

SPACE STATION PRESSURIZED MODULE DESIGN CONSIDERING SPACE DEBRIS HAZARD

Igor Ye. Telitchev, Leonid G. Lukashev, Alexander G. Prokhorov

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

ABSTRACT

The present paper is devoted to a methodical approach to designing the integrated wall of space station pressurized module considering space debris hazard. The Dugdale-Leonov-Panasyuk's model (d_c -model) is used for estimation of the residual toughness of pressurized module shell damaged by space debris. The problem is solved by numerical method of singular integral equations in Chebyshev's polynomials. To test the validity of the proposed models, the problem was investigated in the research laboratory and on the testing ground. The proposed procedure is realized in the form of program package.

1. INTRODUCTION

Considerable recent attention has been focussed on problem of creating a new generation of space vehicles of heightened survivability, able to preserve completely or partly the capacity for work under the impact of meteoroids and manmade particles formed as a result of space pollution by debris. It is beyond questions that pressure vessels are the most critical items onboard spacecraft, that is why an important problem is predicting the type and size of damage made by debris impacting pressurized modules of space station.

2. DAMAGE MODEL

Depending on parameters of the projectile, the damage can have the form of a hole with adjacent fractures. The size of the adjacent fractures can be great enough for destruction of the shell, which is loaded with inner pressure.

According to the proposed approach the real damage can be thought of as two hypothetical cracks originating at the boundary of a circular hole (Fig. 1). 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 damage zone. Thus, carrying out the analysis of damaged space vehicle structural element as an analysis of an infinite plate containing cracks originating at the boundary of an internal circular hole is suggested (Ref.1).

3. FRACTURE MODEL OF DAMAGED STRUCTURAL ELEMENTS

The Dugdale-Leonov-Panasyuk's model (d_c -model) is used for calculation of crack length and estimation of the residual toughness of space vehicles structural elements damaged by space debris. The material will be considered to have elastic - perfectly plastic properties. The problem to be solved involves the definition of the unknown plastic zones size and the crack opening displacement.

The problem is solved by numerical method of singular integral equations in Chebyshev's polynomials (Ref. 2-3). In such a manner the problem of the stress-strained state of the structural element damaged by space debris is reduced to solving the first basic problem of elasticity theory for a plate containing straight crack with load (Ref. 1).

Using the δ_c as a criteria of crack propagation and arrest it should be realized that the stress waves speed exceeds the speed of cracks propagation. That is why, the processes of structural element deforming and fracturing should be considered separately.

4. THE EXPERIMENTAL INVESTIGATION OF THE RESIDUAL TOUGHNESS OF DAMAGED STRUCTURAL ELEMENTS

To test the validity of the proposed model, the problem was investigated in the research laboratory and on the testing ground. Spherical steel and resin-dipped fabric laminate projectiles were used for tests. Projectiles diameters ranged from 4.5 mm to 17.5 mm. The tensile test specimens-targets were produced from duralumin

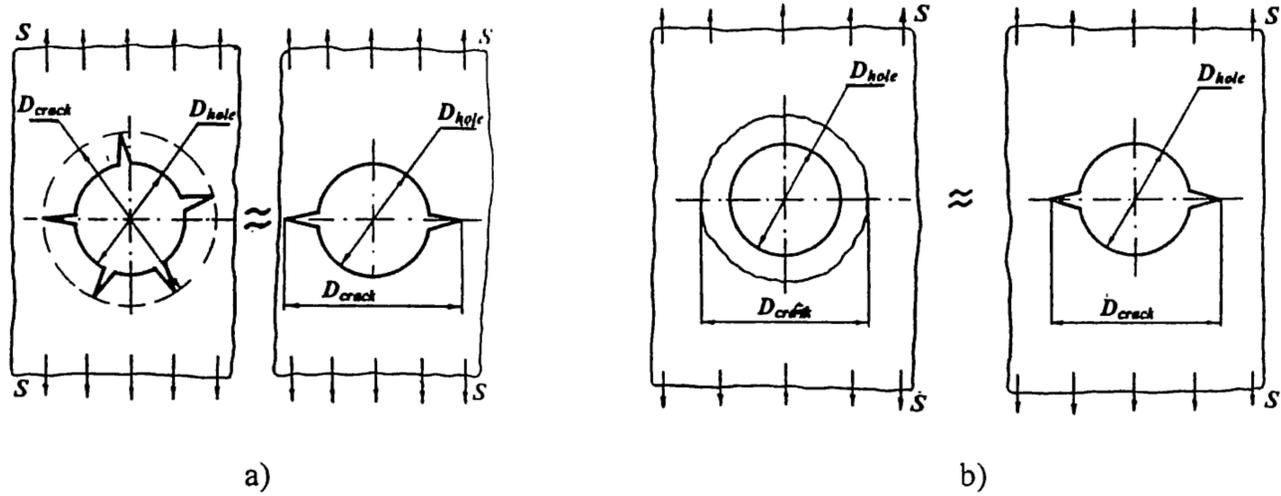


Fig. 1. Damage model.

