A Bee in the Mirror : A Bio-Inspired Model for Vision Based Mid-Air Collision Avoidance

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Context

The objective of much robotics research in recent years has been to develop lightweight autonomous flying robots. Applications for these aircrafts are numerous, including natural disaster monitoring, mapping, and search-and-rescue missions.

One of the major challenges is the development of a control system that is capable of avoiding collisions with moving obstacles whilst being lightweight, energy efficient and requiring low processing power.

Flying insects, like engineers, face similar challenges and have developed solutions that rely primarily upon information extracted from their visual system.

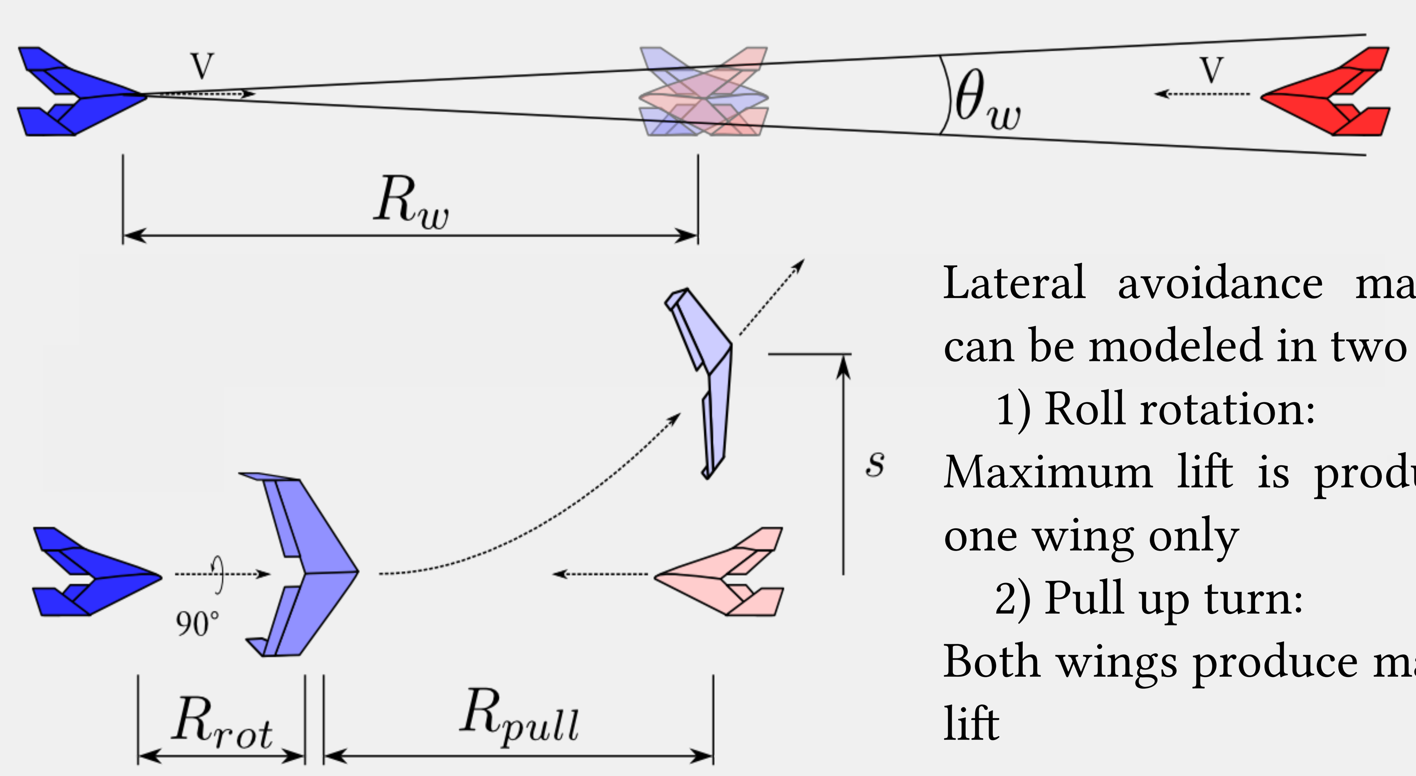
Overview

Detecting and avoiding **head-on collisions** with other flying agents is a challenging task because the approaching agent remains in the centre of focus of the visual field and thus **do not generate visual motion cues**.

Here, we attempt to address this problem by developing an obstacle avoidance model linking a flying animal morphology and the **minimum visual acuity** required to detect and avoid a frontal collision.

