LAUNCH VEHICLE AND MISSILE TECHNOLOGY

IVB. Tech II semester (JNTUH R-15)

BY

Mr. GSD Madhav

Assistant Professor

DEPARTMENT OF AERONAUTICAL ENGINEERING

INSTITUTE OF AERONAUTICAL ENGINEERING

(Autonomous)

DUNDIGAL, HYDERABAD - 500 043

UNIT-1
SPACE LAUNCH VEHICLES

TYPES

1. EXPANDABLE
2. REUSABLE

TYPES OF MISSILES

- TINY MODELS
- SPACE PROBES
- ROCKET TORPEDOS
- ROCKET POWERED AIRCRAFT
- ROCKET CARS

Types of launch vehicles based on

- Launch plaot form :

  Land: space craft & fixed missile silo
  (sterela) for converted ICMB's

  Sea: fixed platform (san marco), mobile plotform (sea launch), submarine for converted SLBM's

  Air: Aircraft, balloon,

- By size:

- Many ways to classify the sizes of launch vehicles

  small, medium, heavy lift launch vehicles

MISSION

- To insert a specified payload into a specified orbit to the reqd tolerances with

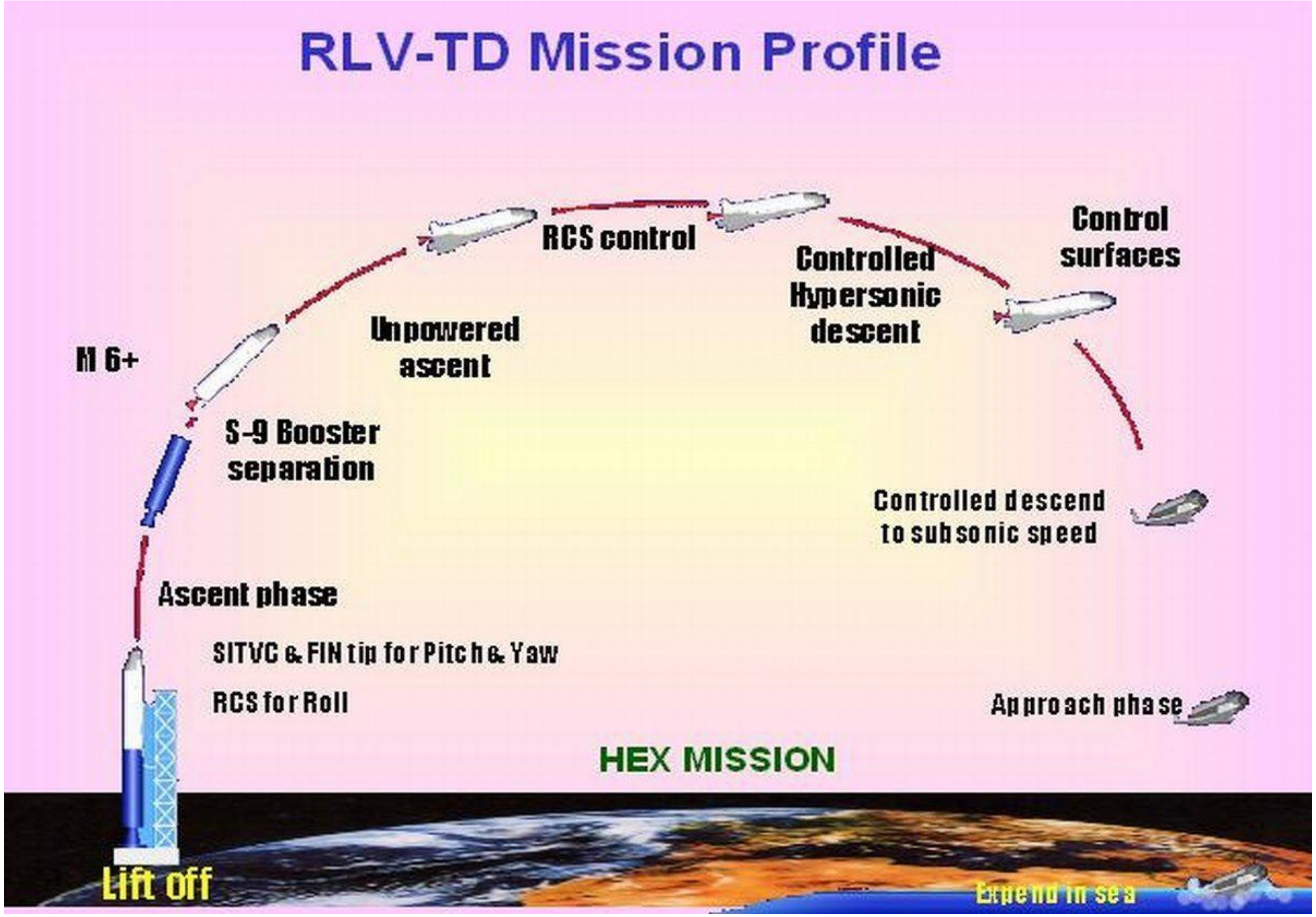
  cost,

  reliability,

  operability and

  scheduled reqmnts

Mission proflie

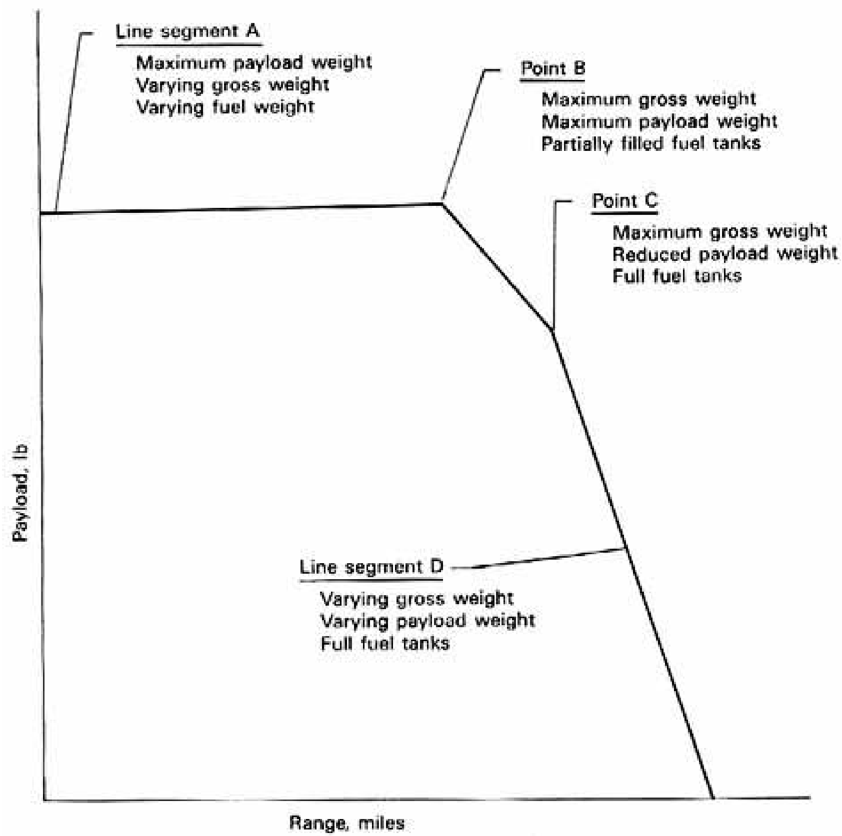


Thrust profile

- It is the force that propels a rocket or space craft and is measured in pound s,kg or Newton
- Physically speaking it is the result of pressure which is exerted on the wall of the combustion chamber and the rate of thrust graph is called thrust profile
- The simplest thrust profile comes from linear burning of a cylindrical grain a constant brining area produces constant thrust

Payload

- It is the carrying capacity of an A/C or space ship, including cargo, scientific instruments or experiments e,t,c,.,
- The fraction of payload to the lift off weight of the air or spacecraft is known as payload fraction
- When the weight of the payload & fuel are considered together it is known as useful load fraction



- Top line represents the max payload and limited structurally by maximum zero fuel weight(MZFW)
- Max payload is the diff between MZFW and operational empty weight (OEW)
- Left to right along the line shows constant max payload as the range increases
- Vertical line shows the range at which the combined weight of the A/C or launch vehicle, max payload and needed fuel reaches the max take off weight(MTOW)

