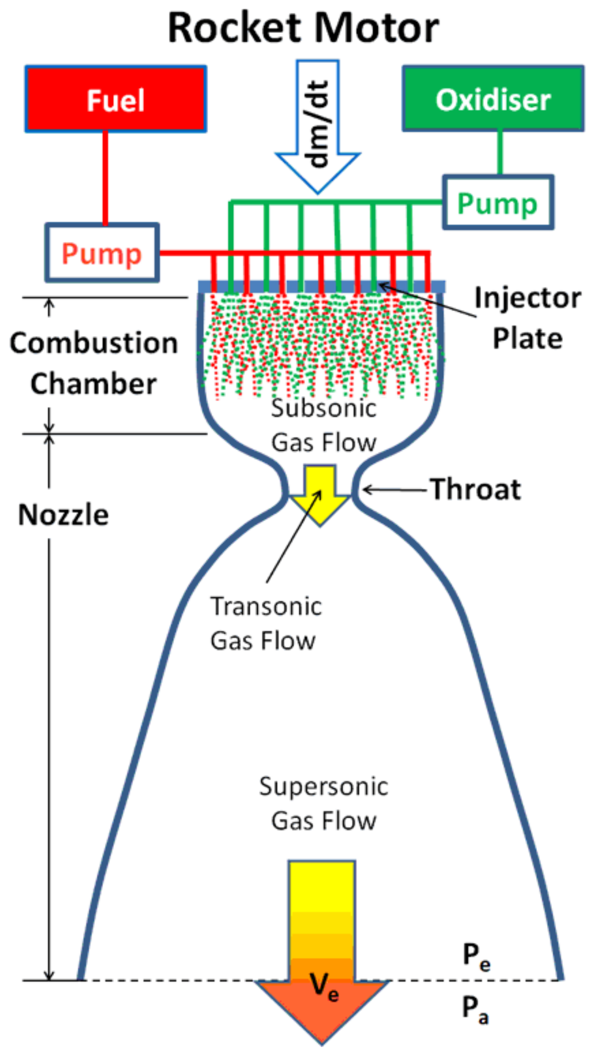
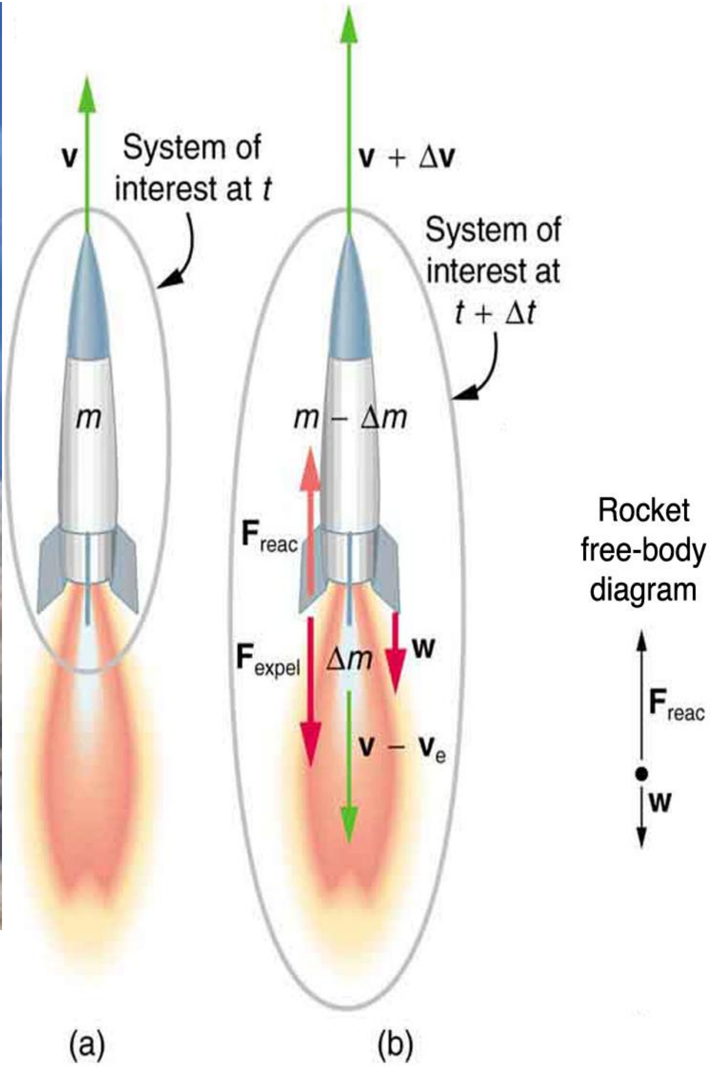
FUNDAMENTALS OF ROCKET PROPULSION

Unit 2


Rocket Motor
Fuel
dm/dt
Oxidiser
Pump
Pump
Injector Plate
Combustion Chamber
Subsonic Gas Flow
Throat
Nozzle
Transonic Gas Flow
Supersonic Gas Flow
P_e
V_e
P_a


v
System of interest at t
m
$\mathbf{v} + \Delta\mathbf{v}$
System of interest at $t + \Delta t$
$m - \Delta m$
F_{reac}
F_{expel}
Δm
w
$\mathbf{v} - \mathbf{v}_e$
(a)
(b)
Rocket free-body diagram
F_{reac}
w

Syllabus

Operating principle, Rocket equation, Specific impulse of a rocket, internal ballistics, Rocket nozzle classification, Rocket performance considerations of rockets, types of igniters, preliminary concepts in nozzle less propulsion, air augmented rockets, pulse rocket motors, static testing of rockets and instrumentation, safety considerations.

Rocket engine: A vehicle or device propelled by one or more rocket engines, especially such a vehicle designed to travel through space.

- A projectile weapon carrying a warhead that is powered and propelled by rockets.
- A projectile firework having a cylindrical shape and a fuse that is lit from the rear.

Missile: An object or weapon that is fired, thrown, dropped, or otherwise projected at a target; a projectile.

PROPELLANT

- Propellant is the chemical mixture burned to produce thrust in rockets and consists of a fuel and an oxidizer.
- A fuel is a substance that burns when combined with oxygen producing gas for propulsion.
- An oxidizer is an agent that releases oxygen for combination with a fuel.
- The ratio of oxidizer to fuel is called the mixture ratio. Propellants are classified according to their state - liquid, solid, or hybrid.
- The gauge for rating the efficiency of rocket propellants is specific impulse, stated in seconds.

Liquid Propellants :

- In a liquid propellant rocket, the fuel and oxidizer are stored in separate tanks, and are fed through a system of pipes, valves, and turbo pumps to a combustion chamber where they are combined and burned to produce thrust.
- Liquid propellant engines are more complex than their solid propellant counter parts, however, they offer several advantages.
- By controlling the flow of propellant to the combustion chamber, the engine can be throttled, stopped, or restarted.

- **Solid Propellants** :
- Solid propellant motors are the simplest of all rocket designs. They consist of a casing, usually steel, filled with a mixture of solid compounds (fuel and oxidizer) that burn at a rapid rate, expelling hot gases from a nozzle to produce thrust.
- When ignited, a solid propellant burns from the center out towards the sides of the casing. The shape of the center channel determines the rate and pattern of the burn, thus providing a means to control thrust.
- Unlike liquid propellant engines, solid propellant motors cannot be shut down.
- Once ignited, they will burn until all the propellant is exhausted.

Hybrid Propellants:

- Hybrid propellant engines represent an intermediate group between solid and liquid propellant engines.
- One of the substances is solid, usually the fuel, while the other, usually the oxidizer, is liquid.
- The liquid is injected into the solid, whose fuel reservoir also serves as the combustion chamber.
- The main advantage of such engines is that they have high performance, similar to that of solid propellants, but the combustion can be moderated, stopped, or even restarted.

Operating principle

- A rocket is a machine that develops thrust by the rapid expulsion of matter.
- The major components of a chemical rocket assembly are a rocket motor or engine, propellant consisting of fuel and an oxidizer, a frame to hold the components, control systems and a cargo such as a satellite.
- A rocket is called a launch vehicle when it is used to launch a satellite or other payload into space.
- A rocket becomes a missile when the payload is a warhead and it is used as a weapon.
- At present, rockets are the only means capable of achieving the altitude and velocity necessary to put a payload into orbit.

Rocket Power

- There are a number of terms used to describe the power generated by a rocket.
- Thrust is the force generated, measured in pounds or kilograms. Thrust generated by the first stage must be greater than the weight of the complete launch vehicle while standing on the launch pad in order to get it moving.
- The impulse, sometimes called total impulse, is the product of thrust and the effective firing duration.
- The efficiency of a rocket engine is measured by its specific impulse (Isp). Specific impulse is defined as the thrust divided by the weight of the propellant consumed per second. The result is expressed in seconds.

Mass ratio

- A rocket's mass ratio is defined as the total mass at lift-off divided by the mass remaining after all the propellant has been consumed.
- A high mass ratio means that more propellant is pushing less launch vehicle and payload mass, resulting in higher velocity.
- A high mass ratio is necessary to achieve the high velocities needed to put a payload into orbit.

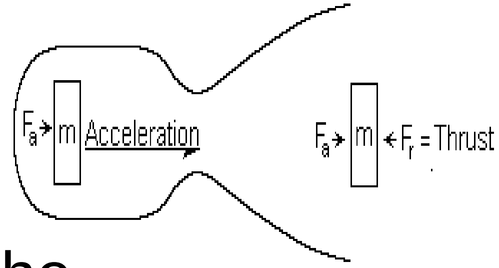
Thrust

Rocket thrust can be explained using Newton's 2nd and 3rd laws of motion.

2nd Law: a force applied to a body is equal to the mass of the body and its acceleration in the direction of the force.

$$F = ma$$

3rd Law: For every action, there is an equal and opposite reaction.



$$F_a = -F_r$$

In rocket propulsion, a mass of propellant (m) is accelerated (via the combustion process) from initial velocity (V_o) to an exit velocity (V_e). The acceleration of this mass is written as:

$$a = (V_e - V_o) / \Delta t$$

Thrust

Combining terms, we get: $F = m(V_e - V_o)/t$

Which can be rearranged:

$$F = \left(\frac{m}{t}\right)(V_e - V_o)$$

The term of mass of propellant divided by time is referred to as mass flow rate (m-dot), expressed as

$$F = \dot{m}(V_e - V_o)$$

Thrust

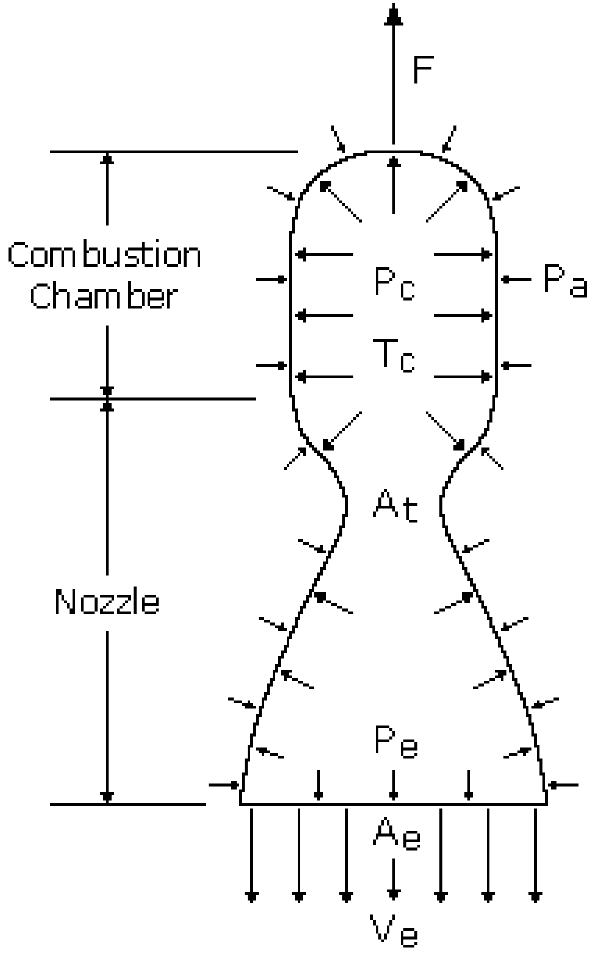
Another component of thrust (*pressure thrust*, F_2) comes from the force exerted by external pressure differences on the system. This is described by the difference of the pressure of the flow leaving the engine (P_e) through the exit area (A_e) compared to the external (ambient) pressure (P_a).

$$F_2 = (P_e - P_a)A_e$$

In space, P_a is assumed to be zero (which explains why thrust rated at vacuum is higher than at sea level).

Combining the two thrust components gives

$$\boxed{F = \frac{\dot{m}}{g}(V)_e + (P_e - P_a)A_e}$$



Rocket equation

- Check your Notes

Specific Impulse

The *total impulse* (I_t) is the thrust integrated over the run duration (time, t)

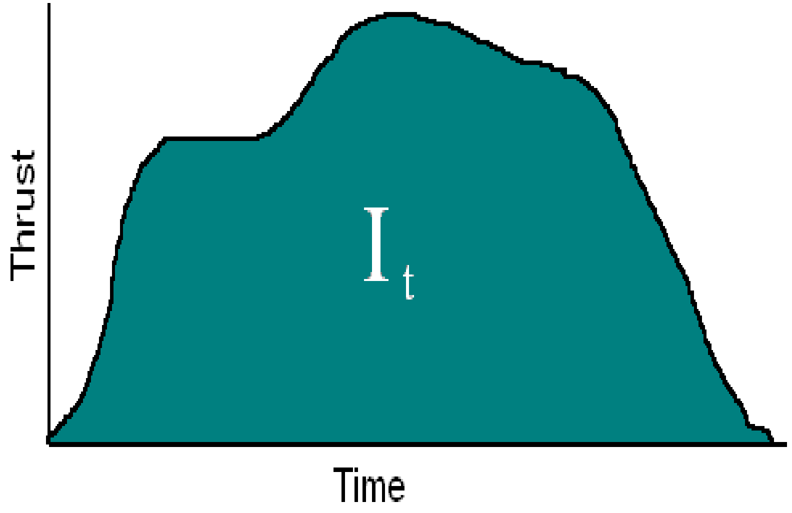
$$I_t = \int_0^t F dt$$

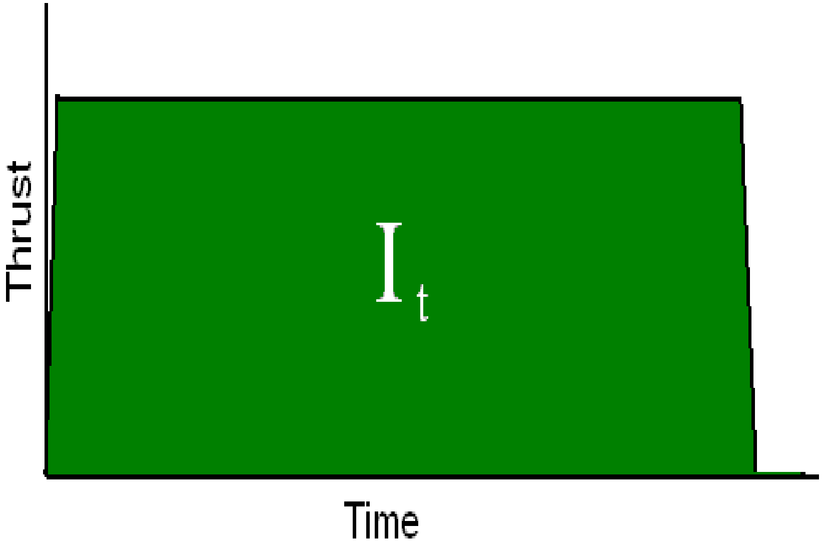
Assuming constant thrust and negligible transients (i.e., start and shutdown), this becomes

$$I_t = Ft$$

The *specific impulse*, (I_{sp}) is the total impulse generated per weight of propellant

$$I_{sp} = \frac{\int_0^t F dt}{g_o \int_0^t \dot{m} dt} = \boxed{\frac{F}{\dot{m}}}$$





