Tower and Antenna Wind Loading as a Function of Height

Do you want to determine the maximum safe height of your freestanding tower—for any antenna configuration—as a function of wind velocity? Use this approach to write a simple spreadsheet that will do the calculations in a matter of seconds and check the mast stress at the same time.

By Frank Travanty, W9JCC

[Author's disclaimer: No liability is assumed for use of these calculations that results in bodily injury or property loss. If there are any questions or concerns regarding safety, they should be referred to the manufacturer of your tower.]

After having a 54-foot, freestanding crank-up tower with a TH6DXX beam up for 29 years in three different states, the wind finally blew hard enough to bend the lower portion of the tower. The tower was cranked down to my "away-from-home" park position of about 30 feet at the time. Our high winds seldom reach 60 mph; but this time, there was a report of 100-mph-plus winds just a few blocks away.

A heavier-duty replacement tower was immediately ordered and, of course, new and larger antennas—and more of them. As winter was rapidly approaching, I put the tower and antennas up as quickly as possible. I also decided it would be a good idea to calculate the bending moments caused by wind loading on the tower base as a function of the tower height. It's better to do these calculations before buying the tower and antennas. As this was an unscheduled event, though, necessity dictated that the new antenna system be ordered immediately so it could be installed before winter.

When the wind began to howl in previous years, I would make the trip outdoors—often in the middle of the night—to crank down the tower. The tower-height/wind-speed curves in this article, along with a check of the weather forecast, let me sleep soundly while the wind howls, and I avoid those midnight trips outdoors.

Most manufacturers of freestanding, crank-up towers specify the permissible wind loading with some specific surface area positioned at a specified distance above the top of the tower, with the tower extended to its maximum height. In many instances, this does not reflect actual use, since many hams stack antennas or place their antennas at a height that does not match the specifications. Some questions always arise when installing a freestanding crank-up tower, such as:

- What is the effect of positioning one or more antennas at various heights on the mast?

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- Once the antenna configuration has been determined, how low must the tower be retracted to survive an anticipated wind velocity?
- Which will fail first because of wind loading: the mast or the tower?

Objectives

My specific objectives are:

1. Determine the constant-moment curve (safe-operating curve) at the base of the tower, based on the tower manufacturer's wind-load specification, as a function of tower height and wind velocity for any generalized antenna and mast configuration.
2. Include the mast moment at the thrust bearing to permit analysis of "what-if" scenarios to determine whether the mast or tower is the weakest link or "fuse" of the system. The mast analysis has been done previously by several others.[1,2,3,4,5] The equations are included here for completeness.
3. Provide the necessary equations to easily calculate the tower and mast bending moments by use of a spreadsheet, and to generate a constant-moment plot for any general installation.

Derivation of Tower Wind Load versus Tower Height

Tower Height as a Function of Section Overlap

This derivation is done for a three-section, freestanding tower. It can be followed for towers with a greater or lesser number of sections. General equations for any number of tower sections are provided in the sidebar "General Equations for the Tower Height and Distance to Section Midpoints."

Refer to Fig 1 for the following definitions. All distances are in feet. All forces are in pounds.

D7 = Distance to the midpoint of the bottom tower section from the tower base.
D6 = Distance to the midpoint of the middle tower section from the tower base.
D5 = Distance to the midpoint of the top tower section from the tower base.
F7 = Wind-load force on the bottom tower section applied at its midpoint.
F6 = Wind-load force on the middle tower section applied at its midpoint.
F5 = Wind-load force on the top tower section applied at its midpoint.
h6 = Overlap distance of middle section into bottom section.
h5 = Overlap distance of top section into middle section.
H = The tower height from the base to the top of the top section. (*H* can vary between 21 feet and 55 feet in this example.)
L = 21 feet (Length of individual tower sections.)

The necessary relationship between tower height and tower-section overlap can now easily be determined as shown below and by inspection of Fig 1. Refer-

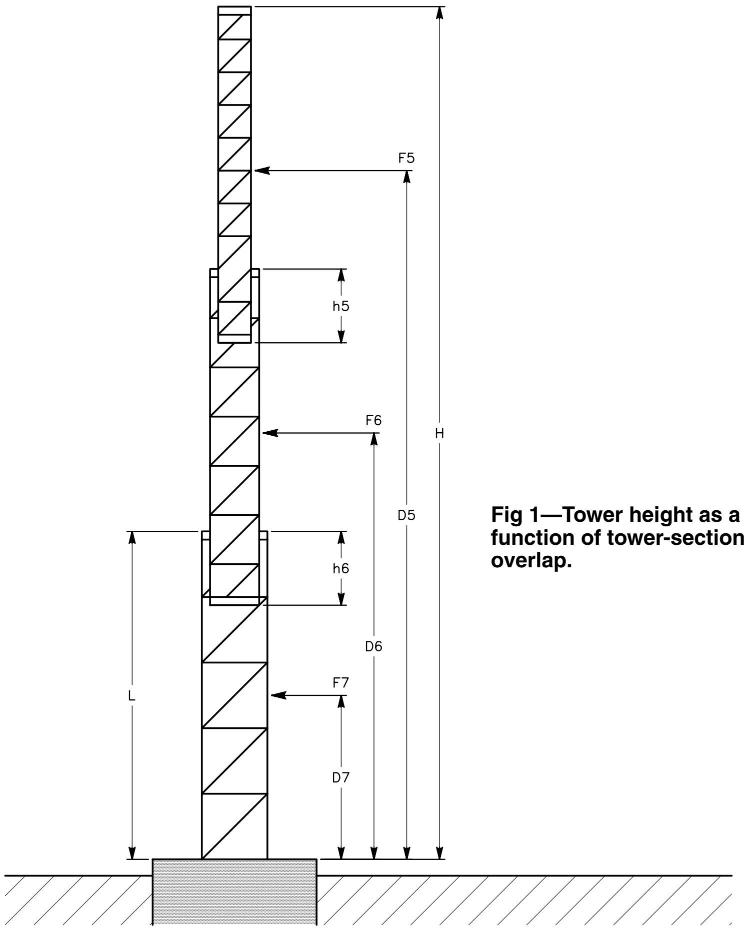

Fig 1—Tower height as a function of tower-section overlap.

