Вывод ур-я относ. массового расхода горючего, отнесенного к массовому расходу на входе в I контур, через относ. массовый расход горючего, отнесенного к массовому расходу на входе в КС.

$$g_{охл\_КС3} = \frac{G_{охл}}{G_{КС3}} = \frac{G_{охл}}{G_I - G_{охл} - G_{ут} + G_{гор}}$$

$$g_{охл\_КС3} = \frac{G_{охл}}{G_I - G_{охл} - G_{ут} + G_{гор}} \text{ solve}, G_{охл} \ = \frac{g_{охл\_КС3}\cdot\left(G_I - G_{ут} + G_{гор}\right)}{g_{охл\_КС3} + 1}$$ (Тихонов)

$$g_{гор\_КС1} = \frac{G_{гор}}{G_{КС1}} = \frac{G_{гор}}{G_I - G_{охл} - G_{ут}}$$

$$g_{гор\_КС1} = \frac{G_{гор}}{G_I - G_{охл} - G_{ут}} \text{ solve}, G_{гор} \ = -g_{гор\_КС1}\cdot\left(G_{ут} - G_I + G_{охл}\right)$$

$$g_{гор\_КС1} = \frac{G_{гор}}{G_I - G_{охл} - G_{ут}} \text{ substitute}, G_{охл} = \frac{g_{охл\_КС3}\cdot\left(G_I - G_{ут} + G_{гор}\right)}{g_{охл\_КС3} + 1} \ = g_{гор\_КС1} = -\frac{G_{гор}\cdot\left(g_{охл\_КС3} + 1\right)}{G_{ут} - G_I + G_{гор}\cdot g_{охл\_КС3}}$$

$$g_{гор\_КС1} = -\frac{G_{гор}\cdot\left(g_{охл\_КС3} + 1\right)}{G_{ут} - G_I + G_{гор}\cdot g_{охл\_КС3}} \text{ solve}, G_{гор} \ = \frac{G_I\cdot g_{гор\_КС1} - G_{ут}\cdot g_{гор\_КС1}}{g_{охл\_КС3} + g_{гор\_КС1}\cdot g_{охл\_КС3} + 1}$$

$$G_{гор} = \frac{G_I\cdot g_{гор\_КС1} - G_{ут}\cdot g_{гор\_КС1}}{g_{охл\_КС3} + g_{гор\_КС1}\cdot g_{охл\_КС3} + 1} = G_I\cdot\frac{g_{гор\_КС1} - g_{ут}\cdot g_{гор\_КС1}}{g_{охл\_КС3} + g_{гор\_КС1}\cdot g_{охл\_КС3} + 1}$$

$$g_{гор} = \frac{G_{гор}}{G_I} = \frac{G_I\cdot\dfrac{g_{гор\_КС1} - g_{ут}\cdot g_{гор\_КС1}}{g_{охл\_КС3} + g_{гор\_КС1}\cdot g_{охл\_КС3} + 1}}{G_I} = \frac{g_{гор\_КС1} - g_{ут}\cdot g_{гор\_КС1}}{g_{охл\_КС3} + g_{гор\_КС1}\cdot g_{охл\_КС3} + 1}$$

Вывод ур-я Тихонова относ. массового расхода на охлаждение, отнесенного к массовому расходу на входе в I контур, через относ. массовый расход на охлаждение, онесенного к массовому расходу на выходе из КС.

$$g_{охл} = \frac{G_{охл}}{G_I} = \frac{\dfrac{g_{охл\_КС3}\cdot\left(G_I - G_{ут} + G_{гор}\right)}{g_{охл\_КС3} + 1}}{G_I} = \frac{G_I\cdot\dfrac{g_{охл\_КС3}\cdot\left(1 - g_{ут} + g_{гор}\right)}{g_{охл\_КС3} + 1}}{G_I} = \frac{g_{охл\_КС3}\cdot\left(1 - g_{ут} + g_{гор}\right)}{g_{охл\_КС3} + 1}$$

Вывод термодинамических парамтеров смешения

Ур-е теплового баланса: $Q + Q_{add} = Q_{СМ}$ или $G\cdot Cp\cdot T + G_{add}\cdot Cp_{add}\cdot T_{add} = G_{СМ}\cdot Cp_{СМ}\cdot T_{СМ} = \left(G + G_{add}\right)\cdot Cp_{СМ}\cdot T_{СМ}$ =>

Температура СМ [К]: $G\cdot Cp\cdot T + G_{add}\cdot Cp_{add}\cdot T_{add} = \left(G + G_{add}\right)\cdot Cp_{СМ}\cdot T_{СМ} \text{ solve}, T_{СМ} \ = \dfrac{Cp\cdot G\cdot T + Cp_{add}\cdot G_{add}\cdot T_{add}}{Cp_{СМ}\cdot\left(G + G_{add}\right)}$ $\quad T_{СМ} = \dfrac{Cp\cdot g\cdot T + Cp_{add}\cdot g_{add}\cdot T_{add}}{Cp_{СМ}\cdot\left(g + g_{add}\right)}$

Давление СМ [Па] как среднемассовое: $P_{СМ} = \dfrac{G\cdot P + G_{add}\cdot P_{add}}{G + G_{add}} = \dfrac{g\cdot P + g_{add}\cdot P_{add}}{g + g_{add}}$

Коэф. избытка окислителя СМ []: $\alpha_{СМ} = \dfrac{G_{ок\Sigma}}{G_{гор\Sigma}} = \dfrac{G_{ок} + G_{add}}{G_{гор}\cdot l_0(Fuel)} = \dfrac{g_{ок} + g_{add}}{g_{гор}\cdot l_0(Fuel)}$

Вывод оптимальной скорости выхода из С I контура

$$L_e = \frac{L_B}{\eta_{PB}\cdot\eta_{мех}} + \frac{c_{CI}{}^2 - \upsilon^2}{2} + \frac{c_{CII}{}^2 - \upsilon^2}{2} \text{ solve}, L_B \rightarrow \eta_{PB}\cdot\eta_{мех}\cdot\left(\upsilon^2 - \frac{c_{CI}{}^2}{2} - \frac{c_{CII}{}^2}{2} + L_e\right)$$

$$L_{тяг}(\upsilon, c_{CI}, c_{CII}, L_e, \eta_{мех}, \eta_{PB}, \eta_B, L_B) = L_B\cdot\eta_B + (c_{CI} - \upsilon)\cdot\upsilon + (c_{CII} - \upsilon) \text{ substitute}, L_B = \eta_{PB}\cdot\eta_{мех}\cdot\left(\upsilon^2 - \frac{c_{CI}{}^2}{2} - \frac{c_{CII}{}^2}{2} + L_e\right) = c_{CII} - \upsilon - \upsilon^2 + \upsilon\cdot c_{CI} + \upsilon^2\cdot\eta_B\cdot\eta_{PB}\cdot\eta_{мех} - \frac{c_{CI}{}^2\cdot\eta_B\cdot\eta_{PB}\cdot\eta_{мех}}{2} - \frac{\eta_B\cdot c_{CII}{}^2\cdot\eta_{PB}\cdot\eta_{мех}}{2} + L_e\cdot\eta_B\cdot\eta_{PB}\cdot\eta_{мех}$$

