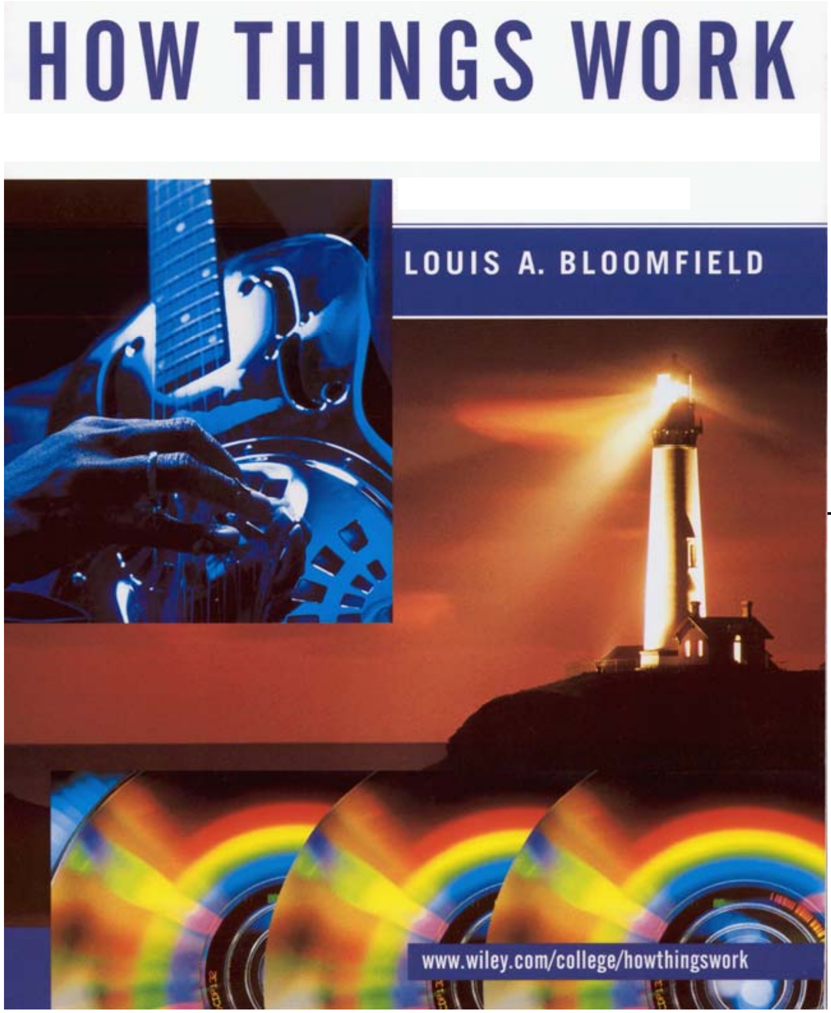

Teaching Physics in the Context of Everyday Objects

Louis Bloomfield

University of Virginia

American Association of Physics Teachers

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What is *How Things Work*?

- It’s Physics in the Context of Objects
  - It puts objects before physics concepts
  - It puts physics concepts before formulas
  - It’s “backwards”
- It’s the “Case Study” Method
- It’s how Scientists actually Discover Science
- It’s what Makes Science Fun

Overview of this Presentation

- Motivation for *How Things Work*
- Structure of *How Things Work*
  - An Example: Music Boxes
- Choosing Objects for a *How Things Work* Course
- The Components of a Course
  - The Book
  - The Classroom Conversation
  - Demonstrations
  - Laboratories
  - Homework Exercises
  - Research Papers
  - Exams
- Observations about *How Things Work*

Why *How Things Work*?

- “Oh, I’m a physicist” … *(end of conversation)*
- Conventional physics outreach is often:
  - magic & mysteries *(no explanation).*
  - factoids *(what, where, when, but never why or how).*
  - names *(memorization of random information).*
  - recipes *(mindless plugging and chugging).*
  - formalized “scientific method” *(repeating canned experiments).*

Why *How Things Work*? (con’t)

- In contrast, *How Things Work*
  - grows naturally from the ordinary, everyday world.
  - explains rather than obscures.
  - emphasizes thought and understanding.
  - builds confidence appropriately rather than destroying it.
  - is useful in everyday life.
- The audience for *How Things Work* is
  - anyone who is curious about the world around them.
  - enormous and largely untapped.

