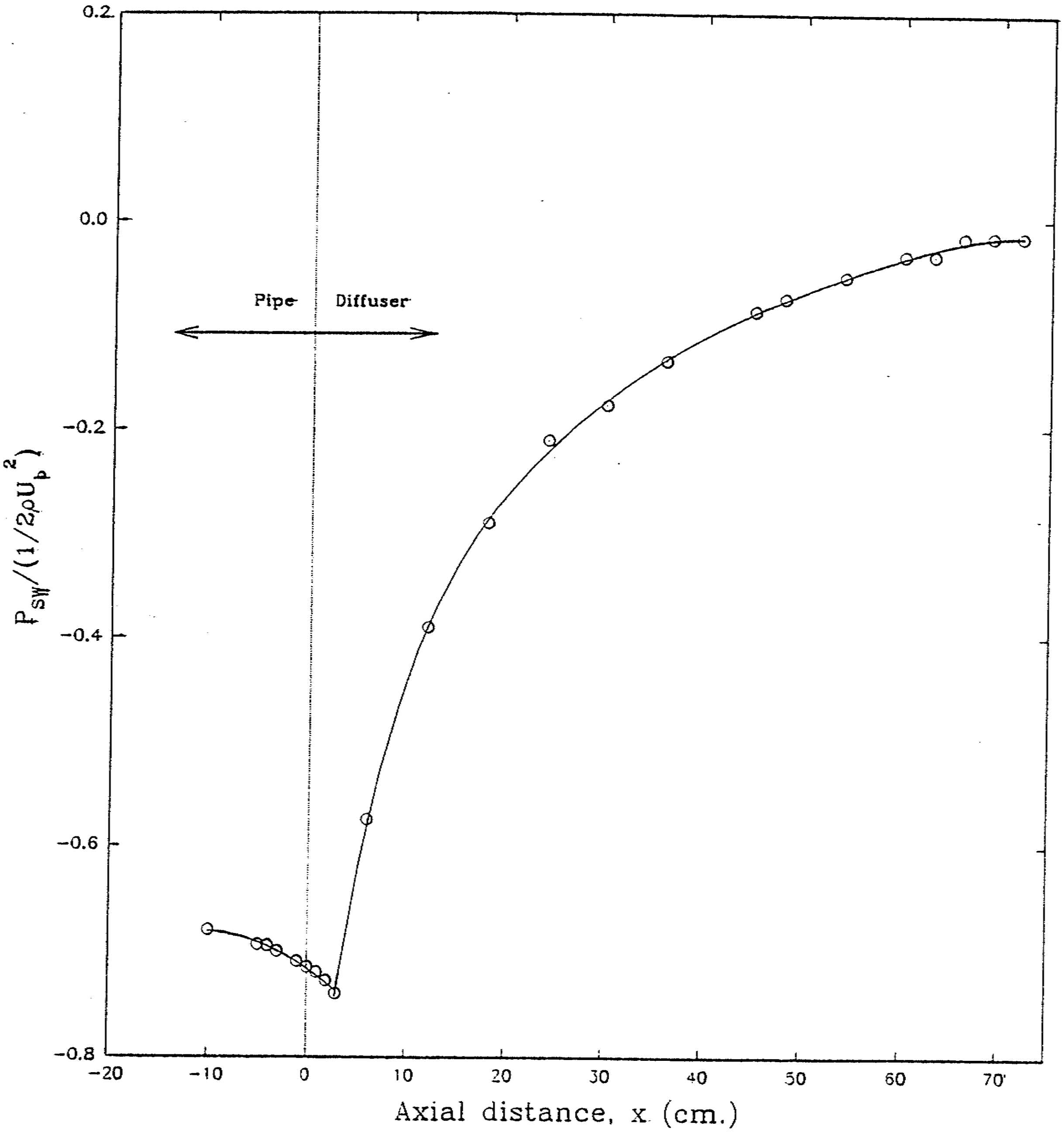


Figure 3.3(a). Wall Static pressure distribution along diffuser wall.

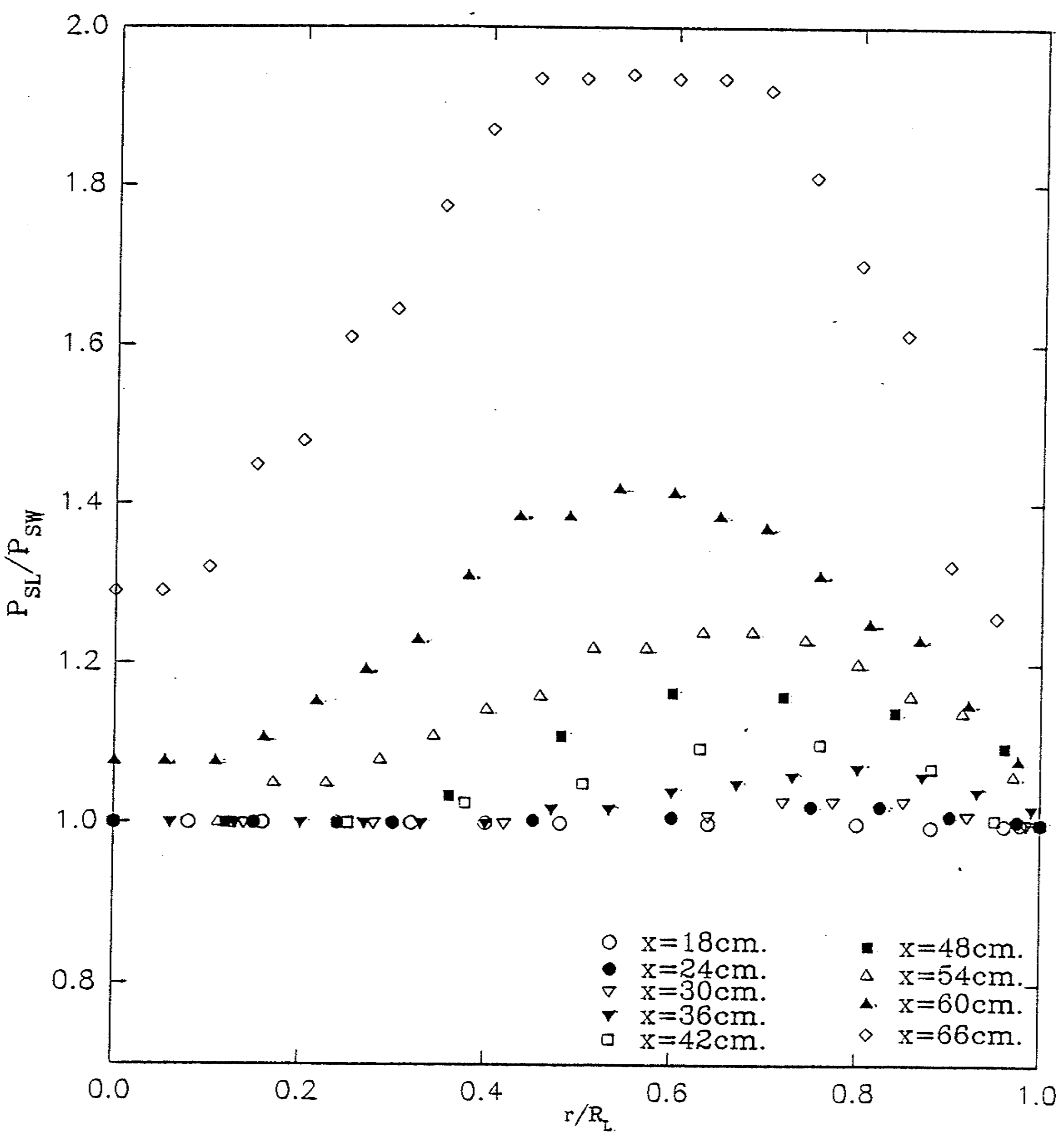
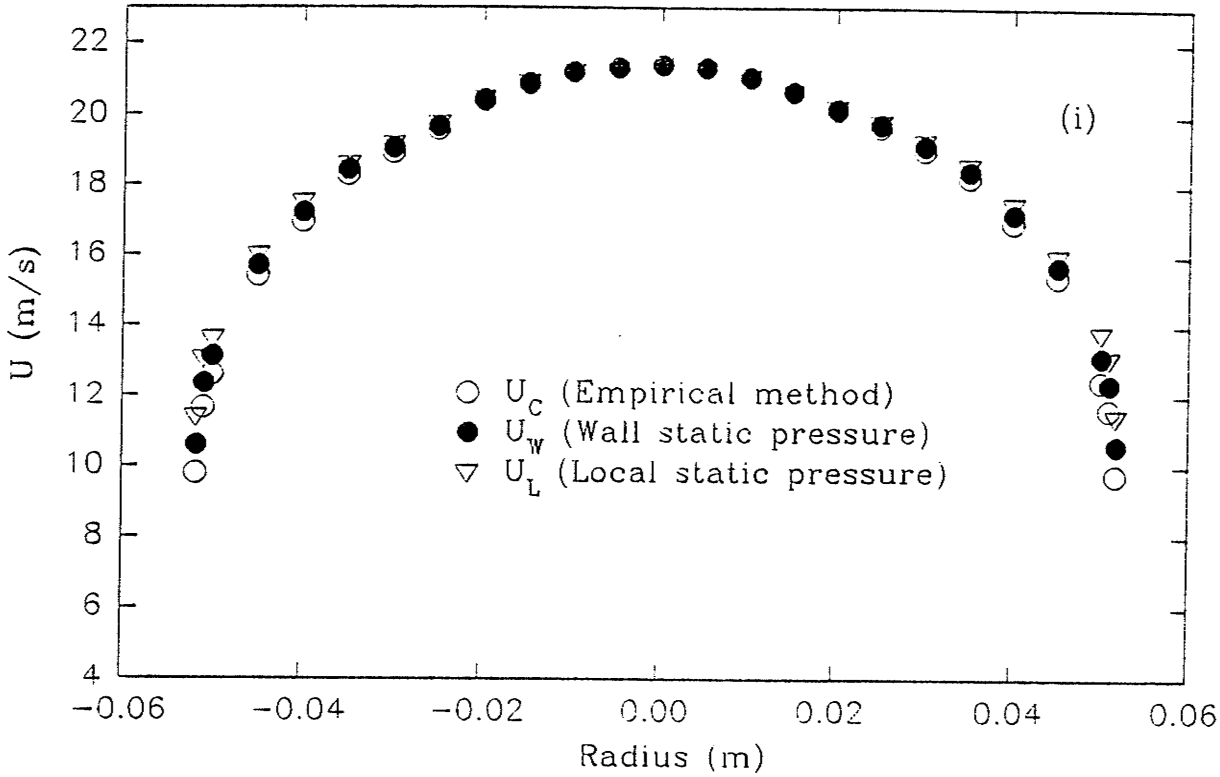


Figure 3.3(b). Local static pressure distribution in radial direction.



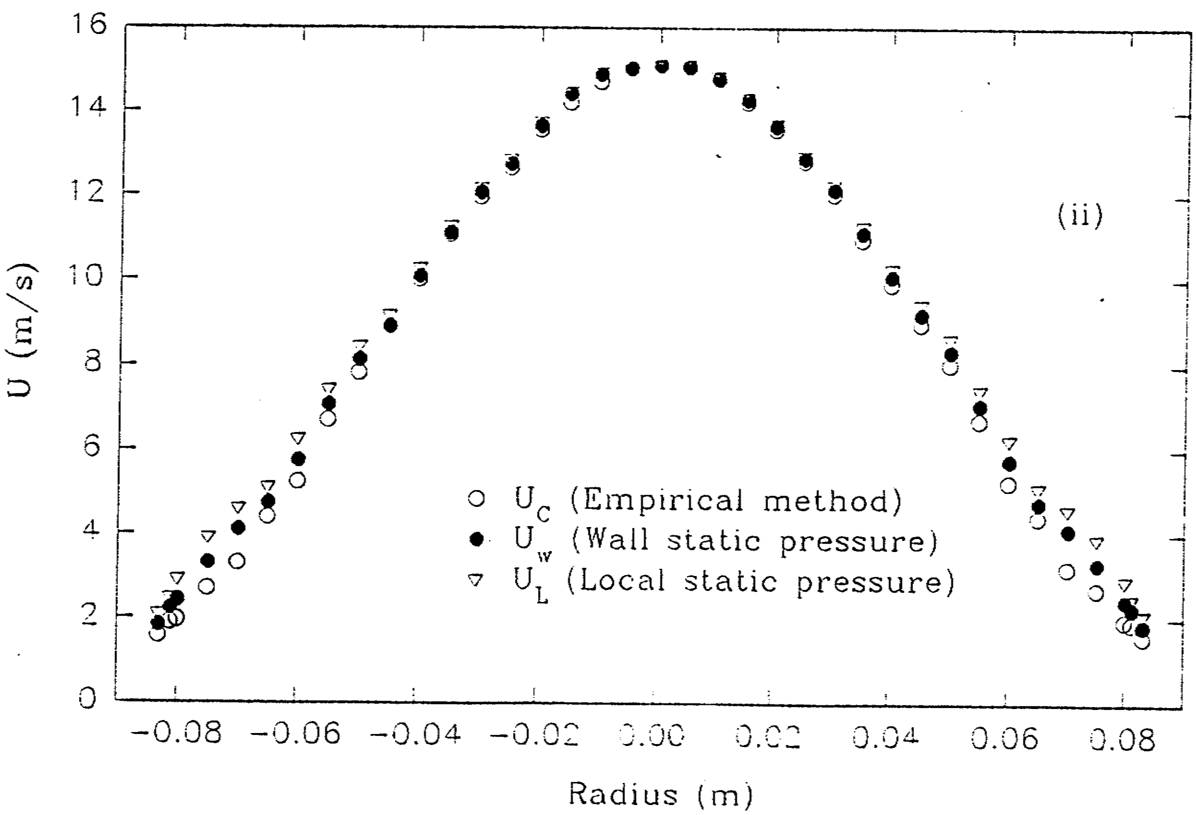


Figure 3.3(c). Mean axial velocity profiles in diffuser for (i) x=3cm. and (ii) x=51cm.

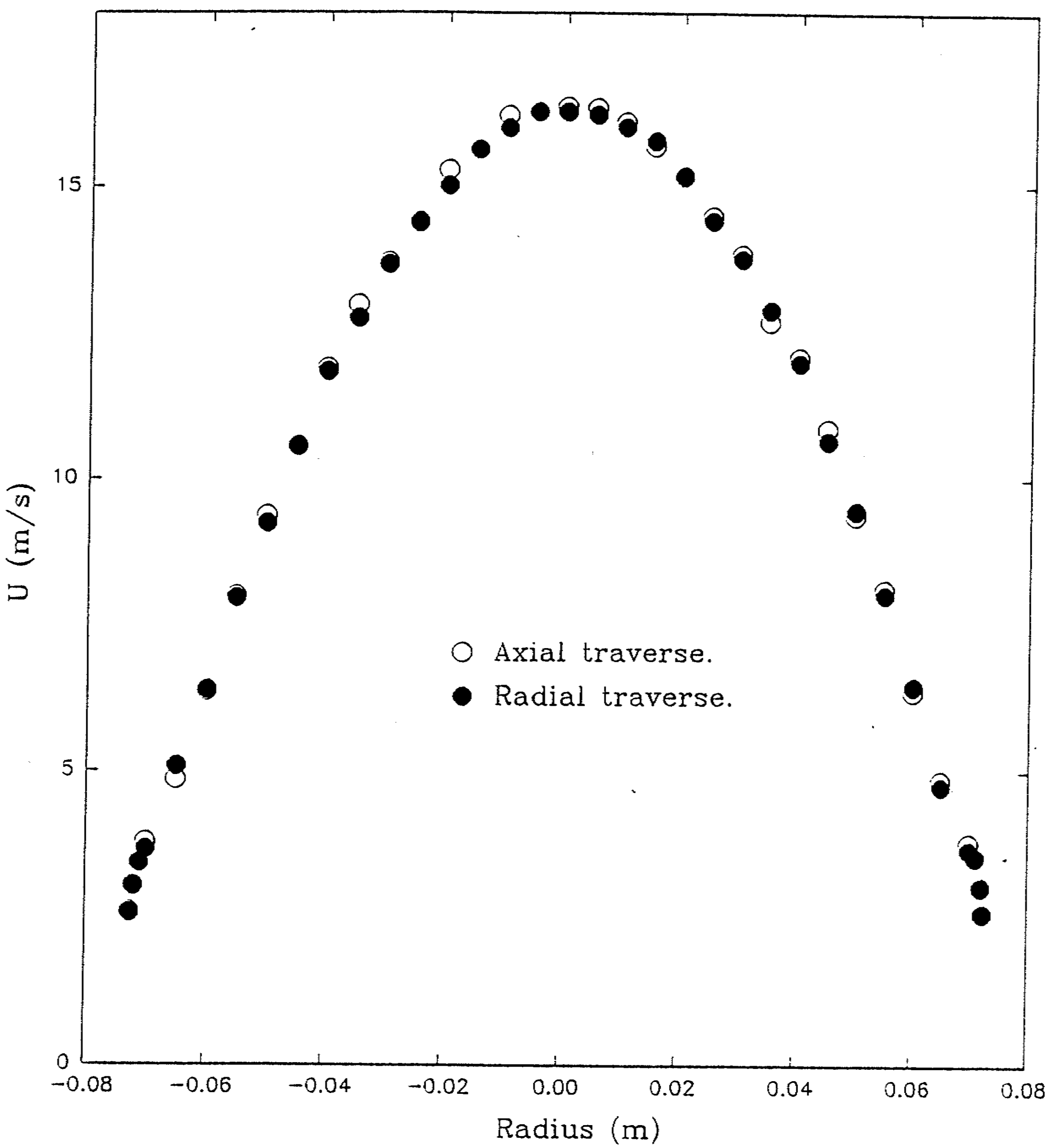


Figure 3.3(d). Axial mean velocity, U, obtained from radial and axial traverse for station 6. Hollow circles correspond to results obtained at different days.

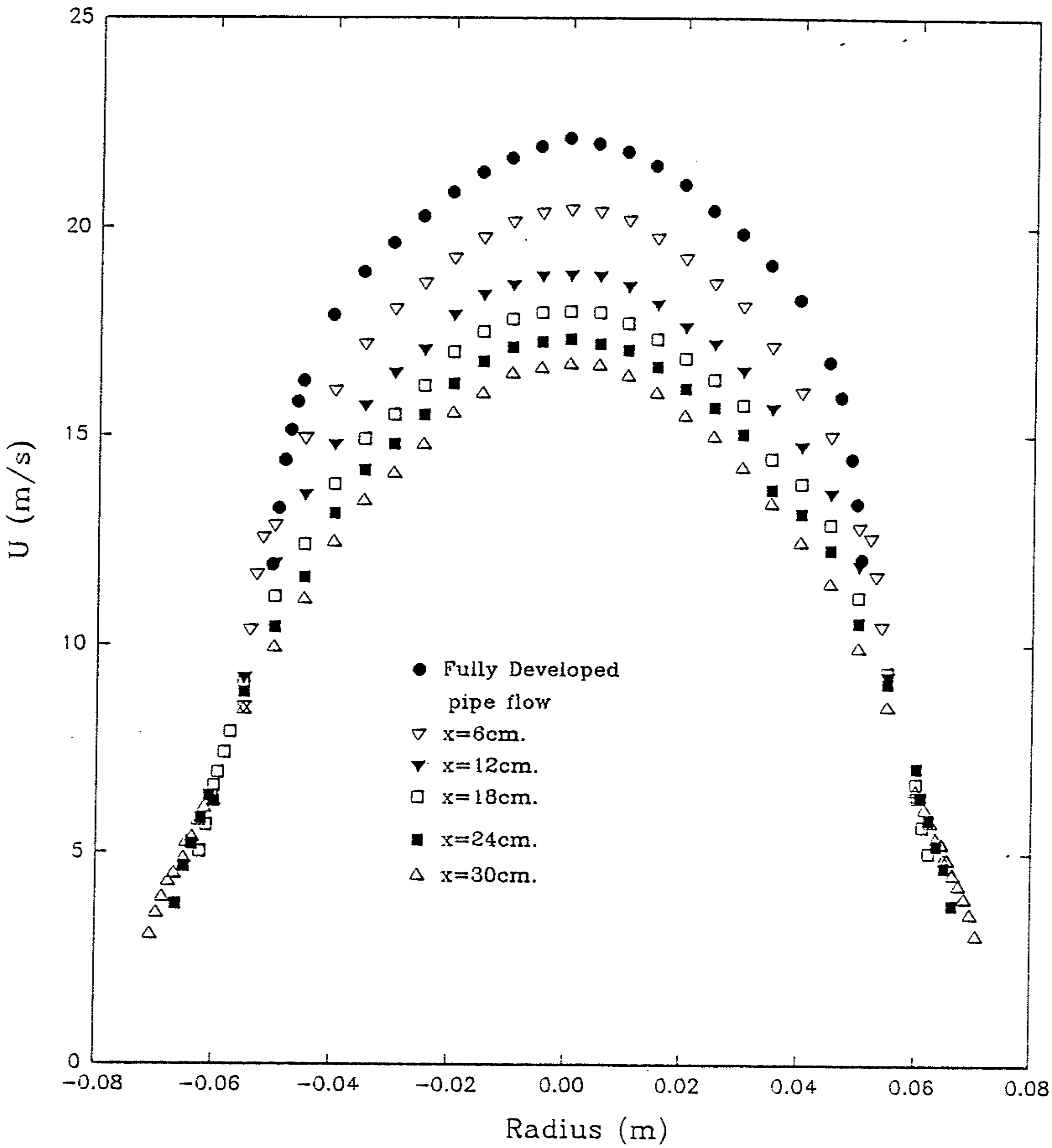


Figure 3.4(a). Corrected Mean axial velocity profiles in diffuser for fully developed pipe flow (Diffuser inlett) at x=0 to x=30cm.

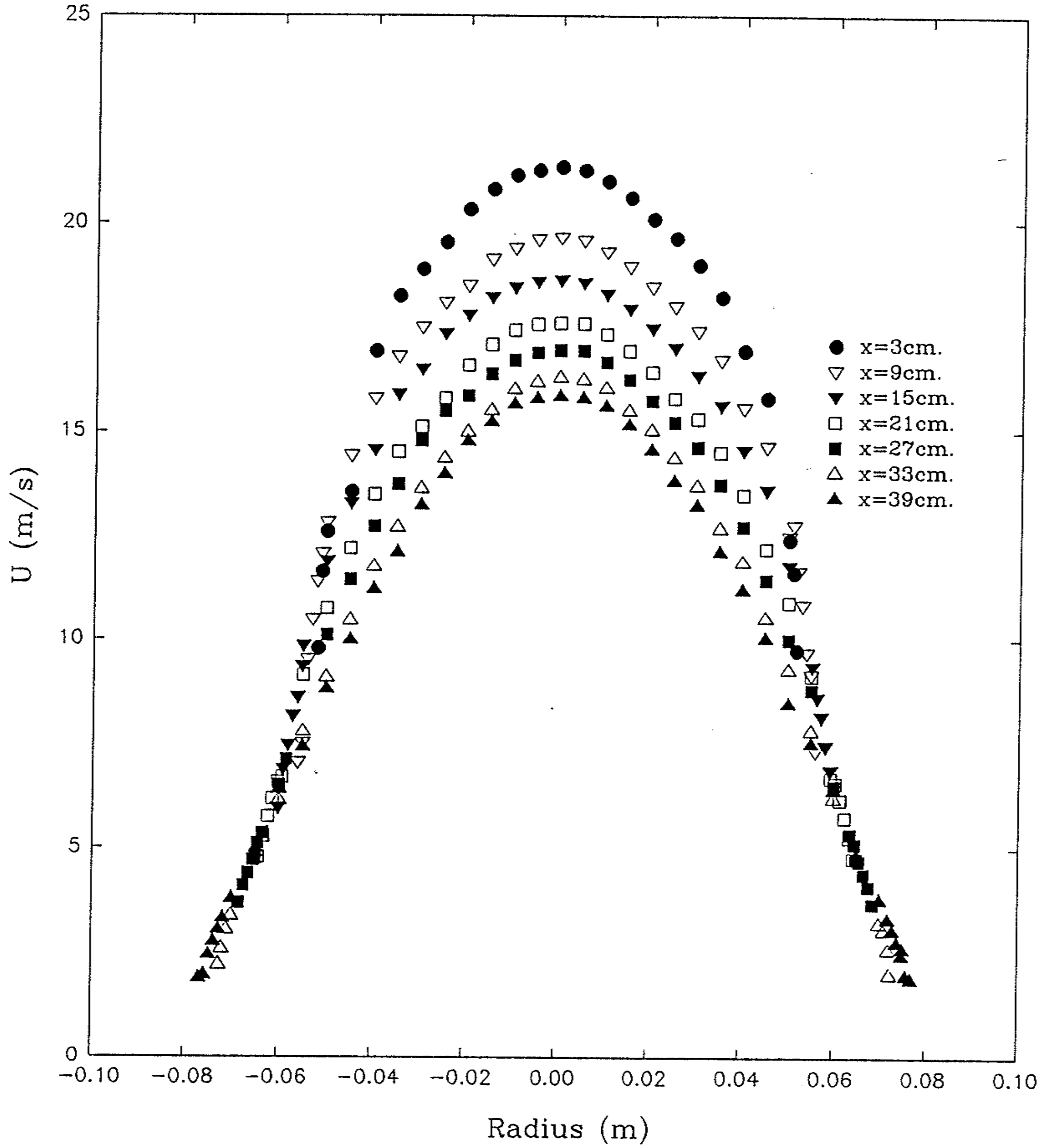


Figure 3.4(b). Corrected mean axial velocity profiles(x=3cm. to 39cm.).

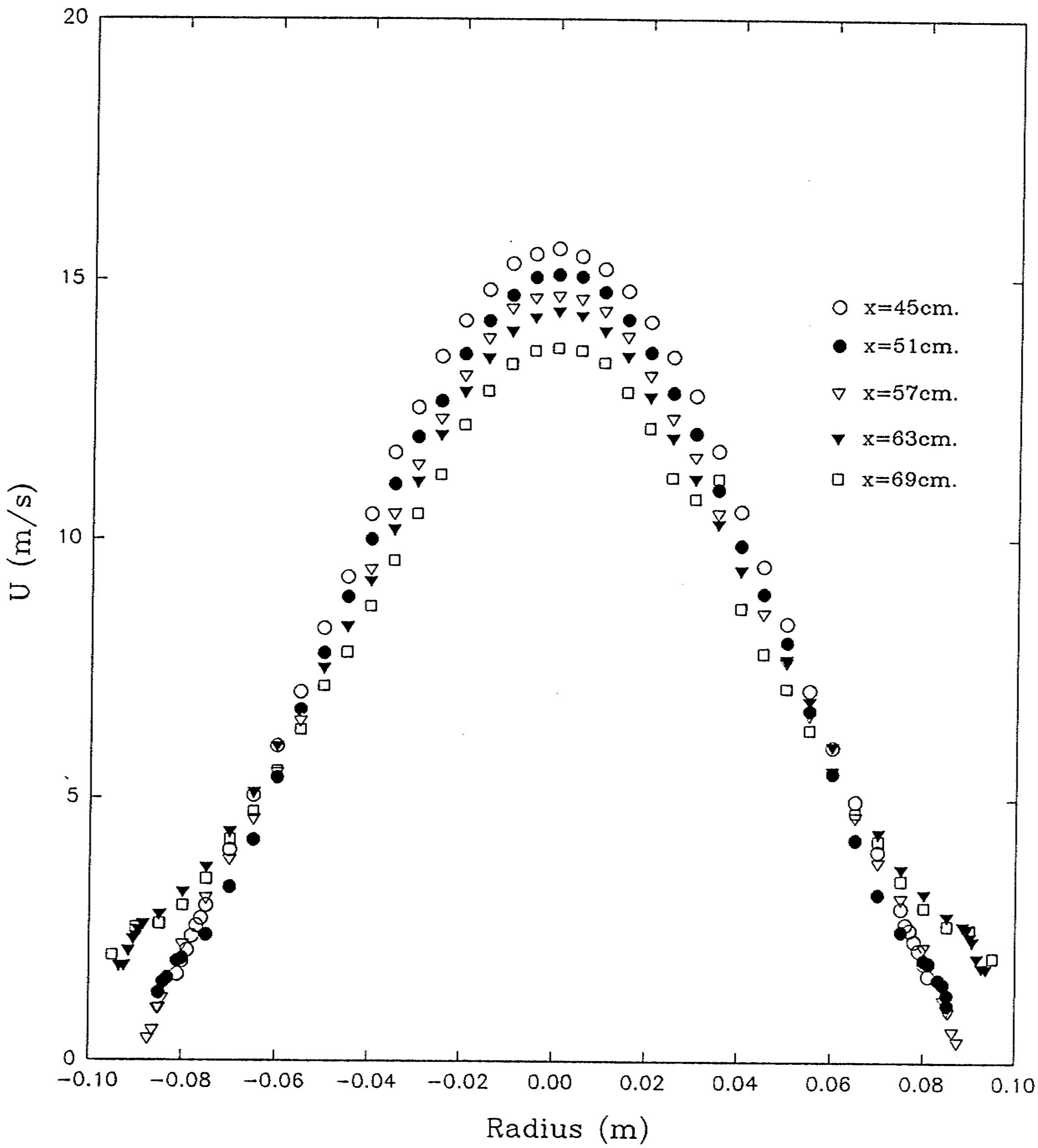


Figure 3.4(c). Corrected Mean axial velocity profiles (x= 45cm. to 69cm.)

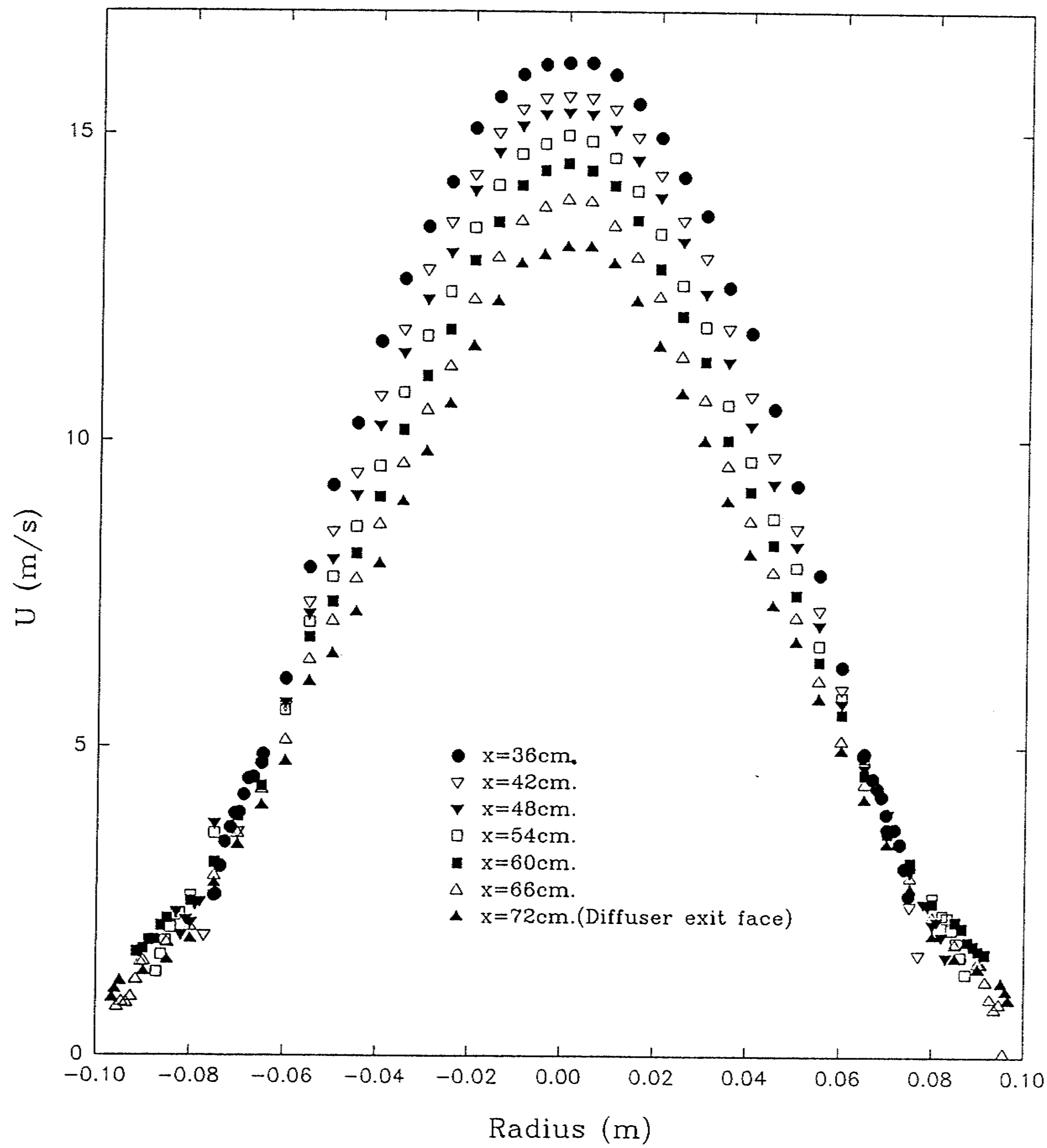


Figure 3.4(d). Corrected mean axial velocity profiles for axial locations x=36cm to x=72cm.

