MEMO #20

MEMORANDUM

TO: W.R. BRUCKMAN DATE: JULY 9, 1990

FROM: P. CHEIMETS

SUBJECT: RESULTS OF WIND SPECTRUM LITERATURE SEARCH

cc: G.U. NYSTROM
R.B. DIAS

1.0 SCOPE:

A search of wind spectrum literature is discussed. Though this review was initially undertaken to gather information for use in predicting pointing performance of the SMA telescopes, no spectrum was found that unambiguously applied to the proposed Mauna Kea site.

It is concluded that spectra measurements of the prevailing winds at the proposed sites are required.

2.0 INTRODUCTION:

The prediction of telescope pointing performance requires a quantitatively good understanding of the disturbances that it will be subjected to. In the case of the SMA telescopes, if they are used undomed, a large disturbance and certainly the largest nonsystematic disturbance is the wind.

To understand the effect that the wind will have on the telescope it is important to understand the likely manner in which the device will be mounted and its orientation controlled. The telescope or antenna, consists of a large (6m) dish and secondary or sub-reflector supported and pointed in an altitude over azimuth mount, similar to the MMT arrangement. Its orientation is determined, unlike the MMT or other optic telescopes, solely by encoders mounted at convenient locations on the mount. The pointed axis or line of sight (LOS) of the telescope is inferred from the encoder readings and experience of the telescope deflections related to the prevailing conditions; hence systematic errors are removed, to the extent and precision that they are known.

The wind acts on the telescope in several ways to reduce the precision of the pointing information. The wind will cause the telescope to "wind-up", resulting in a deflection of the telescope that is related to a time average of the wind speed. This wind-up has two parts, measured and unmeasured. Since the telescope LOS is not measured directly, there is a portion of the structure that will deflect without being controlled. Thus even if the control system reduces the measured portion of the wind-up to zero, there will still be an error in the telescope LOS. By measuring the wind's speed and relative direction some correction can be made for this but the accuracy of the result is questionable for a couple of reasons: the wind speed and direction can not be measured as accurately, the effect it has on the telescope will not be determined as accurately, and finally the time scale of the wind speed average to use in making the correction will be a loosely determined value. Thus the possibility exists of an error that is correct by the wrong amount and at the wrong time.

The wind will also cause thermal gradients of the mount to vary, thus changing the shape of the mount over time. Though this is a slower and smaller phenomenon than the wind-up the uncorrected portion of its induced error may not be.

Finally, the wind variations that are in the frequency range of the control servo and faster will cause errors in LOS pointing in various degrees depending on the frequency response of the controlled system. If the wind contains significant energy out to frequencies of structural response there will be another set of image plane errors related to the resonant deflection of telescope substructure.

Therefore a detailed understanding of the wind speed spectrum that the telescopes are likely to encounter is required to design for, predict and ultimately control their effects.

3.0 WIND SPEED AND ITS MEASUREMENTS:

Though the measurement of wind speed has been going on for years, it was not until the mid-1950's that its spectral content was examined and quantified to any degree. The earliest works, in 1955, and 1956 used several strings of wind cup measurements made over various periods to demonstrate spectral content in the frequency range from .1 cy/decade to .5cy/sec. I. Van der Hoven in the US and later A.G. Davenport in England concerned themselves with the range from .25 cy/dy to .5 cy/sec. The data, reduced to a spectrum reveals two distinct spectral regions, one between .05 cy/day and .2 cy/hr and the other between 10 and 1000 cy/hr. The first is weather, the second is gustiness and between them, centered at 1 cy/hr is a region nearly devoid of spectral content called the "spectral gap". The existence of this gap has proved useful in characterizing wind speed without ambiguity. Since an hourly average avoids much of the wind variation it can be used to define the gustiness in the rest of the spectrum.

Davenport, focusing on the high frequency portion of the data, reduced all the spectra that he had to a single function. The function, shown in equation (1),

$$\frac{n \,.\, S_z(n)}{\kappa V_1^2} = 4{\cdot}0 \frac{x^2}{(1 + x^2)^{4/3}} \quad \text{eq(1)}$$

where: n is frequency in Hz
k is roughness factor (see table 1)
V is average velocity, and
x = 1200*n/V

was empirically derived, and with the adjustment of a single site-specific parameter, describes the power in a given frequency band as a complex function of average wind velocity.

