Lectures and Homework

4/11/16. Lecture 7:

Wind power

Homework #1 due 4/13
Homework #2 assigned on 4/13

Sign up for Kill a watt meters: (you can sign up for 3 days at a time)
Rachel Cordero, Room 119 Baskin

Personal Energy Audit: due May 9, in class

Midterm Exam: May 9, in class

https://courses.soe.ucsc.edu/courses/ee80j/Spring16/01

Personal Energy Audit

The goal of this project is for students to get a full picture of the supply and demand of energy used in their daily life. While working on this report, students will identify all energy services and their energy sources, obtain records of their energy usage, determine the energy consumption for each service, analyze the information, compare, draw conclusions and make recommendations.

Two parts:

report (due in class)
on-line questionnaire (completed on campus)

- Abstract
- Introduction (should include information about the student)
- Calculations
    - List of energy services and sources
    - Transportation
    - Hot water consumption
    - Electricity usage (Wh/week)
        - Calculated from labels
        - Measured with “Kill a Watt” meter
            - When appliances are on
            - When appliances are off
- Analysis
    - If student has access to their PG&E bill and Smart Meter
        - Look for peaks of energy consumption, what do they consist of? What appliances were on during those particular hours.
        - How does your home compare to others
        - How does your energy consumption vary with weather
    - If student does not have access to their PG&E bill
        - Make a plot of energy consumed throughout the week
        - Make a plot of peak outside temperatures throughout the week
        - Compare the two plots for similarities
- Conclusion (should include qualitative and quantitative analysis summary from previous section). It has to answer specific list of questions.

Think about Final Project Proposals
<for example>

1. How to make the Santa Cruz Wharf Energy Self-Sufficient?

2. What is the UCSC Campus Energy/ Power Potential of Renewable Resources?

3. How to reduce energy consumption of on-campus housing?

Santa Cruz Green Wharf Project

Wind turbine

U.S.-Denmark Workshop on Renewable Energy

August 1 - 16, 2016

Participants will learn about the economics, politics, science, and technology behind renewable energy implementation from leading experts, while exploring communities and relevant energy sites where such technology is in place or currently being implemented.

The U.S.-Denmark Summer Workshop on Renewable Energy is a unique educational initiative developed by leading universities in Denmark and California. The two-week workshop, with a week of online prep before the workshop (7/25-7/31), takes place annually in California and Denmark with the 2016 edition in California. It starts with one week of online preparation and continues with two weeks of lectures, seminars and field trips in California. The faculty is composed of U.S. and Danish professors, as well as external professionals and researchers with proven experience in their field. Students will work on team-based projects related to renewable energy solutions to specific problems. The interdisciplinary approach and holistic perspective allows students with various academic backgrounds to interact and develop concrete final project ideas, while targeting today's energy problems from different angles.

Open For All Students!

The workshop is intended for students of all disciplines, chosen on the basis of their academic qualifications, creativity, and commitment to renewable energy. Each year, selected students from engineering, business, science, environmental studies, political science, economics, and other fields are grouped together across disciplines and national ties to form project-based teams that throughout the workshop investigate the opportunities and challenges facing renewable energy implementation.

Application Deadline—April 15, 2016!

Course Fees (tuition): $1,092

Estimated Lodging, Food, and Travel: $2,354 (plus airfare)

This course is worth 4 credits and is offered through UC Santa Cruz Summer Session. **Financial aid fellowships are available for current qualified students at U.S. universities who are U.S. citizens or permanent residents.**

For details on how to apply go to:
http://pire.soe.ucsc.edu/workshops/2016

For more information contact:
Rachel Cordero, Program Coordinator
Center for Sustainable Energy & Power Systems, UC Santa Cruz
831-459-2921 · rcordero@soe.ucsc.edu

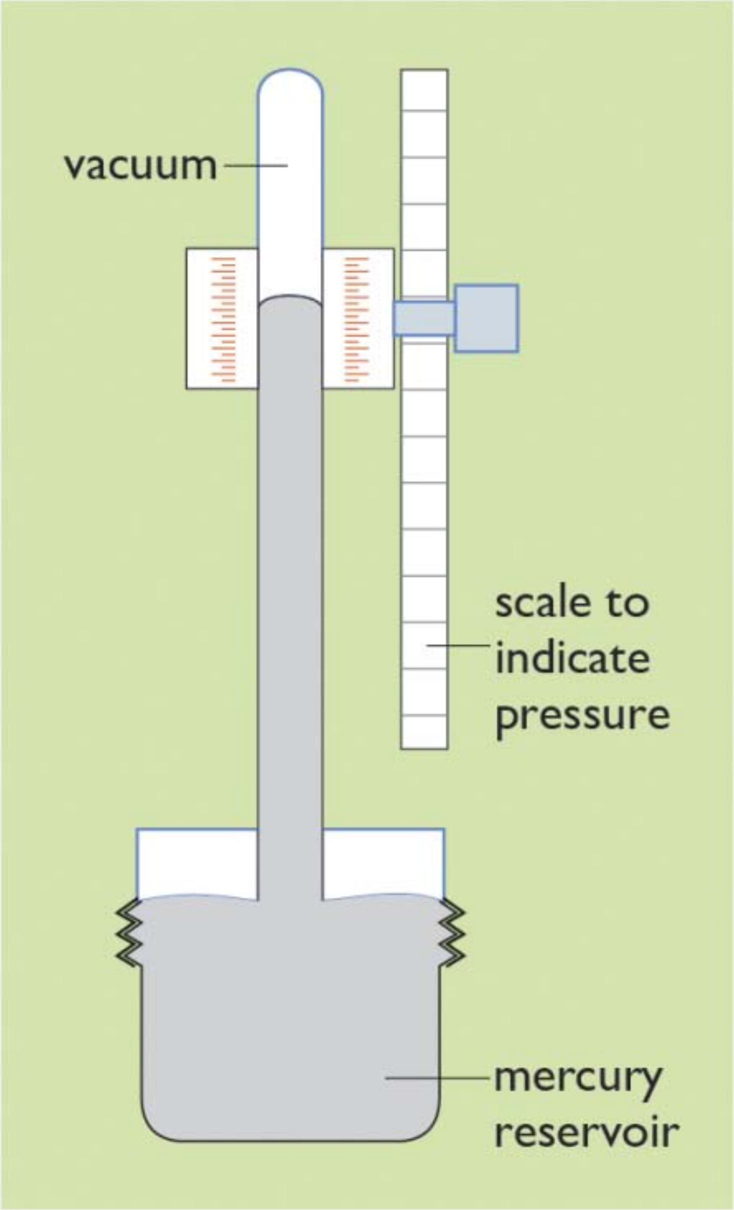
Santa Cruz Green Wharf Project

What is wind?

The Center for Sustainable Energy and Power Systems

CENSEPS

Barometer



Copyright © The Open University 2012

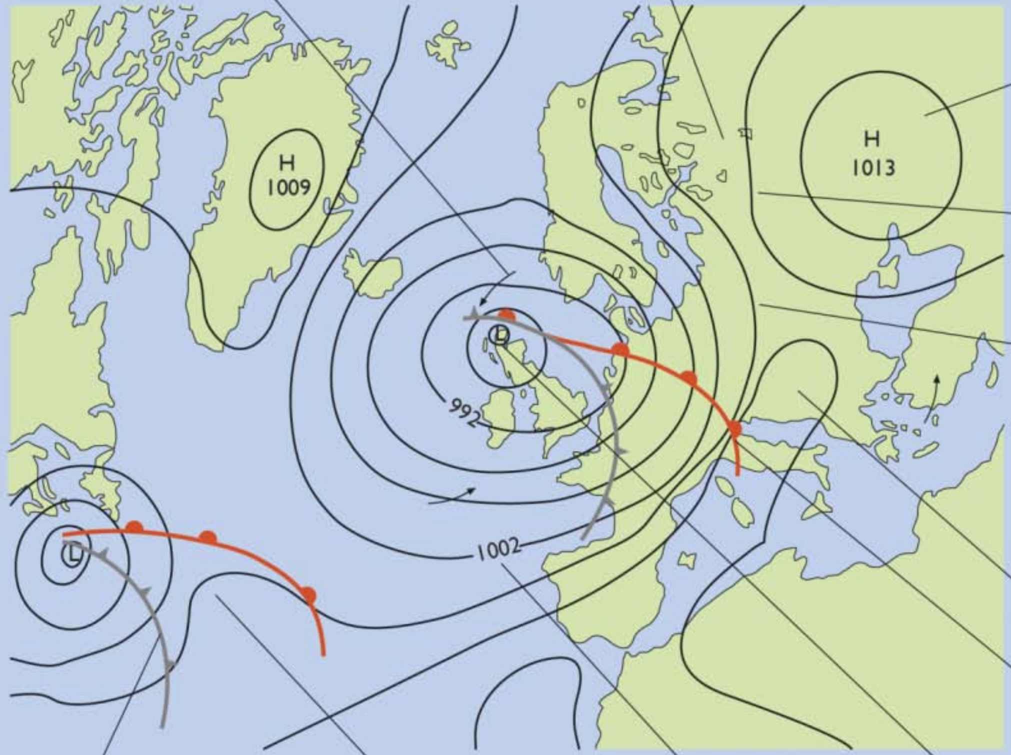
Units of pressure (force/area)

1 Pascal (pa) = 1 N/m^2

1 bar = 100kPa

Average atmospheric pressure at sea level = 1013.2 mbar strong winds spiral in towards the centre of the depression

in winter, highs often sit over large land masses, bringing cold, clear nights and heavy frosts



high pressure zone, or 'anticyclone', giving fine weather with clear skies for days on end

isobars link points where the pressure is equal

closer isobars bring stronger breezes; high cirrus clouds indicate that a warm front is coming

ridge of high pressure

warm front, bringing hours of steady rain

cold front bringing stormy weather and heavy rain

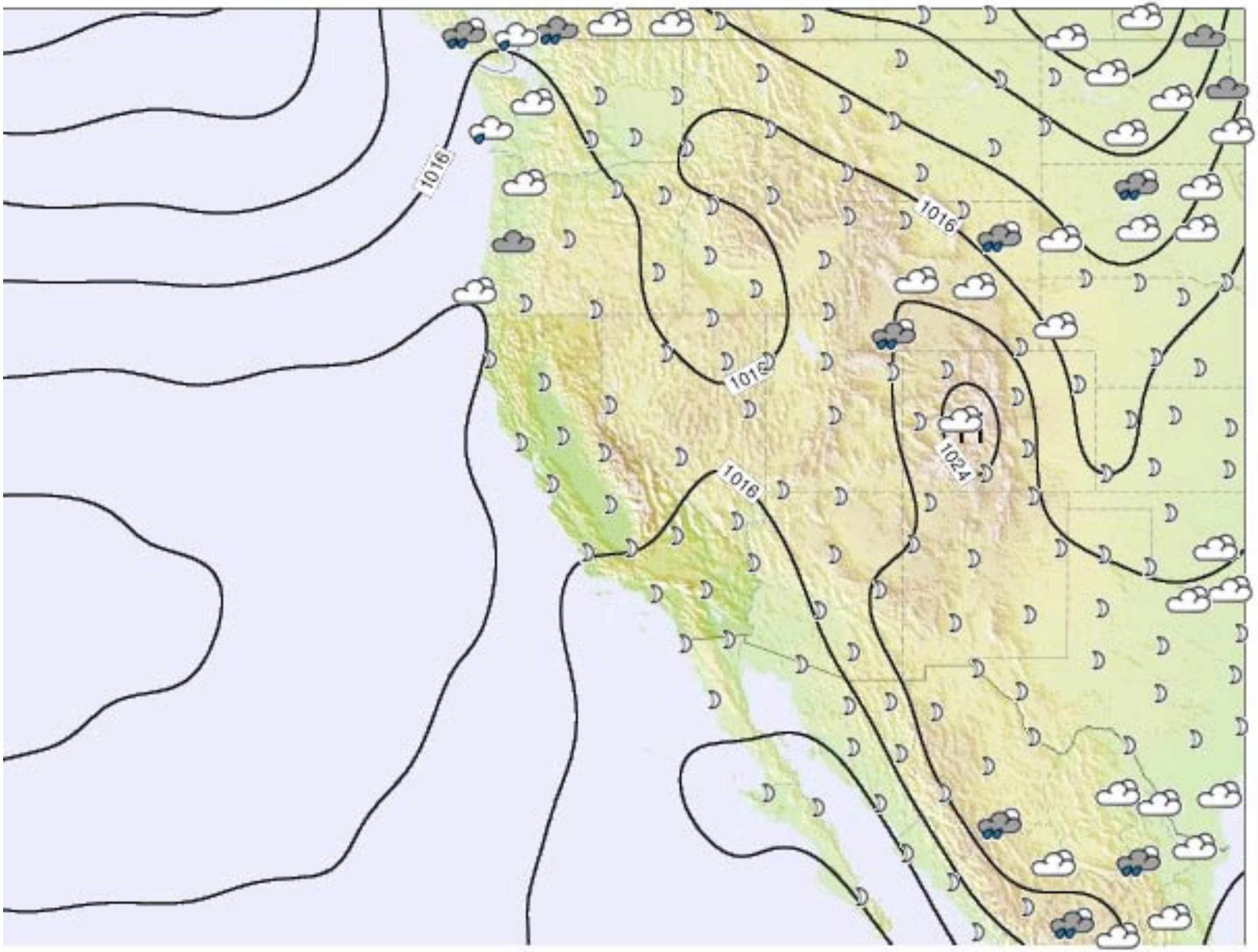
warm sector between fronts bringing milder weather and a break from the rain

figures indicating the pressure in millibars for the isobar

centre of depression or low, where pressure is at its lowest

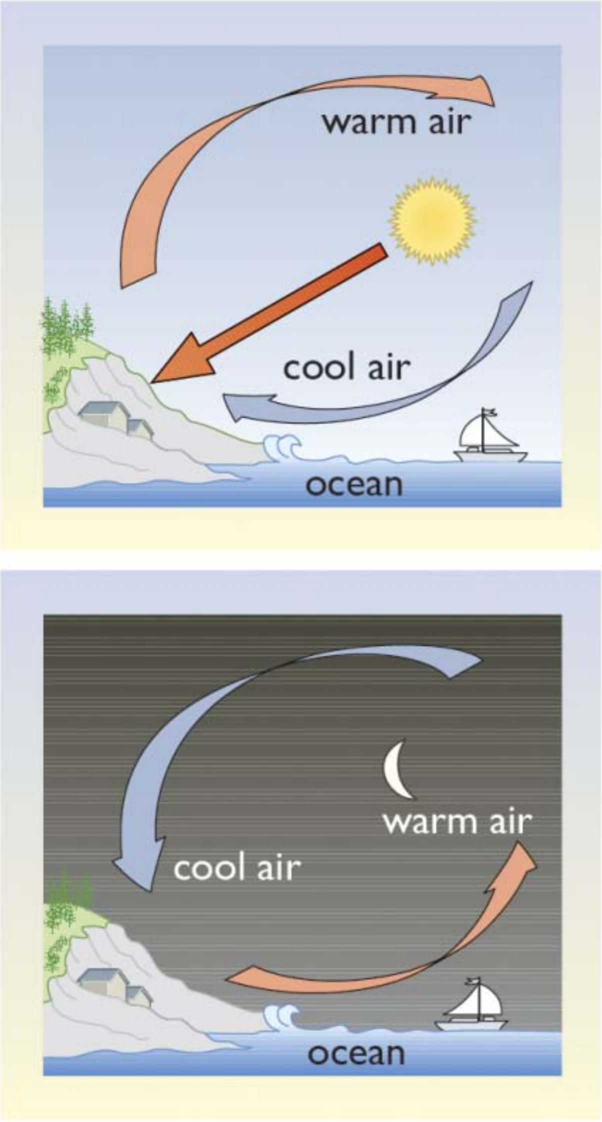
Farndon, J. (1992) How the Earth Works, Dorling Kindersley Ltd

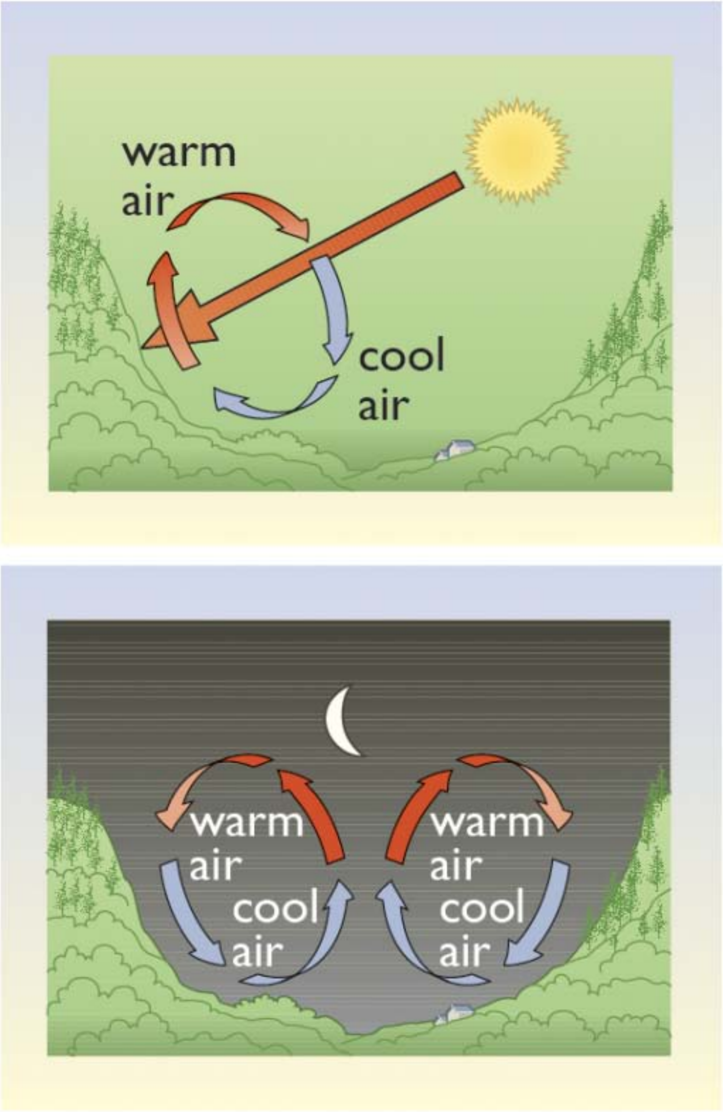
Weather Forecast Monday 13 May 5am PDT



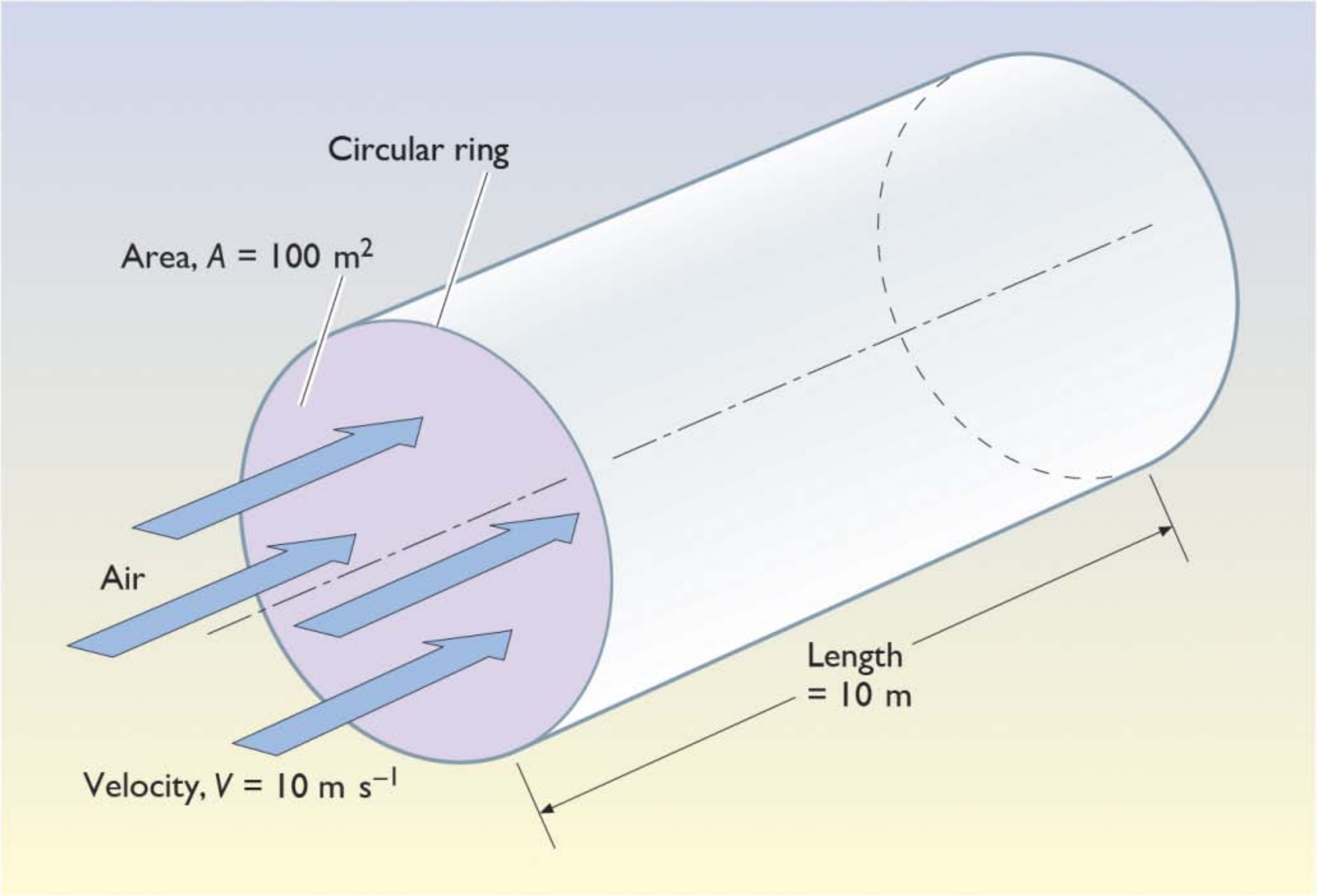
2015

Sea Level Pressure in Millibars Monday 13 May at 5am





Heat capacity of land < heat capacity of the ocean


Circular ring
Area, $A = 100\ \text{m}^2$
Air
Velocity, $V = 10\ \text{m s}^{-1}$
Length = 10 m