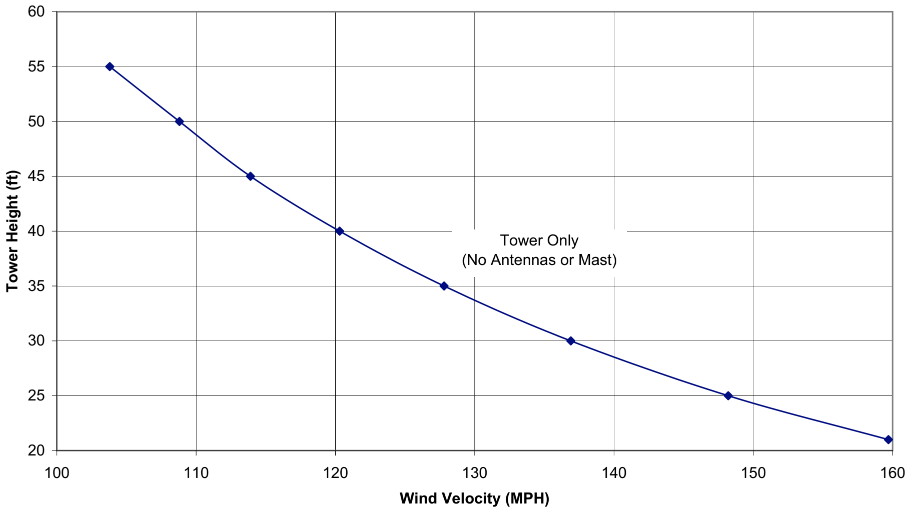

Fig 2—A constant-moment curve for 19,600 ft-lb for the tower only, with a gust factor of 1.28.

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[1] Notes appear on page 33.

ring to Fig 1, the height of the tower, H, for a three-section tower, is:

$$H = L + (L - h6) + (L - h5) \qquad \text{(Eq 1)}$$

The telescoping sections are cabled to telescope uniformly, so the overlaps are equal, yielding $h5 = h6 = h$; the length is fixed at 21 feet. Substituting these values, H becomes:

$$\begin{aligned} H &= 21 + (21 - h) + (21 - h) \\ &= 63 - 2h \end{aligned} \qquad \text{(Eq 2)}$$

Solving for the overlap h:

$$h = \frac{(63 - H)}{2} \qquad \text{(Eq 3)}$$

Distances to the Tower-Section Midpoints from the Base, as a Function of Tower Height

The wind load on the tower proper is determined by applying the total horizontal wind force on each tower section at the center of each of the sections. So, referring to Fig 1 and starting with the lowest section, the distances from the base to the midpoints of the tower sections as a function of tower overlap become:

$$\begin{aligned} D7 &= \frac{L}{2} \\ D6 &= L + \left(\frac{L}{2} - h\right) \\ D5 &= L + (L - h) + \left(\frac{L}{2} - h\right) \end{aligned} \qquad \text{(Eq 3A)}$$

Substituting Eq 3 into the expressions above, and letting $L = 21$ feet, the distances from the base to the midpoints of the tower sections (as a function of tower height) are:

$$\begin{aligned} D7 &= 10.5 \\ D6 &= 0.5H \\ D5 &= H - 10.5 \end{aligned} \qquad \text{(Eq 3B)}$$

Wind Surface Areas for Individual Tower Sections

These data are usually supplied in the engineering calculations from the tower manufacturer. If not, they may be calculated as described in Notes 1, 2, 3 and 4. For my tower, the section wind loading was obtained from the engineering calculations from the tower manufacturer, as listed below.

For the three tower sections, the areas are:

A5 = Area of top section = 4.43 ft^2

A6 = Area of middle section = 5.75 ft^2

A7 = Area of bottom section = 7.12 ft^2

Forces on the Tower Sections

The wind forces $F5$, $F6$ and $F7$ on each of the tower sections is calculated (see Note 1) using:

$$F = \frac{\left(Vg^2\right)(A)}{390} \qquad \text{(Eq 4)}$$

where:

F= Horizontal force, in pounds.

Vg = Wind velocity in mph. Includes gust factor (see Note 2) of 1.28 (~112 ft, hilly terrain)

A = Surface area, in ft^2

Moments Due to Tower Sections Only

The moment at the tower base due to the individual tower-section moments $M5$, $M6$ and $M7$ is calculated using:

$$M = \Sigma(FD) \qquad \text{(Eq 5)}$$

where F is the force applied to each tower section and D is the distance to the midpoint of its respective tower section. Then the moment at the tower base due to the tower sections only is:

$$\begin{aligned} M_{\text{Tower}} &= M5 + M6 + M7 \\ &= (F5)(D5) + (F6)(D6) + (F7)(D7) \end{aligned} \qquad \text{(Eq 6)}$$

The engineering specification from the tower manufacturer is 350 lb of wind force, located one foot above the fully extended tower. This is the basis

