Aerospace Propulsion

Lecture 18

Rocket Propulsion I

Rocket Propulsion: Part I

- Rocket History
- Classification
- Applications

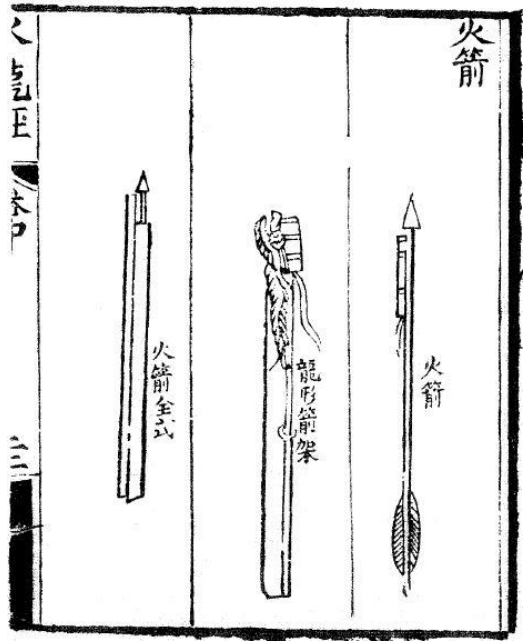
Rocket History

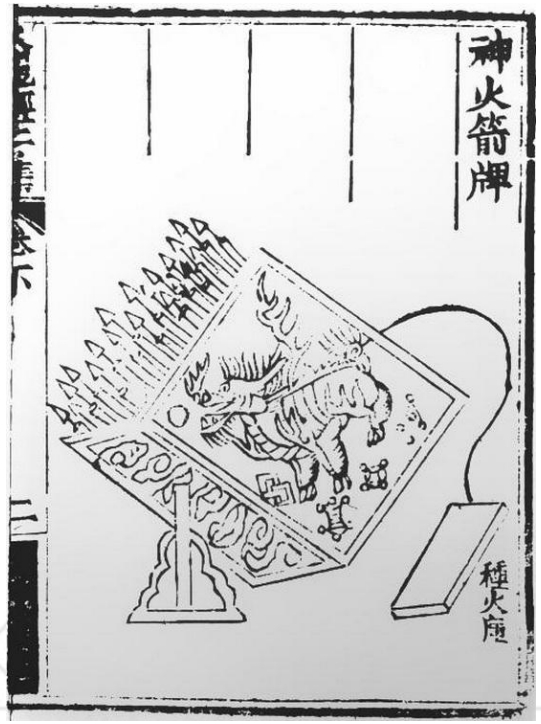
- A rocket is a vehicle that uses jet propulsion to accelerate without using the surrounding air.
- A rocket engine produces thrust by reaction to exhaust expelled at high speed.
- Rocket engines work entirely from propellant carried within the vehicle; therefore a rocket can fly in the vacuum of space.

- Wikipedia “Rocket”

Rocket History

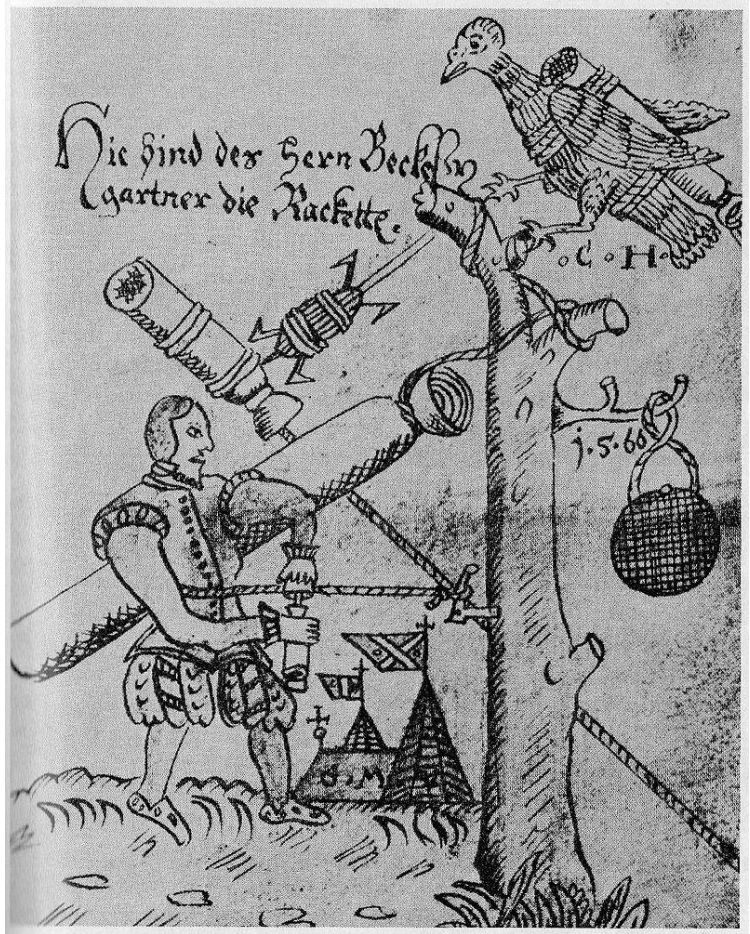
- Rockets were first used during war to propel arrows
  - China - between 10th and 13th century
  - Gunpowder filled tubes attached to arrow
- At approximately the same time, gunpowder-based fireworks (i.e., rockets) were invented
  - Also China – sometime before 13th century
- Mongols spread rocket technology throughout Asia and Europe





