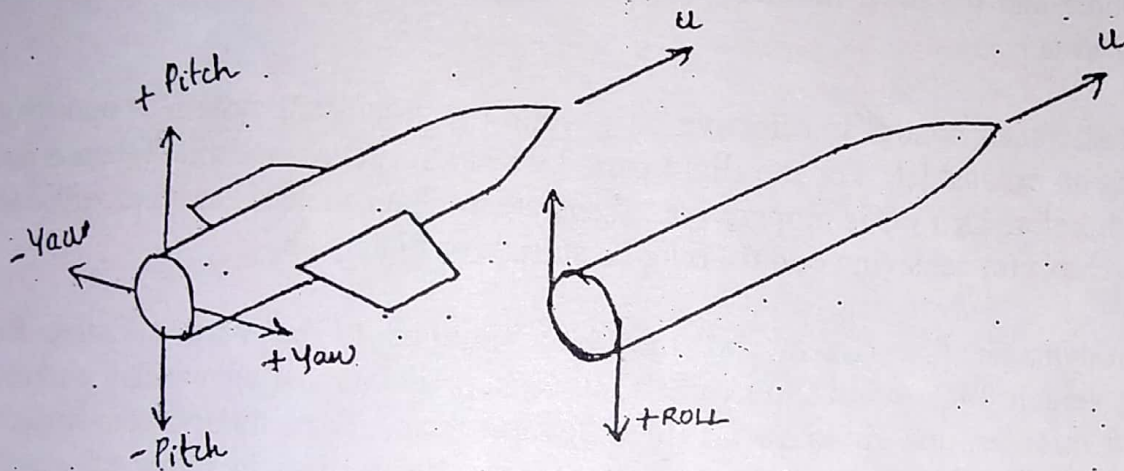


Thrust Vector Control (TVC):

Introduction:

Moving the reference thrust vector through small angles for vehicle stability and maneuvering is called Thrust Vector Control (TVC). The purpose of thrust vector control and aerodynamic surface control systems is to *steer or regulate the trajectory of a vehicle in flight that is to control its attitude at any instant.*

Thrust vector control is the intentional change of direction of the thrust vector with respect to the symmetry axis of the rocket. By changing the direction of the thrust vector, a control moment about a lateral axis of the rocket can be generated. The movements in vector control are three: Pitch, for up and down or dip and rise, yaw for right or left or turn and roll for twist or incline from side to side.



Usually, the thrust vector of the main rocket nozzle is in the direction of the vehicle axis and goes through the vehicle's center of gravity. Thus it is possible to obtain the pitch and yaw control moments by the simple deflection of the main rocket thrust vector; however roll control usually requires the use of two or more rotary vanes or two or more separately hinged propulsion system nozzles.

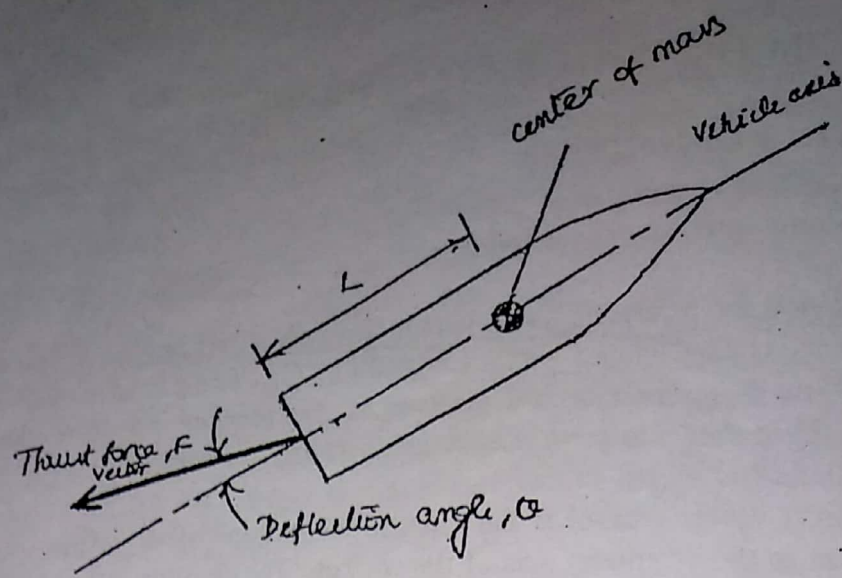


Fig explains the pitch moment obtained by a hinged thrust chamber or nozzle. The side force and the pitch moment vary as the size of the effective angle of thrust vector deflection.

