

# Linear stability equations in cylindrical coordinates

The matrices constituting the eigenvalue problem system given by

$$(\underline{\underline{A}} + \underline{\underline{B}}\omega) \tilde{q} = 0 \quad (1)$$

are detailed in the following for the local and BiGlobal problems. The matrices  $\underline{\underline{A}}$  and  $\underline{\underline{B}}$  matrices retain the same structure for both linear theories, given by

$$\underline{\underline{A}} = \begin{bmatrix} A_{1 \times 1} & A_{1 \times 2} & A_{1 \times 3} & A_{1 \times 4} & A_{1 \times 5} \\ A_{2 \times 1} & A_{2 \times 2} & A_{2 \times 3} & A_{2 \times 4} & A_{2 \times 5} \\ A_{3 \times 1} & A_{3 \times 2} & A_{3 \times 3} & A_{3 \times 4} & A_{3 \times 5} \\ A_{4 \times 1} & A_{4 \times 2} & A_{4 \times 3} & A_{4 \times 4} & A_{4 \times 5} \\ A_{5 \times 1} & A_{5 \times 2} & A_{5 \times 3} & A_{5 \times 4} & A_{5 \times 5} \end{bmatrix}, \quad \underline{\underline{B}} = \begin{bmatrix} 0 & 0 & 0 & B_{1 \times 4} & B_{1 \times 5} \\ B_{2 \times 1} & 0 & 0 & 0 & 0 \\ 0 & B_{3 \times 2} & 0 & 0 & 0 \\ 0 & 0 & B_{4 \times 3} & 0 & 0 \\ 0 & 0 & 0 & B_{5 \times 4} & B_{5 \times 5} \end{bmatrix}, \quad (2)$$

where lines one to five represent namely the continuity, the three momentum, and the energy equations. In the following, sub-matrices are detailed for the streamwise BiGlobal problem assuming the flow as a mixture of gases in LTE. These sub-matrices are expressed in terms of the base-state quantities  $\bar{q}$ , and contain the numerical derivative operators applied to the perturbation quantities  $\tilde{q}$

$$\underline{\underline{D}}_r \tilde{q} = \partial_r \tilde{q}, \quad \underline{\underline{D}}_z \tilde{q} = \partial_z \tilde{q}, \quad \underline{\underline{D}}_{rr} \tilde{q} = \partial_r^2 \tilde{q}, \dots \quad (3)$$

## 1 BiGlobal problem

When assuming the flow in LTE, the sub-matrices composing  $\underline{\underline{B}}$  are

$$\begin{aligned} \mathbf{B}_{1 \times 4} &= \frac{i \bar{G} \bar{p}}{\bar{T}}; & \mathbf{B}_{1 \times 5} &= -i \bar{F}; & \mathbf{B}_{2 \times 1} &= -\frac{i \mathcal{H} \bar{p}}{\bar{T} \bar{\zeta}}; & \mathbf{B}_{3 \times 2} &= -\frac{i \mathcal{H} \bar{p}}{\bar{T} \bar{\zeta}}; \\ \mathbf{B}_{4 \times 3} &= -\frac{i \mathcal{H} \bar{p}}{\bar{T} \bar{\zeta}}; & \mathbf{B}_{5 \times 4} &= -\frac{i \mathcal{H} \bar{h}_T \bar{p}}{\bar{T} \bar{\zeta}}; & \mathbf{B}_{5 \times 5} &= i Ec - \frac{i \mathcal{H} \bar{h}_T \bar{p}}{\bar{T} \bar{\zeta}}. \end{aligned} \quad (4)$$

While the sub-matrices composing  $\underline{\underline{A}}$  are

$$\mathbf{A}_{1 \times 1} = \frac{\bar{p}}{r} + \bar{F} \bar{p}_r - \frac{\bar{G} \bar{T}_r \bar{p}}{\bar{T}} + \mathcal{D}_r \bar{p}; \quad \mathbf{A}_{1 \times 2} = \frac{i m \bar{p}}{r}; \quad \mathbf{A}_{1 \times 3} = \bar{F} \bar{p}_z - \frac{\bar{G} \bar{T}_z \bar{p}}{\bar{T}} + \mathcal{D}_z \bar{p}, \quad (5a)$$

$$\begin{aligned}
\mathbf{A}_{1 \times 4} = & -\frac{i\bar{G}\bar{v}m\bar{p}}{\bar{T}r} - \frac{\bar{G}\bar{u}\bar{p}}{\bar{T}r} + \frac{2\bar{w}\bar{\zeta}_{\bar{T}}\bar{\zeta}_{\bar{p}}\bar{p}\bar{p}_z}{\bar{\zeta}^2} + \frac{\bar{w}\bar{\zeta}_{\bar{p}}\bar{p}\bar{p}_z}{\bar{T}\bar{\zeta}} - \frac{\bar{w}\bar{\zeta}_{\bar{T}\bar{p}}\bar{p}\bar{p}_z}{\bar{\zeta}} - \frac{\bar{w}\bar{\zeta}_{\bar{T}}\bar{p}_z}{\bar{\zeta}} \\
& - \frac{\bar{w}\bar{p}_z}{\bar{T}} + \frac{2\bar{u}\bar{\zeta}_{\bar{T}}\bar{\zeta}_{\bar{p}}\bar{p}\bar{p}_r}{\bar{\zeta}^2} + \frac{\bar{u}\bar{\zeta}_{\bar{p}}\bar{p}\bar{p}_r}{\bar{T}\bar{\zeta}} - \frac{\bar{u}\bar{\zeta}_{\bar{T}\bar{p}}\bar{p}\bar{p}_r}{\bar{\zeta}} - \frac{\bar{u}\bar{\zeta}_{\bar{T}}\bar{p}_r}{\bar{\zeta}} - \frac{\bar{u}\bar{p}_r}{\bar{T}} - \frac{\bar{T}_z\bar{w}\bar{\zeta}_{\bar{T}\bar{T}}\bar{p}}{\bar{\zeta}} \\
& - \frac{\bar{T}_r\bar{u}\bar{\zeta}_{\bar{T}\bar{T}}\bar{p}}{\bar{\zeta}} + \frac{2\bar{T}_z\bar{w}(\bar{\zeta}_{\bar{T}})^2\bar{p}}{\bar{\zeta}^2} + \frac{2\bar{T}_r\bar{u}(\bar{\zeta}_{\bar{T}})^2\bar{p}}{\bar{\zeta}^2} + \frac{2\bar{T}_z\bar{w}\bar{\zeta}_{\bar{T}}\bar{p}}{\bar{T}\bar{\zeta}} + \frac{2\bar{T}_r\bar{u}\bar{\zeta}_{\bar{T}}\bar{p}}{\bar{T}\bar{\zeta}} \\
& - \frac{\bar{G}\bar{w}_z\bar{p}}{\bar{T}} + \frac{2\bar{T}_z\bar{w}\bar{p}}{\bar{T}^2} - \frac{\bar{G}\bar{u}_r\bar{p}}{\bar{T}} + \frac{2\bar{T}_r\bar{u}\bar{p}}{\bar{T}^2} - \frac{\mathcal{D}_z\bar{G}\bar{w}\bar{p}}{\bar{T}} - \frac{\mathcal{D}_r\bar{G}\bar{u}\bar{p}}{\bar{T}},
\end{aligned}$$

