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PRELIMINARY RESULTS FROM AN EXPERIMENTAL INVESTIGATION OF THE INITIAL CONDITION EFFECTS ON A TURBULENT SHEAR LAYER

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1. INTRODUCTION

The purpose of this report is to communicate the partial results obtained to date in our investigation of the title problem. These studies are continuing, and a complete documentation, including a discussion of the relevant literature, will be provided in the future. The present communication will satisfy the requirements of the original grant, however, and will allow it to be terminated.

Since a more complete documentation of the facility, procedures, and results will be forthcoming and since certain alterations and improvements will be affected in these matters, the current results will be presented with minimum discussion. However, it should be noted that the findings to date are considered to add significant information to the extant knowledge concerning initial condition effects on the development of plane shear layers.

1.1. Experimental Facility

A central characteristic of the study was to examine the asymptotic states of the shear layer created from the laminar and turbulent boundary layer states on essentially the same flow system; that is, if the two boundary layer states are achieved with only minor alterations, then any influence of the overall geometric features of the flow field and/or the probe and traverse system will be eliminated. This proved rather more difficult than was anticipated, and numerous geometries were examined. The flow system finally selected is shown in Figure 1. The flow in the indicated contraction is from a 100 x 152 cm plenum chamber fed by a one percent feedback speed controlled fan and is 10 x 100 cm at the exit to the atmosphere. A laminar boundary layer exists at the end of the 25.4 cm plate when a portion of the streaming flow is bled into the small plenum chamber over the gap. Conversely, when the bleed flow is eliminated, a turbulent boundary layer is established at the end of the plate. The shear layer is the upper edge of the 10 x 100 cm wall jet; the flow is bounded on the other three sides.

A computer-controlled stepping motor was used to traverse the single (Disa gold) hot-wire probe utilized for the boundary layer and shear layer velocity traverses. A T.I. 960A minicomputer was used to process the hot-wire signals. The input voltage was digitized, and its statistical character was interpreted using a 0.5 fps increment calibration table. That is, the linearized hot-wire voltage E was processed to store 30-second averages of $\overline{E}$ and $\overline{E^2}$. The combination of these values allowed u and $\hat{u}^2$ to be obtained. (Note: For $< \vec{V} > = i\overline{u} + j\overline{v} + k\overline{w}$, the approximation was made that the single-wire data results in $\overline{u}$ and u^2. This approximation is subject to the usual restrictions of $V << \overline{u}$ and $\dot{v}^2/\overline{u}^2$, $\overline{uv}/\overline{u}^2 << 1$.)

1.2. Experimental Results

The laminar and the turbulent boundary layer velocity profiles are shown in Figure 2. The difference in their physical extent is clearly shown in Figure 2a, and the agreement of the laminar profile with the Blasius solution is shown in Figure 2b. During the acquisition of the data, the scope traces suggested that a heaving motion existed in the laminar layer. That is, the fluctuation level at a point was nonzero, but it was apparently caused by nonvortical or wave-like fluctuations. The turbulent fluctuations were as expected. The velocity fluctuation intensities presented in Figure 3 confirmed this. A simple analysis (wherein the laminar boundary layer profile was assumed to maintain its shape, but with a time varying thickness, δ(t), such that the displacement of any segment of the layer was linearly proportional to its height) was used to compute the fluctuation intensities. The parameter K was arbitrarily selected to provide rough agreement at the midpoint of the velocity profile. The agreement between the resulting analytical form

$$\frac{\Delta u}{\overline{u}_m} = KF''\left[\frac{\overline{(\Delta y^2)}^{1/2}}{\delta}\right] \qquad (1)$$

and the observed $\hat{u}$ values suggests that the physical processes are similar to those described by this model.

However, it was also observed that the upper plenum served as a Helmholtz resonator, and concentrated fluctuations at 70 hz and 80 hz were observed in the boundary layer spectra for the turbulent and laminar boundary layers respectively. The resonator frequencies are not considered to be dynamically significant. Specifically, the spectra at x = 2.54 cm show that the fluctuations in the naturally developing shear layers either swamp the single frequency fluctuation (turbulent case) or are far removed from it (≈800 hz) for the laminar boundary layer. It is pertinent to note that the Strouhal number for the laminar case is far below that which is observed in natural transitions in shear layer studies. (This point will be examined more completely in the final report.)

The normalized shear layer mean velocity data for x = 46, 56, and 66 cm are presented in Figure 4, and the numerical data are presented in Tables 1 and 2 for quantitative reference. The similarity parameter was established by plotting u/u_m versus $y - y(\frac{1}{2})$, where the latter is the relative distance from the "centerline" of the velocity field. The $y(\frac{1}{2})$ distributions were essentially the same for the two conditions and are documented in the tables. The apparent origins, x_o, of the shear layer were then established by linear extrapolations of the u/u_m data from the three x locations such that u/u_m = constant for $[y - y(\frac{1}{2})]/[x - x_o]$. For the laminar and turbulent boundary layer cases, x_o was -1.5 and 2.5 cm, respectively.

The choice of probability coordinates for the normalized data was in response to the interest in the spread rate parameter σ. The following analysis relates σ of the error function description (σ_{flow}) to the standard deviation (σ_{prob}) of a Gaussian process distribution.

The cumulative distribution function for a Gaussian process is

$$F(\alpha) = [\frac{1}{2\pi\sigma_p^2}]^{1/2} \int_{-\infty}^{\alpha} \exp[-\frac{1}{2}(\frac{\zeta - \mu}{\sigma_p})^2] d\zeta \tag{2}$$

and the error function form of the mean velocity distribution is

$$\frac{u(y^*)}{u_m} = \frac{1}{2}\{1 + \text{erf } \sigma_f y^*\} . \tag{3}$$

The error function is defined as

$$\text{erf}(x) = \frac{2}{\sqrt{\pi}} \int_0^x e^{-t^2} dt . \tag{4}$$

In order to force (2) to be of the form shown in (3), the distribution F is rewritten as

$$F(\alpha) = 0.5 + [\frac{1}{2\pi\sigma_p^2}]^{1/2} \int_0^{\alpha} \exp(-\frac{\zeta^2}{2\sigma_p^2}) d\zeta \tag{5}$$

where $\mu = 0$ is considered since $\overline{y^*} = 0$. Note that the integral in (5) is of the form of an error function. Let $\zeta/(\sqrt{2}\sigma_p) = t$ and $d\zeta = \sqrt{2}\sigma_p\, dt$. Using the definition of erf (x) given by (4), rewrite $F(\alpha)$ as

$$F(\alpha) = \frac{1}{2}\{1 + \text{erf}\ \alpha\}\ . \tag{6}$$

Comparing (3) and (6) and noting that α is the value of $\zeta/(\sqrt{2}\,\sigma_p)$ at the point of interest, we obtain

$$\frac{y^*}{\sqrt{2}\sigma_p} = \sigma_f\, y^*$$

or

$$\sigma_f = \frac{1}{\sqrt{2}\,\sigma_p}\ . \tag{7}$$

The "best fit" curves for the experimental data are presented in Figure 5. The σ_{flow} values are essentially the same for the laminar and for the turbulent boundary layer cases, but are markedly different from the $\sigma_{flow} = 12$ value commonly accepted for shear layers generated from a laminar boundary layer. The difference between these results and those of earlier studies may be in the disturbance level of the present laminar layer; this effect is under investigation. Also, it is significant that the error function satisfactorily describes the shear layer only for $u/u_m \lesssim 0.7$. This feature, as well as the evaluation of σ_{flow}, are considered to be best revealed by the use of probability coordinates.

In addition to a further examination of the laminar boundary layer disturbances at $x = 0$, the developing shear layer profiles and conditionally sampled data to search for the coherent structures observed by other investigators are considered to be important extensions of the present studies.

1.3. Summary

A flow facility to create a plane shear layer from a laminar and a turbulent boundary layer has been established. The spread rate parameter, σ_{flow}, for these two conditions has been accurately determined. It is $\sigma_{flow} = 9.3$ for the laminar boundary layer case, and $\sigma_{flow} = 9.5$ for the turbulent boundary layer case. A four percent (maximum), non-turbulent disturbance level exists in the laminar boundary layer. Further experiments are underway to determine the significance of this disturbance level on the asymptotic shear layer.

The commonly used error function, in which σ_{flow} appears, provides a good representation of u/u_{max} for $0 \le u/u_m \lesssim 0.7$. Systematic deviations from the error function are observed for $\bar{u}/u_{max} \gtrsim 0.7$.