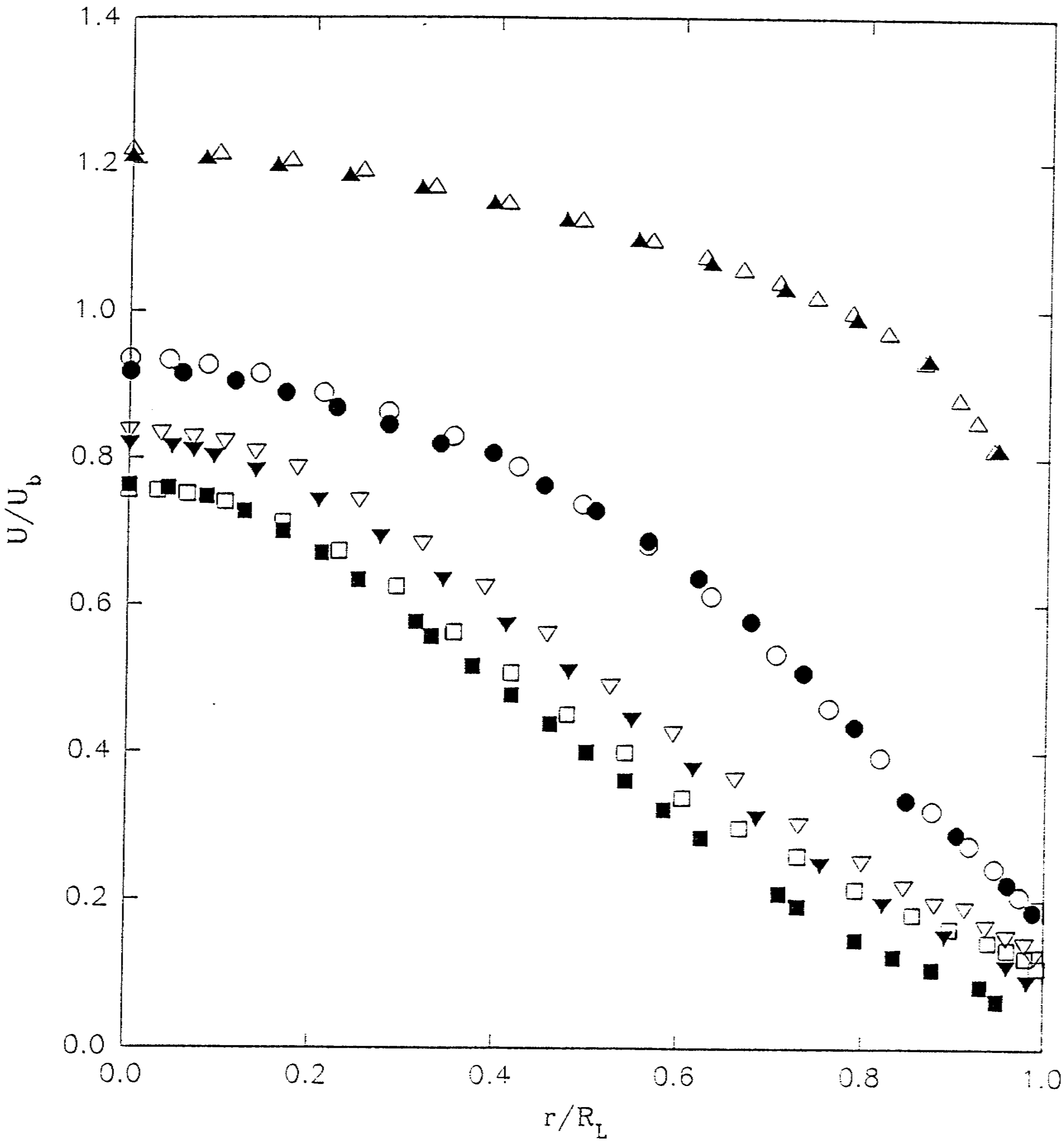


Figure 3.4 (e). Normalized mean axial velocity versus non-dimensional radius. Hollow symbols give hot wire results of Kassab (1986). Solid symbols for present study results. Upright triangles (Fully developed pipe flow); Circles (x=30cm.); Inverted triangles (x=54cm.); Squares (x=66cm.)

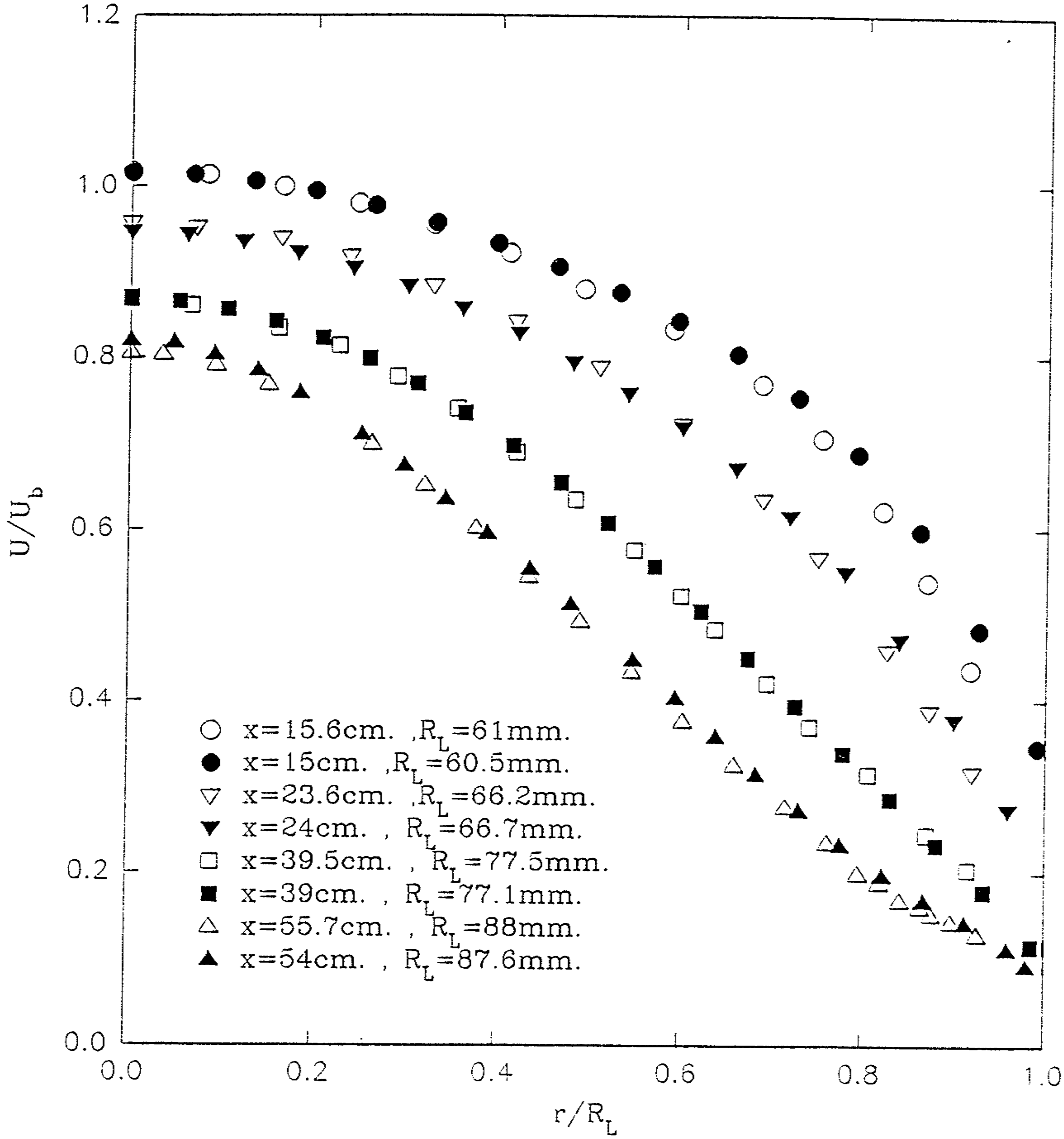


Figure 3.4(f). Mean axial velocity in the diffuser. Hollow symbols give pulsed wire results (Singh, 1995), and solid symbols give present data.

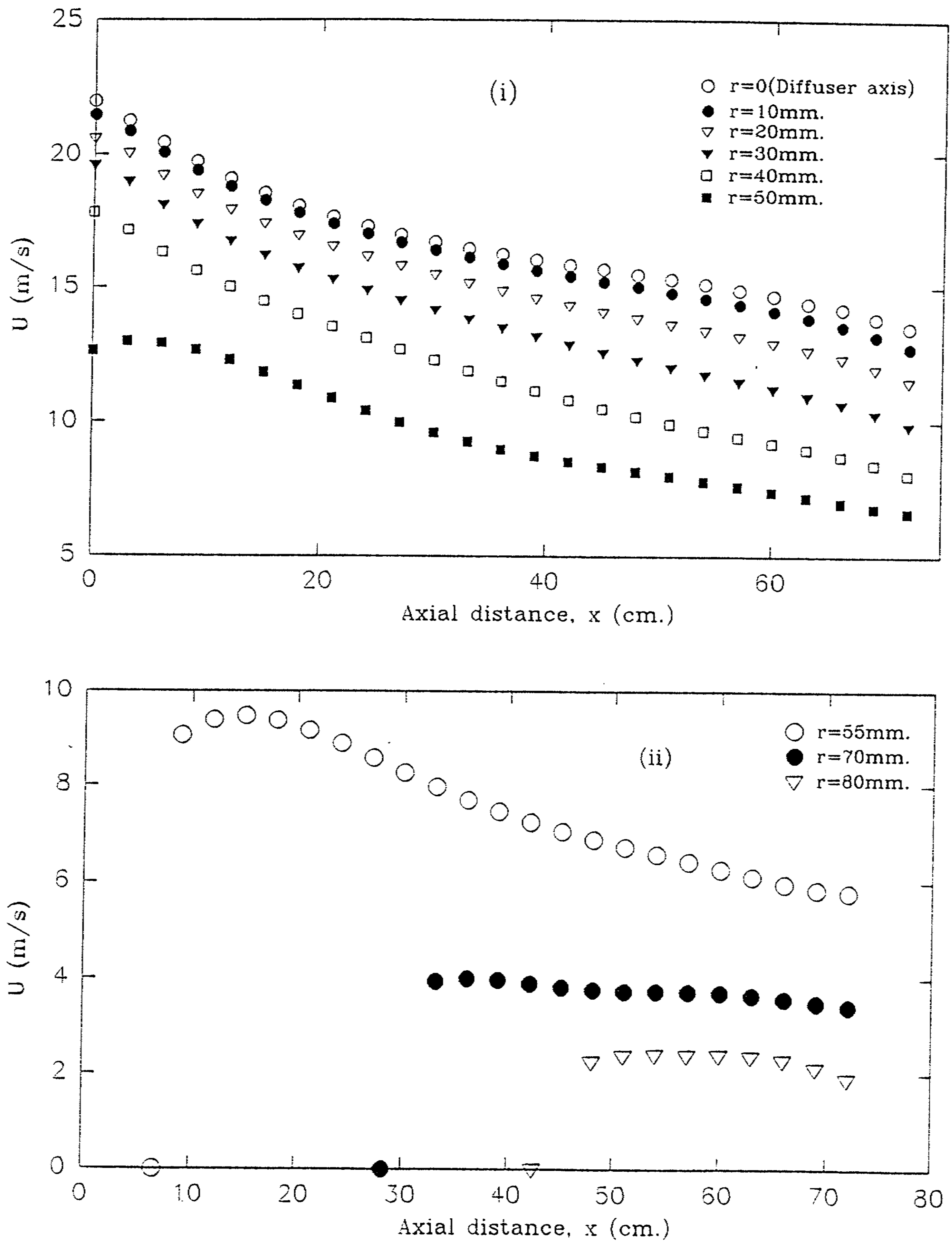


Figure 3.4(g). Distribution of the mean axial velocity in axial direction in (i) the core region and at (ii) the diffuser wall region.

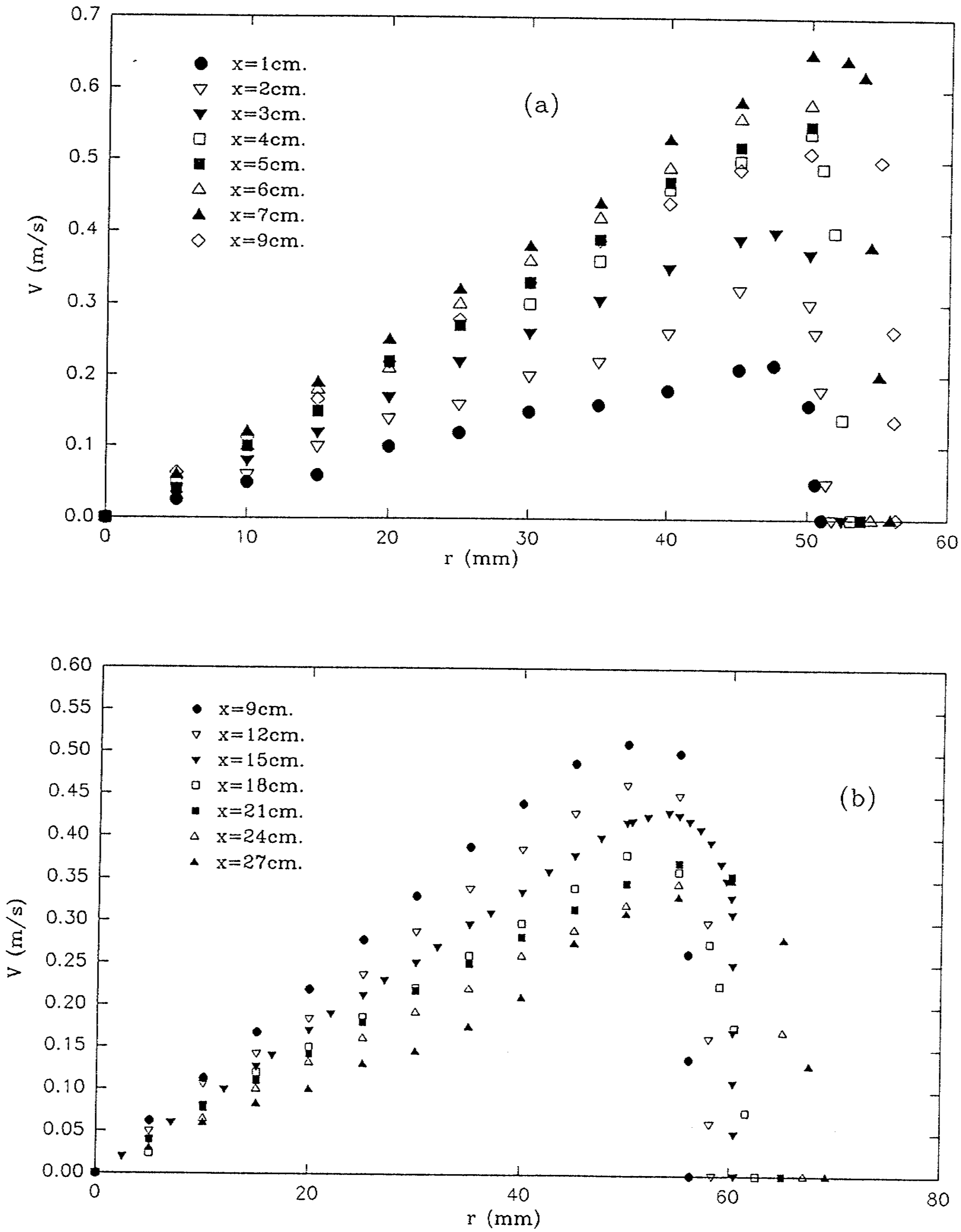


Figure 3.5 Variation of mean radial velocity with radius at (a) the diffuser inlet region, and (b) x=9 to 27cm.

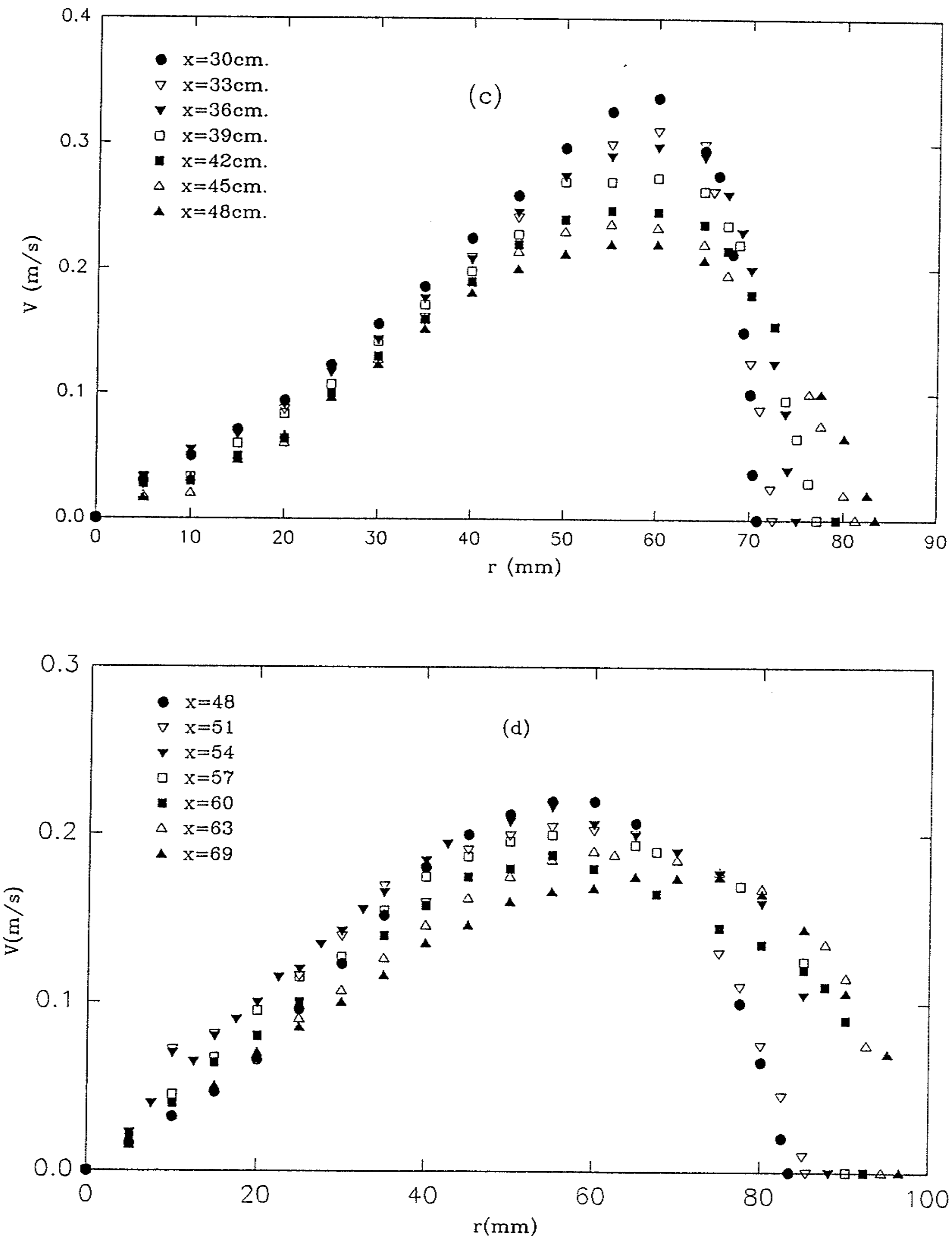


Figure 3.5. Mean radial velocity versus radius, (c) x=27cm. to 48cm. (d) x=48cm. to 69cm.

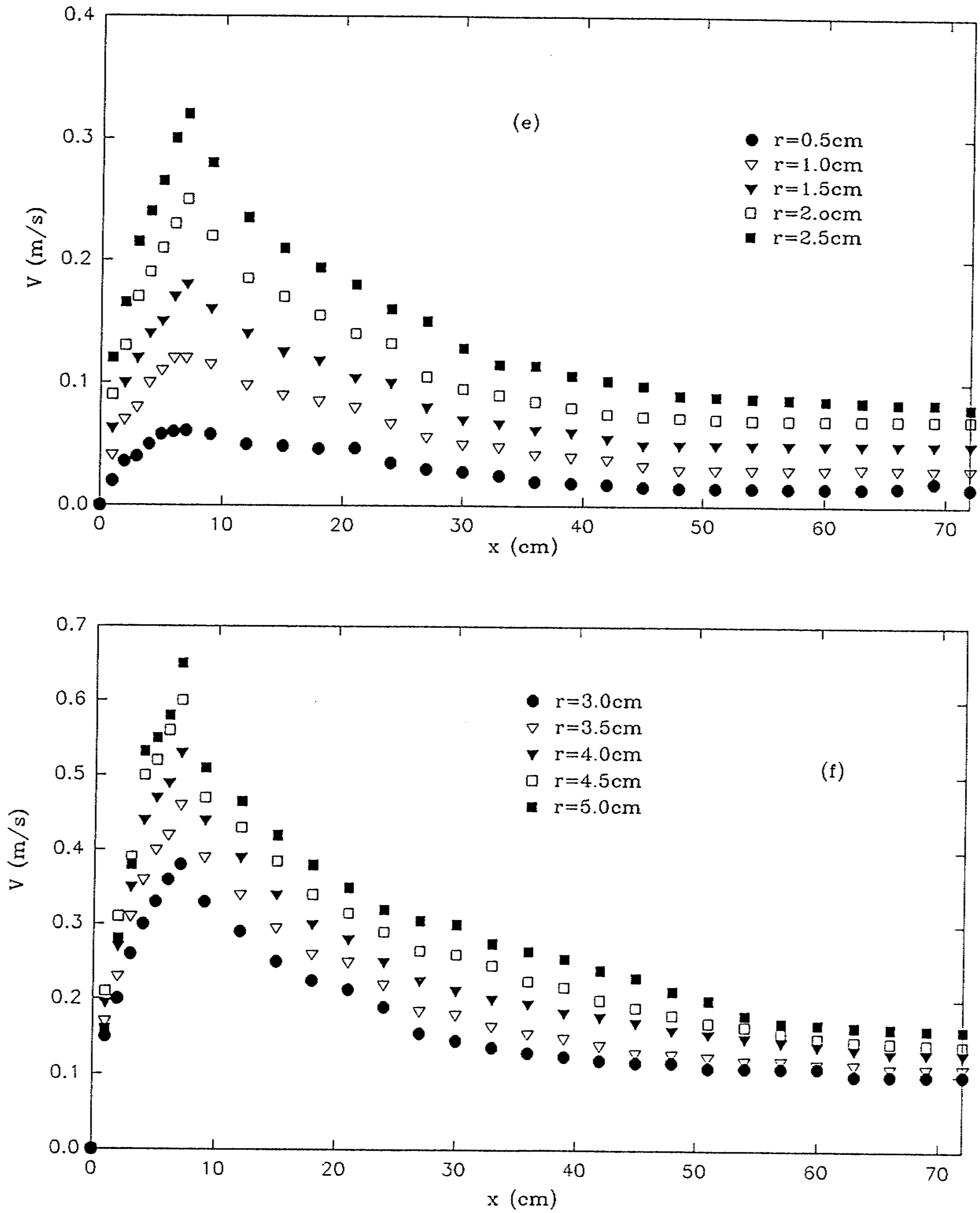


Figure 3.5. Mean radial velocity distribution in axial direction for (e) r=0.5cm. to 2.0cm., and (f) r=3cm. to 5cm.

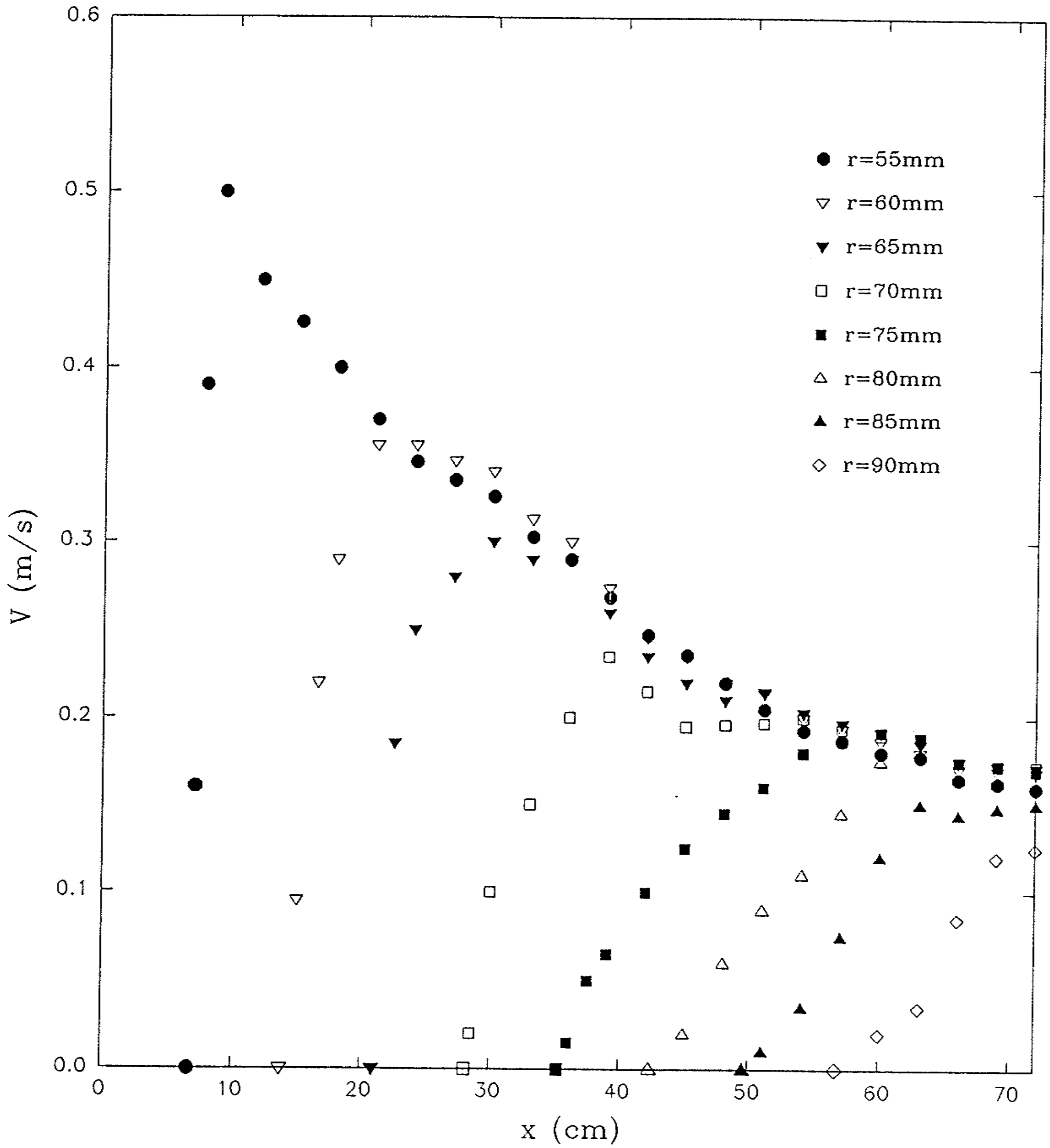


Figure 3.5(g). Mean radial velocity distribution in axial direction in the diffuser wall region.

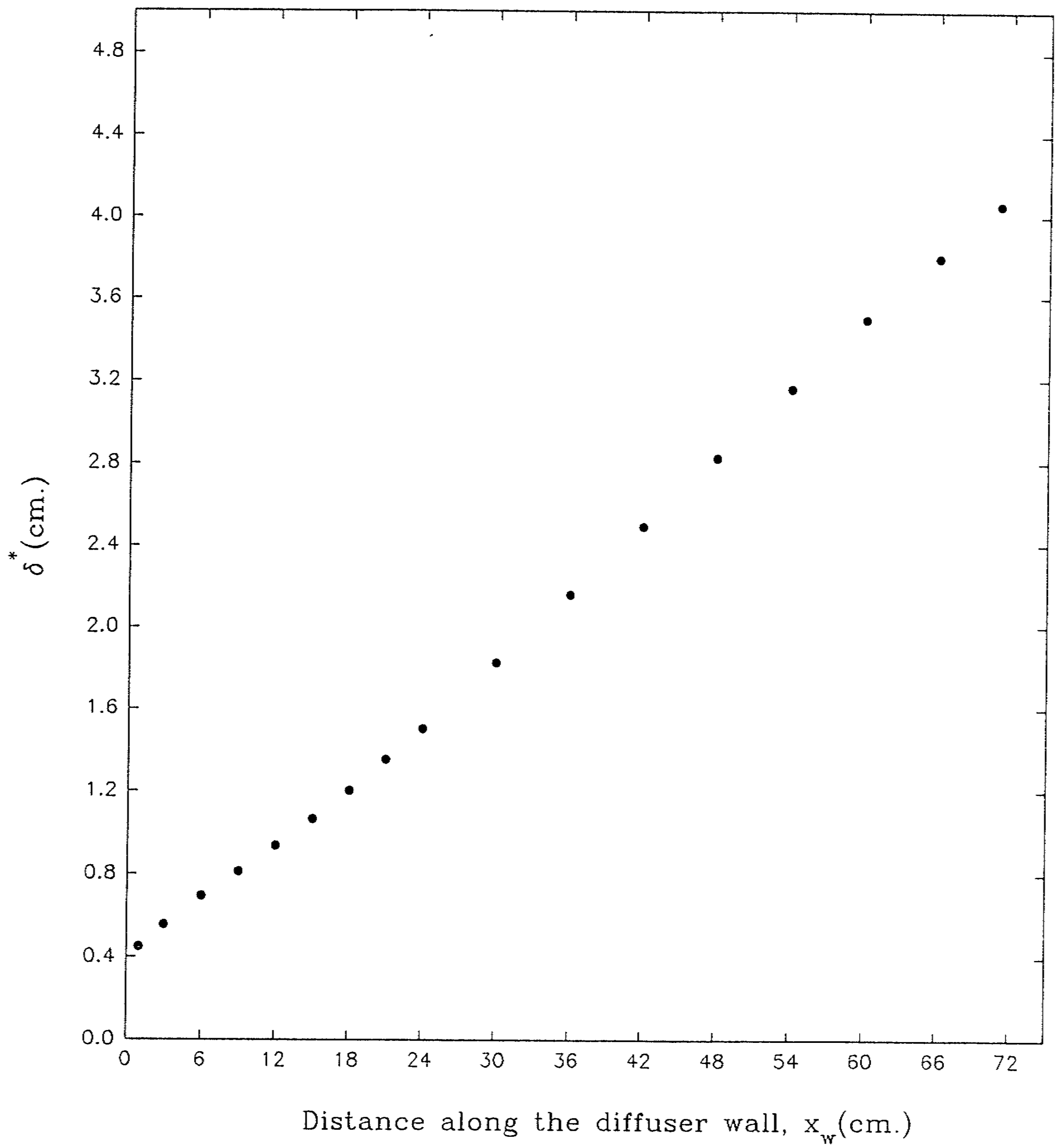


Figure 3.6 (a). Displacement thickness, δ^*, along the wall of the diffuser.

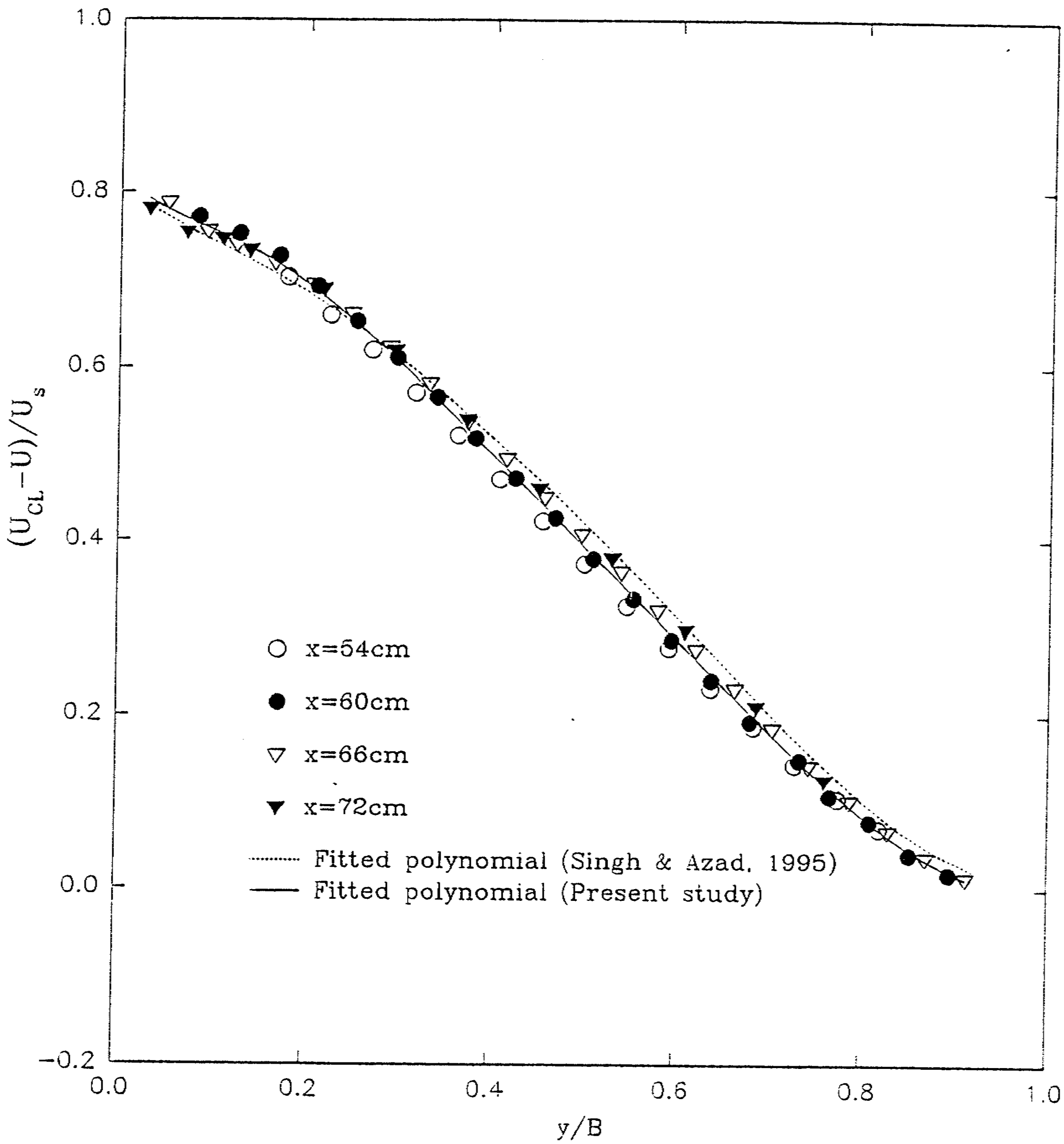


Figure 3.6 (b). Asymptotic velocity profiles in Perry−Schofield coordinates.

