Correlation of the Vortex Lattice Method on Rotor/Wing Configurations

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THE hot-cycle rotor/wing high-speed VTOL aircraft has been described as follows[1]:

> The Hot Cycle Rotor/Wing is a new concept for high-speed vertical takeoff aircraft. It is a unique, dual-purpose lifting device that is basically a Hot Cycle helicopter rotor with an unusually large hub. It acts as a tip-jet-powered rotor for vertical and low-speed flight, and stops during flight to become a low-aspect-ratio, swept wing for high-speed cruise. By stopping the rotor in forward flight, the speed limitations of the helicopter rotor are removed, enabling more efficient cruise and operation at speeds up to 500 knots as a jet airplane. The single, dual-purpose lifting device combined with the simplicity and light weight of the Hot Cycle propulsion system holds promise of high payload capability superior to that of any other high-speed VTOL aircraft concept.

Early low-speed wind-tunnel investigations[2] of the concept considered the two planforms shown in Figs. 1 and 2 to the scale of the models. The tests of the circular and triangular hubs were conducted with the blades off and on in the stopped rotor mode. The reduced data include lift and pitching moment coefficients for angle of attack and rolling moment coefficient for antisymmetrical deflections of the left and right blades. Because the planforms are somewhat unconventional, methods of analysis for estimation of their aerodynamic characteristics are rather limited. Perhaps the vortex lattice method of Hedman[3] and the constant-pressure panel method of Woodward[4] provide the only practical methods of solution at this time. It is the purpose of this Note to present a correlation of the calculated results from Hedman's method with the experimental data.

Linearized estimates of the various measured coefficients are shown in Table 1. The reference area for the coefficients is the rotor disk area; the reference length for the moment coefficients is the rotor disk radius. The moments are taken about the disk center. Although many of the experimental curves were reasonably linear, a number of them had the usual nonlinearities of wind-tunnel data, so the experimental coefficients in Table 1 must be regarded as approximate.

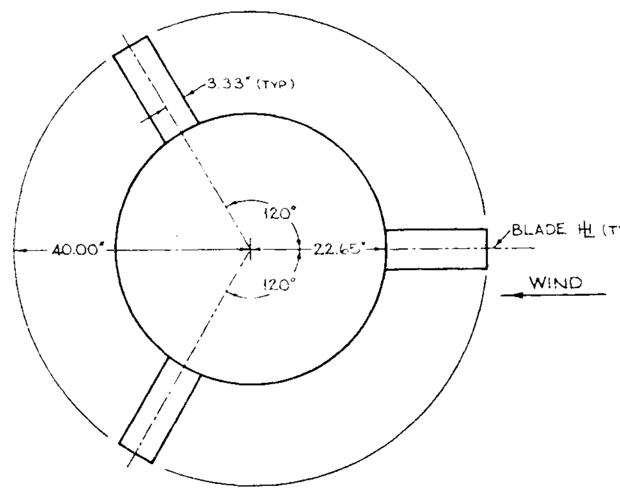

Fig. 1 Circular hub and blades.

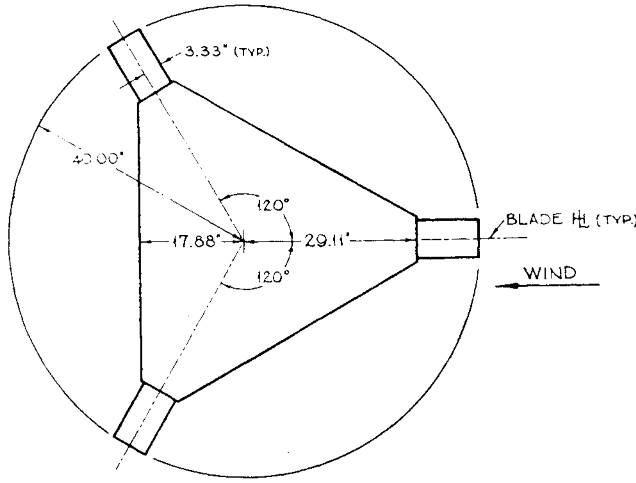

Fig. 2 Triangular hub and blades.

The calculated coefficients are also summarized in Table 1. The calculations for the circular hub were based on 136 vortices with blades off and 172 with blades on. The calculations for the triangular hub were based on 88 vortices with blades off and 108 with blades on. The large number of vortices was required by discontinuities in planform geometry rather than for convergence of the pressure distributions.

A perusal of Table 1 shows generally good correlation between calculation and test. The lift curve slopes $C_{L\alpha}$ are predicted well. The pitching moment curve slopes $C_{m\alpha}$ are predicted well with the blades off, and as well as might be expected with the blades on considering that the blades move the aerodynamic center close to the reference axis (disk center). The rolling moment effectiveness of the blades $C_{l\delta}$ is also predicted well but, surprisingly, is underestimated. In general, we may conclude that the present applications demonstrate the versatility of Hedman's vortex lattice method in treating such unconventional planforms and that the correlations demonstrate its accuracy.

Table 1 Comparison of experimental and calculated coefficients

Coefficient, per deg		Circular hub		Triangular hub	
		Blades off	Blades on	Blades off	Blades on
$C_{L\alpha}$	exp.	0.0114	0.0161	0.0125	0.0150
	calc.	0.0108	0.0169	0.0129	0.0167
$C_{m\alpha}$	exp.	0.0035	0.0025	0.0021	0.0013
	calc.	0.0031	0.0019	0.0018	0.0008
$C_{l\delta}$	exp.	...	0.00116	...	0.00065
	calc.	...	0.00090	...	0.00060

References

[1] Harned, M. and Head, R., "Hot Cycle Rotor/Wing High Speed VTOL Aircraft," presented at the First National V/STOL Aircraft Symposium, Wright-Patterson Air Force Base, Ohio, Nov. 3–4, 1965.

[2] Matthews, J. T., "Low-Speed Wind-Tunnel Investigation of a Circular and a Triangular Rotor-Wing Model in the Stopped-Rotor Mode," Test Report AL23, Oct. 1965, David Taylor Model Basin, Washington, D.C.

[3] Hedman, S. G., "Vortex Lattice Method for Calculation of Quasi-Steady-State Loadings on Thin Elastic Wings in Subsonic Flow," Rept. 105, Oct. 1965, Aeronautical Research Institute of Sweden, Stockholm.

[4] Woodward, F. A., "Analysis and Design of Wing-Body Combinations at Subsonic and Supersonic Speeds," *Journal of Aircraft*, Vol. 5, No. 6, Nov.-Dec. 1968, pp. 528–534.

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