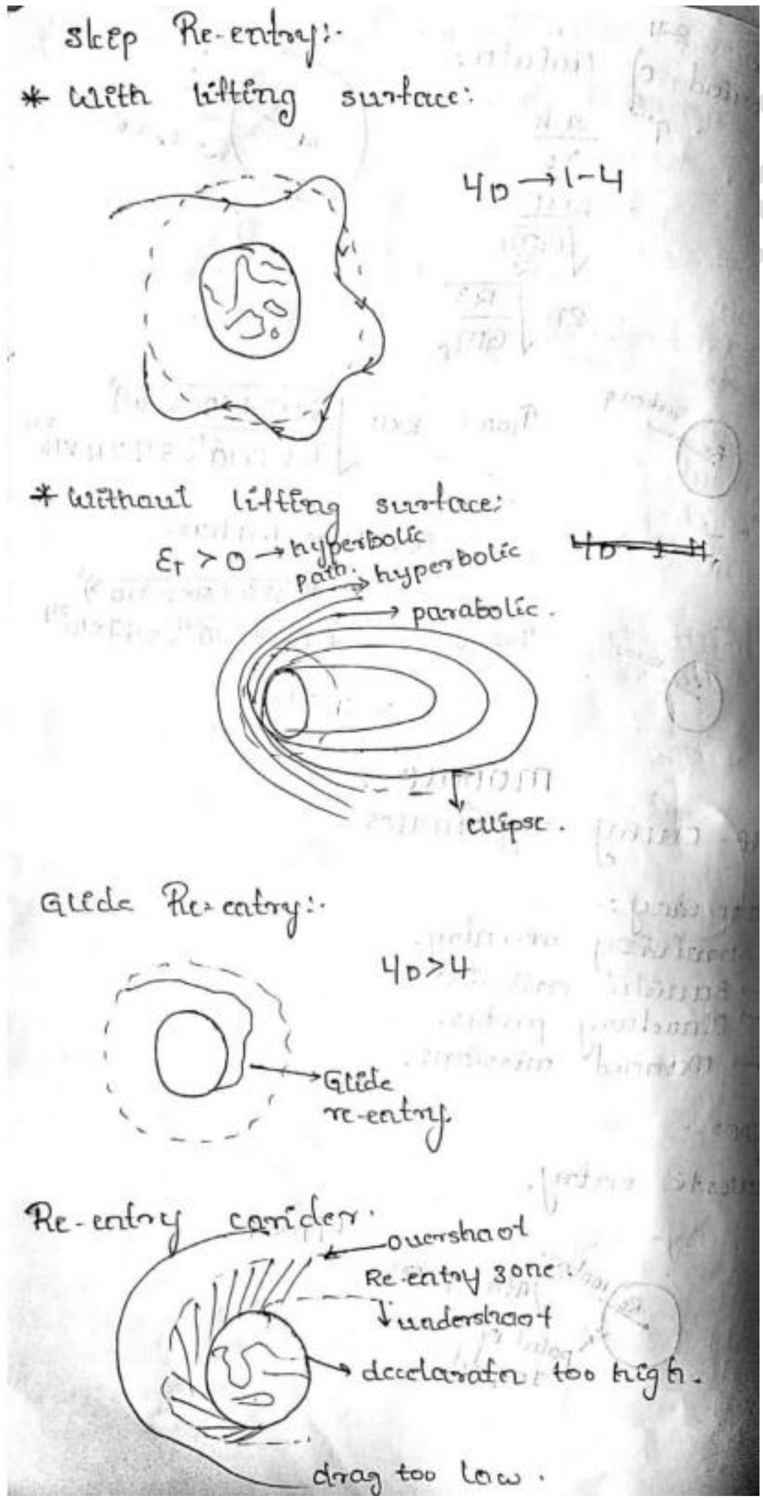
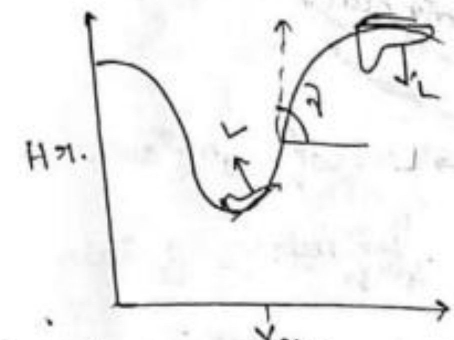
MODULE 2

