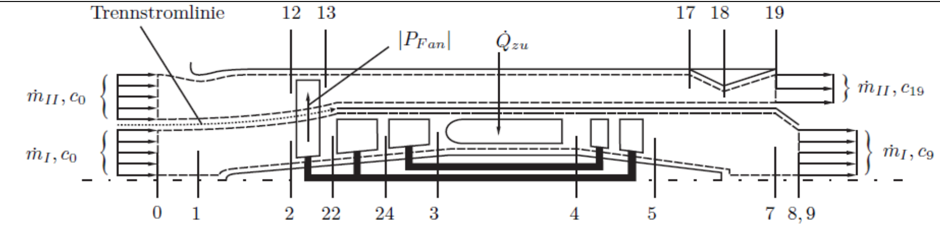
2W-(Z/P)TL-TW © Leo Rauschenberger Print in A3 Format. 2236939196@qq.com Please report any errors. Rot = nur wenn adiabat. Blau = nur bei Zweistrahl-TW					$\boxed{\lambda = \frac{\dot m_{II}}{\dot m_I}}$ Enthalpiekenngröße: $\boxed{N\psi_h = \frac{\Delta h}{u^2/2}}, \psi_h = ¢$ Ideal $\frac{p_3}{p_2} = \left(\frac{p_a}{p_e}\right)_{St}^N, \left(\frac{p_a}{p_e}\right)_{st} = ¢$	$\boxed{w_N = a_K + a_E}$ $\eta_a = \frac{P_F}{-P_N} = \frac{Fc_0}{-w_N}$ $\eta_i = \frac{-P_N}{\dot Q_{zu}}$ Aus 1.HS: $w_{NI} = -\lambda\lvert a_F\rvert + \frac{c_0^2-c_9^2}{2}$ $w_{NII} = \lvert a_F\rvert + \frac{c_0^2-c_{19}^2}{2}$ $w_N = w_{NI} + \lambda w_{NII}$	$\boxed{x = -\frac{\lvert P_F\rvert}{P_{NI}} = -\frac{\lambda\lvert a_F\rvert}{w_{NI}}}$ <0! $\boxed{\eta_{II} = -\frac{a_{EII}}{a_{KII}} = \frac{c_{9,xopt}}{c_{19,xopt}}}$ $a_{KII} = \lvert a_F\rvert + \frac{c_0^2}{2}$ (1) $a_{EII} = \frac{c_{19}^2}{2}$	$c_9 = M_9\sqrt{\kappa' R' T_9} = \sqrt{2w_{NI}(x-1) + c_0^2}$ $c_{19} = \sqrt{2c_p(T_{t19} - T_{19})}$ $= \sqrt{2\eta_{DII}c_pT_{t13}\left(1 - \left(\frac{p_0}{p_{t13}}\right)^{\frac{k-1}{k}}\right)}$ aus η_{DI} wo $T_t = f(T_s)$ $= \sqrt{-2\left(w_{NII} + \frac{x}{\lambda}w_{NI}\right) + c_0^2}$ $= \sqrt{2\eta_{II}\left(\frac{c_0^2}{2} - \frac{x}{\lambda}w_{NI}\right)}$ mit $w_{NII} = a_{KII}(1-\eta_{II})$ mit (1)
	0,1	**2 (12)** $\boxed{NDV/Fan}$ **21 (13)**	**24** $\boxed{HDV}$	**3** $\boxed{BK}$	**4** $\boxed{HDT}$ **41,42**	**45** $\boxed{NDT}$	**5 Übergang 51,15 6**	**7,** $\boxed{8}$ **9 Düse (& Weiteres)**
c π	$\boxed{M_0}$ $c_0 = M_0\sqrt{\kappa R T_0}$ $\rightarrow c_0 = 0$ (Stand) $\pi_E = \frac{p_{t2}}{p_{t0}}$	$\pi_{NDV} = \frac{p_{t24}}{p_{t2}}$ $\pi_F = \frac{p_{t13}}{p_{t2}}$	$\pi_{HDV} = \frac{p_{t3}}{p_{t24}}$	$\boxed{\beta = \frac{\dot m_B}{\dot m_I}}$ $\pi_{BK} = \frac{p_{t4}}{p_{t3}}$ $\boxed{\vartheta_{II} = \frac{T_{t13}}{T_0}}$	$\pi_{HDT} = \frac{p_{t42}}{p_{t4}}$ $\boxed{\vartheta_I = \frac{T_{t4}}{T_0}}$	$\pi_{NDT} = \frac{p_{t5}}{p_{t42}}$	$\pi_Ü = \frac{p_{t6}}{p_{t5}}$	$\pi_{(D)I} = \frac{p_{t9}}{p_{t7}}$ $\pi_{(D)II} = \frac{p_{t18}}{p_{t13}}$
