Wind Loading and Stresses on the Series 7000 (MPT) Antenna Arrays

A Technical Application Note from Doppler Systems

November 21, 2011 - Revised September 27, 2017

1.0 Introduction

This report provides the wind loading on the MPT fixed site antennas. The environmental conditions include both iced and non-iced conditions. The stresses and safety margins are calculated at the critical locations due to the bending moment loads.

2.0 Configuration

There are three sizes of MPT antennas corresponding to the frequency bands used. Each of these antennas consist of a central hub ring, eight arms, and a biconical dipole mounted on the end of each arm. The biconical dipole is supported with a balun box that fastens to a flange on the end of each arm.

The antennas may be used individually, in which case the antenna's central hub is supported by a base mast. Or the antennas may also be stacked either two high or three high using masts that connect the lower side of a one central hub to the upper side of the adjacent lower central hub. Figures 1, 2 and 3 below show the mounting of a single VHF antenna, a UHF/VHF stacked pair, and a THF/UHF/VHF set of all three stacked antennas.

The antenna design analyzed is that defined in the following revisions of these drawings:

DDF6395 Base Mast
DDF6396 U/V Mast
DDF6397 T/U Mast
DDF6380C Biconical Element
DDF6385D Antenna Frame

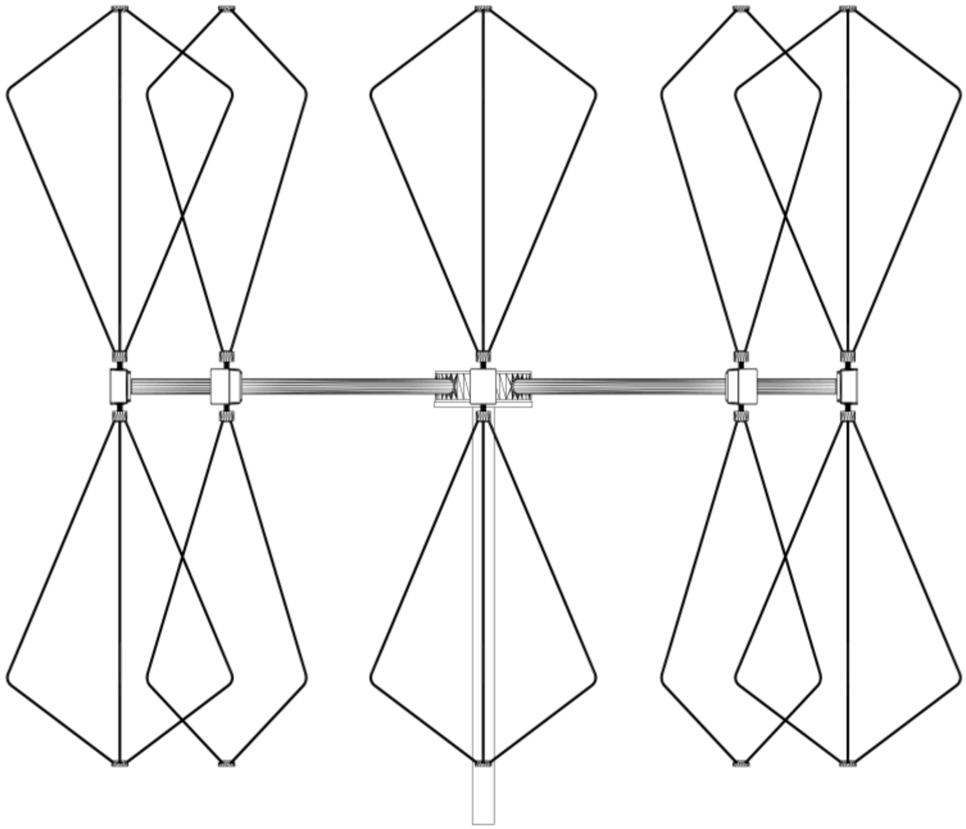


Figure 1 - VHF 8 Element Antenna on Mast

