IDENTIFICATION OF PARTICLE CRITICAL PARAMETERS FOR SCREEN SHIELDING OF VEHICLES AND ORBITAL STATIONS

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ABSTRACT

The problem of protecting space stations against collisions with space debris fragments and meteoroids is of a great practical significance, for instance, in case of designing the ISS protection system. Previously conducted studies have shown,that spaced screen structures provide the most reliable shielding. At present, reliable experimental data on resistance of such screens under tests at light-gas and electrodynamic guns at impact velocities of up-to 6 to 8 km/sec are available, and there are experimental data for higher velocities too, but these data are less reliable. To-day our efforts are focused at development of reliable hydrodynamic programs, ensuring impact calculations for relative velocities of 8 to 15 km/sec. Such programs certified by both available hypervelocity test results and applying results of other hypervelocity experiments should enable to develop optimal screen structures. Development of methods to evaluate screen shielding resistance should be coordinated by the organizations, participating directly in the Alfa Project.

The present paper offers some tentative results of correlation of a three-shieding calculations by the Central Physical-Technological Institute with the data, obtained by the Johnson Space Center.

CALCULATIONAL METHOD

The given paper is devoted to determin the dependence of the spherical aluminium minimal mass pellet capability to pierce a three-layer spaced screen structure on collision velocities of 6 to 14 km/sec. Structures of this type are supposed to be mounted on future space vehicles and orbital stations.

Specific nature of the problem, discussed below is that the screen thickness is some millimeters, while spaces between them are tens of millimeters. Such a difference between their sizes restricts the selection of a computational method and requires a great computer time.

To make computations they applied the associated grid particle method and this method-based computational program for solving two-D dynamic problems of the mechanics of continua with great deformations, random geometry in the gasdynamic and elastoplastic formulation with due regard for material breakdown.

Fig. 1 shows the screen structure for computational procedure. Location of Lagrangian transducers for fixing time changes of velocity local values, density, pressure, target material failure degree is marked in the scheme. The main series of computations was conducted in the range of spherical pellet mass of 0.066 to 0.2 g.

To adequately conduct a numerical experiment and to correctly interpret its results they have chosen physical parameters, which would have reliably demonstrate, that the multi-layer spaced structure and screen had been pierced. When making computations the fact of sceen piercing was considered as complete collapse of the last obstacle in the loading zone and imparting to the destroyed material the velocity, exceeding the speed of the obstacle's undestroyed part deflection. To characterize the failure they used the value of screen material preservation degree in the fragment flow loading zone (L). This value means the relation between a substance «skeleton» volume and its complete volume at the given moment. The L parameter physical sense demonstrates, that its value may change from 1 to 0. Further computation results description uses the L material preservation degree value. Note, that the material is believed to be destroyed when parameter L approaches to zero. This situation occurs if tensile stress intensities surpasses the dynamic maximum strength of a specific material.

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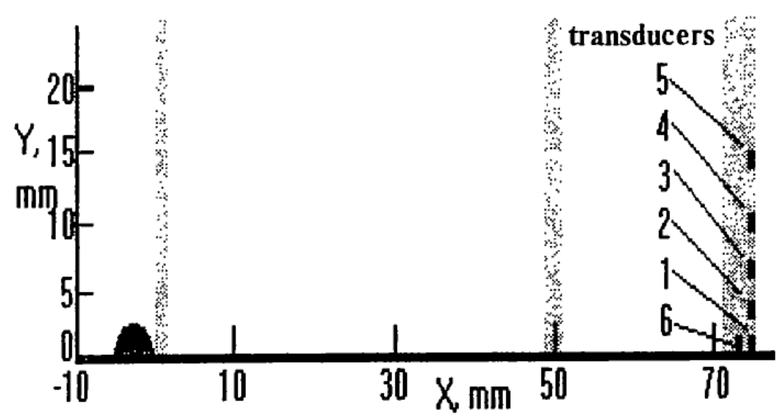

Basic parameters of the screen

Layer thickness: first - 1.27 mm

second - 2.13 mm

third - 3.18 mm

Distances between the screen sheets:

between first and second - 47.5 mm

between second and third - 21 mm

Range of spherical pellet mass and dimension changes:

0.066 to 0.187 g

1.8 to 2.55 mm

Fig. 1 Initial design scheme of the problem for identifying a spherical pellet mass, capable of piercing an aluminium screen in the form of a three-layer spaced obstacle.

