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National Aeronautics and Space Administration

Overview of Rayleigh-Taylor Instability and the Impact on Target Design for a Pulsed Fusion / Fission Propulsion System

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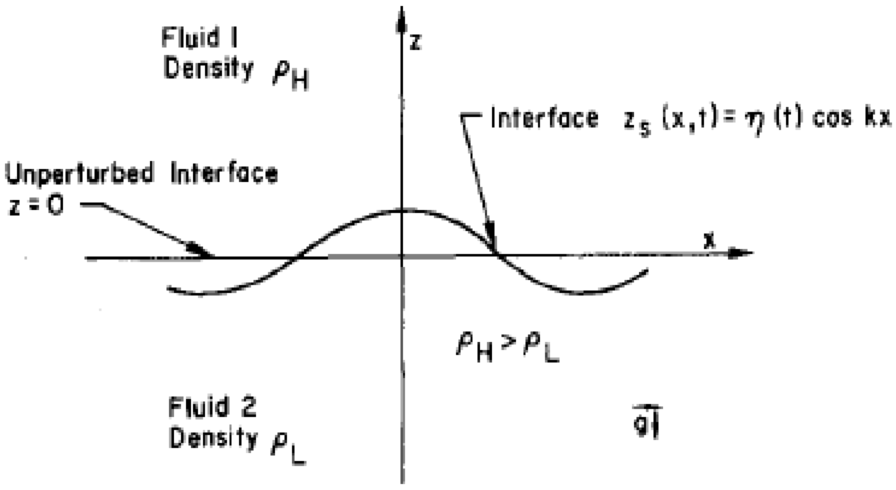
Introduction

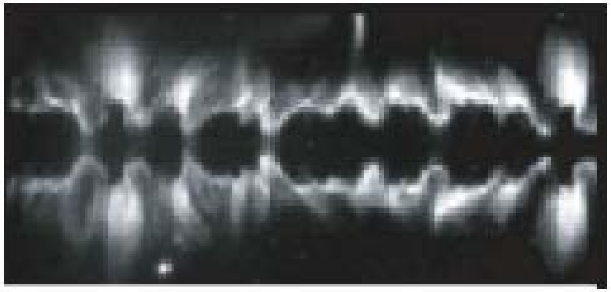
- **Nuclear propulsion systems have the potential for much higher specific impulse than chemical engines**
  - Various concepts have been proposed in the past (NTRs, Orion, etc.)
- **If implemented a Fusion based system could way out perform a fission system such as an NTR, but has suffered from technical challenges**
  - Confinement at the required density and for the necessary length of time has been difficult to achieve due to plasma instabilities
  - However; a fusion / fission hybrid could relax the confinement requirements
  - Management of the instabilities with mitigating processes could improve confinement
- **Interested in the design of a z-pinch target that manages instabilities to achieve fusion / fission reactions for a propulsion system**

Rayleigh-Taylor Instability (RTI)

- **Most destructive**
- **Occurs due to acceleration and density gradient vectors in opposite directions**
  - **Light fluid supports dense fluid**
- **Small perturbations at interface between fluids quickly grow leading to turbulent mixing**



- **Estimates of growth rates of interest**
  - typically calculated with linearized MHD equations
  - Relevant to confinement time
- **Interested in cylindrical geometry in which the magnetic field acts as the lighter fluid (density of zero)**
  - As in a z-pinch

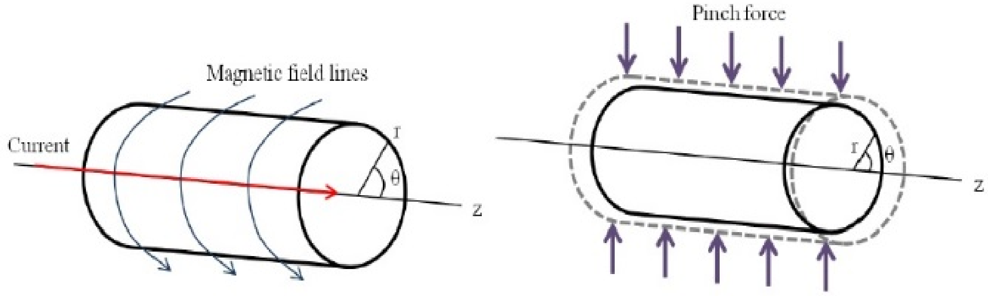


Schlieren image of z-pinch. Cylindrical geometry disrupted by instabilities

- Image: Ben Dudson, *Plasma Instabilities*, University of York

What is a Z-pinch?

