VIRTUAL DESIGN FOR SPACE DEBRIS IMPACT
(VALIDATION OF THE PAM-SHOCK TRANSIENT DYNAMICS CODE)

Argiris Kamoulakos*, Mathias Przybylowicz*, Michel Lambert**

*E.S.I. S.A. 20 rue Saarinen, Silic 270, 94578 Rungis CEDEX, France
**ESA / ESTEC, Structures and Mechanisms Division, Keplerlaan 1. P.O. Box 299,
2200 AG Noordwijk ZH, The Netherlands

ABSTRACT

In this paper the process of virtual design of space debris shields has been touched with emphasis being given to the virtual prototyping stage of the above process as performed by the PAM-SHOCK family of codes. A selection of numerical results is presented to underline the feasibility of simulating by computer the extreme space environment hypervelocity impact conditions.

1. INTRODUCTION

Space debris (hypervelocity) impact is a phenomenon of increasingly great importance for future spacecraft and satellite deployment missions. In this poster paper the process of virtual design of spacecraft shields is demonstrated using numerical simulations with the PAM-SHOCK finite element family of codes. In particular three basic scenarios have been investigated involving the impact of a sphere impacting a Whipple shield at 6.6 km/s and the impact of cylindrical projectiles created from shaped charges and impacting a Whipple and a double bumper shield at 11.1 Km/s. The latter two scenarios do currently represent the limits of experimental testing as far as propelling sizable objects of a given structural integrity to such high speeds is concerned.

The numerical simulations were performed in an axisymmetric space using the PAM-SHOCK2D code, which is a Lagrangian code with rezoning/remeshing capabilities and some features dedicated to hypervelocity impact (e.g. SESAME EOS databank for a range of metallic, non-metallic and composite materials).

The results obtained focused on the correct representation of the bumper penetration process, the debris cloud composition and evolution and the subsequent damage inflicted to the backwall.

However due to the limitation in size of this poster paper only a few of the results of the Whipple shield tests only are presented. The reader is invited to consult references 1 and 2 for a more complete description of the experimental results.

Some of the simulations were repeated with the SPH (Smoothed Particle Hydrodynamics) option of the 3D code PAM-SHOCK. A favourable comparison of some of the results is shown in this paper.

2. NORMAL IMPACT OF ALUMINUM SPHERE UPON ALUMINUM WHIPPLE SHIELD AT 6.6 KM/S

This corresponded to the EMI 7373 experiment (see Ref. 1). Under such conditions of impact the Whipple shield is penetrated by the sphere with a hole diameter of roughly double the diameter of the sphere in question. Figure 1 shows the penetration process as computed by the Lagrangian FE code PAM-SHOCK2D as seen by the superposition of the undeformed and deformed meshes.

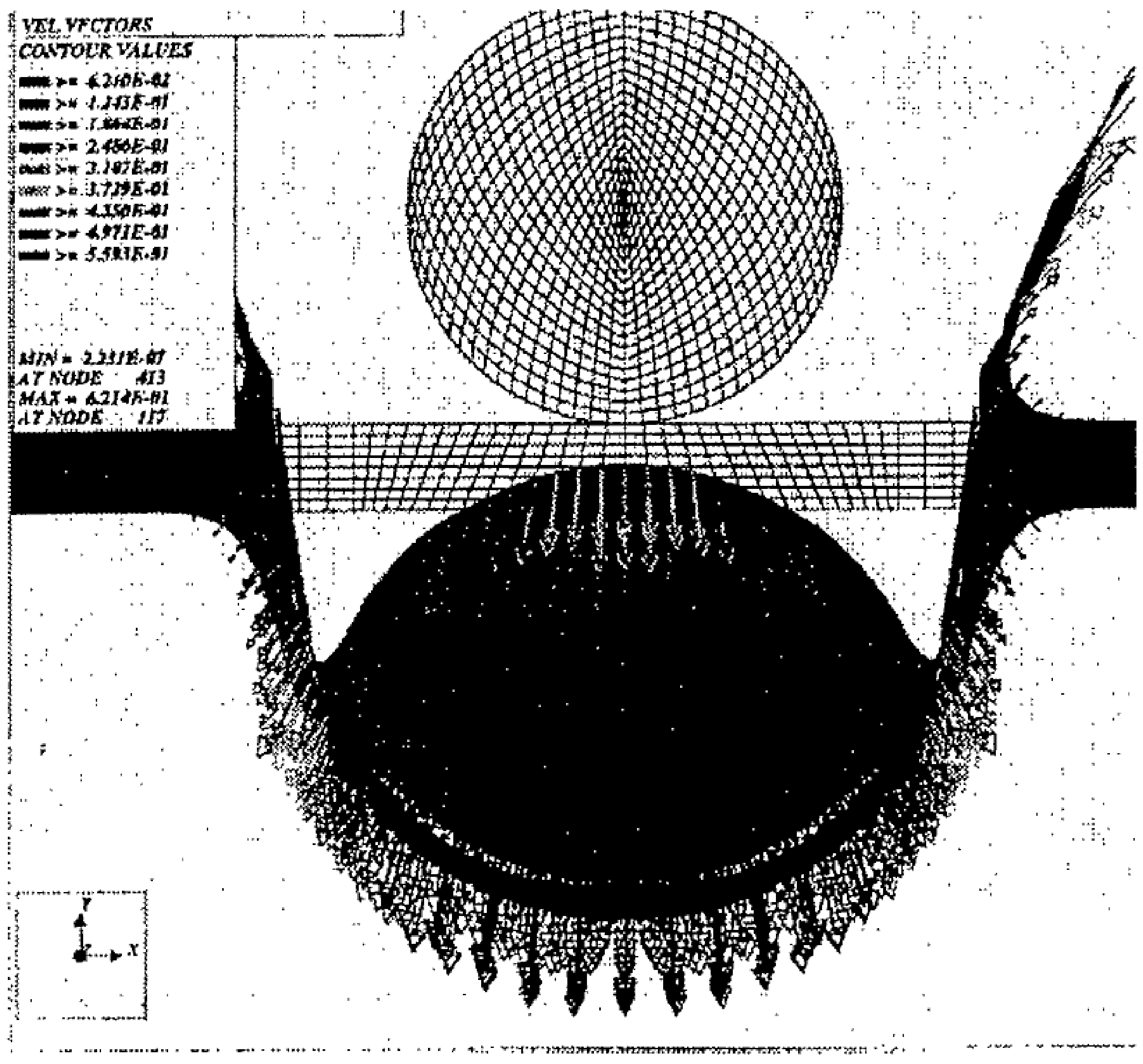

Figure 1: Penetration of the Whipple shield

The remnants of the sphere evolve into a cloud of fragmented solid debris which possesses a radial expansion and a distinct coagulation of matter along the front into a disk-like shape. The FE Lagrangian simulations exhibited this phenomenon by collapsing elements along the front of the debris cloud and expanding the rear ones, where little if no matter is present. This is shown in Figure 2 below while a comparison with a typical experiment is shown in Figure 3.

The impact on the backwall, who was covered by a 21-layered MLI film, resulted into one central hole with petalling around it. The damage evolution of the backwall was monitored through contours of tensile failure (i.e. spallation and through thickness radial cracking). Some of these contours are presented in Figure 4 showing the evolution of the central hole and the radial cracking around it.