Thrust vector control is effective only while the propulsion system is operating and creating an exhaust jet. For the flight period when a rocket propulsion system is not firing and therefore its TVC is inoperative, a separate mechanism needs to be provided to the flying vehicle for achieving control over its attitude or flight path.

Aerodynamic fins (fixed and movable) continue to be very effective for controlling vehicle flight within the earth's atmosphere and almost all weather rockets, anti aircraft missiles, and air to surface missiles use them. Even though aerodynamic control surfaces provide some additional drag, their effectiveness in terms of vehicle weight, turning moment and actuating power consumption is difficult to surpass with any other flight control method.

The reasons for Thrust vector control are

1. To willfully change a flight path or trajectory (E.g., changing the direction of the flight path of a target seeking missile)
2. To rotate the vehicle or change its attitude during powered flight
3. To correct for deviation from the intended trajectory or the attitude during powered flight
4. To correct for the thrust misalignment of a fixed nozzle in the main propulsion system during its operation, when the main thrust vector misses the vehicle's center of gravity.

Methods of Thrust vector control:

1. Aerodynamic fins
2. Auxiliary, ancillary or vernier jets or motors

- a. For each stage
 - b. A single system for all stages (united)
3. Mechanical devices
- a. On the nozzle
 - i. Jet vanes
 - ii. Jetavators
 - iii. Wedges or paddles in the exhaust
 - iv. Asymmetrical nozzle wall extensions
 - v. Jet tabs
 - b. Of the nozzle
 - i. Single axis hinged, swived, movable or pivot
 - ii. Gimbaleed or omni-Axis
 - iii. Rotating or canted
4. Thrust termination, cut off or impulse control
5. Secondary fluid injection (SITVC) into the nozzle cone
6. Nozzle deflection
7. Spoilers
8. Gimbaleed engine
9. Swiveling Nozzles
10. Liquid, side injection
11. Hot gas side injection
12. Movable nozzle (flexible bearing)
13. Movable nozzle (Rotary ball with gas seal)
14. Hinged auxiliary thrust chambers for high thrust engine
15. Turbine exhaust gas swivel for large engine
16. Small auxiliary thrust chambers

1. Aerodynamic fins:

Aerodynamic fins (fixed and movable) continue to be very effective for controlling vehicle flight within the earth's atmosphere and almost all weather rockets, anti aircraft missiles and air to surface missiles use them.

Disadvantages:

Heavy and inoperative at ignition and at high altitudes.

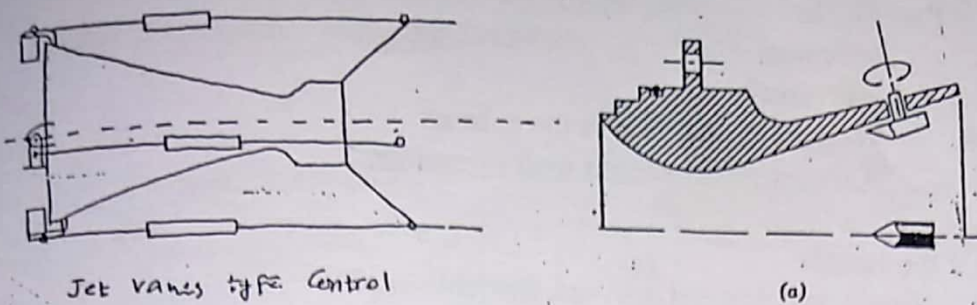
2. Auxiliary jets or motors:

In this method one motor can be used for all stages of missiles.

3. Mechanical devices:

a. On the nozzle

I. Jet vanes



Jet vanes are pairs of heat resistant, aerodynamic wing shaped surfaces submerged in the exhaust jet of a fixed rocket nozzle. They cause extra drag (2 to 5%) less I_{sp} ; drag increase with larger vane deflections) and erosion of the vane material.