- **A z-pinch a large pulsed current with high dI/dt to generate an azimuthal magnetic field and ionize the target. The current and magnetic field produce the Lorentz force and compress the target**
- **This process is one concept for producing fusion reactions**
- **The fusion/fission propulsion system concept of interest uses a z-pinch to compress the fuel**



RTI – Mitigating processes

- **Decades of study and experiment have shown various processes to have mitigating effects upon the growth rate of the Rayleigh-Taylor Instability**
  - E.g. shock waves, tailored density profiles, staged annular collapse, viscosity, shear, and resistivity
- **Past experiments should be well understood and used to guide the development of a target for a z-pinch propulsion system**
- **Several of the following slides highlight particularly interesting experiments**

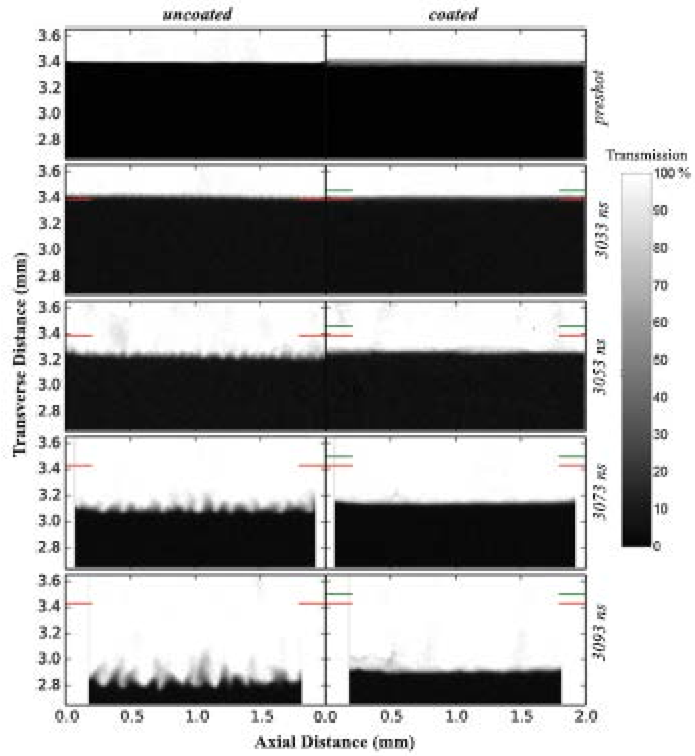
From Literature - Experiments of Interest
Frozen Deuterium Exploding Wires

- Wires of Frozen Deuterium used in z-pinch experiments
- Unexpected level of stability
  - Loss of stability occurred at max current, dI/dt=0, and at complete ablation of wire core
- Expected contributions to stability
  - Sufficient resistivity in plasma
  - Ablation of the wire core

From Literature - Experiments of Interest
Dielectric Coating

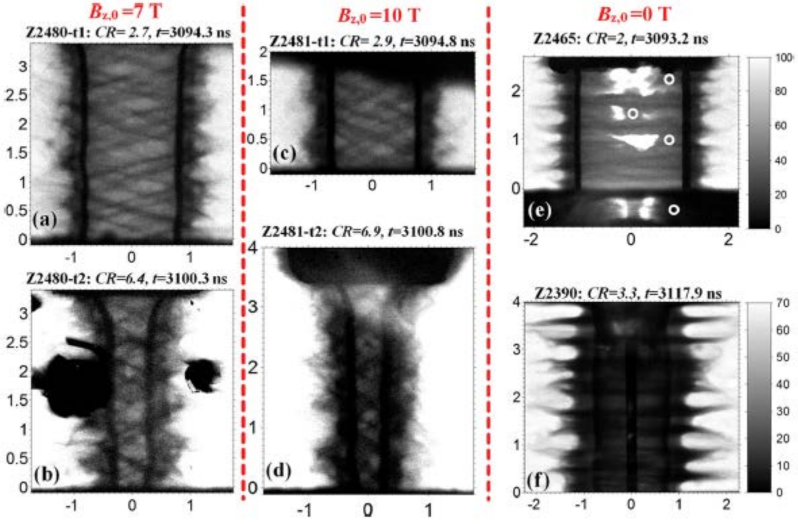
- Dielectric coatings have been used to suppress instability development
  – Reduces electrothermal instabilities at the surface which seed RTI
  – Reduced initial perturbations lead to reduced RTI growth

