The Degradation of Radome Panels due to Probabilistic Extreme Wind Events

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Abstract—**Radomes house and protect valuable satellite equipment worldwide, and the health of the structures is monitored by reliability engineers at NASA Goddard Space Flight Center. The radomes are made up of composite-material panels that are currently maintained by replacing them at the manufacturer's recommendation of twenty (20) years. The goal of this research is to develop a more efficient maintenance schedule for the panels, based on a model of the degradation of the panels over time. The end-of-life prediction model considers the exposure of the panels to weather elements such as extreme wind events, precipitation and humidity, UV exposure, and extreme temperatures. This paper focuses on the contribution of extreme wind events to the degradation of the panels.**

Index Terms—**Aerodynamics, Analytical models, Availability, Fatigue, Probability density function**

I. Introduction

THE health of radome structures positioned worldwide is monitored by reliability engineers at NASA Goddard Space Flight Center (GSFC). The radomes house very valuable satellite equipment, and they are made up of composite-material panels that coat a beam base. The manufacturer of the radome panels recommends the replacement of the panels after twenty (20) years of use; research is being carried out to develop a more efficient schedule for the maintenance of the radome panels. The schedule will be based on the elements that each radome experiences in its particular climate; wind events, precipitation and humidity, UV exposure, and extreme temperatures are among the factors that will be considered in determining the life span of the panels.

Research has begun for the development of a model to describe the degradation rate of a radome stationed in Guam. Weather data for the area has been collected as well as aged panels for strength testing after exposure to the elements. The element of focus for my project is wind.

II. Wind Events In Guam

In the initial stage of my project, I developed a probabilistic model of the wind events in Guam in order to allow for the prediction of the occurrence of extreme wind events in Guam. Wind gust maximum speed data were collected from a database of monthly wind measurements over a period of 20 years (1992 through 2012) in Guam; wind speed values as well as data for the average wind directions during the months were made available by the database. I entered the wind gust maximum speed data into Arena Input Analyzer software to find the distribution to which all the data best fit and to find the outliers for the distribution. I used the outlier values with the Extreme Value Theory [1] and Maximum Likelihood Method [2] to develop a bimodal probability distribution that would account for extreme wind events. The probability density function for the wind events is given in (1) and plotted in Fig. 1 below.

$$f(x) = \begin{cases} \frac{256(x-24)^7 e^{-2(x-24)}}{\Gamma(8)}, & 24 \le x < 57 \\ \frac{1}{9}\left[1+\frac{x-66}{9}\right]^{-2} exp\left\{-\left[1+\frac{x-66}{9}\right]^{-1}\right\}, & x \ge 57 \end{cases} \qquad (1)$$

where x is the wind gust speed, and *f(x)* is the probability of the occurrence of that speed.

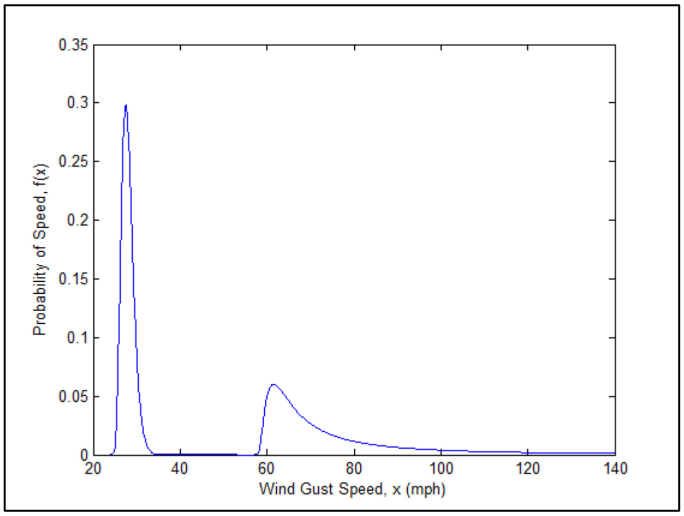

Fig. 1. Probability Density Function for Maximum Wind Gust Speed

III. Fatigue Model Based On Wind Events

The degradation of the radome panel would occur as material fatigue over time and can be modeled using the Palmgren-Miner rule. The rule states that fatigue failure of a structure occurs when

$$\sum_{i=1}^{N} \frac{n_i}{N_i} = 1, \qquad (2)$$

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where n_i represents the number of cycles a structure experiences of a stress at level i, and N_i is the number of cycles at stress level i that a structure can experience before failure, taken from the S-N curve of the structure [3].