Rocket History

- Conrad Haas
  - 16th century Austrian “arsenal master”
  - Experimented with and wrote a manuscript on advanced rocketry concepts
    - Combination of fireworks + weaponry
    - Multi-stage rockets
    - Different fuel mixtures
    - Delta-shaped fins
    - Bell-shaped nozzles



Conrad Haas (1529 – 1569), „Königlicher und Kaiserlicher Zeugmeister“ in Hermannstadt. Entwurf, „Wie du solt machen gar schöne Rackette, die da von im selber oben hienauff in die hoch faren“.

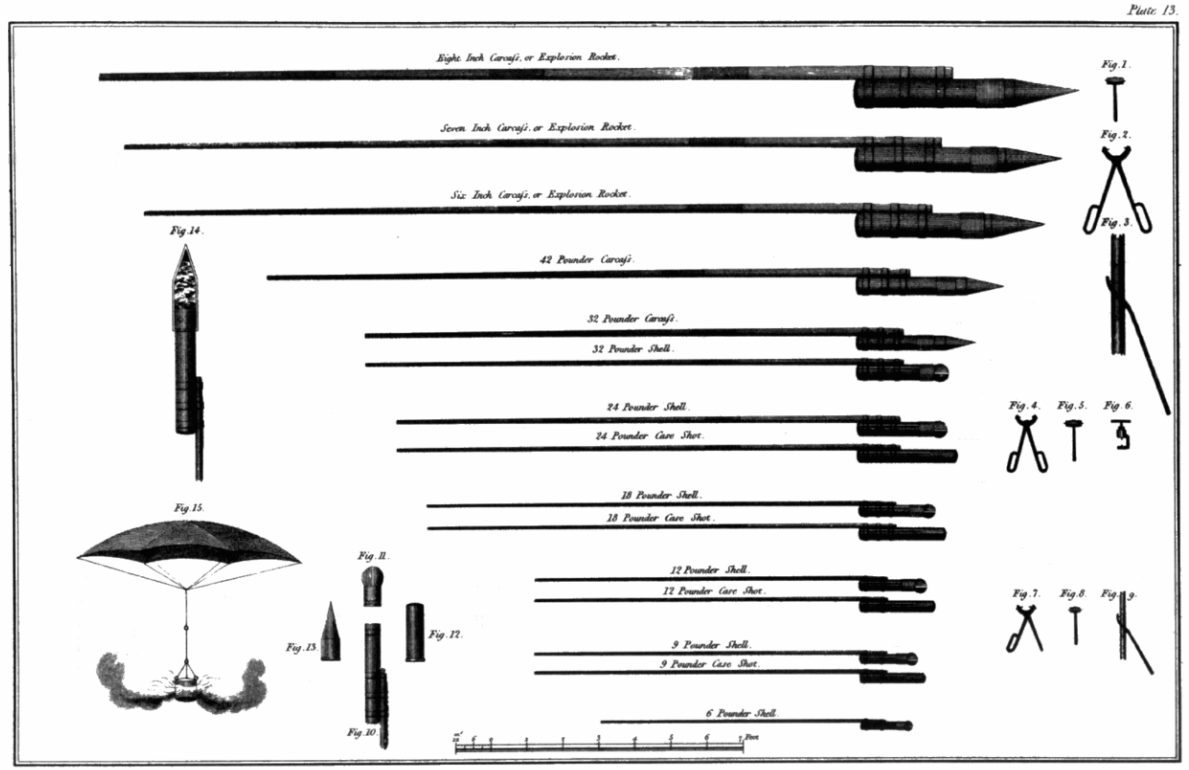
Rocket History

- Lagâri Hasan Çelebi
  - Ottoman scientist, engineer, aviator
  - Reported to have flown on a rocket in Istanbul in 1633
  - Seven-winged rocket with 140 pounds of gunpowder
  - Ascended and landed in the water

  - Mythbusters tested this and “said that it would have been ‘extremely difficult’ for a 17th-century figure, unequipped with modern steel alloys and welding, to land safely or even achieve thrust at all. Although the re-imagined rocket rose, it exploded midflight.

