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# Transition to Turbulence Generated by Interfacial Instabilities During a Cylindrical Implosion

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**Abstract.** In this paper we describe two methods for the analysis of the transition to turbulence at the unstable inner surface of a thin metallic shell subjected to a cylindrical implosion. The first method is based on a comparison of the mixing zone width from the experiment and its simulation in a planar configuration. The second method is a biorthogonal analysis of the simulated implosion. A refined calculation of the experiment is also shown. The two methods show that these flows are highly transitional and may be turbulent.

## 1 Introduction

The transition to turbulence, originating in a hydrodynamic instability, is a very complex problem. On the one hand, both the linear phase of the instability and the first stages of the non linear development of the flow are accessible via either analytical or computational tools at a reasonable cost. On the other hand, statistical models are available for the fully developed turbulent regime. In contrast, the strongly nonlinear transition process can be predicted nowadays only by direct numerical simulations at a high computational cost.

For a long time, at CEA Vaujours-Moronvilliers, we have been developing experimental and numerical tools to study imploding systems such as ICF laser targets. A particularly well suited system for these studies is a detonation wave generator which induces a cylindrical wave in a tin shell (density $\rho = 7.28$ g/cm$^3$) whose inner face is machined in a predetermined way [1]. The shell is filled with silicon (density $\rho = 1.1$

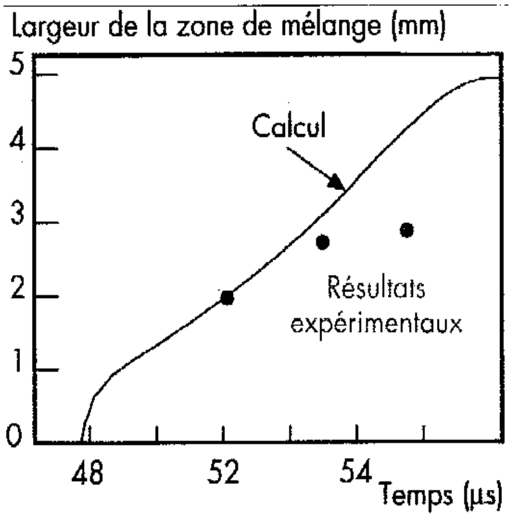


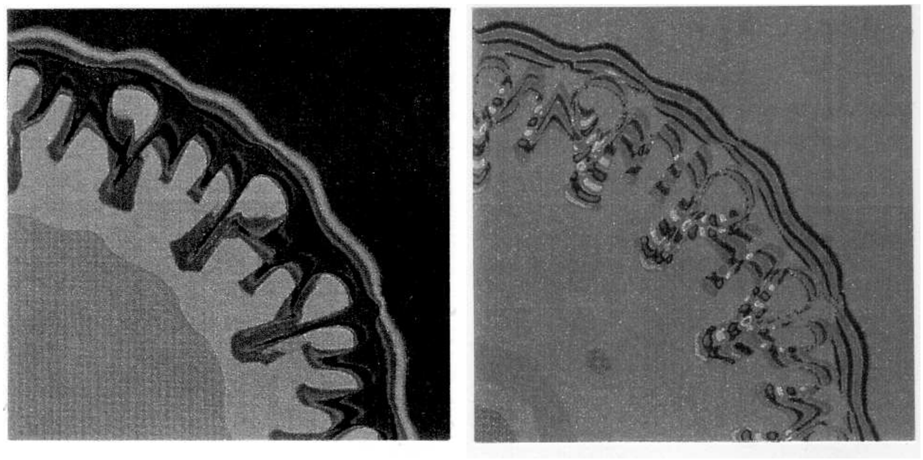
Figure 1: Mixing zone thickness vs. experimental time, comparison of a planar simulation (line) and three experimental points (small defects).

g/cm$^3$) and the initial defect of the tin/silicon interface will grow during the Richtmyer-Meshkov (RM) and Rayleigh-Taylor (RT) phases. The external and internal diameters of the cylindrical wave generator are 200 mm and 100 mm respectively and the thickness of the tin shell is 4 mm. In the previous experiments, the defect was a combination of large modes of wavelength 10, 13 and 22 mm of amplitude 0.5 mm. In the recent experiments, the combining wavelengths were 0.6, 1, 3 and 6 mm with the corresponding amplitudes at 0.08, 0.05, 0.06 and 0.05 mm.