Atmospheric Reentry:

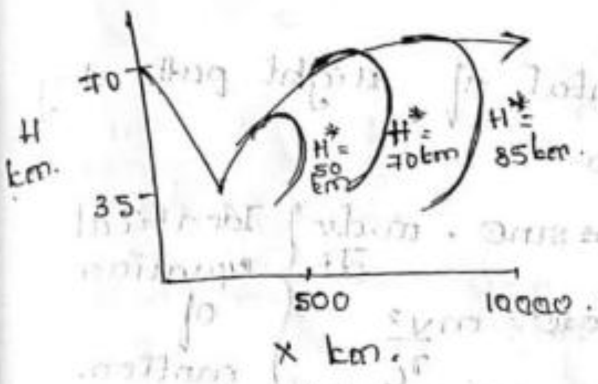
Introduction-Steep Ballistic Reentry, Ballistic Orbital Reentry, Skip Reentry, "Double-Dip" Reentry, Skip reentry, glide reentry, reentry corridor, reentry dynamics for ballistic reentry, reentry heating, Aero-braking, Lifting Body Reentry.



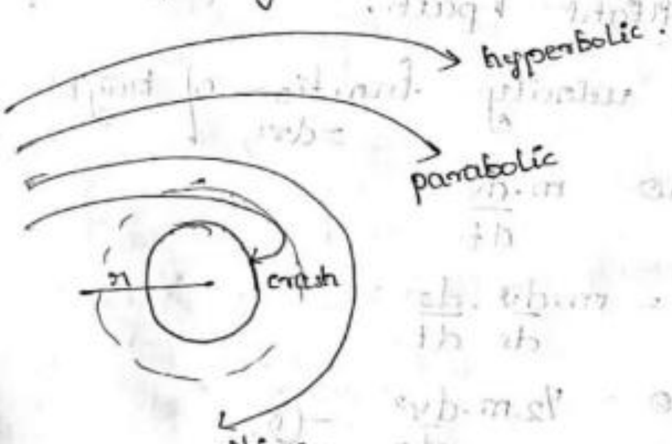
DOUBLE DIP RE-ENTRY :-



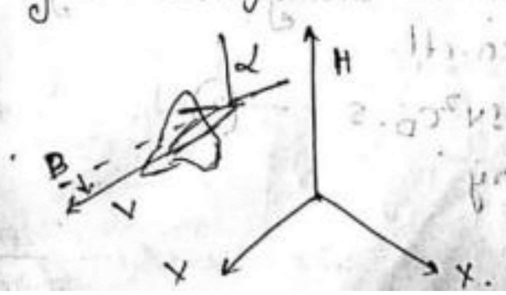
Trajectories Rollercoaster path Hr, Xr



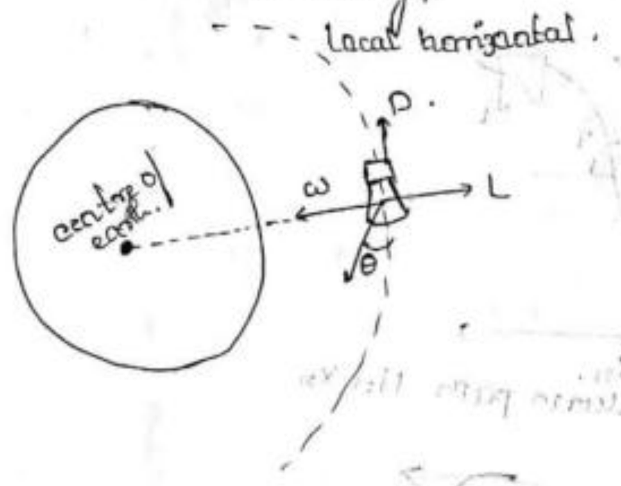
Aero braking



Lifting body re-entry.



General equation of motion of Atmospheric re-entry.



parallel of horizontal of flight path by Newtons 2nd law.

$$-D + W\sin\theta = m.\frac{dv}{dt}$$
$$L - W\cos\theta = m\frac{v^2}{r_C}$$

Identical equation of motion.

where r_C = radius of curvature of flight path.

