Visual Guidance in Insects and applications to MAVs

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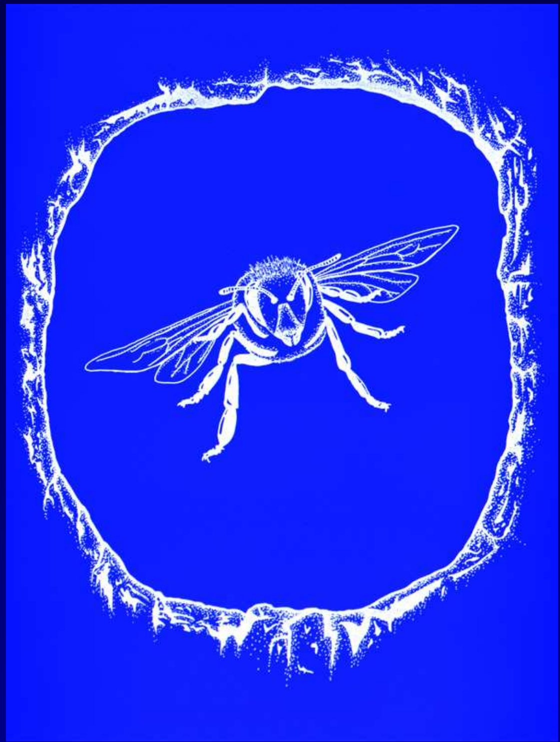
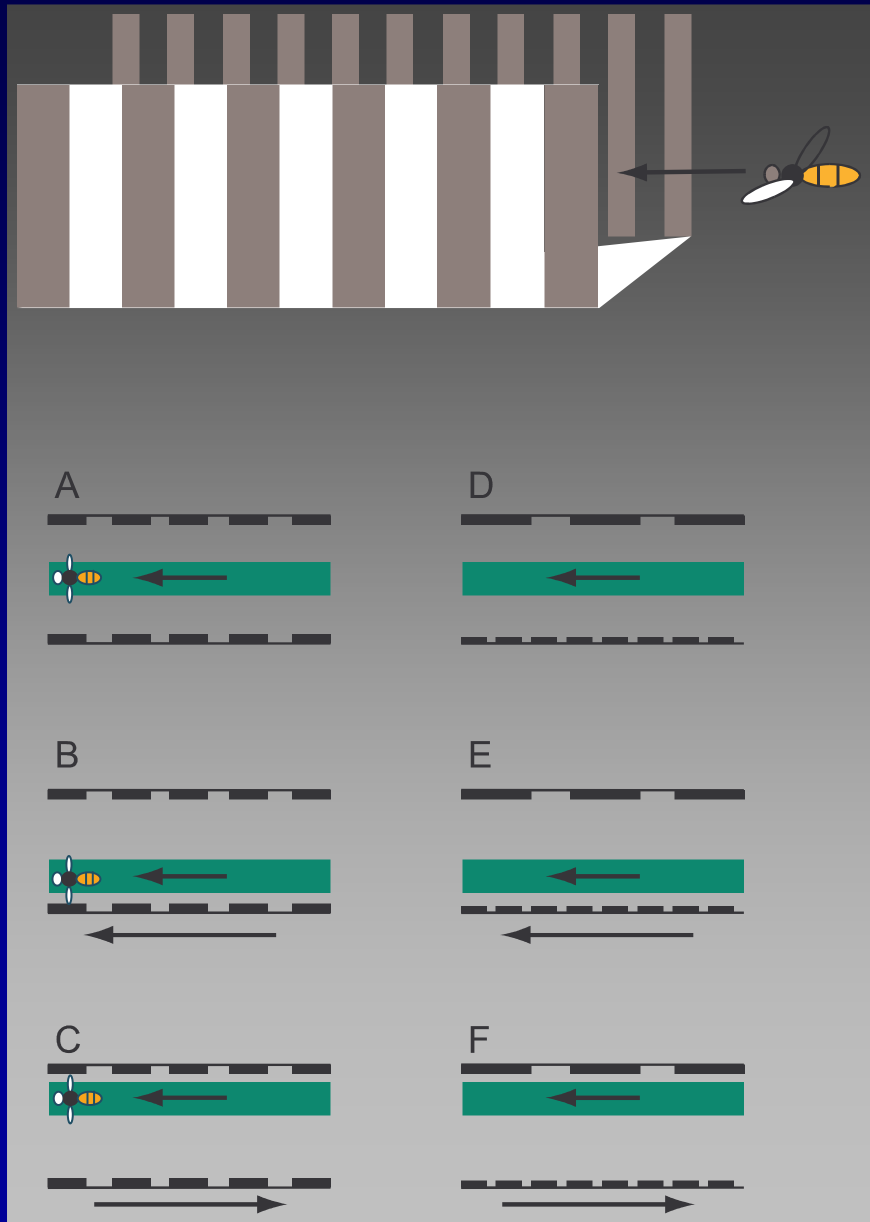
Bees negotiate narrow gaps by balancing the image velocities in the two eyes

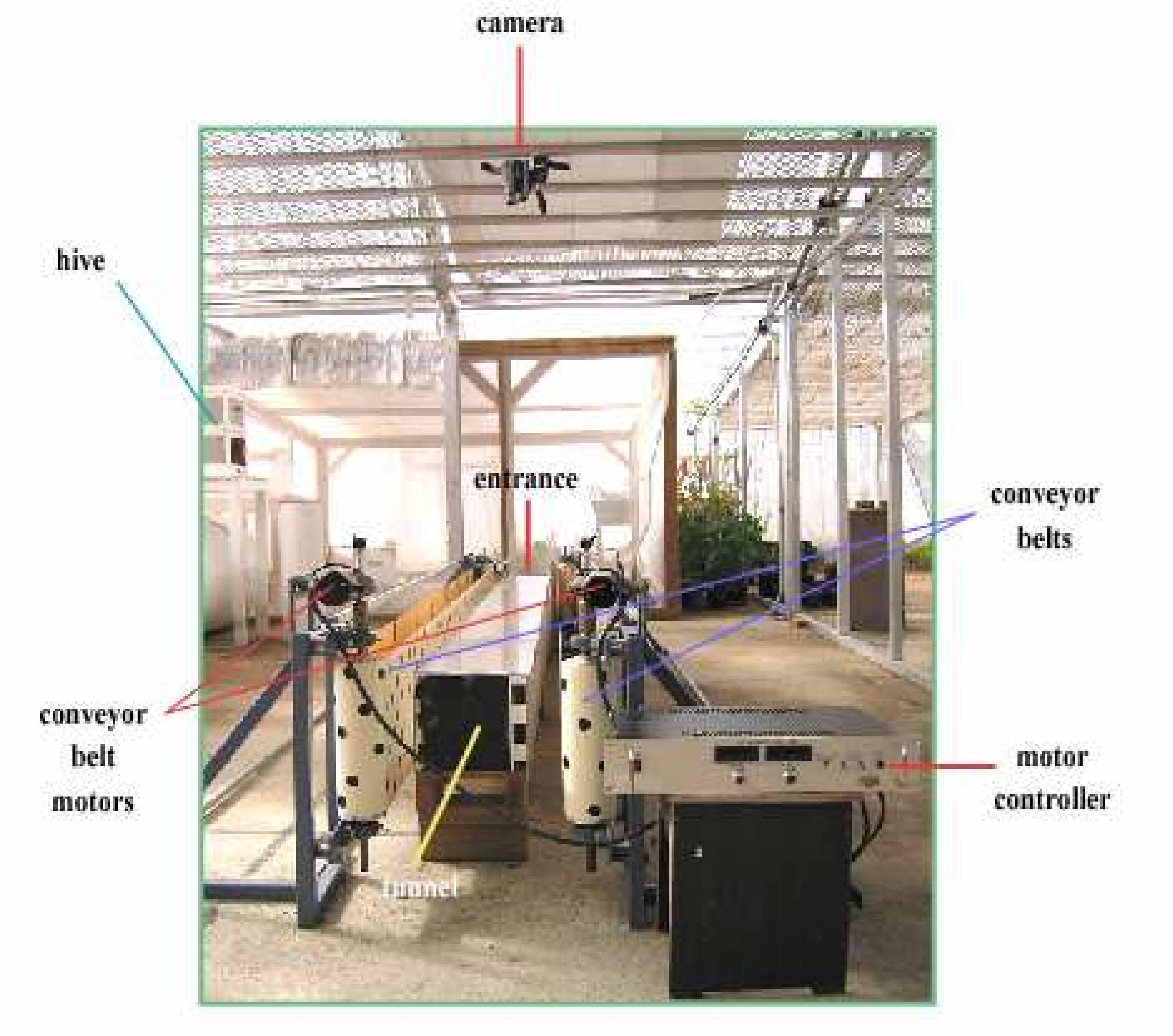




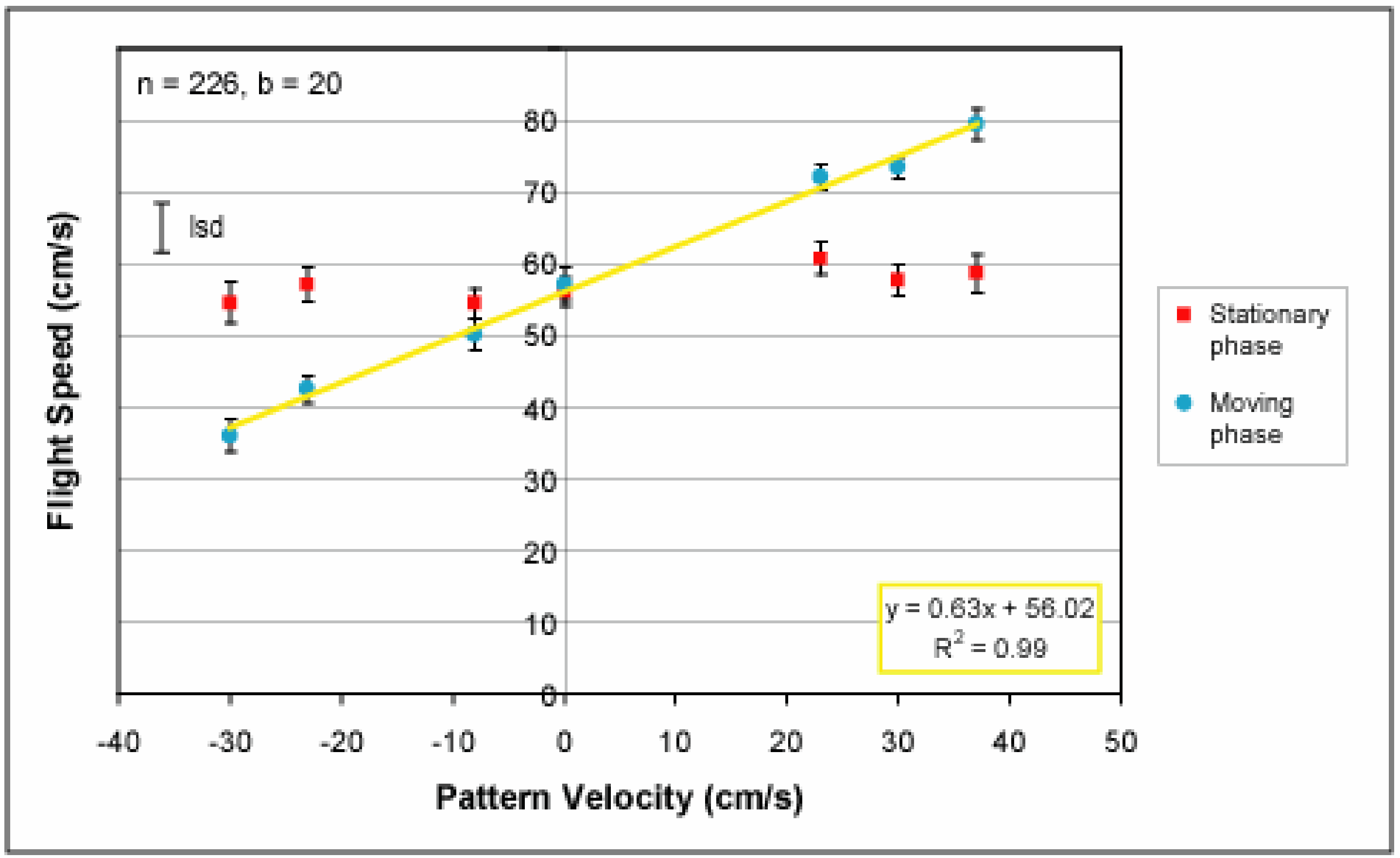
Kirchner & Srinivasan
Naturwissenschaften (1988)

