# Solid Rocket Motor

Part 1 Introduction

# Propulsion

——conception

**Propulsion**: the act of changing the motion of a body

- Moves bodies
- Changes velocity
- Overcomes retarding forces



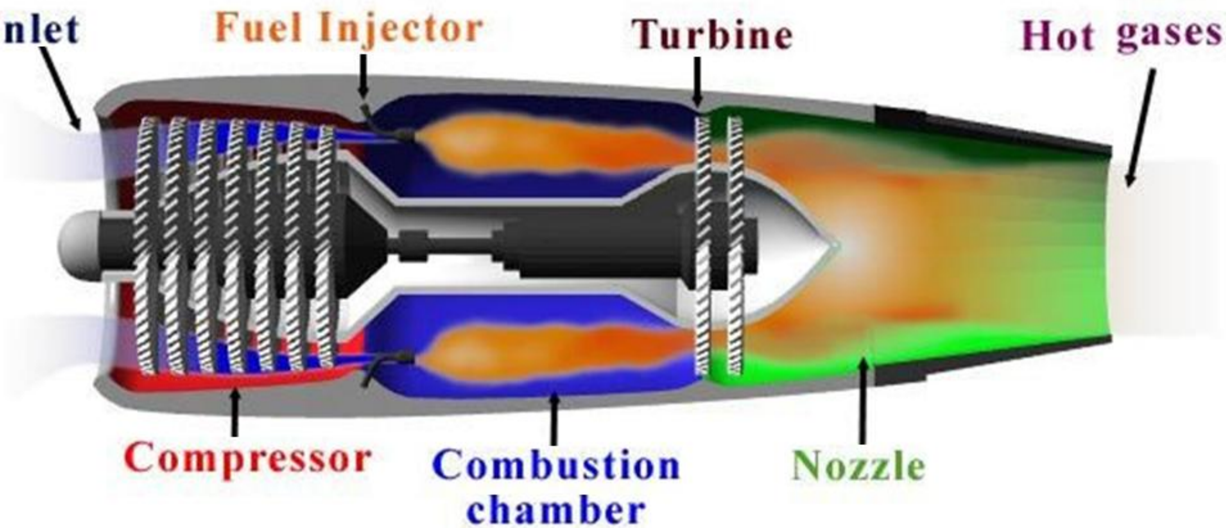



**Jet Propulsion** : reaction force by the momentum of ejected matter

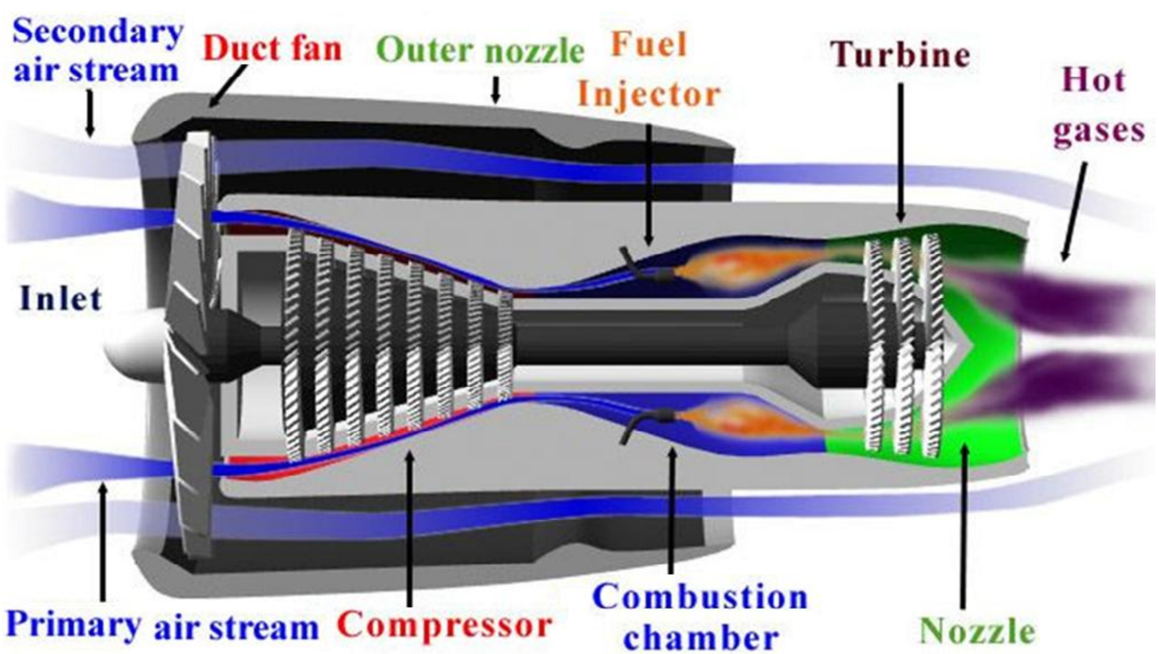
- **Jet Propulsion**
  - **Duct Propulsion**
    Air-breathing
    - Turbojet
    - Turbofan
    - Ramjet
    - Pulsejet

# Duct Jet Propulsion

Turbojet

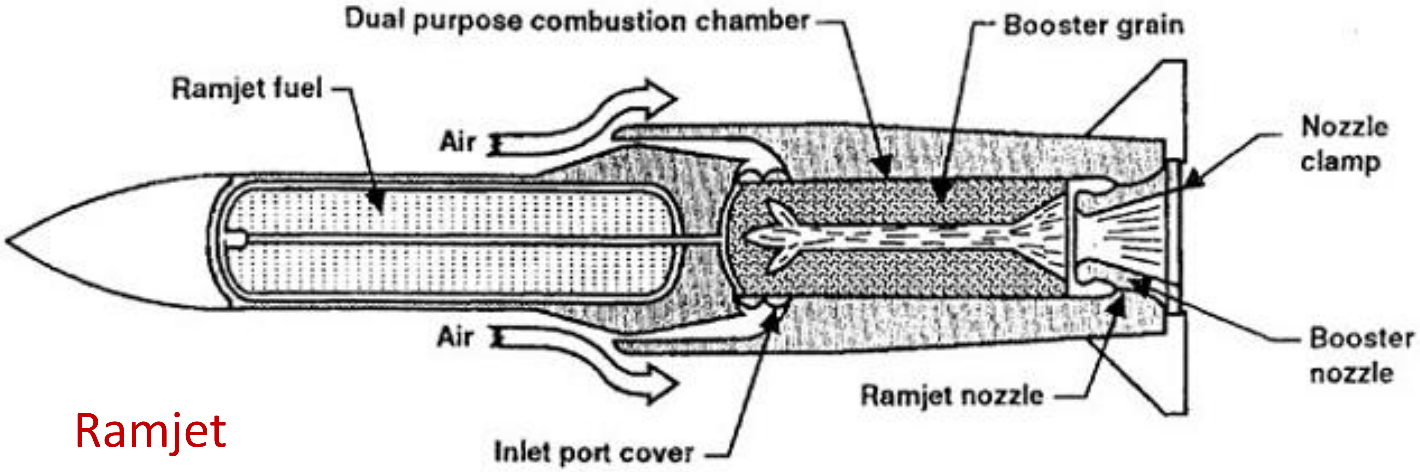



Turbofan



# Duct Jet Propulsion





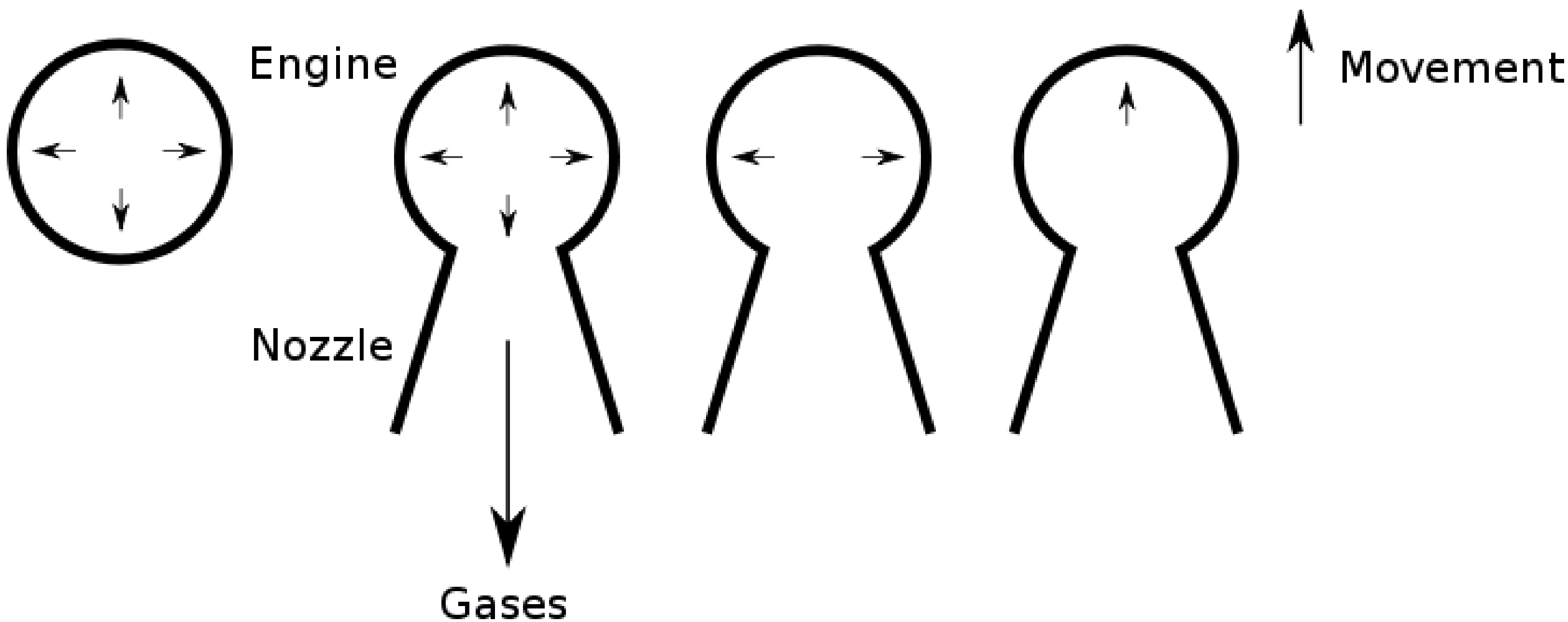

Ramjet

**Jet Propulsion** : reaction force by the momentum of ejected matter

- **Jet Propulsion**
  - **Duct Propulsion**
    Air-breathing
    - Turbojet
    - Turbofan
    - Ramjet
    - Pulsejet
  - **Rocket Propulsion**
    Stored propellant
    - Chemical combustion

## Rocket Propulsion

How rocket works



# Chemical Rocket Propulsion

Chemical Rocket Propulsion

Stored propellant

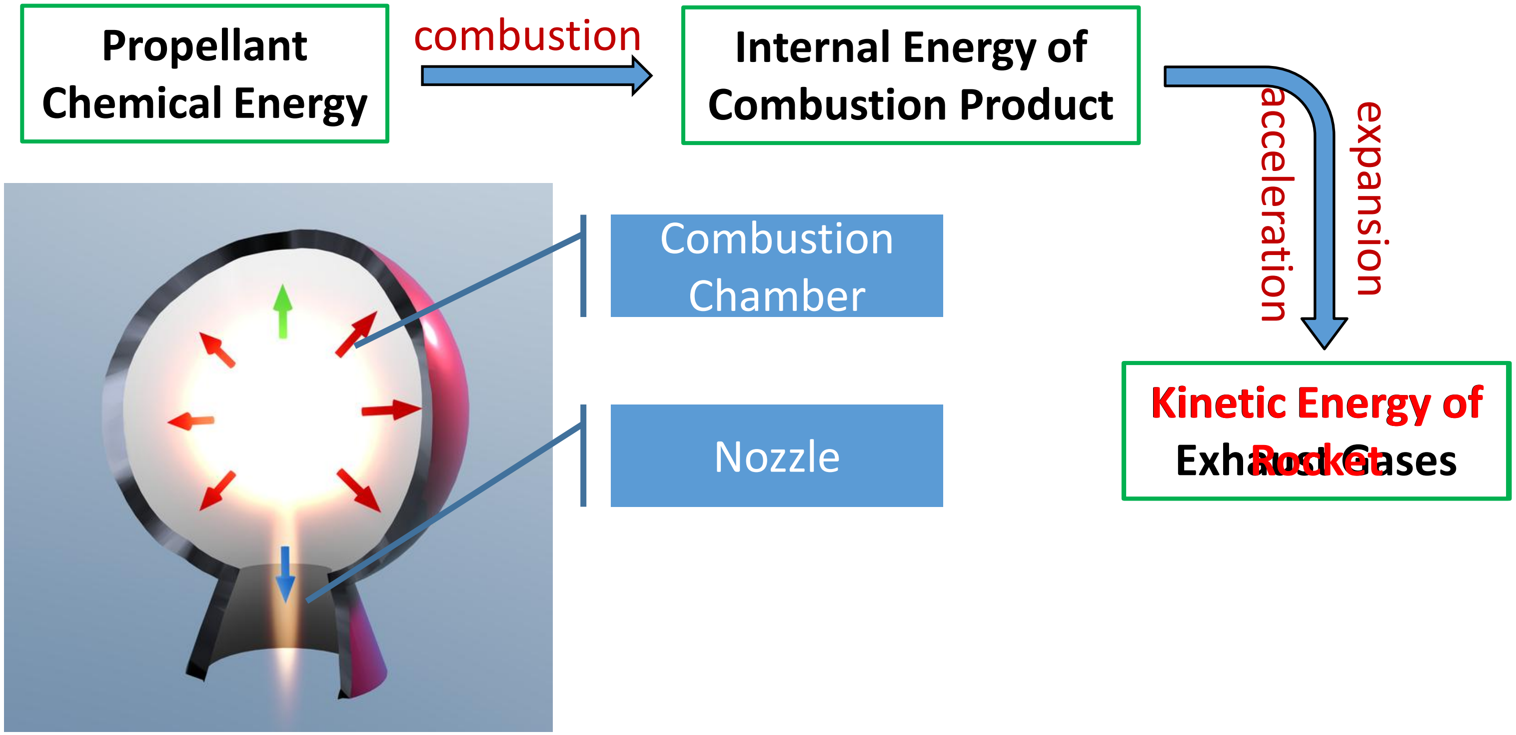
Liquid Rocket Engine( LRE)

Solid Rocket Motor( SRM)

Hybrid Rocket

# Rocket Propulsion

## Working Process of Chemical Rocket Propulsion

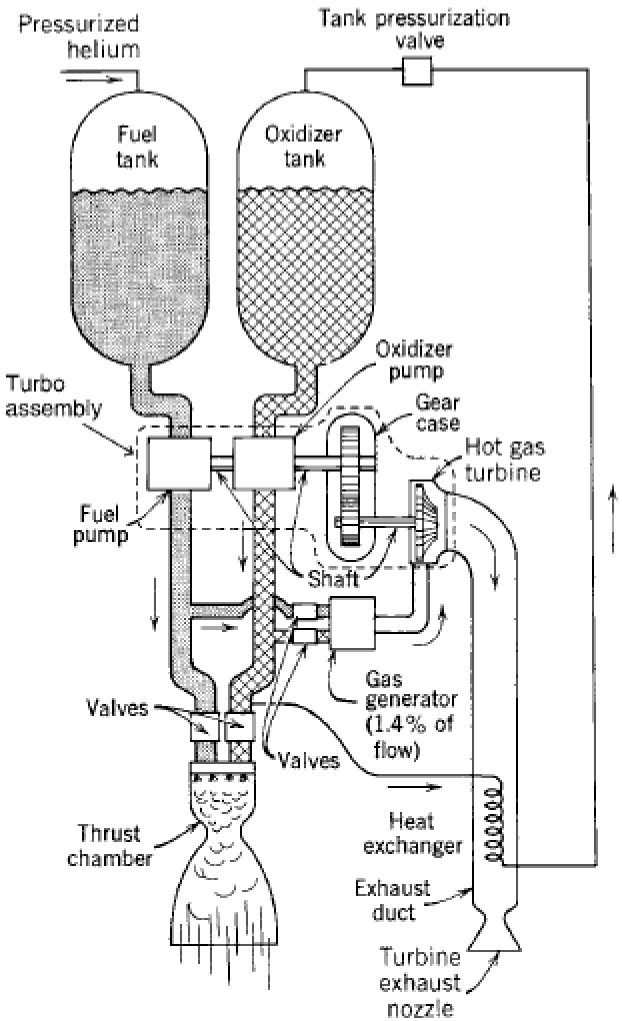


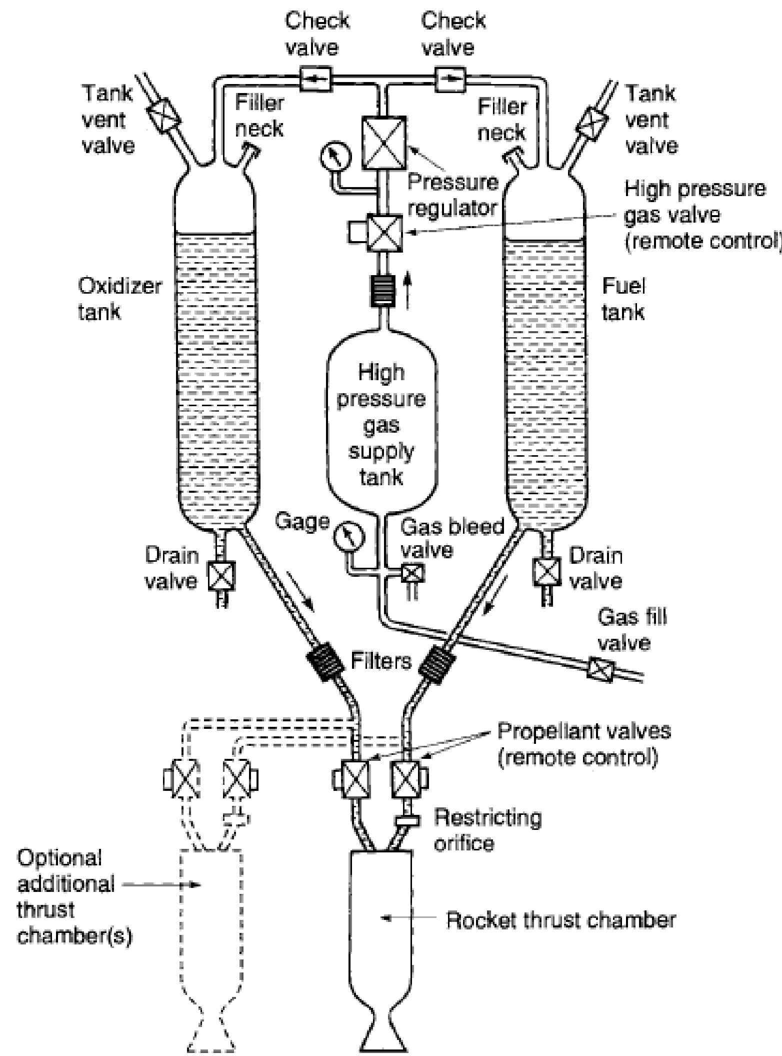

Propellant：

- Chemical energy source
- Working medium（mass）

# Rocket Propulsion

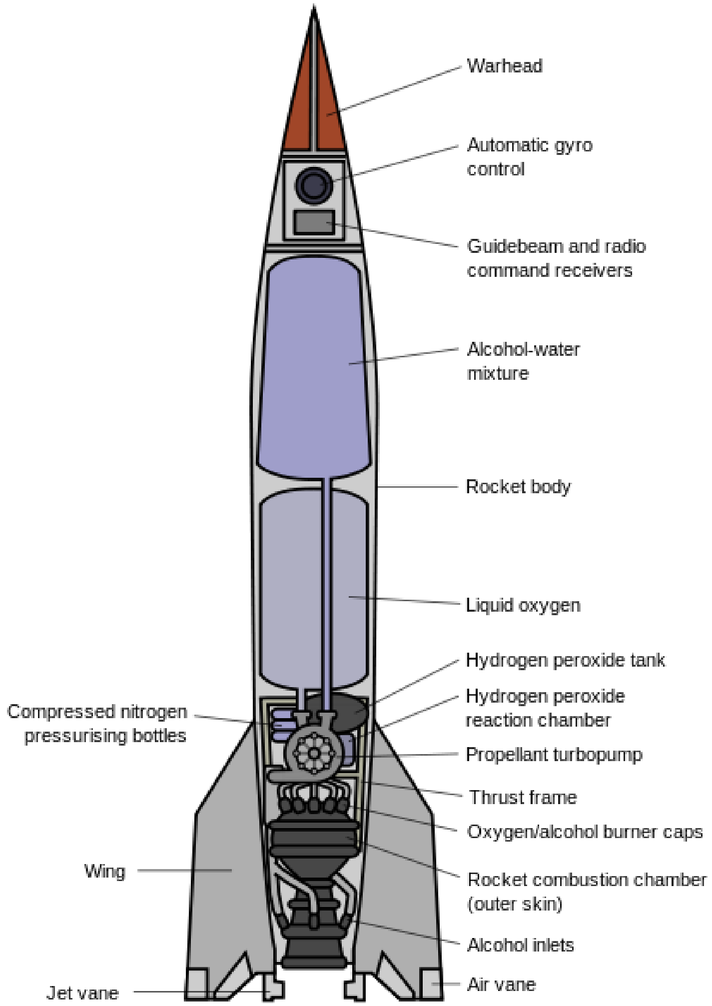
## Liquid Rocket Engine( LRE)



