Mechanical Notes from K7NV

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Wind Loads

What to do about calculating wind loads comes up from time to time. The problem with figuring out wind loads is the wind. In the realm of things near the ground, the wind is very erratic due to interaction with ground features. This can make it difficult to really know what speed is effectively acting on a structure in close proximity to the ground. The generic wind pressure formula is accurate enough for our use, but figuring out what wind speed to use with it is not as straightforward as we would like.
A very informative discussion of the subject can be found in "Physical Design of Yagi Antennas", by Dave Leeson, W6NL.

What we "amateur" folks want out of this stuff is to be able to do something that is reasonably well founded and allows us to design things that will survive the winds we will experience at our locations, and doesn't require thousands of hours of education and research to arrive at. Something we actually will do when it is required, instead of just guessing (although that seems to be pretty entertaining), and will for the most part keep our toys where we put them so we can qrm each other on the designated weekends.

We often refer to wind speeds as though everyone knew what a value meant. There is that perfectly behaving wind that just travels at a constant known speed, but like the frictionless wheel, it doesn't really exist in our world. So, that cannot be what everyone is refering to when they say "the wind speed was....."

There are some structural design standards that provide methods for developing wind loads and if we are to use them, we must make sure that we select the correct wind speeds for them to have the results be meaningful. Most established methods come with geographical wind distribution maps or tables that must be used with them. If we do that, we will find that the pressures generated by various methods are remarkably similar.
Here are a couple of common ones......

The Generic Formula

For using the actual sustained wind speed expected (were we to actually determine it) :

Force, F = A x P x Cd

A = The projected area of the item

P , Wind pressure (Psf), = .00256 x V^2 (V= wind speed in Mph)

Cd , Drag coefficient, = 2.0 for flat plates. For a long cylinder (like most antenna tubes), Cd = 1.2.
Note the relationship between them is 1.2/2 = .6, not quite 2/3.

This is the force on a discreet constant section. I.E. A length of tubing or some other such member that is part of a structure. The Force per unit area would be found by setting the area to 1.
This is the simplest form of all that stuff in the textbooks, at standard temp and atmospheric pressure, for the range of wind speeds we see and the general size of the members on our toys.

Modifications to the Generic Form

We may want to turn to one of the published methods to get some coverage for all those things we don't really know, and don't necessarily want to know. These methods take some of the mystery out of the wind to provide something easier to use. Instead of talking about a single peak sustained wind speed, they talk about some form of statistically averaged wind, often called a "Basic Wind Speed."
Because, virtually all wind speeds are average measurements of the erratic wind flow, the key to understanding any wind speed measurement is to know what reference frame was used to determine the average value stated. Then, and only then, can we know what they mean or compare them to each other. One can be certain that all wind speed measurements are NOT the same.

One popular wind speed definitions is "The fastest mile" wind speed, which is the average speed obtained during the passage of one mile of wind. As used in several specifications, it is accompanied by a statistical probability for that condition. This is NOT the peak wind speed that may be observed at a location via an anemometer , unless that device is configured for calculating the average wind speed for "the fastest mile" of wind.
At an average speed of 60 Mph, one mile of wind passes in one minute, so in this case it represents a 60 second wind speed average. At every other speed, it represents a different time based average. That makes comparing it with a value from a strictly time based device impossible if we don't know what that time base was!

The "fastest mile" wind speed must not be confused with "the wind speed" value from someone's statement, or some report on the Six-O'Clock-News, unless that reading can be defined. Then, we can convert it for use with methods that use the "fastest mile" average speed. ASCE 74, Appendix E, provides a method for converting differently averaged wind speed values.

For using a "Fastest Mile Basic Wind Speed" definition of the wind, some of the choices for calculating wind pressure are:

EIA-222-C

Electronic Industries Assoc., Structural Standards for Steel Antenna Towers and Antenna Supporting Structures. This is now an obsolete spec, but was used by antenna builders during it's time, and is the basis for a part of our empirical antenna database.

