The peculiar behavior of stationary and accelerating vortices

Co-conspirators

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- Olivia R. Dawson
- Matthias Bauer
- Greg Balle
- J. A. Gjestvang
- N. N. Ramkhelawan
- Prateek Ranjan
- Partial support from ONR

Which has the greater entrainment rate?

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are needed to see this picture.

Cotel, Gjestvang, Ramkhelawan, & Breidenthal 1997

Vertical impinging jet (Cotel)

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Cotel, Gjestvang, Ramkhelawan, & Breidenthal 1997

Intrinsic velocity ratio W/V

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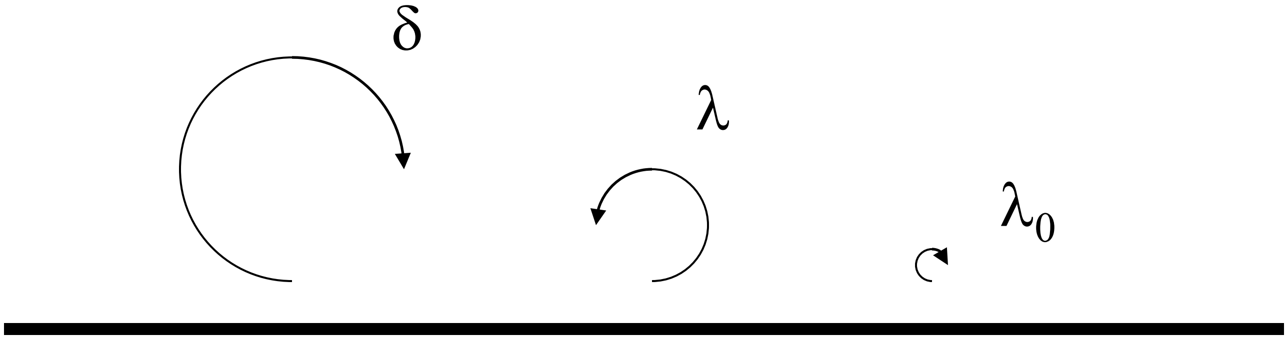
Entrainment hypothesis of Morton, Taylor, and Turner

$$v_e = const. \frac{\delta}{\tau_\delta}$$

Generalized entrainment velocity

$$v_e = const.\frac{\lambda_e}{\tau_{\lambda_e}}$$

Flat interface



$$v_e = const.\ (\mathrm{D}\tau)^{1/2}/\tau$$

$\tau = ?$

τ_δ if persistent

$\tau_{\lambda 0}$ if nonpersistent

What kind of surface?

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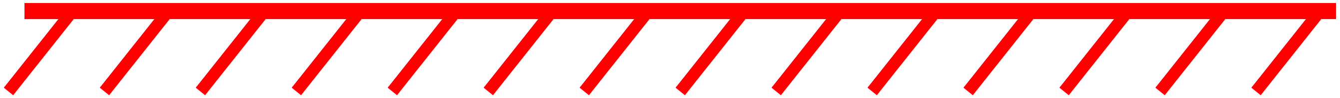

von Karman wake (Balle)

(Nearly) streamwise vortices

wavy walls (Dawson)

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upstream VG’s

Turbulent intermittency over one wavelength (Bauer)

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Sketch of secondary flow (Dawson)

