OPERATIONAL EXPERIENCE WITH VAWT BLADES

AT SANDIA LABORATORIES*

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Sandia Laboratories has operated three Darrieus turbines (2 meter, 5 meter, and 17 meter diameter rotors) at its test facility for the last several years. Through this test program, a variety of blade types and rotor configurations have been tested for structural and aerodynamic performance. This paper will discuss primarily blade structural performance aspects of the tests on the 17 meter rotor.

The first blade installed on the 17 meter rotor was fabricated by Kaman Aerospace Corporation. The Kaman blade, shown in Fig. 1, is a helicopter-type composite of aluminum and fiberglass. The airfoil is a NACA 0012 with a 21 inch chord. A single blade is made up of five individual sections (two straight sections, two struts, and one curved section) joined by flatwise-free pins (Fig. 2). The blades are instrumented with direct strain gages bonded to the extruded aluminum spars at the locations shown in Fig. 2. The rotor was initially configured with two blades and after about 8 months of testing, a third blade was added.

The performance of the Kaman blade was quite acceptable. No maintenance was required and no blade deterioration was evident upon removal of the blades. Installation was tedious because of the many individual blade sections and difficulties in alining the pin connectors. A high frequency (above 4/rev) blade resonance in the lead/lag strain gages was observed in the three-bladed configuration at one test rpm (45.5). This resonance was substantial only with winds above 35 mph and was almost undetectable at rotor rpm's 5% on either side of 45.5. Normal operating rpm for the 17 meter rotor is about 50 rpm. No similar resonances were observed in the two-bladed rotor, apparently because of the lower excitation frequencies present with two blades.

Test results for typical steady and vibratory stress measurements are summarized in Figs. 3 to 5. The details of the data reduction and measurement techniques are discussed in an earlier report.[1] Also shown on Figs. 3 to 5 are predicted values of the stresses based on the MARC quasi-static finite element model. In general, the agreement is very good although scatter in the vibratory data is substantial due to difficulties in measuring the windspeed actually experienced by the blade. The data for the edgewise strain (Fig. 5) do exceed predictions somewhat for winds above 40 mph. We believe this is due to a dynamic excitation of the first lead/lag blade mode (the "butterfly" mode)

[1]W. N. Sullivan, "Preliminary Blade Strain Gage Data on the Sandia 17 Meter Vertical Axis Wind Turbine," SAND77-1176, December 1977.

by 3/rev edgewise force frequencies. A crossing of the 3/rev line with this rotor frequency is predicted at 55 rpm, which is quite near the 52.5 operating rpm shown.

Future testing efforts are planned to center around continued examination of existing data to identify important structural phenomena and guide the development of analysis models. Additional test series are also being planned to expand the data base. These new test series include modal analysis tests on the 17 meter rotor to experimentally determine frequencies and mode shapes, dynamic strain measurements on the 17 meter rotor with the new Alcoa extruded blades without support struts, and flutter tests on the 2 meter rotor.

DISCUSSION

Q. With regard to the very high wind load cases, can one consider having to orient the rotor to a less vulnerable position in high winds?

A. Yes. For two-bladed systems, the rotor is substantially less vulnerable to buckling with the blade chordline oriented parallel to the wind velocity. Mechanical systems to provide this orientation for the rotor may be worthwhile on larger systems where such mechanisms may cost a fairly small fraction of the total.

Of the design requirements that we try to use as guidelines, there is not a single one which totally dominates the design. Thus, if we by some means eliminate the buckling problem, either by lowering the design wind speed or developing an attenuating mechanism, the edgewide blade stress, for example, still prevents us from significantly reducing blade section properties. In his paper, Mr. Kadlec talked about changing all of the design requirements. That is what is required to save blade weight on future designs.

Q. Has anyone considered introducing a lead-lag pin in order to get rid of these edgewise stresses, reduce the butterfly mode, and get some attenuation on torque ripple?

