PLANAR IMPACTS: SCALING OF SHOCK PRESSURE DECAY.

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Introduction: Impact cratering scaling laws [1, 2] are necessary in many problems of planetology. Time to time it is useful to review the scaling law basics to estimate restrictions of simple relationships. Here we discuss the scaling of the shock pressure decay in the simplest case of a planar impact. The "point source" concept is defined in [3] as following: "…the details of the impactor may be of little consequence, and the effects of the impactor can be replaced by an equivalent point source of energy and momentum". We present a set of numerically modeled planar impacts to see how "details of the impactor" become to less and less important with the shock wave propagation.

Shock pressure decay: The point source concept may be formulated as the "late stage equivalence" [4, 5]. Both "point source" and "late equivalence" approaches assume that for from the impactor the shock wave (and the flow behind the shock wave) should be similar (for the same projectile/target materials) if one keeps constant the "coupling parameter" *C* value

$$C = a\,U^{\mu}$$

where a is some (dimensional) coefficient, U is the impact velocity, and μ is the impact velocity scaling component.

In the "point source" solution the "strong" shock wave pressure, p, decays with a distance x as

$$p \sim 1/x^{\alpha}$$

The pressure the pressure decay exponent α is related to the impact velocity scaling exponent, m, as [3]

$$\alpha = 2/\mu$$

For 3D solid to solid impacts $\mu \cong 0.55$-0.58, just between the "momentum" (μ=1/3) and "energy" (μ=2/3) scaling end members. For planar (1D) impacts the end member cases "momentum" μ=1 and "energy" μ=2.

For ideal gases the μ value depends on the heat capacity ratio γ approaching $\mu \sim 1.8$ at $\gamma > 5$ [4, 5]. For solids problems with similarity have been outlined in [6]. We find only a few publications about 1D planar wave scaling in solids [7, 8].

Numerical Modeling: SALEB hydrodynamic solver [9, 10] is used in the Lagrangian mode to model the solid material motion due to impact. The flyer plate and the target are made of the same material. The flyer plate is presented with 100 computational cells.

Tillotsons's equation of state (EOS) [11] is used in most of model runs. For selected model runs the online ANEOS [12] is used with the "library" parameters for aluminum. Tillotsons's parameters describe approximately aluminum, lime, and iron. The low limit linear shock front/particle velocity relations are:

Fe: Us = 4.04 + 1.66 Up (Up <2 km/s)
Al: Us= 5.3 + 1.44 Up (Up <2.6 km/s)
CaO: Us = 5.85 + 1.20 Up (Up <2.6 km/s)

The impact velocity varies from a few kms^{-1} to 800 kms^{-1} in an attempt to reach extremely "high pressure" regime close to the limiting compression.

Results: The planar impact generates a shock impulse decaying into a classic acoustic impulse at large distances. As the material is assumed to have not any strength, the asymptotic decay is $p \sim 1/x^{0.5}$ [13]. Close to the impactor the pressure decay is indeed close to the power law (Fig .1). To see the details we use the "local exponent" $d(\ln p)/d(\ln x)$ (Fig. 2). Here it is visible that even at 800 kms^{-1} the "point source" exponential pressure decay does not occur in the strict sense. The pressure decay local exponent is different for various EOS mostly due to different values of assumed "limiting compressions".

To check the code we computed also a set of model runs for an ideal gas with γ=5/3 with the Al initial density (Fig. 3). The "condensed" Tillotson's Al and the similar ideal gas behave similarly – pressure decay exponent slowly approach the theoretical value of $2/\mu$ at distances of ~50 L (L is the flyer plate thickness). At larger distances the ideal gas reaches the theoretical value of 1.275, while Tillotson's Al decay exponent never reaches their theoretical value of ~1.31.

To find the "coupling parameter we fit the growth of the positive momentum scaling the flyer plate thickness to the L_{800} value. Fig. 1 demonstrates that the scaling works well for the pressure decay.

Estimated in this way "coupling parameter" *C* shows the closeness to the exponential law with $\mu \sim 1.55$ at high impact velocities. However the transition to the low-velocity "momentum" m~1 occurs at unexpectedly high velocities $\sim 5c_0$ (c_0 is the initial bulk sound speed). To show the deviation from the single "high velocity" scaling exponent from a constancy Fig. 4 presents the "local velocity scaling exponent" $d(\ln C)/d(\ln U)$ as a function U/c_0. The transition to the "point source" high velocity regime (μ=const) for various condensed materials in planar impacts and depends on the EOS parameters (see U_s/U_p relations above).

