**Naval Surface Warfare Center**

**Carderock Division**

West Bethesda, MD 20817-5700

**NSWCCD-80-TR-2023/006** **June 2023**

Naval Architecture and Engineering Department

Technical Report

# HIGH REYNOLDS NUMBER TURBULENT BOUNDARY LAYER MEASUREMENTS AT LARGE CAVITATION CHANNEL (LCC)

by

Joel T. Park
Christopher J. Chesnakas
NSWCCD
J. Michael Cutbirth
Former NSWCCD Employee

DISTRIBUTION STATEMENT A. Approved for public release. Distribution is unlimited.

# REPORT DOCUMENTATION PAGE

*Form Approved*
*OMB No. 0704-0188*

Public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing this collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden to Department of Defense, Washington Headquarters Services, Directorate for Information Operations and Reports (0704-0188), 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302. Respondents should be aware that notwithstanding any other provision of law, no person shall be subject to any penalty for failing to comply with a collection of information if it does not display a currently valid OMB control number. **PLEASE DO NOT RETURN YOUR FORM TO THE ABOVE ADDRESS.**

| **1. REPORT DATE** *(DD-MM-YYYY)* | **2. REPORT TYPE** | **3. DATES COVERED** *(From - To)* |
|---|---|---|
| 05-06-2023 | Final Report | Sep-Oct 2021 |

**4. TITLE AND SUBTITLE**

High Reynolds Number Turbulent Boundary Measurements at Large Cavitation Channel (LCC)

**5a. CONTRACT NUMBER**

**5b. GRANT NUMBER**

**5c. PROGRAM ELEMENT NUMBER**

**6. AUTHOR(S)**
Park, Joel T.; Chesnakas, Christopher J.; and Cutbirth, J. Michael

**5d. PROJECT NUMBER**

**5e. TASK NUMBER**

**5f. WORK UNIT NUMBER**
N0001421WX00840

**7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)**
Naval Surface Warfare Center
Carderock Division (Code 85)
9500 Macarthur Boulevard
West Bethesda, MD 20817-5700

**8. PERFORMING ORGANIZATION REPORT NUMBER**

NSWCCD-80-TR-2023/006

**9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES)**
Office of Naval Research (ONR)
Advance Naval Platforms Division (Code 331)
875 North Randolph Street
Arlington, VA 22203-1995

**10. SPONSOR/MONITOR'S ACRONYM(S)**
ONR

**11. SPONSOR/MONITOR'S REPORT NUMBER(S)**
xxxxxx

**12. DISTRIBUTION / AVAILABILITY STATEMENT**
DISTRIBUTION STATEMENT A. Approved for public release. Distribution is unlimited.

**13. SUPPLEMENTARY NOTES**

**14. ABSTRACT**

In recent years, interest has renewed in high Reynolds number turbulent boundary layers. Aircraft, ships, and submarines operate at very high Reynolds numbers with momentum thickness Reynolds number ($Re_\theta$) on the order of $10^5$ to $10^6$. Typically, the highest laboratory $Re_\theta$ has been less than $2 \times 10^4$. Acquisition of boundary layer data at significantly higher $Re_\theta$ has been conducted on the wall of the test section of the Large Cavitation Channel (LCC), the largest water tunnel in the world located in Memphis, Tennessee. The Reynolds number range of the experiments was $2.1 \times 10^4 < Re_\theta < 2.9 \times 10^5$. Boundary layer profiles were acquired at twelve (12) axial stations and four (4) tunnel velocities (2.5, 5, 10, and 15 m/s) via laser Doppler anemometry (LDA). In general, the results were consistent with classical boundary layer theory. Specifically, the overlap region followed a log law while the outer boundary layer was consistent with Coles' wake law. Providing information for improved boundary measurements in the future, validation of computer codes, and the design of experiments in the LCC are the important purposes of the report.

**15. SUBJECT TERMS**
turbulent boundary layer, high Reynolds number, laser Doppler anemometry, water tunnel

| **16. SECURITY CLASSIFICATION OF:** | | | **17. LIMITATION OF ABSTRACT** | **18. NUMBER OF PAGES** | **19a. NAME OF RESPONSIBLE PERSON** |
|---|---|---|---|---|---|
| **a. REPORT** | **b. ABSTRACT** | **c. THIS PAGE** | | | Joel T. Park |
| Unclassified | Unclassified | Unclassified | UU | 258 | **19b. TELEPHONE NUMBER** *(include area code)* 301-227-0011 |



**Standard Form 298 (Rev. 8-98)**
**Prescribed by ANSI Std. Z39.18**

THIS PAGE INTENTIONALLY LEFT BLANK

## CONTENTS

CONTENTS ..... iii
FIGURES ..... v
TABLES ..... vi
ABBREVIATIONS AND ACRONYMS ..... vii
SYMBOLS ..... viii
English ..... viii
Greek ..... ix
Subscripts ..... ix
ADMINISTRATIVE INFORMATION ..... x
ACKNOWLEDGEMENTS ..... x
SUMMARY ..... 1
INTRODUCTION ..... 2
THEORY ..... 3
EXPERIMENTAL METHODS ..... 5
EXPERIMENTAL RESULTS ..... 11
Velocity Profiles ..... 11
Skin Friction Coefficient ..... 16
Shape Factor ..... 19
Velocity Gradient ..... 19
Turbulence Profiles ..... 20
Additional Data ..... 22
Glass Window ..... 22
Acrylic Window ..... 22
CONCLUSIONS ..... 23
REFERENCES ..... 25
APPENDIX A: REVIEWER COMMENTS ON ASME *JOURNAL OF FLUIDS ENGINEERING* PAPER FE-03-1115 ..... A-1
APPENDIX B: COLES 2003 CORRESPONDENCE ..... B-1

APPENDIX C: GRAPHS FROM COLES 2003 ATTACHMENT E ..... C-1
APPENDIX D: COMPUTER DATA FROM COLES 2003 ATTACHMENT F..... D-1
APPENDIX E: CALIBRATION DATA FOR LASER DOPPLER ANEMOMETER (LDA)..... E-1
APPENDIX F: LCC TEST SECTION BOUNDARY LAYER DATA..... F-1
APPENDIX G: GLASS WINDOWS FOR LDA MEASUREMENTS ..... G-1
APPENDIX H: OPTICAL QUALITY OF LCC ACRYLIC WINDOWS..... H-1

## FIGURES

Figure 1. Schematic Drawing of Large Cavitation Channel (LCC) [19] ..... 5
Figure 2. Cross-Section of Large Cavitation Channel (LCC) Test Section [19] ..... 6
Figure 3. LDA Probe Measuring Through LCC Window ..... 8
Figure 4. LDA Probe Volume Relative to LCC Window ..... 8
Figure 3. Velocity Residuals of 310 mm Fiber-Optic Probe Calibration for Test Section Boundary Layer Measurements ..... 10
Figure 4. Velocity Residuals of 800 mm Fiber-Optic Probe Calibration for Tunnel Velocity Measurements ..... 11
Figure 5. Mean Velocity Profiles in Inner Variables for $Re_\theta = 21.1 \times 10^3$ and $292 \times 10^3$ in Comparison to Musker [15] Theory ..... 12
Figure 6. Mean Velocity Defect Profile in Outer Variables for $Re_\theta = 21.1 \times 10^3$ and $292 \times 10^3$ in Comparison to Musker [15] Theory ..... 12
Figure 7. Mean Velocity Profile in Outer Variables and Linear Coordinates for $Re_\theta = 21.1 \times 10^3$ and $292 \times 10^3$ in Comparison to Musker [15] Theory ..... 13
Figure 8. Velocity Residuals for Log Law ..... 14
Figure 9. Boundary Layer Thickness ..... 15
Figure 10. Coles' Wake Parameter ..... 16
Figure 11. Skin-Friction Coefficient as Function of $Re_\theta$ ..... 17
Figure 12. Growth of Boundary Layer Momentum Thickness ..... 18
Figure 13. Skin-Friction Coefficient as Function of Length Reynolds Number, $Re_x$ ..... 18
Figure 14. Location of Virtual Origin of Boundary Layer Upstream of Measurement Location for Tunnel Velocity ..... 19
Figure 15. Shape Factor ..... 20
Figure 16. Test Section Velocity Gradient ..... 20
Figure 17. Relative Turbulence Intensity Profiles in Inner Variables ..... 21
Figure 18. Relative Turbulence Intensity Profiles in Outer Variables ..... 21

## TABLES

Table 1. Constants for Log Law .....4

Table 2. LDA Measurement Locations Relative to Tunnel Velocity Measurement .....7

Table 3. Summary of Optical Parameters for Fiber-Optic Probes.....7

Table 4. Summary of Effects in Change of Probe Position Offset on Friction Velocity and Constant $B$ for $\kappa = 0.41$ and $B = 5.00$ .....14

## ABBREVIATIONS AND ACRONYMS

| | |
|---|---|
| ASME | American Society of Mechanical Engineers |
| BIPM | Bureau International des Poids Mesures |
| DTIC | Defense Technical Information Center |
| GUM | Guide to the expression of Uncertainty in Measurement |
| JCGM | Joint Committee for Guides in Metrology |
| *JFE* | *Journal of Fluids Engineering* |
| LCC | Large Cavitation Channel |
| LDA | Laser Doppler anemometry |
| NSWCCD | Naval Surface Warfare Center Carderock Division |
| ONR | Office of Naval Research |
| PDF | Portable Document Format |

## SYMBOLS

### English

| | | |
|---|---|---|
| $a$ | Slope | |
| $B$ | Log law intercept, Equation (2) | |
| $b$ | Intercept | |
| $C$ | Constant, Equation (1) | |
| $c_f$ | Skin-friction coefficient, $c_f = 2\tau_w/(\rho U_\delta^2)$ | |
| $C_p$ | Pressure coefficient, $C_p = 2(p-p_0) / (\rho U_\delta^2)$ | |
| $d$ | Pipe diameter | m |
| $E$ | constant, Equation (21) | |
| $H$ | Shape factor, $H = \theta/\delta^*$ | 1 |
| $k$ | Roughness height | m |
| $k$ | Coverage factor | |
| $n$ | Number of samples | |
| $Re_x$ | Reynolds number, $Re_x = Ux/\nu$ | 1 |
| $SEE$ | Standard error of estimate | |
| $s$ | Standard deviation | |
| $U$ | Expanded uncertainty, $U = ku$ | |
| $U$ | Average axial velocity | m/s |
| $U_t$ | Tunnel velocity | m/s |
| $U_\delta$ | Average velocity at $y = \delta$ | m/s |
| $U_\infty$ | local freestream velocity | m/s |
| $U^+$ | Velocity in inner variables, $U^+ = U/u_\tau$ | 1 |
| $u$ | Standard uncertainty, $u = s/\sqrt{n}$ | |
| $u'$ | Standard deviation of axial velocity | m/s |
| $u_\tau$ | Wall shear stress velocity, $u_\tau = (\tau_w/\rho)^{1/2}$ | m/s |
| $W$ | Average transverse velocity | m/s |

| | | |
|---|---|---|
| $w'$ | Standard deviation of transverse velocity | m/s |
| $w_k$ | Wake function, Equation (4) | |
| $x$ | Axial coordinate from center of Window 2 Bay 1 or independent variable | m |
| $y$ | Wall-normal coordinate from wall | m |
| $y^+$ | Wall-normal coordinate in inner variables, $yu_\tau/\nu$ | 1 |
| $z$ | Vertical coordinate from tunnel centerline | m |

## Greek

| | | |
|---|---|---|
| $\Gamma$ | Wake modification function, Equation (5) | |
| $\delta$ | Boundary layer thickness | m |
| $\delta^*$ | Displacement thickness, Equation (11) | m |
| $\theta$ | Momentum thickness, Equation (12) | m |
| $\kappa$ | Von Karman's constant | |
| $\mu$ | Absolute viscosity | Pa·s |
| $\nu$ | Kinematic viscosity, $\nu = \mu/\rho$ | $m^2/s$ |
| $\Pi$ | Coles' wake parameter | |
| $\rho$ | Fluid density | $kg/m^3$ |
| $\tau_w$ | Wall shear stress | Pa |

## Subscripts

| | |
|---|---|
| L | Local |
| t | Tunnel |
| w | Wall |
| $\delta$ | Boundary layer edge |
| 0 | Origin |
| $\infty$ | Freestream |

## ADMINISTRATIVE INFORMATION

This report describes work performed at the Naval Surface Warfare Center, Carderock Division (NSWCCD), West Bethesda, Maryland, by the Naval Architecture and Engineering Department (Code 80) in the Surface Ship Hydromechanics Division (Code 85). The work was sponsored by Dr. Peter Chang of the Office of Naval Research, Arlington Virginia, Advanced Naval Platforms Division (ONR 331) as part of the High-Reynolds number Prolate Spheroid (HIPRO) project, ONR work order N0001421WX00840. The NSWCCD Network Activity (NWA) number for the report was 1000017057210020.

## ACKNOWLEDGEMENTS

The research for the unpublished ASME *Journal of Fluids Engineering* paper (*JFE*) was supported by the operational and maintenance funds of the U. S. Navy for the Large Cavitation Channel (LCC). The authors of the paper are grateful to Dr. John Barkyoumb and Mr. Bruce Webster (now retired) of the Naval Surface Warfare Center Carderock Division for additional funding for writing the paper. The authors are particularly indebted to Prof. Donald E. Coles of the California Institute of Technology (CIT) for his analysis and comments on the data in the paper.

The support for the conversion of the *JFE* paper to this report by Dr. Paisan Atsavapranee of NSWCCD and Dr. Peter Chang of ONR is gratefully acknowledged. On a personal note by the lead author, Joel's Ph. D. advisor was Prof. Charles W. Van Atta at the University of California, San Diego (UCSD). Prof. Van Atta's advisor at CIT was Prof. Coles. Regrettably, Prof. Coles died at the age of 89 on 02 May 2013. Joel attended UCSD on the advice of his wife's brother, Prof. Ronald O. Stearman of the University of Texas, who was a student of Prof. Y. C. Fung at CIT. Prof. Fung was also at UCSD at the time of Joel's tenure at UCSD.

## SUMMARY

In recent years, interest has renewed in high Reynolds number turbulent boundary layers. Aircraft, ships, and submarines operate at very high Reynolds numbers based on momentum thickness ($Re_\theta$) on the order of $10^5$ to $10^6$. Typically, the highest laboratory $Re_\theta$ has been less than $2 \times 10^4$. Acquisition of boundary layer data at significantly higher $Re_\theta$ has been conducted on the wall of the test section of the William B. Morgan Large Cavitation Channel (LCC), the largest water tunnel in the world located in Memphis, Tennessee. The Reynolds number range of the experiments was $2.1 \times 10^4 < Re_\theta < 2.9 \times 10^5$. Boundary layer profiles of the axial and transverse velocities were acquired at twelve (12) axial stations and four (4) tunnel velocities (2.5, 5, 10, and 15 m/s) via laser Doppler anemometry (LDA) for 48 boundary layer profiles. The data are reported for a location 250 mm above the tunnel centerline and include the axial mean velocity and the relative turbulence intensity of the axial and transverse velocity components. In general, the results were consistent with classical boundary layer theory. Specifically, the overlap region followed a log law while the outer boundary layer was consistent with Coles' wake law.

Information in the body of this report was originally an unpublished paper for the ASME *Journal of Fluids Engineering* (*JFE*). The report version includes some revisions from the reviewers' comments. The LCC test section has eight (8) window bays on each side of the test section with two (2) windows in each bay. The data include data taken at the center of each window in bay numbers 2 through 7 at vertical locations -250 mm, 0, and +250 mm relative to the center of a window or a total of 36 locations and 144 boundary layer profiles. The *JFE* paper and the body of this report only include the results of the +250 mm location, which were of better quality from the assessment of the data at the time of the paper. Additional details and data for all of the measurements are located in an appendix. Providing information for improved boundary measurements in the future, validation of computer codes, and the design of experiments in the LCC are the important purposes of the report.

A limiting factor in the experiments was the quality of optical access through the acrylic windows. Only two windows were of acceptable quality for the boundary layer measurements by LDA. Since the boundary layer measurements were acquired, a glass window was fabricated as an improvement in optical access to the flow in the test section.

## INTRODUCTION

Most of the classical theories on turbulent boundary layers were developed from laboratory scale flat-plate experiments in wind tunnels, where the Reynolds number based upon momentum thickness ($Re_\theta$) was typically less than $2 \times 10^4$. Österlund [1] [2] has produced one of the more comprehensive data sets from wind tunnel experiments that included five (5) positions from 1.5 to 5.5 m at 10 velocities from 10 to 55 m/s. The Reynolds number ($Re_\theta$) range was $2.5 \times 10^3$ to $27.3 \times 10^3$. The velocity profiles were measured by hot-wire anemometry, and the wall shear stress was measured directly by an oil film method. Shortly before the Österlund results, Osaka et al. [3] reported another data set of hot-wire measurements in a wind tunnel for a Reynolds number range of $0.84 \times 10^3$ to $6.2 \times 10^3$. In their case, the wall shear stress was measured by a floating element device with a diameter of 60 mm. In both cases, the overlap region has been modeled as a log law consistent with classical theory. Österlund et al. [2] have found the overlap region between $y^+ \approx 200$ and $\eta = y/\delta_{95} \approx 0.1$ for $Re_\theta > 6000$, where the normal coordinate in inner variables is $y^+ = yu_\tau/\nu$ and $\delta_{95}$ is the boundary layer thickness at $0.95U_\infty$.

For practical applications, the momentum thickness Reynolds number ($Re_\theta$) for ships is on the order of $10^5$ to $10^6$ [4] while the length Reynolds number ($Re_x$) is about $10^8$ to $10^9$ [5]. New theories have also been proposed on Reynolds number effects on boundary layers. Barenblatt [6] and Barenblatt et al. [7] [8] have suggested that the overlap region is a power law rather than a log law. George and Castillo [9] propose another high Reynolds number model based on the "Asymptotic Invariance Principle." More recently, Buschmann and Gad-el-Hak [10] have suggested a variation of classical theory, where the inner and outer regions are described by Poincare expansions and asymptotic matching is applied in the overlap zone.

In a subsequent paper, Buschmann and Gad-el-Hak [11] concluded that both log law and power law models fit the data within the same statistical uncertainty over an intermediate range within the boundary layer, which covered most of the overlap region. Neither model fits the entire overlap region. Near the wall at the edge of the buffer layer, the log law fits experimental data better while near the wake region at the outer edge of boundary layer the power law is a better model. Their evaluation included data sets from six (6) different laboratories other than their own.

As Buschmann and Gad-el-Hak [11] have stated, most of the data sets available on turbulent boundary layers is heavily dominated by low Reynolds number data. Consequently due to practical applications and the controversy of recent theories, a chase for higher Reynolds number data has occurred. Higher Reynolds numbers have been achieved with boundary layer measurements on the test section wall of a wind tunnel. An example is reported by Castillo et al. [12] at $31 \times 10^3 < Re_\theta < 120 \times 10^3$.

Zagarola et al. [13] have produced some very high Reynolds number data for pipe flow that covers a broad range of pipe Reynolds numbers based upon pipe diameter, $d$, of $31 \times 10^3 < Re_d <$

$35 \times 10^6$. In inner variables, all data covered the range of $10 < y^+ < 5 \times 10^4$. Their conclusion was that the log law was a better fit for the data in the overlap region.

Another very high Reynolds number experiment was reported by Metzger and Klewicki [14] for an atmospheric boundary layer over the Great Salt Lake Desert in western Utah at $Re_\theta \sim 5 \times 10^6$. However, these measurements only included the viscous sub-layer and buffer layer at $2 < y^+ < 30$. These measurements were duplicated in a wind tunnel at $Re_\theta = 2 \times 10^3$. Their results indicated that the near wall features over this Reynolds number range, $2 \times 10^3 < Re_\theta < 5 \times 10^6$, were quite similar in inner variables.

A comprehensive set of boundary layer measurements are described for the test section wall of the William B. Morgan Large Cavitation Channel (LCC), the largest water tunnel in the world located in Memphis, Tennessee. The data were acquired by laser Doppler anemometry (LDA) at twelve (12) axial locations and four (4) tunnel velocities: 2.5, 5, 10, and 15 m/s. The following topics are discussed: theory, experimental methods, experimental results in comparison to theory, and conclusions.

Information in this report was submitted originally as an unpublished ASME *Journal of Fluids Engineering* (*JFE*) paper FE-03-1115 in 2003. Some changes have been incorporated from the comments in APPENDIX A from five (5) reviewers. More recent boundary layer papers have not been included in this report. New or recent boundary layer results refer to information at the time of the draft *JFE* paper in 2003. The primary purpose of the report is to provide information on the boundary layer for the design of experiments in the LCC, validation of computer codes, and improvements for any boundary layer measurements in the future at the LCC. The original data set includes measurements at three vertical locations at -250 mm, 0, and +250 mm relative to the center of each window. The total number of locations is 36. The *JFE* paper and the body of this report look at only the 12 locations at +250 mm above window center. All data locations are in APPENDIX F.

## THEORY

The theory applied to these experiments is a boundary layer model from Musker [15], which was recommended by Coles [16] in APPENDIX B. This model provides a continuous boundary layer profile from the wall to the edge of the boundary layer. The unique feature of this model recommended by Coles [16] is the profile from the wall to the log region given by

$$dU^+/dy^+ = [\kappa + C(y^+)^2]/[\kappa + C(y^+)^2 + \kappa C(y^+)^3] \tag{1}$$

The overlap region is given by the conventional log law

$$U^+ = (1/\kappa)\ln(y^+) + B \tag{2}$$

The wake region is defined from Musker [15] by a modified Coles' wake law [17]

$$(U_\delta - U)/u_\tau = (\Pi/\kappa)(2 - w_k) + (1/\kappa)\ln(y/\delta) - (\Gamma/\kappa) \tag{3}$$

where

$$w_k = 6(y/\delta)^2 - 4(y/\delta)^3 \tag{4}$$

$$\Gamma = 6(y/\delta)^2(1 - y/\delta) \tag{5}$$

Musker [15] determined that $C = 0.001093$ for $\kappa = 0.41$ and $B = 5.0$ where $\kappa$ and $B$ were selected from Coles [18].

For these experiments, only velocity profiles were measured, and wall shear stress was not measured directly. The wall shear stress velocity was computed from Equation (2) with Musker's values for $\kappa$ and $B$. The range of data was selected such that correlation coefficient was a maximum for a linear regression of Equation (2) in the following form:

$$U = ax + b \tag{6}$$

where

$$x = \ln(y - y_0) \tag{7}$$

The wall shear stress and its uncertainty then are computed from the slope from the regression analysis as

$$u_\tau = \kappa a \tag{8}$$

$$U_{u_\tau} = k(\kappa s_a) \tag{9}$$

where $k$ is the coverage factor and $s_a$ is the standard error from the regression analysis for the slope.

The offset $y_0$ is adjusted in a spreadsheet until $B = 5.0$ as computed from the regression intercept, $b$. Presumably, $\kappa$ and $B$ are universal constants; however, as Table 1 indicates, no consensus exits for these constants. Additionally, uncertainty is not stated in the values that have been reported.

**Table 1. Constants for Log Law**

| Author | Year | Ref. | Flow | $\kappa$ | $B$ |
|---|---|---|---|---|---|
| Coles | 1968 | [18] | TBL | 0.41 | 5.0 |
| Zagarola et al. | 1997 | [13] | Pipe | 0.436 | 6.13 |
| Osaka et al. | 1998 | [3] | Flat Plate | 0.41 | 5.0 |
| Österlund et al. | 2000 | [2] | Flat Plate | 0.38 | 4.1 |

TBL: turbulent boundary layer

The values recommended by Coles [18] in 1968 from Table 1 were based upon an evaluation of 44 data sets, where the maximum $Re_\theta$ was $100 \times 10^3$. In an evaluation of more recent data sets, Coles [16] is now applying the constants from Zagarola et al. [13].

Finally, Coles' wake parameter is computed from the sum of the wake function of Equation (3) and the log law Equation (2) at $y = \delta$, which is given by

$$U_\delta^+ = (1/\kappa)\ln(\delta^+) + B + 2\Pi/\kappa \tag{10}$$

For the data analysis of this experiment, the boundary layer thickness, $\delta$, was adjusted until the Reynolds number based upon displacement thickness from the theoretical Musker model, Equation (3), agreed with the value computed from the experimental data. For the momentum and displacement thickness calculations of the experimental data, the data were extrapolated

from the data point nearest the wall to the wall with the Musker model. Analytically, the displacement and momentum thicknesses are defined, respectively, as:

$$\delta^* = \int_0^{\delta} (1 - U/U_\delta) dy \tag{11}$$

$$\theta = \int_0^{\delta} (U/U_\delta)(1 - U/U_\delta) dy \tag{12}$$

In summary for the above data analysis, the boundary layer model has two adjustable constants: $y_0$ and $\delta$.

## EXPERIMENTAL METHODS

The boundary layer data were acquired on the test section wall through the side windows of the William B. Morgan Large Cavitation Channel (LCC) in Memphis, Tennessee. A schematic of the facility is in Figure 1. The test section dimensions are 3 m × 3 m × 13.1 m (10 × 10 × 43 ft). Figure 2 is a schematic of the cross-section. The design features of the tunnel are described in Etter and Wilson [19] [20].

The long term velocity stability or temporal stability is ±0.15 % at the 95 % confidence level for run-times greater than two hours over the velocity range of the channel from 0.5 to 18 m/s (1.6 to 59 ft/s). The spatial non-uniformity has been measured as nominally ±0.4 % at the 95 % confidence level over the accessible area through a window, which is 17 % of the total cross-sectional area The relative turbulence intensity at the center of the channel has been measured by hot-film anemometry as 0.2 to 0.5 % depending on the speed. The details of the hydrodynamic performance of the LCC are described by Park et al. [21] [22] [23].

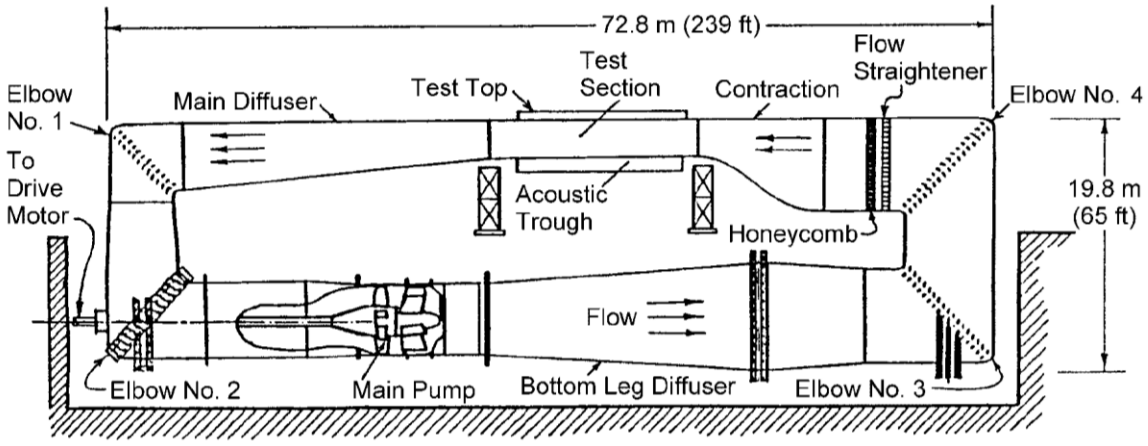



**Figure 1. Schematic Drawing of Large Cavitation Channel (LCC) [19]**

Optical access in the test section consists of eight (8) bays of windows with two (2) windows per bay, where bay 1 is at the test section entrance and bay 8 is at the test section exit. The reference speed of the tunnel was measured by LDA in the second window of bay 1, while

the boundary layer measurements were taken through the windows in bays 2 through 7. The location of the tunnel reference speed is at center of window 2 in bay 1 and is 1.976 m (6.483 ft) from the test section entrance. The axial locations of the measurements are summarized in Table 2 relative to the tunnel velocity-measurement location. The specification on surface finish for the acrylic windows was 0.1 μm (4 μin) rms. The measured surface roughness for the stainless steel channel walls was better than 2.5 μm (100 μin) rms. Windows were flush with the tunnel walls with a gap of 0.89 mm (0.035 in.) between the window frame and the window.

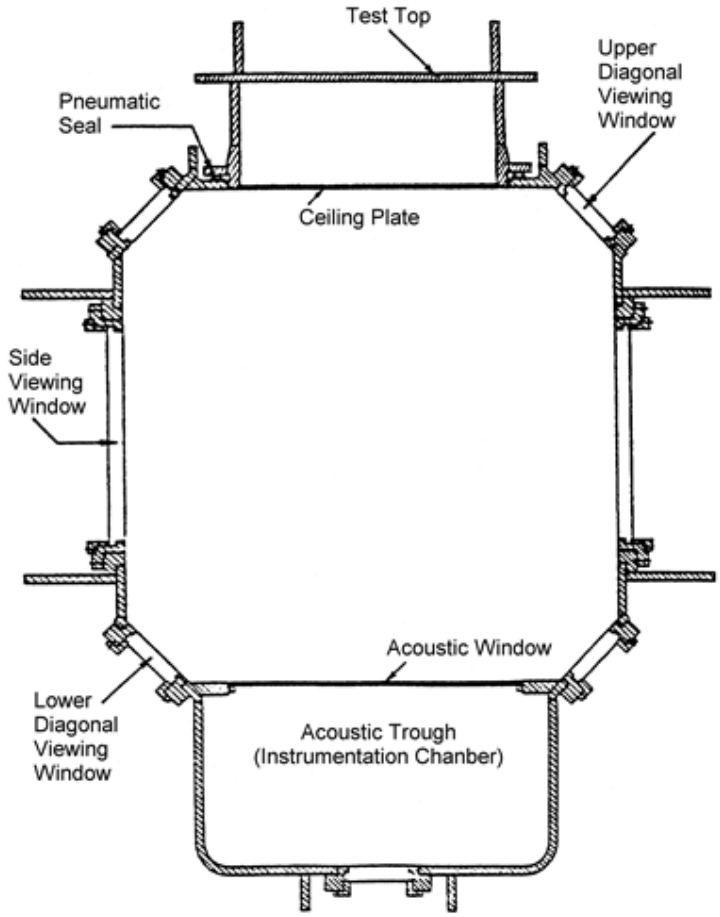



**Figure 2. Cross-Section of Large Cavitation Channel (LCC) Test Section [19]**

The velocities for these experiments were measured with Dantec 85 mm fiber optic probes. Test section velocity was measured with an 800 mm focal length lens with additional beam expansion while the local axial and transverse velocities, *U* and *W*, were measured with a 310 mm lens. The optical characteristics are summarized in Table 3. The traversing system for the boundary layer measurements was a 3-dimensional Cartesian system with traverse distances of 1.3 m axially (*x*), 1.2 m vertically (*y*), and 1.6 m normal (*z*) to the window (4.3 × 3.9 × 5.2 ft.) with a resolution of 5 μm (200 μin). In boundary layer coordinates, *y* is normal, while *z* is normal for the LDA measurements. In boundary coordinates, *z* is transverse, while *x* is transverse and *y* is vertical for the LDA measurements. The probe volume for the tunnel velocity was located at 524 mm (20.6 in) from the tunnel wall in window 2 of bay 1.

**Table 2. LDA Measurement Locations Relative to Tunnel Velocity Measurement**

| Bay No. | Window No. | Measurement Location | |
|---|---|---|---|
| | | x (m) | x (ft) |
| 1 | 2 | 0 | 0 |
| 2 | 1 | 1.23 | 0.375 |
| | 2 | 1.99 | 0.608 |
| 3 | 1 | 3.22 | 0.982 |
| | 2 | 3.99 | 1.216 |
| 4 | 1 | 5.22 | 1.590 |
| | 2 | 5.98 | 1.823 |
| 5 | 1 | 7.21 | 2.198 |
| | 2 | 7.98 | 2.431 |
| 6 | 1 | 9.20 | 2.806 |
| | 2 | 9.97 | 3.039 |
| 7 | 1 | 11.20 | 3.413 |
| | 2 | 11.96 | 3.647 |

**Table 3. Summary of Optical Parameters for Fiber-Optic Probes**

| Optical Parameter | Units | Velocity Component | | |
|---|---|---|---|---|
| | | Tunnel | U | W |
| Laser beam diameter | mm | 1.35 | 1.35 | 1.35 |
| Beam expansion ratio | | 2.775 | 1.77 | 1.77 |
| Expanded beam diameter | | 3.75 | 2.39 | 2.39 |
| Beam spacing | mm | 115 | 73.35 | 73.35 |
| Focal Length | mm | 800 | 310 | 310 |
| Wave length | nm | 476.5 | 488.0 | 514.5 |
| Half angle | degree | 4.11 | 6.75 | 6.75 |
| Fringe spacing | μm | 3.32 | 2.08 | 2.19 |
| Beam waist diameter | μm | 130 | 81 | 85 |
| Probe diameter | μm | 130 | 81 | 86 |
| Probe length | mm | 1.81 | 0.69 | 0.72 |
| No. fringes | | 39 | 39 | 39 |
| Probe length in water | mm | 2.40 | 0.91 | 0.96 |

The LDA probe is shown measuring through an LCC side window with a 1600 mm lens in Figure 3. The measurements presented here had a similar probe arrangement but a shorter 310 mm lens. The size and orientation of the probe volume as configured for these measurements is diagrammed in Figure 4. In the figure with the probe axis normal to the window surface, the probe volume long axis is also normal to the window surface. Though this is not ideal for boundary layer measurements, the probe volume length of 0.96 mm is still small relative to the boundary layer thickness in the LCC, which is on the order of 100 mm, varying with axial location and tunnel speed.

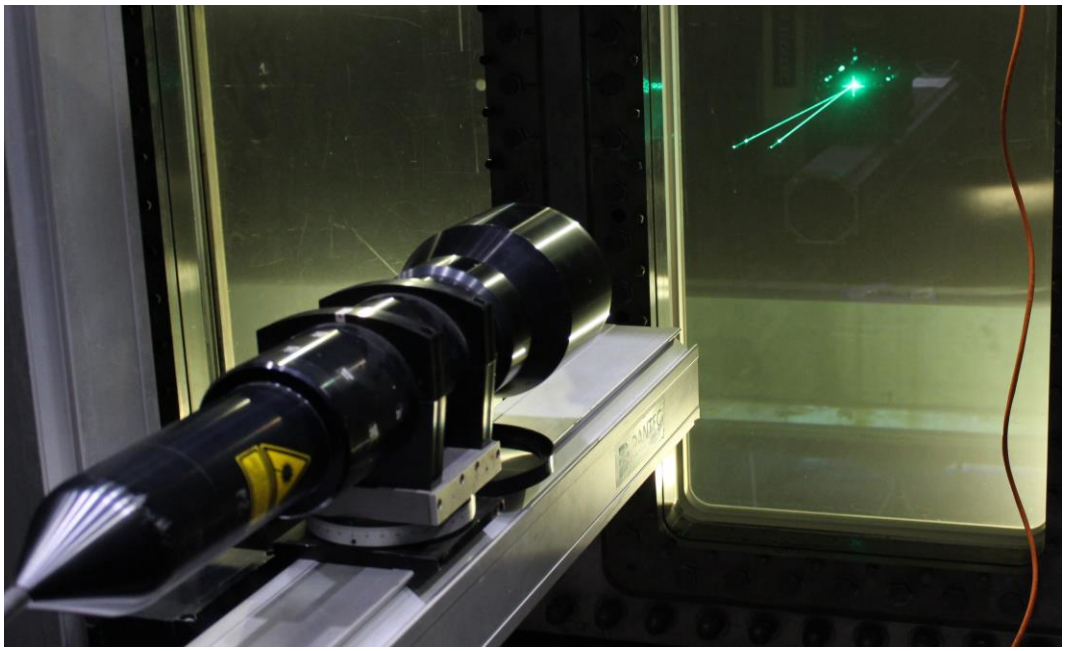


**Figure 3. LDA Probe Measuring Through LCC Window**

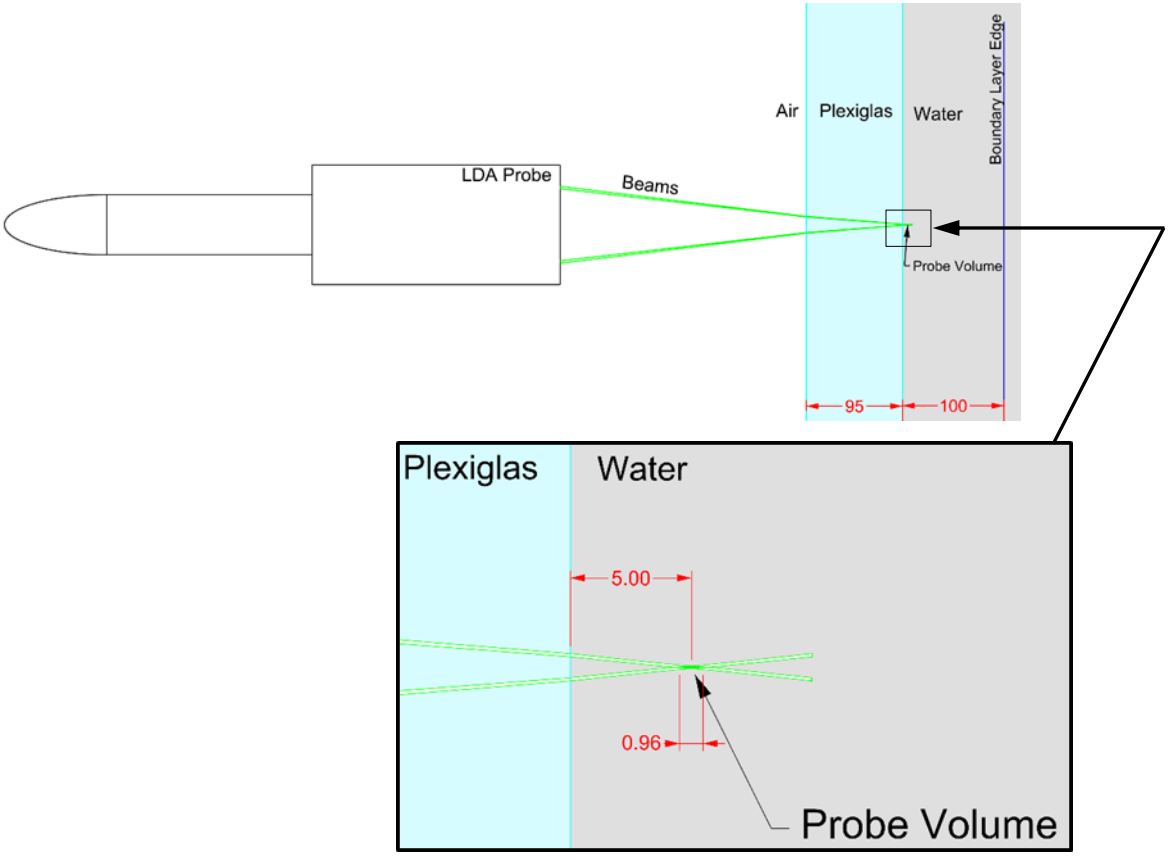



**Figure 4. LDA Probe Volume Relative to LCC Window**

The probes were calibrated with a rotating disk at a radius of 100 mm (3.94 in.). The fiber optic probes were mounted on the LDA traversing system during calibration, and the traverse positioned the probe volume on the wheel. Different velocities were produced by changing the rotational speed of the disk. The manufacturer's stated uncertainty in the rotational speed was ±0.04 revolutions per second (rps).

The largest uncertainty in position was the location of the center of the disk by repeat measurements. The probe is initially located at the center of the disk, and the position was set to zero (0) for the *x*, *y*, *z* location. The probe was then moved off center and then back on center about five or six times with the *x*, *y*, *z* position documented each time center was located. The mean and standard deviation were computed from the multiple measurements. Finally, the probe was located at the mean location of the measurements, and position indexed to zero. For these experiments, the position uncertainty was about ±0.05 mm ($2 \times 10^{-3}$ in) for the 800 mm probe and ±0.03 mm ($1.2 \times 10^{-3}$ in) for the 310 mm probe at the 95 % confidence level. The expanded uncertainty was computed by the Type A method from the Guide to the expression of Uncertainty in Measurement (GUM) [24] by the following equation:

$$U = ku = ks/\sqrt{n} \tag{13}$$

where *u* is the standard uncertainty, *s* the standard deviation, *n* the number of measurements or samples, and *k* the coverage factor, usually $k = 2$. In these measurements, the coverage factor was the inverse Student-*t*, $k = t_{0.025,\, n\text{-}1}$ at the 95 % confidence limit.

The LDA is calibrated directly as a system with a rotating disk. The disk is 228.6 mm (9 inches) in diameter covered with 60-grit emery paper. A precision blind hole is located at the center of the disk with a diameter of 1.02 mm (0.040 inch). The disk is driven by a CompuMotor Model SM233BE-NTQN motor and CompuMotor TQ10X Servo-Controller. The velocity was computed from the rotational speed of the disk and position by the following:

$$U = 2\pi r f \tag{14}$$

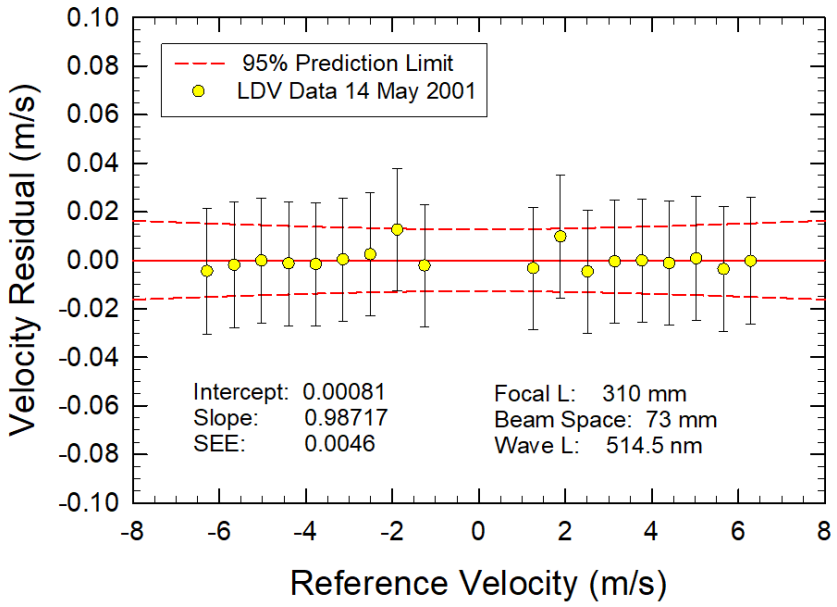
where *r* is the radial location and *f* is the rotational frequency. From the law of propagation of uncertainty in JCGM [24] for independent measurements, the combined and expanded uncertainty is

$$U_U = 2\pi \sqrt{(f U_r)^2 + (r U_f)^2} \approx 2\pi r U_f \tag{15}$$

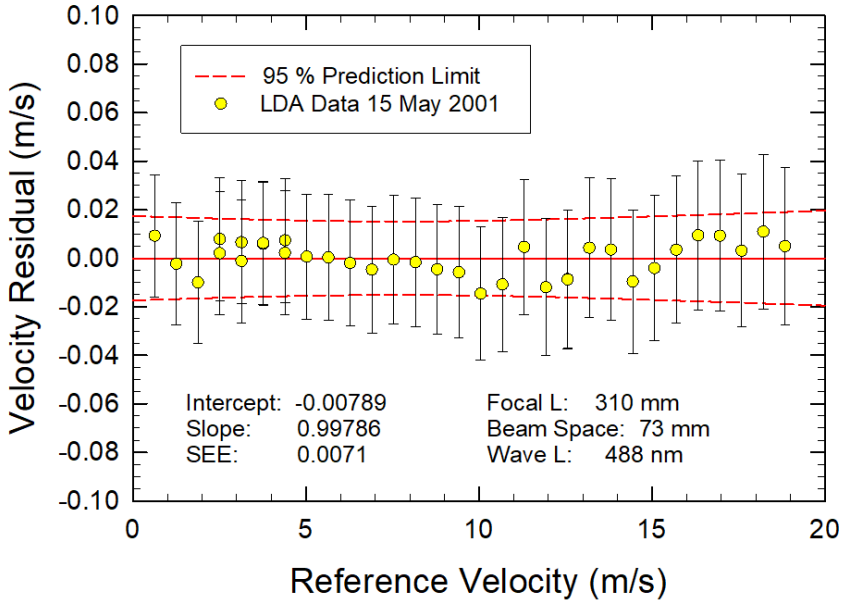
Most of the uncertainty was associated with the uncertainty in rotational speed, which was 25 mm/s (1.0 in/s) for $r = 100$ mm and $U_f = 0.04$ Hz. The contribution of the Type A uncertainty from the standard deviation of LDA velocity measurement is negligible.

An additional uncertainty was associated with the regression analysis of the calibration data from the calibration theory of Scheffe [25] and Carroll et al. [26]. This value was typically 15 to 20 mm/s. Thus, the combined and expanded uncertainty was approximately constant at 30 mm/s (1.2 in/s). The calibration data are plotted as the residuals in Figure 5 for the boundary layer measurements in the test section. In Figure 5, the dashed line is the 95 % prediction limit from calibration theory of Scheffe [25] and Carroll et al. [26], while the error bars are the uncertainties from the rotating disk calibration. A similar plot of the probe calibration for tunnel speed is in

Figure 6. The calibration data for the plots is located in APPENDIX E. Additional details on the calibration procedure and uncertainty analysis are described in Park et al. [21] [22].




**a. Transverse Velocity**




**b. Axial Velocity**

**Figure 5. Velocity Residuals of 310 mm Fiber-Optic Probe Calibration for Test Section Boundary Layer Measurements**

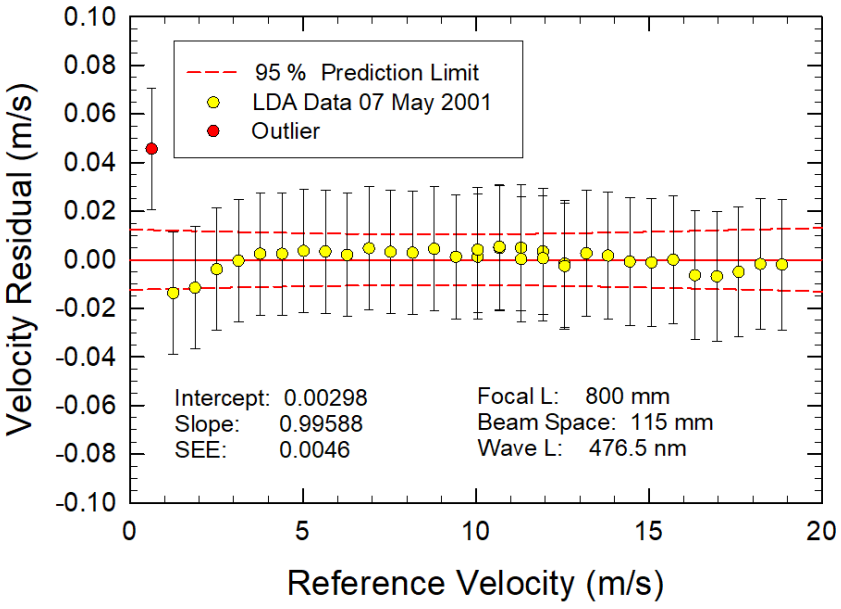



**Figure 6. Velocity Residuals of 800 mm Fiber-Optic Probe Calibration for Tunnel Velocity Measurements**

## EXPERIMENTAL RESULTS

### Velocity Profiles

As stated previously for these experiments, velocity profiles were measured at 12 axial locations and 4 tunnel velocities. Additionally, measurements were taken at three locations in each window at the center, 250 mm above center, and 250 mm below center (9.8 in). The data at 250 mm above center appeared to be the best quality, and only these results will be presented and discussed in the main body of the report. Data on all calculated boundary layer parameters for all three vertical measurement locations are described, plotted, and tabulated in APPENDIX F. The mean velocity profiles for the highest and lowest Reynolds numbers are in Figures 5, 6, and 7, where Figure 7 is in inner variables while Figure 8 and Figure 9 are in outer variables, $\delta$ and $U_\delta$. Each plot emphasizes different regions of the boundary layer, but in general, they are in good agreement with the theory proposed by Musker [15].

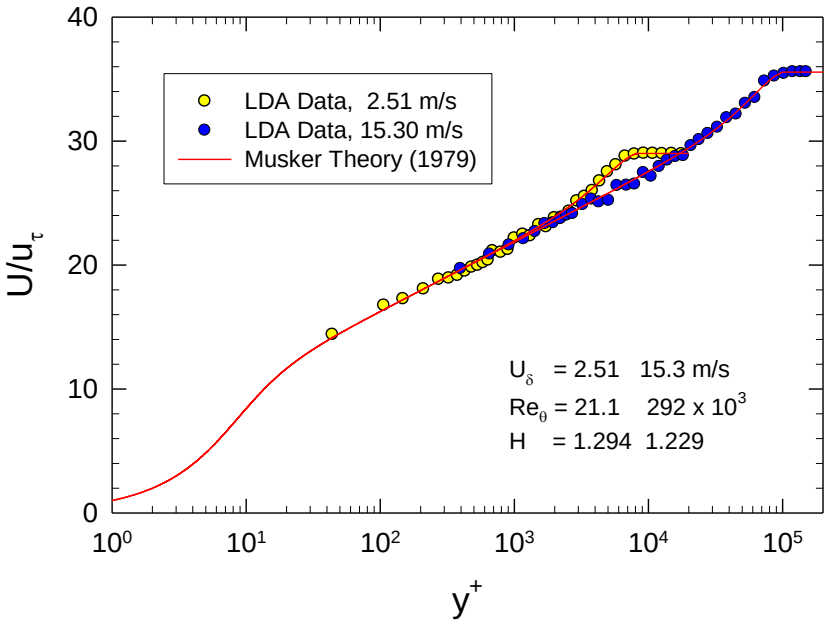



**Figure 7. Mean Velocity Profiles in Inner Variables for $Re_\theta = 21.1 \times 10^3$ and $292 \times 10^3$ in Comparison to Musker [15] Theory**

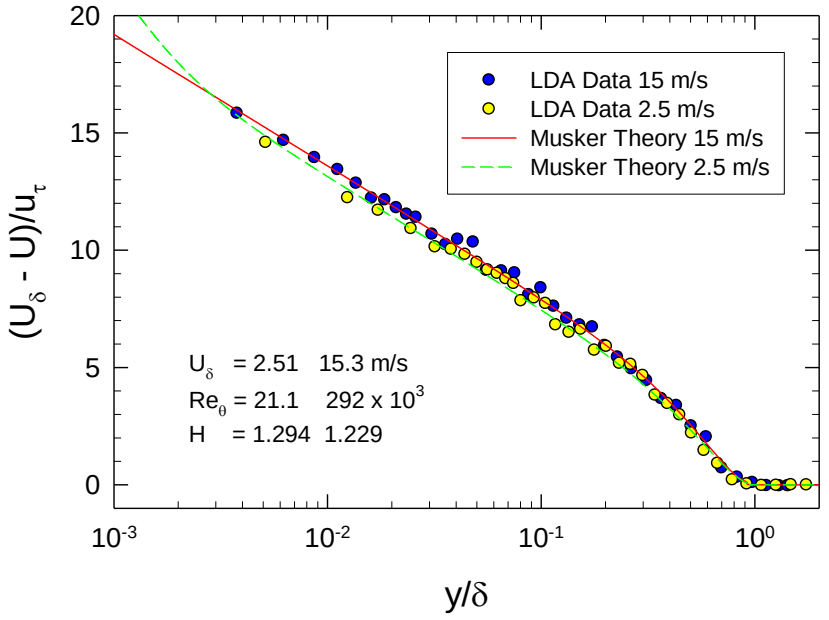



**Figure 8. Mean Velocity Defect Profile in Outer Variables for $Re_\theta = 21.1 \times 10^3$ and $292 \times 10^3$ in Comparison to Musker [15] Theory**

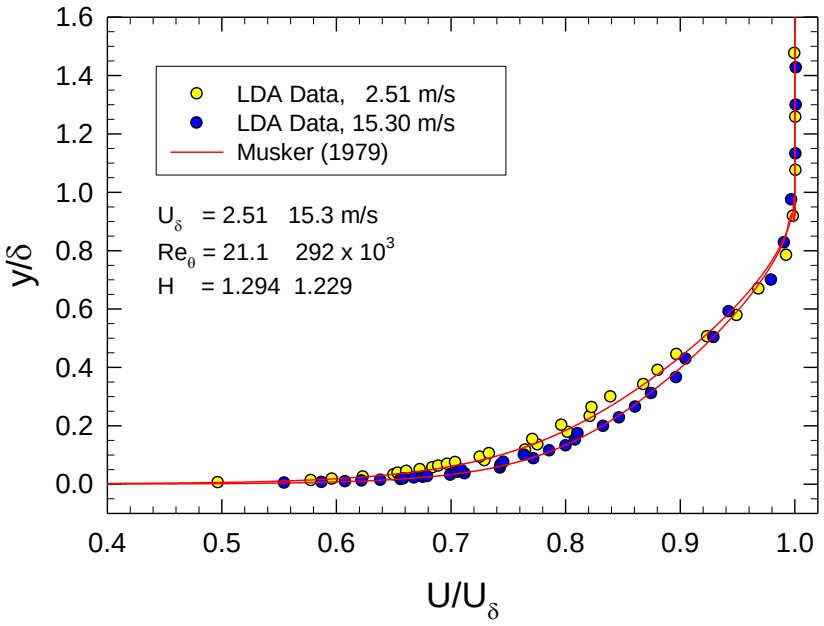



**Figure 9. Mean Velocity Profile in Outer Variables and Linear Coordinates for $Re_\theta$ = 21.1 × 10³ and 292 × 10³ in Comparison to Musker [15] Theory**

The velocity residuals for log law range in Equation (2) of two composite profiles at the highest and lowest Reynolds number are presented in Figure 10, where $\kappa = 0.410$ and $B = 5.00$ were determined from regression analysis. The linear range was selected as the maximum correlation coefficient from the linear regression analysis of Equations (6) and (7). The correlation coefficients for these two data sets were 0.995 and 0.996 for the lowest and highest Reynolds number, respectively. The mean correlation coefficient for all 48 profiles was 0.996 with a maximum of 0.9989 and minimum of 0.9895. The total variation in the residuals with respect to the log law is approximately ±2 %. By comparison, the variation in the super pipe data of Zagarola et al. [13] was approximately ±1.2 %.

For estimates of the wall-shear stress from velocity profile measurements, the uncertainty in the wall shear stress from the log law is dependent on the location of the probe relative to the wall and the uncertainty in the constants $\kappa$ and $B$. In the analysis, $\kappa$ and $B$ remained constant through the adjustment in the probe offset from the wall. From Table 3, the probe length relative the wall was under 1 mm (0.04 in); consequently, the uncertainty in the location of the probe was on the order of half of the probe length or ±0.5 mm (±0.02 in). For the boundary layer measurements, the traverse was located so that the measurements in two windows could be done in a single setup. The probe was always indexed at the center of the second window in a bay. For the boundary layer measurements at this location, the mean offset for 24 measurements was -0.39 mm (-0.015 in) with a standard deviation of 0.10 mm (0.004 in) for an uncertainty in a single location of ±0.21 mm (±0.008 in) at the 95 % confidence level. Essentially, the numerical adjustment in offset is within the location uncertainty of the probe, and the offset adjustment is repeatable with an uncertainty of ±0.21 mm (±0.008 in).

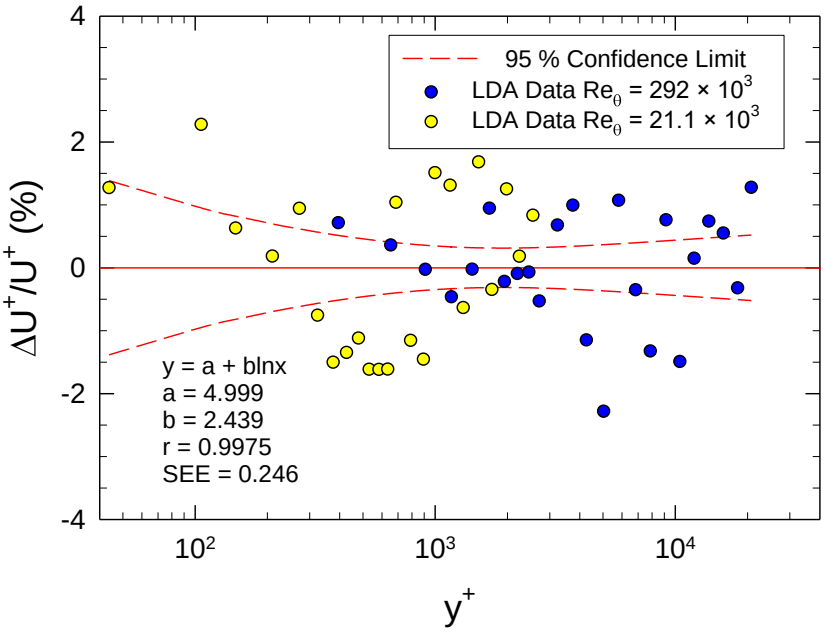



**Figure 10. Velocity Residuals for Log Law**

A sensitivity analysis was conducted on the effect of a ±1.0 mm change in offset on the wall-shear stress velocity, $u_\tau$, and the constant $B$. The initial value of the offset, $y_0$, in Equation (7) was set so that $B$ = 5.0. The results of the analysis for the lowest and highest Reynolds numbers are presented in Table 4. As the table indicates, a ±1.0 mm (±0.04 in) shift in offset will cause a change in wall shear stress velocity of $-4.5 < \Delta u_\tau < +3.9$ % and in $B$ of $-19 < \Delta B < +23$ % at the lower Reynolds number and at the higher Reynolds number $-2.4 < \Delta u_\tau < +2.3$ % and $-13 < \Delta B < +15$ %. The magnitude of the relative error is higher for the lower Reynolds number.

For comparison, the uncertainty estimate for the wall shear stress is included in the table as computed from Equation (9). The coverage factor is 2.4 from the Student-$t$ distribution with $n$-2 degrees of freedom. The uncertainty at the measured value is larger than the uncertainty from the sensitivity analysis for an uncertainty in a location uncertainty of ±1.0 mm.

**Table 4. Summary of Effects in Change of Probe Position Offset on Friction Velocity and Constant *B* for $\kappa$ = 0.41 and *B* = 5.00**

| $Re_\theta/10^3$ | $\Delta y_0$ (mm) | $u_\tau$ (m/s) | $U_{u\tau}$ (m/s) | $U_{u\tau}$ (%) | $B$ | $\Delta B$ (%) |
|---|---|---|---|---|---|---|
| 21.1 | +1 | 0.0826 | | -4.5 | 6.16 | +23 |
| 21.1 | 0 | 0.0866 | 0.0048 | 5.5 | 5.00 | |
| 21.1 | -1 | 0.0900 | | +3.9 | 4.00 | -19 |
| 292 | +1 | 0.420 | | -2.4 | 5.74 | +15 |
| 292 | 0 | 0.430 | 0.013 | 3.1 | 5.00 | |
| 292 | -1 | 0.440 | | +2.3 | 4.33 | -13 |

For the high Reynolds numbers for these experiments, uncertainty in the probe position and the probe length are important challenges. The estimated viscous length scale range as estimated from the highest to the lowest Reynolds number is $1.9 < \nu/u_\tau < 9.6$ μm ($0.076 \times 10^{-3} < \nu/u_\tau < 0.38 \times 10^{-3}$ in). The range for the wall surface roughness 2.5 μm (100 μin) was then $1.3 < \kappa^+ < 3.8$, which is within the range of a hydro-dynamically smooth wall. The range of probe lengths in viscous units was $94 < l^+ < 470$.

As stated in the previous section, the boundary layer thickness was selected so that the experimental displacement thickness agreed with the theory from Musker [15]. A conventional boundary layer thickness is defined as the value of $y$ for a particular local velocity ratio to the freestream velocity such as $U/U_\infty = 0.99$. The Österlund [1] definition was $\delta_{95}$, that is, $y$ at $U/U_\infty = 0.95$. The value of the boundary layer thickness in this paper is essentially for a velocity ratio of one, that is, $U_\delta = U_\infty$. The ratio of the boundary layer thickness for a velocity ratio of 0.99 to the boundary layer thickness at $U_\delta$ is presented in Figure 11. As the figure indicates, the ratio is nearly constant with an average value near 0.8.

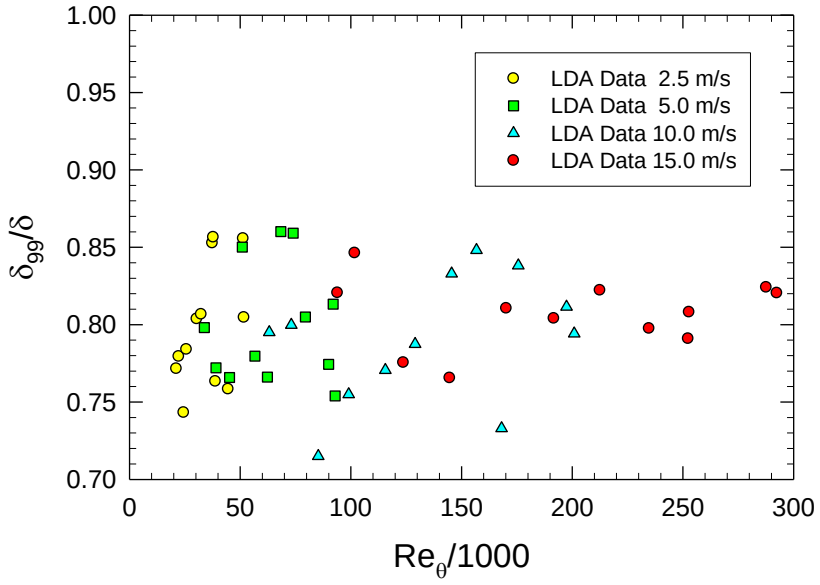



**Figure 11. Boundary Layer Thickness**

The resulting value of Coles' wake parameter is in Figure 12 in comparison to the value proposed by Coles [17]. The results are highly scattered, and the range of values is $0.22 < \Pi < 0.56$. From Österlund [1], $\Pi$ attains a constant value of about 0.48 for $Re_\theta > 8000$ but with different values of $\kappa$ and $B$. For the values of $\kappa$ and $B$ in this research, Osaka et al. [3] propose an asymptotic value of 0.60 to 0.62 for $\Pi$.

In unpublished results of graphs in APPENDIX C and data analysis results in APPENDIX D, Coles [16] has evaluated this data set with another model, which is a variation of classical theory. For the overlap region, a log law was applied with $\kappa = 0.435$ and $B = 6.10$ from Zagarola et al. [13]. The differences in $u_\tau$ between Coles' method and the one here were between 0.05 and 2 %. His calculations for $Re_\theta$ were very close to the ones here.

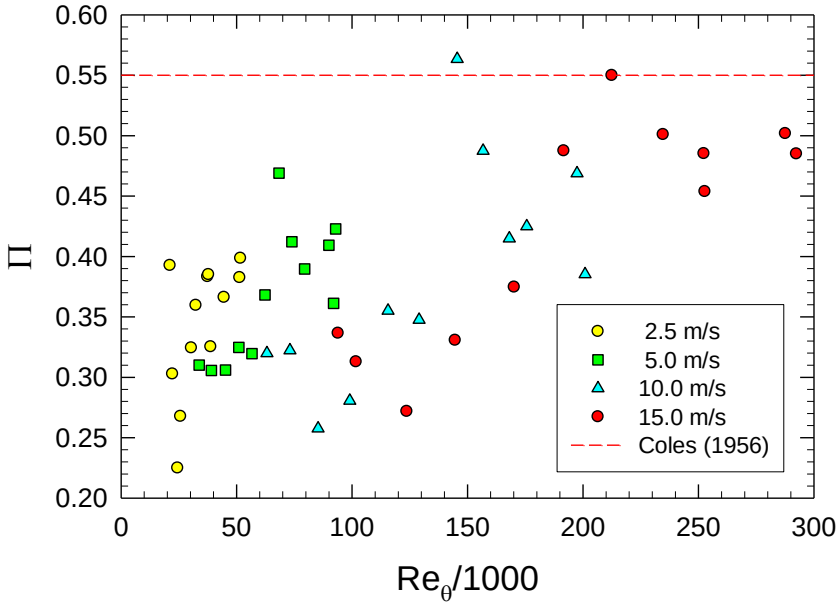



**Figure 12. Coles' Wake Parameter**

## Skin Friction Coefficient

The skin friction coefficient was computed from the friction velocity as determined from the velocity profiles as described in the previous section. The data are compared to the functional model described in Österlund et al [2], where the skin-friction coefficient, $c_f$, is modeled as a function of $Re_\theta$ as follows:

$$c_f = 2[(1/\kappa)\ln(Re_\theta) + C]^{-2} \tag{16}$$

where the skin-friction coefficient is computed from the friction velocity

$$c_f = 2(u_\tau/U_\delta)^2 \tag{17}$$

The value of $C$ was computed for each velocity profile from Equation (16). For these experiments, the average value of $C$ was 4.60 with an uncertainty in the mean value of ±0.067 or ±1.5 % at the 95 % confidence level. A plot of the data is in Figure 13 in comparison to Equation (16) and the results of Österlund et al. [2] where $\kappa = 0.384$ and $C = 4.08$. The figure also includes curves at ±5 % for comparison. The Österlund et al. [2] data were limited to $Re_\theta = 27.3 \times 10^3$, but Figure 13 is extrapolated to a factor of ten (10) larger, $300 \times 10^3$.

The Reynolds number based upon momentum thickness can be readily calculated from experimental data. However, designers are usually interested in skin-friction coefficient based upon length Reynolds number. For these experiments, the length Reynolds number was estimated from the momentum integral equation as follows from Schlichting and Gersten [27], page 192, Equation (7.100)

$$\tau_w/\rho = d(U_\delta^2\theta)/dx + \delta^* U_\delta dU_\delta/dx \tag{18}$$

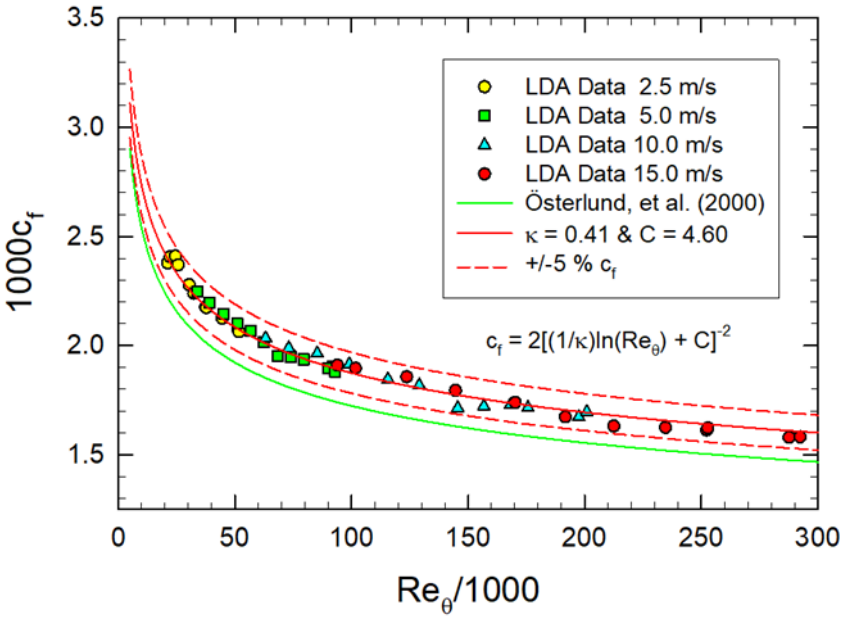



**Figure 13. Skin-Friction Coefficient as Function of $Re_\theta$**

As an approximation, the velocity gradient was assumed zero (0). The previous equation may then be written as

$$dRe_\theta/dRe_x = f(Re_\theta) = c_f/2 \tag{19}$$

where $c_f$ is given by Equation (17). Equation (19) may then be integrated numerically. The resulting boundary layer growth is in Figure 14. The boundary layer growth at 2.5 m/s is not consistent with the remainder of the data, most likely due to the computation of the virtual origin, as discussed in APPENDIX F.

The results of the skin friction as a function of $Re_x$ are presented in Figure 15 in comparison to the theory from White [28].

$$c_f = 0.455/ln^2(0.06Re_x) \tag{20}$$

In this plot, the data are consistent with a smooth flat plate. Skin friction in this case is lower than proposed by White [28], whereas the results were higher in comparison to Österlund et al. [2] in Figure 13. The virtual origin upstream of the tunnel reference velocity as computed from $Re_x$ in Österlund [1] is in Figure 16. The average value of the virtual origin was $2.4 < x_0 < 4.6$ m ($7.9 < x_0 < 15$ ft) over the velocity range of the experiments. Each data point in the figure is from the average at all of the windows at each speed, while uncertainty bars in the figure were computed from the standard deviation by the Type A method in Equation (13). A better estimate of the virtual origin is a fixed value for all data with $x_0 = 4.5$ m or 2.5 m ahead of test section entrance as discussed in APPENDIX F.

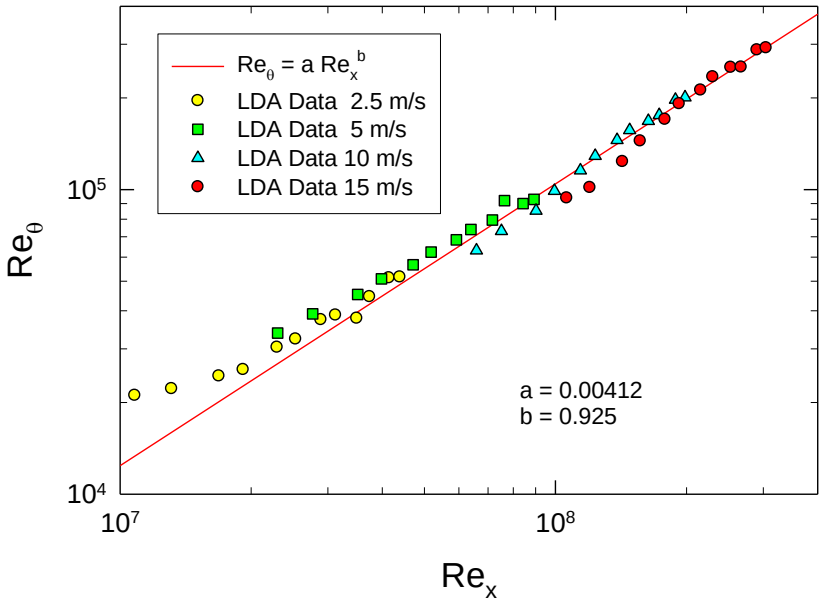



**Figure 14. Growth of Boundary Layer Momentum Thickness**

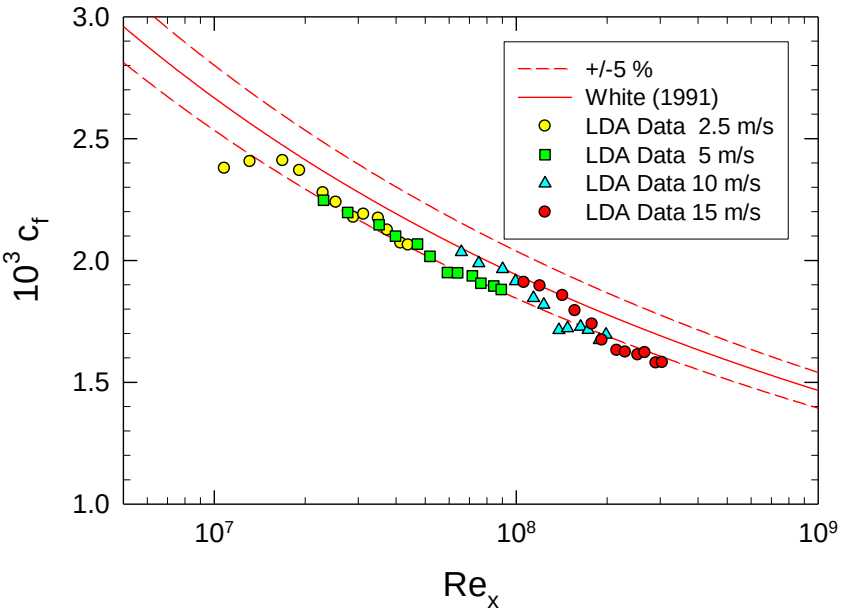



**Figure 15. Skin-Friction Coefficient as Function of Length Reynolds Number, $Re_x$**

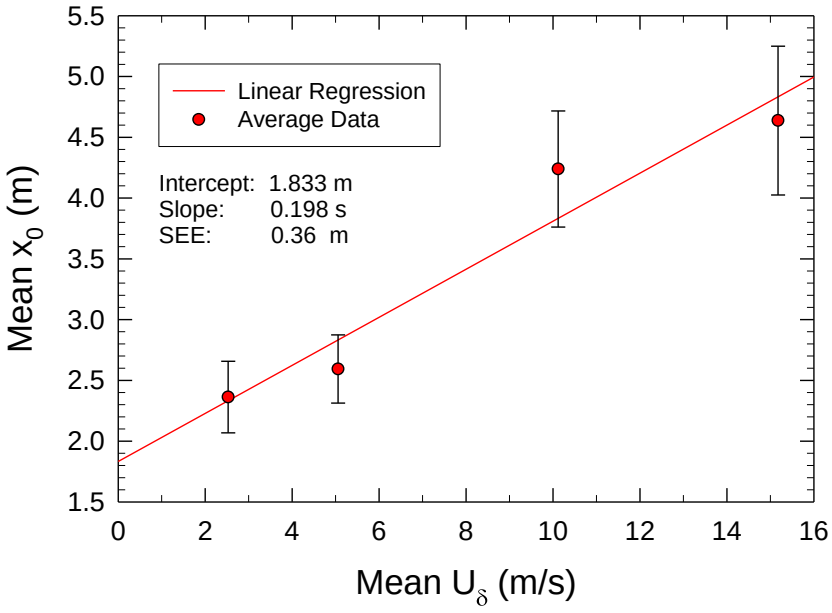



**Figure 16. Location of Virtual Origin of Boundary Layer Upstream of Measurement Location for Tunnel Velocity**

## Shape Factor

The shape factor for these velocity profiles is summarized in Figure 17. The data are compared to a theory from Hama in Hinze [29]. Hama's theory is given by the equation

$$H = \theta/\delta^* = (1 - E\, u_\tau/U_\infty) \tag{21}$$

For this figure, $E$ = 6.3 from Hinze [29], and the velocity ratio, $u_\tau/U_\infty$, has been replaced by $Re_\theta$ from Equation (16). As the figure indicates, $H$ is in reasonable agreement with theory.

## Velocity Gradient

The velocity gradient for these experiments has been measured by two methods: (1) directly from velocity measurements by LDA and (2) indirectly from the axial pressure drop along the centerline of the test section. The results are in Figure 18, where the local freestream velocity is normalized by the tunnel reference velocity. The velocity gradient as measured by these two methods is, respectively, $1.2 \times 10^{-3}$ and $1.5 \times 10^{-3}$ per meter ($0.38 \times 10^{-3}$ and $0.47 \times 10^{-3}$ per foot). The maximum change in velocity over the length of the test section is about 2 %.

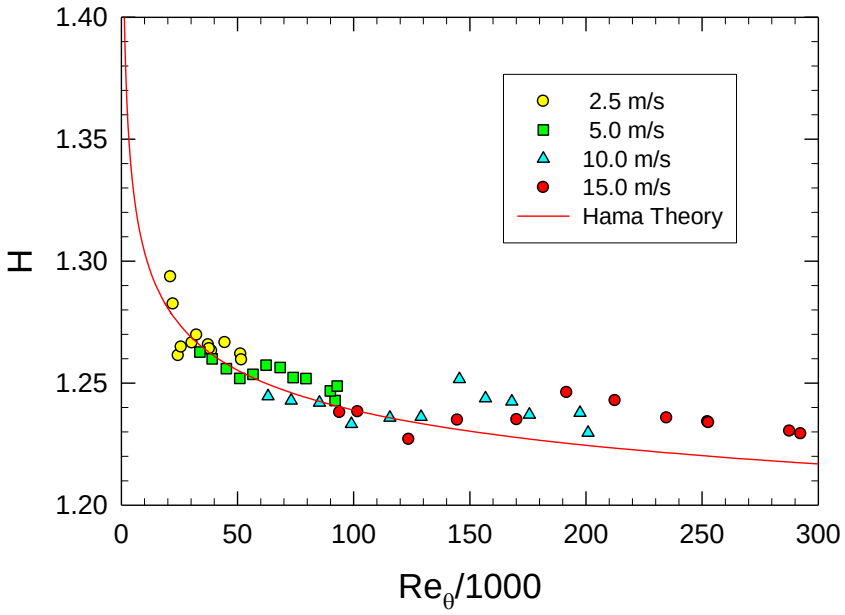



**Figure 17. Shape Factor**

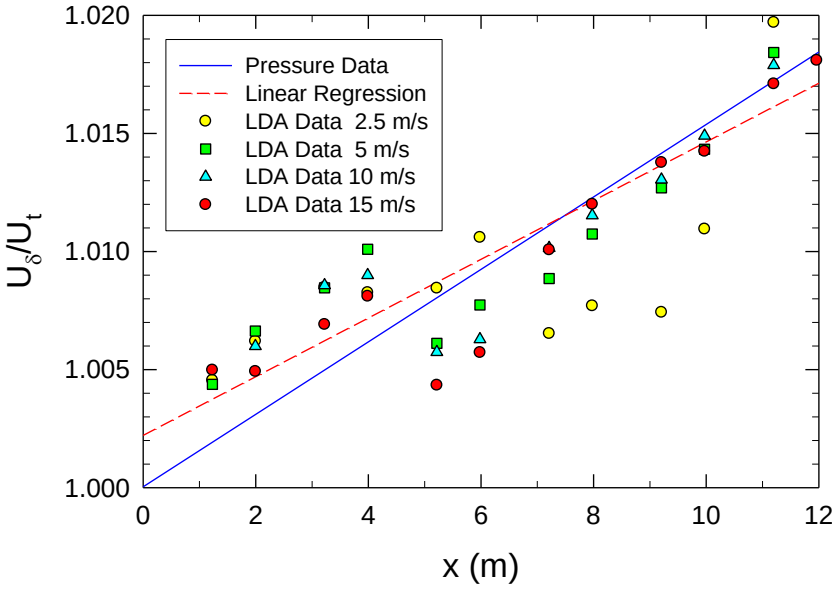



**Figure 18. Test Section Velocity Gradient**

## Turbulence Profiles

The relative turbulence intensity profiles are presented in Figure 19 in inner variables and Figure 20 in outer variables. The turbulence intensity in these figures has been corrected for the background noise level of the LDA system. The results are in qualitative agreement with those of Österlund [1] and Osaka et al. [3]. In the range $10^2 < y^+ < 10^3$, the transverse component,

$w'/u_\tau$, is nearly constant with a value of 1.5 which is near the value of 1.4 reported by Österlund [1] and Osaka et al. [3]. However, $u'/u_\tau$ continues to grow with Reynolds number. Österlund [1] indicates a peak in this range of about 2.3 at $Re_\theta = 22.5 \times 10^3$ in comparison to 2.5 for this research at about the same Reynolds number. This level continues to grow and has a peak value of about 2.8 at $Re_\theta = 292 \times 10^3$.

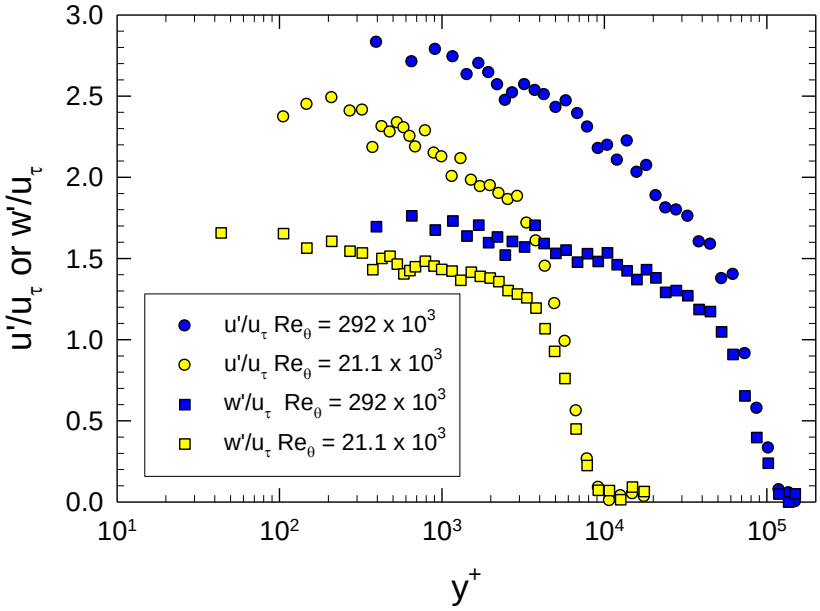



**Figure 19. Relative Turbulence Intensity Profiles in Inner Variables**

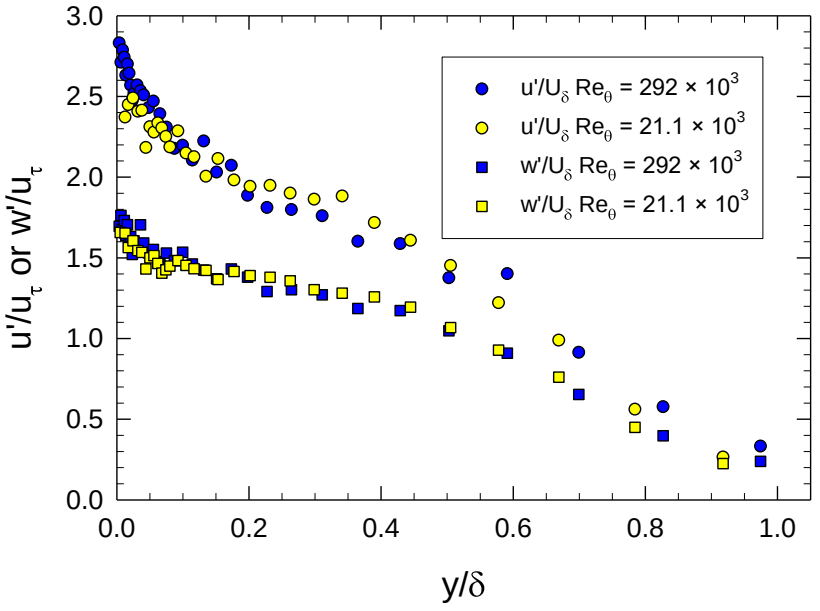



**Figure 20. Relative Turbulence Intensity Profiles in Outer Variables**

## Additional Data

Previous sections have provided results for the window location at 250 mm above the test section centerline. A complete set of all data for all three vertical window locations, -250, 0, and +250 mm, are located in APPENDIX F. The data includes graphs and tables. Table F-7 and Table F-8 contain average boundary layer data for the three locations.

From APPENDIX F, the optimal value for the boundary layer origin, $x_0$, is 4.5 m upstream of the tunnel velocity location at the center of window 2 in bay 1. The 4.5 m value is within the Österlund estimate in Figure 16. Also, the linearity in the plot of Figure F-14 in APPENDIX F is better than that of Figure 14 for $Re_\theta$ as a function of $Re_x$.

## Glass Window

Subsequent to the boundary layer measurements, a glass window was fabricated. Details of the window design are located in APPENDIX G. The results of the comparison of LDA measurements through an acrylic window and the new glass window are compared by Chesnakas [31]. Performance of the LDA was significantly improved with the glass window. The important results are as follows:

1. Flow field. LDA measurements change as the window edge is approached in the acrylic windows. The result is apparently due to a change in diffraction at the window edge, which causes a change in the beam angle. The measurements remain constant across the width of the glass window.
2. Data rate. The data rate is higher for the glass window, particularly near the window edge. The data rate with the glass window will make spectral measurements possible.
3. Uncertainty. The uncertainty in the velocity measurements is improved with the glass window.

Chesnakas [31] has recommended the addition of a commercially available circular glass port at the location of the tunnel speed measurement. The cost would be significantly less than a glass window, and the quality in the tunnel speed measurement will be improved.

## Acrylic Window

The LCC has a total of 43 acrylic windows. An inventory of the windows with the condition is summarized in the table in APPENDIX H. The appendix also includes a report on the optical quality of window numbers 4 and 5. The report in APPENDIX H indicates that the acrylic windows are not suitable for optical measurements. The results independently confirm the measurements of Chesnakas [31], which were discussed in the previous section.

## CONCLUSIONS

The results for a comprehensive data set for a turbulent boundary layer at high Reynolds number have been presented for water tunnel measurements at four (4) velocities (2.5, 5, 10, and 15 m/s) and twelve (12) axial locations. The Reynolds number range was $21.1 \times 10^3 < Re_\theta < 292 \times 10^3$. Example mean velocity profiles for the axial component and the turbulence intensity profiles are provided for the lowest and highest Reynolds numbers. In general, the results for the mean velocity profiles are in agreement with a boundary model proposed by Musker [15], which was a modified classical boundary layer theory. The agreement between the theory and experimental data was dependent on two adjustable constants: a shift in the boundary layer origin ($y_0$) and the boundary layer thickness ($\delta$). These results were in good agreement with an independent analysis by Coles [16]. Additionally, these data were consistent with over 80 data sets that have been evaluated by Coles [16]. The analysis for this data set by Coles is located in APPENDIX C for the plots and APPENDIX D from the computer analysis.

The skin friction coefficient was not measured directly in these experiments, but the uncertainty is probably about ±5 % for the skin friction coefficient from Figure 13 and Figure 15. The skin friction is higher than the direct measurements reported by Österlund [1] but lower than the model proposed by White [28]. The results for the skin friction coefficient are consistent with those for a smooth flat plate.

The uncertainty in the wall shear stress is computed from the standard error in the slope by Equation (9). The result in Table 4 is compared to the sensitivity analysis for an uncertainty in the LDA probe location of ±1.0 mm relative to the wall, which is near the LDA probe length in water. The comparison is for the highest and lowest Reynolds number. The largest relative uncertainty in wall shear stress was 5.5 % in comparison to 4.5 % for a location uncertainty of ±1.0 mm.

Buschmann and Gad-el-Hak [11] have indicated that the best method is a direct measurement of wall shear stress. However, measurements from Johansson and Castillo [30] suggest that skin-friction estimates with an uncertainty of ±2 % are possible by a momentum integral calculation from the velocity profile measurements.

In addition to lack of direct measurements of wall shear stress, the experiment had some other deficiencies. Although the wall was hydro-dynamically smooth for these experiments, the gaps for the windows and window frames were not filled for this experiment. The boundary layer growth at 2.5 m/s was not consistent with the growth at other speeds. Although the precise cause is not known, the computation of the $x$-origin may be the problem. Finally, the time averages were too short and caused some data scatter. A reduction in data scatter can be improved with longer time averages. In defense of the quality of the data, the data were collected to demonstrate that high quality near zero pressure gradient data is possible. The data as acquired are useful as engineering data for the tunnel.

For future experiments, the Reynolds number could be extended to an estimated Reynolds number of $Re_\theta \sim 370 \times 10^3$ at maximum tunnel speed. Additionally, the following are recommendations for improvements in future experiments:

1. Fill the gaps for the windows and window frames.
2. Increase the averaging times for each measurement position.
3. Increase the spatial resolution of the profile measurements, i. e. increase the number of positions within the boundary layer.
4. Reduce the length of the probe volume and improve the location accuracy of the probe relative to the wall.
5. Estimate the skin friction with the momentum integral equation, Equation (18).
6. Measure all three-velocity components.

At the higher Reynolds numbers and the diminishing viscous length scale, near wall measurements less than a 100 viscous lengths is nearly impossible. However, the near wall measurements seem to be universal as indicated by Metzger and Klewicki [14]. In that case, a complete description of the boundary layer can be accomplished by matching near wall measurement at the lower Reynolds numbers with the log region at the higher Reynolds numbers.

Since the boundary layer measurements of this report, two glass windows of optical quality were purchased for the test section measurements. The quality of the data has been improved significantly with higher data rates, reduced uncertainty, and increased optical access to the test section. A commercially available circular optical-quality glass port should be installed at the location for the tunnel-speed measurements.

## REFERENCES


[1] Österlund, J. M., 1999, "Experimental Studies of Zero Pressure-Gradient Turbulent Boundary-Layer Flow," Ph. D. thesis, Royal Institute of Technology, Stockholm, Sweden.

[2] Österlund, J. M., Johansson, A. V., Nagib, H. M., and Hites, M. H., 2000, "A note on the overlap region in turbulent boundary layers," *Physics of Fluids*, 12(1), pp. 1-4.

[3] Osaka, H., Kameda, T., and Mochizuki, S., 1998, "Re-examination of the Reynolds Number Effect on the Mean Flow Quantities in a Smooth Wall Turbulent Boundary Layer," *JSME International Journal*, 41(1), pp. 123-139.

[4] Gad-el-Hak, M., and Bandyopadhyay, P. M., 1994, "Reynolds number effects in wall-bounded turbulent flows," ASME *Appl. Mech. Rev.*, 47(8), p. 309.

[5] Hess, D. E., and Fu, T. C., 2003, "Impact of Flow Control Technologies on Naval Platforms," AIAA Paper 2003-3568.

[6] Barenblatt, G. I., 1993, "Scaling laws for fully developed turbulent shear flows. Part 1. Basic hypotheses and analysis," *J. Fluid Mech*. 248, pp. 513-520.

[7] Barenblatt, G. I., Chorin, A. J., and Prostokishin, V. M., 2000, "Self-similar intermediate structures in turbulent boundary layers at large Reynolds numbers," *J. Fluid Mech.*, 410, pp. 263-283.

[8] Barenblatt, G. I., Chorin, A. J., and Prostokishin, V. M., 2000, "A note on the intermediate region in turbulent boundary layers," *Physics of Fluids*, 12(9), pp. 2159-2161.

[9] George, W. K., and Castillo, L., 1997, "Zero-pressure-gradient turbulent boundary layer," ASME *Appl. Mech. Rev.*, 50(11), pp. 689-729.

[10] Buschmann, M. H., and Gad-el-Hak, M., 2003, "Generalized Logarithmic Law and Its Consequences," *AIAA J.*, 41(1), pp. 40-48.

[11] Buschmann, M. H., and Gad-el-Hak, M., 2003, "Debate Concerning the Mean-Velocity Profile of a Turbulent Boundary Layer," *AIAA J.*, 41(4), pp. 565-572.

[12] Castillo, L., Johansson, T. G., and Hangan, H., 2002, "Experimental Investigation of the Effect of Upstream Conditions on Smooth and Rough Zero Pressure Gradient Turbulent Boundary Layer Flows at Very High Reynolds Numbers," ASME paper FEDSM2002-31069.

[13] Zagarola, M. V., Perry, A. E., and Smits, A. J., 1997, "Log laws or power laws: The scaling in the overlap region," *Physics of Fluids*, 9(7), pp. 2094-2100.

[14] Metzger, M. M., and Klewicki, J. C., 2001, "A comparative study of near-wall turbulence in high and low Reynolds number boundary layers," *Physics of Fluids*, 13(3), pp. 692-701.

[15] Musker, A. J., 1979, "Explicit Expression for the Smooth Wall Velocity Distribution in a Turbulent Boundary Layer," *AIAA J*., 17(6), pp. 655-657.

[16] Coles, D. E., 2003, private communication, APPENDIX B, APPENDIX C, and APPENDIX D.

[17] Coles, D., 1956, "The law of the wake in the turbulent boundary layer," *J. Fluid Mech*, 1(2), pp. 191-226.

[18] Coles, D., 1968, "The Young Person's Guide to the Data," Proceedings Computation of Turbulent Boundary Layers—1968 AFOSR-IFP-Stanford Conference, Volume 2, Compiled Data, Stanford University, California, p. 5.

[19] Etter, R. J. and Wilson, M. B., 1992. "The Large Cavitation Channel," Proceedings of the 23rd American Towing Tank Conference, University of New Orleans, New Orleans, LA, pp 243-252.

[20] Etter, R. J., and Wilson, M. B., 1993, "Testing ship designs in a water tunnel," ASME *Mechanical Engineering*, Vol. 115/No. 10, pp. 74-80, October 1993.

[21] Park, J. T., Cutbirth, J. M., and Brewer, W. H., 2002, "Hydrodynamic Performance of the Large Cavitation Channel (LCC)," Hydromechanics Directorate, Naval Surface Warfare Center Carderock Division, West Bethesda, Maryland, USA, Technical Report NSWCCD-50-TR-2002/068.

[22] Park, J. T., Cutbirth, J. M., and Brewer, W. H., 2003, "Hydrodynamic Performance of the Large Cavitation Channel (LCC)," ASME paper FEDSM2003-45599.

[23] Park, J. T., Cutbirth, J. M., and Brewer, W. H., 2005, "Experimental Methods for Hydrodynamic Characterization of a Very Large Water Tunnel," ASME *J. Fluids Eng.*, 127(6), pp. 1210-1214.

[24] JCGM, 2008, "Evaluation of measurement data – Guide to the expression of uncertainty in measurement," JCGM 100:2008 GUM 1995 with minor corrections, Joint Committee for Guides in Metrology, Bureau International des Poids Mesures (BIPM), Sèvres, France, accessed 2021 November 04, https://www.bipm.org/en/committees/jc/jcgm/.

[25] Scheffe, H., 1973, "A Statistical Theory of Calibration," *The Annals of Statistics*, Vol. 1, No. 1, pp. 1-37.

[26] Carroll, R. J., Spiegelman, C. H., and Sacks, J., 1988, "A Quick and Easy Multiple-Use Calibration-Curve Procedure," *Technometrics*, Vol. 30, No. 2, pp. 137-141.

[27] Schlichting, H., and Gersten, K., 2000, *Boundary-Layer Theory*, Eighth Edition, Springer, Berlin, p. 192.

[28] White, F. M., 1991, *Viscous Fluid Flow*, Second Edition, McGraw-Hill, Inc., New York, pp. 429-432.

[29] Hinze, J. O., 1975, *Turbulence*, Second Edition, McGraw-Hill Book Company, New York, pp. 633-634.

[30] Johansson, T. G., and Castillo, L., 2002, "Near-Wall Measurements in Turbulent Boundary Layers Using Laser Doppler Anemometry," ASME paper FEDSM2002-31070.

[31] Chesnakas, C. J., 2008, "Evaluation of the Performance of the LCC Windows for use in Laser Doppler Velocimetry," Hydromechanics Directorate, Naval Surface Warfare Center Carderock Division, West Bethesda, Maryland, USA, Research and Development Report NSWCCD-50-TR-2008/031.

THIS PAGE INTENTIONALLY LEFT BLANK

## APPENDIX A: REVIEWER COMMENTS ON ASME *JOURNAL OF FLUIDS ENGINEERING* PAPER FE-03-1115

The following correspondence is from Prof. Michael Plesniak, Associate Editor of the ASME *Journal of Fluids Engineering*. The correspondence contains comments on ASME Paper No. FE-03-1115 from five (5) reviewers. The body of the report is a revision of the paper with some of the suggestions from the reviewers. Boundary layer references in the report have not been updated with those of the reviewers or more recent papers. The reviewer comments may be of future use in the design of boundary layer measurements in the Large Cavitation Channel (LCC).

THIS PAGE INTENTIONALLY LEFT BLANK

TECHNICAL ASSOCIATE EDITORS

(full addresses overleaf)
*Fluid Application and Systems*
WILLIAM W. COPENHAVER (2004)
Air Force Research Laboratory
william.copenhaver@wpafb.af.mil

JINKOOK LEE (2006)
Argo-Tech Corporation
leej@argo-tech.com

YOSHINOBU TSUJIMOTO (2005)
Osaka University
tujimoto@me.es.osaka-u.ac.jp

*Fluid Mechanics*
MALCOLM J. ANDREWS (2006)
Texas A&M University
mandrews@mengr.tamu.edu

KENNETH S. BREUER (2006)
Brown University
kbreuer@brown.edu

THOMAS B. GATSKI (2006)
NASA Langley Research Center
t.b.gatski@larc.nasa.gov

M. VOLKAN ÖTÜGEN (2004)
Polytechnic University
votugen@poly.edu

MICHAEL W. PLESNIAK (2004)
Purdue University
plesniak@ecn.purdue.edu

DENNIS SIGINER (2005)
Wichita State University
dennis.siginer@wichita.edu

*Computational Fluid Dynamics*
S. BALACHANDAR (2005)
University of Illinois, Urbana-Champaign
s-bala@uiuc.edu

FERNANDO F. GRINSTEIN (2005)
US Naval Research Laboratory
grinstein@lcp.nrl.navy.mil

*Fluid Measurements*
SIVIRAM GOGINENI (2006)
Innovative Scientific Solutions, Inc.
sivaram.gogineni@wpafb.af.mil

HAMID JOHARI (2006)
Worcester Polytechnic Institute
hjohari@wpi.edu

*Multiphase Flow*

STEVEN L. CECCIO (2004)
University of Michigan
ceccio@engin.umich.edu

GEORGES L. CHAHINE (2006)
Dyna-Flow, Inc.
glchahine@dynaflow-inc.com

KYLE D. SQUIRES (2005)
Arizona State University
squires@asu.edu

**The American Society of Mechanical Engineers**

**Journal of Fluids Engineering**
**Department of Mechanical Engineering**
**The Johns Hopkins University**
**3400 North Charles Street, Baltimore, MD 21218-2686**
**Fax: 410-516-7254 Email: jfe@titan.me.jhu.edu**

*Technical Editor (2005)*
JOSEPH KATZ
410-516-5470
katz@titan.me.jhu.edu

*Editorial Coordinator (2005)*
LAUREL MURPHY
410-516-7286
murphy@titan.me.jhu.edu

March 5, 2004

Dr. Joel T. Park
US Navy William B. Morgan Large Cavitation Channel
Memphis, TN 38113-0428

**Re.: Log No. 6370MP**

Dear Dr. Park:

I am enclosing five reviews of your manuscript entitled "High Reynolds Number Turbulent Boundary Layer Measurements at Near Zero Pressure Gradient" which you submitted to the ASME *Journal of Fluids Engineering*. The consensus of these referees is that the paper in its present form is not acceptable for publication. Four reviewers recommend that the paper may be publishable after revision, while the fifth recommends that the paper undergo major revision and complete re-review. In light of these reviews, I am recommending to the Editor that the paper is not suitable for publication in its present form.

The reviewers generally agreed that the topic is interesting and that the experimental results could potentially contribute to the state of knowledge in turbulent boundary layers. Several shortcomings were noted by each of the reviewers. Categories that were rated as poor or marginal by the referees included *Completeness, Originality, Assumptions Clearly Stated, Clear Presentation & Organization, Freedom from Technical Error, Experimental & Numerical Uncertainty, and Acknowledgement of Prior Work.* The reviewers noted that the uncertainty is inadequately characterized. A complete uncertainty analysis for all relevant quantities and "error bars" on the figures is required as a matter of journal policy.

Reviewers pointed out that the manuscript was deficient in several ways. In general, the most critical reviewers found the manuscript to lack details concerning flow quality (spanwise contamination and 3D effects) and error bounds on the shear stresses. In particular, lack of an independent measurement of friction velocity and poor spatial resolution were cited as shortcomings. One referee was opposed to publication of poorly resolved turbulence data, and I concur with this assessment. Several reviewers were critical of the use of the Musker relationship, and suggested that a less biased presentation of the data would be more useful to the community. Reviewers also pointed out that some of the assertions were contradictory to other published results, and furthermore that several important studies were not cited at all by the authors. Many other detailed comments are listed in each of the individual reviews.