## 2 Simulation and analysis

### 2.1 Measurement of the experimental MZW

The implosion of the cylindrical tin shell has been recorded on photographic film using the flash X-ray generator GREC at 3 different instants, requiring 3 identical experiments. It is very difficult to obtain a direct measure of the MZW from the experimental radiographic image because of the blur induced by the imaging system. We therefore use a convolution method. The blur induced by the imaging system is identified and modeled with specific experiments. The analysis is carried out in 4 steps. The computed radial profile of the density is digitized to create a perfect radiographic image. The image is then convoluted to take into account the blur induced by the real imaging system. A comparison between the mean radial profile of the experimental radiograph



**(a)** **(b)**

Figure 2: (a) first and (b) sixth topo from the biorthogonal analysis of the density (large defects).

and the convoluted one is performed. Finally, if the results are not satisfactory, the initial density profile is modified.

### 2.2 Direct analysis of the numerical results

We are now using two 2D codes capable of simulating the flow: EAD [2] which is implemented on a CRAY YMP computer and a more recent Eulerian code (using a Godunov scheme) implemented on the CRAY T3D, a massively parallel computer. A simulation of a quarter of the entire cylindrical implosion using the latter will be reported in Section 3. EAD simulations have been carried out to define the experiments with small wavelengths. Here, a planar approximation for a small wedge of the cylindrical device has been simulated in order to reduce the computing time [1]. We observe a deviation between the evolution of the computed MZW and the experimental measurements (fig. 1) which is probably due to the planar approximation. The dependence of the computed MZW growth on the initial conditions has been discussed previously [1].

### 2.3 Biorthogonal analysis

In order to perform a more global and quantitative comparison of the full space-time dynamics of the various flows, a biorthogonal analysis [3] has been applied to the results of previous EAD simulations of experiments with longer wavelengths. The first and sixth topos and chronos of the density field are represented in figs.2-3. The chronos in this type of field are close to Fourier modes. Although in the present flow, the first

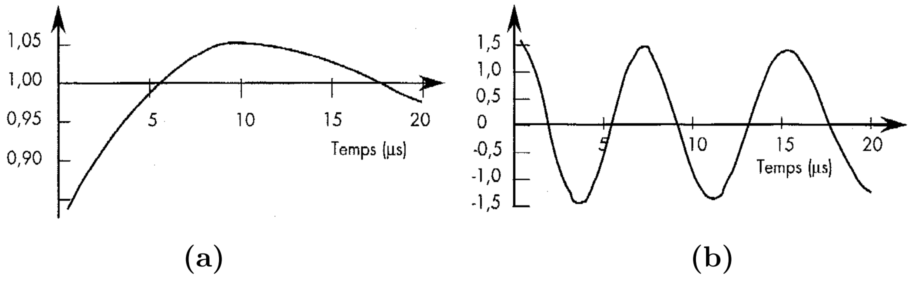


Figure 3: (a) first and (b) sixth chrono from the biorthogonal analysis of the density.

