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Design of an ultra-long timescale Hydrodynamic Instability platform using the Z pulsed power driver

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Abstract

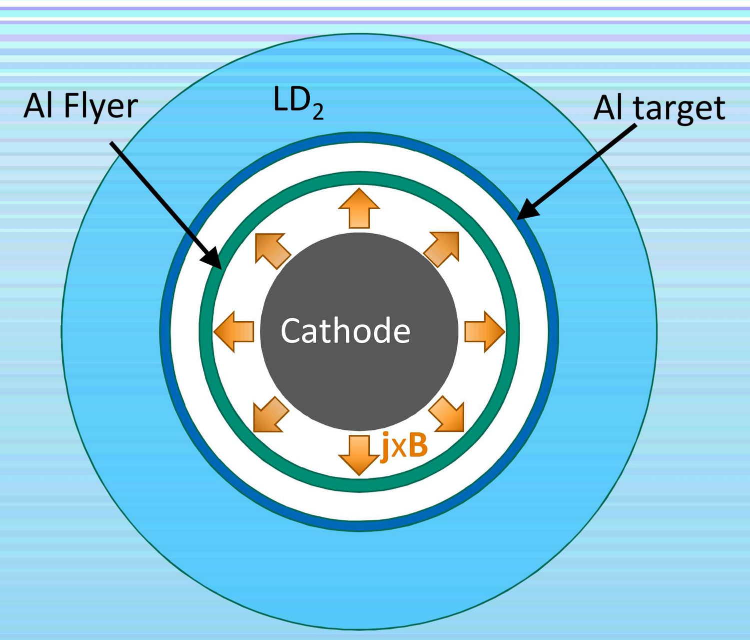
Here we present the design of a new hydrodynamic instability platform using the Z pulsed power driver. In this platform Z is used to accelerate an exploding cylindrical flyer into a sample that contains an interface between two materials with a pre-machined perturbation. The configuration of the experiment is highly flexible and allows for Richtmeyer-Meshkov and/or Rayleigh-Taylor unstable configurations to be explored[1,2,3]. The primary advantage of this configuration is that Z can drive the flyer for very long timescales (>100 ns) allowing many e-foldings and potentially probing the transition to turbulence. We explore the impact of material choices, geometry, and pulse shape on the acceleration history of the unstable interface and growth of the perturbation.

Motivation

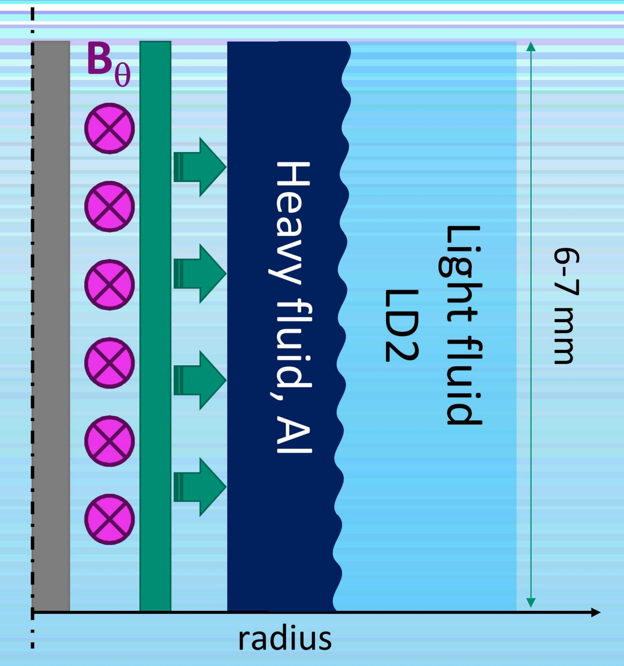
- Planar HED instability experiments, typically driven by high power lasers, require the use of tracer layers to localize the measurement and shock tubes that can limit the timescale due to boundary effects
- Drive time is a major limitation in efforts to achieve steady-state HED turbulence in the laboratory
- Using Z to drive these experiments enables the use of >2 MJ of drive energy over > 100 ns with large test volumes (~cm^3)
- Using a cylindrical geometry further eliminates the need for a tracer layer by removing boundaries in one dimension
- In this proposed concept, Z is used to magnetically accelerate a cylindrical flyer into a target which contains the unstable interface

