Memorial University's

BOUNDARY LAYER WIND TUNNEL

Prepared for **DR. J. H. LEVER**

and **THE DIVISION OF COORDINATION**
FOR THE FACULTY OF ENGINEERING
AND APPLIED SCIENCES

STEPHEN BRUNEAU 8125247
Work Term 3 Dec. 7/84

DEC 0 7 1984

TABLE OF CONTENTS

LIST OF FIGURES

PAGE

INTRODUCTION

The following report has been prepared to inform people~~s~~ ~~concerned,~~ about the new boundary layer wind tunnel situated on the mezzonine in the fluids lab of the Engineering and Geology Building.

This paper may serve as a progress and status report to those who have done work on the tunnel ~~in the past, a report to inform~~ others entirely unfamiliar with it,? and a guide for those who will be working on or with the wind tunnel in the future.

Chapter 1 deals with the work completed as of November 20, 1984. This includes preliminary design and conception of the wind tunnel, final designs, and construction of tunnel components.

Chapter 2 is an indication of the present stage of the wind tunnel. Outlined are the general characteristics of the tunnel itself, inventories of equipment, operating procedures and maintenance suggestions.

Chapter 3** is a review of what work is still to be done. It includes suggestions from several sources such as

DSMA. The suggestions will cover implementation of traversing gear and other equipment, sound protection, and tunnel surface finishing.

Many of the calculations and recommendations made during the construction period have been included in the Appendices. A listing of Appendices and Figures that appear throughout this report is shown on the preceeding pages.

** This chapter has not been included in this report since information that will be received from University of Western Ontario and NRC in Ottawa, will not have been processed in time to be included before the deadline for report submission.

CHAPTER 1

PRELIMINARY WORK

Prior to Construction

Most of the preliminary work on the wind tunnel design was done by Don Philpott as a work term student in 1983. In two work reports and his report prepared for a Term 7 Computer Aided Design Course, Philpott gives a full background to the design of the upstream wind tunnel sections.

After having completed his preliminary descriptive design, Philpott forwarded a copy to DSMA International Inc., an engineering consulting firm, for appraisal.

Much useful information pertaining to the design of the contraction, wide angle diffuser and settling chamber was received from DSMA. Furthermore, recommendations concerning inlet flow conditions, fan noise and wind exhausting were present in their reply.

Jamie Lewington, a first year Masters student, prepared a document reporting how assembly of the upstream sections was to take place. Particular attention was paid to the status of the materials, i.e. in stock, on order, to be ordered, since these were the most important time related constraints.

Lewington incorporated DSMA's recommendations on diffuser, contractor and settling chamber designs in his report. Other factors that he mentioned were the importance of structural rigidity, accuracy of internal dimensions and the precision of the contraction assembly. Many exact details were omitted under the premise that they could best be decided after consultation with the carpenter.

Since all of the wood necessary to build the wind tunnel was immediately at hand, Lewington ordered the screens and the honeycomb that would be necessary to begin assembly. Bolts, screws, glue and nails were to be requisitioned by the carpenter as the need arose.

Some rough calculations and preliminary design work had been done for the boundary layer wind tunnel working sections.

Advanced planning had placed the fan a convenient distance from mezzonine offices and alligned its exhaust with an opening at the rear end of the fluids lab.

Construction and Assembly

Upon my arrival, construction of the diffuser and settling chamber components was completed and the carpenter, John Spurrel, had just begun work on the contraction. These three main components of the upstream section of the wind tunnel were completed separately and then assembled when all of the dimensions were checked. This much of the tunnel is indicated in the first part of Figure 9.

At this stage of construction , Lewington's report for immediate implementation ends. Both Lewington and Philpott did background work for the design of the working and test components of the downstream section of tunnel. With additional information on critical dimensions and manipulative requirements, provided by Dr. Lever, design and construction of these components was able to proceed.

The following is a list of wind tunnel component parts that were built during the Fall semester of 1984.. Included are many of the requirements met and some of the reasons for decisions made during the construction period. The order in which they appear is the order in which they were built. The list is as follows:

Working Section Components

The individual components making up the working section were to flange together at the ends, have removable floors, be easily accessible through the side and have the ability to vary their roof height and slope. Calculations made by Philpott suggested that a cross section of three feet squared provided adequate working section area with the desired low air velocity (approximately 20 m/s). Preliminary design drawings were made and are indicated in Figures 1-3 in the order in which they were drawn and presented for assessment. The addition of adjustable feet allowed the proper leveling of each section since inconsistencies exist in the concrete floor. The floor pieces of the working section components have been cut into two 3x4 ft. sheets and screwed down in only the four corners so that they may be more easily removed. The final design was chosen as a variation of the third drawing after consultation with the carpenter. A three foot dummy section was placed upstream of the working section components to provide space for a test section where non-boundary layer tests may be carried out.

Roof Adjustment and Positioning

The problem of making the roofs airtight, flush from end to end and adjustable, was settled by flanging a 3' x 8' plywood piece that would fit down into the working section components. Since the adjustment for roof height was roughly worked out to be less than 10" for most all applications, it

