APPLICATION BRIEFS FROM FLUENT

EX211

Flapping Wing Flight

The dynamic mesh model in FLUENT 6.1 is used in this example to simulate the unsteady three-dimensional flow around a fly in flight. A real fly geometry is used, and wing kinematics data is approximated from documented high speed video shots from a real fly in a wind tunnel. The simulation shows effects like delayed stall, rotational circulation, and wake capture that are created by the fly by rotating and tilting its wings in a very complex manner.

Insect flight is one of the most interesting and challenging research subjects in the field of bio-locomotion and modern aerodynamics. The flow around the flapping wings of insects is highly unsteady and involves vortex generation and shedding. In addition to biologists [Ref. 1, 2], engineers are interested in understanding this very complex way of flying in order to build micro-aircraft that use tiny flapping wings to overcome gravity and maneuver with the versatility of insects.

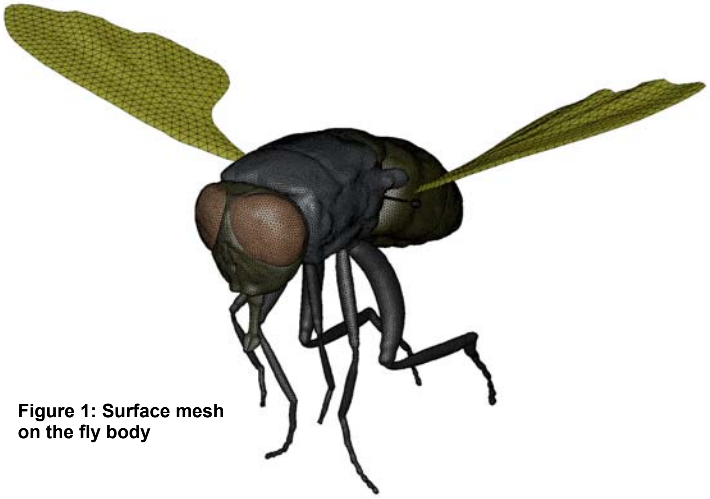

Figure 1: Surface mesh on the fly body

The transient flow around the flapping wings of a fly has been simulated using FLUENT. The fly geometry (in stereo-lithography, or STL format) was imported into GAMBIT, where a surface mesh (Figure 1) was created. With the help of TGrid, a hybrid volume mesh of 600,000 cells was created. All body parts are contiguous in the model, with the exception of the wings, which are displaced from the body by a small amount.

The dynamic mesh model was used to simulate the wing motion of an actual fly, which was adopted from literature data [Ref. 3] and applied as a time-varying boundary condition via a user-defined function (UDF). The wing itself was idealized to be a rigid body with one fixed point at the joint of the wing, around which the wing was rotated. The rotation vector was varied in size and direction over the duration of the flapping cycle. The prescribed motion, in the form of angle of attack vs. time, is shown on the left in Figure 2. The corresponding wing tip path as seen from the side of the fly is shown at right in the figure. The fly makes 125 wing flaps per second, so each cycle takes 8ms. To capture the detailed motion, a time-step of 5μs was used, and dynamic remeshing was performed at every time step. The insect was assumed to fly in laminar conditions in a forward direction at a speed of 2.75 m/s, so a constant velocity

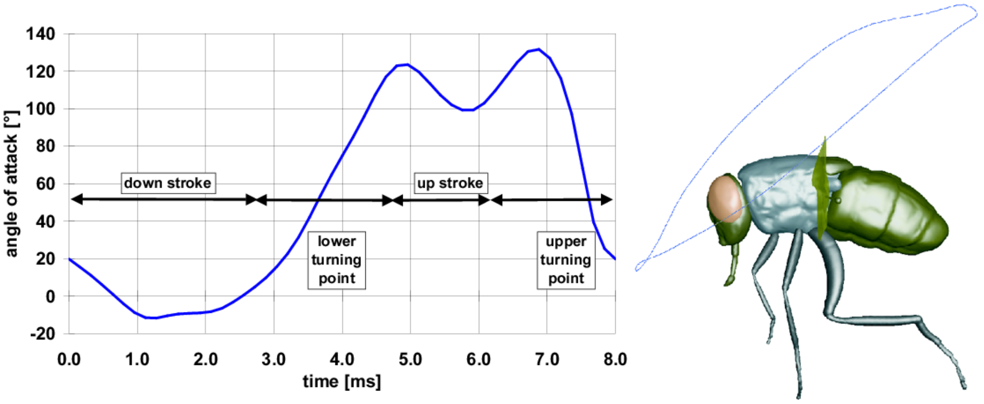

Figure 2: Wing kinematics

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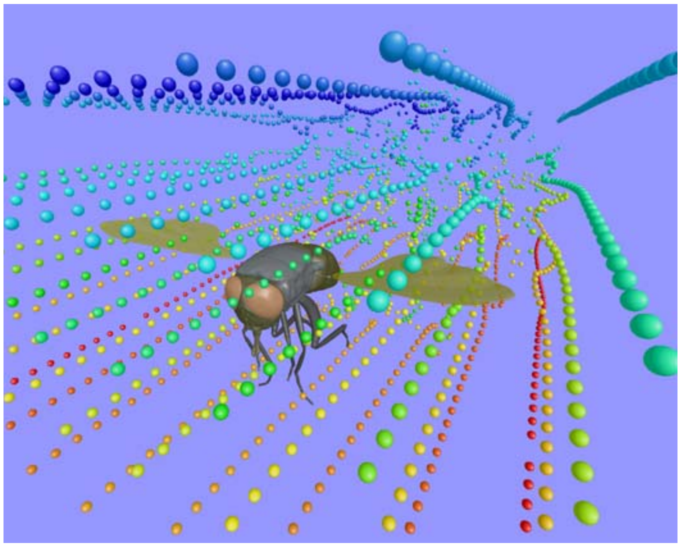

Figure 3: Particle tracks, used to illustrate the air flow

was applied to the inlet boundary upstream of the fly in the model. To keep the dynamic mesh domain as small as possible (about 100,000 tetrahedral cells) only the region covered by the moving wing, plus some space for the mesh deformation, was included.

