VERY HIGH RESOLUTION CALCULATIONS OF VERY YOUNG SUPERNOVA REMNANTS

Eric M. Jones and Barham W. Smith
Los Alamos National Laboratory
University of California
Los Alamos, NM USA

1. Early Supernova Remnant Structure

After the supernova shock wave has swepted up about 8-10 stellar masses of interstellar material, the SNR structure is well described by blast wave theory (eg. Sedov 1959, Chevalier 1977). In fact, both numerical calculations of the early phases (Jones, Smith, and Straka 1981) and small scale, laboratory simulations (Wilke 1982) show transition to blast wave at 8-10 masses. While the late stages have been well understood for some time, the early stages have only been crudely modeled until very recently.

In hindsight, we now know that the transition region between the photosphere (roughly 10^{-9} g/cm^3) and the circumstellar medium (10^{-24} g/cm^3) plays a crucial role. The shock wave is strongly accelerated down the density gradient, putting the shocked material behind into free expansion. When the shock encounters circumstellar material, it begins to decelerate. A second, reverse shock propagates into the stellar material that plows into the shocked circumstellar gas. All this happens on a timescale of days.

The first attempts to include a description of the outer stellar envelope (Chevalier 1976, Falk and Arnett 1973, 1977) were aimed at analysis of the UV and X-Ray bursts produced when the shock wave reaches the photosphere. Falk and Arnett (1977) terminated their calculations before the shock reached the circumstellar gas. Chevalier (1976) mentions a reverse shock forming early but did not go into any details. Apparently, his model was not well enough resolved in the outer regions to detail much of the double-shock behaviour.

For aesthetic reasons, we included the complete transition region in our first calculations (Jones, Smith, and Straka 1981). We noticed and described the double-shock structure but, in hindsight, lacked sufficient resolution to produce the detailed structure between the shocks. Chevalier (1982) derived a similarity solution for the inter-shock region. In this paper we describe very high resolution calculations which reproduce and confirm the Chevalier similarity solution. There are, of course, differences and caveats which must be kept in mind. Nonethless, we have all come a long way in a short time.

J. Danziger and P. Gorenstein (eds.), Supernova Remnants and their X-Ray Emission, 83–86.

2. Comparison with the Chevalier Solution

Rather than attempt a comparison with a model using a detailed stellar model, we first constructed a set of initial conditions which model the assumptions of the similarity solution. Specifically, we use a perfect gas (=5/3) in free expansion with a density profile proportional to r^{-7}. At its outer edge the gas is in contact with a stationary, homogeneous gas (s=0) of density 1.67e-24 g/cm^3. The initial time is 1.0e+06 seconds. These parameters completely specify the problem. Runs were made with different resolution and with a variety of viscosity prescriptions. Figure 1. is a well-resolved run (100 zones in the piston) with relatively high viscosity. We show here only the structure between shocks at the output time, 1.0e+07 seconds. There are differences, probably due to the finite starting time and to transients. Table I is a brief comparison.

Table I

	Chevalier Solution	Calculation
R_2/R_1	0.722	0.829
ρ_2/ρ_1	1.3	1.65
p_2/p_1	0.47	0.62 (poorly determined)
u_2/u_1	1.253	1.33
R_c	3.83e+16 cm	3.75e+16 cm

For most purposes the Chevalier solution represents a great improvement over previous models, especially when detailed numerical calculations are likely to remain quite expensive for some time.

3. Physical Instabilities in the Similarity Solution

A good rule-of-thumb determining the stability of a hydrodynamic flow (Chevalier 1976) is that Rayleigh-Taylor modes are unstable if the local gradients of pressure and density are of opposite sign. The growth time is given by

$$\frac{1}{\tau^2} = \frac{1}{\rho}\frac{dP}{dr}\frac{d}{dr}\left(\frac{p^{1/\gamma}}{\rho}\right) .$$

Examination of the similarity solution shows that for s=0, the region interior to the contact surface is Rayleigh-Taylor unstable while for s=2 the region outside is unstable. For the n=7/s=0 case discussed above the growth times just inside the contact surface are of order 2.0e+6 seconds. They will be longer for the corresponding s=2 case since the gradients are shallower. Nonetheless, the likely prospect that large amplitude instabilities will grow on timescales of weeks must be taken into account when using either the Chevalier solution or numerical calculations to compare with observations.