FIGURE 1

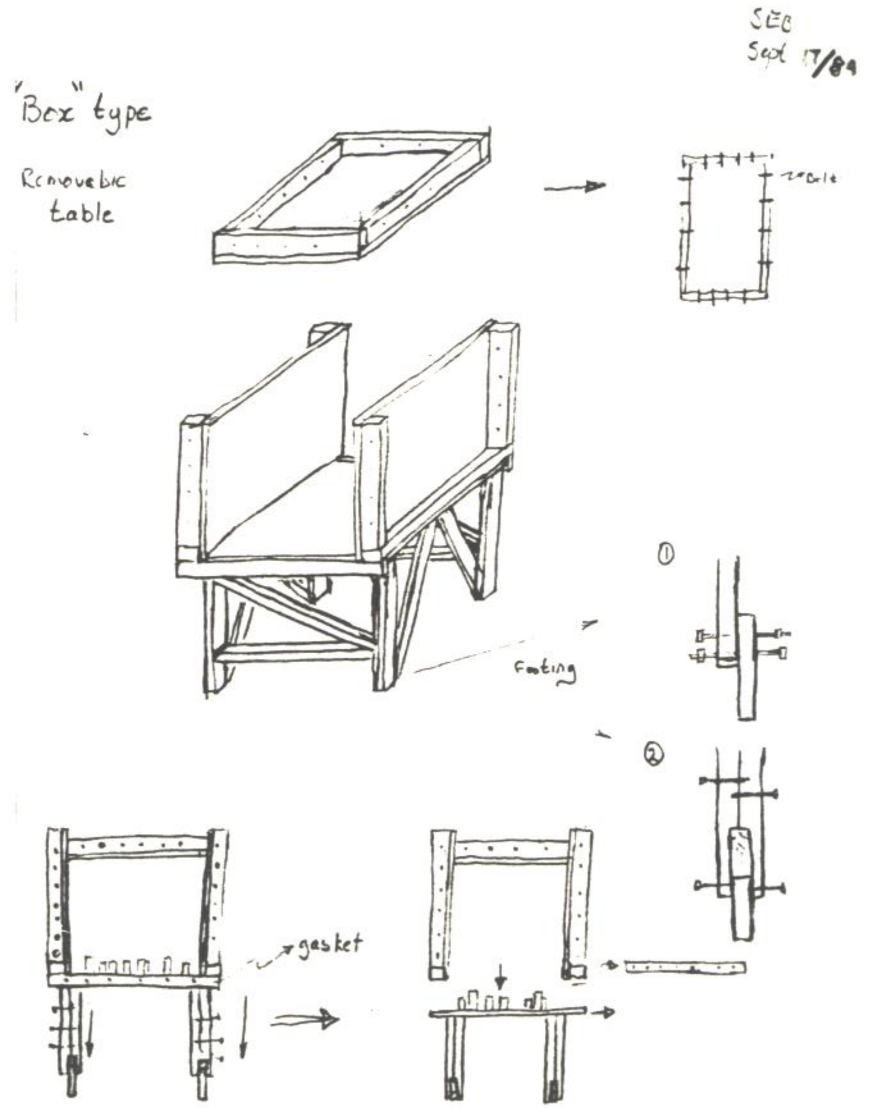


FIGURE 2

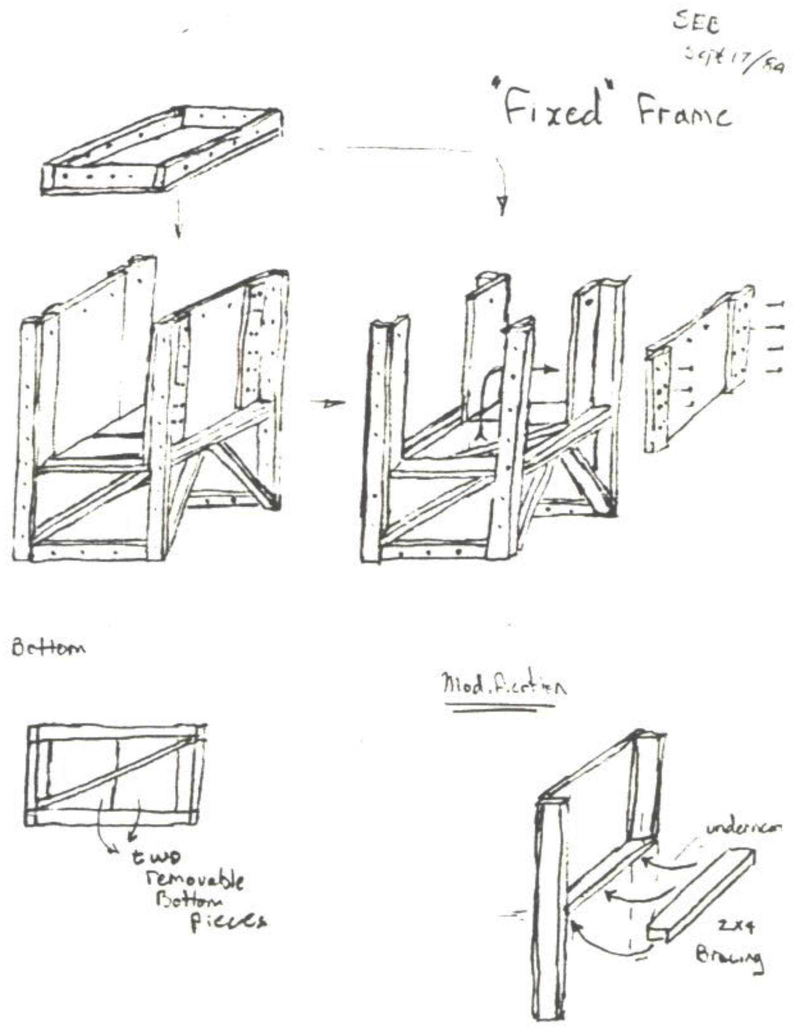
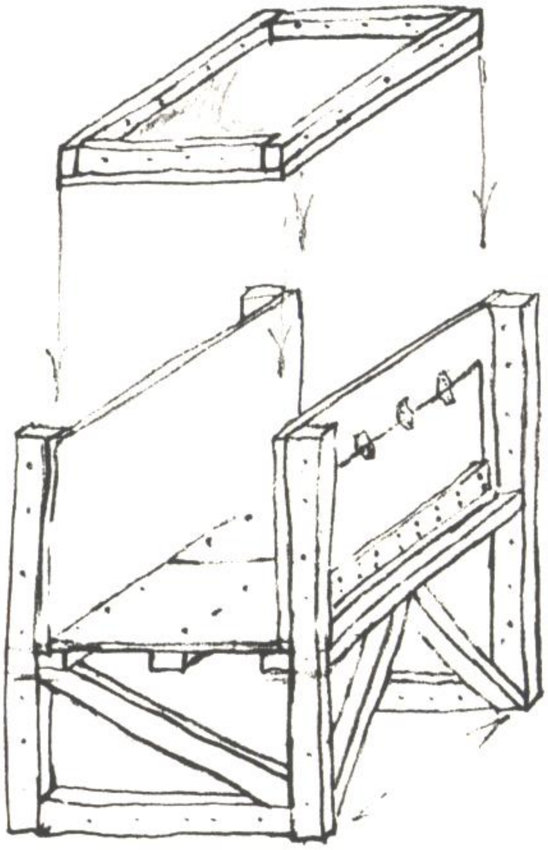
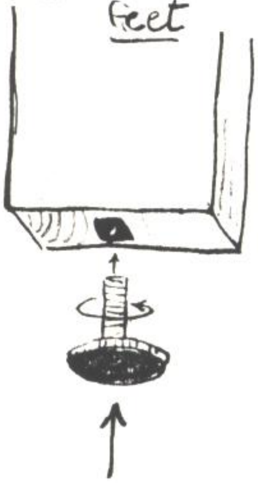


FIGURE 3

Hinged Model



Adjustable feet



was determined that it would be safe to screw the tops into position through the sides of the components at or above the 3' height without fear of exceeding the maximum wall height of four feet. To adjust the roof position, the screws in the walls must be backed out and relocated after the repositioning of the roof.

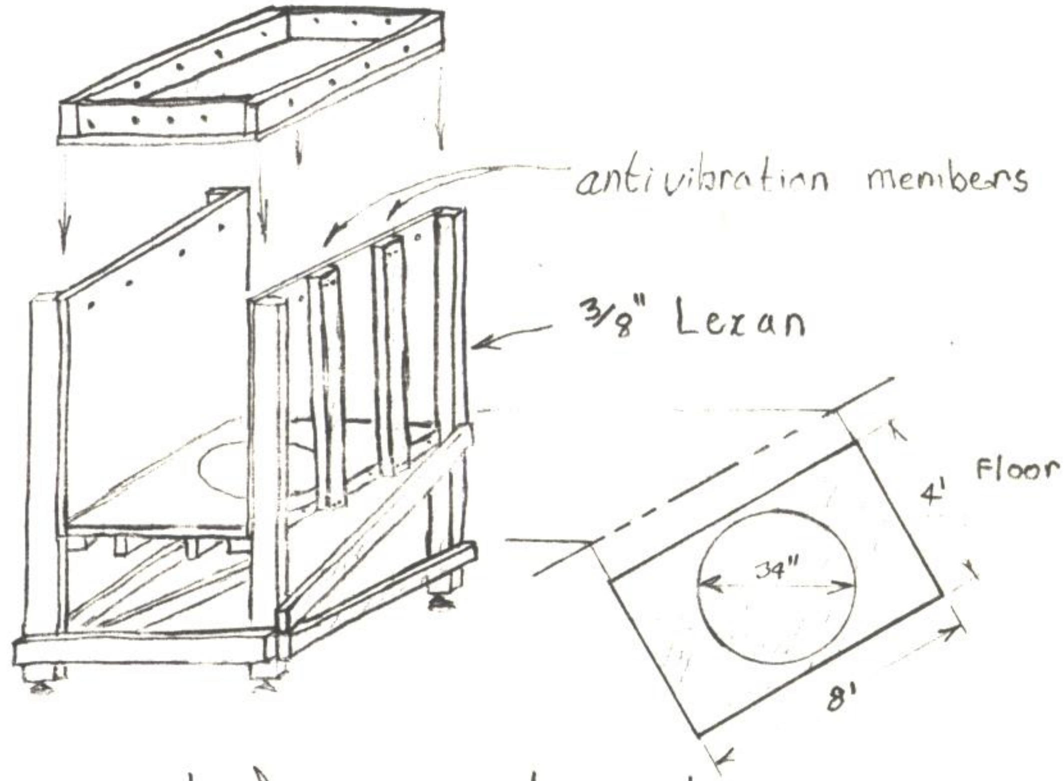
The position of the roof was calculated so that it was to rise 7.1 inches over forty feet of roughness elements with a conservative roughness coefficient (n) of 0.36 (approximately modeling the roughness of an urban downtown region) as shown in Appendix A. Taking into account the boundary layer produced along the walls and roof of the working sections, the rise was changed to 7.5 inches over 40 feet. The coeff. (n) = 0.36 was chosen in the view that tests most likely to be carried out will be those in an urban setting.

Downsteam Test Section

Since it would be necessary to view the inside of the test section during many testing procedures, the outward facing wall of this component was designed to accommodate a 4 x 8 ft. sheet of Lexan. Lexan is a hard, shockproof, transparent plastic. See Figure 4. To avoid damaging the smooth surface of the Lexan, the access door for the test section was placed on

FIGURE 4

Test Section (Downstream) SEB Nov 15th



All interal screw heads are counter sonk the back wall and built to open outwards. Vibrations in the lexan sheet during operation were reduced by bracing the exterior surface with two 2x4's. The roof of this section was made to slope by the same degree as the working section (1.5 in. over 8 ft.) to accommodate for the further reduction in airflow velocity.

Exit Diffuser

For simplicity of design and construction, the exit diffuser was to be a zero screen narrow angle diffuser. Dr. Lever provided the calculation of angles and rough dimensions as found in Appendix B. The final design put forward to the carpenter is shown in Figure 5. Note that original estimates of an internal angle of 15°, which was within the range of successful zero screen diffusers, was reduced to 14° as a double check against too steep an angle for proper diffusion of wind. Also the length of the diffuser was changed from 11.5 feet to 8 feet to accommodate materials, while still giving a reduction in exhaust velocity of approximately 2.5 times (see Figure 5 for calculations).

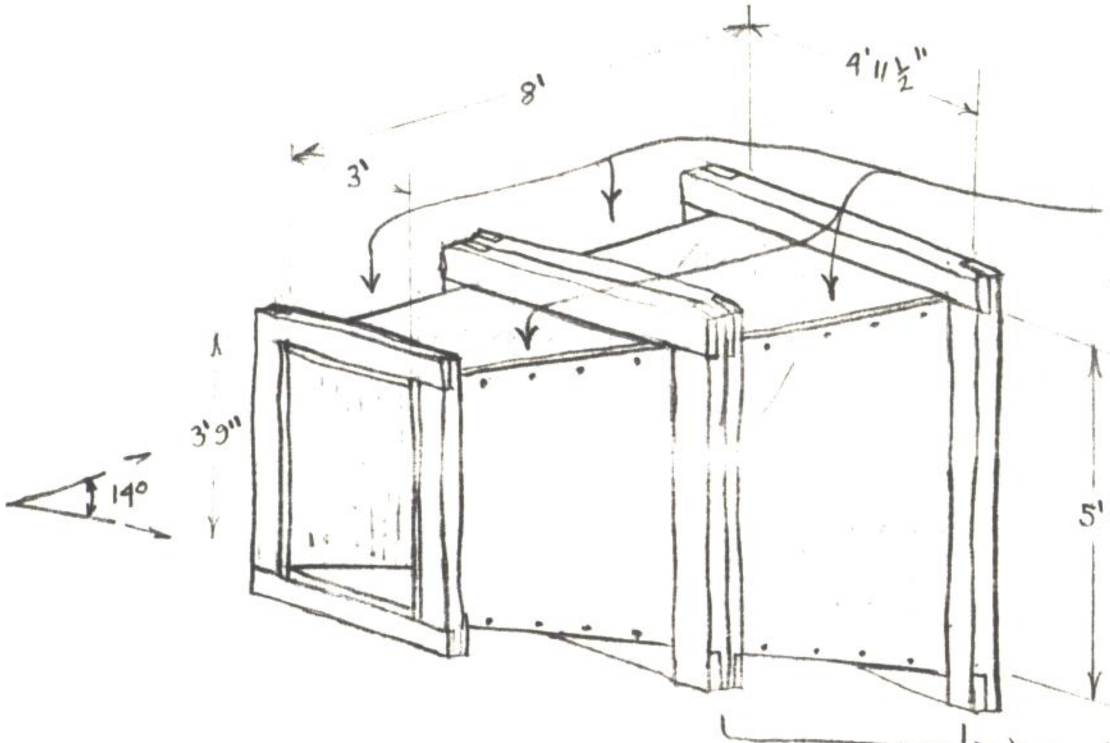
Side Chamber

The chamber built on the side of the three-foot dummy section at the mouth of the contractor was to be built to

FIGURE 5

Exit Diffuser

SEB Nov1st

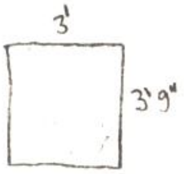


No glue applied so that adjustment to slope may be made.

