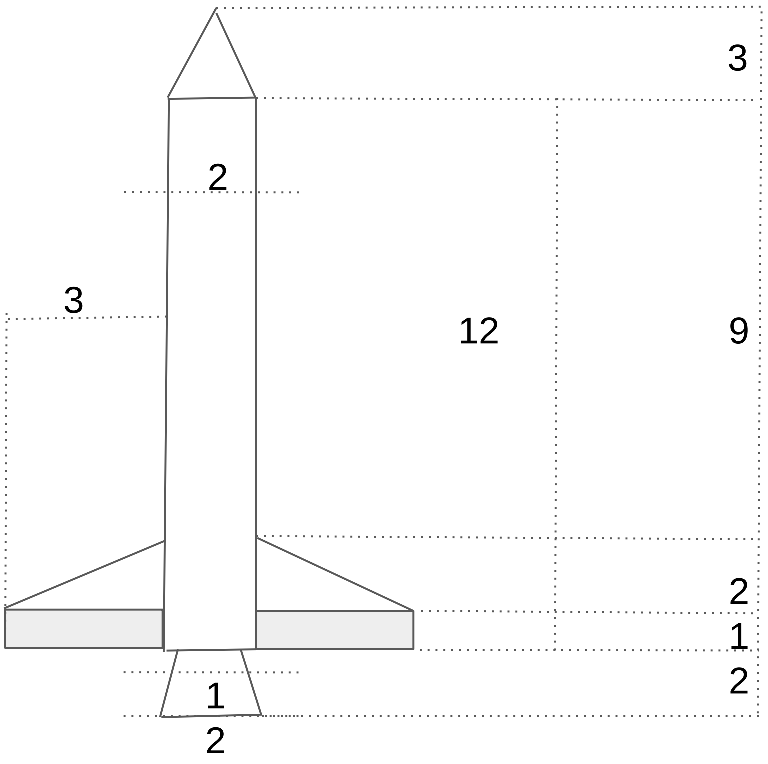
Rocket Geometry Design:



Step 1: Calculating Area(A) in Square units (units^2)

- Nose Cone = bh/2 = (2*3)/2 = 3
- Body = bh = 12 * 2 = 24
- Triangle Fins = bh/2 = (3*2)/2 = 3
- Rectangular Fins = bh = (1*3) = 3
- Nozzle(Trapezium) = [((a+b)/2)*h] = [((1+2)/2)*2] = 3

Step 2: Centre or Centroid of individual parts with reference to top of the rocket in units

- Nose cone = (0 + (⅔)*3) = 2
- Body = (3 + (12/2)) = 9
- Triangle Fins = (12 + (⅔)*2) = 13.33
- Rectangular Fins = (14 + 0.5) = 14.05
- Nozzle = [17 - [(h(2a+b))/(3(a+b))]]

  = [17 - [(2(2*1 + 2))/(3(1+2))]]

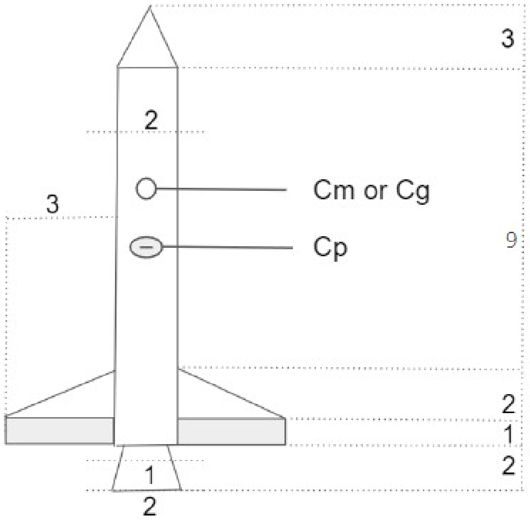
  = [17 - 0.88] = 16.11

Step 3: Centre of Pressure

- Cp = (∑A x C) / (∑A))
  = [(3*2) + (24*9) + 2 * (3 *13.33) +2 * (3 *14.05)+(3*16.11)] / [3 + 24 + 6 + 6 + 3]
  = [6 + 216 + 79.98+ 84.3 + 48.33] / [42]
  = 10.34 unit

Step 4: Centre of Mass

- Cm = (∑M x C) / (∑M))
  = [(50*2) + (200*9) + 2 * (25 *13.33) +2 * (35 *14.05)+(25*16.11)] / [50 + 200 + 50 + 70 + 25]
  = [100 + 1800 + 666.5+ 983.5 + 402.75] / [395]
  = 10 unit



What Is Thrust Vector Control?

