TECHNICAL REPORT STANDARD TITLE PAGE

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
FWHA/TX-90		

4. Title and Subtitle	5. Report Date
Wind Drag Coefficients for Octagonal Cylinders	3/90
	6. Performing Organization Code
7. Author(s) Kishor C. Mehta David L. Ritchie, Walt Oler	8. Performing Organization Report No.
9. Performing Organization Name and Address Center for Applied Research and Engineering Texas Tech University Lubbock, Texas 79409	10. Work Unit No. 11. Contract or Grant No. 11 5 89 1207
12. Sponsoring Agency Name and Address Texas State Dept. of Highways and Public Transp. Transportation Planning Division P.O. Box 5051 Austin, Texas 78763	13. Type of Report and Period Covered Final 14. Sponsoring Agency Code

15. Supplementary Notes

The study was conducted in cooperation with the U.S. Department of Transportation, Federal Highway Administration

16. Abstract

Highway signs, luminaires, and traffic signal structures are exposed to wind loads throughout their lives. The design of the cross section, thus the amount of material and method of fabrication, very often is controlled by wind loads. Improved definitions of wind loads using drag coefficients make luminaires not only more economical but also more reliable.

The Texas Department of Highways and Public Transportation sponsored a research project at Texas Tech University to determine drag coefficients for octagonal shaped luminaire supports. The research used the tow tank of the Mechanical Engineering Dept. at Texas Tech University for the experimental work. The experimental technique was verified using published data for circular cylinders. One of the innovations in the project was the use of actual industry manufactured luminaire poles as test specimens. These specimens matched the surface roughness and the geometric parameters of field poles. Drag coefficient values obtained in this project are about 25% higher than the ones currently specified in the AASHTO standard.

17. Key Words	18. Distribution Statement
Wind, Drag Coefficients, Octagonal, Tow Tank	No restrictions. This document is available to the public through the National Technical Information Service, Springfield, VA 22161.

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
Unclassified	Unclassified	39	

Form DOT F 1700.7 (8-69)

WIND DRAG COEFFICIENTS FOR OCTAGONAL CYLINDERS

by

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Research Report Number 11-5-89-1207

conducted for

Texas State Department of Highways
and Public Transportation

in cooperation with the
U.S. Department of Transportation
Federal Highway Administration

by the

DEPARTMENT OF CIVIL ENGINEERING
TEXAS TECH UNIVERSITY

MARCH, 1990

The contents of this report reflect the views of the authors who are responsible for the facts and the accuracy of the data presented herein. The contents do not necessarily reflect the official views or policies of the Federal Highway Administration or the State Department of Highways and Public Transportation. This report does not constitute a standard, specification, or regulation.

There was no invention or discovery conceived or first actually reduced to practice in the course of or under this contract, including any art, method, process, machine, manufacture, design or composition of matter, or any new and useful improvement thereof, or any variety of plant which is or may be patentable under the patent laws of the United States of America or any foreign country.

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SUMMARY

Wind drag coefficient values for octagonal pole supports were investigated using a tow tank experimental procedure. The use of tow tanks is a relatively new experimental technique for obtaining drag coefficients for structural shapes.

The experimental technique was verified by comparing drag coefficients for circular cylinders in the tow tank with drag coefficients available in published literature. A good match was obtained; thus the experimental technique was verified.

Full dimension cross-section, manufacturer supplied, octagonal specimens were tested in the tow tank. These specimens match the surface roughness and the geometric parameters of field specimens. The average drag coefficient values obtained from the tow tank experimental procedure are about 25% higher than the AASHTO recommended value of 1.2.

The use of tow tank technology provides a methodology to test full-scale specimens to determine design wind drag coefficients. In addition, existing design values of drag coefficients can be verified and refined using this experimental technique.

IMPLEMENTATION STATEMENT

The wind drag coefficients for the octagonal cylinder obtained using the tow tank technique are about 25% higher than the recommended AASHTO value of 1.2. However, no change in the AASHTO design value is recommended at this time. Further investigation is required to verify these results.

The continued use of the tow tank experimental procedure is recommended for the testing of full cross-sectioned specimens. Accurate drag coefficient values are obtained using this procedure.

ABSTRACT

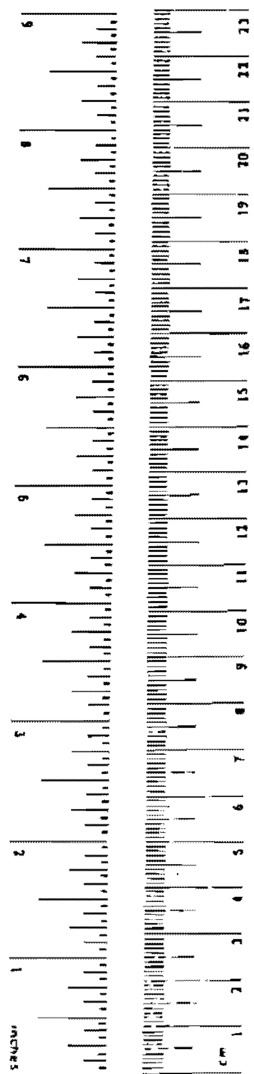
Highway signs, luminaires, and traffic signal structures are exposed to wind loads throughout their lives. The design of the cross section, thus the amount of material and method of fabrication, very often is controlled by wind loads. Improved definitions of wind loads using drag coefficients make luminaires not only more economical but also more reliable.

The Texas Department of Highways and Public Transportation sponsored a research project at Texas Tech University to determine drag coefficients for octagonal shaped luminaire supports. The research used the tow tank of the Mechanical Engineering Department at Texas Tech University for the experimental work. The experimental technique was verified using published data for circular cylinders. One of the innovations in the project was the use of actual industry manufactured luminaire poles as test specimens. These specimens matched the surface roughness and the geometric parameters of field poles. Drag coefficient values obtained in this project are about 25% higher than the ones currently specified in the AASHTO standard.

METRIC CONVERSION FACTORS

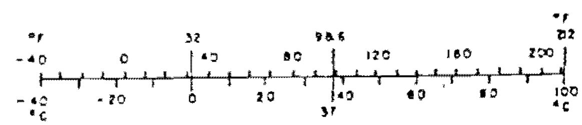
Approximate Conversions to Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
	LENGTH			
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
	AREA			
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
	MASS (weight)			
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
	VOLUME			
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
	TEMPERATURE (exact)			
	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C



Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
	LENGTH			
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
	AREA			
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
	MASS (weight)			
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
	VOLUME			
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
	TEMPERATURE (exact)			
	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	



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SECTION 1 - INTRODUCTION

Single-pole supports have been widely used to support signs and lights for many years. Most early single-pole supports were made with circular cross sections. However, polygonal support poles are being used more frequently since it is easier to manufacture a tapered polygonal pole than a tapered circular pole, and a polygonal pole is structurally stiffer than a cylindrical pole.

Typical support poles are exposed to wind-induced lateral pressures. Once this pressure and its distribution along the length of the pole are defined, the support pole can be optimally designed for lateral wind loading.

The American Association of State Highway and Transportation Officials (AASHTO) specifies in its "Standard Specification for Structural Supports for Highway Signs, Luminaires, and Traffic Signals" (AASHTO, 1975) an equation for the wind-induced pressure experienced by single-pole supports. This equation is:

$$P = 0.00256 \times (1.3 \times V)^2 \times C_d \times C_h \tag{1.1}$$

where:

	P	=	wind pressure on unit area (psf)
	V	=	mean design wind speed (mph)
	C_d	=	drag coefficient (dimensionless)
	C_h	=	coefficient reflecting height and terrain effects (dimensionless)

* 0.00256 converts the kinetic energy of the wind speed to potential energy of velocity pressure.
* 1.3 modifies the mean design wind speed to wind gusts.

The only factor in Equation 1.1 that takes into account interaction between the wind and the pole support is the drag coefficient (C_d). Thus, the drag coefficient is the most important parameter for optimum design of single-pole supports.

From previous studies, the drag coefficient for polygonal poles has been shown to be a function of the shape of the pole, the surface roughness of the pole, the Reynolds number, R_n, the corner radius of the joined flat sides, and the orientation of the pole to the wind direction. The Reynolds number and orientation of the pole are related to wind flow around the pole; other parameters are physical properties of the pole.

The Reynolds number is a dimensionless quantity which is a measure of the ratio of inertial forces to viscous forces in the fluid. R_n is used as an index to characterize the type of flow (laminar or turbulent) and the associated phenomena such as separation point and wake. The equation for the Reynolds number is:

$$R_n = \frac{V D \rho}{\mu} \tag{1.2}$$

where:

	R_n	=	Reynolds number (dimensionless)
	V	=	velocity (ft/sec)
	D	=	test specimen diameter (ft)
	ρ	=	fluid density (lb/ft^3)
	μ	=	coefficient of fluid viscosity (ft-sec/lb)

The Reynolds number is a dimensionless quantity, thus independent of the fluid used for flow.

Research by James (1976) and others has demonstrated that the drag coefficients for circular cylinders decrease dramatically in the Reynolds number range of 1×10^5 to 5×10^5. James' research also showed that the drag coefficients for octagonal cylinders decreased in the critical Reynolds number range of 1×10^5 to 3×10^5. For pole sizes of 9 to 30 inches in diameter and wind speeds between 60 and 100 miles per hour, the Reynolds number varies between 3.8×10^5 and 6.5×10^5. Thus for practical design, flows in the Reynolds number range between 1×10^5 and 7×10^5 are needed to assess drag coefficients.

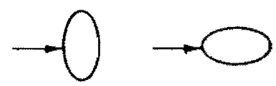
Table 1.1 shows the drag coefficient values recommended by AASHTO for different shape poles. As seen in the table, drag coefficients vary with the Reynolds number for cylindrical and dodecagonal shapes. These values are established from wind tunnel testing of scaled models. The parameters of surface roughness and corner radius are difficult to achieve in a scale model for use in a wind tunnel; therefore these drag coefficients may not accurately reflect the wind forces produced on poles in the field. As can be seen in Table 1.1 drag coefficient values for octagonal shapes are the highest of all shapes for the full range of Reynolds numbers. The drag coefficients will be verified using a tow tank and full-scale pole sections manufactured by industry.

A two-step approach to assess the drag coefficients was used. The first step was to verify the experimental procedure and the data acquisition system by testing circular cylinders in the tow tank. These results were compared to published results to insure the validity of the experimental techniques. The second step was to test octagonal, full size, poles. These tests provided drag coefficient values for octagonal shapes.

This two-step procedure was accomplished using the Texas Tech University Tow Tank and manufacturer supplied pole specimens. The tow tank uses water instead of air as the fluid for flow simulation. The use of water permitted slower test specimen velocities to obtain the desired experimental Reynolds number range for drag coefficient measurement. Pole specimens supplied by manufacturers should yield more accurate drag coefficients.

TABLE 1.1

Wind Drag Coefficients, C_d (AASHTO, 1985)

Type of Member	Shape of Members					
Structural Supports (Vertical & Horizontal)	Cylindrical	Dodecagonal [2]	Octagonal	Flat [1]	Elliptical	
					Broadside facing Wind	Narrow side facing Wind
Single Member or Truss						
$Vd \le 32$ (16)	1.10	1.20	1.2	1.7		
32 (16) $< Vd <$ 64 (32)	$\frac{100^*}{(Vd)^{1.3}}$	$\frac{9.62^{**}}{(Vd)^{.6}}$	1.2	1.7	$1.7(D/d_o - 1) + C_{dn}(2 - D/d_o)$	$C_{dd}\left[\frac{4 - D/d_o}{3}\right]$
$Vd \ge 64$ (32)	0.45	0.79	1.2	1.7		
Two Members or Truss (one in front of other)	1.86			2.86		
Three Trusses Forming Triangular Cross Section	1.73			2.60		
Sign Panel (By Ratio of Length to Width)						
L/W = 1.0	1.12					
2.0	1.19					
5.0	1.20					
10.0	1.23					
15.0	1.30					
Traffic Signals[4]	1.2					
Luminaires (with generally rounded surfaces)	0.5					
Luminaires (with rectangular flat side shapes)	1.2					

[1]Wind drag coefficients for members, sign panels and other shapes not included in this Table shall be established by wind tunnel tests (over an appropriate range of Reynolds numbers), in which comparative tests are made on similar shapes included in this Table.

[2]Valid for members having a ratio of corner radius to distance between parallel faces equal to, or greater than, 0.125.

