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MHD Simulation of Magnetically Driven, Hyper-Velocity Flyer Plates

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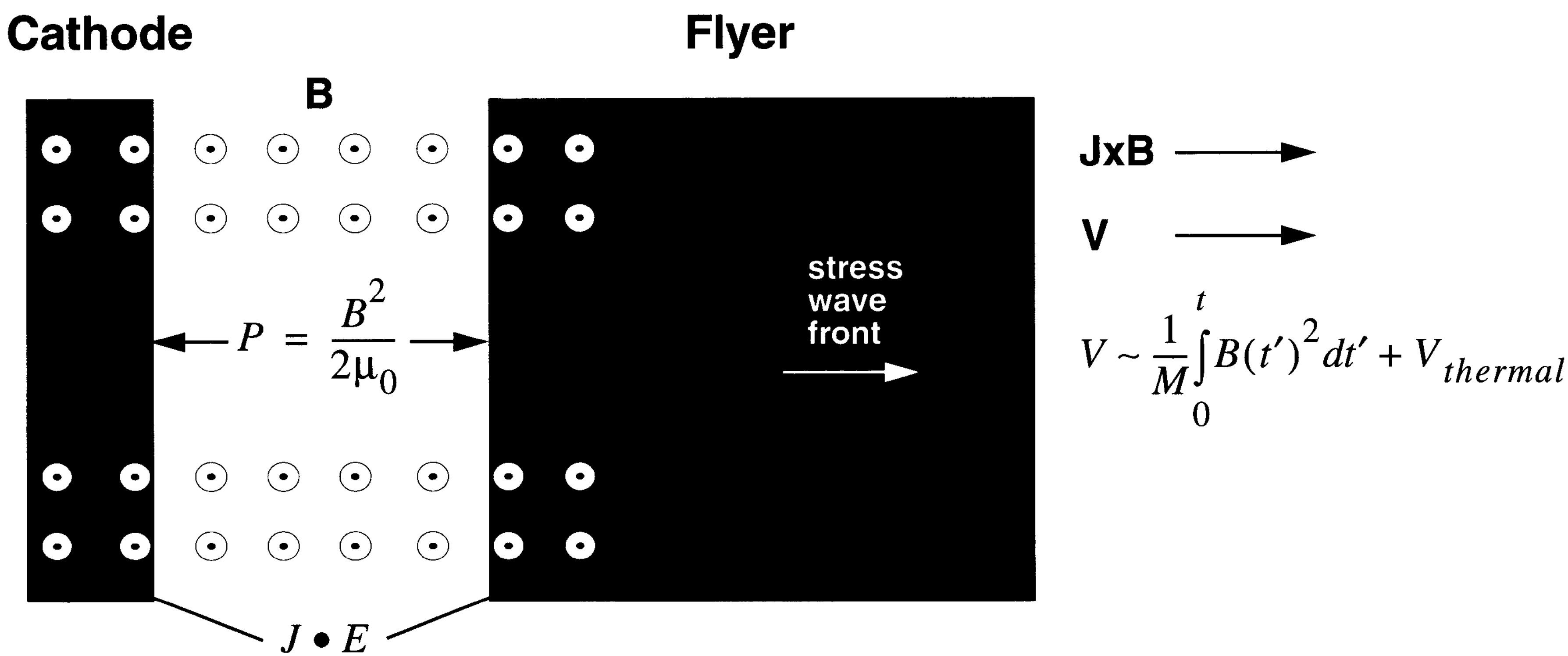
Magnetically Driven Flyers ------- Illustrated



- Magnetic diffusion (Joule heating) significantly modifies flyer; places lower limit on flyer thickness.
- State of flyer at impact with target an important issue.

Introduction

- MHD simulations of magnetically driven flyers on the 20 MA Z-machine.
  - B-field ~ MG; P ~ MB; flyer velocity ~ 5-20 km/s; time scale ~ 500 ns.
  - Code used is ALEGRA, developed at SNL.
- Goals of simulation effort:
  - Code validation / develop predictive capability.
  - Understand physics of magnetically driven flyers.
  - Interpret experimental results.
  - High velocity flyer plate design. 27 km/s (1 MB in D_2) and 40 km/s (2 MB in D_2).
- Outline of talk:
  - Summary of computational modelling.
  - Comparison 1D simulation results for Al flyers with velocity interferometry data.
  - Implications of results.