Staging

- A basic approach to the launch vehicle design, first suggested by konstantin tsiolkovsky is to divide the vehicle into stages
- First stage is the heaviest part of the vehicle and has largets rocket engines, the largest fuel and oxidizer tanks and the highest thrust which is essential to overcome the earths gravity and thus lift the total weight of the vehicle and its payload off the earth
- Second stage own rocket engines ans propellants, continues to accelarate the vehicle
- Most expandable launch vehicles are of two or three stages

Control and guidance requirements

- Space craft is guided and controlled by the two interrelated sub systems

1. Guidance and

2. Navigation system

- The two systems provide rotational, line off flight and rate of speed information
- Both systems contains inertial , optical and computer subsystems

Performance measures

- Laeson & wertz preset several classical performance measures used to
  evaluate the effectiveness of orbit candidates
- The area access rate is the rate at which land enetrs or leaves the access
  area
- Overlap area: area on the sphere that can be viewed simultaneously by all satellites in the formation
- Separation area: region enclosed by the outermost sub-satellite

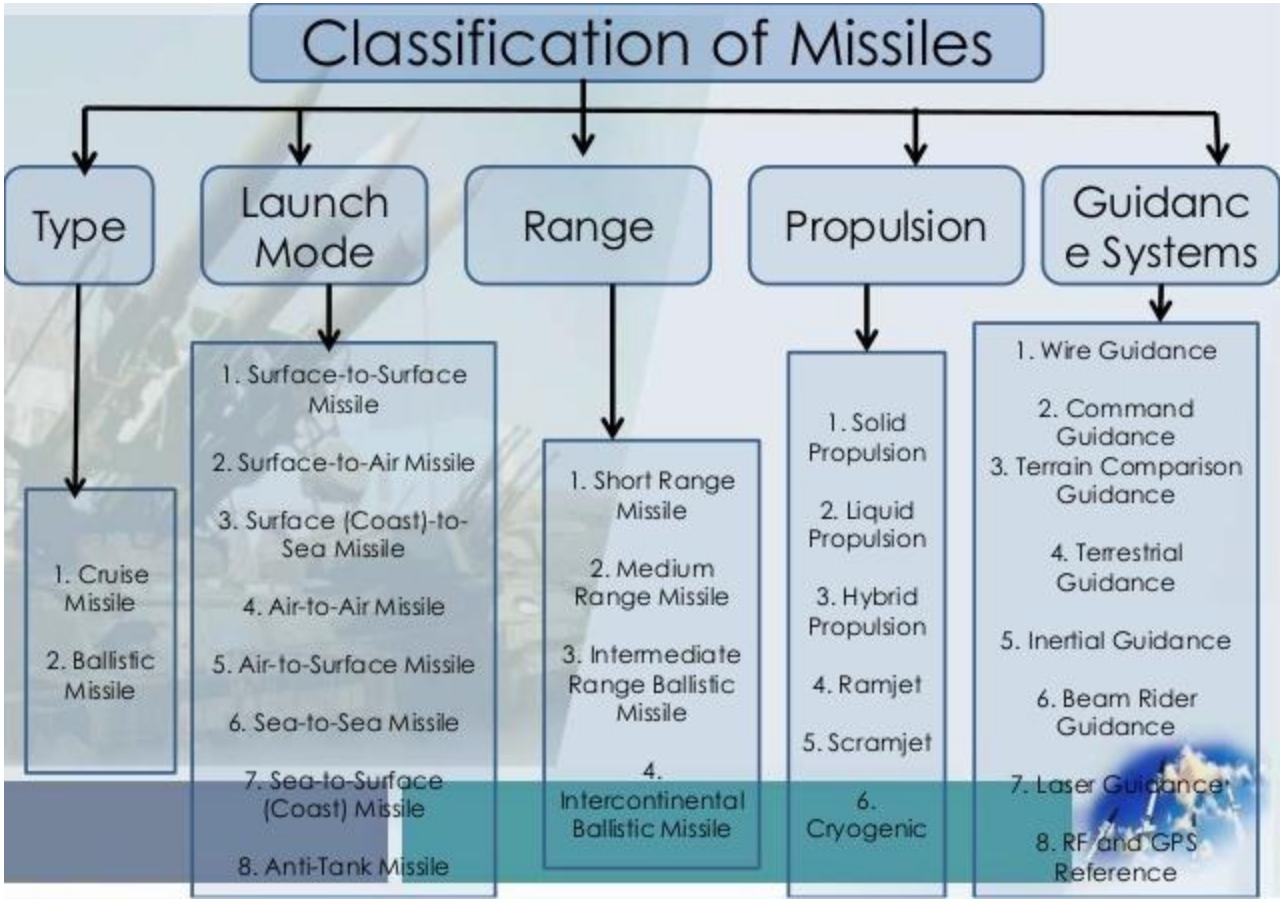
It is developed as a conflict measure to overlap area is small

As separations increase the separation also increases

Orbit performance measures

- We desire measure that allow comparision of candiadfte for the satellites in formation
- strategy takes a measure of the instantaneous relative positions of a formation and integrate the measure over a period
- As separation of the formation increases the overlap area decreases and the separation area increases
- The conflicting nature of the area measures can be utilized ion an orbit performanace measures

Design and construction of military missile



Key drivers in missile design and engineering

- Aerodynamic considerations
- Propulsion consideration
- Weight considerations
- Flight performance considerations
- Measure of merit and launch platform integration

Design process

- Require ments process
- Design
- Build
- Systems integration
- operations

Design and construction of space launch vehicles

- Engineering challenges
  - Design and management considferation s
  - Interactions
  - Failure to meet technology
- Project requirements
  - Performanace
  - Cost
  - Reliability
  - Operability
  - Safety
  - Schedule

Similarities and operations

- Both carry roughly same amount of payload and propellants
- Engines of both provide nearly same thrust 92-4 stages involved)

Some famous launch vehicles

- Avatar spacecraft
- Geosynchronous satellite launch vehicle (GSLV)
- Polar satellite launch vehicle (PSLV)
- Satellite launch vehicle

UNIT-II

SOLID & LIQUID PROPELLANT ROCKET MOTORS

propellants

- Double base propellants: the most important homogeneous propellant is the double base.
- Invented in 1988 by nobel and has a since been gun powder
- Mostly consists od nitrocellulose- which consists of cellulose-nitrate nitro glycerene
- Ng ans nc both combine oxidizer and fule in one molecule
- Composite propellantst:
- Usually form of an organic fuel or binder, plastic or rubber in most cases
- Most propellants are ammonium perchlorate and ammonium nitrate and potassium perchliorate