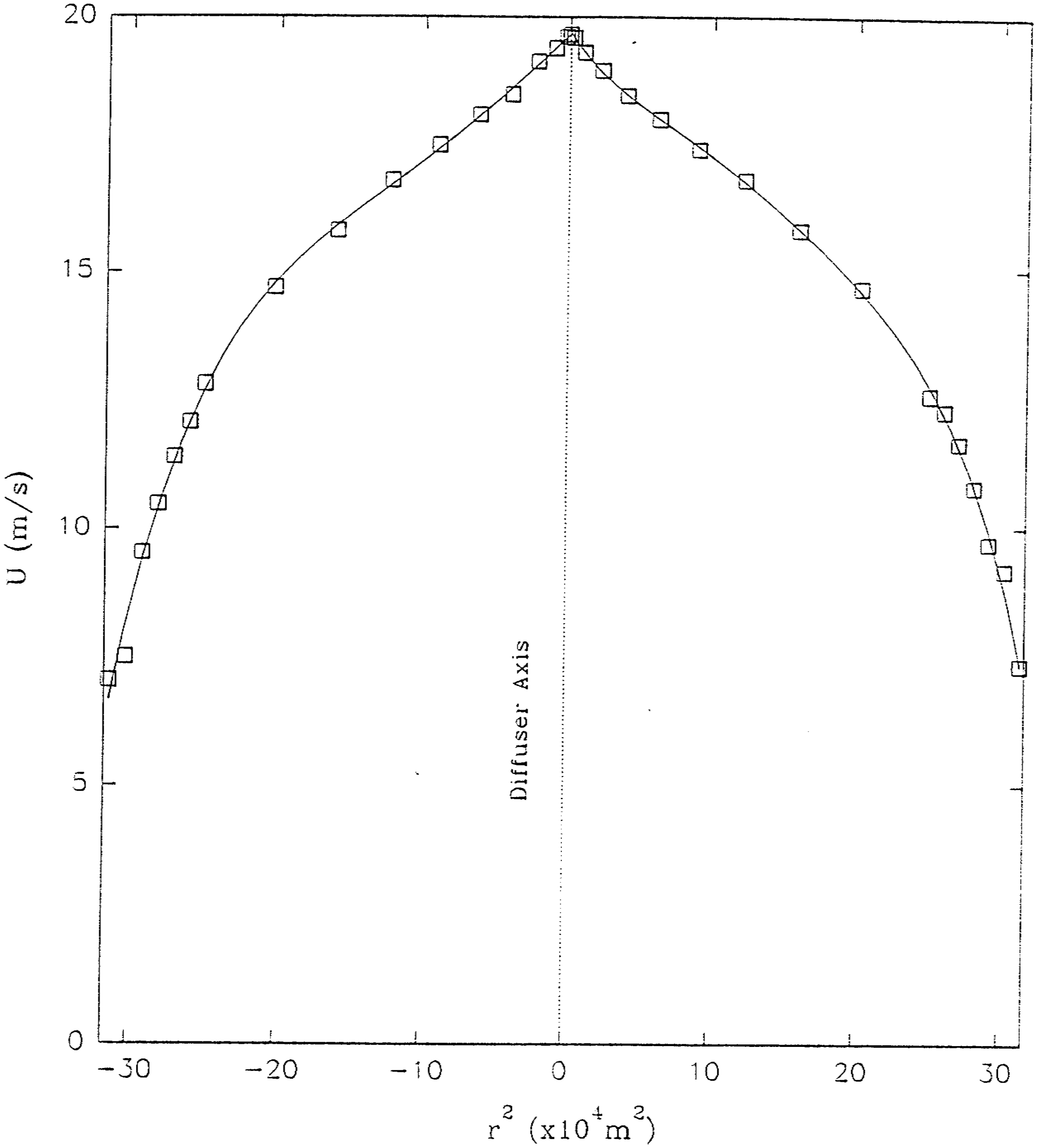


Figure 3.7 (a). Graph used to obtain Mass flow rate for all the stations. Three mass flow rates were obtained for one axial location by integrating profiles of U_W, U_L, and U_C across a radius. Given is graph for x=15cm.

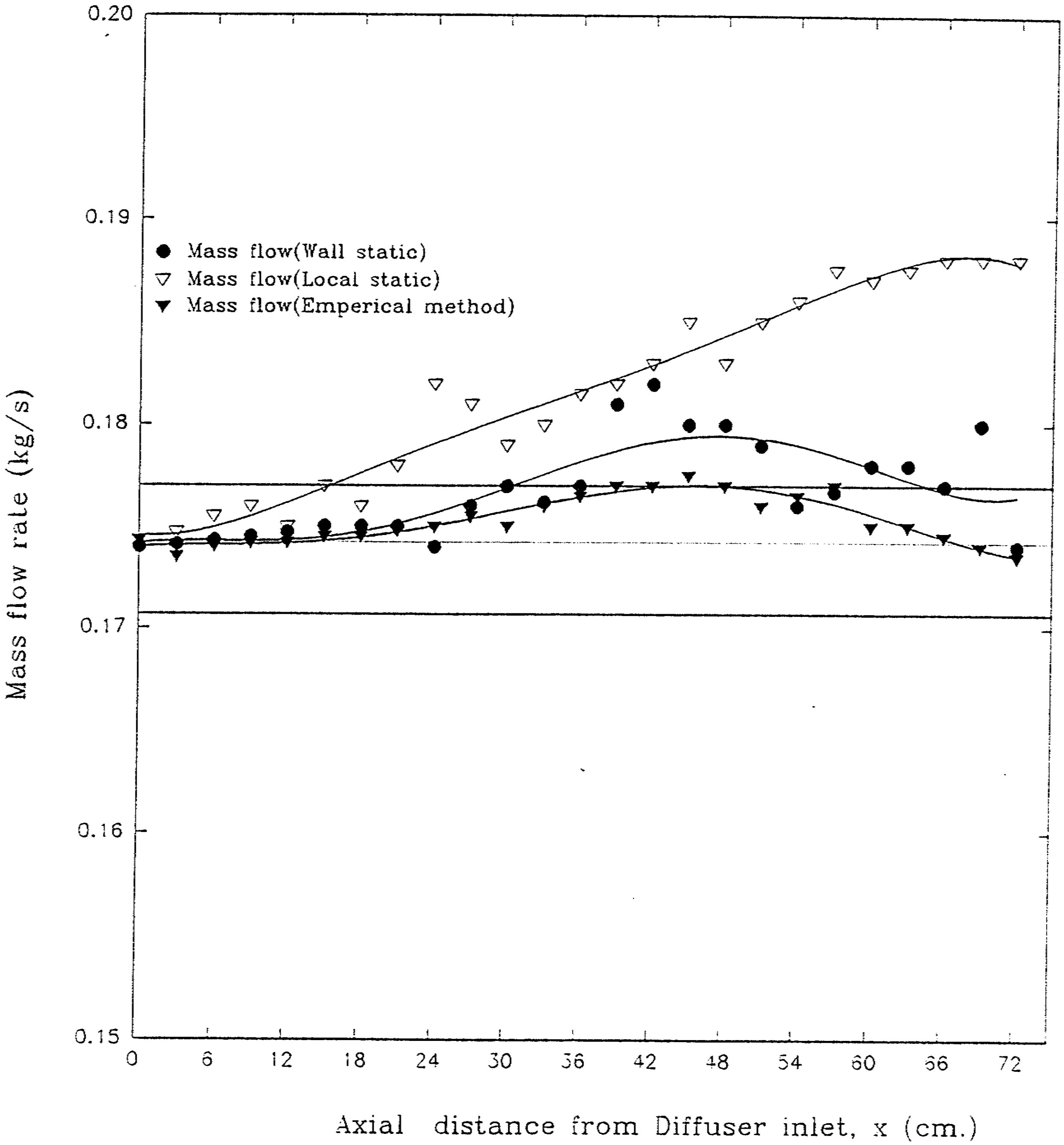


Figure 3.7(b). Mass flow rates in diffuser obtained from different methods. The dotted line shows the mass flow rate at diffuser inlet and the two solid lines give the 2% mass flow rate deviation.

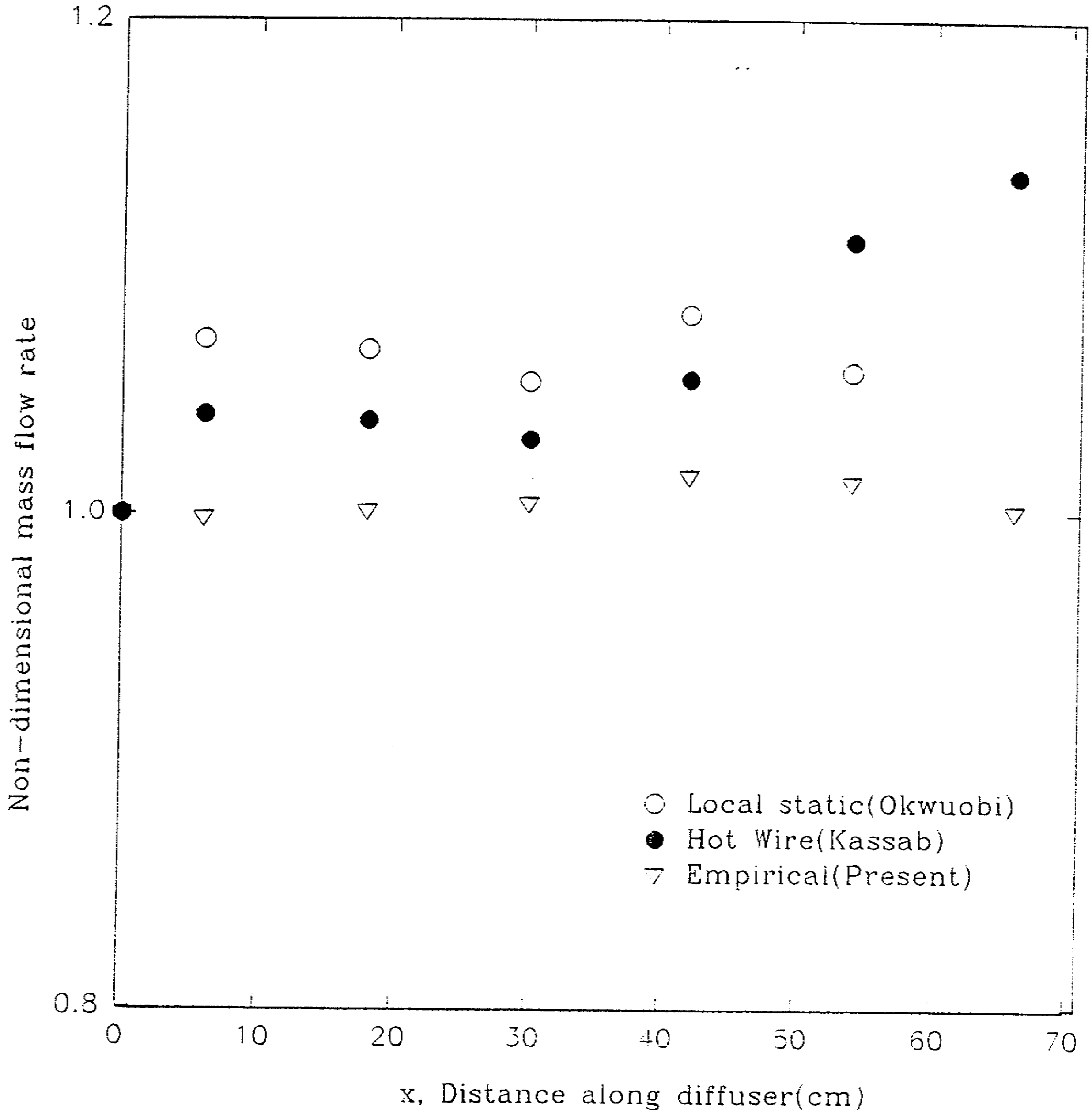


Figure 3.7(c)Variation of mass flow rates at different stations of the diffuser. The mass flow rate is non-dimensionlised with the mass flow rate at diffuser inlet. Open circles show results of Okwuobi(1972), Velocities based on Local static pressures. Solid circles show Kassab's results(1986) based on hot wire measurements. Inverted triangle give present results from the empirical method.

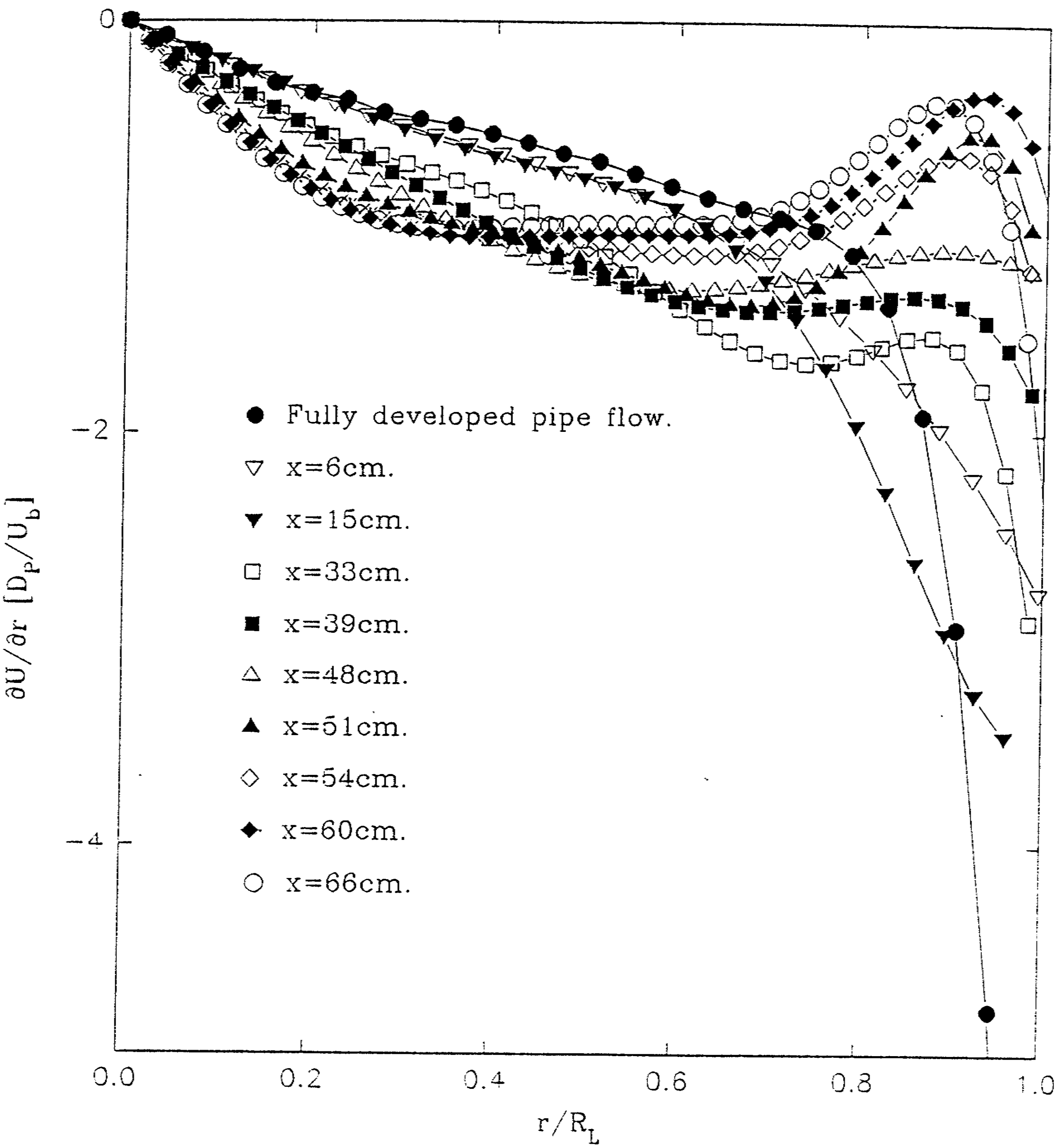


Figure 3.8(a). Basic rate of shear strain, $\partial U/\partial r$, in radial direction.

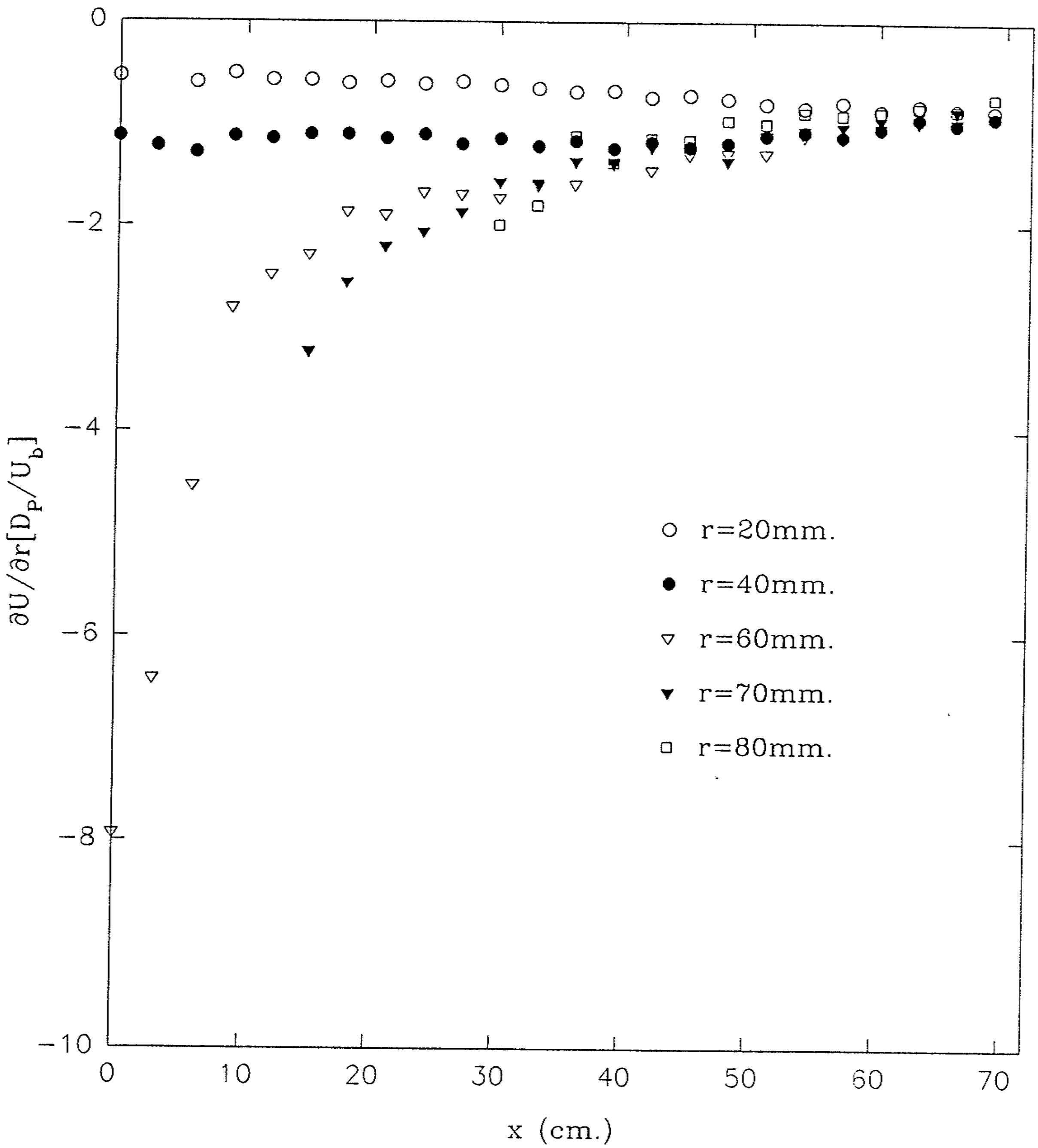


Figure 3.8(b). Basic rate of shear strain, $\partial U/\partial r$, in axial direction.

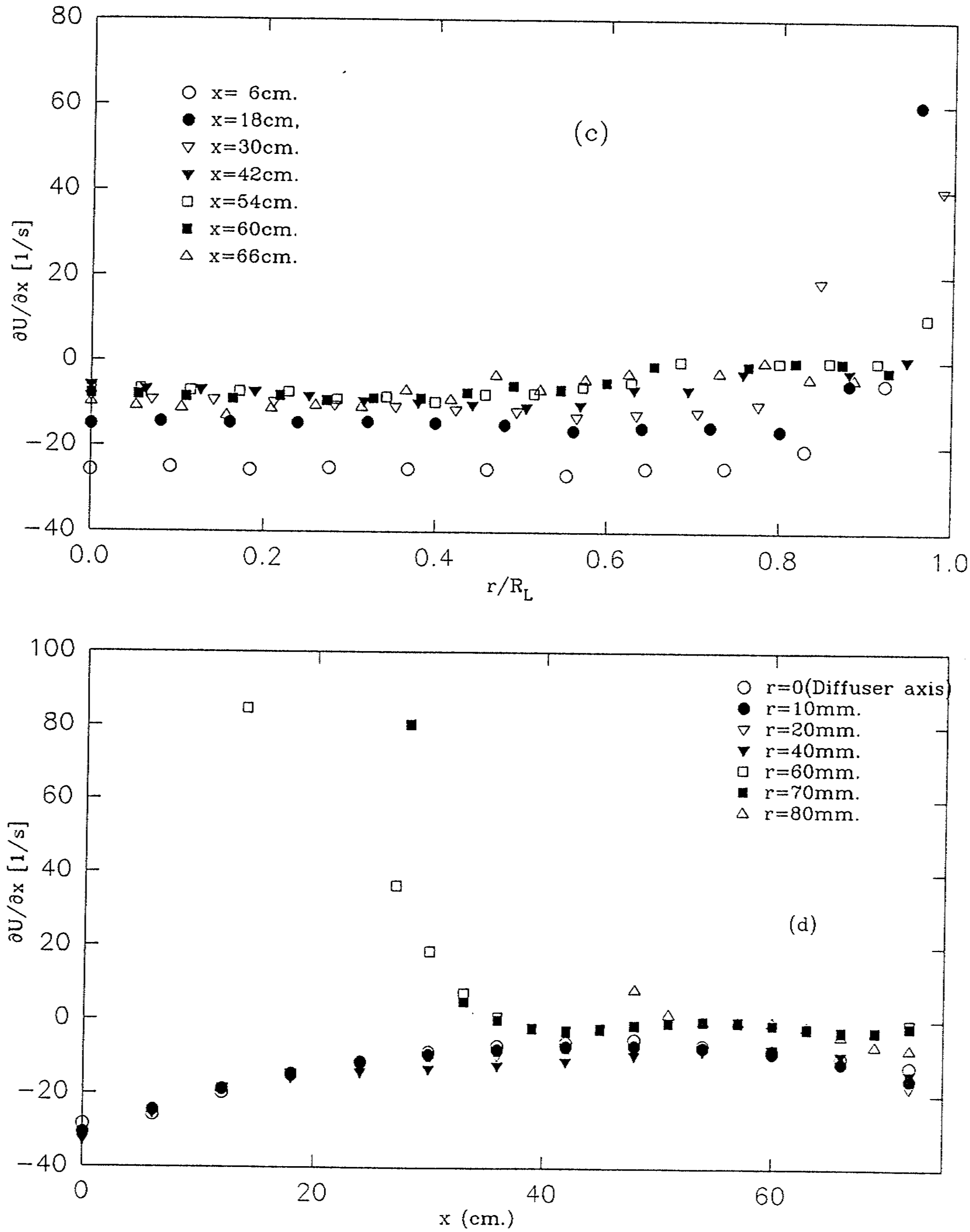
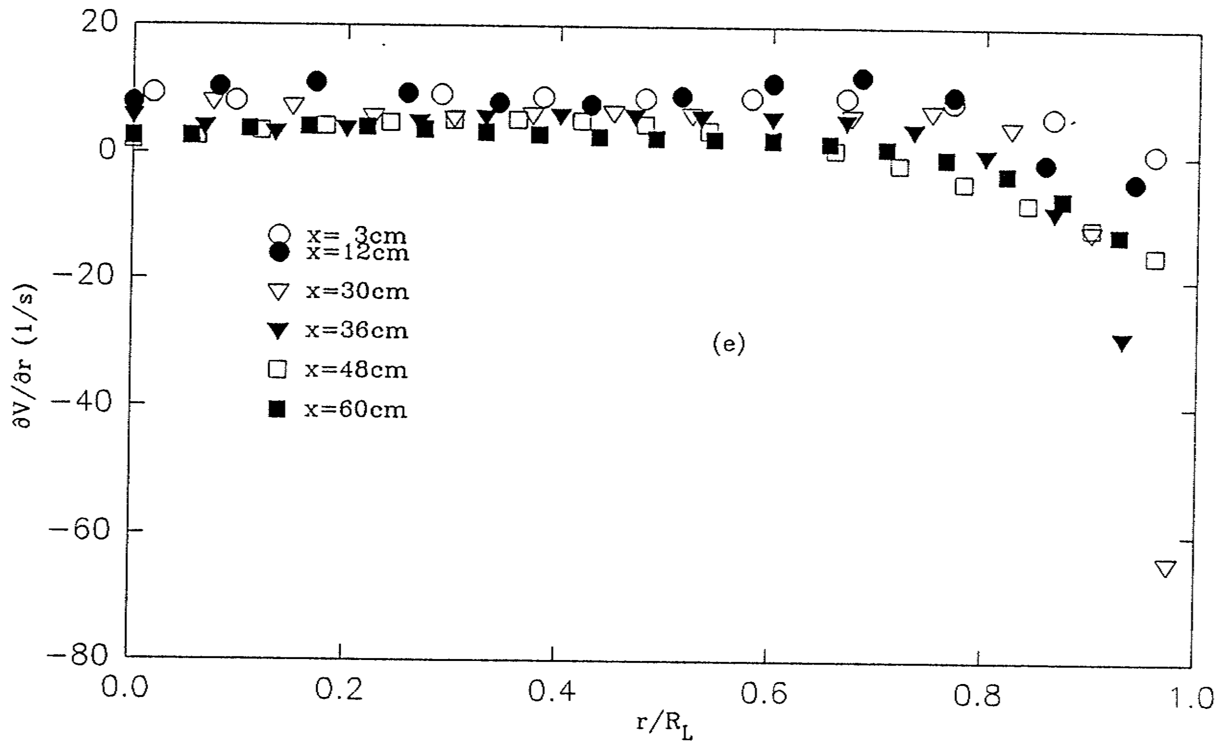


Figure 3.8. Variation of normal strain rate, $\partial U/\partial x$, in (c) Radial direction and (d) Axial direction.



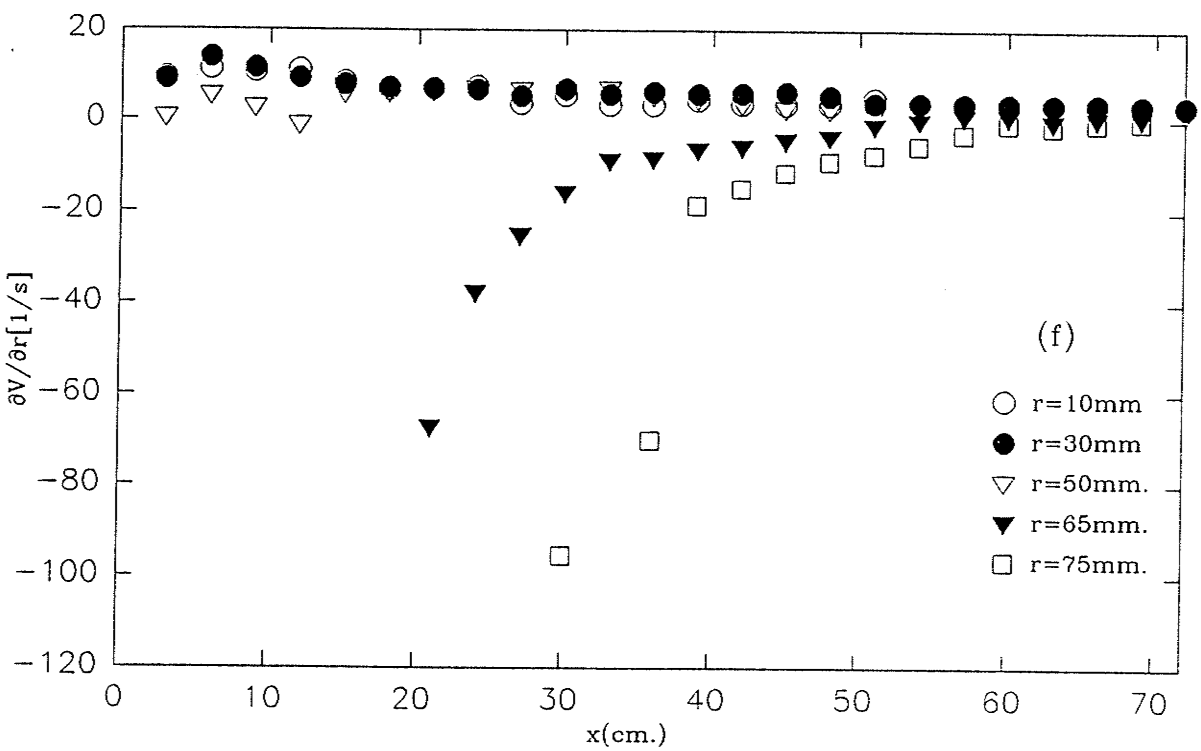


Figure 3.8 Variation of normal strain rate, $\partial V/\partial r$, in (e) Radial direction. and (f) Axial direction.