Mixture Ratio

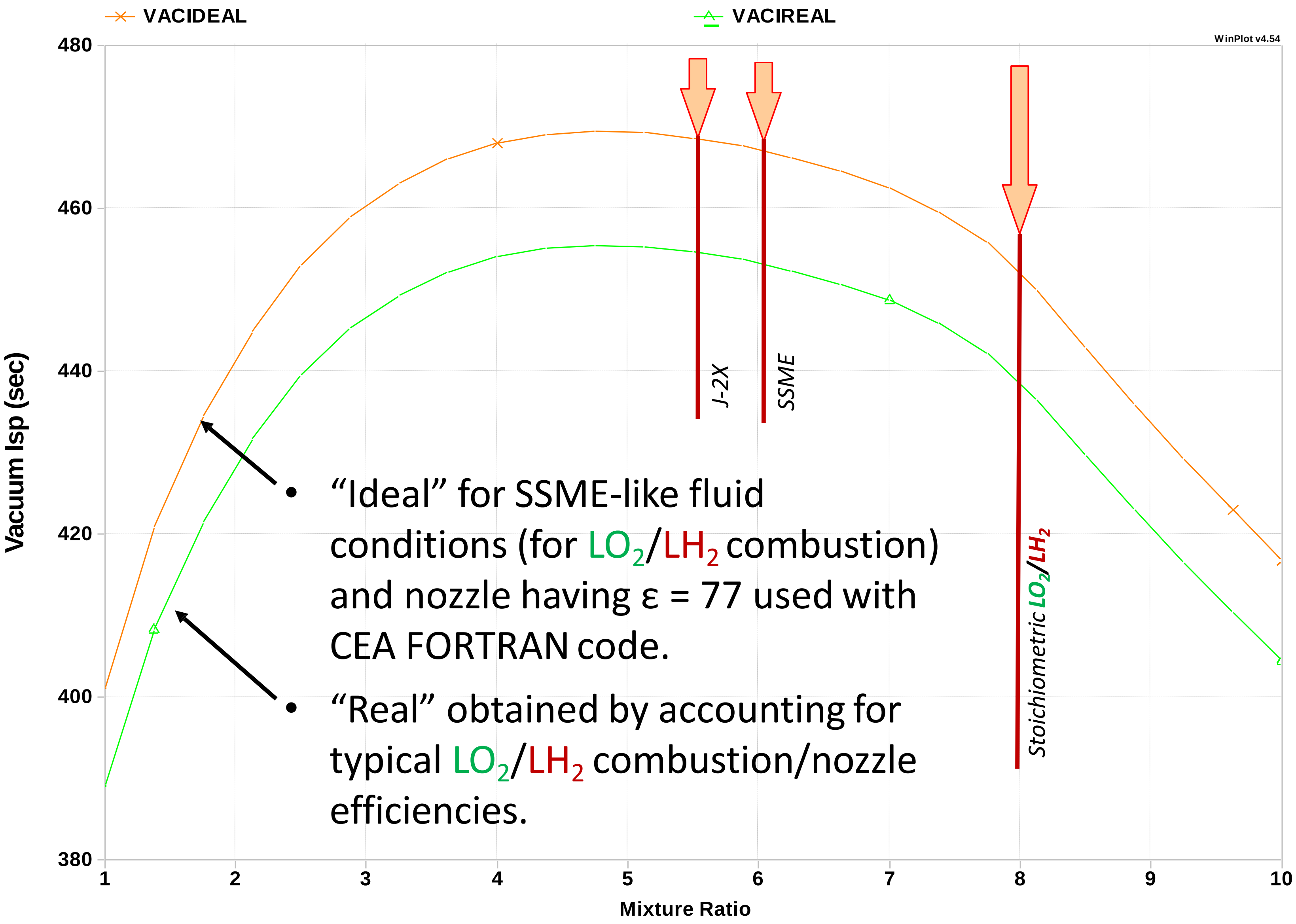
Rocket propellants are mixed in relative quantities to produce the highest possible system I_{sp}. This ratio of propellant consumption is called mixture ratio, MR.

$$MR = \frac{M_o}{M_f}$$

In most cases, MR is selected for maximum energy release per weight of propellant. This can be achieved by mixing the propellants in a stoichiometric reaction in the combustion chamber, where all the propellants are thoroughly combusted. <u>However, a stoichiometric MR does not necessarily provide an optimized I_{sp}.</u>

☞ The SSME uses a MR of ~6 (stoichiometric for LO_2/ LH_2 combustion is 8) to reduce the internal and plume temperatures, but also to allow a small amount of H_2 to remain in the exhaust. The lighter molecule is able to accelerate to a higher velocity and generate higher kinetic energy ($KE = \frac{1}{2} mV^2$) than a H_2O steam exhaust.

I_{sp} vs. MR



- “Ideal” for SSME-like fluid conditions (for LO_2/LH_2 combustion) and nozzle having ε = 77 used with CEA FORTRAN code.
- “Real” obtained by accounting for typical LO_2/LH_2 combustion/nozzle efficiencies.

Density vs. I_{sp}

- Liquid bipropellant combinations offer a wide range of performance capabilities.
- Each combination has multiple factors that should be weighed when selecting one for a vehicle.
  - Performance (I_{sp})
  - Density (higher is better)
  - Storability (venting?)
  - Ground Ops (hazards?)
  - Etc.
- One of the more critical trades is that of performance versus density.
- LO_2/LH_2 offers the highest I_{sp} performance, but at the cost of poor density (thus increasing tank size).
- Trading I_{sp} versus density is sometimes referred to as comparing "bulk impulse" or "density impulse".

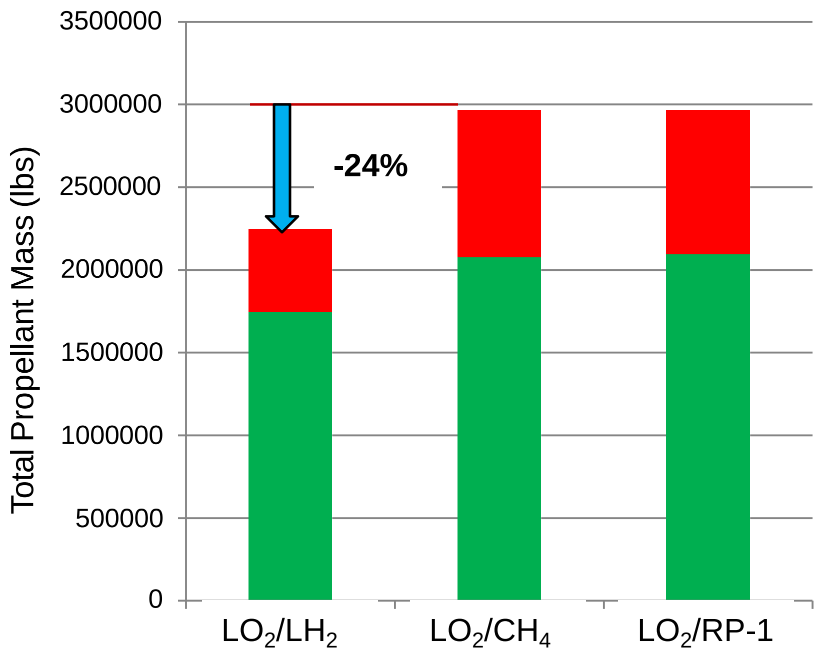
- As an example, the densities and I_{sp} performance of the following propellant combinations will be compared.

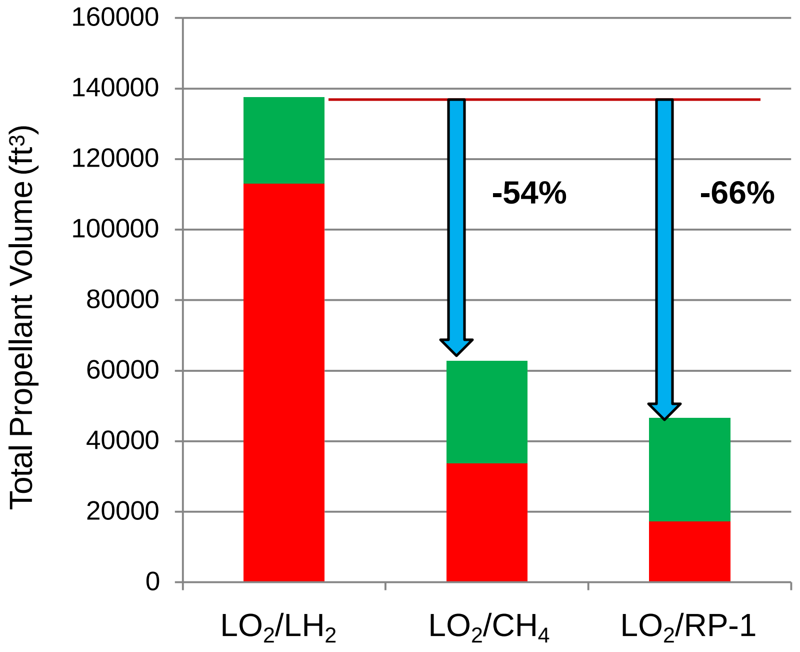
	Density (g/ml)	**Density (lb/ft^3)**
Hydrogen	0.07	4.4
Methane	0.42	26.4
RP-1	0.81	50.6
Oxygen	1.14	71.2

P_c = 300 psia expanded to 14.7 psia	**MR (O/F)**	**I_{sp} (sec)**
LO_2/LH_2	3.5	347 (1)
LO_2/CH_4	2.33	263 (2)
LO_2/RP-1	2.4	263 (2)

(1) SC *(2) FC*

Propellant Mass vs. Volume



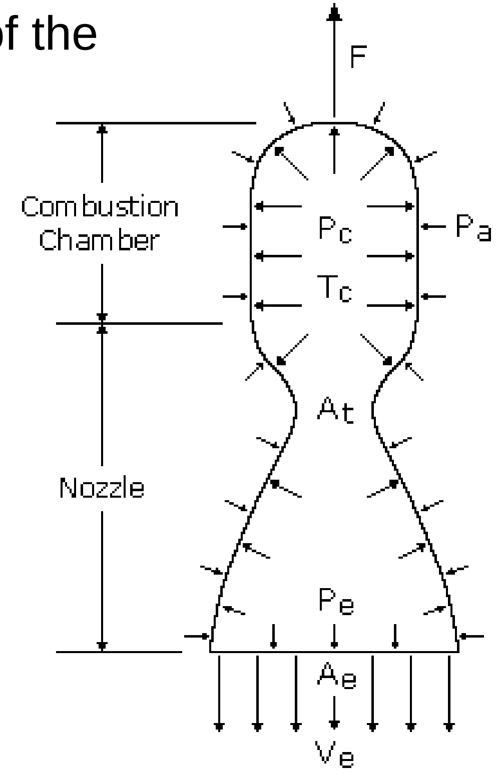


- For an impulse requirement similar to the 3 SSME's used on the Shuttle (~1.5 Mlbf for 520 seconds), the required propellant masses are calculated.
- LO_2/LH_2 requires 24% less propellant mass than the others.
- However…

- When the propellant mass is compared against the tank volume, there is a significant disparity from the low hydrogen density that can adversely impact the size (and total weight) of the vehicle.
- Lesson: *I_{sp} isn't everything – especially with boost stages.*

Area Ratio

The parameter that determines exit velocity and pressure of the exhaust gases is *area ratio* or *nozzle expansion ratio*, MR