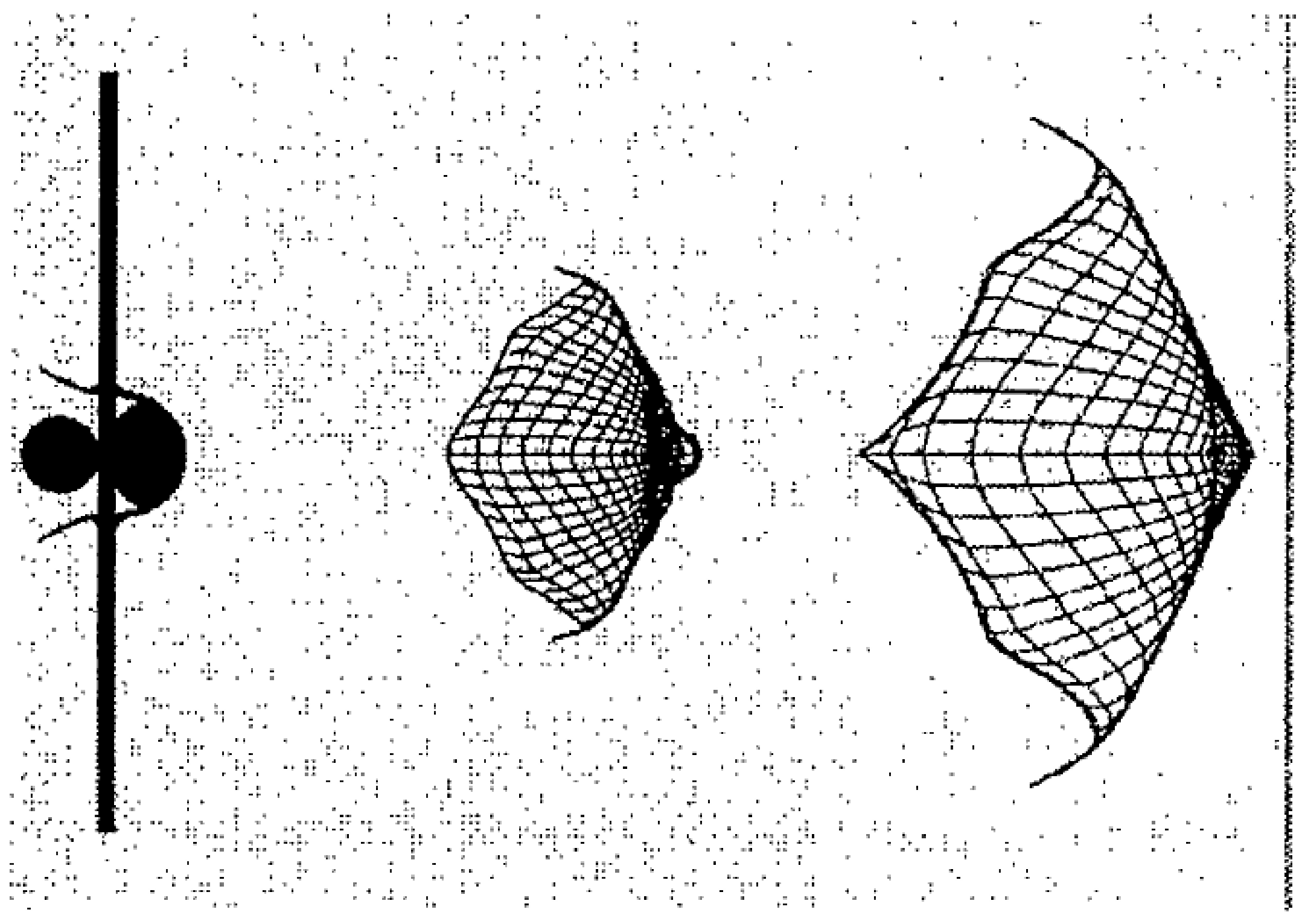

Figure 2 : Debris cloud expansion

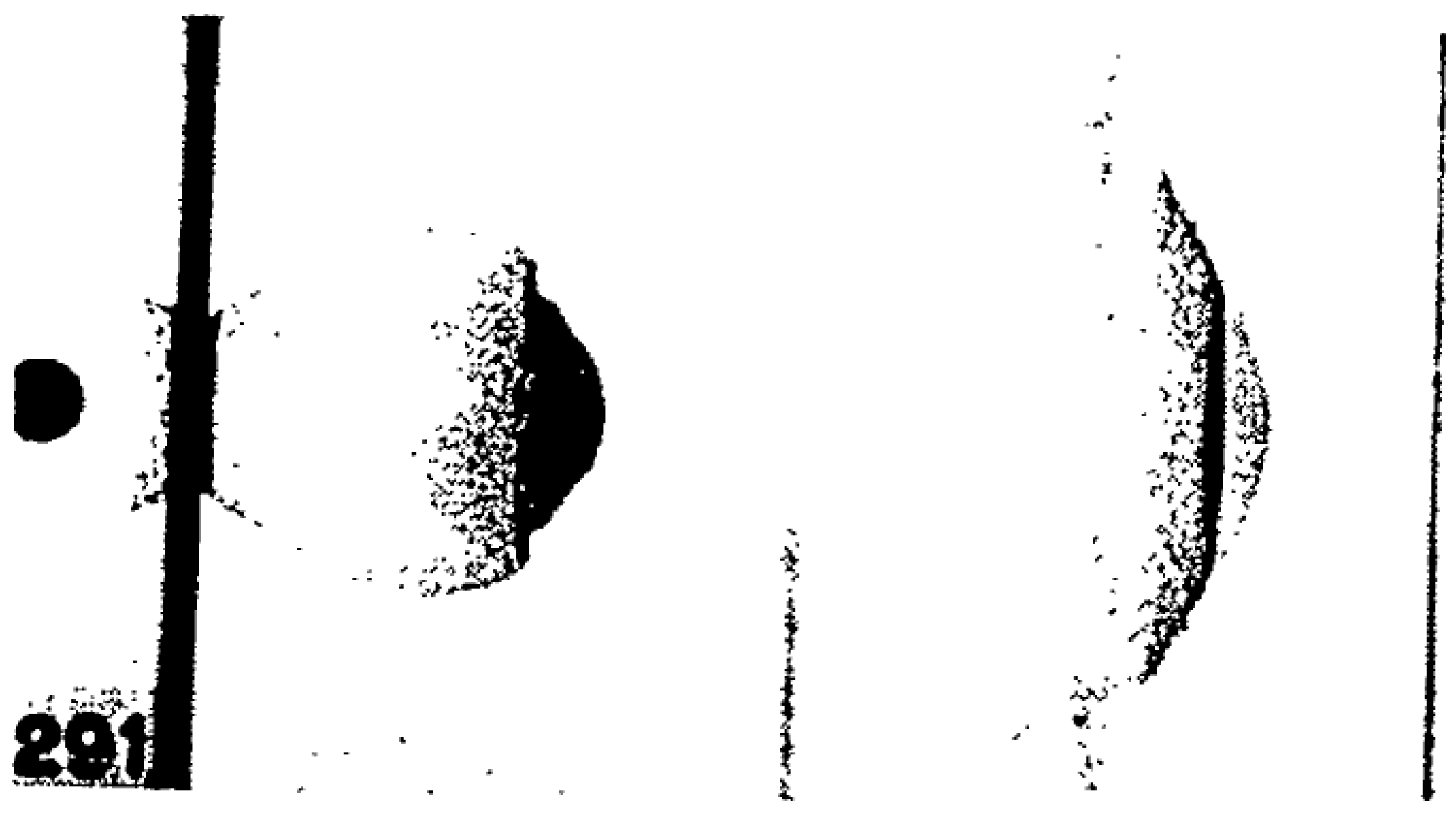

Figure 3 : Typical debris cloud expansion (experiment)