In this setup four vanes per nozzle give pitching, yawing and rolling, control. All four vanes move clockwise or counter clockwise for roll control. Graphic jet vanes were used in the German V-2 missile in World War II and in Sard missiles fired by Iraq in 1991.

Advantages:

1. It is used in both liquid and solid rocket motors
2. Long experience, simple construction
3. The advantage of having roll control with a single nozzle often outweighs the performance penalties
4. It is a proven technology, low actuation power, high slew rate, roll control with single nozzle.

Disadvantages:

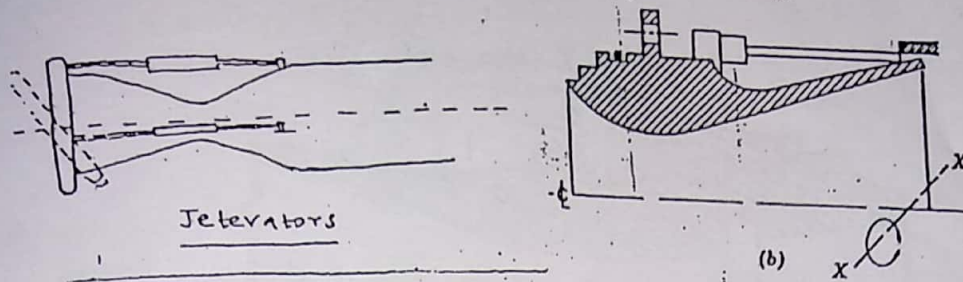
1. High drag losses, heavy supports vulnerable to high temperature and particulate propellants.
2. Thrust loss of 0.5 to 3%
3. Erosion of Jet vanes, limited duration extends missile length.

II. Jetavators

Solid propellant rocket motors require a different method of control. Since the propellant chamber and nozzle is an integral unit. The most common method of thrust direction control is by the use of rings called Jetavators. The Jetavators consists of two rings; one for pitch and one for yaw control, which are pivoted to deflect the jet stream in the desired direction. Since the rings are external to the nozzle, minimum thrust is lost compared to jet vanes. Two servo

actuators are used to position the Jetavators. Roll control can be obtained by the opposing action of several nozzle otherwise auxiliary jets must be used.

The Jetavators was used in submarine launched missiles. The thrust loss is roughly proportional to the vector angle.



Advantages:

1. Low actuation power, it can be light weight
2. Less drag losses

Disadvantages:

1. Erosion and thrust loss
2. Includes vehicle base hot gas re-circulation

III. Jet tabs

The jet tab thrust vector control system has low torque and is simple for flight vehicles with low area ratio nozzles. Its thrust loss is high when tabs are rotated at full angle into the jet, but is zero when the tabs are in their neutral position outside of the jet. On most flights the time-averaged position of the tab is a very small angle and the average thrust loss is small. Jet tabs can form a very compact mechanism and have been used successfully on tactical missiles. A tab that blocks 16% of the nozzle exit area is equivalent to a thrust vector angle deflection of 9° . The maximum angle is 12° and the slew rate is fast ($100^\circ/\text{sec}$). The vanes are driven by four linear small push-pull hydraulic actuators with two servo valves and an automatic integral controller. The power is supplied by compressed nitrogen stored at 3000 psi. An explosive valve releases the gas to pressurize an oil accumulator in a blow down mode. The vanes are made of tungsten to minimize the erosion from the solid particles in the exhaust gas.

