Growth of Instabilities Warm Dense Material (HC-4679)
- report on ESRF experiments in Dec 2021 and Aug 2022

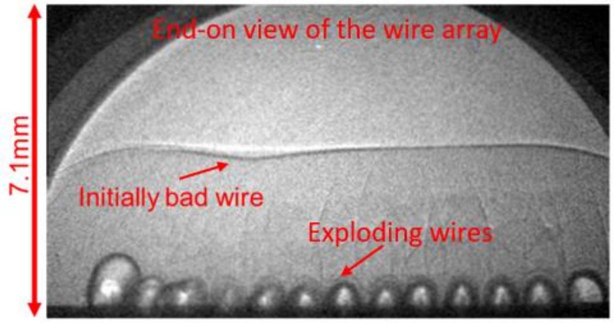
With the removal of COVID travel restrictions, personnel from Imperial College and Technion were able to visit ID19 at ESRF in December 2021 and August 2022 to explore how our pulsed power systems could be utilized for driving instabilities in warm dense matter. Hydrodynamic instabilities – such as the Richtmyer-Meshkov, Rayleigh-Taylor and Kelvin-Helmholtz – affect the dynamics of fluids throughout the universe. The behavior of warm, dense material – the boundary between condensed matter and plasma –meanwhile is extremely difficult to predict, and so exploring how instabilities grow and develop on warm dense conditions is at the forefront of much high energy density physics research. As well as determining how astrophysical phenomena such as supernova remnants form, the research has direct applications on Earth in – for instance – in the pursuit of inertial confinement fusion.

We faced a few initial issues during experiments – on our arrival in December 2021, the equipment had been badly damaged in transport to ESRF, and in experiment the photon flux in 4 bunch mode was lower than expected, however we were still able to image reliably. In August imaging was significantly improved with higher flux, and we took advantage of 16 bunch filling modes for enhanced temporal resolution.

In total over ~7 days 60 experiments were performed.

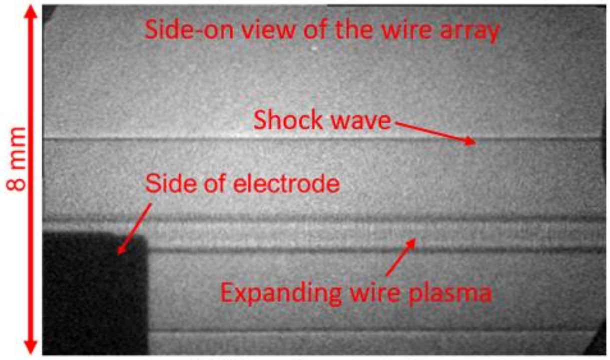
December 2021

The experiments in December were mainly dedicated to producing uniform planar shock waves in water, generated by the explosion of planar arrays of wires - typically 13x75µm Cu wires spaced 900µm apart. Once characterized this shockwave would then be utilized in later experiments in August to drive instabilities on modulated targets. The experiments were highly successful with planar shockwaves observed travelling at 2.1kms^{-1} through the water and the dynamics of shock-launch from the exploding wires being directly observable.



2772ns after start of current

- Expansion of wires unhindered perpendicular to plane of array
- Shock seen from each wire
- Shock merges, becoming uniform planar shockwave travelling at ~2.1kms^{-1} – does not slow substantially with distance