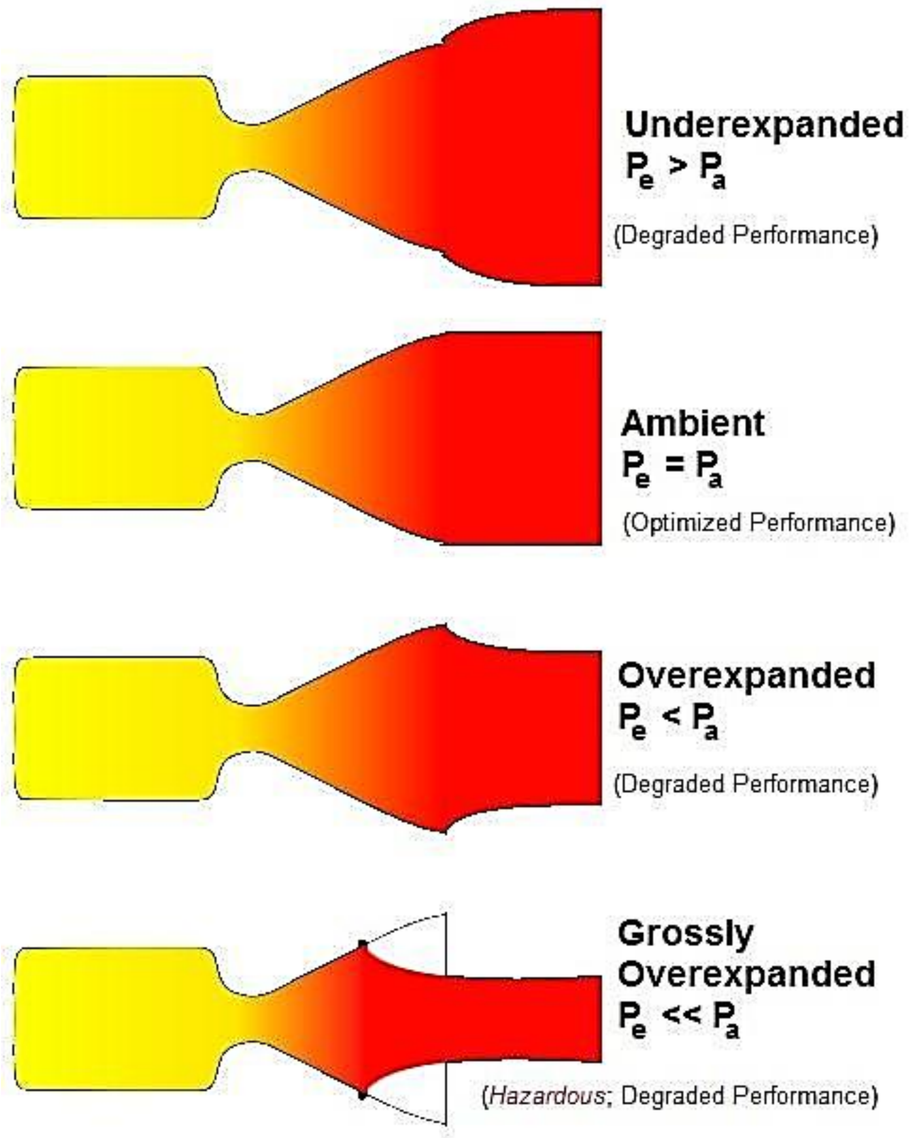


$$\varepsilon = \frac{A_e}{A_t}$$

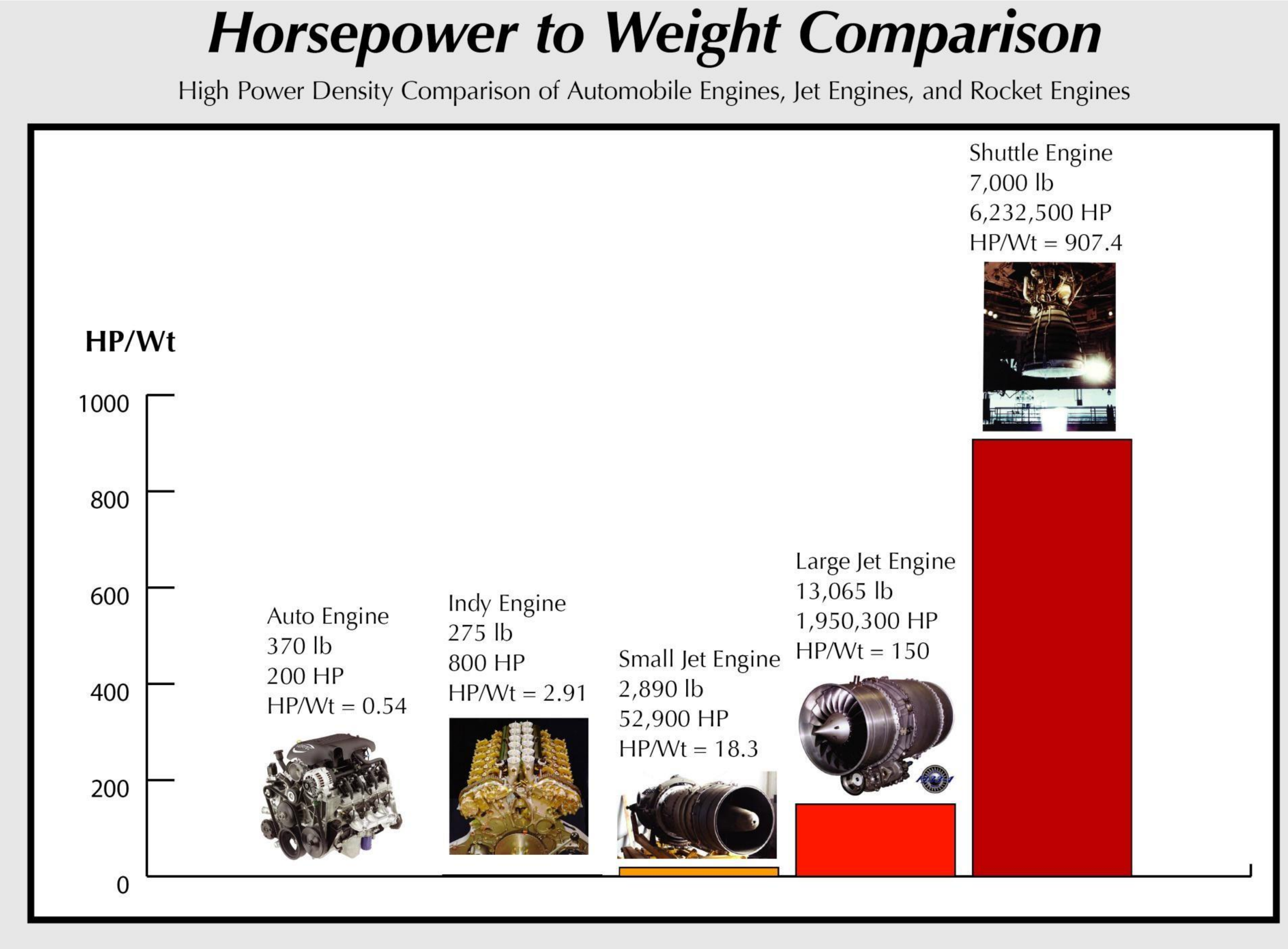
- As ε increases, the exit velocity increases and the exit pressure decreases (higher I_{sp}).
- When possible, ε is selected so that $P_e = P_a$ and the engine operates at optimum thrust.
- For in-space propulsion (i.e., J-2X), the ε is made as large as the weight requirements or volume limitations permit.
- If $P_e > P_a$, then the nozzle is identified as underexpanded and will not provide optimal performance as the plume will continue to expand after exiting the nozzle.
- If $P_e < P_a$, then the nozzle is identified as overexpanded and will not provide optimal performance as the exit shock will migrate inside the nozzle. This can be hazardous from thrust imbalances and damage to the nozzle.

Area Ratio

- Criteria to be considered for selecting a design ε can include the following:
  - ε provides the optimal integrated performance over the engine operating period. Trajectory analysis is used to determine the altitudes (and P_a) that the engine will operate, which can be used to provide an integrated I_{sp} based on ε.
  - ε is optimized to provide the maximum performance during a critical time of the engine operating period. Example: the ε for SSME is optimized at the altitude where the SRBs are staged to provide a needed performance boost at that critical time



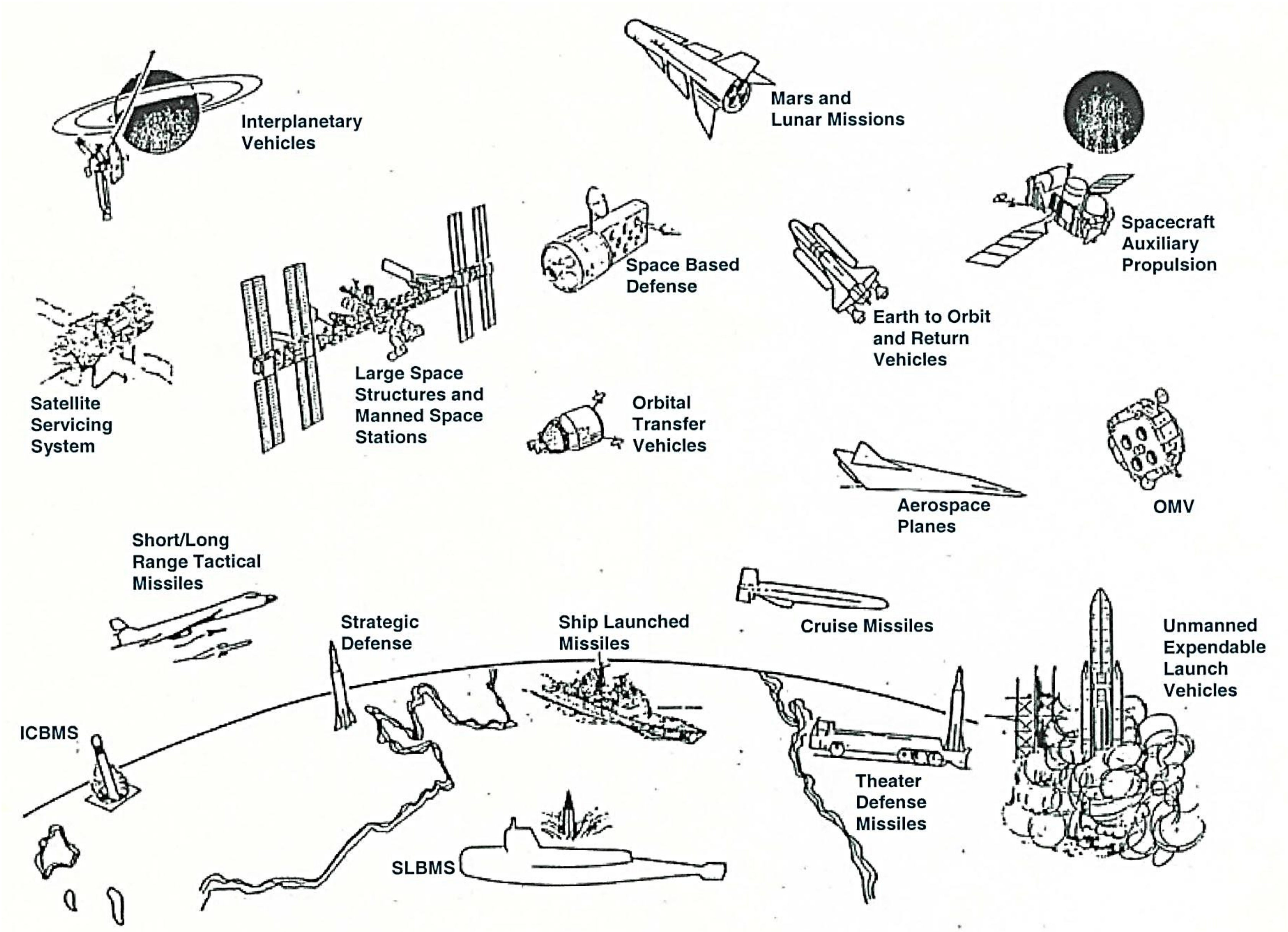
Power Density



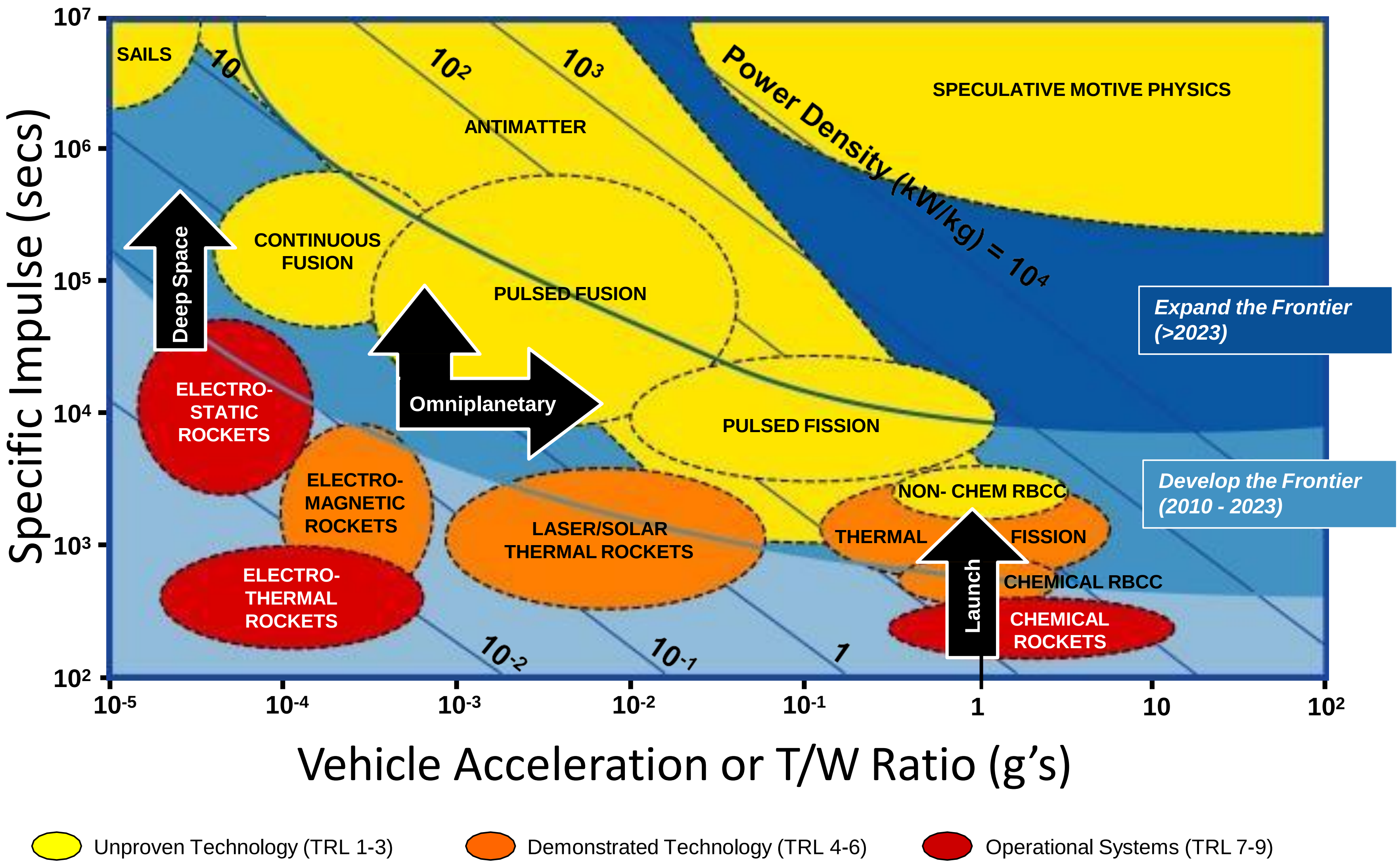
- Problem: Calculate the mass ratio needed to escape Earth’s gravity starting from rest, given that the escape velocity from Earth is about 11.2 10^3 m/s and assuming an exhaust velocity V_e= 2.5x10^3 m/s.