In the paper "Dynamic alongwind fatigue of slender vertical structures" by Repetto and Solari, the researchers present a function derived from Miner's rule to describe the time to fatigue failure for a structure [5]. The equation is as follows:

$$T_F = \left\{\sum_i \sum_j v_{si} P_i \frac{1}{N_{ij}} \left(exp\left[-\frac{(j-i)^2 \delta s^2}{2\sigma_{si}^2}\right] - exp\left[-\frac{j^2 \delta s^2}{2\sigma_{si}^2}\right]\right)\right\}^{-1}, \qquad (3)$$

where N_{ij} is the total number of cycles required at the ij level of stress to bring the material to failure, P_i is the probability of occurrence of the stress, δ_s is the stress interval, and σ_s and v_s are the standard deviation and expected frequency, respectively, of the fluctuating stress [5].

This function will be used to determine the end-of-life of the radome panels due to wind fatigue. Parameter values unique to the radome will be input, including 1) the magnitudes of the stresses that will be applied to the panels, along with the probability of occurrence of those stresses; and 2) the total stress needed to fracture the radome panel. For parameter 1), a model of the probability of the wind events in Guam is available, and what must next be understood is how a wind gust translates to stress in the radome. The value for parameter 2) can be found through stress testing of unused panels.

IV. WIND LOADING AROUND THE RADOME

When a wind gust comes into contact with the radome, the wind will be slowed and separated to travel around the radome structure and to rejoin at the opposite end of the radome. This will result in pressure upon the radome panel at the point of contact and a suction effect on a panel at the opposite end of the radome.

The panels that experience wind loading will be contacted based upon wind direction. Perhaps then the schedule for maintenance of the radome panels will specialized for each panel, as panels at a certain orientation may experience extreme wind loads more often than others and will fatigue at a faster rate. I carried out a statistical experiment, using the wind direction values from the Guam weather data, to test the hypothesis that wind direction has a significant correlation with the occurrence of extreme wind speeds.

The experiment tested the response of wind speed against two main factors: month of the year ("Month") and wind direction ("Angle"). Analysis of variance (ANOVA) results from Minitab, shown in Table I, found no interaction available between the Month and Angle factors, and it was found that the wind direction was a significant factor in the trend of the wind speed.

Table I. ANOVA Results

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Month	11	3160.6	2370.0	215.5	1.49	0.143
Angle	28	8088.1	8.088.1	288.9	2.00	0.005
Error	127	18359.8	18359.8	144.6		
Total	166	29608.5				

The main effects, contour, and residual plots from Minitab showed the flaws in the validity of my experiment, however. The main effects plot for wind speed versus wind direction, shown in Fig. 2, showed a significant increase in the mean wind speed at certain larger angles; the conclusion that panels at these orientations are more likely to experience extreme wind loads would be incorrect, however. The contour plot for wind speed versus wind angle, shown in Fig. 3, gives a more accurate story; the mean wind speed did increase significantly at the angle-in-question, but the increase was only experienced for one month's measurement.

