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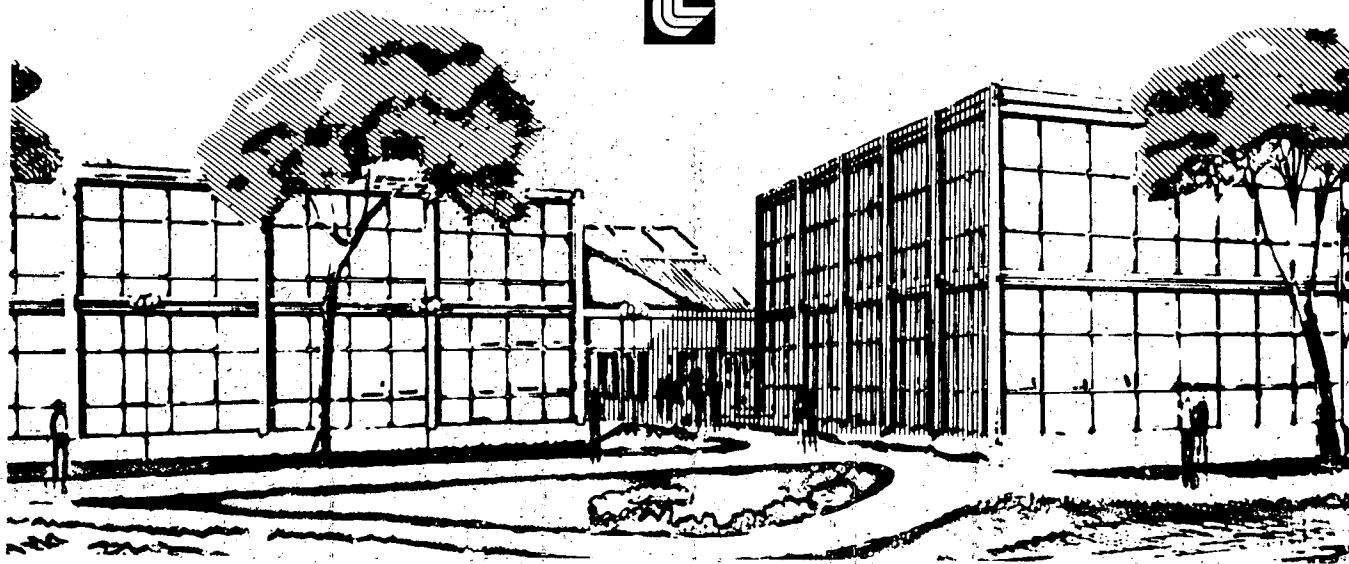
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SLIC (SIMPLE LINE INTERFACE CALCULATION)[*]

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Abstract

SLIC is an alternating-direction method for the geometric ap-
proximation of fluid interfaces. It may be used in one, two, or three
space dimensions, and it is characterized by the following features:
(1) Fluid surfaces are represented locally for each mixed- fluid zone,
and these surfaces are defined as a composition of one space dimen-
sional components, one for each coordinate direction. (2) These one-
dimensional components are composed entirely of straight lines, either
perpendicular to or parallel to that coordinate direction. (3) The
one-dimensional surface approximations for a mixed fluid cell are com-
pletely determined by testing whether or not the various fluids in the
mixed cell are present or absent in the zone just to the left and to
the right in the coordinate direction under consideration. (4) Because
of the completely one-dimensional nature of the SLIC interface descrip-
tion, it is relatively easy to advance the fluid surfaces correctly in
time. With the SLIC fluid-surface definitions, it should be possible
to incorporate any one space dimensional method for advancing contact
discontinuities. This makes SLIC very practical for the numerical
solution of fluid dynamical problems.

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Introduction

This paper deals with the problem of treating fluid interfaces
in the context of multifluid Eulerian hydrodynamic calculations. The
problem presents two fundamental difficulties, that of defining geo-
metrical approximations to the fluid interfaces and that of formulating
essentially Lagrangian equations of motion to advance these fluid in-
terfaces correctly in time.[*] Our discussion will focus on the former
difficulty, although the simplicity of the SLIC surface approximations
lends itself to a solution (see [2]) of the latter difficulty as well.