½ sunk 2"x4" Flanges

Area expansion ratio:

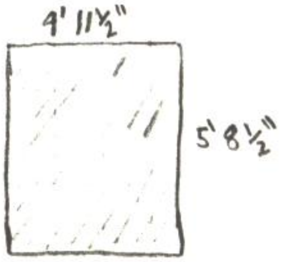
Entrence:



area ≈ 11.25 Ft²

ratio : $\frac{11.25}{28.37} = 0.396$

Exit:



area ≈ 28.37 Ft²

Therefore Exit velocity averages ≈ 0.4 Entrence velocity accommodate a floor mounted heat exchanger tube bundle model upon which vibration tests may be carried out.

Since the option of passing all of the air flow uninterrupted through the lengthy working section or through the side chamber was desirable, considerations were given for ducts and vanes of varying dynamic capabilities. The final design chosen was one that disregarded the uniformity of air flows that the chamber may produce and accommodation for a small settling chamber was made. The option of over-passing the chamber was solved by installing a door in the side of the tunnel which, when opened, became the back wall of the side chamber. See Figure 6.

Roughness Elements

To prepare the floor of the working sections so that desirable boundary layer conditions were met at the downstream test section, a paper prepared by I.G. Gortshore & K.A. DeCroos[1] was consulted.

---

[1] Gortshore & DeCroos, " Roughness Element Geometry Required for Wind Tunnel Simulations of the Atmospheric Wind".

Dr. Lever proceeded to calculate the geometry of roughness elements which best suited the needs and constraints of Memorial's boundary layer wind tunnel. These calculations are found in Appendix C. Note that the arrangement of roughness elements installed was that which modeled a roughness coeff. of n = 0.36. The same that was used in calculating the existing roof slope.

Secondary Settling Chamber

The plenum chamber built to be used as a wind take-off chamber primarily for a floor mounted model was designed and constructed with very little consideration given to the quality of exiting wind in the downsteam direction. Therefore, an additional settling chamber was built. The following recommendations were incorporated into the design:

- Honeycomb should be offset from the upstream screen by at least 4".
- Screen spacing of approximately 6" is best (i.e. 500-600 wire diameter spacing at .006-.01" dia. wire).
- The distance from the last screen to the entrance of a contraction or testing chamber should be at least 0.2 cross sectional diameters, i.e. .2x29.5"= 6" minimum.

- Spacing of approximately one foot from the exit of the side chamber to the first screen of the settling section should be given to accommodate the settling of turbulence caused by the air rounding the corners.

The presence of all the building materials necessary for a conservative design allowed the construction of this section to proceed immediately. See Figure 7 for sketch.

Strain Gauge Balance Table

To accommodate the heavy strain gauge balance which was to be placed under either test section, a table was built. The table was designed to allow leveling on a non-level floor. This was done by adding adjustable feet. Its height is such that the spindle can be adjusted to be above or below the floor of the tunnel and its strong design was in an effort to reduce wabbling under the heavy weight. The table built was a variation of the one shown in Figure 8.

FIGURE 6

Side duct for upstream test section

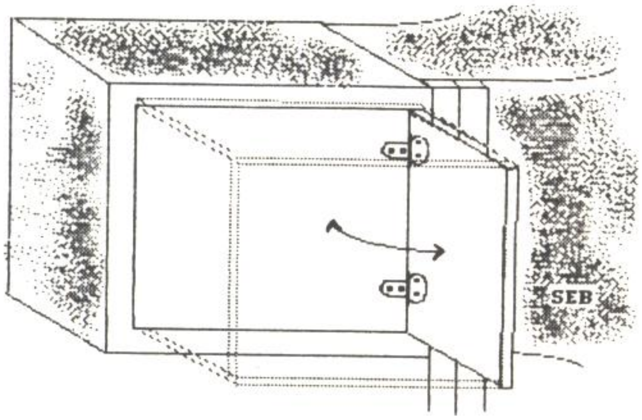
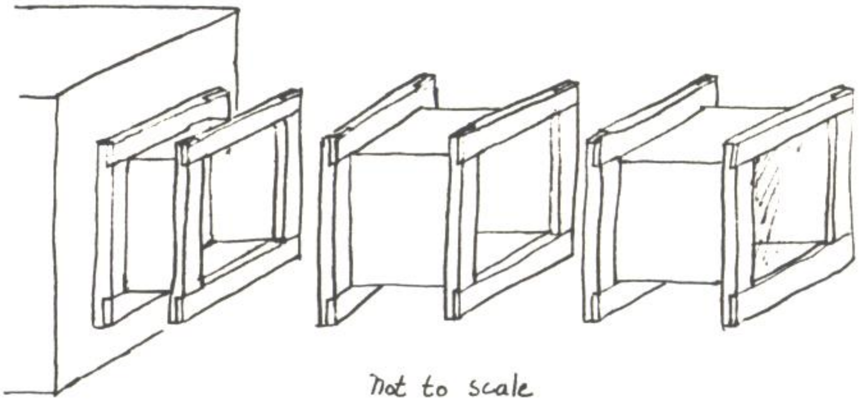


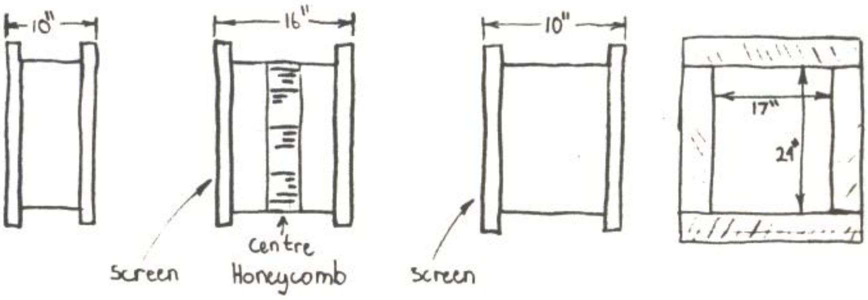
FIGURE 7

Settling Chamber

SeB Nov. 14th



Not to scale



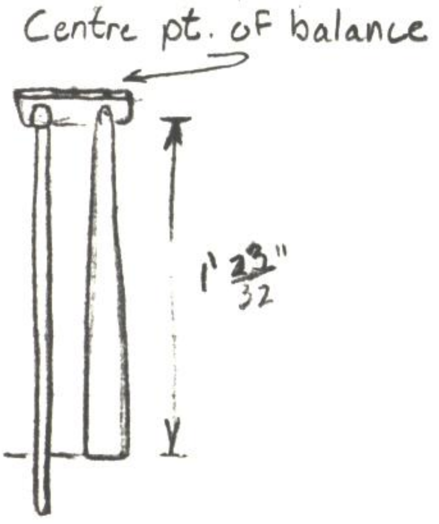
All dimensions are internal.

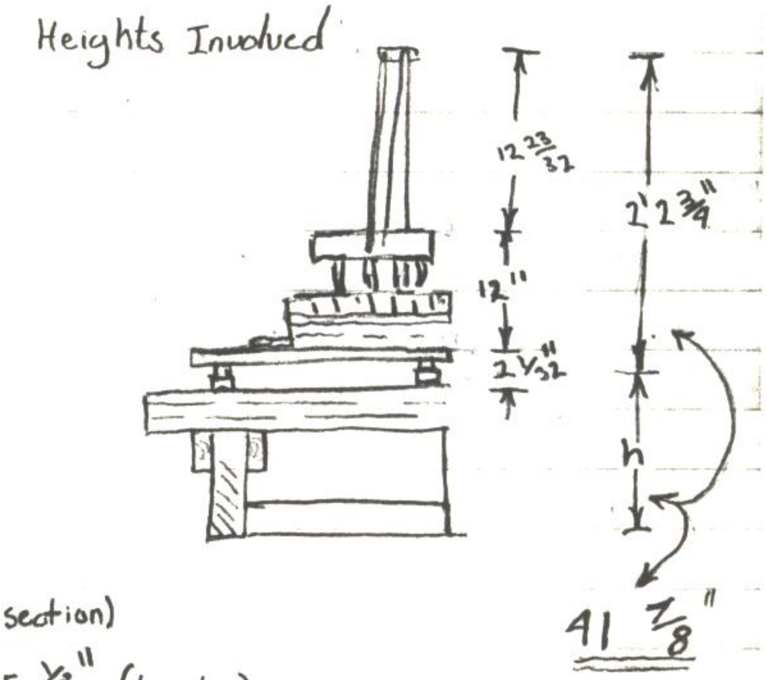
40 mesh screen available at Tek services (ask Andrews)
Honeycomb available on mezzonine