Force, F = A x P x Cd

A = the projected area of the item.

P, Wind pressure (Psf), = .004 x V^2 (V= wind speed in Mph)

This includes the drag coefficient (Cd) for flat plates and a 30% gust factor.

Therefore,

Cd, Drag coefficient, = 1.0 for flat plates, and .67 for cylinders

This spec thinks the wind speed is the "fastest mile basic wind speed" at 33 feet above the ground, not the actual peak sustained wind speed, and is obtained from a map that is specific to itself. The spec defines "Wind Zones," denoted "A", "B", and "C", with corresponding wind pressures to be used. Zone "A" is 30 Psf (pounds per square foot) (86.6 Mph), Zone "B" is 40 Psf (100 Mph), Zone "C" is 50 Psf (111.8 Mph) by it's calculations. Most of the United States is in Zone A, a small part is in Zone B, and a very small part in zone C. There were no additional height related or site terrain specific factors in this spec.

EIA-222-F

This is a newer version of the Electronic Industries Assoc. spec.

Force = A x P x Cd x Kz x Gh

A = the projected area of the item

P, Wind pressure (Psf), **=.00256 x V^2** (V= wind speed in Mph)

Kz, Exposure Coefficient, = **[z/33]^(2/7)** 1.0 <= Kz <= 2.58

z = height above average ground to midpoint of the item (IE, antenna, or tower span) in feet.

Gh, Gust response factor = **.65+.60/(h/33)^(1/7)** 1.0 <= Gh <= 1.25

h = overall height of a tower (used for an antenna mounted at its top) in feet.

Cd = 2.0 for long flat plates and 1.2 for long cylinders. Aspect ratios >=25

Cd = 1.4 for short flat plates and .8 for short cylinders. Aspect ratios <=7

The relationship between drag coefficients for cylinders and flat things is, 1.2/2.0 = .6 or .8/1.4 = .57, in this case less than 2/3

EIA-222-F thinks the wind speed is the "fastest mile basic wind speed" at 33 feet above the ground, not the actual peak sustained wind speed. These values are not the same as the 222-C spec, they are defined by State & County locations, rather that the older wind speed zone maps.
There are no additional site specific exposure factors cited in this spec.

UBC '97

The Uniform Building Code, 1997 revision

Force = A x P

A = the projected area of the item.

P, Wind pressure (Psf), **= Ce x Cq x Qs**

Ce, combined height, exposure and gust response factor is taken from table 16-G

3 terrain exposures termed "B" "C" & "D", are cited in the table. For each one, a variety of heights are listed and a corresponding value for Ce.

Cq, pressure coefficient (same as drag, Cd), is taken from table 16-H

Cq = 1.3 for flat plates, and Cq = .8 for cylinders over 2" in diameter, 1.0 for cylinders 2" or less in diameter.

No differences due to aspect ratio are cited.
The cylinder is either 1/1.3 = .769, or .8/1.3 = .615 of the flat plate value. Not quite 2/3 either.

Qs, wind stagnation pressure, is taken from table 16-F

The values in the table are the same as one would get from using the .00256V^2 formula.

UBC 97 thinks the wind speed is the "fastest mile basic wind speed" at 33 feet above the ground, not the actual peak sustained wind speed, and is obtained from a map that is part of the spec. It also cites the current EIA spec as a suitable method.

The UBC exposure definitions are as follows:

EXPOSURE B has terrain with buildings, forest or surface irregularities, covering at least 20 percent of the ground level area extending 1 mile (1.61 km) or more from the site.

EXPOSURE C has terrain that is flat and generally open, extending 1/2 mile (.81km) or more from the site in any full quadrant.

EXPOSURE D represents the most severe exposure in areas with basic wind speeds of 80 miles per hour (mph) (129 km/h) or greater and has terrain that is flat and unobstructed facing large bodies of water over 1 mile (1.61km) or more in width relative to any quadrant of the building site. Exposure D extends inland from the shoreline 1/4 mile (.40km) or 10 times the building height, which ever is greater.

