# Colliding Surface Instability for a High-Velocity Impact

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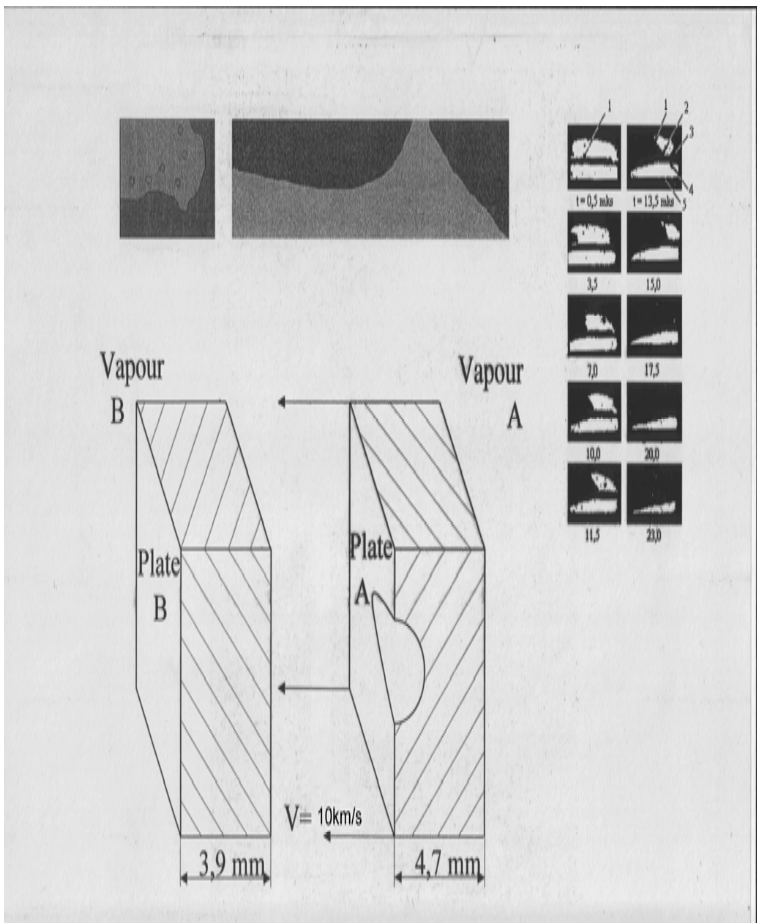
# Experimental investigation of the instability




The following experimental facts were established:

- Presence of melts in the weld;
- The duration of the melted state of the interface was estimated at 5-10μs;
- Loss of stability was accompanied by cone-shaped metal splashing from impacted plate toward the initially accelerated lead plate;
- The perturbation amplitude was estimated on the basis of the distance from the base to the vertex of splash, the breakaway of part of the formation during plate separation being disregarded;
- No instability was observed for thick lead plates (1 cm thick)

# Physical description of collision process. The ideal gas model.

$$B(0)\leftarrow \quad \underset{ShockD_0}{|} \quad B(1) \quad \underset{Interface}{\vdots} \quad A(2) \quad \underset{ShockD_3}{\leftarrow|} \quad A(3)$$

$$\rho_0(U_0-D_0)=\rho_1(U_1-D_0) \qquad \rho_2(U_2-D_3)=\rho_3(U_3-D_3)$$

$$P_0+\rho_0(U_0-D_0)^2=P_1+\rho_1(U_1-D_0)^2 \qquad P_2+\rho_2(U_2-D_3)^2=P_3+\rho_3(U_3-D_3)^2$$

$$(U_0-D_0)(\rho_0E_0+P_0)=(U_1-D_1)(\rho_1E_1+P_1) \qquad (U_2-D_3)(\rho_2E_2+U_2)=(U_3-D_3)(\rho_3E_3+P_3)$$