## TECHNICAL ASSOCIATE EDITORS

*Fluid Application and Systems*

WILLIAM W. COPENHAVER (2004)
Air Force Research Laboratory
AFRL/PRTF Building 18
1950 Fifth St.
Wright Patterson AFB, OH 45433-7251
937-255-6951 Fax: 937-255-1790
william.copenhaver@wpafb.af.mil

JINKOOK LEE (2006)
Argo-Tech Corporation
23555 Euclid Avenue
Cleveland, OH 44117
216-692-6000
leej@argo-tech.com

YOSHINOBU TSUJIMOTO (2005)
Engineering Science
Osaka University
1-3 Machikaneyama, Toyonaka
Osaka 560
Japan
+81-6-850-6165 Fax:+81-6-850-6212
tujimoto@me.es.osaka-u.ac.jp

*Fluid Mechanics*

MALCOLM J. ANDREWS (2006)
Department of Mechanical Engineering
Texas A&M University
College Station, TX 77801
979-847-8843
mandrews@mengr.tamu.edu

KENNETH S. BREUER (2006)
Division of Engineering
Brown University
Providence, RI 02912
401-863-2870 Fax: 401-863-9028
kbreuer@brown.edu

THOMAS B. GATSKI (2006)
Mailstop 128
NASA Langley Research Center
Hampton, VA 23681
Fax: 757-864-8816
t.b.gatski@larc.nasa.gov

MICHAEL W. PLESNIAK (2004)
Purdue University
School of Mechanical Engineering
1288 Mechanical Engineering Building
West Lafayette, IN 47907-1288
765-494-1537 Fax: 765-494-0530
plesniak@ecn.purdue.edu

M. VOLKAN ÖTÜGEN (2004)
Mechanical, Aerospace & Manufacturing Engineering
Polytechnic University
Six Metrotech Center
Brooklyn, NY 11201
718-260-3217 Fax: 718-260-3532
votugen@poly.edu

*Fluid Mechanics, cont.*

DENNIS SIGINER (2005)
Wichita State University
105 Wallace Hall
1845 Fairmount
Wichita,KS 67260-0044
316-978-3400 Fax: 316-978-3853
dennis.siginer@wichita.edu

*Computational Fluid Dynamics*

S. BALACHANDAR (2005)
Dept. of Theoretical & Applied Mechanics
University of Illinois, Urbana-Champaign
216 Talbot Laboratory, MC-262
104 South Wright Street
Urbana, IL 61801-2983
217-244-4371 Fax: 217-244-5707
s-bala@uiuc.edu

FERNANDO F. GRINSTEIN (2005)
US Naval Research Laboratory
4555 Overlook Ave. SW
Washington, DC 20375
(202) 767-6583
grinstein@lcp.nrl.navy.mil

*Fluid Measurements*

SIVIRAM GOGINENI (2006)
Innovative Scientific Solutions, Inc.
2786 Indian Ripple Road
Dayton, OH 45440-3638
937-255-2432 ext. 787Fax: 937-656-4110
sivaram.gogineni@wpafb.af.mil

HAMID JOHARI (2006)
Mechanical Engineering Department
Worcester Polytechnic Institute
Worcester, MA 01609
508-831-5261 Fax: 508-831-5680
hjohari@wpi.edu

*Multiphase Flow*

STEVEN L. CECCIO (2004)
Department of Mechanical Engineering and Applied Mechanics
303 Auto Lab
University of Michigan
Ann Arbor, MI 48109-2121
313-936-0433 Fax: 313-764-4256
ceccio@engin.umich.edu

GEORGES L. CHAHINE (2006)
Dyna-Flow, Inc.
10621-J Iron Bridge Road
Jessup, MD 20794
301-604-3688 Fax: 301-604-3689
glchahine@dynaflow-inc.com

KYLE D. SQUIRES (2005)
Mechanical & Aerospace Engineering
Arizona State University
P. O. Box 876106
Tempe, AZ 85287-6106
480-965-3957 Fax: 480-965-1384
squires@asu.edu

I regret that the submitted manuscript was deemed unacceptable in its present form by the referees. If you wish to *substantially* revise the paper and resubmit it, along with a detailed point-by-point response to the issues raised by all of the referees, please send it to me no later than August 30, 2004. Any resubmission will be sent back to the original reviewers and potentially to additional referees.

Sincerely,

M W. Plesniak

Michael W. Plesniak
Associate Editor

cc. Prof. Joseph Katz, Editor

Enclosures

**Review on**

**High Reynolds number turbulent boundary layer measurements at near zero pressure gradient**

**by J. T. Park & J. M. Cutbirth**

The paper presents and analyses experimental data of turbulent boundary layer (TBL) taken in the LCC. With their work the authors try to contribute to the recent debate on the mean velocity profile of TBL with zero pressure gradient. I recommend that the authors rework the paper. However, before doing that they should make a fundamental decision.

Do they rather want to

(1) show that some recent theories are wrong

or do they want to

(2) confirm a part of the classical boundary layer theory using their own data ?

From the current version of the paper I did not get the feeling that the first way is really possible. However, the second way seems to be promising. After a radical revision the paper can become an interesting and valuable contribution to engineering application of boundary layer theory.

**General comments**

i) The research objectives should be stated clearly. In this context the abstract should be rewritten.

ii) Each item addressed in the paper should be analysed with respect to its physical meaning and its value for a reader. For example fig. 8 and corresponding paragraphs compare two boundary layer thicknesses. What is the physical background of the finding that $\delta_{99} / \delta$ is roughly 0.8?

iii) The style of the paper should be changed. Currently it is more or less an internal report. More physical background should be given where this is possible. For example it is not explained why the Musker-theory was chosen. What are the advantages of this approach compared with other theories?

iv) D. Coles is several times mentioned and cited. Obviously the paper benefits a lot from his cooperation with the authors. Why is he not co-author?

v) Change Osterlund to Österlund (\"{O}sterlund) throughout the paper.

An interesting aspect of the paper is that high Reynolds number experimental data of TBL where taken in water. Such data are rare. Maybe these data can be made available via the internet.

To summarize I recommend to rework the paper in detail.

**Detailed comments**

All quotations from the text are italics.
References mentioned in the review have the same number as in the paper.

page 2 line 2 — *have defined ...* should be
have found the logarithmic region between $y^+ \approx 200$ and $\eta \approx 0.15$ for $Re_\Theta > 6000$
(see ref. 2 p.3 last paragraph)

page 2 line 3 — *for ships is on the order of $10^5$ to $10^6$ [1]*

This sentence refers to fig. 1.1 of ref. 1. However, the origin of this figure is Gad-el-Hak & Bandyopadhyay: Reynolds number effects in wall-bounded turbulent flows, Appl. Mech. Rev., Vol. 47, No. 8, 1994, pp. 307-365 (fig. 1).

page 2 line 4 from the bottom — *boundary layer data for pipe flow*

This phrase is confusing. Either it is a boundary layer or a pipe flow. Please note the differences in the wake region of both flow types.

page 3 eq. 1 to 5 — Please add some more information on Muskers-theory. What is the physical background of eq. 1? Why is this approach superior to other approaches (e.g. mixing-length approach by Granville, JFE, 1989). Accomplishes the wake component the boundary condition at the outer edge of the TBL (du/dy=0)? Does the Musker-theory have the correct $y^{+3}$-dependence close to the wall?

page 4 and following

The wall skin friction is calculated based on the assumption of the standard log law. If this law would be incorrect or even if only the parameters are used here would be wrong than the whole method would fail. As the authors correctly quoted only direct measurements of $\tau_w$ provide an independent value of $u_\tau$ for non-dimensionalzing the velocity profile. Only using such profiles one could answer the question if the standard log law is correct or not.
One of the conclusions of the paper is that the $u_\tau$ dependence on $Re_\Theta$ is different from that one found by Österlund (fig. 10). This result is compelling because of the method used for the determination of $u_\tau$. What happens if instead of $\kappa = 0.41$ and $B = 5$ Österlund's parameters $\kappa = 0.38$ and $B = 4.1$ would have been used for the determination of $u_\tau$?
Additionally the authors introduce an offset $y_0$. What is here in this paper the physical meaning of the offset? Note that one of the standard methods - Clauser-plot - to determine $u_\tau$ works without offset. The offset is alright as long as not the standard log law is assumed. In a recent paper Oberlack (JFM, vol. 427, 2001) showed based on first principles employing Lie-group analysis that the log law has indeed an offset. But this offset has to be determined from experimental data and cannot be used to adjust B.
The bottom line is: Using the standard log law with a certain set of parameters for the determination of $u_\tau$ one cannot neither confirm nor reject any law for the mean velocity profile.

| | |
|---|---|
| page 4 table 1 | The parameters for pipe flow found by Zagarola, et al. (1997) ($\kappa = 0.436$ and $B = 6.13$) where corrected by B. J. McKeon et al. (IUTAM, 2003). They are now $0.421 \pm 0.0002$ and $5.60 \pm 0.08$ (see also McKeon et al., Further observations on the mean velocity distribution in fully developed pipe flow, JFM, 2003).<br>Please mark in the table which experiments are for pipe flow and which are for TBL. |
| page 5 eq. 10 and 11 | The boundary layer thickness $\delta$ can be avoided by integrating until infinity. |
| page 5 last line | The absolute value of the roughness of the channel wall says nothing about roughness effects which may influence the development of the TBL. |
| page 7 second last line | Why do the data *at 250 mm above centre appear to be best quality*? |
| page 8 first line | The data in figure 5 cannot really collapse because the correct outer scaling is not $\delta$. A better collapse would be probably achieved with the Rotta-Clauser boundary layer thickness $$\Delta = \int_0^\infty \frac{u_\delta - u}{u_\tau} dy$$ |
| page 8 line 8 | Note that all previous results by Zagarola et al. (1997) where corrected by subsequent papers of this group. |
| page 8 last paragraph | The objective of the sensitivity analyses is not clear? Which offset was varied and why was this parameter chosen for a sensitivity analyses? |
| page 9 second paragraph | What is the physical meaning of the finding that $\delta_{99} / \delta$ is roughly 0.8? |
| page 9 third paragraph | The value of $\pi$ depends strongly on the used parameters $\kappa$ and B. What happens if the Österlund parameters are used? Is the $\pi$-value by Österlund confirmed? Note that in a recent paper DeGraaff & Eaton (JFM, 422, 2000) using Österlund's parameters confirmed that $\pi$ is constant. |
| page 9 last paragraph | Please note that if $u_\tau$ is determined based on the power law by Barenblatt et al. (JFM, 2000) than the difference to log law based methods (Clauser plot) is also less than 2%. The outcome of the comparison discussed here should be clearly stated. |
| page 10 eq. 14 | Equation (14) is only valid if the flow is two-dimensional. If $u_\tau$ is known than the momentum integral equation can be used to confirm the two-dimensionality of the boundary layer. |
| page 10 under eq. 15 | *analytically* should be substituted by numerically because only discrete values of $c_f$ and $Re_x$ are known. |

| | |
|---|---|
| page 10 second under eq. 15 | *For some unknown reason, the boundary layer growth at 2.5 m/s is not* line *consistent*<br>Please note the departure of the first four points of this data set from all other data in fig. 12. The transition of this boundary layer seems to be not completed. |
| page 10 second last paragraph | Why is the virtual origin of the boundary layer of importance? |
| page 10 last line | Hinze has no reference. |
| page 24 fig. 11 | From 1/7-power law is known that<br>$Re_\Theta = 0.03606\ Re_x^{0.8}$<br>How can the differences in the parameters be explained? |
| page 12 fourth paragraph | Johansson & Castillio has no reference |
| page 12 and 13 | *recommendations for improvement*<br>Are these recommendations helpful for a reader?<br>It is more important that the results and findings of the research work are clearly described and conclusions for the application of boundary layer theory are drawn. |

REFEREE'S REVIEW OF JFE MANUSCRIPT 6370 MP

*'High Reynolds Number Turbulent Boundary Layer Measurements at Near Zero Pressure Gradient'*
*J. T. Park and J. M. Cutbirth*

The authors have set out to demonstrate that good quality high Reynolds number LDA data can be obtained from the near zero pressure gradient boundary layer on the wall of the Large Cavitation Channel (LCC). In order to demonstrate this, they have compared their data with various existing models for medium and high Reynolds number boundary layers, most prominently that due to Musker [14]. It is clear that data may be acquired at significantly higher Reynolds numbers than reached in the majority of boundary layer studies, however to do full justice to this achievement further detail is required to satisfactorily demonstrate the quality of the flow and quantify the errors associated with the measurements. Another criticism would be that there is little original in the paper, since the results relate to existing models, but the limitations of experimental error are taken. I recommend that the paper be published after the authors have adequately addressed the following comments.

The paper would benefit from additional descriptions of the models and theories applied to the data. More specifically, the distinction between sections 'Introduction' and 'Theory' seems a little unnatural. By combining the sections, the authors would be in a position to give a fuller description of the theories under consideration. A definition of the structure of the flow including how an overlap region may be derived ($y^+ >> 1$, $y/\delta << 1$) and approximate limits is vital. Inner and outer variables, used later in the paper, must be defined here (important since 'outer' is used both as the velocity defect and $U/U_\delta$ in figures 5 and 6). The comment 'Presumably $\kappa$ and B are universal constants' (p.4) requires explanation.

The acquisition of high Reynolds number zero pressure gradient (ZPG) boundary layer data is important because of the ongoing debate over the correct form for extrapolation from laboratory to full-scale Reynolds numbers (the "renewed interest" of the abstract), but in order to compare the current results to the majority of the cited literature, a ZPG or near equivalent must be demonstrated in terms of the pressure gradient parameter (e.g. DeGraaf and Eaton, J. Fluid Mech. 422, 2000). Additional information on the spanwise variation of pressure seems necessary also, if only to convince the reader that there is no contamination from the side walls or window gaps. Do the authors have a reason for why the data above the centerline are of the best quality? How much 'worse' are the other datasets?

In terms of accuracy of the measurements, there is in general insufficient detail. Specifically, the sampling time etc. and the background noise level (and correction for this) are not detailed. Some kind of error bounds in terms of $U^+$ and $y^+$ seem important if comparisons are to be made to other data and empirical relationships, although obviously this rests on the accuracy with which the shear stress can be obtained.

More details on the surface are required, with respect to whether the surface may be considered smooth at high Reynolds numbers. Do the authors have an estimate of the window gap size? A comparison to sand grain roughness and more discussion of what may be considered 'smooth' (e.g. Schlicting) should be included.

My last major comments concern the implementation and fit of the Musker model to the current data. Over what range in $y^+$ and $y/\delta$ was the regression of equations 6-8 actually performed (beyond giving a maximum in correlation coefficient) and how well does this range agree with the plot of residuals in figure 7? How sensitive was the value of $u_\tau$ to the range of fit used?

Additional comments

1. The abstract should state that both mean and fluctuating components of velocity were acquired in the streamwise and spanwise directions.
2. 'Laser Doppler Anemometry (LDA)' in abstract should be capitalized.
3. p.2: Barenblatt et al found a power law for both pipe [5] and boundary layer flows [6, 7].
4. Whilst George and Castillo [8] found a power law for boundary layers, Wosnik, Castillo and George (J. Fluid Mech. 421, 2000) used AIP to obtain a log law for pipe and channel flows. This should be discussed since the pipe flow results of Zagarola, Perry and Smits [12] are referenced later.
5. 'George and Castillo propose another high Reynolds number model **based** on the "AIP"" is more correct.
6. A comment that the data of Osaka et al is in the medium Reynolds number range where the wake factor is generally accepted not to be constant with Reynolds number would be appropriate.
7. Osterlund describes a log law for the overlap region only for $Re_\theta > 6000$.
8. 'As Buschmann… data sets… **are**…'
9. 'In inner variables, all data covered the range $10 < y^+ < 5 \times 10^4$'. The Zagarola data for all Reynolds numbers cover $10 < y^+ < 5 \times 10^5$ , with the upper limit still in the proposed overlap region of $y^+ \sim 35 \times 10^4$.
10. The log law proposed by Zagarola et al was valid for an overlap region significantly different than that previously proposed. More care should be taken over the exact proposals that are being compared here. Perhaps the best way to achieve this is to add to table 1 the inner and outer limits of the overlap region proposed in each case. In addition, Zagarola and Smits (J. Fluid Mech. 373, 1998 – perhaps a better reference than Zagarola, Perry and Smits in this case) do propose uncertainty for the reported values of $\kappa$ and B: this could also be added to the table.
11. The font of the 'x' used in the sense of 'multiplied by' should be changed throughout the paper.
12. p.4: '… no consensus **exists**…'

13. p.5: 'The side windows in the test section consist of …' would be more clearly expressed as 'The optical access in the test section…'
14. p.7: the sentence 'The largest uncertainty in position… by repeat measurements' could be clarified.
15. p.8 'The velocity residuals …': the range of the assumed log law, specifically the outer limit, used in determining the appropriate residuals is not given. In addition, what are the respective experimental errors for the two datasets compared in this paragraph relative to the scatter of the data?
16. The effect of varying $y_0$ on $\kappa$ should be included in table 4, since this has also been assumed in the model.
17. p.9: boundary **layer** thickness instead of boundary thickness several times.
18. Whilst confirmation of the shear stress results, within the limits of experimental error, by another, well-respected worker is encouraging, some details of the second model must be given.
19. With reference to figure 10, it should be noted that this is a considerable extrapolation in Reynolds number of the Osterlund results ($Re_\theta < 30{,}000$).
20. White's model for skin friction must be described if used for comparison to the current data.
21. p.10, just below equation 15: should the referenced equation be 15 and not 10?
22. The trend in the 2.5 m/s data at low Reynolds numbers in figure 11 could be due to the velocity gradient in the test section. The 2.5 and 5 m/s data seem to agree where they overlap. Can the authors comment?
23. p.11: $U_{inf}$ in equation 16 and in the text below should be written as $U_\delta$ for consistency.
24. Figure 16 would benefit from the inclusion of either the Osterlund or Osaka data, which are compared to the current data in the discussion.
25. p.12: 'Buschmann and Gad-el-Hak have indicated that the best method of obtaining wall shear stress is a direct measurement' or similar would read better.
26. p.13: Metzger and Klewicki [13] show significant near-wall variation with Reynolds number in the $u`^2$ peak and other parameters. The last paragraph of the Conclusions should be rewritten.
27. Typo in reference 5: '… **shear** flows' not '… sear flows.'
28. Figure 4-6: $Re_\theta$ should be written in full i.e. $21.1 \times 10^3$ and $292 \times 10^3$.
29. Figure 6: outer variables have not been defined in the text, and 'scaled on freestream velocity' would be preferable to 'in outer variables'.
30. Fig 10: Osterlund is misspelled in the legend.

**Referee's Comments on:**

***High-Reynolds Number Turbulent Boundary Layer Measurements at Near Zero Pressure Gradient***

By

**J. T. Park and J. M. Cutbirth**

My opinions regarding the study by Park and Cutbirth are mixed, and thus it is probably useful to state some views (biases) before discussing specific recommendations.

**Reviewer's Viewpoints/Biases**

On the positive side, this manuscript reports on boundary layer LDA measurements in the Large Cavitation Channel (LCC) over a range of $R_\theta$ that is poorly documented (if at all), and thus the technical justification for such measurements is very high. Furthermore, I am admittedly sympathetic to the considerable effort required to truly extend the current understanding of Reynolds number dependence in boundary layers. Arguably, this understanding is only available through difficult measurements such as those undertaken by Park and Cutbirth. Thus, I am of the opinion that these efforts need to be viewed in a different light than the relatively easy experiments that purport to examine Reynolds number dependence; such as those of Osaka et al. (1998) quoted by the authors. That is, this low $R_\theta$ study (and others like it) is by design unable to reveal very much about the asymptotic behavior as $R_\theta$ gets large since it covers such a small $R_\theta$ range outside the range known to have low $R_\theta$ effects. For example, the study by DeGraaff and Eaton JFM 2000 (and other high resolution experiments), clearly shows that boundary layer turbulence exhibits *anomalous* scaling behaviors for $R_\theta$ less than about 2000. Thus, the Osaka et al. study effectively covers an $R_\theta$ range only about a factor of 3 outside this range. $R_\theta$ dependencies, however, tend to be logarithmic (or approximately so), and thus conclusions regarding "asymptotic behavior" from these low $R_\theta$ experiments constitute a highly unwarranted extrapolation. (In my opinion, bordering on ridiculous.) Clearly, asymptotic behavior is only going to be reliably revealed through experiments that cover a significant $R_\theta$ range (such as the study by DeGraaff and Eaton). Given these realities, the efforts by Park and Cutbirth are to be commended and encouraged.

There are, however, some nontrivial problems with this study. As might be expected, these reside at the heart of the difficulties associated with obtaining and interpreting high $R_\theta$ data. Most notable is the lack of an independent measurement of the friction velocity, followed closely by the poor spatial resolution of their sensor. The authors are clearly aware of these problems. For example, regarding the former they are careful to state their conclusions in terms of being "consistent" with classical boundary layer theory rather than verifying or refuting aspects of the theory. Of course, a major motivation for conducting high $R_\theta$ measurements is to critically test the classical notions, and thus determining $u_\tau$ using the classical theory seriously muddles such efforts. (Prof. Nagib at IIT has made this point numerous times in his AIAA and APS talks.) Experiments to

date (some cited in the author's reference list) have shown that, at the level of the mean profile, the differences between competing theories are subtle – essentially buried within the noise of even the most precise measurements. Apart from suggesting that better (more fundamental) ways to distinguish between competing theories need to be devised, this reality also indicates that the author's presentation based on $u_\tau$ values derived from what is effectively a curve-fitting based on theory of Musker probably hides the new information contained within the mean flow data.

The poor spatial resolution of the present study is a significant problem with regard to the turbulence data presented. That is, evidence to date indicates that a sensor spatial scale of less than about 10 viscous units is needed to have measurements devoid of spatial averaging effects and thus reveal $R_\theta$ dependence, DeGraaff and Eaton 2000, Metzger et al. Phys. Fluids 2001. (In this regard it is useful to note that the data of Osterlund, that the author's compare to, only satisfy this criterion up to about $R_\theta = 10000$.) Of course, at large $y^+$ values this criterion might be relaxed. Experiments quantifying the combined effects of $R_\theta$ dependence and spatial resolution, however, have yet to be conducted. In any case, it is only rational to expect that the very large sensor sizes of the present experiments ($97 < l^+ < 470$) are a very serious problem regarding the resolution of fluctuating quantities.

**Recommendations**

Since mean flow data at the $R_\theta$ values provided by Park and Cutbirth are so scarce, my feeling is that they should be published. In the current presentation, however, I believe that the data are too closely tied to the modified classical theory as given by Musker, and thus their potential future utility is diminished. For example, the notion that a portion of the velocity profile is derivable from the overlap of inner/outer expansions is, in fact, a hypothesis, not a theoretical foundation having direct relation to the equations of motion. In fact, alternate, theoretically superior, foundations may exist, and may be testable through the use of parameters different from the friction velocity. Such parameters may be derivable from quantities directly measured in the present experiments. In my estimation, the authors would do well to present their data in a way that recognizes this future potential. Thus, the recommendation is not necessarily that the comparison with the theory of Musker be discarded, but rather that clear direction be given as to how the properties of the quantities that were actually measured (or directly derived from the measurements) may be easily extracted. For example, tables of the mean profiles and the integral parameters derived from the profiles would allow future, currently unknown, uses of these data. If left as currently presented, however, my prediction is that the data would not find much future use.

Though the trends in the turbulence data are suggestive, my recommendation is that these measurements be removed from the paper (though the authors are strongly encouraged to continue to try to obtain well resolved turbulence data). The literature regarding the Reynolds number dependence of boundary layer turbulence is already too littered with poorly resolved measurements. Once in the literature, such results have a confounding effect that makes it increasingly difficult to develop consensus within the community.

We know that spatial resolution is an important issue. As a reviewer, to allow these measurements to be published would deny this and actually contribute to further confusion in the literature. In the terms of the experimental uncertainty estimates required for JFE publication, these data are known to contain bias errors (at any given $R_\theta$). Quantification of these bias errors requires a study of spatial resolution versus Reynolds number that, if available, would already constitute the desired measurements, and thus are obviously unavailable to the authors. I would not support publication of any measurements having such poor spatial resolution.

I believe that the authors should spend a little more effort looking at the literature. In particular, some very good mean profile measurements were acquired by Hites at IIT. Furthermore, the study by DeGraaff and Eaton was not referenced. At present, the DeGraaff and Eaton study represents the only well-resolved set of boundary layer measurements to cover more than a decade in $R_\theta$ outside the aforementioned low $R_\theta$ range. Lastly, some well resolved measurements (up to $R_\theta \sim 20000$) by R. Simpson's group at Virginia Tech. have also been acquired in the last few years.

Rev D 1 of 1

## REVIEW OF PARK AND CUTHBERT

This is an interesting MS for several reasons.

1) D. Coles seems to be a shadow third author.

2) The two authors have acquired and fully documented a quite impressive data base.

3) The authors properly indicate that they do not have a direct evaluation of the wall shear stress. As a result, they make use of the boundary layer velocity profile by Musker.

4) What is totally unclear to this reviewer:

> "Since they have $\overline{u}(x,y)$ in considerable detail (see Table 2), and since their extrapolation to y=0 would allow all terms on the LHS of (14) to be evaluated, *why* did they not use this relationship with the measured and smoothed $\theta(x)$, $\delta^*(x)$, $U_o(x)$ to extract $\tau_w(x)$?"

5) Instead of the seemingly obvious path of Item (4), they have presented a contorted odyssey through the use of the Musker relationship. This use includes the use of an inferred $\delta$ that is in relation to their *measured* $\delta_{99}$ as

$$\delta_{99}/\delta \approx 0.8$$

This irrational relationship should have been a clue that something was fundamentally in error.

Note that by using Musker in lieu of Item (4) above the authors miss an opportunity to add their measurements to the formulation provided by that reference. Were they "under the spell of Coles a la Musker" that Item (4) did not occur to them? They certainly do not seem daunted by the hard work of data processing!

In summary, this will be a useful data set for the interpretation of high $R_\theta$ turbulent boundary layers and the *JFE* will be a good publication outlet for their work. It cannot be recommended that it be accepted in its current form. Extracting $\tau_w$ from their equation (14)...unless there are 3-D effects that invalidate this otherwise fundamental technique to determine $\tau_w$...will make this contribution acceptable. As noted, their detailed u(y) measurements can be used to create the $U_\infty(x)$, $\theta^*(x)$, $\delta^*(x)$ local values which can then be smoothed and differentiated in (14).

In particular, they can then determine the relationship between their $c_f$ values vis a vis those of the Osterland relationship (Fig. 10). They can also examine the relationships a la Musker instead of relying on them.

A strong recommendation for the revised MS: save the pseudo "x" relationships and especially the comments of page 12 starting with:

"The data as acquired is (are) useful as engineering data for the tunnel." – plus – the recommendations, for an internal report. They do not belong in an archival publication.

Rev E 1 of 2

**Re: Review of "High Reynolds Number Turbulent Boundary Layer Measurements at Near Zero Pressure Gradient", by Joel T. Park and J. Michael Cutbirth**

1. Page 1: "In general the results were consistent with the classical theory boundary layer theory." Please indicate in what sense the results were consistent with the classical theory of boundary layer theory.
2. Page 2: "George and Castillo [8] proposed another high Reynolds number model termed the Asymptotic Invariance Principles". The authors should be very careful about their interpretation regarding the George/Castillo theory. It should be written as: George and Castillo [8] suggested that the velocity profile in the overlap region is characterized by two different velocity scales and described by power law functions. Moreover, the coefficients of the power law are Reynolds number dependent. They further showed that the power law solution is a consequence of the streamwise inhomogeneity of the boundary layer flow. Meanwhile, it has been shown that the scales describing the mean velocity and Reynolds stresses were obtained from the RANS equations by means of similarity analysis.
3. Page 2 last paragraph: "Zagarola et al……".
   However, they suggested different constants for $\kappa$ and B; also they proposed that near the wall, the power law and the log law are both necessary to describe the overlap region in pipe flows.
4. Page 3: "The unique features of this model recommended by Prof. Coles is the profile form…….". Remove Prof. Coles and just write Coles [ref.].
5. Page 4: Equation 9.The values for Pi are all over the place instead of just a constant.
6. Page 4: You determined the friction velocity using the log law (eq 2). How good these values are when compared with those determined from the momentum integral? The method you outlined is known as the Clauser method, which assumes at the outset that a log-law exits. Consequently, your experimental data must satisfy that theory. This is basically your conclusion. For this reason it is important to show your results with the option of various theory such as the power law from George/Castillo (1997). In this way, the authors as experimentalists are not forced to satisfy the log-law, instead the authors must let the data speak for itself.
7. Page 5: 'For the data analysis of this experiment, the boundary layer thickness, d, was adjusted until the Reynolds number based upon displacement thickness from the theoretical Musker model agreed with the value computed from the experimental data." This approach does not make any sense. Normally the boundary layer thickness $\delta$ and $\delta^*$ are computed from the measured profiles. Essentially, the authors performed an experiment but then adjusted the experimental results to satisfy a theory which may not be necessarily correct. Meanwhile, they need to use another theory such as by Barrenblat, George and Castillo as a way to compare their experimental and theoretical analysis. It is better to present an experimental data which is not forced to satisfy a particular theory. In other words, let us see what the data is telling us, and then investigate which theory or approach seems to be more consistent with results. To this point, I advise the authors to use other flat plate data (i.e. Osterlund, Hites and Naguib etc.) for comparison.

8. Page 5: 'The LCC is the largest water tunnel in the world."
   It has been repeated too many times in the manuscript.

9. Page 5: What value of $\kappa$ do you use for this experimental data?
10. Page 7: How do you determine the location of the wall and what is the uncertainty in such procedure?
11. Page 7: In the experimental results: Why only show one data set instead of all of them?
12. Page 8: "Each plot emphasizes different regions of the boundary layer, but in general they are in good agreement with the theory proposed by Musker"
    However this is true because you forced your constants to satisfy the theory of Musker.
13. Table 4: Why the values of the friction velocity increase as the Reynolds number increases? This must tell you something about the validity of the theory used-the log law.
14. Page 9: kappa=0.435 and B=6.1, why do you think they are so different from Osterlund's?
15. Page 10: "For some unknown reason, the boundary layer growth at 2.5m/s is not consistent with the remainder of the data." This may be a consequence of the changes in the upstream conditions.
16. Page 12: 'Additionally, these data were consistent with over 80 data sets that have been evaluated by Prof. Coles?
    Please, show evidence of this claim.
17. Page 12: "However, measurements from Johansson and Castillo suggested that skin friction estimates with an uncertainty of ±2% are possible by a momentum integral calculation from the velocity profiles measurements" As long as you considered the pressure gradient and Reynolds stresses in the equation and that enough data point as considered in the profiles.
18. Figure 5: Why do you need to separate the theory of Musker for 15m/s and 2.5m/s?
19. Figure 6: Notice the difference in the shape of profiles for 2.5m/s and 15m/s in the outer region. This may suggest some effects due to upstream conditions, such as wind tunnel speed. Also, what is the effect of the discontinuity between windows along the test section? This small difference in height may act as a flow disturbance. Please, provide some information about the window discontinuity (i.e. thickness) relative to the boundary layer thickness.
20. Figure 8: If your proposed method for $\delta_{99}/\delta$ was correct you should have a ratio of one for this quantity. The differences shown in this figure may indeed give you an indication of the errors incurred for the calculations of the friction velocity.
21. Figure 9: The values of Pi are all over the place, isn't that suspicious to you?
22. Figure 10: Spelling for Osterlund is wrong. Also, error between direct measurements of Osterlund for the skin friction and the log-law theory is more than 5% it is closer to 10%. Show a comparison of the power law from George and Castillo.
23. Figure 12: Include the oil film data from Osterlund. Also, why there is a significant increase in Cf around 10^8?
24. Figure 13: It seems to me that this plot shows that there is a weak adverse pressure gradient in your data, and such variation will play a role in your calculation of $C_f$ using the momentum integral.
25. Figure 14: Could you please explain why there is a sudden jump in the shape factor values after Reynolds number is over 150?

In summary, the authors need to work more in the manuscript before it can be considered for publication. Once the authors addressed the above issues, I think that this paper will have a certain value in the turbulence community.

## APPENDIX B: COLES 2003 CORRESPONDENCE

The correspondence with Prof. Donald Coles dated 2003 April 30 is included in the following pages. The letter included nine (9) attachments lettered A through I. Attachments A and B were notes from a draft textbook, which has been replaced by Coles [B-1]. The equations discussed in the letter are as follows:

Attachment A Equation (3*131) and Coles [B-1] Equation (2.166)

$$u^+ = \frac{1}{\kappa} ln\left(\frac{y^+ - a}{-a}\right) + \frac{R^2}{a(4\alpha - a)}\left[(4\alpha + a) ln\Phi + \frac{\alpha}{\beta}(4\alpha + 5a)\phi\right] \tag{B-1}$$

Attachment A Equation (3*152) and Coles [B-1] Equation (2.167)

$$\Phi = -\frac{a}{R}\frac{[(y^+ - a)^2 + \beta^2]^{1/2}}{(y^+ - a)} \tag{B-2}$$

Attachment A Equation (3*153) and Coles [B-1] Equation (2.168)

$$\phi = \tan^{-1}\left(\frac{y^+ - \alpha}{\beta}\right) + \tan^{-1}\left(\frac{\alpha}{\beta}\right) \tag{B-3}$$

Attachment B Equation (7*226) and Coles [B-1] Equation (4.270)

$$\frac{1}{(Y/\delta)^{1/n}} = 1 + \frac{1}{(y/\delta)^{1/n}} \tag{B-4}$$

Attachment B Equation (7*227) and Coles [B-1] Equation (4.269)

$$\frac{u}{u_\tau} = \frac{1}{\kappa} ln\frac{Yu_\tau}{\nu} + c + \frac{2\Pi}{\kappa} sin^2\left(\frac{\pi}{2}\frac{Y}{\delta}\right) \tag{B-5}$$

Attachment B Equation (7*207) and Coles [B-1] Equation (4.263)

$$Y^+ \to y^+, \quad \frac{y}{\delta} \ll 1$$

$$Y^+ \to \delta^+, \quad \frac{y}{\delta} \gg 1 \tag{B-6}$$

Coles' Attachments C, D, and H are included in this appendix. Sandham [B-2] is included at the end of this appendix. The graphs of Coles' Attachment E are in APPENDIX C, while the data output from Coles' Attachment F is in APPENDIX D. The data sheets were originally on two pages and were split after item 48. Number 49 began on the next page. The data sheets were scanned and converted to tables. The font size was reduced so that a data sheet fits on one page. The Coles' ID numbers for the data are 3683 through 3730. The total number of graphs and data sheets is 48 each, that is, 48 boundary layer profiles at the vertical location of 250 mm. Coles' Attachments G and I are not included in this report.

## REFERENCES

[B-1] Coles, Donald, 2017, *Topics in Shear Flow*, California Institute of Technology, Pasadena, California, USA, unpublished, accessed 2021 October 12, https://authors.library.caltech.edu/84023/.

[B-2] Sandham, N. E., 1991, "An alternative formulation of the outer law of the turbulent boundary layer," lnstitut für Theoretische Strömungsmechanik, DLR Göttingen, Germany.

30 Apr 03

Dear Dr. Park,

First, Musker. I enclose a few pages (Attachment A) from my book. You can verify with some effort that the first two lines of Musker's equation (16) are equivalent to my equations (3.131, (3.152), and (3.153). Musker writes like a research man; I write (I hope) like a teacher. Consider trying to adapt Musker's form vs. my form for a different set of values for kappa and c.

Second, the corner at y = delta. Ignore Musker's review of the polynomial wake-function argument. My source here is Sandham, whose work appears only in an obscure report. I have attached a copy. The enclosed pages (Attachment B) attempt to clarify the situation. The form I use for the mean-velocity profile outside the sublayer is the equation pair (7.226)-(7.227). Note from the equation (7.207) that the variable Y/delta never exceeds unity. The sublayer is not involved here.

The skeleton of my survey is contained in the attachment C. The figure shows a sample of my fitting operation with numbers that refer to columns and rows of a worksheet. The red marks show Sandham's corner correction and the definition of PI as the distance between the two horizontal lines. The parameters determined by the fit are delta, utau, and Sandham's n. The fit is to the profile equation in B above, but includes only data to the right of the small tick mark in order to avoid the sublayer, where the log law does not apply. The tick is usually near yplus = 100. The top display shows the residuals, or differences between the data and the fitted curve, in units of u/uinfinity. The red line here shows that Osterlund's data would be better fitted with kappa = 0.38, as he claims (his data are unique within my survey on this point). Be aware that my survey uses Zagarola's values, kappa = 0.435 and c = 6.10, as noted in the fit algorithm of Attachment D. The graphics program is Sigma Plot.

Attachment E is 48 figures for the Park profiles. The slope corresponding to kappa = 0.435 is quite satisfactory, although the scatter is large.

Attachment F is a set of tables for the fitted profiles.

Back to C. The second and third pages are a key to the first column "DATA 2" of the tables. Lines 22 – 30 are the author's values. Lines 8 – 17 come from the fit. The other lines are miscellaneous. In particular, the line y = delta crosses the experimental profile (linear dot-to-dot) where u/uinfinity has the value on line 50. This is usually about 0.994. The value of deltaplus is on line 8. The value of PI is on line 15. Two other entries that I think are important are delta/w (boundary layer thickness/tunnel width) on line 54 and the ratio (2 dtheta/dx)/ Cf fit on line 57.

Attachment G shows my primitive fit to theta(x) to get dtheta/dx for this momentum check. The last 5 pages are most instructive on data quality. Your case of 2.5 meters/second is strange in that it shows dtheta/dx increasing with increasing x.

Back to C. The last pages list the authors included in my current survey of data for the boundary layer at constant pressure. The supersonic data are still pending.

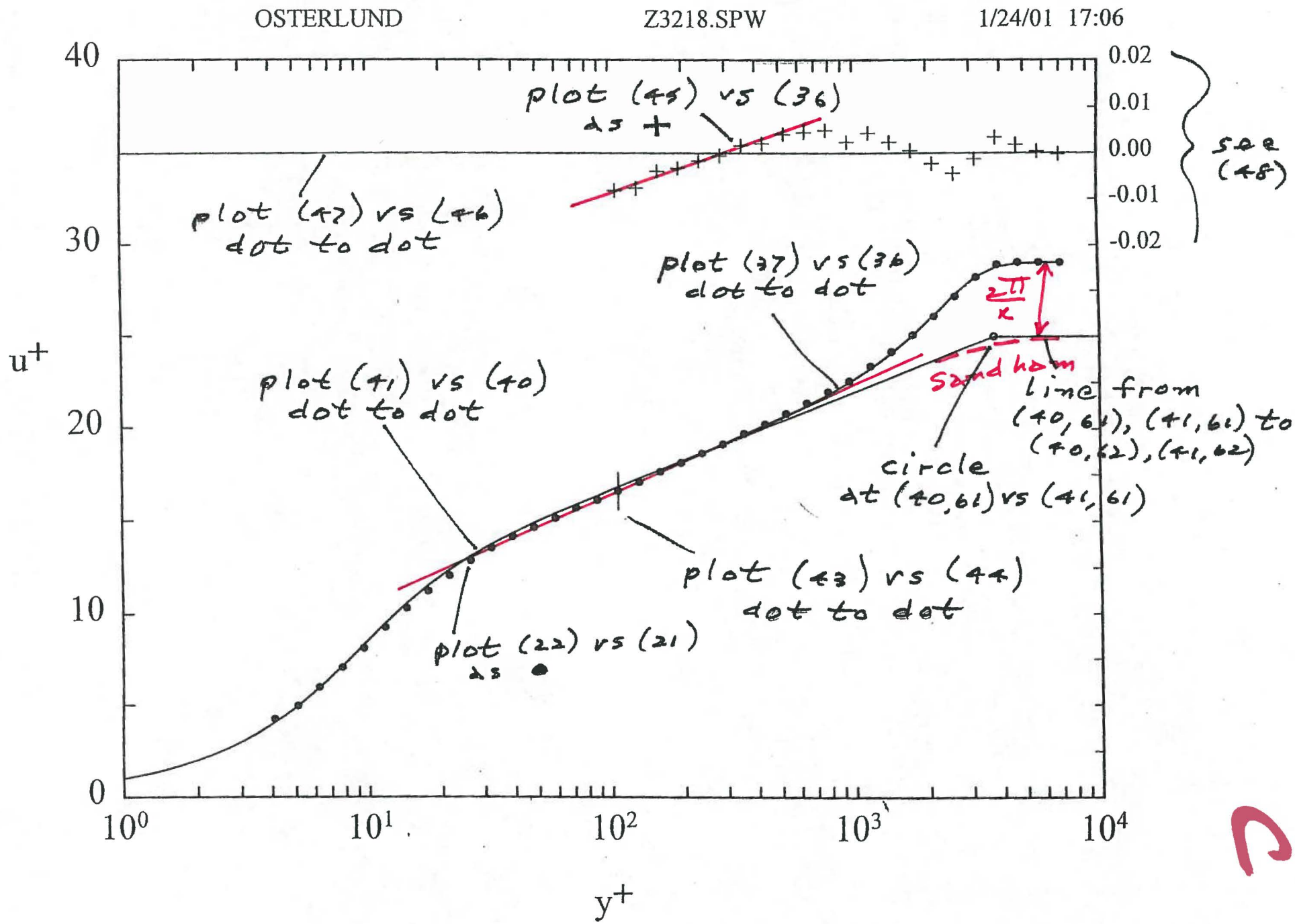
Attachment H is a bibliography of sources for data most closely related to yours, omitting of course Ceccio. Avoid the work by Castillo, which has large problems that I do not understand.

Finally, in response to your question about my recommended value for PI, I enclose Attachment I, which is a plot of PI against Rtheta for the whole of my survey, omitting only data with free-stream turbulence greater than 0.005 or Mach number greater than 0.3. What do I recommend? Sauve qui peut.

If you use any of this material that is clearly mine, cite it as "private communication".
Do not publish attachment I; it is not finished.

D. Coles

D.C.


OSTERLUND
Z3218.SPW
1/24/01 17:06
plot (45) vs (36)
as +
plot (47) vs (46)
dot to dot
plot (37) vs (36)
dot to dot
2π/κ
Sand ham
line from
(40,61), (41,61) to
(40,62), (41,62)
circle
at (40,61) vs (41,61)
plot (41) vs (40)
dot to dot
plot (43) vs (44)
dot to dot
plot (22) vs (21)
as ●
see (48)
u+
y+
40
30
20
10
0
0.02
0.01
0.00
-0.01
-0.02
10^0
10^1
10^2
10^3
10^4

(File name D_mvbl04.tex, version of 27 October 2001)

## Format for mean-velocity profiles in boundary layer

(Reserve files D2001-D4000)

| | |
|---|---|
| DATA(1) | File ID |
| DATA(2) | $N$ (number of points in data sequence) (or author's name) |
| DATA(3) | $x$, cm (streamwise station) |
| DATA(4) | $u_\infty$, cm/sec (free-stream velocity) |
| DATA(5) | $\nu_w$, cm$^2$/sec (viscosity at wall) |
| DATA(6) | $\nu_\infty$, cm$^2$/sec (viscosity in free stream) |
| DATA(7) | $T_w/T_\infty$ |
| DATA(8) | $\delta^+ = \delta u_\tau/\nu$ (fit) |
| DATA(9) | $C_f$ (friction coefficient, fit) |
| DATA(10) | $R_\theta$ (Reynolds number, fit) |
| DATA(11) | $\delta$, cm (layer thickness, fit) |
| DATA(12) | $\delta^*$, cm (displacement thickness, fit) |
| DATA(13) | $\theta$, cm (momentum thickness, fit) |
| DATA(14) | $u_\tau$, cm/sec (friction velocity, fit) |
| DATA(15) | $\Pi$ (wake parameter, fit) |
| DATA(16) | $u_\infty/u_\tau$ (fit) |
| DATA(17) | $2\Pi u_\tau/\kappa u_\infty$ (fit) |
| DATA(18) | $T_w\,(^\circ K)$ |
| DATA(19) | $T_\infty\,(^\circ K)$ |
| DATA(20) | $n$ (fit) |
| DATA(21) | $\epsilon$ (rms dispersion of fit) |
| DATA(22) | $C_f$ (author) |
| DATA(23) | $R_\theta$ (author) |
| DATA(24) | $\delta$, cm (author) |
| DATA(25) | $\delta^*$, cm (author) |
| DATA(26) | $\theta$, cm (author) |

DATA(27) $u_\tau$, cm/sec (author)

DATA(28) $\Pi$ (wake parameter, author)

DATA(29) $n$ (author)

DATA(30) $u'$ (turbulence level)

DATA(31) $T_\tau$ (fit)

DATA(32) ~~$T_\tau$ (author)~~ same as DATA(1)

DATA(33) $M_\infty$ (author)

DATA(34) ~~$C_h$ (heat transfer coefficient, author)~~

DATA(35) ~~$u_{s_\infty}$ (free stream, psia)~~

DATA(36) $T_{0_\infty}$ (° K)

DATA(37) $F$ (index of first fitted point)

DATA(38) lim ($y^+$ for first fitted point)

DATA(39) $Pr$ (after fit)

DATA(40) $L$, cm (turbulence integral scale)

DATA(41) $m$

DATA(42) $\sin^{-1}(m)/m$

DATA(43) $u^*_\infty/u_\tau$ (fit)

DATA(44) $2\Pi u_\tau/ku^*_\infty$

DATA(45) $C_f R_\theta$ (author)

DATA(46) $C_f R_\theta$ (fit)

DATA(47) $\delta^*/\theta$ (author)

DATA(48) $\delta^*/\theta$ (fit)

DATA(49) $u^*_\infty$

DATA(50) $u(\delta)$ ($u/u_\infty$ at $y = \delta$)

DATA(51) index for $u(\delta)$

DATA(52) $2\,d\theta/dx$ (if available)

DATA(53) W (width of channel) cm

DATA(54) $\delta/W$

DATA(55) $C_f$ (FE) (if available) (floating element)

DATA(56) $C_f$ (FE) / $C_f$ (fit)

DATA(57) $(2\,d\theta/dx)/C_f$ (fit)

DATA(58) same as DATA(1)

DATA(59) same as DATA(2)

| ID | Disk | Author |
|---|---|---|
| D2009 to D2016 | | Clauser 2 |
| D2017 to D2056 | | Uram A |
| D2057 to D2111 | | Uram B |
| D2112 to D2187 | ZA to ZM, ~~ZCL to ZCO~~ | Blair |
| D2188 to D2198 | | Herring and Norbury |
| D2199 to D2218 | BS, ZAM, ZAN | Matheson |
| D2219 to D2242 | BT, ZAE, ZAF | Hancock |
| D2243 to D2312 | CG to DA, ZDF to ZDK | Smith and Walker |
| D2313 to D2336 | ZDQ, ZDR | Karlsson |
| D2337 to D2351 | ZAO, ZAP, ZBR, ZBS | Elfstrom |
| D2352 to D2364 | ZBP | Gaudet |
| D2365 to D2388 | BH, ZAI, ZAJ, ZBV, ZBW | Petrie et al |
| D2389 | ZCB | Schewe |
| D2390 to D2395 | preproc +BP | Mabey |
| D2396 to D2405 | | Mabey et al |
| D2406 to D2435 | | Winter and Gaudet |
| D2436 to D2441 | | Allen |
| D2442 to D2465 | preproc +EH | Meier |
| (D2459 missing) | | |
| D2466 to D2471 | preproc +EK | Thomke |
| D2472 to D2481 | preproc +BQ | Jeromin |
| D2482 | | Hopkins and Keener |
| D2483 to D2492 | preproc +EI | Moore and Harkness |
| D2493 to D2504 | | Moore |
| D2505 | | Kistler |
| D2506 to D2508 | | Stalmach |
| D2509 to D2527 | preproc +EJ | Shutts et al |
| D2528 to D2534 | | Chew and Squire |
| (D2535 not used) | | Kussoy et al |
| D2536 to D2551 | ZAH, ZBX, ZBY | Zoric |

| | | |
|---|---|---|
| D2552 to D2557 | BM, ZAS, ZBA | Hicks |
| D2558 to D2603 | BM | Collins et al |
| D2604 to D2609 | preproc | Evans |
| D2610 to D2621 | CA, CB | White |
| D2622 to D2637 | ZAH, ZAK, ZAL, ZBB, ZBC | Anders and Watson |
| D2638 to D2647 | BZ, ZCF | Landweber and Siao |
| D2648 to D2658 | AK, ZAG, ZBN | Purtell |
| D2659 to D2665 | | Purtell $u'$ |
| D2666 to D2737 | ZAA to ZAC, ZDD, ZDE | Totland |
| D2738 to D2807 | ZBD, ZBE | Zijnen |
| D2808 to D2827 | ZDC | Sherman |
| D2828 to D2829 | BN | Kim |
| D2830 to D2832 | BN | Spalart |
| D2833 to D2852 | | Hoffman |
| D2853 to D2862 | ZCG | Johnson |
| D2863 to D2874 | preproc + AW | Marusic |
| D2875 to D2889 | ZAR, ZBZ, ZCA | Wark |
| D2890 to D2936 | ZAT to ZAW, ZCH to ZCK | Coupland |
| D2937 to D2959 | ZDN, ZDO | Wieghardt 33 |
| D2960 to D2979 | ZDL, ZDM | Wieghardt 19 |
| D2980 to D2993 | ZDP | Wieghardt gitter |
| D2994 to D3010 | ZCC, ZCD | Tillmann 18 |
| D3011 to D3020 | ZAD, ZBQ | Smith |
| D3021 to D3032 | | Piadishius |
| D3033 to D3040 | | Nikuradse |
| D3041 to D3068 | | Jackson |
| D3069 to D3074 | | Coles (1953) |
| D3075 to D3142 | ZBF to ZBL | Erm 3105 |
| D3143 to D3154 | ZBM | Bull |
| D3155 to D3240 | ZCX to ZCZ, ZDA, ZDB | Osterlund 3206 |

| | | |
|---|---|---|
| D3241 to D3252 | ZBO | Nockemann |
| D3253 to D3256 | ZBU | Andreopoulos |
| D3257 to D3261 | ZCE | DeGraaf |
| D3262 to D3272 | | Alving |
| D3273 to D3300 | ZCP, ZCQ | Watson |
| D3301 to D3310 | | Dutton |
| D3311 to D3316 | ~~ZCR~~ | Ligrani |
| D3317 to D3344 | | Kline |
| D3345 to D3351 | | Osaka |
| D3352 to D3354 | | not used |
| D3355 to D3372 | | Arik |
| D3373 to D3433 | | Motallebi |
| D3434 to D3493 | ZCS to ZCW | Lanspeary |
| D3494 to D3500 | | Schultz-Grunow |
| D3501 to D3506 | | HitesA |
| D3507 to D3521 | | HitesB |
| D3522 - D3580 | | Castro |
| D3581 - D3586 | | Risbouchinsky |
| D3587 - D3600 | | Winter |
| D3601 - D3641 | | Jones PT |
| D3642 - D3653 | | Ceccio |
| D3654 - D3682 | | Johansson |
| D3683 - D3730 | | Park |
| D3731 - D3746 | | Castillo |
| D3747 - D3767 | | Jones HW |

Park

D3683 - D3730

Data for four speeds in 3 m x 3 m water tunnel at Memphis. Probe is LDV working through side wall (burst mode, backscatter?). Large dimension of test volume is normal to wall. Considerable scatter in profiles, perhaps because of too short averaging time. $R\theta$ is as high as 300,000.

Large scatter, to ten percent, in bulk parameters such as $\theta$. Not caused by processing, because my $\theta$ agrees with his to a few parts in a thousand. Suspect poor LDV technique or drag of window joints.

How does Park explain occasional values u' or w' = 0? (See below)

Groups

3683-3693; x varies at 2.5 m/sec.
3695-3706; x varies at 5 m/sec.
3707-3718; x varies at 10 m/sec.
3719-3730; x varies at 15 m/sec.

N. B. Parameter $y_o$ is apparent position of wall as inferred from fit of profile to his log law. (See letter.)

Reason that u' or w' is occasionally zero is that signal is resolved into sum of two variances, and the observed noise variance is subtracted from the total to get the turbulence variance. Negative result is put equal to zero. (See letter.)

D



```
jsv4R

;Title:      c:\lowspeed\fit.FIT
;Date: 11/7/01

[Parameters]

n=cell(1,29)
delta=cell(1,24)
utau=cell(1,27)

[Variables]

y=col(7)
uoverui=col(8)

[Equations]

ui=cell(1,4)
nu =cell(1,5)
pi=3.141592654
k =0.435
c =6.10

;Define profile equation for cut data.
;Round outer profile using Sandham method.

invn=1/n
yplus=y*utau/nu
dplus=delta*utau/nu
denom=1+{{y/delta}^invn}
YPLUS=yplus/{denom^n}
Y=y/{denom^n}

;DPLUS=dplus is limit of YPLUS as yplus
;goes to infinity;

DPLUS=dplus
wall=(1/k)*ln(YPLUS)+c

;The next line is P=2*PI/k;

P=ui/utau-(1/k)*ln(DPLUS)-c
wake={sin((pi/2)*(Y/delta))}^2
f=(utau/ui)*(wall+P*wake)
fit f to uoverui

[Constraints]
```

Note that the fit is for $u/u_\infty$ as a function of y (cm)

```
n>0

[Options]

stepsize=10
tolerance=0.0000000001

;Store fitted parameters manually
;as follows;
;            cell(9,1)=n
;            cell(9,2)=delta
;            cell(9,3)=utau.

;Put f in col(10) and resid in col(11).

;End of fit.FIT.  Go to 2.XFM.
```

H

ATTACHMENT H

CASTILLO, L. et al. AIAA Paper 2001 – 2913; 2002 – 0577. Rtheta to 113,000

ELFSTROM, G. M. NRC of Canada, National Aeronautical Establishment, Lab Tech. Report LTR-HA-5x5//0146, 1984. Rtheta to 102,000

FERNHOLZ, H.H. et al. Phys. Fluids 7, 1275, 1995. Rtheta to 61,000

JONES, M. Private communication, 2002. Rtheta to 60,000

WATSON, R.D. et al. AIAA paper 2000 – 2392. Rtheta to 290,000

WINTER, F.G. and GAUDET, L. ARC, Great Britain, R&M 3712, 1973 Rtheta to 214,000

Cover

**Deutsche Forschungsanstalt**
**für Luft- und Raumfahrt e.V.**

DLR

7

**IB 221-91 A 10**

# An alternative formulation of the outer law of the turbulent boundary layer

N. D. Sandham

**Institut für Theoretische Strömungsmechanik**
**DLR Göttingen**

Deutsche
Forschungsanstalt
für Luft-
und Raumfahrt e.V.

DLR

Institut für
Theoretische
Strömungsmechanik

Bunsenstraße 10
D-3400 Göttingen

Telefon
(0551) 709-1
Telex 96839 dlrgod
Telefax (0551) 709-2446

Zugänglichkeitsstufe: I

DLR -interne Zuordnung
- Programm: LSEG
- Teilprogramm: 199

Göttingen, Mai 1991

Mit freundlichen Grüßen

Avec nos meilleurs compliments

With compliments

Neil Sandham

9155/018-1/91 G63

## Abstract

An alternative similarity law for the turbulent boundary layer is presented which satisfies the inner and velocity-defect laws, and allows a continuous representation of the mean velocity profile for arbitrary pressure gradients. Data from a wide variety of experiments are shown to collapse on a specified outer-law function. The quality of the data fit is found to be as good as that of Coles' law of the wake, indicating that the wake law is not unique in being able to collapse mean velocity measurements in the outer region of the turbulent boundary layer. An advantage of the current formulation is the better representation of the region near the edge of the boundary layer, due to the avoidance of a discontinuity in the velocity derivative. A good collapse is also obtained for flows with strong favorable pressure gradients, where there is no wake component in the usual sense.

## 1. Introduction

The basic representation of the velocity profile in the two-dimensional turbulent boundary layer is well established and can be found in textbooks (*e.g.* White, 1974). The main justification for this representation lies in experimental fact, rather than rigorous derivation from theory. The main components will be summarized, using the standard notation. A free-stream flow of an incompressible fluid is considered, with density $\rho$, pressure $p$ and viscosity $\mu$ (kinematic viscosity $\nu = \mu/\rho$). The streamwise direction is labelled $x$, and the wall-normal direction $y$. The local mean streamwise velocity is given by $u$ and the free-stream velocity by $u_\infty$. The boundary layer width is $\delta$ and the shear stress at the wall is $\tau_w = \mu(du/dy)_w$. Other related quantities are the skin friction $c_f = \tau_w/(\frac{1}{2}\rho u_\infty^2)$, and the shear velocity $u_\tau = (\tau_w/\rho)^{1/2}$. Useful non-dimensional variables in the near-wall region are $u^+ = u/u_\tau$ and $y^+ = yu_\tau/\nu$. For later use the subscript $i$ is used to refer to a relationship in the inner region of the boundary layer.

The inner law of the turbulent boundary layer states that $u_i^+$ is a function of $y^+$ only. In the viscous sublayer very near the wall ($y^+ < 5$) we have

$$u_i^+ = y^+. \tag{1}$$

Further away from the wall ($y^+ > 50$) we have the logarithmic law

$$u_i^+ = \frac{1}{\kappa} \ln y^+ + b. \tag{2}$$

The standard values of the logarithmic law constants will be used throughout this paper:

$$\kappa = 0.41$$
$$b = 5.0.$$

The neatest complete form of the inner law, containing both (1) and (2), with a smooth fit in the 'buffer' region in between, is that proposed by Spalding (1961). It is, however, specified in a reversed form $y^+ = y^+(u_i^+)$:

$$y^+ = u_i^+ + e^{-\kappa b}\left\{e^{\kappa u_i^+} - 1 - (\kappa u_i^+) - \tfrac{1}{2}(\kappa u_i^+)^2 - \tfrac{1}{6}(\kappa u_i^+)^3\right\}. \tag{3}$$

There is a question mark as to whether the series should be truncated at the third or fourth power of $\kappa u_i^+$. Truncating at the third power gives the correct limiting behavior at the wall (Coles, 1985; Chapman and Kuhn, 1986), while truncating at the fourth power seems to match data in the buffer region a little better (Liakopoulos, 1984).

The outer portion of the turbulent boundary layer is that region where the mean velocity departs from the inner law, in order to match the imposed external boundary conditions. Mean velocity profiles for a flat-plate boundary layer, with zero pressure gradient, collapse when plotted in the form of $(u_\infty - u)/u_\tau$ against $y/\delta$. This velocity-defect law was extended

by Clauser (1954, 1956) to include flows with non-zero pressure gradients. He defined a non-dimensional pressure gradient parameter $\beta$ by

$$\beta = \frac{\delta^*}{\tau_w}\frac{dp}{dx}, \tag{4}$$

where $\delta^*$ is the displacement thickness, defined by $\delta^* = \int_0^\infty (1 - u/u_\infty)\, dy$. If this parameter is held constant then the mean velocity in the outer portion of the turbulent boundary layer collapses, when plotted in velocity-defect law form. Such boundary layers are termed equilibrium turbulent boundary layers. The velocity-defect law from Clauser can be written as

$$\frac{u_\infty - u}{u_\tau} = g(\eta, \beta), \tag{5}$$

where $\eta = y/\delta$, and the precise form of the function $g$ is left unresolved.

The problem of the shape of the boundary layer in the outer region was addressed by Coles (1956). He considered the deviation of the mean velocity from that of the inner law, and proposed to fit the shape of this deviation by a universal function $w(\eta)$. This function was named a wake function, after its resemblance to the half-wake flow (a mixing layer, in today's terminology). The law of the wake can be written as

$$u^+ = u_i^+ + \frac{\Pi}{\kappa} w(\eta), \tag{6}$$

where Coles usually takes the inner law $u_i^+$ from equation (2), ignoring the region $y^+ < 50$. The parameter $\Pi$ determines the strength of the wake. In Coles (1956) tabulated values of the form of $w(\eta)$ based on a collection of experimental results were given. Later Coles (1968) approximated the wake function by

$$w(\eta) = 2\sin^2(\frac{\pi}{2}\eta). \tag{7}$$

The fit of the data to the wake function (7) presented by Coles (1968) is very good. The only real problem concerns the representation at the edge of the boundary layer. The law of the wake has a discontinuity in the derivative of the velocity profile at $\eta = 1$. In inner variables the derivative $du^+/d(\ln y^+)$ changes abruptly from $1/\kappa$ to 0. Coles calls this a corner effect, and the practical problem is that velocity profiles are not properly represented around $\eta = 1$. In fitting data to the law of the wake, Coles ignores the region $\eta > 0.9$. The corner effect is especially noticable for flows with favorable pressure gradients ($dp/dx < 0$). However, it should be noted that the overall fit is not too badly affected, since for these flows the wake component is small. The wake function can be modified (Rotta, 1974; Granville, 1976; Dean, 1976; Li and Perry, 1989) so that the first derivative of velocity is continuous at the edge of the boudary layer. However, with these formulations higher derivatives remain discontinuous.

It is the intention of this paper to present a new formulation of the outer law, that avoids the problem of a discontinuity in the mean profile derivatives at the edge of the boundary layer, and at the same time fits the experimental data as well as Coles' law of the wake.

## 2. Mathematical formulation

An alternative similarity form for the outer region of the turbulent boundary layer, which expresses the resemblance to a mixing layer even more explicitly than Coles' law is

$$\frac{u_\infty - u}{u_\infty - u_i} = f(\eta), \tag{8}$$

where $u_i$ is the velocity from the inner law and $\eta = y/\delta$. Compared to the similarity form for the mixing layer, the two free-stream velocities have been replaced with $u_\infty$ and $u_i$. The inner law is thus regarded as a separate solution of the Navier-Stokes equations, and the function $f(\eta)$ represents a transition between two valid solutions. A sketch of the arrangement is shown on figure 1 for a flat-plate turbulent boundary layer with zero pressure gradient. It can be seen that $f(\eta)$ is equal to 1 in the inner region ($u = u_i$) and tends to 0 in the far field ($u \to u_\infty$). The similarity function $f(\eta)$ will be referred to as the outer-law function and can be represented by

$$f(\eta) = e^{-c(e^{\eta^d}-1)}\,. \tag{9}$$

For the constants the values $c = 3.0$ and $d = 1/\kappa = 2.44$ are used. The use of an exponentially decaying term for $f(\eta)$ guarantees no discontinuity. However, if the usual inner law is used, there is a possibility that for strong favorable pressure gradients $u_i$ may overshoot $u_\infty$ before the exponential term has reduced the velocity defect to zero. In this case one would obtain the solution of $u > u_\infty$.

To overcome the possibility of overshoot, the inner law of the turbulent boundary layer will be reformulated. The basic idea is to introduce the free-stream velocity into the inner law, and make the inner law satisfy the external boundary condition of $u \to u_\infty$ as $y \to \infty$. This can be formulated in a simple manner by writing

$$u_i^+ = \frac{1}{\kappa}\ln\left(\frac{y^+\delta_i^+}{y^+ + \delta_i^+}\right) + b, \tag{10}$$

where $\delta_i^+$ is the ready-made lengthscale of the value of $y^+$ at which the original logarithmic law would have matched the free-stream velocity. From (2) this is

$$\delta_i^+ = e^{\kappa(u_\infty^+ - b)}\,, \tag{11}$$

where $u_\infty^+ = u_\infty/u_\tau$. If Spalding's equation (3) is used instead of (2) then the equivalent form is to define a new $y_s^+$ by

$$y_s^+ = \frac{y^+\delta_s^+}{\delta_s^+ - y^+}, \tag{12}$$

where $y^+$ is from (3) and the length scale $\delta_s^+$ is given by

$$\delta_s^+ = u_\infty^+ + e^{-\kappa b}\left\{e^{\kappa u_\infty^+} - 1 - (\kappa u_\infty^+) - \tfrac{1}{2}(\kappa u_\infty^+)^2 - \tfrac{1}{6}(\kappa u_\infty^+)^3\right\}\,, \tag{13}$$

which is very close to $\delta_i^+$ for the usual range of $u_\infty^+$. The shape of the modified inner law, using equations (12) and (13) is shown on figure 2 for various values of $u_\infty^+$. As $u_\infty^+$ is increased the length scale $\delta_i^+$ increases, and one is left with the usual inner law at low $y^+$.

A velocity-defect law in the same form as equation (5) can be derived by combining equations (8), (10) and (11):

$$\frac{u_\infty - u}{u_\tau} = \frac{1}{\kappa} \ln(1 + \frac{\alpha}{\eta}) f(\eta), \tag{14}$$

where

$$\alpha = \frac{u_\infty^+ \delta_i^+}{Re_\delta}, \tag{15}$$

with $Re_\delta = u_\infty \delta / \nu$. This equation is valid for $y^+ > 50$. The quantity $\alpha$ is a parameter that uniquely determines the size of the velocity defect at a given $\eta$. (The related quantity $\frac{1}{2}\ln(1+\alpha)$ is very similar to Coles' strength of the wake parameter $\Pi$.) Equation (14) demonstrates that the new form of the similarity law (8) is completely consistent with the velocity-defect law (5), with a one-to-one correspondence between $\alpha$ and Clauser's $\beta$ parameter.

A comparison of the velocity profile shapes in the outer region of the turbulent boundary layer is shown on figure 3. Coles wake laws (both the tabulated function and equation (7)) are compared with the outer-law function $f(\eta)$. The comparison is only strictly valid for large values of the wake parameter, due to the different formulation of the inner law for $y \to \infty$. Differences between the three functions are not large. In practice it is found that small adjustments in $\delta$ and $c_f$ are sufficient to make the data fit either the outer law (8) or the wake law (6).

## 3. Comparison with experimental data

For the purpose of comparing the proposed velocity-defect law with experiment, the extensive tabulated velocity profiles prepared for the 1968 Stanford Conference by Coles and Hirst (1968) have been used. The profiles will be referred to by the names of the originating authors and the 4-digit code assigned for the Stanford Conference. References to the original works can be found in Coles and Hirst, although these often do not contain the tabulated data.

The first test was made for the two near-equilibrium experiments from Clauser, as well as for a standard flat plate flow. The velocity defects for the three different turbulent boundary layer flows are shown on figure 4. The data are taken for $\beta = 0$ (upper curve) from Wieghardt, for $\beta \approx 1.8$ from Clauser 1 and for $\beta \approx 8.0$ from Clauser 2. Clauser's original skin friction estimate was used so that the data points match those on his original plots. The curves are taken from equations (8) and (9), using equation (12) for the inner law. (Spalding's formula was numerically inverted into the form $u_i^+(y^+)$ using a Newton-Raphson iterative procedure.) Parameters for calculation were chosen as $Re_\delta = 80000$ and $u_\infty^+ = 27.0$, 31.8 and 42.5 for the three cases $\beta \approx 0$, 1.8 and 8.0 respectively. The boundary-layer width $\delta$ was adjusted until a good fit was obtained.

For a more rigorous comparison with the data the procedure of Coles (1968) was adopted. The method is to adjust the skin friction $c_f$ and boundary-layer width $\delta$ for each profile until the least squares error, between the outer-law function $f(\eta)$ and the data points in the form of $(u_\infty - u)/(u_\infty - u_i)$, is minimized. As before, Spalding's formula was used for the inner law. Similarly to Coles, the region $\eta < 0.125$ was excluded from the fit. This avoids the near-wall region, where there is a large scatter in the data, and avoids biassing the fit towards the logarithmic region, where there are usually a large number of data points. Unlike Coles, however, points at the outer edge of the boundary layer were not excluded. Results from this procedure are shown on figure 5, using data from 8 separate experiments. The ability of equation (8) to collapse the data is seen to be excellent. A residual error was computed in the same manner as Coles (1968), as the root mean square of the error between the original velocity data and the fitted profile, with the velocity normalized to unity in the free-stream. Residual errors, although averaged over more points, were found to be consistently similar to those published by Coles. For example, the average residual for Clauser 1 was 0.0034 compared to Coles' 0.0036, and for Clauser 2 the average residual was 0.0063 compared to Coles' 0.0061. The law of the wake is not unique in being able to accurately collapse the data from the outer portion of the turbulent boundary layer.

The method of fitting the data returns $\delta$ and $c_f$. The boundary-layer width $\delta$ is defined as the value of $y$ where $(u_\infty - u)/(u_\infty - u_i) = f(1) = e^{-c(e-1)}$. Values of $\delta$ were usually 5-10% above those of Coles (1968). More important is what happens to the skin friction $c_f$. Values for skin friction computed using Coles formulation are, when compared to a best fit through the logarithmic region (Coles and Hirst, 1968), on average 3.5% low for adverse pressure gradients, 1.8% low for zero pressure gradients and 0.3% low for favorable pressure gradients. With the current formulation the corresponding numbers are 1.5% low, 0.05% high and 3.6% high. These variations are not large, especially when one considers the margin of uncertainty of fitting data to the logarithmic law. Variations of a few percent are quite common between the values of skin friction estimated by Coles and Hirst, and those published by the original experimenters.

One very small but explainable deviation from the fit can be observed in figure 5. This occurs when the last data point in a profile is not far enough away from the wall to be fully in the free-stream. When this happens the last few data points are pulled downwards. This is noticeable in the data of Bell, and in the fourth profile of Bradshaw and Ferriss (marked $\times$). Profiles with the last data point at $\eta < 1.0$ are susceptible to this error.

Deviations from the fit for $\eta < 0.125$ are not consistent, although very close to the wall there appears to be a trend for the data to lie below the outer-law function. There is usually a large scatter in this near-wall region, and the possibility of experimental error has been discussed by Coles (1968). A lot of the data do not accurately fit the logarithmic law. When the wake-component is small the fit is especially sensitive to the form of the inner law. For example, the first group of data points in the plot from Bell's data are at around $y^+ = 50$. If one assumes that the inner law is the standard logarithmic form, rather than Spalding's law, then these points move upwards by about 0.05, and are much closer to the outer-law function.

The lower three curves in figure 5 are for the flat plate flow of Wieghardt, the mild favorable pressure gradient of Bell, and the strong favorable pressure gradient case of Herring and Norbury. These are flows where the corner effect becomes very noticeable when the data are plotted in wake-law form. No such deterioration in the quality of the fit is apparent in figure 5. The similarity law of equation (8) seems to be valid throughout the range from strong adverse pressure gradients to strong favorable pressure gradients.

To show how the outer law of equation (8) continues to hold for strong favorable pressure gradients the velocity profiles from Herring and Norbury are replotted in inner variables on figure 6. The solid line is the profile fit, while the dashed line is the modified version of Spalding's inner law. It can be seen how the change in the inner law as the pressure gradient becomes more favorable (or alternatively as $u_\infty^+$ reduces) allows the outer-law similarity to continue to hold, even when there is no wake component (in fact Coles' fitting procedure gave $\Pi$ negative to the last two profiles on figure 6).

For equilibrium turbulent boundary layers there is a one-to-one correspondence between the parameter $\alpha$ from equation (15) and Clauser's pressure gradient parameter $\beta$ from equation (4). On figure 7 the quantity $\frac{1}{2}\ln(1+\alpha)$ is plotted against $\beta$ for all the near-equilibrium flows (all the flows from figure 5, excluding Ludwieg and Tillman). If a flow were strictly in equilibrium it would be represented by a single point on this plot. It can be seen that equilibrium is much harder to obtain experimentally at high values of $\beta$. In particular, Clauser 2 is not very close to equilibrium. Also shown on the plot is an empirical correlation, in a form borrowed from White (1974)

$$\tfrac{1}{2}\ln(1+\alpha) = (\beta + 0.5)^{0.6}. \tag{16}$$

The fit is acceptable over the range of data $-0.2 < \beta < 5$, and has been anchored to the point $\alpha = 0$ at $\beta = -0.5$, so that the range of possible solutions corresponds to that from the constant eddy-viscosity theory of Mellor and Gibson (1966). Using this fit one can construct a complete family of curves for the velocity defect of equilibrium turbulent boundary layers (at a specified Reynolds number). The curves shown on figure 4 correspond to $\beta = 0.01$, 1.78 and 9.24 using the correlation, compared to the nominal $\beta = 0.0$, 1.8 and 8.0. It should be stressed that the empirical relationship (16) is only valid for flows that are close to equilibrium.

## 4. Discussion

In section 2 the modified inner law was presented as a practical way to avoid the mean velocity overshooting the free-stream velocity. Is it anything more than that? Let us postulate that a physical mechanism of momentum redistribution exists for turbulent flow near a wall (resulting in $u_i$) and consider a hypothetical boundary layer, in which only the inner law mechanism is working and the outer law is suppressed. At some distance from the wall the conventional logarithmic region must merge into the free-stream velocity. Equation (10) satisfies the requirement, using the only available lengthscale. But it is not a unique solution.

A family of such curves can be defined, with parameter $a$:

$$u^+ = \frac{1}{a\kappa} \ln \left( \frac{(y^+)^a (\delta_i^+)^a}{(y^+)^a + (\delta_i^+)^a} \right) + b \tag{17}$$

The choice of $a = 1$ must for the time being be based on the success of the collapse for flows with favorable pressure gradients. A physical situation in which the hypothetical pure-inner flow is approximated can be seen in figure 6. This is the flow with a very strong favorable pressure gradient. In this case the boundary layer is not growing (and possibly thinning) in the streamwise direction. The ultimate effect of such a pressure gradient is relaminarization, so to obtain the pure-inner flow over a significant streamwise extent one would have to start with a very high Reynolds number turbulent boundary layer.

Sensitivity to the values of the constants in the outer-law function (9) was checked by adjusting these until a minimum in the residual, averaged over all the data shown on figure 5, was obtained. The results were $c = 2.95 \pm 0.35$ and $d = 2.43 \pm 0.03$, where the bands were fixed by the range in which the residual was within one percent of the minimum. The constant $d$ seems to be well defined. The obvious connection with the Kármán constant $\kappa$ was made, setting $d = 1/\kappa = 2.44$. The quality of the fit is less sensitive to the choice of $c$; all the plots were made using $c = 3.0$. The reappearance of the Kármán constant $\kappa$ in the outer-law function is intriguing. The term $y^{1/\kappa}$ now appears, under different non-dimensionalization, in both the inner and outer laws of the turbulent boundary layer. The term appears inside a logarithm in the inner law and inside a double exponential in the outer law.

The usual theoretical approach is via the boundary-layer equations, with a simple eddy-viscosity turbulence model. Clauser (1954,1956) found that a constant eddy-viscosity was sufficient for an approximate fit to the data in the outer portion of the turbulent boundary layer. This idea was exploited by Mellor and Gibson (1966) in a general theory of equilibrium turbulent boundary layers. In fact the velocity profiles from the constant eddy-viscosity theory do not match the data very well in the region $\eta > 0.8$. The velocity approaches the free-stream velocity more slowly than the experimental data. This is a common problem with such models, occurring also in free shear layers (Townsend, 1976), and is attributed to intermittency. To correct this problem the eddy-viscosity would have to be reduced to zero in the outer portion of the boundary layer. The constant eddy-viscosity approach gives a good first approximation to the mean-velocity profile, but does not seem to be the route to deriving the exact turbulent velocity profile.

Matched asymptotic expansion methods have been applied to the outer region of the turbulent boundary layer by Phillips and Ratnanather (1990), making certain assumptions about the scaling of turbulence quantities. An interesting result is the prediction of a small (0.5%) overshoot in the mean velocity profile relative to the freestream velocity at the outer edge of the boundary layer. Such an overshoot is so small as to be almost undetectable in most experimental data, and cannot be observed in any of the data presented at the Stanford Conference. With respect to the current formulation it should be pointed out that this overshoot is not the same as the one specifically excluded by the new formulation of the inner

law. Tests of this showed very poor agreement with data for favorable pressure gradient flows. If the overshoot exists, it should be possible to incorporate it into the outer-law function $f(\eta)$.

## 5. Conclusions

The combination of an inner law, modified to match the free-stream velocity, and a new formulation of the outer law has been shown to be able to collapse mean velocity data from a wide variety of turbulent boundary-layer experiments. The accuracy of the fit is as good as that demonstrated for the law of the wake. Since the present formulation has no discontinuity in the velocity derivative at the edge of the boundary layer, data from the whole boundary layer can be effectively collapsed. The modified form of the inner law is interpreted as the mean velocity profile of the turbulent boundary layer in the case of a large favorable pressure gradient.

## References


Chapman, D. R. and Kuhn, G. D., 1986 The limiting behaviour of turbulence near a wall. *J. Fluid Mech.* **170**, 265-292.

Clauser, F. H., 1954 Turbulent boundary layers in adverse pressure gradients. *J. Aero. Sci.* **21**, 91-108.

Clauser, F. H., 1956 The turbulent boundary layer. *Adv. Appl. Mech.* **4**, 1-51.

Coles, D. E., 1956 The law of the wake in the turbulent boundary layer. *J. Fluid Mech.* **1**, 191-226.

Coles, D. E., 1968 The young person's guide to the data. In Coles and Hirst (1968), 1-45.

Coles, D. E., 1985 The uses of coherent structure. *AIAA-85-0506.*

Coles, D. E. and Hirst, E. A., 1968 *Computation of Turbulent Boundary Layers – 1968 AFOSR-IFP-Stanford Conference. Volume II Compiled Data.*

Dean, R. B., 1976 A single formula for the complete velocity profile in a turbulent boundary layer. *J. Fluids Eng.* **98**, 723-727.

Granville, P. S., 1976 A modified law of the wake for turbulent shear flows. *J. Fluids Eng.* **98**, 578-580.

Li, J. D. and Perry, A. E., 1989 Shear stress profiles in zero-pressure-gradient turbulent boundary layers. *Tenth Australasian Fluid Mechanics Conference*, University of Melbourne.

Liakopoulos, A., 1984 Explicit representations of the complete velocity profile in a turbulent boundary layer. *AIAA J.* **22**, 844-846.

Mellor, G. L. and Gibson, D. M., 1966 Equilibrium turbulent boundary layers. *J. Fluid Mech.* **24**, 225-253.

Phillips, W. C. and Ratnanather, J. T., 1990 The outer region of a turbulent boundary layer. *Phys. Fluids A* **2**, 427-434.

Rotta, J. C. 1974 Die turbulente Grenzschicht an einer stark geheizten ebenen Platte bei Unterschallströmung. *Wärme- und Stoffübertragung* **7**, 133-144.

Spalding, D. B., 1961 A single formula for the 'law of the wall'. *J. Appl. Mech.* **28**, 455-458.

Townsend, A. A., 1976 *The structure of turbulent shear flow.* Cambridge University Press, Cambridge.

White, F. M., 1974 *Viscous fluid flow.* McGraw-Hill, New York.

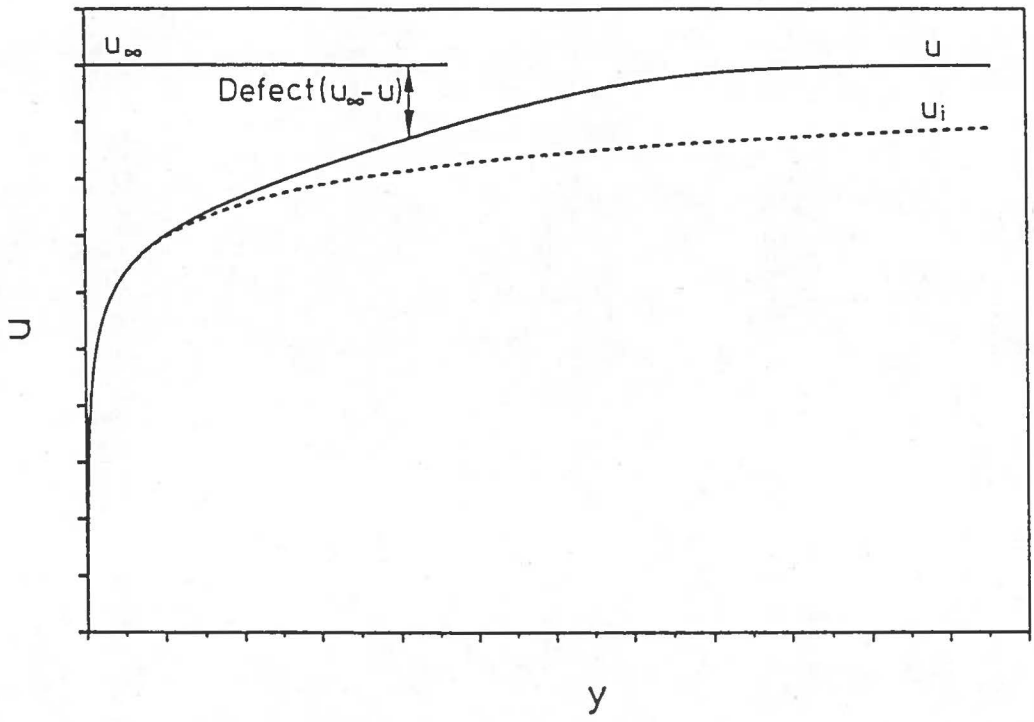



Figure 1. Turbulent boundary layer profile for a zero pressure gradient flat plate flow.——, $u$;- - -, $u_i$.

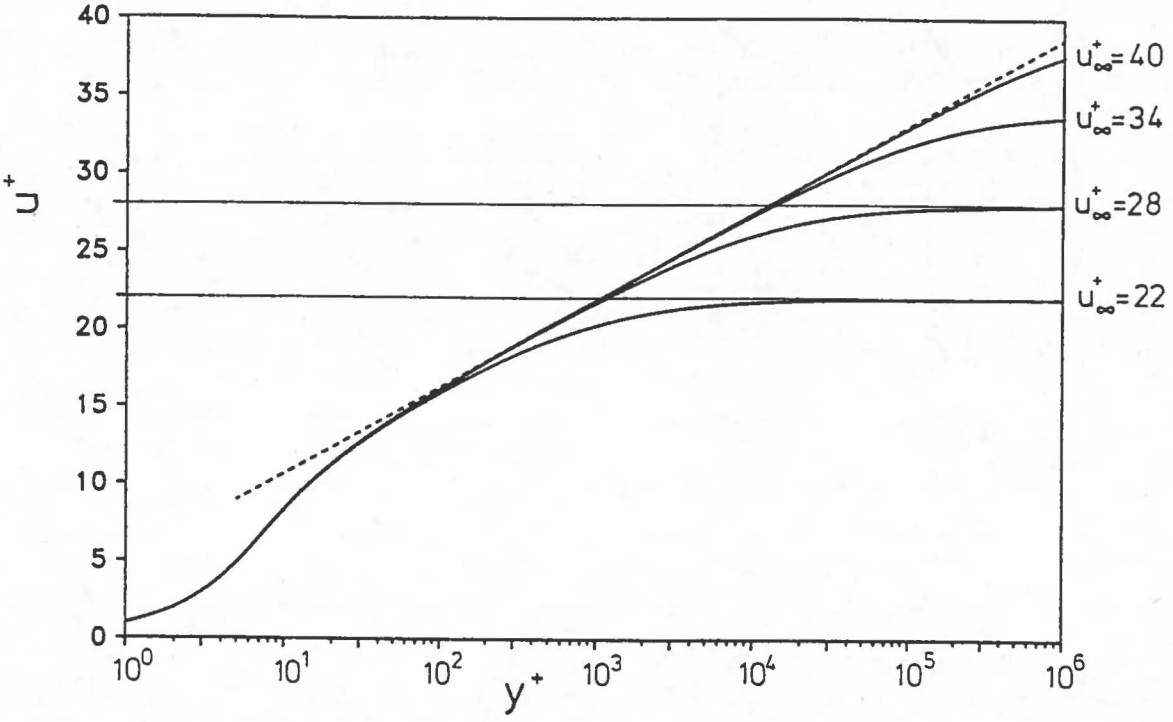



Figure 2. The modified inner law of the turbulent boundary layer for various values of $u^+_\infty$. ——, $u_i$; – – –, $2.44 \ln y^+ + 5.0$.

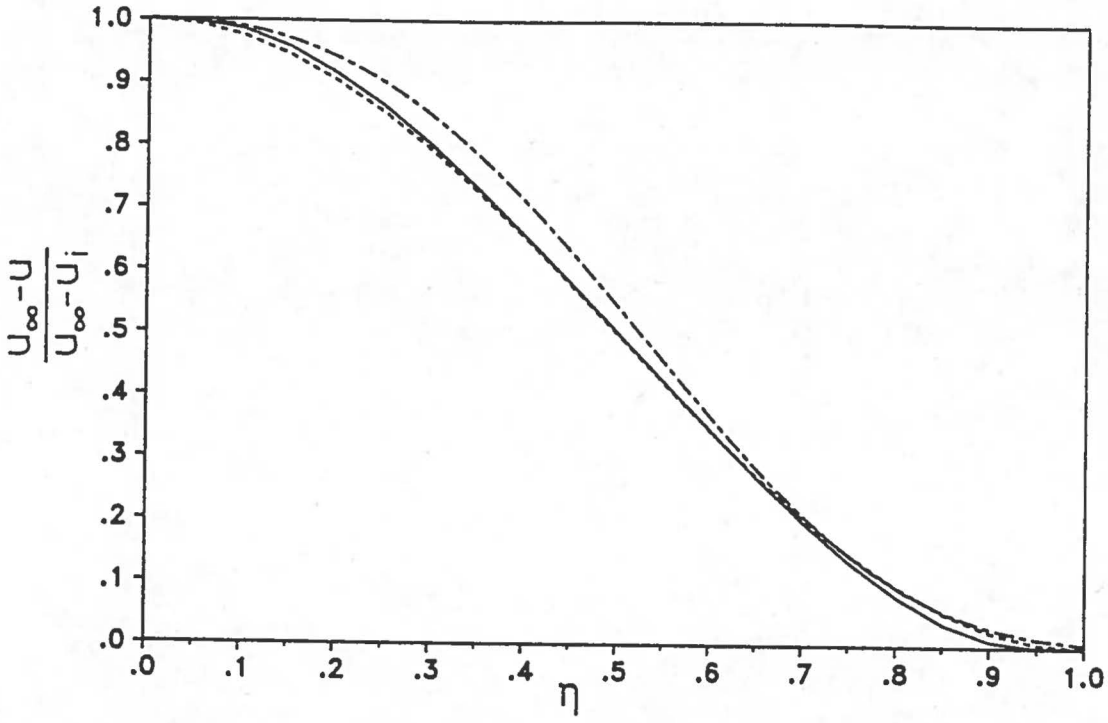



Figure 3. Comparison of separating flow profiles.——, Coles tabulated function;- - -, Coles, $\sin^2$;— -, outer-law function, equation (9).

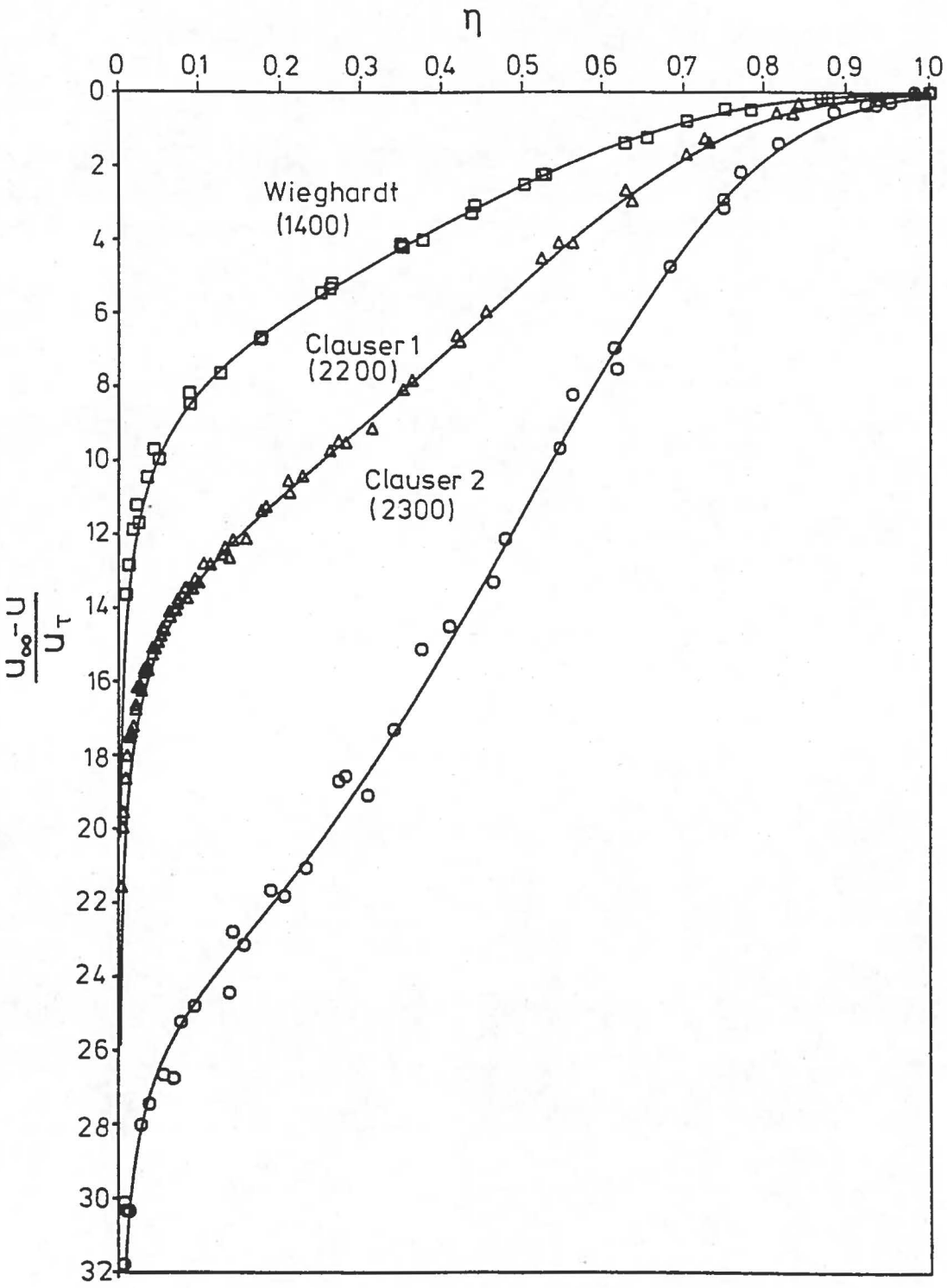



Figure 4. Velocity-defect profiles from the current formulation, compared with data from Wieghardt, Clauser 1 and Clauser 2.

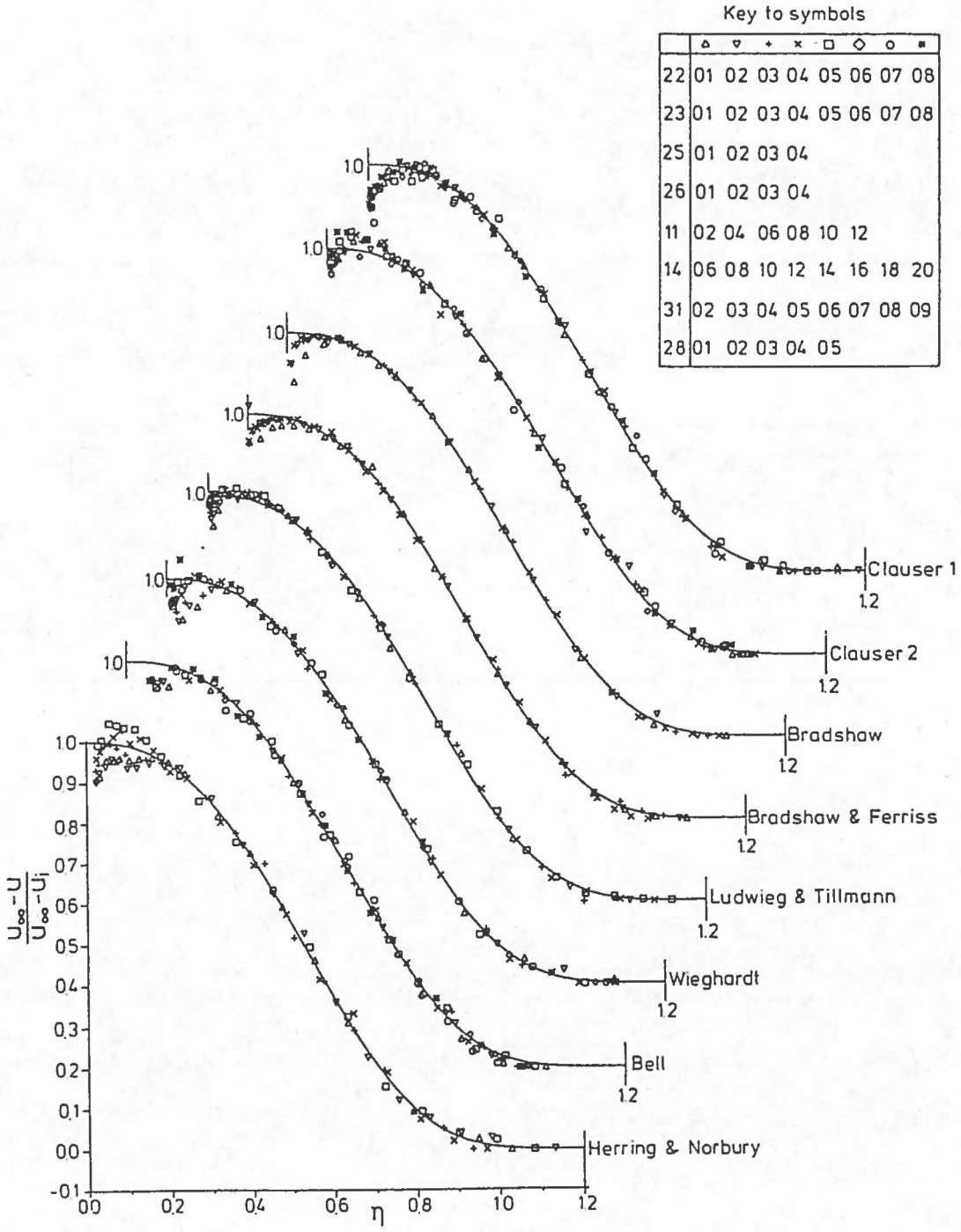



Figure 5. Data from 8 separate experiments, plotted in the format of equation (8). The solid line is the outer-law function (9). The first column in the table gives the first two digits of the 4-digit reference code. Table entries give the last two digits and associate a given velocity profile with a symbol on the plot.

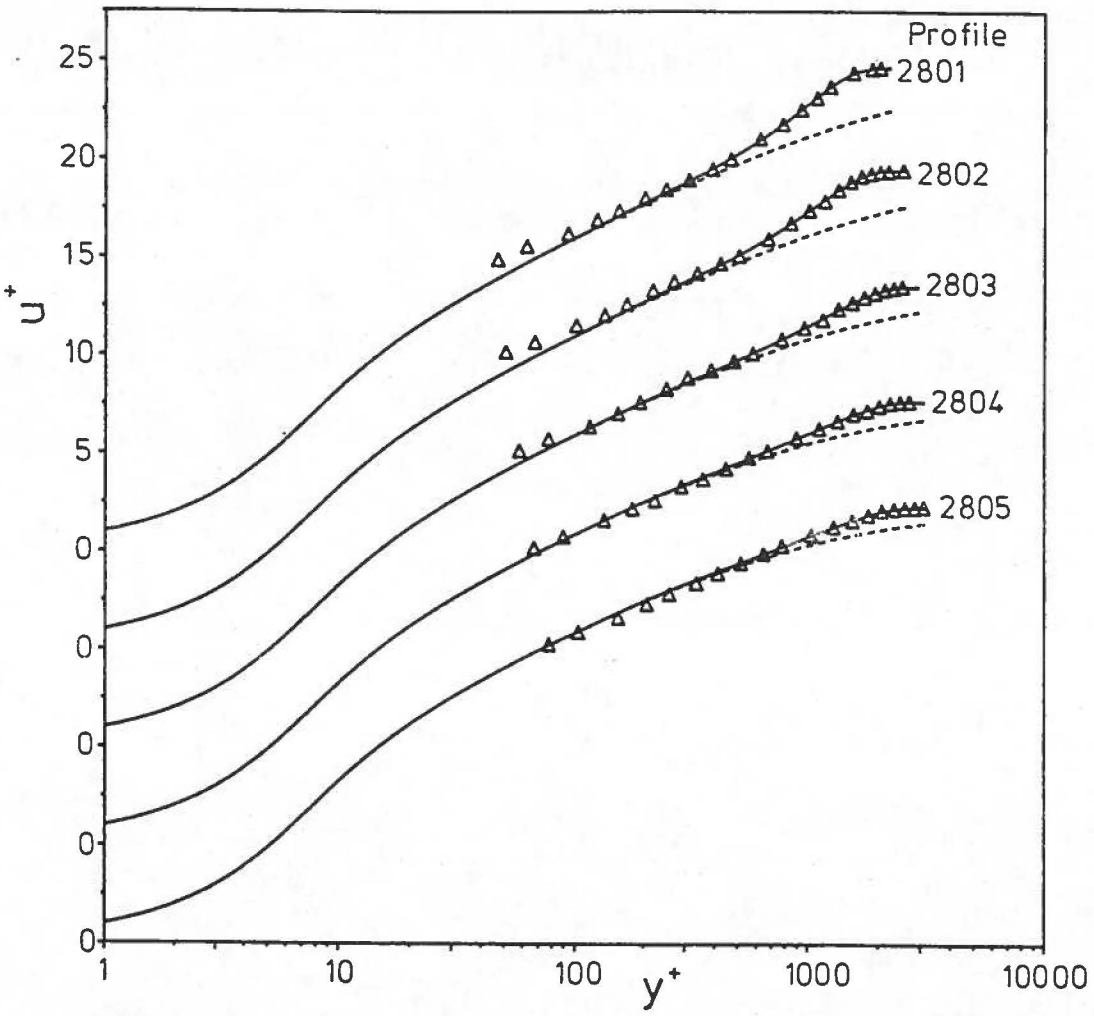



Figure 6. Data points from Herring and Norbury plotted in inner variables. ——, fitted profile; – – –, inner law.

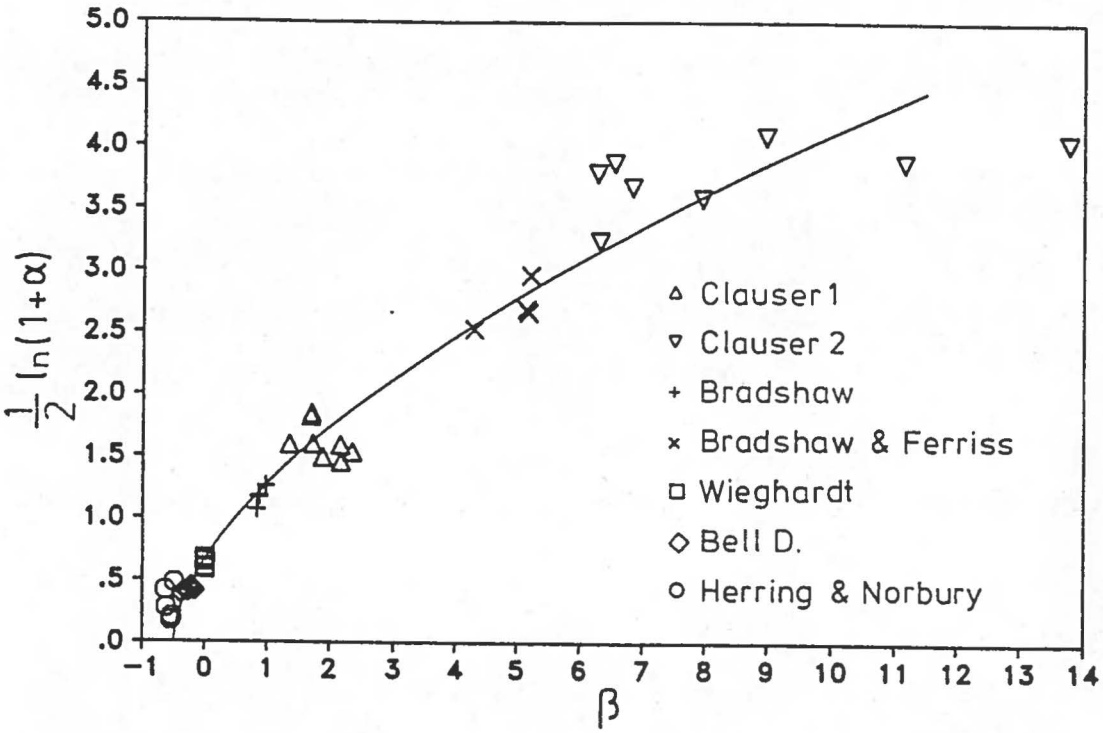



Figure 7. Plot of $\frac{1}{2}\ln(1+\alpha)$ against $\beta$ for near-equilibrium turbulent boundary layers. The solid line is the empirical correlation of equation (16).