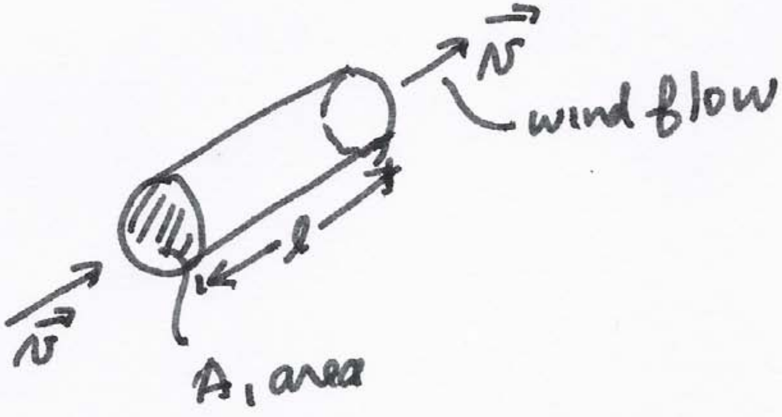
Energy and Power in the Wind

kinetic energy of a moving air mass:

$KE = \frac{1}{2} m v^2$, m = mass in kg

v = velocity in m/sec

[1 m/sec = 2.24 mph]



: for incompressible fluid/mass/sec constant,

Energy and Power in the Wind

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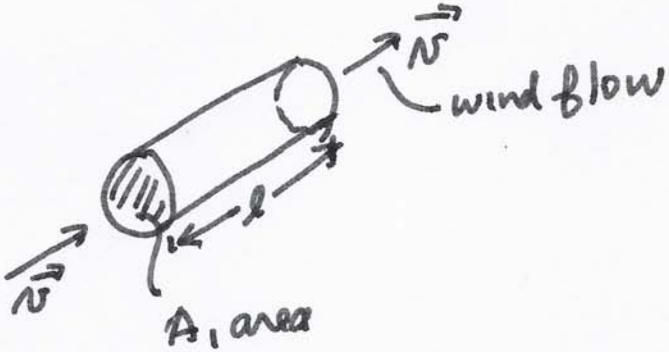

mass of air moving through ring of area A/sec.

$= \rho_{AIR} \times V_{AIR}/sec$, V_{AIR} = volume of air (m^3)

$= \rho_{AIR} \times Al/sec$, $l/sec = v$ velocity

$m/_{sec} = \rho_{AIR} A v$

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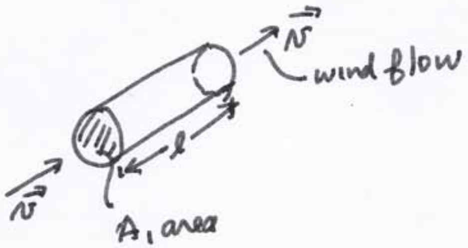

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$= \rho_{AIR} \times A\ell/\text{sec}$, $\ell/\text{sec} = v$ velocity

$m/_{\text{sec}} = \rho_{AIR} A v$

$\therefore$ power $P = KE/\text{sec} = \frac{1}{2} m v^2/\text{sec}$
$= \frac{1}{2}(\rho_{AIR} A v) v^2$

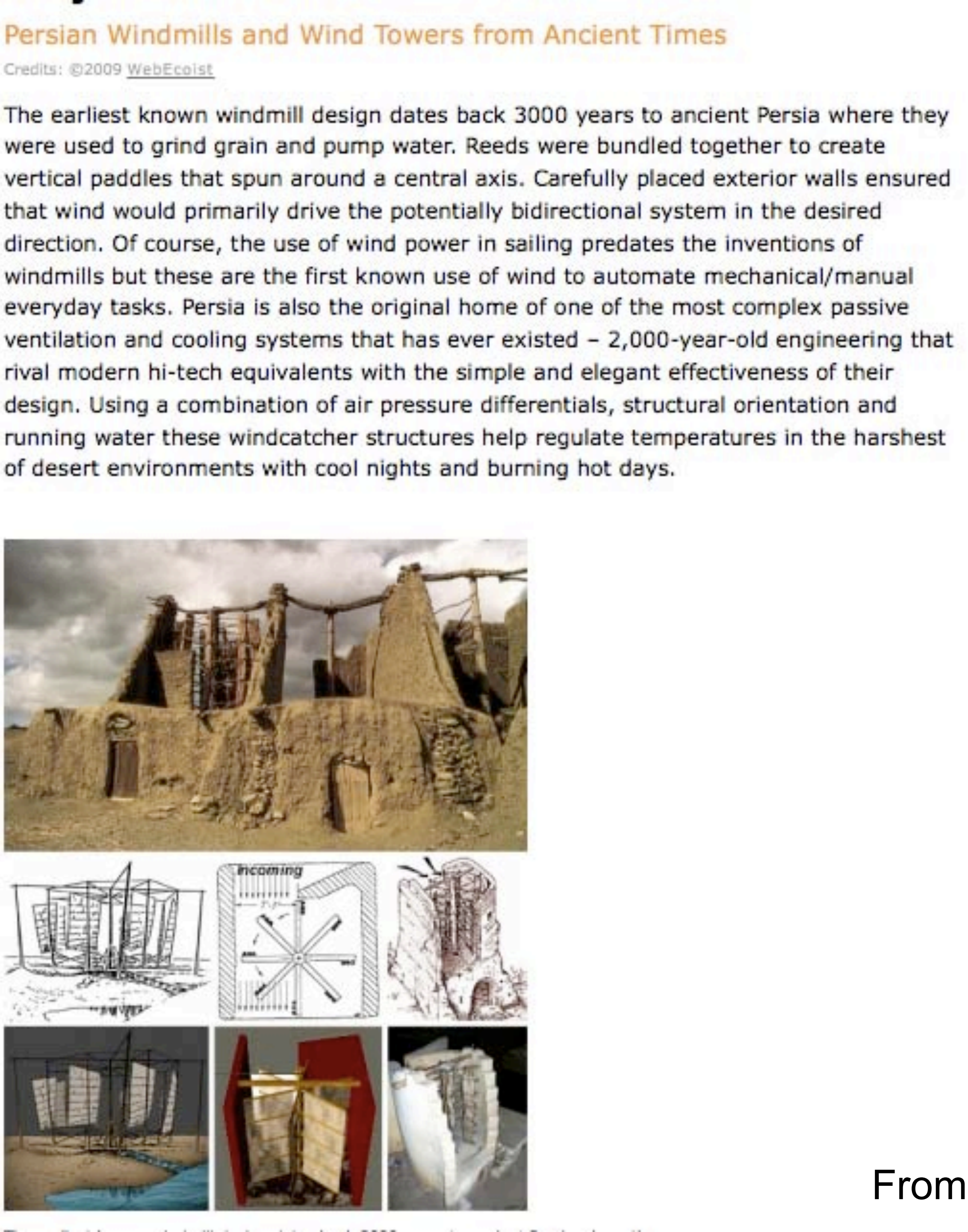
$$\therefore \boxed{P = \frac{1}{2} \rho_{AIR} A v^3}$$

the power of the wind,
"if we could extract it ALL"

NOTE: v^3 dependance
eg. if v goes from 6-8 m/sec → P goes up 2.37

What if we used flowing water?

what are effects that prevent us from extracting all the energy of the wind?



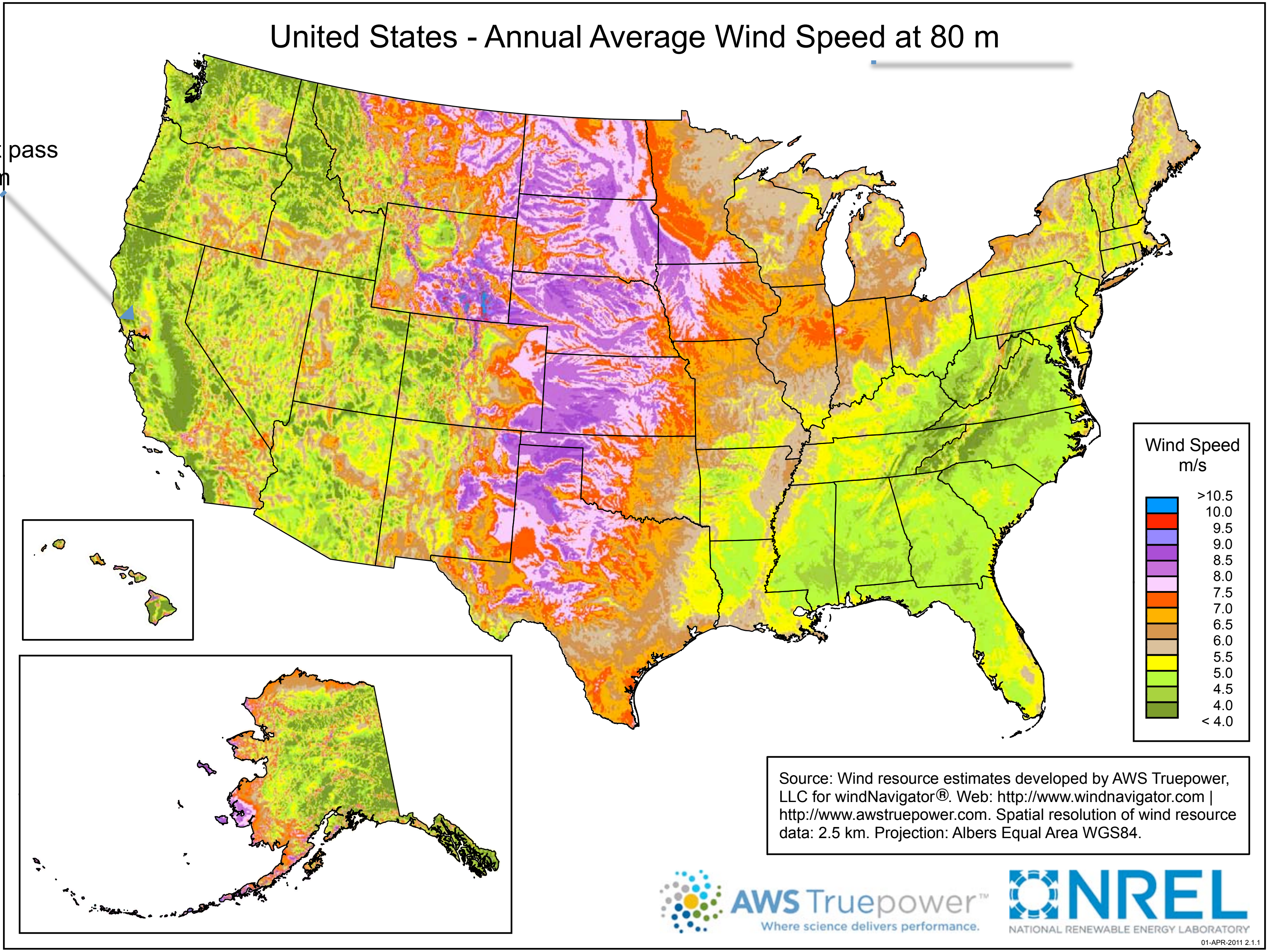
Persian Windmills and Wind Towers from Ancient Times

Credits: ©2009 WebEcoist

The earliest known windmill design dates back 3000 years to ancient Persia where they were used to grind grain and pump water. Reeds were bundled together to create vertical paddles that spun around a central axis. Carefully placed exterior walls ensured that wind would primarily drive the potentially bidirectional system in the desired direction. Of course, the use of wind power in sailing predates the inventions of windmills but these are the first known use of wind to automate mechanical/manual everyday tasks. Persia is also the original home of one of the most complex passive ventilation and cooling systems that has ever existed – 2,000-year-old engineering that rival modern hi-tech equivalents with the simple and elegant effectiveness of their design. Using a combination of air pressure differentials, structural orientation and running water these windcatcher structures help regulate temperatures in the harshest of desert environments with cool nights and burning hot days.

From Boyle

Altamont pass
wind farm

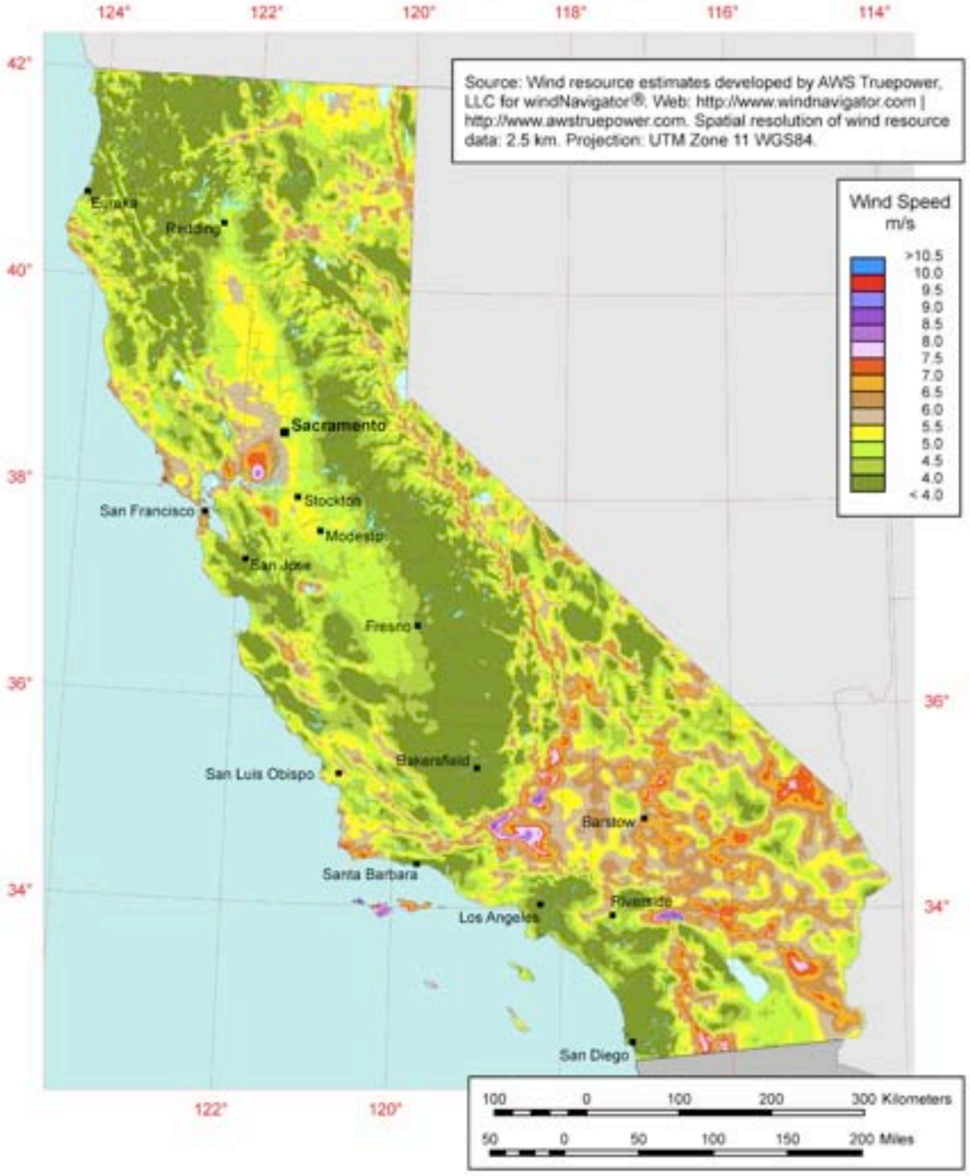


United States - Annual Average Wind Speed at 80 m

Source: Wind resource estimates developed by AWS Truepower, LLC for windNavigator®. Web: http://www.windnavigator.com | http://www.awstruepower.com. Spatial resolution of wind resource data: 2.5 km. Projection: Albers Equal Area WGS84.

1 m/sec = 2.24mph

California - Annual Average Wind Speed at 80 m



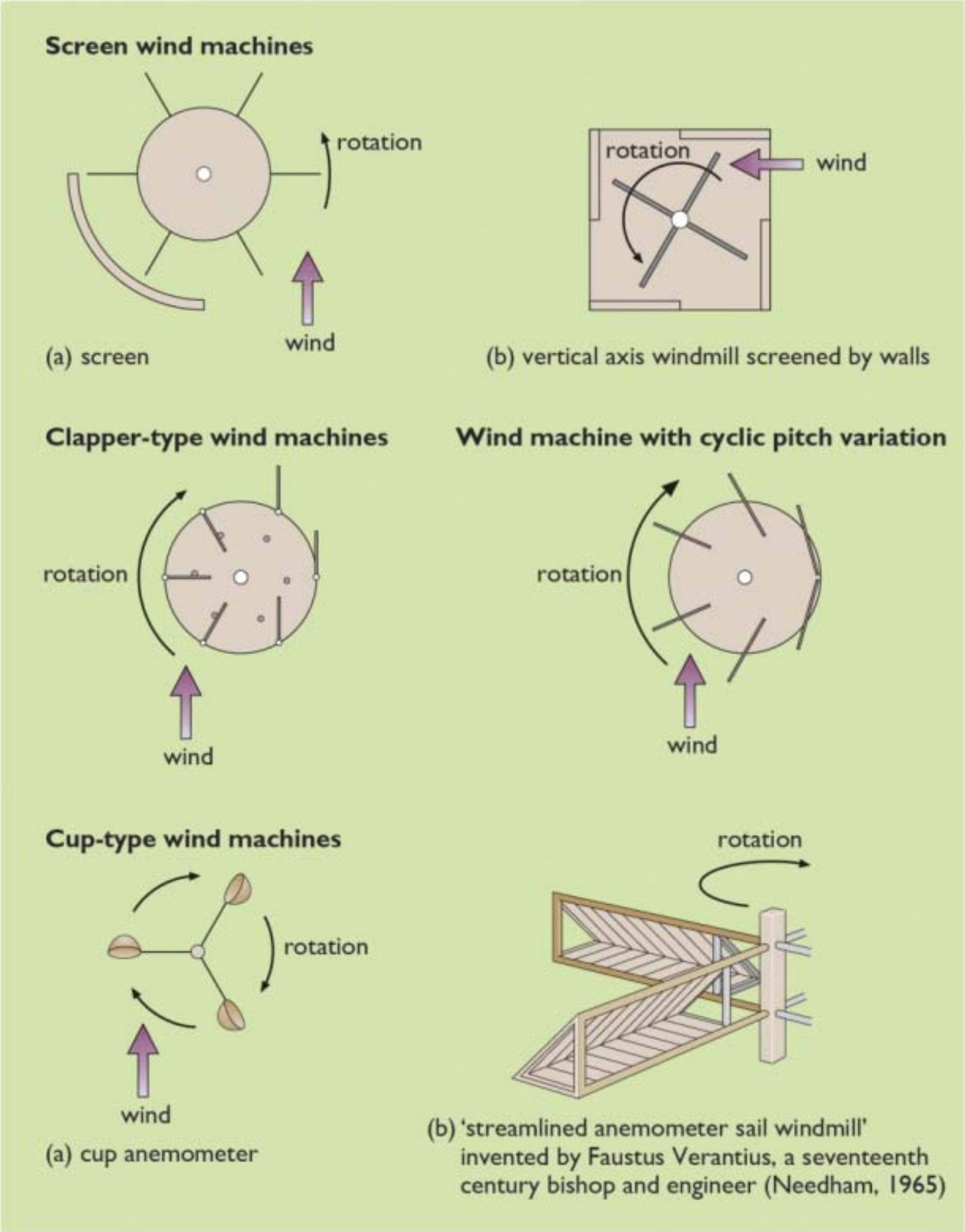
Source: Wind resource estimates developed by AWS Truepower, LLC for windNavigator®. Web: http://www.windnavigator.com | http://www.awstruepower.com. Spatial resolution of wind resource data: 2.5 km. Projection: UTM Zone 11 WGS84.

