Institute of Paper Science and Technology
Atlanta, Georgia

SLIDE MATERIAL

to the

PAPERMAKING

PROJECT ADVISORY COMMITTEE

March 23, 1998

INSTITUTE OF PAPER SCIENCE AND TECHNOLOGY
PURPOSE AND MISSIONS

The Institute of Paper Science and Technology is a unique organization whose charitable, educational, and scientific purpose evolves from the singular relationship between the Institute and the pulp and paper industry which has existed since 1929. The purpose of the Institute is fulfilled through three missions, which are:

- to provide high quality students with a multidisciplinary graduate educational experience which is of the highest standard of excellence recognized by the national academic community and which enables them to perform to their maximum potential in a society with a technological base; and
- to sustain an international position of leadership in dynamic scientific research which is participated in by both students and faculty and which is focused on areas of significance to the pulp and paper industry; and
- to contribute to the economic and technical well-being of the nation through innovative educational, informational, and technical services.

ACCREDITATION

The Institute of Paper Science and Technology is accredited by the Commission on Colleges of the Southern Association of Colleges and Schools to award the Master of Science and Doctor of Philosophy degrees.

INSTITUTE OF PAPER SCIENCE AND TECHNOLOGY

Atlanta, Georgia

SLIDE MATERIAL

PAPERMAKING

March 23, 1998

FUNDAMENTALS OF DRYING

SLIDE MATERIAL

FOR

PROJECT F001

March 23, 1998
Institute of Paper Science and Technology
Atlanta, Georgia

FUNDAMENTALS OF DRYING

SPRING 1998

PAPERMAKING PAC PRESENTATION

By: D. Orloff

March 1998

STAFFING & BUDGET

- P.I.: Orloff
- Staff: Phelan, Patterson, Rudman, Bloom, Woods, Dowdell
- Funding:
  - Dues - $190,200
  - DOE/Beloit - $212,800

RESEARCH LINE / ROADMAP

- *Increase paper-machine productivity by 30% over '97 levels via focus on breakthrough forming, dewatering, and drying concepts.*
- *Develop technologies for increased press solids, improved runnability, and methods to control sheet properties and structure.*

OBJECTIVE

- *Develop an understanding and a database for commercialization of advanced water removal systems based on high intensity drying principles.*

BACKGROUND

- *The project seeks to develop and demonstrate impulse drying of board grades of paper.*
- *In recent years IPST has invented a ramp decompression method that shows promise for opening the operating window to allow a wider range of furnishes and refining levels.*

SUMMARY OF RESULTS

- *A U.S. patent on the use of ramped decompression to eliminate delamination was issued on September 23, 1997, as U.S. Patent number 5,669,159.*
- *An apparatus patent issued on March 3, 1998 as U.S. Patent number 5,722,183.*

SUMMARY OF RESULTS

- *Four papers were presented at the 1997 TAPPI Engineering & Papermakers Conference, three were accepted for publication in TAPPI Journal.*

SUMMARY OF RESULTS

- *Experiments on the Beloit X4 machine demonstrated that an earlier roll coating durability problem has been solved.*
- *Experiments also showed that further work on sheet picking, implementation of delamination suppression techniques and CD temperature control were necessary.*

SUMMARY OF RESULTS

- *The Beloit X2 machine was used to resolve issues identified on the Beloit X4 machine.*
- *Two methods of implementing ramp decompression were investigated. One of these was successful.*
- *Techniques to minimize picking were also discovered.*

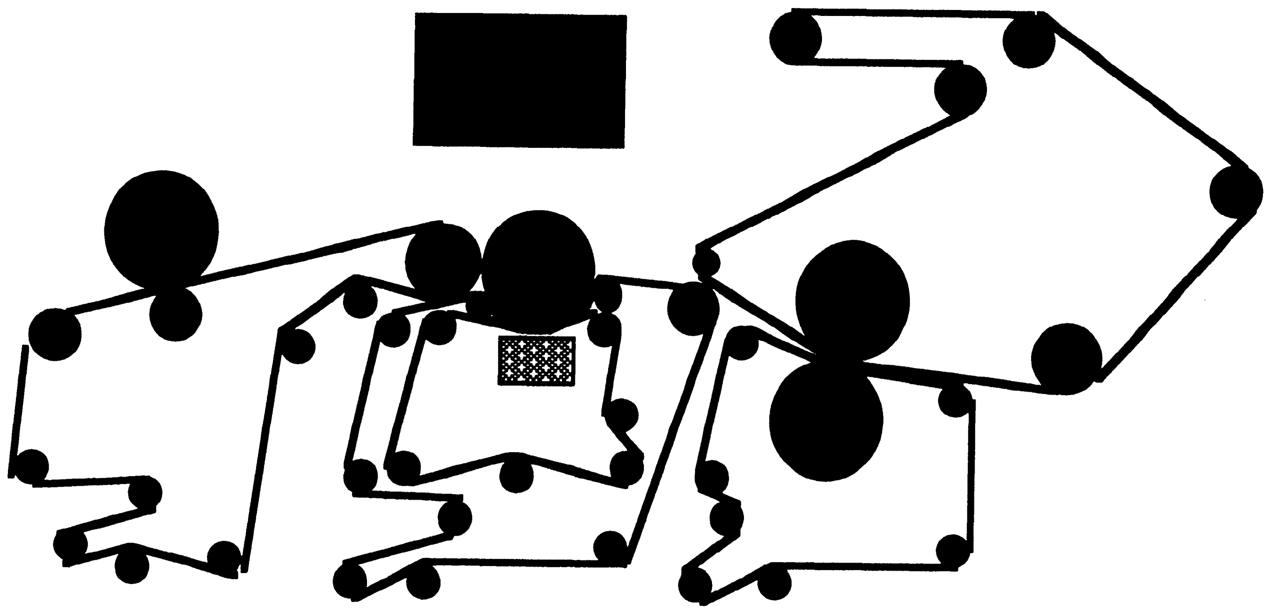
SUMMARY OF RESULTS

- *A proposal, titled "Press and Dryer Roll Surfaces and Web Transfer Systems For Ultra High Paper Machine Speeds," was submitted to the DOE Agenda 2020 capital effectiveness initiative.*

SUMMARY OF RESULTS

- *A report titled "Delamination Bucking and Spalling of Plasma Sprayed Thermal Barrier Coating for Impulse Drying", was completed.*

BELOIT X2 MACHINE



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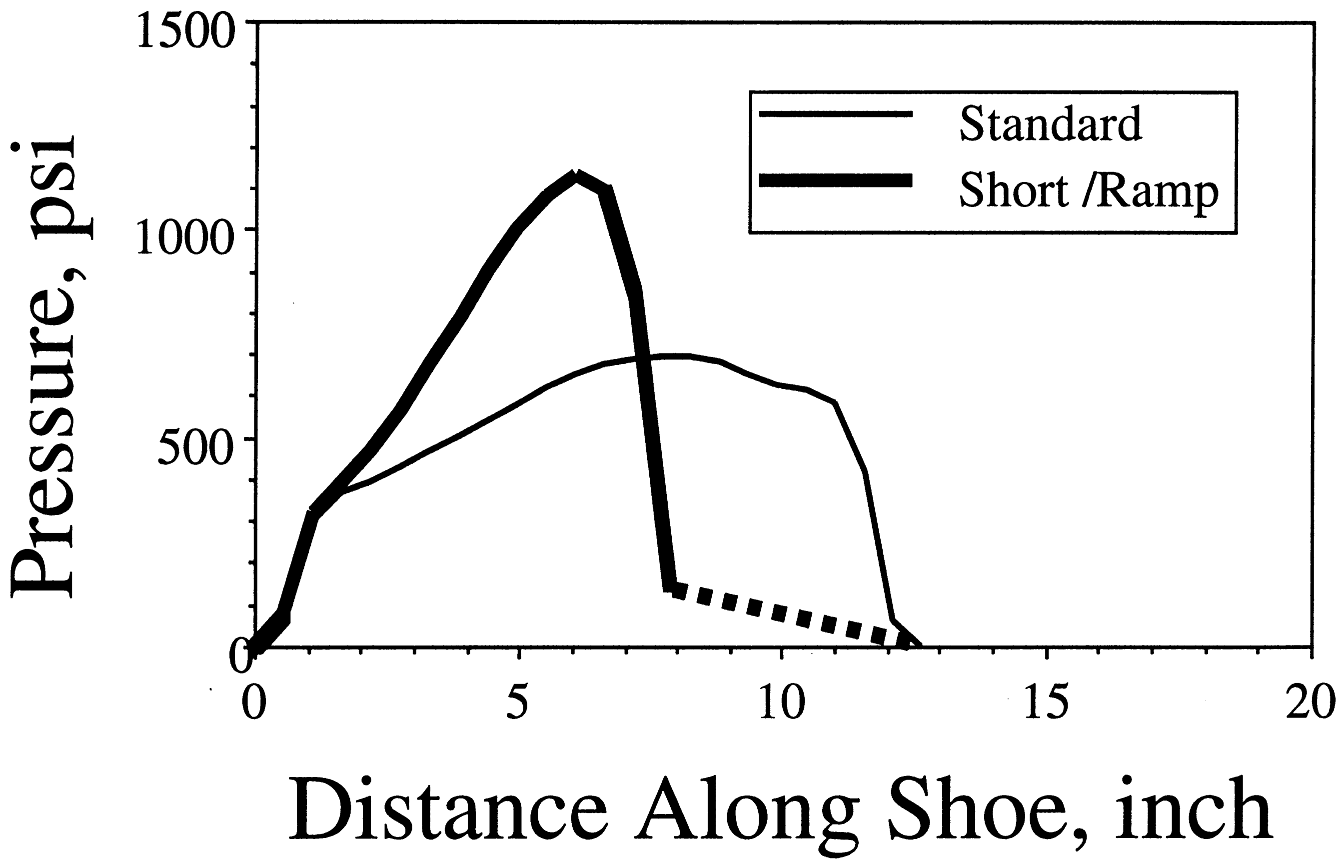
SUMMER' 97 PROFILES



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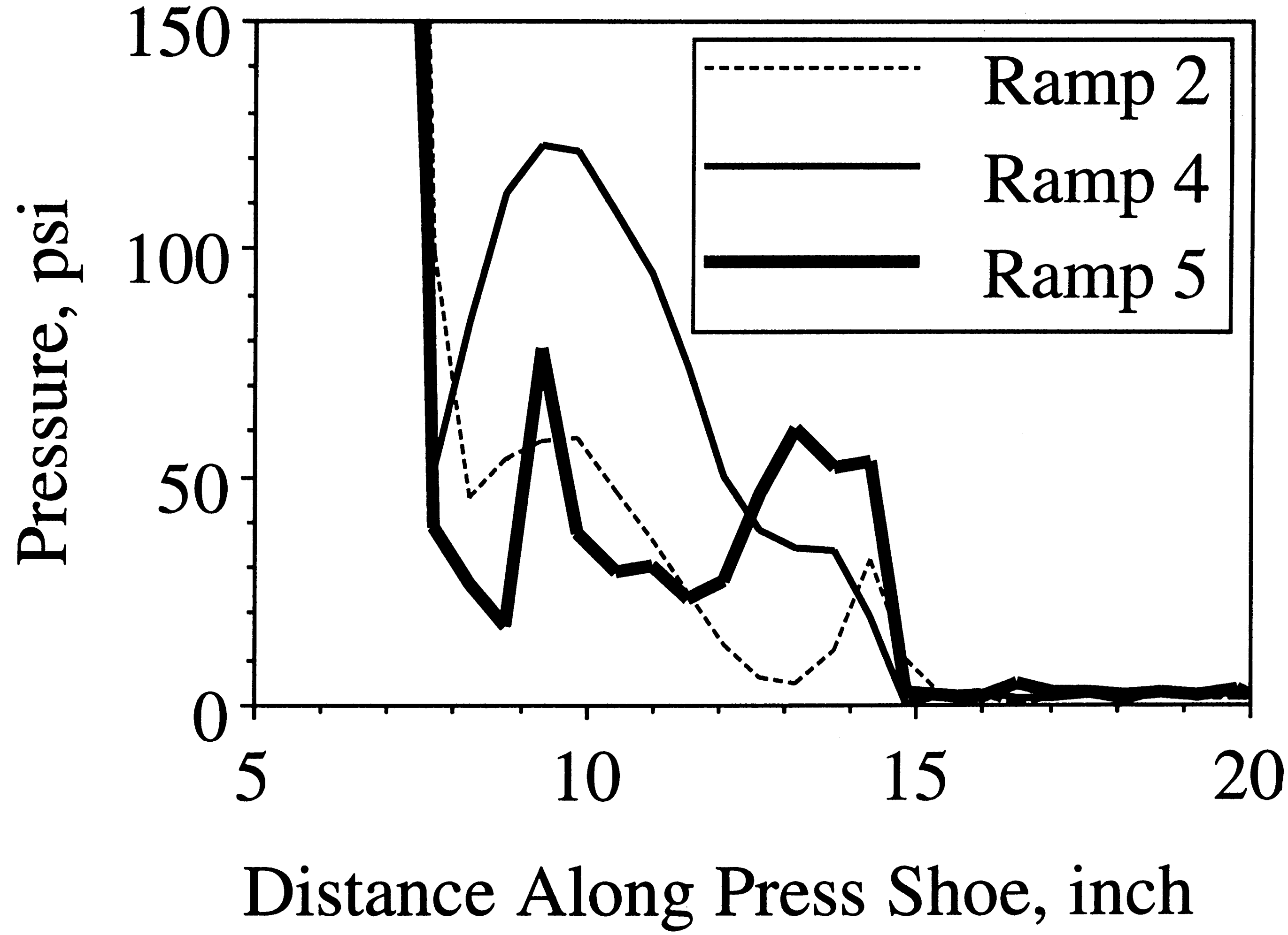
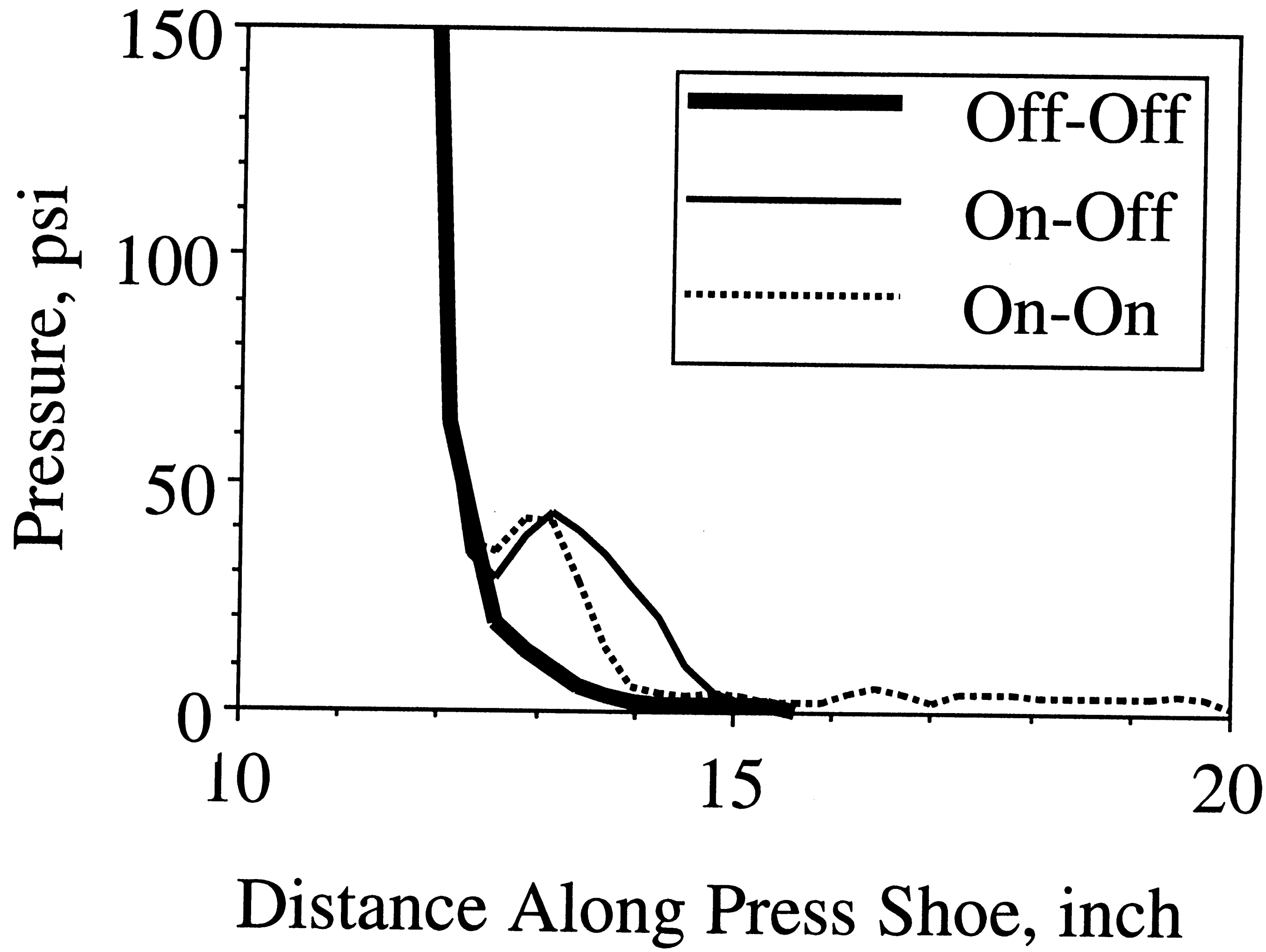
SUMMER' 97 RAMPS



WINTER' 98 RAMPS



OPERATING CONDITIONS

Section	Condition	Summer' 97	Winter' 98
Pressing	Solids In	30 - 32 %	25 - 28 %
	Shoe Type	10-inch standard or 6-inch with ramp	10-inch with ramp
	Felt Serial No.	Al 289250 CSX	Al 289249 CSX
	Wrap Roll	Inside Link	Outside Link
	Blanket	Grooved	Blind Drilled and Grooved

INGOING WEB PROPERTIES

Case	Machine Speeds, ft/min	Freeness, ml CSF	Ingoing Solids, %	Specific Surface, m^2/g
Aug' 97 Ramp 4	1250	570	32.2	3.2
Aug' 97 Ramp 5	1250	570	31.5	4.1
Jan' 98 Ramp 8	1250	540	24.6	6.6
Jan' 98 Ramp 8	1250	458	27.5	11.2
Jan' 98 Ramp 8	2500	460	26.1	15.0

CRITICAL TEMPERATURE

Case	Shoe Press Configuration	$T_{critical}$, °F	
		Blind Drilled	Grooved
Jul' 97, 570 ml CSF, 1250 ft/min	10-inch std.	NA	328
Aug' 97, 570 ml CSF, 1250 ft/min	6-inch w/ ramp 4	NA	424
	6-inch w/ ramp 5	NA	408
Jan' 98. 540 ml CSF, 1250 ft/min	10-inch std. w/ ramp off-hover off	370	398
	10-inch std. w/ ramp on-hover off	421	421
	10-inch std. w/ ramp on-hover on	422	422
Jan' 98. 458 ml CSF, 1250 ft/min	10-inch std. w/ ramp off-hover off	390	390
	10-inch std. w/ ramp on-hover off	450	450
	10-inch std. w/ ramp on-hover on	470	470
Jan' 98. 460 ml CSF, 2500 ft/min	10-inch std. w/ ramp off-hover off	420	420
	10-inch std. w/ ramp on-hover off	442	442

SOLIDS & ROUGHNESS

Case	Shoe Press Configuration	Sout % Incr	Bendtsen % Decr
Jul' 97, 570 ml CSF, 1250 ft/min	10-inch std.	0.02	44.3
Aug' 97, 570 ml CSF, 1250 ft/min	6-inch w/ ramp 4	10.8	51.5
	6-inch w/ ramp 5	10.1	45.4
Jan' 98. 540 ml CSF, 1250 ft/min	10-inch std. w/ ramp off-hover off	5.6	23.0
	10-inch std. w/ ramp on-hover off	4.4	28.2
	10-inch std. w/ ramp on-hover on	(2.6)	23.6
Jan' 98. 458 ml CSF, 1250 ft/min	10-inch std. w/ ramp off-hover off	9.0	0.0
	10-inch std. w/ ramp on-hover off	13.4	43.8
	10-inch std. w/ ramp on-hover on	10.0	44.4
Jan' 98. 460 ml CSF, 2500 ft/min	10-inch std. w/ ramp off-hover off	7.9	22.6
	10-inch std. w/ ramp on-hover off	7.9	22.0

CD & GM STFI INDEX

Case	Shoe Press Configuration	CD % Incr	GM % Incr
Jul' 97, 570 ml CSF, 1250 ft/min	10-inch std.	15.7	10.2
Aug' 97, 570 ml CSF, 1250 ft/min	6-inch w/ ramp 4	18.8	17.6
	6-inch w/ ramp 5	20.3	12.9
Jan' 98. 540 ml CSF, 1250 ft/min	10-inch std. w/ ramp off-hover off	(0.9)	(0.4)
	10-inch std. w/ ramp on-hover off	7.5	1.5
	10-inch std. w/ ramp on-hover on	(0.5)	(3.0)
Jan' 98. 458 ml CSF, 1250 ft/min	10-inch std. w/ ramp off-hover off	(5.6)	(2.9)
	10-inch std. w/ ramp on-hover off	3.4	0.7
	10-inch std. w/ ramp on-hover on	(5.1)	(1.6)
Jan' 98. 460 ml CSF, 2500 ft/min	10-inch std. w/ ramp off-hover off	3.3	1.0
	10-inch std. w/ ramp on-hover off	4.3	3.5

CONCLUSIONS

- *Pilot experiments confirmed that the ramp decompression concept can be used to increase critical temperature.*
- *The adjustable shoe worked well.*
- *The "hover press" in its present form increased rewet and hurt properties.*

CONCLUSIONS

- *A combination of the roll surface and the Teflon doctor minimized picking.*
- *Blanket groove geometry is an important variable that should be optimized.*
- *Improvements were greatest at higher freeness, higher ingoing solids and at slower speeds.*

GOALS FOR FY 98-99

- *Produce 26 lb/1000 ft^2 linerboard on the Beloit X2 machine, where impulse dryer operates as a third press.*
- *Demonstrate impulse drying of 42 lb/1000 ft^2 linerboard on the Beloit X4 machine. Produce rolls of paper for converting trials.*
- *Conduct converting trials and report results.*

DELIVERABLES

- *Report: Optimization of the press shoe pressure profile, blanket, felt, and post-nip decompression for 26 lb/1000 ft^2 linerboard.*
- *Report: Runnability and drying efficiency of the Beloit X4 machine, lineboard physical properties, convertibility and containerboard properties.*

SCHEDULE

TASKS	1st Qtr'98	2nd Qtr'98	3rd Qtr'98
Beloit X2 experiments to optimize conditions to produce 26 # linerboard where impulse dryer is a third press.	-----x		
Shakedown trial on Beloit X4 to produce 42# linerboard for physical testing.		--x	
Production of 42# linerboard on the Beloit X4 for physical testing and in quantities required for converting trials.		--x	
Double-back corrugating trial.		--x	
Post-printing printability trial.		--x	
Box making and testing		--x	
Analysis of results and report writing			-----x

PROPOSAL

- *Press and Dryer Roll Surfaces and Web Transfer Systems for Ultra-High Paper Machine Speeds.*

ABSTRACT

- *To significantly increase paper-machine speeds, new technology is needed to allow ultra-high-speed web transfer from press rolls and dryer cylinders.*
- *Research is proposed that will provide the fundamental knowledge and diagnostic tools needed to design these new technologies.*

FUNDAMENTAL QUESTIONS

- *What materials deposit on roll surfaces and what are the conditions that influence that deposition?*
- *The work of adhesion is dominated by the work required to fracture the thin film of water between the wet web and the roll surface. How do these films fracture and how does roll surface chemistry and topology influence that mechanism?*

FUNDAMENTAL QUESTIONS

- *Do current theoretical equations properly predicts web transfer at ultra-high speeds?*
- *Can new doctoring, wiping, roll cleaning or roll treatment technologies be developed to reduce picking on roll surfaces?*

BENEFITS TO THE INDUSTRY

- *Improved paper-machine runnability that will be seen by the paper producer as less breaks per day. This will increase machine uptime and favorably impact capital effectiveness.*

BENEFITS TO THE INDUSTRY

- *Improved utilization of the first dryer section that will improve machine efficiency and energy usage.*
- *Increased machine operating speeds.*
- *Improved paper sheet surface properties, less damage to the sheet.*

FUNDAMENTALS OF WEB HEATING

SLIDE MATERIAL

FOR

PROJECT F002

March 23, 1998
Institute of Paper Science and Technology
Atlanta, Georgia

F002 Fundamentals of Web Heating

1998 Spring PAC Meeting
Timothy Patterson (PI)
Isaak Rudman, Zhigang Feng,
Andre Dowdell

Project Objective

To develop a quantitative understanding of the processes occurring during web preheating and during pressing of heated webs.

