On Tiny Insects and Investigating Passive Dispersal

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Outline

Insect Flight

- Winged insects exist in essentially all terrestrial ecosystems.
- Winged insects incredibly diverse; over one million species described.
- Taxonomic diversity $\rightarrow$ morphological diversity.

Wings Adapted

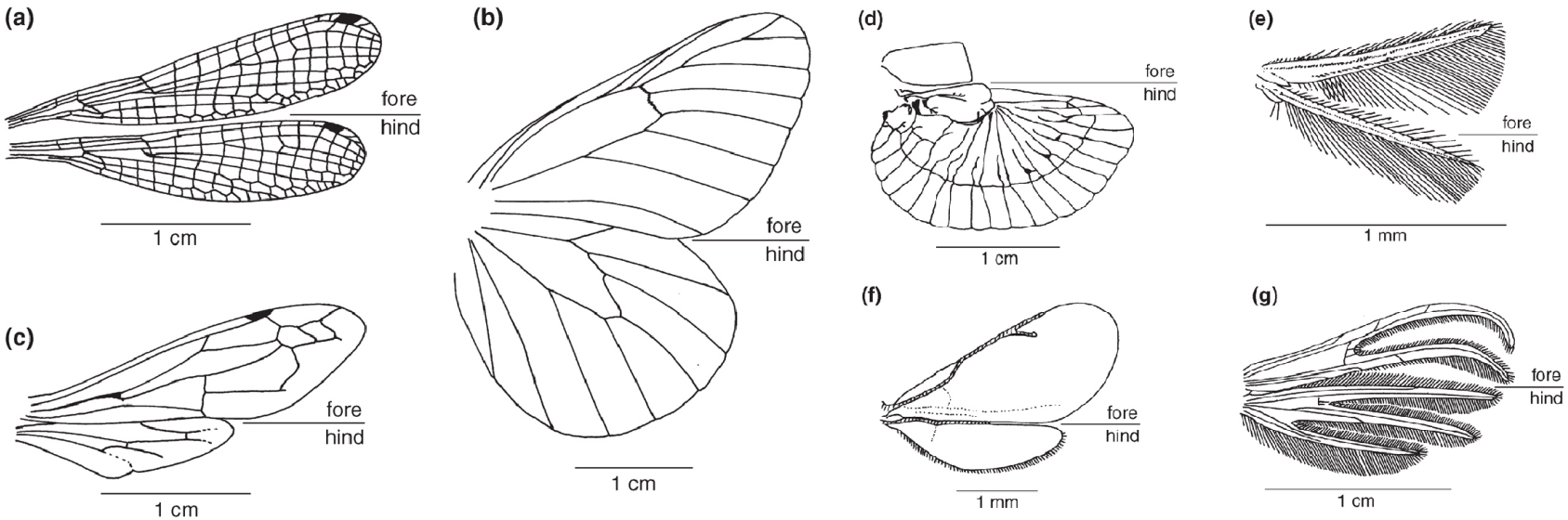


Figure: Different wing morphologies, after Chapman.

Thrips (Thysanoptera)

- Thrips are an order of very small (1.5 mm and less) flying insects.
- Many species are pests, but some are predatory on mites or other species of thrips.
- Some species eusocial, but not all.