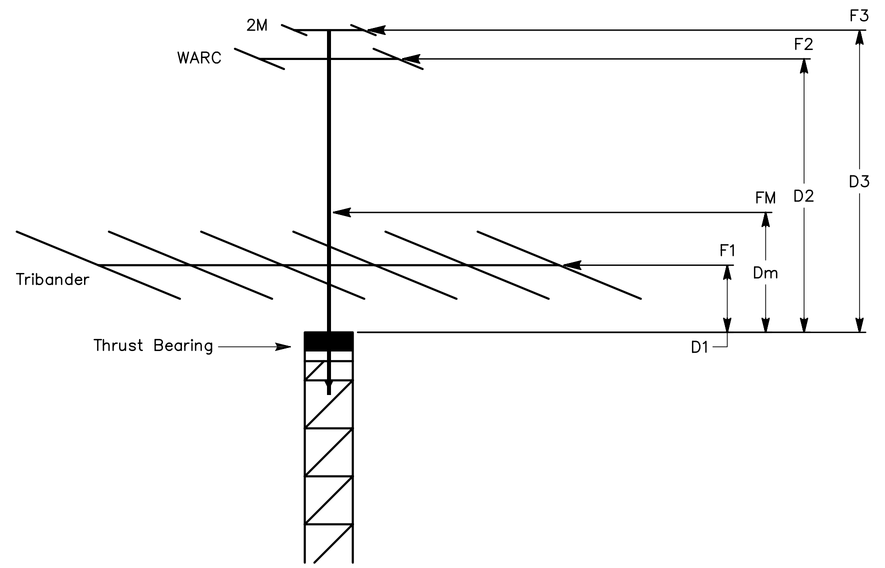

Fig 3—Information for the mast analysis.

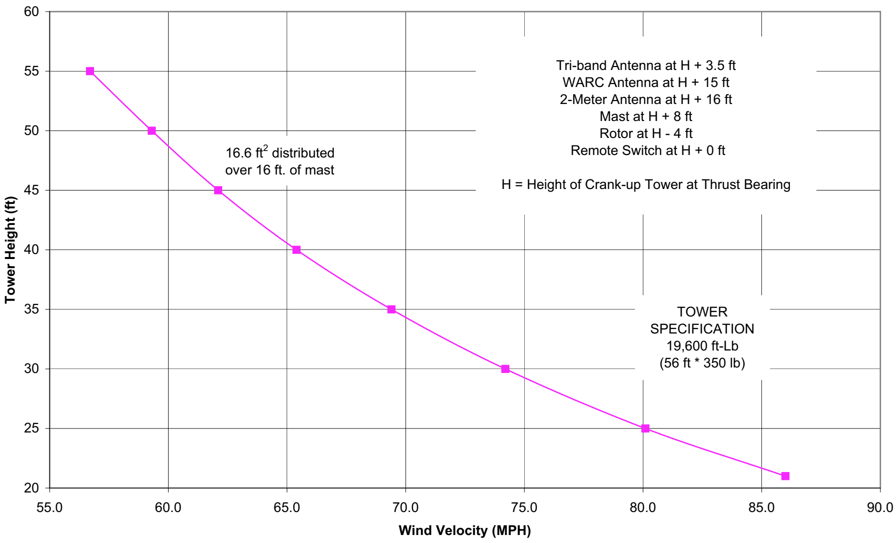

Fig 4—A constant-moment curve for a specific installation (gust factor 1.28).

for determining the safe bending moment at the base of the tower; that is, (350 lb)(55 ft +1 ft) = 19,600 ft-lb.

Fig 2 is a plot of wind force versus tower height, for the rating of the tower described above, with no additional wind loads applied to the tower and a gust factor of 1.28 applied.

The curves of Fig 2 and the others were generated using a spreadsheet on a personal computer. First, a two-column table is generated containing tower height and wind velocity, as shown in Table 1.[6] The tower heights are first inserted into the table for the full range of heights possible. In this case, increments of five feet were chosen. Then, the spreadsheet is used to calculate the allowable wind velocity at the specified load of 19,600 ft-lb. Excerpts from the spreadsheet, Tables 2 and 3, show the input cells in bold for the specified bending moment, and Table 4 shows the result of the calculation compared to the design limit. With a 133-MHz personal computer, the calculation for any single table entry is complete in less than about 0.5 s. Three or four iterations will usually get you close enough to the target bending moment. In this example, the target bending moment is 19,600 ft-lb. The entire table and chart can be completed in 5-10 minutes.

Reality

The tower, at full height and without loads, can stand a wind velocity of about 104 mph. Now let's add the mast, antennas and accessories. We will need to know the wind loading of the mast and antennas anyway, so let's do the mast analysis next. The mast analysis will be included in the spreadsheet to determine the failure points for both the tower and mast.

Mast Analysis

Mast analyses have appeared in previous issues of Amateur Radio publications (Notes 2 and 3), so only a summary is provided here, with the necessary equations and a specific example. The articles referenced were used as a guide, with the wind-load force equation described by K5BP used for all wind-load force calculations. Only the loads above the top of the tower and thrust bearing are pertinent to the mast analysis.

Mast Parameters

The parameters used for this mast analysis are as follows:

Mast OD =	2.00 in
Mast Wall Thickness =	0.375 in
Mast ID =	1.25 in
Mast Yield Strength =	108,000 psi

The mast is loaded in the configuration of Fig 3, with the values given in Table 5.

Horizontal Forces on the Mast

Forces on the mast loads are calculated in a similar manner to those for the tower sections, using Eq 4. F1, F2, F3 and Fm, as a function of wind speed, are easily determined at various wind speeds by solving for the force, using Eq 4, for each load on the mast.

