Experimental Study of Cerebrospinal Fluid (CSF) Cavitation in Blast- and Impact-Induced Traumatic Brain Injury

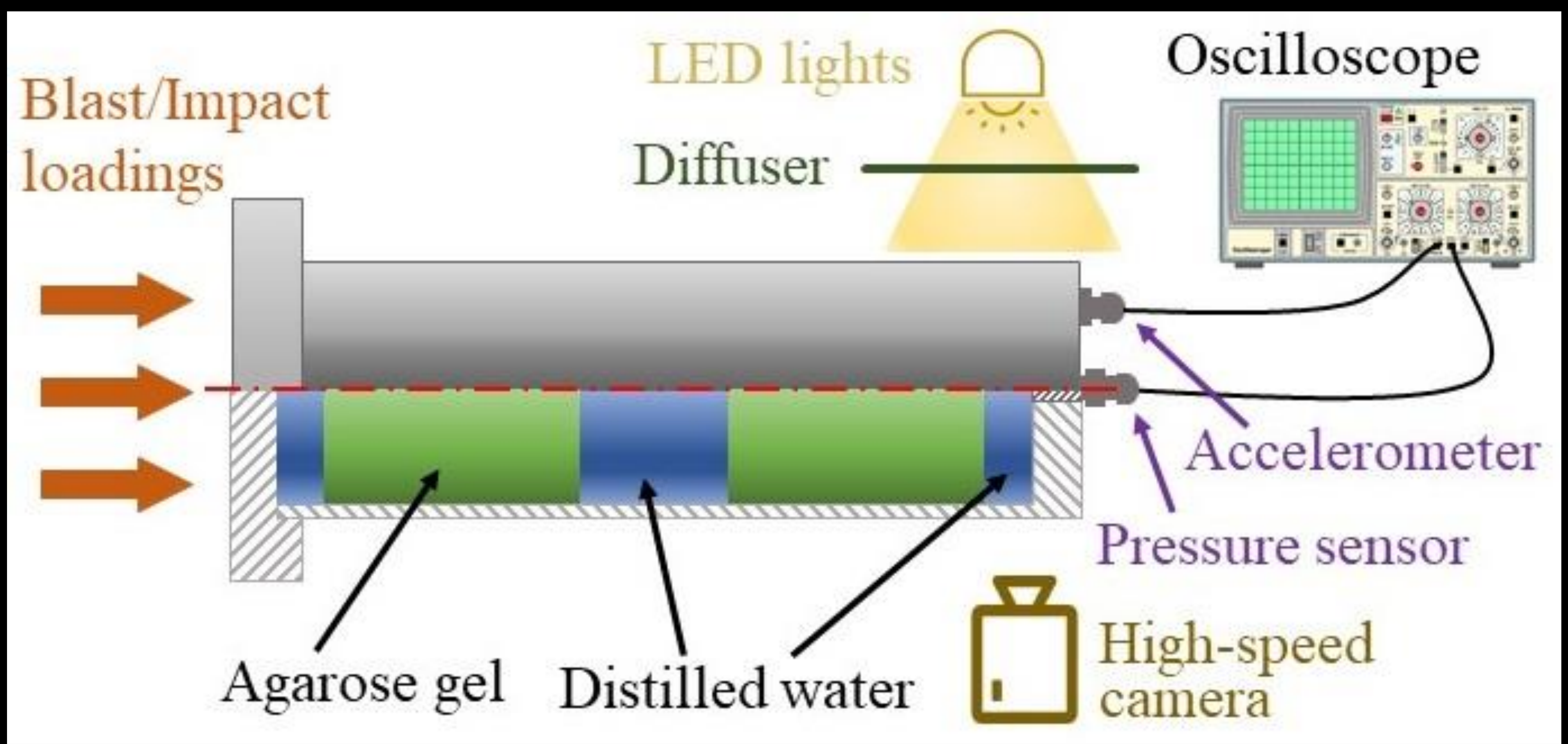
Xiancheng YU[1,2], Mazdak Ghajari[1,2]

[1]Dyson School of Design Engineering, Faculty of Engineering, [2]Centre for Blast Injury Studies, Imperial College London.

Introduction

Mechanisms of blast induced traumatic brain injury (bTBI), particularly the role of primary pressure wave, are still not fully understood. Recent neuropathological analyses of brain tissue from post-mortem cases of blast and impact induced TBIs have shown that blast exposure produces unique patterns of damage (astroglial scarring) that are distinct from those associated with impact exposure [1]. The damage mainly located at the boundaries between the brain tissue and fluid in cases with blast exposure. However, cases with impact exposure did not show the same pattern of damage. A likely physical mechanism for producing damage at the brain/fluid interfaces is cerebrospinal fluid (CSF) cavitation. In our previous study [2], we studied the CSF cavitation effect on brain deformation during blast exposure, using numerical simulations. Here, we developed a physical surrogate model to study CSF cavitation and showed the difference between blast and impact.

FIGURE 1: The test set-up of the 1D surrogate model.



Methods

We simplified the human head as a one-dimensional (1D) surrogate model (FIGURE 1). We used surrogate materials whose acoustic impedances are similar to the human tissues to achieve realistic pressure propagation and reflection; these include an acrylic tube (200mm in length), distilled water and agarose gel to model skull, CSF/ventricles and brain tissue, respectively. Three blast and impact tests were conducted. The test conditions are summarized in TABLE 1.