Such an understanding will make possible the optimum use of web preheating for both production increases and product quality improvements.

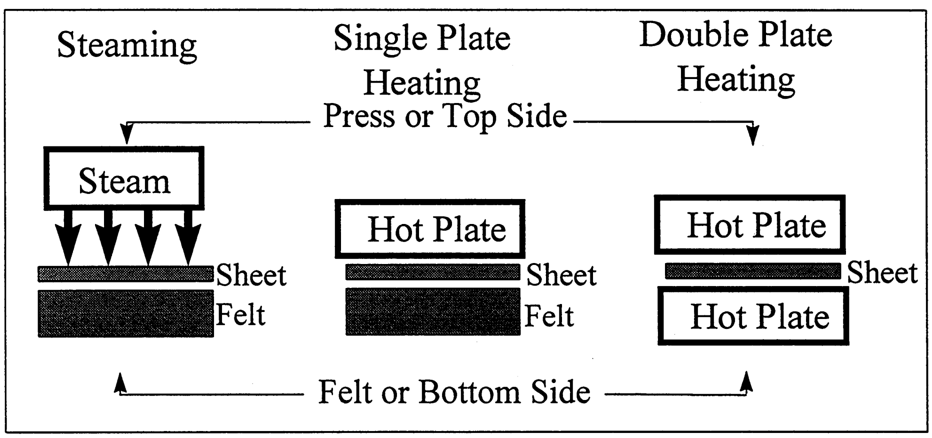
Summary

- Work Completed
  - Member Report 5 MTS Pressing
  - Georgia Tech/IPST Infrared Heating
- Work in Progress
  - Steambox Location Relative to Press
  - Sheet Permeability
  - Steam Jet Impingement Characterization/Optimization
- Work Planned
  - 3rd Rocket Sled/MTS Experiment
  - Steambox Guidelines

Member Report 5 - MTS Heated Web Pressing

Literature on Laboratory Pressing

Various Sheet Heating Methods Used



Member Report 5 - MTS Heated Web Pressing

Objective:

Determine

1. Does heating method affect the sheet moisture profile? *(Yes)*
2. Does heating method affect pressing results? *(Yes)*
3. Is average sheet solids level a factor? *(Yes)*
4. Is pressing pulse a factor? *(Yes)*
5. Possible benefit multiple heating/pressing. *(5 pts)*
6. Implications for commercial pressing.

Member Report 5 - MTS Heated Web Pressing

1. Does heating method affect the sheet moisture profile?

Yes - steam heating yields a sheet which is wetter on the press side. Plate heating yields a sheet which is drier on the press side.

The felt side of the sheet has the greatest water removal.

Member Report 5 - MTS Heated Web Pressing

2. Does heating method affect pressing results?
3. Is average sheet solids level a factor?

Yes -

At low solids (25%)

- Too much steaming on the press side reduces water removal despite increased temperature.
- CD STFI, Density, SEM generally increase with temperature
- An increase in sheet properties does not indicate a similar change in water removal.

Member Report 5 - MTS Heated Web Pressing

2. Does heating method affect pressing results?
3. Is average sheet solids level a factor?

Yes -

At high solids (45%)

- Plate heating on the press side reduces water removal despite increased temperature.
- Steam heating on the press side increases water removal.
- Heating does not significantly enhance sheet properties.

Member Report 5 - MTS Heated Web Pressing

4. Is pressing pulse a factor?

   Yes -

   - Higher solids requires a high impulse to obtain water removal.
   - There appears to be a minimum press impulse required to obtain increased water removal with a heated sheet.

Member Report 5 - MTS Heated Web Pressing

5. Possible benefit multiple heating/pressing.
   - Heating prior to each of three successive pressings yielded 5 pts. greater dryness than no heating.
   - Proper press pulse selection important to optimum results.

Member Report 5 - MTS Heated Web Pressing

6. Implications for commercial pressing.
   - Laboratory pressing results require interpretation.
   - Steaming early in press section can yield sheet property enhancement.
   - Steaming late in press section will probably yield limited or no sheet property improvement.
   - If sheet heating has not yielded a water removal increase an increase in pressing pulse is probably required.
   - Steamboxes - more is better.

IPST/Ga Tech Seed Grant

Objective: Produce a more even sheet temperature profile using narrow band infrared emitters. *(--> Better water removal)*

Rationale: The literature states that at shorter wavelengths wet paper is partially transmissive to infrared.

IPST/Ga Tech Seed Grant

- High temperature black body emitter is not significantly better than low temperature black body emitter.

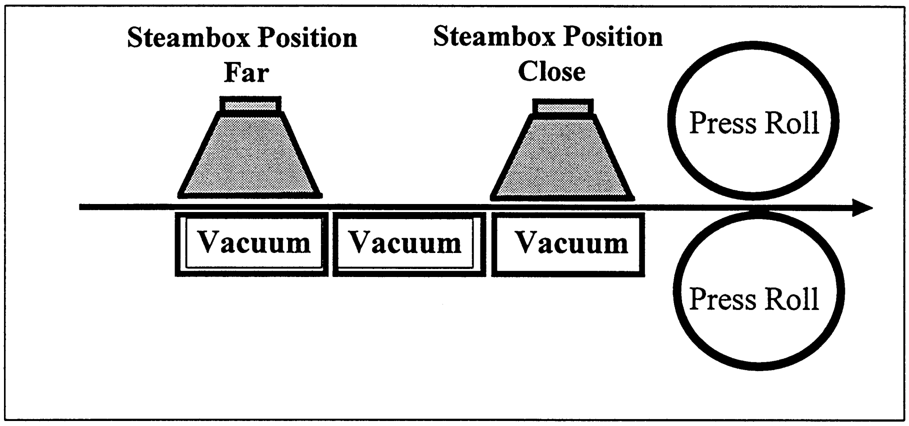
- Using a narrow band emitting coating on a blackbody emitter does not result in a narrow band infrared emission.

Steambox Location

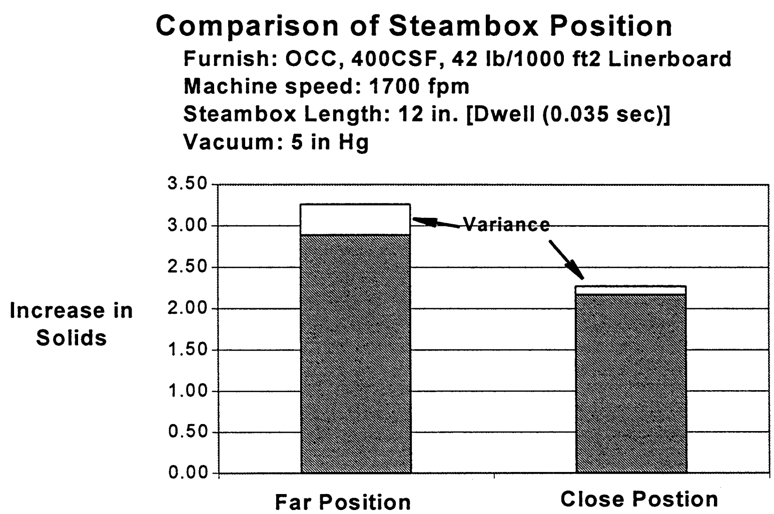
Objective: Determine if position of steambox relative to the closest downstream press effects water removal. *(Farther away can be better)*

Rationale: Previous Rocket Sled experiments
- heat conducts into the sheet after exiting the steambox.
- little convective loss from the sheet surface.

Steambox Location



Steambox Location



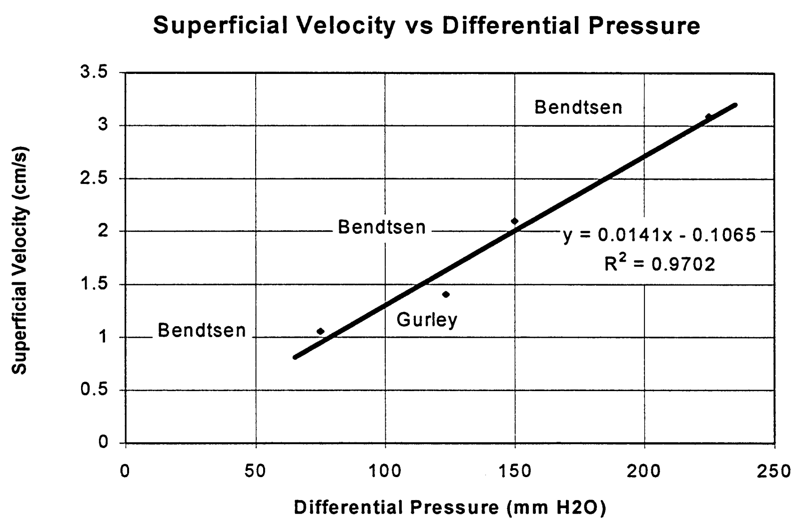
Air/Water Permeability

Objective: Validate the use of wet sheet air permeability as a valid measurement technique,

- using multiple levels of ΔP *(Darcy's Law is valid)*
- correlation with water permeability

Rationale: Previous work has shown a relationship between wet sheet air permeability (a non standard measurement) and steam energy absorbed by the sheet.

Air Permeability



Steam Jet Impingement

Ultimate Objective: Determine steambox geometry/jet configuration for maximum sheet heating.
(get the most steambox in the least space)

Intermediate Objective: Model the steambox jet impingement, develop a plan for experimental verification.

Rationale: The steambox is easier to modify than the sheet. There is almost no current literature on steam jet impingement of porous media.

Steam Jet Impingement

Color overhead

Static case, pressure field calculated from flow field.
Heat transfer can be found using flow field results.
Condensation and permeability not accounted for, but will be in future results. The image file is too big for Power Point

Jets far from entrance/exit affect boundary layer, jets close to entrance/exit do not affect boundary layer.

Steam Jet Impingement

Color overhead

Dynamic case, pressure field calculated from flow field.
Heat transfer can be found using flow field. Condensation and permeability not accounted for, but will be in further results.

Highest pressures reached near exit, little affect near entrance.

Third Steambox Experiment

Objective:

- Verify the wet sheet permeability vs steam energy absorbed relationship developed as a result of the 2nd Steambox Experiment. Use a wider range of furnishes and basis weights.
- Perform related pressing study to determine relative benefits of preheating.

Third Steambox Experiment

Rationale: Verification of the wet sheet air permeability/steam energy absorbed relationship will make possible the determination of a sheet's preheating potential without extensive testing.

Third Steambox Experiment

Furnish Types
- Softwood (southern pine), kraft, unbleached
- Softwood (Douglas Fir), kraft, unbleached
- OCC, unbleached
- Softwood kraft, bleached
- Hardwood kraft, bleached
- Mechanical

Third Steambox Experiment

Part 1 Refining, Pressing, Permeability Study.

What is needed to get sheets of similar permeability, and basis weight.

Part 2 Rocket Sled - Single Ply, All Furnishes Basis Weight For Steam Penetration.

Is furnish a factor in the permeability/energy absorbed relationship?

Part 3 Rocket Sled - Multi-ply, Two Furnishes.

What is the maximum basis weight & freeness range for the permeability/energy absorbed relationship?

Steam Heating Guidelines

The guidelines would address:

- Method for evaluating steam heating potential of a furnish, relative to a standard steambox (energy absorbed, temperature profile).
- Method for comparing a "standard steambox" to an actual steambox.
- Steambox/Vacuum box placement relative to one another.
- Steambox placement relative to a press.
- Steambox placement within the forming/pressing section.
- Optimum steambox design - geometry and jet configuration.

FUNDAMENTALS OF COATING SYSTEMS

SLIDE MATERIAL

FOR

PROJECT F003

March 23, 1998
Institute of Paper Science and Technology
Atlanta, Georgia

FUNDAMENTALS OF COATING SYSTEMS (F003)

REPORT TO THE

PAPER MAKING PROJECT ADVISORY COMMITTEE

Spring 1998

DUES-FUNDED PROJECT

Project Title: Fundamentals of Coating Hydrodynamics

Project Code: Coat

Project Number: F003

PAC: Paper Making

Division: Engineering

Supporting Research

M.S. Students: K. Yanagisawa

Ph.D. Students: C. Chen, C. Cody

RESEARCH LINE/ROADMAP: Paper Machine Productivity

To enhance coating quality and productivity by reducing coating defects and increasing coating speed.

PROJECT OBJECTIVE:

Objectives of this project are to

1. investigate the cause and origin of coat weight nonuniformities reported in high-speed blade coating of paper and board,

2. explore novel coating systems for application of a more uniform coat weight profile at higher machine speeds,

3. develop methods for analysis of suspension dynamics and rheology of coating suspensions under high-shear regions in blade coating processes

PROJECT SCOPE:

The focus of the project during the 1996-97 has been to:

1. evaluation of the computational method for analysis of suspensions in coating systems and interaction of the coating with the substrate;

2. preparation for pilot trials of the second version of the vortex-free coater; and

3. experimental trials of the vortex-free coater at IPST.

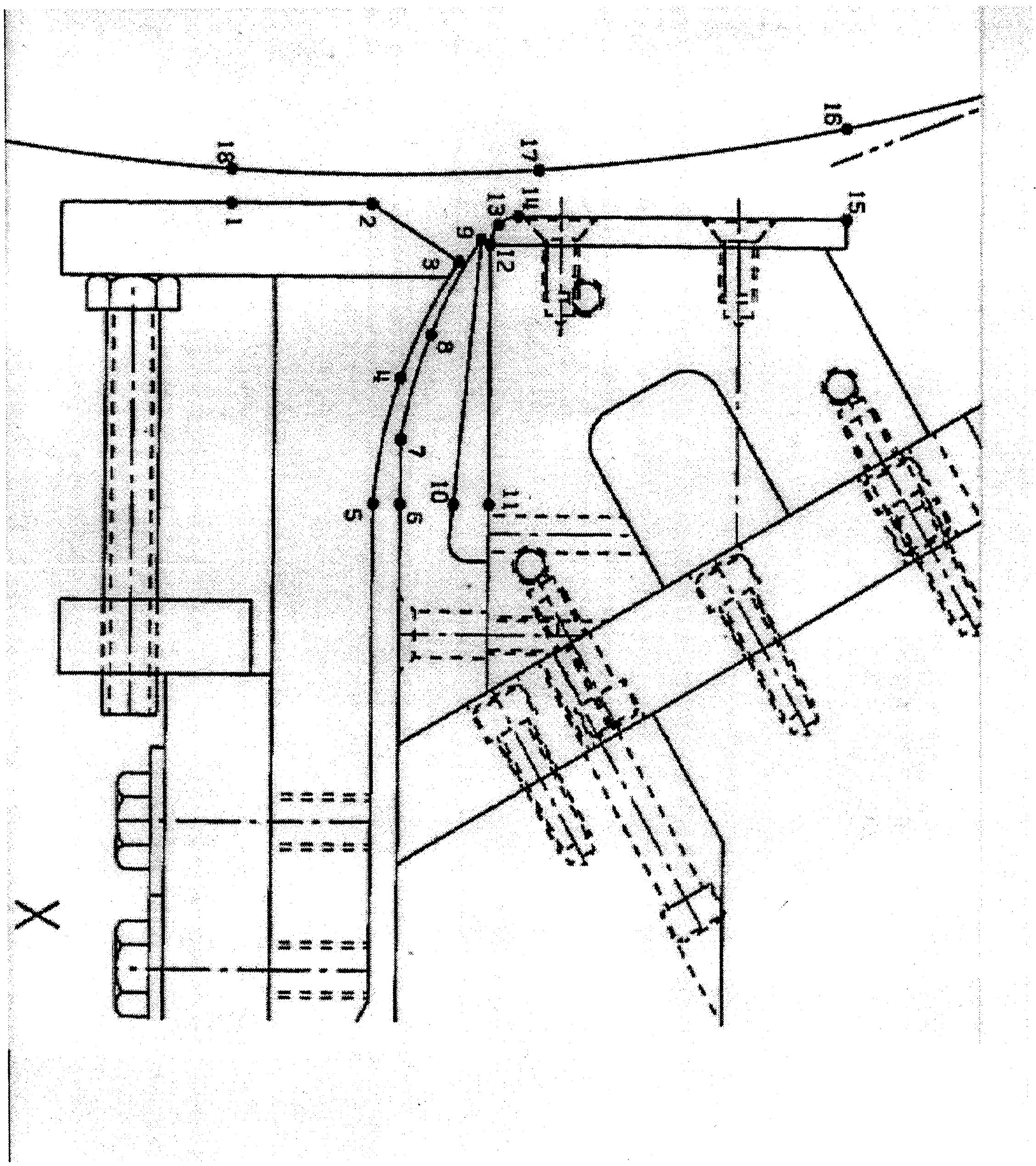


Figure 1a. The drawing of the coater head with the air jet channel (10, 11, 12, and 9) on the development coater.

The solution procedure,

based on a parametric continuation approach, is as follows:

Step 1: obtain a complete flow flied solution with free-slip condition at the free surfaces and uniform fluid properties using Newton-Raphson iteration procedure;

step 2: restart the solver from solution obtained in step 1 as an initial condition, release one free surface from the free-slip condition and solve the complete solution using segregated iterative method;

step 3, restart the solution from step 2, release another free surface and solve by using segregated iterative method;

step 4, restart the solution from step 3, change the density and viscosity ratios of both fluids gradually in a stepwise manner until target properties are reached. Parameter continuation methods are used to assist in the variation of parameters to reach the desired solution for given boundary conditions. Typically, convergence is achieved when the norm of the difference in solution from one iterative step to the next is less than 10^{-3} and that of free surfaces is less than 10^{-2}.