[3]Flat members are those shapes which are essentially flat in elevation, including plates, angles and squares.

[4]Wind loads on free swinging traffic signals may be modified, as agreed by the owner of the structure, based on experimental data in Reference 38.

Nomenclature: V = Wind velocity (mph) (kmph).
d = Depth (diameter) of member (ft.) (m).
D/d_o = Ratio of major to minor diameter of ellipse (max. of 2).
C_{dn} = Drag coefficient of cylindrical shape, diameter D.
C_{dd} = Drag coefficient of cylindrical shape, diameter d_o.

*In metric units this becomes 40.62.
**In metric units this becomes 6.35.

SECTION 2 - LITERATURE REVIEW

WIND TUNNEL STUDIES

The vast majority of experiments conducted to determine the forces on structures involve the use of wind tunnel technology. Wind tunnels allow specimens of various cross sections to be tested to determine the wind-induced forces exerted on the member.

Studies on Circular Cylinders

Von Karman's classical works in the early 1900's gave insight into the vortex shedding phenomenon of flow around circular cylinders. Taylor (1915) documented the change in drag of a circular cylinder with respect to the smoothness of the cylinder surface. Taylor also identified the influence of aspect ratio on drag. Fage and Warsap (1930) investigated the effect of free stream turbulence and surface roughness on the drag and pressure distribution around a circular cylinder. Roshko (1961) was first to suggest at least three identifiable regimes of flow: subcritical (purely laminar boundary layer separation), supercritical (laminar separation followed by turbulent reattachment and eventual turbulent separation), and transcritical (transition to turbulence in the boundary layer occurring ahead of separation). These regimes of flow are related to a dimensionless parameter, namely the Reynolds number (R_n). In subsequent works, Achenbach (1968) and Bearman (1968) firmly established that this "laminar-separation/turbulent-reattachment" was responsible for the low drag coefficient (C_d) which occurs at the beginning of the supercritical regime. The boundary between the subcritical and supercritical regimes is marked by a highly distinguishable drop in C_d (1.15 at R_n of 1.5×10^5 to 0.25 at R_n of 4×10^5). Using data for a circular cylinder from Schewe (1983), obtained in a pressurized wind tunnel, a plot of C_d versus R_n is shown in Figure 2.1.

Data from a report by James (1976) on circular cylinders is plotted in Figure 2.2. The plot demonstrates that C_d is dependant on the Reynolds number and surface roughness. Surface roughness is usually measured as a ratio of roughness to cylinder diameter. When comparing data of one circular cylinder to another, the surface condition must be considered. For the purposes of this study, standard roughness values for manufactured specimens are obtained from the Cameron Hydraulic Handbook (Ingersoll-Rand, 1984).

Studies on Octagonal Cylinders

The most extensive experimental work to date on polygonal cylinder shapes is the research performed by James at Iowa State University in 1976. James used wind tunnel technology to obtain drag coefficients for octagonal, dodecagonal, and hexdecagonal cross sections. James verified his experimental procedure by comparing his circular cylinder results with previously published data.

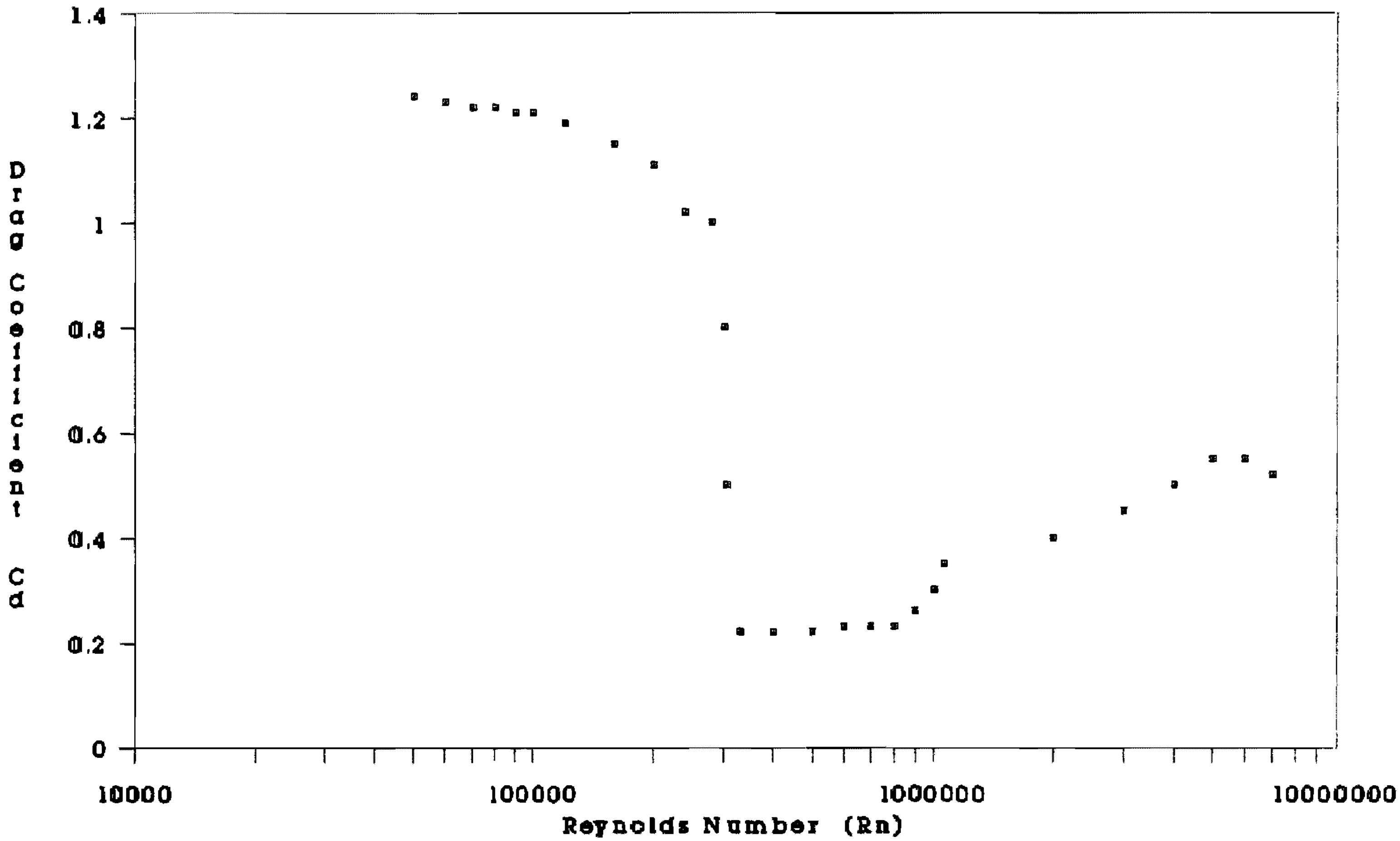


Figure 2.1 Drag Coefficient for Circular Cylinder Obtained in Wind Tunnel.

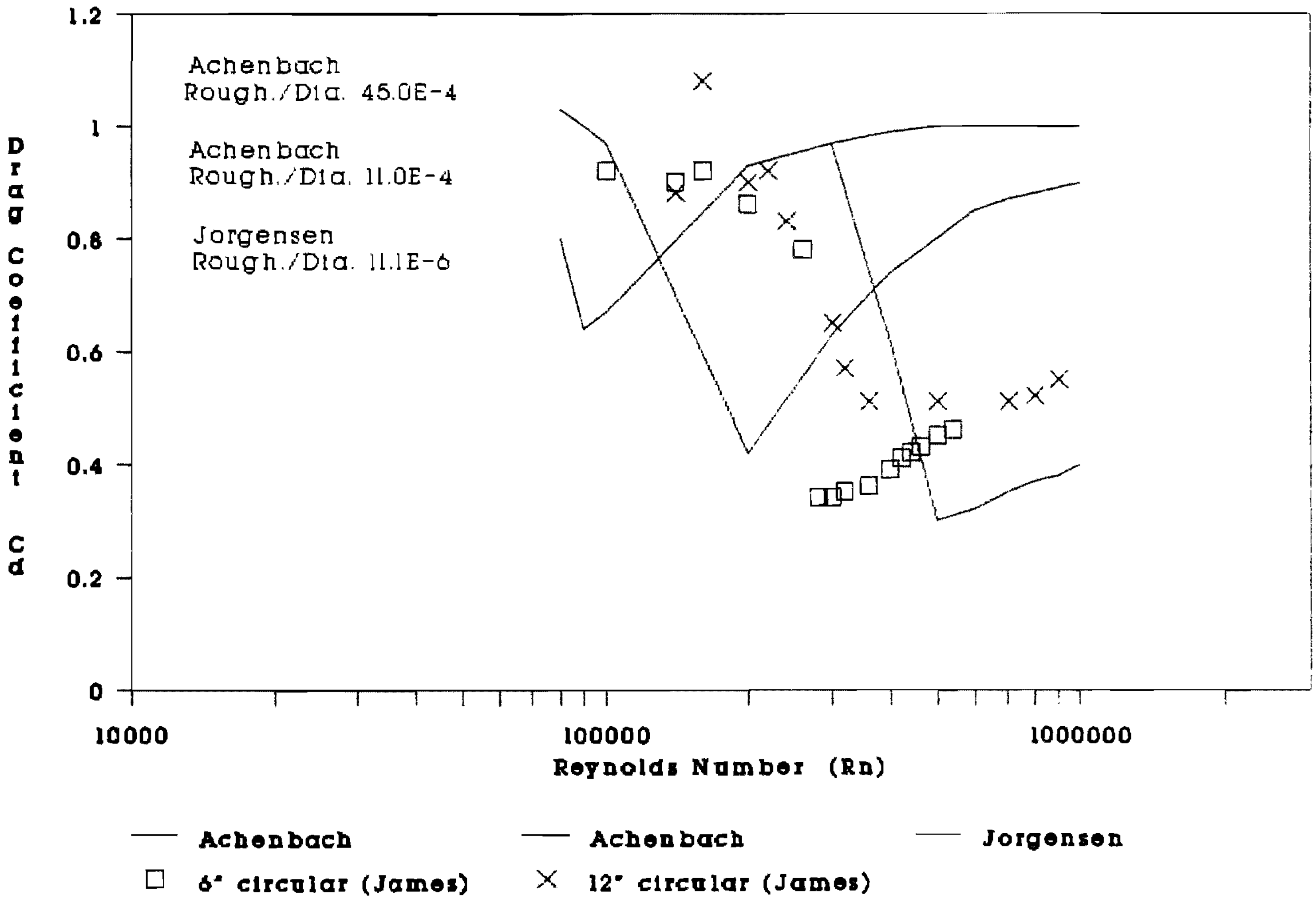


Figure 2.2 Drag Coefficients for Circular Cylinders

James conducted tests on various polygonal models manufactured in the lab. During these two-dimensional tests, James measured the cross-flow lift and drag forces on each specimen. Models ranging from 6 to 24 inches in diameter and wind tunnel speeds up to 210 feet per second were used to obtain his data. Using different combinations of wind speed and cylinder diameter, James achieved Reynolds number values of up to 2.1×10^6.

From James' experimental results, several conclusions were drawn about drag coefficients of the octagonal shape. One conclusion was that the corner radius of the octagonal shape influences the drag coefficient. The corner radius is the radius of the arc where two flat sides of the octagonal cylinder meet, usually expressed as a ratio of the corner radius to the inscribed circle radius of the cylinder. As the corner radius ratio increased (the corner became more rounded), the drag coefficient decreased. Figure 2.3 shows data obtained by James (1976) for the octagonal shape with various corner radii ratios. The experiment also indicated that the of angle of attack of the wind on the cylinder influences the drag coefficient. Although not true for every corner radius ratio and Reynolds number, the maximum drag force was generally experienced when the flow was directed toward a corner. A plot showing the influence of the angle of attack on the drag coefficient is shown in Figure 2.4. Flow normal to a flat side and toward a corner was found to be the controlling angle of attack for drag coefficients.

Drag coefficients for the octagonal, dodecagonal, and hexagonal shapes are shown in Fig. 2.5 (James, 1976). Octagonal shapes demonstrate higher drag coefficient values than for any of the other polygonal shapes.

TOW TANK OR WATER TUNNEL STUDIES

The use of water as the fluid for simulating flows around structures (as in tow tanks or water tunnels) is far less common than the use of air (as in wind tunnels). There are relatively few published works in this area.