Proposed Experimental Configuration

Top View



Cross Section

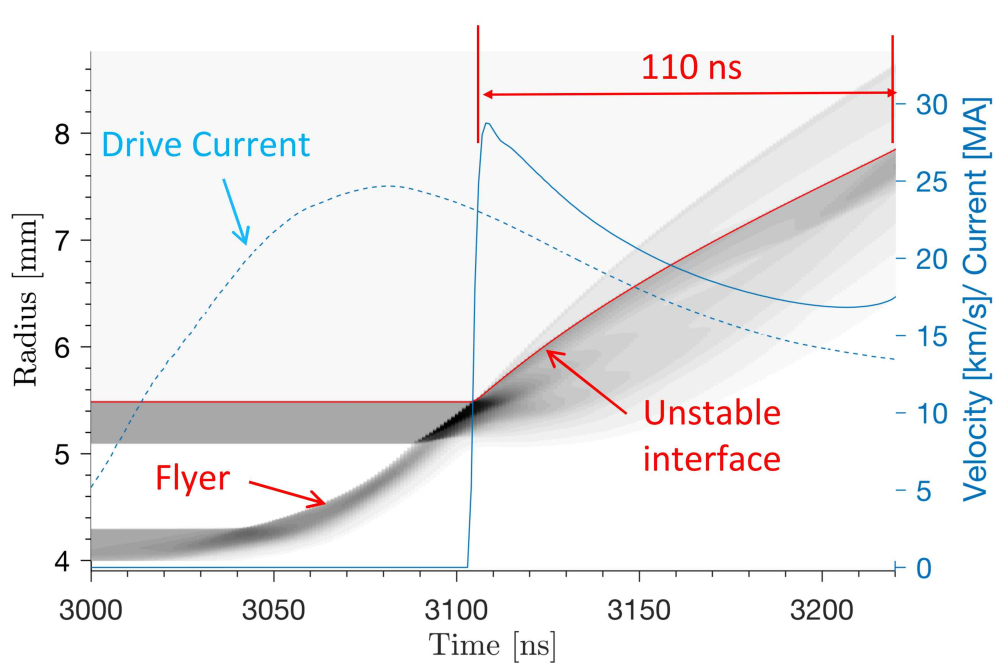


Magnetic Pressure $P=\frac{B^2}{2\mu_o}=140\cdot\left(\frac{I_{[MA]}/30}{R(t)_{[mm]}}\right)^2$ [Mbar]

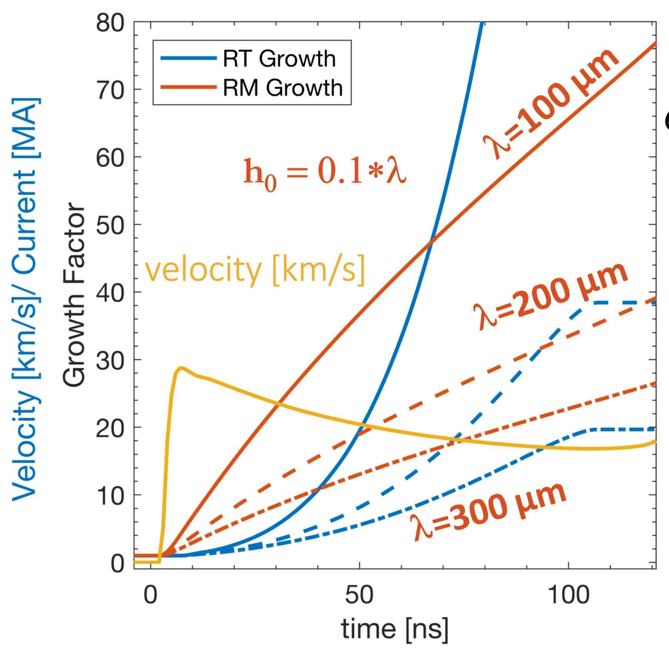
1D Design

- Z is used in standard short-pulse mode for simplicity in initial scoping
- 1D Scoping calculations performed using the ALEGRA-MHD[4] code