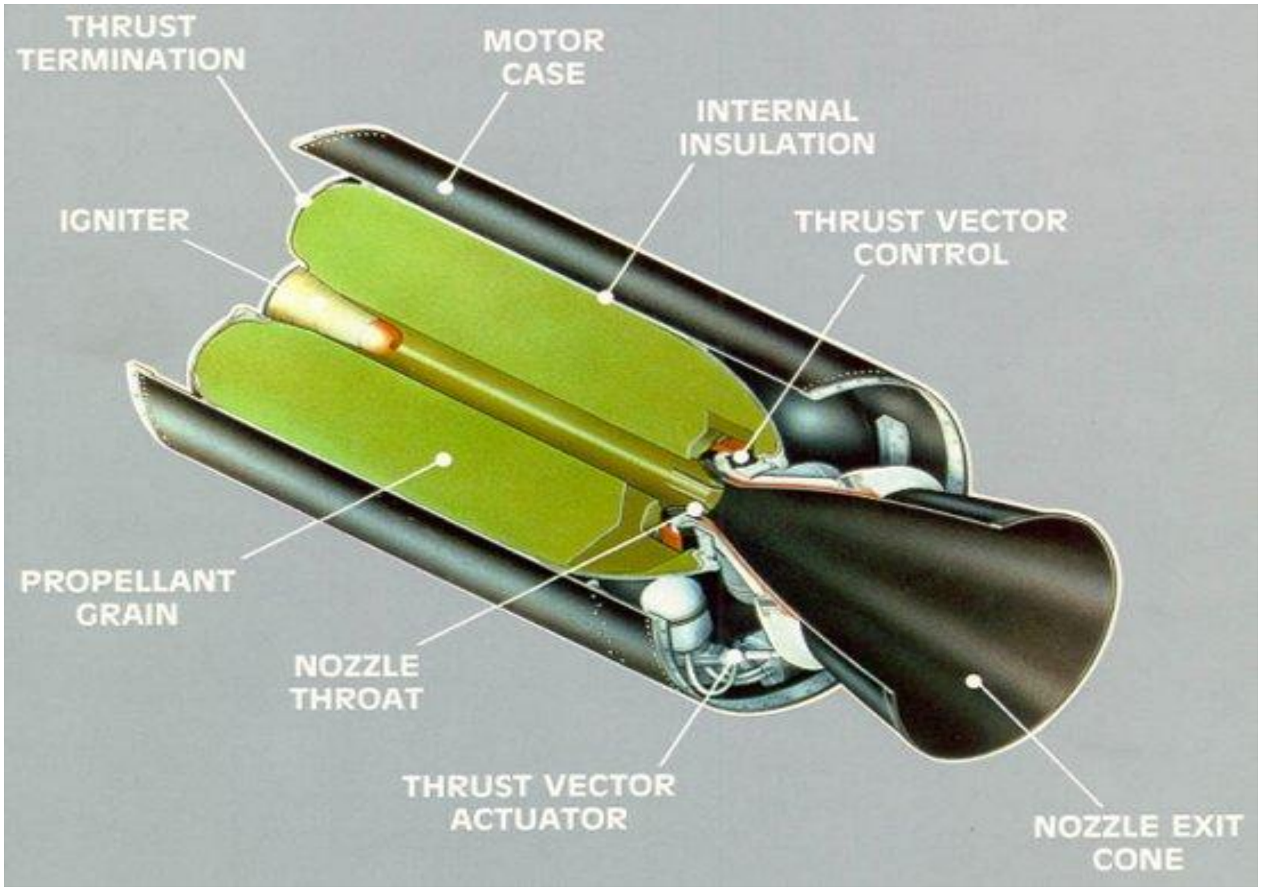
# Rocket Propulsion

Liquid Rocket Engine( LRE)

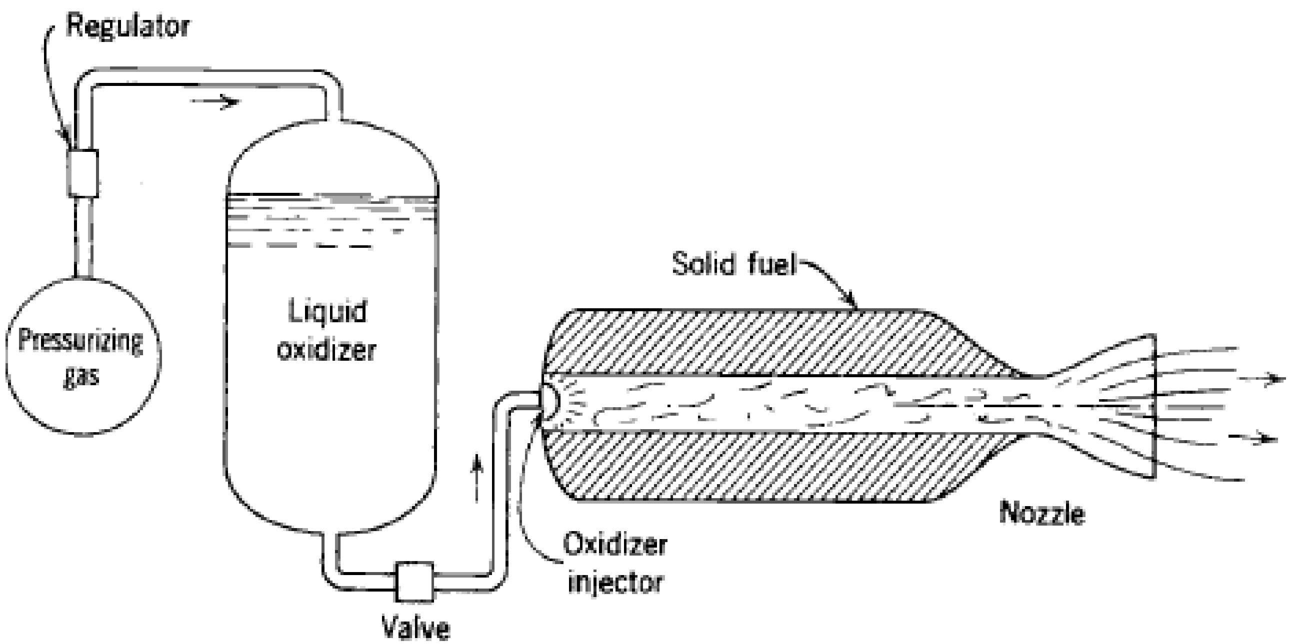
## Rocket Propulsion

Solid Rocket Motor( SRM)



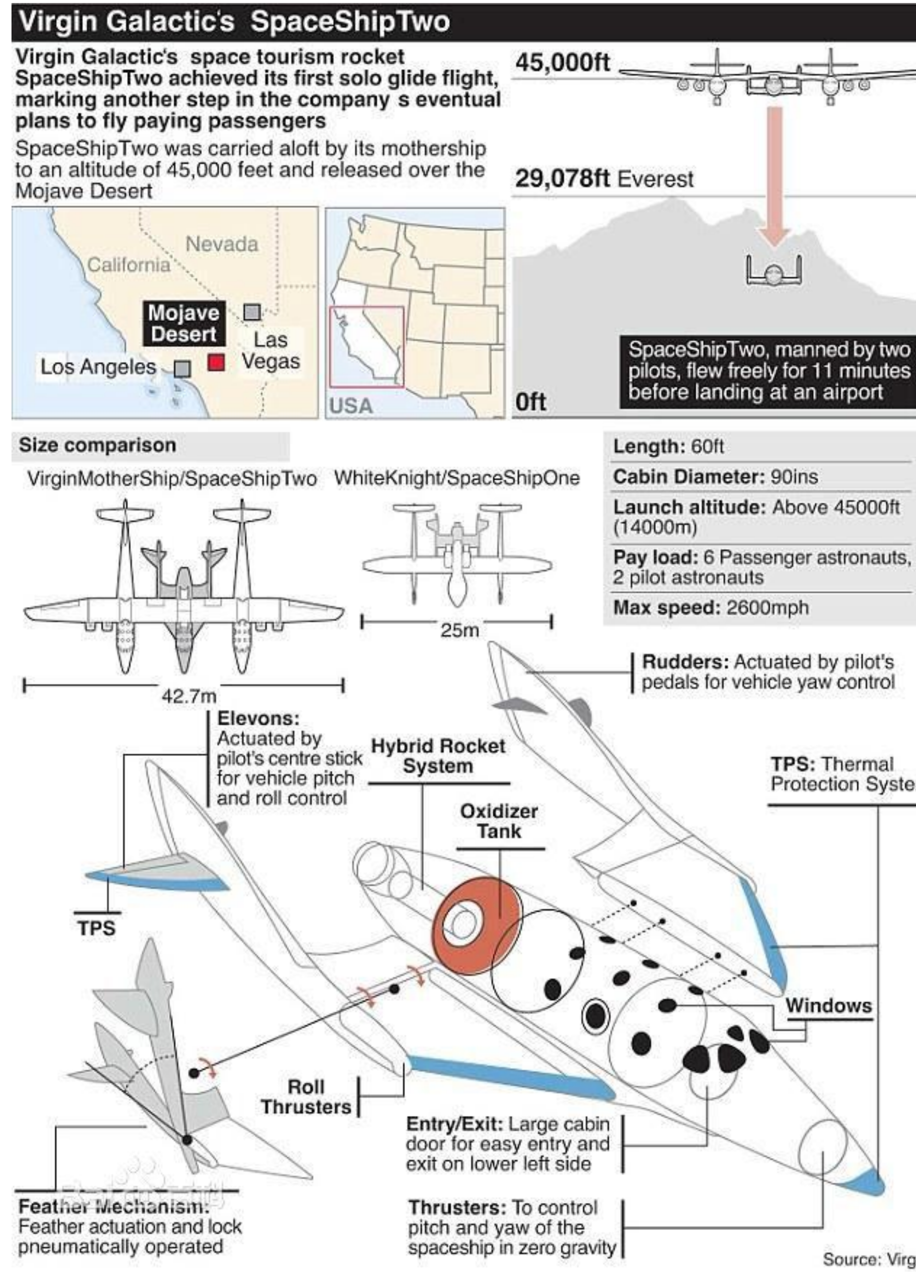
# Rocket Propulsion

Hybrid Rocket



# Rocket Propulsion

## Hybrid Rocket

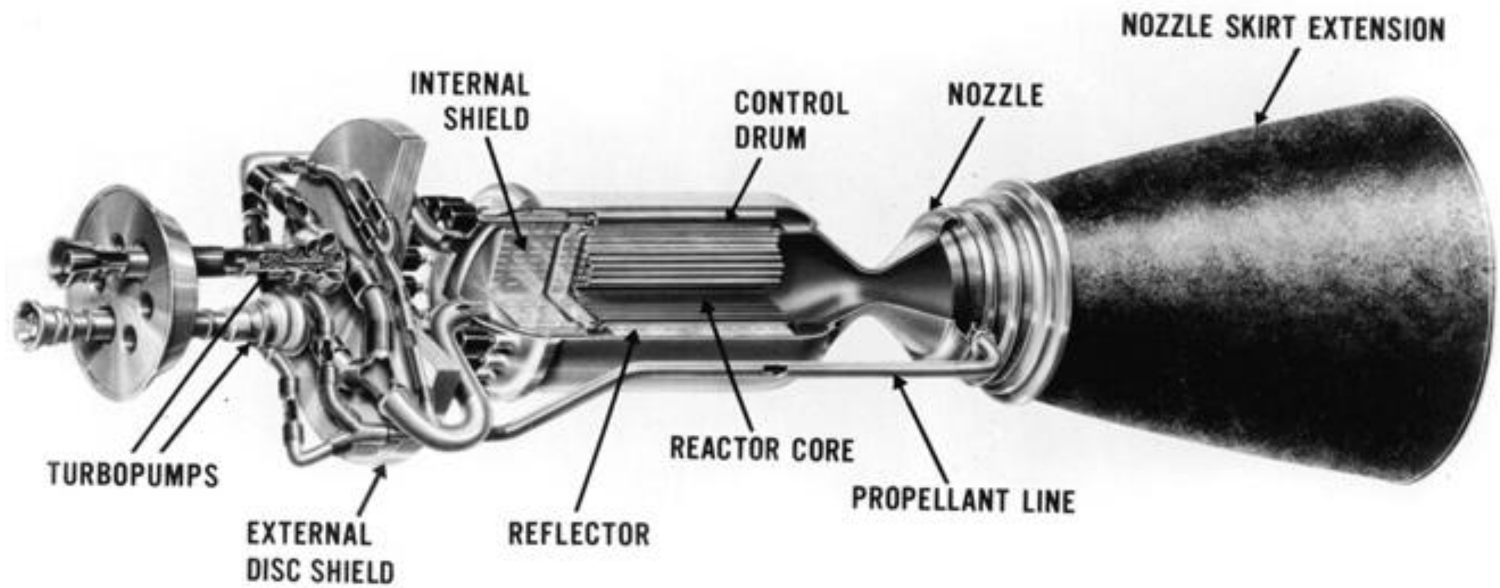


**Jet Propulsion** : reaction force by the momentum of ejected matter

- **Jet Propulsion**
  - **Duct Propulsion**
    Air-breathing
    - Turbojet
    - Turbofan
    - Ramjet
    - Pulsejet
  - **Rocket Propulsion**
    Stored propellant
    - Chemical combustion
    - Solar radiation
    - Nuclear reaction

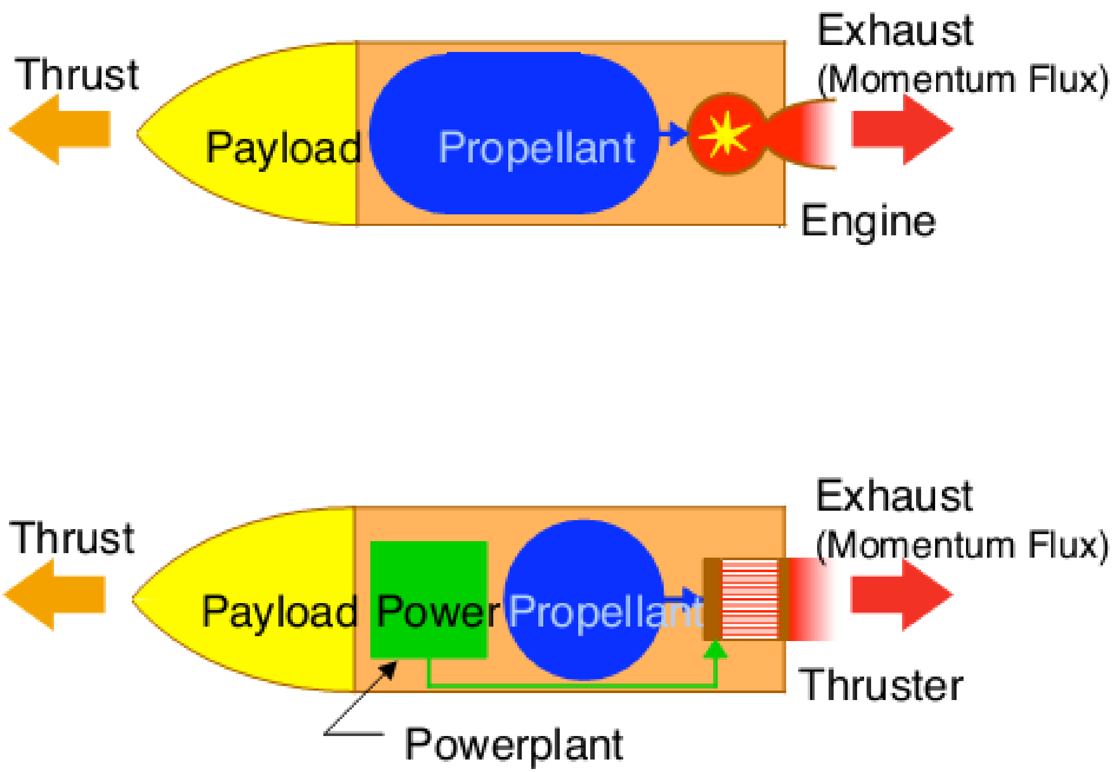
# Rocket Propulsion

Nuclear Rocket



# Rocket Propulsion

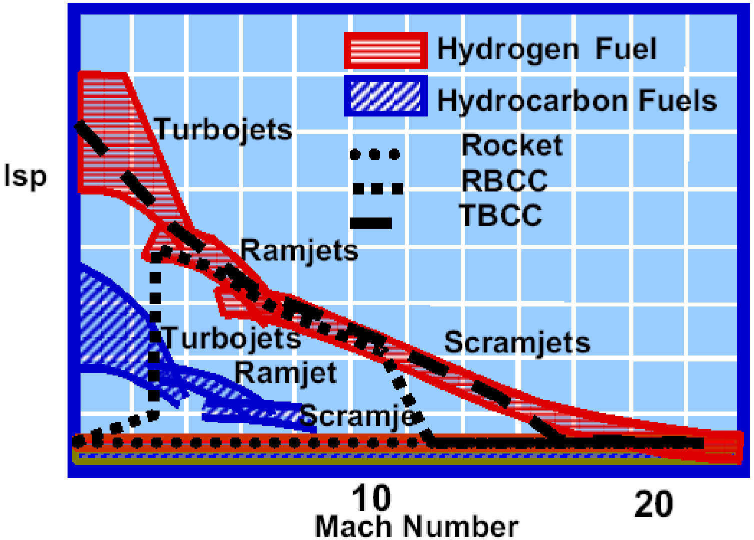
Electric Rocket



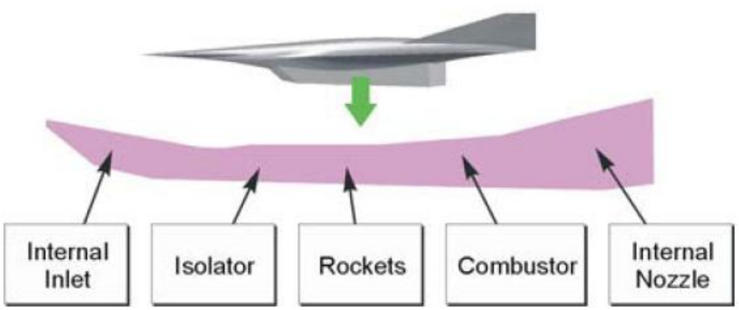
**Jet Propulsion** : reaction force by the momentum of ejected matter

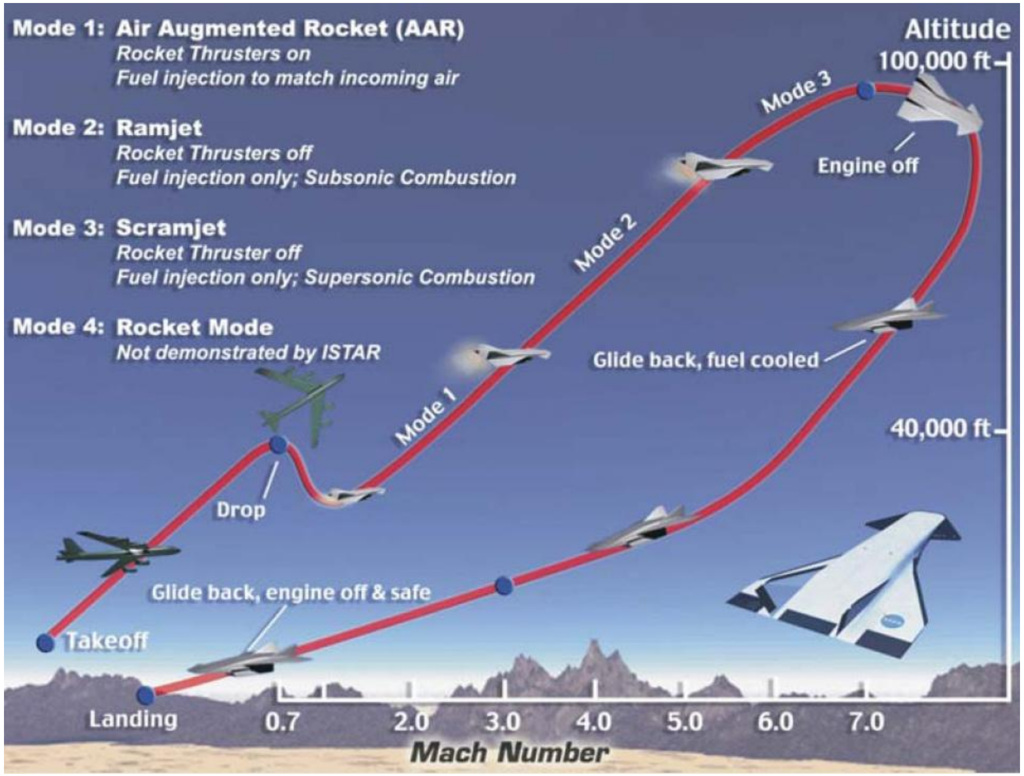
- **Jet Propulsion**
  - **Duct Propulsion**
    Air-breathing
    - Turbojet
    - Turbofan
    - Ramjet
    - Pulsejet
  - **Rocket Propulsion**
    Stored propellant
    - Chemical combustion
    - Solar radiation
    - Nuclear reaction
  - Others RBCC/TBCC
    - Rocket-Based Combined Cycle
    - Turbine-Based Combined Cycle