AWS Truepower™
Where science delivers performance.

NREL
NATIONAL RENEWABLE ENERGY LABORATORY

Altamont Pass Windfarm in Northern California

Types of Wind Turbines


Screen wind machines

(a) screen

(b) vertical axis windmill screened by walls

Clapper-type wind machines

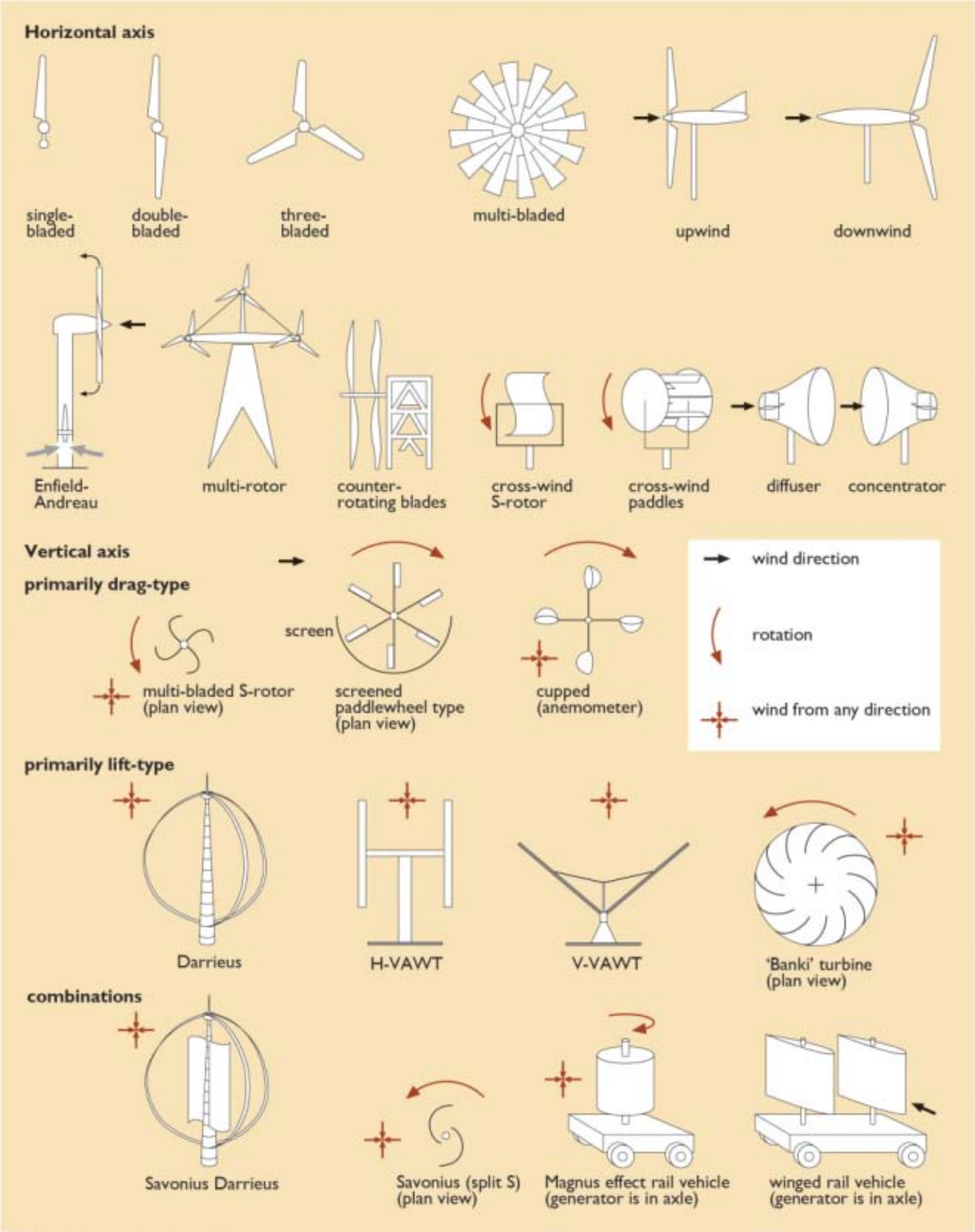
Wind machine with cyclic pitch variation

Cup-type wind machines

(a) cup anemometer

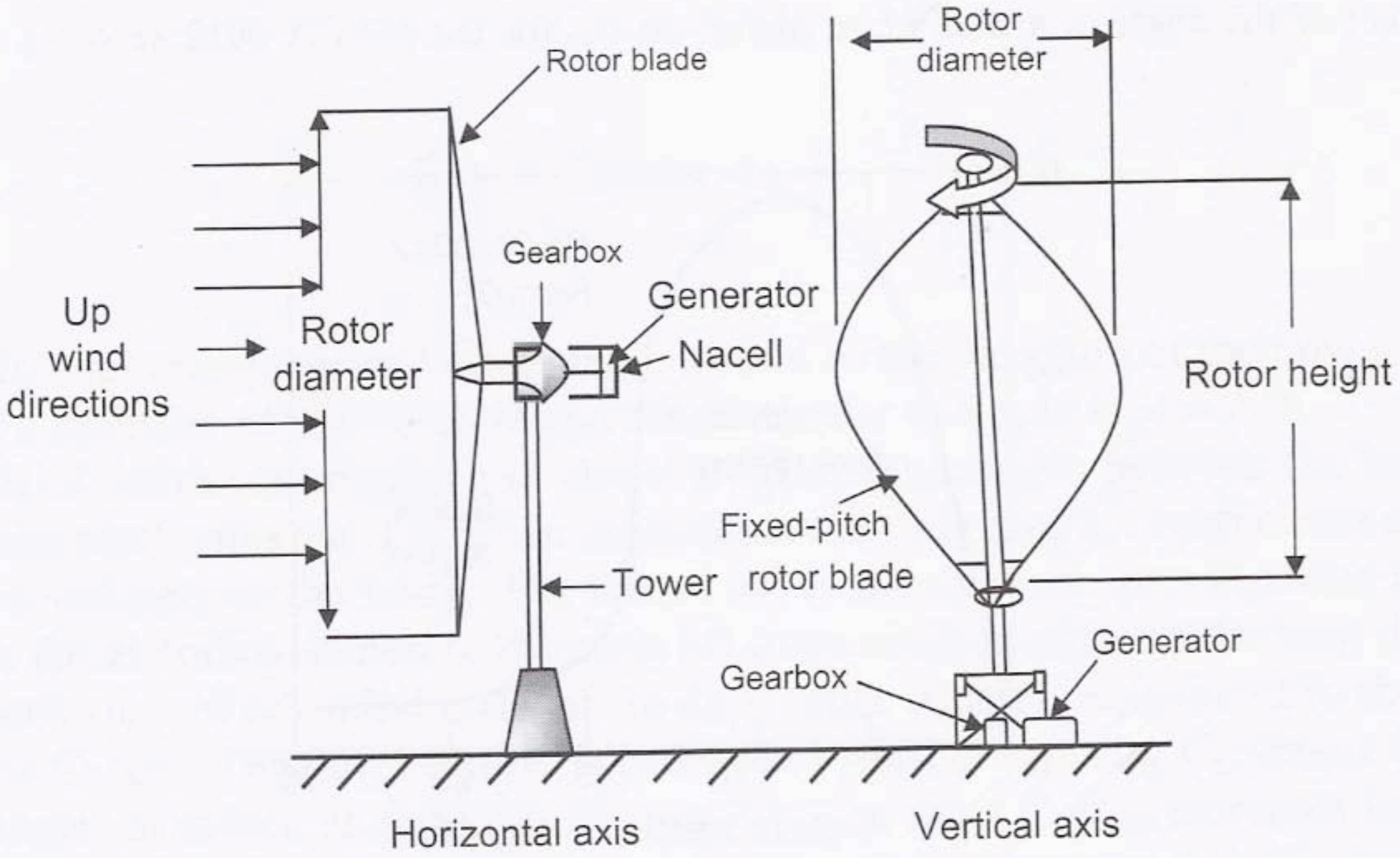
(b) 'streamlined anemometer sail windmill' invented by Faustus Verantius, a seventeenth century bishop and engineer (Needham, 1965)

Needham, J. with the collaboration of Ling, W. (1965) Science and Civilisation in China, Vol 4, Part II. Cambridge University Press


Horizontal axis
single-bladed
double-bladed
three-bladed
multi-bladed
upwind
downwind
Enfield-Andreau
multi-rotor
counter-rotating blades
cross-wind S-rotor
cross-wind paddles
diffuser
concentrator
Vertical axis
primarily drag-type
multi-bladed S-rotor (plan view)
screen
screened paddlewheel type (plan view)
cupped (anemometer)
wind direction
rotation
wind from any direction
primarily lift-type
Darrieus
H-VAWT
V-VAWT
'Banki' turbine (plan view)
combinations
Savonius Darrieus
Savonius (split S) (plan view)
Magnus effect rail vehicle (generator is in axle)
winged rail vehicle (generator is in axle)

From Boyle

HAWT vs VAWT



TIWARI AND MISHRA

The Center for Sustainable Energy and Power Systems

CENSEPS

4KW Vertical Axis Wind Turbine, Hartnell College Salinas, Ca.

Northern European Windmill

Derek Taylor/Altechnica

Multi-Bladed Wind Turbine. Horizontal Axis

John Mead/Science Photo Library

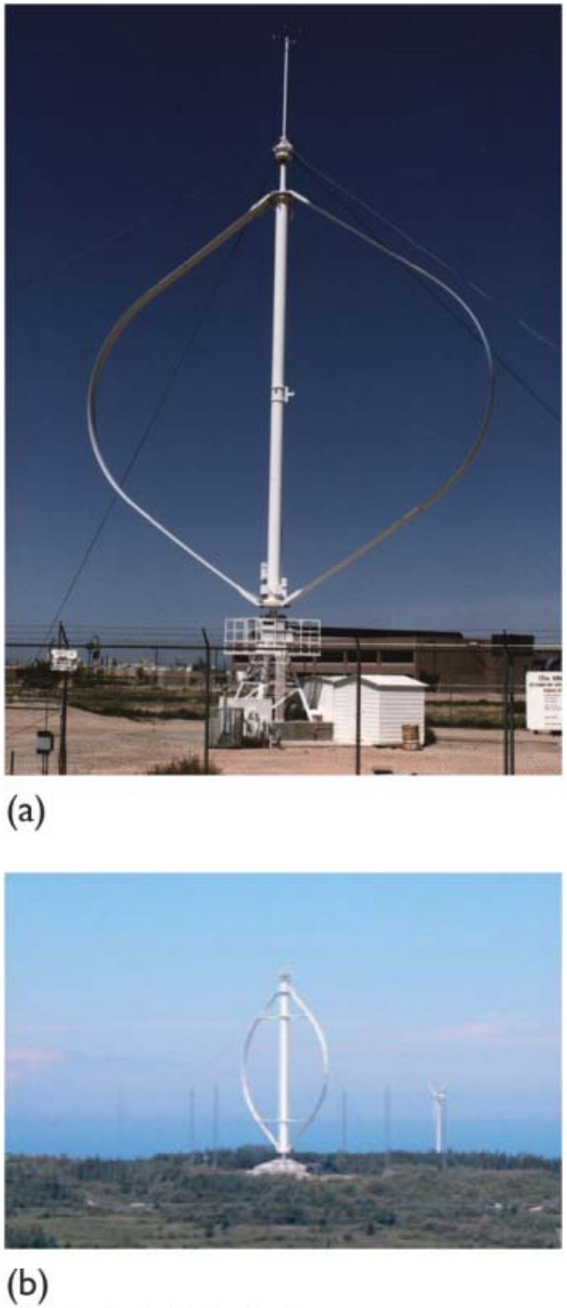
(Vestas, 850kWatt)porizontal Axis Wind Turbine

Courtesy of Vestas Wind A/S

Off shore Wind Farms in Denmark

Altamont Pass Windfarm in Northern California

Vertical Axis Wind Turbines



Derek Taylor/Altechnica

Bernoulli's Principle

fluid flow

$$\frac{v^2}{2} + gz + \frac{P}{\rho} = \text{constant}$$

v = velocity of flow

P = pressure

ρ = fluid density

g = 9.8 m/sec^2 (acc. due to gravity)

z = height of surface above some
reference plane,

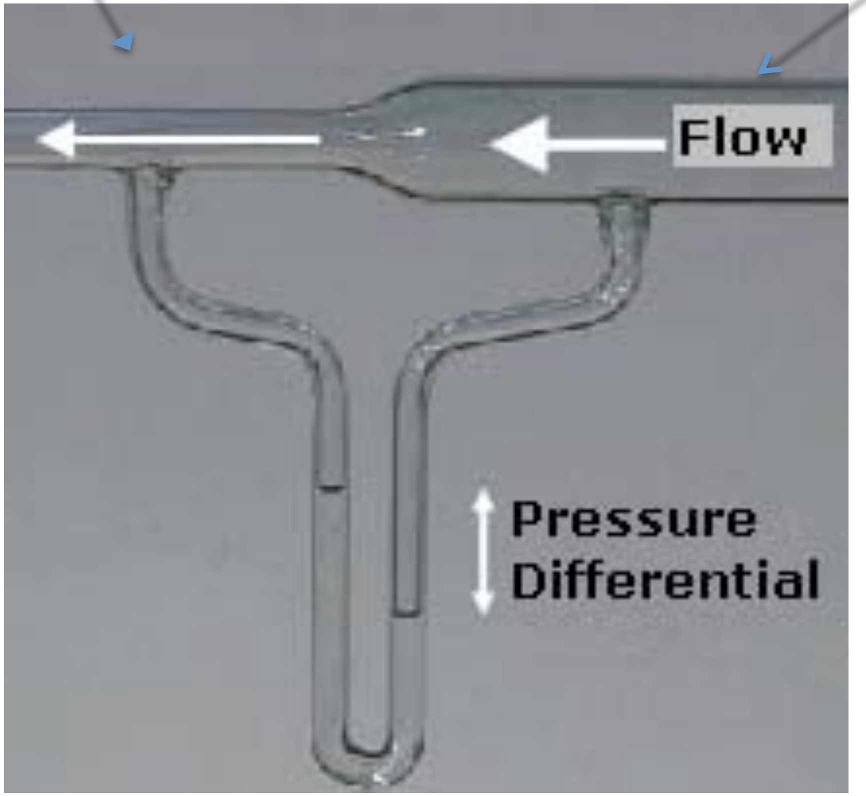
manifestation of the conservation of energy

kinetic energy + potential energy = constant.