$$\begin{aligned}
\mathbf{A}_{1 \times 5} = & \frac{i\bar{F}\bar{v}m}{r} + \frac{\bar{F}\bar{u}}{r} - \frac{\bar{w}\bar{\zeta}_{\bar{p}}\bar{p}\bar{p}_z}{\bar{\zeta}} + \frac{2\bar{w}(\bar{\zeta}_{\bar{p}})^2\bar{p}\bar{p}_z}{\bar{\zeta}^2} - \frac{2\bar{w}\bar{\zeta}_{\bar{p}}\bar{p}_z}{\bar{\zeta}} - \frac{\bar{u}\bar{\zeta}_{\bar{p}}\bar{p}\bar{p}_r}{\bar{\zeta}} + \frac{2\bar{u}(\bar{\zeta}_{\bar{p}})^2\bar{p}\bar{p}_r}{\bar{\zeta}^2} \\
& - \frac{2\bar{u}\bar{\zeta}_{\bar{p}}\bar{p}_r}{\bar{\zeta}} + \frac{2\bar{T}_z\bar{w}\bar{\zeta}_{\bar{T}}\bar{\zeta}_{\bar{p}}\bar{p}}{\bar{\zeta}^2} + \frac{2\bar{T}_r\bar{u}\bar{\zeta}_{\bar{T}}\bar{\zeta}_{\bar{p}}\bar{p}}{\bar{\zeta}^2} + \frac{\bar{T}_z\bar{w}\bar{\zeta}_{\bar{p}}\bar{p}}{\bar{T}\bar{\zeta}} + \frac{\bar{T}_r\bar{u}\bar{\zeta}_{\bar{p}}\bar{p}}{\bar{T}\bar{\zeta}} - \frac{\bar{T}_z\bar{w}\bar{\zeta}_{\bar{T}\bar{p}}\bar{p}}{\bar{\zeta}} \\
& - \frac{\bar{T}_r\bar{u}\bar{\zeta}_{\bar{T}\bar{p}}\bar{p}}{\bar{\zeta}} - \frac{\bar{T}_z\bar{w}\bar{\zeta}_{\bar{T}}}{\bar{\zeta}} - \frac{\bar{T}_r\bar{u}\bar{\zeta}_{\bar{T}}}{\bar{\zeta}} + \bar{F}\bar{w}_z - \frac{\bar{T}_z\bar{w}}{\bar{T}} + \bar{F}\bar{u}_r - \frac{\bar{T}_r\bar{u}}{\bar{T}} + \mathcal{D}_z\bar{F}\bar{w} + \mathcal{D}_r\bar{F}\bar{u},
\end{aligned}$$

$$\begin{aligned}
\mathbf{A}_{2 \times 1} = & -\frac{\bar{\lambda}_{\bar{p}}\bar{p}_r}{\text{Re}r} + \frac{i\mathcal{H}\bar{v}m\bar{p}}{\bar{T}\bar{\zeta}r} - \frac{\bar{T}_r\bar{\lambda}_{\bar{T}}}{\text{Re}r} + \frac{m^2\bar{\mu}}{\text{Re}r^2} + \frac{2\bar{\mu}}{\text{Re}r^2} + \frac{\bar{\lambda}}{\text{Re}r^2} + \frac{\mathcal{H}\bar{u}_r\bar{p}}{\bar{T}\bar{\zeta}} \\
& + \mathcal{D}_r \left( -\frac{2\bar{\mu}}{\text{Re}r} - \frac{\bar{\lambda}}{\text{Re}r} - \frac{2\bar{\mu}_{\bar{p}}\bar{p}_r}{\text{Re}} - \frac{\bar{\lambda}_{\bar{p}}\bar{p}_r}{\text{Re}} + \frac{\mathcal{H}\bar{u}\bar{p}}{\bar{T}\bar{\zeta}} - \frac{2\bar{T}_r\bar{\mu}_{\bar{T}}}{\text{Re}} - \frac{\bar{T}_r\bar{\lambda}_{\bar{T}}}{\text{Re}} \right) \\
& + \mathcal{D}_z \left( -\frac{\bar{\mu}_{\bar{p}}\bar{p}_z}{\text{Re}} + \frac{\mathcal{H}\bar{w}\bar{p}}{\bar{T}\bar{\zeta}} - \frac{\bar{T}_z\bar{\mu}_{\bar{T}}}{\text{Re}} \right) + \underline{\underline{\mathcal{D}_{rr}}} \left( -\frac{2\bar{\mu}}{\text{Re}} - \frac{\bar{\lambda}}{\text{Re}} \right) - \frac{\underline{\underline{\mathcal{D}_{zz}}}\bar{\mu}}{\text{Re}},
\end{aligned}$$

$$\mathbf{A}_{2 \times 2} = -\frac{im\bar{\lambda}_{\bar{p}}\bar{p}_r}{\text{Re}r} - \frac{2\mathcal{H}\bar{v}\bar{p}}{\bar{T}\bar{\zeta}r} - \frac{i\bar{T}_r m\bar{\lambda}_{\bar{T}}}{\text{Re}r} + \frac{3im\bar{\mu}}{\text{Re}r^2} + \frac{im\bar{\lambda}}{\text{Re}r^2} + \mathcal{D}_r \left( -\frac{im\bar{\mu}}{\text{Re}r} - \frac{im\bar{\lambda}}{\text{Re}r} \right),$$

$$\mathbf{A}_{2 \times 3} = \mathcal{D}_r \left( -\frac{\bar{\mu}_{\bar{p}}\bar{p}_z}{\text{Re}} - \frac{\bar{T}_z\bar{\mu}_{\bar{T}}}{\text{Re}} \right) + \mathcal{D}_z \left( -\frac{\bar{\lambda}_{\bar{p}}\bar{p}_r}{\text{Re}} - \frac{\bar{T}_r\bar{\lambda}_{\bar{T}}}{\text{Re}} \right) + \frac{\mathcal{H}\bar{u}_z\bar{p}}{\bar{T}\bar{\zeta}} + \underline{\underline{\mathcal{D}_{rz}}} \left( -\frac{\bar{\mu}}{\text{Re}} - \frac{\bar{\lambda}}{\text{Re}} \right),$$