# RBCC ——a kind of duct jet propulsion




$I_{sp}$: The total impulse per unit weight of propellant

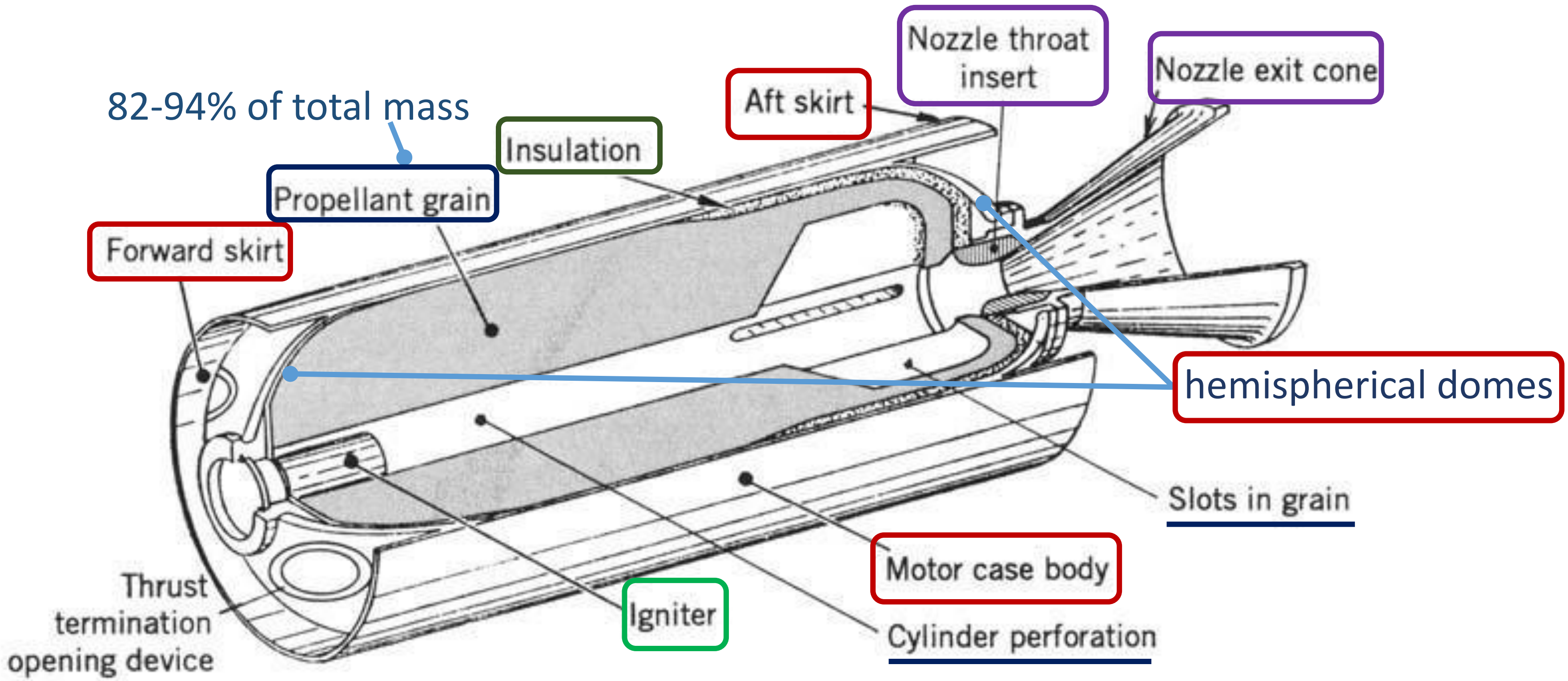


# Solid Rocket Motor

——components and functions

# Solid Rocket Motor

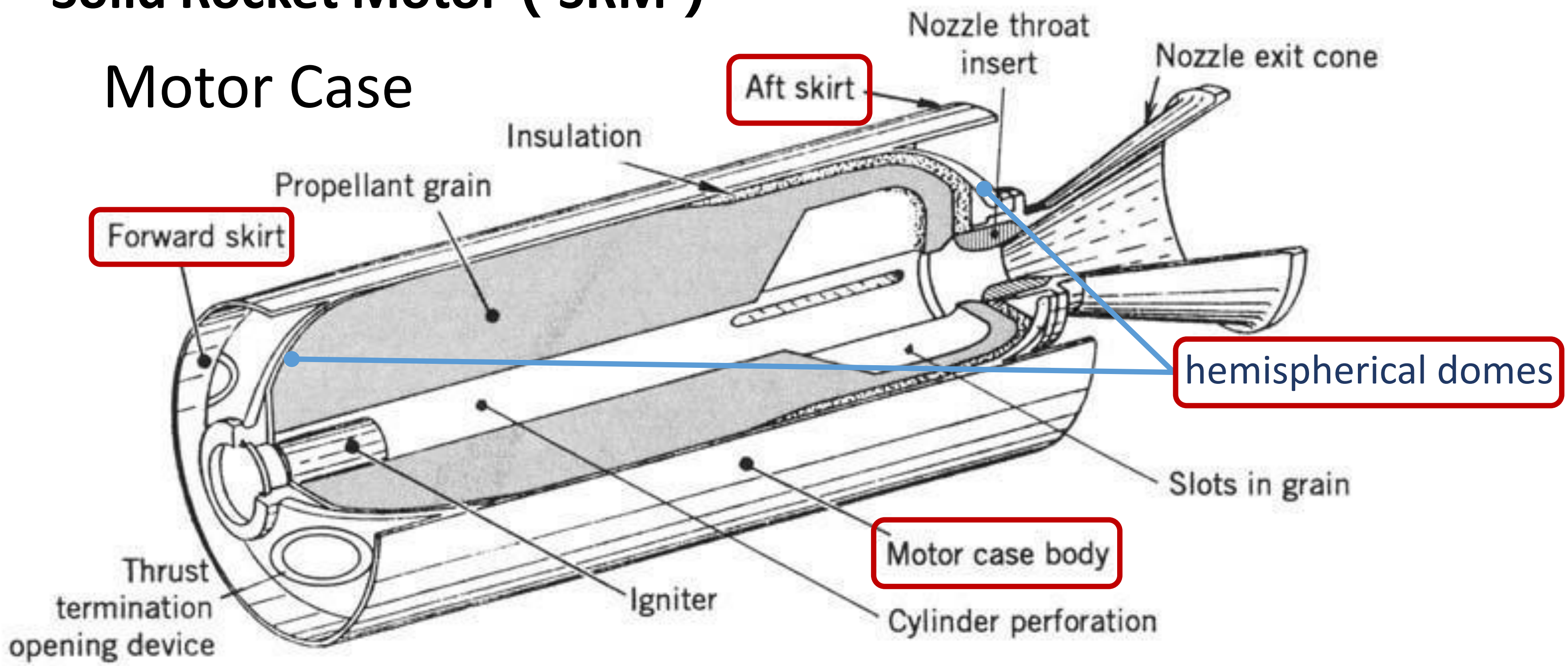



- MOTOR CASE
- INSULATION
- IGNITER
- PROPELLANT GRAIN
- NOZZLE

Typical solid propellant rocket motor

## Solid Rocket Motor（SRM）

### Motor Case




## Functions

- containing the propellant grain
- highly loaded pressure vessel
- primary structure of the missile or launch vehicle

## MOTOR CASE

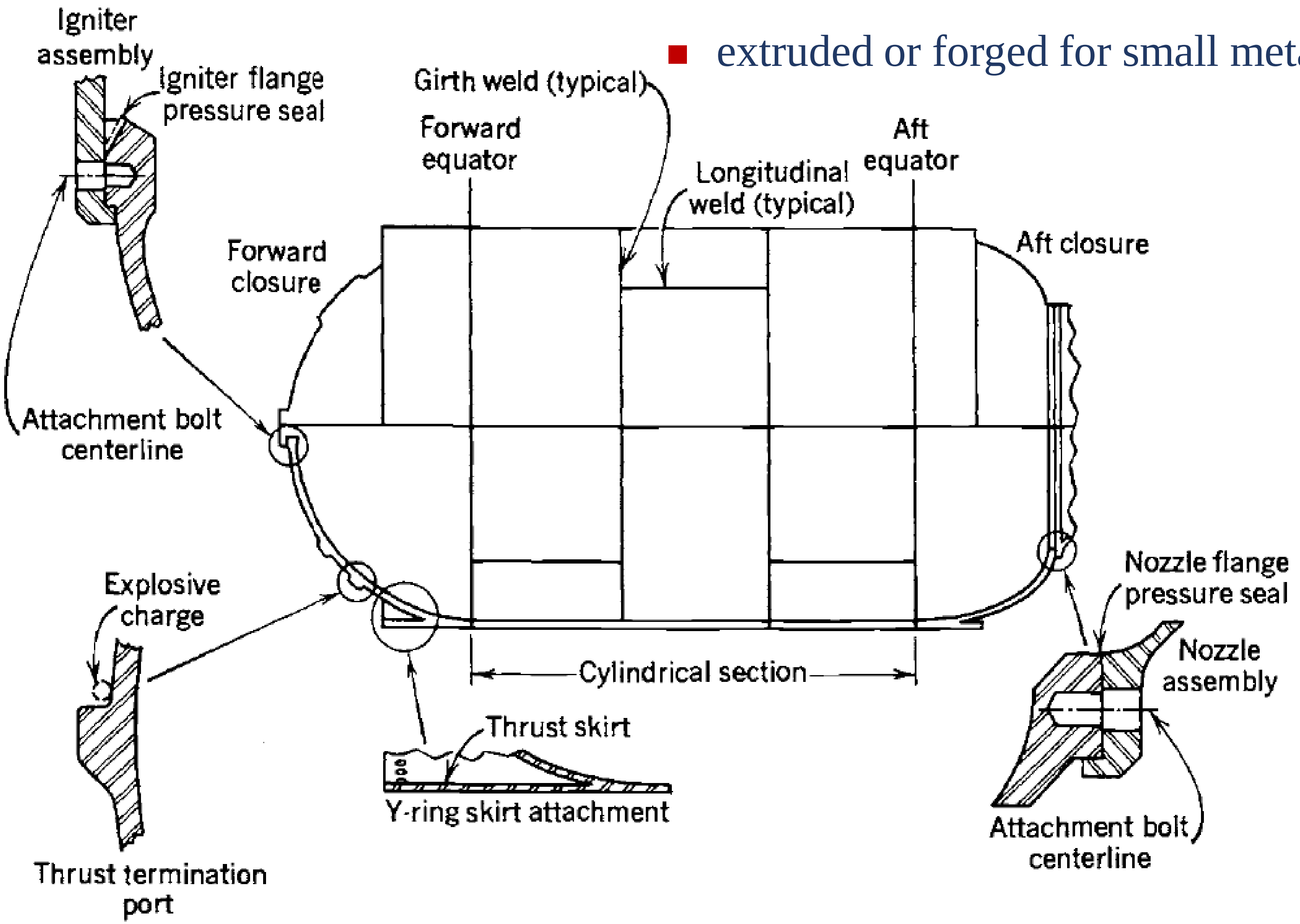
### Metal Cases

***advantages compared to filament-reinforced plastic cases***

- rugged and take considerable rough handling
- reasonably ductile and can yield before failure
- can be heated to a relatively high temperature (700 to 1000°C)
- not deteriorate significantly with time or weather exposure
- easily adapted to take concentrated loads
- Can made in sections for very large and long motors

# MOTOR CASE ——*Metal Cases*

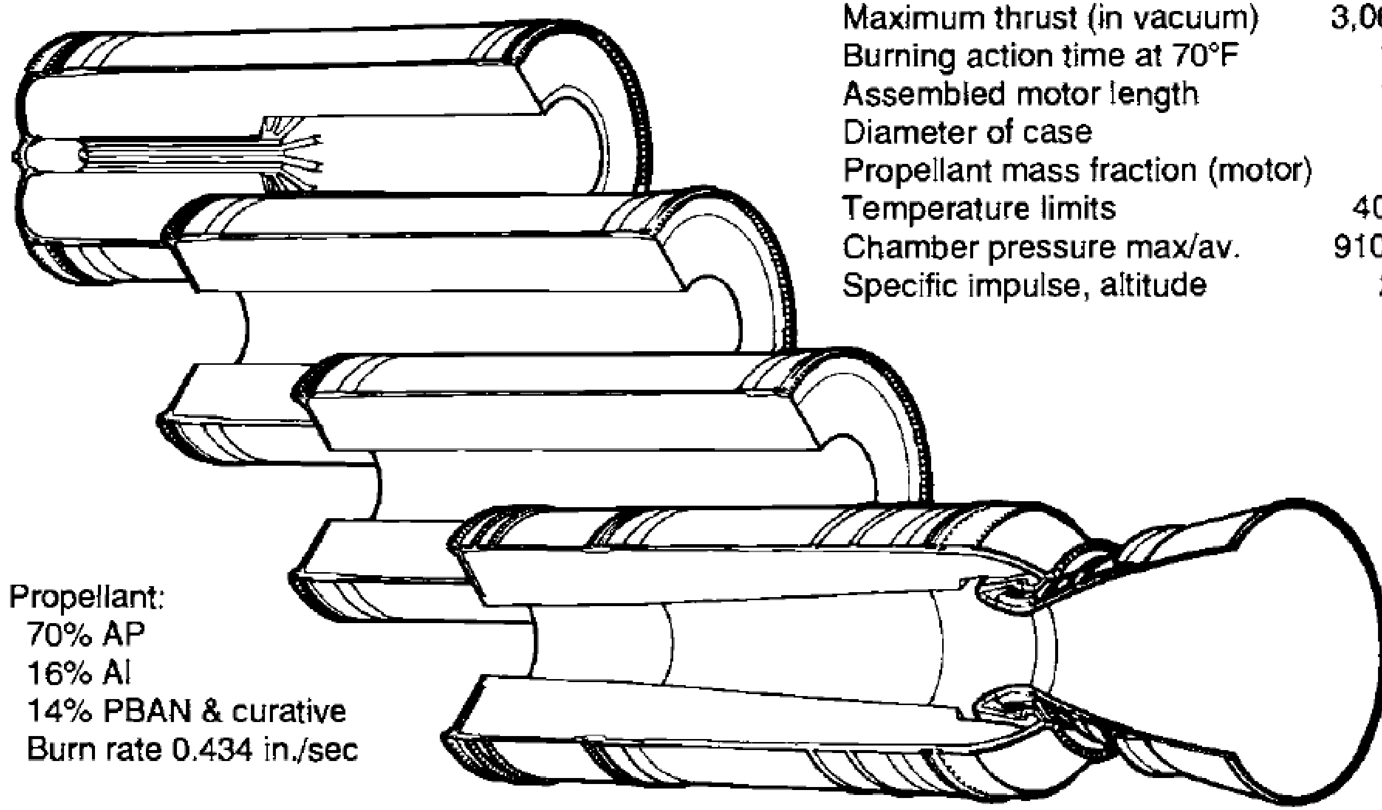
- welded steel for large metal cases
- extruded or forged for small metal cases




***Typical large solid rocket motor case made of welded alloy steel***

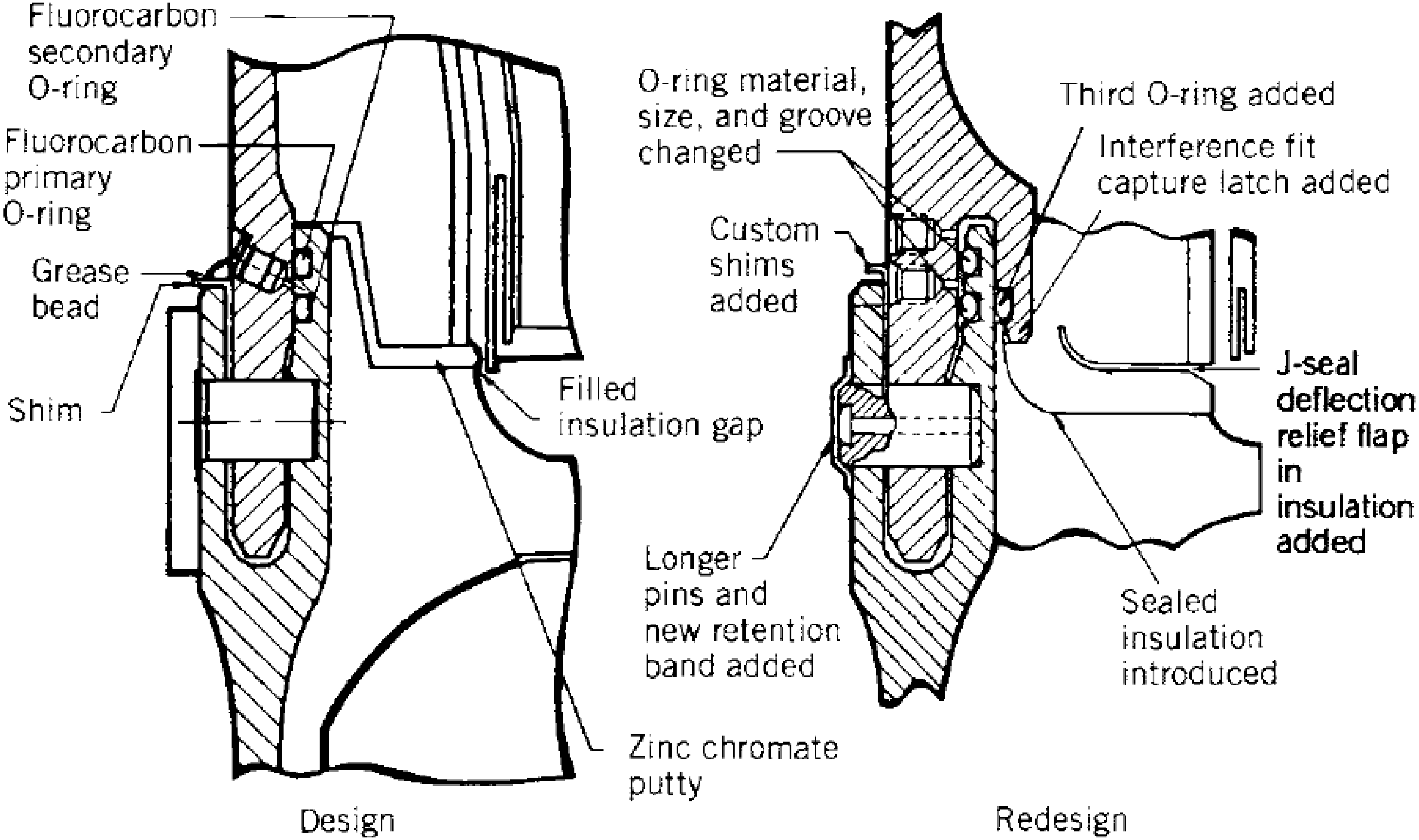
# **MOTOR CASE** ——*Metal Cases*

| | |
|---|---|
| Total propellant weight | 1,106,280 lbf |
| Total RSRM weight | 1,255,592 lbf |
| Maximum thrust (in vacuum) | 3,060,000 lbf |
| Burning action time at 70°F | 123.7 sec |
| Assembled motor length | 1513 inch |
| Diameter of case | 146 inch |
| Propellant mass fraction (motor) | 88.2% |
| Temperature limits | 40 to 120°F |
| Chamber pressure max/av. | 910/662 psia |
| Specific impulse, altitude | 268.2 sec |




*Simplified diagram of the four segments of the Space Shuttle solid rocket motor*

**MOTOR CASE** ——*Metal Cases*




*The joints between segments of the Shuttle solid rocket booster (SRB)*

## MOTOR CASE

# Wound-Filament-Reinforced Plastic Cases

***continuous filaments of strong fibers wound in precise patterns and bonded together with a plastic***

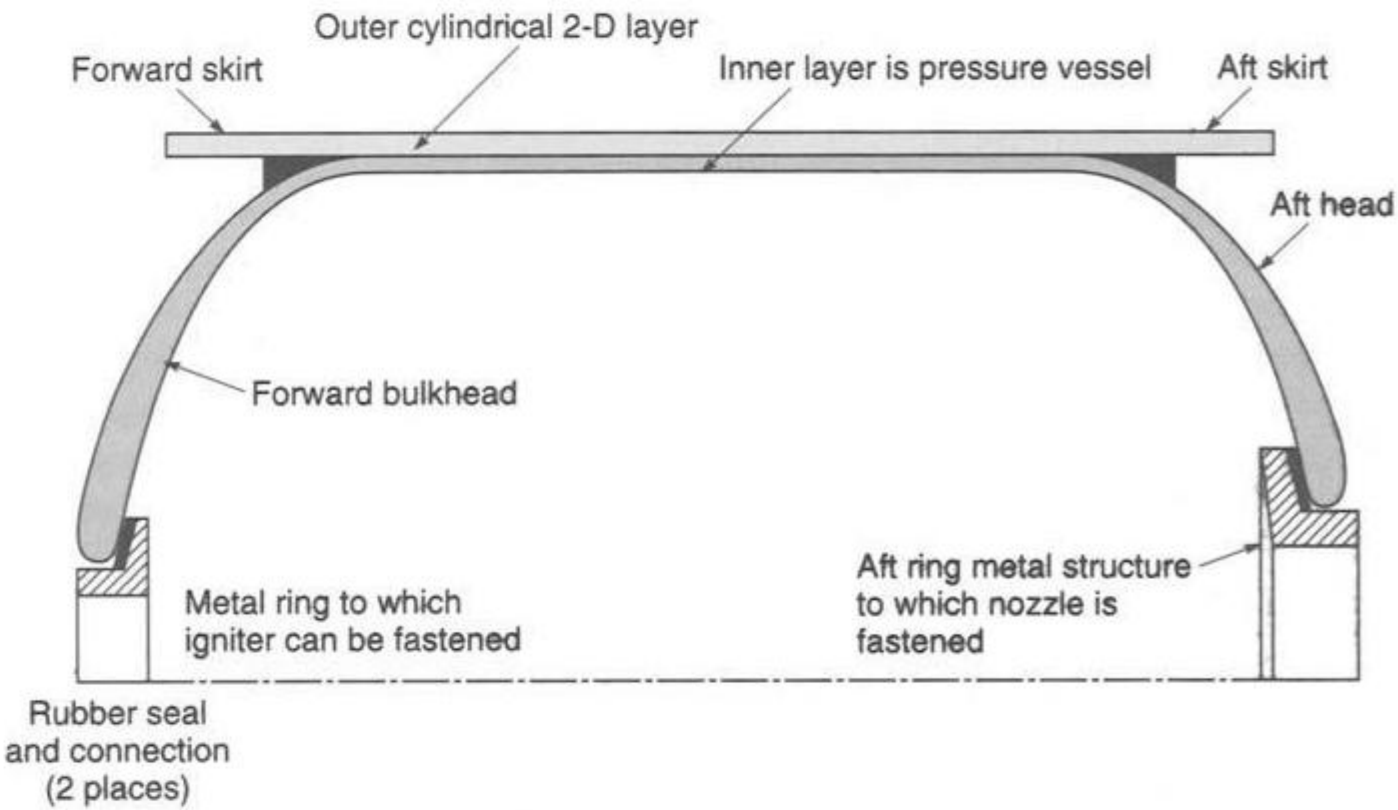
**Fibers:** very high tension 2400 to 6800 Mpa, but can not withstand shear force