Summary of Results

- Have successfully used highly accurate (1%) velocity interferometry data in conjunction with 1D simulation to elucidate flyer physics.
  - Good agreement with measured quantities allows physics to be deduced.
- Comparison of simulation with experiment shows significant fraction (but not all) of flyer melted/vaporized due to Joule heating.
  - Results very sensitive to details of conductivity model.
  - Reduction in Joule heating necessary to get good agreement with experiment.
- Magnetic diffusion imposes minimum flyer thickness.

ALEGRA Physics Capabilities

- ALEGRA is a 3D radiation magneto-hydrodynamic code.
  - Finite element; runs Eulerian, Lagrangian, or ALE in 1D, 2D, or 3D.
- Physics options:

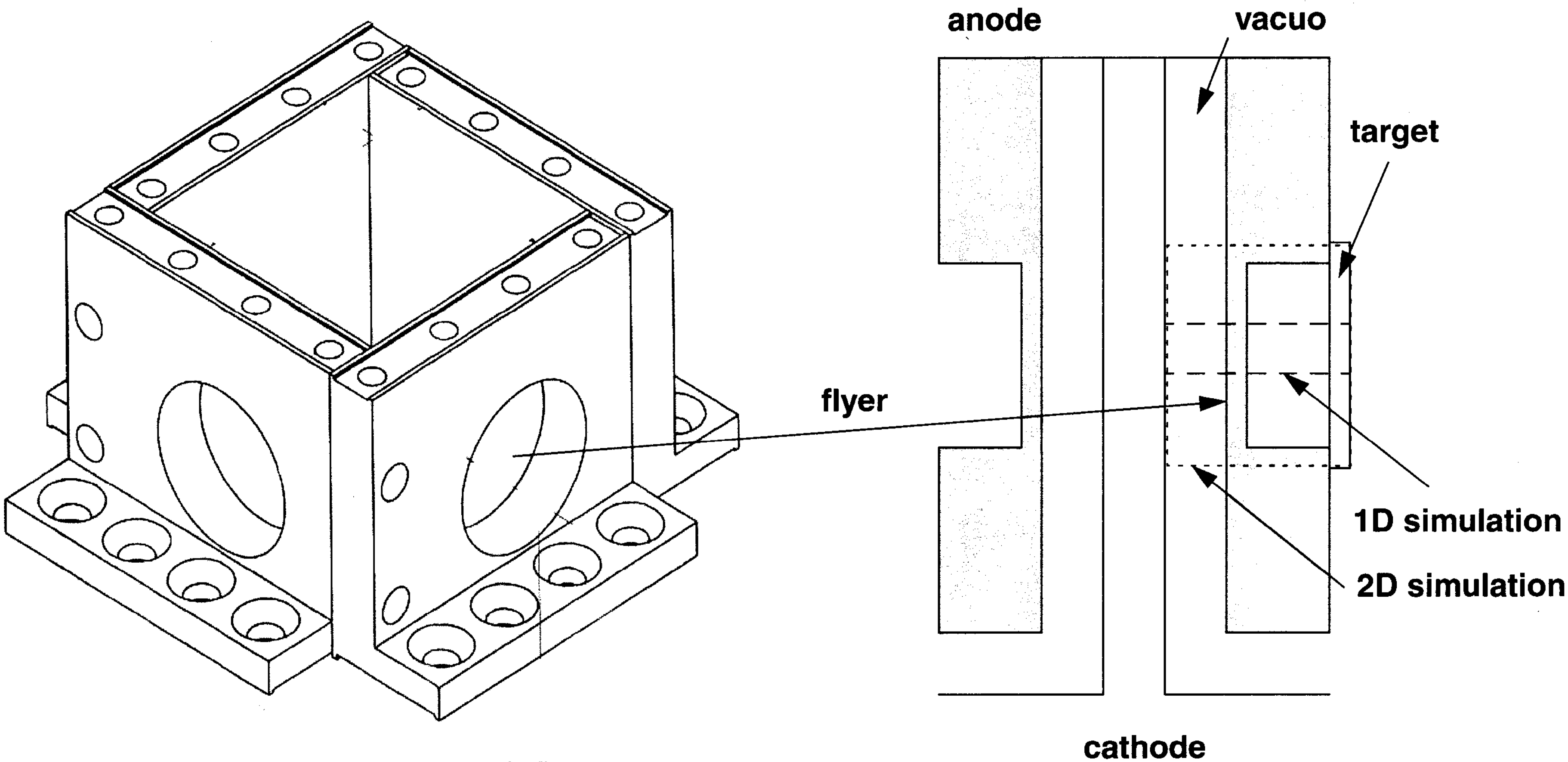
HYDRODYNAMICS	*MATERIAL MODELS*
SOLID DYNAMICS	*EQUATION OF STATE*
STRUCTURAL DYNAMICS	*THERMAL CONDUCTIVITY*
MHD	*ELECTRICAL CONDUCTIVITY*
RADIATION MHD	*ELASTIC PLASTIC*
OPACITY	*FRACTURE*

