AE 330/708

AEROSPACE PROPULSION

Instructor

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History of Rockets

Chinese Fire Arrows, A.D. 1232

First known use of rockets – By 1232, these primitive rockets were attached to arrows against Mongol invaders

Propellant combination – Mixture of saltpeter, sulfur, and charcoal dust (also called as gun powder)

Tubes of bamboo and leather, closed off at one end, were packed with propellant mixture.

Depending upon how the powder was packed and the size of the opening, a fountain of sparks or a bang would result when the powder was ignited.

Scientific theories that were later helpful in development of rocketry as Science

Galileo Galilei, 1564 to 1642
This Italian astronomer and mathematician rekindled the spirit of scientific experimentation and challenged old beliefs relating to mass and gravity. He proved that an object in motion does not need the continuous application of force to keep moving. He called this property of matter, which causes it to resist changes in velocity, "inertia." Inertia is one of the fundamental properties that Isaac Newton would later incorporate into his laws of motion.

Newton's Laws of Motion, 1642 to 1727
English scientist Sir Isaac Newton condensed all rocket science into three elegant scientific laws. Published in *Philosophiae Naturalis Principia Mathematica* his laws, previously understood intuitively by early rocketeers, provided the foundation for all modern rocket science. (The "Rocket Principles" chapter focuses on these laws and the "Practical Rocketry" chapter demonstrates the applications of these laws.)

In India

Tipu's Rockets (1770 - 1790)

Used in wars against British. Use of cast iron cylinders.

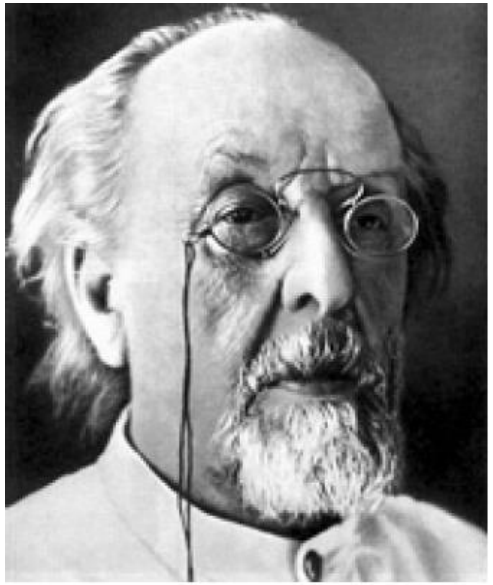
Large pressures – large thrust

Range ~ 1.5 miles (Much longer than earlier rockets)

Rockets were much improved and effective, but the knowledge was intuitive

Era of Modern Rocketry

Modern Rocket Pioneers

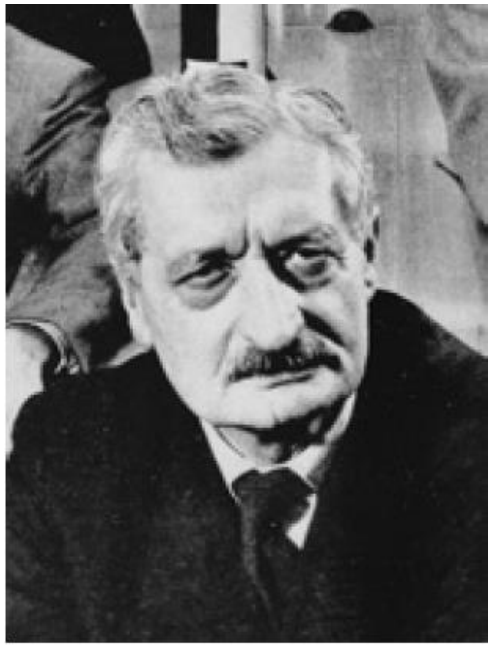


Konstantin E. Tsiolkovski, 1857 to 1935

His rocket equation, based on Newton's second law of motion, relates rocket engine exhaust velocity to the change in velocity of the vehicle itself.

Robert H. Goddard, 1882 to 1945

built and flew the world's first liquid propellant rocket on March 16, 1926. developed a gyroscope system to control his rockets in flight, instrumentation payload compartments, and parachute recovery systems. He is often referred to as the "father of modern rocketry."



Hermann Oberth, 1894 to 1989

explained the mathematics of spaceflight and proposed practical rocket designs and space stations. Inspired the development of the V2 rocket.

