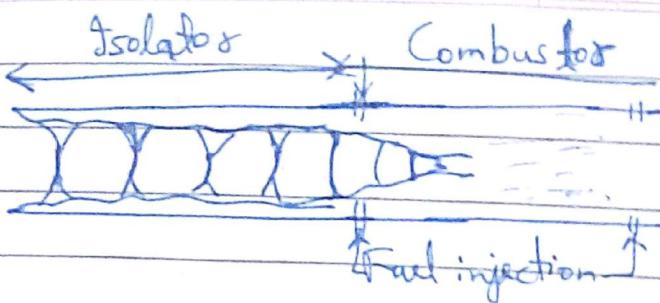


Isolators

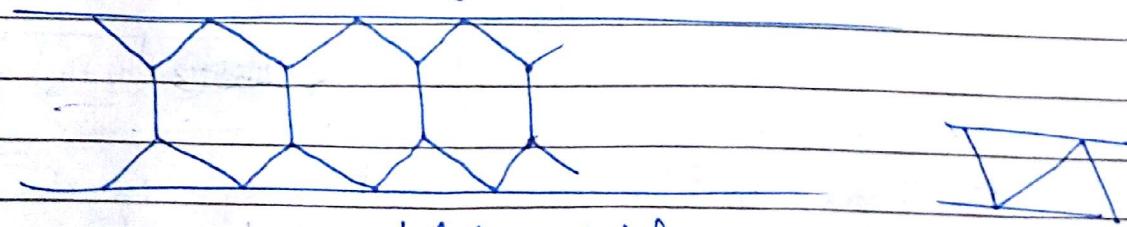
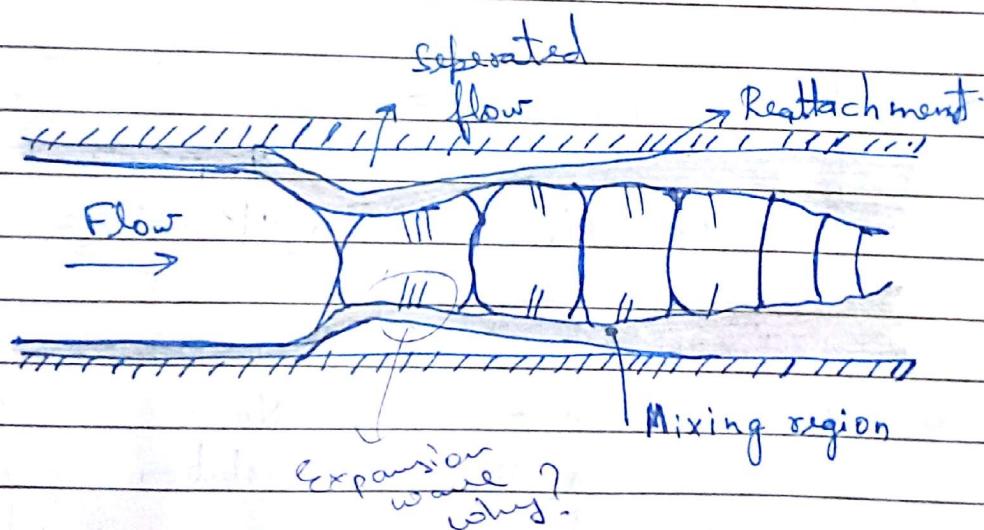
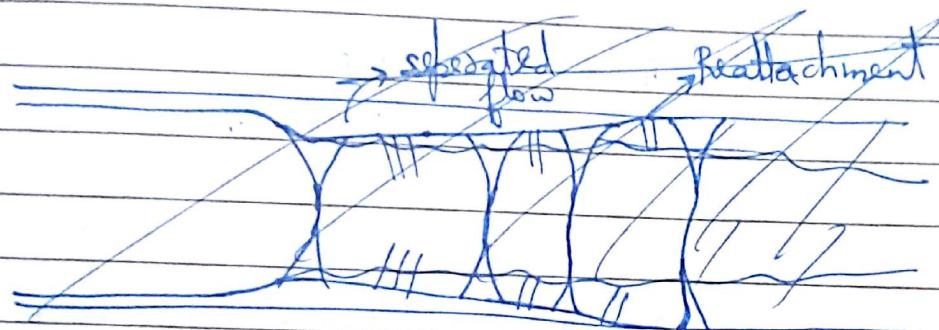
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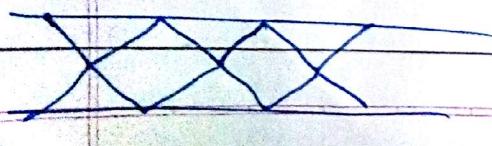
Geometry:



Function: The disturbances generated by heat-release in the combustor can propagate upstream and affect the operation of the inlet. 'Isolators' is used to avoid that.



