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Data Article

Numerical simulation data of an elongated cavitation bubble induced by long-pulsed laser

Xuning Zhao, Wentao Ma, Kevin Wang*

Department of Aerospace and Ocean Engineering, Virginia Polytechnic Institute and State University, Blacksburg, Virginia 24061, USA

A R T I C L E I N F O

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Elongated_Bubble_Induced_by_Long-pulsed_Laser (Original data)

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Long-pulsed laser
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Bubble dynamics
Level set method
Embedded boundary method

A B S T R A C T

The simulation data presented in this paper describes the formation and growth of an elongated bubble induced by a long-pulsed laser. The simulation is performed using the M2C solver, which is a recently developed three-dimensional finite volume Navier-Stokes CFD solver. The solver is used to simulate the fluid dynamics of the liquid water, the laser radiation, the laser-induced vaporization, and the fluid dynamics of the bubble after its formation. The data presented in this paper corresponds to a representative case of the cavitation induced by a narrow Gaussian beam (cf. [1]). Simulation data include laser radiance, fluid velocity, pressure, temperature, and bubble dynamics. The input files and the workflow to perform this simulation are also provided. With the information provided in this paper, researchers can repeat this simulation, and use it as a starting point to study related problems involving laser-induced cavitation, continuous vaporization, and bubble dynamics in general.

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* Corresponding author.
E-mail address: kevinwgy@vt.edu (K. Wang).

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Specifications Table

Subject	Mechanical Engineering
Specific subject area	laser-induced cavitation, bubble dynamics, computational fluid dynamics
Type of data	Image Video ASCII files (simulation inputs and outputs)
How the data were acquired	The simulation output data was generated using the M2C solver and the Tinkercliffs computer cluster at Virginia Tech.
Data format	Raw Visualized
Description of data collection	The simulation was performed using the M2C solver. The images and videos were generated using ParaView 5.9.1.
Data source location	• Institution: Virginia Polytechnic Institute and State • City/Town/Region: Blacksburg, VA • Country: USA
Data accessibility	Repository name: Mendeley Data Data identification number: 10.17632/bfrpzp8fz7.1 Direct URL to data: https://data.mendeley.com/datasets/bfrpzp8fz7/1
Related research article	[1] Zhao, Xuning and Ma, Wentao and Wang, Kevin G., Simulating Laser-Fluid Coupling and Laser-Induced Cavitation Using Embedded Boundary and Level Set Methods, Journal of Computational Physics 472 (2023): 111656.Available at: https://www.sciencedirect.com/science/article/pii/S0021999122007197

Value of the Data

- The simulation data describe the nucleation and expansion of an elongated bubble induced by a long-pulsed laser. The simulation accounts for the continuous vaporization, the non-spherical bubble expansion, and the formation of a bubble channel that extends the range of laser radiation. It also accounts for the emission of acoustic and shock waves.
- The simulation predicts the formation of a non-spherical bubble induced by the long-pulsed laser, which is primarily driven by the continuation of vaporization.
- The data presented in this manuscript allows researchers to repeat the simulation, which is a representative case in the co-submitted paper [1].

1. Objective

The objective of this paper is to provide additional data related to the co-submitting paper, entitled "Simulating Laser-Fluid Coupling and Laser-Induced Cavitation Using Embedded Boundary and Level Set Methods" [1], together with the necessary simulation inputs for readers to replicate some of the results presented in the paper.

2. Data Description

This paper presents a set of data associated with the numerical simulation of the formation and expansion of an elongated bubble induced by a Gaussian laser beam, in the context of laser-induced cavitation. The fluid dynamics are simulated using the finite volume method implemented in the M2C solver. The laser radiation is simulated using the module for solving the laser radiation equation in the M2C solver [1].

Figure 1 illustrates the problem investigated in this work. A cylindrical domain is filled with water initially, as shown in Figure 1(a). A Holmium: YAG laser with a wavelength of 2120 nm is used. The laser beam with a spatial Gaussian profile propagates through the water from the