Density Evolution



Instability Growth



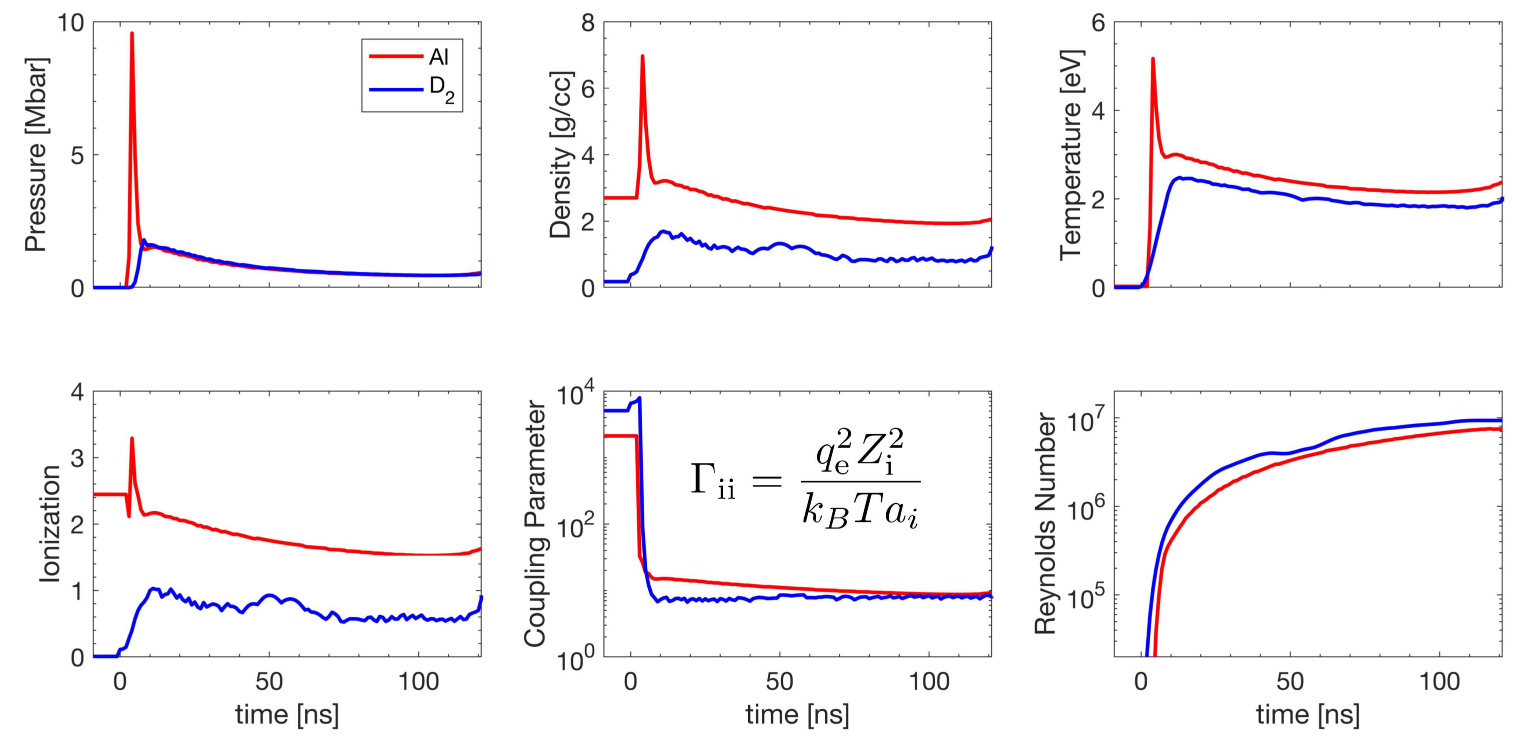
RM and RT Growth Factors

$$G_{RT}(t) = \exp\left(\int_0^t \gamma_{RT}(t')dt'\right) \quad \gamma_{RT} \approx \sqrt{-k_z A_N \frac{dv_i}{dt'}}$$