Studies on Circular Cylinders

One report was a study of transition flow around circular cylinders in a water tunnel. The study was performed at the Ames Research Center and Aeromechanics Laboratory, U.S. Army Research and Technology Laboratories, by Almosnino and McAlister (1984). The purpose of this study was to confirm the phenomenon of asymmetric flow separation from a circular cylinder in the critical Reynolds number range. In addition, an attempt was made to visualize this flow separation and correlate the visualizations with measured lift and drag coefficients.

The study examined the flow around circular cylinders for Reynolds numbers of up to 5×10^5. As can be seen in Figure 2.6, the average drag coefficient measured for the

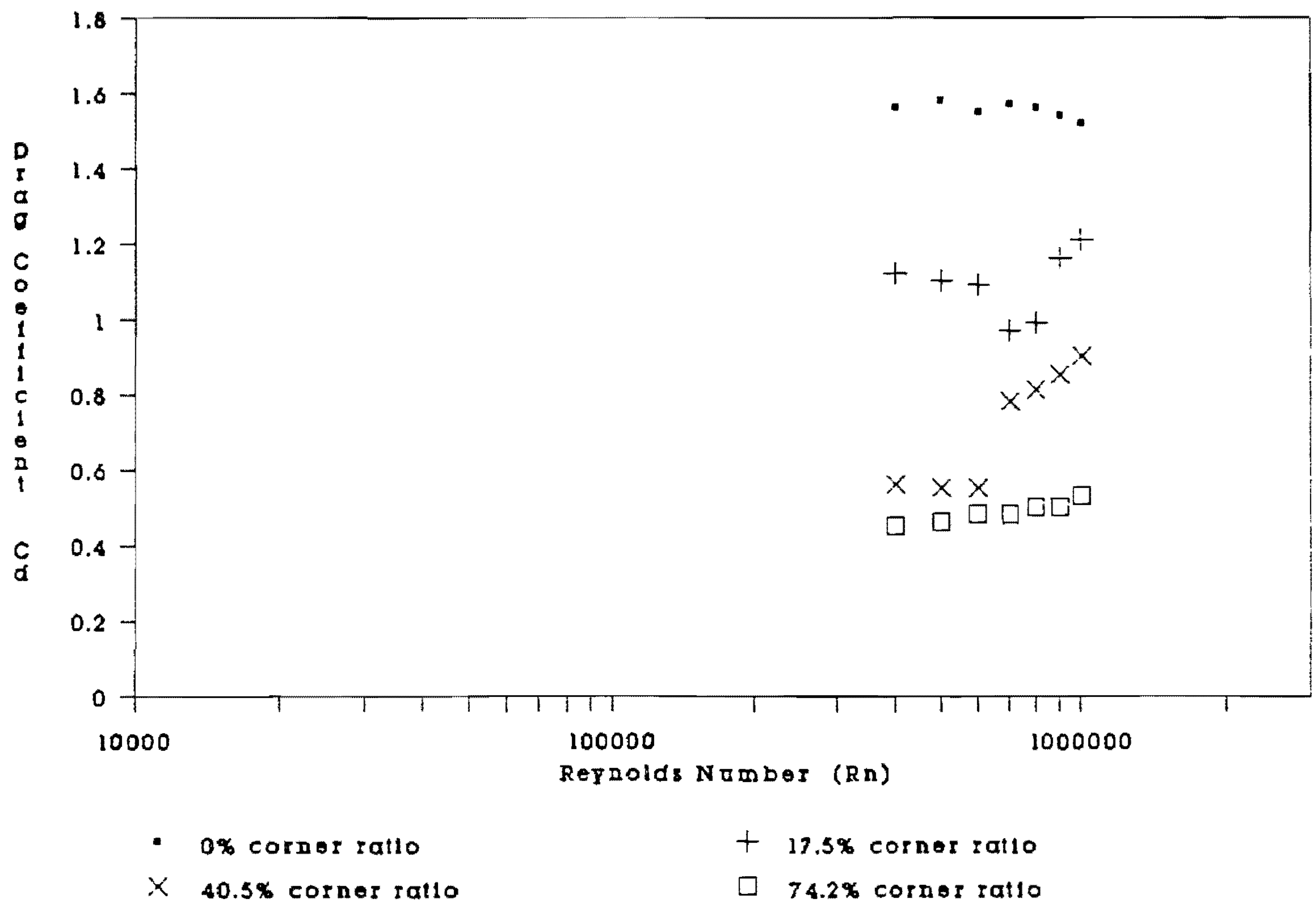


Figure 2.3 Drag Coefficients for Octagonal Cylinders with Variable Corner Radius Ratios.

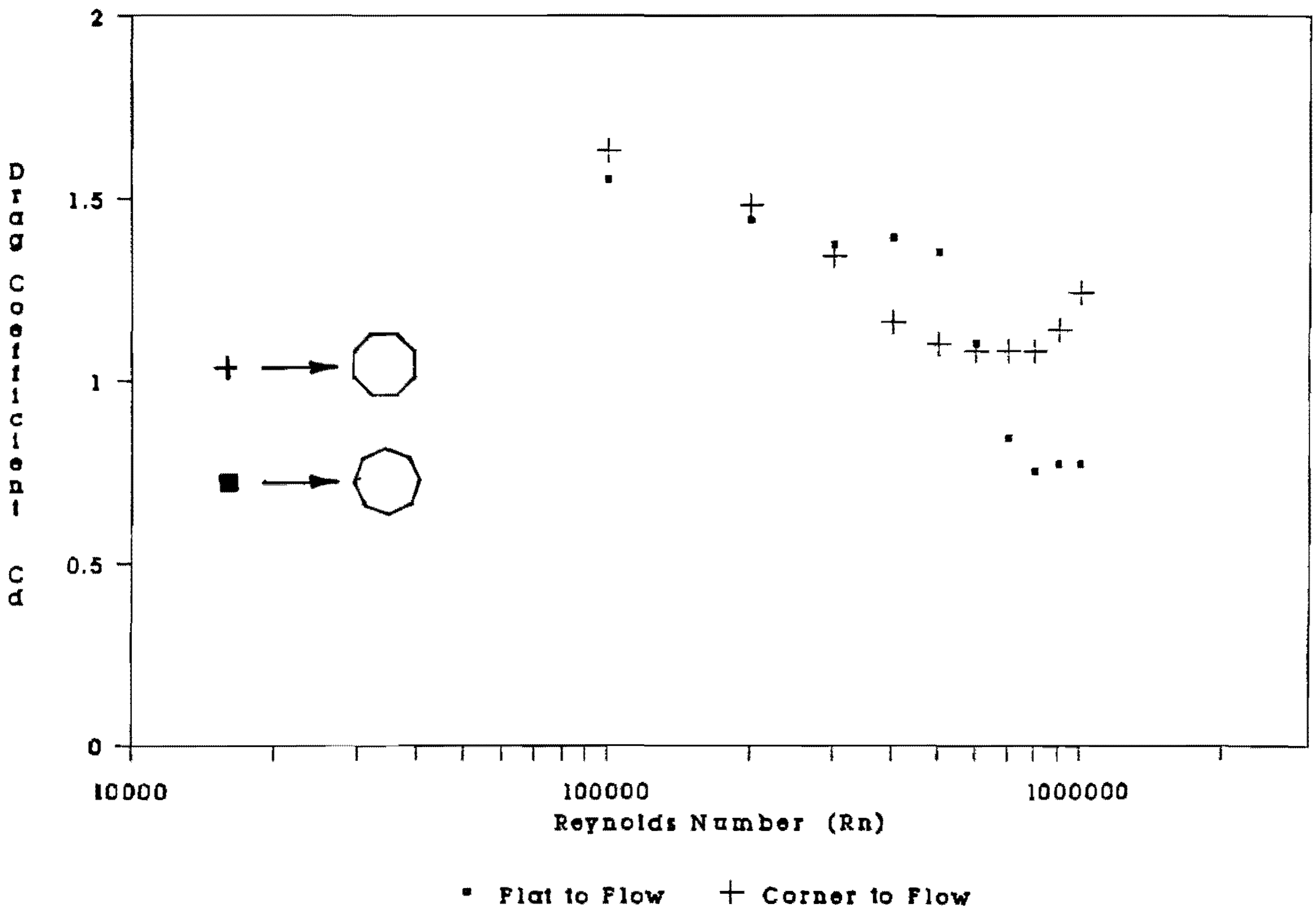


Figure 2.4 Drag Coefficients for Octagonal Cylinders with Two Angles of Attack.

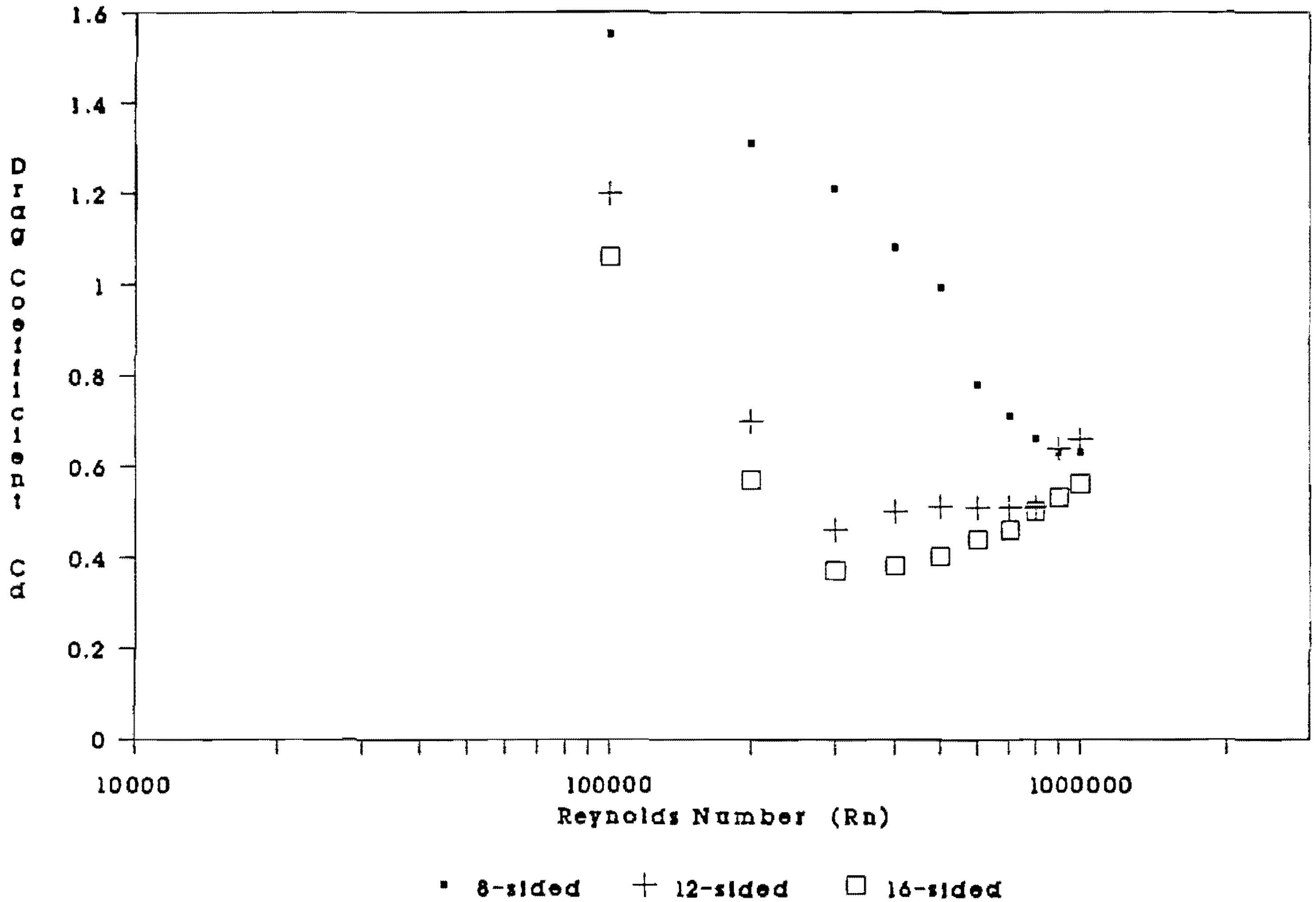


Figure 2.5 Drag Coefficients for 8-sided, 12-sided, and 16-sided Polygonal Cylinders.

