August 14, 2021

Lift calculation in FreeWake

With the before August 2021 versions of FreeWake it can be observed that increasing the numbers of spanwise lifting lines, m, resulted in more time steps that are required for the solution to converge. Furhtermore, different numbers of lifting lines result in different lift solutions for zero-time steps. One can, however, show that a simple 2-D vortex system always yields the same lift independently of the number of vortices (even as the chordwise load distribution changes). What causes the different convergence behavior and initial lift calculations?

Ultimately the m-dependency (i.e. changes in lift convergence with respect to the number of spanwise rows) is related to the treatment of the trailing edge. In the older versions, when the D-matrix is assembled, the influnece coefficients (lower 1/3 of D-matrix) uses the influence of full DVEs of the surface, that is accounting for induction by leading and trailing edge vortex plus vortex sheet. This includes the surface DVEs that are aligned along the trailing edge. The subsequent vortex filament along the trailing edge is canceled by an opposite vortex that is aligned along the leading edge of the first post-trailing edge DVEs of the wake, thus satisfying the Kutta condition.

A consequence of the described trailing edge treatment is , however, that without a wake, for example at time step zero, the subsequent chordial circulation distribution is symmetrical about the wing's midchord and requires a fair number of iterations/time steps to converge to the final solution.

The easiest way to improve the convergence behavior I rewrote the code (more details later). Specifically, when calculating the D-matrix in the updated version, the influence of the surface DVEs that are located along the trailing edge, only consists of their leading edge vortex and the vortex sheet. Obviously, this also required the change of the wake influence calculation by no longer including the influence of the leading edge vortex of the first post-trailing edge row.

At least for planar wings with fixed, drag-free wakes, this yields the correct lift already right after solving the equaiton system at the zeroth-time step. For nonplanar systems and relaxed, the lift convergence behavior is greatly improved as well as well induced drag seems to converge faster as well.

The changs that were made to the code are limited to three locations:

1. When computing the influence coefficients of the lower 1/3 of the D-matrix: The treatment of the surface DVEs that are located along the wing's trailing edge no longer included the DVEs' trailing egde vortices.
2. When computing the induced velocities of the wake: the treatment of the wake DVEs directly aft of the wing's trailing edge no longer inlcudes the DVEs' leading edge vortices.

3. When comptuing the induced velocities of the lifting surfaces: the treatment of the surface DVEs that are located along the trailing edge no longer includes the DVEs' trailing vortices (similar to 1.).

The changes are relatively minor but improve the convergency of the calculations significantly. In the past we were luckky enough that we ususally limited our number of spanwise DVE rows on a lifting surface to one to three rows, which usually converged quite fast. Now, even larger numbers, for example m=100, lift converges essentiallyimmediately (for planar wings and wakes).

Please let me know your thoughts and questions. Thanks and cheers

Goetz