Table 1 Results for different helicopter blades

Example No.	Source (Ref. No.)	(EI_f), N-m^2	(EI_t), N-m^2	(GJ), N-m^2	(EA), N	b, m	b/a, Eq. (3)	$(G/E)_{eq}$, Eq. (2a)	$(G/E)_{eq}$, Eq. (2b)
1	3	126.3	3444	149.4			0.192		0.307
2	4	57.1	1813	66.0			0.177		0.298
3	5	0.0461×10^5	1.53×10^5	0.0717×10^5			0.174		0.401
4	6	0.861×10^5	43.95×10^5	0.708×10^5			0.140		0.209
5	7	0.155×10^5	6.641×10^5	0.201×10^5	7.928×10^7	0.0177	0.153	0.809	0.332

Table 1 contains details about the properties of different blades of modern rotors. Since the properties vary along the blade the numbers in the table are typical values that represent the mean value along main portions of the blade. Example 1 is a Mach scaled model of the UTTAS YUH-61A of fiberglass composite construction. The second example is also a model for wind tunnel experiments. In this case the blade construction consists of a basically oval titanium spar, Nomex core in the trailing portion, and foam filler in the nose to maintain contour. Fiberglass cloth was bonded around the Nomex, spar, and filler to form a closed blade skin. The blade of example 3 is of a tail rotor that is made of composite materials. The example 4 blade is a common all-metal blade. The last blade (example 5) belongs to the Advanced Technology Rotor System. In this case the blade employs titanium spar construction with a fiberglass skin and utilizes graphite composite trailing edge strips. The five blades represent different construction techniques, different materials, and different manufacturers. (EA) was given only for the last example and therefore only in that case was the equivalent G/E calculated using Eq. (2a). In all cases the equivalent G/E was calculated using Eq. (2b). If one recalls that for isotropic material $G/E=0.38$-0.4, then it may be concluded that the equivalent G/E of anisotropic blades is very similar to that of isotropic materials and is clearly of the same order of magnitude. None of the cases is even close to the value of 0.025 that was used in Ref. 1 as representative for helicopter blades. It should also be noted that the values of the equivalent G/E according to the two equations in example 5 are considerably different, although they are both of the same order of magnitude. This difference probably results from the approximation where a solid elliptical cross section represents the blade cross section.

Conclusions

It has been shown that the equivalent G/Es of rotor blades—taking into account different kinds of constructions, different materials, and different manufacturers—are very similar to those of isotropic materials. Therefore, many results that were obtained for isotropic beams may also be applied to rotor blades.

There are certain limitations to using the concept of equivalent G/E for investigating the behavior of rotor blades, and it seems preferable to treat the blades as beams by considering equivalent beam properties which may be validated by experiments.

References

[1] Hodges, D. H., "Torsion of Pretwisted Beams Due to Axial Loading," *ASME Journal of Applied Mechanics*, Vol. 47, June 1980, pp. 393-397.

[2] Hodges, D. H., "Author's Closure," *ASME Journal of Applied Mechanics*, Vol. 48, Sept. 1981, pp. 680-681.

[3] Doman, G. S., Tarzanin, F. J. Jr., and Show J. Jr., "Investigation of Aeroelastically Adaptive Rotors," USAA MRDL-TR-77-3, May 1977.

[4] Weller, W. H., "Experimental Investigation of Effects of Blade Tip Geometry on Loads and Performance for an Articulated Rotor System," NASA TP-1303, Jan. 1979.

[5] Banerjee, D., Head, R. E., Marthe, R., and Plaudre, M., "The YAH-64A Composite Flexbeam Tail Rotor," presented at the National Specialists Meeting on "Rotor System Design," Philadelphia, Pa., Oct. 1980.

[6] Lee, B. L., "Experimental Measurements of the Rotating Frequencies and Modes of a Full Scale Helicopter Rotor in a Vacuum and Correlation with Calculated Results," presented at the 35th Annual National Forum of the American Helicopter Society, May 1979.

[7] Jepson, D., Moffitt, R., Helzinger, K., and Bissell, J., "Analysis and Correlation of Test Data From an Advanced Technology Rotor System," NASA CR-152366, July 1980.

Reply by Author to A. Rosen

Dewey H. Hodges
U.S. Army Research and Technology Laboratories (AVRADCOM), Ames Research Center, Moffett Field, California

DR. Rosen's paper focuses on effective values of G/E for helicopter rotor blades. I have previously stated that effective values of G/E "*may* be much less than unity"[1] and "*may* differ from those encountered in isotropic structures by one or more orders of magnitude."[2] References 1 and 2 do not suggest "using the concept of equivalent G/E for investigating the behavior of rotor blades" as Rosen claims. Its use was limited in Refs. 1 and 2 to assessing the importance of certain terms in the blade torsion equation. In Ref. 2 it is further stated that "the terms in question are not negligible for certain composite rotor blades, especially the flexbeam portion of bearingless rotor blades."

