Effect of Inflow Boundary Conditions on Hovering Tilt-Rotor Flows

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A study on the effect of inflow turbulence boundary conditions on the local flow on and around a body in flight has been carried out. The study has been carried out using OVERFLOW2 flow solver using the default Spalart-Allmaras turbulence model in OVERFLOW. Many OVERFLOW turbulent flow simulations have been reported using the SA-fv3 model[1] over the years. The present study demonstrates that the turbulence levels imposed as a boundary condition (b.c.) in the far-field as implemented in OVERFLOW are not correct. In fact, very low level of turbulence at the far-field boundary as implemented in OVERFLOW results in the SA-fv3 model predicting transition-like profiles on a given body. By choosing sufficiently high levels of the Reynolds number of turbulence, R_t, as a boundary condition, this anomalous behavior of SA-fv3 model is eliminated. Since numerous papers using OVERFLOW have been presented in the literature including that by the author[2] using low level of inflow turbulence, it will be beneficial to the CFD community at large and in particular to the OVERFLOW community to understand this effect of the inflow b.c. in the SA-fv3 model. Various results reported over the years in domains such as high-lift applications, drag prediction applications and rotorcraft flow applications can be revisited using the new turbulence inflow boundary condition prescription as suggested in this study. It has been demonstrated in the literature[3,4] that the effect of inflow turbulence level on the downstream development of flow is too important to be ignored.

Demonstrative results are shown and compared with experiment[5,6] for the case of hovering XV-15 rotor flow at a tip Reynolds number of 4.9x10^6 and Mach number of 0.69 in Figs. 1 and 2 below. Fig. 1(a,b) shows skin friction predictions at radial station of r/R = 0.28 corresponding to 5 different inflow boundary conditions obtained with the SA-fv3 model. As the inflow turbulence is increased monotonically, from a value of R_t = 0.1 to 100.0 as shown in Fig. 1, a fully developed turbulent skin friction profile is realized progressively as shown in Fig. 1(b). Similarly skin friction results shown in Fig. 2(a,b) corresponding to radial stations of r/R = 0.72 reinforce the postulate made here that as the inflow turbulence level is increased gradually, fully turbulent on-the-blade simulation is realized uniformly.

In the full paper extensive results on skin friction, pressure and velocity profiles as well as the Figure of Merit will be presented and compared with experiment that will illustrate the substantial effect of the inflow boundary conditions on the development of hovering rotor flow downstream.

1 References

[1]"http://turbmodels.larc.nasa.gov", Turbulence Modeling Resource, Langley Research Center

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[3]Kaul, U. K., "Effect of Inflow Boundary Conditions on the Turbulence Solution in Internal Flows," AIAA J., Vol. 49, No. 2, February 2011 pp 426-432

[4]Spalart, P. R. and Rumsey, C. L., "Effective Inflow Conditions for Turbulence Models in Aerodynamic Calculations," AIAA Journal, Vol. 45, No. 10, 2007, pp. 2544-2553.

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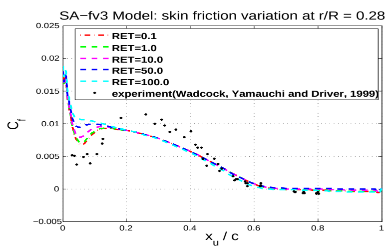
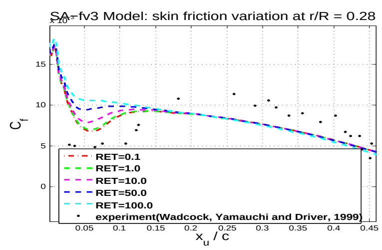
[5]Wadcock, A. J. , Yamauchi, G. K. and Driver, D. M., “Skin Friction Measurements on a Rotor in Hover,” American Helicopter Society Technical Specialists’ Meeting for Rotorcraft Acoustics and Aerodynamics, October 28-30, 1997, Williamsburg, VA.

[6]Wadcock, A. J. , Yamauchi, G. K. and Driver, D. M., “Skin Friction Measurements on a Hovering Full-Scale Tilt Rotor,” J. American Helicopter Society, October 1999, Vol. 44, No. 4, pp. 312-319.

2 Figures

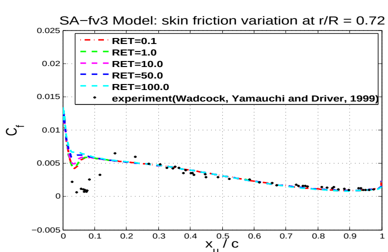


(a) Skin friction with 5 different inflow b.c.

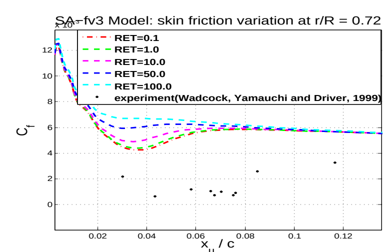


(b) enlarged view near the leading edge

Figure 1: Skin friction predictions at r/R=0.28 with SA-fv3 model



(a) Skin friction with 5 different inflow b.c.



(b) enlarged view near the leading edge

Figure 2: Skin friction predictions at r/R=0.72 with SA-fv3 model