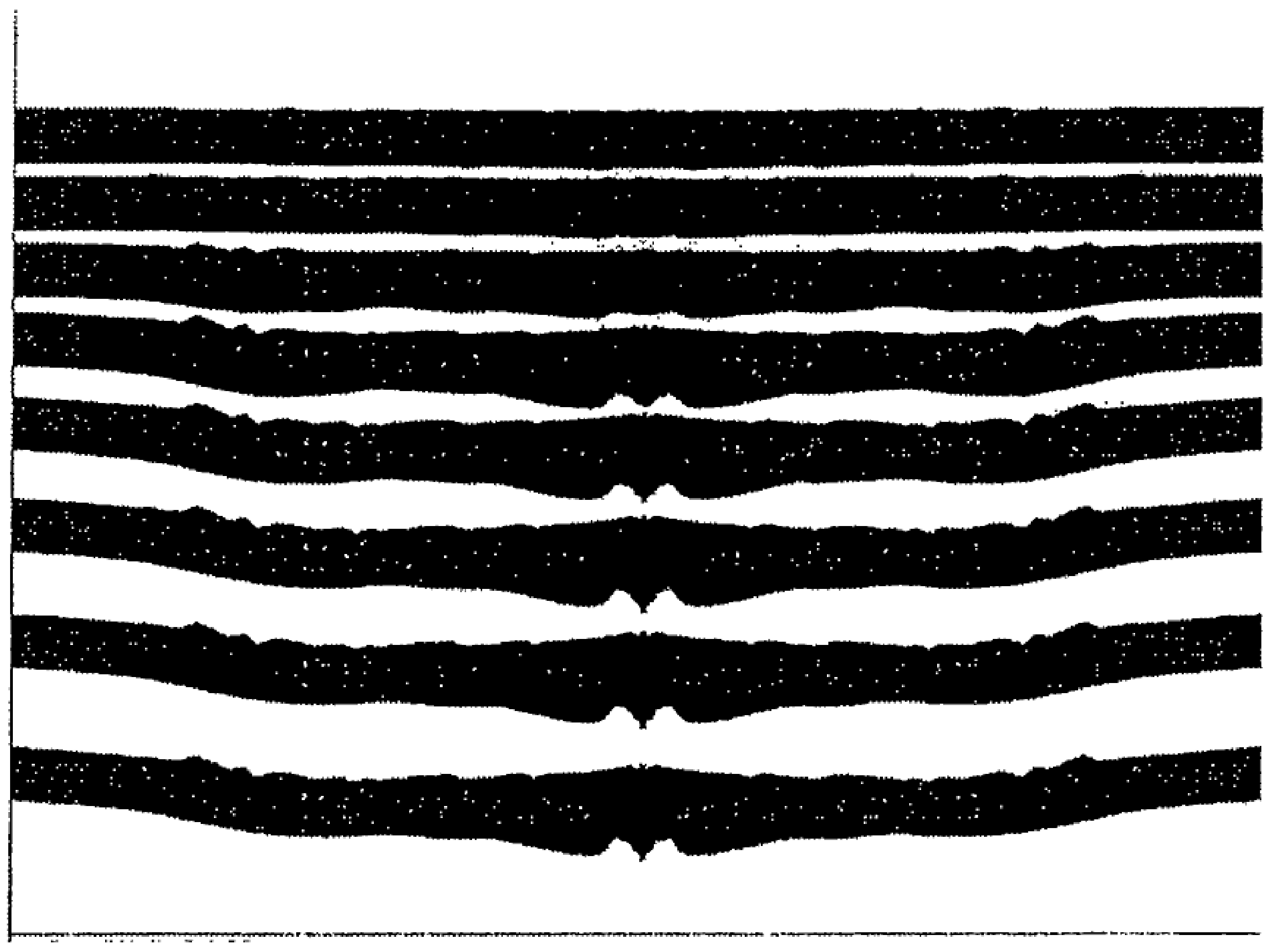

Figure 4 : Backwall damage evolution

The above results were found to represent adequately well the experimental evidence (see Ref. 1). They were then re-analyzed using the SPH option of PAM-SHOCK but without the MLI layer upon the backwall for the sake of simplicity. The correspondence between the results thus obtained and the above results was quite satisfactory.

Figure 5 shows the penetration of the bumper as calculated by the 3D SPH version of PAM-SHOCK. The image contains the vertical velocity gradient distribution which results into the eventual coagulation of matter along the front of the debris cloud. Figure 6 depicts the disk-like coagulation along the front of the debris cloud which is typical of the expansion of such a fragmented medium.