$$\frac{d}{dc_{CI}}L_{тяг}(\upsilon, c_{CI}, c_{CII}, L_e, \eta_{мех}, \eta_{PB}, \eta_B, L_B) \rightarrow \upsilon - c_{CI}\cdot\eta_B\cdot\eta_{PB}\cdot\eta_{мех}$$

$$\frac{d}{dc_{CI}}L_{тяг}(\upsilon, c_{CI}, c_{CII}, L_e, \eta_{мех}, \eta_{PB}, \eta_B, L_B) = 0 \text{ solve}, c_{CI} = \frac{\upsilon}{\eta_B\cdot\eta_{PB}\cdot\eta_{мех}}$$

$$L_e(\upsilon, c_{CI}, c_{CII}, m2, L_{ВлII}) = m2\cdot L_{ВлII} + \frac{c_{CI}(L_{ВлII})^2 - \upsilon^2}{2}$$

$$\frac{d}{dL_{ВлII}}L_e(\upsilon, c_{CI}, c_{CII}, m2, L_{ВлII}) = m2 + c_{CI}(L_{ВлII})\cdot\frac{d}{dL_{ВлII}}c_{CI}(L_{ВлII}) \text{ solve}, \frac{d}{dL_{ВлII}}c_{CI}(L_{ВлII}) = -\frac{m2}{c_{CI}(L_{ВлII})}$$

Баланс энергии II контура: $$L_{ВлII}\cdot\eta_{II} = \frac{c_{CII}(\upsilon, \eta_{II}, L_{ВлII})^2 - \upsilon^2}{2} \text{ solve}, c_{CII}(\upsilon, \eta_{II}, L_{ВлII}) = \begin{pmatrix}\sqrt{\upsilon^2 + 2\cdot\eta_{II}\cdot L_{ВлII}} \\ -\sqrt{\upsilon^2 + 2\cdot\eta_{II}\cdot L_{ВлII}}\end{pmatrix}$$

$$c_{CII}(\upsilon, \eta_{II}, L_{ВлII}) = \sqrt{\upsilon^2 + 2\cdot\eta_{II}\cdot L_{ВлII}}$$

$$\frac{d}{dL_{ВлII}}c_{CII}(\upsilon, \eta_{II}, L_{ВлII}) = \frac{\eta_{II}}{\sqrt{\upsilon^2 + 2\cdot\eta_{II}\cdot L_{ВлII}}}$$

Удельная тяга двигателя: $$R_{уд}(\upsilon, c_{CI}, c_{CII}, m2, L_{ВлII}, \eta_{II}) = \frac{R_{удI} + m2\cdot R_{удII}}{1 + m2} \left| \begin{array}{l} \text{substitute}, R_{удI} = c_{CI}(L_{ВлII}, m2) - \upsilon \\ \text{substitute}, R_{удII} = c_{CII}(\upsilon, \eta_{II}, L_{ВлII}) - \upsilon \end{array} \right. = -\frac{\upsilon - m2\cdot c_{CII}(\upsilon, \eta_{II}, L_{ВлII}) + \upsilon\cdot m2 - c_{CI}(L_{ВлII}, m2)}{m2 + 1}$$

Условие получения max тяги: $$\frac{d}{dL_{ВлII}}R_{уд}(\upsilon, c_{CI}, c_{CII}, m2, L_{ВлII}, \eta_{II}) = 0$$

$$\frac{d}{dL_{ВлII}}R_{уд}(\upsilon, c_{CI}, c_{CII}, m2, L_{ВлII}, \eta_{II}) = \frac{\frac{d}{dL_{ВлII}}c_{CI}(L_{ВлII}, m2) + \frac{m2\cdot\eta_{II}}{\sqrt{\upsilon^2 + 2\cdot\eta_{II}\cdot L_{ВлII}}}}{m2 + 1} \left| \begin{array}{l} \text{substitute}, \frac{d}{dL_{ВлII}}c_{CI}(L_{ВлII}, m2) = -\frac{m2}{c_{CI}(L_{ВлII}, m2)} \\ \text{substitute}, \frac{d}{dL_{ВлII}}c_{CII}(\upsilon, \eta_{II}, L_{ВлII}) = \frac{\eta_{II}}{c_{CII}(L_{ВлII})} \end{array} \right. = -\frac{m2\cdot\left(\sqrt{\upsilon^2 + 2\cdot\eta_{II}\cdot L_{ВлII}} - \eta_{II}\cdot c_{CI}(L_{ВлII}, m2)\right)}{\sqrt{\upsilon^2 + 2\cdot\eta_{II}\cdot L_{ВлII}}\cdot(m2 + 1)\cdot c_{CI}(L_{ВлII}, m2)} \text{ solve}, c_{CI}(L_{ВлII}, m2) = \frac{\sqrt{\upsilon^2 + 2\cdot\eta_{II}\cdot L_{ВлII}}}{\eta_{II}}$$

Вывод общего ур-я профилирования Л цилиндрической ступени К

Дано:

(0) $$\frac{d}{dr}H_T = \frac{d}{dr}\left(\frac{c_a^2}{2}\right) + c_u\cdot\left(\frac{d}{dr}c_u\right) + \frac{c_u^2}{r} = 0 \quad \Rightarrow \quad \frac{d}{dr}\left(\frac{c_a^2}{2}\right) = -c_u\cdot\left(\frac{d}{dr}c_u\right) - \frac{c_u^2}{r} \quad (00)$$

Домножим на 2 =>
$$\frac{d}{dr}\left(c_a^2\right) = -2\cdot c_u\cdot\left(\frac{d}{dr}c_u\right) - \frac{2\cdot c_u^2}{r} \quad (000)$$

(1) $$\frac{c_{1u}+c_{2u}}{2}\cdot r^m = \text{const}$$

(2) $$H_T = \left(c_{2u}\cdot u_2 - c_{1u}\cdot u_1\right) = \left(c_{2u} - c_{1u}\right)u$$

(3) $$R = 1 - \frac{c_{1u}+c_{2u}}{u_1+u_2} = 1 - \frac{c_{1u}+c_{2u}}{2\cdot u}$$

$u = \omega\cdot r$ $\quad u_1 = \omega\cdot r_1$ $\quad u_2 = \omega\cdot r_2$ $\quad \omega = \text{const}$ $\quad \frac{u_1}{r_1} = \frac{u_2}{r_2}$

$$1 - \frac{c_{1u}+c_{2u}}{2\cdot u} - \frac{c_{a2}^2 - c_{a1}^2}{2\cdot H_T}$$

Вывод:

(2) (3) =>
$$c_{1u} = (1-R)\cdot\omega\cdot r + \frac{H_T}{2\cdot\omega\cdot r} \quad (c1u)$$
$$c_{2u} = -(1-R)\cdot\omega\cdot r + \frac{H_T}{2\cdot\omega\cdot r} \quad (c2u)$$

(2) =>
$$\frac{c_{1u}+c_{2u}}{2} = (1-R)\cdot\omega\cdot r$$

(1):
$$\text{const} = \frac{c_{1u}+c_{2u}}{2}\cdot r^m = (2) = (1-R)\omega\cdot r\cdot r^m = (1-R)\omega\cdot r^{m+1} = \left(1-R_{cp}\right)\omega r_{cp}^{m+1} \quad \Rightarrow \quad (1-R)\omega = \frac{\left[\left(1-R_{cp}\right)\cdot\omega\cdot r_{cp}^{m+1}\right]}{r^{m+1}} \quad (\&)$$