Van der Hoven seems to imply and Davenport later asserted empirically that the spectra of wind gustiness at a given site is constant at a given wind velocity, and that the gustiness at another velocity is related by a single function. Though the form of the spectral function is questioned in later literature that the spectrum is constant for a given wind speed and site, is not.

3.1 RECENT WIND MEASUREMENTS:

Three more sources of wind spectrum information were uncovered in the literature search. The first was the German information from MAN, presented in a paper entitled "Active Structural Control of Very Large Telescopes", and later in their report to us (see Figure 1 & 2). There seems to be a discrepancy between the two presentations of what was thought to be the same data. Furthermore, the spectrum that they present seems to be the same as Davenport's. The second source was several papers by Fred Forbes of the Kitt Peak Observatory, describing wind measurements at Mt Hopkins, Graham and Mauna Kea, made as part of the effort to locate the NMMT. In a 1982 paper given to an SPIE conference he presents several wind spectra. The data are interesting (see Figure 3) in that they appear to show a 10 fold difference in power at a given frequency between the gustiness at Mauna Kea and Mt Graham. The difference is such that power at a given frequency is greater at Mt Graham in spite of the fact that it has lower average winds. Questions about the generality of the curves were such that Forbes felt that he should report the data qualitatively, thus the spectra are reported without vertical axis scale.