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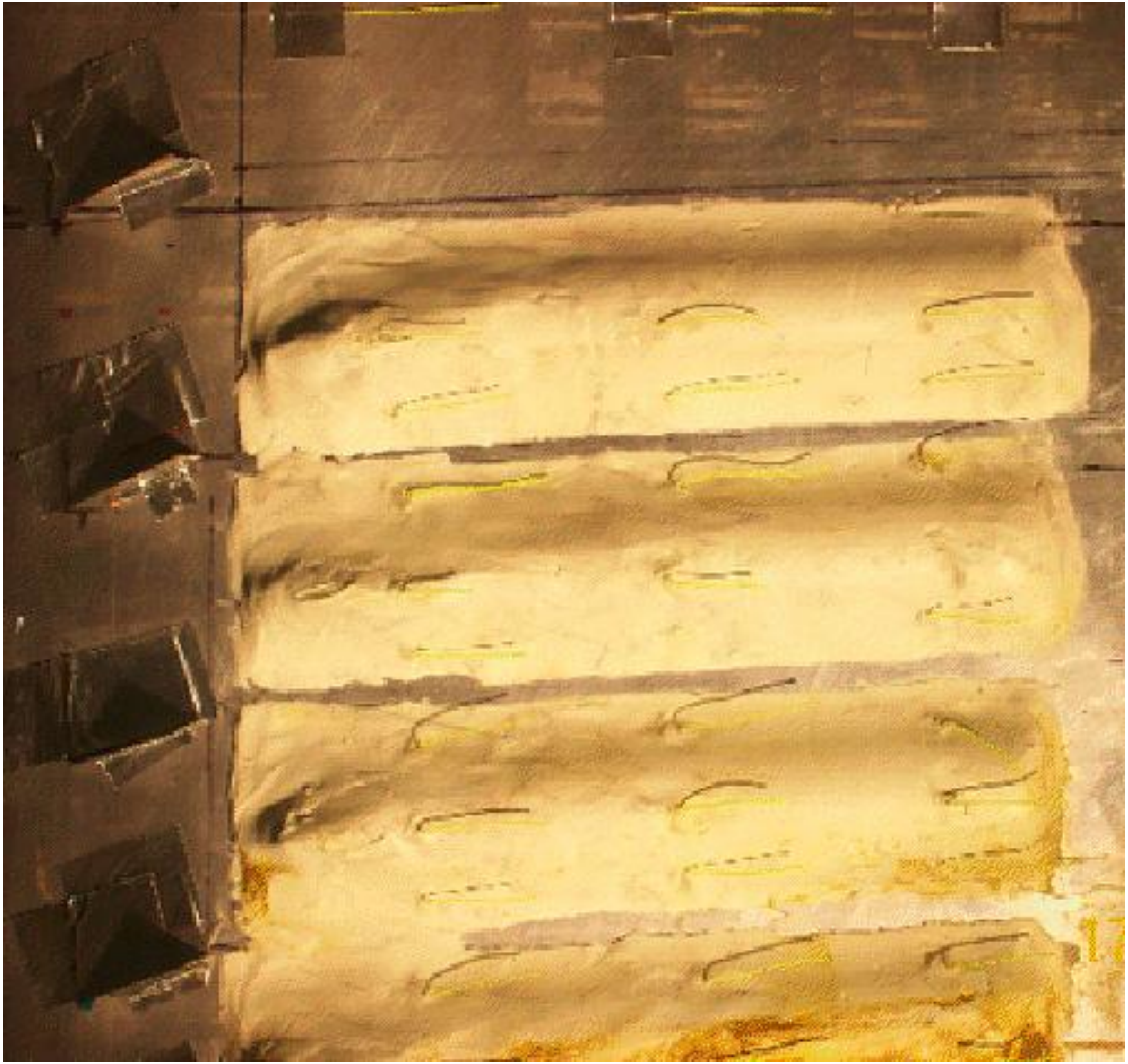