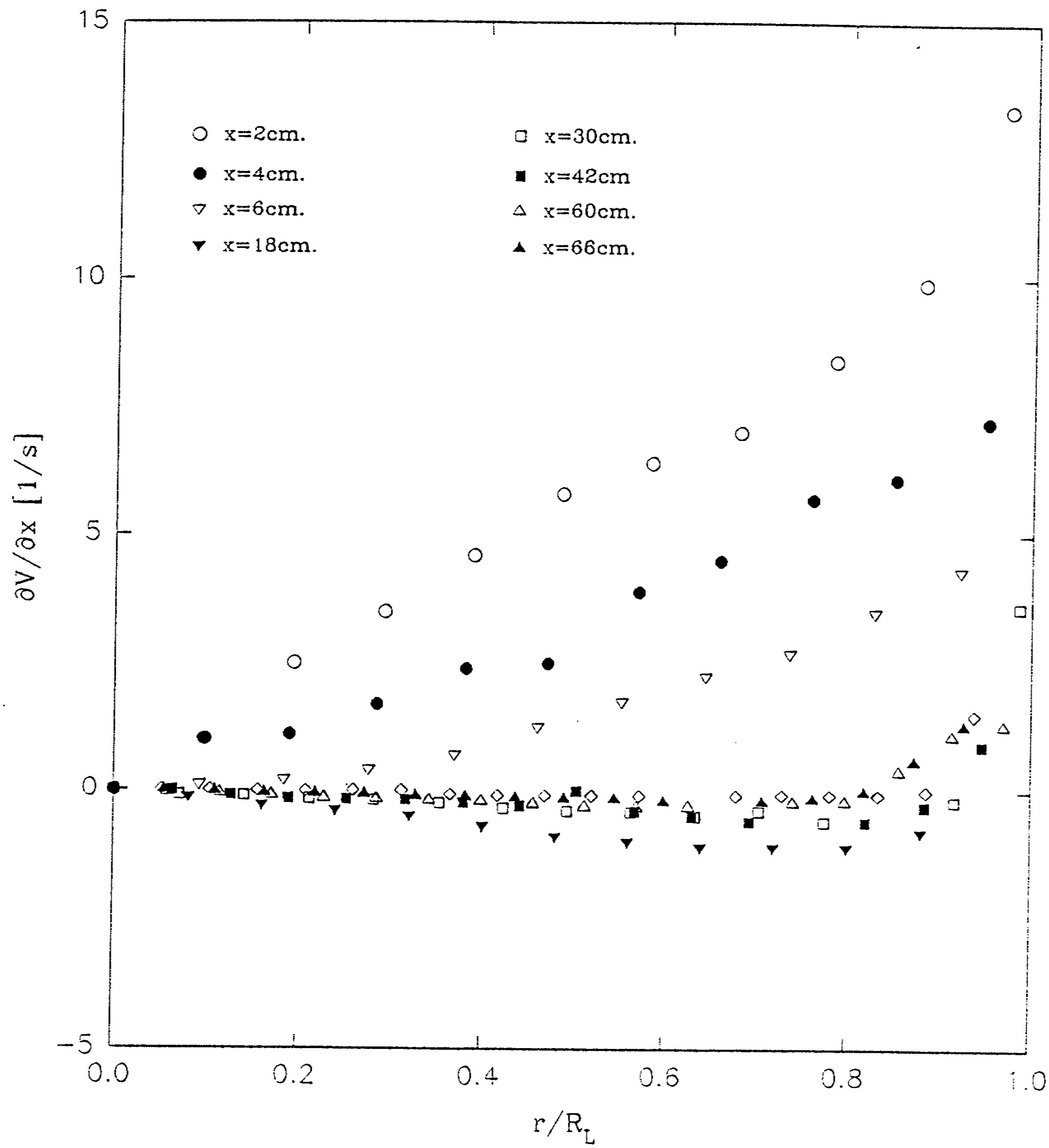


Figure 3.8(g). Radial distribution of strain rate, $\partial V/\partial x$

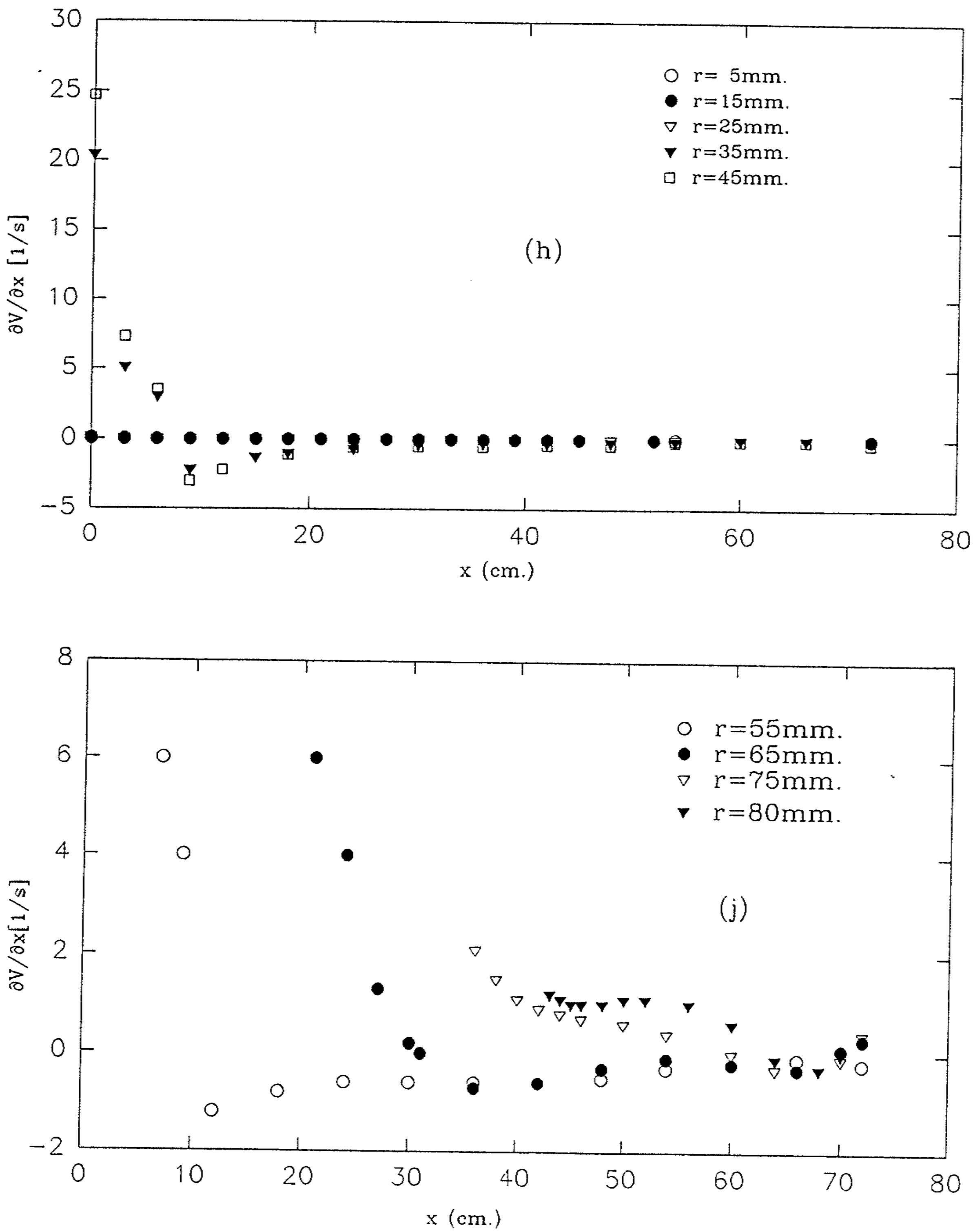


Figure 3.8 Variation of extra strain rate, ∂V/∂x, in axial direction.
(h) Diffuser core region.
(j) Diffuser wall region.

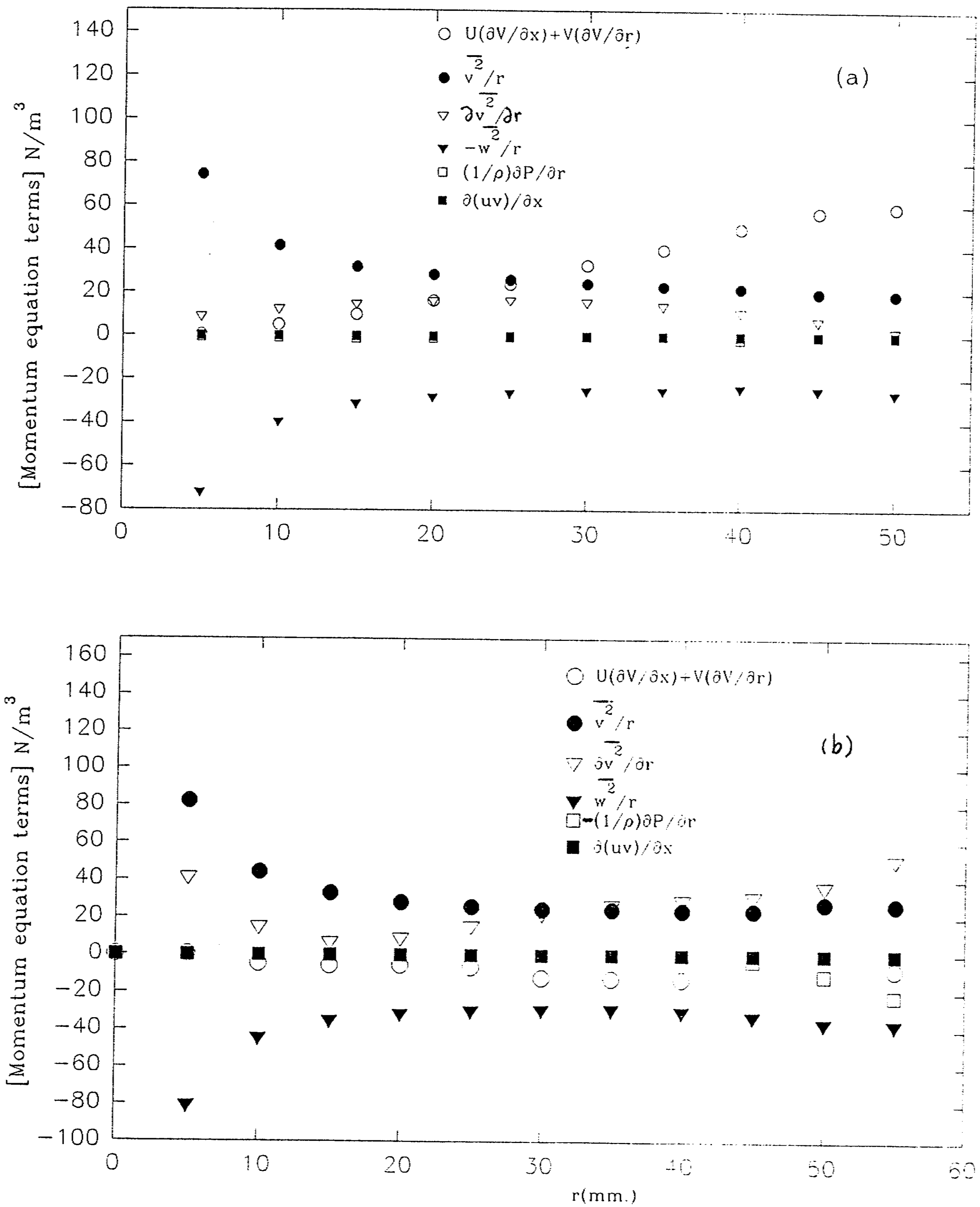


Figure 3.9. r−direction momentum balance at (a)x=6cm; (b)x=18cm.

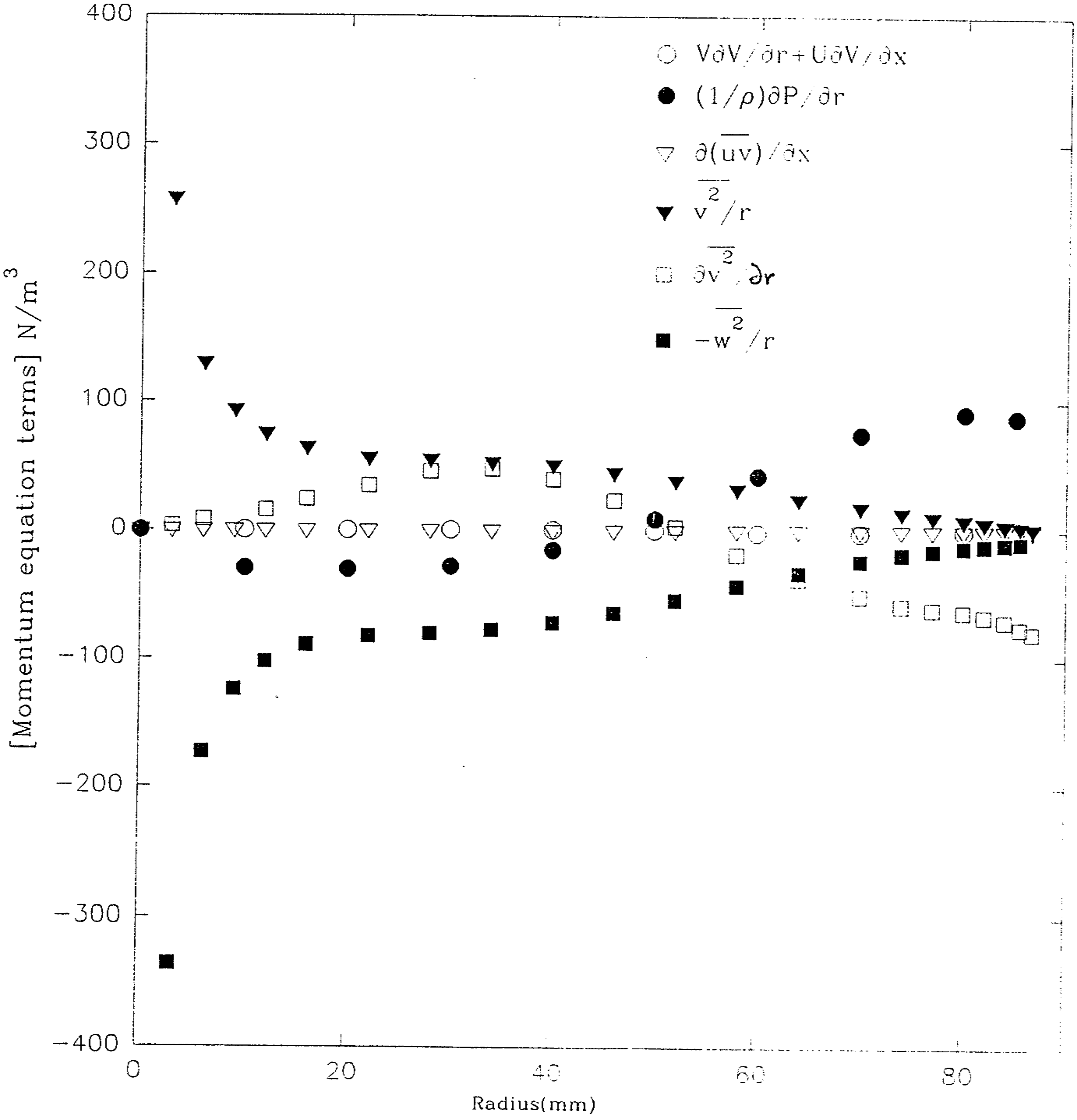


Figure 3.9 (c). r-direction momentum balances for station 9(x=54cm).).

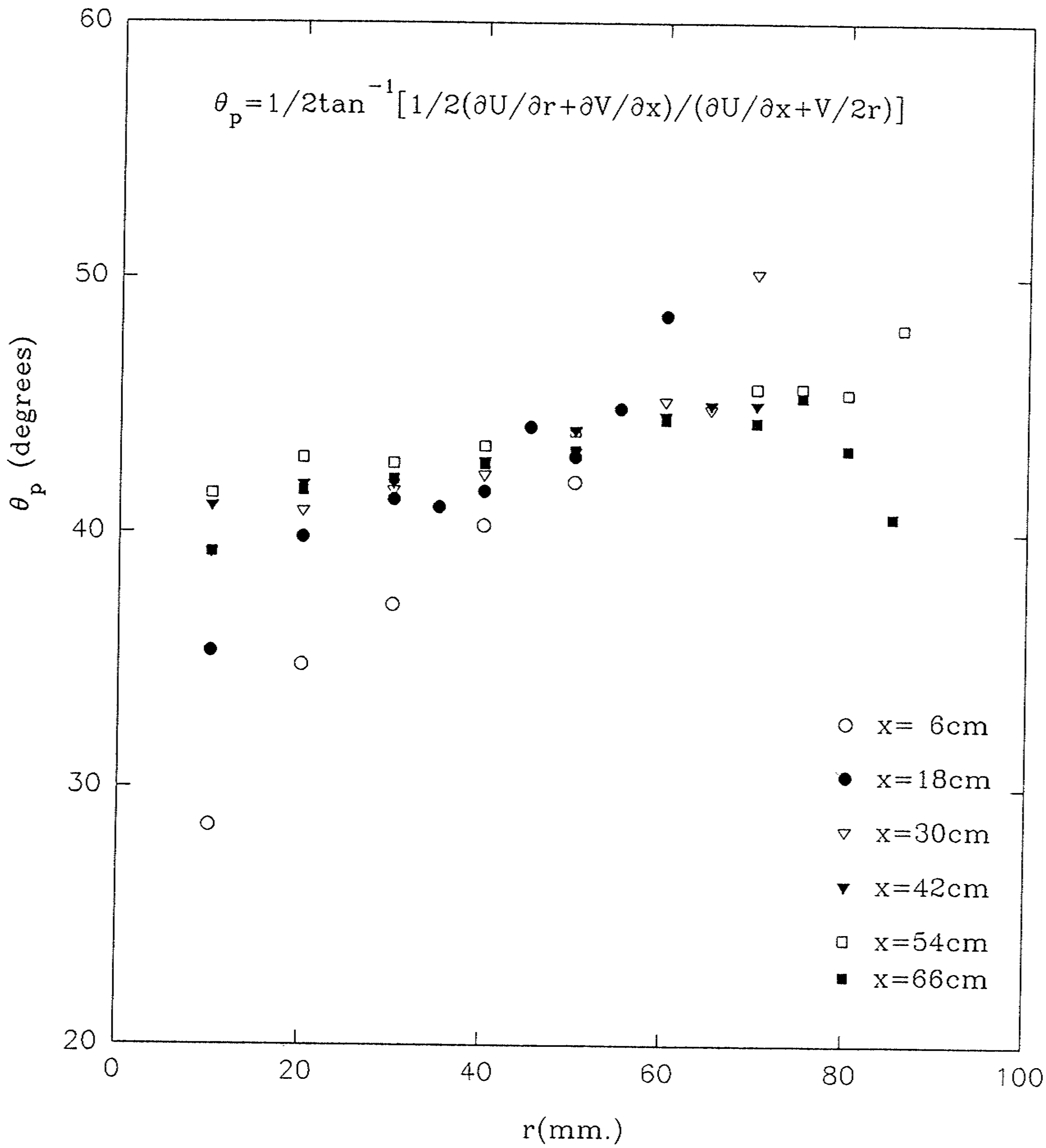


Figure 4.1 Direction of mean principal rate of strain, θ_p, in conical diffuser.

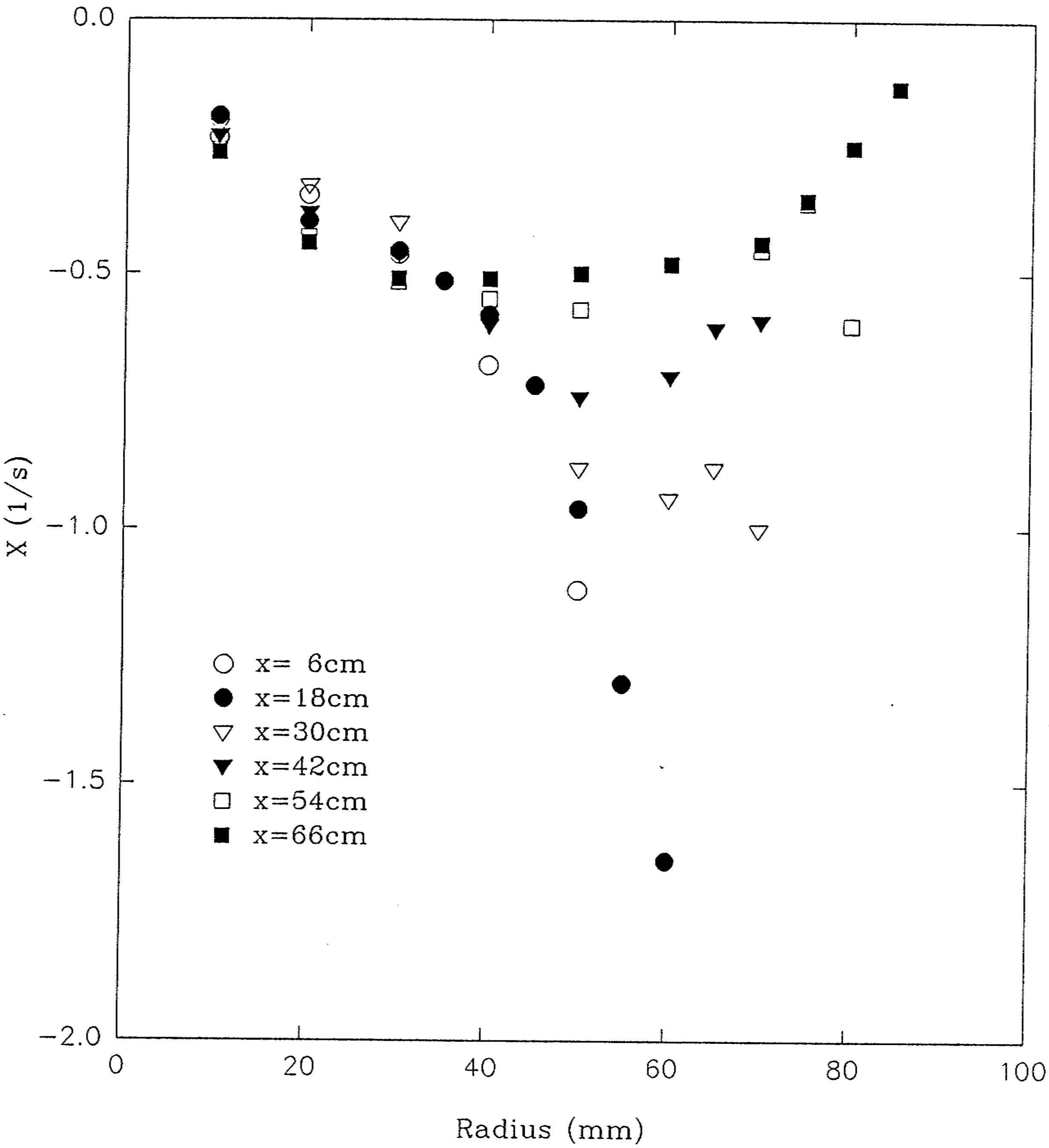


Figure 4.2 Principal mean strain rate,X, in conical diffuser for some selected stations. Where $X=\partial U/\partial x \mathrm{Cos}2\theta_p+1/2(\partial U/\partial r+\partial V/\partial x)-V/r\mathrm{Sin}^2 2\theta_p$

A.1.1 AXIAL POSITION x=0cm.(Diffuser Inlet)

Local Radius R_L=50.80mm.

Centreline Velocity=22.124m/s U_b=18.3m/s
Mass flow rate=0.1732kg/s Diameter of Pipe=0.1016m.

y(mm)	y/R_L	r(mm)	r/R_L	U(m/s)	U/U_c	$\left(\frac{\partial U}{\partial r}\right)\frac{D_p}{U_b}$
50.800	1.000	0.000	0.000	22.124	1.000	0.000
48.800	0.961	2.000	0.039	22.116	1.000	-0.067
46.800	0.921	4.000	0.079	22.076	0.998	-0.154
44.800	0.882	6.000	0.118	22.006	0.995	-0.234
42.800	0.843	8.000	0.157	21.909	0.990	-0.303
40.800	0.803	10.000	0.197	21.789	0.985	-0.360
38.800	0.764	12.000	0.236	21.651	0.979	-0.407
36.800	0.724	14.000	0.276	21.497	0.972	-0.444
34.800	0.685	16.000	0.315	21.332	0.964	-0.475
32.800	0.646	18.000	0.354	21.155	0.956	-0.504
30.800	0.606	20.000	0.394	20.968	0.948	-0.537
28.800	0.567	22.000	0.433	20.768	0.939	-0.575
26.800	0.528	24.000	0.472	20.553	0.929	-0.621
24.800	0.488	26.000	0.512	20.319	0.918	-0.676
22.800	0.449	28.000	0.551	20.065	0.907	-0.735
20.800	0.409	30.000	0.591	19.789	0.894	-0.796
18.800	0.370	32.000	0.630	19.492	0.881	-0.852
16.800	0.331	34.000	0.669	19.177	0.867	-0.901
14.800	0.291	36.000	0.709	18.844	0.852	-0.947
12.800	0.252	38.000	0.748	18.493	0.836	-1.008
10.800	0.213	40.000	0.787	18.111	0.819	-1.126
8.800	0.173	42.000	0.827	17.665	0.798	-1.382
6.800	0.134	44.000	0.866	17.083	0.772	-1.913
4.800	0.094	46.000	0.906	16.228	0.734	-2.938
2.800	0.055	48.000	0.945	14.868	0.672	-4.785
0.800	0.016	50.000	0.984	12.625	0.571	-7.933
0.000	0.000	50.80	1.000	0.000	0.000	-211.0

A.1.2 AXIAL POSITION x=3.0cm.

Local Radius R_L=52.115mm.

Centreline Velocity U_{cL}=21.45m/s U_b=18.3m/s
Mass flow rate=0.170kg/s Diameter of Pipe=0.1016m.

y(mm)	y/R_L	r(mm)	r/R_L	U(m/s)	U/Uc	$\left(\frac{\partial U}{\partial r}\right)\frac{D_P}{U_b}$
52.115	1.000	0.000	0.000	21.446	1.000	0.000
50.115	0.962	2.000	0.038	21.408	0.998	-0.156
48.115	0.923	4.000	0.077	21.335	0.995	-0.245
46.115	0.885	6.000	0.115	21.233	0.990	-0.318
44.115	0.846	8.000	0.154	21.108	0.984	-0.374
42.115	0.808	10.000	0.192	20.966	0.978	-0.411
40.115	0.770	12.000	0.230	20.814	0.971	-0.431
38.115	0.731	14.000	0.269	20.657	0.963	-0.440
36.115	0.693	16.000	0.307	20.498	0.956	-0.443
34.115	0.655	18.000	0.345	20.337	0.948	-0.450
32.115	0.616	20.000	0.384	20.172	0.941	-0.470
30.115	0.578	22.000	0.422	19.996	0.932	-0.509
28.115	0.539	24.000	0.461	19.802	0.923	-0.573
26.115	0.501	26.000	0.499	19.580	0.913	-0.662
24.115	0.463	28.000	0.537	19.322	0.901	-0.772
22.115	0.424	30.000	0.576	19.023	0.887	-0.892
20.115	0.386	32.000	0.614	18.680	0.871	-1.008
18.115	0.348	34.000	0.652	18.299	0.853	-1.104
16.115	0.309	36.000	0.691	17.888	0.834	-1.168
14.115	0.271	38.000	0.729	17.462	0.814	-1.198
12.115	0.232	40.000	0.768	17.027	0.794	-1.218
10.115	0.194	42.000	0.806	16.578	0.773	-1.293
8.115	0.156	44.000	0.844	16.074	0.749	-1.552
6.115	0.117	46.000	0.883	15.411	0.719	-2.220
4.115	0.079	48.000	0.921	14.382	0.671	-3.659
2.115	0.041	50.000	0.959	12.618	0.588	-6.413
0.115	0.002	52.000	0.998	9.511	0.443	-11.273
0.000	0.000	52.115	1.000	0.00	0.000	-166.90

A.1.3 AXIAL POSITION x=6.0cm.

Local Radius R_L=54.23mm.

Centreline Velocity U_{cl}=20.46m/s U_b=18.3m/s

Mass flow rate=0.1745kg/s Diameter of Pipe=0.1016m.

y(mm)	y/R_L	r(mm)	r/R_L	U(m/s)	U/U_{cl}	$\left(\frac{\partial U}{\partial r}\right)\frac{D_P}{U_b}$
54.230	1.000	0.000	0.000	20.460	1.000	0.000
52.230	0.963	2.000	0.037	20.449	0.999	-0.068
50.230	0.926	4.000	0.074	20.411	0.998	-0.140
48.230	0.889	6.000	0.111	20.348	0.995	-0.210
46.230	0.852	8.000	0.148	20.260	0.990	-0.277
44.230	0.816	10.000	0.184	20.149	0.985	-0.340
42.230	0.779	12.000	0.221	20.015	0.978	-0.400
40.230	0.742	14.000	0.258	19.861	0.971	-0.454
38.230	0.705	16.000	0.295	19.688	0.962	-0.505
36.230	0.668	18.000	0.332	19.498	0.953	-0.552
34.230	0.631	20.000	0.369	19.291	0.943	-0.597
32.230	0.594	22.000	0.406	19.068	0.932	-0.640
30.230	0.557	24.000	0.443	18.829	0.920	-0.684
28.230	0.521	26.000	0.479	18.575	0.908	-0.729
26.230	0.484	28.000	0.516	18.303	0.895	-0.779
24.230	0.447	30.000	0.553	18.013	0.880	-0.835
22.230	0.410	32.000	0.590	17.701	0.865	-0.899
20.230	0.373	34.000	0.627	17.364	0.849	-0.974
18.230	0.336	36.000	0.664	16.997	0.831	-1.063
16.230	0.299	38.000	0.701	16.597	0.811	-1.166
14.230	0.262	40.000	0.738	16.155	0.790	-1.286
12.230	0.226	42.000	0.774	15.668	0.766	-1.425
10.230	0.189	44.000	0.811	15.126	0.739	-1.585
8.230	0.152	46.000	0.848	14.523	0.710	-1.767
6.230	0.115	48.000	0.885	13.850	0.677	-1.972
4.230	0.078	50.000	0.922	13.099	0.640	-2.204
2.230	0.041	52.000	0.959	12.259	0.599	-2.465
0.230	0.004	54.000	0.996	11.319	0.553	-2.760
0.000	0.000	54.230	1.000	0.000	0.000	-132.42

A.1.4 AXIAL POSITION x=9.0cm.

Local Radius R_L=56.29mm.

Centreline Velocity U_{cL}=19.68m/s U_b=18.3m/s

Mass flow rate=0.175kg/s Diameter of Pipe=0.1016m.

y(mm)	y/R_L	y(mm)	r/R_L	U(m/s)	U/U_c	$\left(\frac{\partial U}{\partial r}\right)\frac{D_P}{U_b}$
56.290	1.000	0.000	0.000	19.683	1.000	0.000
54.290	0.964	2.000	0.036	19.656	0.999	-0.113
52.290	0.929	4.000	0.071	19.602	0.996	-0.183
50.290	0.893	6.000	0.107	19.525	0.992	-0.247
48.290	0.858	8.000	0.142	19.425	0.987	-0.302
46.290	0.822	10.000	0.178	19.308	0.981	-0.350
44.290	0.787	12.000	0.213	19.174	0.974	-0.389
42.290	0.751	14.000	0.249	19.028	0.967	-0.423
40.290	0.716	16.000	0.284	18.870	0.959	-0.452
38.290	0.680	18.000	0.320	18.702	0.950	-0.481
36.290	0.645	20.000	0.355	18.524	0.941	-0.511
34.290	0.609	22.000	0.391	18.334	0.931	-0.546
32.290	0.574	24.000	0.426	18.129	0.921	-0.589
30.290	0.538	26.000	0.462	17.909	0.910	-0.640
28.290	0.503	28.000	0.497	17.668	0.898	-0.699
26.290	0.467	30.000	0.533	17.404	0.884	-0.766
24.290	0.432	32.000	0.568	17.115	0.870	-0.838
22.290	0.396	34.000	0.604	16.800	0.854	-0.911
20.290	0.360	36.000	0.640	16.459	0.836	-0.982
18.290	0.325	38.000	0.675	16.093	0.818	-1.051
16.290	0.289	40.000	0.711	15.701	0.798	-1.123
14.290	0.254	42.000	0.746	15.282	0.776	-1.211
12.290	0.218	44.000	0.782	14.824	0.753	-1.343
10.290	0.183	46.000	0.817	14.303	0.727	-1.569
8.290	0.147	48.000	0.853	13.672	0.695	-1.971
6.290	0.112	50.000	0.888	12.847	0.653	-2.673
4.290	0.076	52.000	0.924	11.689	0.594	-3.855
2.290	0.041	54.000	0.959	9.982	0.507	-5.774
0.290	0.005	56.000	0.995	7.399	0.376	-8.783
0.000	0.000	56.290	1.000	0.000	0.000	-105.7

A.1.5

AXIAL POSITION x=12.0cm.

Local Radius R_L=58.40mm.

Centreline Velocity U_{cL}=18.90m/s

U_b=18.3m/s

Mass flow rate=0.175kg/s

Diameter of Pipe=0.1016m.

y(mm)	y/R_L	r(mm)	r/R_L	U(m/s)	U/U_c	$\left(\frac{\partial U}{\partial r}\right)\frac{D_P}{U_b}$
58.400	1.000	0.000	0.000	18.908	1.000	0.000
56.400	0.966	2.000	0.034	18.879	0.998	-0.112
54.400	0.932	4.000	0.068	18.827	0.996	-0.173
52.400	0.897	6.000	0.103	18.754	0.992	-0.231
50.400	0.863	8.000	0.137	18.661	0.987	-0.286
48.400	0.829	10.000	0.171	18.549	0.981	-0.338
46.400	0.795	12.000	0.205	18.418	0.974	-0.387
44.400	0.760	14.000	0.240	18.270	0.966	-0.435
42.400	0.726	16.000	0.274	18.105	0.958	-0.480
40.400	0.692	18.000	0.308	17.924	0.948	-0.525
38.400	0.658	20.000	0.342	17.727	0.938	-0.570
36.400	0.623	22.000	0.377	17.513	0.926	-0.614
34.400	0.589	24.000	0.411	17.284	0.914	-0.658
32.400	0.555	26.000	0.445	17.039	0.901	-0.704
30.400	0.521	28.000	0.479	16.777	0.887	-0.751
28.400	0.486	30.000	0.514	16.498	0.873	-0.800
26.400	0.452	32.000	0.548	16.200	0.857	-0.853
24.400	0.418	34.000	0.582	15.883	0.840	-0.910
22.400	0.384	36.000	0.616	15.543	0.822	-0.976
20.400	0.349	38.000	0.651	15.178	0.803	-1.053
18.400	0.315	40.000	0.685	14.783	0.782	-1.147
16.400	0.281	42.000	0.719	14.349	0.759	-1.266
14.400	0.247	44.000	0.753	13.866	0.733	-1.422
12.400	0.212	46.000	0.788	13.319	0.704	-1.627
10.400	0.178	48.000	0.822	12.685	0.671	-1.903
8.400	0.144	50.000	0.856	11.936	0.631	-2.275
6.400	0.110	52.000	0.890	11.031	0.583	-2.774
4.400	0.075	54.000	0.925	9.917	0.525	-3.442
2.400	0.041	56.000	0.959	8.524	0.451	-4.332
0.400	0.007	58.000	0.993	6.762	0.358	-5.507
0.000	0.000	58.400	1.000	0.000	0.000	-85.45

A.1.6 AXIAL POSITION x=15.0cm.

Local Radius R_L=60.49mm.

