Experimental investigation of flyer plate launch at the M3 pulsed-power facility

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first light

First Light Fusion

First Light Fusion Ltd. is a privately funded company researching ICF target designs that are driven by strong shocks from high velocity projectile impacts.

A new pulsed-power generator called M3 has been commissioned. The large current pulse from the generator is used to launch flyer plates for impact into targets.

Experiments are performed to study launch mechanisms and benchmark our hydrodynamics and MHD codes, which we use for designing fusion targets.

M3: a low inductance pulsed power driver

New machine built to demonstrate fusion at FLF.

125 µF bipolar capacitor discharge. +/- 100 kV.

92 multi-channel ball gap switches.

Low inductance parallel plate transmission lines with multilayer Mylar insulation.

2.5 MJ of stored energy at full charge.

8 MA in 1.5 µs through a flyer plate load.

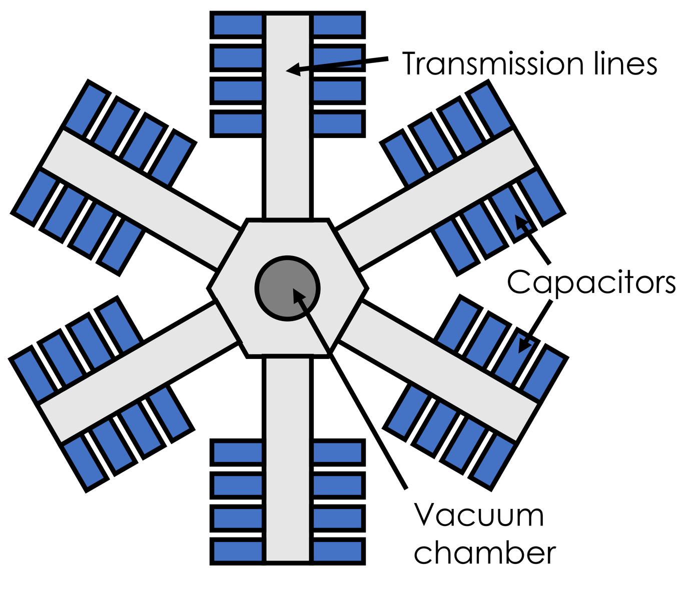

Fig. 2: Top-down schematic of M3.

Fig. 3: Photograph of completed M3.

The stripline load design

Flyer plates at First Light Fusion are launched using the 'stripline' load configuration, shown in Figure 1 and used previously at other facilities.[1-3] In this configuration, the current is forced through two narrow rectangular slabs, connected at one end by a conducting shim. For small anode-cathode gap widths (g), the magnetic field B in the gap is given by

$$B = \mu_0 I/(g + w)$$

where I is the input current and w is the width of the stripline. This field applies a magnetic pressure on the electrodes equal to:

$$P_B = B^2/2\mu_0.$$

For a flyer plate load design, a section of the top electrode is made much thinner than the rest, meaning that it accelerates at a faster rate. This flyer is allowed to travel a short distance before impacting a target.

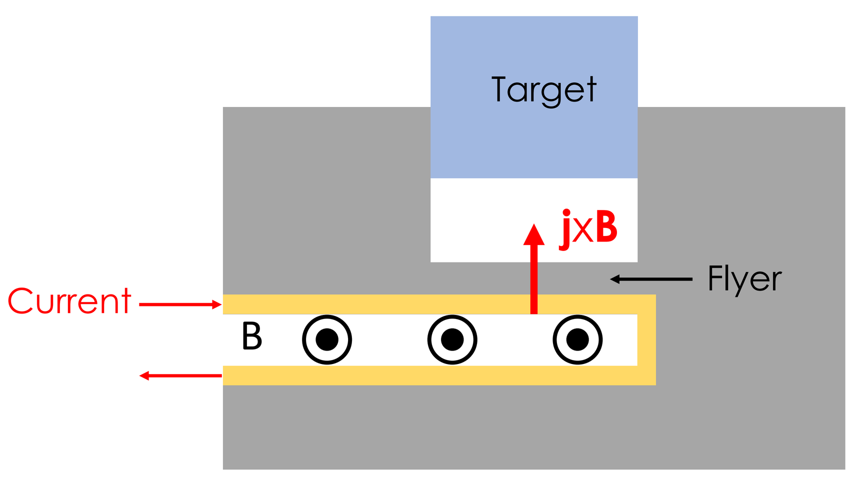

Fig. 1: Schematic of a flyer plate experiment.