**Plastic:** binder/matrix to prevent fibers slipping and weakening in shear or bending

- lower weight
- soften when heated above ~180°C
- need inserts or reinforcements to assemble other components
- thermal expansion higher than metal
- thermal conductivity is much lower

## MOTOR CASE

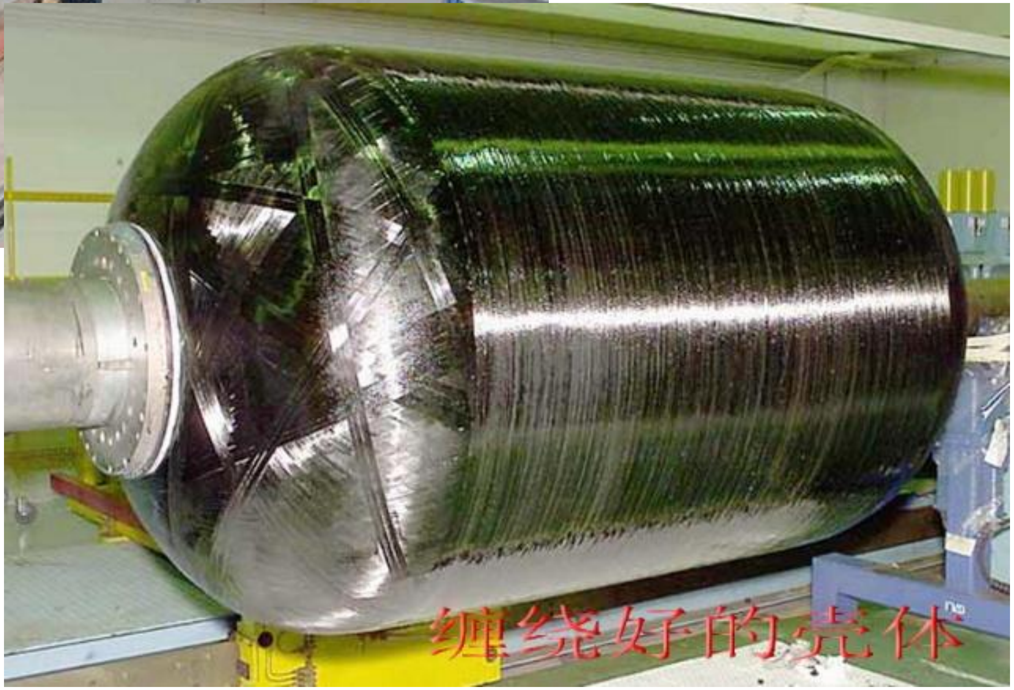
# Wound-Filament-Reinforced Plastic Cases




*typical design of a filament-wound composite material case*

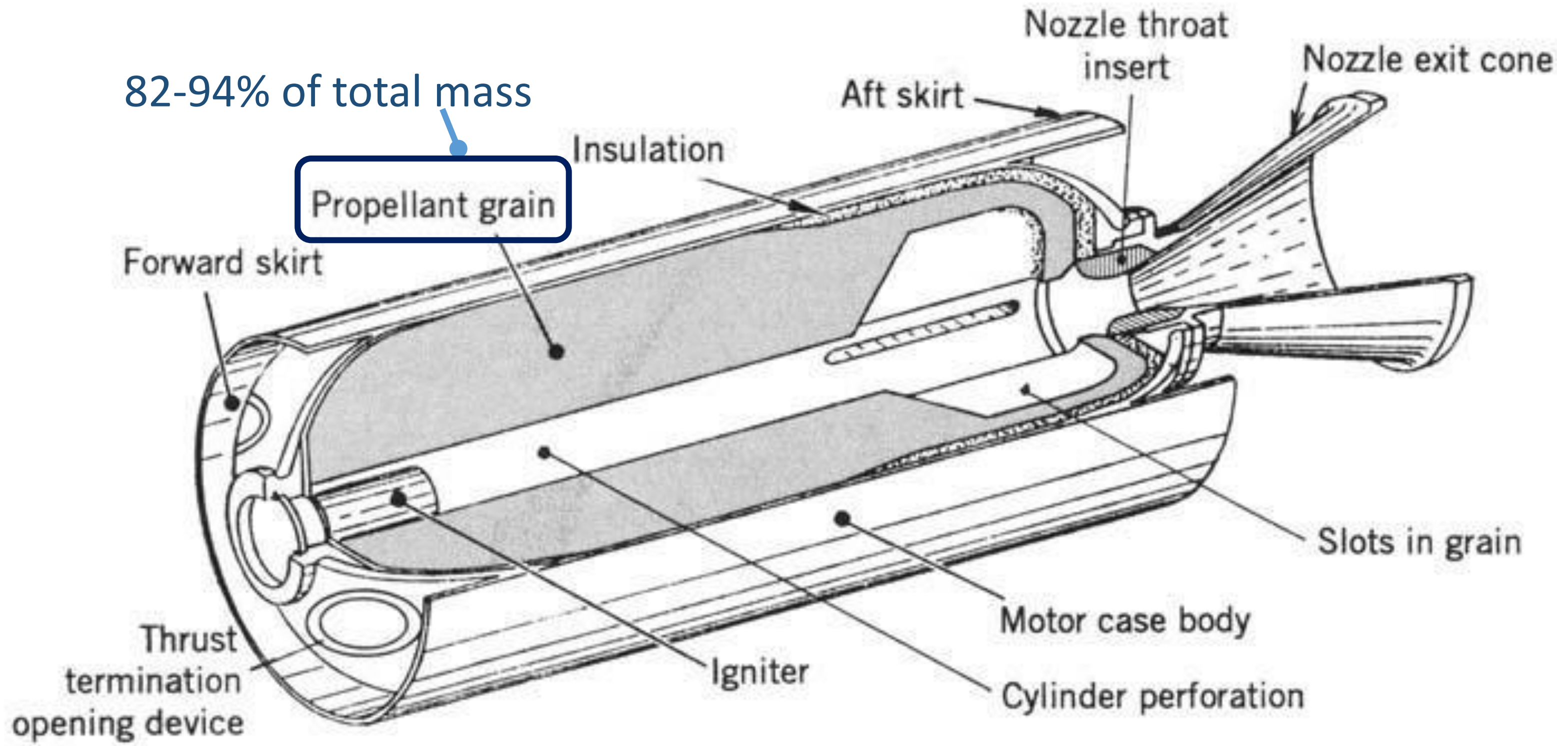
MOTOR CASE

## Wound-Filament-Reinforced Plastic Cases



## Solid Rocket Motor

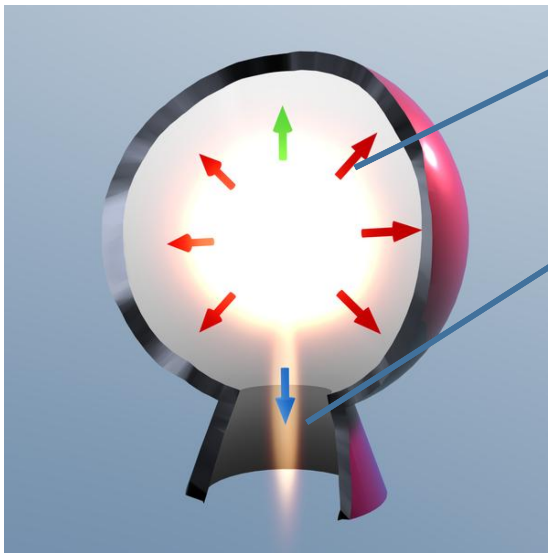
### Propellant grain




Typical solid propellant rocket motor

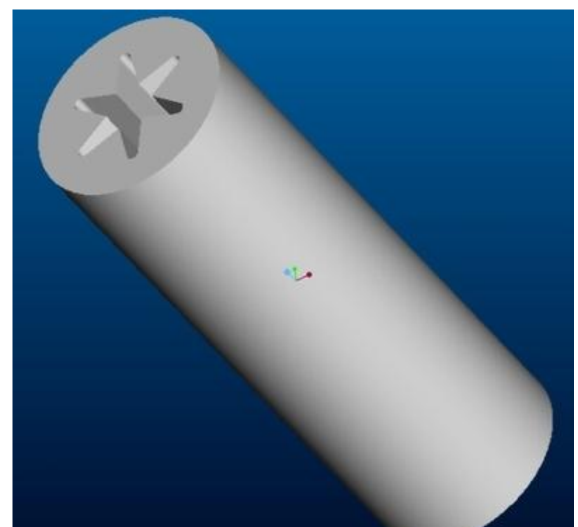
# PROPELLANT GRAIN

**Propellant Chemical Energy** → combustion → **Internal Energy of Combustion Product** → acceleration / expansion → **Kinetic Energy of Exhaust Gases**



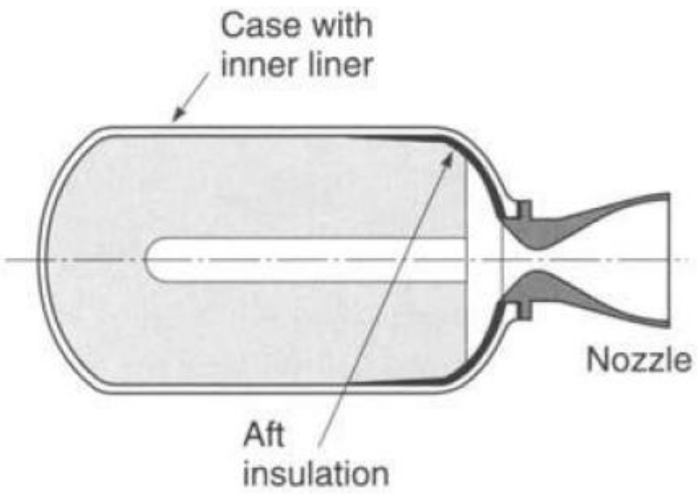

Solid Propellant：

- Chemical energy source
- Working medium（mass）

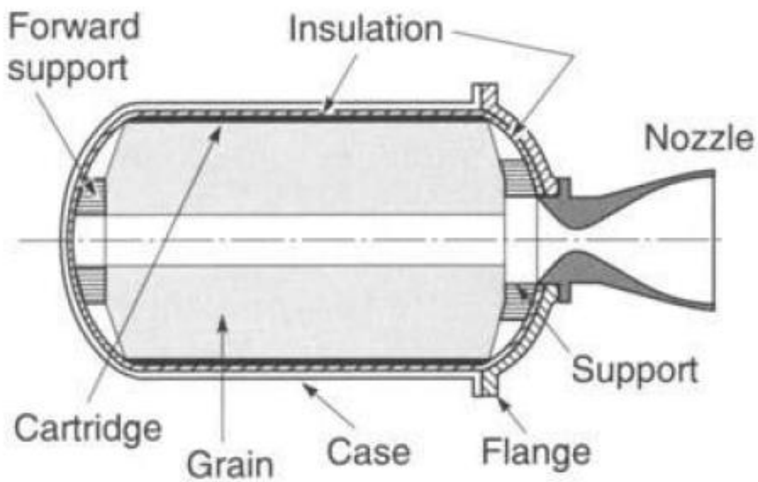


# PROPELLANT GRAIN

- *rubbery or plastic-like mixture of oxidizer, fuel*
- *ingredients that have been processed and constitute the finished grain*
- *the processed but uncured product*
- *single ingredient, such as the fuel or the oxidizer*



Case–bonded grain



Cartridge–loaded grain
(free–standing)

## Solid Propellant ——*classification*

- classified by specific applications
  - space launch booster propellants
  - tactical missile propellants
  - gas generator applications
  - Igniter Propellants
- double-base and composite propellants
  - double-base (DB): *homogeneous propellant*

nitrocellulose (NC) —— ***solid ingredient***

\+

nitroglycerine (NG) —— ***liquid ingredient***

\+

additives ——***crystalline nitramines (HMX or RDX)***

**explosives**

**fuel & oxidizer**

## Solid Propellant ——*classification*

- double-base and composite propellants
  - double-base (DB): *homogeneous propellant*

nitrocellulose (NC)

+

nitroglycerine (NG)

+

additives

extruded DB

cast DB

+

crystalline nitramines (HMX or RDX)

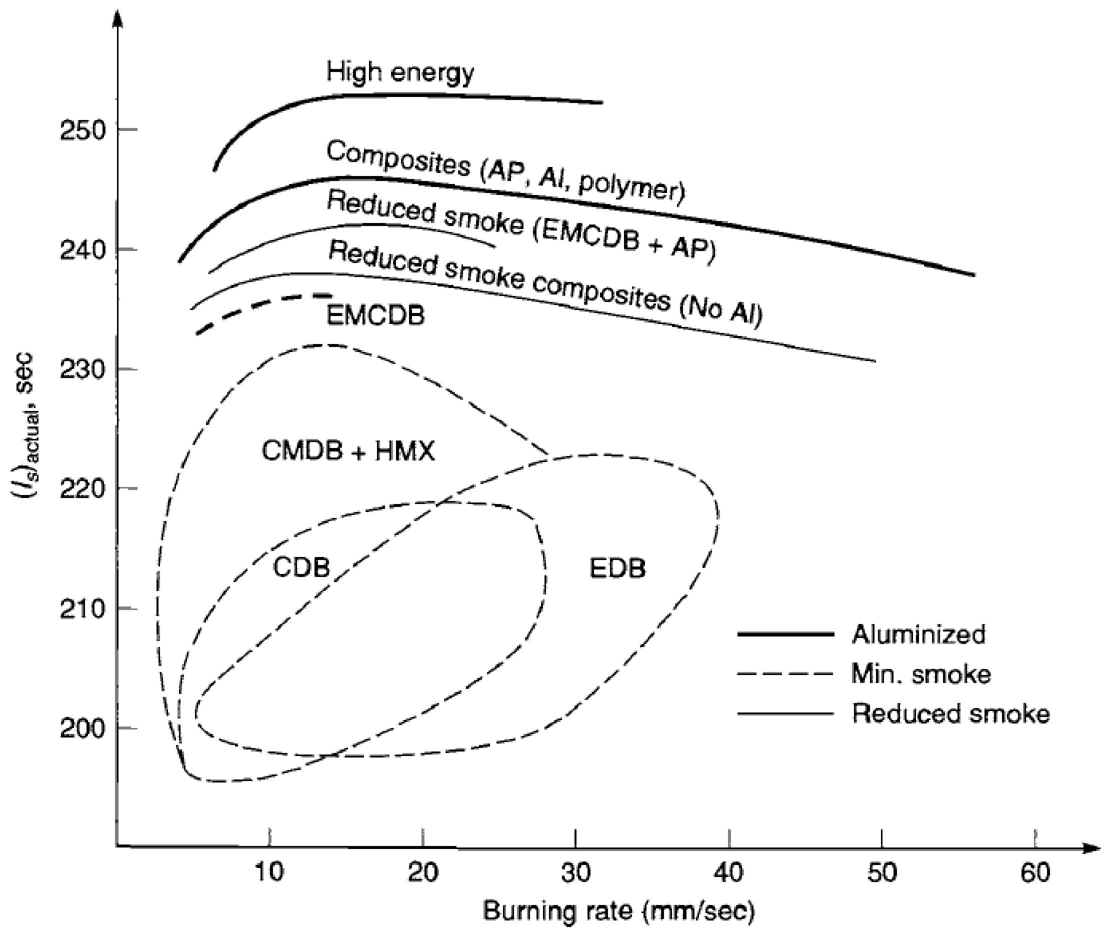
modified DB

+

ammonium perchlorate (AP) and aluminum (Al)

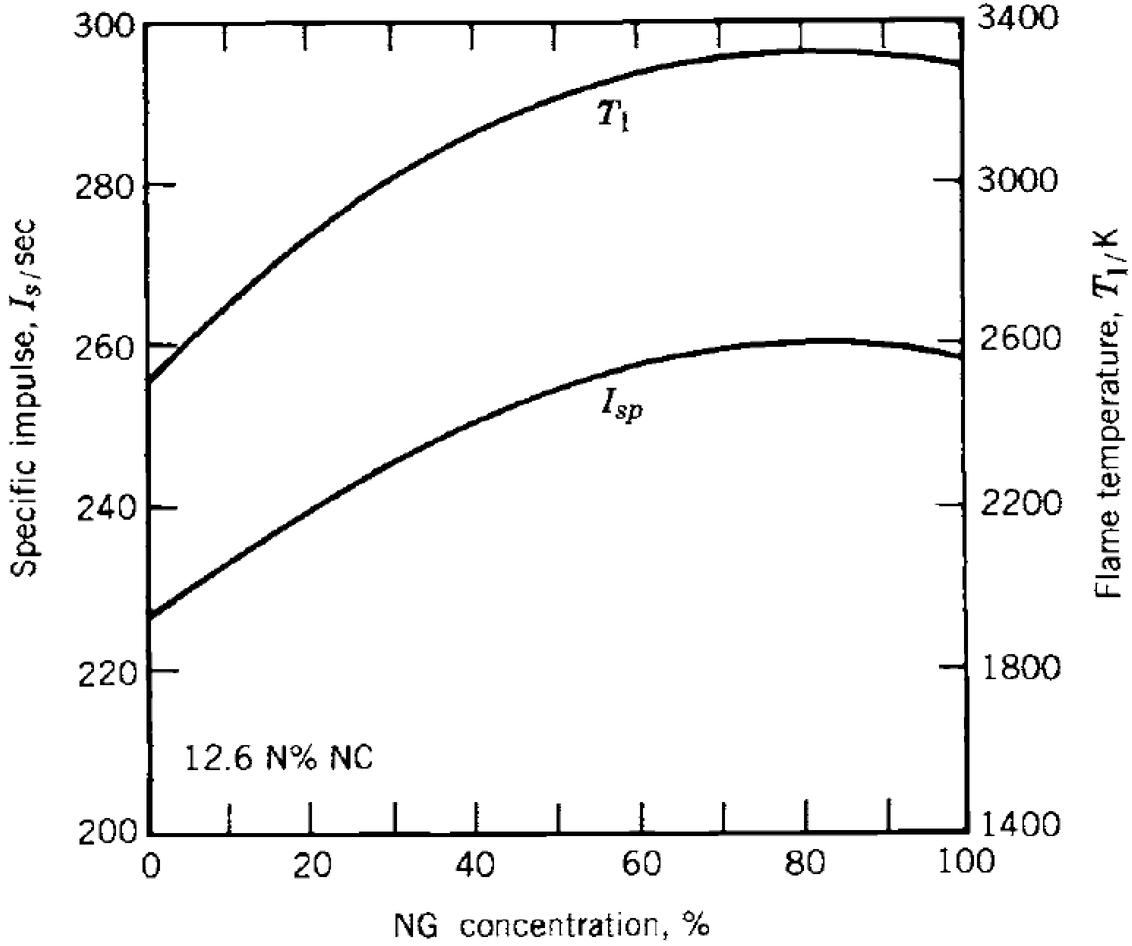
composite modified DB

# Solid Propellant




*Estimated actual specific impulse and burning rate of DB propellant*

## Solid Propellant




***Specific impulse and flame temperature versus nitroglycerine (NG) concentration***

## Solid Propellant ——*classification*

- double-base and composite propellants
  - Composite propellants: *heterogeneous propellant*