Centreline Velocity U_{cL}=18.61m/s U_b=18.3m/s
Mass flow rate=0.175kg/s Diameter of Pipe=0.1016m.

y(mm)	y/R_L	r(mm)	r/R_L	U(m/s)	U/U_c	$\left(\frac{\partial U}{\partial r}\right)\frac{D_P}{U_b}$
60.490	1.000	0.000	0.000	18.609	1.000	0.000
58.490	0.967	2.000	0.033	18.590	0.999	-0.079
56.490	0.934	4.000	0.066	18.552	0.997	-0.130
54.490	0.901	6.000	0.099	18.496	0.994	-0.184
52.490	0.868	8.000	0.132	18.419	0.990	-0.240
50.490	0.835	10.000	0.165	18.323	0.985	-0.298
48.490	0.802	12.000	0.198	18.205	0.978	-0.356
46.490	0.769	14.000	0.231	18.066	0.971	-0.414
44.490	0.735	16.000	0.265	17.907	0.962	-0.470
42.490	0.702	18.000	0.298	17.728	0.953	-0.524
40.490	0.669	20.000	0.331	17.530	0.942	-0.573
38.490	0.636	22.000	0.364	17.316	0.930	-0.617
36.490	0.603	24.000	0.397	17.086	0.918	-0.657
34.490	0.570	26.000	0.430	16.843	0.905	-0.692
32.490	0.537	28.000	0.463	16.588	0.891	-0.725
30.490	0.504	30.000	0.496	16.320	0.877	-0.759
28.490	0.471	32.000	0.529	16.040	0.862	-0.797
26.490	0.438	34.000	0.562	15.745	0.846	-0.844
24.490	0.405	36.000	0.595	15.431	0.829	-0.906
22.490	0.372	38.000	0.628	15.090	0.811	-0.990
20.490	0.339	40.000	0.661	14.714	0.791	-1.103
18.490	0.306	42.000	0.694	14.291	0.768	-1.252
16.490	0.273	44.000	0.727	13.807	0.742	-1.443
14.490	0.240	46.000	0.760	13.246	0.712	-1.678
12.490	0.206	48.000	0.794	12.593	0.677	-1.958
10.490	0.173	50.000	0.827	11.831	0.636	-2.276
8.490	0.140	52.000	0.860	10.950	0.588	-2.619
6.490	0.107	54.000	0.893	9.944	0.534	-2.960
4.490	0.074	56.000	0.926	8.822	0.474	-3.262
2.490	0.041	58.000	0.959	7.606	0.409	-3.466
0.490	0.008	60.000	0.992	6.346	0.341	-3.491
0.000	0.000	60.480	1.000	0.000	0.000	-67.34

A.1.7 AXIAL POSITION x=18.0cm.

Local Radius R_L=62.56mm.

Centreline Velocity U_{cL}=18.016m/s U_b=18.3m/s

Mass flow rate=0.176kg/s Diameter of Pipe=0.1016m.

y(mm)	y/R_L	r(mm)	r/R_L	U(m/s)	U/U_c	$\left(\frac{\partial U}{\partial r}\right)\frac{D_P}{U_b}$
62.560	1.000	0.000	0.000	18.017	1.000	0.000
60.560	0.968	2.000	0.032	17.998	0.999	-0.080
58.560	0.936	4.000	0.064	17.959	0.997	-0.138
56.560	0.904	6.000	0.096	17.899	0.993	-0.195
54.560	0.872	8.000	0.128	17.818	0.989	-0.253
52.560	0.840	10.000	0.160	17.717	0.983	-0.312
50.560	0.808	12.000	0.192	17.594	0.977	-0.371
48.560	0.776	14.000	0.224	17.449	0.969	-0.430
46.560	0.744	16.000	0.256	17.284	0.959	-0.489
44.560	0.712	18.000	0.288	17.097	0.949	-0.548
42.560	0.680	20.000	0.320	16.889	0.937	-0.605
40.560	0.648	22.000	0.352	16.661	0.925	-0.660
38.560	0.616	24.000	0.384	16.414	0.911	-0.712
36.560	0.584	26.000	0.416	16.149	0.896	-0.761
34.560	0.552	28.000	0.448	15.866	0.881	-0.806
32.560	0.520	30.000	0.480	15.568	0.864	-0.849
30.560	0.488	32.000	0.512	15.255	0.847	-0.890
28.560	0.457	34.000	0.543	14.927	0.828	-0.933
26.560	0.425	36.000	0.575	14.582	0.809	-0.980
24.560	0.393	38.000	0.607	14.220	0.789	-1.035
22.560	0.361	40.000	0.639	13.835	0.768	-1.104
20.560	0.329	42.000	0.671	13.422	0.745	-1.193
18.560	0.297	44.000	0.703	12.972	0.720	-1.309
16.560	0.265	46.000	0.735	12.475	0.692	-1.456
14.560	0.233	48.000	0.767	11.919	0.662	-1.639
12.560	0.201	50.000	0.799	11.289	0.627	-1.862
10.560	0.169	52.000	0.831	10.573	0.587	-2.122
8.560	0.137	54.000	0.863	9.757	0.542	-2.411
6.560	0.105	56.000	0.895	8.835	0.490	-2.712
4.560	0.073	58.000	0.927	7.805	0.433	-2.999
2.560	0.041	60.000	0.959	6.681	0.371	-3.225
0.560	0.009	62.000	0.991	5.496	0.305	-3.327
0.000	0.000	62.560	1.000	0.000	0.000	-55.53

A.1.8 AXIAL POSITION x=21.0cm.

Local Radius R_L=64.64mm.

Centreline Velocity U_{cl}=17.65m/s U_b=18.3m/s
Mass flow rate=0.175kg/s Diameter of Pipe=0.1016m.

y(mm)	y/R_L	r(mm)	r/R_L	U(m/s)	U/U_c	$\left(\frac{\partial U}{\partial r}\right)\frac{D_P}{U_b}$
64.640	1.000	0.000	0.000	17.655	1.000	0.000
62.640	0.969	2.000	0.031	17.632	0.999	-0.099
60.640	0.938	4.000	0.062	17.584	0.996	-0.165
58.640	0.907	6.000	0.093	17.513	0.992	-0.228
56.640	0.876	8.000	0.124	17.420	0.987	-0.289
54.640	0.845	10.000	0.155	17.306	0.980	-0.346
52.640	0.814	12.000	0.186	17.171	0.973	-0.400
50.640	0.783	14.000	0.217	17.018	0.964	-0.450
48.640	0.752	16.000	0.248	16.847	0.954	-0.498
46.640	0.722	18.000	0.278	16.660	0.944	-0.542
44.640	0.691	20.000	0.309	16.457	0.932	-0.585
42.640	0.660	22.000	0.340	16.239	0.920	-0.625
40.640	0.629	24.000	0.371	16.007	0.907	-0.665
38.640	0.598	26.000	0.402	15.760	0.893	-0.704
36.640	0.567	28.000	0.433	15.499	0.878	-0.746
34.640	0.536	30.000	0.464	15.222	0.862	-0.791
32.640	0.505	32.000	0.495	14.928	0.846	-0.842
30.640	0.474	34.000	0.526	14.615	0.828	-0.900
28.640	0.443	36.000	0.557	14.279	0.809	-0.968
26.640	0.412	38.000	0.588	13.916	0.788	-1.049
24.640	0.381	40.000	0.619	13.522	0.766	-1.145
22.640	0.350	42.000	0.650	13.089	0.741	-1.258
20.640	0.319	44.000	0.681	12.613	0.714	-1.390
18.640	0.288	46.000	0.712	12.085	0.685	-1.541
16.640	0.257	48.000	0.743	11.501	0.651	-1.709
14.640	0.226	50.000	0.774	10.853	0.615	-1.890
12.640	0.196	52.000	0.804	10.138	0.574	-2.077
10.640	0.165	54.000	0.835	9.357	0.530	-2.258
8.640	0.134	56.000	0.866	8.514	0.482	-2.416
6.640	0.103	58.000	0.897	7.623	0.432	-2.523
4.640	0.072	60.000	0.928	6.706	0.380	-2.547
2.640	0.041	62.000	0.959	5.804	0.329	-2.438
0.640	0.009	64.000	0.991	4.973	0.200	-2.135
0.000	0.000	64.64	1.000	0.000	0.000	-44.85

A.1.9 AXIAL POSITION x=24.0cm.

Local Radius R_L=66.72mm.

Centreline Velocity U_{cL}=17.32m/s U_b=18.3m/s

Mass flow rate=0.177kg/s Diameter of Pipe=0.1016m.

y(mm)	y/R_L	r(mm)	r/R_L	U(m/s)	U/U_c	$\left(\frac{\partial U}{\partial r}\right)\frac{D_P}{U_b}$
66.720	1.000	0.000	0.000	17.330	1.000	0.000
64.720	0.970	2.000	0.030	17.316	0.999	-0.071
62.720	0.940	4.000	0.060	17.279	0.997	-0.136
60.720	0.910	6.000	0.090	17.219	0.994	-0.200
58.720	0.880	8.000	0.120	17.135	0.989	-0.264
56.720	0.850	10.000	0.150	17.028	0.983	-0.327
54.720	0.820	12.000	0.180	16.900	0.975	-0.388
52.720	0.790	14.000	0.210	16.749	0.967	-0.447
50.720	0.760	16.000	0.240	16.578	0.957	-0.503
48.720	0.730	18.000	0.270	16.387	0.946	-0.557
46.720	0.700	20.000	0.300	16.177	0.933	-0.609
44.720	0.670	22.000	0.330	15.949	0.920	-0.657
42.720	0.640	24.000	0.360	15.704	0.906	-0.703
40.720	0.610	26.000	0.390	15.442	0.891	-0.748
38.720	0.580	28.000	0.420	15.165	0.875	-0.790
36.720	0.550	30.000	0.450	14.873	0.858	-0.833
34.720	0.520	32.000	0.480	14.565	0.840	-0.877
32.720	0.490	34.000	0.510	14.240	0.822	-0.924
30.720	0.460	36.000	0.540	13.898	0.802	-0.976
28.720	0.430	38.000	0.570	13.536	0.781	-1.036
26.720	0.400	40.000	0.600	13.151	0.759	-1.105
24.720	0.371	42.000	0.629	12.739	0.735	-1.186
22.720	0.341	44.000	0.659	12.295	0.709	-1.282
20.720	0.311	46.000	0.689	11.813	0.682	-1.395
18.720	0.281	48.000	0.719	11.288	0.651	-1.525
16.720	0.251	50.000	0.749	10.712	0.618	-1.673
14.720	0.221	52.000	0.779	10.080	0.582	-1.838
12.720	0.191	54.000	0.809	9.387	0.542	-2.015
10.720	0.161	56.000	0.839	8.628	0.498	-2.198
8.720	0.131	58.000	0.869	7.804	0.450	-2.375
6.720	0.101	60.000	0.899	6.919	0.399	-2.532
4.720	0.071	62.000	0.929	5.985	0.345	-2.644
2.720	0.041	64.000	0.959	5.022	0.290	-2.684
0.720	0.011	66.000	0.989	4.065	0.235	-2.610
0.000	0.000	66.720	1.000	0.000	0.000	-37.59

A.1.10 AXIAL POSITION x=27.0cm.

Local Radius R_L=68.81mm.

Centreline Velocity U_{cl}=16.94m/s U_b=18.3m/s

Mass flow rate=0.1764kg/s Diameter of Pipe=0.1016m.

y(mm)	y/R_L	r(mm)	r/R_L	U(m/s)	U/U_c	$\left(\frac{\partial U}{\partial r}\right)\frac{D_P}{U_b}$
68.810	1.000	0.000	0.000	16.949	1.000	0.000
66.810	0.971	2.000	0.029	16.932	0.999	-0.076
64.810	0.942	4.000	0.058	16.894	0.997	-0.137
62.810	0.913	6.000	0.087	16.834	0.993	-0.197
60.810	0.884	8.000	0.116	16.752	0.988	-0.257
58.810	0.855	10.000	0.145	16.649	0.982	-0.315
56.810	0.826	12.000	0.174	16.525	0.975	-0.372
54.810	0.797	14.000	0.203	16.381	0.967	-0.428
52.810	0.767	16.000	0.233	16.217	0.957	-0.482
50.810	0.738	18.000	0.262	16.034	0.946	-0.535
48.810	0.709	20.000	0.291	15.832	0.934	-0.586
46.810	0.680	22.000	0.320	15.612	0.921	-0.637
44.810	0.651	24.000	0.349	15.373	0.907	-0.688
42.810	0.622	26.000	0.378	15.116	0.892	-0.740
40.810	0.593	28.000	0.407	14.840	0.876	-0.793
38.810	0.564	30.000	0.436	14.544	0.858	-0.848
36.810	0.535	32.000	0.465	14.228	0.839	-0.908
34.810	0.506	34.000	0.494	13.890	0.820	-0.972
32.810	0.477	36.000	0.523	13.527	0.798	-1.041
30.810	0.448	38.000	0.552	13.139	0.775	-1.117
28.810	0.419	40.000	0.581	12.722	0.751	-1.199
26.810	0.390	42.000	0.610	12.274	0.724	-1.288
24.810	0.361	44.000	0.639	11.793	0.696	-1.383
22.810	0.331	46.000	0.669	11.277	0.665	-1.484
20.810	0.302	48.000	0.698	10.724	0.633	-1.589
18.810	0.273	50.000	0.727	10.132	0.598	-1.694
16.810	0.244	52.000	0.756	9.503	0.561	-1.797
14.810	0.215	54.000	0.785	8.839	0.521	-1.892
12.810	0.186	56.000	0.814	8.142	0.480	-1.972
10.810	0.157	58.000	0.843	7.420	0.438	-2.031
8.810	0.128	60.000	0.872	6.682	0.394	-2.059
6.810	0.099	62.000	0.901	5.942	0.351	-2.045
4.810	0.070	64.000	0.930	5.216	0.308	-1.976
2.810	0.041	66.000	0.959	4.527	0.267	-1.837
0.810	0.012	68.000	0.988	3.902	0.230	-1.613
0.000	0.000	68.810	1.000	0.000	0.000	-30.97

A.1.11 AXIAL POSITION x=30.0cm.

Local Radius R_L=70.89mm.

Centreline Velocity U_{cl}=16.80m/s U_b=18.3m/s

Mass flow rate=0.1735kg/s Diameter of Pipe=0.1016m.

y(mm)	y/R_L	r(mm)	r/R_L	U(m/s)	U/U_c	$\left(\frac{\partial U}{\partial r}\right)\frac{D_P}{U_b}$
70.890	1.000	0.000	0.000	16.801	1.000	0.000
68.890	0.972	2.000	0.028	16.786	0.999	-0.085
66.890	0.944	4.000	0.056	16.740	0.996	-0.171
64.890	0.915	6.000	0.085	16.663	0.992	-0.253
62.890	0.887	8.000	0.113	16.558	0.986	-0.329
60.890	0.859	10.000	0.141	16.427	0.978	-0.398
58.890	0.831	12.000	0.169	16.273	0.969	-0.458
56.890	0.803	14.000	0.197	16.098	0.958	-0.510
54.890	0.774	16.000	0.226	15.906	0.947	-0.553
52.890	0.746	18.000	0.254	15.700	0.934	-0.589
50.890	0.718	20.000	0.282	15.482	0.922	-0.619
48.890	0.690	22.000	0.310	15.255	0.908	-0.646
46.890	0.661	24.000	0.339	15.017	0.894	-0.671
44.890	0.633	26.000	0.367	14.771	0.879	-0.698
42.890	0.605	28.000	0.395	14.514	0.864	-0.730
40.890	0.577	30.000	0.423	14.244	0.848	-0.770
38.890	0.549	32.000	0.451	13.958	0.831	-0.819
36.890	0.520	34.000	0.480	13.652	0.813	-0.881
34.890	0.492	36.000	0.508	13.321	0.793	-0.957
32.890	0.464	38.000	0.536	12.961	0.771	-1.047
30.890	0.436	40.000	0.564	12.565	0.748	-1.149
28.890	0.408	42.000	0.592	12.131	0.722	-1.262
26.890	0.379	44.000	0.621	11.655	0.694	-1.383
24.890	0.351	46.000	0.649	11.135	0.663	-1.505
22.890	0.323	48.000	0.677	10.571	0.629	-1.623
20.890	0.295	50.000	0.705	9.967	0.593	-1.729
18.890	0.266	52.000	0.734	9.328	0.555	-1.816
16.890	0.238	54.000	0.762	8.662	0.516	-1.877
14.890	0.210	56.000	0.790	7.980	0.475	-1.906
12.890	0.182	58.000	0.818	7.293	0.434	-1.902
10.890	0.154	60.000	0.846	6.614	0.394	-1.866
8.890	0.125	62.000	0.875	5.952	0.354	-1.808
6.890	0.097	64.000	0.903	5.311	0.316	-1.749
4.890	0.069	66.000	0.931	4.687	0.279	-1.722
2.890	0.041	68.000	0.959	4.060	0.242	-1.778
0.890	0.013	70.000	0.987	3.387	0.202	-1.992
0.000	0.000	70.890	1.000	0.000	0.000	-25.95

A.1.12 AXIAL POSITION x=33.0cm.

Local Radius R_L=73.070mm.

Centreline Velocity U_{cL}=16.34m/s U_b=18.3m/s

Mass flow rate=0.175kg/s Diameter of Pipe=0.1016m.

y(mm)	y/R_L	r(mm)	r/R_L	u(m/s)	u/U_c	$\left(\frac{\partial U}{\partial r}\right)\frac{D_P}{U_b}$
73.070	1.000	0.000	0.000	16.340	1.000	0.000
71.070	0.973	2.000	0.027	16.326	0.999	-0.080
69.070	0.945	4.000	0.055	16.282	0.996	-0.163
67.070	0.918	6.000	0.082	16.209	0.992	-0.242
65.070	0.891	8.000	0.109	16.108	0.986	-0.317
63.070	0.863	10.000	0.137	15.981	0.978	-0.387
61.070	0.836	12.000	0.164	15.830	0.969	-0.451
59.070	0.808	14.000	0.192	15.657	0.958	-0.510
57.070	0.781	16.000	0.219	15.464	0.946	-0.562
55.070	0.754	18.000	0.246	15.252	0.933	-0.609
53.070	0.726	20.000	0.274	15.025	0.920	-0.653
51.070	0.699	22.000	0.301	14.782	0.905	-0.694
49.070	0.672	24.000	0.328	14.525	0.889	-0.734
47.070	0.644	26.000	0.356	14.253	0.872	-0.776
45.070	0.617	28.000	0.383	13.966	0.855	-0.821
43.070	0.589	30.000	0.411	13.661	0.836	-0.870
41.070	0.562	32.000	0.438	13.338	0.816	-0.926
39.070	0.535	34.000	0.465	12.993	0.795	-0.990
37.070	0.507	36.000	0.493	12.624	0.773	-1.061
35.070	0.480	38.000	0.520	12.228	0.748	-1.138
33.070	0.453	40.000	0.547	11.803	0.722	-1.222
31.070	0.425	42.000	0.575	11.347	0.694	-1.308
29.070	0.398	44.000	0.602	10.860	0.665	-1.394
27.070	0.370	46.000	0.630	10.343	0.633	-1.476
25.070	0.343	48.000	0.657	9.798	0.600	-1.547
23.070	0.316	50.000	0.684	9.230	0.565	-1.604
21.070	0.288	52.000	0.712	8.645	0.529	-1.642
19.070	0.261	54.000	0.739	8.050	0.493	-1.657
17.070	0.234	56.000	0.766	7.454	0.456	-1.648
15.070	0.206	58.000	0.794	6.865	0.420	-1.618
13.070	0.179	60.000	0.821	6.290	0.385	-1.575
11.070	0.151	62.000	0.849	5.730	0.351	-1.535
10.07	0.138	63.000	0.862	5.438	0.332	-1.735
8.07	0.111	65.000	0.890	4.840	0.296	-1.735
6.07	0.083	67.000	0.918	4.250	0.260	-1.732
4.07	0.056	69.000	0.944	3.560	0.218	-1.735
2.07	0.028	71.000	0.972	3.060	0.187	-2.080
0.54	0.007	72.440	0.993	2.315	0.141	-15.77
0.00	0.000	73.070	1.000	0.000	0.000	-22.24

A.1.13 AXIAL POSITION x=36.0cm.

Local Radius R_L=75.060mm.

Centreline Velocity U_{cl}=16.33m/s U_b=18.3m/s

Mass flow rate=0.1768kg/s Diameter of Pipe=0.1016m

y(mm)	y/R_L	r(mm)	r/R_L	U(m/s)	U/U_c	$\left(\frac{\partial U}{\partial r}\right)\frac{D_p}{U_b}$
75.060	1.000	0.000	0.000	16.326	1.000	0.000
73.060	0.973	2.000	0.027	16.307	0.999	-0.098
71.060	0.947	4.000	0.053	16.256	0.996	-0.186
69.060	0.920	6.000	0.080	16.173	0.991	-0.271
67.060	0.893	8.000	0.107	16.061	0.984	-0.350
65.060	0.867	10.000	0.133	15.921	0.975	-0.423
63.060	0.840	12.000	0.160	15.757	0.965	-0.489
61.060	0.813	14.000	0.187	15.570	0.954	-0.548
59.060	0.787	16.000	0.213	15.363	0.941	-0.599
57.060	0.760	18.000	0.240	15.139	0.927	-0.643
55.060	0.734	20.000	0.266	14.901	0.913	-0.682
53.060	0.707	22.000	0.293	14.649	0.897	-0.716
51.060	0.680	24.000	0.320	14.385	0.881	-0.749
49.060	0.654	26.000	0.346	14.109	0.864	-0.781
47.060	0.627	28.000	0.373	13.822	0.847	-0.816
45.060	0.600	30.000	0.400	13.521	0.828	-0.855
43.060	0.574	32.000	0.426	13.205	0.809	-0.901
41.060	0.547	34.000	0.453	12.871	0.788	-0.955
39.060	0.520	36.000	0.480	12.516	0.767	-1.018
37.060	0.494	38.000	0.506	12.137	0.743	-1.090
35.060	0.467	40.000	0.533	11.730	0.718	-1.170
33.060	0.440	42.000	0.560	11.293	0.692	-1.258
31.060	0.414	44.000	0.586	10.823	0.663	-1.349
29.060	0.387	46.000	0.613	10.321	0.632	-1.440
27.060	0.361	48.000	0.639	9.786	0.599	-1.525
25.060	0.334	50.000	0.666	9.223	0.565	-1.599
23.060	0.307	52.000	0.693	8.637	0.529	-1.654
21.060	0.281	54.000	0.719	8.034	0.492	-1.685
19.060	0.254	56.000	0.746	7.426	0.455	-1.685
17.060	0.227	58.000	0.773	6.824	0.418	-1.651
15.060	0.201	60.000	0.799	6.241	0.382	-1.581
13.060	0.174	62.000	0.826	5.689	0.348	-1.480
11.060	0.147	64.000	0.853	5.177	0.317	-1.358
9.060	0.121	66.000	0.879	4.711	0.289	-1.233
7.060	0.094	68.000	0.906	4.285	0.262	-1.139
5.060	0.067	70.000	0.933	3.881	0.238	-1.122
3.060	0.041	72.000	0.959	3.459	0.212	-1.249
1.060	0.014	74.000	0.986	2.953	0.181	-1.612
0.000	0.000	75.060	1.000	0.000	0.000	-19.65

A.1.14 AXIAL POSITION x=39.0cm.

Local Radius R_L=77.14mm.

Centreline Velocity U_{cl}=15.90m/s U_b=18.3m/s
Mass flow rate=0.176kg/s Diameter of Pipe=0.1016m.

y(mm)	y/R_L	r(mm)	r/R_L	U(m/s)	U/U_c	$\left(\frac{\partial U}{\partial r}\right)\frac{D_P}{U_b}$
77.140	1.000	0.000	0.000	15.902	1.000	0.000
75.140	0.974	2.000	0.026	15.880	0.999	-0.095
73.140	0.948	4.000	0.052	15.834	0.996	-0.161
71.140	0.922	6.000	0.078	15.764	0.991	-0.227
69.140	0.896	8.000	0.104	15.670	0.985	-0.293
67.140	0.870	10.000	0.130	15.553	0.978	-0.357
65.140	0.844	12.000	0.156	15.413	0.969	-0.421
63.140	0.819	14.000	0.181	15.250	0.959	-0.484
61.140	0.793	16.000	0.207	15.064	0.947	-0.547
59.140	0.767	18.000	0.233	14.856	0.934	-0.610
57.140	0.741	20.000	0.259	14.625	0.920	-0.672
55.140	0.715	22.000	0.285	14.371	0.904	-0.734
53.140	0.689	24.000	0.311	14.096	0.886	-0.795
51.140	0.663	26.000	0.337	13.798	0.868	-0.856
49.140	0.637	28.000	0.363	13.479	0.848	-0.917
47.140	0.611	30.000	0.389	13.138	0.826	-0.976
45.140	0.585	32.000	0.415	12.776	0.803	-1.034
43.140	0.559	34.000	0.441	12.393	0.779	-1.091
41.140	0.533	36.000	0.467	11.990	0.754	-1.145
39.140	0.507	38.000	0.493	11.569	0.727	-1.196
37.140	0.481	40.000	0.519	11.129	0.700	-1.243
35.140	0.456	42.000	0.544	10.674	0.671	-1.286
33.140	0.430	44.000	0.570	10.204	0.642	-1.323
31.140	0.404	46.000	0.596	9.721	0.611	-1.354
29.140	0.378	48.000	0.622	9.229	0.580	-1.378
27.140	0.352	50.000	0.648	8.729	0.549	-1.395
25.140	0.326	52.000	0.674	8.225	0.517	-1.404
23.140	0.300	54.000	0.700	7.718	0.485	-1.406
21.140	0.274	56.000	0.726	7.213	0.454	-1.399
19.140	0.248	58.000	0.752	6.711	0.422	-1.387
17.140	0.222	60.000	0.778	6.214	0.391	-1.370
15.140	0.196	62.000	0.804	5.724	0.360	-1.352
13.140	0.170	64.000	0.830	5.240	0.330	-1.336
11.140	0.144	66.000	0.856	4.760	0.299	-1.330
9.140	0.118	68.000	0.882	4.280	0.269	-1.340
7.140	0.093	70.000	0.907	3.791	0.238	-1.377
5.140	0.067	72.000	0.933	3.283	0.206	-1.454
3.140	0.041	74.000	0.959	2.737	0.172	-1.587
1.140	0.015	76.000	0.985	2.130	0.134	-1.796
0.000	0.000	77.140	1.000	0.000	0.000	-17.23

A.1.15 AXIAL POSITION X=42.0cm.

Local Radius R_L=79.22mm.

Centreline Velocity U_{cl}=15.77m/s U_b=18.3m/s

Mass flow rate=0.175kg/s Diameter of Pipe=0.1016m.

y(mm)	y/R_L	r(mm)	r/R_L	U(m/s)	U/U_c	$\left(\frac{\partial U}{\partial r}\right)\frac{D_P}{U_b}$
79.220	1.000	0.000	0.000	15.768	1.000	0.000
77.220	0.975	2.000	0.025	15.752	0.999	-0.092
75.220	0.950	4.000	0.050	15.702	0.996	-0.184
73.220	0.924	6.000	0.076	15.619	0.991	-0.274
71.220	0.899	8.000	0.101	15.505	0.983	-0.358
69.220	0.874	10.000	0.126	15.362	0.974	-0.438
67.220	0.849	12.000	0.151	15.191	0.963	-0.511
65.220	0.823	14.000	0.177	14.995	0.951	-0.577
63.220	0.798	16.000	0.202	14.776	0.937	-0.636
61.220	0.773	18.000	0.227	14.537	0.922	-0.689
59.220	0.748	20.000	0.252	14.280	0.906	-0.737
57.220	0.722	22.000	0.278	14.007	0.888	-0.779
55.220	0.697	24.000	0.303	13.719	0.870	-0.819
53.220	0.672	26.000	0.328	13.417	0.851	-0.856
51.220	0.647	28.000	0.353	13.103	0.831	-0.893
49.220	0.621	30.000	0.379	12.774	0.810	-0.931
47.220	0.596	32.000	0.404	12.432	0.788	-0.971
45.220	0.571	34.000	0.429	12.074	0.766	-1.016
43.220	0.546	36.000	0.454	11.699	0.742	-1.065
41.220	0.520	38.000	0.480	11.306	0.717	-1.119
39.220	0.495	40.000	0.505	10.893	0.691	-1.176
37.220	0.470	42.000	0.530	10.458	0.663	-1.237
35.220	0.445	44.000	0.555	10.001	0.634	-1.298
33.220	0.419	46.000	0.581	9.523	0.604	-1.357
31.220	0.394	48.000	0.606	9.025	0.572	-1.409
29.220	0.369	50.000	0.631	8.509	0.540	-1.452
27.220	0.344	52.000	0.656	7.981	0.506	-1.479
25.220	0.318	54.000	0.682	7.445	0.472	-1.488
23.220	0.293	56.000	0.707	6.911	0.438	-1.474
21.220	0.268	58.000	0.732	6.386	0.405	-1.437
19.220	0.243	60.000	0.757	5.879	0.373	-1.376
17.220	0.217	62.000	0.783	5.397	0.342	-1.297
15.220	0.192	64.000	0.808	4.946	0.314	-1.210
13.220	0.167	66.000	0.833	4.524	0.287	-1.135
11.220	0.142	68.000	0.858	4.124	0.262	-1.098
9.220	0.116	70.000	0.884	3.724	0.236	-1.141
7.220	0.091	72.000	0.909	3.285	0.208	-1.321
5.220	0.066	74.000	0.934	2.746	0.174	-1.715
3.220	0.041	76.000	0.959	2.012	0.128	-2.424
1.220	0.015	78.000	0.985	0.947	0.060	-3.578
0.000	0.000	79.220	1.000	0.000	0.000	-14.96

A.1.16 AXIAL POSITION x=45.0cm.

Local Radius R_L=81.30mm.

Centreline Velocity U_{cl}=15.57m/s U_b=18.3m/s
Mass flow rate=0.1759kg/s Diameter of Pipe=0.1016m.

y(mm)	y/R_L	r(mm)	r/R_L	U(m/s)	U/U_c	$\left(\frac{\partial U}{\partial r}\right)\frac{D_P}{U_b}$
81.305	1.000	0.000	0.000	15.571	1.000	0.000
79.305	0.975	2.000	0.025	15.552	0.999	-0.089
77.305	0.951	4.000	0.049	15.507	0.996	-0.163
75.305	0.926	6.000	0.074	15.435	0.991	-0.236
73.305	0.902	8.000	0.098	15.337	0.985	-0.307
71.305	0.877	10.000	0.123	15.214	0.977	-0.378
69.305	0.852	12.000	0.148	15.065	0.967	-0.448
67.305	0.828	14.000	0.172	14.891	0.956	-0.517
63.305	0.779	18.000	0.221	14.470	0.929	-0.651
61.305	0.754	20.000	0.246	14.224	0.913	-0.716
59.305	0.729	22.000	0.271	13.955	0.896	-0.779
57.305	0.705	24.000	0.295	13.663	0.877	-0.841
55.305	0.680	26.000	0.320	13.349	0.857	-0.901
53.305	0.656	28.000	0.344	13.014	0.836	-0.958
51.305	0.631	30.000	0.369	12.659	0.813	-1.012
49.305	0.606	32.000	0.394	12.285	0.789	-1.063
47.305	0.582	34.000	0.418	11.894	0.764	-1.111
45.305	0.557	36.000	0.443	11.486	0.738	-1.154
43.305	0.533	38.000	0.467	11.063	0.710	-1.192
41.305	0.508	40.000	0.492	10.627	0.683	-1.225
39.305	0.483	42.000	0.517	10.181	0.654	-1.253
37.305	0.459	44.000	0.541	9.725	0.625	-1.274
35.305	0.434	46.000	0.566	9.263	0.595	-1.290
33.305	0.410	48.000	0.590	8.797	0.565	-1.299
31.305	0.385	50.000	0.615	8.328	0.535	-1.301
29.305	0.360	52.000	0.640	7.860	0.505	-1.297
27.305	0.336	54.000	0.664	7.395	0.475	-1.287
23.305	0.287	58.000	0.713	6.479	0.416	-1.252
21.305	0.262	60.000	0.738	6.031	0.387	-1.229
19.305	0.237	62.000	0.763	5.593	0.359	-1.204
17.305	0.213	64.000	0.787	5.164	0.332	-1.178
15.305	0.188	66.000	0.812	4.745	0.305	-1.153
13.305	0.164	68.000	0.836	4.333	0.278	-1.132
11.305	0.139	70.000	0.861	3.929	0.252	-1.116
10.305	0.127	71.000	0.873	3.750	0.240	-1.055
8.305	0.102	73.000	0.898	3.343	0.214	-1.208
6.305	0.077	75.000	0.923	2.940	0.189	-1.218
4.305	0.053	77.000	0.947	2.500	0.160	-1.390
2.305	0.028	79.000	0.972	2.000	0.128	-1.908
0.585	00072	80.720	0.993	1.125	0.072	-6.020
0.000	0.000	81.305	1.000	0.000	0.000	-12.85

A.1.17 AXIAL POSITION x=48.0cm.

Local Radius R_L=83.39mm.