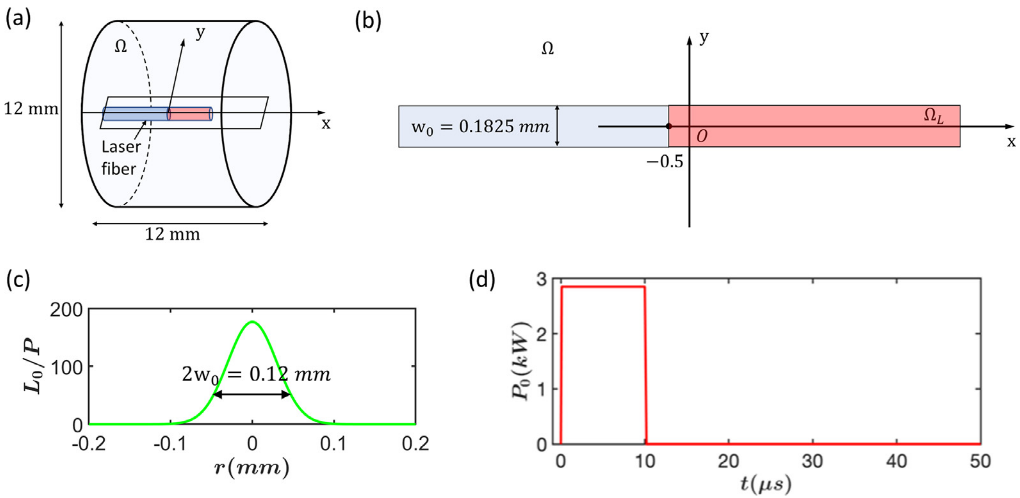

Fig. 1. Setup of the numerical experiment [1]. (a) Computational domain. (b) Geometry of the laser radiation domain. (c) Spatial profile of laser radiance (at peak power). (d) Temporal profile of laser power.

Table 1
Simulation input and output files.

File path	File description
Simulation/input.st	Input parameters
Simulation/laser_power.txt	The temporal profile of laser power (input)
Simulation/tinkercliffs_sbatch.sh	The bash script for submitting the simulation on Tinkercliffs
Simulation/log.out	The screen outputs generated by the simulation
Simulation/meshinfo.txt	Mesh information (output)
Images.zip	A sequence of images generated using the simulation result
Video/radiance_temperature.avi	An animation of the laser radiance and temperature fields
Video/pressure_velocity.avi	An animation of the pressure and velocity fields

Table 2
The properties of the laser beam [1].

Type	Wavelength	Laser fiber diameter	Beam waist	Divergence	Peak power
Holmium: YAG	2120 nm	0.1825 mm	0.06 mm	7.5°	2.854 kW

Table 3
Properties of the liquid water [1].

Initial pressure	Initial density	Initial temperature	Initial velocity	Specific heat at constant pressure	Laser absorption coefficient	Vaporization temperature	Latent heat
100 kPa	0.001 g/mm^3	273.15 K	0 mm/s	$\mathbf{4.2 \times 10^9}$ $mm^2/(s^2K)$	2.42 mm^{-1}	373.15 K	2256.4 J/g

Table 4
Properties of the water vapor [1].

Specific heat at constant pressure	Laser absorption coefficient	Heat capacity
$\mathbf{2.0 \times 10^9}$ $mm^2/(s^2K)$	0.001 mm^{-1}	1.34 [2]

laser source. The detailed setup of the numerical experiment is shown in Figure 1(b). Figure 1(c) shows the spatial profile of laser radiance at the laser source under peak power. The temporal profile of the laser power is shown in Figure 1(d). Specifically, P_0 increases linearly from 0 to 2.854 kW within 0.2 μs. It remains a constant until time reaches 10 μs. After that, P_0 is set to 0.

Table 1 presents the files that have been uploaded to the online repository, including the input files that are required to launch the simulation and selected simulation outputs. The file paths are relative to the main directory. Specifically, the input files are placed inside the ***Simulation*** folder. A sequence of 404 image files is placed in the ***Images*** folder, which shows the evolution of the laser radiance, bubble dynamics, and the temperature, velocity and pressure fields. Two animations created using these images are located in the ***Video*** folder. A file of mesh information is also output and placed in the ***Simulation*** folder. The screen outputs generated by the simulation are recorded in a file, and placed inside the ***Simulation*** folder.

3. Experimental Design, Materials and Methods

3.1. Laser and Material Properties

Table 2 presents the properties of the laser. The properties of the liquid water are listed in Table 3. The physical properties of the water vapor inside the bubble are listed in Table 4.

Table 5
External libraries used by M2C.

Name	Versions
Boost	1.71.0
Intel MPI	2018.5.288
Eigen	3.3.8
METIS	5.1.0
MUMPS	5.2.1

The liquid water is modelled by the stiffened gas EOS [1,3] with γ =6.12 and p_c = 343 MPa, where γ and p_c are fitting parameters and determined from the shockwave Hugoniot data of water [4]. Water vapor is modeled by the perfect gas EOS.

3.2. Solver and External libraries

The simulation was performed using *changeset* e0fcb17f381f4f58ca046bcd9dd3da785f0f2fae in the M2C repository. The versions of external libraries used by the M2C solvers are listed in Table 5.

3.3. Simulation Process

The fluid domain is divided into 512 subdomains, with each one assigned to one CPU core. The simulation parameters are specified in ***input.st***. The temporal profile of laser power is specified in ***laser_power.txt***. The simulation was launched on the Tinkercliffs computer cluster using the sbatch script ***tinkercliffs_sbatch.sh***.

The simulation is carried out on a two-dimensional mesh, leveraging the cylindrical symmetry of the problem. The mesh is Cartesian, with approximately 338, 000 elements. The time step size was around 3×10^{-4} s. After 167, 749 time steps ($t = 50$ μs), the simulation was terminated. The total wall-clock time was approximately 3.8 hours.