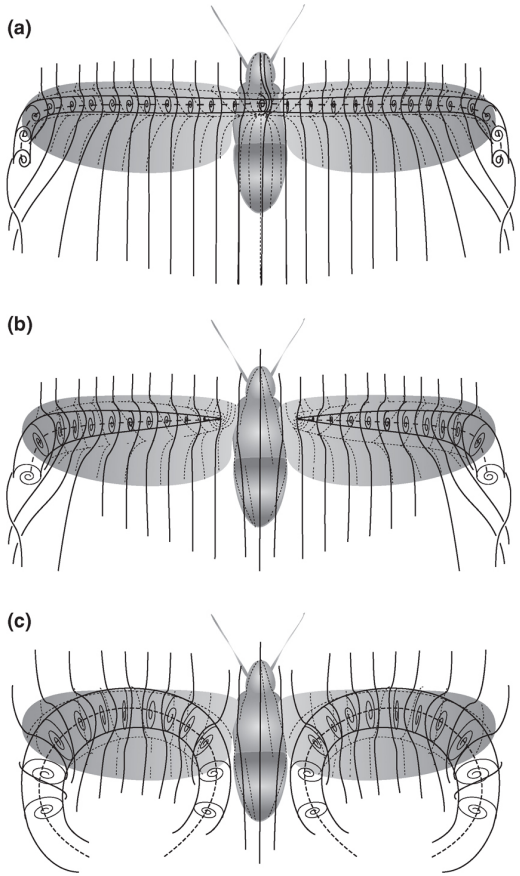
Active Flight

Leading Edge Vertex

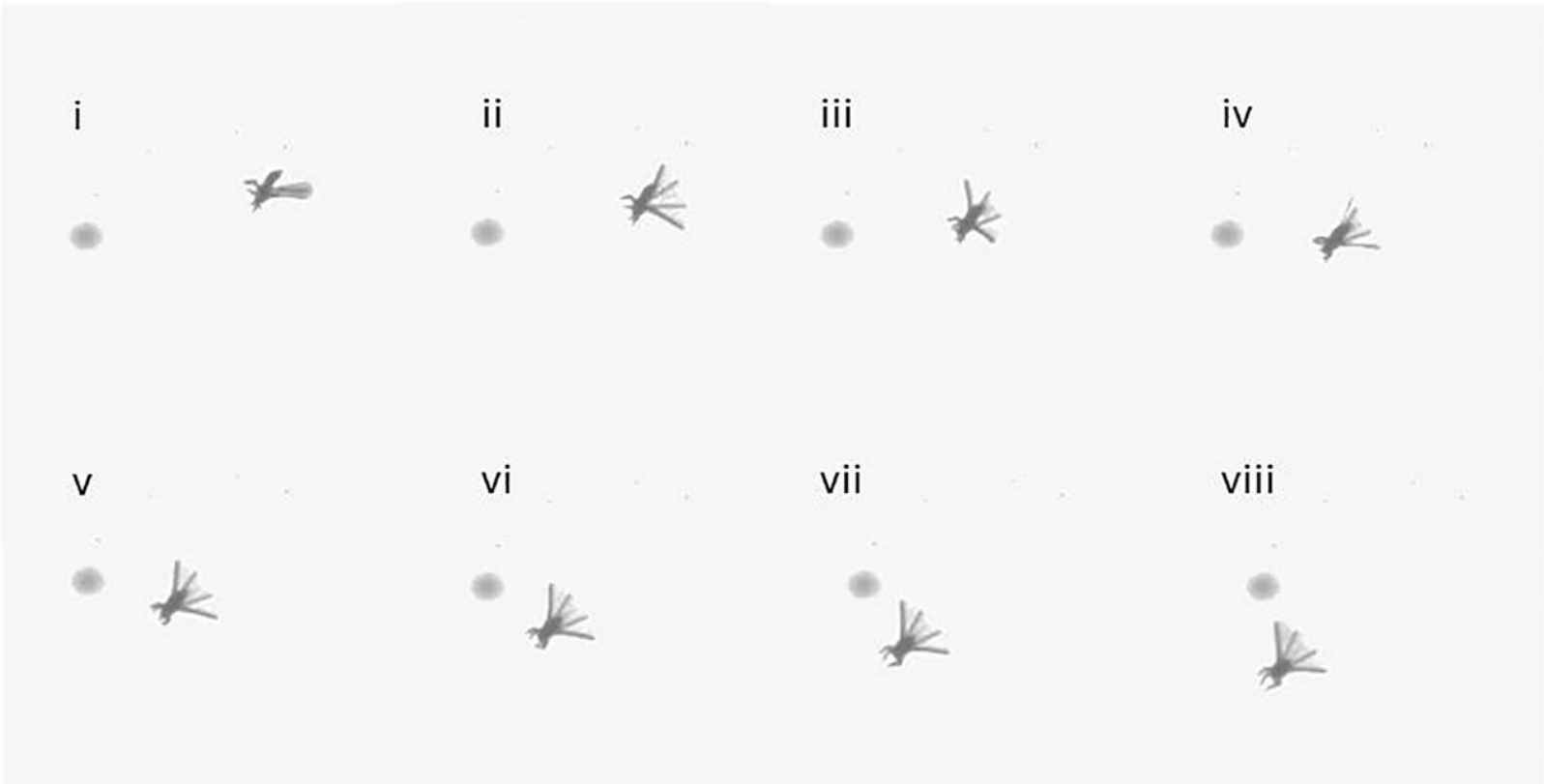
- Most common mechanism.
- Creates leading edge vortex (cf. fig)

Clap-and-Fling

- More common in tiny insects.
- Consists of two parts: clap and fling.