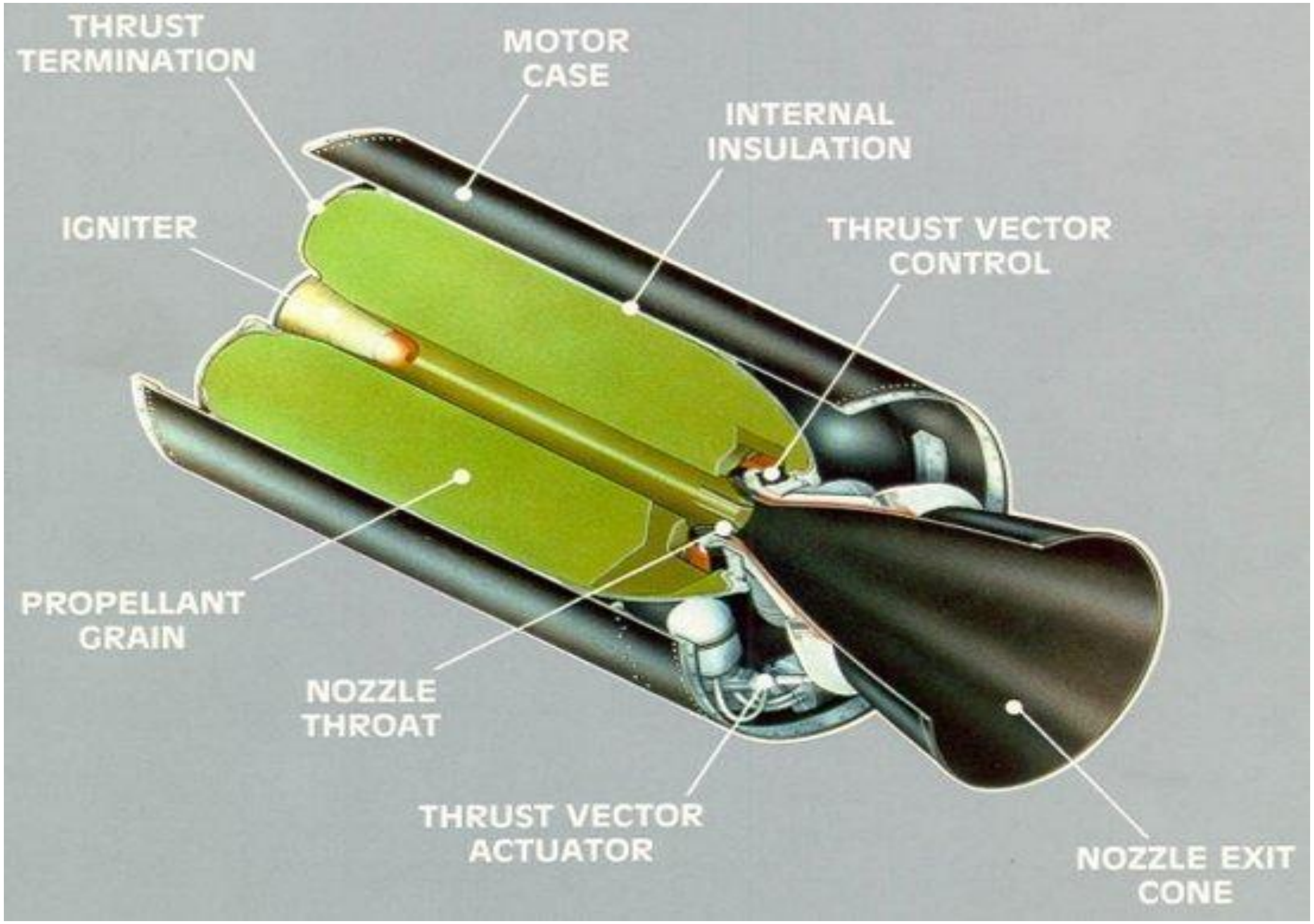
Solid Rocket Motors

- A solid rocket motor is a system that uses ***solid*** propellants to produce thrust
- Advantages
  - High thrust
  - Simple
  - Storability
  - High density Isp
- Disadvantages
  - Low Isp (compared to liquids)
  - Complex throttling
  - Difficult to stop and restart
  - Safety

Solid Rocket Motors

- Solid rocket motors are used for
  - Launch vehicles
    - High thrust (high F/W ratio)
    - High storage density
  - Ballistic Missiles
    - Propellant storability
    - Excellent aging
    - Quick response
      - storability
      - high F/W ratio)

Solid Rocket Motor Components



Thermal 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
  - For the cylindrical part of the case, the walls are only exposed to hot combustion gases at the end of the burn

The Nozzle

- The design of the nozzle follows similar steps as for other thermodynamic rockets
  - Throat area determined by desired stagnation pressure and thrust level
  - Expansion ratio determined by ambient pressure or pressure range to allow maximum efficiency
- Major difference for solid propellant nozzles is the technique used for cooling
  - Ablation
  - Fiber reinforced material used in and near the nozzle throat (carbon, graphite, silica, phenolic)

Types of nozzles

- Fixed
- Movable
- Submerged
- Extendible
- Blast tube –mounted

Nozzle thermal protection

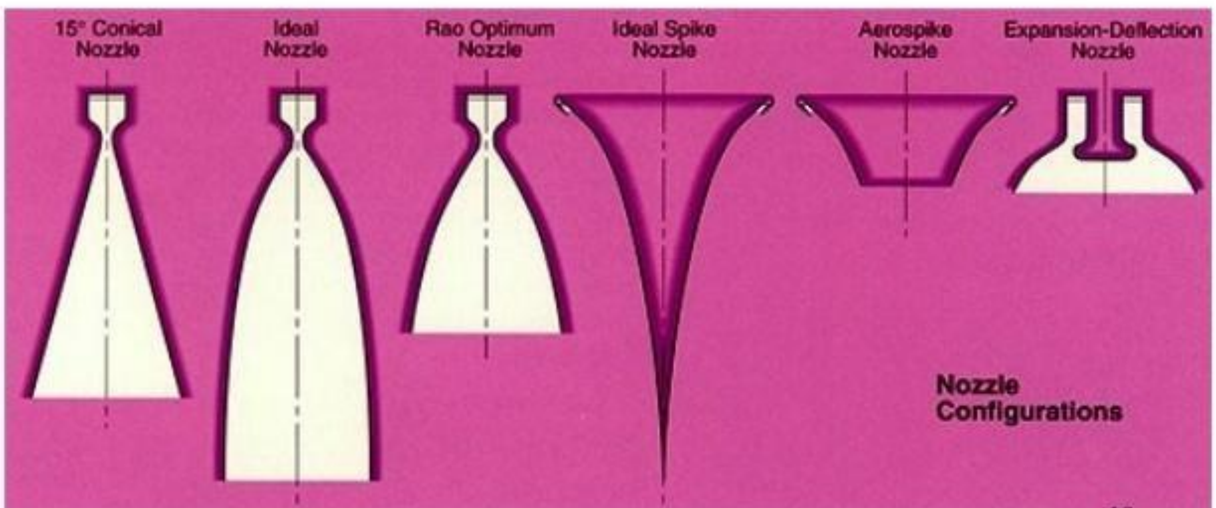
- Nozzle and throat are protectes from the haeat of the exhaust by using similar techniques to those used to protect the casing, here the problem is more severe bcoz of high velocity of exhaust gases
- Ablation heat diffusion inot he heat sink and the thermally insulating properties of the throat lining keep the steel cool long enough to do its job
- A heat sink is also used at the throat 8to reduce the transfer of heat to steel structure

types

NOZZLE TYPES

3 primary groups of nozzle types

1. Cone (conical, linear)
2. Bell (contoured, shaped, classic converging-diverging)
3. Annular (spike, aerospike, plug, expansion, expansion-deflection)



MOTOR CASE

MATERIALS

FILAMENTS: E-GLASS, ARAMID(KEVLAR 49), CARBON FIBRE OR GRAPHITE,

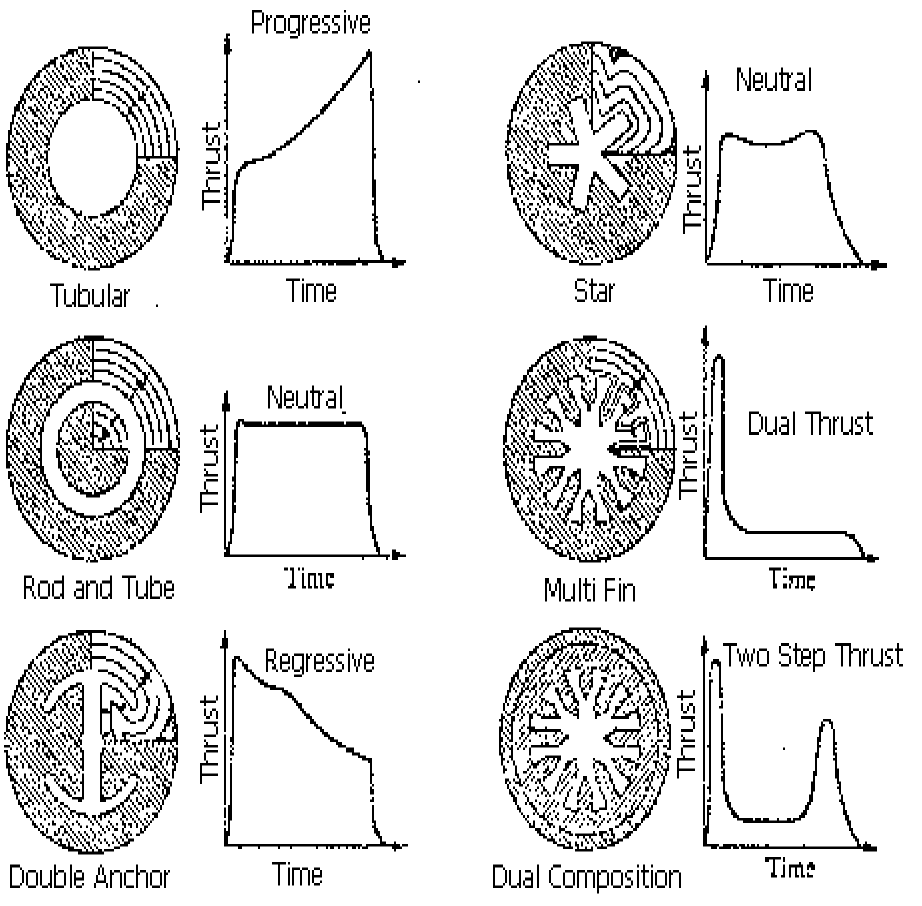
FILAMENT REINFORCED(_COMPOSITE MATERIAL): E-GLASS, KEVLAR 49, GRAPHIOTE tm,