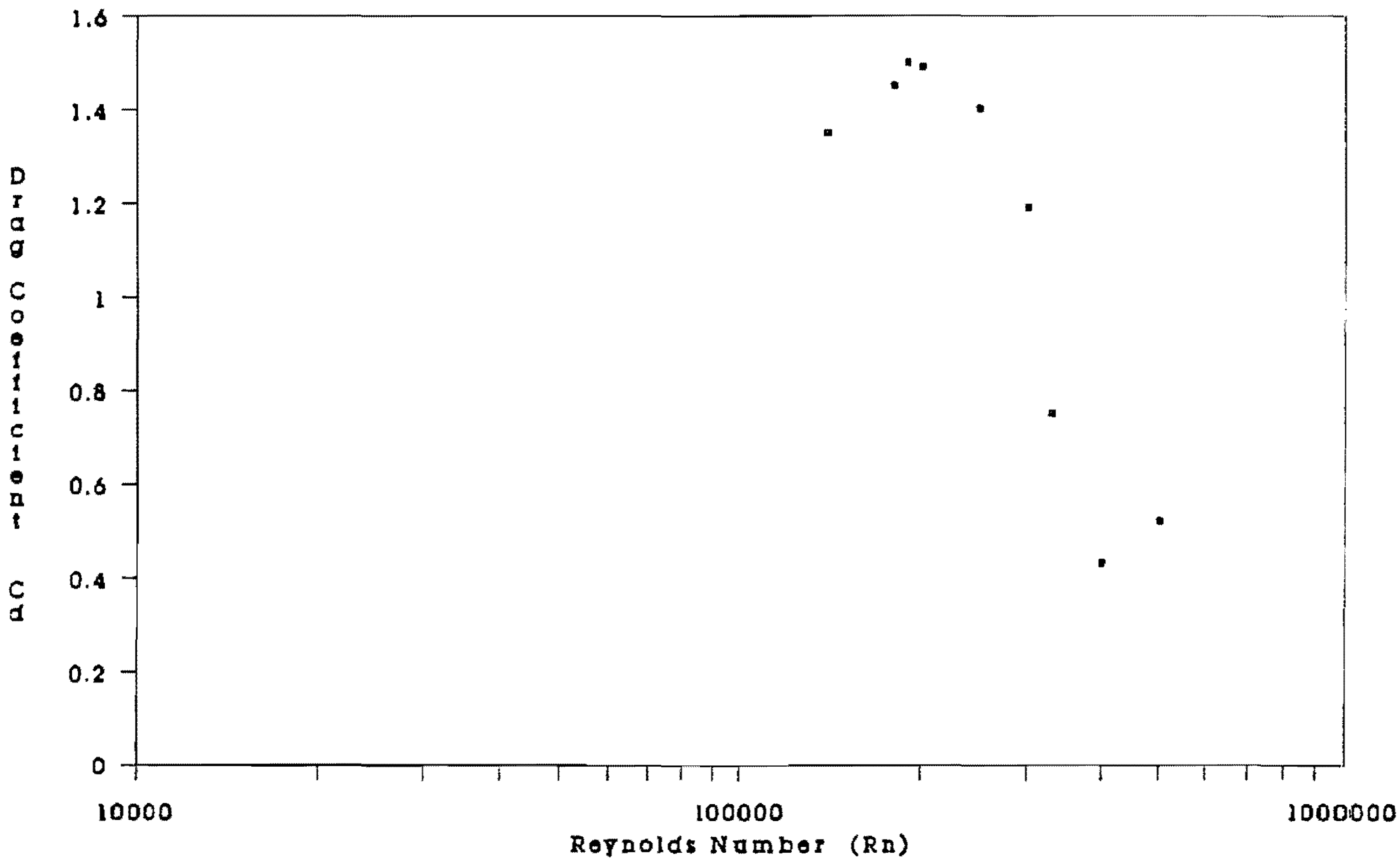


Figure 2.6 Drag Coefficients for Circular Cylinder in Water Tunnel.

circular cylinder tested remained in a somewhat constant range between 1.3 to 1.5 until a Reynolds number of 3.1×10^5 was reached. At this point, the average drag coefficient for the cylinder abruptly decreased to 0.8. The decrease continued up to a Reynolds number of 3.45×10^5 where the drag coefficient reached a minimum value of 0.44. Continuing to increase the Reynolds number brought a slight increase in the drag coefficient. No surface roughness parameters were available in this published study, but the data obtained exhibited the same trend as the drag coefficients for circular cylinders in previous wind tunnel studies.

<u>Studies on Octagonal Cylinders</u>

As of the time of this study, no published literature was available that utilized either the tow tank or the water tunnel to measure and document drag forces on octagonal cylinders.

SECTION 3 - SPECIMENS, EXPERIMENTAL PROCEDURE, AND VERIFICATION

SPECIMENS

One of the most significant aspects of this study was the use of full-size, manufacturer supplied, sections of support poles as test specimens. The sections were supplied by Falcon Steel Company of Fort Worth, Texas and by Valmont Industries of Valley, Nebraska. By using these sections as test specimens, drag coefficient values obtained in this study should closely simulate the drag experienced in the field.

The test specimens received from the manufacturers included both circular and octagonal cross sections. The octagonal cross sections were constructed of 3/16 inch thick steel plate with diameters (measured by the inscribed circle of the cylinder) of 9, 16, 24, and 30 inches. Figure 3.1 shows a cross-sectional view of the octagonal cylinders and identifies the inscribed circle of the cylinder along with the corner radius of the cylinder. Although most support poles are manufactured with a slight taper along their lengths, the specimens received for this project are not tapered. The exterior surface of the octagonal cylinders has a galvanized coating. The coating on the test specimens provides the same surface roughness as support poles used in the field. Circular cylinder specimens were obtained from a pole manufacturer and a pipe supplier. These circular cylinders have diameters of 9, 16, 18, and 36 inches. All circular test specimens are constructed of 1/8 inch thick steel with a single coat of paint on the exterior.

All the test specimens obtained from the manufacturers were initially 5 feet long. The length of each specimen was cut to 48.625 inches long for placement into the tow tank. When the test specimens are mounted on to the attachment plate, the gap between the bottom of the tank and the bottom of the test specimen is less than one-half inch. This clearance is intentionally held as small as possible to simulate two-dimensional flow around the specimen.

EXPERIMENTAL PROCEDURE

The first step in obtaining the drag coefficients for cylinders was the verification of the experimental techniques used to perform the study. This verification was accomplished by testing circular cylinders using the experimental techniques and comparing the results with published values. The experimental apparatus used to obtain the drag coefficients was the Texas Tech University tow tank and its associated equipment.

The tow tank, shown in Figure 3.2, is located in the Mechanical Engineering Aerodynamics Laboratory on the Texas Tech University campus. The tank is an above-ground fiber reinforced structure 32 feet long, 16 feet wide, and 5 feet deep. The tank is

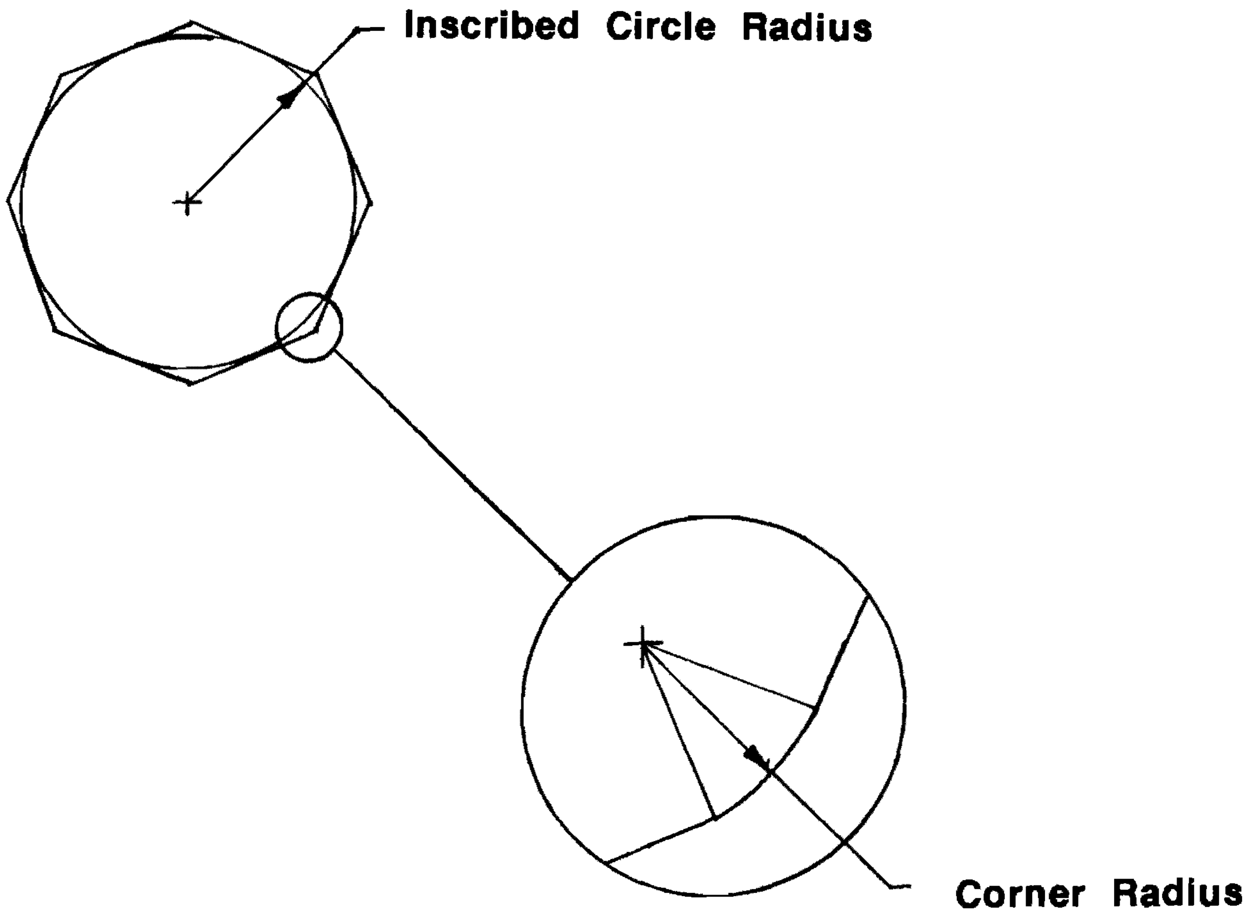


Figure 3.1 Inscribed Circle Radius and Corner Radius for Octagonal Cylinder Cross Section.

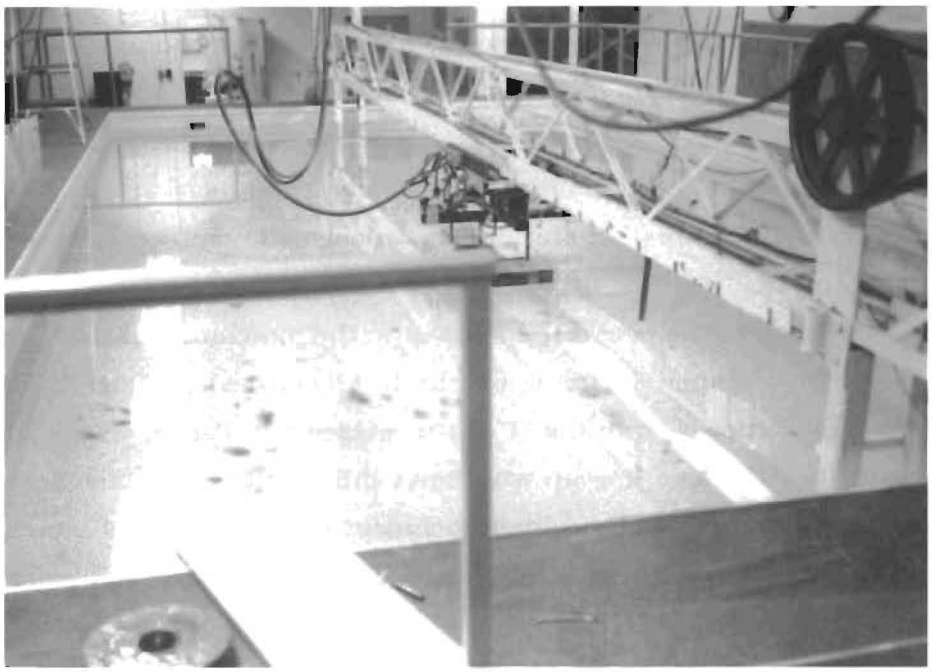


Figure 3.2 Texas Tech University Tow Tank.

designed to hold a water depth of 42 inches. The towing system associated with the tank includes a structural bridge (spanning the length of the tank) which supports a carriage plate for the attachment of test specimens. A Zenith Data Systems personal computer with a Metrabyte Das 16 A/D converter is used to control the acceleration, deceleration, and velocity of the specimen for each test run from operator inputs. Receiving output from the computer, a Westinghouse Accutrol 110 adjustable frequency controller controls the frequency signal sent to a Reliance 5-HP, 1730 RPM, AC motor. The frequency sent to the motor determines the speed at which the test specimen is towed through the water. A 22:1 reduction V-belt drive system, connected to the motor, and tow cable attached to the carriage plate permit the specimen to be tested at a variable speed of up to 4 feet per second. The control system also has a switch box which allows the operator to manually control the towing direction and speed and also provides a safety "dead man" switch for emergency stop of the towing system. Figures 3.3 and 3.4 show schematic representations of the tow tank and towing system.