oxidizer crystal ——***ammonium perchlorate (AP)***

+

powdered fuel ——***aluminum (Al)***

+

matrix/binder ——***synthetic rubber (or plastic)***

- *Conventional composite propellant*

  ***- AP 60-72%, Al <22%, binder 8-16%***

- *Modified composite propellant*

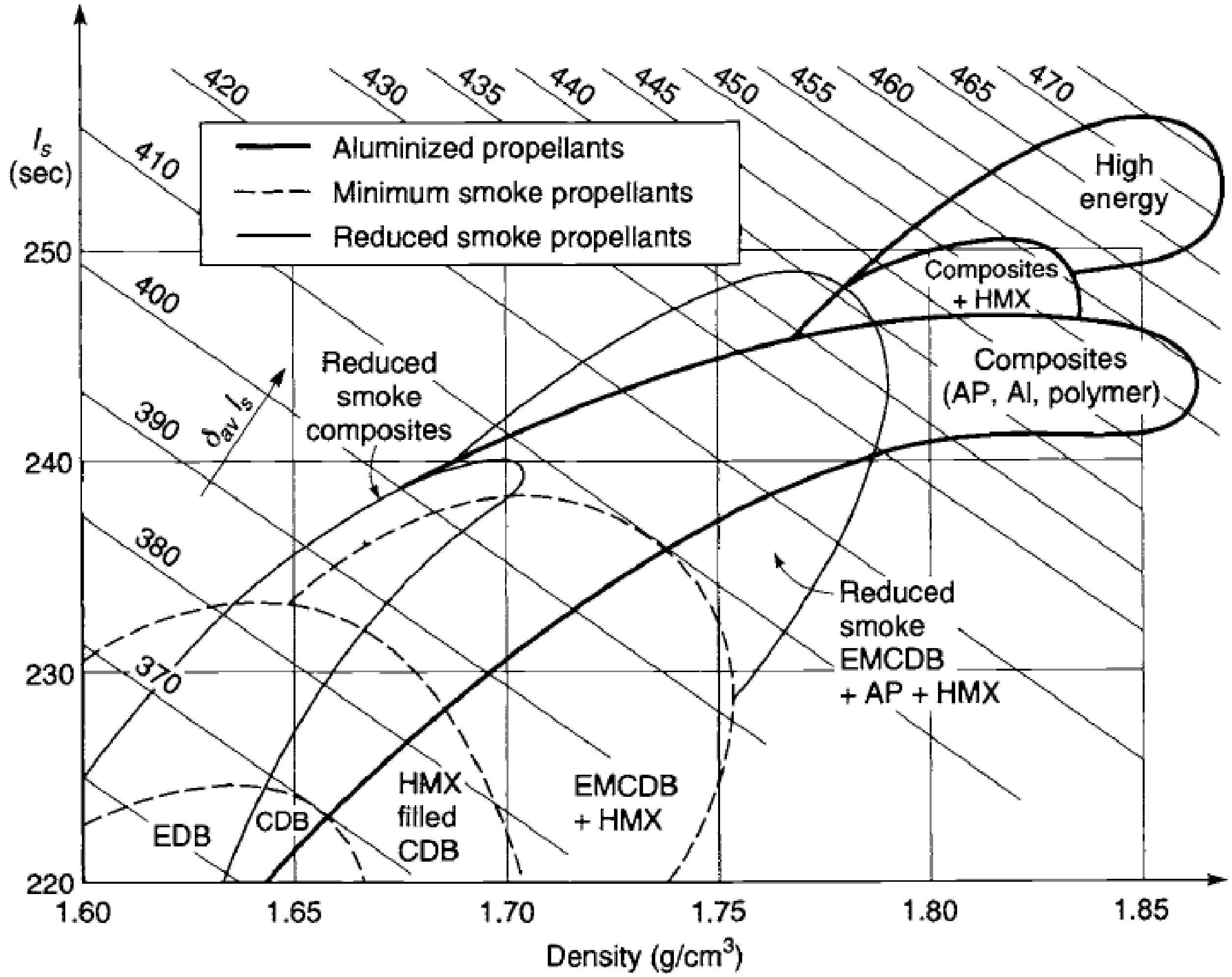
  ***- energetic nitramine (HMX or RDX)***

  ***- energetic plasticizer (NG)***

## Solid Propellant ——*classification*

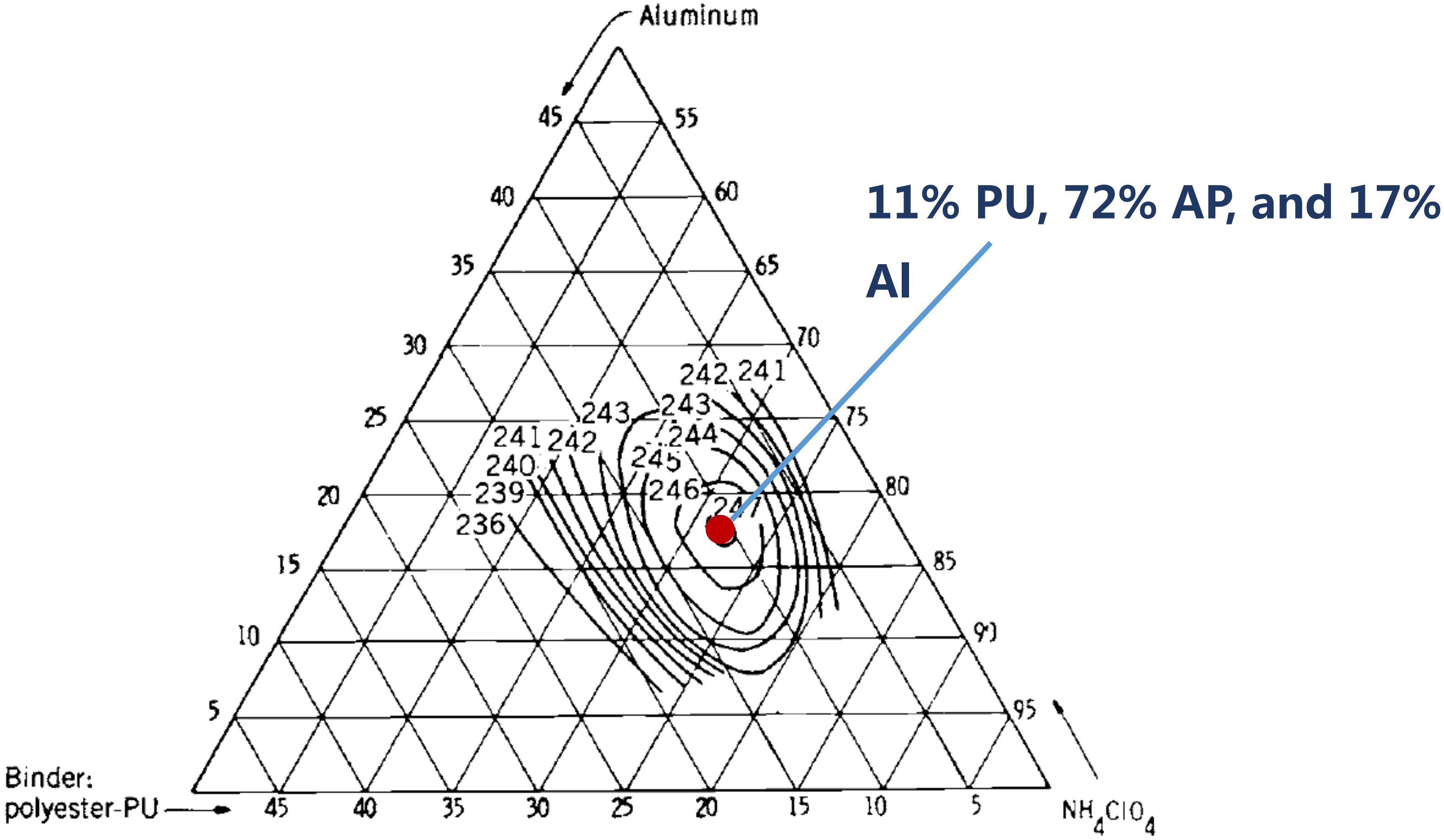
- double-base and composite propellants
  - Composite propellants*: heterogeneous propellant*
    - *Conventional composite propellant*
      - ***- AP 60-72%, Al <22%, binder 8-16%***
    - *Modified composite propellant*
      - ***- energetic nitramine (HMX or RDX)***
      - ***- energetic plasticizer (NG)***
    - *high-energy composite solid propellant*
      - ***- energetic materials replace organic binder***
      - ***- HMX replace AP***
    - *lower-energy composite propellant*
      - ***- ammonium nitrate（AN）as oxidizer crystal***

## Solid Propellant ——*classification*




*Estimated actual specific impulse and specific gravity of composite propellant*

## Solid Propellant ——*classification*




*specific impulse for an ammonium perchlorate-aluminum-polyurethane*

## Solid Propellant ——*classification*

- smoke density of the in the exhaust plume
  - smoky, reduced smoke, or minimum smoke
- safety rating for detonation
  - detonable material or as a nondetonable material
- manufacturing processes
  - cast propellant or extruded propellant
- principal ingredien
  - principal oxidizer/fuel/ binder
- toxic and nontoxic

## PROPELLANT CHARACTERISTICS

——*desirable propellant characteristics*

- High performance/high specific impulse
  - high gas temperature and/or low molecular mass
- Predictable, reproducible, and initially adjustable burning rate
  - fitting the grain design and the thrust-time requirement
- small burning rate exponent and the temperature coefficient
  - minimum variation in thrust or chamber pressure

$$r = a p_1^n$$

$p_1$ : chamber pressure in MPa

$a$ : temperature coefficient

$n$ : burning rate exponent or *combustion index*

## PROPELLANT CHARACTERISTICS

——*desirable propellant characteristics*

- physical properties
  - adequate strength over operating temperature range
- High density：allows a small-volume motor
- Predictable, reproducible ignition qualities
  - reasonable ignition overpressure
- Good aging characteristics and long life
- Low absorption of moisture
- availability of all raw materials and purchased components
- Low technical risk
- Non-toxic exhaust gases
- Not prone to combustion instability

## PROPELLANT INGREDIENTS

*—— more than 200 ingredients have been tried*

MAJOR FUNCTION

- Oxidizer
- Fuel
- Binder
- Plasticizer
- curing agent
- …

*seen in Table 12-7 on Page 496-497*

### ■ Inorganic Oxidizers

- Ammonium Perchlorate ($NH_4ClO_4$)

  *good compatibility with other ingredients*
  *good performance, quality ,uniformity, and availability*

- inorganic nitrates: Ammonium Nitrate/potassium nitrate

  *low-performance*
  *low-cost, low burning rate, smokeless, relatively nontoxic*

## PROPELLANT INGREDIENTS

- Inorganic Oxidizers

| Oxidizer | Chemical Symbol | Molecular Mass (kg/kg-mol) | Density ($kg/m^3$) | Oxygen Content (wt %) | Remarks |
|---|---|---|---|---|---|
| Ammonium perchlorate | $NH_4ClO_4$ | 117.49 | 1949 | 54.5 | Low $n$, low cost, readily available |
| Potassium perchlorate | $KClO_4$ | 138.55 | 2519 | 46.2 | Low burning rate, medium performance |
| Sodium perchlorate | $NaClO_4$ | 122.44 | 2018 | 52.3 | Hygroscopic, high performance |
| Ammonium nitrate | $NH_4NO_3$ | 80.0 | 1730 | 60.0 | Smokeless, medium performance |
| Potassium nitrate | $KNO_3$ | 101.10 | 2109 | 47.5 | Low cost, low performance |

## PROPELLANT INGREDIENTS

- Fuels
  - Powdered spherical aluminum

    *small spherical particles (5 to 60μm)* AP: ~600μm

    *composite and composite-modified DB propellant*

    *usually constituting 14 to 20% by weight*

    *oxidized into aluminum oxide in combustion*

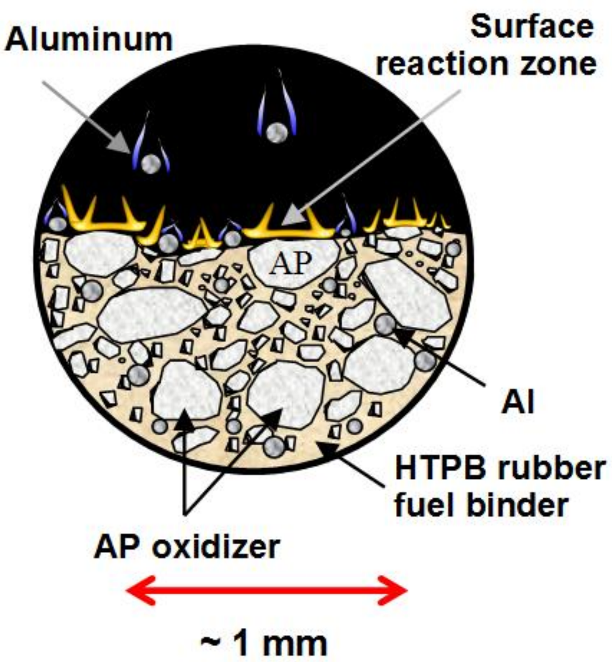
  - Boron

    *high-energy and high melting point (2304℃)*

    *lighter than aluminum*

    *difficult to burn*

    *used in rocket-air-burning engines*



## PROPELLANT INGREDIENTS

- Fuels
  - Powdered spherical aluminum
  - Boron
  - Beryllium

    *burns much more easily than boron*
    *improves specific impulse by about 15 sec*
    *oxide are highly toxic*

  - aluminum hydride (AlH3) and beryllium hydride (BeH2)

    *high heat release and*
    *gas-volume contribution*
    *Specific impulse gains 10 to 15 sec for $AlH_3$ and 25 to 30 sec for $BeH_2$*
    *difficult to manufacture*
    *deteriorate chemically during storage*

## PROPELLANT INGREDIENTS

- Binders *provides the structural glue or matrix*
- Burning-Rate Modifiers *accelerate or decelerate the combustion*
- Plasticizers *low-viscosity liquid, to improve the elongation and processing properties*
- Curing Agents or Crosslinkers
- Energetic Binders and Plasticizers
- Organic Oxidizers or Explosives
- Additives

# PROPELLANT PROCESSING AND MANUFACTURE

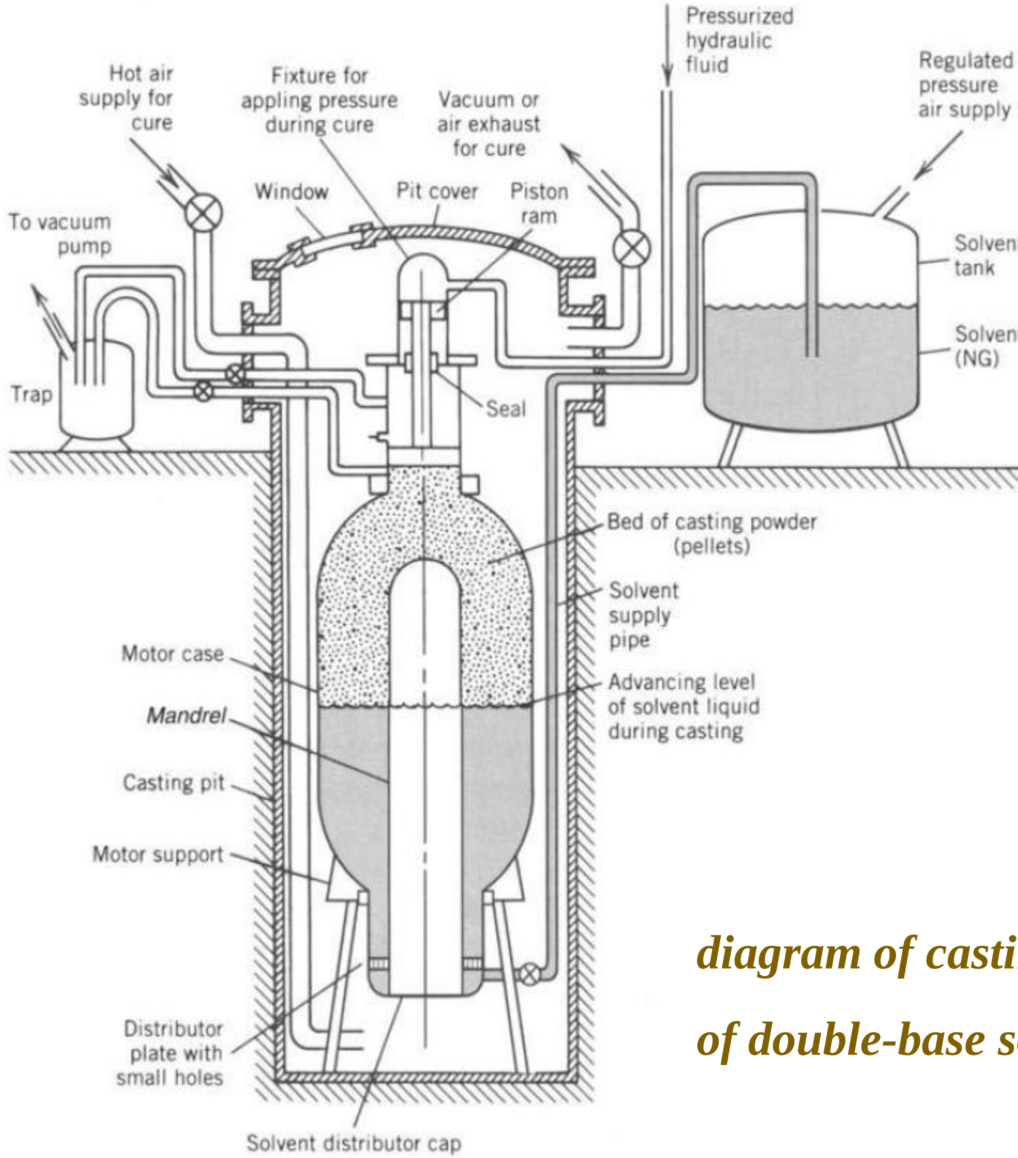
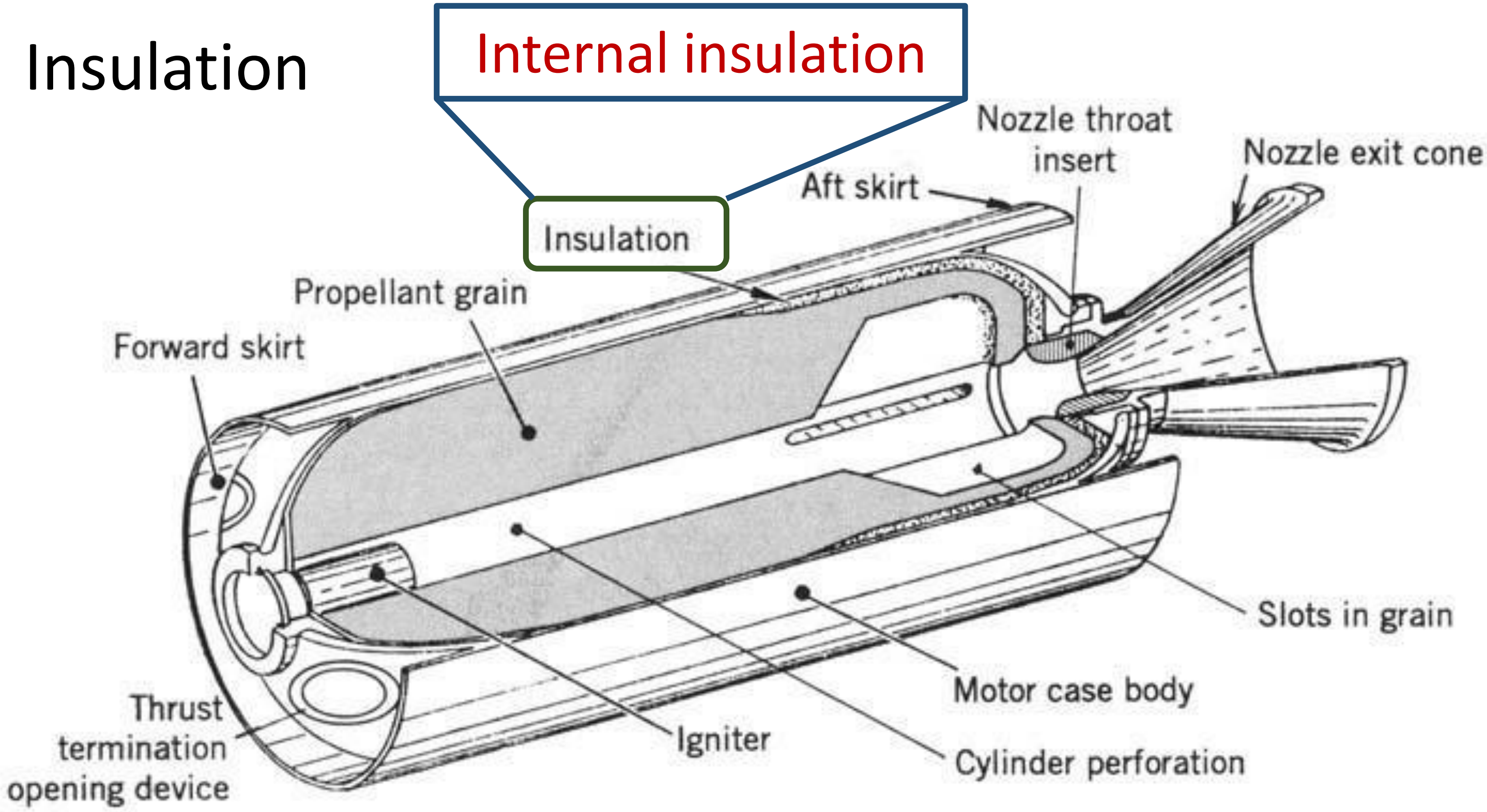