Of the many approaches to calculating multifluid flow in a two-
dimensional Eulerian context, three methods are particularly noteworthy:
(1) the particle-in-cell (PIC) method [4], which uses mass particles
to tag and keep track of the various fluids; (2) the coupled-Eulerian-
Lagrangian (CEL) method [1], which explicitly uses Lagrangian polygonal
lines to define fluid interfaces; and (3) the highly successful, though
less well publicized, KRAKEN method [5], in which fluid interfaces are
defined locally for each mixed-fluid zone.

In the method to be described here, we have followed the KRAKEN
approach in which a local surface approximation for each mixed-fluid
zone is defined. However, we have sought the simplest possible inter-
face description, and this has led us to an alternating-direction
method, referred to as SLIC (simple line interface calculation).
Roughly, the SLIC rule for approximating surfaces is that lines per-
pendicular to the coordinate axis are to be preferred to parallel lines
and that for three fluid zones in which (in two dimensions) surfaces
meet in a "Y like" intersection, then that intersection is to be approx-
imated by a "T". Also a few symmetry considerations are invoked to
ensure that fluids get equal treatment when the same information is
known about each.

Surprisingly enough, the limited information obtained merely by
looking to the left and to the right in each coordinate direction is
sufficient, when coupled with the simplicity of the straight-line sur-
face approximations, to construct a reasonable and workable represen-
tation of all possible fluid surface configurations of any number of
different fluids occupying a mixed-fluid cell. The alternating-
direction feature of SLIC makes it easily generalizable to more than

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[*] See [1], [2], [3] for examples and a more detailed exposition of the
problems associated with the correct numerical approximation of contact
discontinuities.

two dimensions and allows a detailed one-dimensional calculation of the interface acceleration for each coordinate direction (see [2] for a discussion of how such a calculation can be performed).

We became involved in this work through our efforts to improve the local surface approximation for fluid interfaces in early versions of the BBC code [6]. The SLIC method we will present here has now been implemented in BBC, and this code has been used to generate the results reported here.

The SLIC Algorithm

We will consider the problem of drawing a geometrical picture representing approximately the configurations of fluids 1, 2, ... , n within a given zone. This picture will in general be drawn differently in each one-dimensional pass within an alternating-direction hydro-dynamics calculation. It is this freedom to construct different pictures in each of the different coordinate directions that gives SLIC its power and allows it to treat interfaces accurately despite the rather crude representations it uses in each coordinate direction separately. We will construct our picture in each coordinate direction, entirely from the following information:

f_1, f_2, ... , f_n = the fractional volumes occupied by the fluids within the zone of interest.

IL_1, IL_2, ... , IL_n = fluid occupation numbers (1 means present, 0 means absent) for the zone on the left.

IR_1, IR_2, ... , IR_n = fluid occupation numbers in the zone on the right.

There are four possible combinations of fluid occupation numbers, (IL_i, IR_i) = (0,0), (0,1), (1,0), or (1.1), which characterize the _i_th fluid in the mixed-fluid zone, and we refer to these combinations as the _i_th fluid index numbers.

First, we state the obvious symmetry requirement that all fluids with identical index numbers (IL, IR) should be treated equally. Such fluids are regarded as indistinguishable and are considered as a single fluid group. This is equivalent to drawing a horizontal interface (i.e. a plane parallel to the coordinate axis) between the different fluids within the same fluid group. The height of the horizontal interface reflects the fractional volume information for the fluids in question. This is illustrated in Fig. 1. The two zones depicted are completely equivalent if fluid α is considered as fluid 1 and fluid β

(a)

$IL_1 = 1$	f_1	f_2 $(0,1)$	$IR_1 = 0$
$IL_2 = 0$	$(1,0)$		$IR_2 = 1$
$IL_3 = 0$		f_3 $(0,1)$	$IR_3 = 1$

(b)

$IL_\alpha = 1$	f_α	f_β	$IR_\alpha = 0$
	$(1,0)$	$(0,1)$	
$IL_\beta = 0$			$IR_\beta = 1$

Fig. 1. (a) A three-fluid zone. (b) The SLIC representation of (a) with fluids 2 and 3 grouped as a single fluid (β).

is considered as a homogeneous mixture of fluids 2 and 3 in the proportion f_2/f_3 by volume. (Of course, it must also be assumed that $f_\beta = f_2 + f_3$.) Thus, we can reduce the problem of treating any n-fluid zone to that of treating a zone with at most four fluids, as only four combinations of IL and IR values (i.e. only four different fluid index numbers) are possible. SLIC recognizes only six fluid-configuration types within a zone. These types are completely classified in terms of the fluid index numbers (IL_i, IR_i), $i \leq 4$ and are displayed in Fig. 2.[*] It is understood that the sizes of the component rectangles for each of the fluid groups are determined from the fractional volumes $f_1, \ldots, f_4$.

