SAND2018-7486C

Sandia National Laboratories

Equation-of-State Measurements on Iron Along an Elevated Isentrope to 400 GPa

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Introduction

What are we doing?

- Measuring the equation of state (EOS) of liquid iron at high pressures by studying samples at previously unexplored off-Hugoniot isentropes

Why?

- Expanding the region of measured EOS values allows for the refinement of broader EOS models which are used in many high energy density applications
- Iron is the primary constituent of rocky planet cores
- Measurements are taken at conditions very close to the Earth's core which not only improve the models, but do so with minimal extrapolations for this critical application

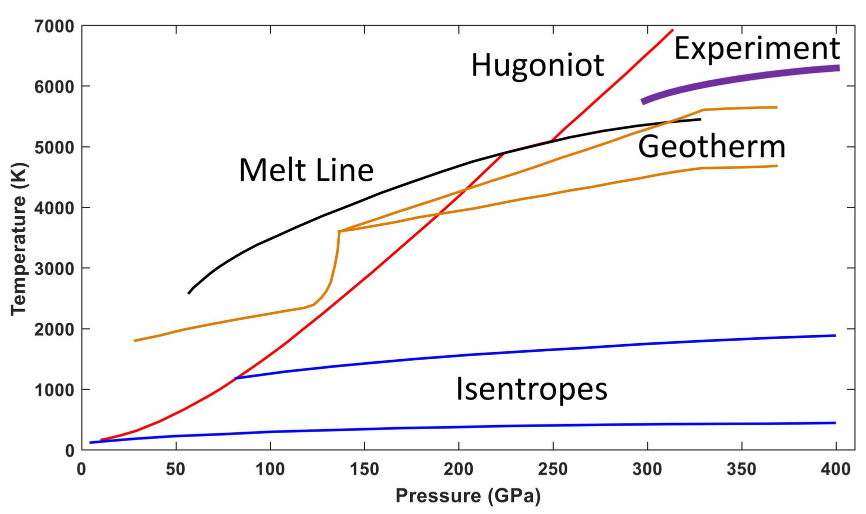


Figure 1: Estimation of our ramp path in P-T space (purple), along with several relevant references; Hugoniot[1] (red), iron melt curve[2] (black), Earth geotherm[3] (orange), and two other previously measured isentropes[4] (blue).

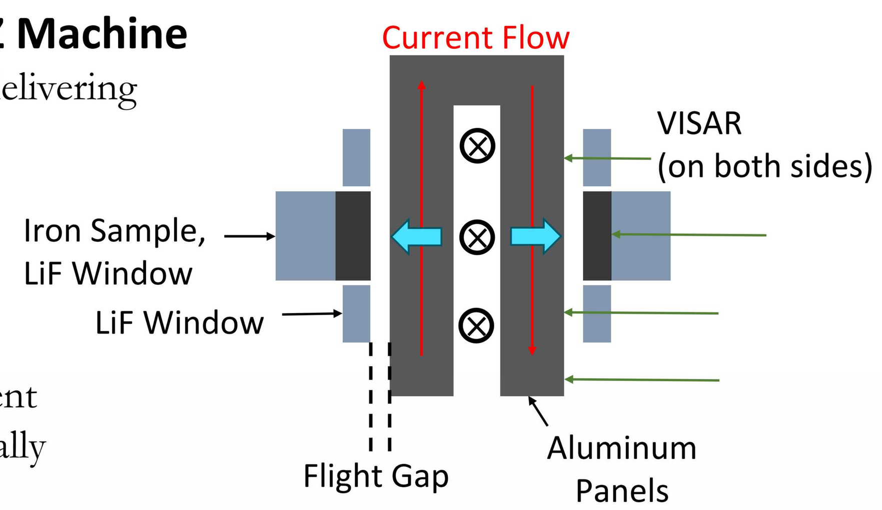
Experiment

Sandia National Laboratories Z Machine

- Pulsed power facility capable of delivering 26 MAmps to the load

Load Hardware

- Samples are paired across the panels with differing thicknesses
- Parallel counter-propagating current drives the panels apart symmetrically



Shock-Ramp Drive

- The Z machine's pulse shaping capability is utilized to drive the panel such that it impacts the sample at a steady velocity, leading to an initial shock state, and then subsequently drives the pressure higher through a quasi-isentropic compression