Bernouilli's principle
Venturi Effect

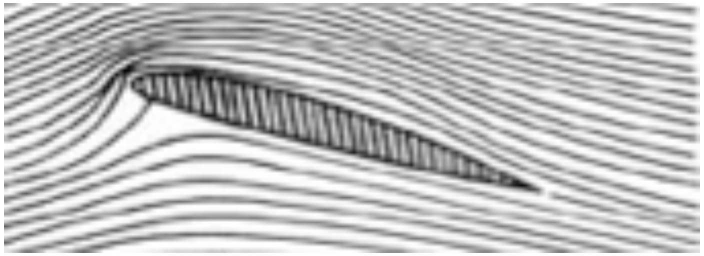
High v, low P

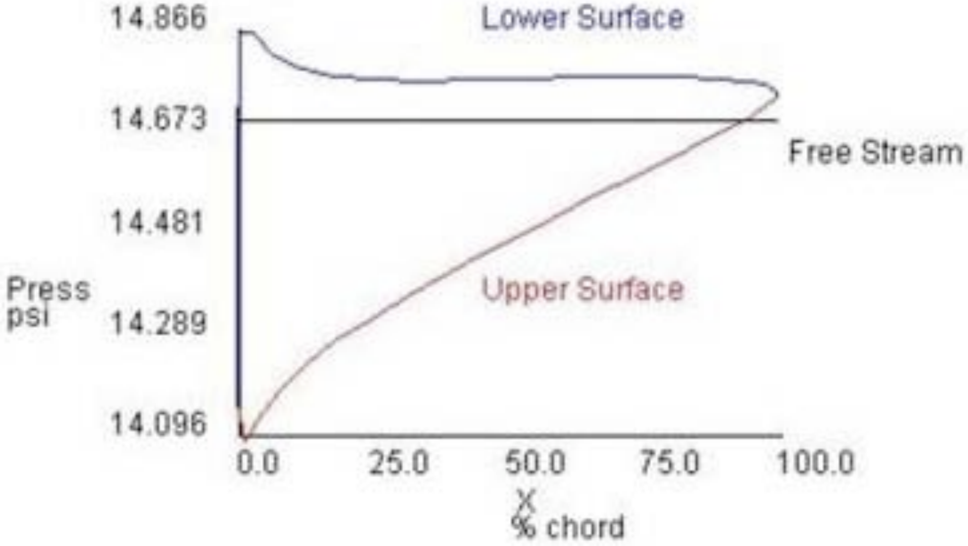
Low v, high P

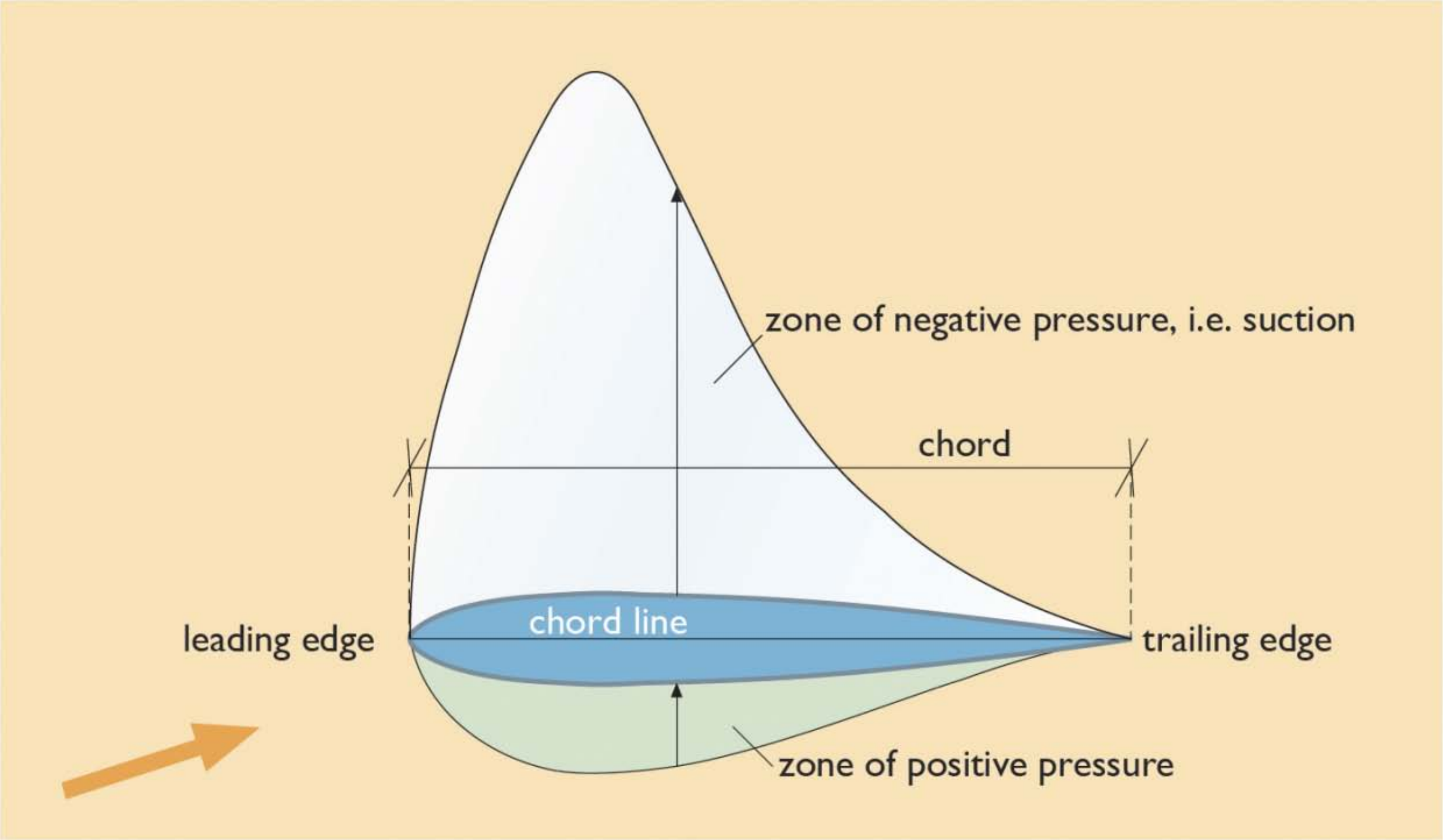


Increase of v between closely spaced buildings

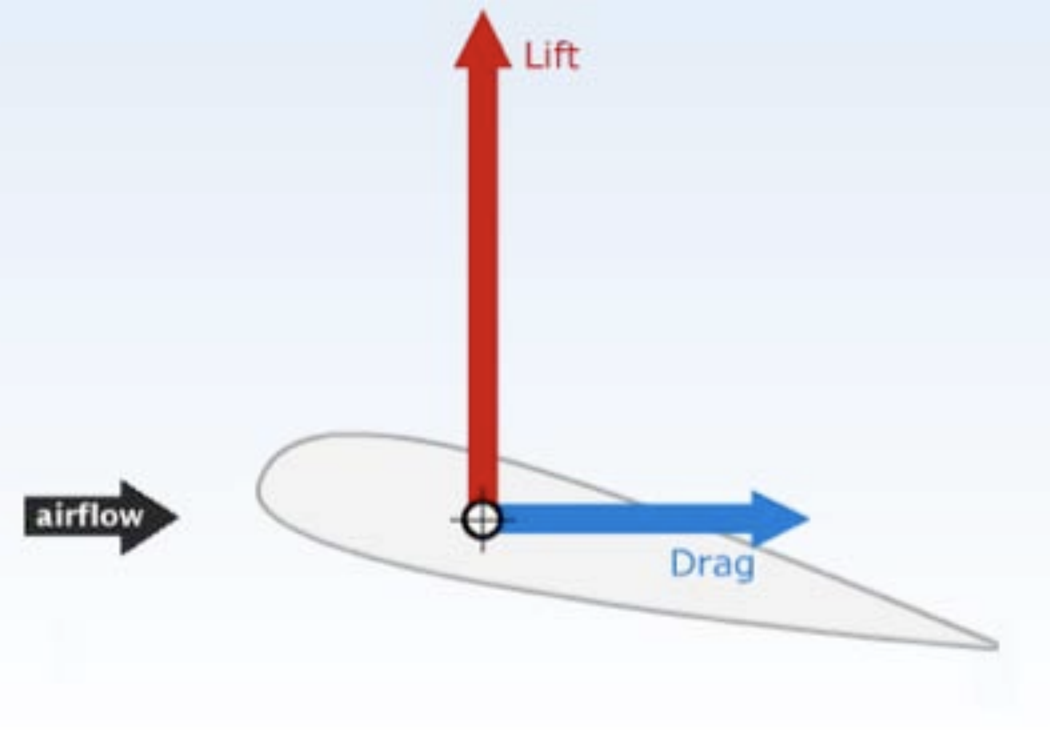
How does one “fly”?

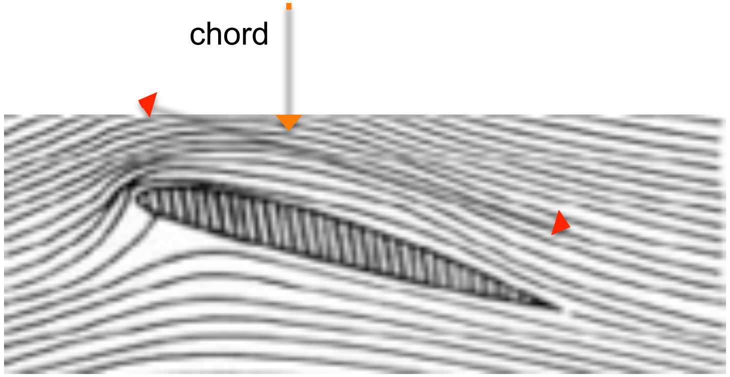


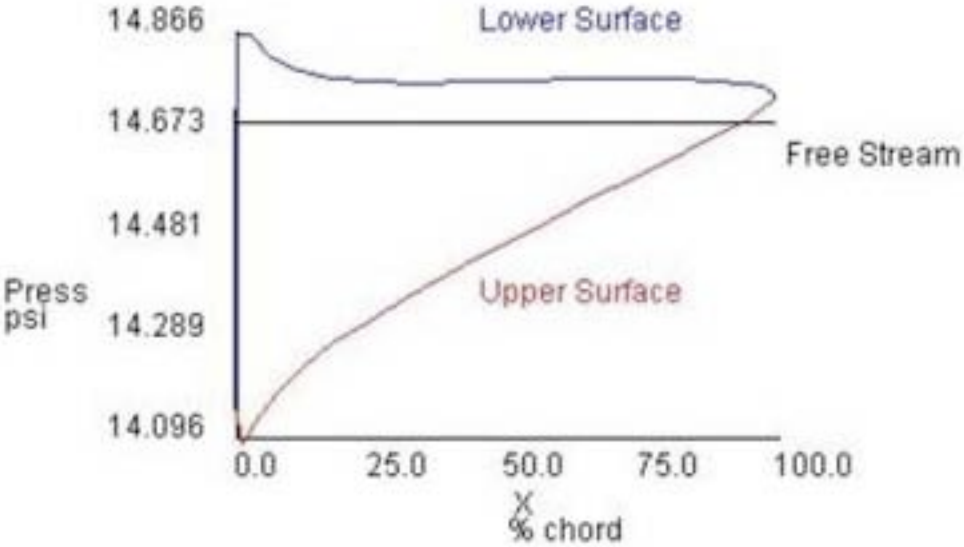


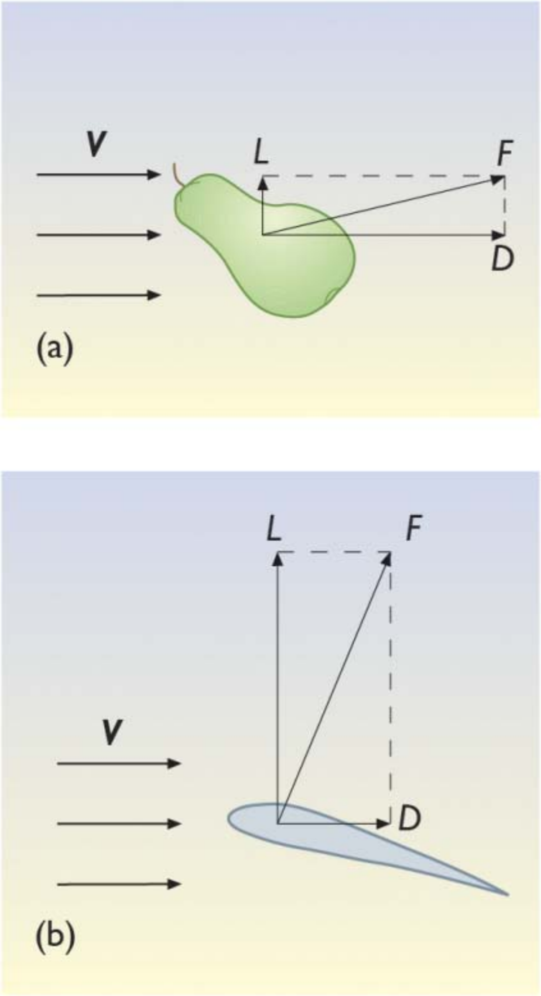

zone of negative pressure, i.e. suction
chord
chord line
leading edge
trailing edge
zone of positive pressure

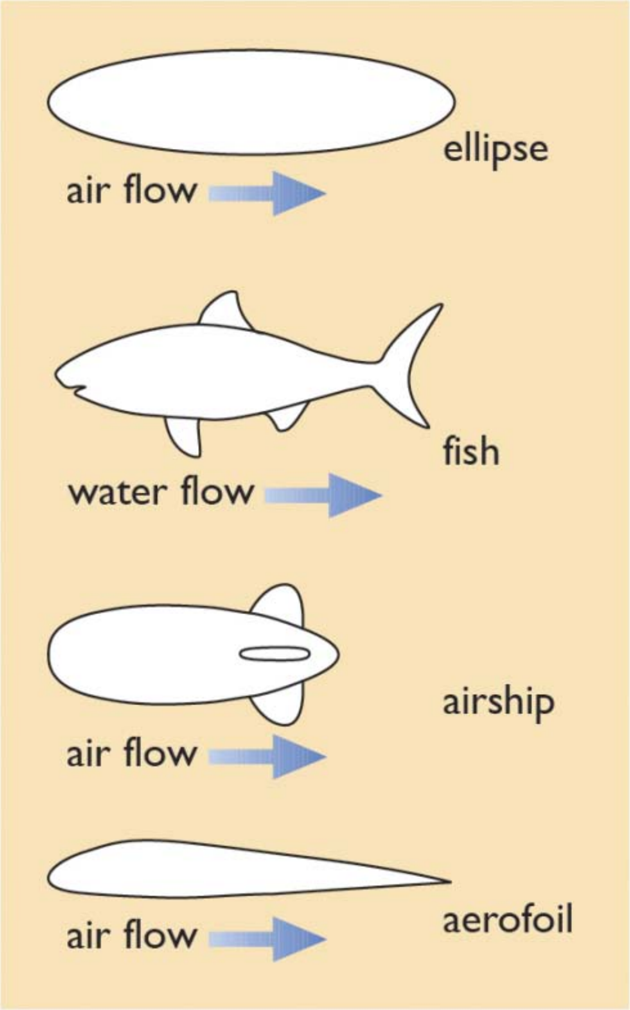
Lift and Drag

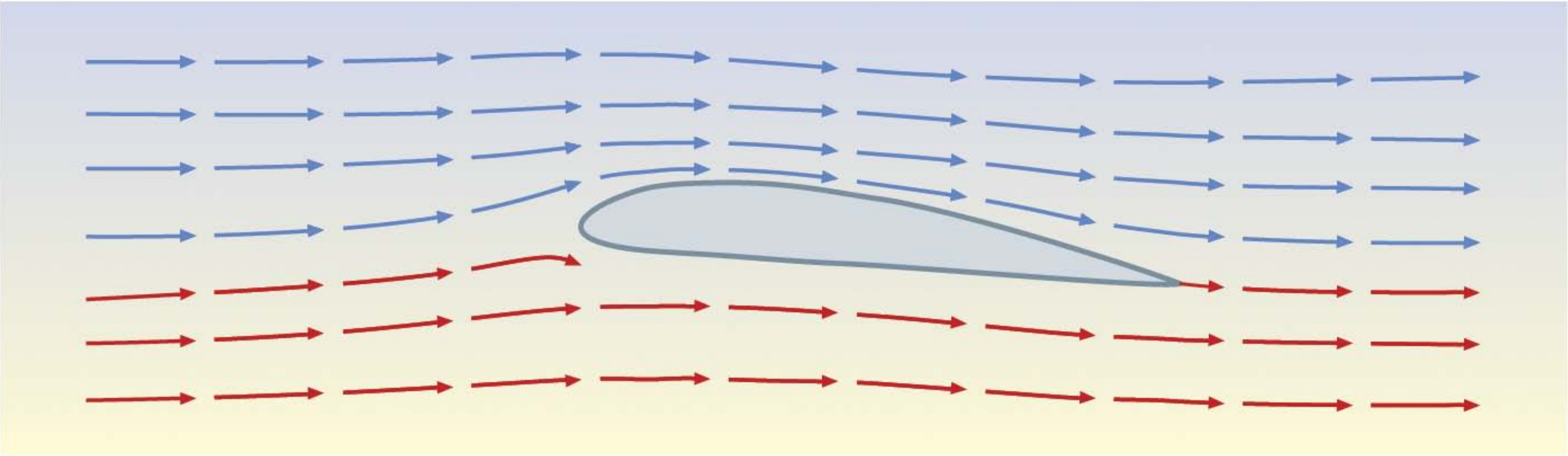


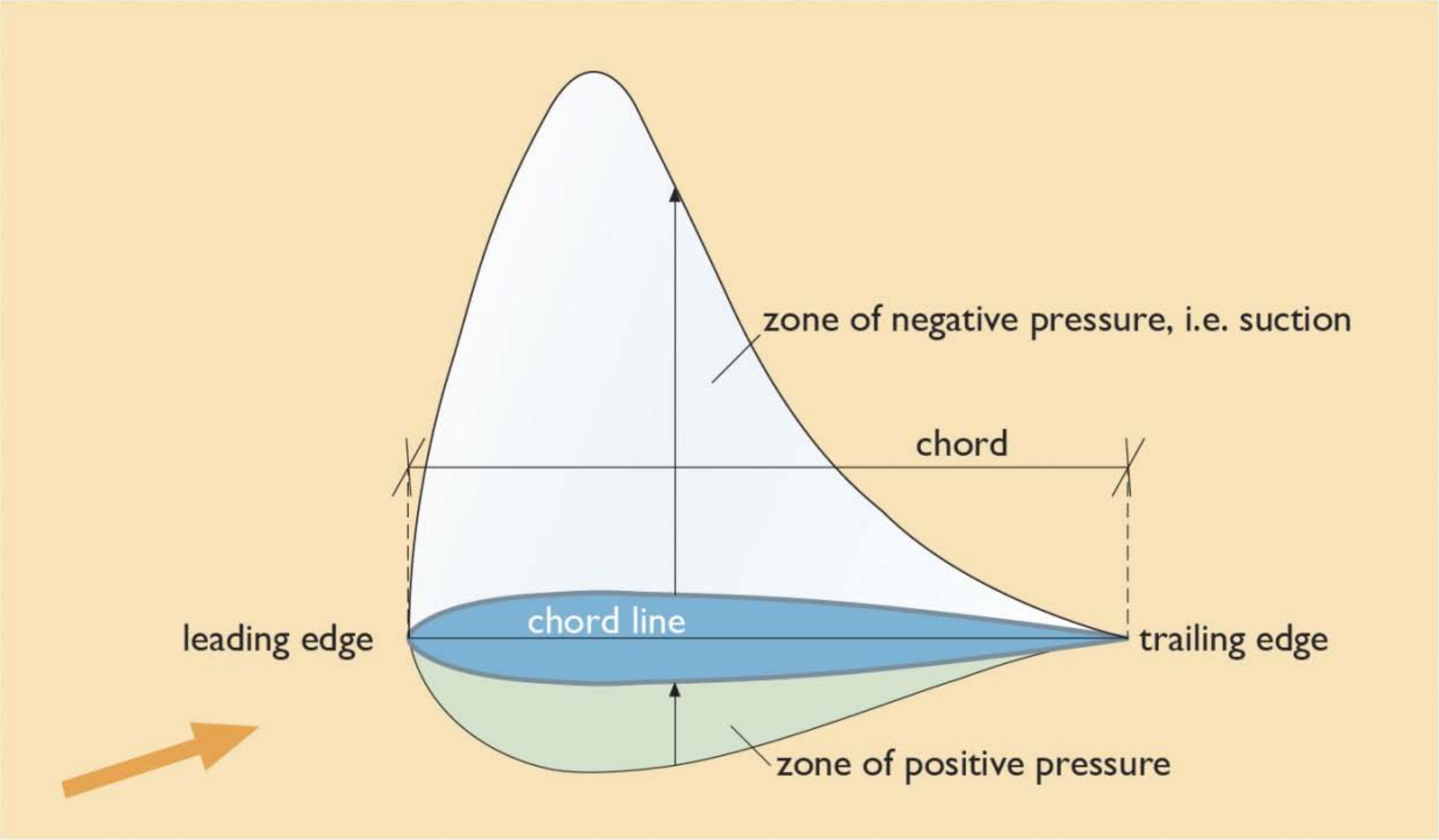





V
L
F
D
(a)
L
F
V
D
(b)