Total Moment at the Thrust Bearing

The total moment at the thrust bearing is determined by summing the moments of the individual loads on the mast. Referring to Fig 3, the total moment of the mast at the thrust bearing is:

$$\begin{aligned} M_{\text{Total}} &= \Sigma(FD) \\ &= (F1)(D1)+(F2)(D2)+(F3)(D3)+(Fm)(Dm) \end{aligned} \qquad \text{(Eq 7)}$$

Mast Stress

The mast stress can be expressed as:[4, 7, 8]

$$f = \frac{Mc}{I} \qquad \text{(Eq 8)}$$

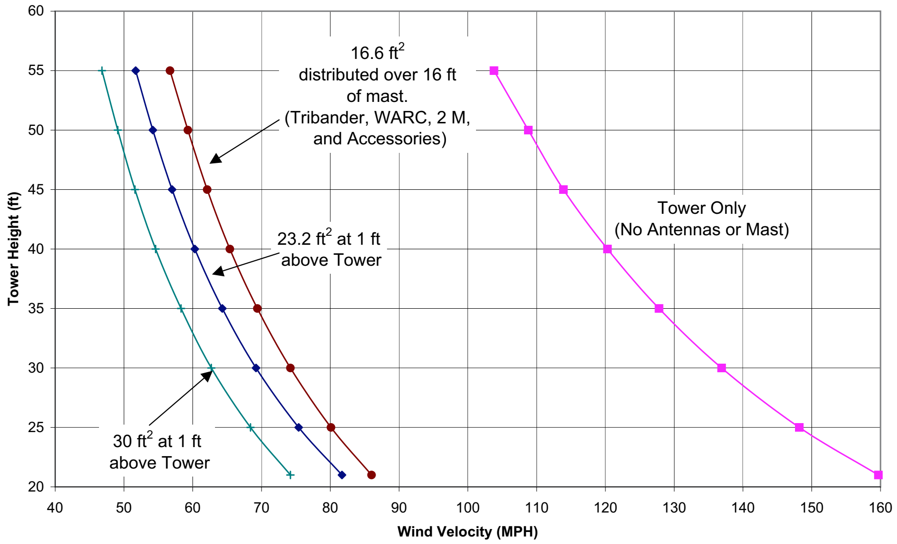

Fig 5—Overlayed constant-moment curves for a 1.28 gust factor.

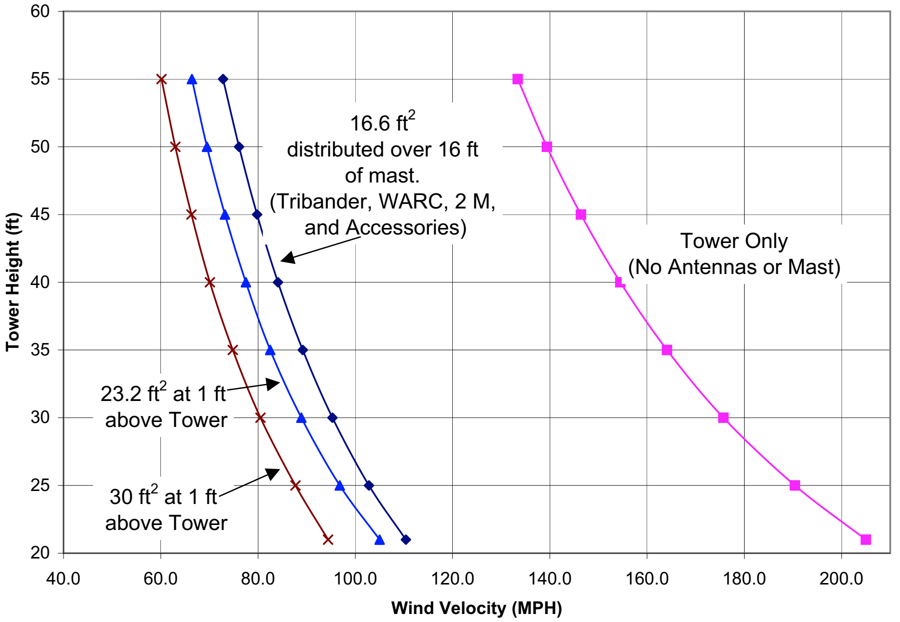

Fig 6—Overlayed constant-moment curves for a 1.00 gust factor.

where:

$$I = \left(\frac{\pi}{64}\right)\left(D^4 - d^4\right)$$

f = Mast stress, in lb/in^2
$M = M_{\mathrm{Total}}$ = Bending moment, in in-lb
c = Half the mast diameter in inches
d = inner diameter of mast in inches
D = Outer diameter of mast in inches

The hope was to have the mast survive a 100-mph wind with the mast loading given above. This was accomplished with a 3/8-inch-wall, 2-inch-OD chrome-moly mast, with a mast yield strength of 108,000 psi, as shown in Table 6 from the spreadsheet.

The mast stress at 100 mph is 76,843 lb/in^2, compared to the mast yield of 108,000 lb/in^2, so the mast is okay for 100-mph winds as it is loaded. The survivable wind speed of the mast in this configuration is 118 mph.

Checking For the "Fuse"

Fig 4 is a constant-moment curve for the loading configuration shown in Fig 3 and Table 5, when the tower, mast and antennas are accounted for and the accessories are added to the tower. The wind surface areas used for the rotor and remote switch are additional loads of 1.0 ft^2 and 0.3 ft^2, respectively. If the 100-mph wind returns, I may have a problem. The antenna system should survive about 86 mph with the tower cranked down to minimum height. The mast is okay for 118 mph, while the tower will handle 86 mph retracted to 21 feet, and 54 mph at a height of 55 feet, using a gust factor of 1.28.

