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

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

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

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

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

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

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

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

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

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

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

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

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

Вывод общего ур-я профилирования Л цилиндрической ступени К

Дано:

(0) $\frac{d}{dr}H_т = \frac{d}{dr}\left(\frac{c_a^2}{2}\right) + c_u\cdot\left(\frac{d}{dr}c_u\right) + \frac{c_u^2}{r} = 0$ => $\frac{d}{dr}\left(\frac{c_a^2}{2}\right) = -c_u\cdot\left(\frac{d}{dr}c_u\right) - \frac{c_u^2}{r}$ (00) Домножим на 2 => $\frac{d}{dr}\left(c_a^2\right) = -2\cdot c_u\cdot\left(\frac{d}{dr}c_u\right) - \frac{2\cdot c_u^2}{r}$ (000)

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

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

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

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

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

Вывод:

(2) (3) =>

$c_{1u} = (1 - R)\cdot\omega\cdot r - \frac{H_т}{2\cdot\omega\cdot r}$ (c1u)

$c_{2u} = (1 - R)\cdot\omega\cdot r + \frac{H_т}{2\cdot\omega\cdot r}$ (c2u)

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

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

(&) -> (c1u) $c_{1u} = (1 - R)\cdot\omega\cdot r - \frac{H_т}{2\cdot\omega\cdot r} = \frac{\left[\left(1 - R_{cp}\right)\cdot\omega\cdot r_{cp}^{m+1}\right]}{r^{m+1}}\cdot r - \frac{H_т}{2\cdot\omega\cdot r} = \frac{\left[\left(1 - R_{cp}\right)\cdot\omega\cdot r_{cp}^{m+1}\right]}{r^m} - \frac{\left(\frac{H_т}{2\cdot\omega}\right)}{r}$ (AB1) $A = \left[\left(1 - R_{cp}\right)\cdot\omega\cdot r_{cp}^{m+1}\right]$ $\quad c_{1u}(r, m, A, B) = \frac{(A)}{r^m} - \frac{(B)}{r}$

(&) -> (c2u) $c_{2u} = (1 - R)\cdot\omega\cdot r + \frac{H_т}{2\cdot\omega\cdot r} = \frac{\left[\left(1 - R_{cp}\right)\cdot\omega\cdot r_{cp}^{m+1}\right]}{r^{m+1}}\cdot r + \frac{H_т}{2\cdot\omega\cdot r} = \frac{\left[\left(1 - R_{cp}\right)\cdot\omega\cdot r_{cp}^{m+1}\right]}{r^m} + \frac{\left(\frac{H_т}{2\cdot\omega}\right)}{r}$ (AB2) $B = \left(\frac{H_т}{2\cdot\omega}\right)$ $\quad c_{2u}(r, m, A, B) = \frac{(A)}{r^m} + \frac{(B)}{r}$

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

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

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

=>

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

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

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

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

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

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

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

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

Вывод общего ур-я профилирования Л цилиндрической ступени Т

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

Ур-е Бернулли:

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

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

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

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

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

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

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

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

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

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

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

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

$$\sqrt{c_{a1.cp}{}^{2}+\int_{r_{cp}}^{r}-2\cdot c_{1u}(r,m,A,B)\cdot\left(\frac{d}{dr}c_{1u}(r,m,A,B)\right)-2\cdot\varphi^{2}\cdot\frac{c_{1u}(r,m,A,B)^{2}}{r}\,dr}\ \left|\begin{array}{l}\text{assume},r_{cp}>0,r\ge0,m=-1\\ \text{substitute},m=-1\\ \text{simplify}\end{array}\right.=\frac{\sqrt{B^{2}\cdot r^{2}-B^{2}\cdot r_{cp}{}^{2}-B^{2}\cdot\varphi^{2}\cdot r^{2}+B^{2}\cdot\varphi^{2}\cdot r_{cp}{}^{2}+A^{2}\cdot r^{2}\cdot r_{cp}{}^{4}-A^{2}\cdot r^{4}\cdot r_{cp}{}^{2}+r^{2}\cdot r_{cp}{}^{2}\cdot c_{a1.cp}{}^{2}+A^{2}\cdot\varphi^{2}\cdot r^{2}\cdot r_{cp}{}^{4}-A^{2}\cdot\varphi^{2}\cdot r^{4}\cdot r_{cp}{}^{2}-4\cdot A\cdot B\cdot\varphi^{2}\cdot r^{2}\cdot r_{cp}{}^{2}\cdot\ln(r)+4\cdot A\cdot B\cdot\varphi^{2}\cdot r^{2}\cdot r_{cp}{}^{2}\cdot\ln}}{r\cdot r_{cp}}$$

