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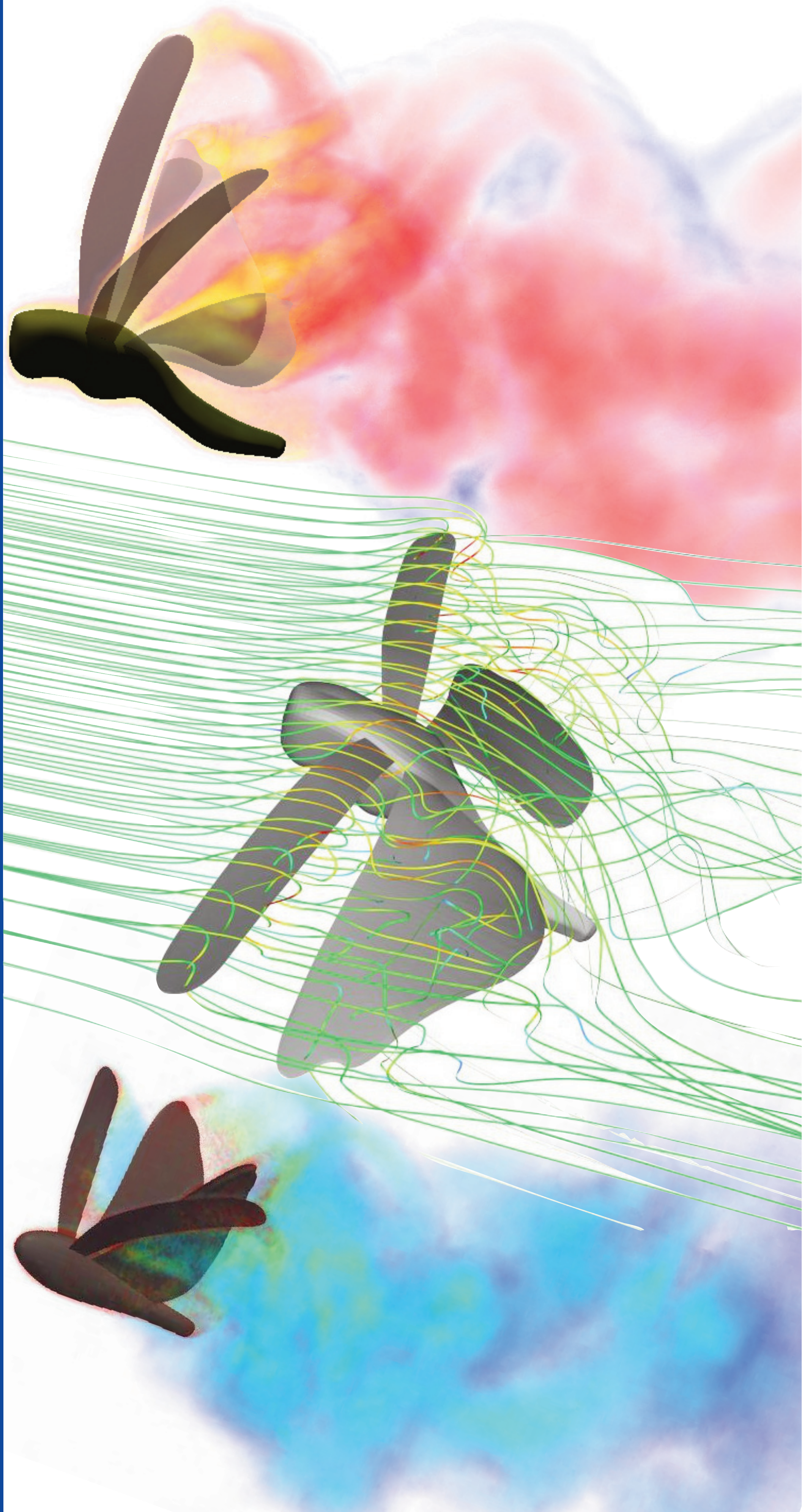

Bulletin for The International Association for Computational Mechanics

Nº 32
December 2012

Flapping-Wing Aerodynamics of an Actual Locust

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Flapping-wing aerodynamics is a class of problems that the Team for Advanced Flow Simulation and Modeling (T★AFSM) <www.tafsm.org> <www.jp.tafsm.org> has been focusing on in recent years (see [1-3]). The wing motion and deformation data is from an actual locust, extracted from high-speed, multi-camera video recordings of the locust in a wind tunnel at Baylor College of Medicine (BCM) in Houston *(figure 1)*.