Figure 2(a) shows the only single-fluid configuration. It is characterized by the fact that all of the fluids in it have a common index number, either (1,1), (1,0), (0,1) or (0,0). As illustrated in Fig. 1, the surfaces of any number of fluids with the same index number are represented by horizontal lines, each fluid having the appropriate partial volume. Figure 2(b) shows the most common two-fluid type (encompassing 10 out of 16 possible combinations of two fluids). It is characterized by the fact that one of the fluids has either index number (0,1) (i.e., is only present on the right) or index number (1,0) (i.e., is only present on the left). When this is the case, the other fluid, no matter what its index number, is represented as shown in Fig. 2(b). The only other two-fluid type is shown in Fig. 2(c). It is characterized by the

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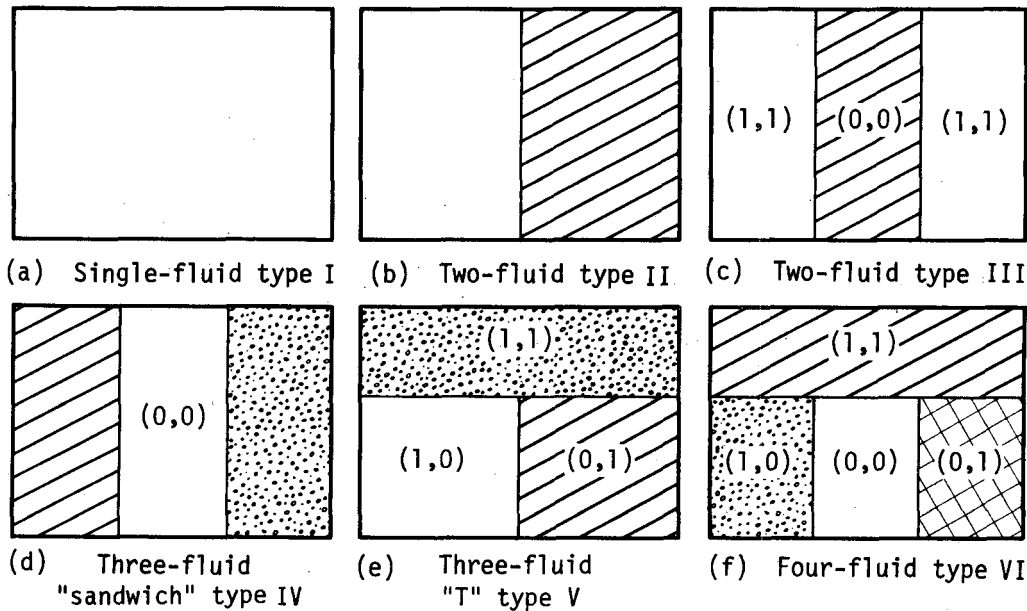[*]See [7] for more examples and a more detailed exposition of the SLIC surfaces.

Fig. 2. The six fluid-configuration types defined by SLIC.

presence of a fluid with index number (0,0). This fluid is in the center. The other fluid has index number (1,1), and it is distributed evenly on either side of the center fluid. Figure 2(d) shows the three-fluid "sandwich" configuration, characterized by the presence of one fluid with index (0,0). The other two fluids, whether they be $\{(1,0),(0,1)\}$, $\{(1,1),(0,1)\}$, or $\{(1,0) (1.1)\}$ are then separated by vertical lines as shown in Fig. 2(d). The three-fluid "T" configuration, involving fluids with index number (1,1), (0,1), and (0,1) is represented in Fig. 2(e). In the only four-fluid configuration, shown in Fig. 2(f), all index numbers are present. As explained above, all of the fluids occupy their correct partial volumes f_1, f_2, f_3 and f_4.

Discussion

The reader can best grasp the reasonableness of the SLIC surface definitions by drawing some arbitrary fluid interfaces and comparing how they would be represented by the SLIC method in each of the coordinate directions.[*] Figures 3 and 4 give two such comparisons.