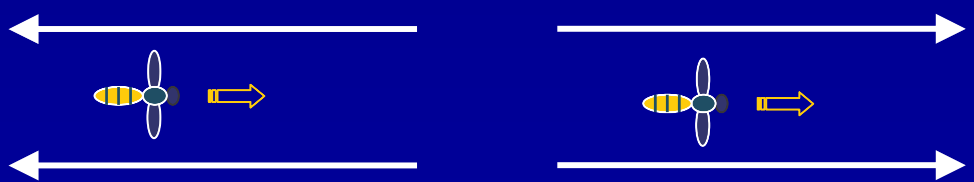
Srinivasan, Lehrer, Kirchner & Zhang
Vis. Neurosci. (1991)

Indoor tunnel: AWBFF



Transient change of optic flow: static to moving



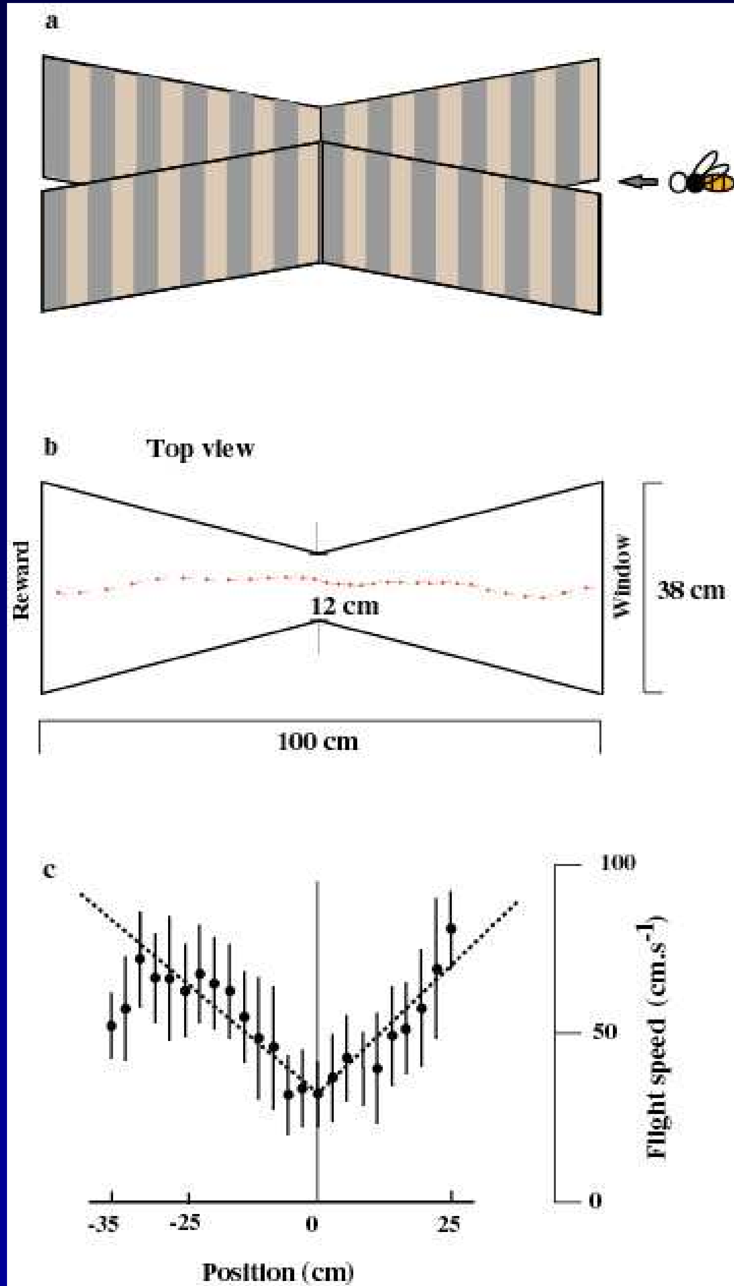


Baird, Srinivasan & Zhang, JEB 2005

Control of flight speed

Speed of flight is regulated by holding the global image velocity constant

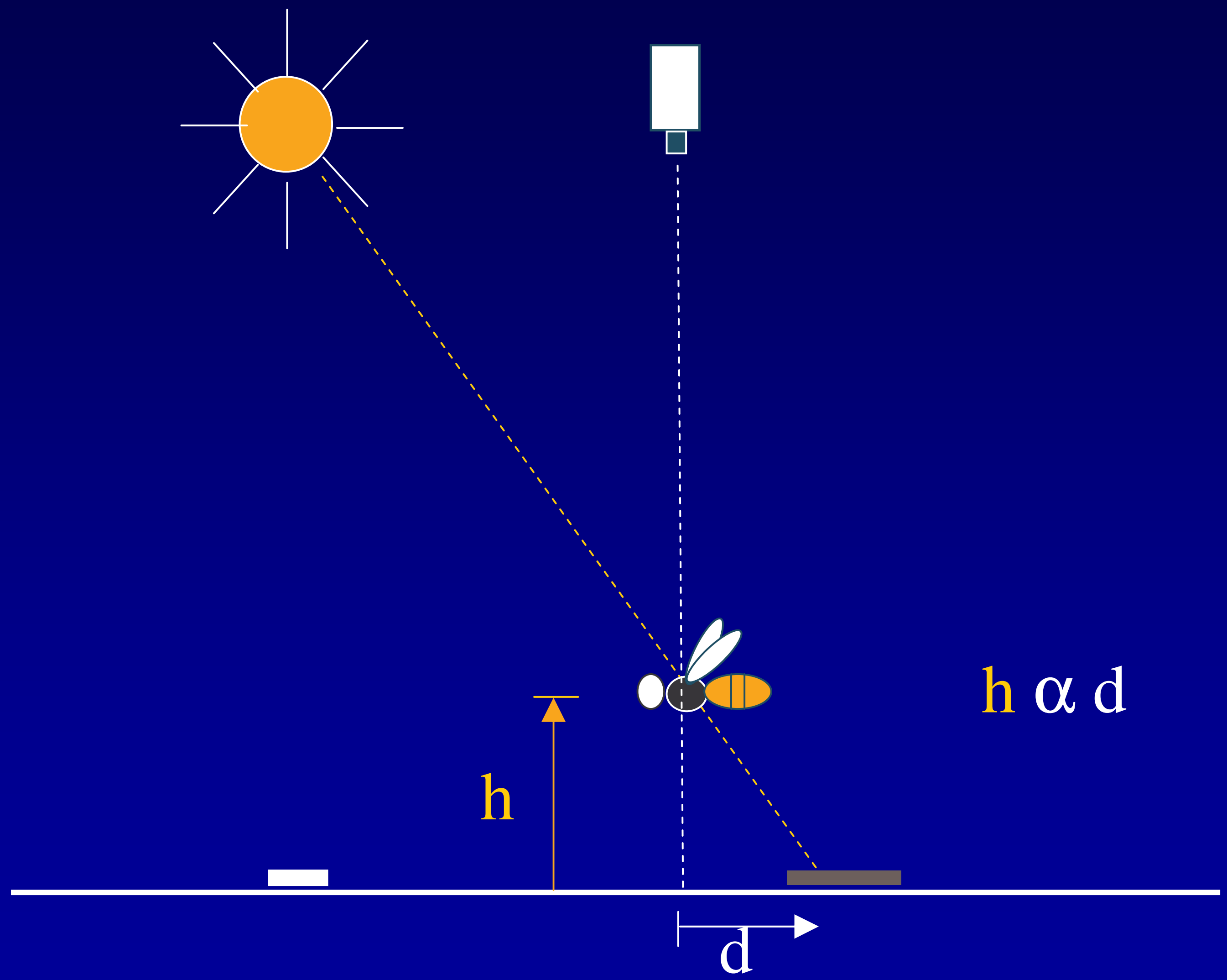
Srinivasan, Zhang, Lehrer & Collett
J. Exp. Biol. (1996)



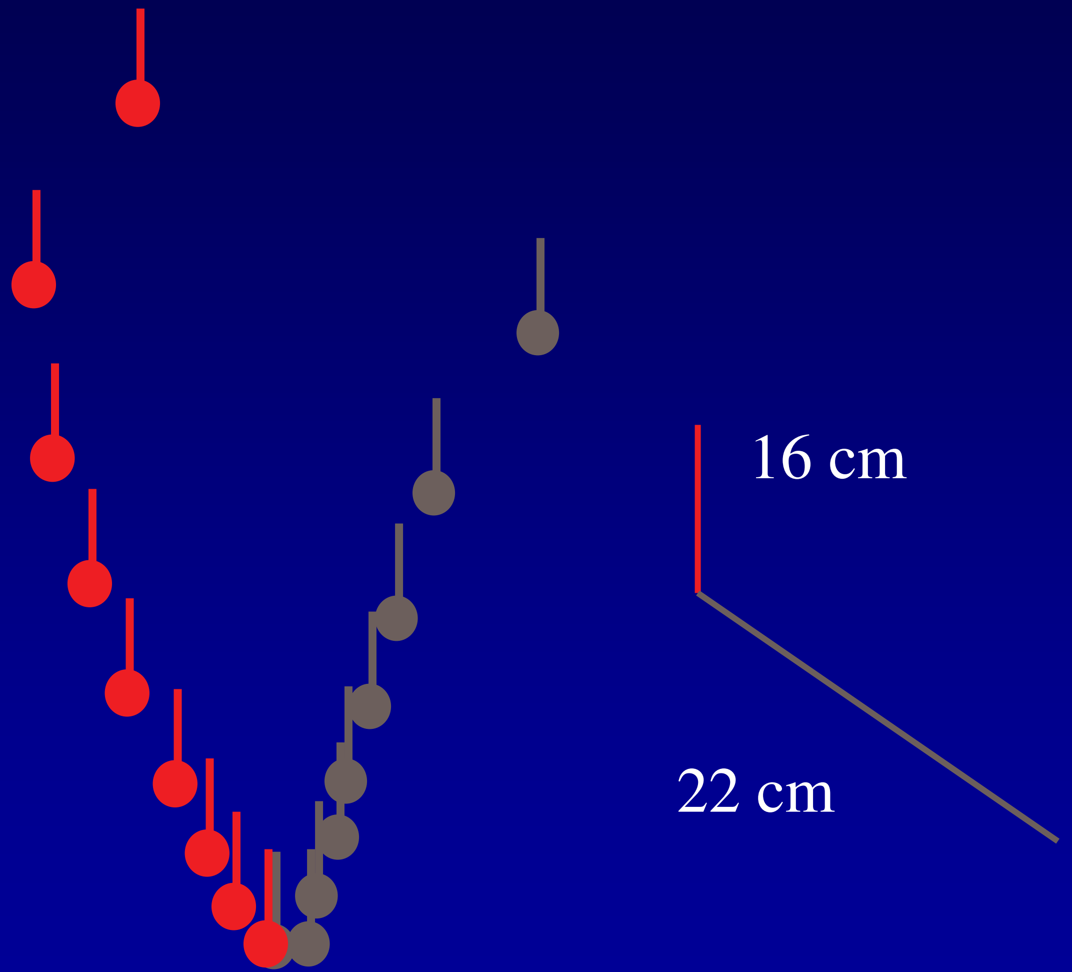
Landing

How does a bee perform a smooth, grazing landing on a horizontal surface ?