(&) -> (c1u)
$$c_{1u} = (1-R)\cdot\omega\cdot r - \frac{H_T}{2\cdot\omega\cdot r} = \frac{\left[\left(1-R_{cp}\right)\cdot\omega\cdot r_{cp}^{m+1}\right]}{r^{m+1}}\cdot r - \frac{H_T}{2\cdot\omega\cdot r} = \frac{\left[\left(1-R_{cp}\right)\cdot\omega\cdot r_{cp}^{m+1}\right]}{r^{m+1}}\cdot r - \frac{\left(\frac{H_T}{2\cdot\omega}\right)}{r}$$

(&) -> (c2u)
$$c_{2u} = (1-R)\cdot\omega\cdot r + \frac{H_T}{2\cdot\omega\cdot r} = \frac{\left[\left(1-R_{cp}\right)\cdot\omega\cdot r_{cp}^{m+1}\right]}{r^{m+1}}\cdot r + \frac{H_T}{2\cdot\omega\cdot r} = \frac{\left[\left(1-R_{cp}\right)\cdot\omega\cdot r_{cp}^{m+1}\right]}{r^{m+1}}\cdot r + \frac{\left(\frac{H_T}{2\cdot\omega}\right)}{r}$$

(AB1) $$A = \left[\left(1-R_{cp}\right)\cdot\omega\cdot r_{cp}^{m+1}\right] \qquad c_{1u}(r,m,A,B) = \frac{(A)}{r^m} - \frac{(B)}{r}$$

(AB2) $$B = \left(\frac{H_T}{2\cdot\omega}\right) \qquad c_{2u}(r,m,A,B) = \frac{(A)}{r^m} + \frac{(B)}{r}$$

(000)
$$\int_{r_{cp}}^{r}\frac{d}{dr}\left(c_a^2\right)dr = c_a^2 - c_{a.cp}^2 = \int_{r_{cp}}^{r}-2\cdot c_u\cdot\left(\frac{d}{dr}c_u\right) - \frac{2\cdot c_u^2}{r}\,dr$$

=>
$$c_{a1}^2 - c_{a1.cp}^2 = \int_{r_{cp}}^{r}-2\cdot c_{u1}\cdot\left(\frac{d}{dr}c_{u1}\right) - \frac{2\cdot c_{u1}^2}{r}\,dr$$
$$c_{a2}^2 - c_{a2.cp}^2 = \int_{r_{cp}}^{r}-2\cdot c_{u2}\cdot\left(\frac{d}{dr}c_{u2}\right) - \frac{2\cdot c_{u2}^2}{r}\,dr$$

=>
$$c_{a1} = \sqrt{c_{a1.cp}^2 + \int_{r_{cp}}^{r}-2\cdot c_{u1}\cdot\left(\frac{d}{dr}c_{u1}\right) - \frac{2\cdot c_{u1}^2}{r}\,dr}$$
$$c_{a2} = \sqrt{c_{a2.cp}^2 + \int_{r_{cp}}^{r}-2\cdot c_{u2}\cdot\left(\frac{d}{dr}c_{u2}\right) - \frac{2\cdot c_{u2}^2}{r}\,dr} \quad (0000)$$

$$\sqrt{c_{a1.cp}{}^{2}+\int_{r_{cp}}^{r}-2\,c_{1u}(r,m,A,B)\cdot\left(\frac{d}{dr}c_{1u}(r,m,A,B)\right)-\frac{2\,c_{1u}(r,m,A,B)^{2}}{r}\,dr}\ \left|\begin{array}{l}\text{assume},r_{cp}>0,r\geq 0,m=-1\\ \text{substitute},m=-1\end{array}\right.=\sqrt{c_{a1.cp}{}^{2}-2\cdot A^{2}\cdot r^{2}+2\cdot A^{2}\cdot r_{cp}{}^{2}+4\cdot A\cdot B\cdot\ln(r)-4\cdot A\cdot B\cdot\ln\left(r_{cp}\right)}$$

$$\sqrt{c_{a2.cp}{}^{2}+\int_{r_{cp}}^{r}-2\,c_{2u}(r,m,A,B)\cdot\left(\frac{d}{dr}c_{2u}(r,m,A,B)\right)-\frac{2\,c_{2u}(r,m,A,B)^{2}}{r}\,dr}\ \left|\begin{array}{l}\text{assume},r_{cp}>0,r\geq 0,m=-1\\ \text{substitute},m=-1\end{array}\right.=\sqrt{c_{a2.cp}{}^{2}-2\cdot A^{2}\cdot r^{2}+2\cdot A^{2}\cdot r_{cp}{}^{2}-4\cdot A\cdot B\cdot\ln(r)+4\cdot A\cdot B\cdot\ln\left(r_{cp}\right)}$$

$$\sqrt{c_{a1.cp}{}^{2}+\int_{r_{cp}}^{r}-2\,c_{1u}(r,m,A,B)\cdot\left(\frac{d}{dr}c_{1u}(r,m,A,B)\right)-\frac{2\,c_{1u}(r,m,A,B)^{2}}{r}\,dr}\ \text{assume},r_{cp}>0,r\geq 0,m=0\ =\sqrt{2\cdot A^{2}\cdot\ln\left(r_{cp}\right)-2\cdot A^{2}\cdot\ln(r)+c_{a1.cp}{}^{2}-\frac{2\cdot A\cdot B}{r}+\frac{2\cdot A\cdot B}{r_{cp}}}$$

$$\sqrt{c_{a2.cp}{}^{2}+\int_{r_{cp}}^{r}-2\,c_{2u}(r,m,A,B)\cdot\left(\frac{d}{dr}c_{2u}(r,m,A,B)\right)-\frac{2\,c_{2u}(r,m,A,B)^{2}}{r}\,dr}\ \text{assume},r_{cp}>0,r\geq 0,m=0\ =\sqrt{2\cdot A^{2}\cdot\ln\left(r_{cp}\right)-2\cdot A^{2}\cdot\ln(r)+c_{a2.cp}{}^{2}+\frac{2\cdot A\cdot B}{r}-\frac{2\cdot A\cdot B}{r_{cp}}}$$

$$\sqrt{c_{a1.cp}{}^{2}+\int_{r_{cp}}^{r}-2\,c_{1u}(r,m,A,B)\cdot\left(\frac{d}{dr}c_{1u}(r,m,A,B)\right)-\frac{2\,c_{1u}(r,m,A,B)^{2}}{r}\,dr}\ \text{assume},r_{cp}>0,r\geq 0,-1<m\leq 1,m\neq 0\ =\sqrt{c_{a1.cp}{}^{2}+\frac{A\cdot(m-1)\cdot\left(A\cdot r\cdot r^{2\cdot m}\cdot r_{cp}-A\cdot r\cdot r_{cp}\cdot r_{cp}{}^{2\cdot m}-2\cdot B\cdot m\cdot r\cdot r^{2\cdot m}\cdot r_{cp}{}^{m}+2\cdot B\cdot m\cdot r^{m}\cdot r_{cp}\cdot r_{cp}{}^{2\cdot m}+A\cdot m\cdot r\cdot r^{2\cdot m}\cdot r_{cp}-A\cdot m\cdot r\cdot r_{cp}\cdot r_{cp}{}^{2\cdot m}\right)}{m\cdot(m+1)\cdot\left(r\cdot r_{cp}\right)^{2\cdot m+1}}}$$