Simplistic Model



Questions:

- (3) why does the boundary layer reattach?
- (2) How to add Fanno analysis to the isolator?
- (1) How does it work (isolator)?

the
the

$$\frac{dp}{dx} = \frac{89 C_{f0}}{D_h} \cdot \frac{\rho V^2}{2} \rightarrow ①$$

~~$$dH_o = Q_R f_{st} d\phi - dQ$$~~

$$T_w = \frac{C_f \rho V^2}{2}, A_w = \frac{4A dx}{D_h}$$

$$\frac{dp}{P} + \frac{dV}{V} + \frac{dA_c}{A_c} = 0$$

$$\frac{dp}{P} +$$

$$M, p, A_c, x, T_0 \quad]$$

$$M = \frac{V}{a}$$

$$a = \frac{(V)}{(M)}$$

Derivation
of equation ③:

$$h_0 = h + \frac{1}{2} V^2$$

$$C_p T_0 = C_p T + \frac{1}{2} V^2$$

$$T_0 = T + \frac{V^2}{2C_p} = T + \frac{TV^2(\gamma-1)}{2\gamma RT}$$

$$T_0 = T + \frac{TV^2(\gamma-1)}{2a^2}$$

$$T_0 = T + \frac{T(\gamma-1)M^2}{2} = T \left(1 + \frac{(\gamma-1)M^2}{2} \right)$$

$$\Rightarrow \log(T_0) = \log T + \log \left(1 + \frac{(\gamma-1)M^2}{2} \right)$$

$$\frac{dT_0}{T_0} = \frac{dT}{T} + \frac{1}{1 + \frac{(\gamma-1)M^2}{2}} \frac{d(M^2)}{M^2} \frac{(\gamma-1)}{2}$$

$$\left(1 + \frac{(\gamma-1)M^2}{2} \right) \frac{dT_0}{T_0} = \left(1 + \frac{(\gamma-1)M^2}{2} \right) \frac{dT}{T} + \cancel{\frac{d(M^2)}{M^2} \frac{(\gamma-1)}{2}}$$

$$+ \cancel{\frac{d(V^2/a^2)}{a^2} \frac{(\gamma-1)}{2}}$$

$$\left(1 + \frac{(\gamma-1)M^2}{2} \right) \frac{dT}{T} + \left(1 + \frac{(\gamma-1)M^2}{2} \right) \frac{d(V^2/a^2)}{a^2} = \left(1 + \frac{(\gamma-1)M^2}{2} \right) \frac{dT}{T} + \frac{\gamma RT}{V^2} \frac{d(V^2/a^2)}{a^2}$$

$$= \left(1 + \frac{(\gamma-1)M^2}{2} \right) \frac{dT}{T} + \left(1 + \frac{(\gamma-1)M^2}{2} \right) \frac{d(V^2)}{V^2} - \frac{d(a^2)}{a^2}$$

$$= \left(1 + \frac{(\gamma-1)M^2}{2} \right) \frac{dT}{T} + \left(1 + \frac{(\gamma-1)M^2}{2} \right) \frac{d(V^2)}{V^2} - \frac{\gamma R(dT)}{\gamma RT}$$

$$= \frac{dT}{T} + \left(\frac{\gamma-1}{2} M^2 \right) \frac{d(V^2)}{V^2}$$

$$M, p, \underline{A_c}, \underline{x}, T_0, \underline{\rho}, \underline{T}, \underline{V}$$

(stagn. vars)