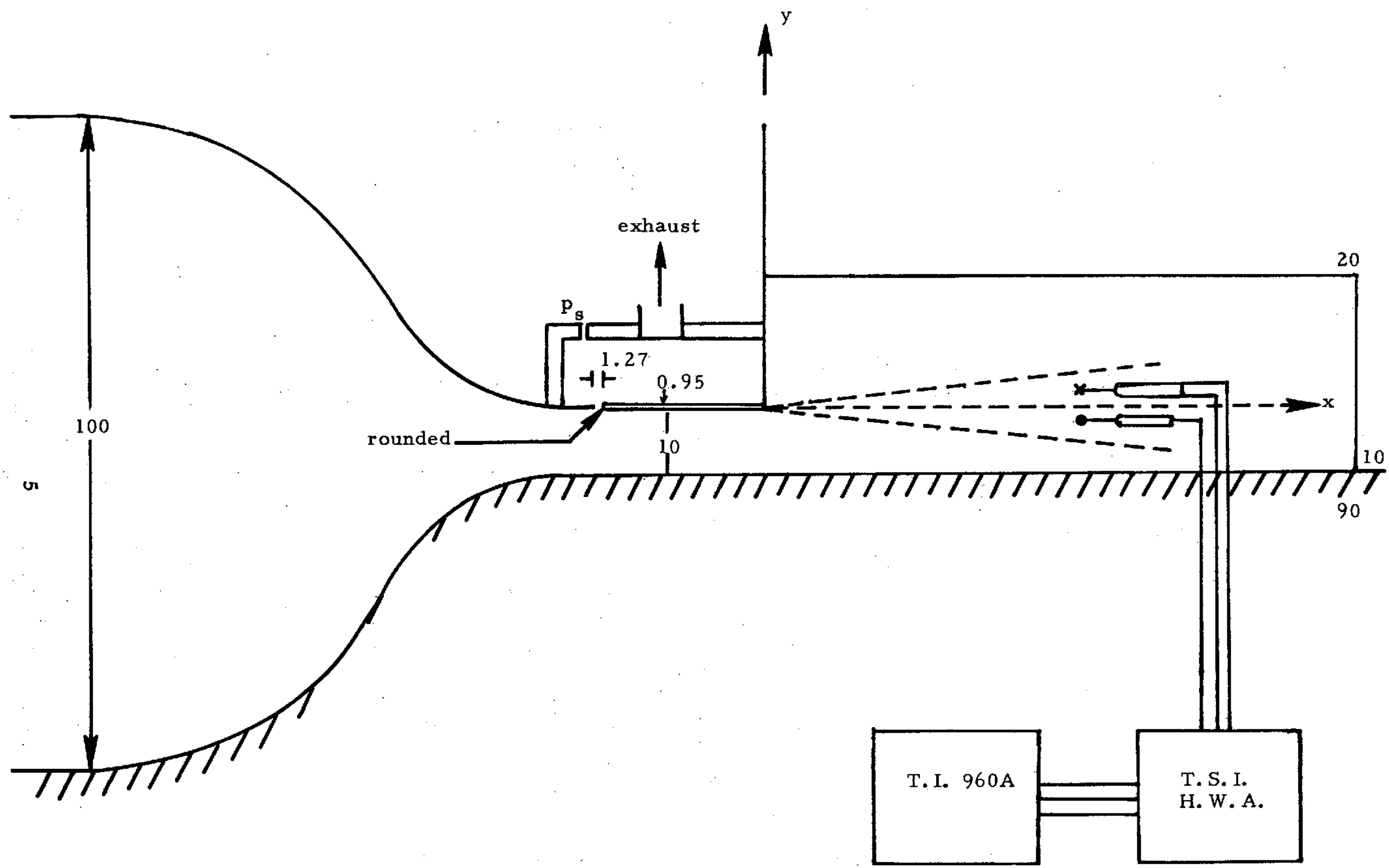


Figure 1. Schematic representation of the experimental facility.
(all dimensions in c.m.)

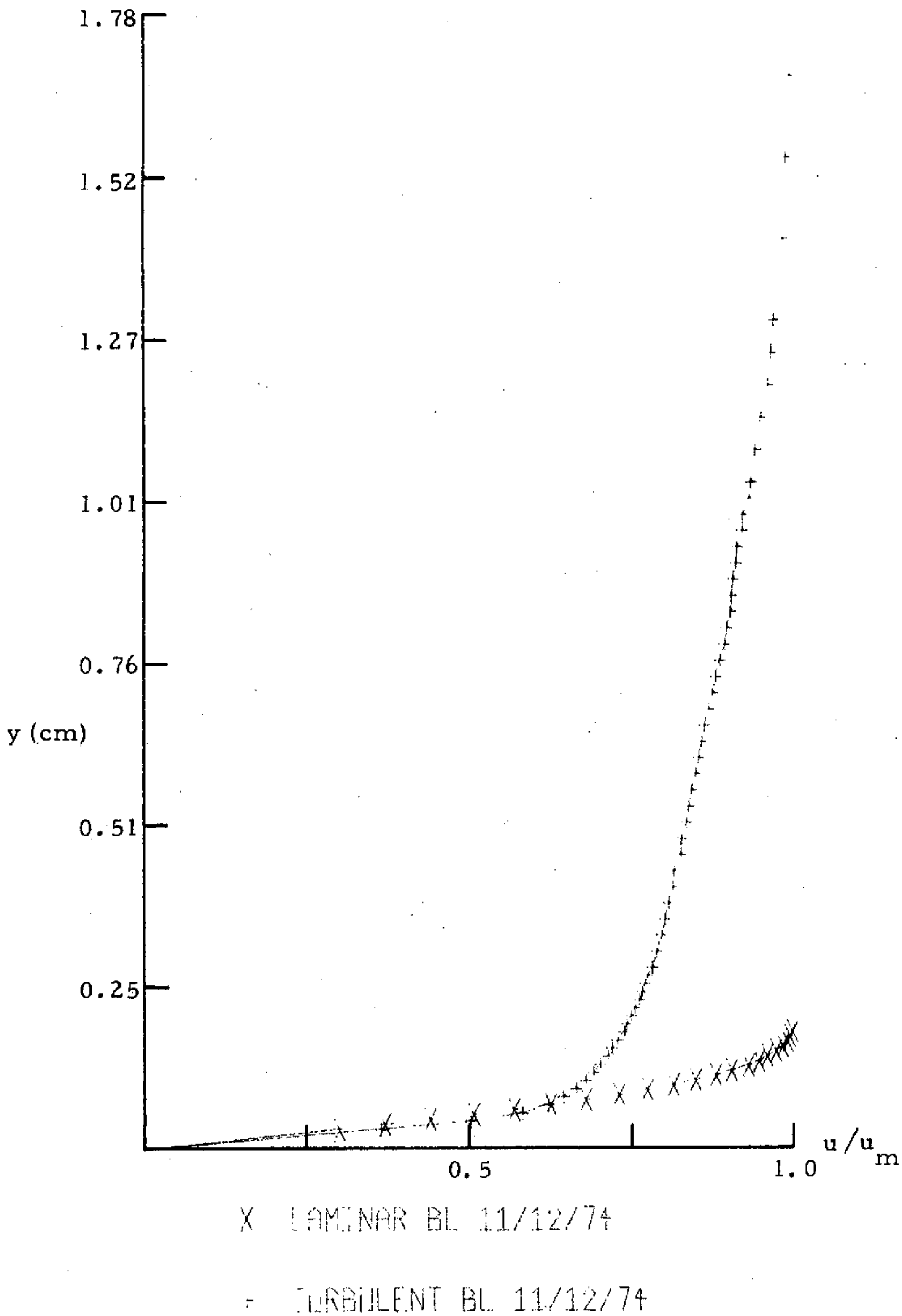


Figure 2a. Boundary layer velocity velocity profiles - dimensional representation.

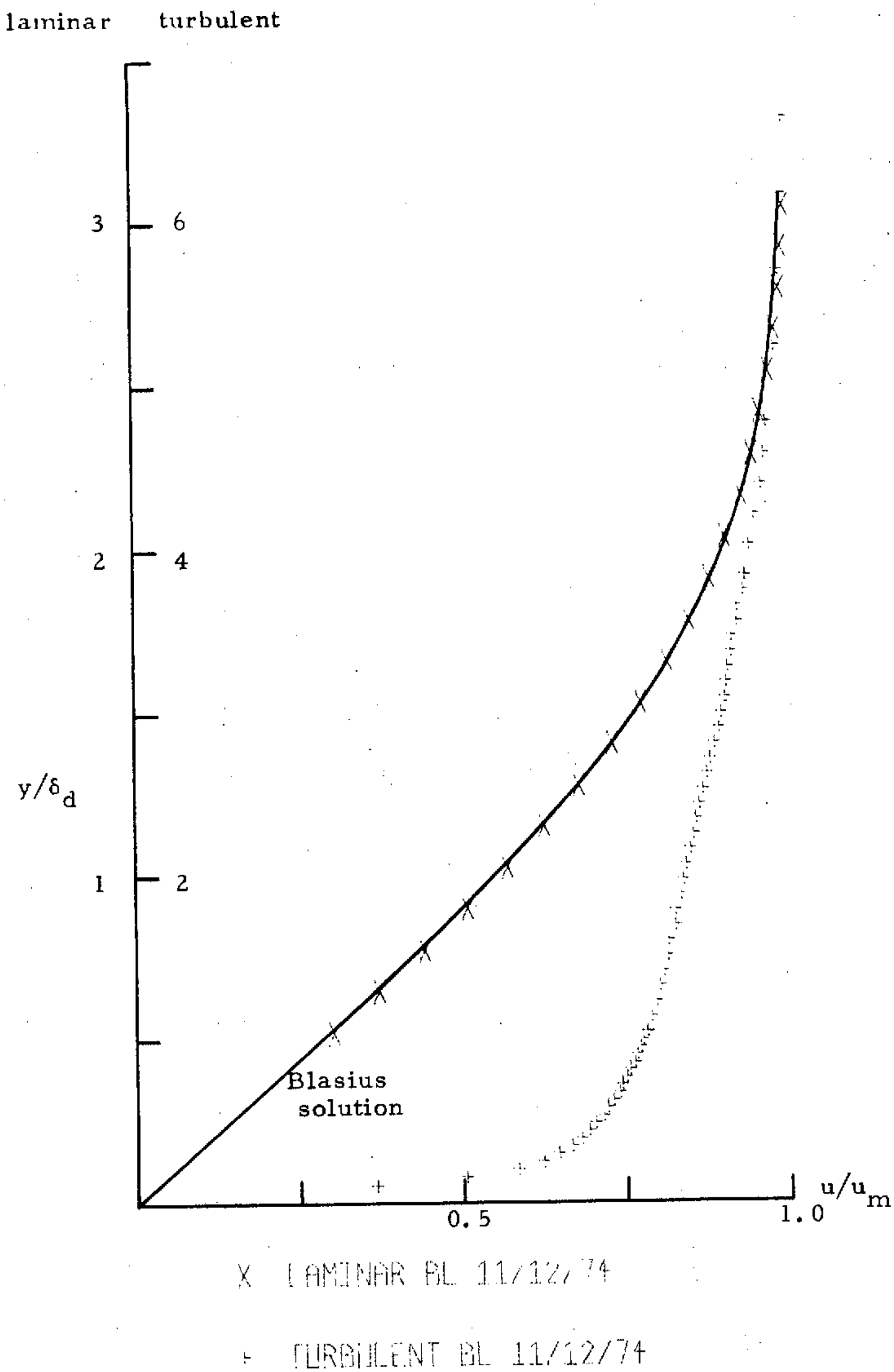


Figure 2b. Non-dimensional representation.