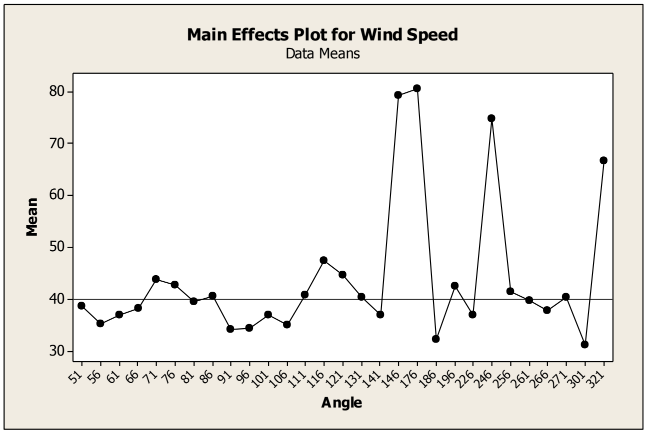

Fig. 2. Wind Direction Main Effects Plot

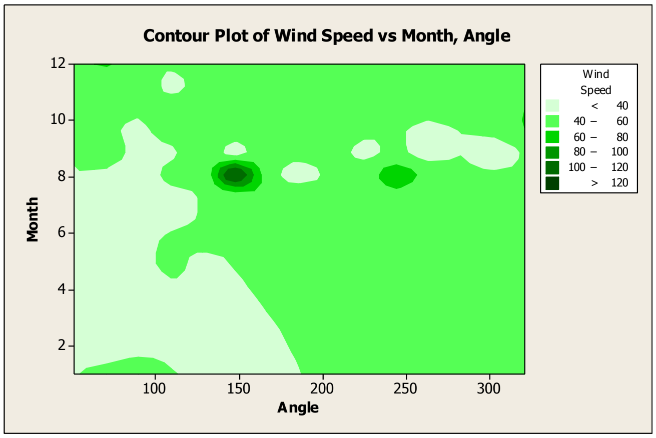

Fig. 3. Wind Direction and Month versus Wind Speed Contour Plot

The residuals plots, shown in Fig. 4, further showed the inadequacy of my model, as the residuals did not follow a normal distribution, and they seemed to follow a pattern when plotted versus fitted values. I was not able to make a full model for the testing of each wind direction, as multiple wind speed data were not available for many of the larger angle orientations. Data was available for each month level every year, but my experimental model became invalid when I used varying amounts of replications for the wind angle levels.

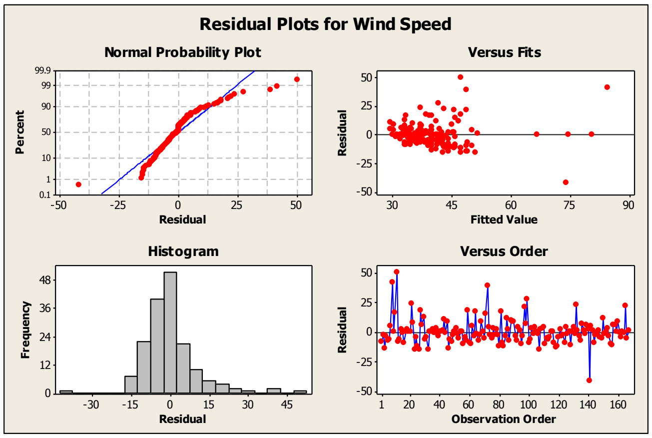

Fig. 4. Residual Plots from Minitab

My conclusion from this experiment was that in order to make valid conclusions about the factors that affect measured wind gust speeds, I must wait for further data to be recorded in Guam. Over time, a more accurate full model can be used to test the effects of wind direction.

I continued my research with my focus on the radome structure as a whole, and I would consider the maintenance requirements of each panel as similar. The month and wind direction factors would not be considered in the probabilistic model of the degradation of the radome; the degradation due to forces from the wind speeds alone would be modeled.

V. FORCES DUE TO WIND LOADING

The ASCE7 manual Chapter 6 describes the minimal wind loads that must be accounted for in the design of buildings and other enclosed structures. Three methods are introduced for determining the force that will be applied to a structure based upon wind behavior: 1) the Simplified Procedure, 2) the Analytical Procedure, and 3) the Wind Tunnel Procedure [4].

The analytical method gives the formula in (4) for calculating wind pressure based on wind velocity [4]. The geometry of the structure as well as the terrain of the structure's location is considered in the modifiers of the formula. The resulting force upon the structure can be determined by multiplying by the contact area perpendicular to the wind gust.

$$q_z = 0.00256 * K_z K_{zt} K_d V^2 I \qquad (4)$$

where V is the wind velocity; K_z, K_{zt}, and K_{zd} are all modifiers; and I is the importance factor. K_z accounts for changes in pressure at different altitudes above the ground (higher altitude gives higher value), K_{zt} accounts for changes in pressure as wind approaches and descends from hilltops (1 for flat terrain), and K_{zd} accounts for pressure changes due to wind directionality and "combined loading effects" (is equal to 1 when considering wind velocity alone) [7].

There are assumptions, however, for use of this procedure to calculate wind load, and the radome structure may not meet these qualifications. Firstly, the structure must be regular-shaped as according to Section 6.2 of the ASCE7 manual. Secondly, the structure must not have "response characteristics that make it subject to across wind loading, vortex shedding, instability due to galloping or flutter" [4]. The radome has a very unique geometry, so the use of this procedure may be invalid. The section that follows this procedure in the manual suggests use of the third procedure if the structure-in-question does not meet the specifications, so further research will be carried out in use of the wind tunnel procedure.

VI. FUTURE RESEARCH

The unique geometry of the radome structure must be further studied to understand the response characteristics that the radome will experience. The wind tunnel procedure will also be studied to determine the valid procedure for calculation of the wind loads experienced by the radome.

New and weathered radome panels will be physically tested for the total allowed stress value for input into the Palmgren-Miner time-to-failure model. The force formulas due to wind velocity and the total stress value will be used to create a model into which probabilistic wind speeds can be entered to determine the life span of the panels at a specific location.

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