CALCULATIONAL RESULTS

Results of numerical modeling of the spherical pellet and screen collisions are depicted in Fig. 2.3 as instantaneous images of the last screen sheet axial cross-section. The dynamics of deformation and failure processes is pictured by the graphs of relationships the axial velocity V_x and L value of the Lagrangian transducers versus time. Amplitude values and the nature of these changes enable to monitor, when the screen is pierced or not.

It has been established, that at the 6 km/sec impact velocity the screen is pierced by a pellet of the mass of approximately 0.187 g. Calculations demonstrated, that when a 0.176 g pellet is used there appear first signs of puncture formation, but if this mass is 0.187 g these signs become more definite, the target central portion significantly deflects in the pellet motion direction and breaks up.

At the impact velosity of 8 km/sec the mass of a pellet, capable of piercing a screen is in the range of 0.104 to 0.137 g. Results of calculations proving this fact are shown in Fig.2. A pellet of mass 0.105 g can slightly damage the surface and slightly deflect the third sheet of a screen only. The free surface velocity of the sheet does not exceed 60 m/sec and the surface pressure is less than 0.06 kilobars, these values being much lower than the cleavage strength value of solid aluminium alloys. A 0.137 g pellet fully destroys the target material in the area from the first to the second transducer and a considerable difference of mass velocities in the central and peripheral transducers is observed. Therefore one can think, that a spherical pellet of about 0.14 g is capable of piercing the screen under consideration.

At the impact velocity of 10 km/sec the mass of a pellet, capable of piercing the screen may be still lower. Calculations show, that a pellet of the 0.066 g can not yet pierce the screen, and if this mass is 0.09 g one can assuredly say, that it can pierce the screen.

Some results of the numerical modeling of an impact at the 14 km/sec velocity are shown in Fig.3. With the mass of a pellet of 0.105 g a crater is formed in the third sheet without any puncture. It is demonstrated by the relationships the axial velocity and material preservation degree versus time, shown in Fig.3. They show, that the screen material is destroyed in depth where transducer 6 is placed just in the middle of the third sheet, while there is no collapse in the area of transducer 1 near the screen rear surface. Increase of the pellet mass to 0.12 g results in formation of a puncture in the screen. The nature of the screen destruction in the position of transducers 1 and 2 features formation of cleavage fragments in the axis vicinity. So, one can consider, that at the 14 km/sec impact velocity the screen is pierced by a pellet of the 0.12 g.

The computational results obtained are generalized in the form of a ballistic curve - relationships between the pellet minimal mass, capable of piercing the screen and the impact velocity. This results are presented at Fig. 4.

When analyzing the computational results the protection properties of a screen similar to the investigated one stated in article [2] were taken into account. Data given in the mentioned article concerning the minimal masses of a spherical pellet, capable of piercing the screen differ from the above-stated results by 2-3 times in masses and accordingly by 20 - 40% in particle dimensions.

We believe that our results may be considered to be an evaluation «from below» - that is particles, masses of which lie below this