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$$\frac{dp}{\rho} + \frac{dV}{V} + \frac{dA_c}{A_c} = 0 \rightarrow ①$$

$$\frac{dp}{\rho} - \frac{dp}{\rho} - \frac{dT}{T} = 0 \rightarrow ②$$

$$\frac{d(M^2)}{M^2} = - \left(1 + \left(\frac{r-1}{2}\right)M^2\right) \left[\frac{dp/\rho}{\frac{rM^2}{2} \frac{A_c}{A}} + \frac{4Q_f dx/D}{\frac{A_c}{A}} + \frac{dT_0}{T_0} \right] \rightarrow ③$$

$$\frac{d(A_c/A_2)}{(A_c/A_2)} = \left[\frac{1 - M^2 \{ 1 - r(1 - A_c/A_2) \}}{2 \cdot M^2 A_c / A_2} \right] \frac{dp}{\rho} + \left(\frac{1 + (r-1)M^2}{2 A_c / A_2} \right) \frac{4Q_f dx}{D} + \left(1 + \left(\frac{r-1}{2} \right) M^2 \right) \frac{dT_0}{T_0} \rightarrow ④$$

$$\frac{dM^2}{M^2} - \frac{dV^2}{V^2} + \frac{dT}{T} = 0 \rightarrow ⑤$$

$$\frac{dp}{dx} = \frac{89}{P_b} c_{f0} \left(\frac{\rho V^2}{2} \right) \rightarrow ⑥$$

$$T_0 = T_{02} + \frac{(\alpha R f_{st} \phi n_c - \phi Q)}{c_p}$$

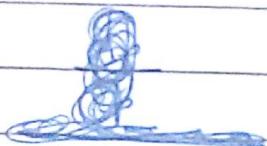
$$n_c = n_{c,tot} \left[\frac{\theta x}{1 + (\theta - 1)x} \right] \Rightarrow n_c =$$

$$x = \frac{(x - n_3)}{(x_4 - n_3)}$$

$$x_3 = 0.2 \text{ m} \\ x_4 = 0.5 \text{ m} \\ \theta = 5 \\ n_{c,tot} = 0.8$$

$$\Rightarrow x = \frac{(x - 0.2)}{0.3}$$

$$\frac{dp}{p} + \frac{\gamma M^2}{2} \frac{4C_f du}{D} + \frac{\gamma M^2}{2} \frac{A_c}{A} \frac{dv^2}{v^2} = 0$$



$$\frac{\frac{dp}{p}}{\frac{\gamma M^2}{2} \frac{A_c}{A}} + \frac{\frac{4C_f du}{D}}{\frac{A_c}{A}} + \frac{\frac{dv^2}{v^2}}{\frac{(\gamma-1)M^2}{2}} = 0$$

$$\frac{dv^2}{v^2} = \left(\left(1 + \frac{\gamma-1}{2} M^2 \right) \frac{dT_k}{T_k} - \frac{dT}{T} \right) \frac{(\gamma-1)M^2}{2}$$

$$\Rightarrow \frac{dp}{p} = \cancel{\frac{\gamma M^2}{2} \frac{A_c}{A}}$$

$$\Rightarrow \left(\frac{dp}{p} + \frac{4C_f du}{D} \right) + \left(1 + \left(\frac{\gamma-1}{2} M^2 \right) \frac{dT_k}{T_k} - \frac{dT}{T} \right) = 0$$

$$\rightarrow \frac{dp}{du} = \frac{8g}{D_h} C_{f_0} \left(\frac{\rho V^2}{2} \right)$$

$$\rightarrow \left(\dots \right) + \left(\frac{1}{\left(\frac{\gamma-1}{2} M^2 \right)} + 1 \right) \frac{dT_k}{T_k} - \frac{dT}{T} = 0$$

$$\boxed{\left[\left(\dots \right) + \frac{dT_k}{T_k} \right]} = \left(\frac{dT}{T} \right) - \frac{dT_k/T_k}{\left(\frac{\gamma-1}{2} M^2 \right)}$$

$$\frac{dp/p}{\gamma M^2 \frac{Ac}{A}} + \frac{4C_f dx}{D} + \frac{dM^2}{M^2} + \frac{dT}{T} = 0$$

$$T_F = T \left(1 + \frac{\gamma - 1}{2} M^2 \right)$$

$$\frac{dT_F}{T_F} = \frac{dT}{T} \left(\dots \right) + \frac{dT}{T_F}$$

Derivation of equation (g):

$$\frac{dp}{p} + \frac{\gamma M^2}{2} \frac{4C_f dx}{D} + \frac{\gamma M^2}{2} \frac{Ac}{A} \frac{dv^2}{v^2} = 0 \rightarrow (5)$$

$$\frac{dT}{T} + \left(\frac{\gamma - 1}{2} M^2 \right) \frac{dv^2}{v^2} = \left(1 + \frac{\gamma - 1}{2} M^2 \right) \frac{dT_F}{T_F} \rightarrow (6)$$

$$\frac{dM^2}{M^2} - \frac{dv^2}{v^2} + \frac{dT}{T} = 0 \rightarrow (8)$$

$$\text{From (6), } \frac{dT}{T} = \left(1 + \frac{\gamma - 1}{2} M^2 \right) \frac{dT_F}{T_F} - \left(\frac{\gamma - 1}{2} M^2 \right) \frac{dv^2}{v^2}$$