$$P_1=P_2;P_j=(\gamma_j-1)\rho_j\varepsilon_j;j=0\div 3 \qquad U_1=U_2;E_j=\varepsilon_j+U_j^2/2;\gamma_j=5/3$$

$$\rho_0=7.9g/cm^3;U_0=0;P_0=3.04\cdot 10^7\,dyn/cm^2;\rho_3=11.37g/cm^3;U_3=-10^6cm/s;P_3=1.18\cdot 10^7\,dyn/cm^2;$$

$$\rho_1=31.6g/cm^3;\rho_2=45.48g/cm^3;U_1=U_2=-5.454*10^5cm/s;$$

$$P_1=P_2=3.133*10^{12}dyn/cm^2;D_0=-7.272*10^5cm/s;D_3=-3.939*10^5cm/s$$

# Physical description of collision process. The Gruneisen-type equation of state(Zababakhin).

$$\rho_0(U_0-D_0)=\rho_1(U_1-D_0)$$

$$P_0+\rho_0(U_0-D_0)^2=P_1+\rho_1(U_1-D_0)^2$$

$$\rho_1=\rho_0\frac{P_1h_0+\alpha_0}{P_1+\alpha_0}$$

$$P_1=P_2;U_1=U_2$$

$$\rho_2(U_2-D_3)=\rho_3(U_3-D_3)$$

$$P_2+\rho_2(U_2-D_3)^2=P_3+\rho_3(U_3-D_3)^2$$

$$\rho_2=\rho_3\frac{P_2h_3+\alpha_3}{P_2+\alpha_3};h_j=\frac{\gamma_j+1}{\gamma_j-1};$$

$$\alpha_j=\rho_jC_j^2(h_j-1);j=0,3$$

$$0.7933Y^6-56.79Y^5+22.3Y^4+8.466Y^3+0.8128Y^2+0.02767Y+0.0003086=0$$

$$Y=P_1/\rho_3(U_0-U_3)^2;\rho_1=13.76g/cm^3;\rho_2=21.8g/cm^3;U_1=U_2=-5.3*10^5cm/s;$$

$$P_1=P_2=5.18*10^{12}dyn/cm^2;D_0=-1.239*10^6cm/s;D_3=-2.46*10^4cm/s$$

# Physical description of collision process

It’s convenient to take a basis coordinate system moving together with the impact surface. The propagation time of a shock wave traveling through the material of a sample of thickness δ at a shock velocity D is equal

$$t_0 = \frac{\delta}{|V - D_0|},$$

where V is the velocity of the impinging plate. The shocked layer thickness Δ is expressed in terms of the shock wave velocity and time $t_0$

$$\Delta = \frac{\delta D}{|V - D|}$$

The time of propagation of the rarefaction wave from the free surface to the interface is equal

$$t_1 = \frac{\delta D}{|V - D| C},$$

where C is the sound velocity.The total time of the process from the instant of plate collision to the arrival of the rarefaction wave at the interface is equal $t_1 + t_0$

# Mathematical model and formulation of the problem

The mathematical model is constituted by the system of Euler equations written in cylindrical coordinate system

$$\frac{\partial \rho}{\partial t}+\frac{1}{r}\frac{\partial (r\rho U)}{\partial r}+\frac{\partial (\rho V)}{\partial z}=0$$

$$\frac{\partial (\rho \xi)}{\partial t}+\frac{1}{r}\frac{\partial (r\rho \xi U)}{\partial r}+\frac{\partial (\rho \xi V)}{\partial z}=0$$

$$\frac{\partial (\rho U)}{\partial t}+\frac{1}{r}\frac{\partial r(\rho U^2+p)}{\partial r}+\frac{\partial (\rho UV)}{\partial z}=\frac{p}{r}$$