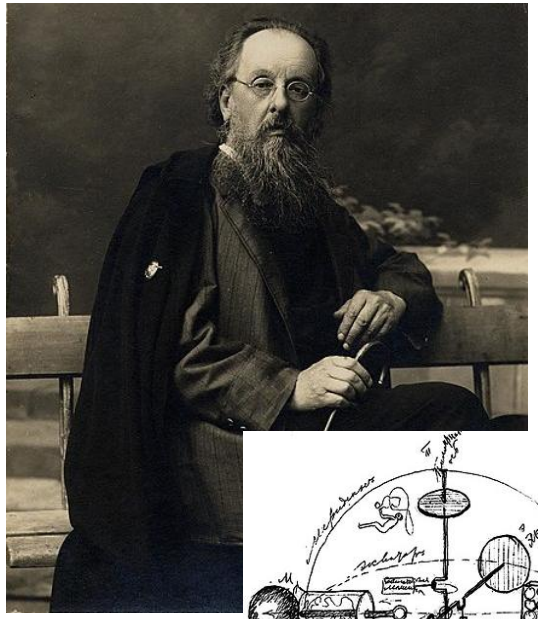
Rocket History

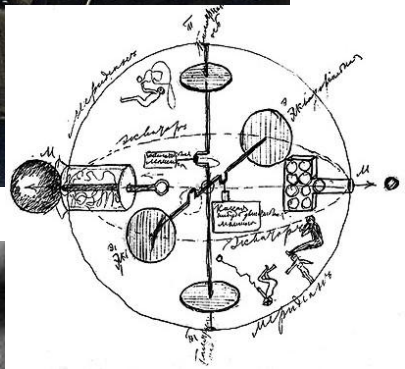
- Rockets were mainly weapons until 20th century
- Improvements before this point mainly focused on:
  - Increasing range
    - Fuels
    - Casings
  - Increasing accuracy
    - Attach a long stick
    - Spinning

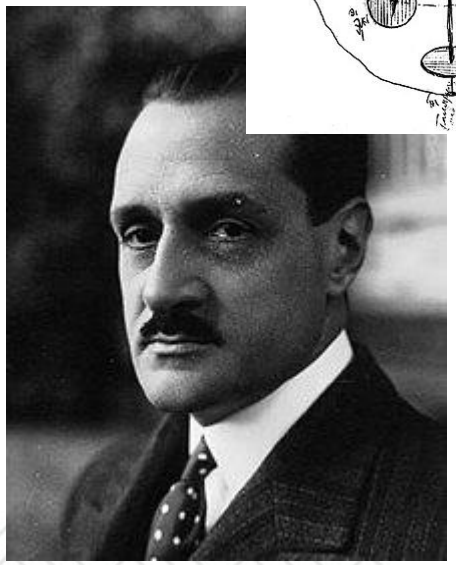


Rocket History

- Exploration of space becomes a major interest in the early 20th century
  - Konstantin Tsiolkovsky
    - Russian high school math teacher
    - Published “The Exploration of Cosmic Space by Means of Reaction Devices” in 1903
  - Robert Esnault-Pelterie
    - Published a lecture on rocket theory and interplanetary travel in 1912.
    - Basic calculations about the energy required to make round trips to the Moon and planets
    - Proposed the use of atomic power to power a jet drive.







Rocket History

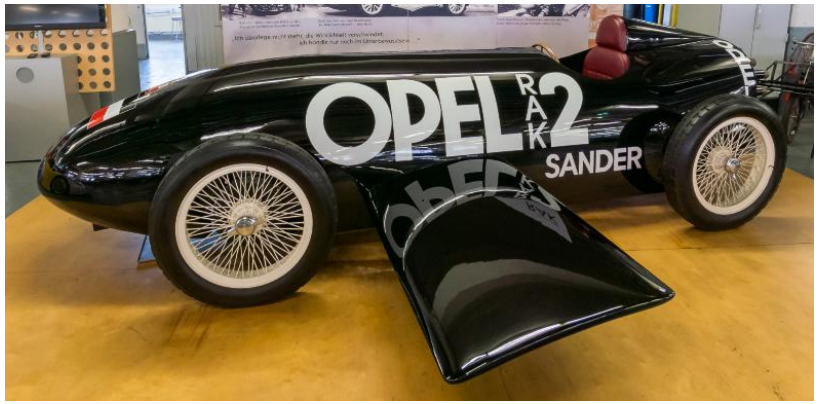
- Robert Goddard
  - American engineer, professor, physicist, inventor
  - Concluded in 1912 that conventional solid-rockets should:
    - Burn fuel in smaller chambers
    - Be arranged in stages
    - **Use De Laval nozzles to reach supersonic exhaust**
  - Published “A Method of Reaching Extreme Altitudes”
    - Discussed sending a rocket to the moon
    - “That Professor Goddard, with his 'chair' in Clark College and the countenancing of the Smithsonian Institution, does not know the relation of action to reaction, and of the need to have something better than a vacuum against which to react – to say that would be absurd. Of course he only seems to lack the knowledge ladled out daily in high schools."
    - New York Times, 13 January 1920