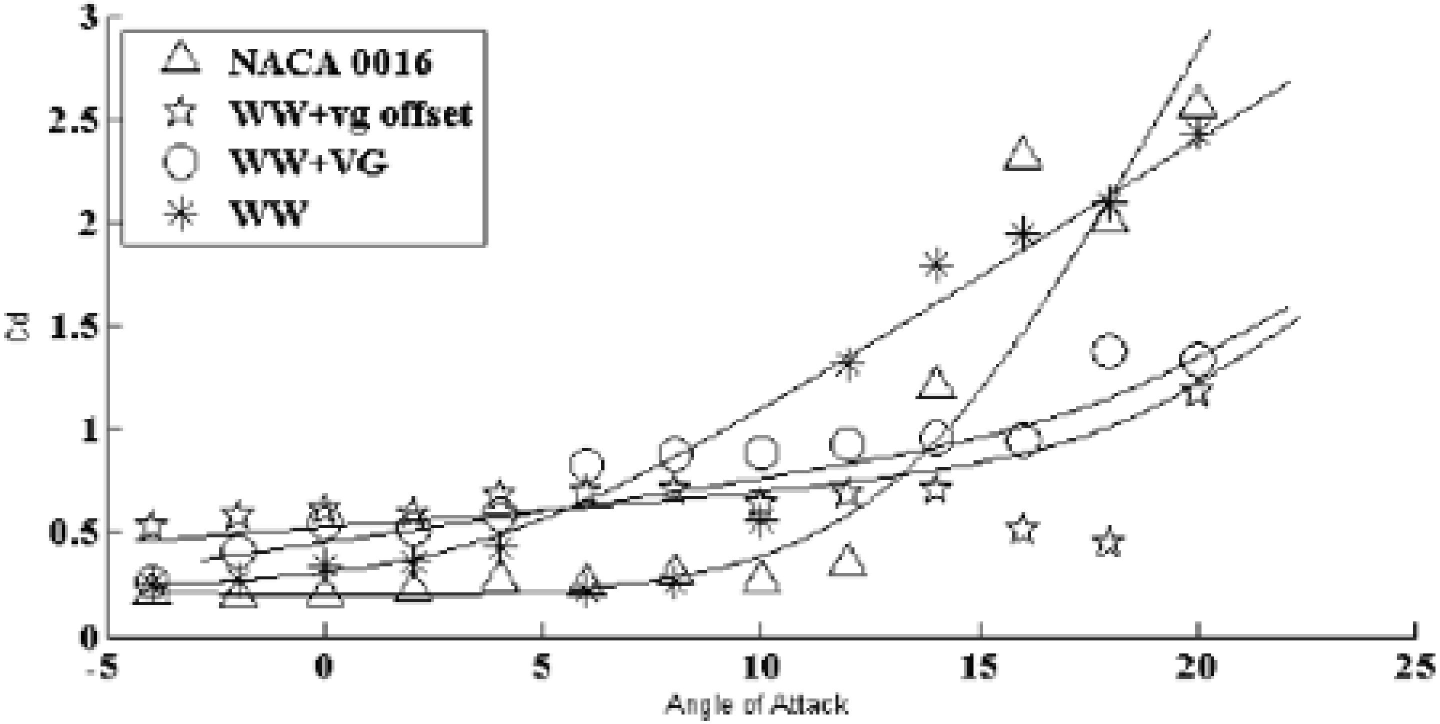
von Karman wake