- Produces accurate results for numerous problems with known solutions (e.g. impact generated shocks, cold diffusion).

Configuration for ALEGRA Flyer Simulations

3D View of Anode Hardware Showing Flyer Regions

Side View Showing Simulation Regions



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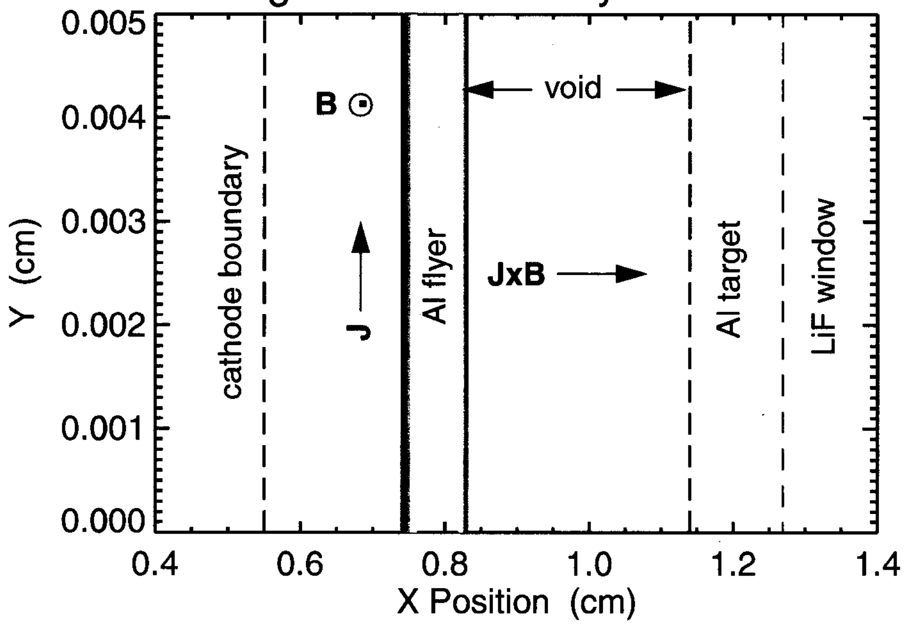
Simulation Procedure

- Specify grid, physics (MHD), and material models (EOS, conductivity, strength).
  - Kerley EOS 3700 for Al (consistent with experimental results).
  - Lee-More-Desjarlais (LMD) model of conductivity (electrical and thermal).
  - In 1D and 2D calculations $B(t) = \frac{\mu_0 I(t)}{4L_{eff}}$ on cathode.
  - Determine L_{eff} using 3D EM simulation (Quicksilver).
  - Input current waveform I(t); start with a measured waveform.
  - Test for numerical dependencies (mesh resolution, solvers, etc.).