Characteristic scales:

Characteristic Velocity	Roll velocity	20 $m.s^{-1}$
Characteristic Length	Width of the inlet liquid channel	0.00149 m
Density	liquid density	1500 $kg.m^{-3}$

Boundary conditions	Roll speed (U_{web})	20 $m.s^{-1}$
	Inlet liquid velocity (non-dimensionalized)	$u(x)=c1-c2\,x^2$ $\overline{U}=\frac{1}{2h}\int_{-h}^{h}u(x)dx$ where, h=0.029 c1=1.36 c2=1582.52 $\overline{U}$=0.91
	The velocity of walls (including the top, V-shape, and the first part of the bottom surface along the inlet liquid flow)	No Slip.
	The roll speed (non-dimensionalized)	U_t =1.0; U_n =0.0 (Dirichlet)
	The outlets of air and liquid	σ_t= 0.0 ; σ_n= 0.0 (Neumann)
Initial condition		
	Velocity field	Stokes Flow
	The contact angles at the free surface	right = 0.0, left=127
	The contact angles at the air-liquid interface.	Right = 151.5

Physical properties of the fluids and the boundary conditions:

Physical properties	The density of liquid (ρ_{liq})	1500 $kg.m^{-3}$
	The density of air(ρ_{air})	1.1614 $kg.m^{-3}$
	The dynamic viscosity of liquid (μ_{liq})	1.0 Pa.s
	The dynamic viscosity of air (μ_{air})	$1.846.10^{-5}$ Pa.s
	Surface tension (γ)	0.0478 $N.m^{-1}$

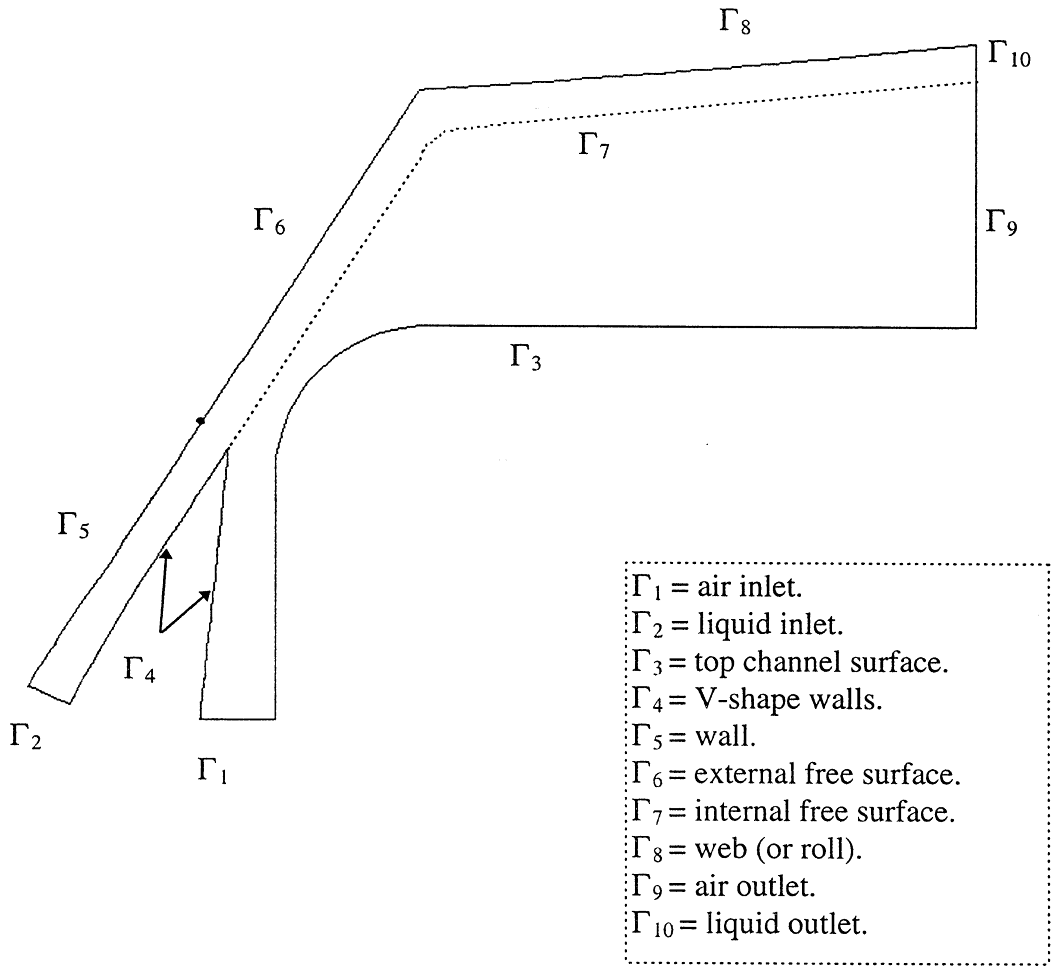


Figure 1-b. Outline of geometry and boundary of the computational domain

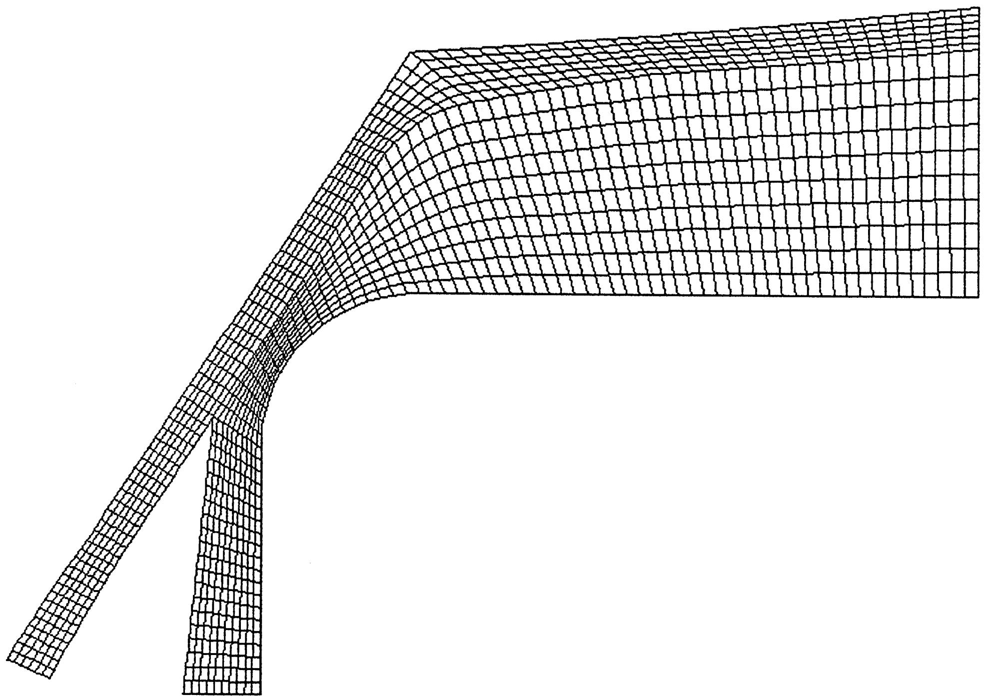


Figure 2. Initial computational grid structure for the coating liquid and air jets.

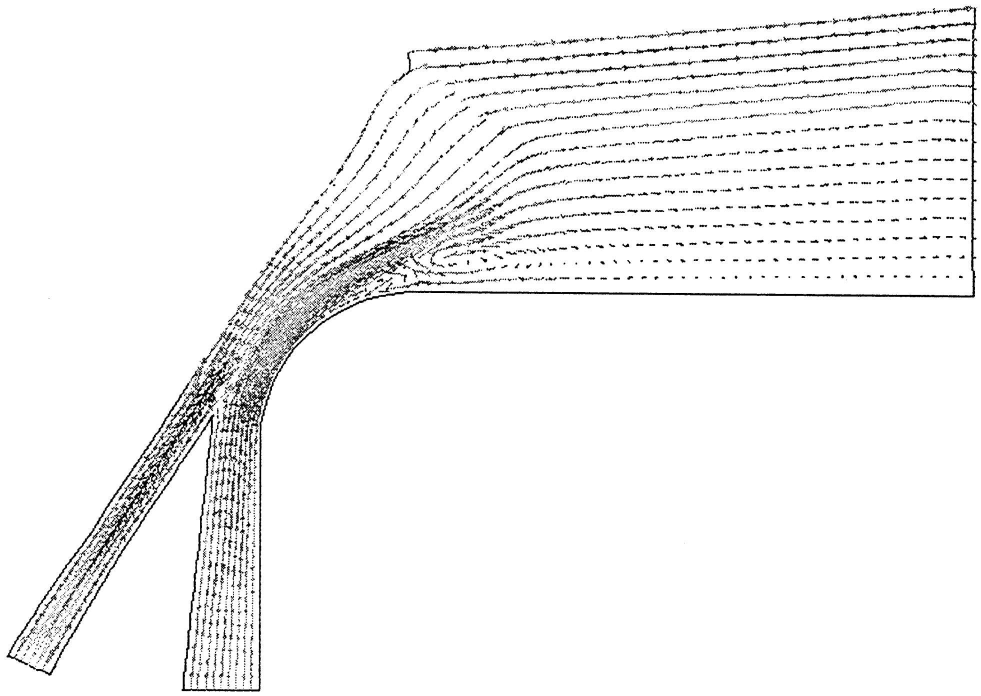


Figure 3. Velocity vector plot of the air and liquid coating jet.

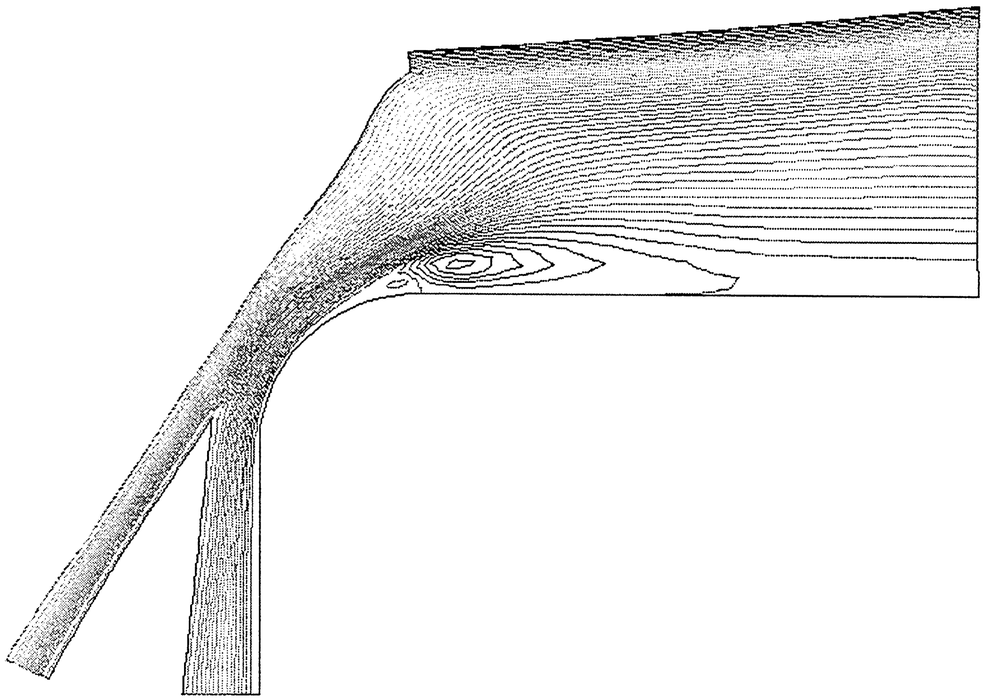


Figure 4. Stream lines of the air and liquid coating jet.

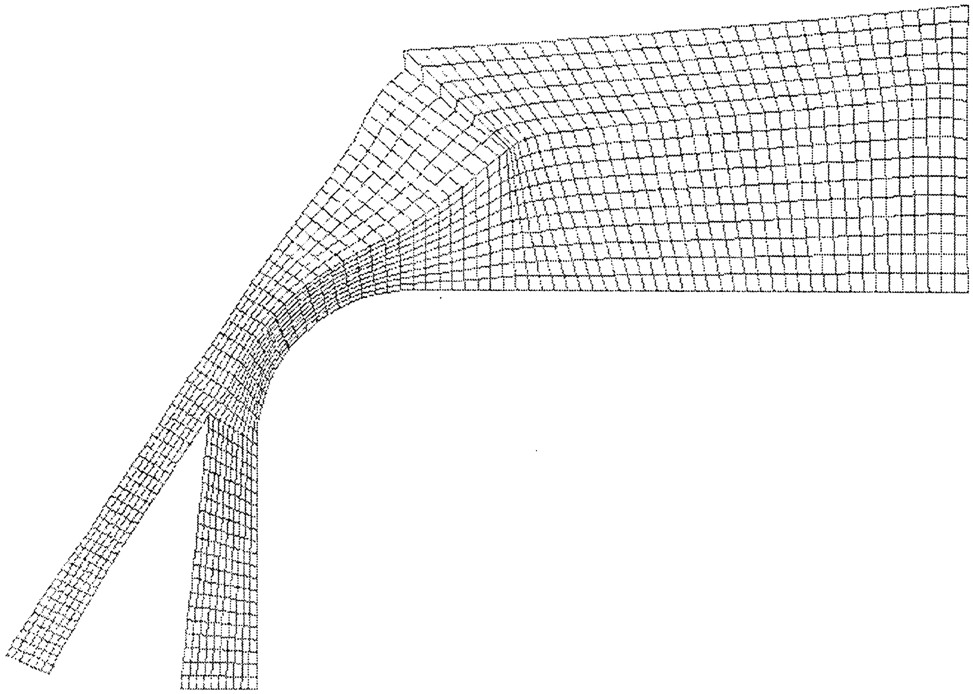
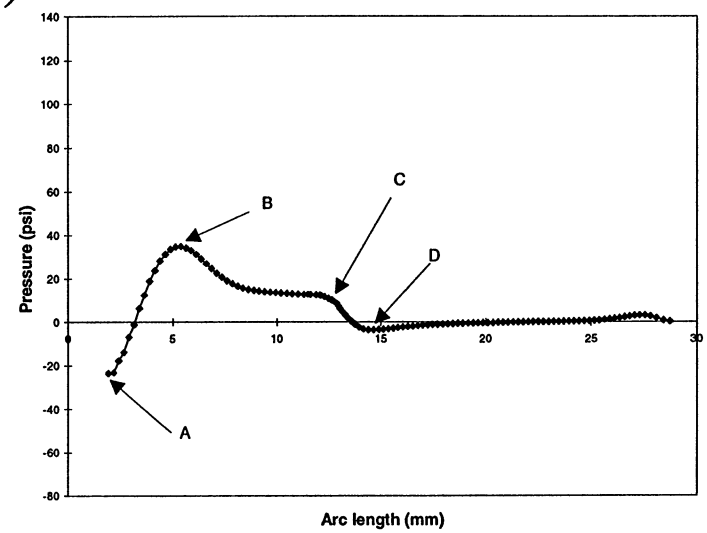


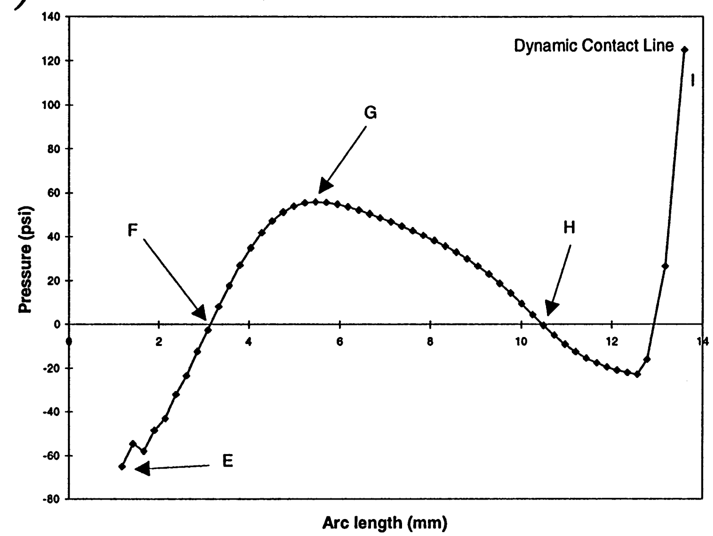
Figure 5. Converged solution showing the deformation of the free surface and the air-liquid interface. (note the irregular grid deformation due to numerical problems near the pinned contact point.)

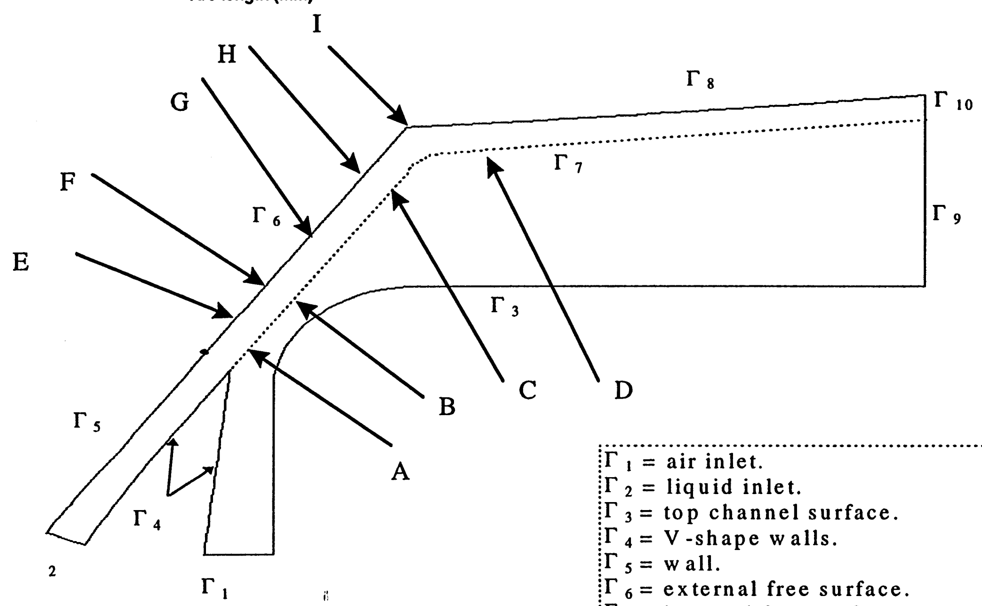
Pressure profile along the (a) downstream (internal) side, Γ_7 ,and (b) upstream (external) side, Γ_6 , of the liquid jet.

(a)



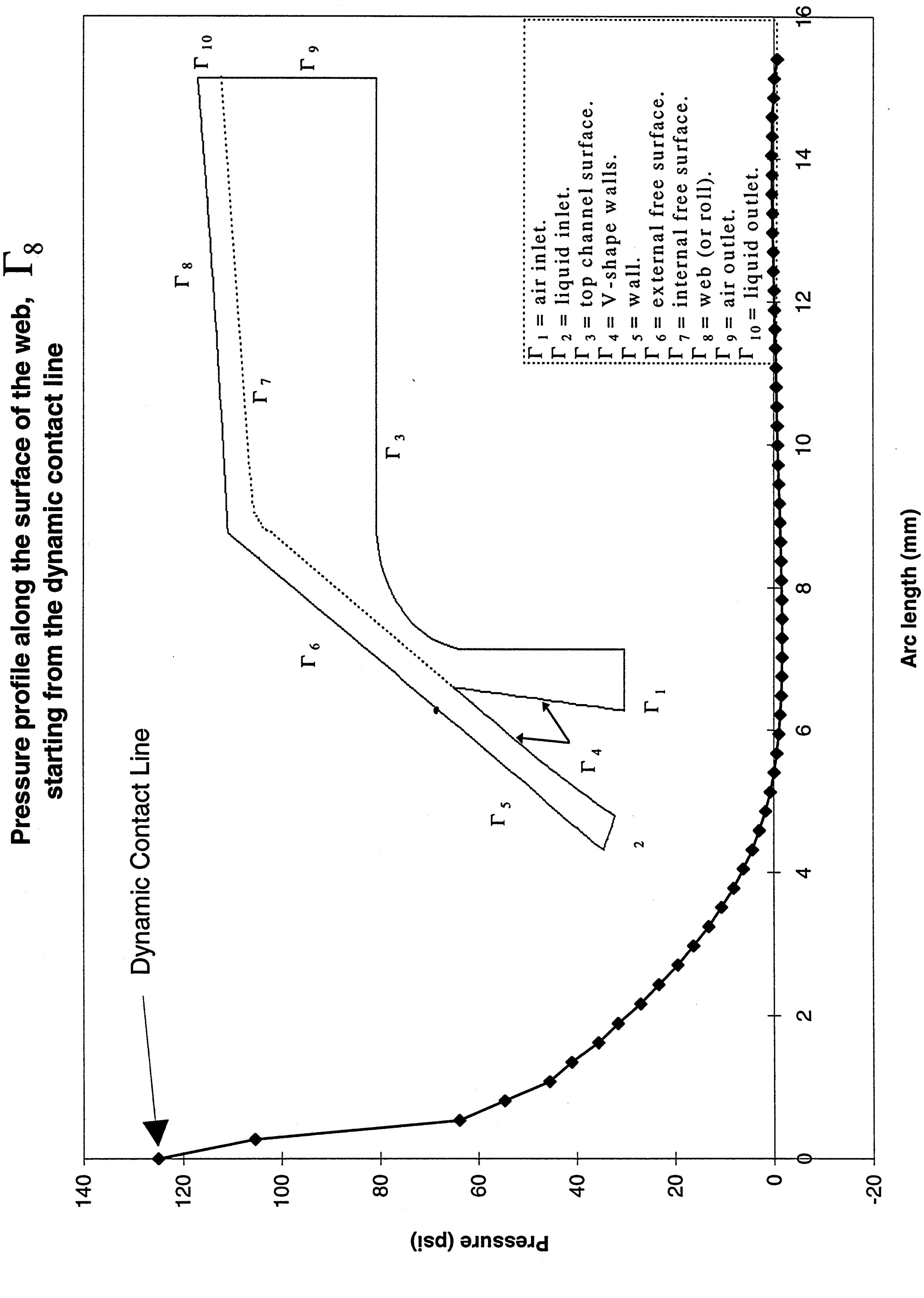
(b)





Γ_1 = air inlet.
Γ_2 = liquid inlet.
Γ_3 = top channel surface.
Γ_4 = V-shape walls.
Γ_5 = wall.
Γ_6 = external free surface.
Γ_7 = internal free surface.
Γ_8 = web (or roll).
Γ_9 = air outlet.
Γ_{10} = liquid outlet.

Note: The positions are visually located.


Pressure profile along the surface of the web, Γ 8
starting from the dynamic contact line
Dynamic Contact Line
Pressure (psi)
Arc length (mm)
140
120
100
80
60
40
20
0
-20
0
2
4
6
8
10
12
14
16
Γ 1 = air inlet.
Γ 2 = liquid inlet.
Γ 3 = top channel surface.
Γ 4 = V-shape walls.
Γ 5 = wall.
Γ 6 = external free surface.
Γ 7 = internal free surface.
Γ 8 = web (or roll).
Γ 9 = air outlet.
Γ 10 = liquid outlet.

GOALS FOR FY 98-99:

- Demonstration of the commercial viability of the vortex-free coater
- Commercial implementation of the vortex-free coater

DELIVERABLES, FY 98-99:

- Results from computational analysis and optimization of the vortex-free coater
- Demonstration of the superior performance of a new coating system through pilot trials at Beloit R&D

SCHEDULE:

The computational procedure for design optimization of the new vortex-free coater is under development.