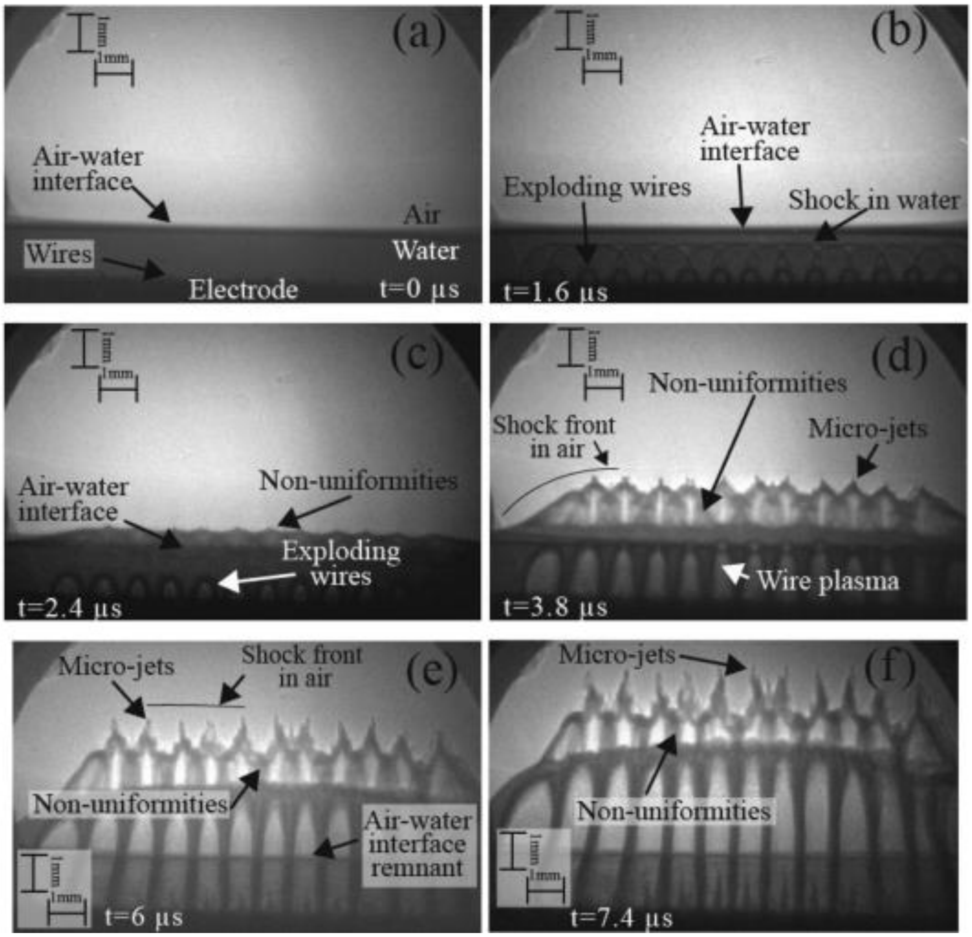


2130ns after start of current

- Expansion of wires is clearly observed – uniform along the wires
- Again shock appears to be planar and does not vary in speed along wires

Radiography enabled accurate measurements of the water density behind the shock to be made, which combined with the shock velocity enabled all thermodynamic state variables of the water properties behind the shockwave to be determined. The planar shockwave results were presented the week after the experiments at a **plenary talk by Dr Bland at the International IEEE Pulsed Power Conference** and are presently being written into an article to be submitted to the **Journal of Applied Physics.**

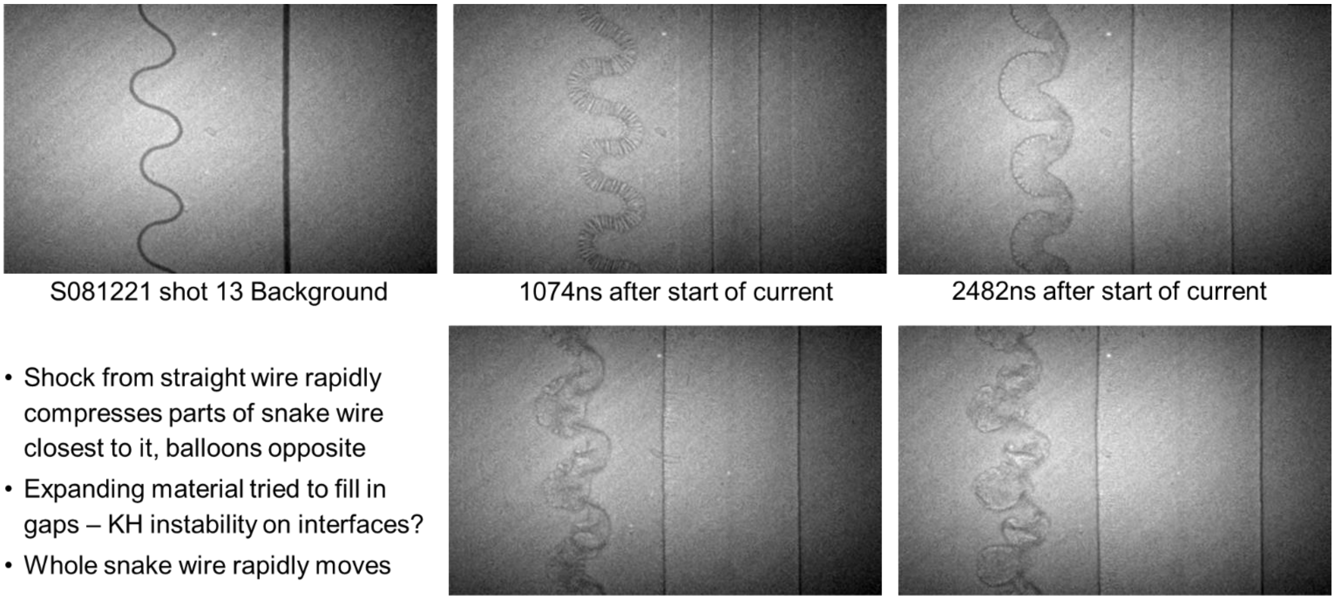
In some of the December experiments we went on to explore the interaction of the planar shockwave with an air/water interface close to the wires. This was to explore results seen in experiments with much larger pulsed power drivers, which attempted to launch flyers into air via the explosion of planar arrays of wires in water. Here inconsistencies in the planarity of the flyer and in its acceleration had been observed, but there were multiple possible explanations. With an air water interface spaced close to the wires, the interaction of the shockwaves between the wires resulted in jetting phenomena:



And if a target was employed at the air water interface, cavitation could be observed inside the water due to shockwaves reflecting back and forth from the target. These observations helped explain the behavior of the flyer plates and were written into a paper by Daniel Maler in Physics of Plasmas: **Physics of Plasmas 29, 063502 (2022); https://doi.org/10.1063/5.0095506**

The results were also presented at the **International IEEE ICOPS conference in Seattle, winning Daniel a coveted student paper award**.

Finally in December we performed several initial experiments to directly probe instability dynamics in warm dense material utilizing just 2 wires – one modulated (zig-zagged or 'snaked') the other straight. Both wires would be exploded by the pulsed power system, with the shockwave from the straight wire then driving instabilities in the modulated target:



S081221 shot 13 Background

1074ns after start of current

2482ns after start of current

- Shock from straight wire rapidly compresses parts of snake wire closest to it, balloons opposite
- Expanding material tried to fill in gaps – KH instability on interfaces?
- Whole snake wire rapidly moves

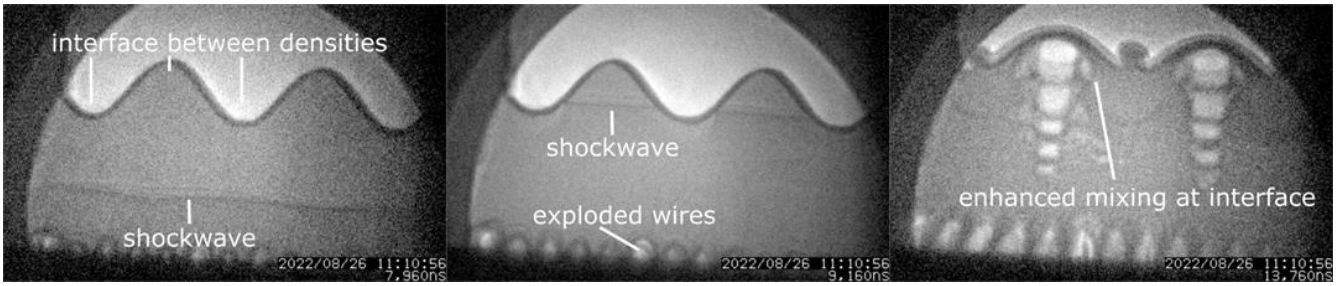
3890ns after start of current

5298ns after start of current

These initial measurements proved the capabilities of the pulsed power system for driving such experiments on much larger scales and over significantly longer time periods than experiments typically fielded at large, usually national laser facilities. Again these results were presented in the **Plenary talk by Dr Bland at the IEEE Pulsed Power Conference** and follow-on research, conducted in August is now being analyzed for publication.