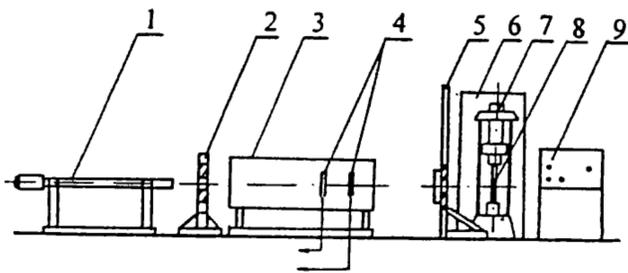


Fig. 2. Experimental equipment. 1 - gun; 2 - separator; 3 - protective box; 4 - initial velocity measurement device; 5 - protective wall; 6 - protective case; 7 - machine for tensile tests; 8 - tension target; 9 - pump.

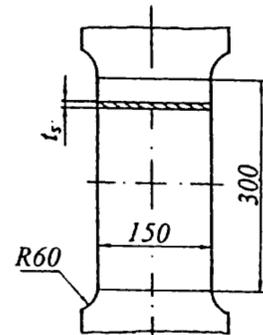


Fig. 3. Test specimen (target).

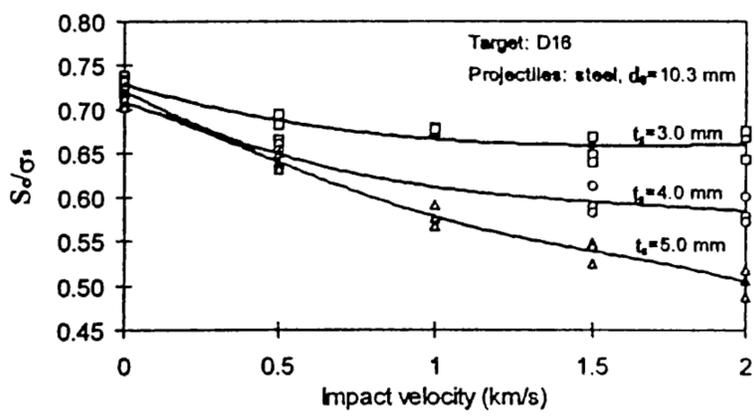


Fig. 4. The residual toughness of structural elements damaged by spherical steel projectiles

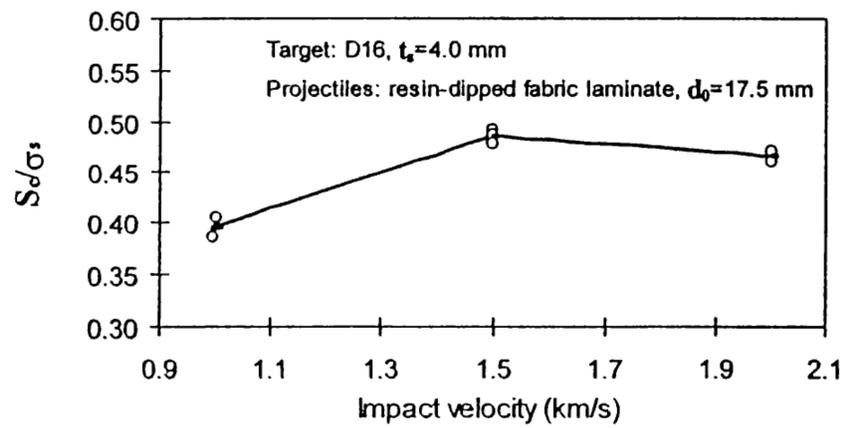


Fig. 5. The residual toughness of structural elements damaged by spherical projectiles