The connection of the pole test specimen to the attachment plate is accomplished by mounting a 4 inch channel "T" frame on the test specimen. Figure 3.5 shows the test specimen standing vertically, with the "T" frame welded into the top of the specimen. Three holes drilled in the "T" frame line up with holes drilled into the attachment plate allowing the specimen to be bolted rigidly to the attachment plate. This rigid attachment transfers the forces acting on the test specimen to the attachment plate and subsequently to the load cell (see Figure 3.3).

For octagonal specimens, the ability to rotate the test specimen was necessary to determine the change in drag coefficient due to a varying angle of attack of the fluid on the cylinder. As would be expected, and verified by James (1976), the orientation of the octagonal cylinder to the fluid flow has a significant effect on the drag coefficient values. For this reason, and to accommodate different size test specimens, the attachment plate is provided with a series of holes. Using conclusions drawn from James' study of octagonal cylinders, two orientations of the cylinders to the towing direction, shown in Figure 3.6, were studied in this project. The first orientation studied is flat face of the octagonal cylinder normal to the towing direction. The second orientation studied was a corner of the octagonal cylinder normal to the towing direction of the cylinder. These two orientations provided controlling drag coefficient values (James 1976).

Measurements of the drag force on the specimens was accomplished using a Lebow 3132-500 load cell rated at 500 pounds capacity. As shown in Figure 3.3, the test specimens are suspended vertically from an attachment plate into the tow tank. Figure 3.7 indicates forces in static equilibrium and the two couples, one produced by the horizontal forces and

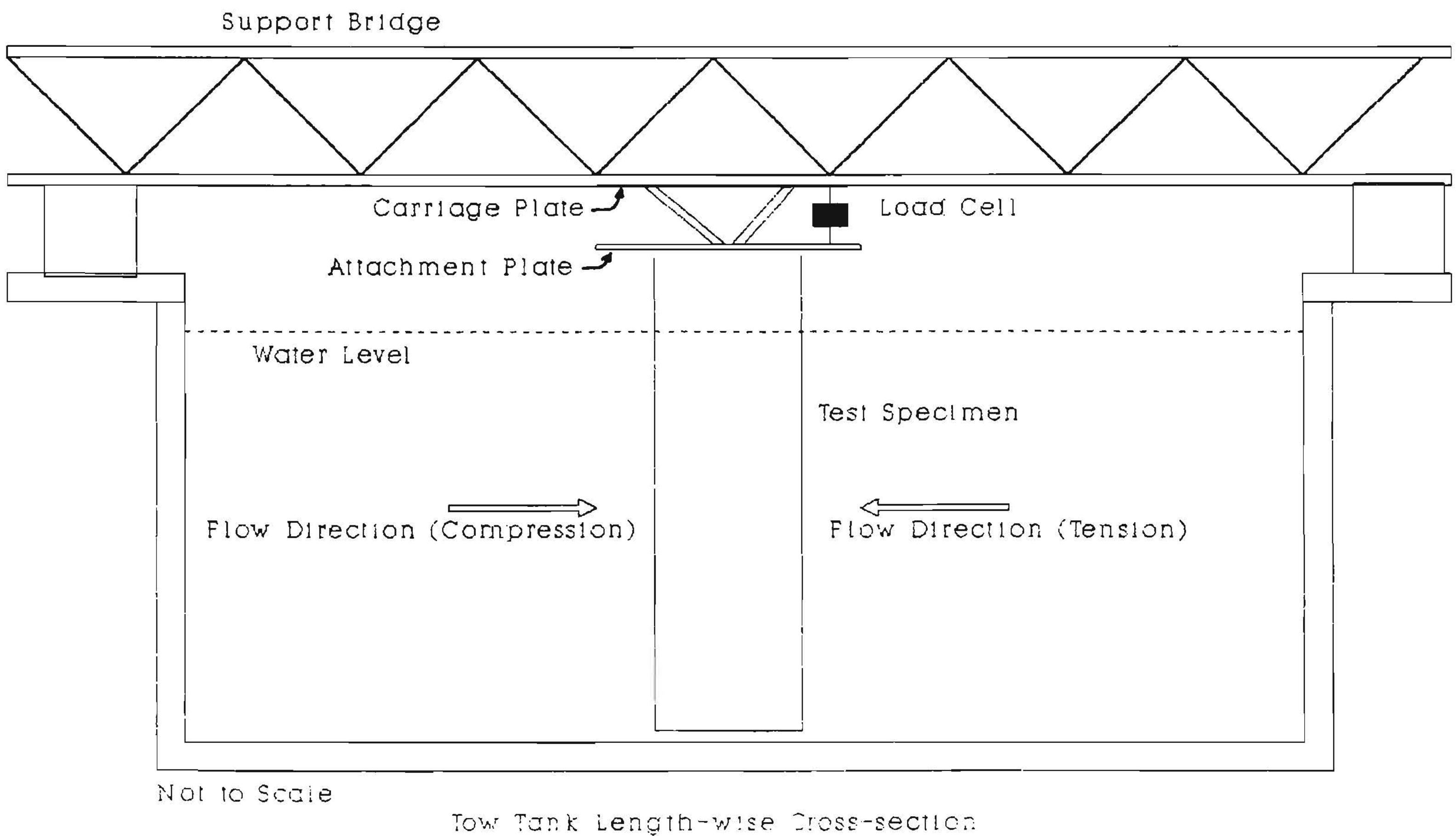


Figure 3.3 Tow Tank, Support Bridge, and Test Specimen Schematic.

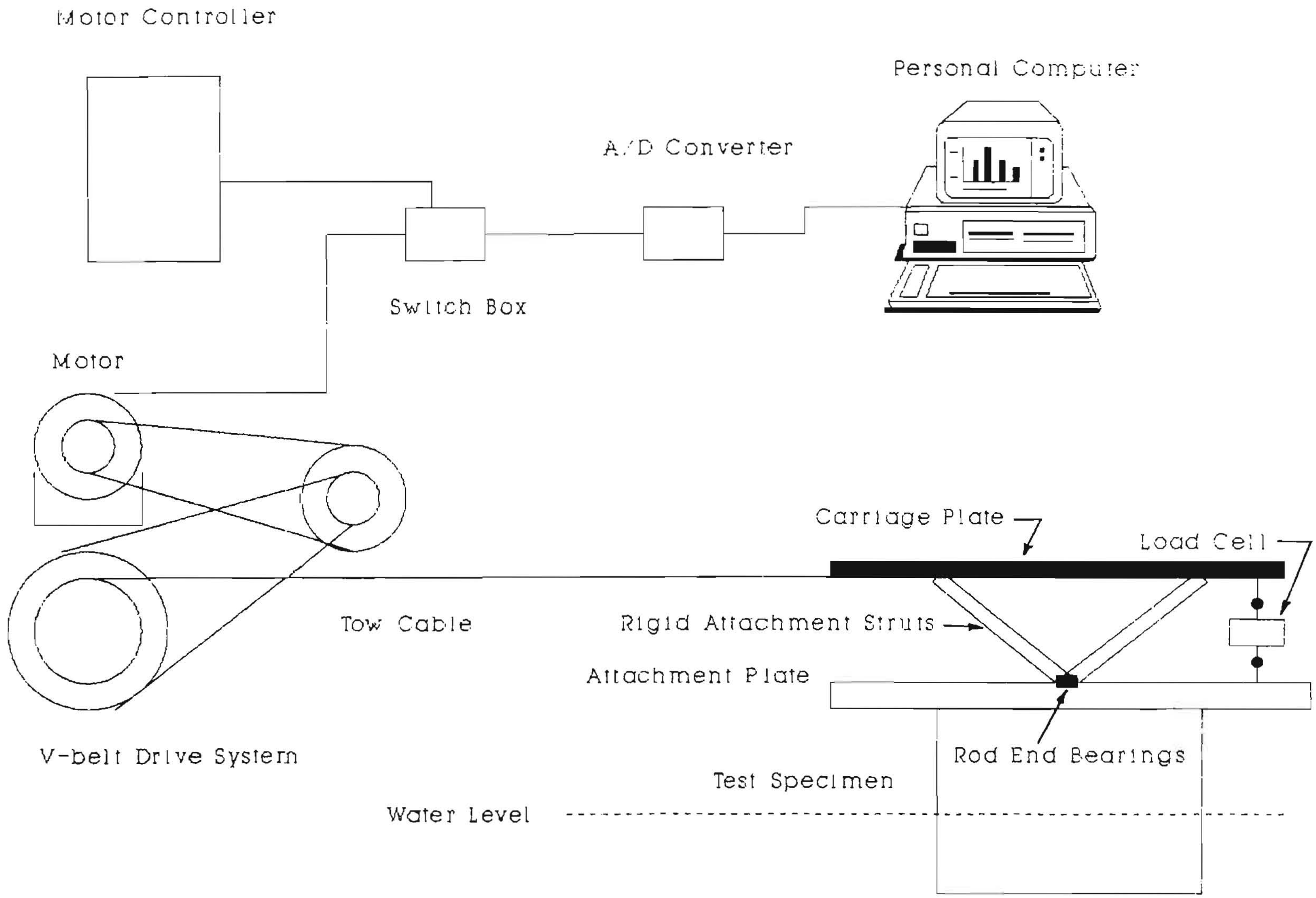


Figure 3.4 Towing System Schematic.

Figure 3.5 Test Specimens with "T" Frame Attachment.