## APPENDIX C: GRAPHS FROM COLES 2003 ATTACHMENT E

The graphs in this appendix are plots of the data in APPENDIX D. The header in the graphs has the author's name, Coles' ID, and date. The following table summarizes the data by ID number. Data from the LDA boundary-layer measurements are for the location 250 mm (9.8 inches) above tunnel centerline.

### Table C-1. Summary of Data

| Coles' ID | $U_t$ (m/s) | x (m) | Page |
|---|---|---|---|
| 3683 | 2.5 | 1.23 | C-3 |
| 3694 | 2.5 | 11.96 | C-14 |
| 3695 | 5.0 | 1.23 | C-15 |
| 3706 | 5.0 | 11.96 | C-26 |
| 3707 | 10.0 | 1.23 | C-27 |
| 3718 | 10.0 | 11.96 | C-38 |
| 3719 | 15.0 | 1.23 | C-39 |
| 3730 | 15.0 | 11.96 | C-50 |

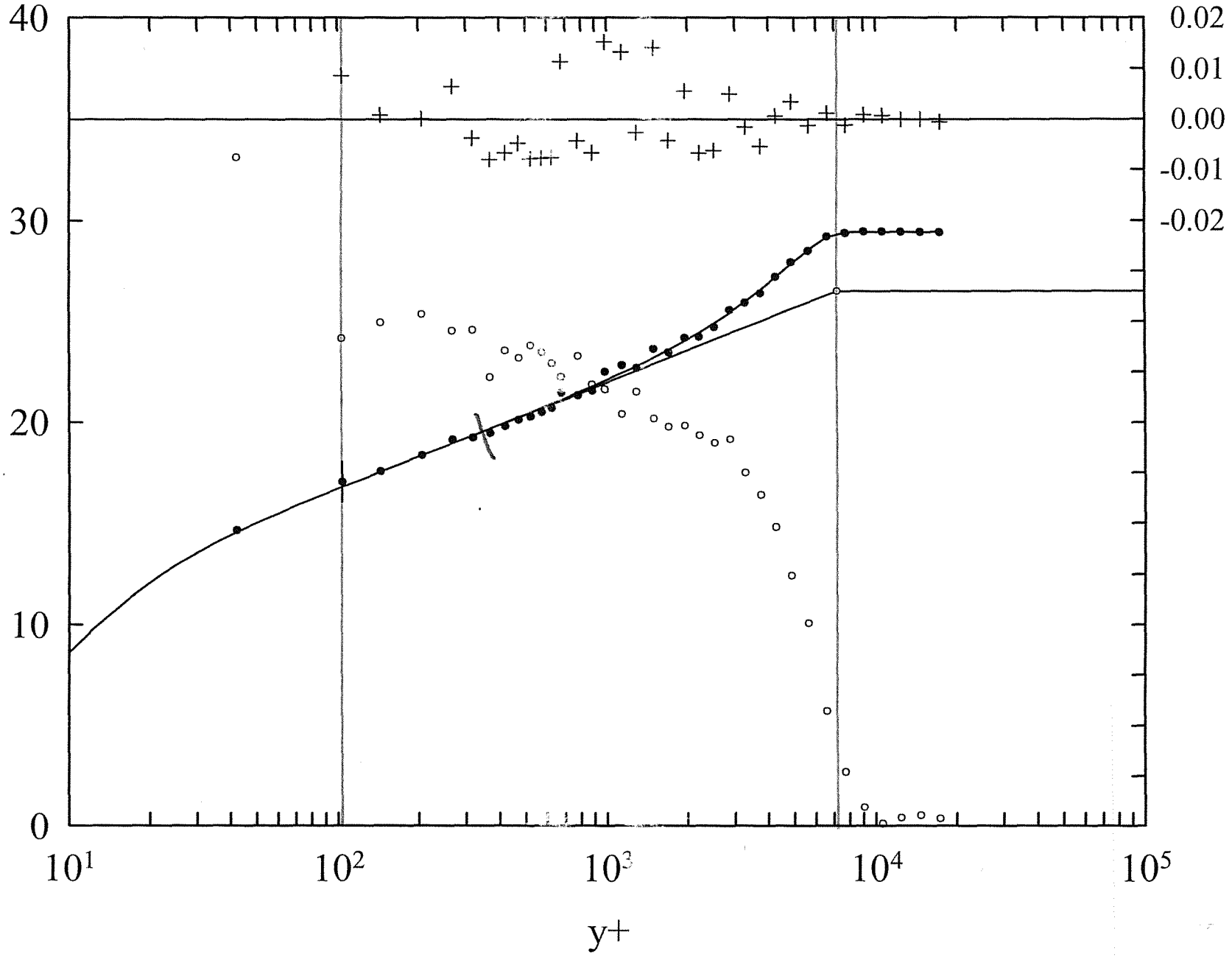
$U_t$: Nominal tunnel speed
x: Distance from tunnel-speed measurement location

Plot symbols

- \+ Residuals of velocity, $u/U_\infty$, with axis values on right
- • Boundary layer data of $u^+ = u/u_\tau$ versus $y^+ = yu_\tau/\nu$
- ○ Axial turbulence intensity of $u'^+ = u'/u_\tau$ versus $y^+$, where abscissa value is $u^+/10$

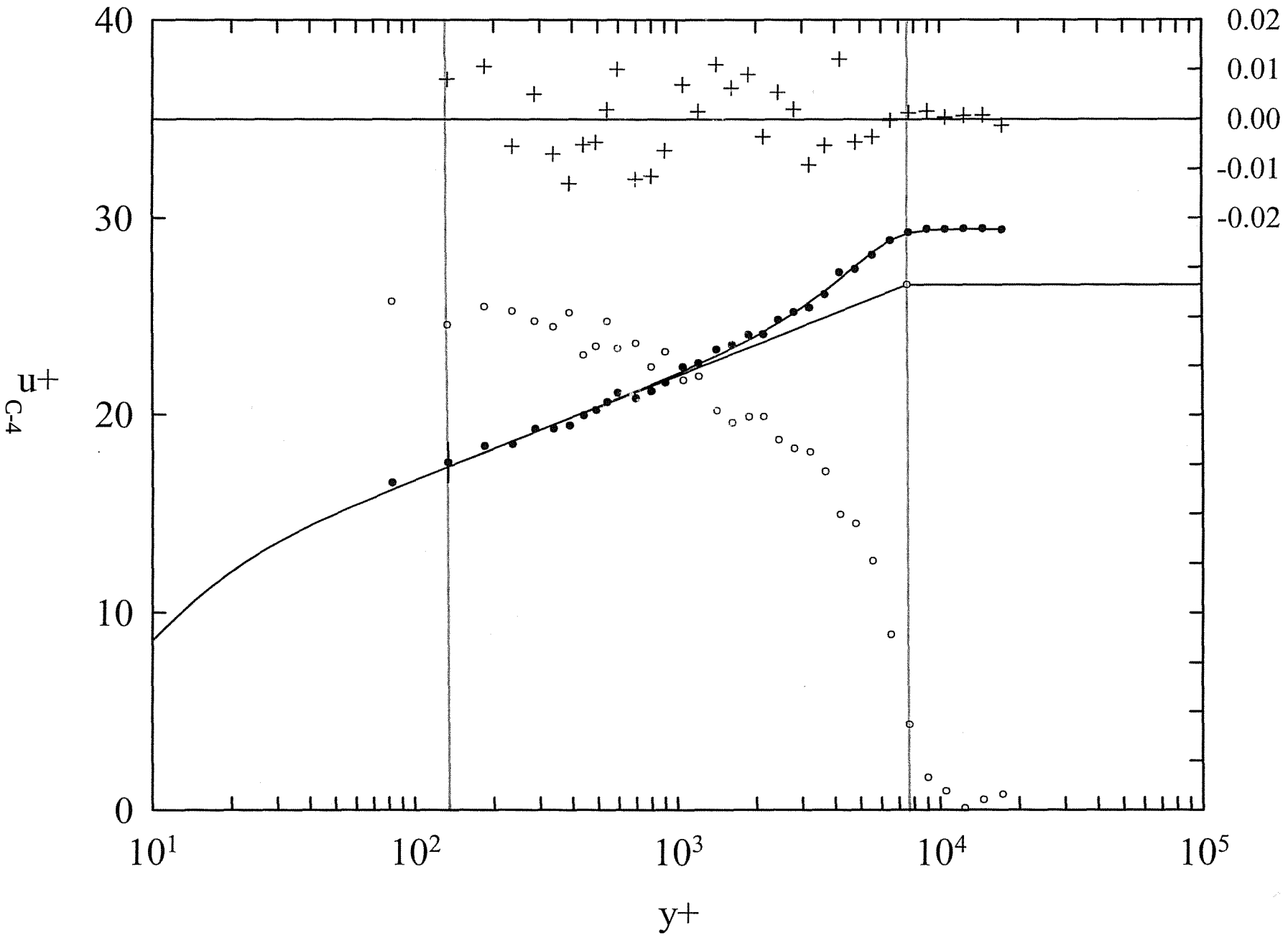
THIS PAGE INTENTIONALLY LEFT BLANK

PARK 3683 8/27/02

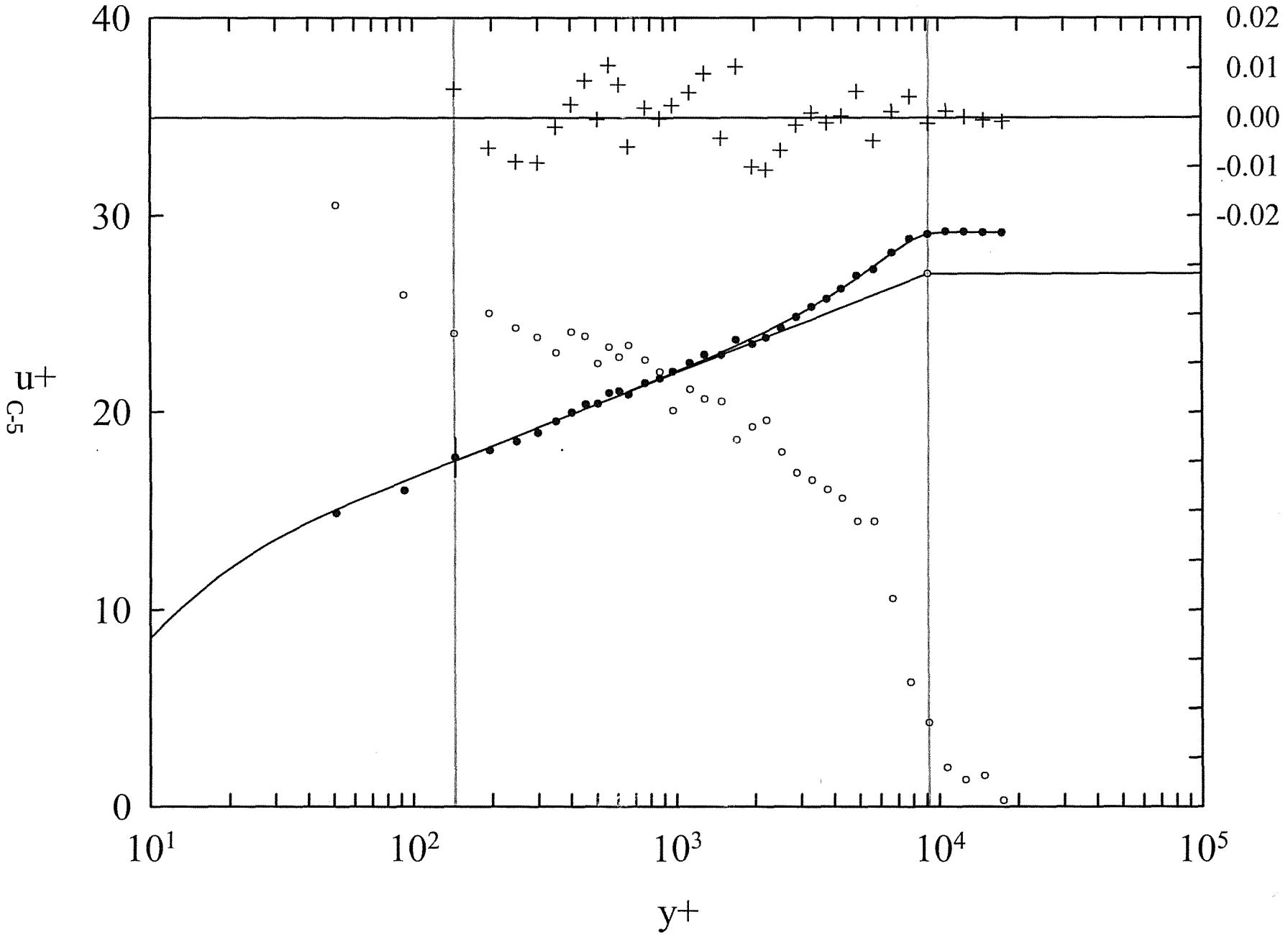


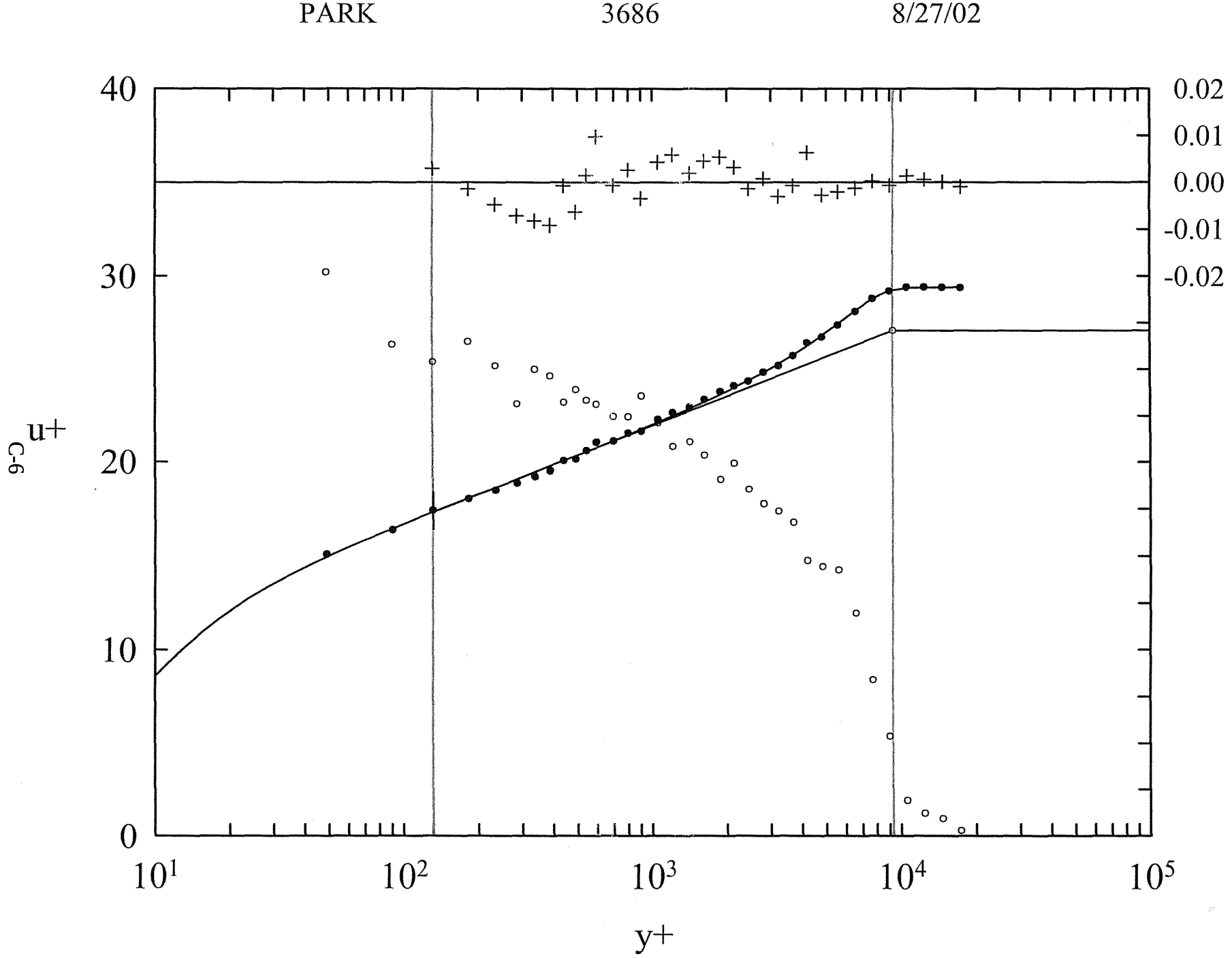

C-3

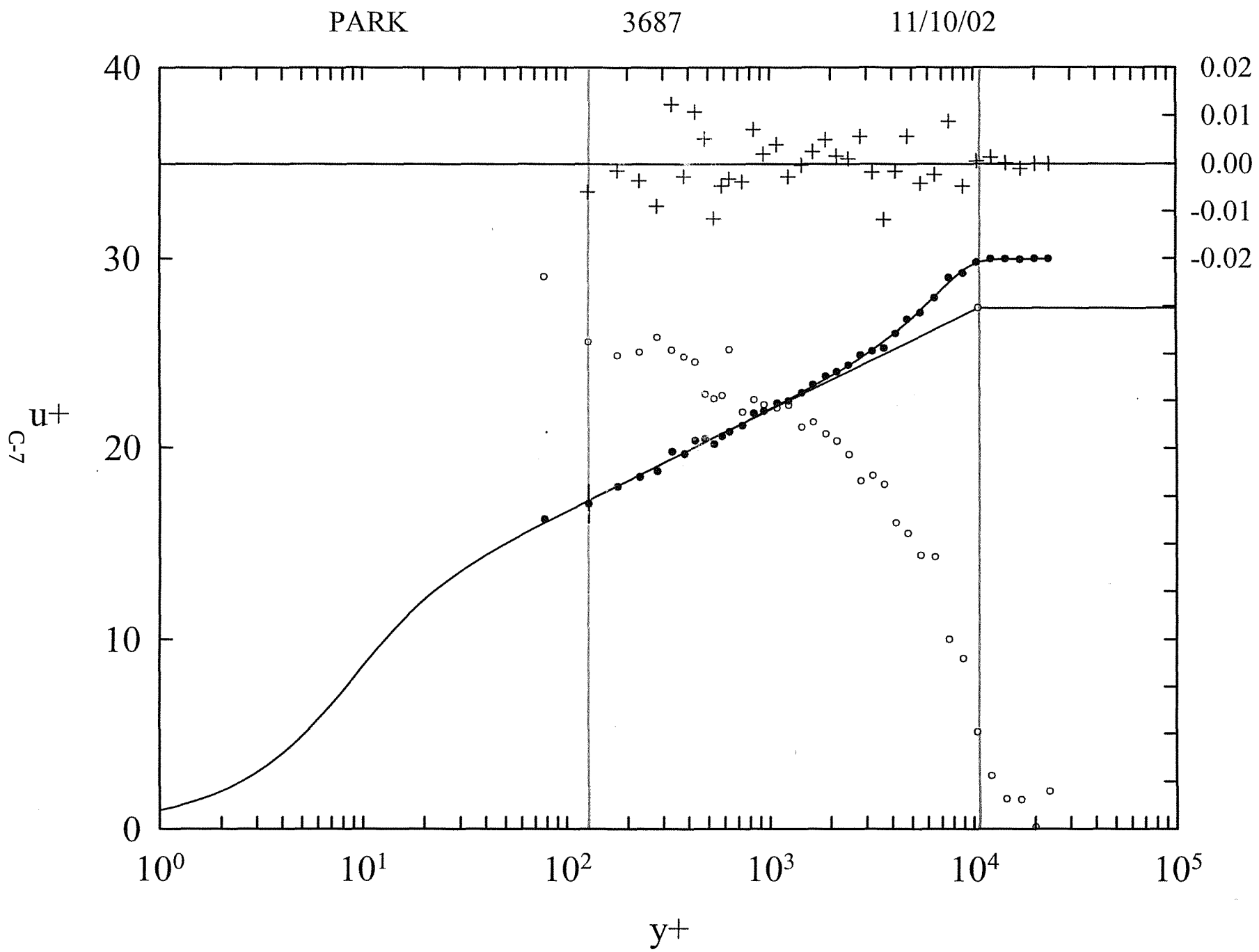
PARK 3684 8/27/02



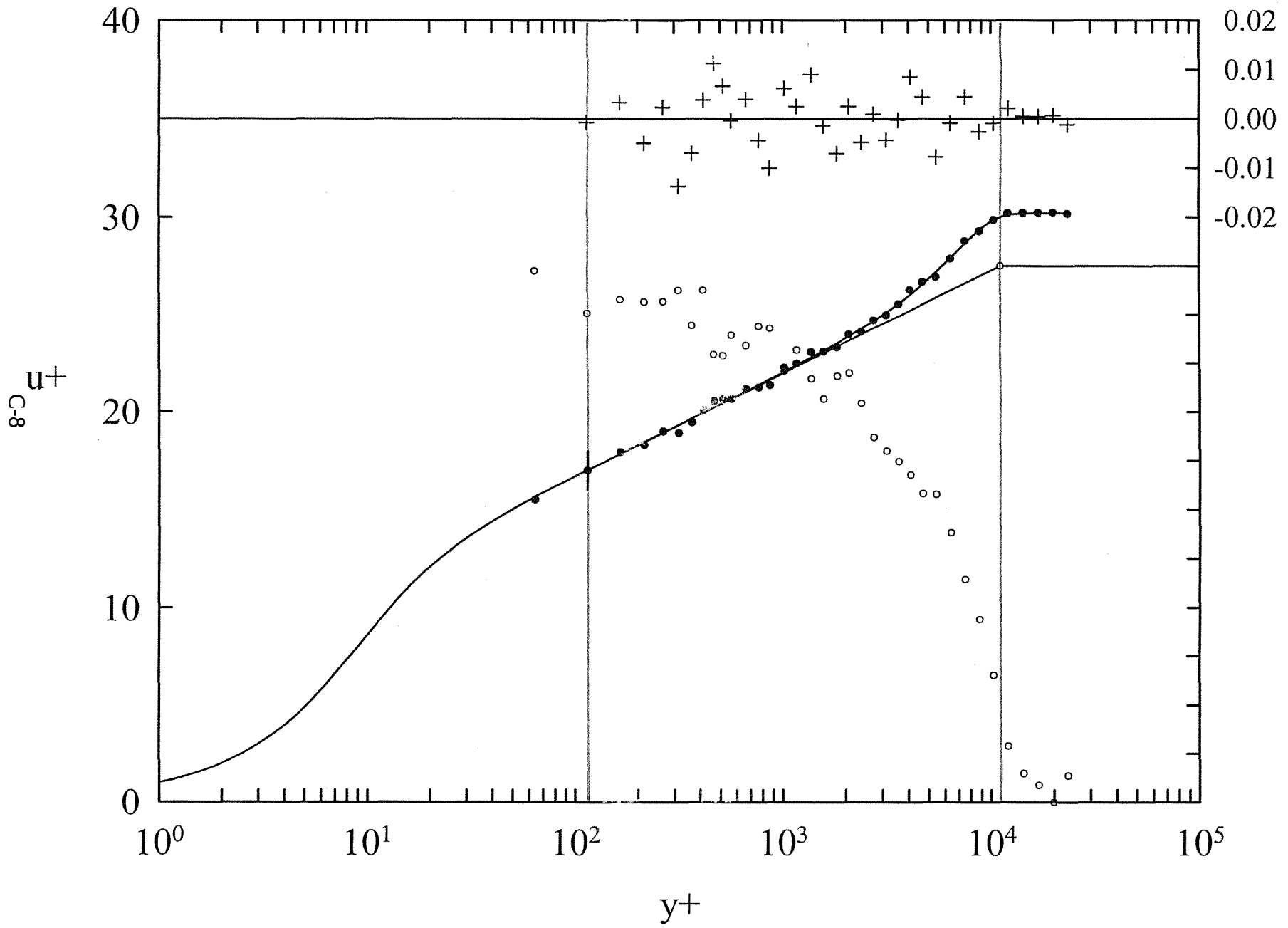
PARK 3685 8/27/02



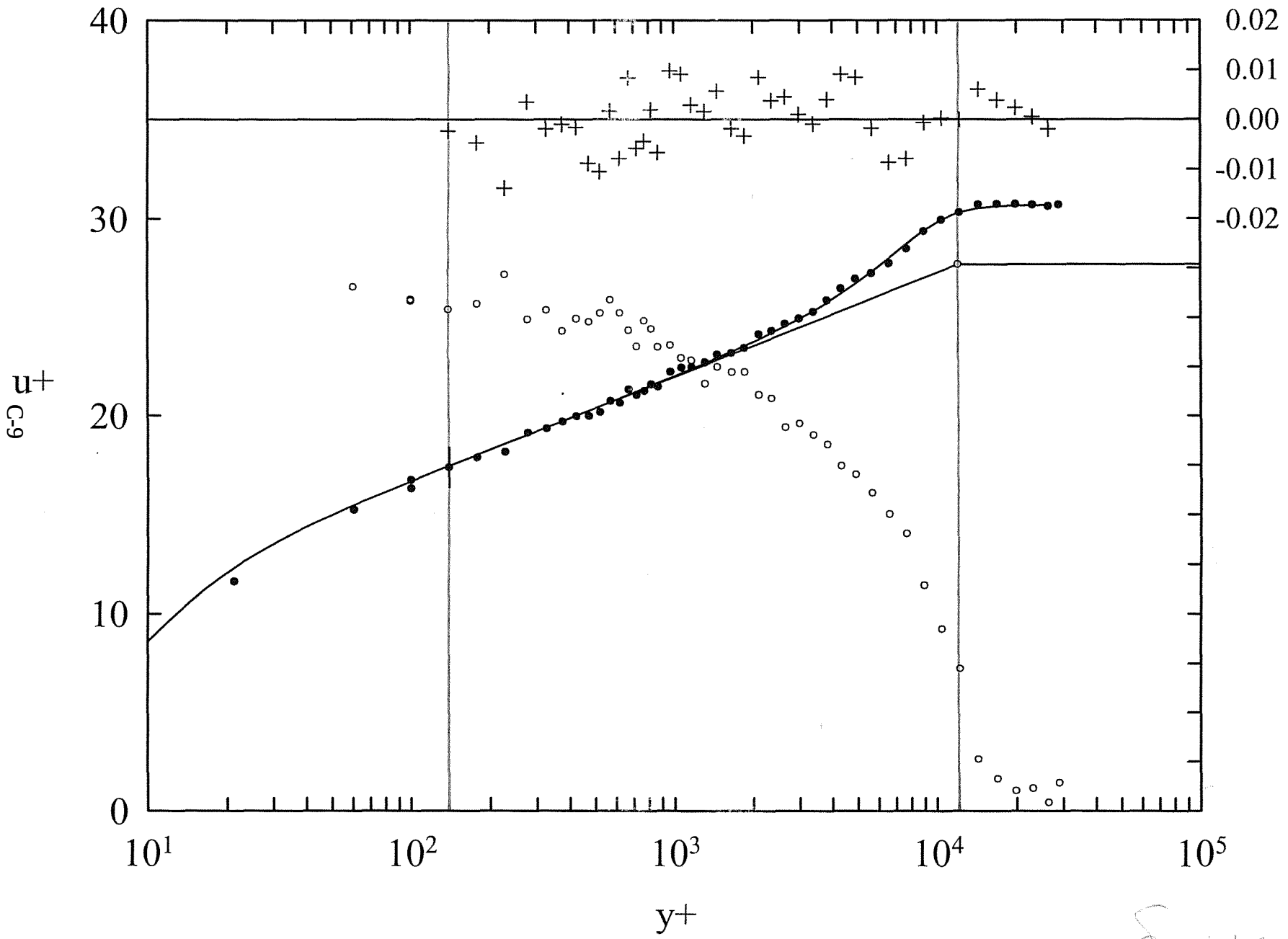

PARK
3686
8/27/02
40
30
20
10
0
0.02
0.01
0.00
-0.01
-0.02
u+
C-6
$10^1$
$10^2$
$10^3$
$10^4$
$10^5$
y+


PARK
3687
11/10/02
40
30
20
10
0
0.02
0.01
0.00
-0.01
-0.02
u+
y+
$10^0$
$10^1$
$10^2$
$10^3$
$10^4$
$10^5$

PARK 3688 8/27/02

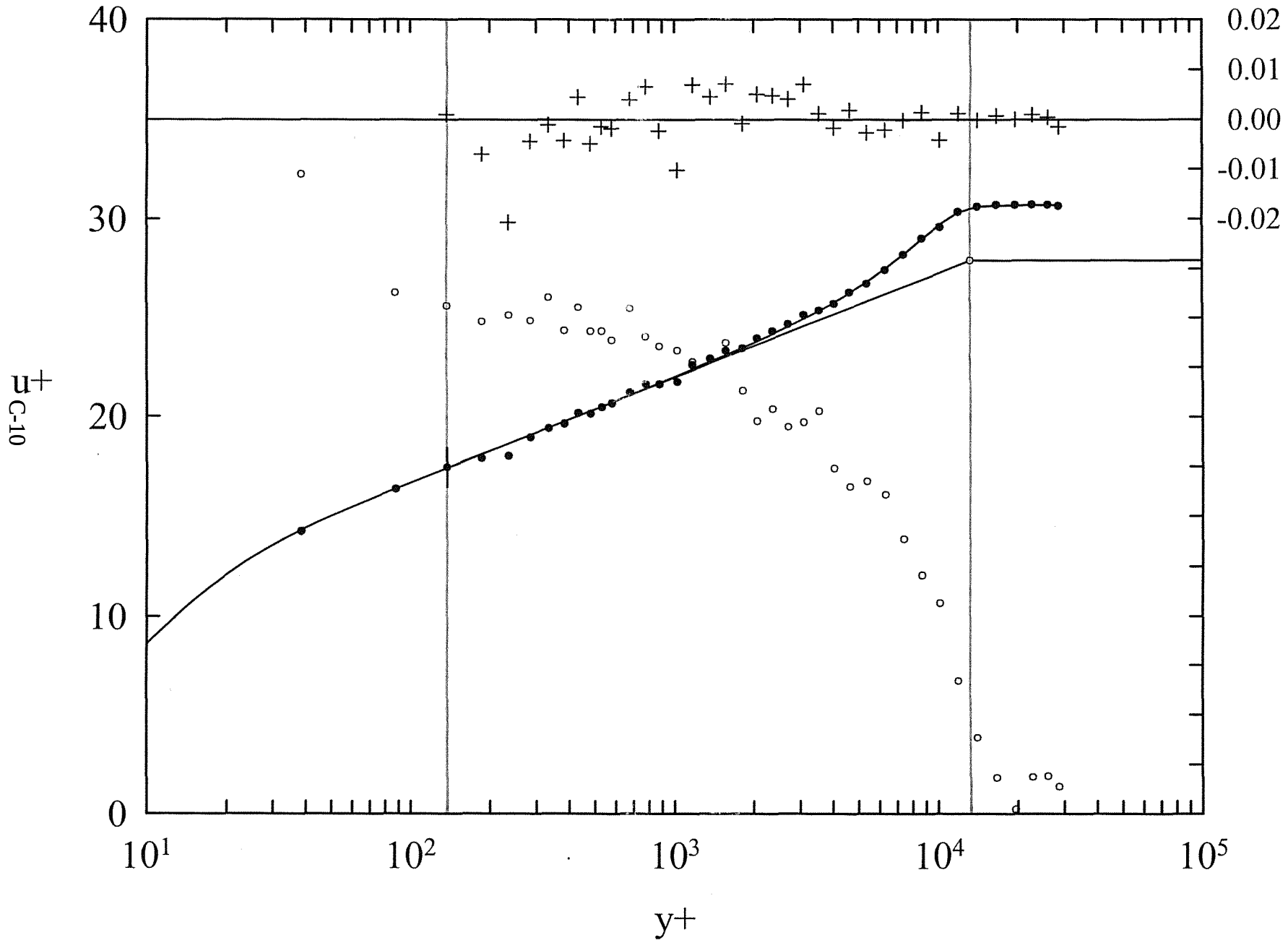


PARK 3689 8/27/02



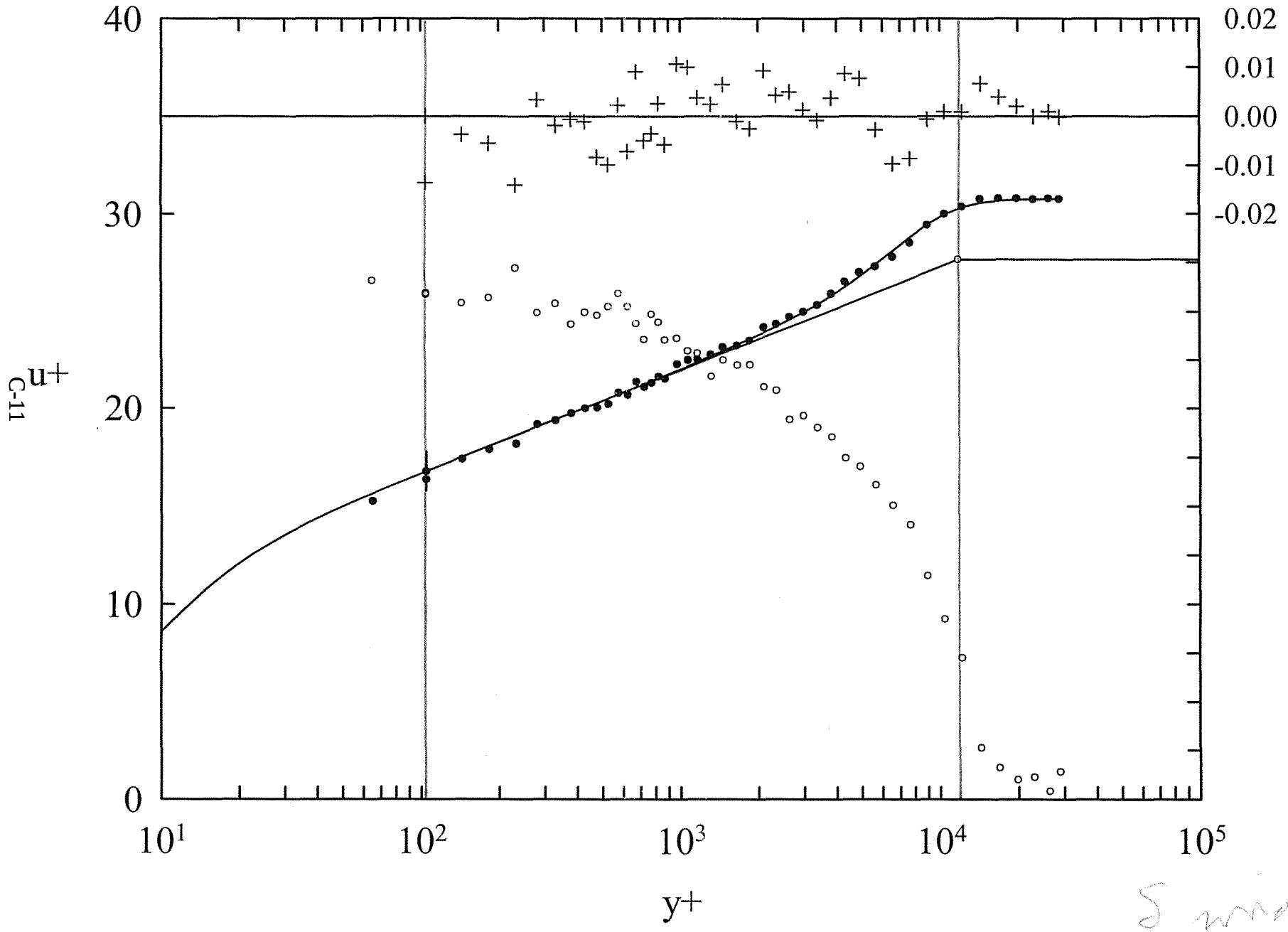

Smirnov

PARK 3690 8/27/02

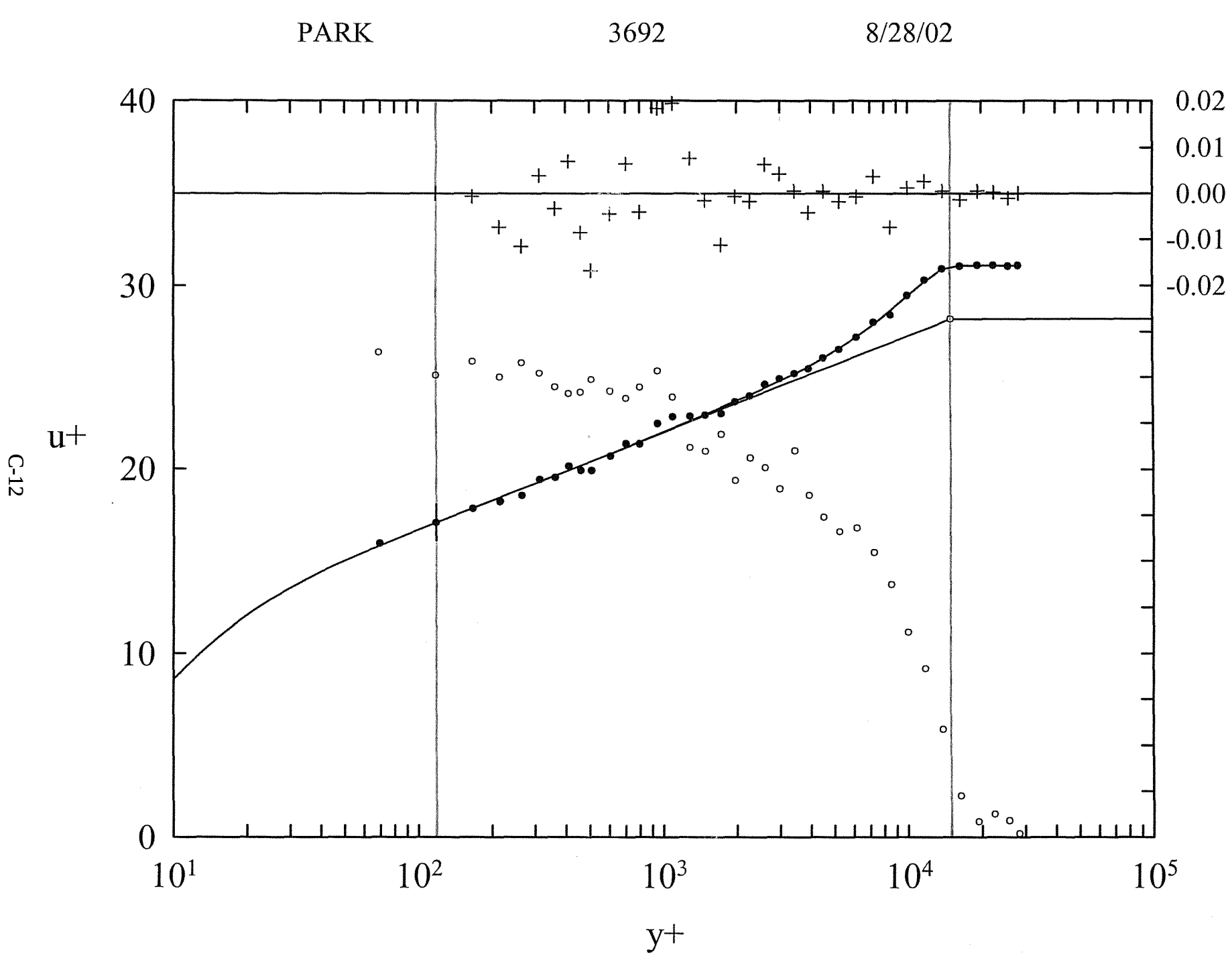



C-10

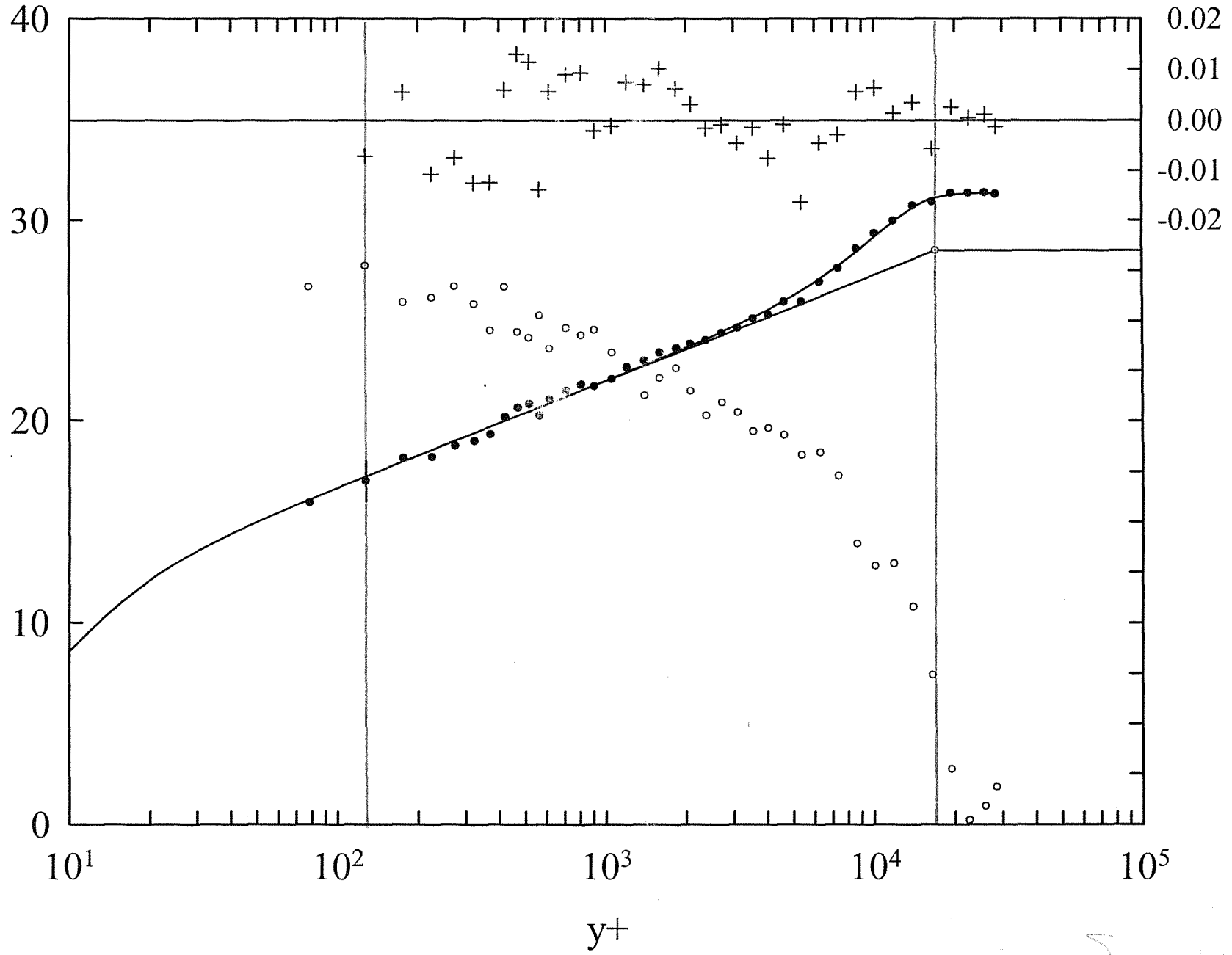
PARK 3691 8/27/02




5 wrong

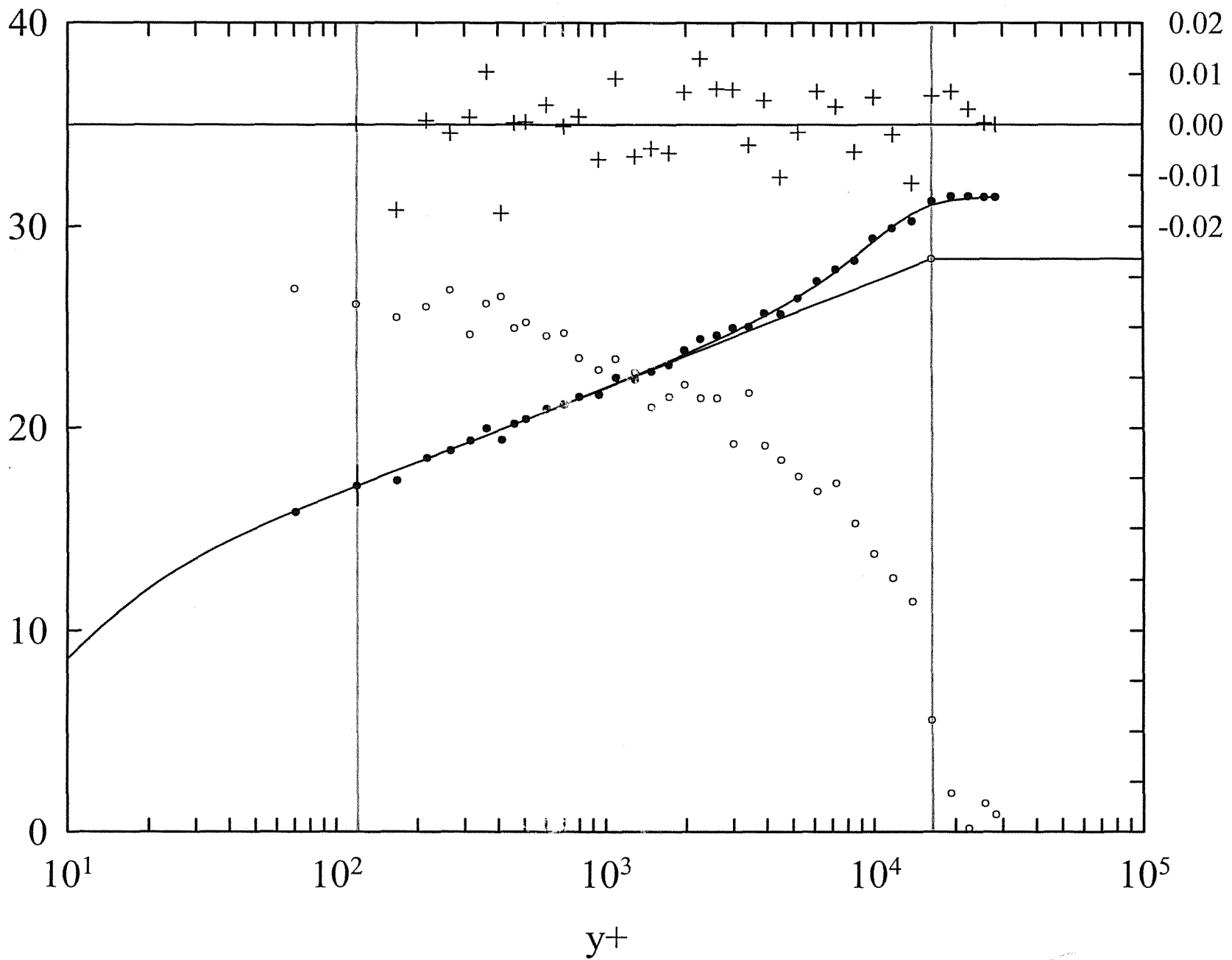

PARK
3692
8/28/02
40
30
20
10
0
0.02
0.01
0.00
-0.01
-0.02
u+
$10^1$
$10^2$
$10^3$
$10^4$
$10^5$
y+

PARK 3693 8/28/02

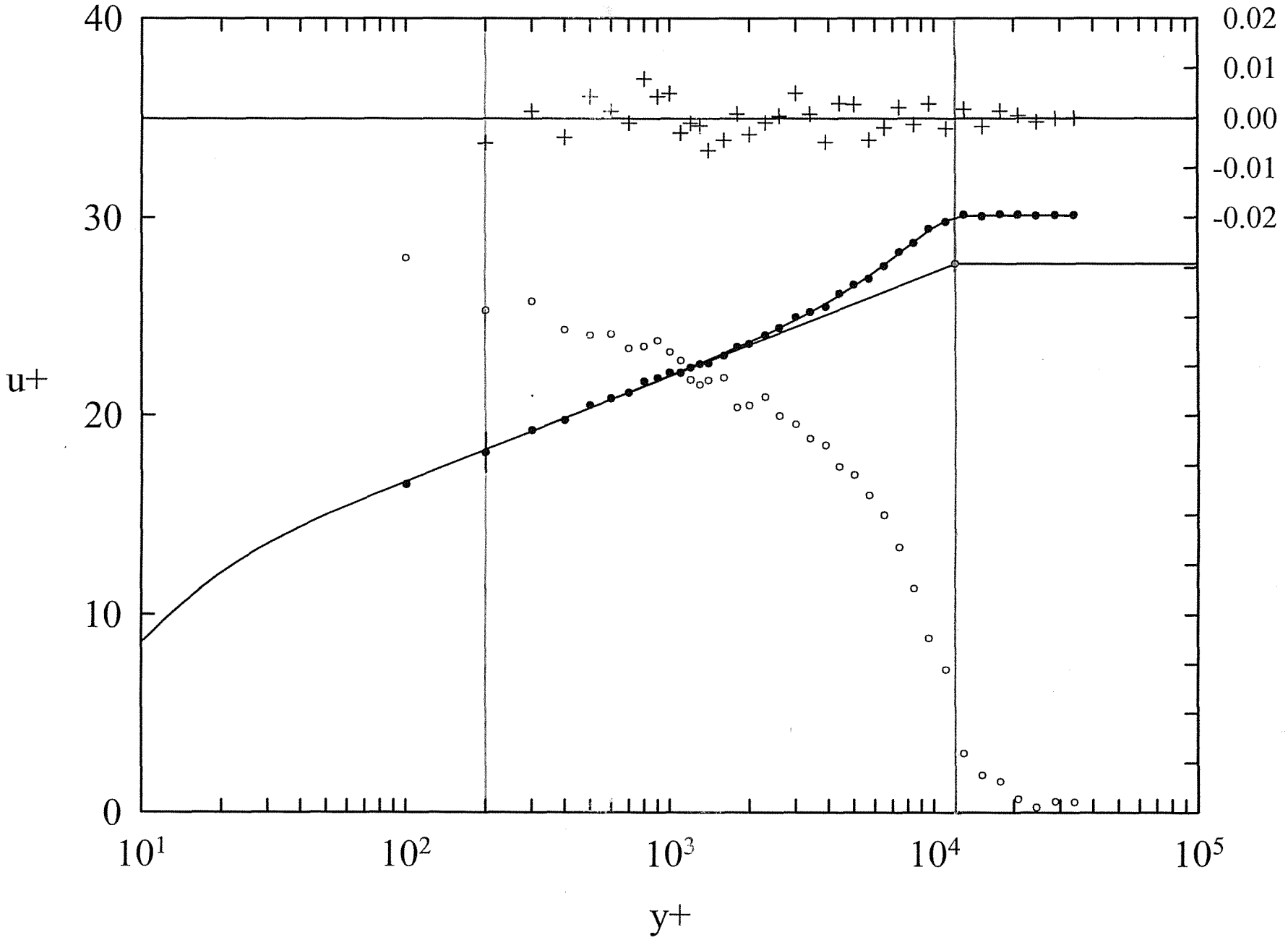


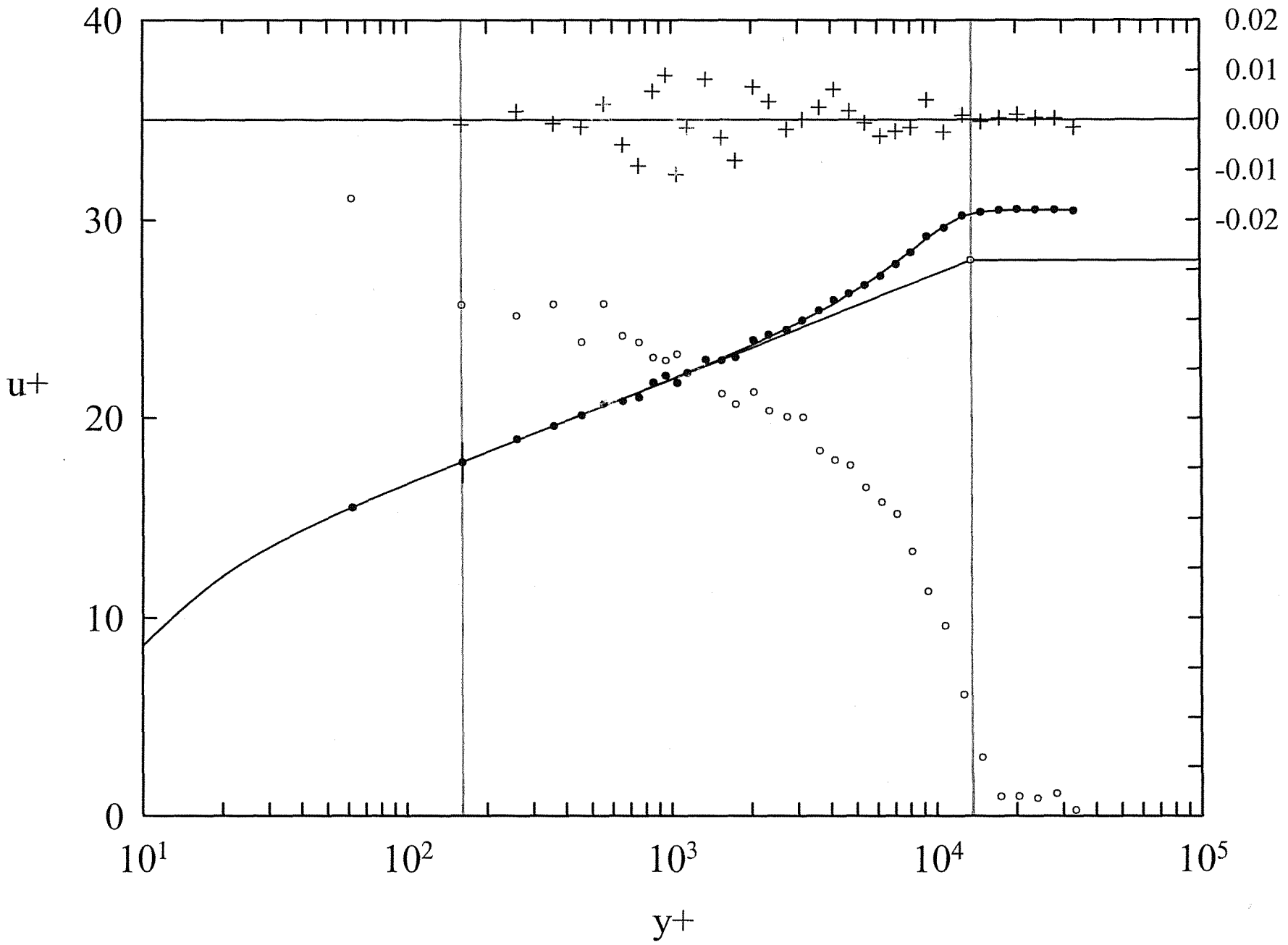

C-13

PARK 3694 8/28/02

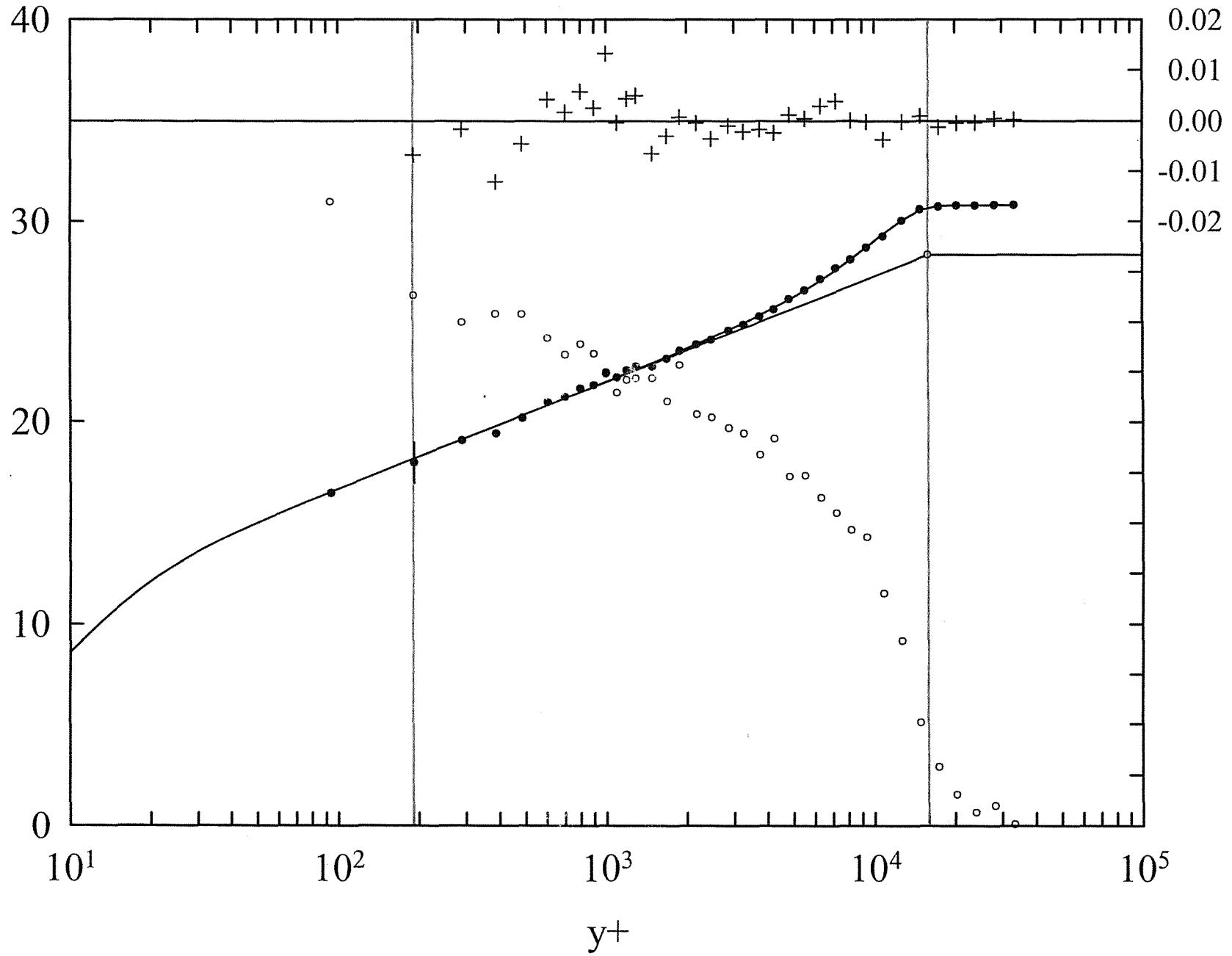



C-14

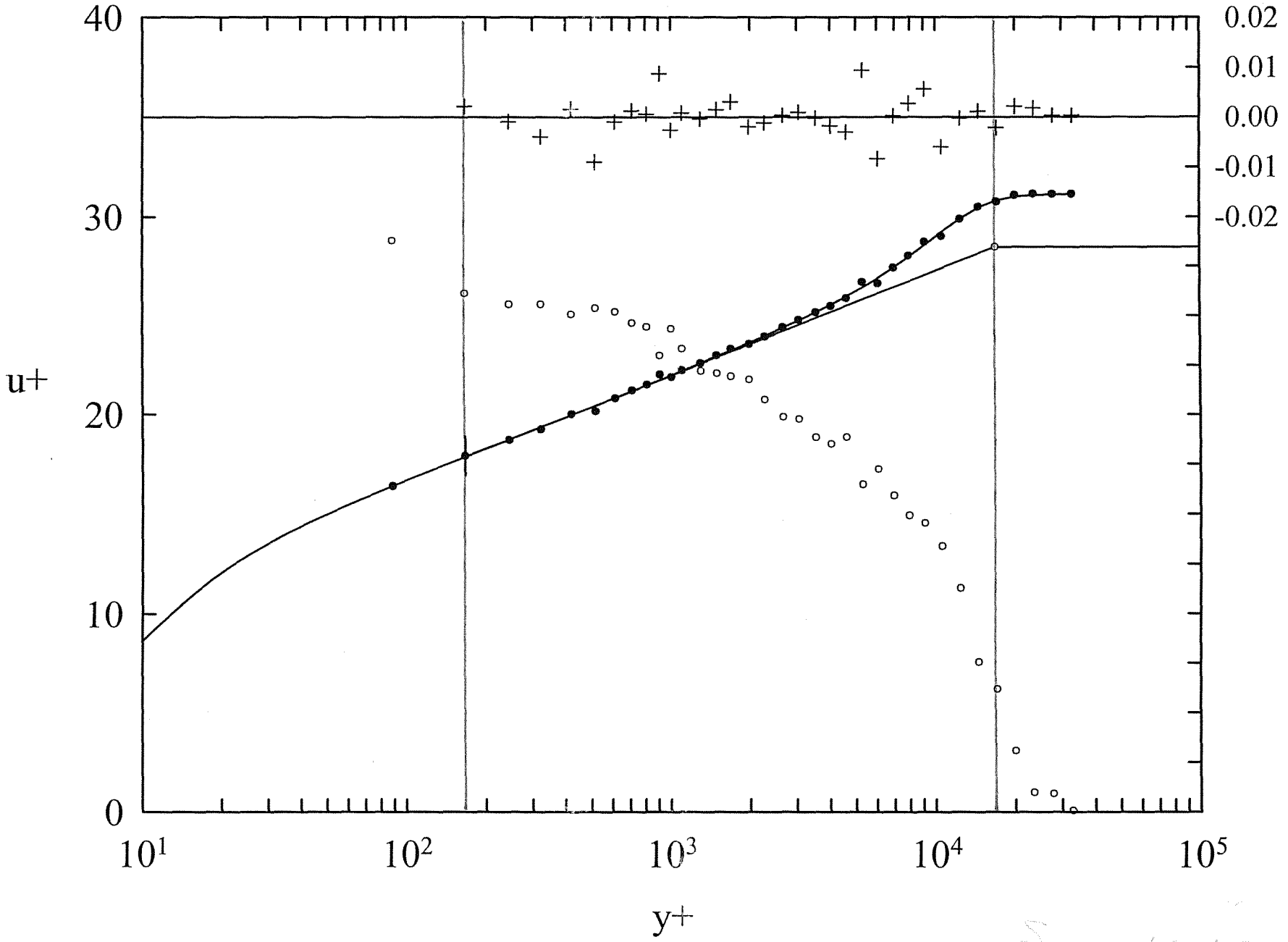

40
30
20
10
0
u+
0.02
0.01
0.00
-0.01
-0.02
$10^1$
$10^2$
$10^3$
$10^4$
$10^5$
y+

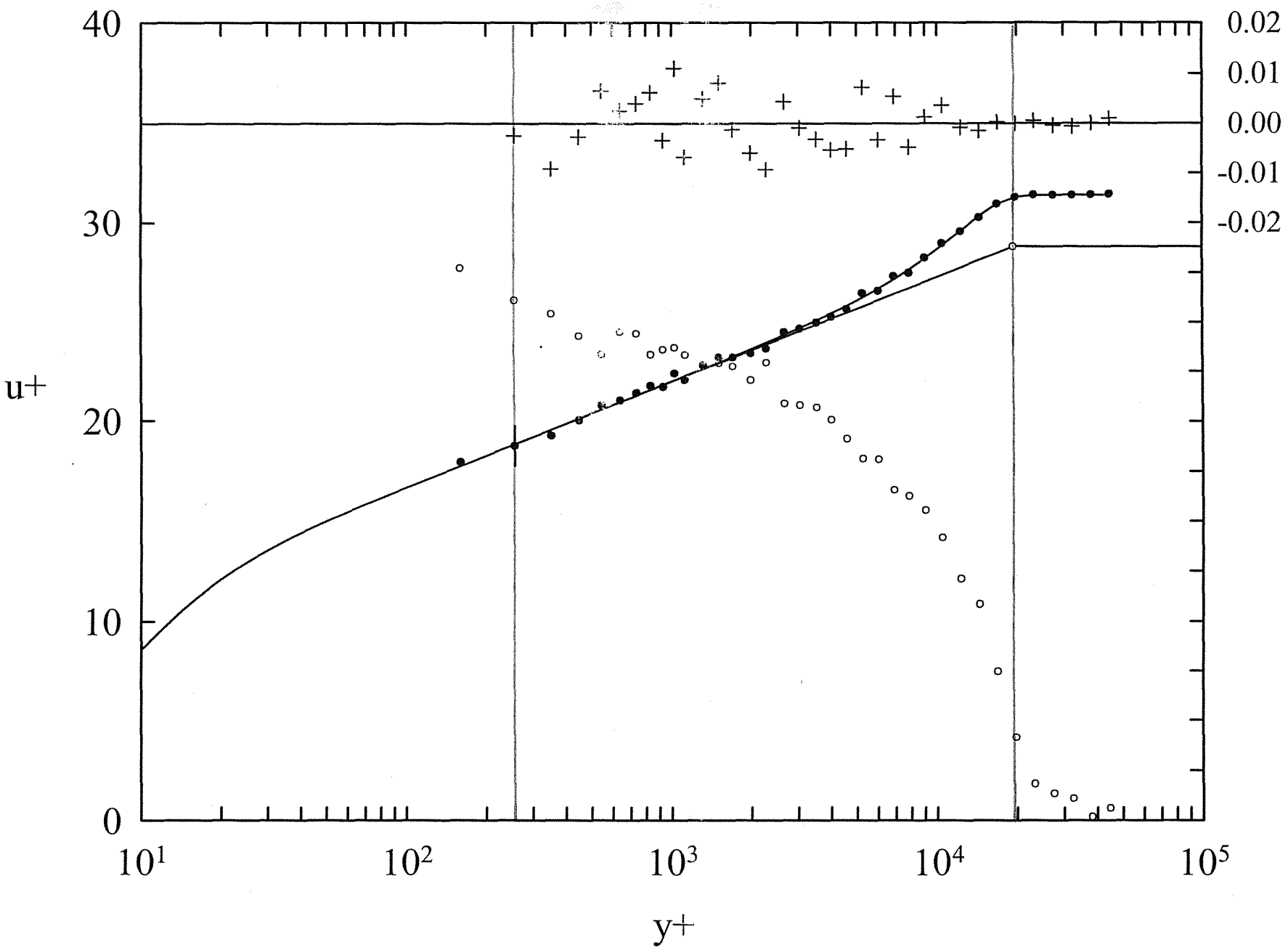

40
30
20
10
0
u+
0.02
0.01
0.00
-0.01
-0.02
$10^1$
$10^2$
$10^3$
$10^4$
$10^5$
y+

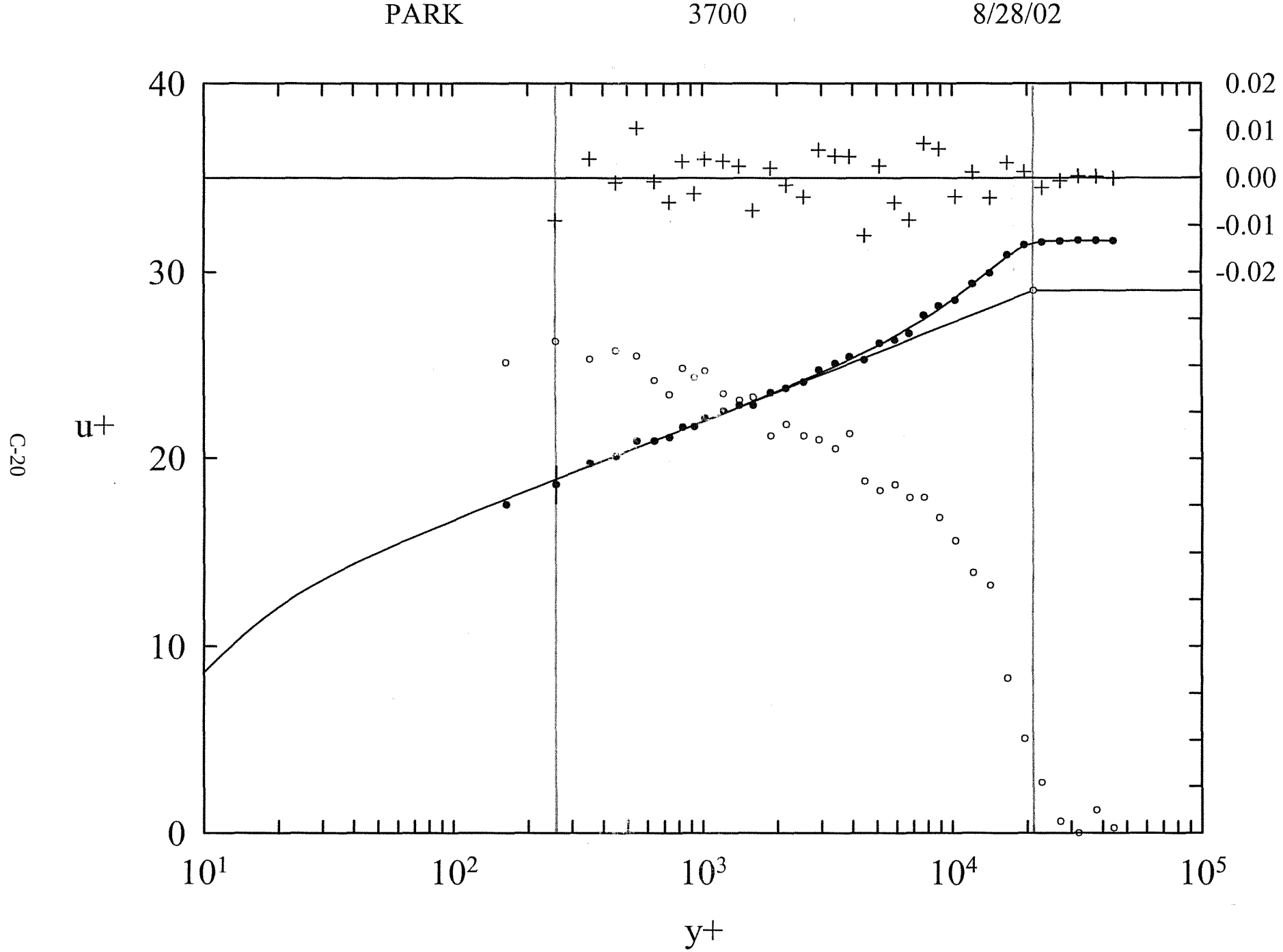
PARK 3697 8/28/02



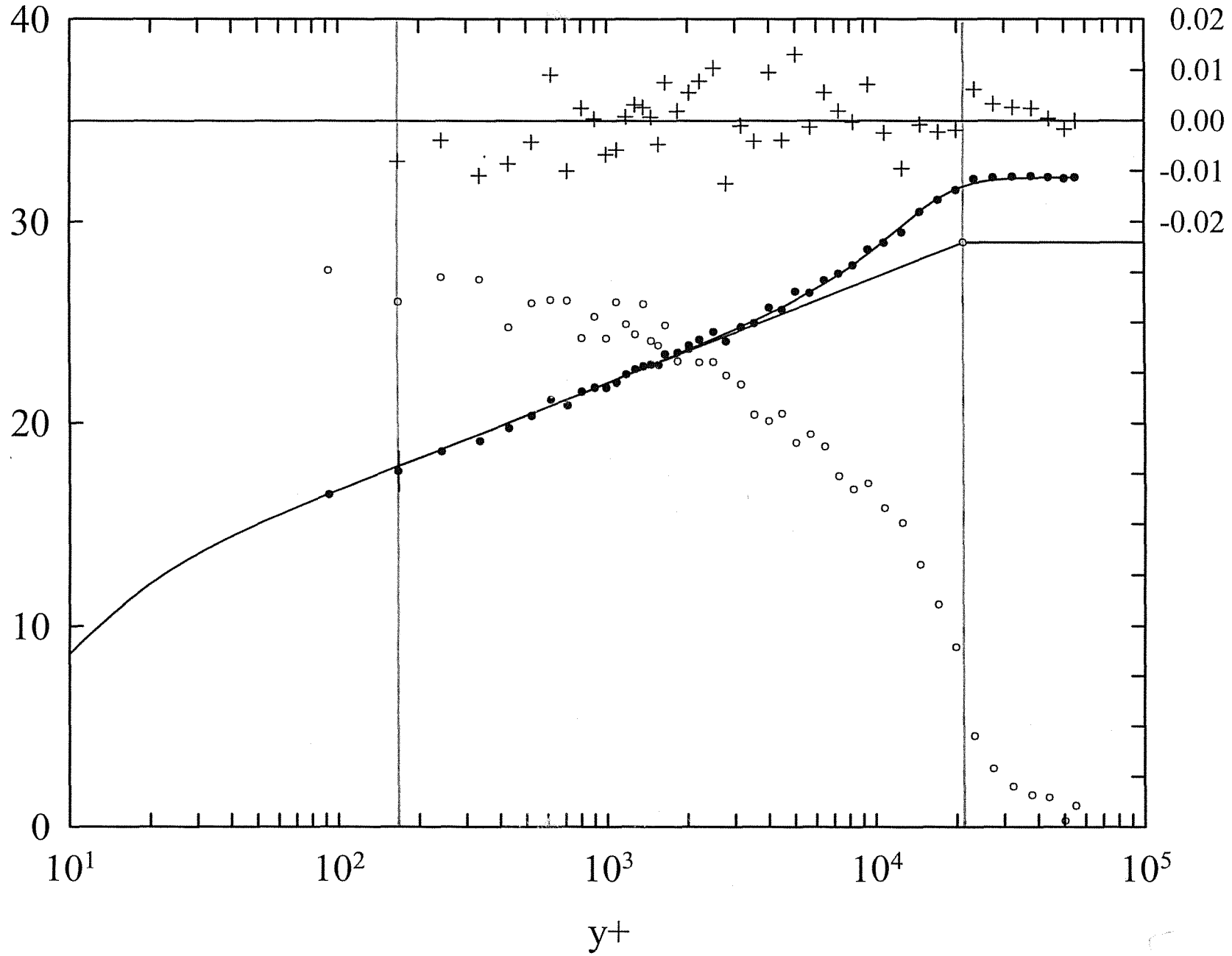
PARK 3698 8/28/02




40
30
20
10
0
u+
0.02
0.01
0.00
-0.01
-0.02
$10^1$
$10^2$
$10^3$
$10^4$
$10^5$
y+

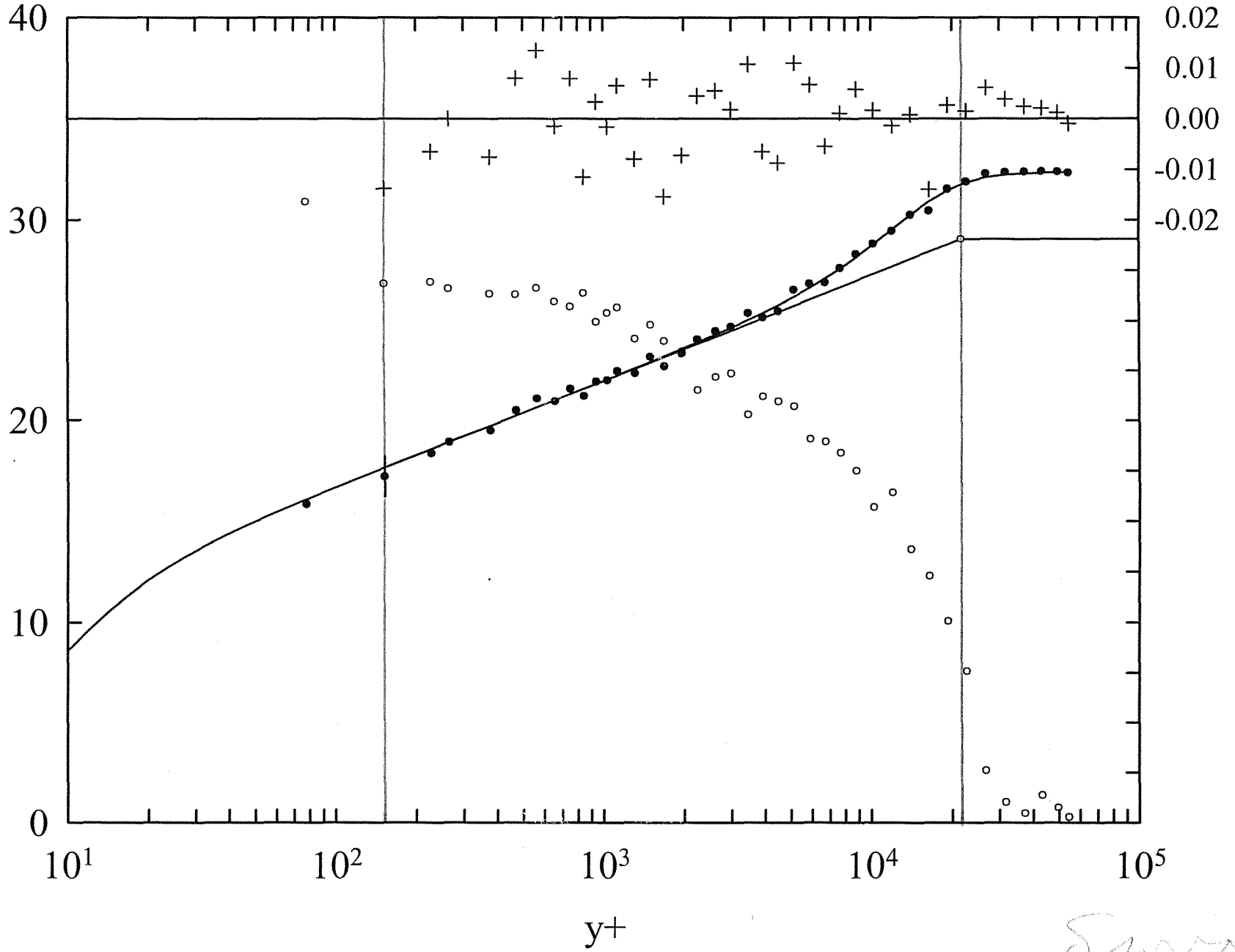

PARK
3700
8/28/02
40
30
20
10
0
u+
0.02
0.01
0.00
-0.01
-0.02
$10^1$
$10^2$
$10^3$
$10^4$
$10^5$
y+

PARK 3701 8/28/02

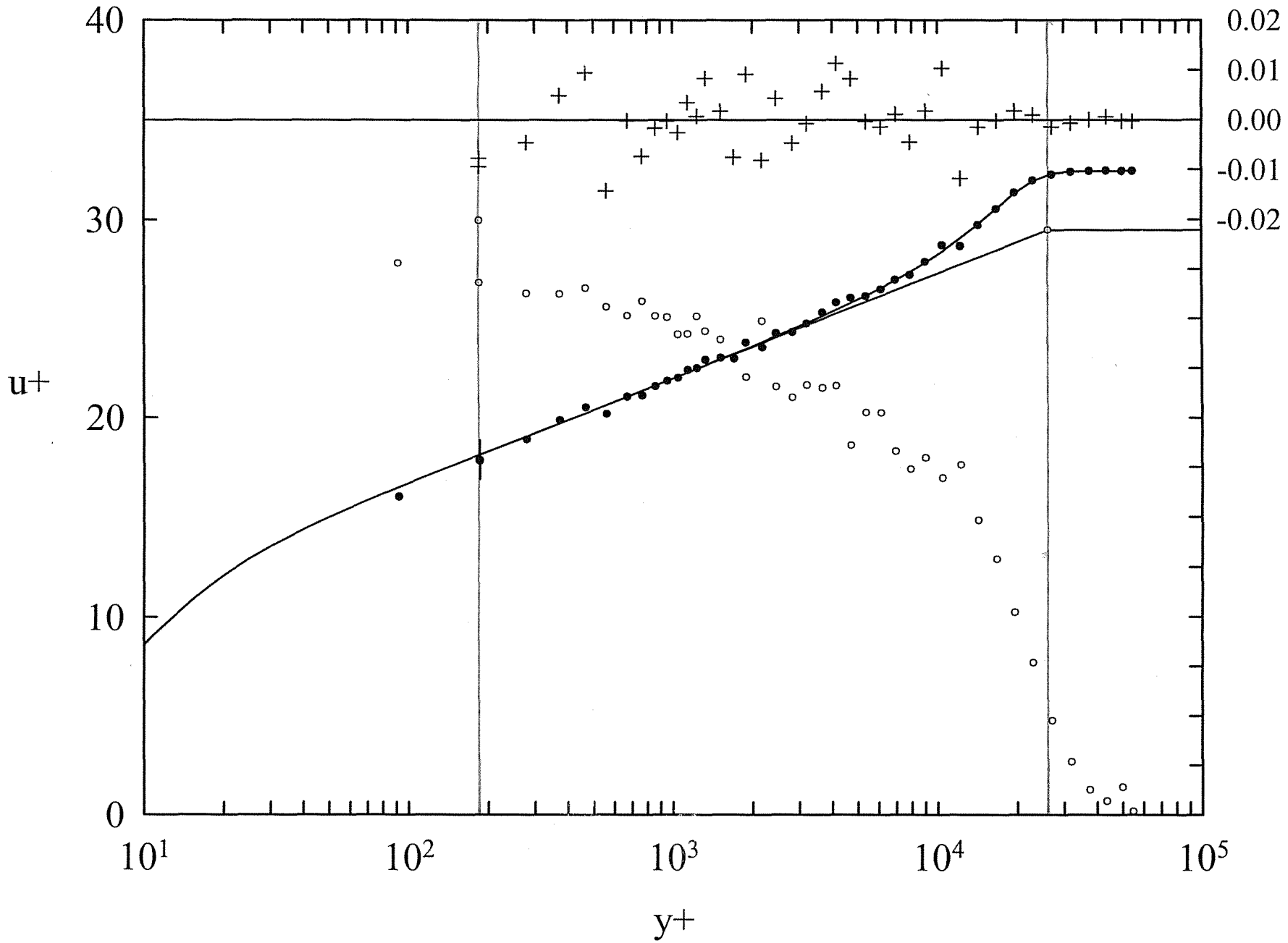



C-21

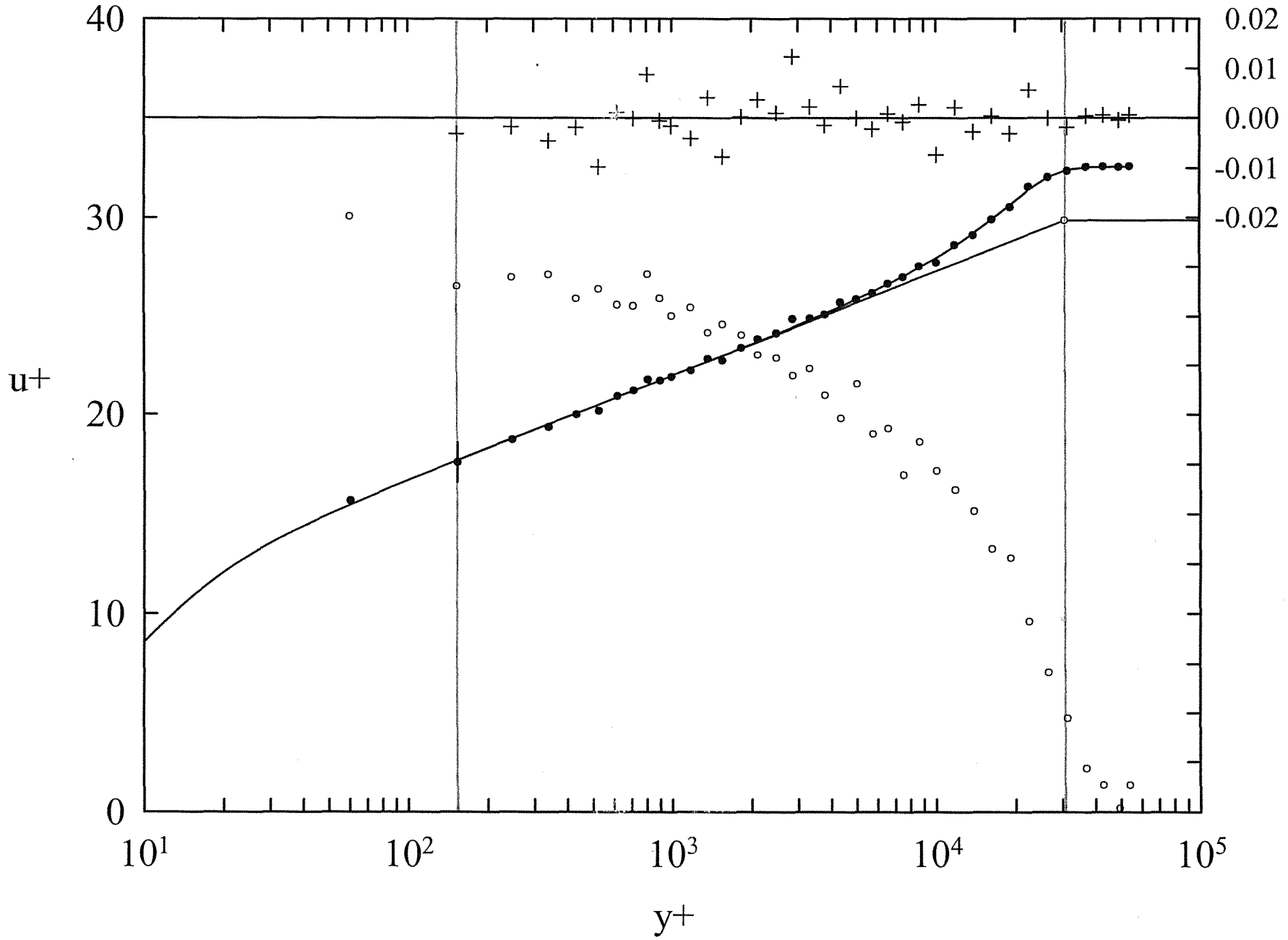
PARK 3702 8/28/02



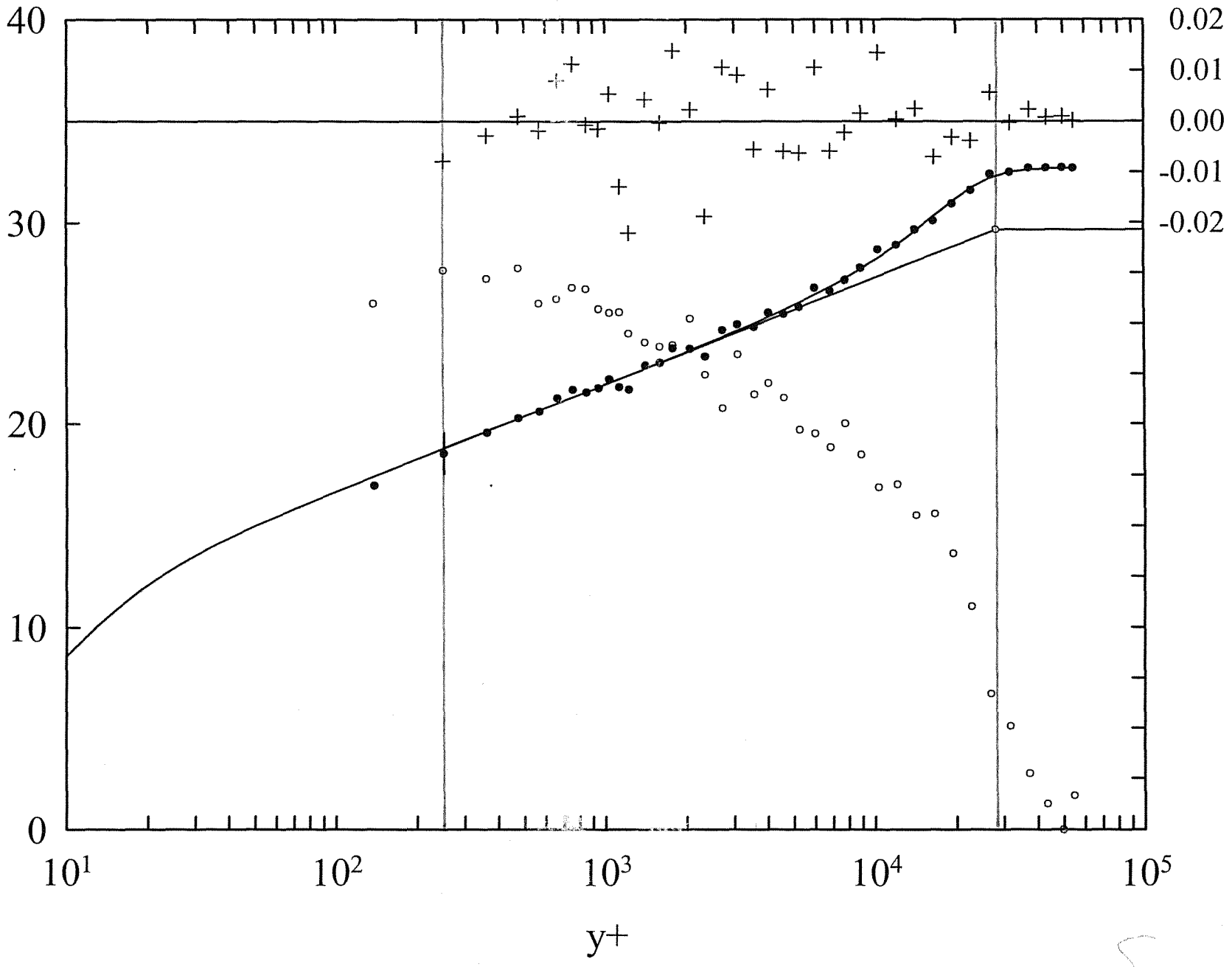

C-22


PARK 3703 8/28/02
40
30
20
10
0
0.02
0.01
0.00
-0.01
-0.02
u+
y+
$10^1$
$10^2$
$10^3$
$10^4$
$10^5$

PARK 3704 8/28/02

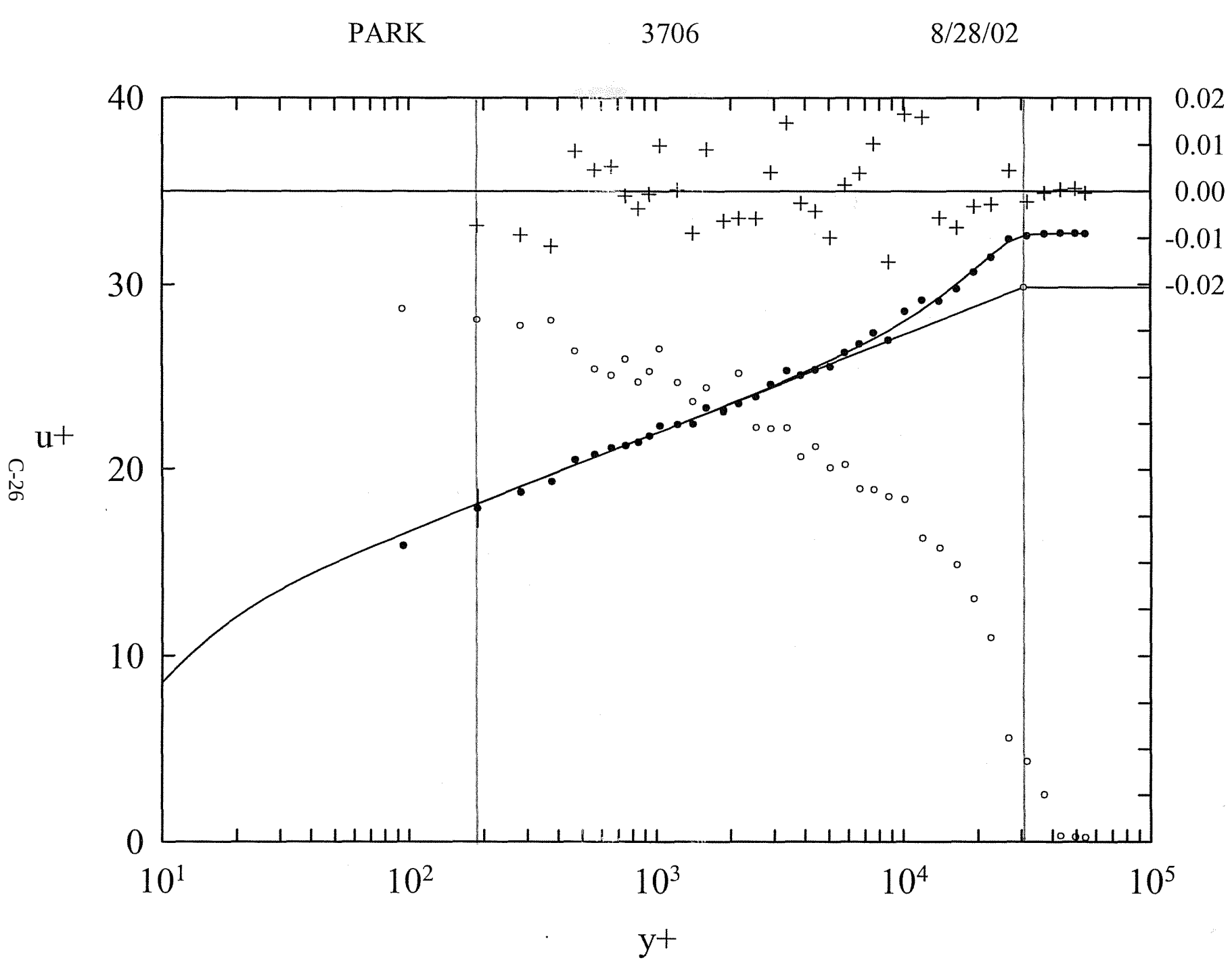


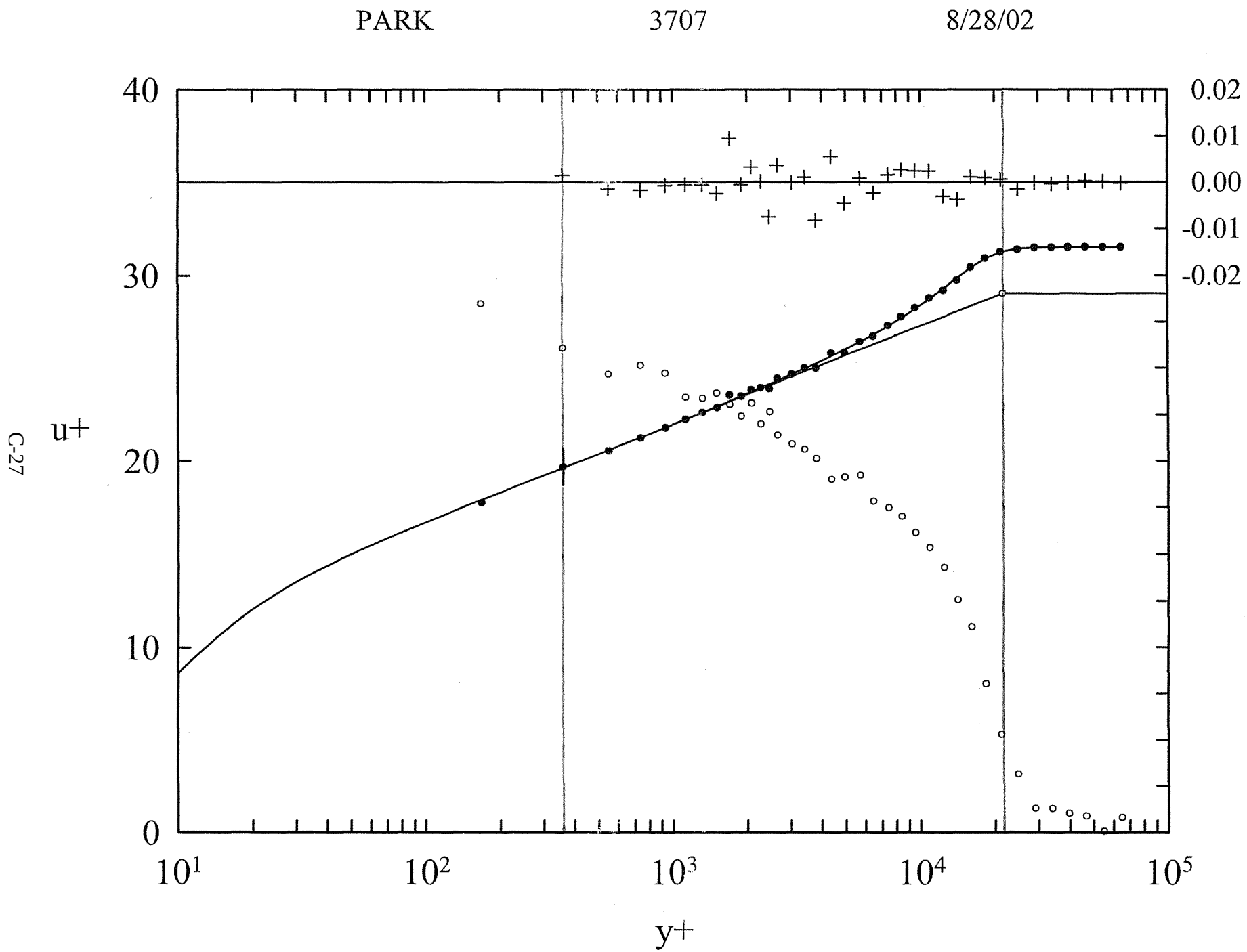
PARK 3705 8/28/02



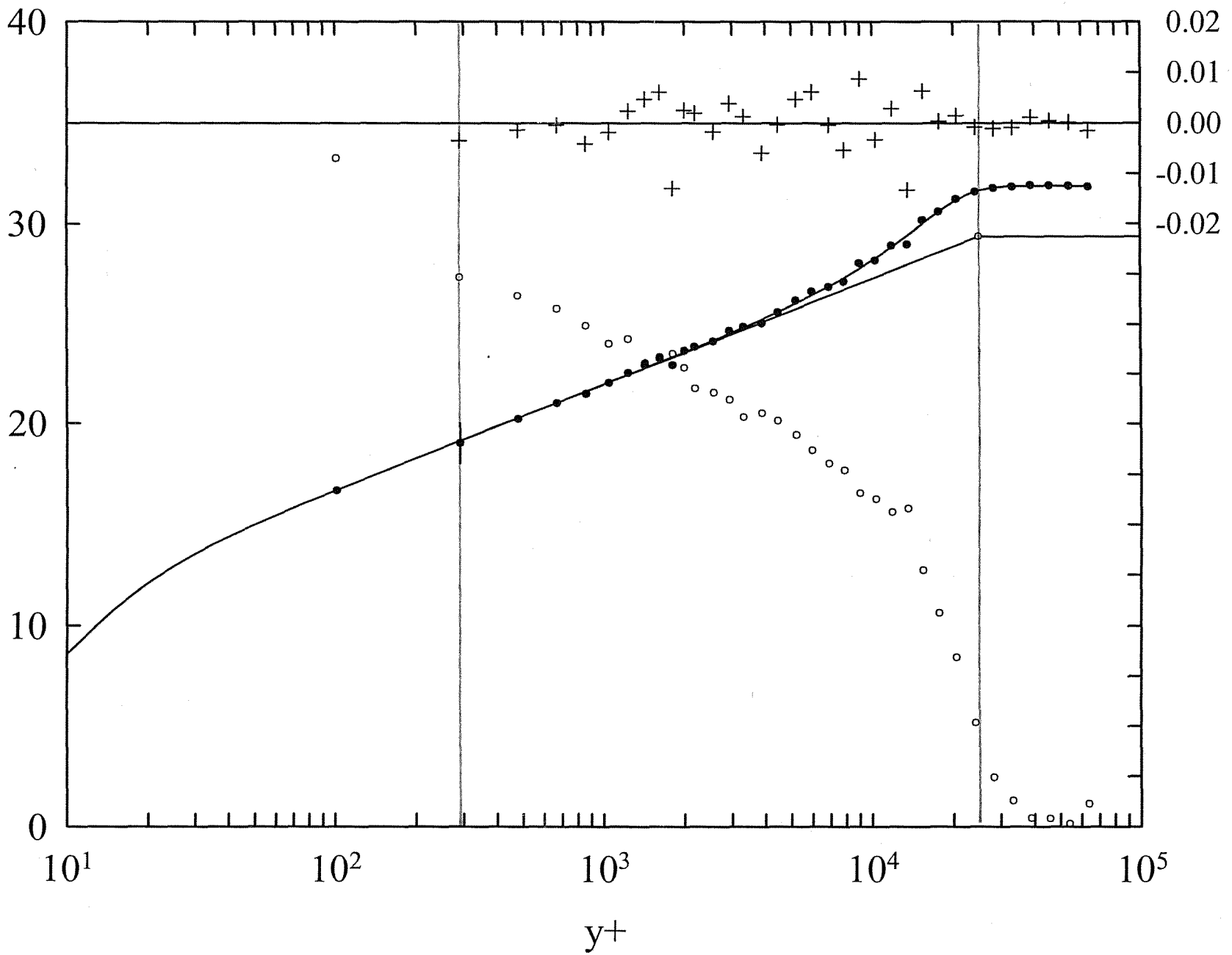

C-25

Swang

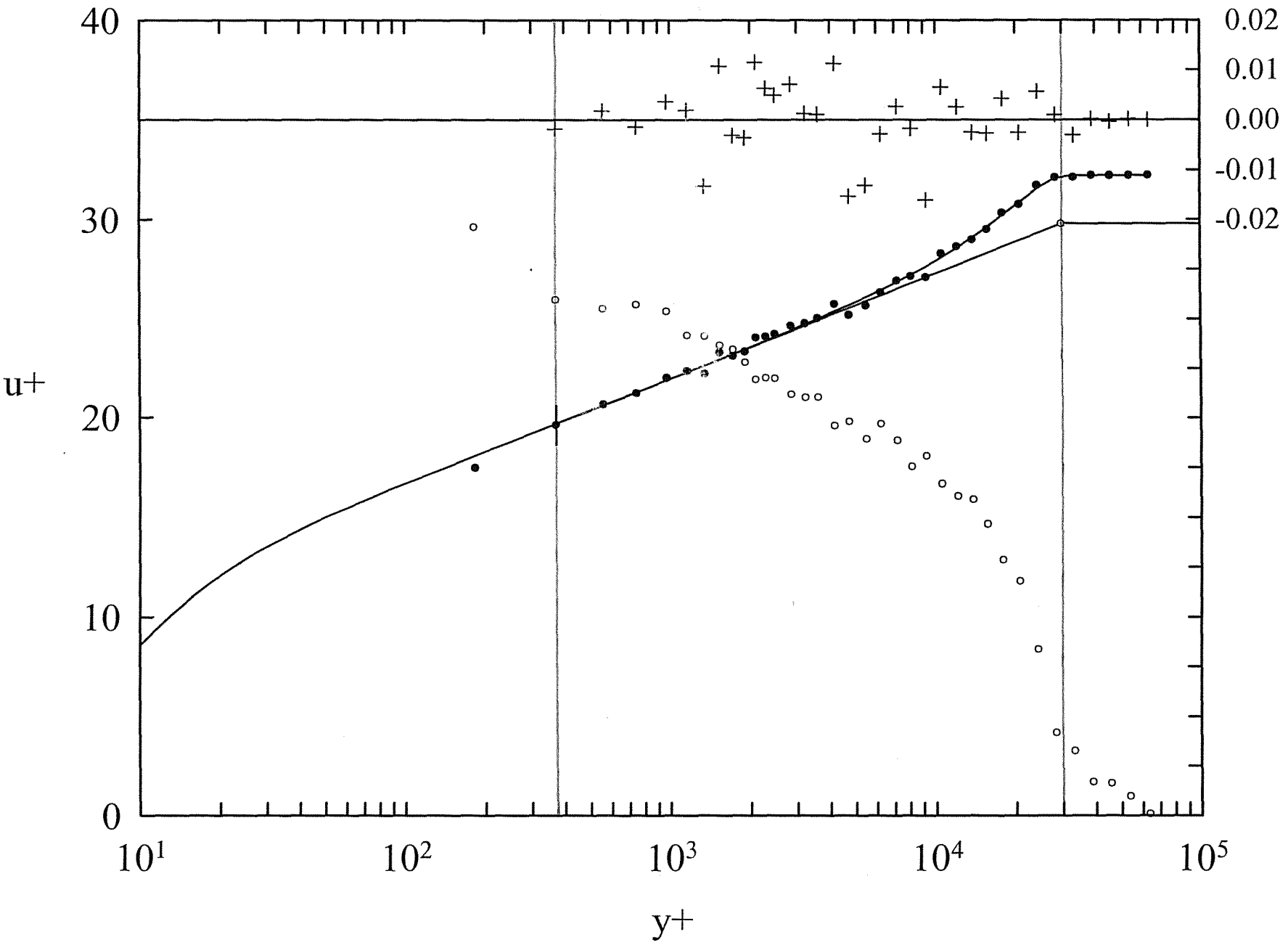

PARK
3706
8/28/02
40
30
20
10
0
u+
0.02
0.01
0.00
-0.01
-0.02
$10^1$
$10^2$
$10^3$
$10^4$
$10^5$
y+