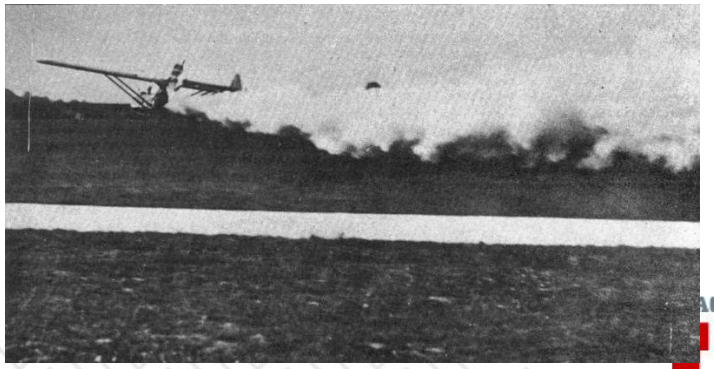
Rocket History

- Robert Goddard
  - Addition of De Laval nozzle increase rocket efficiency from 2% to 64%
  - Launched the first liquid fueled rocket in 1926
    - Auburn, Massachusetts
    - Liquid oxygen and gasoline
- Things began to move quickly here…

Rocket History

- Fritz von Opel
  - German owner of “Opel” car company
  - Began to research rocket vehicles in 1927
  - Led to first rocket cars and planes
    - Opel RAK.1 and Opel RAK.2 (Rocket cars)
      - Achieved 145 mph on May 23, 1928
    - Opel RAK.3 and Opel RAK.4 (Rocket rail vehicle)
      - Achieved ~155 mph
    - Opel RAK.1 (Rocket plane)
      - Flown September 30, 1929
  - Ultimately designed rockets with goal of crossing the English channel





Rocket History

- V2 Rocket (Vengeance Weapon 2)
  - German WW2 missile produced in 1943
  - First vehicle to reach outer space
  - 200 mile range
  - 2,500 pound warhead
  - 2,500 mph speed
  - Bombarded England and Western Europe
  - Could not be defended against at the time

Rocket History

- The Cold War
  - After WW2, many German rocket scientists were captured
  - The 1960's were one of the most rapid periods of rocket development
  - Intercontinental Ballistic Missiles
    - Unstoppable nuclear weaponry
  - Manned spaceflight
    - Race to be first
    - Strategic "ownership" of space

Rocket History

- United States human spaceflight
  - Project Mercury (1958-1963)
  - Project Gemini (1961-1966)
  - Project Apollo (1961-1972)

  - Saturn V rocket (1967-1973)
    - Human-rated, three stages, liquid fuel
    - Nine crewed flights to the moon
    - Launched first US space station

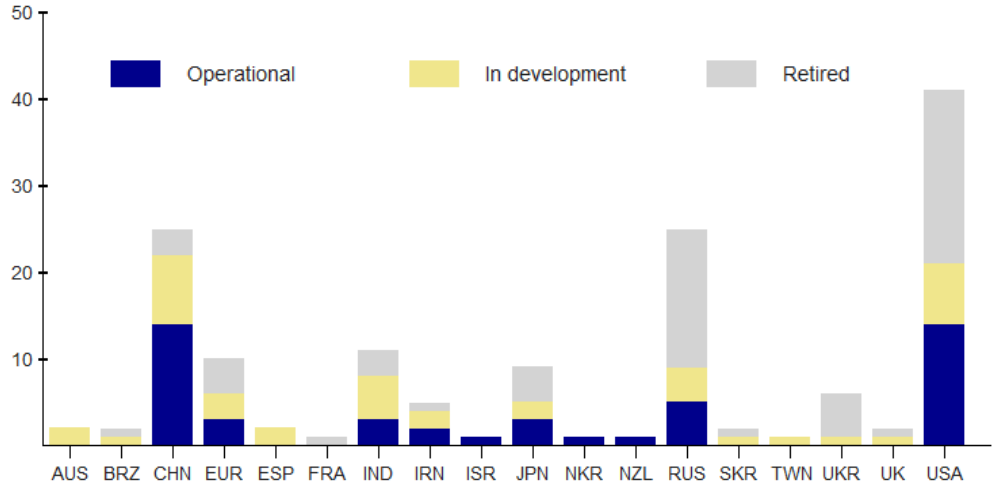
Further investigation and experimentation have confirmed the findings of Isaac Newton in the 17th century and it is now definitely established that a rocket can function in a vacuum as well as in an atmosphere. The Times regrets the error.
—New York Times, 17 June 1969 - A Correction