FIGURE 8

Balance Table

SEB 9th

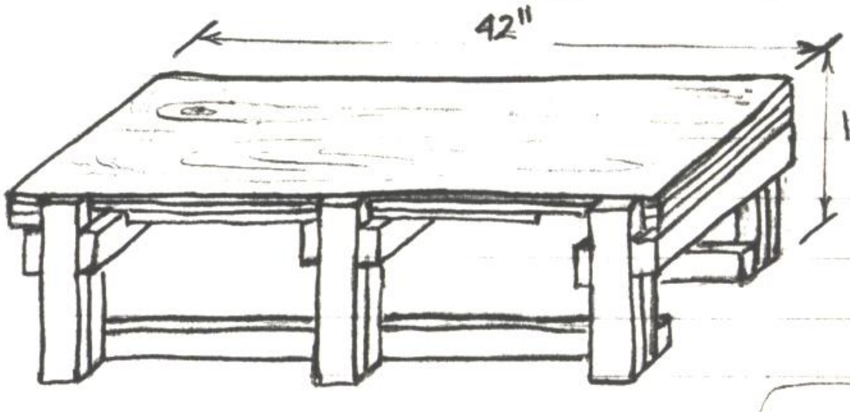




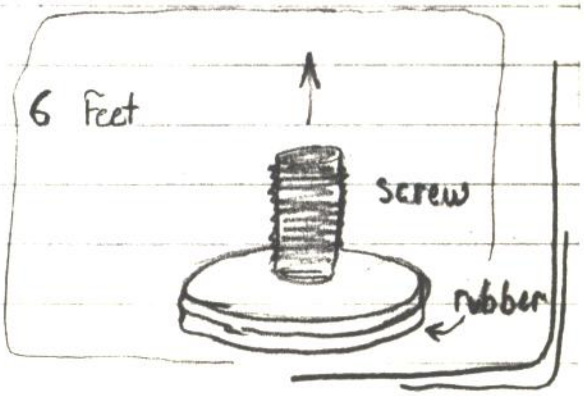
Height of Floor = 41 1/8 (Floor of test section)
Table height (h) = 41 1/8 - 26 3/4 = 15 1/8" (to top)

table

cut 3" off each end of present table



15 1/8" → including the Feet at Middle adj.



Note: - Cross braces are omitted from drawing for clarity.
- Find wheels with similar thread screw as Feet.

CHAPTER 2

PRESENT STAGE OF WIND TUNNEL

General

As of November 20, 1984, the wind tunnel was comprised of the components as indicated in Figure 9.

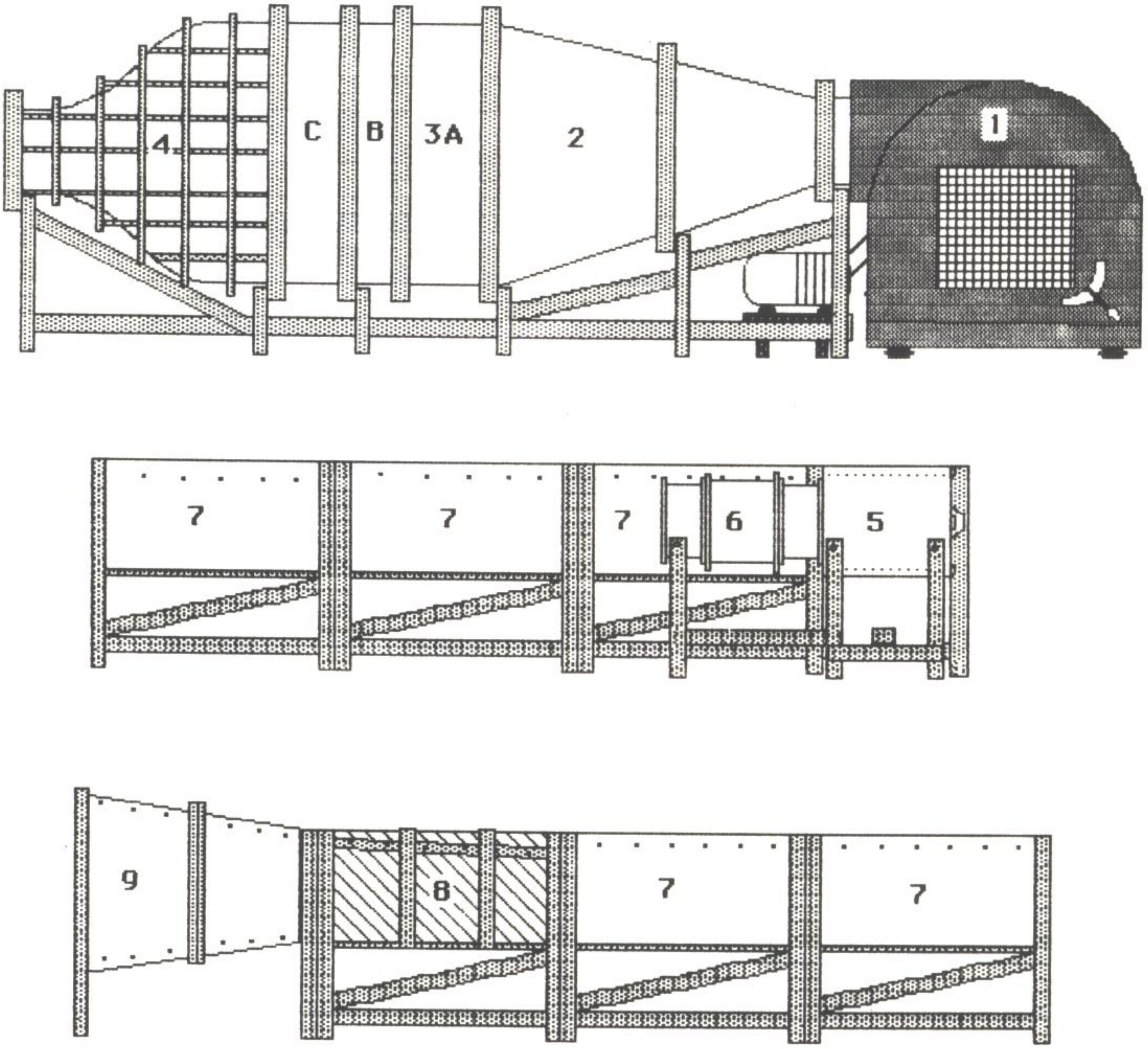
The tunnel is 81 feet 5 inches long, 8 feet 9 inches at its highest point, and 7 feet 7 inches at its widest. The entire tunnel is approximately centered on the mezzonine with just over 14 feet of open space between the exit diffuser and the exhaust doors on the rear of the building.

The 3-phase 1760 rpm, 25 hp motor that runs the Canadian built Buffalo 805 BL class 2 centrifugal ventilating fan has performance curves at 973 rpm as shown in Appendix D.

In order to properly test models in a wind tunnel test section, the dynamic characteristics of the test section must be known and proper calibration of instruments must be done. The latter of the two is a lengthy, time-consuming operation to be done at a stage when all of the equipment is on hand and fully understood, a stage that we have not yet reached. The first, however, requires a process that can and has been readily carried out. The dynamic characteristic that is

FIGURE 9

BOUNDARY LAYER WIND TUNNEL
COMPONENTS



- 1 Fan
- 2 Wide angle diffuser
- 3 Settling chamber
  - A- Honeycomb
  - B- Screen section
  - C- Settling section
- 4 Contraction
- 5 Side chamber
- 6 Secondary settling chamber
- 7 Working section components
- 8 Downsteam test section
- 9 Zero screen exit diffuser

vitally important is the distribution of wind velocities throughout the cross section of the testing range.

Velocity Measurements

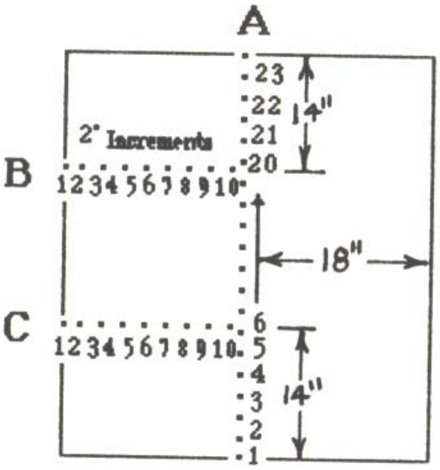
To measure the mean velocity at certain points in the tunnel, a manometer was used. A reading (1) taken from the inclined manometer may be converted to a velocity reading by the following equation: $v(m/s) = [83.1x(1)]0.5$. See Appendix E for the derivation of the equation and Appendix F for an illustration of the apparatus and a basic program used to calculate velocities readily.

Mean velocities measured at the half-way point of the downsteam test section with the blower vanes fully opened are given in Figures 10 through 15 in the form of computer readouts and plotted profiles. At this point the air has travelled 47 feet down the tunnel after exiting the contraction stage. Forty-two feet of this distance has roughness elements at a coeff. of $n = 0.36$. The roof at the mid-point in the test section is approximately 44.25 inches from the floor, while the width remains constant throughout at 36 inches.