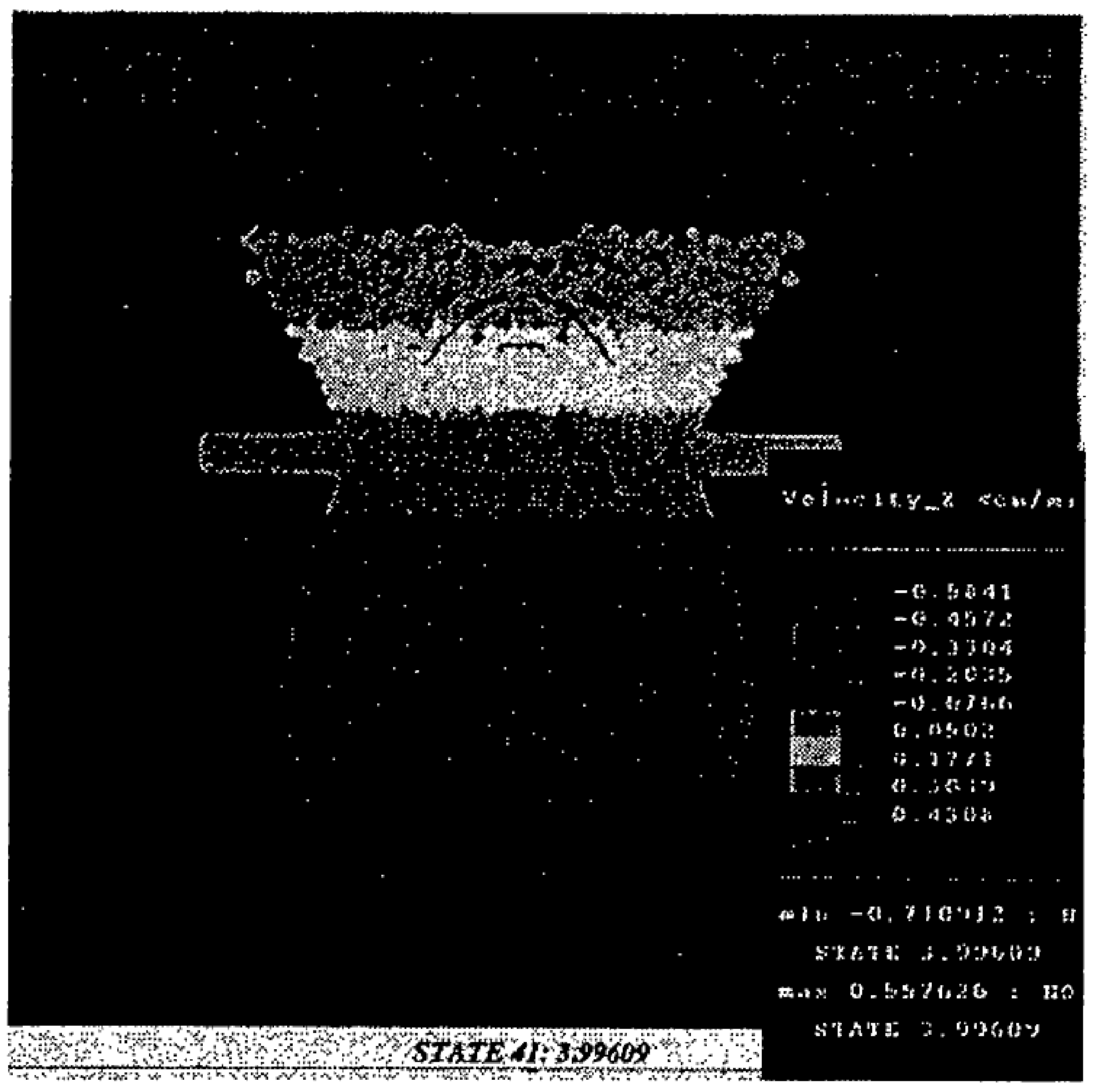

Figure 5 : Whipple shield penetration (SPH)

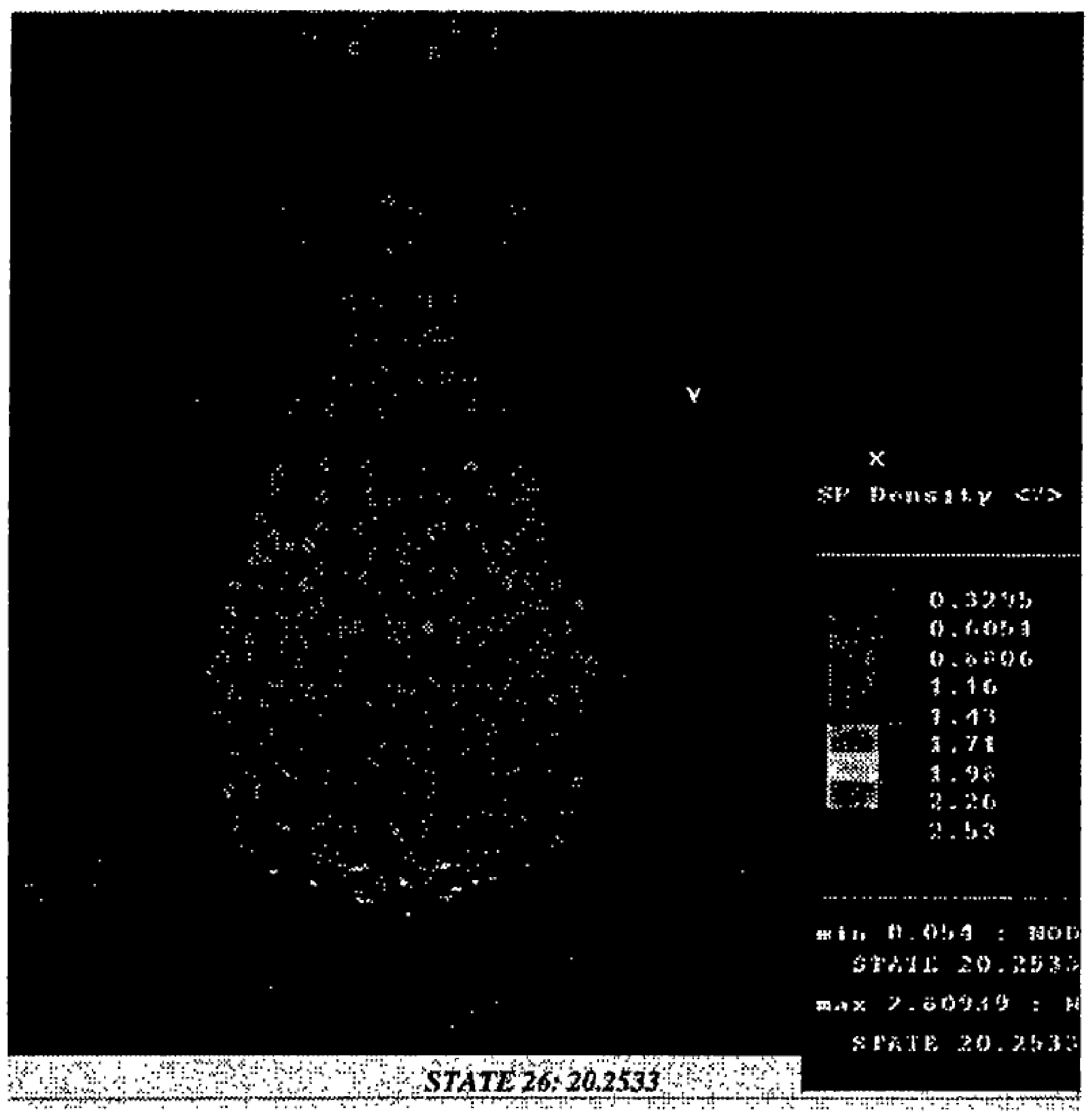

Figure 6 : Debris cloud coagulation (SPH)

Finally figure 7 finally shows the distribution of damage on the backwall through vertical displacement contours. The hole opening at the central point is evident, together with tendency for gross deformations around the hole, which would lead to petalling. The damage pattern is more severe than in the 2D calculation which is in accordance to the fact that the MLI was absent from this calculation, hence the shock resulting from the impacting debris cloud upon the backwall was more acute.