Rocket History

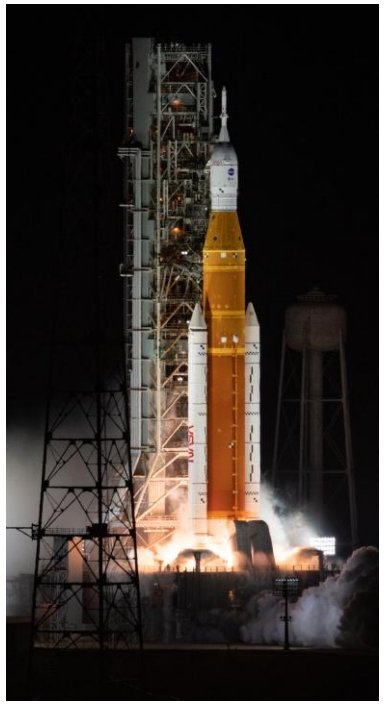
- Space Shuttle (1981-2011)
  - Orbiter vehicle (reusable)
    - Glide landing
    - Three engines
  - Two recoverable solid rocket boosters
  - Expendable external tank
    - LH2/LOX

  - Five space shuttles built
  - Flew 135 missions total
  - Two lost in accidents

Rocket History



- Current landscape
  - >60 existing orbital launch systems
  - >40 upcoming orbital launch systems
  - Does not begin to cover number of existing/upcoming missiles
- Government (E.g., NASA)
  - Space Launch System
    - Highest payload capacity of any rocket in operation
- Private (E.g., SpaceX)
  - SpaceX Falcon 9
  - Boeing Starliner



Classification

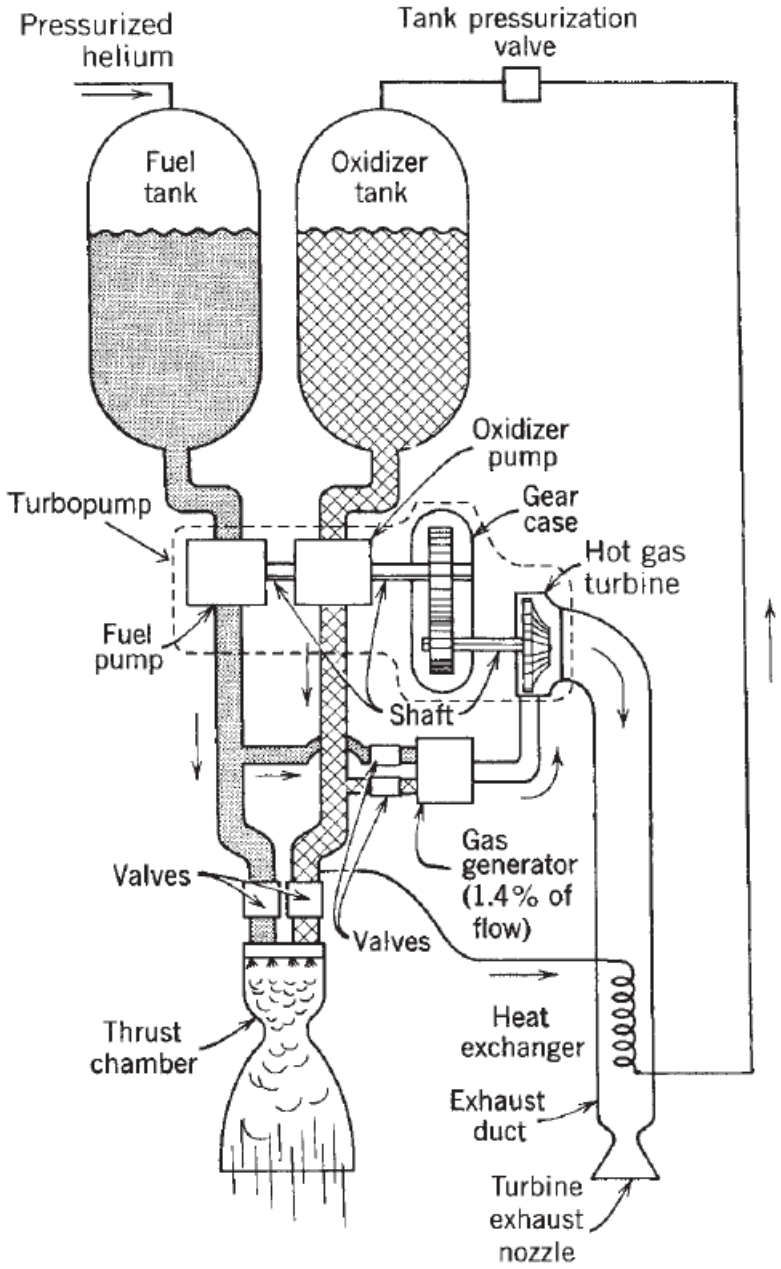
- Energy Source
  - Pressure rocket
    - Power input from pressurized gases
  - Chemical rocket
    - Power input from combustion of fuel and oxidizer
  - Nuclear thermal rocket
    - Power input from nuclear reactor
  - Electric rocket
    - Power input from electrical source (stored or harvested)
  - Combined rocket + airbreathing
    - Power input typically from combustion