$$\begin{aligned}
\mathbf{A}_{2 \times 4} = & -\frac{\bar{u}\bar{\lambda}_{\bar{T}\bar{p}}\bar{p}_r}{\text{Re}r} + \frac{\bar{G}\mathcal{H}\bar{v}^2\bar{p}}{\bar{T}^2\bar{\zeta}r} - \frac{i\bar{v}_r m\bar{\mu}_{\bar{T}}}{\text{Re}r} - \frac{2\bar{u}_r\bar{\mu}_{\bar{T}}}{\text{Re}r} - \frac{\bar{T}_r\bar{u}\bar{\lambda}_{\bar{T}\bar{T}}}{\text{Re}r} - \frac{\bar{u}_r\bar{\lambda}_{\bar{T}}}{\text{Re}r} + \frac{i\bar{v}m\bar{\mu}_{\bar{T}}}{\text{Re}r^2} \\
& + \frac{2\bar{u}\bar{\mu}_{\bar{T}}}{\text{Re}r^2} + \frac{\bar{u}\bar{\lambda}_{\bar{T}}}{\text{Re}r^2} - \frac{\bar{w}_r\bar{\mu}_{\bar{T}\bar{p}}\bar{p}_z}{\text{Re}} - \frac{\bar{u}_z\bar{\mu}_{\bar{T}\bar{p}}\bar{p}_z}{\text{Re}} - \frac{2\bar{u}_r\bar{\mu}_{\bar{T}\bar{p}}\bar{p}_r}{\text{Re}} - \frac{\bar{w}_z\bar{\lambda}_{\bar{T}\bar{p}}\bar{p}_r}{\text{Re}} \\
& - \frac{\bar{u}_r\bar{\lambda}_{\bar{T}\bar{p}}\bar{p}_r}{\text{Re}} - \frac{\bar{G}\mathcal{H}\bar{u}_z\bar{w}\bar{p}}{\bar{T}^2\bar{\zeta}} - \frac{\bar{G}\mathcal{H}\bar{u}\bar{u}_r\bar{p}}{\bar{T}^2\bar{\zeta}} - \frac{\bar{T}_z\bar{w}_r\bar{\mu}_{\bar{T}\bar{T}}}{\text{Re}} - \frac{\bar{T}_z\bar{u}_z\bar{\mu}_{\bar{T}\bar{T}}}{\text{Re}} - \frac{2\bar{T}_r\bar{u}_r\bar{\mu}_{\bar{T}\bar{T}}}{\text{Re}} \\
& - \frac{\bar{w}_{rz}\bar{\mu}_{\bar{T}}}{\text{Re}} - \frac{\bar{u}_{zz}\bar{\mu}_{\bar{T}}}{\text{Re}} - \frac{2\bar{u}_{rr}\bar{\mu}_{\bar{T}}}{\text{Re}} - \frac{\bar{T}_r\bar{w}_z\bar{\lambda}_{\bar{T}\bar{T}}}{\text{Re}} - \frac{\bar{T}_r\bar{u}_r\bar{\lambda}_{\bar{T}\bar{T}}}{\text{Re}} - \frac{\bar{w}_{rz}\bar{\lambda}_{\bar{T}}}{\text{Re}} - \frac{\bar{u}_{rr}\bar{\lambda}_{\bar{T}}}{\text{Re}} \\
& + \mathcal{D}_r \left( -\frac{\bar{u}\bar{\lambda}_{\bar{T}}}{\text{Re}r} - \frac{2\bar{u}_r\bar{\mu}_{\bar{T}}}{\text{Re}} - \frac{\bar{w}_z\bar{\lambda}_{\bar{T}}}{\text{Re}} - \frac{\bar{u}_r\bar{\lambda}_{\bar{T}}}{\text{Re}} \right) + \mathcal{D}_z \left( -\frac{\bar{w}_r\bar{\mu}_{\bar{T}}}{\text{Re}} - \frac{\bar{u}_z\bar{\mu}_{\bar{T}}}{\text{Re}} \right),
\end{aligned}$$

$$\begin{aligned}
\mathbf{A}_{2 \times 5} = & -\frac{\bar{u} \bar{\lambda}_{\bar{p} \bar{p}} \bar{p}_r}{Re r} - \frac{i \bar{v}_r m \bar{\mu}_{\bar{p}}}{Re r} - \frac{2 \bar{u}_r \bar{\mu}_{\bar{p}}}{Re r} - \frac{\bar{u}_r \bar{\lambda}_{\bar{p}}}{Re r} - \frac{\bar{T}_r \bar{u} \bar{\lambda}_{\bar{T} \bar{p}}}{Re r} - \frac{\bar{F} \mathcal{H} \bar{v}^2}{\bar{T} \bar{\zeta} r} + \frac{i \bar{v} m \bar{\mu}_{\bar{p}}}{Re r^2} + \frac{2 \bar{u} \bar{\mu}_{\bar{p}}}{Re r^2} + \frac{\bar{u} \bar{\lambda}_{\bar{p}}}{Re r^2} \\
& - \frac{\bar{w}_r \bar{\mu}_{\bar{p} \bar{p}} \bar{p}_z}{Re} - \frac{\bar{u}_z \bar{\mu}_{\bar{p} \bar{p}} \bar{p}_z}{Re} - \frac{2 \bar{u}_r \bar{\mu}_{\bar{p} \bar{p}} \bar{p}_r}{Re} - \frac{\bar{w}_z \bar{\lambda}_{\bar{p} \bar{p}} \bar{p}_r}{Re} - \frac{\bar{u}_r \bar{\lambda}_{\bar{p} \bar{p}} \bar{p}_r}{Re} - \frac{\bar{w}_r \bar{z} \bar{\mu}_{\bar{p}}}{Re} - \frac{\bar{u}_z \bar{z} \bar{\mu}_{\bar{p}}}{Re} - \frac{2 \bar{u}_{r r} \bar{\mu}_{\bar{p}}}{Re} \\
& - \frac{\bar{T}_z \bar{w}_r \bar{\mu}_{\bar{T} \bar{p}}}{Re} - \frac{\bar{T}_z \bar{u}_z \bar{\mu}_{\bar{T} \bar{p}}}{Re} - \frac{2 \bar{T}_r \bar{u}_r \bar{\mu}_{\bar{T} \bar{p}}}{Re} - \frac{\bar{w}_r \bar{z} \bar{\lambda}_{\bar{p}}}{Re} - \frac{\bar{u}_{r r} \bar{\lambda}_{\bar{p}}}{Re} - \frac{\bar{T}_r \bar{w}_z \bar{\lambda}_{\bar{T} \bar{p}}}{Re} - \frac{\bar{T}_r \bar{u}_r \bar{\lambda}_{\bar{T} \bar{p}}}{Re} + \frac{\bar{F} \mathcal{H} \bar{u}_z \bar{w}}{\bar{T} \bar{\zeta}} \\
& + \frac{\bar{F} \mathcal{H} \bar{u} \bar{u}_r}{\bar{T} \bar{\zeta}} + \mathcal{D}_r \left( -\frac{\bar{u} \bar{\lambda}_{\bar{p}}}{Re r} - \frac{2 \bar{u}_r \bar{\mu}_{\bar{p}}}{Re} - \frac{\bar{w}_z \bar{\lambda}_{\bar{p}}}{Re} - \frac{\bar{u}_r \bar{\lambda}_{\bar{p}}}{Re} + 1 \right) + \mathcal{D}_z \left( -\frac{\bar{w}_r \bar{\mu}_{\bar{p}}}{Re} - \frac{\bar{u}_z \bar{\mu}_{\bar{p}}}{Re} \right),
\end{aligned}$$