Impact velocity of 8 km/sec

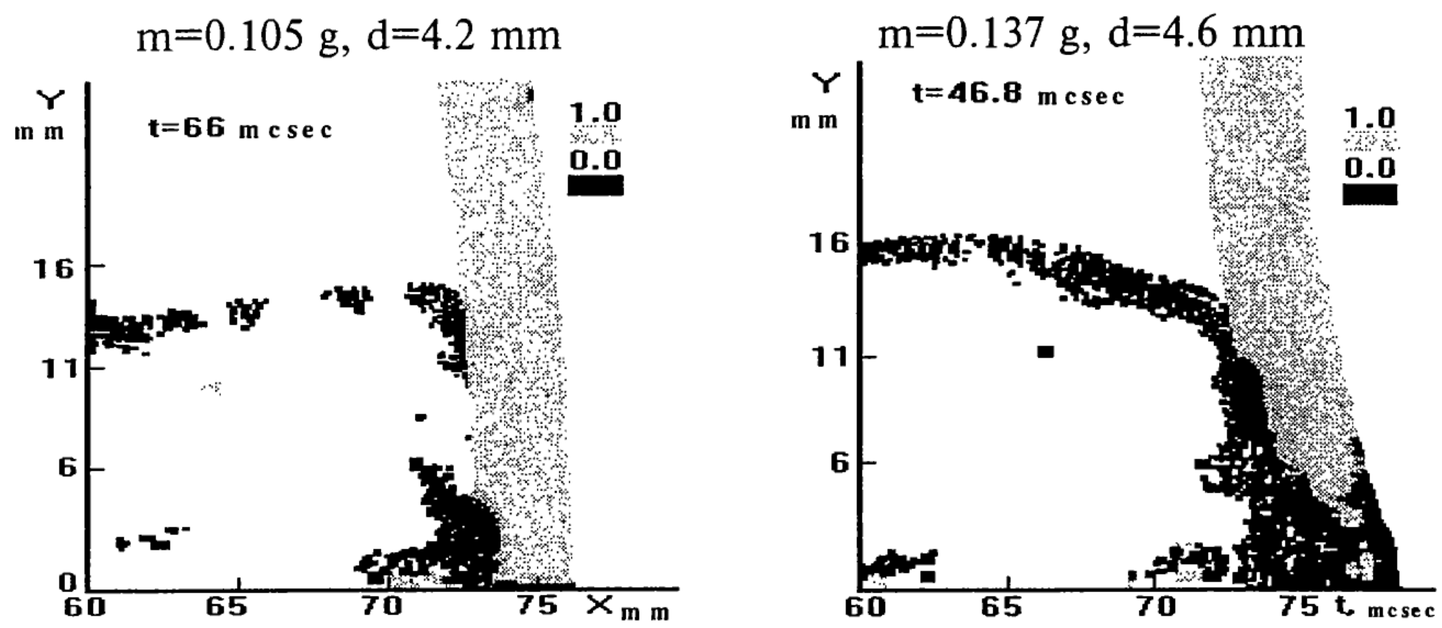

Fig. 2a Nature of damages of the screen's third sheet