EIA-RS-409

Electronic Industries Assoc., Minimum Standards for Amateur Radio Antenna, Part I - Base or Fixed Station Antenna

Once upon a time, during the RS-222-C era, this was a real specification for "Amateur Radio Antennas." It followed the EIA-222-C methodology, requiring a 30 Psf (flat plate) windload (equivalent to 86.6 mph Zone A), and required the use of a safety factor of 1.2 on the material yield strength.
It contained a host of electrical performance criteria, which may have caused it's demise, but structurally was compatible with it's companion tower spec.
This is not a big deal, but surely is interesting.

Note:
From these methods, we can see that the relationship between a flat thing and a cylindrical thing is in the neighborhood of .67, so that's where that "2/3 factor" came from.

Comparing the Different Methods

If we take each method and determine the force per unit area (projected) on a tubular yagi member like a 20 meter element, for the wind speed zones that cover the majority of the US, there is:

For the minimum wind speed zones:

METHOD	WIND ZONE	HEIGHT (Ft)	PRESSURE (Psf)
EIA-222-C	"A" (ref: 87 Mph)	N/A	20.0
EIA-222-F	70 Mph	45	20.0
EIA-222-F	70 Mph	70	22.2
EIA-222-F	70 Mph	100	24.0
UBC'97	70 Mph (Exp. D)	45	20.7
UBC'97	70 Mph (Exp. C)	70	18.6
UBC'97	70 Mph (Exp. D)	70	22.2
UBC'97	70 Mph (Exp. C)	100	20.2
UBC'97	70 Mph (Exp. B)	140	15.7
UBC'97	70 Mph (Exp. C)	140	21.7
Generic Formula	81 Mph	N/A	20.2

EIA-222-F is essentially the same as the most severe UBC'97 exposure "D" at 100'. If we had a sustained gust of 81 Mph, during the passage of that one mile of wind in the 70 Mph zone,

we'd have about the same load as the basic zone speed suggests. The 3 second average speed for a 70 Mph average mile of wind would be 85 Mph. Notice that the UBC definition of exposure D states that it is for basic zones of 80 mph or more, so it does not apply here.

For the medium wind speed zones:

METHOD	WIND ZONE	HEIGHT (Ft)	PRESSURE (Psf)
EIA-222-C	"B" (ref: 100 Mph)	N/A	26.7
EIA-222-F	80 Mph	45	26.3
EIA-222-F	80 Mph	70	29.0
EIA-222-F	80 Mph	100	31.4
UBC'97	80 Mph (Exp. D)	45	27.0
UBC'97	80 Mph (Exp. C)	70	24.2
UBC'97	80 Mph (Exp. D)	70	29.0
UBC'97	80 Mph (Exp. C)	100	26.4
UBC'97	80 Mph (Exp. B)	140	20.6
UBC'97	80 Mph (Exp. C)	140	28.3
Generic Formula	93 Mph	N/A	26.6

The 3 second average wind speed for an 80 Mph "fastest mile" speed is about 100 Mph. This means that if you live in a UBC or EIA 80 Mph zone, and your 3 second averaging anemometer reads a 100 Mph peak, then it would be consistent with the "fastest mile" basic wind speed for that zone. Coincidentally, it happens to agree with the EIA-222-C wind speed calculation for that zone.

Comments

The two zones listed cover the majority of area in the continental US.
The wind pressures listed are what would be applied to the projected areas of long cylinders incorporating all the formulas and drag coefficients used in each method.
The key to comparing them is to look at their applied pressures by zone, instead of just their respective wind speed values or any differences in the specific internal values used.
The different methods can produce different results over the entire range of variables, but for the most common conditions in the majority of locations they are very close.
Most of us live in UBC exposures B & C. The EIA values are the same as the UBC exposure D, which is only for the most severely exposed sites.