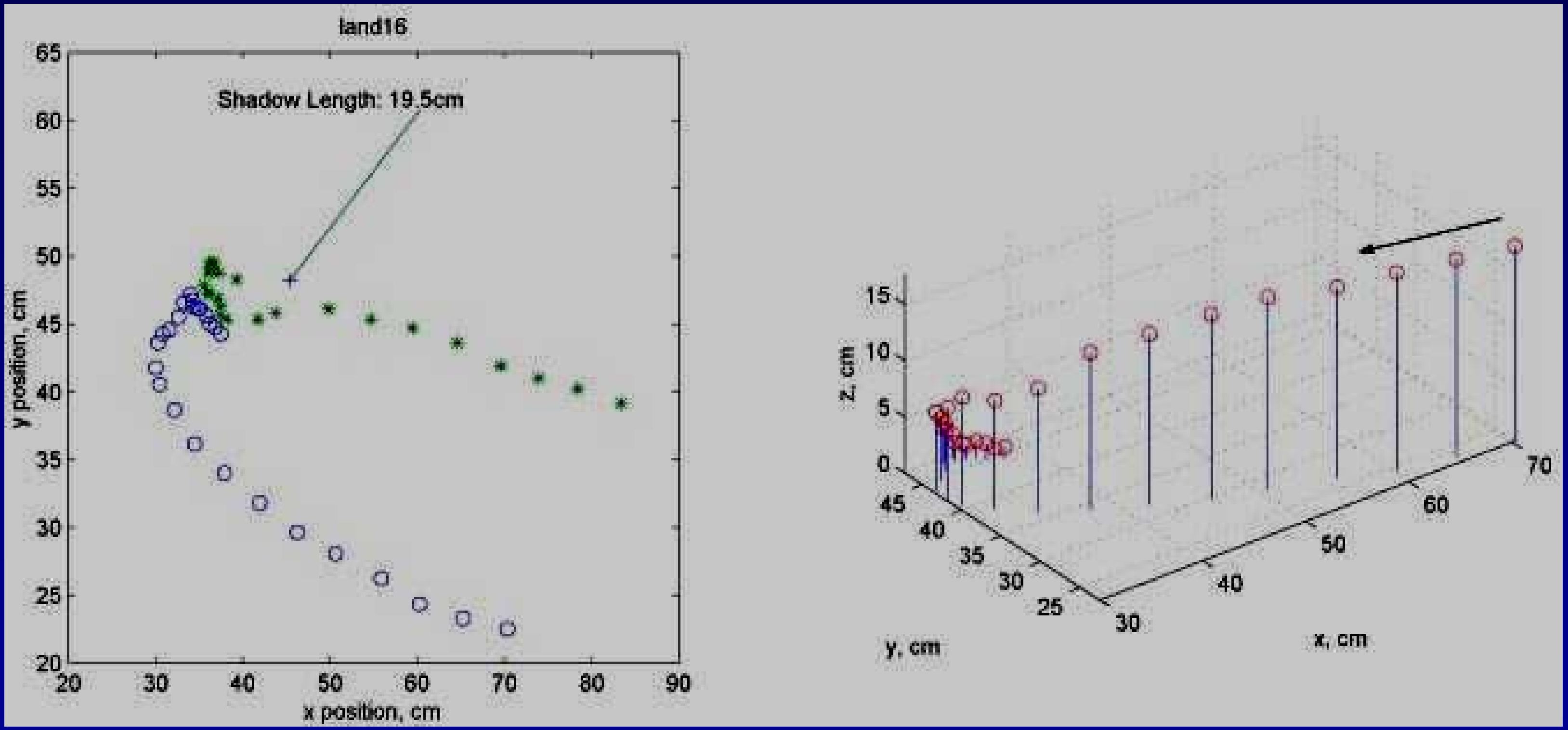
Filming trajectories of landing bees in 3-d



Typical landing trajectory

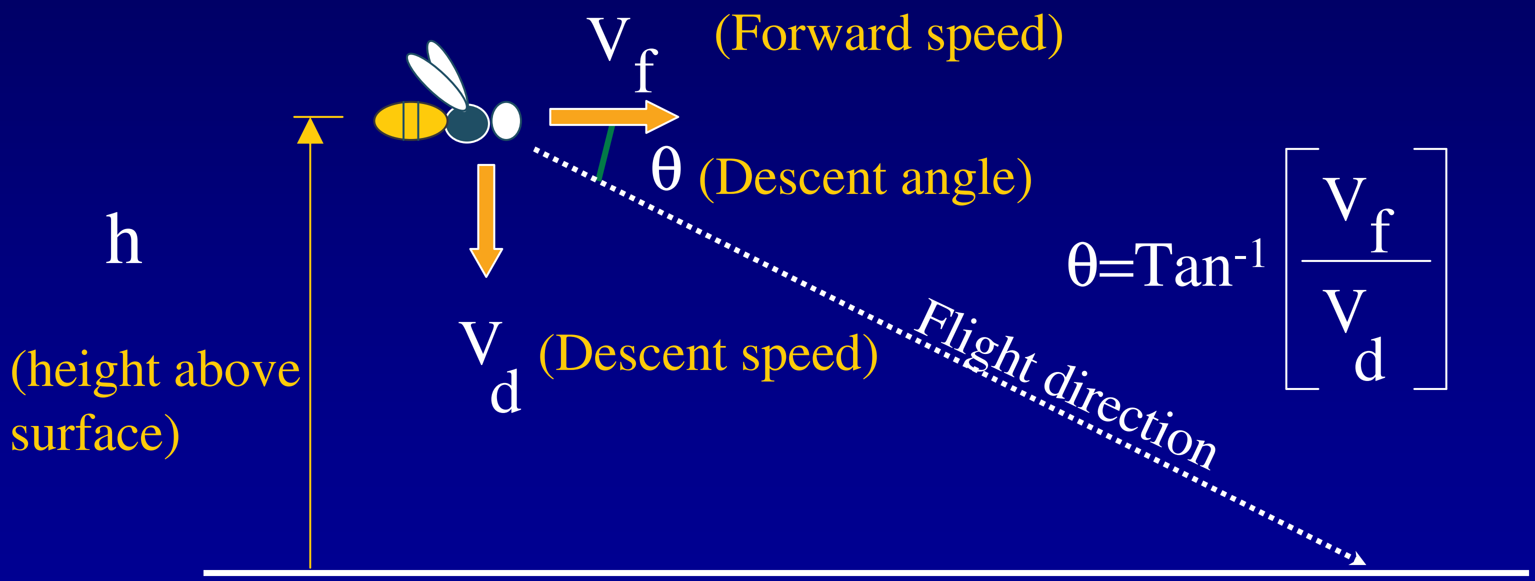


Reconstruction of landing trajectories in 3d

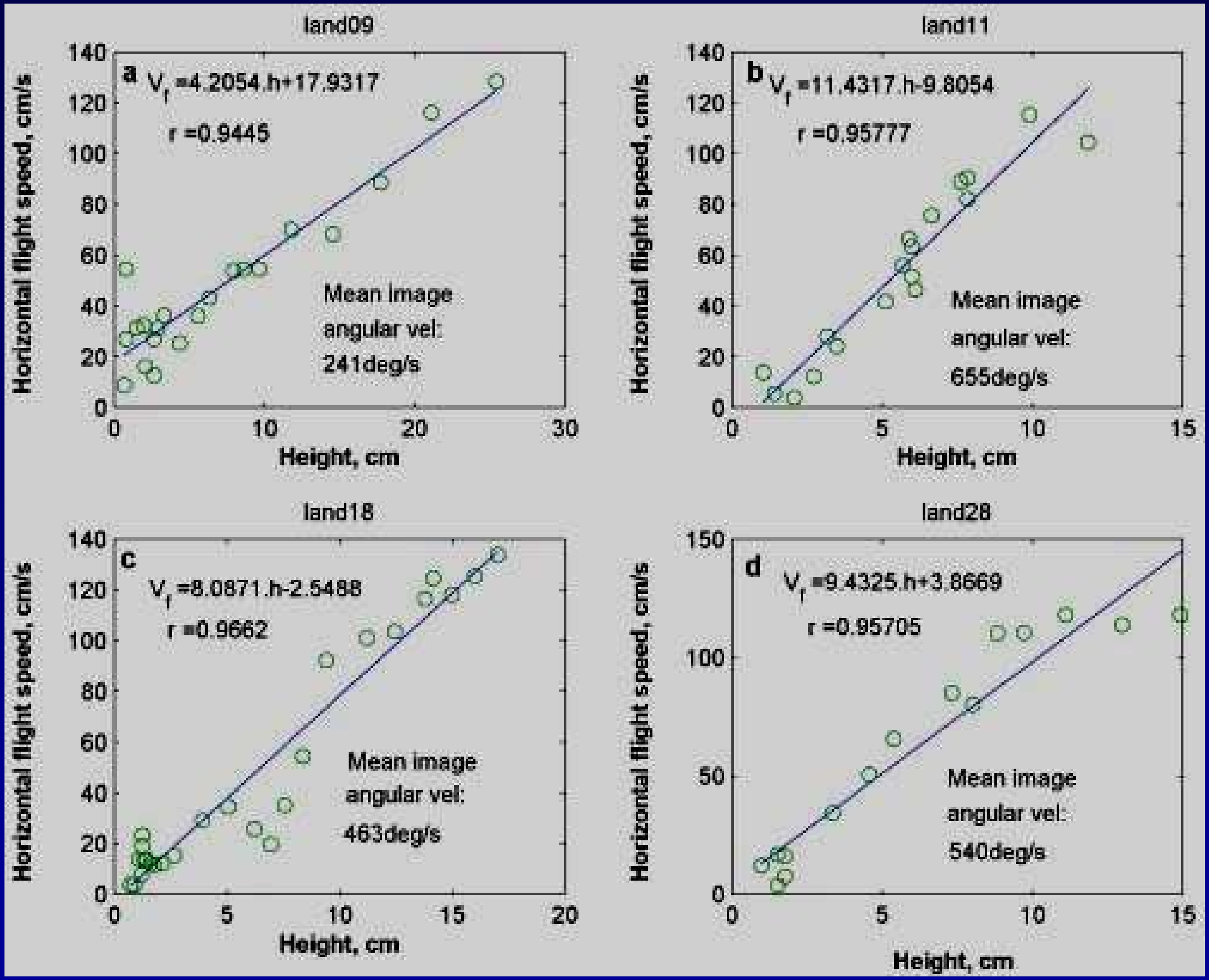


Srinivasan, Zhang, Chahl, Barth & Venkatesh, *Biol. Cybern.* (2000)

Landing parameters



Horizontal flight speed versus height



Srinivasan, Zhang, Chahl, Barth & Venkatesh, *Biol. Cybern* (2000)

Rules for landing

1. Ground image speed is held constant

$$V_f(t) = \omega . h(t)$$

2. Instantaneous descent speed $V_d(t)$ is coupled to instantaneous forward flight speed $V_f(t)$:

$$V_d(t) = -\frac{dh(t)}{dt} = B.V_f(t)$$

Rules for landing

- Forward flight speed $V_f(t)$ is proportional to instantaneous height $h(t)$ above ground:

$$V_f(t) = \omega.h(t) \qquad (1)$$

where ω is the angular velocity of the image in radians/sec.

- Make descent speed $V_d(t)$ proportional to forward flight speed $V_f(t)$:

$$V_d(t) = -\frac{dh(t)}{dt} = B.V_f(t) \qquad (2)$$

Inserting (1) into (2),

$$B.\omega.h(t) + \frac{dh(t)}{dt} = 0 \qquad (3)$$

which can be solved for $h(t)$ to yield

$$h(t) = h(t_0).e^{-\omega.B.(t-t_0)} \qquad (4)$$

where $h(t_0)$ is the height at the initial time $t = t_o$.

$\Rightarrow$ ***Height decreases exponentially with time***

Inserting (4) into (1),

$$V_f(t) = \omega.h(t_0).e^{-\omega.B.(t-t_0)}$$

(5)

$\Rightarrow$ ***Forward speed decreases exponentially with time***

Inserting (5) into (2),

$$V_d(t) = B.\omega.h(t_0).e^{-\omega.B.(t-t_0)}$$

(6)

$\Rightarrow$ ***Descent speed also decreases exponentially with time***

Dividing (6) by (5),

$$\frac{V_d(t)}{V_f(t)} = B$$

(7)

as required by the descent constraint.