Advantages:

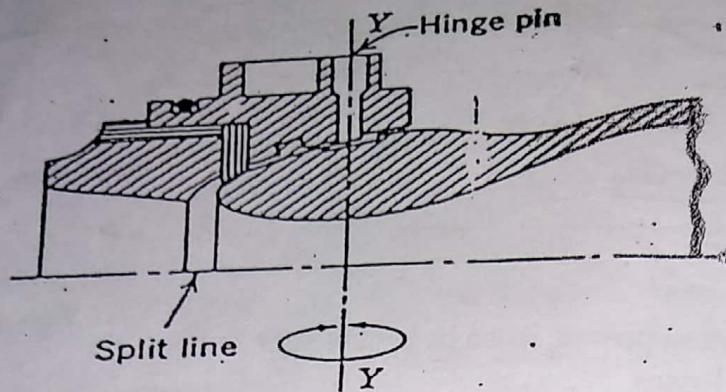
1. High slew rate
2. Low actuation power and compact package
3. It is used in solid rockets

Disadvantages:

1. Erosion of tabs
2. Thrust loss, but only when tab is in the jet.

b. Of the nozzle

I. Single axis:
One nozzle for pitching or yawing minimum four nozzles to obtain
pitching, rolling and yawing

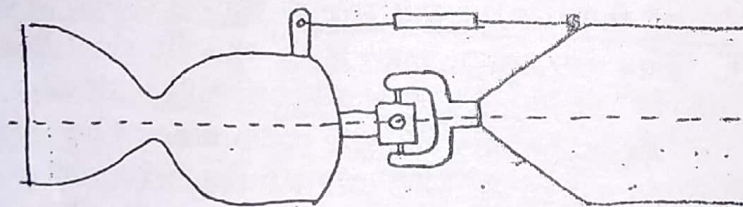


Advantages:

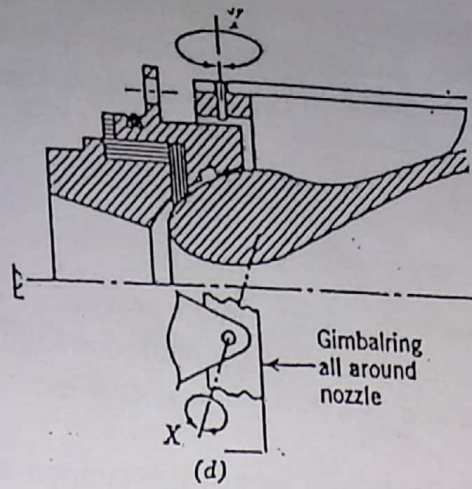
Light weight, high performance and Reliable

II. Gimbaled Engine

The most common method of thrust direction control for liquid engines is to gimbal the entire thrust chamber. Two actuators are attached as shown in fig. For pitch and yaw control. If two or more engines are used in a stage, they can be moved in opposing direction for roll control. Otherwise small auxiliary engines can be used to obtain roll control or the turbine exhaust can be swiveled.



Gimbaled Engine Type



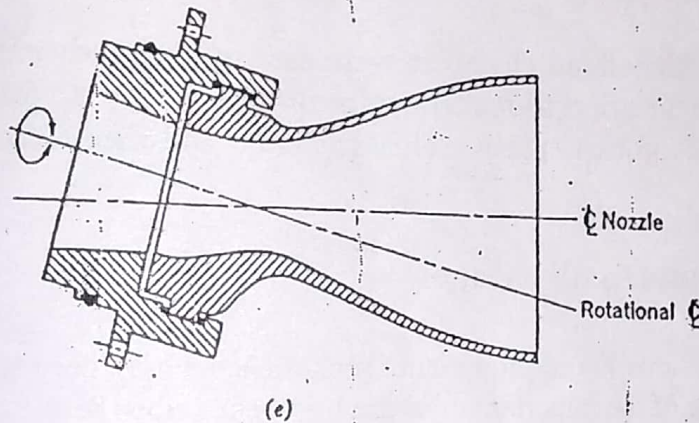
Advantages:

Deflected through only half angles to achieve same vector control as a single axis nozzle when comparing four nozzle clusters.

Disadvantages:

Extra weight of gimbal ring

II. Rotating or control nozzle



One nozzle gives pitching and yawing. At least two nozzles for rolling.

Advantages:

Suited to offset, multiple nozzle applications

Disadvantages:

Needs large bearing and heavy bearing support structure. Mechanically to provide 8° vector, must be rotated about 30° . Thus power requirements is higher.

Spoilers:

Spoilers at the nozzle exit can be used to block off a part of the exit area. Due to the resulting shock waves the flow becomes asymmetrical and side forces are produced.