Dynamics of Post-Reconnection Magnetic Flux Tubes

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Introduction

- Building off of previous work done by Dr. Longcope and others ([2] [3] [4]).
- My project was to evaluate different sets of initial conditions with upward flows.
- One potential application was to see how this matched Type-II spicules [1].
Background: Flux Tubes

- Flux tubes describe when magnetic field lines occur in field-free environments (like the sun’s corona).
- Plasma conforms to these tubes and travels along them as a propagating wave.
- When the waves are much longer than the width of the tube, we get a nice simplification of their dynamics called the ”thin flux tube” model. This allows us to use the equations of MHD to approximate their motion.
Reconnection

- Flux tubes in the upper regions of the sun's atmosphere can become crossed.
- When this occurs, they can reconnect:
  ![Flux Tubes Reconnection Diagram]
  - These then retract at the Alfvén speed.
  - My project was to see what happens next.
Numerical Model

Initial Conditions:

- One pre-reconnection tube is a large, low-density, high-temperature coronal flux tube approximate by a vertical line.
- The other is a low-lying, high-density, lower-temperature tube.
- We ignore gravitational forces and assume a low $\beta$ ($\ll 1$).

This gives the following equation of motion[4] which we solve using a Lagrangian numerical method (PREFT):

$$\rho \frac{d\vec{v}}{dt} = -\hat{b} \frac{\partial p}{\partial l} + \frac{B^2}{4\pi} \frac{\partial \hat{b}}{\partial l} - \frac{1}{4\pi} \nabla \perp B^2 + B \frac{\partial}{\partial l} \left( \frac{\mu}{B} \hat{b} \hat{b} \cdot \frac{\partial \vec{v}}{\partial l} \right)$$
Analytic Solution

Derivation:

- Assume we can divide the tube into five regions:
  - The two endpoints
  - The center
  - A point between each end and the center where there is a shock.
- Ignore thermal conduction.
- Numerical model is computationally intensive. This gives us a closed-form solution.
Example Run
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Results: Parameter Studies

- Interested in what causes the maximum upflow velocities.
- Conducted runs with angles ranging from 10 to 135 degrees and density ratios from 0.1 to 100
- Also evaluated temperature, pressure, and some other parameters.
Velocity

```
max z-velocity
```

```
density ratio
```

```
angle (degrees)
```

```
40 50 60 70 80 90
```

```
100.0
```

```
10.0
```

```
1.0
```

```
0.1
```

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Pressure

![Graph showing max pressure vs angle and density ratio]
Temperature

max temperature

density ratio

angle (degrees)

constant pressure or temperature?
Constant Pressure or Temperature?

- Original code fixed the temperature ratio between the two connecting tubes.
- Modified to hold pressure constant and allow temperature to vary.
- Not much changed.
Images shows $B=100$, 200, and 300.

Alfvén speed changes when $B$ does. Graph compensates for that.

Magnitude of different quantities tend to be proportional to changes in magnetic field.

Stronger fields also cause jagged lines...
Spikes

- Runs were cutting out, returning \(-\text{NaN}\) for all variables after some amount of time.
- Stronger fields caused it to happen sooner.
- Looks like a mathematical error—information outrunning the grid.
- Smoothing out the code didn’t solve it.
Magnetic $\beta$

- $\beta = \frac{p}{B^2/4\pi}$
- Tells us the relative importance of tension versus pressure forces.
- $\beta > 2$ means pressure dominates.
- code assumes $\beta \ll 1$.
- Here’s the issue:
Not a numerics problem, actually a physical issue! The assumptions behind our equations quickly become invalid at extreme angles and densities.
Conclusions

What did we learn?

- We now understand the dependence of this model upon various parameters much better.
- We found some physical limits on when the code is useful.

Does this tell us anything about spicules?

- I have no idea.
- It does give a method of launching heating material into the corona.
- Further work should be done here.
De Pontieu et. al. 2007, PASJ, 59, S655-S662