Actual values of G/E for some composite materials with uniaxial fiber orientation are considerably less than 0.4. The value of 0.025 used in example calculations in Refs. 1 and 2 is typical of such materials. These materials are relevant for construction of the flexbeam portion of bearingless rotor blades.

Rosen has chosen several example blade sections to demonstate that equivalent G/E is on the order of 0.4. All these blade sections have torsion rigidity levels that are typical for rotor blade applications. His five examples include nonisotropic metal and composite construction. However, when composite materials are used in blade applications, they normally have fiber orientations that produce a relatively high torsion stiffness. Therefore it is not surprising that his calculated equivalent G/E values are typical of isotropic materials. The important point quoted above from Ref. 2 concerning the flexbeam portion of bearingless rotor blades is not addressed by Rosen. Although the terms in question in the torsion equation are not particularly relevant for portions of blades with relatively high torsion rigidity, they are important

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*Research Scientist, Rotorcraft Dynamics Division, Aeromechanics Laboratory. Associate Fellow AIAA.

for the flexbeam portion of bearingless rotor blades, which is normally designed to be relatively soft in torsion. Hence, the terms in Ref. 1 that Rosen would exclude are important in some rotor blade applications and not in others. Since they do not complicate the equations or present additional difficulties in solving them, it would appear logical to include these terms in any general purpose blade analysis.

References

[1]Hodges, D.H., "Torsion of Pretwisted Beams due to Axial Loading," ASME *Journal of Applied Mechanics,* Vol. 47, June 1980, pp. 393-397.

[2]Hodges, D.H., "Author's Closure," ASME *Journal of Applied Mechanics,* Vol. 48, Sept. 1981, pp. 680-681.

Errata: "Karman Vortex Shedding and the Effect of Body Motion"

L.E. Ericsson
Lockheed Missiles & Space Company, Inc.
Sunnyvale, California

[AIAAJ **18**, pp. 935-944 (1980)]

THE results[1] in Fig. 13 for the structural angle cross section were interpreted assuming that the flow pattern was similar to that for the triangular cross section[2] in Fig. 2, with flow separation occurring on the 45-deg "boat tail" when the angle cross section faced the stream with the open, concave side. The measured Strouhal frequency[1] was, however, smaller when the apex faced downstream ($S_{v0} \approx 0.12$) than when it faced upstream ($S_{v0} \approx 0.20$). Thus according to Eq. (2), the wake width cannot have been smaller or even as small with the apex facing downstream as when it faced upstream.

The enclosed Fig. 1 shows Fig. 13 with the correct conceptual flow patterns. Comparing the flow pattern for $\alpha = -45$ deg with that for the rectangular cross section in Fig. 2 of Ref. 3, one can conclude that the large amplitude response at $\alpha = -45$ deg in Fig. 1 is likely to have the same source as the large amplitude response of the rectangular cross section.[3] That is, the nose-induced flow separation generates negative lift on the embedded aft body until the amplitude becomes very large.

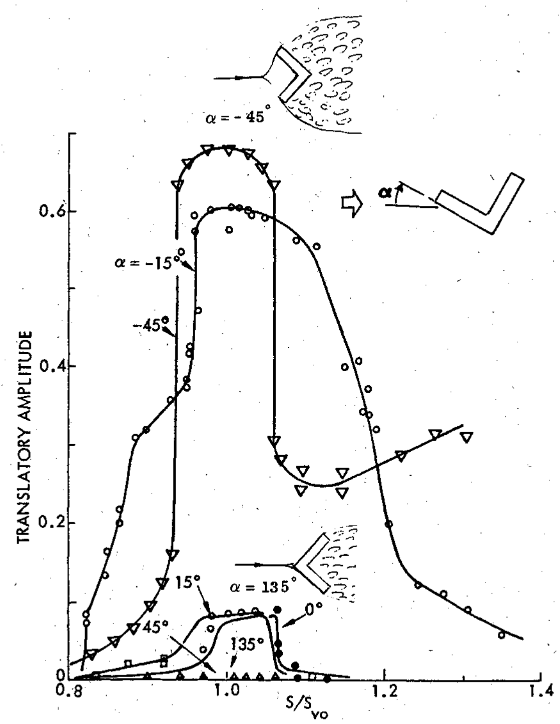

Fig. 1 Response of structural angle cross section to vortex excitation.[1]

References

[1]Modi, V.J. and Slater, J.E., "Unsteady Aerodynamics and Vortex Induced Aeroelastic Instability of a Structural Angle Section," AIAA Paper 77-160, Los Angles, Calif., Jan. 1977.

[2]Delany, N.K. and Sorensen, N.E., "Low Speed Drag of Cylinders of Various Shapes," NACA TN-3038, Nov. 1953.

[3]Ericsson, L.E., "Hydroelastic Effects of Separated Flow," *AIAA Journal,* Vol. 21, March 1983, pp. 452-458.

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Errata: "Comment on Potential of Transformation Methods in Optimal Design"

B. Prasad
Ford Motor Company, Dearborn, Michigan

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THE second line in Table 2 on page 1631 should read:

Refs. 3, 5-6	1	NCON	—	—	NCON + 1

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