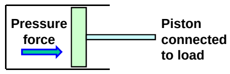
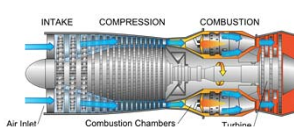
Engine general working principle



- Pressure force pushes a load
  - Expansion process; the higher the expansion, the more work is produced
- Pressure created by combustion
- End pressure limited by ability to exhaust
  - Need compression process to generate high combustion pressure for large expansion

1

Engines used in transportation



Gas Turbine engines
- **Continuous operation**
- **High rotating speed**
- **High power density**
- **Mostly for aircraft application**

Reciprocating engines
- **Intermittent operation**
- **Good fuel economy**
- **Moderate rotating speed**
- **Mostly for ground and sea automotive applications**

2

Otto and Langen free-piston engine

(from Lichty, Internal-Combustion Engines, 6th ed., 1951, McCraw-Hill)

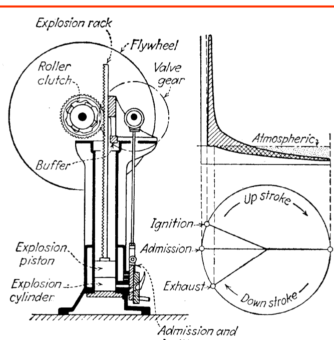


FIG. 2. Otto and Langen's free-piston engine (1866). (*From "Evolution of the Internal-combustion Engine" by Edward Butler, Charles Griffin & Co., Ltd., London, 1912.*)

Notes:

Lecture 1: Introduction to ICE

Vocabulary

Engine: Device to convert fuel energy to mechanical energy
- Fuel energy to thermal energy by combustion
- Thermal energy to mechanical energy by expansion

Internal combustion: combustion takes place in working fluid
External combustion: combustion occurs externally; energy coupled to working fluid by heat transfer device
Open cycle: working fluid discharged to atmosphere; e.g. all ICE
Close cycle: working fluid recycled through engine; e.g. steam engine with condenser

ICE

Size: displacement volume 1cc to $1m^3$; comment on why it is difficult to build engine outside this range.
Power: 10 W to 10^7 W
Applications: Automotive, marine, power generation, mechanical devices
Classification:
- by application: Car, Truck, Marine, Rail, Stationary generation, …
- by basic engine design: reciprocating, rotary, in-line block, V-block, radial, oppose piston, pre-/open chamber
- by working cycle: 2-stroke, 4-stroke, naturally aspirated , turbo-charged, super-charged, turbo-compound
- by fuel: gasoline, diesel, alcohol, natural gas, …
- by mixture preparation: carbureted, fuel injection
- by ignition: spark ignited, compression ignited

History

Circa	Event	People and key concept
1860	Rudimentary ICE	Jean J. Lenoir. — Key concept: Combustion increases temperature and gas expands. Expanding gas drives piston to produce mechanical energy. — Modified steam energy; no compression — Operated at 10 cycles/s; efficiency <5% because of low effective compression ratio Sold 500 of them
1867	Atmospheric free piston engine	Nicolaus Otto and Eugene Langen — Key concept: still no compression, but use the inertia of a heavy piston to over-expand the combustion gas to below atmosphere, thereby increasing the expansion ratio. Output mechanical work stored as gravitational potential energy in heavy piston first, and then extracted by clutching piston to fly wheel on downward stroke. — Larger expansion ratio: efficiency increased to 11% — Operate at 28 cycles/minute — Used a flame ignitor through a sliding window Sold 5000, dominated market for 10 years until introduction of the 4-stroke engine
1876	4-stroke engine	Nicolaus Otto
1878	2-stroke engine	Dougald Clerk
1892	Compression Ignition 4-stroke	Rudolf Diesel — Key concepts: prevent the very rapid and high pressure heat release process (knocking) by controlling the combustion

		process via introducing fuel late in the cycle; compression ignition — Concept developed by the company MAN — Diesel was in heavy debt, and jumped off a ship.
1870's	Development of the Petroleum Industry	
1900's	Spark plug dominated the market of ignition devices	Spark plug was invented by Edmond Berger in 1839. Albert Champion was the most successful manufacturer.
1920's	ICE dominated the market of automotive power plant	Main reason for not using the steam engine for vehicles was that too much water was needed.
1920's	Tetra-ethyl lead as anti-knock agent	Thomas Midgley, under the direction of Carles Kettering at GM found the compound to suppress knock after extensive search. With leaded gasoline, maximum compression ratio was raised from 5 to 9, and engine efficiency increased substantially
1920-1960	Steady development	
1960's	Vehicle emissions became an issue	Smog mechanism was discovered by Haagen Smit
1970's	Oil embargo; energy crisis	
1980's	Start of global competition	
1980's	Catalytic converter and unleaded gasoline	The 3 way catalyst reduced emissions of CO, HC and NOx by more than an order of magnitude, and was the enabler for the vehicles to meet emissions regulations
1990's	Recognition of importance of green house gas	
2000's	Towards sustainable transportation	

Gas exchange process of 4- and 2-stroke engines

See figures 1-2 and 1-3.

- 2-stroke engine theoretically has twice the power density of 2-stroke engine; in practice, the ratio is about 1.4 (value larger for low speed turbo-charger engines) because of incompleteness of scavenging.
- For effective scavenging of the 2-stroke, there will be excess air in the exhaust, and the 3-way catalyst would not work. Therefore 2-stroke SI engine would not be able to meet the stringent emission regulations

Engine pressure traces

See Fig. 1.8 and 1.15 for SI and Compression Ignition engines

- Pressure measurement is an important diagnostic because it is directly related to the mechanical energy output of the engine (Torque = $P\, dV/d\theta$, where θ is the crank angle); furthermore, interpretation of pressure is unambiguous since it is uniform in the cylinder (except in knocking), whereas temperature is not.
- Empirically for most efficient operation, peak pressure for SI engine is at 14-17^o CA-ATC; for diesel is at 7-10^o CA-ATC.
- The very rapid pressure rise in the beginning of diesel combustion is the cause of the diesel noise.