The pilot coater head will be designed to provide considerable flexibility to vary the geometry and observe the effects on the coating uniformity at various air and liquid flow rates.

We estimate that two series of pilot trials would be required. The second design will incorporate the experience and information from the first series of pilot trials.

Item Time ==> April July Oct. Jan. April

1. Computational Optimization--|

2. Pilot Trial Demonstration (@ Beloit)

    Design & Fabrication ------------------| ------------------------------|

    Pilot Trials ---------------------| -----------------------|

3. Annual Report -----------------|

APPROACH FLOW SYSTEMS

SLIDE MATERIAL

FOR

PROJECT F004

March 23, 1998
Institute of Paper Science and Technology
Atlanta, Georgia

APPROACH FLOW SYSTEMS (F004)

Xiaodong Wang, Assistant Professor of Engineering
Institute of Paper Science and Technology
500 10th St., NW, Atlanta, GA 30318

Staff: F. Bloom (Consultant)
Z. Feng (Assistant Scientist)

Budget: $ 120,730

Matching Funds: 0

Student: 0

PROJECT OBJECTIVES

Improve Approach Flow System Designs

- Uniform stock delivery to headbox (consistency)
- Smooth stock delivery to headbox (pressure)
- Optimum designs (system)

Investigate various components of approach flow systems and the whole system behavior

- Silo pipe mixing unit
- Pressure pulsation attenuator

PROJECT BACKGROUND

Project Started From PAC Proposal Spring 96

- Consistency, Pressure, and Basis Weight Variation Analysis (Done)
- Silo pipe system mixing analysis (Done)
- Silo pipe vibration analysis (Done)
- Pressure pulsation attenuation (On-going)
- Other approach flow system components

SIGNIFICANT FINDING (MIXING)

- In paper industry, transverse mixers with acute injection angles are more desirable than right or obtuse injection angles
- In paper industry, concentric mixers have higher mixing efficiency than transverse and multijet mixers
- In concentric mixers, a flat nozzle with various cut angles does not affect mixing significantly, however, the mixing efficiency can be greatly improved in the case of the contracting nozzle
- In the silo mixing unit design, increasing the outlet pipe length has a much greater effect on the mixing efficiency than the corner cut

SIGNIFICANT FINDING (VIBRATION)

- In the silo mixing unit design, inclination angle, depth of submerged pipe, gravity are not important design parameters as far as the pipe stability concerned
- For a piping system with fixed volume flow rates, there exists an optimal inner pipe radius
- In the silo design example, there exist low frequency (~ 1 Hz) pipe vibration modes
- Tapered pipe

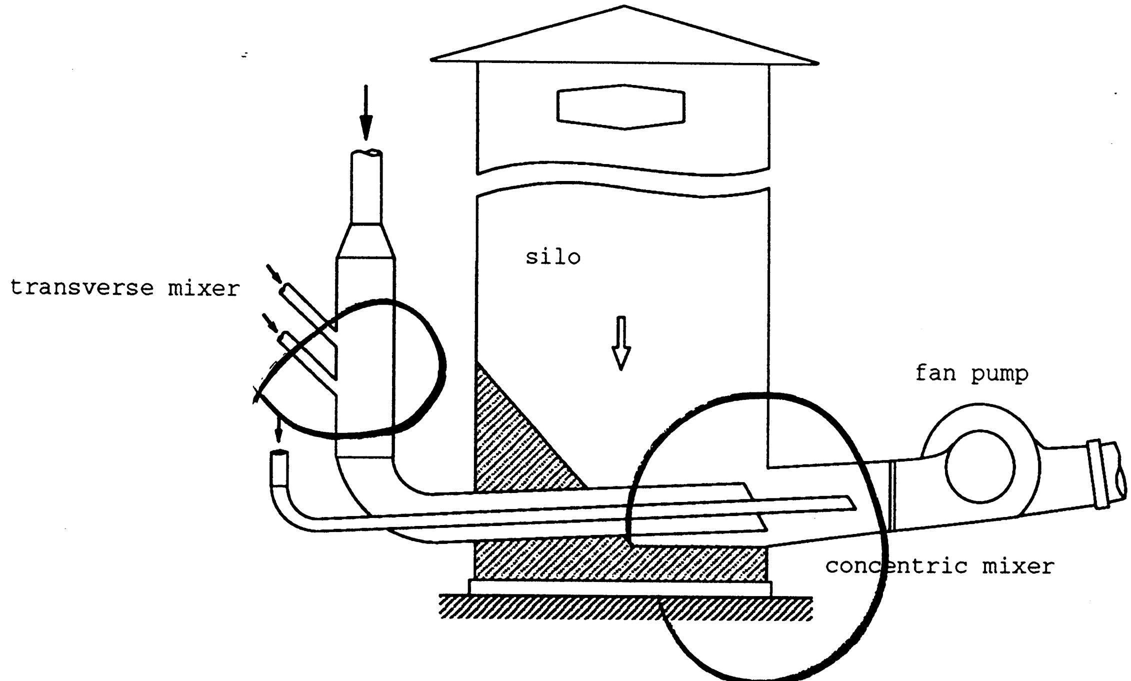
FUTURE RESEARCH PLAN

Experimental validation of computation constants

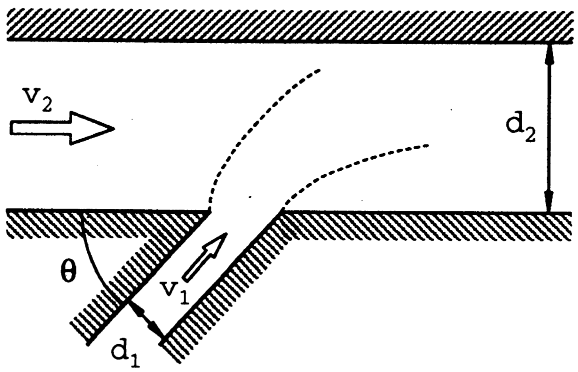
- Liquid-liquid model validation (Fall 98)
- Stock-liquid model validation (Spring 99)

Further work on the pulsating flow effects on pipe vibration

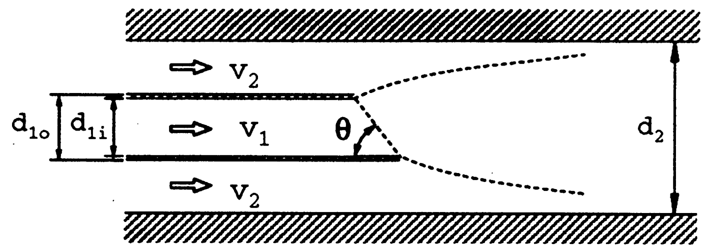
Pressure pulsation attenuation



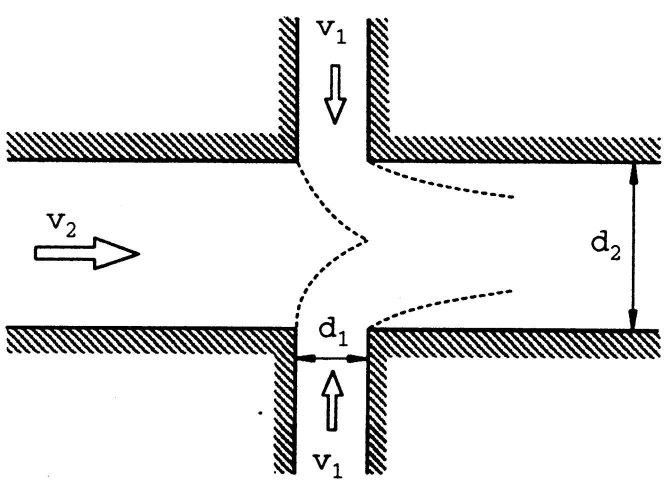
A typical silo pipe mixing system.

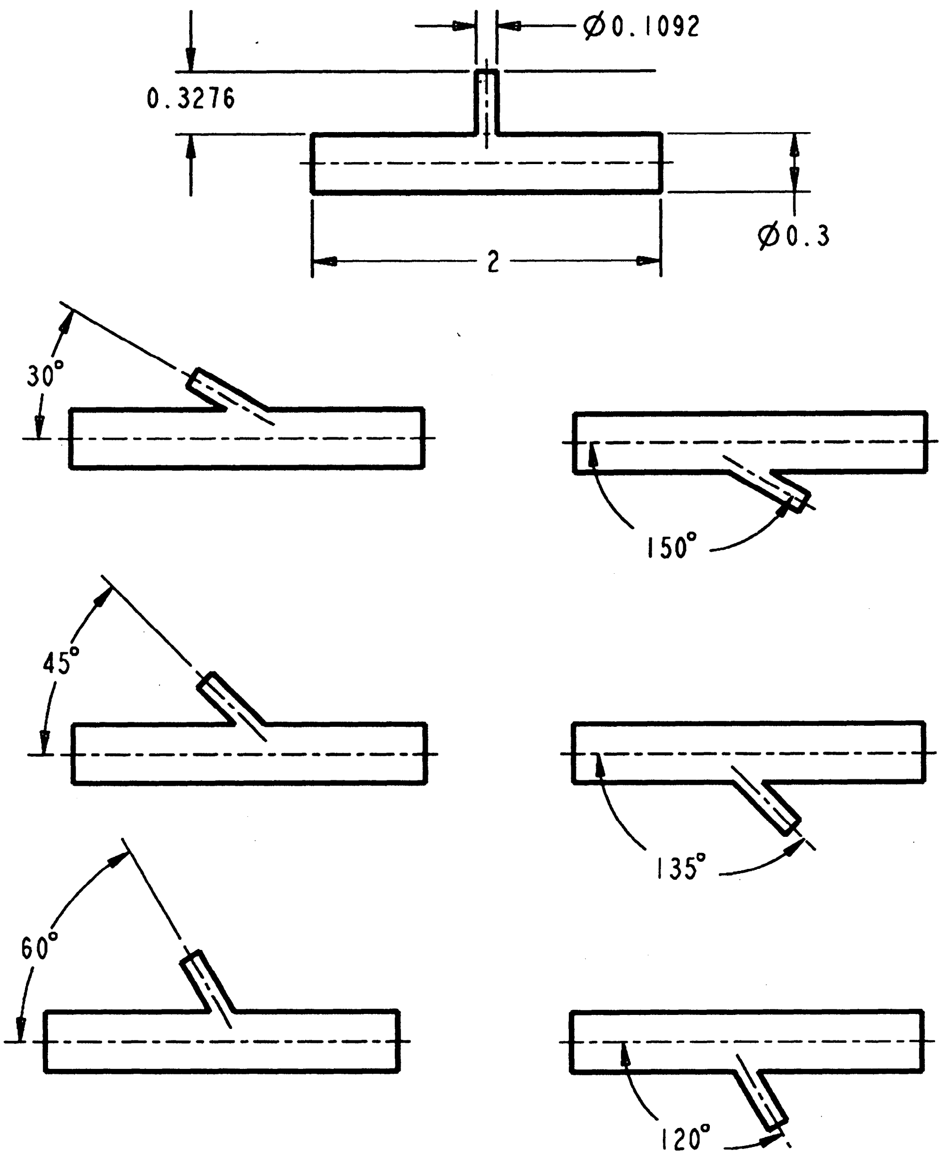


A typical transverse pipe mixing model.

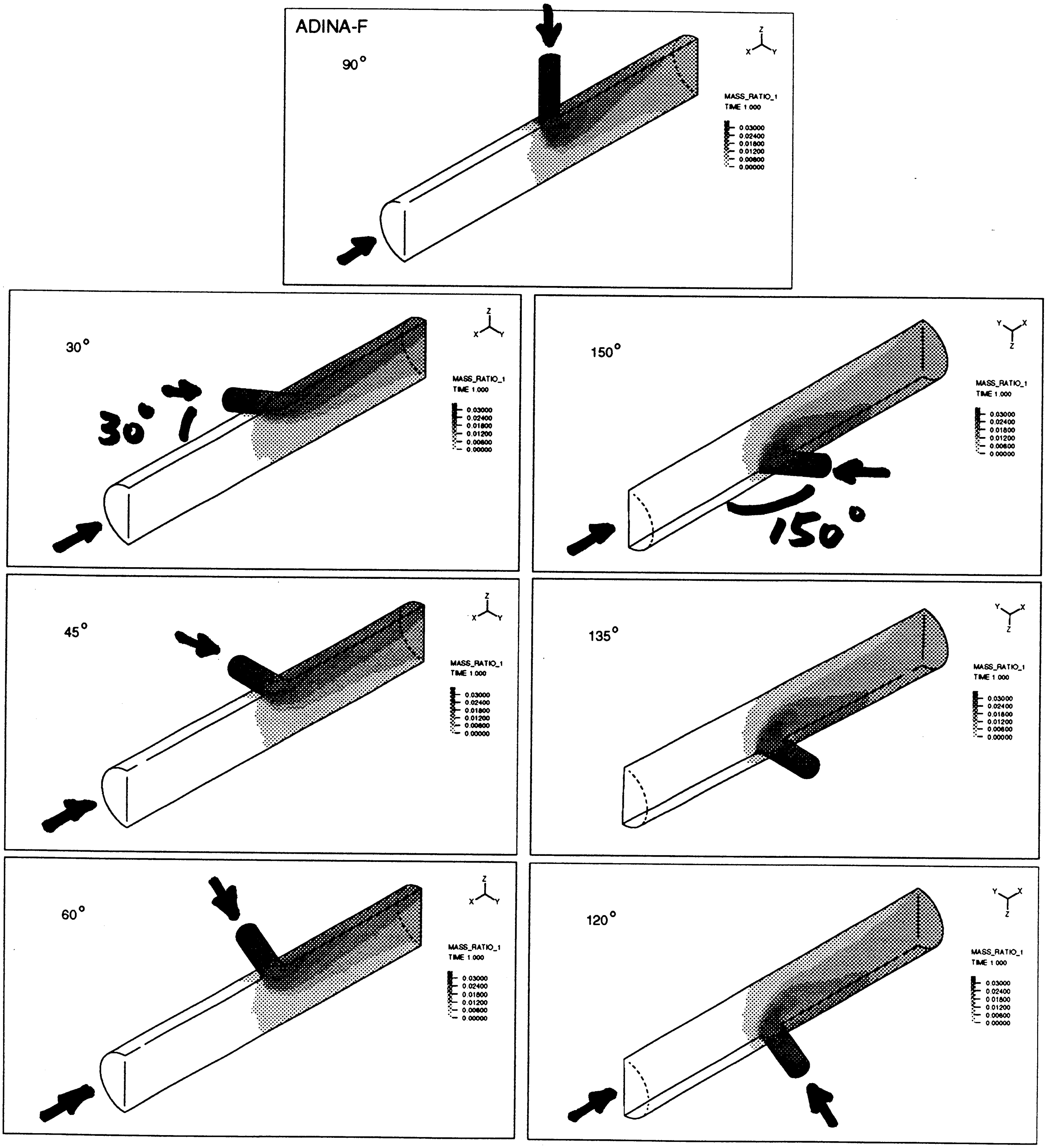


A typical concentric pipe mixing model.

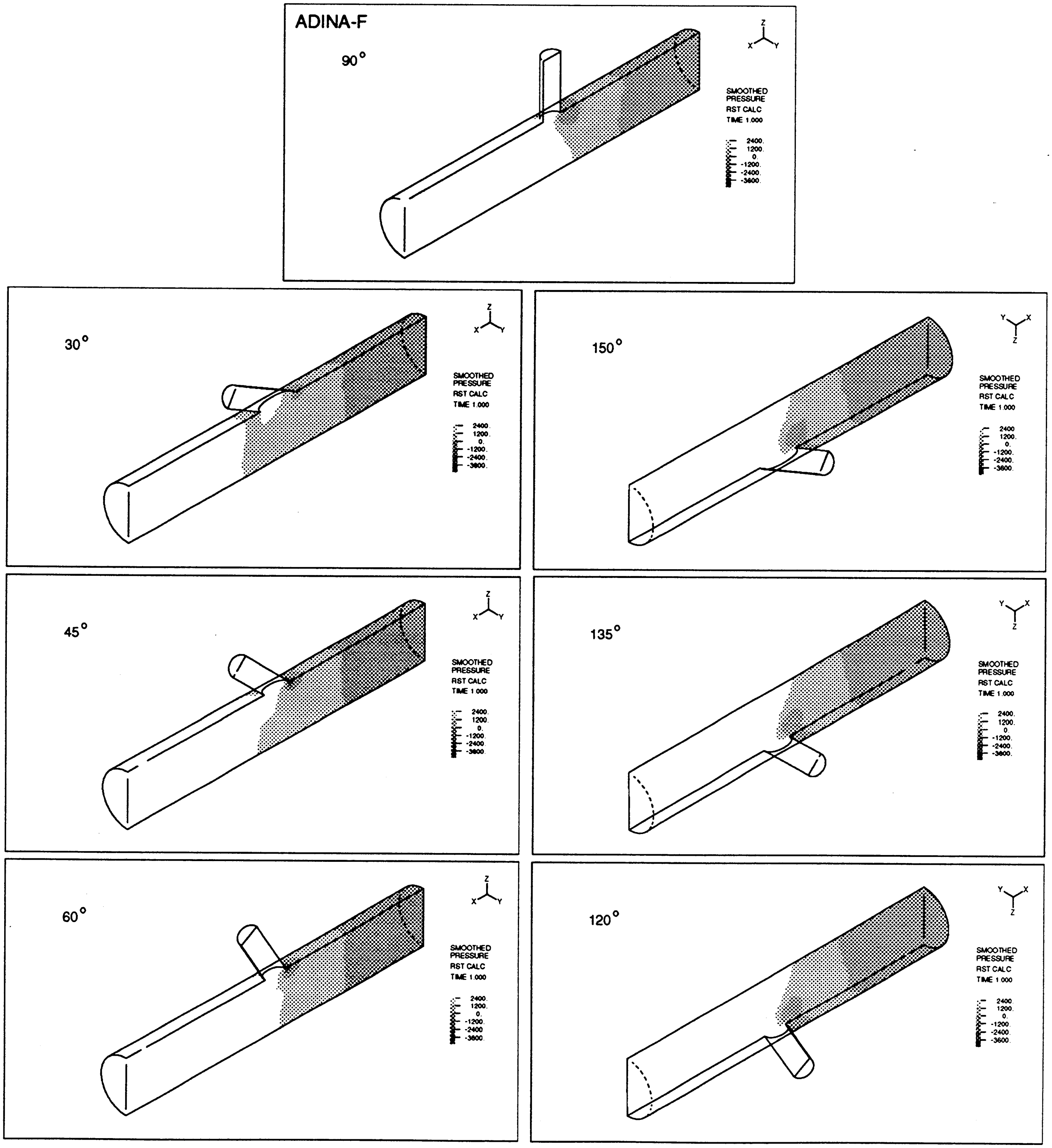




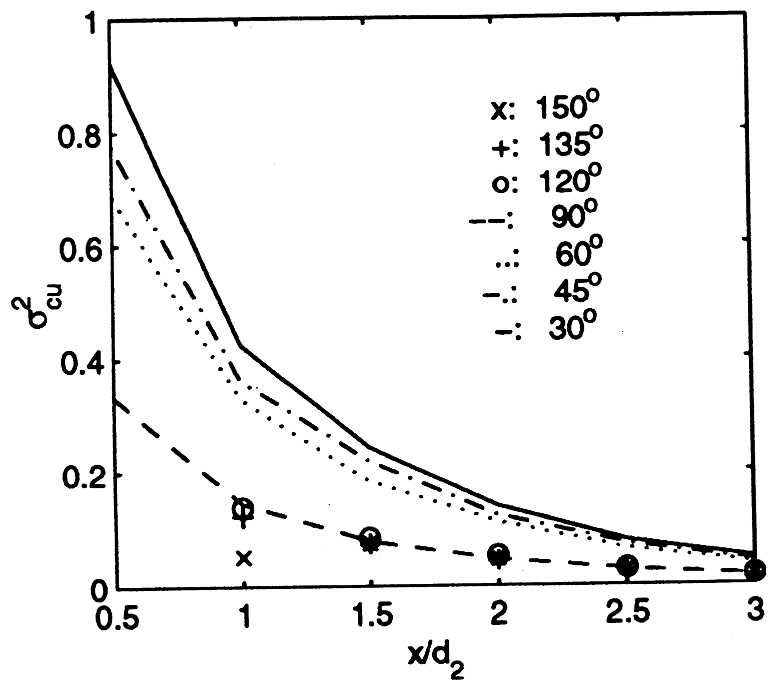
Solid models of transverse mixers with various jet injetion angles. (Generated with the ProENGINEER software.)