*diagram of casting and curing*

*of double-base solid propellant*

**Solid Rocket Motor**

Insulation



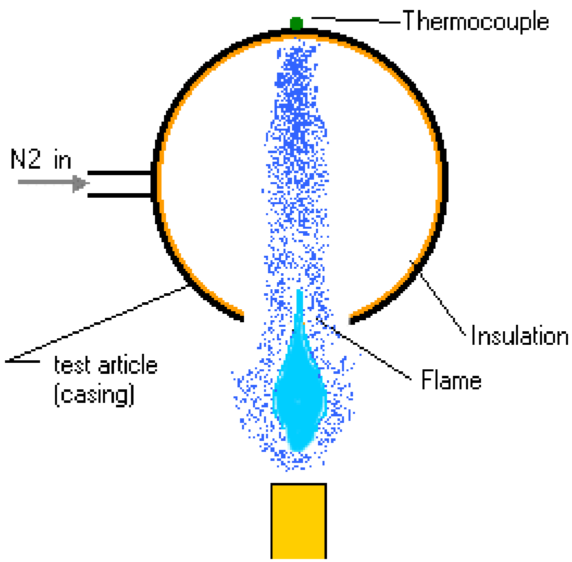

$T_c$: 1500~3500K

Typical solid propellant rocket motor

## Solid Rocket Motor

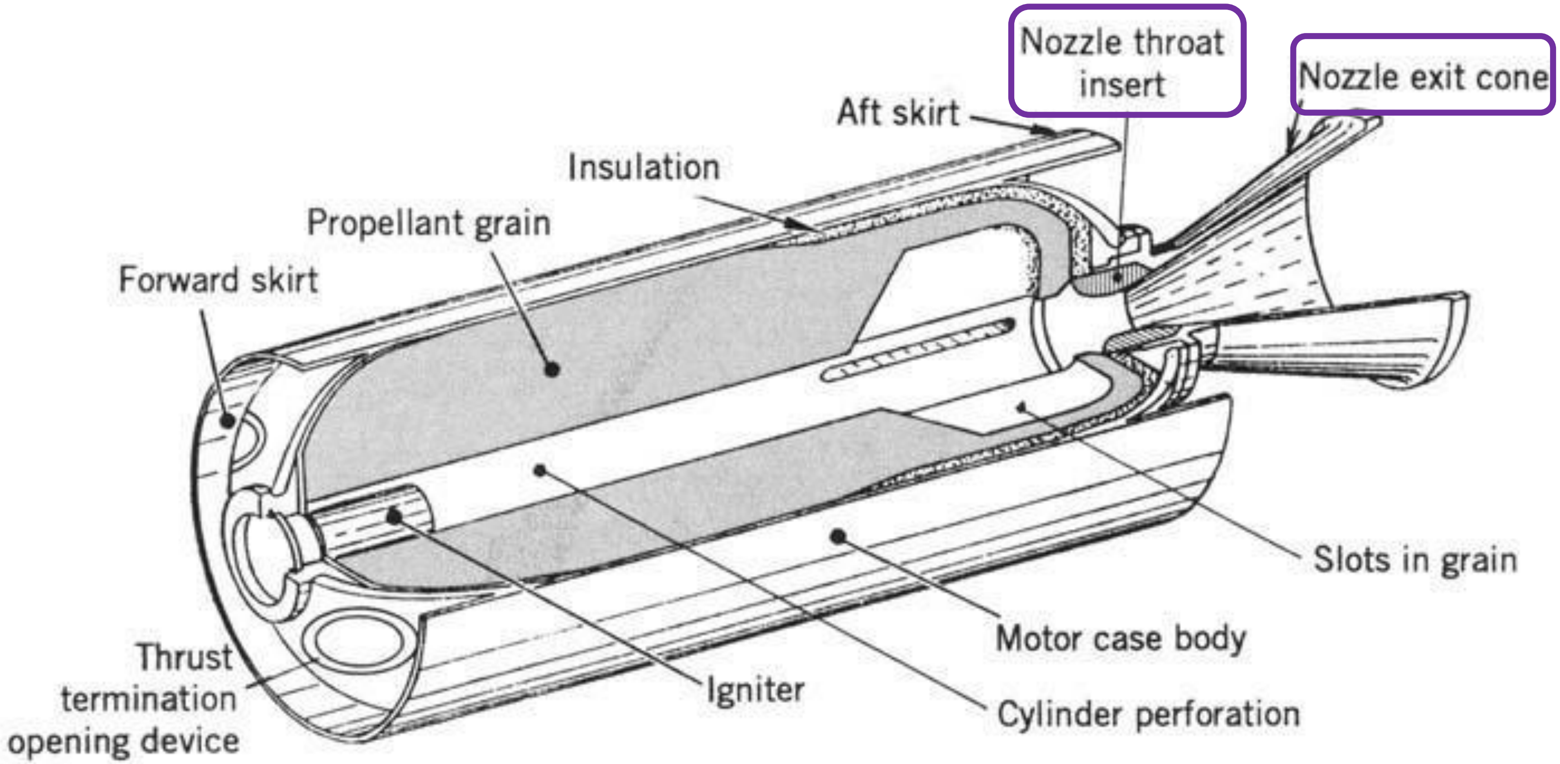
### Insulation -Design involves

- Analysis of combustion chamber environment
  - Stagnation temperature
  - Stagnation pressure
  - Propellant gases (material compatibility)
- Selection of insulation material
- Material thickness determination for various areas of the motor case




**Solid Rocket Motor**

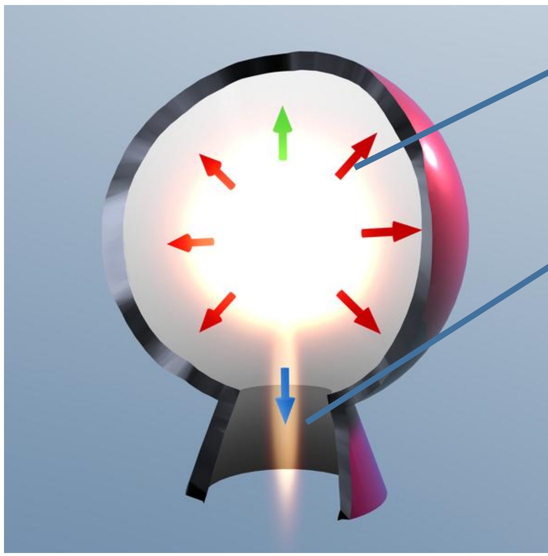
Nozzle




Typical solid propellant rocket motor

# Nozzle

**Propellant Chemical Energy** $\xrightarrow{\text{combustion}}$ **Internal Energy of Combustion Product** $\xrightarrow{\text{acceleration / expansion}}$ **Kinetic Energy of Exhaust Gases**



Combustion Chamber

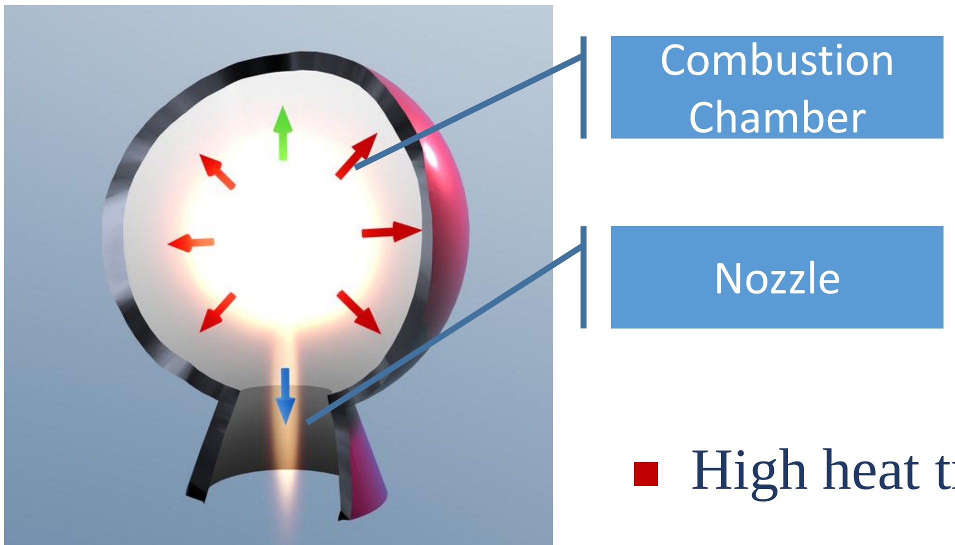
Nozzle

- ✓ Mechanics
- ✓ Thermodynamics
- ✓ Chemistry

- ***expanding and accelerating the combustion gases produced by burning propellants so that the exhaust gases exit the nozzle at hypersonic velocities.***

# Nozzle

**Propellant Chemical Energy** $\xrightarrow{\text{combustion}}$ **Internal Energy of Combustion Product** $\xrightarrow{\text{acceleration / expansion}}$ **Kinetic Energy of Exhaust Gases**




- ✓ Mechanics
- ✓ Thermodynamics
- ✓ Chemistry

- High heat transfer and erosion
- Throat diameter 0.05~54 in.
- Operating durations less than 1 sec to several minutes

# A Typical Rocket Nozzle

*-Laval Nozzle*

**Configuration/three distinct regions :**

**converging section**

- *inlet with subsonic gas flow*
- *subsonic accelerating*

**throat (minimum cross section)**

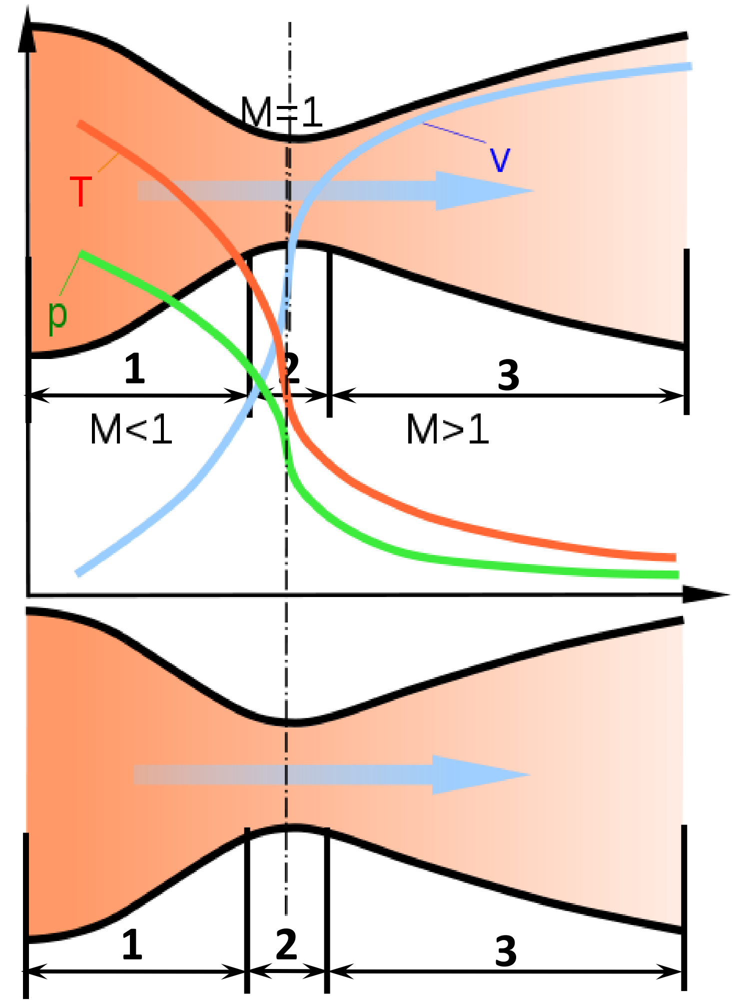
- *maintains chamber pressure and mass flow*

**diverging section/cone**

- *supersonic accelerating*

**area ratios**

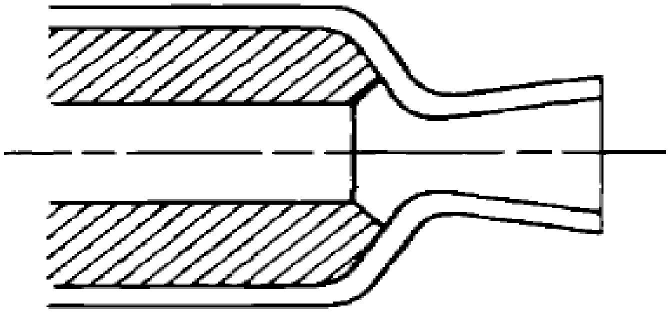
$$\epsilon = A_2/A_t$$



## NOZZLES

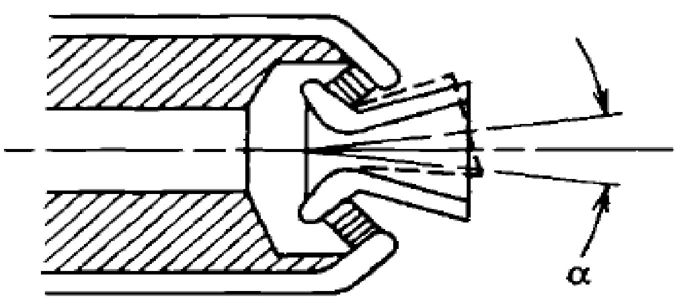
## Classification

- Fixed Nozzle



- *simplest*
- *frequently used in tactical weapon*
- *no submerged and thrust vector control*

- Movable Nozzle (TVC)

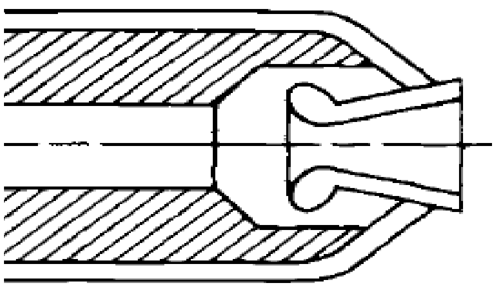



- *Provides thrust vector control*
- *typically submerged*
- *use flexible sealed joint or bearing*
- *primarily used in long-range strategic and large space launch boosters*

## NOZZLES

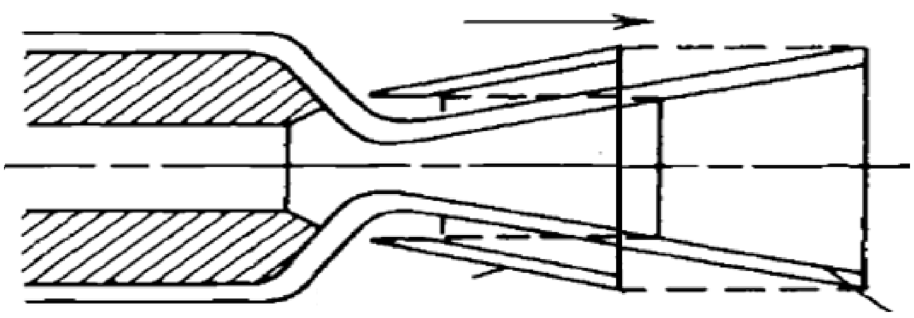
## Classification

- Submerged Nozzle



- *reduce the overall motor length*
- *for length-limited applications*
- *submarine-launched strategic missiles*

- Extendible Nozzle

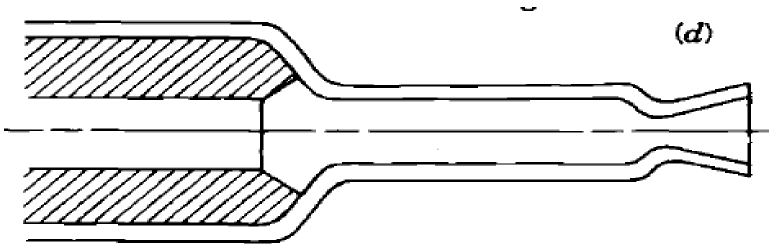


- *used on strategic missile propulsion upper-stage systems and upper stages for space launch vehicles to maximize motor-delivered specific impulse.*

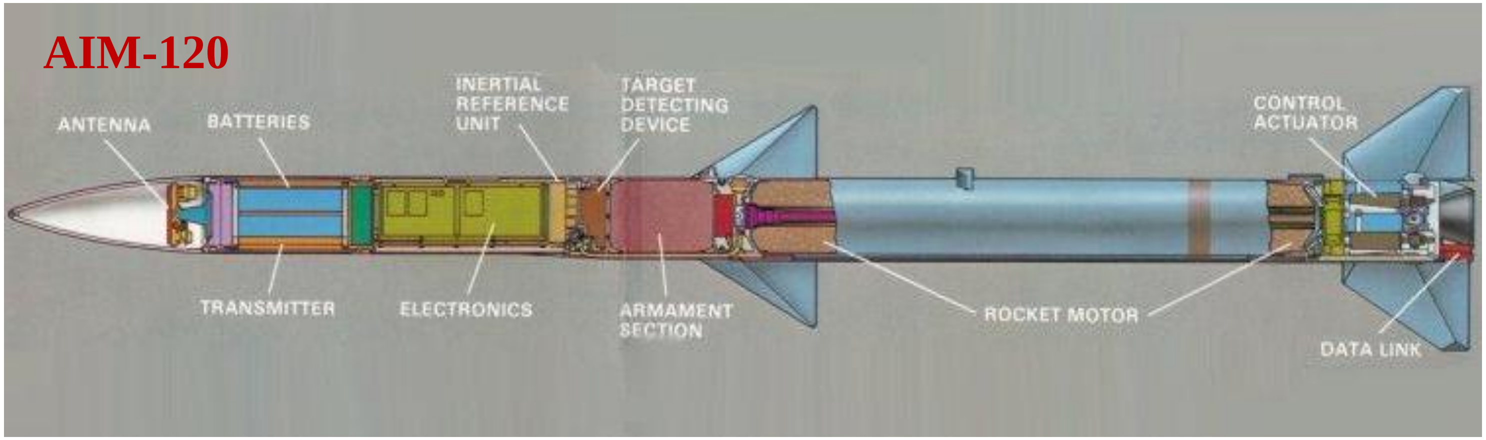
NOZZLES

## Classification

- Blast-Tube-Mounted Nozzle

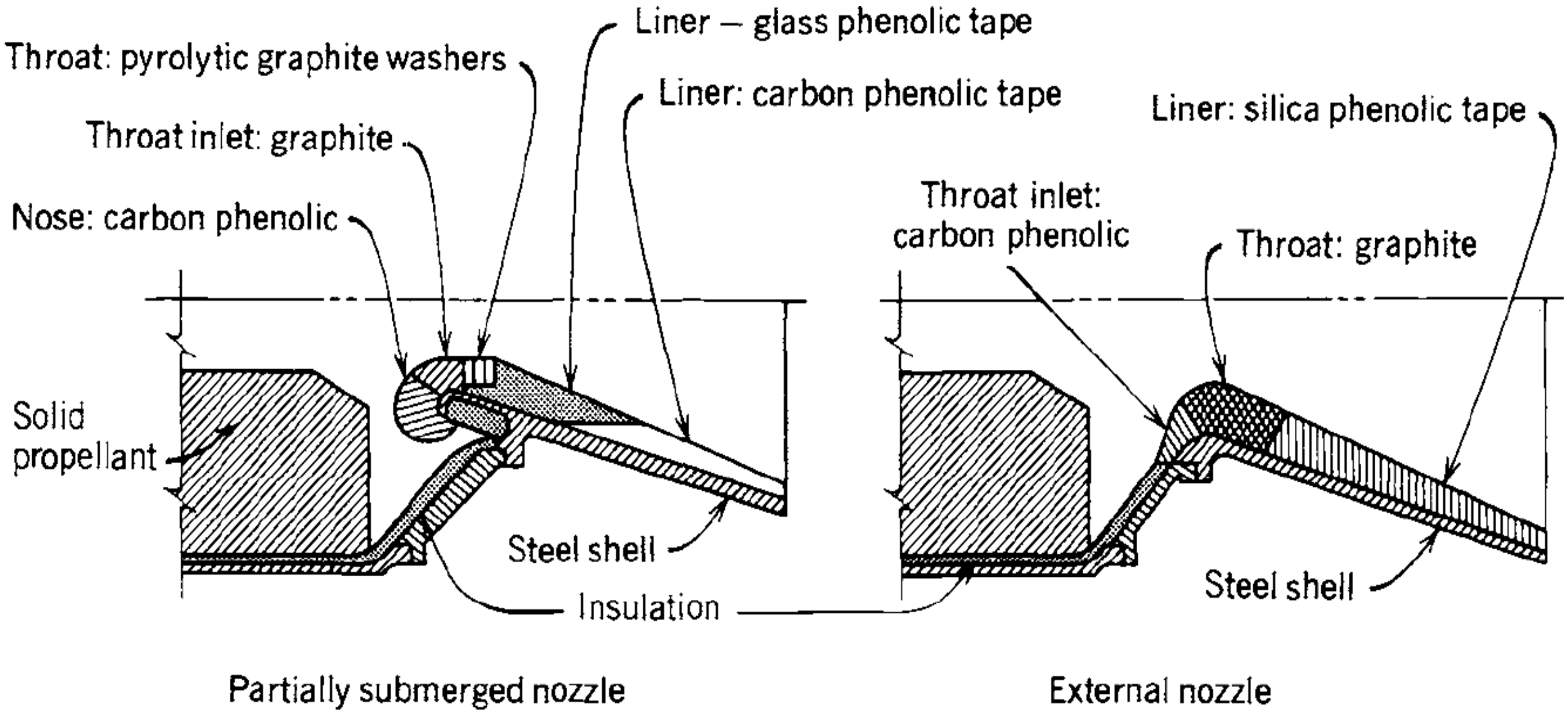



- *allow space for aerodynamic fin actuation or TVC power supply systems*
- *allows rocket motor's CG close/ahead of the vehicle CG*