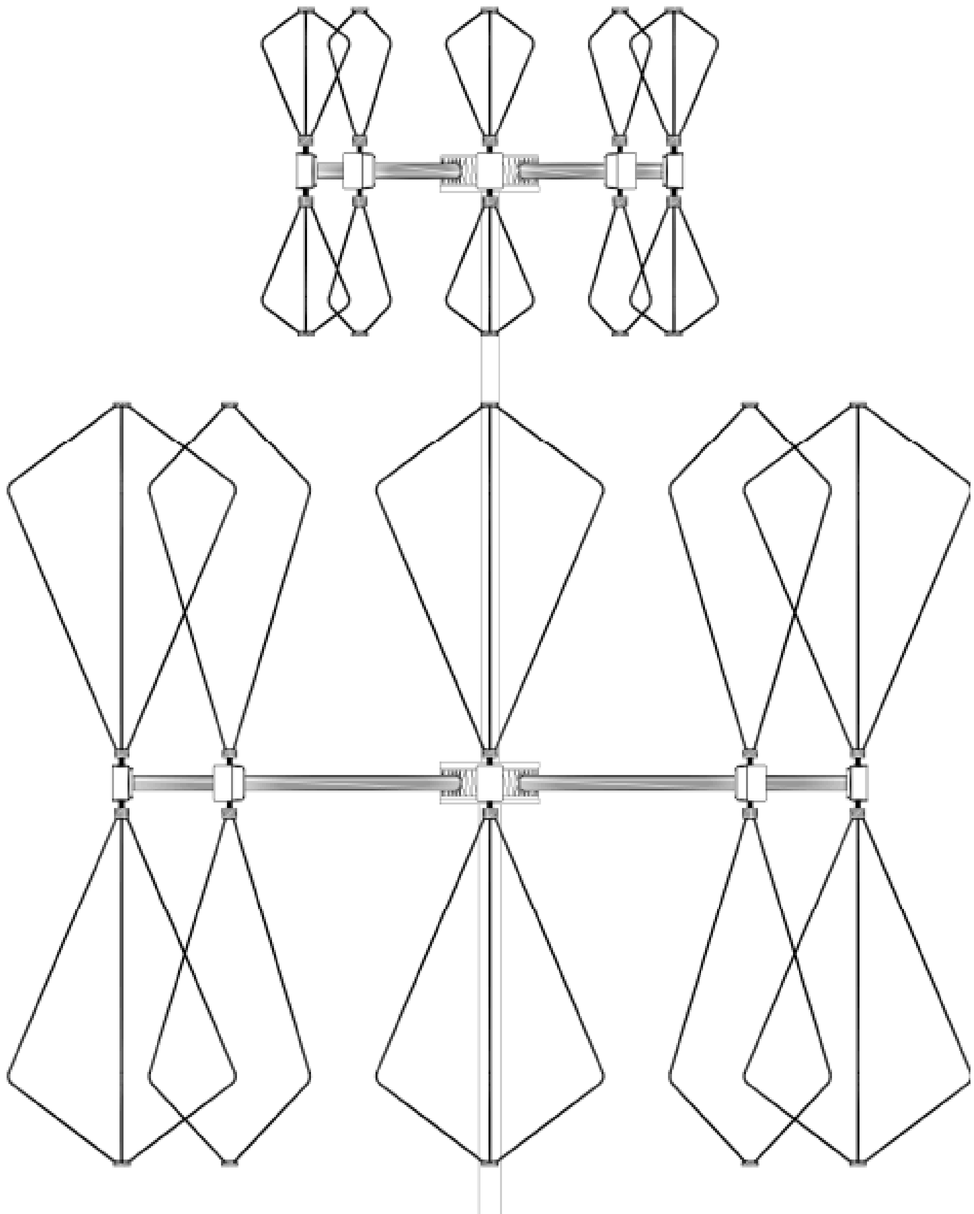


Figure 2 - UHF/VHF 8 Element Stacked Array

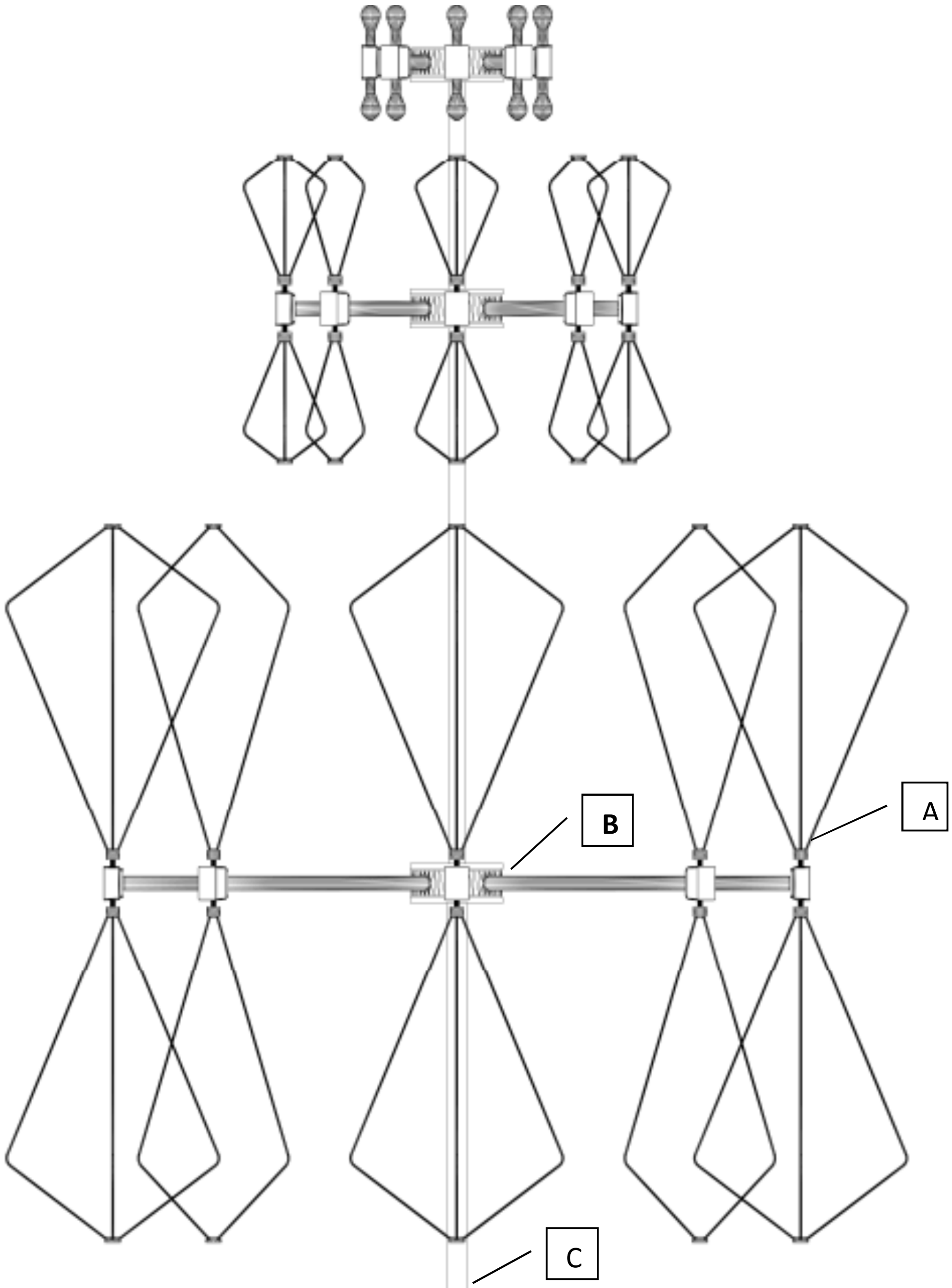


Figure 3 - THF/UHF/VHF 8 Element Stacked Array

The locations where stress is of concern are:

- The lower end of one of the wire elements used in the biconical antenna. This will be greatest for the VHF antenna since both the surface area of the antenna and the moment arm are much larger than the other antennas. See **A** in Figure 3.
- The interface between the antenna arm and the central hub ring on the VHF antenna. See **B** in Figure 3.
- The lower end of the three connecting masts. The load on the lowest mast will be highest for the three antenna stack shown in Figure 3 – see **C**.