Ans : 1/88

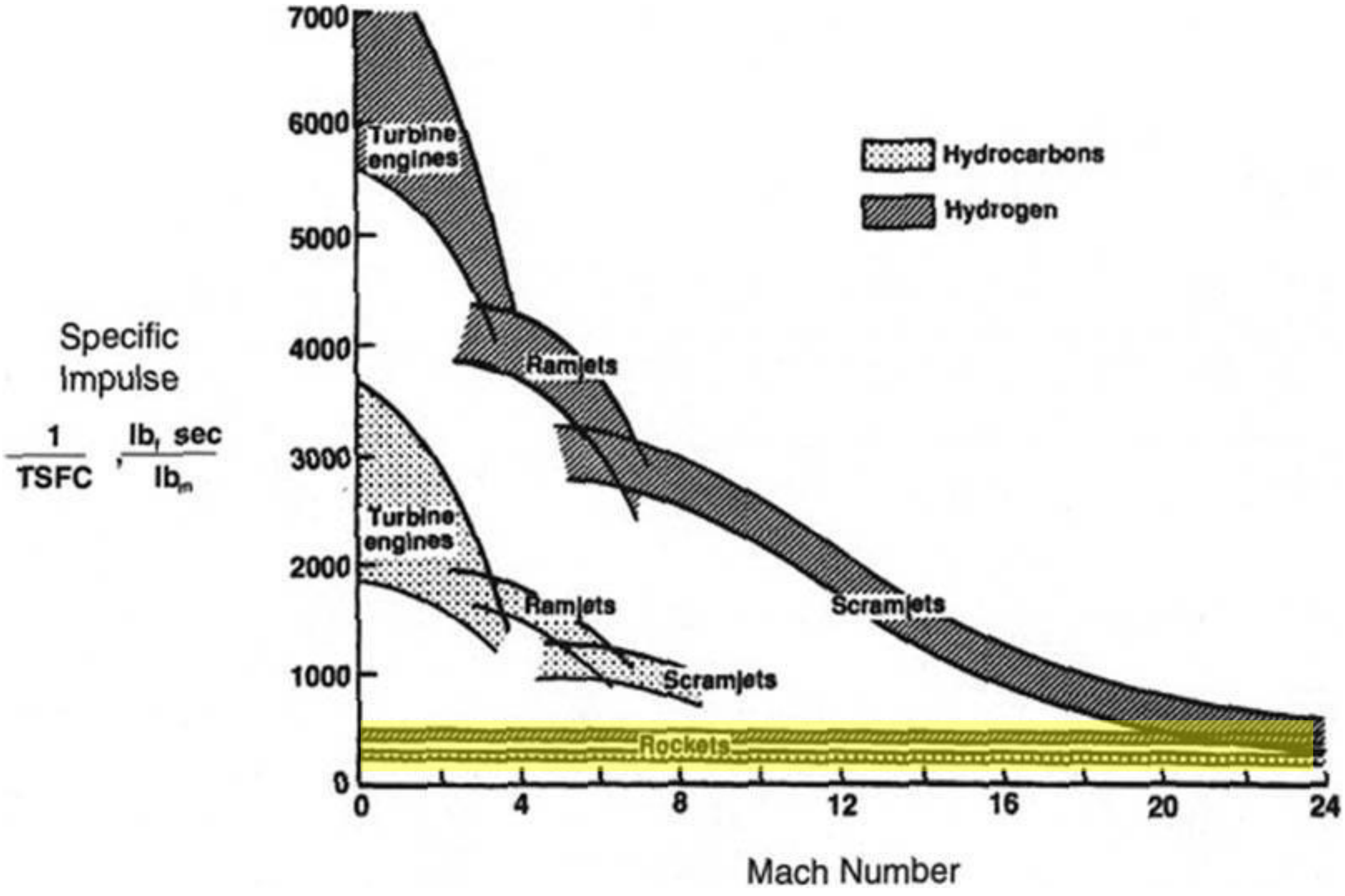
Rocket Propulsion Applications



In-Space Propulsion Performance



Jet Propulsion Options



BALLISTICS

- Knowledge of physical forces acting on a projectile and missile is called Ballistics

OR

- Ballistics is the simply science of motion of a projectile

Types

- Exterior or External Ballistics
- Interior or Internal Ballistics
- Terminal or Wound Ballistics

✓ **Exterior Ballistics** deals with the study of motion of a projectile after it leaves the barrel of a firearm.

✓ **Terminal Ballistics** is the study of effect of impact of a projectile on the target leading to wound formation (Also called Wound Ballistics).

INTERIOR / INTERNAL BALLISTICS

Interior Ballistics is the study of physio-chemical phenomenon within the firearm from the movement of the detonation of primer to the time the projectile leaves the barrel.

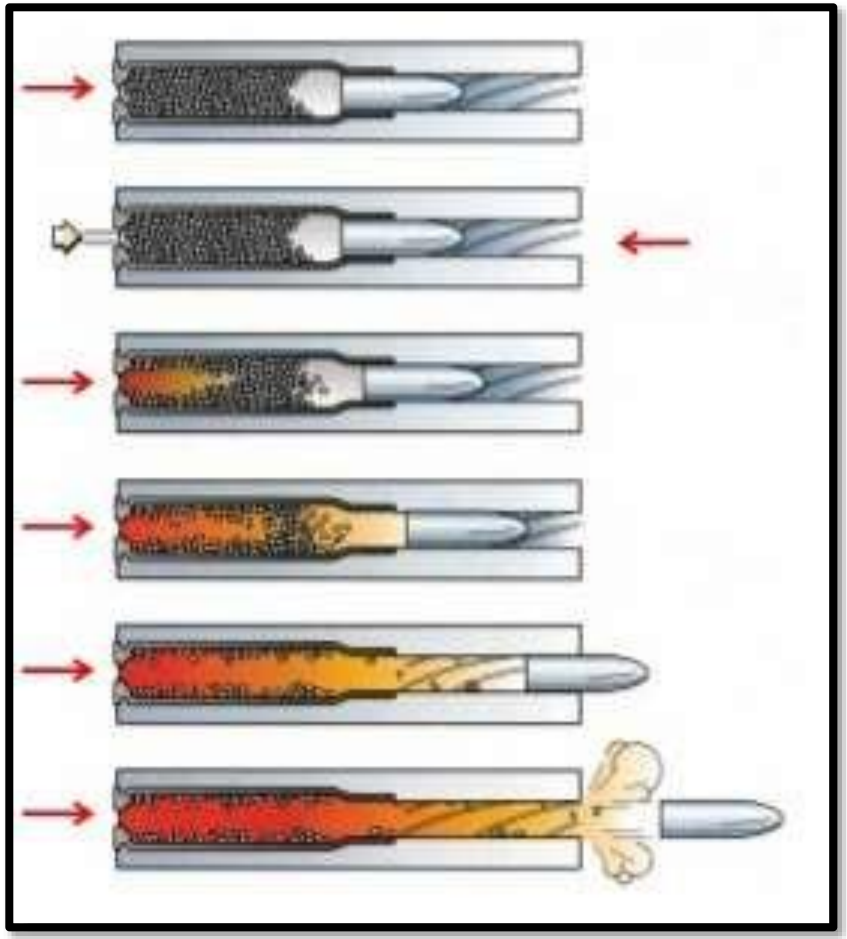
OR

The study of the process originally accelerating the principles is called Interior Ballistics, for example the passage of a bullet through the barrel of a rifle.

Internal Ballistics

- Internal Ballistics, a subfield of ballistics is the study of projectile's behavior from the time its propellant's ignites is initiated until it exits the gun barrel.
- The study of internal ballistics is important to designers and users of firearms of all types.


EXTERIOR BALLISTICS?
I'M OUT OF THE GUN ACCORDING TO PLAN —NOW WHAT?
Initial Speed and Direction
INTERIOR BALLISTICS
Bore Erosion
Propelling Charge and Burning Rate
Powder Temperature
Density and Manner of Loading



The three main factors are-

- Lock Time
- Ignition Time
- Barrel Time

Lock Time

- Lock time is the time interval between release of the sear and the impact of the striker on the percussion cap.
- A short time internal is advantageous in rapid fire.
- The lock time can be measured in a number of ways, in one such system the use of linear Motion sensors and an oscilloscope is made.

Ignition Time

- Ignition time is the duration or interval between the striking of the firing pin to blow the ignition of the first grain of powder.
- The ignition, under the normal conditions, takes place at an interval of about 0.002 seconds.

Barrel Time

- Barrel time is the time interval from the pressing of the trigger to the exit of the bullet from the muzzle end.
- In case of most of the weapons Lock time + Ignition time + barrel time varies from 0.003 to 0.007 seconds.

INTERIOR / INTERNAL BALLISTICS

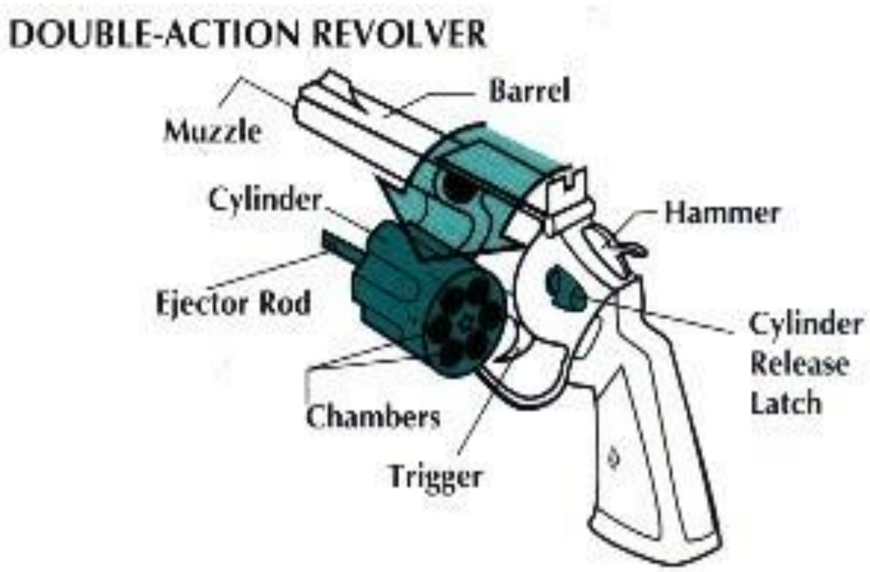
It includes……

I. Structure of Firearm.
II. Design of Ammunition.
III. Chain/Sequence of events.

i. Structure of firearm

Every firearm is basically divided into three parts…..

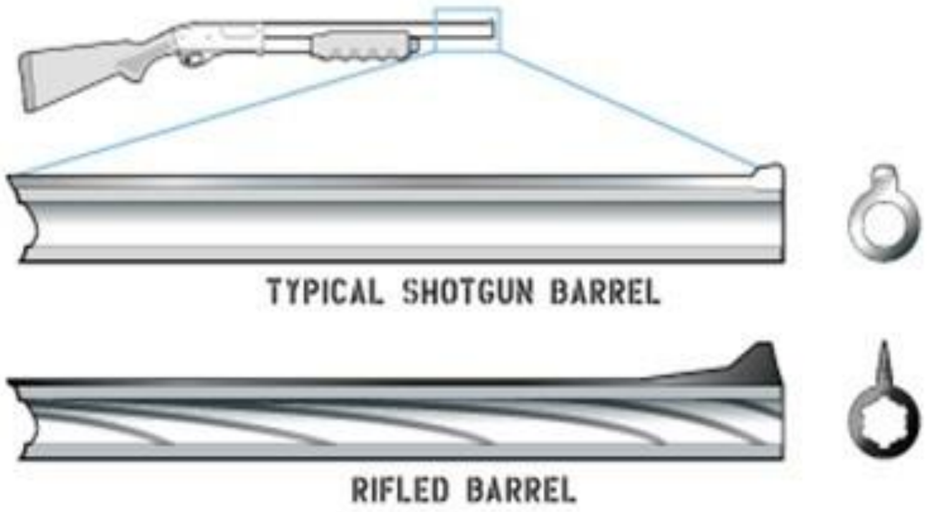
- Grip portion
- Action portion having thr trigger
- Front portion called the barrel



Structure of firearm

- Barrel….. Steel tube for jetting of the projectile
  - Breach end
  - Muzzle end

- Bore/Callibre….. Internal diameter of the barrel.
  - Smooth
  - Choked
  - Non-Choked
- Rifled
  - Short barrel
  - Long barrel



Rifling

- It consists of grooves or cuts formed in a spiral nature lengthwise down the barrel of a firearm.

- Because bullets are oblong objects, they must spin in their fight like a thrown football, to be accurate

Lands….. Raised areas between two grooves

Grooves….. Depressed areas

- Rifling pattern of eight grooves will also have eight lands.

II. AMMUNITION DESIGN

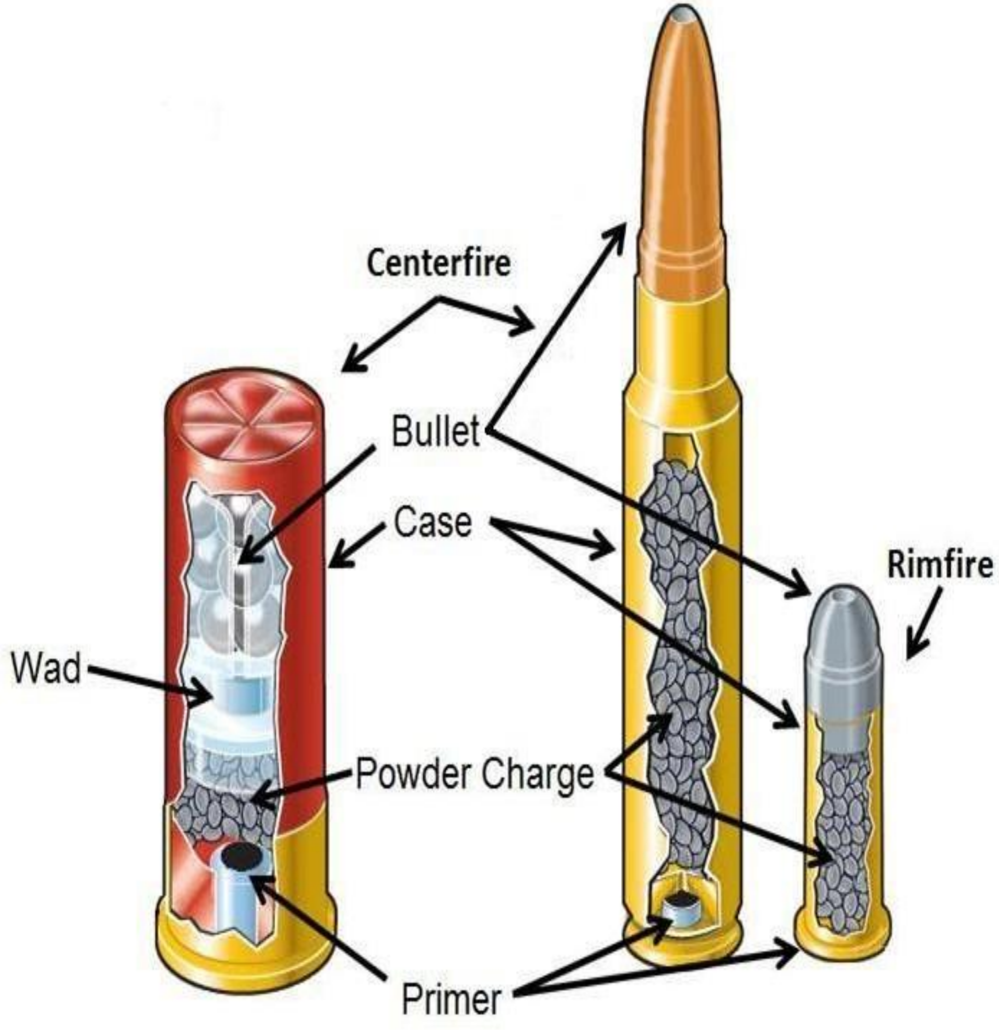
- Cartridge Case
- Primer

Powder Charge

I. Black
II. Smokeless

- Plastic wad
- Short charge

I. Bullet
II. Pellets



AMMUNITION CASES

- **Cartridge cases** are made up of plastic and card board.
- **Bullet cases** are made up of brass(70% copper & 30% Zinc, some have nickel coating).
- **Primer cases** are of similar composition (Copper & Zinc).
- **Bullet cores** are most often lead and antimony with a very few have ferrous alloy core.
- **Bullet jackets** are usually brass, 90% copper with 10% Zinc but some are a ferrous alloy & some are aluminum. Some bullet coating may also contain nickel.

Types of Ammunition

Primer

- The major primer elements are lead, barium or Antimony. Usually all three are present.
- Less common elements include aluminium, Sulphur, Tin, Calcium, Potassium, Chlorine and Silicon.
- Primer elements may be easier to detect in residue because they don’t get as hot as powder and compounds may be detectable.

Powder Charge

- Modern gun powder or smokeless powder can contain upto 23 organic compounds.
- Nitrocellulose is virtually always present along with other compounds containing nitrates or nitrogen.