Centreline Velocity U_{cl}=15.43/s U_b=18.3m/s
Mass flow rate=0.176kg/s Diameter of Pipe=0.1016m.

y(mm)	y/R_L	r(mm)	r/R_L	U(m/s)	U/U_c	$\left(\frac{\partial U}{\partial r}\right)\frac{D_P}{U_b}$
83.390	1.000	0.000	0.000	15.431	1.000	0.000
81.390	0.976	2.000	0.024	15.405	0.998	-0.112
79.390	0.952	4.000	0.048	15.350	0.995	-0.195
77.390	0.928	6.000	0.072	15.265	0.989	-0.275
75.390	0.904	8.000	0.096	15.152	0.982	-0.352
73.390	0.880	10.000	0.120	15.012	0.973	-0.427
71.390	0.856	12.000	0.144	14.845	0.962	-0.498
69.390	0.832	14.000	0.168	14.653	0.950	-0.567
67.390	0.808	16.000	0.192	14.438	0.936	-0.632
65.390	0.784	18.000	0.216	14.199	0.920	-0.694
63.390	0.760	20.000	0.240	13.938	0.903	-0.753
61.390	0.736	22.000	0.264	13.657	0.885	-0.809
59.390	0.712	24.000	0.288	13.356	0.866	-0.862
55.390	0.664	28.000	0.336	12.699	0.823	-0.960
53.390	0.640	30.000	0.360	12.345	0.800	-1.005
51.390	0.616	32.000	0.384	11.975	0.776	-1.047
49.390	0.592	34.000	0.408	11.591	0.751	-1.087
47.390	0.568	36.000	0.432	11.192	0.725	-1.125
45.390	0.544	38.000	0.456	10.780	0.699	-1.160
43.390	0.520	40.000	0.480	10.357	0.671	-1.191
41.390	0.496	42.000	0.504	9.922	0.643	-1.220
39.390	0.472	44.000	0.528	9.478	0.614	-1.244
35.390	0.424	48.000	0.576	8.568	0.555	-1.279
33.390	0.400	50.000	0.600	8.105	0.525	-1.288
31.390	0.376	52.000	0.624	7.641	0.495	-1.291
29.390	0.352	54.000	0.648	7.176	0.465	-1.286
27.390	0.328	56.000	0.672	6.715	0.435	-1.272
25.390	0.304	58.000	0.696	6.261	0.406	-1.251
23.390	0.280	60.000	0.720	5.815	0.377	-1.220
21.390	0.257	62.000	0.743	5.383	0.349	-1.181
19.390	0.233	64.000	0.767	4.965	0.322	-1.134
17.390	0.209	66.000	0.791	4.566	0.296	-1.081
15.390	0.185	68.000	0.815	4.187	0.271	-1.023
13.390	0.161	70.000	0.839	3.829	0.248	-0.965
11.390	0.137	72.000	0.863	3.492	0.226	-0.911
9.390	0.113	74.000	0.887	3.172	0.206	-0.952
7.390	0.089	76.000	0.911	2.864	0.186	-0.958
5.390	0.065	78.000	0.935	2.559	0.166	-0.912
3.390	0.041	80.000	0.959	2.243	0.145	-1.040
1.390	0.040	81.700	0.960	1.896	0.123	-3.570
0.000	0.000	83.390	1.000	0.000	0.000	-11.53

A.1.18 AXIAL POSITION x=51.0cm.

Local Radius R_L=85.47mm.

Centreline Velocity U_{CL}=15.16m/s U_b=18.3m/s
Mass flow rate=0.170kg/s Diameter of Pipe=0.1016m.

y(mm)	y/R_L	r(mm)	r/R_L	U(m/s)	U/U_c	$\left(\frac{\partial U}{\partial r}\right)\frac{D_P}{U_b}$
85.470	1.000	0.000	0.000	15.163	1.000	0.000
83.470	0.977	2.000	0.023	15.147	0.999	-0.094
79.470	0.930	6.000	0.070	15.008	0.990	-0.289
77.470	0.906	8.000	0.094	14.887	0.982	-0.382
75.470	0.883	10.000	0.117	14.734	0.972	-0.469
73.470	0.860	12.000	0.140	14.550	0.960	-0.550
69.470	0.813	16.000	0.187	14.100	0.930	-0.692
67.470	0.789	18.000	0.211	13.840	0.913	-0.752
63.470	0.743	22.000	0.257	13.261	0.875	-0.851
61.470	0.719	24.000	0.281	12.947	0.854	-0.890
57.470	0.672	28.000	0.328	12.282	0.810	-0.955
55.470	0.649	30.000	0.351	11.933	0.787	-0.982
53.470	0.626	32.000	0.374	11.574	0.763	-1.007
49.470	0.579	36.000	0.421	10.831	0.714	-1.057
47.470	0.555	38.000	0.445	10.445	0.689	-1.084
45.470	0.532	40.000	0.468	10.050	0.663	-1.113
43.470	0.509	42.000	0.491	9.643	0.636	-1.145
39.470	0.462	46.000	0.538	8.793	0.580	-1.216
37.470	0.438	48.000	0.562	8.348	0.551	-1.254
35.470	0.415	50.000	0.585	7.890	0.520	-1.290
33.470	0.392	52.000	0.608	7.419	0.489	-1.323
31.470	0.368	54.000	0.632	6.937	0.458	-1.351
27.470	0.321	58.000	0.679	5.952	0.393	-1.375
25.470	0.298	60.000	0.702	5.458	0.360	-1.365
23.470	0.275	62.000	0.725	4.971	0.328	-1.335
21.470	0.251	64.000	0.749	4.499	0.297	-1.283
19.470	0.228	66.000	0.772	4.049	0.267	-1.209
15.470	0.181	70.000	0.819	3.251	0.214	-0.995
13.470	0.158	72.000	0.842	2.915	0.192	-0.866
11.470	0.134	74.000	0.866	2.627	0.173	-0.737
10.470	0.122	75.000	0.877	2.500	0.164	-0.680
9.470	0.111	76.000	0.889	2.382	0.157	-0.624
8.470	0.099	77.000	0.901	2.285	0.151	-0.616
7.470	0.087	78.000	0.913	2.172	0.143	-0.553
5.470	0.064	80.000	0.936	1.975	0.130	-0.559
4.470	0.052	81.000	0.947	1.875	0.123	-0.520
3.470	0.041	82.000	0.959	1.755	0.116	-0.688
2.470	0.030	83.000	0.971	1.562	0.103	-1.040
1.470	0.017	84.000	0.983	1.457	0.096	-1.001
0.77	0.009	84.700	0.991	1.063	0.070	-5.450
0.000	0.000	85.470	1.000	0.000	0.000	-10.90

A.1.19 AXIAL POSITION x=54.0cm.

Local Radius R_L=87.55mm.

Centreline Velocity U_{CL}=15.035m/s U_b=18.3m/s

Mass flow rate=0.177kg/s Diameter of Pipe=0.1016m.

y(mm)	y/R_L	r(mm)	r/R_L	U(m/s)	U/U_c	$\left(\frac{\partial U}{\partial r}\right)\frac{D_P}{U_b}$
87.550	1.000	0.000	0.000	15.036	1.000	0.000
85.550	0.977	2.000	0.023	15.013	0.998	-0.114
83.550	0.954	4.000	0.046	14.954	0.995	-0.215
81.550	0.931	6.000	0.069	14.858	0.988	-0.313
79.550	0.909	8.000	0.091	14.729	0.980	-0.407
75.550	0.863	12.000	0.137	14.372	0.956	-0.579
73.550	0.840	14.000	0.160	14.150	0.941	-0.655
71.550	0.817	16.000	0.183	13.901	0.925	-0.724
69.550	0.794	18.000	0.206	13.629	0.906	-0.786
65.550	0.749	22.000	0.251	13.025	0.866	-0.887
63.550	0.726	24.000	0.274	12.698	0.844	-0.927
61.550	0.703	26.000	0.297	12.358	0.822	-0.960
59.550	0.680	28.000	0.320	12.007	0.799	-0.988
57.550	0.657	30.000	0.343	11.646	0.775	-1.010
55.550	0.634	32.000	0.366	11.279	0.750	-1.029
53.550	0.612	34.000	0.388	10.906	0.725	-1.043
51.550	0.589	36.000	0.411	10.528	0.700	-1.056
49.550	0.566	38.000	0.434	10.145	0.675	-1.066
47.550	0.543	40.000	0.457	9.760	0.649	-1.076
45.550	0.520	42.000	0.480	9.370	0.623	-1.085
43.550	0.497	44.000	0.503	8.978	0.597	-1.095
39.550	0.452	48.000	0.548	8.182	0.544	-1.113
37.550	0.429	50.000	0.571	7.780	0.517	-1.121
35.550	0.406	52.000	0.594	7.375	0.491	-1.127
33.550	0.383	54.000	0.617	6.969	0.463	-1.130
31.550	0.360	56.000	0.640	6.561	0.436	-1.130
29.550	0.338	58.000	0.662	6.155	0.409	-1.123
27.550	0.315	60.000	0.685	5.753	0.383	-1.108
25.550	0.292	62.000	0.708	5.358	0.356	-1.085
23.550	0.269	64.000	0.731	4.973	0.331	-1.051
21.550	0.246	66.000	0.754	4.602	0.306	-1.006
19.550	0.223	68.000	0.777	4.249	0.283	-0.951
17.550	0.200	70.000	0.800	3.918	0.261	-0.886
15.550	0.178	72.000	0.822	3.612	0.240	-0.816
13.550	0.155	74.000	0.845	3.330	0.221	-0.746
11.550	0.132	76.000	0.868	3.073	0.204	-0.686
9.550	0.109	78.000	0.891	2.833	0.188	-0.649
7.550	0.086	80.000	0.914	2.600	0.173	-0.654
5.550	0.063	82.000	0.937	2.354	0.157	-0.725
3.550	0.041	84.000	0.959	2.066	0.137	-0.894
1.550	0.018	86.000	0.982	1.693	0.113	-1.202
0.000	0.000	87.550	1.000	0.000	0.000	-9.810

A.1.20

AXIAL POSITION x=57.0cm.
Local Radius R_L=89.64mm.

Centreline Velocity U_{CL}=14.75m/s U_b=18.3m/s
Mass flow rate=0.170kg/s Diameter of Pipe=0.1016m.

y(mm)	y/R_L	r(mm)	r/R_L	U(m/s)	U/U_c	$\left(\frac{\partial U}{\partial r}\right)\frac{D_P}{U_b}$
89.635	1.000	0.000	0.000	14.745	1.000	0.000
87.635	0.978	2.000	0.022	14.728	0.999	-0.094
85.635	0.955	4.000	0.045	14.678	0.995	-0.184
83.635	0.933	6.000	0.067	14.595	0.990	-0.272
79.635	0.888	10.000	0.112	14.338	0.972	-0.440
77.635	0.866	12.000	0.134	14.165	0.961	-0.519
75.635	0.844	14.000	0.156	13.965	0.947	-0.593
73.635	0.821	16.000	0.179	13.739	0.932	-0.662
71.635	0.799	18.000	0.201	13.488	0.915	-0.727
69.635	0.777	20.000	0.223	13.216	0.896	-0.787
65.635	0.732	24.000	0.268	12.610	0.855	-0.891
63.635	0.710	26.000	0.290	12.281	0.833	-0.935
61.635	0.688	28.000	0.312	11.937	0.810	-0.975
59.635	0.665	30.000	0.335	11.579	0.785	-1.010
57.635	0.643	32.000	0.357	11.210	0.760	-1.040
55.635	0.621	34.000	0.379	10.831	0.735	-1.066
53.635	0.598	36.000	0.402	10.443	0.708	-1.088
51.635	0.576	38.000	0.424	10.048	0.681	-1.106
49.635	0.554	40.000	0.446	9.647	0.654	-1.120
47.635	0.531	42.000	0.469	9.241	0.627	-1.131
45.635	0.509	44.000	0.491	8.833	0.599	-1.138
43.635	0.487	46.000	0.513	8.422	0.571	-1.141
41.635	0.464	48.000	0.536	8.011	0.543	-1.141
39.635	0.442	50.000	0.558	7.600	0.515	-1.138
37.635	0.420	52.000	0.580	7.191	0.488	-1.130
35.635	0.398	54.000	0.602	6.786	0.460	-1.119
33.635	0.375	56.000	0.625	6.386	0.433	-1.103
29.635	0.331	60.000	0.669	5.605	0.380	-1.060
27.635	0.308	62.000	0.692	5.228	0.355	-1.033
25.635	0.286	64.000	0.714	4.862	0.330	-1.002
23.635	0.264	66.000	0.736	4.506	0.306	-0.971
19.635	0.219	70.000	0.781	3.829	0.260	-0.911
17.635	0.197	72.000	0.803	3.505	0.238	-0.891
15.635	0.174	74.000	0.826	3.185	0.216	-0.884
13.635	0.152	76.000	0.848	2.865	0.194	-0.898
11.635	0.130	78.000	0.870	2.535	0.172	-0.943
9.635	0.107	80.000	0.893	2.181	0.148	-1.030
7.635	0.085	82.000	0.915	1.785	0.121	-1.177
5.635	0.063	84.000	0.937	1.323	0.090	-1.402
3.635	0.041	86.000	0.959	0.763	0.052	-1.729
1.635	0.018	88.000	0.982	0.062	0.004	-2.189
0.000	0.000	89.635	1.000	0.000	0.000	-9.110

A.1.21 AXIAL POSITION x=60cm.

Local Radius R_L=91.72mm.

Centreline Velocity U_{CL}=14.56m/s U_b=18.3m/s

Mass flow rate=0.1743kg/s Diameter of Pipe=0.1016m.

y(mm)	y/R_L	r(mm)	r/R_L	U(m/s)	U/U_c	$\left(\frac{\partial U}{\partial r}\right)\frac{D_P}{U_b}$
91.720	1.000	0.000	0.000	14.556	1.000	0.000
89.720	0.978	2.000	0.022	14.540	0.999	-0.099
87.720	0.956	4.000	0.044	14.485	0.995	-0.205
85.720	0.935	6.000	0.065	14.392	0.989	-0.309
81.720	0.891	10.000	0.109	14.099	0.969	-0.503
79.720	0.869	12.000	0.131	13.901	0.955	-0.592
77.720	0.847	14.000	0.153	13.673	0.939	-0.673
75.720	0.826	16.000	0.174	13.418	0.922	-0.746
73.720	0.804	18.000	0.196	13.137	0.902	-0.811
71.720	0.782	20.000	0.218	12.834	0.882	-0.867
69.720	0.760	22.000	0.240	12.513	0.860	-0.915
67.720	0.738	24.000	0.262	12.176	0.836	-0.954
65.720	0.717	26.000	0.283	11.826	0.812	-0.986
61.720	0.673	30.000	0.327	11.100	0.763	-1.026
59.720	0.651	32.000	0.349	10.728	0.737	-1.037
57.720	0.629	34.000	0.371	10.353	0.711	-1.043
55.720	0.608	36.000	0.392	9.977	0.685	-1.045
51.720	0.564	40.000	0.436	9.225	0.634	-1.042
49.720	0.542	42.000	0.458	8.850	0.608	-1.039
47.720	0.520	44.000	0.480	8.477	0.582	-1.035
45.720	0.498	46.000	0.502	8.104	0.557	-1.033
43.720	0.477	48.000	0.523	7.732	0.531	-1.031
41.720	0.455	50.000	0.545	7.361	0.506	-1.031
39.720	0.433	52.000	0.567	6.990	0.480	-1.031
37.720	0.411	54.000	0.589	6.618	0.455	-1.032
33.720	0.368	58.000	0.632	5.875	0.404	-1.030
31.720	0.346	60.000	0.654	5.505	0.378	-1.024
29.720	0.324	62.000	0.676	5.138	0.353	-1.014
27.720	0.302	64.000	0.698	4.776	0.328	-0.996
25.720	0.280	66.000	0.720	4.421	0.304	-0.969
21.720	0.237	70.000	0.763	3.752	0.258	-0.882
19.720	0.215	72.000	0.785	3.445	0.237	-0.819
17.720	0.193	74.000	0.807	3.163	0.217	-0.745
15.720	0.171	76.000	0.829	2.910	0.200	-0.661
13.720	0.150	78.000	0.850	2.688	0.185	-0.571
11.720	0.128	80.000	0.872	2.498	0.172	-0.482
9.720	0.106	82.000	0.894	2.339	0.161	-0.405
7.720	0.084	84.000	0.916	2.203	0.151	-0.354
5.720	0.062	86.000	0.938	2.078	0.143	-0.349
3.720	0.041	88.000	0.959	1.943	0.133	-0.416
1.720	0.019	90.000	0.981	1.766	0.121	-0.588
0.000	0.000	91.72	1.000	0.000	0.000	-8.550

A.1.22

AXIAL POSITION x=63 0cm.

Local Radius R_L=93.8 mm.

Centreline Velocity U_{CL}=14.44m/s U_b=18.3m/s

Mass flow rate=0.1765kg/s Diameter of Pipe=0.1016m

y(mm)	y/R_L	r(mm)	r/R_L	U(m/s)	U/U_c	$\left(\frac{\partial U}{\partial r}\right)\frac{D_P}{U_b}$
93.800	1.000	0.000	0.000	14.436	1.000	0.000
91.800	0.979	2.000	0.021	14.412	0.998	-0.116
89.800	0.957	4.000	0.043	14.352	0.994	-0.217
87.800	0.936	6.000	0.064	14.257	0.988	-0.314
85.800	0.915	8.000	0.085	14.127	0.979	-0.407
83.800	0.893	10.000	0.107	13.964	0.967	-0.494
81.800	0.872	12.000	0.128	13.772	0.954	-0.575
79.800	0.851	14.000	0.149	13.551	0.939	-0.648
77.800	0.829	16.000	0.171	13.306	0.922	-0.713
75.800	0.808	18.000	0.192	13.039	0.903	-0.769
71.800	0.765	22.000	0.235	12.451	0.862	-0.858
69.800	0.744	24.000	0.256	12.136	0.841	-0.890
67.800	0.723	26.000	0.277	11.811	0.818	-0.914
63.800	0.680	30.000	0.320	11.140	0.772	-0.943
61.800	0.659	32.000	0.341	10.800	0.748	-0.949
59.800	0.638	34.000	0.362	10.457	0.724	-0.951
57.800	0.616	36.000	0.384	10.114	0.701	-0.951
55.800	0.595	38.000	0.405	9.772	0.677	-0.949
53.800	0.574	40.000	0.426	9.431	0.653	-0.946
51.800	0.552	42.000	0.448	9.091	0.630	-0.943
49.800	0.531	44.000	0.469	8.752	0.606	-0.941
45.800	0.488	48.000	0.512	8.074	0.559	-0.942
43.800	0.467	50.000	0.533	7.734	0.536	-0.945
41.800	0.446	52.000	0.554	7.393	0.512	-0.949
39.800	0.424	54.000	0.576	7.050	0.488	-0.954
37.800	0.403	56.000	0.597	6.705	0.465	-0.958
35.800	0.382	58.000	0.618	6.360	0.441	-0.961
33.800	0.360	60.000	0.640	6.014	0.417	-0.960
31.800	0.339	62.000	0.661	5.669	0.393	-0.953
27.800	0.296	66.000	0.704	4.994	0.346	-0.914
25.800	0.275	68.000	0.725	4.671	0.324	-0.879
23.800	0.254	70.000	0.746	4.362	0.302	-0.832
21.800	0.232	72.000	0.768	4.073	0.282	-0.771
19.800	0.211	74.000	0.789	3.808	0.264	-0.700
17.800	0.190	76.000	0.810	3.570	0.247	-0.619
15.800	0.168	78.000	0.832	3.363	0.233	-0.533
13.800	0.147	80.000	0.853	3.185	0.221	-0.452
9.800	0.104	84.000	0.896	2.904	0.201	-0.351
7.800	0.083	86.000	0.917	2.776	0.192	-0.369
3.800	0.041	90.000	0.959	2.424	0.168	-0.685
1.800	0.019	92.000	0.981	2.115	0.146	-1.066
0.000	0.000	93.800	1.000	0.000	0.000	-8.000

A.1.23 AXIAL POSITION x=66.0cm.

Local Radius R_L=95.88mm.

Centreline Velocity U_{CL}=13.96m/s U_b=18.3m/s

Mass flow rate=0.176kg/s Diameter of Pipe=0.1016m.

y(mm)	y/R_L	r(mm)	r/R_L	U(m/s)	U/U_c	$\left(\frac{\partial U}{\partial r}\right)\frac{D_P}{U_b}$
95.880	1.000	0.000	0.000	13.964	1.000	0.000
93.880	0.979	2.000	0.021	13.947	0.999	-0.101
91.880	0.958	4.000	0.042	13.891	0.995	-0.207
87.880	0.917	8.000	0.083	13.668	0.979	-0.409
83.880	0.875	12.000	0.125	13.306	0.953	-0.589
81.880	0.854	14.000	0.146	13.080	0.937	-0.669
79.880	0.833	16.000	0.167	12.826	0.919	-0.740
77.880	0.812	18.000	0.188	12.548	0.899	-0.802
75.880	0.791	20.000	0.209	12.249	0.877	-0.856
73.880	0.771	22.000	0.229	11.932	0.855	-0.900
71.880	0.750	24.000	0.250	11.601	0.831	-0.936
69.880	0.729	26.000	0.271	11.259	0.806	-0.964
65.880	0.687	30.000	0.313	10.551	0.756	-0.996
63.880	0.666	32.000	0.334	10.191	0.730	-1.004
61.880	0.645	34.000	0.355	9.829	0.704	-1.006
59.880	0.625	36.000	0.375	9.467	0.678	-1.005
53.880	0.562	42.000	0.438	8.388	0.601	-0.990
51.880	0.541	44.000	0.459	8.033	0.575	-0.984
47.880	0.499	48.000	0.501	7.326	0.525	-0.978
45.880	0.479	50.000	0.521	6.975	0.499	-0.977
43.880	0.458	52.000	0.542	6.623	0.474	-0.977
41.880	0.437	54.000	0.563	6.270	0.449	-0.979
39.880	0.416	56.000	0.584	5.917	0.424	-0.981
37.880	0.395	58.000	0.605	5.564	0.398	-0.981
35.880	0.374	60.000	0.626	5.211	0.373	-0.978
33.880	0.353	62.000	0.647	4.860	0.348	-0.971
27.880	0.291	68.000	0.709	3.840	0.275	-0.903
25.880	0.270	70.000	0.730	3.522	0.252	-0.859
23.880	0.249	72.000	0.751	3.222	0.231	-0.803
21.880	0.228	74.000	0.772	2.945	0.211	-0.735
19.880	0.207	76.000	0.793	2.694	0.193	-0.658
17.880	0.186	78.000	0.814	2.471	0.177	-0.576
15.880	0.166	80.000	0.834	2.278	0.163	-0.496
11.880	0.124	84.000	0.876	1.967	0.141	-0.387
10.880	0.113	85.000	0.886	1.813	0.129	-0.260
6.880	0.061	89.000	0.939	1.530	0.109	-0.690
4.880	0.040	91.000	0.960	1.181	0.085	-0.870
1.080	0.011	94.800	0.989	0.625	0.045	-1.950
0.000	0.000	95.880	1.000	0.000	0.000	-7.480

A.1.24 AXIAL POSITION x=69.0cm.

Local Radius R_L=97.90mm.

Centreline Velocity U_{CL}=13.59m/s U_b=18.3m/s

Mass flow rate=0.176kg/s Diameter of Pipe=0.1016m.

y(mm)	y/R_L	r(mm)	r/R_L	U(m/s)	U/U_c	$\left(\frac{\partial U}{\partial r}\right)\frac{D_P}{U_b}$
97.900	1.000	0.000	0.000	13.590	1.000	0.000
95.900	0.980	2.000	0.020	13.622	1.002	-0.051
91.900	0.939	6.000	0.061	13.485	0.992	-0.281
87.900	0.898	10.000	0.102	13.238	0.974	-0.408
85.900	0.877	12.000	0.123	13.077	0.962	-0.490
83.900	0.857	14.000	0.143	12.884	0.948	-0.585
81.900	0.837	16.000	0.163	12.655	0.931	-0.685
79.900	0.816	18.000	0.184	12.390	0.912	-0.782
77.900	0.796	20.000	0.204	12.093	0.890	-0.868
75.900	0.775	22.000	0.225	11.767	0.866	-0.937
69.900	0.714	28.000	0.286	10.692	0.787	-1.024
67.900	0.694	30.000	0.306	10.324	0.760	-1.019
65.900	0.673	32.000	0.327	9.959	0.733	-1.004
63.900	0.653	34.000	0.347	9.601	0.706	-0.983
61.900	0.632	36.000	0.368	9.251	0.681	-0.961
59.900	0.612	38.000	0.388	8.909	0.656	-0.940
55.900	0.571	42.000	0.429	8.243	0.607	-0.913
53.900	0.551	44.000	0.449	7.915	0.582	-0.908
51.900	0.530	46.000	0.470	7.588	0.558	-0.907
49.900	0.510	48.000	0.490	7.261	0.534	-0.908
47.900	0.489	50.000	0.511	6.934	0.510	-0.910
45.900	0.469	52.000	0.531	6.606	0.486	-0.910
43.900	0.448	54.000	0.552	6.278	0.462	-0.907
41.900	0.428	56.000	0.572	5.953	0.438	-0.899
37.900	0.387	60.000	0.613	5.315	0.391	-0.866
35.900	0.367	62.000	0.633	5.008	0.369	-0.842
33.900	0.346	64.000	0.654	4.710	0.347	-0.816
31.900	0.326	66.000	0.674	4.421	0.325	-0.790
29.900	0.305	68.000	0.695	4.142	0.305	-0.762
25.900	0.265	72.000	0.735	3.613	0.266	-0.712
23.900	0.244	74.000	0.756	3.359	0.247	-0.682
21.900	0.224	76.000	0.776	3.123	0.230	-0.646
19.900	0.203	78.000	0.797	2.897	0.213	-0.597
15.900	0.162	82.000	0.838	2.523	0.186	-0.439
13.900	0.142	84.000	0.858	2.382	0.175	-0.322
11.900	0.122	86.000	0.878	2.287	0.168	-0.183
7.000	0.070	91.000	0.930	2.180	0.160	-0.030
3.000	0.031	95.000	0.969	2.110	0.155	-0.860
1.000	0.011	97.000	0.989	2.000	0.147	-5.110
0.000	0.000	98.000	1.000	0.000	0.000	-6.980

A.1.25 AXIAL POSITION x=72.0cm.(Diffuser Exit)

Local Radius R_L=100.00mm.

Centreline Velocity U_{CL}=13.24m/s U_b=18.3m/s
Mass flow rate=0.1735kg/s Diameter of Pipe=0.1016m.

y(mm)	y/R_L	r(mm)	r/R_L	U(m/s)	U/U_c	$\left(\frac{\partial U}{\partial r}\right)\frac{D_P}{U_b}$
00.000	1.000	0.000	0.000	13.243	1.000	0.000
98.000	0.980	2.000	0.020	13.227	0.999	-0.097
94.000	0.940	6.000	0.060	13.082	0.988	-0.306
92.000	0.920	8.000	0.080	12.954	0.978	-0.404
90.000	0.900	10.000	0.100	12.791	0.966	-0.497
88.000	0.880	12.000	0.120	12.596	0.951	-0.583
84.000	0.840	16.000	0.160	12.121	0.915	-0.731
80.000	0.800	20.000	0.200	11.552	0.872	-0.842
76.000	0.760	24.000	0.240	10.917	0.824	-0.915
74.000	0.740	26.000	0.260	10.583	0.799	-0.938
72.000	0.720	28.000	0.280	10.242	0.773	-0.952
66.000	0.660	34.000	0.340	9.207	0.695	-0.954
64.000	0.640	36.000	0.360	8.865	0.669	-0.945
62.000	0.620	38.000	0.380	8.527	0.644	-0.933
58.000	0.580	42.000	0.420	7.864	0.594	-0.906
56.000	0.560	44.000	0.440	7.540	0.569	-0.893
54.000	0.540	46.000	0.460	7.220	0.545	-0.883
52.000	0.520	48.000	0.480	6.904	0.521	-0.875
48.000	0.480	52.000	0.520	6.276	0.474	-0.870
46.000	0.460	54.000	0.540	5.963	0.450	-0.873
44.000	0.440	56.000	0.560	5.647	0.426	-0.878
40.000	0.400	60.000	0.600	5.009	0.378	-0.894
38.000	0.380	62.000	0.620	4.685	0.354	-0.901
34.000	0.340	66.000	0.660	4.034	0.305	-0.904
32.000	0.320	68.000	0.680	3.709	0.280	-0.895
30.000	0.300	70.000	0.700	3.390	0.256	-0.876
28.000	0.280	72.000	0.720	3.080	0.233	-0.844
26.000	0.260	74.000	0.740	2.784	0.210	-0.797
22.000	0.220	78.000	0.780	2.255	0.170	-0.660
20.000	0.200	80.000	0.800	2.033	0.154	-0.571
18.000	0.180	82.000	0.820	1.845	0.139	-0.474
16.000	0.160	84.000	0.840	1.692	0.128	-0.374
14.000	0.140	86.000	0.860	1.574	0.119	-0.284
12.000	0.120	88.000	0.880	1.485	0.112	-0.217
11.000	0.110	89.000	0.890	1.375	0.104	-0.120
9.000	0.090	91.000	0.910	1.313	0.099	-0.230
7.000	0.070	93.000	0.930	1.250	0.094	-0.257
3.000	0.030	97.000	0.970	0.825	0.062	-0.860
1.000	0.010	99.000	0.990	0.437	0.033	-1.915
0.000	0.000	00.000	1.000	0.132	0.010	-1.983

TABLES A.2.1-A.2.18: DISTRIBUTION OF MEAN AXIAL VELOCITY, U, AND NORMAL STRAIN RATE, ∂U/∂x, IN AXIAL DIRECTION OF DIFFUSER

A.2.1

Diffuser axis

x(cm)	U(m/s)	∂U/∂x(1/s)	$\left(\frac{\partial U}{\partial x}\right)\frac{D_P}{U_b}$
0.000	22.124	-28.40	-0.158
3.000	21.272	-29.10	-0.161
6.000	20.452	-25.70	-0.142
9.000	19.730	-22.50	-0.125
12.000	19.096	-19.70	-0.109
15.000	18.543	-17.20	-0.095
18.000	18.062	-15.00	-0.083
21.000	17.643	-13.00	-0.072
24.000	17.280	-11.30	-0.063
27.000	16.965	-9.80	-0.054
30.000	16.689	-8.60	-0.048
33.000	16.447	-7.60	-0.042
36.000	16.230	-6.90	-0.038
39.000	16.033	-6.30	-0.035
42.000	15.848	-6.00	-0.033
45.000	15.671	-5.90	-0.033
48.000	15.494	-5.09	-0.028
51.000	15.312	-6.20	-0.034
54.000	15.121	-6.60	-0.037
57.000	14.914	-7.20	-0.040
60.000	14.687	-7.90	-0.040
63.000	14.436	-8.80	-0.049
66.000	14.156	-9.90	-0.055
69.000	13.842	-11.00	-0.060
72.000	13.493	-12.30	-0.068

A.2.2

Radius=5mm.

x(cm)	U(m/s)	∂U/∂x(1/s)	$\left(\frac{\partial U}{\partial x}\right)\frac{D_P}{U_b}$
0.00	22.04	-32.00	-0.18
3.00	21.08	-28.90	-0.16
6.00	20.27	-24.92	-0.14
9.00	19.57	-21.56	-0.12
12.00	18.97	-18.75	-0.10
15.00	18.44	-16.40	-0.09
18.00	17.98	-14.44	-0.08
21.00	17.58	-12.80	-0.07
24.00	17.21	-11.43	-0.06
27.00	16.89	-10.28	-0.06
30.00	16.59	-9.32	-0.05
33.00	16.33	-8.52	-0.05
36.00	16.08	-7.86	-0.04
39.00	15.85	-7.32	-0.04
42.00	15.64	-6.91	-0.04
45.00	15.44	-6.63	-0.04
48.00	15.24	-6.51	-0.04
51.00	15.05	-6.55	-0.04
54.00	14.85	-6.80	-0.04
57.00	14.64	-7.30	-0.04
60.00	14.40	-8.10	-0.04
63.00	14.15	-9.26	-0.05
66.00	13.84	-10.85	-0.06
69.00	13.49	-12.95	-0.07
72.00	13.06	-15.64	-0.08

A.2.3

Radius=10mm.

x(cm)	U(m/s)	∂U/∂x(1/s)	$\left(\frac{\partial U}{\partial x}\right)\frac{D_P}{U_b}$
0.00	21.79	-30.67	-0.17
3.00	20.87	-28.15	-0.16
6.00	20.08	-24.54	-0.14
9.00	19.39	-21.44	-0.12
12.00	18.79	-18.79	-0.10
15.00	18.26	-16.53	-0.09
18.00	17.79	-14.60	-0.08
21.00	17.38	-12.96	-0.07
24.00	17.01	-11.57	-0.06
27.00	16.68	-10.39	-0.06
30.00	16.39	-9.40	-0.05
33.00	16.12	-8.58	-0.05
36.00	15.87	-7.91	-0.04
39.00	15.64	-7.39	-0.04
42.00	15.42	-7.02	-0.04
45.00	15.22	-6.79	-0.04
48.00	15.02	-6.73	-0.04
51.00	14.81	-6.85	-0.04
54.00	14.60	-7.18	-0.04
57.00	14.38	-7.75	-0.04
60.00	14.13	-8.59	-0.05
63.00	13.86	-9.75	-0.05
66.00	13.55	-11.29	-0.06
69.00	13.18	-13.25	-0.07
72.00	12.75	-15.70	-0.09