Kelvin’s cat’s eyes

Miles



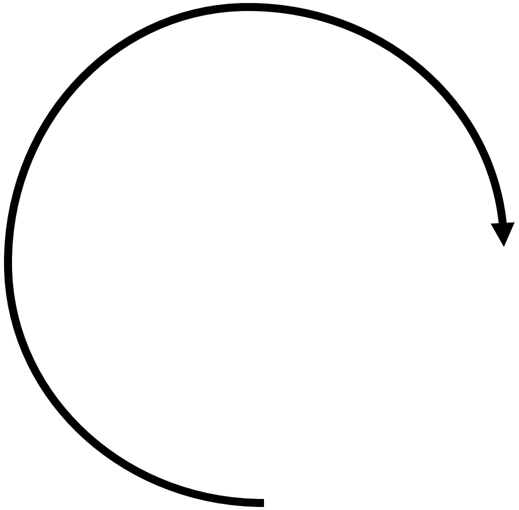

△ NACA 0016
☆ WW+vg offset
○ WW+VG
✳ WW
Cd
3
2.5
2
1.5
1
0.5
0
-5
0
5
10
15
20
25
Angle of Attack

Ranjan 2013

Conclusion - Part 1

- Stationary vortices behave differently than nonstationary ones
- Stratified entrainment
- Relaminarization of a turbulent boundary layer

Accelerating vortices



$$\tau_v(t)$$

Brown & Roshko shear layer

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Chemically-reacting shear layer

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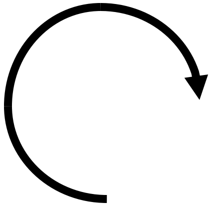
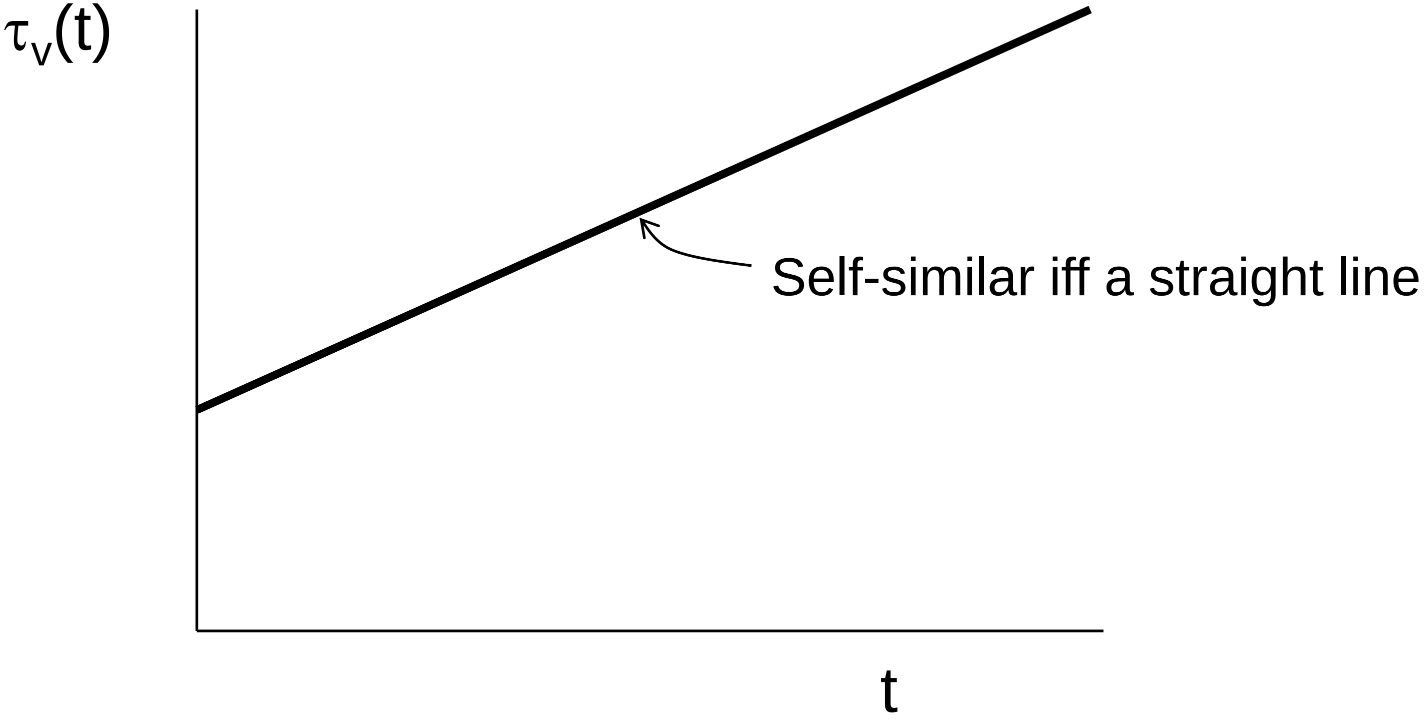
Evolution of ordinary turbulence