Metals: titanium alloy, alloy steel(heat traeted). Aluminium alloy 2024(heat treated)

Propellant Grain & grain configuration

- Two main catagories
  - Double Base: A homogeneous propellant grain, usually nitrocellulose dissolved in nitroglycerin. Both ingredients are explosive and act as a combined fuel, oxidizer and binder
  - Composite: A heterogeneous propellant grain with oxidizer crystals and powdered fuel held together in a matrix of synthetic rubber binder.
    - Less hazardous to manufacture and handle

Grain structure



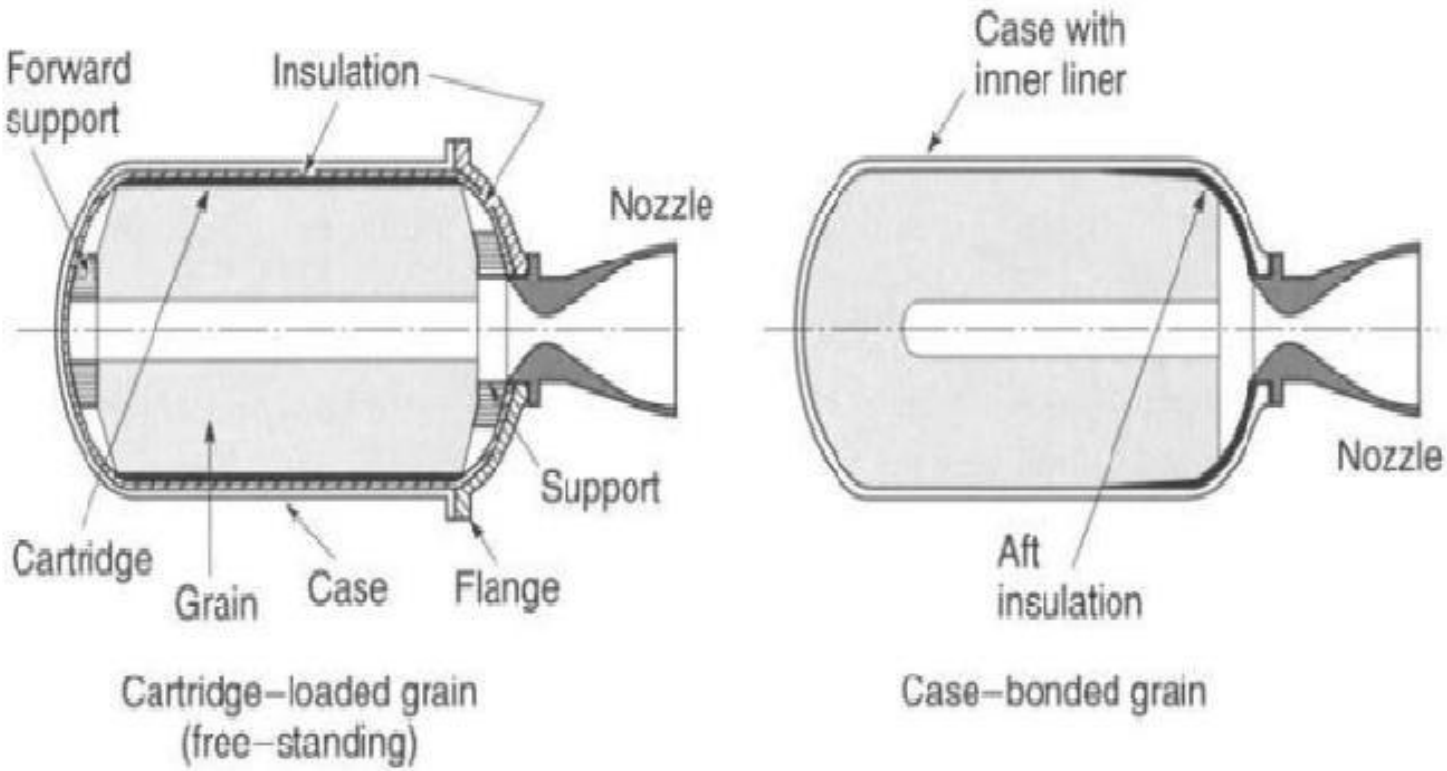
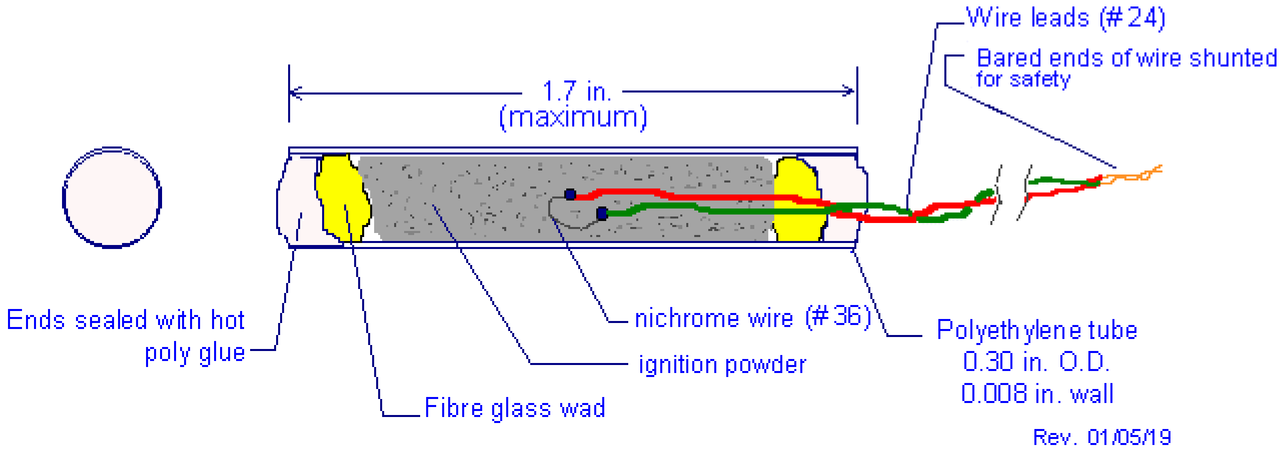