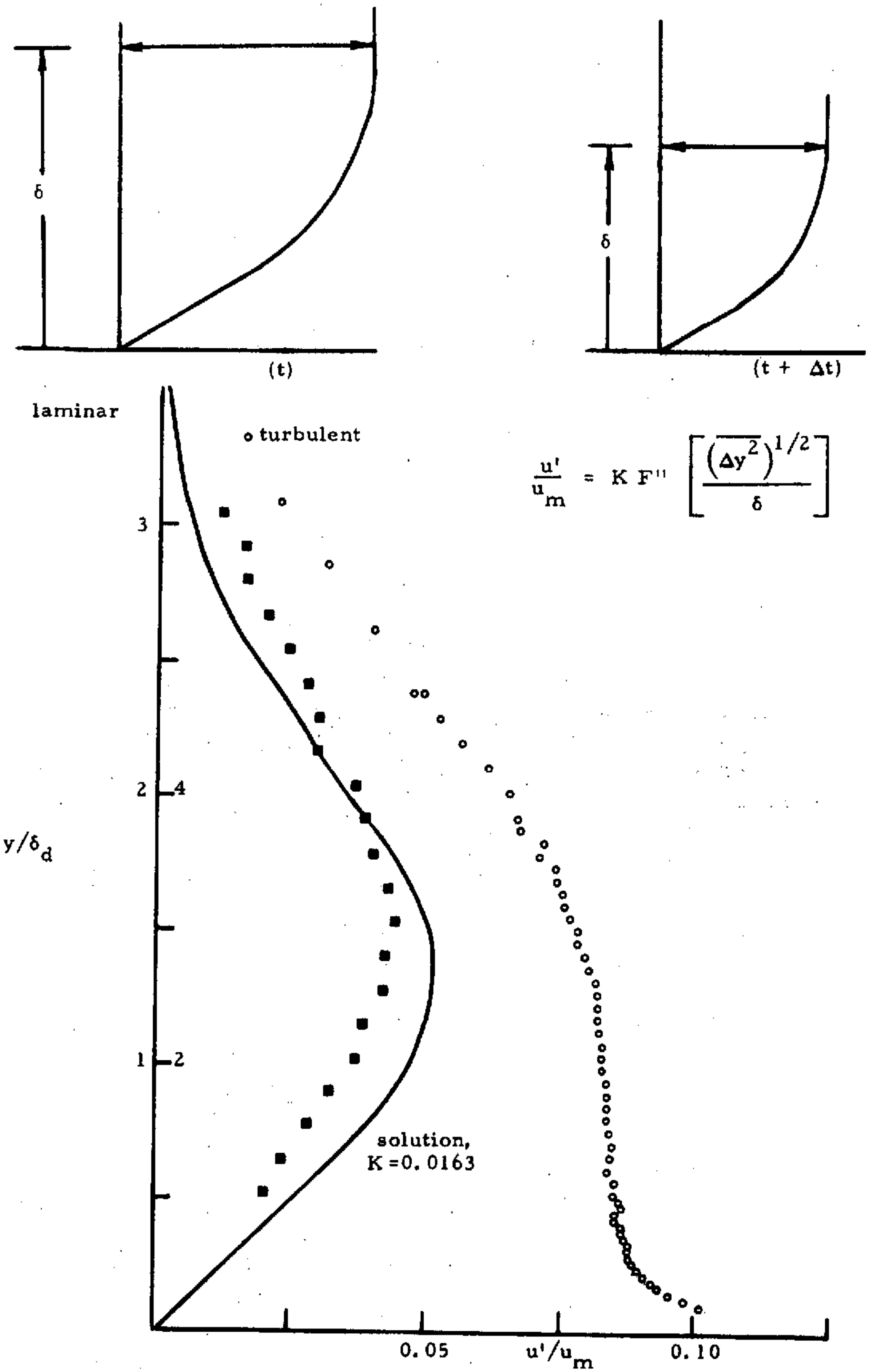


Figure 3a. Mean square fluctuation intensities for the laminar and turbulent boundary layers and the near field shear layers. Note: See equation (1) for the theoretical solution of $\hat{u}$ in the unsteady laminar boundary layer.

Spectra to characterize the boundary layer, y location at $u/u_m = 0.5$

Note: $u_m/\delta \cong 1.2 \times 10^4$ laminar

$\cong 960$ turbulent

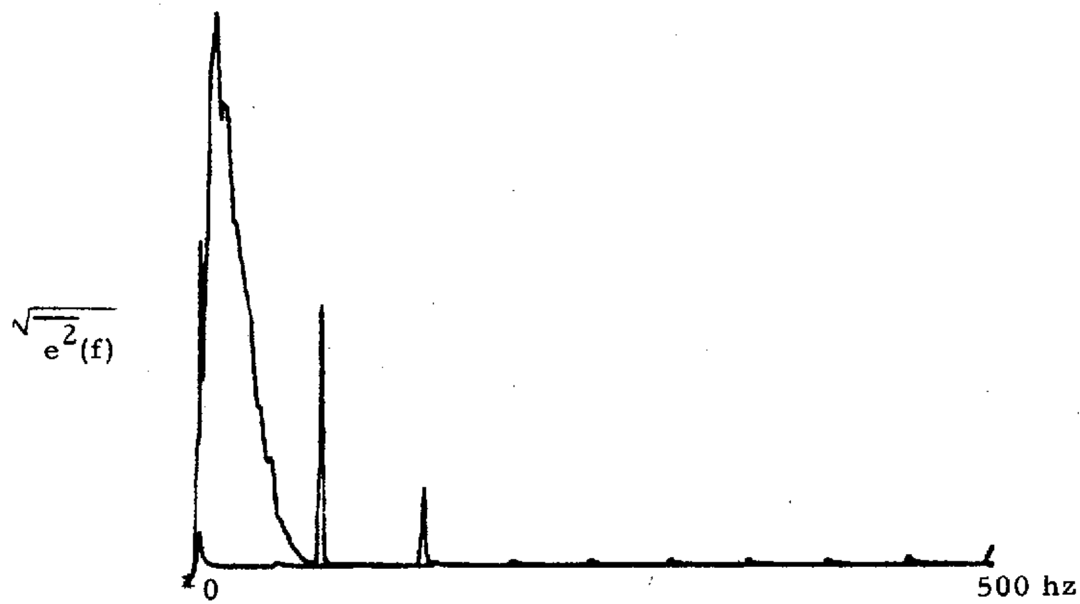


Figure 3b. Spectral content of the laminar boundary layer fluctuations (arbitrary ordinate).

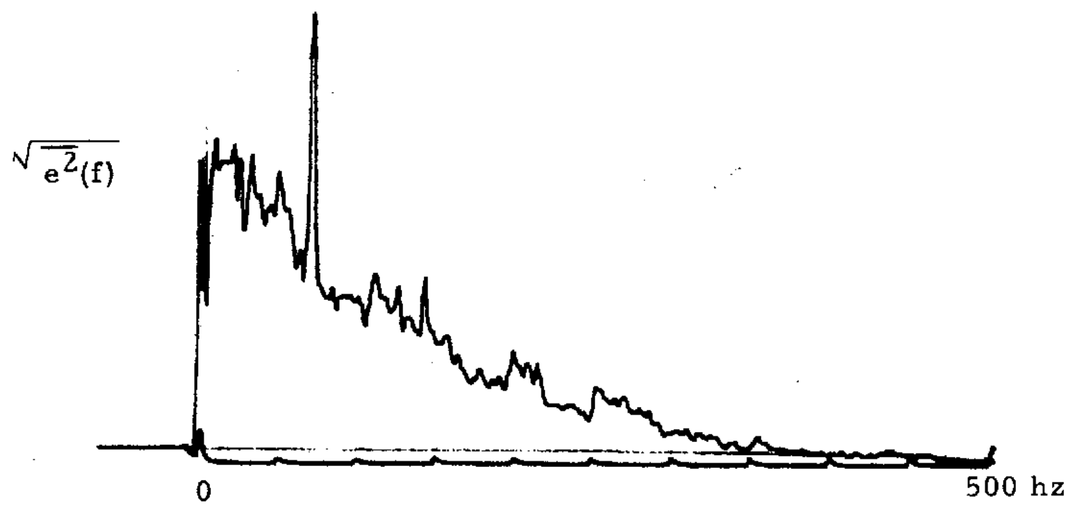


Figure 3c. Spectral content of the turbulent boundary layer fluctuations (arbitrary ordinate).