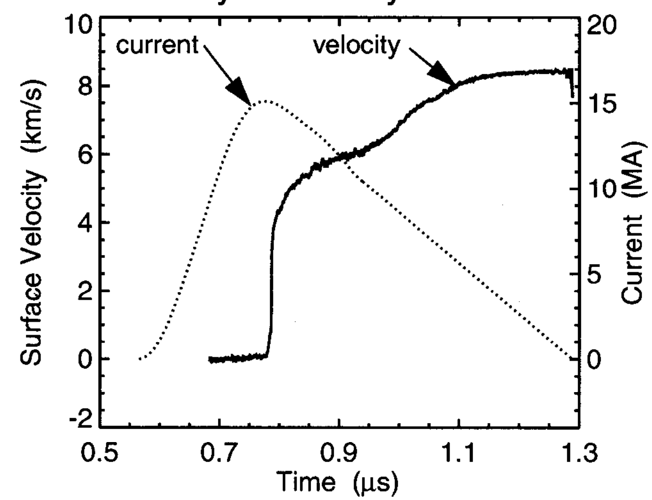
1D Simulation 925 μm Al Flyer: Interferometry Data Used to Determine Spatial Density Profile

925 μm Al flyer; 1 mm Al target
2.6 mm LiF window

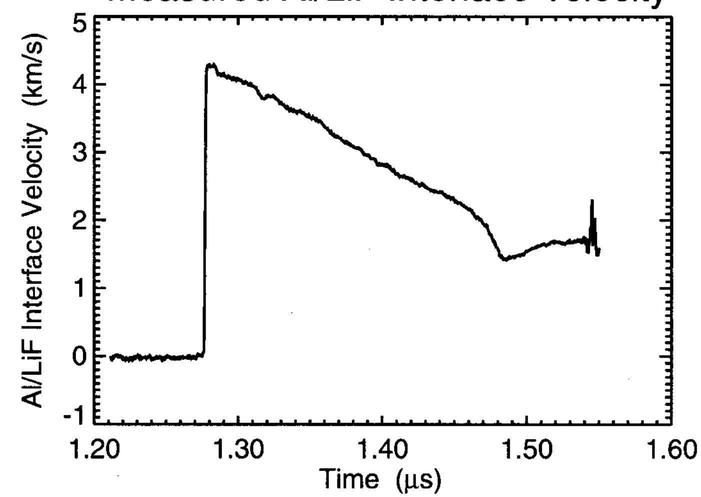
Configuration for 1D Flyer Simulation



Measured Flyer Velocity / Drive Current



Measured Al/LiF Interface Velocity



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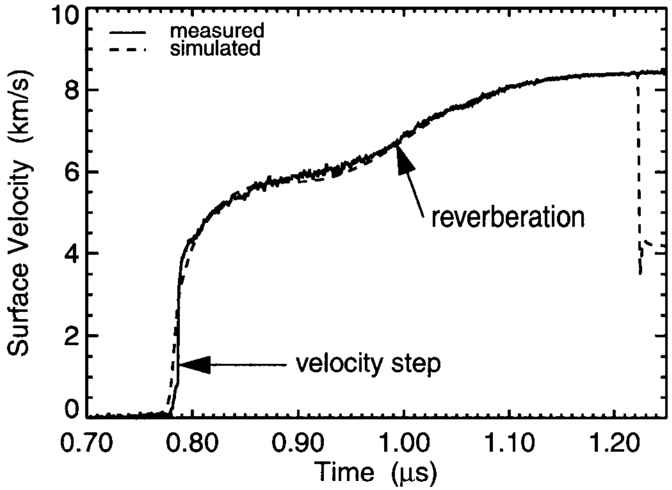
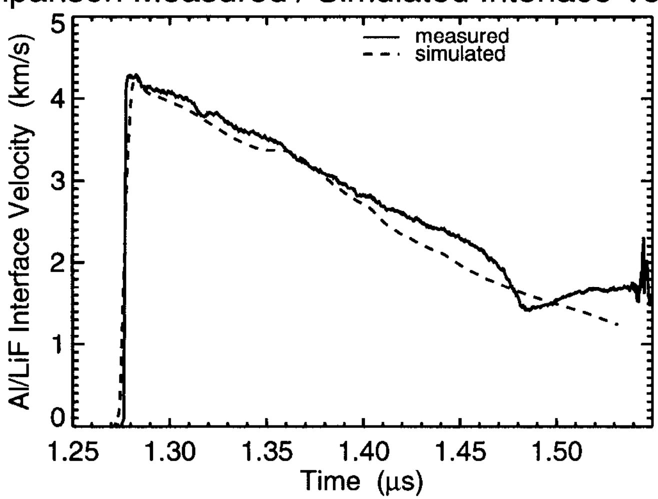
Simulated and Measured Velocities in Good Agreement: Yields Density Profile at Impact