Our model results are tested on bumblebees. According to our model, these flying insects have to detect objects substending only 2° to 5° in their visual field, which is close to the spatial resolution of their visual system.

Avoidance Maneuver Modelisation



Lateral avoidance maneuvers can be modeled in two steps:
1) Roll rotation: Maximum lift is produced by one wing only
2) Pull up turn: Both wings produce maximum lift

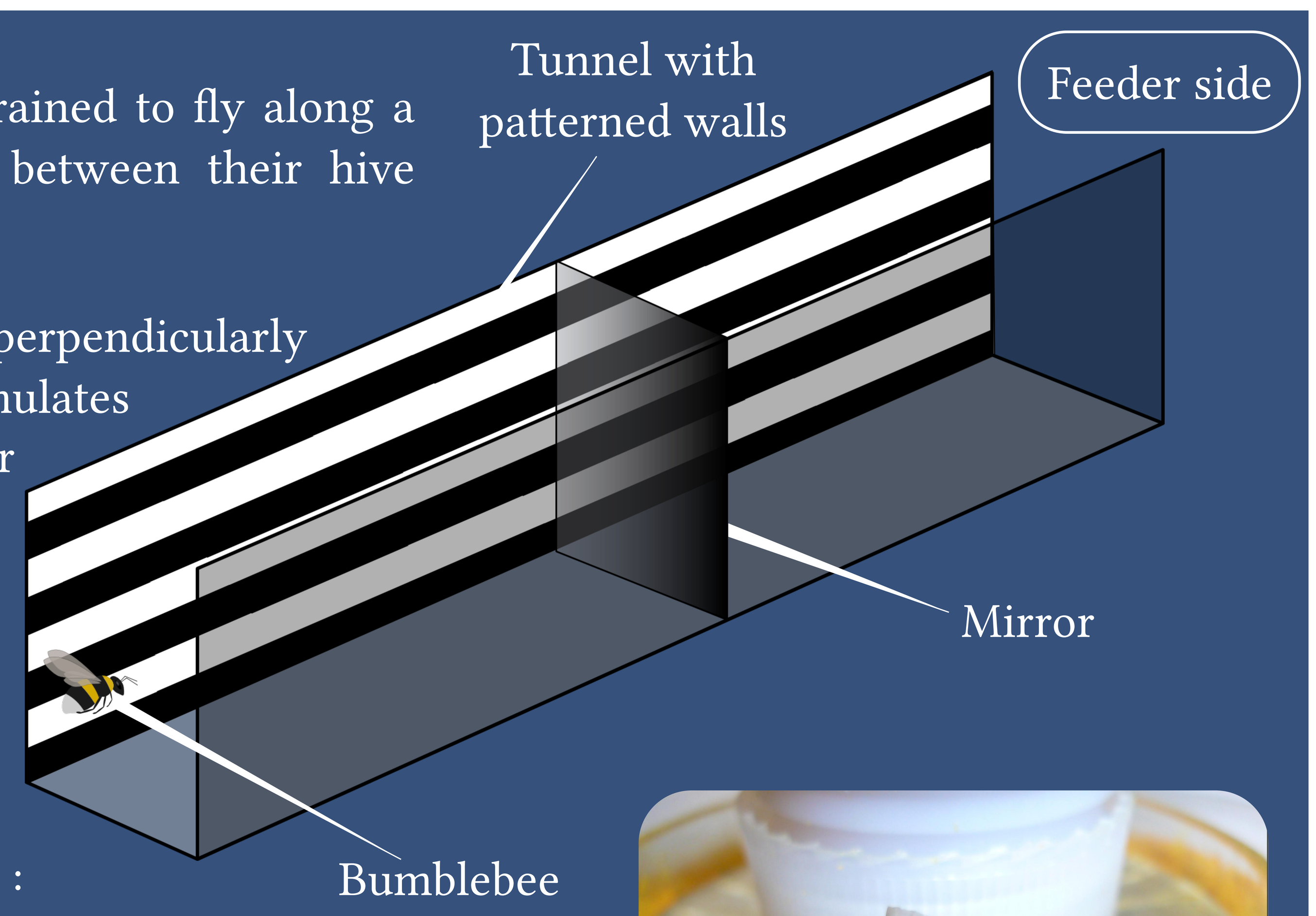
$$\theta_w = \arctan\left(\frac{b}{2V\left(\sqrt{\frac{6\pi.\sigma_{rot}}{b.L_{max}}}+\sqrt{\frac{4b.M}{L_{max}}}\right)}\right)$$