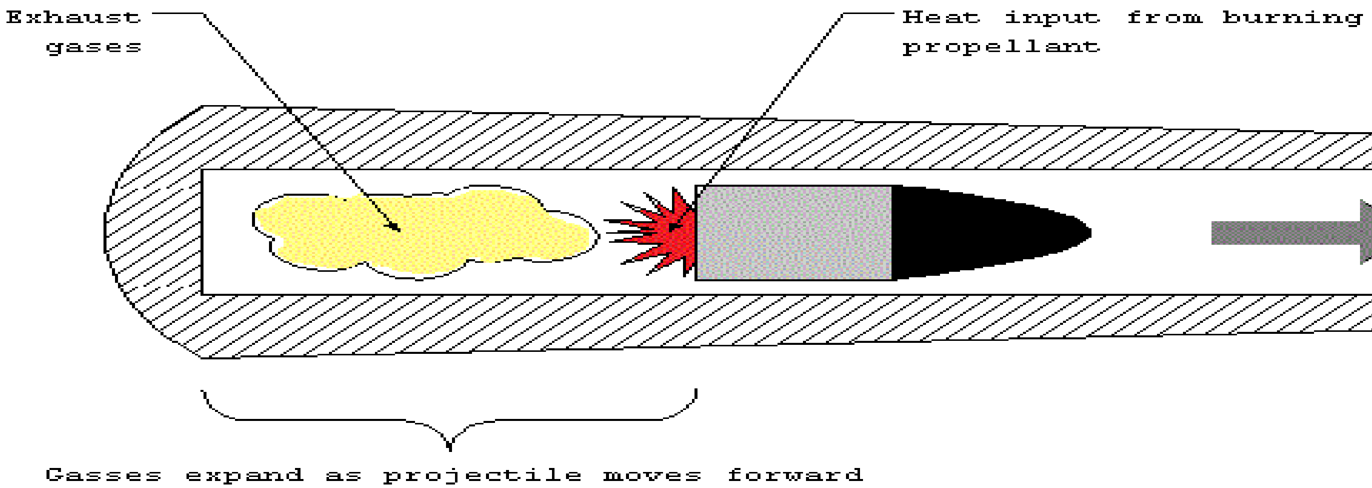
I. **Single base…..** The basic ingredient is nitrocellulose.

II. **Double base…..** When there is added 40% Nitroglycerine to nitrocellulose.

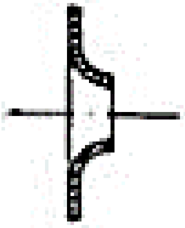
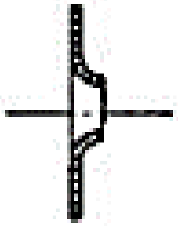
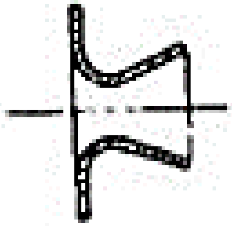
Powder Charge

Chain Sequence of Events

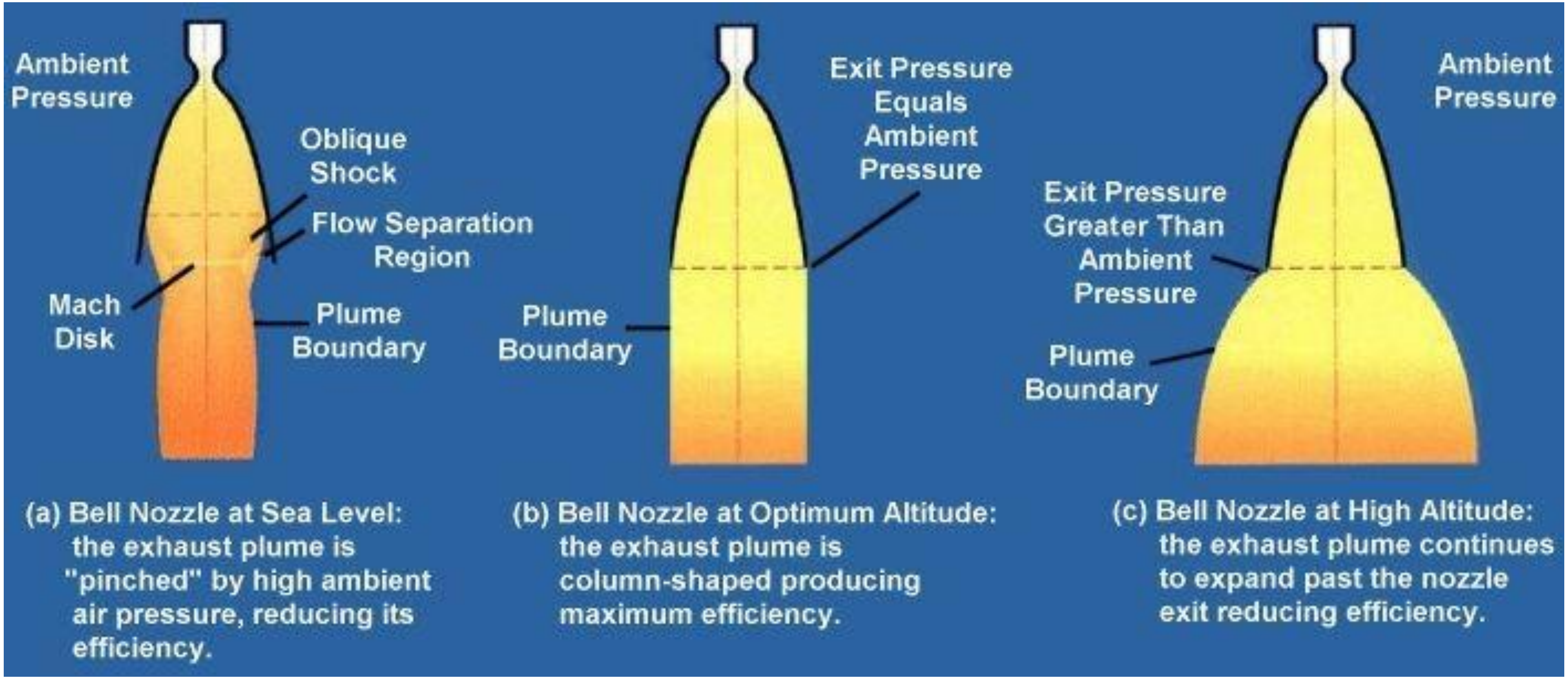
- Hammer Strikes
- Primer Ignites
- Powder charge burns
- Temperature increases
- Gases produced
- Chamber pressure increased
- Bullet charge moves
- Exit of bullet
- Chamber pressure = Zero



Nozzle Types

	Subsonic	Sonic	Supersonic
Throat velocity	$v_1 < a_t$	$v_t = a_t$	$v_t = a_t$
Exit velocity	$v_2 < a_2$	$v_2 = v_t$	$v_2 > v_t$
Mach number	$M_2 < 1$	$M_2 = M_t = 1.0$	$M_2 > 1$
Pressure ratio	$\frac{p_1}{p_2} < \left(\frac{k+1}{2}\right)^{k/(k-1)}$	$\frac{p_1}{p_2} = \frac{p_1}{p_t} = \left(\frac{k+1}{2}\right)^{k/(k-1)}$	$\frac{p_1}{p_2} > \left(\frac{k+1}{2}\right)^{k/(k-1)}$
Shape			

Rocket Nozzle Classification



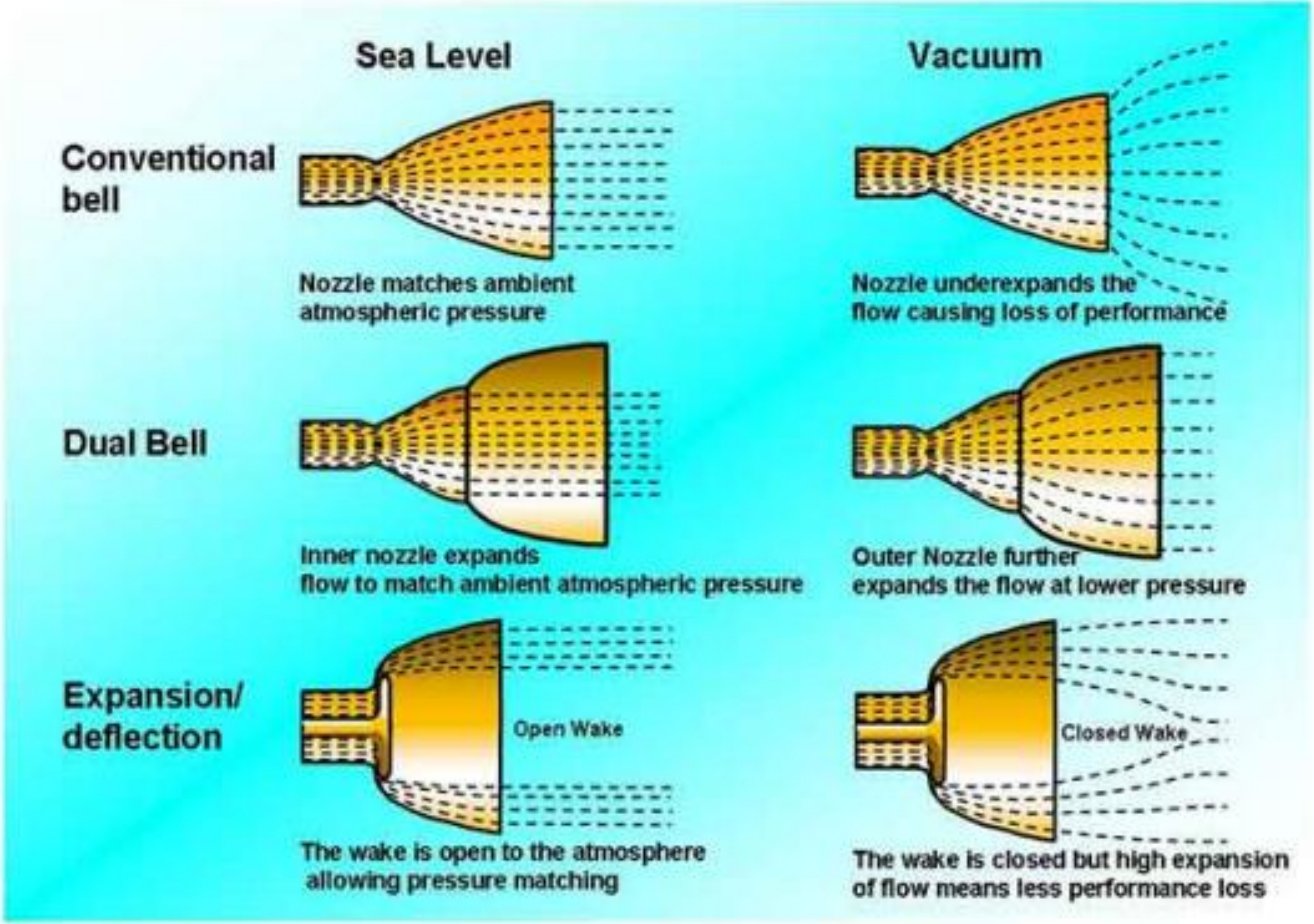
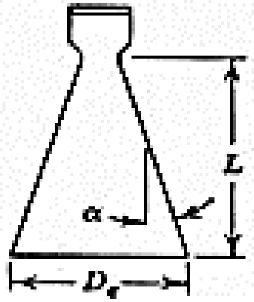
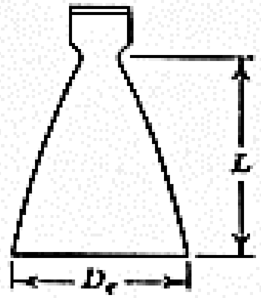
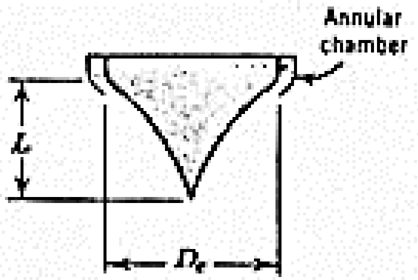
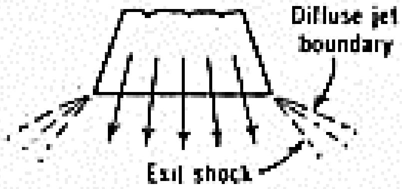
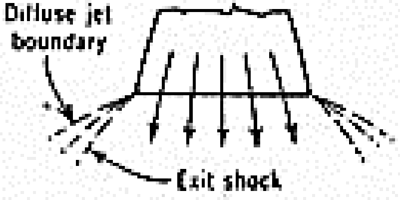
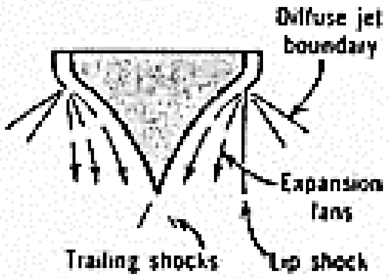
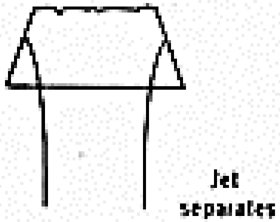
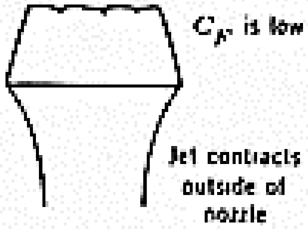
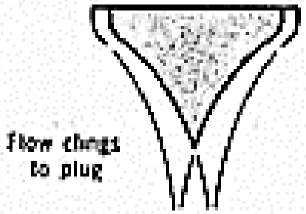
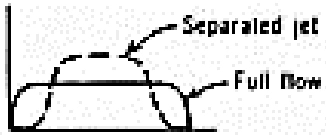
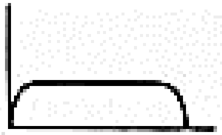
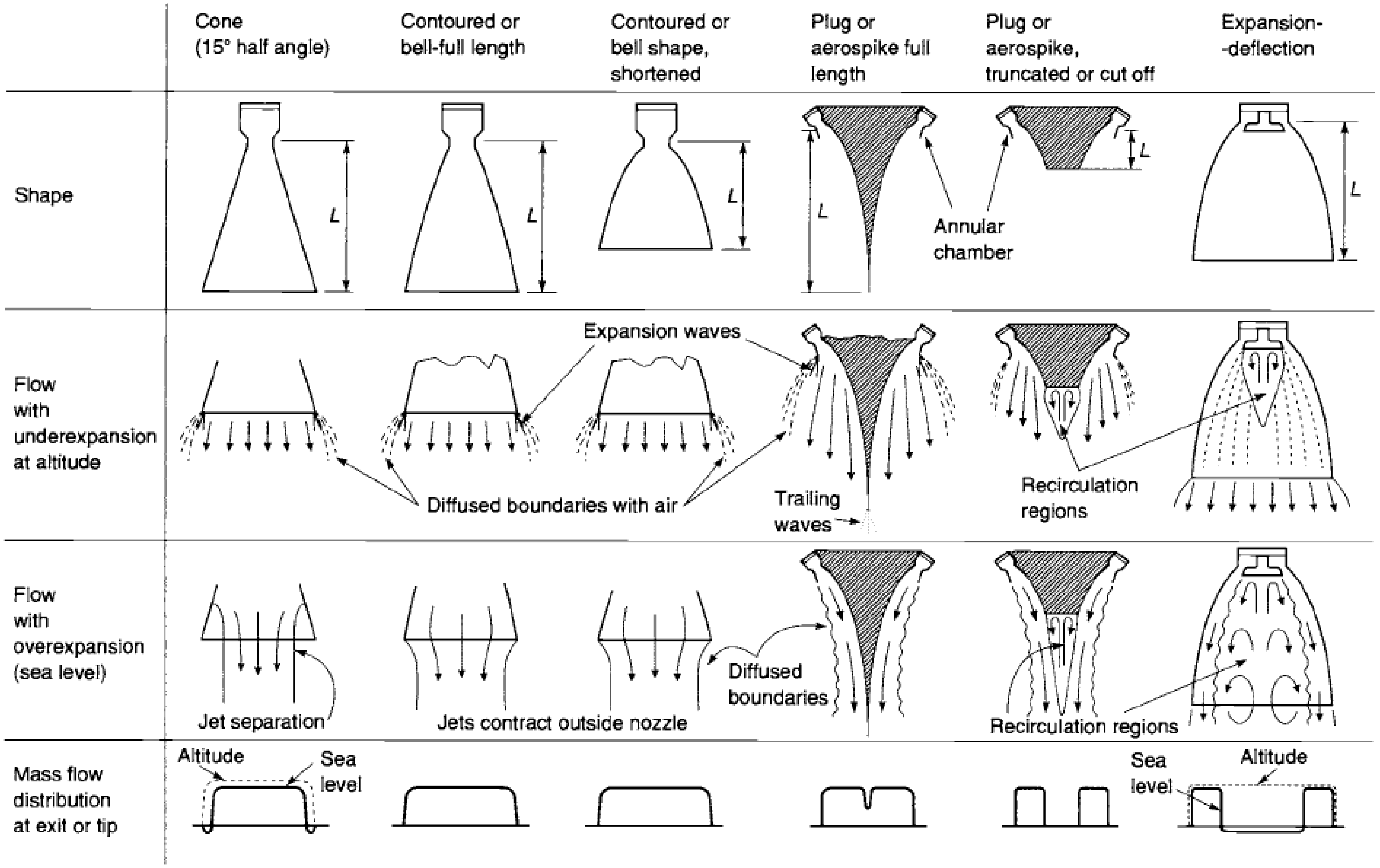
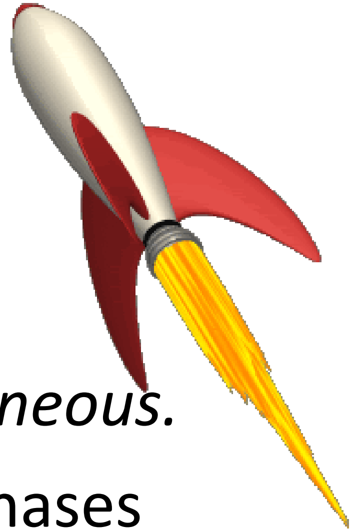