Structure of *How Things Work*

- A hierarchy with three levels
  - Level 1: Areas of Physics – for the instructor
  - Level 2: Objects of Everyday Life – for the students
  - Level 3: Concepts of Physics – for both

7. Heat and Phase Transitions

7.1 Woodstoves

(thermal energy, heat, temperature, chemical bonds and reactions, conduction, thermal conductivity, convection, radiation, heat capacity)

7.2 Water, Steam, and Ice

(phases of matter, phase transitions, melting, freezing, condensation, evaporation, boiling, relative humidity, latent heats of melting and vaporization)

7.3 Incandescent Lightbulbs

(electromagnetic spectrum, light, black body spectrum, emissivity, Stefan-Boltzmann law, thermal expansion)

An Example: Music Boxes

- Introduces New Concepts:

  9. Resonance and Mechanical Waves

  9.1 Music Boxes

  (natural resonance, harmonic oscillators, simple harmonic motion, frequency, pitch, sound, music, harmonic and non-harmonic overtones, sympathetic vibration, standing and traveling waves, transverse and longitudinal waves, velocity, frequency, and wavelength in mechanical waves, superposition)

- Reinforces Old Concepts:
  - Energy and Work (Chapter 1)
  - Springs and Stable Equilibria (Chapter 3)
  - Aerodynamics (Chapter 6)

Music Boxes: Questions to Address

- *What* are vibration, pitch, sound, and music?
- *Why* does a tine vibrate?
- *Why* do different tines have different pitches?
- *Why* is a tine's pitch independent of its volume?
- *How* does sound from the music box reach us?
- *How* does the music box produce sound?
- *Why* does a music box sound like a music box?

There is a great deal of physics here in these *why* and *how* questions!

Why Does a Tine Vibrate?

- It has a stable equilibrium shape
- It experiences a restoring force when bent
- It accelerates toward the equilibrium
- Its inertia causes it to coast through the equilibrium
- It oscillates about that equilibrium
- It oscillates until it runs out of excess energy

Why Do Different Tines have Different Pitches?

A shorter tine

- is stiffer
- has less mass
- accelerates more quickly
- reverses directions sooner
- takes less time to complete each cycle of oscillation
- has a higher pitch

Why is a Tine's Pitch Independent of its Volume?

- As the tine becomes quieter, its motion shrinks
  - Its tip covers less distance per cycle
  - Its restoring forces become weaker
  - It takes just as much time to reverse directions
  - It takes just as much time to complete an oscillation cycle
- Its restoring force is proportional to displacement
- It is a harmonic oscillator

How Does Sound from the Music Box Reach Us?

- Air has a stable equilibrium density
- It experiences restoring forces when disturbed
- It accelerates toward that equilibrium
- Its inertia causes it to coast through the equilibrium
- It oscillates about that equilibrium
- It oscillates until it runs out of excess energy
- Air behaves as many harmonic oscillators…

How Does the Music Box Produce Sound?

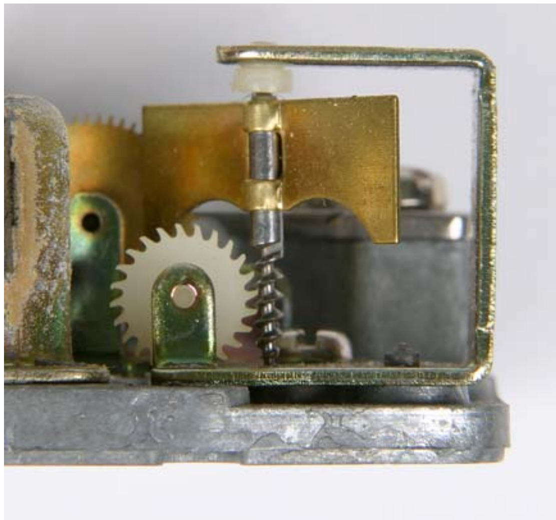
- Sound is a density disturbance in air
- Air flows easily around narrow moving objects
- A vibrating tine barely affects air's density
- A vibrating surface can affect air's density
- The vibrating tine causes a surface to vibrate
- The vibrating surface actually emits the sound

Why Does a Music Box Sound like a Music Box?