$$\mathbf{A}_{3 \times 1} = -\frac{i m \bar{\mu}_{\bar{p}} \bar{p}_r}{Re r} + \frac{\mathcal{H} \bar{v} \bar{p}}{\bar{T} \bar{\zeta} r} - \frac{i \bar{T}_r m \bar{\mu}_{\bar{T}}}{Re r} - \frac{3 i m \bar{\mu}}{Re r^2} - \frac{i m \bar{\lambda}}{Re r^2} + \frac{\mathcal{H} \bar{v}_r \bar{p}}{\bar{T} \bar{\zeta}} + \mathcal{D}_r \left( -\frac{i m \bar{\mu}}{Re r} - \frac{i m \bar{\lambda}}{Re r} \right),$$

$$\begin{aligned}
\mathbf{A}_{3 \times 2} = & \frac{\bar{\mu}_{\bar{p}} \bar{p}_r}{Re r} + \frac{i \mathcal{H} \bar{v} m \bar{p}}{\bar{T} \bar{\zeta} r} + \frac{\mathcal{H} \bar{u} \bar{p}}{\bar{T} \bar{\zeta} r} + \frac{\bar{T}_r \bar{\mu}_{\bar{T}}}{Re r} + \frac{2 m^2 \bar{\mu}}{Re r^2} + \frac{\bar{\mu}}{Re r^2} + \frac{m^2 \bar{\lambda}}{Re r^2} \\
& + \mathcal{D}_r \left( -\frac{\bar{\mu}}{Re r} - \frac{\bar{\mu}_{\bar{p}} \bar{p}_r}{Re} + \frac{\mathcal{H} \bar{u} \bar{p}}{\bar{T} \bar{\zeta}} - \frac{\bar{T}_r \bar{\mu}_{\bar{T}}}{Re} \right) + \mathcal{D}_z \left( -\frac{\bar{\mu}_{\bar{p}} \bar{p}_z}{Re} + \frac{\mathcal{H} \bar{w} \bar{p}}{\bar{T} \bar{\zeta}} - \frac{\bar{T}_z \bar{\mu}_{\bar{T}}}{Re} \right) - \frac{\underline{\underline{\mathcal{D}}}_{zz} \bar{\mu}}{Re} - \frac{\underline{\underline{\mathcal{D}}}_{rr} \bar{\mu}}{Re},
\end{aligned}$$

$$\mathbf{A}_{3 \times 3} = -\frac{i m \bar{\mu}_{\bar{p}} \bar{p}_z}{Re r} - \frac{i \bar{T}_z m \bar{\mu}_{\bar{T}}}{Re r} + \frac{\mathcal{H} \bar{v}_z \bar{p}}{\bar{T} \bar{\zeta}} + \mathcal{D}_z \left( -\frac{i m \bar{\mu}}{Re r} - \frac{i m \bar{\lambda}}{Re r} \right),$$

$$\begin{aligned}
\mathbf{A}_{3 \times 4} = & \frac{\bar{v} \bar{\mu}_{\bar{T} \bar{p}} \bar{p}_r}{Re r} - \frac{\bar{G} \mathcal{H} \bar{u} \bar{v} \bar{p}}{\bar{T}^2 \bar{\zeta} r} + \frac{\bar{T}_r \bar{v} \bar{\mu}_{\bar{T} \bar{T}}}{Re r} - \frac{\bar{v}_r \bar{\mu}_{\bar{T}}}{Re r} - \frac{i \bar{w}_z m \bar{\lambda}_{\bar{T}}}{Re r} - \frac{i \bar{u}_r m \bar{\lambda}_{\bar{T}}}{Re r} - \frac{2 i \bar{u} m \bar{\mu}_{\bar{T}}}{Re r^2} \\
& + \frac{\bar{v} \bar{\mu}_{\bar{T}}}{Re r^2} - \frac{i \bar{u} m \bar{\lambda}_{\bar{T}}}{Re r^2} - \frac{\bar{v}_z \bar{\mu}_{\bar{T} \bar{p}} \bar{p}_z}{Re} - \frac{\bar{v}_r \bar{\mu}_{\bar{T} \bar{p}} \bar{p}_r}{Re} - \frac{\bar{G} \mathcal{H} \bar{v}_z \bar{w} \bar{p}}{\bar{T}^2 \bar{\zeta}} - \frac{\bar{G} \mathcal{H} \bar{u} \bar{v}_r \bar{p}}{\bar{T}^2 \bar{\zeta}} \\
& - \frac{\bar{T}_z \bar{v}_z \bar{\mu}_{\bar{T} \bar{T}}}{Re} - \frac{\bar{T}_r \bar{v}_r \bar{\mu}_{\bar{T} \bar{T}}}{Re} - \frac{\bar{v}_{zz} \bar{\mu}_{\bar{T}}}{Re} - \frac{\bar{v}_{r r} \bar{\mu}_{\bar{T}}}{Re} + \mathcal{D}_r \left( \frac{\bar{v} \bar{\mu}_{\bar{T}}}{Re r} - \frac{\bar{v}_r \bar{\mu}_{\bar{T}}}{Re} \right) - \frac{\mathcal{D}_z \bar{v}_z \bar{\mu}_{\bar{T}}}{Re},
\end{aligned}$$