Constant-Moment Curves: Tower Alone, 30 ft^2, 23.2 ft^2 and Typical Installation

Fig 5 overlays the curves of Figs 2 and 4 and single loads of 23.2 ft^2 and 30.0 ft^2 at one foot above the tower. These curves have a wind gust factor of 1.28 applied to the wind-load calculations. None of the loaded configurations is guaranteed to survive 100-mph winds, even with the tower fully lowered to 21 feet. The survivability of a moderately-to-fully-loaded tower is in the 75-86 mph range when the tower is fully retracted and a gust factor of 1.28 is applied.

Fig 6 uses a constant wind velocity or gust factor of 1.00. These curves closely match the manufacturer's specifications for loads at one foot above the tower top. These are:

- 70 mph with 23.2 ft^2 one foot above the tower top (from the engineering specifications) and
- 50 mph with 30 ft^2 of antennas (no mast height or antenna distribution specified, from catalog descriptions) with the tower fully extended to 55 feet.

The survivability of the antenna system, with the tower fully lowered and loaded, increases by about 21 mph when experiencing a constant wind force, as opposed to the gusting winds indicated by Fig 5.

Required Inputs

The following inputs are required to calculate the total system survivability as determined by wind loading:

1. Wind surface area of the individual tower sections (usually included in the tower manufacturer's engineering calculation). This is needed to determine the base-bending moment caused by wind load on the individual tower sections, as a function of tower height.
2. Wind loading specification from the tower manufacturer. In my case, the tower was rated for 23.3 ft^2 of antenna located one foot above the top of the tower. This is a 350-lb wind load at that point, or 19,600 ft-lb, referred to the base of the tower.
3. The mast's inner and outer diameter, length and yield strength.
4. Wind surface area for all antennas and accessories on the tower.
5. Heights, above or below the thrust bearing, for all antennas and accessories.
6. Minimum and maximum tower heights.
7. Number and length of tower sections.
8. Wind surface area of all tower sections.

Assumptions, Approximations and Omissions

The engineering specifications from the tower manufacturer were used as the basis for establishing the safe moment at the tower base. That is, (55 ft + 1 ft)(350 lb) = 19,600 ft-lb.

Coax and control-line wind loading were not considered in the calculations (see Notes 1 and 2).

Tower surface-area reduction, or wind shielding due to section overlap was neglected. A physical survey of the tower indicated that—even when the tower was fully retracted—a high percentage of the inner tower-section areas were exposed at certain angles. At full height, this would be further diminished by an additional 81% for the bottom and top sections and by 62% for the intermediate sections.

The wind surface areas were taken as-is from the antenna and tower manufacturers. There was no attempt to rationalize differences caused by different standards or methods used in their calculation.

The section of mast within the tower, between the thrust bearing and the rotor, was inadvertently left out of the wind-load calculation for the tower. For completeness this should be added, although the effective area of 0.6 ft^2 at H–2 feet has only a minor effect on the resulting curves.

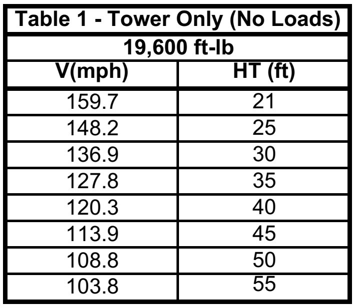

Table 1 - Tower Only (No Loads)	
19,600 ft-lb	
V(mph)	HT (ft)
159.7	21
148.2	25
136.9	30
127.8	35
120.3	40
113.9	45
108.8	50
103.8	55

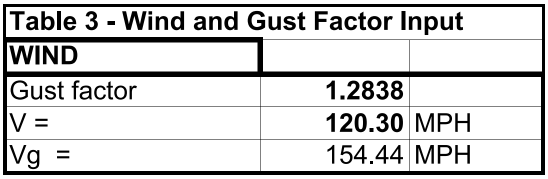

Table 3 - Wind and Gust Factor Input		
WIND		
Gust factor	**1.2838**	
V =	**120.30**	MPH
Vg =	154.44	MPH

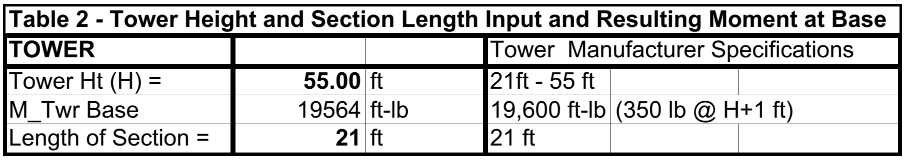

Table 2 - Tower Height and Section Length Input and Resulting Moment at Base					
TOWER			Tower Manufacturer Specifications		
Tower Ht (H) =	**55.00**	ft	21ft - 55 ft		
M_Twr Base	19564	ft-lb	19,600 ft-lb	(350 lb @ H+1 ft)	
Length of Section =	**21**	ft	21 ft		

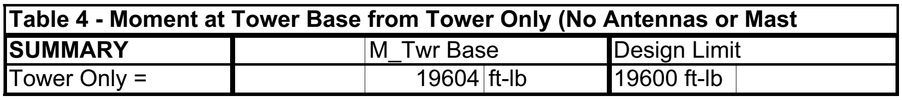

Table 4 - Moment at Tower Base from Tower Only (No Antennas or Mast					
SUMMARY		M_Twr Base		Design Limit	
Tower Only =		19604	ft-lb	19600 ft-lb	

Spreadsheet

Table 7 shows the summary portion of the spreadsheet. The items in **bold**, the wind velocity and tower height, are inputs for a particular installation. The spreadsheet then returns the mast yield, total moment at the tower base for the complete system and the moment of the tower without antennas. The design limits for the particular tower are entered for easy comparison to the calculated values. The mast configuration is easily set—say, for one antenna —using the spreadsheet. Simply set the wind forces equal to zero on the unused antennas and insert the new antenna height and wind surface area on the mast, as in Table 8.