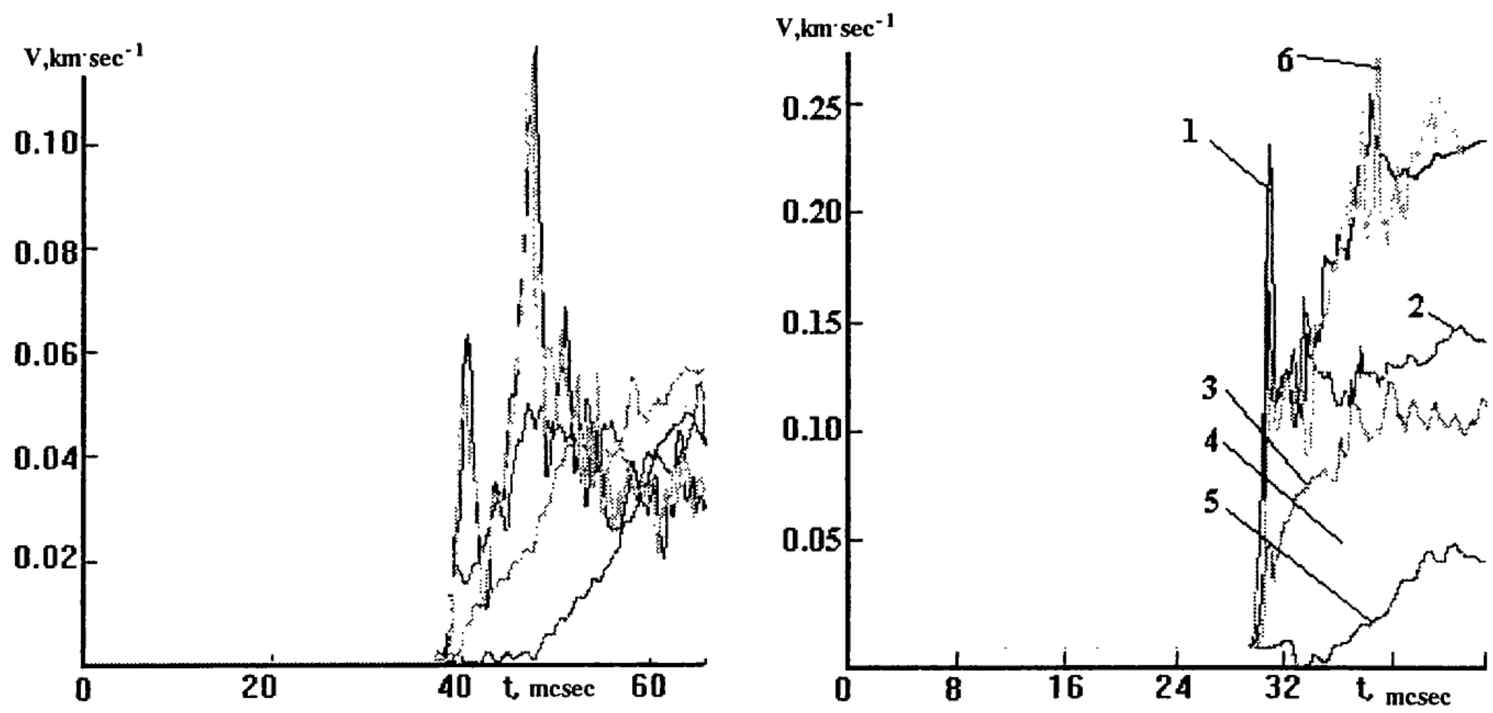

Fig. 2b Time as a function of the mass velocity of the screen substance in transducers 1 to 6

