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## Vision based autopilot in flies

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Keynote lecture at  
**Visual Processing in Insects: From Anatomy to Behavior**  
**Janelia Farm Research Campus, Howard Hughes Medical Institute**  
**April 29 - May 2, 2007**  
**VA, USA**

Presentation Title:

**Vision based autopilot in flies**

Presentation Authors:

**Nicolas Franceschini, Franck Ruffier, Julien R Serres**

Abstract:

When insects are flying forwards, the image of the ground sweeps backwards across their ventral view field, forming an ‘optic flow’, which depends on both the ground speed and the height of flight. To explain how these animals manage to avoid the ground using this image motion cue, we suggest that insect navigation hinges on a visual feedback loop we have called the optic flow regulator, which controls the vertical lift. To test this idea, we built a micro-helicopter equipped with a fly-inspired optic flow sensor and an optic flow regulator. We showed that this fly-by-sight microrobot can perform exacting tasks such as take-off, level flight and landing. Our control scheme accounts for many hitherto unexplained findings published during the last 70 years on insects’ visually guided performances, including the fact that honeybees descend by headwind, land with a constant slope, and drown when travelling over mirror-smooth water. Our control scheme explains how insects manage to fly safely without any of the instruments used onboard aircraft to measure the height of flight, the air speed, the ground speed and the descent speed. An optic flow regulator is quite simple in terms of its neural implementation and just as appropriate for insects [1] as it would be for aircraft [2, 3].

[1] Franceschini, N., Ruffier, F., Serres, J. (2007)

A bio-inspired flying robot sheds light on insect piloting abilities.  
*Current Biology*, 17(4), 329-335.

[2] Ruffier, F., Franceschini, N. (2005)

Optic flow regulation: the key to aircraft automatic guidance.  
*Robotics and Autonomous Systems* 50(4), 177-194.

[3] Franceschini, N., Ruffier, F., Viollet, S., Boyron, M. (2008)

Steering aid system for altitude and horizontal speed, perpendicular to the vertical, of an aircraft and aircraft equipped therewith *U.S. Patent No. 7,440,826*. Washington, DC: U.S. Patent and Trademark Office.

Keywords:

motion vision, optic flow, visuo-motor control, elementary motion detectors, visually-guided behavior, micro-air vehicles,

Research Interests:

We are interested in discovering the laws of control underlying visually guided navigation in creatures able to operate in the 3D world. We are interested in both the neural principles underlying visually guided behavior and their neuronal implementation. The new approach that we initiated in 1985 consists in ‘reconstructing for better understanding’. Meanwhile we have produced seven fly-inspired robotic demonstrators that helped us clarify particular biological processes.

# Vision based autopilot in insects

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**Inspiration**



**Biology**

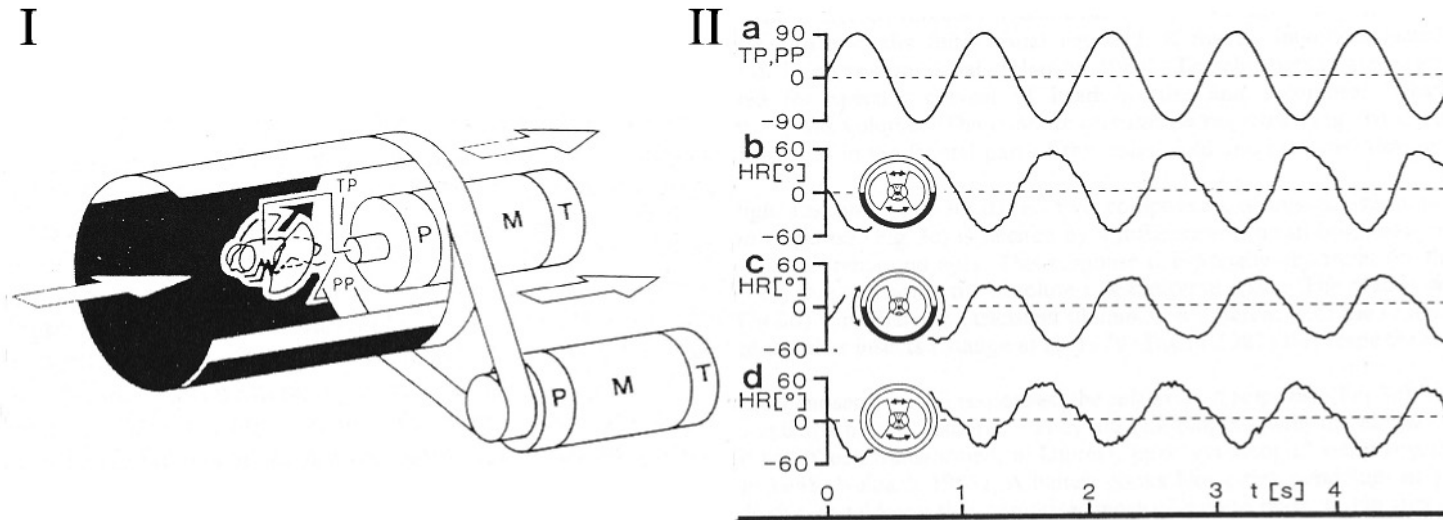


**Robotics**

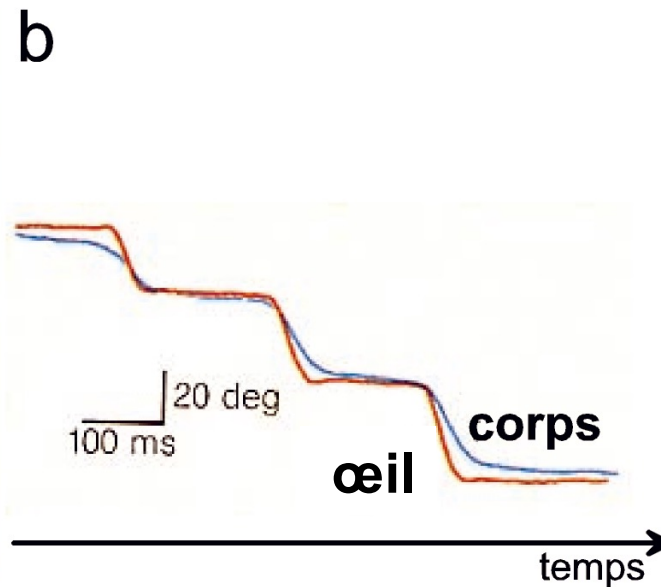
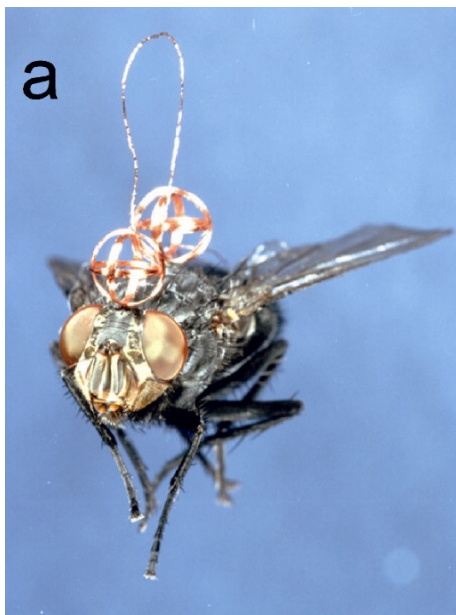


**Hypotheses**

# Flies generates preferably translational optic flow



Roll compensation reflex of the eye (Hengstenberg, 1988)

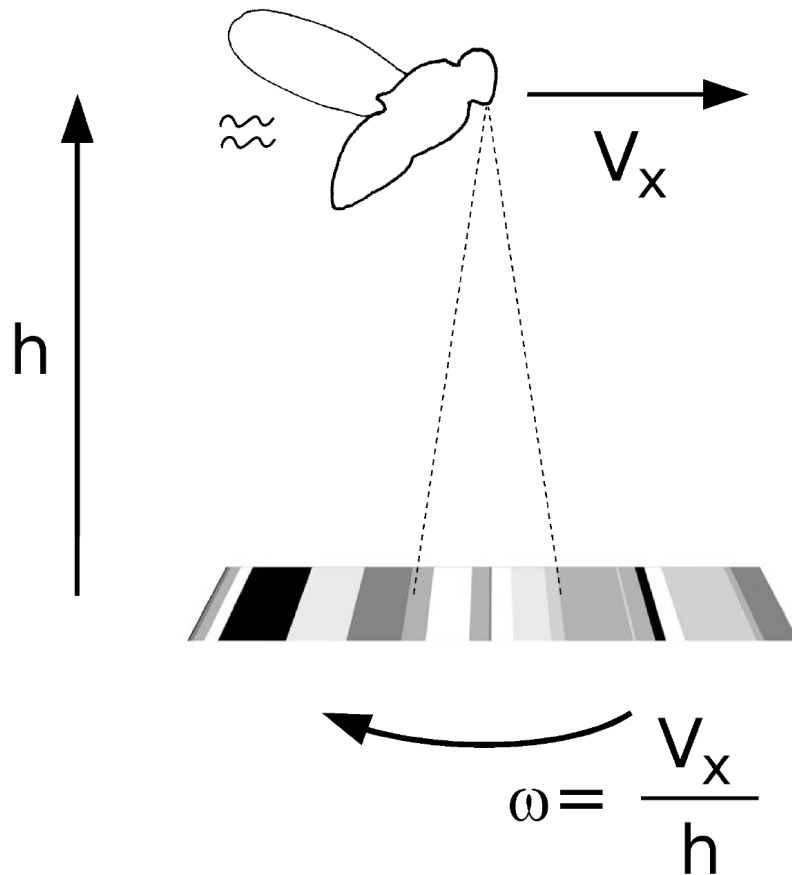


Yaw saccades

(van Hateren & Schilstra 1999)