Machine and target diagnostics on M3

Machine

- 1550 nm fibre-based Faraday rotation to measure the current
- 96 B-dot probes monitoring each switch
- 120 V-dot probes monitoring the switches and transmission lines

Load / target

- VISAR – 1D streaked and 2D imaging for measuring flyer velocity and planarity
- Optical backlighting and self-emission imaging
- PMT-coupled plastic scintillators to detect neutrons

References

1. R. W. Lemke, M D Knudson, & J-P Davis, *Int. J. Impact. Eng.* **38** 480 (2011)
2. A. Lefrançois et al., *IEEE Trans. Plasma Sci.* **39** 288 (2011)
3. X. Zhang et al., *Rev. Sci. Instrum.* **85** 055110 (2014)

Flyer plate experiments

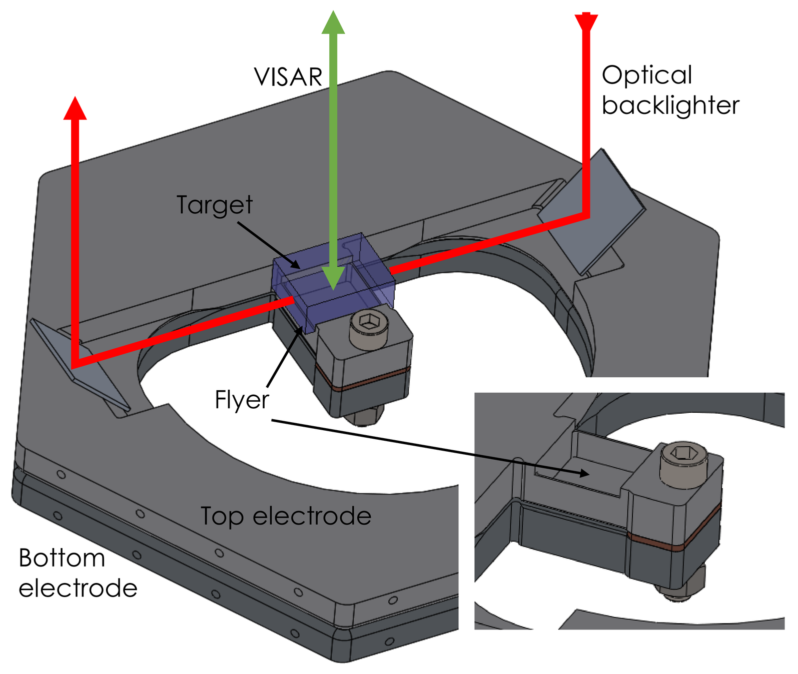

Fig. 4: M3 flyer plate experimental setup

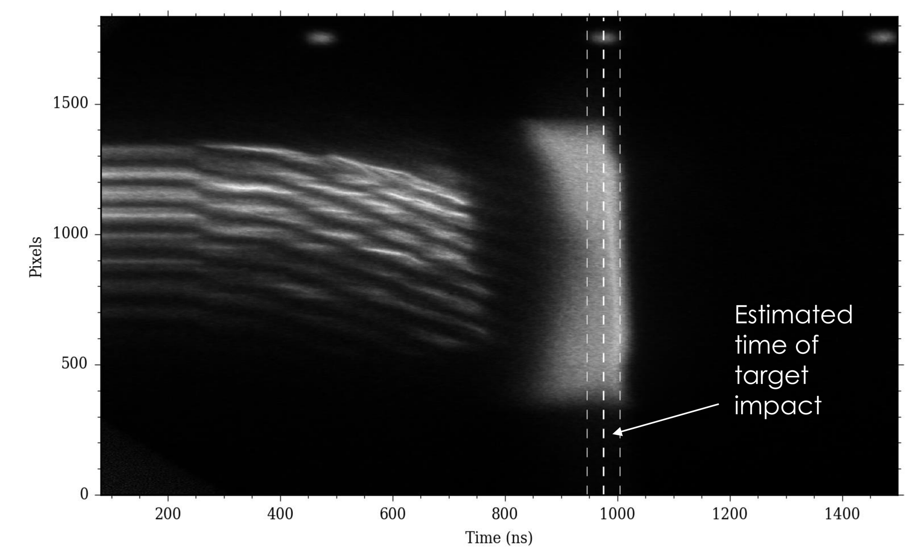

Fig. 5: Raw VISAR data from a flyer experiment

A number of flyer plate experiments have now been performed on M3, using the basic idea shown in Figure 1. A schematic of the actual experimental setup used is given in Figure 4. In the experiment presented here, the flyer plate is impacted into a clear PMMA block. The flyer is made of aluminium, has a thickness of 1mm and an initial area of 10x9mm. The bottom electrode is made of stainless steel. The initial target offset distance was 4mm.