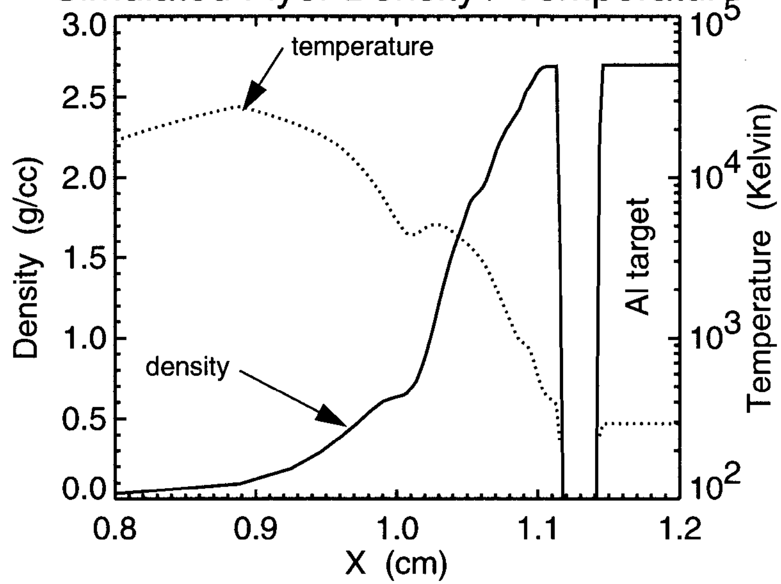
Comparison Measured / Simulated Flyer Velocity