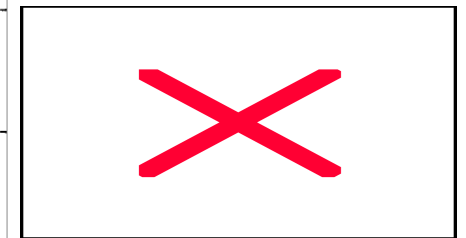
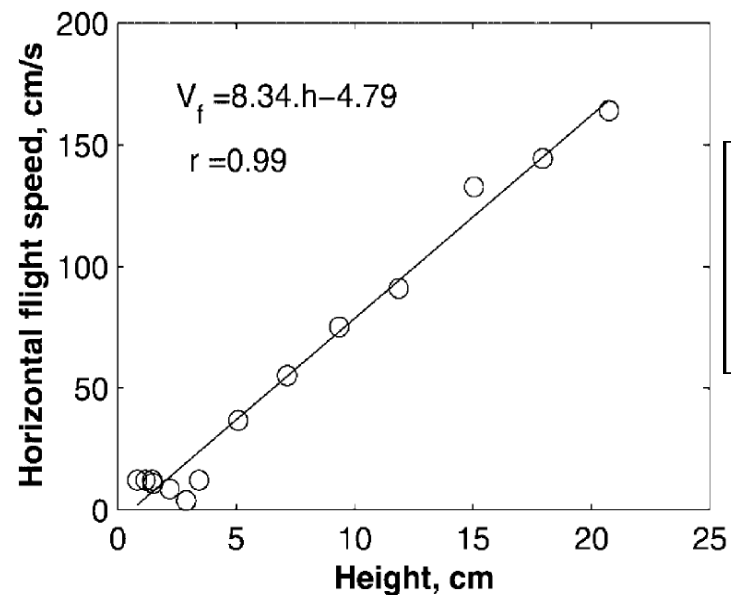
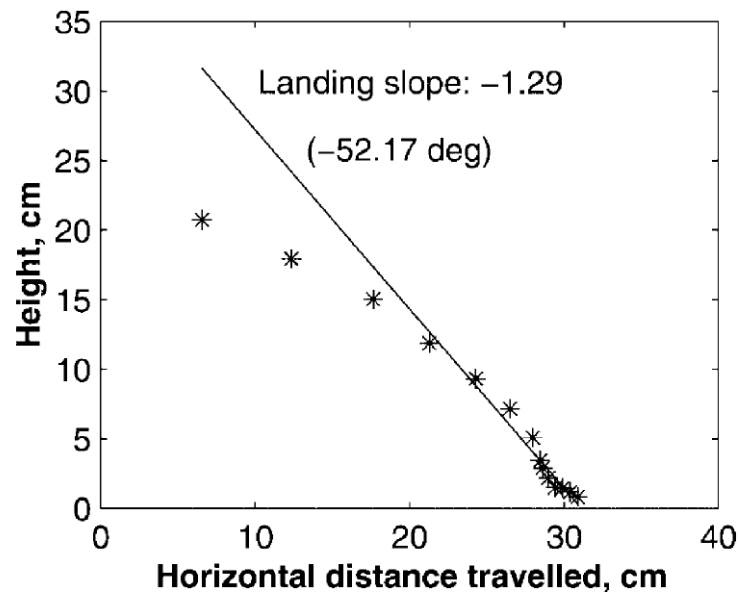
# Ventral optic flow for navigation in the vertical plane

A



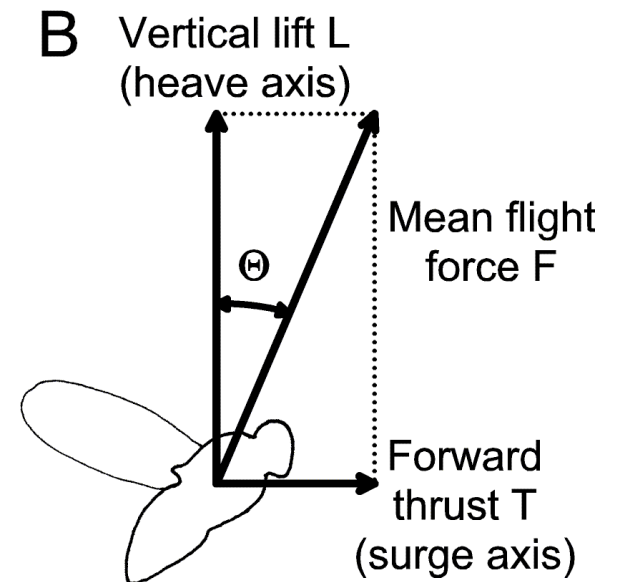
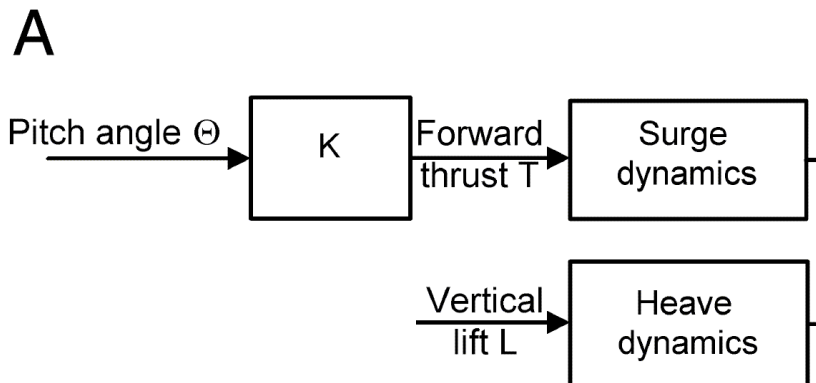
# “Constant ventral optic flow” hypothesis

1. “Preferred retinal velocity” hypothesis from observations on desert locust (Kennedy 1951)
2. **Quantitative** observations on landing bees (Srinivasan et al. 1996, 2000) :