$$\begin{aligned}
\mathbf{A}_{3 \times 5} = & \frac{\bar{v} \bar{\mu}_{\bar{p} \bar{p}} \bar{p}_r}{Re r} - \frac{\bar{v}_r \bar{\mu}_{\bar{p}}}{Re r} + \frac{\bar{T}_r \bar{v} \bar{\mu}_{\bar{T} \bar{p}}}{Re r} - \frac{i \bar{w}_z m \bar{\lambda}_{\bar{p}}}{Re r} - \frac{i \bar{u}_r m \bar{\lambda}_{\bar{p}}}{Re r} + \frac{i m}{r} + \frac{\bar{F} \mathcal{H} \bar{u} \bar{v}}{\bar{T} \bar{\zeta} r} - \frac{2 i \bar{u} m \bar{\mu}_{\bar{p}}}{Re r^2} \\
& + \frac{\bar{v} \bar{\mu}_{\bar{p}}}{Re r^2} - \frac{i \bar{u} m \bar{\lambda}_{\bar{p}}}{Re r^2} - \frac{\bar{v}_z \bar{\mu}_{\bar{p} \bar{p}} \bar{p}_z}{Re} - \frac{\bar{v}_r \bar{\mu}_{\bar{p} \bar{p}} \bar{p}_r}{Re} - \frac{\bar{v}_{zz} \bar{\mu}_{\bar{p}}}{Re} - \frac{\bar{v}_{r r} \bar{\mu}_{\bar{p}}}{Re} - \frac{\bar{T}_z \bar{v}_z \bar{\mu}_{\bar{T} \bar{p}}}{Re} \\
& - \frac{\bar{T}_r \bar{v}_r \bar{\mu}_{\bar{T} \bar{p}}}{Re} + \frac{\bar{F} \mathcal{H} \bar{v}_z \bar{w}}{\bar{T} \bar{\zeta}} + \frac{\bar{F} \mathcal{H} \bar{u} \bar{v}_r}{\bar{T} \bar{\zeta}} + \mathcal{D}_r \left( \frac{\bar{v} \bar{\mu}_{\bar{p}}}{Re r} - \frac{\bar{v}_r \bar{\mu}_{\bar{p}}}{Re} \right) - \frac{\mathcal{D}_z \bar{v}_z \bar{\mu}_{\bar{p}}}{Re},
\end{aligned}$$

$$\begin{aligned}
\mathbf{A}_{4 \times 1} = & -\frac{\bar{\lambda}_{\bar{p}} \bar{p}_z}{Re r} - \frac{\bar{T}_z \bar{\lambda}_{\bar{T}}}{Re r} + \frac{\mathcal{H} \bar{w}_r \bar{p}}{\bar{T} \bar{\zeta}} + \mathcal{D}_z \left( -\frac{\bar{\mu}}{Re r} - \frac{\bar{\lambda}}{Re r} - \frac{\bar{\mu}_{\bar{p}} \bar{p}_r}{Re} - \frac{\bar{T}_r \bar{\mu}_{\bar{T}}}{Re} \right) \\
& + \mathcal{D}_r \left( -\frac{\bar{\lambda}_{\bar{p}} \bar{p}_z}{Re} - \frac{\bar{T}_z \bar{\lambda}_{\bar{T}}}{Re} \right) + \underline{\underline{\mathcal{D}}}_{rz} \left( -\frac{\bar{\mu}}{Re} - \frac{\bar{\lambda}}{Re} \right),
\end{aligned}$$

$$\mathbf{A}_{4 \times 2} = -\frac{i m \bar{\lambda}_{\bar{p}} \bar{p}_z}{\text{Re } r} - \frac{i \bar{T}_z m \bar{\lambda}_{\bar{T}}}{\text{Re } r} + \mathcal{D}_z \left( -\frac{i m \bar{\mu}}{\text{Re } r} - \frac{i m \bar{\lambda}}{\text{Re } r} \right),$$

$$\begin{aligned} \mathbf{A}_{4 \times 3} &= \frac{i \mathcal{H} \bar{v} m \bar{p}}{\bar{T} \bar{\zeta} r} + \frac{m^2 \bar{\mu}}{\text{Re } r^2} + \frac{\mathcal{H} \bar{w}_z \bar{p}}{\bar{T} \bar{\zeta}} + \mathcal{D}_r \left( -\frac{\bar{\mu}}{\text{Re } r} - \frac{\bar{\mu}_{\bar{p}} \bar{p}_r}{\text{Re}} + \frac{\mathcal{H} \bar{u} \bar{p}}{\bar{T} \bar{\zeta}} - \frac{\bar{T}_r \bar{\mu}_{\bar{T}}}{\text{Re}} \right) \\ &+ \mathcal{D}_z \left( -\frac{2 \bar{\mu}_{\bar{p}} \bar{p}_z}{\text{Re}} - \frac{\bar{\lambda}_{\bar{p}} \bar{p}_z}{\text{Re}} + \frac{\mathcal{H} \bar{w} \bar{p}}{\bar{T} \bar{\zeta}} - \frac{2 \bar{T}_z \bar{\mu}_{\bar{T}}}{\text{Re}} - \frac{\bar{T}_z \bar{\lambda}_{\bar{T}}}{\text{Re}} \right) + \underline{\underline{\mathcal{D}_{zz}}} \left( -\frac{2 \bar{\mu}}{\text{Re}} - \frac{\bar{\lambda}}{\text{Re}} \right) - \frac{\underline{\underline{\mathcal{D}_{rr}}} \bar{\mu}}{\text{Re}}, \end{aligned}$$