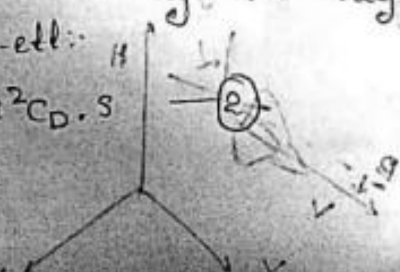
Analysis - yield velocity function of height = drag

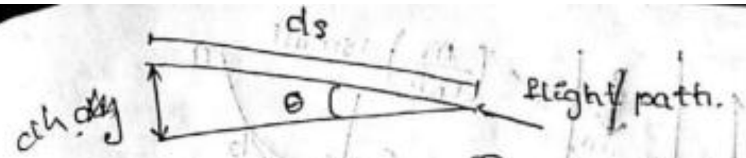
$$-D + W\sin\theta = m.\frac{dv}{dt}$$
$$= m.\frac{dv}{ds}.\frac{ds}{dt}.$$
$$-D + W\sin\theta = \frac{1}{2}m.\frac{dv^2}{ds} \quad -(1)$$

where
s - distance along the flight path.

From drag co-eff:
$$D = \frac{1}{2}\rho V^2 C_D . S \quad -(2)$$

From geometry





$$ds = -\frac{dh}{\sin\theta} \quad — (3)$$

$$-\frac{1}{2}\rho V^2 S C_D + \omega \sin\theta = \frac{1}{2} m \sin\theta \frac{dV^2}{dh} \quad — (4).$$

Obtaining velocity is function of h.

WKT

$$\rho = f(h)$$

$$\frac{\rho}{\rho_0} = e^{-g_0 h/RT}$$

$$= e^{-zh} \quad — (5)$$

when

$$z = g_0/RT \cdot$$

Relation b/w the velocity & density.

diff the above eqtn.

$$\frac{\delta\rho}{\rho_0} = e^{-zh}[-z\,dh]$$

$$= \frac{\rho}{\rho_0}[-z\,dh] \quad — (6)$$

$$dh = \frac{-\delta\rho}{z\rho}$$

eq (6) in (4)

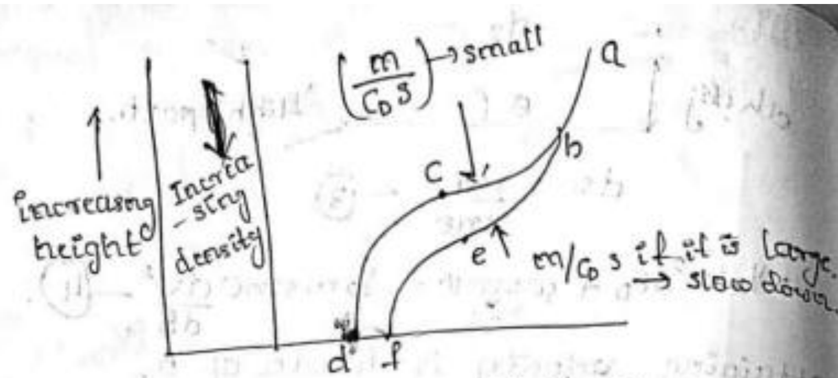
$$-\frac{1}{2}\rho V^2 S C_D + \omega \sin\theta = -\frac{1}{2} m \sin\theta \frac{dV^2}{d\rho}[-z\rho]$$

$\div \frac{1}{2}\rho z m \sin\theta$

$$\frac{V^2 \rho C_D}{z m \sin\theta} - \frac{2mg}{z\rho m} = -\frac{dV^2}{d\rho}.$$

$$\frac{dV^2}{d\rho} + \frac{1}{\frac{m}{C_D S}} \cdot \frac{V^2}{z \sin\theta} = \frac{2g}{z\rho} \Bigg\} \text{ velocity reentry into the atmosphere.}$$

$\frac{m}{C_D S} \rightarrow$ ballastic parameter.



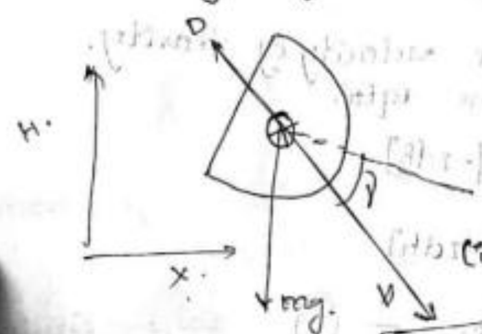
Increasing velocity →

abcd → ballastic.

BALASTIC RE-ENTRY:

Ballastic vehicle without lift for the steep entry angle.

u → forward motion.



where

x → downrange distance.