# Ventral optic flow feedback regulator that acts upon the **lift**

- No pressure altitude servoing
- No ground speed servoing

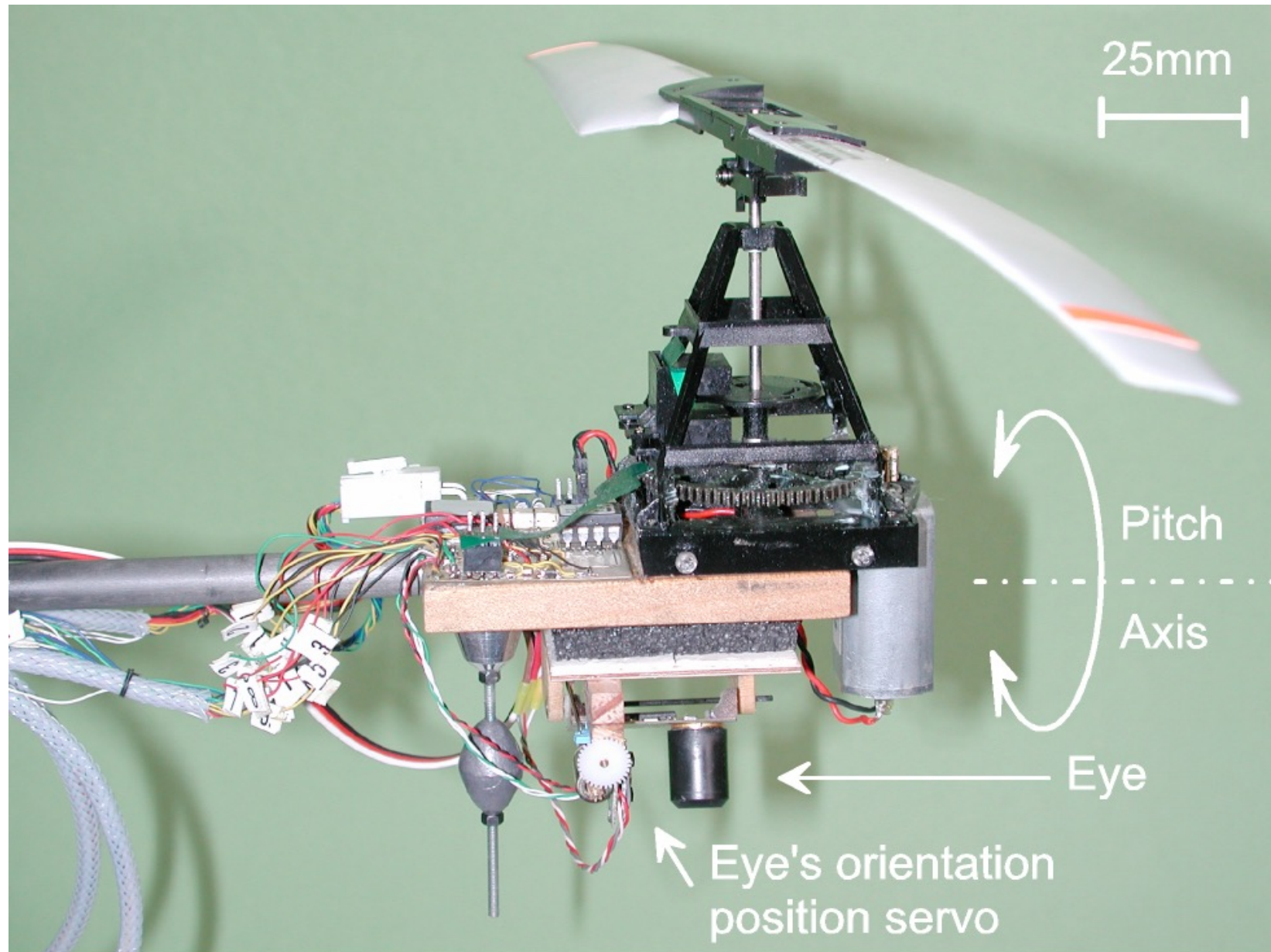


Ruffier & Franceschini, SPIE Vol. 5119, May 2003

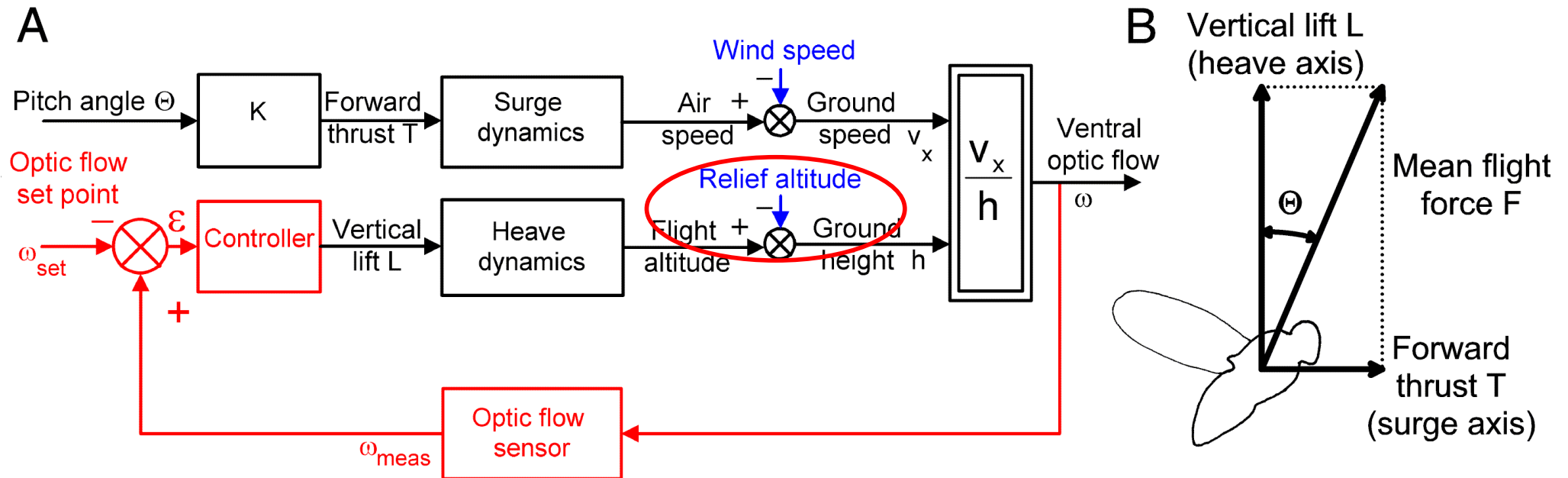
Franceschini, Ruffier, Serres, Current Biology 2007



# Robotic model called OCTAVE robot



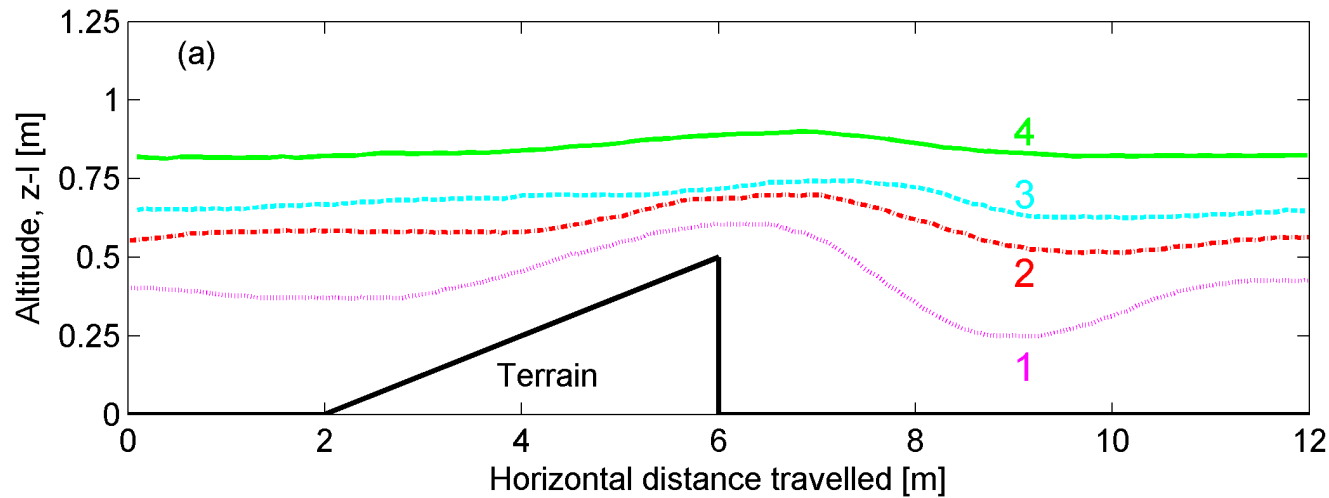
# Level flight and terrain following



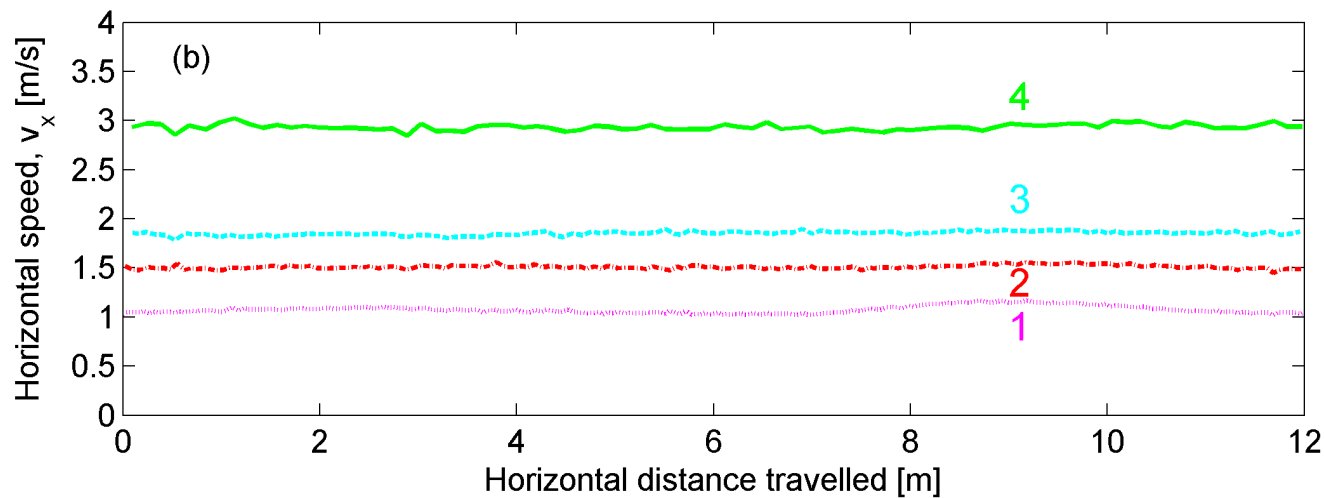
Ruffier & Franceschini, SPIE Vol. 5119, May 2003

Franceschini, Ruffier, Serres, Current Biology 2007

# Level flight and terrain following



➤ Robotic model automatically generates a *safe altitude*, which suitably increases with ground speed

