

High-resolution 2D simulations of deceleration-phase RTI in the non-linear regime.

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The Rayleigh-Taylor instability (RTI) developing at the inner surface of an imploding capsule represents a serious threat to ICF. Beyond the linear phase, the unstable surface distorts up to the point of forming ‘spikes’, narrow dense structures penetrating the hot spot, and ‘bubbles’ of rarefied gas expanding into the wall of the capsule and eventually disrupting the shell. Linear analysis of RTI has been carried out in convergent geometry both classically [1, 2], and including ablative stabilisation [3, 5, 6]. Due to the complexity of active physical phenomena and energy transport mechanisms, the study of the non-linear regime of deceleration-phase RTI demands for high-resolution 2D and 3D numerical simulations [6, 7, 8, 9, 10]. Here we present numerical investigations of the late stages of the implosion of an indirect-drive NIF-like target, the same that had been used for a previous analysis in the linear regime [6].

At the end of the coasting phase, 280 ps before shell stagnation, a large amplitude perturbation was imposed on the density profile at the hot spot radius. This served as a seed for the instability. The amplitude of the mass displacement was set to 1/100 of the hot spot radius at that time. The perturbation had a gaussian profile in the azimuthal direction and was set to decay exponentially in the radial direction. By changing the sign of the amplitude, it was possible to initialise a single gaussian spike or a single gaussian bubble. In order to compare with usual analysis based on Legendre polynomials, the gaussian perturbation was labelled with a mode number ‘ l ’. For a given l , the FWHM of the spike/bubble was set equal to the azimuthal period of the corresponding Legendre polynomial of order l .

Two different physical models were used in the simulations [11] to highlight the effects of energy transport phenomena in the evolution of the deceleration-phase RTI. The more realistic and complete model, hereafter called ‘FUSION’, included hydrodynamic motion, electron thermal conduction, Bremsstrahlung losses, fuel burn and multi-group α particle diffusion in two dimensions. The second model, called ‘CLASSICAL’, included just the motion of the fluid, neglecting the energy transport phenomena and the nuclear reactions in the fuel. Figure 1 presents density maps of the evolution of a single gaussian spike of mode $l = 72$ before, at, and after the stagnation point. The classical instability (top frames) is characterised by an almost ‘free-falling’ spike penetrating the hot spot. The ablative stabilisation of the spike is clear when the fusion model was used (bottom frames). The effectiveness of this stabilisation increases going

to higher modes, as predicted by the linear analysis [3, 4, 5, 6], and as shown by the non-linear regime simulations presented in Figure 2. In order to study the differences between 2D and 3D non-linear evolution of the instability, a series of gaussian spikes/bubbles was initialised at fixed $\Delta\theta$ intervals, covering a whole 90° sector. It was found that the perturbation on axis $\theta = 0$ (best representing the 3D case) is growing slightly faster than the off-axis perturbations, as shown in Fig. 3. Here, using the classical model, the spike contamination and the disrupting effect of the bubbles are evident. In the fusion model, stabilisation of the spikes is very effective, whereas the expansion of the bubbles is not greatly inhibited by the energy transport mechanisms. We also investigated further the non-linear effects on the efficiency of capsule burn. The perturbation was initialised using a larger spectrum (up to $l = 144$) than in our previous analysis [6]. A high-resolution mesh was used to accurately track the higher modes in the unstable layer. More than 12 points per wavelength in the azimuthal direction and more than 30 points in the radial direction were used to resolve the highest mode. Such requirements correspond to a typical mesh of about half a million mesh points. Target specification spectra and DT-ice one-dimensional modal power measurements were coded into a synthetic 3-band *ice spectrum*. Several test spectra were obtained by varying the relative amplitude of each band. Burn degradation was then investigated for each class of spectrum by varying the overall σ_{rms} of the inner surface and obtaining the expected yield of the capsule. Figure 4 presents two density snapshots of a typical multi-mode implosion. The rescaled yield as a function of the perturbation σ_{rms} is also shown here for a *white* spectrum and an *ice* spectrum. Detailed analysis of these simulations is presently in progress and will be published in the near future.