Our choice of surface definitions, as illustrated in Fig. 2, will also be better understood if one keeps in mind that we prefer

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[*]See [7] for numerous examples of the SLIC surface approximation of mixed-fluid zones.
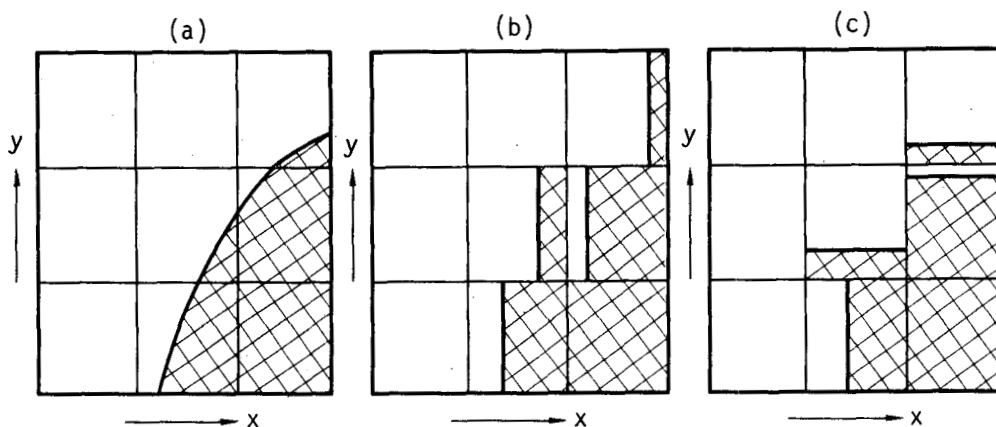
Fig. 3. Comparison of an actual fluid interface (a), with the SLIC representation of it in x-pass (b), and y-pass (c).
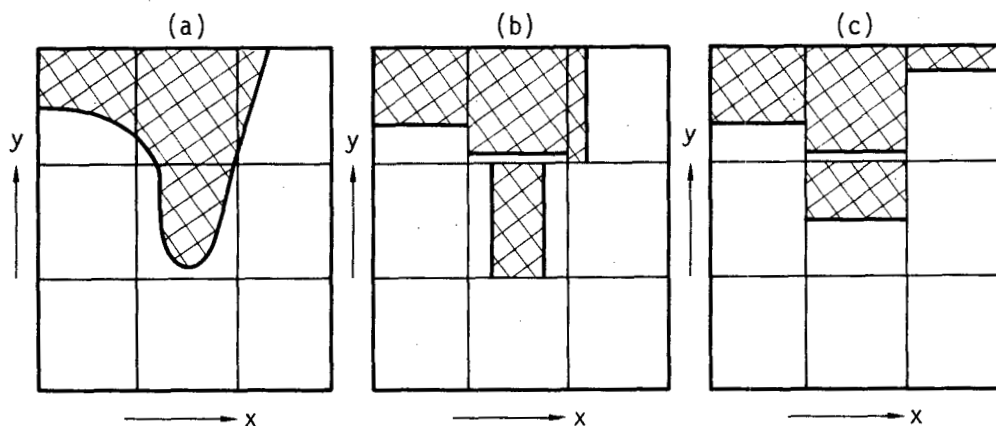

Fig. 4. Comparison of an actual fluid interface (a), with the SLIC representation of it in x-pass (b), and y-pass (c).

vertical to horizontal interfaces [as in 2(b) and 2(d)]. This choice allows fluids to be advected one at a time from mixed-fluid zones in hydrodynamical calculations. Numerical experiments (using SLIC in the BBC Code [6]) have shown that in calculations dealing with strongly interacting flows, our particular choice of vertical and horizontal planes (to approximate fluid surfaces) prevents the non-physical diffusion and thus the subsequent disastrous proliferation of mixed-fluid zones that often occurs in other surface-approximation methods.