R_W : distance required for avoidance
Θ_W : maximum viewing angle for safe detection and avoidance
s : separation (two wingspans b)
V : flight speed
M : mass
L_{max} : maximum lift
σ_{rot} : roll inertia
l : body length

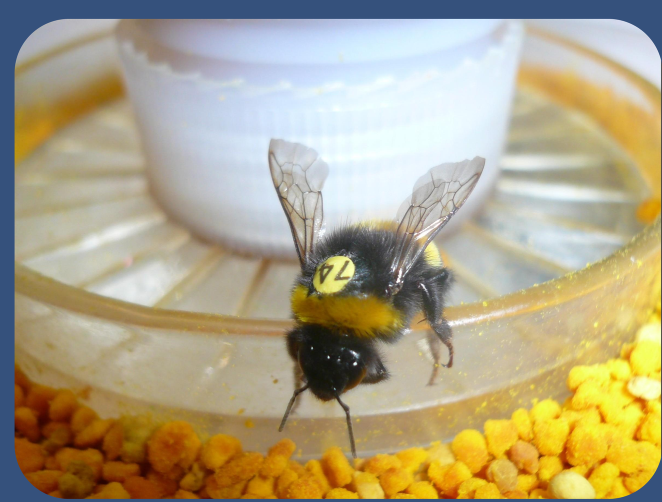
Experiments on Bumblebees

Bumblebees are trained to fly along a patterned tunnel between their hive and a feeder.

A mirror presented perpendicularly to the flight path simulates an incoming mid-air collision.



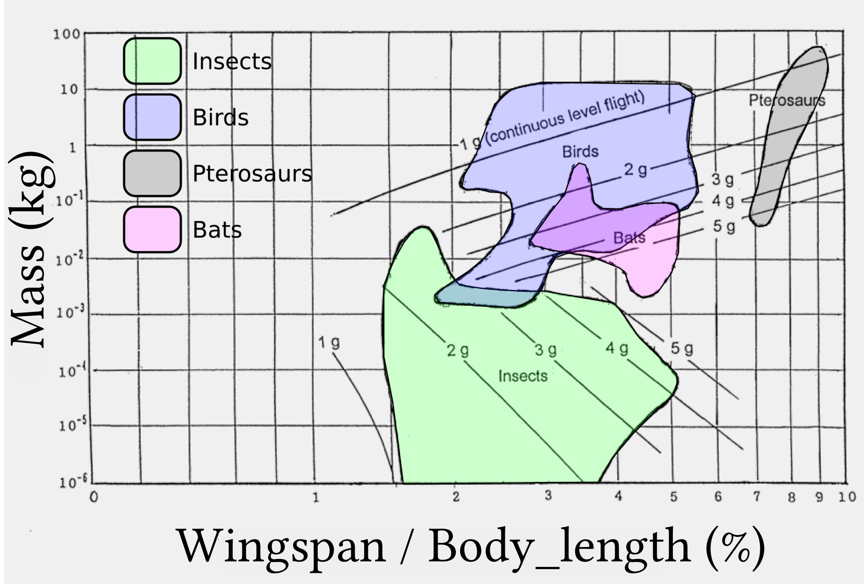
The main goals are to :
- Observe if bumblebees react to their image in the mirror.
- Evaluate the distance from the mirror when reaction occurs.
- Infer minimum viewing angle required to detect an incoming flying counterpart.



