Hydrodynamic Instabilities in Ion-Beam Accelerated Shells

M. Basko[1] and J. A. Maruhn
Institut für Theoretische Physik, Universität Frankfurt am Main

The role of Rayleigh-Taylor instabilities (RTI) in layers accelerated by heating with heavy-ion beams is of obvious importance but has received little attention. Owing to the lack of ablative stabilization, it is of special interest to what extent the density gradient can play a stabilizing role.

We regard the situation shown in Fig. 1: an absorber region is heated by a beam in order to accelerate a payload. Both initial regions may have different densities. Later on, however, part of the heated material leaves the deposition region as pushed-out absorber material. For this general investigation, the ideal gas equation of state was used throughout and the ion beam was coupled into the absorber as a space and time-varying specific power added to the energy balance equation.

An analytic solution was constructed for the unperturbed one-dimensional motion in the case of ideal translational invariance in the x-direction of both the initial configuration and the beam deposition. This was then used as a basis for studying the development of the RTI generated by a small initial perturbation. The analytical solution described a constant acceleration of the payload with spatially homogeneous density in both absorber and payload, linked by exponential increase in the transition region. To produce this idealized solution required a highly specific (but not completely unrealistic) beam profile: a parabolic deposition distribution in space combined with a strong exponential time dependence.

For the case of a continuous exponential density variation, the growth rates were analyzed by Mikaelian [2], although with a fixed width *s* of the transition layer. Nevertheless, this formula turned out to be even quantitatively useful. For the case of $s >> h$ the growth rate for the fastest-growing mode is given by

$$\omega^2 = \begin{cases} gk, & 0 < kh < 1/2 \\ \dfrac{g/h}{1+(2kh)^{-2}}, & 1/2 < kh \end{cases} \qquad (1)$$

We performed a series of calculations using a small perturbation in the velocity given by

$$\delta u = 2a_0 k \sin(kx) \exp\left(-k^2 (y-h)^2\right) \qquad (2)$$

as the starting configuration. First the accuracy of the numerical method was tested by a series of calculations of the classical RTI with conditions close to a density jump. The classical growth rate was reproduced within about 1% in the linear stage and only in the nonlinear stage did strong deviations occur. Fig. 2 similarly compares some numerical growth rates with the analytical values for the case of homogeneous initial density.

Of even more interest for the applications is the case of a pronounced exponential transition layer. The perturbation continues to grow close to exponentially, but the growth rates show a surprising behavior: they increase by more than 10% between t=2.5 and t=6. This is not due to the expansion of the layer, as shown by the comparison to a situation with a fixed layer thickness (accelerated by a boundary pressure instead of a beam heating). Clearly from among a large number of modes present in the initial perturbation the fastest-growing one emerges relatively late.

The growth rates obtained in the simulations in general are adequately described by the formula (1) scaled down by about 20%. Combining these results for the linear growth rates with a qualitative analysis of the nonlinear regime, we deduce an enhancement of 1.5(h/d) for the distance-moved-over-thickness ratio compared to the discontinuous initial density case (Atwood number 1). With realistic values of h/d=3...5, this is as good as in the best cases of ablative stabilization.

There is the additional problem of beam nonuniformity, which is not directly linked to the RTI (in fact, it can lead to a destruction of the layer even without hydrodynamic instability). Numerical studies for some representative cases showed that 1 to 10% variation in the heating rate may be tolerable.

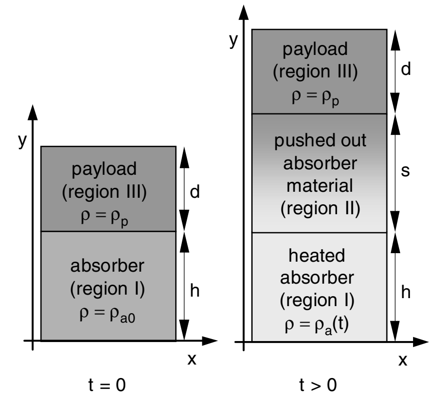

Fig. 1: Layout of the system studied. The lower boundary is assumed to be a motionless plane of symmetry.

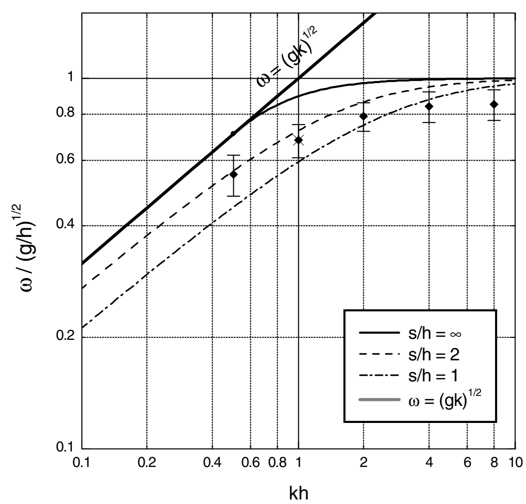

Fig. 2: Linear growth rate normalized to $(g/h)^{1/2}$ as a function of the dimensionless wave number *kh*. The numerical points are compared to the analytical formulae plotted for three different values of *s/h*.

References

[1] Permanent address: I.T.E.P., Moscow

[2] K. O. Mikaelian, Phys. Rev. **26**, 2140 (1982).