- A tine is an extended object that’s fixed at one end
- Parts of the tine *can* move opposite one another
- The tine has many modes of vibration
- In its fundamental mode, the tine moves as a whole
- In its overtone modes, its parts move oppositely
- The different modes have different pitches
- The fundamental mode sets the main pitch
- The overtones create timbre – the music box sound

An Opportunity for Review: Air Drag

- The music box needs something to set its tempo
- A speed-dependent force can limit the tempo
- The pressure drag force is highly speed-dependent
- Music box uses pressure drag to control its tempo!



Choosing Objects for a *How Things Work* Course

- Set your physics agenda first, then choose objects
- Most objects have one central physics issue
- Play up that central issue whenever possible
- Caveats *(learned from painful experience)*
  - Some objects present physics concepts better than others
  - Some objects aren't of general interest
  - Less is more; you can't do everything
- *HTW*'s Table of Contents follows this approach

How Things Work Table of Contents

How Things Work Table of Contents (con't)

A One Semester *HTW* Course on Mechanics, Fluids, Heat, and Resonance

1. The Laws of Motion, Part I
   - 1.1 Skating
   - 1.2 Falling Balls
   - 1.3 Ramps
2. The Laws of Motion, Part II
   - 2.1 Seesaws
   - 2.2 Wheels
   - 2.3 Bumper Cars
3. Mechanical Objects, Part I
   - 3.1 Spring Scales
   - 3.2 Bouncing Balls
   - 3.3 Carousels and Roller Coasters
4. Mechanical Objects, Part II
   - 4.1 Bicycles
   - 4.2 Rockets and Space Travel
5. Fluids
   - 5.1 Balloons
   - 5.2 Water Distribution
6. Fluids and Motion
   - 6.1 Garden Watering
   - 6.2 Balls and Air
   - 6.3 Airplanes
7. Heat and Phase Transitions
   - 7.1 Woodstoves
   - 7.2 Water, Steam, and Ice
   - 7.3 Incandescent Lightbulbs
8. Thermodynamics
   - 8.1 Air Conditioners
   - 8.2 Automobiles
9. Resonance and Mechanical Waves
   - 9.1 Clocks
   - 9.2 Musical Instruments
   - 9.3 The Sea

A One Semester *HTW* Course on E & M, Electronics, Light, Optics, and Modern Physics

1. The Laws of Motion, Part I
   - 1.1 Skating
   - 1.2 Falling Balls
   - 1.3 Ramps
2. The Laws of Motion, Part II
   - 2.1 Seesaws
   - 2.2 Wheels
   - 2.3 Bumper Cars

10. Electricity
    - 10.1 Static Electricity
    - 10.2 Xerographic Copiers
    - 10.3 Flashlights
11. Magnetism and Electrodynamics
    - 11.1 Household Magnets
    - 11.2 Electric Power Distribution
    - 11.3 Electric Generators and Motors
12. Electronics
    - 12.1 Power Adapters
    - 12.2 Audio Players
13. Electromagnetic Waves
    - 13.1 Radio
    - 13.2 Microwave Ovens
14. Light
    - 14.1 Sunlight
    - 14.2 Discharge Lamps
    - 14.3 Lasers and LEDs
15. Optics
    - 15.1 Cameras
    - 15.2 Optical Recording and Communication
16. Modern Physics
    - 16.1 Nuclear Weapons
    - 16.2 Medical Imaging and Radiation

A One Semester General Survey *HTW* Course

1. The Laws of Motion, Part I
   - 1.1 Skating
   - 1.2 Falling Balls
   - 1.3 Ramps
2. The Laws of Motion, Part II
   - 2.1 Seesaws
   - 2.2 Wheels
   - 2.3 Bumper Cars
3. Mechanical Objects, Part I
   - 3.1 Spring Scales
   - 3.2 Bouncing Balls
   - 3.3 Carousels and Roller Coasters
4. Mechanical Objects, Part II
   - 4.2 Rockets and Space Travel
5. Fluids
   - 5.1 Balloons
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   - 7.2 Water, Steam, and Ice
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   - 9.2 Musical Instruments
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   - 10.1 Static Electricity
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   - 10.3 Flashlights
11. Magnetism and Electrodynamics
   - 11.1 Household Magnets
   - 11.2 Electric Power Distribution
13. Electromagnetic Waves
   - 13.1 Radio
14. Light
   - 14.1 Sunlight
15. Optics
   - 15.1 Cameras
16. Modern Physics
   - 16.1 Nuclear Weapons