Other data collected on velocity distributions at other sections of the tunnel is given in Appendix G. These include

FIGURE 10

Cross Section at Test Section Mid-Point



Series A

Apparatus

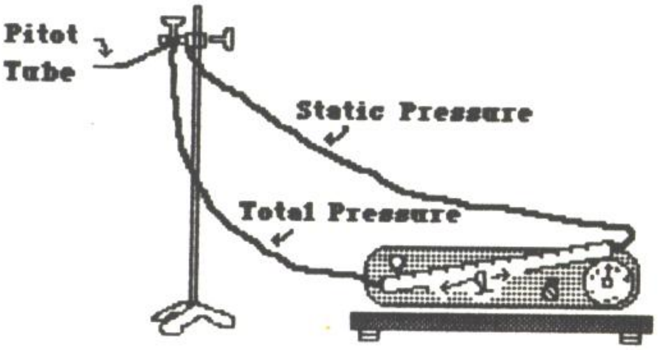


FIGURE 11

```
 PROGRAM GENERATES VELOCITY MEASUREMENTS FROM PITOT TUBE DATA

INPUT THE NUMBER OF MEASUREMENTS TO BE CONSIDERED
 INPUT THE PITOT TUBE SLOPE MEASUREMENTS, IN INCHES, ONE AT A TIME

Test #     L in inches        velocity in m/s
1               .6             7.061161377564
2              1.15            9.7757352664645
3              1.58            11.458533937638
4              2.05            13.052011339254
5              2.45            14.268671977448
6              2.8             15.253851972535
7              3.15            16.179153253493
8              3.42            16.858291728405
9              3.62            17.344220939552
10             3.7             17.534822496963
11             3.72            17.582150039174
12             3.75            17.65290344391
13             3.77            17.699915254035
14             3.78            17.723374396542
15             3.78            17.723374396542
16             3.78            17.723374396542
17             3.79            17.746802528907
18             3.78            17.723374396542
19             3.63            17.368160524362
20             3.27            16.484447215482
21             2.8             15.253851972535
22             2.27            13.73451855727
23             1.3             10.393748120866
```

FIGURE 12

CROSS SECTION DATA CONTINUED

Series B

```
PROGRAM GENERATES VELOCITY MEASUREMENTS FROM PITOT TUBE DATA

INPUT THE NUMBER OF MEASUREMENTS TO BE CONSIDERED
 INPUT THE PITOT TUBE SLOPE MEASUREMENTS, IN INCHES, ONE AT A TIME

Test #    L in inches       velocity in m/s
1              1.15           9.7757352664645
2              1.85           12.398991894505
3              2.25           13.673880210094
4              2.6            14.698979556418
5              3.05           15.920270098212
6              3.42           16.858291728405
7              3.71           17.558502214028
8              3.79           17.746802528907
9              3.79           17.746802528907
10             3.79           17.746802528907
```

FIGURE 13

Series C

```
PROGRAM GENERATES VELOCITY MEASUREMENTS FROM PITOT TUBE DATA

INPUT THE NUMBER OF MEASUREMENTS TO BE CONSIDERED
 INPUT THE PITOT TUBE SLOPE MEASUREMENTS, IN INCHES, ONE AT A TIME

Test #    L in inches       velocity in m/s
1              1.05           9.341038486164
2              1.78           12.162154414412
3              2.25           13.673880210094
4              2.6            14.698979556418
5              2.92           15.577291163742
6              3.08           15.998374917472
7              3.28           16.509633551354
8              3.37           16.734604865368
9              3.38           16.759415264263
10             3.38           16.759415264263
```

FIGURE 14

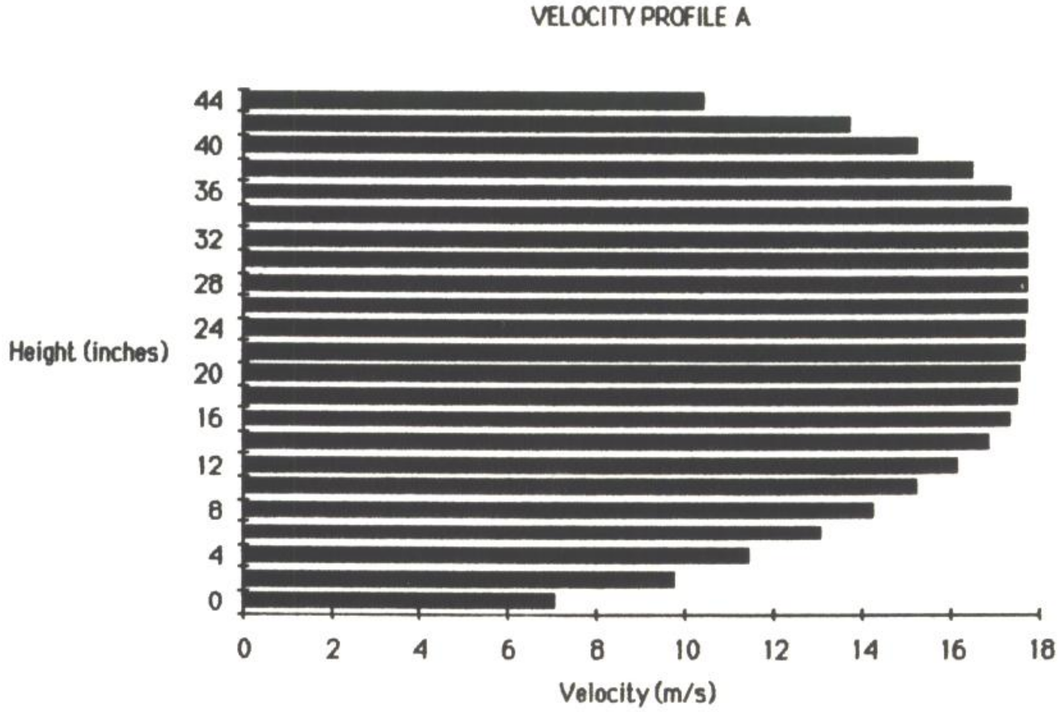
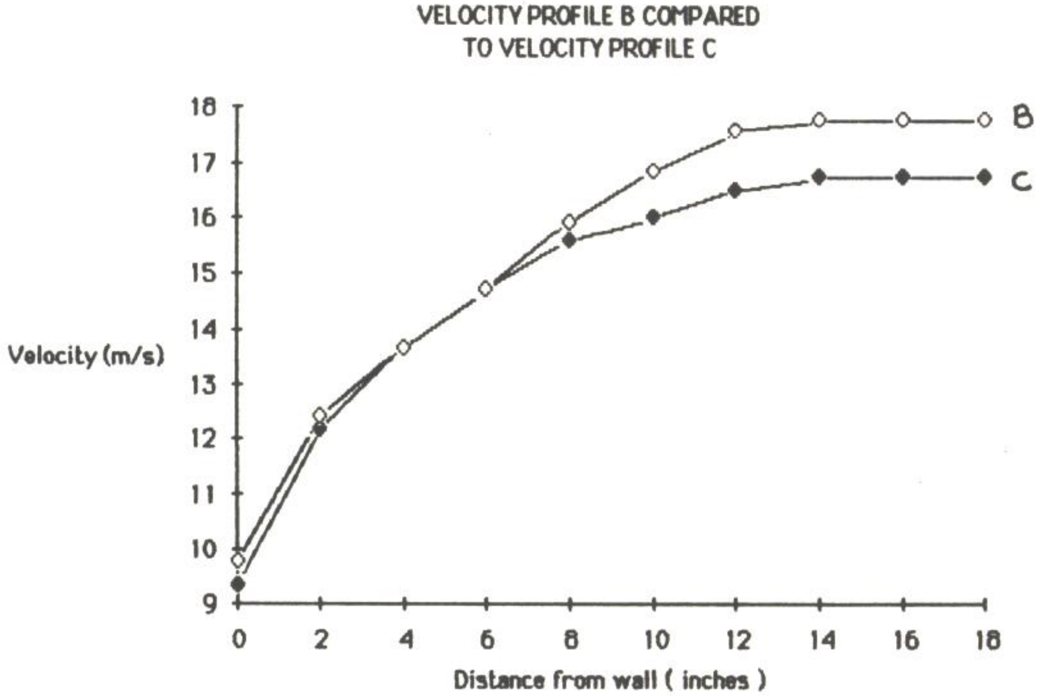


FIGURE 15



the exit diffuser before the addition of roughness elements and the upstream test or dummy section, all taken with the blower air vanes fully opened.

Inventory of Equipment

The following is a list of the wind tunnel instruments-equipment that was on hand as of November 20, 1984:

	MUN #
DISA	
Digital voltmeter, type 55 d 31	1963
RMS Unit, type 55 d 35	1936
Main Unit, type 55 m 01	1935
100m Cable Compensation Unit	1936
Battery operated CTA, type 55 d 05	1808
Battery operated CTA, type 55 d 05	1809
Comparator, type 52 b 10	1158
Signal Normalizer, type 52 b 05	1161
True Integrator, type 52 b 30	1159
Sweep Drive Unit, type 52 b 01	1160
Constant Temp. Anem., type 55 d 01	55
Auxiliary Unit, type 55 d 25	56

CABLES

All power cables necessary

Coaxial, Soca Flex,

	MUN #
BNC and Banana Cables	
PROBES**	
1 Probe Holder, Narrow insert probe - BNC	
2 Good Probes That fit the holder above:	
- Probe type 55 p 05	
- Shorting Probe 55 h 30	
AEROLAB	
Pyramidal Strain Gauge Balance	3043
Balance Control Unit	3045
Smoke Maker (incl. parafin oil)	
OTHER	
Doric, Integrating Microvoltmeter (specifically for the balance)	3045
Airflow Dev. Ltd, Mark 4 Manometer	54

The information available on the general operation of this equipment will be handed over to Dr. Lever.

** For a more complete listing of the probes that are on hand, see Appendix H.

How To Safely Operate the Wind Tunnel

The following steps must be carried out for safe operation of the wind tunnel.

1) Check the wind tunnel for any objects that may be inside and would threaten to become projectiles, i.e. pencils or forgotten models. This may reduce the risk of damaging equipment or personnel.

