Shock Tube Benchmark Simulations and Importing VMEC Equilibria

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Thanks to Scott Kruger and Jake King at Tech-X for their valuable assistance.
Outline

1. Fluid and MHD Shock Tube Benchmarks
2. Importing Equilibria from VMEC
   i. Objective
   ii. Overview
3. Summary
Simulations of one-dimensional shock tube benchmark cases

- Sod (non-conducting fluid) shock tube\(^1\)
- Brio-Wu MHD shock tube\(^2\)

\(\text{lamprof} = \text{“briowu”} \text{ is implemented in my branch, in rect\_init.f}\)

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Sod Shock Tube Initial Conditions

Fluid dynamics problem commonly used in validation of CFD codes
Sod Shock Tube Parameters

Units:

\[ \mu_0 = k_B = m_i = 1 \]

Physical and numerical parameters:

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>t_dart_upw</td>
<td>0.01</td>
</tr>
<tr>
<td>nd_dart_upw</td>
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</tr>
<tr>
<td>iso_visc</td>
<td>0.1</td>
</tr>
<tr>
<td>elecd</td>
<td>$10^5$</td>
</tr>
<tr>
<td>be0</td>
<td>$10^{-15}$</td>
</tr>
<tr>
<td>( \gamma )</td>
<td>1.4</td>
</tr>
<tr>
<td>( \Delta x )</td>
<td>1</td>
</tr>
<tr>
<td>poly_degree</td>
<td>3</td>
</tr>
<tr>
<td>( cfl_{max} )</td>
<td>0.9</td>
</tr>
<tr>
<td>lphi</td>
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</tbody>
</table>
Sod: Density and Pressure

Exact solution obtained from NPARC Alliance Validation Archive, http://www.grc.nasa.gov/WWW/wind/valid/stube/stube.html
Sod: $v_x$
Brio-Wu MHD Shock Tube

Parameters for MHD shock tube that are different:

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\gamma$</td>
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<tr>
<td>nd_dart_upw</td>
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</tr>
<tr>
<td>t_dart_upw</td>
<td>10</td>
</tr>
<tr>
<td>elecd</td>
<td>0</td>
</tr>
<tr>
<td>be0</td>
<td>1</td>
</tr>
</tbody>
</table>
Brio-Wu Shock Tube Initial Conditions

Density, $t = 0$

Pressure, $t = 0$

$B_x$, $t = 0$

$B_y$, $t = 0$
Leading edges of features (except ‘SM’) are consistent with characteristic speeds.

Image taken directly from M. Brio and C.C. Wu (1988)
Brio-Wu: Pressure

Pressure, t = 80

Image taken directly from M. Brio and C.C. Wu (1988)
Brio-Wu: $v_x$

$V_x, t = 80$

Image taken directly from M. Brio and C.C. Wu (1988)
Brio-Wu: $v_y$

Image taken directly from M. Brio and C.C. Wu (1988)
Brio-Wu: $B_y$

Image taken directly from M. Brio and C.C. Wu (1988)
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What is CTH?

• CTH is a stellarator-tokamak hybrid
  ▪ Has both a helical coil and an ohmic heating transformer
Objective of Simulations

To gain insight into CTH low-q disruptions by whole device simulations in NIMROD.

Will be loading the equilibrium informed by reconstructions sometime in the middle of the shot before a disruption would occur.
Disruptions in CTH

- Three types of disruptions observed in CTH:
  - Density Limit
  - VDE
  - Low-q

- Low-q disruptions don’t occur when relative strength of stellarator field is increased
  - Can run with $q_a$ down to 1.25
  - Growing $(m, n) = (3,2)$ activity observed in external magnetics before disruption
  - Why does stellarator field prevent disruption?
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What is VMEC?

• VMEC is a 3D inverse equilibrium code
  ▪ Grad-Shafranov equilibrium codes cannot be used to study CTH
  ▪ VMEC also used to study tokamaks and other devices that are nearly axisymmetric but not exactly

• inverse code → nested flux surfaces
  ▪ A non-axisymmetric equilibrium with nested flux surfaces may have singularities in the current density
  ▪ Equilibrium ‘relaxation’ has been used in M3D simulations initialized with VMEC data¹

More VMEC Details

- VMEC model: ideal MHD plasma surrounded by a vacuum region

- Does not output fields in the vacuum region
  - Vacuum region fields must be computed to load into NIMROD
nimset VMEC Import Module

- Capability to load VMEC equilibria into NIMROD dump file added
- User must provide
  - VMEC ‘wout’ file
  - makegrid ‘mgrid’ file
- The evolving field arrays are loaded, and the equilibrium field arrays are set to zero
  - Exception: the n=0 coefficient for number density $n$ is loaded into the equilibrium field array to avoid divide by zero error
Flux Surfaces

Flux Surfaces, VMEC data vs. NIMFL data at $\phi = 30^\circ$, $l_{phi} = 7$
Rotational Transform Profile

\( \tau \text{ along } (\theta, \phi) = (0, 0) \)

\[ \begin{align*}
\tau_{nimfl} \\
\tau_{vme} \end{align*} \]

8/13/2014
NIMROD Team Meeting, Logan, UT
Magnetic Axis
Current Density has Artifacts and Spurious Features

- Possible ‘quick fix’:
  - Prescribing $n = 0$ components of $\vec{j}$ and $\vec{B}$ in equilibrium fields?
  - Will noise at edge ‘go away’ during relaxation process?

- Possibly a problem with my vacuum region field calculation
  - Magnetic fields look smooth

\[ n = 0 \text{ coefficient for } j_z. \]
Fluxgrid Capability

• Can interface with fluxgrid to produce a flux aligned grid
  ▪ Useful for equilibria that are nearly axisymmetric
Library Dependencies

• LIBSTELL: A VMEC library

• Functionality provided by LIBSTELL:
  - Optimized rootfinding\(^1\) function for computing VMEC coordinates \((s, u, v)\) given \((R, Z, \phi)\).
  - Accurate extrapolation\(^1\) of \( \vec{B} \) near the magnetic axis.
  - Loads wout and mgrid files, accounting for file version.

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Summary

• Shock tubes
  ▪ Demonstrate that NIMROD has some capacity to handle shocks and rarefactions in 1D if upwind smoothing is used
  ▪ Shock tubes in Fourier direction not explored

• Setting initial conditions in NIMROD for a VMEC equilibria
  ▪ Need to do more experimenting with trying to ‘relax’ equilibrium while maintaining profiles
  ▪ Some short simulations have been run and logged
Questions?


