Wind Loading on Fixed Site Series 6000 Antennas

A Technical Application Note from Doppler Systems

December 4, 2001

1.0 Introduction

This report provides the wind loadings on Doppler fixed site antennas. The environmental conditions for the purpose of this analysis are a 100 mph wind, with and without 0.5 inch of ice coating the surfaces of all components. Information for evaluating the loadings on the mast and other supporting structures is also given.

The loads apply to either the DDF605X or 609X series of antennas having wire whip type elements. Loads on the earlier DDF605X antennas using 5/8" diameter tubular elements would be higher.

2.0 Configuration

Figure 1 shows a DDF6052/6092 antenna and identifies the major components subject to wind loading. The mast can be either of two types. When a single antenna is ordered, it is supplied with a 5 ft long aluminum mast which is identified in the analysis as a "single mast". When multiple antennas are stacked, a different combination of masts is used which are identified as "stacking masts" in the analysis.

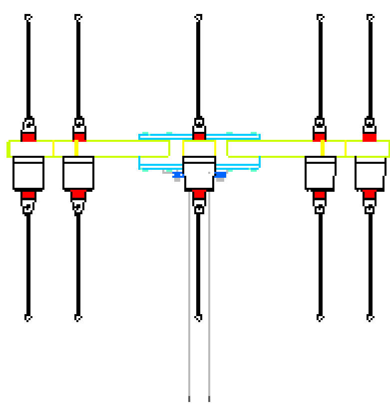

Figure 1 - DDF6052/6092 Antenna

3.0 Approach

Loads are calculated by summing the individual loads on the antenna components under both no ice and ½ inch icing conditions. This is done for the three different antenna sizes

(DDF6052/6092, DDF6055/6095, and DDF6057/6097). The antenna components shown in Figure 1 are listed in the first column of Tables 1 through 6. Each of these has an applicable windage drag equal to:

$$F_d := C_d \cdot A \cdot \rho \cdot \frac{V^2}{2}$$

Average density value for air, ρ , is taken as .0024 lb-sec^2/ft^4. A is the projected frontal area of the antenna component calculated from its length and width. V is the wind speed in ft/sec. The drag force calculated from this equation is listed in the "Basic Drag" column of the tables.

The drag coefficient, C_d, is a function of the Reynold's number which is calculated from:

$$Re := V \cdot \frac{d}{\nu}$$

In this equation, V is the wind speed and d is the characteristic length in ft. (usually a diameter or width). The average viscosity value for air, ν , is 1.5x10^{-4} ft^2/sec.

Once the Reynold's number is known, the drag coefficient can be determined from Figure 2 for the component's shape. (Table 12 is included for further reference.) It should be noted that for a given component geometry the drag coefficient doesn't vary significantly between the non-iced and iced condition.