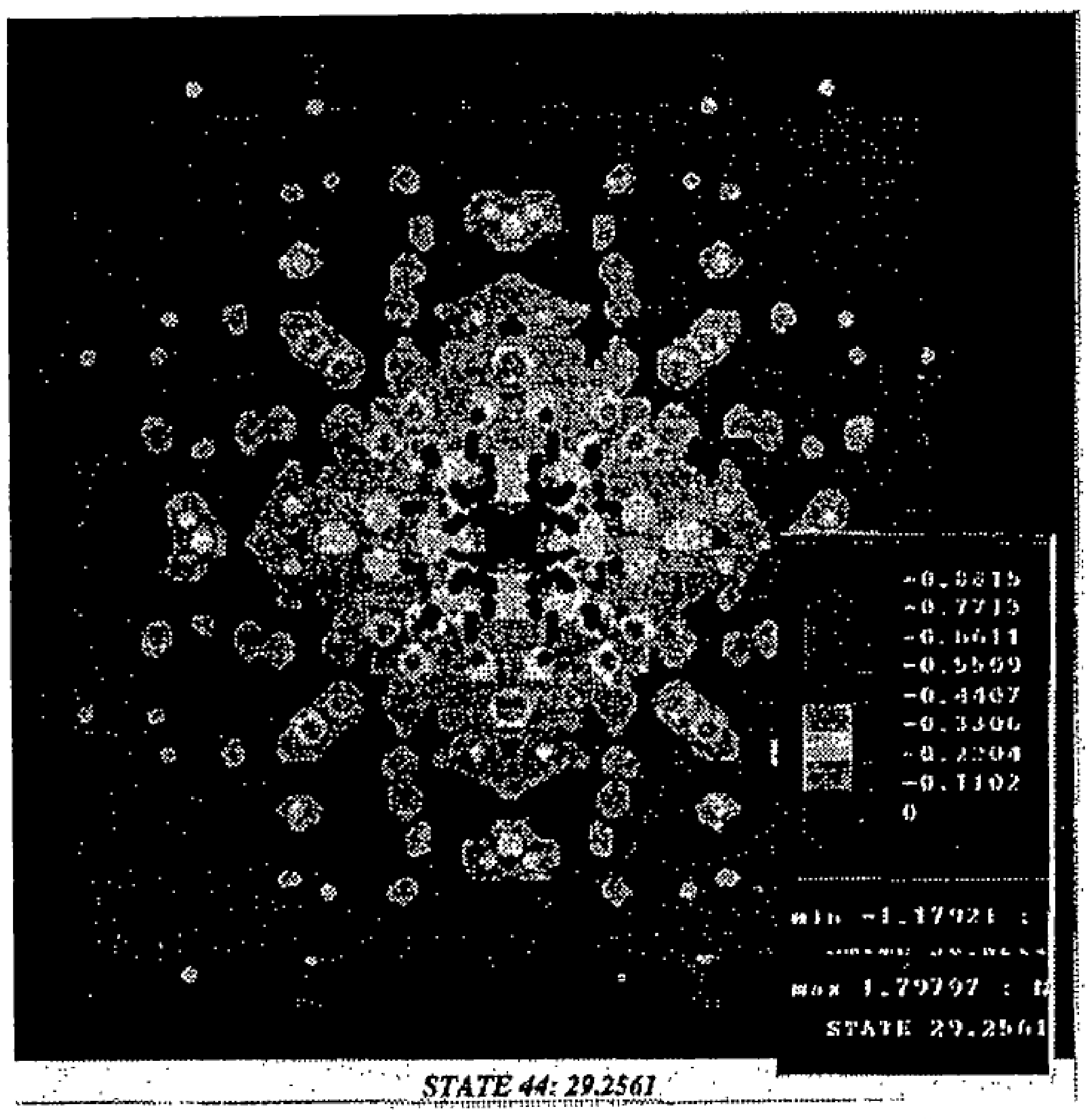

Figure 7 : Backwall damage (SPH)

3. NORMAL IMPACT OF ALUMINUM CYLINDER UPON ALUMINUM WHIPPLE SHIELD AT 11.1 KM/S

This corresponded to the Batelle experiment 9476 (see Ref. 2). Under such conditions the cylinder will perforate the Whipple shield with a hole of roughly 4 times the cylinder diameter. The majority of the cylinder will eventually flow-away into a lyered cloud of molten pieces/droplets while about 1/4 of the cylinder will survive to impact the backwall and perforate it.

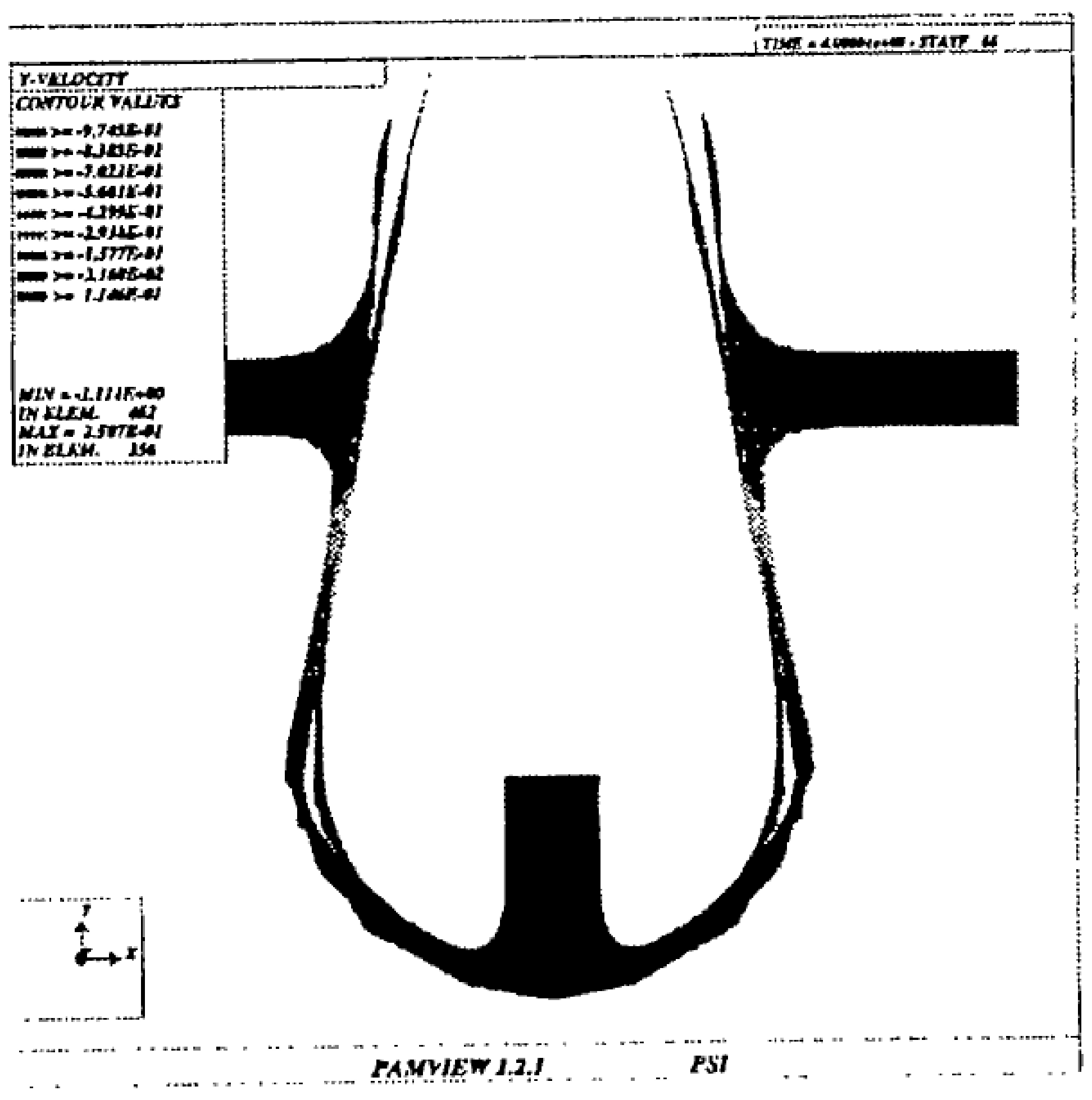

Figure 8 : Penetration of Whipple shield

Figure 8 shows the penetration of the Whipple shield as computed by the Lagrangian solution while figure 9 shows the post-impact evolution of the cylinder. The decrease in size due to the 'melt-away' effect is evident by comparing the left-hand-side (initial size) of the cylinder to that on the right-hand-side (final size) in figure 8.