$$\begin{aligned} \mathbf{A}_{4 \times 4} &= -\frac{\bar{u} \bar{\lambda}_{\bar{T} \bar{p}} \bar{p}_z}{\text{Re } r} - \frac{i \bar{v}_z m \bar{\mu}_{\bar{T}}}{\text{Re } r} - \frac{\bar{w}_r \bar{\mu}_{\bar{T}}}{\text{Re } r} - \frac{\bar{u}_z \bar{\mu}_{\bar{T}}}{\text{Re } r} - \frac{\bar{T}_z \bar{u} \bar{\lambda}_{\bar{T} \bar{T}}}{\text{Re } r} - \frac{\bar{u}_z \bar{\lambda}_{\bar{T}}}{\text{Re } r} - \frac{2 \bar{w}_z \bar{\mu}_{\bar{T} \bar{p}} \bar{p}_z}{\text{Re}} - \frac{\bar{w}_z \bar{\lambda}_{\bar{T} \bar{p}} \bar{p}_z}{\text{Re}} \\ &- \frac{\bar{u}_r \bar{\lambda}_{\bar{T} \bar{p}} \bar{p}_z}{\text{Re}} - \frac{\bar{w}_r \bar{\mu}_{\bar{T} \bar{p}} \bar{p}_r}{\text{Re}} - \frac{\bar{u}_z \bar{\mu}_{\bar{T} \bar{p}} \bar{p}_r}{\text{Re}} - \frac{\bar{G} \mathcal{H} \bar{w} \bar{w}_z \bar{p}}{\bar{T}^2 \bar{\zeta}} - \frac{\bar{G} \mathcal{H} \bar{u} \bar{w}_r \bar{p}}{\bar{T}^2 \bar{\zeta}} - \frac{2 \bar{T}_z \bar{w}_z \bar{\mu}_{\bar{T} \bar{T}}}{\text{Re}} - \frac{\bar{T}_r \bar{w}_r \bar{\mu}_{\bar{T} \bar{T}}}{\text{Re}} \\ &- \frac{\bar{T}_r \bar{u}_z \bar{\mu}_{\bar{T} \bar{T}}}{\text{Re}} - \frac{2 \bar{w}_{zz} \bar{\mu}_{\bar{T}}}{\text{Re}} - \frac{\bar{w}_{rr} \bar{\mu}_{\bar{T}}}{\text{Re}} - \frac{\bar{u}_{rz} \bar{\mu}_{\bar{T}}}{\text{Re}} - \frac{\bar{T}_z \bar{w}_z \bar{\lambda}_{\bar{T} \bar{T}}}{\text{Re}} - \frac{\bar{T}_z \bar{u}_r \bar{\lambda}_{\bar{T} \bar{T}}}{\text{Re}} - \frac{\bar{w}_{zz} \bar{\lambda}_{\bar{T}}}{\text{Re}} \\ &- \frac{\bar{u}_{rz} \bar{\lambda}_{\bar{T}}}{\text{Re}} + \mathcal{D}_z \left( -\frac{\bar{u} \bar{\lambda}_{\bar{T}}}{\text{Re } r} - \frac{2 \bar{w}_z \bar{\mu}_{\bar{T}}}{\text{Re}} - \frac{\bar{w}_z \bar{\lambda}_{\bar{T}}}{\text{Re}} - \frac{\bar{u}_r \bar{\lambda}_{\bar{T}}}{\text{Re}} \right) + \mathcal{D}_r \left( -\frac{\bar{w}_r \bar{\mu}_{\bar{T}}}{\text{Re}} - \frac{\bar{u}_z \bar{\mu}_{\bar{T}}}{\text{Re}} \right), \end{aligned}$$

$$\begin{aligned} \mathbf{A}_{4 \times 5} &= -\frac{\bar{u} \bar{\lambda}_{\bar{p} \bar{p}} \bar{p}_z}{\text{Re } r} - \frac{i \bar{v}_z m \bar{\mu}_{\bar{p}}}{\text{Re } r} - \frac{\bar{w}_r \bar{\mu}_{\bar{p}}}{\text{Re } r} - \frac{\bar{u}_z \bar{\mu}_{\bar{p}}}{\text{Re } r} - \frac{\bar{u}_z \bar{\lambda}_{\bar{p}}}{\text{Re } r} - \frac{\bar{T}_z \bar{u} \bar{\lambda}_{\bar{T} \bar{p}}}{\text{Re } r} - \frac{2 \bar{w}_z \bar{\mu}_{\bar{p} \bar{p}} \bar{p}_z}{\text{Re}} - \frac{\bar{w}_z \bar{\lambda}_{\bar{p} \bar{p}} \bar{p}_z}{\text{Re}} \\ &- \frac{\bar{u}_r \bar{\lambda}_{\bar{p} \bar{p}} \bar{p}_z}{\text{Re}} - \frac{\bar{w}_r \bar{\mu}_{\bar{p} \bar{p}} \bar{p}_r}{\text{Re}} - \frac{\bar{u}_z \bar{\mu}_{\bar{p} \bar{p}} \bar{p}_r}{\text{Re}} - \frac{2 \bar{w}_{zz} \bar{\mu}_{\bar{p}}}{\text{Re}} - \frac{\bar{w}_{rr} \bar{\mu}_{\bar{p}}}{\text{Re}} - \frac{\bar{u}_{rz} \bar{\mu}_{\bar{p}}}{\text{Re}} - \frac{2 \bar{T}_z \bar{w}_z \bar{\mu}_{\bar{T} \bar{p}}}{\text{Re}} \\ &- \frac{\bar{T}_r \bar{w}_r \bar{\mu}_{\bar{T} \bar{p}}}{\text{Re}} - \frac{\bar{T}_r \bar{u}_z \bar{\mu}_{\bar{T} \bar{p}}}{\text{Re}} - \frac{\bar{w}_{zz} \bar{\lambda}_{\bar{p}}}{\text{Re}} - \frac{\bar{u}_{rz} \bar{\lambda}_{\bar{p}}}{\text{Re}} - \frac{\bar{T}_z \bar{w}_z \bar{\lambda}_{\bar{T} \bar{p}}}{\text{Re}} - \frac{\bar{T}_z \bar{u}_r \bar{\lambda}_{\bar{T} \bar{p}}}{\text{Re}} + \frac{\bar{F} \mathcal{H} \bar{w} \bar{w}_z}{\bar{T} \bar{\zeta}} \\ &+ \frac{\bar{F} \mathcal{H} \bar{u} \bar{w}_r}{\bar{T} \bar{\zeta}} + \mathcal{D}_z \left( -\frac{\bar{u} \bar{\lambda}_{\bar{p}}}{\text{Re } r} - \frac{2 \bar{w}_z \bar{\mu}_{\bar{p}}}{\text{Re}} - \frac{\bar{w}_z \bar{\lambda}_{\bar{p}}}{\text{Re}} - \frac{\bar{u}_r \bar{\lambda}_{\bar{p}}}{\text{Re}} + 1 \right) + \mathcal{D}_r \left( -\frac{\bar{w}_r \bar{\mu}_{\bar{p}}}{\text{Re}} - \frac{\bar{u}_z \bar{\mu}_{\bar{p}}}{\text{Re}} \right), \end{aligned}$$