World War II – Much needed push for the development of rockets (although unwanted)

Flying Bombs

The necessities of war led to massive technological improvements in aeronautics and rocketry. Almost overnight, rockets graduated from novelties and dream flying machines to sophisticated weapons of destruction. Rockets propelled nearly unstoppable German fighter planes and Japanese Kamikaze with bombs into ships. War would never be the same again.

Vergeltungswaffe 2 - V2

In the late 1930s, the most advanced rocket for the time, the V2. Wernher von Braun created a rocket powered by alcohol and liquid oxygen.

With a range of 200 miles and a maximum altitude of 55 miles, the V2 could deliver a 1-ton explosive warhead to the heart of London without warning.

Thousands of V2s were built, but they entered the war too late to affect the outcome.

Cold War – Competition to explore space

The World's First Artificial Satellite: The Soviet Union launched its *Sputnik I* satellite on October 4, 1957. It weighed 83.6 kg. Two months later, the 508.3-kg *Sputnik II* reached space with a living passenger. Laika, a small dog, orbited Earth for a few hours.

Explorer 1: The United States entered the satellite-launching business on January 31, 1958 with the successful launch of *Explorer 1*.

X-15: Between 1959 and 1968, the X-15 experimental aircraft flew to the edge of space. Max. speed (7,274 kph or 4,520 mph) and altitude records (108 kilometers or 67 miles).

Yuri Gagarin Goes Into Orbit: April 12, 1961.

Moon Mission: July 20, 1969.

What is happening today? Space Age!

Deep Space Missions

Sounding Rockets

Space Shuttle: LEO transfers and ISS supports; Reusable

Dream Chaser
Support to ISS

Space Tourism
SpaceShipOne

Rocket Propulsion

- A class of jet propulsion that produces thrust by ejecting stored matter, called the propellant
- Most of the applications require working outside the atmosphere and hence lack of Oxygen
- Non-air breathing propulsion; Carry oxidizer with itself
- Characterized by high levels of thrust and acceleration
- Use of exotic, highly energetic propellants to produce thrust by thermodynamic expansion of the gas (in nozzle)
- Significant reduction in the mass of the vehicle over the course of the operation

Types of Rocket Engines

Gas acceleration

Thermal: Gas pushes directly on walls by P (pressure) forces
Nozzle accelerates gas by P forces
(most large rockets, chem, nuclear, some electric…)

Electrostatic
Ions accelerated by $\vec{E}$ field
(a) Electrostatic force (push) on electrodes (Ion engines)
(b) Force (push) on magnetic coils through gas $\vec{j}$ (Hall thrusters)

Electromagnetic
Gas accelerated by $\vec{j} \times \vec{B}$ forces
Force (push) on coils or conductors
(MPD thrusters)

Energy Source

Chemical (always thermal)
- Solid Propellant
- Liquid Propellant
  - Monopropellant
  - Bipropellant
- Hybrid