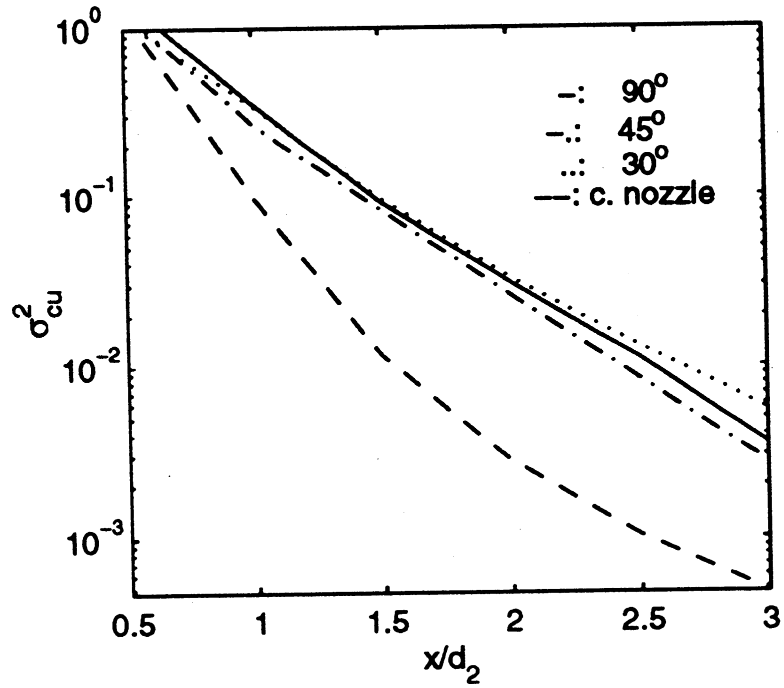


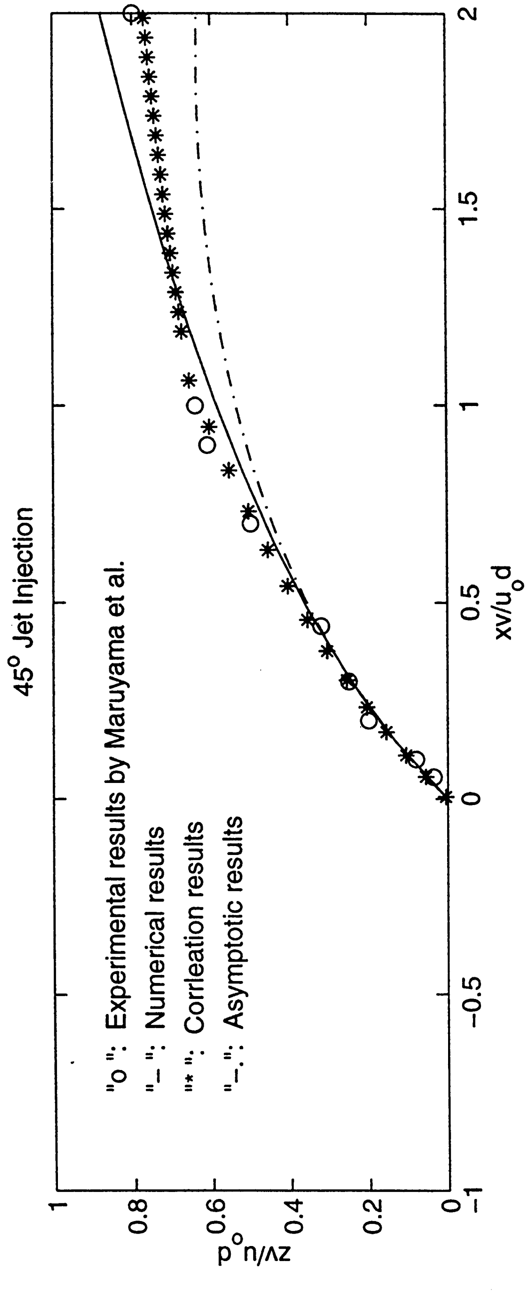
Tracer distribution (mass-ratio) of transverse pipe mixers with various injection angles.

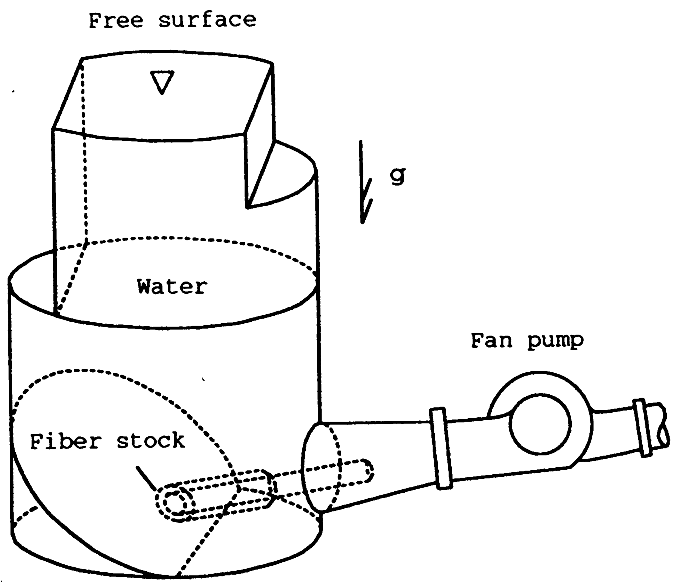


Pressure band plots of transverse pipe mixers with various injection angles.

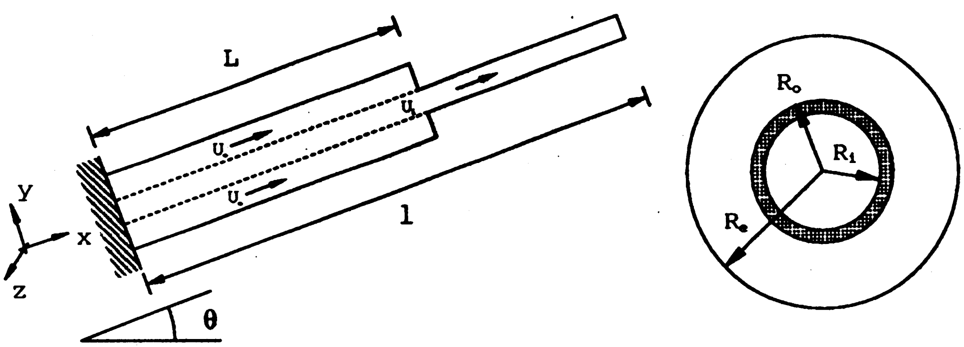

x: 150°
+: 135°
o: 120°
--: 90°
..: 60°
-.: 45°
-: 30°
0.8
0.6
0.4
0.2
0
1
0.5
1
1.5
2
2.5
3
x/d2
σ²cu


-: 90°
-.: 45°
..: 30°
--: c. nozzle
10^0
10^-1
10^-2
10^-3
0.5
1
1.5
2
2.5
3
x/d2
σ²cu

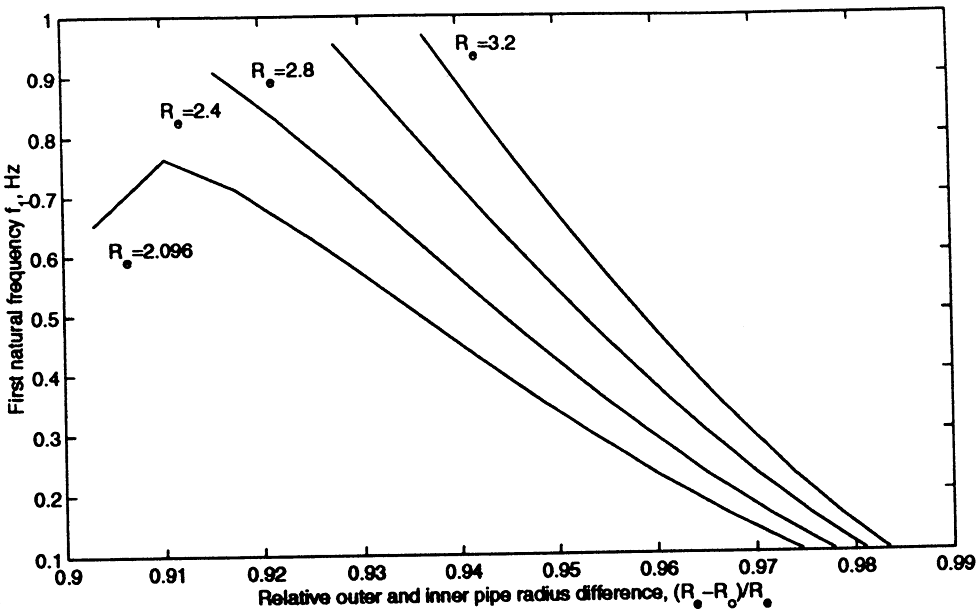

45° Jet Injection
"o": Experimental results by Maruyama et al.
"_": Numerical results
"*": Corrleation results
"_.": Asymptotic results
xv/u_o d
zv/u_o d
−1
−0.5
0
0.5
1
1.5
2
0
0.2
0.4
0.6
0.8
1

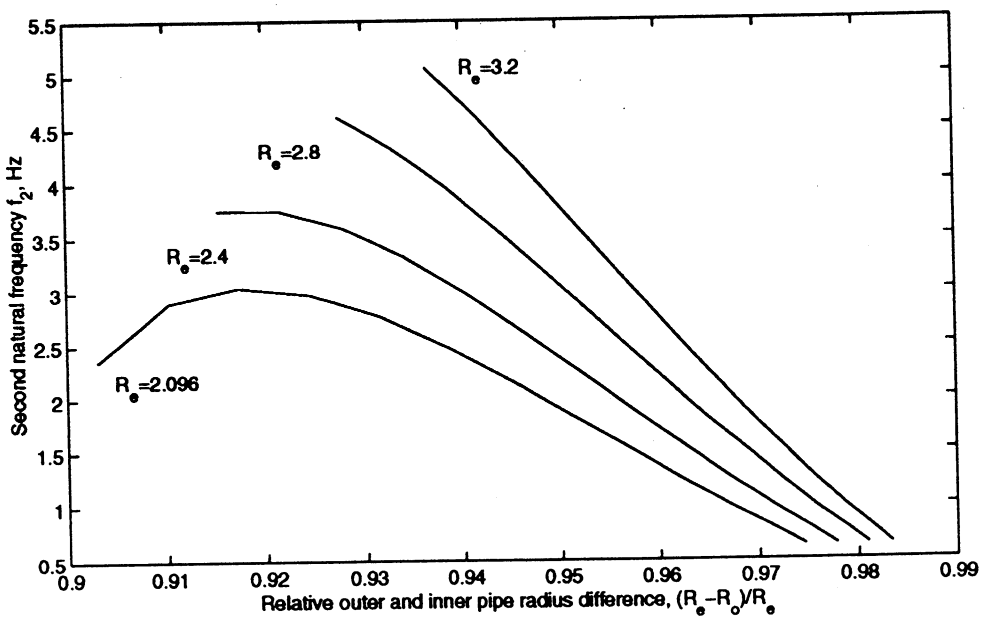


Location of the mixing pipe in the silo unit.

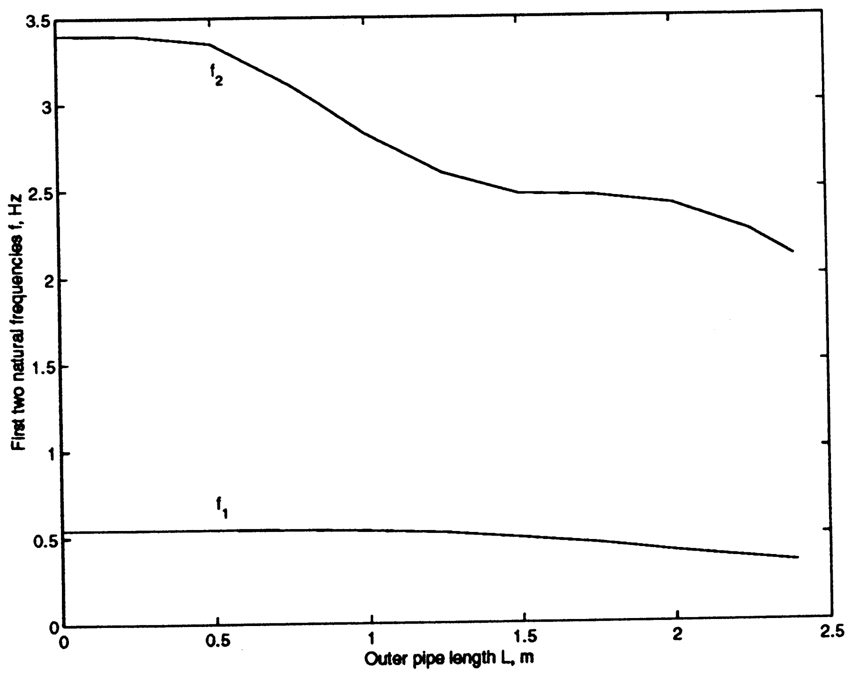


The concentric piping equilibrium configuration.

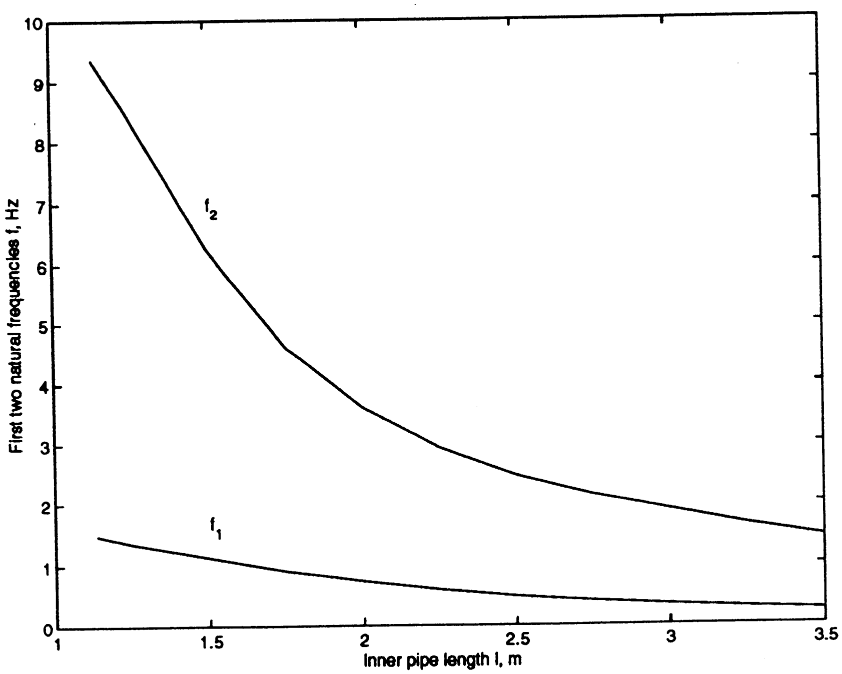




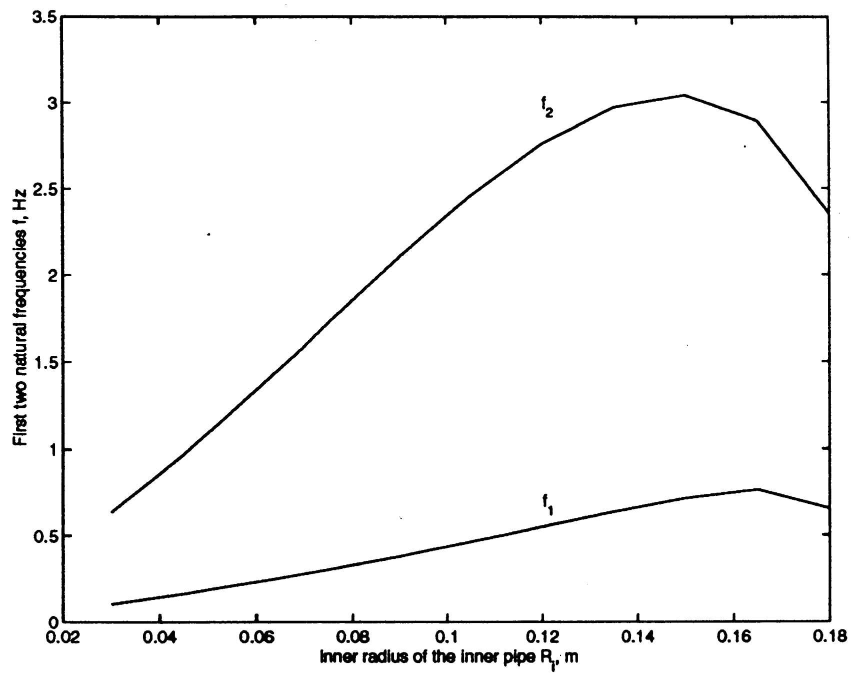
First two natural frequencies vs. relative outer and inner pipe radius difference $(R_e - R_o)/R_e$. (Forty-two grid points.)



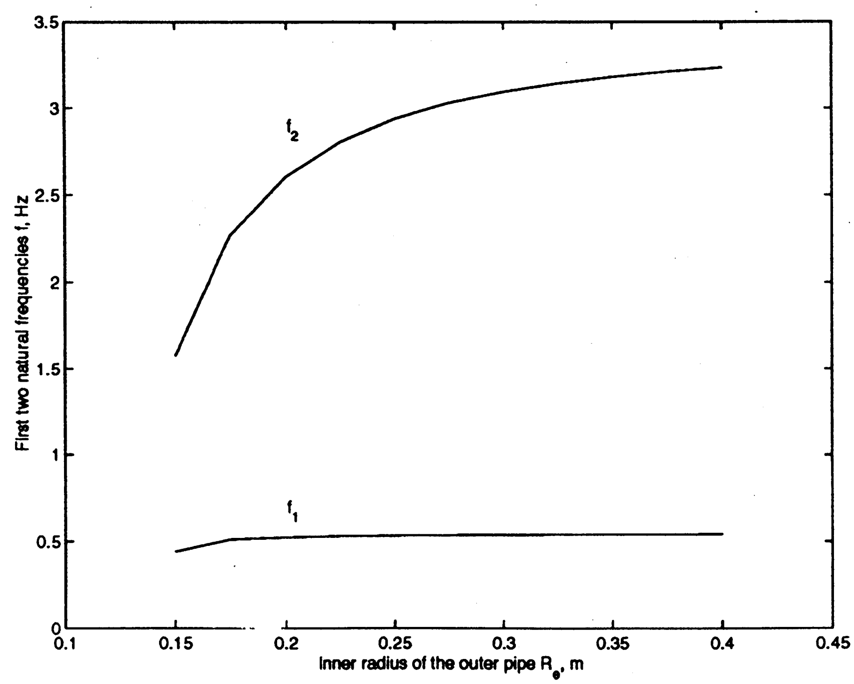
First two natural frequencies *vs.* the outer pipe length L. (Forty-two grid points.)



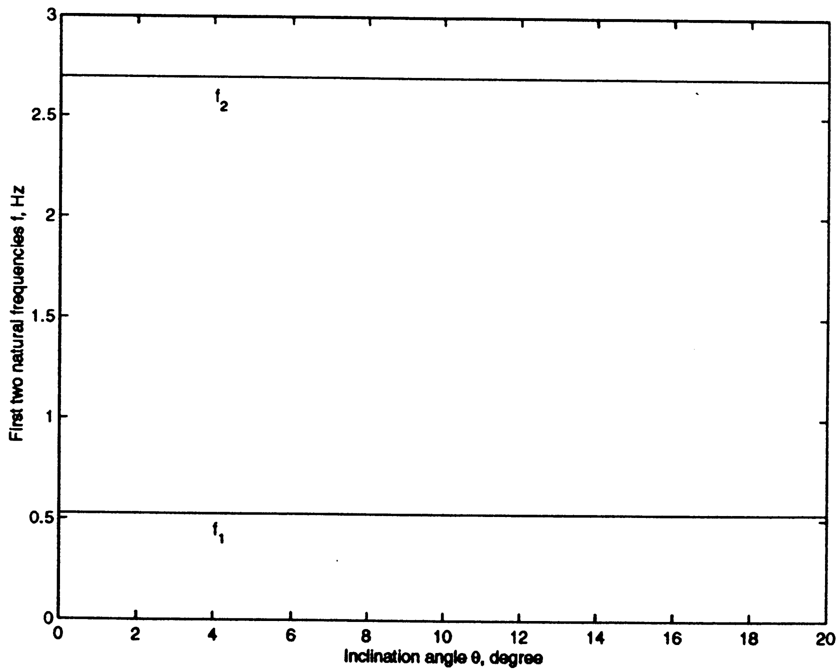
First two natural frequencies *vs.* the inner pipe length l. (Forty-two grid points.)



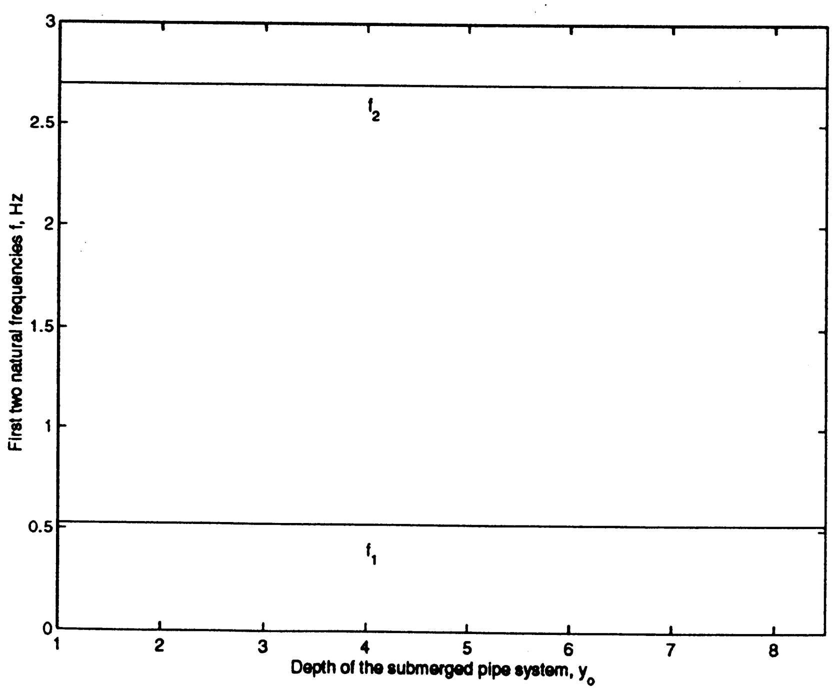
First two natural frequencies *vs.* the inner radius of the inner pipe R_i. (Forty-two grid points.)



First two natural frequencies *vs.* the inner radius of the outer pipe R_e. (Forty-two grid points.)



First two natural frequencies *vs.* the inclination angle θ. (Forty-two grid points.)



First two natural frequencies *vs.* the depth of the submerged pipe system y_o. (Forty-two grid points.)

ACKNOWLEDGMENT

- Dr. Frederick Bloom;
- Dr. Larry J. Forney;
- Dr. Zhigang Feng;
- Mr. Andy Brown.