2) Make sure that all doors are secured, or at least latched shut.

3) Operators and experimenters should wear ear muffs for hearing protection from noise and pressure changes, as well as eye goggles to avoid the sawdust, etc., that gets picked up along the wind tunnel interior.

4) Do as much as possible to prepare testing (model set-up, etc.) before the tunnel is turned on. The fewer starts and stops, the better.

5) To provide power for the motor switch turn the large wall switch "ON". (This switch does not start the blower. Also note that it is the one out of which a cord runs along the ceiling and down to the fan.)

6) Make sure that the vane control lever on the fan is fully shut down or the motor will not start.

7) Press the "ON" switch above this lever.

8) Wait for at least sixty seconds and then open the lever to whatever intake is desired. Take at least ten seconds to open the vanes, i.e. open the lever slowly or else the tunnel will explode, then implode.

9) Doors can be opened or closed during operation but caution must be taken not to get pinched in an almost closed door during rapid pressure changes.

10) When closing the vanes, take the same time it took to open them.

11) When closed, then push off the switch on the fan.

12) Then proceed to turn off wall switch.

NOTE: The fan does not sound like it is off, when it is first shut off. Don't worry - it is, but do not get close to the fan belts which may continue to turn for as long as two minutes after shut off.

Tunnel Maintenance and Adjustments

The following is a list of the operations that may be carried out to maintain and/or adjust the wind tunnel components:

1) The diffuser screens may be cleaned by removing the side walls and carefully vacuuming the screen surfaces.

2) Doors to working section components may be secured by screwing them shut or temporarily latching them shut.

3) Floors of working section can be removed in half sections and worked upon individually, by undoing four corner screws.

4) The ceilings are adjustable by backing out the holding screws and redrilling them into the working section and exit diffuser walls when the ceilings are relocated.

5) The working sections may be leveled using their adjustable feet.

6) Any component may be separated and worked on individually by undoing the flange bolts and moving it.

ACKNOWLEDGEMENTS

During this work period, I have received support from a number of sources. Some of these people are:

Dr. J. Lever, Supervisor
John Spurrel, Carpenter
Dave Tilly, Technician
Jim Andrews, Tech Services
Ruby Martin, Secretary

Thank you for your help and cooperation.

APPENDICES

①

Appendix A

Boundary Layer Wind Tunnel

SEB

Profile of working section

$$u_z = u_F \left[\frac{z}{z_b}\right]^{\alpha}$$

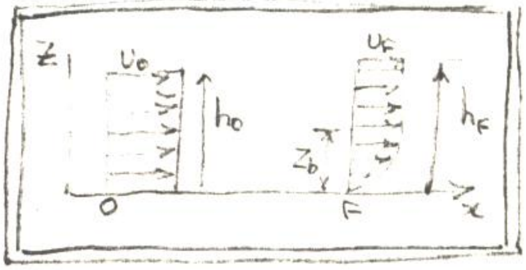
z = height from Section floor
z_b = height of boundary layer
u_z = Velocity at height z.
U_F = Free Stream Velocity
α = Floor roughness coeff.

Allowing for a conservative roughness coeff of $\boxed{\alpha = 0.36}$

also assuming for $z > z_b$ $u_z = u_F = \overset{⊛}{20\ \text{m/s}} = 65.6\ \frac{\text{ft}}{\text{sec}}$

∴ through conservation of mass:

$$u_0 h_0 = \int_0^{h_F} u_z \, dz$$

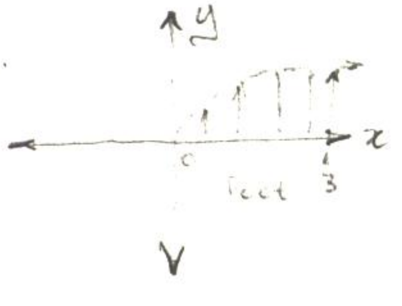


$$u_z h_F = \int_0^{h_b} u_F \frac{z^{\alpha}}{(z_b)^{\alpha}} \, dz + \int_{h_b}^{h_F} u_F \, dz$$

Also from Figure 34-2 "Developement of B.L." (Don Philpott)
e have $h_b \approx 2.25$ Ft at 40 Feet from exit of Contractor.

$$y = 656 \left[\frac{x}{2.25}\right]^{0.36}$$

given



$$3 \times 656 = \int_0^{2.25} 65.6 \frac{x^{0.36}}{2.25^{0.36}} \, dx + U_F(h_F - h_b)$$

Appendix A

ontinued

SEB

$$196.8 = \frac{65.6}{1.339}\int_0^{2.25} x^{0.36}\,dx + 65.6(h_F - h_b)$$

$$196.8 = (48.99)\left.\frac{x^{1.36}}{1.36}\right]_0^{2.25} + 65.6(h_F - h_b)$$

$$196.8 = (48.99)\frac{3.01}{1.36} + 65.6(h_F - h_b)$$

$$196.8 - 108.53 = 65.6(h_F - h_b)$$

$$88.27 = 65.6(h_F - h_b)$$

$(h_F - h_b) = 1.34$ ft above z_b

therefore the total height of Section h_F:

$$h_F = h_b + (h_F - h_b)$$

$$= 2.25 + 1.34$$

$$= \underline{\underline{3.60}} \quad > \quad \underline{\underline{3'\ 7.1''}}$$

⊛ Philpotts Don Page 1 Summary Modif of Low Speed W.T.

Continued

SEB

Given: 40' working section of 5 pieces

we have a total rise of 7.1" or

7.1 ÷ 5 = <u>1.42 inches per section.</u>

check

For inviscid flow above Z_b bernoulli's equation holds:

$$P_o + \frac{\rho U_o^2}{2} = P_F + \frac{\rho U_F^2}{2}$$

Note:

$$U_F = \frac{U_o}{\frac{h_F}{h_o} - \frac{\alpha Z_b}{(\alpha+1) h_o}}$$

$$\Delta P_{\substack{\text{working}\\ \text{section}}} = P_o - P_F = \frac{\rho}{2}\left(U_F^2 - U_o^2\right)$$

$$\Delta P_{ws} = \frac{U_o^2 \rho}{2}\left[\frac{1}{\left[\frac{h_F}{h_o} - \frac{\alpha Z_b}{(\alpha+1) h_o}\right]^2} - 1\right]$$

$$0 = \frac{65.6^2(.07556)}{2}\left[\frac{1}{\left[\frac{h_F}{3} - \frac{.36(2.25)}{(1.36)\,3}\right]^2} - 1\right]$$

$$1 = \left[\frac{1.}{\left(\frac{h_F}{3} - 0.1985\right)^2}\right]$$

$$\frac{h_F}{3} - 0.1985 = 1$$

$$h_F = 3.5955 = \underline{\underline{3'\,7.1''}}$$

For zero pressure gradient in the horizontal dirn

↑
A

④

Continued Boundary Layer Wind Tunnel SEB

For Profile of working section with $\boxed{\alpha = 0.15}$ as is the case over grasslands.

Over 40 ft of carpeted working section the Z_b (boundary layer thickness) is .833 ft.

The following is a calculation of roof height adjustment necessary for simulation of grasslands ($\alpha = 0.15$)

$$U_z h_o = \int_0^{h_b} U_F \frac{Z^\alpha}{Z_b^\alpha} dz + \int_{h_b}^{h_F} U_F dz$$

$$3(65.6) = \int_0^{.833} \frac{65.6(x)^{0.15}}{.833^{0.15}} dx + 65.6(h_F - h_b)$$

$$196.8 = \frac{65.6}{.973} \left. \frac{x^{1.15}}{1.15} \right]_0^{.833} + 65.6(h_F - h_b)$$

$$196.8 = (67.42)(.705) + 65.6(h_F - h_b$$

$$196.8 - 47.52 = 65.6(h_F - h_b)$$

$$\frac{149.28}{65.6} = (h_F - .833)$$

$$2.28 + .833 = h_F \qquad h_F = 3.12\text{ ft} = \underline{\underline{3'\ 1.3''}}$$

Appendix A

Continued

SEB

Calculation to determine Δ Pressure in working section with horizontal roof and carpeted ($\alpha = 0.15$) floor.

$$\Delta P_{ws} = \frac{U_0^2 \rho}{2}\left[\frac{1}{\left[\frac{h_f}{h_0} - \frac{\alpha Z_b}{(\alpha+1)h_0}\right]^2} - 1\right]$$

$U_0 = 65.6$ ft/s

$\rho = .07556$ lb/ft³

$h_f = h_0 = 3$ ft

$Z_b = 0.833$ ft

$\alpha = 0.15$

$$\Delta P_{ws} = \frac{(65.6)^2 \frac{ft^2}{sec^2} .07556 \text{ lb/ft}^3}{2} \times$$

$$\left[\frac{1}{\left[1 - \frac{(0.15)(.833)ft}{(1.15)\,3ft}\right]^2} - 1\right]$$

$$\Delta P_{ws} = (162.58)(0.07657) = 12.448 = \underline{\underline{12.4}}\ \frac{lb}{s^2 ft}$$

$$\underline{\underline{12.4}} = \frac{ft\ lb}{s^2} / ft^2$$

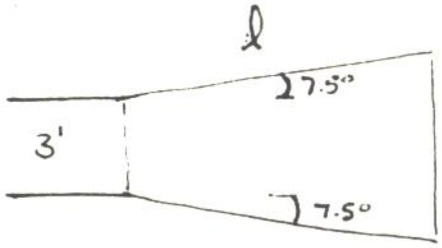
S E Bruneau.