- X-Ray images to the right show large improvement in stability for coated surface



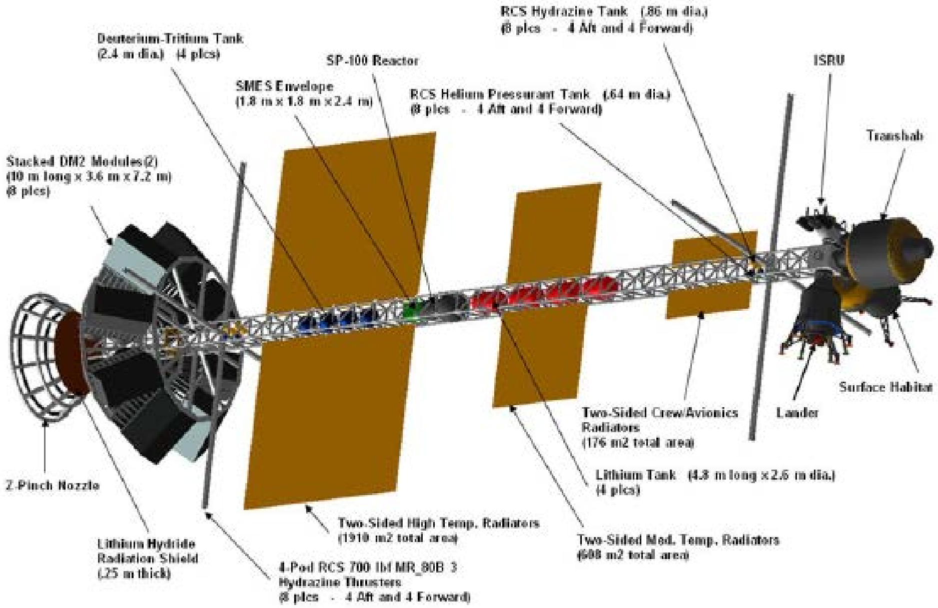
From Literature - Experiments of Interest
Axial Magnetic Field

- Largest growth rates occur when wave number and magnetic field are perpendicular
- An axial magnetic field in the z-pinch of a liner with a pre-ionized gas fill can increase stability
  - Magnetic field compresses along with liner
- Radiographs show improved stability for higher axial magnetic field in the image to the right



Pulsed Fusion Fission Propulsion System Concept (PuFF)

- **Concept uses a z-pinch to compress the target and burn the fuel through fusion and fission reactions**
  - Using a hybrid reaction is intended to relax the conditions under which the plasma must be compressed
- **After compression the products are expanded through a magnetic nozzle to produce thrust**
- **As is the case for other z-pinch applications, RTI is an obstacle**
  - Must be managed to achieve successful compression and reaction
  - Stabilizing processes from other experiments may be incorporated into the target design to improve stability and performance



Stability Concepts for Target Design

- **Frozen Deuterium/Uranium Pellet**
  - A cylindrical pellet with a frozen deuterium core and Uranium shell
    - Frozen core and the ablation process may be stabilizing
  - Frozen deuterium or other dielectric outer coating may be used to suppress electrothermal instabilities to further increase stability
- **Uranium liner with Deuterium Plasma fill and Axial B-field**
  - Such a concept may employ the stabilizing effect of an axial magnetic field
  - Dielectric coating may also be used to suppress instability development
- **Staged Collapse of Deuterium/Lithium plasma onto Uranium Pellet**
  - Carful design of the radial density profile, annular stages, and shock waves may stabilize annular plasma shells that could be collapsed onto a uranium pellet

Forward Work

- **Ongoing review of past experiments and analysis**
  - Continued maturation of concepts
- **Modeling of targets and compression using SPFMax**
  - SPFMax is a smooth particle fluid magneto hydrodynamic code under development at the University of Alabama in Huntsville (UAH)
  - Results will influence the design of experiments for Charger 1, a 1 TW pulsed power facility at UAH

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