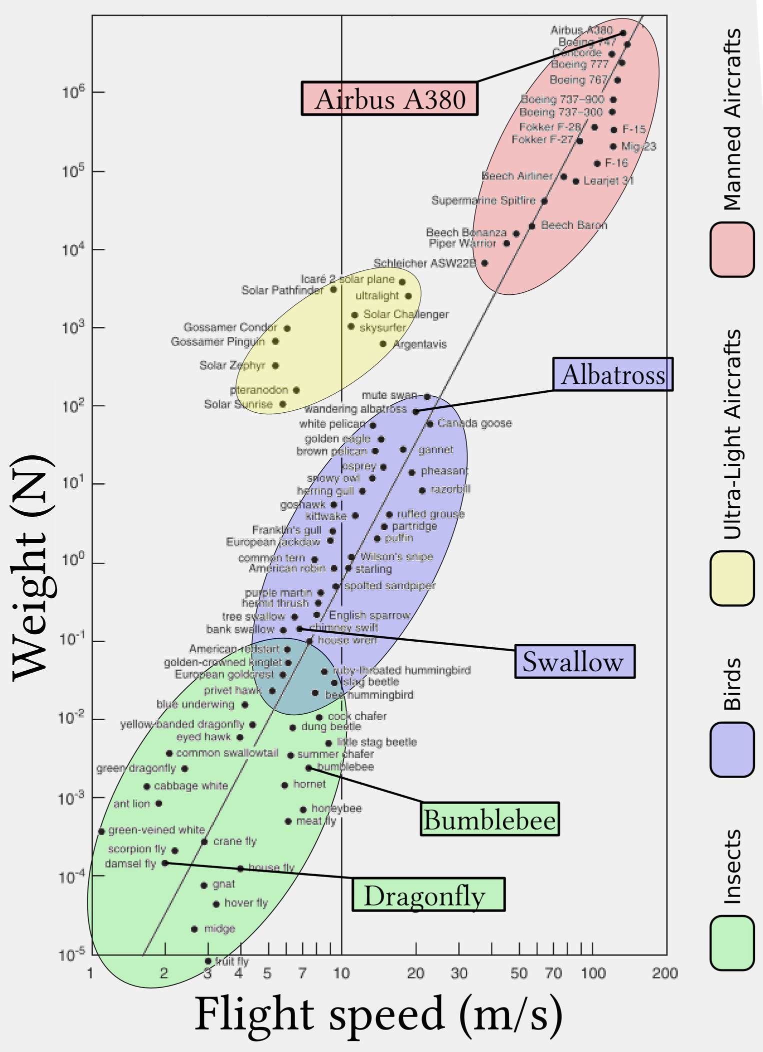
A bumblebee on the feeder

Scaling Laws for Flying Animals

Based on morphological studies, we show that it is possible to combine scaling laws to **express Θ_w** (the maximum viewing angle that the incoming aircraft can substend when detected to allow safe avoidance) **as a function of the animal mass only.**



R. J. Templin, « The spectrum of animal flight : insects to pterosaurs », 2000



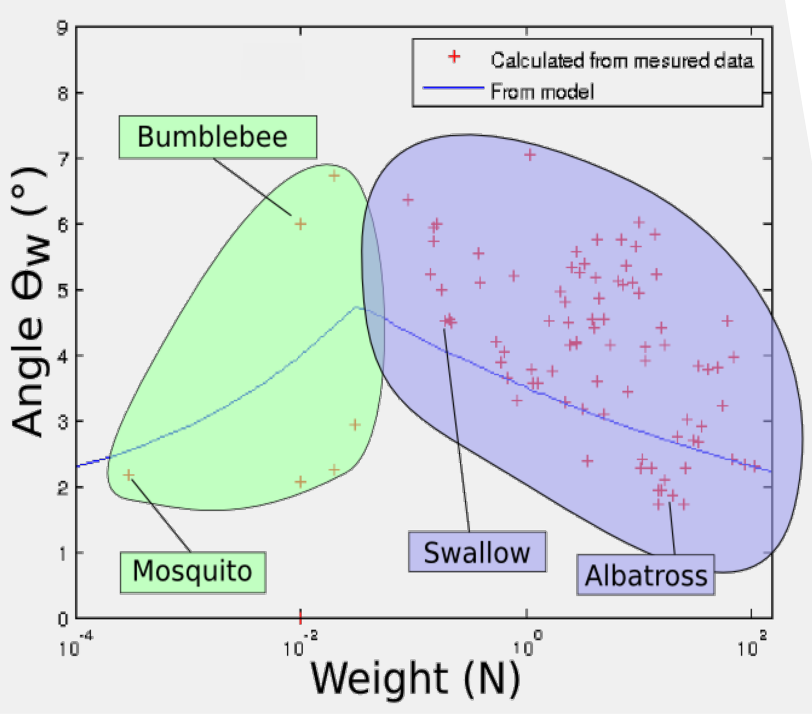
H. Tennekes, The Simple Science of Flight, 20009