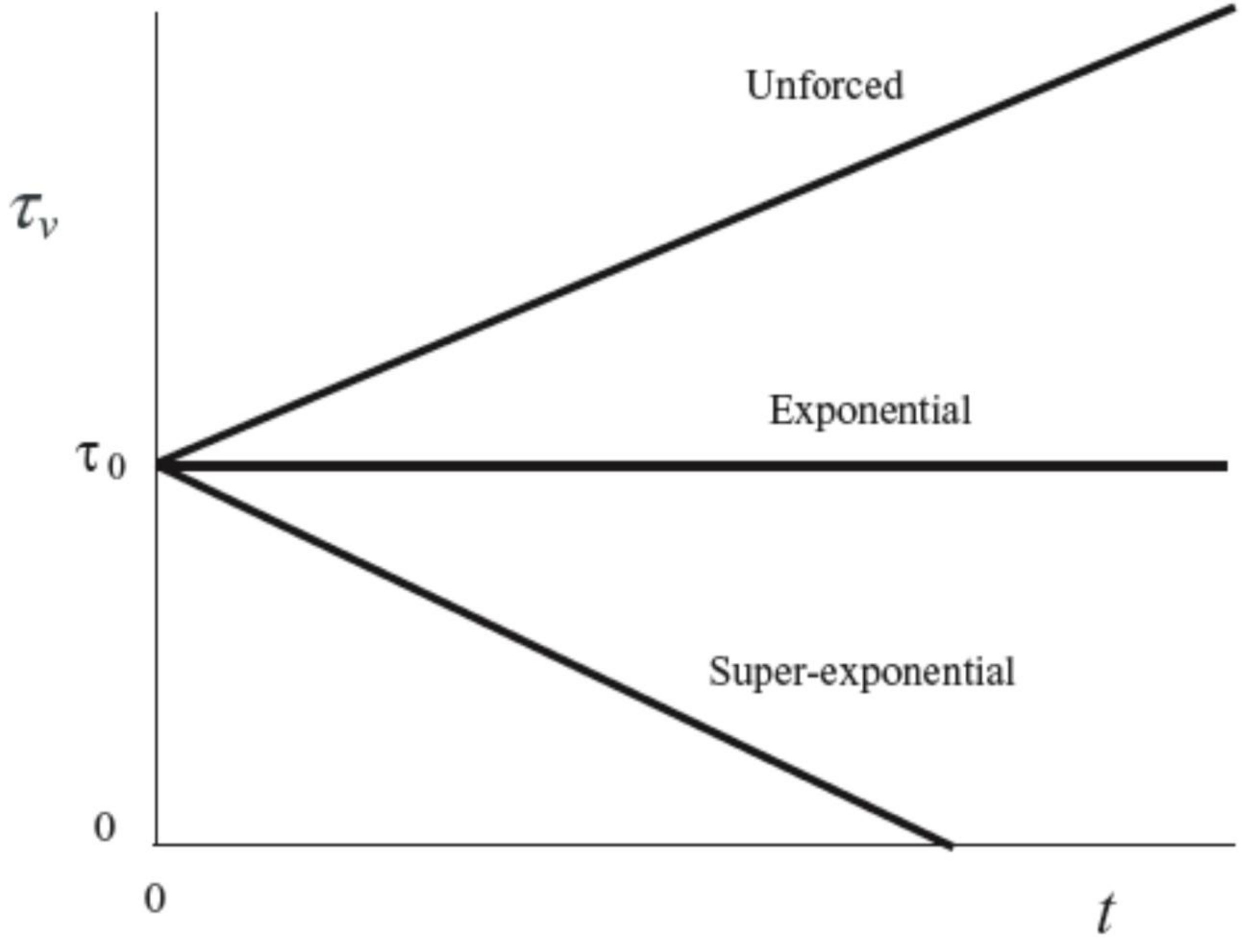
Self-similar iff a straight line

Basic idea

$e^{t/\tau}$ forcing function

$\tau_v(t) \rightarrow \tau$ e-folding time of acceleration

Self-similar turbulence



Exponential jet (Zhang & Johari)

Velocity time histories

What if the e-folding time is itself a function of time?