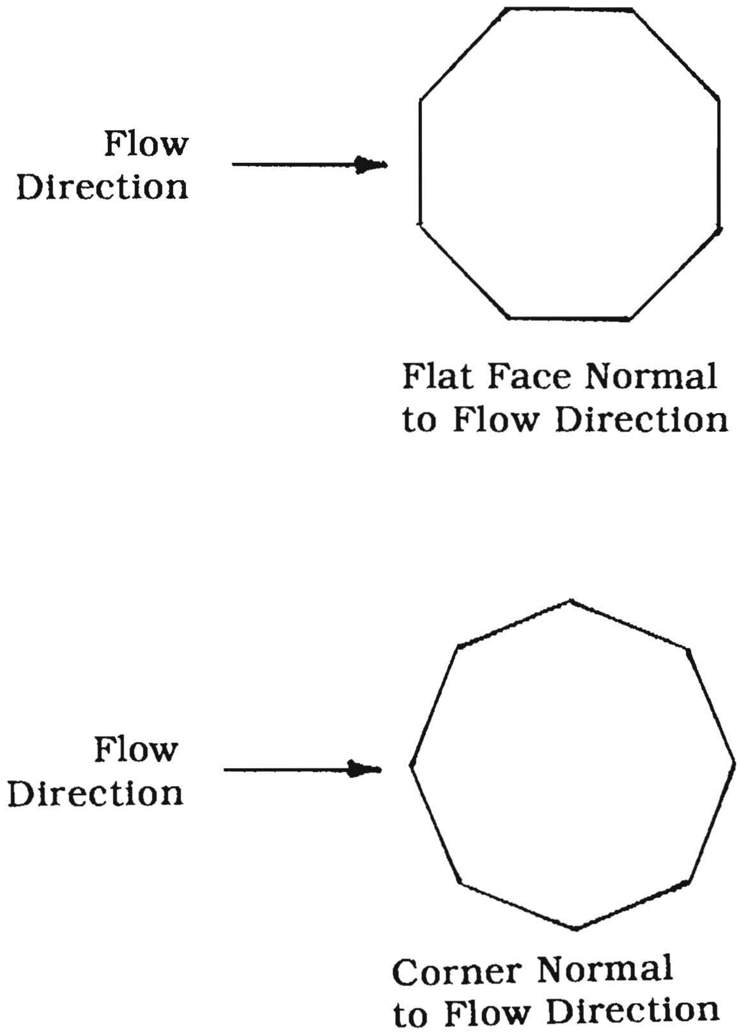


Figure 3.6 Octagonal Cylinder Orientation

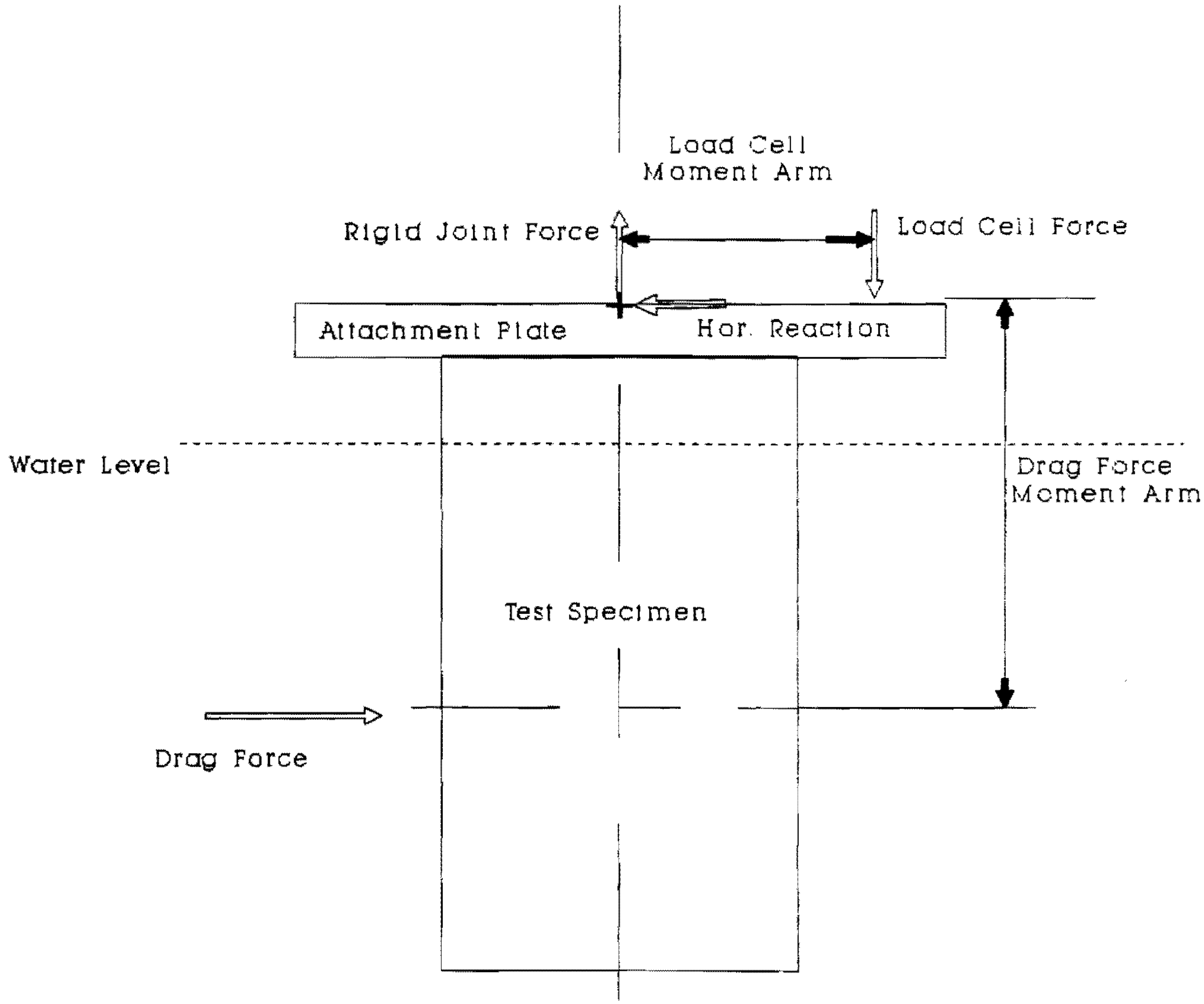


Figure 3.7 Test Specimen Force Diagram.

the other produced by the vertical forces. The load cell measures one vertical force. The horizontal drag force is the resultant force of the uniformly distributed forces acting on the test specimen. All other forces imparted on the test specimen by the fluid are self-equilibriating; thus the resultant horizontal force acts at mid-depth of the water height.

In designing the three-point connection to the attachment plate, care has been exercised to insure that no horizontal force is transferred to the load cell. To accomplish this, rod end bearings are placed on the top and bottom of the load cell to isolate the load cell and make the connection incapable of resisting any horizontal force. The total horizontal force on the test specimen is resisted by the remaining two rigid attachment strut connections.

For the load cell to sense the full vertical load reaction, the two rigid attachment struts must allow the attachment plate to rotate. As shown in Figure 3.7, the rotation of the attachment plate transfers the vertical reaction force to the load cell. The rotation of the attachment plate is allowed by placing a rod end bearing at the connection of the two attachment struts and the attachment plate.

The force that the load cell senses is transmitted to a Measurements Group Model 2310 signal conditioner/amplifier/filter. The output signal is amplified for recording by the personal computer. The conditioning ability of the 2310 instrument is used to produce a "false" zero reading, thereby eliminating the effect of the weight of the test specimen. This "new" zero reading allows calculation of the drag coefficient directly without having to compensate for the weight of the test specimen. The amplified and conditioned load cell output signal is sent to the Metrabyte DAS-16 analog to digital converter that can be processed by the computer.

The procedure for obtaining the data desired follows a simple straight-forward sequence. Each test specimen is mounted to the attachment plate which in turn is attached through the three-point support system. A computer program called "cyldrag," developed and refined throughout the study, is used to collect data during the tests. The program prompts the operator for input variables such as: the number of data samples per second, the speed of the test specimen, the magnitude of amplification, and the inscribed cylinder diameter of the specimen.

The testing of a particular specimen requires the following steps. The signal conditioner is reset to give the "new" zero reading described earlier. Once this has been accomplished, the computer program is started and the desired test variables requested by the program are input. With the test specimen at the starting position in the tow tank (at one end of the tow tank), the program is engaged and the test begins. Using the input variables, the program calculates the distance the specimen will travel and sends a signal to the motor controller. The test specimen is accelerated to the desired speed which is held constant during the data acquisition period. The program collects data samples based on the input before the program was engaged (normally at the rate of 80 Hz). The data is collected while the test specimen is being towed at the constant speed. As the specimen reaches the end of the test run, the computer stops collecting data, decelerates the specimen and brings the specimen to a stop. The program utilizes the data collected during the constant speed section of the test run and calculates the drag coefficient for each data sample point using the following equation:

$$C_d = \frac{F}{.5\rho V^2 A} \tag{3.1}$$

where: F = drag force (lbs)

C_d = drag coefficient (dimensionless)

ρ = fluid density (slugs/ft^3)

V = velocity of specimen (ft/sec)

A = projected area of specimen (ft^2)

The procedure described above is referred to as a test run. The test run is repeated ten times with the same test specimen at the same speed. The program then takes each of the data sample points collected during all the test runs and calculates the average drag coefficient value.

For this study, Reynolds number values encompassing a range from 5×10^4 to 7×10^5 are desired. Knowing the Reynolds number at which drag coefficients are wanted, the required velocities, to be input into the computer program, are calculated using the following equation:

$$V = \frac{R_n \, \mu}{D \, \rho} \tag{3.2}$$

where: R_n = Reynolds number (dimensionless)

μ = coefficient of fluid viscosity (lb/ft-sec)

D = specimen diameter (ft)

ρ = fluid density (lb/ft^3)

The desired Reynolds number range from 5×10^4 to 7×10^5 was obtained by varying the size of the test specimens and the towing speed (maximum of 4 ft per second).

VERIFICATION OF EXPERIMENTAL PROCEDURE

The verification process used drag coefficients for circular cylinders from previous experimental projects for comparison with values obtained during this study. The study of circular cylinder drag coefficients dates back to the early 1900's and is the best benchmark available for verifying a new experimental technique for obtaining drag coefficients.

To verify this study's experimental procedure, several circular cylinders of different diameters were tested and the drag coefficients measured. The cylinders available were of 9, 16, 18, and 36 inches in diameter. The specimens were towed in both directions to induced tension and compression in the load cells. It was found that results with the load cell in tension and compression matched well. The large 36 inch diameter cylinder showed significant scatter, probably because the length of the tank permitted test distance of only a few diameters.

Drag coefficients obtained with 9 and 16 inch diameter cylinders are shown in Figure 3.8. The figure also shows the results obtained by James (1976). It is observed in the figure that drag coefficients obtained in this study show the same trend as the ones obtained by James. Admittedly, there is some scatter in the results, though a similar scatter is also noted in the results obtained by James. Looking at the trend and values of drag coefficient in Figure 3.8, it is concluded that the tow-tank procedure gives reasonable results.

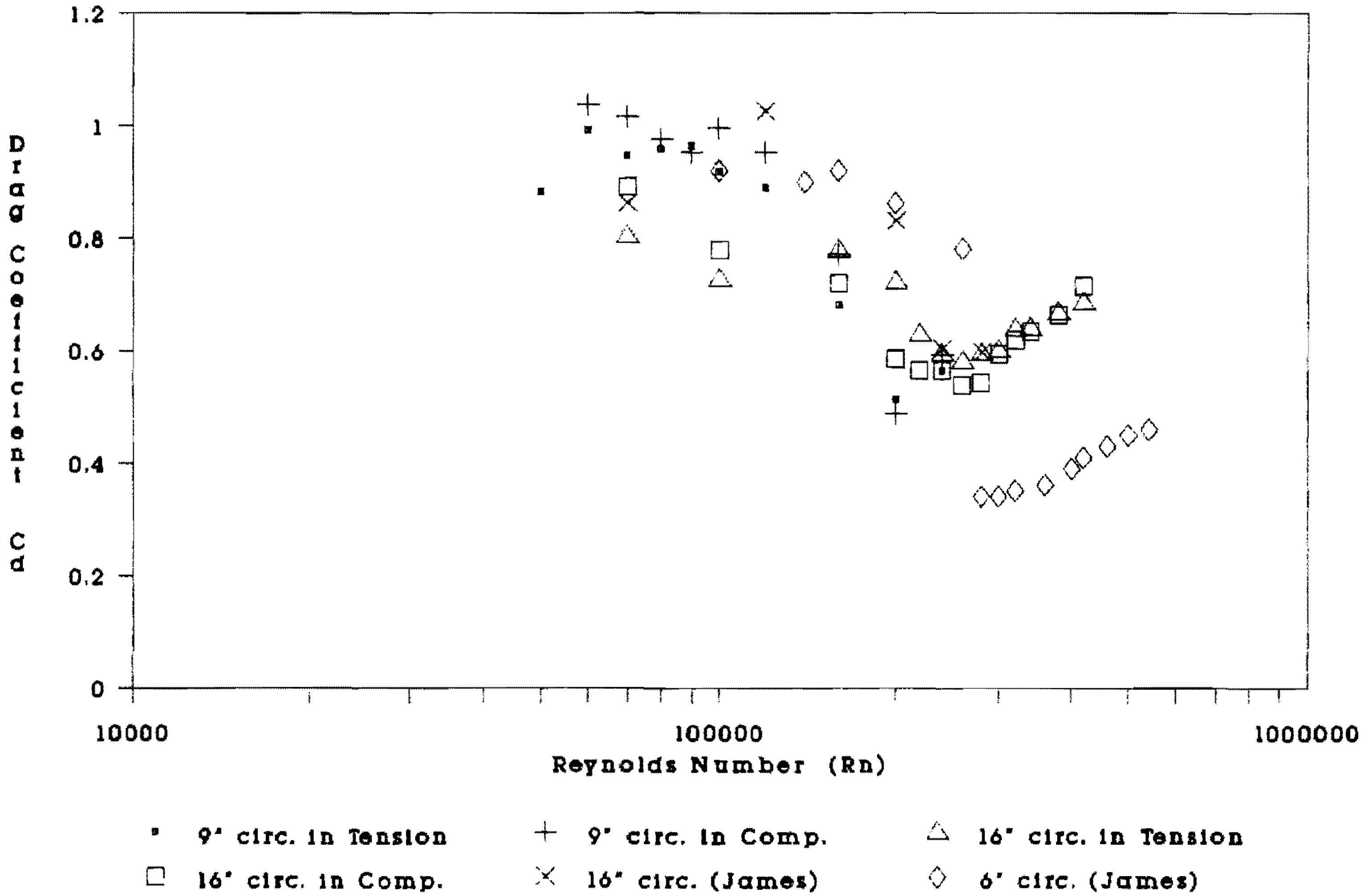


Figure 3.8 Experimental 9" and 16" Circular Cylinder Drag Coefficients and Reference Drag Coefficients.