$$\sqrt{c_{a2.cp}{}^{2}+\int_{r_{cp}}^{r}-2\,c_{2u}(r,m,A,B)\cdot\left(\frac{d}{dr}c_{2u}(r,m,A,B)\right)-\frac{2\,c_{2u}(r,m,A,B)^{2}}{r}\,dr}\ \text{assume},r_{cp}>0,r\geq 0,-1<m\leq 1,m\neq 0\ =\sqrt{c_{a2.cp}{}^{2}+\frac{A\cdot(m-1)\cdot\left(A\cdot r\cdot r^{2\cdot m}\cdot r_{cp}-A\cdot r\cdot r_{cp}\cdot r_{cp}{}^{2\cdot m}+2\cdot B\cdot m\cdot r\cdot r^{2\cdot m}\cdot r_{cp}{}^{m}-2\cdot B\cdot m\cdot r^{m}\cdot r_{cp}\cdot r_{cp}{}^{2\cdot m}+A\cdot m\cdot r\cdot r^{2\cdot m}\cdot r_{cp}-A\cdot m\cdot r\cdot r_{cp}\cdot r_{cp}{}^{2\cdot m}\right)}{m\cdot(m+1)\cdot\left(r\cdot r_{cp}\right)^{2\cdot m+1}}}$$

Вывод общего ур-я профилирования Л цилиндрической ступени Т

(1) $\frac{c_{1u}+c_{2u}}{2}\cdot r^m = const$

$$const = \frac{c_{1u}+c_{2u}}{2}\cdot r^m = (3) = (1-R)\omega\cdot r\cdot r^m = (1-R)\omega\cdot r^{m+1} = (1-R_{cp})\omega\cdot r_{cp}^{m+1} \Rightarrow (1-R)\omega\cdot r = \frac{\left[(1-R_{cp})\cdot\omega\cdot r_{cp}^{m+1}\right]}{r^m}$$

$$A = \left[(1-R_{cp})\cdot\omega\cdot r_{cp}^{m+1}\right]$$

$$c_{1u}(r,m,A,B) = \frac{(A)}{r^m} + \frac{(B)}{r} \qquad c_{2u}(r,m,A,B) = -\frac{A}{r^m} + \frac{(B)}{r}$$

(2) $L_u = c_{2u}\cdot u_2 + c_{1u}\cdot u_1 = (c_{2u}+c_{1u})u$ $\quad u = \omega\cdot r \quad$ $L_u = c_{2u}\cdot\omega\cdot r_2 + c_{1u}\cdot\omega\cdot r_1 = (c_{2u}+c_{1u})\omega\cdot r$

$$c_{1u} = c_{2u} + \frac{L_u}{\omega\cdot r} \qquad c_{2u} = c_{1u} + \frac{L_u}{\omega\cdot r}$$

$$c_{1u} = (1-R)\cdot\omega\cdot r + \frac{L_u}{2\cdot\omega\cdot r} = (1-R)\cdot\omega\cdot r + \frac{\left(\frac{L_u}{2\cdot\omega}\right)}{r}$$

$$c_{2u} = -(1-R)\cdot\omega\cdot r + \frac{L_u}{2\cdot\omega\cdot r} = -(1-R)\cdot\omega\cdot r + \frac{\left(\frac{L_u}{2\cdot\omega}\right)}{r}$$

$$B = \left(\frac{L_u}{2\cdot\omega}\right)$$

(3) $R = 1 - \frac{c_{1u}-c_{2u}}{2\cdot u}$ $\quad u = \omega\cdot r \quad$ $R = 1 - \frac{c_{1u}-c_{2u}}{2\cdot\omega\cdot r}$

$$c_{1u} = (1-R)\cdot 2\cdot\omega\cdot r - c_{2u} \qquad c_{2u} = -(1-R)\cdot 2\cdot\omega\cdot r - c_{1u}$$

Работа сил трения: $L_{тр} = \left(\frac{1}{\varphi^2}-1\right)\cdot\frac{c_1^2}{2} = \frac{c_1^2}{2\cdot\varphi^2} - \frac{c_1^2}{2}$

Работа гидравлических сил сопротивления:

$$L_{гид} = \left(\frac{1}{\varphi^2}-1\right)\cdot\frac{c_1^2}{2} + \left(\frac{1}{\psi^2}-1\right)\cdot\frac{w_2^2}{2} = \left(\frac{1}{\varphi^2}-1\right)\cdot\frac{c_{a1}^2+c_{u1}^2}{2} + \left(\frac{1}{\psi^2}-1\right)\cdot\frac{(c_{2u}+u_2)^2+c_{2a}^2}{2}$$

Ур-е радиадьного равновесия: $\frac{1}{\rho}\cdot\frac{d}{dr}P = \frac{c_u^2}{r}$

Ур-е Бернулли:

$$\frac{1}{\rho}\cdot dP + d\left(\frac{c_1^2}{2}\right) + d(L_{тр}) = d(H_т) \qquad 0 = \frac{c_1^2}{2} + \int_0^1 \frac{1}{\rho}\,dP + L_{тр}$$

$$\frac{1}{\rho}\cdot dP + d\left(\frac{c_2^2}{2}\right) + d(L_{гид}) + d(L_{ст}) = d(H_т) \qquad 0 = \frac{c_2^2}{2} + \int_0^2 \frac{1}{\rho}\,dP + L_{гид} + L_{ст}$$

Допущения: $H_т(r) = const \quad \frac{d}{dr}H_т(r) = 0$

$\varphi(r) = const \quad \frac{d}{dr}\varphi(r) = 0$

$\psi(r) = const \quad \frac{d}{dr}\psi(r) = 0$

$$0 = \frac{c_1^2}{2} + \int_0^1 \frac{1}{\rho}\,dP + L_{тр} = \frac{c_1^2}{2} + \int_0^1 \frac{1}{\rho}\,dP + \frac{c_1^2}{2\cdot\varphi^2} - \frac{c_1^2}{2} = \frac{c_1^2}{2\cdot\varphi^2} + \int_0^1 \frac{1}{\rho}\,dP = \frac{c_{a1}^2+c_{u1}^2}{2\cdot\varphi^2} + \int_0^1 \frac{1}{\rho}\,dP = \frac{1}{\varphi^2}\cdot\left(\frac{c_{a1}^2}{2}+\frac{c_{u1}^2}{2}\right) + \int_0^1 \frac{1}{\rho}\,dP$$

$$0 = \frac{d}{dr}\left[\frac{1}{\varphi^2}\cdot\left(\frac{c_{a1}^2}{2}+\frac{c_{u1}^2}{2}\right) + \int_0^1 \frac{1}{\rho}\,dP\right] = \frac{1}{\varphi^2}\cdot\left(c_{a1}\cdot\frac{d}{dr}c_{a1} + c_{u1}\cdot\frac{d}{dr}c_{u1}\right) + \frac{1}{\rho}\cdot\frac{d}{dr}P = \frac{1}{\varphi^2}\cdot\left(c_{a1}\cdot\frac{d}{dr}c_{a1} + c_{u1}\cdot\frac{d}{dr}c_{u1}\right) + \frac{c_{u1}^2}{r}$$