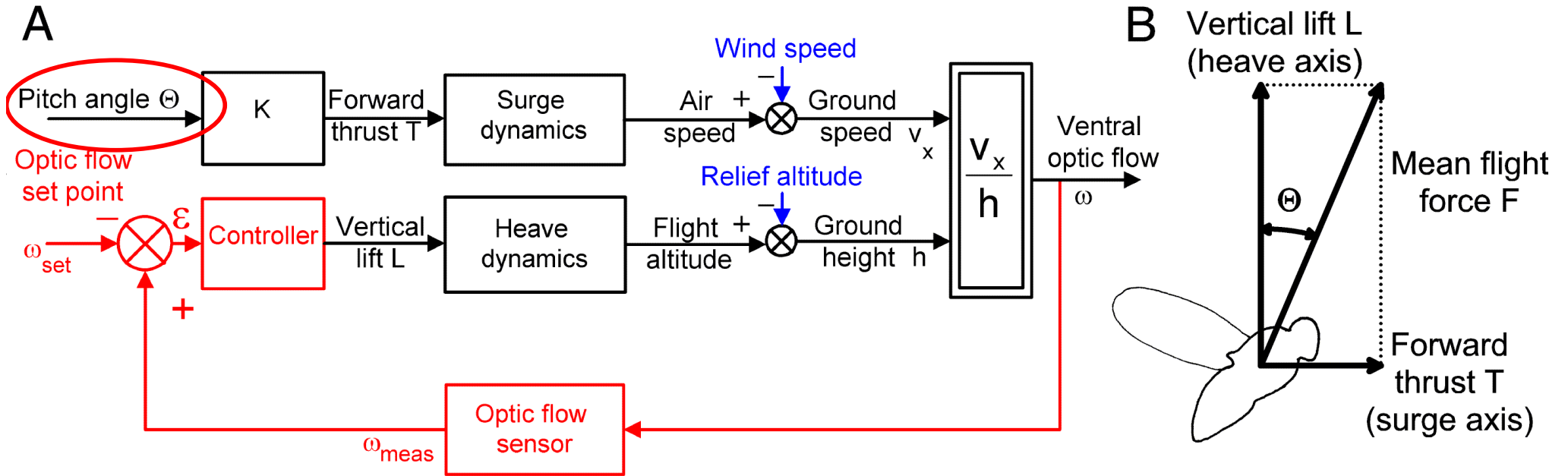


# Level flight and terrain following

Our robotic model accounts for terrain following abilities described for :

- Migrating butterflies in canyon (Williams 1965) and in dense forest (Srygley & Oliveira 2001)
- Dung beetles (Steiner 1953)

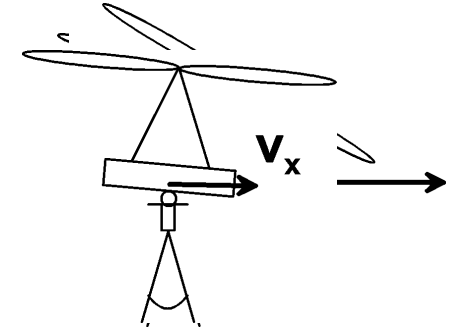
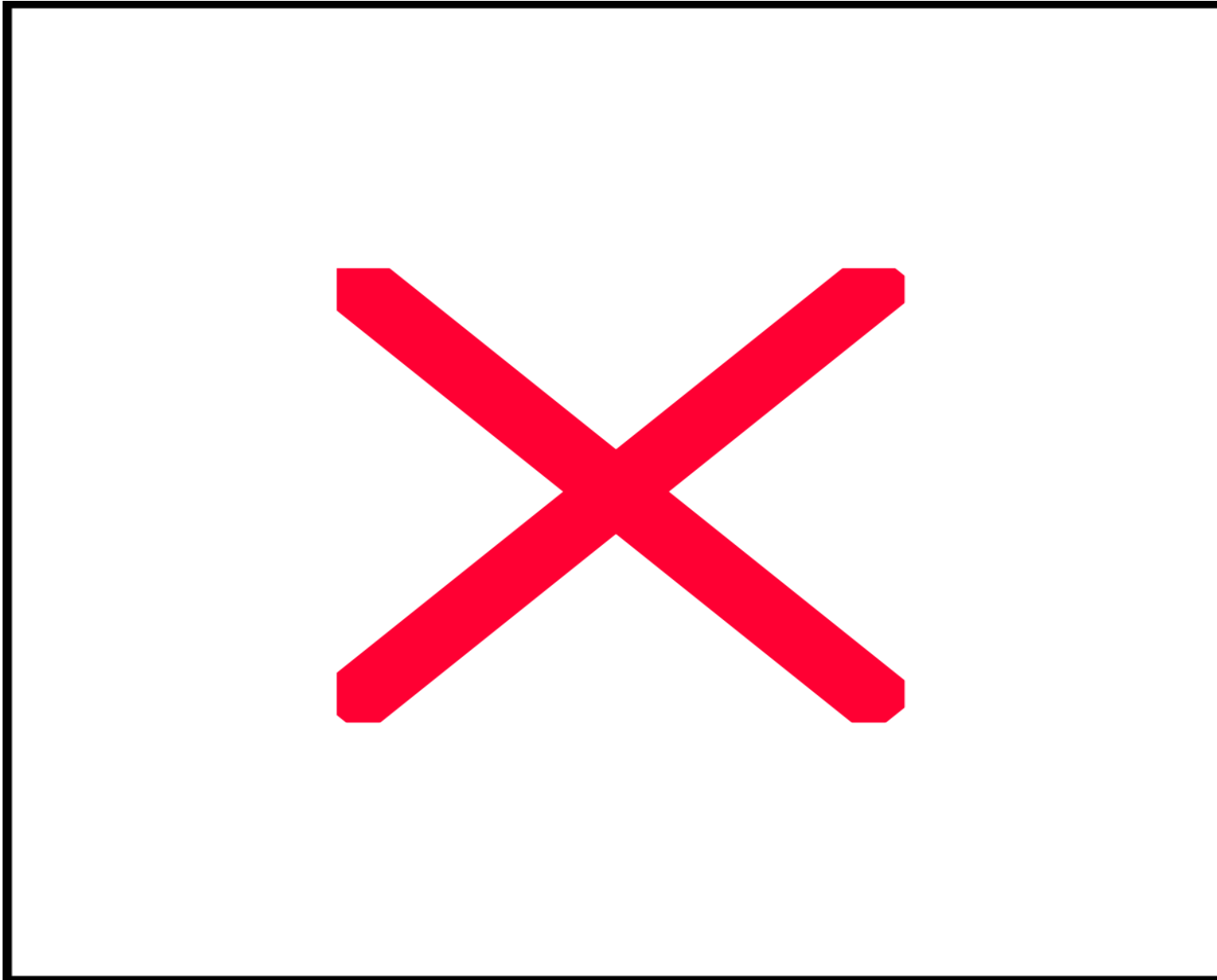
# Take off by forward pitching



Ruffier, Franceschini IEEE *ICRA New Orleans* 2004

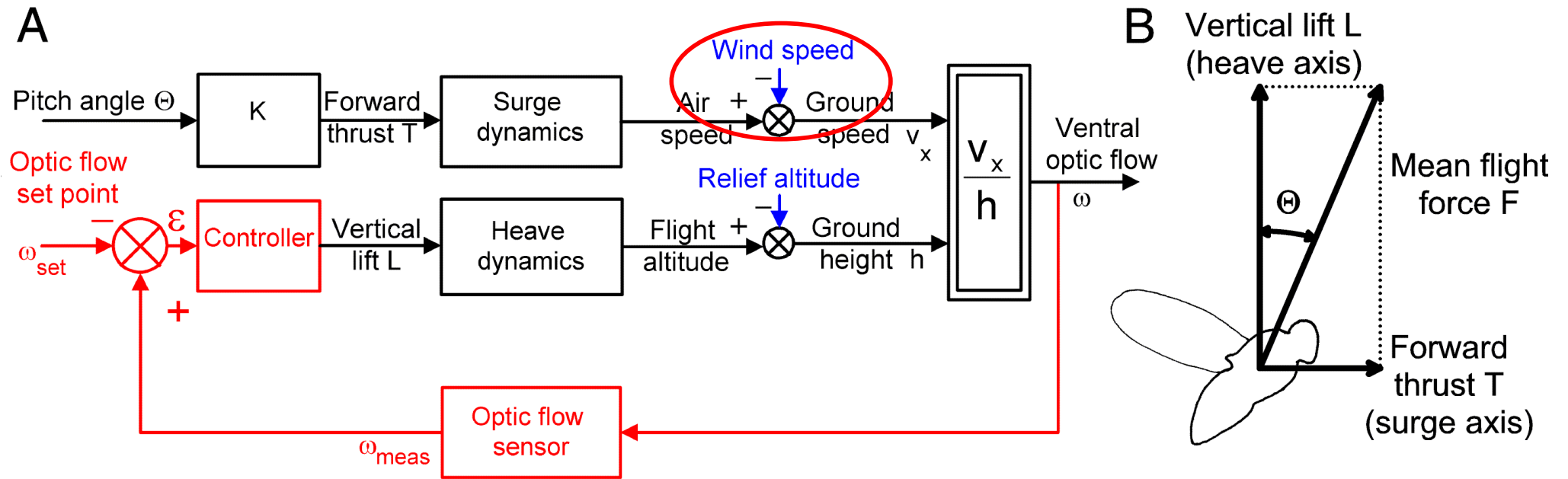
Franceschini, Ruffier, Serres, *Current Biology* 2007