In addition to providing a propulsive force to a flying vehicle, a rocket propulsion system can provide moments to rotate the flying vehicle and thus provide control of the vehicle’s attitude and flight path. By controlling the direction of the thrust vectors through the mechanisms, it is possible to control a vehicle’s pitch, yaw, and roll motions.

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.

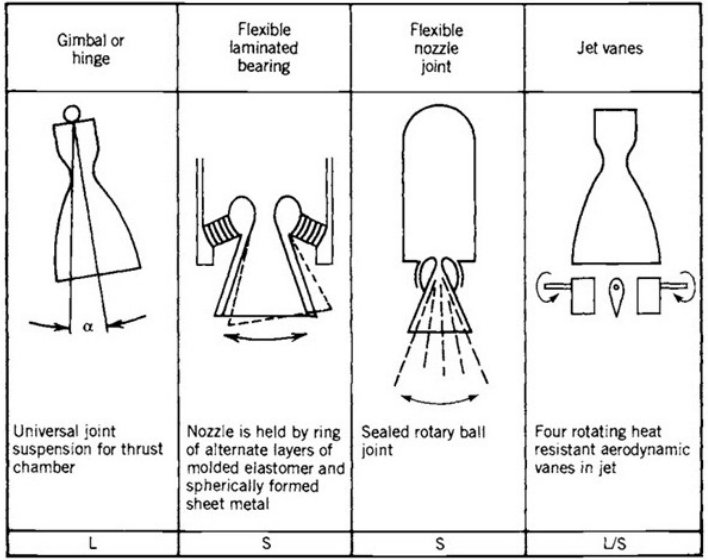
Reasons For Thrust Vector Control:

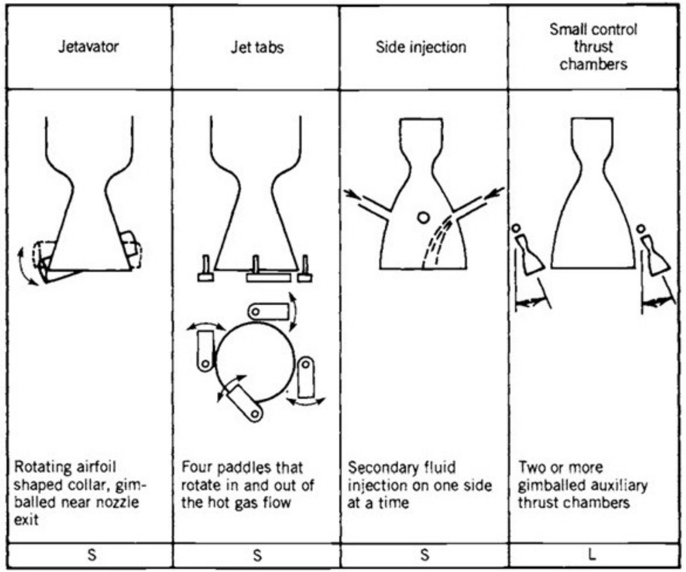
1. **To willfully change a flight path or trajectory** (e.g., changing the direction of the flight path of a target-seeking missile).
2. To rotate the vehicle or change its attitude during powered flight.
3. To correct for deviation from the intended trajectory or the attitude during powered flight.

Thrust Vector Control With A Single Nozzle:

Many different mechanisms have been used successfully. They can be classified into four categories:

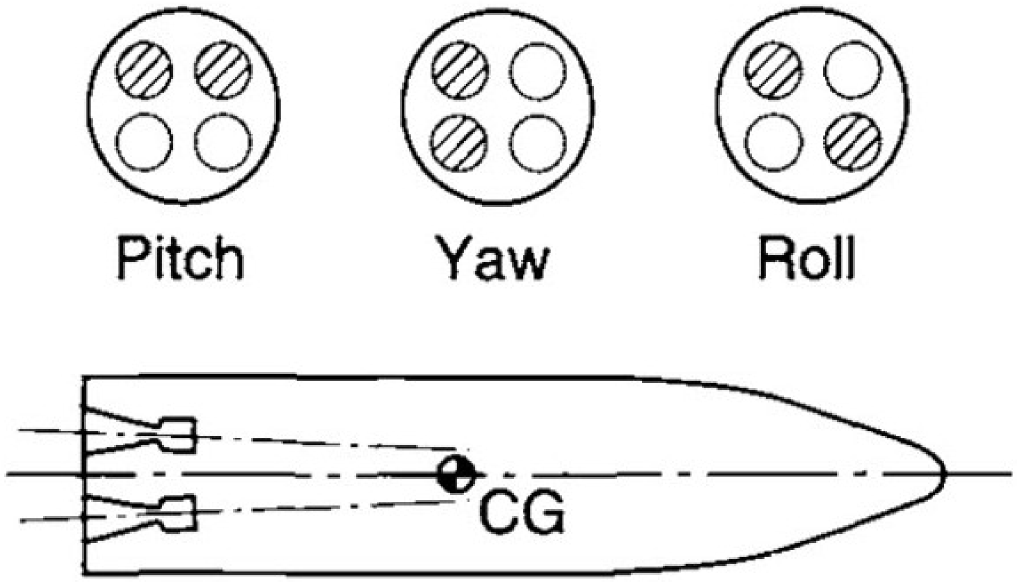
- Mechanical deflection of the nozzle or thrust chamber.
- Insertion of heat-resistant movable bodies into the exhaust jet; these experience aerodynamic forces and cause a deflection of a part of the exhaust gas flow.
- Injection of fluid into the side of the diverging nozzle section, causing an asymmetrical distortion of the supersonic exhaust flow.
- Separate thrust-producing devices that are not part of the main flow through the nozzle.