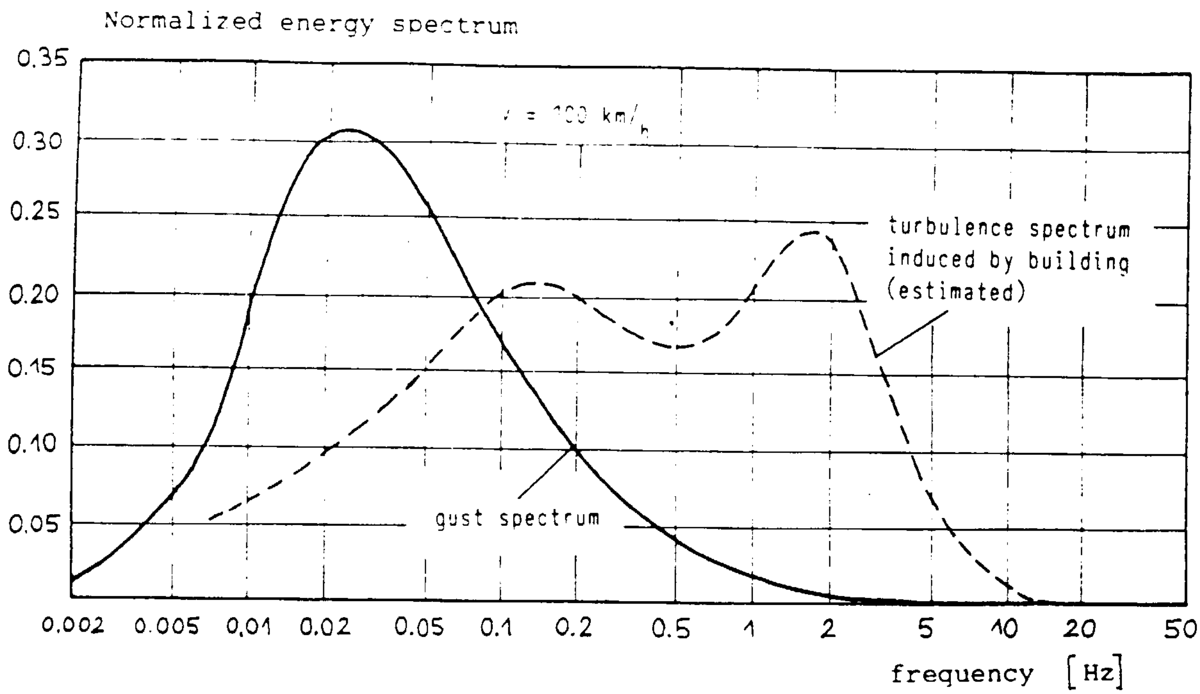


Figure 1. Wind Spectrum from MAN Report

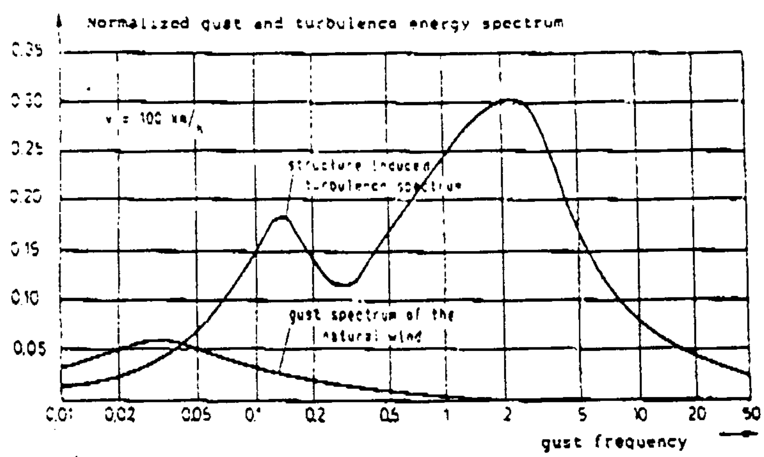


Figure 2. Wind Spectrum from Karcher & Nicklas

Note the different peak height for the same wind spectrum (i.e. natural wind)

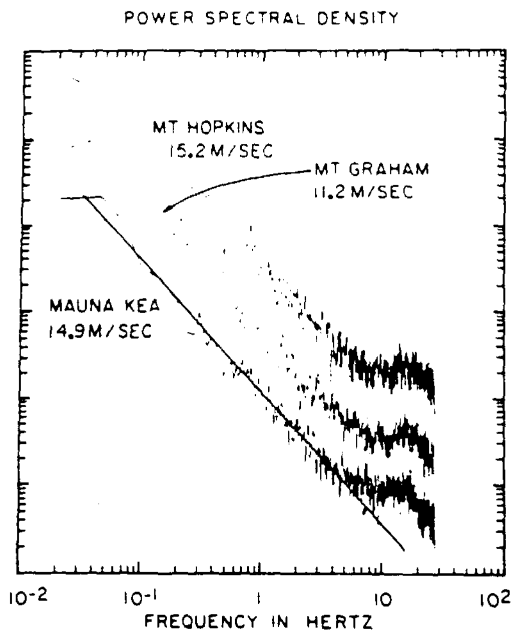


Figure 7. Characteristic site spectra for Mt. Hopkins, Mt. Graham, and Mauna Kea. Each spectra is the summation of eight 100 second power spectral desnity transforms. The Mauna Kea spectra has superimposed a line representation of the Davenport spectra model referred to above.

Figure 3. Spectra Measured by Forbes

Forbes has compared the spectra he measured to the Davenport spectrum by laying the Mauna Kea data on top of one. The interesting result of this is the appearance of considerable energy in the wind at frequencies higher than 5 Hz, higher than the Davenport spectrum predicts. It should be remembered that the Davenport spectrum was derived using data that cutoff at .5Hz; it is not too surprising that extrapolation beyond that point is imprecise. Forbes suggests in a later paper that the wind gustiness spectrum should take on the same form as the Kolmogorov spectrum describing turbulence.

The final source is a book on the effect of wind load on the design of structures, by Simiu and Scanlan called "Wind Effects on Structures", published by Wiley in 1978. Simiu suggests a new wind spectrum, equation (2),

$$\frac{nS(z,n)}{u_*^2} = \frac{200f}{(1+50f)^{5/3}} \qquad \text{eq (2)}$$

where: n is frequency, in Hz
f=n*z/U(z)
z is height above the ground
U(z) is average velocity at height
u* is friction velocity, a value that depends on local conditions

compares it to Davenport's (see Figure 4) and discusses the different results that one gets using the different spectra.

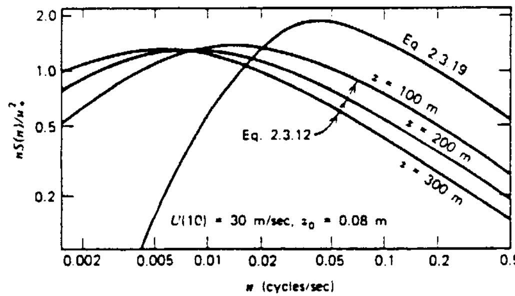
3.2 DATA REDUCTION:

The use that we are going to put this data to requires that we extract a set of pseudo sine amplitudes for variable wind velocity from the wind gustiness information, which is invariably presented as power spectra. To do this the method of determining and presenting the power spectra must be examined. The early spectra (e.g. Davenport) were the result of hand calculation or slow computer. The method for determining the spectrum in the early cases was an estimation procedure based on a set of autocorrelations using different offsets or lags. This method was used because the FFT had not yet been discovered and it required far fewer calculations than a direct discrete Fourier transform. The resulting spectrum are smoothed using a moving average on the adjacent Fourier coefficients resulting in a set of numbers that represent the average power in overlapping frequency domains. The later data is all the result of FFT calculations and are much closer to being exact, if a far less smooth representation of the wind spectral content.