~~Putting in (8)~~ Put this in (8):

$$\Rightarrow \frac{dM^2}{M^2} - \frac{dv^2}{v^2} + \left(1 + \frac{\gamma - 1}{2} M^2 \right) \frac{dT_F}{T_F} - \left(\frac{\gamma - 1}{2} M^2 \right) \frac{dv^2}{v^2} = 0$$

$$\Rightarrow \frac{dM^2}{M^2} + \left(1 + \frac{\gamma - 1}{2} M^2 \right) \left(\frac{dT_F}{T_F} - \frac{dv^2}{v^2} \right) = 0 \rightarrow (i)$$

From (5),

$$\frac{dv^2}{v^2} = \frac{1 - \frac{dp/p}{\gamma M^2 \frac{Ac}{A}} - \frac{4C_f dx}{D}}{\left(Ac/A \right)} \rightarrow (ii)$$

Put (ii) in (i).

$$\frac{dM^2}{M^2} = - \left(1 + \frac{r-1}{2} M^2 \right) \left[\frac{dp/p}{rM^2 A_c} + \frac{4C_f dA}{D} + \frac{dT}{T_0} \right]$$

→ (9)

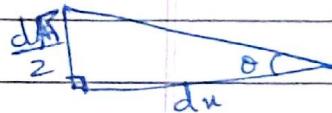
Derivation of equation (2) :

$\Sigma F_x = \text{rate of change of momentum}$

$$\Sigma F_x = PA_c - (P + dP)(A_c + dA_c)$$

$$= \frac{1}{2} \rho V^2 C_f (A_c + A_c + dA_c) dA_c$$

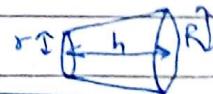
$$= \frac{1}{2} \rho V^2 C_f \pi (R + R + dR) \sqrt{\frac{(R+dR)^2}{(R+dR-R)^2} + (dn)^2} \cdot dn$$



$$\cos\theta = \frac{dn}{\sqrt{(dn)^2 + \left(\frac{dA_c}{2}\right)^2}} \approx 1$$

C.S.A. of a frustum of cone

$$= \pi(R+r)\sqrt{(R-r)^2 + h^2}$$



$$\Sigma F_x = PA_c - (P + dP)A_c - \frac{1}{2} \rho V^2 C_f 2\pi R dn$$

$$= -A_c dP - \frac{1}{2} \rho V^2 C_f 2\pi R dn$$

Rate of change of momentum = mom. flux exiting
- mom. flux entering

$$= m(V + dV) - mV$$

$$= mdV$$

$$= \rho V A_c dV$$

$$\Rightarrow \left[-A_c dP - \frac{1}{2} \rho V^2 C_f 2\pi R dn = \rho V A_c dV \right] \div A_c$$

$$\cancel{-\frac{dP}{A_c} + \rho V dV} = -\frac{1}{2} \rho V^2 C_f \pi R \frac{dn}{A_c} = -\frac{1}{2} \rho V^2 C_f \frac{A}{RA_c} dx$$

$$\Rightarrow \frac{A}{A_c} dP + \rho V dV = -2\rho V^2 \frac{C_f}{D} \frac{A}{A_c} dx$$

$$\frac{A}{A_c} dP + \rho V dV = -\frac{1}{2} \rho V^2 \left(\frac{4 C_f D x}{D} \right) \left(\frac{A}{A_c} \right) \rightarrow (i)$$

$$\frac{1}{2} \rho V^2 = \frac{1}{2} \frac{P}{RT} V^2 = \frac{1}{2} \frac{P \gamma M^2}{R} \rightarrow (ii)$$

$$d(V^2) = 2V dV$$

$$\Rightarrow \rho V dV = \frac{\rho \gamma}{RT} \frac{d(V^2)}{2} = \frac{\rho \gamma M^2}{2 R} \frac{d(V^2)}{V^2} \rightarrow (iii)$$

$$\Rightarrow \frac{A}{A_c} dP + \frac{\rho \gamma M^2}{2} \frac{d(V^2)}{V^2} = -\frac{1}{2} \rho \gamma M^2 \left(\frac{4 C_f D x}{D} \right) \frac{A}{A_c}$$

$$\Rightarrow \boxed{\frac{dP}{P} + \frac{\gamma M^2}{2} \frac{4 C_f D x}{D} + \frac{\gamma M^2}{2} \frac{A_c}{A} \frac{dV^2}{V^2}}$$