A One Semester
Survey of Technology *HTW* Course

1. The Laws of Motion, Part I
   - 1.1 Skating
   - 1.2 Falling Balls
   - 1.3 Ramps
2. The Laws of Motion, Part II
   - 2.1 Seesaws
   - 2.2 Wheels
   - 2.3 Bumper Cars
3. Mechanical Objects, Part I
   - 3.1 Spring Scales
7. Heat and Phase Transitions
   - 7.1 Woodstoves
   - 7.3 Incandescent Lightbulbs
8. Thermodynamics
   - 8.1 Air Conditioners
   - 8.2 Automobiles
9. Resonance and Mechanical Waves
   - 9.1 Clocks
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11. Magnetism and Electrodynamics
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    - 15.1 Cameras
    - 15.2 Optical Recording and Communication
16. Modern Physics
    - 16.1 Nuclear Weapons
    - 16.2 Medical Imaging and Radiation

Many other paths through the book…

- Physics of Sound and Light
- Physics of Communication
- Physics of Transportation
- There are supplementary components on the web
  - Materials Science (knives, windows, plastic)
  - Chemical Physics (oil refineries, laundry, batteries)
  - Others (elevators, paint, telescopes, etc.)

The Classroom Conversation

- There is more to *HTW* than teaching physics
- My goals for *HTW* are to help students
  - begin to see science in everyday life
  - learn that science isn’t frightening
  - learn to think logically in order to solve problems
  - develop and expand their physical intuition
  - learn how things work
  - see that the universe is predictable rather than magical
  - see the history of science and technology
- The classroom’s purpose is to engage the student

The Classroom Conversation (con't)

- Employ any of the best classroom techniques
  - Good lecturing
  - Active learning
  - Peer instruction
  - A seminar
  - A full conversation
  - A tutorial
- HTW sets the stage for exceptional productivity

Demonstrations

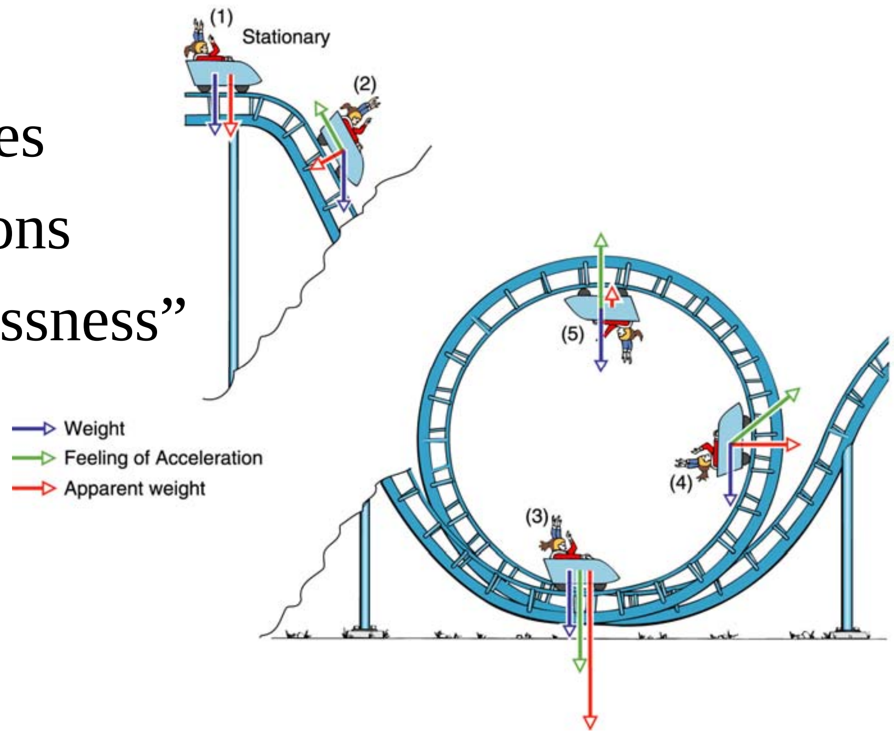
- Demonstrations are the centerpiece of a *HTW* course
- HTW is about building connections
  - between real objects and physics concepts
  - between personal experience and understanding
  - between broader knowledge and physics
- Most students are "visual learners"
  - They have to *see* it to understand it or to remember it
  - They need to hang concepts under *tangible* objects
- Demonstrations make physics real

Demonstrations (con't)

