

Surface structures over a plant canopy

Thigmomorphogenesis [Jeff 1993]



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Hanomi

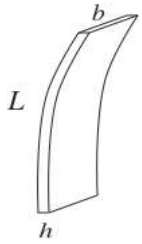
Surface structures over a plant canopy

Lodging [Berry 2002]



10-20% annual loses in world production!

Lodging



Horizontal stiffness: $K \sim \frac{EI}{L^3} \sim \frac{Eh^3b}{L^3}$

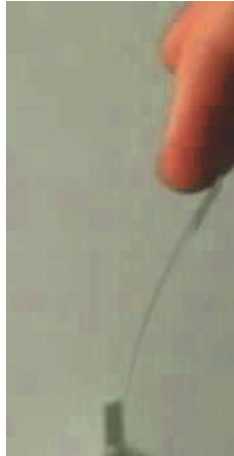
Mass: $m = \rho b L h$

Natural frequency:

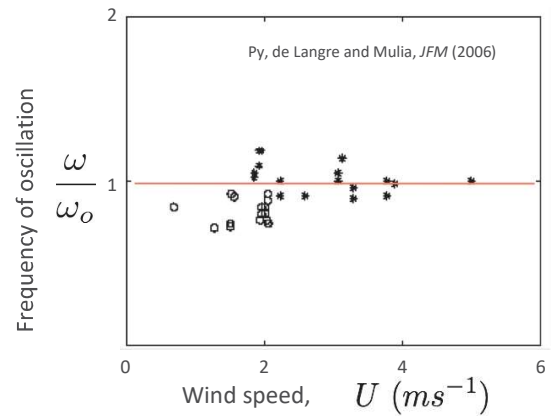
$$\omega_o = \sqrt{\frac{K}{m}}$$

$$\omega_o \sim \sqrt{\frac{Eh^3b}{L^3} \cdot \frac{1}{\rho b L h}} \sim \sqrt{\frac{E}{\rho} \cdot \frac{h}{L^2}}$$

$$\omega_o = \frac{\pi}{16\sqrt{3}} \sqrt{\frac{E}{\rho} \cdot \frac{h}{L^2}}$$

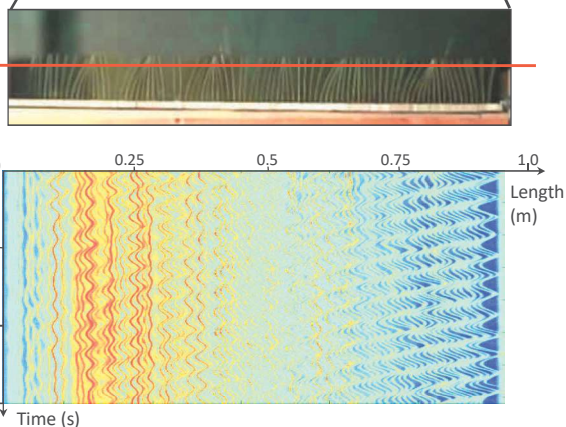
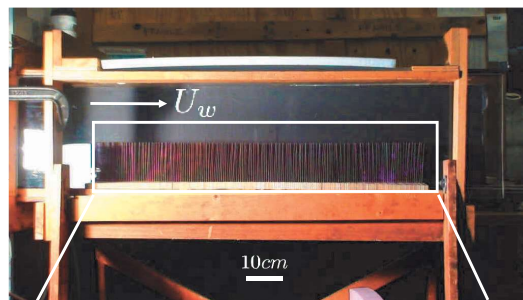


