Key Points

- IV Characteristics of the Biased Electrode
  - Evidence of Two Time Scale Damping in HSX
  - Neoclassical Modeling of Plasma Flows
  - Experimental Verification of Reduced viscous damping with quasi-symmetry
  - Computational Study of different Configurations

1. Structure of the Experiments

   Mach Probes in HSX
   - 6 tip mach probes measure plasma flow speed and 4 are on a magnetic axis
   - 2 probes are used to infer density measurement by measuring the Mach number of the flow, and the density is assumed to be constant.
   - Data is analyzed using the unprimed model by addition.
   -Probe measures \( V \) and \( \mu \) from \( \dot{\beta} \)
   - Probe measure \( V \) with a gridded probe

   Symmetry can be intentionally Broken with Auxiliary Coils

   Model Fits Flow Rise Well

2. I-V Characteristics of Electrode Indicate Transport Limits the Current

   Bias Wavesforms Indicate a “Forced E” and an Impedance
   - Current peaks at the collision frequency
   - Impedance is Smaller in the Mirror Configuration
   - Radial Conductivity Has a 1/n Scaling
   - Positive Part of I-V Curve is Linear
   - Capacitance is Linear in the Density

   Decay Time: \( \tau = \frac{L}{V} \) (for the HSX coils)
   - Current peaks at the collision frequency
   - Current decays exponentially
   - Impedance is smaller in the mirror configuration
   - Radial conductivity scaling is \( \frac{1}{n} \)
   - Linear IV relationship: \( V \) needs density scaling
   - Capacitance is linear in the density
   - \( \frac{dV}{dt} \) tells the \( \frac{dV}{dt} \) due to \( \mu \)
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3. Two Time Scales Observed in Flow Damping

   Simple Flow Damping Example
   - Take a simple 1D damping problem: \( \frac{DV}{dt} = -\mu \frac{dV}{dt} \)
   - Heat scallop: \( \frac{dv}{dt} < 0 \)
   - As the damping is reduced, the flow rises more slowly, faster rising flow.
   - Full problem involves two momentum equations on a flux surface and a time scale \( \tau \) and \( \alpha \)

   Flow Analysis Method
   - Code is written to simulate cold and single flux flow in these dimensions:
   - \( \frac{dv}{dt} = -\mu \frac{dV}{dt} \)
   - Predicted from model:
   - \( \frac{dv}{dt} = -\mu \frac{dV}{dt} \)
   - \( \frac{dv}{dt} \) at model:
   - \( \frac{dv}{dt} \) at model:
   - Similar model 2 time scales 2 direction fit is used to time flow decay.


   Solve the Momentum Equations on a Flux Surface
   - Flux time scales depend on the coupled momentum
   - Flux flow speed evolves, not from real time evolution
   - Solve these with Ampere’s Law
   - Very little current drawn
   - Plotted with Ampere’s Law
   - Use手册 to combine the neoclassical viscosity, no propagation velocity included.

   Formulation 1: The External Radial Current is Quickly Turned On.
   - Original calculation by Coronado and Talmadge
   - Two time scales/directions come from the coupled momentum
   - Predicted calculation and experimental representations.
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   Formulation 2: The Electric Field is Quickly Turned On.
   - Assumes the electric field is known and quickly turned on.
   - Flux lines and compensating pinch dilutant flow will grow as the same time scale as the electric field.
   - Flux lines grow with a time constant \( \alpha \) determined by viscosity and radial convection.
   - \( \frac{dv}{dt} = -\mu \frac{dV}{dt} \)
   - \( \frac{dv}{dt} \) time scales due to flow evolution.

5. Comparisons Between QHS and Mirror Configurations of HSX and with Modeling

   QHS Flow Damps Slower, Goes Faster For Less Drive.
   - QHS modeled radial conductivity agrees to factor of \( \alpha^2 \)
   - \( \frac{dv}{dt} \) is slower in the HSX model and faster in the mirror.
   - \( \frac{dv}{dt} \) is slower in the HSX model and faster in the mirror.

   The “Forced E” Model Underestimates the QHS time.
   - Corredos and Talmadge Model Overestimates the Rise Times.
   - QHS Damping Data appears to scale with the neutrals.

6. Computational Study: Viscous Damping In Different Configurations of HSX

   Many Different Configurations are Accessible with the Auxiliary Coils.
   - Increasing the N4 mirror percentage is efficient at increasing the damping.
   - Other Mirror Configurations result in less damping.

   Large Change in Surface Shape for Deep Hill Configuration
   - Deep Hill Mode leads to a slight damping increase.