$$\sqrt{c_{a2.cp}{}^{2}+\int_{r_{cp}}^{r}-2\,c_{2u}(r,m,A,B)\cdot\left(\frac{d}{dr}c_{2u}(r,m,A,B)\right)-2\cdot\varphi^{2}\cdot\frac{c_{2u}(r,m,A,B)^{2}}{r}\,dr}\ \left|\begin{array}{l}\text{assume},r_{cp}>0,r\ge0,m=-1\\ \text{substitute},m=-1\\ \text{simplify}\end{array}\right.=\frac{\sqrt{B^{2}\cdot r^{2}-B^{2}\cdot r_{cp}{}^{2}-B^{2}\cdot\varphi^{2}\cdot r^{2}+B^{2}\cdot\varphi^{2}\cdot r_{cp}{}^{2}+A^{2}\cdot r^{2}\cdot r_{cp}{}^{4}-A^{2}\cdot r^{4}\cdot r_{cp}{}^{2}+r^{2}\cdot r_{cp}{}^{2}\cdot c_{a2.cp}{}^{2}+A^{2}\cdot\varphi^{2}\cdot r^{2}\cdot r_{cp}{}^{4}-A^{2}\cdot\varphi^{2}\cdot r^{4}\cdot r_{cp}{}^{2}+4\cdot A\cdot B\cdot\varphi^{2}\cdot r^{2}\cdot r_{cp}{}^{2}\cdot\ln(r)-4\cdot A\cdot B\cdot\varphi^{2}\cdot r^{2}\cdot r_{cp}{}^{2}\cdot\ln}}{r\cdot r_{cp}}$$

$$\sqrt{c_{a1.cp}{}^{2}+\int_{r_{cp}}^{r}-2\,c_{1u}(r,m,A,B)\cdot\left(\frac{d}{dr}c_{1u}(r,m,A,B)\right)-2\cdot\varphi^{2}\cdot\frac{c_{1u}(r,m,A,B)^{2}}{r}\,dr}\ \left|\begin{array}{l}\text{assume},r_{cp}>0,r\ge0,m=0\\ \text{simplify}\end{array}\right.=\frac{\sqrt{B^{2}\cdot r^{2}-B^{2}\cdot r_{cp}{}^{2}-B^{2}\cdot\varphi^{2}\cdot r^{2}+B^{2}\cdot\varphi^{2}\cdot r_{cp}{}^{2}+r^{2}\cdot r_{cp}{}^{2}\cdot c_{a1.cp}{}^{2}-2\cdot A\cdot B\cdot r\cdot r_{cp}{}^{2}+2\cdot A\cdot B\cdot r^{2}\cdot r_{cp}+4\cdot A\cdot B\cdot\varphi^{2}\cdot r\cdot r_{cp}{}^{2}-4\cdot A\cdot B\cdot\varphi^{2}\cdot r^{2}\cdot r_{cp}-2\cdot A^{2}\cdot\varphi^{2}\cdot r^{2}\cdot r_{cp}{}^{2}\cdot\ln(r)+2\cdot A^{2}\cdot\varphi^{2}\cdot r^{2}\cdot r_{c}}}{r\cdot r_{cp}}$$