$$\frac{1}{\varphi^2}\cdot\left(c_{a1}\cdot\frac{d}{dr}c_{a1} + c_{u1}\cdot\frac{d}{dr}c_{u1}\right) + \frac{c_{u1}^2}{r} = 0 \qquad \frac{d}{dr}\left(\frac{c_{a1}^2}{2}\right) = -c_{u1}\cdot\left(\frac{d}{dr}c_{u1}\right) - \varphi^2\cdot\frac{c_{u1}^2}{r} \qquad \frac{d}{dr}c_{a1}^2 = -2\cdot c_{u1}\cdot\left(\frac{d}{dr}c_{u1}\right) - 2\cdot\varphi^2\cdot\frac{c_{u1}^2}{r}$$

$$\int_{r_{cp}}^{r} \frac{d}{dr}c_{a1}^2\,dr = c_{a1}^2 - c_{a1.cp}^2 = \int_{r_{cp}}^{r} -2\cdot c_{u1}\cdot\left(\frac{d}{dr}c_{u1}\right) - 2\cdot\varphi^2\cdot\frac{c_{u1}^2}{r}\,dr$$

$$c_{a1} = \sqrt{c_{a1.cp}^2 + \int_{r_{cp}}^{r} -2\cdot c_{u1}\cdot\left(\frac{d}{dr}c_{u1}\right) - 2\cdot\varphi^2\cdot\frac{c_{u1}^2}{r}\,dr} \qquad (c.a1)$$

$$0=\frac{d}{dr}c_{a2}{}^2+\frac{d}{dr}c_{u2}{}^2+\left(\frac{1}{\varphi^2}-1\right)\cdot\psi^2\cdot\left(\frac{d}{dr}c_{a1}{}^2+\frac{d}{dr}c_{u1}{}^2\right)+\psi^2\cdot\frac{2\cdot c_{u2}{}^2}{r}+\left(1-\psi^2\right)\cdot\frac{d}{dr}\left(2\cdot c_{u2}\cdot u+u^2\right)$$

$$\frac{d}{dr}c_{a2}{}^2=-\frac{d}{dr}c_{u2}{}^2-\left(\frac{1}{\varphi^2}-1\right)\cdot\psi^2\cdot\left(\frac{d}{dr}c_{a1}{}^2+\frac{d}{dr}c_{u1}{}^2\right)-\psi^2\cdot\frac{2\cdot c_{u2}{}^2}{r}-\left(1-\psi^2\right)\cdot\frac{d}{dr}\left[2\cdot c_{u2}\cdot\omega\cdot r+(\omega\cdot r)^2\right]$$

$$\int_{r_{cp}}^{r}\frac{d}{dr}c_{a2}{}^2\,dr=c_{a2}{}^2-c_{a2.cp}{}^2=\int_{r_{cp}}^{r}-\frac{d}{dr}c_{u2}{}^2-\left(\frac{1}{\varphi^2}-1\right)\cdot\psi^2\cdot\left(\frac{d}{dr}c_{a1}{}^2+\frac{d}{dr}c_{u1}{}^2\right)-\psi^2\cdot\frac{2\cdot c_{u2}{}^2}{r}-\left(1-\psi^2\right)\cdot\frac{d}{dr}\left[2\cdot c_{u2}\cdot\omega\cdot r+(\omega\cdot r)^2\right]dr=\int_{r_{cp}}^{r}-\frac{d}{dr}c_{u2}{}^2-\left(\frac{1}{\varphi^2}-1\right)\cdot\psi^2\cdot\left(\frac{d}{dr}c_{a1}{}^2+\frac{d}{dr}c_{u1}{}^2\right)-\psi^2\cdot\frac{2\cdot c_{u2}{}^2}{r}-\left(1-\psi^2\right)\cdot\frac{d}{dr}\left[2\cdot c_{u2}\cdot\omega\cdot r+(\omega\cdot r)^2\right]dr$$

$$c_{a2}=\sqrt{c_{a2.cp}{}^2+\int_{r_{cp}}^{r}-\frac{d}{dr}c_{u2}{}^2-\left(\frac{1}{\varphi^2}-1\right)\cdot\psi^2\cdot\left(\frac{d}{dr}c_{a1}{}^2+\frac{d}{dr}c_{u1}{}^2\right)-\psi^2\cdot\frac{2\cdot c_{u2}{}^2}{r}-\left(1-\psi^2\right)\cdot\frac{d}{dr}\left[2\cdot c_{u2}\cdot\omega\cdot r+(\omega\cdot r)^2\right]dr}=\sqrt{c_{a2.cp}{}^2+\int_{r_{cp}}^{r}-\frac{d}{dr}c_{u2}{}^2-\left(\frac{1}{\varphi^2}-1\right)\cdot\psi^2\cdot\left[\frac{d}{dr}\left[c_{a1.cp}{}^2+\int_{r_{cp}}^{r}-2\cdot c_{u1}\cdot\left(\frac{d}{dr}c_{u1}\right)-2\cdot\varphi^2\cdot\frac{c_{u1}{}^2}{r}\,dr\right]+\frac{d}{dr}c_{u1}{}^2\right]-\psi^2\cdot\frac{2\cdot c_{u2}{}^2}{r}-\left(1-\psi^2\right)\cdot\frac{d}{dr}\left[2\cdot c_{u2}\cdot\omega\cdot r+(\omega\cdot r)^2\right]dr}$$

$$\sqrt{c_{a1.cp}{}^2+\int_{r_{cp}}^{r}-2\cdot c_{1u}(r,m,A,B)\cdot\left(\frac{d}{dr}c_{1u}(r,m,A,B)\right)-2\cdot\varphi^2\cdot\frac{c_{1u}(r,m,A,B)^2}{r}dr}\ \Bigg|\ \begin{array}{l}\text{assume}, r_{cp}>0, r\ge 0, m=-1\\ \text{substitute}, m=-1\\ \text{simplify}\end{array}=\frac{\sqrt{B^2\cdot r^2-B^2\cdot r_{cp}{}^2-B^2\cdot\varphi^2\cdot r^2+B^2\cdot\varphi^2\cdot r_{cp}{}^2+A^2\cdot r^2\cdot r_{cp}{}^4-A^2\cdot r^4\cdot r_{cp}{}^2+r^2\cdot r_{cp}{}^2\cdot c_{a1.cp}{}^2+A^2\cdot\varphi^2\cdot r^2\cdot r_{cp}{}^4-A^2\cdot\varphi^2\cdot r^4\cdot r_{cp}{}^2-4\cdot A\cdot B\cdot\varphi^2\cdot r^2\cdot r_{cp}{}^2\cdot\ln(r)+4\cdot A\cdot B\cdot\varphi^2\cdot r^2\cdot r_{cp}{}^2\cdot\ln\cdots}}{r\cdot r_{cp}}$$