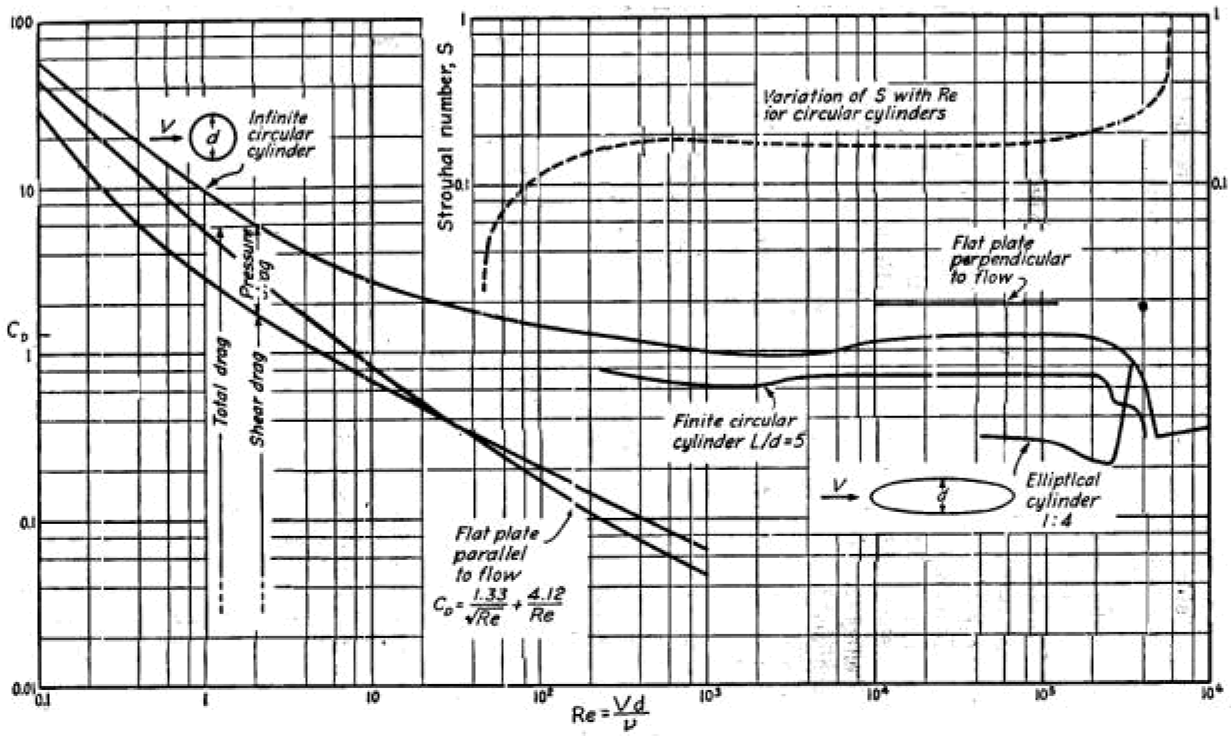

Figure 2 - Drag Coefficient

When ice is included in the calculations the ice thickness is doubled and added to the thickness of each component.

Although there are eight arms on the antenna, 4.8 is taken as the effective number due to the fact that two of the arms are parallel to the airstream, two are normal to it, and four arms are at 45 degrees. Their effective arm length is taken as .707 times the actual length. It is assumed that the drag variation is small as the wind changes direction.

In this analysis all components were assumed to be in the free stream. Components in the wake of another will have less drag than the same component in the free air stream. On the other hand, the analysis assumes smooth surfaces which may not be the case with icing.

4.0 Results

The results for a DDF6052/6092 antenna are shown in Tables 1 and 2. The results for DDF6055/95 and DDF6057/97 are given in Tables 3 through 6. The totals shown in these tables are for a single antenna. When the antennas are stacked, the value listed for "stacking mast" is used in place of the "single mast" value as explained in the next section.

Table 1 - Wind Loads for DDF6052/6092 without Ice

Component	Component Characteristic Dimension inch	Ice Thick. inch	Char. Dim. d Inch	Wind Speed mph	Reynolds Number	C_d	Frontal Dimensions inch		Frontal Area $inch^2$	Basic Drag lbs	No. of Comp.	Total Drag lbs
							Length	Width				
Whips	0.1	0	0.1	100	7,753	1	17	0.1	1.70	0.307	16	4.91
Cones	1.37	0	1.37	100	106,218	1.2	2	1.37	2.74	0.594	8	4.75
Ferrules	0.5	0	0.5	100	38,766	1.2	1.12	0.5	0.56	0.121	16	1.94
Arms	0.75	0	0.75	100	58,149	2	13.75	0.75	10.31	3.726	4.8	17.89
Hub	5.5	0	5.5	100	426,424	1.2	1.25	5.5	6.88	1.490	1	1.49
Single Mast	1	0	1	100	77,532	1.2	60	1	60.00	13.008	1	13.01
											TOTAL	**43.99**
Stacking Mast	1	0	1	100	77,532	1.2	19.2	1	19.20	4.162	1	4.16

Table 2 - Wind Loads for DDF6052/6092 with Ice

Component	Component Characteristic Dimension inch	Ice Thick. inch	Char. Dim. d Inch	Wind Speed mph	Reynolds Number	C_d	Frontal Dimensions inch		Frontal Area $inch^2$	Basic Drag lbs	No. of Comp.	Total Drag lbs
							Length	Width				
Whips	0.1	0.5	1.1	100	85,285	1	17	1.1	18.70	3.38	16	54.05
Cones	1.37	0.5	2.37	100	183,750	1.2	2	2.37	4.74	1.03	8	8.22
Ferrules	0.5	0.5	1.5	100	116,297	1.2	1.12	1.5	1.68	0.36	16	5.83
Arms	0.75	0.5	1.75	100	135,680	2	13.75	1.75	24.06	8.69	4.8	41.73
Hubs	5.5	0.5	6.5	100	503,956	1.2	1.25	6.5	8.13	1.76	1	1.76
Single Mast	1	0.5	2	100	155,063	1.2	60	2	120.00	26.015	1	26.02
											TOTAL	**137.6**
Stacking Mast	1	0.5	2	100	155,063	1.2	19.2	2	38.40	8.32	1	8.32