How comparable the spectra developed by the separate method are is undetermined. The trends in the regions were the Davenport spectrum applies are clearly the same, but whether the amount of power at a given frequency can be shown to be the same has been impossible for me to say.

U(Z)

(a)



(b)

FIGURE 2.3.2. (a) Longitudinal turbulence spectra measured at Sale, Australia (based on 20 records) [2-58]. From A. G. Davenport, "The Spectrum of Horizontal Gustiness Near the Ground in High Winds." *Quarterly Journal of the Royal Meterological Society*, **87** (1961) 202. (b) Comparision of spectra given by Eqs. 2.3.12 and 2.3.19. From E. Simiu, "Wind Spectra and Dynamic Alongwind Response," *J. Struc. Div.*, ASCE, **100** (1974) 1897–1910.

Figure 4. Comparison of Davenport and Simiu Spectra

3.3 EXTRACTING USABLE DATA:

The goal of this literature search is the extraction of a wind speed spectrum that can in turn be used to predict the torque disturbances that affect the antenna. The spectra that were found all have several problems in this regard. The Davenport spectrum, though it gives an unambiguous function for wind spectrum requires the knowledge of the site-specific aerodynamic roughness. The Forbes spectra are for winds at the right mountains, but not the right parts, at least in the case of Mauna Kea, and the actual values of the power spectrum are unavailable. I spoke with Forbes, he says that he no longer has the raw data either. The data that we got from Germany, MAN etc, is obscure and contradictory, not at all useful in determining the level of possible disturbances from the wind, furthermore it is not taken at the correct site and may just be a reiteration of the Davenport data. The Simiu spectrum, probably the truest to the natural phenomena, again requires knowledge of local terrain information that is unavailable. In a discussion with Simiu about using his spectrum for this purpose he suggested that we could guess a value for local surface roughness, but the literature would not have a value specifically for mountain terrain.

I made an attempt to use the Davenport and Forbes spectra in tandem to extract a quantitative power spectra that applied to the Mauna Kea site. This was done by calculating a number of Davenport spectra with the aerodynamic roughness as a parameter, until one was found that overlaid the measured spectrum. This has all the problems related to both spectra. We still can not be sure that this is the right spectrum, both because the measurements were taken elsewhere on the mountain and that the spectrum could be off by a factor of 10 one way or the other (the roughness could be wrong by a factor of 10 and the spectrum would just be shifted down by that amount, there is no scale on the graph).

3.4 SITE PROBLEMS WITH USING EXISTING WIND INFORMATION:

Because the proposed Mauna Kea site for the SMA is at a distance from and at a lower altitude than the site of the Forbes data, the spectra he measured may not be representative of the wind that affects the antennas. The site is, for the most part in the wind shadow of a 125m knob. The array is large enough that the wind spectrum will vary across the site, if only because of the knob. In order to have usable wind data to predict the pointing performance of the telescopes wind data should be measured at the site along the various points of the array. No one at Mauna Kea is currently taking wind data near the proposed SMA site. It is recommended that SMA program set up a test program to gather the required data.

3.5 DATA MEASUREMENT:

The measurement of wind spectra that are usable to predict pointing performance over a wide range of wind speeds is not as enormous as it might seem. The wind spectrum at a given location and in a given direction can be determined from a single 10 minute record. This will permit us to determine the local roughness parameters. Thus, if we make our measures at the site in tandem with average wind speed and direction measurements at the summit we will be assured of measuring a spectrum that corresponds to the prevailing winds. The rig would then be moved to a new portion of the site. By carefully selecting the season, the measurements could all be done in a couple of days.

4.0 SUMMARY:

Though there is a lot of data available on the spectrum of wind gustiness none of it is particularly suited to use in this application. The range of variation in the spectra from one site to the next is large enough that using a general spectrum or one measured at a different site would be misleading at best. Furthermore, we have reason to believe that there is variation in wind spectra across the site itself.

In order to ensure an accurate measure of the installed telescope pointing performance, some locally measured data is required. In the meantime, we can use the Forbes data to characterize a wind spectrum and do rough predictions of telescope pointing.