SECTION 4 - OCTAGONAL CYLINDER RESULTS

Drag coefficients for octagonal shaped specimens were obtained using the experimental procedures described in Section 3. Unlike the circular cylinder, the octagonal cylinder drag coefficients are dependent on the orientation of the cylinder to the fluid flow.

The test specimens were supplied by manufacturers of support poles. The four specimens each had different diameters, as measured by the inscribed circle of the cross section, of 9, 16, 24, and 30 inches. Different diameters were used to obtain a Reynolds number range from 5×10^4 to 7×10^5.

Table 4.1 summarizes the testing performed and the results obtained. As shown in the table, the specimen size varied from 9 inches to 30 inches and the towing speed between 0.43 and 3.63 feet per second. These combinations of specimen size and towing speed yielded results with the Reynolds number between 5×10^4 and 7×10^5. The table also shows the measured corner radius ratio, and the minimum, maximum, and average values of the drag coefficient obtained with (a) the flow normal to a flat surface on the test specimen and (b) the flow normal to a corner of the specimen. Figures 4.1 through 4.4 graphically show the results summarized in Table 4.1 for each test specimen.

As can be seen in Figures 4.1 through 4.4 the flow toward the corner generally has higher drag coefficient values than for the flow normal to a flat side. Also, these figures indicate a larger scatter in results for large diameter specimens. This larger scatter is probably due to the short test distance available; for the 30 inch specimen the test distance is 8 times the diameter while for the 9 inch specimen it is 40 times the diameter. The drag coefficient values shown in Table 4.1 indicate that there is no trend with respect to corner radius ratio, at least in the range of 11 to 44 percent ratio.

Combined results for all test specimens are shown in Figure 4.5. The figure also shows results of octagonal shapes obtained by James (1976) and the value recommended in AASHTO specifications (1975). The results shown are for the flow directed toward a corner of the specimen since this provides controlling drag coefficients. The drag coefficient results of this study and the ones obtained by James' study are consistent for low Reynolds number range. For higher Reynolds number range, where specimens of 24 and 36 inch diameter are used, drag coefficient values obtained in this study are significantly higher than the ones obtained by James. The reason for this difference may be that in James' study the drag coefficient reduced with increasing Reynolds number while in this study no correlation is found between drag coefficient and Reynolds number. Not enough data is available to suggest definitively which drag coefficient trend is correct.

TABLE 4.1

Test Results for Octagonal Shape

SPECIMEN DIAMETER (in.)	PARAMETERS				RESULTS			
	Min V ft/sec	Max V ft/sec	Corner Radius Ratio % *	Specimen Orientation	C_d min	C_d avg	C_d max	Comments
9	0.83	3.63	44	A	.97	1.20	1.38	Fig. 4.1
				B	1.23	1.35	1.58	
16	0.57	3.26	25	A	1.06	1.30	1.44	Fig. 4.2
				B	1.20	1.35	1.59	
24	0.54	2.72	13	A	1.10	1.25	1.45	Fig. 4.3
				B	1.28	1.50	1.74	
30	0.43	3.04	11	A	1.02	1.30	1.61	Fig. 4.4
				B	1.40	1.77	2.25	

A. Flow directed at flat face of specimen
B. Flow directed at corner of specimen

*Ratio of corner radius to inscribed radius of specimen

Note 1. Galvenized surface roughness of 0.006 in. (Ingersoll-Rand 1984).

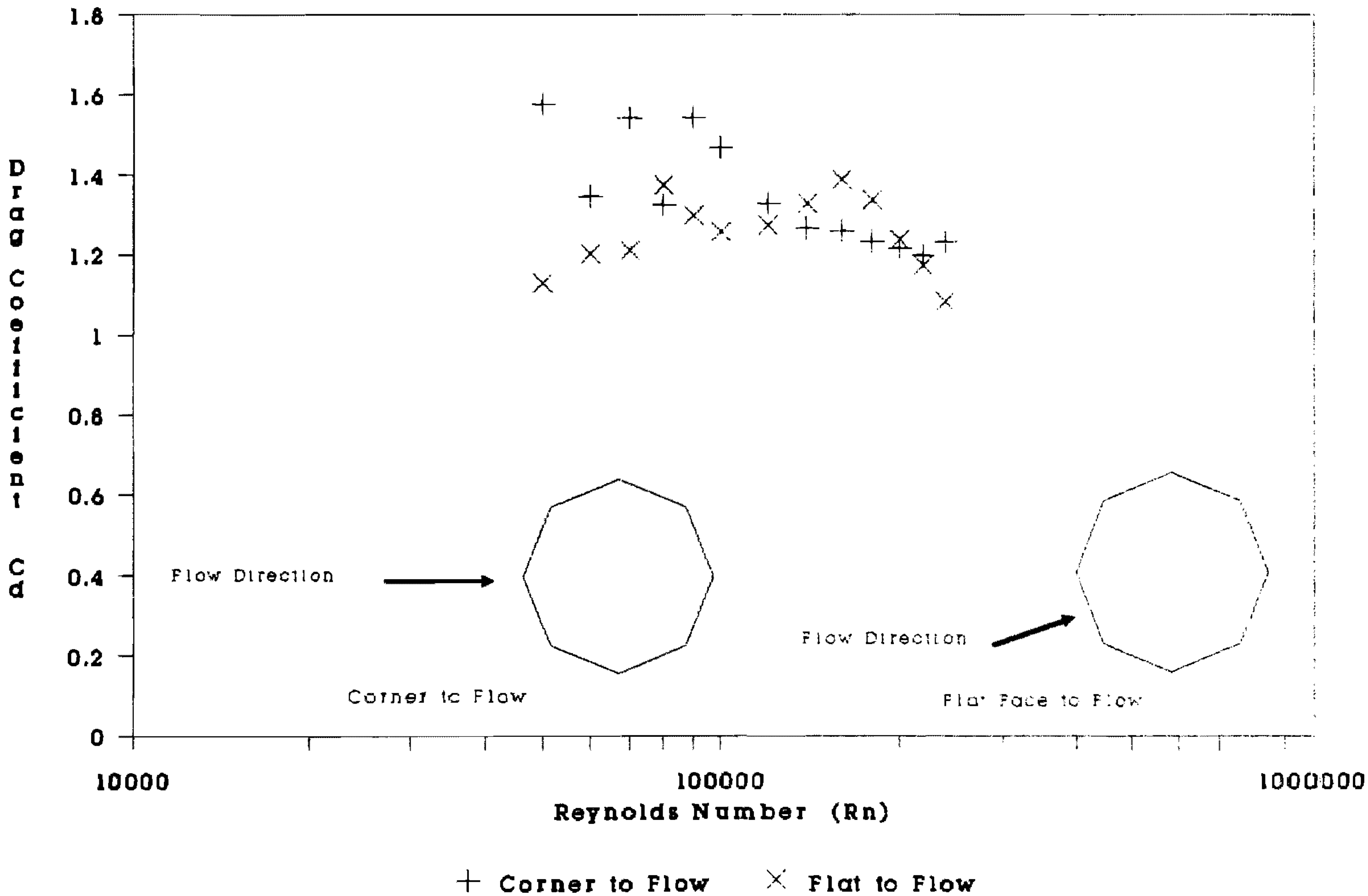


Figure 4.1 9 inch Octagonal Cylinder Drag Coefficients

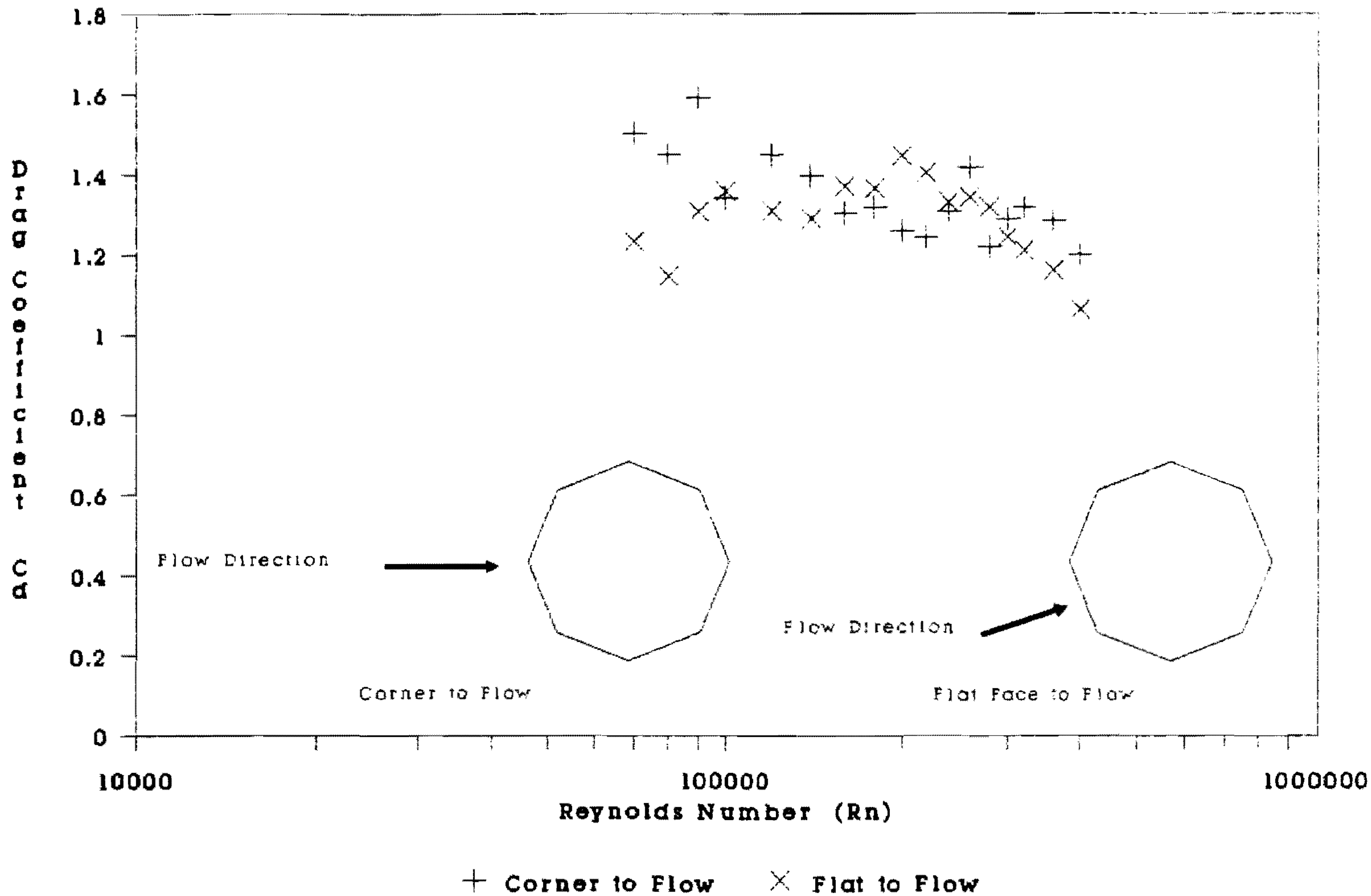


Figure 4.2 16 inch Octagonal Cylinder Drag Coefficients.