Figure 1. Nozzle types

	Cone	Contoured or Bell-Shaped	Plug
Shape			
Flow with underexpansion, altitude			
Flow with overexpansion, (Sea level)			
Mass flow distribution at exit			


Cone
(15° half angle)
Contoured or
bell-full length
Contoured or
bell shape,
shortened
Plug or
aerospike full
length
Plug or
aerospike,
truncated or cut off
Expansion-
-deflection
Shape
L
Annular
chamber
Flow
with
underexpansion
at altitude
Expansion waves
Diffused boundaries with air
Trailing
waves
Recirculation
regions
Flow
with
overexpansion
(sea level)
Jet separation
Jets contract outside nozzle
Diffused
boundaries
Recirculation regions
Mass flow
distribution
at exit or tip
Altitude
Sea
level

Rocket performance considerations



1. The working substance (or chemical reaction products) is *homogeneous.*
2. All the species of the working fluid are *gaseous.* Any condensed phases (liquid or solid) add a negligible amount to the total mass.
3. The working substance obeys the *perfect gas law.*
4. There is no *heat transfer* across the rocket walls; therefore, the flow is adiabatic.
5. There is no appreciable *friction* and all *boundary layer* effects are neglected.

Contd..

6. There are no *shock waves* or *discontinuities* in the nozzle flow.

7. The *propellant flow* is *steady* and *constant.* The expansion of the working fluid is uniform and steady, without vibration. Transient effects (i.e., start up and shut down) are of very short duration and may be neglected.

8. All exhaust gases leaving the rocket have an *axially directed velocity.*

9. The gas velocity, pressure, temperature, and density are all uniform across any section normal to the nozzle axis.

10. *Chemical equilibrium* is established within the rocket chamber and the gas composition does not change in the nozzle (frozen flow).

11. Stored propellants are at room temperature. Cryogenic propellants are at their boiling points.

IGNITION SYSTEM IN ROCKETS

- 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 chamber pressure and flow

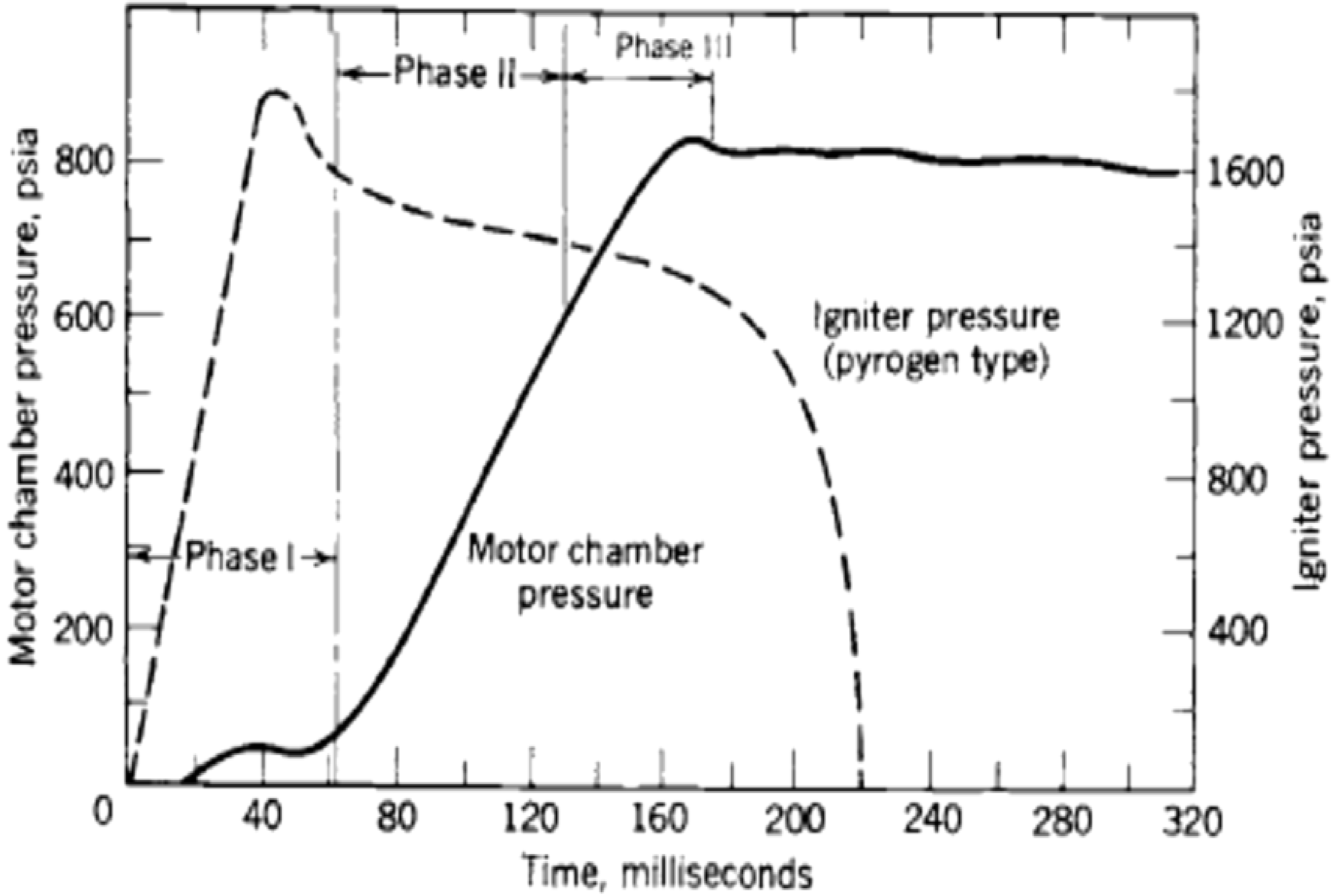
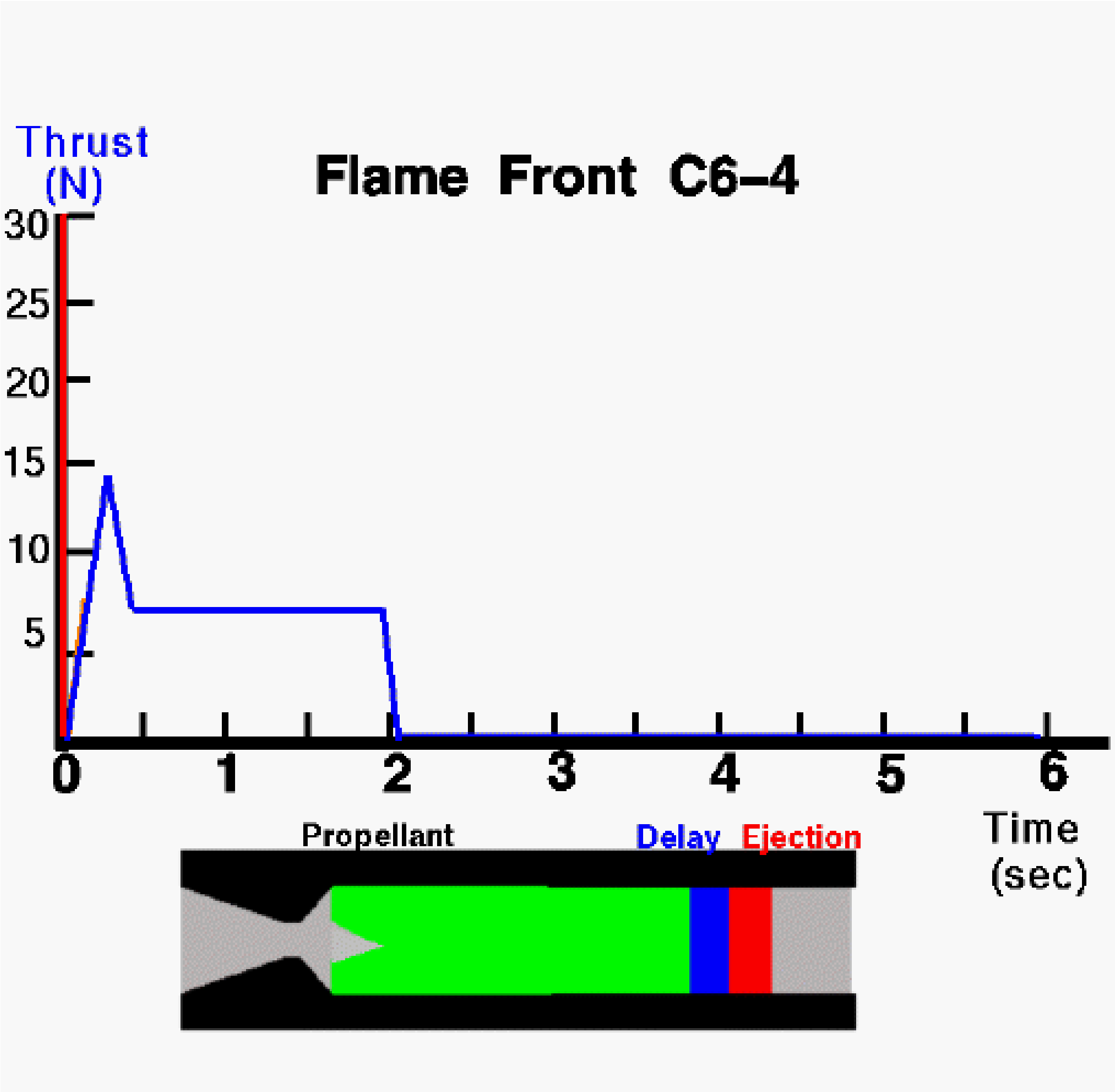
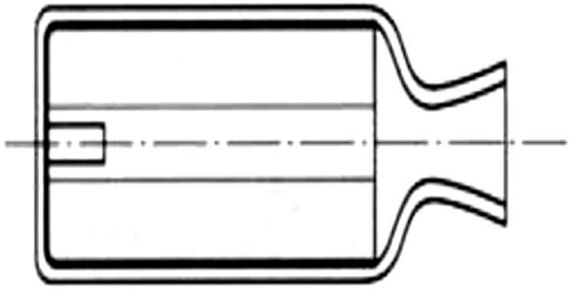


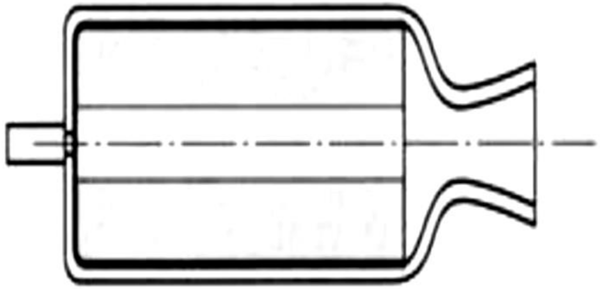
Fig. Typical ignition pressure transient portion of motor chamber pressure time trace with igniter pressure trace and ignition process phases


Flame Front C6–4
Thrust
(N)
30
25
20
15
10
5
0
1
2
3
4
5
6
Time
(sec)
Propellant
Delay
Ejection

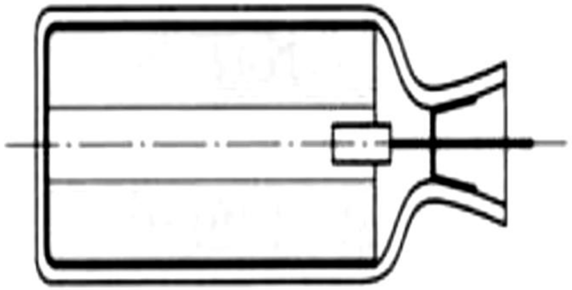
Types of igniters



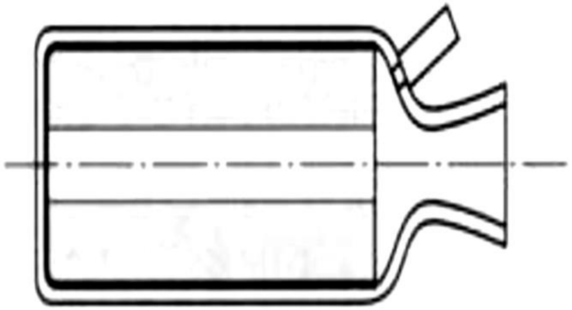
Aft, internal



Aft, external



Forward, internal
(supported by nozzle exit cone)