There is a fundamental problem with trying to use either the later EIA or UBC spec (or similar others) for general consumption antenna design. Both of them require a specific antenna height and/or a siting factor to develop their loads. I doubt that antenna manufacturers are going to design all of their antennas for every concievable height and/or exposure with each spec. If there is already some confusion about what to do with existing antenna figures, adding 20 more figures per antenna is not likely to make things easier.

The 222-C method does not require these factors to provide a reasonably accurate value for the majority of locations across the country. It has been used in the past for amateur antennas. So, our empirical database has some value when comparing newer designs to it.

Another Comparison

Let's take a look at what these methods say about a real antenna element, for instance a Hygain 204BA reflector.
This is an old design done by Roger Cox, and was designed with the EIA-222-C method. We have a whole bunch of empirical experience with the element, and other than the tip fatigue problem, it is usually a reliable element. The tip problem is one that comes from dynamic phenomena, and would not be found in any of the static analyses used by any of these methods.
During the original YagiStress software development, Roger Cox sent me YS models of the 204BA, and he had been very forthright in telling the public what was being done with his yagi designs. The 204BA has been one of the example antennas distributed with YS from day one, with permission.

Using the EIA-222-C method YS reports the element is safe at 100 Mph, with no ice. This puts it right at the 222-C Zone "B" wind speed, covering everything but the most severe zones in it's map.

Using the EIA-222-F method, with no ice, the element is safe at:

50' & 80 Mph
75' & 76 Mph
100' & 74 Mph

Using the UBC'97 method, with no ice,
For exposure "D":

50' & 80 Mph
75' & 76 Mph
100' & 74 Mph

And, exposure "C":

50' & 87 Mph
75' & 83 Mph
100' & 80 Mph

More

The comparisons indicate that we can use any one of them to arrive at about the same loads. The simpler 222-C method, at 100 Mph "Basic Speed" (Zone B), covers the majority of the locations in the US, without having to introduce the height & exposure complexities.

The special zones and/or locations which experience severe conditions need to be dealt with on their own. Leeson pointed out, in his book, that with the 222-C method, he found that it took designs for 120+ mph to survive his hilltop location. Leeson reported that the 204BA++ modification is safe at 123 Mph (using the 222-C method) which when analyzed with the other methods gives:

Using the EIA-222-F method, with no ice:

50' & 98 Mph
75' & 93 Mph
100' & 90 Mph

Using the UBC'97 method, with no ice,
For exposure "C":

50' & 107 Mph
75' & 102 Mph
100' & 99 Mph

Per the UBC zone map, this element would not quite be rated for beach sites along the Southeast US, Gulf, and Pacific Northwest coasts. But, it would be suitable for siting in the next inland zones.

EIA-222-C using its zones and wind speeds, while not the most current approach, is easy to use and provides reasonable results. It is actually quite conservative for many of the UBC scenarios.

A whole lot of antennas have been designed with 222-C, some have survived and some have not. But, that's probably not from selecting a bad method. More likely from not using the correct wind speeds, or not designing for the right load cases like updrafts and ice. Things always break because they weren't strong enough, that much is absolutely certain, the real question is "strong enough for what?"

Pick a method, use a wind speed that is correct for it, and things should be about as good as they can be.

Remember, a site can see higher short term wind speeds than it's "basic wind speed". Their values depend on the averaging time constants of the gizmo making the measurements. So, we have to make sure we don't get our "Super Weather Station Mark X" wind speeds confused with the "basic" ones.

73, Kurt

As is customary for this kind of work, I only offer comments to stimulate thought, and hopefully help fellow Amateurs. None of the information provided is authoritative in any manner or guaranteed to be correct. The reader is encouraged to research these subjects and make his own determinations about these things, before trying to apply them in the real world.

There are more interesting articles about towers and antennas in the K7NV **NOTEBOOK**

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