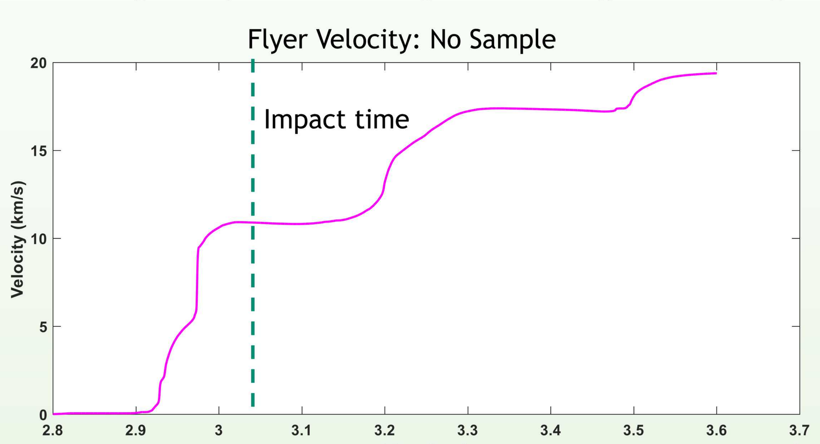


Figure 2: Simulated panel velocity assuming no sample present. The nominal impact time, should a sample be present, is indicated (dashed line).

Analysis

Backward Integration

- The Lagrangian hydrodynamic equations are backward integrated to obtain the drive profile along with a guess of the equation of state:

$$\frac{\delta[P(\rho)]}{\delta x} = -\rho_0 \frac{\delta u}{\delta t}$$

$$\frac{1}{\rho_0}\frac{\delta u}{\delta x} = \frac{\delta\left[\frac{1}{\rho}\right]}{\delta t}$$

Forward Propagation

- The drive state can then be propagated forward to the sample interface to obtain the *in-situ* particle velocity (the particle velocity that would have been present at that location had there not been a release interface)

Lagrangian Sound Speed and EOS

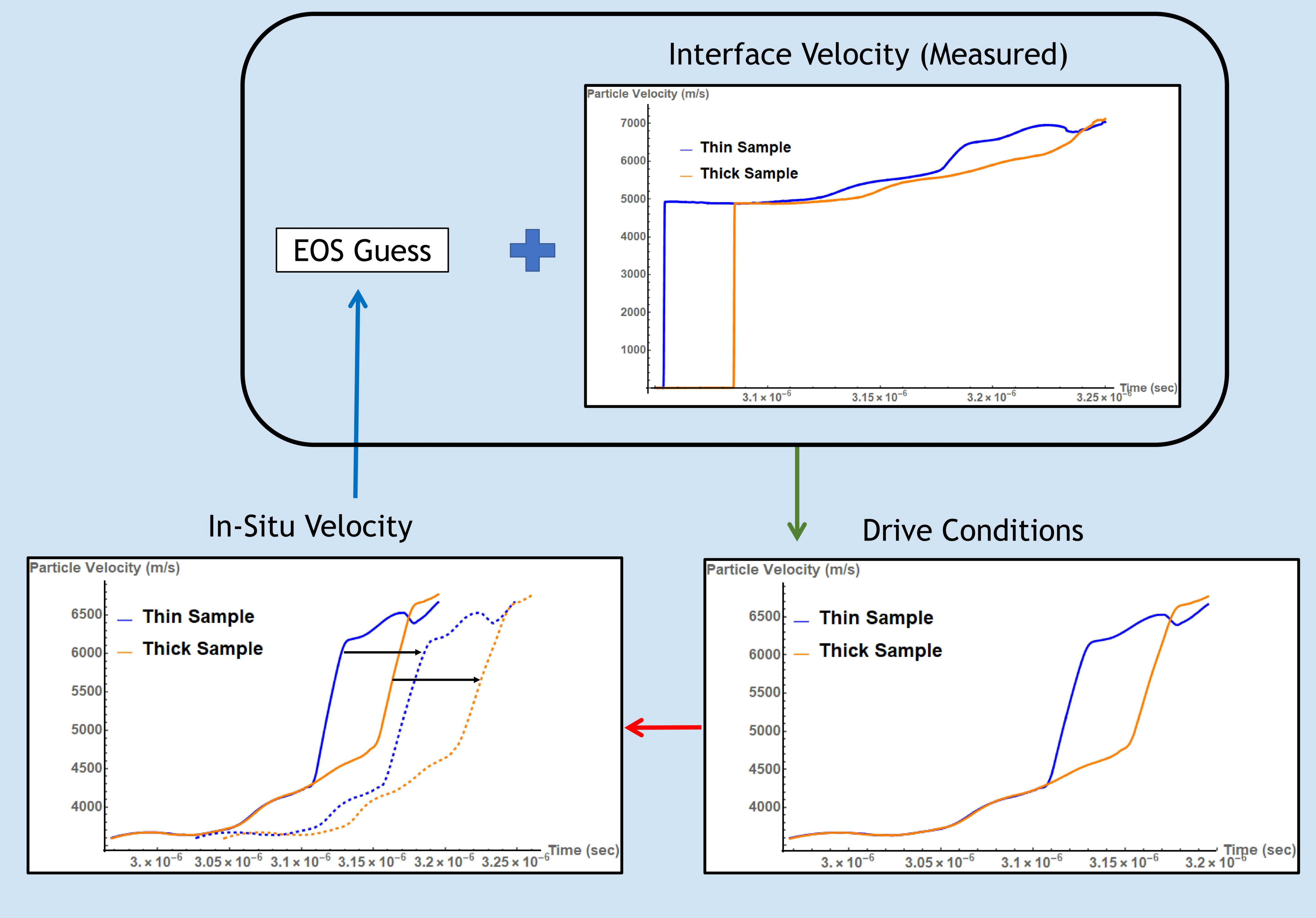
- A sound speed can then be directly calculated from $\Delta x/\Delta t$ measurements and an EOS formed from the sound speed:

$$\frac{1}{\rho_f} = \frac{1}{\rho_s} - \int_{u_{ps}}^{u_{pf}} \frac{du_p}{\rho_0 C_L}$$

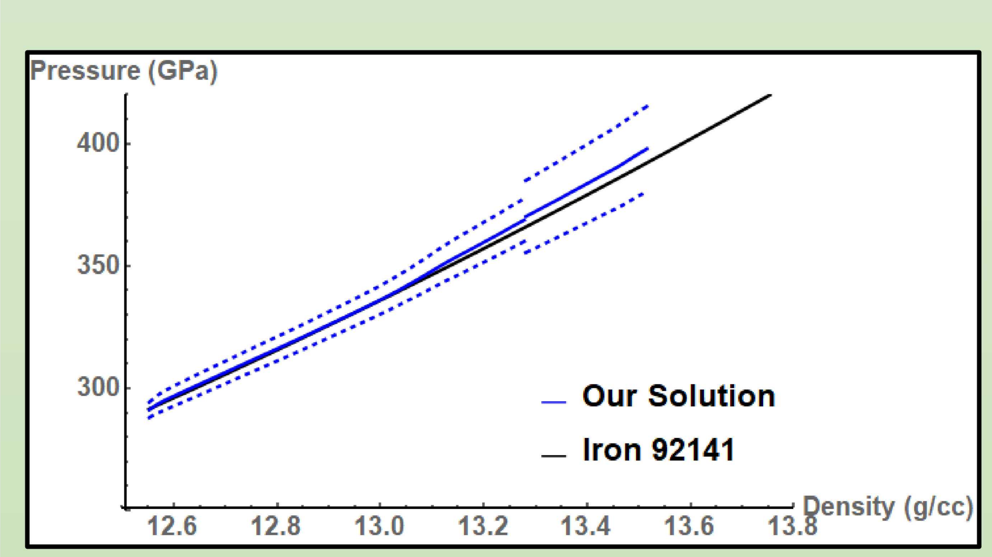
$$P_f = P_s + \int_{u_{ps}}^{u_{pf}} \rho_0 C_L du_p$$

Iterate

- The process is then repeated with this new EOS, iterating until the EOS reaches convergence



Results



Equation of State Solution

- The derived Pressure-Density is shown to the left (blue), compared to the extracted values from the iron 92141 EOS table from Los Alamos National Laboratory (black).

Conclusions

We have performed shock-ramp experiments on Sandia National Laboratories' Z Machine to evaluate the equation of state of liquid iron along an elevated isentrope near Earth core pressure and temperature conditions. The results agree well with current EOS tables, validating their use at and near these conditions.

Literature Cited

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[4] J. Wang, R. F. Smith, J. H. Eggert, D. G. Braun, T. R. Boehly, J. Reed Patterson, P. M. Celliers, R. Jeanloz, G. W. Collins, and T. S. Duffy. Journal of Applied Physics, 114(2), p.023513. doi:10.1063/1.4813091 (2013).

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