$$\begin{aligned} \mathbf{A}_{5 \times 1} &= -\frac{2 i E c \bar{v}_r m \bar{\mu}}{\text{Re } r} - \frac{2 E c \bar{w}_z \bar{\lambda}}{\text{Re } r} - \frac{2 E c \bar{u}_r \bar{\lambda}}{\text{Re } r} + \frac{2 i E c \bar{v} m \bar{\mu}}{\text{Re } r^2} \\ &- \frac{4 E c \bar{u} \bar{\mu}}{\text{Re } r^2} - \frac{2 E c \bar{u} \bar{\lambda}}{\text{Re } r^2} + \frac{\mathcal{H} \bar{h}_{\bar{p}} \bar{p} \bar{p}_r}{\bar{T} \bar{\zeta}} - E c \bar{p}_r + \frac{\mathcal{H} \bar{T}_r \bar{h}_{\bar{T}} \bar{p}}{\bar{T} \bar{\zeta}} \\ &+ \mathcal{D}_r \left( -\frac{2 E c \bar{u} \bar{\lambda}}{\text{Re } r} - \frac{4 E c \bar{u}_r \bar{\mu}}{\text{Re}} - \frac{2 E c \bar{w}_z \bar{\lambda}}{\text{Re}} - \frac{2 E c \bar{u}_r \bar{\lambda}}{\text{Re}} \right) + \mathcal{D}_z \left( -\frac{2 E c \bar{w}_r \bar{\mu}}{\text{Re}} - \frac{2 E c \bar{u}_z \bar{\mu}}{\text{Re}} \right), \end{aligned}$$

$$\begin{aligned} \mathbf{A}_{5 \times 2} &= \frac{2 E c \bar{v}_r \bar{\mu}}{\text{Re } r} - \frac{2 i E c \bar{w}_z m \bar{\lambda}}{\text{Re } r} - \frac{2 i E c \bar{u}_r m \bar{\lambda}}{\text{Re } r} - \frac{4 i E c \bar{u} m \bar{\mu}}{\text{Re } r^2} - \frac{2 E c \bar{v} \bar{\mu}}{\text{Re } r^2} \\ &- \frac{2 i E c \bar{u} m \bar{\lambda}}{\text{Re } r^2} + \mathcal{D}_r \left( \frac{2 E c \bar{v} \bar{\mu}}{\text{Re } r} - \frac{2 E c \bar{v}_r \bar{\mu}}{\text{Re}} \right) - \frac{2 \mathcal{D}_z E c \bar{v}_z \bar{\mu}}{\text{Re}}, \end{aligned}$$

$$\mathbf{A}_{5 \times 3} = -\frac{2i Ec \bar{v}_z m \bar{\mu}}{Re r} + \frac{\mathcal{H} \bar{h}_{\bar{p}} \bar{p} \bar{p}_z}{\bar{T} \bar{\zeta}} - Ec \bar{p}_z + \frac{\mathcal{H} \bar{T}_z \bar{h}_{\bar{T}} \bar{p}}{\bar{T} \bar{\zeta}} \\ + \mathcal{D}_z \left( -\frac{2 Ec \bar{u} \bar{\lambda}}{Re r} - \frac{4 Ec \bar{w}_z \bar{\mu}}{Re} - \frac{2 Ec \bar{w}_z \bar{\lambda}}{Re} - \frac{2 Ec \bar{u}_r \bar{\lambda}}{Re} \right) + \mathcal{D}_r \left( -\frac{2 Ec \bar{w}_r \bar{\mu}}{Re} - \frac{2 Ec \bar{u}_z \bar{\mu}}{Re} \right),$$

$$\mathbf{A}_{5 \times 4} = \mathcal{D}_z \left( -\frac{\bar{p}_z \bar{\kappa}_{\bar{p}}}{Pr Re} - \frac{2 \bar{T}_z \bar{\kappa}_{\bar{T}}}{Pr Re} + \frac{\mathcal{H} \bar{w} \bar{h}_{\bar{T}} \bar{p}}{\bar{T} \bar{\zeta}} \right) + \mathcal{D}_r \left( -\frac{\bar{p}_r \bar{\kappa}_{\bar{p}}}{Pr Re} - \frac{2 \bar{T}_r \bar{\kappa}_{\bar{T}}}{Pr Re} - \frac{\bar{\kappa}}{Pr Re r} + \frac{\mathcal{H} \bar{u} \bar{h}_{\bar{T}} \bar{p}}{\bar{T} \bar{\zeta}} \right) \\ - \frac{(\bar{T}_z)^2 \bar{\kappa}_{\bar{T}\bar{T}}}{Pr Re} - \frac{(\bar{T}_r)^2 \bar{\kappa}_{\bar{T}\bar{T}}}{Pr Re} - \frac{\bar{T}_z \bar{p}_z \bar{\kappa}_{\bar{T}\bar{p}}}{Pr Re} - \frac{\bar{T}_r \bar{p}_r \bar{\kappa}_{\bar{T}\bar{p}}}{Pr Re} - \frac{\bar{T}_r \bar{\kappa}_{\bar{T}}}{Pr Re r} - \frac{\bar{T}_{zz} \bar{\kappa}_{\bar{T}}}{Pr Re} - \frac{\bar{T}_{rr} \bar{\kappa}_{\bar{T}}}{Pr Re} \\ + \frac{m^2 \bar{\kappa}}{Pr Re r^2} + \frac{i \mathcal{H} \bar{v} m \bar{h}_{\bar{T}} \bar{p}}{\bar{T} \bar{\zeta} r} + \frac{2 Ec \bar{v} \bar{v}_r \bar{\mu}_{\bar{T}}}{Re r} - \frac{2 Ec \bar{u} \bar{w}_z \bar{\lambda}_{\bar{T}}}{Re r} - \frac{2 Ec \bar{u} \bar{u}_r \bar{\lambda}_{\bar{T}}}{Re r} - \frac{Ec \bar{v}^2 \bar{\mu}_{\bar{T}}}{Re r^2} \\ - \frac{2 Ec \bar{u}^2 \bar{\mu}_{\bar{T}}}{Re r^2} - \frac{Ec \bar{u}^2 \bar{\lambda}_{\bar{T}}}{Re r^2} - \frac{\bar{G} \mathcal{H} \bar{w} \bar{h}_{\bar{p}} \bar{p} \bar{p}_z}{\bar{T}^2 \bar{\zeta}} + \frac{\mathcal{H} \bar{w} \bar{h}_{\bar{T}\bar{p}} \bar{p} \bar{p}_z}{\bar{T} \bar{\zeta}} - \frac{\bar{G} \mathcal{H} \bar{u} \bar{h}_{\bar{p}} \bar{p} \bar{p}_r}{\bar{T}^2 \bar{\zeta}} + \frac{\mathcal{H} \bar{u} \bar{h}_{\bar{T}\bar{p}} \bar{p} \bar{p}_r}{\bar{T} \bar{\zeta}} \\ + \frac{\mathcal{H} \bar{T}_z \bar{w} \bar{h}_{\bar{T}\bar{T}} \bar{p}}{\bar{T} \bar{\zeta}} + \frac{\mathcal{H} \bar{T}_r \bar{u} \bar{h}_{\bar{T}\bar{T}} \bar{p}}{\bar{T} \bar{\zeta}} - \frac{\bar{G} \mathcal{H} \bar{T}_z \bar{w} \bar{h}_{\bar{T}} \bar{p}}{\bar{T}^2 \bar{\zeta}} - \frac{\bar{G} \mathcal{H} \bar{T}_r \bar{u} \bar{h}_{\bar{T}} \bar{p}}{\bar{T}^2 \bar{\zeta}} - \frac{2 Ec (\bar{w}_z)^2 \bar{\mu}_{\bar{T}}}{Re} \\ - \frac{Ec (\bar{w}_r)^2 \bar{\mu}_{\bar{T}}}{Re} - \frac{2 Ec \bar{u}_z \bar{w}_r \bar{\mu}_{\bar{T}}}{Re} - \frac{Ec (\bar{v}_z)^2 \bar{\mu}_{\bar{T}}}{Re} - \frac{Ec (\bar{v}_r)^2 \bar{\mu}_{\bar{T}}}{Re} - \frac{Ec (\bar{u}_z)^2 \bar{\mu}_{\bar{T}}}{Re} \\ - \frac{2 Ec (\bar{u}_r)^2 \bar{\mu}_{\bar{T}}}{Re} - \frac{Ec (\bar{w}_z)^2 \bar{\lambda}_{\bar{T}}}{Re} - \frac{2 Ec \bar{u}_r \bar{w}_z \bar{\lambda}_{\bar{T}}}{Re} - \frac{Ec (\bar{u}_r)^2 \bar{\lambda}_{\bar{T}}}{Re} - \frac{\underline{\underline{\mathcal{D}_{zz} \bar{\kappa}}}}{Pr Re} - \frac{\underline{\underline{\mathcal{D}_{rr} \bar{\kappa}}}}{Pr Re},$$