HEADBOX AND FORMING HYDRODYNAMICS

SLIDE MATERIAL

FOR

PROJECT F005

March 23, 1998
Institute of Paper Science and Technology
Atlanta, Georgia

HEADBOX AND PAPER FORMING ANALYSIS AND OPTIMIZATION (F005)

REPORT TO THE

PAPER MAKING PROJECT ADVISORY COMMITTEE

Spring 1998

DUES-FUNDED PROJECT SUMMARY

Project Title: Fundamentals of Headbox and Forming Hydrodynamics

Project Number: F005

PAC: Paper Making

Division: Engineering

Supporting Research Students

M.S. Students: A. Vorakunpinij

Ph.D. Students: C. Park

RESEARCH LINE/ROADMAP

Paper Machine Productivity and Quality

PROJECT OBJECTIVE:

The objectives of this project are to:

(1) Better understanding of the paper and board forming processes,

(2) develop novel methods for analysis and control of paper forming, and

(3) develop more effective headbox design and paper forming procedures

PROJECT SCOPE:

Based on the Headbox & Paper Forming questionnaires, the top three issues of importance are:

i. CD nonuniformities (basis-weight, streaks, fiber orientation, moisture, filler and fines distribution ...)

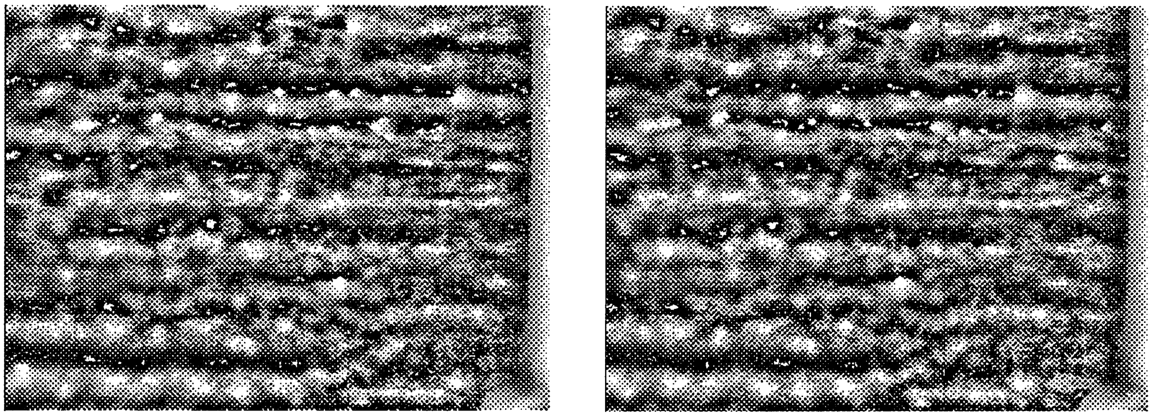
ii. Understand and improve formation (fiber dispersion in the headbox and on the forming wire, ...)

iii. Enhance CD properties (stiffness), ring-crush, STFI, ...

the long-term issue of importance is:

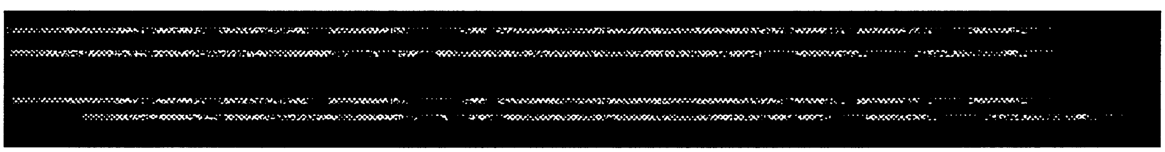
iv. Design an optimized headbox and forming section

DIGITAL IMAGES OF THE TURBULENT FLOW ON THE FORMING TABLE
(taken at 1 ms apart)



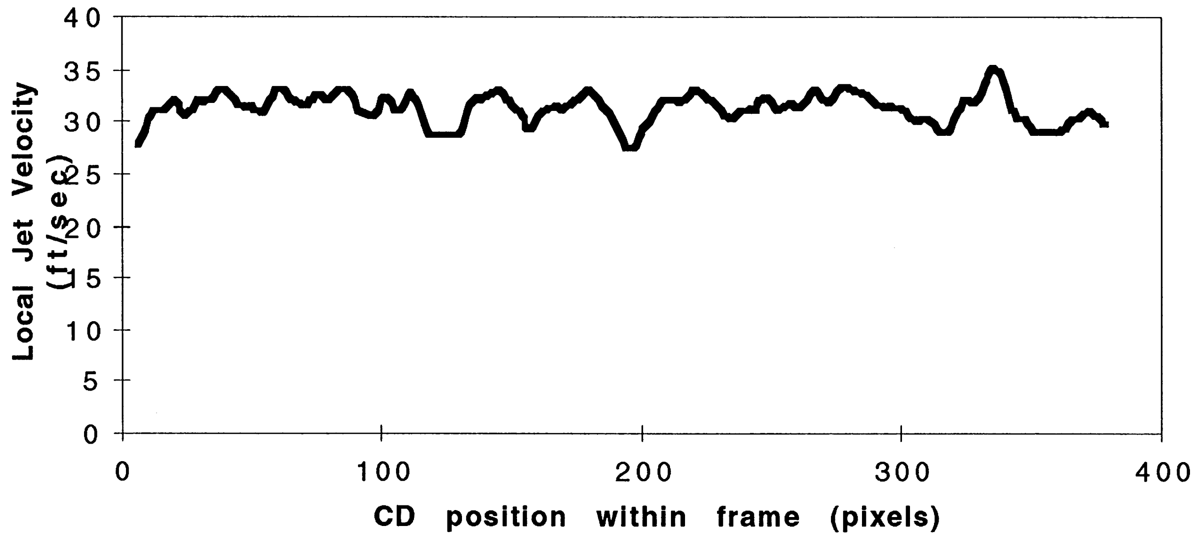
The machine direction is from right to left and the photograph on the left is taken first. Notice the patterns due to turbulence superimposed on the mean streak patterns within the images. This method uses patterned features in the images to estimate the surface velocity profile of the forming jet. Each image represents a 4.7" x 6.3" region of the forming table.

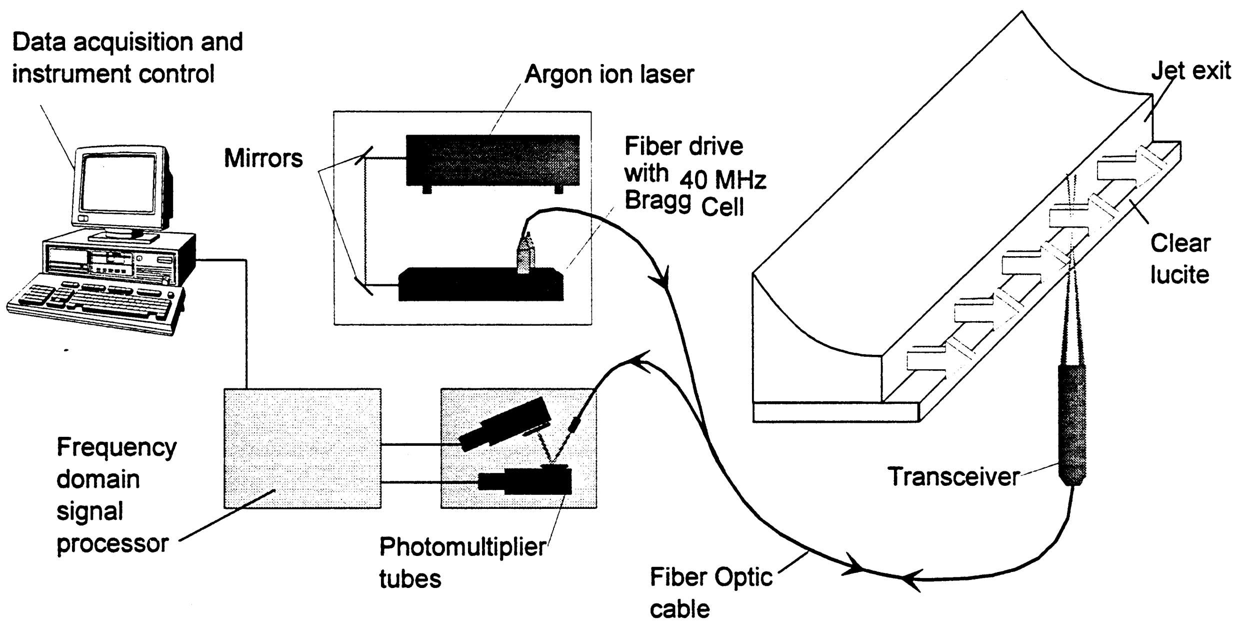
LINE SEGMENTS DEMONSTRATING THE CROSS-CORRELATION OF DIDGITAL IMAGES TO MEASURE THE SURFACE JET VELOCITY PROFILE



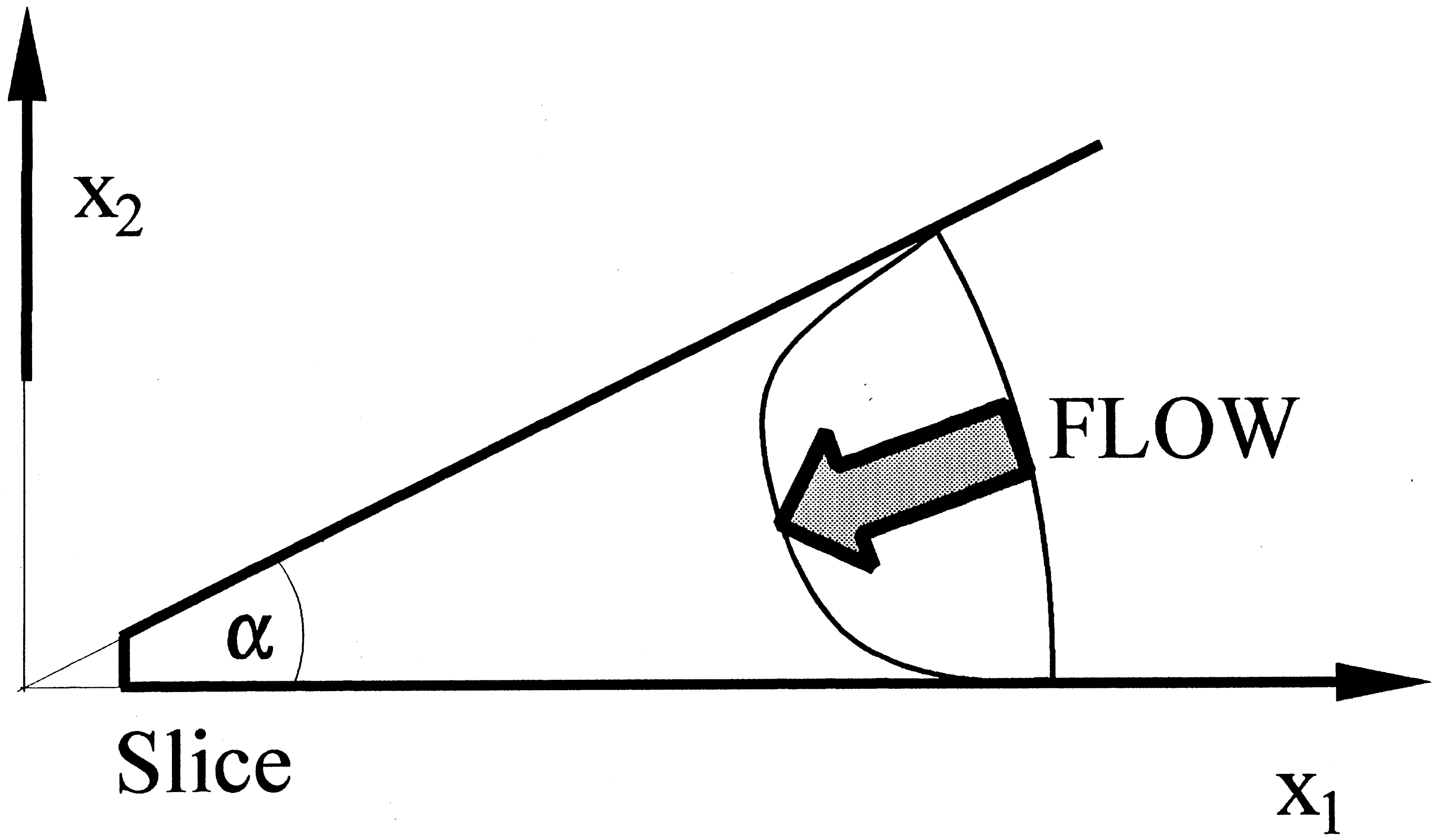
The top two lines are line segments from the two digital images similar to those used in the cross-correlation program. At the bottom, the two images are lined up according to their respective grayscale values. The displacement of the bottom line is equal to the lag, or the distance the line of fluid has moved within the 1 ms time interval between exposures.

AVERAGE FORMING JET VELOCITY PROFILE OVER 4.7" of CD SECTION DETERMINED BY LINE-LINE CROSS-CORRELATION OF THE HIGH-SPEED DIGITAL IMAGES

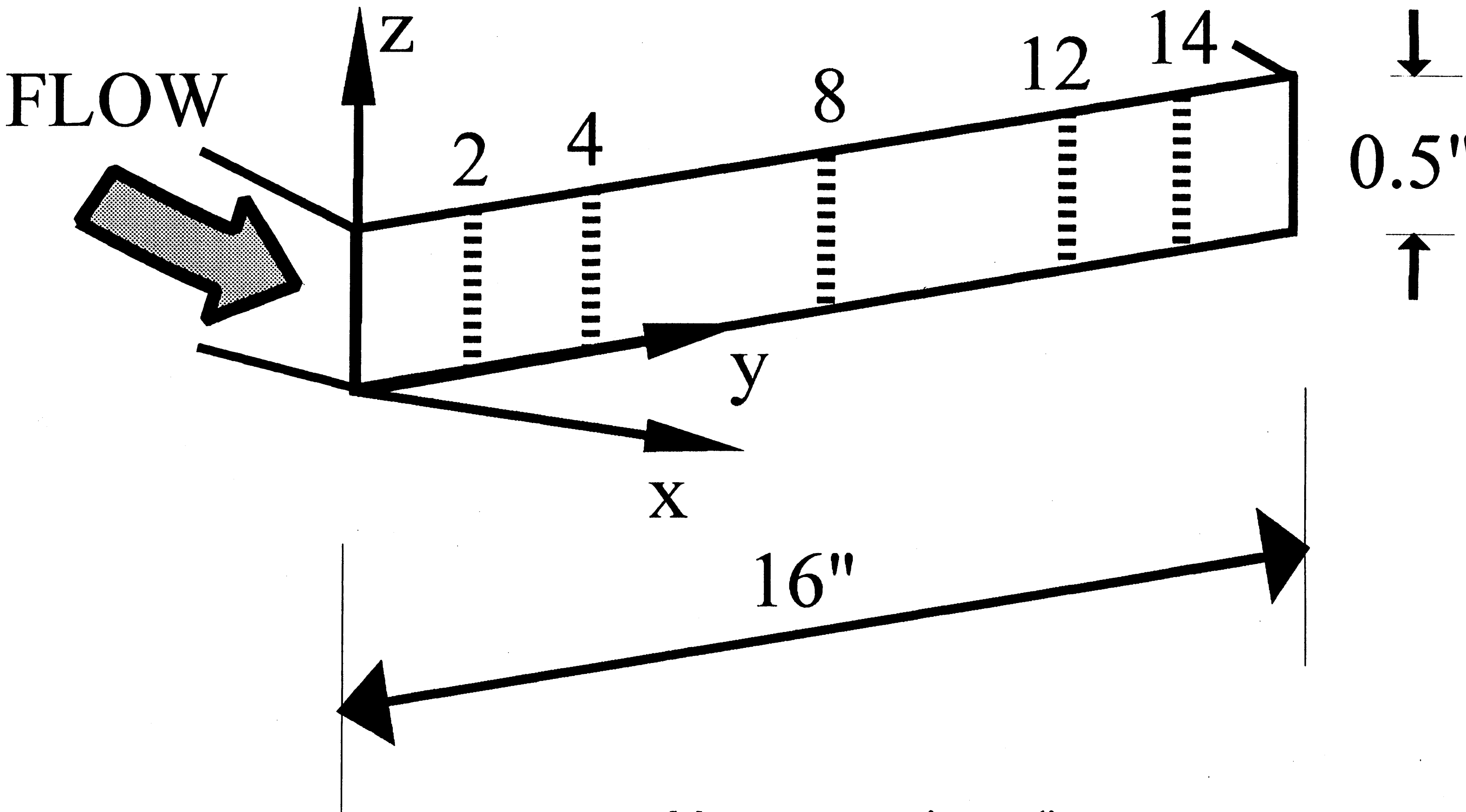




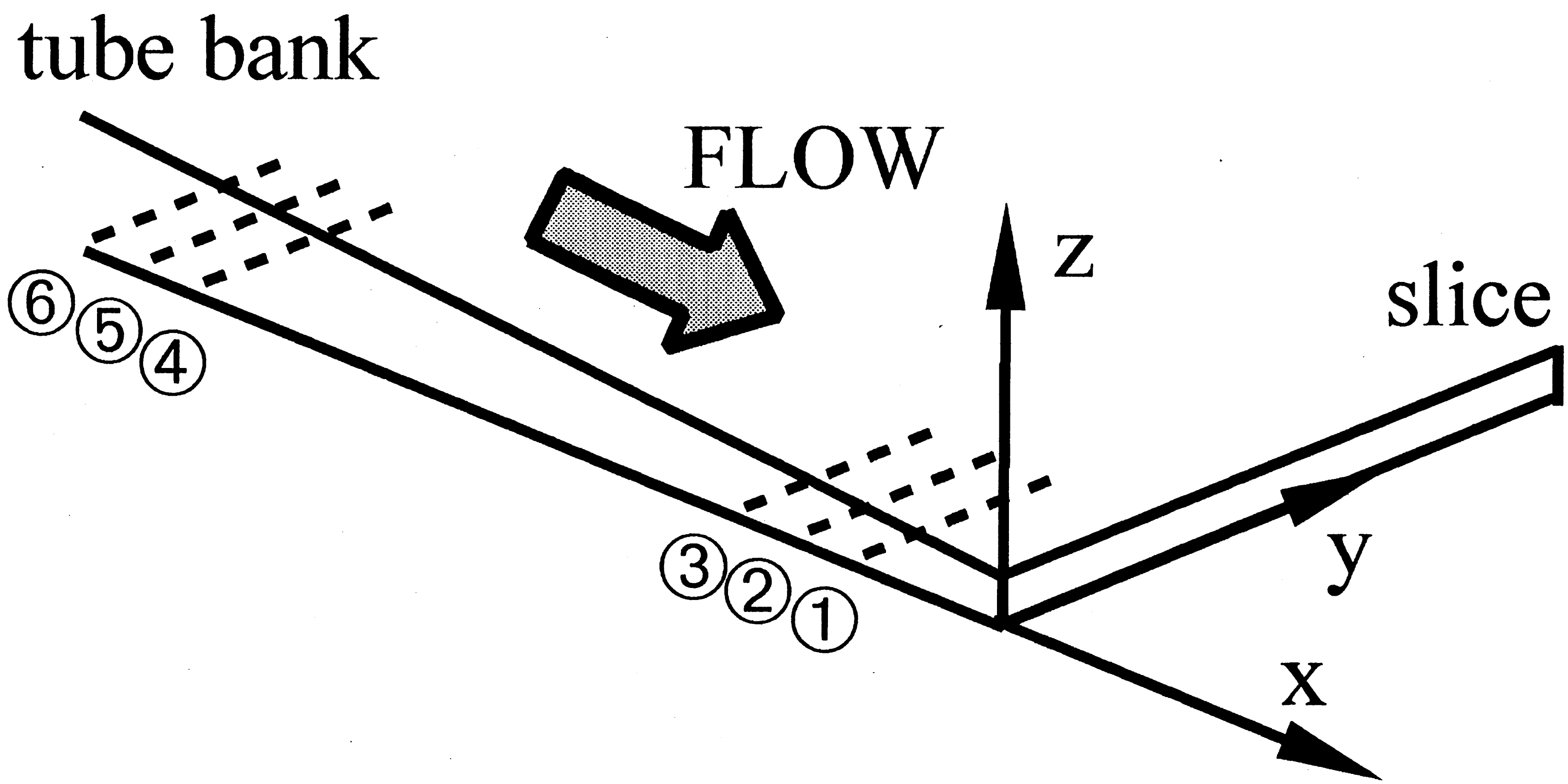
Schematic Depiction of LDV Experimental Configuration