Since fluid diffusion can easily occur, one must not be cavalier about modifying the given SLIC surface definitions (see [7] for a discussion of the future planned modifications of SLIC). Indeed, because of the alternating-direction aspect of the SLIC representations, the surface definitions are not as simple as they might appear.
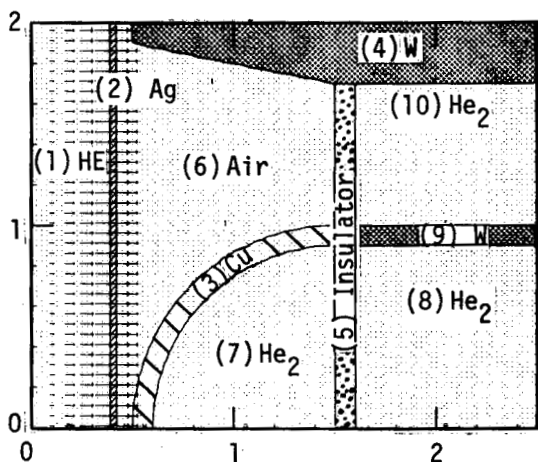
Fig. 5. Velocity vectors and material interfaces (T = 1.0 μs, cycle 9). Region 1 is a high explosive (HE) that is accelerating a silver (Ag) flyer plate. On the right is a coaxial assembly made up of a dense tungsten wall (region 4), a hollow spherically ended copper cap (region 3) and a tungsten center rod (region 9). Region 5 is an insulating support. Regions 7, 8, and 10 contain helium.
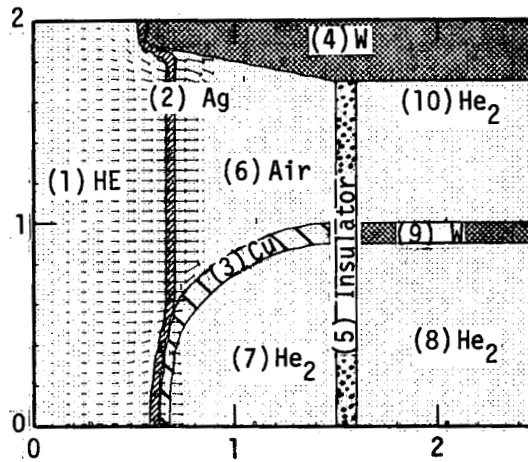
Fig. 6. Velocity vectors and material interfaces (T = 2.0 μs, cycle 41). The silver flyer plate strikes the tungsten wall and the hollow copper center rod.

Results

To demonstrate the capabilities of the SLIC method, we have chosen a problem involving very complex fluid-surface interactions. This calculation might be considered typical of problems of interest. The results, given in Figs. 5 through 12, were obtained using the SLIC method, which is now implemented in the BBC code [6].

In Fig. 5, we consider a high-explosive-driven (H.E., region 1) silver flyer plate (Ag, region 2), which subsequently strikes (and shorts out) a coaxial cable (on the right in Fig. 5). The coaxial cable consists of a dense tungsten wall (W, region 4) and a hollow spherically ended copper center rod (Cu, region 3). As a further complication, there is an insulting washer (region 5) supporting the Cu center rod.
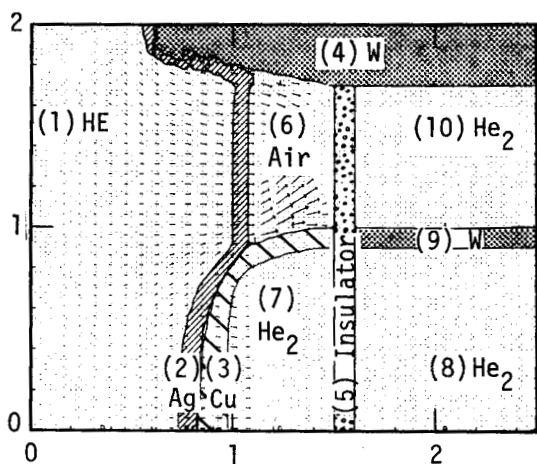
Fig. 7. Velocity vectors and material interfaces (T = 3.0 μs, cycle 91). Note the onset of Rayleigh-Taylor-Helmholtz instabilities on the upper tungsten wall (region 4).

