Fly on a Wall: A Combined Experimental-Computational Study of the Aero and Body Dynamics of Landing in a Fruit Fly

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I. Introduction

While flying insects can perform a dazzling variety of flight maneuvers, one maneuver that continues to confound is the ability of a fly to land upside-down on a ceiling. An understanding of this maneuver:

- would assist biologists studying insect flight dynamics.
- has practical significance for designers of micro-aerial vehicles (MAV).

MAVs are being designed for a variety of missions including environmental monitoring, search-and-rescue, and reconnaissance. There is much that can be learned from insects because evolution has created an incredible variety of flying insects that have successfully colonized almost all known terrestrial habitats. One area where MAVs are lacking is maneuverability during landing; for example, a MAV may need to land during a mission because it needs to recharge, and it may need to land upside-down to take pictures during a reconnaissance mission.

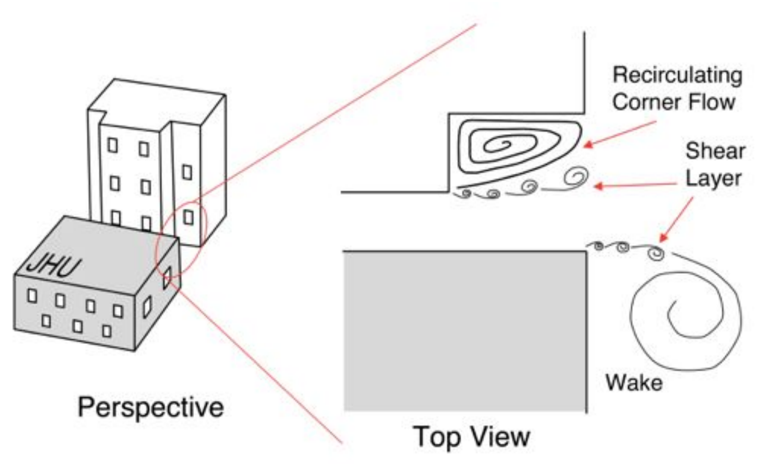

Fig. 1a. MAVs will have to operate in complex urban environments

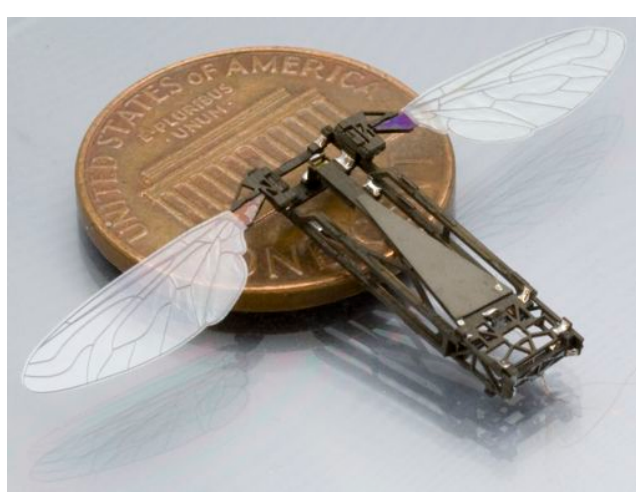

Fig. 1b. Example of an insect-inspired flapping-wing MAV under development at Harvard [1]

II. Methods

The fruit fly chosen for this research is the *Drosophila virilis*. The fruit flies fly inside the main glass chamber – three synchronized high-speed cameras are pointed at the glass ceiling, and are used to capture videos of the fruit flies' landings. A small region on the glass ceiling is marked to indicate the region of focus of the cameras. The three cameras are calibrated in three dimensions with a rig that is photographed at the end of each recording session.

Fig. 2. Calibration rig used for defining the spatial coordinates in the glass tanks for analysis with the Direct Linear Transformation (DLT) algorithm

Because the flapping frequency of the fruit flies is about 250 Hz, a recording frame rate of 3000 frames per second is used. Many difficulties were encountered while recording the fruit flies:

1. Insect size.
The fruit flies are very small (width ≈ 3-4 mm). Thus, the cameras are focused on a very small region in the tank; honey and rotten fruit are used to attract the flies. There is a very low probability that a fly will land in the region of focus.

2. Exposure requirements for video.
Due to the high flapping frequencies of the fruit fly, there are strict exposure requirements for a well exposed sequence of images. The chamber is illuminated intensely with multiple halogen lamps; however, due to the large amount of heat emitted, there is a limit to the number of lamps that can be used. Thus, there is a balance between the time the shutter must be open (shutter speed) and the size of the aperture (controls depth-of-field, or D.O.F.).

$$[Exposure] = [Shutter\ Speed] + [D.O.F.]$$

Balance between motion blur and depth blur

In order to capture a sharp image at each frame and to have a sufficient depth of the tank in focus, the optimal exposure was determined to be:

$$Exposure\ Used \Rightarrow \begin{array}{l} Frame\ Rate = 3000\ fps \\ Shutter\ Speed = 150\ \mu s \\ Aperture = f/8\ or\ f/11 \end{array}$$

III. Videogrammetry Setup

Two videogrammetry setups were used for recording.