Passive Flight

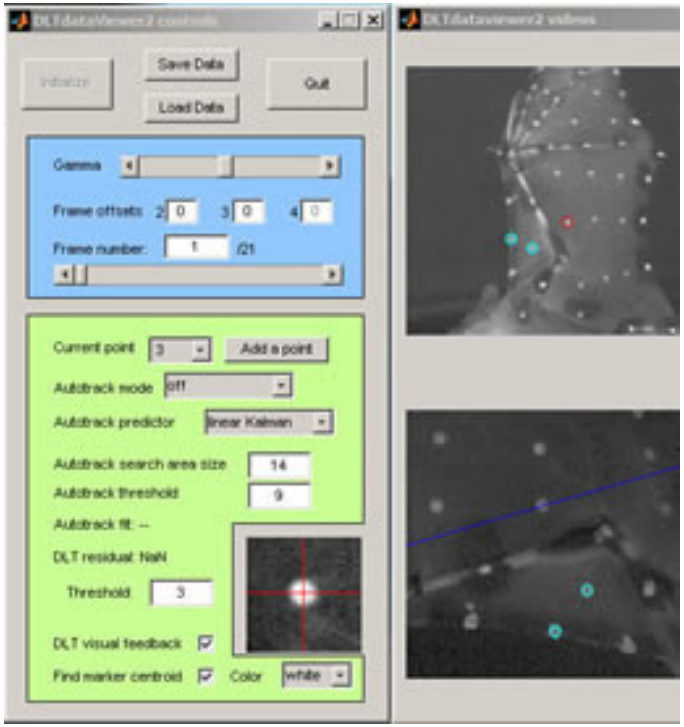


Why is this a Cool Problem...?

- Insect flight research is challenging.
- Passive flight in particular is less studied.
- Passive flight aerodynamics can hold important information for long distance dispersal.
- Interdisciplinary appeal: ecology, mechanics, numerical methods.

Extracting Data from Footage

- Manually tracked insect motion using DLTdv.
- Reconstruct position and velocity in space.
- Very undergrad friendly job.



Navier Stokes Equation

Newton's Second Law:

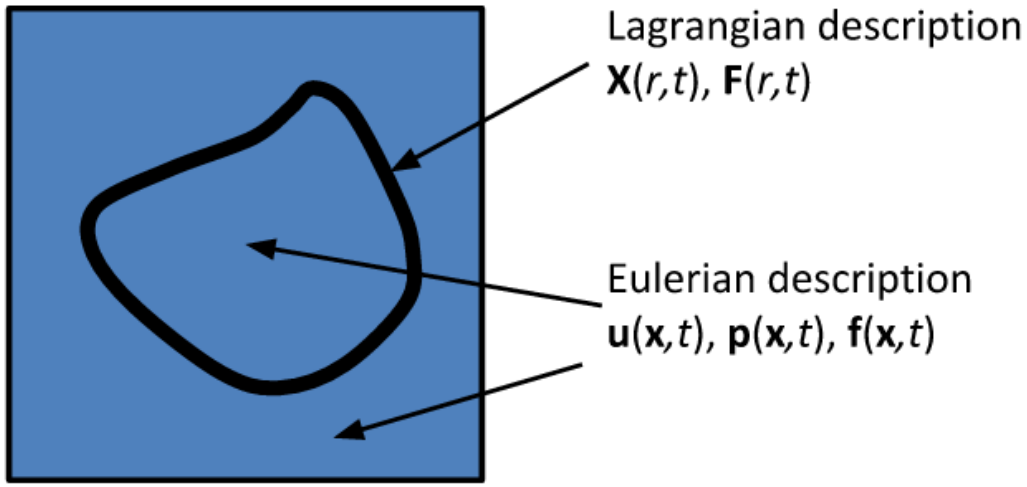
$$\underbrace{\rho}_{\text{mass}} \underbrace{\left(\frac{\partial \mathbf{u}}{\partial t} + \mathbf{u} \cdot \nabla \mathbf{u}\right)}_{\text{acceleration}} = -\nabla \mathbf{p} + \mu \nabla^2 \mathbf{u} + \mathbf{f}$$

Incompressibility condition:

$$\nabla \cdot \mathbf{u} = 0.$$

Immersed Boundary Method

- Eulerian equations on Cartesian grid used to solve for velocity and pressure.
- Lagrangian equations on curvilinear mesh used to solve for force density and position.