# Take off by forward pitching

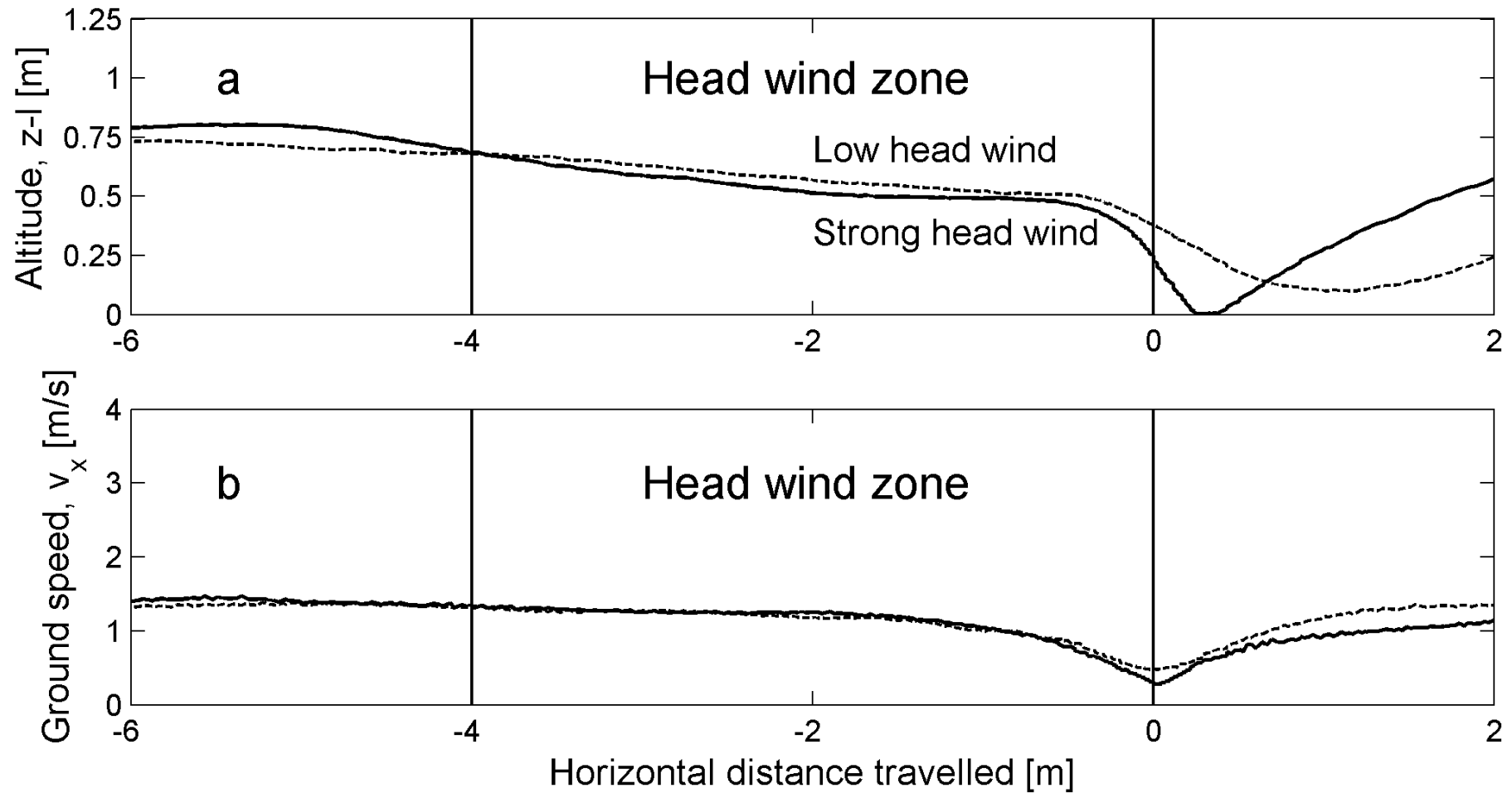


6-second ramp to reach an inclination of  $10^\circ$

# Flight against wind

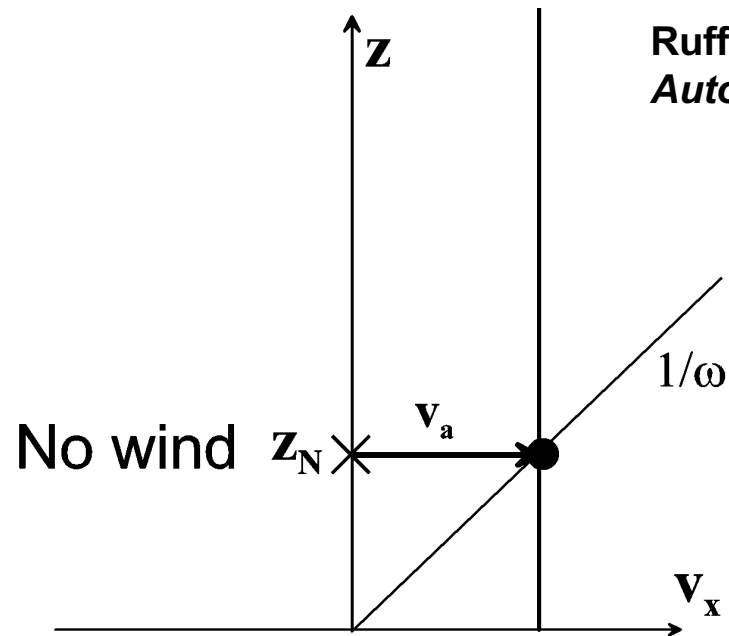


# Flight against wind





a)



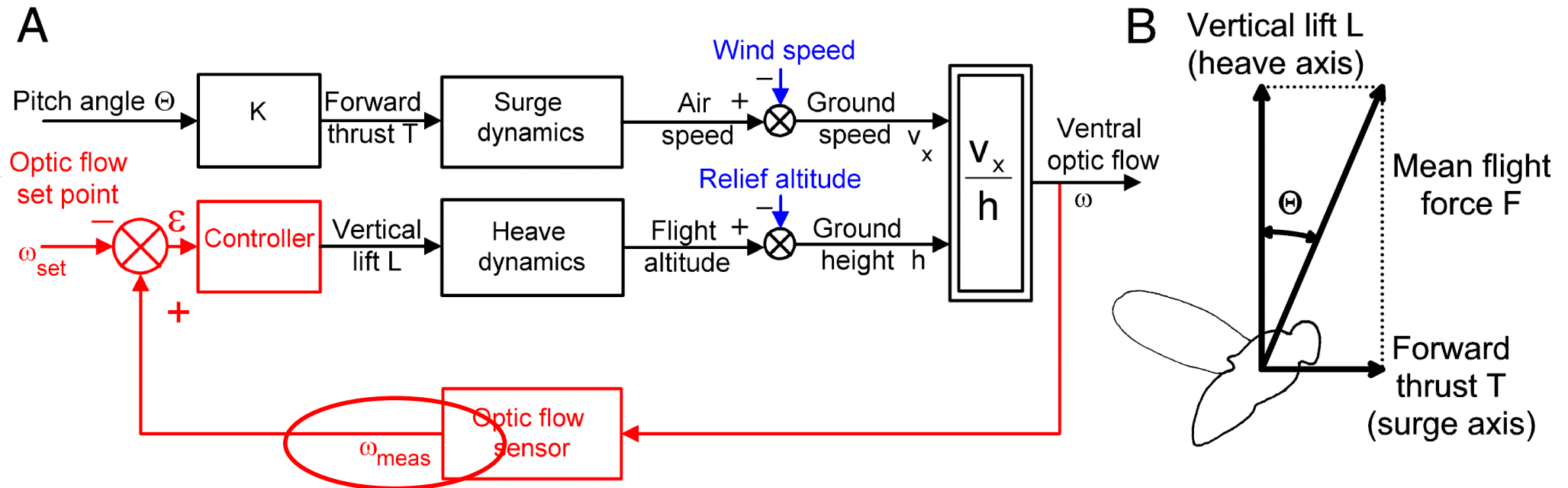
1. Unfavorable wind leads the robotic model to fly at lower altitude  
 **$\Rightarrow$ Invaluable energy savings**
2. Favorable wind leads the robotic model to fly at higher altitude