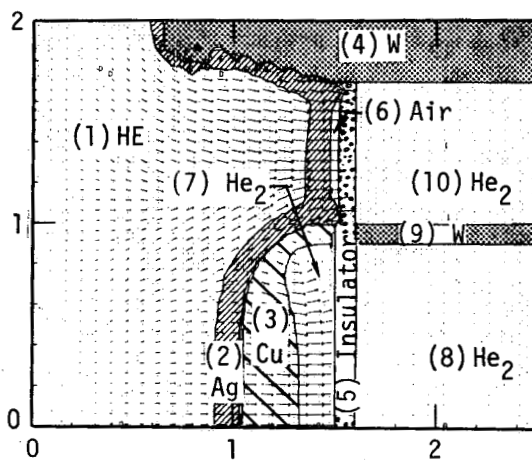Fig. 8. Velocity vectors and material interfaces (T = 4.00 μs, cycle 156). The flyer plate (2) strikes insulator (5). Instabilities on the wall (4) continue to grow. The copper end cap (3) is smoothly collapsed (the contact is physically stable because $\rho_{Ag} > \rho_{Cu}$).
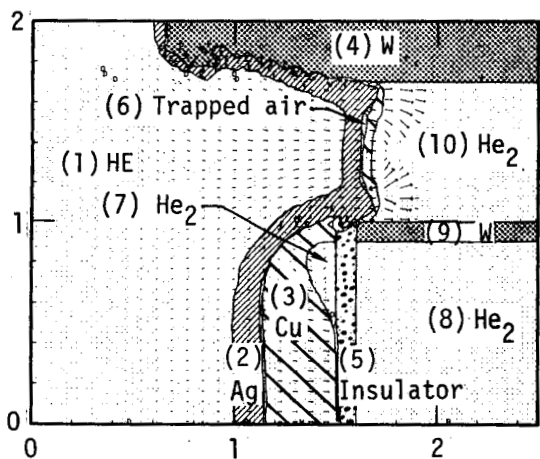
Fig. 9. Velocity vectors and material interfaces (T = 4.50 μs, cycle 175). The insulator(s) is clipped by the silver flyer plate (2). The copper end cap (3) is almost completely collapsed.
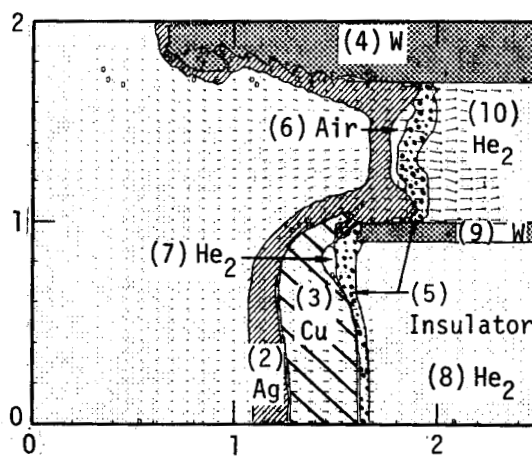
Fig. 10. Velocity vectors and material interfaces (T = 5.0 μs, cycle 201). The insulator (5) is now being driven down between the tungsten walls (4 and 9). The copper end cap (3) is now collapsed.
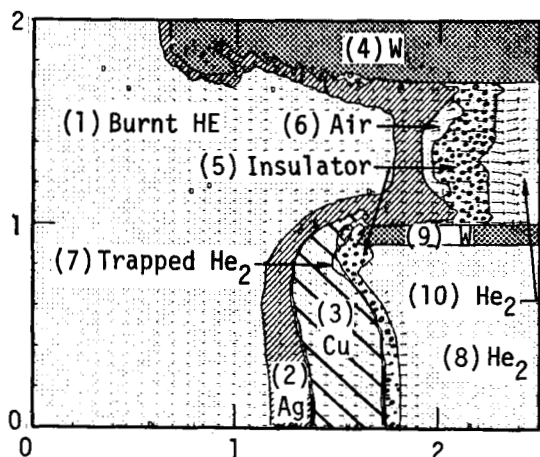
Fig. 11. Velocity vectors and material interfaces (T = 5.5 μs, cycle 220). The silver plate (2) is now breaking up at the Taylor-unstable upper tungsten wall (4).