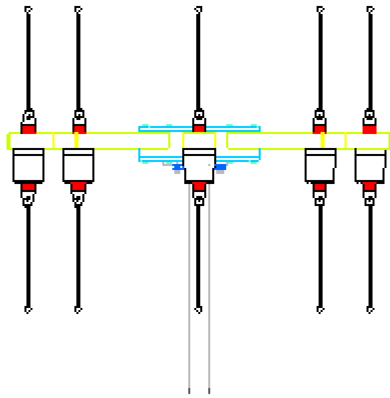

Figure 3 - DDF6055/6095 Antenna

Table 3 - Wind Loads for DDF6055/6095 without Ice												
Component	Component Characteristic Dimension inch	Ice Thick. inch	Char. Dim. d Inch	Wind Speed mph	Reynolds Number	C_d	Frontal Dimensions inch		Frontal Area inch^2	Basic Drag lbs	No. of Comp.	Total Drag lbs
							Length	Width				
Whips	0.1	0	0.1	100	7,753	1	4.5	0.1	0.45	0.08	16	1.30
Cones	1.37	0	1.37	100	106,218	1.2	2	1.37	2.74	0.59	8	4.75
Ferrules	0.5	0	0.5	100	38,766	1.2	1.12	0.5	0.56	0.12	16	1.94
Arms	0.75	0	0.75	100	58,149	2	6	0.75	4.50	1.63	4.8	7.80
Hub	5.5	0	5.5	100	426,424	1.2	1.25	5.5	6.88	1.49	1	1.49
Single Mast	1	0	1	100	77,532	1.2	60	1	60.00	13.01	1	13.01
											TOTAL	**30.30**
Stacking Mast	1	0	1	100	77,532	1.2	37.3	1	37.30	8.09	1	8.09

Table 4 - Wind Loads for DDF6055/6095 with Ice												
Component	Component Characteristic Dimension inch	Ice Thick. inch	Char. Dim. d Inch	Wind Speed mph	Reynolds Number	C_d	Frontal Dimensions inch		Frontal Area inch^2	Basic Drag lbs	No. of Comp.	Total Drag lbs
							Length	Width				
Whips	0.1	0.5	1.1	100	85,285	1	4.5	1.1	4.95	0.89	16	14.31
Cones	1.37	0.5	2.37	100	183,750	1.2	2	2.37	4.74	1.03	8	8.22
Ferrules	0.5	0.5	1.5	100	116,297	1.2	1.12	1.5	1.68	0.36	16	5.83
Arms	0.75	0.5	1.75	100	135,680	2	6	1.75	10.50	3.79	4.8	18.21

Hub	5.5	0.5	6.5	100	503,956	1.2	1.25	6.5	8.13	1.76	1	1.76
Single Mast	1	0.5	2	100	155,063	1.2	60	2	120.00	26.02	1	26.02
											TOTAL	**74.34**
Stacking	1	0.5	2	100	155,063	1.2	37.3	2	74.60	16.17	1	16.17