ellipse
air flow
fish
water flow
airship
air flow
aerofoil
air flow




zone of negative pressure, i.e. suction
chord
chord line
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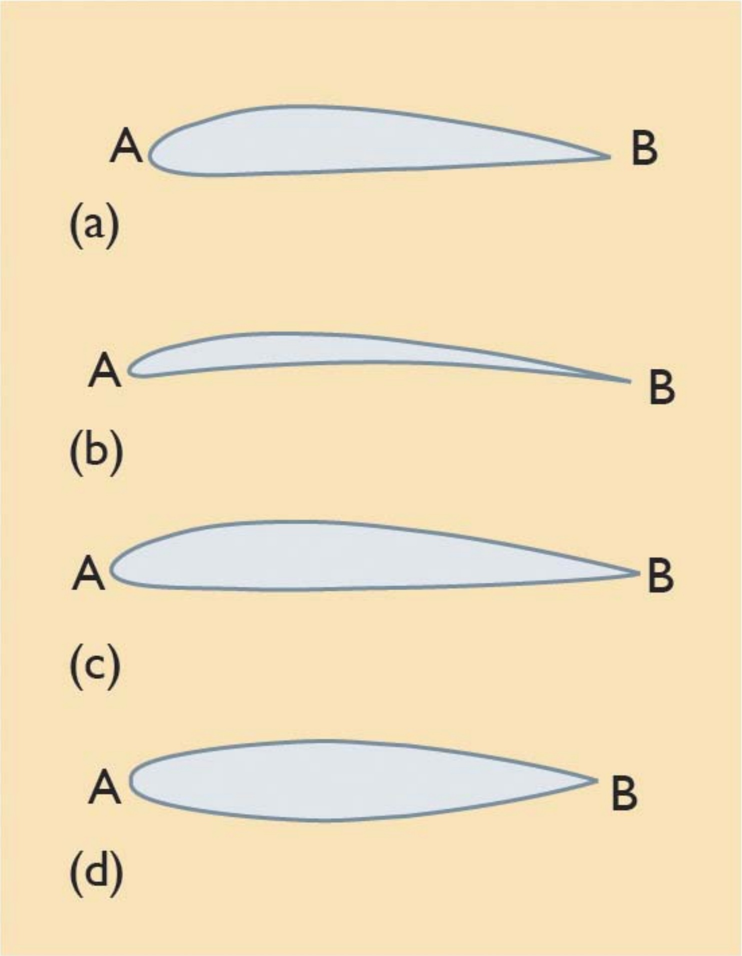
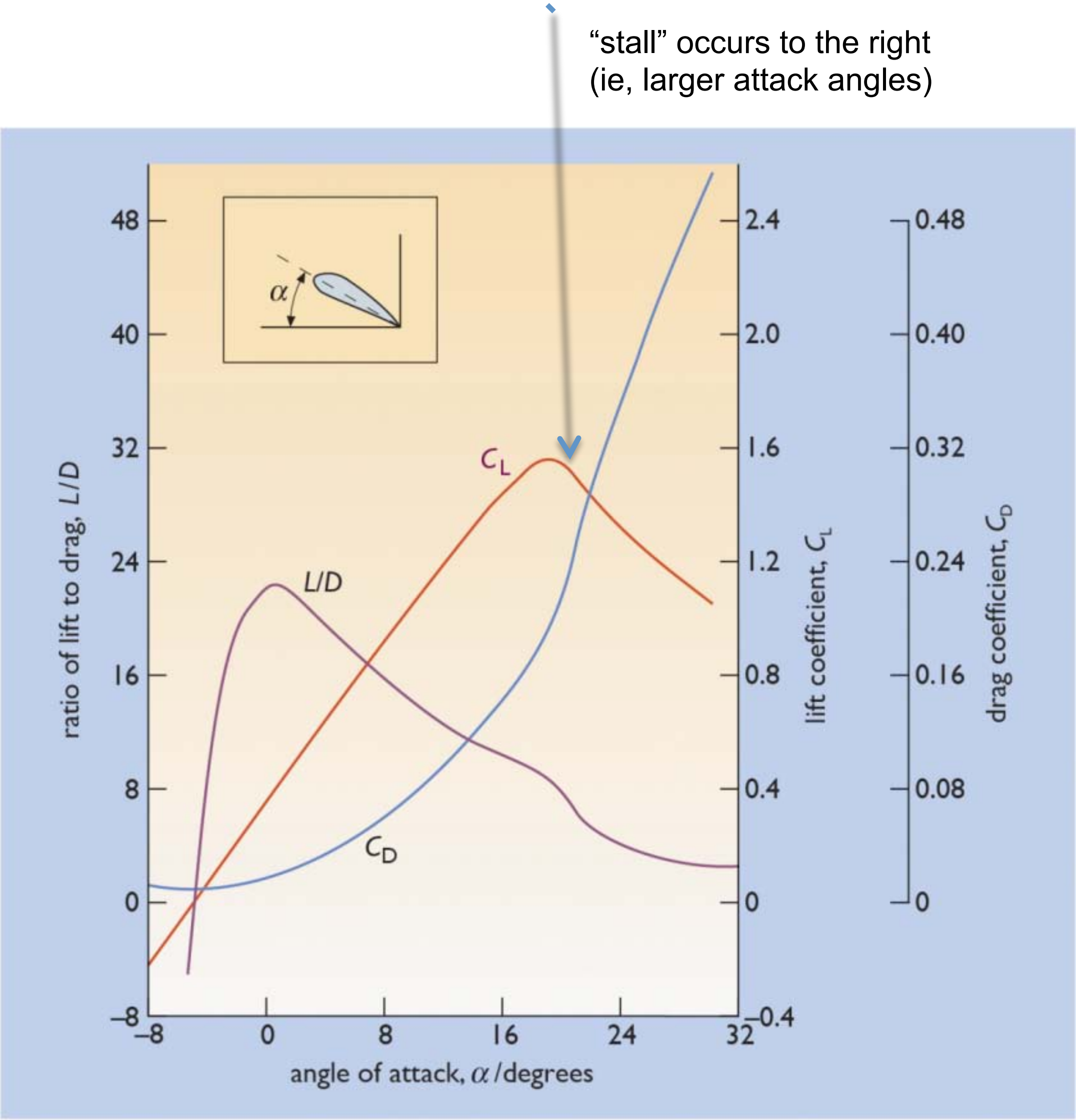
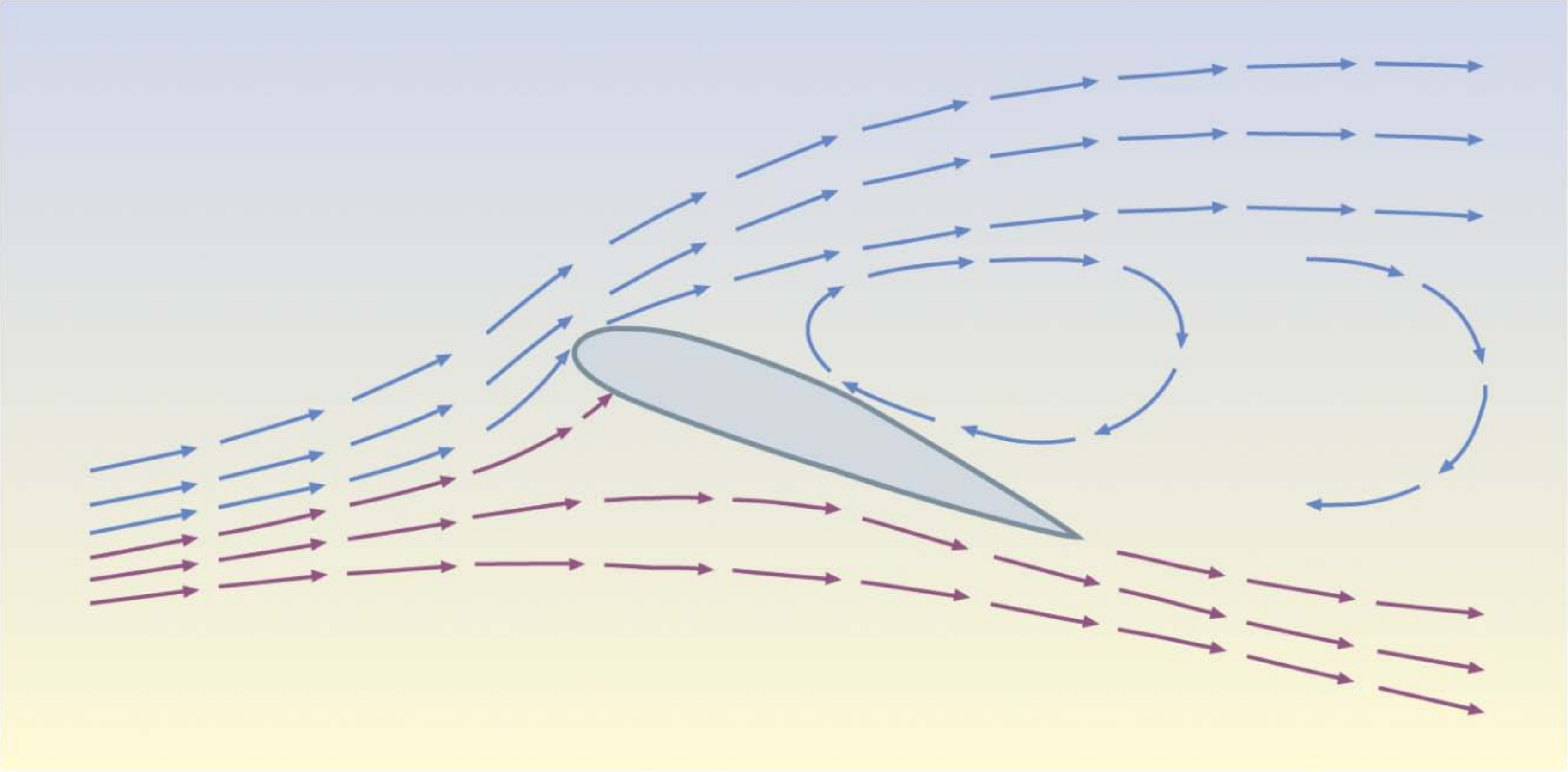
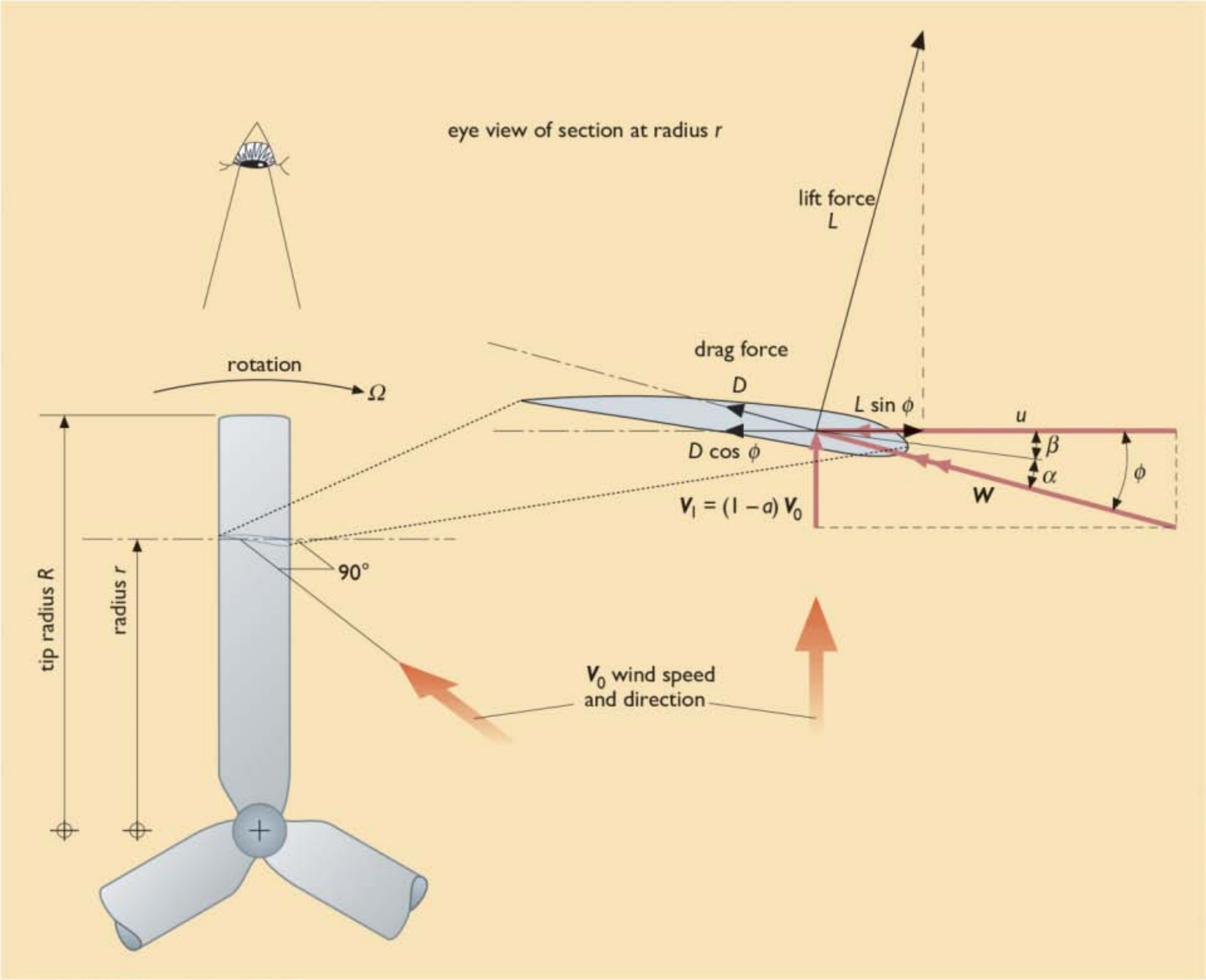
zone of positive pressure


A
B
(a)
A
B
(b)
A
B
(c)
A
B
(d)

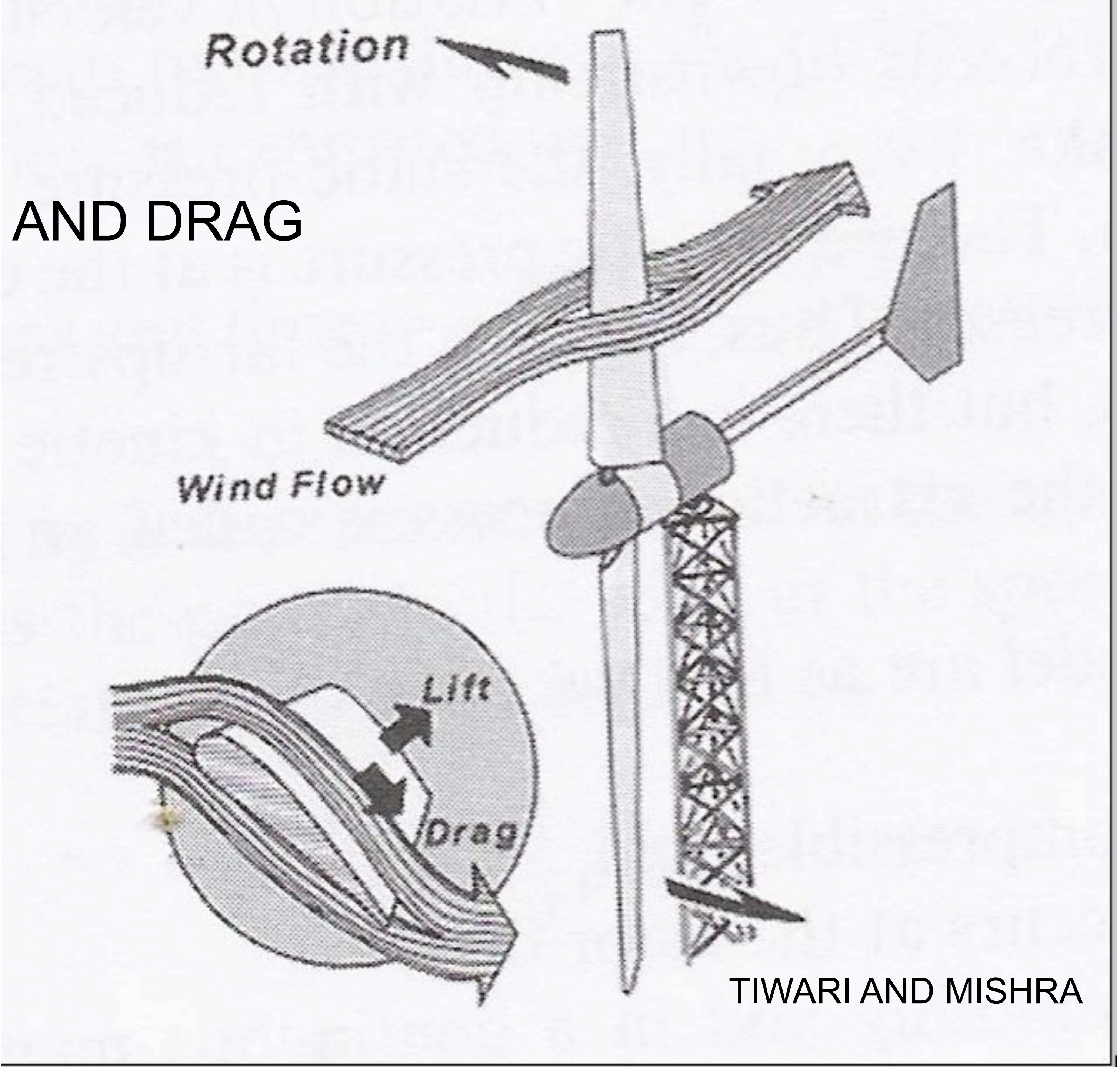
“stall” occurs to the right
(ie, larger attack angles)



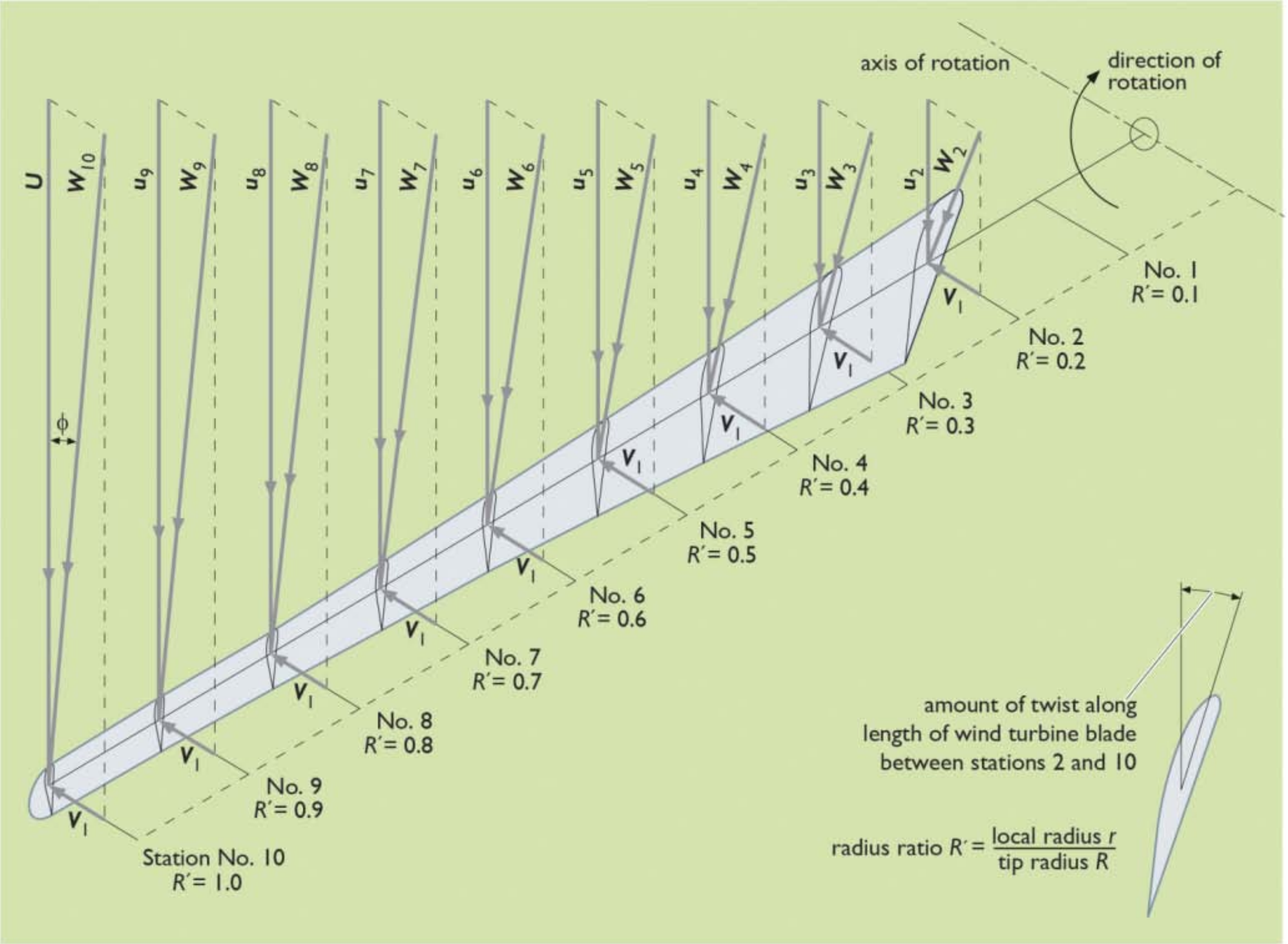



eye view of section at radius r
lift force L
drag force
D
$L \sin \phi$
u
$D \cos \phi$
β
α
ϕ
$\boldsymbol{W}$
$\boldsymbol{V}_1 = (1 - a)\,\boldsymbol{V}_0$
rotation
Ω
tip radius R
radius r
90°
$\boldsymbol{V}_0$ wind speed and direction