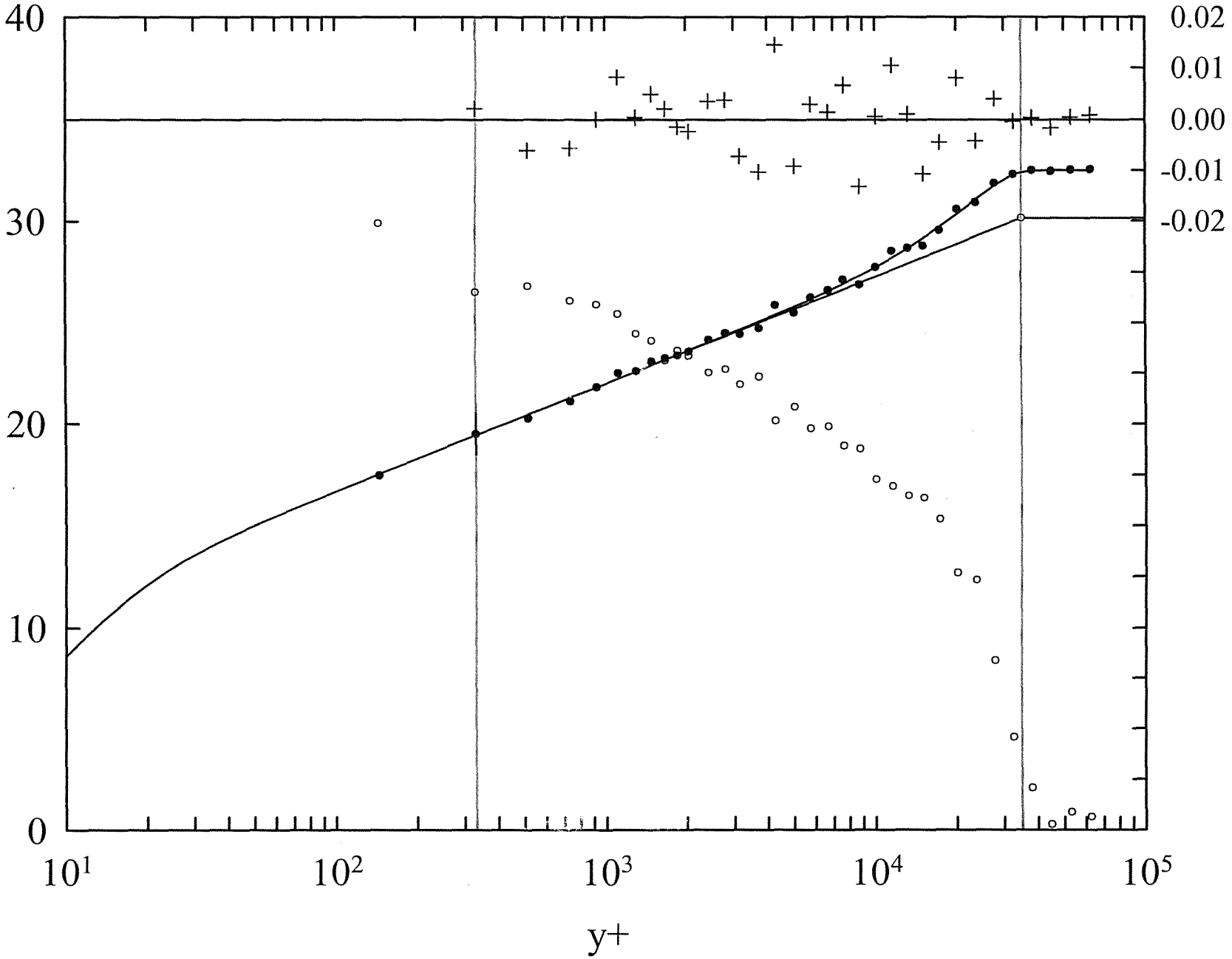

PARK
3707
8/28/02
40
30
20
10
0
0.02
0.01
0.00
-0.01
-0.02
u+
y+
$10^1$
$10^2$
$10^3$
$10^4$
$10^5$

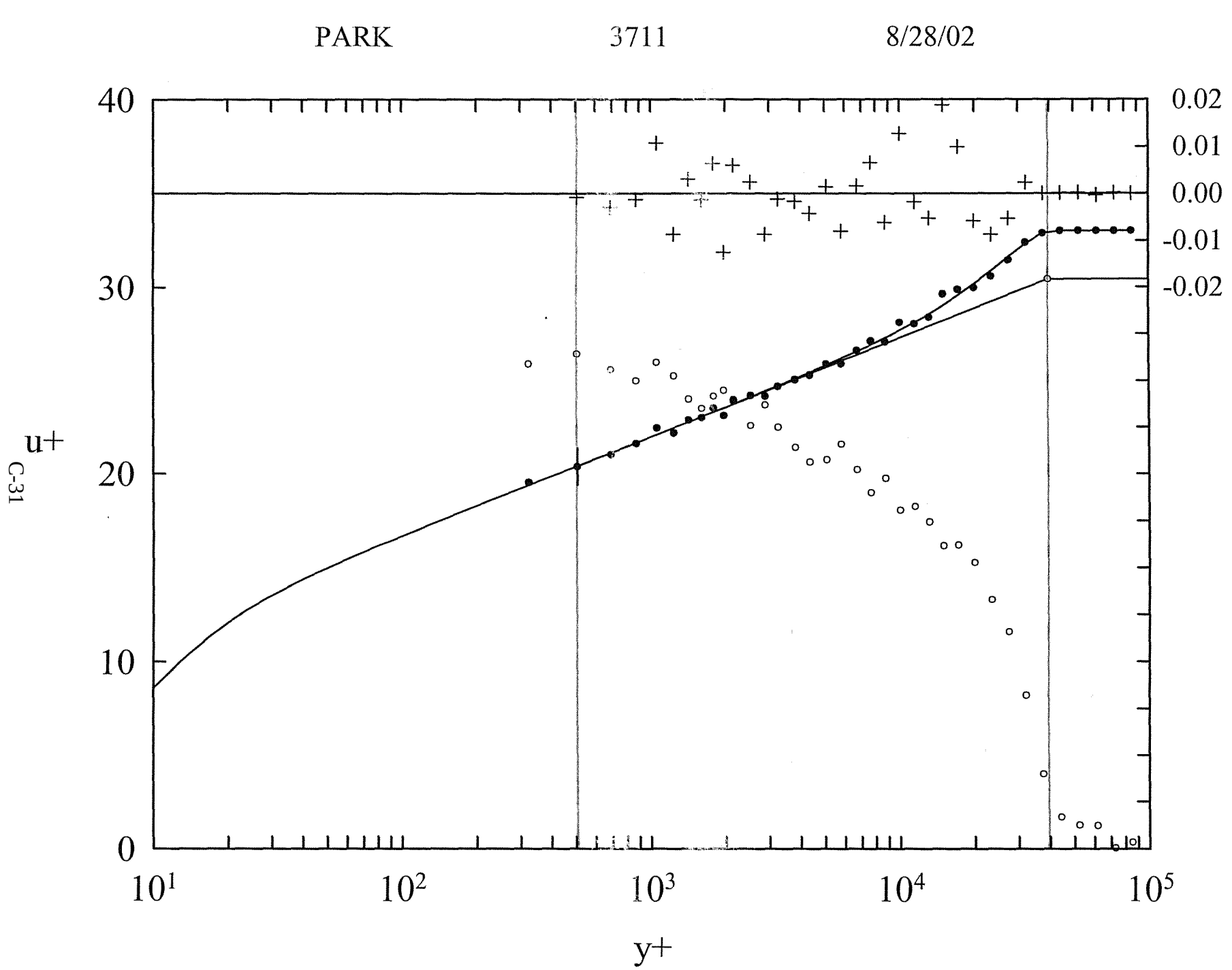
PARK 3708 8/28/02

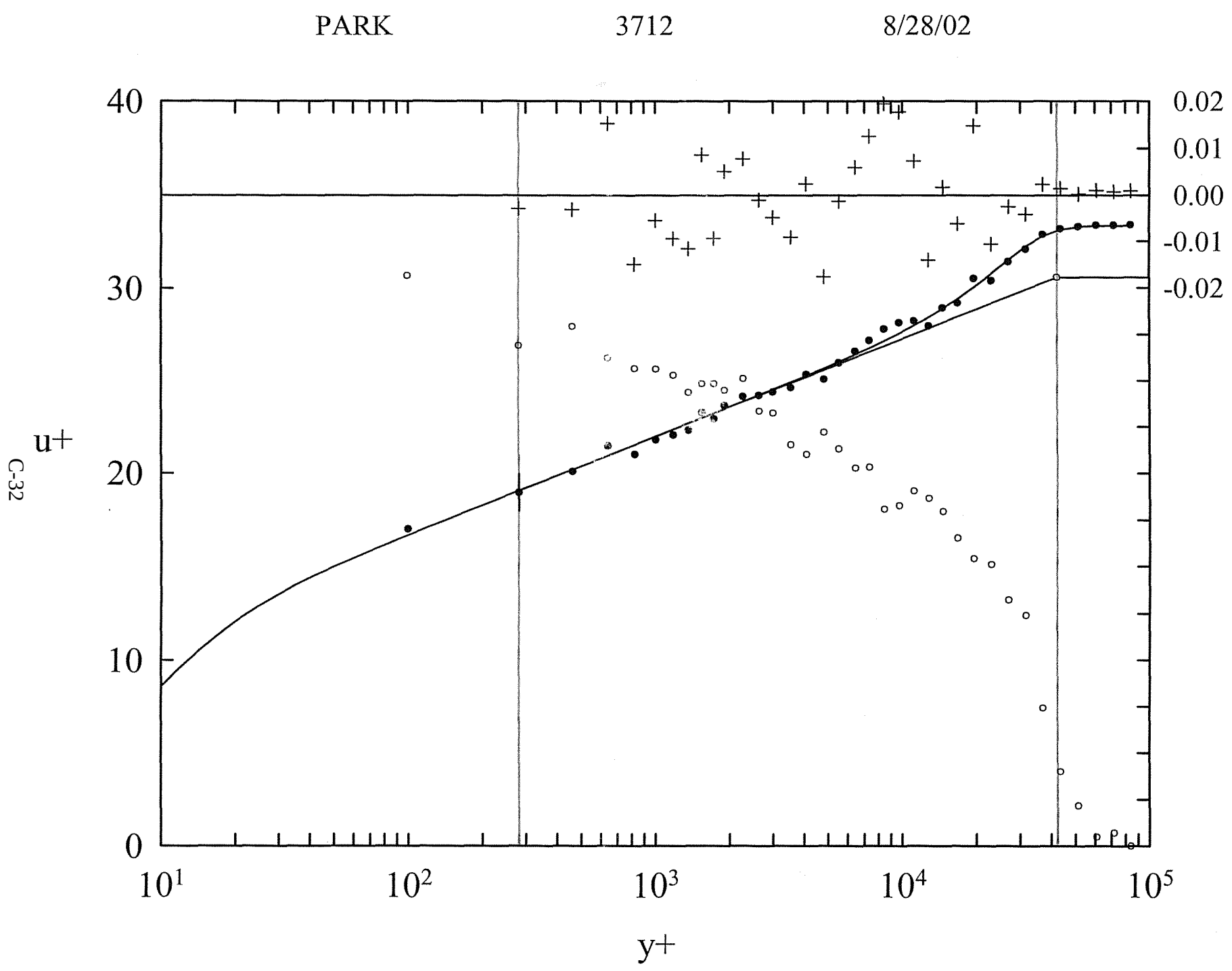


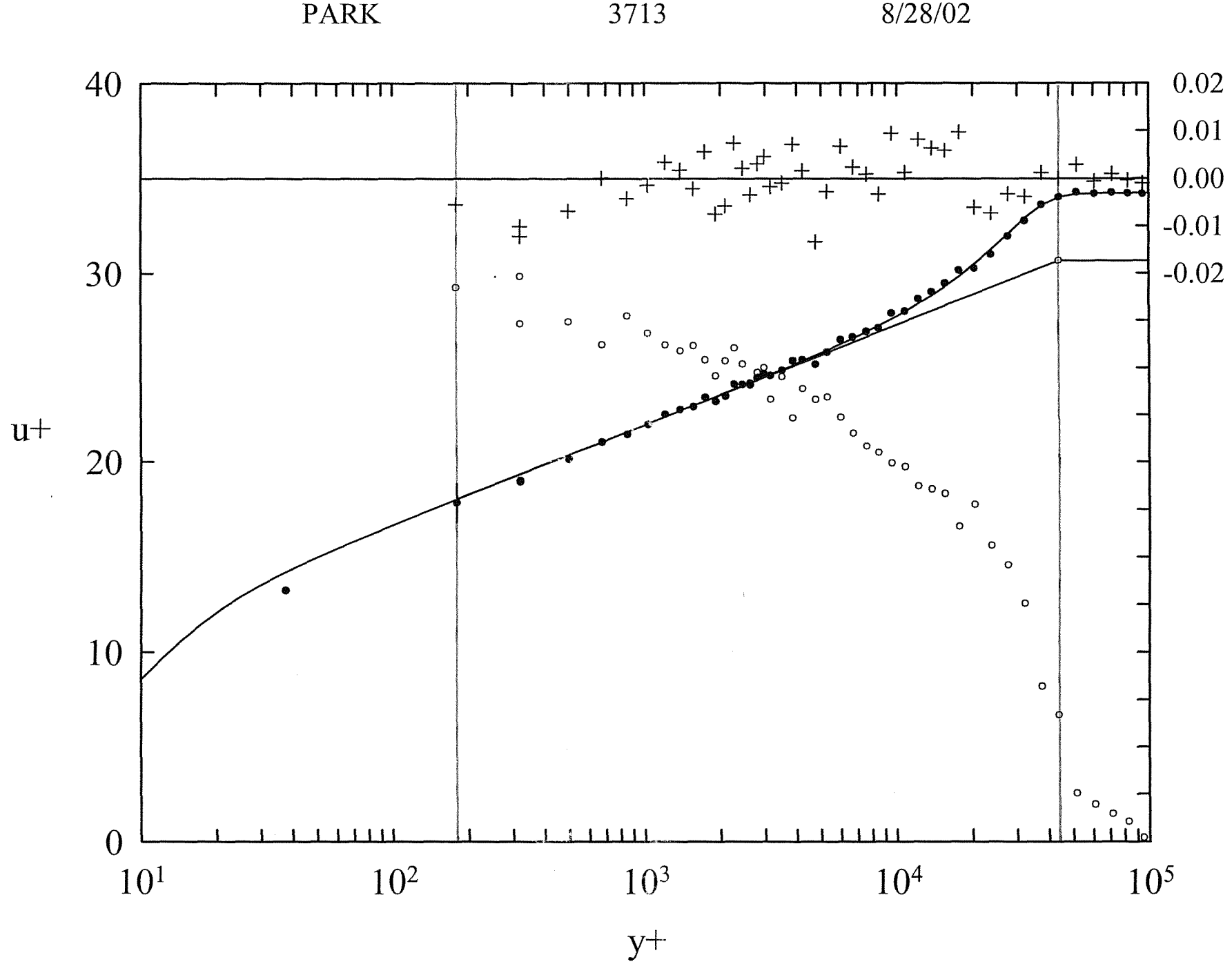
PARK 3709 8/28/02

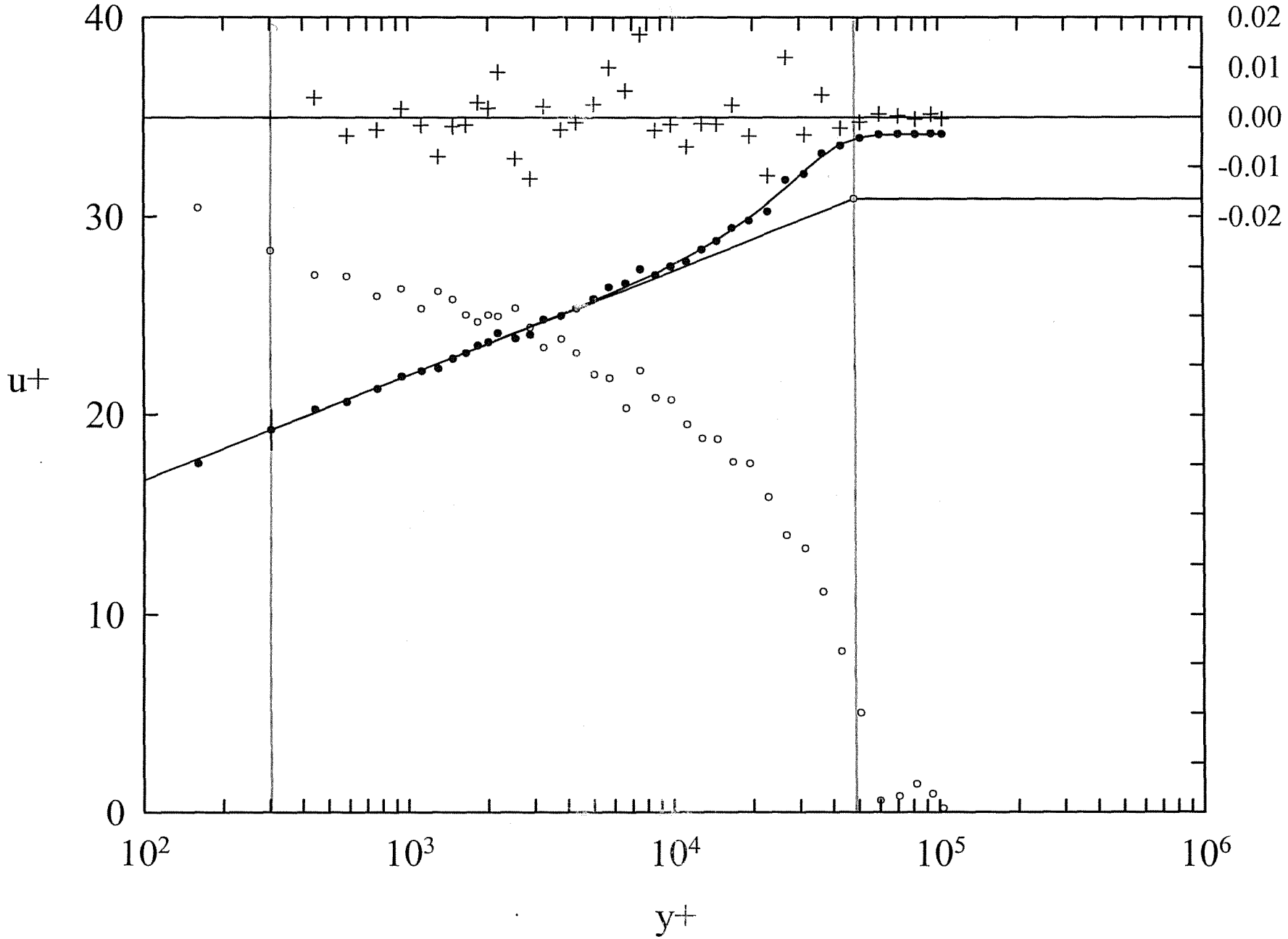


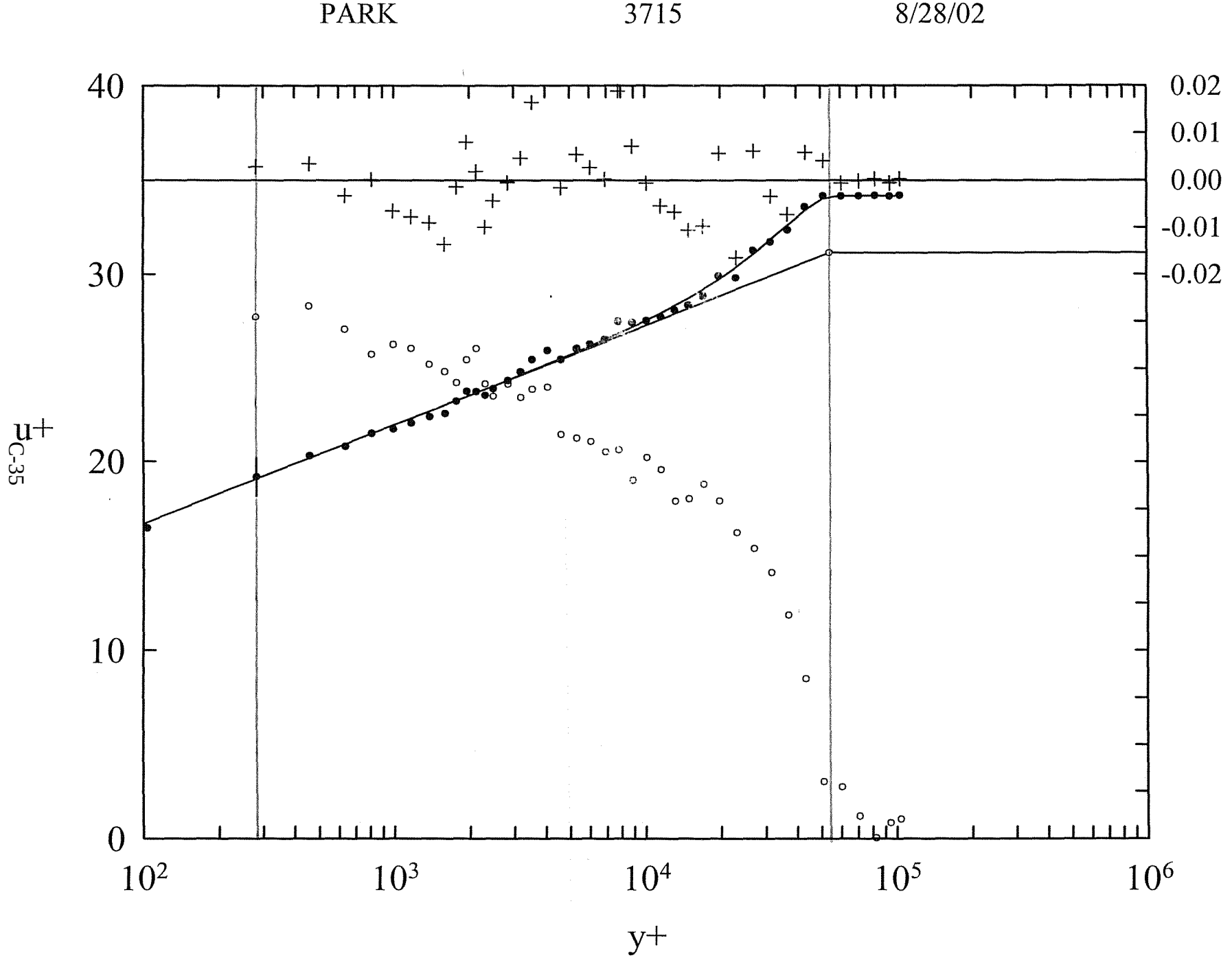

40
30
20
10
0
u+
0.02
0.01
0.00
-0.01
-0.02
$10^1$
$10^2$
$10^3$
$10^4$
$10^5$
y+


PARK
3711
8/28/02
40
30
20
10
0
0.02
0.01
0.00
-0.01
-0.02
u+
y+
$10^1$
$10^2$
$10^3$
$10^4$
$10^5$

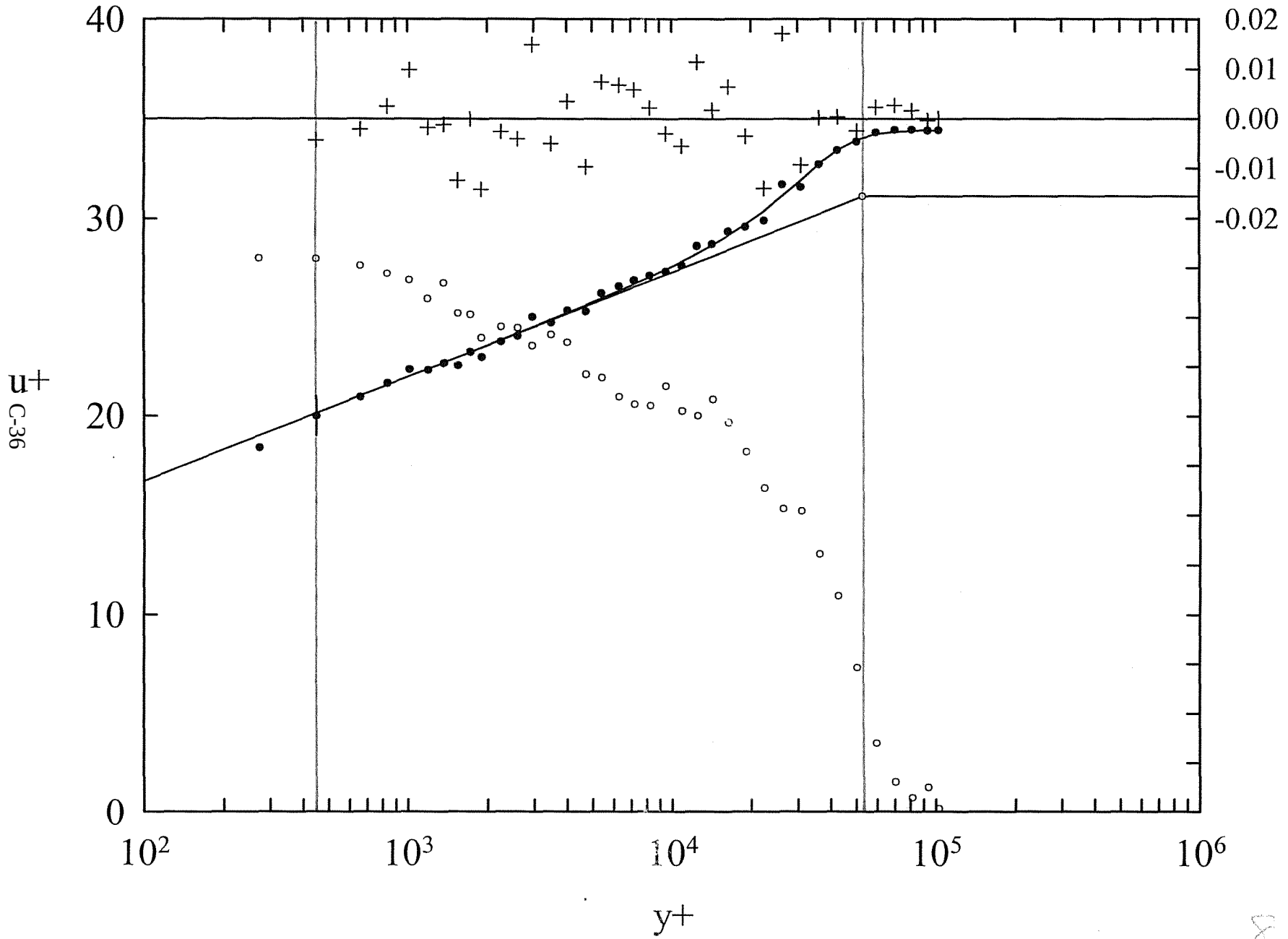

PARK
3712
8/28/02
40
30
20
10
0
u+
0.02
0.01
0.00
-0.01
-0.02
$10^1$
$10^2$
$10^3$
$10^4$
$10^5$
y+

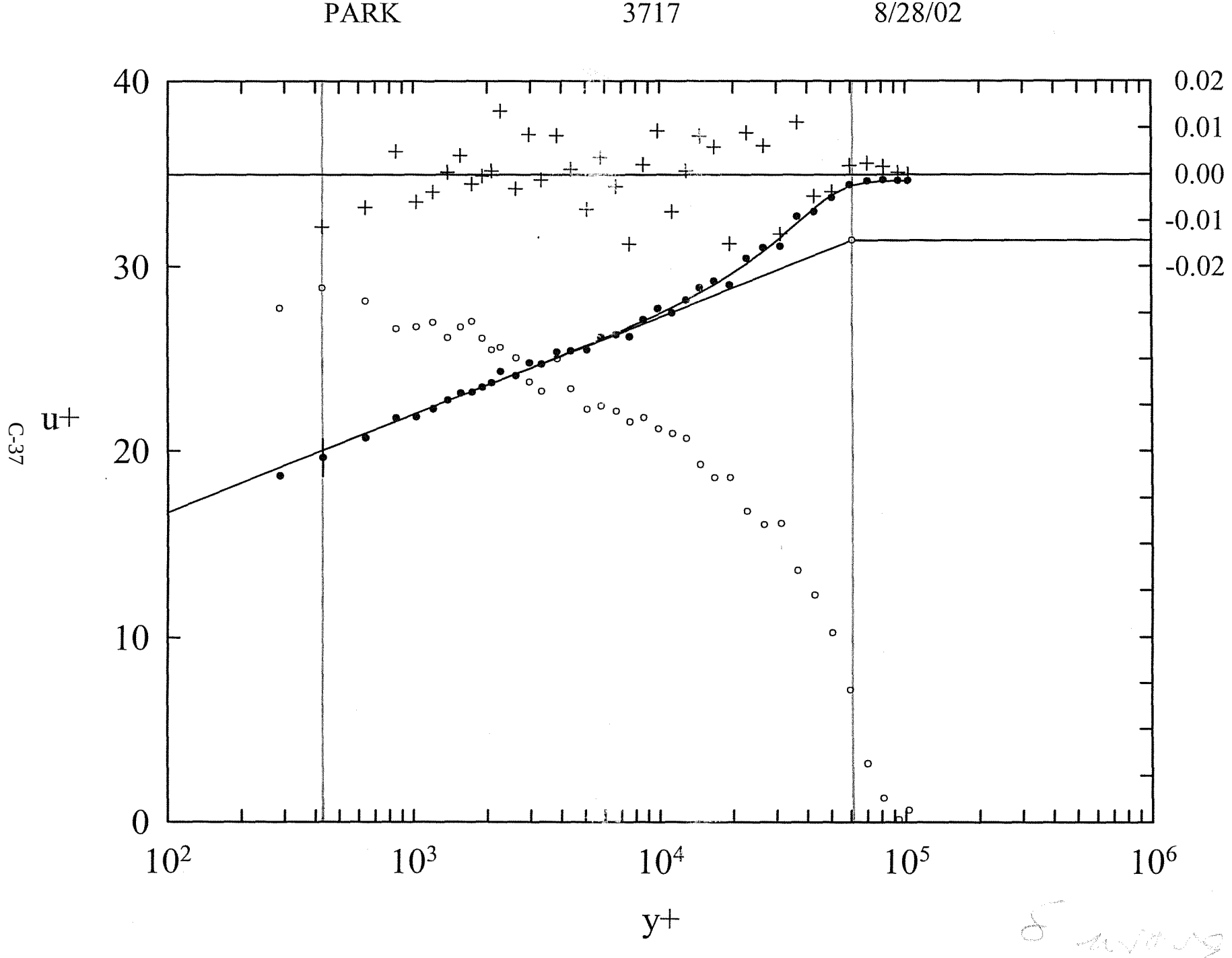

PARK
3713
8/28/02
40
30
20
10
0
u+
0.02
0.01
0.00
-0.01
-0.02
$10^1$
$10^2$
$10^3$
$10^4$
$10^5$
y+


40
30
20
10
0
u+
0.02
0.01
0.00
-0.01
-0.02
$10^2$
$10^3$
$10^4$
$10^5$
$10^6$
y+

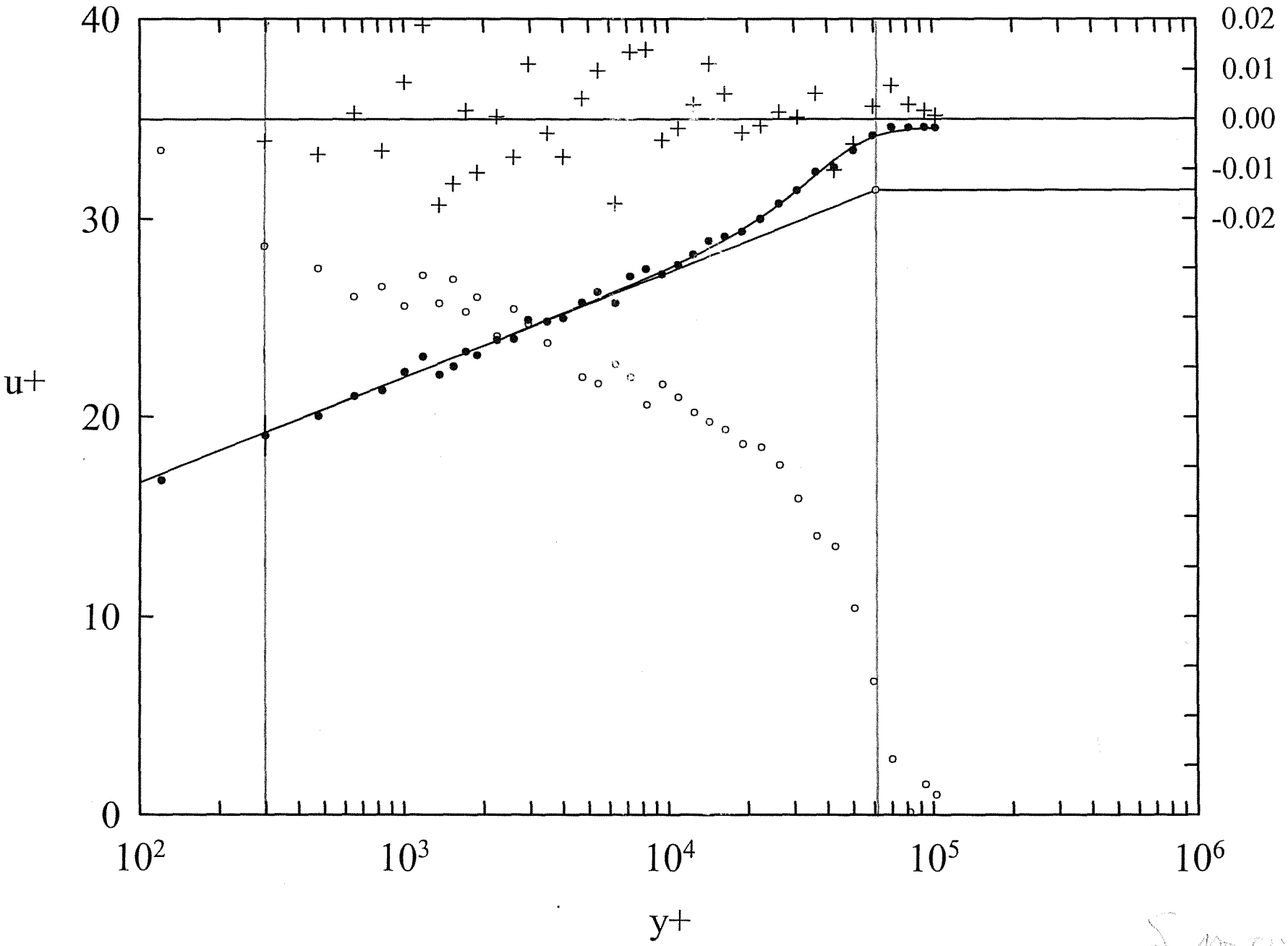

PARK
3715
8/28/02
40
30
20
10
0
0.02
0.01
0.00
-0.01
-0.02
u+
C-35
$10^2$
$10^3$
$10^4$
$10^5$
$10^6$
y+

PARK 3716 8/28/02

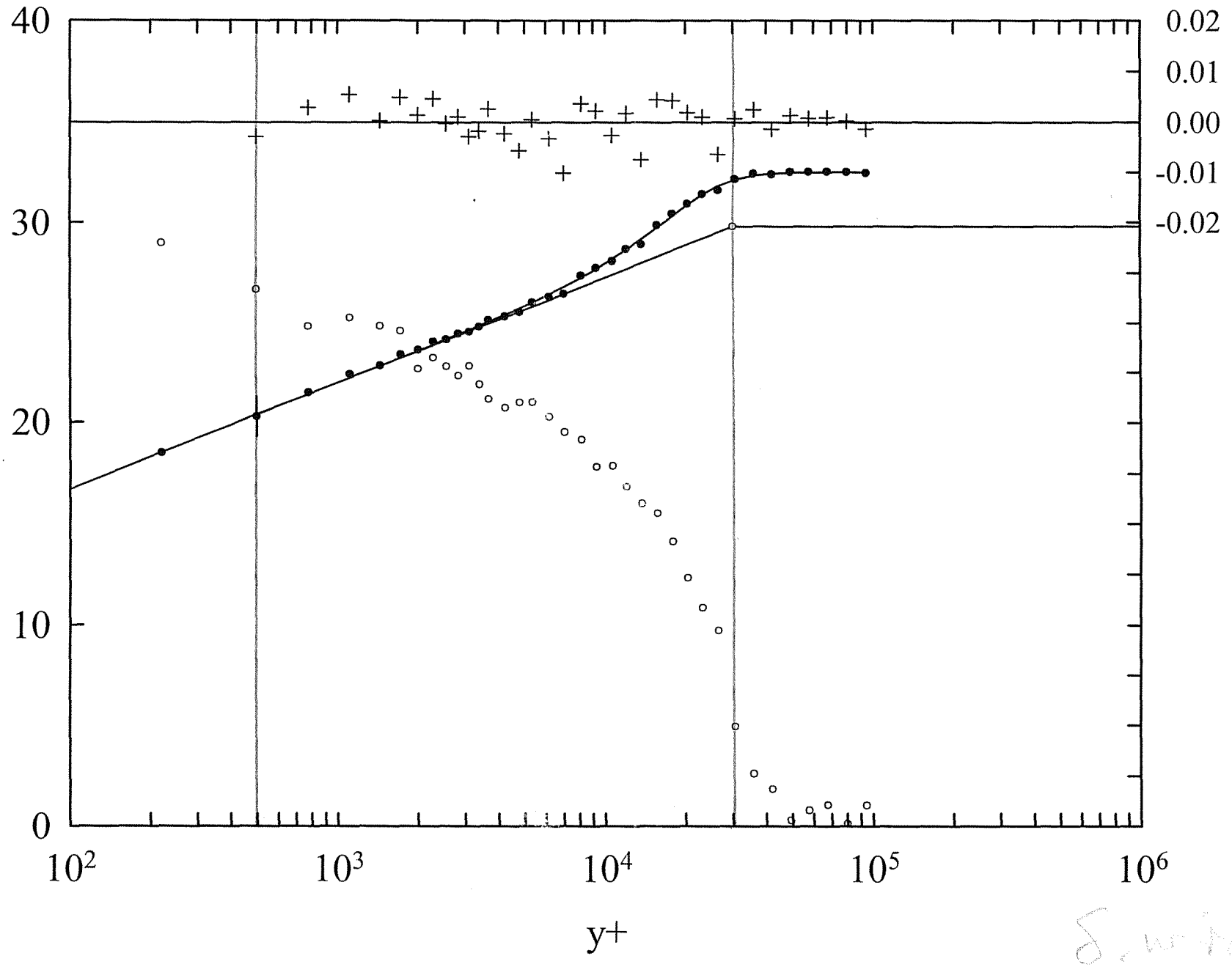



PARK 3717 8/28/02
40
30
20
10
0
0.02
0.01
0.00
-0.01
-0.02
u+
$10^2$
$10^3$
$10^4$
$10^5$
$10^6$
y+

PARK 3718 8/28/02

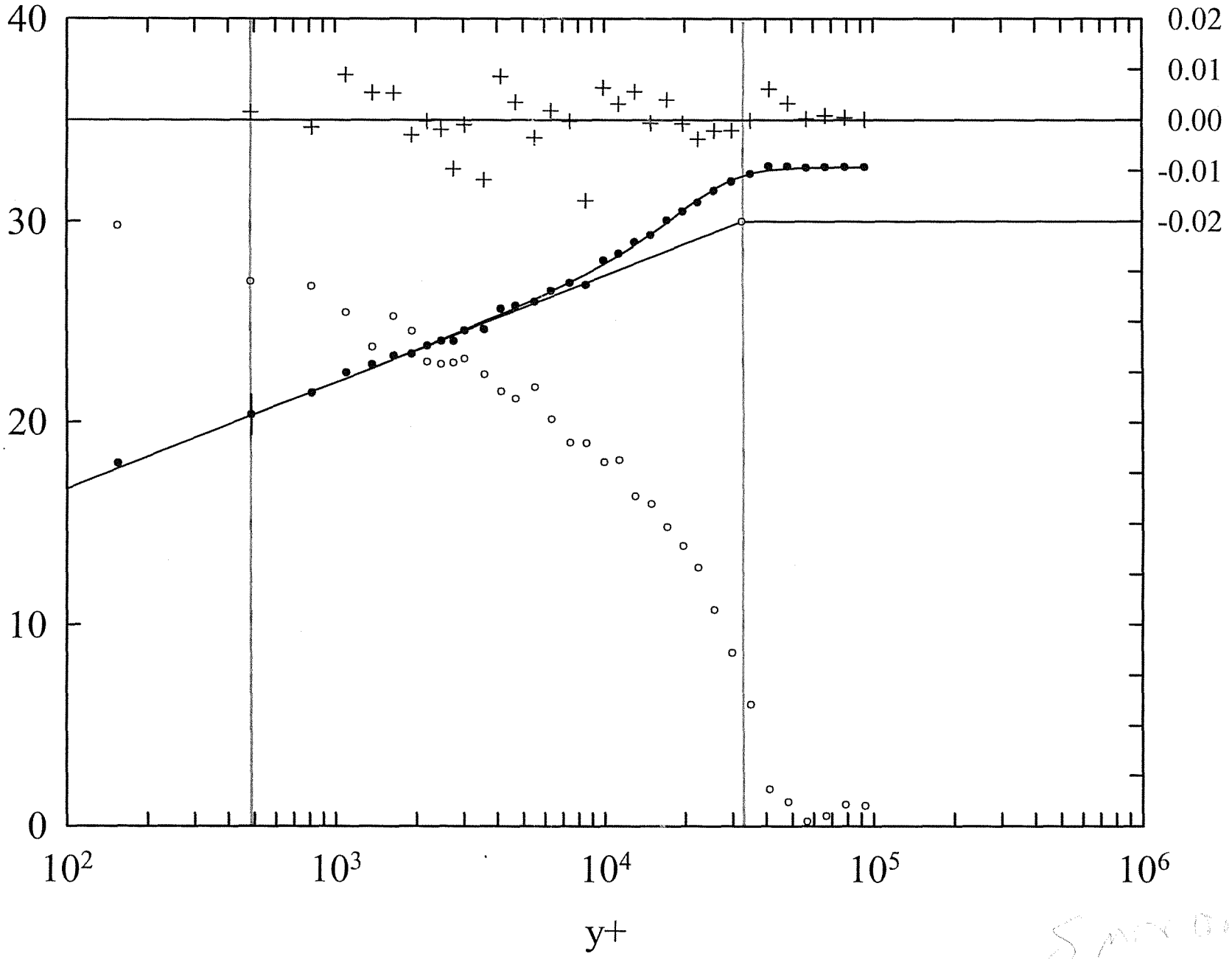


PARK 3719 8/29/02

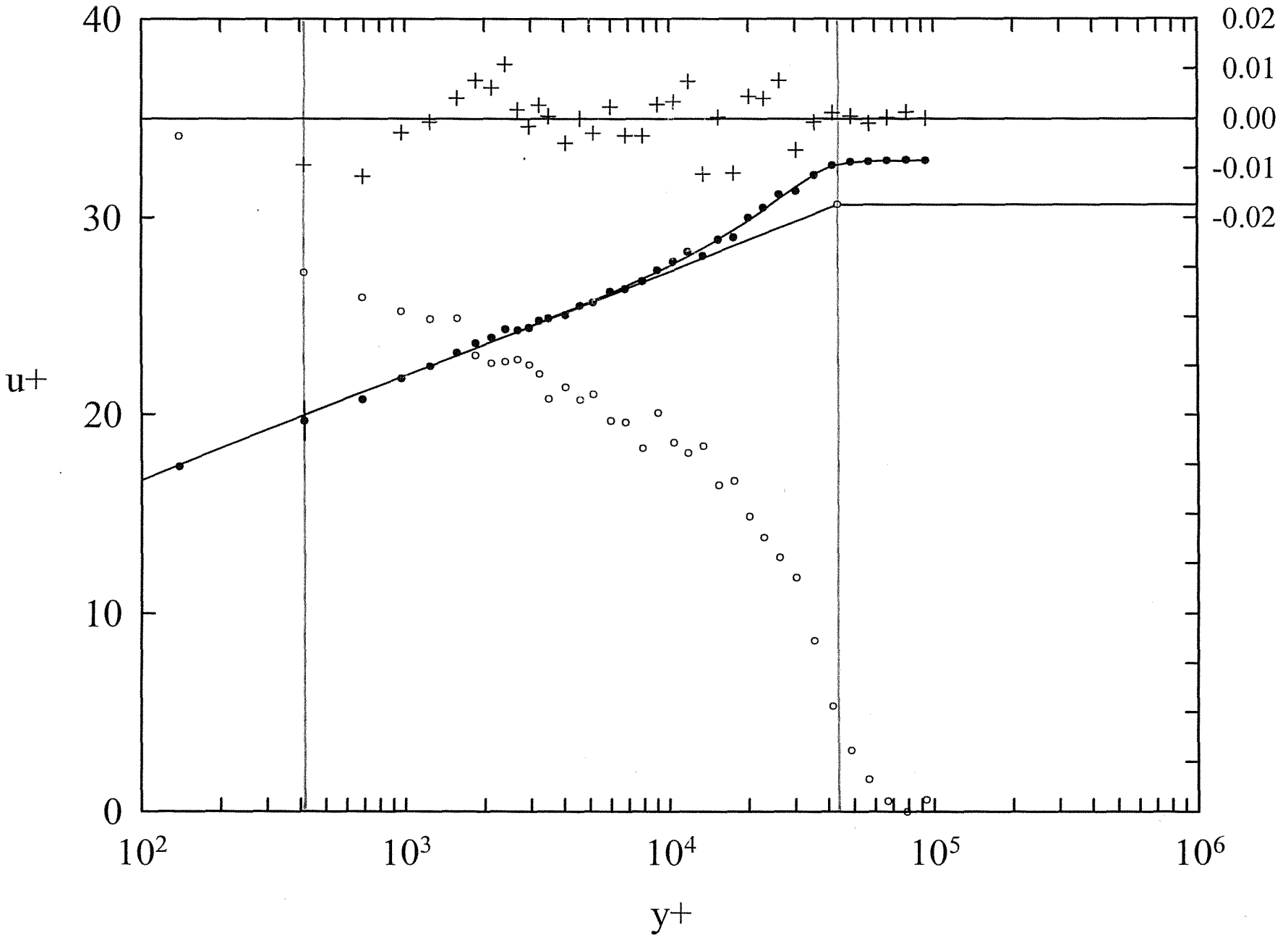



C-39

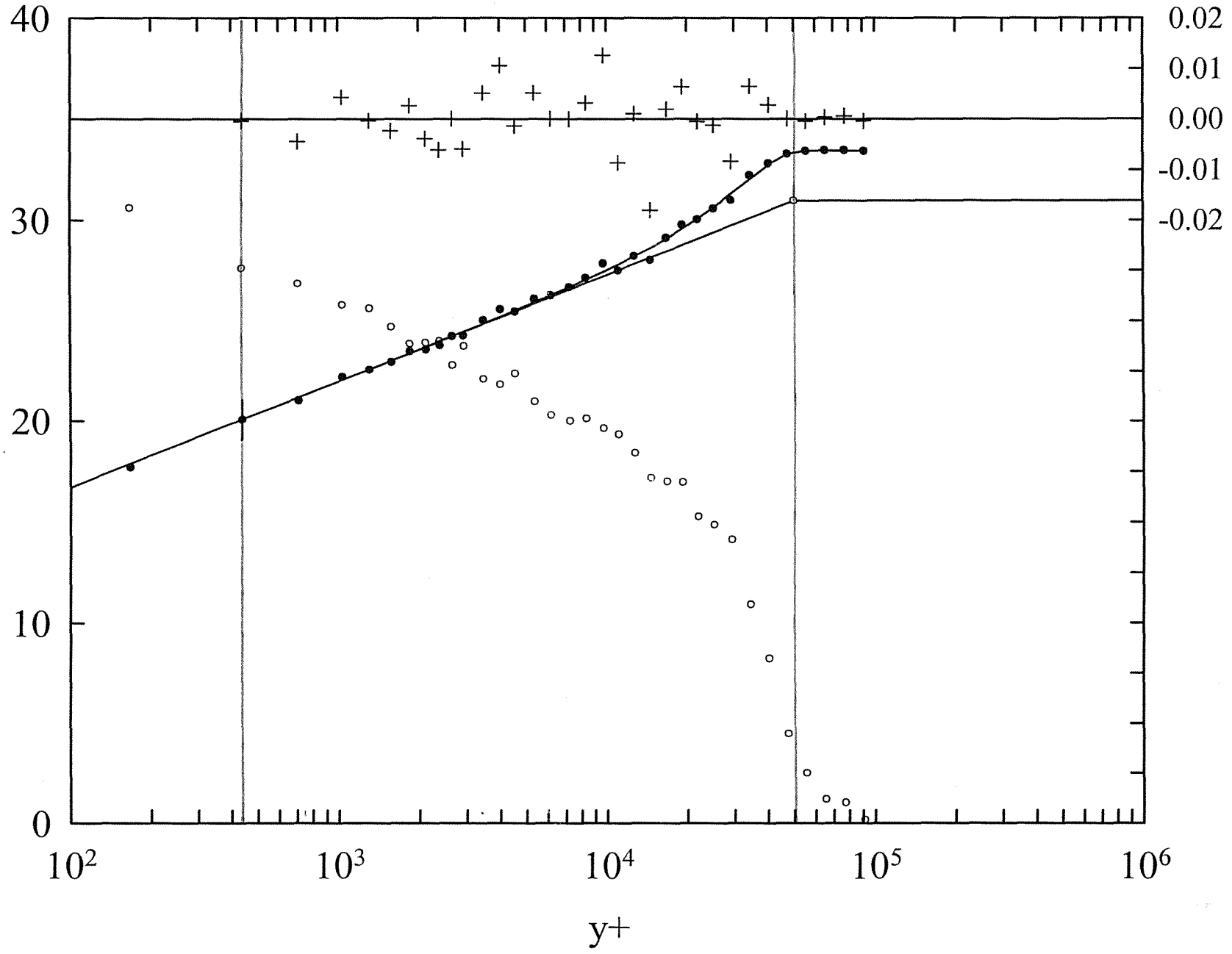
PARK 3720 8/29/02



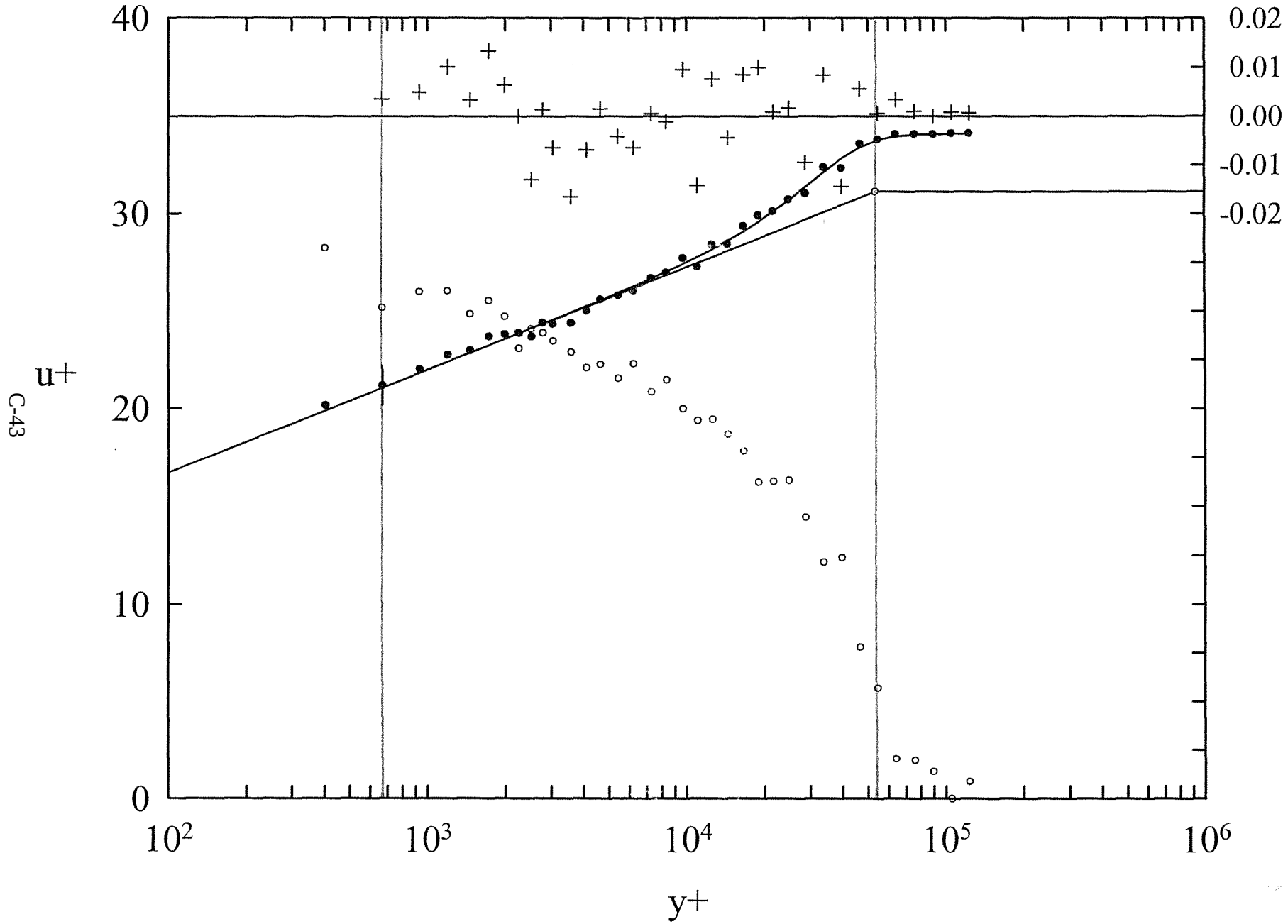

C-40


40
30
20
10
0
u+
0.02
0.01
0.00
-0.01
-0.02
$10^2$
$10^3$
$10^4$
$10^5$
$10^6$
y+

PARK 3722 8/29/02

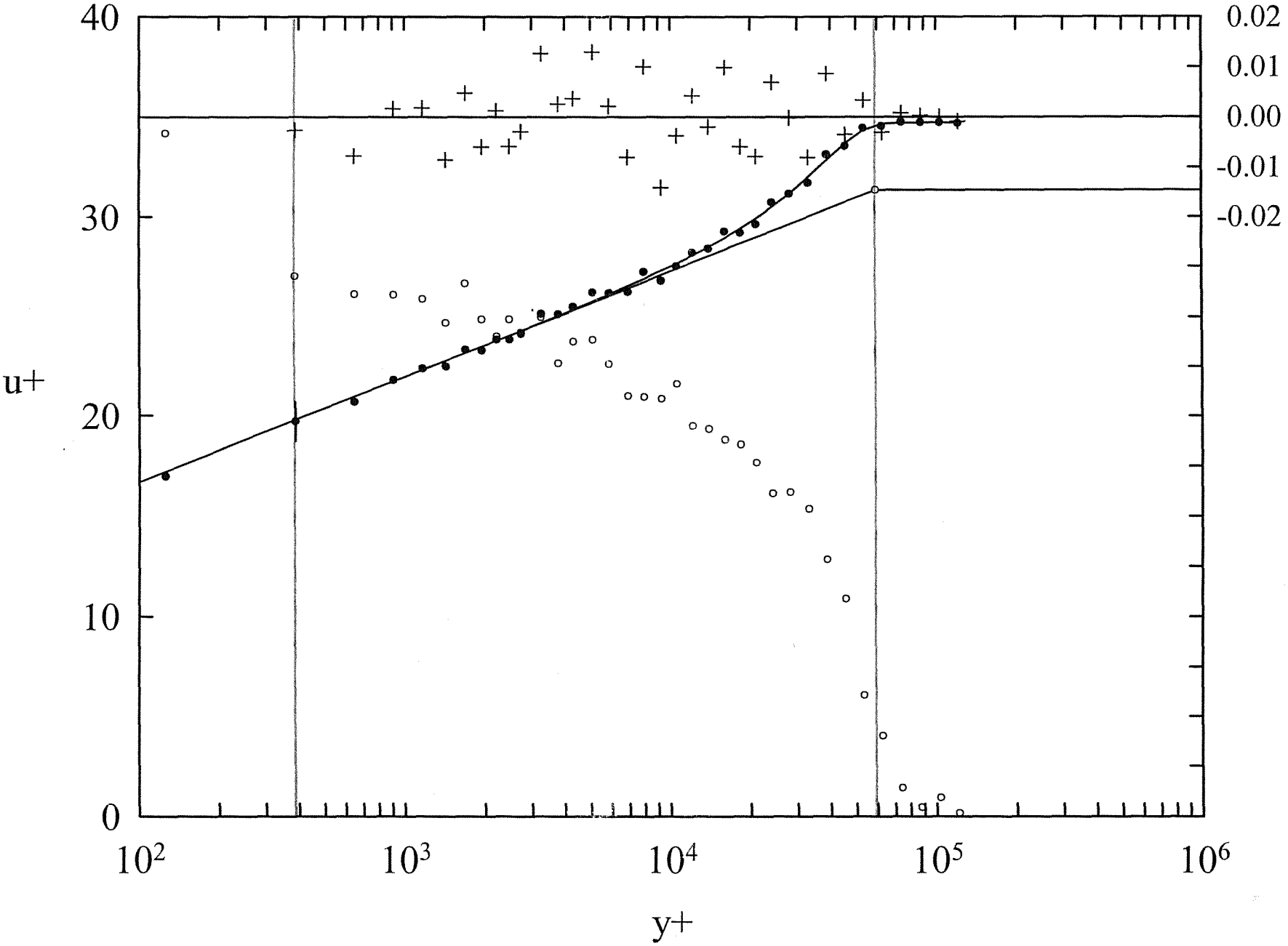


PARK 3723 8/29/02

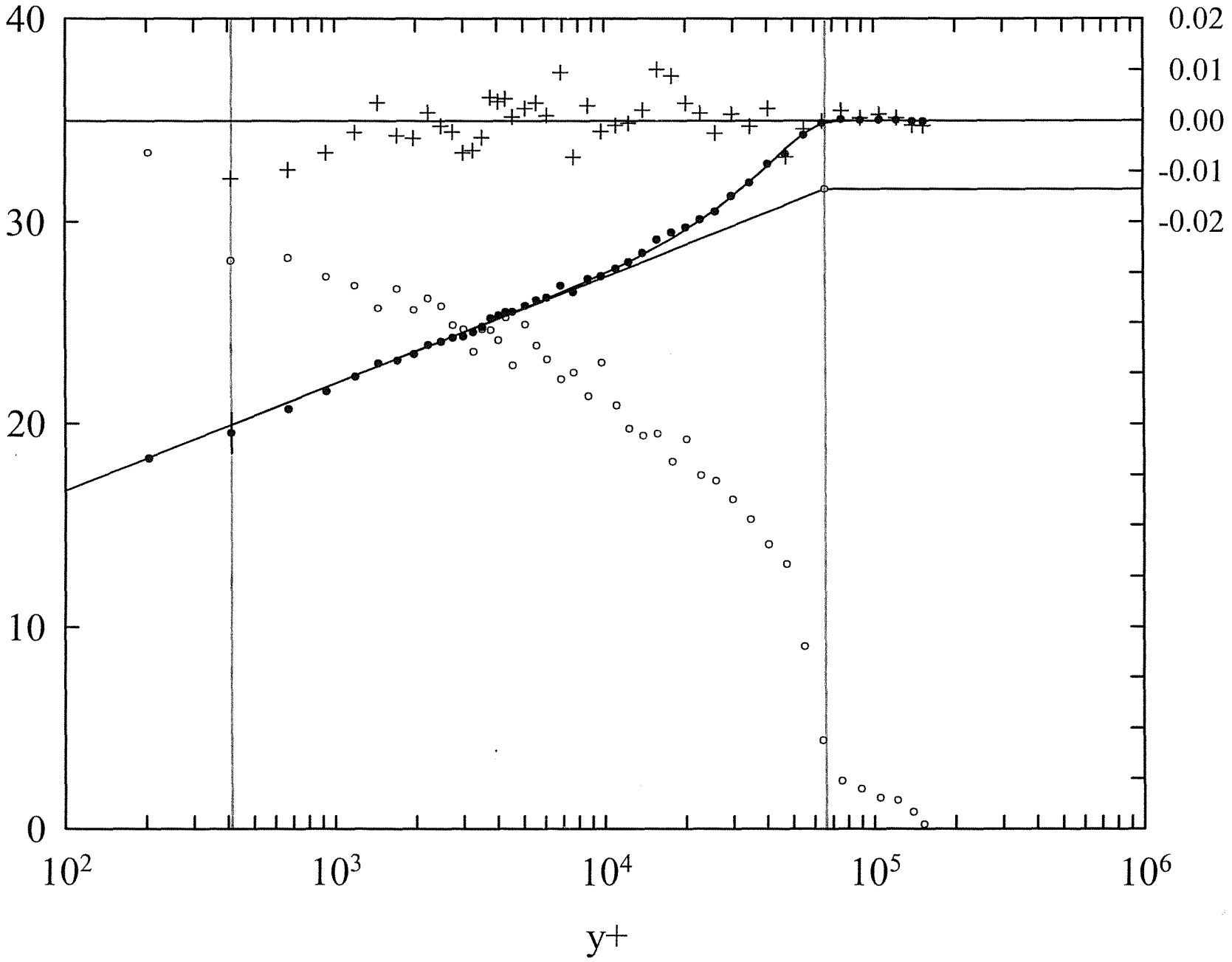



C-43

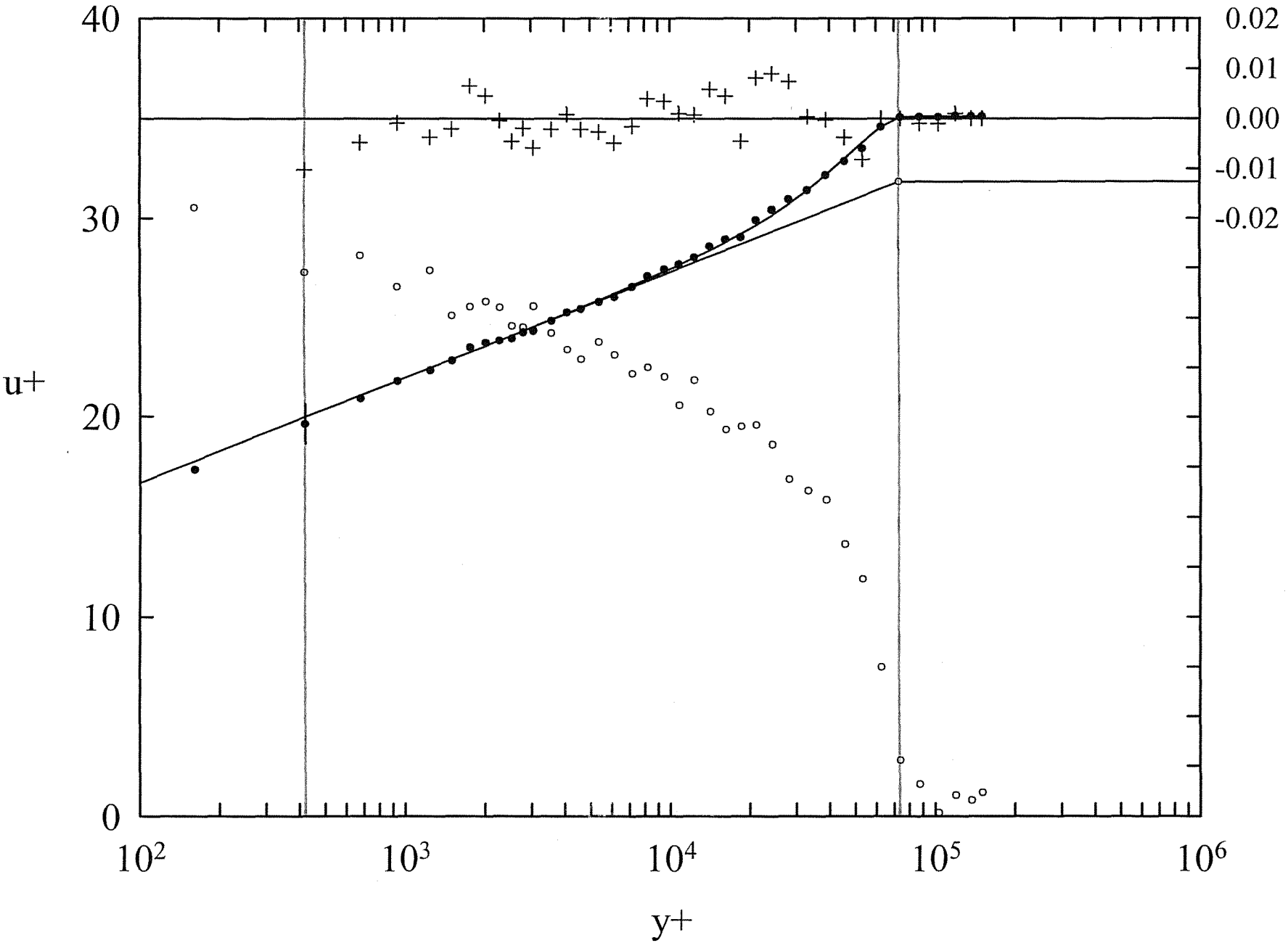
PARK 3724 8/29/02



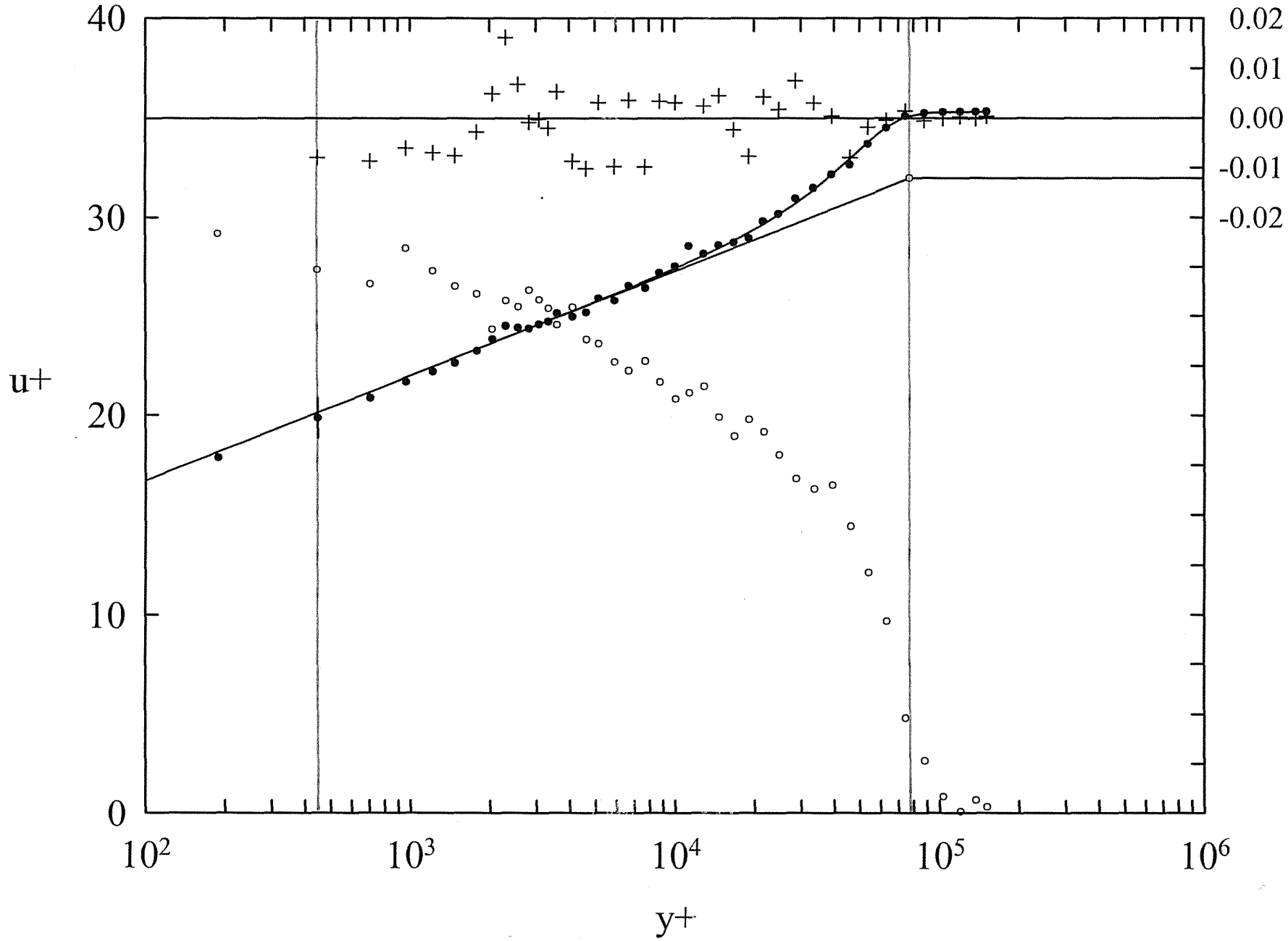
PARK 3725 8/29/02



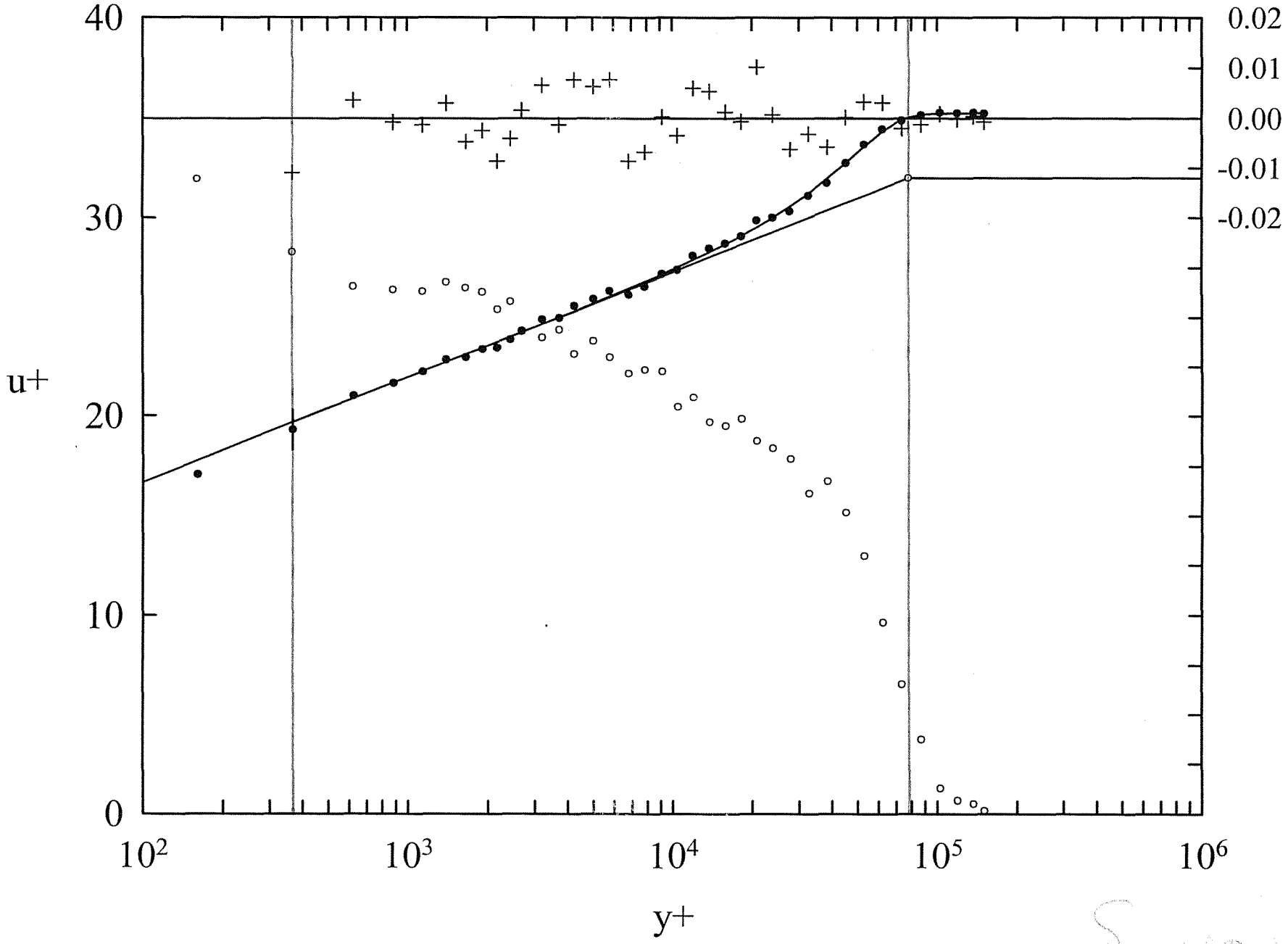
PARK 3726 8/29/02

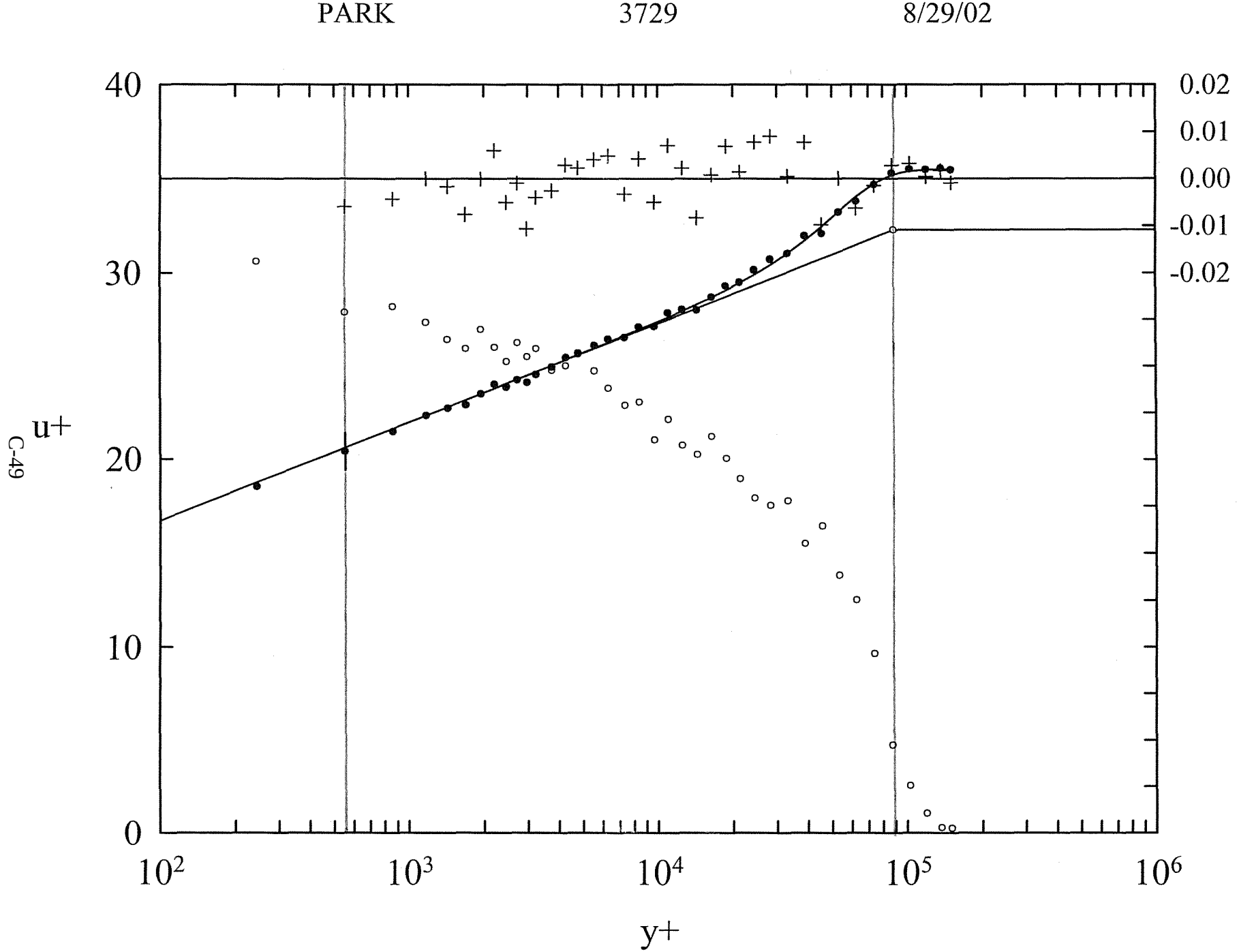


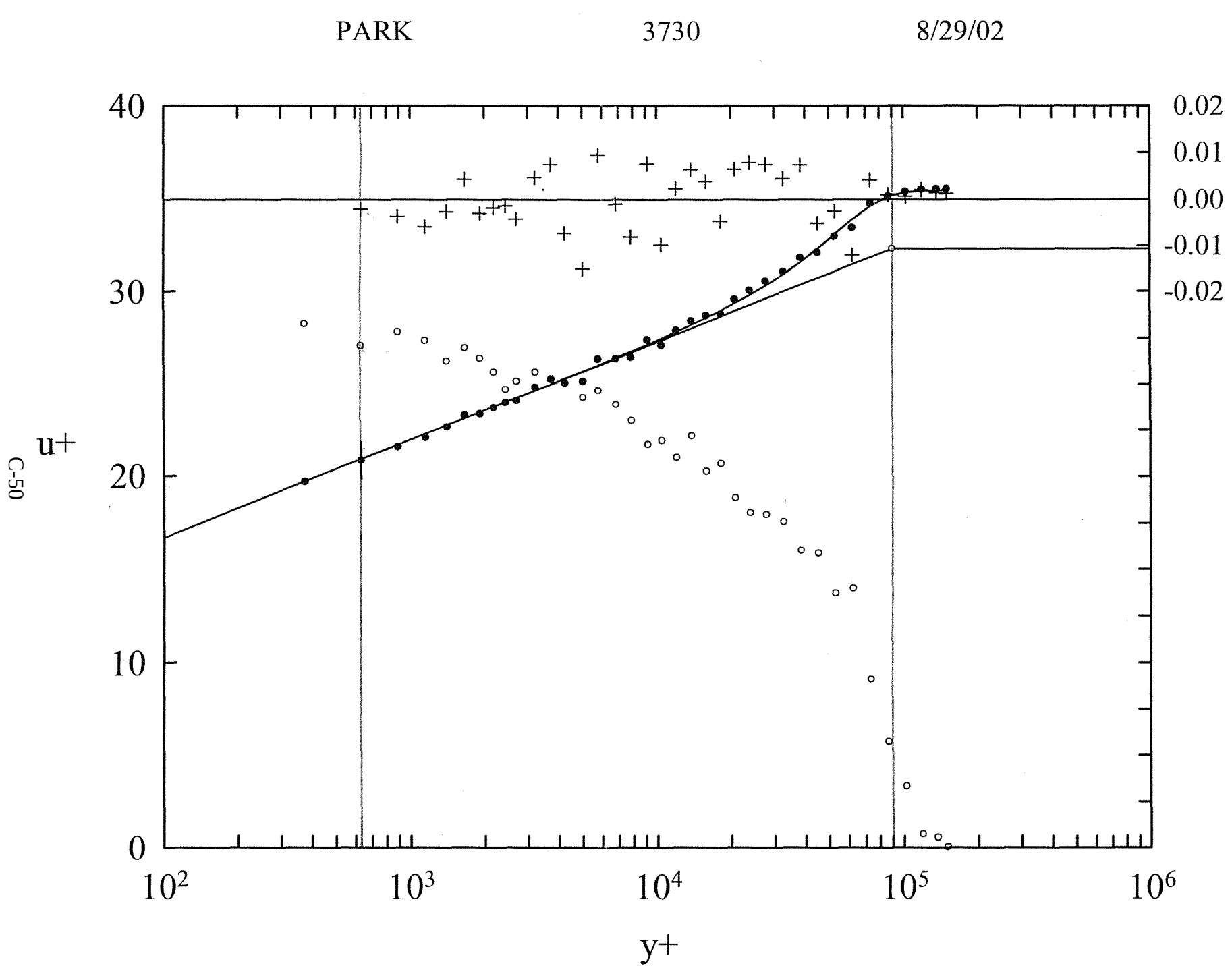
PARK 3727 8/29/02



PARK 3728 8/29/02




PARK
3729
8/29/02
40
30
20
10
0
0.02
0.01
0.00
-0.01
-0.02
u+
y+
$10^2$
$10^3$
$10^4$
$10^5$
$10^6$


PARK
3730
8/29/02
40
30
20
10
0
0.02
0.01
0.00
-0.01
-0.02
u+
C-50
$10^2$
$10^3$
$10^4$
$10^5$
$10^6$
y+

## APPENDIX D: COMPUTER DATA FROM COLES 2003 ATTACHMENT F

The following pages are the data sheets from Coles' Attachment F. The original data sheets were scanned and then converted to tables. The original data sheets for each boundary layer profile consisted of two pages and were split at line item 48 with item 49 beginning on the next page. The font size has been reduced so that a data sheet is on one page. The first page of the data set is the definition of the line items listed as DATA2. The remaining pages are Coles' ID 3683 through ID 3730 for a total of 48 data sets. The data are summarized in the following table. Data from the LDA boundary-layer measurements are for the location 250 mm (9.8 inches) above tunnel centerline.