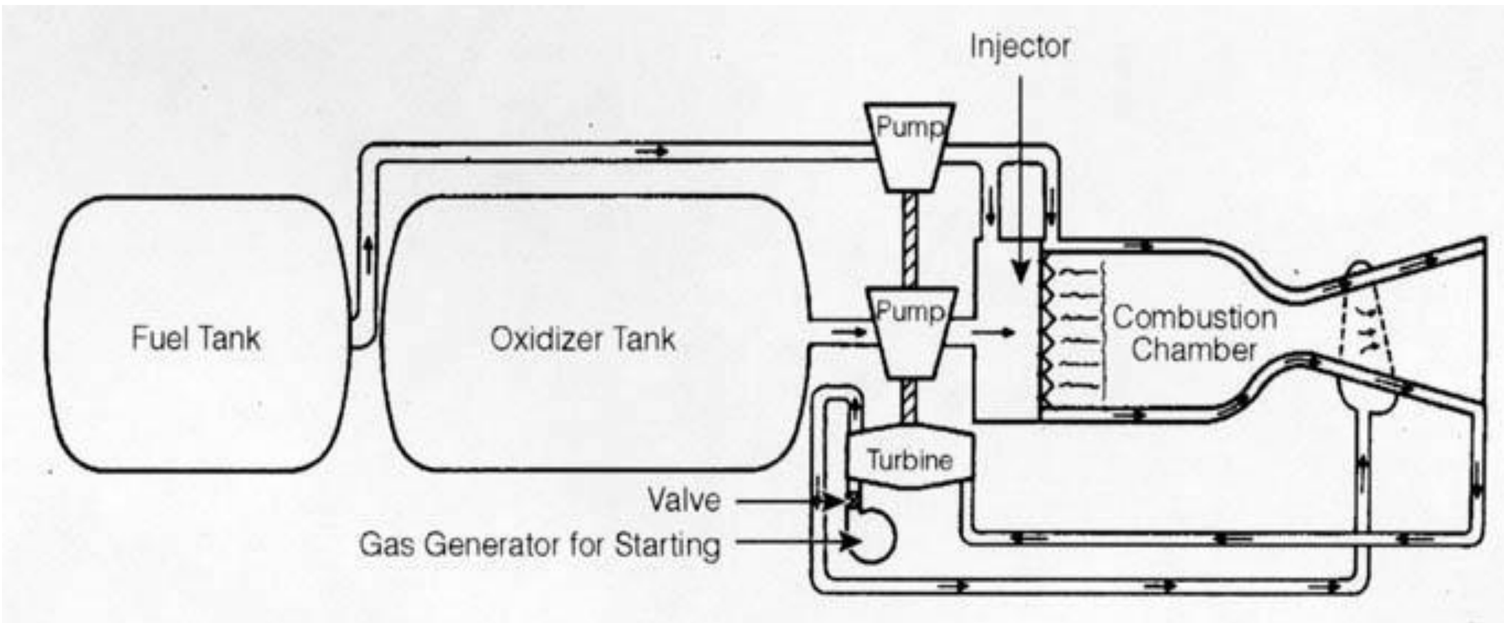
FIGURE 11–14. Simplified schematic diagrams of a free-standing (or cartridge-loaded)

Pyrotechnic igniter



Pyrogen igniter

OUT LINE FOR LIQUID PROPELLANT ROCKET ENGINE



LIQUID PROPELLANTS

- Mono propellants and bi propellants

- Monergols: mono propellants belongs to such explosives as nitroglycerine, piric acid, trinitratrotolune,
- Katergols: well known Katergols is applied to a liquid monopropellant system

  concentrated hydrogen peroxide,
- Lithergols

- Bipropellants
- Diergols: utilizes a liquid oxidizer and a liquid fuel which are when mixed together called diergols—fuming nitric acid, liquid oxygen, ethonal

- Hypergols: oxidant and fule which is self igniting when its components are bought in contact with each other is called hypergolic combination

Other propellants like

- Liquid
- Gelled
- Gaseous

PROPELLANT PROPERTIES

Economic Factors

- Performance of Propellants
- Common Physical Hazards
- Corrosion.
- Explosion Hazard.
- Fire Hazard.
- Accidental Spills.
- Health Hazards.
- Material Compatibility.

Desirable Physical Properties:

- Low freezing pouint
- High specific gravity
- Stability
- Heat transfer properties
- Pumping properties
- Temperature variation

- Ignition , combustion and flame properties
- Property variations and specifications
- additive

Propellant tanks

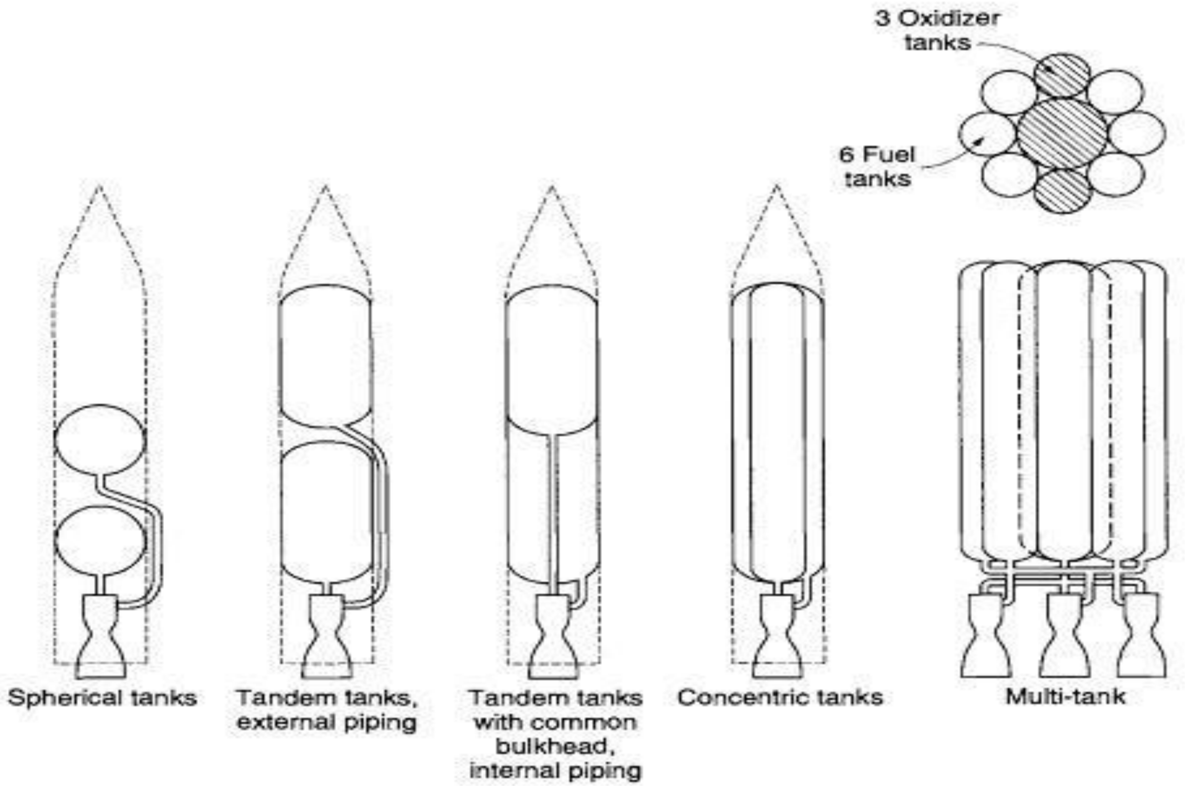


FIGURE 6–5. Typical tank arrangements for large turbopump-fed liquid propellant rocket engines.

Tank pressurization

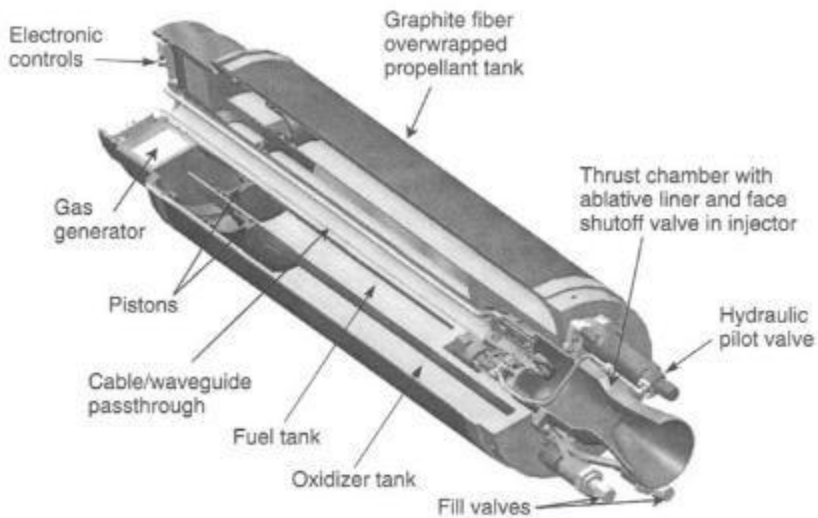


FIGURE 6–8. Simplified diagram of a compact pre-loaded, pressure-fed, bipropellant experimental rocket engine aimed at propelling smart maneuvering ground-to-ground missiles. It uses gelled red fuming nitric acid and gelled monomethylhydrazine as propellants. A solid propellant gas generator provides the gas for tank pressurization and the hot gases are isolated from the propellants by pistons. The concentric spray injector allows restart, throttling, and flow shut-off at the injector face. The rocket engine is 6 in. diameter and 23.5 in. long. (Courtesy of Space and Electronics Group, TRW, Inc.)