References

- [1] M. S. Plesset, J. Appl. Phys. **25**, 96 (1954)
- [2] P. Amendt *et al*, Phys. Plasmas **10**, 820 (2003)
- [3] V. B. Lobatchev and R. Betti, Phys. Rev. Lett. **85** 4522 (2000)
- [4] H. Takabe, K. Mima, L. Montierth and R. L. Morse, Phys. Fluids **28** 3676 (1985)
- [5] S. Atzeni and M. Temporal, Phys. Rev. E **67**, 057401 (2003)
- [6] S. Atzeni, M. Temporal and A. Schiavi, Plasma Phys. Controll. Fusion **46**, B111 (2004)
- [7] M. Marinak *et al*, Phys. Plasmas **8**, 2275 (2001)
- [8] P. W. McKenty *et al*, Phys. Plasmas **8**, 2315 (2001)
- [9] R. Kishony and D. Shvarts, *Phys Plasmas* **8**, 4925 (2001)
- [10] D. S. Clark and M. Tabak, Phys. Rev. E **71**, 055302(R) (2005); Phys. Rev. E **72**, 056308 (2005)
- [11] S. Atzeni *et al.*, Comput. Phys. Commun. **169**, 153 (2005)

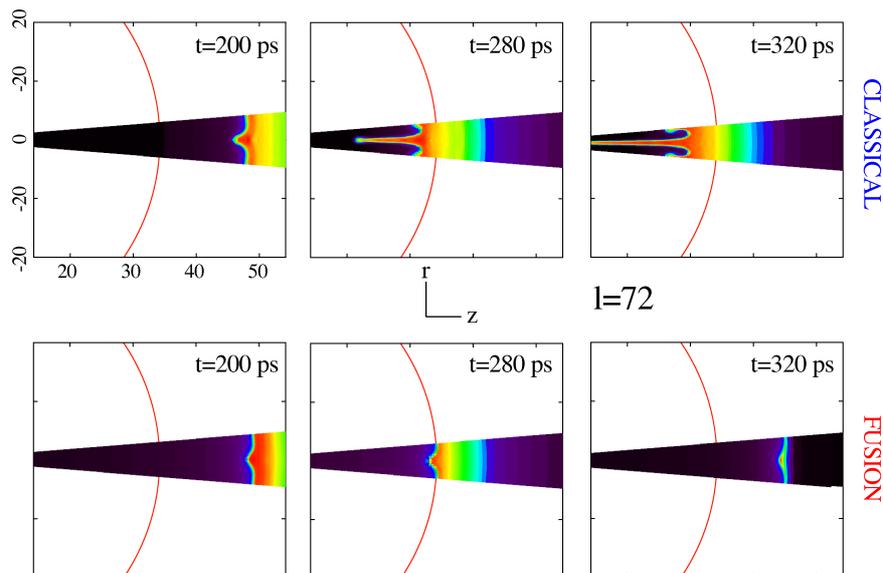


Figure 1: Single spike sequence for an equivalent Legendre mode $l=72$: evolution of the same perturbation seed for the two models at $t = -100$, $t = 0$ and $t = +40$ ps with respect to the stagnation time. Spatial units are in μm . The red thin line depicts the stagnation radius for the 1D fusion model.