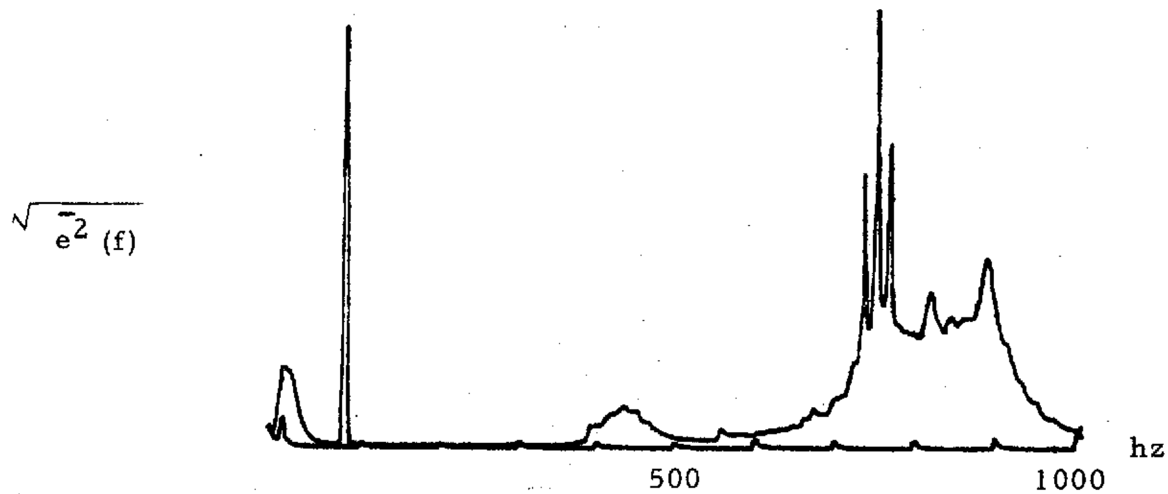


Figure 3d. x=1, y= -0.02 (in.) Laminar B. L. Case

Spectral distributions in the shear layer.

Note: $\sqrt{\bar{e}^2 (f)}$ - arbitrary units

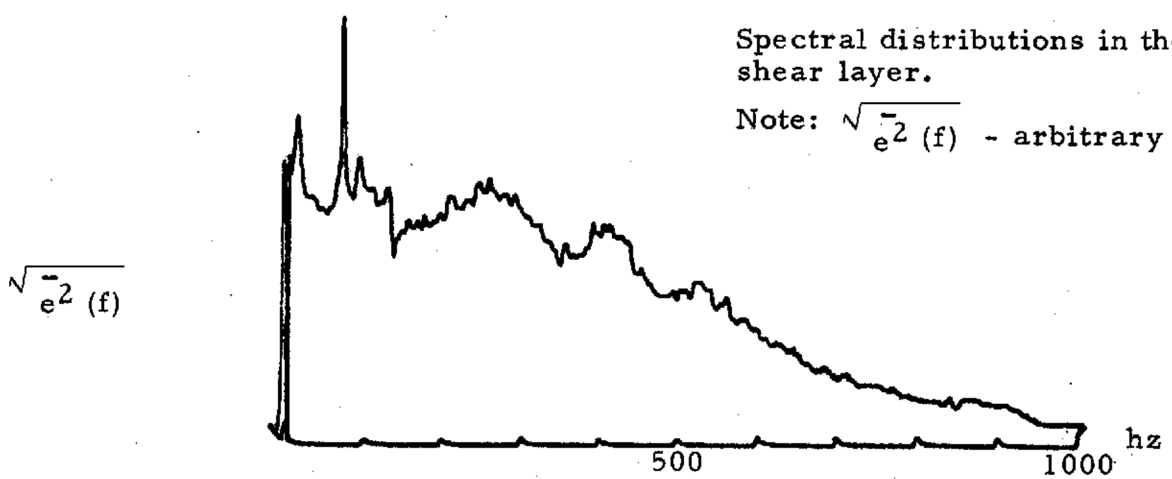
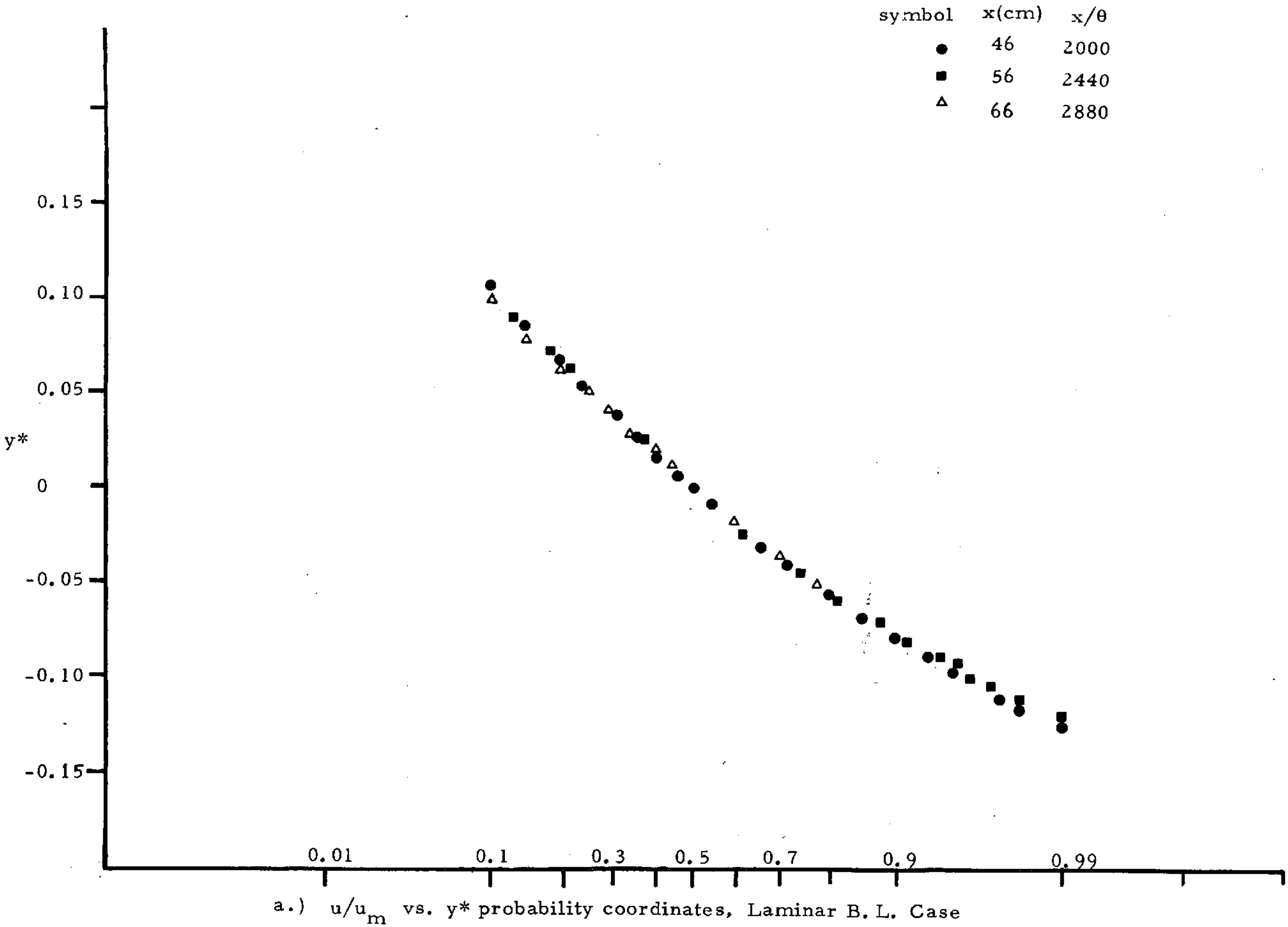


Figure 3e. x=1, y=-0.02 (in.) Turbulent B. L. Case.



a.) u/u_m vs. y* probability coordinates, Laminar B. L. Case

Figure 4. Normalized shear layer mean velocity profiles.