Conclusion

The calculations required to determine the total bending moment at the base of the tower, and the mast stress, are simple but numerous. This is an ideal spreadsheet application to quickly determine the wind-load performance of an entire antenna system and do what-if analysis of the tower and mast. The ability to check the system at any given tower height and antenna

Continued on page 33.

Table 5—Mast Loading (Fixed Parameters for this Example)

Load	*Distance (ft)*	*Wind Surface Area (ft^2)*
Tribander	D1 = **3.50**	A1 = **10.50**
WARC	D2 = **15.00**	A2 = **3.10**
2-m Ant	D3 = **16.00**	A3 = **0.50**
Mast center	Dm = **8.00**	Am = **1.20**

Table 6 - Wind and Gust Factor Input and Resulting Yield for Mast					
MAST			**WIND**		
M_tot =	51143	in-lb	Gust factor	**1.2838**	
f =	76843	lb/in**2	V =	**100.00**	MPH
Mast Yield =	108,000	lb/in**2	Vg =	128.38	MPH

Table 7					
MAST			**WIND**		
M_tot =	16442	in-lb	Gust factor	**1.2838**	
Actual Yield f =	24704	lb/in**2	V =	**56.70**	MPH
Mfgr. Mast Yield =	108,000	lb/in**2	Vg =	72.79	MPH
TOWER			Tower Manufacturer Specifications		
Tower Ht (H) =	**55.00**	ft	21ft - 55 ft		
M_Twr Base	19564	ft-lb	19,600 ft-lb	(350 lb @ H+1 ft)	
Length of Sect. =	**21**	ft	21 ft		
SUMMARY		M_Twr Base		Design Limit	
Tower Only =		5844	ft-lb	19600 ft-lb	
Total System =		19564	ft-lb	19600 ft-lb	

General Equations for the Tower Height and Distance to Section Midpoints

These equations can be used to determine the tower-section wind loading as a function of tower height for any crank-up tower with *any number* of uniformly overlapping equal sections.

$$H = nL - (n-1)h \qquad \text{(Eq A0)}$$

$$h = \frac{(nL - H)}{n-1} \qquad \text{(Eq A1)}$$

$$Di = L + (L-h)(i-2) + \left(\frac{L}{2} - h\right) \qquad \text{(Eq A2)}$$

(For sections *i* = 1, 2, 3 etc)
Substituting Eq A1 into Eq A2 results in:

$$Di = L(i - 0.5) - \frac{nL - H}{n-1}(i-1) \qquad \text{(Eq A3)}$$

where
H = Tower height (any height between minimum and maximum)
L = Tower section length
h = Overlap distance of tower sections (for equal overlaps between sections)
n = Number of tower sections
i = Tower section to which midpoint above the base of the tower will be determined.
Di =Distance to the *i* th tower section midpoint.

For example, if *D1* = *L*/2 is the midpoint of the lowest tower section, then *D2*, *D3*, *D4*, *D5* . . . would follow in sequence. For a five-section tower, the distance from the base to the midpoint of the fifth tower section would then be written as:

$$D5 = L + (L-h)(3) + \left(\frac{L}{2} - h\right) = H - 0.5L \qquad \text{(Eq A4)}$$

Note*: The midpoints of the bottom and top sections of any configuration are always the same. That is, (L/2 and* H – 0.5L *respectively, regardless of the number of sections.)*

For a four-section tower, the distance from the base to the midpoint of the third section from the base would be written as:

$$D3 = L(i - 0.5) - \frac{nL - H}{n-1}(i-1) \qquad \text{(Eq A5)}$$

where
i = 3
n = 4
L = 21
Then,

$$D3 = \frac{2H}{3} - 3.5 \qquad \text{(Eq A6)}$$

So if the tower is at a height of, say, 72 feet, *H* = 72 feet and the midpoint of the third section would be at 44.5 feet above the base.*

*A generalized *Excel* worksheet is available for readers with appropriate software who want to make their own calculations. You can download this package from the ARRL Web **http://www.arrl.org/qexfiles/**. Look for TRAVANTY.ZIP.

Example Spreadsheet, Formulas and Data Tables

Mast & Tower Loading

MAST			**WIND**			
M_tot =	16442	in-lb	Gust factor	**1.2838**		**1.2838**
Actual Yield f =	24704	lb/in**2	V =	**56.70**	MPH	
Mfgr. Mast Yield =	108,000 lb/in	lb/in**2	Vg =	72.79	MPH	
TOWER			Tower Manufacturer Specifications			
Tower Ht (H) =	**55.00**	ft	21ft - 55 ft			
M_Twr Base	19564	ft-lb	19,600 ft-lb	(350 lb @ H+1 ft)		
Length of Sect. =	**21**	ft	21 ft			
SUMMARY		M_Twr Base		Design Limit		
Tower Only =		5844	ft-lb	19600 ft-lb		
Total System =		19564	ft-lb	19600 ft-lb		
MAST ANALYSIS						
			D1 =	**3.50**	ft	Tribander
Mast OD =	**2.00**	in	D2 =	**15.00**	ft	WARC
Mast Wall =	**0.38**	in	D3 =	**16.00**	ft	2M Ant
Mast ID =	**1.25**	in	Dm =	**8.00**	ft	Mast center
Horizontal Forces on Mast						
*F=(V**2)*(WSA)/390*			WSA_1 =	**10.50**	ft**2	Tribander
			WSA_2 =	**3.10**	ft**2	WARC
			WSA_3 =	**0.50**	ft**2	2M Ant
			WSA_m	**1.20**	ft**2	16 ft Mst
			F1 =	142.65	lb	Tribander
			F2 =	42.12	lb	WARC
			F3 =	6.79	lb	2M Ant
			Fm =	16.30	lb	Mast
Total Moment at Trust Bearing						
Mtot = F1(D1) + F2(D2) + F3(D3) +Fm(Dm)						
			M1 =	499.3	ft-lb	Tribander
			M2 =	631.8	ft-lb	WARC
			M3 =	108.7	ft-lb	2M Ant
			Mm =	130.4	ft-lb	Mast
Mtot =	1370.16	ft-lb =	16441.95	in-lb		