- Cumulative horizontal distance travelled $(Hordist)$:

$$Hordist = \int_{t_0}^{t} V_f(t).dt = \int_{t_0}^{t} \omega.h(t_0).e^{-\omega.B.(t-t_0)}.dt \qquad (8)$$

Integrating, we get

$$Hordist = \frac{h(t_0)}{B}.\left[1 - e^{-\omega.B.(t-t_0)}\right]$$

(9)

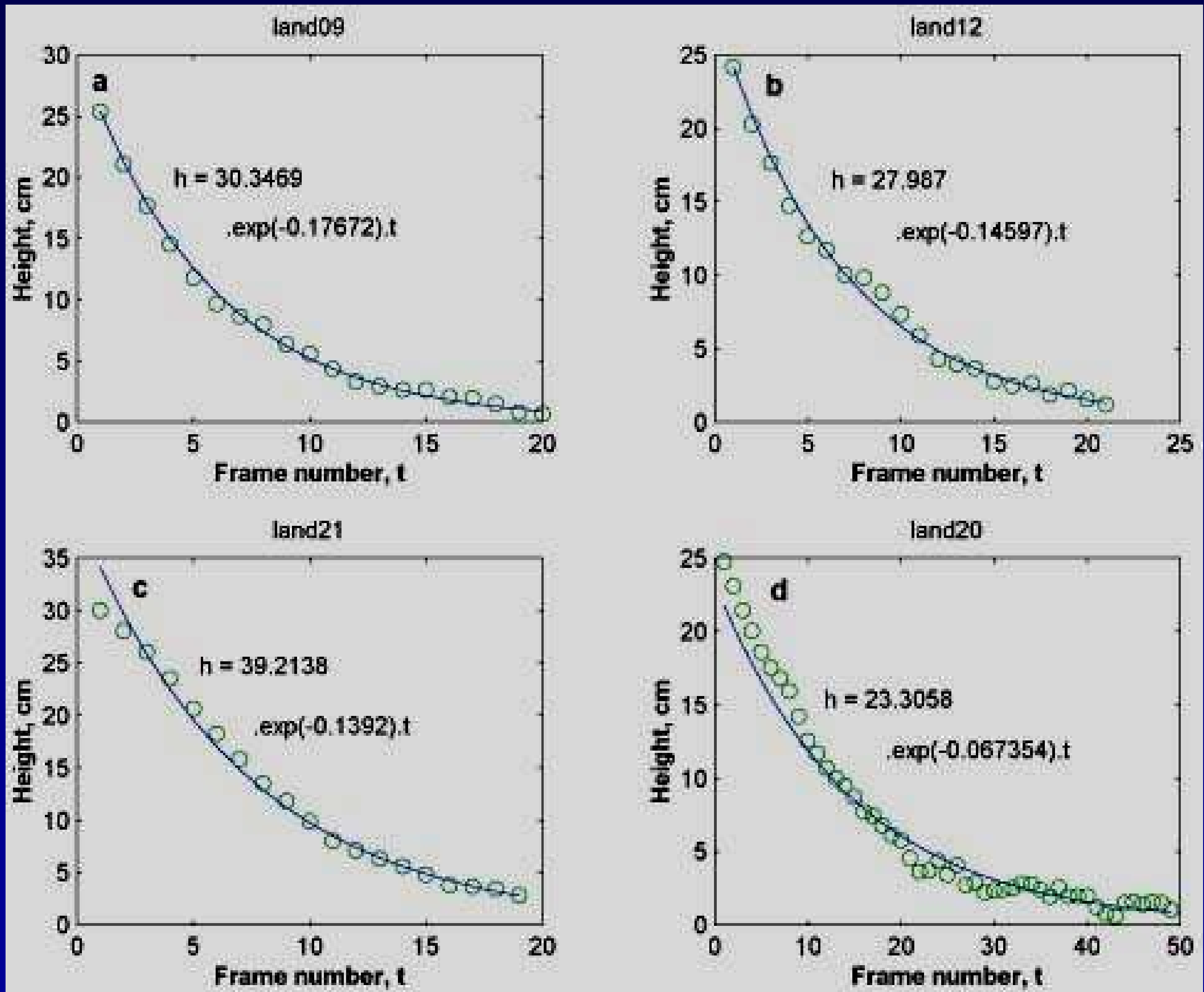
$\Rightarrow$ ***Horizontal distance travelled is a saturating exponential function of time***

Model prediction 1:

$$h(t) = h(t_0).e^{-\omega.B.t}$$

$\Rightarrow$ Height decreases exponentially with time

Test of prediction 1



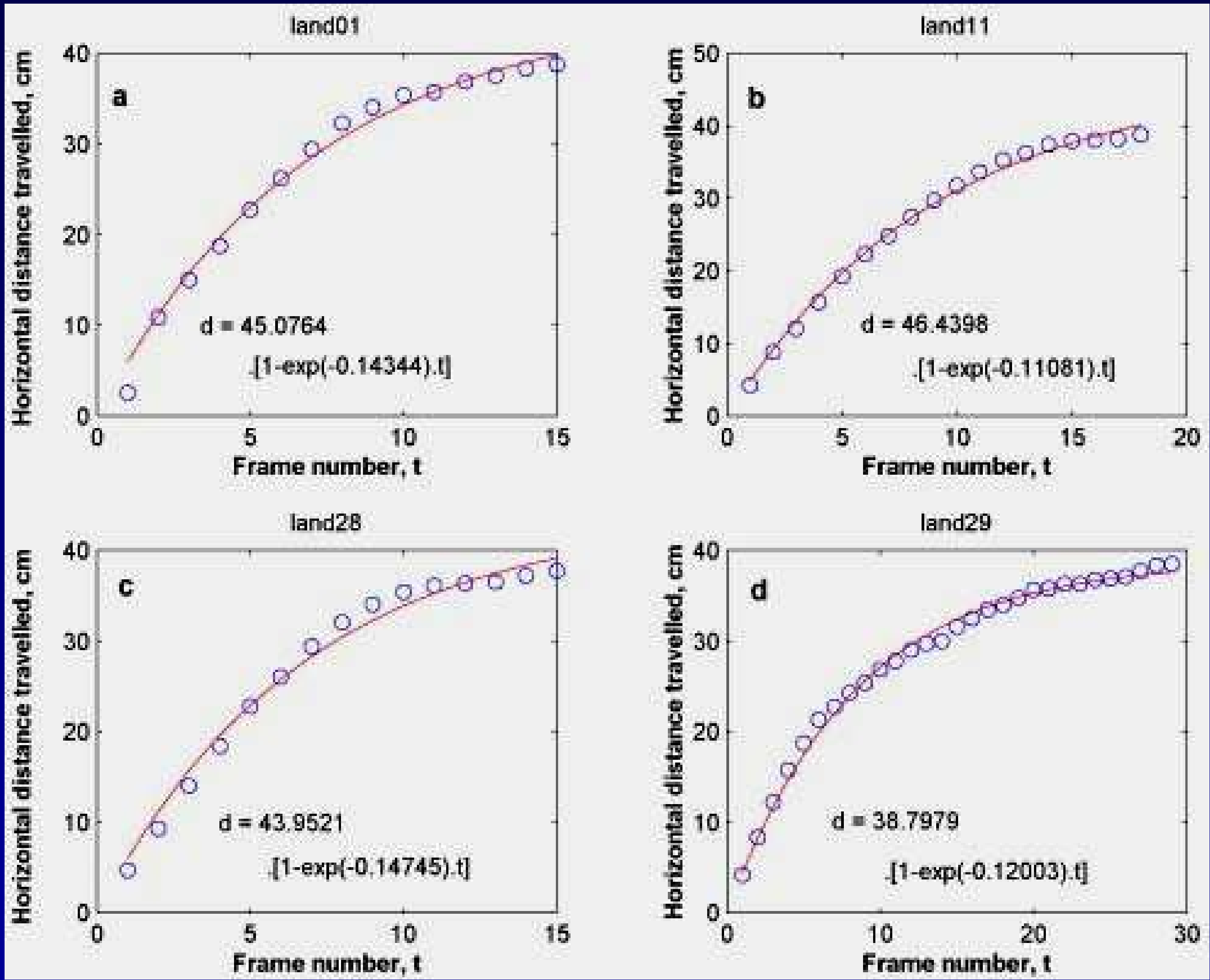
Srinivasan, Zhang, Chahl, Barth & Venkatesh, *Biol. Cybern* (2000)

Model prediction 2:

$$Hordist = \frac{h(t_0)}{B}.\left[1 - e^{-\omega.B.t}\right]$$

$\Rightarrow$ Cumulative horizontal distance travelled is a saturating exponential function of time

Test of Prediction 2



Srinivasan, Zhang, Chahl, Barth & Venkatesh, *Biol. Cybern* (2000)

Projected time to touchdown

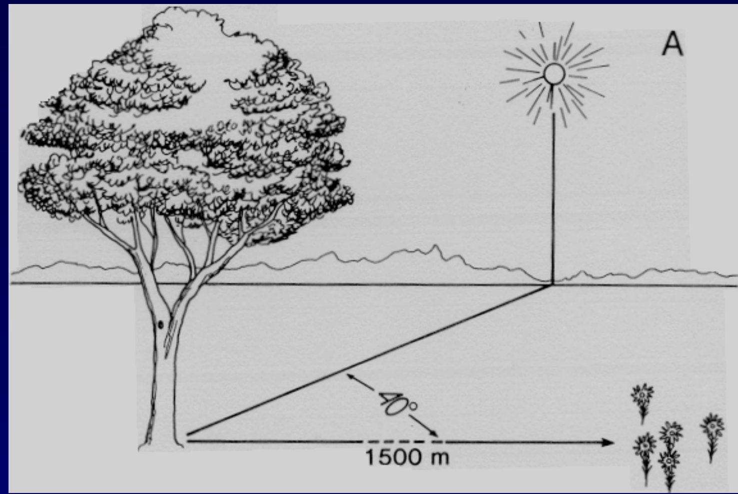
$$TTT = \frac{1}{B.\omega}$$

$$\simeq 0.22 \text{ sec}$$

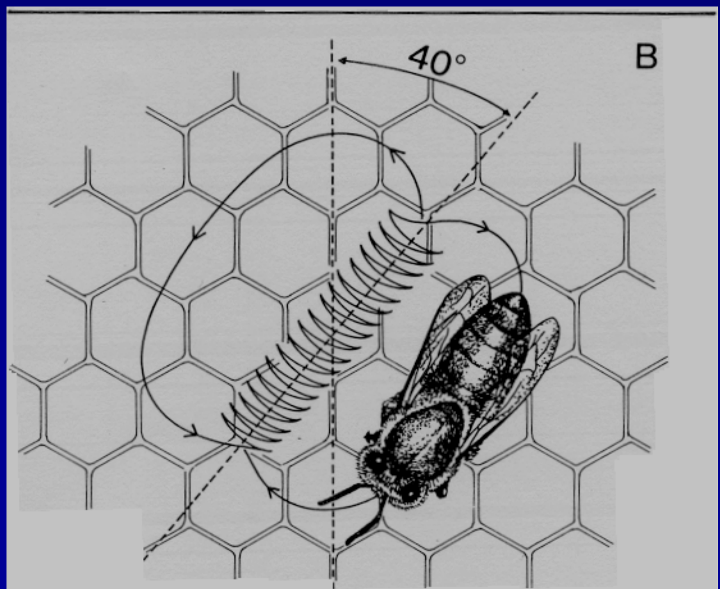
Is constant through the landing process!

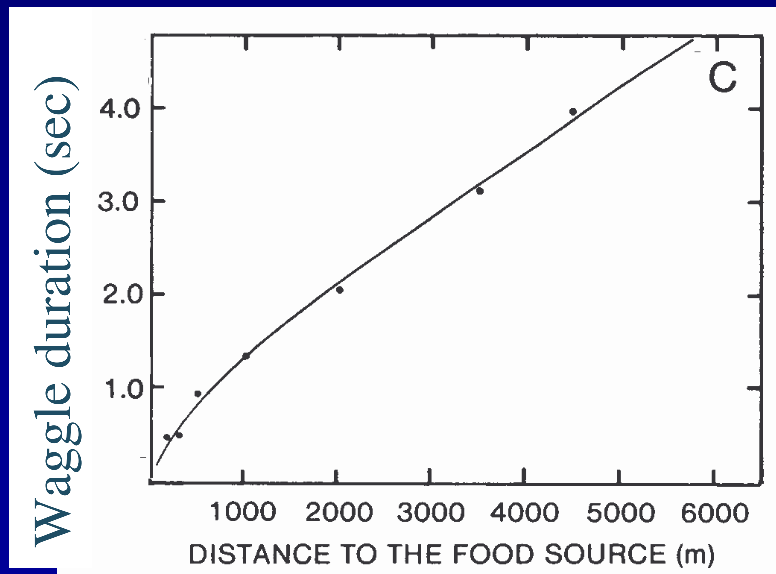
Honeybee odometry

The waggle dance

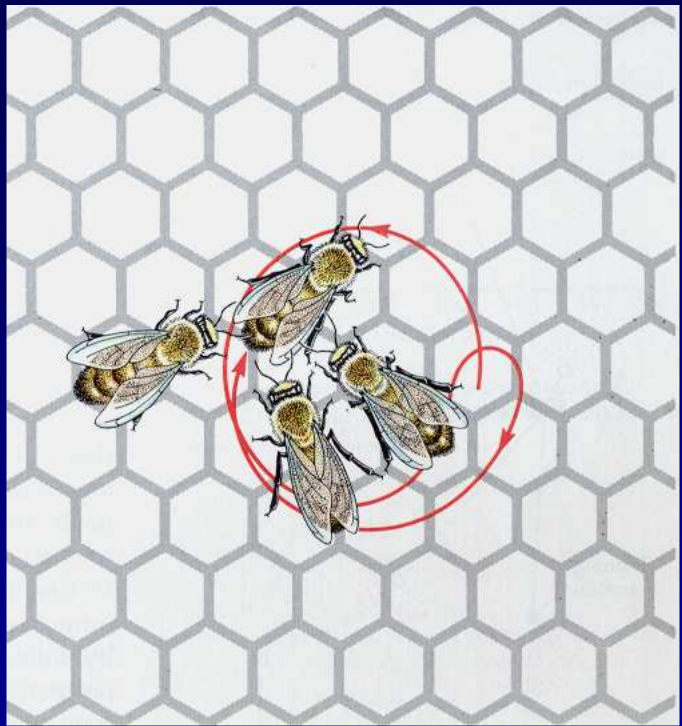


Q: How does a bee work out how far she has flown?