A $\dot m$ η	$\dot m_0 = \dot m_I + \dot m_{II}$ $= \dot m_I(1+\lambda)$	η_{NDV} η_F $\eta_P = \frac{P_{FII}}{\lvert P_P\rvert} = \frac{F_{II}c_0}{\lvert P_P\rvert}$	η_{HDV}	$\eta_{BK} = \frac{\dot Q_{zu}}{\dot m_B H_u} =$ $\boxed{B_s = \frac{\dot m_B}{F} = \frac{c_0}{H_u\eta_g}}$ Für PTL: $B_{s,PTL} = \frac{\dot m_B}{P_{äq}} = \frac{1}{H_u\eta_g}$	η_{HDT} $\boxed{\tau_{TDH} = 1}$	η_{NDT} $\boxed{\tau_{TDN} = 1}$		$\boxed{A_8}$ Stellgröße $\boxed{\tau_8 = \tau_{18} = 1}$ $\dot m_{II} = \lambda\,\dot m_I = \rho_{19}c_{19}A_{19}$ $\dot m_I = \rho_9c_9A_9$ $\boxed{\eta_{DI} = \frac{c_9^2}{c_{9,s}^2}}$ $\boxed{\eta_{DII} = \frac{c_{19}^2}{c_{19,s}^2}}$
$p_{(t)}$	$\boxed{p = \rho RT}$ $p_0 = p_9$ (angepasst) $\frac{p_{t0}}{p_0} = \left(\frac{T_{t0}}{T_0}\right)^{\frac{\kappa}{\kappa-1}}$ $\rightarrow p_{t0} = p_0$ (Stand)	$p_{t2} = \pi_E p_{t0}$ $p_{t13} = \frac{p_{t13}}{p_{t2}}p_{t2}$ $(p_{t12} = p_{t2})$ KF: $\frac{p_{t24}}{p_{t2}} = f(a_{NDV})$	$p_{t24} = \frac{p_{t24}}{p_{t2}}p_{t2}$	$p_{t3} = \pi_V p_{t2}$ $p_{t3} = \frac{p_{t3}}{p_{t24}}p_{t24}$ $\boxed{\frac{p_3}{p_2} = \left[i\frac{\Psi_h u^2}{2C_p}\frac{1}{T_2} + 1\right]^{\frac{n}{n-1}}}$ $Y_{II} = \left(\frac{p_{t13}}{p_0}\right)^{\frac{\kappa-1}{\kappa}}$ $Y_I = \left(\frac{p_{t3}}{p_0}\right)^{\frac{\kappa-1}{\kappa}}$	$p_{t4} = \pi_{BK}p_{t3}$ Using $\dot m_{TDH} = \dot m_{TDN}$ $\frac{p_{t4}}{p_{t42}} = \left(\frac{K_{NDT}}{K_{HDT}}\frac{A_{TDN}}{A_{TDH}}\right)^{\frac{2n_H}{n_H+1}} = C\left(\frac{A_{TDN}}{A_{TDH}}\right)$	$p_{t42} = \frac{p_{t42}}{p_{t4}}p_{t4}$ Using $\dot m_8 = \dot m_{TDN}$	$p_{t5} = p_{t4}\left(\frac{T_{t4}}{T_{t5}}\right)^{\frac{k}{k-1}}$ $p_{t5} = f(a_T)$	$p_9 = p_{19} = p_0$ (angepasst, Check ①) $p_{t9} = \pi_Ü\,\pi_{DI}\,p_{t5} = p_9(T_9)$ $p_{t19} = \pi_{DII}\,p_{t13}$