3.4. Simulation Data

Outputs of the simulation include, but are not limited to, the laser radiance, the fluid pressure, velocity, temperature, and level-set (for liquid-gas interface tracking) fields [5]. Figure 2 presents a sequence of images showing the laser radiance fields and the formation of an elongated bubble. Each sub-figure is taken at a time instant labeled at the bottom. Figure 3 presents a sequence of images showing the pressure fields and the expansion of an elongated bubble.

Additional data in the form of images and animation can be found in the uploaded folder. All the images were generated using ParaView, version 5.9.1.

Ethics Statements

This work does not involve human subjects, animal experiments, or data collected from social media platforms.

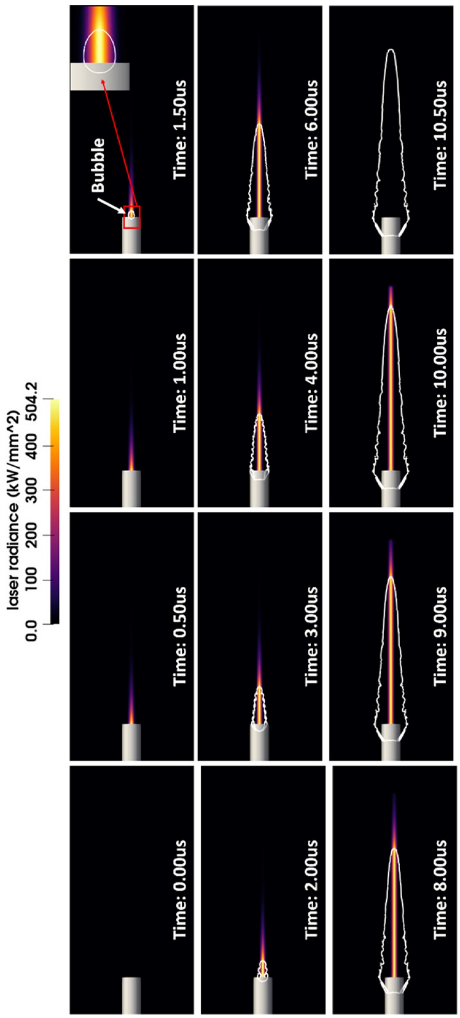

Fig. 2. Solution snapshots of the laser radiance.

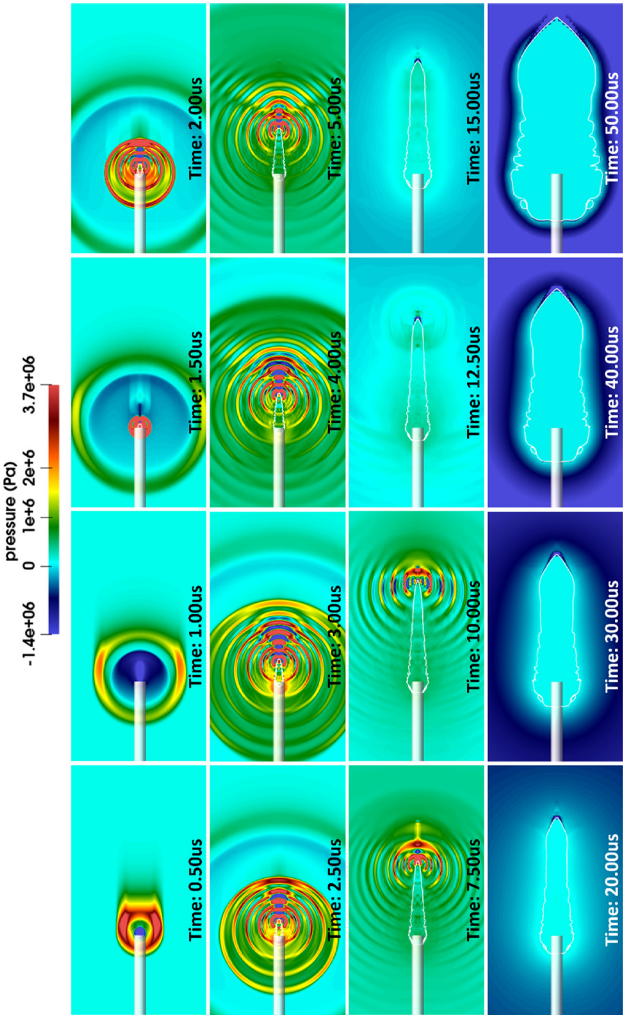

Fig. 3. Solution snapshots of the pressure.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data Availability

Elongated_Bubble_Induced_by_Long-pulsed_Laser (Original data) (Mendeley Data).

CRediT Author Statement

Xuning Zhao: Conceptualization, Methodology, Investigation, Visualization, Software, Writing – original draft, Writing – review & editing; **Wentao Ma:** Investigation, Visualization, Writing – review & editing; **Kevin Wang:** Conceptualization, Methodology, Software, Writing – original draft, Writing – review & editing, Project administration.

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