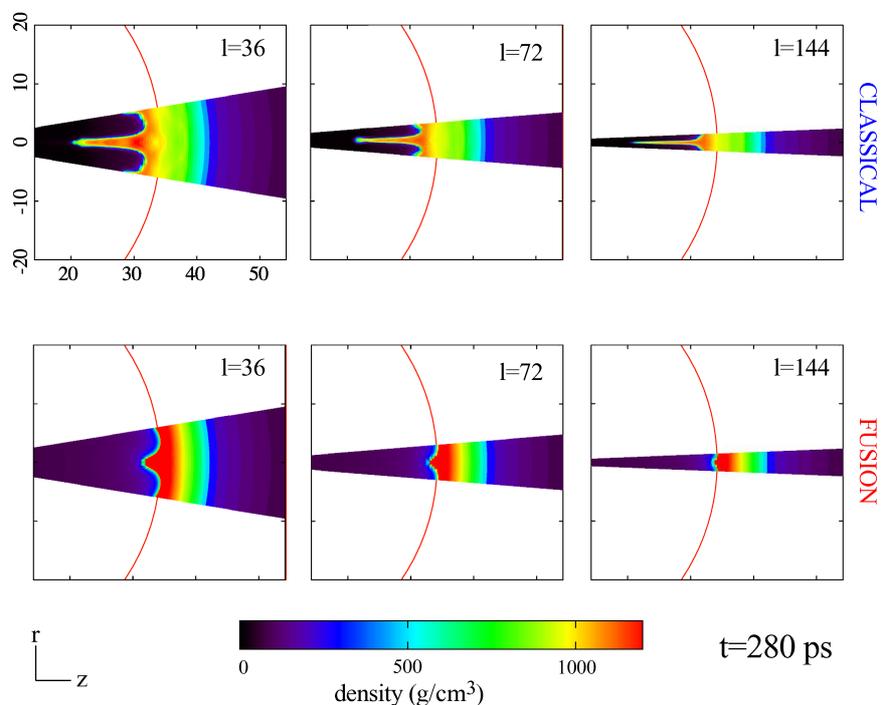


Figure 2: Single gaussian spikes at stagnation time: comparison of perturbation amplitude for equivalent mode numbers $l = 36, 72, 144$ and for the two physical models. Linear colour scheme of the density map applies to all frames. Layout same as in Fig. 1.

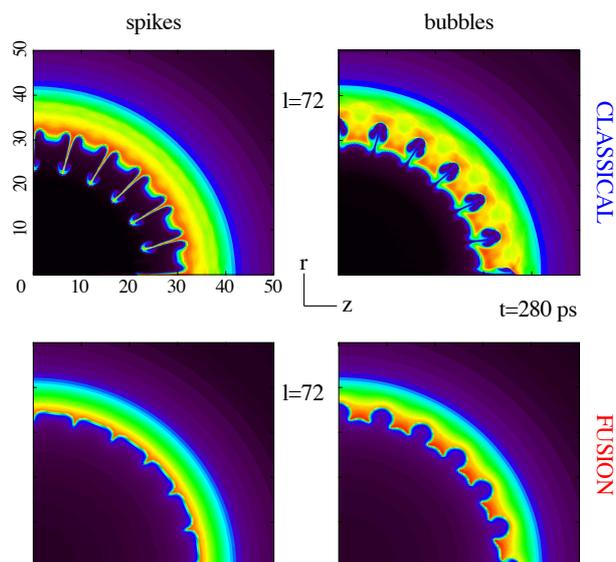


Figure 3: Density maps of spikes and bubbles for equivalent mode $l = 72$ at stagnation time for the classical (top) and the fusion model (bottom).

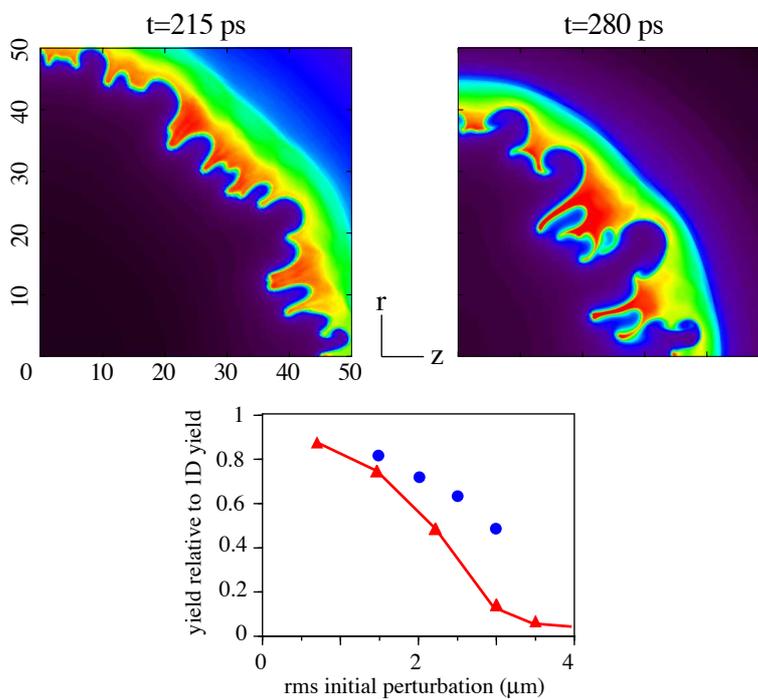


Figure 4: Evolution of an *ice-like* multi-mode spectrum. High modes were included up to $l = 144$. The plot shows the scaled yield as a function of the initial inner surface σ_{rms} for a *white* spectrum (red triangles) and for an *ice* spectrum (blue dots).