We have two objectives in this computational mechanics research. The first one is computer modeling and analysis and a good understanding of the flapping-wing aerodynamics of a locust, which one assumes has good flight skills coming from thousands of years of evolution. The second one is using what we learn from the locust flight in designing flapping wings for a micro aerial vehicle (MAV).

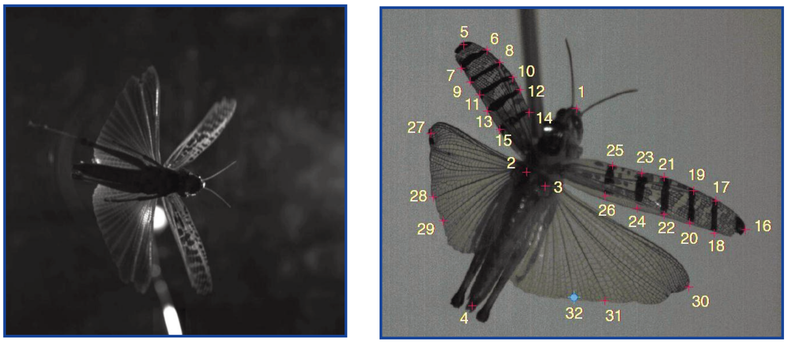


Figure 1:
Wing motion and deformation data is extracted from video recordings of a locust in a wind tunnel, with a large number of tracking points marked on the wings.
Left: *locust in a wind tunnel at BCM.*
Right: *tracking points in the video data set. Pictures courtesy of Fabrizio Gabbiani and Raymond Chan (BCM)*

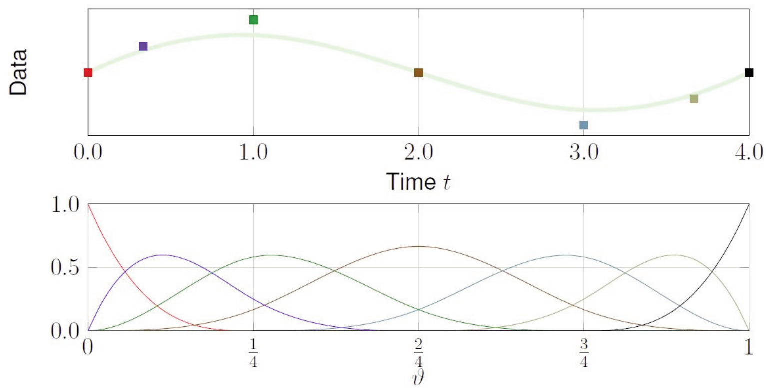


Figure 2:
Temporal NURBS basis functions are used in representing the motion and deformation data for the locust wings.
Top: *data and temporal-control variables.*
Bottom: *basis functions corresponding to the control variables in the parametric space. For details, see [1, 2]*

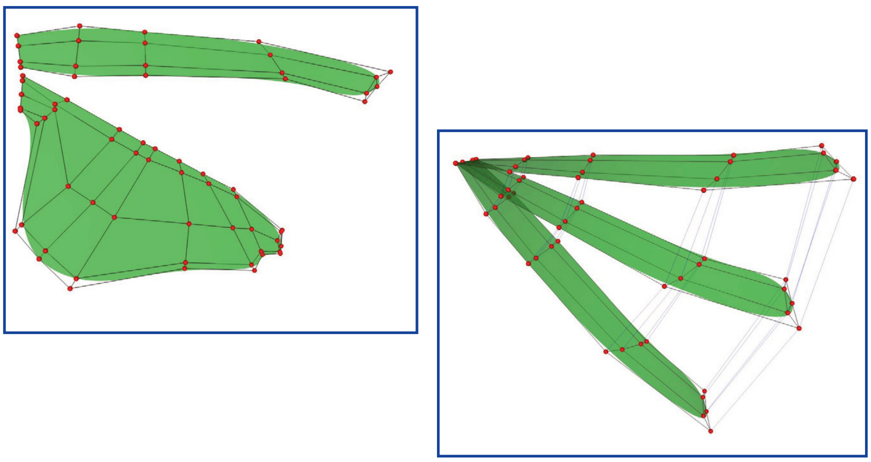
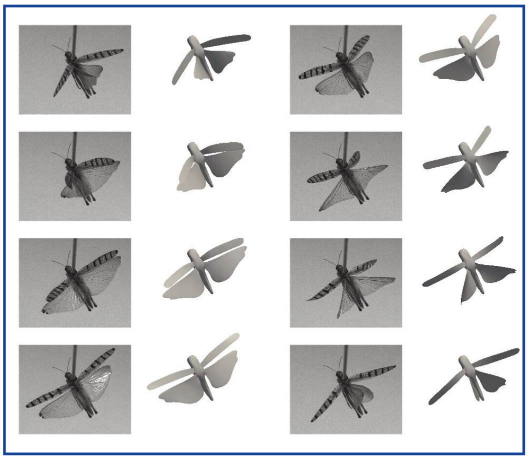