3.0 Method of Calculation

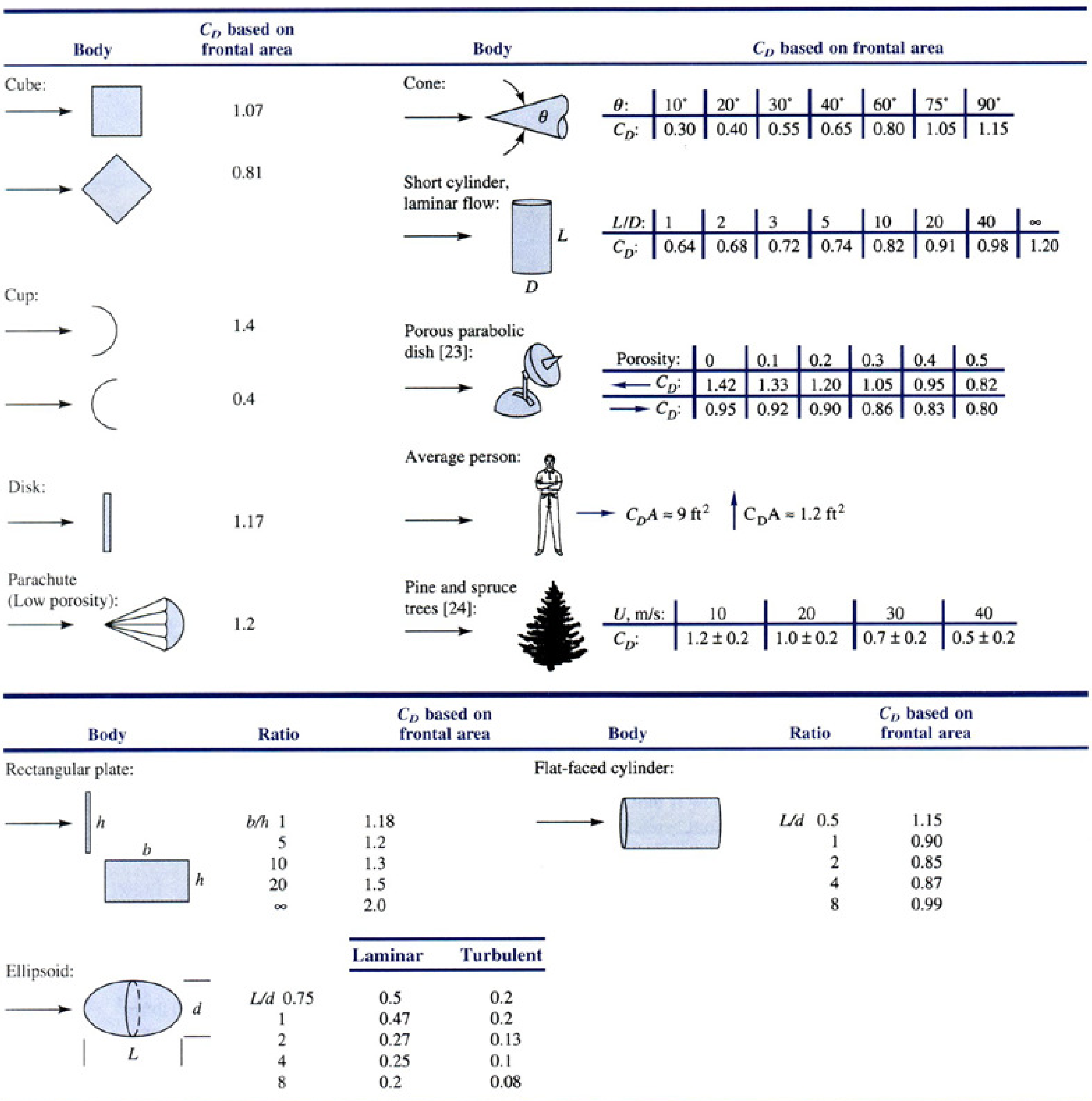
The wind load on each element is calculated using the equation:

$$F = C_D \cdot A \cdot \rho \cdot \frac{V^2}{2}$$

where,

F is the drag in lbs
C_D is the drag coefficient discussed below
A is the area of the element normal to the wind in ft^2
ρ is the density of air = 0.0024 $lb\text{-}s^2/ft^4$
V is the wind velocity in ft/s

The drag coefficient in general is a function of the Reynolds number but for the geometries, viscosity and wind speeds considered here, it may be neglected and the drag coefficient is simply taken from the shapes shown in Figure 4. Most of the elements are modeled as cylinders with L/D ratios between 1 and 20. The baluns are modeled as cubes.



Body	C_D based on frontal area
Cube: (face to flow)	1.07
Cube: (edge to flow)	0.81
Cup: (concave side downstream)	1.4
Cup: (concave side upstream)	0.4
Disk:	1.17
Parachute (Low porosity):	1.2

Cone:

θ:	10°	20°	30°	40°	60°	75°	90°
C_D:	0.30	0.40	0.55	0.65	0.80	1.05	1.15

Short cylinder, laminar flow:

L/D:	1	2	3	5	10	20	40	∞
C_D:	0.64	0.68	0.72	0.74	0.82	0.91	0.98	1.20

Porous parabolic dish [23]:

Porosity:	0	0.1	0.2	0.3	0.4	0.5
← C_D:	1.42	1.33	1.20	1.05	0.95	0.82
→ C_D:	0.95	0.92	0.90	0.86	0.83	0.80

Average person: → $C_D A \approx 9\ ft^2$ ↑ $C_D A \approx 1.2\ ft^2$

Pine and spruce trees [24]:

U, m/s:	10	20	30	40
C_D:	1.2 ± 0.2	1.0 ± 0.2	0.7 ± 0.2	0.5 ± 0.2

Body	Ratio	C_D based on frontal area	Body	Ratio	C_D based on frontal area
Rectangular plate:	b/h 1	1.18	Flat-faced cylinder:	L/d 0.5	1.15
	5	1.2		1	0.90
	10	1.3		2	0.85
	20	1.5		4	0.87
	∞	2.0		8	0.99

Ellipsoid:

Ratio	Laminar	Turbulent
L/d 0.75	0.5	0.2
1	0.47	0.2
2	0.27	0.13
4	0.25	0.1
8	0.2	0.08

Figure 4 - Drag Coefficients of Three Dimensional Bodies (Re > 10^4)

The stress calculations are based on the moment loads:

$$M = \sum F_i \cdot L_i$$

where the summation is taken for all drag forces above the point at which the moment is calculated.

The stress in all cases is that of a cantilevered cylindrical beam at the surface:

$$\sigma = M \cdot \frac{R}{I}$$

where,

σ is the stress in lbs/in^2 (psi)

R is the radius of the cylindrical section

I is the area moment of inertia in in^4. For a hollow cylinder,

$$I = \frac{\pi}{4} \cdot \left[\left(\frac{OD}{2} \right)^4 - \left(\frac{ID}{2} \right)^4 \right]$$

The safety margin is:

$$SM = \frac{\sigma_y}{\sigma} - 1$$

where σ_y is the yield stress of the material listed in the table below.

Material	Yield stress (psi)	Used in
17-4 Condition H900	200,000	Biconical wires on VHF antenna
17-4 Condition A	145,000	Biconical wires on UHF antenna
316 Stainless	30,000	Biconical hubs & bolts; THF antenna elements
6061 T6	40,000	Arms, center hub
Fibreglass	70,000	Masts

4.0 Loads and Stresses with 120 mph Wind, No Ice

The following tables show the loads and stresses with 120 mph wind and no ice buildup. The minimum safety margin is 125% and occurs at the base of the mast.

THF Biconic Antenna Elements

Element Material: 316 Stainless

Arm Material: 6061-T6

Universal Parameters

Wind Speed = 120 mph

Ice Load = 0 inches

Antenna elements

Element	Frontal Area in^2	C_D	Force Each Pounds	Count	Total Force Pounds	Moment Distance Inches	Safety Margin
Biconic Elements	2.0913	0.64	0.3431	2	0.686	1.352	1000.00%

Wind Loading for THF Biconic Antenna Array

Element	Frontal Area in^2	C_D	Force Each Pounds	Count	Total Force Pounds	Moment Distance Inches	Safety Margin
Biconic Dipoles			0.686	8	5.489		
Balums[2]	3.3314	0.95	0.811	8	6.490		
Arm	0.4655	0.91	0.108	1	1.606	1.170	1000.00%
Arms[3]			0.108	4.828	0.524		
Hub	11.3410	0.64	1.858	1	1.858		
	Total side load for Array				14.360		

T/U Mast

Hub C-C Distance = 15

Mast Material: Fiberglass

1/Area Moment = 14.133304

Outside Diameter = 1.25

Mast Side Load = 3.90 lbs

Load at Stress Point = 1969.5789

Inside Diameter = 1

Safety Margin = 1000.00%

UHF Biconic Antenna Elements

Stub Diameter = 0.2603 Inches
Element Diameter = 0.125 Inches
Element Material 17-4PH Cond. A

Antenna elments normal to wind direction

Element	Frontal Area in²	C_D	Force Each Pounds	Count	Total Force Pounds	Moment Distance Inches	Safety Margin
Parallel Biconic Elements	0.7438	1.20	0.228	2	0.457		
Perpendicular Biconic Elements	0.9531	1.20	0.293	2	0.586		
Upper Hub	0.2938	0.64	0.048	1	0.048		
Lower Hub Load	--	--	--	--	1.091	4.204	1000.00%
Lower Hub	0.4190	0.64	0.069	1	0.069		
			Total for Antenna		1.159	5.043	1000.00%