$$\tau_v = \tau = \tau_0 - \alpha t$$

α acceleration parameter

$$e^{\frac{t}{\tau_0 - \alpha t}}$$

Self-similar turbulence

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Conserved quantity Q

$$[Q] = \frac{length^m}{time^n}$$

$$Q = Q_0 e^{[t/(\tau_0 - \alpha t)]}$$

Dissipation rate

$$D = const.Q^{2/m}\,{\tau_v}^{-(3-2n/m)}$$

$$\beta \equiv -\left(3 - 2n/m\right)$$

$$\frac{dD}{D} = \frac{d\alpha}{\beta}$$

$$D = exp[(\alpha - \alpha^*)/\beta]$$

flow	Q	m	n	β
shear layer	ΔU	1	1	-1
round jet	$\Delta U^2\delta^2$	4	2	-2
round plume	$g'\Delta U\delta^2$	4	3	-3/2
Rayleigh-Taylor	g'	1	2	1
inertial cascade	$v_\lambda{}^3/\lambda$	2	3	0

Exponential jet

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Eroglu & Breidenthal 1998

Effect of α on entrainment

ssor

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Eroglu & Breidenthal 1998

Effect of acceleration on a jet

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Accelerating plume

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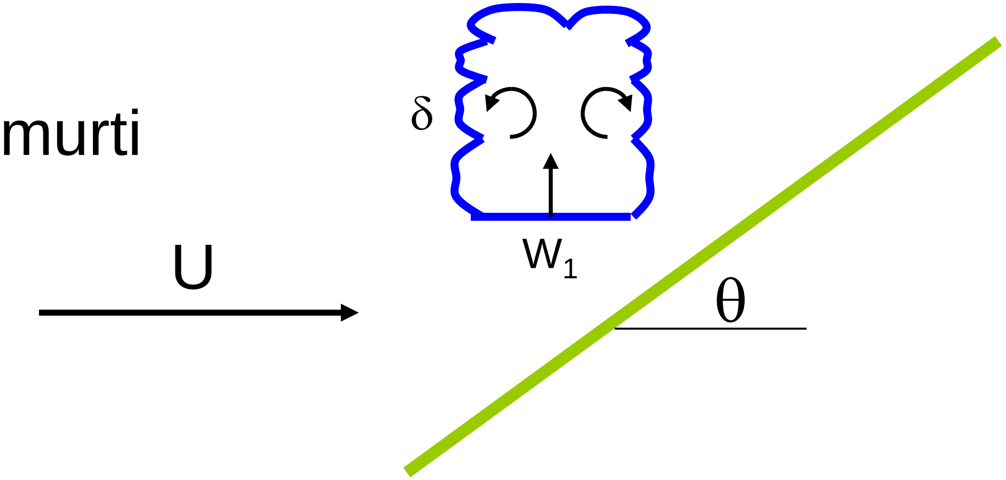
Critical slope for orographic rain