Figure 3:
Left: *forewing (FW) and hindwing (HW) surfaces represented by NURBS and the control points.*
Right: *FW control mesh and corresponding surface at three temporal-control points. This process gives us a NURBS-represented data set in both space and time for each wing. For details on how the time histories of the tracking points from the video recordings are converted to spatial and temporal representations with NURBS basis functions, see [1, 2]*



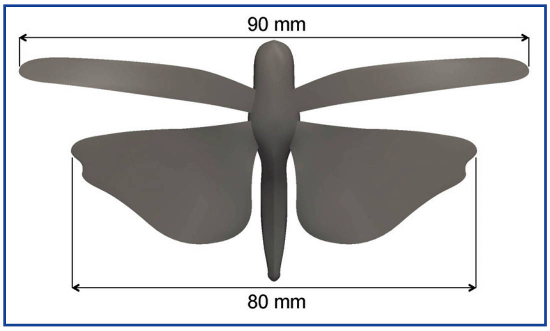


Figure 5:
Length scales involved in the model used in the computations

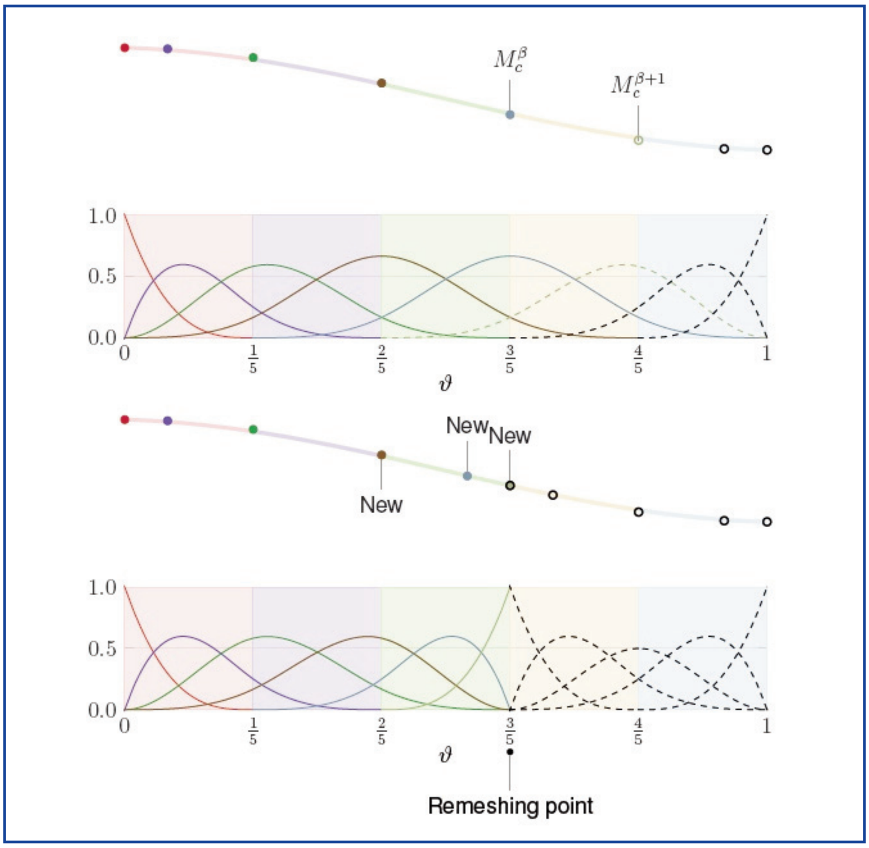
Figure 4:
Comparison of computational model and wind tunnel pictures at eight points in time.
Viewing angles are matched approximately.
Wind tunnel pictures courtesy of Gabbiani and Chan