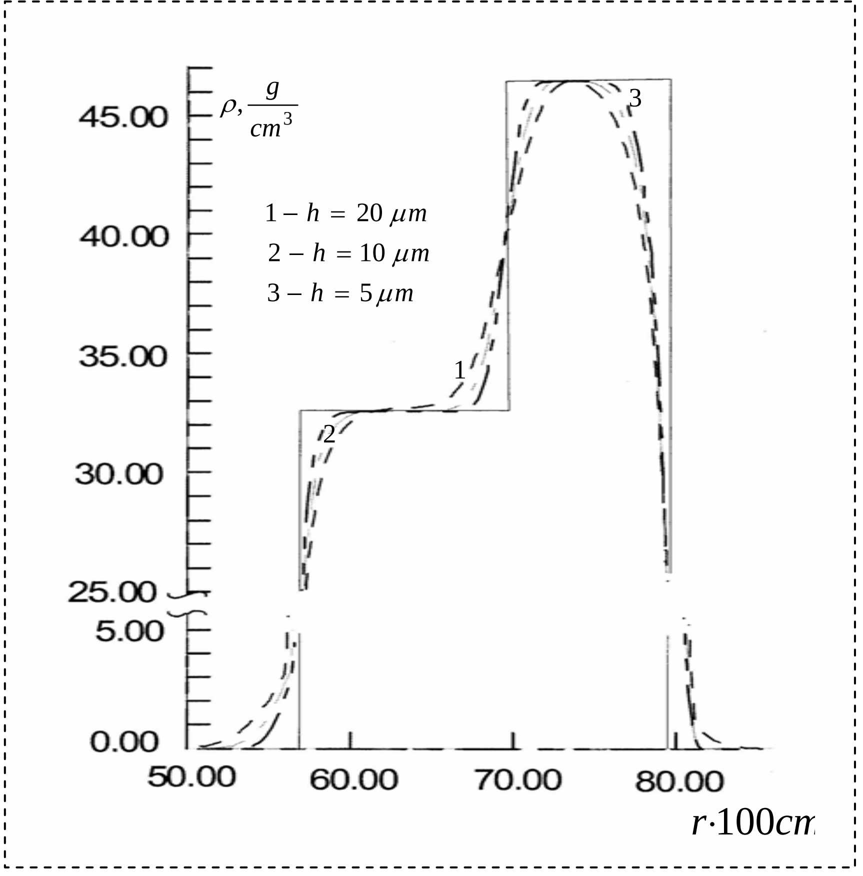
$$\frac{\partial (\rho V)}{\partial t}+\frac{1}{r}\frac{\partial (r\rho UV)}{\partial r}+\frac{\partial (\rho V^2+p)}{\partial z}=0$$

$$\frac{\partial (\rho E)}{\partial t}+\frac{1}{r}\frac{\partial [rU(\rho E+p)]}{\partial r}+\frac{\partial [V(\rho E+p)]}{\partial z}=0$$