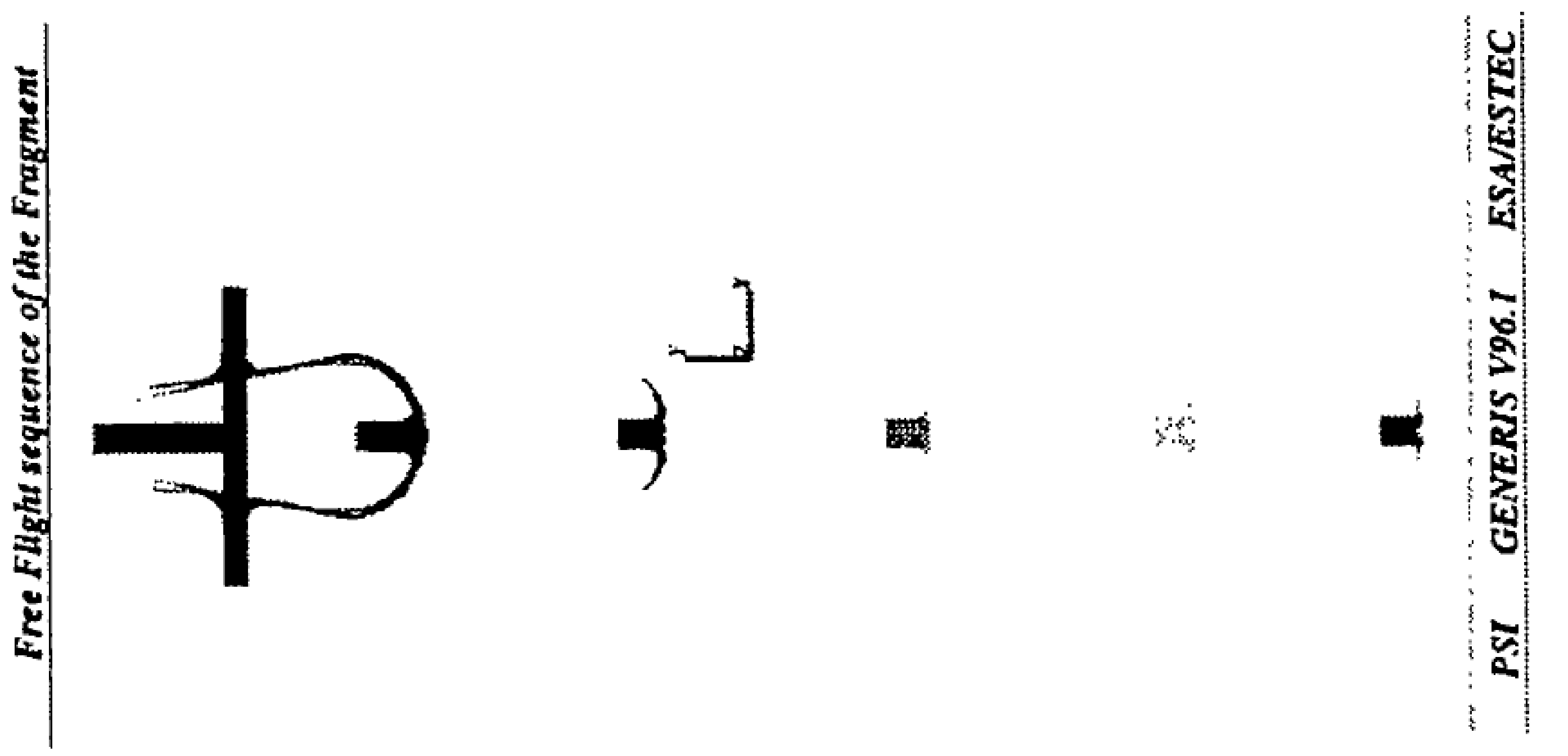

Figure 9 : Post-impact evolution of the cylinder length

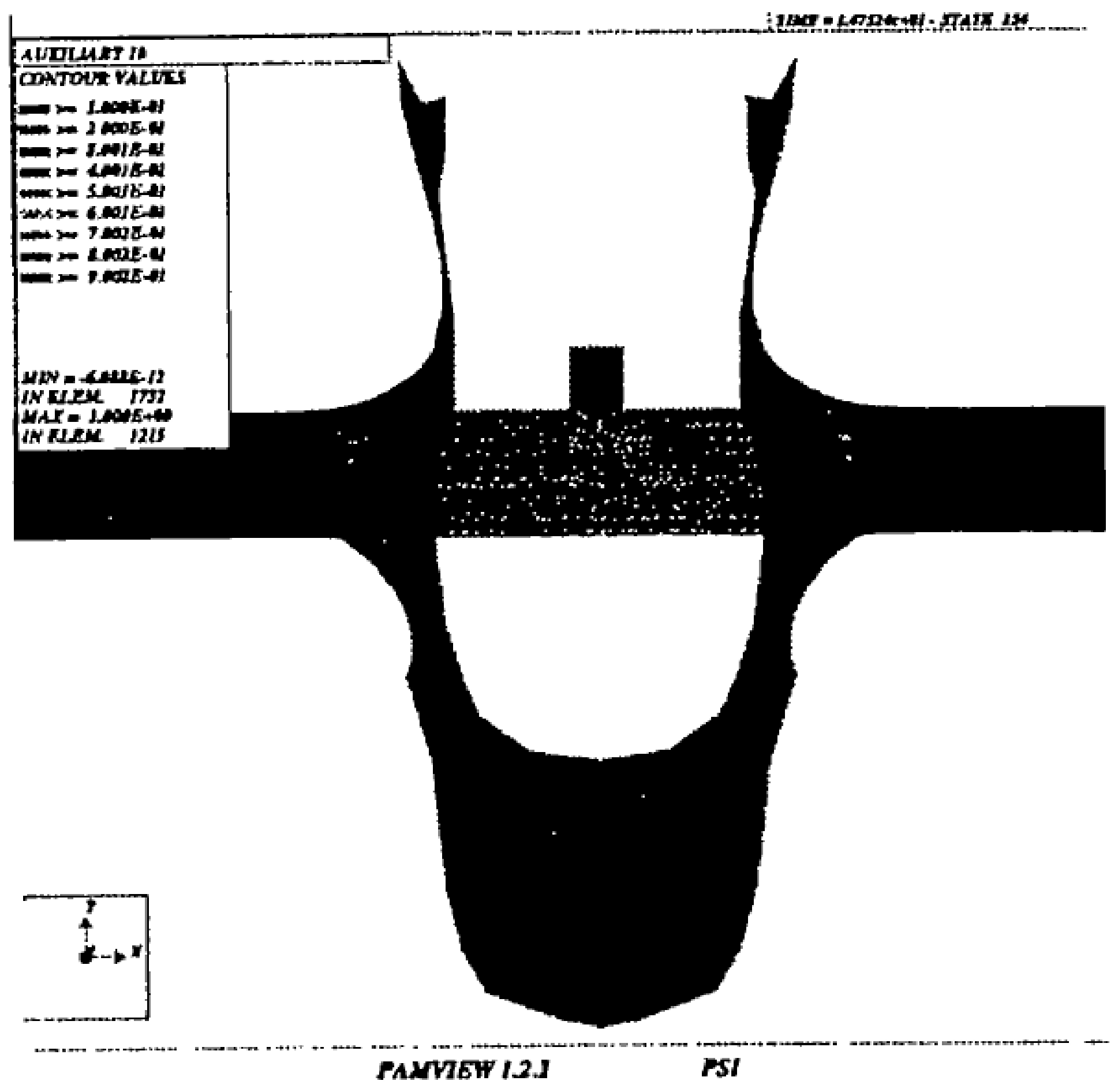

Figure 10 : Impact and penetration of the backwall

Figure 10 shows the impact of the remnants of the cylinder upon the backwall and its subsequent penetration and perforation, the plugging effect being clearly visible from the superposition of the undeformed and deformed meshes. Figure 11 depicts a sequence of the perforation process of the backwall and the evolution of the plugging.

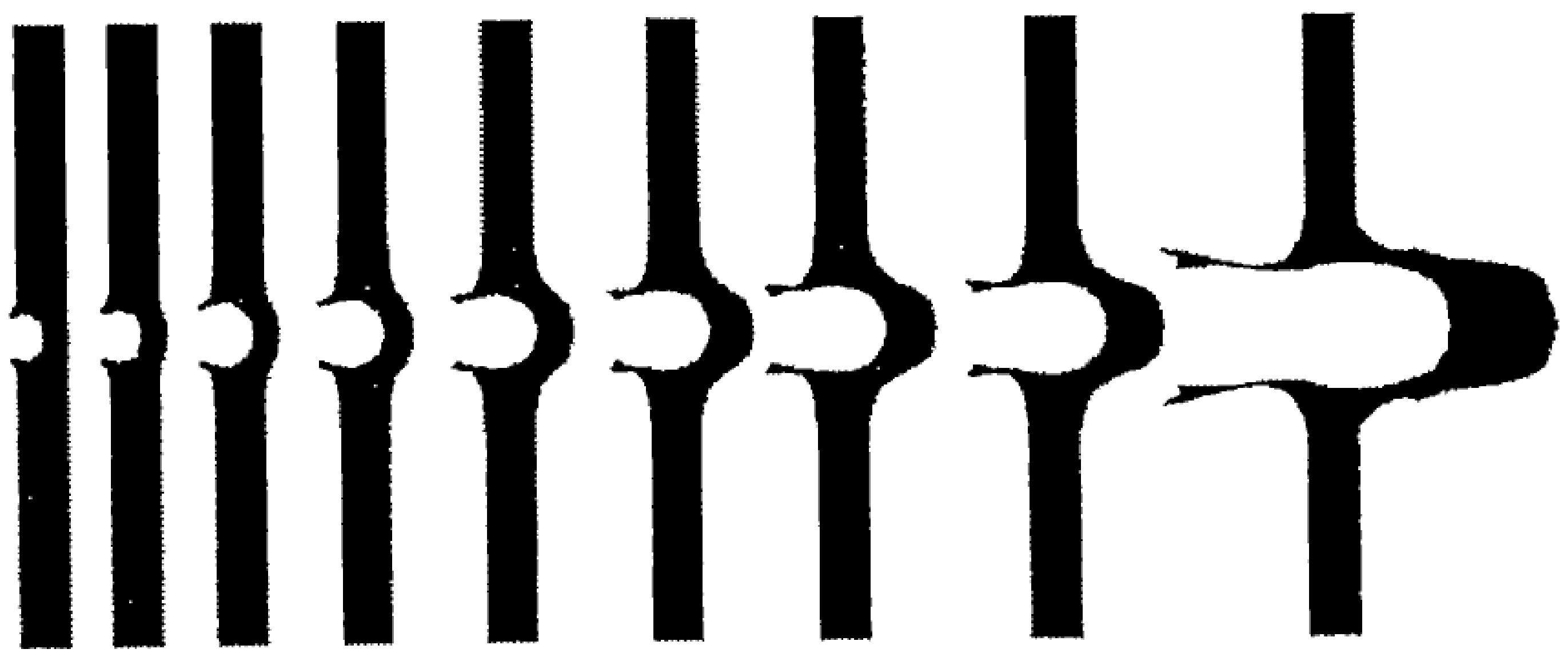

Figure 11 : Perforation of the backwall

The above results were found to represent adequately well the experimental evidence (see Ref. 2). They were then re-analyzed using the SPH option of PAM-SHOCK. The correspondence between the results thus obtained and the above results was quite encouraging.

Figure 12 shows a comparison between the penetration process of the Whipple shield with both the Lagrangian (left) and the SPH (right) methods. It can be seen that there is encouraging correspondence between the two regarding crater size and shape. Observe the spallation in the front of the projectile being represented differently by the two methods.