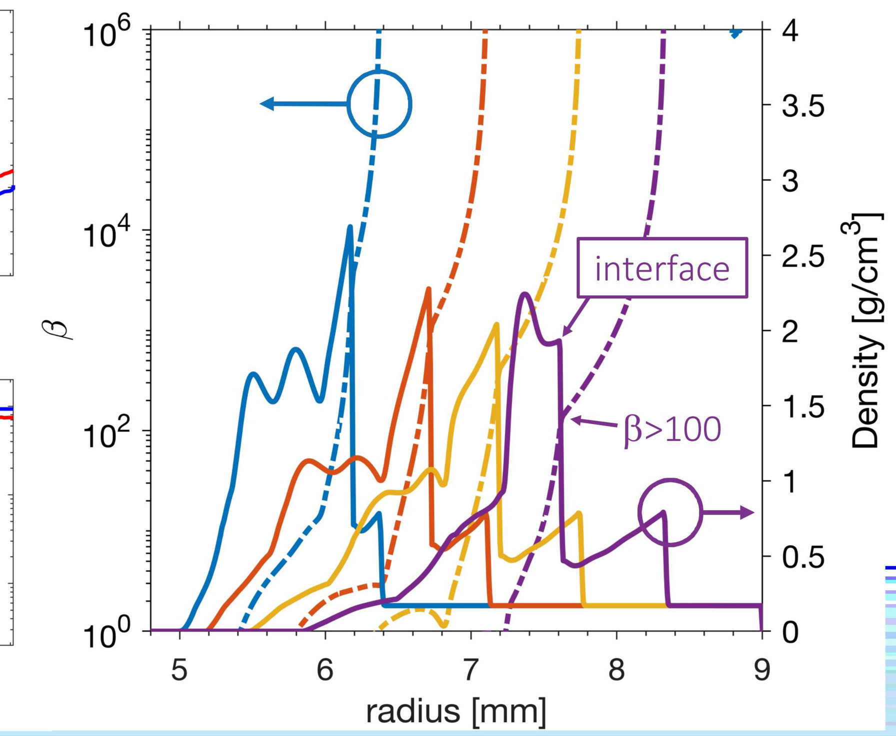
$$G_{RM} = \frac{1}{h_0}\int_0^t \frac{h_0}{R_0} v_i(t')\left(1+\frac{k_z A_N}{f(n,k_z)}\right)dt'$$

- Interface is driven for >100 ns
- Cylindrical RM calculated using theory of Lombardini et al.[5]
- RM growth dominates initially, overtaken by RT at ~70 ns depending on wavelength