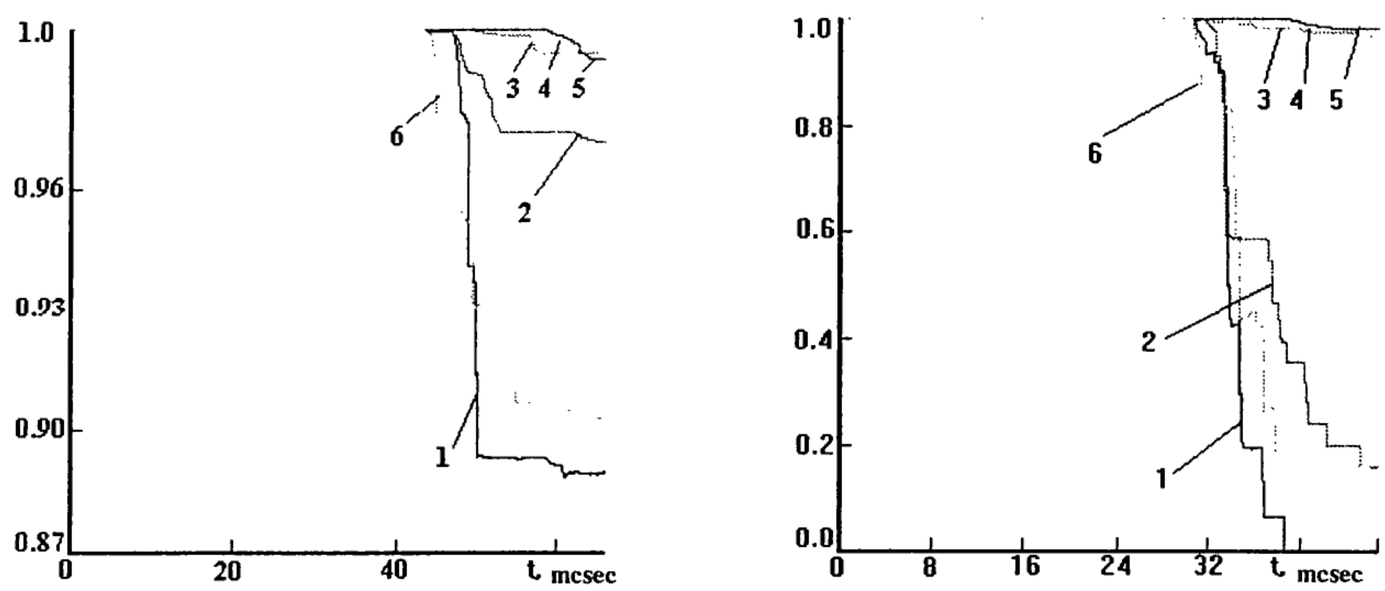

Fig. 2c Change of the screen material preservation degree in transducers under loading