Forward, external

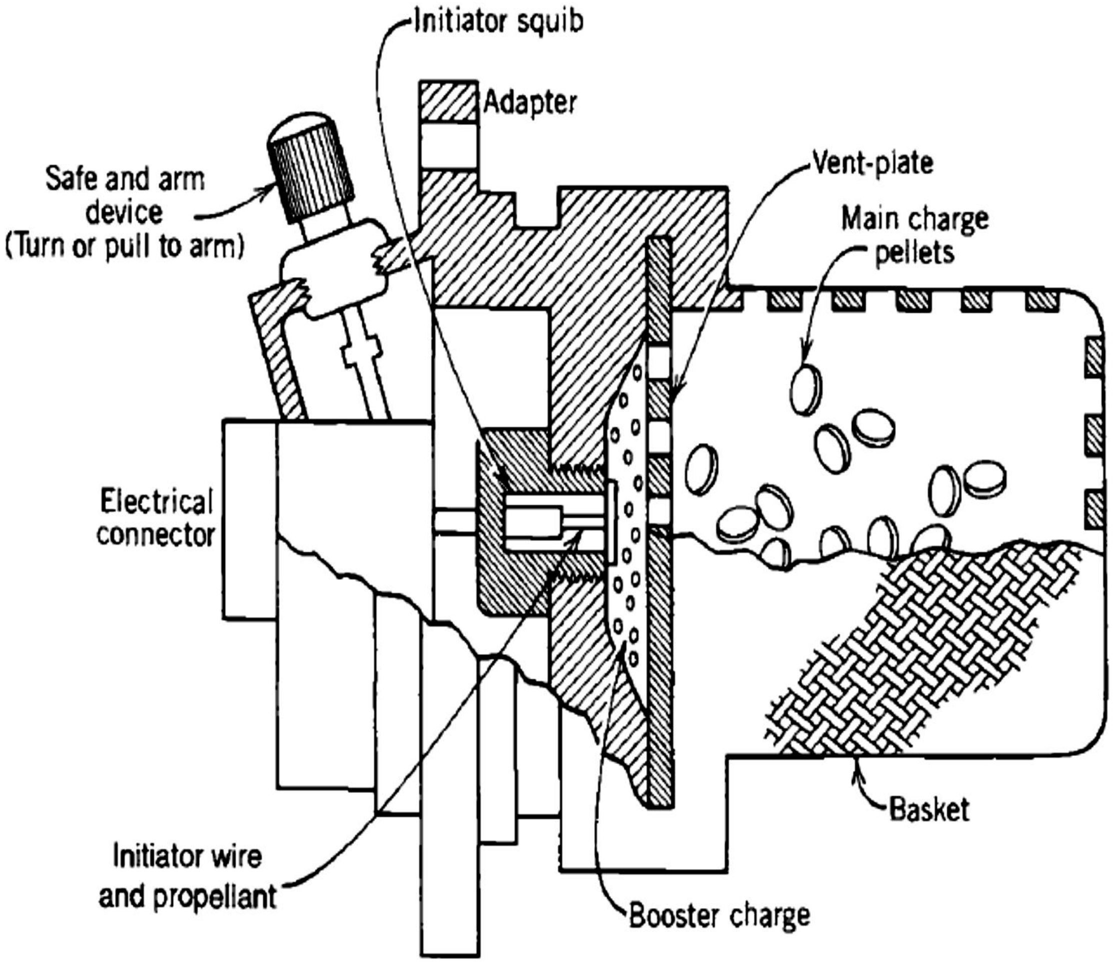
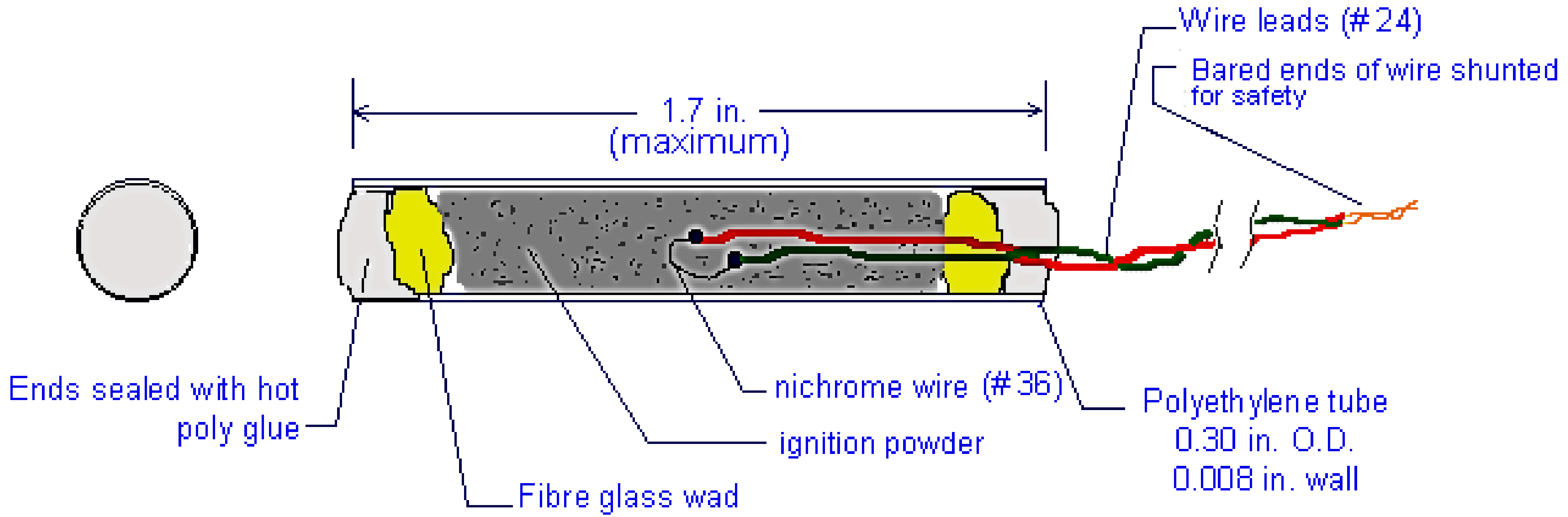


Fig. Typical pyrotechnic igniter with three different propellant charges that ignite in sequence

Pyrotechnic Igniters

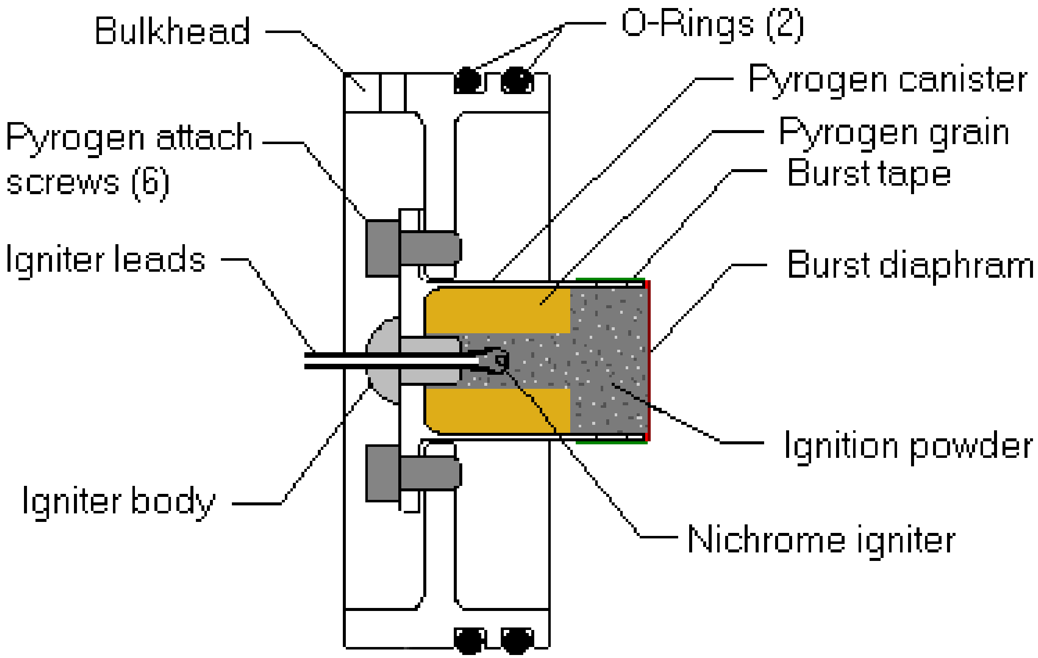
- In industrial practice, pyrotechnic igniters are defined as igniters (other than pyrogen-type igniters as defined further on) using solid explosives or energetic propellant-like chemical formulations (usually small pellets of propellant which give a large burning surface and a short burning time) as the heat-producing material.
- This definition fits a wide variety of designs, known as bag and carbon igniters, powder can, plastic case, pellet basket, perforated tube, combustible case, jellyroll, string, or sheet igniters.

Pyrotechnic Igniter

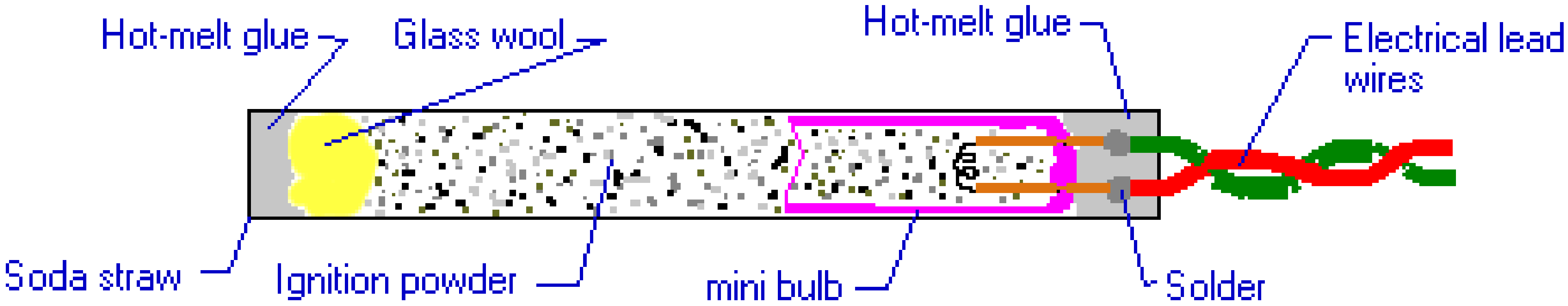


Pyrogen Ignition

- A pyrogen is essentially a small rocket motor mounted at the bulkhead. Nearly instantaneous ignition of the motor grain is assured by the high velocity, particle-laden flame that emanates from the pyrogen. The pyrogen used for the Kappa rocket motor is shown in Figure.



Mini-bulb Igniter



- The igniter described here may be used for either *motor ignition* or for firing a *parachute ejection charge*.
- To make this igniter (shown in Figure), the plastic base of the mini-bulb is first removed (by pulling) and discarded. This exposes the two copper wire leads, which are then scraped clean of oxide, The glass bulb is then carefully broken open. The simplest means is to slowly squeeze the upper half of the bulb in a bench vise. The bulb is first covered with a cloth rag to catch the tiny shards of glass the erupt once the vacuum seal is broken. Safely glasses must be worn during this operation as a redundant safety measure. Care must be taken to prevent damage to the filament bridge wire or to break the lower portion of the bulb.

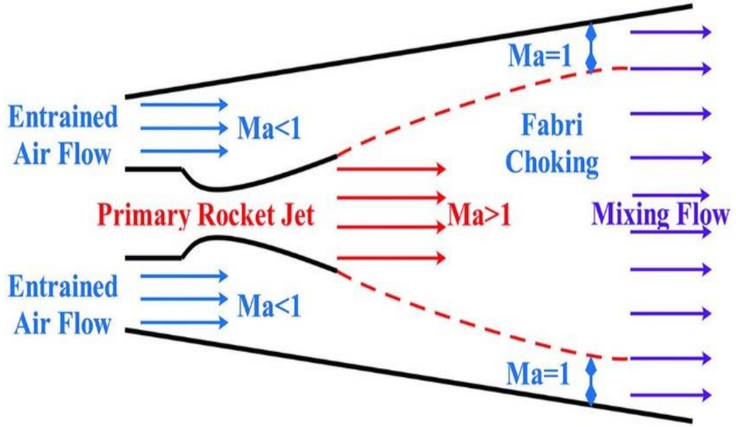
Ultra-low Current Igniter

An igniter that requires very low electrical power, requiring only 20 mA at 1.2V (= 25mW) to fire. As such, this design is exceptionally reliable and especially useful in cold weather operation, which greatly reduces a typical battery's available power. This igniter may be used for either motor ignition or for firing a parachute ejection charge.

The "Ultra-low Current Igniter" was developed for EARco (Experimental Aerospace Research) by Ken Tucker to increase the safety of Rocketry.

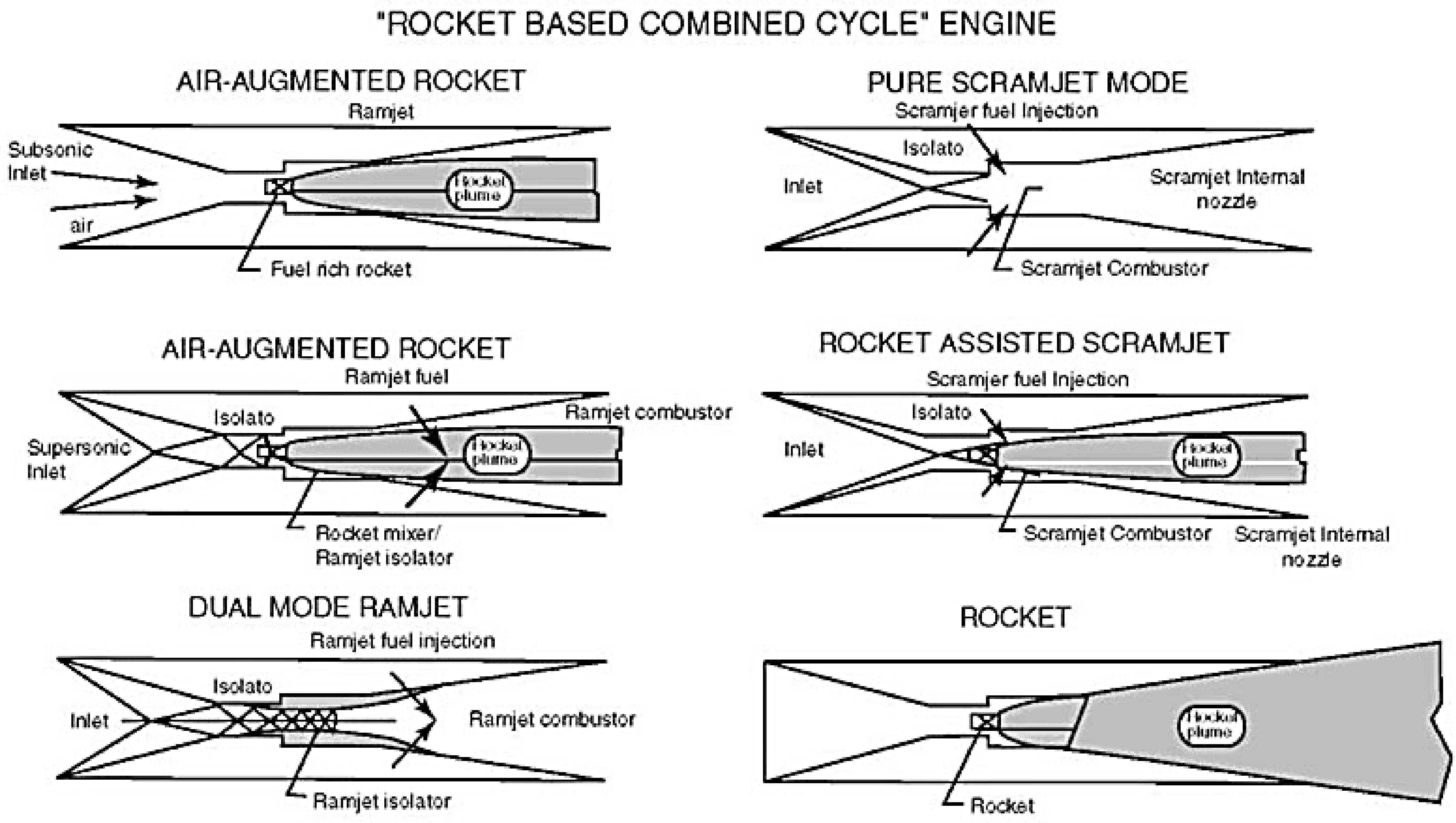
Preliminary concepts in nozzle less propulsion

Air augmented rockets



Air-augmented rockets (also known as rocket-ejector, ramrocket, ducted rocket, integral rocket/ramjets, or ejector ramjets) use the supersonic exhaust of some kind of rocket engine to further compress air collected by ram effect during flight to use as additional working mass, leading to greater effective thrust for any given amount of fuel than either the rocket or a ramjet alone.