The core computational technology used is the Deforming-Spatial-Domain/Stabilized Space–Time (DSD/SST) formulation [4, 5], specifically, a new DSD/SST version [6, 7] derived in connection with the residual-based variational multiscale (VMS) method [8, 9]. This new version is called "DSD/SST-VMST." We also use a number of special space–time techniques [1-3] targeting flapping-wing aerodynamics. In the space–time flow computations, we use NURBS basis functions [10] for the temporal representation of the motion and deformation of the locust wings (*figure 2*). This is in addition to using NURBS basis functions for the spatial representation of the wings (*figure 3*). Converting the time histories of the tracking points from the video recordings to spatial and temporal representations with NURBS basis functions is a fairly complex process, with a number of projections in space and time, explained in detail in [1, 2].

Prescribing an accurate wing motion and deformation is important in achieving an accurate flow computation. For that reason, before we start the computation, we compare the wing motion and deformation in our model to the pictures recorded in the wind tunnel (*figure 4*). The length scales involved in the computations are shown in *figure 5*. The air speed is 2.4 m/s, which represents the average wind tunnel speed used in the video recordings. The Reynolds number, based on the air speed and the FW span of 90 mm, is 1.48 x 10^4. The flapping period is 0.047 s.

We use temporal NURBS basis functions also in representation of the motion of the volume meshes computed and in remeshing (i.e., in generating new set of nodes and elements). Given the surface mesh,

Figure 6:
Mesh motion and remeshing using temporal NURBS basis functions. Meshes computed with the mesh moving method introduced in [11] serve as temporal-control points, with longer time in between. Mesh-related information, such as the coordinates and their time derivatives, can be obtained from the temporal representation whenever needed. When we need to remesh, we do that by multiple knot insertions where we want to remesh, making that point in time a patch boundary. For more details, see [1, 2].



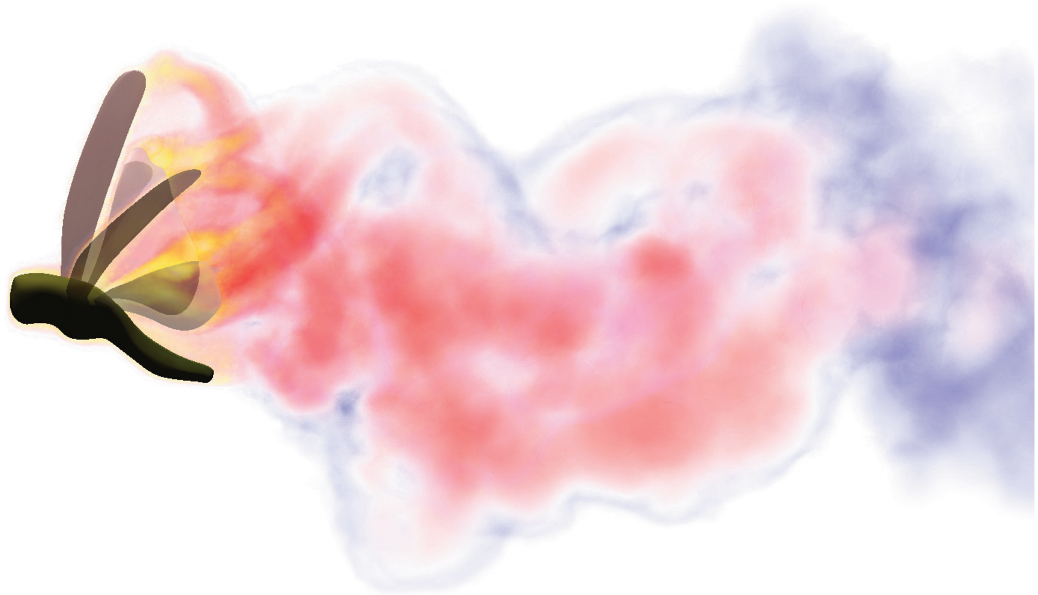
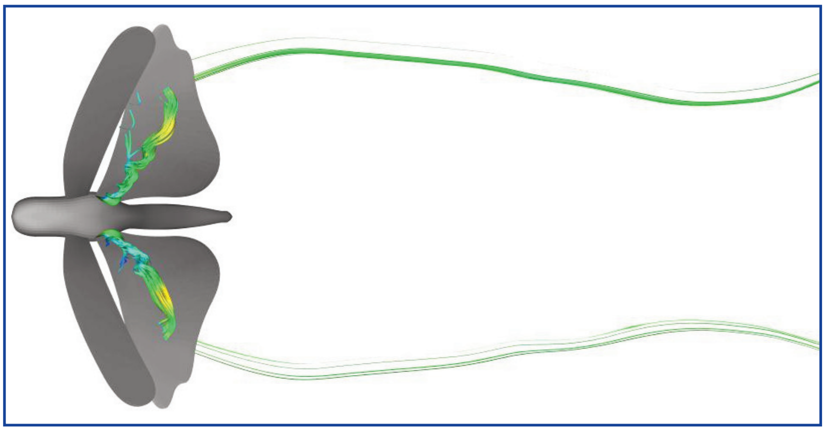


