Fluid Modelling of the Far-SOL Region
(Status and preliminary results)

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• **Goal:** To extend fluid modelling up to the physical outer wall (interesting for, e.g., ICRH)

Couple ASPOEL code (development @ PoliTo based on Control Volume/Finite Elements) for far-SOL, with B2, for near-SOL

• **Test case here:** ASDEX Upgrade
  – Take inner boundary conditions from a B2 well converged case (frozen, i.e. not yet self-consistent)
  – First simulation is running but not completed ➔ Preliminary results to be presented
ASPOEL Model

Simplified two-fluid model (under development)

\[
\frac{\partial n}{\partial t} + \nabla \cdot (n \overline{V}) = S_n
\]

\[
n_e = n_i = n
\]

\[
\frac{\partial \Gamma_{ii,i}}{\partial t} + \overline{e}_{ii} \cdot \left[ \nabla \cdot \left( \overline{V_i \Gamma_i} + p_i \hat{I} + \hat{\Pi}_i \right) \right] = S_{\Gamma_{ii}}
\]

\[
n_i V_{r,i} = -D_r \nabla r n_i
\]

\[
\frac{\partial}{\partial t} \left( \frac{3}{2} n_e T_e \right) + \nabla \cdot \left( \frac{5}{2} n_e T_e \overline{V_e} + \overline{q_e} \right) = -Q_{ei} + S_{E_e}
\]

\[
\frac{\partial}{\partial t} \left( \frac{3}{2} n_i T_i \right) + \nabla \cdot \left( \frac{5}{2} n_i T_i \overline{V_i} + \overline{q_i} \right) = Q_{ei} + S_{E_i}
\]

\[
\overline{V_e} = \overline{V_i}
\]
B2-ASPOEL Meshes

AUG shot # 18737 @ t = 4.7s
(selected by EFDA / ITER)

B2 mesh: 3724 cells
ASPOEL mesh: 6026 elements
Input Fluxes from B2

\[ \Gamma_n \text{ (1/s)} \]
\[ \Gamma_V \text{ (kg m/s)} \]
\[ \Gamma_{Ee} \text{ (W)} \]
\[ \Gamma_{Ei} \text{ (W)} \]
Density min/max evolution

Tend to stabilize for sufficiently many iterations
Ti min/max evolution

T\text{\textsubscript{i max}} still increasing! 

Maybe a problem from severe boundary condition at B2 interface + effect of relaxation parameter alphaT
$T_i$ Inner Boundary Evolution

![Graph showing evolution of $T_i$ with poloidal distance](image)

- $\alpha_T = 0.4$
- $\alpha_T = 0.2$
- $\alpha_T = 0.1$
Density Inner Boundary Evolution

Slowly stabilizing
Global Conservation Check

- **Particles:**
  - Input/Output $\sim 0.998 \rightarrow$ OK

- **Energy (ions + electrons, because of equipartition):**
  - Input/Output $\sim 6.38$
    - Still far from convergence
A minimum density develops in the most isolated domain region.
B2 Ion Heat Flux (I)

- B2 radial heat flux does not fit into the form

\[
\frac{\Gamma_{E,i}}{S} = \frac{5}{2} \Gamma_n T_i - n\chi_{i,r} \frac{\partial T_i}{\partial r}
\]

For example:

\[
\Gamma_n = nV_r \approx 4.3 \times 10^{17} \text{ (1/m}^2\text{/s)} \quad \lambda_{T_i,r} = T_i / (\partial T_i / \partial r) = 0.5 \text{ (m)}
\]

\[
T_i \approx 3.2 \text{ (eV)} \quad n \approx 6.4 \times 10^{16} \text{ (m}^{-3}) \quad \chi \approx 0.5 \text{ (m}^2\text{/s)}
\]

\[
\frac{\Gamma_{E,i}}{S} \approx 0.58 \text{ (W/m}^2\text{)}
\]

B2 corresponding value: 26 (kW/m}^2\text{) !!!
B2 Ion Heat Flux (II)

- Where does this difference come from?
  - The heat ion heat flux terms from ASPOEL and B2 might in principle be different

\[
q_{iy} = \frac{3}{2} n T_i \frac{B_z}{B^2} \frac{1}{h_x} \frac{\partial \phi}{\partial x} + \frac{5}{2} n T_i \left( - \frac{D}{T_e + T_i} \frac{1}{h_y} \left( \frac{\partial p}{\partial y} - \frac{3}{2} \frac{\partial T_e}{\partial y} \right) - D_{AN} \frac{1}{h_y n} \frac{\partial n}{\partial y} - D_{AN}^{\prime} \frac{1}{h_y n} \frac{\partial p_i}{\partial y} \right)
\]

\[-n \chi_{iy} \frac{1}{h_y} \frac{\partial T_i}{\partial y} + \frac{5}{2} n T_i \tilde{V}_y^{(dia)}
\]

Not strictly equal to

\[
\frac{5}{2} \Gamma_n T_i - n \chi_{i,r} \frac{\partial T_i}{\partial r}
\]

May the difference be so large? To be investigated
Conclusions

• An ASDEX Upgrade case is being investigated. Preliminary results of not yet fully converged run were shown.
• Run is very slow, possibly influenced by large number of nodes in far SOL region, not optimized relaxation parameters, ...
• Continuity, parallel momentum momentum results show some reasonable features.
• Ion/electrons show the most critical behaviour.

Open issues:
– Effect of very strong ion energy input fluxes from B2
– Strong influence of relaxation parameter
Additional Slides
Residuals and Corrections

A: $\alpha_p 0.1 \rightarrow 0.8$, $\alpha_v 0.3 \rightarrow 0.1$

B: $\alpha_T 0.1 \rightarrow \ldots \rightarrow 0.4$

C: Change radial visc.
Definitions

\[ \overline{R}_M^0 \quad \text{Mass residual} \Rightarrow \quad R_M^k = \left\| \overline{R}_M^k \right\|_2 / \left\| \overline{R}_M^0 \right\|_2 \]

\[ \delta p^k = p' - p^{k-1} \quad \text{P correction} \Rightarrow \quad \delta p^k = \left\| \delta p^k \right\|_2 / \left\| \delta p^0 \right\|_2 \]

\[ \overline{p}^k = \overline{p}^{k-1} + \alpha_p (\delta p^k) \]

\[ \delta \overline{V}^k = \overline{V}^k - \overline{V}^{k-1} \quad \text{V correction} \Rightarrow \quad \delta \overline{V}^k = \left\| \delta \overline{V}^k \right\|_2 / \left\| \delta \overline{V}^0 \right\|_2 \]

\[ \delta \overline{T}^k = \overline{T}^k - \overline{T}^{k-1} \quad \text{T correction} \Rightarrow \quad \delta \overline{T}^k = \left\| \delta \overline{T}^k \right\|_2 / \left\| \delta \overline{T}^0 \right\|_2 \]

Generic relaxation:

\[ A \overline{\phi}^k = \overline{Q} \]

\[ \left[ \frac{D_A}{\alpha} + (A - D_A) \right] \overline{\phi}^k = \overline{Q} + \frac{1 - \alpha}{\alpha} D_A \overline{\phi}^{k-1}; \quad D_A = \text{diag}(A) \]

\[ \phi = T, V \]
$T_e$ Inner Boundary Evolution

Slowly but steadily evolving
Pressure Inner Boundary Evolution

Still evolving
Ne/Vpar maps

Peaking near the top
Possibly the effect of stagnation point
Te map

Te drops strongly in the upper-left corner
Possibly developing a double SOL structure