(independent) H → altitude.

Eqtn of motn:

$$\frac{dx}{dt} = V\cos\gamma$$

$$\frac{dH}{dt} = V\sin\gamma$$

$$\frac{dx}{dH} = \frac{V\cos\gamma}{V\sin\gamma} = \cot\gamma$$

In track acceleration component:

$$m \cdot \frac{dv}{dt} = -D - mg\sin\gamma$$

cross-track acceleration comp

$$m \cdot V \cdot \frac{d\gamma}{dt} = -mg\cos\gamma$$

centripetal acceleration $= g_c - \frac{V^2 [\cos^2\gamma]}{\gamma}$

H as the independent variables the eqtn $\frac{dH}{dt} = V\sin\gamma$ & new eqtn of motn.

$\frac{dx}{dH} = \cot\gamma$ → trajectory is stright line.

$$M \cdot V \cdot \frac{dv}{dH} = \left(\frac{-D}{\sin\gamma}\right) - mg$$

deceleration of vehicle

$\frac{d\gamma}{dH} = \frac{-g\cot\gamma}{V^2}$ → relatively changes (γ)

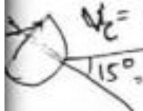
for the case of steep entry we the cotangent is small

① Consider a solid mass in a shape of sphere entering a earth atm. at 13 km/sec. at a vel of 15° below the local horizontal. sphere diameter is 1m the drag co-eff for the sphere at hypersonic speed is approx is 1. The density of mass is 6963 kg/m³. Calc

* altitude at wch max decelaratn occur.
* value of max decelaratn.
* velocity at wch the sphere would impact the earth surface.

{re-entr mach no > 27. } $= \left\{ \frac{13000}{340} = 38 \right.$ mach no. → re-entr

$V_E = 13$ km/sec $= 13000$ m/s.



$15°, 7$

at sea level.
$T = 288k$.
$P = 1.01325 \times 10^5 N/m^2$.
$\rho_0 = 1.225$ kg/m³.

$\theta = 15°$

$D_{sphere} = 1m$.

$C_d = 1$.

$\rho = 6963$ kg/m³.

to find:-

* h
* max decelaratn $\left[\frac{dv}{dt}\right]_{max}$.
* velocity.

formula:-

* $h = -\frac{1}{Z} \ln \frac{\rho}{\rho_0}$

$Z = \frac{g_0}{RT}$

$\beta = \left(\frac{m}{C_D \cdot S}\right) \cdot Z \sin\theta$

* $\left[\frac{dv}{dt}\right]_{max} = \frac{V_E^2 Z \sin\theta}{2e}$.

* $\left(\frac{V}{V_E}\right) = e^{-\rho/2\left[\frac{m}{C_D \cdot S}\right] Z \sin\theta}$

* $m = \rho V$.

$V = \frac{4}{3}\pi r^3$.

$S = \pi r^2$

soln:-

0.5419

0.2588

$m = 3645.81\ kg.$

$\rho = \dfrac{3645.81}{1 \times 0.785} \times z \cdot \sin 15$

$z = \dfrac{9.81}{287 \times 288}$

$= 0.000118\ m^{-1}$

$\rho = 0.1418\ kg/m^3$

$h = \dfrac{-1}{z} \ln \dfrac{\rho}{\rho_0}$

$= \dfrac{-1}{0.000118} \ln . \dfrac{0.1418}{1.225}$

$= 18273.5\ m.$

$= 18.2\ km.$

$\left(\dfrac{dv}{dt}\right)_{max} = \dfrac{V_E^2\, z \sin\theta}{2e}$

$= \dfrac{(13000)^2 \times [0.000118] \times \sin 15}{2e}$

$= 949.3\ m/s^2$

$\dfrac{949.3}{9.8} = 96.87\ g/s.$

$\dfrac{V}{V_E} = e^{-\frac{\rho}{2}\left[\frac{m}{C_D \cdot S}\right] z \sin\theta}$

$\dfrac{V}{13000} = e^{\frac{-1.225}{2}[4642][0.000118][\sin 15]}$

$= \dfrac{998.8}{340}$

$V = 998.8\ m/s.$

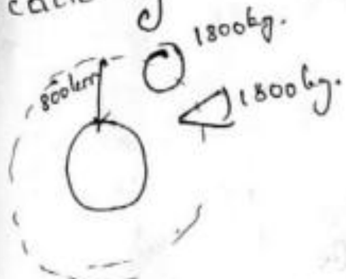
$M = 2.9$

Compare 2 bodies ... at an altitude of 800 km. above the earth surface of the earth. Each body as a mass of ~~tot~~ 1800 kg. 1 body is a cone shape with a total vertex, ∠le of 10°. The other body is sphere, for the cone at hypersonic pressure drag co-eff at mach no is 0.017. & skin friction drag co-eff is 0.01. for the sphere pressure drag co-eff is 1. friction drag co-eff 0.001 calc & compare the total aerodynamic heating input to each body during atm entry.