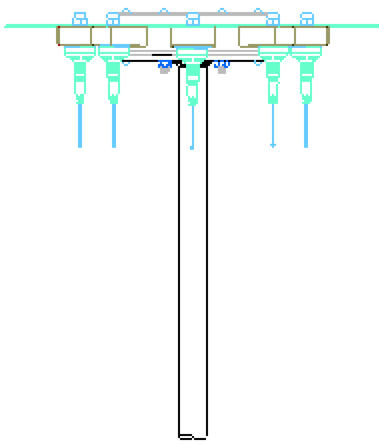

Figure 4 - DDF6057/6097 Antenna

Table 5 - Wind Loads for DDF6057/6097 without Ice

Component	Component Characteristic Dimension inch	Ice Thick. inch	Char. Dim. d Inch	Wind Speed mph	Reynolds Number	C_d	Frontal Dimensions inch		Frontal Area inch^2	Basic Drag lbs	No. of Comp.	Total Drag lbs
							Length	Width				
Whips	0.1	0	0.1	100	7,753	1	1.5	0.1	0.15	0.0271	8	0.22
Cones	1.37	0	1.37	100	106,218	1.2	0.96	1.37	1.32	0.2851	8	2.28
Ferrules	0.5	0	0.5	100	38,766	1.2	1.75	0.5	0.88	0.1897	16	3.04
Arms	0.75	0	0.75	100	58,149	2	2.12	0.75	1.59	0.5745	4.8	2.76
Hub	5.5	0	5.5	100	426,424	1.2	1.25	5.5	6.88	1.4904	1	1.49
Single	1	0	1	100	77,532	1.3	60	1	60.00	14.091	1	14.09
Plate	14.7	0	14.7	100	1,139,715	0.003	14.7	11.54	169.63	0.0919	2	0.18
											TOTAL	**24.06**
Stacking Mast	1	0	1	100	77,532	1.2	16	1	16.00	3.4687	1	3.47

Table 6 - Wind Loads for DDF6057/6097 with Ice												
Component	Component Characteristic Dimension inch	Ice Thick. inch	Char. Dim. d Inch	Wind Speed mph	Reynolds Number	C_d	Frontal Dimensions inch		Frontal Area $inch^2$	Basic Drag lbs	No. of Comp.	Total Drag lbs
							Length	Width				
Whips	0.1	0.5	1.1	100	85,285	1	1.5	1.1	1.65	0.30	8	2.38
Cones	1.37	0.5	2.37	100	183,750	1.2	2	2.37	4.74	1.03	8	8.22
Ferrules	0.5	0.5	1.5	100	116,297	1.2	1.12	1.5	1.68	0.36	16	5.83
Arms	0.75	0.5	1.75	100	135,680	2	2.12	1.75	3.71	1.34	4.8	6.43
Hub	5.5	0.5	6.5	100	503,956	1.2	1.25	6.5	8.13	1.76	1	1.76
Single	1	0.5	2	100	155,063	1.3	60	2	120.00	28.18	1	28.18
Plate	0.093	0.5	1.093	100	84,742	0.3	14.7	0.593	8.72	0.47	1	0.47
											TOTAL	**53.28**
Stacking Mast	1	0.5	2	100	155,063	1.3	16	2	32.00	7.52	1	7.52

5.0 Wind Loading on Multiple Antennas

Occasionally multiple antennas are stacked and mounted on a common mast. In this case, the wind loadings must be combined and reflected down to the base of the lower mast where the highest moment loads occur. For example, three antennas can be arranged as shown in Figure 5. The procedure is to use the forces calculated in the preceding tables, and calculate their moment with respect to the bottom of the mast. Tables 7 and 8 list the results for three stacked masts.