Engine cooling/ cooling of liquid engines

- Cooling is necessary mainly from strength considerations
- Types: active and passive cooling

Active cooling methods are forced convention heat transport , as to actively cool the hot spots

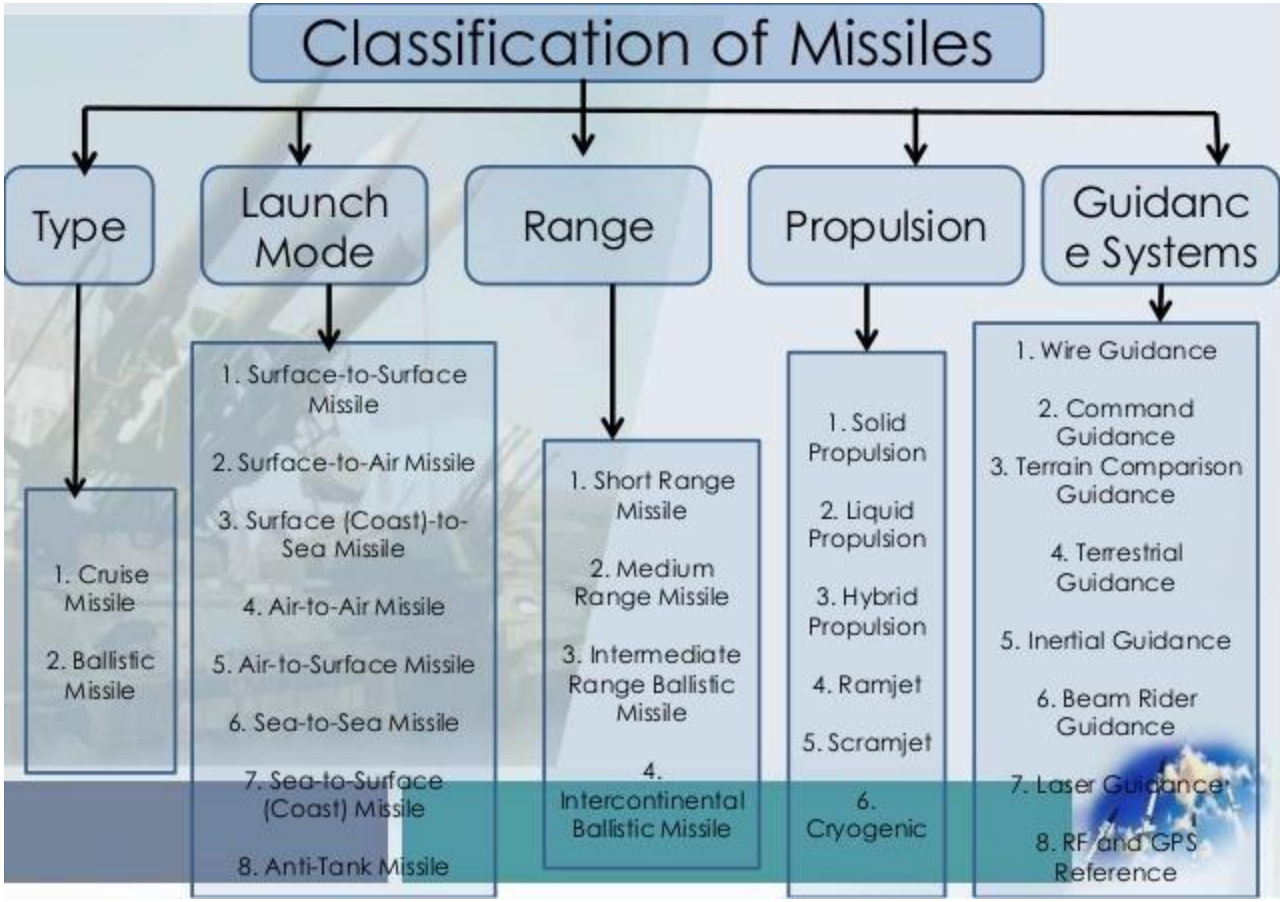
Active cooling systems : regenarative
film
transportation
dump cooling

Passive cooling systems do not make use of a special heat transport system but are designed such that during motor operation they prevent structural parts becoming too hot

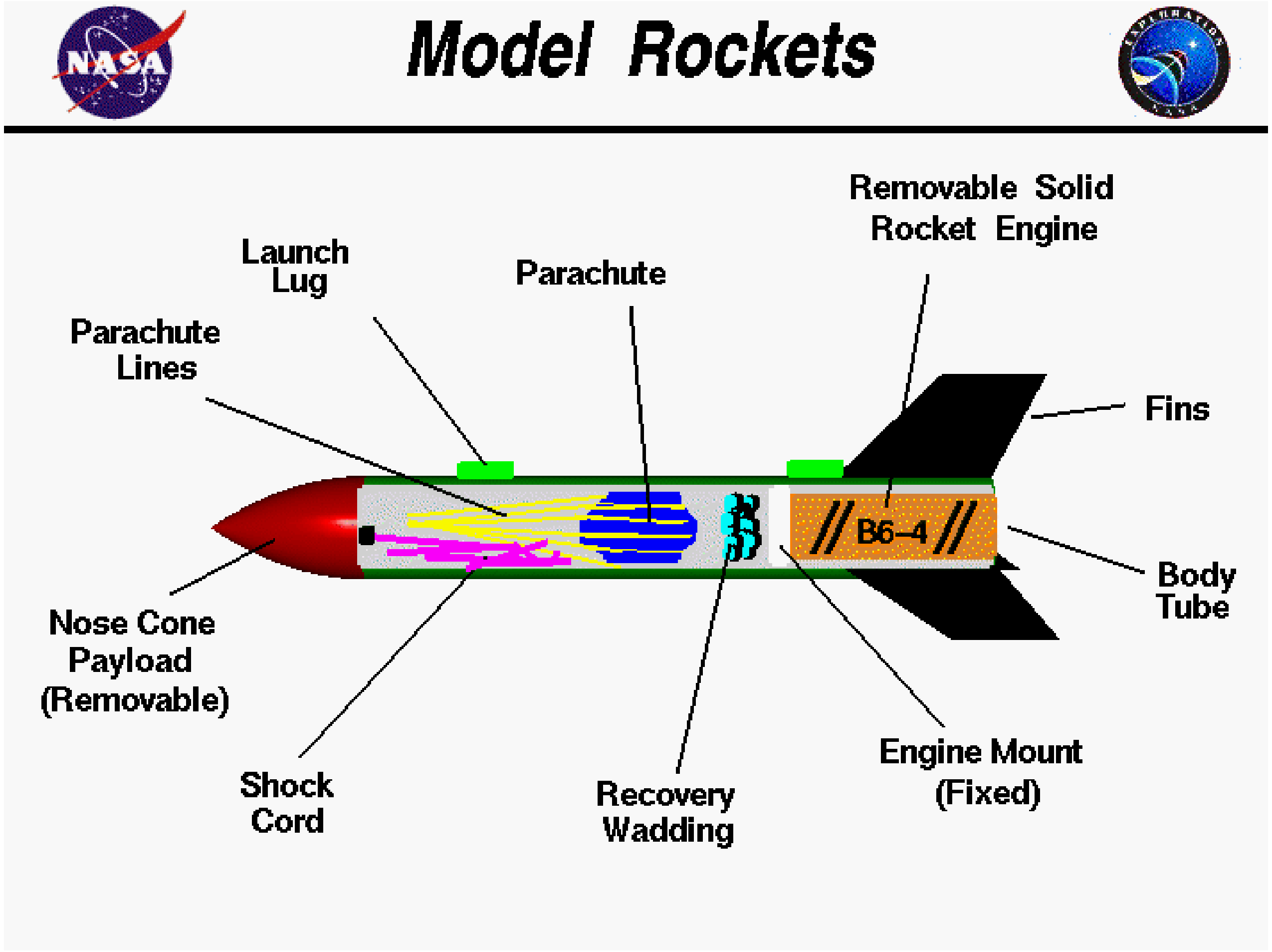
Passive cooling systems are : insulation
heat sink
ablative
radiation