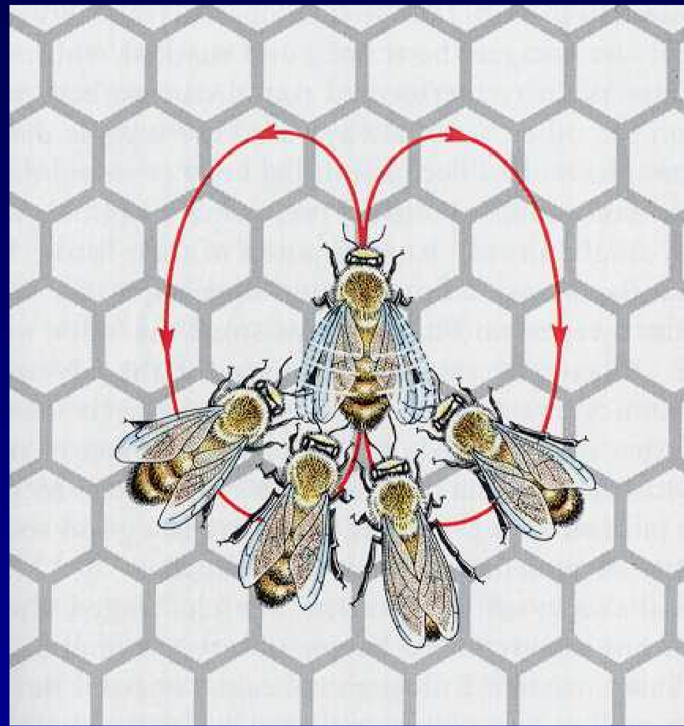



1H00M00s



Round dance

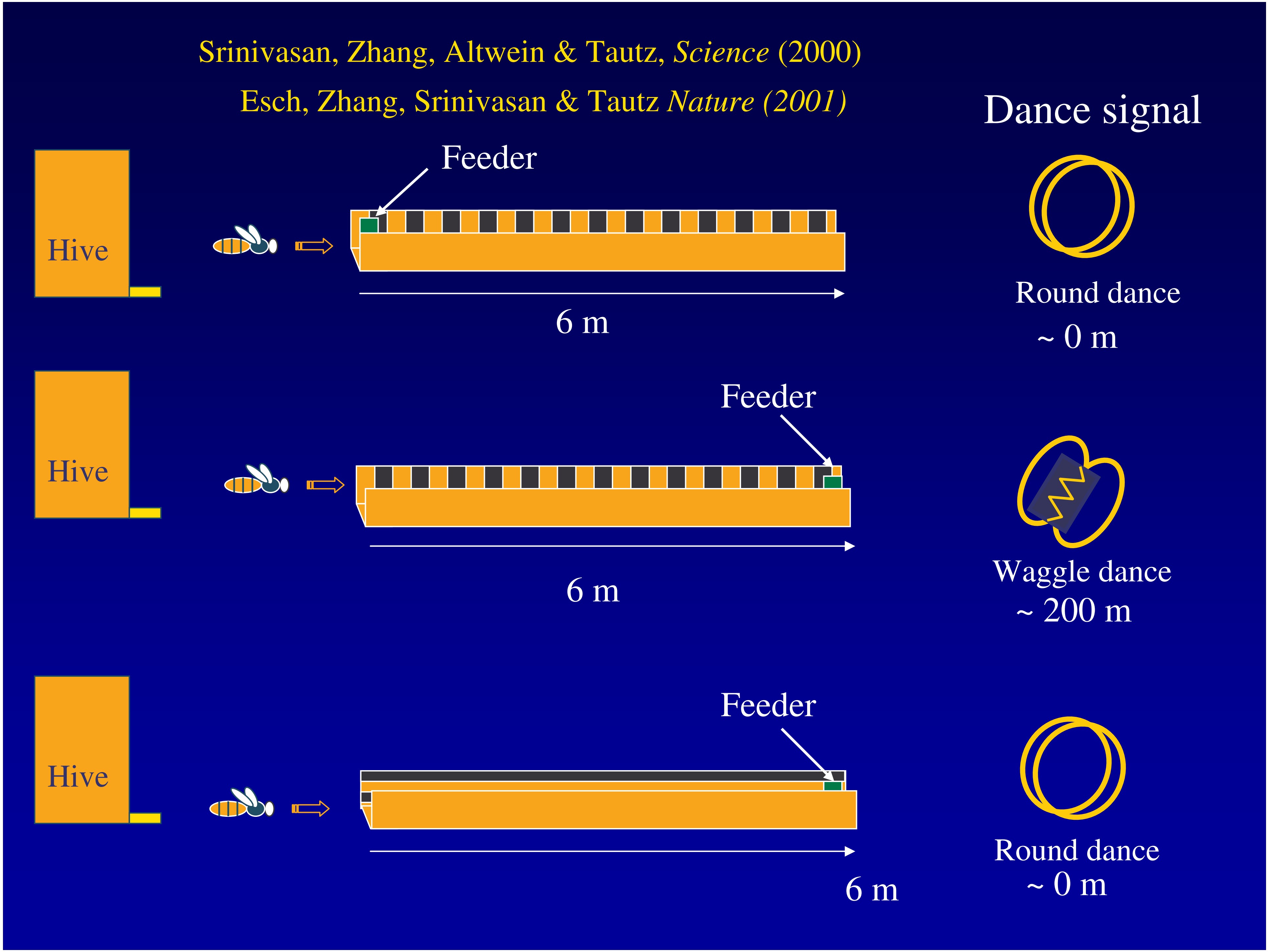
(feeder distance < 50m)



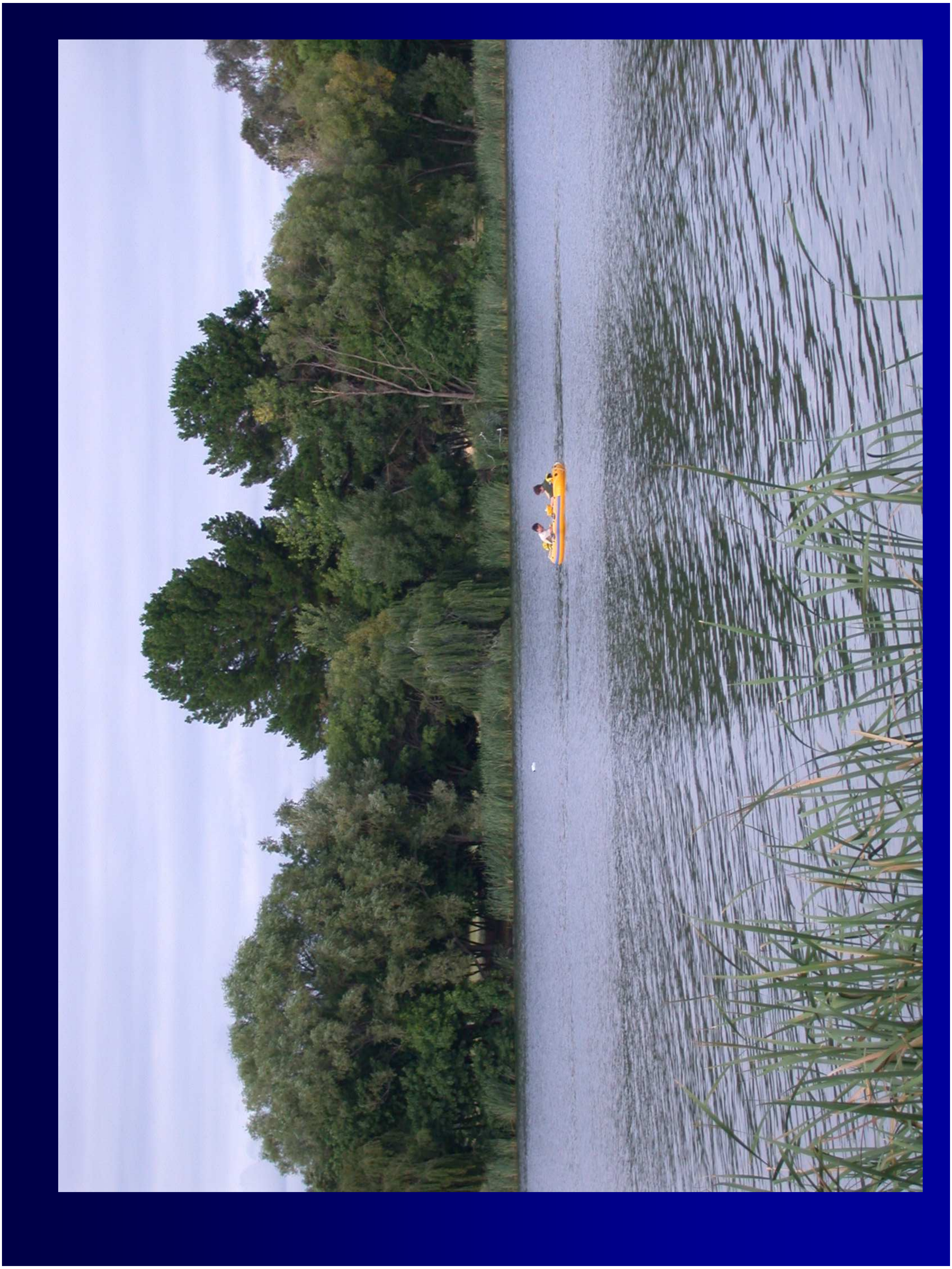
Waggle dance

(feeder distance > 50m)

What distance do bees “perceive” when they fly inside a narrow tunnel?

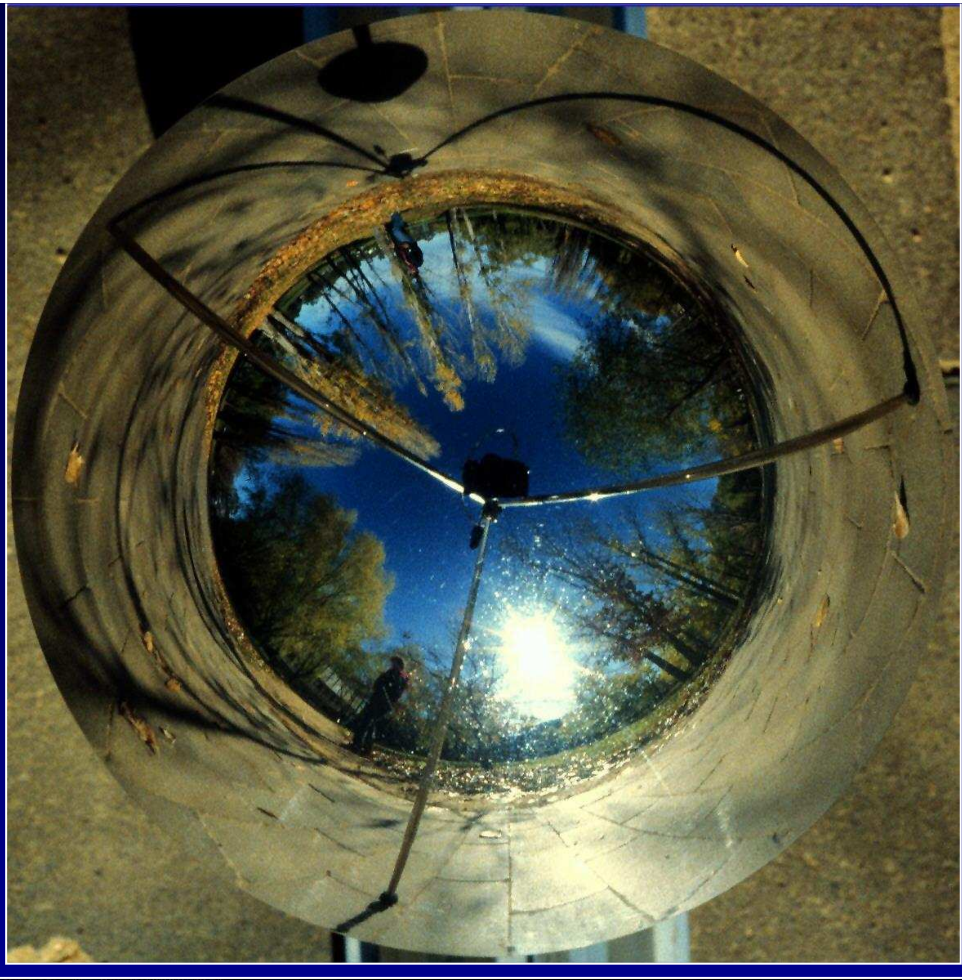

Srinivasan, Zhang, Altwein & Tautz, *Science* (2000)
Esch, Zhang, Srinivasan & Tautz *Nature (2001)*
Dance signal
Hive
Feeder
6 m
Round dance
~ 0 m
Hive
Feeder
6 m
Waggle dance
~ 200 m
Hive
Feeder
6 m
Round dance
~ 0 m