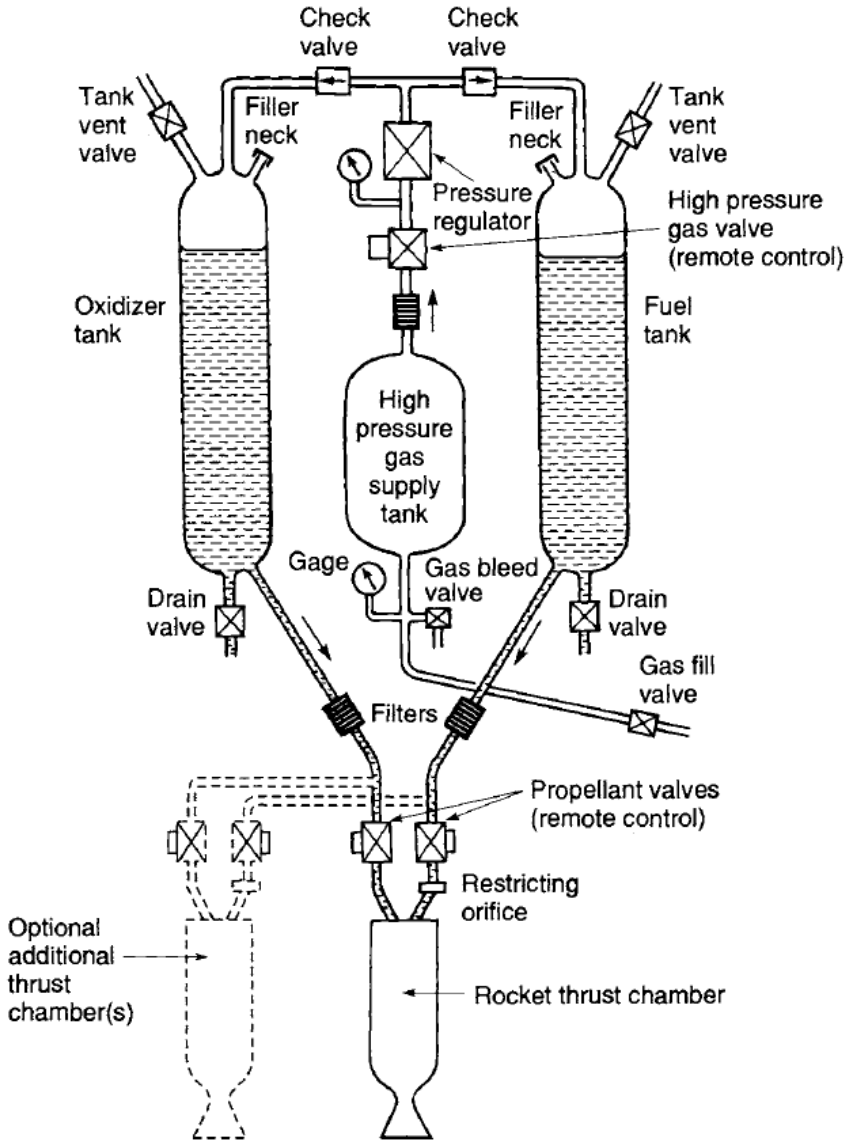
Nuclear (Thermal)
Nuclear (Electric)
- Electrostatic
- Electromagnetic

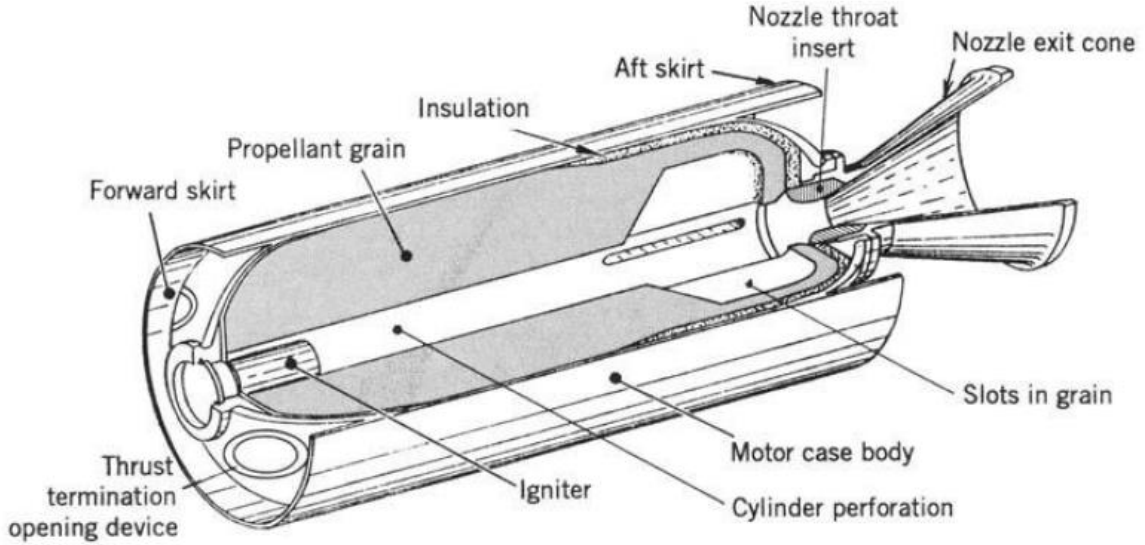
Solar (Thermal)
Solar (Electric)
- Electrostatic
- Electromagnetic