1. Tank horizontal, cameras tilted towards the ceiling
2. Cameras horizontal, tank tilted

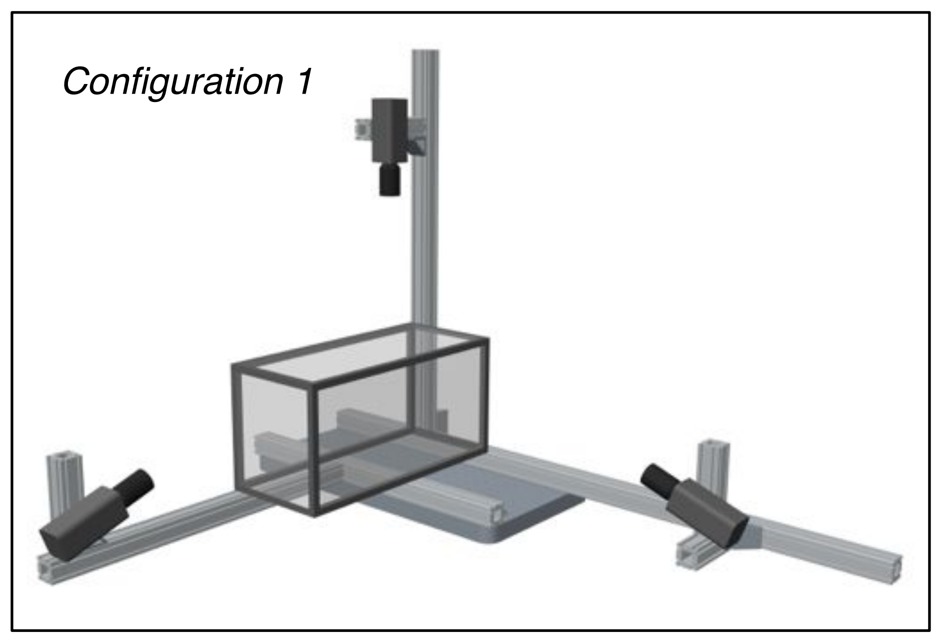

Fig. 3a. The tank is placed horizontally with respect to the lab, and the front and side cameras are fastened to the rig such that they are oriented towards the ceiling of the tank.

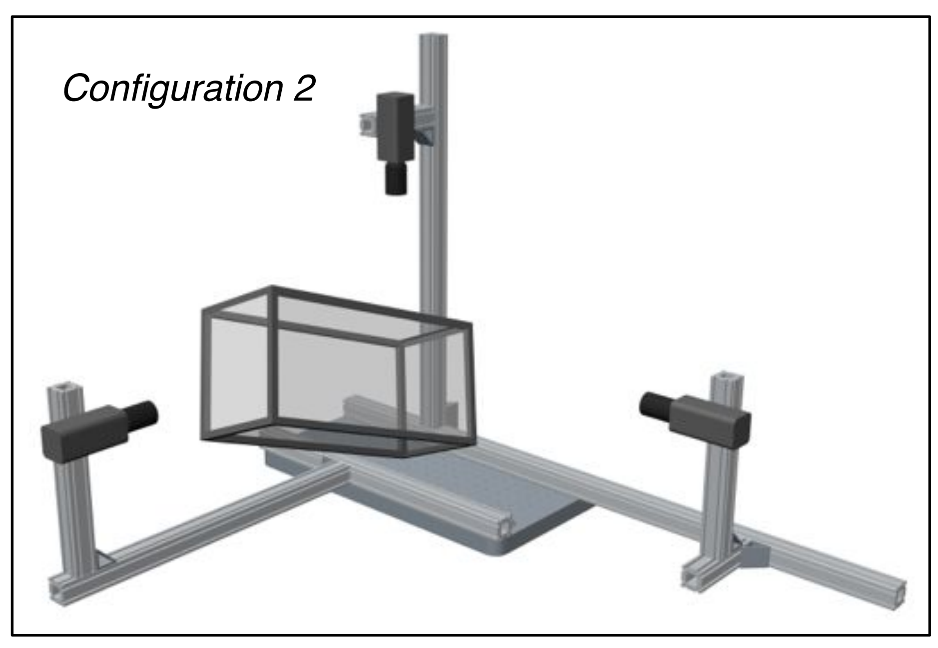

Fig. 3b. The three cameras are fastened such that they are orthogonal to one another. The tank is secured such that the cameras are all oriented towards the slanted ceiling of the tank (supports attached to the tank are not shown in the model for clarity).