Predicted Required Acuity

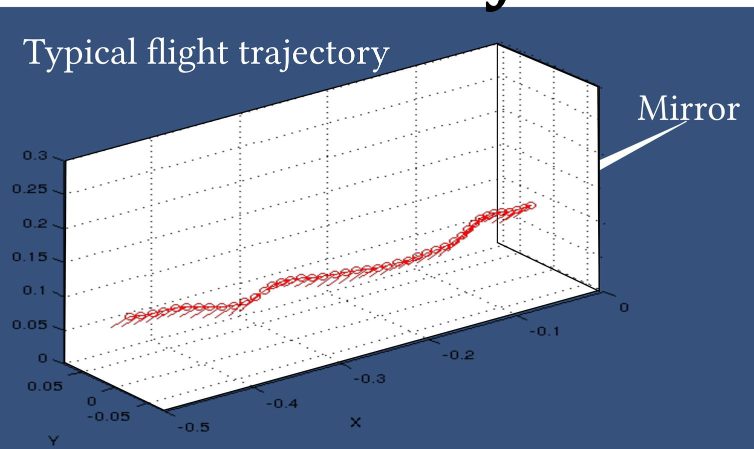
Our model predicts that, to avoid head-on collisions, a flying agent must detect an approaching object when it subtends **only 2° to 5° in its visual field**.

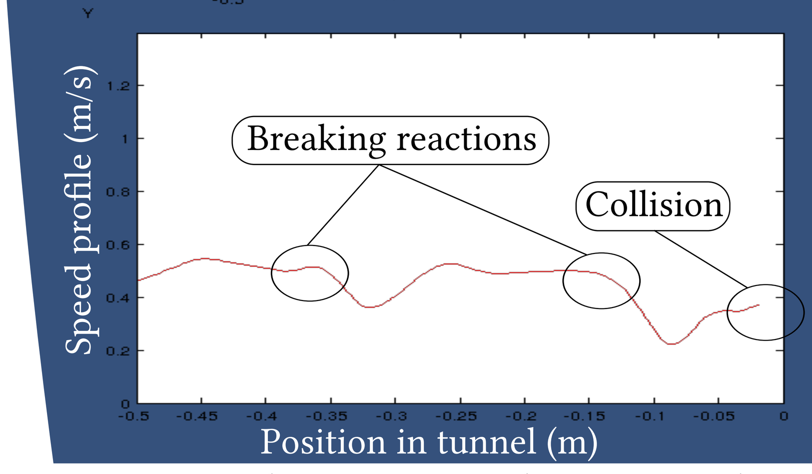
In the case of **flying insects,** this angle lies just above the threshold of their visual acuity in the frontal visual field.

An insect would have to react when the approaching agent covers **only a few ommatidia**.



Observed Trajectories





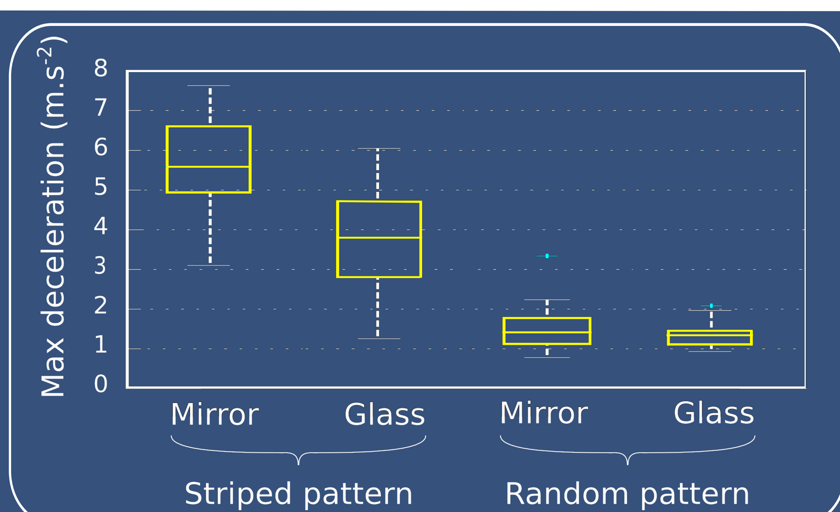
The main observations are :
- The trajectories do not show clear avoidance maneuvers.
- Flight speed reduction is visible when bumblebees are presented with a mirror, but not when a transparent glass is used.
- Collisions are less frequent when using a horizontal striped pattern (ie. at higher flight speed) than with a random pattern:

Pattern / Obstacle	Mirror	Glass
Random	94%	98%
Stripes	22.5%	93%

Collision rates

Results and Outlook

With striped patterned walls (ie. at higher flight speeds), the maximum acceleration was significatively higher with a mirror than with a transparent glass.



This holds true even when excluding the last 20 centimeters before collision.

This result is in accordance with our model and confirms that bumblebees can detect static objects substending only a few ommatidia.

Such detection suits well the requirements of miniature autonomous flying vehicles as it requires only low-resolution sensors, which can be small, lightweight, and energy efficient.