$$\sqrt{c_{a2.cp}{}^2+\int_{r_{cp}}^{r}-2\,c_{2u}(r,m,A,B)\cdot\left(\frac{d}{dr}c_{2u}(r,m,A,B)\right)-2\cdot\varphi^2\cdot\frac{c_{2u}(r,m,A,B)^2}{r}dr}\ \Bigg|\ \begin{array}{l}\text{assume}, r_{cp}>0, r\ge 0, m=-1\\ \text{substitute}, m=-1\\ \text{simplify}\end{array}=\frac{\sqrt{B^2\cdot r^2-B^2\cdot r_{cp}{}^2-B^2\cdot\varphi^2\cdot r^2+B^2\cdot\varphi^2\cdot r_{cp}{}^2+A^2\cdot r^2\cdot r_{cp}{}^4-A^2\cdot r^4\cdot r_{cp}{}^2+r^2\cdot r_{cp}{}^2\cdot c_{a2.cp}{}^2+A^2\cdot\varphi^2\cdot r^2\cdot r_{cp}{}^4-A^2\cdot\varphi^2\cdot r^4\cdot r_{cp}{}^2+4\cdot A\cdot B\cdot\varphi^2\cdot r^2\cdot r_{cp}{}^2\cdot\ln(r)-4\cdot A\cdot B\cdot\varphi^2\cdot r^2\cdot r_{cp}{}^2\cdot\ln\cdots}}{r\cdot r_{cp}}$$

$$\sqrt{c_{a1.cp}{}^2+\int_{r_{cp}}^{r}-2\,c_{1u}(r,m,A,B)\cdot\left(\frac{d}{dr}c_{1u}(r,m,A,B)\right)-2\cdot\varphi^2\cdot\frac{c_{1u}(r,m,A,B)^2}{r}dr}\ \Bigg|\ \begin{array}{l}\text{assume}, r_{cp}>0, r\ge 0, m=0\\ \text{simplify}\end{array}=\frac{\sqrt{B^2\cdot r^2-B^2\cdot r_{cp}{}^2-B^2\cdot\varphi^2\cdot r^2+B^2\cdot\varphi^2\cdot r_{cp}{}^2+r^2\cdot r_{cp}{}^2\cdot c_{a1.cp}{}^2-2\cdot A\cdot B\cdot r\cdot r_{cp}{}^2+2\cdot A\cdot B\cdot r^2\cdot r_{cp}+4\cdot A\cdot B\cdot\varphi^2\cdot r\cdot r_{cp}{}^2-4\cdot A\cdot B\cdot\varphi^2\cdot r^2\cdot r_{cp}-2\cdot A^2\cdot\varphi^2\cdot r^2\cdot r_{cp}{}^2\cdot\ln(r)+2\cdot A^2\cdot\varphi^2\cdot r^2\cdot r_{c}\cdots}}{r\cdot r_{cp}}$$

$$\sqrt{c_{a2.cp}{}^2+\int_{r_{cp}}^{r}-2\,c_{2u}(r,m,A,B)\cdot\left(\frac{d}{dr}c_{2u}(r,m,A,B)\right)-2\cdot\varphi^2\cdot\frac{c_{2u}(r,m,A,B)^2}{r}dr}\ \Bigg|\ \begin{array}{l}\text{assume}, r_{cp}>0, r\ge 0, m=0\\ \text{simplify}\end{array}=\frac{\sqrt{B^2\cdot r^2-B^2\cdot r_{cp}{}^2-B^2\cdot\varphi^2\cdot r^2+B^2\cdot\varphi^2\cdot r_{cp}{}^2+r^2\cdot r_{cp}{}^2\cdot c_{a2.cp}{}^2+2\cdot A\cdot B\cdot r\cdot r_{cp}{}^2-2\cdot A\cdot B\cdot r^2\cdot r_{cp}-4\cdot A\cdot B\cdot\varphi^2\cdot r\cdot r_{cp}{}^2+4\cdot A\cdot B\cdot\varphi^2\cdot r^2\cdot r_{cp}-2\cdot A^2\cdot\varphi^2\cdot r^2\cdot r_{cp}{}^2\cdot\ln(r)+2\cdot A^2\cdot\varphi^2\cdot r^2\cdot r_{c}\cdots}}{r\cdot r_{cp}}$$

$$\sqrt{c_{a1.cp}{}^2+\int_{r_{cp}}^{r}-2\,c_{1u}(r,m,A,B)\cdot\left(\frac{d}{dr}c_{1u}(r,m,A,B)\right)-2\cdot\varphi^2\cdot\frac{c_{1u}(r,m,A,B)^2}{r}dr}\ \Bigg|\ \begin{array}{l}\text{assume}, r_{cp}>0, r\ge 0, -1<m\le 1, m\ne 0\\ \text{simplify}\end{array}=\sqrt{\frac{B^2\cdot m+B^2\cdot m^2+m\cdot r_{cp}{}^2\cdot c_{a1.cp}{}^2+A^2\cdot m\cdot r_{cp}{}^{2-2\cdot m}-B^2\cdot\varphi^2\cdot m^2+m^2\cdot r_{cp}{}^2\cdot c_{a1.cp}{}^2-A^2\cdot\varphi^2\cdot r_{cp}{}^{2-2\cdot m}+A^2\cdot m^2\cdot r_{cp}{}^{2-2\cdot m}-B^2\cdot\varphi^2\cdot m+2\cdot A\cdot B\cdot m\cdot r_{cp}{}^{1-m}-\cdots}{\cdots}}$$

$$\sqrt{c_{a2.cp}{}^2+\int_{r_{cp}}^{r}-2\,c_{2u}(r,m,A,B)\cdot\left(\frac{d}{dr}c_{2u}(r,m,A,B)\right)-2\cdot\varphi^2\cdot\frac{c_{2u}(r,m,A,B)^2}{r}dr}\ \Bigg|\ \begin{array}{l}\text{assume}, r_{cp}>0, r\ge 0, -1<m\le 1, m\ne 0\\ \text{simplify}\end{array}=\sqrt{\frac{B^2\cdot m+B^2\cdot m^2+m\cdot r_{cp}{}^2\cdot c_{a2.cp}{}^2+A^2\cdot m\cdot r_{cp}{}^{2-2\cdot m}-B^2\cdot\varphi^2\cdot m^2+m^2\cdot r_{cp}{}^2\cdot c_{a2.cp}{}^2-A^2\cdot\varphi^2\cdot r_{cp}{}^{2-2\cdot m}+A^2\cdot m^2\cdot r_{cp}{}^{2-2\cdot m}-B^2\cdot\varphi^2\cdot m-2\cdot A\cdot B\cdot m\cdot r_{cp}{}^{1-m}-\cdots}{\cdots}}$$