- Students struggle with generalization
- Students are put off by unfamiliarity
- Demonstrations range in value
  - A: involves the familiar object itself
  - B: involves a similar, but familiar object
  - C: involves a similar, but unfamiliar object
  - D: involves seemingly unrelated and unfamiliar objects
- Demonstrations need a clear purpose
- Demonstrations are best done by the students

Roller Coasters

- How do loop-the-loops work?
- Physics concepts involved:
  - Inertia
  - Acceleration and forces
  - Centripetal accelerations
  - Weight and “weightlessness”

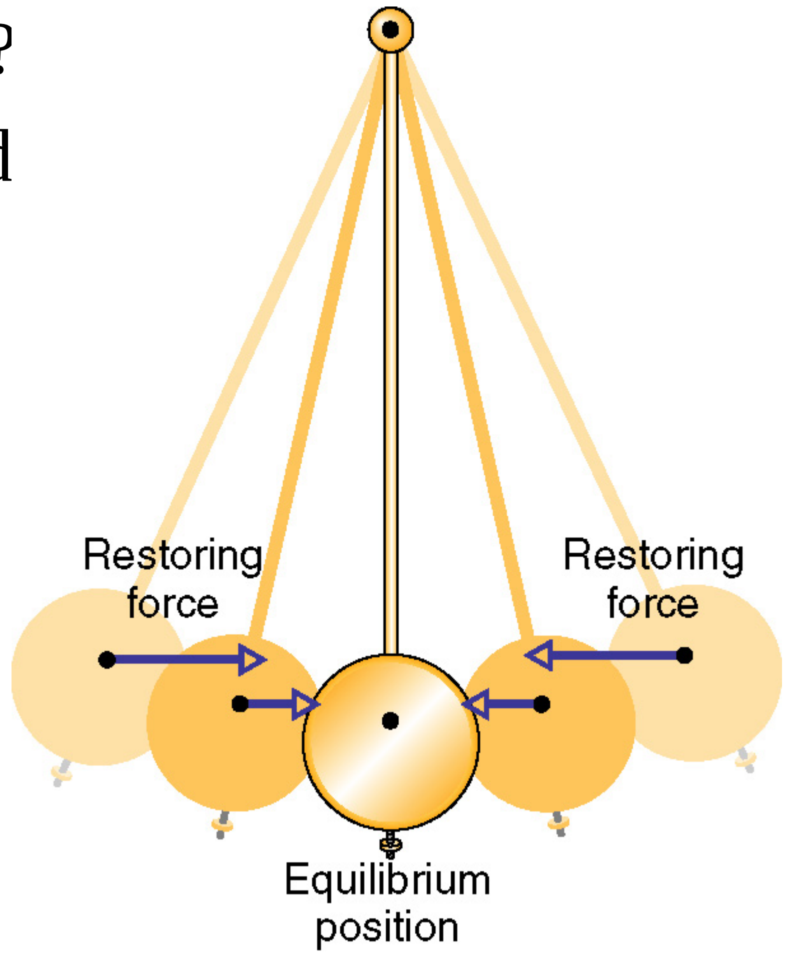


Bicycles

- Why are bicycles so stable?
- Physics concepts involved:
  - Equilibrium
  - Energy and acceleration
  - Stable and unstable equilibriums
  - Static stability
  - Gyroscopic precession
  - Dynamic stability