Classification

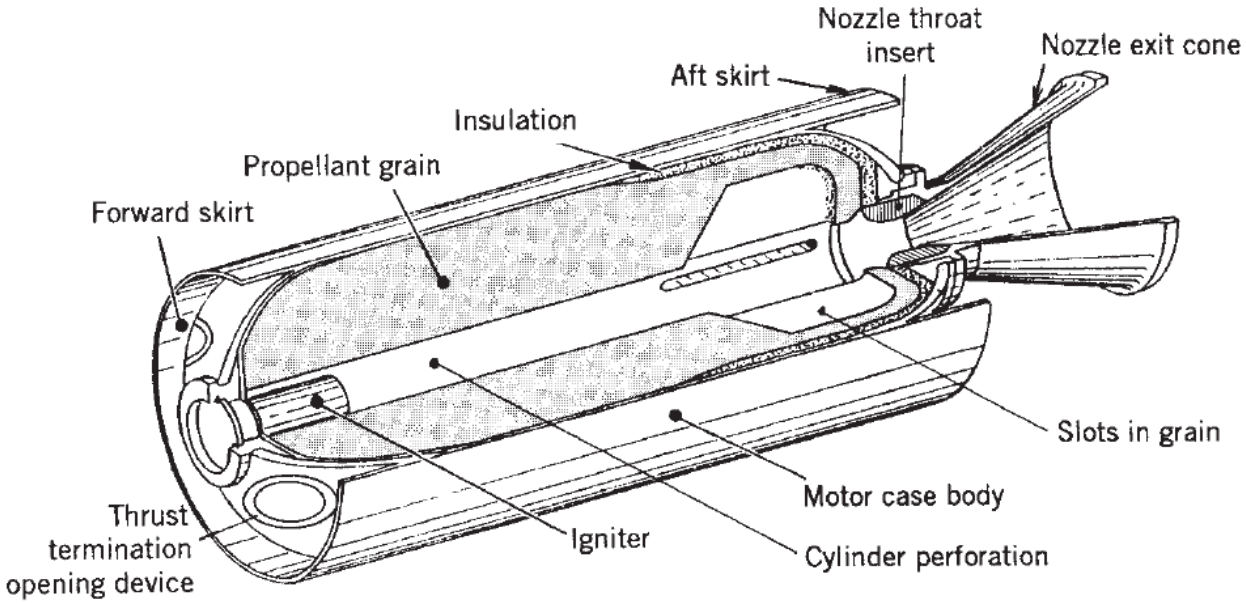
- Pressure rocket
  - Simplest possible rocket
  - Fill a container with high pressure gas held back by a valve
    - Commonly air, nitrogen, helium
  - When thrust is needed, release some gas
  - Much like systems we studied in early compressible flow lectures
  - Primarily used for maneuvering and attitude control
    - Common in early rockets, still occasionally exists today
  - Gases can be heated (e.g., electrically) to improve performance

Classification

- Chemical rocket
  - Liquid propellants
    - Typically bipropellants
  - Fuel and oxidizer are fed into a thrust chamber where they are ignited
  - Propellants can be fed by pressurized gas or turbopumps (powered by turbine)
  - Liquid propellants can typically be turned on and off through valves
  - Historically goes by “engine”