$c_{a1.cp} = 160$ $r = 0.8$ $r_{cp} = 0.4$ $L_u = 250000$ $\omega = 3200$ $\varphi = -1$ $R_{cp} = 0.3$ $m = -1$ $c_{a2.cp} = 150$

$$B = \left(\frac{L_u}{2\cdot\omega}\right)$$

$$A = \left[\left(1 - R_{cp}\right)\cdot\omega\cdot r_{cp}{}^{m+1}\right]$$

$$\sqrt{c_{a1.cp}{}^2 - \frac{2\cdot\varphi^2\cdot\left(\ln(r) - \ln\left(r_{cp}\right)\right)\cdot\left(A\cdot r^2 + B\right)^2}{r^2}} = 2161.496i$$

$$\frac{\sqrt{B^2\cdot r^2 - B^2\cdot r_{cp}{}^2 - B^2\cdot\varphi^2\cdot r^2 + B^2\cdot\varphi^2\cdot r_{cp}{}^2 + A^2\cdot r^2\cdot r_{cp}{}^4 - A^2\cdot r^4\cdot r_{cp}{}^2 + r^2\cdot r_{cp}{}^2\cdot c_{a1.cp}{}^2 + A^2\cdot\varphi^2\cdot r^2\cdot r_{cp}{}^4 - A^2\cdot\varphi^2\cdot r^4\cdot r_{cp}{}^2 - 4\cdot A\cdot B\cdot\varphi^2\cdot r^2\cdot r_{cp}{}^2\cdot\ln(r) + 4\cdot A\cdot B\cdot\varphi^2\cdot r^2\cdot r_{cp}{}^2\cdot\ln\left(r_{cp}\right)}}{r\cdot r_{cp}} = 2243.635i$$

Вывод общего ур-я профилирования Л Т по радиусу с потерями

Ур-е радиального равновесия: $\frac{1}{\rho}\cdot\left(\frac{d}{dr}p\right) = \frac{c_u^2}{r}$ (РР)

$$\frac{1}{\rho}\cdot\left(\frac{d}{dr}p\right) = \frac{c_u^2}{r}$$

Ур-е Бернулли: $\frac{c^2}{2} = -\int_0^1 \frac{1}{\rho}\,dp - L_{тр}$ (Б)

Работа трения: $L_{тр} = \left(\frac{1}{\varphi^2} - 1\right)\cdot\frac{c^2}{2}$

Общий случай: $c_u\cdot r^m = const$ следовательно $c_u\cdot r^m = c_{u.cp}\cdot r_{cp}^m$ следовательно $c_u(r) = c_{u.cp}\cdot\left(\frac{r_{cp}}{r}\right)^m$

$$\frac{d}{dr}c_u(r) = \left| \begin{array}{l} x0 = 0.8 \\ \frac{d}{dx0}c_u(x0) \end{array}\right. \quad \text{simplify} = \left| \begin{array}{l} x0 = 0.8 \\ \frac{d}{dx0}c_u(x0) \end{array}\right.$$

Допущение: $\varphi(r) = const$ следовательно $\frac{d}{dr}\varphi = 0$

(Б) $\frac{c^2}{2} = -\int_0^1 \frac{1}{\rho}\,dp - L_{тр}$ $\quad \frac{c^2}{2} = -\int_0^1 \frac{1}{\rho}\,dp - \left(\frac{1}{\varphi^2} - 1\right)\cdot\frac{c^2}{2}$ $\quad \frac{c^2}{2} + \left(\frac{1}{\varphi^2} - 1\right)\cdot\frac{c^2}{2} + \int_0^1 \frac{1}{\rho}\,dp = 0$ $\quad \frac{1}{\varphi^2}\cdot\frac{c^2}{2} + \int_0^1 \frac{1}{\rho}\,dp = 0$ $\quad \frac{1}{\varphi^2}\cdot\frac{c_a^2 + c_u^2}{2} + \int_0^1 \frac{1}{\rho}\,dp = 0$ (РР) $\frac{1}{\varphi^2}\cdot\frac{c_a^2 + c_u^2}{2} + \int_0^1 \frac{c_u^2}{r}\,dr = 0$

$$\frac{d}{dr}\left(\frac{1}{\varphi^2}\cdot\frac{c_a^2 + c_u^2}{2} + \int_0^1 \frac{c_u^2}{r}\,dr\right) = 0 \qquad \frac{d}{dr}\left(\frac{1}{\varphi^2}\cdot\frac{c_a^2 + c_u^2}{2}\right) + \frac{d}{dr}\left(\int_0^1 \frac{c_u^2}{r}\,dr\right) = 0 \qquad \frac{1}{2\cdot\varphi^2}\cdot\frac{d}{dr}\left(c_a^2 + c_u^2\right) + \frac{c_u^2}{r} = 0$$

$$\frac{1}{2\cdot\varphi^2}\cdot\left[\frac{d}{dr}\left(c_a^2\right) + \frac{d}{dr}\left(c_u^2\right)\right] + \frac{c_u^2}{r} = 0 \qquad \frac{1}{\varphi^2}\cdot\left[c_a\cdot\frac{d}{dr}(c_a) + c_u\cdot\frac{d}{dr}(c_u)\right] + \frac{c_u^2}{r} = 0$$

$$c_a\cdot\frac{d}{dr}(c_a) + c_u\cdot\frac{d}{dr}(c_u) + \varphi^2\cdot\frac{c_u^2}{r} = 0$$

$$c_a\cdot\frac{d}{dr}(c_a) + \left[c_{u.cp}\cdot\left(\frac{r_{cp}}{r}\right)^m\right]\cdot\left[-\frac{m\cdot c_{u.cp}\cdot\left(\frac{r_{cp}}{r}\right)^m}{r}\right] + \varphi^2\cdot\frac{\left[c_{u.cp}\cdot\left(\frac{r_{cp}}{r}\right)^m\right]^2}{r} = 0$$

$$c_a\cdot\frac{d}{dr}(c_a) + \left[c_{u.cp}\cdot\left(\frac{r_{cp}}{r}\right)^m\right]\cdot\left[-\frac{m\cdot c_{u.cp}\cdot\left(\frac{r_{cp}}{r}\right)^m}{r}\right] + \varphi^2\cdot\frac{\left[c_{u.cp}\cdot\left(\frac{r_{cp}}{r}\right)^m\right]^2}{r} = 0$$

$$\int \left[c_a(r)\cdot\frac{d}{dr}\left(c_a(r)\right) + \left[c_{u.cp}\cdot\left(\frac{r_{cp}}{r}\right)^m\right]\cdot\left[-\frac{m\cdot c_{u.cp}\cdot\left(\frac{r_{cp}}{r}\right)^m}{r}\right] + \varphi^2\cdot\frac{\left[c_{u.cp}\cdot\left(\frac{r_{cp}}{r}\right)^m\right]^2}{r}\right]dr = \frac{c_a(0.8)^2}{2} + 4\cdot c_{u.cp}^2$$