Impact velocity of 14 km/sec

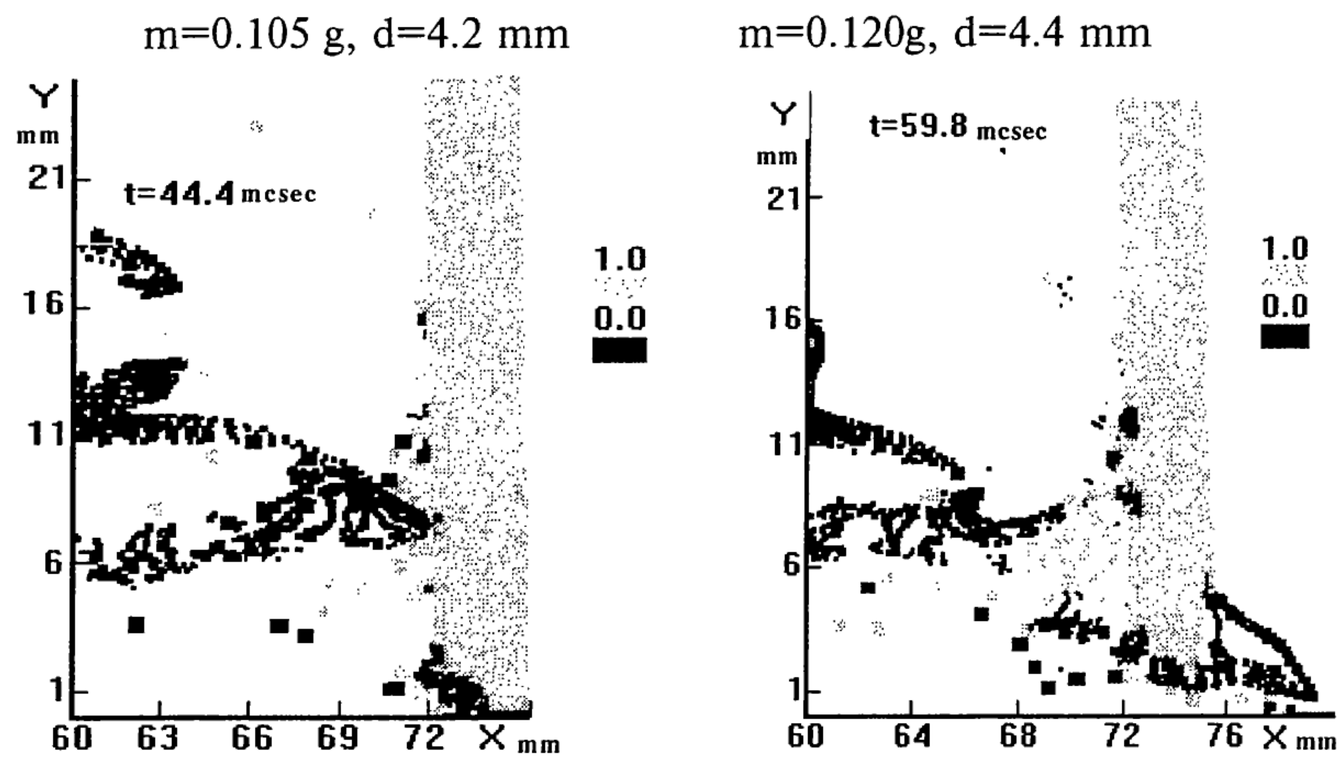

Fig. 3a Nature of damage of the screen's third sheet

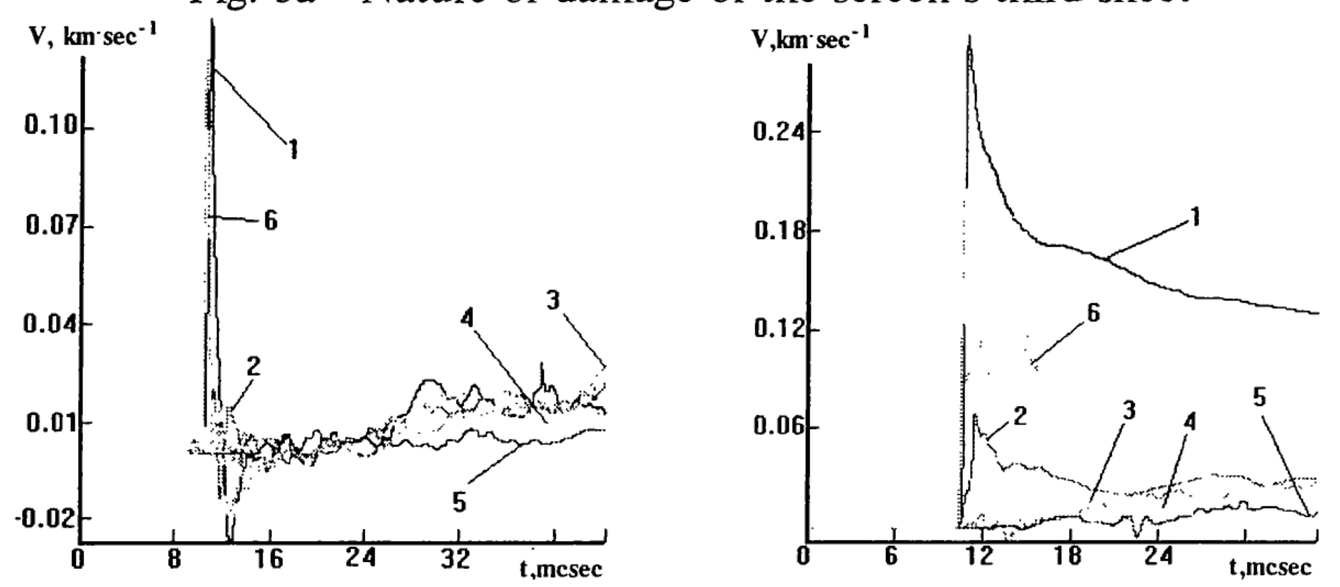

Fig. 3b Time as a function of the mass velocity of the screen substance in transducers 1 to 6