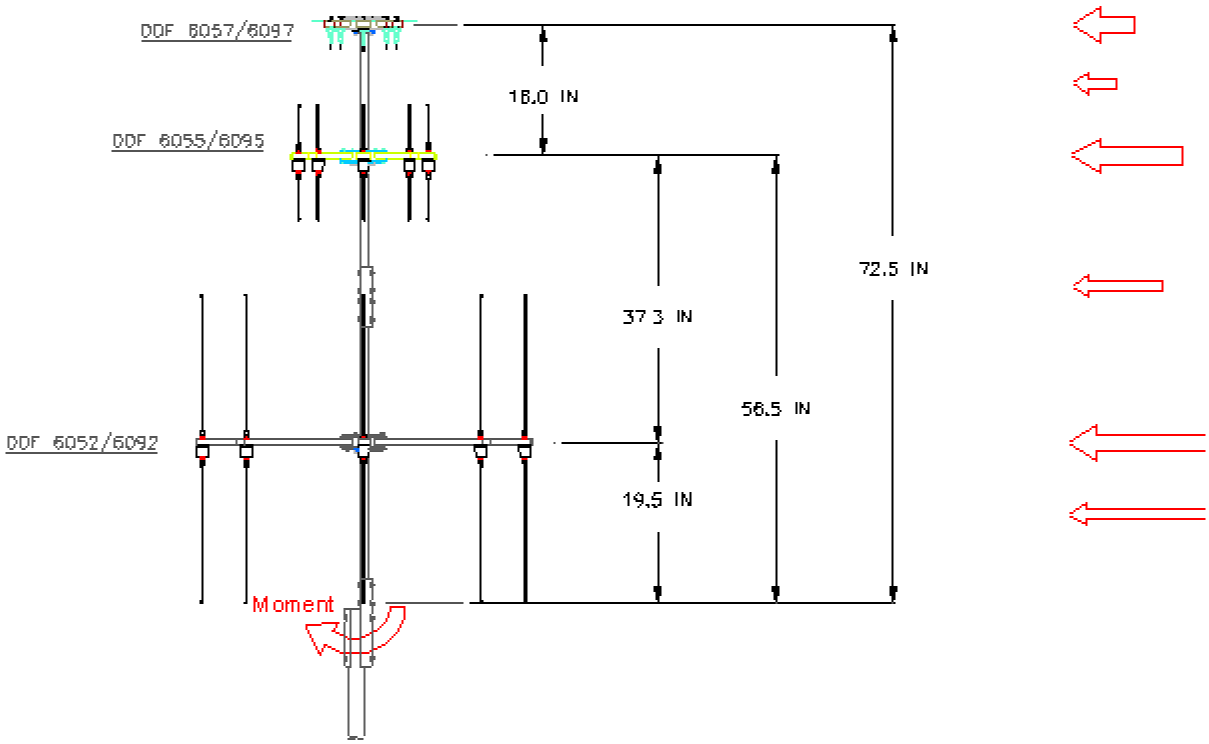

Figure 5 - Three Antenna Stack

Table 7 - Wind Loads on Mast Supporting Three Antenna Stack without Ice			
Antenna Assembly	Wind Load at 100 mph	Component Moment Arm	Component Moment at Mast Base
	lbs	inch	ft-lbs
DDF6052/6092 Less Mast	30.98	19.2	49.6
DDF6052/6092 Stacking Mast	4.16	9.6	3.3
DDF6055/6095 Less Mast	17.29	56.5	81.4
DDF6055/6095 Stacking Mast	8.09	38.1	25.7
DDF6057/6097 Less Mast	9.96	72.5	60.2
DDF6057/6097 Stacking Mast	3.47	64.5	18.6
		Total	**238.8**

Table 8 - Wind Loads on Mast Supporting Three Antenna Stack with Ice			
Antenna Assembly	Wind Load at 100 mph	Component Moment Arm	Component Moment at Mast Base

	lbs	inch	ft-lbs
DDF6052/6092 Less Mast	111.60	19.2	178.6
DDF6052/6092 Stacking Mast	8.32	9.6	6.7
DDF6055/6095 Less Mast	48.33	56.5	227.5
DDF6055/6095 Stacking Mast	16.17	38.1	51.3
DDF6057/6097 Less Mast	52.81	72.5	319.1
DDF6057/6097 Stacking Mast	7.52	64.5	40.4
		Total	**823.6**

Similarly, the moment loads at the base of the two antenna stack shown in Figure 6 is calculated and results given in Tables 9 and 10.