LIFT AND DRAG

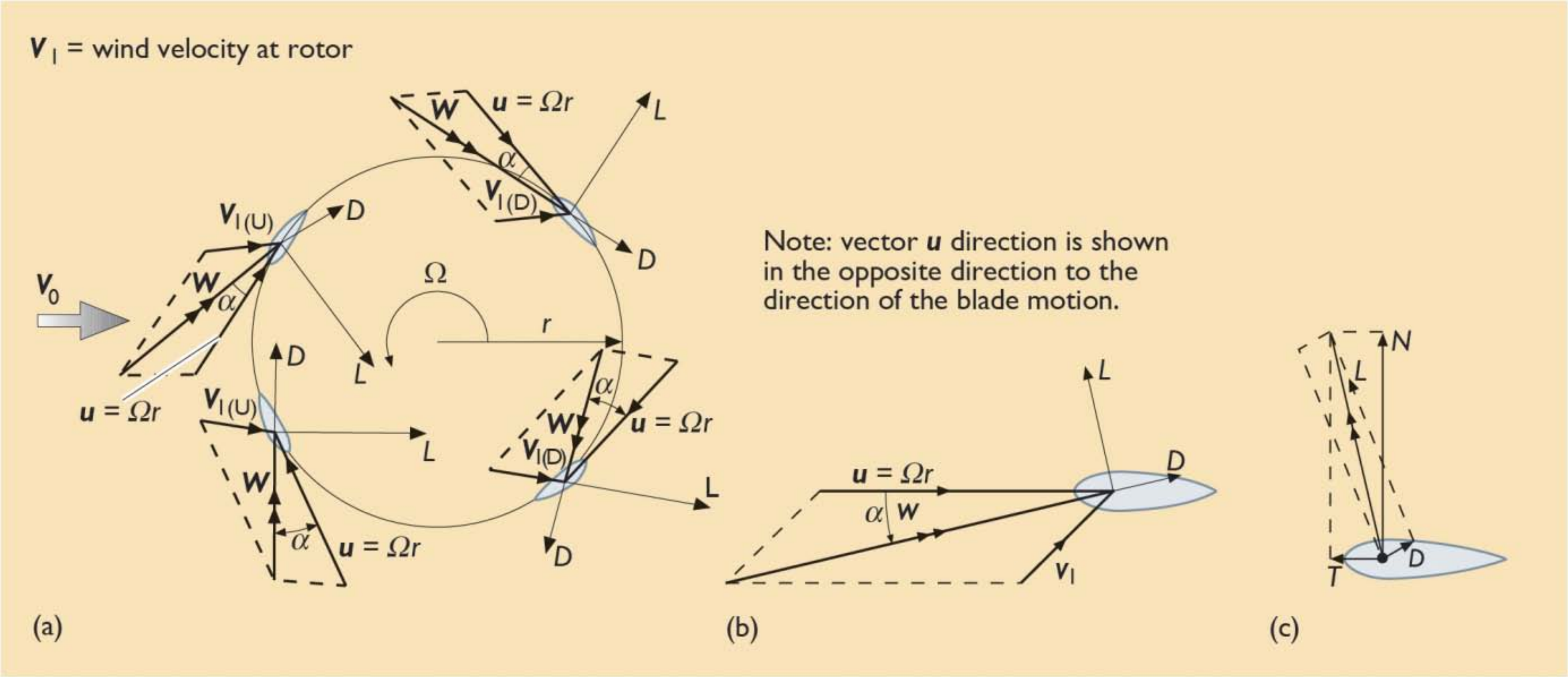


TIWARI AND MISHRA



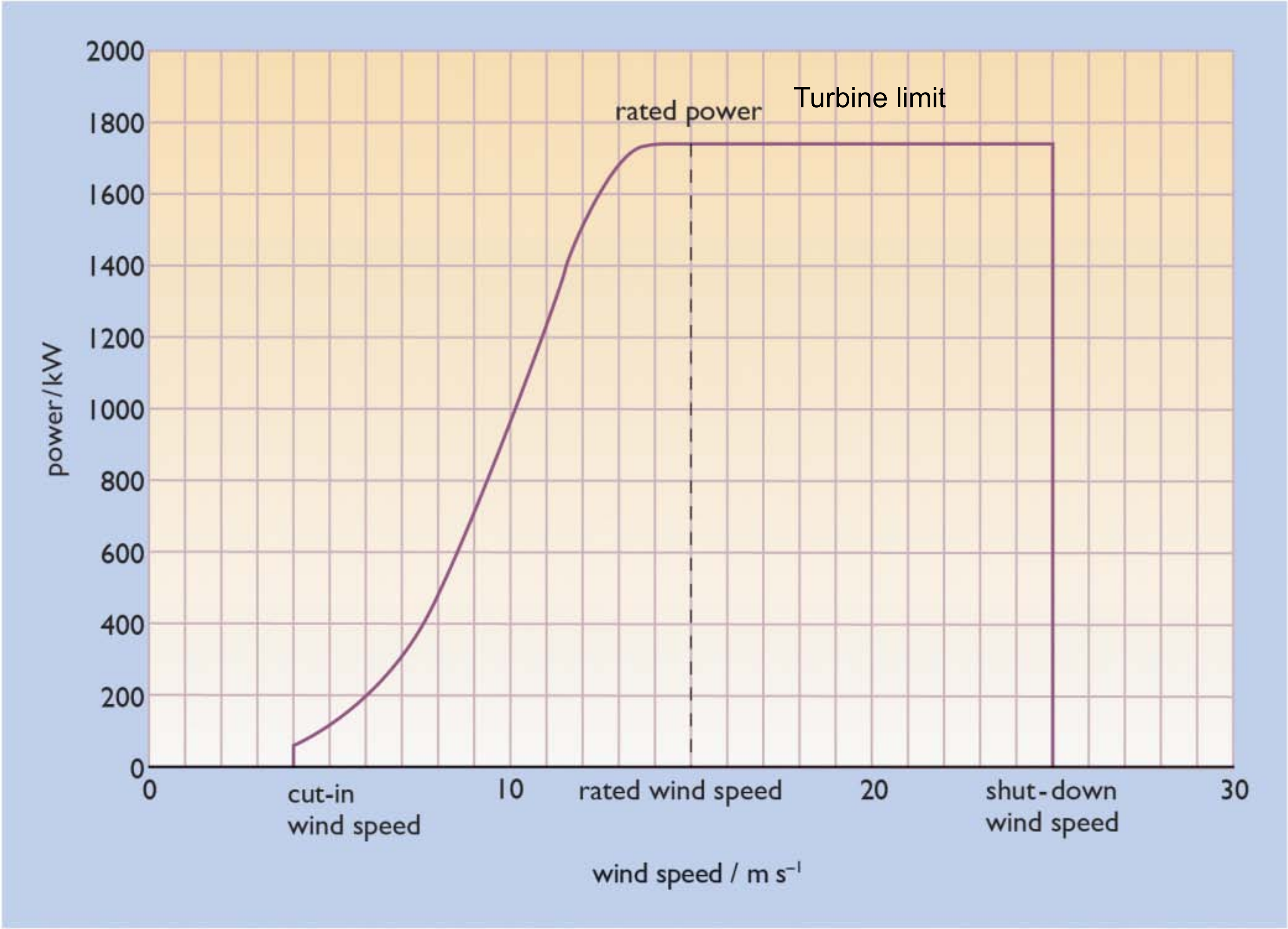
axis of rotation
direction of rotation
U
W10
u9
W9
u8
W8
u7
W7
u6
W6
u5
W5
u4
W4
u3
W3
u2
W2
ϕ
V1
No. 1 R′= 0.1
No. 2 R′= 0.2
No. 3 R′= 0.3
No. 4 R′= 0.4
No. 5 R′= 0.5
No. 6 R′= 0.6
No. 7 R′= 0.7
No. 8 R′= 0.8
No. 9 R′= 0.9
Station No. 10 R′= 1.0
amount of twist along length of wind turbine blade between stations 2 and 10
radius ratio R′ = local radius r / tip radius R

Aerodynamics of Vertical Axis Wind Turbines

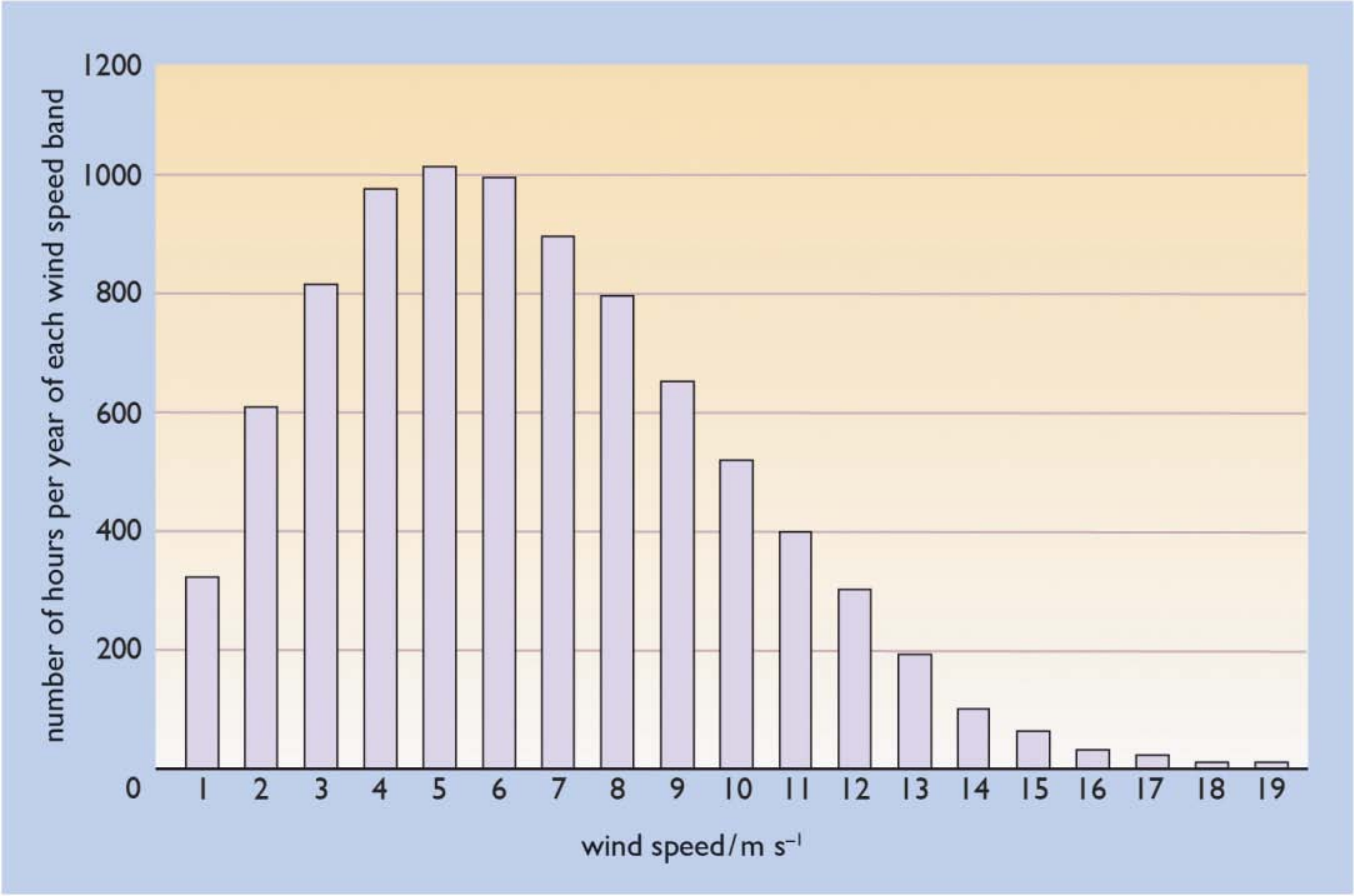


Note: vector ***u*** direction is shown in the opposite direction to the direction of the blade motion.

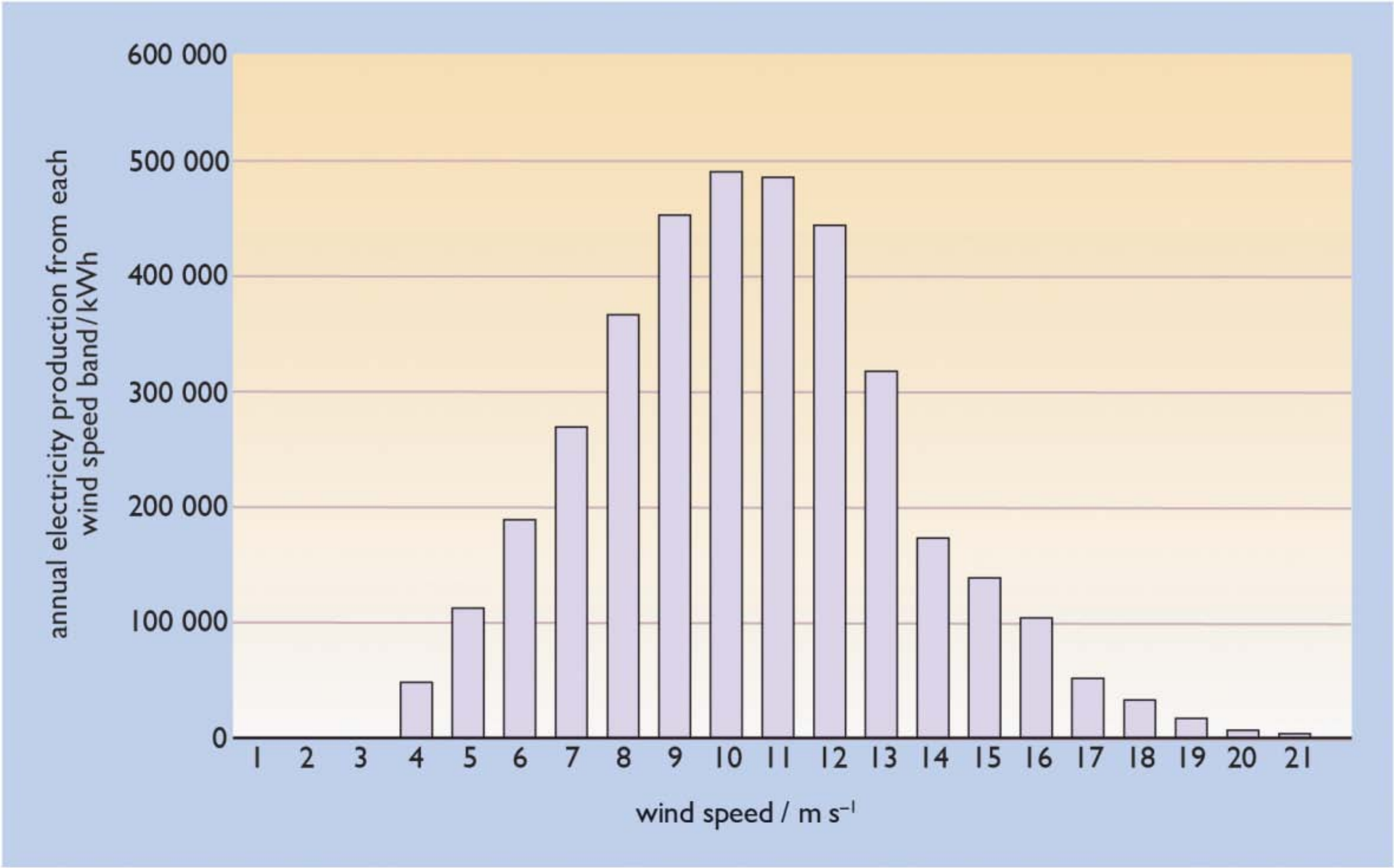
Wind Turbine Speed Power Curve



http://www.wind-power-program.com/turbine_characteristics.htm

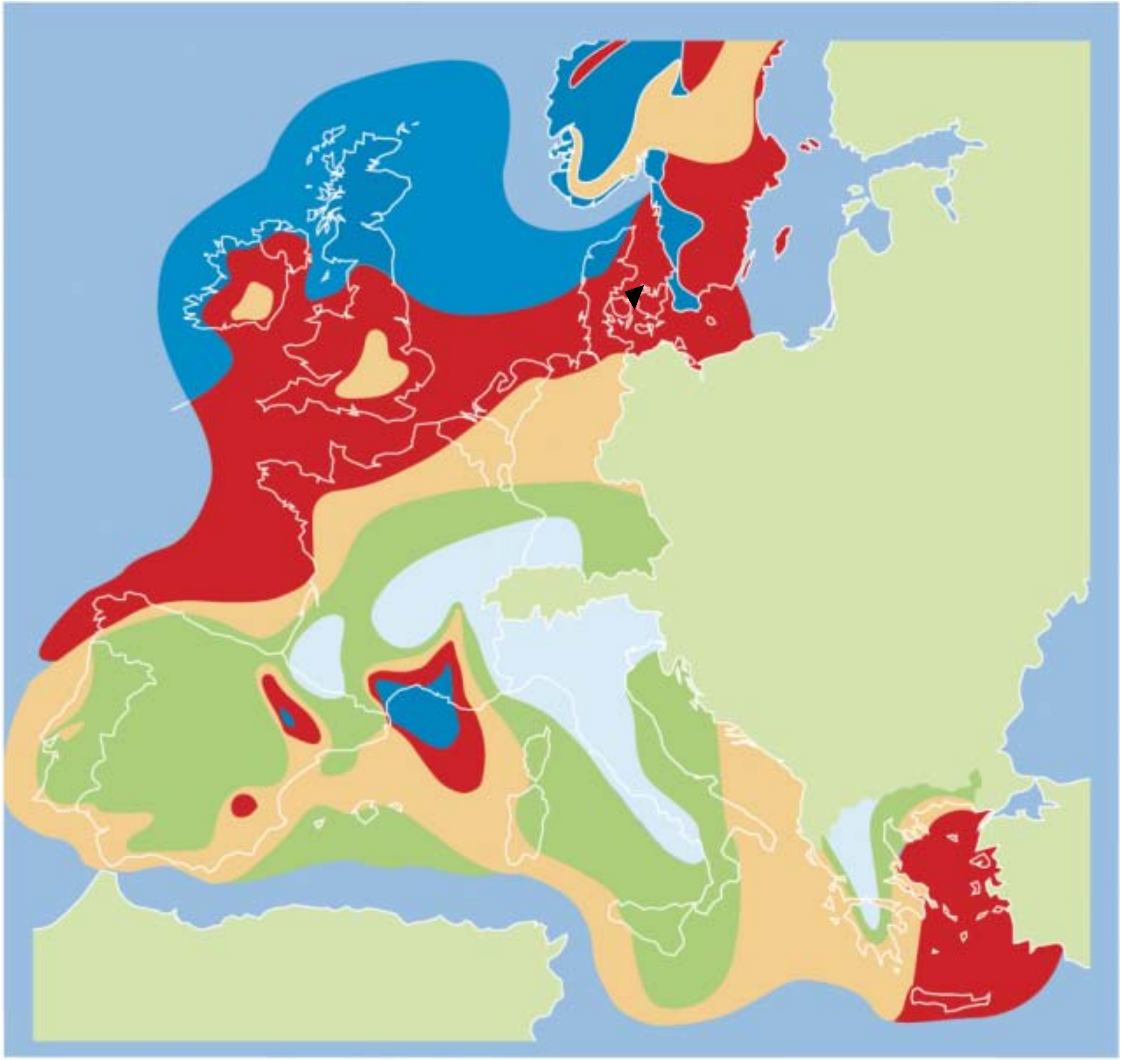


Wind speed frequency distribution at a particular site



Wind energy distribution at a particular site with the previous wind speed powqer curve

Wind Map in Europe

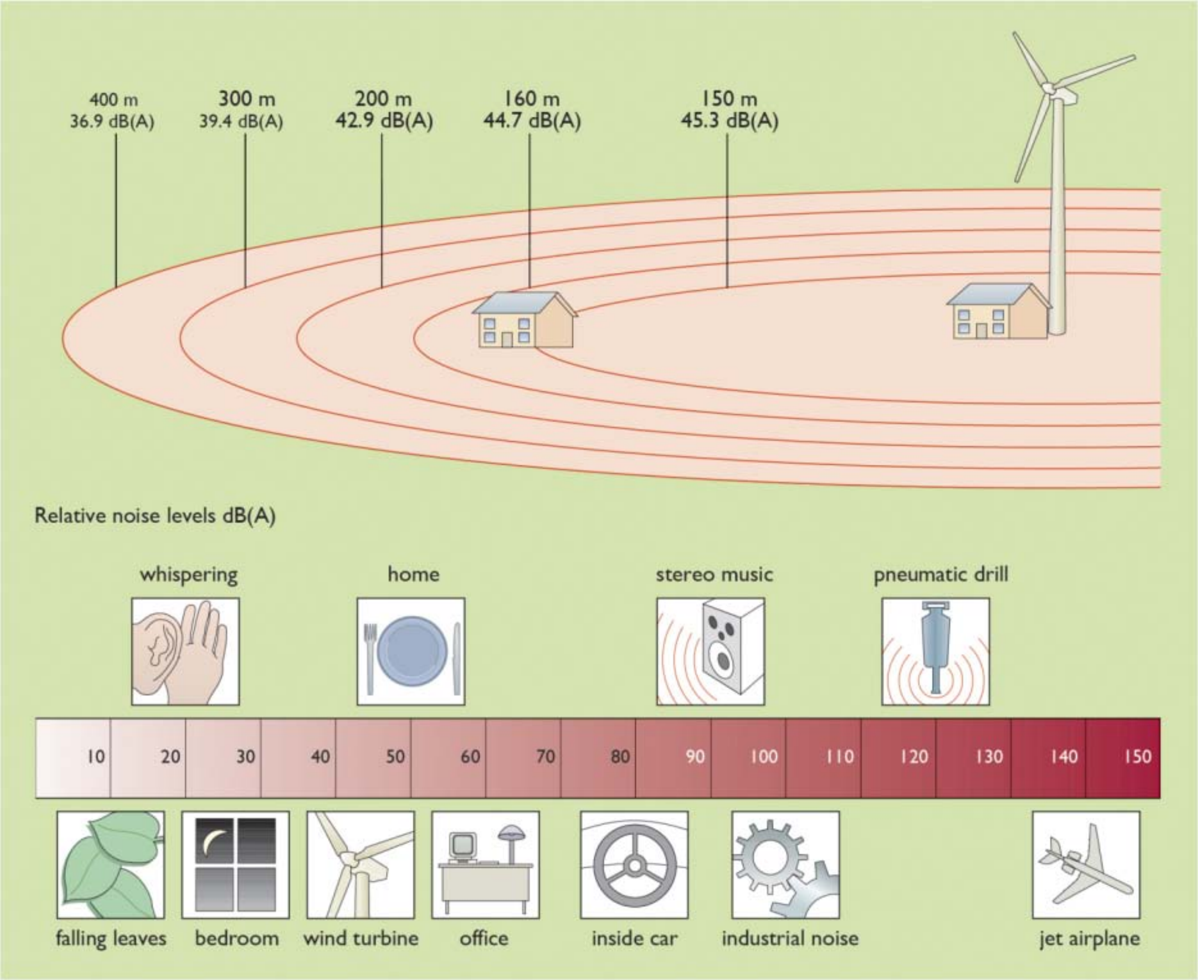


、Denmark

Wind resources at 50 m above ground level for five different topographic conditions

