Surface structures over a plant canopy

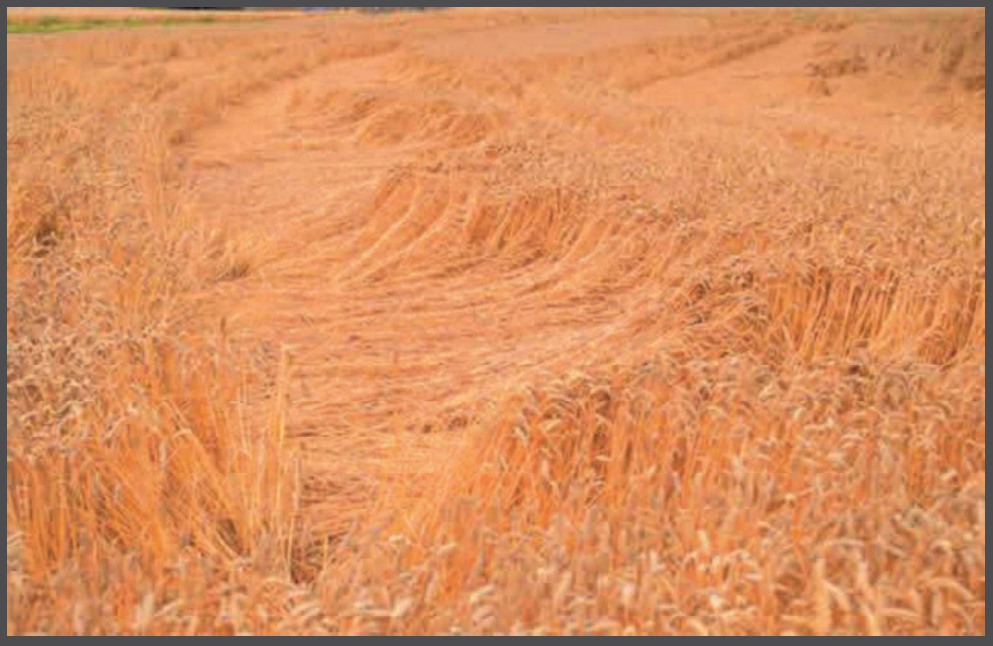
Thigmomorphogenesis [Jeff 1993]

Charlotte Py, MSC, Paris

Hanomi

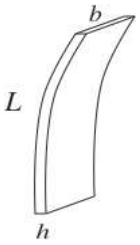
Surface structures over a plant canopy

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: $m = \rho bLh$

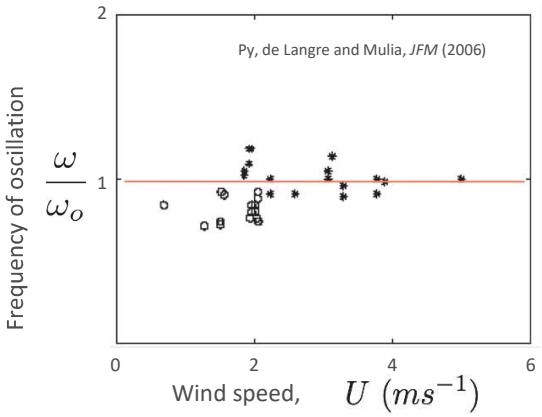
Charlotte Py, MSC, Paris

Natural frequency:

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

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

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

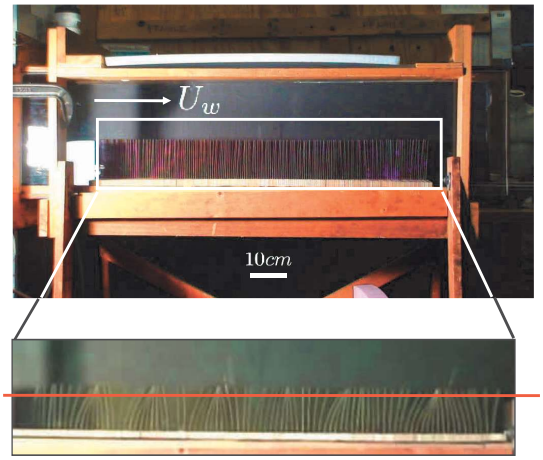


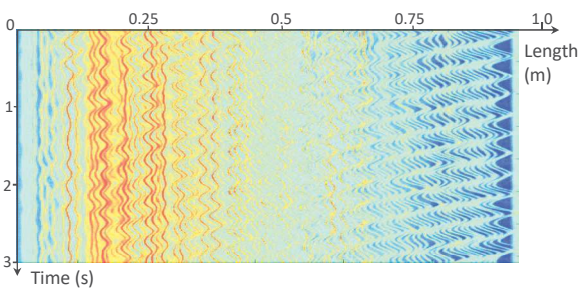
Wind tunnel experiments:

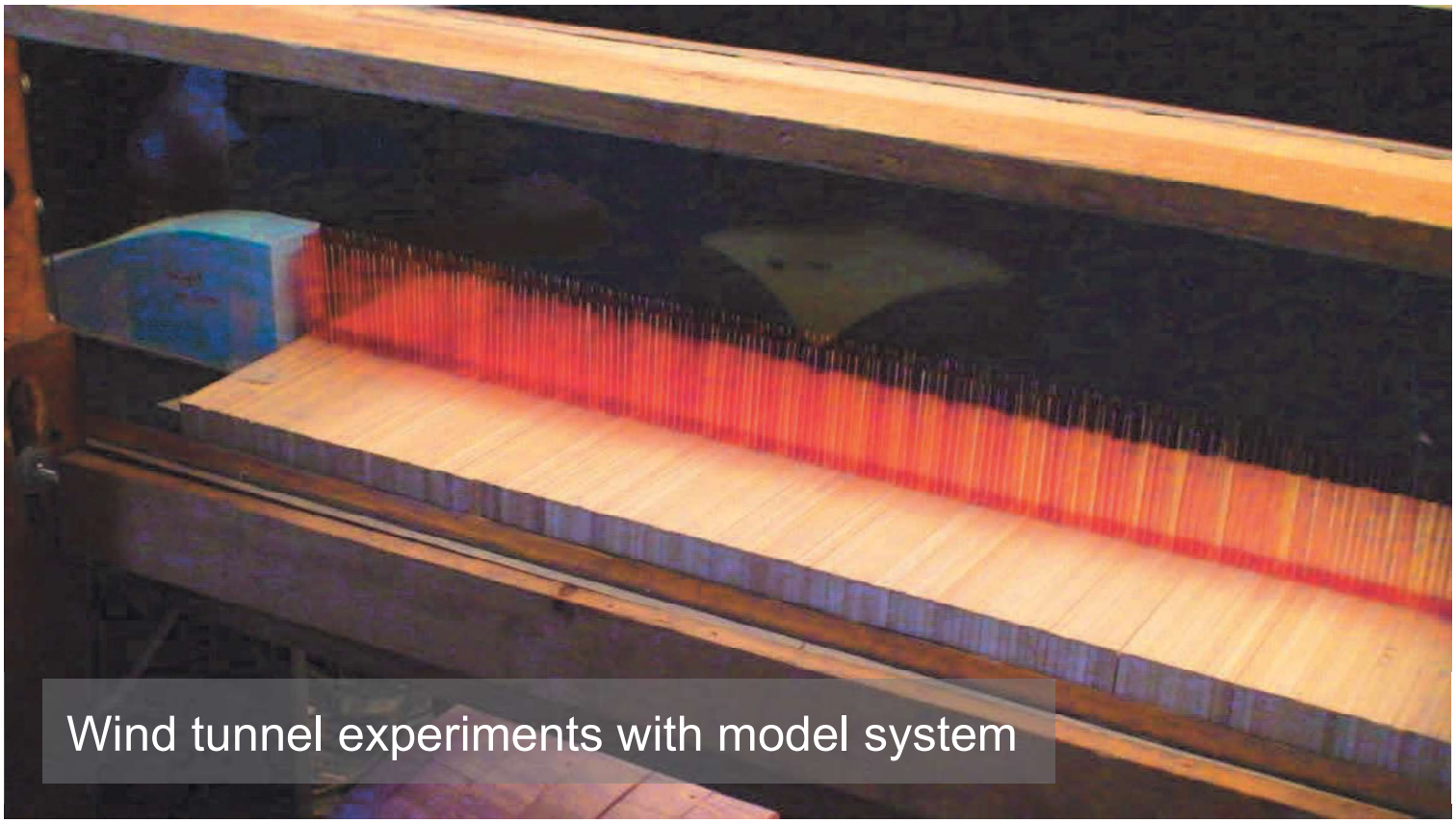
- Wind speed: $U_w : 0.5 - 50m/s$
- Acetate sheets:

Young's Modulus:	$E = 7Gpa$
Density:	$\rho = 1.3gcm^{-3}$
Thickness:	$h = 102\mu$
Span:	$b = 2.54cm$
Length:	$L : 7 - 12cm$
Sheet spacing:	$d : 0.48 - 1.91cm$

- Imaging with fast camera (120fps)
- Space time diagram along horizontal line.
- Extract properties of surface structures:
  - Wavelength: λ
  - Speed: v
  - Frequency: f







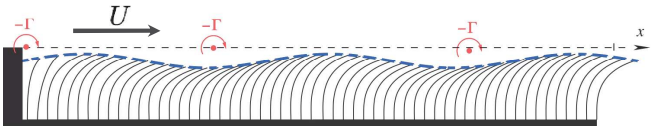
Videos @ 120fps

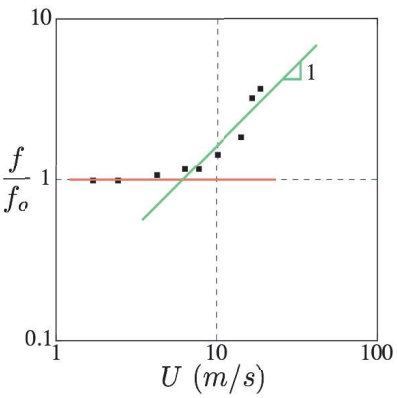
Regime I:

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

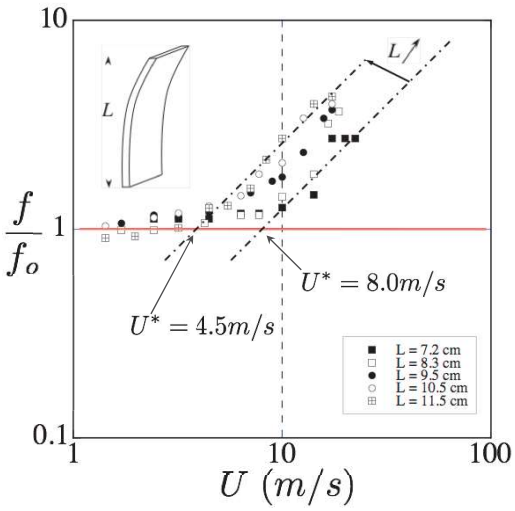
Regime II:

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

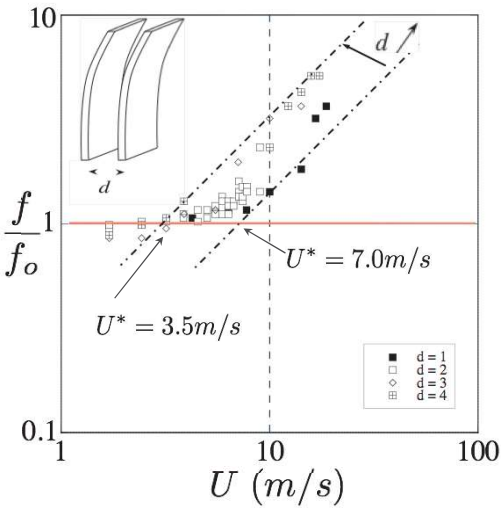




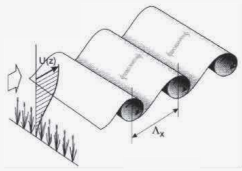
Change *7<L<12cm*
fix *d=4.8mm*



Change *4.8<d<19.1mm*
fix *L=8.3cm*



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



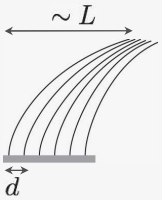
- Characteristic size of turbulent eddies $\sim L$
- Characteristic velocity fluctuations $\sim U$

Drag on single sheet:
$F_w \propto \rho_w U^2 L b$

Elastic restoring force:
$F_s \propto \frac{EI}{L^2}$ with $I = \frac{bh^3}{12}$

in Strong Wind → Sheets push each other

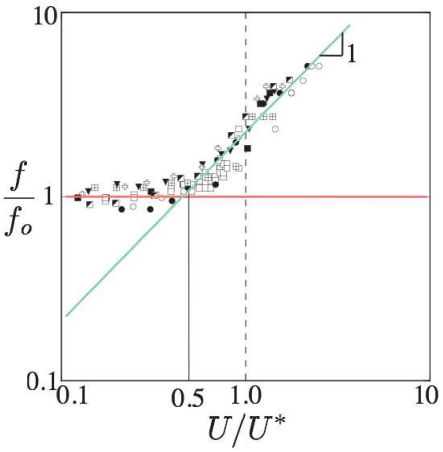
Restoring force $\sim$ # of sheets in contact $\frac{L}{d}$



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

$$U^* \sim \sqrt{\frac{E}{\rho_w}\frac{I}{d.bL^2}}$$

Transition wind speed



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

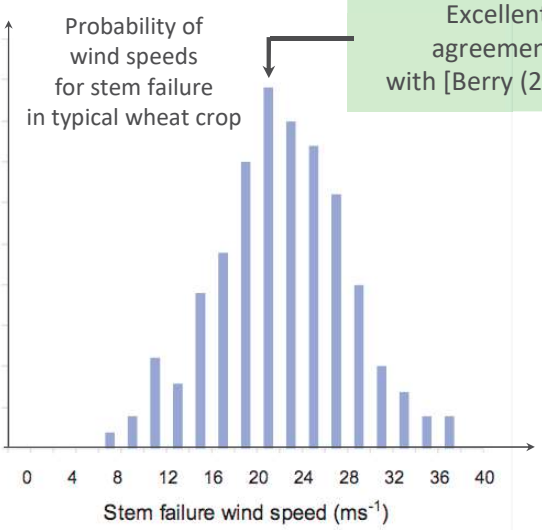
[Py et. al *JFM* (2006)]

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

Excellent agreement with [Berry (2002)]

Example of stem lodging

[Berry (2002)]



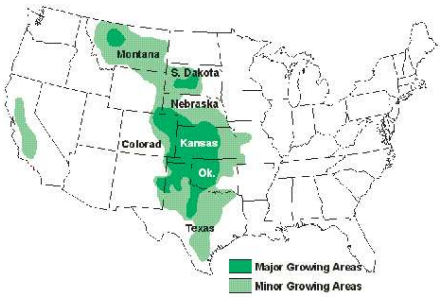
$$U^* = \frac{8}{\pi} f_o \sqrt{\frac{mL}{\rho_w bd}}$$

[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

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