A.2.4

Radius=15mm

x(cm)	U(m/s)	∂U/∂x(1/s)	$\left(\frac{\partial U}{\partial x}\right)\frac{D_P}{U_b}$
0.00	21.41	-28.00	-0.16
3.00	20.57	-29.31	-0.16
6.00	19.75	-25.12	-0.14
9.00	19.05	-21.67	-0.12
12.00	18.45	-18.85	-0.10
15.00	17.92	-16.55	-0.09
18.00	17.45	-14.66	-0.08
21.00	17.04	-13.12	-0.07
24.00	16.66	-11.84	-0.07
27.00	16.32	-10.76	-0.06
30.00	16.01	-9.86	-0.05
33.00	15.73	-9.08	-0.05
36.00	15.47	-8.42	-0.05
39.00	15.22	-7.87	-0.04
42.00	14.99	-7.43	-0.04
45.00	14.78	-7.12	-0.04
48.00	14.57	-6.98	-0.04
51.00	14.36	-7.05	-0.04
54.00	14.14	-7.39	-0.04
57.00	13.91	-8.07	-0.05
60.00	13.65	-9.17	-0.05
63.00	13.35	-10.79	-0.06
66.00	13.00	-13.04	-0.07
69.00	12.56	-16.03	-0.09
72.00	12.03	-19.91	-0.11

A.2.5

Radius=20mm

x(cm)	U(m/s)	∂U/∂x(1/s)	$\left(\frac{\partial U}{\partial x}\right)\frac{D_P}{U_b}$
0.00	20.60	-30.67	-0.17
3.00	20.05	-30.25	-0.17
6.00	19.22	-25.34	-0.14
9.00	18.52	-21.48	-0.12
12.00	17.92	-18.47	-0.10
15.00	17.40	-16.17	-0.09
18.00	16.94	-14.41	-0.08
21.00	16.53	-13.07	-0.07
24.00	16.16	-12.05	-0.07
27.00	15.81	-11.24	-0.06
30.00	15.48	-10.58	-0.06
33.00	15.17	-10.00	-0.06
36.00	14.88	-9.47	-0.05
39.00	14.60	-8.98	-0.05
42.00	14.34	-8.51	-0.05
45.00	14.09	-8.08	-0.04
48.00	13.86	-7.73	-0.04
51.00	13.63	-7.51	-0.04
54.00	13.40	-7.48	-0.04
57.00	13.18	-7.74	-0.04
60.00	12.94	-8.39	-0.05
63.00	12.67	-9.55	-0.05
66.00	12.36	-11.36	-0.06
69.00	11.98	-14.00	-0.08
72.00	11.51	-17.62	-0.10

A.2.6

Radius=25mm

x(cm)	U(m/s)	∂U/∂x(1/s)	$\left(\frac{\partial U}{\partial x}\right)\frac{D_P}{U_b}$
0.00	20.40	-30.2	-1.68
3.00	19.53	-29.81	-0.17
6.00	18.70	-25.31	-0.14
9.00	18.00	-21.68	-0.12
12.00	17.39	-18.77	-0.10
15.00	16.87	-16.48	-0.09
18.00	16.40	-14.70	-0.08
21.00	15.98	-13.33	-0.07
24.00	15.60	-12.29	-0.07
27.00	15.24	-11.50	-0.06
30.00	14.91	-10.91	-0.06
33.00	14.59	-10.46	-0.06
36.00	14.28	-10.11	-0.06
39.00	13.98	-9.82	-0.05
42.00	13.69	-9.59	-0.05
45.00	13.40	-9.40	-0.05
48.00	13.12	-9.24	-0.05
51.00	12.85	-9.14	-0.05
54.00	12.57	-9.11	-0.05
57.00	12.30	-9.20	-0.05
60.00	12.02	-9.43	-0.05
63.00	11.73	-9.88	-0.05
66.00	11.43	-10.60	-0.06
69.00	11.09	-11.67	-0.06
72.00	10.72	-13.17	-0.07

A.2.7

Radius=30mm

x(cm)	U(m/s)	∂U/∂x(1/s)	$\left(\frac{\partial U}{\partial X}\right)\frac{D_P}{U_b}$
0.00	19.79	-27.00	-0.15
3.00	18.98	-32.04	-0.18
6.00	18.10	-26.65	-0.15
9.00	17.37	-22.45	-0.12
12.00	16.74	-19.24	-0.11
15.00	16.21	-16.83	-0.09
18.00	15.73	-15.05	-0.08
21.00	15.30	-13.76	-0.08
24.00	14.90	-12.83	-0.07
27.00	14.52	-12.15	-0.07
30.00	14.17	-11.63	-0.06
33.00	13.83	-11.19	-0.06
36.00	13.50	-10.79	-0.06
39.00	13.18	-10.39	-0.06
42.00	12.87	-9.98	-0.06
45.00	12.58	-9.56	-0.06
48.00	12.30	-9.16	-0.05
51.00	12.03	-8.82	-0.05
54.00	11.77	-8.61	-0.05
57.00	11.51	-8.60	-0.05
60.00	11.25	-8.89	-0.05
63.00	10.97	-9.61	-0.05
66.00	10.67	-10.90	-0.06
69.00	10.31	-12.91	-0.07
72.00	9.88	-15.82	-0.09

A.2.8

Radius=35mm

x(cm)	U(m/s	∂U/∂x(1/s)	$\left(\frac{\partial U}{\partial x}\right)\frac{D_P}{U_b}$
0.00	19.01	-29.68	-0.16
3.00	18.12	-27.97	-0.16
6.00	17.33	-25.04	-0.14
9.00	16.62	-22.41	-0.12
12.00	15.98	-20.09	-0.11
15.00	15.41	-18.06	-0.10
18.00	14.90	-16.32	-0.09
21.00	14.43	-14.86	-0.08
24.00	14.00	-13.64	-0.08
27.00	13.61	-12.67	-0.07
30.00	13.24	-11.91	-0.07
33.00	12.89	-11.33	-0.06
36.00	12.56	-10.92	-0.06
39.00	12.23	-10.63	-0.06
42.00	11.92	-10.44	-0.06
45.00	11.61	-10.30	-0.06
48.00	11.30	-10.17	-0.06
51.00	11.00	-10.02	-0.06
54.00	10.70	-9.78	-0.05
57.00	10.41	-9.42	-0.05
60.00	10.14	-8.88	-0.05
63.00	9.88	-8.10	-0.04
66.00	9.65	-7.03	-0.04
69.00	9.46	-5.59	-0.03
72.00	9.32	-3.73	-0.02

A.2.9

Radius=40mm

x(cm)	U(m/s)	∂U/∂x(1/s)	$\left(\frac{\partial U}{\partial x}\right)\frac{D_P}{U_b}$
0.00	18.11	-32.67	-0.18
3.00	17.13	-29.62	-0.16
6.00	16.31	-24.91	-0.14
9.00	15.62	-21.38	-0.12
12.00	15.02	-18.80	-0.10
15.00	14.48	-16.95	-0.09
18.00	14.00	-15.66	-0.09
21.00	13.54	-14.77	-0.08
24.00	13.11	-14.14	-0.08
27.00	12.69	-13.66	-0.08
30.00	12.29	-13.23	-0.07
33.00	11.90	-12.78	-0.07
36.00	11.52	-12.27	-0.07
39.00	11.16	-11.67	-0.06
42.00	10.82	-10.98	-0.06
45.00	10.50	-10.22	-0.06
48.00	10.21	-9.42	-0.05
51.00	9.94	-8.66	-0.05
54.00	9.69	-8.01	-0.04
57.00	9.45	-7.60	-0.04
60.00	9.23	-7.54	-0.04
63.00	9.00	-8.00	-0.04
66.00	8.74	-9.14	-0.05
69.00	8.44	-11.18	-0.06
72.00	8.06	-14.32	-0.08

A.2.10

Radius=45mm

x(cm)	U(m/s)	∂U/∂x(1/s)	$\left(\frac{\partial U}{\partial x}\right)\frac{D_P}{U_b}$
0.00	16.65	-37.18	-0.21
3.00	15.54	-22.76	-0.13
6.00	14.88	-20.80	-0.12
9.00	14.29	-19.12	-0.11
12.00	13.73	-17.68	-0.10
15.00	13.22	-16.46	-0.09
18.00	12.75	-15.42	-0.09
21.00	12.30	-14.53	-0.08
24.00	11.87	-13.77	-0.08
27.00	11.47	-13.11	-0.07
30.00	11.09	-12.52	-0.07
33.00	10.72	-11.98	-0.07
36.00	10.37	-11.47	-0.06
39.00	10.03	-10.96	-0.06
42.00	9.71	-10.43	-0.06
45.00	9.40	-9.87	-0.05
48.00	9.12	-9.25	-0.05
51.00	8.85	-8.56	-0.05
54.00	8.60	-7.78	-0.04
57.00	8.38	-6.89	-0.04
60.00	8.19	-5.88	-0.03
63.00	8.03	-4.73	-0.03
66.00	7.91	-3.44	-0.02
69.00	7.83	-1.99	-0.01
72.00	7.79	-0.37	-0.00

A.2.11

Radius=50mm

x(cm)	U(m/s)	∂U/∂x(1/s)	$\left(\frac{\partial U}{\partial x}\right)\frac{D_P}{U_b}$
0.00	12.76	12.54	0.05
3.00	12.98	2.17	0.01
6.00	12.92	-5.41	-0.03
9.00	12.67	-10.66	-0.06
12.00	12.30	-13.97	-0.08
15.00	11.85	-15.73	-0.08
18.00	11.37	-16.27	-0.09
21.00	10.88	-15.91	-0.09
24.00	10.42	-14.91	-0.08
27.00	9.99	-13.53	-0.08
30.00	9.61	-11.95	-0.07
33.00	9.28	-10.36	-0.06
36.00	8.99	-8.89	-0.05
39.00	8.74	-7.64	-0.04
42.00	8.53	-6.69	-0.04
45.00	8.34	-6.07	-0.03
48.00	8.16	-5.79	-0.03
51.00	7.99	-5.80	-0.03
54.00	7.81	-6.04	-0.03
57.00	7.62	-6.42	-0.04
60.00	7.42	-6.80	-0.04
63.00	7.22	-7.00	-0.04
66.00	7.01	-6.84	-0.04
69.00	6.81	-6.06	-0.03
72.00	6.65	-4.41	-0.02

A.2.12

r=55mm

x (cm)	U (m/s)	∂U/∂x (1/s)	$\left(\frac{\partial U}{\partial x}\right)\frac{D_P}{U_b}$
6.65	0.00	248.20	1.37
9.00	9.06	16.05	0.09
12.00	9.39	6.38	0.04
15.00	9.47	-0.60	0.00
18.00	9.38	-5.35	-0.03
21.00	9.17	-8.32	-0.05
24.00	8.89	-9.90	-0.05
27.00	8.58	-10.44	-0.06
30.00	8.27	-10.23	-0.06
33.00	7.97	-9.56	-0.05
36.00	7.70	-8.64	-0.05
39.00	7.46	-7.66	-0.04
42.00	7.24	-6.74	-0.04
45.00	7.05	-5.99	-0.03
48.00	6.88	-5.46	-0.03
51.00	6.72	-5.15	-0.03
54.00	6.57	-5.05	-0.03
57.00	6.42	-5.06	-0.03
60.00	6.26	-5.08	-0.03
63.00	6.11	-4.94	-0.03
66.00	5.97	-4.44	-0.02
69.00	5.85	-3.34	-0.02
72.00	5.78	-1.35	-0.01

A.2.13

r=60mm

x (cm)	U (m/s)	∂U/∂x (1/s)	$\left(\frac{\partial U}{\partial x}\right)\frac{D_P}{U_b}$
13.80	0.00	84.68	0.47
27.00	2.71	36.40	0.20
30.00	3.52	18.59	0.10
33.00	3.89	7.29	0.04
36.00	4.00	0.86	0.00
39.00	3.98	-2.10	-0.01
42.00	3.90	-2.83	-0.02
45.00	3.82	-2.32	-0.01
48.00	3.76	-1.34	-0.01
51.00	3.74	-0.48	-0.00
54.00	3.73	-0.08	-0.00
57.00	3.73	-0.31	-0.00
60.00	3.71	-1.08	-0.01
63.00	3.66	-2.11	-0.01
66.00	3.58	-2.92	-0.02
69.00	3.49	-2.79	-0.02
72.00	3.43	-0.80	-0.00

A.2.14

r=65mm

x (cm)	U (m/s)	∂U/∂x (1/s)	$\left(\frac{\partial U}{\partial x}\right)\frac{D_P}{U_b}$
21.60	0.00	189.17	1.05
24.00	4.53	7.82	-0.04
27.00	4.87	5.17	-0.03
30.00	4.99	3.06	-0.02
33.00	4.84	1.40	-0.00
36.00	4.94	0.14	-0.00
39.00	5.00	-0.78	-0.00
42.00	4.74	-1.43	-0.00
45.00	4.95	-1.87	-0.00
48.00	4.76	-2.16	-0.01
51.00	4.72	-2.36	-0.01
54.00	4.78	-2.55	-0.01
57.00	4.68	-2.77	-0.02
60.00	4.60	-3.09	-0.02
63.00	4.46	-3.58	-0.02
66.00	4.20	-4.30	-0.02
69.00	4.18	-5.31	-0.03
72.00	4.05	-6.67	-0.04

A.2.15

r=7cm

x (cm)	U (m/s)	∂U/∂x (1/s)	$\left(\frac{\partial U}{\partial x}\right)\frac{D_P}{U_b}$
33.00	3.94	4.93	0.03
36.00	4.00	0.06	0.00
39.00	3.97	-2.14	-0.01
42.00	3.89	-2.60	-0.01
45.00	3.82	-2.12	-0.01
48.00	3.77	-1.30	-0.00
51.00	3.74	-0.58	-0.00
54.00	3.73	-0.25	-0.00
57.00	3.72	-0.43	-0.00
60.00	3.70	-1.08	-0.00
63.00	3.65	-1.98	-0.01
66.00	3.58	-2.76	-0.02
69.00	3.49	-2.88	-0.02
72.00	3.42	-1.64	0.00

A.2.16

r=75mm

x (cm)	U (m/s)	∂U/∂x (1/s)	$\left(\frac{\partial U}{\partial x}\right)\frac{D_P}{U_b}$
39.00	2.95	-0.91	-0.005
42.00	2.93	-0.45	-0.003
45.00	2.92	-0.19	-0.001
48.00	2.92	-0.07	-0.000
51.00	2.92	-0.05	-0.000
54.00	2.91	-0.07	-0.000
57.00	2.91	-0.12	-0.000
60.00	2.91	-0.15	-0.000
63.00	2.90	-0.17	-0.001
66.00	2.90	-0.16	-0.001
69.00	2.89	-0.14	-0.001
72.00	2.89	-0.10	-0.000

A.2.17

r=80mm

x (cm)	U (m/s)	∂U/∂x (1/s)	$\left(\frac{\partial U}{\partial x}\right)\frac{D_P}{U_b}$
48.00	2.26	8.38	0.05
51.00	2.39	1.74	0.00
54.00	2.41	-0.12	-0.00
57.00	2.40	-0.15	-0.00
60.00	2.40	-0.33	-0.00
63.00	2.37	-1.64	-0.00
66.00	2.29	-4.09	-0.02
69.00	2.12	-6.71	-0.04
72.00	1.90	-7.55	-0.04

A.2.18

r=85mm

x (cm)	U (m/s)	∂U/∂x (1/s)	$\left(\frac{\partial U}{\partial x}\right)\frac{D_P}{U_b}$
54.00	1.90	10.25	0.06
57.00	2.09	2.49	0.01
60.00	2.08	-2.30	-0.01
63.00	1.98	-4.11	-0.02
66.00	1.85	-4.18	-0.02
69.00	1.72	-5.01	-0.03
72.00	1.51	-10.38	-0.06

TABLES A.3.1-A.3.21: DISTRIBUTION OF MEAN RADIAL VELOCITY, V AND NORMAL STRAIN RATE, ∂V/∂r, IN RADIAL DIRECTION

A.3.1

Axial Distance, x=3cm.

r (mm)	V (m/s)	∂V/∂r (1/s)	$\frac{\partial V}{\partial r}\left(\frac{D_P}{U_b}\right)$	V/r (1/s)	$\frac{V}{r}\left(\frac{D_P}{U_b}\right)$
0.00	0.00	6.00	0.03	-	-
5.00	0.03	8.24	0.05	6.70	0.249
10.00	0.08	9.38	0.05	7.83	0.043
15.00	0.13	9.35	0.05	8.36	0.046
20.00	0.17	9.02	0.05	8.57	0.048
25.00	0.22	8.88	0.05	8.64	0.048
30.00	0.26	9.02	0.05	8.69	0.048
35.00	0.31	9.14	0.05	8.75	0.048
40.00	0.35	8.56	0.047	8.77	0.049
45.00	0.39	6.18	0.034	8.64	0.048
50.00	0.41	0.53	0.003	8.14	0.045

A.3.2

x=6cm.

r (mm)	V (m/s)	∂V/∂r (1/s)	$\frac{\partial V}{\partial r}\left(\frac{D_P}{U_b}\right)$	V/r (1/s)	$\frac{V}{r}\left(\frac{D_P}{U_b}\right)$
0.00	0.00	10.00	0.06	-	-
5.00	0.05	10.70	0.06	9.79	0.05
10.00	0.10	11.23	0.06	10.36	0.06
15.00	0.16	12.07	0.07	10.78	0.06
20.00	0.22	12.96	0.07	11.22	0.06
25.00	0.29	13.66	0.08	11.64	0.06
30.00	0.36	13.90	0.08	12.01	0.07
35.00	0.43	13.45	0.08	12.25	0.07
40.00	0.49	12.05	0.07	12.33	0.07
45.00	0.55	9.45	0.05	12.17	0.07
50.00	0.59	5.39	0.03	11.70	0.07

A.3.3

x=9cm.

r (mm)	V (m/s)	∂V/∂r (1/s)	$\frac{\partial V}{\partial r}\left(\frac{D_P}{U_b}\right)$	V/r (1/s)	$\frac{V}{r}\left(\frac{D_P}{U_b}\right)$
0.00	0.00	12.00	0.07	-	-
5.00	0.06	11.00	0.06	12.00	0.07
10.00	0.11	10.60	0.06	11.46	0.06
15.00	0.17	10.47	0.06	11.14	0.06
20.00	0.22	10.73	0.06	11.00	0.06
25.00	0.27	11.15	0.06	10.99	0.06
30.00	0.33	11.43	0.06	11.04	0.06
35.00	0.39	11.20	0.06	11.09	0.06
40.00	0.44	10.02	0.06	11.04	0.06
45.00	0.49	7.38	0.04	10.80	0.06
50.00	0.51	2.70	0.01	10.24	0.06

A.3.4

x=12cm.

r (mm)	V (m/s)	∂V/∂r (1/s)	$\frac{\partial V}{\partial r}\left(\frac{D_P}{U_b}\right)$	V (1/s)	$\frac{V}{r}\left(\frac{D_P}{U_b}\right)$
0.00	0.00	8.00	0.04	-	-
5.00	0.04	10.45	0.06	8.75	0.05
10.00	0.10	11.11	0.06	9.91	0.06
15.00	0.15	9.57	0.05	10.08	0.06
20.00	0.20	8.10	0.04	9.75	0.05
25.00	0.23	7.93	0.04	9.38	0.05
30.00	0.28	9.29	0.05	9.23	0.05
35.00	0.33	11.38	0.06	9.39	0.05
40.00	0.39	12.41	0.07	9.72	0.05
45.00	0.45	9.54	0.05	9.92	0.06
50.00	0.47	-1.05	-0.01	9.43	0.05

A.3.5

x=15cm.

r (mm)	V (m/s)	∂V/∂r (1/s)	$\frac{\partial V}{\partial r}\left(\frac{D_P}{U_b}\right)$	V/r (1/s)	$\frac{V}{r}\left(\frac{D_P}{U_b}\right)$
0.00	0.00	8.00	0.04	-	-
5.00	0.04	7.97	0.04	8.27	0.05
10.00	0.08	8.46	0.05	8.21	0.05
20.00	0.17	8.86	0.05	8.40	0.05
25.00	0.21	8.31	0.05	8.55	0.05
30.00	0.25	7.88	0.04	8.47	0.05
35.00	0.29	8.04	0.04	8.39	0.05
40.00	0.34	8.72	0.05	8.44	0.05
50.00	0.42	5.83	0.03	8.37	0.05
55.00	0.43	-4.79	-0.03	7.74	0.04

A.3.6

x=21cm

r (mm)	V (m/s)	∂V/∂r (1/s)	$\frac{\partial V}{\partial r}\left(\frac{D_P}{U_b}\right)$	V/r (1/s)	$\frac{V}{r}\left(\frac{D_P}{U_b}\right)$
0.00	0.00	8.00	0.04	-	-
5.00	0.04	7.78	0.04	8.20	0.05
10.00	0.08	6.67	0.04	7.68	0.04
15.00	0.11	6.58	0.04	7.30	0.04
20.00	0.14	7.11	0.04	7.18	0.04
25.00	0.18	7.41	0.04	7.21	0.04
30.00	0.22	7.08	0.04	7.22	0.04
35.00	0.25	6.45	0.04	7.16	0.04
40.00	0.28	6.30	0.03	7.05	0.04
45.00	0.31	6.88	0.04	6.99	0.04
50.00	0.35	6.38	0.04	6.98	0.04
55.00	0.37	-1.30	-0.01	6.67	0.04

A.3.7

x=24cm

r (mm)	V (m/s)	∂V/∂r (1/s)	$\frac{\partial V}{\partial r}\left(\frac{D_P}{U_b}\right)$	V/r (1/s)	$\frac{V}{r}\left(\frac{D_P}{U_b}\right)$
0.00	0.00	6.00	0.03	-	-
5.00	0.03	8.12	0.05	5.53	0.03
10.00	0.07	7.42	0.04	6.79	0.04
15.00	0.10	5.91	0.03	6.72	0.04
20.00	0.13	5.74	0.03	6.47	0.04
25.00	0.16	6.38	0.04	6.38	0.04
30.00	0.19	6.75	0.04	6.42	0.04
35.00	0.23	6.42	0.04	6.45	0.04
40.00	0.26	5.94	0.03	6.42	0.04
45.00	0.29	6.23	0.03	6.37	0.04
50.00	0.32	7.04	0.04	6.40	0.04
55.00	0.35	4.56	0.03	6.40	0.04
60.00	0.34	-11.91	-0.07	5.72	0.03
65.00	0.17	-64.17	-0.36	2.68	0.02

A.3.8

x=27cm.

r (mm)	V (m/s)	∂V/∂r (1/s)	$\frac{\partial V}{\partial r}\left(\frac{D_P}{U_b}\right)$	V/r (1/s)	$\frac{V}{r}\left(\frac{D_P}{U_b}\right)$
5.00	0.04	5.06	0.03	7.49	0.04
10.00	0.06	3.64	0.02	5.77	0.03
15.00	0.08	4.28	0.02	5.15	0.03
20.00	0.10	5.02	0.03	5.03	0.02
25.00	0.13	5.29	0.03	5.06	0.03
30.00	0.15	5.36	0.03	5.11	0.03
35.00	0.18	5.87	0.03	5.17	0.03
40.00	0.21	7.25	0.04	5.33	0.03
45.00	0.25	9.21	0.05	5.65	0.03
50.00	0.30	10.22	0.06	6.08	0.03
55.00	0.35	6.98	0.04	6.36	0.04
60.00	0.36	-6.12	-0.03	5.96	0.03
65.00	0.26	-37.51	-0.21	3.97	0.02
70.00	0.00	-98.98	-0.55	-0.97	-0.00

A.3.9

x=30cm.

r (mm)	V (m/s)	∂V/∂r (1/s)	$\frac{\partial V}{\partial r}\left(\frac{D_P}{U_b}\right)$	V/r (1/s)	$\frac{V}{r}\left(\frac{D_P}{U_b}\right)$
5.00	0.02	2.65	0.01	4.63	0.03
10.00	0.04	5.43	0.03	4.46	0.02
15.00	0.07	4.93	0.03	4.75	0.03
20.00	0.09	4.83	0.03	4.74	0.03
25.00	0.12	6.07	0.03	4.88	0.03
30.00	0.15	6.86	0.04	5.16	0.03
35.00	0.19	6.65	0.04	5.39	0.03
40.00	0.22	6.65	0.04	5.54	0.03
45.00	0.26	7.23	0.04	5.70	0.03
50.00	0.29	6.42	0.04	5.84	0.03
55.00	0.31	1.65	0.01	5.71	0.03
60.00	0.30	-6.81	-0.04	5.04	0.03
65.00	0.23	-25.01	-0.14	3.56	0.02
70.00	0.00	-112.64	-0.63	-0.80	-0.00

A.3.10

x=33cm.

r (mm)	V (m/s)	∂V/∂r (1/s)	$\frac{\partial V}{\partial r}\left(\frac{D_p}{U_b}\right)$	V/r (1/s)	$\frac{V}{r}\left(\frac{D_p}{U_b}\right)$
5.00	0.03	4.24	0.02	5.97	0.03
10.00	0.05	3.39	0.02	4.79	0.03
15.00	0.07	4.05	0.02	4.41	0.02
20.00	0.09	4.92	0.03	4.44	0.02
25.00	0.11	5.49	0.03	4.60	0.03
30.00	0.14	5.76	0.03	4.77	0.03
35.00	0.17	6.00	0.03	4.93	0.03
40.00	0.20	6.45	0.04	5.09	0.03
45.00	0.24	7.04	0.04	5.27	0.03
50.00	0.27	7.16	0.04	5.46	0.03
60.00	0.32	-1.02	-0.00	5.32	0.03
65.00	0.28	-15.88	-0.09	4.33	0.02
70.00	0.14	-33.33	-0.19	1.95	0.01
73.40	0.00	-41.18	-0.23	-2.71	-0.02

A.3.11

x=36cm.

r (mm)	V (m/s)	∂V/∂r (1/s)	$\frac{\partial V}{\partial r}\left(\frac{D_p}{U_b}\right)$	V/r (1/s)	$\frac{V}{r}\left(\frac{D_p}{U_b}\right)$
5.00	0.03	4.28	0.02	5.96	0.03
10.00	0.05	3.33	0.02	4.77	0.03
15.00	0.07	4.08	0.02	4.39	0.02
20.00	0.09	5.18	0.03	4.45	0.02
25.00	0.12	5.97	0.03	4.69	0.03
30.00	0.15	6.27	0.03	4.93	0.03
35.00	0.18	6.25	0.03	5.12	0.03
40.00	0.21	6.10	0.03	5.26	0.03
45.00	0.24	5.94	0.03	5.34	0.03
50.00	0.27	5.53	0.03	5.38	0.03
55.00	0.29	4.10	0.02	5.34	0.03
60.00	0.31	0.15	0.00	5.10	0.03
65.00	0.29	-8.78	-0.05	4.42	0.02

A.3.12

x=39cm.

r (mm)	V (m/s)	∂V/∂r (1/s)	$\frac{\partial V}{\partial r}\left(\frac{D_P}{U_b}\right)$	V/r (1/s)	$\frac{V}{r}\left(\frac{D_P}{U_b}\right)$
5.00	0.01	3.56	0.02	2.79	0.01
10.00	0.03	4.45	0.02	3.42	0.02
15.00	0.06	4.95	0.02	3.85	0.02
20.00	0.08	5.27	0.03	4.17	0.02
25.00	0.11	5.57	0.03	4.42	0.02
30.00	0.14	5.89	0.03	4.64	0.03
35.00	0.17	6.18	0.03	4.84	0.03
40.00	0.20	6.28	0.03	5.02	0.03
45.00	0.23	5.95	0.03	5.14	0.03
50.00	0.26	4.82	0.03	5.18	0.03
55.00	0.28	2.46	0.01	4.67	0.03
65.00	0.26	-8.27	-0.05	3.95	0.02
70.00	0.19	-18.02	-0.10	2.71	0.02
77.20	0.00	-86.36	-0.48	0.00	0.00

A.3.13

x=42cm.

r (mm)	(m/s)	∂V/∂r (1/s)	$\frac{\partial V}{\partial r}\left(\frac{D_P}{U_b}\right)$	V/r (1/s)	$\frac{V}{r}\left(\frac{D_P}{U_b}\right)$
5.00	0.01	2.64	0.01	2 32	0.01
10.00	0.03	3.67	0.02	2.74	0.02
15.00	0.05	4.50	0.02	3.19	0.02
20.00	0.07	5.18	0.03	3.61	0.02
25.00	0.10	5.69	0.03	3.98	0.02
30.00	0.13	6.02	0.03	4.29	0.02
35.00	0.16	6.09	0.03	4.55	0.03
40.00	0.19	5.80	0.03	4.73	0.03
45.00	0.22	5.05	0.03	4.81	0.03
50.00	0.24	3.66	0.02	4.77	0.03
55.00	0.25	1.45	0.00	4.58	0.03
60.00	0.25	-1.79	-0.01	4.19	0.02
65.00	0.23	-6.32	-0.04	3.56	0.02
70.00	0.18	-17.00	-0.09	2.57	0.01
75.00	0.06	-18.56	-0.10	0.80	0.00
79.2	0.00	-19.60	0.00	0.00	0.00

A.3.14

x=45cm.

r (mm)	V (m/s)	∂V/∂r (1/s)	$\frac{\partial V}{\partial r}\left(\frac{D_P}{U_b}\right)$	V/r (1/s)	$\frac{V}{r}\left(\frac{D_P}{U_b}\right)$
5.00	0.01	2.13	0.01	1.59	0.01
10.00	0.02	3.48	0.02	2.21	0.01
15.00	0.04	4.61	0.03	2.83	0.02
20.00	0.07	5.47	0.03	3.39	0.02
25.00	0.10	6.03	0.02	3.86	0.02
30.00	0.13	6.25	0.03	4.25	0.02
35.00	0.16	6.07	0.03	4.53	0.03
40.00	0.19	5.46	0.03	4.69	0.03
45.00	0.21	4.38	0.02	4.72	0.03
50.00	0.23	2.77	0.02	4.61	0.03
55.00	0.24	0.58	0.00	4.35	0.02
60.00	0.24	-2.23	-0.01	3.92	0.02
65.00	0.22	-5.71	-0.03	3.32	0.02
70.00	0.18	-9.93	-0.06	2.53	0.01
75.00	0.11	-14.94	-0.08	1.53	0.00
80.00	0.03	-20.79	-0.12	0.32	0.00

A.3.15

x=48cm.

r (mm)	V (m/s)	∂V/∂r (1/s)	$\frac{\partial V}{\partial r}\left(\frac{D_P}{U_b}\right)$	V/r (1/s)	$\frac{V}{r}\left(\frac{D_P}{U_b}\right)$
5.00	0.01	2.62	0.01	2.62	0.01
10.00	0.03	3.51	0.02	2.85	0.02
15.00	0.05	4.29	0.02	3.20	0.02
20.00	0.07	4.91	0.03	3.55	0.02
25.00	0.10	5.31	0.03	3.87	0.02
30.00	0.12	5.45	0.03	4.13	0.02
35.00	0.15	5.29	0.03	4.31	0.02
40.00	0.18	4.78	0.03	4.40	0.02
45.00	0.20	3.88	0.02	4.40	0.02
50.00	0.21	2.56	0.01	4.28	0.02
55.00	0.22	0.78	0.00	4.05	0.02
60.00	0.22	-1.48	-0.01	3.68	0.02
65.00	0.21	-4.26	-0.02	3.18	0.02
70.00	0.18	-7.57	-0.04	2.54	0.01
75.00	0.13	-11.44	-0.06	1.74	0.01
80.00	0.06	-15.88	-0.09	0.78	0.00

A.3.16
x=51cm.

r (mm)	V (m/)	∂V/∂r (1/s)	$\frac{\partial V}{\partial r}\left(\frac{D_P}{U_b}\right)$	V/r (1/s)	$\frac{V}{r}\left(\frac{D_P}{U_b}\right)$
5.00	0.0	5.62	0.03	5.73	0.03
10.00	0.05	4.96	0.03	5.50	0.03
15.00	0.08	4.56	0.03	5.24	0.03
20.00	0.10	4.32	0.02	5.04	0.03
25.00	0.12	4.14	0.02	4.88	0.03
30.00	0.14	3.95	0.02	4.74	0.03
35.00	0.16	3.66	0.02	4.61	0.03
40.00	0.18	3.20	0.02	4.46	0.02
45.00	0.19	2.52	0.01	4.29	0.02
50.00	0.20	1.55	0.01	4.06	0.02
55.00	0.21	0.25	0.00	3.78	0.02
60.00	0.21	-1.42	-0.01	3.42	0.02
65.00	0.19	-3.50	-0.02	2.97	0.02
70.00	0.17	-6.00	-0.03	2.42	0.01
75.00	0.13	-8.96	-0.05	1.76	0.01
80.00	0.08	-12.37	-0.07	0.99	0.01
85.00	0.01	-16.24	-0.09	0.09	0.00

A.3.17
x=54cm.

r (mm)	V (m/s	∂V/∂r (m/s)	$\frac{\partial V}{\partial r}\left(\frac{D_P}{U_b}\right)$	V/r (1/s)	$\frac{V}{r}\left(\frac{D_P}{U_b}\right)$
5.00	0.01	3.14	0.02	2.70	0.01
10.00	0.03	3.89	0.02	3.13	0.02
15.00	0.05	4.20	0.02	3.44	0.02
20.00	0.07	4.25	0.02	3.64	0.02
25.00	0.09	4.14	0.02	3.76	0.02
30.00	0.11	3.96	0.02	3.81	0.02
35.00	0.13	3.75	0.02	3.81	0.02
40.00	0.15	3.50	0.02	3.79	0.02
45.00	0.17	3.19	0.02	3.74	0.02
50.00	0.18	2.72	0.02	3.66	0.02
55.00	0.20	1.98	0.01	3.55	0.02
60.00	0.20	0.82	0.01	3.37	0.02
65.00	0.20	-0.98	-0.01	3.11	0.02
70.00	0.19	-3.65	-0.02	2.73	0.02
75.00	0.16	-7.47	-0.04	2.18	0.01
80.00	0.11	-12.75	-0.07	1.42	0.01
85.00	0.03	-19.86	-0.11	0.39	0.00
90.00	-0.09	-29.20	-0.16	-0.98	-0.01

