Technical Comments

Comment on "Potential Flow about Impulsively Started Rotors"

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THE work of Summa,[1] has been a most welcome addition to the knowledge of the flow and performance of impulsively started rotors. Although the rotor configuration used in the calculations by Summa had no twist, was without thickness and, of course, inviscid incompressible flow was assumed, the prediction of the indicial rotor thrust performance agrees well with the earlier experimental work of Lehman and Besold.[2] Summa states,[1] "The outstanding feature of these calculations is that the indicial thrust coefficient initially overshoots and then approaches from above its final steady-state value." It was precisely this feature which was identified experimentally in Ref. 2.

In Ref. 2, the effort was directed towards an investigation of test section size and its influence on model helicopter rotor performance. These studies were performed in a water tunnel because of two major advantages pointed out by Goodman and Lehman[3]: 1) sufficiently large Reynolds numbers can be obtained with water as a test fluid using small models; and 2) the walls of a tunnel can be 3 to 5 times closer to the model (relative to the size of the model) when water is the test medium rather than air without undue wall interference. Moreover, because of the physical set-up of the test arrangement in the water tunnel during those tests, the rotor attempted to rotate at the preset rotational speed as soon as the motor switch was closed, and, in fact, based on observations of rotor rpm on a memoscope screen, the rotor did achieve steady operational speed within the order of one second. Therefore, in the tests reported in Ref. 2 an impulsive start of the rotor was closely approximated and, consequently, the experimental results can be realistically compared with the calculations of Summa.

In Ref. 2, a model of the UH-1D 2-bladed 48-ft diam rotor was tested. In observing the development of rotor lift as a function of time (starting with rotor motor switch closure) an overshoot of the lift was always observed for the hover situation with a typical output trace of the lift as a function of time shown in Fig. 1. In commenting on this observation of lift overshoot, Lehman and Besold offered the argument that for the case of a rotor operating in a closed test section, flow circulation patterns in the test section resulting from rotor action introduce an additional velocity into the rotor intake field which, in turn, produces a decrease in the effective angle of attack of the rotor and, correspondingly, a decrease in rotor lift. A steady-state lift situation resulted once the flow circulation pattern had been established.

While agreeing with Summa that the proximity of the tip vortex to the rotor will affect the development of lift during an impulsive start, it is believed that the movement of flow towards the rotor produced by rotor action cannot be overlooked because of the resulting decrease in the effective angle of attack of the rotor blades. The contention that the change in the effective angle of attack due to the rotor-produced flow is significant is strengthened by observing what happened during the experiments with the introduction of forward velocity, that is, a forward velocity that is initially established in the test section before the rotor is started (and with the rotor appropriately oriented to the flow). When this was done, the lift overshoot decreased as the forward velocity increased until, at an equivalent velocity of 15 knots, no overshoot was noted. The general trend of those observations is shown in Fig. 2.

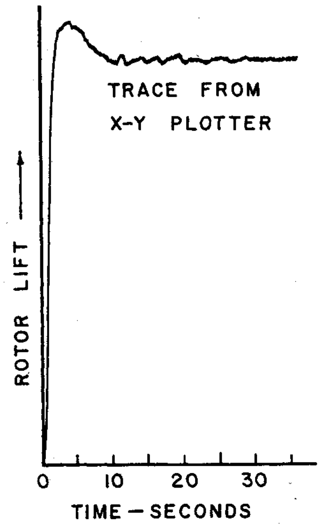

Fig. 1 Model rotor lift-time history at hover.[2]

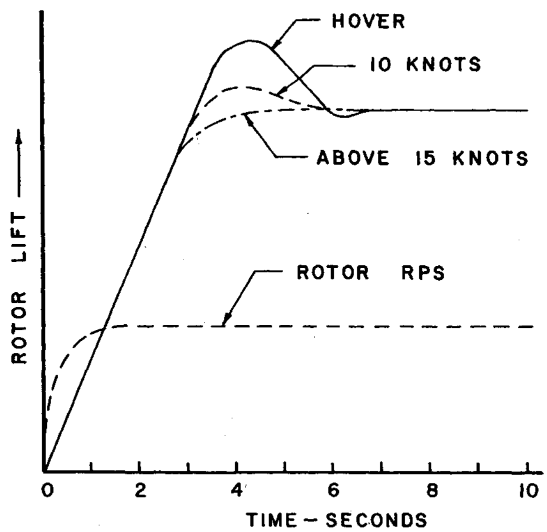

Fig. 2 General form of model rotor-time-rotor RPS histories.[2]

While the introduction of forward velocity will also change the spacial postion of the tip vortex relative to the blade tip, the physical change in the tip vortex spacial position (in the near field) at an equivalent 15-knot velocity, when compared to the spacial position of the vortex at hover does not intuitively appear sufficiently large to completely account for the elimination of the lift overshoot. It therefore seems reasonable to conclude that the rotor induced velocity component of the flow entering the rotor is at least partially responsible for the absence of lift overshoot in the presence of forward velocity because the rotor induced velocity component will exhibit an ever decreasing percentage of the total velocity as forward velocity is introduced.