# Flight against wind

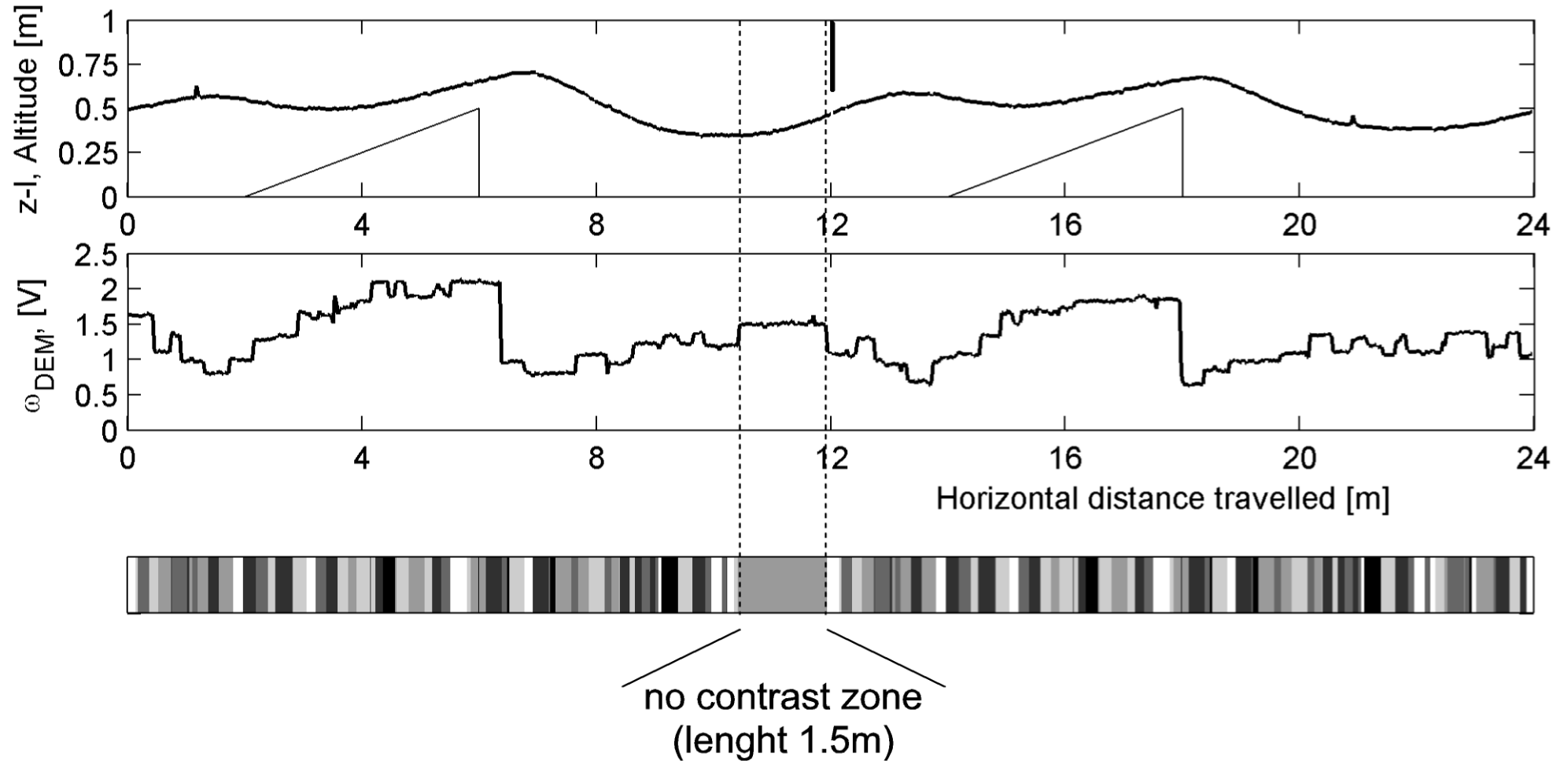
Our robotic model accounts for insect descent in a headwind and ascent in a tailwind :

- Migrating insects (Williams 1965, Kennedy 1951)
- Dung beetles (Steiner 1953)
- Honeybees (Braüninger 1964)

# Flight over a no contrast zone



# Flight over a no contrast zone

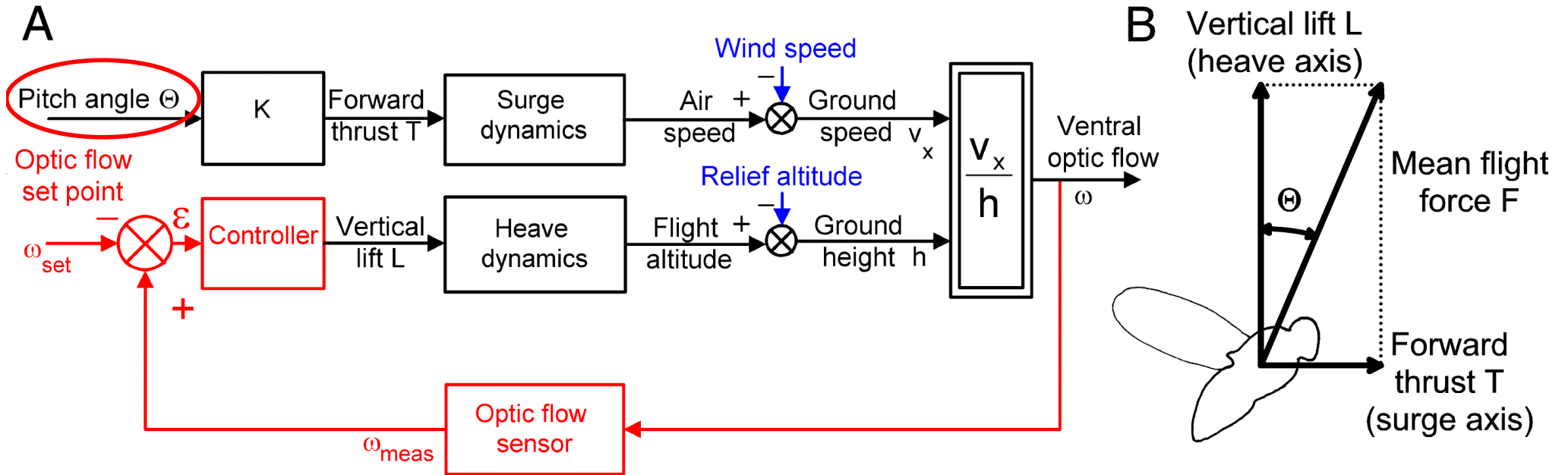


# Flight over a no contrast zone

Our robotic model accounts for crash into the water described in :

- Honeybees crossing mirror-smooth water (Heran, Lindauer 1963)

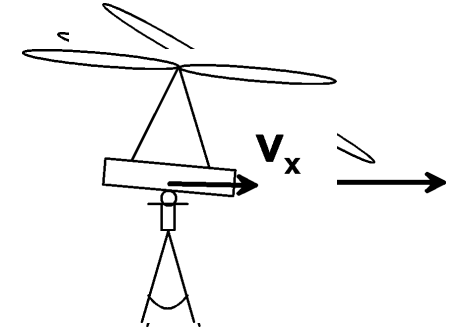
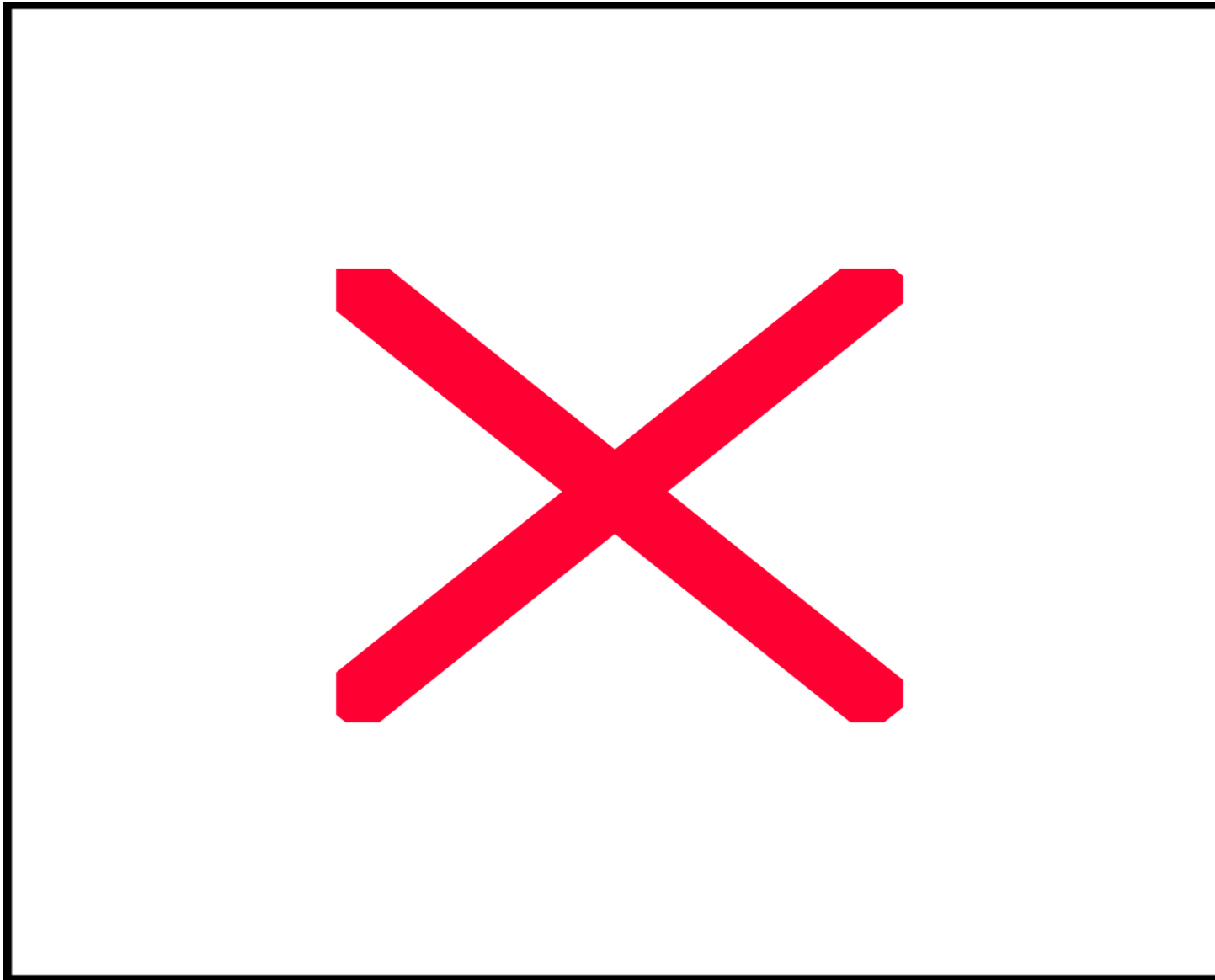
# Landing by backward pitching