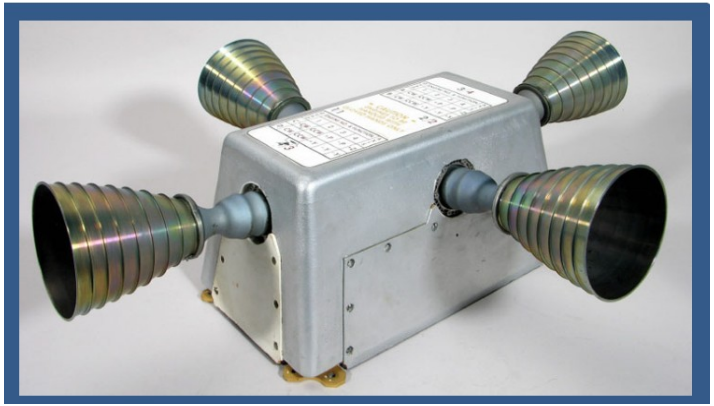


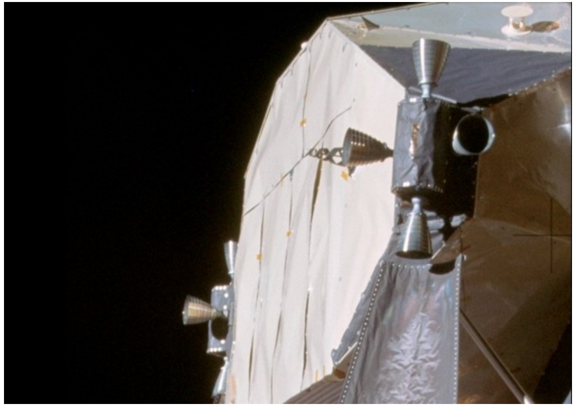
Thrust Vector Control With Multiple Thrust Chambers Or Nozzles:

- Differential throttling with four fixed-position thrust chambers can provide flight maneuvers. In this simple diagram the shaded nozzle exits indicate a throttled condition or reduced thrust. The larger forces from the unthrottled engines impose turning moments on the vehicle. For roll control the nozzles are slightly inclined and their individual thrust vectors do not go through the center of gravity of the vehicle.



Reaction Control System (RCS)