Flow in a converging channel at high Reynolds number

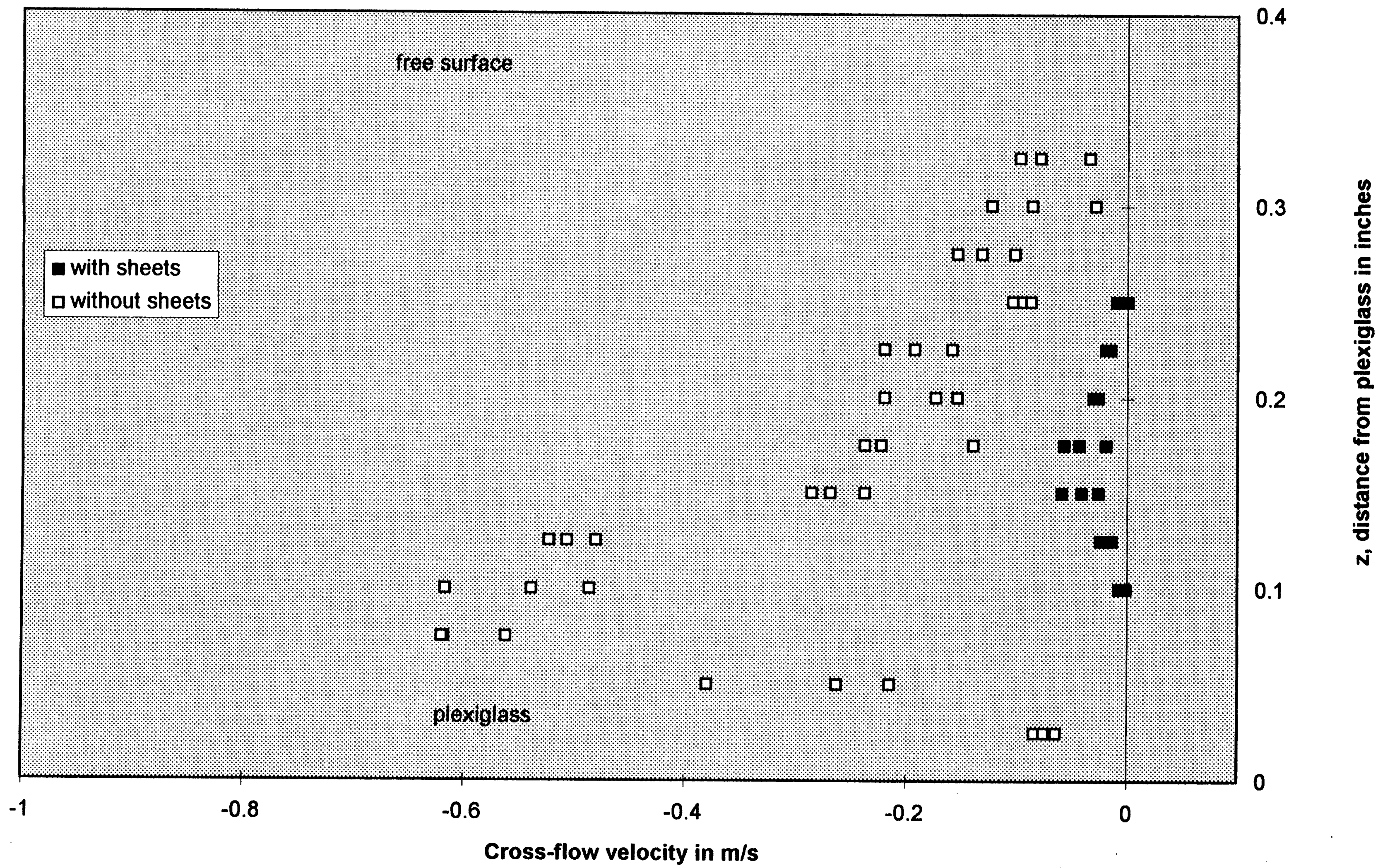


Measurement vertices at slice



Velocity measurement records along the side of the headbox

Cross-flow velocity at slice vertice y=2"



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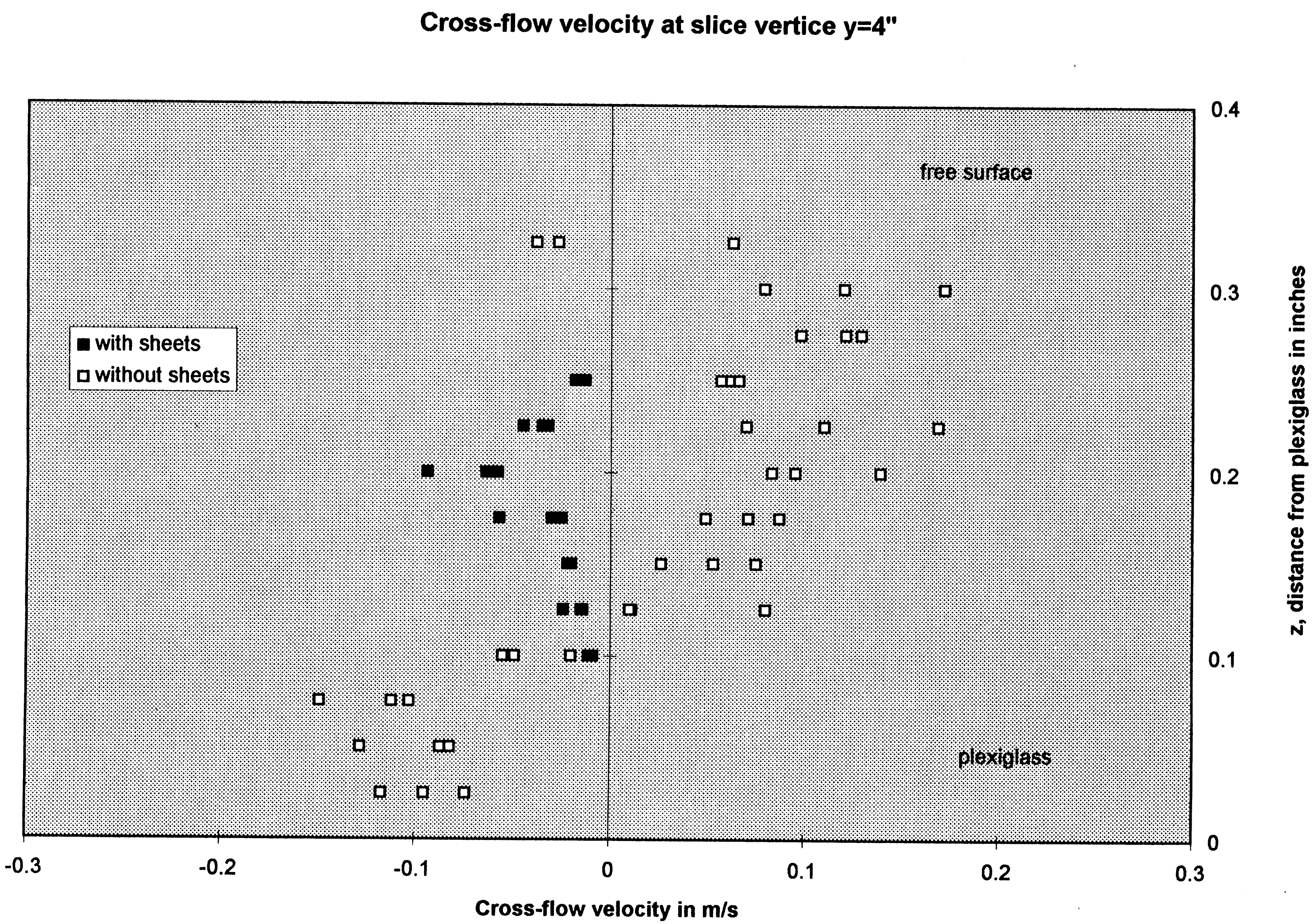

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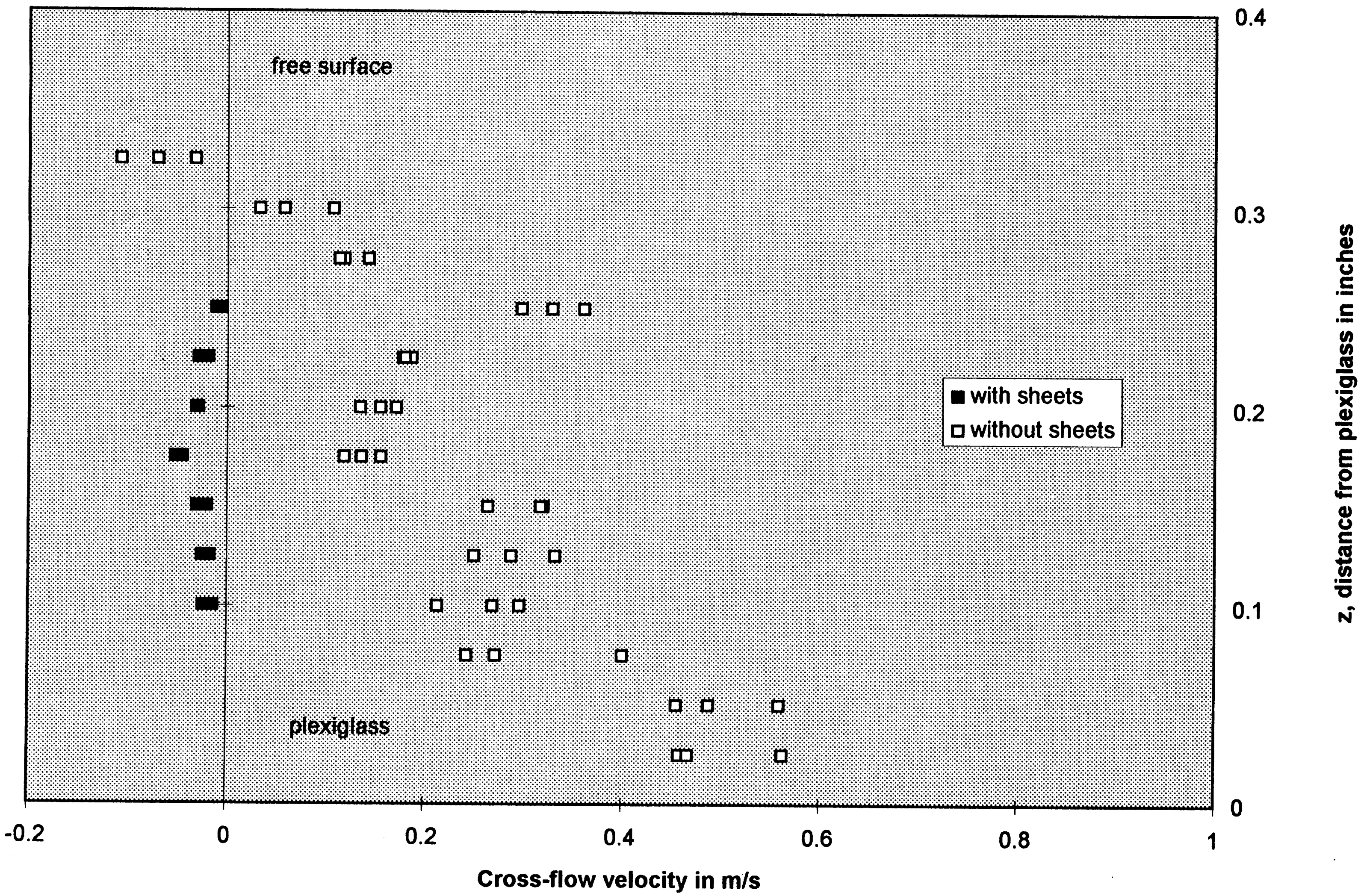
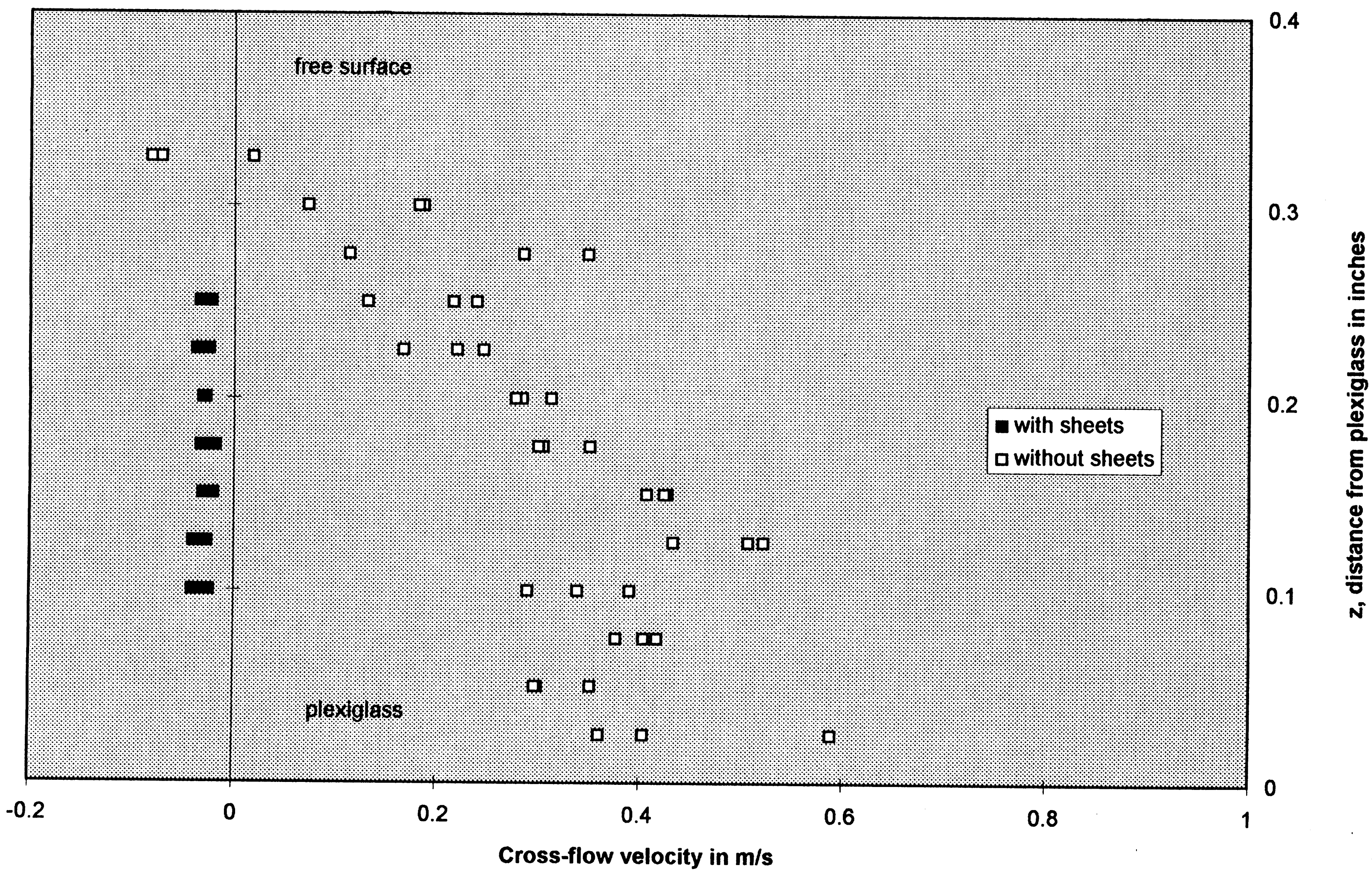
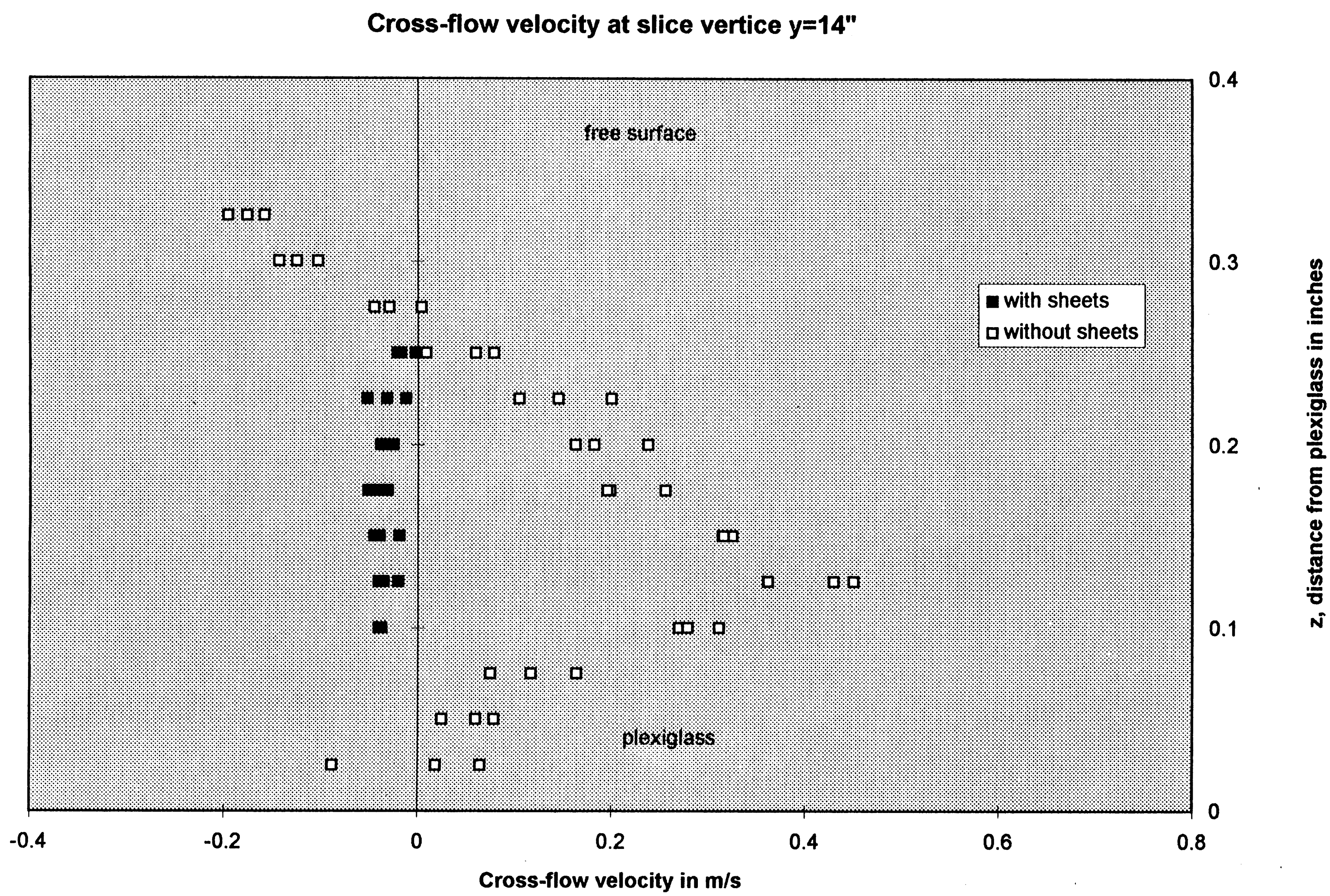
Cross-flow velocity at slice vertice y=8"



Cross-flow velocity at slice vertice y=12"





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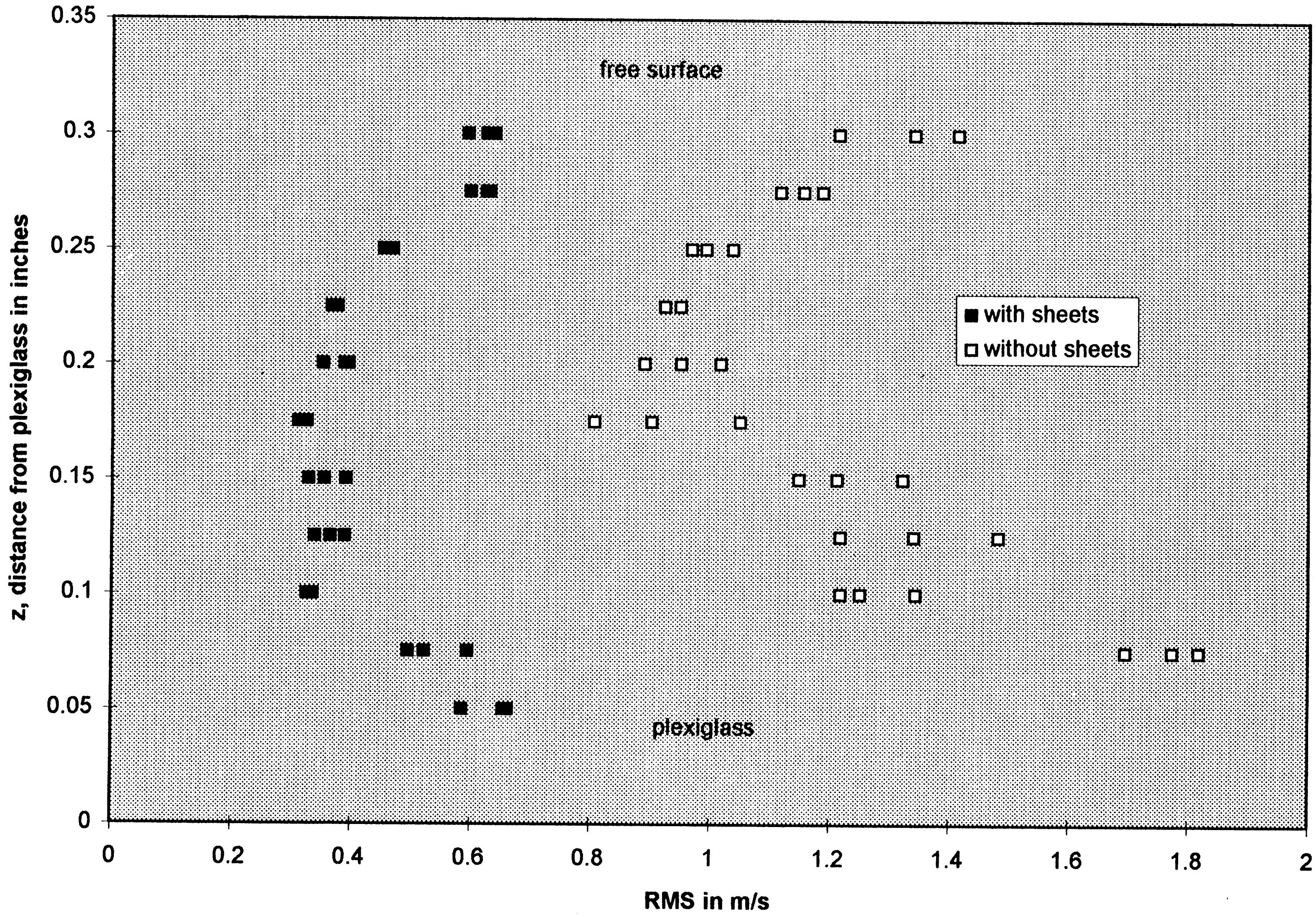
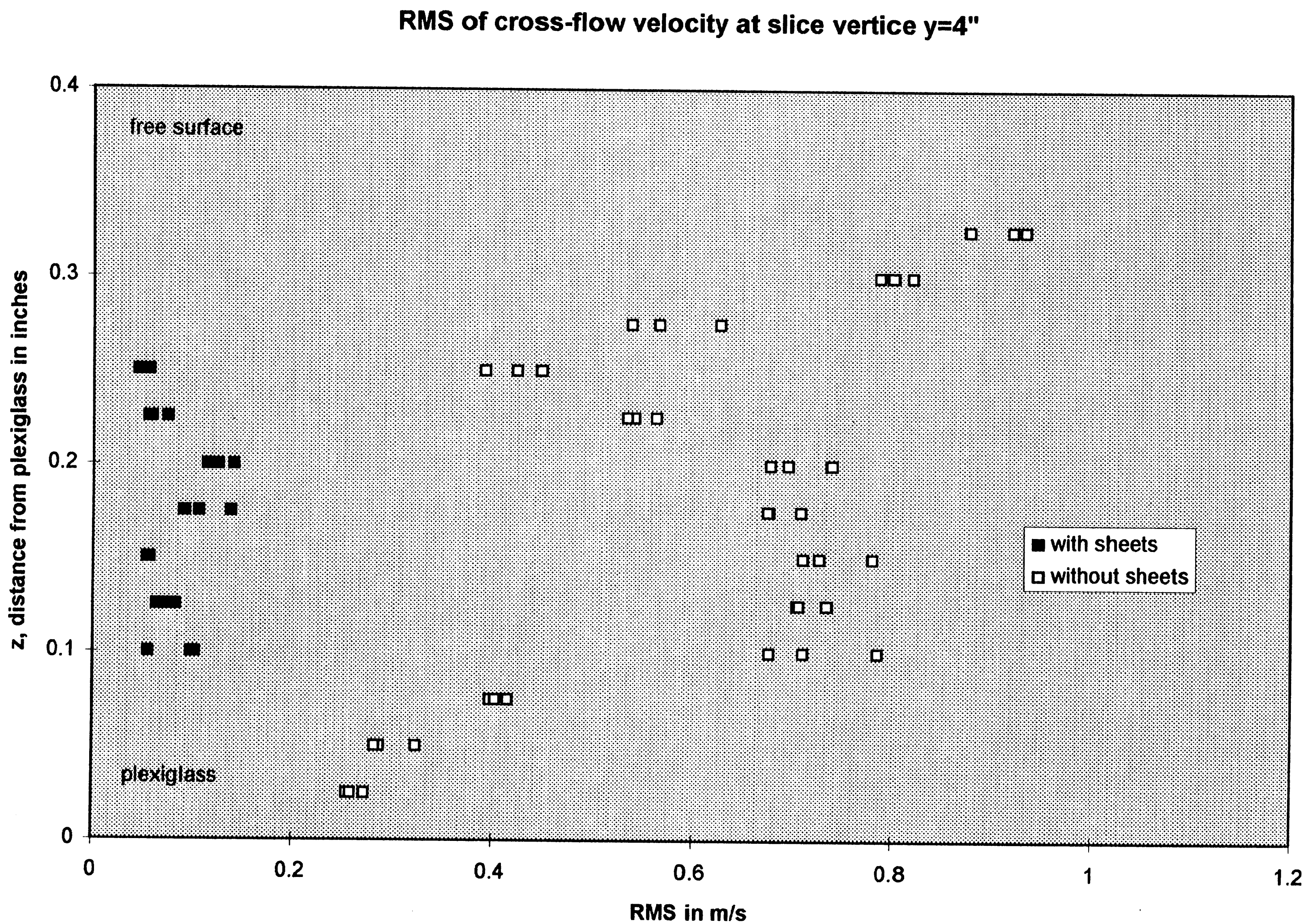
RMS of streamwise velocity at slice vertice y=4"