**Table D-1. Summary of Data**


| Coles' ID | $U_t$ (m/s) | x (m) | Page |
|---|---|---|---|
| Index | | | D-3 |
| 3683 | 2.5 | 1.23 | D-5 |
| 3694 | 2.5 | 11.96 | D-16 |
| 3695 | 5.0 | 1.23 | D-17 |
| 3706 | 5.0 | 11.96 | D-28 |
| 3707 | 10.0 | 1.23 | D-29 |
| 3718 | 10.0 | 11.96 | D-40 |
| 3719 | 15.0 | 1.23 | D-41 |
| 3730 | 15.0 | 11.96 | D-52 |


Plots of the data are located in APPENDIX C. Columns in the data tables are defined as follows:

yplus: Boundary-layer coordinate, $y^+ = yu_\tau/\nu$

uplus: Non-dimensional boundary-layer axial velocity, $u^+ = u/u_\tau$

uprplus: Axial turbulence intensity, $u'^+ = u'/u_\tau$

wprplus: Transverse turbulence intensity, $w'^+ = w'/u_\tau$

THIS PAGE INTENTIONALLY LEFT BLANK

| No. | DATA2 | Units | | Definition |
|---|---|---|---|---|
| 1 | File ID | | | |
| 2 | Author | | | Author's last name |
| 3 | $x$ | $cm$ | | Streamwise station |
| 4 | $U_\infty$ | cm/s | | Free-stream velocity |
| 5 | $\nu_w$ | $cm^2/s$ | | Viscosity at wall |
| 6 | $\nu_\infty$ | $cm^2/s$ | | Free-stream viscosity |
| 7 | $T_w/T_\infty$ | | 1 | |
| 8 | $\delta^+$ | | 1 | $\delta^+ = \delta u_\tau/\nu$ |
| 9 | $c_f$ | | 1 | Friction coefficient, fit |
| 10 | $Re_\theta$ | | 1 | Reynolds number, fit |
| 11 | $\delta$ | cm | | Boundary layer thickness, fit |
| 12 | $\delta^*$ | cm | | Displacement thickness, fit |
| 13 | $\theta$ | cm | | Momentum thickness, fit |
| 14 | $u_\tau$ | cm/s | | Friction velocity, fit |
| 15 | $\Pi$ | | 1 | Wake parameter, fit |
| 16 | $U_\infty/u_\tau$ | | 1 | Fit |
| 17 | $2\Pi u_\tau/\kappa U_\infty$ | | 1 | Fit |
| 18 | $T_w$ | °K | | |
| 19 | $T_\infty$ | °K | | |
| 20 | $n$ | | | Fit |
| 21 | $\varepsilon$ | | | Rms dispersion of fit |
| 22 | $c_f$ | | 1 | Author |
| 23 | $Re_\theta$ | | 1 | Author |
| 24 | $\delta$ | cm | | Author |
| 25 | $\delta^*$ | cm | | Author |
| 26 | $\theta$ | cm | | Author |
| 27 | $u_\tau$ | cm/s | | Author |
| 28 | $\Pi$ | | 1 | Wake parameter, Author |
| 29 | $n$ | | | Author |
| 30 | $u'$ | | | Turbulence level |
| 31 | $T_\tau$ | | | Fit |
| 32 | File ID | | | |
| 33 | $M_\infty$ | | | Author |
| 34 | | | | |
| 35 | | | | |
| 36 | $T_{0\infty}$ | °K | | |
| 37 | $F$ | | | Index of first fittted point |
| 38 | lim | | | $y^+$ for first fitted point |
| 39 | $Pr$ | | | After fit |
| 40 | $L$ | cm | | Turbulence integral scale |
| 41 | $m$ | | | |
| 42 | $\sin^{-1}(m)/m$ | | | |
| 43 | $U_\infty^*/u_\tau$ | | | Fit |
| 44 | $2\Pi u_\tau/kU_\infty^*$ | | | |
| 45 | $c_f Re_\theta$ | | | Author |
| 46 | $c_f Re_\theta$ | | | Fit |
| 47 | $\delta^*/\theta$ | | | Author |
| 48 | $\delta^*/\theta$ | | | Fit |
| 49 | $U_\infty$* | | | |
| 50 | $U(\delta)$ | | | $U/U_\infty$ at $y = \delta$ |
| 51 | Index | | | for $y = \delta$ |
| 52 | $2d\theta/dx$ | | | |
| 53 | $w$ | cm | | Width of channel |
| 54 | $\delta/w$ | | | |
| 55 | $c_f$(FE) | | | Floating element |
| 56 | $c_f$(FE)/$c_f$ | | | Fit |
| 57 | $2d\theta/dx/c_f$ | | | Fit |
| 58 | File ID | | | |
| 59 | Author | | | Author's last name |

THIS PAGE INTENTIONALLY LEFT BLANK

| | DATA2 | yplus | uplus | uprplus | wprplus |
|---|---|---|---|---|---|
| 1 | 3683 | 42.061 | 14.625 | 3.311 | 1.688 |
| 2 | PARK | 103.314 | 17.016 | 2.416 | 1.684 |
| 3 | 122.9 | 144.149 | 17.555 | 2.495 | 1.593 |
| 4 | 251 | 205.403 | 18.35 | 2.536 | 1.635 |
| 5 | 0.00835 | 266.656 | 19.142 | 2.452 | 1.574 |
| 6 | | 317.7 | 19.248 | 2.458 | 1.562 |
| 7 | | 368.745 | 19.469 | 2.223 | 1.458 |
| 8 | 7189.53671 | 419.789 | 19.813 | 2.355 | 1.528 |
| 9 | 0.002307 | 470.833 | 20.14 | 2.32 | 1.542 |
| 10 | 21188.0798 | 521.878 | 20.29 | 2.379 | 1.493 |
| 11 | 7.042437 | 572.922 | 20.517 | 2.348 | 1.431 |
| 12 | 0.907332 | 623.966 | 20.726 | 2.293 | 1.452 |
| 13 | 0.704862 | 675.011 | 21.477 | 2.227 | 1.475 |
| 14 | 8.524411 | 777.1 | 21.356 | 2.328 | 1.511 |
| 15 | 0.637314 | 879.188 | 21.595 | 2.189 | 1.48 |
| 16 | 29.444849 | 981.277 | 22.519 | 2.166 | 1.459 |
| 17 | 0.099514 | 1134.41 | 22.837 | 2.042 | 1.449 |
| 18 | | 1287.543 | 22.708 | 2.154 | 1.391 |
| 19 | | 1491.721 | 23.615 | 2.019 | 1.442 |
| 20 | 0.029562 | 1695.898 | 23.453 | 1.979 | 1.416 |
| 21 | 0.006459 | 1951.12 | 24.183 | 1.985 | 1.405 |
| 22 | 0.0022 | 2206.342 | 24.23 | 1.935 | 1.382 |
| 23 | 21606 | 2512.609 | 24.713 | 1.898 | 1.326 |
| 24 | 6.36 | 2869.919 | 25.558 | 1.917 | 1.305 |
| 25 | 0.94 | 3278.274 | 25.926 | 1.75 | 1.281 |
| 26 | 0.719 | 3737.674 | 28.409 | 1.638 | 1.216 |
| 27 | 8.33 | 4248.177 | 27.201 | 1.479 | 1.087 |
| 28 | | 4860.65 | 27.952 | 1.244 | 0.945 |
| 29 | 0.1 | 5626.316 | 28.514 | 1.008 | 0.774 |
| 30 | 0.0015 | 6596.159 | 29.227 | 0.572 | 0.458 |
| 31 | | 7719.135 | 29.404 | 0.27 | 0.229 |
| 32 | 3683 | 9046.289 | 29.471 | 0.092 | 0.074 |
| 33 | | 10577.62 | 29.465 | 0.009 | 0.072 |
| 34 | | 12415.218 | 29.442 | 0.039 | 0.014 |
| 35 | | 14661.171 | 29.445 | 0.052 | 0.094 |
| 36 | | 17315.478 | 29.427 | 0.035 | 0.066 |
| 37 | 2 | | | | |
| 38 | 103.313823 | | | | |
| 39 | | | | | |
| 40 | | | | | |
| 41 | | | | | |
| 42 | | | | | |
| 43 | | | | | |
| 44 | | | | | |
| 45 | 47.5332 | | | | |
| 46 | 48.87682 | | | | |
| 47 | 1.307371 | | | | |
| 48 | 1.287247 | | | | |
| 49 | | | | | |
| 50 | 0.99577 | | | | |
| 51 | 30 | | | | |
| 52 | 0.001725 | | | | |
| 53 | 300 | | | | |
| 54 | 0.023475 | | | | |
| 55 | | | | | |
| 56 | | | | | |
| 57 | 0.747787 | | | | |
| 58 | 3683 | | | | |
| 59 | PARK | | | | |

| | DATA2 | yplus | uplus | uprplus | wprplus |
|---|---|---|---|---|---|
| 1 | 3684 | 82.162 | 16.569 | 2.577 | 1.64 |
| 2 | PARK | 133.322 | 17.585 | 2.46 | 1.701 |
| 3 | 199.4 | 184.482 | 18.411 | 2.552 | 1.636 |
| 4 | 251.4 | 235.642 | 18.503 | 2.529 | 1.622 |
| 5 | 0.00835 | 286.801 | 19.265 | 2.476 | 1.586 |
| 6 | | 337.961 | 19.294 | 2.45 | 1.531 |
| 7 | | 389.121 | 19.447 | 2.521 | 1.567 |
| 8 | 7559.90763 | 440.28 | 19.965 | 2.305 | 1.531 |
| 9 | 0.00231 | 491.44 | 20.239 | 2.35 | 1.504 |
| 10 | 22344.7054 | 542.6 | 20.665 | 2.478 | 1.527 |
| 11 | 7.388539 | 593.759 | 21.119 | 2.339 | 1.546 |
| 12 | 0.948382 | 696.079 | 20.851 | 2.366 | 1.517 |
| 13 | 0.742157 | 798.398 | 21.201 | 2.244 | 1.537 |
| 14 | 8.543669 | 900.718 | 21.651 | 2.323 | 1.517 |
| 15 | 0.607945 | 1054.197 | 22.437 | 2.178 | 1.421 |
| 16 | 29.425299 | 1207.676 | 22.631 | 2.196 | 1.437 |
| 17 | 0.094991 | 1412.314 | 23.331 | 2.022 | 1.391 |
| 18 | | 1616.953 | 23.57 | 1.958 | 1.391 |
| 19 | | 1872.752 | 24.088 | 1.99 | 1.361 |
| 20 | 0.11392 | 2128.55 | 24.126 | 1.991 | 1.387 |
| 21 | 0.006857 | 2435.508 | 24.841 | 1.874 | 1.357 |
| 22 | 0.00221 | 2793.626 | 25.241 | 1.83 | 1.336 |
| 23 | 22270 | 3202.904 | 25.45 | 1.811 | 1.313 |
| 24 | 7.14 | 3663.341 | 26.138 | 1.714 | 1.185 |
| 25 | 0.951 | 4174.938 | 27.245 | 1.497 | 1.043 |
| 26 | 0.739 | 4788.854 | 27.401 | 1.45 | 1.087 |
| 27 | 8.36 | 5556.25 | 28.122 | 1.263 | 0.867 |
| 28 | | 6528.284 | 28.843 | 0.892 | 0.614 |
| 29 | 0.1 | 7653.797 | 29.261 | 0.433 | 0.328 |
| 30 | 0.0022 | 8983.949 | 29.416 | 0.165 | 0.153 |
| 31 | | 10518.74 | 29.422 | 0.096 | 0.014 |
| 32 | 3684 | 12360.489 | 29.443 | 0.01 | 0.077 |
| 33 | | 14611.515 | 29.449 | 0.051 | 0.127 |
| 34 | | 17271.819 | 29.387 | 0.079 | 0.117 |
| 35 | | | | | |
| 36 | | | | | |
| 37 | 2 | | | | |
| 38 | 133.322158 | | | | |
| 39 | | | | | |
| 40 | | | | | |
| 41 | | | | | |
| 42 | | | | | |
| 43 | | | | | |
| 44 | | | | | |
| 45 | 49.2167 | | | | |
| 46 | 51.613448 | | | | |
| 47 | 1.286874 | | | | |
| 48 | 1.277872 | | | | |
| 49 | | | | | |
| 50 | 0.993215 | | | | |
| 51 | 28 | | | | |
| 52 | 0.001756 | | | | |
| 53 | 300 | | | | |
| 54 | 0.024628 | | | | |
| 55 | | | | | |
| 56 | | | | | |
| 57 | 0.760215 | | | | |
| 58 | 3684 | | | | |
| 59 | PARK | | | | |

| | DATA2 | yplus | uplus | uprplus | wprplus |
|---|---|---|---|---|---|
| 1 | 3685 | 50.983 | 14.857 | 3.053 | 1.704 |
| 2 | PARK | 92.349 | 16.015 | 2.597 | 1.641 |
| 3 | 322.3 | 144.056 | 17.696 | 2.4 | 1.579 |
| 4 | 251.9 | 195.763 | 18.051 | 2.503 | 1.658 |
| 5 | 0.00835 | 247.47 | 18.512 | 2.43 | 1.555 |
| 6 | | 299.178 | 18.941 | 2.38 | 1.585 |
| 7 | | 350.885 | 19.525 | 2.301 | 1.517 |
| 8 | 9119.75381 | 402.592 | 19.977 | 2.409 | 1.519 |
| 9 | 0.00235 | 454.299 | 20.397 | 2.385 | 1.509 |
| 10 | 24523.4126 | 506.006 | 20.42 | 2.247 | 1.491 |
| 11 | 8.818657 | 557.713 | 20.966 | 2.331 | 1.482 |
| 12 | 1.02479 | 609.421 | 21.059 | 2.28 | 1.471 |
| 13 | 0.812904 | 661.128 | 20.881 | 2.338 | 1.493 |
| 14 | 8.635096 | 764.542 | 21.456 | 2.264 | 1.427 |
| 15 | 0.458985 | 867.956 | 21.695 | 2.202 | 1.434 |
| 16 | 29.171651 | 971.371 | 22.045 | 2.008 | 1.468 |
| 17 | 0.07234 | 1126.492 | 22.48 | 2.115 | 1.403 |
| 18 | | 1281.614 | 22.911 | 2.067 | 1.358 |
| 19 | | 1488.442 | 22.908 | 2.054 | 1.296 |
| 20 | 0.043104 | 1695.271 | 23.667 | 1.859 | 1.335 |
| 21 | 0.005613 | 1953.807 | 23.457 | 1.925 | 1.298 |
| 22 | 0.00222 | 2212.343 | 23.787 | 1.958 | 1.366 |
| 23 | 24467 | 2522.586 | 24.285 | 1.797 | 1.302 |
| 24 | 7.85 | 2884.536 | 24.851 | 1.692 | 1.286 |
| 25 | 1.024 | 3298.193 | 25.362 | 1.655 | 1.218 |
| 26 | 0.811 | 3763.557 | 25.764 | 1.607 | 1.137 |
| 27 | 8.4 | 4280.629 | 26.287 | 1.562 | 1.129 |
| 28 | | 4901.115 | 26.966 | 1.446 | 1.045 |
| 29 | 0.1 | 5676.722 | 27.284 | 1.444 | 0.926 |
| 30 | 0.0032 | 6659.158 | 28.127 | 1.058 | 0.724 |
| 31 | | 7796.716 | 28.822 | 0.632 | 0.497 |
| 32 | 3685 | 9141.102 | 29.067 | 0.428 | 0.288 |
| 33 | | 10692.317 | 29.207 | 0.199 | 0.116 |
| 34 | | 12553.775 | 29.175 | 0.135 | 0.071 |
| 35 | | 14828.89 | 29.157 | 0.158 | 0.034 |
| 36 | | 17517.662 | 29.148 | 0.032 | 0.02 |
| 37 | 3 | | | | |
| 38 | 144.05615 | | | | |
| 39 | | | | | |
| 40 | | | | | |
| 41 | | | | | |
| 42 | | | | | |
| 43 | | | | | |
| 44 | | | | | |
| 45 | 54.31674 | | | | |
| 46 | 57.635344 | | | | |
| 47 | 1.262639 | | | | |
| 48 | 1.260653 | | | | |
| 49 | | | | | |
| 50 | 0.996267 | | | | |
| 51 | 31 | | | | |
| 52 | 0.001802 | | | | |
| 53 | 300 | | | | |
| 54 | 0.029396 | | | | |
| 55 | | | | | |
| 56 | | | | | |
| 57 | 0.766738 | | | | |
| 58 | 3685 | | | | |
| 59 | PARK | | | | |

| | DATA2 | yplus | uplus | uprplus | wprplus |
|---|---|---|---|---|---|
| 1 | 3686 | 48.92 | 15.081 | 3.023 | 1.568 |
| 2 | PARK | 89.943 | 16.361 | 2.633 | 1.687 |
| 3 | 398.8 | 130.967 | 17.396 | 2.539 | 1.603 |
| 4 | 251.9 | 182.246 | 18.026 | 2.649 | 1.617 |
| 5 | 0.00835 | 233.525 | 18.499 | 2.518 | 1.599 |
| 6 | | 284.804 | 18.885 | 2.315 | 1.61 |
| 7 | | 336.083 | 19.238 | 2.5 | 1.594 |
| 8 | 9271.62609 | 387.362 | 19.541 | 2.465 | 1.566 |
| 9 | 0.002311 | 438.641 | 20.076 | 2.323 | 1.565 |
| 10 | 25716.866 | 489.92 | 20.167 | 2.391 | 1.523 |
| 11 | 9.040363 | 541.199 | 20.632 | 2.335 | 1.56 |
| 12 | 1.075698 | 592.478 | 21.088 | 2.314 | 1.502 |
| 13 | 0.852465 | 695.036 | 21.155 | 2.247 | 1.419 |
| 14 | 8.563603 | 797.594 | 21.582 | 2.246 | 1.488 |
| 15 | 0.503697 | 900.153 | 21.688 | 2.359 | 1.437 |
| 16 | 29.41519 | 1053.99 | 22.303 | 2.214 | 1.424 |
| 17 | 0.07873 | 1207.827 | 22.685 | 2.087 | 1.412 |
| 18 | | 1412.943 | 22.961 | 2.111 | 1.418 |
| 19 | | 1618.059 | 23.391 | 2.039 | 1.413 |
| 20 | 0.071234 | 1874.455 | 23.812 | 1.91 | 1.36 |
| 21 | 0.004228 | 2130.85 | 24.103 | 1.993 | 1.377 |
| 22 | 0.0022 | 2438.524 | 24.362 | 1.856 | 1.351 |
| 23 | 25685 | 2797.478 | 24.85 | 1.778 | 1.288 |
| 24 | 8.47 | 3207.71 | 25.188 | 1.737 | 1.243 |
| 25 | 1.078 | 3669.222 | 25.732 | 1.679 | 1.189 |
| 26 | 0.851 | 4182.012 | 26.438 | 1.477 | 1.198 |
| 27 | 8.35 | 4797.361 | 26.724 | 1.444 | 1.11 |
| 28 | | 5566.547 | 27.383 | 1.427 | 1.035 |
| 29 | 0.1 | 6540.849 | 28.112 | 1.198 | 0.846 |
| 30 | 0.003 | 7668.988 | 28.8 | 0.84 | 0.642 |
| 31 | | 9002.244 | 29.221 | 0.54 | 0.39 |
| 32 | 3686 | 10540.615 | 29.43 | 0.192 | 0.192 |
| 33 | | 12386.661 | 29.43 | 0.123 | 0.035 |
| 34 | | 14642.94 | 29.418 | 0.093 | 0.085 |
| 35 | | 17309.451 | 29.386 | 0.029 | 0.018 |
| 36 | | | | | |
| 37 | 3 | | | | |
| 38 | 130.966712 | | | | |
| 39 | | | | | |
| 40 | | | | | |
| 41 | | | | | |
| 42 | | | | | |
| 43 | | | | | |
| 44 | | | | | |
| 45 | 56.507 | | | | |
| 46 | 59.443546 | | | | |
| 47 | 1.266745 | | | | |
| 48 | 1.261868 | | | | |
| 49 | | | | | |
| 50 | 0.994643 | | | | |
| 51 | 31 | | | | |
| 52 | 0.001829 | | | | |
| 53 | 300 | | | | |
| 54 | 0.030135 | | | | |
| 55 | | | | | |
| 56 | | | | | |
| 57 | 0.791274 | | | | |
| 58 | 3686 | | | | |
| 59 | PARK | | | | |

| | DATA2 | yplus | uplus | uprplus | wprplus |
|---|---|---|---|---|---|
| 1 | 3687 | 77.672 | 16.272 | 2.904 | 1.636 |
| 2 | PARK | 128.108 | 17.081 | 2.562 | 1.653 |
| 3 | 521.7 | 178.545 | 17.98 | 2.49 | 1.726 |
| 4 | 252.4 | 228.981 | 18.489 | 2.509 | 1.616 |
| 5 | 0.00835 | 279.418 | 18.789 | 2.588 | 1.591 |
| 6 | | 329.854 | 19.808 | 2.52 | 1.591 |
| 7 | | 380.29 | 19.688 | 2.484 | 1.628 |
| 8 | 10599.3462 | 430.727 | 20.377 | 2.455 | 1.623 |
| 9 | 0.002227 | 481.163 | 20.467 | 2.283 | 1.6 |
| 10 | 30486.6993 | 531.599 | 20.197 | 2.26 | 1.485 |
| 11 | 10.50764 | 582.036 | 20.617 | 2.277 | 1.502 |
| 12 | 1.274989 | 632.472 | 20.856 | 2.523 | 1.596 |
| 13 | 1.008573 | 733.345 | 21.186 | 2.19 | 1.495 |
| 14 | 8.422876 | 834.218 | 21.815 | 2.254 | 1.475 |
| 15 | 0.556584 | 935.09 | 21.935 | 2.227 | 1.545 |
| 16 | 29.966013 | 1086.4 | 22.355 | 2.21 | 1.502 |
| 17 | 0.085397 | 1237.709 | 22.475 | 2.225 | 1.436 |
| 18 | | 1439.454 | 22.924 | 2.111 | 1.403 |
| 19 | | 1641.2 | 23.344 | 2.137 | 1.39 |
| 20 | 0.091428 | 1893.382 | 23.793 | 2.074 | 1.425 |
| 21 | 0.005332 | 2145.564 | 24.033 | 2.037 | 1.399 |
| 22 | 0.00212 | 2448.182 | 24.392 | 1.966 | 1.369 |
| 23 | 30457 | 2801.237 | 24.932 | 1.83 | 1.324 |
| 24 | 10 | 3204.728 | 25.141 | 1.858 | 1.3 |
| 25 | 1.278 | 3658.655 | 25.291 | 1.81 | 1.351 |
| 26 | 1.007 | 4163.019 | 26.07 | 1.6 | 1.262 |
| 27 | 8.22 | 4768.255 | 26.82 | 1.555 | 1.244 |
| 28 | | 5524.801 | 27.149 | 1.438 | 1.144 |
| 29 | 0.1 | 6483.092 | 27.928 | 1.431 | 0.997 |
| 30 | 0.0052 | 7592.693 | 28.977 | 1.001 | 0.773 |
| 31 | | 8904.039 | 29.217 | 0.9 | 0.685 |
| 32 | 3687 | 10417.13 | 29.786 | 0.511 | 0.363 |
| 33 | | 12232.84 | 29.966 | 0.282 | 0.179 |
| 34 | | 14452.04 | 29.966 | 0.16 | 0.065 |
| 35 | | 17074.732 | 29.936 | 0.156 | 0.021 |
| 36 | | 20100.915 | 29.966 | 0.01 | 0.007 |
| 37 | 2 | 23530.589 | 29.966 | 0.199 | 0.081 |
| 38 | 128.108407 | | | | |
| 39 | | | | | |
| 40 | | | | | |
| 41 | | | | | |
| 42 | | | | | |
| 43 | | | | | |
| 44 | | | | | |
| 45 | 64.56884 | | | | |
| 46 | 67.901985 | | | | |
| 47 | 1.269116 | | | | |
| 48 | 1.264151 | | | | |
| 49 | | | | | |
| 50 | 0.994602 | | | | |
| 51 | 32 | | | | |
| 52 | 0.001869 | | | | |
| 53 | 300 | | | | |
| 54 | 0.035025 | | | | |
| 55 | | | | | |
| 56 | | | | | |
| 57 | 0.839145 | | | | |
| 58 | 3687 | | | | |
| 59 | PARK | | | | |

| | DATA2 | yplus | uplus | uprplus | wprplus |
|---|---|---|---|---|---|
| 1 | 3688 | 64.07 | 15.457 | 2.724 | |
| 2 | PARK | 114.203 | 16.97 | 2.507 | 1.687 |
| 3 | 598.2 | 164.336 | 17.928 | 2.576 | 1.641 |
| 4 | 252.9 | 214.47 | 18.293 | 2.565 | 1.599 |
| 5 | 0.00835 | 264.603 | 18.997 | 2.567 | 1.661 |
| 6 | | 314.736 | 18.916 | 2.626 | 1.661 |
| 7 | | 364.869 | 19.456 | 2.443 | 1.591 |
| 8 | 11081.8436 | 415.002 | 20.082 | 2.626 | 1.635 |
| 9 | 0.002192 | 465.135 | 20.574 | 2.294 | 1.597 |
| 10 | 32419.3063 | 515.268 | 20.671 | 2.288 | 1.548 |
| 11 | 11.052415 | 565.401 | 20.674 | 2.393 | 1.519 |
| 12 | 1.355897 | 665.668 | 21.187 | 2.34 | 1.531 |
| 13 | 1.070388 | 765.934 | 21.266 | 2.439 | 1.514 |
| 14 | 8.372233 | 866.2 | 21.387 | 2.428 | 1.512 |
| 15 | 0.586739 | 1016.6 | 22.26 | 2.211 | 1.506 |
| 16 | 30.206993 | 1166.999 | 22.483 | 2.318 | 1.449 |
| 17 | 0.089306 | 1367.532 | 23.072 | 2.171 | 1.492 |
| 18 | | 1568.064 | 23.102 | 2.069 | 1.47 |
| 19 | | 1818.73 | 23.317 | 2.185 | 1.438 |
| 20 | 0.088866 | 2069.396 | 23.951 | 2.2 | 1.403 |
| 21 | 0.005382 | 2370.194 | 24.111 | 2.046 | 1.385 |
| 22 | 0.00208 | 2721.126 | 24.691 | 1.87 | 1.336 |
| 23 | 32332 | 3122.191 | 24.96 | 1.799 | 1.417 |
| 24 | 10.46 | 3573.39 | 25.534 | 1.744 | 1.329 |
| 25 | 1.356 | 4074.721 | 26.271 | 1.676 | 1.268 |
| 26 | 1.067 | 4676.319 | 26.679 | 1.579 | 1.244 |
| 27 | 8.16 | 5428.315 | 26.939 | 1.575 | 1.205 |
| 28 | | 6380.845 | 27.878 | 1.38 | 1.016 |
| 29 | 0.1 | 7483.774 | 28.79 | 1.144 | 0.875 |
| 30 | 0.0029 | 8787.236 | 29.292 | 0.939 | 0.723 |
| 31 | | 10291.23 | 29.869 | 0.652 | 0.513 |
| 32 | 3688 | 12096.022 | 30.201 | 0.289 | 0.23 |
| 33 | | 14301.88 | 30.21 | 0.147 | 0.139 |
| 34 | | 16908.803 | 30.219 | 0.086 | 0.13 |
| 35 | | 19916.791 | 30.228 | 0 | 0 |
| 36 | | 23325.845 | 30.171 | 0.135 | 0.101 |
| 37 | 2 | | | | |
| 38 | 114.20328 | | | | |
| 39 | | | | | |
| 40 | | | | | |
| 41 | | | | | |
| 42 | | | | | |
| 43 | | | | | |
| 44 | | | | | |
| 45 | 67.25056 | | | | |
| 46 | 71.058938 | | | | |
| 47 | 1.270853 | | | | |
| 48 | 1.266734 | | | | |
| 49 | | | | | |
| 50 | 0.993619 | | | | |
| 51 | 31 | | | | |
| 52 | 0.001893 | | | | |
| 53 | 300 | | | | |
| 54 | 0.036841 | | | | |
| 55 | | | | | |
| 56 | | | | | |
| 57 | 0.863646 | | | | |
| 58 | 3688 | | | | |
| 59 | PARK | | | | |

| | DATA2 | yplus | uplus | uprplus | wprplus |
|---|---|---|---|---|---|
| 1 | 3689 | 21.621 | 11.634 | 4.301 | |
| 2 | PARK | 60.933 | 15.256 | 2.656 | |
| 3 | 721 | 100.244 | 16.76 | 2.593 | 1.648 |
| 4 | | 251.9 | 100.244 | 16.33 | 2.585 |
| 5 | 0.00835 | 139.555 | 17.374 | 2.542 | 1.751 |
| 6 | | 178.867 | 17.865 | 2.569 | 1.644 |
| 7 | | 228.006 | 18.172 | 2.719 | 1.626 |
| 8 | 11974.2067 | 277.145 | 19.154 | 2.492 | 1.632 |
| 9 | 0.002123 | 326.284 | 19.339 | 2.539 | 1.683 |
| 10 | 37716.5304 | 375.423 | 19.707 | 2.433 | 1.655 |
| 11 | 12.183972 | 424.562 | 19.983 | 2.495 | 1.715 |
| 12 | 1.578145 | 473.702 | 20.014 | 2.48 | 1.613 |
| 13 | 1.25023 | 522.841 | 20.198 | 2.523 | 1.604 |
| 14 | 8.206242 | 571.98 | 20.751 | 2.59 | 1.599 |
| 15 | 0.654407 | 621.119 | 20.659 | 2.524 | 1.584 |
| 16 | 30.696145 | 670.258 | 21.334 | 2.436 | 1.604 |
| 17 | 0.098018 | 719.398 | 21.088 | 2.355 | 1.563 |
| 18 | | 768.537 | 21.272 | 2.485 | 1.53 |
| 19 | | 817.676 | 21.61 | 2.444 | 1.55 |
| 20 | 0.18289 | 866.815 | 21.487 | 2.352 | 1.507 |
| 21 | 0.005584 | 965.093 | 22.255 | 2.362 | 1.62 |
| 22 | 0.00201 | 1063.372 | 22.47 | 2.295 | 1.568 |
| 23 | 37444 | 1161.65 | 22.47 | 2.284 | 1.491 |
| 24 | 12.77 | 1309.068 | 22.746 | 2.165 | 1.468 |
| 25 | 1.572 | 1456.485 | 23.114 | 2.249 | 1.527 |
| 26 | 1.241 | 1653.042 | 23.206 | 2.224 | 1.469 |
| 27 | 7.98 | 1849.599 | 23.483 | 2.225 | 1.465 |
| 28 | | 2095.294 | 24.158 | 2.109 | 1.367 |
| 29 | 0.1 | 2340.99 | 24.311 | 2.092 | 1.47 |
| 30 | 0.0035 | 2635.825 | 24.68 | 1.942 | 1.388 |
| 31 | | 2979.8 | 24.956 | 1.961 | 1.425 |
| 32 | 3689 | 3372.913 | 25.294 | 1.902 | 1.402 |
| 33 | | 3815.165 | 25.877 | 1.855 | 1.342 |
| 34 | | 4306.557 | 26.491 | 1.747 | 1.276 |
| 35 | | 4896.227 | 26.951 | 1.704 | 1.316 |
| 36 | | 5633.315 | 27.258 | 1.612 | 1.175 |
| 37 | 5 | 6566.959 | 27.749 | 1.506 | 1.157 |
| 38 | 139.555255 | 7648.021 | 28.486 | 1.406 | 0.992 |
| 39 | | 8925.64 | 29.376 | 1.144 | 0.808 |
| 40 | | 10399.815 | 29.959 | 0.925 | 0.653 |
| 41 | | 12168.825 | 30.328 | 0.725 | 0.486 |
| 42 | | 14330.949 | 30.727 | 0.263 | 0.19 |
| 43 | | 16886.186 | 30.758 | 0.162 | 0 |
| 44 | | 19834.536 | 30.727 | 0.101 | 0.094 |
| 45 | 75.26244 | 22979.443 | 30.696 | 0.113 | 0.132 |
| 46 | 80.056029 | 26320.907 | 30.635 | 0.042 | 0.082 |
| 47 | 1.26672 | 28876.144 | 30.727 | 0.141 | 0.143 |
| 48 | 1.262284 | | | | |
| 49 | | | | | |
| 50 | 0.98668 | | | | |
| 51 | 40 | | | | |
| 52 | 0.001929 | | | | |
| 53 | 300 | | | | |
| 54 | 0.040613 | | | | |
| 55 | | | | | |
| 56 | | | | | |
| 57 | 0.908803 | | | | |
| 58 | 3689 | | | | |
| 59 | PARK | | | | |

| | DATA2 | yplus | uplus | uprplus | wprplus |
|---|---|---|---|---|---|
| 1 | 3690 | 38.587 | 14.225 | 3.225 | |
| 2 | PARK | 87.806 | 16.36 | 2.63 | |
| 3 | 797.6 | 137.024 | 17.443 | 2.561 | 1.465 |
| 4 | 252.2 | 186.243 | 17.904 | 2.48 | 1.682 |
| 5 | 0.00835 | 235.461 | 18.023 | 2.514 | 1.612 |
| 6 | | 284.68 | 18.962 | 2.486 | 1.565 |
| 7 | | 333.899 | 19.432 | 2.606 | 1.676 |
| 8 | 13200.5585 | 383.117 | 19.653 | 2.435 | 1.616 |
| 9 | 0.002124 | 432.336 | 20.199 | 2.554 | 1.666 |
| 10 | 39039.2286 | 481.554 | 20.162 | 2.431 | 1.542 |
| 11 | 13.410148 | 530.773 | 20.493 | 2.432 | 1.649 |
| 12 | 1.631347 | 579.991 | 20.687 | 2.386 | 1.593 |
| 13 | 1.292536 | 678.428 | 21.23 | 2.549 | 1.597 |
| 14 | 8.219496 | 776.865 | 21.625 | 2.404 | 1.538 |
| 15 | 0.602827 | 875.303 | 21.635 | 2.355 | 1.643 |
| 16 | 30.683145 | 1022.958 | 21.76 | 2.333 | 1.525 |
| 17 | 0.09033 | 1170.614 | 22.61 | 2.276 | 1.444 |
| 18 | | 1367.488 | 22.914 | 2.294 | 1.546 |
| 19 | | 1564.362 | 23.322 | 2.372 | 1.494 |
| 20 | 0.079292 | 1810.455 | 23.448 | 2.131 | 1.443 |
| 21 | 0.005234 | 2056.548 | 23.957 | 1.979 | 1.459 |
| 22 | 0.00201 | 2351.859 | 24.307 | 2.04 | 1.422 |
| 23 | 38890 | 2696.389 | 24.663 | 1.95 | 1.375 |
| 24 | 12.32 | 3090.137 | 25.148 | 1.974 | 1.38 |
| 25 | 1.631 | 3533.104 | 25.381 | 2.029 | 1.366 |
| 26 | 1.287 | 4025.289 | 25.719 | 1.741 | 1.37 |
| 27 | 7.99 | 4615.912 | 26.311 | 1.649 | 1.285 |
| 28 | | 5354.19 | 26.737 | 1.675 | 1.284 |
| 29 | 0.1 | 6289.342 | 27.428 | 1.608 | 1.143 |
| 30 | 0.0045 | 7372.15 | 28.207 | 1.385 | 1.046 |
| 31 | | 8651.832 | 29.02 | 1.207 | 0.948 |
| 32 | 3690 | 10128.388 | 29.582 | 1.066 | 0.785 |
| 33 | | 11900.256 | 30.349 | 0.67 | 0.507 |
| 34 | | 14065.872 | 30.606 | 0.386 | 0.288 |
| 35 | | 16625.236 | 30.698 | 0.183 | 0.195 |
| 36 | | 19578.348 | 30.683 | 0.023 | 0.165 |
| 37 | 3 | 22728.335 | 30.714 | 0.187 | 0.194 |
| 38 | 137.024418 | 26075.195 | 30.698 | 0.191 | 0.012 |
| 39 | | 28634.56 | 30.64 | 0.138 | 0.164 |
| 40 | | | | | |
| 41 | | | | | |
| 42 | | | | | |
| 43 | | | | | |
| 44 | | | | | |
| 45 | 78.1689 | | | | |
| 46 | 82.933782 | | | | |
| 47 | 1.267288 | | | | |
| 48 | 1.262129 | | | | |
| 49 | | | | | |
| 50 | 0.994144 | | | | |
| 51 | 33 | | | | |
| 52 | 0.00195 | | | | |
| 53 | 300 | | | | |
| 54 | 0.0447 | | | | |
| 55 | | | | | |
| 56 | | | | | |
| 57 | 0.917919 | | | | |
| 58 | 3690 | | | | |
| 59 | PARK | | | | |

| | DATA2 | yplus | uplus | uprplus | wprplus |
|---|---|---|---|---|---|
| 1 | 3691 | 65.165 | 15.274 | 2.658 | |
| 2 | PARK | 104.42 | 16.788 | 2.594 | 1.649 |
| 3 | | 920.4 | 104.42 | 16.37 | 2.587 |
| 4 | 252.2 | 143.676 | 17.407 | 2.543 | 1.752 |
| 5 | 0.00835 | 182.932 | 17.909 | 2.57 | 1.646 |
| 6 | | 232.002 | 18.192 | 2.721 | 1.627 |
| 7 | | 281.072 | 19.17 | 2.494 | 1.633 |
| 8 | 11759.165 | 330.141 | 19.383 | 2.541 | 1.684 |
| 9 | 0.002112 | 379.211 | 19.74 | 2.435 | 1.656 |
| 10 | 38049.8904 | 428.281 | 20.008 | 2.497 | 1.716 |
| 11 | 11.982091 | 477.351 | 20.038 | 2.482 | 1.614 |
| 12 | 1.591456 | 526.42 | 20.217 | 2.524 | 1.605 |
| 13 | 1.25978 | 575.49 | 20.799 | 2.591 | 1.6 |
| 14 | 8.194649 | 624.56 | 20.7 | 2.525 | 1.585 |
| 15 | 0.680875 | 673.63 | 21.377 | 2.438 | 1.606 |
| 16 | 30.776181 | 722.699 | 21.109 | 2.357 | 1.565 |
| 17 | 0.101717 | 771.769 | 21.309 | 2.487 | 1.531 |
| 18 | | 820.839 | 21.645 | 2.445 | 1.551 |
| 19 | | 869.909 | 21.525 | 2.354 | 1.508 |
| 20 | 0.21892 | 968.048 | 22.288 | 2.363 | 1.621 |
| 21 | 0.006015 | 1066.188 | 22.497 | 2.297 | 1.569 |
| 22 | 0.00199 | 1164.327 | 22.522 | 2.285 | 1.492 |
| 23 | 37887 | 1311.536 | 22.774 | 2.167 | 1.469 |
| 24 | 12.92 | 1458.746 | 23.165 | 2.251 | 1.529 |
| 25 | 1.588 | 1655.025 | 23.258 | 2.225 | 1.47 |
| 26 | 1.254 | 1851.304 | 23.507 | 2.227 | 1.466 |
| 27 | 7.95 | 2096.652 | 24.205 | 2.11 | 1.368 |
| 28 | | 2342.001 | 24.366 | 2.093 | 1.471 |
| 29 | 0.1 | 2636.42 | 24.735 | 1.944 | 1.389 |
| 30 | 0.0035 | 2979.908 | 24.999 | 1.963 | 1.426 |
| 31 | | 3372.466 | 25.341 | 1.904 | 1.402 |
| 32 | 3691 | 3814.094 | 25.914 | 1.856 | 1.343 |
| 33 | | 4304.791 | 26.52 | 1.749 | 1.277 |
| 34 | | 4893.628 | 27.009 | 1.705 | 1.317 |
| 35 | | 5629.675 | 27.295 | 1.613 | 1.175 |
| 36 | | 6562 | 27.785 | 1.506 | 1.157 |
| 37 | 2 | 7641.535 | 28.52 | 1.407 | 0.993 |
| 38 | 104.420437 | 8917.348 | 29.422 | 1.145 | 0.809 |
| 39 | | 10389.441 | 29.998 | 0.925 | 0.653 |
| 40 | | 12155.952 | 30.37 | 0.726 | 0.486 |
| 41 | | 14315.021 | 30.77 | 0.263 | 0.19 |
| 42 | | 16866.648 | 30.798 | 0.162 | 0 |
| 43 | | 19810.834 | 30.792 | 0.101 | 0.094 |
| 44 | | 22951.298 | 30.752 | 0.113 | 0.132 |
| 45 | 75.39513 | 26288.041 | 30.795 | 0.042 | 0.082 |
| 46 | 80.344092 | 28839.668 | 30.764 | 0.141 | 0.143 |
| 47 | 1.266348 | | | | |
| 48 | 1.263281 | | | | |
| 49 | | | | | |
| 50 | 0.984082 | | | | |
| 51 | 39 | | | | |
| 52 | 0.001983 | | | | |
| 53 | 300 | | | | |
| 54 | 0.03994 | | | | |
| 55 | | | | | |
| 56 | | | | | |
| 57 | 0.939122 | | | | |
| 58 | 3691 | | | | |
| 59 | PARK | | | | |

| | DATA2 | yplus | uplus | uprplus | wprplus |
|---|---|---|---|---|---|
| 1 | 3692 | 69.243 | 15.929 | 2.636 | 1.64 |
| 2 | PARK | 118.006 | 17.067 | 2.51 | 1.68 |
| 3 | 997 | 166.768 | 17.844 | 2.587 | 1.691 |
| 4 | 253.2 | 215.531 | 18.223 | 2.501 | 1.623 |
| 5 | 0.00835 | 264.294 | 18.565 | 2.579 | 1.622 |
| 6 | | 313.057 | 19.436 | 2.522 | 1.643 |
| 7 | | 361.819 | 19.545 | 2.445 | 1.637 |
| 8 | 14953.5041 | 410.582 | 20.157 | 2.41 | 1.65 |
| 9 | 0.002069 | 459.345 | 19.934 | 2.417 | 1.585 |
| 10 | 44629.3345 | 508.107 | 19.909 | 2.484 | 1.603 |
| 11 | 15.332929 | 605.633 | 20.702 | 2.422 | 1.527 |
| 12 | 1.861289 | 703.158 | 21.389 | 2.383 | 1.598 |
| 13 | 1.471781 | 800.684 | 21.364 | 2.443 | 1.548 |
| 14 | 8.143373 | 946.972 | 22.455 | 2.534 | 1.504 |
| 15 | 0.629576 | 1093.26 | 22.828 | 2.391 | 1.531 |
| 16 | 31.092767 | 1288.311 | 22.853 | 2.117 | 1.461 |
| 17 | 0.093096 | 1483.362 | 22.909 | 2.098 | 1.491 |
| 18 | | 1727.175 | 22.981 | 2.187 | 1.432 |
| 19 | | 1970.989 | 23.643 | 1.94 | 1.508 |
| 20 | 0.004039 | 2263.565 | 23.966 | 2.062 | 1.414 |
| 21 | 0.007 | 2604.904 | 24.588 | 2.008 | 1.465 |
| 22 | 0.00196 | 2995.006 | 24.912 | 1.894 | 1.491 |
| 23 | 44451 | 3433.87 | 25.194 | 2.101 | 1.371 |
| 24 | 13.79 | 3921.497 | 25.456 | 1.857 | 1.362 |
| 25 | 1.856 | 4506.65 | 26.059 | 1.738 | 1.381 |
| 26 | 1.466 | 5238.091 | 26.525 | 1.659 | 1.288 |
| 27 | 7.92 | 6164.582 | 27.194 | 1.679 | 1.238 |
| 28 | | 7237.362 | 28.021 | 1.546 | 1.167 |
| 29 | 0.1 | 8505.192 | 28.431 | 1.375 | 10.371 |
| 30 | 0.0029 | 9968.074 | 29.476 | 1.116 | 0.895 |
| 31 | | 11723.531 | 30.297 | 0.918 | 0.695 |
| 32 | 3692 | 13869.091 | 30.9 | 0.586 | 0.376 |
| 33 | | 16404.752 | 31.052 | 0.224 | 0.277 |
| 34 | | 19330.514 | 31.111 | 0.085 | 0.091 |
| 35 | | 22451.328 | 31.102 | 0.125 | 0.14 |
| 36 | | 25767.192 | 31.062 | 0.089 | 0.1 |
| 37 | 2 | 28302.853 | 31.096 | 0.018 | 0.012 |
| 38 | 118.005763 | | | | |
| 39 | | | | | |
| 40 | | | | | |
| 41 | | | | | |
| 42 | | | | | |
| 43 | | | | | |
| 44 | | | | | |
| 45 | 87.12396 | | | | |
| 46 | 92.327622 | | | | |
| 47 | 1.26603 | | | | |
| 48 | 1.264651 | | | | |
| 49 | | | | | |
| 50 | 0.995896 | | | | |
| 51 | 32 | | | | |
| 52 | 0.002002 | | | | |
| 53 | 300 | | | | |
| 54 | 0.05111 | | | | |
| 55 | | | | | |
| 56 | | | | | |
| 57 | 0.967727 | | | | |
| 58 | 3692 | | | | |
| 59 | PARK | | | | |

| | DATA2 | yplus | uplus | uprplus | wprplus |
|---|---|---|---|---|---|
| 1 | 3693 | 78.315 | 15.952 | 2.669 | 1.794 |
| 2 | PARK | 127.019 | 17.012 | 2.773 | 1.678 |
| 3 | 1119.8 | 175.722 | 18.154 | 2.594 | 1.716 |
| 4 | 255.1 | 224.426 | 18.21 | 2.616 | 1.722 |
| 5 | 0.00835 | 273.129 | 18.765 | 2.672 | 1.587 |
| 6 | | 321.833 | 18.985 | 2.584 | 1.703 |
| 7 | | 370.536 | 19.314 | 2.453 | 1.615 |
| 8 | 16947.4264 | 419.239 | 20.17 | 2.669 | 1.637 |
| 9 | 0.002033 | 467.943 | 20.647 | 2.446 | 1.556 |
| 10 | 51409.4649 | 516.646 | 20.829 | 2.418 | 1.64 |
| 11 | 17.398581 | 565.35 | 20.242 | 2.528 | 1.553 |
| 12 | 2.11915 | 614.053 | 21.042 | 2.362 | 1.6 |
| 13 | 1.682748 | 711.46 | 21.491 | 2.465 | 1.54 |
| 14 | 8.13348 | 808.867 | 21.801 | 2.428 | 1.546 |
| 15 | 0.626025 | 906.274 | 21.71 | 2.456 | 1.505 |
| 16 | 31.364188 | 1052.385 | 22.09 | 2.343 | 1.468 |
| 17 | 0.09177 | 1198.495 | 22.664 | 2.271 | 1.578 |
| 18 | | 1393.309 | 23.009 | 2.126 | 1.424 |
| 19 | | 1588.123 | 23.423 | 2.214 | 1.427 |
| 20 | 0.108913 | 1831.64 | 23.645 | 2.264 | 1.505 |
| 21 | 0.007338 | 2075.158 | 23.862 | 2.148 | 1.502 |
| 22 | 0.00193 | 2367.378 | 24.05 | 2.026 | 1.446 |
| 23 | 51327 | 2708.303 | 24.42 | 2.092 | 1.418 |
| 24 | 17.74 | 3097.931 | 24.668 | 2.042 | 1.386 |
| 25 | 2.121 | 3536.262 | 25.138 | 1.948 | 1.415 |
| 26 | 1.68 | 4023.297 | 25.327 | 1.963 | 1.43 |
| 27 | 7.92 | 4607.738 | 25.96 | 1.929 | 1.352 |
| 28 | | 5338.29 | 25.966 | 1.832 | 1.305 |
| 29 | 0.1 | 6.263.656 | 26.923 | 1.844 | 1.33 |
| 30 | 0.0029 | 7335.133 | 27.61 | 1.728 | 1.242 |
| 31 | | 8601.423 | 28.573 | 1.393 | 1.148 |
| 32 | 3693 | 10062.527 | 29.335 | 1.28 | 1.019 |
| 33 | | 11815.852 | 29.956 | 1.292 | 0.913 |
| 34 | | 13958.805 | 30.74 | 1.079 | 0.634 |
| 35 | | 16491.386 | 30.928 | 0.743 | 0.539 |
| 36 | | 19413.594 | 31.377 | 0.273 | 0.173 |
| 37 | 2 | 22530.616 | 31.361 | 0.022 | 0.016 |
| 38 | 127.018659 | 25842.453 | 31.396 | 0.091 | 0.151 |
| 39 | | 28375.033 | 31.323 | 0.185 | 0.107 |
| 40 | | | | | |
| 41 | | | | | |
| 42 | | | | | |
| 43 | | | | | |
| 44 | | | | | |
| 45 | 99.06111 | | | | |
| 46 | 104.521342 | | | | |
| 47 | 1.2625 | | | | |
| 48 | 1.259339 | | | | |
| 49 | | | | | |
| 50 | 0.988332 | | | | |
| 51 | 35 | | | | |
| 52 | 0.002032 | | | | |
| 53 | 300 | | | | |
| 54 | 0.057995 | | | | |
| 55 | | | | | |
| 56 | | | | | |
| 57 | 0.999452 | | | | |
| 58 | 3693 | | | | |
| 59 | PARK | | | | |

| | DATA2 | yplus | uplus | uprplus | wprplus |
|---|---|---|---|---|---|
| 1 | 3694 | 70.39 | 15.78 | 2.692 | 1.667 |
| 2 | PARK | 119.069 | 17.092 | 2.614 | 1.642 |
| 3 | 1196.3 | 167.747 | 17.35 | 2.548 | 1.604 |
| 4 | 255.7 | 216.426 | 18.489 | 2.601 | 1.727 |
| 5 | 0.00835 | 265.105 | 18.875 | 2.686 | 1.639 |
| 6 | | 313.784 | 19.363 | 2.463 | 1.642 |
| 7 | | 362.463 | 19.979 | 2.617 | 1.708 |
| 8 | 16326.525 | 411.142 | 19.394 | 2.652 | 1.654 |
| 9 | 0.002022 | 459.821 | 20.209 | 2.494 | 1.623 |
| 10 | 51801.0094 | 508.5 | 20.448 | 2.523 | 1.56 |
| 11 | 16.76962 | 605.857 | 20.961 | 2.457 | 1.604 |
| 12 | 2.126527 | 703.215 | 21.172 | 2.469 | 1.595 |
| 13 | 1.691586 | 800.573 | 21.536 | 2.346 | 1.592 |
| 14 | 8.129372 | 946.609 | 21.662 | 2.29 | 1.62 |
| 15 | 0.664188 | 1092.646 | 22.505 | 2.343 | 1.51 |
| 16 | 31.453844 | 1287.362 | 22.408 | 2.274 | 1.488 |
| 17 | 0.097086 | 1482.077 | 22.798 | 2.104 | 1.488 |
| 18 | | 1725.471 | 23.141 | 2.155 | 1.535 |
| 19 | | 1968.866 | 23.845 | 2.214 | 1.519 |
| 20 | 0.185434 | 2260.939 | 24.408 | 2.148 | 1.425 |
| 21 | 0.006937 | 2601.691 | 24.587 | 2.148 | 1.378 |
| 22 | 0.00191 | 2991.122 | 24.962 | 1.922 | 1.422 |
| 23 | 51684 | 3429.232 | 25.006 | 2.173 | 1.39 |
| 24 | 16.57 | 3916.021 | 25.682 | 1.912 | 1.481 |
| 25 | 2.126 | 4500.167 | 25.647 | 1.84 | 1.353 |
| 26 | 1.687 | 5230.:::10 | 26.443 | 1.758 | 1.362 |
| 27 | 7.91 | 6155.249 | 27.311 | 1.683 | 1.258 |
| 28 | | 7226.184 | 27.881 | 1.724 | 1.198 |
| 29 | 0.1 | 8491.835 | 28.327 | 1.526 | 1.173 |
| 30 | 0.0036 | 9952.201 | 29.409 | 1.375 | 1.038 |
| 31 | | 11704.641 | 29.919 | 1.258 | 0.868 |
| 32 | 3694 | 13846.511 | 30.262 | 1.145 | 0.554 |
| 33 | | 16377.813 | 31.234 | 0.557 | 0.352 |
| 34 | | 19298.545 | 31.485 | 0.192 | 0.107 |
| 35 | | 22413.993 | 31.473 | 0.016 | 0.013 |
| 36 | | 25724.157 | 31.426 | 0.142 | 0.101 |
| 37 | 2 | 28255.458 | 31.432 | 0.085 | 0.06 |
| 38 | 119.068528 | | | | |
| 39 | | | | | |
| 40 | | | | | |
| 41 | | | | | |
| 42 | | | | | |
| 43 | | | | | |
| 44 | | | | | |
| 45 | 98.71644 | | | | |
| 46 | 104.717862 | | | | |
| 47 | 1.260225 | | | | |
| 48 | 1.257121 | | | | |
| 49 | | | | | |
| 50 | 0.992374 | | | | |
| 51 | 32 | | | | |
| 52 | 0.00205 | | | | |
| 53 | 300 | | | | |
| 54 | 0.055899 | | | | |
| 55 | | | | | |
| 56 | | | | | |
| 57 | 1.014078 | | | | |
| 58 | 3694 | | | | |
| 59 | PARK | | | | |

| | DATA2 | yplus | uplus | uprplus | wprplus |
|---|---|---|---|---|---|
| 1 | 3695 | 100.393 | 16.53 | 2.799 | 1.548 |
| 2 | PARK | 200.286 | 18.138 | 2.534 | 1.633 |
| 3 | 122.9 | 300.179 | 19.261 | 2.58 | 1.599 |
| 4 | 502.3 | 400.073 | 19.767 | 2.436 | 1.552 |
| 5 | 0.00835 | 499.966 | 20.529 | 2.408 | 1.544 |
| 6 | | 599.859 | 20.863 | 2.413 | 1.578 |
| 7 | | 699.752 | 21.152 | 2.341 | 1.537 |
| 8 | 12032.5399 | 799.646 | 21.73 | 2.351 | 1.485 |
| 9 | 0.002206 | 899.539 | 21.902 | 2.38 | 1.465 |
| 10 | 33996.4361 | 999.432 | 22.17 | 2.322 | 1.445 |
| 11 | 6.022698 | 1099.325 | 22.161 | 2.279 | 1.476 |
| 12 | 0.710663 | 1199.219 | 22.429 | 2.181 | 1.436 |
| 13 | 0.565141 | 1299.112 | 22.607 | 2.155 | 1.446 |
| 14 | 16.682176 | 1399.005 | 22.64 | 2.178 | 1.462 |
| 15 | 0.524486 | 1598.792 | 23.031 | 2.191 | 1.462 |
| 16 | 30.10998 | 1798.578 | 23.489 | 2.041 | 1.42 |
| 17 | 0.080087 | 1998.365 | 23.636 | 2.052 | 1.359 |
| 18 | | 2298.045 | 24.079 | 2.094 | 1.402 |
| 19 | | 2597.725 | 24.455 | 1.999 | 1.39 |
| 20 | 0.059765 | 2997.298 | 25.006 | 1.957 | 1.309 |
| 21 | 0.003192 | 3396.871 | 25.262 | 1.885 | 1.272 |
| 22 | 0.00208 | 3896.337 | 25.536 | 1.852 | 1.281 |
| 23 | 33849 | 4395.803 | 26.184 | 1.745 | 1.272 |
| 24 | 5.63 | 4995.163 | 26.65 | 1.702 | 1.259 |
| 25 | 0.711 | 5694.416 | 26.954 | 1.6 | 1.206 |
| 26 | 0.563 | 6493.562 | 27.581 | 1.5 | 1.047 |
| 27 | 16.2 | 7392.602 | 28.273 | 1.337 | 0.954 |
| 28 | | 8391.534 | 28.74 | 1.132 | 0.814 |
| 29 | 0.1 | 9590.254 | 29.436 | 0.882 | 0.64 |
| 30 | 0.0018 | 11088.653 | 29.782 | 0.723 | 0.501 |
| 31 | | 12986.625 | 30.131 | 0.297 | 0.23 |
| 32 | 3695 | 15184.277 | 30.059 | 0.188 | 0.142 |
| 33 | | 17781.502 | 30.155 | 0.157 | 0.063 |
| 34 | | 20778.3 | 30.128 | 0.068 | 0.039 |
| 35 | | 24374.458 | 30.089 | 0.026 | 0.012 |
| 36 | | 28769.762 | 30.11 | 0.055 | 0.073 |
| 37 | 2 | 33964.212 | 30.113 | 0.052 | 0.089 |
| 38 | 200.28601 | | | | |
| 39 | | | | | |
| 40 | | | | | |
| 41 | | | | | |
| 42 | | | | | |
| 43 | | | | | |
| 44 | | | | | |
| 45 | 70.40592 | | | | |
| 46 | 74.996751 | | | | |
| 47 | 1.262877 | | | | |
| 48 | 1.257497 | | | | |
| 49 | | | | | |
| 50 | 0.994869 | | | | |
| 51 | 30 | | | | |
| 52 | 0.002155 | | | | |
| 53 | 300 | | | | |
| 54 | 0.020076 | | | | |
| 55 | | | | | |
| 56 | | | | | |
| 57 | 0.976873 | | | | |
| 58 | 3695 | | | | |
| 59 | PARK | | | | |

| | DATA2 | yplus | uplus | uprplus | wprplus |
|---|---|---|---|---|---|
| 1 | 3696 | 61.986 | 15.518 | 3.109 | 1.799 |
| 2 | PARK | 160.88 | 17.751 | 2.571 | 1.742 |
| 3 | 199.4 | 259.773 | 18.934 | 2.517 | 1.613 |
| 4 | 503.7 | 358.666 | 19.605 | 2.575 | 1.592 |
| 5 | 0.00835 | 457.56 | 20.145 | 2.386 | 1.569 |
| 6 | | 556.453 | 20.736 | 2.574 | 1.557 |
| 7 | | 655.346 | 20.871 | 2.418 | 1.566 |
| 8 | 13525.4169 | 754.24 | 21.072 | 2.387 | 1.494 |
| 9 | 0.00215 | 853.133 | 21.813 | 2.309 | 1.524 |
| 10 | 39253.4225 | 952.026 | 22.173 | 2.295 | 1.497 |
| 11 | 6.838387 | 1050.92 | 21.801 | 2.327 | 1.445 |
| 12 | 0.816332 | 1149.813 | 22.295 | 2.23 | 1.502 |
| 13 | 0.650717 | 1347.6 | 22.978 | 2.297 | 1.446 |
| 14 | 16.515186 | 1545.386 | 22.951 | 2.127 | 1.501 |
| 15 | 0.550664 | 1743.173 | 23.112 | 2.072 | 1.417 |
| 16 | 30.499203 | 2039.853 | 23.96 | 2.135 | 1.46 |
| 17 | 0.083012 | 2336.533 | 24.222 | 2.038 | 1.405 |
| 18 | | 2732.106 | 24.479 | 2.007 | 1.365 |
| 19 | | 3127.68 | 24.918 | 2.003 | 1.371 |
| 20 | 0.104001 | 3622.146 | 25.436 | 1.835 | 1.307 |
| 21 | 0.004397 | 4116.613 | 25.955 | 1.788 | 1.273 |
| 22 | 0.00204 | 4709.973 | 26.281 | 1.763 | 1.308 |
| 23 | 39121 | 5402.226 | 26.711 | 1.652 | 1.217 |
| 24 | 6.36 | 6193.373 | 27.169 | 1.58 | 1.13 |
| 25 | 0.818 | 7083.413 | 27.77 | 1.521 | 1.064 |
| 26 | 0.648 | 8072.346 | 28.376 | 1.335 | 0.967 |
| 27 | 16.1 | 9259.066 | 29.163 | 1.132 | 0.772 |
| 28 | | 10742.466 | 29.593 | 0.96 | 0.669 |
| 29 | 0.1 | 12621.439 | 30.197 | 0.615 | 0.475 |
| 30 | 0.0032 | 14797.092 | 30.396 | 0.298 | 0.23 |
| 31 | | 17368.319 | 30.487 | 0.098 | 0.093 |
| 32 | 3696 | 20335.119 | 30.527 | 0.098 | 0.031 |
| 33 | | 23895.279 | 30.508 | 0.088 | 0.007 |
| 34 | | 28246.585 | 30.508 | 0.113 | 0.056 |
| 35 | | 33389.038 | 30.453 | 0.028 | 0.046 |
| 36 | | | | | |
| 37 | 2 | | | | |
| 38 | 160.879667 | | | | |
| 39 | | | | | |
| 40 | | | | | |
| 41 | | | | | |
| 42 | | | | | |
| 43 | | | | | |
| 44 | | | | | |
| 45 | 79.80684 | | | | |
| 46 | 84.397689 | | | | |
| 47 | 1.262346 | | | | |
| 48 | 1.254511 | | | | |
| 49 | | | | | |
| 50 | 0.992801 | | | | |
| 51 | 29 | | | | |
| 52 | 0.00209 | | | | |
| 53 | 300 | | | | |
| 54 | 0.022795 | | | | |
| 55 | | | | | |
| 56 | | | | | |
| 57 | 0.97206 | | | | |
| 58 | 3696 | | | | |
| 59 | PARK | | | | |

| | DATA2 | yplus | uplus | uprplus | wprplus |
|---|---|---|---|---|---|
| 1 | 3697 | 93.556 | 16.471 | 3.098 | 1.747 |
| 2 | PARK | 191.623 | 17.977 | 2.634 | 1.68 |
| 3 | 322.3 | 289.69 | 19.085 | 2.5 | 1.65 |
| 4 | 504.3 | 387.757 | 19.433 | 2.541 | 1.566 |
| 5 | 0.00835 | 485.824 | 20.188 | 2.539 | 1.616 |
| 6 | | 603.505 | 20.958 | 2.418 | 1.539 |
| 7 | | 701.572 | 21.232 | 2.335 | 1.45 |
| 8 | 15830.4924 | 799.639 | 21.66 | 2.388 | 1.55 |
| 9 | 0.002109 | 897.706 | 21.832 | 2.341 | 1.442 |
| 10 | 45290.3073 | 995.773 | 22.402 | 2.247 | 1.481 |
| 11 | 8.071258 | 1093.84 | 22.205 | 2.145 | 1.489 |
| 12 | 0.938738 | 1191.907 | 22.553 | 2.209 | 1.479 |
| 13 | 0.749899 | 1289.974 | 22.759 | 2.216 | 1.473 |
| 14 | 16.377201 | 1486.108 | 22.747 | 2.218 | 1.428 |
| 15 | 0.535839 | 1682.243 | 23.153 | 2.102 | 1.41 |
| 16 | 30.792808 | 1878.377 | 23.538 | 2.282 | 1.371 |
| 17 | 0.080007 | 2172.578 | 23.864 | 2.038 | 1.415 |
| 18 | | 2466.779 | 24.092 | 2.022 | 1.388 |
| 19 | | 2859.047 | 24.56 | 1.971 | 1.326 |
| 20 | 0.06434 | 3251.316 | 24.874 | 1.944 | 1.37 |
| 21 | 0.004183 | 3741.651 | 25.287 | 1.838 | 1.355 |
| 22 | 0.00199 | 4231.986 | 25.635 | 1.918 | 1.338 |
| 23 | 45231 | 4820.389 | 26.155 | 1.731 | 1.318 |
| 24 | 7.36 | 5506.858 | 26.583 | 1.737 | 1.267 |
| 25 | 0.941 | 6291.395 | 27.141 | 1.627 | 1.23 |
| 26 | 0.749 | 7173.998 | 27.683 | 1.551 | 1.199 |
| 27 | 15.9 | 8154.669 | 28.093 | 1.466 | 1.036 |
| 28 | | 9331.474 | 28.684 | 1.428 | 1.015 |
| 29 | 0.1 | 10802.48 | 29.238 | 1.153 | 0.836 |
| 30 | 0.0026 | 12665.754 | 30.032 | 0.918 | 0.628 |
| 31 | | 14823.23 | 30.586 | 0.508 | 0.368 |
| 32 | 3697 | 17372.974 | 30.725 | 0.291 | 0.229 |
| 33 | | 20314.986 | 30.777 | 0.154 | 0.102 |
| 34 | | 23845.4 | 30.784 | 0.066 | 0.026 |
| 35 | | 28160.351 | 30.808 | 0.1 | 0 |
| 36 | | 33259.839 | 30.802 | 0.008 | 0.025 |
| 37 | 2 | | | | |
| 38 | 191.623054 | | | | |
| 39 | | | | | |
| 40 | | | | | |
| 41 | | | | | |
| 42 | | | | | |
| 43 | | | | | |
| 44 | | | | | |
| 45 | 90.00969 | | | | |
| 46 | 95.529316 | | | | |
| 47 | 1.256342 | | | | |
| 48 | 1.251819 | | | | |
| 49 | | | | | |
| 50 | 0.995078 | | | | |
| 51 | 31 | | | | |
| 52 | 0.002007 | | | | |
| 53 | 300 | | | | |
| 54 | 0.026904 | | | | |
| 55 | | | | | |
| 56 | | | | | |
| 57 | 0.951516 | | | | |
| 58 | 3697 | | | | |
| 59 | PARK | | | | |

| | DATA2 | yplus | uplus | uprplus | wprplus |
|---|---|---|---|---|---|
| 1 | 3698 | 88.089 | 16.378 | 2.88 | 1.674 |
| 2 | PARK | 165.785 | 17.917 | 2.612 | 1.675 |
| 3 | 398.8 | 243.482 | 18.705 | 2.555 | 1.627 |
| 4 | 505.2 | 321.178 | 19.247 | 2.555 | 1.652 |
| 5 | 0.00835 | 418.299 | 20.031 | 2.507 | 1.547 |
| 6 | | 515.42 | 20.181 | 2.538 | 1.521 |
| 7 | | 612.541 | 20.832 | 2.518 | 1.513 |
| 8 | 16773.7375 | 709.662 | 21.243 | 2.463 | 1.523 |
| 9 | 0.002061 | 806.782 | 21.52 | 2.442 | 1.554 |
| 10 | 50904.3603 | 903.903 | 22.041 | 2.299 | 1.482 |
| 11 | 8.635503 | 1001.024 | 21.925 | 2.433 | 1.498 |
| 12 | 1.050676 | 1098.145 | 22.249 | 2.333 | 1.47 |
| 13 | 0.841353 | 1292.386 | 22.598 | 2.222 | 1.551 |
| 14 | 16.219173 | 1486.628 | 22.991 | 2.211 | 1.514 |
| 15 | 0.584225 | 1680.87 | 23.336 | 2.196 | 1.432 |
| 16 | 31.148321 | 1972.232 | 23.57 | 2.179 | 1.506 |
| 17 | 0.086236 | 2263.594 | 23.941 | 2.078 | 1.435 |
| 18 | | 2652.078 | 24.395 | 1.989 | 1.397 |
| 19 | | 3040.561 | 24.778 | 1.978 | 1.36 |
| 20 | 0.167211 | 3526.165 | 25.152 | 1.885 | 1.399 |
| 21 | 0.003736 | 4011.769 | 25.479 | 1.851 | 1.364 |
| 22 | 0.00196 | 4594.493 | 25.856 | 1.885 | 1.314 |
| 23 | 50943 | 5274.339 | 26.7 | 1.648 | 1.29 |
| 24 | 9.12 | 6051.305 | 26.629 | 1.724 | 1.261 |
| 25 | 1.055 | 6925.393 | 27.414 | 1.593 | 1.269 |
| 26 | 0.842 | 7896.6 | 28.027 | 1.494 | 1.154 |
| 27 | 15.8 | 9062.05 | 28.716 | 1.456 | 1.08 |
| 28 | | 10518.862 | 29.021 | 1.341 | 0.977 |
| 29 | 0.1 | 12364.157 | 29.893 | 1.129 | 0.803 |
| 30 | 0.003 | 14500.814 | 30.494 | 0.758 | 0.586 |
| 31 | | 17025.955 | 30.762 | 0.622 | 0.448 |
| 32 | 3698 | 19939.579 | 31.083 | 0.312 | 0.237 |
| 33 | | 23435.928 | 31.155 | 0.098 | 0.129 |
| 34 | | 27709.243 | 31.139 | 0.092 | 0.123 |
| 35 | | 32759.524 | 31.151 | 0.007 | 0.117 |
| 36 | | | | | |
| 37 | 2 | | | | |
| 38 | 165.785196 | | | | |
| 39 | | | | | |
| 40 | | | | | |
| 41 | | | | | |
| 42 | | | | | |
| 43 | | | | | |
| 44 | | | | | |
| 45 | 99.84828 | | | | |
| 46 | 104.933871 | | | | |
| 47 | 1.252969 | | | | |
| 48 | 1.248794 | | | | |
| 49 | | | | | |
| 50 | 0.986741 | | | | |
| 51 | 30 | | | | |
| 52 | 0.001965 | | | | |
| 53 | 300 | | | | |
| 54 | 0.028785 | | | | |
| 55 | | | | | |
| 56 | | | | | |
| 57 | 0.953239 | | | | |
| 58 | 3698 | | | | |
| 59 | PARK | | | | |

| | DATA2 | yplus | uplus | uprplus | wprplus |
|---|---|---|---|---|---|
| 1 | 3699 | 159.398 | 17.963 | 2.772 | 1.748 |
| 2 | PARK | 255.421 | 18.767 | 2.61 | 1.673 |
| 3 | 521.7 | 351.444 | 19.291 | 2.544 | 1.59 |
| 4 | 503.5 | 447.467 | 20.051 | 2.43 | 1.601 |
| 5 | 0.00835 | 543.49 | 20.789 | 2.337 | 1.599 |
| 6 | | 639.513 | 21.04 | 2.45 | 1.572 |
| 7 | | 735.536 | 21.407 | 2.443 | 1.556 |
| 8 | 19387.8394 | 831.559 | 21.762 | 2.335 | 1.568 |
| 9 | 0.002029 | 927.582 | 21.715 | 2.361 | 1.604 |
| 10 | 56723.9827 | 1023.605 | 22.396 | 2.371 | 1.569 |
| 11 | 10.095412 | 1119.628 | 22.048 | 2.333 | 1.555 |
| 12 | 1.175829 | 1311.675 | 22.789 | 2.282 | 1.493 |
| 13 | 0.940706 | 1503.721 | 23.213 | 2.291 | 1.493 |
| 14 | 16.035845 | 1695.767 | 23.203 | 2.274 | 1.469 |
| 15 | 0.566203 | 1983.836 | 23.436 | 2.205 | 1.487 |
| 16 | 31.398408 | 2271.905 | 23.662 | 2.295 | 1.462 |
| 17 | 0.08291 | 2655.997 | 24.481 | 2.087 | 1.571 |
| 18 | | 3040.089 | 24.663 | 2.08 | 1.478 |
| 19 | | 3520.204 | 24.981 | 2.069 | 1.445 |
| 20 | 0.07856 | 4000.319 | 25.263 | 2.006 | 1.375 |
| 21 | 0.004818 | 4576.457 | 25.659 | 1.913 | 1.369 |
| 22 | 0.00192 | 5248.619 | 26.463 | 1.815 | 1.352 |
| 23 | 56682 | 6016.803 | 26.572 | 1.81 | 1.399 |
| 24 | 9.44 | 6881.01 | 27.313 | 1.657 | 1.249 |
| 25 | 1.179 | 7841.24 | 27.483 | 1.626 | 1.177 |
| 26 | 0.94 | 8993.516 | 28.224 | 1.554 | 1.187 |
| 27 | 15.6 | 10433.862 | 28.943 | 1.417 | 1.056 |
| 28 | | 12258.299 | 29.543 | 1.212 | 0.881 |
| 29 | 0.1 | 14370.806 | 30.249 | 1.085 | 0.73 |
| 30 | 0.0028 | 16867.404 | 30.934 | 0.749 | 0.551 |
| 31 | | 19748.095 | 31.279 | 0.416 | 0.355 |
| 32 | 3699 | 23204.924 | 31.398 | 0.184 | 0.242 |
| 33 | | 27429.937 | 31.383 | 0.135 | 0.222 |
| 34 | | 32423.134 | 31.38 | 0.109 | 0.206 |
| 35 | | 38184.516 | 31.402 | 0.019 | 0.208 |
| 36 | | 44714.081 | 31.43 | 0.062 | 0.202 |
| 37 | 2 | | | | |
| 38 | 255.421244 | | | | |
| 39 | | | | | |
| 40 | | | | | |
| 41 | | | | | |
| 42 | | | | | |
| 43 | | | | | |
| 44 | | | | | |
| 45 | 108.82944 | | | | |
| 46 | 115.075127 | | | | |
| 47 | 1.254255 | | | | |
| 48 | 1.249944 | | | | |
| 49 | | | | | |
| 50 | 0.994824 | | | | |
| 51 | 30 | | | | |
| 52 | 0.001907 | | | | |
| 53 | 300 | | | | |
| 54 | 0.033651 | | | | |
| 55 | | | | | |
| 56 | | | | | |
| 57 | 0.940018 | | | | |
| 58 | 3699 | | | | |
| 59 | PARK | | | | |

| | DATA2 | yplus | uplus | uprplus | wprplus |
|---|---|---|---|---|---|
| 1 | 3700 | 163.044 | 17.505 | 2.515 | 1.729 |
| 2 | PARK | 258.391 | 18.588 | 2.629 | 1.665 |
| 3 | 598.2 | 353.738 | 19.722 | 2.533 | 1.629 |
| 4 | 504.3 | 449.086 | 20.111 | 2.579 | 1.618 |
| 5 | 0.00835 | 544.433 | 20.922 | 2.55 | 1.558 |
| 6 | | 639.78 | 20.935 | 2.42 | 1.535 |
| 7 | | 735.127 | 21.118 | 2.344 | 1.585 |
| 8 | 21241.0751 | 830.475 | 21.673 | 2.484 | 1.58 |
| 9 | 0.001994 | 925.822 | 21.711 | 2.436 | 1.581 |
| 10 | 62366.2381 | 1021.169 | 22.17 | 2.472 | 1.58 |
| 11 | 11.138798 | 1211.864 | 22.556 | 2.349 | 1.561 |
| 12 | 1.291096 | 1402.558 | 22.863 | 2.313 | 1.532 |
| 13 | 1.032636 | 1593.253 | 22.87 | 2.33 | 1.584 |
| 14 | 15.922991 | 1879.294 | 23.548 | 2.121 | 1.475 |
| 15 | 0.579887 | 2165.336 | 23.776 | 2.184 | 1.437 |
| 16 | 31.671185 | 2546.725 | 24.095 | 2.121 | 1.427 |
| 17 | 0.084182 | 2928.114 | 24.761 | 2.101 | 1.406 |
| 18 | | 3404.85 | 25.109 | 2.053 | 1.455 |
| 19 | | 3881.587 | 25.457 | 2.132 | 1.415 |
| 20 | 0.045822 | 4453.67 | 25.308 | 1.878 | 1.422 |
| 21 | 0.00498 | 5121.101 | 26.179 | 1.828 | 1.329 |
| 22 | 0.00189 | 5883.879 | 26.363 | 1.859 | 1.373 |
| 23 | 62296 | 6742.004 | 26.696 | 1.79 | 1.375 |
| 24 | 9.96 | 7695.477 | 27.677 | 1.791 | 1.263 |
| 25 | 1.297 | 8839.644 | 28.172 | 1.685 | 1.28 |
| 26 | 1.031 | 10259.853 | 28.476 | 1.563 | 1.175 |
| 27 | 15.5 | 12081.45 | 29.366 | 1.394 | 1.066 |
| 28 | | 14179.09 | 29.948 | 1.326 | 0.926 |
| 29 | 0.1 | 16658.119 | 30.921 | 0.831 | 0.661 |
| 30 | 0.0029 | 19518.536 | 31.453 | 0.508 | 0.414 |
| 31 | | 22951.037 | 31.589 | 0.27 | 0.333 |
| 32 | 3700 | 27146.316 | 31.652 | 0.062 | 0.226 |
| 33 | | 32104.373 | 31.684 | 0 | 0.218 |
| 34 | | 37825.209 | 31.681 | 0.121 | 0.236 |
| 35 | | 44308.822 | 31.668 | 0.028 | 0.217 |
| 36 | | | | | |
| 37 | 2 | | | | |
| 38 | 258.391055 | | | | |
| 39 | | | | | |
| 40 | | | | | |
| 41 | | | | | |
| 42 | | | | | |
| 43 | | | | | |
| 44 | | | | | |
| 45 | 117.73944 | | | | |
| 46 | 124.351468 | | | | |
| 47 | 1.258002 | | | | |
| 48 | 1.250292 | | | | |
| 49 | | | | | |
| 50 | 0.995258 | | | | |
| 51 | 30 | | | | |
| 52 | 0.001876 | | | | |
| 53 | 300 | | | | |
| 54 | 0.037129 | | | | |
| 55 | | | | | |
| 56 | | | | | |
| 57 | 0.940874 | | | | |
| 58 | 3700 | | | | |
| 59 | PARK | | | | |

| | DATA2 | yplus | uplus | uprplus | wprplus |
|---|---|---|---|---|---|
| 1 | 3701 | 91.908 | 16.457 | 2.761 | 1.657 |
| 2 | PARK | 166.935 | 17.606 | 2.603 | 1.773 |
| 3 | 721 | 241.962 | 18.594 | 2.726 | 1.785 |
| 4 | 504 | 335.745 | 19.121 | 2.715 | 1.633 |
| 5 | 0.00835 | 429.529 | 19.765 | 2.475 | 1.582 |
| 6 | | 523.312 | 20.36 | 2.597 | 1.585 |
| 7 | | 617.096 | 21.171 | 2.613 | 1.636 |
| 8 | 21135.3454 | 710.88 | 20.882 | 2.609 | 1.65 |
| 9 | 0.001931 | 804.663 | 21.574 | 2.422 | 1.556 |
| 10 | 68808.4218 | 898.447 | 21.76 | 2.529 | 1.567 |
| 11 | 11.268147 | 992.23 | 21.763 | 2.421 | 1.591 |
| 12 | 1.427401 | 1086.014 | 22.005 | 2.603 | 1.605 |
| 13 | 1.139981 | 1179.798 | 22.41 | 2.491 | 1.573 |
| 14 | 15.66186 | 1273.581 | 22.668 | 2.441 | 1.574 |
| 15 | 0.693068 | 1367.365 | 22.819 | 2.593 | 1.612 |
| 16 | 32.180087 | 1461.148 | 22.912 | 2.408 | 1.507 |
| 17 | 0.099021 | 1554.932 | 22.886 | 2.386 | 1.507 |
| 18 | | 1648.716 | 23.421 | 2.486 | 1.585 |
| 19 | | 1836.283 | 23.498 | 2.307 | 1.495 |
| 20 | 0.192103 | 2023.85 | 23.852 | 2.367 | 1.572 |
| 21 | 0.005979 | 2211.417 | 24.142 | 2.302 | 1.541 |
| 22 | 0.00182 | 2492.768 | 24.524 | 2.304 | 1.495 |
| 23 | 68324 | 2774.119 | 24.058 | 2.237 | 1.473 |
| 24 | 11.57 | 3149.253 | 24.756 | 2.191 | 1.477 |
| 25 | 1.422 | 3524.387 | 24.959 | 2.043 | 1.422 |
| 26 | 1.132 | 3993.305 | 25.744 | 2.012 | 1.439 |
| 27 | 15.19 | 4462.223 | 25.631 | 2.048 | 1.438 |
| 28 | | 5024.925 | 26.536 | 1.904 | 1.353 |
| 29 | 0.1 | 5681.41 | 26.468 | 1.947 | 1.316 |
| 30 | 0.0033 | 6431.679 | 27.112 | 1.886 | 1.335 |
| 31 | | 7275.731 | 27.446 | 1.738 | 1.357 |
| 32 | 3701 | 8213.567 | 27.855 | 1.672 | 1.268 |
| 33 | | 9338.97 | 28.637 | 1.701 | 1.213 |
| 34 | | 10745.724 | 28.969 | 1.579 | 1.175 |
| 35 | | 12527.612 | 29.474 | 1.505 | 1.14 |
| 36 | | 14590.851 | 30.471 | 1.301 | 0.896 |
| 37 | 2 | 17029.224 | 31.067 | 1.107 | 0.802 |
| 38 | 166.934791 | 19842.732 | 31.553 | 0.896 | 0.593 |
| 39 | | 23218.941 | 32.109 | 0.453 | 0.319 |
| 40 | | 27345.419 | 32.17 | 0.29 | 0.141 |
| 41 | | 32222.166 | 32.215 | 0.2 | 0.089 |
| 42 | | 37849.182 | 32.238 | 0.158 | 0.117 |
| 43 | | 43851.331 | 32.183 | 0.145 | 0.133 |
| 44 | | 50228.615 | 32.122 | 0.031 | 0.121 |
| 45 | 124.34968 | 55105.362 | 32.177 | 0.106 | 0.014 |
| 46 | 132.891491 | | | | |
| 47 | 1.256184 | | | | |
| 48 | 1.252127 | | | | |
| 49 | | | | | |
| 50 | 0.987123 | | | | |
| 51 | 38 | | | | |
| 52 | 0.001833 | | | | |
| 53 | 300 | | | | |
| 54 | 0.03756 | | | | |
| 55 | | | | | |
| 56 | | | | | |
| 57 | 0.949089 | | | | |
| 58 | 3701 | | | | |
| 59 | PARK | | | | |

| | DATA2 | yplus | uplus | uprplus | wprplus |
|---|---|---|---|---|---|
| 1 | 3702 | 77.539 | 15.848 | 3.092 | |
| 2 | PARK | 152.275 | 17.208 | 2.684 | 1.741 |
| 3 | 797.6 | 227.011 | 18.364 | 2.693 | 1.635 |
| 4 | 505.1 | 264.379 | 18.924 | 2.661 | 1.67 |
| 5 | 0.00835 | 376.483 | 19.493 | 2.634 | 1.6 |
| 6 | | 469.903 | 20.507 | 2.631 | 1.637 |
| 7 | | 563.323 | 21.103 | 2.663 | 1.653 |
| 8 | 21673.2469 | 656.743 | 20.973 | 2.597 | 1.685 |
| 9 | 0.001908 | 750.163 | 21.585 | 2.571 | 1.65 |
| 10 | 74234.7476 | 843.584 | 21.229 | 2.638 | 1.62 |
| 11 | 11.599884 | 937.004 | 21.954 | 2.496 | 1.577 |
| 12 | 1.53263 | 1030.424 | 22.016 | 2.541 | 1.565 |
| 13 | 1.227203 | 1123.844 | 22.482 | 2.568 | 1.58 |
| 14 | 15.601157 | 1310.684 | 22.375 | 2.411 | 1.663 |
| 15 | 0.72307 | 1497.524 | 23.197 | 2.481 | 1.586 |
| 16 | 32.375803 | 1684.364 | 22.731 | 2.4 | 1.48 |
| 17 | 0.102683 | 1964.625 | 23.366 | 2.347 | 1.495 |
| 18 | | 2244.885 | 24.071 | 2.153 | 1.52 |
| 19 | | 2618.566 | 24.489 | 2.219 | 1.496 |
| 20 | 0.254924 | 2992.246 | 24.712 | 2.237 | 1.538 |
| 21 | 0.007141 | 3459.346 | 25.386 | 2.031 | 1.447 |
| 22 | 0.0018 | 3926.447 | 25.175 | 2.121 | 1.444 |
| 23 | 73930 | 4486.968 | 25.486 | 2.096 | 1.442 |
| 24 | 12.96 | 5140.908 | 26.538 | 2.072 | 1.328 |
| 25 | 1.531 | 5888.269 | 26.836 | 1.908 | 1.352 |
| 26 | 1.222 | 6729.05 | 26.908 | 1.895 | 1.365 |
| 27 | 15.14 | 7663.251 | 27.604 | 1.84 | 1.37 |
| 28 | | 8784.292 | 28.306 | 1.752 | 1.275 |
| 29 | 0.1 | 10185.594 | 28.814 | 1.57 | 1.233 |
| 30 | 0.0023 | 11960.576 | 29.452 | 1.643 | 1.187 |
| 31 | | 14015.818 | 30.252 | 1.362 | 0.997 |
| 32 | 3702 | 16444.741 | 30.453 | 1.23 | 0.928 |
| 33 | | 19247.344 | 31.537 | 1.009 | 0.67 |
| 34 | | 22610.468 | 31.897 | 0.76 | 0.526 |
| 35 | | 26720.952 | 32.295 | 0.26 | 0.209 |
| 36 | | 31578.798 | 32.36 | 0.103 | 0.052 |
| 37 | 2 | 37184.004 | 32.382 | 0.048 | 0.082 |
| 38 | 152.27477 | 43162.891 | 32.402 | 0.139 | 0.101 |
| 39 | | 49515.458 | 32.392 | 0.076 | 0.095 |
| 40 | | 54373.303 | 32.327 | 0.028 | 0.015 |
| 41 | | | | | |
| 42 | | | | | |
| 43 | | | | | |
| 44 | | | | | |
| 45 | 133.074 | | | | |
| 46 | 141.643332 | | | | |
| 47 | 1.252864 | | | | |
| 48 | 1.248881 | | | | |
| 49 | | | | | |
| 50 | 0.982107 | | | | |
| 51 | 33 | | | | |
| 52 | 0.001808 | | | | |
| 53 | 300 | | | | |
| 54 | 0.038666 | | | | |
| 55 | | | | | |
| 56 | | | | | |
| 57 | 0.947566 | | | | |
| 58 | 3702 | | | | |
| 59 | PARK | | | | |

| | DATA2 | yplus | uplus | uprplus | wprplus |
|---|---|---|---|---|---|
| 1 | 3703 | 91.699 | 16.002 | 2.78 | |
| 2 | PARK | 185.27 | 17.854 | 2.996 | |
| 3 | 920.4 | 185.27 | 17.798 | 2.681 | 1.66 |
| 4 | 506.6 | 278.841 | 18.897 | 2.627 | 1.584 |
| 5 | 0.00835 | 372.411 | 19.87 | 2.624 | 1.697 |
| 6 | | 465.982 | 20.535 | 2.654 | 1.738 |
| 7 | | 559.553 | 20.188 | 2.558 | 1.633 |
| 8 | 26070.9264 | 671.838 | 21.066 | 2.514 | 1.622 |
| 9 | 0.001903 | 765.408 | 21.134 | 2.586 | 1.631 |
| 10 | 80164.3544 | 858.979 | 21.585 | 2.512 | 1.611 |
| 11 | 13.931135 | 952.55 | 21.87 | 2.506 | 1.631 |
| 12 | 1.649278 | 1046.121 | 22.013 | 2.419 | 1.622 |
| 13 | 1.321304 | 1139.691 | 22.408 | 2.421 | 1.62 |
| 14 | 15.62631 | 1233.262 | 22.503 | 2.51 | 1.573 |
| 15 | 0.640243 | 1326.833 | 22.921 | 2.435 | 1.531 |
| 16 | 32.419681 | 1513.974 | 23.015 | 2.392 | 1.525 |
| 17 | 0.090798 | 1701.116 | 22.989 | 2.296 | 1.449 |
| 18 | | 1888.257 | 23.777 | 2.206 | 1.556 |
| 19 | | 2168.969 | 23.546 | 2.487 | 1.482 |
| 20 | 0.095073 | 2449.681 | 24.243 | 2.157 | 1.484 |
| 21 | 0.005837 | 2823.964 | 24.299 | 2.104 | 1.473 |
| 22 | 0.00178 | 3198.247 | 24.736 | 2.166 | 1.45 |
| 23 | 79569 | 3666.101 | 25.294 | 2.151 | 1.406 |
| 24 | 13.28 | 4133.954 | 25.79 | 2.162 | 1.383 |
| 25 | 1.643 | 4695.379 | 26.033 | 1.86 | 1.458 |
| 26 | 1.311 | 5350.374 | 26.121 | 2.027 | 1.38 |
| 27 | 15.13 | 6098.94 | 26.471 | 2.026 | 1.368 |
| 28 | | 6941.076 | 26.957 | 1.829 | 1.303 |
| 29 | 0.1 | 7876.783 | 27.194 | 1.739 | 1.403 |
| 30 | 0.0021 | 8999.632 | 27.874 | 1.796 | 1.312 |
| 31 | | 10403.193 | 28.714 | 1.695 | 1.165 |
| 32 | 3703 | 12181.036 | 28.665 | 1.76 | 1.218 |
| 33 | | 14239.592 | 29.722 | 1.484 | 1.044 |
| 34 | | 16672.431 | 30.536 | 1.292 | 0.942 |
| 35 | | 19479.553 | 31.347 | 1.024 | 0.751 |
| 36 | | 22848.098 | 31.956 | 0.768 | 0.512 |
| 37 | 2 | 26965.21 | 32.241 | 0.477 | 0.349 |
| 38 | 185.270026 | 31830.888 | 32.371 | 0.267 | 0.173 |
| 39 | | 37445.131 | 32.416 | 0.126 | 0.057 |
| 40 | | 43433.657 | 32.439 | 0.07 | 0.124 |
| 41 | | 49796.466 | 32.413 | 0.14 | 0.074 |
| 42 | | 54662.143 | 32.41 | 0.017 | 0.009 |
| 43 | | | | | |
| 44 | | | | | |
| 45 | 141.63282 | | | | |
| 46 | 152.543537 | | | | |
| 47 | 1.253242 | | | | |
| 48 | 1.24822 | | | | |
| 49 | | | | | |
| 50 | 0.992589 | | | | |
| 51 | 36 | | | | |
| 52 | 0.001773 | | | | |
| 53 | 300 | | | | |
| 54 | 0.046437 | | | | |
| 55 | | | | | |
| 56 | | | | | |
| 57 | 0.931743 | | | | |
| 58 | 3703 | | | | |
| 59 | PARK | | | | |

| | DATA2 | yplus | uplus | uprplus | wprplus |
|---|---|---|---|---|---|
| 1 | 3704 | 60.277 | 15.662 | 3.008 | |
| 2 | PARK | 153.586 | 17.571 | 2.651 | 1.786 |
| 3 | 997 | 246.894 | 18.707 | 2.697 | 1.718 |
| 4 | 507.5 | 340.203 | 19.355 | 2.711 | 1.684 |
| 5 | 0.00835 | 433.511 | 19.997 | 2.589 | 1.619 |
| 6 | | 526.82 | 20.193 | 2.637 | 1.683 |
| 7 | | 620.128 | 20.919 | 2.557 | 1.703 |
| 8 | 30677.8014 | 713.437 | 21.202 | 2.552 | 1.628 |
| 9 | 0.001886 | 806.745 | 21.779 | 2.712 | 1.678 |
| 10 | 92025.5349 | 900.053 | 21.726 | 2.591 | 1.637 |
| 11 | 16.438916 | 993.362 | 21.919 | 2.502 | 1.57 |
| 12 | 1.878423 | 1179.979 | 22.238 | 2.544 | 1.616 |
| 13 | 1.514115 | 1366.596 | 22.844 | 2.419 | 1.529 |
| 14 | 15.582514 | 1553.213 | 22.759 | 2.46 | 1.605 |
| 15 | 0.591264 | 1833.138 | 23.404 | 2.406 | 1.561 |
| 16 | 32.568556 | 2113.064 | 23.85 | 2.304 | 1.503 |
| 17 | 0.083469 | 2486.297 | 24.15 | 2.29 | 1.548 |
| 18 | | 2859.531 | 24.856 | 2.197 | 1.53 |
| 19 | | 3326.074 | 24.892 | 2.234 | 1.476 |
| 20 | 0.094652 | 3792.616 | 25.097 | 2.098 | 1.43 |
| 21 | 0.004177 | 4352.467 | 25.703 | 1.98 | 1.386 |
| 22 | 0.00177 | 5005.626 | 25.853 | 2.156 | 1.443 |
| 23 | 91956 | 5752.094 | 26.159 | 1.9 | 1.385 |
| 24 | 15.86 | 6591.87 | 26.641 | 1.928 | 1.313 |
| 25 | 1.88 | 7524.955 | 26.977 | 1.695 | 1.361 |
| 26 | 1.513 | 8644.656 | 27.524 | 1.86 | 1.322 |
| 27 | 15.1 | 10044.283 | 27.703 | 1.716 | 1.302 |
| 28 | | 11817.144 | 28.605 | 1.622 | 1.241 |
| 29 | 0.1 | 13869.931 | 29.09 | 1.515 | 1.266 |
| 30 | 0.0041 | 16295.951 | 29.901 | 1.326 | 1.038 |
| 31 | | 19095.205 | 30.527 | 1.28 | 0.984 |
| 32 | 3704 | 22454.31 | 31.562 | 0.963 | 0.739 |
| 33 | | 26559.883 | 32.044 | 0.707 | 0.54 |
| 34 | | 31411.923 | 32.363 | 0.474 | 0.33 |
| 35 | | 37010.431 | 32.552 | 0.216 | 0.128 |
| 36 | | 42982.173 | 32.582 | 0.134 | 0.113 |
| 37 | 2 | 49327.149 | 32.552 | 0.018 | 0.141 |
| 38 | 153.585741 | 54179.19 | 32.588 | 0.135 | 0.111 |
| 39 | | | | | |
| 40 | | | | | |
| 41 | | | | | |
| 42 | | | | | |
| 43 | | | | | |
| 44 | | | | | |
| 45 | 162.76212 | | | | |
| 46 | 173.516719 | | | | |
| 47 | 1.242564 | | | | |
| 48 | 1.240608 | | | | |
| 49 | | | | | |
| 50 | 0.992217 | | | | |
| 51 | 33 | | | | |
| 52 | 0.001754 | | | | |
| 53 | 300 | | | | |
| 54 | 0.054796 | | | | |
| 55 | | | | | |
| 56 | | | | | |
| 57 | 0.930243 | | | | |
| 58 | 3704 | | | | |
| 59 | PARK | | | | |

| | DATA2 | yplus | uplus | uprplus | wprplus |
|---|---|---|---|---|---|
| 1 | 3705 | 138.243 | 16.978 | 2.6 | 1.864 |
| 2 | PARK | 250.332 | 18.541 | 2.76 | 1.913 |
| 3 | 1119.8 | 362.421 | 19.555 | 2.721 | 1.632 |
| 4 | 510.1 | 474.51 | 20.301 | 2.773 | 1.707 |
| 5 | 0.00835 | 567.917 | 20.621 | 2.6 | 1.593 |
| 6 | | 661.325 | 21.295 | 2.623 | 1.638 |
| 7 | | 754.732 | 21.707 | 2.678 | 1.648 |
| 8 | 28214.132 | 848.139 | 21.586 | 2.672 | 1.625 |
| 9 | 0.00187 | 941.547 | 21.802 | 2.574 | 1.563 |
| 10 | 90088.618 | 1034.954 | 22.243 | 2.554 | 1.596 |
| 11 | 15.102726 | 1128.362 | 21.851 | 2.557 | 1.681 |
| 12 | 1.834415 | 1221.769 | 21.736 | 2.453 | 1.56 |
| 13 | 1.474691 | 1408.584 | 22.923 | 2.407 | 1.557 |
| 14 | 15.599038 | 1595.399 | 23.067 | 2.387 | 1.642 |
| 15 | 0.66187 | 1782.214 | 23.793 | 2.394 | 1.547 |
| 16 | 32.700733 | 2062.436 | 23.757 | 2.524 | 1.553 |
| 17 | 0.093059 | 2342.658 | 23.378 | 2.247 | 1.53 |
| 18 | | 2716.288 | 24.692 | 2.08 | 1.494 |
| 19 | | 3089.917 | 24.96 | 2.348 | 1.475 |
| 20 | 0.175857 | 3556.954 | 24.836 | 2.148 | 1.472 |
| 21 | 0.007773 | 4023.991 | 25.533 | 2.204 | 1.422 |
| 22 | 0.00175 | 4584.436 | 25.484 | 2.132 | 1.465 |
| 23 | 90049 | 5238.288 | 25.837 | 1.972 | 1.439 |
| 24 | 14.28 | 5985.547 | 26.766 | 1.952 | 1.426 |
| 25 | 1.839 | 6826.214 | 26.625 | 1.887 | 1.387 |
| 26 | 1.474 | 7760.288 | 27.151 | 2.005 | 1.311 |
| 27 | 15.1 | 8881.177 | 27.737 | 1.851 | 1.279 |
| 28 | | 10282.288 | 28.672 | 1.691 | 1.282 |
| 29 | 0.1 | 12057.029 | 28.888 | 1.704 | 1.23 |
| 30 | 0.0035 | 14111.992 | 29.653 | 1.553 | 1.089 |
| 31 | | 16540.585 | 30.091 | 1.56 | 1.154 |
| 32 | 3705 | 19342.808 | 30.951 | 1.364 | 0.916 |
| 33 | | 22705.475 | 31.592 | 1.102 | 0.765 |
| 34 | | 26815.401 | 32.4 | 0.674 | 0.556 |
| 35 | | 31672.587 | 32.485 | 0.51 | 0.451 |
| 36 | | 37277.032 | 32.694 | 0.275 | 0.173 |
| 37 | 2 | 43255.106 | 32.691 | 0.128 | 0.072 |
| 38 | 250.331875 | 49606.811 | 32.717 | 0 | 0 |
| 39 | | 54463.996 | 32.697 | 0.167 | 0.049 |
| 40 | | | | | |
| 41 | | | | | |
| 42 | | | | | |
| 43 | | | | | |
| 44 | | | | | |
| 45 | 157.58575 | | | | |
| 46 | 168.494191 | | | | |
| 47 | 1.247626 | | | | |
| 48 | 1.243932 | | | | |
| 49 | | | | | |
| 50 | 0.991549 | | | | |
| 51 | 34 | | | | |
| 52 | 0.001725 | | | | |
| 53 | 300 | | | | |
| 54 | 0.050342 | | | | |
| 55 | | | | | |
| 56 | | | | | |
| 57 | 0.922304 | | | | |
| 58 | 3705 | | | | |
| 59 | PARK | | | | |

| | DATA2 | yplus | uplus | uprplus | wprplus |
|---|---|---|---|---|---|
| 1 | 3706 | 94.351 | 15.909 | 2.868 | 1.545 |
| 2 | PARK | 187.953 | 17.897 | 2.809 | 1.761 |
| 3 | 1196.3 | 281.554 | 18.761 | 2.776 | 1.709 |
| 4 | 511.8 | 375.156 | 19.344 | 2.806 | 1.617 |
| 5 | 0.00835 | 468.758 | 20.522 | 2.639 | 1.712 |
| 6 | | 562.36 | 20.807 | 2.544 | 1.676 |
| 7 | | 655.962 | 21.187 | 2.511 | 1.644 |
| 8 | 30637.8231 | 749.564 | 21.289 | 2.596 | 1.604 |
| 9 | 0.001866 | 843.166 | 21.472 | 2.475 | 1.572 |
| 10 | 92983.0282 | 936.767 | 21.816 | 2.531 | 1.631 |
| 11 | 16.366033 | 1030.369 | 22.379 | 2.652 | 1.536 |
| 12 | 1.89032 | 1217.573 | 22.451 | 2.472 | 1.631 |
| 13 | 1.517015 | 1404.777 | 22.484 | 2.37 | 1.532 |
| 14 | 15.631511 | 1591.98 | 23.364 | 2.446 | 1.477 |
| 15 | 0.629543 | 1872.786 | 23.243 | 2.315 | 1.555 |
| 16 | 32.741556 | 2153.592 | 23.59 | 2.521 | 1.496 |
| 17 | 0.088403 | 2527.999 | 23.97 | 2.23 | 1.437 |
| 18 | | 2902.407 | 24.625 | 2.223 | 1.46 |
| 19 | | 3370.416 | 25.339 | 2.226 | 1.48 |
| 20 | 0.053513 | 3838.425 | 25.1 | 2.069 | 1.431 |
| 21 | 0.007612 | 4400.036 | 25.391 | 2.125 | 1.49 |
| 22 | 0.00174 | 5055.249 | 25.571 | 2.01 | 1.388 |
| 23 | 92844 | 5804.064 | 26.314 | 2.027 | 1.378 |
| 24 | 14.2 | 6646.481 | 26.783 | 1.896 | 1.447 |
| 25 | 1.892 | 7582.5 | 27.388 | 1.892 | 1.395 |
| 26 | 1.614 | 8705.722 | 27.002 | 1.856 | 1.336 |
| 27 | 15.1 | 10109.75 | 28.551 | 1.84 | 1.306 |
| 28 | | 11888.185 | 29.14 | 1.634 | 1.231 |
| 29 | 0.1 | 13947.426 | 29.097 | 1.581 | 1.169 |
| 30 | 0.001 | 16381.075 | 29.759 | 1.49 | 1.143 |
| 31 | | 19189.131 | 30.672 | 1.306 | 1.028 |
| 32 | 3706 | 22558.798 | 31.478 | 1.097 | 0.864 |
| 33 | | 26677.28 | 32.434 | 0.56 | 0.481 |
| 34 | | 31544.576 | 32.607 | 0.432 | 0.373 |
| 35 | | 37160.688 | 32.725 | 0.252 | 0.213 |
| 36 | | 43151.207 | 32.751 | 0.033 | 0.131 |
| 37 | 2 | 49516.134 | 32.761 | 0.026 | 0.059 |
| 38 | 187.95254 | 54383.431 | 32.728 | 0.023 | 0.01 |
| 39 | | | | | |
| 40 | | | | | |
| 41 | | | | | |
| 42 | | | | | |
| 43 | | | | | |
| 44 | | | | | |
| 45 | 161.54856 | | | | |
| 46 | 173.474259 | | | | |
| 47 | 1.24967 | | | | |
| 48 | 1.246079 | | | | |
| 49 | | | | | |
| 50 | 0.994913 | | | | |
| 51 | 33 | | | | |
| 52 | 0.001708 | | | | |
| 53 | 300 | | | | |
| 54 | 0.054553 | | | | |
| 55 | | | | | |
| 56 | | | | | |
| 57 | 0.915496 | | | | |
| 58 | 3706 | | | | |
| 59 | PARK | | | | |

| | DATA2 | yplus | uplus | uprplus | wprplus |
|---|---|---|---|---|---|
| 1 | 3707 | 168.125 | 17.725 | 2.849 | 1.75 |
| 2 | PARK | 359.176 | 19.676 | 2.605 | 1.7 |
| 3 | 122.9 | 550.227 | 20.568 | 2.466 | 1.71 |
| 4 | 1005.4 | 741.279 | 21.245 | 2.513 | 1.648 |
| 5 | 0.00835 | 932.33 | 21.809 | 2.472 | 1.612 |
| 6 | | 1123.381 | 22.247 | 2.342 | 1.503 |
| 7 | | 1314.432 | 22.613 | 2.337 | 1.52 |
| 8 | 21555.1302 | 1505.484 | 22.874 | 2.365 | 1.567 |
| 9 | 0.002014 | 1696.535 | 23.53 | 2.303 | 1.521 |
| 10 | 63140.3201 | 1887.586 | 23.47 | 2.242 | 1.418 |
| 11 | 5.641192 | 2078.637 | 23.823 | 2.311 | 1.504 |
| 12 | 0.650364 | 2269.688 | 23.936 | 2.201 | 1.48 |
| 11 | 0.52439 | 2460.74 | 23.892 | 2.266 | 1.488 |
| 14 | 31.905553 | 2651.791 | 24.431 | 2.142 | 1.45 |
| 15 | 0.537872 | 3033.893 | 24.645 | 2.093 | 1.412 |
| 16 | 31.511756 | 3415.996 | 24.989 | 2.064 | 1.47 |
| 17 | 0.078478 | 3798.098 | 24.973 | 2.014 | 1.38 |
| 18 | | 4371.252 | 25.789 | 1.901 | 1.389 |
| 19 | | 4944.405 | 25.818 | 1.912 | 1.41 |
| 20 | 0.119811 | 5708.61 | 26.416 | 1.923 | 1.402 |
| 21 | 0.003171 | 6472.815 | 26.713 | 1.781 | 1.294 |
| 22 | 0.00189 | 7428.071 | 27.299 | 1.748 | 1.303 |
| 23 | 63237 | 8383.327 | 27.768 | 1.7 | 1.222 |
| 24 | 5.38 | 9529.635 | 28.253 | 1.614 | 1.192 |
| 25 | 0.654 | 10866.993 | 28.792 | 1.534 | 1.076 |
| 26 | 0.525 | 12395.403 | 29.192 | 1.429 | 1.055 |
| 27 | 30.94 | 14114.864 | 29.747 | 1.268 | 0.937 |
| 28 | | 16025.376 | 30.444 | 1.111 | 0.734 |
| 29 | 0.1 | 18317.99 | 30.929 | 0.803 | 0.555 |
| 30 | 0.0026 | 21183.759 | 31.272 | 0.532 | 0.418 |
| 31 | | 24813.732 | 31.386 | 0.315 | 0.239 |
| 32 | 3707 | 29016.859 | 31.487 | 0.129 | 0.107 |
| 33 | | 33984.19 | 31.496 | 0.128 | 0.055 |
| 34 | | 39715.727 | 31.505 | 0.101 | 0.102 |
| 35 | | 46593.57 | 31.521 | 0.088 | 0 |
| 36 | | 54999.824 | 31.518 | 0.007 | 0.071 |
| 37 | 2 | 64934.487 | 31.502 | 0.079 | 0.115 |
| 38 | 359.176284 | | | | |
| 39 | | | | | |
| 40 | | | | | |
| 41 | | | | | |
| 42 | | | | | |
| 43 | | | | | |
| 44 | | | | | |
| 45 | 119.51793 | | | | |
| 46 | 127.172018 | | | | |
| 47 | 1.245714 | | | | |
| 48 | 1.240229 | | | | |
| 49 | | | | | |
| 50 | 0.992768 | | | | |
| 51 | 30 | | | | |
| 52 | 0.002498 | | | | |
| 53 | 300 | | | | |
| 54 | 0.018804 | | | | |
| 55 | | | | | |
| 56 | | | | | |
| 57 | 1.240245 | | | | |
| 58 | 3707 | | | | |
| 59 | PARK | | | | |

| | DATA2 | yplus | uplus | uprplus | wprplus |
|---|---|---|---|---|---|
| 1 | 3708 | 101.111 | 16.683 | 3.327 | |
| 2 | PARK | 290.104 | 19.027 | 2.733 | 1.662 |
| 3 | 199.4 | 479.096 | 20.248 | 2.641 | 1.705 |
| 4 | 1006.4 | 668.089 | 21.045 | 2.578 | 1.628 |
| 5 | 0.00835 | 857.082 | 21.504 | 2.494 | 1.585 |
| 6 | | 1046.074 | 22.037 | 2.403 | 1.574 |
| 7 | | 1235.067 | 22.557 | 2.427 | 1.528 |
| 8 | 24859.1331 | 1424.059 | 22.962 | 2.305 | 1.576 |
| 9 | 0.001967 | 1613.052 | 23.3 | 2.337 | 1.504 |
| 10 | 73337.4097 | 1802.045 | 22.955 | 2.353 | 1.499 |
| 11 | 6.576747 | 1991.037 | 23.682 | 2.283 | 1.497 |
| 12 | 0.753439 | 2180.03 | 23.883 | 2.178 | 1.454 |
| 13 | 0.608473 | 2558.015 | 24.151 | 2.157 | 1.494 |
| 14 | 31.561769 | 2936.001 | 24.664 | 2.12 | 1.495 |
| 15 | 0.548112 | 3313.986 | 24.884 | 2.035 | 1.494 |
| 16 | 31.886679 | 3880.964 | 25.06 | 2.054 | 1.47 |
| 17 | 0.079032 | 4447.942 | 25.595 | 2.016 | 1.395 |
| 18 | | 5203.912 | 26.185 | 1.945 | 1.431 |
| 19 | | 5959.883 | 26.619 | 1.869 | 1.404 |
| 20 | 0.111528 | 6904.846 | 26.861 | 1.805 | 1.309 |
| 21 | 0.004653 | 7849.809 | 27.116 | 1.772 | 1.284 |
| 22 | 0.00185 | 8983.765 | 28.035 | 1.657 | 1.22 |
| 23 | 73099 | 10306.713 | 28.166 | 1.627 | 1.162 |
| 24 | 6.3 | 11818.654 | 28.912 | 1.562 | 1.159 |
| 25 | 0.754 | 13519.588 | 28.975 | 1.58 | 1.1 |
| 26 | 0.606 | 15409.514 | 30.187 | 1.274 | 0.929 |
| 27 | 30.62 | 17677.426 | 30.608 | 1.063 | 0.761 |
| 28 | | 20512.315 | 31.233 | 0.846 | 0.592 |
| 29 | 0.1 | 24103.175 | 31.597 | 0.518 | 0.41 |
| 30 | 0.0014 | 28261.013 | 31.778 | 0.245 | 0.243 |
| 31 | | 33174.821 | 31.839 | 0.13 | 0.154 |
| 32 | 3708 | 38844.6 | 31.919 | 0.043 | 0.113 |
| 33 | | 45648.335 | 31.899 | 0.043 | 0.045 |
| 34 | | 53964.011 | 31.893 | 0.016 | 0.165 |
| 35 | | 63791.628 | 31.839 | 0.116 | 0.01 |
| 36 | | | | | |
| 37 | 2 | | | | |
| 38 | 290.103688 | | | | |
| 39 | | | | | |
| 40 | | | | | |
| 41 | | | | | |
| 42 | | | | | |
| 43 | | | | | |
| 44 | | | | | |
| 45 | 135.23315 | | | | |
| 46 | 144.257031 | | | | |
| 47 | 1.244224 | | | | |
| 48 | 1.238245 | | | | |
| 49 | | | | | |
| 50 | 0.991936 | | | | |
| 51 | 29 | | | | |
| 52 | 0.002414 | | | | |
| 53 | 300 | | | | |
| 54 | 0.021922 | | | | |
| 55 | | | | | |
| 56 | | | | | |
| 57 | 1.22723 | | | | |
| 58 | 3708 | | | | |
| 59 | PARK | | | | |