Tautz, Zhang, Spaethe, Brockmann, Aung Si, Srinivasan (*PLOS Biology*, 2004)



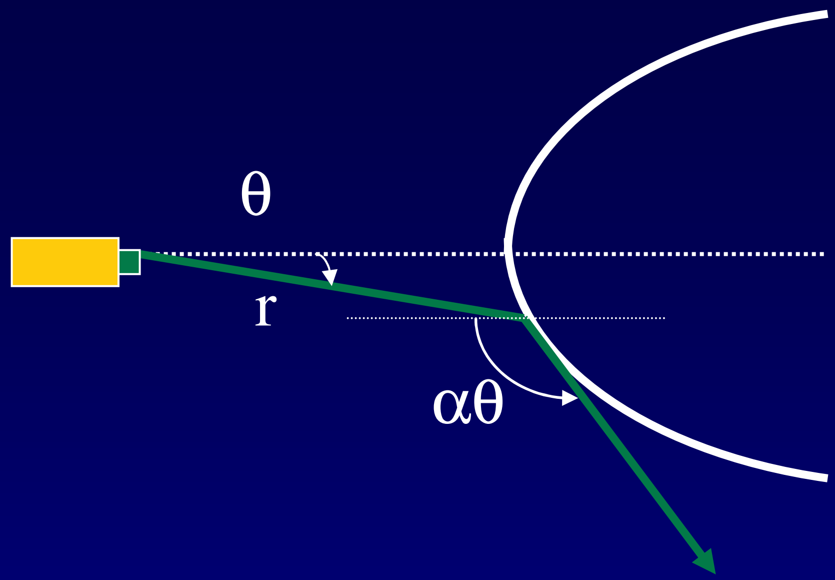
Panoramic Imaging System

Image acquired by camera



Digitally unwarped panoramic image

Panoramic Imaging System



The system comprises a standard video camera viewing a specially shaped reflective surface. The surface has the property that a given change in the angular elevation of view in the external environment maps to a constant radial displacement in the camera's image

$$\frac{d}{d\theta}\left[\tan^{-1}\left(r\frac{d\theta}{dr}\right)\right] = \kappa$$

where $\kappa = -(1+\alpha)/2$

$$\Rightarrow \quad \mathrm{Sin}[A-\theta(1+\alpha)/2] = (Br)^{(1-\alpha)/2}$$

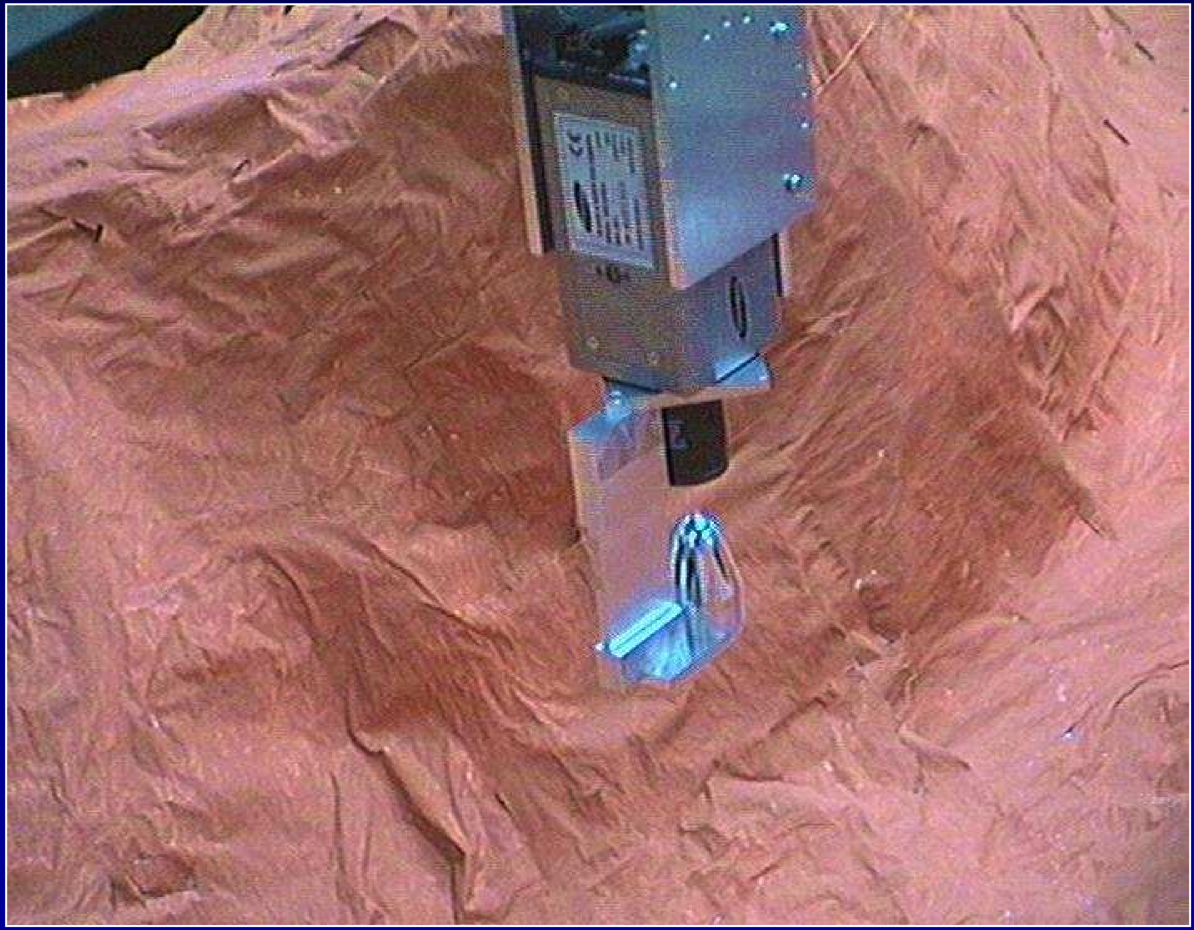
Constraint equation for generating profile of panoramic imaging surface

Constants of integration A and B are set by boundary conditions: distance r_0 and slope of surface at $\theta = 0$

Chahl & Srinivasan, *Applied Optics,* 1997

Navigation in 3-D

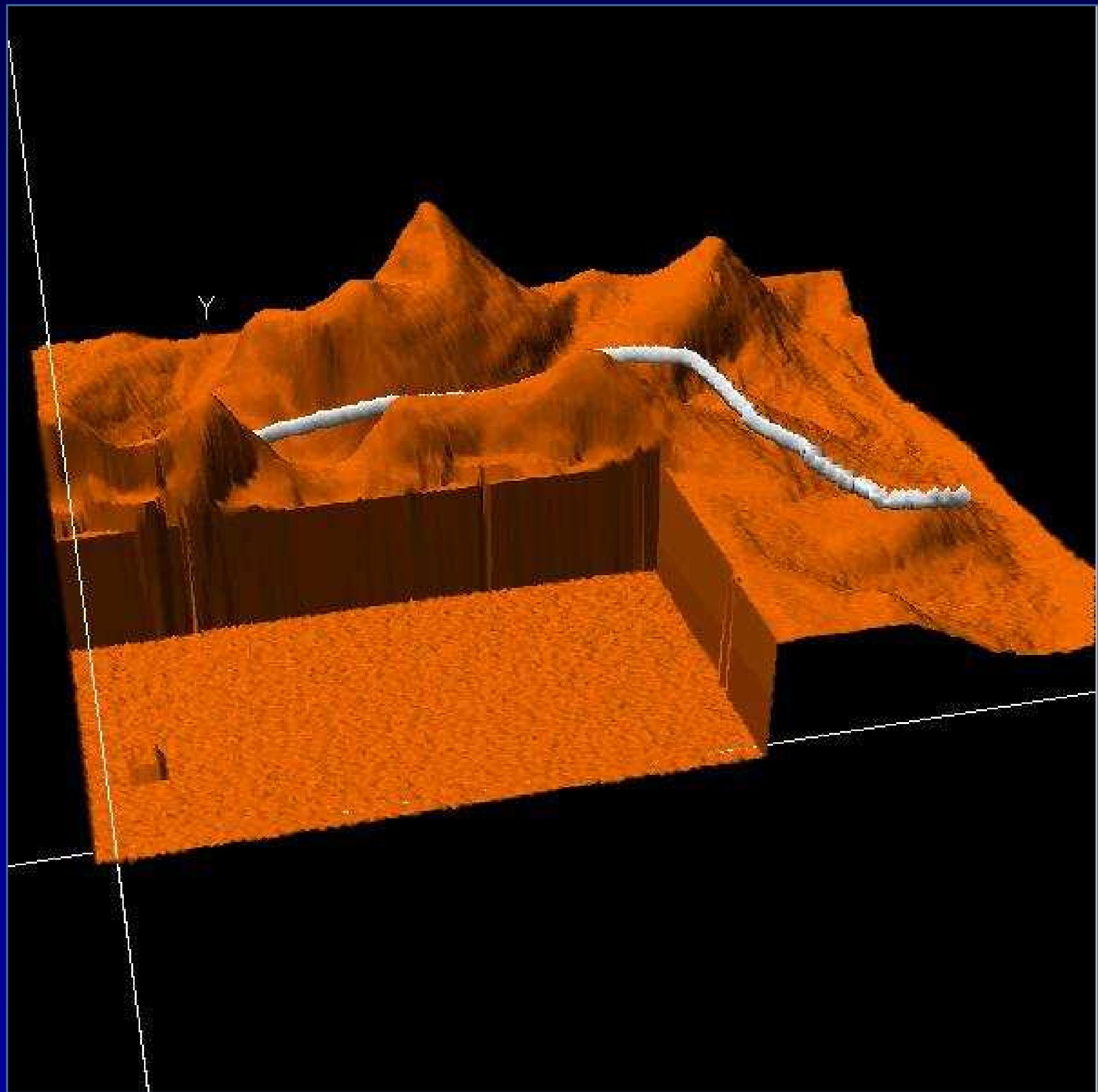
Gantry -based, insect-inspired navigation system emulates flight in realistic terrain



Navigation in 3-D(contd.)