It represents a hybrid class of rocket/ramjet engines, similar to a ramjet, but able to give useful thrust from zero speed, and is also able in some cases to operate outside the atmosphere, with fuel efficiency not worse than both a comparable ramjet or rocket at every point.



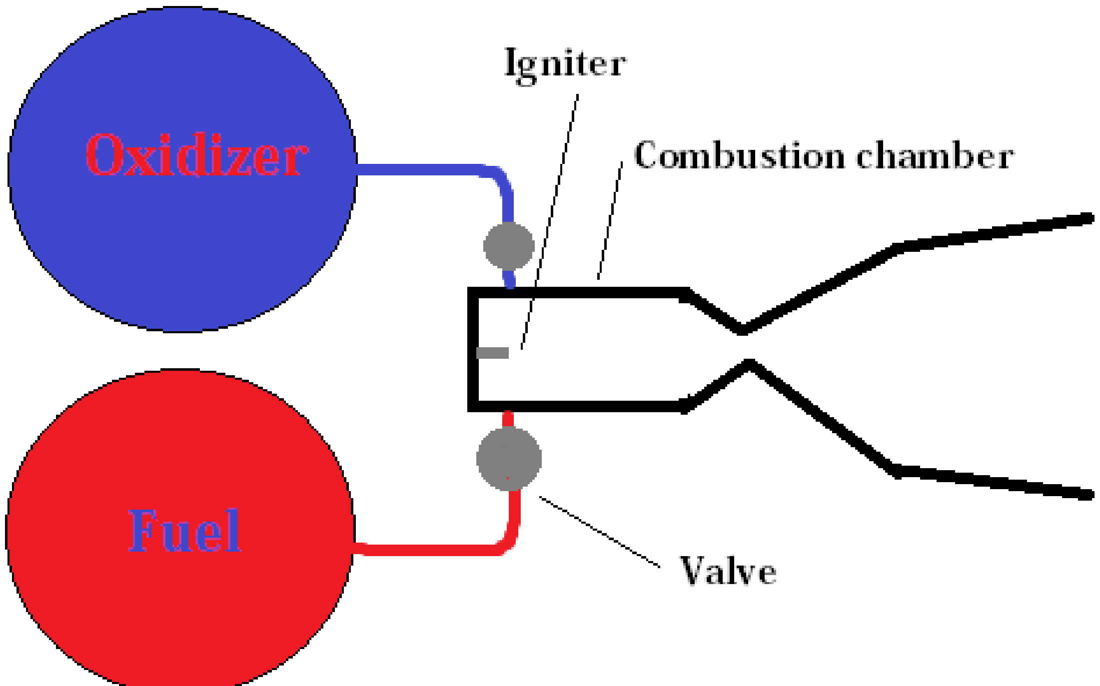
"ROCKET BASED COMBINED CYCLE" ENGINE
AIR-AUGMENTED ROCKET
Ramjet
Subsonic
Inlet
air
Fuel rich rocket
PURE SCRAMJET MODE
Scramjer fuel Injection
Isolato
Inlet
Scramjet Internal
nozzle
Scramjet Combustor
AIR-AUGMENTED ROCKET
Ramjet fuel
Isolato
Ramjet combustor
Supersonic
Inlet
Rocket mixer/
Ramjet isolator
ROCKET ASSISTED SCRAMJET
Scramjer fuel Injection
Isolato
Inlet
Scramjet Combustor
Scramjet Internal
nozzle
DUAL MODE RAMJET
Ramjet fuel injection
Isolato
Inlet
Ramjet combustor
Ramjet isolator
ROCKET
Rocket

Pulse rocket motors

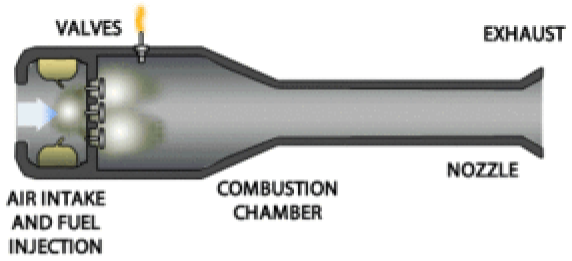
- A pulsed rocket motor is typically defined as a multiple pulse solid-fuel rocket motor. This design overcomes the limitation of solid propellant motors that they cannot be easily shut down and reignited. The pulse rocket motor allows the motor to be burned in segments (or pulses) that burn until completion of that segment. The next segment (or pulse) can be ignited on command by either an onboard algorithm or in pre-planned phase. All of the segments are contained in a single rocket motor case as opposed to staged rocket motors.[1]

- The pulsed rocket motor is made by pouring each segment of propellant separately. Between each segment is a barrier that prevents the other segments from burning until ignited. At ignition of a second pulse the burning of the propellant generally destroys the barrier.

- The benefit of the pulse rocket motor is that by the command ignition of the subsequent pulses, near optimal energy management of the propellant burn can be accomplished. Each pulse can have different thrust level, burn time, and achieved specific impulse depending on the type of propellant used, its burn rate, its grain design, and the current nozzle throat diameter.[2]



ANIMATION OF A PULSE JET ENGINE

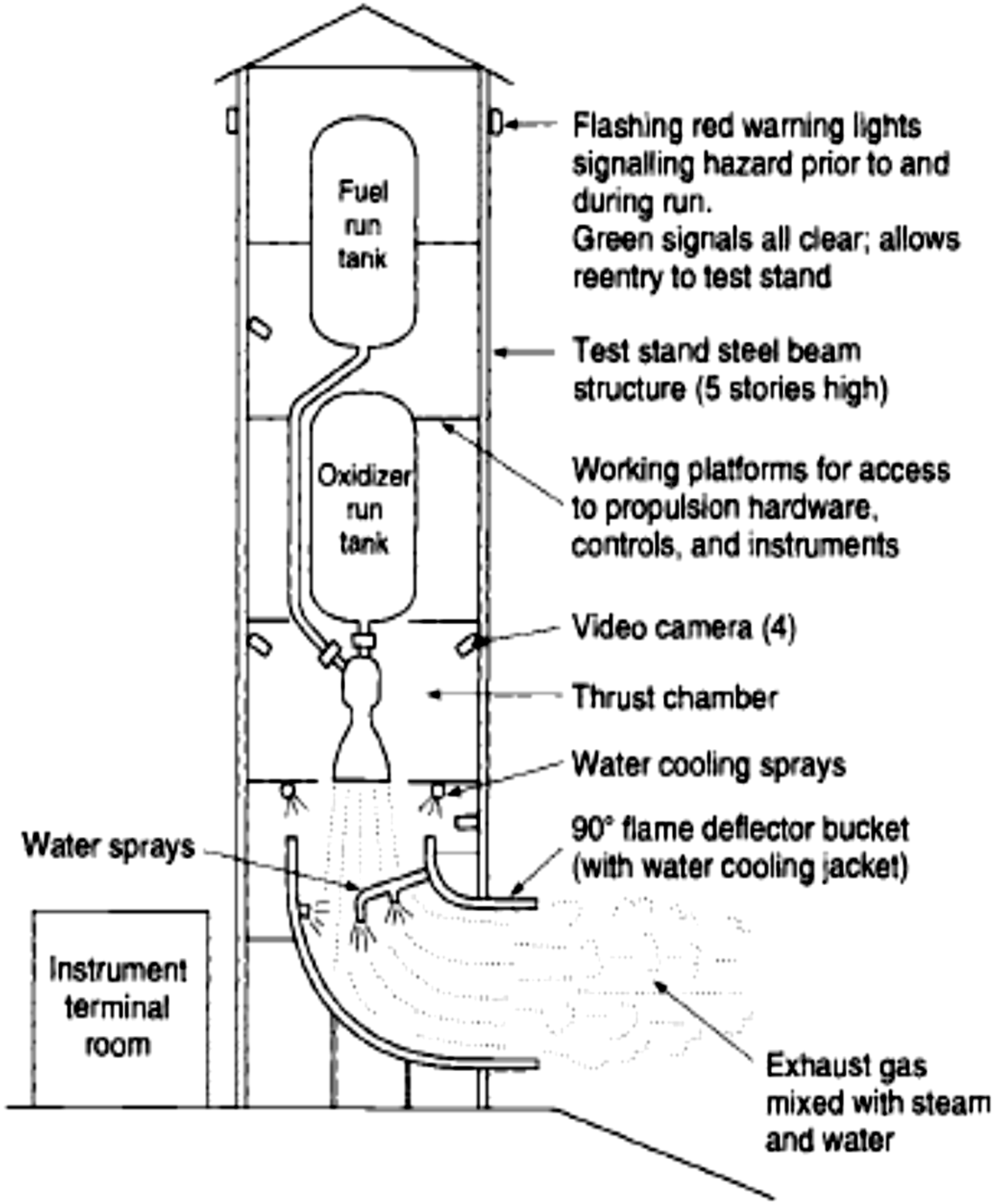


1. Valves are opened and a load of gaseous propellent enters the chamber at a low pressure ~ 3 atm
2. Valves are closed and the propellent is ignited in a high pressue pulse.
3. Valves are opened and a new load of propellent fills the chamber.
4. Valves are closed and the propellent is ignited in a high pressue pulse.
5. The cycle continues.

Static testing of rockets and instrumentation,

For chemical rocket propulsion systems, each test facility usually has the following major systems or components:

1. A test cell or test bay where the article to be tested is mounted, usually in a special test fixture. If the test is hazardous, the test facility must have provisions to protect operating personnel and to limit damage in case of an accident.
2. An instrumentation system with associated computers for sensing, maintaining, measuring, analyzing, correcting, and recording various physical and chemical parameters. It usually includes calibration systems and timers to accurately synchronize the measurements.
3. A control system for starting, stopping, and changing the operating conditions.
4. Systems for handling heavy or awkward assemblies, supplying liquid propellant, and providing maintenance, security, and safety.
5. For highly toxic propellants and toxic plume gases it has been required to capture the hazardous gas.


Fuel run tank
Oxidizer run tank
Flashing red warning lights signalling hazard prior to and during run.
Green signals all clear; allows reentry to test stand
Test stand steel beam structure (5 stories high)
Working platforms for access to propulsion hardware, controls, and instruments
Video camera (4)
Thrust chamber
Water cooling sprays
Water sprays
90° flame deflector bucket (with water cooling jacket)
Instrument terminal room
Exhaust gas mixed with steam and water

Safety considerations

1. Concrete-walled blockhouse or control stations for the protection of personnel and instruments remote from the actual rocket propulsion location.
2. Remote control, indication, and recording of all hazardous operations and measurements; isolation of propellants from the instrumentation and control room.
3. Automatic or manual water deluge and fire-extinguishing systems.
4. Closed circuit television systems for remotely viewing the test.
5. Warning signals (siren, bells, horns, lights, speakers) to notify personnel to clear the test area prior to a test, and an all-clear signal when the conditions are no longer hazardous.
6. Quantity and distance restrictions on liquid propellant tankage and solid propellant storage to minimize damage in the event of explosions; separation of liquid fuels and oxidizers.
7. Barricades around hazardous test articles to reduce shrapnel damage in the event of a blast.
8. Explosion-proof electrical systems, spark-proof shoes, and non-spark hand tools to prevent ignition of flammable materials.
9. For certain propellants also safety clothing , including propellant- and fire-resistant suits, face masks and shields, gloves, special shoes, and hard hats.
10. Rigid enforcement of rules governing area access, smoking, safety inspections, and so forth.
11. Limitations on the number of personnel that may be in a hazardous area at any time.

Instrumentation

1. Forces (thrust, thrust vector control side forces, short thrust pulses).

2. Flows (hot and cold gases, liquid fuel, liquid oxidizer, leakage).

3. Pressures (chamber, propellant, pump, tank, etc.).

4. Temperatures (chamber walls, propellant, structure, nozzle).

5. Timing and command sequencing of valves, switches, igniters, etc.

6. Stresses, strains, and vibrations (combustion chamber, structures, propellant lines, accelerations of vibrating parts).

7. Time sequence of events (ignition, attainments of full pressure).

8. Movement and position of parts (valve stems, gimbal position, deflection of parts under load or heat).Voltages, frequencies, and currents in electrical or control subsystems.

9. Visual observations (flame configuration, test article failures, explosions) using high-speed cameras or video cameras.

THANK YOU

Answer These Questions ?

- What is the meaning of thrust, total impulse and specific impulse?
- What are the advantages and disadvantages of solid fueled rockets?
- What are the advantages and disadvantages of liquid fueled rockets?
- What are the advantages and disadvantages of hypergolic fueled rockets?
- What was the main contribution of Tsiolkovsky to rocket science?
- What was the main contribution of Oberth to rocket science?
- What was the main contribution of Goddard to rocket science?
- What is the V-2 program and how was it such a technological leap over previous rocket research?

- Explain the difference between how a jet engine, like that described in Theory of Flight, and a rocket engine function. Why don't we use jet engines on rockets?
- Using what you know about forces, explain whether the rocket in the following situations is balanced or unbalanced. If it is unbalanced, describe which force is greater than the others. Use a free-body diagram to help you.
- a. Rocket during launch.
- b. Rocket during re-entry.
- c. Rocket in orbit at constant velocity.
- d. Rocket accelerating in orbit.
- e. A Lunar Excursion Module (LEM) sitting on the moon.
- Why don't we use ailerons, rudders and elevators to control the direction of flight in space?
- Using what you have learned about Mass Fraction (MF) describe the characteristics of rockets with the following MF's. Will they fly? If so, how much payload can they carry? On what types of missions can they be used?
- a. 0.0
- b. 0.27
- c. 0.49
- d. 0.77
- e. 0.96