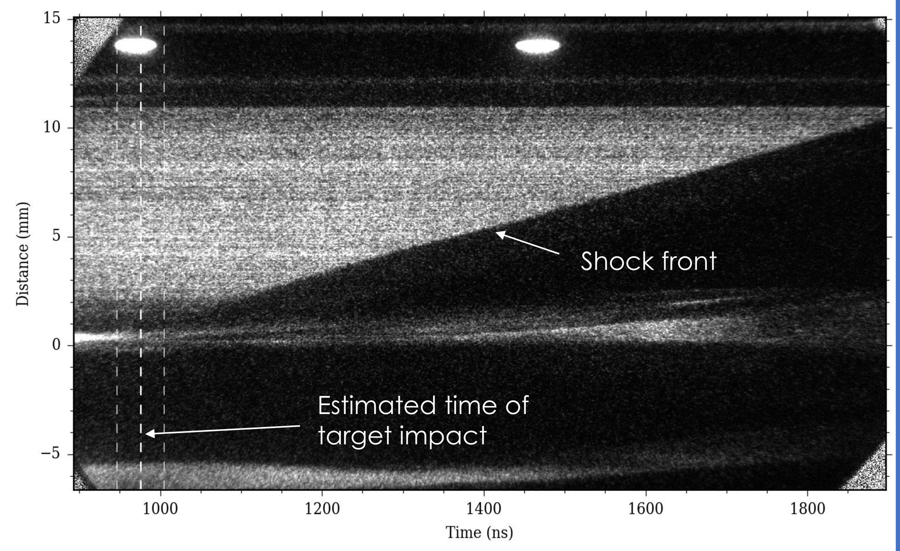

Fig. 6: Streaked shadography through the PMMA target. The driven shock wave can be seen as a light-dark diagonal transition across the image.

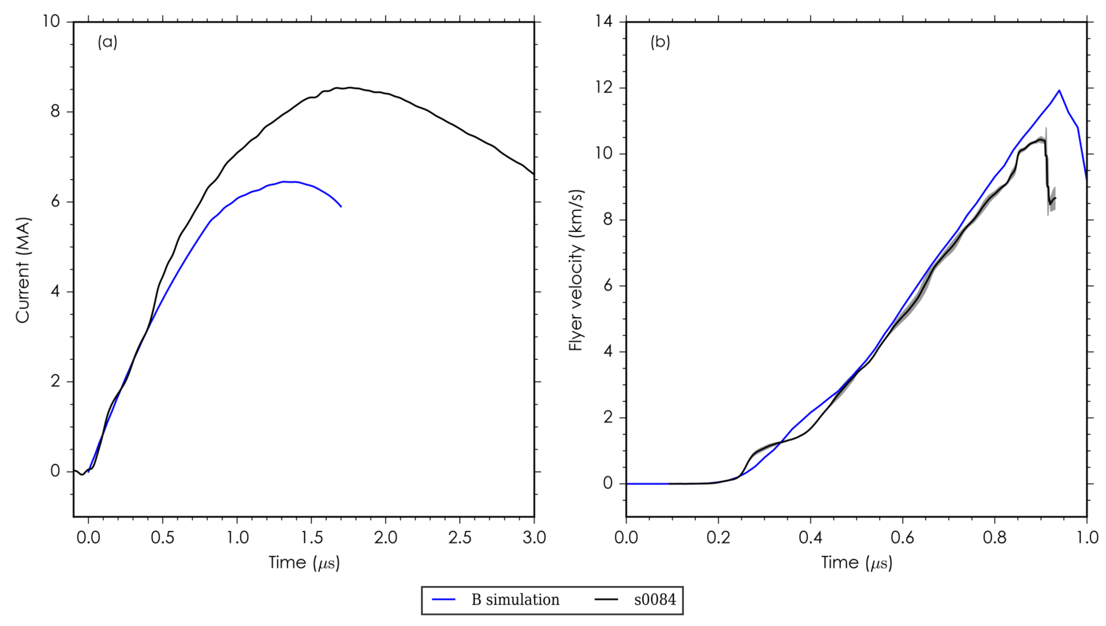

Fig. 7: Variation in (a) drive current and (b) flyer velocity with time, for a flyer plate experiment and a matched B simulation

Flyer velocity is measured using a 1D streaked VISAR system; the raw output from the streak camera is shown in Figure 5. The inferred velocity vs time trace is given in Figure 7. Also shown in this figure is the current as measured using the Faraday rotation measurement, and the results of a matched simulation of the problem. This simulation was conducted using our in-house resistive MHD code 'B'.