Hence Proved.

$$\frac{dp}{du} = \frac{89}{D_h} C_{f0} \frac{PV^2}{2}$$

$$\therefore \frac{89}{D_h} C_{f0} \frac{P}{RT} \frac{V^2}{2} = \frac{89}{D_h} C_{f0} \frac{PM^2}{2}$$

$$\Rightarrow \frac{dp}{P} = \frac{89}{D_h} C_{f0} \frac{\gamma M^2}{2} du$$

$$\Rightarrow \frac{d(M^2)}{M^2} = -\left(1 + \frac{\gamma-1}{2} M^2\right) \left[\frac{89 C_{f0} du}{D_h} + \frac{4 C_f du}{D} + \frac{dT_f}{T_f} \right]$$

$$\text{Let } \frac{A_c}{A} = \alpha_A(x)$$

$$\Rightarrow \frac{d(M^2)}{M^2} = -\left(1 + \frac{\gamma-1}{2} M^2\right) \left[\frac{89 C_{f0} du}{D_h} + \frac{4 C_f du}{D \alpha_A} + \frac{dT_f}{T_f} \right] \quad \hookrightarrow ①$$

$$\frac{dq}{dx} = \frac{C_p dT_0}{dx} = K$$

$$\Rightarrow \frac{d(M^2)}{M^2} = -\left(1 + \frac{\gamma-1}{2} M^2\right) \left[\frac{dp/b}{\frac{\gamma M^2}{2} \sigma_a} + \frac{4 C_f d_n}{\sigma_a} \right]$$

$$\frac{dp}{dn} = \frac{89}{D_h} C_{f0} \frac{PV^2}{2} \Rightarrow \frac{dp}{p} = \frac{89 C_{f0}}{D_h} \frac{\gamma M^2}{2} dn$$

$$\frac{d(\sigma_a)}{\sigma_a} = \left[\frac{1 - M^2 \{1 - \gamma(1 - \sigma_a)\}}{\gamma M^2 \sigma_a} \right] \frac{dp}{p} + \left(\frac{1 + (\gamma-1)M^2}{2\sigma_a} \right) \frac{4 C_f d_n}{D}$$

$$\Rightarrow 2 \frac{dM}{M} = -\left(1 + \frac{\gamma-1}{2} M^2\right) \left[\frac{4 C_f d_n}{D \sigma_a} + \frac{\frac{89 C_{f0}}{D_h} \frac{\gamma M^2}{2} dn}{\frac{\gamma M^2}{2} \sigma_a} \right]$$

$$2 \frac{dM}{M} = -\left(1 + \left(\frac{\gamma-1}{2}\right) M^2\right) \left[\frac{4 C_f d_n}{D \sigma_a} + \frac{89 C_{f0} d_n}{D \sigma_a} \right]$$

$$2 \frac{dM}{M} = -\left(1 + \frac{\gamma-1}{2} M^2\right) \left[\frac{93 C_f d_n}{D \sigma_a} \right]$$

$$\boxed{\frac{dM}{dn} = -\frac{M}{2} \left(1 + \left(\frac{\gamma-1}{2}\right) M^2\right) \frac{93 C_f}{D \sigma_a}} \rightarrow ①$$

$$\boxed{\frac{d\sigma_a}{dn} = \frac{C_f}{2D} \left[93 + M^2 \{93(\gamma+1) - 89\gamma\sigma_a^2\} \right]} \rightarrow ②$$

$$\Rightarrow \textcircled{2} \quad b_0 = b \left(1 + \left(\frac{\gamma-1}{2} M^2 \right) \right)^{\gamma/(\gamma-1)}$$

$$\ln b_0 = \ln b + \frac{\gamma}{\gamma-1} \ln \left(1 + \frac{\gamma-1}{2} M^2 \right)$$

