VG100: INTRODUCTION TO ENGINEERING

Conduction
Fan Aerodynamics

Dr. Qiang Zhang

1

Preview

- Introduction to Conduction
- Basic Principles in Fluid Mechanics
- Flow around an airfoil
- Fan aerodynamics
- Our core project

2

Introduction to Heat Transfer

3

Introduction to Conduction

Direct transfer of energy via

(i) lattice **vibrations**

(ii) electron movement

(iii) molecular collision

4

Thermal Conductivity

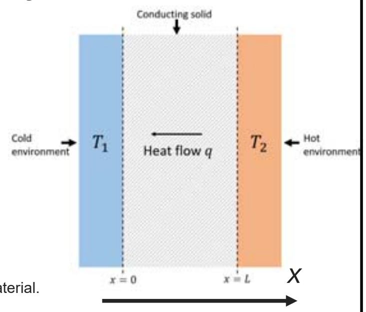
Fourier's law

- An observation for many materials.

$q = -k\,(T_2 - T_1)/L$

$\frac{w}{m^2}$

k: thermal conductivity,
a physical property of the material.



What is the unit of k?

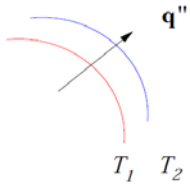
W/(m·K)

5

Fourier's law

$$q'' = -k\frac{\partial T}{\partial s}$$

$$q'' = -k\nabla T$$

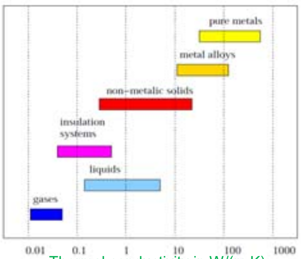


- proportional to the local gradient of temperature
- a vectorial quantity, which points in the direction opposite the temperature gradient, i.e. heat goes from hot to cold.
- heat flux lines are perpendicular to *isotherms*.

6

Thermal Conductivity

- Pure substances (gold, synthetic diamond carbon) have the highest conductivities, highly desirable for heat sink applications in computing. High conductivities are associated with regular lattices with little structural defects.



Thermal conductivity in W/(m K)

- Insulating materials are typically amorphous, such as glasses and ceramics.
- The thermal conductivity of solids and liquids can either increase or decrease with temperature.

7

Thermal Diffusivity

$$\alpha = \frac{k}{\rho c}$$

- K thermal conductivity (W/(m·K))
- C specific heat (J/(kg·K))
- ρ density (kg/m³)

- Thermal diffusivity is the measure of thermal inertia.
- What does high thermal diffusivity mean?

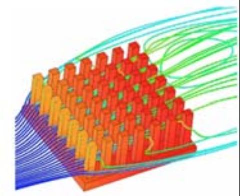
Heat moves rapidly through it because the substance conducts heat quickly relative to its volumetric heat capacity or 'thermal bulk'.

- Copper at 25 °C 1.11 × 10−4
- Iron 2.3 × 10−5
- Glass, window 3.4 × 10−7
- Wood (Yellow Pine) 8.2 × 10−8

8

Extended Surfaces

- “Fins” create additional heat transfer area in a compact volume to enhance heat transfer.



Fins are used in:
- computer heat sinks, engine radiators, home heaters, heat exchangers, etc.

- The price to be paid?

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9

Fan aerodynamics

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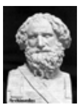
10

History

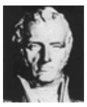

Archimedes (C. 287-212 BC)


Newton (1642-1727)


Leibniz (1646-1716)


Bernoulli (1667-1748)


Euler (1707-1783)


Navier (1785-1836)


Stokes (1819-1903)


Reynolds (1842-1912)


Prandtl (1875-1953)


Taylor (1886-1975)

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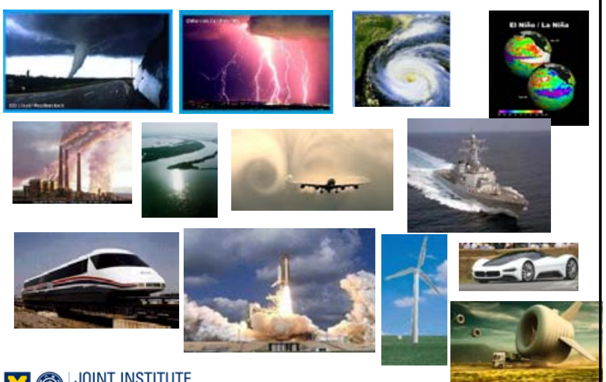
Applications