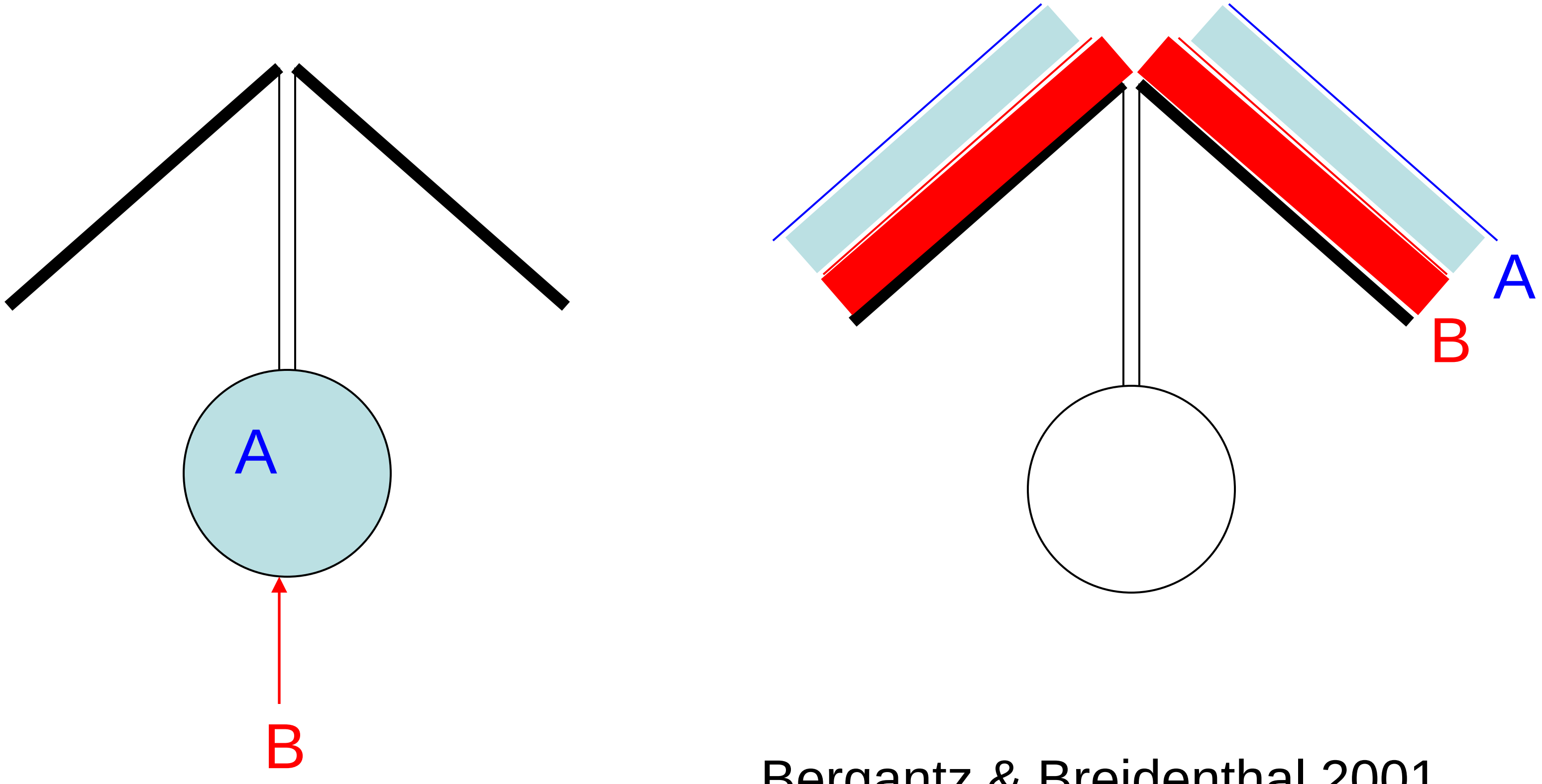
Krishnamurti



$$\alpha = [1 + (U/W_1) \tan \theta](\delta/\Delta z_e)$$

Also pre-humidifying air for subsequent moist convection

Volcano



Bergantz & Breidenthal 2001

Dissipation rate

$$D = const.Q^{2/m} \tau_v^{-(3-2n/m)}$$

$$\beta \equiv -\left(3 - 2n / m\right)$$

$$\frac{dD}{D} = \frac{d\alpha}{\beta}$$

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Rayleigh-Taylor	g'	1	2	1
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$\beta < 0$ for all flows except Rayleigh-Taylor and inertial cascade

Accelerating Rayleigh-Taylor

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Under large acceleration, vortex becomes stationary

ssor

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$$\lim_{\alpha\to\infty}\frac{W}{V}\to\infty$$

Conclusion - Part 2

- Stationary vortices behave differently than nonstationary ones
- Stratified entrainment
- Relaminarization of a turbulent boundary layer
- Acceleration inhibits entrainment*

*except for Rayleigh-Taylor and inertial cascade