$$\frac{1}{b_0} \frac{db_0}{dx} = \frac{1}{b} \frac{db}{dx} + \frac{\gamma}{\gamma-1} \cdot \frac{1}{1 + \left(\frac{\gamma-1}{2} M^2 \right)} \left(\frac{\gamma-1}{2} \right) Z M dM$$

$$\textcircled{3} \quad \frac{db_0}{b_0} = \frac{db}{b} + \frac{\gamma}{\gamma-1} \cdot \frac{1}{\left(1 + \left(\frac{\gamma-1}{2} M^2 \right) \right)} \left(\frac{\gamma-1}{2} \right) Z M dM$$

$$\frac{db_0}{dx} = \frac{\gamma M dM}{1 + \left(\frac{\gamma-1}{2} M^2 \right)} + \frac{89 C_f \frac{\gamma M^2}{2}}{D_h}$$

$$\frac{1}{b_0} \frac{db_0}{dx} = \frac{89 C_f \frac{\gamma M^2}{2}}{D_h} + \frac{\gamma M}{1 + \left(\frac{\gamma-1}{2} M^2 \right)} \frac{dM}{dx}$$

$$= \frac{89 C_f \frac{\gamma M^2}{2}}{D_h} + \frac{\gamma M}{\left(1 + \frac{\gamma-1}{2} M^2 \right)} \left[- \frac{M}{2} \frac{(1 + \frac{\gamma-1}{2} M^2) 93 C_f}{D_h} \right]$$

$$= \frac{89 C_f \frac{\gamma M^2}{2}}{D_h} - \frac{\gamma M^2}{2} \frac{93 C_f}{D_h}$$

$$\frac{db_0}{dx} = \frac{C_f \frac{\gamma M^2}{2}}{D_h} \times \left(89 - \frac{93}{\gamma} \right) \times b_0$$

$$\Rightarrow \left[\frac{db_0}{dx} + \textcircled{2} \frac{C_f \frac{\gamma M^2}{2} \left(\frac{93}{\gamma} - 89 \right) b_0}{D_h} \right] \rightarrow \textcircled{4}$$

$$\boxed{\frac{db}{dx} = \frac{89 C_f \frac{\gamma M^2}{2} b}{D_h}} \rightarrow \textcircled{3}$$

~~$\frac{db}{dx}$~~

$$1 + 2x^4 + 4x^8 + 6x^{12} + \dots$$

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$$\rightarrow \text{Ques} \quad p(n) = \frac{p_2}{\sigma_a(n)} \frac{M_2}{M(n)} \sqrt{\frac{T(n)}{T_2}}$$

$$\log p = \log \left(\frac{p_2 M_2}{\sigma_a T_2} \right) - \log (\sigma_a) - \log (M) + \frac{1}{2} \log T$$

$$\frac{dp}{p} = -\frac{d\sigma}{\sigma} - \frac{dM}{M} + \frac{1}{2} \frac{dT}{T}$$

$$T_0 = \left(1 + \frac{r-1}{2} M^2 \right) T$$

$$dT_0 = dT$$

$$\log T_0 = \log \left(1 + \frac{r-1}{2} M^2 \right) + \log T$$

$$0 = \frac{dT_0}{T_0} = \frac{1}{\left(1 + \frac{r-1}{2} M^2 \right)} \cancel{(r-1)} \cancel{\frac{1}{2}} M dM + \frac{dT}{T}$$

$$\Rightarrow \frac{dT}{T} = -\frac{(r-1) M dM}{2 \left(1 + \frac{r-1}{2} M^2 \right)}$$

$$\Rightarrow \frac{dp}{pdn} = -\frac{d\sigma}{\sigma dn} - \frac{dM}{MdN} - \frac{(r-1) M dM}{(2 + (r-1) M^2) dn}$$

$$s = 1$$

$$s = 1 + [(1+2) + (1+2+2) + (1+2+2+2) + (1+2+2+2+2)] = s_1$$

$$s = s_1 + [(9+4) + (9+4+4) + (9+4+4+4) + (9+4+4+4+4)]$$

$$n=3 \rightarrow j_{\max} = 1$$

$$n=5 \rightarrow j_{\max} = 2$$

$$n=7 \rightarrow j_{\max} = 3$$

$$(j_{\max} B + 1) = n$$

0, 0.5, 1

0, 0.25, 0.5, 0.75, 1

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$$\rightarrow \frac{2MdM}{M^2} = - \left(1 + \frac{\gamma-1}{2} M^2 \right) \left(\frac{dp/p}{\gamma M^2 \delta} + \frac{4C_f dx}{D} \right)$$