UNIT-3
AERODYNAMICS OF ROCKETS AND MISSILES

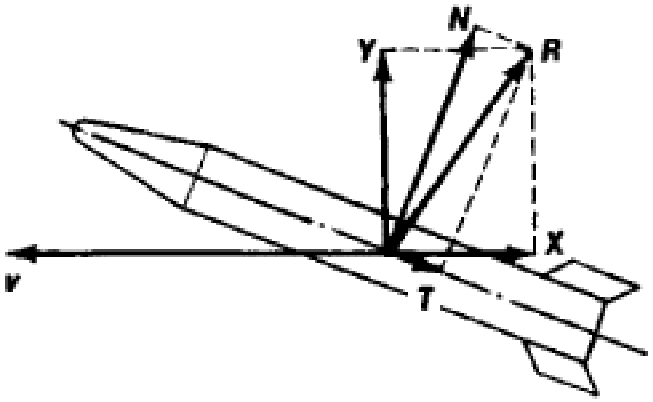
Classification of missiles



Airframe components of rockets and missiles

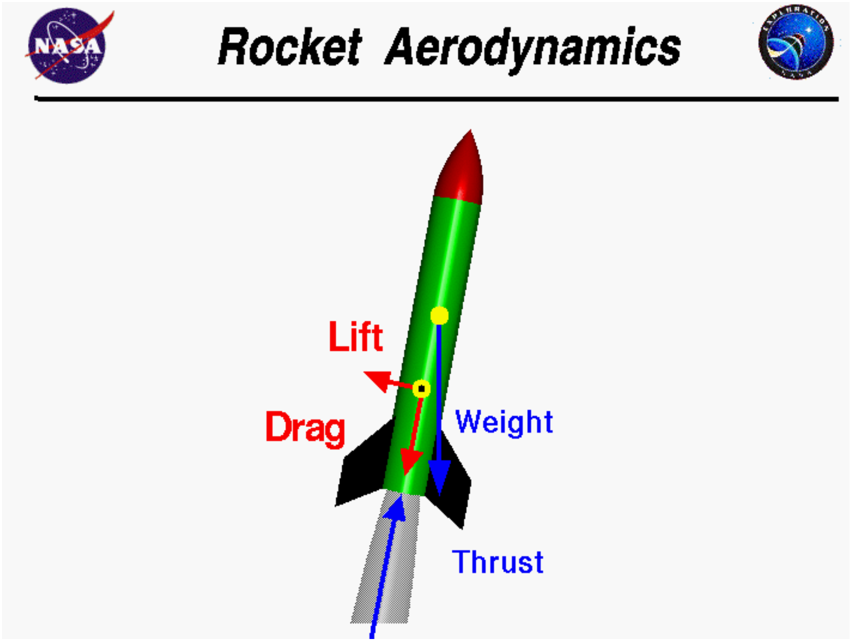


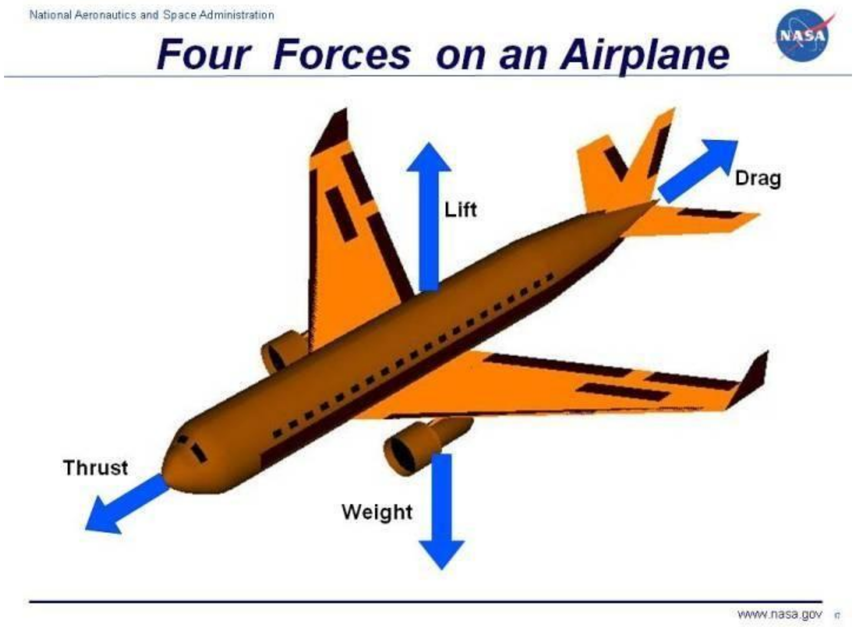
Aerodynamic forces and moments



- The forces of pressure and friction acting on the surface of the body can be reduced to a resultant R of these forces, called the aerodynamic force and a pair of forces having a moment M, which is called the aerodynamic moment

Lift and drag forces

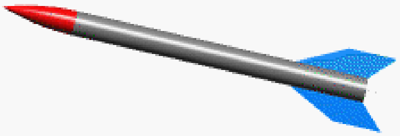




- On an airplane the lift force (the aerodynamic force perpendicular to the flight direction) is used to overcome the weight on a rocket thrust is used in opposite to weight on many rockets , lift is used to stabilize and control the direction of flight
- On airplane , most of the aerodynamuic forces are generated by the wings and the tail surfaces for both aiaplane and rocket ,the aerodynamic forces act through the centre of the pressure while the weight acts through the centre of the gravity

Drag estimation

The Drag Equation



$$D = Cd \, \frac{\rho V^2}{2} A$$

Drag = coefficient x density x $\frac{\text{velocity squared}}{\text{two}}$ x reference area

Coefficient Cd contains all the complex dependencies and is usually determined experimentally.

Choice of reference area A affects the value of Cd.

- Atmospheric entry is the movement of human made or natural objects as they enter the atmosphere of celestial body from outer space in the case of earth from an altitude above the known line -100km

- Design typically considers two worst case trajectories
- Undershoot trajectory: defined by the steepest allowable trajectory for manned missions the steepest entry angle in limited by the peak deceleration

  this trajectory has the highest heat flux and therefore defines selection of the TPS material
- Overshoot trajectory: defined as the shallowest allowable entry velocity angle prior to atmosphere skip-off

  the overshoot trajectory has the highest heat load and sets the TPS thickness
- Peak heat flux: selects the TPS(thermal protection system material)
- Heat loads: selects the thickness of the TPS material stack
- Peak deceleration → major importance for manned missions
- Peak dynamic pressure: also influence the selection of the outer most TPS material if spallation is an issue

Moments of rocket

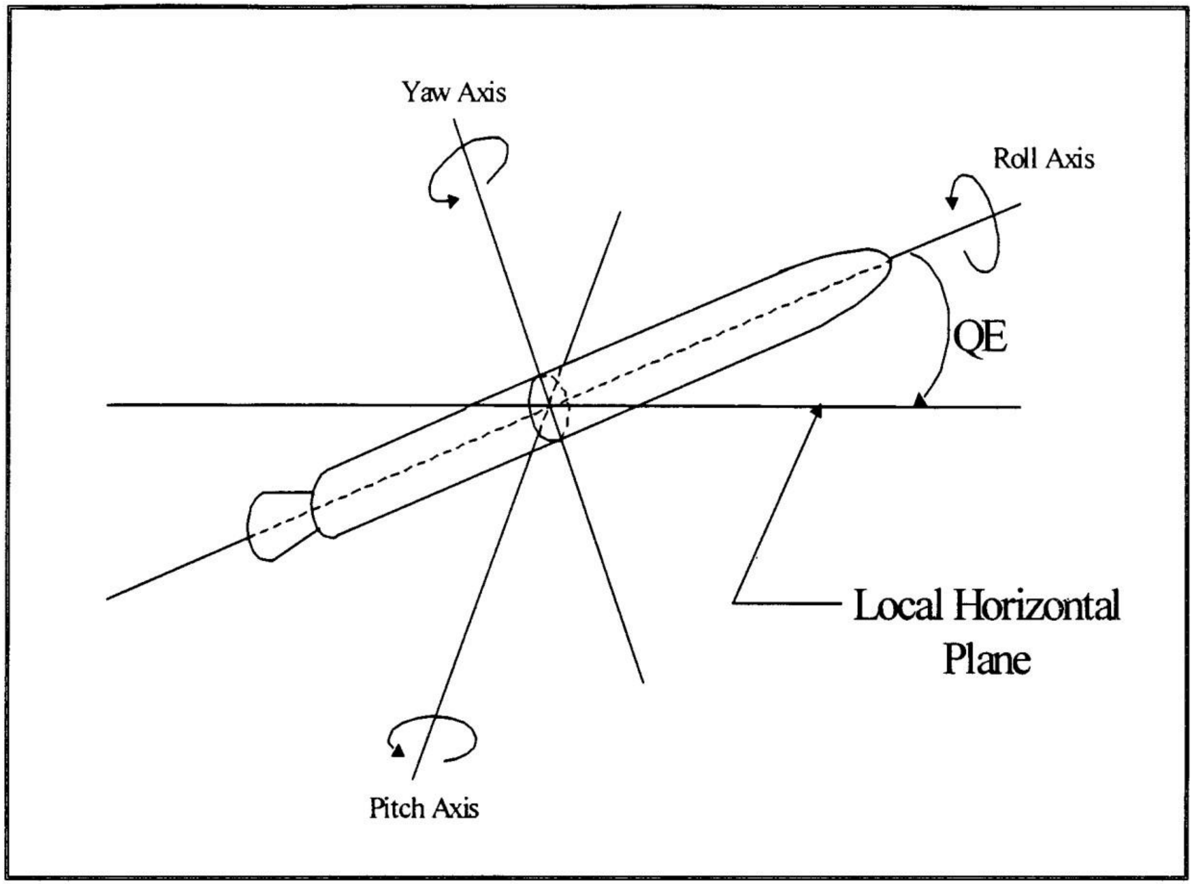


Figure 417.207-6, Illustrative Longitudinal Axis Quadrant Elevation (QE)