$+C$

$$\frac{c_a(r)^2}{2} + \frac{c_{u.cp}^2 \cdot \left(\frac{r_{cp}}{r}\right)^{2\cdot m}}{2} - \frac{\varphi^2 \cdot c_{u.cp}^2 \cdot \left(\frac{r_{cp}}{r}\right)^{2\cdot m}}{2\cdot m} + C = 0 \;\Bigg|\; \begin{array}{l} \text{substitute}, r = r_{cp} \\ \text{substitute}, c_a(r_{cp}) = c_{a.cp} \end{array} \;=\; 4\cdot c_{u.cp}^2 + C + 0.5\cdot c_a\left(\frac{2}{5}\right)^2 = 0 \text{ simplify } \;=\; 4\cdot c_{u.cp}^2 + C + 0.5\cdot c_a\left(\frac{2}{5}\right)^2 = 0 \text{ solve}, C \;=\; -4\cdot c_{u.cp}^2 - 0.5\cdot c_a\left(\frac{2}{5}\right)^2$$

$$\frac{c_a(r)^2}{2} + \frac{c_{u.cp}^2 \cdot \left(\frac{r_{cp}}{r}\right)^{2\cdot m}}{2} - \frac{\varphi^2 \cdot c_{u.cp}^2 \cdot \left(\frac{r_{cp}}{r}\right)^{2\cdot m}}{2\cdot m} + C = 0 \text{ substitute}, C = -\frac{m\cdot c_{a.cp}^2 - \varphi^2\cdot c_{u.cp}^2 + m\cdot c_{u.cp}^2}{2\cdot m} \;=\; 3\cdot c_{u.cp}^2 - 0.5\cdot c_{a.cp}^2 + 0.5\cdot c_a\left(\frac{4}{5}\right)^2 = 0$$

$$-\frac{m\cdot c_{a.cp}^2 + m\cdot c_{u.cp}^2 - m\cdot c_a(r)^2 - \varphi^2\cdot c_{u.cp}^2 - m\cdot c_{u.cp}^2\cdot\left(\frac{r_{cp}}{r}\right)^{2\cdot m} + \varphi^2\cdot c_{u.cp}^2\cdot\left(\frac{r_{cp}}{r}\right)^{2\cdot m}}{2\cdot m} = 0 \text{ simplify } \;=\; 3\cdot c_{u.cp}^2 - 0.5\cdot c_{a.cp}^2 + 0.5\cdot c_a\left(\frac{4}{5}\right)^2 = 0$$

$$\frac{c_a(r)^2}{2} - \frac{c_{u.cp}^2}{2} - \frac{c_{a.cp}^2}{2} + \frac{c_{u.cp}^2\cdot\left(\frac{r_{cp}}{r}\right)^{2\cdot m}}{2} + \frac{\varphi^2\cdot c_{u.cp}^2}{2\cdot m} - \frac{\varphi^2\cdot c_{u.cp}^2\cdot\left(\frac{r_{cp}}{r}\right)^{2\cdot m}}{2\cdot m} = 0 \text{ solve}, c_a(r) \;=$$

Проверка:

$m = 0.6$

$\varphi = 0.98$

$$\begin{pmatrix} r \\ r_{cp} \end{pmatrix} = \begin{pmatrix} 0.45 \\ 0.5 \end{pmatrix}$$

$$\begin{pmatrix} c_{a.cp} \\ c_{u.cp} \end{pmatrix} = \begin{pmatrix} 12 \\ 120 \end{pmatrix}$$

$$\frac{\sqrt{m\cdot c_{a.cp}^2 + m\cdot c_{u.cp}^2 - \varphi^2\cdot c_{u.cp}^2 - m\cdot c_{u.cp}^2\cdot\left(\frac{r_{cp}}{r}\right)^{2\cdot m} + \varphi^2\cdot c_{u.cp}^2\cdot\left(\frac{r_{cp}}{r}\right)^{2\cdot m}}}{\sqrt{m}} = 36.19$$

$$\sqrt{c_{a.cp}^2 + c_{u.cp}^2\cdot\left(1 - \frac{\varphi^2}{m}\right)\cdot\left[1 - \left(\frac{r_{cp}}{r}\right)^{2\cdot m}\right]} = 36.19$$

(c.a2)

$\ln\left(r_{cp}\right)$

$\left(r_{cp}\right)$

$p^{2}\cdot\ln\left(r_{cp}\right)$

$p^{2}\cdot\ln\left(r_{cp}\right)$

$$\frac{\dfrac{A^{2}\cdot\varphi^{2}\cdot m\cdot r_{cp}{}^{2-2\cdot m} + A^{2}\cdot\varphi^{2}\cdot r_{cp}{}^{2}\cdot\left(\dfrac{1}{r^{2}}\right)^{m} - A^{2}\cdot m^{2}\cdot r_{cp}{}^{2}\cdot\left(\dfrac{1}{r^{2}}\right)^{m} - \dfrac{B^{2}\cdot m^{2}\cdot r_{cp}{}^{2}}{r^{2}} + 2\cdot A\cdot B\cdot m^{2}\cdot r_{cp}{}^{1-m} - A^{2}\cdot m\cdot r_{cp}{}^{2}\cdot\left(\dfrac{1}{r^{2}}\right)^{m} - \dfrac{B^{2}\cdot m\cdot r_{cp}{}^{2}}{r^{2}} - \dfrac{2\cdot A\cdot B\cdot m\cdot r_{cp}{}^{2}}{r^{m+1}} + \dfrac{B^{2}\cdot\varphi^{2}\cdot m^{2}\cdot r_{cp}{}^{2}}{r^{2}} - \dfrac{2\cdot A\cdot B\cdot m^{2}\cdot r_{cp}{}^{2}}{r^{m+1}} + A^{2}\cdot\varphi^{2}\cdot m\cdot r_{cp}{}^{2}\cdot\left(\dfrac{1}{r^{2}}\right)^{m} + \dfrac{B^{2}\cdot\varphi^{2}\cdot m\cdot r_{cp}{}^{2}}{r^{2}} - 4\cdot A\cdot B\cdot\varphi^{2}\cdot m\cdot r_{cp}{}^{1-m} + \dfrac{4\cdot A\cdot B\cdot\varphi^{2}\cdot m\cdot r_{cp}{}^{2}}{r^{m+1}}}{m\cdot(m+1)}}{r_{cp}}$$

$$\frac{\dfrac{A^{2}\cdot\varphi^{2}\cdot m\cdot r_{cp}{}^{2-2\cdot m} + A^{2}\cdot\varphi^{2}\cdot r_{cp}{}^{2}\cdot\left(\dfrac{1}{r^{2}}\right)^{m} - A^{2}\cdot m^{2}\cdot r_{cp}{}^{2}\cdot\left(\dfrac{1}{r^{2}}\right)^{m} - \dfrac{B^{2}\cdot m^{2}\cdot r_{cp}{}^{2}}{r^{2}} - 2\cdot A\cdot B\cdot m^{2}\cdot r_{cp}{}^{1-m} - A^{2}\cdot m\cdot r_{cp}{}^{2}\cdot\left(\dfrac{1}{r^{2}}\right)^{m} - \dfrac{B^{2}\cdot m\cdot r_{cp}{}^{2}}{r^{2}} + \dfrac{2\cdot A\cdot B\cdot m\cdot r_{cp}{}^{2}}{r^{m+1}} + \dfrac{B^{2}\cdot\varphi^{2}\cdot m^{2}\cdot r_{cp}{}^{2}}{r^{2}} + \dfrac{2\cdot A\cdot B\cdot m^{2}\cdot r_{cp}{}^{2}}{r^{m+1}} + A^{2}\cdot\varphi^{2}\cdot m\cdot r_{cp}{}^{2}\cdot\left(\dfrac{1}{r^{2}}\right)^{m} + \dfrac{B^{2}\cdot\varphi^{2}\cdot m\cdot r_{cp}{}^{2}}{r^{2}} + 4\cdot A\cdot B\cdot\varphi^{2}\cdot m\cdot r_{cp}{}^{1-m} - \dfrac{4\cdot A\cdot B\cdot\varphi^{2}\cdot m\cdot r_{cp}{}^{2}}{r^{m+1}}}{m\cdot(m+1)}}{r_{cp}}$$