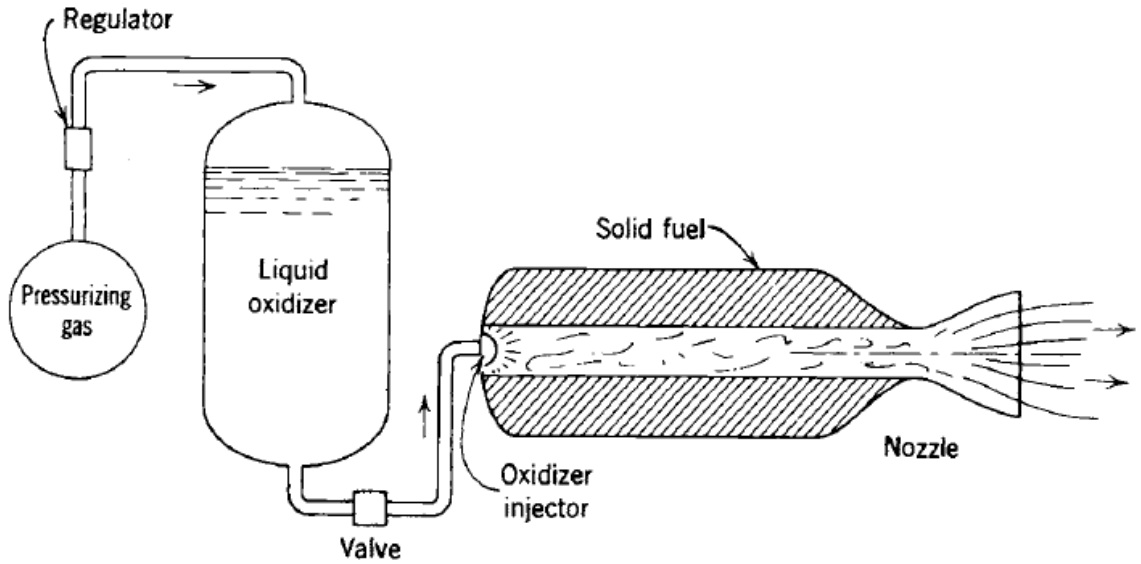
Thrust level (per unit mass)

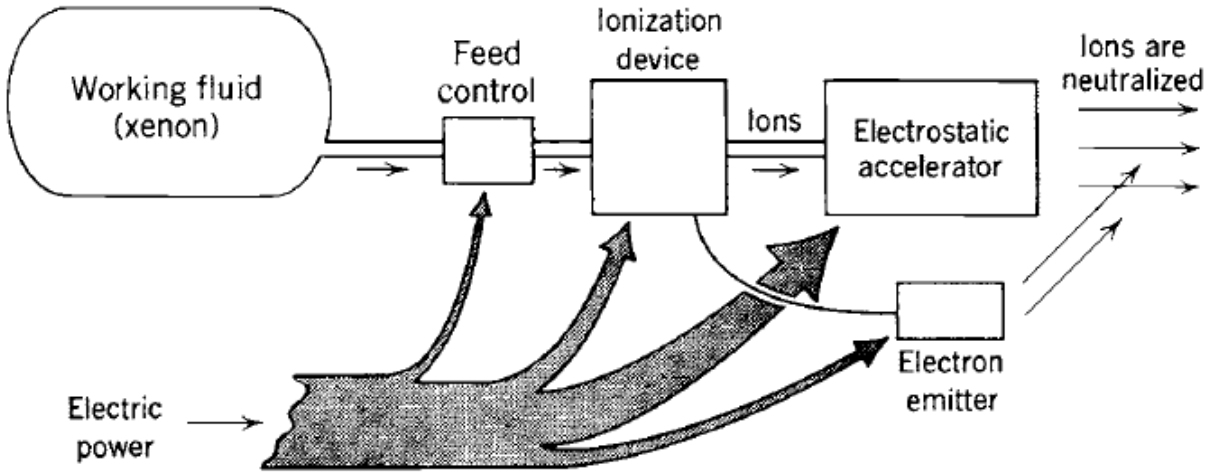
- High thrust ($\geq 1g$) for launch, fast space maneuvering