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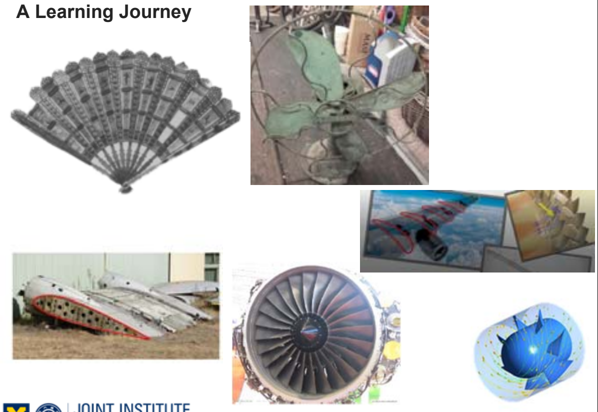
Beautiful nature

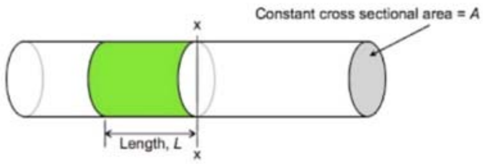
A Learning Journey



Basic Principles

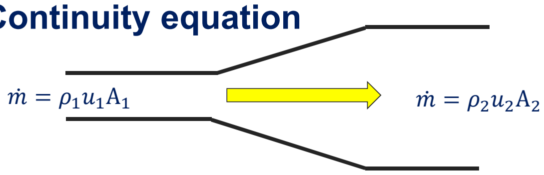
- Continuity equation
- Energy in fluid and flow work
- Bernoulli's equation
- How information travels in fluids

Continuity equation



- Volumetric flow rate: $\dot{V} = \frac{AL}{t} = uA$
- Mass flow rate: $\dot{m} = \rho\dot{V} = \rho uA$

Continuity equation



$$\boxed{\rho_1 u_1 A_1 = \rho_2 u_2 A_2}$$

- In low speed air flow or incompressible fluids, density change can be neglected.
- In high speed air flow, the story becomes different!

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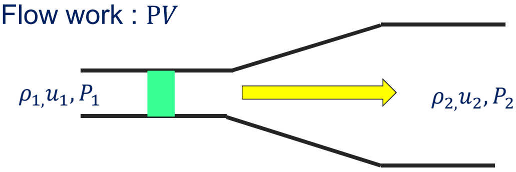
Energy in Fluid

- Kinetic energy: $\frac{1}{2}mu^2$
- Potential energy: $\mathrm{mg}Z$
- Internal energy: U
- Flow work : PV



$$W_{\text{flow}} = FL = PAL = PV \qquad \text{(kJ)}$$

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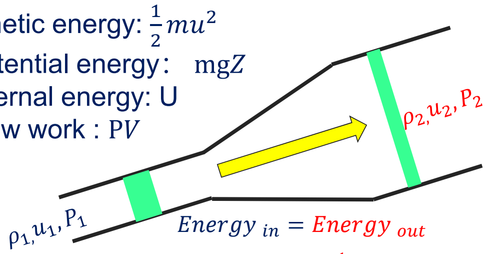
18

Energy in Fluid

- Kinetic energy: $\frac{1}{2}mu^2$
- Potential energy: $\mathrm{mg}Z$
- Internal energy: U
- Flow work : PV



- Assume no other energy going to the CV

$Energy_{\ in}$	=	$Energy_{\ out}$
$\frac{1}{2}mu^2$		$\frac{1}{2}mu^2$
$\mathrm{mg}Z$		$\mathrm{mg}Z$
PV		PV
U		U

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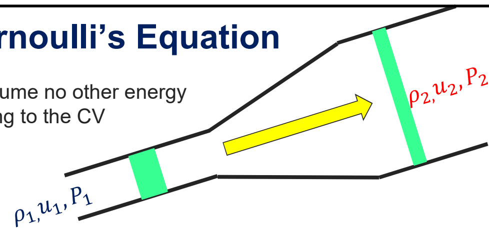
Bernoulli's Equation

Assume no other energy going to the CV



$$P_1V_1 + \frac{1}{2}m{u_1}^2 + mgZ_1 = P_2V_2 + \frac{1}{2}m{u_2}^2 + mgZ_2$$

$$P_1 + \frac{1}{2}\rho{u_1}^2 + \rho g Z_1 = P_2V_2 + \frac{1}{2}\rho{u_2}^2 + \rho g Z_2 = Constant$$

$$\boxed{\boldsymbol{P} \quad + \frac{\mathbf{1}}{\mathbf{2}}\boldsymbol{\rho u}^{\ \mathbf{2}} + \boldsymbol{\rho g Z} \quad = \boldsymbol{Total\ Pressure}}$$