Evolution of Interface Parameters



Plasma Density and β



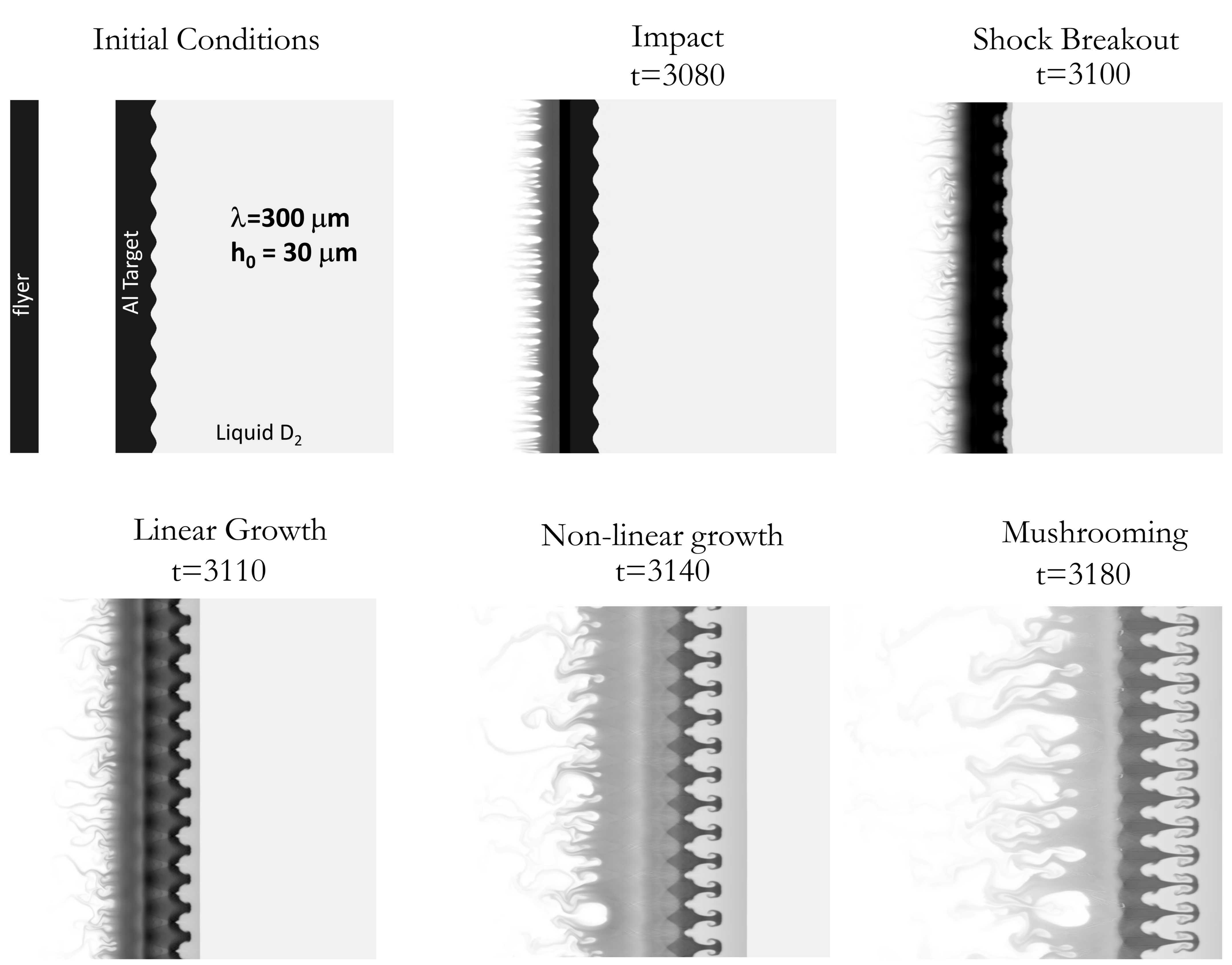
$$\nu(cm^2/s) = 6.55\times10^{-10} Z m_i^{1/2} n_i^{5/6} \times \begin{cases} 1.1\Gamma_{ii}^{-1.895}, & \Gamma_{ii}<2 \\ \lambda I_1 + \frac{1+\lambda I_2}{\lambda I_3}, & \Gamma_{ii}>2 \end{cases}$$

Since the interface is moderately coupled we use the the viscosity from Clérouin et al.[6]

- Re_N is calculated following Robey et al.[7]
- Re_N is greater than the threshold for turbulence for ~100 ns
- There is some field diffusion at the unstable interface, but the plasma β> 100 at all times
- This can be further reduced through pulse shaping, but should be adequate

2D Design

- The GORGON MHD code was used to run 2D calculations with ideal electrodes



- Next step in design will examine
  - the impact of MRT feedthrough on the evolution of the perturbation
  - the impact of realistic electrodes and the wall instability
  - Modeling with xRAGE to study turbulent mixing

Conclusions and Future Work

- We have established a conceptual design for a long drive duration (> 100 ns) combined RM/RT platform on Z
- We estimate that this platform will be able to observe a transition from unstable flow to steady state turbulence due to the large Reynold's number (Re_N>10^6) and the long duration
- We will use xRAGE and other tools to study turbulent mixing and evolution
- Future work will aim to increase the drive duration towards ~200 ns.
- We will explore variations of this platform to further minimize field diffusion, and to isolate the RM and RT instabilities
- Small variations to this platform may enable the study of magnetized flows and MHD turbulence

This platform shows strong potential to reach the required conditions and timescales to achieve a truly turbulent state

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(1) Richtmyer, Robert D., *Communications on pure and applied mathematics* 13.2 (1960). (2) Meshkov, E. E., *Fluid Dynamics* 4.5 (1969). (3) Taylor, Geoffrey Ingram. *Proceedings of the Royal Society of London. Series A. Mathematical and Physical Sciences* 201.1065 (1950). (4) Robinson, Allen, et al. *46th AIAA Aerospace Sciences Meeting and Exhibit*. 2008. (5) Lombardini, M., and D. I. Pullin. *Physics of Fluids* 21.11 (2009). (6) Clérouin, et al. *EPL (Europhysics Letters)* 42.1 (1998). (7) Robey, H. F., et al. *Physics of Plasmas* 10.3 (2003).

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