Ruffier, Franceschini IEEE *ICRA New Orleans* 2004

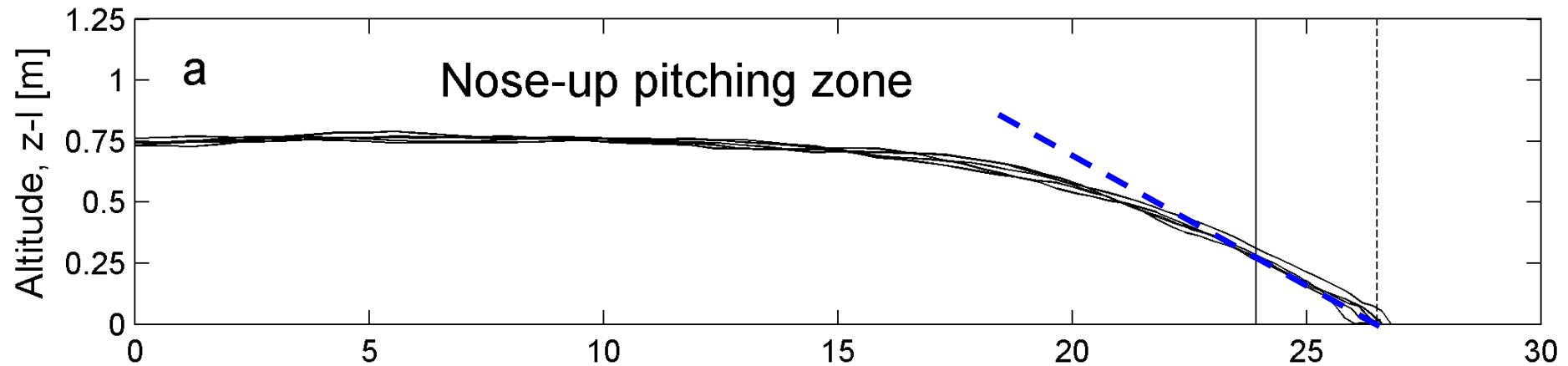
Franceschini, Ruffier, Serres, *Current Biology* 2007

# Landing by backward pitching



6-second ramp to reduce the pitch from  $10^\circ$  to  $0^\circ$

# Landing with a constant slope

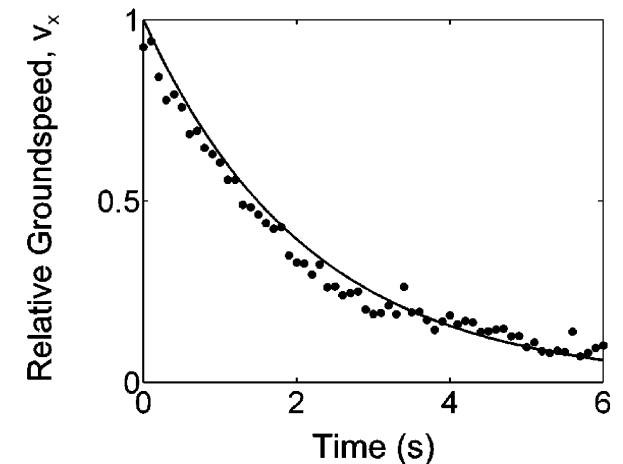


$V_x$  is an exponential

$\Rightarrow h$  is an exponential

$\Rightarrow V_z$  is an exponential

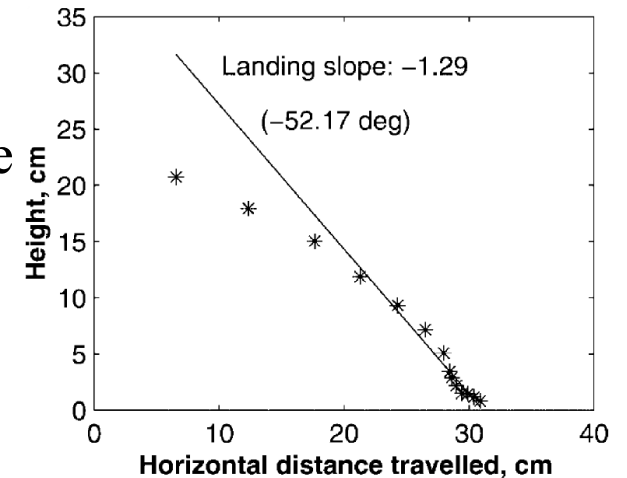
$\Rightarrow V_x/V_z$  is constant





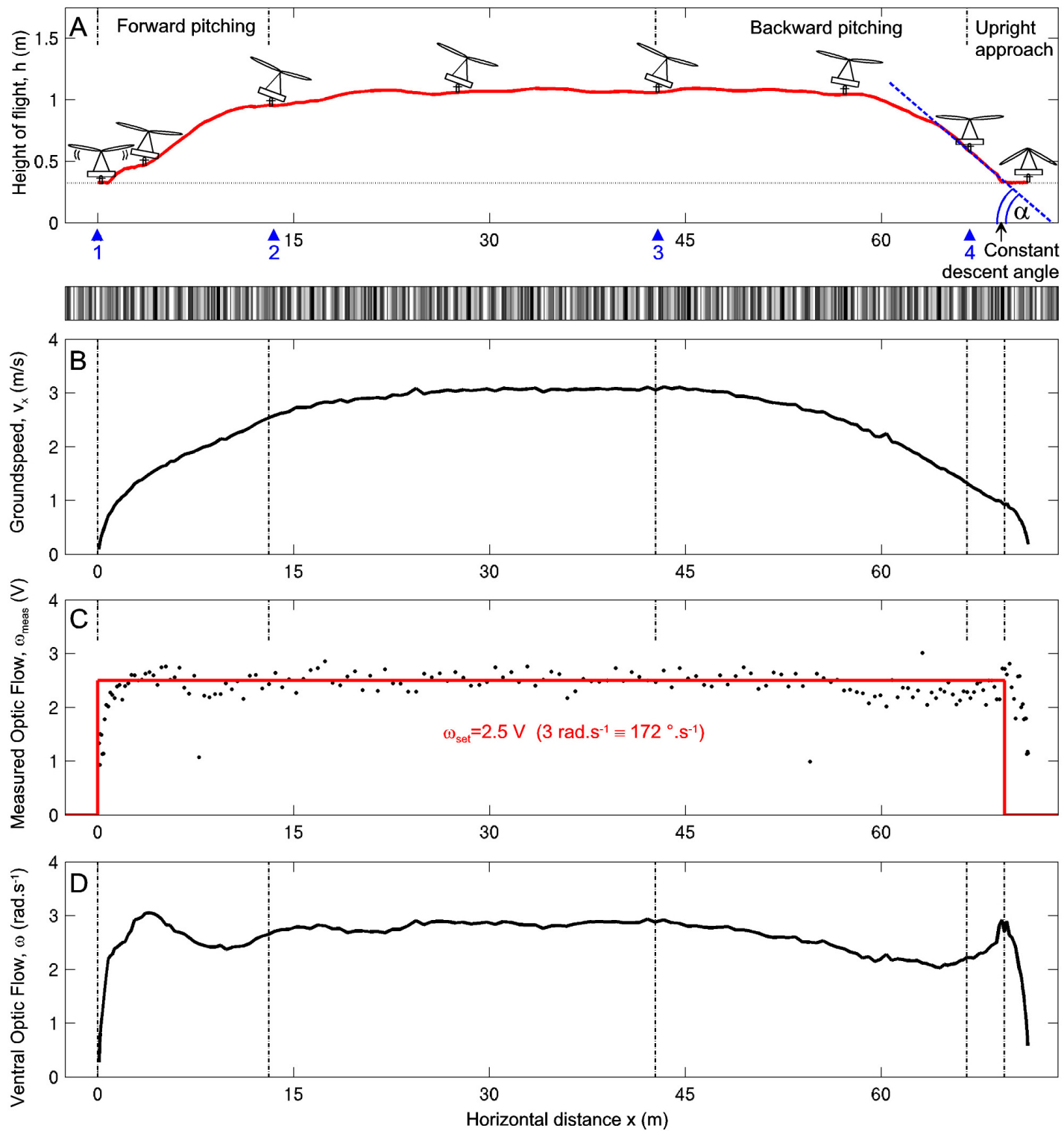
# Landing with a constant slope

Our robotic model accounts for landing with a constant slope described in honeybees by Srinivasan et al (1996).



Srinivasan et al. (1996)

In addition, we show that *landing with a constant slope* is not *requirement* but a *consequence* of the optical flow regulator.