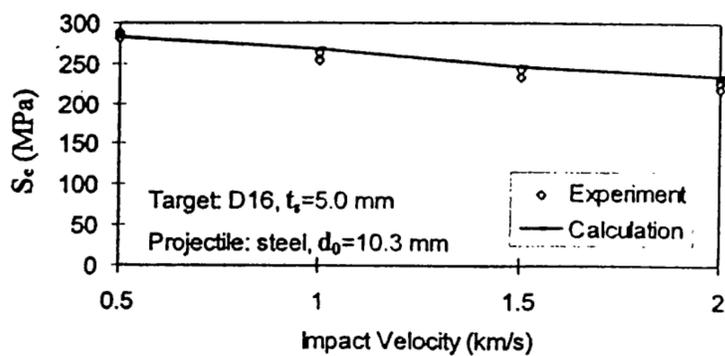


Fig. 6. Experimental and computational results

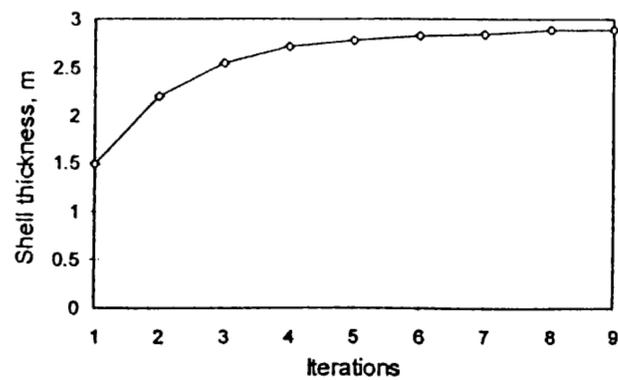


Fig. 7. Shell thickness computing.

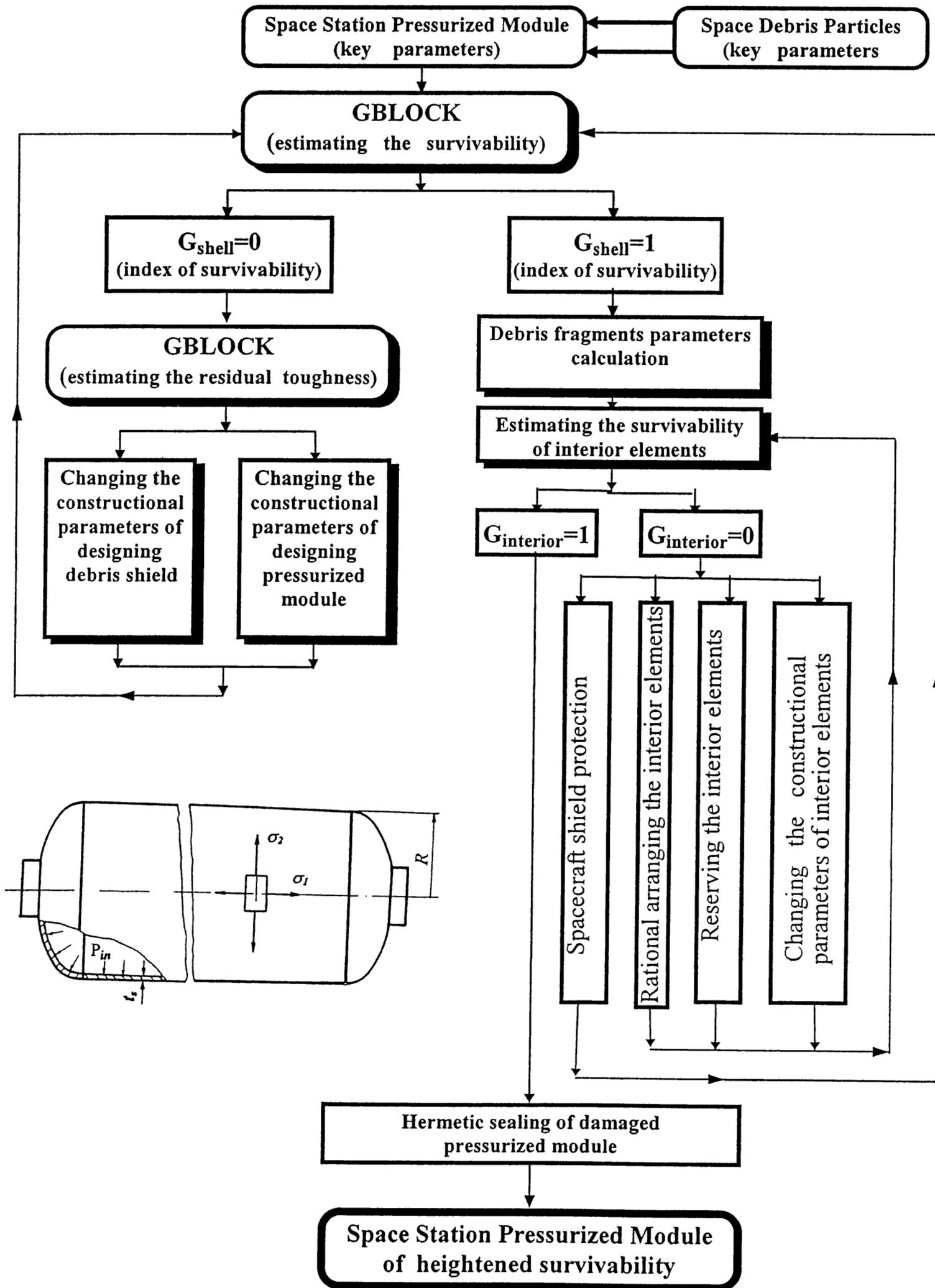


Figure 8 . Space station pressurized module design considering space debris hazard.