$$\left(\frac{dM}{dx} \right)$$

$$= - \left(1 + \frac{\gamma-1}{2} M^2 \right) \left(\frac{\frac{89}{D} C_f (\gamma M^2) dx}{\frac{(\gamma M^2)}{2} \delta} + \frac{4C_f dx}{D \delta} \right)$$

$$\boxed{\frac{dM}{M} = - \frac{M}{2} \left(1 + \frac{(\gamma-1)M^2}{2} \right) \frac{93 C_f dx}{D \delta}}$$

$$\rightarrow \frac{d\delta}{\delta} = \left(\frac{1 - M^2 \{ 10 - \gamma(1-\delta) \}}{\gamma M^2 \delta} \right) \frac{dp}{p} + \left(\frac{1 + (\gamma-1)M^2}{2\delta} \right) \frac{4C_f dx}{D}$$

$$= \left(\frac{1 - M^2 \{ 1 - \gamma(1-\delta) \}}{\gamma M^2 \delta} \right) \frac{89}{D} C_f \frac{\gamma M^2}{2} dx$$

$$+ \left(\frac{1 + (\gamma-1)M^2}{2\delta} \right) \frac{4C_f dx}{D}$$

$$\frac{d\delta}{\delta} = (C_f dx) \cdot \frac{[89 - M^2 \{ 89 - \gamma \cdot 89 \cdot (1-\delta) \} + 4 + 4M^2(\gamma-1)]}{2D\delta}$$

$$\frac{d\delta}{\delta} = (C_f dx) \cdot \frac{[93 - 89M^2 + 89\gamma M^2 - 89\gamma \delta M^2 + 4M^2(\gamma-1)]}{2D\delta}$$

$$\boxed{\frac{d\delta}{dx} = \frac{C_f}{2D} \cdot [93 + M^2 (93(\gamma-1) - 89\gamma \delta(x))]}$$

0, 0.5, 1

0, 0.25, 0.5, 0.75, 1

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$$\rightarrow \frac{2M dM}{M^2} = - \left(1 + \frac{\gamma-1}{2} M^2 \right) \left(\frac{dp/p}{\frac{\gamma M^2}{2} \sigma} + \frac{4C_f dx}{D \sigma} \right).$$

$$\frac{dM}{dx}$$

$$= - \left(1 + \frac{\gamma-1}{2} M^2 \right) \left(\frac{89 C_f (\gamma M^2)}{D} \frac{dx}{2} + \frac{4C_f dx}{D \sigma} \right)$$

$$\boxed{\frac{dM}{M} = - \frac{M}{2} \left(1 + \frac{(\gamma-1)M^2}{2} \right) \frac{93 C_f dx}{D \sigma}}$$

$$\rightarrow \frac{d\sigma}{\sigma} = \left(\frac{1 - M^2 \{ 10 - \gamma(1-\sigma) \}}{\gamma M^2 \sigma} \right) \frac{dp}{p} + \left(\frac{1 + (\gamma-1)M^2}{2\sigma} \right) \frac{4C_f dx}{D}$$

$$= \left(\frac{1 - M^2 \{ 1 - \gamma(1-\sigma) \}}{\gamma M^2 \sigma} \right) \frac{89 C_f \gamma M^2}{D} \frac{dx}{2}$$

$$+ \left(\frac{1 + (\gamma-1)M^2}{2\sigma} \right) \frac{4C_f dx}{D}$$

$$\frac{d\sigma}{\sigma} = \frac{(C_f dx)}{2D\sigma} \left[\frac{89}{2} - M^2 \{ 89 - \gamma \cdot 89 \cdot (1-\sigma) \} + 4 + 4M^2(\gamma-1) \right]$$

$$\frac{d\sigma}{\sigma} = \frac{(C_f dx)}{2D\sigma} \left[\frac{93}{2} - \frac{89M^2}{2} + \frac{89\gamma M^2}{2} - \frac{89\gamma \sigma M^2}{2} + \frac{4M^2\gamma - 4M^2}{2} \right]$$