Antenna elements 45° to wind direction

Element	Frontal Area in²	C_D	Force Each Pounds	Count	Total Force Pounds	Moment Distance Inches	Safety Margin
Biconic Element	0.9190	1.20	0.282	4	1.129		
Upper Hub	0.2938	1.20	0.090	1	0.090		
Lower Hub Load	--	--	--	--	1.219	4.287	1000.00%
Lower Hub	0.4190	0.64	0.069	1	0.069		
			Total for Antenna		1.288	5.126	1000.00%

Wind Loading for UHF Biconic Antenna Array

Element	Frontal Area in²	C_D	Force Each Pounds	Count	Total Force Pounds	Moment Distance Inches	Safety Margin
Biconic Dipoles[1]			2.447	8	19.580		
Balums[2]	3.3314	0.95	0.810	8	6.481		
Arm	3.8946	0.91	0.907	1	4.165	5.089	1000.00%
Arms[3]			0.907	4.828	4.380		
Hub	13.0625	0.64	2.140	1	2.140		
	Total side load for Array				32.582		

U/V Mast

Hub C-C Distance = 35
Outside Diameter = 1.25
Inside Diameter = 1

Mast Material Fiberglass
Mast Side Load = 9.73 lbs
Safety Margin = 298.91%

1/Area Moment^2 = 14.133304
Load at Stress Point = 17547.703

VHF Biconic Antenna Elements

Stub Diameter = 0.2603 Inches
Element Diameter = 0.125 Inches
Element Material 17-4PH Cond. H900

Antenna elements normal to wind direction

Element	Frontal Area in^2	C_D	Force Each Pounds	Count	Total Force Pounds	Moment Distance Inches	Safety Margin
Parallel Biconic Elements	2.4334	1.20	0.748	2	1.495		
Perpendicular Biconic Elements	2.9825	1.20	0.916	2	1.832		
Upper Hub	0.2938	0.64	0.048	1	0.048		
Lower Hub Load	--	--	--	--	3.376	11.154	307.39%
Lower Hub	0.4190	0.64	0.069	1	0.069		
		Total for Monopole			3.444	11.993	738.35%

Antenna elements 45° to wind direction

Element	Frontal Area in^2	C_D	Force Each Pounds	Count	Total Force Pounds	Moment Distance Inches	Safety Margin	
Biconic Element	2.7759	1.20	0.853	4	3.411			
Upper Hub	0.2938	0.64	0.048	1	0.048			
Lower Hub Load	--	--	--	--	3.459	11.374	289.89%	<< Loc A
Lower Hub	0.4190	0.64	0.069	1	0.069			
		Total for Monopole			3.528	12.213	703.76%	

Wind Loading for VHF Biconic Antenna Array

Element	Frontal Area in^2	C_D	Force Each Pounds	Count	Total Force Pounds	Moment Distance Inches	Safety Margin	
Biconic Dipoles[1]			6.972	8	55.777			
Balums[2]	3.3314	0.95	0.810	8	6.481			
Arms	10.7546	0.91	2.505	1	10.288	12.929	714.97%	<< Loc B
Arms[3]			2.505	4.828	12.096			
Hub	13.0625	0.64	2.140	1	2.140			
	Total side load for Array				76.494			

Base Mast

Load Point to Hub Center = 32
Outside Diameter = 1.25
Inside Diameter = 0

Mast Material Fiberglass
Mast Side Load = 8.86 lbs
Safety Margin = 124.98% <<Loc C

1/Area Moment^2 = 8.3443027
Load at Stress Point = 31113.846
Moment Load at Base = 5966.0052

Notes:

1. Average area of eight dipoles, assuming four are perpendicular to the wind and four are rotated 45º to the wind.
2. Average area of eight balum boxes, assuming two are showing top/bottom surface to the wind, two are showing side, and four are rotated 45º to the wind. Average of eight drag coefficients is used, assuming four perpendicular to the wind and four are rotated 45º to the wind. The thickness of the mounting flange is included as an extension of the balum face.
3. Average area of six arms, assuming two are perpendicular to the wind and four are at a 45º angle to the wind. Two are assumed hidden from the wind, one by the balum box and one by the center hub.
4. Ice thickness is added to each dimension of node elements and subtracted from the length of joining elements.

5.0 Loads and Stresses with 60 mph Wind, ½ Inch Ice

The following tables present the loads and stresses with ½ inch radial ice and 60 mph wind. The lowest safety margin is about 78% and occurs at the base of the mast.