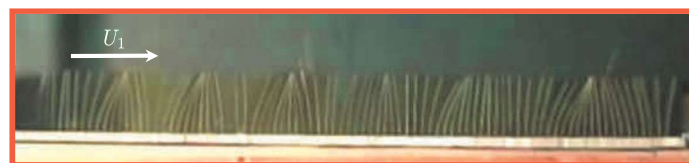
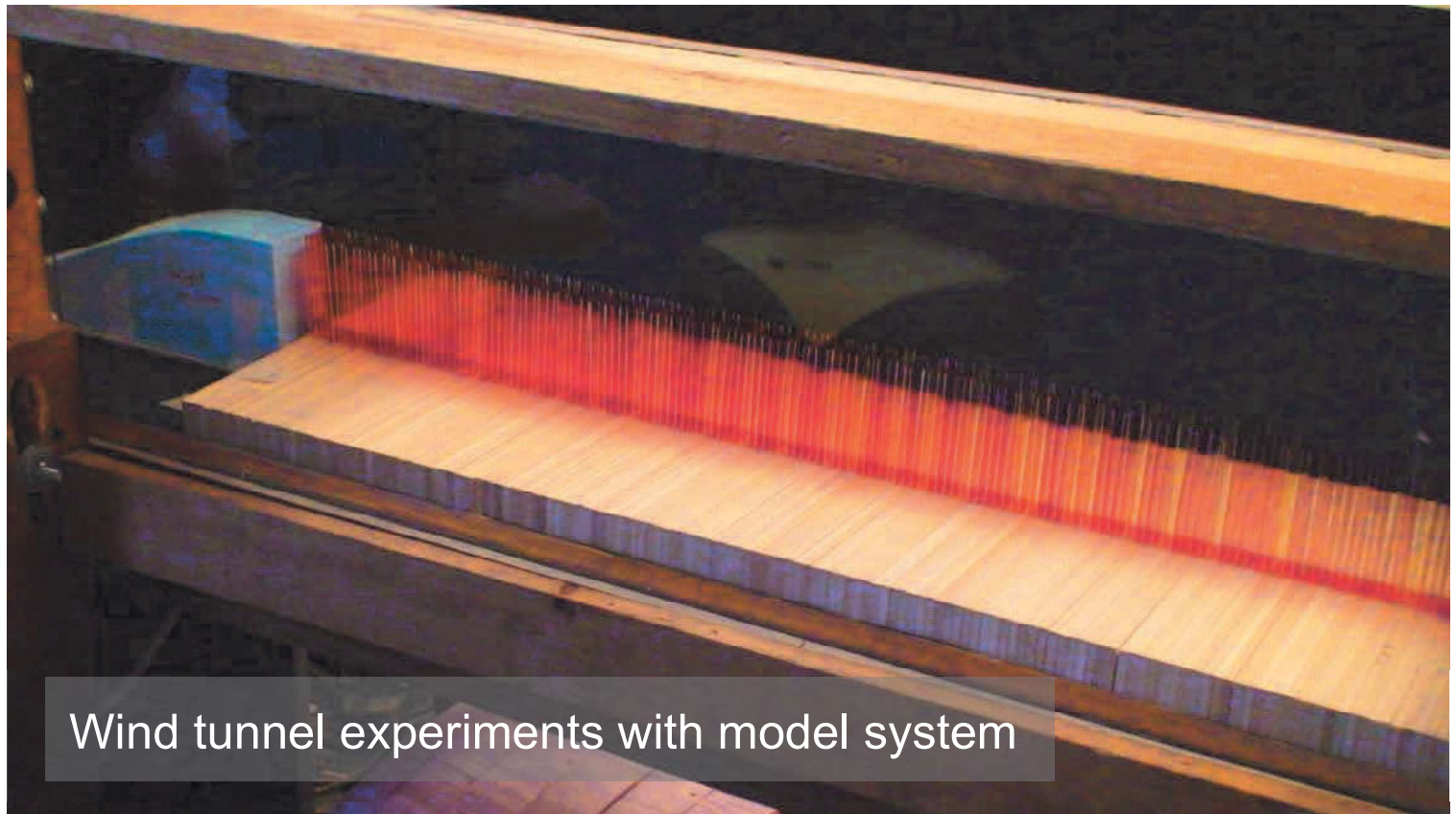
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Wind tunnel experiments:

- Wind speed: $U_w : 0.5 - 50 \text{ m/s}$
- Acetate sheets:
 - Young's Modulus: $E = 7 \text{ GPa}$
 - Density: $\rho = 1.3 \text{ gcm}^{-3}$
 - Thickness: $h = 102 \mu$
 - Span: $b = 2.54 \text{ cm}$
 - Length: $L : 7 - 12 \text{ cm}$
 - Sheet spacing: $d : 0.48 - 1.91 \text{ cm}$
- Imaging with fast camera (120fps)
- Space time diagram along horizontal line.
- Extract properties of surface structures:
 - Wavelength: λ
 - Speed: v
 - Frequency: f





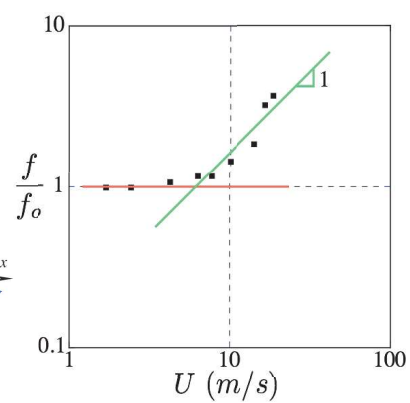
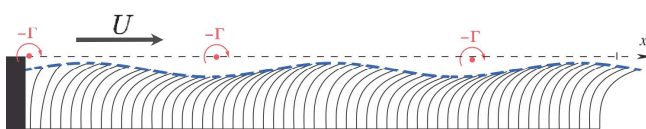
Videos @
120fps

Regime I:

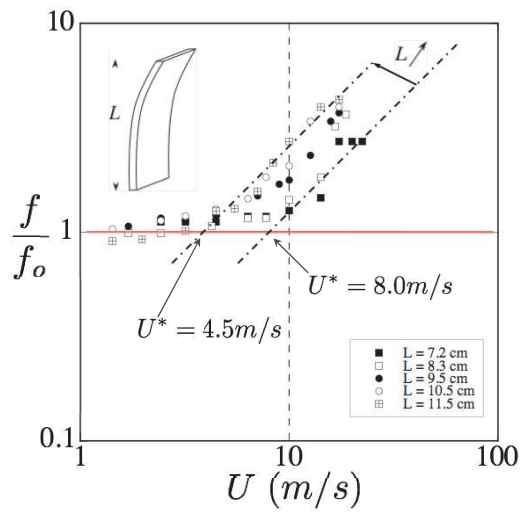
- Elasticity-dominated;
sheets oscillate at their natural frequency.

Regime II:

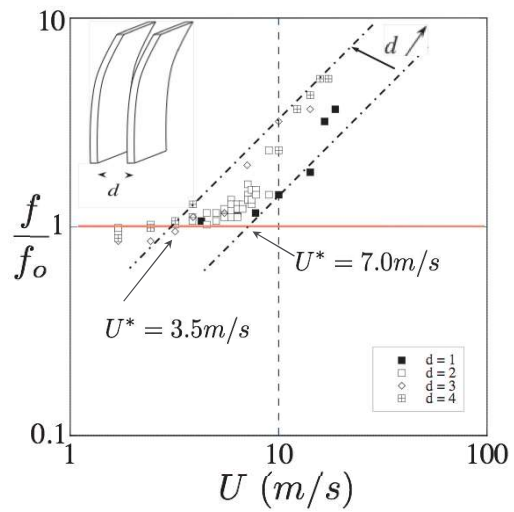
- Flow-dominated;
Reduced frequency linear with wind speed.