https://doi.org/10.1017/S0074180900033702 Published online by Cambridge University Press

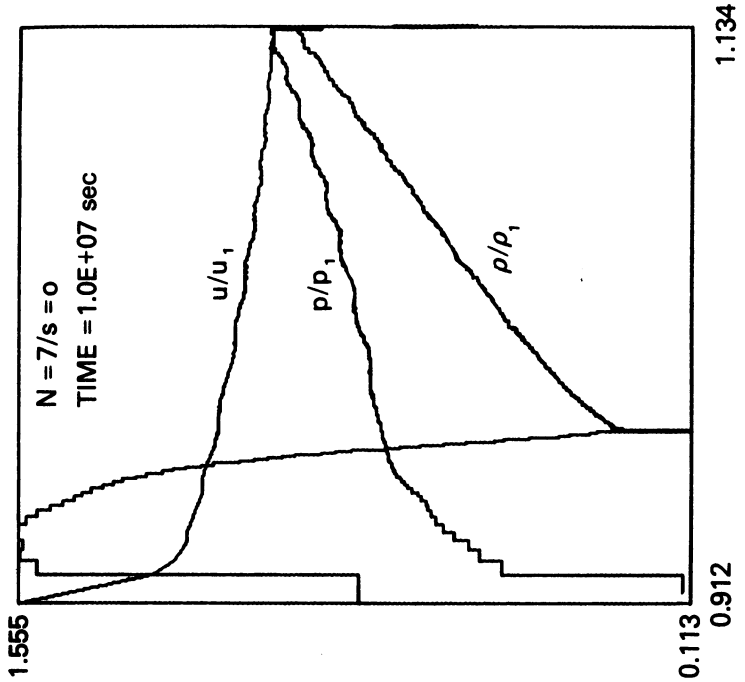

Figure 1 - Velocities, pressures and densities between the shocks, normalized to shock values derived from the Chevalier Solution are plotted versus radius normalized to the similarity contact radius.

Figure 2 - Same problem as in Figure 1 except that the artificial viscosity coefficient has been reduced by a factor of four. The oscillations are of numerical origin, as discussed in the text.

https://doi.org/10.1017/S0074180900033702 Published online by Cambridge University Press

4. Numerical Instabilities (Non-Physical?) in the Calculations

Finally, we call attention to a significant numerical problem that can plague calculations of this kind. Figure 2 shows the pressure profile produced at 1.0e+07 seconds for the problem described above. The amplitude grows large at later times. The only difference between this run and the one shown previously is that the artifical viscosity coefficient has been reduced by a factor of four. The oscillations in the pressure and velocity profiles originate at the direct (outer) shock front and travel as acoustic waves toward the contact surface. The wavelength increases inward in response to the increasing sound speed. Consequently, the disturbance is resolved over many cells except very near the shock. Persistence of well-resolved disturbances is usually a sign that they have a physical rather than a numerical origin. However, we have done runs with different resolution and/or viscosity and have shown that, among other things, the wavelength decreases proportional to cell size. Apparently, frequency is just the frequency at which new cells are encountered by the shock.

We thank W. I. Newman and R. A. Chevalier for useful discussions. This work has been supported by the Los Alamos National Laboratory which is operated for the United States Department of Energy by the University of California.

5. References

Chavelier, R. A. 1976, Astrophy. J., vol.207. p.872.
Chevalier, R. A. 1977, Ann. Rev. Astron. Astrophys., vol.15, p.175.
Chevalier, R. A. 1982, Astrophys. J., vol.258, p.790.
Falk, S. W. and Arnett, W. D. 1973, Astrophys. J. Letters, vol. 180 p.L65.
Falk, S. W. and Arnett, W. D. 1977, Astrophys. J. Supp., vol.33, p.515.
Jones, E. M., Smith, B. W., and Straka, W. C., 1981, Astrophys. J., vol.249, p. 185.
Sedov, L. I. 1959, Similarity and Dimensional Methods in Mechanics, (New York:Academic Press).
Wilke, M. D. 1982, Los Alamos National Laboratory Report LA-9182 (Thesis).