THF Biconic Antenna Elements

Element Material: 316 Stainless

Arm Material: 6061-T6

Universal Parameters
Wind Speed = 60 mph
Ice Load = 0.5 inches

Antenna elements

Element	Frontal Area in^2	C_D	Force Each Pounds	Count	Total Force Pounds	Moment Distance Inches	Safety Margin
Biconic Elements	6.6877	0.64	0.2743	2	0.549	1.352	1000.00%

Wind Loading for THF Biconic Antenna Array

Element	Frontal Area in^2	C_D	Force Each Pounds	Count	Total Force Pounds	Moment Distance Inches	Safety Margin
Biconic Dipoles			0.549	8	4.388		
Balums[2]	5.4205	0.95	0.330	8	2.640		
Arm	0.0000	0.91	0.000	1	0.879	1.170	1000.00%
Arms[3]			0.000	4.828	0.000		
Hub	19.9030	0.64	0.815	1	0.815		
	Total side load for Array				7.843		

T/U Mast

Hub C-C Distance = 15
Outside Diameter = 1.25
Inside Diameter = 1

Mast Material: Fiberglass
Mast Side Load = 1.26 lbs
Safety Margin = 1000.00%

1/Area Moment = 14.133304
Load at Stress Point = 1027.4005

UHF Biconic Antenna Elements

Stub Diameter = 0.2603 Inches
Element Diameter = 0.125 Inches
Element Material: 17-4PH Cond. A

Antenna elments normal to wind direction

Element	Frontal Area in^2	C_D	Force Each Pounds	Count	Total Force Pounds	Moment Distance Inches	Safety Margin
Parallel Biconic Elements	5.5688	1.20	0.428	2	0.855		
Perpendicular Biconic Elements	7.4530	1.20	0.572	2	1.145		
Upper Hub	2.5413	0.64	0.104	1	0.104		
Lower Hub Load	--	--	--	--	2.104	4.204	1000.00%
Lower Hub	0.0975	0.64	0.004	1	0.004		
			Total for Antenna		2.108	5.043	1000.00%

Antenna elements 45° to wind direction

Element	Frontal Area in^2	C_D	Force Each Pounds	Count	Total Force Pounds	Moment Distance Inches	Safety Margin
Biconic Element	7.1456	1.20	0.549	4	2.195		
Upper Hub	2.5413	1.20	0.195	1	0.195		
Lower Hub Load	--	--	--	--	2.390	4.287	985.38%
Lower Hub	0.0975	0.64	0.004	1	0.004		
			Total for Antenna		2.394	5.126	1000.00%

Wind Loading for UHF Biconic Antenna Array

Element	Frontal Area in^2	C_D	Force Each Pounds	Count	Total Force Pounds	Moment Distance Inches	Safety Margin
Biconic Dipoles[1]			4.503	8	36.020		
Balums[2]	5.4205	0.95	0.330	8	2.637		
Arm	6.4706	0.91	0.377	1	5.209	5.089	1000.00%
Arms[3]			0.377	4.828	1.819		
Hub	21.9375	0.64	0.899	1	0.899		
	Total side load for Array				41.375		

U/V Mast

Hub C-C Distance = 35
Outside Diameter = 1.25
Inside Diameter = 1

Mast Material: Fiberglass
Mast Side Load = 3.30 lbs
Safety Margin = 328.48%

1/Area Moment^2 = 14.133304
Load at Stress Point = 16336.949

VHF Biconic Antenna Elements

Stub Diameter = 0.2603 Inches

Element Diameter = 0.125 Inches

Element Material 17-4PH Cond. H900

Antenna elements normal to wind direction

Element	Frontal Area in^2	C_D	Force Each Pounds	Count	Total Force Pounds	Moment Distance Inches	Safety Margin
Parallel Biconic Elements	20.7754	1.20	1.596	2	3.191		
Perpendicular Biconic Elements	25.7175	1.20	1.975	2	3.950		
Upper Hub	2.5413	0.64	0.104	1	0.104		
Lower Hub Load	--	--	--	--	7.245	11.154	89.81%
Lower Hub	0.0975	0.64	0.004	1	0.004		
		Total for Monopole			7.249	11.993	298.31%