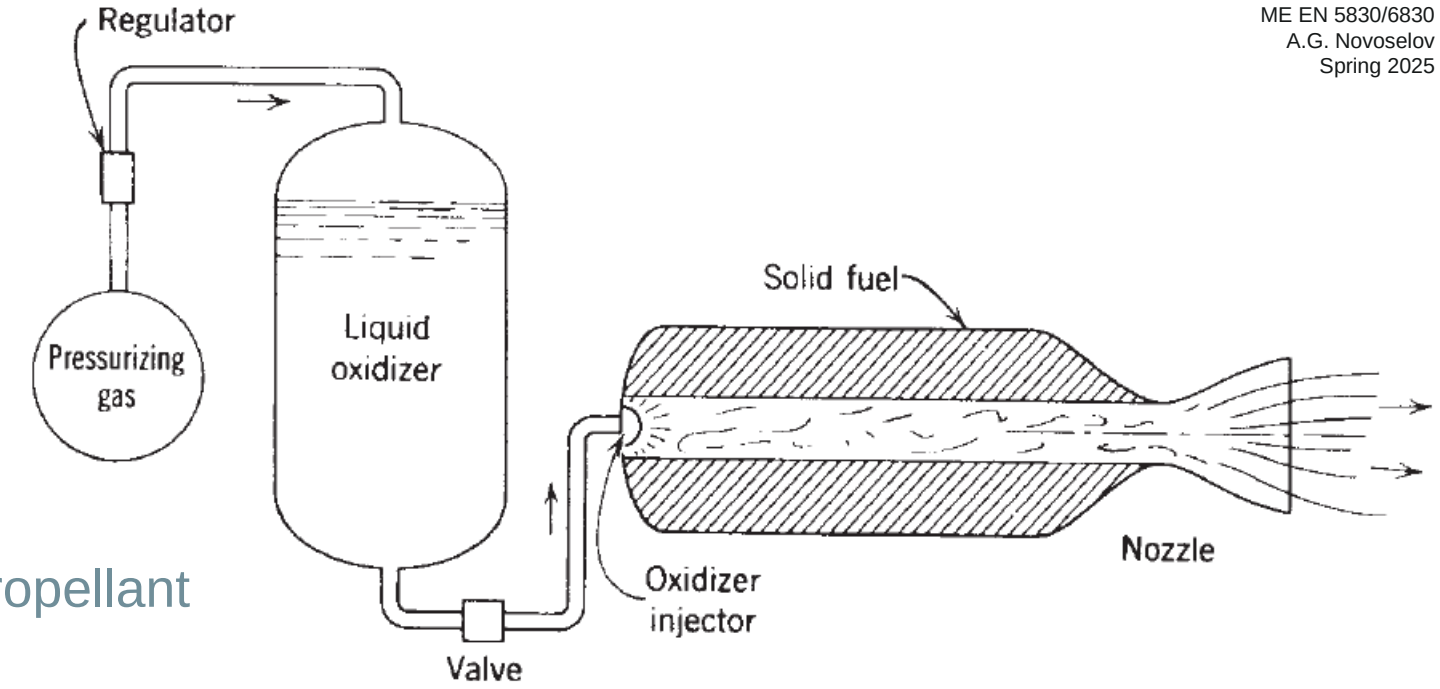


Classification



- Chemical rocket
  - Solid propellants
    - Combustible solid material
    - See Lecture 6 for more info on fuels
  - Solid fuel is ignited and burns smoothly at predetermined rate
  - No feed systems or valves
    - Once a solid propellant is ignited, it does not stop
  - Historically goes by “motor”

Classification



- Chemical rocket
  - Hybrid propellants
    - Combined liquid and solid propellant
  - Feed liquid propellants through a solid
  - Provides a baseline load + additional controllable thrust