$T_{(t)}$	$\boxed{T_0}$ $\boxed{\frac{T_{t0}}{T_0} = 1 + \frac{\kappa-1}{2}M_0^2}$ $\frac{T_{t0}}{T_0} = \left(\frac{p_{t0}}{p_0}\right)^{\frac{\kappa-1}{\kappa}}$	$T_{t2} = T_{t0}$ (a) $T_{t2} = T_{t3} + \frac{\eta_m a_T}{c_p} = f(a_V)$ $T_{t13} = T_{t2} + \frac{a_F}{c_p}$ $(T_{t12} = T_{t2})$	$T_{t24} = T_{t2} + \frac{a_{NDV}}{c_p}$	$T_{t3} = T_{t24} + \frac{a_{HDV}}{c_p}$ $T_{t3} = T_{t2} + \frac{a_v}{c_p}$	$\boxed{T_{t4} \sim 1400 - 1800\,K}$ Stellgröße $T_{t4} = T_{t5} + \frac{a_V}{\eta_m c_p'} = f(a_T)$ $T_{t42} = T_{t4} - \frac{a_{HDT}}{c_p'}$ $\frac{T_{t4}}{T_{t42}} = \left(\frac{K_{NDT}}{K_{HDT}}\frac{A_{TDN}}{A_{TDH}}\right)^{\frac{2(n_H-1)}{n_H+1}} = C\left(\frac{A_{TDN}}{A_{TDH}}\right)$	$\frac{T_{t45}}{T_{45}} = \frac{1+\kappa'}{2}$ da $M_{TDN} = 1$ sperrt	$T_{t5} = T_{t9}$ $T_{t5} = T_{t4} - \frac{a_V}{\eta_m c_p'}$ $T_{t15} = T_{t13}$ keine TemperaturΔ im NS	$\frac{T_{t9}}{T_9} = 1 + \frac{\kappa'-1}{2}M_9^2 = \left(\frac{p_{t9}}{p_9}\right)^{\frac{\kappa'-1}{\kappa'}}$ $\frac{T_{t19}}{T_{19}} = \left(\frac{p_{t19}}{p_{19}}\right)^{\frac{\kappa'-1}{\kappa'}}$ $T_{t7} = T_{t9}$ $T_{t19} = T_{t13}$
a **EB**		$a_{NDV} = c_p(T_{t24} - T_{t2})$ $= \frac{c_pT_{t2}}{\eta_{NDV,s}}\left(\pi_{NDV}^{\frac{k-1}{k}} - 1\right)$ $a_F = c_p(T_{t13} - T_{t2})$ $= \frac{c_pT_{t2}}{\eta_{F,s}}\left(\pi_F^{\frac{k-1}{k}} - 1\right)$	$a_{HDV} = c_p(T_{t3} - T_{t24})$ $= \frac{c_pT_{t24}}{\eta_{HDV,s}}\left(\left(\frac{p_{t3}}{p_{t24}}\right)^{\frac{\kappa-1}{\kappa}} - 1\right)$	**EB_BK:** $H_{in} + Q_{in} = H_{out}$ $\rightarrow 0\dot m_I c_p T_{t3} + \dot m_B H_u \eta_{BK} =$ $(\dot m_I + \dot m_B)c_p' T_{t4}$	$a_{HDT} = c_p'(T_{t42} - T_{t4})$ $= c_p'\eta_{HDT,s}T_{t4}\left(\left(\frac{p_{t42}}{p_{t4}}\right)^{\frac{\kappa'-1}{\kappa'}} - 1\right)$ $= T_{t4}\cdot C\left(\frac{A_{TDN}}{A_{TDH}}\right)$	$a_{NDT} = c_p'(T_{t5} - T_{t42})$ $= c_p'\eta_{NDT,s}T_{t42}\left(\left(\frac{p_{t5}}{p_{t42}}\right)^{\frac{\kappa'-1}{\kappa'}} - 1\right)$ $= T_{t42}\cdot C\left(\frac{A_8}{A_{TDN}}\right)$ $= T_{t4}\cdot C\left(\frac{A_{TDN}}{A_8}, \frac{A_{TDN}}{A_{TDH}}\right) \sim