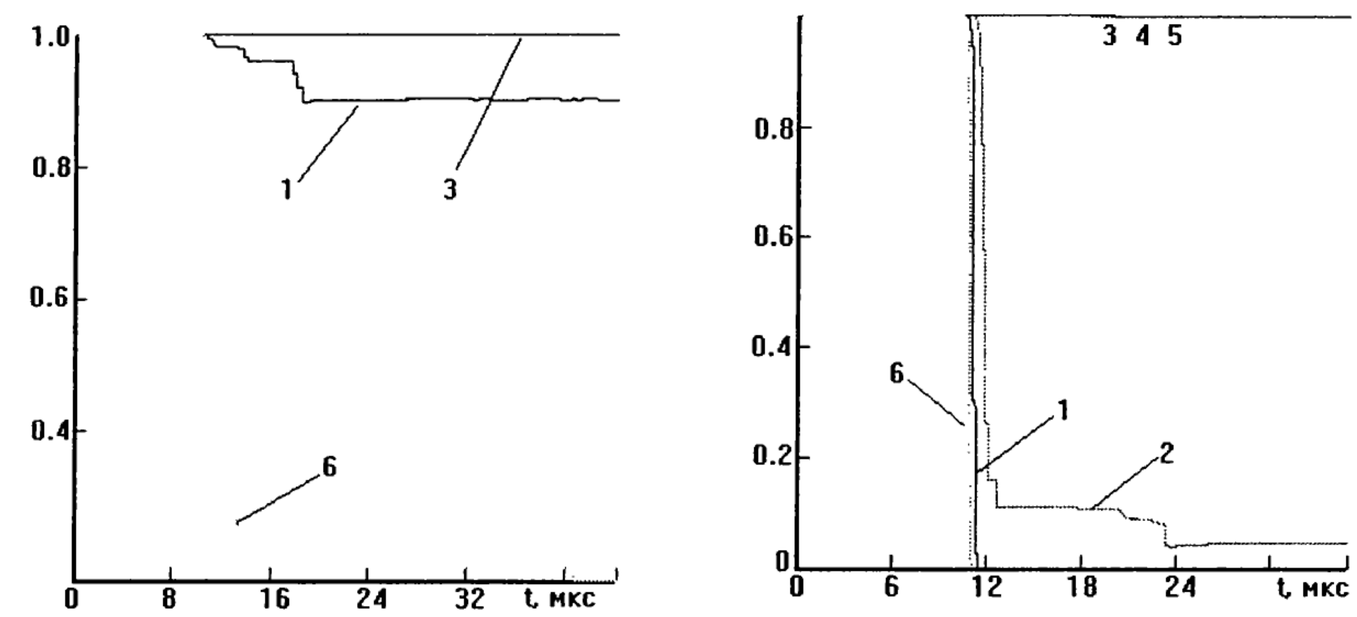

Fig 3c Change of the screen material preservation degree in transducers under loading