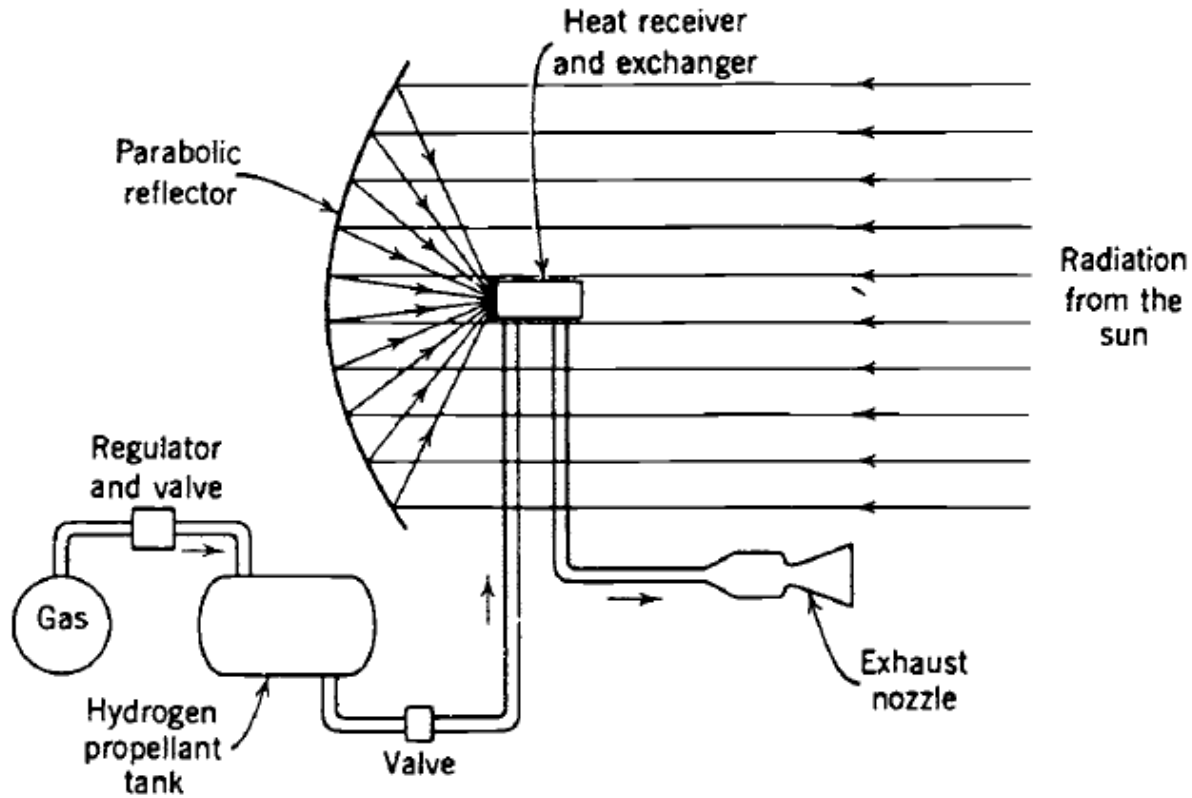
- Low thrust ($10^{-5} – 10^{-2}\ g$) for efficient in-space maneuvers


Check valve
Check valve
Tank vent valve
Filler neck
Filler neck
Tank vent valve
Pressure regulator
High pressure gas valve (remote control)
Oxidizer tank
Fuel tank
High pressure gas supply tank
Gage
Gas bleed valve
Drain valve
Drain valve
Gas fill valve
Filters
Propellant valves (remote control)
Restricting orifice
Optional additional thrust chamber(s)
Rocket thrust chamber


Nozzle throat insert
Nozzle exit cone
Aft skirt
Insulation
Propellant grain
Forward skirt
Slots in grain
Motor case body
Thrust termination opening device
Igniter
Cylinder perforation


Regulator
Pressurizing gas
Liquid oxidizer
Solid fuel
Nozzle
Oxidizer injector
Valve


Working fluid
(xenon)
Feed
control
Ionization
device
Ions
Electrostatic
accelerator
Ions are
neutralized
Electron
emitter
Electric
power


Heat receiver
and exchanger
Parabolic
reflector
Radiation
from the
sun
Regulator
and valve
Gas
Hydrogen
propellant
tank
Valve
Exhaust
nozzle

Applications

Space launch vehicles

Expendable, recoverable or reusable
Multistaging – Each stage itself is a complete rocket

Combination of solid, liquid and cryogenic rockets

Examples – Titan, Saturn, Soyuz, PSLV, GSLV

Spacecrafts

Space shuttle – Booster + Orbiter

Very complex assembly of large number of rockets due to reusable nature

Orbiter: 3 main cryo engines + 2 LPRs for flight control + 40 small LPRs for different functions + 6 LPRs for attitude control

Missiles

Strategic, Tactical, Ballistic, ICBM

Mostly solid propellant rockets to minimize the complexity and reduce the cost

Also combination of air breathing engines

Examples - Agni, Minuteman, and so many

Miscellaneous

Rocket assisted take off for planes

Sounding rockets