N_N$	**EB_Mischung:** $\dot m_{II}c_pT_{t15} + (\dot m_I + \dot m_B)c_p'T_{t51} =$ $(\dot m_{II} + \dot m_I + \dot m_B)c_p'T_{t6}$	$\boxed{a_V = a_{NDV} + a_{HDV}} = c_p(T_{t3} - T_0)$ $\boxed{a_T = a_{HDT} + a_{NDT}} = c_p'(T_{t5} - T_{t4})$ $a_V = -\eta_m(1+\beta)a_T$ $\boxed{\lvert a_F\rvert\lambda + a_{NDV} = -a_{NDT}\eta_{mN}}$ $\boxed{a_{HDV} = -a_{HDT}\eta_{mH}}$
BL	**Fan zu NDT** $\boxed{\dot m_2 = \dot m_{TDN}}$ $\rightarrow \frac{T_{t42}}{T_{t2}} = \left(\frac{p_{t42}}{p_{t2}}\right)^2\left(\frac{A_{TDN}}{A_2}\frac{K_{NDT}}{K_{NDV}}\right)^2\frac{1}{\tau_{NDV}^2}$ Mit: $\frac{p_{t42}}{p_{t2}} = C\left(\frac{A_{TDN}}{A_{TDH}}\right)\pi_{BK}\frac{p_{t3}}{p_{t24}}\frac{p_{t24}}{p_{t2}}$ $\boxed{\lvert a_F\rvert\lambda + a_{NDV} = -\eta_{mN}a_{NDT}}$ $\rightarrow \frac{T_{t42}}{T_{t2}} = \cdots$ mit $a_{NDT}T_{t42}\cdot C\left(\frac{A_8}{A_{TDN}}\right)$ **BL_NDV:** $\frac{\tau_{NDV}^2\left(\frac{\left(\frac{p_{t24}}{p_{t2}}\right)^{\frac{\kappa-1}{\kappa}}-1}{\eta_{NDV,s}} + \lambda\frac{\left(\frac{p_{t13}}{p_{t12}}\right)^{\frac{\kappa-1}{\kappa}}-1}{\eta_{F,s}}\right)}{\left(\frac{p_{t24}}{p_{t2}}\right)^2\left(\frac{p_{t3}}{p_{t24}}\right)^2} = C_{11}\left(\frac{A_{TDN}}{A_2}, \frac{A_{TDN}}{A_{TDH}}, \frac{A_8}{A_{TDN}}\right)$ $= f(x, \lambda, A_8, A_{18}, T_{t4} \ldots)$ **Kühlsche Geraden NDV:** aus LGGW $\frac{p_{t24}}{p_{t2}} = \left(1 - \eta_{NDV,s}\frac{T_{t4}}{T_{t2}}\frac{\eta_{mN}}{c_p}\frac{C_5}{C_7}\right)^{\frac{\kappa}{\kappa-1}}$ nahezu Horizontalen		**HDV zu HDT:** $\boxed{\dot m_{24} = \dot m_{TDH}}$ $\rightarrow \frac{T_{t42}}{T_{t2}} = \left(\frac{p_{t42}}{p_{t2}}\right)^2\left(\frac{A_{TDN}}{A_2}\frac{K_{NDT}}{K_{NDV}}\right)^2\frac{1}{\tau_{NDV}^2}$ **LGGW H:** $\boxed{a_{HDV} = -\eta_{mH}a_{HDT}}$ $\rightarrow \frac{T_{t42}}{T_{t2}} = \cdots$ mit $a_{HDT} = T_{t4}\cdot C\left(\frac{A_{TDN}}{A_{TDH}}\right)$ **BL_HDV:** $\frac{\tau_{HDV}^2\left(1 - \left(\frac{p_{t3}}{p_{t24}}\right)^{\frac{\kappa-1}{\kappa}}\right)}{\left(\frac{p_{t3}}{p_{t24}}\right)^2\eta_{HDV,s}} = C_8\left(\frac{A_{TDH}}{A_{24}}, \frac{A_{TDN}}{A_{TDH}}\right)$ $\neq f(x, \lambda, A_8, A_{18}, T_{t4} \ldots)$ **Kühlsche Gerade HDV:** aus Konti $\rightarrow \frac{p_{t3}}{p_{t24}} = \cdots$ $\frac{p_{t3}}{p_{t24}} = \sqrt{\frac{T_{t4}}{T_{t2}}}\sqrt{\frac{T_{t2}}{T_{t24}}}\tau_{HDV}C_9\left(\frac{A_{24}}{A_{TDH}}\right)$ keine Geraden		**HDT zu NDT:** $\boxed{\dot m_{TDH} = \dot m_{TDN}}$ (4.29) $\frac{p_{t4}}{p_{t42}} = \left(\frac{T_{t4}}{T_{t42}}\right)^{\frac{n_H}{n_H-1}}$ $\frac{p_{t4}}{p_{t42}} = \left(\frac{K_{NDT}}{K_{HDT}}\frac{A_{TDN}}{A_{TDH}}\right)^{\frac{2n_H}{n_H+1}}$ $\rightarrow \frac{p_{t4}}{p_{t42}} = C_1\left(\frac{A_{TDN}}{A_{TDH}}\right); \frac{T_{t4}}{T_{t42}} = C_2\left(\frac{A_{TDN}}{A_{TDH}}\right)$	$\frac{a_{HDT}}{a_{NDT}} = C_7\left(\frac{A_{TDN}}{A_{TDH}}, \frac{A_8}{A_{TDN}}\right)$	**NDT zu Düse** $\boxed{\dot m_{TDN} = \dot m_8}$ (4.36) $\frac{p_{t42}}{p_{t5}} = \left(\frac{K_8}{K_{NDT}}\frac{A_8}{A_{TDN}}\pi_D\right)^{\frac{2n_N}{n_N+1}} = C\left(\frac{A_8}{A_{TDN}}\right)$ $\rightarrow \frac{p_{t42}}{p_{t5}} = C_3\left(\frac{A_8}{A_{TDH}}\right)$; $\frac{T_{t42}}{T_{t5}} = C_4\left(\frac{A_8}{A_{TDH}}\right)$	**Nebenstrom Ein- zu Aus** $\boxed{\dot m_{II} = \dot m_{18}}$ $\dot m_{II} = \frac{p_{t13}A_{18}\pi_{II}}{\sqrt{T_{t13}}}K_{II}$ $\lvert\cdot\frac{\sqrt{T_{t2}}}{p_{t2}}$ Mit $\dot m_{II} = (\dot m_I + \dot m_{II})\frac{\lambda}{1+\lambda}$ $\rightarrow \frac{T_{t13}}{T_{t2}} = \cdots$ $\boxed{Fan\ iso}$ $a_F = c_pT_{t2}\left(\frac{T_{t13}}{T_{t2}} - 1\right) = \frac{c_pT_{t2}}{\eta_{F,s}}\left(\left(\frac{p_{t13}}{p_{t2}}\right)^{\frac{\kappa}{\kappa-1}} - 1\right) \rightarrow \frac{T_{t13}}{T_{t2}} = \cdots$ **BL_Fan:** $\frac{\left(\frac{(\dot m_I + \dot m_{II})\sqrt{T_{t2}}}{p_{t2}}\right)^2\left(\frac{\left(\frac{p_{t13}}{p_{t2}}\right)^{\frac{\kappa}{\kappa-1}}-1}{\eta_{F,s}} + 1\right)}{\left(\frac{p_{t13}}{p_{t2}}\right)^2}\left(\frac{\lambda}{1+\lambda}\right)^2 = (A_{18}\pi_{II}K_{II})^2$