→ heat transfer when entered to atmos = ?

→ cone & circular shape.

r of earth = 6.4×10^6 m.



$m_s = 1800$ kg.

$m_c = 1800$ kg.

$h_g = 800$ km.

$r_e = 6.4 \times 10^6$ m.

$\theta = 10^\circ$

$\left.\begin{array}{l} C_{D_p} = 0.017 \\ C_f = 0.01 \end{array}\right\}$ cone

$\left.\begin{array}{l} C_{D_p} = 1 \\ C_f = 0.001 \end{array}\right\}$ sphere

To find:- aerodynamic heating into the body = ?

Formulae:-

$$Q = \frac{1}{2}\frac{C_f}{C_D}\left[\frac{1}{2}mV_c^2\right]$$

$$v = \sqrt{\frac{k}{r}}$$

$K = G.M \rightarrow$ mass of earth.

$r = r_E + h_g$

$C_D = C_{Dp} + C_f \rightarrow$ skin fridn coeff

drag co-eff, pressure drag co-eff

soln :- [cone]

$C_D = C_{Dp} + C_f$

$= 0.017 + 0.01$

$= 0.027$

$r = r_E + h_g$

$= (6.4 \times 10^6) + (800 \times 10^3)$

$= 7.2 \times 10^6$ m.

$$v_c = \sqrt{\frac{(5.974 \times 10^{24} \times 6.67 \times 10^{-11})}{7.2 \times 10^6}}$$

$= \cancel{1.484 \times 10^{11}}$ 7439.25 m/s

$$Q_{cone} = \frac{1}{2} \times \frac{0.01}{0.027} \times \left[\frac{1}{2} \times 1800 \times (7439.25)^2\right]$$

$= 9.2 \times 10^9$ J.

[Sphere]

$C_D = C_{Dp} + C_f$

$= 1 + 0.001$

$= 1.001$

$r = 7.8 \times 10^{?} m.$

$V_e = 7439.25 m/s.$

$$Q = \frac{1}{2} \times \frac{0.001}{1.001} \left[\frac{1}{2} \times 1800 \times (7439.25)^2\right]$$

$= 2.48 \times 10^{7} J.$

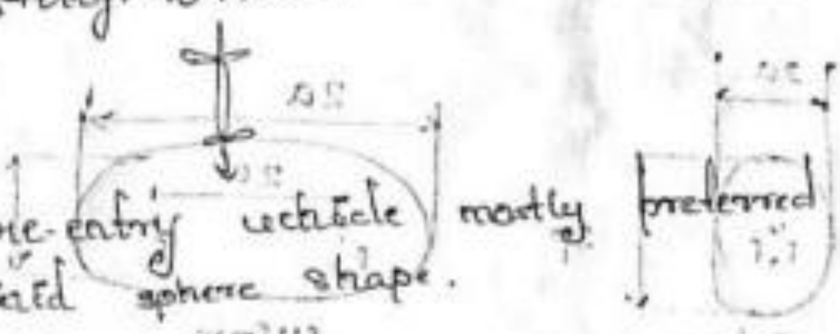
Q.-

[The flow where it gets separated is called wake regn]

[max angle of attack reaches the wing surface. at that time flow separates & wake regn is produced.]

→ stall is ~~occur~~ produced. [fall from dead weight].

→ change the aircraft movement in the downward directn & move in the ~~frong~~. forward movement.



→ re-entry vehicle mostly preferred hed sphere shape.

. ~~for an obj~~ Consider a ballistic re-entry for an object with the fall specifications. of $V_e = 8 km/s$, & γ [gamma] $= 10°$ & ballastic parameter $= \frac{m}{scd}$ is 5000 kg/m² at temp 288K. Find the h at which deceleratn is max what is the max deceleratn, velocity at this altitude & velocity of the vehicle when it reaches surface of the earth.