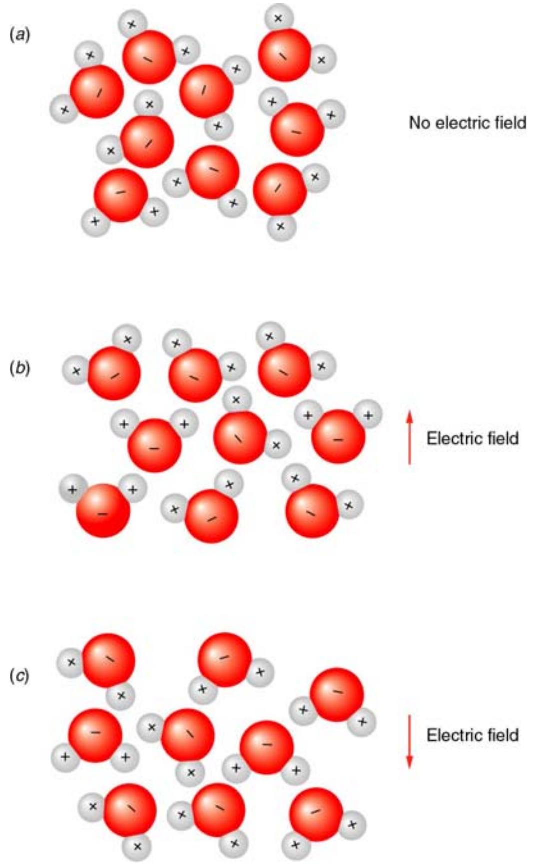
Clocks

- How do clocks keep time?
- Physics concepts involved
  - Time and Space
  - Forces and Acceleration
  - Harmonic Oscillators



Microwave Ovens

- How do microwave ovens cook?
- Physics concepts involved:
  - Electric fields
  - Polar molecules and free charges
  - Electrostatic forces and torques
  - Electromagnetic waves
  - Wavelength and frequency



Laboratories

- My *HTW* course does not have a laboratory
- Faculty elsewhere have taught successful labs
  - John Krupczak at Hope College
  - Robert Welsh at College of William and Mary
- Three obvious laboratory approaches:
  - Use the object
  - Build the object
  - Disassemble the object

Homework Exercises

- Focus on
  - concepts
  - familiarity
  - relevance
- Ideal exercises make students think hard about the object or related objects to understand their physics
- For example: (last exercise of a sequence)
  - Why does gum thrown out the front window of a car often fly back in the rear window?

Research Papers

- Select a new object and explain its physics
- Requires the student to
  - identify physics issues in a new situation
  - apply physics concepts to that situation
  - use the language of science meaningfully
  - develop a logical discussion of physics in context
  - understand how their object works
- Done well, it's the capstone project for *HTW*

Exams

- Primarily conceptual questions
- Based on familiar, relevant observations
- Require understanding and thought to answer
- Multiple choice or short answer

A conceptual question about airplanes

You watch an airplane fly past upside-down. It is flying level at a steady speed on a windless day. The air it leaves behind is moving

A. upward.

B. forward.

C. downward.

D. backward.

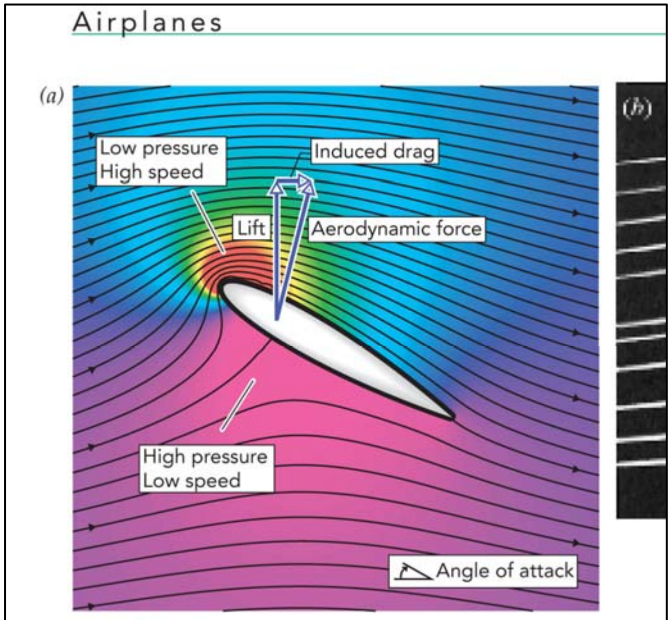


Fig. 6.3.3 (*a*) This airplane wing is shaped and oriented so that b
it, bend downward. The wing experiences a large aerodynamic fo

Philosophy of *How Things Work*

- It's a true outreach course
- Its purpose is not to recruit future scientists
- Its purpose is to inform bright, eager non-scientists
  - They don't know what physics is
  - They don't know why physics matters
  - They respond to relevance, value, and respect
  - *HTW* is about *them*, not about *us*
- If you build it, they will come

Observations about *How Things Work*

- The impact of *How Things Work*
  - Many non-science students are now learning physics
  - These students find physics useful
  - There is less fear of physics – a cultural change
  - Physics has become a valued part of the curriculum
  - Other physics courses are flourishing

Observations about *How Things Work* (con't)

- My own experiences
  - I'm enjoying teaching more than ever
  - I feel as though I make a difference
  - I get to explain physics widely
  - I've learned a great deal of science