Franceschini,  
Ruffier,  
Serres,  
*Current  
Biology* 2007

# Conclusions

## One and the same autopilot to perform:

1. Cruise flight, Terrain following,
2. Sensible wind reaction,
3. Landing and Take off.

## “Optic flow regulator” does not need any knowledge of:

1. Airspeed (no “pitot” tube),
2. Ground speed (no Doppler, no laser-velocimeter)
3. Descent speed (no variometer)
4. Ground height (no radio-altimeter),
5. Pressure altitude (no Barometer)
6. Wind speed (no wind forecast),
7. Relief data (no cartography)

## “Optic flow regulator” :

Well suited to **natural aircraft** drastic constraints such as flying insects

**Inspirations**



**Biology**

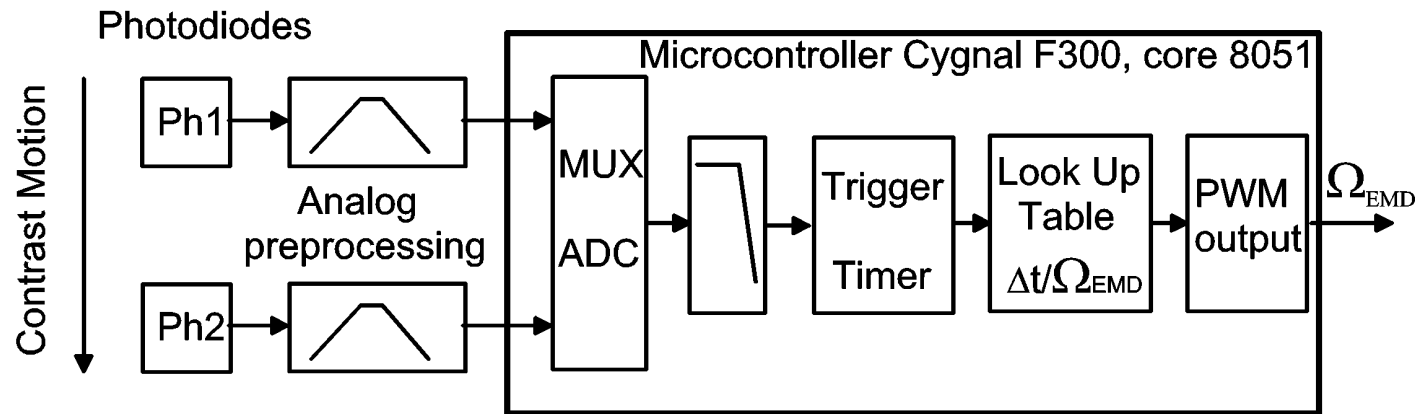
**Robotics**



**Hypotheses**

Thank you !!!

# $\mu$ c-based EMD design



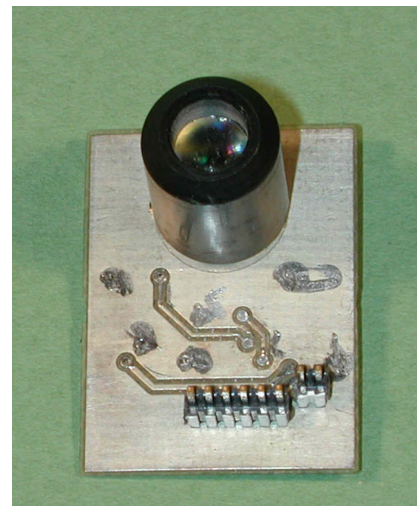
Franceschini et al. 1986;

Ruffier, Viollet, Amic & Franceschini IEEE ISCAS May 2003

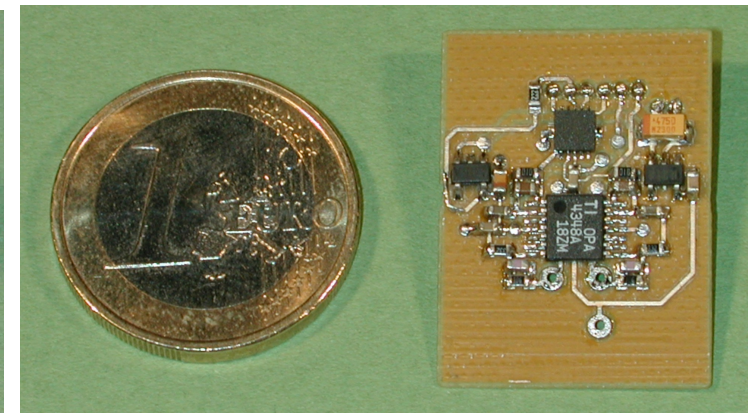
⇒ Functional diagram relies on findings in fly's EMD neurons (characterization of the dynamics and the various nonlinearities, **Franceschini 1985, Franceschini and al. 1989**)

- Implemented in a tiny 8 bits Microcontroller (3×3 mm)
- Digital filtering
- Sampling Freq : 1 kHz
- Fixed point processing with MATLAB (RTW embedded coder)

Top view



Bottom view



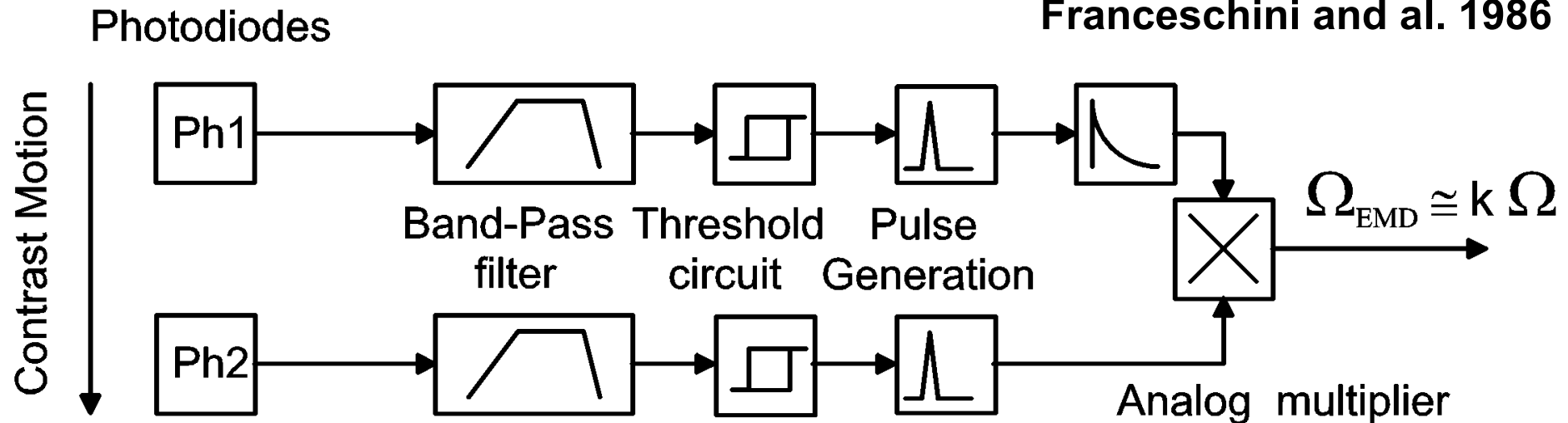
40mW, 0.8 grams

# EMD processes $\Delta t$ to estimate the optic flow $\Omega$

## Original Analog EMD design

Blanes 1986,

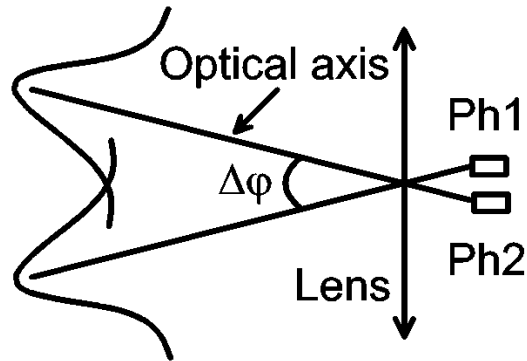
Franceschini and al. 1986



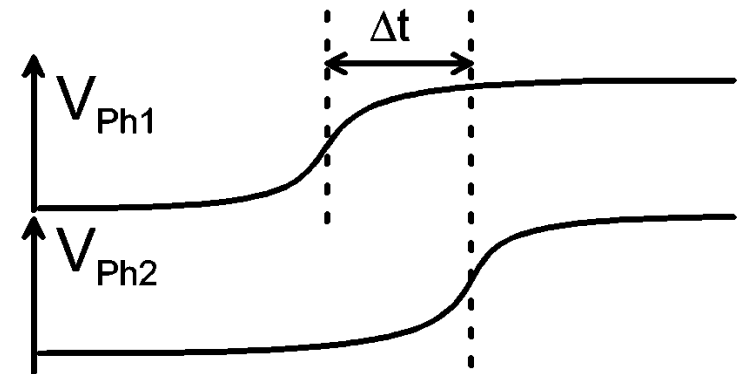
- Functional diagram relies on findings in fly's EMD neurons (characterization of dynamics and various nonlinearities, Franceschini 1985, Franceschini and al. 1989)

# Elementary eye

(a) Eye geometry



(b) Photoreceptor outputs



A delay  $\Delta t$  appears between the two photoreceptors outputs

$\Rightarrow$  The optic converts the optic flow  $\omega$  into a delay  $\Delta t$

Elementary Motion Detector (EMD) processes  $\Delta t$  to estimate  $\omega$



# EMD : true optic flow sensor