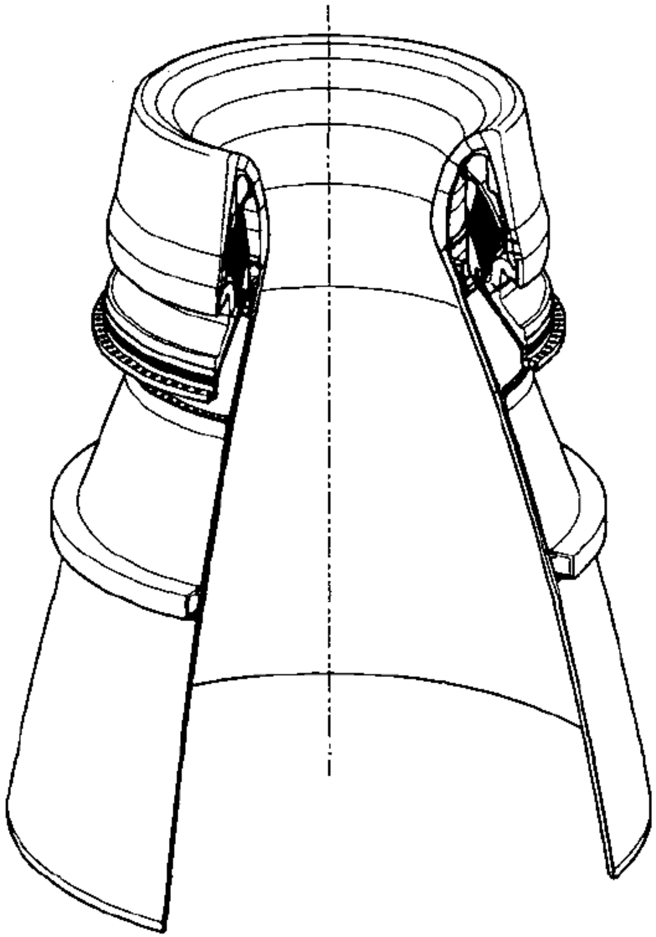
## Design and Construction

- Almost all solid rocket nozzles are ablatively cooled
- Use ablative liners to insulate steel or aluminum housings



**NOZZLES**

# Design and

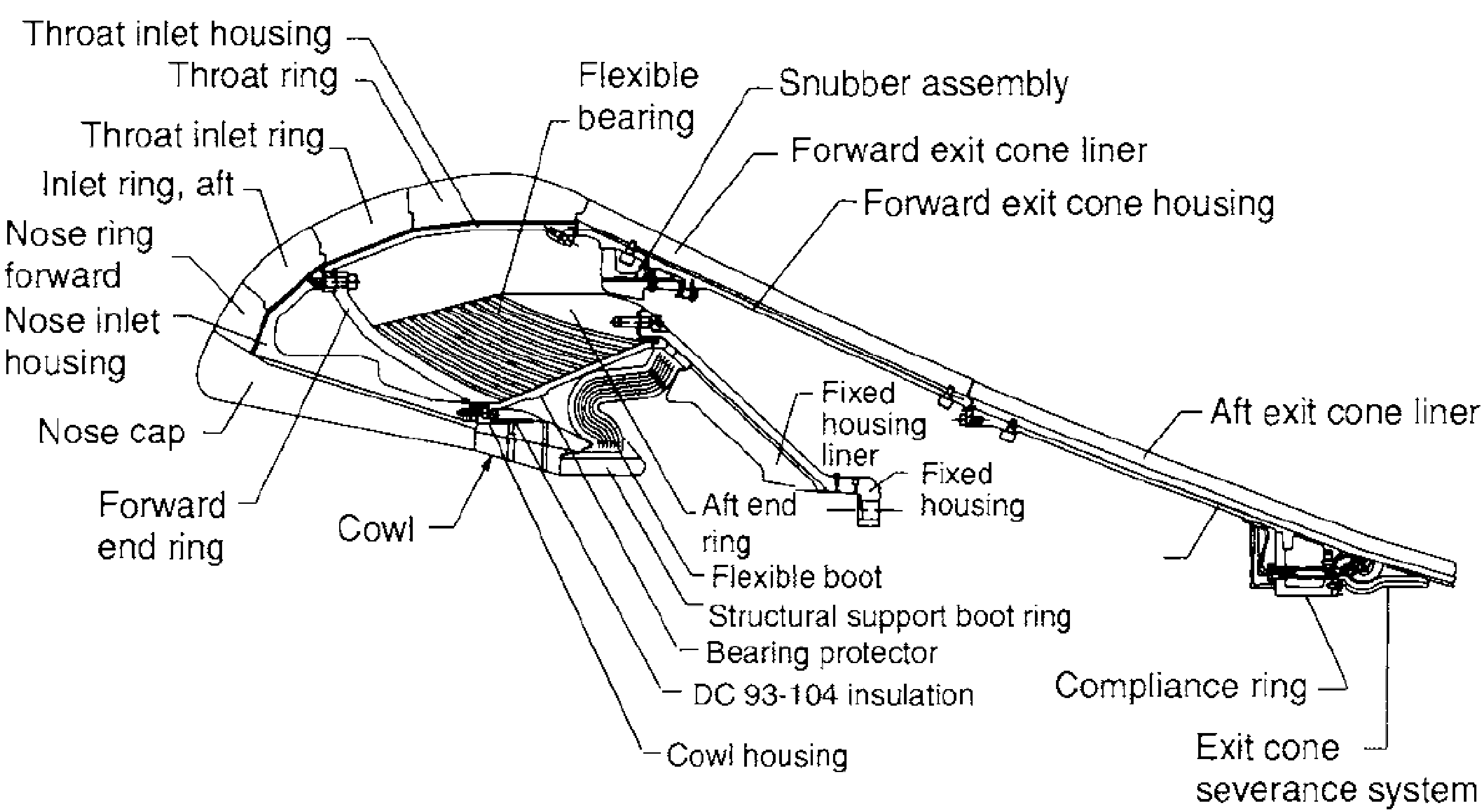


RSRM Nozzle Characteristics

| | |
|---|---|
| Type | Contoured or bell |
| Thrust vector control | Flexible bearing |
| Expansion area ratio | 7.72 |
| Throat diameter | 53.86 in. |
| Exit diameter | 149.64 in. |
| Total length | 178.75 in. |
| Nozzle weight | 23, 941 lbf |
| Maximum pressure | 1.016 psi |
| Maximum thrust (vac.) | 3, 070, 000 lbf |
| Burn time | 123.7 sec |
| Materials | |
| Housings | Steel and aluminum |
| Liners | Carbon cloth phenolic |

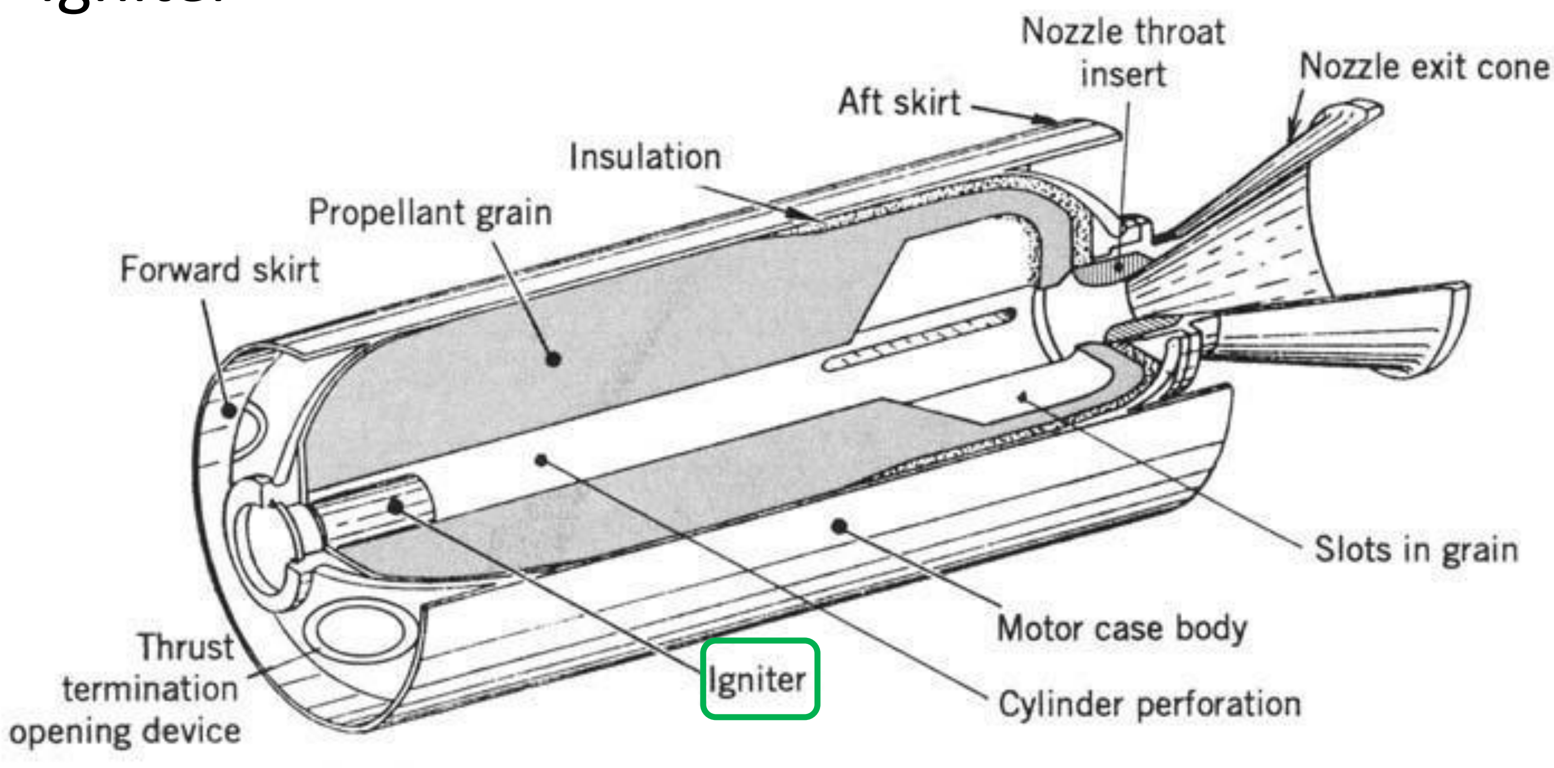
NOZZLES

# Design and Construction



**Solid Rocket Motor**

Igniter




Typical solid propellant rocket motor

## IGNITER

## function :

- Initiate propellant grain combustion

## process :

① receipt of a signal (usually electric)

② heat generation (igniter)

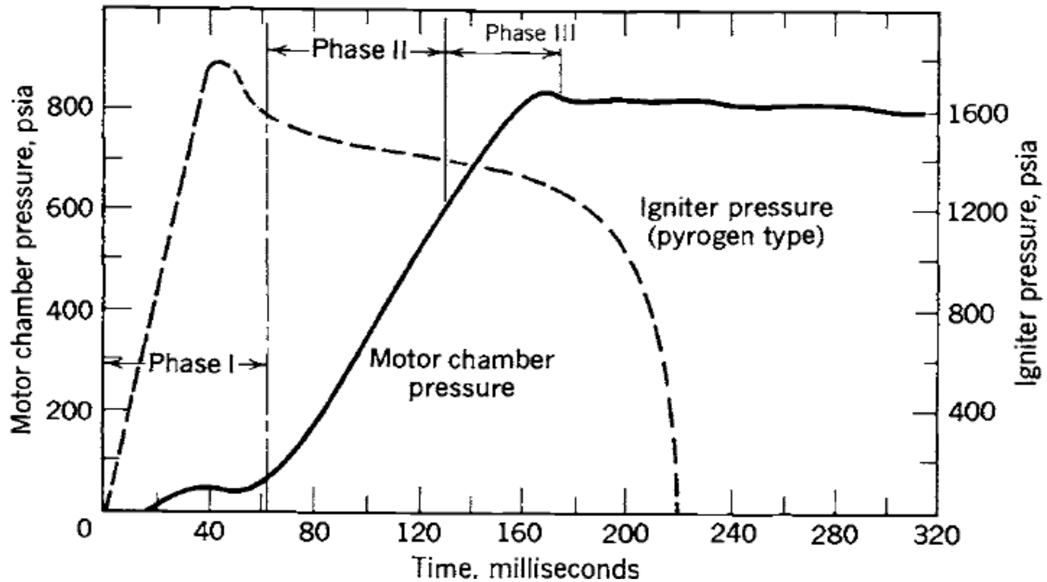
③ heat transfer from igniter to motor grain surface

④ flame spreading over the entire burning surface area

⑤ filling the chamber with hot gas and elevating pressure

**IGNITER**

## process：



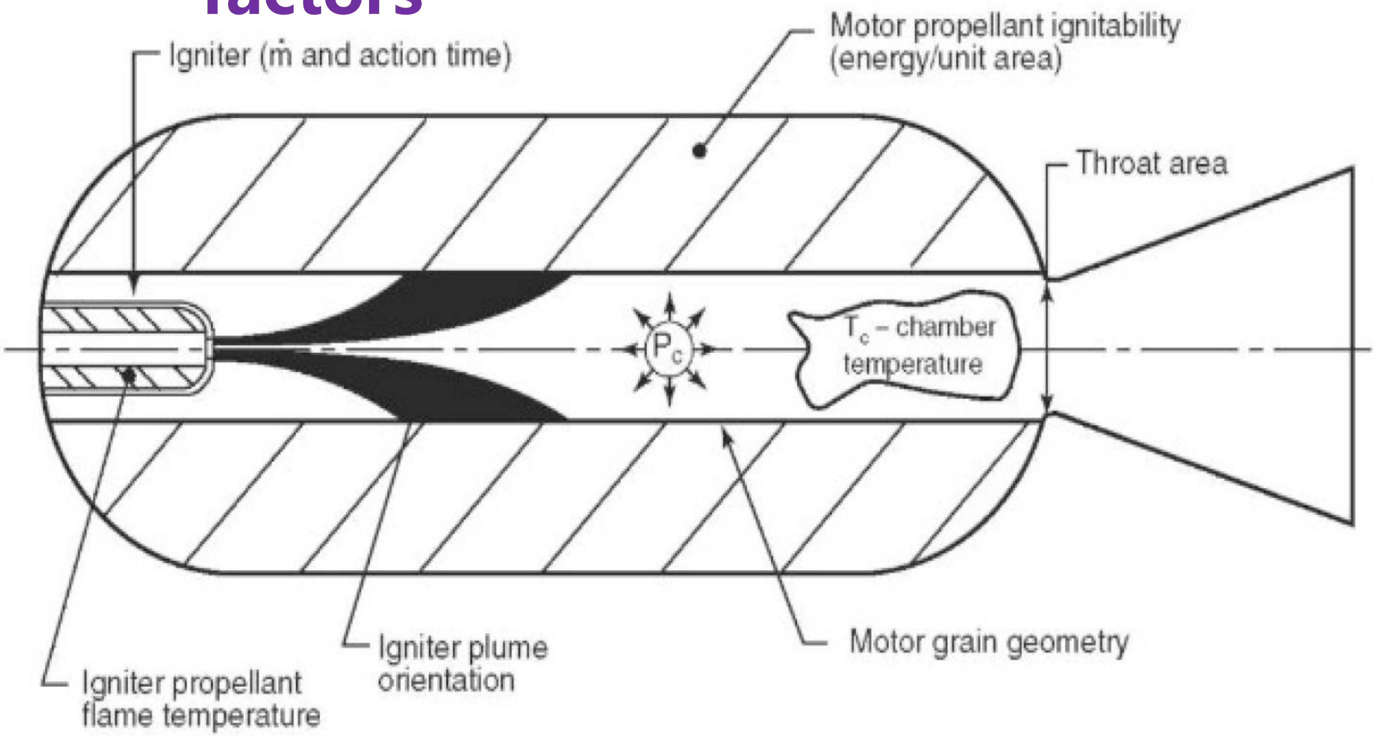

**Phase Ⅰ:** *ignition time lag.* The period from the moment the igniter receives a signal until the first bit of grain surface burns.

**Phase Ⅱ:** *flame-spreading interval.* The time from first ignition of the grain surface until the complete grain burning area has been ignited.

**Phase Ⅲ:** *chamber-filling interval.* The time for completing the chamber-filling process and for reaching equilibrium pressure and flow.

IGNITER

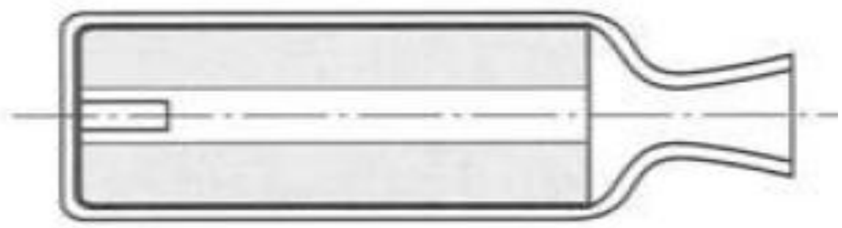
# Propellant ignition factors



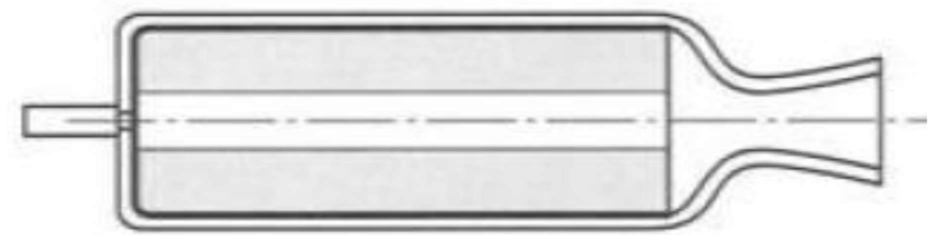

- igniter location and mass flow rate
- igniter flow impingement on grain surface
- propellant grain geometry
- combustion chamber free volume
- nozzle throat size

## IGNITER

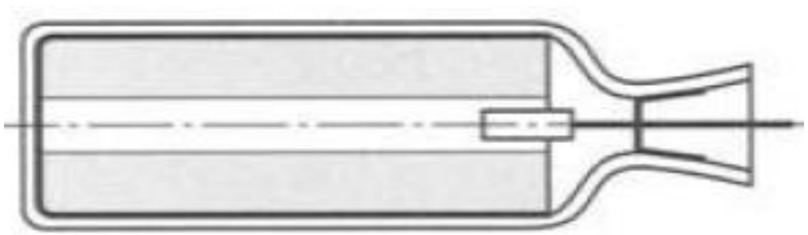
# Mounting Location:



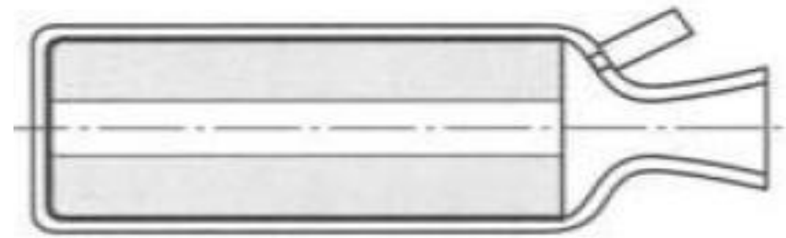
**Aft， Internal**



**Aft， External**



**Forward， Internal**

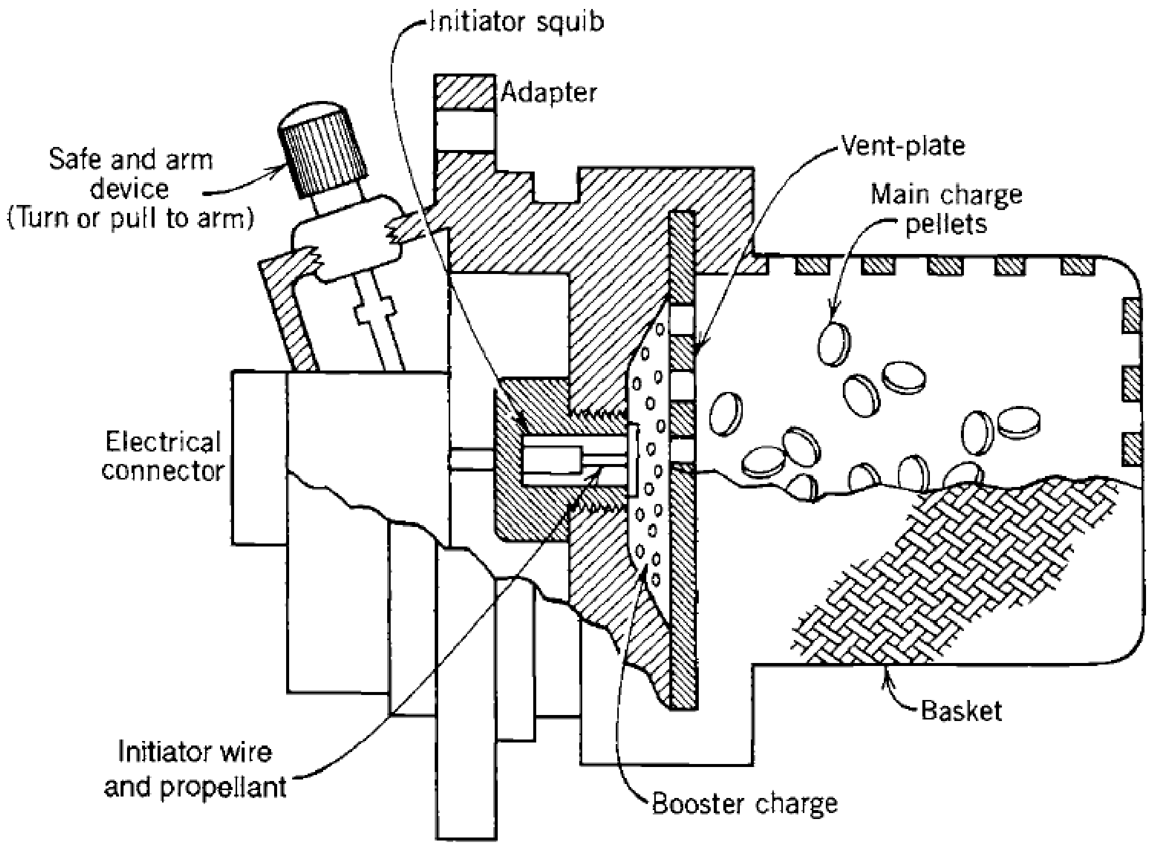


**Forward， External**

- igniter propellant mass is small (<1% motor propellant)
- burns at low chamber pressure