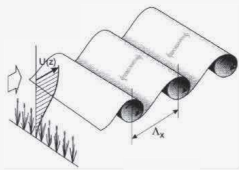
Change $7 < L < 12 \text{ cm}$
fix $d = 4.8 \text{ mm}$



Change $4.8 < d < 19.1 \text{ mm}$
fix $L = 8.3 \text{ cm}$



[Finnigan, *Annu. Rev. Mech.* 2000]



- Characteristic size of turbulent eddies $\sim L$
- Characteristic velocity fluctuations $\sim U$

Drag on single sheet:

$$F_w \propto \rho_w U^2 L b$$

Elastic restoring force:

$$F_s \propto \frac{EI}{L^2} \quad \text{with} \quad I = \frac{bh^3}{12}$$

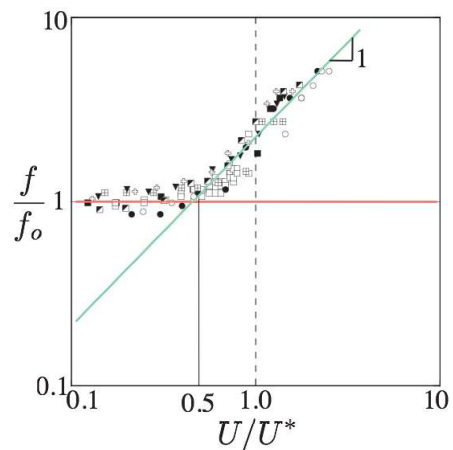
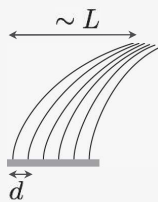
in Strong Wind $\rightarrow$ Sheets push each other

Restoring force $\sim$ # of sheets in contact $\frac{L}{d}$

@ Transition: $F_w \sim \frac{L}{d} F_s$

$$U^* \sim \sqrt{\frac{E}{\rho_w} \frac{I}{d \cdot b L^2}}$$

Transition wind speed



$$U^* = \frac{8}{\pi} f_o \sqrt{\frac{mL}{\rho_w b d}}$$

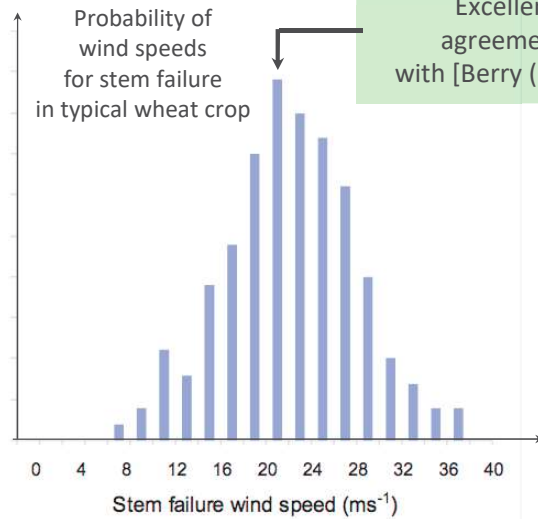
[Py et. al *JFM* (2006)]

	f_o (Hz)	L (m)	d (m)	m (g)	U^* (m/s)
Alfalfa	1.05	0.69	0.05	12.3	12
Wheat	2.5	0.68	0.05	7.5	22



Example of stem lodging

[Berry (2002)]



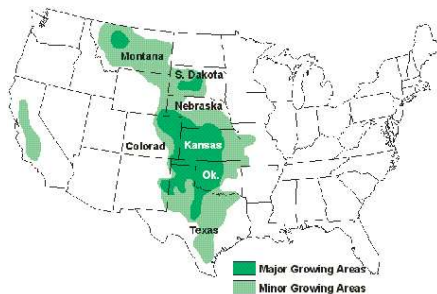
$$U^* = \frac{8}{\pi} f_o \sqrt{\frac{mL}{\rho_w b d}}$$

[Py et. al *JFM* (2006)]

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Excellent agreement with [Berry et. al *JFM* (2002)]

Kansas is the largest producing state of Hard Red Winter Wheat.



Daily Maxima Wind speeds for Topeka, KS (1965-1979)

Raw data from National Institute of Standards and Technology