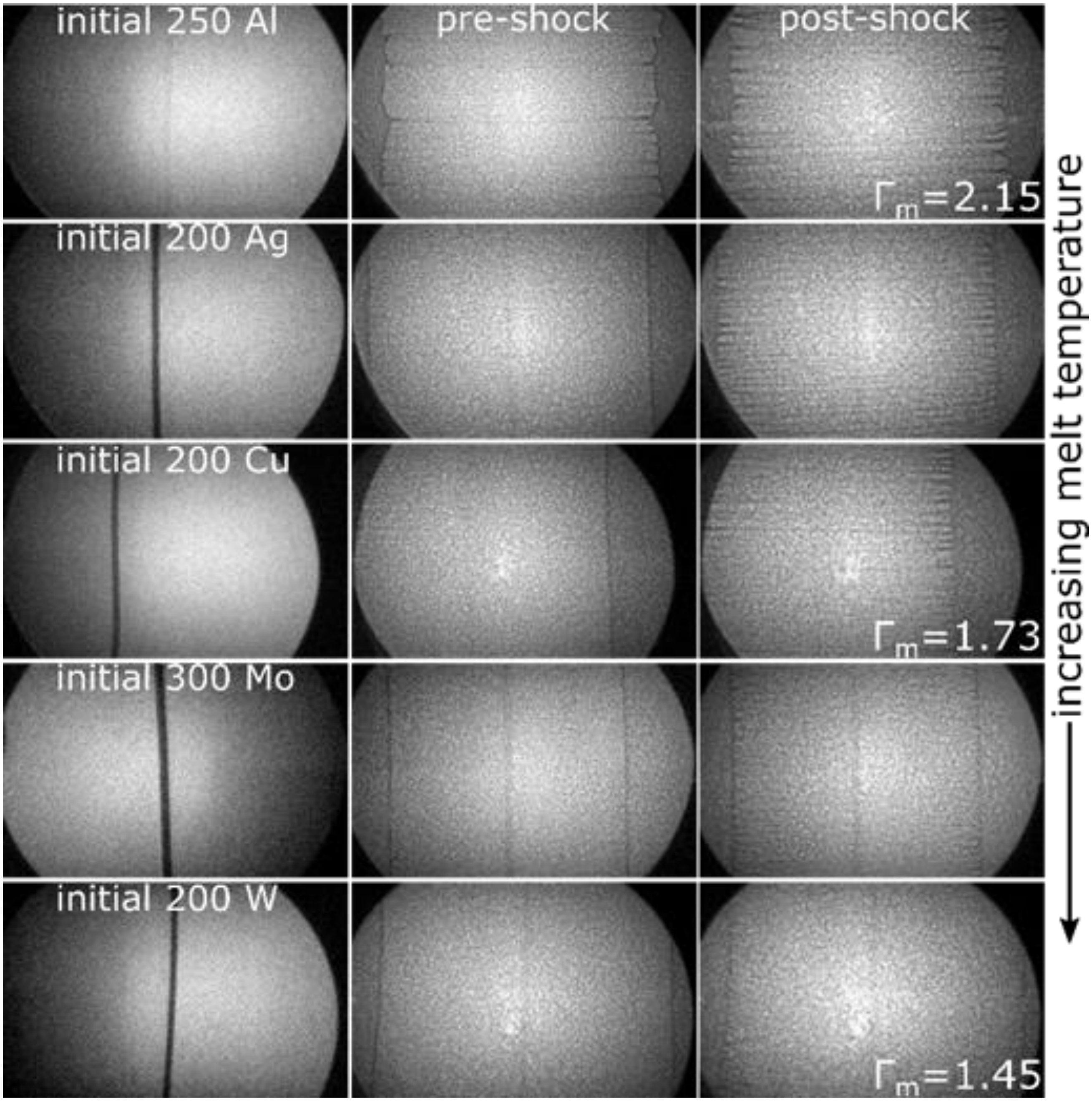
August 2022

In our experiments in August we primarily built upon the December results, utilizing the planar shock wave to directly produce hydrodynamic instabilities in low density, modulated aerogel foam targets:



These highly accurate, quantitative measurements of instability growth are being prepared for a High impact paper in **Physics of Fluids by Jergus Strucka** who is aiming to build upon the results exploring growth in converging and diverging geometries, which will represent world first measurements in these regimes.

Some of the experiments in August also utilized to perform accurate measurements of the wires conductivity during explosion and how this might be affected by the current driven electrothermal instability:



This work, which began with our initial ESRF experiment in 2018, is now coming to fruition. It proves that the data traditionally used to generate resistivity tables for large scale magneto-hydrodynamic simulations of HEDP phenomena cannot be relied upon and needs to be revisited in many cases. The results will be subject of an **invited talk by Jergus Strucka at the APS-DPP** conference in October 2022, which is the largest gathering of plasma physicists each year. The results are also being prepared for a **submission to Nature Communications**.