and aluminium-magnesium alloys (D16 - similar to 2024; AMg6) and mild steel. The results of experimental investigation disclosed that the residual toughness of structural elements damaged in the process of high velocity interaction depended heavily on structural element thickness, velocity, diameter and specific density of projectile. So, the residual toughness of the D16 aluminium specimen ($t_s=5.0$ mm) damaged by spherical 10.3 mm diameter steel projectiles was reduced by 20 percent as the projectile velocity increased from 0.5 km/s to 2.0 km/s (Fig. 4).

It seems reasonable to say that the enhancement of dependence $S_c=S_c(u_0)$ because of increase in structural element thickness is accountable to increase with the interaction time of particles with the test specimens (target). As a consequence D_{hole}, D_{crack} increases. Hence S_c decreases.

Also we have made studies into particle specific density influence on residual toughness of structural elements. Spherical steel projectiles ($d_0=11.1$ mm) and resin-dipped fabric laminate projectiles ($d_0=17.5$ mm, $r_p=1.2$ g/cm³) were used for tests. These projectiles are equal in mass. The tensile test specimens-targets were produced from duralumin D16 ($t_s=4.0$ mm).

The results of investigation disclosed that the impact action of resin-dipped fabric laminate projectile with velocity $u_0=390$ m/s resulted in non-perforation of the target. The target bulge and permanent deflection has been seen in the contact area. An increase in projectiles velocity up to 1.0 km/s resulted in the target perforation and petalling. The additional tests extending the range of impact velocities beyond this limit showed a subsequent continuously decreasing in the magnitude of the permanent deformation. The further increase in projectiles velocity up to 2.0 km/s caused the rear spallation at the target's back side. The petaling type of damage was found to be most hazardous to the capability of constructions. Thus, the residual toughness test specimen so damaged ($u_0=1.0$ km/s) was 22 percent less than residual toughness of test specimen damaged by the same projectile with the velocity $u_0=1.5$ km/s. The residual toughness of damaged specimen was reduced by 4.0 percent as the projectile velocity increased from 1.5 km/s to 2.0 km/s (Fig. 5). It is necessary to stress that the petalling type of damage can form by space debris particles in the space station wall after debris shields perforation.

5. PROCEDURE OF SPACE STATION PRESSURIZED MODULE DESIGN

The general procedure for design of integrated wall of space station pressurized module working in space

debris environment has been developed on the basis of proposed damage model, empirical relationships for calculating the damage parameters and fracture model of damaged structural elements (Fig. 8). The proposed procedure is realized in the form of program package and can be used for the construction behaviour analysis and designing the space station pressurized modules with a minimum of mass and with predetermined safety factor in the case of perforation. This program package includes program GBLOCK whereby a space station modules designer can solve the following problems:

- deforming and cracking process simulation.
- the survivability estimation of damaged pressure vessel;
- the residual toughness estimation of damaged pressure vessel;
- shell thickness computing of the pressure vessel with a minimum of mass and with predetermined safety factor in the case of perforation (Fig. 7).

In the process of shell thickness computing the change in value of shell thickness leads to changes in values of the stress intensity factor (K_I), COD- δ_c , damage parameters (D_{hole}, D_{crack}) and, consequently, results in new value of fracture load for designing shell. The parameters of projectiles ($u_0, d_0(m_0), \rho_p$) and parameters of pressure vessel ($p_{in}, \sigma_y, \sigma_s, E, \delta_c, \rho_r, c_0$) are considered as a key parameters.

6. EXPERIMENTAL AND COMPUTATIONAL RESULTS ANALYSIS

To test the validity of the proposed model the problem is solved using the program GBLOCK. The comprehensive body of data on the residual toughness of loaded structural elements damaged in the process of high velocity interaction with projectile speed obtained during investigation was found to be in excellent agreement with predictions for the D16 aluminium targets (Fig. 6) and in satisfactory correspondence for the mild steel targets.

7. REFERENCES

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Chapter 7

Re-entry of Risk Objects