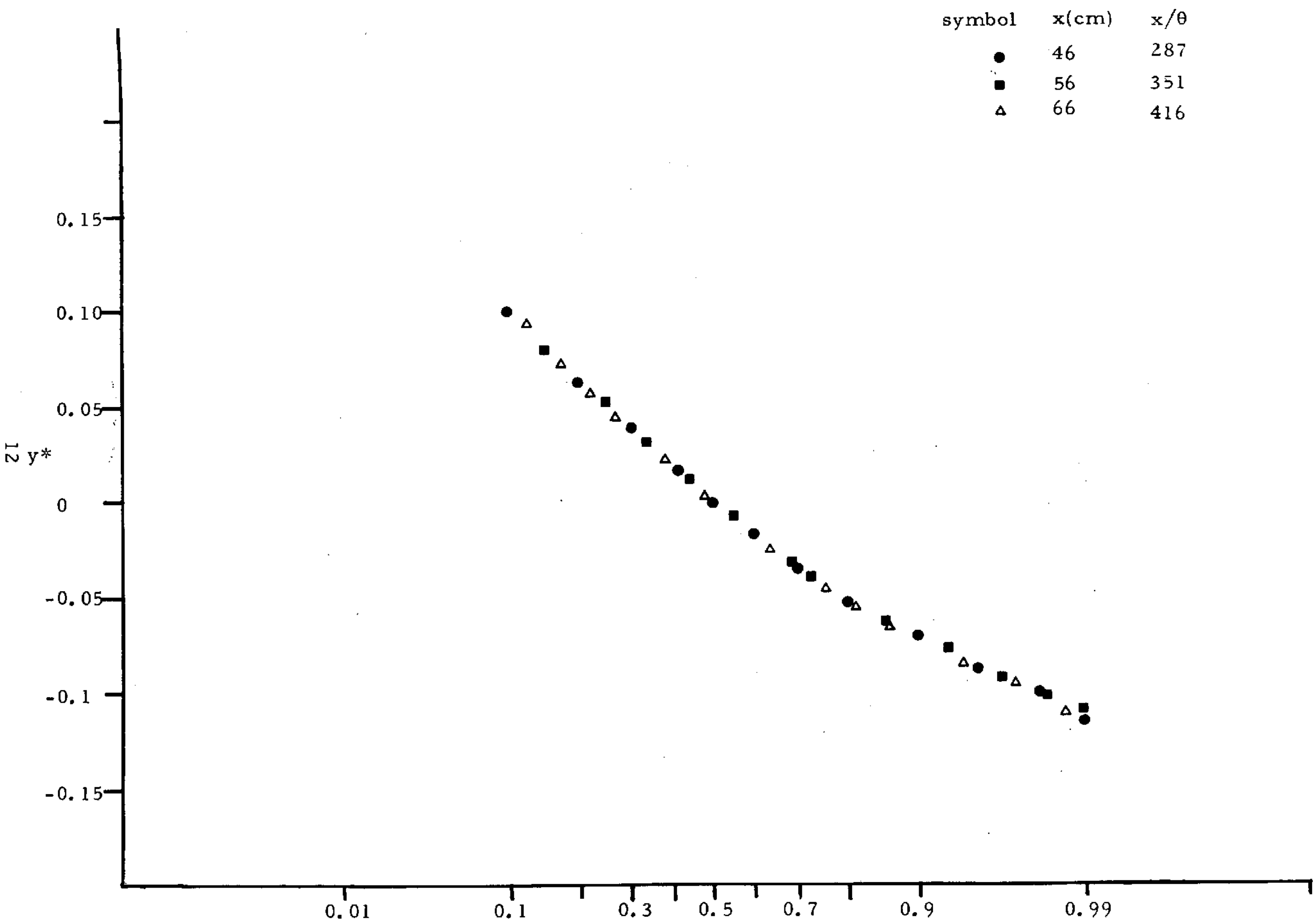


Figure 4b. u/u_m vs. y^* on probability coordinates, Turbulent Boundary Layer Case

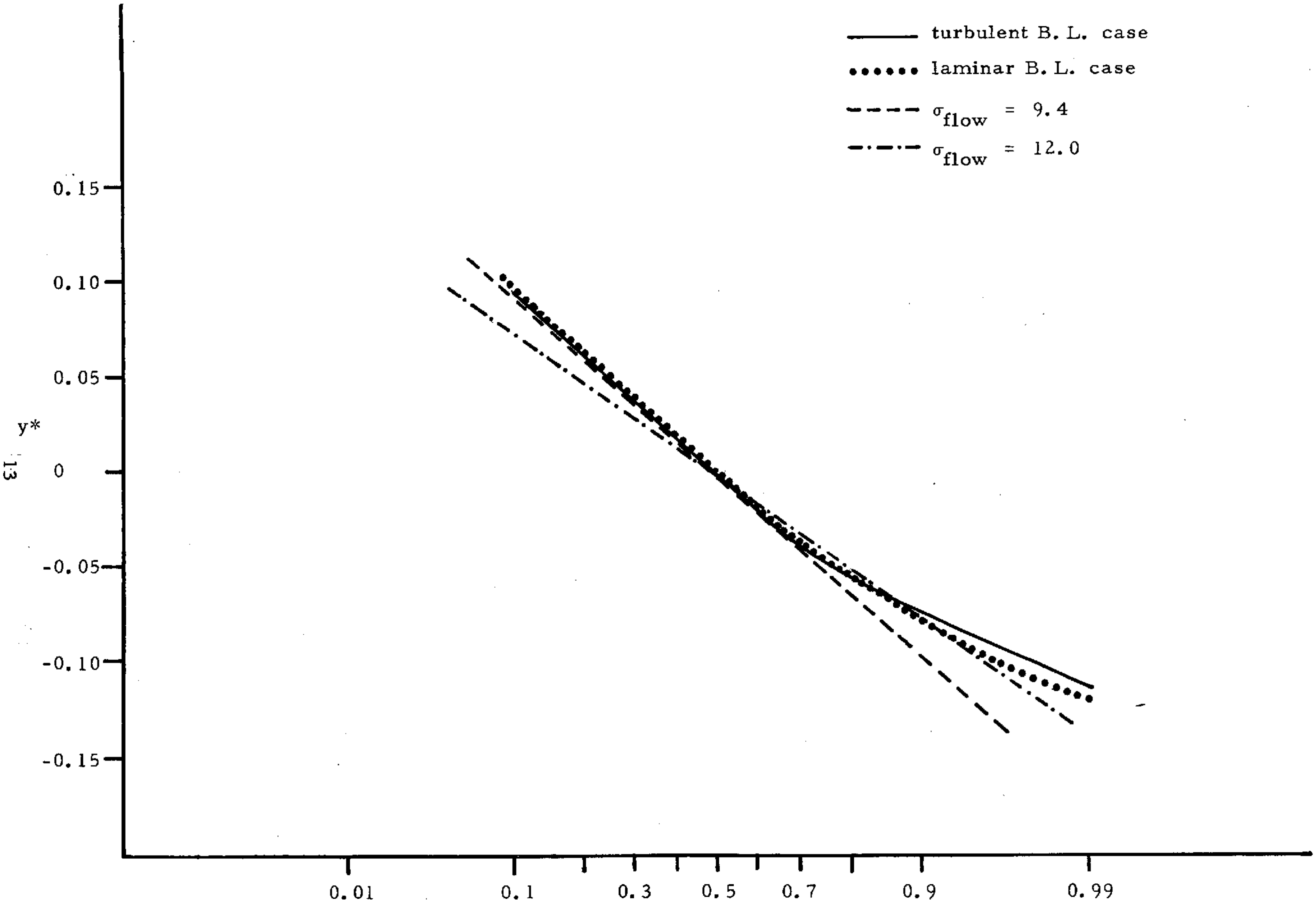


Figure 5. u/u_m vs. y*, probability coordinates, composite plot.

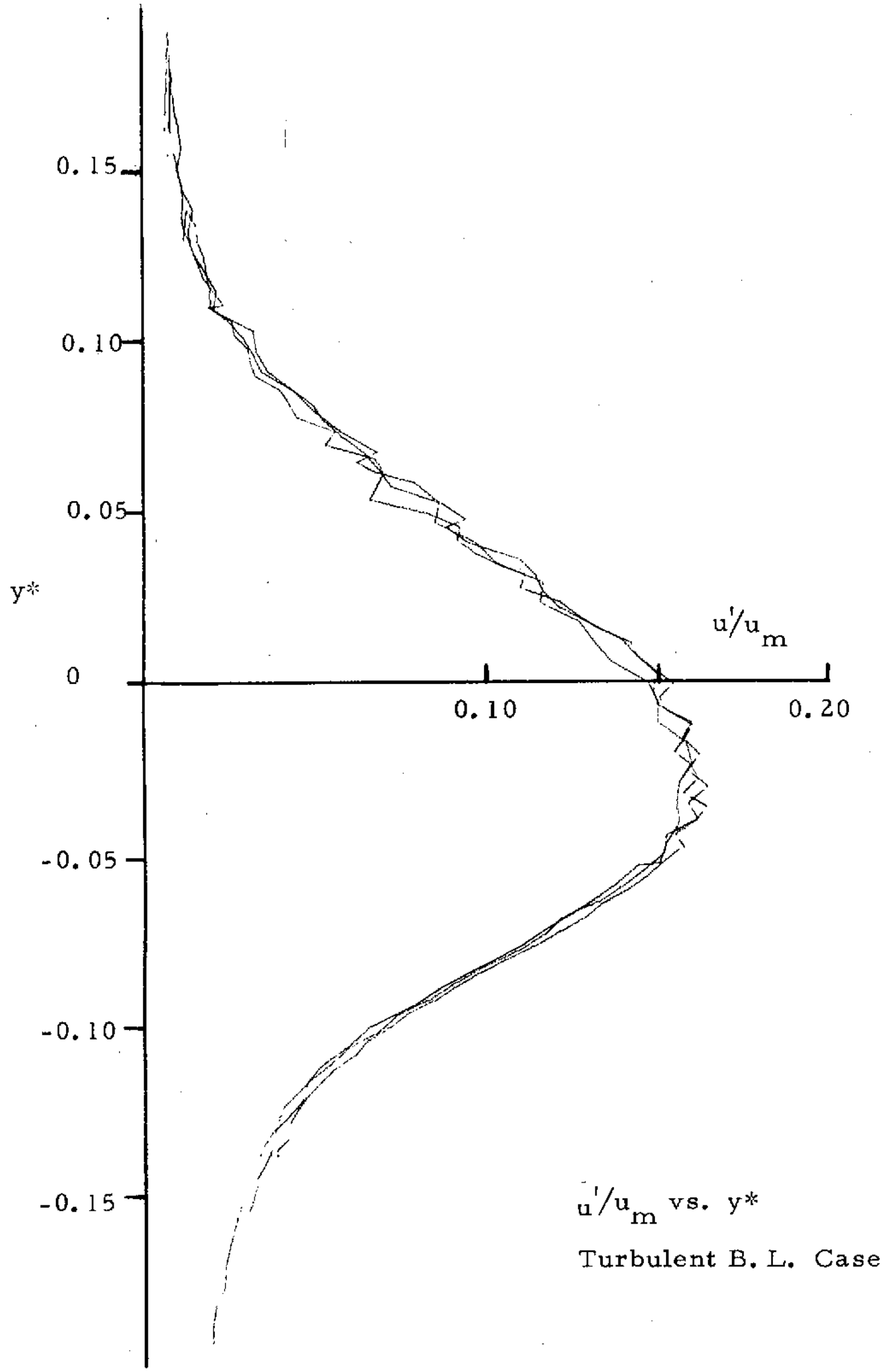


Figure 6. Characteristic turbulence intensity data.