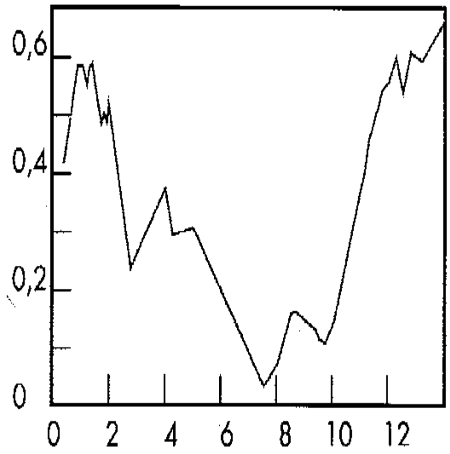


Figure 4: Spatial entropy of the velocity vs. simulation time (planar case).

chrono (fig.3(a)) is close to the average of the flow, this is not always the case (see a necessary and sufficient condition in [4]).

The method has also been applied to the planar EAD simulations with short wavelengths (a more detailed report can be found in [3]). The most interesting results concerning the transitional character of the flow are related to the temporal variations of the spatial entropy of the velocity field (fig. 4). It is close to zero at early times and abruptly grows during the RM phase. The complexity of the flow then decreases before increasing under the effect of the RT instability. It is clear that turbulence can start "settling" only after the beginning of this second growth. Although it is very likely that the strongly nonlinear, transitional phase of the flow is reached at this point, whether the flow is fully developed or not still remains a challenging question (see other arguments in [3]). The transition phase is obtained but it is impossible to say whether

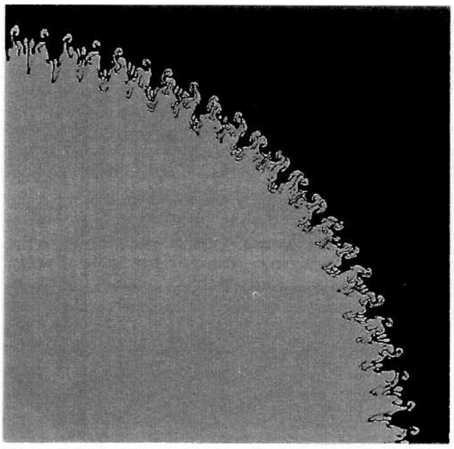


Figure 5: Concentration from a refined simulation (small defects).

we obtain a fully turbulent flow. The answer to this question may be reached via the analysis of more accurate numerical simulations data, such as the one described below.

## 3 Refined calculation

With massively parallel computers like Cray T3D it is now possible to have a complete simulation of the experiment. We then can take into account all the physics included in the experiment from detonation of the external HE to the growth of the RT and RM instabilities into bubbles and spikes and this on the whole cylinder. Fig. 5 is the result of such a calculation on a quarter cylinder using the same refined grid for the interface defects as in the planar EAD simulations. The code solves the 2D, non-stationary and compressible Euler equations using an interface reconstruction method. Chemical kinetics is used to simulate the detonics and the behavior of materials is described by a stiffened gas equation of state. In the region around the 45° line, we used 25 cells for the shortest wavelength of the defect allowing a correct tracking of the growth of the defects. A coarser grid is used elsewhere with $4\ 10^6$ cells in total. At the present time, the analysis is a huge problem because of the enormous volume of data and the necessity to have appropriate tools. The precision of the first results is higher that of the experimental data (of the order of 1.3 mm). The numerical parameters (scheme, mesh, boundary conditions etc.) have a strong influence. In particular mesh effects are clearly evidenced on fig. 5 as the instability is better described around the 45° line.

## 4 Conclusion

Different methods of analysis applied to the same flow have led to a description of the transitional character of the latter. This result is promising because of the completely different nature of the methods. We intend to extract from our DNS calculations the parameters needed to initialize our turbulent codes based on statistical techniques. For instance, it is possible to obtain the turbulent energy $\kappa$ and the turbulent dissipation $\varepsilon$ from our DNS calculations as well and compare them with the results of statistical models (such as $\kappa$-$\varepsilon$). The possibility to determine a MZW experimentally with small initial defects (such that the resulting structures are not resolved by the radiography) allowed us to study quasi turbulent flows. Our next step is to analyze the refined calculations using the same methods as shown here for the EAD calculations.

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