Development and testing of algorithms for landing, terrain following, gorge following, obstacle avoidance and point-to-point navigation

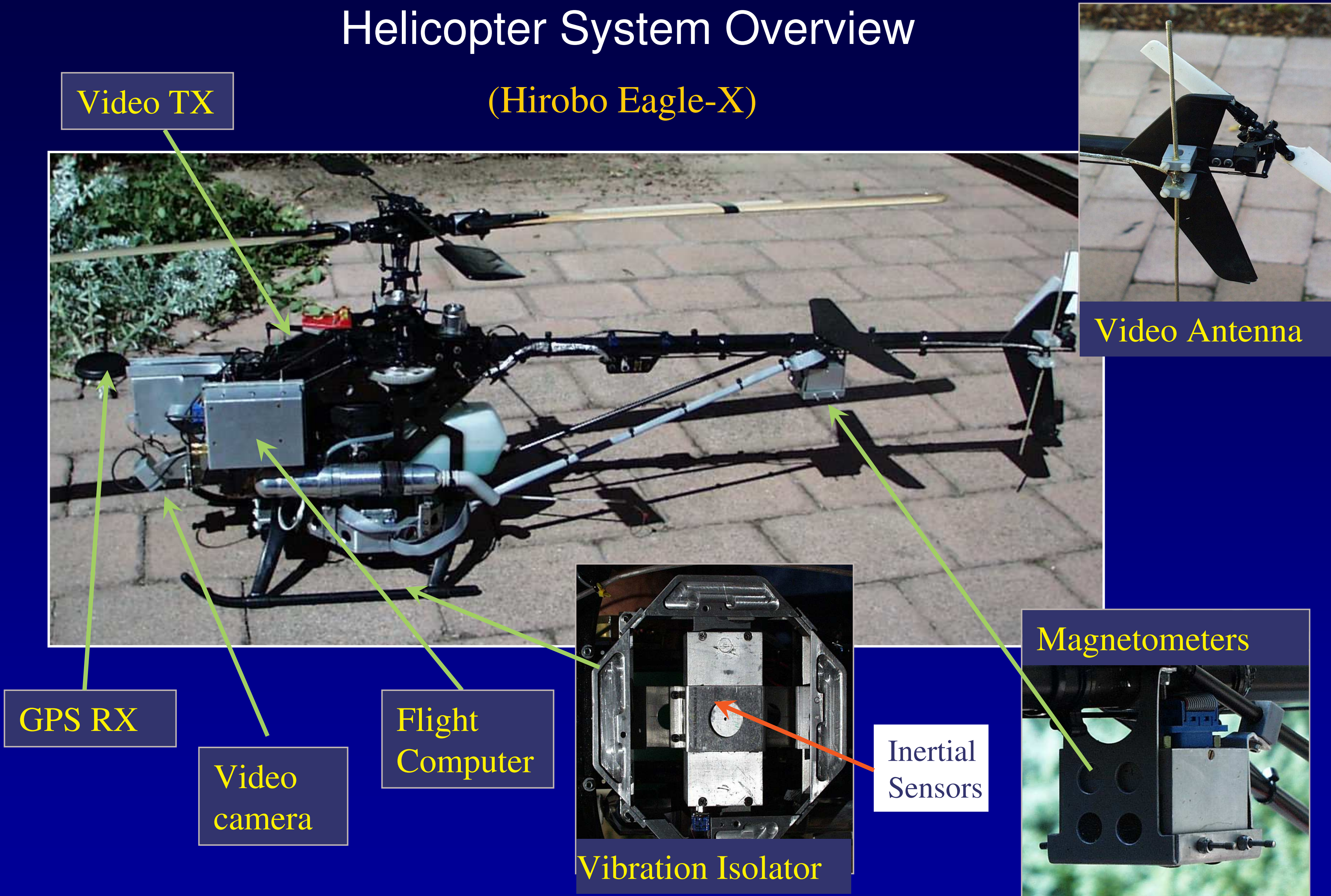
Chahl & Srinivasan (2000b)




Commands
Alt
50
200
700
Start

Helicopter System Overview

(Hirobo Eagle-X)

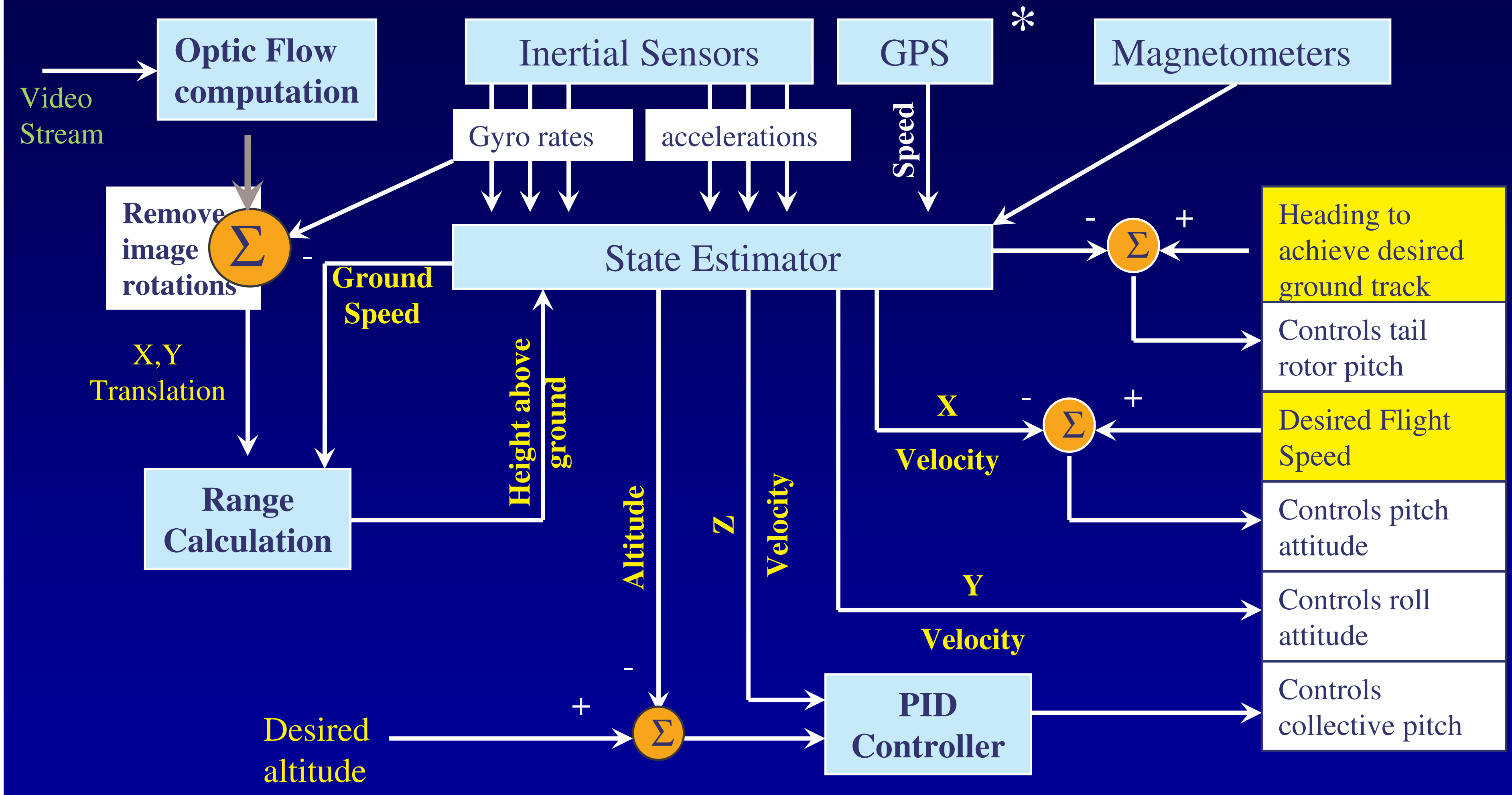


Visually Stabilized Hover

View of
helicopter

View from
helicopter

Forward Flight Controller Design



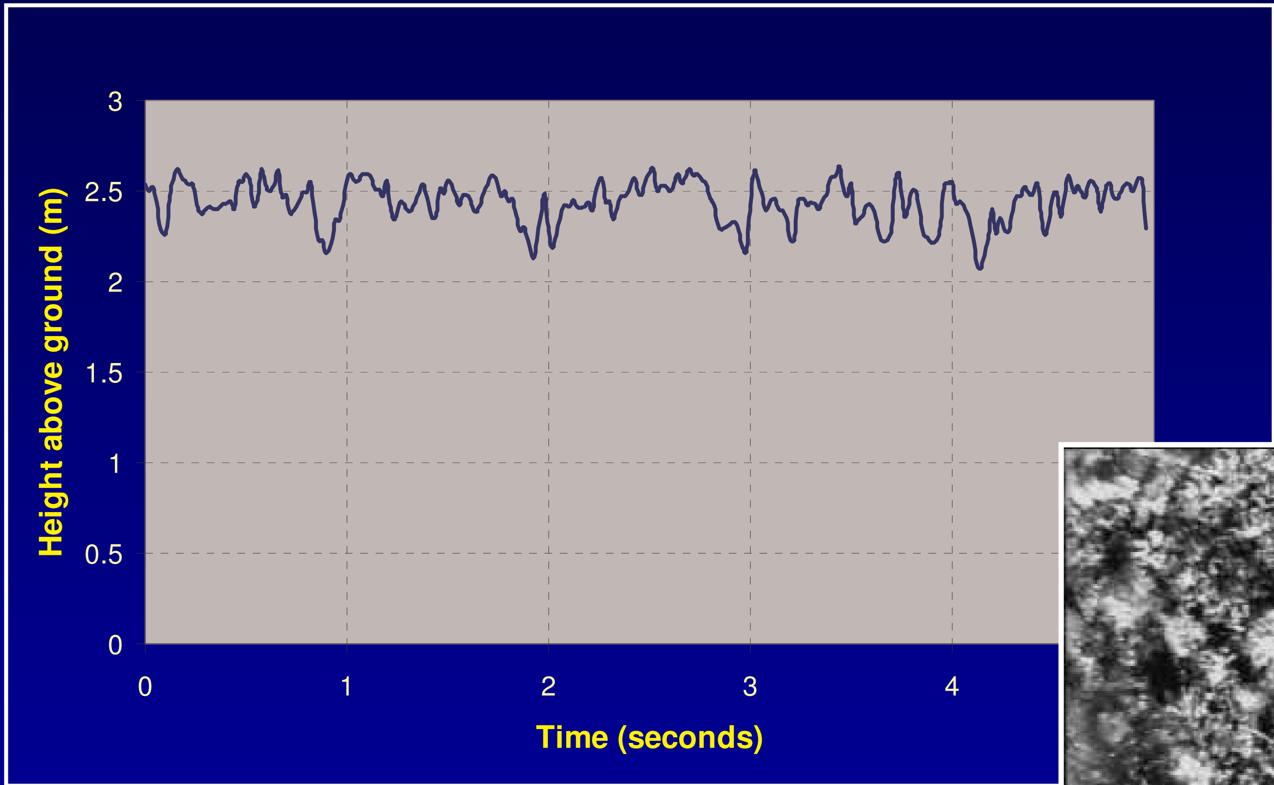
* GPS can be replaced with any suitable ground speed measure.

Field testing of forward flight controller

View from helicopter

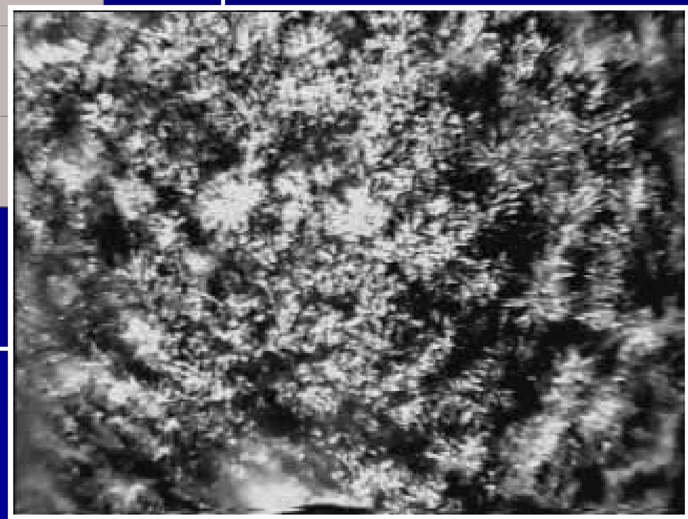
Method adopted for testing forward flight algorithms on actual helicopter. A safety pilot observes from the back of the chase vehicle, poised to take control from the automatic controller for take off, landing and in case of an emergency.