$$\sqrt{c_{a2.cp}{}^{2}+\int_{r_{cp}}^{r}-2\,c_{2u}(r,m,A,B)\cdot\left(\frac{d}{dr}c_{2u}(r,m,A,B)\right)-2\cdot\varphi^{2}\cdot\frac{c_{2u}(r,m,A,B)^{2}}{r}\,dr}\ \left|\begin{array}{l}\text{assume},r_{cp}>0,r\ge0,m=0\\ \text{simplify}\end{array}\right.=\frac{\sqrt{B^{2}\cdot r^{2}-B^{2}\cdot r_{cp}{}^{2}-B^{2}\cdot\varphi^{2}\cdot r^{2}+B^{2}\cdot\varphi^{2}\cdot r_{cp}{}^{2}+r^{2}\cdot r_{cp}{}^{2}\cdot c_{a2.cp}{}^{2}+2\cdot A\cdot B\cdot r\cdot r_{cp}{}^{2}-2\cdot A\cdot B\cdot r^{2}\cdot r_{cp}-4\cdot A\cdot B\cdot\varphi^{2}\cdot r\cdot r_{cp}{}^{2}+4\cdot A\cdot B\cdot\varphi^{2}\cdot r^{2}\cdot r_{cp}-2\cdot A^{2}\cdot\varphi^{2}\cdot r^{2}\cdot r_{cp}{}^{2}\cdot\ln(r)+2\cdot A^{2}\cdot\varphi^{2}\cdot r^{2}\cdot r_{c}}}{r\cdot r_{cp}}$$

$$\sqrt{c_{a1.cp}{}^{2}+\int_{r_{cp}}^{r}-2\,c_{1u}(r,m,A,B)\cdot\left(\frac{d}{dr}c_{1u}(r,m,A,B)\right)-2\cdot\varphi^{2}\cdot\frac{c_{1u}(r,m,A,B)^{2}}{r}\,dr}\ \left|\begin{array}{l}\text{assume},r_{cp}>0,r\ge0,-1<m\le1,m\ne0\\ \text{simplify}\end{array}\right.=\sqrt{\frac{B^{2}\cdot m+B^{2}\cdot m^{2}+m\cdot r_{cp}{}^{2}\cdot c_{a1.cp}{}^{2}+A^{2}\cdot m\cdot r_{cp}{}^{2-2\cdot m}-B^{2}\cdot\varphi^{2}\cdot m^{2}+m^{2}\cdot r_{cp}{}^{2}\cdot c_{a1.cp}{}^{2}-A^{2}\cdot\varphi^{2}\cdot r_{cp}{}^{2-2\cdot m}+A^{2}\cdot m^{2}\cdot r_{cp}{}^{2-2\cdot m}-B^{2}\cdot\varphi^{2}\cdot m+2\cdot A\cdot B\cdot m\cdot r_{cp}{}^{1-m}-A}{}}$$

$$\sqrt{c_{a2.cp}{}^{2}+\int_{r_{cp}}^{r}-2\,c_{2u}(r,m,A,B)\cdot\left(\frac{d}{dr}c_{2u}(r,m,A,B)\right)-2\cdot\varphi^{2}\cdot\frac{c_{2u}(r,m,A,B)^{2}}{r}\,dr}\ \left|\begin{array}{l}\text{assume},r_{cp}>0,r\ge0,-1<m\le1,m\ne0\\ \text{simplify}\end{array}\right.=\sqrt{\frac{B^{2}\cdot m+B^{2}\cdot m^{2}+m\cdot r_{cp}{}^{2}\cdot c_{a2.cp}{}^{2}+A^{2}\cdot m\cdot r_{cp}{}^{2-2\cdot m}-B^{2}\cdot\varphi^{2}\cdot m^{2}+m^{2}\cdot r_{cp}{}^{2}\cdot c_{a2.cp}{}^{2}-A^{2}\cdot\varphi^{2}\cdot r_{cp}{}^{2-2\cdot m}+A^{2}\cdot m^{2}\cdot r_{cp}{}^{2-2\cdot m}-B^{2}\cdot\varphi^{2}\cdot m-2\cdot A\cdot B\cdot m\cdot r_{cp}{}^{1-m}-A}{}}$$

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

$$B = \left(\frac{L_u}{2\cdot\omega}\right) \qquad A = \left[\left(1 - R_{cp}\right)\cdot\omega\cdot r_{cp}^{m+1}\right]$$

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

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

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

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

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

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

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

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

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

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

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

$+C$

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

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

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

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

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)

(r_{cp})

(r_{cp})

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

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

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

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