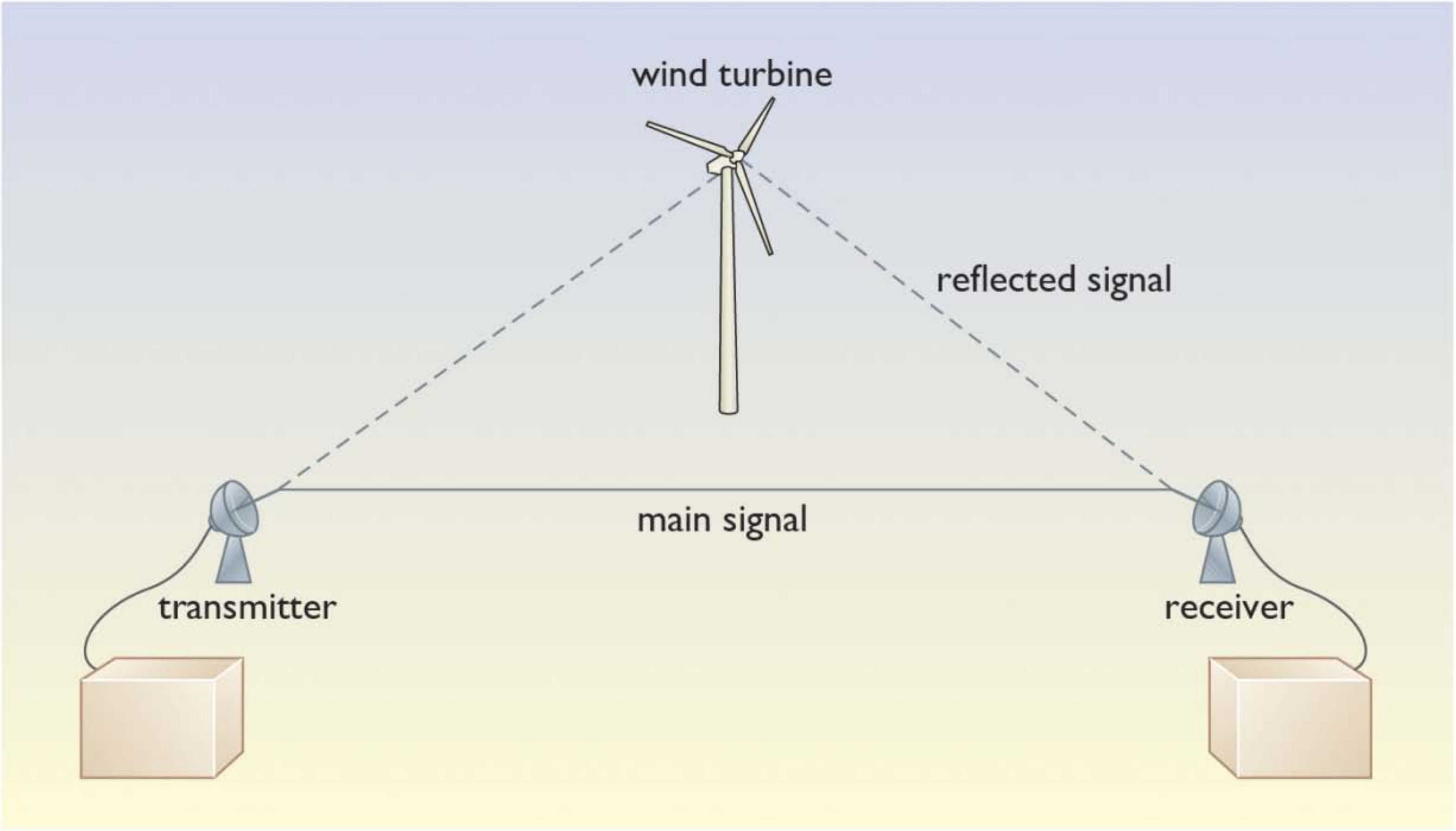
Wind class		Sheltered terrain		Open plain		At a sea coast		Open sea		Hills and ridges	
		m s^{-1}	W m^{-2}	m s^{-1}	W m^{-2}	m s^{-1}	W m^{-2}	m s^{-1}	W m^{-2}	m s^{-1}	W m^{-2}
5	🟦	>6.0	>250	>7.5	>500	>8.5	>700	>9.0	>800	>11.5	>1800
4	🟥	5.0–6.0	150–250	6.5–7.5	300–500	7.0–8.5	400–700	8.0–9.0	600–800	10.0–11.5	1200–1800
3	🟧	4.5–5.0	100–150	5.5–6.5	200–300	6.0–7.0	250–400	7.0–8.0	400–600	8.5–10.0	700–1200
2	🟩	3.5–4.5	50–100	4.5–5.5	100–200	5.0–6.0	150–250	5.5–7.0	200–400	7.0–8.5	400–700
1	⬜	<3.5	<50	<4.5	<100	<5.0	<150	<5.5	<200	<7.0	<400

