

DAMAGE PARAMETERS ANALYSIS OF SHIELDED PRESSURE VESSELS
UNDER SPACE DEBRIS IMPACT

Igor Ye. Telitchev, Alexander G. Prokhorov

Samara State Aerospace University, Moskovskoe shosse 34,
443086 Samara, Russia

ABSTRACT

The present paper is devoted to a damage parameters analysis of shielded pressurized module. The developed damage model is suggested for estimation of the residual toughness of pressurized module shell with petalling type of damage. To test the validity of the proposed models, the problem was investigated in the research laboratory and on the testing ground. As a result of analysis the combined space debris protective system "distant shield-loaded shell-interior shield" is suggested.

1. INTRODUCTION

Shielding is a most traditional method of affording the space vehicles survivability. For the proficiency estimation of the different types of spacecraft shield protection the analysis of corresponding shield ballistic limit curves are carried out in this investigation (Ref. 1-2). As a result of analysis the range of impact velocities from 1 km/s to 5 km/s was found to be the most hazardous for the shielded pressure vessels. Under these impact velocities either the space debris particle perforates shield without particle fragmentation or particle fragmentation takes place but the particle fragments offer high enough momentum to damage the shielded structural element. It should be realized that the implementation of space debris shields for space station pressurized module protecting in the case of shield and shell perforation produces sizable change in the damage parameters of the shell, which is loaded with inner pressure.

2. EXPERIMENTAL RESULTS ANALYSIS

The direct relationship between shield design characteristics and damage parameters of shielded structural element was investigated by an experimental approach. The multi-wall system involving ceramic shield and specimen-witness was impacted by spherical steel projectiles with diameter of 4.5 mm. The test specimens-witnesses were produced from duralumin and aluminium-magnesium alloys (D16 and AMg6). Specimen-witness thicknesses (t_s) ranged from 1.2 mm to 4.0 mm. The tests involved a specimen sizes that minimized or

eliminated the influence of the boundary or plate deformation. Ceramic shield thicknesses (t_{cer}) ranged from 5.0 mm to 13.0 mm. The surfaces of ceramic shields and specimens-witnesses were set at right angles to the impact direction.

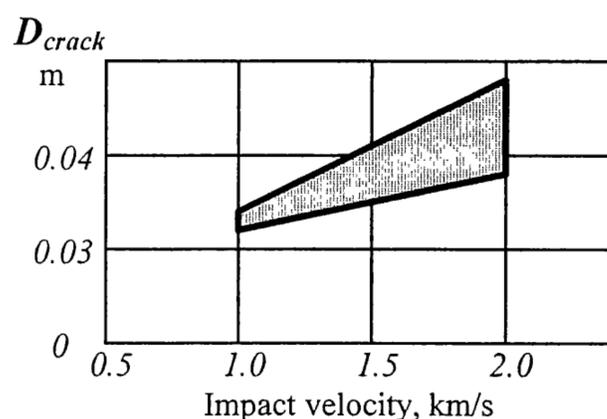


Fig.1. Damage parameters of shielded target (D16, $t_s=2.0$ mm, $t_{cer}=7.5$ mm)

The results of investigation disclosed that the impact action of projectile with velocity below the ballistic limit resulted in non-perforation of the specimens-witnesses and permanent deflection in the contact area.

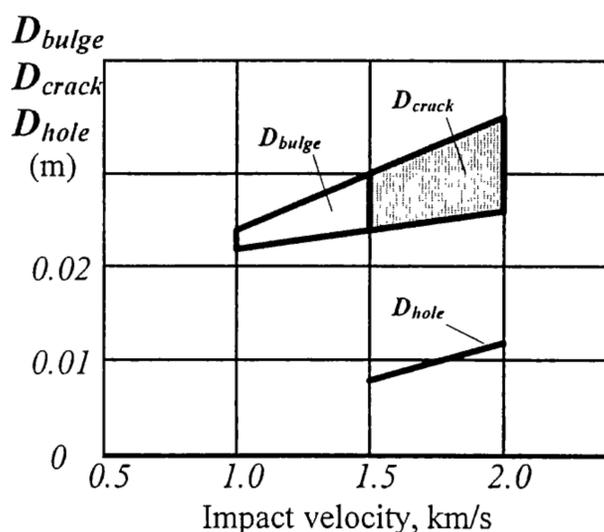


Fig.2. Damage parameters of shielded target (AMg6, $t_s=3.0$ mm, $t_{cer}=9.0$ mm)