Mast Stress						
f = Mc/I				M =	16441.95	in-lb
				c =	1.00	in
I = pi/64(D**4 - d**4)						
				d1**4 =	16.00	
I =	0.67	in**4		d2**4 =	2.44	
			(D**4) - (d**4) =		13.56	
f =	24704.09	lb/in**2				
Where:						
M = Bending Moment in in-lb				d = inner diameter of mast		
c = Half the mast diameter in inches				D = Outer diameter of mast		
I = Moment of Inertia of the mast in inches				pi = 3.14159…		
TOWER LOADING						
Tower is at H =	55.00	ft				
TOT Base Momen	19564	ft-lb	33651 ft-lb Max		19,600 ft-lb = 350 lb @ H+1 ft	
F1 =	142.65	lb	D1 =	3.50	ft	Tribander
F2 =	42.12	lb	D2 =	15.00	ft	WARC
F3 =	6.79	lb	D3 =	16.00	ft	2M Ant
Fm =	16.30	lb	Dm =	8.00	ft	Mast
F_Rot	13.59	lb	Drot =	-4	ft	Rotor
F_SW =	4.08	lb	Dsw =	0	ft	Switch
			WSA_Rot =	**1**	ft**2	Rot Area
			WSA SW =	**0.3**	ft**2	SW Area
Moment at Base of Tower						
M1 =	8345.29	ft-lb	M due to Tribander		*M1=(H+D1)(F1)*	
M2 =	2948.19	ft-lb	M due to WARC		*M2=(H+D2)(F2)*	
M3 =	482.31	ft-lb	M due to 2M Ant		*M3=(H+D3)(F3)*	
Mm =	1027.11	ft-lb	M due to Mast		*Mm=(H+Dm)(Fm)*	
M_Ro t =	692.89	ft-lb	M due to Rotor		*M_Ro t=(H+Drot)(F_Rot)*	
M_SW =	224.17	ft-lb	M due to ant. Switch		M_SW=(H+Dsw)(F_SW)	
M_TWR =	5844.27	ft-lb	M due to Tower		*M_TWR=Sum of Tower sect's*	
Total M @ base	19564.24	ft-lb				

Tower Wind Loading without Antennas or Mast						
For a three section 55 foot crank up tower with 21 foot sections the section						
overlap as a fuction of tower height can be expessed as:						
h = (63-H)/2			where:			
h =	4.00	ft.	H = Height of tower (21 ft to 55 ft)			
			h = Tower section overlap in Ft.			
Distances from tower base to center of tower sections.						
	D5 =	44.50	ft.	*D5=2.5L-2h*		
	D6 =	27.5	ft.	*D6=1.5L-h*		
	D7 =	10.5	ft.	*D7=L/2*		
Wind Surface area of Tower Sections in ft2/ft**						
	Section 5=	0.211	ft**2/ft			
	Section 6=	0.274	ft**2/ft			
	Section 7=	0.339	ft**2/ft			
21 foot Tower Section Areas						
Top Section	A5 =	**0.211**	(ft**2/ft) (L) =	4.43	ft**2	
Mid Section	A6 =	**0.274**	(ft**2/ft) (L) =	5.75	ft**2	
Bot Section	A7 =	**0.339**	(ft**2/ft) (L) =	7.12	ft**2	
Forces on Tower Sections						
	F5 = (Vg**2)(A5)/390		60.2	lb		
	F6 = (Vg**2)(A6)/390		78.2	lb		
	F7 = (Vg**2)(A7)/390		96.7	lb		
Moments due to tower sections loading only						
	M5 = (F5)(D5) =		2679	ft-lb.		
	M6 = (F6)(D6) =		2150	ft-lb.		
	M7 = (F7)(D7) =		1016	ft-lb.		
Total Tower =	M_TWR = M5+M6+M7=		5844	ft-lb.		

GUST FACTOR = 1.28

Example Configuration		Tower Only - No Loads	
V(mph) 19600_ft-lb	HT (ft) 19600_ft-lb	V(mph) 19600_ft-lb	HT (ft) 19600_ft-lb
86.0	21	159.7	21
80.1	25	148.2	25
74.2	30	136.9	30
69.4	35	127.8	35
65.4	40	120.3	40
62.1	45	113.9	45
59.3	50	108.8	50
56.7	55	103.8	55

Tower+30ft**2@H+1ft		Tower+23.2ft**2@H+1ft	
V(mph) 19600_ft-lb	HT (ft) 19600_ft-lb	V(mph) 19600_ft-lb	HT (ft) 19600_ft-lb
74.2	21	81.7	21
68.4	25	75.4	25
62.7	30	69.2	30
58.3	35	64.3	35
54.6	40	60.3	40
51.6	45	57.0	45
49.1	50	54.2	50
46.8	55	51.7	55

GUST FACTOR = 1.00

Example Configuration		Tower Only - No Loads	
V(mph) 19600_ft-lb	HT (ft) 19600_ft-lb	V(mph) 19600_ft-lb	HT (ft) 19600_ft-lb
110.4	21	205.0	21
102.8	25	190.4	25
95.3	30	175.7	30
89.2	35	164.1	35
84.1	40	154.5	40
79.8	45	146.4	45
76.1	50	139.4	50
72.8	55	133.4	55