Appendix B

Oct14-4

Exit Diffuser

- Mehta - Fig 5. indicates 0 screen diffuser curve (by Kline)
  - shows 15° included angle possible



$3' + 2 l \sin 7.5° = 6'$ say
$\rightarrow l = 11.5'$

- this would give area ratio of 4 to drop velocity by 4 and pressure by 16

ie: exit velocity ≈ 4m/s

- floor + side walls can diverge 7.5° without adjustment
- roof must open to 6' at exit, adjust to entrance location (3' + 7.15" etc)

①

Appendix C

S E [illegible]

Roughness Element Geometry for BLWT

Oct 14/84

using Gartshore + deCroos

G. + deC - δ at 1/400 scale for suburban wind = 0.9 m
$n = 0.28$

$$\frac{U}{U_1} = \left(\frac{z}{\delta}\right)^n$$

Davenport + Isyumov - δ at 1/400 scale for urban wind = 4 ft.
with $n = 0.36$
- δ at 1/400 scale for open country = 2 ft
with $n = 0.16$

(a) - say we wish to model at 1:600 scale for urban settings

- then δ = 2.7 ft = 0.81 m

- tunnel height $h_f - h_o = h_\delta \frac{\alpha}{\alpha+1}$ - from Sept 27/84

$= 2.7'(\cdot 36/1.36)$

$= \cdot 71'$ = 8.6 inches (achievable)

≈ 9" for ceiling to diffuser

- from fig 2., for $n = 0.36$

can try $\frac{\delta}{k} = 10 \rightarrow k = 8.1\text{ cm}$.

$\frac{\lambda_e}{k} = 13 \rightarrow \lambda_e = 105\text{ cm}$

say $x \sim 500k = 40\text{ m}$ - much too long.

$\frac{A_p}{A_f} \simeq \frac{\lambda_e}{k} = 6$

$A_f = kw$, $A_p = \lambda_e \times T$

$\therefore \frac{T}{w} = 6$

- to put 10 across tunnel T = 9cm
- to put 5 across tunnel ✓

T = 18 cm ; w = 3cm

try $\frac{\delta}{k} = 25 \rightarrow k = 3.2\text{ cm}$ (≈ 1¼")

$\frac{\lambda_e}{k} = 6 \rightarrow \lambda_e$ 19 cm (≈ 7½")

say $x \sim 400k = 12.8\text{ m}$ (L = 12.1 m now)

$x = 500k = 16\text{ m}$ good. but need another section

- also - another section would give req'd tunnel height

Appendix C

[illegible]

Oct 14-2

(b) - to model open country (open water) at 1/300 scale

- $n = 0.16$
- then $\delta = 2.7\text{ ft} = 0.81\text{ m}$
- tunnel height $\Delta h = 2.7' \cdot (.16/1.16) = 4.5$ inches (achievable)
- from fig 2, for $n = 0.16 \rightarrow$ offscale
- try fig 1 $\quad \dfrac{U_1 \delta^*}{U_2 \delta} = 4 \quad \therefore \dfrac{U_1}{U_2} = 4 \times \dfrac{\delta}{\delta^*}$ or $\dfrac{U_2}{U_1} = \dfrac{1}{4}\dfrac{\delta^*}{\delta}$

$$\delta^*/\delta = n/(n+1) = .16/1.16 = .14$$

$$\therefore \frac{U_2}{U_1} = \frac{1}{4}(.14) = .034$$

from fig 1, $\dfrac{\delta^*}{k} = 45 \quad \therefore k = \dfrac{\delta^*}{45} = \dfrac{.14(.81\text{ m})}{45} = 3\text{ mm}$

$\dfrac{\lambda_e}{k} = 100 \quad \lambda_e = 300\text{ mm} = .3\text{ m}$

- very small roughness required

$x \sim 500 \times 3\text{ mm} = 1.5\text{ m} \sim 5'$

- might be difficult to achieve one sided boundary layer
- we may need very smooth sides and top to prevent large boundary layer growth on other walls.

③

Appendix C

E Brunner

Oct 14-3

(c) suburban $n = 0.28$ at 1:500 scale
$\delta = 0.72\,m = 2.4$ ft.

$\Delta h = 2.4\,(.28/1.28) = 6.3''$ o.k.

from fig 2, for $n = 0.28$, $k = 3.2\,cm$ (use same pieces)
require $\rightarrow \frac{\delta}{k} = \frac{.72m}{.032m} = 23$
gives $\frac{\lambda_e}{k} = 20 \simeq (3 \times 6)$ so remove 2 of every 3 rows.

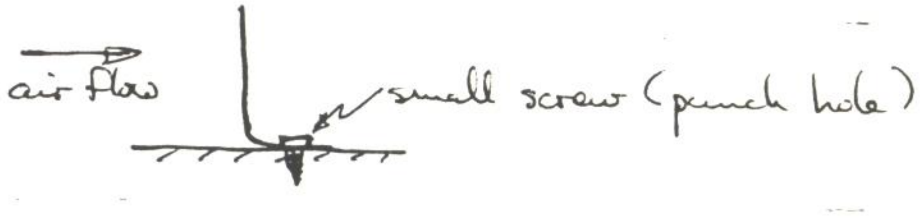
$\frac{I}{w} = \frac{\lambda_e}{k} = 20$ $w = 3\,cm \rightarrow T = 60\,cm$
(could put half width one near wall)

- - - - - - - - - - - - - - -

- so if we use and install additional 8' tunnel length (48' total) (14.5 m)

$w = 3\,cm$
$k = 3.2\,cm$ (bend ~5 cm long strip)
have 5 elements / line
~19 cm between lines → 77 lines
→ 385 elements of 3×5 cm
or $.58\,m^2$ worth of material

- use one sheet of fairly heavy guage aluminum



- could use trips at entrance, reduce test section length and install a diffuser ppendix D

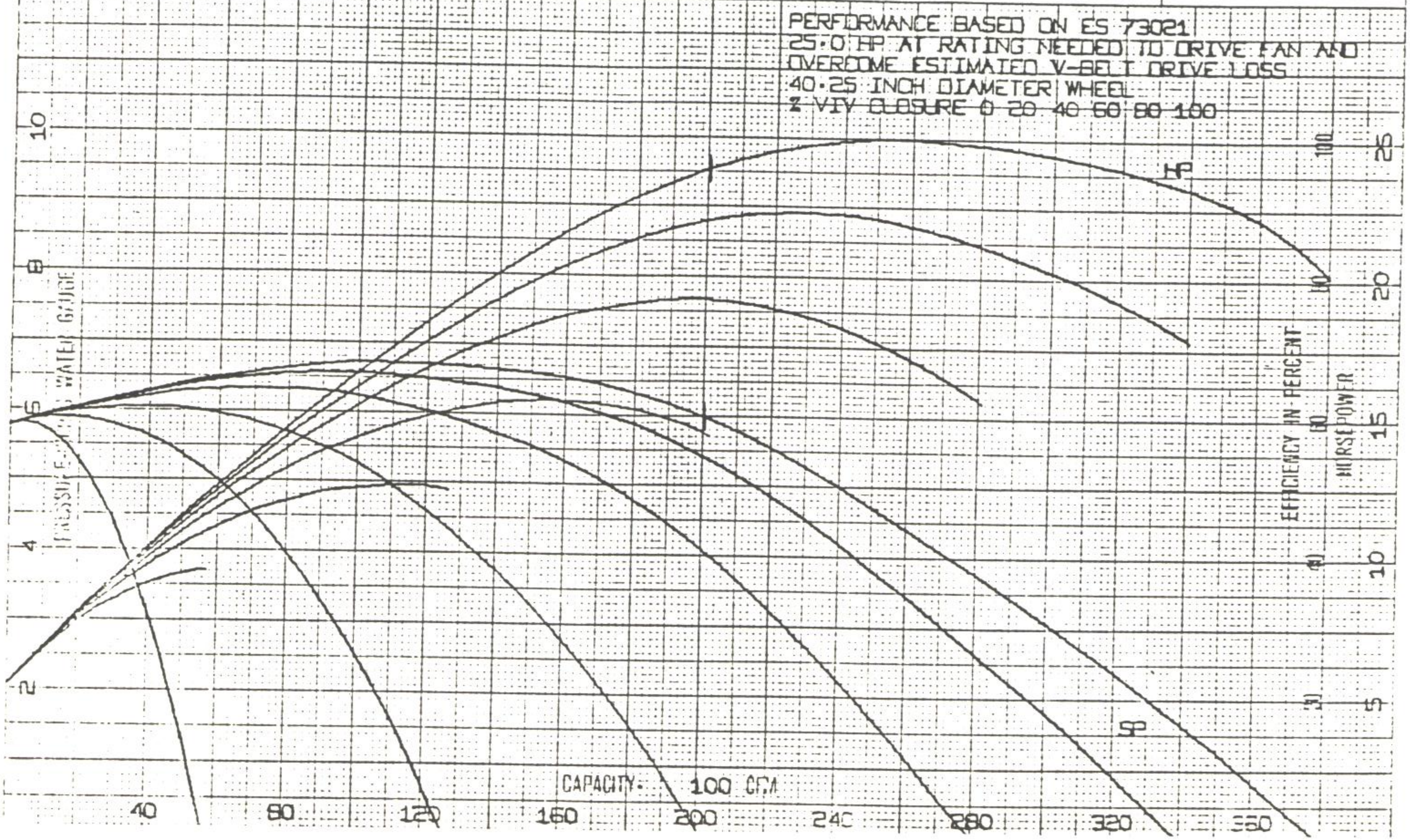
Buffalo®

Canadian Blower/Canada Pumps
LIMITED
KITCHENER, ONTARIO

PERFORMANCE CURVES

FOR MEMORIAL UNIVERSITY OF NEWFOUNDLAND
SIZE & TYPE 805 BL SWSI WIND TUNNEL FAN
973 RPM 70. °F 29.92 IN.HG 0.0750 LB/CU FT