Comparison Measured / Simulated Interface Velocity



Simulated Flyer Density / Temperature



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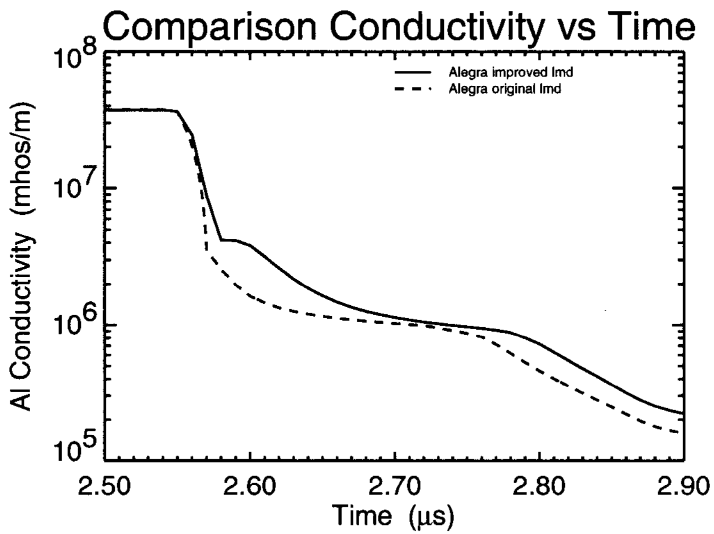
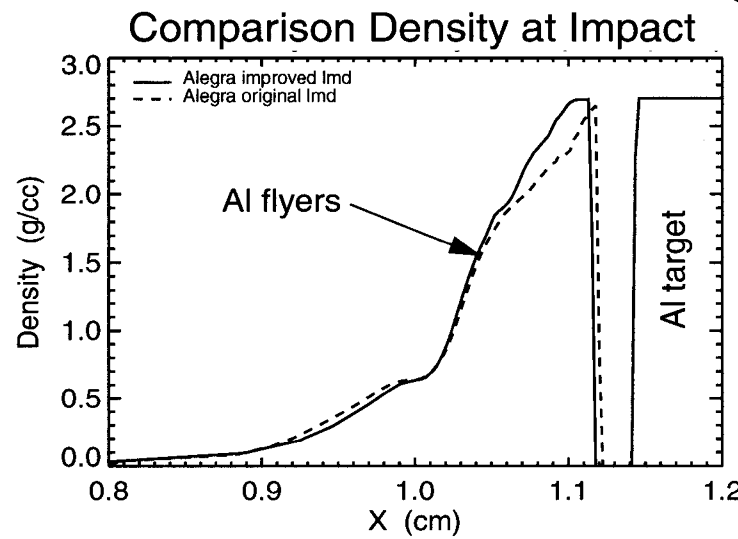
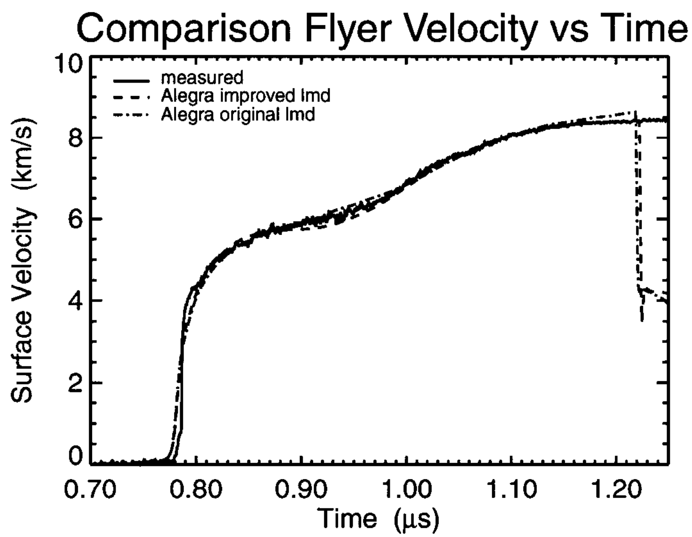
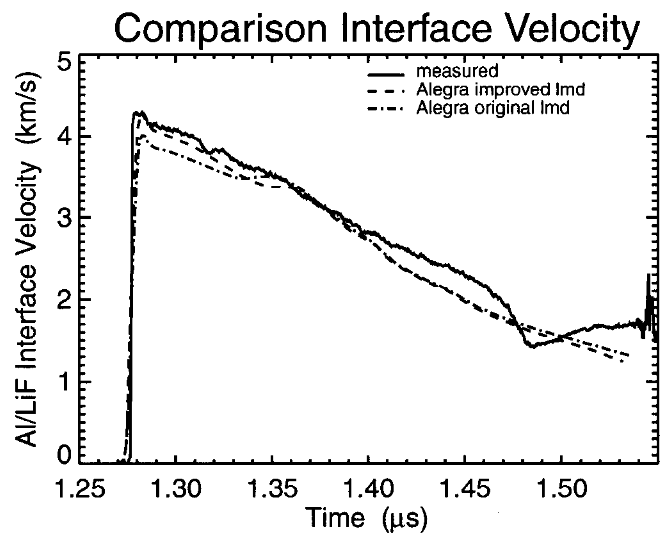
Quantum Calculations Show Conductivity Higher After Melt: Yields Best Agreement with Experiment