Static Pressure / Dynamic Pressure / Hydrostatic Pressure

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20

Bernoulli's Equation

$$P_1 + \frac{1}{2}\rho {u_1}^2 + \rho g Z_1 = P_2 V_2 + \frac{1}{2}\rho {u_2}^2 + \rho g Z_2 = Constant$$

Conditions:
- Assume no heat transfer (adiabatic)
- No other work done to the CV
- Frictionless
- Incompressible (density is constant)

- Can be derived from momentum equation

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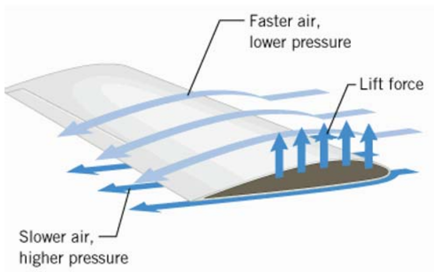
21



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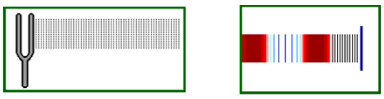
22

The Speed of Sound



- Sound waves in air are **travelling fluctuations** in pressure.
  - the pressure changes are of the order of only 1 Pa.
- They convey energy from one point in the medium to another.
  - The process be regarded as **isentropic** **(0 entropy)**
  - This is how information travels in a flow field:
    - information is passed on by molecular contact – pressure waves

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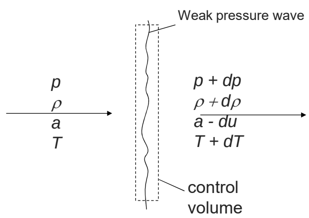
The Speed of Sound and Mach Number

- About **three quarters of the average molecular velocity**.
- Speed of sound in a perfect gas depends only on temperature of gas.

$$a^2 = \frac{dp}{d\rho}$$

$$a = \sqrt{\gamma \frac{p}{\rho}} = \sqrt{\gamma RT}$$



$$M \equiv \frac{V}{a}$$

•If $M < 0.3$ flow may be considered incompressible

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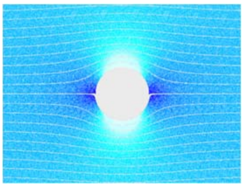
24

The Speed of Sound



- The concept of streamtubes being ‘aware’ of neighbouring flow

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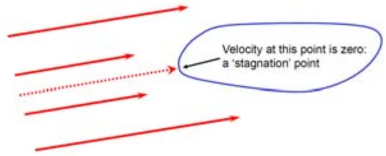
The generation of Lift force

What happens when a **frictionless fluid** stream meets a stationary body?



- The flow comes to a stop at one point on the windward side of the body
  - The stagnation point
- What is the static pressure p at the stagnation point?

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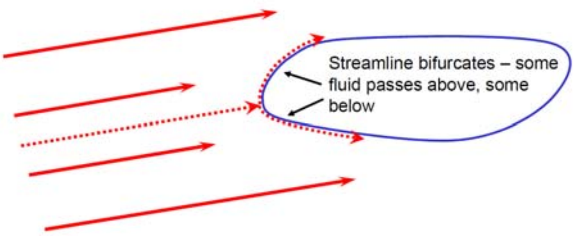
What happens when a **frictionless fluid** stream meets a stationary body?



$$p+\frac{1}{2}\rho\left(u^2+v^2\right)=p_0=\text{constant}$$

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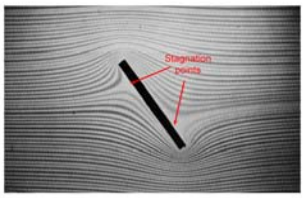
27

What happens when a **frictionless fluid** stream meets a stationary body?



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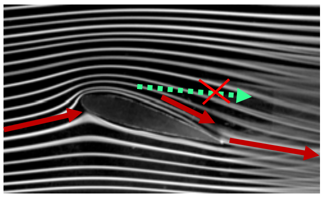
What happens when a **real fluid** stream meets an airfoil?



- Fluids over the top surface tends to get attached to a convex surface ("Coanda effect")

- In nature, the fluid over the top and bottom will meet up at the trailing edge ("Kutta Condition")

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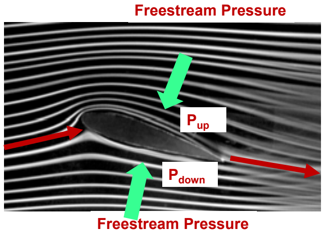
29

What happens when a **real fluid** stream meets an airfoil?