A. I think that the Magdalen Island machine, through the linkages on the struts, has a form of lead-lag hinging, or at least a lead-lag damping. We have not considered too actively the lead-lag hinge because, I guess, the hub diameter is relatively small. With small diameter hubs, the blade must lead the tower quite a bit to get the torque out of the blade. I do think that kind of activity may well be appropriate in the future, just as the teetered hub evolved for horizontal axis systems. We still are trying to keep these new ideas in mind as we proceed.

Q. In the last two slides that were presented, it appeared that the results and experimental data were on a different slope in both cases, and there appeared to be a significant variation in the magnitude of the results. Do you feel that the source of the variation is atmospheric in nature – turbulence, or relating to something else? Also, do you feel the MARC Program is predicting the proper phenomena that you are measuring, and what is causing the variation, in your opinion?

A. I think you may have alluded to the scatter in the data. It is just tremendously difficult to measure blade strains and wind speed at the same time. I believe that the anemometer reading is not necessarily reflective of the wind speed that occurs all over the disc at the time that it was rotating, and I think that induces tremendous scatter. The slope of the data and theory is in reasonable agreement in the flatwise direction. There is about as much data below the prediction line as above it. In the case of the edge-wise stresses, I agree there is a different slope, and I believe it is due to dynamic effects that are inherently neglected in the model. We happen to know that we are relatively near a resonance frequency, and I think that is what is causing it.

Q. You use the static criteria for a machine that is designed for 30 years. How confident are you in using the static criteria after it was subjected to dynamic loading? Secondly, what kind of dynamic loading has been included?

A. I think the dynamic factors are important enough to warrant being quite conservative in the static design requirements. I think you are asking me whether I think the static design requirements are conservative enough. The answer is I think they are, but only because I have seen the data on machines that have been designed to those requirements. I will not deny that there is an element of judgment involved, and that the risk of some disastrous dynamic effects remains. This is why we plan to expand our efforts to analyze and include dynamic effects throughout the design process.
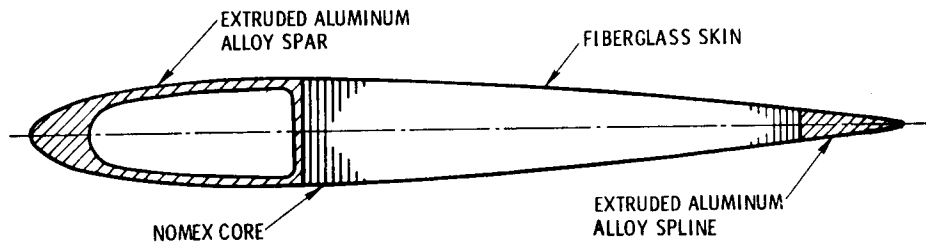
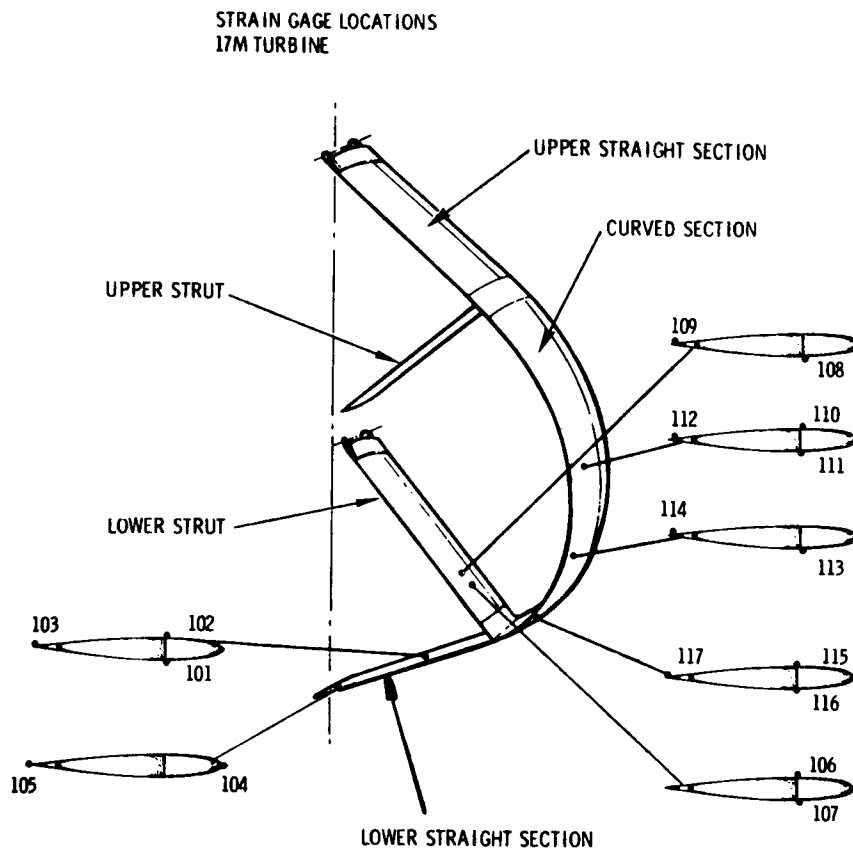FIGURE 1. Cross Section of the Kaman Blade. Blade Chord is 21".