Classification

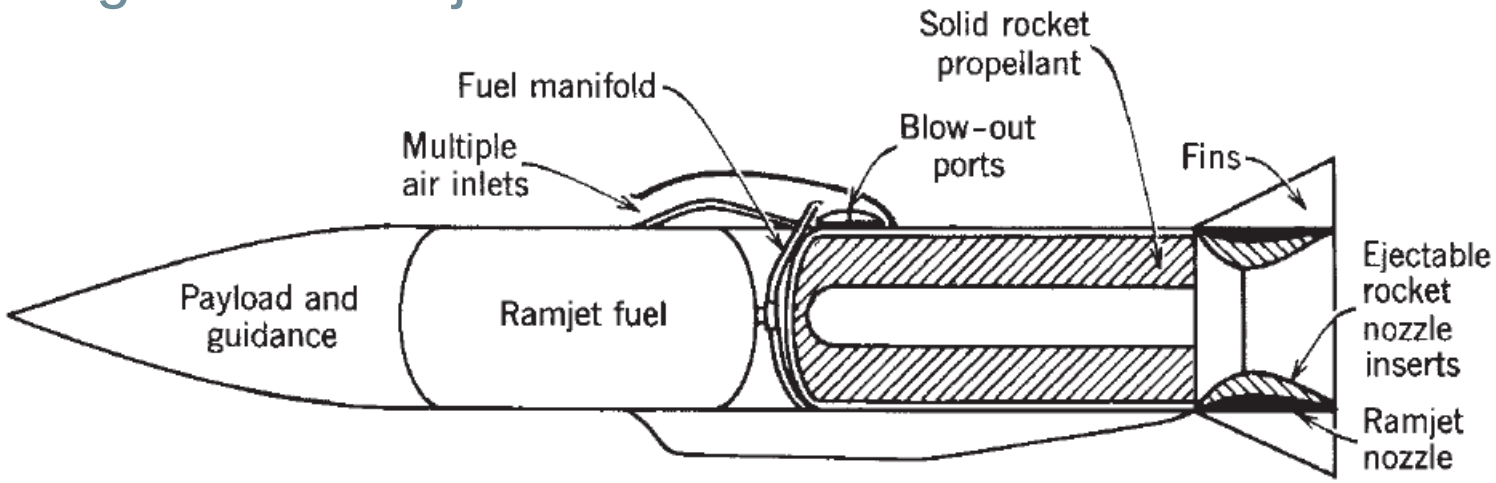
- Nuclear thermal rocket
  - Conceptually similar to chemical rockets
  - Power input comes from a nuclear reactor, rather than from combustion
  - Tested in the 1960's but didn't continue
  - Failure of such a rocket could be very bad
    - Essentially a nuclear missile falling out of the sky

Classification

- Electrical rocket
  - Electrothermal rocket
    - Improved pressure rocket
    - Heat propellant electrically to improve performance
  - Ion propulsion
    - Working fluid like Xenon is first stripped of electrons
    - Ions are accelerated out of the rocket at massive speed by electrostatic field
  - Electromagnetic propulsion
    - Plasma ejected at high velocity by electric currents and magnetic fields
  - Ion/Electromagnetic propulsion only work in vacuums
  - Most electrical rockets are highly efficient, but provide low thrust
    - Bad for take-off, great for long trips

Classification

- Combined rocket + airbreathing
  - Solid/liquid propellant to initiate flight
  - Drop rocket component when up to speed
  - Switch to airbreathing for longer flight
  - Useful for accelerating ram/scramjets



Applications

- Space Launch Vehicles (e.g., space shuttle)
  - Get something into space
  - Overcome gravitational field
- Spacecraft (e.g., satellites, ISS)
  - Vehicles already in space
  - Move along flight path/attitude control
- Military applications
  - Satellites and missiles

Applications

Application	Type of Propellant	Thrust Profile	Typical Firing Duration	Maximum Acceleration[a]
Large space launch vehicle	Liquid or cryogenic liquid	Nearly constant thrust	2–8 min	1.2–6 g_0
Strap-on booster	Solid or liquid	100,000 to 3,300,000 lbf	½ to 2 min	1.2 to 3 g_0
Spent strap-on stage separation	4 to 8 SPRMs	10,000 to 20,000 lbf each	Less than 1 sec	N. A.
Antiaircraft or antimissile-missile	Solid, some with liquid terminal divert stage	High thrust boost, decreasing thrust sustain phase; high thrust divert	2–75 sec each	5 to 20 g_0, but can be up to 100 g_0
Spacecraft orbit maneuvers and/or maintenance	Storable liquid or cryogenic liquid; electric propulsion	Multiple restarts in space; can be pulsed	Up to 10 min cumulative duration	0.2–6 g_0
Air-launched guided missile	Solid	High thrust boost phase with low thrust or decreasing thrust for sustain phase; sometimes 2 pulses	Boost: 2–5 sec Sustain: 10–30 sec	Up to 25 g_0
Battlefield support—surface launched	Solid	Decreasing thrust	Up to 2 min each stage	Up to 10 g_0
Rocket-assisted projectile, gun launched	Solid	Constant or decreasing thrust	A few sec	Up to 20,000 g_0 in gun barrel
Spacecraft attitude control—large vehicles	Storable liquid (monopropellant or bipropellant); electric propulsion; xenon	Many restarts (up to several thousands); pulsing	Up to several hours cumulative duration	Less than 0.1 g_0
Spacecraft attitude control—small vehicle	Electric propulsion; Cold or warm gas or storable liquid.	Same	Up to several hours cumulative	Same
Reusable main engines for Space Shuttle	Cryogenic liquid (O_2/H_2)	Variable thrust, many flights with same engine	8 min, over 7 hr cumulative in several missions	
Lunar landing	Storable bipropellant	10:1 thrust variation	4 min	Several g_0
Weather sounding rocket	Solid	Single burn period—often decreasing thrust	5–30 sec	Up to 15 g_0
Antitank	Solid	Single burn period	0.2–3 sec	Up to 20 g_0