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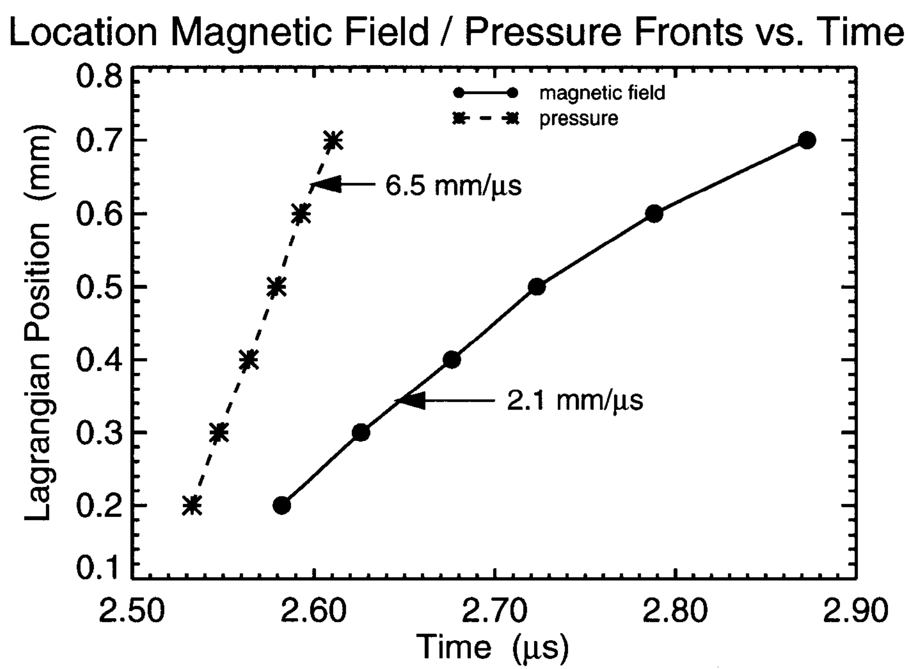
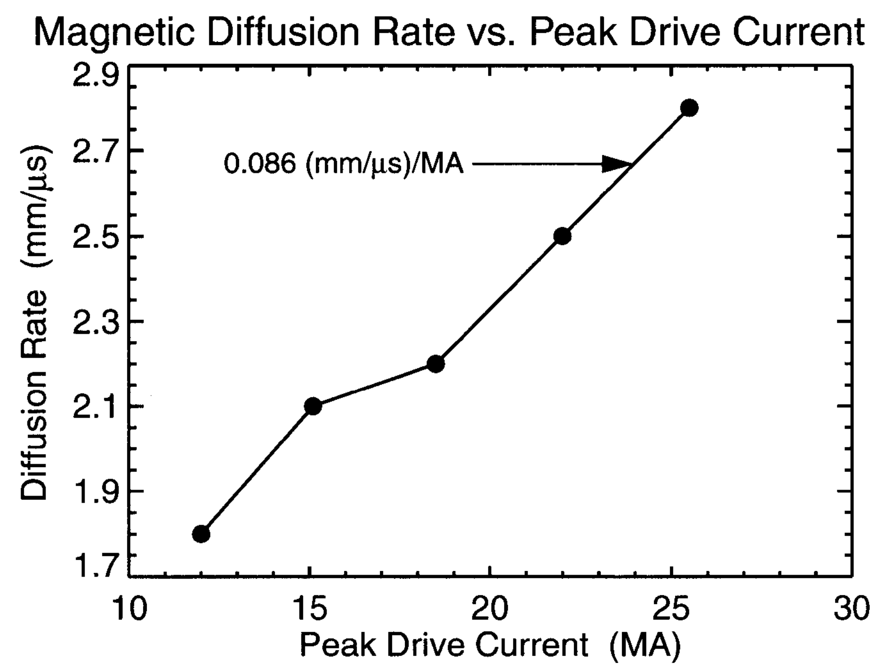
Magnetic Field Diffusion Rate Slower than Pressure Wave: Increases with Increasing Current





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Conclusions

- Joule heating has significant effect on flyer dynamics.
    - Most (but not all) of flyer is melted/vaporized at impact.
    - Velocity due to thermal expansion significant (~ 10-20% total velocity).
    - Affects amplitude of reverberation, and therefore peak velocity.
- Magnetic diffusion rate ($\Re_B$) and minimum dwell (τ_{min}) time impose lower limit on flyer thickness (D_{min}):
    - $D_{min} = \dfrac{\tau_{min} U_S}{(1 + U_S / U_R)} + \Re_B \Delta t$
    - $D_{min} = 355\mu m + 470\mu m$ = 825 μm (Al flyer/target; 3 mm gap; peak u_0=20 km/s)
- Good agreement with velocity interferometry data obtained when conductivity larger after melt (quantum calculations).
    - ALEGRA MHD simulation reveals basic physics of magnetically driven flyers.
    - More research needed on transport phenomenon.

References

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