Conclusions: The very useful "point source" ("late stage equivalence") concept in strict sense is only an approximation to "real" non-power relations describing mechanics of high-velocity impacts. Even for the ideal gas in the planar impact the pressure decay approaches the theoretical value only at ~50 L_0. The velocity scaling with a single μ works well above U/c_0~5. The work should be extended into real 3D, but the lack of exact analytical solutions demands much more computational power than 1D.

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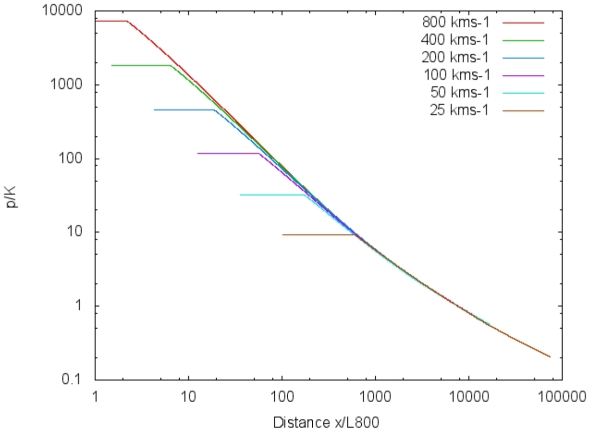

Fig. 1. Pressure (normalized to the initial bulk modulus K) vs. distance normalized to the thickness of the 800 kms^{-1} flyer plate (L_{800}).

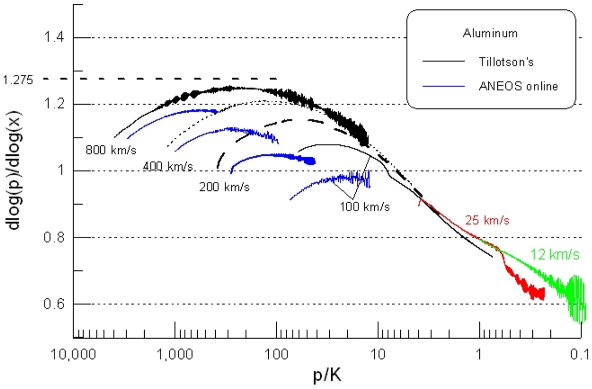

Fig. 2. Local pressure decay exponent for Tillotson's and ANEOS Al for impact velocities from 12 to 800 kms^{-1}. The horizontal normalized pressure scale is used hear instead of normalized distance.

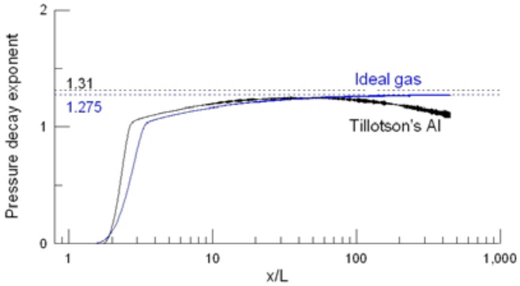

Fig. 3. Compararison of 800 kms^{-1} model runs for Tillotson's Al and the Al-like ideal gas with γ=1.667.

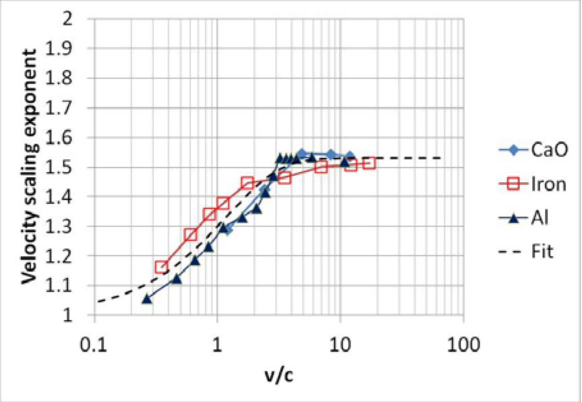

Fig. 4. The "local" velocity scaling exponent vs. the impact velocity normalized to the material sound speed.