Table Ia.
Laminar Boundary Layer Case
x = 46 cm.

89 POINTS TRAV	AT X= 18.0000	WITH 30.000 SECS/PT	11/12/74
Y	Y*	U/UMAX	U*/UMAX
5.362500	0.258709	0.068625	0.002523
5.262500	0.253333	0.067469	0.002545
5.162499	0.247956	0.067374	0.002472
5.062500	0.242580	0.069196	0.002690
4.962500	0.237203	0.069959	0.003050
4.862500	0.231827	0.069787	0.002840
4.762500	0.226451	0.069167	0.003042
4.662499	0.221074	0.070414	0.003219
4.562500	0.215698	0.071313	0.003138
4.462500	0.210322	0.071547	0.003632
4.362500	0.204945	0.071592	0.003326
4.262500	0.199569	0.072178	0.003850
4.162499	0.194193	0.072253	0.004040
4.062500	0.188816	0.072599	0.004019
3.962500	0.183440	0.072737	0.004106
3.862500	0.178064	0.073176	0.004431
3.762500	0.172687	0.073566	0.004663
3.662500	0.167311	0.074785	0.005225
3.562500	0.161935	0.075733	0.005284
3.462500	0.156558	0.076589	0.005903
3.362500	0.151182	0.077560	0.005586
3.347489	0.150375	0.077077	0.005591
3.247499	0.144999	0.078790	0.005852
3.147500	0.139623	0.080065	0.006221
3.047490	0.134246	0.082026	0.006824
2.947500	0.128870	0.084769	0.008343
2.847489	0.123493	0.088234	0.010041
2.747499	0.118117	0.092430	0.009536
2.647500	0.112741	0.097229	0.011315
2.547490	0.107364	0.101650	0.014864
2.447500	0.101988	0.112105	0.016736
2.347500	0.096612	0.122494	0.016051
2.247499	0.091236	0.132563	0.022551
2.147500	0.085859	0.140040	0.021477
2.047490	0.080482	0.159606	0.027907
1.947490	0.075106	0.178845	0.032648
1.847500	0.069730	0.191799	0.035479
1.747500	0.064354	0.212131	0.036244
1.647500	0.058978	0.224781	0.041623
1.547490	0.053601	0.242161	0.043521
1.447500	0.048225	0.265166	0.043318
1.397500	0.045537	0.284799	0.046531
1.347500	0.042849	0.286845	0.046795
1.297490	0.040160	0.310310	0.051815
1.197490	0.034784	0.331218	0.058830
1.097500	0.029408	0.361948	0.062769
0.997500	0.024031	0.383518	0.067125
0.897499	0.018655	0.412974	0.067193
0.797499	0.013279	0.438975	0.066563
0.697499	0.007902	0.460802	0.075294
0.597500	0.002526	0.485209	0.075586
0.497498	-0.002849	0.516683	0.078489
0.397499	-0.008226	0.541147	0.078716
0.297499	-0.013602	0.573103	0.080774
0.197499	-0.018978	0.602617	0.083981
0.097499	-0.024355	0.629438	0.082653
-0.002500	-0.029731	0.662957	0.082351
-0.102499	-0.035107	0.689509	0.080219
-0.202500	-0.040484	0.721479	0.078797
-0.302500	-0.045860	0.752769	0.078904
-0.402499	-0.051236	0.781804	0.078165
-0.502499	-0.056613	0.804676	0.075150
-0.602500	-0.061989	0.825554	0.071977
-0.612500	-0.062527	0.826255	0.071737
-0.712500	-0.067903	0.856551	0.066443
-0.812500	-0.073279	0.875934	0.063314
-0.912500	-0.078656	0.897716	0.057734
-1.012500	-0.084032	0.914374	0.054458
-1.112500	-0.089408	0.932988	0.049240
-1.212499	-0.094785	0.950388	0.042916
-1.312500	-0.100161	0.958633	0.039583
-1.412500	-0.105537	0.967093	0.034983
-1.512500	-0.110916	0.976032	0.030971
-1.612500	-0.116290	0.981864	0.028250
-1.712499	-0.121667	0.989420	0.024273
-1.812500	-0.127043	0.990682	0.022662
-1.912500	-0.132419	0.993619	0.019616
-2.012500	-0.137796	0.995780	0.017564
-2.112500	-0.143172	0.995978	0.016596
-2.212500	-0.148548	0.996353	0.015810
-2.312500	-0.153925	0.996498	0.014525
-2.412500	-0.159301	0.997863	0.013351
-2.512500	-0.164677	0.996994	0.012477
-2.612500	-0.170054	0.997553	0.012087
-2.612500	-0.170054	0.999322	0.012129
-2.712500	-0.175430	1.000000	0.011013
-2.812500	-0.180806	0.998231	0.010726
-2.912500	-0.186183	[illegible]	0.010619
-3.012500	-0.191559	0.997760	0.010819

Table Ib
Laminar Boundary Layer Case
x = 56 cm.

88 POINTS TRAV Y	AT X= 22.0000 Y*	WITH 30.000 SECS/PT U/UMAX	11/12/74 U*/UMAX
5.362500	0.206119	0.072332	0.003525
5.262500	0.201694	0.072203	0.003682
5.162499	0.197269	0.071041	0.003282
5.062500	0.192845	0.070104	0.003114
4.962500	0.188420	0.072332	0.003750
4.862500	0.183995	0.072688	0.003828
4.762500	0.179570	0.072596	0.003158
4.662499	0.175146	0.072953	0.004049
4.562500	0.170721	0.073443	0.004356
4.462500	0.166296	0.073936	0.004993
4.362500	0.161871	0.075088	0.006172
4.262500	0.157446	0.074915	0.005054
4.162499	0.153022	0.075859	0.005074
4.062500	0.148597	0.077523	0.004644
3.962500	0.144172	0.078513	0.006096
3.862500	0.139747	0.079615	0.006276
3.762500	0.135323	0.081855	0.006987
3.662500	0.130898	0.082307	0.006825
3.562500	0.126473	0.085248	0.007364
3.462500	0.122048	0.088477	0.009193
3.347489	0.116959	0.090565	0.009820
3.247499	0.112535	0.095751	0.013204
3.147500	0.108110	0.098302	0.015813
3.047490	0.103685	0.106261	0.015788
2.947500	0.099261	0.112841	0.018486
2.847489	0.094835	0.124389	0.018522
2.747499	0.090411	0.125852	0.019342
2.647500	0.085986	0.139643	0.020907
2.547490	0.081561	0.148127	0.023990
2.447500	0.077137	0.160454	0.024712
2.347500	0.072712	0.178460	0.027995
2.247499	0.068287	0.195105	0.034050
2.147500	0.063862	0.209369	0.037969
2.047490	0.059437	0.220512	0.040013
1.947490	0.055012	0.234275	0.042693
1.847500	0.050588	0.256102	0.043280
1.747500	0.046163	0.269193	0.043191
1.647500	0.041739	0.293770	0.047464
1.547490	0.037313	0.309490	0.054935
1.447500	0.032889	0.327101	0.051552
1.397500	0.030677	0.342061	0.059025
1.347500	0.028464	0.344071	0.054261
1.297490	0.026251	0.370188	0.062134
1.197490	0.021827	0.395510	0.064067
1.097500	0.017402	0.419328	0.065606
0.997500	0.012977	0.436566	0.070101
0.897499	0.008553	0.457839	0.072443
0.797499	0.004128	0.479313	0.070716
0.697499	-0.000296	0.501485	0.075927
0.597500	-0.004721	0.529643	0.077122
0.497498	-0.009146	0.548325	0.077245
0.397499	-0.013570	0.574527	0.076586
0.297499	-0.017995	0.592299	0.079355
0.197499	-0.022420	0.622371	0.078752
0.097499	-0.026845	0.647255	0.081679
-0.002500	-0.031269	0.669439	0.082380
-0.102499	-0.035694	0.693291	0.082183
-0.202500	-0.040119	0.716499	0.081133
-0.302500	-0.044544	0.745617	0.080640
-0.402499	-0.048968	0.769667	0.078858
-0.502499	-0.053393	0.793711	0.076012
-0.602500	-0.057818	0.815053	0.073218
-0.612500	-0.058260	0.815873	0.073593
-0.712500	-0.062685	0.832970	0.071245
-0.812500	-0.067110	0.858697	0.068445
-0.912500	-0.071535	0.880664	0.063704
-1.012500	-0.075960	0.897298	0.060612
-1.112500	-0.080384	0.908852	0.057583
-1.212499	-0.084809	0.925945	0.052295
-1.312500	-0.089234	0.942633	0.048599
-1.412500	-0.093659	0.952954	0.043903
-1.512500	-0.098084	0.964361	0.040482
-1.612500	-0.102508	0.971402	0.035838
-1.712499	-0.106933	0.977085	0.033682
-1.812500	-0.111358	0.981909	0.030202
-1.912500	-0.115783	0.986815	0.026764
-2.012500	-0.120207	0.990757	0.025117
-2.112500	-0.124632	0.994254	0.022669
-2.212500	-0.129057	0.994849	0.020951
-2.312500	-0.133482	0.995736	0.019434
-2.412500	-0.137907	1.000000	0.017388
-2.512500	-0.142331	0.999957	0.016826
-2.612500	-0.146756	0.999424	0.015913
-2.612500	-0.146756	0.997419	0.015217
-2.712500	-0.151181	0.996744	0.015390
-2.812500	-0.155606	0.996641	0.014879
-2.912500	-0.160030	0.995448	0.014536
-3.012500	-0.164455	[illegible]	0.014520