An increase in projectiles velocity above the ballistic limit resulted in perforation and petalling, and it was found that increasing the impact velocity increases the hole diameter D_{hole} and the diameter of the damage zone D_{crack} (Fig. 1-2). So, the diameter of the damage zone of the D16 aluminium specimen-witness ($t_s=3.0$ mm) pro-

ected by exterior ceramic shield was increased from 22 mm to 45 mm as the projectile velocity increased from 1.5 km/s (ballistic limit) to 2.0 km/s. In the absence of a shield for the impact velocities of 2.0 km/s the same specimen-witness was perforated and perforation-hole diameter was 5.2 mm (Fig. 3).

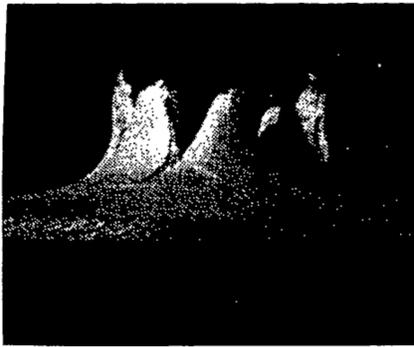


Fig.3. Damage parameters
(target: D16; projectile: steel, Ø10.3)

3. DAMAGE MODEL

In the case of non-perforation the diameter of permanent deflection (D_{bulge}) was used as a damage parameter; otherwise the hole diameter (D_{hole}) and the diameter of the damage zone (D_{crack}) were used for these purposes.

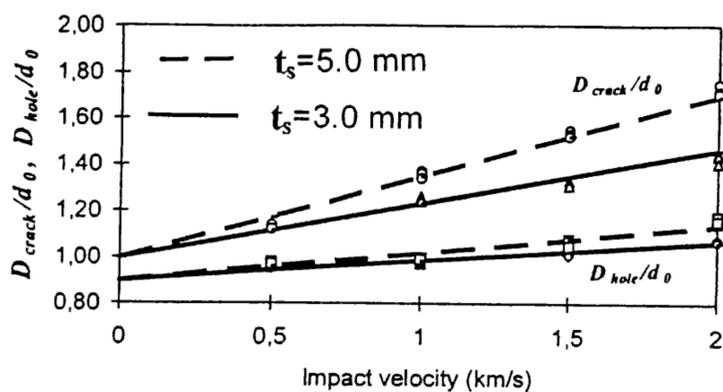


Fig.4. Damage structural element after debris shield perforation.

Despite the external distinctions, parameters D_{bulge} and D_{crack} characterize the same phenomenon - specimens material deforming under space debris impact, because in the process of petalling the liberating of elastic energy results in propagation of radial crack closely to the boundary of permanent deflection (Fig.4). That is why the damage zone (zone of radial crack) is coincident geometrically with the zone of permanent deflection and $D_{bulge} = D_{crack}$.

According to the proposed methodical approach to estimating the survivability of space vehicle structural elements with crack-like damage (Ref. 3) the petalling type of damage can be thought of as two cracks originating at the boundary of a circular hole. The diameter of the

model hole is equal to the diameter of the hole made with debris in structural elements. The radial cracks are normal to the direction of load (S), where the load S is a function of the space station module inner pressure (p_{in}), and the length of cracks is bounded by zone of radial crack.

The validity of the proposed damage model was checked experimentally. The tensile test specimens (D16Am) with petalling type of damages and man-made model damages were used for tests. The man-made model hole were machined by drilling, the radial cracks were produced using fret-saw and fractuating load up to appearance of the fatigue crack. The tensile tests demonstrated that proposed damage model correlated well to test data. The differences in values of fracture load for specimens with different types of damages were no more than 3%.

The results of numerical and experimental investigation of the residual toughness of damaged specimens disclosed that in the absence of a shield the simple perforation of pressure vessel wall take place under the impact of meteoroids and manmade particles. Perforation of back wall of shielded pressure vessels leads to the catastrophic failure of the vessels for the wide range of space debris impact velocities.