Figure 7:
Vorticity magnitude at an instant during the flapping cycle

we compute the volume mesh using the mesh moving technique we have been using [11]. Here, we apply this technique to computing the meshes that serve as temporal-control points. This allows us to do mesh computations with longer time in between but get the mesh-related information, such as the coordinates and their time derivatives, from the temporal representation whenever we need. Obviously this also reduces the storage amount and access associated with the meshes. The concept of using temporal NURBS basis functions in mesh motion and remeshing is illustrated in *figure 6*. More details can be found in [1, 2].



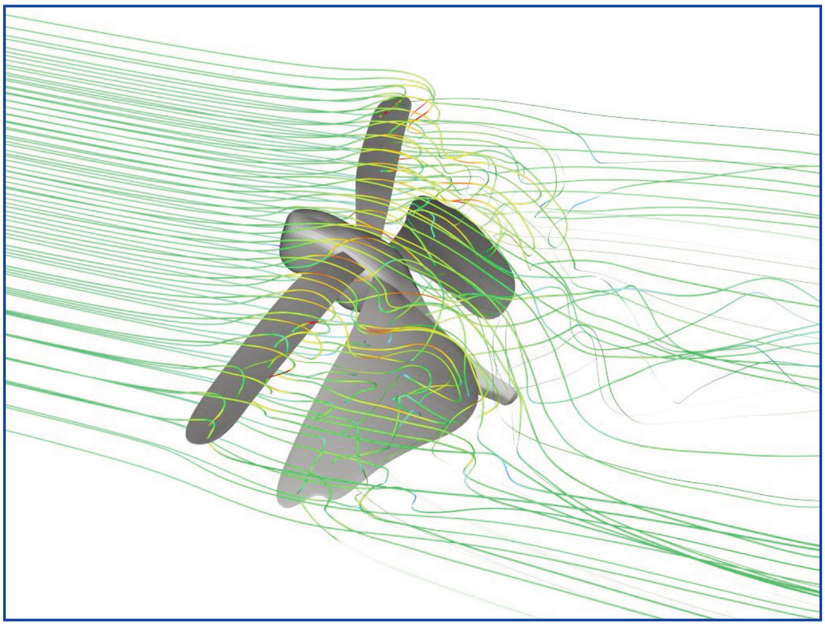


Figure 8:
*Streamlines colored by velocity magnitude at approximately 25% **(top)** and 50% **(bottom)** of the flapping cycle. The vortex structure on the HW is highlighted at top*

Figure 7 shows the vorticity magnitude at an instant during the flapping cycle, and *figure 8* shows the streamlines at two instants.

We use this set of techniques in computation of the bio-inspired flapping-wing aerodynamics of an MAV. The MAV body was inspired by the current unmanned aerial vehicle (UAV) designs. The wing shapes, motion and deformation are from the locust, with some changes in the way the HWs are attached to the body (*figure 9*). The flight conditions are the same as those for the locust. *Figure 10* shows the vorticity magnitude at two instants during the flapping cycle.

This article shows that the core and special space–time methods we have developed can be very effective in modeling flapping-wing aerodynamics of an actual locust, and what we learn from that can be used in designing bio-inspired flapping wings for an MAV. The core and special techniques used can be found in [4-7, 1, 2, 12]. The readers can also find material on this subject, and some movies, at our Web sites <www.tafsm.org> <www.jp.tafsm.org>.
Research was supported in part by NSF. Method development and evaluation components of the work were supported in part by ARO (second author) and Rice–Waseda research agreement (first author). We

thank Fabrizio Gabbiani and Raymond Chan (BCM) for providing us the the wind tunnel data. Several members of the T★AFSM contributed to this research; they are the coauthors of the cited articles [1-3]. ●