Table Ic
Laminar Boundary Layer Case
x = 66 cm.

105 POINTS TRAV	AT X= 26.0000	WITH 30.000 SECS/PT	11/19/74
Y	Y*	U/UMAX	U*/UMAX
7.737500	0.258126	0.083021	0.001837
7.637500	0.254367	0.082796	0.001762
7.537499	0.250608	0.083033	0.001941
7.437500	0.246848	0.083007	0.001944
7.337500	0.243089	0.083091	0.001982
7.237500	0.239329	0.083602	0.002017
7.137500	0.235570	0.083646	0.002120
7.037499	0.231810	0.083600	0.002006
6.937500	0.228051	0.083428	0.002212
6.837500	0.224292	0.083651	0.002617
6.737500	0.220532	0.083832	0.002358
6.637500	0.216773	0.084023	0.002506
6.537499	0.213014	0.084304	0.002611
6.437500	0.209254	0.084368	0.002457
6.337500	0.205495	0.084739	0.002594
6.237500	0.201735	0.084783	0.002976
6.137500	0.197976	0.085160	0.002991
6.037499	0.194216	0.085411	0.003028
5.937500	0.190457	0.085401	0.003012
5.837500	0.186698	0.086571	0.003615
5.737500	0.182938	0.086507	0.003378
5.562500	0.168841	0.086305	0.003820
5.262500	0.165081	0.086827	0.003754
5.162499	0.161322	0.087019	0.003426
5.062500	0.157562	0.087784	0.003351
4.962500	0.153803	0.088302	0.004176
4.862500	0.150044	0.088685	0.004734
4.762500	0.146284	0.088927	0.005083
4.662499	0.142525	0.089374	0.004902
4.562500	0.138765	0.090436	0.006347
4.462500	0.135006	0.090732	0.006026
4.362500	0.131247	0.091167	0.006735
4.262500	0.127487	0.091476	0.008275
4.162499	0.123728	0.091704	0.007448
4.062500	0.119968	0.092293	0.007866
3.962500	0.116209	0.099653	0.009527
3.862500	0.112450	0.103760	0.010993
3.762500	0.108690	0.108442	0.012364
3.662500	0.104931	0.112744	0.013769
3.562500	0.101171	0.120282	0.014260
3.462500	0.097412	0.122030	0.012932
3.362500	0.093653	0.126556	0.017497
3.347489	0.093088	0.124545	0.016803
3.247499	0.089329	0.133896	0.018233
3.147500	0.085570	0.144107	0.018899
3.047490	0.081810	0.150875	0.021873
2.947500	0.078051	0.162039	0.024987
2.847489	0.074291	0.175275	0.026843
2.747499	0.070532	0.187622	0.027965
2.647500	0.066773	0.200377	0.030682
2.547490	0.063013	0.211775	0.032129
2.447500	0.059254	0.218337	0.031964
2.347500	0.055495	0.234468	0.039225
2.247499	0.051735	0.246135	0.037967
2.147500	0.047976	0.266284	0.043578
2.047490	0.044216	0.280887	0.040921
1.947490	0.040457	0.300361	0.045032
1.847500	0.036698	0.316337	0.051401
1.747500	0.032938	0.329777	0.049214
1.647500	0.029179	0.339938	0.055041
1.547490	0.025419	0.363917	0.057454
1.447500	0.021660	0.382536	0.059478
1.347500	0.017901	0.404382	0.060959
1.397500	0.019780	0.411781	0.065214
1.297490	0.016021	0.425103	0.062341
1.197490	0.012261	0.445689	0.065028
1.097500	0.008502	0.458312	0.066388
0.997500	0.004743	0.480605	0.069746
0.897499	0.000983	0.493953	0.068119
0.797499	-0.002775	0.517057	0.072294
0.697499	-0.006534	0.540556	0.070401
0.597500	-0.010294	0.559762	0.074989
0.497498	-0.014053	0.583292	0.076975
0.397499	-0.017813	0.606308	0.076614
0.297499	-0.021572	0.624691	0.078018
0.197499	-0.025331	0.641723	0.079532
0.097499	-0.029091	0.661369	0.075659
-0.002500	-0.032850	0.684067	0.078158
-0.102499	-0.036610	0.704432	0.076532
-0.202500	-0.040369	0.725986	0.078143
-0.302500	-0.044128	0.746619	0.077076
-0.402499	-0.047888	0.765467	0.076943
-0.502499	-0.051647	0.791507	0.074846
-0.602500	-0.055407	0.814899	0.073048
-0.612500	-0.055783	0.816427	0.073938
-0.712500	-0.059542	0.828586	0.070654
-0.812500	-0.063301	0.851925	0.068120
-0.912500	-0.067061	0.867296	0.065581
-1.012500	-0.070820	0.881986	0.062346
-1.112500	-0.074580	0.896209	0.059272
-1.212499	-0.078339	0.909884	0.056104
-1.312500	-0.082098	0.919755	0.053862
-1.412500	-0.085858	0.933954	0.050034
-1.512500	-0.089617	0.946583	0.045563
-1.612500	-0.093377	0.955013	0.042139
-1.712499	-0.097136	0.964477	0.040321
-1.812500	-0.100895	0.969916	0.036695
-1.912500	-0.104655	0.978137	0.032322
-2.012500	-0.108414	0.985612	0.029617
-2.112500	-0.112173	0.989773	0.027068
-2.212500	-0.115933	0.993477	0.024811
-2.312500	-0.119692	0.996589	0.021704
-2.412500	-0.123452	0.997075	0.020533
-2.512500	-0.127211	1.000000	0.019600
-2.612500	-0.130970	0.998913	0.018800

Table II a
Turbulent Boundary Layer Case
x = 46 cm.

68 POINTS TRAV Y	AT X= 18.0000 Y*	WITH 30.000 SECS/PT U/UMAX	11/12/74 U*/UMAX
3.347489	0.179841	0.075155	0.004251
3.247499	0.173959	0.075354	0.004445
3.147500	0.168077	0.076011	0.004629
3.047490	0.162194	0.076597	0.005366
2.947500	0.156312	0.077781	0.005722
2.847489	0.150429	0.078756	0.005116
2.747499	0.144548	0.080536	0.005897
2.647500	0.138665	0.082699	0.007445
2.547490	0.132782	0.084213	0.006643
2.447500	0.126901	0.088352	0.007240
2.347500	0.121018	0.089504	0.009072
2.247499	0.115136	0.094868	0.010849
2.147500	0.109254	0.097992	0.010504
2.047490	0.103371	0.111963	0.016462
1.947490	0.097488	0.117376	0.016959
1.847500	0.091606	0.127981	0.018568
1.747500	0.085724	0.142503	0.022582
1.647500	0.079842	0.156961	0.025580
1.547490	0.073959	0.175788	0.029407
1.447500	0.068077	0.195514	0.034813
1.397500	0.065136	0.202483	0.031589
1.347500	0.062195	0.211908	0.034538
1.297490	0.059253	0.222580	0.040035
1.197490	0.053371	0.250699	0.043697
1.097500	0.047489	0.264835	0.043059
0.997500	0.041606	0.292846	0.049136
0.897499	0.035724	0.320224	0.051957
0.797499	0.029842	0.347045	0.058883
0.697499	0.023959	0.380706	0.058566
0.597500	0.018077	0.410655	0.064363
0.497498	0.012195	0.439087	0.066507
0.397499	0.006312	0.464044	0.068995
0.297499	0.000430	0.497749	0.074516
0.197499	-0.005451	0.528509	0.075894
0.097499	-0.011334	0.565520	0.075875
-0.002500	-0.017216	0.598238	0.080083
-0.102499	-0.023098	0.631460	0.080600
-0.202500	-0.028981	0.663434	0.078818
-0.302500	-0.034863	0.702813	0.078558
-0.402499	-0.040745	0.739089	0.078756
-0.502499	-0.046628	0.770323	0.076905
-0.602500	-0.052510	0.800232	0.075840
-0.612500	-0.053098	0.815852	0.072719
-0.712500	-0.058981	0.844131	0.069142
-0.812500	-0.064863	0.871811	0.064913
-0.912500	-0.070745	0.896181	0.059817
-1.012500	-0.076628	0.919028	0.055373
-1.112500	-0.082510	0.936866	0.049522
-1.212499	-0.088393	0.953549	0.044071
-1.312500	-0.094275	0.968456	0.039438
-1.412500	-0.100157	0.980367	0.033337
-1.512500	-0.106040	0.987403	0.029981
-1.612500	-0.111922	0.991852	0.025884
-1.712499	-0.117804	0.992019	0.023469
-1.812500	-0.123687	0.995865	0.020472
-1.912500	-0.129569	0.997490	0.019391
-2.012500	-0.135451	0.998717	0.017504
-2.112500	-0.141334	0.999008	0.016353
-2.212500	-0.147216	0.999377	0.014963
-2.312500	-0.153098	0.999006	0.014065
-2.412500	-0.158981	0.999159	0.013144
-2.512500	-0.164863	1.000000	0.012332
-2.612500	-0.170745	0.999196	0.011750
-2.612500	-0.170745	0.998301	0.011881
-2.712500	-0.176628	0.998239	0.011636
-2.812500	-0.182510	0.998059	0.010300
-2.912500	-0.188392	0.997496	0.009822
-3.012500	-0.194275	0.996528	0.009908