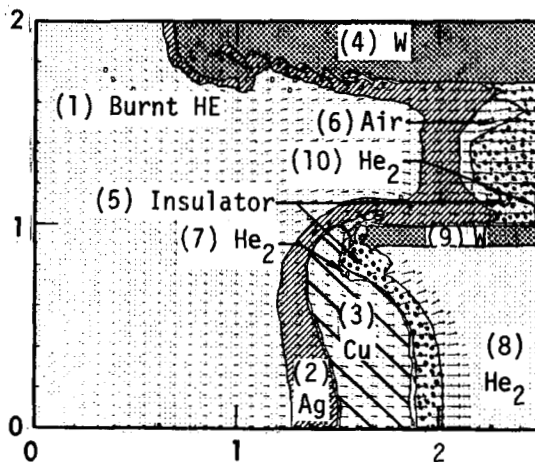Fig. 12. Velocity vectors and material interfaces (T = 6.0 μs, cycle 253). The insulator (5) is stopped at the right-hand rigid wall, trapping the helium (10). SLIC continues to approximate the increasingly complicated mixed-fluid zones.

In Figs. 5 through 12, it is clear that there are a large variety of mixed-fluid zone types that must be automatically approximated at every time step. The SLIC method classifies these multifluid zones and defines appropriate geometric approximations for each of the surfaces represented. It does this automatically no matter how complicated the mixed-fluid zones become as time advances. Hence, the SLIC method meets the challenge of a truly universal multifluid surface approximation.

Of particular interest is the appearance (in Fig. 7 and thereafter) of the Rayleigh-Taylor-Helmholtz instabilities, which grow at the contact surfaces of the silver and tungsten (i.e. regions 2 and 4). These instabilities (i.e., $\rho_{Ag} < \rho_W$) grow with time, and eventually begin to break up. All of this is automatically taken into account by the SLIC approximations. That these instabilities are not a product of the SLIC surface approximations is seen at the same time by the physically stable ($\rho_{Ag} > \rho_{Cu}$) contact of the silver-copper interface. That stability is maintained is shown by the smoothness with which the Cu hollow end cap is imploded by the silver flyer plate.

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Conclusions

There are five major advantages to the SLIC procedure:

(1) The method is entirely one space dimensional (in each of
the coordinate directions). Thus, it is as easy to approximate two-
and three-dimensional surfaces by the SLIC alternating-direction pro-
cedure as it is to define a fluid surface in one space dimension.
[This one space dimensional SLIC procedure can then be coupled with
any suitable one space dimensional, multifluid, Eulerian difference
method to produce an alternating-direction difference method for the
numerical solution of one, two, or three space dimensional, multifluid,
Eulerian hydrodynamics problems.]

(2) The SLIC surface approximations are completely general in
that the procedure automatically defines the structure (i.e. approxi-
mates the surfaces) of any number of different fluids in any computa-
tional cell.

(3) SLIC approximations are among the simplest and most econom-
ical to apply. The algorithm leads to just six different stereotypes
of mixed-fluid zones. These six fluid-zone types can and will, in
general, be different for each coordinate direction. It is this dif-
ference that gives the method its power. Indeed, the SLIC procedure
will define a reasonable approximation no matter how many fluids occupy
a given cell. If the computational mesh is further refined, the method
becomes even more exact.

(4) An extremely important attribute of the SLIC surface defi-
nitions is that they permit the number of different fluids occupying
a mixed-fluid cell to change (either increase or decrease) with time;
that is, the SLIC surface definitions are not time-dependent. Hence,
in fluid calculations, different fluids may collide, and these new
surface intersections will also have SLIC approximations. This is
most important because one of the primary reasons for using the
Eulerian fluid description is to allow the collision of different
fluids. Fluid surfaces are also allowed to break up (e.g. as a result
of the bursting of a bubble and subsequent droplet formation, or of
the shedding of fluid spikes formed in Raleigh-Taylor-Helmholtz un-
stable flow, etc.). (See Figs. 7 through 12.) Hence, fluid breakup or
fluid collisions are a straightforward part of the SLIC alternating-
direction surface definitions.

(5) The prescription for the surface approximations is care-
fully chosen to ensure that fluids cannot diffuse artificially across

an interface. Such diffusion produces the flotsam and jetsam (that is, the small remnants of mixed-fluid zones) so common (and so troublesome) in many multifluid surface approximation methods. Our procedure avoids this difficulty by defining a unique "picture" of a mixed-fluid zone, and further by ensuring that the "nearest" fluid exits first. This anti-diffusional characteristic of SLIC has important consequences in the calculational running time, since any artificial diffusion of mixed-fluid zones not only reduces the problem accuracy, it also results in an ever-increasing number of new mixed-fluid zones.

Acknowledgements

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