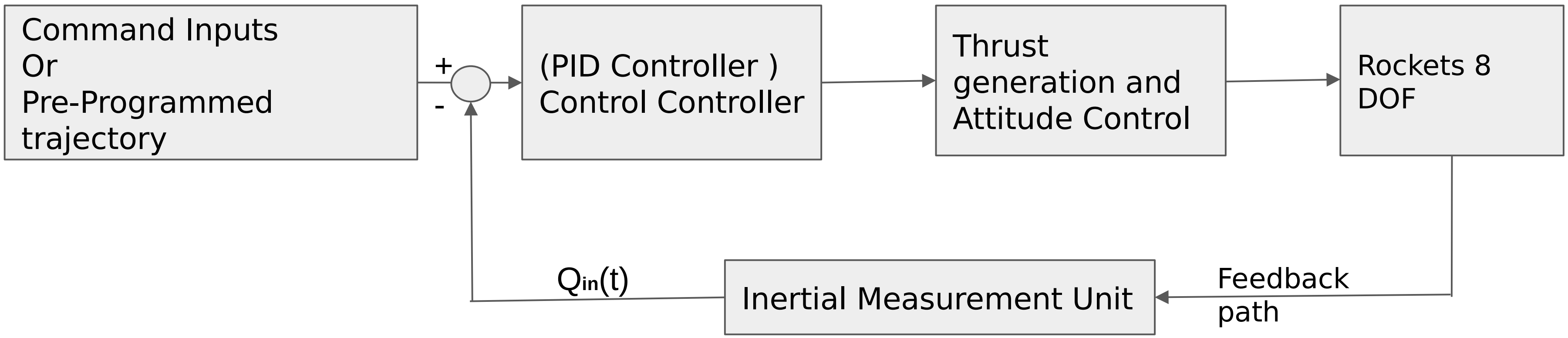




It provides Velocity Vector Adjustments and minor in flight correction maneuver as well as a simple rotation maneuvers.The RCS includes the following subsystems such as:

- Inertial measurement Unit Or IMU
- Controller or Control
- Devices for changing the angular position

RCS - Block Diagram



$Q_{in}(t)$ = Input provides By Inertial measurement Unit at a time instant (t)

Understanding RCS,

1. Block C - Thrust generation and Attitude Control Provides the rocket 8 Degrees of Freedom.

2. Block C is provided the input from Block B - PID Controller which in turn gets its reference and initial input data from the Block A - command inputs or Pre-programmed trajectory.

3. In order to compare its present position with the designated path, a feedback loop is there, which is provided by the Block D - Inertial Measurement unit.

Proportional Integral Derivative Controller (PID) :

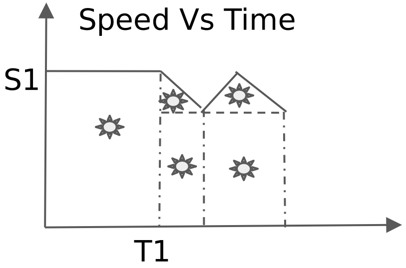
Proportional Constant:

When something changes with respect to something else,it does not mean both the values are equal.It just means they change with respect to each other.

Distance ∝ Speed
Distance ∝ Time

So, Distance = k x Speed x Time
Where k is constant of Proportionality

Integral Constant:



- Integral means that to combine (or) add up all the past value to form a complete entity.
- In order to find the total distance covered,calculate the area under this curve as
  - Speed * Time = Distance
- For the First half of the graph,it is quite easy to calculate the distance as it forms a rectangle.
  - (S1 xT1)
- For the second half of the curve, it is not possible to easily calculate the area.
- As navigate, this area can be divided into small areas that can be easily calculated.
- The Integral will keep adding this infinitesimally small areas.
- By the time integral reaches final point; the complete area is calculated by means of known areas i.e triangle and rectangle.

Derivative Constant:

- Derivative means sensitivity to the change of value.
- Derivative of a position with respect to time is called as its velocity.

  Consider $f(x) = 5t^2 + 2t$ [x = distance and t = time]

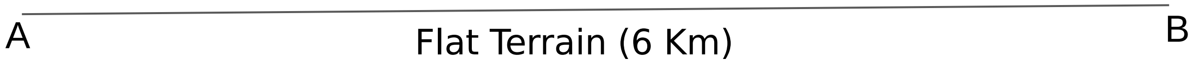
  $$dx/dt = 10t + 2$$

  If t = 2 sec >>> $dx/dt = v = 22$ m/sec

  If t = 5 sec >>> $dx/dt = v = 52$ m/sec

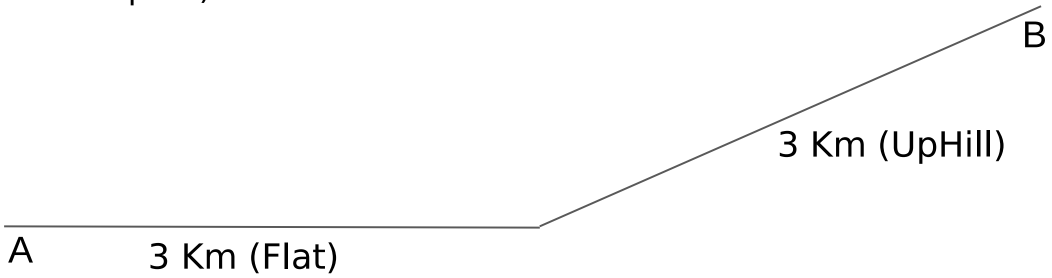
- If a system parameter is expressed by a function, the derivative component gives an idea about further values.