| | DATA2 | yplus | uplus | uprplus | wprplus |
|---|---|---|---|---|---|
| 1 | 3709 | 182.242 | 17.484 | 2.964 | |
| 2 | PARK | 369.734 | 19.633 | 2.598 | 1.635 |
| 3 | 322.3 | 557.225 | 20.694 | 2.552 | 1.624 |
| 4 | 1009.1 | 744.717 | 21.261 | 2.573 | 1.562 |
| 5 | 0.00835 | 969.707 | 22.031 | 2.539 | 1.563 |
| 6 | | 1157.199 | 22.386 | 2.419 | 1.531 |
| 7 | | 1344.69 | 22.247 | 2.415 | 1.539 |
| 8 | 29868.653 | 1532.182 | 23.327 | 2.368 | 1.489 |
| 9 | 0.001926 | 1719.674 | 23.143 | 2.347 | 1.451 |
| 10 | 85619.76 | 1907.166 | 23.372 | 2.283 | 1.408 |
| 11 | 7.965327 | 2094.657 | 24.084 | 2.196 | 1.427 |
| 12 | 0.877962 | 2282.149 | 24.113 | 2.203 | 1.424 |
| 13 | 0.708478 | 2469.641 | 24.258 | 2.201 | 1.475 |
| 14 | 31.311114 | 2844.624 | 24.667 | 2.12 | 1.443 |
| 15 | 0.530595 | 3219.608 | 24.777 | 2.104 | 1.421 |
| 16 | 32.228173 | 3594.591 | 25.041 | 2.106 | 1.407 |
| 17 | 0.075695 | 4157.066 | 25.734 | 1.959 | 1.424 |
| 18 | | 4719.541 | 25.202 | 1.982 | 1.412 |
| 19 | | 5469.508 | 25.66 | 1.892 | 1.37 |
| 20 | 0.001843 | 6219.475 | 26.34 | 1.969 | 1.32 |
| 21 | 0.006611 | 7156.933 | 26.917 | 1.884 | 1.339 |
| 22 | 0.0018 | 8094.392 | 27.146 | 1.755 | 1.296 |
| 23 | 85648 | 9219.342 | 27.101 | 1.809 | 1.276 |
| 24 | 6.96 | 10531.784 | 28.277 | 1.667 | 1.254 |
| 25 | 0.882 | 12031.718 | 28.635 | 1.608 | 1.196 |
| 26 | 0.709 | 13719.143 | 28.983 | 1.591 | 1.136 |
| 27 | 30.3 | 15594.06 | 29.511 | 1.469 | 1.106 |
| 28 | | 17843.96 | 30.327 | 1.287 | 0.885 |
| 29 | 0.1 | 20656.336 | 30.768 | 1.181 | 0.837 |
| 30 | 0.003 | 24218.678 | 31.719 | 0.837 | 0.57 |
| 31 | | 28343.496 | 32.125 | 0.42 | 0.332 |
| 32 | 3709 | 33218.28 | 32.128 | 0.326 | 0.254 |
| 33 | | 38843.031 | 32.235 | 0.169 | 0.047 |
| 34 | | 45592.732 | 32.215 | 0.162 | 0.11 |
| 35 | | 53842.367 | 32.235 | 0.097 | 0.001 |
| 36 | | 63591.936 | 32.228 | 0.008 | 0.034 |
| 37 | 2 | | | | |
| 38 | 369.733637 | | | | |
| 39 | | | | | |
| 40 | | | | | |
| 41 | | | | | |
| 42 | | | | | |
| 43 | | | | | |
| 44 | | | | | |
| 45 | 154.1664 | | | | |
| 46 | 164.866583 | | | | |
| 47 | 1.244006 | | | | |
| 48 | 1.239222 | | | | |
| 49 | | | | | |
| 50 | 0.996831 | | | | |
| 51 | 31 | | | | |
| 52 | 0.002312 | | | | |
| 53 | 300 | | | | |
| 54 | 0.026551 | | | | |
| 55 | | | | | |
| 56 | | | | | |
| 57 | 1.200685 | | | | |
| 58 | 3709 | | | | |
| 59 | PARK | | | | |

| | DATA2 | yplus | uplus | uprplus | wprplus |
|---|---|---|---|---|---|
| 1 | 3710 | 144.672 | 17.47 | 2.99 | |
| 2 | PARK | 330.626 | 19.508 | 2.652 | 1.705 |
| 3 | 398.8 | 516.579 | 20.265 | 2.68 | 1.674 |
| 4 | 1009.5 | 739.724 | 21.107 | 2.609 | 1.559 |
| 5 | 0.00835 | 925.677 | 21.809 | 2.592 | 1.615 |
| 6 | | 1111.631 | 22.495 | 2.545 | 1.558 |
| 7 | | 1297.585 | 22.603 | 2.447 | 1.551 |
| 8 | 34924.5236 | 1483.539 | 23.058 | 2.409 | 1.563 |
| 9 | 0.001893 | 1669.492 | 23.24 | 2.313 | 1.502 |
| 10 | 99338.579 | 1855.446 | 23.373 | 2.361 | 1.517 |
| 11 | 9.390651 | 2041.4 | 23.565 | 2.335 | 1.478 |
| 12 | 1.013185 | 2413.307 | 24.15 | 2.253 | 1.489 |
| 13 | 0.821671 | 2785.214 | 24.498 | 2.271 | 1.479 |
| 14 | 31.054266 | 3157.122 | 24.436 | 2.195 | 1.484 |
| 15 | 0.513183 | 3714.983 | 24.729 | 2.233 | 1.469 |
| 16 | 32.507611 | 4272.844 | 25.876 | 2.017 | 1.44 |
| 17 | 0.072582 | 5016.659 | 25.509 | 2.085 | 1.403 |
| 18 | | 5760.473 | 26.256 | 1.978 | 1.408 |
| 19 | | 6690.242 | 26.604 | 1.988 | 1.341 |
| 20 | 0.034995 | 7620.01 | 27.134 | 1.894 | 1.314 |
| 21 | 0.00611 | 8735.732 | 26.881 | 1.879 | 1.348 |
| 22 | 0.00178 | 10037.408 | 27.752 | 1.729 | 1.255 |
| 23 | 99227 | 11525.038 | 28.519 | 1.694 | 1.218 |
| 24 | 8.41 | 13198.621 | 28.685 | 1.648 | 1.213 |
| 25 | 1.013 | 15058.158 | 28.795 | 1.638 | 1.136 |
| 26 | 0.821 | 17289.602 | 29.549 | 1.532 | 1.06 |
| 27 | 30.1 | 20078.907 | 30.593 | 1.268 | 0.916 |
| 28 | | 23612.027 | 30.911 | 1.233 | 0.853 |
| 29 | 0.1 | 27703.008 | 31.867 | 0.84 | 0.517 |
| 30 | 0.0024 | 32537.804 | 32.293 | 0.459 | 0.377 |
| 31 | | 38116.415 | 32.514 | 0.209 | 0.137 |
| 32 | 3710 | 44810.748 | 32.456 | 0.029 | 0.137 |
| 33 | | 52992.71 | 32.524 | 0.089 | 0.032 |
| 34 | | 62662.302 | 32.537 | 0.066 | 0 |
| 35 | | | | | |
| 36 | | | | | |
| 37 | 2 | | | | |
| 38 | 330.625656 | | | | |
| 39 | | | | | |
| 40 | | | | | |
| 41 | | | | | |
| 42 | | | | | |
| 43 | | | | | |
| 44 | | | | | |
| 45 | 176.62406 | | | | |
| 46 | 188.008647 | | | | |
| 47 | 1.233861 | | | | |
| 48 | 1.233078 | | | | |
| 49 | | | | | |
| 50 | 0.996309 | | | | |
| 51 | 30 | | | | |
| 52 | 0.002261 | | | | |
| 53 | 300 | | | | |
| 54 | 0.031302 | | | | |
| 55 | | | | | |
| 56 | | | | | |
| 57 | 1.19465 | | | | |
| 58 | 3710 | | | | |
| 59 | PARK | | | | |

| | DATA2 | yplus | uplus | uprplus | wprplus |
|---|---|---|---|---|---|
| 1 | 3711 | 322.379 | 19.532 | 2.589 | 1.717 |
| 2 | PARK | 505.134 | 20.384 | 2.641 | 1.633 |
| 3 | 521.7 | 687.889 | 21.024 | 2.559 | 1.62 |
| 4 | 1007.3 | 870.643 | 21.621 | 2.5 | 1.584 |
| 5 | 0.00835 | 1053.398 | 22.46 | 2.596 | 1.572 |
| 6 | | 1236.153 | 22.186 | 2.526 | 1.595 |
| 7 | | 1418.907 | 22.892 | 2.401 | 1.556 |
| 8 | 39462.2099 | 1601.662 | 23.027 | 2.353 | 1.561 |
| 9 | 0.001836 | 1784.417 | 23.536 | 2.416 | 1.536 |
| 10 | 115521.774 | 1967.171 | 23.139 | 2.449 | 1.589 |
| 11 | 10.796498 | 2149.926 | 23.955 | 2.39 | 1.565 |
| 12 | 1.181715 | 2515.435 | 24.206 | 2.259 | 1.548 |
| 13 | 0.957616 | 2880.945 | 24.159 | 2.37 | 1.513 |
| 14 | 30.520032 | 3246.454 | 24.691 | 2.25 | 1.483 |
| 15 | 0.560191 | 3794.718 | 25.047 | 2.141 | 1.485 |
| 16 | 33.004552 | 4342.982 | 25.295 | 2.063 | 1.4 |
| 17 | 0.078037 | 5074.001 | 25.862 | 2.076 | 1.494 |
| 18 | | 5805.02 | 25.892 | 2.159 | 1.379 |
| 19 | | 6718.793 | 26.592 | 2.023 | 1.386 |
| 20 | 0.018195 | 7632.567 | 27.097 | 1.896 | 1.392 |
| 21 | 0.006523 | 8729.095 | 27.057 | 1.975 | 1.347 |
| 22 | 0.00172 | 10008.377 | 28.084 | 1.804 | 1.239 |
| 23 | 115730 | 11470.415 | 28.031 | 1.825 | 1.306 |
| 24 | 9.66 | 13115.207 | 28.364 | 1.742 | 1.248 |
| 25 | 1.186 | 14942.754 | 29.628 | 1.617 | 1.1 |
| 26 | 0.959 | 17135.81 | 29.863 | 1.619 | 1.095 |
| 27 | 29.5 | 19877.13 | 29.965 | 1.527 | 1.072 |
| 28 | | 23349.469 | 30.589 | 1.329 | 0.919 |
| 29 | 0.1 | 27370.072 | 31.437 | 1.159 | 0.851 |
| 30 | 0.0035 | 32121.694 | 32.394 | 0.821 | 0.494 |
| 31 | | 37604.335 | 32.876 | 0.399 | 0.192 |
| 32 | 3711 | 44183.503 | 33.008 | 0.168 | 0.134 |
| 33 | | 52224.709 | 33.011 | 0.125 | 0.041 |
| 34 | | 61727.953 | 32.991 | 0.122 | 0.039 |
| 35 | | 72693.234 | 33.011 | 0.004 | 0.02 |
| 36 | | 85120.552 | 33.005 | 0.033 | 0.003 |
| 37 | 2 | | | | |
| 38 | 505.133944 | | | | |
| 39 | | | | | |
| 40 | | | | | |
| 41 | | | | | |
| 42 | | | | | |
| 43 | | | | | |
| 44 | | | | | |
| 45 | 199.0556 | | | | |
| 46 | 212.102677 | | | | |
| 47 | 1.236705 | | | | |
| 48 | 1.234018 | | | | |
| 49 | | | | | |
| 50 | 0.99723 | | | | |
| 51 | 31 | | | | |
| 52 | 0.002193 | | | | |
| 53 | 300 | | | | |
| 54 | 0.035988 | | | | |
| 55 | | | | | |
| 56 | | | | | |
| 57 | | | | | |
| | 1.194418 | | | | |
| 58 | 3711 | | | | |
| 59 | PARK | | | | |

| | DATA2 | yplus | uplus | uprplus | wprplus |
|---|---|---|---|---|---|
| 1 | 3712 | 99.64 | 17.008 | 3.067 | 1.736 |
| 2 | PARK | 280.476 | 18.963 | 2.692 | 1.685 |
| 3 | 598.2 | 461.311 | 20.101 | 2.794 | 1.704 |
| 4 | 1007.7 | 642.146 | 21.472 | 2.624 | 1.69 |
| 5 | 0.00835 | 822.982 | 21.039 | 2.568 | 1.603 |
| 6 | | 1003.817 | 21.813 | 2.564 | 1.619 |
| 7 | | 1184.652 | 22.063 | 2.532 | 1.693 |
| 8 | 42184.8353 | 1365.487 | 22.317 | 2.436 | 1.597 |
| 9 | 0.001796 | 1546.323 | 23.281 | 2.484 | 1.618 |
| 10 | 129512.312 | 1727.158 | 22.937 | 2.486 | 1.582 |
| 11 | 11.663882 | 1907.993 | 23.648 | 2.449 | 1.46 |
| 12 | 1.32227 | 2269.664 | 24.145 | 2.513 | 1.556 |
| 13 | 1.073164 | 2631.335 | 24.199 | 2.335 | 1.508 |
| 14 | 30.199497 | 2993.005 | 24.375 | 2.324 | 1.493 |
| 15 | 0.605905 | 3535.511 | 24.629 | 2.155 | 1.522 |
| 16 | 33.368105 | 4078.017 | 25.356 | 2.104 | 1.47 |
| 17 | 0.083486 | 4801.358 | 25.089 | 2.221 | 1.478 |
| 18 | | 5524.7 | 25.984 | 2.132 | 1.383 |
| 19 | | 6428.876 | 26.614 | 2.029 | 1.362 |
| 20 | 0.136864 | 7333.053 | 27.182 | 2.034 | 1.43 |
| 21 | 0.009151 | 8418.065 | 27.792 | 1.807 | 1.375 |
| 22 | 0.00169 | 9683.912 | 28.136 | 1.827 | 1.283 |
| 23 | 129070 | 11130.594 | 28.216 | 1.906 | 1.331 |
| 24 | 11.15 | 12758.112 | 27.949 | 1.866 | 1.317 |
| 25 | 1.323 | 14566.465 | 28.937 | 1.796 | 1.262 |
| 26 | 0.069 | 16736.489 | 29.2 | 1.653 | 1.209 |
| 27 | 29.3 | 19449.019 | 30.515 | 1.543 | 1.202 |
| 28 | | 22884.89 | 30.392 | 1.513 | 1.055 |
| 29 | 0.1 | 26863.267 | 31.413 | 1.323 | 0.842 |
| 30 | 0.0021 | 31564.985 | 32.08 | 1.243 | 0.894 |
| 31 | | 36990.044 | 32.868 | 0.743 | 0.438 |
| 32 | 3712 | 43500.115 | 33.191 | 0.401 | 0.254 |
| 33 | | 51456.869 | 33.305 | 0.217 | 0.121 |
| 34 | | 60860.305 | 33.381 | 0.047 | 0.011 |
| 35 | | 71710.424 | 33.388 | 0.07 | 0.004 |
| 36 | | 84007.225 | 33.398 | 0 | 0.062 |
| 37 | 2 | | | | |
| 38 | 280.47557 | | | | |
| 39 | | | | | |
| 40 | | | | | |
| 41 | | | | | |
| 42 | | | | | |
| 43 | | | | | |
| 44 | | | | | |
| 45 | 218.1283 | | | | |
| 46 | 232.636557 | | | | |
| 47 | 1.237605 | | | | |
| 48 | 1.232122 | | | | |
| 49 | | | | | |
| 50 | 0.99274 | | | | |
| 51 | 31 | | | | |
| 52 | 0.002157 | | | | |
| 53 | 300 | | | | |
| 54 | 0.03888 | | | | |
| 55 | | | | | |
| 56 | | | | | |
| 57 | 1.200835 | | | | |
| 58 | 3712 | | | | |
| 59 | PARK | | | | |

| | DATA2 | yplus | uplus | uprplus | wprplus |
|---|---|---|---|---|---|
| 1 | 3713 | 38.859 | 13.251 | 4.517 | 1.429 |
| 2 | PARK | 180.163 | 17.839 | 2.924 | 1.758 |
| 3 | 721 | 321.468 | 19.038 | 2.986 | 1.594 |
| 4 | 1010 | 321.468 | 18.935 | 2.733 | 1.724 |
| 5 | 0.00835 | 498.098 | 20.133 | 2.744 | 1.718 |
| 6 | | 674.729 | 21.092 | 2.624 | 1.749 |
| 7 | | 851.36 | 21.469 | 2.773 | 1.726 |
| 8 | 43749.0688 | 1027.99 | 22.017 | 2.681 | 1.712 |
| 9 | 0.001706 | 1204.621 | 22.53 | 2.622 | 1.702 |
| 10 | 146124.824 | 1381.252 | 22.804 | 2.592 | 1.676 |
| 11 | 12.384337 | 1557.882 | 22.941 | 2.618 | 1.591 |
| 12 | 1.509212 | 1734.513 | 23.455 | 2.543 | 1.641 |
| 13 | 1.208062 | 1911.144 | 23.249 | 2.459 | 1.599 |
| 14 | 29.497319 | 2087.774 | 23.489 | 2.537 | 1.633 |
| 15 | 0.777424 | 2264.405 | 24.139 | 2.606 | 1.638 |
| 16 | 34.2404 | 2441.036 | 24.139 | 2.522 | 1.625 |
| 17 | 0.10439 | 2617.666 | 24.105 | 2.422 | 1.527 |
| 18 | | 2794.297 | 24.482 | 2.477 | 1.604 |
| 19 | | 2970.928 | 24.687 | 2.502 | 1.63 |
| 20 | 0.111651 | 3147.558 | 24.619 | 2.335 | 1.623 |
| 21 | 0.00542 | 3500.82 | 24.893 | 2.455 | 1.539 |
| 22 | 0.00159 | 3854.081 | 25.406 | 2.236 | 1596 |
| 23 | 145560 | 4207.342 | 25.406 | 2.39 | 1.538 |
| 24 | 11.82 | 4737.234 | 25.201 | 2.333 | 1.567 |
| 25 | 1.507 | 5267.126 | 25.852 | 2.347 | 1.519 |
| 26 | 1.203 | 5973.649 | 26.468 | 2.238 | 1.456 |
| 27 | 28.48 | 6680.171 | 26.639 | 2.153 | 1.486 |
| 28 | | 7563.325 | 26.913 | 2.086 | 1.485 |
| 29 | 0.1 | 8446.478 | 27.084 | 2.051 | 1.463 |
| 30 | 0.003 | 9506.262 | 27.872 | 1.995 | 1.383 |
| 31 | | 10742.676 | 27.974 | 1.975 | 1.391 |
| 32 | 3713 | 12155.721 | 28.625 | 1.873 | 1.414 |
| 33 | | 13745.397 | 29.036 | 1.857 | 1.353 |
| 34 | | 15511.704 | 29.481 | 1.834 | 1.318 |
| 35 | | 17631.272 | 30.166 | 1.662 | 1.268 |
| 36 | | 20280.731 | 30.269 | 1.777 | 1.231 |
| 37 | 2 | 23636.714 | 31.022 | 1.562 | 1.175 |
| 38 | 180.163265 | 27522.588 | 31.981 | 1.458 | 1.011 |
| 39 | | 32114.985 | 32.768 | 1.255 | 0.819 |
| 40 | | 37413.905 | 33.624 | 0.823 | 0.52 |
| 41 | | 43772.608 | 34.035 | 0.671 | 0.426 |
| 42 | | 51544.357 | 34.275 | 0.255 | 0.106 |
| 43 | | 60729.151 | 34.206 | 0.197 | 0.105 |
| 44 | | 71326.99 | 34.275 | 0.148 | 0.062 |
| 45 | 231.4404 | 82631.351 | 34.24 | 0.106 | 0.011 |
| 46 | 249.273628 | 94642.236 | 34.206 | 0.022 | 0.171 |
| 47 | 1.252702 | 103827.03 | 34.24 | 0.119 | 0.145 |
| 48 | 1.249283 | | | | |
| 49 | | | | | |
| 50 | 0.993956 | | | | |
| 51 | 40 | | | | |
| 52 | 0.002107 | | | | |
| 53 | 300 | | | | |
| 54 | 0.041281 | | | | |
| 55 | | | | | |
| 56 | | | | | |
| 57 | 1.235129 | | | | |
| 58 | 3713 | | | | |
| 59 | PARK | | | | |

| | DATA2 | yplus | uplus | uprplus | wprplus |
|---|---|---|---|---|---|
| 1 | 3714 | 160.254 | 17.526 | 3.044 | |
| 2 | PARK | 302.072 | 19.224 | 2.828 | 1.771 |
| 3 | 797.6 | 443.889 | 20.252 | 2.707 | 1.795 |
| 4 | 1011.4 | 585.707 | 20.625 | 2.701 | 1.741 |
| 5 | 0.00835 | 762.979 | 21.274 | 2.6 | 1.738 |
| 6 | | 940.252 | 21.902 | 2.637 | 1.673 |
| 7 | | 1117.524 | 22.186 | 2.537 | 1.66 |
| 8 | 48374.984 | 1294.796 | 22.309 | 2.624 | 1.625 |
| 9 | 0.001714 | 1472.068 | 22.815 | 2.583 | 1.631 |
| 10 | 156850.506 | 1649.34 | 23.088 | 2.503 | 1.631 |
| 11 | 13.64427 | 1826.612 | 23.481 | 2.469 | 1.593 |
| 12 | 1.607948 | 2003.884 | 23.658 | 2.505 | 1.622 |
| 13 | 1.294939 | 2181.157 | 24.099 | 2.496 | 1.615 |
| 14 | 29.60445 | 2535.701 | 23.857 | 2.54 | 1.584 |
| 15 | 0.710504 | 2890.245 | 24.024 | 2.439 | 1.602 |
| 16 | 34.163783 | 3244.79 | 24.799 | 2.339 | 1.558 |
| 17 | 0.095618 | 3776.606 | 24.998 | 2.384 | 1.568 |
| 18 | | 4308.422 | 25.367 | 2.31 | 1.531 |
| 19 | | 5017.511 | 25.865 | 2.203 | 1.453 |
| 20 | 0.119899 | 5726.6 | 26.446 | 2.183 | 1.451 |
| 21 | 0.005658 | 6612.961 | 26.658 | 2.035 | 1.456 |
| 22 | 0.0016 | 7499.321 | 27.369 | 2.221 | 1.407 |
| 23 | 156710 | 8562.954 | 27.075 | 2.086 | 1.393 |
| 24 | 13.54 | 9803.859 | 27.498 | 2.075 | 1.386 |
| 25 | 1.609 | 11222.037 | 27.751 | 1.953 | 1.319 |
| 26 | 1.293 | 12817.486 | 28.335 | 1.881 | 1.386 |
| 27 | 28.65 | 14590.208 | 28.776 | 1.878 | 1.379 |
| 28 | | 16717.473 | 29.412 | 1.764 | 1.328 |
| 29 | 0.1 | 19376.556 | 29.798 | 1.755 | 1.28 |
| 30 | 0.0027 | 22744.727 | 30.238 | 1.583 | 1.254 |
| 31 | | 26644.714 | 31.827 | 1.393 | 1.015 |
| 32 | 3714 | 31253.79 | 32.114 | 1.327 | 1.008 |
| 33 | | 36571.955 | 33.166 | 1.114 | 0.745 |
| 34 | | 42953.753 | 33.563 | 0.815 | 0.559 |
| 35 | | 50753.727 | 33.962 | 0.503 | 0.365 |
| 36 | | 59971.88 | 34.143 | 0.059 | 0.124 |
| 37 | 2 | 70608.209 | 34.164 | 0.083 | 0.069 |
| 38 | 302.071754 | 81953.627 | 34.15 | 0.143 | 0.098 |
| 39 | | 94008.133 | 34.188 | 0.094 | 0.123 |
| 40 | | 103226.286 | 34.154 | 0.018 | 0.07 |
| 41 | | | | | |
| 42 | | | | | |
| 43 | | | | | |
| 44 | | | | | |
| 45 | 250.736 | | | | |
| 46 | 268.771997 | | | | |
| 47 | 1.244393 | | | | |
| 48 | 1.241716 | | | | |
| 49 | | | | | |
| 50 | 0.990532 | | | | |
| 51 | 34 | | | | |
| 52 | 0.00208 | | | | |
| 53 | 300 | | | | |
| 54 | 0.045481 | | | | |
| 55 | | | | | |
| 56 | | | | | |
| 57 | 1.213851 | | | | |
| 58 | 3714 | | | | |
| 59 | PARK | | | | |

| | DATA2 | yplus | uplus | uprplus | wprplus |
|---|---|---|---|---|---|
| 1 | 3715 | 103.413 | 16.462 | 4.032 | |
| 2 | PARK | 281.098 | 19.159 | 2.772 | 1.727 |
| 3 | 920.4 | 458.784 | 20.308 | 2.833 | 1.817 |
| 4 | 1014.5 | 636.469 | 20.835 | 2.709 | 1.696 |
| 5 | 0.00835 | 814.154 | 21.515 | 2.577 | 1.722 |
| 6 | | 991.84 | 21.744 | 2.628 | 1.622 |
| 7 | | 1169.525 | 22.083 | 2.609 | 1.674 |
| 8 | 54132.7159 | 1382.748 | 22.424 | 2.523 | 1.714 |
| 9 | 0.001711 | 1595.97 | 22.599 | 2.486 | 1.539 |
| 10 | 168218.578 | 1773.655 | 23.259 | 2.426 | 1.688 |
| 11 | 15.232744 | 1951.341 | 23.802 | 2.548 | 1.646 |
| 12 | 1.717553 | 2129.026 | 23.792 | 2.608 | 1.598 |
| 13 | 1.384549 | 2306.712 | 23.577 | 2.419 | 1.571 |
| 14 | 29.673457 | 2484.397 | 23.942 | 2.354 | 1.525 |
| 15 | 0.659718 | 2839.768 | 24.383 | 2.42 | 1.562 |
| 16 | 34.188804 | 3195.138 | 24.835 | 2.346 | 1.571 |
| 17 | 0.088719 | 3550.509 | 25.488 | 2.392 | 1.587 |
| 18 | | 4083.565 | 25.966 | 2.402 | 1.483 |
| 19 | | 4616.621 | 25.498 | 2.147 | 1.541 |
| 20 | 0.002797 | 5327.363 | 26.083 | 2.126 | 1.487 |
| 21 | 0.007882 | 6038.104 | 26.298 | 2.109 | 1.458 |
| 22 | 0.0016 | 6926.531 | 26.558 | 2.054 | 1.462 |
| 23 | 168150 | 7814.958 | 27.505 | 2.064 | 1.449 |
| 24 | 13.16 | 8881.07 | 27.443 | 1.902 | 1.433 |
| 25 | 1.72 | 10124.868 | 27.536 | 2.021 | 1.436 |
| 26 | 1.384 | 11546.351 | 27.748 | 1.957 | 1.435 |
| 27 | 28.71 | 13145.519 | 28.093 | 1.79 | 1.429 |
| 28 | | 14922.373 | 28.366 | 1.804 | 1.298 |
| 29 | 0.1 | 17054.597 | 28.852 | 1.881 | 1.301 |
| 30 | 0.0025 | 19719.878 | 29.919 | 1.793 | 1.231 |
| 31 | | 23095.9 | 29.806 | 1.626 | 1.254 |
| 32 | 3715 | 27004.978 | 31.279 | 1.541 | 1.199 |
| 33 | | 31624.798 | 31.717 | 1.411 | 1.09 |
| 34 | | 36955.359 | 32.373 | 1.185 | 0.952 |
| 35 | | 43352.032 | 33.59 | 0.85 | 0.62 |
| 36 | | 51170.189 | 34.179 | 0.301 | 0.244 |
| 37 | 2 | 60409.828 | 34.168 | 0.272 | 0.205 |
| 38 | 281.098259 | 71070.951 | 34.185 | 0.119 | 0.096 |
| 39 | | 82442.814 | 34.199 | 0.003 | 0.098 |
| 40 | | 94525.42 | 34.172 | 0.085 | 0.091 |
| 41 | | 103765.059 | 34.199 | 0.105 | 0.149 |
| 42 | | | | | |
| 43 | | | | | |
| 44 | | | | | |
| 45 | 269.04 | | | | |
| 46 | 287.830059 | | | | |
| 47 | 1.242775 | | | | |
| 48 | 1.240514 | | | | |
| 49 | | | | | |
| 50 | 0.999604 | | | | |
| 51 | 36 | | | | |
| 52 | 0.00204 | | | | |
| 53 | 300 | | | | |
| 54 | 0.050776 | | | | |
| 55 | | | | | |
| 56 | | | | | |
| 57 | 1.192252 | | | | |
| 58 | 3715 | | | | |
| 59 | PARK | | | | |

| | DATA2 | yplus | uplus | uprplus | wprplus |
|---|---|---|---|---|---|
| 1 | 3716 | 272.344 | 18.366 | 2.798 | 1.668 |
| 2 | PARK | 449.191 | 19.99 | 2.795 | 1.744 |
| 3 | 997 | 661.407 | 20.958 | 2.761 | 1.643 |
| 4 | 1016.5 | 838.254 | 21.663 | 2.721 | 1.718 |
| 5 | 0.00835 | 1015.101 | 22.355 | 2.688 | 1.67 |
| 6 | | 1191.948 | 22.327 | 2.594 | 1.72 |
| 7 | | 1368.794 | 22.665 | 2.671 | 1.719 |
| 8 | 53095.4394 | 1545.641 | 22.561 | 2.52 | 1.622 |
| 9 | 0.001688 | 1722.488 | 23.236 | 2.513 | 1.625 |
| 10 | 176463.19 | 1899.335 | 22.978 | 2.397 | 1.627 |
| 11 | 15.011703 | 2253.029 | 23.773 | 2.452 | 1.598 |
| 12 | 1.792469 | 2606.722 | 24.062 | 2.447 | 1.567 |
| 13 | 1.44955 | 2960.416 | 25.012 | 2.356 | 1.51 |
| 14 | 29.53342 | 3490.956 | 24.716 | 2.412 | 1.62 |
| 15 | 0.71938 | 4021.497 | 25.346 | 2.374 | 1.557 |
| 16 | 34.418635 | 4728.884 | 25.28 | 2.212 | 1.442 |
| 17 | 0.096096 | 5436.271 | 26.213 | 2.194 | 1.512 |
| 18 | | 6320.506 | 26.568 | 2.099 | 1.476 |
| 19 | | 7204.74 | 26.867 | 2.06 | 1.43 |
| 20 | 0.172114 | 8265.821 | 27.105 | 2.054 | 1.423 |
| 21 | 0.007114 | 9503.748 | 27.308 | 2.153 | 1.433 |
| 22 | 0.00158 | 10918.523 | 27.618 | 2.027 | 1.393 |
| 23 | 176420 | 12510.145 | 28.612 | 2.003 | 1.319 |
| 24 | 15.56 | 14278.613 | 28.709 | 2.086 | 1.32 |
| 25 | 1.797 | 16400.775 | 29.349 | 1.968 | 1.398 |
| 26 | 1.449 | 19053.477 | 29.576 | 1.82 | 1.293 |
| 27 | 28.53 | 22413.567 | 29.896 | 1.636 | 1.272 |
| 28 | | 26304.197 | 31.7 | 1.533 | 1.169 |
| 29 | 0.1 | 30902.215 | 31.583 | 1.522 | 1.12 |
| 30 | 0.0028 | 36207.619 | 32.694 | 1.309 | 0.948 |
| 31 | | 42574.105 | 33.41 | 1.096 | 0.784 |
| 32 | 3716 | 50355.366 | 33.844 | 0.733 | 0.573 |
| 33 | | 59551.401 | 34.295 | 0.35 | 0.273 |
| 34 | | 70162.21 | 34.432 | 0.153 | 0.138 |
| 35 | | 81480.407 | 34.443 | 0.073 | 0 |
| 36 | | 93505.991 | 34.391 | 0.125 | 0.075 |
| 37 | 2 | 102702.026 | 34.412 | 0.015 | 0.116 |
| 38 | 449.190941 | | | | |
| 39 | | | | | |
| 40 | | | | | |
| 41 | | | | | |
| 42 | | | | | |
| 43 | | | | | |
| 44 | | | | | |
| 45 | 278.7436 | | | | |
| 46 | 297.918067 | | | | |
| 47 | 1.240166 | | | | |
| 48 | 1.236569 | | | | |
| 49 | | | | | |
| 50 | 0.987203 | | | | |
| 51 | 32 | | | | |
| 52 | 0.002018 | | | | |
| 53 | 300 | | | | |
| 54 | 0.050039 | | | | |
| 55 | | | | | |
| 56 | | | | | |
| 57 | 1.195304 | | | | |
| 58 | 3716 | | | | |
| 59 | PARK | | | | |

| | DATA2 | yplus | uplus | uprplus | wprplus |
|---|---|---|---|---|---|
| 1 | 3717 | 287.271 | 18.665 | 2.777 | 1.845 |
| 2 | PARK | 428.09 | 19.636 | 2.885 | 1.713 |
| 3 | 1119.8 | 639.319 | 20.708 | 2.816 | 1.716 |
| 4 | 1019.3 | 850.547 | 21.783 | 2.666 | 1.755 |
| 5 | 0.00835 | 1026.571 | 21.838 | 2.677 | 1.64 |
| 6 | | 1202.595 | 22.279 | 2.701 | 1.703 |
| 7 | | 1378.619 | 22.74 | 2.618 | 1.713 |
| 8 | 60854.3186 | 1554.643 | 23.142 | 2.677 | 1.654 |
| 9 | 0.001663 | 1730.666 | 23.177 | 2.705 | 1.661 |
| 10 | 197670.817 | 1906.69 | 23.461 | 2.614 | 1.595 |
| 11 | 17.285817 | 2082.714 | 23.704 | 2.552 | 1.637 |
| 12 | 2.003175 | 2258.738 | 24.331 | 2.566 | 1.588 |
| 13 | 1.619299 | 2610.786 | 24.096 | 2.507 | 1.619 |
| 14 | 29.395982 | 2962.833 | 24.792 | 2.375 | 1.605 |
| 15 | 0.706902 | 3314.881 | 24.72 | 2.323 | 1.564 |
| 16 | 34.674807 | 3842.953 | 25.396 | 2.504 | 1.533 |
| 17 | 0.093732 | 4371.024 | 25.451 | 2.337 | 1.488 |
| 18 | | 5075.119 | 25.51 | 2.226 | 1.533 |
| 19 | | 5779.215 | 26.211 | 2.243 | 1.491 |
| 20 | 0.13484 | 6659.334 | 26.346 | 2.216 | 1.467 |
| 21 | 0.00699 | 7539.453 | 26.221 | 2.157 | 1.508 |
| 22 | 0.00155 | 8595.596 | 27.157 | 2.181 | 1.425 |
| 23 | 197640 | 9827.763 | 27.761 | 2.122 | 1.442 |
| 24 | 16.57 | 11235.954 | 27.528 | 2.094 | 1.387 |
| 25 | 2.005 | 12820.168 | 28.215 | 2.07 | 1.387 |
| 26 | 1.619 | 14580.407 | 28.863 | 1.928 | 1.408 |
| 27 | 28.4 | 16692.693 | 29.224 | 1.859 | 1.352 |
| 28 | | 19333.051 | 29.012 | 1.859 | 1.394 |
| 29 | 0.1 | 22677.504 | 30.458 | 1.678 | 1.307 |
| 30 | 0.0019 | 26550.028 | 31.034 | 1.605 | 1.252 |
| 31 | | 31126.648 | 31.117 | 1.612 | 1.231 |
| 32 | 3717 | 36407.363 | 32.736 | 1.359 | 1.016 |
| 33 | | 42744.222 | 32.993 | 1.227 | 0.867 |
| 34 | | 50489.271 | 33.752 | 1.026 | 0.721 |
| 35 | | 59642.51 | 34.425 | 0.714 | 0.444 |
| 36 | | 70203.941 | 34.654 | 0.316 | 0.201 |
| 37 | 2 | 81469.467 | 34.699 | 0.132 | 0.104 |
| 38 | 428.089983 | 93439.088 | 34.678 | 0.014 | 0.007 |
| 39 | | 102592.328 | 34.671 | 0.066 | 0.076 |
| 40 | | | | | |
| 41 | | | | | |
| 42 | | | | | |
| 43 | | | | | |
| 44 | | | | | |
| 45 | 306.342 | | | | |
| 46 | 328.80956 | | | | |
| 47 | 1.238419 | | | | |
| 48 | 1.237063 | | | | |
| 49 | | | | | |
| 50 | 0.993557 | | | | |
| 51 | 35 | | | | |
| 52 | 0.001986 | | | | |
| 53 | 300 | | | | |
| 54 | 0.057619 | | | | |
| 55 | | | | | |
| 56 | | | | | |
| 57 | 1.193926 | | | | |
| 58 | 3717 | | | | |
| 59 | PARK | | | | |

| | DATA2 | yplus | uplus | uprplus | wprplus |
|---|---|---|---|---|---|
| 1 | 3718 | 120.365 | 16 | 791 | 3.343 |
| 2 | PARK | 297.374 | 19.038 | 2.862 | 1.749 |
| 3 | 1196.3 | 474.382 | 20.019 | 2.748 | 1.77 |
| 4 | 1021.9 | 651.39 | 21.036 | 2.603 | 1.621 |
| 5 | 0.00835 | 828.398 | 21.326 | 2.655 | 1.646 |
| 6 | | 1005.406 | 22.249 | 2.555 | 1.68 |
| 7 | | 1182.414 | 23.017 | 2.714 | 1.718 |
| 8 | 61456.8381 | 1359.422 | 22.094 | 2.569 | 1.552 |
| 9 | 0.001674 | 1536.43 | 22.526 | 2.693 | 1.621 |
| 10 | 201209.112 | 1713.438 | 23.283 | 2.527 | 1.614 |
| 11 | 17.359899 | 1890.446 | 23.079 | 2.6 | 1.573 |
| 12 | 2.020343 | 2244.462 | 23.867 | 2.406 | 1.587 |
| 13 | 1.644091 | 2598.478 | 23.922 | 2.541 | 1.573 |
| 14 | 29.560345 | 2952.494 | 24.87 | 2.468 | 1.525 |
| 15 | 0.679172 | 3483.518 | 24.773 | 2.371 | 1.538 |
| 16 | 34.569962 | 4014.543 | 24.946 | 2.496 | 1.521 |
| 17 | 0.090328 | 4722.575 | 25.737 | 2.199 | 1.535 |
| 18 | | 5430.607 | 26.27 | 2.168 | 1.452 |
| 19 | | 6315.647 | 25.713 | 2.264 | 1.507 |
| 20 | 0.195303 | 7200.688 | 27.089 | 2.199 | 1.521 |
| 21 | 0.008281 | 8262.736 | 27.452 | 2.06 | 1.414 |
| 22 | 0.00156 | 9501.792 | 27.189 | 2.164 | 1.41 |
| 23 | 201190 | 10917.857 | 27.646 | 2.098 | 1.545 |
| 24 | 17.29 | 12510.929 | 28.199 | 2.022 | 1.41 |
| 25 | 2.023 | 14281.01 | 28.873 | 1.974 | 1.327 |
| 26 | 1.644 | 16405.106 | 29.104 | 1.936 | 1.251 |
| 27 | 28.5 | 19060.227 | 29.34 | 1.863 | 1.317 |
| 28 | | 22423.38 | 29.996 | 1.846 | 1.359 |
| 29 | 0.1 | 26317.557 | 30.747 | 1.756 | 1.248 |
| 30 | 0.0029 | 30919.767 | 31.431 | 1.59 | 1.155 |
| 31 | | 36230.008 | 32.34 | 1.404 | 1.051 |
| 32 | 3718 | 42602.298 | 32.561 | 1.352 | 0.971 |
| 33 | | 50390.652 | 33.415 | 1.041 | 0.792 |
| 34 | | 59595.071 | 34.162 | 0.674 | 0.539 |
| 35 | | 70215.554 | 34.573 | 0.28 | 0.197 |
| 36 | | 81544.069 | 34.563 | 0.014 | 0.135 |
| 37 | 2 | 93580.617 | 34.577 | 0.152 | 0.093 |
| 38 | 297.373528 | 102785.036 | 34.563 | 0.1 | 0.003 |
| 39 | | | | | |
| 40 | | | | | |
| 41 | | | | | |
| 42 | | | | | |
| 43 | | | | | |
| 44 | | | | | |
| 45 | 313.8564 | | | | |
| 46 | 336.728466 | | | | |
| 47 | 1.230535 | | | | |
| 48 | 1.228852 | | | | |
| 49 | | | | | |
| 50 | 0.990286 | | | | |
| 51 | 34 | | | | |
| 52 | 0.001968 | | | | |
| 53 | 300 | | | | |
| 54 | 0.057866 | | | | |
| 55 | | | | | |
| 56 | | | | | |
| 57 | 1.175961 | | | | |
| 58 | 3718 | | | | |
| 59 | PARK | | | | |

| | DATA2 | yplus | uplus | uprplus | wprplus |
|---|---|---|---|---|---|
| 1 | 3719 | 219.951 | 18.494 | 2.897 | 1.519 |
| 2 | PARK | 497.666 | 20.286 | 2.668 | 1.638 |
| 3 | 122.9 | 775.382 | 21.495 | 2.484 | 1.598 |
| 4 | 1508.2 | 1108.641 | 22.406 | 2.527 | 1.555 |
| 5 | 0.00835 | 1441.9 | 22.848 | 2.486 | 1.564 |
| 6 | | 1719.615 | 23.407 | 2.46 | 1.565 |
| 7 | | 1997.331 | 23.648 | 2.269 | 1.587 |
| 8 | 30027.3018 | 2275.047 | 24.058 | 2.326 | 1.548 |
| 9 | 0.001891 | 2552.762 | 24.175 | 2.28 | 1.517 |
| 10 | 94307.311 | 2830.478 | 24.468 | 2.233 | 1.493 |
| 11 | 5.406123 | 3108.194 | 24.568 | 2.284 | 1.467 |
| 12 | 0.643286 | 3385.909 | 24.812 | 2.189 | 1.501 |
| 13 | 0.522123 | 3663.625 | 25.15 | 2.117 | 1.455 |
| 14 | 46.378517 | 4219.057 | 25.349 | 2.075 | 1.423 |
| 15 | 0.591281 | 4774.488 | 25.557 | 2.099 | 1.452 |
| 16 | 32.519366 | 5329.919 | 26.051 | 2.101 | 1.395 |
| 17 | 0.083597 | 6163.066 | 26.331 | 2.029 | 1.403 |
| 18 | | 6996.213 | 26.471 | 1.953 | 1.316 |
| 19 | | 8107.076 | 27.372 | 1.916 | 1.309 |
| 20 | 0.190012 | 9217.939 | 27.742 | 1.781 | 1.33 |
| 21 | 0.003571 | 10606.517 | 28.077 | 1.788 | 1.253 |
| 22 | 0.00178 | 11995.095 | 28.682 | 1.684 | 1.216 |
| 23 | 93837 | 13661.389 | 28.903 | 1.601 | 1.208 |
| 24 | 5.58 | 15605.399 | 29.859 | 1.552 | 1.078 |
| 25 | 0.643 | 17827.124 | 30.441 | 1.413 | 1.008 |
| 26 | 0.519 | 20326.566 | 30.936 | 1.232 | 0.912 |
| 27 | 44.99 | 23103.722 | 31.417 | 1.086 | 0.74 |
| 28 | | 26436.31 | 31.612 | 0.974 | 0.673 |
| 29 | 0.1 | 30602.045 | 32.175 | 0.495 | 0.415 |
| 30 | 0.0029 | 35878.643 | 32.432 | 0.263 | 0.246 |
| 31 | | 41988.388 | 32.402 | 0.185 | 0.188 |
| 32 | 3719 | 49208.996 | 32.532 | 0.03 | 0.145 |
| 33 | | 57540.466 | 32.532 | 0.08 | 0.092 |
| 34 | | 67538.23 | 32.545 | 0.106 | 0 |
| 35 | | 79757.72 | 32.526 | 0.012 | 0.088 |
| 36 | | 94198.935 | 32.477 | 0.105 | 0.126 |
| 37 | 2 | | | | |
| 38 | 497.666486 | | | | |
| 39 | | | | | |
| 40 | | | | | |
| 41 | | | | | |
| 42 | | | | | |
| 43 | | | | | |
| 44 | | | | | |
| 45 | 167.02986 | | | | |
| 46 | 178.35743 | | | | |
| 47 | 1.238921 | | | | |
| 48 | 1.232057 | | | | |
| 49 | | | | | |
| 50 | 0.987013 | | | | |
| 51 | 28 | | | | |
| 52 | 0.002662 | | | | |
| 53 | 300 | | | | |
| 54 | 0.01802 | | | | |
| 55 | | | | | |
| 56 | | | | | |
| 57 | 1.407545 | | | | |
| 58 | 3719 | | | | |
| 59 | PARK | | | | |

| | DATA2 | yplus | uplus | uprplus | wprplus |
|---|---|---|---|---|---|
| 1 | 3720 | 154.132 | 17.951 | 2.978 | 1.518 |
| 2 | PARK | 485.6 | 20.373 | 2.699 | 1.706 |
| 3 | 199.4 | 817.067 | 21.475 | 2.677 | 1.637 |
| 4 | 1508 | 1093.29 | 22.488 | 2.546 | 1.658 |
| 5 | 0.00835 | 1369.513 | 22.893 | 2.376 | 1.585 |
| 6 | | 1645.736 | 23.315 | 2.523 | 1.56 |
| 7 | | 1921.958 | 23.41 | 2.453 | 1.588 |
| 8 | 32632.4503 | 2198.181 | 23.815 | 2.302 | 1.623 |
| 9 | 0.001871 | 2474.404 | 24.041 | 2.29 | 1.456 |
| 10 | 102459.848 | 2750.627 | 24.041 | 2.298 | 1.44 |
| 11 | 5.906907 | 3026.85 | 24.554 | 2.318 | 1.455 |
| 12 | 0.697937 | 3579.295 | 24.606 | 2.24 | 1.391 |
| 13 | 0.567334 | 4131.741 | 25.63 | 2.155 | 1.44 |
| 14 | 46.129211 | 4684.187 | 25.78 | 2.117 | 1.416 |
| 15 | 0.586964 | 5512.855 | 25.976 | 2.176 | 1.447 |
| 16 | 32.690783 | 6341.523 | 26.532 | 2.016 | 1.394 |
| 17 | 0.082552 | 7446.415 | 26.921 | 1.898 | 1.387 |
| 18 | | 8551.306 | 26.826 | 1.897 | 1.321 |
| 19 | | 9932.42 | 28.036 | 1.802 | 1.382 |
| 20 | 0.208914 | 11313.534 | 28.382 | 1.813 | 1.395 |
| 21 | 0.005263 | 12970.871 | 28.967 | 1.637 | 1.208 |
| 22 | 0.00177 | 14904.431 | 29.317 | 1.598 | 1.194 |
| 23 | 101730 | 17114.213 | 30.053 | 1.486 | 1.108 |
| 24 | 6.37 | 19600.219 | 30.484 | 1.391 | 0.999 |
| 25 | 0.698 | 22362.447 | 30.942 | 1.284 | 0.956 |
| 26 | 0.563 | 25677.121 | 31.52 | 1.075 | 0.714 |
| 27 | 44.81 | 29820.463 | 31.975 | 0.863 | 0.523 |
| 28 | | 35068.696 | 32.357 | 0.607 | 0.281 |
| 29 | 0.1 | 41145.598 | 32.733 | 0.18 | 0.147 |
| 30 | 0.0031 | 48327.392 | 32.727 | 0.117 | 0.061 |
| 31 | | 56614.076 | 32.665 | 0.023 | 0.104 |
| 32 | 3720 | 66558.098 | 32.704 | 0.05 | 0.108 |
| 33 | | 78711.902 | 32.701 | 0.104 | 0.095 |
| 34 | | 93075.488 | 32.691 | 0.099 | 0.007 |
| 35 | | | | | |
| 36 | | | | | |
| 37 | 2 | | | | |
| 38 | 485.599713 | | | | |
| 39 | | | | | |
| 40 | | | | | |
| 41 | | | | | |
| 42 | | | | | |
| 43 | | | | | |
| 44 | | | | | |
| 45 | 180.0621 | | | | |
| 46 | 191.748981 | | | | |
| 47 | 1.239787 | | | | |
| 48 | 1.230204 | | | | |
| 49 | | | | | |
| 50 | 0.984369 | | | | |
| 51 | 27 | | | | |
| 52 | 0.002517 | | | | |
| 53 | 300 | | | | |
| 54 | 0.01969 | | | | |
| 55 | | | | | |
| 56 | | | | | |
| 57 | 1.344943 | | | | |
| 58 | 3720 | | | | |
| 59 | PARK | | | | |

| | DATA2 | yplus | uplus | uprplus | wprplus |
|---|---|---|---|---|---|
| 1 | 3721 | 138.726 | 17.359 | 3.414 | |
| 2 | PARK | 413.976 | 19.648 | 2.722 | 1.617 |
| 3 | 322.3 | 689.226 | 20.743 | 2.597 | 1.596 |
| 4 | 1511.8 | 964.476 | 21.809 | 2.526 | 1.533 |
| 5 | 0.00835 | 1239.727 | 22.457 | 2.487 | 1.615 |
| 6 | | 1570.027 | 23.16 | 2.491 | 1.535 |
| 7 | | 1845.277 | 23.65 | 2.303 | 1.479 |
| 8 | 43520.4876 | 2120.527 | 23.923 | 2.262 | 1.584 |
| 9 | 0.001849 | 2395.777 | 24.364 | 2.27 | 1.525 |
| 10 | 124300.237 | 2671.027 | 24.318 | 2.282 | 1.5 |
| 11 | 7.905625 | 2946.277 | 24.44 | 2.254 | 1.44 |
| 12 | 0.83922 | 3221.528 | 24.788 | 2.206 | 1.487 |
| 13 | 0.686537 | 3496.778 | 24.91 | 2.078 | 1.454 |
| 14 | 45.966772 | 4047.278 | 25.081 | 2.138 | 1.417 |
| 15 | 0.486108 | 4597.778 | 25.548 | 2.074 | 1.444 |
| 16 | 32.888975 | 5148.278 | 25.729 | 2.102 | 1.4 |
| 17 | 0.067955 | 5974.029 | 26.268 | 1.967 | 1.426 |
| 18 | | 6799.779 | 26.41 | 1.96 | 1.337 |
| 19 | | 7900.78 | 26.798 | 1.83 | 1.345 |
| 20 | 0.106942 | 9001.78 | 27.354 | 2.008 | 1.328 |
| 21 | 0.005327 | 10378.031 | 27.768 | 1.859 | 1.327 |
| 22 | 0.00173 | 11754.282 | 28.268 | 1.806 | 1.281 |
| 23 | 124170 | 13405.782 | 28.064 | 1.841 | 1.228 |
| 24 | 7.35 | 15332.533 | 28.883 | 1.645 | 1.215 |
| 25 | 0.843 | 17534.534 | 28.985 | 1.665 | 1.149 |
| 26 | 0.686 | 20011.786 | 29.991 | 1.485 | 1.113 |
| 27 | 44.5 | 22764.287 | 30.495 | 1.378 | 1.032 |
| 28 | | 26067.289 | 31.182 | 1.277 | 0.943 |
| 29 | 0.1 | 30196.041 | 31.35 | 1.177 | 0.831 |
| 30 | 0.0017 | 35425.793 | 32.152 | 0.865 | 0.617 |
| 31 | | 41481.296 | 32.646 | 0.531 | 0.394 |
| 32 | 3721 | 48637.8 | 32.826 | 0.308 | 0.268 |
| 33 | | 56895.304 | 32.84 | 0.161 | 0.207 |
| 34 | | 66804.308 | 32.892 | 0.052 | 0.158 |
| 35 | | 78915.314 | 32.932 | 0 | 0.16 |
| 36 | | 93228.321 | 32.892 | 0.059 | 0.193 |
| 37 | 2 | | | | |
| 38 | 413.9762 | | | | |
| 39 | | | | | |
| 40 | | | | | |
| 41 | | | | | |
| 42 | | | | | |
| 43 | | | | | |
| 44 | | | | | |
| 45 | 214.8141 | | | | |
| 46 | 229.827127 | | | | |
| 47 | 1.228863 | | | | |
| 48 | 1.222396 | | | | |
| 49 | | | | | |
| 50 | 0.994167 | | | | |
| 51 | 31 | | | | |
| 52 | 0.002349 | | | | |
| 53 | 300 | | | | |
| 54 | 0.026352 | | | | |
| 55 | | | | | |
| 56 | | | | | |
| 57 | 1.270439 | | | | |
| 58 | 3721 | | | | |
| 59 | PARK | | | | |

| | DATA2 | yplus | uplus | uprplus | wprplus |
|---|---|---|---|---|---|
| 1 | 3722 | 166.869 | 17.687 | 3.063 | |
| 2 | PARK | 437.761 | 20.065 | 2.761 | 1.678 |
| 3 | 398.8 | 708.653 | 21.041 | 2.684 | 1.662 |
| 4 | 1513.1 | 1033.723 | 22.202 | 2.578 | 1.64 |
| 5 | 0.00835 | 1304.615 | 22.583 | 2.562 | 1.549 |
| 6 | | 1575.507 | 22.951 | 2.471 | 1.599 |
| 7 | | 1846.399 | 23.486 | 2.387 | 1.598 |
| 8 | 50155.1011 | 2117.291 | 23.587 | 2.393 | 1.547 |
| 9 | 0.001788 | 2388.183 | 23.791 | 2.399 | 1.58 |
| 10 | 144854.241 | 2659.075 | 24.246 | 2.28 | 1.544 |
| 11 | 9.257403 | 2929.966 | 24.276 | 2.376 | 1.463 |
| 12 | 0.982197 | 3471.75 | 25.042 | 2.21 | 1.531 |
| 13 | 0.799374 | 4013.534 | 25.57 | 2.184 | 1.446 |
| 14 | 45.238941 | 4555.318 | 25.47 | 2.239 | 1.42 |
| 15 | 0.536502 | 5367.993 | 26.085 | 2.099 | 1.452 |
| 16 | 33.446848 | 6180.669 | 26.259 | 2.031 | 1.412 |
| 17 | 0.073749 | 7264.236 | 26.664 | 2.002 | 1.352 |
| 18 | | 8347.804 | 27.129 | 2.013 | 1.381 |
| 19 | | 9702.263 | 27.848 | 1.965 | 1.4 |
| 20 | 0.027075 | 11056.722 | 27.5 | 1.935 | 1.332 |
| 21 | 0.005622 | 12682.074 | 28.222 | 1.841 | 1.321 |
| 22 | 0.00168 | 14578.317 | 28.0'18 | 1.718 | 1.28 |
| 23 | 144730 | 16745.451 | 29.142 | 1.7 | 1.19 |
| 24 | 8.26 | 19183.478 | 29.774 | 1.697 | 1.176 |
| 25 | 0.987 | 21892.397 | 30.045 | 1.529 | 1.117 |
| 26 | 0.798 | 25143.099 | 30.59 | 1.489 | 1.064 |
| 27 | 43.8 | 29206.477 | 31.005 | 1.415 | 0.998 |
| 28 | | 34353.423 | 32.239 | 1.093 | 0.768 |
| 29 | 0.1 | 40313.044 | 32.811 | 0.824 | 0.56 |
| 30 | 0.003 | 47356.232 | 33.29 | 0.45 | 0.323 |
| 31 | | 55482.988 | 33.43 | 0.251 | 0.202 |
| 32 | 3722 | 65235.095 | 33.457 | 0.119 | 0.142 |
| 33 | | 77154.337 | 33.467 | 0.103 | 0.109 |
| 34 | | 91240.714 | 33.433 | 0.017 | 0.108 |
| 35 | | | | | |
| 36 | | | | | |
| 37 | 2 | | | | |
| 38 | 437.761252 | | | | |
| 39 | | | | | |
| 40 | | | | | |
| 41 | | | | | |
| 42 | | | | | |
| 43 | | | | | |
| 44 | | | | | |
| 45 | 243.1464 | | | | |
| 46 | 258.970808 | | | | |
| 47 | 1.236842 | | | | |
| 48 | 1.228708 | | | | |
| 49 | | | | | |
| 50 | 0.996746 | | | | |
| 51 | 30 | | | | |
| 52 | 0.00227 | | | | |
| 53 | 300 | | | | |
| 54 | 0.030858 | | | | |
| 55 | | | | | |
| 56 | | | | | |
| 57 | 1.269715 | | | | |
| 58 | 3722 | | | | |
| 59 | PARK | | | | |

| | DATA2 | yplus | uplus | uprplus | wprplus |
|---|---|---|---|---|---|
| 1 | 3723 | 403.287 | 20.181 | 2.827 | 1.675 |
| 2 | PARK | 668.259 | 21.176 | 2.517 | 1.658 |
| 3 | 521.7 | 933.23 | 21.992 | 2.599 | 1.675 |
| 4 | 1509.2 | 1198.202 | 22.745 | 2.606 | 1.572 |
| 5 | 0.00835 | 1463.174 | 22.977 | 2.486 | 1.671 |
| 6 | | 1728.145 | 23.697 | 2.555 | 1.565 |
| 7 | | 1993.117 | 23.796 | 2.473 | 1.627 |
| 8 | 53406.2939 | 2258.089 | 23.867 | 2.309 | 1.514 |
| 9 | 0.001719 | 2523.061 | 23.68 | 2.408 | 1.528 |
| 10 | 171263.511 | 2788.032 | 24.403 | 2.387 | 1.531 |
| 11 | 10.077735 | 3053.004 | 24.352 | 2.346 | 1.511 |
| 12 | 1.165818 | 3582.947 | 24.382 | 2.289 | 1.531 |
| 13 | 0.947555 | 4112.891 | 25.041 | 2.21 | 1.504 |
| 14 | 44.250275 | 4642.834 | 25.617 | 2.227 | 1.501 |
| 15 | 0.648464 | 5437.749 | 25.808 | 2.155 | 1.426 |
| 16 | 34.106003 | 6232.664 | 26.067 | 2.231 | 1.484 |
| 17 | 0.087417 | 7292.551 | 26.702 | 2.087 | 1.48 |
| 18 | | 8352.438 | 26.998 | 2.149 | 1.392 |
| 19 | | 9677.297 | 27.759 | 2.002 | 1.402 |
| 20 | 0.175192 | 11002.155 | 27.309 | 1.941 | 1.409 |
| 21 | 0.007432 | 12591.985 | 28.455 | 1.947 | 1.286 |
| 22 | 0.00162 | 14446.787 | 28.475 | 1.869 | 1.272 |
| 23 | 170970 | 16566.561 | 29.379 | 1.784 | 1.299 |
| 24 | 10.12 | 18951.306 | 29.918 | 1.623 | 1.207 |
| 25 | 1.17 | 21601.023 | 30.119 | 1.627 | 1.183 |
| 26 | 0.946 | 24730.684 | 30.733 | 1.634 | 1.037 |
| 27 | 42.9 | 28755.259 | 31.023 | 1.443 | 1.105 |
| 28 | | 33789.722 | 32.394 | 1.218 | 0.832 |
| 29 | 0.1 | 39619.099 | 32.319 | 1.238 | 0.832 |
| 30 | 0.0026 | 46508.364 | 33.588 | 0.781 | 0.6 |
| 31 | | 54457.515 | 33.785 | 0.57 | 0.409 |
| 32 | 3723 | 63996.496 | 34.082 | 0.205 | 0.136 |
| 33 | | 75655.251 | 34.086 | 0.198 | 0.119 |
| 34 | | 89433.78 | 34.086 | 0.14 | 0.075 |
| 35 | | 105332.082 | 34.126 | 0 | 0 |
| 36 | | 123350.158 | 34.126 | 0.089 | 0.044 |
| 37 | 2 | | | | |
| 38 | 668.258642 | | | | |
| 39 | | | | | |
| 40 | | | | | |
| 41 | | | | | |
| 42 | | | | | |
| 43 | | | | | |
| 44 | | | | | |
| 45 | 276.9714 | | | | |
| 46 | 294.464668 | | | | |
| 47 | 1.236786 | | | | |
| 48 | 1.230343 | | | | |
| 49 | | | | | |
| 50 | 0.989833 | | | | |
| 51 | 30 | | | | |
| 52 | 0.002167 | | | | |
| 53 | 300 | | | | |
| 54 | 0.033592 | | | | |
| 55 | | | | | |
| 56 | | | | | |
| 57 | 1.260348 | | | | |
| 58 | 3723 | | | | |
| 59 | PARK | | | | |

| | DATA2 | yplus | uplus | uprplus | wprplus |
|---|---|---|---|---|---|
| 1 | 3724 | 125.554 | 16.979 | 3.42 | 1.597 |
| 2 | PARK | 386.04 | 19.701 | 2.701 | 1.684 |
| 3 | 598.2 | 646.525 | 20.711 | 2.614 | 1.694 |
| 4 | 1510.4 | 907.011 | 21.815 | 2.611 | 1.653 |
| 5 | 0.00835 | 1167.496 | 22.402 | 2.59 | 1.701 |
| 6 | | 1427.982 | 22.51 | 2.472 | 1.628 |
| 7 | | 1688.467 | 23.357 | 2.667 | 1.677 |
| 8 | 59235.908 | 1948.953 | 23.319 | 2.489 | 1.566 |
| 9 | 0.001659 | 2209.439 | 23.857 | 2.403 | 1.677 |
| 10 | 192083.618 | 2469.924 | 23.871 | 2.489 | 1.66 |
| 11 | 11.370286 | 2730.41 | 24.207 | 2.413 | 1.555 |
| 12 | 1.319261 | 3251.381 | 25.159 | 2.5 | 1.583 |
| 13 | 1.061903 | 3772.352 | 25.155 | 2.267 | 1.503 |
| 14 | 43.501089 | 4293.323 | 25.499 | 2.375 | 1.569 |
| 15 | 0.730419 | 5074.78 | 26.228 | 2.385 | 1.514 |
| 16 | 34.12097 | 5856.236 | 26.197 | 2.264 | 1.542 |
| 17 | 0.096721 | 6898.179 | 26.253 | 2.101 | 1.472 |
| 18 | | 7940.121 | 27.242 | 2.097 | 1.437 |
| 19 | | 9242.549 | 26.801 | 2.087 | 1.427 |
| 20 | 0.068584 | 10544.977 | 27.523 | 2.163 | 1.413 |
| 21 | 0.006375 | 12107.89 | 28.193 | 1.948 | 1.392 |
| 22 | 0.00155 | 13931.289 | 28.405 | 1.934 | 1.333 |
| 23 | 191890 | 16015.173 | 29.273 | 7.882 | 1.344 |
| 24 | 10.69 | 18359.543 | 29.2 | 1.858 | 1.354 |
| 25 | 1.323 | 20964.399 | 29.638 | 1.767 | 1.306 |
| 26 | 1.061 | 24090.226 | 30.728 | 1.615 | 1.128 |
| 27 | 42.1 | 27997.509 | 31.169 | 1.621 | 1.24 |
| 28 | | 32946.735 | 31.707 | 1.538 | 1.007 |
| 29 | 0.1 | 38677.417 | 33.138 | 1.285 | 0.941 |
| 30 | 0.0027 | 45450.042 | 33.554 | 1.09 | 0.774 |
| 31 | | 53264.609 | 34.457 | 0.608 | 0.521 |
| 32 | 3724 | 62642.089 | 34.551 | 0.403 | 0.233 |
| 33 | | 74103.454 | 34.742 | 0.142 | 0.059 |
| 34 | | 87648.703 | 34.728 | 0.045 | 0.003 |
| 35 | | 103277.837 | 34.721 | 0.094 | 0.094 |
| 36 | | 120990.856 | 34.69 | 0.017 | 0.042 |
| 37 | 2 | | | | |
| 38 | 386.039605 | | | | |
| 39 | | | | | |
| 40 | | | | | |
| 41 | | | | | |
| 42 | | | | | |
| 43 | | | | | |
| 44 | | | | | |
| 45 | 297.4295 | | | | |
| 46 | 318.666661 | | | | |
| 47 | 1.246937 | | | | |
| 48 | 1.242356 | | | | |
| 49 | | | | | |
| 50 | 0.994119 | | | | |
| 51 | 31 | | | | |
| 52 | 0.002113 | | | | |
| 53 | 300 | | | | |
| 54 | 0.037901 | | | | |
| 55 | | | | | |
| 56 | | | | | |
| 57 | 1.273659 | | | | |
| 58 | 3724 | | | | |
| 59 | PARK | | | | |

| | DATA2 | yplus | uplus | uprplus | wprplus |
|---|---|---|---|---|---|
| 1 | 3725 | 203.425 | 18.29 | 3.342 | |
| 2 | PARK | 411.001 | 19.536 | 2.809 | 1.791 |
| 3 | 721 | 670.471 | 20.722 | 2.823 | 1.724 |
| 4 | 1516.5 | 929.941 | 21.594 | 2.73 | 1.696 |
| 5 | 0.00835 | 1189.411 | 22.3 | 2.684 | 1.651 |
| 6 | | 1448.882 | 22.962 | 2.572 | 1.666 |
| 7 | | 1708.352 | 23.116 | 2.67 | 1.685 |
| 8 | 65900.7127 | 1967.822 | 23.424 | 2.565 | 1.618 |
| 9 | 0.001633 | 2227.292 | 23.889 | 2.622 | 1.631 |
| 10 | 214516.186 | 2486.763 | 24.05 | 2.584 | 1.626 |
| 11 | 12.69909 | 2746.233 | 24.239 | 2.487 | 1.648 |
| 12 | 1.463736 | 3005.703 | 24.306 | 2.466 | 1.625 |
| 1.3 | 1.181147 | 3265.173 | 24.516 | 2.354 | 1.585 |
| 14 | 43.331526 | 3524.643 | 24.785 | 2.467 | 1.589 |
| 15 | 0.737279 | 3784.114 | 25.226 | 2.463 | 1.645 |
| 16 | 34.997614 | 4043.584 | 25.356 | 2.412 | 1.631 |
| 17 | 0.096858 | 4303.054 | 25.524 | 2.526 | 1.639 |
| 18 | | 4562.524 | 25.538 | 2.287 | 1.523 |
| 19 | | 5081.465 | 25.853 | 2.49 | 1.597 |
| 20 | 0.042567 | 5600.405 | 26.126 | 2.386 | 1.594 |
| 21 | 0.00454 | 6119.346 | 26.252 | 2.316 | 1.584 |
| 22 | 0.00152 | 6897.756 | 26.843 | 2.22 | 1.552 |
| 23 | 212600 | 7676.167 | 26.525 | 2.251 | 1.53 |
| 24 | 11.67 | 8714.048 | 27.207 | 2.137 | 1.482 |
| 25 | 1.455 | 9751.929 | 27.323 | 2.3 | 1.524 |
| 26 | 1.17 | 11049.28 | 27.701 | 2.091 | 1.493 |
| 27 | 41.78 | 12346.631 | 28.026 | 1.977 | 1.429 |
| 28 | | 13903.452 | 28.464 | 1.941 | 1.402 |
| 29 | 0.1 | 15719.743 | 29.122 | 1.951 | 1.38 |
| 30 | 0.0024 | 17795.505 | 29.482 | 1.814 | 1.359 |
| 31 | | 20130.737 | 29.727 | 1.925 | 1.32 |
| 32 | 3725 | 22725.439 | 30.115 | 1.747 | 1.32 |
| 33 | | 25839.082 | 30.5 | 1.72 | 1.311 |
| 34 | | 29731.135 | 31.26 | 1.628 | 1.174 |
| 35 | | 34661.069 | 31.925 | 1.528 | 1.114 |
| 36 | | 40369.414 | 32.849 | 1.406 | 1.023 |
| 37 | 2 | 47115.639 | 33.339 | 1.31 | 0.974 |
| 38 | 411.000818 | 54899.746 | 34.291 | 0.905 | 0.649 |
| 39 | | 64240.673 | 34.879 | 0.44 | 0.339 |
| 40 | | 75657.363 | 35.064 | 0.237 | 0.19 |
| 41 | | 89149.814 | 35.019 | 0.198 | 0.172 |
| 42 | | 104718.027 | 35.043 | 0.154 | 0.152 |
| 43 | | 121324.12 | 35.019 | 0.141 | 0.132 |
| 44 | | 138968.095 | 34.966 | 0.083 | 0.187 |
| 45 | 323.152 | 152460.546 | 34.963 | 0.022 | 0.213 |
| 46 | 350.278268 | | | | |
| 47 | 1.24359 | | | | |
| 48 | 1.239249 | | | | |
| 49 | | | | | |
| 50 | 0.997371 | | | | |
| 51 | 39 | | | | |
| 52 | 0.002041 | | | | |
| 53 | 300 | | | | |
| 54 | 0.04233 | | | | |
| 55 | | | | | |
| 56 | | | | | |
| 57 | 1.249942 | | | | |
| 58 | 3725 | | | | |
| 59 | PARK | | | | |

| | DATA2 | yplus | uplus | uprplus | wprplus |
|---|---|---|---|---|---|
| 1 | 3726 | 160.624 | 17.343 | 3.055 | |
| 2 | PARK | 419.696 | 19.625 | 2.726 | 1.704 |
| 3 | 797.6 | 678.768 | 20.924 | 2.812 | 1.716 |
| 4 | 1518.9 | 937.839 | 21.801 | 2.654 | 1.743 |
| 5 | 0.00835 | 1248.725 | 22.363 | 2.737 | 1.731 |
| 6 | | 1507.797 | 22.855 | 2.512 | 1.703 |
| 7 | | 1766.868 | 23.522 | 2.556 | 1.644 |
| 8 | 73315.0235 | 2025.94 | 23.767 | 2.583 | 1.671 |
| 9 | 0.001623 | 2285.011 | 23.873 | 2.553 | 1.678 |
| 10 | 235508.236 | 2544.083 | 23.978 | 2.46 | 1.599 |
| 11 | 14.149568 | 2803.155 | 24.294 | 2.454 | 1.627 |
| 12 | 1.597192 | 3062.226 | 24.364 | 2.56 | 1.664 |
| 13 | 1.294683 | 3580.369 | 24.856 | 2.425 | 1.656 |
| 14 | 43.264956 | 4098.513 | 25.277 | 2.342 | 1.702 |
| 15 | 0.707748 | 4616.656 | 25.453 | 2.294 | 1.509 |
| 16 | 35.106935 | 5393.871 | 25.804 | 2.38 | 1.601 |
| 17 | 0.092689 | 6171.085 | 26.049 | 2.315 | 1.579 |
| 18 | | 7207.372 | 26.541 | 2.217 | 1.549 |
| 19 | | 8243.658 | 27.067 | 2.252 | 1.532 |
| 20 | 0.027855 | 9539.016 | 27.419 | 2.204 | 1.461 |
| 21 | 0.004283 | 10834.374 | 27.664 | 2.059 | 1.374 |
| 22 | 0.0015 | 12388.803 | 28.015 | 2.186 | 1.476 |
| 23 | 234840 | 14202.305 | 28.577 | 2.026 | 1.44 |
| 24 | 12.86 | 16274.877 | 28.928 | 1.937 | 1.388 |
| 25 | 1.596 | 18606.522 | 29.033 | 1.952 | 1.368 |
| 26 | 1.291 | 21197.238 | 29.911 | 1.959 | 1.345 |
| 27 | 41.66 | 24306.097 | 30.438 | 1.863 | 1.304 |
| 28 | | 28192.171 | 30.964 | 1.689 | 1.273 |
| 29 | 0.1 | 33114.531 | 31.421 | 1.634 | 1.25 |
| 30 | 0.003 | 38814.106 | 32.158 | 1.586 | 1.148 |
| 31 | | 45549.967 | 32.86 | 1.364 | 0.922 |
| 32 | 3726 | 53322.115 | 33.527 | 1.191 | 0.895 |
| 33 | | 62648.692 | 34.58 | 0.751 | 0.584 |
| 34 | | 74047.842 | 35.072 | 0.28 | 0.272 |
| 35 | | 87519.565 | 35.072 | 0.161 | 0.222 |
| 36 | | 103063.86 | 35.072 | 0.017 | 0.153 |
| 37 | 2 | 119644.442 | 35.142 | 0.105 | 0.149 |
| 38 | 419.695977 | 137261.31 | 35.107 | 0.079 | 0.212 |
| 39 | | 150733.033 | 35.107 | 0.118 | 0.173 |
| 40 | | | | | |
| 41 | | | | | |
| 42 | | | | | |
| 43 | | | | | |
| 44 | | | | | |
| 45 | 352.26 | | | | |
| 46 | 382.164426 | | | | |
| 47 | 1.236251 | | | | |
| 48 | 1.233655 | | | | |
| 49 | | | | | |
| 50 | 0.9981 | | | | |
| 51 | 33 | | | | |
| 52 | 0.002001 | | | | |
| 53 | 300 | | | | |
| 54 | 0.047165 | | | | |
| 55 | | | | | |
| 56 | | | | | |
| 57 | 1.233113 | | | | |
| 58 | 3726 | | | | |
| 59 | PARK | | | | |

| | DATA2 | yplus | uplus | uprplus | wprplus |
|---|---|---|---|---|---|
| 1 | 3727 | 188.449 | 17.852 | 2.918 | |
| 2 | PARK | 446.598 | 19.844 | 2.735 | 1.759 |
| 3 | 920.4 | 704.747 | 20.868 | 2.663 | 1.772 |
| 4 | 1522.5 | 962.896 | 21.677 | 2.843 | 1.72 |
| 5 | 0.00835 | 1221.045 | 22.193 | 2.729 | 1.697 |
| 6 | | 1479.195 | 22.613 | 2.651 | 1.632 |
| 7 | | 1788.974 | 23.224 | 2.612 | 1.676 |
| 8 | 77403.8156 | 2047.123 | 23.81 | 2.432 | 1.69 |
| 9 | 0.001604 | 2305.272 | 24.477 | 2.577 | 1.629 |
| 10 | 252667.334 | 2563.421 | 24.396 | 2.546 | 1.682 |
| 11 | 14.992073 | 2821.57 | 24.347 | 2.632 | 1.656 |
| 12 | 1.710185 | 3079.719 | 24.569 | 2.583 | 1.572 |
| 13 | 1.385729 | 3337.868 | 24.693 | 2.537 | 1.632 |
| 14 | 43.110908 | 3596.018 | 25.131 | 2.454 | 1.595 |
| 15 | 0.72606 | 4112.316 | 24.947 | 2.543 | 1.583 |
| 16 | 35.315888 | 4628.614 | 25.173 | 2.38 | 1.562 |
| 17 | 0.094524 | 5144.913 | 25.894 | 2.358 | 1.577 |
| 18 | | 5919.36 | 25.77 | 2.268 | 1.55 |
| 19 | | 6693.807 | 26.543 | 2.225 | 1.537 |
| 20 | 0.094265 | 7726.404 | 26.413 | 2.272 | 1.53 |
| 21 | 0.006833 | 8759.001 | 27.197 | 2.169 | 1.425 |
| 22 | 0.00149 | 10049.746 | 27.536 | 2.084 | 1.521 |
| 23 | 252590 | 11340.492 | 28.553 | 2.114 | 1.514 |
| 24 | 13.87 | 12889.387 | 28.168 | 2.147 | 1.441 |
| 25 | 1.711 | 14696.431 | 28.609 | 1.991 | 1.417 |
| 26 | 1.385 | 16761.624 | 28.747 | 1.896 | 1.387 |
| 27 | 41.52 | 19084.967 | 28.963 | 1.979 | 1.368 |
| 28 | | 21666.458 | 29.81 | 1.917 | 1.275 |
| 29 | 0.1 | 24764.248 | 30.195 | 1.801 | 1.311 |
| 30 | 0.0021 | 28636.485 | 30.965 | 1.681 | 1.251 |
| 31 | | 33541.319 | 31.488 | 1.629 | 1.253 |
| 32 | 3727 | 39220.6 | 32.134 | 1.647 | 1.082 |
| 33 | | 45932.478 | 32.646 | 1.443 | 1.038 |
| 34 | | 53676.952 | 33.684 | 1.213 | 0.925 |
| 35 | | 62970.322 | 34.5 | 0.967 | 0.684 |
| 36 | | 74328.884 | 35.108 | 0.481 | 0.382 |
| 37 | 2 | 87752.64 | 35.242 | 0.266 | 0.26 |
| 38 | 446.598026 | 103241.589 | 35.302 | 0.084 | 0.153 |
| 39 | | 119763.134 | 35.323 | 0.007 | 0.07 |
| 40 | | 137317.276 | 35.309 | 0.066 | 0.1 |
| 41 | | 150741.032 | 35.33 | 0.031 | 0.156 |
| 42 | | | | | |
| 43 | | | | | |
| 44 | | | | | |
| 45 | 376.3591 | | | | |
| 46 | 405.17144 | | | | |
| 47 | 1.235379 | | | | |
| 48 | 1.234141 | | | | |
| 49 | | | | | |
| 50 | 0.99497 | | | | |
| 51 | 36 | | | | |
| 52 | 0.001946 | | | | |
| 53 | 300 | | | | |
| 54 | 0.049974 | | | | |
| 55 | | | | | |
| 56 | | | | | |
| 57 | 1.213537 | | | | |
| 58 | 3727 | | | | |
| 59 | PARK | | | | |

| | DATA2 | yplus | uplus | uprplus | wprplus |
|---|---|---|---|---|---|
| 1 | 3728 | 160.39 | 17.073 | 3.196 | |
| 2 | PARK | 367.345 | 19.294 | 2.827 | 1.704 |
| 3 | 997 | 626.039 | 21.029 | 2.656 | 1.796 |
| 4 | 1523.3 | 884.733 | 21.674 | 2.641 | 1.698 |
| 5 | 0.00835 | 1143.426 | 22.246 | 2.631 | 1.654 |
| 6 | 1402.12 | 22.866 | 2.679 | 1.701 | |
| 7 | 1660.814 | 22.99 | 2.65 | 1.66 | |
| 8 | 77985.7387 | 1919.508 | 23.402 | 2.63 | 1.702 |
| 9 | 0.001609 | 2178.202 | 23.476 | 2.544 | 1.679 |
| 10 | 253358.928 | 2436.895 | 23.896 | 2.582 | 1.654 |
| 11 | 15.072984 | 2695.589 | 24.326 | 2.43 | 1.597 |
| 12 | 1.71208 | 3212.977 | 24.908 | 2.4 | 1.593 |
| 13 | 1.388792 | 3730.364 | 24.982 | 2.439 | 1.533 |
| 14 | 43.201859 | 4247.752 | 25.599 | 2.317 | 1.602 |
| 15 | 0.710172 | 5023.833 | 25.944 | 2.383 | 1.485 |
| 16 | 35.260056 | 5799.914 | 26.336 | 2.299 | 1.574 |
| 17 | 0.092602 | 6834.689 | 26.159 | 2.218 | 1.544 |
| 18 | | 7869.464 | 26.568 | 2.236 | 1.466 |
| 19 | | 9162.933 | 27.193 | 2.227 | 1.494 |
| 20 | 0.098857 | 10456.402 | 27.401 | 2.048 | 1.471 |
| 21 | 0.004834 | 12008.565 | 28.092 | 2.097 | 1.421 |
| 22 | 0.0015 | 13819.421 | 28.451 | 1.97 | 1.414 |
| 23 | 253010 | 15888.971 | 28.705 | 1.951 | 1.42 |
| 24 | 14.47 | 18217.215 | 29.051 | 1.986 | 1.349 |
| 25 | 1.712 | 20804.153 | 29.858 | 1.876 | 1.338 |
| 26 | 1.387 | 23908.478 | 30.003 | 1.841 | 1.328 |
| 27 | 41.7 | 27788.885 | 30.327 | 1.788 | 1.329 |
| 28 | | 32704.066 | 31.113 | 1.615 | 1.277 |
| 29 | 0.1 | 38395.329 | 31.759 | 1.677 | 1,214 |
| 30 | 0.0019 | 45121.367 | 32.774 | 1.518 | 1.043 |
| 31 | | 52882.18 | 33.705 | 1.297 | 0.935 |
| 32 | 3728 | 62195.156 | 34.484 | 0.965 | 0.687 |
| 33 | | 73577.682 | 34.883 | 0.655 | 0.471 |
| 34 | | 87029.758 | 35.147 | 0.375 | 0.377 |
| 35 | | 102551.384 | 35.278 | 0.128 | 0.163 |
| 36 | | 119107.785 | 35.253 | 0.068 | 0.132 |
| 37 | 2 | 136698.961 | 35.274 | 0.051 | 0.162 |
| 38 | 367.345151 | 150151.037 | 35.235 | 0.016 | 0.15 |
| 39 | | | | | |
| 40 | | | | | |
| 41 | | | | | |
| 42 | | | | | |
| 43 | | | | | |
| 44 | | | | | |
| 45 | 379.515 | | | | |
| 46 | 407.568116 | | | | |
| 47 | 1.234319 | | | | |
| 48 | 1.232783 | | | | |
| 49 | | | | | |
| 50 | 0.991758 | | | | |
| 51 | 33 | | | | |
| 52 | 0.001915 | | | | |
| 53 | 300 | | | | |
| 54 | 0.050243 | | | | |
| 55 | | | | | |
| 56 | | | | | |
| 57 | 1.190433 | | | | |
| 58 | 3728 | | | | |
| 59 | PARK | | | | |

| | DATA2 | yplus | uplus | uprplus | wprplus |
|---|---|---|---|---|---|
| 1 | 3729 | 243.95 | 18.508 | 3.06 | 1.832 |
| 2 | PARK | 553.4 | 20.408 | 2.787 | 1.754 |
| 3 | 1119.8 | 862.85 | 21.487 | 2.819 | 1.743 |
| 4 | 1529 | 1172.3 | 22.346 | 2.734 | 1.726 |
| 5 | 0.00835 | 1430.176 | 22.744 | 2.642 | 1.679 |
| 6 | | 1688.051 | 22.915 | 2.592 | 1.619 |
| 7 | | 1945.926 | 23.511 | 2.695 | 1.676 |
| 8 | 88536.6055 | 2203.801 | 24.015 | 2.599 | 1.647 |
| 9 | 0.001587 | 2461.676 | 23.877 | 2.524 | 1.58 |
| 10 | 288370.293 | 2719.551 | 24.253 | 2.624 | 1.633 |
| 11 | 17.166564 | 2977.426 | 24.118 | 2.549 | 1.637 |
| 12 | 1.931972 | 3235.302 | 24.548 | 2.592 | 1.64 |
| 13 | 1.574815 | 3751.052 | 24.942 | 2.478 | 1.619 |
| 14 | 43.065149 | 4266.802 | 25.435 | 2.5 | 1.619 |
| 15 | 0.69986 | 4782.552 | 25.684 | 2.563 | 1.615 |
| 16 | 35.504347 | 5556.178 | 26.099 | 2.475 | 1.566 |
| 17 | 0.09063 | 6329.803 | 26.437 | 2.382 | 1.534 |
| 18 | | 7361.304 | 26.504 | 2.29 | 1.52 |
| 19 | | 8392.804 | 27.093 | 2.308 | 1.502 |
| 20 | 0.137869 | 9682.18 | 27.115 | 2.105 | 1.512 |
| 21 | 0.005043 | 10971.556 | 27.86 | 2.215 | 1.47 |
| 22 | 0.00147 | 12518.807 | 28.027 | 2.077 | 1.505 |
| 23 | 287660 | 14323.933 | 28.006 | 2.027 | 1.413 |
| 24 | 16.31 | 16386.934 | 28.702 | 2.123 | 1.392 |
| 25 | 1.933 | 18707.81 | 29.302 | 2.006 | 1.41 |
| 26 | 1.571 | 21286.562 | 29.497 | 1.896 | 1.36 |
| 27 | 41.5 | 24381.063 | 30.164 | 1.793 | 1.349 |
| 28 | | 28249.191 | 30.725 | 1.754 | 1.346 |
| 29 | Q.100000 | 33148.818 | 31.034 | 1.779 | 1.271 |
| 30 | 0.0025 | 38822.072 | 31.965 | 1.552 | 1.211 |
| 31 | | 45526.825 | 32.085 | 1.644 | 1.193 |
| 32 | 3729 | 53263.08 | 33.218 | 1.385 | 1.058 |
| 33 | | 62546.585 | 33.789 | 1.253 | 0.895 |
| 34 | | 73893.091 | 34.677 | 0.966 | 0.689 |
| 35 | | 87302.599 | 35.295 | 0.476 | 0.387 |
| 36 | | 102775.108 | 35.515 | 0.256 | 0.131 |
| 37 | 2 | 119279.117 | 35.483 | 0.107 | 0.011 |
| 38 | 553.400062 | 136814.627 | 35.554 | 0.028 | 0.117 |
| 39 | | 150224.134 | 35.465 | 0.025 | 0.039 |
| 40 | | | | | |
| 41 | | | | | |
| 42 | | | | | |
| 43 | | | | | |
| 44 | | | | | |
| 45 | 422.8602 | | | | |
| 46 | 457.527767 | | | | |
| 47 | 1.230426 | | | | |
| 48 | 1.226793 | | | | |
| 49 | | | | | |
| 50 | 0.994594 | | | | |
| 51 | 35 | | | | |
| 52 | 0.001871 | | | | |
| 53 | 300 | | | | |
| 54 | 0.057222 | | | | |
| 55 | | | | | |
| 56 | | | | | |
| 57 | 1.179253 | | | | |
| 58 | 3729 | | | | |
| 59 | PARK | | | | |

| | DATA2 | yplus | uplus | uprplus | wprplus |
|---|---|---|---|---|---|
| 1 | 3730 | 373.632 | 19.694 | 2.827 | 1.694 |
| 2 | PARK | 631.665 | 20.852 | 2.709 | 1.761 |
| 3 | 1196.3 | 889.699 | 21.583 | 2.784 | 1.673 |
| 4 | 1530.2 | 1147.732 | 22.091 | 2.738 | 1.729 |
| 5 | 0.00835 | 1405.765 | 22.673 | 2.628 | 1.637 |
| 6 | | 1663.798 | 23.306 | 2.699 | 1.705 |
| 7 | | 1921.832 | 23.38 | 2.642 | 1.594 |
| 8 | 90219.6696 | 2179.865 | 23.714 | 2.567 | 1.63 |
| 9 | 0.001586 | 2437.898 | 23.987 | 2.472 | 1.52 |
| 10 | 293349.747 | 2695.931 | 24.119 | 2.518 | 1.602 |
| 11 | 17.482179 | 3211.998 | 24.84 | 2.567 | 1.57 |
| 12 | 1.961583 | 3728.064 | 25.283 | 2.532 | 1.701 |
| 13 | 1.600752 | 4244.131 | 25.06 | 2.507 | 1.591 |
| 14 | 43.091554 | 5018.231 | 25.177 | 2.429 | 1.53 |
| 15 | 0.691769 | 5792.331 | 26.384 | 2.468 | 1.548 |
| 16 | 35.510439 | 6824.464 | 26.406 | 2.39 | 1.474 |
| 17 | 0.089567 | 7856.597 | 26.491 | 2.305 | 1.527 |
| 18 | | 9146.763 | 27.418 | 2.173 | 1.481 |
| 19 | | 10436.929 | 27.126 | 2.195 | 1.534 |
| 20 | 0.139648 | 11985.129 | 27.908 | 2.102 | 1.459 |
| 21 | 0.006002 | 13791.362 | 28.419 | 2.219 | 1.424 |
| 22 | 0.00148 | 15855.628 | 28.707 | 2.028 | 1.367 |
| 23 | 292010 | 18177.927 | 28.788 | 2.07 | 1.428 |
| 24 | 16.64 | 20758.259 | 29.58 | 1.886 | 1.378 |
| 25 | 1.957 | 23854.659 | 30.07 | 1.807 | 1.289 |
| 26 | 1.593 | 27725.157 | 30.567 | 1.797 | 1.3 |
| 27 | 41.6 | 32627.789 | 31.068 | 1.758 | 1.268 |
| 28 | | 38304.521 | 31.839 | 1.602 | 1.186 |
| 29 | 0.1 | 45013.386 | 32.13 | 1.587 | 1.172 |
| 30 | 0.0021 | 52754.383 | 33 | 1.374 | 1.048 |
| 31 | | 62043.58 | 33.469 | 1.399 | 0.909 |
| 32 | 3730 | 73397.044 | 34.786 | 0.913 | 0.653 |
| 33 | | 86814.773 | 35.184 | 0.575 | 0.398 |
| 34 | | 102296.769 | 35.407 | 0.334 | 0.238 |
| 35 | | 118810.897 | 35.539 | 0.075 | 0.05 |
| 36 | | 136357.158 | 35.546 | 0.057 | 0 |
| 37 | 2 | 149774.888 | 35.546 | 0.004 | 0.05 |
| 38 | 631.665412 | | | | |
| 39 | | | | | |
| 40 | | | | | |
| 41 | | | | | |
| 42 | | | | | |
| 43 | | | | | |
| 44 | | | | | |
| 45 | 432.1748 | | | | |
| 46 | 465.268476 | | | | |
| 47 | 1.2285 | | | | |
| 48 | 1.225414 | | | | |
| 49 | | | | | |
| 50 | 0.992186 | | | | |
| 51 | 33 | | | | |
| 52 | 0.001845 | | | | |
| 53 | 300 | | | | |
| 54 | 0.058274 | | | | |
| 55 | | | | | |
| 56 | | | | | |
| 57 | 1.163264 | | | | |
| 58 | 3730 | | | | |
| 59 | PARK | | | | |

# APPENDIX E: CALIBRATION DATA FOR LASER DOPPLER ANEMOMETER (LDA)

THIS PAGE INTENTIONALLY LEFT BLANK

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| **Project:** | Hydrodynamic Performance of LCC | | | | | | **Date:** | 05/15/2001 | |
| **Project Manager:** | Joel T. Park, Ph. D. | | | | | | **Barcode:** | | |
| **Transducer:** | Dantec BSA U1 (Axial Velocity) | | | Serial # | | | Range (m/s) = 19 | | |
| **Signal Conditioner:** | | | | | | | | | |
| | SR (Hz) | | Time (s) | | Samples | 0 | | | |
| | **DAQ A/D:** | | | | | | | **HDR#** | |

**Input and output values**

| xref (rps) | x f(xref) (m/s) | y Output (m/s) | Std Dev (m/s) | Std Resid | xref2 (units) |
|---|---|---|---|---|---|
| 1 | 0.6283 | 0.62834 | | 1.305 | |
| 2 | 1.2566 | 1.2696 | | -0.325 | |
| 3 | 1.8850 | 1.9070 | | -1.420 | |
| 4 | 2.5133 | 2.5187 | | 1.113 | |
| 5 | 3.1416 | 3.1497 | | 0.929 | |
| 6 | 3.7699 | 3.7800 | | 0.833 | |
| 7 | 4.3982 | 4.4082 | | 1.039 | |
| 4 | 2.5133 | 2.5245 | | 0.289 | |
| 5 | 3.1416 | 3.1574 | | -0.164 | |
| 6 | 3.7699 | 3.7796 | | 0.888 | |
| 7 | 4.3982 | 4.4134 | | 0.306 | |
| 8 | 5.0265 | 5.0447 | | 0.081 | |
| 9 | 5.6549 | 5.6746 | | 0.042 | |
| 10 | 6.2832 | 6.3066 | | -0.284 | |
| 11 | 6.9115 | 6.9390 | | -0.674 | |
| 12 | 7.5398 | 7.5646 | | -0.092 | |
| 13 | 8.1681 | 8.1953 | | -0.237 | |
| 14 | 8.7965 | 8.8279 | | -0.650 | |
| 15 | 9.4248 | 9.4588 | | -0.828 | |
| 16 | 10.0531 | 10.0973 | | -2.067 | |
| 17 | 10.6814 | 10.7231 | | -1.529 | |
| 18 | 11.3097 | 11.3373 | | 0.653 | |
| 19 | 11.9381 | 11.9837 | | -1.703 | |
| 20 | 12.5664 | 12.6100 | | -1.223 | |
| 20 | 12.5664 | 12.6102 | | -1.251 | |
| 21 | 13.1947 | 13.2267 | | 0.605 | |
| 22 | 13.8230 | 13.8571 | | 0.499 | |
| 23 | 14.4513 | 14.4999 | | -1.360 | |
| 24 | 15.0796 | 15.1241 | | -0.586 | |
| 25 | 15.7080 | 15.7462 | | 0.492 | |
| 26 | 16.3363 | 16.3699 | | 1.329 | |
| 27 | 16.9646 | 16.9997 | | 1.308 | |
| 28 | 17.5929 | 17.6356 | | 0.436 | |
| 29 | 18.2212 | 18.25738 | | 1.545 | |
| 30 | 18.8496 | 18.89303 | | 0.700 | |

Outlier Data

**Reference Standards**

| Instrument | Barcode | Cal Date | Cal Due |
|---|---|---|---|
| CompuMotor SM233BE-NT( | | | |
| CompuMotor TQ10X Servo- | | | |
| | | | |
| | | | |
| | | | |
| | | | |

**Sensor Excitation:**

**(+) EXC:** VDC

**(-) EXC:** VDC

$x = 2*\pi*r*xref$

Ship Model Sign Convention:

**SENSOR SIGN CONVENTION:**

**CURVE FIT:**

| y = a + b x | | x = (1/b) y - a/b | | |
|---|---|---|---|---|
| **b =** | 1.0021 | **1/b =** | 0.99786 | m/s/V |
| **a =** | 0.0079 | **-a/b =** | -0.00789 | m/s |
| **r =** | 0.9999991 | **Std Err=** | 0.00706 | m/s |

**Diagram of Alignment Setup:**

r = 0.1 m

**Calibration Conducted by:** Joel T. Park

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| **Project:** | Hydrodynamic Performance of LCC | | | | | | **Date:** | 05/14/2001 | |
| **Project Manager:** | Joel T. Park, Ph. D. | | | | | | **Barcode:** | | |
| **Transducer:** | Dantec BSA U2 (Transverse Velocity) | | | Serial # | | | Range (m/s) = 7 | | |
| **Signal Conditioner:** | | | | | | | | | |
| | SR (Hz) | | Time (s) | | Samples | 0 | | | |
| | **DAQ A/D:** | | | | | | **HDR#** | | |

**Input and output values**

| xref (rps) | x f(xref) (m/s) | y Output (m/s) | Std Dev (m/s) | Std Resid | xref2 (units) |
|---|---|---|---|---|---|
| 10 | 6.2832 | 6.36432 | | -0.063 | |
| 9 | 5.6549 | 5.7313 | | -0.792 | |
| 8 | 5.0265 | 5.0904 | | 0.151 | |
| 7 | 4.3982 | 4.4558 | | -0.264 | |
| 6 | 3.7699 | 3.8183 | | -0.035 | |
| 5 | 3.1416 | 3.1822 | | -0.123 | |
| 4 | 2.5133 | 2.5499 | | -1.013 | |
| 3 | 1.8850 | 1.8988 | | 2.098 | |
| 2 | 1.2566 | 1.2755 | | -0.713 | |
| -2 | -1.2566 | -1.2715 | | -0.480 | |
| -3 | -1.8850 | -1.9231 | | 2.732 | Outlier |
| -4 | -2.5133 | -2.5492 | | 0.522 | |
| -5 | -3.1416 | -3.1836 | | 0.066 | |
| -6 | -3.7699 | -3.8181 | | -0.355 | |
| -7 | -4.3982 | -4.4548 | | -0.294 | |
| -8 | -5.0265 | -5.0926 | | -0.028 | |
| -9 | -5.6549 | -5.7272 | | -0.433 | |
| -10 | -6.2832 | -6.3611 | | -0.976 | |
| Outlier Data | | | | | |

**Reference Standards**

| Instrument | Barcode | Cal Date | Cal Due |
|---|---|---|---|
| CompuMotor SM233BE-NTC | | | |
| CompuMotor TQ10X Servo- | | | |
| | | | |
| | | | |
| | | | |
| | | | |

**Sensor Excitation:**

| | | |
|---|---|---|
| **(+) EXC:** | | VDC |
| **(-) EXC:** | | VDC |

x = 2*π*r*xref

Ship Model Sign Convention:

**SENSOR SIGN CONVENTION:**

**CURVE FIT:**

| **y = a + b x** | | **x = (1/b) y - a/b** | | |
|---|---|---|---|---|
| **b =** | 1.0130 | **1/b =** | 0.98717 | m/s/V |
| **a =** | -0.0008 | **-a/b =** | 0.00081 | m/s |
| **r =** | 0.9999994 | **Std Err=** | 0.00462 | m/s |

**Diagram of Alignment Setup:**

r = 0.1 m

**Calibration Conducted by:** Joel T. Park

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| **Project:** | Hydrodynamic Performance of LCC | | | | | | **Date:** | 05/07/2001 | | |
| **Project Manager:** | Joel T. Park, Ph. D. | | | | | | **Barcode:** | | | |
| **Transducer:** | Dantec BSA U3 (Tunnel Speed) | | | Serial # | | | Range (m/s) = 19 | | | |
| **Signal Conditioner:** | | | | | | | | | | |
| | SR (Hz) | | Time (s) | | Samples | 0 | | | | |
| | **DAQ A/D:** | | | | | | | **HDR#** | | |

**Input and output values**

| xref (rps) | x f(xref) (m/s) | y Output (m/s) | Std Dev (m/s) | Std Resid | xref2 (units) |
|---|---|---|---|---|---|
| 2 | 1.2566 | 1.2727 | | -2.975 | |
| 3 | 1.8850 | 1.9014 | | -2.497 | |
| 4 | 2.5133 | 2.5246 | | -0.844 | |
| 5 | 3.1416 | 3.1520 | | -0.089 | |
| 6 | 3.7699 | 3.7801 | | 0.525 | |
| 7 | 4.3982 | 4.4111 | | 0.509 | |
| 8 | 5.0265 | 5.0408 | | 0.767 | |
| 9 | 5.6549 | 5.6720 | | 0.706 | |
| 10 | 6.2832 | 6.3043 | | 0.413 | |
| 11 | 6.9115 | 6.9324 | | 1.009 | |
| 12 | 7.5398 | 7.5648 | | 0.687 | |
| 13 | 8.1681 | 8.1961 | | 0.613 | |
| 14 | 8.7965 | 8.8254 | | 0.955 | |
| 15 | 9.4248 | 9.4596 | | 0.257 | |
| 16 | 10.0531 | 10.0905 | | 0.259 | |
| 17 | 10.6814 | 10.7179 | | 1.014 | |
| 18 | 11.3097 | 11.3486 | | 1.054 | |
| 19 | 11.9381 | 11.9811 | | 0.726 | |
| 20 | 12.5664 | 12.6171 | | -0.368 | |
| 16 | 10.0531 | 10.0876 | | 0.885 | |
| 17 | 10.6814 | 10.7173 | | 1.143 | |
| 18 | 11.3097 | 11.3533 | | 0.040 | |
| 19 | 11.9381 | 11.9839 | | 0.121 | |
| 20 | 12.5664 | 12.6181 | | -0.579 | |
| 21 | 13.1947 | 13.2437 | | 0.566 | |
| 22 | 13.8230 | 13.8756 | | 0.352 | |
| 23 | 14.4513 | 14.5089 | | -0.174 | |
| 24 | 15.0796 | 15.1402 | | -0.256 | |
| 25 | 15.7080 | 15.7700 | | -0.007 | |
| 26 | 16.3363 | 16.40733 | | -1.392 | |
| 27 | 16.9646 | 17.0387 | | -1.494 | |
| 28 | 17.5929 | 17.6678 | | -1.092 | |
| 29 | 18.2212 | 18.29541 | | -0.386 | |
| 30 | 18.8496 | 18.92661 | | -0.447 | |
| Outlier Data | | | | | |
| 1 | 0.6283 | 0.5822 | | 9.854 | |

**Reference Standards**

| Instrument | Barcode | Cal Date | Cal Due |
|---|---|---|---|
| CompuMotor SM233BE-NTC | | | |
| CompuMotor TQ10X Servo- | | | |
| | | | |
| | | | |
| | | | |

**Sensor Excitation:**

**(+) EXC:** VDC

**(-) EXC:** VDC

x = 2*π*r*xref

Ship Model Sign Convention:

**SENSOR SIGN CONVENTION:**

**CURVE FIT:**

| y = a + b x | | x = (1/b) y - a/b | | |
|---|---|---|---|---|
| **b =** | 1.0041 | **1/b =** | 0.99588 | m/s/V |
| **a =** | -0.0030 | **-a/b =** | 0.00298 | m/s |
| **r =** | 0.9999995 | **Std Err=** | 0.00462 | m/s |

**Diagram of Alignment Setup:**

r = 0.1 m

**Calibration Conducted by:** Joel T. Park

THIS PAGE INTENTIONALLY LEFT BLANK

# APPENDIX F: LCC TEST SECTION BOUNDARY LAYER DATA

## CONTENTS

CONTENTS ..... F-1
FIGURES ..... F-1
TABLES ..... F-2
INTRODUCTION ..... F-3
RESULTS ..... F-3
Derived Boundary-Layer Parameters ..... F-3

## FIGURES

Figure F-1. Boundary Layer Thickness at 0.99 Freestream Velocity, mm ..... F-4
Figure F-2. Boundary Layer Thickness at 0.999 Freestream Velocity, mm ..... F-4
Figure F-3. Ratio of Boundary Layer Thicknesses ..... F-5
Figure F-4. Displacement Thickness, mm ..... F-5
Figure F-5. Momentum Thickness, mm ..... F-6
Figure F-6. Shape Factor ..... F-6
Figure F-7. Skin-Friction Coefficient ..... F-7
Figure F-8. Local Velocity Relative to Nominal Tunnel Speed ..... F-7
Figure F-9. Local Velocity, Wall Units ..... F-8
Figure F-10. Pressure Coefficient, from Velocity and Pressure Tap Measurements ..... F-8
Figure F-11. Shape Factor vs Momentum Thickness Reynolds Number ..... F-9
Figure F-12. Virtual Origin from Österlund ..... F-10
Figure F-13. Momentum Thickness Re vs. Length Re from Test Section Entrance ..... F-11
Figure F-14. Momentum Thickness Re vs. $Re_x$ with Virtual Origin Upstream 2.5 m ..... F-11
Figure F-15. Skin-Friction Coefficient vs. Length Reynolds Number ..... F-12
Figure F-16. Skin-Friction Coefficient vs. Momentum Thickness Reynolds Number ..... F-12

## TABLES

Table F-1. Boundary Layer Summary at z = -250 mm, Part 1 ..... F-13
Table F-2. Boundary Layer Summary at z = -250 mm, Part 2 ..... F-15
Table F-3. Boundary Layer Summary at z = 0 mm, Part 1 ..... F-17
Table F-4. Boundary Layer Summary at z = 0 mm, Part 2 ..... F-19
Table F-5. Boundary Layer Summary at z = +250 mm, Part 1 ..... F-21
Table F-6. Boundary Layer Summary at z = +250 mm, Part 2 ..... F-23
Table F-7. Boundary Layer Summary for Average of z Locations, Part 1 ..... F-25
Table F-8. Boundary Layer Summary for Average of z Locations, Part 2 ..... F-27

# INTRODUCTION

The body of the report is focused on high Reynolds number turbulent boundary layer measurements at 250 mm above the LCC test section centerline. This appendix is a summary of all of the boundary layer measurements at vertical window locations at 250 mm above the centerline, center, and 250 mm below the centerline. The data are provided for future design of tests, validation and verification of computer codes, and guide for future boundary layer measurements. The following is a summary of the analysis.