Weiteres	$c_p(\kappa = 1{,}4) = 1004{,}5\frac{J}{kgK}$ $c_p'(\kappa' = 1{,}3) = 1243{,}7\frac{J}{kgK}$ $T(H \le 11km) = T_0(= 288{,}15\,K) - 6{,}5\frac{K}{km} * H$ $p(H \le 11km) = p_0(= 101325Pa)\left(1 + \frac{6{,}5\frac{K}{km}H}{T_0}\right)^{\frac{g}{6{,}5\frac{K}{km}R}}$ $T_t = T + \frac{c^2}{2c_p} = T_s + \frac{c_s^2}{2c_p}$ $p_t = p + \frac{c^2}{2c_p}$ $\rho = \rho_t$ $p = \rho RT$ $h = u + pv$ $Tds = u + qdV$ $\boxed{\tau = \frac{\dot m\sqrt{T_t}}{Ap_tK}}$		$F = F_I + F_{II}$ $= (\dot m_I + \dot m_B)c_9 + \dot m_{II}c_{19} - (\dot m_I + \dot m_{II})c_0$ Gemischt: $c_{19} = c_9$ $F_I = (\dot m_I + \dot m_B)c_9 - \dot m_Ic_0 + (p_9 - p_0)A_9$ $F_{II} = \dot m_{II}(c_{19} - c_0) + (p_{19} - p_0)A_{19}$ Energieglg (1.HS): $-\lvert P_F\rvert + \dot Q_{zu} + \dot m_{0,I}\left(h_0 + \frac{c_0^2}{2}\right) - \dot m_9\left(h_9 + \frac{c_9^2}{2}\right) = 0$ $\lvert P_F\rvert + \dot m_{0,I}\left(h_0 + \frac{c_0^2}{2}\right) - \dot m_{19}\left(h_{19} + \frac{c_9^2}{2}\right) = 0$		**LGGW:** ND: $\boxed{\lvert P_F\rvert + P_{NDV} = -\eta_{mN}\cdot P_{NDT}}$ $\rightarrow \dot m_{II}\lvert a_F\rvert + \dot m_Ia_{NDV} =$ $-\eta_{mN}(\dot m_I + \dot m_B)a_{NDT}$ HD: $\boxed{P_{HDV} = -\eta_{mH}\cdot P_{HDT}}$ $\rightarrow \dot m_Ia_{HDV} = -\eta_{mH}(\dot m_I + \dot m_B)a_{HDT}$	**Überschalldiffusor** $\pi_E = \frac{p_{t2}}{p_{t1}}\frac{p_{t1}}{p_{t0}}$ $M_1 = \frac{M_1' + M_1''}{2}$	**PTL-TW** $\frac{\lvert P_P\rvert}{\dot m_I} = \lvert a_P\rvert = -\eta_{mN}a_{NDT}$ $\boxed{P_{äq} = \frac{P_{F,PTL}}{\eta_P}}$ $P_F = Fc_0$ $\eta_P = \frac{P_{FII}}{\lvert P_P\rvert}$ $\left(\frac{c_9}{c_0}\right)_{opt} = \frac{\eta_D}{\eta_{mN}\eta_{NDT,s}\eta_P}$	① **Angepasst? Prüfen, ob in Düse krit. Druckverhältnis vorliegt:** $\left.\frac{p_{t9}}{p_9}\right\rvert_{krit} = \left(1 + \frac{\kappa'-1}{2}\right)^{\frac{\kappa'-1}{\kappa'}}$ $(= 1.8324\ bei\ \kappa = 1.3)$ $(= 1.8929\ bei\ \kappa = 1.4)$ $< \left.\frac{p_{t9}}{p_9}\right\rvert_{given}$ $\rightarrow$ $M_9 = 1$ überkritisch.