Table II b
Turbulent Boundary Layer Case
x : 56 cm.

68 POINTS TRAV	AT X= 22.0000	WITH 30.000 SECS/PT	11/12/74
Y	Y*	U/UMAX	U*/UMAX
3.347489	0.137612	0.081521	0.006478
3.247499	0.132851	0.083162	0.007825
3.147500	0.128089	0.085501	0.008057
3.047490	0.123327	0.087690	0.009042
2.947500	0.118565	0.089249	0.009459
2.847489	0.113803	0.094175	0.010033
2.747499	0.109041	0.098498	0.010129
2.647500	0.104279	0.100927	0.013037
2.547490	0.099517	0.107640	0.015120
2.447500	0.094756	0.116149	0.016525
2.347500	0.089994	0.127606	0.017693
2.247499	0.085232	0.141099	0.022043
2.147500	0.080470	0.145015	0.025284
2.047490	0.075708	0.165269	0.026921
1.947490	0.070946	0.175381	0.029767
1.847500	0.066184	0.192540	0.033026
1.747500	0.061422	0.203623	0.034972
1.647500	0.056660	0.226406	0.036740
1.547490	0.051898	0.247574	0.044048
1.447500	0.047137	0.264242	0.047694
1.397500	0.044756	0.282094	0.044753
1.347500	0.042375	0.278885	0.046481
1.297490	0.039993	0.298851	0.048023
1.197490	0.035231	0.320540	0.055501
1.097500	0.030470	0.341481	0.057892
0.997500	0.025708	0.369542	0.058967
0.897499	0.020946	0.391209	0.061409
0.797499	0.016184	0.417233	0.065979
0.697499	0.011422	0.440368	0.070530
0.597500	0.006660	0.465080	0.072855
0.497498	0.001898	0.492674	0.075599
0.397499	-0.002862	0.511044	0.075045
0.297499	-0.007624	0.547953	0.075768
0.197499	-0.012386	0.569870	0.080678
0.097499	-0.017148	0.603765	0.079391
-0.002500	-0.021910	0.628186	0.081806
-0.102499	-0.026672	0.659025	0.079993
-0.202500	-0.031434	0.680419	0.082992
-0.302500	-0.036196	0.710998	0.080191
-0.402499	-0.040958	0.733977	0.081489
-0.502499	-0.045720	0.767581	0.076803
-0.602500	-0.050481	0.794213	0.076581
-0.612500	-0.050958	0.796475	0.076624
-0.712500	-0.055720	0.824311	0.073721
-0.812500	-0.060481	0.843463	0.070507
-0.912500	-0.065243	0.864348	0.066935
-1.012500	-0.070005	0.891391	0.061492
-1.112500	-0.074767	0.908371	0.058928
-1.212499	-0.079529	0.924972	0.054984
-1.312500	-0.084291	0.940094	0.049955
-1.412500	-0.089053	0.952246	0.045723
-1.512500	-0.093815	0.965823	0.042002
-1.612500	-0.098577	0.975126	0.037200
-1.712499	-0.103339	0.979478	0.034310
-1.812500	-0.108101	0.990194	0.029829
-1.912500	-0.112862	0.993030	0.027241
-2.012500	-0.117624	0.995936	0.023998
-2.112500	-0.122386	0.996854	0.023614
-2.212500	-0.127148	0.998592	0.021523
-2.312500	-0.131910	0.999832	0.019184
-2.412500	-0.136672	0.999129	0.018936
-2.512500	-0.141434	1.000000	0.017985
-2.612500	-0.146196	0.999419	0.016606
-2.612500	-0.146196	0.999021	0.016897
-2.712500	-0.150958	0.999111	0.016149
-2.812500	-0.155720	0.998204	0.015418
-2.912500	-0.160481	0.998665	0.015224
-3.012500	-0.165243	0.997256	0.015175

Table IIc
Turbulent Boundary Layer Case
x = 66 cm.

78 POINTS TRAV	AT X= 26.0000	WITH 30.000 SECS/PT	11/12/74
Y	Y*	U/UMAX	[illegible]
5.362500	0.190597	0.072346	0.003782
5.162499	0.182597	0.074486	0.004025
4.962500	0.174597	0.075042	0.004123
4.762500	0.166597	0.075776	0.004073
4.562500	0.158597	0.076850	0.004221
4.362500	0.150597	0.077822	0.005127
4.162499	0.142597	0.080786	0.005951
3.962500	0.134597	0.082679	0.005784
3.762500	0.126597	0.085832	0.007477
3.562500	0.118597	0.091868	0.008952
3.362500	0.110597	0.097270	0.011983
3.347489	0.109997	0.095666	0.009692
3.247499	0.105997	0.099939	0.013244
3.147500	0.101997	0.102579	0.013567
3.047490	0.097997	0.109140	0.015659
2.947500	0.093997	0.115756	0.015940
2.847489	0.089997	0.127911	0.016699
2.747499	0.085997	0.131993	0.020532
2.647500	0.081997	0.144316	0.021717
2.547490	0.077997	0.152084	0.022926
2.447500	0.073997	0.169724	0.028477
2.347500	0.069997	0.178396	0.026872
2.247499	0.065997	0.193085	0.034337
2.147500	0.061997	0.204832	0.035532
2.047490	0.057997	0.218104	0.034636
1.947490	0.053997	0.232484	0.033501
1.847500	0.049997	0.253651	0.042005
1.747500	0.045997	0.267065	0.046788
1.647500	0.041997	0.289576	0.046438
1.547490	0.037997	0.302604	0.049236
1.447500	0.033997	0.323104	0.053208
1.397500	0.031997	0.341501	0.056291
1.347500	0.029997	0.338417	0.055856
1.297490	0.027997	0.357869	0.055509
1.197490	0.023997	0.379726	0.061262
1.097500	0.019997	0.399395	0.063930
0.997500	0.015997	0.422286	0.067125
0.897499	0.011997	0.444957	0.071757
0.797499	0.007997	0.462294	0.072708
0.697499	0.003997	0.482968	0.075202
0.597500	-0.000002	0.500009	0.078043
0.497498	-0.004002	0.523675	0.075998
0.397499	-0.008002	0.550159	0.077013
0.297499	-0.012002	0.577380	0.080839
0.197499	-0.016002	0.595874	0.079606
0.097499	-0.020002	0.621371	0.078146
-0.002500	-0.024002	0.636399	0.080642
-0.102499	-0.028002	0.667435	0.081560
-0.202500	-0.032002	0.683088	0.079406
-0.302500	-0.036002	0.706453	0.082864
-0.402499	-0.040002	0.730501	0.081339
-0.502499	-0.044002	0.757545	0.078255
-0.602500	-0.048002	0.776082	0.079498
-0.612500	-0.048402	0.787657	0.078734
-0.712500	-0.052402	0.810131	0.076190
-0.812500	-0.056402	0.831566	0.073940
-0.912500	-0.060402	0.847950	0.071037
-1.012500	-0.064402	0.864516	0.067254
-1.112500	-0.068402	0.884067	0.064838
-1.212499	-0.072402	0.901279	0.061239
-1.312500	-0.076402	0.918003	0.057652
-1.412500	-0.080402	0.931321	0.053414
-1.512500	-0.084402	0.943150	0.049552
-1.612500	-0.088402	0.954319	0.045979
-1.712499	-0.092402	0.963044	0.043010
-1.812500	-0.096402	0.974605	0.038822
-1.912500	-0.100402	0.978965	0.036319
-2.012500	-0.104402	0.985718	0.032895
-2.112500	-0.108402	0.990917	0.031286
-2.212500	-0.112402	0.994604	0.028158
-2.312500	-0.116402	0.996027	0.026081
-2.412500	-0.120402	0.998483	0.024128
-2.512500	-0.124402	0.998923	0.022681
-2.612500	-0.128402	1.000000	0.021504
-2.612500	-0.128402	0.999782	0.021612
-2.712500	-0.132402	0.999388	0.021635
-2.812500	-0.136402	0.999334	0.019649
-2.912500	-0.140402	0.998308	0.019432