- Files of boundary layer measurements were consolidated. The goal was to have all the boundary layer parameters calculated the same way for all measurement locations and conditions, to tabulate the data, and to plot the data in a useful format.
- Integrated boundary layer characteristics were not available for all files. The $z$ = -250 mm measurements had several conditions not calculated. All measured boundary layers were recalculated generally following the earlier work of Park and Cutbirth. In a few cases, the calculated parameters changed when parameters in the original calculation appeared to be incorrect. For example, some files needed the boundary-layer edge velocity modified slightly from what was earlier calculated, and in one or two cases the range of points to calculate shear-stress velocity, $u_\tau$, were changed where some points that appeared to be in the wake region were included in the curve fit of the log region. In addition, the new calculations applied a slightly different method for integrating to the wall. A slip velocity at the wall was assumed for the integration, instead of fitting the Musker profile to the data and integrating, since the original code to do this could not be found. The differences from the change in integration methods are within the measurement scatter. At all points, $\delta$, $\delta$*, and $\theta$ were recalculated so that all data presented here would be consistent.
- For all points, the virtual boundary-layer origin, $x_0$, was calculated following the method of Österlund. Results from this method were inconsistent. This will be commented on further with the plots.
- A spread in results between the measurements occurred at the three (3) $z$ locations. Several plots here only have the data averaged over the three $z$ locations in order to indicate trends better. These points are labeled “Average.”

# RESULTS

## Derived Boundary-Layer Parameters

Two boundary layer thicknesses were calculated, $\delta_{99}$ and $\delta$. The $\delta$ was calculated where the interpolated velocity reached 0.999 times the local edge velocity, $U_L$, or 0.999$U_L$. The $\delta_{99}$ is the location of 0.99$U_L$. The calculation of $\delta$ is more error prone than that of $\delta_{99}$, therefore, $\delta$ exhibits more scatter. The data for the three (3) vertical locations indicated as low, center, and high for -250, 0, and +250 mm are presented in Figure F-1 through Figure F-11.

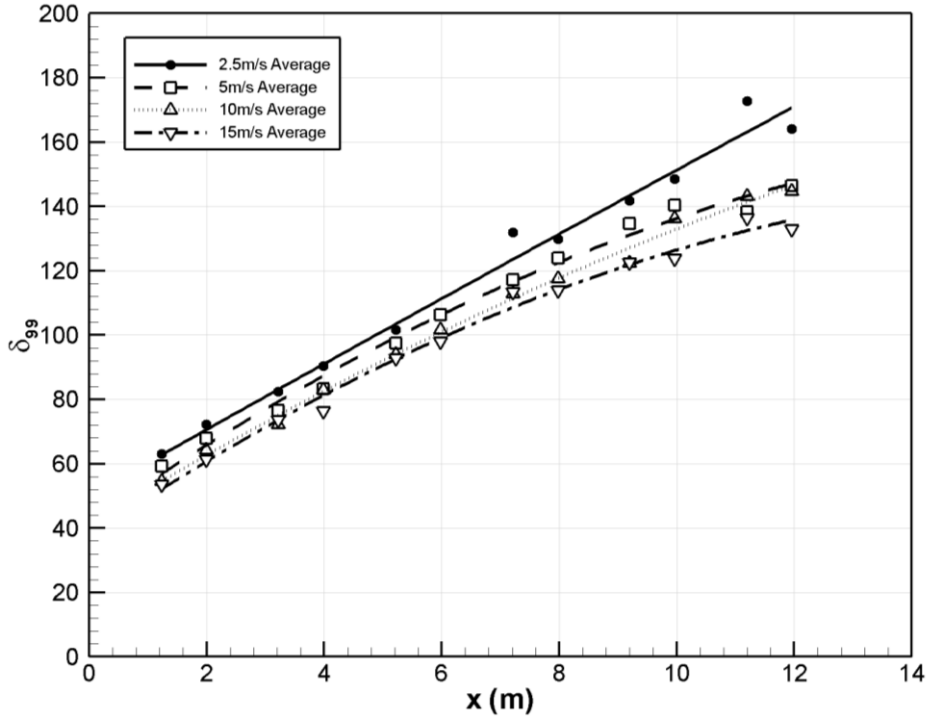



**Figure F-1. Boundary Layer Thickness at 0.99 Freestream Velocity, mm**

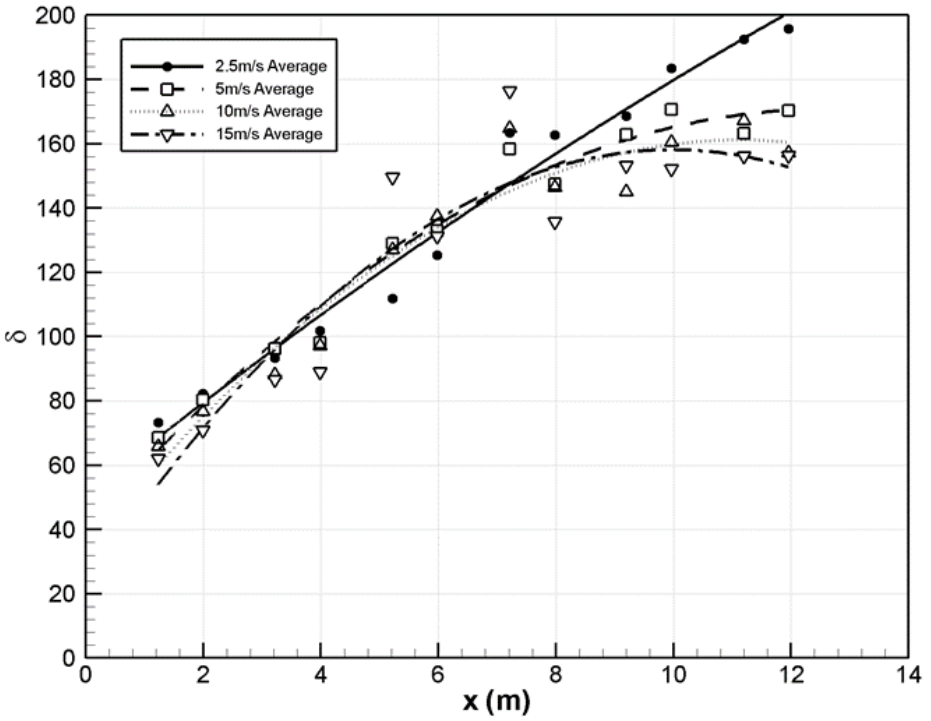



**Figure F-2. Boundary Layer Thickness at 0.999 Freestream Velocity, mm**

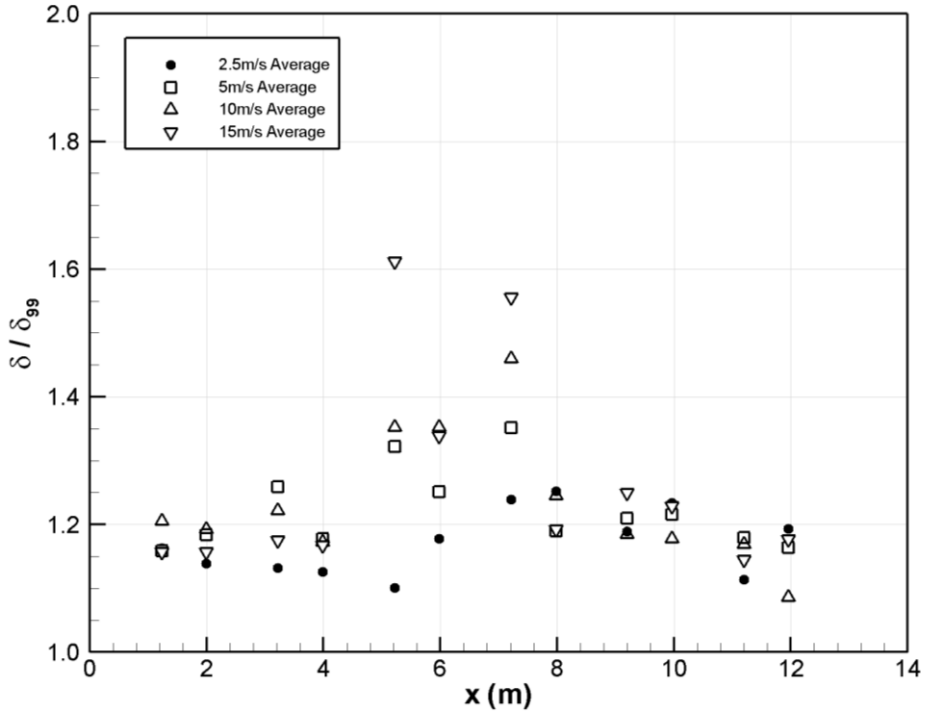



**Figure F-3. Ratio of Boundary Layer Thicknesses**

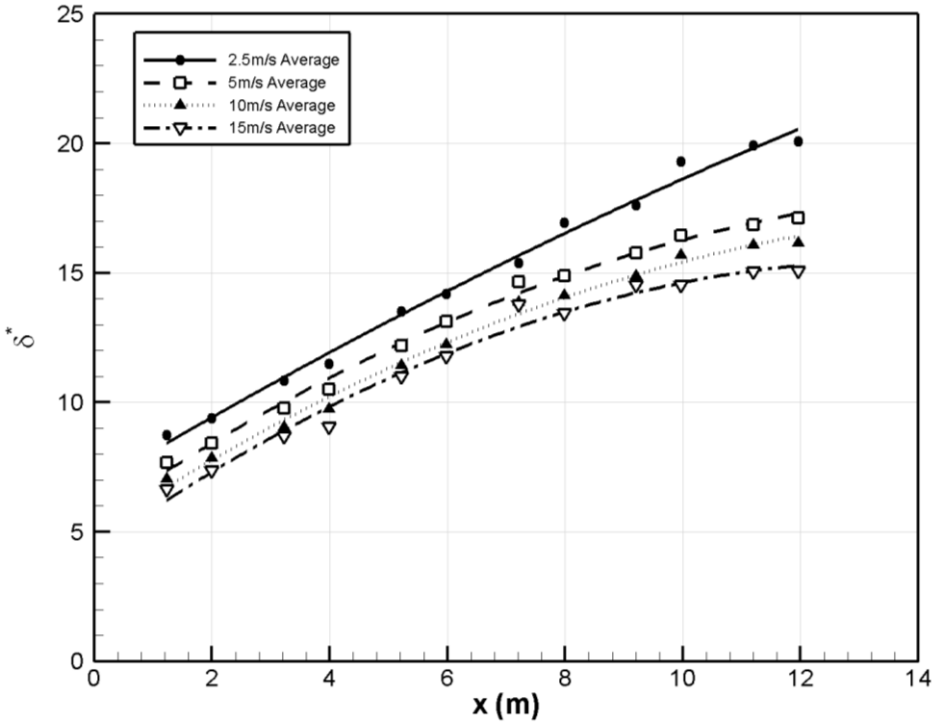



**Figure F-4. Displacement Thickness, mm**

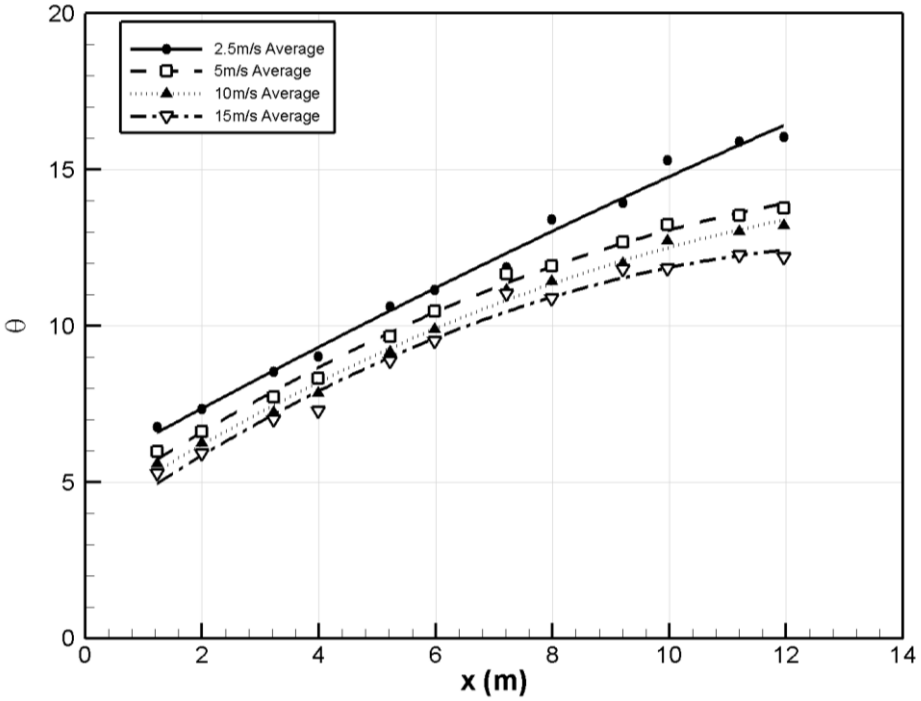



**Figure F-5. Momentum Thickness, mm**

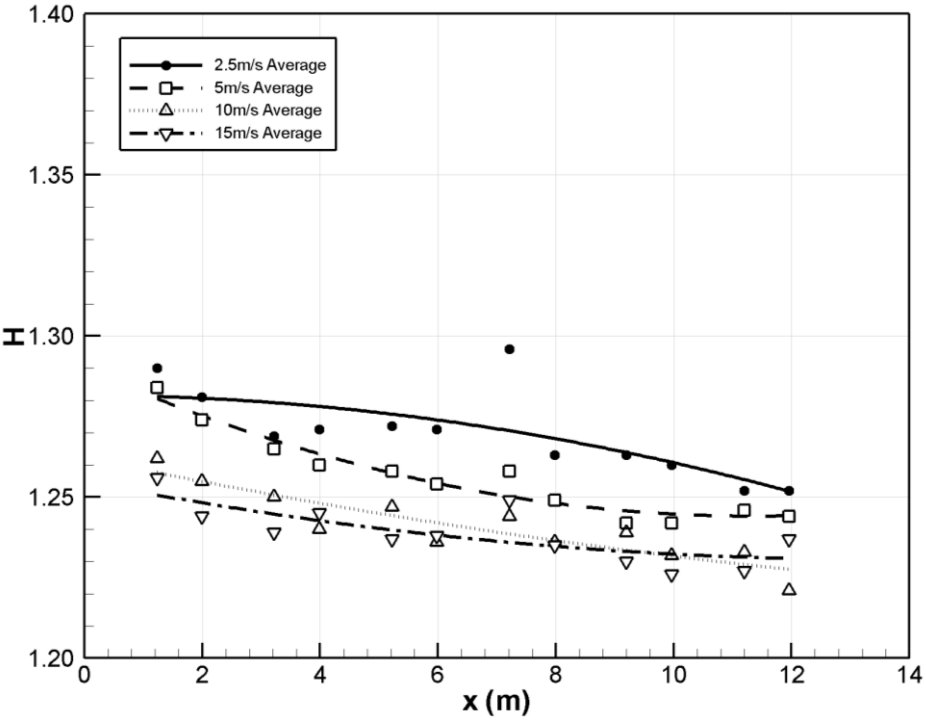



**Figure F-6. Shape Factor**

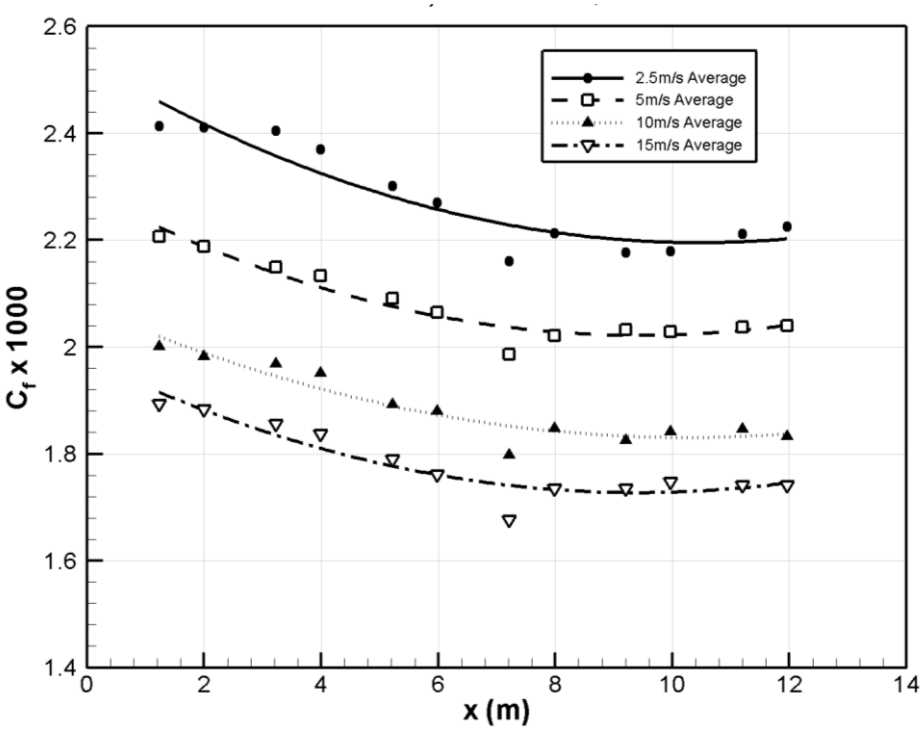



**Figure F-7. Skin-Friction Coefficient**

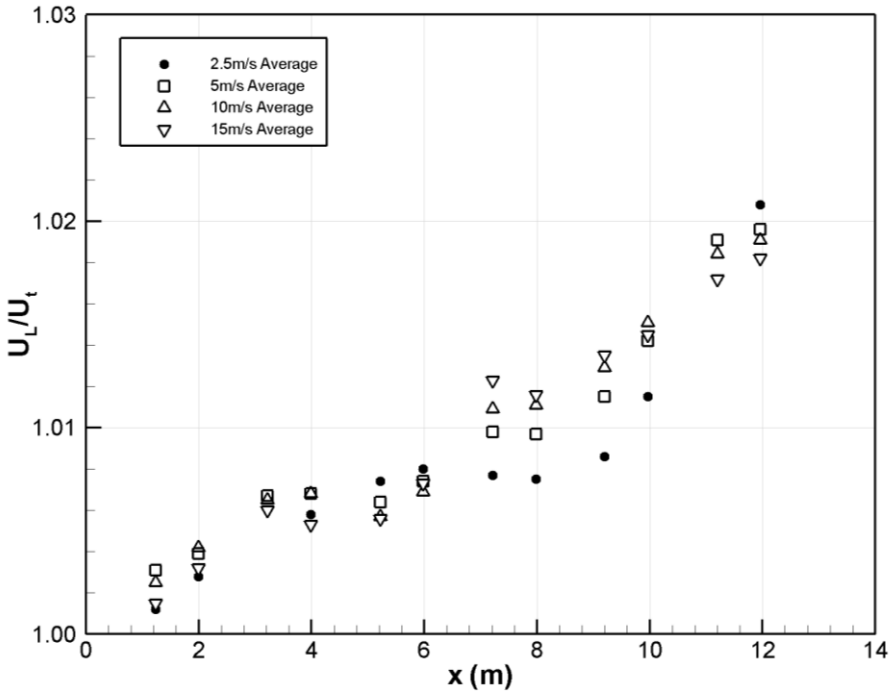



**Figure F-8. Local Velocity Relative to Nominal Tunnel Speed**

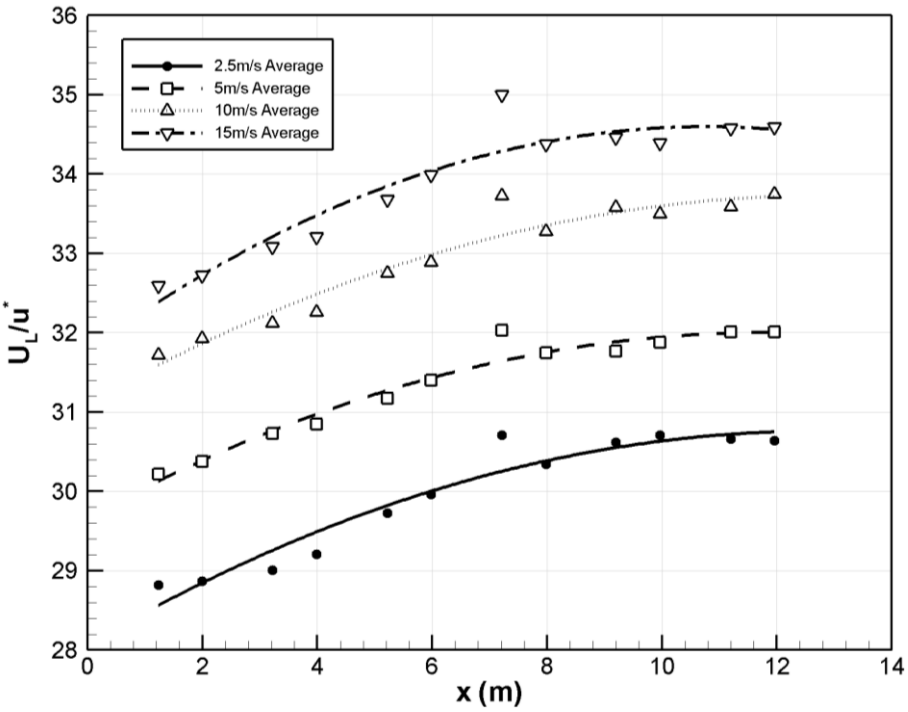



**Figure F-9. Local Velocity, Wall Units**

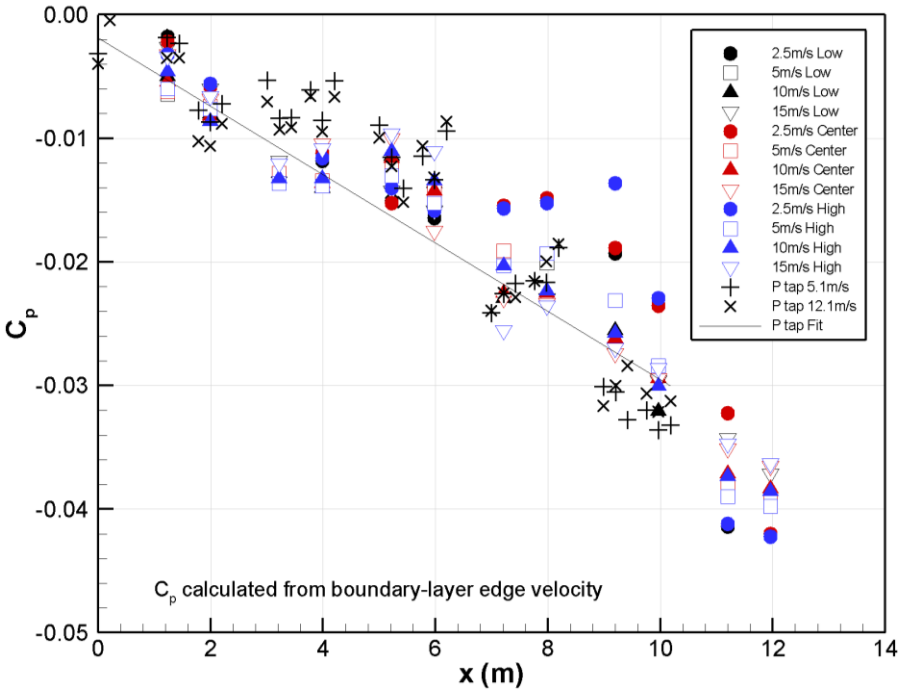



**Figure F-10. Pressure Coefficient, from Velocity and Pressure Tap Measurements**

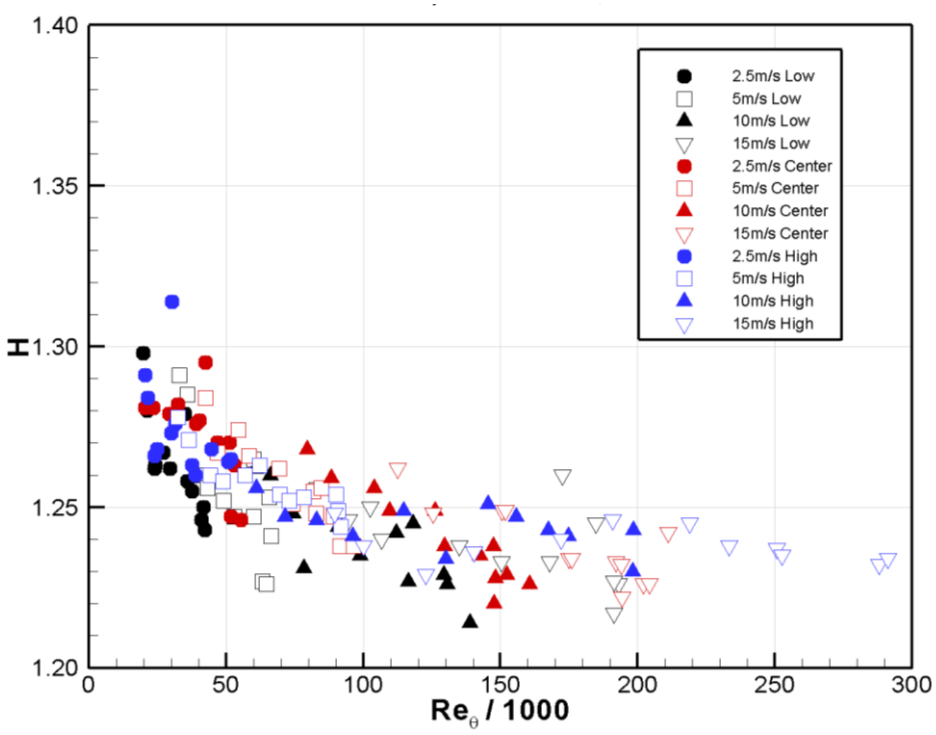



**Figure F-11. Shape Factor vs Momentum Thickness Reynolds Number**

The pressure coefficient calculated from measurements of the flow for an empty test section is in Figure F-10. The pressure calculated from the LDA measurements of the boundary layer edge or local, velocity is plotted by the values measured with pressure taps in 1998. The LDA and pressure tap data match within the scatter of the data. The measured pressure gradient is $dC_p/dx = -0.0300\ m^{-1}$.

As mentioned previously, the calculation of the virtual boundary-layer origin, $x_0$, following the method of Österlund, gave inconsistent results. This is illustrated in Figure F-12. In this figure, the size of the spheres represents the value of the calculated virtual origin. By the Österlund method, the calculated virtual origin became smaller as the measurements moved downstream for both the center and low $z$ measurement locations.

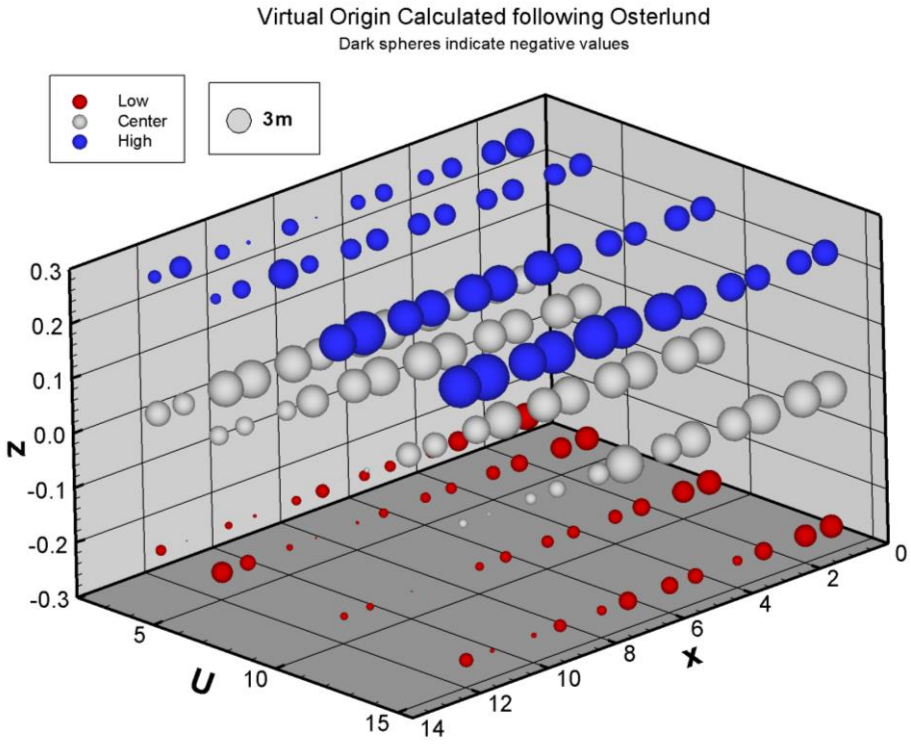



**Figure F-12. Virtual Origin from Österlund**

To obtain a consistent value for $x_0$, $Re_\theta$ versus $Re_x$ was plotted. For a flat plate $C_f = f(Re_\theta)$ and $C_f = f(Re_x)$, then $Re_\theta = f(Re_x)$ and all data on this plot should collapse to single curve. Setting the test section entrance as the $x$ origin did not produce this result. The best alignment was found with the $x$ origin 2.5 m ahead of the test section entrance, or $x_0$ = 4.5 m ahead of the tunnel-velocity measurement location at the center of window 2 in bay 1. The difference in the results illustrated in Figure F-13 and Figure F-14. This suggests that a virtual origin of $x_0$ = 4.5 m should be applied for *all* measurements.

The numerical results are listed in Table F-1 and Table F-2 for $z$ = -250 mm (lower location), Table F-3 and Table F-4 for $z$ = 0 (center), and Table F-5 and Table F-6 for $z$ = +250 mm (upper location). Table F-7 and Table F-8 contain the average values of the three locations. The tables are split into two parts from the Excel spreadsheet to accommodate the width of the page.

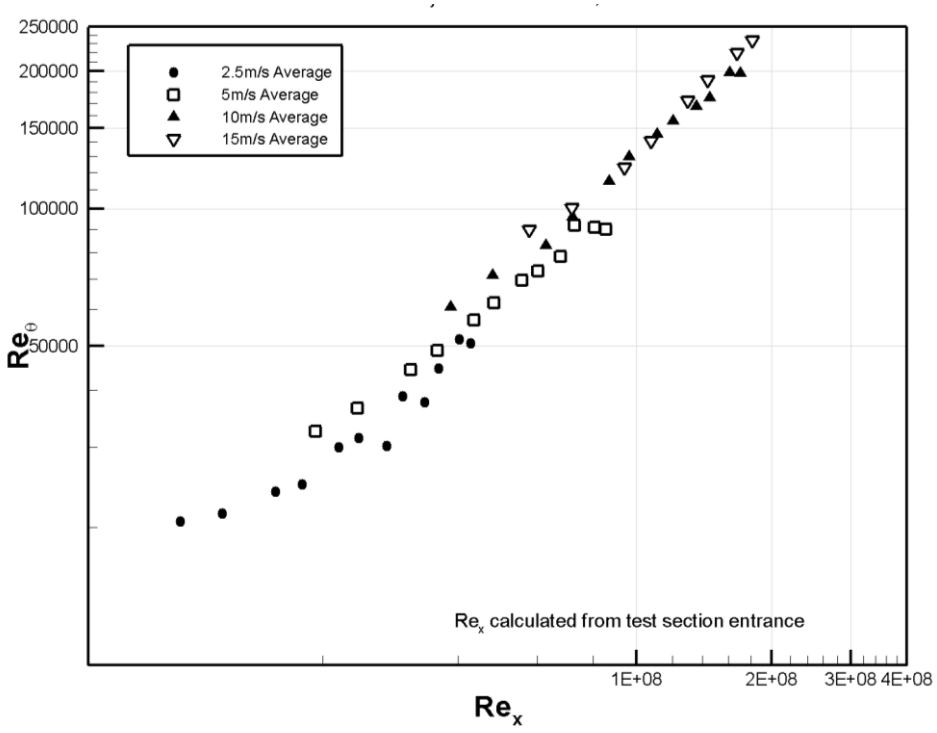



**Figure F-13. Momentum Thickness Re vs. Length Re from Test Section Entrance**

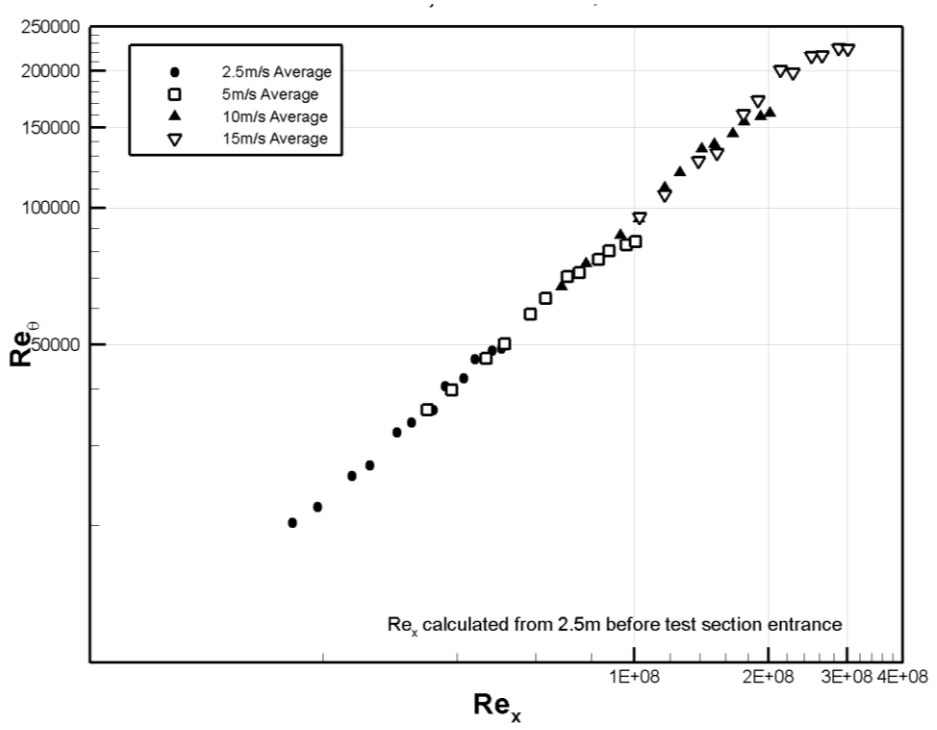



**Figure F-14. Momentum Thickness Re vs. $Re_X$ with Virtual Origin Upstream 2.5 m**

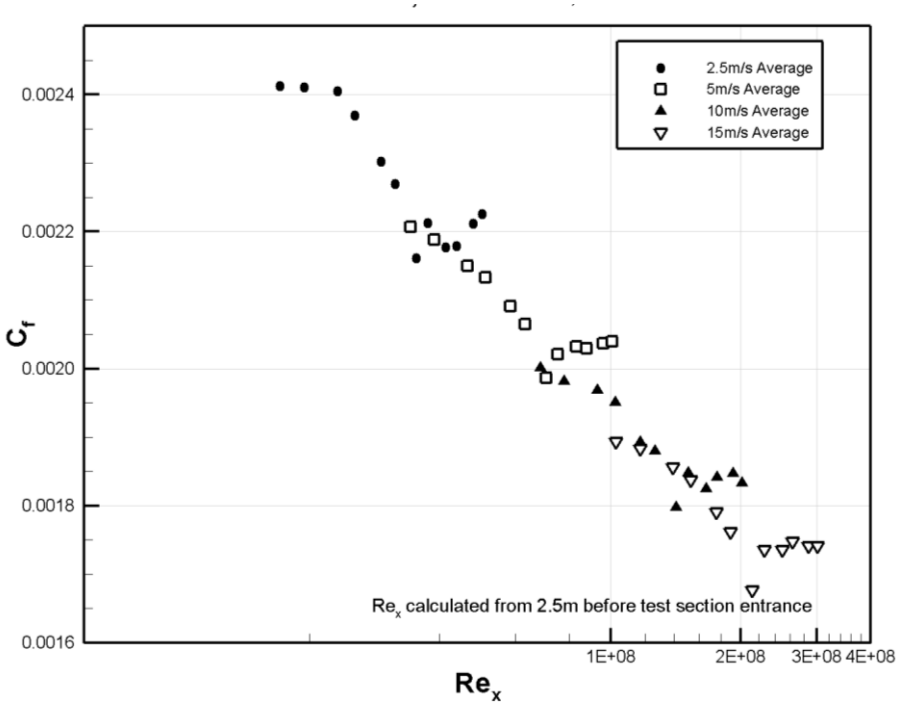



**Figure F-15. Skin-Friction Coefficient vs. Length Reynolds Number**

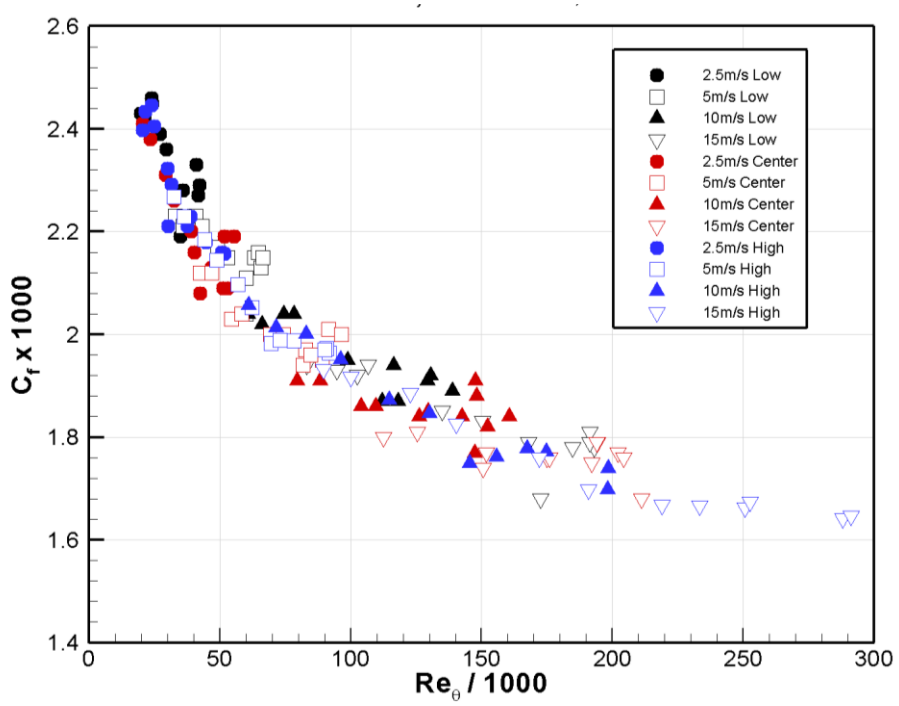



**Figure F-16. Skin-Friction Coefficient vs. Momentum Thickness Reynolds Number**

## Table F-1. Boundary Layer Summary at z = -250 mm, Part 1

| Nominal Speed | Bay | Window | Measurement Location | | | Local Freestream Velocity | Tunnel Velocity | Velocity Ratio | Boundary Layer Thickness | Boundary Layer Thickness | Displace-ment Thickness | Momentum Thickness |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| (m/s) | | | (m) | | | (m/s) | (m/s) | | (mm) | (mm) | (mm) | (mm) |
| | # | # | x | $x_T$ | z | $U_L$ | $U_t$ | $U_L/U_t$ | $\delta_{99}$ | $\delta$ | $\delta^*$ | $\theta$ |
| 2.5 | 2 | 1 | 1.23 | 3.21 | -0.25 | 2.503 | 2.500 | 1.0009 | 57.9 | 64.2 | 8.56 | 6.60 |
| 2.5 | 2 | 2 | 1.99 | 3.97 | -0.25 | 2.506 | 2.499 | 1.0029 | 68.5 | 72.8 | 9.02 | 7.05 |
| 2.5 | 3 | 1 | 3.22 | 5.20 | -0.25 | 2.514 | 2.498 | 1.0065 | 82.2 | 87.2 | 10.00 | 7.92 |
| 2.5 | 3 | 2 | 3.99 | 5.96 | -0.25 | 2.513 | 2.498 | 1.0059 | 80.3 | 92.2 | 10.15 | 8.03 |
| 2.5 | 4 | 1 | 5.22 | 7.19 | -0.25 | 2.521 | 2.502 | 1.0075 | 91.0 | 102.3 | 11.37 | 8.97 |
| 2.5 | 4 | 2 | 5.98 | 7.96 | -0.25 | 2.522 | 2.502 | 1.0082 | 98.5 | 102.0 | 12.34 | 9.78 |
| 2.5 | 5 | 1 | 7.21 | 9.19 | -0.25 | 2.522 | 2.503 | 1.0077 | 113.3 | 157.3 | 14.79 | 11.57 |
| 2.5 | 5 | 2 | 7.98 | 9.95 | -0.25 | 2.522 | 2.503 | 1.0075 | 116.2 | 139.4 | 14.91 | 11.85 |
| 2.5 | 6 | 1 | 9.20 | 11.18 | -0.25 | 2.527 | 2.503 | 1.0096 | 132.9 | 156.8 | 15.56 | 12.39 |
| 2.5 | 6 | 2 | 9.97 | 11.95 | -0.25 | 2.533 | 2.504 | 1.0114 | 141.5 | 165.5 | 17.16 | 13.72 |
| 2.5 | 7 | 1 | 11.20 | 13.17 | -0.25 | 2.552 | 2.501 | 1.0205 | 154.9 | 168.1 | 17.19 | 13.83 |
| 2.5 | 7 | 2 | 11.96 | 13.94 | -0.25 | 2.554 | 2.502 | 1.0208 | 144.0 | 180.2 | 16.69 | 13.39 |
| 5 | 2 | 1 | 1.23 | 3.21 | -0.25 | 5.017 | 5.001 | 1.0032 | 54.3 | 62.1 | 7.09 | 5.49 |
| 5 | 2 | 2 | 1.99 | 3.97 | -0.25 | 5.023 | 5.003 | 1.0041 | 59.9 | 68.2 | 7.68 | 5.98 |
| 5 | 3 | 1 | 3.22 | 5.20 | -0.25 | 5.035 | 5.001 | 1.0068 | 71.4 | 79.7 | 8.54 | 6.78 |
| 5 | 3 | 2 | 3.99 | 5.96 | -0.25 | 5.036 | 5.002 | 1.0067 | 72.1 | 82.2 | 9.03 | 7.18 |
| 5 | 4 | 1 | 5.22 | 7.19 | -0.25 | 5.037 | 5.005 | 1.0065 | 83.3 | 108.4 | 10.16 | 8.12 |
| 5 | 4 | 2 | 5.98 | 7.96 | -0.25 | 5.043 | 5.005 | 1.0076 | 95.5 | 106.8 | 10.95 | 8.79 |
| 5 | 5 | 1 | 7.21 | 9.19 | -0.25 | 5.047 | 4.997 | 1.0099 | 96.8 | 122.6 | 12.55 | 9.92 |
| 5 | 5 | 2 | 7.98 | 9.95 | -0.25 | 5.045 | 4.995 | 1.0100 | 104.6 | 126.0 | 12.40 | 9.95 |
| 5 | 6 | 1 | 9.20 | 11.18 | -0.25 | 5.060 | 5.002 | 1.0115 | 118.6 | 138.6 | 12.81 | 10.44 |
| 5 | 6 | 2 | 9.97 | 11.95 | -0.25 | 5.073 | 5.002 | 1.0142 | 127.0 | 139.2 | 13.08 | 10.66 |
| 5 | 7 | 1 | 11.20 | 13.17 | -0.25 | 5.105 | 5.008 | 1.0193 | 114.5 | 128.9 | 13.46 | 10.74 |
| 5 | 7 | 2 | 11.96 | 13.94 | -0.25 | 5.108 | 5.010 | 1.0196 | 127.9 | 138.3 | 13.45 | 10.84 |

X is from center of Bay 1 Window 2. Z is from test section centerline. $X_T$ is from test section entrance.
Distance from test section entrance to center of Bay 1 Window 2 is 1.976 m.
Distance from bay to bay is 78.50 in = 1.994 m

## Table F-1. Boundary Layer Summary at z = -250 mm, Part 1 (continued)

| Nominal Speed | Bay | Window | Measurement Location | | | Local Freestream Velocity | Tunnel Velocity | Velocity Ratio | Boundary Layer Thickness | Boundary Layer Thickness | Displace-ment Thickness | Momentum Thickness |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| (m/s) | | | (m) | | | (m/s) | (m/s) | | (mm) | (mm) | (mm) | (mm) |
| | # | # | x | $x_T$ | z | $U_L$ | $U_t$ | $U_L/U_t$ | $\delta_{99}$ | $\delta$ | $\delta^*$ | $\theta$ |
| 10 | 2 | 1 | 1.23 | 3.21 | -0.25 | 10.030 | 10.005 | 1.0025 | 48.1 | 54.5 | 6.40 | 5.07 |
| 10 | 2 | 2 | 1.99 | 3.97 | -0.25 | 10.047 | 10.007 | 1.0040 | 55.8 | 62.8 | 6.93 | 5.50 |
| 10 | 3 | 1 | 3.22 | 5.20 | -0.25 | 10.072 | 10.007 | 1.0064 | 63.8 | 71.5 | 7.72 | 6.18 |
| 10 | 3 | 2 | 3.99 | 5.96 | -0.25 | 10.071 | 10.000 | 1.0070 | 73.9 | 83.0 | 8.01 | 6.51 |
| 10 | 4 | 1 | 5.22 | 7.19 | -0.25 | 10.071 | 10.014 | 1.0057 | 82.7 | 100.5 | 9.36 | 7.52 |
| 10 | 4 | 2 | 5.98 | 7.96 | -0.25 | 10.081 | 10.013 | 1.0068 | 85.1 | 98.1 | 10.12 | 8.19 |
| 10 | 5 | 1 | 7.21 | 9.19 | -0.25 | 10.116 | 10.002 | 1.0114 | 100.5 | 136.1 | 11.48 | 9.24 |
| 10 | 5 | 2 | 7.98 | 9.95 | -0.25 | 10.110 | 10.000 | 1.0111 | 99.6 | 116.7 | 11.80 | 9.62 |
| 10 | 6 | 1 | 9.20 | 11.18 | -0.25 | 10.143 | 10.015 | 1.0127 | 98.9 | 115.7 | 12.11 | 9.73 |
| 10 | 6 | 2 | 9.97 | 11.95 | -0.25 | 10.170 | 10.011 | 1.0159 | 114.7 | 130.4 | 13.05 | 10.62 |
| 10 | 7 | 1 | 11.20 | 13.17 | -0.25 | 10.199 | 10.015 | 1.0184 | 132.1 | 140.1 | 13.10 | 10.69 |
| 10 | 7 | 2 | 11.96 | 13.94 | -0.25 | 10.206 | 10.015 | 1.0190 | 129.7 | 137.7 | 13.78 | 11.35 |
| 15 | 2 | 1 | 1.23 | 3.21 | -0.25 | 15.033 | 15.014 | 1.0013 | 45.5 | 50.3 | 5.81 | 4.62 |
| 15 | 2 | 2 | 1.99 | 3.97 | -0.25 | 15.055 | 15.009 | 1.0030 | 51.0 | 58.4 | 6.54 | 5.25 |
| 15 | 3 | 1 | 3.22 | 5.20 | -0.25 | 15.105 | 15.016 | 1.0059 | 61.9 | 69.8 | 7.31 | 5.89 |
| 15 | 3 | 2 | 3.99 | 5.96 | -0.25 | 15.090 | 15.011 | 1.0052 | 65.0 | 70.6 | 7.09 | 5.68 |
| 15 | 4 | 1 | 5.22 | 7.19 | -0.25 | 15.135 | 15.028 | 1.0071 | 76.2 | 100.3 | 9.21 | 7.44 |
| 15 | 4 | 2 | 5.98 | 7.96 | -0.25 | 15.128 | 15.010 | 1.0079 | 95.2 | 122.5 | 10.23 | 8.30 |
| 15 | 5 | 1 | 7.21 | 9.19 | -0.25 | 15.205 | 15.014 | 1.0127 | 100.4 | 121.1 | 11.95 | 9.48 |
| 15 | 5 | 2 | 7.98 | 9.95 | -0.25 | 15.184 | 15.014 | 1.0114 | 99.8 | 113.9 | 11.39 | 9.23 |
| 15 | 6 | 1 | 9.20 | 11.18 | -0.25 | 15.220 | 15.019 | 1.0134 | 103.4 | 133.6 | 12.99 | 10.59 |
| 15 | 6 | 2 | 9.97 | 11.95 | -0.25 | 15.243 | 15.021 | 1.0147 | 107.9 | 118.4 | 12.75 | 10.48 |
| 15 | 7 | 1 | 11.20 | 13.17 | -0.25 | 15.292 | 15.037 | 1.0170 | 117.1 | 132.4 | 12.81 | 10.44 |
| 15 | 7 | 2 | 11.96 | 13.94 | -0.25 | 15.300 | 15.023 | 1.0184 | 120.0 | 135.5 | 12.55 | 10.08 |

X is from center of Bay 1 Window 2. Z is from test section centerline. $X_T$ is from test section entrance.
Distance from test section entrance to center of Bay 1 Window 2 is 1.976 m.
Distance from bay to bay is 78.50 in = 1.994 m

## Table F-2. Boundary Layer Summary at z = -250 mm, Part 2

| Nominal Speed | Bay | Window | Measurement Location | | | Shape Factor | Momentum Thickness Reynolds No. | Reynolds No. from test section entrance | Skin Friction | Wall Shear Stress Velocity | | Virtual origin Österlund |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| (m/s) | | | (m) | | | | | | | (m/s) | | (m) |
| | # | # | x | $x_T$ | z | H | $Re_\theta$ | $Re_x$ | $c_f$ | $u_\tau$ | $U_L/u_\tau$ | $x_0$ |
| 2.5 | 2 | 1 | 1.23 | 3.21 | -0.25 | 1.298 | 1.978E+04 | 9.608E+06 | 2.43E-03 | 0.087 | 28.74 | 3.364 |
| 2.5 | 2 | 2 | 1.99 | 3.97 | -0.25 | 1.280 | 2.116E+04 | 1.192E+07 | 2.42E-03 | 0.087 | 28.82 | 2.975 |
| 2.5 | 3 | 1 | 3.22 | 5.20 | -0.25 | 1.262 | 2.387E+04 | 1.566E+07 | 2.46E-03 | 0.088 | 28.66 | 2.486 |
| 2.5 | 3 | 2 | 3.99 | 5.96 | -0.25 | 1.263 | 2.418E+04 | 1.795E+07 | 2.45E-03 | 0.087 | 28.74 | 1.814 |
| 2.5 | 4 | 1 | 5.22 | 7.19 | -0.25 | 1.267 | 2.710E+04 | 2.172E+07 | 2.39E-03 | 0.086 | 29.19 | 1.399 |
| 2.5 | 4 | 2 | 5.98 | 7.96 | -0.25 | 1.262 | 2.956E+04 | 2.405E+07 | 2.36E-03 | 0.086 | 29.37 | 1.341 |
| 2.5 | 5 | 1 | 7.21 | 9.19 | -0.25 | 1.279 | 3.496E+04 | 2.776E+07 | 2.19E-03 | 0.083 | 30.51 | 1.712 |
| 2.5 | 5 | 2 | 7.98 | 9.95 | -0.25 | 1.258 | 3.581E+04 | 3.007E+07 | 2.28E-03 | 0.084 | 29.87 | 1.204 |
| 2.5 | 6 | 1 | 9.20 | 11.18 | -0.25 | 1.255 | 3.752E+04 | 3.385E+07 | 2.23E-03 | 0.083 | 30.27 | 0.470 |
| 2.5 | 6 | 2 | 9.97 | 11.95 | -0.25 | 1.250 | 4.164E+04 | 3.624E+07 | 2.27E-03 | 0.084 | 30.07 | 0.941 |
| 2.5 | 7 | 1 | 11.20 | 13.17 | -0.25 | 1.243 | 4.227E+04 | 4.028E+07 | 2.29E-03 | 0.085 | 30.19 | -0.179 |
| 2.5 | 7 | 2 | 11.96 | 13.94 | -0.25 | 1.246 | 4.098E+04 | 4.265E+07 | 2.33E-03 | 0.085 | 29.93 | -1.346 |
| 5 | 2 | 1 | 1.23 | 3.21 | -0.25 | 1.291 | 3.300E+04 | 1.926E+07 | 2.23E-03 | 0.167 | 30.02 | 2.963 |
| 5 | 2 | 2 | 1.99 | 3.97 | -0.25 | 1.285 | 3.595E+04 | 2.389E+07 | 2.21E-03 | 0.166 | 30.20 | 2.637 |
| 5 | 3 | 1 | 3.22 | 5.20 | -0.25 | 1.260 | 4.089E+04 | 3.136E+07 | 2.23E-03 | 0.167 | 30.13 | 2.149 |
| 5 | 3 | 2 | 3.99 | 5.96 | -0.25 | 1.256 | 4.334E+04 | 3.598E+07 | 2.21E-03 | 0.166 | 30.29 | 1.763 |
| 5 | 4 | 1 | 5.22 | 7.19 | -0.25 | 1.252 | 4.897E+04 | 4.340E+07 | 2.17E-03 | 0.165 | 30.57 | 1.417 |
| 5 | 4 | 2 | 5.98 | 7.96 | -0.25 | 1.247 | 5.307E+04 | 4.807E+07 | 2.15E-03 | 0.164 | 30.79 | 1.298 |
| 5 | 5 | 1 | 7.21 | 9.19 | -0.25 | 1.265 | 5.997E+04 | 5.554E+07 | 2.04E-03 | 0.160 | 31.61 | 1.179 |
| 5 | 5 | 2 | 7.98 | 9.95 | -0.25 | 1.247 | 6.013E+04 | 6.014E+07 | 2.11E-03 | 0.162 | 31.07 | 0.442 |
| 5 | 6 | 1 | 9.20 | 11.18 | -0.25 | 1.227 | 6.330E+04 | 6.777E+07 | 2.15E-03 | 0.164 | 30.83 | -0.293 |
| 5 | 6 | 2 | 9.97 | 11.95 | -0.25 | 1.226 | 6.481E+04 | 7.260E+07 | 2.16E-03 | 0.164 | 30.89 | -0.833 |
| 5 | 7 | 1 | 11.20 | 13.17 | -0.25 | 1.253 | 6.570E+04 | 8.056E+07 | 2.13E-03 | 0.163 | 31.30 | -1.972 |
| 5 | 7 | 2 | 11.96 | 13.94 | -0.25 | 1.241 | 6.631E+04 | 8.530E+07 | 2.15E-03 | 0.164 | 31.14 | -2.644 |

X is from center of Bay 1 Window 2. Z is from test section centerline. $X_T$ is from test section entrance.
Distance from test section entrance to center of Bay 1 Window 2 is 1.976 m.
Distance from bay to bay is 78.50 in = 1.994 m

## Table F-2. Boundary Layer Summary at z = -250 mm, Part 2 (continued)

| Nominal Speed | Bay | Window | Measurement Location | | | Shape Factor | Momentum Thickness Reynolds No. | Reynolds No. from test section entrance | Skin Friction | Wall Shear Stress Velocity | | Virtual origin Österlund |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| (m/s) | | | (m) | | | | | | | (m/s) | | (m) |
| | # | # | x | $x_T$ | z | H | $Re_\theta$ | $Re_x$ | $c_f$ | $u_\tau$ | $U_L/u_\tau$ | $x_0$ |
| 10 | 2 | 1 | 1.23 | 3.21 | -0.25 | 1.262 | 6.089E+04 | 3.851E+07 | 2.04E-03 | 0.319 | 31.44 | 3.068 |
| 10 | 2 | 2 | 1.99 | 3.97 | -0.25 | 1.260 | 6.620E+04 | 4.779E+07 | 2.02E-03 | 0.318 | 31.58 | 2.735 |
| 10 | 3 | 1 | 3.22 | 5.20 | -0.25 | 1.248 | 7.456E+04 | 6.273E+07 | 2.04E-03 | 0.320 | 31.50 | 2.196 |
| 10 | 3 | 2 | 3.99 | 5.96 | -0.25 | 1.231 | 7.849E+04 | 7.195E+07 | 2.04E-03 | 0.320 | 31.52 | 1.765 |
| 10 | 4 | 1 | 5.22 | 7.19 | -0.25 | 1.244 | 9.073E+04 | 8.678E+07 | 1.96E-03 | 0.313 | 32.16 | 1.592 |
| 10 | 4 | 2 | 5.98 | 7.96 | -0.25 | 1.235 | 9.890E+04 | 9.611E+07 | 1.95E-03 | 0.312 | 32.30 | 1.536 |
| 10 | 5 | 1 | 7.21 | 9.19 | -0.25 | 1.242 | 1.120E+05 | 1.113E+08 | 1.87E-03 | 0.306 | 33.08 | 1.443 |
| 10 | 5 | 2 | 7.98 | 9.95 | -0.25 | 1.227 | 1.165E+05 | 1.205E+08 | 1.94E-03 | 0.311 | 32.46 | 1.086 |
| 10 | 6 | 1 | 9.20 | 11.18 | -0.25 | 1.245 | 1.182E+05 | 1.358E+08 | 1.87E-03 | 0.306 | 33.16 | -0.015 |
| 10 | 6 | 2 | 9.97 | 11.95 | -0.25 | 1.229 | 1.294E+05 | 1.455E+08 | 1.91E-03 | 0.309 | 32.89 | 0.205 |
| 10 | 7 | 1 | 11.20 | 13.17 | -0.25 | 1.226 | 1.306E+05 | 1.610E+08 | 1.92E-03 | 0.310 | 32.90 | -0.947 |
| 10 | 7 | 2 | 11.96 | 13.94 | -0.25 | 1.214 | 1.388E+05 | 1.704E+08 | 1.89E-03 | 0.307 | 33.20 | -0.970 |
| 15 | 2 | 1 | 1.23 | 3.21 | -0.25 | 1.256 | 8.326E+04 | 5.772E+07 | 1.94E-03 | 0.468 | 32.14 | 2.899 |
| 15 | 2 | 2 | 1.99 | 3.97 | -0.25 | 1.246 | 9.461E+04 | 7.160E+07 | 1.93E-03 | 0.466 | 32.33 | 2.787 |
| 15 | 3 | 1 | 3.22 | 5.20 | -0.25 | 1.240 | 1.067E+05 | 9.408E+07 | 1.94E-03 | 0.467 | 32.34 | 2.253 |
| 15 | 3 | 2 | 3.99 | 5.96 | -0.25 | 1.250 | 1.026E+05 | 1.078E+08 | 1.92E-03 | 0.464 | 32.50 | 1.253 |
| 15 | 4 | 1 | 5.22 | 7.19 | -0.25 | 1.238 | 1.350E+05 | 1.304E+08 | 1.85E-03 | 0.456 | 33.16 | 1.962 |
| 15 | 4 | 2 | 5.98 | 7.96 | -0.25 | 1.233 | 1.504E+05 | 1.442E+08 | 1.83E-03 | 0.454 | 33.35 | 2.158 |
| 15 | 5 | 1 | 7.21 | 9.19 | -0.25 | 1.260 | 1.727E+05 | 1.673E+08 | 1.68E-03 | 0.435 | 34.98 | 2.288 |
| 15 | 5 | 2 | 7.98 | 9.95 | -0.25 | 1.233 | 1.680E+05 | 1.810E+08 | 1.79E-03 | 0.448 | 33.86 | 1.237 |
| 15 | 6 | 1 | 9.20 | 11.18 | -0.25 | 1.226 | 1.931E+05 | 2.038E+08 | 1.78E-03 | 0.447 | 34.02 | 1.592 |
| 15 | 6 | 2 | 9.97 | 11.95 | -0.25 | 1.217 | 1.913E+05 | 2.181E+08 | 1.81E-03 | 0.451 | 33.76 | 0.692 |
| 15 | 7 | 1 | 11.20 | 13.17 | -0.25 | 1.227 | 1.913E+05 | 2.413E+08 | 1.79E-03 | 0.449 | 34.06 | -0.572 |
| 15 | 7 | 2 | 11.96 | 13.94 | -0.25 | 1.245 | 1.848E+05 | 2.555E+08 | 1.78E-03 | 0.448 | 34.16 | -1.757 |

X is from center of Bay 1 Window 2. Z is from test section centerline. $X_T$ is from test section entrance.
Distance from test section entrance to center of Bay 1 Window 2 is 1.976 m.
Distance from bay to bay is 78.50 in = 1.994 m

## Table F-3. Boundary Layer Summary at z = 0 mm, Part 1

| Nominal Speed | Bay | Window | Measurement Location | | | Local Freestream Velocity | Tunnel Velocity | Velocity Ratio | Boundary Layer Thickness | Boundary Layer Thickness | Displace-ment Thickness | Momentum Thickness |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| (m/s) | | | (m) | | | (m/s) | (m/s) | | (mm) | (mm) | (mm) | (mm) |
| | # | # | x | $x_T$ | z | $U_L$ | $U_t$ | $U_L/U_t$ | $\delta_{99}$ | $\delta$ | $\delta^*$ | $\theta$ |
| 2.5 | 2 | 1 | 1.23 | 3.21 | 0 | 2.503 | 2.500 | 1.0011 | 68.7 | 84.6 | 8.77 | 6.85 |
| 2.5 | 2 | 2 | 1.99 | 3.97 | 0 | 2.506 | 2.499 | 1.0029 | 79.4 | 96.1 | 9.96 | 7.78 |
| 2.5 | 3 | 1 | 3.22 | 5.20 | 0 | 2.514 | 2.498 | 1.0067 | 89.0 | 101.3 | 12.43 | 9.72 |
| 2.5 | 3 | 2 | 3.99 | 5.96 | 0 | 2.513 | 2.499 | 1.0056 | 108.4 | 118.7 | 13.79 | 10.76 |
| 2.5 | 4 | 1 | 5.22 | 7.19 | 0 | 2.521 | 2.502 | 1.0076 | 114.8 | 119.7 | 16.52 | 12.95 |
| 2.5 | 4 | 2 | 5.98 | 7.96 | 0 | 2.522 | 2.503 | 1.0079 | 119.5 | 159.3 | 16.99 | 13.30 |
| 2.5 | 5 | 1 | 7.21 | 9.19 | 0 | 2.522 | 2.503 | 1.0077 | 152.7 | 187.8 | 18.18 | 14.04 |
| 2.5 | 5 | 2 | 7.98 | 9.95 | 0 | 2.522 | 2.503 | 1.0074 | 150.7 | 193.7 | 19.71 | 15.53 |
| 2.5 | 6 | 1 | 9.20 | 11.18 | 0 | 2.527 | 2.504 | 1.0094 | 164.2 | 205.6 | 21.51 | 16.94 |
| 2.5 | 6 | 2 | 9.97 | 11.95 | 0 | 2.533 | 2.504 | 1.0117 | 166.0 | 204.9 | 22.05 | 17.46 |
| 2.5 | 7 | 1 | 11.20 | 13.17 | 0 | 2.542 | 2.502 | 1.0160 | 184.3 | 211.2 | 21.18 | 16.98 |
| 2.5 | 7 | 2 | 11.96 | 13.94 | 0 | 2.554 | 2.502 | 1.0208 | 183.5 | 221.1 | 22.61 | 18.15 |
| 5 | 2 | 1 | 1.23 | 3.21 | 0 | 5.017 | 5.001 | 1.0031 | 68.1 | 81.1 | 9.05 | 7.05 |
| 5 | 2 | 2 | 1.99 | 3.97 | 0 | 5.023 | 5.004 | 1.0037 | 81.3 | 98.7 | 9.87 | 7.78 |
| 5 | 3 | 1 | 3.22 | 5.20 | 0 | 5.035 | 5.003 | 1.0064 | 85.4 | 122.0 | 11.52 | 9.05 |
| 5 | 3 | 2 | 3.99 | 5.96 | 0 | 5.036 | 5.002 | 1.0067 | 91.3 | 112.3 | 12.24 | 9.67 |
| 5 | 4 | 1 | 5.22 | 7.19 | 0 | 5.037 | 5.006 | 1.0062 | 114.4 | 160.4 | 14.49 | 11.48 |
| 5 | 4 | 2 | 5.98 | 7.96 | 0 | 5.043 | 5.007 | 1.0071 | 124.0 | 155.9 | 15.38 | 12.30 |
| 5 | 5 | 1 | 7.21 | 9.19 | 0 | 5.044 | 4.996 | 1.0095 | 137.8 | 197.3 | 17.01 | 13.55 |
| 5 | 5 | 2 | 7.98 | 9.95 | 0 | 5.045 | 4.997 | 1.0096 | 139.7 | 167.9 | 17.11 | 13.71 |
| 5 | 6 | 1 | 9.20 | 11.18 | 0 | 5.060 | 5.002 | 1.0115 | 155.6 | 184.4 | 18.31 | 14.69 |
| 5 | 6 | 2 | 9.97 | 11.95 | 0 | 5.073 | 5.002 | 1.0143 | 136.0 | 178.2 | 17.48 | 13.92 |
| 5 | 7 | 1 | 11.20 | 13.17 | 0 | 5.105 | 5.011 | 1.0188 | 157.2 | 168.4 | 18.52 | 14.96 |
| 5 | 7 | 2 | 11.96 | 13.94 | 0 | 5.108 | 5.010 | 1.0195 | 170.7 | 193.9 | 19.48 | 15.74 |

X is from center of Bay 1 Window 2. Z is from test section centerline. $X_T$ is from test section entrance.
Distance from test section entrance to center of Bay 1 Window 2 is 1.976 m.
Distance from bay to bay is 78.50 in = 1.994 m

## Table F-3. Boundary Layer Summary at z = 0 mm, Part 1 (continued)

| Nominal Speed | Bay | Window | Measurement Location | | | Local Freestream Velocity | Tunnel Velocity | Velocity Ratio | Boundary Layer Thickness | Boundary Layer Thickness | Displace-ment Thickness | Momentum Thickness |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| (m/s) | | | (m) | | | (m/s) | (m/s) | | (mm) | (mm) | (mm) | (mm) |
| | # | # | x | $x_T$ | z | $U_L$ | $U_t$ | $U_L/U_t$ | $\delta_{99}$ | $\delta$ | $\delta^*$ | $\theta$ |
| 10 | 2 | 1 | 1.23 | 3.21 | 0 | 10.030 | 10.004 | 1.0027 | 63.7 | 75.9 | 8.39 | 6.62 |
| 10 | 2 | 2 | 1.99 | 3.97 | 0 | 10.047 | 10.006 | 1.0041 | 75.4 | 87.2 | 9.23 | 7.33 |
| 10 | 3 | 1 | 3.22 | 5.20 | 0 | 10.072 | 10.006 | 1.0066 | 84.9 | 104.0 | 10.83 | 8.63 |
| 10 | 3 | 2 | 3.99 | 5.96 | 0 | 10.071 | 10.003 | 1.0068 | 93.0 | 113.9 | 11.35 | 9.09 |
| 10 | 4 | 1 | 5.22 | 7.19 | 0 | 10.071 | 10.013 | 1.0058 | 102.8 | 165.7 | 13.08 | 10.47 |
| 10 | 4 | 2 | 5.98 | 7.96 | 0 | 10.081 | 10.010 | 1.0071 | 107.4 | 157.2 | 13.30 | 10.74 |
| 10 | 5 | 1 | 7.21 | 9.19 | 0 | 10.108 | 9.996 | 1.0112 | 120.0 | 219.3 | 15.09 | 12.18 |
| 10 | 5 | 2 | 7.98 | 9.95 | 0 | 10.110 | 9.998 | 1.0112 | 118.6 | 157.1 | 14.55 | 11.78 |
| 10 | 6 | 1 | 9.20 | 11.18 | 0 | 10.143 | 10.013 | 1.0130 | 137.1 | 176.4 | 15.40 | 12.53 |
| 10 | 6 | 2 | 9.97 | 11.95 | 0 | 10.160 | 10.014 | 1.0146 | 138.7 | 163.2 | 16.19 | 13.20 |
| 10 | 7 | 1 | 11.20 | 13.17 | 0 | 10.199 | 10.015 | 1.0184 | 130.8 | 158.3 | 14.89 | 12.13 |
| 10 | 7 | 2 | 11.96 | 13.94 | 0 | 10.206 | 10.015 | 1.0190 | 134.7 | 141.5 | 14.74 | 12.08 |
| 15 | 2 | 1 | 1.23 | 3.21 | 0 | 15.033 | 15.009 | 1.0016 | 61.3 | 72.8 | 7.89 | 6.25 |
| 15 | 2 | 2 | 1.99 | 3.97 | 0 | 15.055 | 15.003 | 1.0034 | 70.5 | 83.4 | 8.68 | 6.95 |
| 15 | 3 | 1 | 3.22 | 5.20 | 0 | 15.105 | 15.016 | 1.0060 | 86.3 | 101.5 | 10.39 | 8.32 |
| 15 | 3 | 2 | 3.99 | 5.96 | 0 | 15.090 | 15.012 | 1.0052 | 83.9 | 105.9 | 10.49 | 8.40 |
| 15 | 4 | 1 | 5.22 | 7.19 | 0 | 15.099 | 15.024 | 1.0050 | 99.9 | 177.7 | 11.94 | 9.68 |
| 15 | 4 | 2 | 5.98 | 7.96 | 0 | 15.139 | 15.009 | 1.0087 | 98.1 | 136.2 | 11.98 | 9.71 |
| 15 | 5 | 1 | 7.21 | 9.19 | 0 | 15.186 | 15.014 | 1.0114 | 120.4 | 223.4 | 14.37 | 11.56 |
| 15 | 5 | 2 | 7.98 | 9.95 | 0 | 15.184 | 15.009 | 1.0116 | 113.9 | 151.5 | 13.02 | 10.56 |
| 15 | 6 | 1 | 9.20 | 11.18 | 0 | 15.220 | 15.016 | 1.0136 | 126.2 | 142.5 | 13.61 | 11.09 |
| 15 | 6 | 2 | 9.97 | 11.95 | 0 | 15.243 | 15.023 | 1.0146 | 118.8 | 151.8 | 13.71 | 11.18 |
| 15 | 7 | 1 | 11.20 | 13.17 | 0 | 15.292 | 15.031 | 1.0174 | 128.9 | 142.5 | 12.96 | 10.60 |
| 15 | 7 | 2 | 11.96 | 13.94 | 0 | 15.300 | 15.027 | 1.0181 | 112.6 | 120.2 | 13.05 | 10.59 |

X is from center of Bay 1 Window 2. Z is from test section centerline. $X_T$ is from test section entrance.
Distance from test section entrance to center of Bay 1 Window 2 is 1.976 m.
Distance from bay to bay is 78.50 in = 1.994 m

## Table F-4. Boundary Layer Summary at z = 0 mm, Part 2

| Nominal Speed | Bay | Window | Measurement Location | | | Shape Factor | Momentum Thickness Reynolds No. | Reynolds No. from test section entrance | Skin Friction | Wall Shear Stress Velocity | | Virtual origin Österlund |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| (m/s) | | | (m) | | | | | | | (m/s) | | (m) |
| | # | # | x | $x_T$ | z | H | $Re_\theta$ | $Re_x$ | $c_f$ | $u_\tau$ | $U_L/u_\tau$ | $x_0$ |
| 2.5 | 2 | 1 | 1.23 | 3.21 | 0 | 1.281 | 2.053E+04 | 9.608E+06 | 2.41E-03 | 0.087 | 28.81 | 3.573 |
| 2.5 | 2 | 2 | 1.99 | 3.97 | 0 | 1.281 | 2.336E+04 | 1.192E+07 | 2.38E-03 | 0.086 | 29.06 | 3.591 |
| 2.5 | 3 | 1 | 3.22 | 5.20 | 0 | 1.279 | 2.928E+04 | 1.566E+07 | 2.31E-03 | 0.085 | 29.62 | 4.044 |
| 2.5 | 3 | 2 | 3.99 | 5.96 | 0 | 1.282 | 3.239E+04 | 1.795E+07 | 2.26E-03 | 0.084 | 29.91 | 4.200 |
| 2.5 | 4 | 1 | 5.22 | 7.19 | 0 | 1.276 | 3.910E+04 | 2.172E+07 | 2.20E-03 | 0.083 | 30.42 | 4.966 |
| 2.5 | 4 | 2 | 5.98 | 7.96 | 0 | 1.277 | 4.020E+04 | 2.405E+07 | 2.16E-03 | 0.082 | 30.71 | 4.531 |
| 2.5 | 5 | 1 | 7.21 | 9.19 | 0 | 1.295 | 4.242E+04 | 2.776E+07 | 2.08E-03 | 0.081 | 31.27 | 3.984 |
| 2.5 | 5 | 2 | 7.98 | 9.95 | 0 | 1.270 | 4.690E+04 | 3.007E+07 | 2.13E-03 | 0.082 | 30.93 | 4.621 |
| 2.5 | 6 | 1 | 9.20 | 11.18 | 0 | 1.270 | 5.130E+04 | 3.385E+07 | 2.09E-03 | 0.081 | 31.27 | 4.754 |
| 2.5 | 6 | 2 | 9.97 | 11.95 | 0 | 1.263 | 5.297E+04 | 3.624E+07 | 2.09E-03 | 0.081 | 31.36 | 4.491 |
| 2.5 | 7 | 1 | 11.20 | 13.17 | 0 | 1.247 | 5.170E+04 | 4.012E+07 | 2.19E-03 | 0.083 | 30.71 | 2.807 |
| 2.5 | 7 | 2 | 11.96 | 13.94 | 0 | 1.246 | 5.554E+04 | 4.265E+07 | 2.19E-03 | 0.083 | 30.89 | 3.194 |
| 5 | 2 | 1 | 1.23 | 3.21 | 0 | 1.284 | 4.237E+04 | 1.926E+07 | 2.12E-03 | 0.163 | 30.83 | 4.393 |
| 5 | 2 | 2 | 1.99 | 3.97 | 0 | 1.267 | 4.684E+04 | 2.389E+07 | 2.12E-03 | 0.163 | 30.85 | 4.321 |
| 5 | 3 | 1 | 3.22 | 5.20 | 0 | 1.274 | 5.457E+04 | 3.136E+07 | 2.03E-03 | 0.159 | 31.58 | 4.309 |
| 5 | 3 | 2 | 3.99 | 5.96 | 0 | 1.266 | 5.833E+04 | 3.598E+07 | 2.04E-03 | 0.160 | 31.50 | 4.153 |
| 5 | 4 | 1 | 5.22 | 7.19 | 0 | 1.262 | 6.926E+04 | 4.340E+07 | 2.00E-03 | 0.158 | 31.84 | 4.727 |
| 5 | 4 | 2 | 5.98 | 7.96 | 0 | 1.251 | 7.428E+04 | 4.807E+07 | 2.00E-03 | 0.158 | 31.92 | 4.793 |
| 5 | 5 | 1 | 7.21 | 9.19 | 0 | 1.255 | 8.189E+04 | 5.550E+07 | 1.94E-03 | 0.156 | 32.40 | 4.858 |
| 5 | 5 | 2 | 7.98 | 9.95 | 0 | 1.248 | 8.288E+04 | 6.014E+07 | 1.97E-03 | 0.157 | 32.18 | 4.258 |
| 5 | 6 | 1 | 9.20 | 11.18 | 0 | 1.247 | 8.902E+04 | 6.777E+07 | 1.95E-03 | 0.156 | 32.39 | 4.050 |
| 5 | 6 | 2 | 9.97 | 11.95 | 0 | 1.256 | 8.463E+04 | 7.260E+07 | 1.96E-03 | 0.157 | 32.38 | 2.495 |
| 5 | 7 | 1 | 11.20 | 13.17 | 0 | 1.238 | 9.151E+04 | 8.056E+07 | 2.01E-03 | 0.158 | 32.21 | 2.367 |
| 5 | 7 | 2 | 11.96 | 13.94 | 0 | 1.238 | 9.633E+04 | 8.530E+07 | 2.00E-03 | 0.158 | 32.34 | 2.426 |

X is from center of Bay 1 Window 2. Z is from test section centerline. $X_T$ is from test section entrance.
Distance from test section entrance to center of Bay 1 Window 2 is 1.976 m.
Distance from bay to bay is 78.50 in = 1.994 m

## Table F-4. Boundary Layer Summary at z = 0 mm, Part 2 (continued)

| Nominal Speed | Bay | Window | Measurement Location | | | Shape Factor | Momentum Thickness Reynolds No. | Reynolds No. from test section entrance | Skin Friction | Wall Shear Stress Velocity | | Virtual origin Österlund |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| (m/s) | | | (m) | | | | | | | (m/s) | | (m) |
| | # | # | x | $x_T$ | z | H | $Re_\theta$ | $Re_x$ | $c_f$ | $u_\tau$ | $U_L/u_\tau$ | $x_0$ |
| 10 | 2 | 1 | 1.23 | 3.21 | 0 | 1.268 | 7.951E+04 | 3.851E+07 | 1.91E-03 | 0.309 | 32.45 | 4.634 |
| 10 | 2 | 2 | 1.99 | 3.97 | 0 | 1.259 | 8.826E+04 | 4.779E+07 | 1.91E-03 | 0.309 | 32.54 | 4.615 |
| 10 | 3 | 1 | 3.22 | 5.20 | 0 | 1.256 | 1.041E+05 | 6.273E+07 | 1.86E-03 | 0.305 | 33.02 | 4.761 |
| 10 | 3 | 2 | 3.99 | 5.96 | 0 | 1.249 | 1.096E+05 | 7.195E+07 | 1.86E-03 | 0.305 | 33.03 | 4.492 |
| 10 | 4 | 1 | 5.22 | 7.19 | 0 | 1.249 | 1.263E+05 | 8.678E+07 | 1.84E-03 | 0.304 | 33.17 | 4.770 |
| 10 | 4 | 2 | 5.98 | 7.96 | 0 | 1.238 | 1.297E+05 | 9.611E+07 | 1.85E-03 | 0.304 | 33.18 | 4.312 |
| 10 | 5 | 1 | 7.21 | 9.19 | 0 | 1.238 | 1.475E+05 | 1.112E+08 | 1.77E-03 | 0.298 | 33.95 | 4.703 |
| 10 | 5 | 2 | 7.98 | 9.95 | 0 | 1.235 | 1.426E+05 | 1.205E+08 | 1.84E-03 | 0.304 | 33.31 | 3.479 |
| 10 | 6 | 1 | 9.20 | 11.18 | 0 | 1.229 | 1.523E+05 | 1.358E+08 | 1.82E-03 | 0.302 | 33.58 | 3.109 |
| 10 | 6 | 2 | 9.97 | 11.95 | 0 | 1.226 | 1.606E+05 | 1.454E+08 | 1.84E-03 | 0.304 | 33.48 | 3.109 |
| 10 | 7 | 1 | 11.20 | 13.17 | 0 | 1.228 | 1.482E+05 | 1.610E+08 | 1.88E-03 | 0.307 | 33.27 | 0.668 |
| 10 | 7 | 2 | 11.96 | 13.94 | 0 | 1.220 | 1.477E+05 | 1.704E+08 | 1.91E-03 | 0.309 | 33.02 | -0.145 |
| 15 | 2 | 1 | 1.23 | 3.21 | 0 | 1.262 | 1.125E+05 | 5.772E+07 | 1.80E-03 | 0.451 | 33.37 | 4.626 |
| 15 | 2 | 2 | 1.99 | 3.97 | 0 | 1.248 | 1.254E+05 | 7.160E+07 | 1.81E-03 | 0.451 | 33.40 | 4.636 |
| 15 | 3 | 1 | 3.22 | 5.20 | 0 | 1.249 | 1.505E+05 | 9.408E+07 | 1.74E-03 | 0.443 | 34.11 | 4.935 |
| 15 | 3 | 2 | 3.99 | 5.96 | 0 | 1.249 | 1.518E+05 | 1.078E+08 | 1.77E-03 | 0.446 | 33.83 | 4.260 |
| 15 | 4 | 1 | 5.22 | 7.19 | 0 | 1.234 | 1.750E+05 | 1.301E+08 | 1.76E-03 | 0.445 | 33.96 | 4.499 |
| 15 | 4 | 2 | 5.98 | 7.96 | 0 | 1.234 | 1.760E+05 | 1.443E+08 | 1.76E-03 | 0.445 | 34.05 | 3.771 |
| 15 | 5 | 1 | 7.21 | 9.19 | 0 | 1.242 | 2.104E+05 | 1.671E+08 | 1.68E-03 | 0.435 | 34.93 | 4.731 |
| 15 | 5 | 2 | 7.98 | 9.95 | 0 | 1.233 | 1.921E+05 | 1.810E+08 | 1.75E-03 | 0.444 | 34.22 | 2.777 |
| 15 | 6 | 1 | 9.20 | 11.18 | 0 | 1.226 | 2.022E+05 | 2.038E+08 | 1.77E-03 | 0.446 | 34.16 | 2.181 |
| 15 | 6 | 2 | 9.97 | 11.95 | 0 | 1.226 | 2.042E+05 | 2.181E+08 | 1.76E-03 | 0.445 | 34.28 | 1.527 |
| 15 | 7 | 1 | 11.20 | 13.17 | 0 | 1.222 | 1.942E+05 | 2.413E+08 | 1.79E-03 | 0.449 | 34.09 | -0.385 |
| 15 | 7 | 2 | 11.96 | 13.94 | 0 | 1.232 | 1.941E+05 | 2.555E+08 | 1.79E-03 | 0.449 | 34.05 | -1.161 |

X is from center of Bay 1 Window 2. Z is from test section centerline. $X_T$ is from test section entrance.
Distance from test section entrance to center of Bay 1 Window 2 is 1.976 m.
Distance from bay to bay is 78.50 in = 1.994 m

## Table F-5. Boundary Layer Summary at z = +250 mm, Part 1

| Nominal Speed | Bay | Window | Measurement Location | | | Local Freestream Velocity | Tunnel Velocity | Velocity Ratio | Boundary Layer Thickness | Boundary Layer Thickness | Displace-ment Thickness | Momentum Thickness |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| (m/s) | | | (m) | | | (m/s) | (m/s) | | (mm) | (mm) | (mm) | (mm) |
| | # | # | x | $x_T$ | z | $U_L$ | $U_t$ | $U_L/U_t$ | $\delta_{99}$ | $\delta$ | $\delta^*$ | $\theta$ |
| 2.5 | 2 | 1 | 1.23 | 3.21 | 0.25 | 2.503 | 2.498 | 1.0016 | 62.5 | 71.0 | 8.87 | 6.87 |
| 2.5 | 2 | 2 | 1.99 | 3.97 | 0.25 | 2.506 | 2.499 | 1.0028 | 68.7 | 77.7 | 9.18 | 7.15 |
| 2.5 | 3 | 1 | 3.22 | 5.20 | 0.25 | 2.514 | 2.497 | 1.0068 | 75.9 | 91.3 | 10.08 | 7.96 |
| 2.5 | 3 | 2 | 3.99 | 5.96 | 0.25 | 2.513 | 2.498 | 1.0058 | 82.6 | 94.6 | 10.49 | 8.27 |
| 2.5 | 4 | 1 | 5.22 | 7.19 | 0.25 | 2.521 | 2.503 | 1.0070 | 98.9 | 113.5 | 12.64 | 9.93 |
| 2.5 | 4 | 2 | 5.98 | 7.96 | 0.25 | 2.522 | 2.503 | 1.0079 | 101.5 | 115.0 | 13.25 | 10.39 |
| 2.5 | 5 | 1 | 7.21 | 9.19 | 0.25 | 2.522 | 2.503 | 1.0078 | 129.7 | 145.1 | 13.14 | 10.00 |
| 2.5 | 5 | 2 | 7.98 | 9.95 | 0.25 | 2.522 | 2.503 | 1.0076 | 122.9 | 155.1 | 16.17 | 12.83 |
| 2.5 | 6 | 1 | 9.20 | 11.18 | 0.25 | 2.520 | 2.503 | 1.0068 | 128.2 | 143.5 | 15.76 | 12.48 |
| 2.5 | 6 | 2 | 9.97 | 11.95 | 0.25 | 2.533 | 2.504 | 1.0114 | 138.4 | 179.8 | 18.67 | 14.73 |
| 2.5 | 7 | 1 | 11.20 | 13.17 | 0.25 | 2.552 | 2.501 | 1.0204 | 178.9 | 197.8 | 21.38 | 16.91 |
| 2.5 | 7 | 2 | 11.96 | 13.94 | 0.25 | 2.554 | 2.502 | 1.0209 | 164.7 | 186.1 | 20.93 | 16.57 |
| 5 | 2 | 1 | 1.23 | 3.21 | 0.25 | 5.017 | 5.001 | 1.0030 | 55.3 | 62.6 | 6.90 | 5.40 |
| 5 | 2 | 2 | 1.99 | 3.97 | 0.25 | 5.023 | 5.004 | 1.0038 | 62.5 | 74.2 | 7.71 | 6.06 |
| 5 | 3 | 1 | 3.22 | 5.20 | 0.25 | 5.035 | 5.001 | 1.0068 | 72.6 | 87.3 | 9.26 | 7.35 |
| 5 | 3 | 2 | 3.99 | 5.96 | 0.25 | 5.036 | 5.001 | 1.0069 | 86.6 | 99.7 | 10.19 | 8.10 |
| 5 | 4 | 1 | 5.22 | 7.19 | 0.25 | 5.037 | 5.005 | 1.0065 | 94.9 | 117.9 | 11.88 | 9.43 |
| 5 | 4 | 2 | 5.98 | 7.96 | 0.25 | 5.043 | 5.005 | 1.0076 | 99.5 | 136.4 | 12.99 | 10.29 |
| 5 | 5 | 1 | 7.21 | 9.19 | 0.25 | 5.047 | 4.996 | 1.0101 | 117.0 | 155.3 | 14.42 | 11.50 |
| 5 | 5 | 2 | 7.98 | 9.95 | 0.25 | 5.045 | 4.997 | 1.0096 | 127.7 | 148.7 | 15.14 | 12.09 |
| 5 | 6 | 1 | 9.20 | 11.18 | 0.25 | 5.060 | 5.002 | 1.0115 | 129.9 | 165.7 | 16.23 | 12.95 |
| 5 | 6 | 2 | 9.97 | 11.95 | 0.25 | 5.073 | 5.003 | 1.0141 | 158.0 | 194.7 | 18.77 | 15.09 |
| 5 | 7 | 1 | 11.20 | 13.17 | 0.25 | 5.105 | 5.008 | 1.0193 | 143.5 | 192.6 | 18.57 | 14.87 |
| 5 | 7 | 2 | 11.96 | 13.94 | 0.25 | 5.108 | 5.009 | 1.0197 | 140.7 | 178.9 | 18.47 | 14.73 |

X is from center of Bay 1 Window 2. Z is from test section centerline. $X_T$ is from test section entrance.
Distance from test section entrance to center of Bay 1 Window 2 is 1.976 m.
Distance from bay to bay is 78.50 in = 1.994 m

## Table F-5. Boundary Layer Summary at z = +250 mm, Part 1 (continued)

| Nominal Speed | Bay | Window | Measurement Location | | | Local Freestream Velocity | Tunnel Velocity | Velocity Ratio | Boundary Layer Thickness | Boundary Layer Thickness | Displace-ment Thickness | Momentum Thickness |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| (m/s) | | | (m) | | | (m/s) | (m/s) | | (mm) | (mm) | (mm) | (mm) |
| | # | # | x | $x_T$ | z | $U_L$ | $U_t$ | $U_L/U_t$ | $\delta_{99}$ | $\delta$ | $\delta^*$ | $\theta$ |
| 10 | 2 | 1 | 1.23 | 3.21 | 0.25 | 10.030 | 10.007 | 1.0023 | 52.2 | 67.1 | 6.37 | 5.07 |
| 10 | 2 | 2 | 1.99 | 3.97 | 0.25 | 10.047 | 10.004 | 1.0043 | 61.7 | 80.2 | 7.41 | 5.94 |
| 10 | 3 | 1 | 3.22 | 5.20 | 0.25 | 10.072 | 10.005 | 1.0066 | 67.9 | 89.2 | 8.57 | 6.88 |
| 10 | 3 | 2 | 3.99 | 5.96 | 0.25 | 10.071 | 10.005 | 1.0066 | 81.8 | 94.6 | 9.88 | 7.96 |
| 10 | 4 | 1 | 5.22 | 7.19 | 0.25 | 10.071 | 10.016 | 1.0055 | 96.4 | 115.0 | 11.89 | 9.52 |
| 10 | 4 | 2 | 5.98 | 7.96 | 0.25 | 10.081 | 10.014 | 1.0067 | 112.3 | 157.0 | 13.29 | 10.77 |
| 10 | 5 | 1 | 7.21 | 9.19 | 0.25 | 10.100 | 9.999 | 1.0101 | 118.2 | 139.2 | 15.05 | 12.03 |
| 10 | 5 | 2 | 7.98 | 9.95 | 0.25 | 10.110 | 9.999 | 1.0111 | 134.7 | 165.2 | 16.03 | 12.85 |
| 10 | 6 | 1 | 9.20 | 11.18 | 0.25 | 10.143 | 10.014 | 1.0128 | 131.3 | 142.8 | 17.12 | 13.78 |
| 10 | 6 | 2 | 9.97 | 11.95 | 0.25 | 10.165 | 10.016 | 1.0149 | 155.4 | 187.8 | 17.82 | 14.35 |
| 10 | 7 | 1 | 11.20 | 13.17 | 0.25 | 10.199 | 10.014 | 1.0185 | 166.4 | 203.6 | 20.20 | 16.25 |
| 10 | 7 | 2 | 11.96 | 13.94 | 0.25 | 10.206 | 10.014 | 1.0191 | 169.6 | 192.3 | 19.95 | 16.22 |
| 15 | 2 | 1 | 1.23 | 3.21 | 0.25 | 15.033 | 15.008 | 1.0017 | 54.0 | 62.8 | 6.22 | 4.98 |
| 15 | 2 | 2 | 1.99 | 3.97 | 0.25 | 15.055 | 15.006 | 1.0033 | 62.4 | 70.7 | 6.88 | 5.56 |
| 15 | 3 | 1 | 3.22 | 5.20 | 0.25 | 15.105 | 15.015 | 1.0060 | 72.8 | 88.4 | 8.33 | 6.78 |
| 15 | 3 | 2 | 3.99 | 5.96 | 0.25 | 15.090 | 15.010 | 1.0054 | 80.1 | 90.8 | 9.60 | 7.77 |
| 15 | 4 | 1 | 5.22 | 7.19 | 0.25 | 15.099 | 15.027 | 1.0048 | 102.4 | 171.0 | 11.80 | 9.52 |
| 15 | 4 | 2 | 5.98 | 7.96 | 0.25 | 15.101 | 15.018 | 1.0055 | 100.7 | 135.0 | 13.14 | 10.55 |
| 15 | 5 | 1 | 7.21 | 9.19 | 0.25 | 15.205 | 15.014 | 1.0127 | 119.5 | 184.8 | 14.97 | 12.03 |
| 15 | 5 | 2 | 7.98 | 9.95 | 0.25 | 15.184 | 15.009 | 1.0117 | 128.1 | 142.0 | 15.88 | 12.83 |
| 15 | 6 | 1 | 9.20 | 11.18 | 0.25 | 15.220 | 15.018 | 1.0134 | 138.2 | 183.6 | 17.00 | 13.74 |
| 15 | 6 | 2 | 9.97 | 11.95 | 0.25 | 15.233 | 15.019 | 1.0142 | 144.6 | 186.1 | 17.09 | 13.84 |
| 15 | 7 | 1 | 11.20 | 13.17 | 0.25 | 15.292 | 15.033 | 1.0172 | 163.4 | 193.6 | 19.38 | 15.73 |
| 15 | 7 | 2 | 11.96 | 13.94 | 0.25 | 15.300 | 15.030 | 1.0180 | 166.2 | 213.6 | 19.61 | 15.89 |

X is from center of Bay 1 Window 2. Z is from test section centerline. $X_T$ is from test section entrance.
Distance from test section entrance to center of Bay 1 Window 2 is 1.976 m.
Distance from bay to bay is 78.50 in = 1.994 m.