$$p=(\gamma-1)\rho\varepsilon, E=\varepsilon+\frac{U^2+V^2}{2}$$

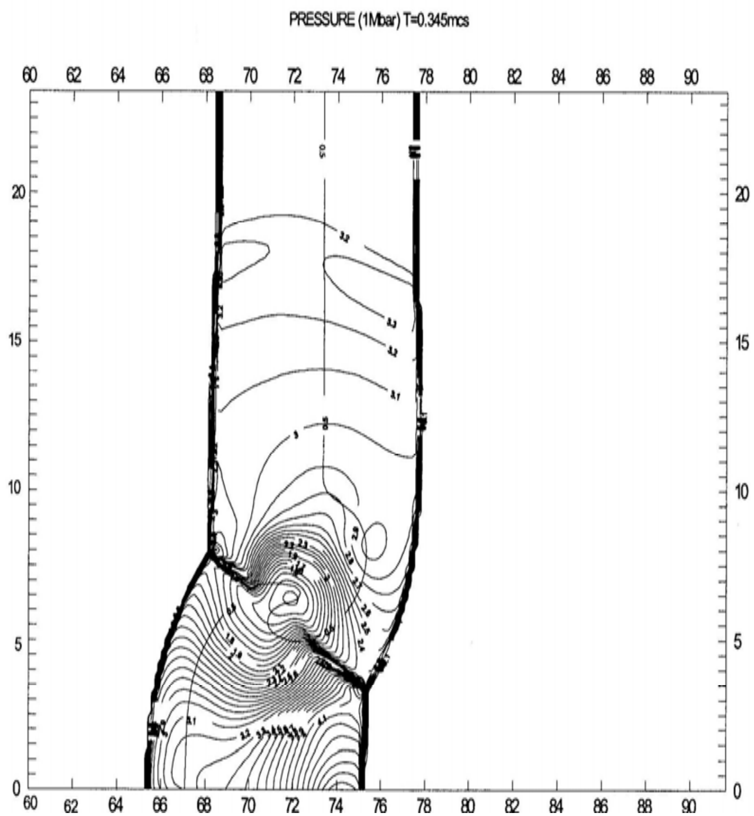
*where* $\rho$ *is the density* ; $\xi$ *– the mass concentrat ion of one of components* ;
$U$ *– the radial velocity component* ; $V$ *– axial velocity component* ;
$E$ *– the total specific energy* ; $\varepsilon$ *– the in ternal specific energy* ;
$P$ *– the pressure* ; $\gamma$ *– const ant of the adiabatic process* .

# *One-dimensional test calculations*




The comparison of the analytic results with the data of the numerical calculations with reference to the problem of discontinuity breakdown (the Riemann problem)

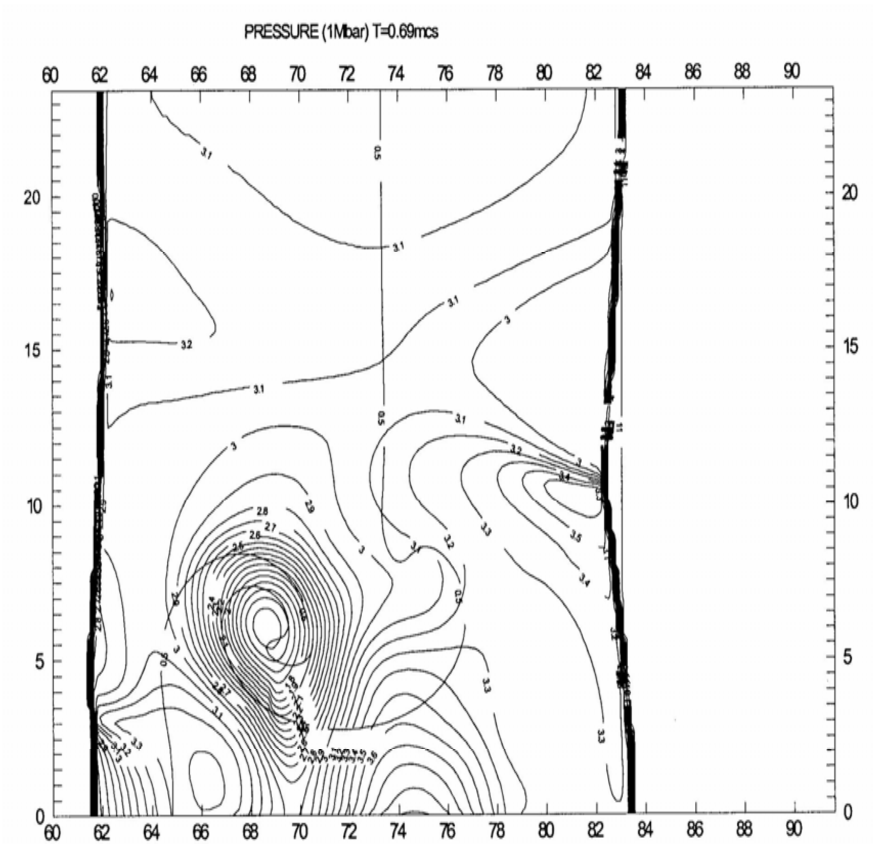
# *Physical mechanisms of instability development*