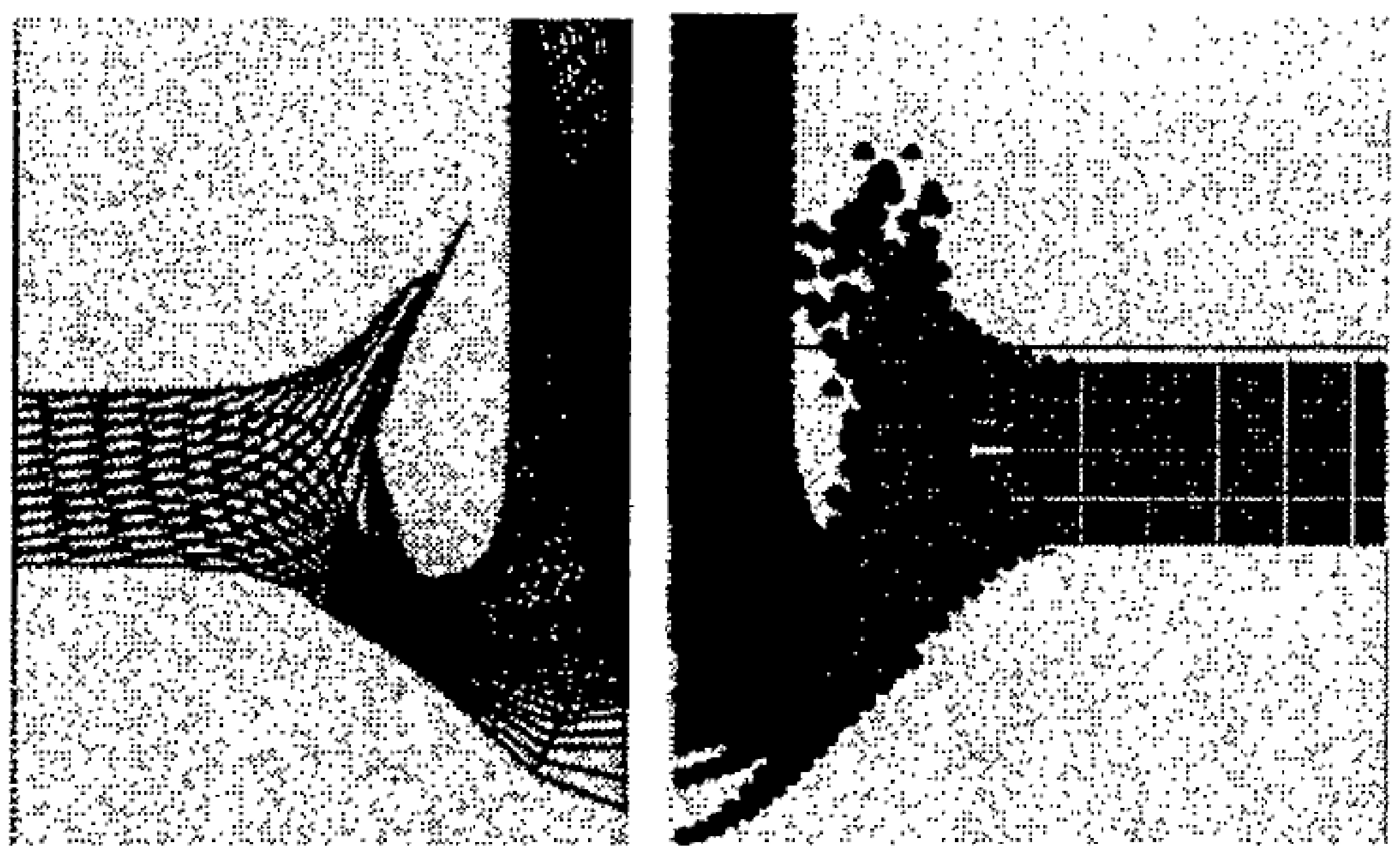

Figure 12 : Comparison between Lagrangian and SPH solutions

Similarly figure 13 shows the same comparison at a later stage into the perforation of the Whipple shield. The time of the Lagrangian and SPH images is not exactly the same but close enough for the correspondence to be evident. The SPH solution is shown from a 45 degree latitude viewpoint ; the through in-depth projection gives the illusion of depth. The debris layered cloud is thin, in accordance to the Lagrangian solution. Once more, the correspondence between the shapes of the debris cloud and the sizes of the cylinder remnants are very comparable between the two methods.

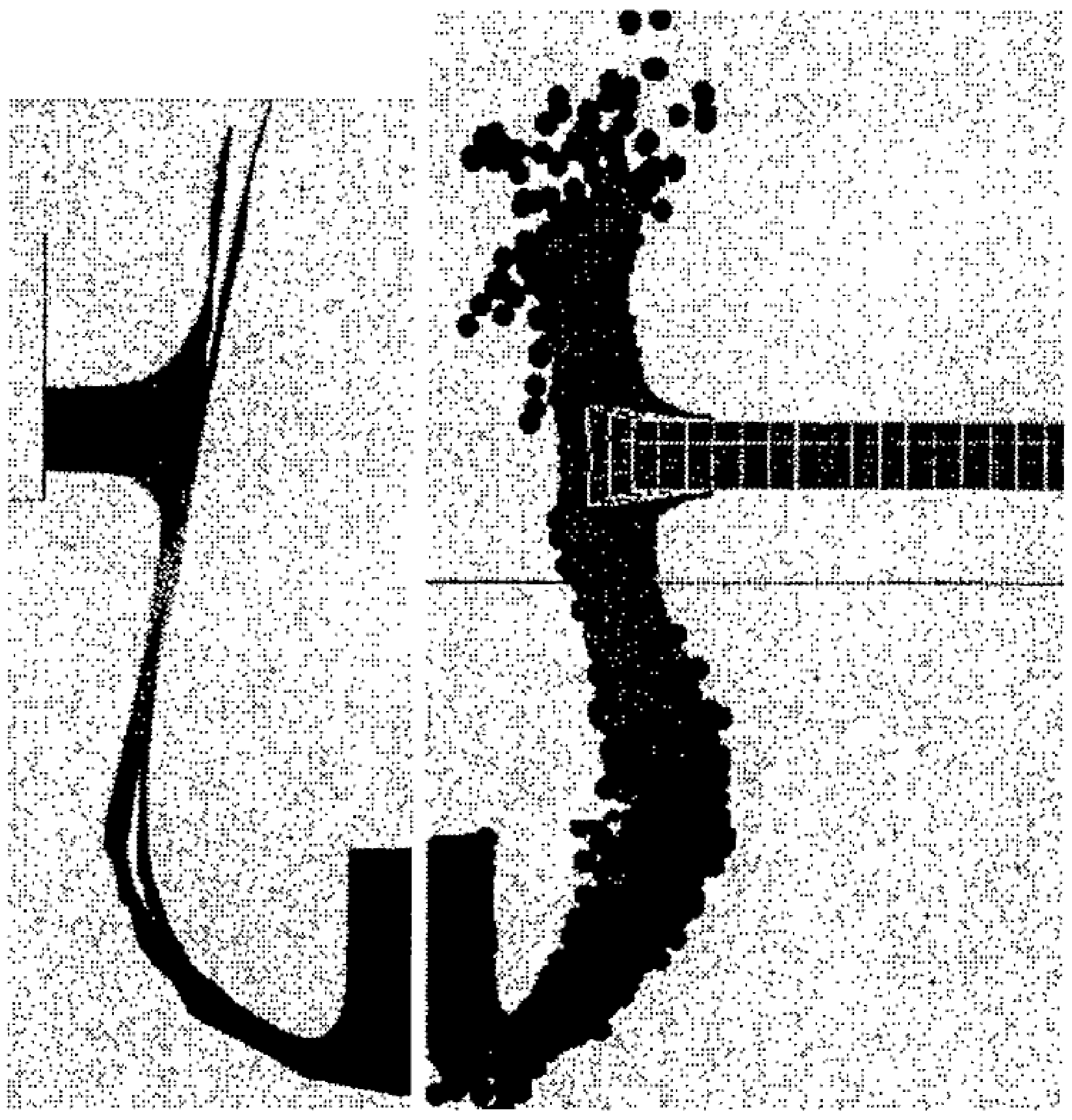

Figure 13 : Comparison between Lagrangian and SPH solutions

4. CONCLUSIONS

In this poster-paper the process of virtual design of space debris shields has been touched with emphasis being given to the virtual prototyping stage of the above process as performed by the PAM-SHOCK family of codes. The feasibility of simulating by computer the extreme space environment hypervelocity impact conditions has been demonstrated by successfully simulating a set of basic experimental configurations some of which represent the limits of experimental testing of this kind. The satisfactory set of results that were obtained with both Lagrangian FE and the relatively new SPH options of PAM-SHOCK underline the feasibility of the method and open the way for the SPH option to be tested against cases of inclined hypervelocity impacts where classical Lagrangian FE solution would be rendered impracticable.

5. ACKNOWLEDGMENTS

The writers would like to acknowledge the support of the European Space Technology Center (ESA/ESTEC) YME Group and COLUMBUS Group under the contract 11720/95.

6. REFERENCES

1. ESA CR(P) 3615 Meteoroid and Debris Protection Study Report (1992)
2. ESTEC CONTRACT 10.969/94/NL/PP(SC) Final Report (1997)