$$\mathbf{A}_{5 \times 5} = -\frac{\bar{T}_z \bar{p}_z \bar{\kappa}_{\bar{p}\bar{p}}}{Pr Re} - \frac{\bar{T}_r \bar{p}_r \bar{\kappa}_{\bar{p}\bar{p}}}{Pr Re} - \frac{\bar{T}_r \bar{\kappa}_{\bar{p}}}{Pr Re r} - \frac{\bar{T}_{zz} \bar{\kappa}_{\bar{p}}}{Pr Re} - \frac{\bar{T}_{rr} \bar{\kappa}_{\bar{p}}}{Pr Re} - \frac{(\bar{T}_z)^2 \bar{\kappa}_{\bar{T}\bar{p}}}{Pr Re} - \frac{(\bar{T}_r)^2 \bar{\kappa}_{\bar{T}\bar{p}}}{Pr Re} \\ + \frac{i \mathcal{H} \bar{v} m \bar{h}_{\bar{p}} \bar{p}}{\bar{T} \bar{\zeta} r} + \frac{2 Ec \bar{v} \bar{v}_r \bar{\mu}_{\bar{p}}}{Re r} - \frac{2 Ec \bar{u} \bar{w}_z \bar{\lambda}_{\bar{p}}}{Re r} - \frac{2 Ec \bar{u} \bar{u}_r \bar{\lambda}_{\bar{p}}}{Re r} - \frac{i Ec \bar{v} m}{r} - \frac{Ec \bar{v}^2 \bar{\mu}_{\bar{p}}}{Re r^2} - \frac{2 Ec \bar{u}^2 \bar{\mu}_{\bar{p}}}{Re r^2} \\ - \frac{Ec \bar{u}^2 \bar{\lambda}_{\bar{p}}}{Re r^2} + \frac{\mathcal{H} \bar{w} \bar{h}_{\bar{p}\bar{p}} \bar{p} \bar{p}_z}{\bar{T} \bar{\zeta}} + \frac{\bar{F} \mathcal{H} \bar{w} \bar{h}_{\bar{p}} \bar{p}_z}{\bar{T} \bar{\zeta}} + \frac{\mathcal{H} \bar{u} \bar{h}_{\bar{p}\bar{p}} \bar{p} \bar{p}_r}{\bar{T} \bar{\zeta}} + \frac{\bar{F} \mathcal{H} \bar{u} \bar{h}_{\bar{p}} \bar{p}_r}{\bar{T} \bar{\zeta}} + \frac{\mathcal{H} \bar{T}_z \bar{w} \bar{h}_{\bar{T}\bar{p}} \bar{p}}{\bar{T} \bar{\zeta}} \\ + \frac{\mathcal{H} \bar{T}_r \bar{u} \bar{h}_{\bar{T}\bar{p}} \bar{p}}{\bar{T} \bar{\zeta}} - \frac{2 Ec (\bar{w}_z)^2 \bar{\mu}_{\bar{p}}}{Re} - \frac{Ec (\bar{w}_r)^2 \bar{\mu}_{\bar{p}}}{Re} - \frac{2 Ec \bar{u}_z \bar{w}_r \bar{\mu}_{\bar{p}}}{Re} - \frac{Ec (\bar{v}_z)^2 \bar{\mu}_{\bar{p}}}{Re} - \frac{Ec (\bar{v}_r)^2 \bar{\mu}_{\bar{p}}}{Re} \\ - \frac{Ec (\bar{u}_z)^2 \bar{\mu}_{\bar{p}}}{Re} - \frac{2 Ec (\bar{u}_r)^2 \bar{\mu}_{\bar{p}}}{Re} - \frac{Ec (\bar{w}_z)^2 \bar{\lambda}_{\bar{p}}}{Re} - \frac{2 Ec \bar{u}_r \bar{w}_z \bar{\lambda}_{\bar{p}}}{Re} - \frac{Ec (\bar{u}_r)^2 \bar{\lambda}_{\bar{p}}}{Re} + \frac{\bar{F} \mathcal{H} \bar{T}_z \bar{w} \bar{h}_{\bar{T}}}{\bar{T} \bar{\zeta}} \\ + \frac{\bar{F} \mathcal{H} \bar{T}_r \bar{u} \bar{h}_{\bar{T}}}{\bar{T} \bar{\zeta}} + \mathcal{D}_z \left( -\frac{\bar{T}_z \bar{\kappa}_{\bar{p}}}{Pr Re} + \frac{\mathcal{H} \bar{w} \bar{h}_{\bar{p}} \bar{p}}{\bar{T} \bar{\zeta}} - Ec \bar{w} \right) + \mathcal{D}_r \left( -\frac{\bar{T}_r \bar{\kappa}_{\bar{p}}}{Pr Re} + \frac{\mathcal{H} \bar{u} \bar{h}_{\bar{p}} \bar{p}}{\bar{T} \bar{\zeta}} - Ec \bar{u} \right),$$