Isobars in Mbar and location of the 0.5 mass concentraion isoline at the instant of time 0.345$\mu$s

Here the variant in which the initial perturbation is specified on the impinging plate and has a convex shape of radius R=750μm and an amplitude Δz=750μm is represented.We can see the presence of two zones of higher pressure as compared with the one-dimensional case.One of them is located in the neighborhood of the axis of symmetry in plate A and the other on the boundary of the perturbation domain between the shock waves and the interface. Their appearance is due to the deviation and interaction of the flows in the region of distortion of the shock fronts. A zone of low pressure is located between the fronts.

# *Physical mechanisms of instability development*

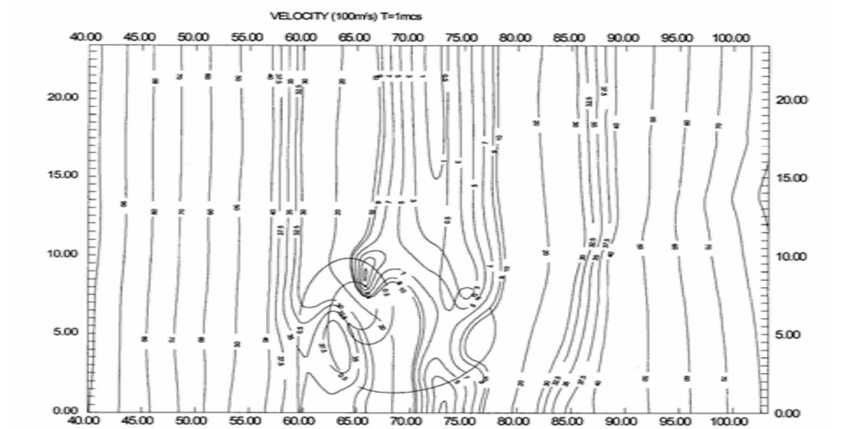



Isobar distribution in Mbar and 0.5 mass concentration isoline at the instant of time 0.69$\mu$s when in one-dimensional case the shock waves approach the free surfaces of the plates

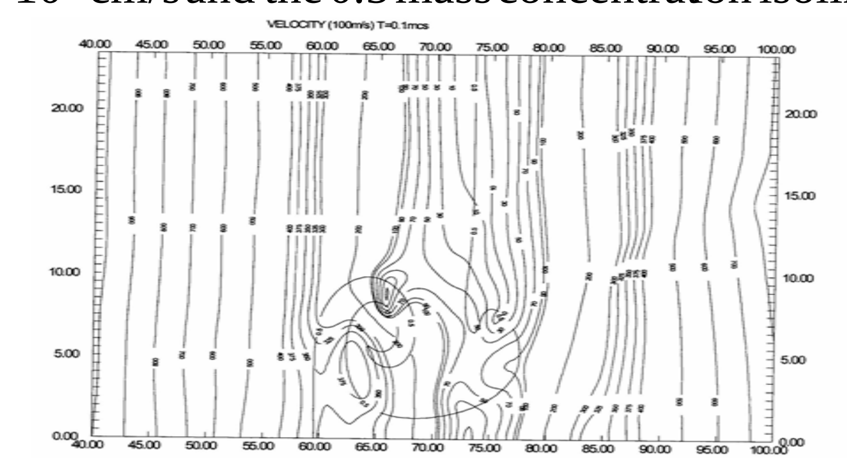
The secondary waves from the higher pressure zones, overtaking the shock waves formed in the plate collision and interacting with them, tend to straighten and flatten the shock fronts. However the flow along the interface is conserved, the process of deformation of the interface continues and it becomes “mushroom-shaped’.