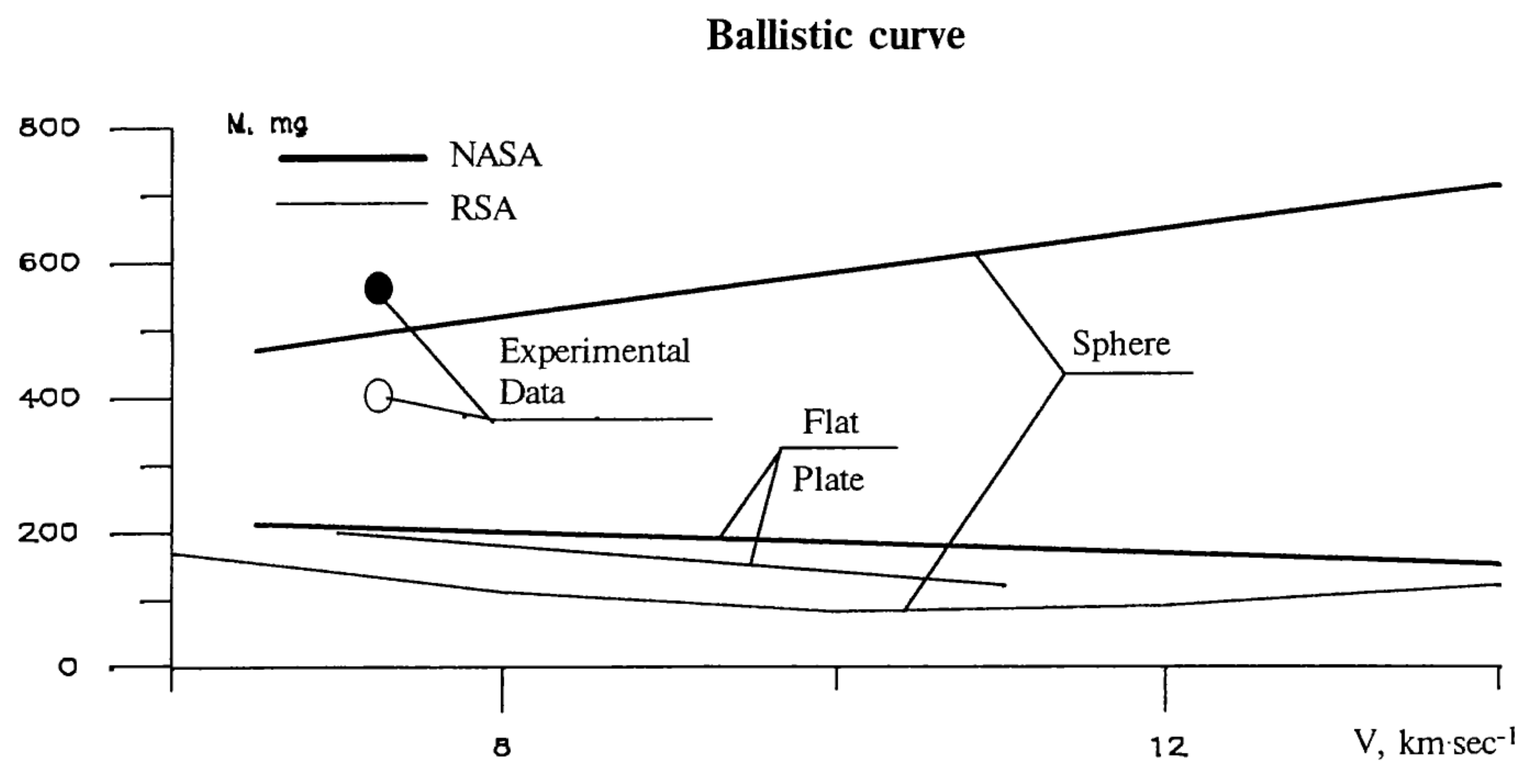

Fig. 4 Impact velocity as a function of the minimal masses of spherical and plat-shaped pellets, piercing the screen.

curve will not pierce the given structure in all probability.

Comparison of computational data, conducted by the authors of the present paper with the results stated in paper [2] enables to make several remarks.

Design values of critical masses of spherical pellets differ by more than 2.5 times for the velocity of 6 -7 km/sec. With the velocity growing these differences grow as compared with the continuous curve (see Fig.2 of paper [2]) and lower as compared with the dotted curve and corresponding semiempirical formula (1) of paper [2].

Taking into account the complexity of simulating such a structure and practically absolute lack of information about experiment conditions, capabilities of hydrocodes and applied equations of state the obtained data should be considered to be satisfactory within the limits of uncertainties available.

Check calculations of thin sheet impacts (repeation of calculations S9 and SIO of paper [2]) showed the complete and confident conformity of the results.

This circumstance requires a conservative and critical attitude towards the results [2]. In particular, in our opinion it concerns the statement of a high piercing capability of a thin plate as compared with a pellet of the same mass. In our point of view it should be vise versa.

In conclusion one should note, that the qualitative plotting of such ballistic curves turned out to be more labour-intensive as it seemed to us from the outset. From the methodological point of view a desired accuracy of computations should be evaluated more exactly by conducting test calculations applying grid cells of different sizes and different counts of particles. In all probability, the impact initial phase, i.e. dynamics of pellet collapse at impact with the first sheet should be simulated more thoroughly, thus making it possible to evaluate the influence of the pellet shape on its piercing capability. Naturally, more detailed information about properties of materials used is required.

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2. J.H.Kerr, E.L.Christiansen, J.L.Crews Hydrocode Modelling Of Advanced Dedris Shield Desing. Space Science Branch, NASA Johnson Center, Houston, Texas 77058.