CPD 3
ORDER MTL-WI
DATE 3/ 9/83
BY

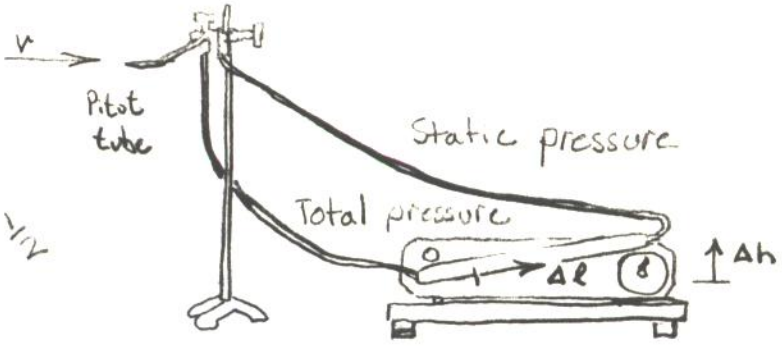


PERFORMANCE BASED ON ES 73021
25.0 HP AT RATING NEEDED TO DRIVE FAN AND OVERCOME ESTIMATED V-BELT DRIVE LOSS
40.25 INCH DIAMETER WHEEL
% VIV CLOSURE 0 20 40 60 80 100

Appendix E

Velocity Calculation. Oct 15th JEB

Dynamic Pressure:



$$\frac{1}{2}\rho_a V^2 = \rho_F g \Delta h$$

$$V = \left[\frac{\rho_F}{\rho_a} \times 2 g \Delta h\right]^{1/2}$$

now since $\rho_a = 1.2\ \mathrm{kg/m^3}$ $\rho_F = 1000\ \mathrm{kg/m^3}$

$g = 9.81\ \mathrm{m/s^2}$

we have:

$$V(\mathrm{m/s}) = \left[16350\ \Delta h\right]^{1/2}$$ where $\Delta h \Rightarrow$ meters

or $$V(\mathrm{m/s}) = \left[415.3\ \Delta h\right]^{1/2}$$ where $\Delta h \Rightarrow$ inches

taking into account a multiplier of .2 for the slope of the pitot measuring instrument,

we have

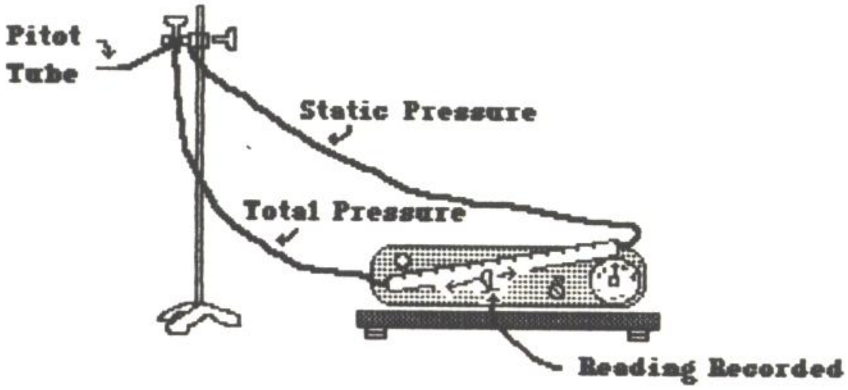
$$V(\mathrm{m/s}) = \left[83.1\ \Delta l\right]^{1/2}$$

✓

where Δh is in inches

Appendix F

Manometer apparatus



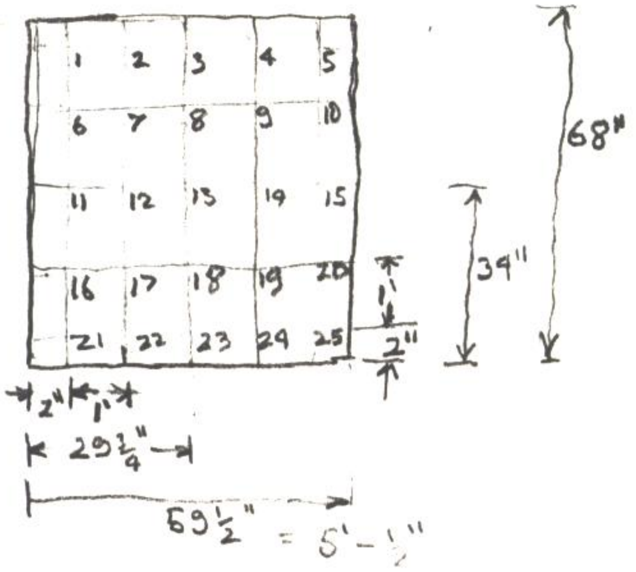
```
5 DIM K(50), J(50)
00 REM LPRINT " PROGRAM GENERATES VELOCITY MEASUREMENTS FROM PITOT TUBE DATA"
01 PRINT " PROGRAM GENERATES VELOCITY MEASUREMENTS FROM PITOT DATA
10 LPRINT" "
11 PRINT" "
15 REM LPRINT "INPUT THE NUMBER OF MEASUREMENTS TO BE CONSIDERED"
16 PRINT "INPUT THE NUMBER OF MEASUREMENTS TO BE CONSIDERED"
17 INPUT N
20 REM LPRINT " INPUT THE PITOT TUBE SLOPE MEASUREMENTS, IN INCHES, ONE AT A TIME"
21 PRINT " INPUT THE PITOT TUBE SLOPE MEASUREMENTS, IN INCHES, ONE AT A TIME"
30 FOR I = 1 TO N
40   INPUT K(I)
45  LET J(I) = (83.1*K(I))^.5
50 NEXT I
55 LPRINT " "
56 PRINT " "
60 REM LPRINT " Test #    L in inches      velocity in m/s"
61 PRINT " Test #    L in inches      velocity in m/s"
70 FOR I = 1 TO N
80  REM  LPRINT I;;"  ",K(I);;"   ",J(I)
81   PRINT I;;"  ",K(I);;"   ",J(I)
85 NEXT I
10 OPEN "CLIP" FOR OUTPUT AS #1
20 FOR I = 1 TO N
30   WRITE #1,J(I)
40 NEXT I
50 CLOSE #1
60 END
```

①

Appendix G

B Oct 22.

Velocity Profile for End Diffuser



Device: Air Flow Meter.
HUN # =1868

	Velocity
1	Negative
2	Negative
3	Negative
4	Negative
5	Negative
6	25 ± 10
7	9.0 ± 3.0
8	10 ± 2.0
9	9.0 ± 3.0
10	25 ± 10
11	2.5 ± 2.5
12	9.0 ± 3.0
13	19.0 ± 0.2

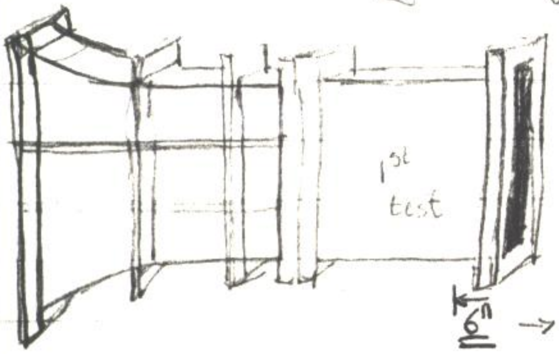
	Velocity M/S
14	9.0 ± 3.0
15	2.5 ± 2.5
16	2.5 ± 1.5
17	4.0 ± 2.0
18	5.0 ± 2.0
19	4.0 ± 2.0
20	2.5 ± 1.5
21	1.2 ± 1.0
22	2.0 ± 1.0
23	2.0 ± 10
24	2.0 ± 1.0
25	1.5 ± 1.0

these flow readings appear to be interchangeable.

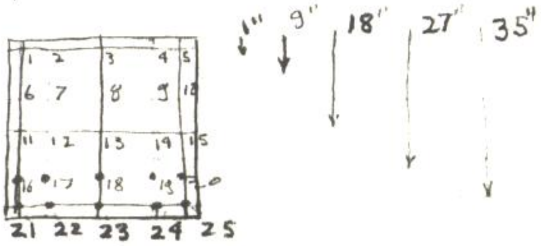
②

Appendix G

Velocity Profile for 1st test section



→ measurement area



test	Δl	Velocity	test	Δl	Velocity
1	3.21	16.33	14	3.49	17.02
2	3.59	17.27	15	3.50	17.05
3	3.58	17.24	16	3.48	17.00
4	3.55	17.17	17	3.45	16.93
5	3.40	16.80	18	3.44	16.90
6	3.53	17.12	19	3.51	17.07
7	3.52	17.10	20	3.57	17.22
8	3.52	17.10	21	3.20	16.30
9	3.50	17.05	22	3.40	16.80
10	3.51	17.07	23	3.47	16.98
11	3.51	16.07	24	3.55	17.17
12	3.48	16.00	25	3.58	17.25
13	3.45	17.93			

Note: Constant balance check critical on consistency of manometer readings.

Appendix H

Probe Inventory

SEB Nov 1st

1 Probe holder (For probes with narrow mounting ends)
Holder → BNC

Good Probes:

- ✓ - Probe type 55 P05 (Boundary layer Probe) narrow
- ✓ - Shorting Probe 55 H 30 "
- Probe type 55 A51 (Hot film) wide
- one: Probe type 55 A57 (BNC - little probe Hot film)
- Shorting Probe wide
- 2 General-purpose strait type (with case wide

No Good Probes

- 5 Hot Film probes (wide)
- 2 Strait General Purpose (wide)
- one Probe type 55 A57 (BNC - little, probe Hot film)