Particle tracks are used in Figure 3 to illustrate the air disturbances caused by the flapping wings at one point during the cycle. The formation of vortices behind the wings was also predicted by the transient simulations. Shedding of these vortices occurs during the quick rotation of the wings at the top and bottom extremes of the stroke, as is shown in Figure 4. Other unsteady effects like delayed stall and wake capture were visible during the cycle as well. The pressure distribution on the underside of the wings is shown in Figure 5. Using these results and the pressure distribution on the top of the wings, the unsteady lift and drag coefficients were calculated throughout the cycle.

In summary, the simulation has shown that with the dynamic mesh model, it is possible to simulate the three-dimensional flow around flapping wings to better understand the unsteady aerodynamics of insects, and to contribute to the development of micro-aircraft. The dynamic mesh model can also be used to examine critical flight situations for fixed-wing aircraft, like the undercarriage lowering at low air speed, or the movement of swept wings on fighter jets at high air speed. Expanding beyond flight applications, the model can also be used for simulations of moving heart valves in the biomedical area, or small flapping membrane valves in micro-technology.

References:

1. C.P. Ellington, Phil. Trans. R. Soc. Lond. **B305**, p. 1-181 (1984).

2. M.H. Dickinson, F.-O. Lehmann, and S.P. Sane, Science **284**, p. 1954-1960 (1999).

3. W. Nachtigall, Dipterenflug. In: Biona-Report **11**, Biology and Related Natural Sciences, p. 115-156, Fischer Verlag (1997).

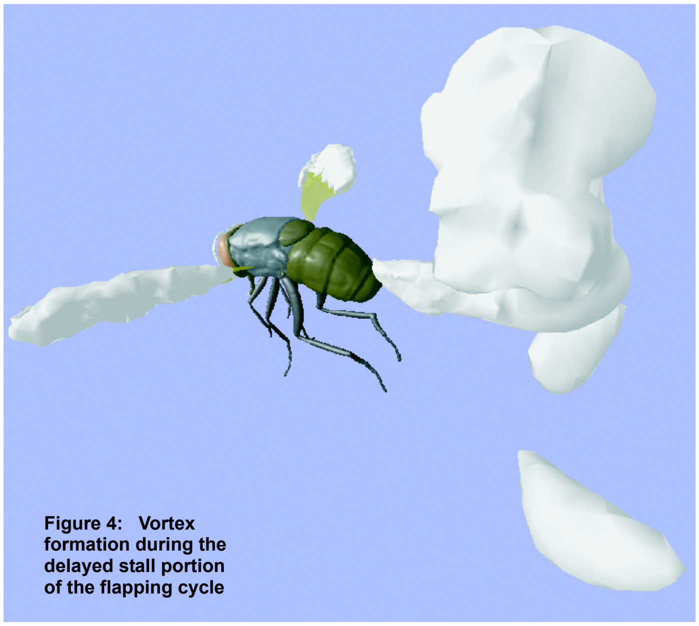

Figure 4: Vortex formation during the delayed stall portion of the flapping cycle

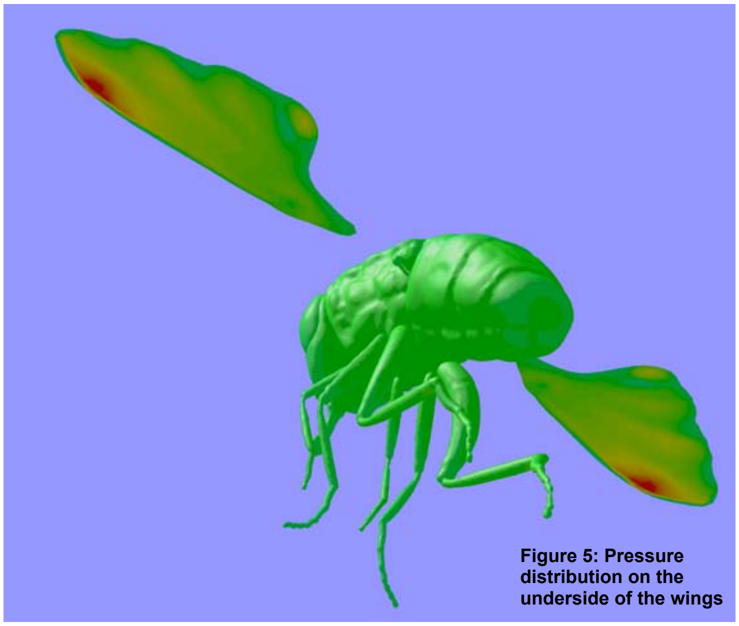

Figure 5: Pressure distribution on the underside of the wings

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