**IGNITER** **Pyrotechnic Igniters**

*using solid explosives or energetic propellant-like chemical formulations*

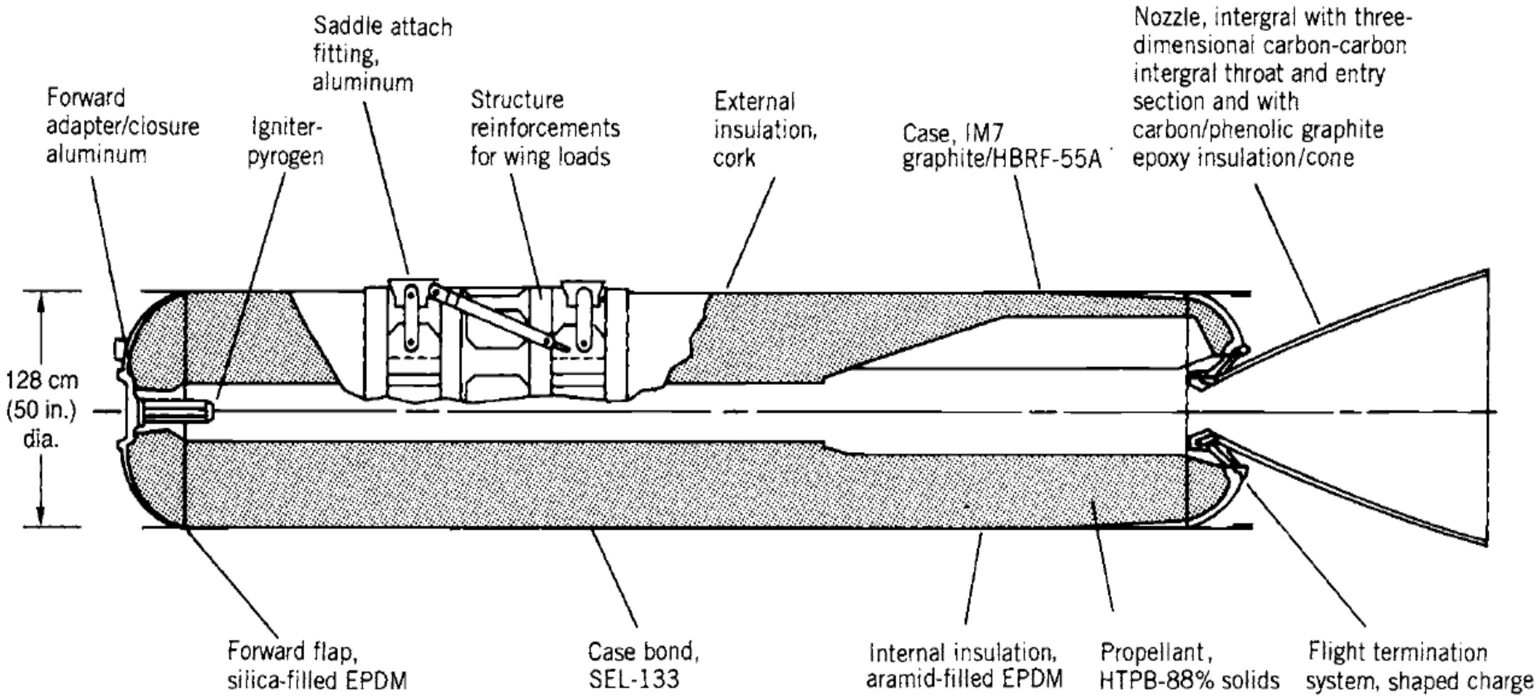



**Typical pyrotechnic igniter with three different propellant charges that ignite in sequence**

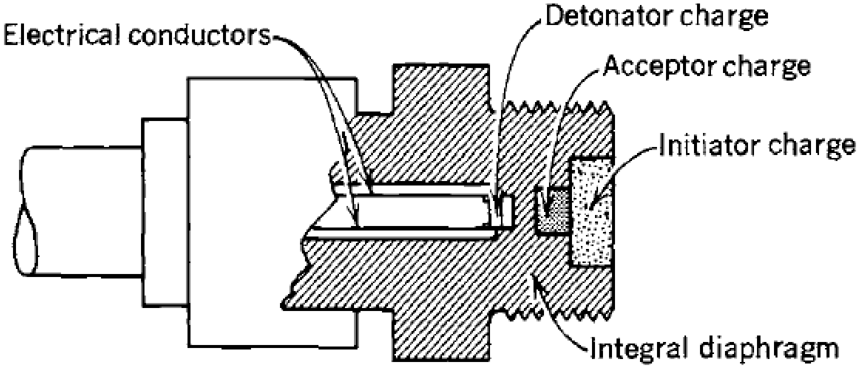
## IGNITER

**Pyrogen Igniters** — *a small rocket motor that is used to ignite a larger rocket motor*

- not designed to produce thrust
- use one or more nozzle
- use conventional rocket motor grain formulations and design technology

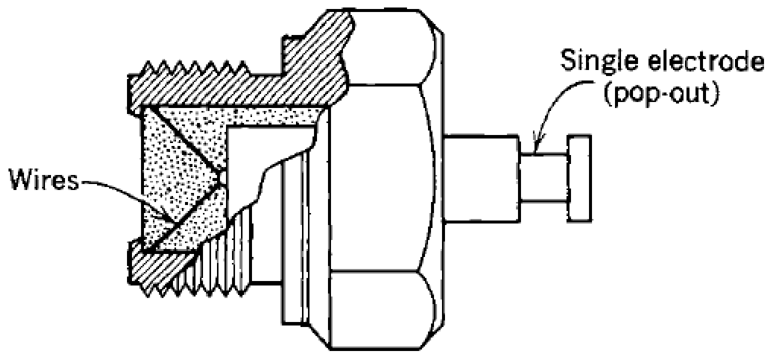


# IGNITER electric initiator



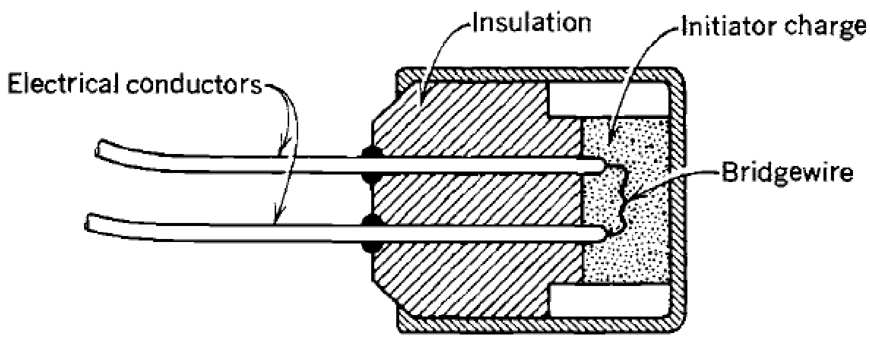

(a)

integral diaphragm type




(b)

header type with double bridgewire

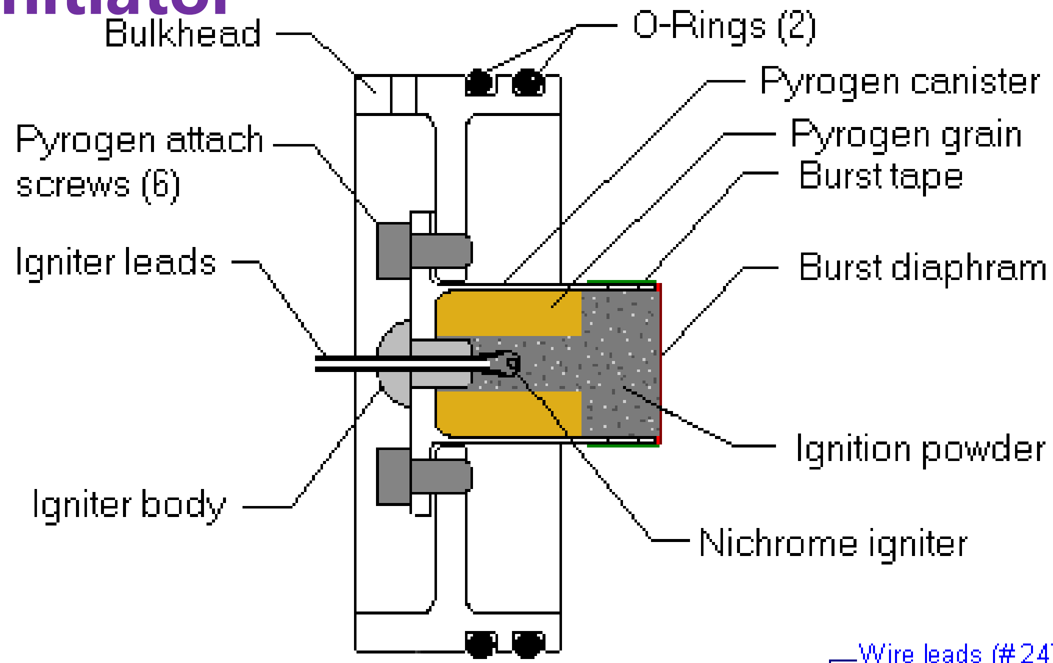


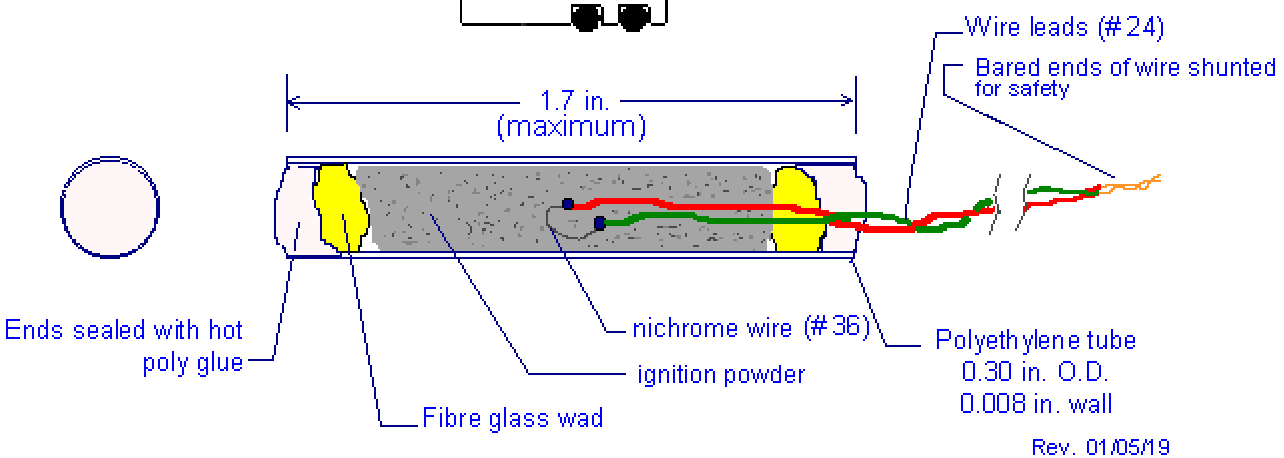

(c)

exploding bridgewire type

*Typical electric initiators*

# IGNITER electric initiator



**IGNITER** **electric initiator**

# Mass ratio

$$\mathrm{MR} = m_f/m_0$$

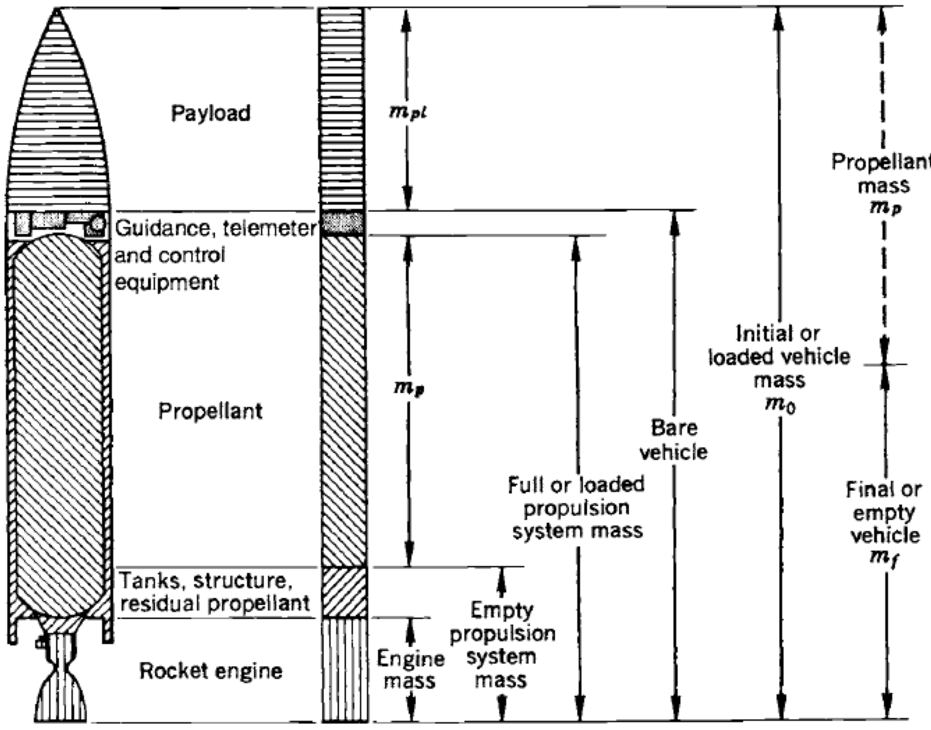
- range from 60% to less than 10%.

# Propellant mass fraction

$$\zeta = m_p/m_0$$

$$m_0 = m_f + m_p$$

$$\zeta = (m_0 - m_f)/m_0 = 1 - \mathrm{MR}$$




- Indicates the quality of the design.

# Solid Rocket Motor

——characteristics and applications

## Characteristics of Modern SRM

- Cast loading case banded grain
- Huge propellant loading, 10s~100s tonnes
- Advantage structural material, with high propellant fraction(>0.9)
- High energy propellant
- High thrust characteristics and accuracy
- Thrust vector control

## Characteristics of SRM

——*advantages and disadvantages*

- Simple design (few or no moving parts)*
- Thrust varying from 2N to over 4 MN
- Higher overall density
- long-time storage (5 to 20 years)
- relatively simple, easy to apply and require little servicing

- *Specific impulse slight lower*
- *Cannot be fully checked out prior to use*
- *thrust cannot be randomly varied in flight*

***movable nozzle for thrust vector control***

# Application of SRM

**Category** ***Large booster and second-stage motors***

**Application**

- Space launch vehicles
- lower stages of long-range ballistic missiles

ICBM: Inter-continental ballistic missile

**Typical Characteristics**

- *Large diameter (~ 48 in.);*
- *L/D of case = 2 to 7;*
- *Burn time t = 60 to 120 sec;*
- *low nozzle area ratios (6 to 16)*

# Application of SRM

**Category** ***High-altitude motors***

**Application**

- upper stages of multistage;
- ballistic missiles, space launch;
- space maneuvers

**Typical Characteristics**

- *High-performance propellant;*
- *large nozzle area ratio (20 to 200);*
- *L/D of case = 1 to 2;*
- *burn time t = 40 to 120 sec*

# Application of SRM

**Category** ***Tactical missiles***

**Application**

- High acceleration

***short-range bombardment and antitank missile***

**Typical Characteristics**

- *tube launched, L/D=4 to 13;*
- *very short burn time t=0.25 to 1 sec;*
- *small diameter (2.75 to 18in.);*
- *some are spin stabilized*

# Application of SRM

**Category** ***Tactical missiles***

**Application**

- High acceleration
- Modest acceleration

***surface-to-air, short-range surface-to-surface, air-to-air missiles***

**Typical Characteristics**

- *small diameter (5 to 18 in.);*
- *L/D=5 to 10;*
- *fins or wings;*
- *thrust is high at launch and then is reduced (boost-sustain)*
- *many have blast tubes;*
- *-53 to +71 ℃;*
- *high acceleration;*
- *low-smoke or smokeless propellant*

# Application of SRM

**Category** ***Ballistic missile defense***

**Application**

- Defense against long and medium-range ballistic missiles

**Typical Characteristics**

- *Booster rocket and a small upper maneuverable stage with multiple attitude control nozzles and one or more side or divert nozzles*

## Application of SRM

**Category** ***Gas generator***

**Application**

- Pilot emergency escape
- push missiles from submarine launch tubes or land mobile canisters
- actuators and valves
- short term power supply
- jet engine starter
- munition dispersion
- rocket turbine drive starter
- automotive air bags

**Typical Characteristics**

- *low gas temperature (< 1300 ℃);*
- *many different configurations, designs, and propellants;*
- *purpose is to create high-pressure, energetic gas rather than thrust*

# Application of SRM

| Category | Application |
|---|---|
| Large booster and second-stage motors | ■ Space launch vehicles<br>■ lower stages of long-range ballistic missiles |
| High-altitude motors | ■ Upper stages of multistage<br>■ ballistic missiles, space launch<br>■ space maneuvers |
| Tactical missiles | ■ High acceleration<br>■ Modest acceleration |
| Ballistic missile defense | ■ Defense against long and medium-range ballistic missiles |
| Gas generator | ■ Pilot emergency escape<br>■ push missiles from launch tubes<br>■ actuators and valves<br>■ short term power supply<br>■ jet engine starter<br>■ munition dispersion<br>■ rocket turbine drive starter<br>■ automotive air bags |

## Classification of SRM

| Basis of Classification | Examples of Classification |
|---|---|
| Application | |
| Diameter/Length | *D:0.005-6.6 m; L:0.025 to 45 m* |
| Propellant | *Composite / Double-base / Composite-modified double-base* |
| Case design | *Steel monolithic / Fiber monolithic / Segmented* |
| Grain configuration | *Cylindrical / End-burning / Other configurations* |
| Grain installation | *Case-bonded / Cartridge-loaded (free-standing)* |
| Explosive hazard | *Class 1.3 / Class1.1* |
| Thrust action | *Neutral / Progressive / Regressive / Pulse / Step-thrust* |
| Toxicity | *Toxic and nontoxic exhaust gases* |

# Solid Rocket Motor

——Design approach

# Solid Rocket Motor Design

## Content of SRM Design

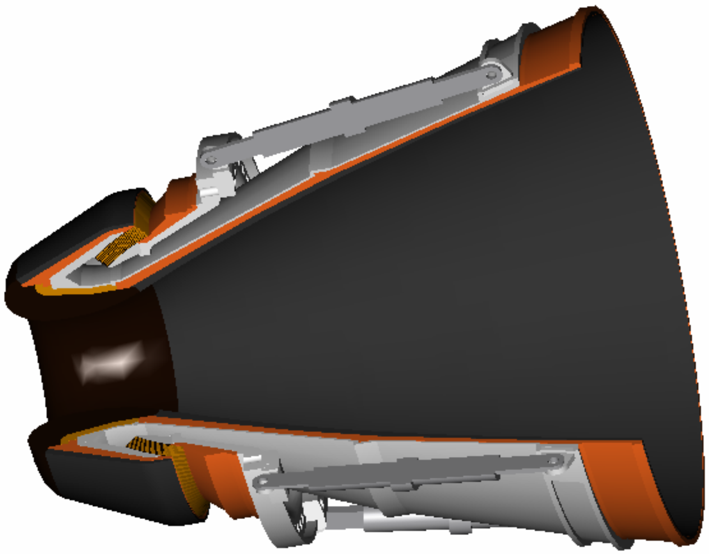
- Preliminary Design
  - Select the structure, propellant and case material
  - Determine the working pressure, expansion ratio, package size and other design parameters

- Propellant grain Design
  - Select the configurations, determine geometry
  - Thermodynamic calculation
  - Evaluate the internal ballistic performance
  - Structural analysis

# Solid Rocket Motor Design

## Content of SRM Design

- Combustion chamber Design
  - Case design
  - Internal insulation design
- Nozzle Design
  - structural design
  - thermal protection design
- Igniter device Design
  - type and structure selection
  - energy release system design
- Thrust vector control and termination Design



# Solid Rocket Motor

——Development and Future

## Development and Future of SRM

- **High performance, high reliability, long life, low cost**
- High pressure, improve energy efficiency
- Improve the propellant mass ratio to 0.93, by advanced materials usage and design optimization
- Miniaturization, precision thrust vector control
- High energy, low signal characteristics, environmental friendly propellant
- Advanced manufacturing process

THE
END