- Fluids over the top surface tends to get attached to a convex surface ("Coanda effect")

Why?

- In nature, the fluid over the top and bottom will meet up at the trailing edge ("Kutta Condition")

Which side has a higher pressure?
What is the Newton's 3rd law of motion?

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Which end has the higher velocity? Top vs bottom

Viscosity of Fluids

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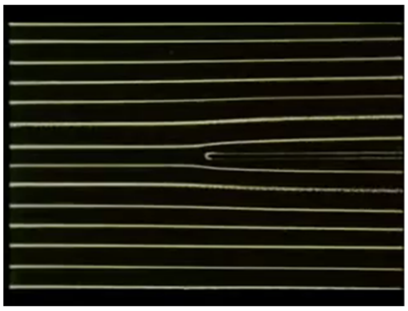
31

"Boundary layer"



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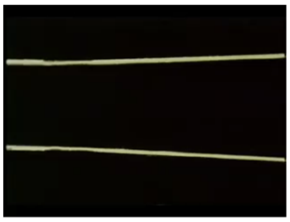
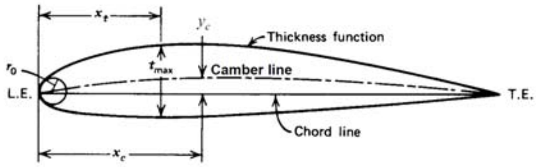
32

A behavior of “Boundary layer”



33



- Note the rounded leading edge and sharp trailing edge
- Chord line: straight line joining leading and trailing edges
- Camber line: average of upper and lower surface
  - For a symmetrical section, the camber line = the chord line
- Angle of incidence (also called angle of attack)
  - Angle between chord line and direction of travel

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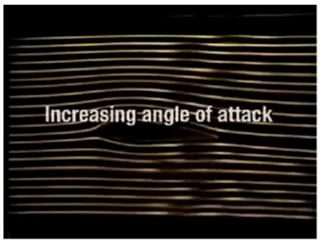
34



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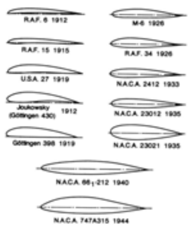
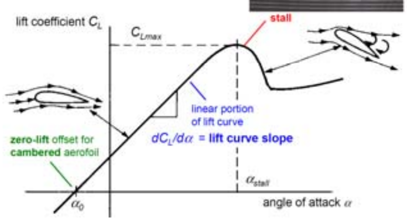
35



The Lift Curve

- Lift varies mainly with incidence



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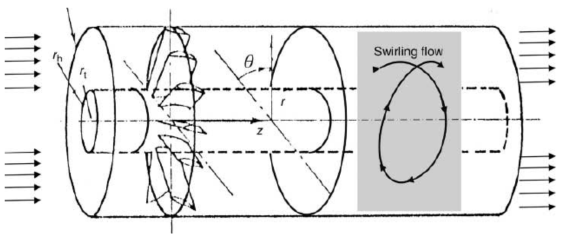
36

Fan Aerodynamics



Exit kinetic energy: $\frac{mV^2}{2}$ How do we calculate & measure this?

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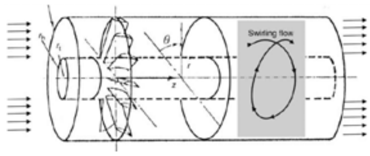
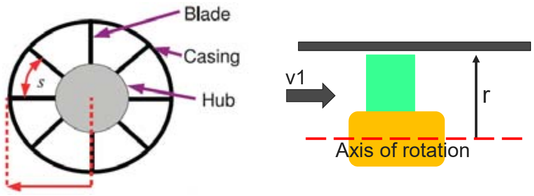
37

Fan design – Relative Frames



- Absolute observer
- Relative observer



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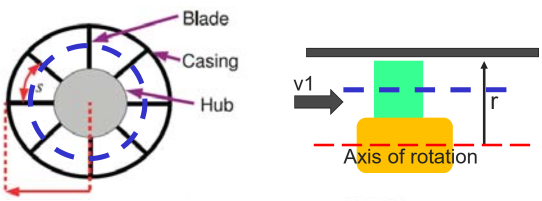
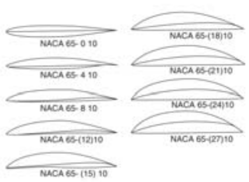
38

Fan design – 1-D approach





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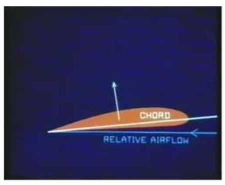
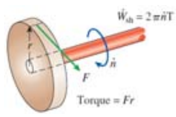
39