# *Results of the numerical simulation*

- In figure the isolines of absolute value of the velocity are plotted for the two variants:in top- the initial collision velocity is equal 10km/s and the rarefaction waves arrive at the interface at 1μs and in bottom- the velocity is equal 100km/s ,the instant of arrival fell to 0.1μs
- In their cases the shape and location of the mass concentration isolines remain practically the same. It is possible to assume that exists a self-similar variable equal to the ratio of the plate thickness to the product of the relative collision velocity and the duration of the process.

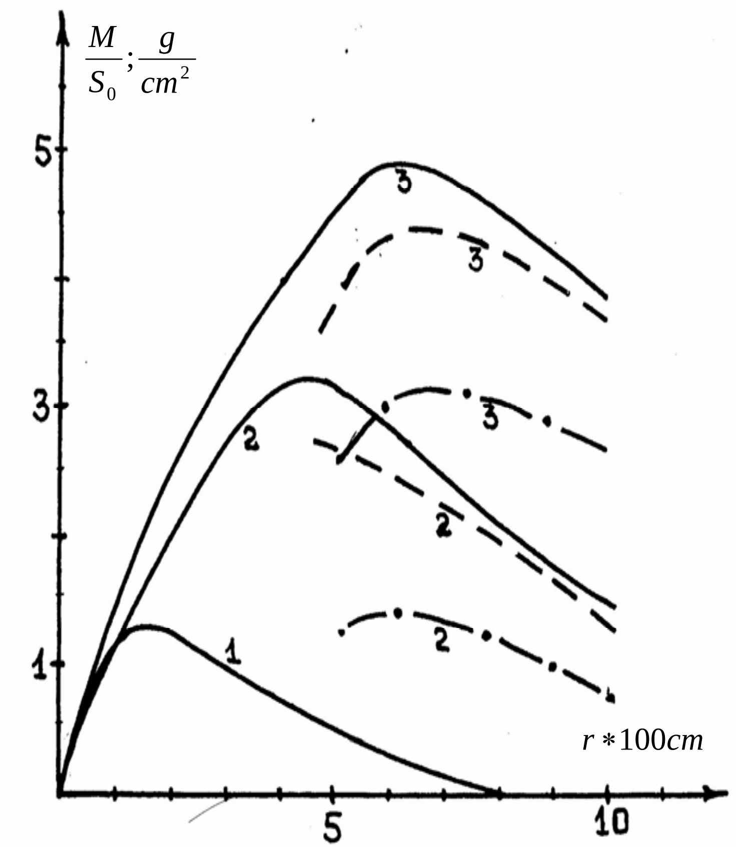



Isolines of the absolute value of the velocity in $10^4$ cm/s and the 0.5 mass concentration isoline



# Results of the numerical simulation

The effect of the scale of the initial perturbation on the mass of the mixed material was investigated for a relative collision velocity of 10km/s and given thickness of the two plates. When the scale of the initial perturbation changes, its shape remained similar. In figure the graphs of the specific surface mass of the mixed material are plotted as a function of the perturbation radius at the instants of time 0.345,0.69 and 1µs. The specific surface mass is the ratio of the mass of the mixed material to the plane area of the initial perturbation.The maximum is displaced with time toward longwave perturbations.



# Summary

- A new physical mechanism of development of instability from initial perturbations of the shape of the interacting surfaces of the plates is proposed. The determining elements of this mechanisms are: the deviation of the mass flows behind the curved sections of the shock waves and the interaction of the secondary compression waves and shock waves with the initial shock waves.
- A quantitative dependence of the specific surface mixed mass of the materials of the colliding plates on the radius of an initial axisymmetric perturbation of given shape is obtained.

# Summary

- The maximum specific surface mixed mass is displaced with the time from the short to the long-wave part of the spectrum.
- The dependence of the specific surface mixed mass on a dimensionless quantity equal to the ratio of the plate thickness to the product of the relative impact velocity the duration of the process is shown to be self-similar.