## Table F-6. Boundary Layer Summary at z = +250 mm, Part 2

| Nominal Speed | Bay | Window | Measurement Location | | | Shape Factor | Momentum Thickness Reynolds No. | Reynolds No. from test section entrance | Skin Friction | Wall Shear Stress Velocity | | Virtual origin Österlund |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| (m/s) | | | (m) | | | | | | | (m/s) | | (m) |
| | # | # | x | $x_T$ | z | H | $Re_\theta$ | $Re_x$ | $c_f$ | $u_\tau$ | $U_L/u_\tau$ | $x_0$ |
| 2.5 | 2 | 1 | 1.23 | 3.21 | 0.25 | 1.291 | 2.061E+04 | 9.608E+06 | 2.397E-03 | 0.087 | 28.91 | 3.593 |
| 2.5 | 2 | 2 | 1.99 | 3.97 | 0.25 | 1.284 | 2.147E+04 | 1.192E+07 | 2.434E-03 | 0.087 | 28.73 | 3.062 |
| 2.5 | 3 | 1 | 3.22 | 5.20 | 0.25 | 1.266 | 2.397E+04 | 1.566E+07 | 2.446E-03 | 0.087 | 28.76 | 2.516 |
| 2.5 | 3 | 2 | 3.99 | 5.96 | 0.25 | 1.268 | 2.490E+04 | 1.795E+07 | 2.405E-03 | 0.087 | 28.98 | 2.019 |
| 2.5 | 4 | 1 | 5.22 | 7.19 | 0.25 | 1.273 | 2.998E+04 | 2.172E+07 | 2.323E-03 | 0.085 | 29.59 | 2.234 |
| 2.5 | 4 | 2 | 5.98 | 7.96 | 0.25 | 1.276 | 3.139E+04 | 2.405E+07 | 2.292E-03 | 0.085 | 29.81 | 1.878 |
| 2.5 | 5 | 1 | 7.21 | 9.19 | 0.25 | 1.314 | 3.021E+04 | 2.776E+07 | 2.211E-03 | 0.083 | 30.35 | 0.304 |
| 2.5 | 5 | 2 | 7.98 | 9.95 | 0.25 | 1.260 | 3.877E+04 | 3.007E+07 | 2.229E-03 | 0.083 | 30.22 | 2.101 |
| 2.5 | 6 | 1 | 9.20 | 11.18 | 0.25 | 1.263 | 3.768E+04 | 3.375E+07 | 2.211E-03 | 0.083 | 30.32 | 0.547 |
| 2.5 | 6 | 2 | 9.97 | 11.95 | 0.25 | 1.268 | 4.469E+04 | 3.624E+07 | 2.179E-03 | 0.083 | 30.70 | 1.882 |
| 2.5 | 7 | 1 | 11.20 | 13.17 | 0.25 | 1.265 | 5.170E+04 | 4.028E+07 | 2.157E-03 | 0.082 | 31.09 | 2.750 |
| 2.5 | 7 | 2 | 11.96 | 13.94 | 0.25 | 1.264 | 5.068E+04 | 4.265E+07 | 2.159E-03 | 0.082 | 31.09 | 1.655 |
| 5 | 2 | 1 | 1.23 | 3.21 | 0.25 | 1.278 | 3.248E+04 | 1.926E+07 | 2.268E-03 | 0.168 | 29.80 | 2.885 |
| 5 | 2 | 2 | 1.99 | 3.97 | 0.25 | 1.271 | 3.649E+04 | 2.389E+07 | 2.229E-03 | 0.167 | 30.09 | 2.718 |
| 5 | 3 | 1 | 3.22 | 5.20 | 0.25 | 1.260 | 4.431E+04 | 3.136E+07 | 2.184E-03 | 0.165 | 30.47 | 2.680 |
| 5 | 3 | 2 | 3.99 | 5.96 | 0.25 | 1.258 | 4.886E+04 | 3.598E+07 | 2.144E-03 | 0.164 | 30.76 | 2.630 |
| 5 | 4 | 1 | 5.22 | 7.19 | 0.25 | 1.260 | 5.689E+04 | 4.340E+07 | 2.097E-03 | 0.162 | 31.12 | 2.686 |
| 5 | 4 | 2 | 5.98 | 7.96 | 0.25 | 1.263 | 6.214E+04 | 4.807E+07 | 2.052E-03 | 0.160 | 31.49 | 2.770 |
| 5 | 5 | 1 | 7.21 | 9.19 | 0.25 | 1.254 | 6.953E+04 | 5.554E+07 | 1.982E-03 | 0.157 | 32.06 | 2.759 |
| 5 | 5 | 2 | 7.98 | 9.95 | 0.25 | 1.252 | 7.305E+04 | 6.014E+07 | 1.989E-03 | 0.158 | 31.99 | 2.588 |
| 5 | 6 | 1 | 9.20 | 11.18 | 0.25 | 1.253 | 7.847E+04 | 6.777E+07 | 1.988E-03 | 0.158 | 32.10 | 2.243 |
| 5 | 6 | 2 | 9.97 | 11.95 | 0.25 | 1.244 | 9.172E+04 | 7.260E+07 | 1.964E-03 | 0.157 | 32.38 | 3.717 |
| 5 | 7 | 1 | 11.20 | 13.17 | 0.25 | 1.249 | 9.092E+04 | 8.056E+07 | 1.972E-03 | 0.157 | 32.51 | 2.265 |
| 5 | 7 | 2 | 11.96 | 13.94 | 0.25 | 1.254 | 9.012E+04 | 8.530E+07 | 1.970E-03 | 0.157 | 32.55 | 1.354 |

X is from center of Bay 1 Window 2. Z is from test section centerline. $X_T$ is from test section entrance.
Distance from test section entrance to center of Bay 1 Window 2 is 1.976 m.
Distance from bay to bay is 78.50 in = 1.994 m

## Table F-6. Boundary Layer Summary at z = +250 mm, Part 2 (continued)

| Nominal Speed | Bay | Window | Measurement Location | | | Shape Factor | Momentum Thickness Reynolds No. | Reynolds No. from test section entrance | Skin Friction | Wall Shear Stress Velocity | | Virtual origin Österlund |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| (m/s) | | | (m) | | | | | | | (m/s) | | (m) |
| | # | # | x | $x_T$ | z | H | $Re_\theta$ | $Re_x$ | $c_f$ | $u_\tau$ | $U_L/u_\tau$ | $x_0$ |
| 10 | 2 | 1 | 1.23 | 3.21 | 0.25 | 1.256 | 6.098E+04 | 3.851E+07 | 2.057E-03 | 0.321 | 31.28 | 3.075 |
| 10 | 2 | 2 | 1.99 | 3.97 | 0.25 | 1.247 | 7.149E+04 | 4.779E+07 | 2.014E-03 | 0.317 | 31.66 | 3.178 |
| 10 | 3 | 1 | 3.22 | 5.20 | 0.25 | 1.246 | 8.302E+04 | 6.273E+07 | 2.001E-03 | 0.316 | 31.84 | 2.917 |
| 10 | 3 | 2 | 3.99 | 5.96 | 0.25 | 1.241 | 9.607E+04 | 7.195E+07 | 1.952E-03 | 0.312 | 32.24 | 3.288 |
| 10 | 4 | 1 | 5.22 | 7.19 | 0.25 | 1.249 | 1.148E+05 | 8.678E+07 | 1.873E-03 | 0.306 | 32.91 | 3.733 |
| 10 | 4 | 2 | 5.98 | 7.96 | 0.25 | 1.234 | 1.301E+05 | 9.611E+07 | 1.847E-03 | 0.304 | 33.17 | 4.348 |
| 10 | 5 | 1 | 7.21 | 9.19 | 0.25 | 1.251 | 1.455E+05 | 1.111E+08 | 1.749E-03 | 0.296 | 34.15 | 4.524 |
| 10 | 5 | 2 | 7.98 | 9.95 | 0.25 | 1.247 | 1.557E+05 | 1.205E+08 | 1.762E-03 | 0.297 | 34.06 | 4.699 |
| 10 | 6 | 1 | 9.20 | 11.18 | 0.25 | 1.243 | 1.674E+05 | 1.358E+08 | 1.778E-03 | 0.298 | 34.01 | 4.531 |
| 10 | 6 | 2 | 9.97 | 11.95 | 0.25 | 1.241 | 1.748E+05 | 1.455E+08 | 1.772E-03 | 0.298 | 34.15 | 4.436 |
| 10 | 7 | 1 | 11.20 | 13.17 | 0.25 | 1.243 | 1.985E+05 | 1.610E+08 | 1.739E-03 | 0.295 | 34.59 | 5.433 |
| 10 | 7 | 2 | 11.96 | 13.94 | 0.25 | 1.230 | 1.983E+05 | 1.704E+08 | 1.698E-03 | 0.291 | 35.03 | 4.637 |
| 15 | 2 | 1 | 1.23 | 3.21 | 0.25 | 1.248 | 8.971E+04 | 5.772E+07 | 1.931E-03 | 0.466 | 32.25 | 3.273 |
| 15 | 2 | 2 | 1.99 | 3.97 | 0.25 | 1.238 | 1.002E+05 | 7.160E+07 | 1.916E-03 | 0.464 | 32.43 | 3.117 |
| 15 | 3 | 1 | 3.22 | 5.20 | 0.25 | 1.229 | 1.227E+05 | 9.408E+07 | 1.886E-03 | 0.461 | 32.80 | 3.216 |
| 15 | 3 | 2 | 3.99 | 5.96 | 0.25 | 1.236 | 1.404E+05 | 1.078E+08 | 1.826E-03 | 0.453 | 33.30 | 3.549 |
| 15 | 4 | 1 | 5.22 | 7.19 | 0.25 | 1.240 | 1.722E+05 | 1.301E+08 | 1.760E-03 | 0.445 | 33.93 | 4.316 |
| 15 | 4 | 2 | 5.98 | 7.96 | 0.25 | 1.246 | 1.908E+05 | 1.440E+08 | 1.697E-03 | 0.437 | 34.57 | 4.749 |
| 15 | 5 | 1 | 7.21 | 9.19 | 0.25 | 1.245 | 2.190E+05 | 1.673E+08 | 1.667E-03 | 0.433 | 35.11 | 5.282 |
| 15 | 5 | 2 | 7.98 | 9.95 | 0.25 | 1.238 | 2.333E+05 | 1.810E+08 | 1.666E-03 | 0.433 | 35.08 | 5.474 |
| 15 | 6 | 1 | 9.20 | 11.18 | 0.25 | 1.237 | 2.506E+05 | 2.038E+08 | 1.662E-03 | 0.432 | 35.20 | 5.364 |
| 15 | 6 | 2 | 9.97 | 11.95 | 0.25 | 1.235 | 2.526E+05 | 2.180E+08 | 1.673E-03 | 0.434 | 35.12 | 4.723 |
| 15 | 7 | 1 | 11.20 | 13.17 | 0.25 | 1.232 | 2.881E+05 | 2.413E+08 | 1.641E-03 | 0.430 | 35.59 | 5.826 |
| 15 | 7 | 2 | 11.96 | 13.94 | 0.25 | 1.234 | 2.913E+05 | 2.555E+08 | 1.646E-03 | 0.430 | 35.56 | 5.265 |

X is from center of Bay 1 Window 2. Z is from test section centerline. $X_T$ is from test section entrance.
Distance from test section entrance to center of Bay 1 Window 2 is 1.976 m.
Distance from bay to bay is 78.50 in = 1.994 m

## Table F-7. Boundary Layer Summary for Average of z Locations, Part 1

| Nominal Speed | Bay | Window | Measurement Location | | | Local Freestream Velocity | Tunnel Velocity | Velocity Ratio | Boundary Layer Thickness | Boundary Layer Thickness | Displace-ment Thickness | Momentum Thickness |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| (m/s) | | | (m) | | | (m/s) | (m/s) | | (mm) | (mm) | (mm) | (mm) |
| | # | # | x | $x_T$ | z | $U_L$ | $U_t$ | $U_L/U_t$ | $\delta_{99}$ | $\delta$ | $\delta^*$ | $\theta$ |
| 2.5 | 2 | 1 | 1.23 | 3.21 | 0 | 2.503 | 2.500 | 1.0012 | 63.0 | 73.3 | 8.74 | 6.77 |
| 2.5 | 2 | 2 | 1.99 | 3.97 | 0 | 2.506 | 2.499 | 1.0028 | 72.2 | 82.2 | 9.39 | 7.33 |
| 2.5 | 3 | 1 | 3.22 | 5.20 | 0 | 2.514 | 2.498 | 1.0067 | 82.4 | 93.3 | 10.84 | 8.53 |
| 2.5 | 3 | 2 | 3.99 | 5.96 | 0 | 2.513 | 2.498 | 1.0058 | 90.4 | 101.8 | 11.48 | 9.02 |
| 2.5 | 4 | 1 | 5.22 | 7.19 | 0 | 2.521 | 2.502 | 1.0074 | 101.6 | 111.8 | 13.51 | 10.62 |
| 2.5 | 4 | 2 | 5.98 | 7.96 | 0 | 2.522 | 2.502 | 1.0080 | 106.5 | 125.4 | 14.19 | 11.16 |
| 2.5 | 5 | 1 | 7.21 | 9.19 | 0 | 2.522 | 2.503 | 1.0077 | 131.9 | 163.4 | 15.37 | 11.87 |
| 2.5 | 5 | 2 | 7.98 | 9.95 | 0 | 2.522 | 2.503 | 1.0075 | 129.9 | 162.7 | 16.93 | 13.40 |
| 2.5 | 6 | 1 | 9.20 | 11.18 | 0 | 2.525 | 2.503 | 1.0086 | 141.8 | 168.6 | 17.61 | 13.94 |
| 2.5 | 6 | 2 | 9.97 | 11.95 | 0 | 2.533 | 2.504 | 1.0115 | 148.6 | 183.4 | 19.29 | 15.30 |
| 2.5 | 7 | 1 | 11.20 | 13.17 | 0 | 2.549 | 2.501 | 1.0190 | 172.7 | 192.4 | 19.92 | 15.90 |
| 2.5 | 7 | 2 | 11.96 | 13.94 | 0 | 2.554 | 2.502 | 1.0208 | 164.1 | 195.8 | 20.08 | 16.04 |
| 5 | 2 | 1 | 1.23 | 3.21 | 0 | 5.017 | 5.001 | 1.0031 | 59.2 | 68.6 | 7.68 | 5.98 |
| 5 | 2 | 2 | 1.99 | 3.97 | 0 | 5.023 | 5.004 | 1.0039 | 67.9 | 80.4 | 8.42 | 6.61 |
| 5 | 3 | 1 | 3.22 | 5.20 | 0 | 5.035 | 5.002 | 1.0067 | 76.5 | 96.3 | 9.78 | 7.72 |
| 5 | 3 | 2 | 3.99 | 5.96 | 0 | 5.036 | 5.002 | 1.0068 | 83.3 | 98.1 | 10.49 | 8.32 |
| 5 | 4 | 1 | 5.22 | 7.19 | 0 | 5.037 | 5.005 | 1.0064 | 97.5 | 128.9 | 12.18 | 9.67 |
| 5 | 4 | 2 | 5.98 | 7.96 | 0 | 5.043 | 5.006 | 1.0074 | 106.3 | 133.0 | 13.11 | 10.46 |
| 5 | 5 | 1 | 7.21 | 9.19 | 0 | 5.046 | 4.996 | 1.0098 | 117.2 | 158.4 | 14.66 | 11.66 |
| 5 | 5 | 2 | 7.98 | 9.95 | 0 | 5.045 | 4.996 | 1.0097 | 124.0 | 147.5 | 14.88 | 11.92 |
| 5 | 6 | 1 | 9.20 | 11.18 | 0 | 5.060 | 5.002 | 1.0115 | 134.7 | 162.9 | 15.78 | 12.69 |
| 5 | 6 | 2 | 9.97 | 11.95 | 0 | 5.073 | 5.002 | 1.0142 | 140.4 | 170.7 | 16.44 | 13.23 |
| 5 | 7 | 1 | 11.20 | 13.17 | 0 | 5.105 | 5.009 | 1.0191 | 138.4 | 163.3 | 16.85 | 13.53 |
| 5 | 7 | 2 | 11.96 | 13.94 | 0 | 5.108 | 5.010 | 1.0196 | 146.4 | 170.4 | 17.13 | 13.77 |

X is from center of Bay 1 Window 2. Z is from test section centerline. $X_T$ is from test section entrance.
Distance from test section entrance to center of Bay 1 Window 2 is 1.976 m.
Distance from bay to bay is 78.50 in = 1.994 m

## Table F-7. Boundary Layer Summary for Average of z Locations, Part 1 (continued)

| Nominal Speed | Bay | Window | Measurement Location | | | Local Freestream Velocity | Tunnel Velocity | Velocity Ratio | Boundary Layer Thickness | Boundary Layer Thickness | Displace-ment Thickness | Momentum Thickness |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| (m/s) | | | (m) | | | (m/s) | (m/s) | | (mm) | (mm) | (mm) | (mm) |
| | # | # | x | $x_T$ | z | $U_L$ | $U_t$ | $U_L/U_t$ | $\delta_{99}$ | $\delta$ | $\delta^*$ | $\theta$ |
| 10 | 2 | 1 | 1.23 | 3.21 | 0 | 10.030 | 10.005 | 1.0025 | 54.6 | 65.8 | 7.05 | 5.59 |
| 10 | 2 | 2 | 1.99 | 3.97 | 0 | 10.047 | 10.006 | 1.0042 | 64.3 | 76.7 | 7.86 | 6.26 |
| 10 | 3 | 1 | 3.22 | 5.20 | 0 | 10.072 | 10.006 | 1.0065 | 72.2 | 88.2 | 9.04 | 7.23 |
| 10 | 3 | 2 | 3.99 | 5.96 | 0 | 10.071 | 10.003 | 1.0068 | 82.9 | 97.2 | 9.75 | 7.85 |
| 10 | 4 | 1 | 5.22 | 7.19 | 0 | 10.071 | 10.014 | 1.0057 | 94.0 | 127.1 | 11.44 | 9.17 |
| 10 | 4 | 2 | 5.98 | 7.96 | 0 | 10.081 | 10.013 | 1.0069 | 101.6 | 137.4 | 12.23 | 9.90 |
| 10 | 5 | 1 | 7.21 | 9.19 | 0 | 10.108 | 9.999 | 1.0109 | 112.9 | 164.8 | 13.87 | 11.15 |
| 10 | 5 | 2 | 7.98 | 9.95 | 0 | 10.110 | 9.999 | 1.0111 | 117.6 | 146.4 | 14.13 | 11.42 |
| 10 | 6 | 1 | 9.20 | 11.18 | 0 | 10.143 | 10.014 | 1.0129 | 122.4 | 145.0 | 14.88 | 12.01 |
| 10 | 6 | 2 | 9.97 | 11.95 | 0 | 10.165 | 10.014 | 1.0151 | 136.3 | 160.5 | 15.68 | 12.72 |
| 10 | 7 | 1 | 11.20 | 13.17 | 0 | 10.199 | 10.014 | 1.0184 | 143.1 | 167.3 | 16.07 | 13.02 |
| 10 | 7 | 2 | 11.96 | 13.94 | 0 | 10.206 | 10.015 | 1.0191 | 144.7 | 157.2 | 16.16 | 13.22 |
| 15 | 2 | 1 | 1.23 | 3.21 | 0 | 15.033 | 15.010 | 1.0015 | 53.6 | 62.0 | 6.64 | 5.28 |
| 15 | 2 | 2 | 1.99 | 3.97 | 0 | 15.055 | 15.006 | 1.0032 | 61.3 | 70.9 | 7.37 | 5.92 |
| 15 | 3 | 1 | 3.22 | 5.20 | 0 | 15.105 | 15.016 | 1.0060 | 73.7 | 86.6 | 8.68 | 7.00 |
| 15 | 3 | 2 | 3.99 | 5.96 | 0 | 15.090 | 15.011 | 1.0053 | 76.3 | 89.1 | 9.06 | 7.28 |
| 15 | 4 | 1 | 5.22 | 7.19 | 0 | 15.111 | 15.026 | 1.0056 | 92.8 | 149.6 | 10.99 | 8.88 |
| 15 | 4 | 2 | 5.98 | 7.96 | 0 | 15.123 | 15.012 | 1.0073 | 98.0 | 131.2 | 11.78 | 9.52 |
| 15 | 5 | 1 | 7.21 | 9.19 | 0 | 15.199 | 15.014 | 1.0123 | 113.4 | 176.4 | 13.76 | 11.02 |
| 15 | 5 | 2 | 7.98 | 9.95 | 0 | 15.184 | 15.011 | 1.0116 | 113.9 | 135.8 | 13.43 | 10.87 |
| 15 | 6 | 1 | 9.20 | 11.18 | 0 | 15.220 | 15.017 | 1.0135 | 122.6 | 153.2 | 14.53 | 11.81 |
| 15 | 6 | 2 | 9.97 | 11.95 | 0 | 15.240 | 15.021 | 1.0145 | 123.8 | 152.1 | 14.52 | 11.83 |
| 15 | 7 | 1 | 11.20 | 13.17 | 0 | 15.292 | 15.034 | 1.0172 | 136.4 | 156.2 | 15.05 | 12.26 |
| 15 | 7 | 2 | 11.96 | 13.94 | 0 | 15.300 | 15.027 | 1.0182 | 132.9 | 156.4 | 15.07 | 12.19 |

X is from center of Bay 1 Window 2. Z is from test section centerline. $X_T$ is from test section entrance.
Distance from test section entrance to center of Bay 1 Window 2 is 1.976 m.
Distance from bay to bay is 78.50 in = 1.994 m

## Table F-8. Boundary Layer Summary for Average of z Locations, Part 2

| Nominal Speed | Bay | Window | Measurement Location | | | Shape Factor | Momentum Thickness Reynolds No. | Reynolds No. from test section entrance | Skin Friction | Wall Shear Stress Velocity | | Virtual origin Österlund |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| (m/s) | | | (m) | | | | | | | (m/s) | | (m) |
| | # | # | x | $x_T$ | z | H | $Re_\theta$ | $Re_x$ | $c_f$ | $u_\tau$ | $U_L/u_\tau$ | $x_0$ |
| 2.5 | 2 | 1 | 1.23 | 3.21 | 0 | 1.290 | 2.030E+04 | 9.608E+06 | 2.413E-03 | 0.087 | 28.82 | 3.510 |
| 2.5 | 2 | 2 | 1.99 | 3.97 | 0 | 1.281 | 2.200E+04 | 1.192E+07 | 2.411E-03 | 0.087 | 28.87 | 3.209 |
| 2.5 | 3 | 1 | 3.22 | 5.20 | 0 | 1.269 | 2.571E+04 | 1.566E+07 | 2.405E-03 | 0.087 | 29.01 | 3.015 |
| 2.5 | 3 | 2 | 3.99 | 5.96 | 0 | 1.271 | 2.716E+04 | 1.795E+07 | 2.370E-03 | 0.086 | 29.21 | 2.678 |
| 2.5 | 4 | 1 | 5.22 | 7.19 | 0 | 1.272 | 3.206E+04 | 2.172E+07 | 2.302E-03 | 0.085 | 29.73 | 2.866 |
| 2.5 | 4 | 2 | 5.98 | 7.96 | 0 | 1.271 | 3.371E+04 | 2.405E+07 | 2.270E-03 | 0.084 | 29.96 | 2.583 |
| 2.5 | 5 | 1 | 7.21 | 9.19 | 0 | 1.296 | 3.586E+04 | 2.776E+07 | 2.161E-03 | 0.082 | 30.71 | 2.000 |
| 2.5 | 5 | 2 | 7.98 | 9.95 | 0 | 1.263 | 4.050E+04 | 3.007E+07 | 2.213E-03 | 0.083 | 30.34 | 2.642 |
| 2.5 | 6 | 1 | 9.20 | 11.18 | 0 | 1.263 | 4.216E+04 | 3.382E+07 | 2.177E-03 | 0.082 | 30.62 | 1.924 |
| 2.5 | 6 | 2 | 9.97 | 11.95 | 0 | 1.260 | 4.643E+04 | 3.624E+07 | 2.179E-03 | 0.083 | 30.71 | 2.438 |
| 2.5 | 7 | 1 | 11.20 | 13.17 | 0 | 1.252 | 4.856E+04 | 4.022E+07 | 2.212E-03 | 0.083 | 30.66 | 1.793 |
| 2.5 | 7 | 2 | 11.96 | 13.94 | 0 | 1.252 | 4.907E+04 | 4.265E+07 | 2.226E-03 | 0.083 | 30.64 | 1.168 |
| 5 | 2 | 1 | 1.23 | 3.21 | 0 | 1.284 | 3.595E+04 | 1.926E+07 | 2.207E-03 | 0.166 | 30.22 | 3.414 |
| 5 | 2 | 2 | 1.99 | 3.97 | 0 | 1.274 | 3.976E+04 | 2.389E+07 | 2.188E-03 | 0.165 | 30.38 | 3.225 |
| 5 | 3 | 1 | 3.22 | 5.20 | 0 | 1.265 | 4.659E+04 | 3.136E+07 | 2.150E-03 | 0.164 | 30.73 | 3.046 |
| 5 | 3 | 2 | 3.99 | 5.96 | 0 | 1.260 | 5.018E+04 | 3.598E+07 | 2.133E-03 | 0.163 | 30.85 | 2.849 |
| 5 | 4 | 1 | 5.22 | 7.19 | 0 | 1.258 | 5.837E+04 | 4.340E+07 | 2.091E-03 | 0.162 | 31.17 | 2.943 |
| 5 | 4 | 2 | 5.98 | 7.96 | 0 | 1.254 | 6.317E+04 | 4.807E+07 | 2.065E-03 | 0.161 | 31.40 | 2.954 |
| 5 | 5 | 1 | 7.21 | 9.19 | 0 | 1.258 | 7.046E+04 | 5.552E+07 | 1.986E-03 | 0.158 | 32.03 | 2.932 |
| 5 | 5 | 2 | 7.98 | 9.95 | 0 | 1.249 | 7.202E+04 | 6.014E+07 | 2.021E-03 | 0.159 | 31.75 | 2.429 |
| 5 | 6 | 1 | 9.20 | 11.18 | 0 | 1.242 | 7.693E+04 | 6.777E+07 | 2.032E-03 | 0.159 | 31.77 | 2.000 |
| 5 | 6 | 2 | 9.97 | 11.95 | 0 | 1.242 | 8.039E+04 | 7.260E+07 | 2.029E-03 | 0.159 | 31.88 | 1.793 |
| 5 | 7 | 1 | 11.20 | 13.17 | 0 | 1.246 | 8.271E+04 | 8.056E+07 | 2.037E-03 | 0.160 | 32.01 | 0.887 |
| 5 | 7 | 2 | 11.96 | 13.94 | 0 | 1.244 | 8.425E+04 | 8.530E+07 | 2.040E-03 | 0.160 | 32.01 | 0.378 |

X is from center of Bay 1 Window 2. Z is from test section centerline. $X_T$ is from test section entrance.
Distance from test section entrance to center of Bay 1 Window 2 is 1.976 m.
Distance from bay to bay is 78.50 in = 1.994 m

## Table F-8. Boundary Layer Summary for Average of z Locations, Part 2 (continued)

| Nominal Speed | Bay | Window | Measurement Location | | | Shape Factor | Momentum Thickness Reynolds No. | Reynolds No. from test section entrance | Skin Friction | Wall Shear Stress Velocity | | Virtual origin Österlund |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| (m/s) | | | (m) | | | | | | | (m/s) | | (m) |
| | # | # | x | $x_T$ | z | H | $Re_\theta$ | $Re_x$ | $c_f$ | $u_\tau$ | $U_L/u_\tau$ | $x_0$ |
| 10 | 2 | 1 | 1.23 | 3.21 | 0 | 1.262 | 6.712E+04 | 3.851E+07 | 2.001E-03 | 0.316 | 31.72 | 3.592 |
| 10 | 2 | 2 | 1.99 | 3.97 | 0 | 1.255 | 7.532E+04 | 4.779E+07 | 1.982E-03 | 0.315 | 31.93 | 3.509 |
| 10 | 3 | 1 | 3.22 | 5.20 | 0 | 1.250 | 8.722E+04 | 6.273E+07 | 1.969E-03 | 0.314 | 32.12 | 3.292 |
| 10 | 3 | 2 | 3.99 | 5.96 | 0 | 1.240 | 9.473E+04 | 7.195E+07 | 1.951E-03 | 0.312 | 32.26 | 3.181 |
| 10 | 4 | 1 | 5.22 | 7.19 | 0 | 1.247 | 1.106E+05 | 8.678E+07 | 1.893E-03 | 0.308 | 32.75 | 3.365 |
| 10 | 4 | 2 | 5.98 | 7.96 | 0 | 1.236 | 1.196E+05 | 9.611E+07 | 1.880E-03 | 0.307 | 32.89 | 3.398 |
| 10 | 5 | 1 | 7.21 | 9.19 | 0 | 1.244 | 1.350E+05 | 1.112E+08 | 1.798E-03 | 0.300 | 33.73 | 3.556 |
| 10 | 5 | 2 | 7.98 | 9.95 | 0 | 1.236 | 1.383E+05 | 1.205E+08 | 1.848E-03 | 0.304 | 33.28 | 3.088 |
| 10 | 6 | 1 | 9.20 | 11.18 | 0 | 1.239 | 1.459E+05 | 1.358E+08 | 1.825E-03 | 0.302 | 33.58 | 2.541 |
| 10 | 6 | 2 | 9.97 | 11.95 | 0 | 1.232 | 1.549E+05 | 1.455E+08 | 1.842E-03 | 0.303 | 33.50 | 2.583 |
| 10 | 7 | 1 | 11.20 | 13.17 | 0 | 1.233 | 1.591E+05 | 1.610E+08 | 1.847E-03 | 0.304 | 33.59 | 1.718 |
| 10 | 7 | 2 | 11.96 | 13.94 | 0 | 1.221 | 1.616E+05 | 1.704E+08 | 1.833E-03 | 0.303 | 33.75 | 1.174 |
| 15 | 2 | 1 | 1.23 | 3.21 | 0 | 1.256 | 9.516E+04 | 5.772E+07 | 1.893E-03 | 0.461 | 32.59 | 3.599 |
| 15 | 2 | 2 | 1.99 | 3.97 | 0 | 1.244 | 1.067E+05 | 7.160E+07 | 1.883E-03 | 0.460 | 32.72 | 3.513 |
| 15 | 3 | 1 | 3.22 | 5.20 | 0 | 1.239 | 1.266E+05 | 9.408E+07 | 1.856E-03 | 0.457 | 33.08 | 3.468 |
| 15 | 3 | 2 | 3.99 | 5.96 | 0 | 1.245 | 1.316E+05 | 1.078E+08 | 1.837E-03 | 0.455 | 33.21 | 3.021 |
| 15 | 4 | 1 | 5.22 | 7.19 | 0 | 1.237 | 1.607E+05 | 1.302E+08 | 1.790E-03 | 0.449 | 33.68 | 3.592 |
| 15 | 4 | 2 | 5.98 | 7.96 | 0 | 1.238 | 1.724E+05 | 1.442E+08 | 1.761E-03 | 0.445 | 33.99 | 3.560 |
| 15 | 5 | 1 | 7.21 | 9.19 | 0 | 1.249 | 2.007E+05 | 1.673E+08 | 1.676E-03 | 0.434 | 35.00 | 4.100 |
| 15 | 5 | 2 | 7.98 | 9.95 | 0 | 1.235 | 1.978E+05 | 1.810E+08 | 1.735E-03 | 0.442 | 34.38 | 3.163 |
| 15 | 6 | 1 | 9.20 | 11.18 | 0 | 1.230 | 2.153E+05 | 2.038E+08 | 1.735E-03 | 0.442 | 34.46 | 3.045 |
| 15 | 6 | 2 | 9.97 | 11.95 | 0 | 1.226 | 2.160E+05 | 2.181E+08 | 1.747E-03 | 0.443 | 34.39 | 2.314 |
| 15 | 7 | 1 | 11.20 | 13.17 | 0 | 1.227 | 2.245E+05 | 2.413E+08 | 1.741E-03 | 0.442 | 34.58 | 1.623 |
| 15 | 7 | 2 | 11.96 | 13.94 | 0 | 1.237 | 2.234E+05 | 2.555E+08 | 1.741E-03 | 0.443 | 34.59 | 0.782 |

X is from center of Bay 1 Window 2. Z is from test section centerline. $X_T$ is from test section entrance.
Distance from test section entrance to center of Bay 1 Window 2 is 1.976 m.
Distance from bay to bay is 78.50 in = 1.994 m

# APPENDIX G: GLASS WINDOWS FOR LDA MEASUREMENTS

All windows initially installed in the Large Cavitation Channel (LCC) were fabricated from 95.2 mm (3.75 inch) thick clear acrylic (Plexiglas). The acrylic windows are suitable for qualitative viewing of the channel flow but proved marginal for quantitative Laser Doppler Anemometry (LDA) measurements. The acrylic windows have several limitations for LDA including: insufficient flatness of the window surfaces, non-homogeneity of the material which causes diffraction of the laser beams, and residual stresses in the material which cause the polarization of light passing through to change. Testing of the acrylic windows demonstrated that most were unsuitable for LDA, and those that were still had some problems such as inability to measure near the window edges, regions of the window that produced poor data rates, and variations in the velocity measurements that were not representative of the flow. Two windows, numbers 20 and 25, were found to work best with LDA.

In order to improve the performance of the external LDA system, two glass windows were procured. These windows were delivered in 2008. The glass windows are the same overall size as the acrylic windows but differ at the window edges. The glass windows are sealed differently than the acrylic windows and the window clamps are more complex to ensure that clamping forces on the window edges are distributed uniformly. The window dimensions and specifications are in Figure G-1, and the window frame assembly is in Figure G-2. The optical specifications of the windows include:

- Transmissive range 350-2000 nm
- Parallelism better than 10 arc seconds
- Scratch and Dig of 60-40
- Long range index of refraction homogeneity of ± 0.000050 or better
- Flatness within ¼ wavelength of 632 nm within any 1 inch radius
- Clear aperture to within 19.0 mm (¾ inch) of the smaller (inner) surface of the window

Naval Surface Warfare Center Carderock Division (NSWCCD) contracted with the Arnold Engineering Development Center (AEDC) for engineering and analysis support for the windows and the supporting window frame. The windows were made from S-BSL-7 castings from Ohara. This glass is a BK-7 equivalent. The glass blanks were finished and polished by Zygo.

Upon delivery, the windows were inspected and tested as documented in Chesnakas [G-1]. This testing verified the improved LDA performance for the glass windows relative to the acrylic windows. The data rate was uniform across the measurement aperture of the window, variations in the measured flow velocity were reduced, and the usable aperture of the window was found to extend to the window edge. Unfortunately, the inspection also found an internal inclusion in one of the windows. The inclusion showed stress concentrations that could lead to crack propagation under pressure cycling. At that time, the window still met the specifications of the contract with

Zygo, and any fix or replacement of the window would be at government expense. Funds were not available for window replacement at that time, and the flawed glass window was removed from the frame and replaced with an acrylic window. LDA measurements are only acquired through the glass window.

In the normal orientation of the window frame, the glass window is in the downstream location of the bay. If measurements are in the upstream location of the bay, the window frame must be rotated 180 degrees.

## REFERENCES

[G-1] Chesnakas, C. J., 2008, "Evaluation of the Performance of the LCC Windows for use in Laser Doppler Velocimetry, " Hydromechanics Directorate, Naval Surface Warfare Center Carderock Division, West Bethesda, Maryland, USA, Research and Development Report NSWCCD-50-TR-2008/031.

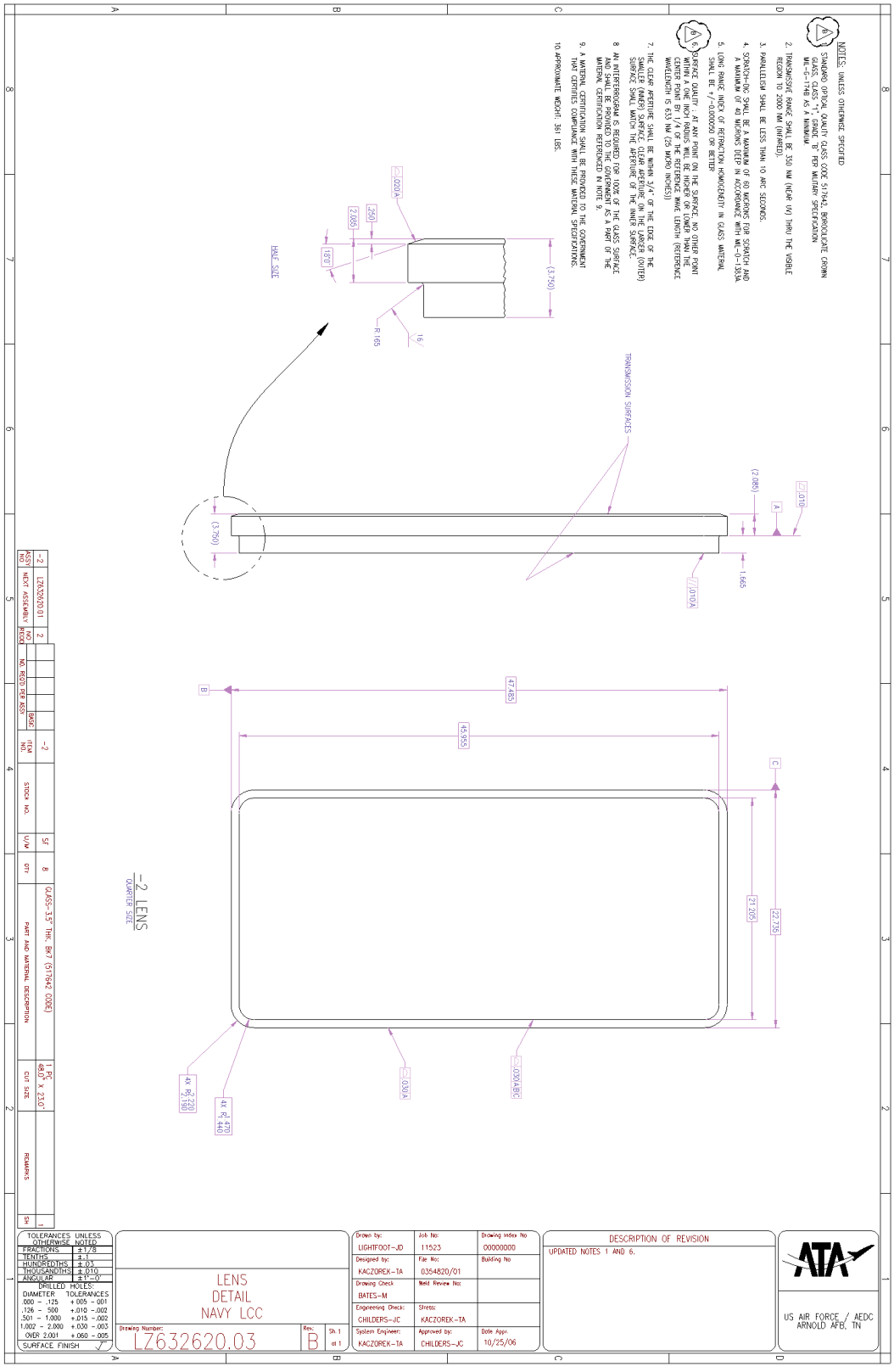



**Figure G-1. LCC Glass Window Dimensions and Specifications**

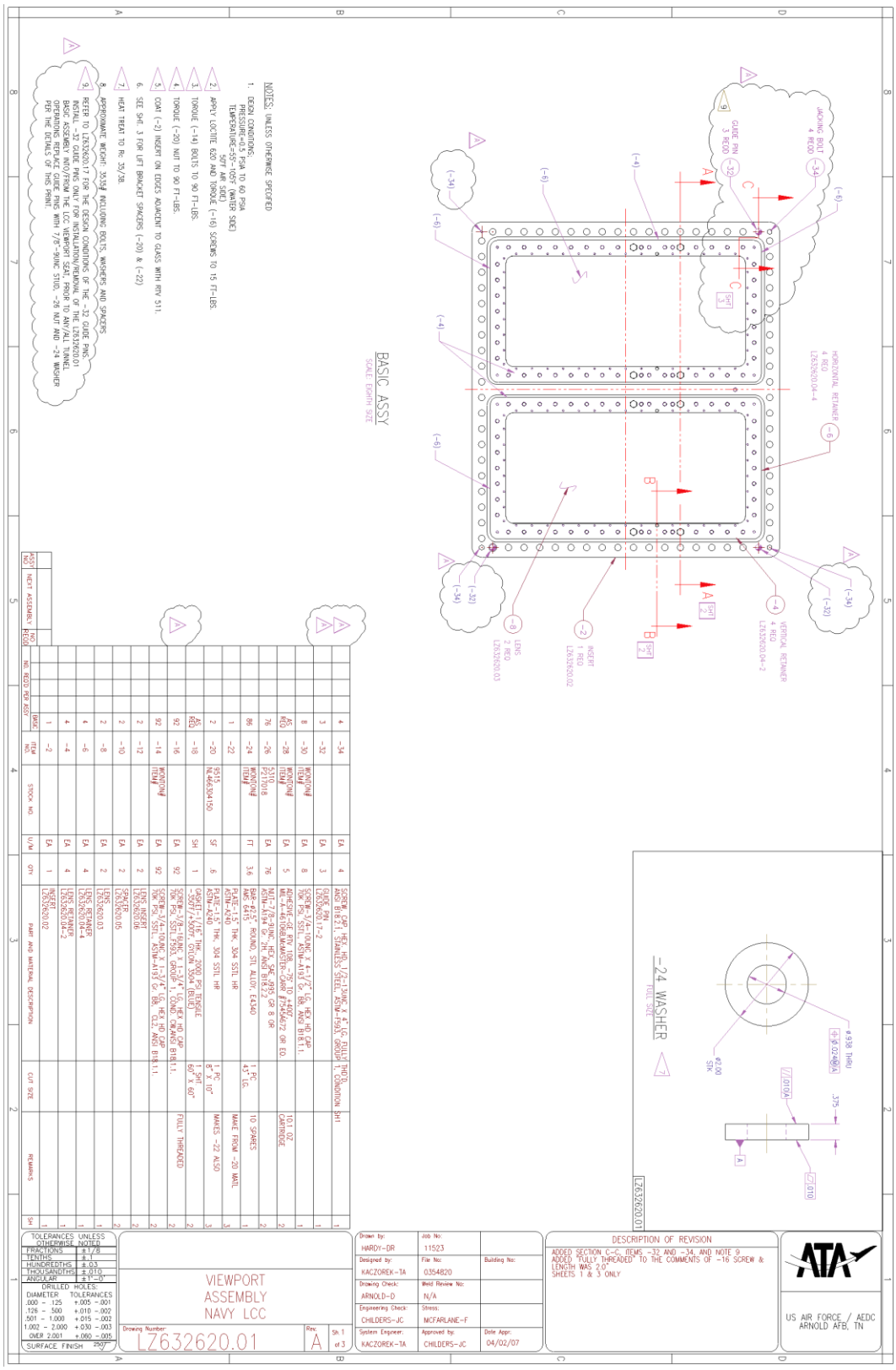


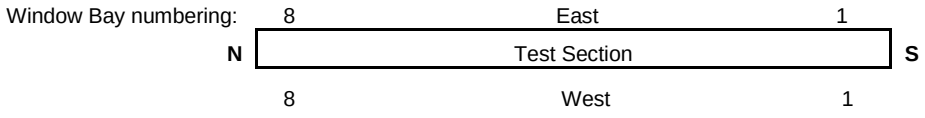

**Figure G-2. LCC Glass Window Assembly Dimensions**

# APPENDIX H: OPTICAL QUALITY OF LCC ACRYLIC WINDOWS

THIS PAGE INTENTIONALLY LEFT BLANK

## Table H-1. LCC Window Inventory and Condition

| Window | Location | Surface Condition | Optical Condition |
|---|---|---|---|
| 1 | Shop 4 | | |
| 2 | Shop 4 | | |
| 3 | Shop 4 | | |
| 4 | Shop 4 | Deep scratches 1/16 deep-HiFoil trailing edge damage; 9 screw head marks 5/16 diam.; Edge chip; deep edge fracture; | Best (China Lake)* |
| 5 | Shop 4 | Paint spots | Poor (China Lake)* |
| 6 | Shop 4 | Tar spot | |
| 7 | Shop 4 | | |
| 8 | Shop 4 | "S" scratch; HiPlate Line | |
| 9 | Shop 4 | | |
| 10 | Shop 4 | HiPlate Line | |
| 11 | Shop 5 | Non repairable broken edges | |
| 12 | West Platform | | |
| 13 | East Platform | | |
| 14 | East Platform | | |
| 15 | East Test Section E1B | | |
| 16 | East Test Section E8B | HiPlate Line | |
| 17 | East Test Section E8A | HiPlate Line; vertical scratches (From tubing) | |
| 18 | West Test Section W1A | | |
| 19 | West Test Section W1B | | |
| 20 | West Test SectionW2A | Scratches 1/32 deep; 2 scratches ("L"-shape 13/8 x 11/8") (2nd is "I" shaped 3/8" x 1/8") | |
| 21 | West Test Section W2B | | |
| 22 | West Test Section W3A | Deep scratches 1/16 deep; 12 screw head marks diam. 5/16"; HiFoil Leading edge damage | Best |
| 23 | West Test Section W3B | | |
| 24 | West Test Section W4A | | |
| 25 | West Test Section W4B | Tape residue | |
| 26 | West Test Section W5A | Tape residue; scratches 1/32 deep | |
| 27 | West Test Section W5B | Major dent (Melted?) elliptical 3/4 x 1/4" | |
| 28 | West Test Section W6A | Major scrape and scratches 1/32 deep; HiPlate line | |
| 29 | West Test Section W6B | | |
| 30 | West Test Section W7A | | |
| 31 | West Test Section W7B | | |
| 32 | West Test Section W8A | | |
| 33 | West Test Section W8B | Scratches 1/64 deep | |
| 34 | Test top | Scratches 1/64 deep | |
| 35 | Test top | | |
| 36 | Test top | | |
| 37 | Test top | | |
| 38 | Test top | | |
| 39 | Test top | | |
| 40 | Test top | | |
| 41 | Test top | | |
| 42 | Test top | | |
| 43 | Test top | | |




by: Immual Mills, Joel Park & Sam Hick

8 October 2003

*Marrs, C. Denton, and Decker, Donald, 2002, "Optical Characterization of Acrylic Windows Used on the William B. Morgan Large Cavitation Channel at NSWC-Memphis," Code 4T4100D, Sensor and Signal Sciences Division, Naval Air Warfare Center Weapons Division, China Lake, CA. 93555.

THIS PAGE INTENTIONALLY LEFT BLANK

# Optical Characterization of Acrylic Windows Used on the William B. Morgan Large Cavitation Channel at NSWC-Memphis

**28 June 2002**

**by**
**C. Denton Marrs and Donald Decker**
**Code 4T4100D**
**Sensor and Signal Sciences Division**
**Naval Air Warfare Center Weapons Division**
**China Lake, CA. 93555**

## Table of Contents

**Introduction..... 3**

**Stress Birefrigence Test..... 3**

**Grid Board Test..... 9**

**Index of Refraction Measurement..... 16**

**Wavefront Distortion Measurement..... 17**

**Summary and Recommendations..... 22**

## Introduction

At the request of the William B. Morgan Large Cavitation Channel Laboratory located at Naval Surface Warfare Center, Memphis, the Naval Air Warfare Center Weapons Division (NAWCWD) characterized two of the large acrylic windows used on the cavitation channel. This characterization was requested due to the use of the windows as optical ports into the channel to measure the flow fields of the water in the channel and the observation that some of the windows were useable for this application, while others were not. To try and understand the optical difference between these windows, NAWCWD, received two windows, one marked "Not for laser use" and the other unmarked. Each window was subjected to four tests,

A. Stress Birefringence
B. Grid Board
C. Index of Refraction
D. Interferometric Wavefront Distortion.

The Stress Birefringence test looks at stress lines in the window material and gives a measure of depolarization of the incident light. The Gird Board test looks at the uniformity of the refractive index and provides a measure of the angular deviations that light will encounter passing through the material. The Index of refraction measurement was accomplished to further look at spot to spot material uniformity and to positively identify the material since there was some question in that regard. The wavefront distortion test was accomplished in double pass and measures the wavefront error induced to an incident plane wave upon its passing both directions through the same volume of a material of the window. The specifics of each measurement will be discussed in the remainder of this report.

Before the tests were started a simple mount was constructed to hold the windows on their edge. This can be seen in Figure 1. Throughout the remainder of this report the "Unmarked Window" will be assumed to be the "Good Window" and the window marked "Not for laser use" will be called the "Bad Window".

The digital camera that was used for recording the images was a Olympus Model 3030. It was used on maximum resolution of 2048 X 1024 in a manual focus and exposure mode.

## A. Stress Birefrigence Test

The set-up for the Stress Birefringence measurement is shown in Figure 1. Three areas per window were measured, right, center and left. Each area was a 9 inch square. This size limitation was due to the aperture of the polarizing waveplates. The optical axes of the two polarizers are aligned to be orthogonal to each other. .This is shown in Figure 2 where no transmitted green 546 nm light is observed. The light source is a mercury discharge lamp with a 546 filter in place to remove other mercury

lines. This was done to simulate the nearby argon laser line 514 nm used in the flow field measurement. This light is then polarized by the first polarizer as shown in Figure 1 then passes through the window under test and is then analyzed by the second orthogonally aligned polarizer. Figure 2 shows this null condition. No light reaches the camera lens to be recorded. Figure 3 shows the appearance at the observation point with the introduction of a high quality optical glass window , 12 in diameter, 0.5 in thick, into the sample area. Again a null condition is obtained. However, when either of the two chamber windows are introduced, bright images are obtained at the camera. Bright areas that are visible are the result of rotation of the plane of polarization by stress birefringence or by depolarization by the bulk material. We made no attempt at calibrating this measurement but are using the qualitative results to provide a top level assessment of window optical quality and guidance for other measurements.

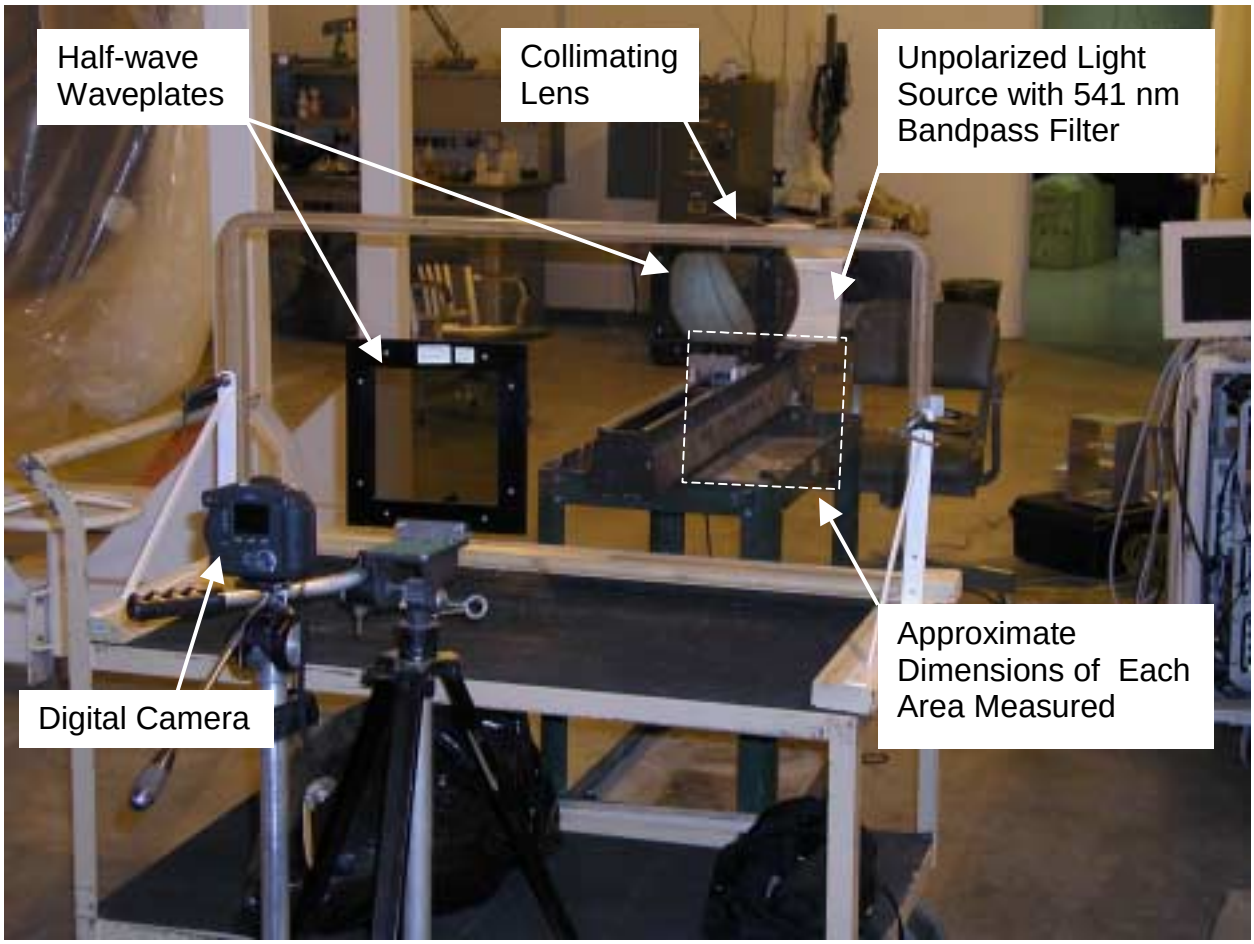


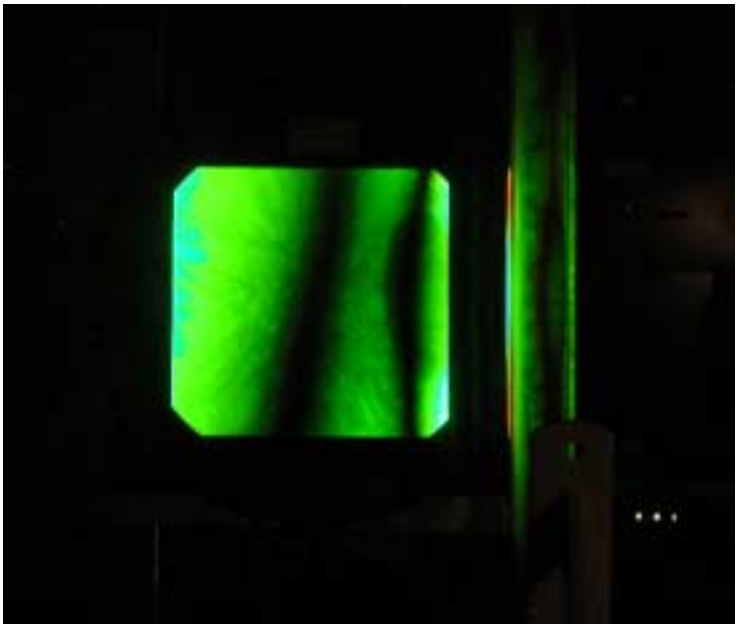

**Figure 1. Stress Birefrigence Set-up.** Three areas per window were measured, Left, Center, and Right.

**Figure 2. Orthogonally-Aligned Polarizing Waveplates**

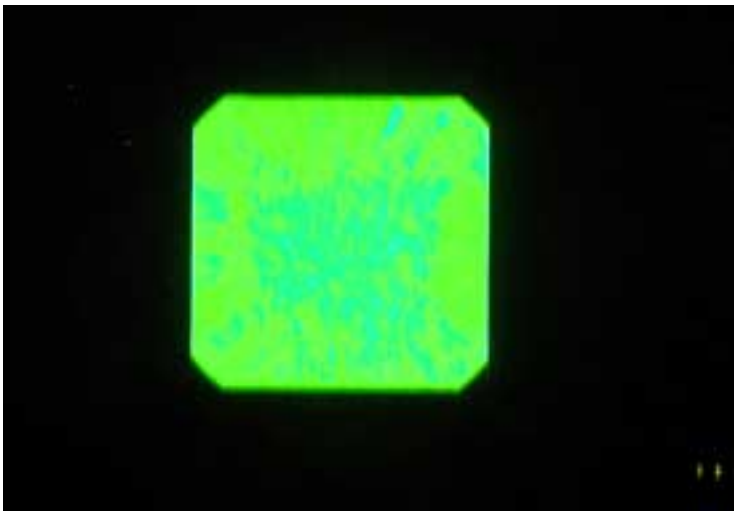
**Figure 3. 12 inch Optical Flat between Orthogonally-Aligned Polarizing Wave Plates**

Figures 4 and 5 show the stress birefringence patterns for the three positions measured on the "Good Window" and "Bad Window", respectively. The analyzing polarizer was rotated for all three positions and windows to observe variations in the depolarization. In the case of the "Good Window" and "Bad Window", no variation in the depolarization was observed with rotation of the analyzer. This is evidence of very strong depolarization by the windows. Such an effect is the result of microscale variation in the index of refraction of the bulk material and is typical of condensed polymer plastic materials such as acrylic. This statement is also supported by the fact that the stress lines observed on each end of both windows are fuzzy and not sharp edged. This is particularly true in the "Bad Window". The stress lines are very strong and are associated with the end features of the windows. Lesser banding is visible along the top and bottom edges. The stress birefringence observed is probably a result of the machining of the edge features. These observations are in very strong contrast to the null result shown for the optical glass window in Figure 3.

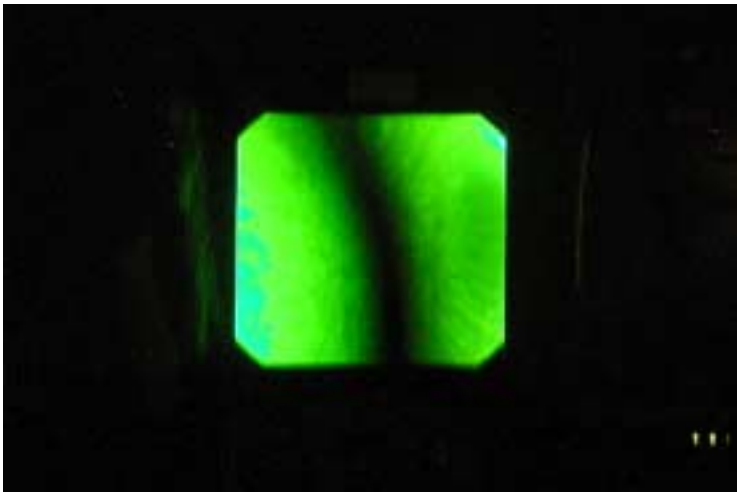
**Figure 4. “Good Window”**



Right-side Area, ~8 inches from edge.

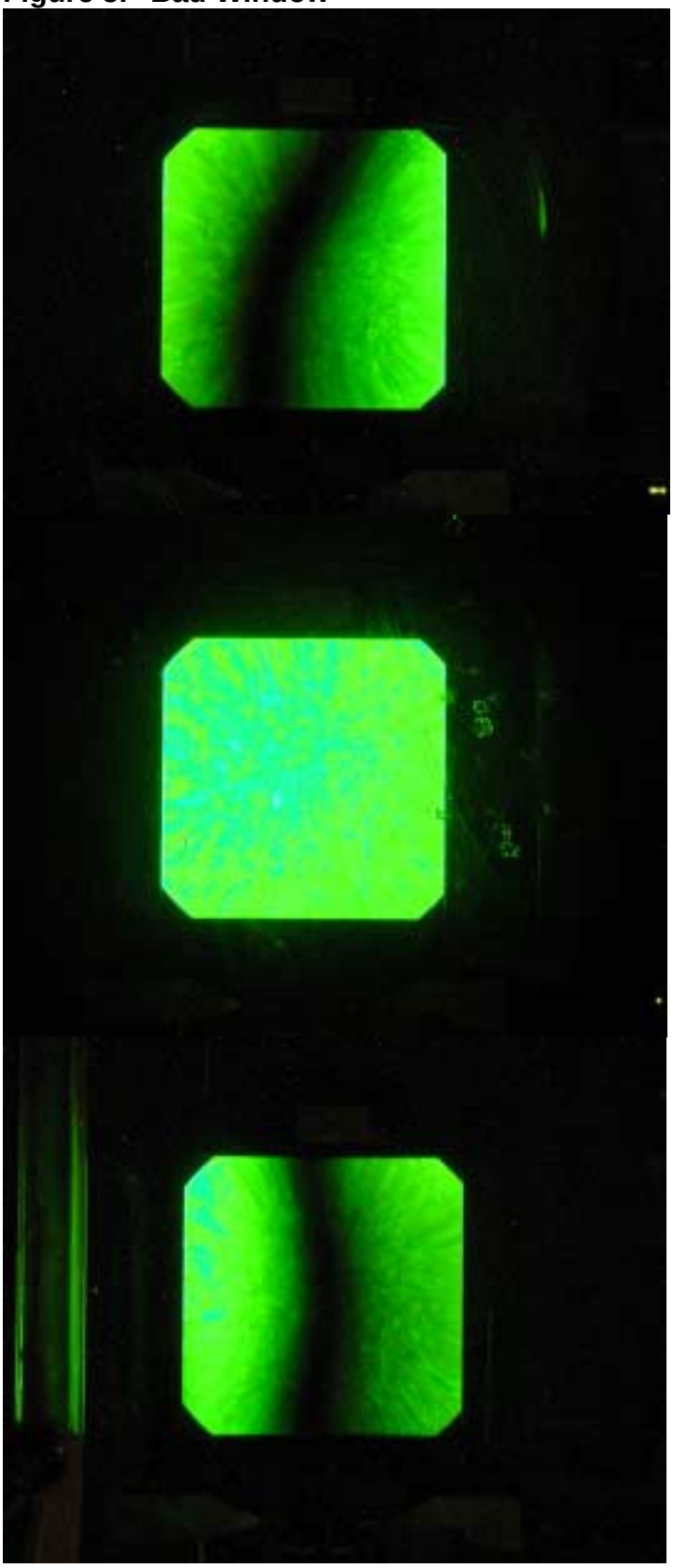


Center Area



Left-side Area, ~8 inches from edge.

**Figure 5. “Bad Window”**



Right-side Area , ~8 inches from edge.

Center Area

Left-side Area, ~8 inches from edge.

## B. Grid Board Test

The experimental set-up used for the Grid Board test is shown in Figure 6. The grid is projected to a screen so as to have a 1 inch spacing. The object under test is placed a fixed distance from the screen, in this case 88 inches. The camera is placed in position immediately behind the object under test to record grid line straightness. This is a standard test for aircraft transparency optical quality. Measuring the observed deviations in the lines making up the grid allows the computation of angular deviation that is induced in the light propagating through the window. This gives a measure of index of refraction uniformity and general flatness and parallelism.

Figure 7 is the reference image of the grid observed without a window. Figures 8-9 and 10-11 show the images of the two windows for the two areas, each 18 x 20 inches observed on each window. It is apparent from comparison of these images that both windows are good from an angular deviation prospective. The largest observed deviation was <0.1inch. This translates into an angular deviation of <1 mrad. This was observed on the "Bad Window" in the corner of the observation area near the radius corner of the window. This is close to the region that stress lines were observed in this window.

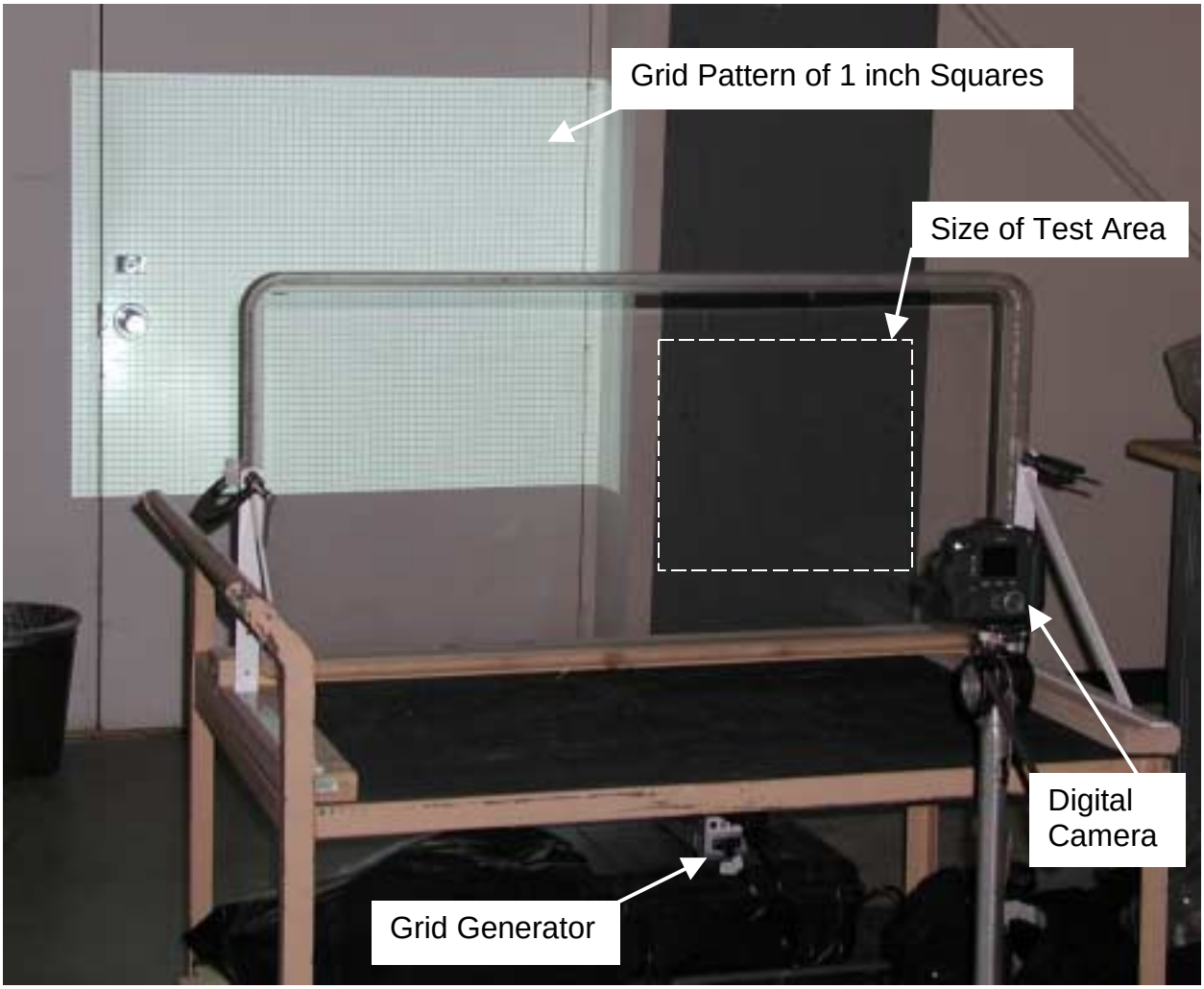



**Figure 6. Grid Broad Test Set-up** Two Area were measured per window

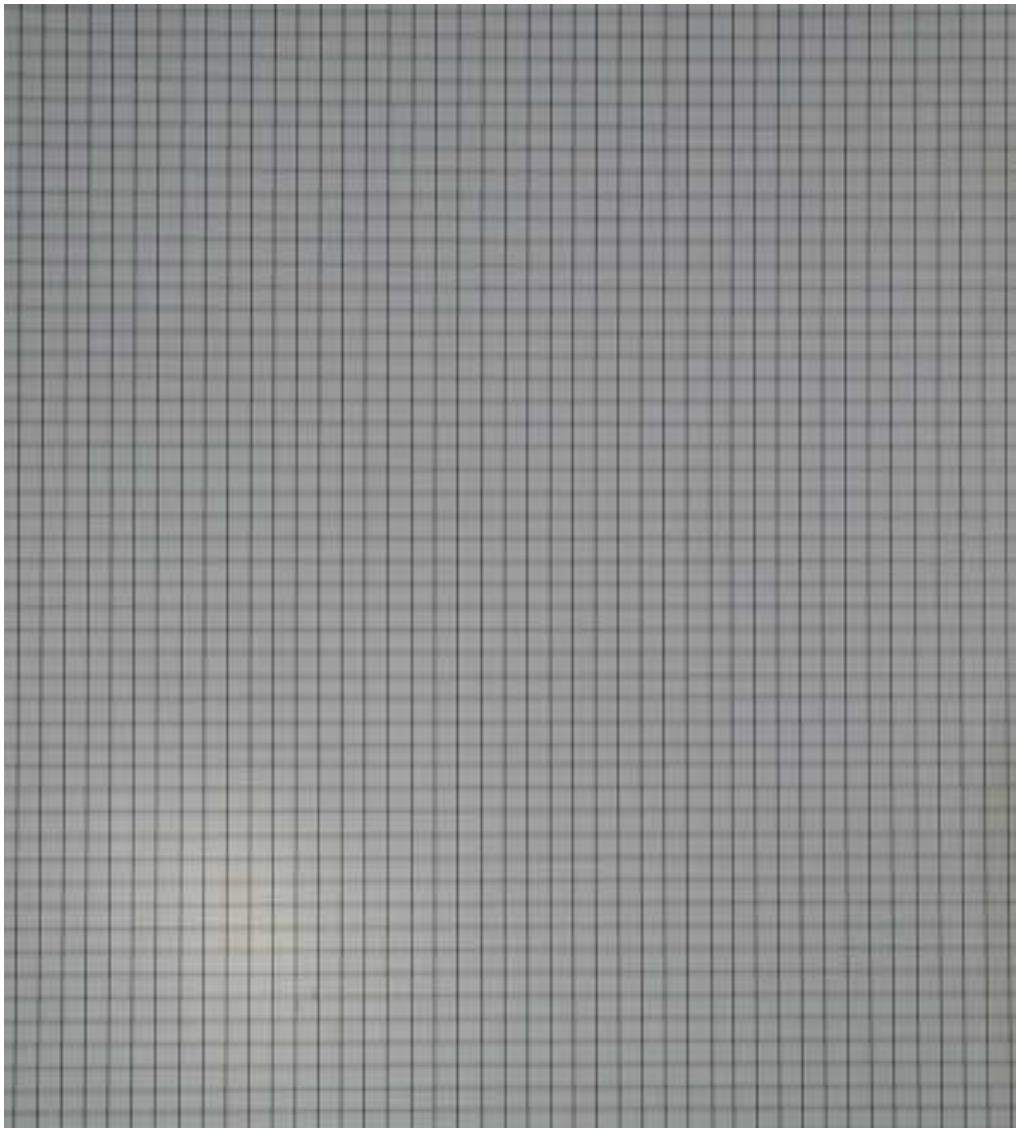


**Figure 7. Reference Grid**

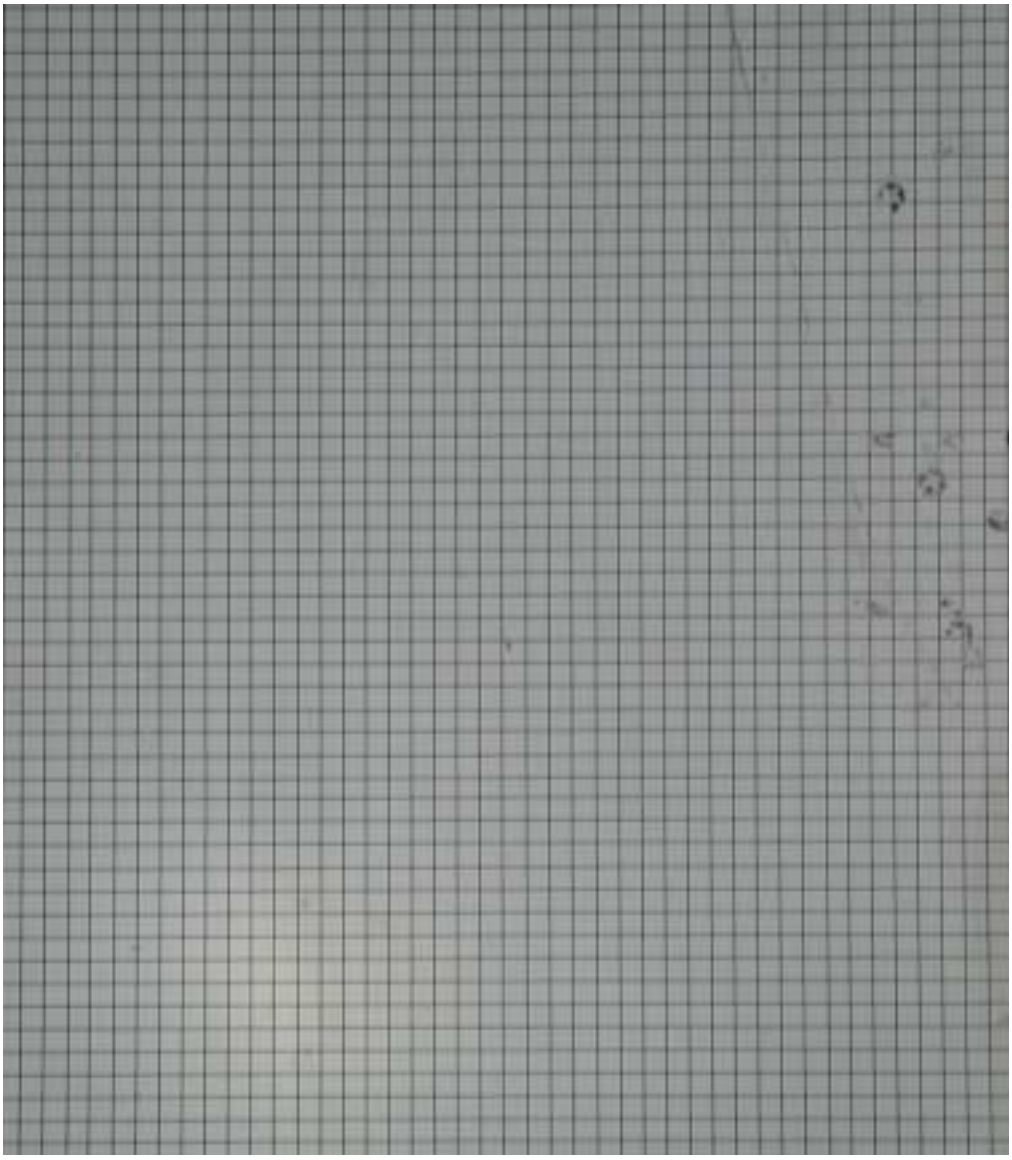


**Figure 8. Right-Side, Good Window**

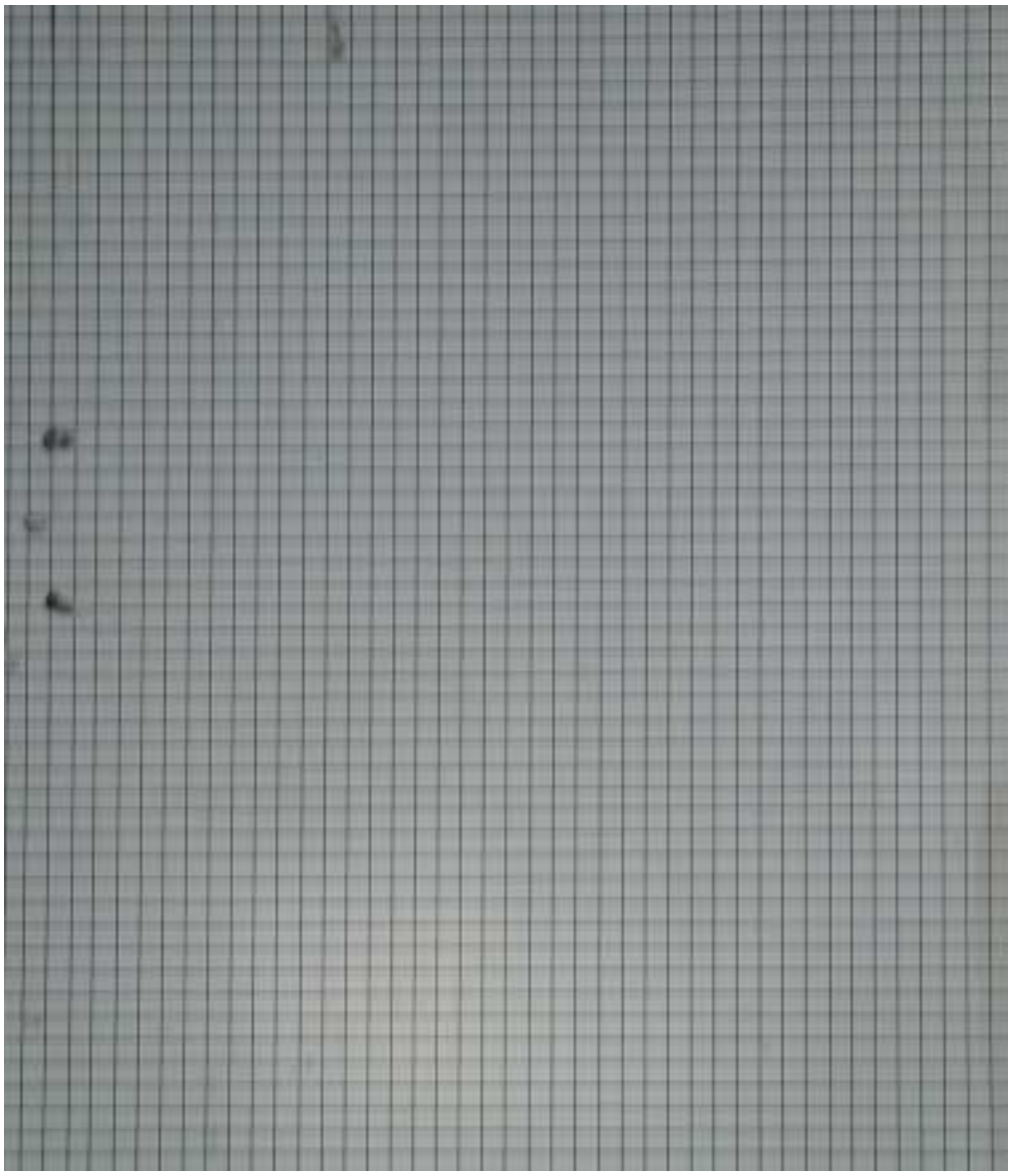


**Figure 9. Left-Side, Good Window**

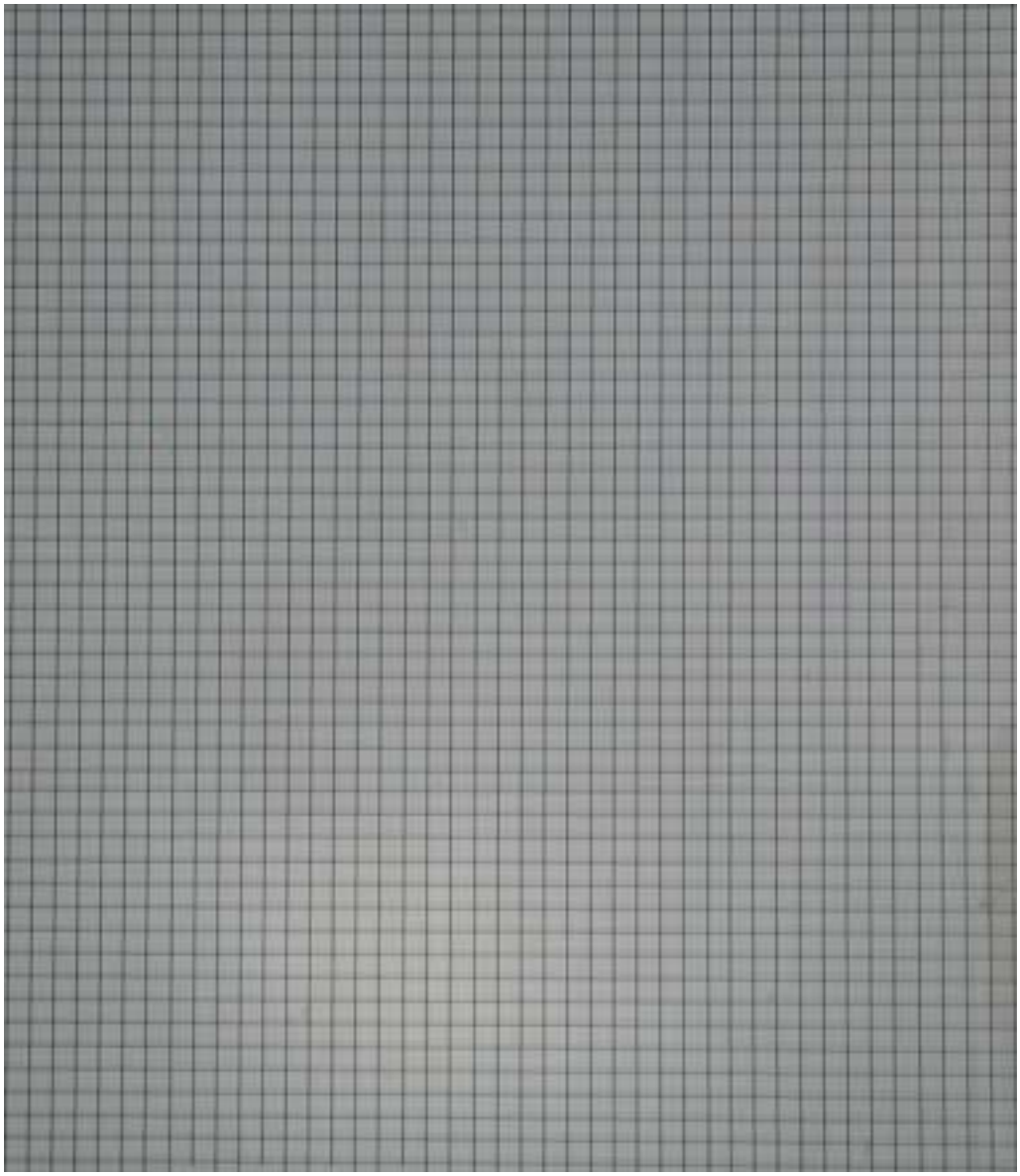


**Figure 10. Right-Side, Bad Window**

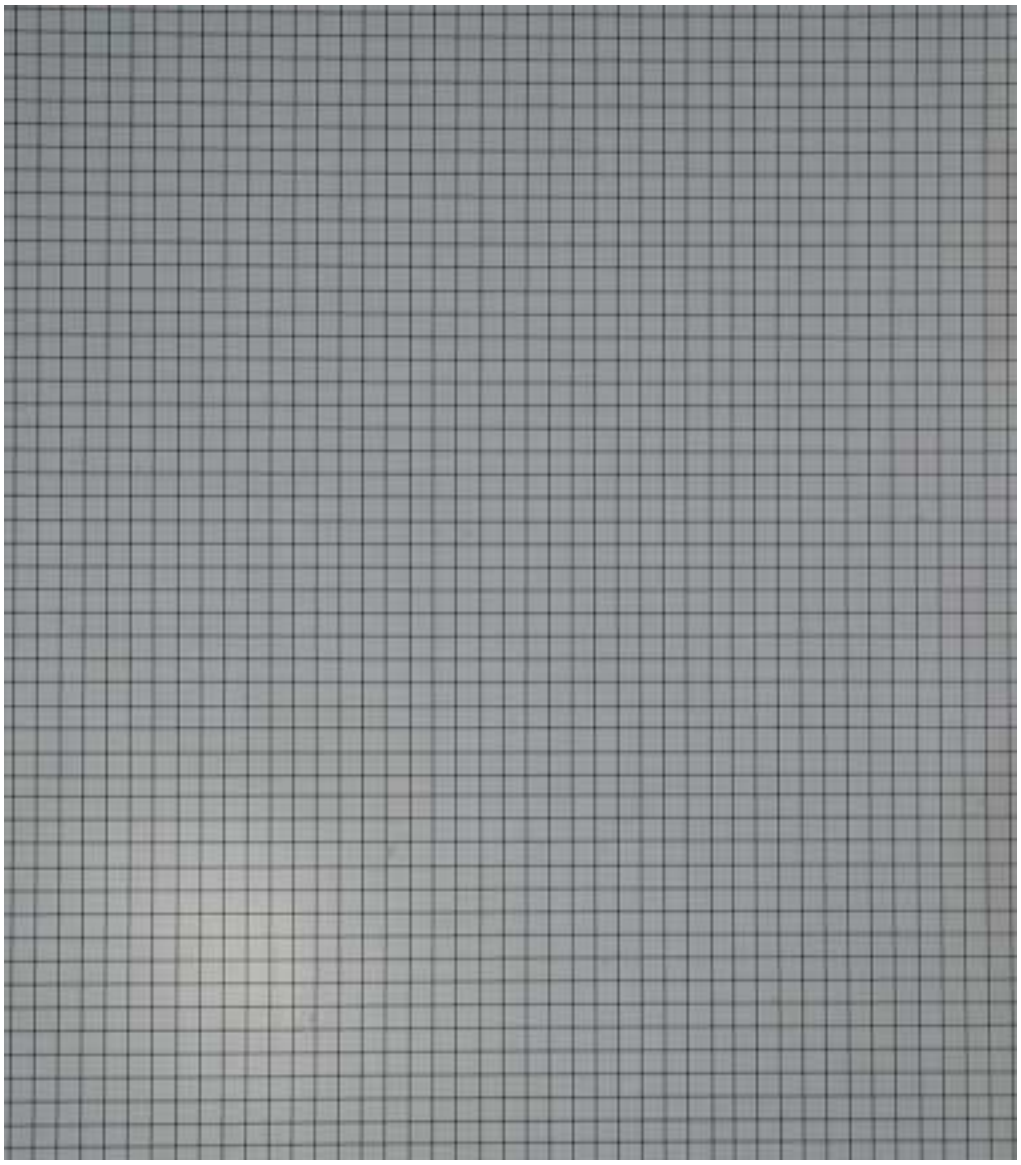


**Figure 11. Left-Side, Bad Window**

## C. Index of Refraction Measurement

Figure 12 shows the measurement of the index of refraction of the two windows. A portable refractometer was used that has the capability to measure the index of refraction at any visible wavelength, but a He/Ne line filter at 633 nm was used for convenience. This measurement was undertaken to confirm the composition of the material of the window. It was observed that the windows are not the same color, when viewed through the edge with white light. Table 1 shows the measured index of refraction for the two windows.

**Table 1. Index of Refraction for Cavitation Channel Windows/Materials**

| Window/Material | Index of Refraction |
|---|---|
| "Good Window" | 1.4862 |
| "Bad Window" | 1.4855 |
| Acrylic Polymer | 1.485 (Handbook value) |

Note: The index of acrylic polymer is provided for reference.

The index of refraction reported is the average of three measurements at several locations. No variation in index of refraction was noted on a given window. The indices of refraction are essentially the same for both windows and the value obtained is identical to the published Handbook value for polymethylmethacrylate (acrylic plastic). The color differences of the two windows probably relate to differences in the condensation rate when the plastic was polymerized. It was observed that the two windows appear to have different physical density as well but no weight measurements were made. Three people observed the "Good Window" appeared heavier than the "Bad Window" during the handling process of doing the measurements. However, it is unlikely that the small differences in density likely to be present could actually be detected in lifting. The windows are typical of commercially available acrylic material.

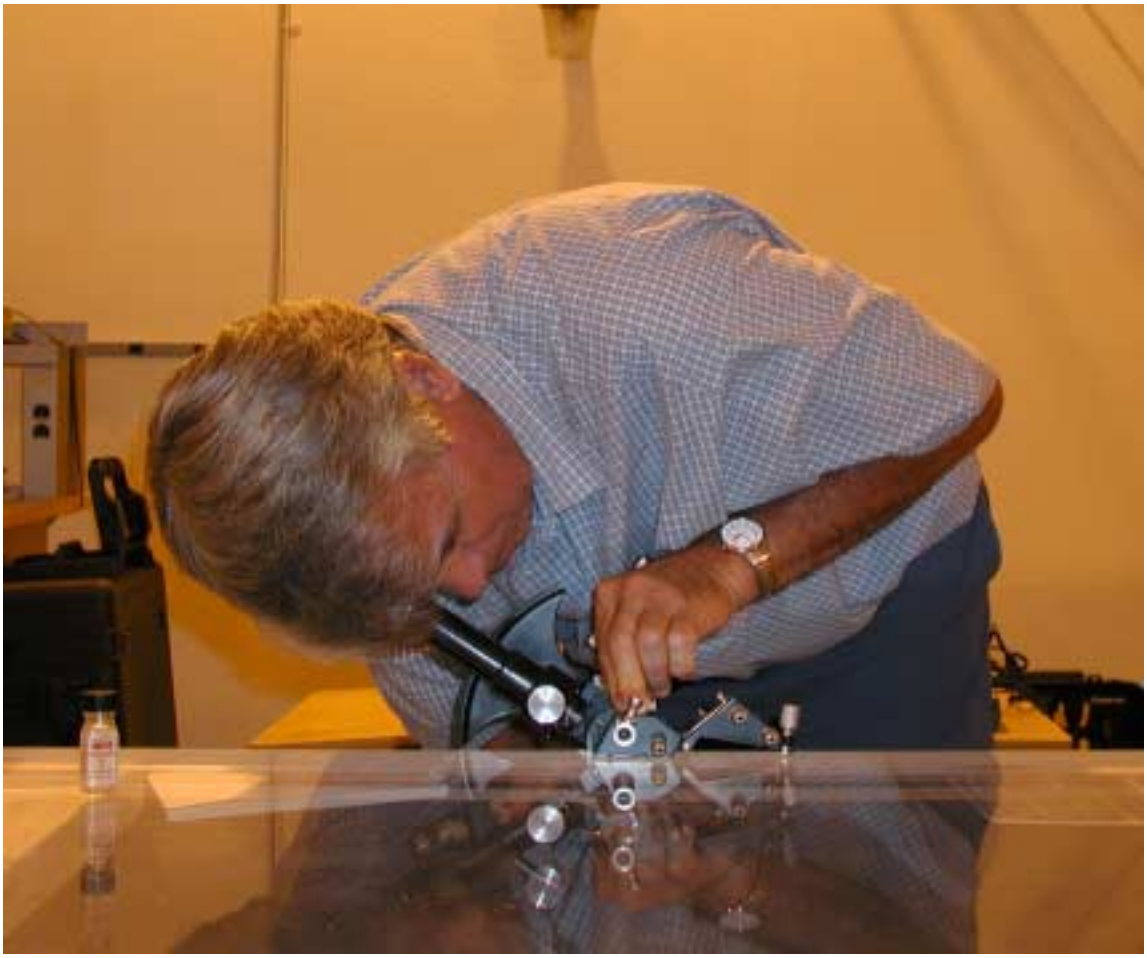


**Figure 12. Optical Refractometer**

## D. Wavefront Distortion Measurement

The set-up for the double-pass wavefront distortion measurement is shown in Figure 13. A Zygo interferometer was used to measure the wavefront distortion with a 6 inch beam expander. The beam expander was operated in a “zoom” mode and the interferograms shown in the following figures are for apertures about 1½ inches in diameter. Three measurements were made per window and these areas are denoted as right, center, and left locations.

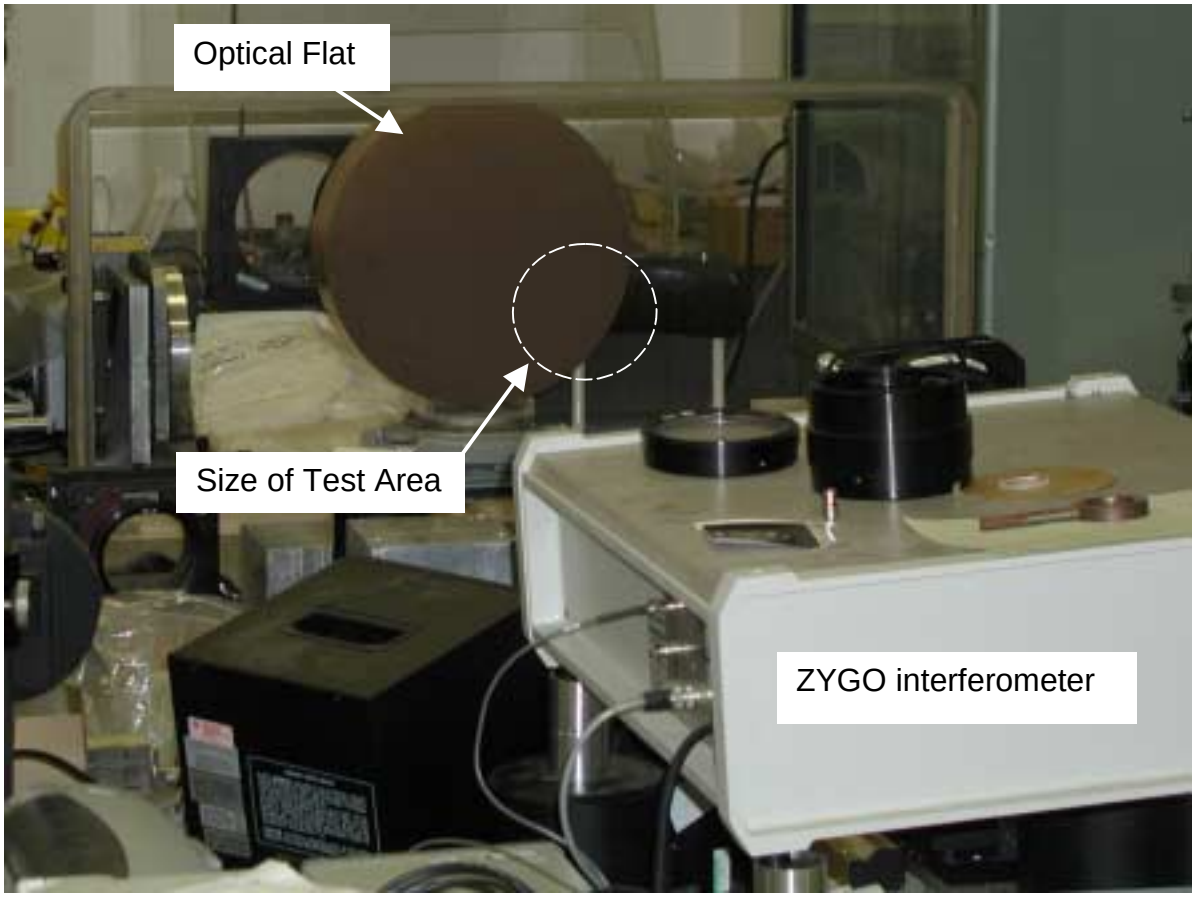



**Figure 13. Wavefront Distortion Measurement** Three areas were measured per window- right, center, and left.

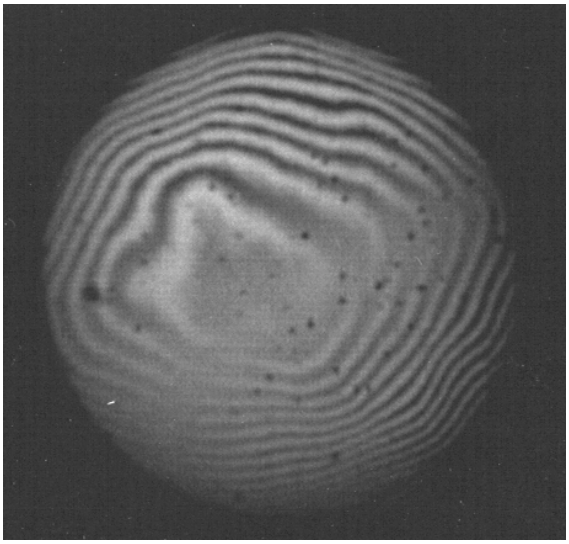
The interferograms for the "Good Window" are shown in Figure 14. It was difficult to get the interferometer into alignment due to the very bad distortion induced in the returning wavefront. The interferograms obtained show that the planar wavefront that was incident on the window has been distorted into a steep wavefront with a lot of both spherical and cylindrical power. The circular-like central region, in Figure 14 - right side, is the peak of the wavefront and the increasing number of constant phase lines and decreasing distance between these lines as the wavefront moves to the edge of the interferogram indicate the increasing steepness or slope of the phase error induced in the wavefront. Note that at the edge of the interferogram the phase lines are so close together that they are not distinguishable. The other sites measured on the "Good Window" are not much different. The Zygo software deduced an induced wavefront error of 5-6 waves over a very limited area of just an inch or so in diameter. The single pass wavefront error is thus 2.5 to 3 waves across an aperture of one inch.

The interferograms for the "Bad Window" are shown in Figure 15. Comparison to the results for the "Good Window" show that the wavefront distortion is even more severe. In fact, in the center of this window the distortion is so extreme that only a few fringes are visible due to lack of sufficient uniformity to produce a cavity from which to

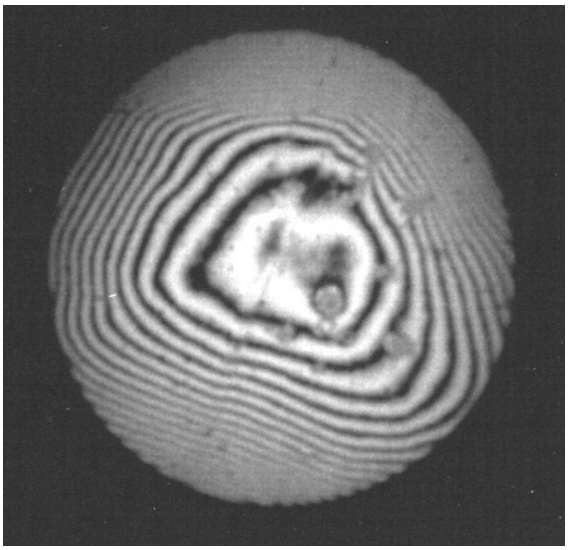
actually form fringes. The deduced single pass wavefront error is in the 8-10 waves per inch of aperture range. The wavefront errors observed are largely due to the lack of optical flatness of the surfaces. There is large small scale(mm) and large scale (cm) irregularity present on both windows. The surfacing has apparently been done with soft tools in a buffing type operation.

It is a rule of thumb that when the wavefront error exceeds a half wave across the system aperture the resulting image distortion is usually not acceptable for "precision" imaging. For measurements involving interference (as in the present use of these windows) a wavefront quality of 1/10 of a wave is commonly specified. It is clear that the windows examined are not actually useable for optical application requiring wavefront uniformity.

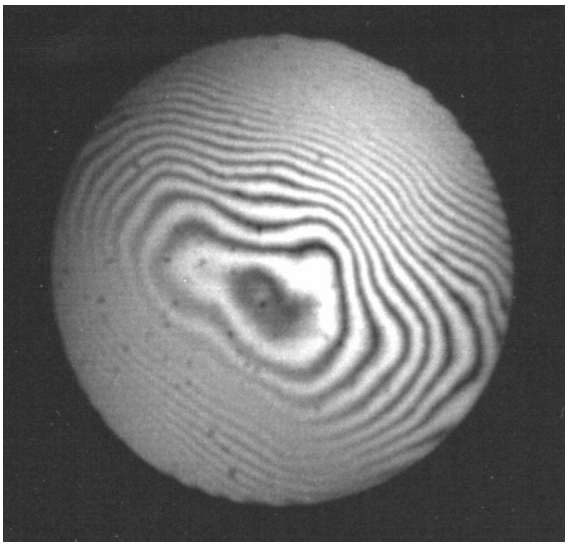
**Figure 14. Wavefront Distortion in "Good Window"**



1a Right Side

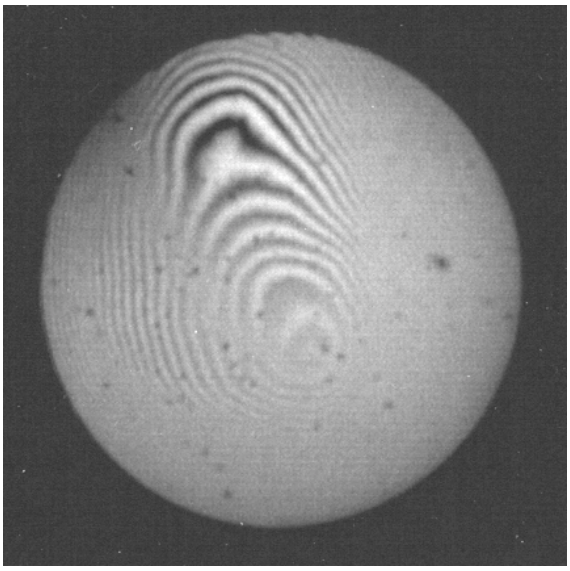


2a Center

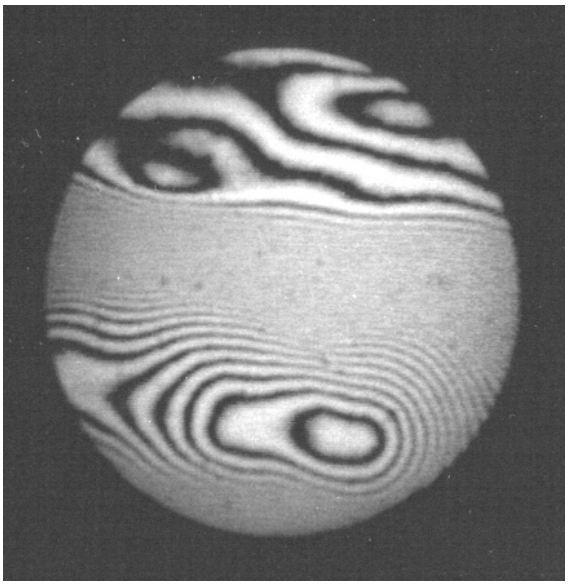


3 Left Side

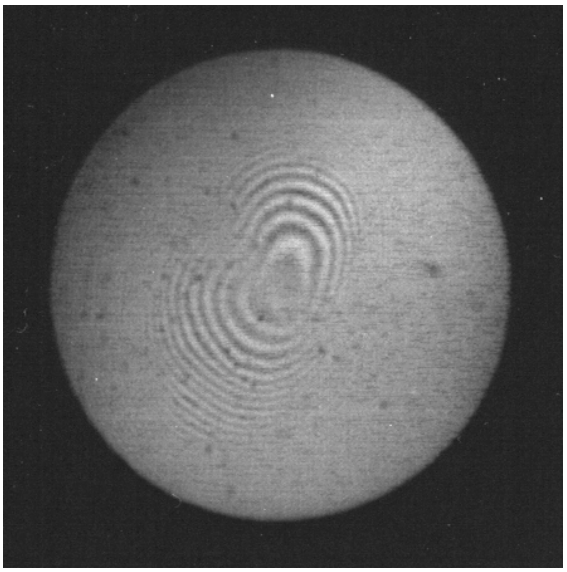
**Figure 15. Wavefront Distortion in "Bad Window"**



4 Right Side



5 Center



6 Left Side

## Summary and Recommendations

The characterization of the two windows received from the William B. Morgan Large Channel Cavitation Laboratory indicate they are not usable for transmission measurements requiring polarization or wavefront sensitive methodology. While the windows are optically transparent in the visible, they are not precision optical window materials. Such a window may be useful for qualitative imaging such as has been demonstrated in the grid board testing provided here. However, the nonuniformity of the window materials themselves and the lack of precision surface finish together result in very poor precision optical performance.

It is recommended that the material used for the flow field measurements be changed to a boro-silicate glass (BSG). This type of glass is harder than the acrylic and would be much more durable mechanically and chemically. Several types are available in the sizes required to replacement of the acrylic windows, but would be expensive. An alternative would be to modify the present acrylic window to accept smaller, easily manufactured BSG window inserts.

NAWCWD will be happy to assist the William B. Morgan Large Channel Cavitation Laboratory in the development of the specifications for the BSG-window blanks that would be used in this manner.

## Distribution

| | *Hard Copies* | *Digital Copies* |
|---|---|---|
| | # | # |
| Office of Naval Research<br>875 North Randolph Street<br>Arlington, VA 22203-1995<br>Attn: Dr. Peter Chang (Code 331) | | 1 |
| | | 1 |
| Defense Technical Information Center<br>8725 John J. Kingman Road<br>Ft. Belvoir, VA 22060-6218 | | |

| | | *Hard Copies* | *Digital Copies* |
|---|---|---|---|
| **NSWC, CARDEROCK DIVISION INTERNAL DISTRIBUTION** | | | |
| Code | Name | | |
| 1033 | TIC - Scribe | | 1 |
| 803 | P. Atsavapranee | | 1 |
| 85 | M. J. Donnelly | | 1 |
| 852 | J. W. Turner | | 1 |
| 852 | J. T. Park | | 1 |
| 853 | C. A. Peguero | | 1 |
| 853 | C. J. Chesnakas | | 1 |
| 872 | T. J. Michael | | 1 |
| 872 | J. A. Webster | | 1 |
| 89 | H. J. Moeller III | | 1 |
| 892 | M. L. Brantz | | 1 |

NAVSEA
WARFARE CENTERS
Carderock