Case Study 1: (Flat)



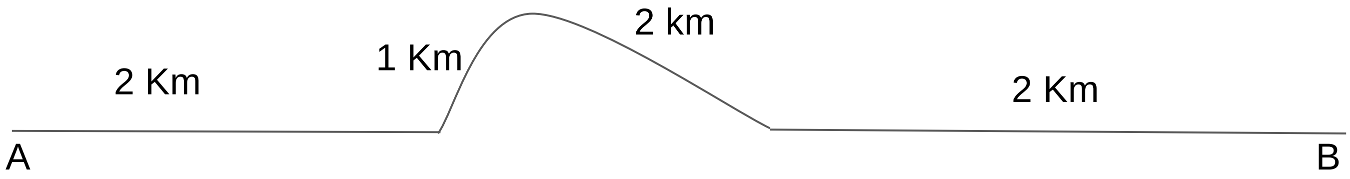
- If a Person starts with 5 m/sec , he requires 20 minutes to reach the destination
- If a Person starts with 10 m/sec , he requires 10 minutes to reach destination.
- Here Brain of a person acts a “Proportional Controller” making use of the present set of values i.e what time the person should start and accordingly what proportional speed needs to be maintained.

Case Study 2: (Flat + UpHill)



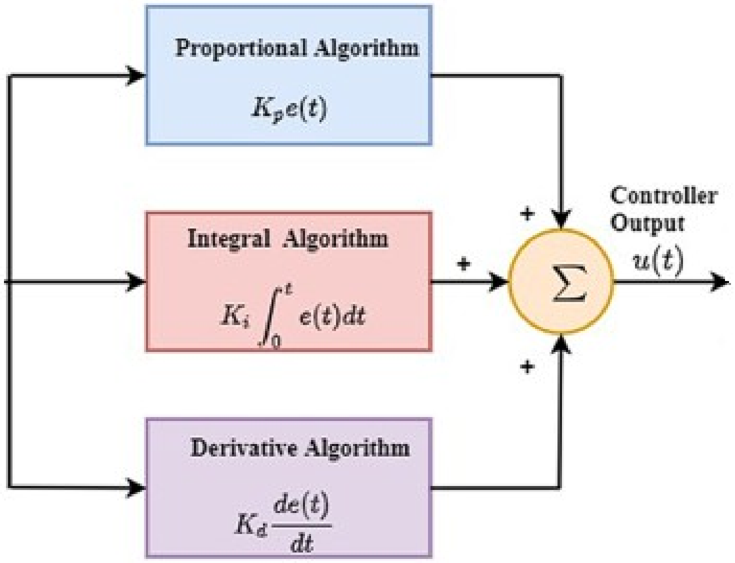
- As terrain is changing,brain acts as a Integral Controller.
- Thus Brain will use the Past information and keeps a running total of inputs over time. I.e How much distance have been covered, how much is left and how much energy person have used up till now.
- Thus will enable it to adjust the pedaling speed depending upon the steepness of the hill, so that person can reach the destination on time.

Case Study 3: (Flat + UpHill + Down Hill + Flat)



- As brain of a person acts as a “Integral Controller”, person reaches the UpHill.
- By the time person comes to Downhill , He don’t have to pedal.
- Person when coming down in Down Hill, He has to decide to slow down to have stable when he start off again on Flat.
- During Downhill motion, Person Brain acts as “Derivative Controller”.
- Derivative Controller is sensitivity to change of value and predict the future scenario,hence brain will do the same.

Summary (PID)



- Proportional Controller >> Present
- Integral Controller >> Past
- Derivative Controller >> Future

- These are the key value which a control system engineer designs and this is tuning the controller.

Kp = Proportional Gain
Ki = Integral Gain
Kd = Derivative Gain

$$u(t) = K_p e(t) + K_i \int_0^t e(\tau) d\tau + K_d \frac{d}{dt} e(t)$$

The mathematical expression for open loop PID controller with no feedback

IMU and PID

It is an electronic device that measures and accurately reports a rocket velocity and position by finding out the specific force,angular rate and the orientation of the body,using a combination of sensors such as,

- Accelerometers
- Gyroscope
- Magnetometers and GPS data

This helps the PID controller compare with the preprogrammed trajectory or command inputs from the ground and decide on future course of actions.

- If the attitude is incorrect by five degrees, then P controller sends a signal to the thrusters to correct for five degrees.
- The Derivative control component adds a dampingthrust.It determines the rate at which a thrust should decrease or increase to damp out the disturbance.
- Integral Controller Looks at a longer period of time of the changing attitude and looks for longer acting attitude errors.
- These errors are usually instantaneously small,but can cause large course errors over time.The integral component is needed as a check and balance to each of the other more abrupt control components to maintain flight path accuracy.
- Due to the large mechanical forces involved with rocket systems the PID controller is quite ideally suited