Fan design – 1-D approach



Shaft Work $W_{sh} = Fs = \left(\frac{T}{r}\right)(2\pi rn) = 2\pi n T$ (kJ)



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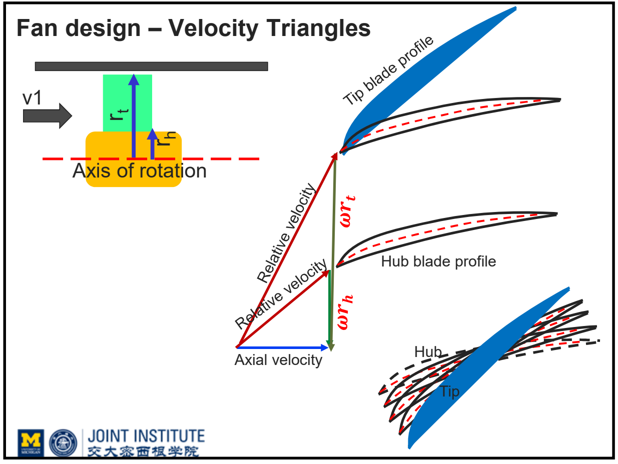
40

Fan design – Velocity Triangles



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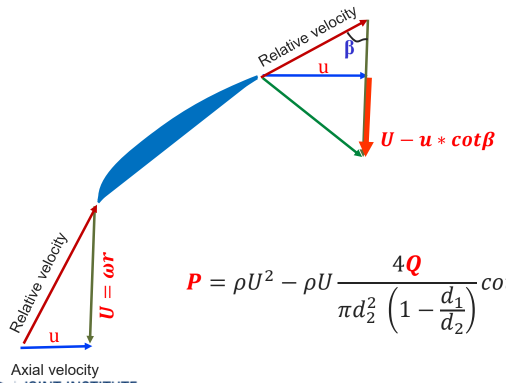
Fan design –trailing edge region



$$P = \rho U^2 - \rho U \frac{4Q}{\pi d_2^2 \left(1 - \frac{d_1}{d_2}\right)} cot\beta$$

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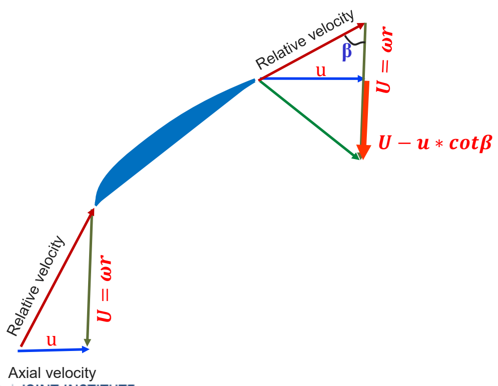
Fan design – Exit flow



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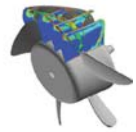
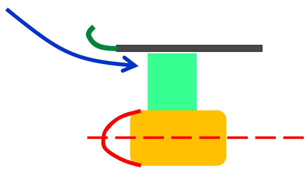
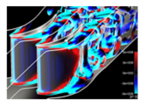
Some Possible Follow-up Project Ideas

- Guide vane ?
- Contra-rotating blade ?
- Better duct?
- No duct?
- Better hub design?







- Keep exploring other thoughts during your lab!

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- Ducted propeller?
- Wind turbine?

Hovercraft

Hiller VZ-1 Pawnee 1955

The Altaeros BAT

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45

Our core project

- Get it going and improve ver 2.0
- Plan a “spare tire plan”
- Plan your follow-up project idea
- Teamwork !
- Understanding !
- A "team log book"

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46

Some Safety Rules (Again!)

- Absolutely NO out-of-lab testing (playing with alcohol burner lamp outside of the lab is forbidden and will lead to failure of this course)
- The lab supervisor/manager, technicians, and teaching assistants will ensure that you know of specific hazards and use personal protection equipment (PPE).
- Read and obey all operational signs and warnings.
- Power must be switched off whenever an experiment or project is being assembled or disassembled.
- Make measurements in live circuits with well-insulated probes and one hand behind your back. Do not allow any part of your body to contact any part of the circuit or equipment connected to the circuit.
- Never handle wet, damp or ungrounded electrical equipment.
- Avoid contact with the hot components.
- Never short-circuit a power source.
- When using a voltmeter or ammeter, begin with the highest range and work your way down to a suitable range.

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47

Review

- Introduction to Conduction
- Basic Principles in Fluid Mechanics
- Flow around an airfoil
- Fan aerodynamics
- Our core project

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48