A.3.18
x=57cm.

r (mm)	V (m/s)	∂V/∂r (1/s)	$\frac{\partial V}{\partial r}\left(\frac{D_P}{U_b}\right)$	V/r (1/s)	$\frac{V}{r}\left(\frac{D_P}{U_b}\right)$
0.00	0.00	2.00	0.01	-	-
5.00	0.01	2.97	0.02	2.50	0.01
10.00	0.03	3.83	0.02	2.98	0.02
15.00	0.05	4.14	0.02	3.33	0.02
20.00	0.07	4.11	0.02	3.53	0.02
25.00	0.09	3.91	0.02	3.63	0.02
30.00	0.11	3.65	0.02	3.65	0.02
35.00	0.13	3.41	0.02	3.64	0.02
40.00	0.14	3.21	0.02	3.60	0.02
45.00	0.16	3.02	0.02	3.54	0.02
50.00	0.17	2.76	0.02	3.48	0.02
55.00	0.19	2.31	0.01	3.39	0.02
60.00	0.20	1.51	0.01	3.27	0.02
65.00	0.20	0.12	0.00	3.09	0.02
70.00	0.20	-2.11	-0.01	2.80	0.02
75.00	0.18	-5.51	-0.03	2.37	0.01
80.00	0.14	-10.44	-0.06	1.73	0.01
85.00	0.07	-17.32	-0.10	0.82	0.01

A.3.19
x=60cm.

r (mm)	V (m/s)	∂V/∂r (1/s)	$\frac{\partial V}{\partial r}\left(\frac{D_P}{U_b}\right)$	V/r (1/s)	$\frac{V}{r}\left(\frac{D_P}{U_b}\right)$
0.00	0.00	2.00	0.01	-	-
5.00	0.01	2.67	0.01	2.10	0.01
10.00	0.03	3.84	0.02	2.72	0.02
15.00	0.05	4.26	0.02	3.18	0.02
20.00	0.07	4.20	0.02	3.45	0.02
25.00	0.09	3.88	0.02	3.57	0.02
30.00	0.11	3.47	0.02	3.59	0.02
35.00	0.12	3.10	0.02	3.54	0.02
40.00	0.14	2.82	0.02	3.47	0.02
45.00	0.15	2.63	0.01	3.39	0.02
50.00	0.17	2.49	0.01	3.30	0.02
55.00	0.18	2.31	0.01	3.22	0.02
60.00	0.19	1.91	0.01	3.13	0.02
65.00	0.20	1.09	0.01	3.01	0.02
70.00	0.20	-0.42	-0.00	2.82	0.02
75.00	0.19	-2.93	-0.02	2.53	0.01
80.00	0.17	-6.83	-0.04	2.08	0.01
85.00	0.12	-12.55	-0.07	1.39	0.01
90.00	0.0	-20.56	-0.11	0.41	0.00

A.3.20 x=63cm

r (mm)	V (m/s	∂V/∂r (1/s)	$\frac{\partial V}{\partial r}\left(\frac{D_P}{U_b}\right)$	V/r (1/s)	$\frac{V}{r}\left(\frac{D_P}{U_b}\right)$
5.00	0.01	2.95	0.02	2.50	0.01
10.00	0.03	3.46	0.02	2.87	0.02
15.00	0.05	3.71	0.02	3.11	0.02
20.00	0.07	3.81	0.02	3.28	0.02
25.00	0.08	3.79	0.02	3.38	0.02
30.00	0.10	3.64	0.02	3.44	0.02
35.00	0.12	3.36	0.02	3.45	0.02
40.00	0.14	2.98	0.02	3.42	0.02
45.00	0.15	2.54	0.01	3.34	0.02
50.00	0.16	2.10	0.01	3.24	0.02
55.00	0.17	1.72	0.01	3.12	0.02
60.00	0.18	1.40	0.01	2.99	0.02
65.00	0.19	1.08	0.01	2.86	0.02
70.00	0.19	0.52	0.00	2.71	0.02
75.00	0.19	-0.74	0.00	2.53	0.01
80.00	0.18	-3.45	-0.02	2.25	0.01
85.00	0.15	-8.80	-0.05	1.77	0.01
90.0	0.08	- 8.48	-0.10	0.94	0.01

A.3.21 x=66cm.

r (mm)	V (m/s)	∂V/∂r (1/s)	$\frac{\partial V}{\partial r}\left(\frac{D_P}{U_b}\right)$	V (1/s)	$\frac{V}{r}\left(\frac{D_P}{U_b}\right)$
0.000	0.000	4.000	0.022	-	-
5.000	0.021	3.758	0.021	4.171	0.023
10.000	0.039	3.447	0.019	3.857	0.021
15.000	0.056	3.610	0.020	3.740	0.021
20.000	0.075	3.862	0.021	3.740	0.021
25.000	0.094	3.968	0.022	3.779	0.021
30.000	0.114	3.825	0.021	3.802	0.021
35.000	0.132	3.422	0.019	3.780	0.021
40.000	0.148	2.817	0.016	3.699	0.021
45.000	0.160	2.109	0.012	3.562	0.020
50.000	0.169	1.404	0.008	3.381	0.019
55.000	0.174	0.791	0.004	3.172	0.018
60.000	0.177	0.311	0.002	2.953	0.016
65.000	0.178	-0.073	0.000	2.735	0.015
70.000	0.176	-0.504	-0.003	2.520	0.014
75.000	0.172	-1.259	-0.007	2.296	0.013
80.000	0.163	-2.781	-0.015	2.032	0.011
85.000	0.142	-5.704	-0.032	1.671	0.009
90.000	0.102	-10.885	-0.060	1.130	0.006
95.000	0.028	-11.000	-0.108	0.291	0.002

A.3.22 x=69cm.

r (mm)	V (m/s)	∂V/∂r (1/s)	$\frac{\partial V}{\partial r}\left(\frac{D_P}{U_b}\right)$	V/r (1/s)	$\frac{V}{r}\left(\frac{D_P}{U_b}\right)$
0.000	0.000	3.600	0.020	-	-
5.000	0.018	3.468	0.019	3.588	0.020
10.000	0.035	3.347	0.019	3.480	0.019
15.000	0.052	3.487	0.019	3.456	0.019
20.000	0.070	3.634	0.020	3.484	0.019
25.000	0.088	3.646	0.020	3.518	0.020
30.000	0.106	3.469	0.019	3.527	0.020
35.000	0.122	3.114	0.017	3.496	0.019
40.000	0.137	2.636	0.015	3.419	0.019
45.000	0.149	2.111	0.012	3.303	0.018
50.000	0.158	1.616	0.009	3.158	0.018
55.000	0.165	1.202	0.007	2.999	0.017
60.000	0.170	0.877	0.005	2.835	0.016
65.000	0.174	0.581	0.003	2.673	0.015
70.000	0.176	0.164	0.001	2.510	0.014
75.000	0.175	-0.636	-0.004	2.330	0.013
80.000	0.168	-2.213	-0.012	2.101	0.012
85.000	0.150	-5.121	-0.028	1.769	0.010
90.000	0.113	-10.091	-0.056	1.260	0.007
95.000	0.045	-18.053	-0.100	0.469	0.003
97.900	0.000	-15.510	-0.086	0.000	0.000

A.3.23 x=72cm.

r (mm)	V (m/s)	∂V/∂r (1/s)	$\frac{\partial V}{\partial r}\left(\frac{D_P}{U_b}\right)$	V/r (1/s)	$\frac{V}{r}\left(\frac{D_P}{U_b}\right)$
0.000	0.000	3.600	0.020	-	-
5.000	0.018	3.390	0.019	3.602	0.020
10.000	0.034	3.033	0.017	3.382	0.019
15.000	0.049	3.082	0.017	3.267	0.018
20.000	0.065	3.252	0.018	3.242	0.018
25.000	0.081	3.364	0.019	3.257	0.018
30.000	0.098	3.328	0.018	3.274	0.018
35.000	0.114	3.122	0.017	3.269	0.018
40.000	0.129	2.774	0.015	3.230	0.018
45.000	0.142	2.338	0.013	3.156	0.018
50.000	0.153	1.880	0.010	3.051	0.017
55.000	0.161	1.455	0.008	2.925	0.016
60.000	0.167	1.089	0.006	2.787	0.015
65.000	0.172	0.757	0.004	2.643	0.015
70.000	0.175	0.365	0.002	2.495	0.014
75.000	0.175	-0.268	-0.001	2.334	0.013
80.000	0.171	-1.434	-0.008	2.139	0.012
85.000	0.159	-3.549	-0.020	1.872	0.010
90.000	0.133	-7.182	-0.040	1.479	0.008
95.000	0.084	-13.065	-0.073	0.880	0.005
100.000	0.000	-18.118	-0.100	0.000	0.000

TABLES A.4.1-A.4.18: DISTRIBUTION OF MEAN RADIAL VELOCITY, V AND SHEAR STRAIN RATE, ∂V/∂x, IN AXIAL DIRECTION OF DIFFUSER

A.4.1

Radius=5mm

x (cm)	V (m/s)	$\frac{\partial V}{\partial x}$ (1/s)	$\frac{\partial V}{\partial x}\left(\frac{D_P}{U_b}\right)$
0.00	0.00	2.00	0.011
1.00	0.02	2.00	0.011
2.00	0.03	1.00	0.006
3.00	0.05	1.00	0.006
4.00	0.05	1.00	0.000
5.00	0.06	0.00	0.000
6.00	0.06	0.00	0.000
7.00	0.06	0.00	0.000
8.00	0.06	0.00	0.000
9.00	0.06	0.00	0.000
10.00	0.06	0.00	0.000
12.00	0.06	0.00	0.000
15.00	0.05	0.00	0.000
18.00	0.04	0.00	0.000
21.00	0.04	-0.10	0.000
24.00	0.03	-0.10	0.000
27.00	0.03	-0.10	0.000
30.00	0.02	-0.10	0.000
33.00	0.02	-0.10	0.000
36.00	0.03	-0.10	0.000
39.00	0.01	-0.10	0.000
42.00	0.01	0.00	0.000
45.00	0.01	0.00	0.000
48.00	"	"	0.000
51.00	"	"	0.000
54.00	"	"	0.000
.			0.000
.			0.000
72.00	"	"	0.000

Table A.4.2

Radius=10mm

x (cm)	V (m/s)	$\frac{\partial V}{\partial x}$ (1/s)	$\frac{\partial V}{\partial x}\left(\frac{D_P}{U_b}\right)$
0.000	0.00	4.70	0.026
1.000	0.04	3.40	0.018
2.000	0.07	2.50	0.014
3.000	0.08	1.70	0.009
4.000	0.08	1.10	0.006
5.000	0.09	0.60	0.003
6.000	0.10	0.20	0.001
7.000	0.12	0.00	0.000
8.000	0.12	-0.20	-0.001
9.000	0.12	-0.30	-0.002
10.000	0.12	-0.30	-0.002
11.000	0.11	-0.40	-0.002
12.000	0.10	-0.40	-0.002
13.000	0.11	-0.40	-0.002
14.000	0.10	-0.40	-0.002
15.000	0.08	-0.30	-0.002
16.000	0.09	-0.30	-0.002
17.000	0.09	-0.30	-0.002
18.000	0.08	-0.30	-0.002
19.000	0.08	-0.30	-0.002
20.000	0.08	-0.20	-0.001
21.000	0.08	-0.10	-0.000
22.000	0.08	0.00	0.000
23.000	0.08	0.10	0.000
24.000	0.07	0.40	0.002
25.000	0.09	0.70	0.004
26.000	0.09	1.10	0.006
.	"	"	"
.	"	"	"
72.000	0.09	1.10	0.006

A.4.3

Radius=15mm

x (cm)	V (m/s)	$\frac{\partial V}{\partial x}$ (1/s)	$\frac{\partial V}{\partial x}\left(\frac{D_P}{U_b}\right)$
0.00	0.00	6.00	0.033
1.00	0.06	4.70	0.026
2.00	0.10	3.50	0.019
3.00	0.13	2.50	0.014
4.00	0.15	1.70	0.009
5.00	0.16	1.00	0.006
6.00	0.16	0.40	0.002
7.00	0.16	0.00	0.000
8.00	0.16	-0.40	-0.002
9.00	0.16	-0.60	-0.003
10.00	0.16	-0.70	-0.004
11.00	0.15	-0.80	-0.004
12.00	0.15	-0.70	-0.004
13.00	0.14	-0.70	-0.004
14.00	0.13	-0.60	-0.003
15.00	0.13	-0.50	-0.003
16.00	0.12	-0.40	-0.002
17.00	0.12	-0.30	-0.002
18.00	0.12	-0.40	-0.002
19.00	0.11	-0.50	-0.003
20.00	0.11	-0.70	-0.004
21.00	0.11	-1.00	-0.006
22.00	0.08	-1.60	-0.009
23.00	0.07	-2.30	-0.013
24.00	0.04	-3.30	-0.018
25.00	0.00	-2.60	-0.014
26.00	0.00	-1.70	-0.009
.	"	"	"
.	"	"	"
72.00	0.00	-1.70	-0.009

A.4.4

Radius=20mm

x (cm)	V (m/s)	$\frac{\partial V}{\partial x}$ (1/s)	$\frac{\partial V}{\partial x}\left(\frac{D_P}{U_b}\right)$
0.00	0.00	7.20	0.04
1.00	0.08	5.80	0.032
2.00	0.13	4.60	0.026
3.00	0.17	3.40	0.019
4.00	0.20	2.40	0.013
5.00	0.22	1.50	0.008
6.00	0.22	0.70	0.004
7.00	0.22	0.10	0.000
8.00	0.24	-0.40	-0.002
9.00	0.22	-0.80	-0.004
10.00	0.22	-1.00	-0.005
11.00	0.21	-1.10	-0.006
12.00	0.20	-1.10	-0.006
13.00	0.19	-1.10	-0.006
14.00	0.18	-0.90	-0.005
15.00	0.17	-0.80	-0.004
16.00	0.16	-0.60	-0.003
17.00	0.16	-0.40	-0.002
18.00	0.15	-0.40	-0.002
19.00	0.15	-0.40	-0.002
20.00	0.14	-0.50	-0.003
21.00	0.14	-0.90	-0.005
22.00	0.13	-1.40	-0.008
23.00	0.13	-2.30	-0.013
24.00	0.13	-3.50	-0.019
25.00	0.04	-5.10	-0.028
26.00	0.04	0.00	0.000
.	0.04	0.00	0.000
.	"	"	"
72.00	0.04	0.00	0.000

A.4.5

Radius=25mm

x (cm)	V (m/s)	$\frac{\partial V}{\partial x}$ (1/s)	$\frac{\partial V}{\partial x}\left(\frac{D_P}{U_b}\right)$
0.00	0.00	10.60	0.058
1.00	0.12	8.00	0.044
2.00	0.19	5.80	0.032
3.00	0.22	4.00	0.022
4.00	0.27	2.50	0.014
5.00	0.29	1.30	0.007
6.00	0.29	0.30	0.002
7.00	0.30	-0.40	-0.002
8.00	0.30	-0.80	-0.004
9.00	0.27	-1.20	-0.007
10.00	0.27	-1.30	-0.007
11.00	0.26	-1.30	-0.007
12.00	0.23	-1.30	-0.007
13.00	0.23	-1.20	-0.007
14.00	0.22	-1.00	-0.005
15.00	0.21	-0.80	-0.004
16.00	0.21	-0.70	-0.004
17.00	0.20	-0.50	-0.003
18.00	0.19	-0.50	-0.003
19.00	0.19	-0.50	-0.003
20.00	0.18	-0.70	-0.004
21.00	0.18	-1.00	-0.005
22.00	0.16	-1.40	-0.007
23.00	0.15	-2.00	-0.011
24.00	0.16	-2.90	-0.016
25.00	0.09	-3.90	-0.022
26.00	0.04	-5.20	-0.029
.	0.04	0.00	0.000
.	"	"	"
.	"	"	"
72.00	0.04	0.00	0.000

A.4.6

Radius=30mm

x (mm)	V (m/s)	$\frac{\partial V}{\partial x}$ (1/s)	$\frac{\partial V}{\partial x}\left(\frac{D_P}{U_b}\right)$
0.00	0.00	19.50	0.197
1.00	0.14	9.50	0.052
2.00	0.21	5.20	0.029
3.00	0.26	3.90	0.020
4.00	0.29	3.90	0.020
5.00	0.33	3.60	0.020
6.00	0.36	2.40	0.013
7.00	0.38	2.00	-0.011
8.00	0.37	-2.50	-0.013
9.00	0.33	-4.40	-0.024
10.00	0.32	-1.50	-0.008
12.00	0.28	-1.40	-0.007
15.00	0.25	-1.10	-0.006
18.00	0.23	-0.90	-0.005
21.00	0.22	-0.80	-0.005
24.00	0.19	-0.60	-0.003
27.00	0.15	-0.50	-0.003
30.00	0.15	-0.40	-0.002
33.00	0.14	-0.30	-0.002
36.00	0.14	-0.20	-0.001
39.00	0.14	-0.20	-0.001
42.00	0.13	-0.20	-0.001
45.00	0.13	-0.10	-0.001
48.00	0.12	-0.10	-0.001
51.00	0.11	-0.10	-0.001
54.00	0.11	-0.10	-0.001
57.00	0.11	-0.10	-0.001
60.00	0.10	-0.10	-0.001
63.00	0.10	-0.10	-0.001
66.00	0.10	0.00	0.000
69.00	0.10	0.00	0.000
70.00	0.10	0.00	0.000
71.00	0.10	0.00	0.000
72.00	0.10	0.00	0.000

A.4.7

Radius=35mm

x (cm)	V (m/s)	$\frac{\partial V}{\partial x}$ (1/s)	$\frac{\partial V}{\partial x}\left(\frac{D_P}{U_b}\right)$
0.00	0.00	20.40	0.110
1.00	0.16	11.50	0.064
2.00	0.25	7.00	0.039
3.00	0.31	5.10	0.028
4.00	0.35	4.50	0.025
5.00	0.40	4.10	0.022
6.00	0.43	3.00	0.017
7.00	0.45	0.80	0.004
8.00	0.44	-2.90	-0.016
9.00	0.39	-2.20	-0.012
12.00	0.33	-1.70	-0.009
15.00	0.29	-1.30	-0.007
18.00	0.26	-1.00	-0.006
21.00	0.25	-0.80	-0.004
24.00	0.23	-0.70	-0.004
27.00	0.20	-0.50	-0.003
30.00	0.19	-0.40	-0.002
33.00	0.17	-0.40	-0.002
36.00	0.16	-0.30	-0.017
39.00	0.17	-0.30	-0.017
42.00	0.16	-0.30	-0.017
45.00	0.16	-0.20	-0.001
48.00	0.15	-0.20	-0.001
51.00	0.13	-0.10	-0.001
54.00	0.13	-0.10	-0.001
57.00	0.13	-0.10	-0.001
60.00	0.13	0.00	0.000
63.00	0.13	0.00	0.000
66.00	0.13	0.00	0.000
69.00	0.13	-0.01	-0.001
70.00	0.13	-0.01	-0.001
71.00	0.13	-0.02	-0.001
72.00	0.13	0.00	0.000

A.4.8

Radius=40mm

x (cm)	V (m/s)	$\frac{\partial V}{\partial x}$ (1/s)	$\frac{\partial V}{\partial x}\left(\frac{D_P}{U_b}\right)$
0.00	0.00	23.40	0.130
1.00	0.18	13.20	0.070
2.00	0.28	8.40	0.047
3.00	0.35	6.50	0.036
4.00	0.41	5.70	0.032
5.00	0.47	4.60	0.025
6.00	0.49	2.70	0.015
7.00	0.52	-0.40	-0.002
8.00	0.49	-0.40	-0.022
9.00	0.44	-0.73	-0.040
10.00	0.43	-0.24	-0.013
12.00	0.39	-0.20	-0.011
15.00	0.34	-0.15	-0.008
18.00	0.29	-1.10	-0.006
21.00	0.28	-0.90	-0.005
24.00	0.26	-0.70	-0.004
27.00	0.23	-0.50	-0.003
30.00	0.22	-0.40	-0.002
33.00	0.20	-0.40	-0.002
36.00	0.19	-0.30	-0.002
39.00	0.20	-0.30	-0.002
42.00	0.18	-0.30	-0.002
45.00	0.19	-0.30	-0.002
48.00	0.18	-0.20	-0.001
51.00	0.18	-0.20	-0.001
54.00	0.15	-0.20	-0.001
57.00	0.14	-0.20	-0.001
60.00	0.14	-0.10	-0.001
63.00	0.14	-0.10	-0.001
66.00	0.13	-0.10	-0.001
69.00	0.13	-0.10	-0.001
72.00	0.13	-0.10	-0.001

A.4.9

Radius=45mm

x (cm)	V (m/s)	$\frac{\partial V}{\partial x}$ (1/s)	$\frac{\partial V}{\partial x}\left(\frac{D_P}{U_b}\right)$
0.00	0.00	24.70	0.137
1.00	0.20	15.20	0.084
2.00	0.32	9.99	0.055
3.00	0.39	7.30	0.040
4.00	0.47	6.10	0.030
5.00	0.53	5.20	0.030
6.00	0.55	3.50	0.019
7.00	0.59	0.10	0.000
8.00	0.57	-5.60	-0.031
9.00	0.49	-3.00	-0.016
10.00	0.48	-2.70	-0.015
12.00	0.45	-2.20	-0.012
15.00	0.38	-1.50	-0.008
18.00	0.34	-1.10	-0.006
21.00	0.31	-0.80	-0.004
24.00	0.29	-0.60	-0.003
27.00	0.27	-0.50	-0.003
30.00	0.26	-0.50	-0.003
33.00	0.24	-0.40	-0.002
36.00	0.24	-0.50	-0.003
39.00	0.23	-0.50	-0.003
42.00	0.22	-0.40	-0.002
45.00	0.21	-0.40	-0.002
48.00	0.20	-0.40	-0.002
51.00	0.19	-0.30	-0.002
54.00	0.16	-0.20	-0.001
57.00	0.15	-0.20	-0.001
60.00	0.15	-0.10	-0.001
63.00	0.15	0.00	0.000
66.00	0.15	-0.10	-0.001
69.00	0.14	-0.20	-0.001
72.00	0.14	-0.20	-0.001
71.00	0.14	-0.30	-0.002
72.00	0.14	-0.30	-0.002

Table A.4.10

Radius=50mm

x (cm)	V (m/s)	$\frac{\partial V}{\partial x}$ (1/s)	$\frac{\partial V}{\partial x}\left(\frac{D_P}{U_b}\right)$
0.00	0.00	12.20	0.068
1.00	0.15	15.00	0.083
2.00	0.28	13.30	0.074
3.00	0.41	10.10	0.056
4.00	0.49	7.20	0.039
5.00	0.55	5.50	0.031
6.00	0.59	4.30	0.023
7.00	0.64	1.80	0.009
8.00	0.63	-4.90	-0.027
12.00	0.47	-2.30	-0.013
15.00	0.42	-1.60	-0.009
18.00	0.36	-1.10	-0.006
21.00	0.35	-0.70	-0.004
24.00	0.32	-0.50	-0.003
27.00	0.30	-0.40	-0.002
30.00	0.29	-0.40	-0.002
33.00	0.27	-0.40	-0.002
36.00	0.27	-0.50	-0.003
39.00	0.26	-0.50	-0.003
42.00	0.24	-0.50	-0.003
45.00	0.21	-0.50	-0.003
48.00	0.21	-0.50	-0.003
51.00	0.20	-0.40	-0.002
54.00	0.18	-0.30	-0.002
57.00	0.17	-0.20	-0.001
60.00	0.17	-0.10	-0.001
63.00	0.16	0.00	0.000
66.00	0.17	0.00	0.000
69.00	0.17	0.00	0.000
70.00	0.17	0.00	0.000
71.00	0.17	0.10	0.001
72.00	0.17	0.00	0.000

A.4.11

Radius=55mm

x (cm)	V (m/s)	$\frac{\partial V}{\partial x}$ (1/s)	$\frac{\partial V}{\partial x}\left(\frac{D_P}{U_b}\right)$
7.00	0.00	6.00	0.033
9.00	0.50	4.00	0.022
12.00	0.45	-1.20	-0.007
15.00	0.43	-1.00	-0.005
18.00	0.40	-0.80	-0.004
21.00	0.37	-0.70	-0.004
24.00	0.35	-0.60	-0.004
27.00	0.35	-0.60	-0.004
30.00	0.31	-0.60	-0.004
33.00	0.30	-0.60	-0.004
36.00	0.29	-0.60	-0.004
39.00	0.28	-0.60	-0.004
42.00	0.25	-0.60	-0.004
45.00	0.24	-0.50	-0.003
48.00	0.22	-0.50	-0.003
51.00	0.21	-0.40	-0.002
54.00	0.20	-0.30	-0.002
57.00	0.19	-0.30	-0.002
60.00	0.18	-0.20	-0.001
63.00	0.17	-0.20	-0.001
66.00	0.17	-0.10	-0.001
69.00	0.16	-0.20	-0.001
72.00	0.16	-0.20	-0.001

A.4.12

Radius=60mm

x (cm)	V (m/s)	$\frac{\partial V}{\partial x}$ (1/s)	$\frac{\partial V}{\partial x}\left(\frac{D_P}{U_b}\right)$
13.80	0.00	5.00	0.028
15.00	0.06	4.04	0.022
18.00	0.17	3.33	0.018
21.00	0.26	2.38	0.013
24.000	0.21	0.00	0.000
27.000	0.20	-0.64	-0.003
30.000	0.15	-0.70	-0.002
33.000	0.17	-0.72	-0.002
36.000	0.16	-0.68	-0.017
39.000	0.15	-0.62	-0.017
42.000	0.14	-0.53	-0.017
45.000	0.13	-0.42	-0.001
48.000	0.13	-0.31	-0.001
51.000	0.12	-0.21	-0.001
54.000	0.12	-0.13	-0.001
57.000	0.12	-0.07	-0.001
60.000	0.12	0.05	0.000
63.000	0.12	0.08	0.000
66.000	0.11	0.16	0.000
69.000	0.11	-0.31	-0.001
72.000	0.11	-0.54	-0.001

A.4.13

Radius=65mm

x (cm)	V (m/s)	$\frac{\partial V}{\partial x}$ (1/s)	$\frac{\partial V}{\partial x}\left(\frac{D_P}{U_b}\right)$
21.000	0.00	6.00	0.033
24.000	0.25	4.00	0.022
27.000	0.27	1.30	0.007
28.000	0.29	0.90	0.005
30.000	0.30	0.20	0.001
31.000	0.30	0.00	0.000
33.000	0.28	-0.04	-0.002
36.000	0.28	-0.70	-0.004
39.000	0.26	-0.70	-0.004
42.000	0.23	-0.60	-0.003
45.000	0.22	-0.40	-0.002
48.000	0.21	-0.30	-0.002
51.000	0.20	-0.20	-0.001
54.000	0.20	-0.10	-0.000
57.000	0.20	-0.20	-0.001
60.000	0.19	-0.20	-0.001
63.000	0.19	-0.30	-0.002
66.000	0.18	-0.30	-0.002
67.000	0.17	-0.20	-0.001
68.000	0.17	-0.20	-0.001
69.000	0.17	-0.10	-0.000
70.000	0.17	0.00	0.000
71.000	0.17	0.10	0.000
72.000	0.17	0.30	0.002

Table A.4.14

Radius=70mm

x (cm)	V (m/s)	$\frac{\partial V}{\partial x}$ (1/s)	$\frac{\partial V}{\partial x}\left(\frac{D_P}{U_b}\right)$
29.00	0.042	4.40	0.024
30.00	0.081	3.60	0.019
31.00	0.114	2.90	0.016
33.00	0.14	1.80	0.009
34.00	0.17	1.40	0.008
35.00	0.18	1.00	0.006
36.00	0.22	0.70	0.004
37.00	0.20	0.40	0.002
38.00	0.20	0.20	0.001
39.00	0.19	0.00	0.000
40.00	0.19	-0.10	-0.000
41.00	0.19	-0.20	-0.001
42.00	0.18	-0.30	-0.002
45.00	0.19	-0.30	-0.002
48.00	0.18	-0.30	-0.002
51.00	0.17	-0.30	-0.002
54.00	0.17	-0.20	-0.001
57.00	0.15	-0.30	-0.002
60.00	0.15	-0.30	-0.002
63.00	0.14	-0.40	-0.002
66.00	0.13	-0.50	-0.003
69.00	0.11	-0.40	-0.002
70.00	0.11	-0.40	-0.002
71.00	0.11	-0.30	-0.002
72.00	0.11	-0.20	-0.001

A.4.15

Radius=75mm

x (cm)	V (m/s)	$\frac{\partial V}{\partial x}$ (1/s)	$\frac{\partial V}{\partial x}\left(\frac{D_P}{U_b}\right)$
36.000	0.01	2.10	0.011
37.000	0.03	1.80	0.009
38.000	0.05	1.50	0.008
39.000	0.06	1.30	0.007
40.000	0.07	1.10	0.006
41.000	0.08	1.00	0.006
42.000	0.09	0.90	0.005
43.000	0.10	0.80	0.004
44.000	0.11	0.80	0.004
45.000	0.12	0.70	0.004
46.000	0.12	0.70	0.004
47.000	0.13	0.70	0.004
48.000	0.13	0.60	0.003
49.000	0.15	0.60	0.003
50.000	0.15	0.60	0.003
51.000	0.16	0.60	0.003
52.000	0.17	0.50	0.003
53.000	0.17	0.50	0.003
54.000	0.17	0.40	0.002
55.000	0.17	0.40	0.002
56.000	0.18	0.30	0.002
57.000	0.18	0.20	0.001
58.000	0.18	0.20	0.001
59.000	0.19	0.10	0.000
60.000	0.19	0.00	0.000
61.000	0.19	-0.10	-0.000
62.000	0.19	-0.20	-0.001
63.000	0.19	-0.20	-0.001
64.000	0.18	-0.30	-0.002
65.000	0.18	-0.30	-0.002
66.000	0.17	-0.30	-0.002
67.000	0.17	-0.30	-0.002
68.000	0.17	-0.30	-0.002
69.000	0.17	-0.20	-0.002
70.000	0.16	-0.10	-0.000
71.000	0.16	0.10	-0.000
72.000	0.16	0.40	-0.002

A.4.16

Radius=80mm

x (cm)	V (m/s)	$\frac{\partial V}{\partial x}$ (1/s)	$\frac{\partial V}{\partial x}\left(\frac{D_P}{U_b}\right)$
43.00	0.01	1.20	0.007
44.00	0.02	1.10	0.006
45.00	0.03	1.00	0.006
46.00	0.04	1.00	0.006
47.00	0.05	1.00	0.006
48.00	0.06	1.00	0.006
49.00	0.07	1.00	0.006
50.00	0.08	1.10	0.006
51.00	0.09	1.10	0.006
52.00	0.10	1.10	0.006
53.00	0.11	1.10	0.006
54.00	0.11	1.10	0.006
55.00	0.14	1.10	0.006
56.00	0.15	1.00	0.006
57.00	0.16	0.90	0.005
58.00	0.17	0.80	0.004
59.00	0.17	0.70	0.004
60.00	0.17	0.60	0.003
61.00	0.18	0.40	0.002
62.00	0.18	0.20	0.001
63.00	0.18	0.10	0.001
64.00	0.18	-0.10	-0.000
65.00	0.17	-0.20	-0.001
66.00	0.16	-0.30	-0.002
67.00	0.17	-0.30	-0.002
68.00	0.16	-0.30	-0.002
69.00	0.18	-0.20	-0.001
70.00	0.18	0.00	0.000
71.00	0.18	0.20	0.001
72.00	0.19	0.70	0.004

A.4.17

Radius=85mm

x (cm)	V (m/s)	$\frac{\partial V}{\partial x}$ (1/s)	$\frac{\partial V}{\partial x}\left(\frac{D_P}{U_b}\right)$
49.00	0.00	0.20	0.001
50.00	0.00	0.40	0.002
51.00	0.01	0.70	0.004
52.00	0.01	0.90	0.005
53.00	0.02	1.10	0.006
54.00	0.03	1.30	0.007
55.00	0.05	1.40	0.008
56.00	0.06	1.50	0.008
57.00	0.07	1.50	0.008
58.00	0.09	1.50	0.008
59.00	0.11	1.40	0.008
60.00	0.12	1.30	0.008
61.00	0.13	1.10	0.006
62.00	0.14	0.90	0.005
63.00	0.15	0.70	0.004
64.00	0.16	0.40	0.002
65.00	0.16	0.20	0.001
66.00	0.16	0.00	0.000
67.00	0.16	-0.10	-0.000
68.00	0.16	-0.20	-0.001
69.00	0.16	-0.10	-0.000
70.00	0.16	0.10	0.001
71.00	0.17	0.50	0.003
72.00	0.17	1.20	0.007