$$\boxed{\frac{d\sigma}{\sigma} = \frac{C_f}{2D} \left[\frac{93}{2} + M^2 \left(\frac{93(\gamma-1)}{2} - \frac{89\gamma \sigma}{2} \right) \right]}$$

$$P_{\text{AV}} = \text{const}$$

$$\ln P + \ln A + \ln V = \ln \text{const}$$

$$\frac{dP}{P} + \frac{dA}{A} + \frac{dV}{V} = 0$$

is plane \mathcal{F}

$$P = \rho R T$$

$$\frac{dM^2}{M^2} = - \left(1 + \frac{\gamma-1}{2} M^2 \right) \left[\frac{dP/P}{\frac{\gamma M^2}{2} \left(\frac{Ac}{A} \right)} + \frac{\frac{4C_f dx}{D}}{\frac{Ac/A}{A}} + \frac{dT_e}{\frac{d}{\gamma} T_e} \right]$$

$$\begin{cases} \frac{dP}{P} + \frac{\gamma M^2}{2} \frac{4C_f dx}{D} + \frac{\gamma M^2}{2} \frac{Ac}{A} \frac{dV^2}{V^2} = 0 \\ \frac{dT}{T} + \frac{\gamma-1}{2} M^2 \frac{dV^2}{V^2} = \left(1 + \frac{\gamma-1}{2} M^2 \right) \frac{dT_e}{T_e} \end{cases} \quad \begin{cases} \frac{dM^2}{M^2} - \frac{dV^2}{V^2} + \frac{dT}{T} = 0 \end{cases}$$

$$\frac{dP}{dn} \approx \frac{89}{D_n} C_f \left(\frac{PV^2}{2} \right) \quad \textcircled{2}$$

$$\frac{dP}{P} - \frac{dP}{S} - \frac{dT}{T} = 0 \quad \textcircled{3}$$

$$\frac{dP}{P} + \frac{dV}{V} + \frac{fdAc}{Ac} = 0 \quad \textcircled{4}$$

$$\frac{dM^2}{M^2} = \frac{dV^2}{V^2} - \frac{dT}{T}$$

$$\frac{dM^2}{M^2} = - \left(\frac{dP}{P} + \frac{\gamma M^2}{2} \left(\frac{4C_f dx}{D} \right) \right) - \frac{dT}{T}$$

$$\frac{dM^2}{M^2} = - \left(\frac{(dP/P)}{\frac{\gamma M^2 \cdot Ac}{2}} + \frac{\frac{4C_f dn}{D}}{\frac{Ac/A}{A}} \right) - \frac{dT}{T}$$

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$$\frac{dM^2}{M^2} = + \left(\frac{dV^2}{V^2} \right) - \left(1 + \frac{\gamma-1}{2} M^2 \right) \frac{dT_E}{T_E} + \left(\frac{\gamma-1}{2} M^2 \frac{dV^2}{V^2} \right)$$

$$\frac{dM^2}{M^2} = + \left(\frac{dV^2}{V^2} \right) - \left(1 + \frac{\gamma-1}{2} M^2 \right) \frac{dT_E}{T_E} + \left(\frac{\gamma-1}{2} M^2 \frac{dV^2}{V^2} \right)$$

$$= \frac{dV^2}{V^2} \left(1 + \frac{\gamma-1}{2} M^2 \right) - \left(1 + \frac{\gamma-1}{2} M^2 \right) \frac{dT_E}{T_E}$$

$$\frac{dM^2}{M^2} = - \left(1 + \frac{\gamma-1}{2} M^2 \right) \left(- \frac{dV^2}{V^2} + \frac{dT_E}{T_E} \right)$$

$$\frac{dM^2}{M^2} = - \left(1 + \frac{\gamma-1}{2} M^2 \right) \left(\frac{dP/p}{(\frac{\gamma M^2}{2})(Ac/A)} + \frac{(\frac{\gamma M^2}{2}) \cdot (\frac{4C_f dx}{D})}{(\frac{\gamma M^2}{2})(Ac/A)} \right) + \frac{dT_E}{T_E}$$

$$\frac{dM^2}{M^2} = - \left(1 + \frac{\gamma-1}{2} M^2 \right) \left(\frac{dP/p}{(\frac{\gamma M^2}{2})(Ac/A)} + \frac{(\frac{4C_f dx}{D})}{(Ac/A)} \right) + \frac{dT_E}{T_E}$$