Downwash and Upwash

- aeronautics **downwash** is the change in direction of air deflected by the aerodynamic action of an airfoil, wing or helicopter rotor blade in motion, as part of the process of producing lift.
- Upwash is the relative laminar airflow blowing from underneath the wing which at the trailing edge moves upwards where as downwash is the laminar airflow blowing from the top of the wing moving downwards at the end of the trailing edge,when they meet with each other ,it gives rise to vortices or eddis.

UNIT- 4
ATTITUDE CONTORL OF ROCKETS AND MISSILES

ROCKET THRUST VECTOR CONTROL METHODS

- THRUST VECTOR FOR SOLID PROPULSION SYSTEM
- THRUST VECTOR FOR LIQUID PROPULSION SYSTEM

THRUST MAGNITUDE CONTROL

- Tmc Allows For Large Thrust Variaations With Small Variation In Chamber Pressure
- Some Liquid Propellants-tms Used With Out Varying The Throat Area By Reducing The Mass Flow Into The Chamber
- Which Results In Chamber Pressure Reduce Due To Reduction In Mass Flow
- Two Systems With Out Adverse Effects
- One Is Translating Inlet And Other Pintle Nozzle

THRUST TERMINATION

- It is desirable bcoz delivered impulse cannot be predicted exactly
- It depends on the temperature of the grain
- It allows a spacecraft to measure velocity gained and shutdown when the desired velicity is reached

Demonstrated thrust termination methods

ACTION	Result
Venting forward ports	Balance thrust/ reduce pressure
Chamber destruction	Reduced chamber pressure
Liquid quenching	Extinguish flame
Nozzle ejection	Reduced chamber pressure

Selection of stage seperation systems

- It is an extensive and exhaustive process for selection of the stages seperation systems for launch vehicle
- It is primarily goverened by system requirements
  - Reliability
  - Joint rotation
  - Low shock levels
  - Weight
  - Cost

Selected seperation systems also meet all the functional requirements namely

- Serve the structural connection
- Impact minimum tip off rate to ongoing stage
- No damage due to contamination for the contuing stages
- Min shock transmission to the payload interfaces or the continuing stages

Stage separation of space launch vehicles

- Stage separation
- Strap on separation
- Ullage rocket separation
- Space craft separation

Forces and moments

- gravity , retro/ullage rockets
- Tail of thrust, jet damping
- Release and jettisioning mechanisms e,t,c.,

Separation elements

- Actuator: word indicates the triggering of the separation events usually actuators are either electric or pyro based
- Severence/release mechanisms: mechanical systems and pyro technique devices

Design reqmts: minimum system weight and minimum volume

high reliability,

maintainability and long storage lifesafe handling and easy transportation

Jettisioning devices

- Used to provide the reqd relative separation velocity to the separating bodies
- Energy reqd for jettisioning the systems are provide by employing any one of the thrusters

1. Spring thrusters
2. Pneumatic
3. Rocket thrusters

UNIT-5
ROCKET TESTING

Types of testing

- Manufacturing
- Component testing
- Static rocket testing
  - partial
  -complete propulsuion system tsest
- Static vehicle tetsing
- Flight tests
- Research and developemet
- Evaluation
- Production and quality assurance of rocket propulsion system

Test facilities and safegaurds

- A test cell or test bay where the article to be tested is mounted
- An instrumentation systems with associated computers for sensing, maintaining, measuring, analyzing, correcting, and recording various physical and chemical paramaeters
- A control; for handling havey or awkward assemblies supplying liquid propellants and providing mainatenance security and safety
- In some tests specialiazed test equipment and unique facilities Are needed to conduct static testing under different environmental conditions or under simulated emergency conditions

Monitoring and control of toxic materials

- In ground test the toxic cloud source is treated as a point source and in flight tests it is a ribbon source
- A highly stable atmospheric condition tends to keep the exhaust plumes or cloud intact and away from the earths surface except when the exhaust products are much heavier than the surrounding air
- For short firings <500sec the approx dosage downwind are about the same as from an instrumentation point source
- High wind increases the rate of diffudsion and raduces the thermal effects

Instrumentation and data management

- Forces
- Flows
- Pressures
- Temperatures
- Timnings
- Stresses, strauins,vibrations
- Time sequence of events
- Movement and position parts
- Voltages , frequencies and currents in electrical or control sub systems
- Visual observations using high speed cameras or video camearos
- Spacial quantities such as turbopump shaft speed, liquid levels in propellant tank, burnuing rates, flame luminosity, or exhaust gas composition

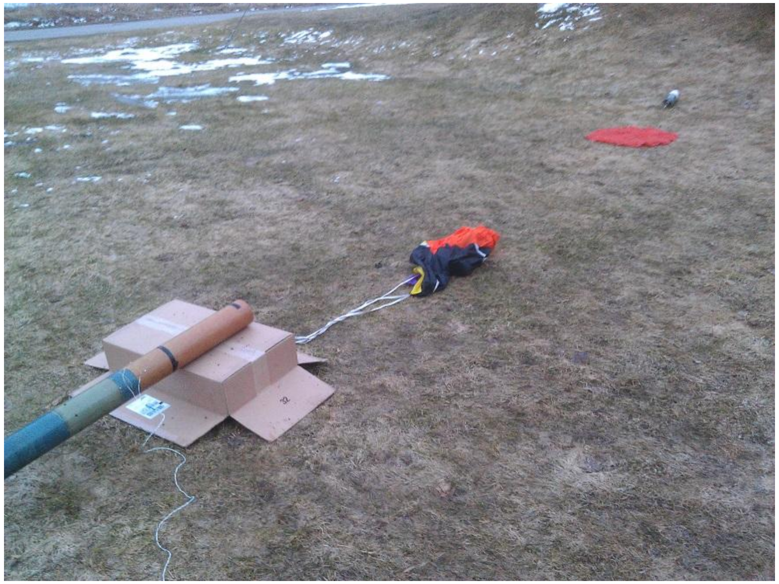
Ground testing and flight testing Procedures

Function	Testing Procedure
Charge Testing	The recovery systems were ground tested by prepping the rocket and ejecting the parachutes and primary payload.
Fin Testing	Fin flutter was tested theoretically with fin flutter velocity theory and then compared to physical testing in a wind tunnel.
Parachute Testing	Parachute testing was conducted by dropping the primary payload and vehicle off of a tall structure with the parachutes open to study the velocity at impact.
Altimeter testing	Altimeter testing was conducted within a pressured chamber and also by creating an impulse on the accelerometer.

Tests of the Staged Recovery System

- Deployed the main and drogue parachutes.
- Deployed the nose cone.
- Successfully tested the main parachutes ejection charge potential of deploying the nose cone in the event of a nose cone deployment failure

Ejection charge testing set up.



Successful deployment of main parachute and nose cone by main parachute charge.

Full-scale Flight Test #1

Successful exit from rails
Successful main payload deployment
Issues with vehicle recovery systems caused total parachute failure or “lawn dart”
Failure causes determined and improved through post flight inspection

Full-scale Flight Test #2

Mission success for all vehicle requirements
Payload flown with mass simulators
Drift well controlled in high winds

Thank You