IB Software

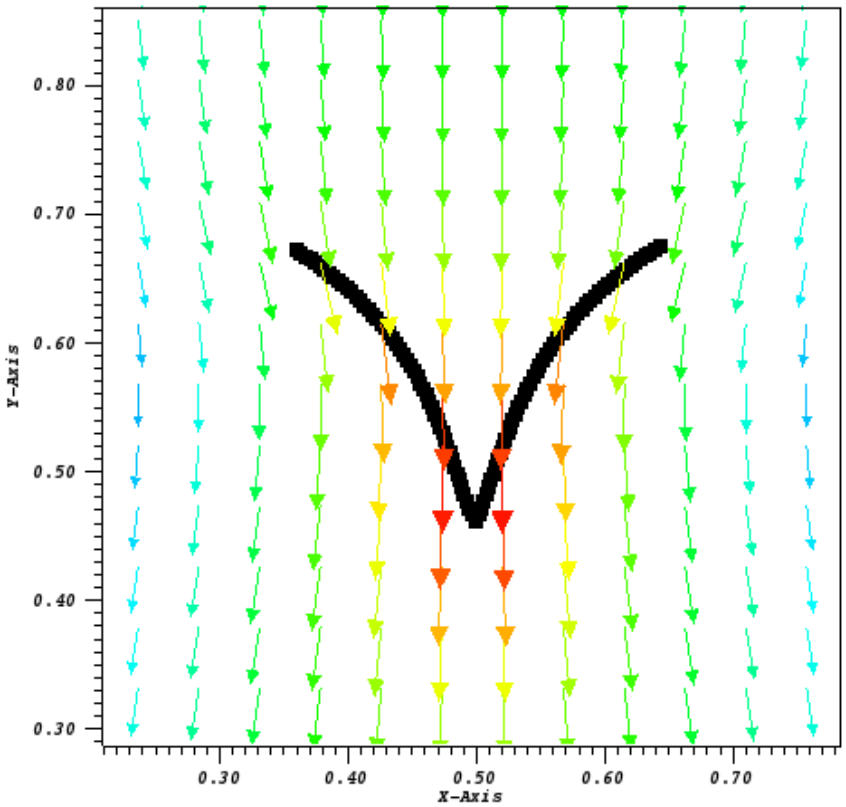
IBAMR

- Optimized C++ and parallelized code.
- Adaptive mesh refinement.
- Very fast, good for high resolution.
- Can run 2D/3D simulations.
- Module avialable on killdevil.

IB2d

- Matlab/Python versions available.
- Fixed Mesh size.
- Runs locally.
- Get preliminary (low-res) data.
- Implements porous points.