Tower+30ft**2@H+1ft		Tower+23.2ft**2@H+1ft	
V(mph) 19600_ft-lb	HT (ft) 19600_ft-lb	V(mph) 19600_ft-lb	HT (ft) 19600_ft-lb
94.4	21	105.0	21
87.7	25	96.8	25
80.5	30	88.9	30
74.8	35	82.5	35
70.1	40	77.5	40
66.3	45	73.2	45
63.0	50	69.5	50
60.2	55	66.4	55

Continued from page 28.

configuration allows the user to try various antenna-loading configurations prior to investing in towers and antennas. This is especially valuable in determining the survivability at intermediate and minimum tower heights, where most towers are not specified.

Table 8			
D1 =	**1.00**	ft	H+1ft
D2 =	**0.00**	ft	
D3 =	**0.00**	ft	
Dm =	**0.50**	ft	Mast centr
WSA_1 =	**30.00**	ft**2	Tribander
WSA_2 =	**0.00**	ft**2	
WSA_3 =	**0.00**	ft**2	
WSA_m	**0.06**	ft**2	1 ft Mst

Notes

[1] S. E. Bonney, K5PB, "Practical Application of Wind-Load Standards to Yagi Antennas: Part 1," *QEX*, Jan/Feb 1999, pp 46-50.

[2] S. E. Bonney, K5PB, "Practical Application of Wind-Load Standards to Yagi Antennas: Part 2," *QEX*, Mar/Apr 1999, pp 44-49.

[3] R. A. Cox, WB0DGF, "Match your antenna to your tower," *ham radio*, June 1984, pp14-20.

[4] S. Griffiths, W7NI, "Antenna Mast Design," *NCJ*, Sept/Oct 1982 and March/April 1983.

[5] Tom Taormina, K5RC, "A Layman's Guide to Mast Material," *CQ*, June 1995, pp 24.

[6] Figs 2, 4, 5, 6, Tables 1, 2, 3, 4, 6, 7, 8 and the sidebar "Example Spreadsheet, Formulas and Data Tables" are taken directly from the author's spreadsheet. This means that certain spreadsheet/programming conventions are used. Some quantities are variable names with underscore characters in the place of spaces. For example, the total moment is "M_tot." Some mathematical operators are unconventional: A star indicates multiplication; two stars precede an exponent.

[7] R. L. Norton, *Machine Design: An Integrated Approach*, Prentice-Hall, 1998, pp 990.

[8] J. Marin and J. A. Sauer, *Strength of Materials*, MacMillan, 1960, pp 120.

Frank Travanty was first licensed as W9JCC in 1954, while in middle school, after having built a crystal radio described in Boy's Life Magazine. He also held W2CPX and K4HND, prior to regaining his original call through the vanity-call system.

Frank graduated from the University of Wisconsin with a degree in Electrical Engineering. He worked for the General Electric Company for most of 35 years, in the fields of military avionics, industrial controls and medical imaging, until his retirement in February 2000.

His current interests are HF operation, DX, jogging, gardening and spending time with his children and grandchildren.

New Book

RADIO RECEIVER DESIGN

By Kevin McClaning and Tom Vito

Noble Publishing Corporation, Norcross, Georgia, 2001, ISBN 1-884932-07-X, $89, hardcover, 796 pages.

Receiver design is a demanding endeavor that involves many variables. Interaction of those variables creates a complex choreography that can be difficult to manage without sufficient knowledge, experience and planning. McClaning and Vito are two engineers who have obviously been through it a few times. In their new book, they impart some of their collective wisdom and especially focus on what works and what doesn't.

Radio Receiver Design covers contemporary implementations of many, but not all, critical receiver subsystems. Notably absent is detail about modern frequency-synthesis techniques, although a chapter on oscillators and direct digital synthesis is included. The authors provide almost no information about control systems or DSP-based design. The material on AGC is too sparse to be useful to the neophyte, although common questions about gain distribution and cascaded linearity performance are answered quite clearly.

The book begins with some definitions and heads rapidly into a discussion of transmission-line, matching and modulation theories. Significant is the statement that source-matched amplifiers cannot have an efficiency exceeding 50%. That is: When an amplifier's source impedance is equal to its load impedance, all available power is delivered to the load; but only half the power is available compared to that of an amplifier having a low source resistance.

Examples, sanity checks and "war stories" are liberally employed to aid comprehension. Enough mathematics is retained to make this work an outstanding reference without bogging down the flow. Sometimes, though, the information is a little off-target for full understanding.

Instances of that are found mainly in the introductory chapter during the treatment of modulation. Fig 1-47 depicts a real sine wave as a single phasor, rotating in the complex plane; a better representation would be two phasors rotating in opposite directions. That is corrected later in the chapter when vectors for AM are introduced (Fig 1-71). SSB is not discussed at all. When explaining PM waves, the mathematical descriptions are correct, but the authors sometimes imply an unintended meaning. For example, they state on p 126 that the envelope of FM and PM waves is always constant. In their mention of occupied bandwidth that immediately follows, though, they fail to point out that is only true when bandwidth is infinite.

The rest of the book is loaded with practical information and valuable insight about filters, amplifiers and mixers. You will find it a very good place to start if you are learning how to put those things together to build a receiver. It is well organized and well written. I recommend it for novice and intermediate-level engineers, students, experimenters and hobbyists. Kevin McClaning teaches at Johns Hopkins University and Tom Vito works for the US Department of Defense.—*Doug Smith, KF6DX*