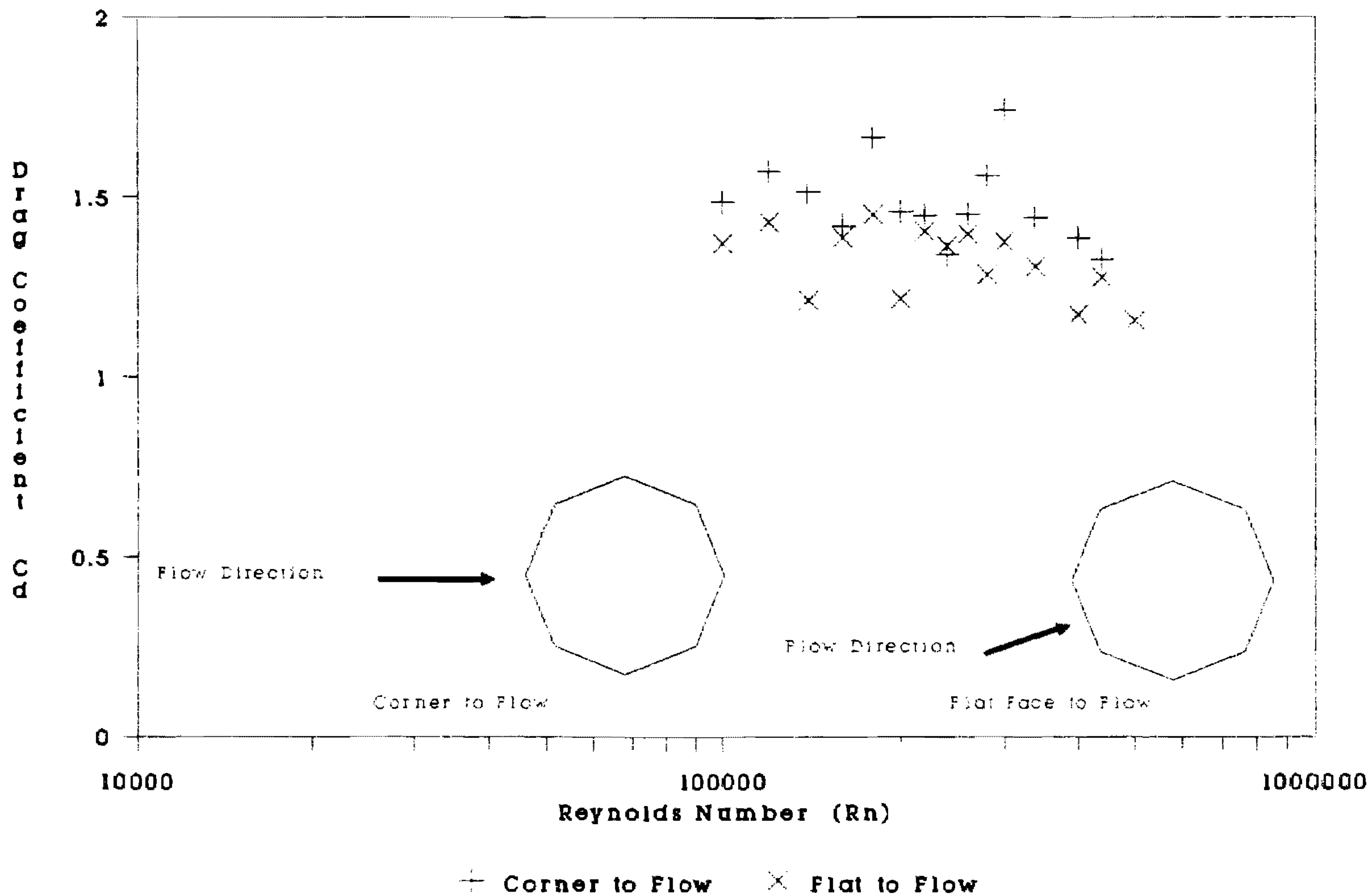


Figure 4.3 24 inch Octagonal Cylinder Drag Coefficients

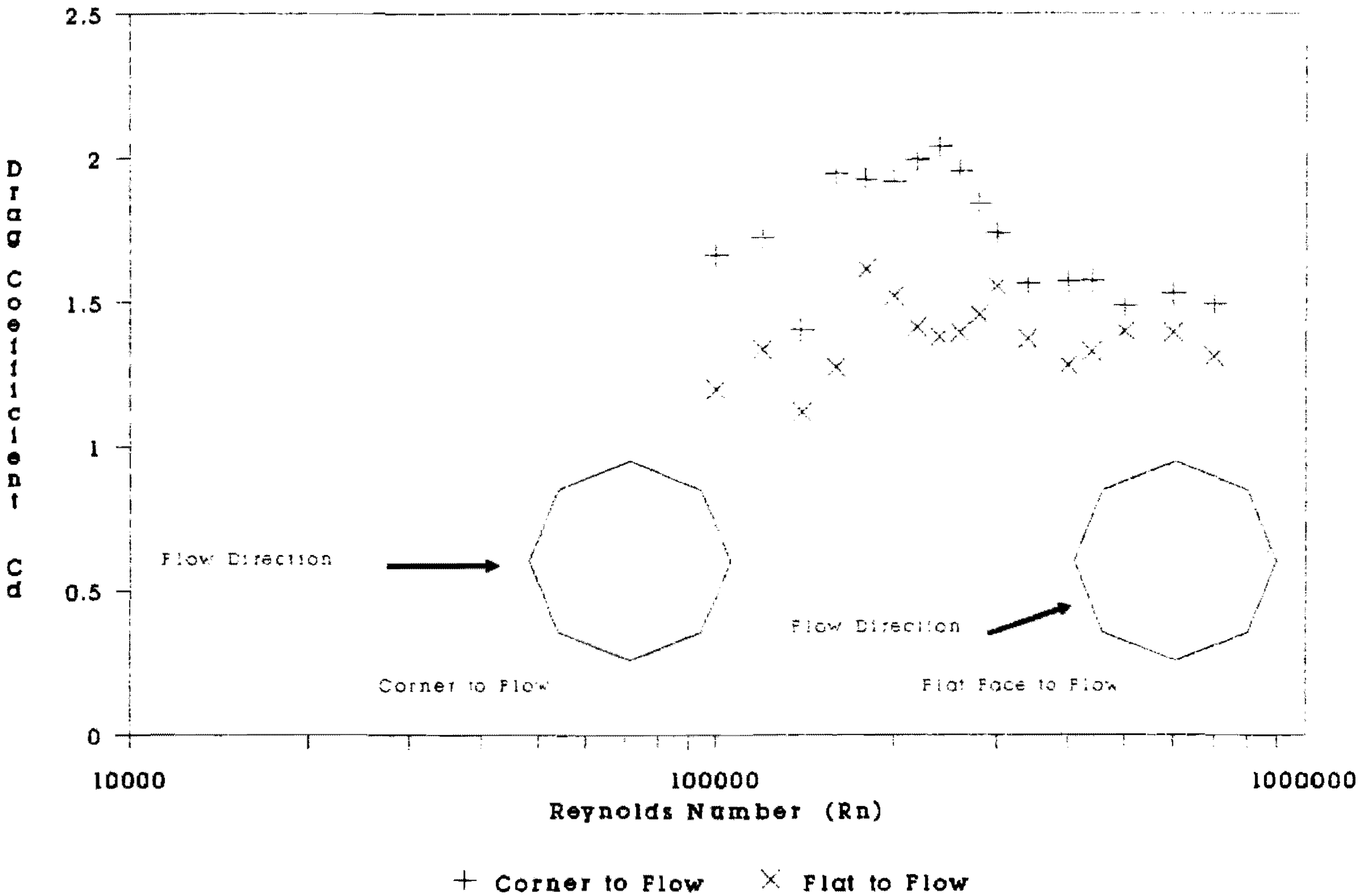


Figure 4.4 30 inch Octagonal Cylinder Drag Coefficients.

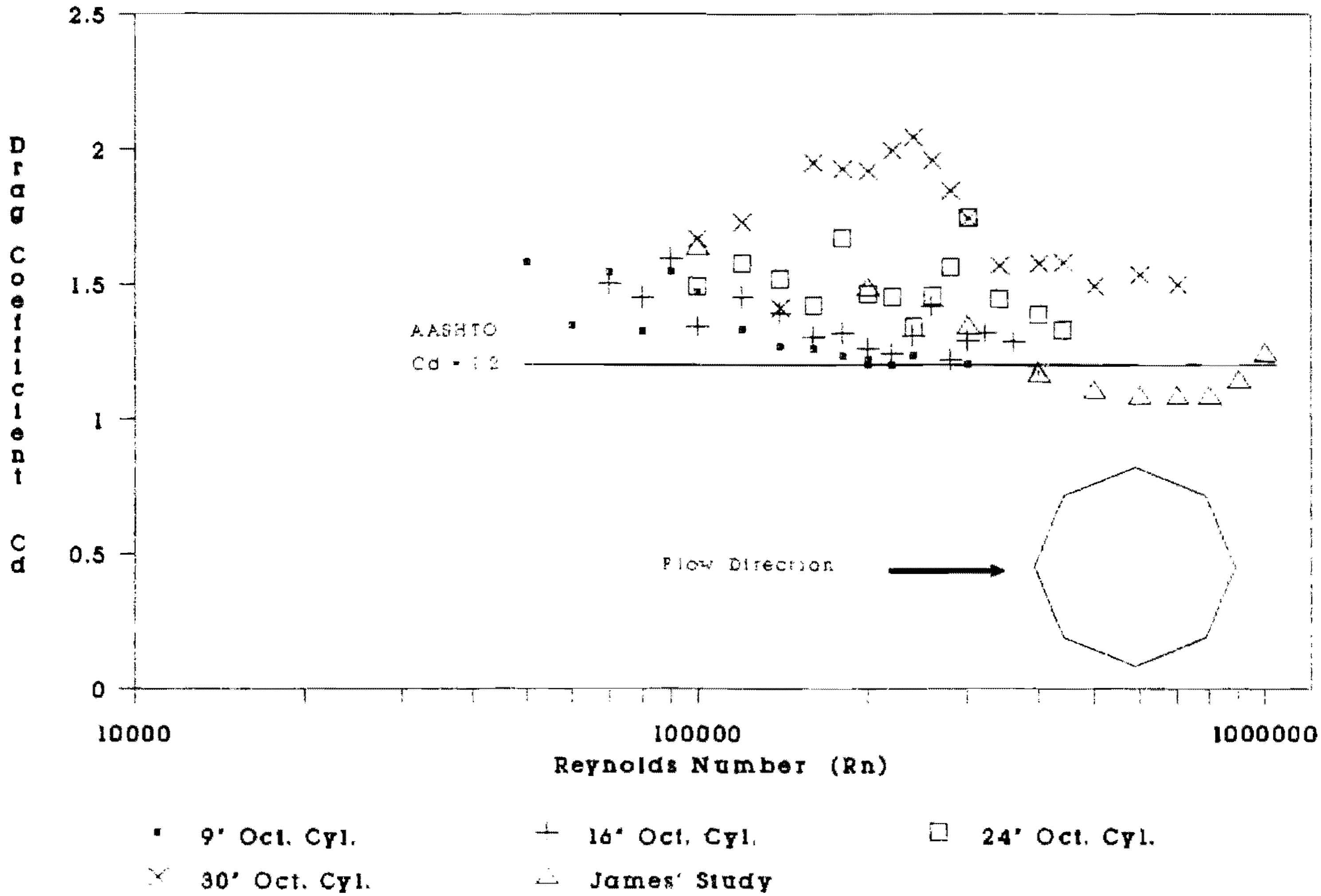


Figure 4.5 Combined Drag Coefficients for Octagonal Shape for Flow Toward a Corner.

The test results fall to a large extent above the drag coefficient value of 1.2 recommended by AASHTO (see Figure 4.5). The average drag coefficient value of the four specimens for flow directed at the corner (see Table 4.1) is 1.5, about 25% higher than recommended by the AASHTO specification. More data with longer test run distances (longer tow tank) is needed to establish definitively the drag coefficient value.

SECTION 5 - CONCLUSIONS

The results of this research project have provided additional information about drag coefficients for the octagonal shaped luminaire supports. The research has also demonstrated the viability of tow tank experimental procedures to produce drag coefficients. Conclusions derived from the project are:

1. The tow tank experimental procedure can be a viable and effective procedure for determining wind drag coefficients for luminaire poles.
2. Flow normal to a corner of the octagonal cylinder produced drag coefficient values of 10% to 20% higher than that for flow normal to a flat face.
3. Drag coefficient values for octagonal shapes did not exhibit dependency on the Reynolds number as shown in previous studies. The drag coefficient values remained in a range of 1.2 to 1.7 over the range of Reynolds numbers of from 5×10^4 to 7×10^5.
4. The corner radius ratio in the range of 11 to 44 percent did not have an effect on the drag coefficient values obtained.
5. For the octagonal cylinders tested with the corner normal to flow direction orientation, the drag coefficient had an average value of 1.5. This value is 25% higher than the one recommended in the current AASHTO standard.

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