Flight test results for helicopter at 50 km/hr

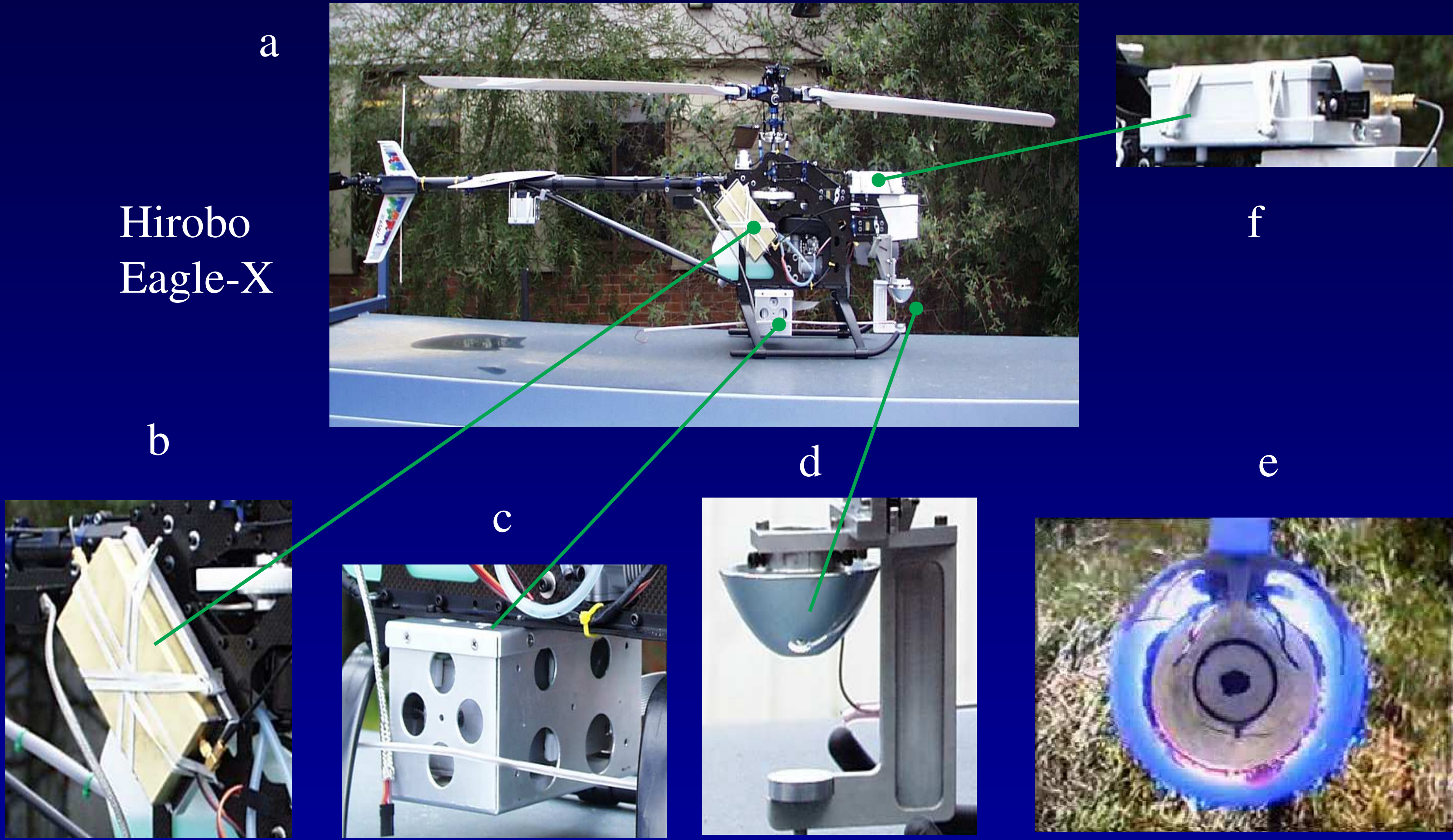


Height above ground calculated by optic flow

Image from downward looking camera

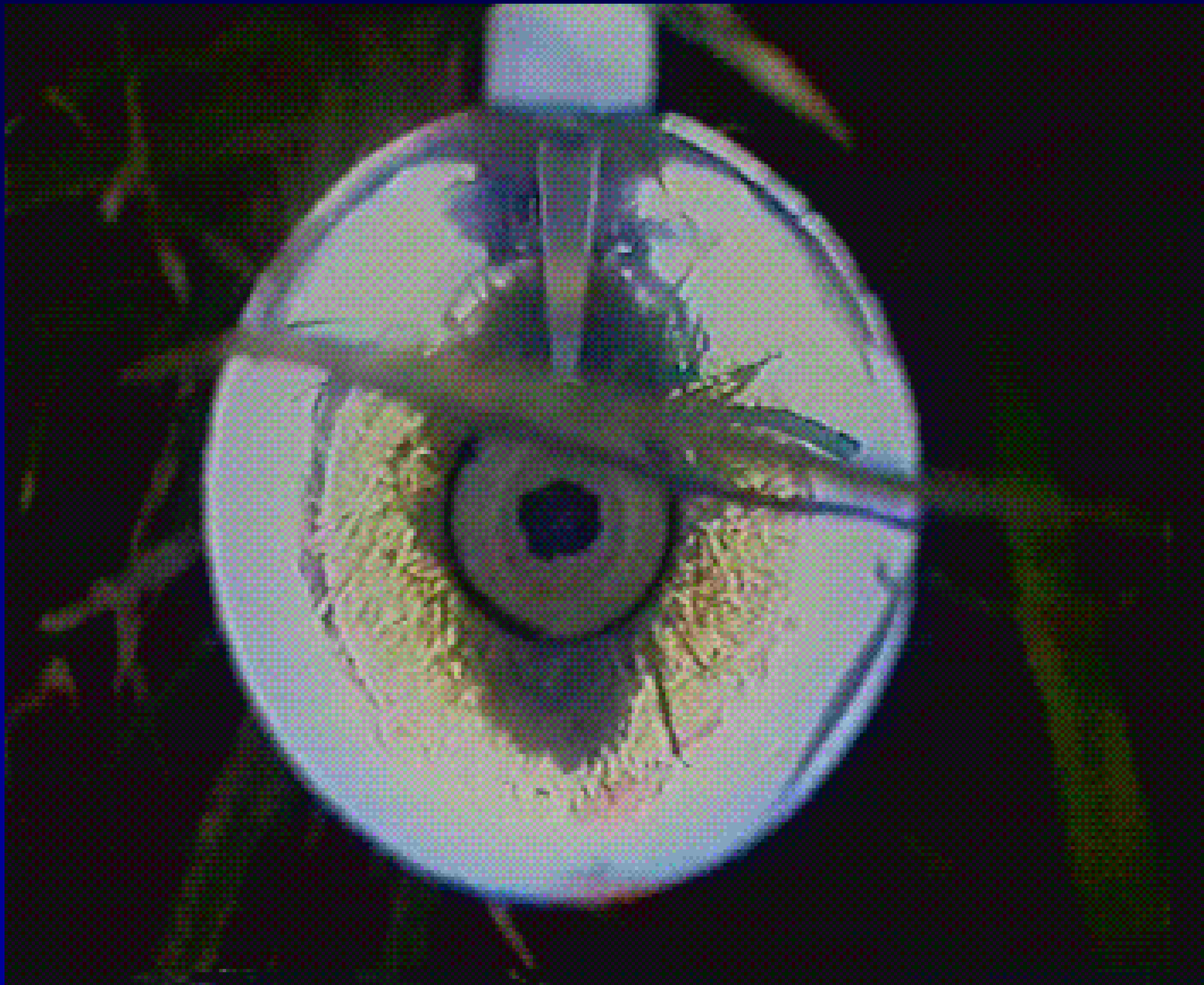


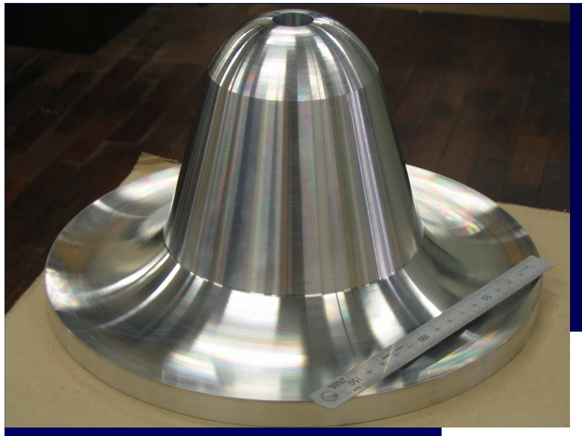
Helicopter system



Overview of one helicopter system showing (a) craft (ca. 1.5 m fuselage, 1600g payload), (b) video and telemetry transmitter (c) custom designed inertial sensor housing (d) in-house designed and patented panoramic optical system (e) in-flight panoramic image (f) flight computer

Panoramic video imaging from helicopter

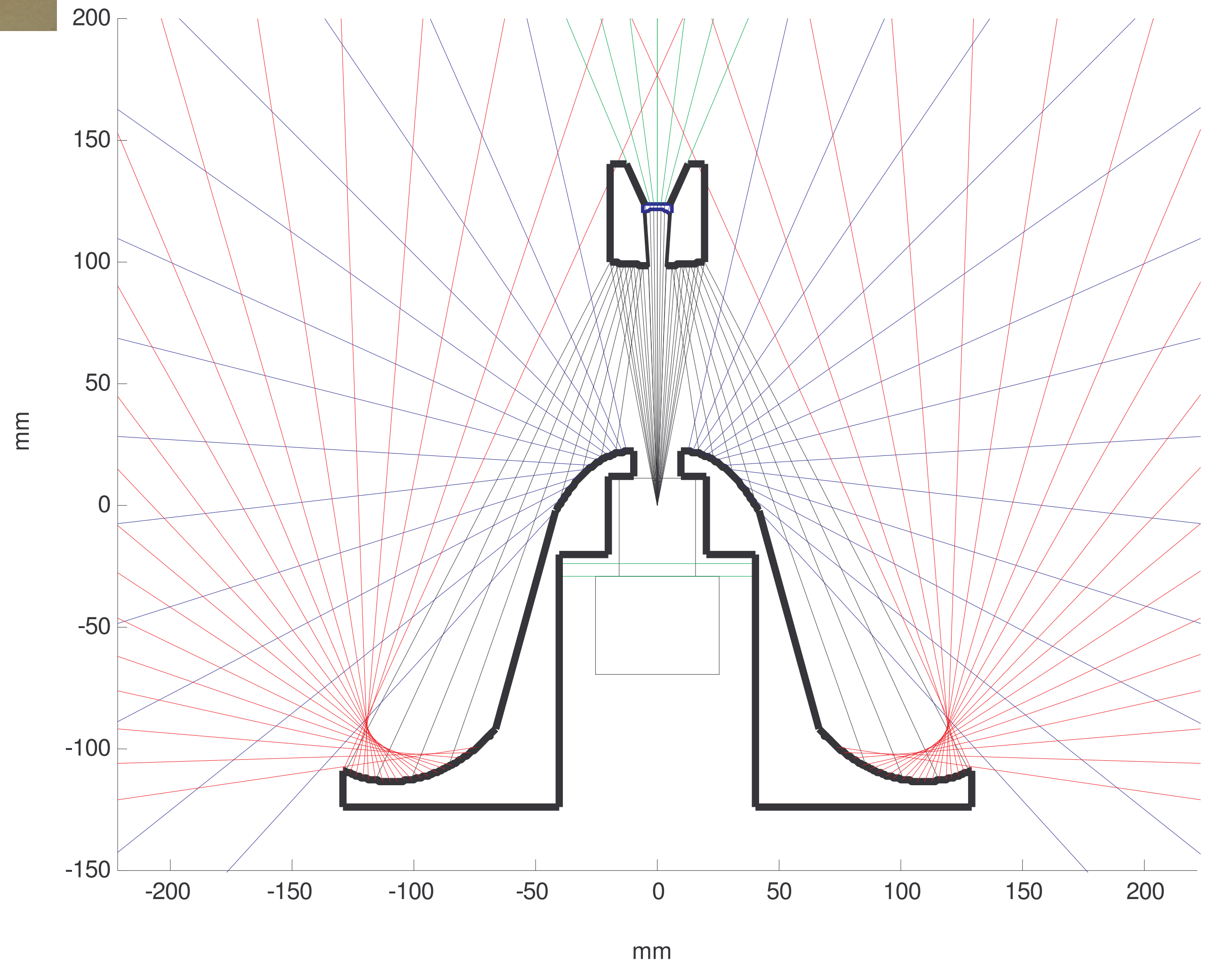




Vision system for panoramic stereo

Features:

- Panoramic stereo
- Frontal stereo
- Frontal mono to eliminate blind zone



Driven by an interest in understanding and applying biological principles, rather than outright biological mimicry


Shaowu Zhang


Javaan Chahl

Funding

Australian National University

Australian Research Council

Australian Defense Science and Technology Organisation (DSTO)

International Human Frontiers Science Program (HFSP)

U.S. Defense Advanced Research Projects Agency (DARPA)

U.S. Air Force

U.S. Office of Naval Research (ONR)

U.S. National Aeronautics and Space Administration (NASA)

Jet Propulsion Laboratory, Caltech (JPL)

Australia-Germany Research Collaboration Grant

U.S. Army Research Office

Thank you