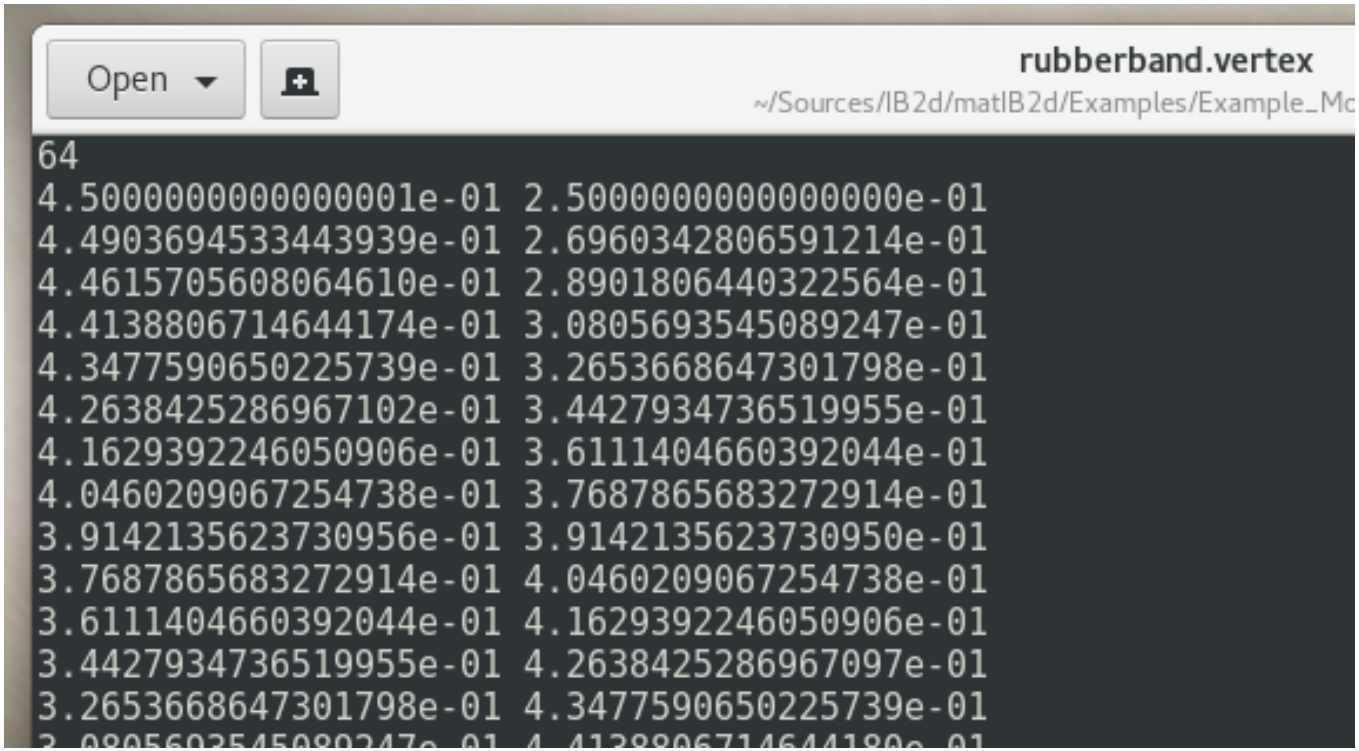
IB2d Simulations



- simulations with IB2d
- varied porosity values
- compared velocities

Creating Geometries for Simulations

IB2d and IBAMR use `.vertex` files to store the initial coordinates of points on curvilinear mesh.



How are Geometries Created?

- Old method: find a function that resembles the geometry of interest, and sample accordingly.
- Problem: need to find functions that resemble geometry, requires scripting, slow.

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- Problem: need to find functions that resemble geometry, requires scripting, slow.
- Wouldn't it be great if we didn't have to do this manually?

Introducing MeshmerizeMe

- MeshmerizeMe is part of tool-chain being developed by the Miller lab.
- It utilizes SVG files and input parameters from IB2d to automatically create the vertex file.

Why Bézier Curves?

Bézier curves are family of interpolating polynomials. An nth degree Bézier curve in $\mathbb{R}$ is mathematically described by

$$\gamma(t) = \sum_{i=0}^{n} b_{i,n}(t) P_i$$

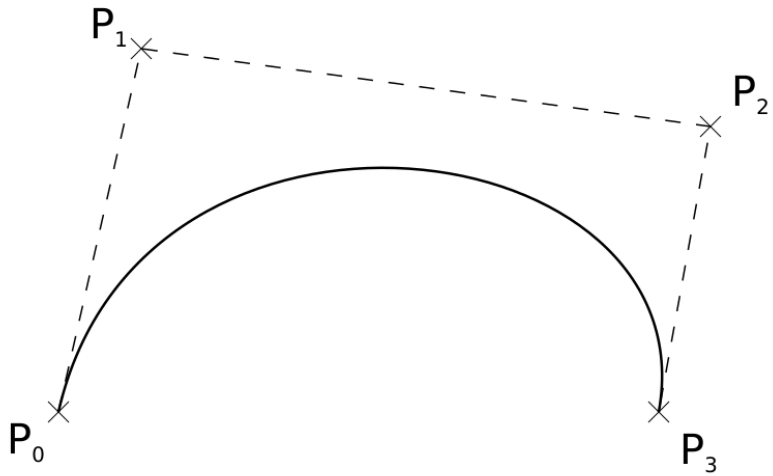
where the P_i are the control points and $b_{i,n}(t)$ are Bernstein basis polynomials given by

$$b_{i,n}(t) = \binom{n}{i} t^i (1-t)^{n-i}.$$

Why Bézier Curves?

Lots of useful properties:

- affinely invariant
- smoothness
- curve defined by control points
- easily manipulated



Where do the SVG files come from?

SVG files are XML documents. Aside from hand-coding them, they can be generated by vector graphics software such as Adobe Illustrator or Inkscape.
We are also developing a tool that can generate the SVG files automatically from images by using edge-detection algorithms.

Summary

- Thrips provide an interesting fluid-structure interaction problem.
- Thrips provide an interesting biological problem.
- Some initial simulations suggest fringed wings resist air flow as though they were solid.
- MeshmerizeMe is a tool to aid in creation of geometries for use with IB2d.

Future Work

- Re-run 2D simulations with beams added.
- Run 3D simulations in IBAMR with solid wings.
- Finish first release of MeshmerizeMe.

Thanks

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