Acoustical effects of Wind Turbines

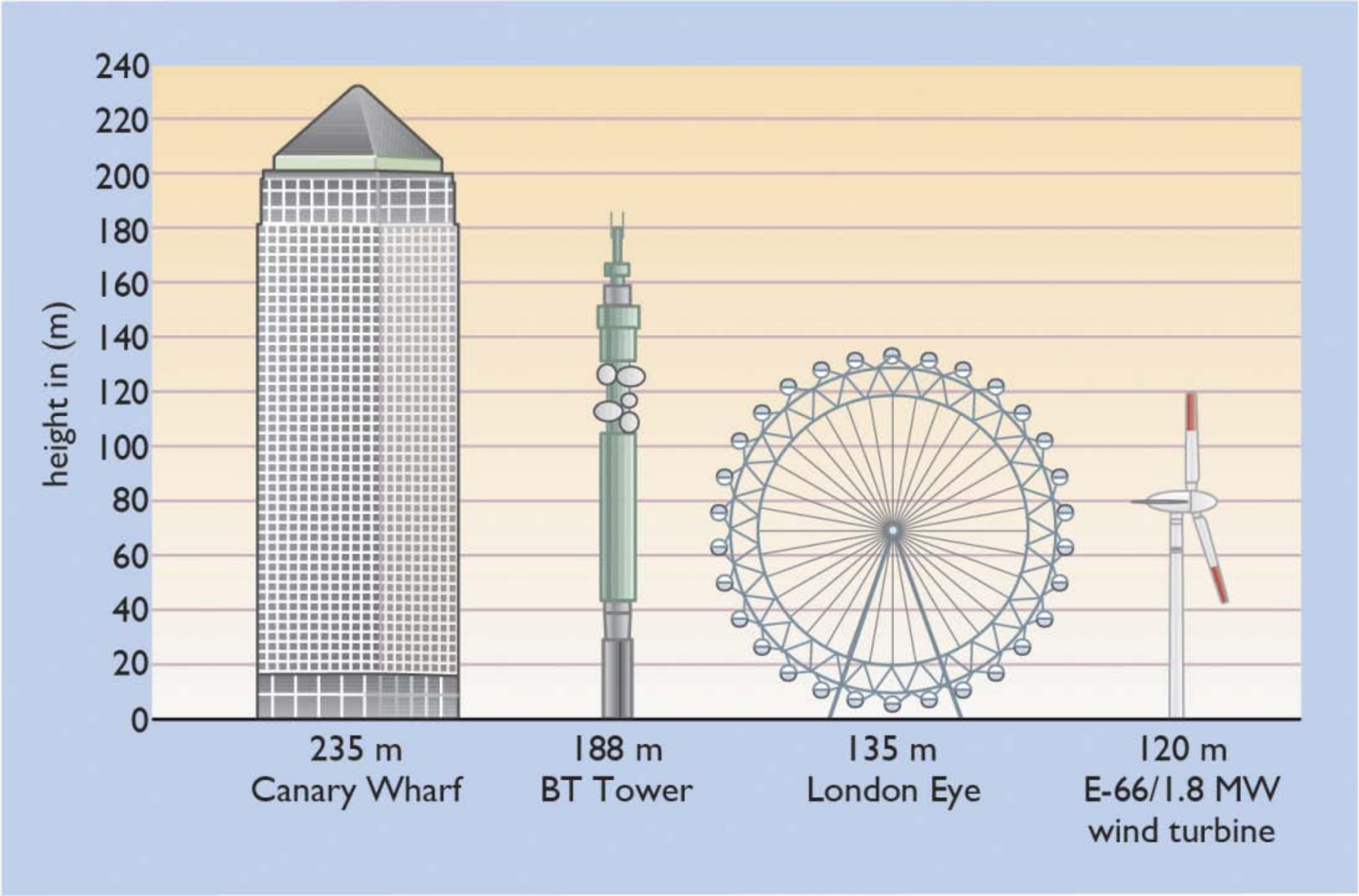


Time for Action: Wind Energy in Europe (1991) European Wind Energy Association

Scattering of Radio Signals by Wind Turbines

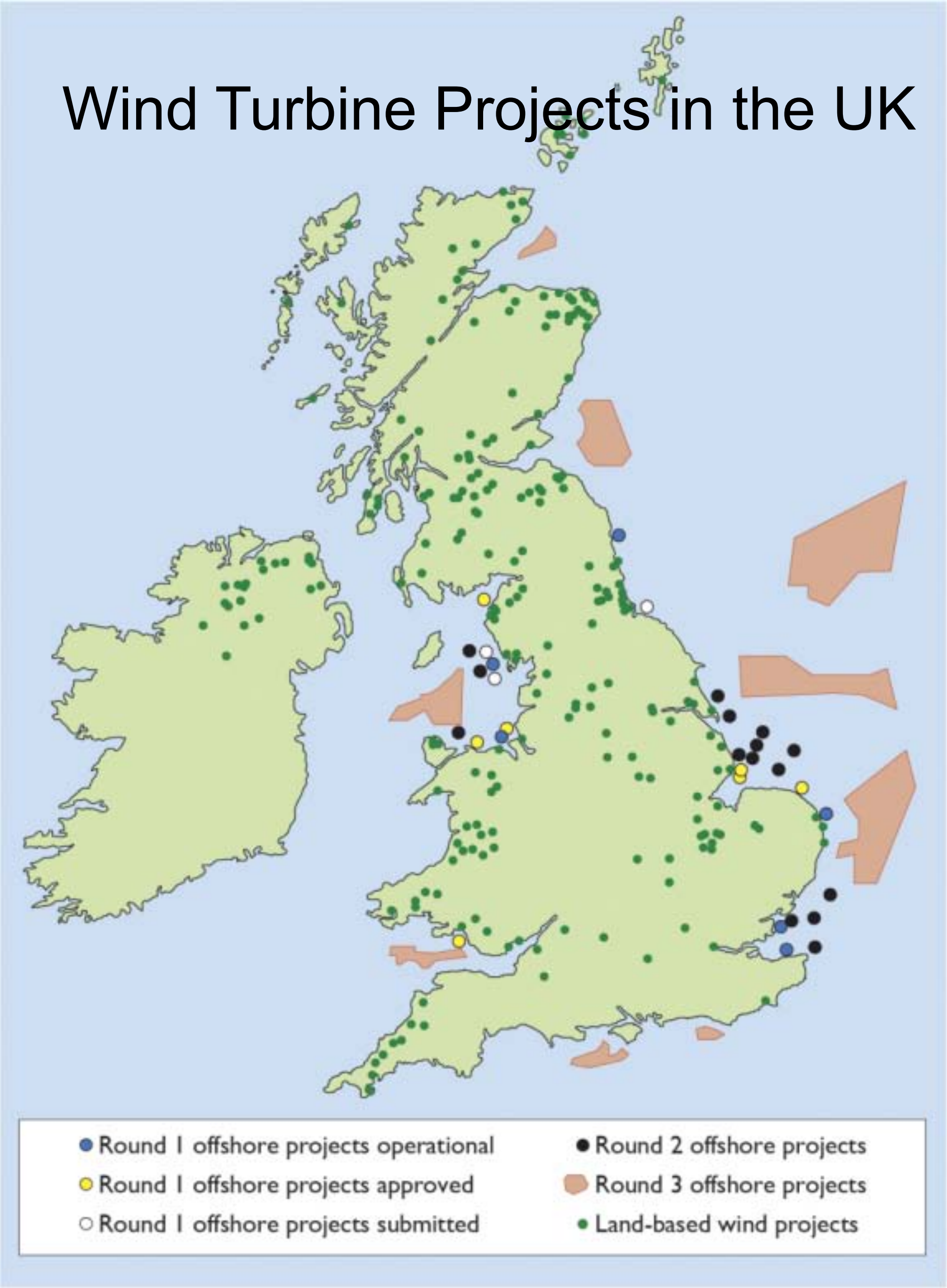


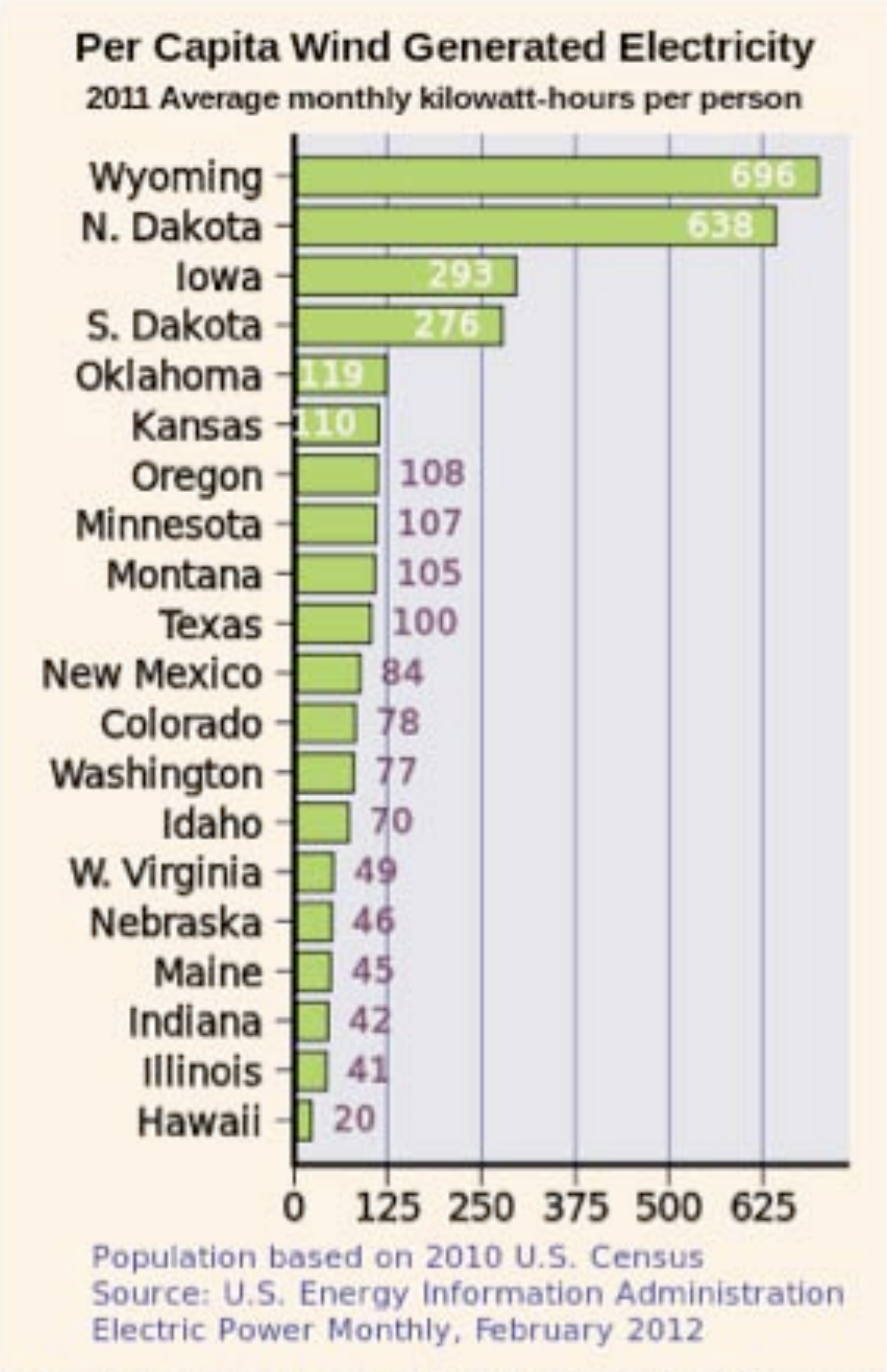
Public Perception of Wind Turbines



SkyscraperPage.com

Wind Turbine Projects in the UK





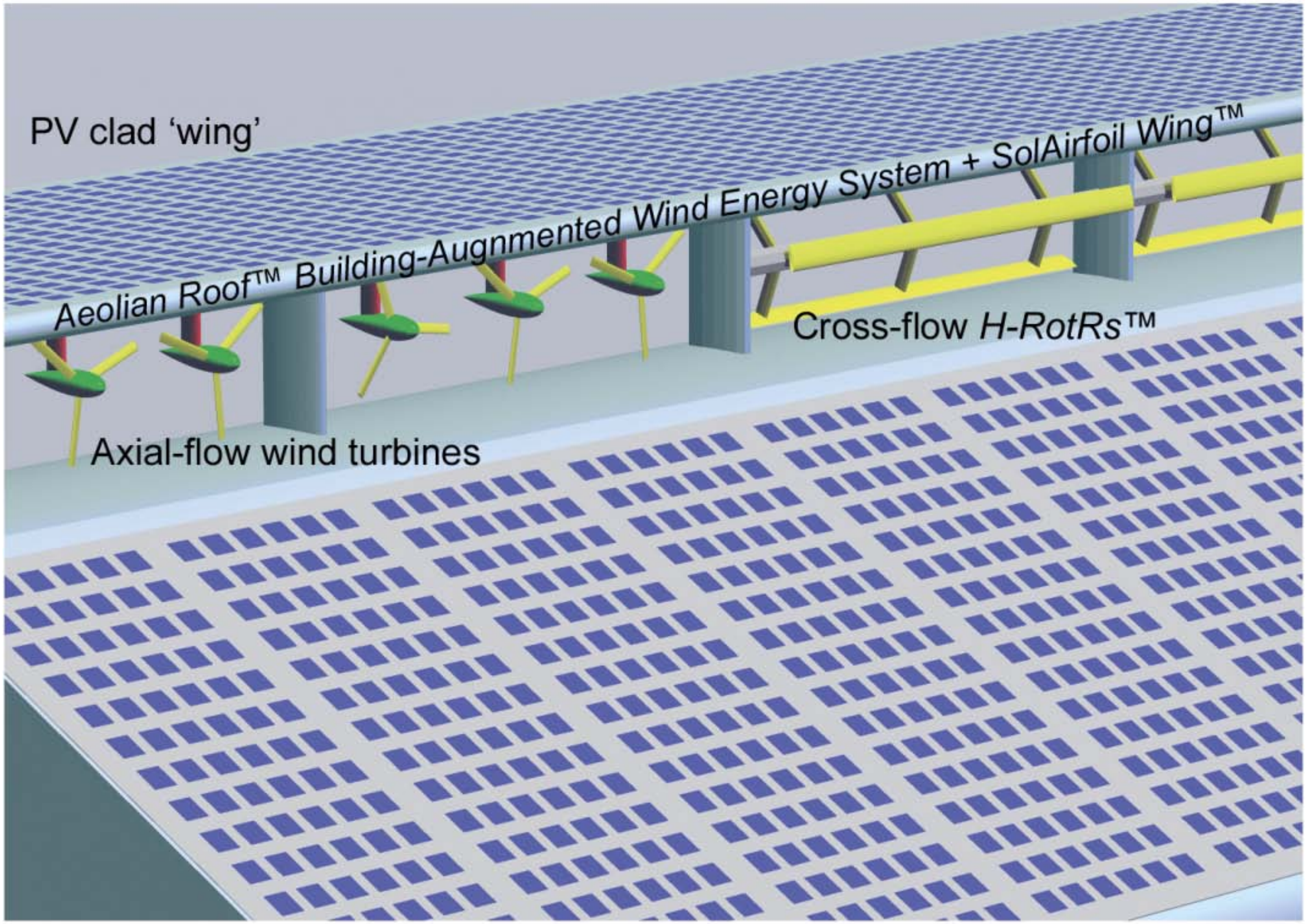
Per Capita Wind Generated Electricity

2011 Average monthly kilowatt-hours per person

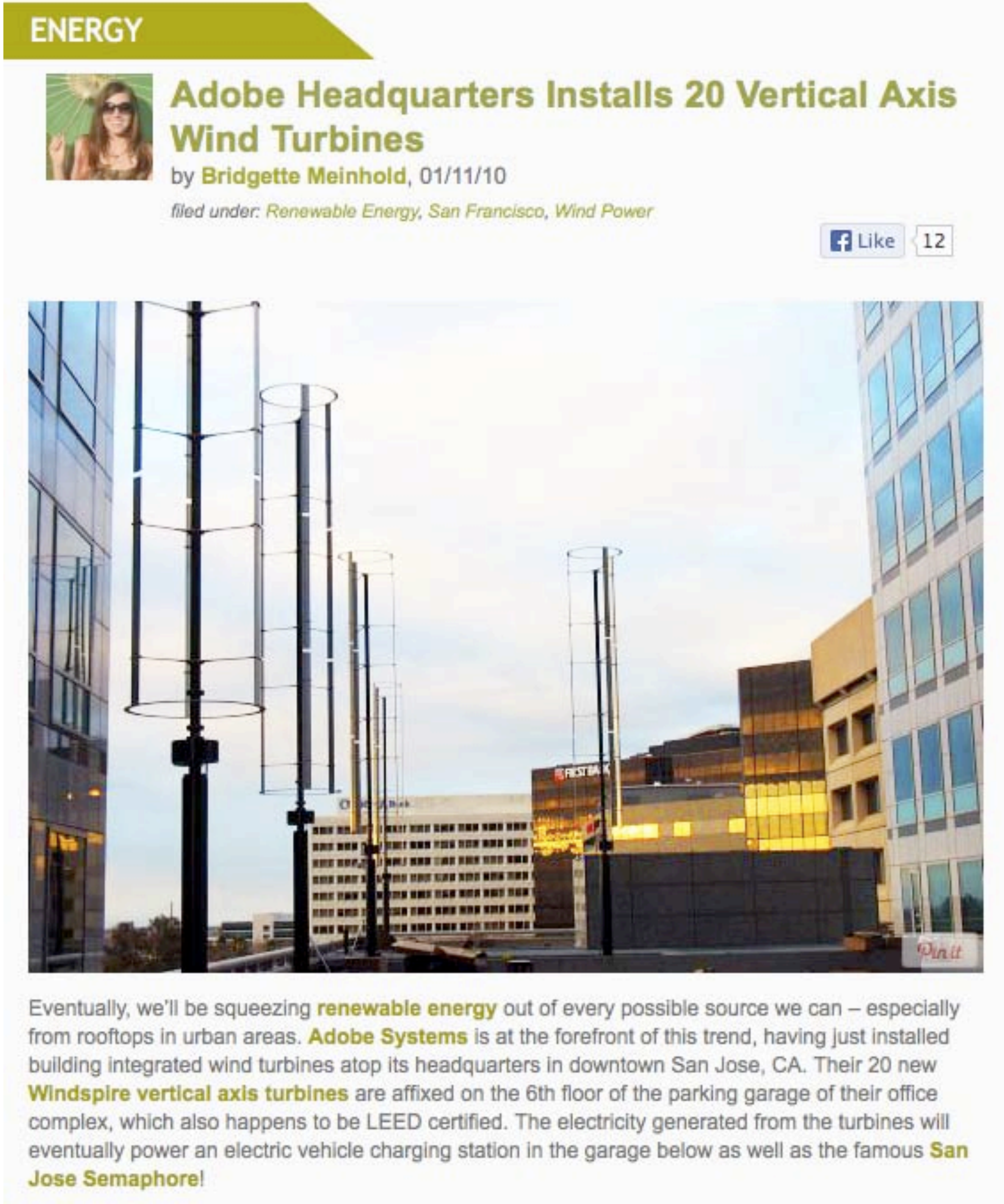
Population based on 2010 U.S. Census
Source: U.S. Energy Information Administration
Electric Power Monthly, February 2012

U.S. State 2011 Monthy Per Capita Wind Generated

Building Augmented Wind Turbine Systems



Derek Taylor/Altechnica



ENERGY

Adobe Headquarters Installs 20 Vertical Axis Wind Turbines

by **Bridgette Meinhold**, 01/11/10

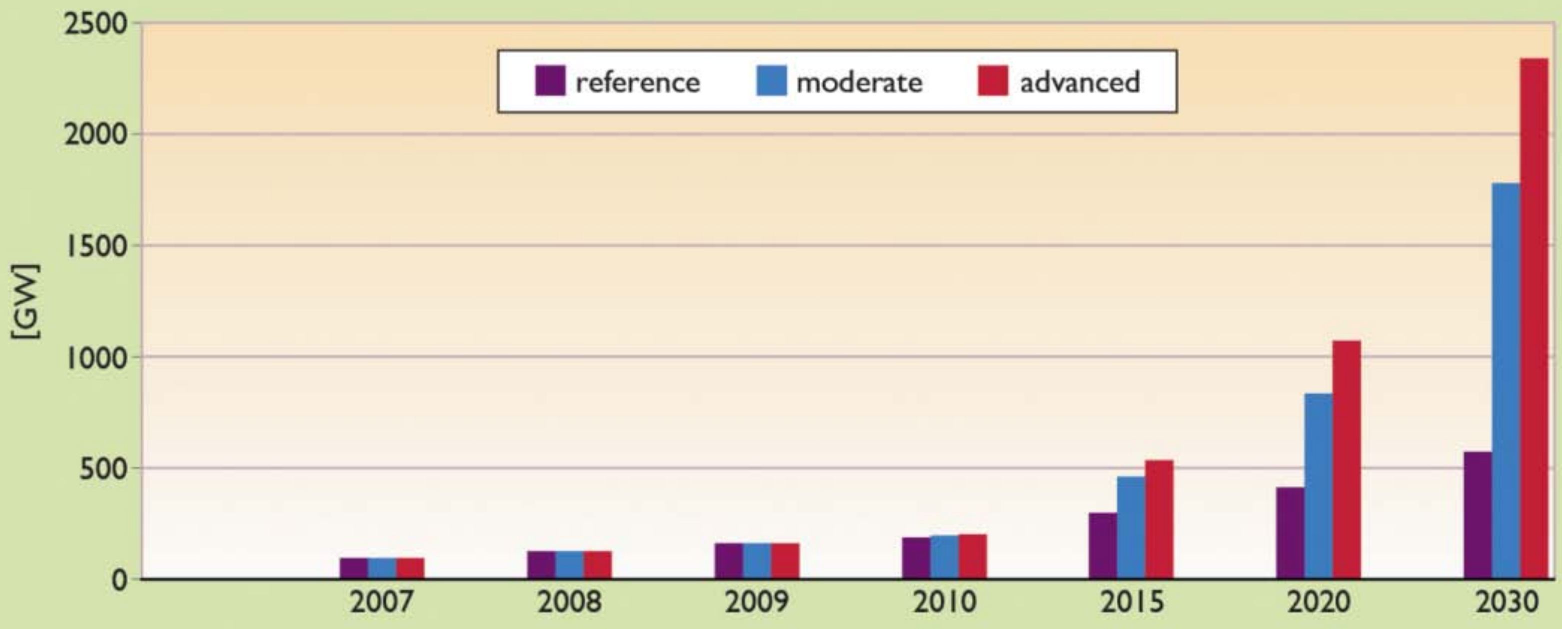
filed under: Renewable Energy, San Francisco, Wind Power

Eventually, we'll be squeezing **renewable energy** out of every possible source we can – especially from rooftops in urban areas. **Adobe Systems** is at the forefront of this trend, having just installed building integrated wind turbines atop its headquarters in downtown San Jose, CA. Their 20 new **Windspire vertical axis turbines** are affixed on the 6th floor of the parking garage of their office complex, which also happens to be LEED certified. The electricity generated from the turbines will eventually power an electric vehicle charging station in the garage below as well as the famous **San Jose Semaphore**!

Google Plus/Makani

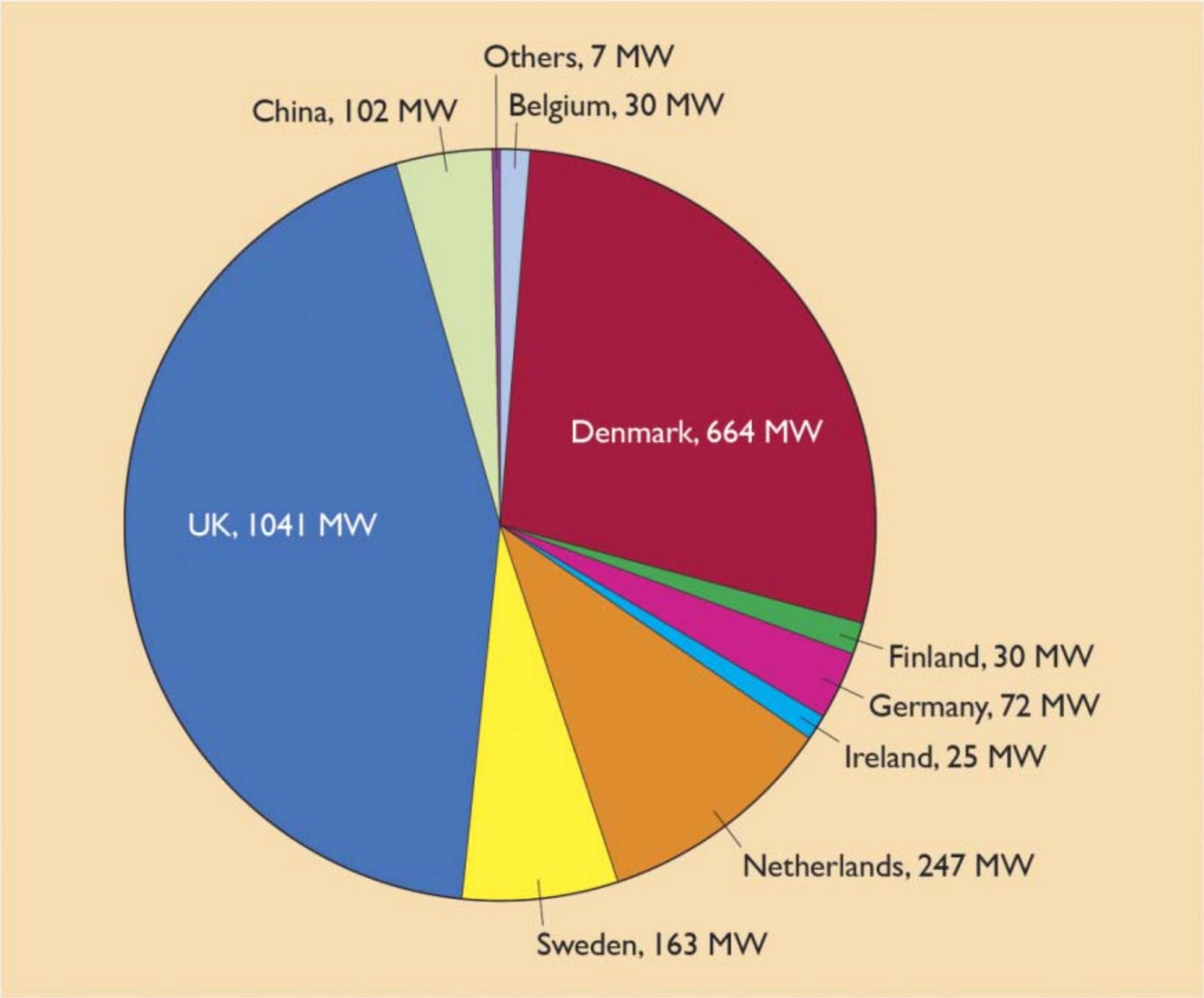
Makani Power makes a wind turbine that functions like a kite, but looks like a small plane.

GLOBAL WIND POWER CAPACITY

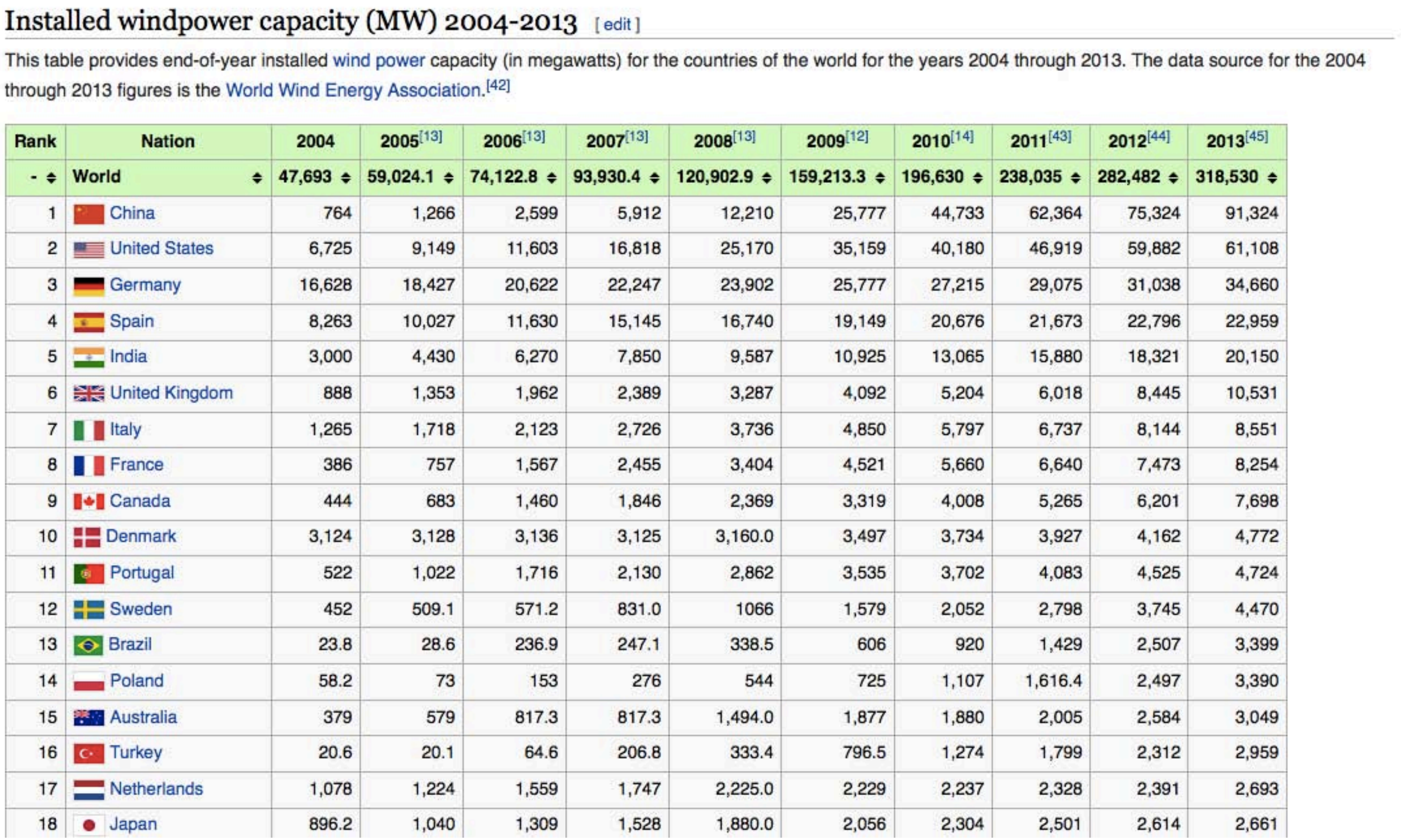


	2007	2008	2009	2010	2015	2020	2030
reference [MW]	93,864	120,297	158,505	185,258	295,783	415,433	572,733
[TWh]	206	263	347	406	725	1,019	1,405
moderate [MW]	93,864	120,297	158,505	198,717	460,364	832,251	1,777,550
[TWh]	206	263	347	435	1,129	2,041	4,360
advanced [MW]	93,864	120,297	158,505	201,657	533,233	1,071,415	2,341,984
[TWh]	206	263	347	442	1,308	2,628	5,429

GWEC (2010) The Global Wind Energy Outlook Scenarios, The Global Wind Energy Council



Musial, W. and Ram, B. (2010) Large Scale Wind Power in the United States – Assessment of Opportunities and barriers, National Laboratory for Renewable Energy

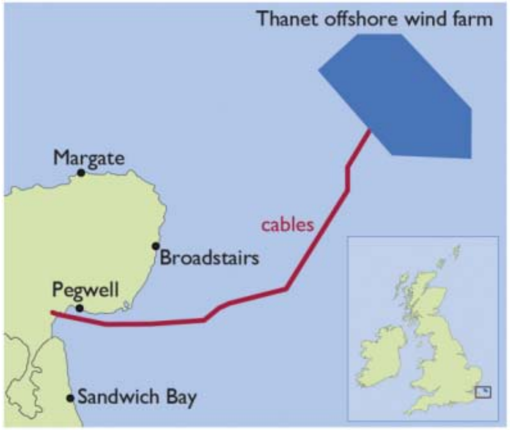


Installed windpower capacity (MW) 2004-2013

This table provides end-of-year installed wind power capacity (in megawatts) for the countries of the world for the years 2004 through 2013. The data source for the 2004 through 2013 figures is the World Wind Energy Association.[42]

Rank	Nation	2004	2005[13]	2006[13]	2007[13]	2008[13]	2009[12]	2010[14]	2011[43]	2012[44]	2013[45]
-	**World**	**47,693**	**59,024.1**	**74,122.8**	**93,930.4**	**120,902.9**	**159,213.3**	**196,630**	**238,035**	**282,482**	**318,530**
1	China	764	1,266	2,599	5,912	12,210	25,777	44,733	62,364	75,324	91,324
2	United States	6,725	9,149	11,603	16,818	25,170	35,159	40,180	46,919	59,882	61,108
3	Germany	16,628	18,427	20,622	22,247	23,902	25,777	27,215	29,075	31,038	34,660
4	Spain	8,263	10,027	11,630	15,145	16,740	19,149	20,676	21,673	22,796	22,959
5	India	3,000	4,430	6,270	7,850	9,587	10,925	13,065	15,880	18,321	20,150
6	United Kingdom	888	1,353	1,962	2,389	3,287	4,092	5,204	6,018	8,445	10,531
7	Italy	1,265	1,718	2,123	2,726	3,736	4,850	5,797	6,737	8,144	8,551
8	France	386	757	1,567	2,455	3,404	4,521	5,660	6,640	7,473	8,254
9	Canada	444	683	1,460	1,846	2,369	3,319	4,008	5,265	6,201	7,698
10	Denmark	3,124	3,128	3,136	3,125	3,160.0	3,497	3,734	3,927	4,162	4,772
11	Portugal	522	1,022	1,716	2,130	2,862	3,535	3,702	4,083	4,525	4,724
12	Sweden	452	509.1	571.2	831.0	1066	1,579	2,052	2,798	3,745	4,470
13	Brazil	23.8	28.6	236.9	247.1	338.5	606	920	1,429	2,507	3,399
14	Poland	58.2	73	153	276	544	725	1,107	1,616.4	2,497	3,390
15	Australia	379	579	817.3	817.3	1,494.0	1,877	1,880	2,005	2,584	3,049
16	Turkey	20.6	20.1	64.6	206.8	333.4	796.5	1,274	1,799	2,312	2,959
17	Netherlands	1,078	1,224	1,559	1,747	2,225.0	2,229	2,237	2,328	2,391	2,693
18	Japan	896.2	1,040	1,309	1,528	1,880.0	2,056	2,304	2,501	2,614	2,661

OFFSHORE WIND CAPACITY IN UK



(a)

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(b)

Jamie Cook/Vattenfall

(c)

Jamie Cook/Vattenfall

What is the off shore wind capacity in Monterey Bay?

Table 7.6 Global offshore wind energy development in permitting and unde construction stages

Country	Permitting, approved or under construction (MW)	In operation (M
Belgium	1194	30
Canada	1826	0
China	201	102
Denmark	653	664
Estonia	1000	0
Finland	1306	30
France	1455	0
Germany	25411	72
Greece	1101	0
Ireland	1530	25
Italy	2526	0
Japan	0	1
Maldives	75	0
Netherlands	3969	247
Norway	565	2
Romania	500	0
Spain	70	0
Sweden	3346	163
United Kingdom	6085	1041
United States	~2000	0
Total	54813	2377

Sources: Musial and Ram, 2010; 4C Offshore, 2010 http://www.energy.ca.gov/wind/overview.html

Overview of Wind Energy in California

In the year 2004, wind energy in California produced 4,258 million kilowatt-hours of electricity, about 1.5 percent of the state's total electricity. That's more than enough to light a city the size of San Francisco.

More than 13,000 of California's wind turbines, or 95 percent of all of California's wind generating capacity and output, are located in three primary regions: Altamont Pass (east of San Francisco - a portion of which is shown on the right in this photo from NREL), Tehachapi (south east of Bakersfield) and San Gorgonio (near Palm Springs, east of Los Angeles). In 1995, these areas produced 30 percent of the entire world's wind-generated electricity.

According to the Electric Power Research Institute, the cost of producing wind energy has decreased nearly four fold since 1980. The levelized cost of energy from wind turbines in 1993 was about 7.5 cents per kilowatt/hour. With current wind research and development efforts, the Energy Commission estimates that newer technologies can reduce the cost of wind energy to 3.5 cents per kilowatt-hour.