FIGURE 2. Kaman Blade Geometry Indicating Locations of the Strain Gages.
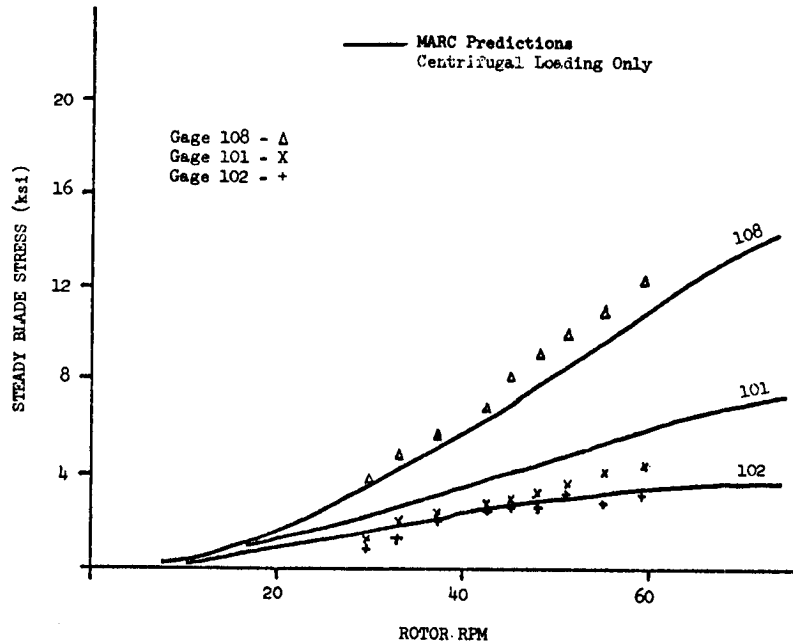
FIGURE 3. Steady Stresses as Measured and Predicted for the
17-m Rotor. Steady Stresses are Measured by Operating
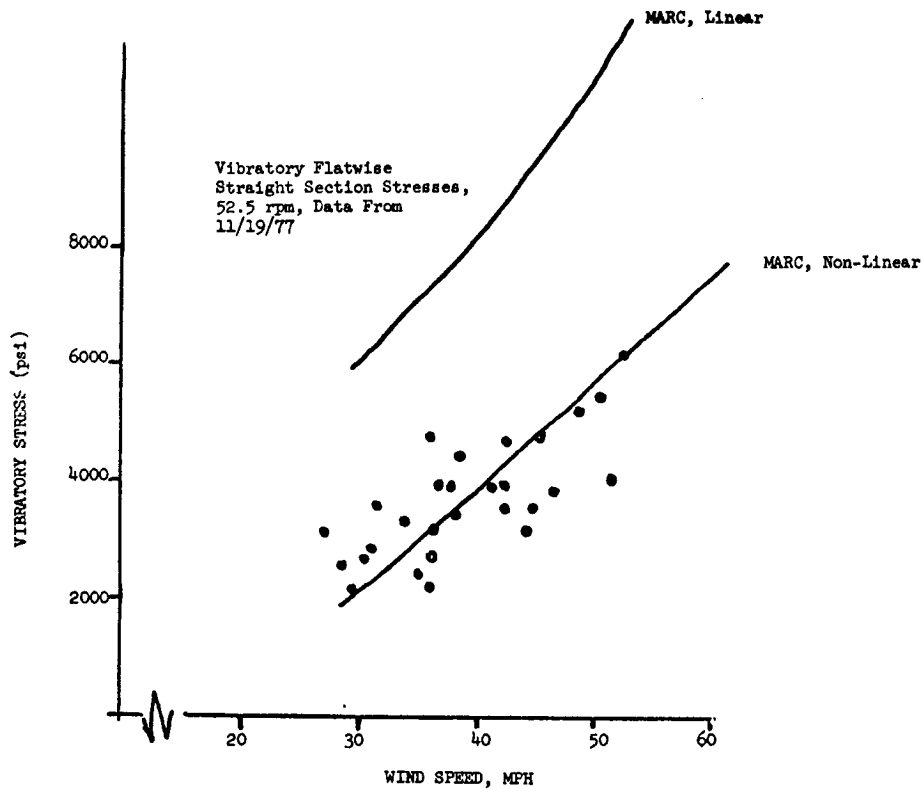the Rotor in Negligible Wind.

