# Constraining Physical Models at Gigabar Pressures

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Large-scale, high-energy-density (HED) experimental facilities are able to generate states of matter that push beyond the limits of where most physical models were developed. This necessitates quantitative experiments to guide theories and techniques at such conditions. Convergent geometries, either spherical or cylindrical, amplify the pressure generated from HED drivers, such as lasers or pulsed-power machines, and create the most-extreme thermodynamic states currently achievable in the laboratory. These convergent experiments complicate measurements, however, making it difficult to directly measure the state of variables and transport properties. Often, measurements are the result of an integrated system, where many properties of the system are responsible for observations, rather than a small number of key physical quantities. Such integrated system analysis requires a new way of approaching how experimental data are interpreted.

This work proposes using the well-established methodology of Bayesian inference[1,2] to derive quantitative physical information from integrated HED experiments. This process includes the synthesis of a model that contains the essential physics from the experiment and is used in a forward analysis, generating synthetic experimental data to directly compare to the measurements. Given the proper parameterization and set of measurements the model can be constrained, giving a quantitative assessment of the input parameters.

This process is demonstrated using a direct-drive exploding-pusher experiment carried out on the 60-beam OMEGA Laser System, where the trajectory of an exploding shell is measured via x-ray self-emission on an x-ray framing camera. Synthetic data generated using the 1-D hydrodynamics code *LILAC* is also analyzed, confirming that the parameterization accurately represents the physical quantities of interest. The process is used to infer the temporal pressure profile felt by an in-flight shell and the subsequent trajectory from experimental measurements, demonstrating how a large amount of physical insight can be gained by using integrated measurements.

The model used to describe the experimental data is a thin-shell subject to force pushing in to greater convergence due to mass ablation and an outward force resisting convergences due to pressure from the compressed fuel. The equation of motion

$$\frac{d^2 R}{\mathrm{d} t^2} = a, \tag{1}$$

is solved, where $R$ is the trajectory of the shell and $a$ is the acceleration given by

$$a(t)=\begin{cases}0 & t<t_a\\[2ex] \dfrac{4\pi R^2 P}{M}-\dfrac{\dot{M}v_\mathrm{e}}{M} & t_a\le t<t_1,\\[2ex] \dfrac{4\pi R^2 P}{M} & t\ge t_1\end{cases} \tag{2}$$

where $P$ is pressure at the fuel–shell interface given by

$$P(t)=\begin{cases}\left(P_\mathrm{rs}\right)e^{-\gamma_g\left(t_s-t\right)} & t\le t_s\\[2ex] \left(P_\mathrm{rs}\right)e^{-\gamma_d\left(t-t_s\right)} & t\ge t_s\end{cases} \tag{3}$$

and $M$ is the shell mass given by

$$M(t)=\begin{cases}M_0-\dot{M}\left(t-t_a\right) & t\le\min\left[t_s,t_M\right]\\[2ex] M_\mathrm{min}+\dot{M}\left[t-\min\left(t_s,t_M\right)\right] & t>\min\left[t_s,t_M\right]\end{cases} \tag{4}$$

with $\dot{M}$ and all subscripted variables parameters in the model.

The resulting trajectory and pressure profile that follow from the Bayesian inference process are shown in Figs. 1(a) and 1(b), respectively. The framing-camera measurements of the outgoing shell trajectory, in conjunction with conservation laws and initial conditions, are sufficient to constrain the shell trajectory at all times, from laser on to shell decompression, and also to constrain the pressure profile at the fuel–shell interface.

The methods presented here showed how a seemingly isolated, integrated measurement of an evolving system can be used to reconstruct a model of the entire system with enough fidelity to gain quantifiable physical insight. This methodology has a strong

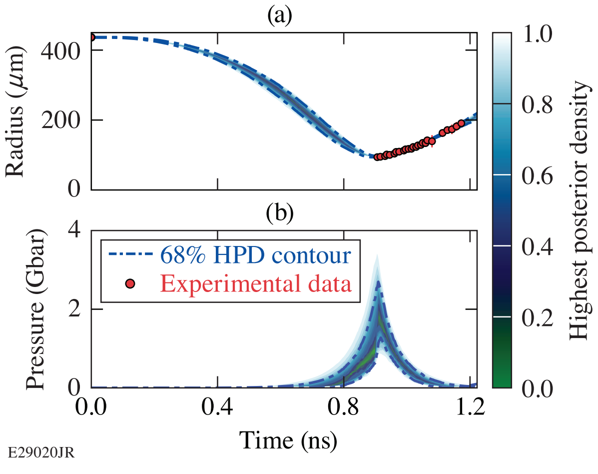

Figure 1
The highest posterior density (HPD) confidence intervals for the (a) shell trajectory and (b) pressure profile at the fuel–shell interface determined from fitting the shell model described here. The trajectory measurements of the outgoing shell and initial conditions of the shell are sufficient to constrain the trajectory and pressure at all times.

history of being used in other fields of physics and has the potential to greatly impact HED physics by making possible quantified measurements in conditions otherwise inaccessible.

The combination of high-quality experimental methods and facilities that already exist in HED physics are able to create conditions otherwise impossible on Earth, and new analysis techniques for integrated measurements promise to provide new insight into our understanding of physics at extreme conditions.

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