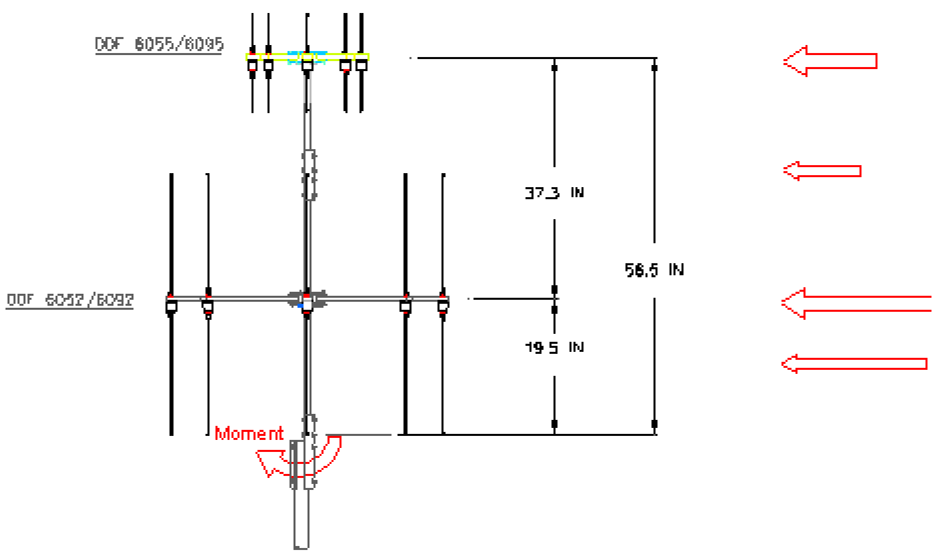

Figure 6 - Two Antenna Stack

Table 9 - Wind Loads on Mast Supporting Two Antenna Stack without Ice			
Antenna Assembly	Wind Load at 100 mph	Component Moment Arm	Component Moment at Mast Base
	lbs	inch	ft-lbs
DDF6052/6092 Less Mast	30.98	19.2	49.6
DDF6052/6092 Stacking Mast	4.16	9.6	1.7
DDF6055/6095 Less Mast	17.29	56.5	81.4
DDF6055/6095 Stacking Mast	8.09	37.85	12.8
		Total	**145.4**

Table 10 - Wind Loads on Mast Supporting Two Antenna Stack with Ice			
Antenna Assembly	Wind Load at 100 mph	Component Moment Arm	Component Moment at Mast Base
	lbs	inch	ft-lbs
DDF6052/6092 Less Mast	111.60	19.2	178.6
DDF6052/6092 Stacking Mast	8.32	9.6	3.3
DDF6055/6095 Less Mast	48.33	56.5	227
DDF6055/6095 Stacking Mast	16.17	37.85	25.5
		Total	**284.7**

6.0 Scaling Results

Any of the drag results can be scaled to another wind speed by multiplying the load or moment by the ratio of the speeds squared. For example, an ice covered 6052/6055 tandem pair has a 284.7 ft-lb moment load at the mast base (at 100 mph). Scaling this drag to 120 mph gives,

$(284.7)(120/100)^2$=410 ft-lbs

Table 11 shows a scaling example for an added 24 inch length of lower mast. The 24 inch extension is added to the moment arm of each component. This new moment arm is multiplied by the wind load to get a new moment at the base for each component. These are summed to get the total moment for the entire stack.

Table 11 - Scaling Table 10 for Extended Mast Length					
Antenna Assembly	Wind Load at 100 mph	Component Moment Arm	Mast Extension	New Moment Arm	Component Moment at Base
	lbs	inch	inch	inch	ft-lbs
DDF6052/6092 Less Mast	111.60	19.2	24	43.2	401.7
DDF6052/6092 Stacking Mast	8.32	9.6	24	33.6	23.3
DDF6055/6095 Less Mast	48.33	19.2	24	43.2	174.0
DDF6055/6095 Stacking Mast	16.17	37.85	24	61.85	83.4
				Total	**682.4**

7.0 References

Table 12- Drag Coefficients for Various Shapes is given below:

Object (Flow from L to R)	L/d	$Re = Vd/\nu$	C_D
1. Circular Cylinder, Axis Perpendicular to the Flow	1	10^5	0.63
	5		0.74
	20		0.90
	∞		1.20
	5	$>5 \times 10^5$	0.35
	∞		0.33
2. Circular Cylinder, Axis Parallel to the Flow	0	$>10^3$	1.12
	1		0.91
	2		0.85
	4		0.87
	7		0.99
3. Elliptical Cylinder (2:1)		4×10^4	0.6
		10^5	0.46
(4:1)		2.5×10^4 to 10^5	0.32
(8:1)		2.5×10^4	0.29
		2×10^5	0.20
4. Airfoil (1:3)	∞	$>4 \times 10^4$	0.07
5. Rectangular Plate for which L = length, d = width	1	$>10^3$	1.16
	5		1.20
	20		1.50
	∞		1.90
6. Square Cylinder ■		3.5×10^4	2.0
◆		$10^4 \times 10^5$	1.6
7. Triangular Cylinder 120°		$>10^4$	2.0
			1.72
60°			2.20
			1.39
30°		$>10^5$	1.80
			1.0
8. Hemispherical Shell		$>10^3$	1.33
		10^3 to 10^5	0.4
9. Circular Disk, normal to the flow		$>10^3$	1.12
10. Tandem Disks, spacing is L	0	$>10^3$	1.12
	1		0.93
	2		1.04
	3		1.54

Albertson, Barton and Simons, Fluid Mechanics for Engineers, Prentice-Hall, 1960, pp. 391, 407