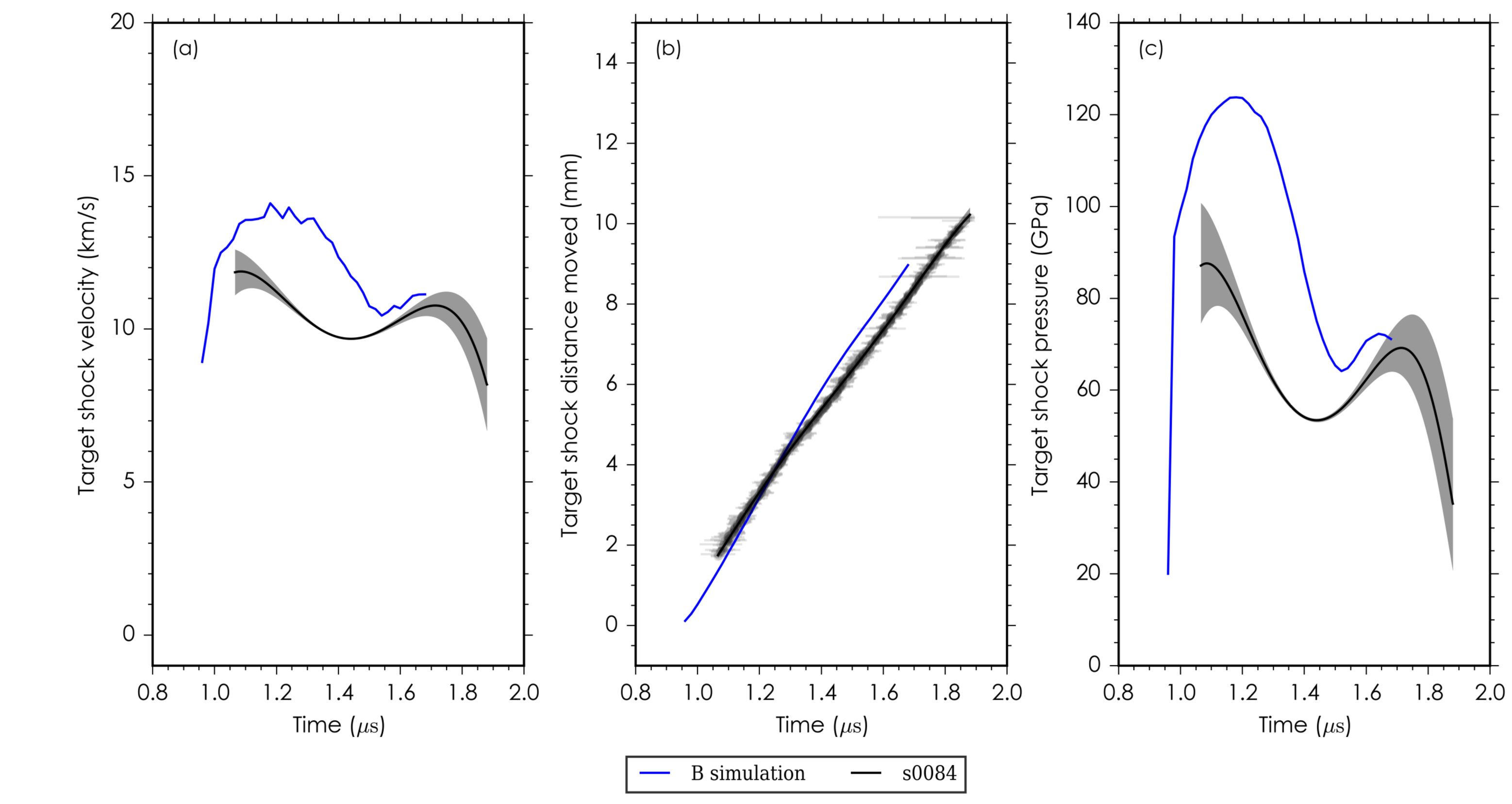

Fig. 8: Variation in (a) target shock velocity, (b) target shock distance moved and (c) estimated target shock pressure with time, for a flyer plate experiment and a matched B simulation.

On impact of the flyer plate on the PMMA target, a shock is driven in the target which occludes the optical back-lighter. By imaging the target from the side, we can measure the velocity of this shock wave as it propagates, and estimate the shock pressure.

The raw output of a streak image, taken across the centre of the shock is given in Figure 6. A comparison of the inferred target shock conditions with time, to the prediction from the B simulation is given in Figure 8.

Summary and future work

- We have designed, built and commissioned a 2.5 MJ pulsed power facility for performing EM launch and target fusion experiments
- The facility is equipped with a range of machine and experimental diagnostics
- Initial experiments have demonstrated flyer plate velocities of up to 13 km/s, and target shock pressures in excess of 150 GPa in PMMA.
- Measured flyer velocities agree well with simulations. However, at present measured experimental currents significantly exceed predictions, while target shock pressures are lower than expected.

Future work:

- Further load design studies
- EM launch flyer optimisation
- Fusion target shots