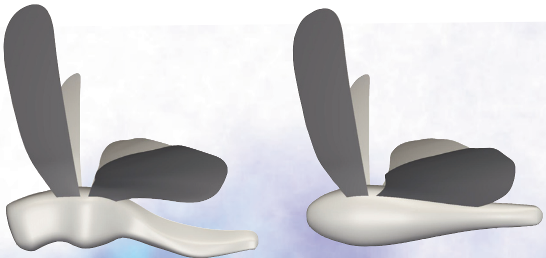


Figure 9: *Body and wings for the locust (left) and MAV (right)*

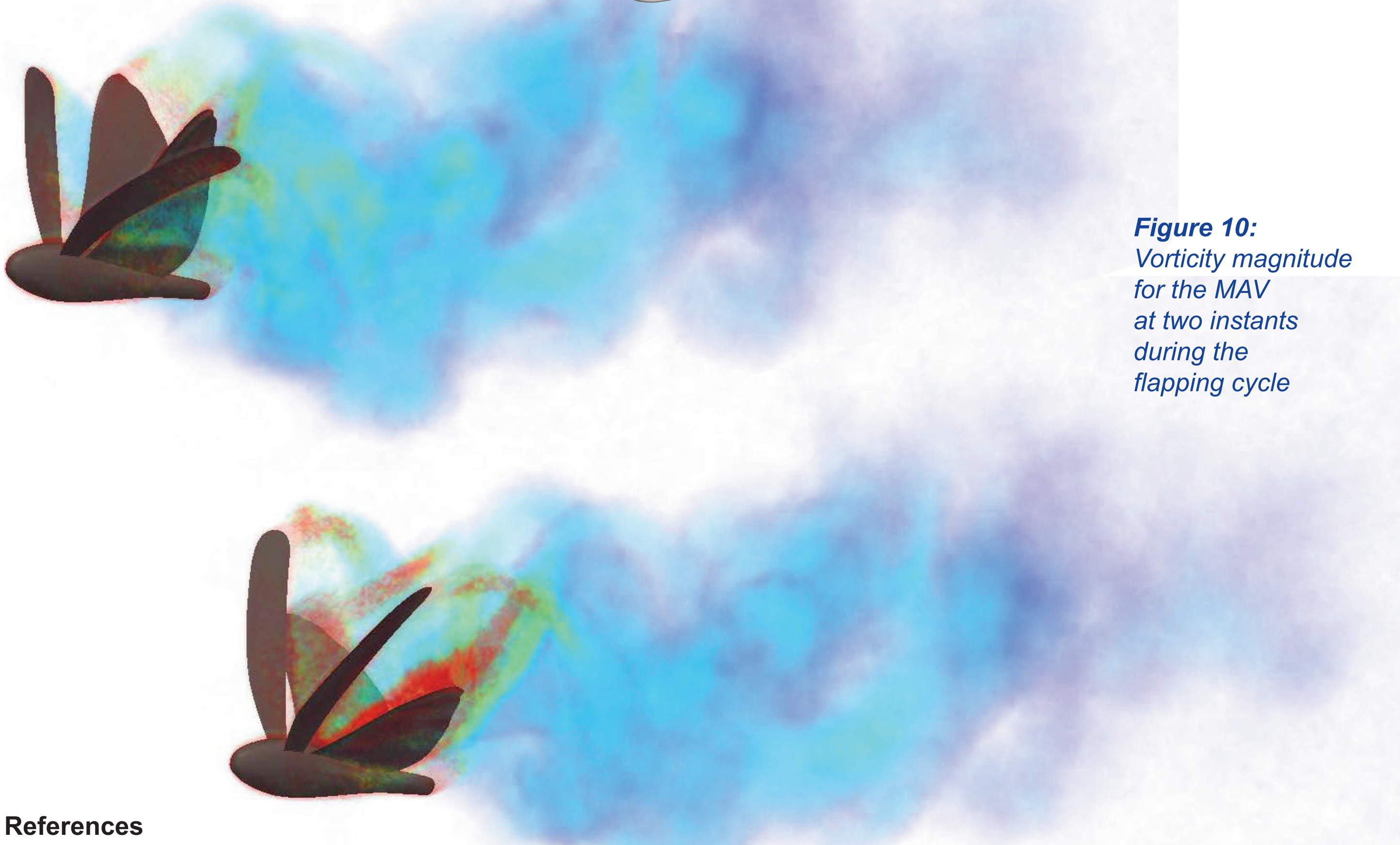


Figure 10: *Vorticity magnitude for the MAV at two instants during the flapping cycle*

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