IV. Discussion

For each video acquired, the *(x, y, z)* coordinates of the fly's center-of-mass are tracked during a landing maneuver. The tangential velocity of the insect, and thus its linear momentum, can then be estimated. The two hypotheses describing how a fly lands upside-down after its front legs have grabbed the ceiling are:

1. Using its wings to accelerate its body upside-down.
This would be characterized by a sudden increase and a subsequent decrease in tangential velocity, indicating a generation of aerodynamic forces.

2. Using its linear momentum to flip itself around.
This would be characterized by a gradual decrease in tangential velocity during the landing maneuver.

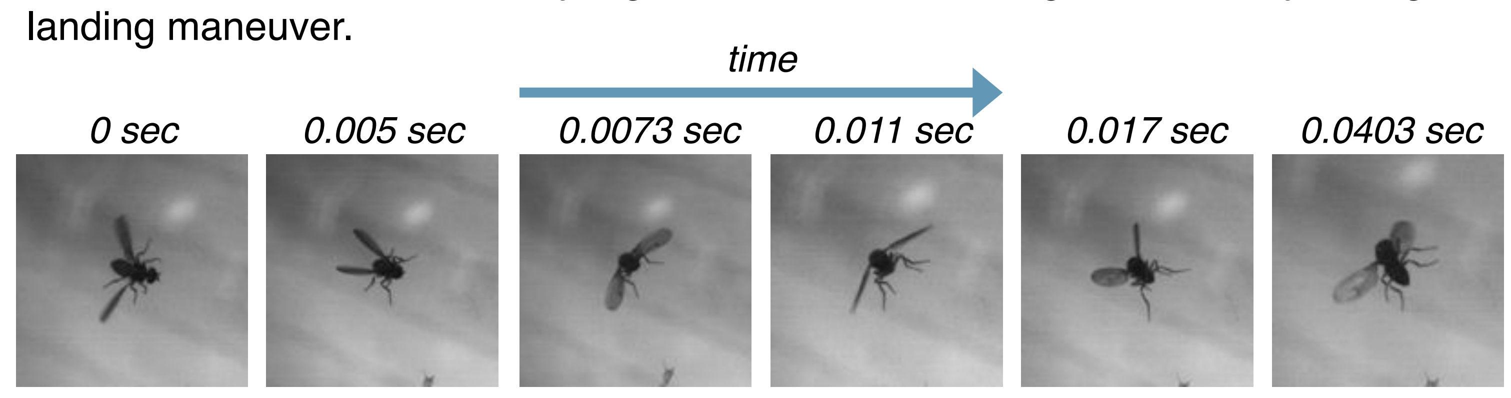

Fig. 4a. Top view of fruit fly landing maneuver

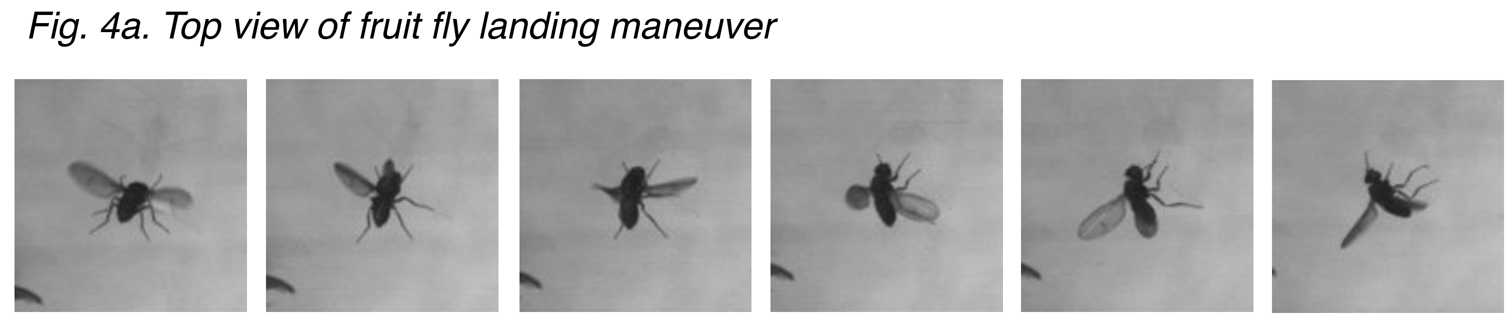

Fig. 4b. Side view of fruit fly landing maneuver

Approximately 10 sets of videos of landing maneuvers were recorded. Of these, only a few showed a clear sequence of images depicting the rotation of the fly's body to an upside-down orientation. From the videogrammetry analysis of these videos, both hypotheses were observed, indicating that upside-down landings may involve both aerodynamic forces and the momentum of the insect flipping its body upside-down. Future work will involve refining the videogrammetry methods and more clearly delineating the roles of these two features. This will be used to construct a computational model of the insect.

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