Furthermore, it seems reasonable to deduce that the time required for the generation of lift (including the lift overshoot) together with the time required for the stabilization of rotor lift should be considerably greater for a real fluid than

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for the case calculated by Summa and this longer time is also indicated in the experimental results.

References

[1]Summa, J. M., "Potential Flow About Impulsively Started Rotors," *Journal of Aircraft*, Vol. 13, April 1976, pp. 317-319.
[2]Lehman, A. F. and Besold, J., "Test Section Size Influence on Model Helicopter Rotor Performance," Oceanics, Inc., Plainview, N. Y., Rept. No. 70-76 (AD 724191), Aug. 1970.
[3]Goodman, T. R. and Lehman, A. F., "Advantage of Testing Aircraft Rotor Models with Sharply Deflected Wakes in Water," *Journal of Aircraft*, Vol. 8, July 1971, pp. 585-586.

Reply by Author to A. F. Lehman

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I WISH to thank A. F. Lehman for his comment. It is encouraging to find that existing experimental data[1] confirm, at least qualitatively, my numerical calculations. I should emphasize, however, that the calculations in Ref. 2 represent impulsive motion of a *four-bladed* rotor in an infinite fluid medium, i.e., out-of-ground-effect. I therefore believe my discussion of the flow physics of the calculated indicial thrust behavior to be correct. That is, the indicial thrust overshoot and eventual decay to an asymptotic steady-state hover value are due to the time-dependent velocity field induced at the blades by the complicated wake system. The thrust overshoot itself occurs as the blades approach the upwash velocity field associated with the rolled-up starting vortices shed by the fore-running blades at the instant of impulsive motion. At some later time, the influence of the starting vortices wane and the largest contributors to the wake-induced velocity field at the blades are the strong rolled-up tip vortices which produce a downwash at the blade surfaces except for a small region near the tips. Consequently, the thrust eventually decays asymptotically to the steady-state value. Of course, in a closed test section the additional inflow discussed by Lehman due to a secondary circulation field would contribute to the thrust (lift) decay. However, I expect that the addition of forward velocity reduces the overshoot primarily because the starting vortices are convected away from the rotor disk at rates increased by the component of forward velocity normal to the disk. Finally, the longer time required for the development of lift overshoot in the experiment[1] is because the model was a *two-bladed* rotor (the overshoot should occur at approximately π radians of rotor movement after start-up) and because the experimental start-up required one second rather than its being mathematically impulsive.

References

[1]Lehman, A. F. and Besold, J., "Test Section Size Influence on Model Helicopter Rotor Performance," Oceanics, Inc., Plainview, N. Y., Rept. 70-76, (AD 724191), Aug. 1970.
[2]Summa, J. M., "Potential Flow About Impulsively Started Rotors," *Journal of Aircraft*, Vol. 13, April 1976, pp. 317-319.

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Errata

Early Detection of Fatigue Damage in Composite Materials

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THE Fig. 10 caption is correct and the correct figure is the small figure which appears just above the caption. However, immediately above the correct figure is a large logic diagram from another paper which has no connection whatsoever with this paper. The correct figure is shown below.

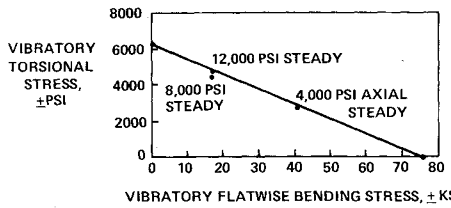

Fig. 10 Combined load fatigue diagram for graphite epoxy based on 10% torsional stiffness reduction at 10^7 cycles.

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A Wing-Jet Interaction Theory for USB Configurations

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[J. Aircraft **13**, 718-726 (1976)]

ON page 719, column 1, first paragraph, from the middle of line 4, it should read "to have less than 2% thickness." The camber term in Eq. (13) should be $\partial z_c/\partial x$. Three lines below Eq. (33), γ_j should be $\bar{\gamma}_j$. Four lines below Eq. (33), ρ_π should be ρ_j. In Eq. (41), $\bar{c}\bar{c}$ should be $\bar{c}c$. In Eq. (45), there should be an "=" in front of $[Nww]_i$. On page 723, second column, first paragraph, line 4, ρ_j should be δ_j. The footnote in Table 1 should read $C_T = 2.095$, $\eta = 80\%$. The first vector product inside the braces of Eq. (A7) should read $\boldsymbol{b}' \cdot \boldsymbol{\ell}'$. In the denominator of the last term in Eq. (A15), y_{ik} should be y_{Ik}.

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