# FLUTTER OF DARRIEUS WIND TURBINE BLADES: CORRELATION OF THEORY AND EXPERIMENT

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Acquisition of frequency data for the Alcoa 17-M LC and 1238229 wind turbines has permitted some limited correlation of the flutter analysis of Ref. 1 with experimental data for flutter of Darrieus blades from Ref. 2.

The natural frequencies of the non-rotating critical blade bending modes can be written as

$$\omega_{20} = \lambda_2 \sqrt{\frac{EI_F}{mR^4}} \text{ rad./sec.}$$

$$\bar{\omega}_{20} = \bar{\lambda}_2 \sqrt{\frac{GJ}{mR^4}} \text{ rad./sec.}$$

where $\lambda_2$, $\bar{\lambda}_2$ are frequency parameters, and

$EI_F$ = blade flatwise bending stiffness, lb-ft$^2$

$GJ$ = blade torsion stiffness, lb-ft$^2$

$m$ = blade running mass, slugs/ft.

$R$ = radius of circular arc portion of blade

Also, the effect of turbine rotational speed $\Omega$ is given by

$$\omega_2^2 = \omega_{20}^2 + K_2\Omega^2$$

$$\bar{\omega}_2^2 = \bar{\omega}_{20}^2 + \bar{K}_2\Omega^2$$

where $K_2$, $\bar{K}_2$ are Southwell coefficients.

Data provided by Alcoa has made possible the following tabulation for turbines of h/D = 1.5:

TABLE I

| TYPE | $\lambda_2$ | $\bar{\lambda}_2$ | $K_2$ | $\bar{K}_2$ |
|---|---|---|---|---|
| 17-Meter LC | 5.72 | 23.7 | 2.74 | 4.57 |
| 1238229 | 10.0 | 23.5 | 4.32 | 3.99 |

Proceedings of the Second DOE/NASA Wind Turbine Dynamics Workshop, Cleveland, February 1981.

The bracing struts of Type 1238229 appear to have a significant effect on the flatwise bending parameters $\lambda_2$ and $K_2$. It is suspected that significant mode shape variations may also be related to the clamping effect of the struts.

Experimental flutter data for wind tunnel models of Darrieus wind turbines of h/D = 1.5 are shown in Fig. 1 taken from Ref. 2. The correlating parameters are the reduced flutter speed

$$\frac{U_c \ell}{t} \sqrt{\frac{\rho_B}{G}}$$

where $U_c$ = blade tangential velocity at flutter = $\Omega_F R_c$

$\ell$ = blade length

$t$ = blade section maximum thickness

$\rho_B$ = blade material density

$G$ = blade material torsion modulus

and the density ratio

$$\frac{\rho_B A_B}{\frac{\pi}{4}\rho c^2}$$

where $A_B$ = blade material cross-section area

$\rho$ = air density

$c$ = blade chord

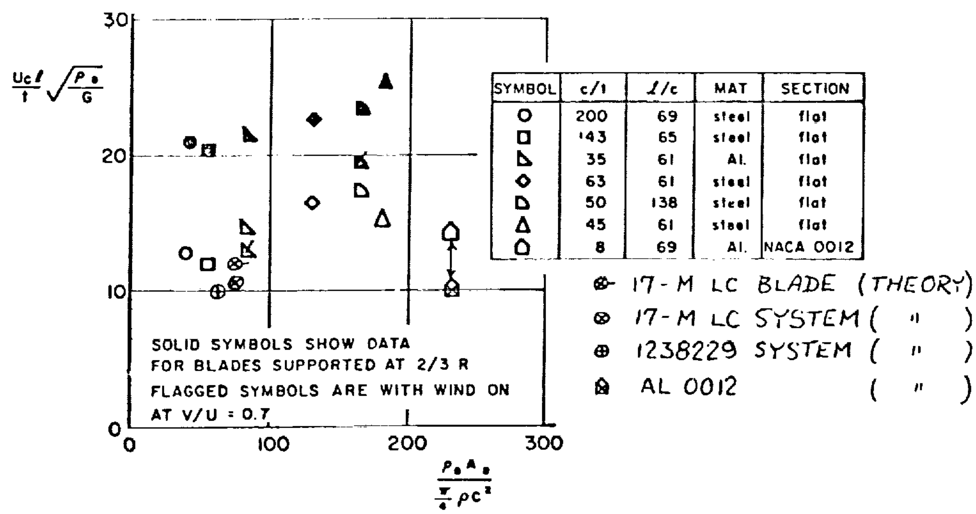
These parameters were calculated for the 17-Meter LC and 1238229 wind turbines using their theoretical flutter speeds $\Omega_F$ of 108 rpm and 57 rpm respectively as calculated by the method of Ref. 1. The results are plotted in Fig. 1. The theory is seen to give a conservative prediction of flutter speed.

An attempt was made to predict the experimental flutter speed directly for the particular case of the aluminum blade of 0012 section of Fig. 1, using blade frequencies estimated by means of the parameters tabulated in TABLE I for the 17-Meter LC turbine, and the flutter parameter values $C_2$ = -6.5 and $m_\beta/m_g$ = 0.75 for that strutless turbine. Again, the theoretical prediction is seen to be conservative.

REFERENCES

1. Ham, N.D., "Flutter of Darrieus Wind Turbine Blades", from "Wind Turbine Structural Dynamics", NASA Publication CONF-2034, November 1977.

2. Templin, R.J. and South, P., "Canadian Wind Energy Program", Proc. of the VAWT Technology Workshop, SAND76-5686, Sandia Laboratories, Albuquerque, N.M., July 1976.


| SYMBOL | c/t | ℓ/c | MAT | SECTION |
|---|---|---|---|---|
| ○ | 200 | 69 | steel | flat |
| □ | 143 | 65 | steel | flat |
| ◺ | 35 | 61 | Al. | flat |
| ◇ | 63 | 61 | steel | flat |
| D | 50 | 138 | steel | flat |
| △ | 45 | 61 | steel | flat |
| ⌂ | 8 | 69 | Al. | NACA 0012 |

**Fig.1.** Variation of blade flutter parameter with density ratio for turbine with h/d = 1.5.