4. SPACE DEBRIS SHIELD PROTECTION ANALYSIS

So, for every space debris shield there exists a reasonable wide range of impact velocities, when the shielding is not only ineffective but it also has adverse effect on residual toughness of damaged pressure vessel wall because of damage size increase. However it is impossible to given up the idea to use the shielding for spacecraft protection because it can lead to the failure of interior structural elements and terminate prematurely spacecraft missions. Hence there take place the technical contradiction.

One way to resolve this problem is to place shield protection back of the pressure vessel wall, that is, inside of pressure vessel. Proposed configuration makes possible to combine case of simple perforation to minimize damage size with interior structural elements protection and avoid the case of pressure vessel catastrophic burst. The perforated pressure vessel wall can be hermetically sealed, using one of the well-known ways of doing this. Relatively small size of damage in the case of "interior" positioning of shield protection alleviates the problem of hermetic sealing of damaged pressurized module. It is of particular assistance during flight in the automatic mode of operating without crew. An additional point to emphasize is that arrangement of shield protection inside of pressurized module provides easy access to the shield, mounting and dismantling according to the orien-

tation of spacecraft and changes in the flight program. This is especially important when space debris impact probability rises steeply (satellite explosion). The structural elements and some special equipment, placed inside of module, also can be used for an "interior" shields.

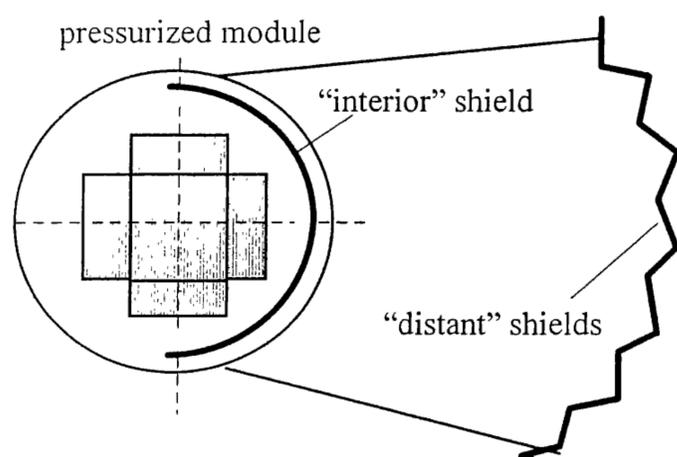


Fig. 5. Combined space debris protective system

The another way to resolve above stated problem is to use space debris shield, which contrary to the traditional shield protection is far removed from module shell (the order of 10 m). Because of "spacing" as large as this, the part of fragments from periphery of bumper and projectile debris cloud will miss the pressurized module and escape the impact collision. The other debris cloud fragments impacting pressurized module will be distributed throughout the large area of module surface and will not form the great single damage of petalling type. This type of shield can be built in space after orbital injection and docking of the space station modules.

The size of damage of shell loaded with inner pressure can be also reduced by using not a single shield but several layers-shields placed in series. Because the "focusing" phenomenon there is take place the narrowing the debris cloud and therefore reducing the damage size. This way is well-known and often used in multi-layer protections, but in this case the size of damage is reasonable large and "focusing" and narrowing the debris cloud is no good for interior elements.

As a result of analysis the combined space debris protective system "distant shield-loaded shell-interior shield" is suggested. This protective system combines the advantages of space debris protections with "interior" and traditional positioning of shield. It is the authors's opinion that the presented way is a most efficient for the space debris protection of space station "Alfa".

It has been known that most large-sized fragments (most dangerous) are generally grouped in the center of debris cloud. Hence, if "distant shield" is designed in form of tilted surfaces, the debris cloud fragments will be deflected. It is possible, that the path of most dangerous fragments will change sufficiently to avoid the impacting the module shell (Fig. 5).

In such a manner the presented space debris protective system will provide the projectile fragmentation and fragments path deflection. In the case when the kinetic energy of some fragments is high enough to perforate the module wall and to damage the elements inside of module, the system "shell-interior shield" will provide the second fragmentation and dissipation of debris kinetic energy. In this situation the size of damage of pressurized module wall will be minimal.

The authors suppose that realization of presented conception will provide a powerful protection of space station pressurized modules against untrackable orbital object and this protection will be efficient under impact of "large-sized" and "slow" space debris particles.

5. REFERENCES

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