Lecture 5
GEOS24705

Thermodynamics of heat engines
What is a “heat engine”? 

A device that generates converts thermal energy to mechanical work by exploiting a temperature gradient

• **Makes something more ordered:** random motions of molecules → ordered motion of entire body

• **Makes something less ordered:** degrades a temperature gradient (transfers heat from hot to cold)
The two technological leaps of the Industrial Revolution that bring in the modern energy era

1. "Heat to Work"
   Chemical energy $\rightarrow$ mechanical work via mechanical device
   Use a temperature gradient to drive motion
   Allows use of stored energy in fossil fuels
   Late 1700’s: commercial adoption of steam engine

2. Efficient transport of energy: electrification
   Mechanical work $\rightarrow$ electrical energy $\rightarrow$ mech. work
   Allows central generation of power
   Late 1800s: rise of electrical companies
First true steam engine:

Thomas Newcomen, 1712, blacksmith

Copy of Papin’s engine of design of 1690, with piston falling as steam cooled, drawn down by the low pressure generated

First *reciprocating engine*: force transmitted by motion of piston

Can pump water to arbitrary height.

Force only on downstroke of piston

Very low efficiency: 0.5%

Intermittent force transmission

*Newcomen’s design is state of the art for 60+ years*
First true steam engine:

Thomas Newcomen, 1712, blacksmith

Copy of Papin’s engine of design of 1690, with piston falling as steam cooled, drawn down by the low pressure generated

First reciprocating engine: force transmitted by motion of piston

Can pump water to arbitrary height.

Force only on downstroke of piston

Very low efficiency: 0.5%

Intermittent force transmission

Newcomen’s design is state of the art for 60+ years
First modern steam engine:

James Watt, 1769 (patent), 1774 (prod.)
Higher efficiency than Newcomen by introducing separate condense
Reduces wasted heat by not requiring heating and cooling entire cylinder
First modern steam engine:

James Watt, 1769 (patent), 1774 (prod.)
Higher efficiency than Newcomen by introducing separate condenser
First modern steam engine:

James Watt, 1769 patent
(1774 production model)

Like Newcomen engine only with separate condenser
Higher efficiency: 2%

Force only on downstroke of piston

Intermittent force transmission

No rotational motion
**Improved Watt steam engine:**

James Watt, 1783 model
Albion Mill, London

Separate condenser
Higher efficiency: ca. 3%

**Force on both up- and downstroke**

Continuous force transmission

Rotational motion
(sun and planet gearing)

Engine speed regulator
Steam engines got more powerful AND more efficient over time.

**Figure 5.3** The rising power and improving efficiency of the best steam engines, 1700–1930. Sources: Plotted from data in Dickinson (1939) and von Tunzelmann (1978).

From V. Smil
How were both accomplished?

POWER
• More pressure
• Bigger cylinders
• More cylinders

EFFICIENCY
• Removing obvious losses
• Higher temperatures

*Pressure and temperature are related for steam*
Prince Consort Beam engine (world’s largest steam engine)

Prince Consort Beam engine

Beam engine train (see 6:20)
Double-action steam engine:

Why use suction to pull the piston down – why not just push it down with another injection of steam?

Piston pushed by steam on both up- and down-stroke.

No more need for a condenser. Steam is simply vented at high temperature.
Double-action steam engine:
Double-action steam engine:

primary use: transportation
Indicator diagrams told engineers how much work a cylinder put out on each stroke.