Antenna elements 45° to wind direction

Element	Frontal Area in^2	C_D	Force Each Pounds	Count	Total Force Pounds	Moment Distance Inches	Safety Margin	
Biconic Element	23.8579	1.20	1.832	4	7.329			
Upper Hub	2.5413	0.64	0.104	1	0.104			
Lower Hub Load	--	--	--	--	7.433	11.374	81.44%	<< Loc A
Lower Hub	0.0975	0.64	0.004	1	0.004			
		Total for Monopole			7.437	12.213	281.26%	

Wind Loading for VHF Biconic Antenna Array

Element	Frontal Area in^2	C_D	Force Each Pounds	Count	Total Force Pounds	Moment Distance Inches	Safety Margin	
Biconic Dipoles[1]			14.687	8	117.493			
Balums[2]	5.4205	0.95	0.330	8	2.637			
Arms	21.1706	0.91	1.233	1	16.249	12.929	415.97%	<< Loc B
Arms[3]			1.233	4.828	5.953			
Hub	21.9375	0.64	0.899	1	0.899			
	Total side load for Array				126.981			

Base Mast

Load Point to Hub Center =	32	Mast Material	Fiberglass	1/Area Moment^2 =	8.3443027
Outside Diameter =	1.25	Mast Side Load =	3.00 lbs	Load at Stress Point =	39378.839
Inside Diameter =	0	Safety Margin =	77.76% <<Loc C	Moment Load at Base =	7550.7979

(Same notes apply).

6.0 Maximum Wind Speed vs Ice Buildup

Figure 5 shows the maximum wind speed that results in zero safety margin (failure) as a function of the radial ice buildup on the three antenna stack. The two purple markers are the design goals.

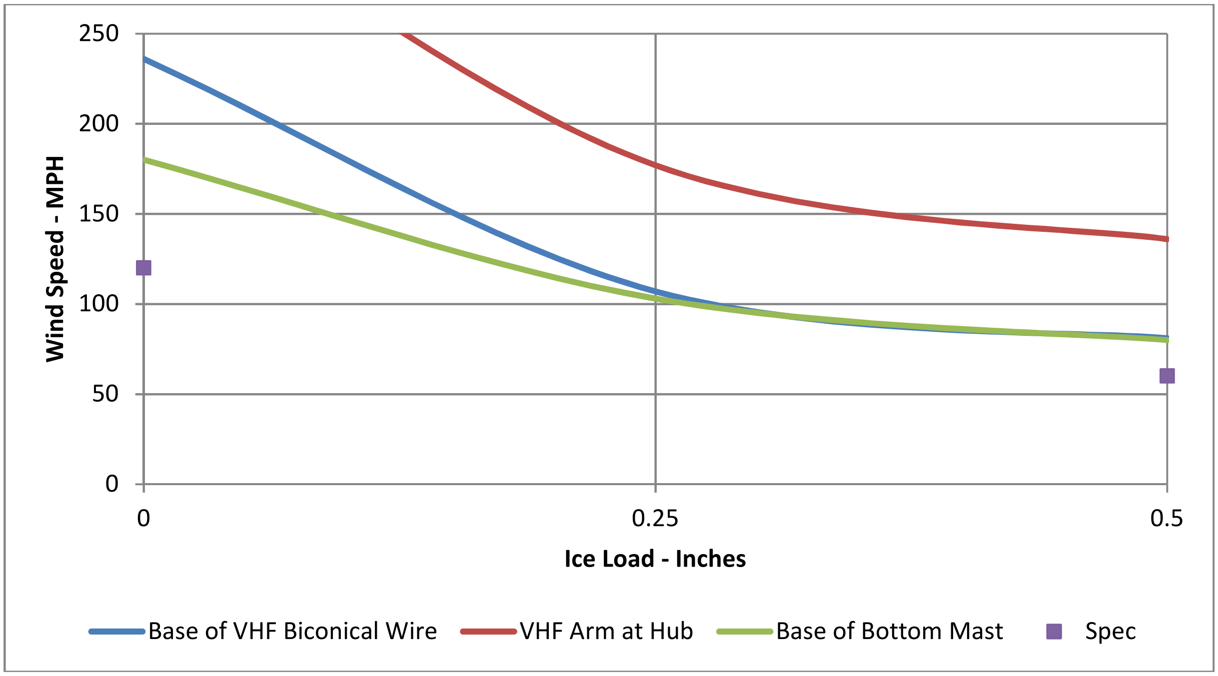


Figure 5 - Maximum Wind Speed vs Ice Buildup

7.0 Conclusions

The three antenna array with biconical elements will withstand more than 120 mph wind with no ice and 60 mph wind with ½ inch ice.