TABLE 1: Blast and impact test conditions

Blast tests	Overpressure (bar)	Positive duration (ms)
Blast 1	1.415	0.676
Blast 2	1.832	1.015
Blast 3	2.191	1.434
Impact tests	Impactor speed (m/s)	Paddings
Impact 1	5.68	40mm EPS 50
Impact 2	4.90	30mm EPS 70
Impact 3	4.90	20mm EPS 50

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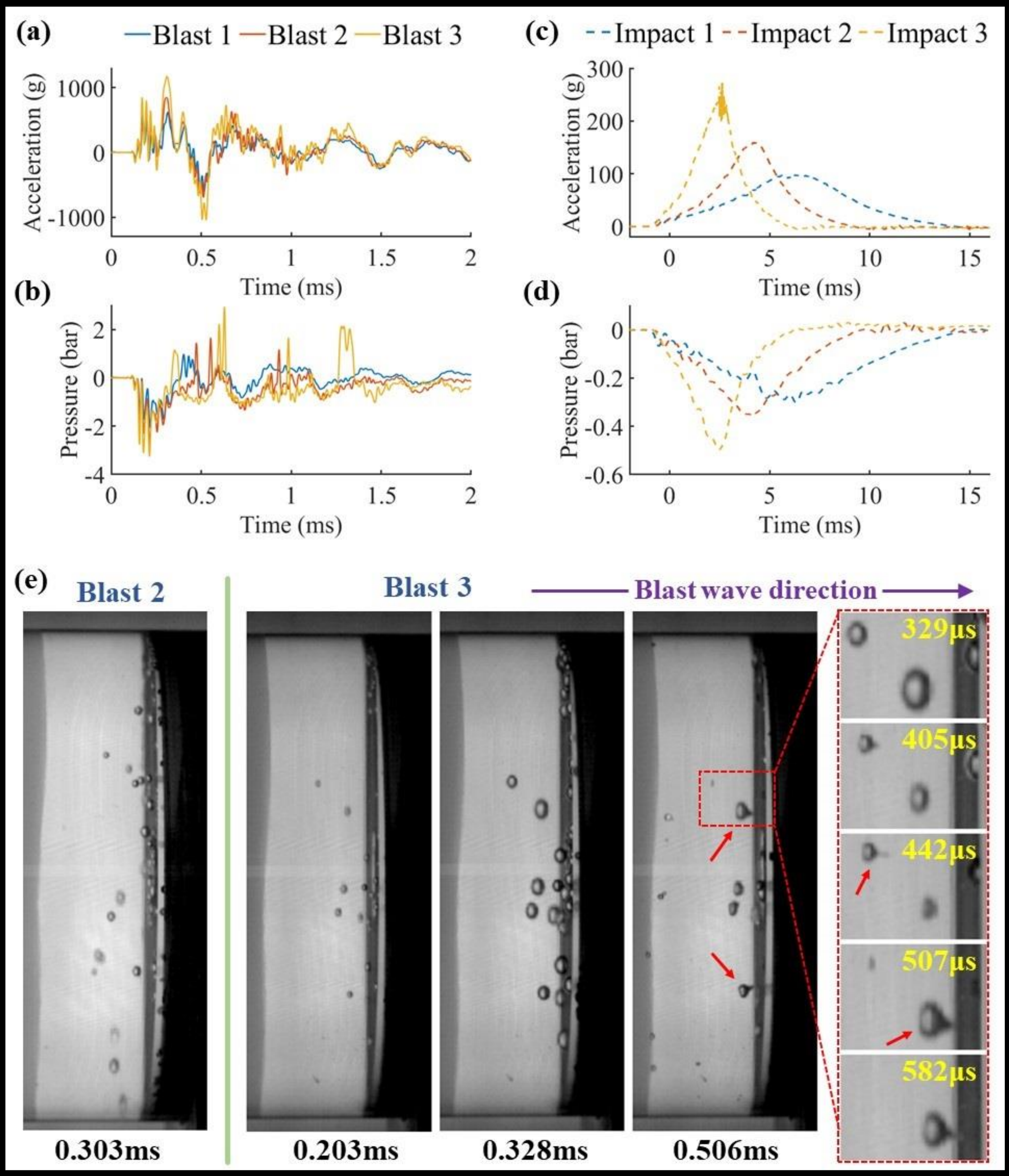
Results

We firstly compared the acceleration and pressure histories of the blast and impact tests (Figure 3a-d). The difference between the blast and impact is the rise time and peak of the acceleration histories. Blast-induced accelerations reach their first peaks within a rise time of at least 60-130 times shorter than that induced by impacts. This large difference produces the different type of contrecoup pressure histories in blast and impact tests shown in Figure 3b&d. Similar to the acceleration histories, the contrecoup pressure takes much less time to reach its peak under blast than impact (70-148 times faster).

We observed fluid cavitation phenomenon only in blast 2 and 3 tests. Figure 2e shows the formation and collapse of the cavitation bubbles in blast 3, compared to the maximum amount of bubbles in blast 2. The sequential video footage (zoom-in region, Figure 2e) shows the process of a micro-jet formation from the asymmetric collapse of a bubble.

FIGURE 2: The acceleration and pressure histories of (a, b) blast tests and (c, d) impact tests. (e) The high-speed video footages of blast tests and the formation of micro-jets (red arrow).



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