FIGURE 4. Flatwise Straight Section Vibratory Stresses at 52.5 rpm
as a Function of Windspeed. MARC Quasi-Static Analysis
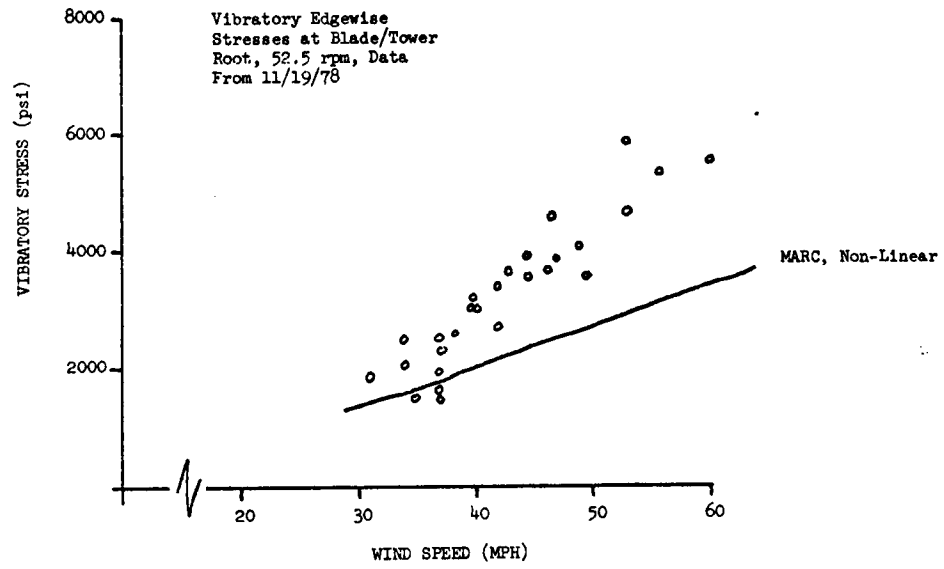Also Shown, With and Without Non-Linear Options.

FIGURE 5. Edgewise Straight Section Vibratory Stresses at the Blade/Tower Attachment Region.