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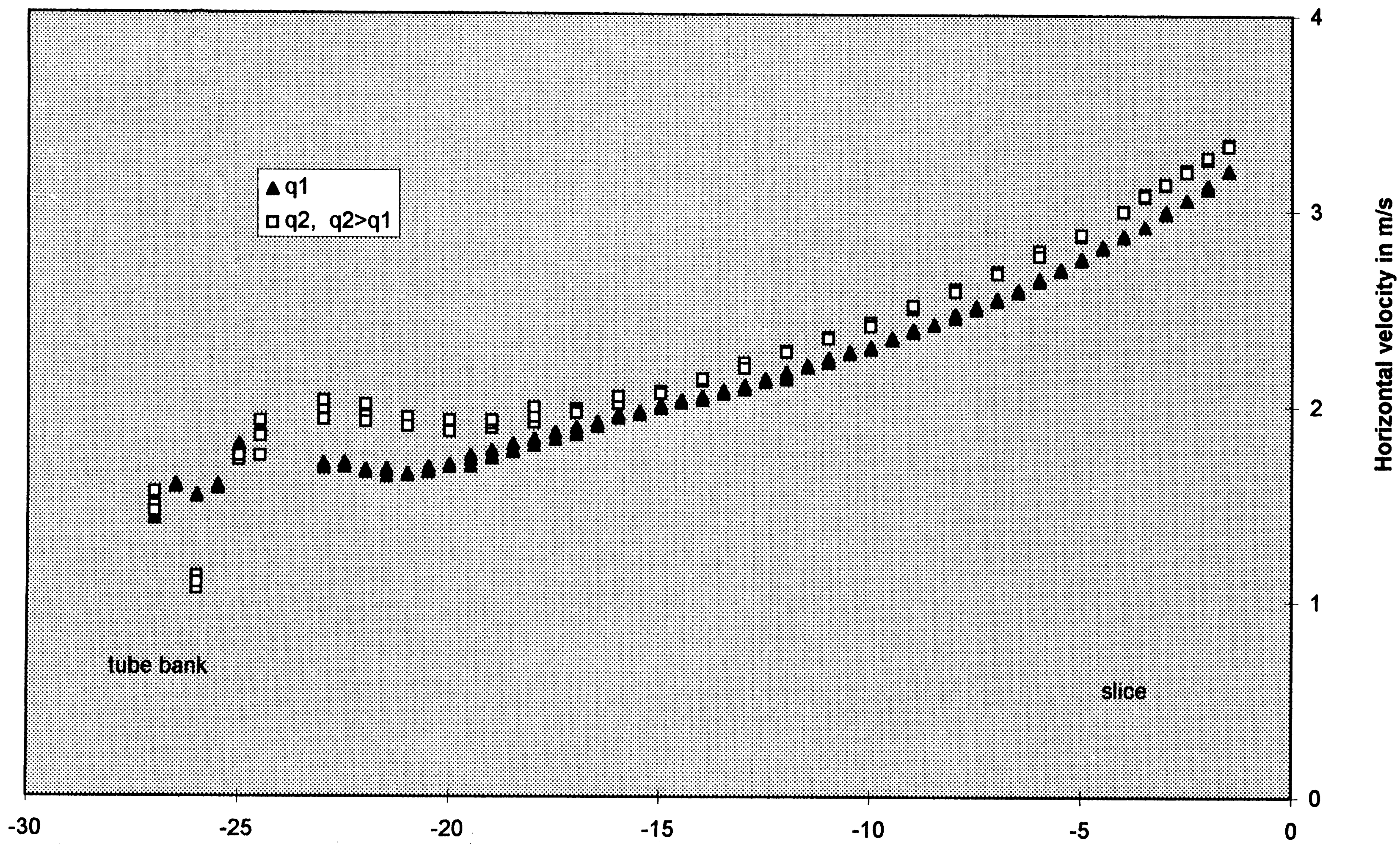
Horizontal velocity along headbox centerline without sheets



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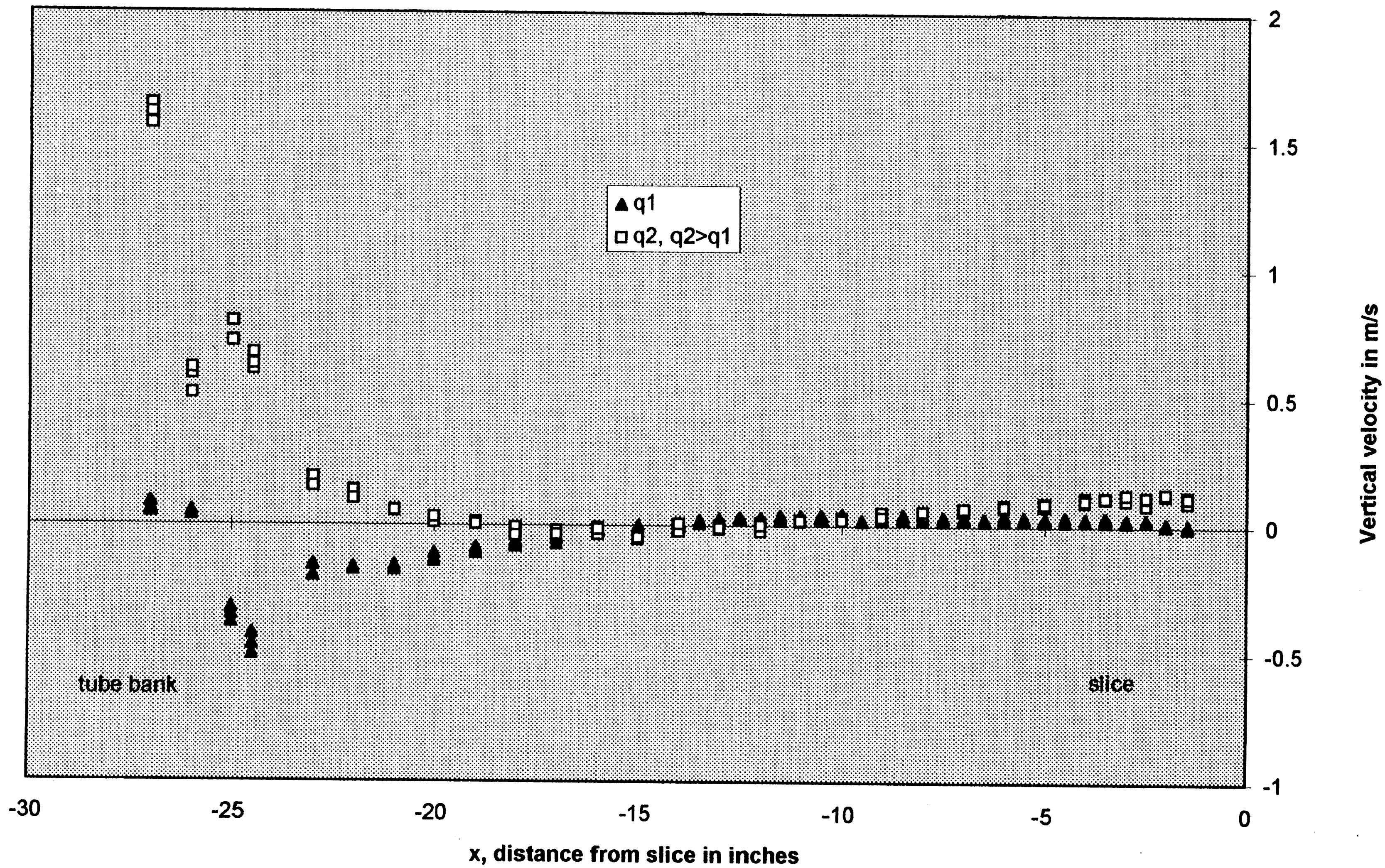
Vertical velocity along headbox centerline without sheets



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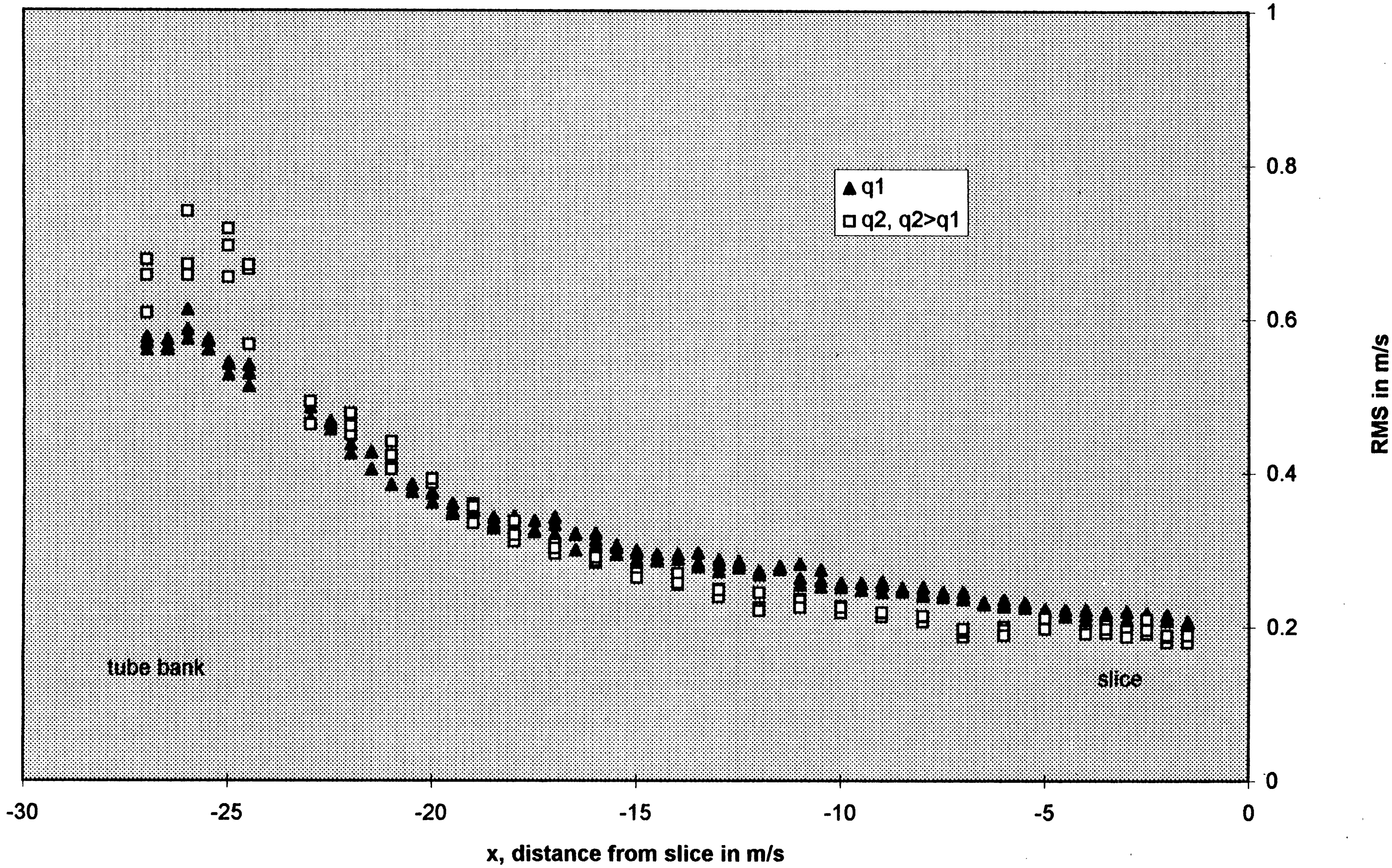
RMS of horizontal velocity along headbox centerline without sheets



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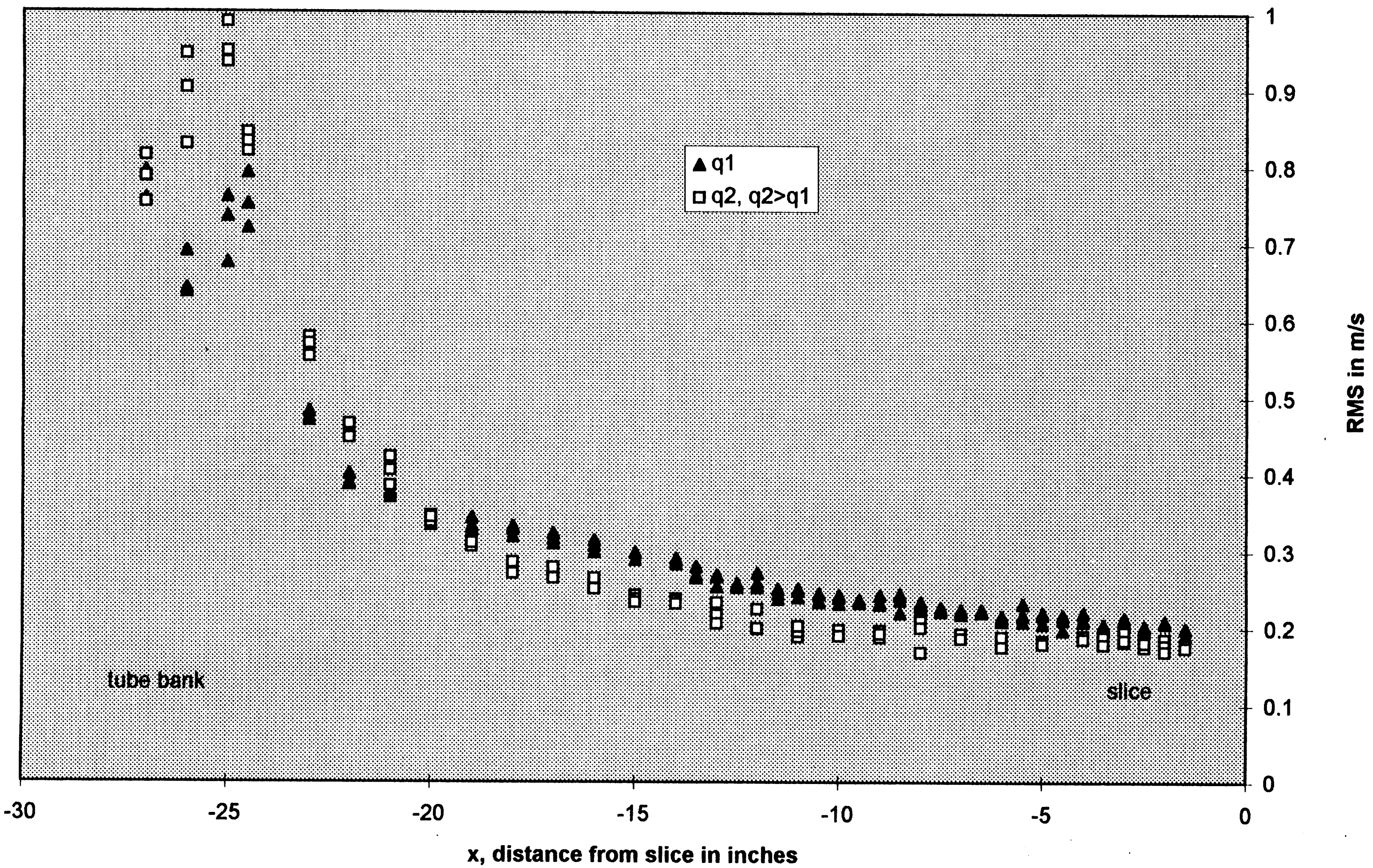
RMS of vertical velocity along headbox centerline without sheets



SUMMARY OF RESULTS

The details of the results are provided in an annual report for this project. In this section, we simply summarize the results and their applications.

Immediately applicable results:

1. Methods to quantify and compare the results from high-speed digital imaging and image analysis of various forming sections have been developed. This method can be used as a diagnostics tool for characterization of the forming section. Application to four headboxes with different design features show that the structure of the forming jet depends strongly on the flow properties inside the headbox. For example, the forming jet from heaboxes with the extended sheets from the tube block show a completely different structure compared to the headboxes without the sheets. It appears that the sheets reduce the size of the turbulent eddies as well as the turbulent kinetic energy inside the headbox.

2. A method based on one-dimensional cross-correlation of the high-speed digital images of the forming layer has been developed and tested for surface velocity measurement of the forming jet. This method provides more accurate measurement of the forming jet velocity. The preliminary results show that there is considerable streamwise velocity variation on the jet surface. Current results show that the velocity profile does not have a correlation with the streaks. Further refinement of the procedure including the hardware and extension to on-line analysis of the images and velocity measurements are planned for the next six months.

3. The flow characteristics in a headbox with and without the sheets have been examined and compared with accurate measurements of the mean velocity as well as the turbulent fluctuations using an LDV system. The results show that the role of the sheets is to reduce the scale of turbulence, as well as, reduce the turbulent kinetic energy.

CONCLUSIONS

1. The streamwise velocity of the flow leaving the headbox at the jet exit is more uniform with the sheets.

2. Cross-flow velocities without the sheets can be quite substantial. This indicates the presence of secondary circulations.

3. The cross-flow velocities are smaller with the sheets.

4. The magnitude of the turbulent fluctuations (expressed as their rms values) are smaller and more spatially uniform over the jet exit with the sheets than without. Relative turbulence intensities over the jet exit are typically about 3 to 6 % with the sheets and are much larger without.

5. The streamwise velocity inside the headbox increases more uniformly with the sheets than without them. Vertical velocities in the headbox are essentially eliminated by the sheets but can be quite large without them.

6. With the sheets, the relative turbulence intensity decreases rapidly with distance inside the headbox. It is about 40 % near the outlet of the tubes and about 3% at the forming jet near the slice. This is due to the rapid decay of the turbulence intensity.

7. The results from cross-correlation of scanned lines from the high-speed digital images provides a relatively accutate measure of the velocity profile across the surface of the forming jet.

8. The preliminary results show that the variations in the streamwise velocity can be quite large (20-30%).

9. From the preliminary results, the variations in the streamwise velocity do not correlate with the streak pattern in the forming jet.

10. The effect of the streamwise flow variation on the surface of the forming jet on the wire side could be the main cause of the small scale variations in fiber orientation.

TASKS FOR FY 98-99

1. Develop the cross-correlation surface velocimeter as an on-line method for measurement of the CD mean velocity profile on the surface of the forming jet to examine CD variability,

2. examine the temporal variations of the CD velocity profile (fluctuations from the mean),

3. three series of pilot trials to produce 100-150 gram fine paper with anisotropic, as well as, isotropic in-plane fiber orientation,

4. examine the effect of fiber orientation isotropy on physical properties of fine paper

DELIVERABLES for 1998-99

1. Annual report for the 1997-98 Fiscal year, (June 1998)

2. An on-line method for measurement of the CD mean velocity profile on the surface of the forming jet as a diagnostics tool for process optimization,

3. Methods to enhance sheet properties by modifications to the wet end,

4. Measurement of the turbulent Reynolds stress in the tube section and in the converging section of a headbox using a two-componenet LDV system to improve formation,

5. Annual report for the 1998-99 Fiscal Year (June 1999).

SCHEDULE for 98/99:

Month =>	July	Aug.	Oct.	Dec.	Feb.	April	June
ITEM							
1. Report	--|						
2. On-line velocimeter	-------	-------	-------	-------	-------	-------	----|
3. Wet end Mod.		----	-------	-------	-------	-------	-----|
4. Reynolds Stress	-------	-------	-------	-------	-------	-------	------|
5. Annul Report						-------	------|

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