Modelling the destruction process of a thermal reactor by man-made space debris impact

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Abstract. The three-dimensional transient problem of the interaction of artificial space debris particles (steel bolt M12) with a spacecraft model reactor is solved. Two cases of interaction are considered, the first is the reactor filled with water, and the second is the empty reactor. The calculations show that the impact of a high-speed steel bolt on the reactor with water at a speed of 11.17 m/s leads to the reactor failure. A water-free reactor obtains catastrophic damage to the hull shell and fuel cells.

1. Introduction
Protecting a spacecraft in orbit is currently a big concern. Collision with cosmic or man-made debris is a serious danger for spacecraft [1–3]. For example, a strike on spacecraft by a debris element with critical mass and velocity parameters damages it or even destroys it into fragments.

This article is a continuation of researches [4–6] based on the usage of the REACTOR software package [7]. The process of the interaction of a bolt, as an element of junk, with a model of a spacecraft thermal reactor is considered.

2. The work purpose and problem statement
The purpose of this work is to investigate in the 3D approximation the behavior of the thermal part of a spacecraft reactor made of 316TiSteel alloy during high-speed interaction with space debris.

The mathematical formulation of the problem, including a set of equations for balance of mass, momentum, and energy, a model of behavior of a solid deformable body, namely, equations of state and elastoplastic flow, as well as initial data and boundary conditions, was considered in detail in [8–10]. These works also contained descriptions of the explicit difference scheme and the construction of a symmetric algorithm for calculating contact boundaries.

Let a steel bolt M12 with length of 6 cm hits at a high speed a 40 cm diameter reactor containing seven rods with UO₂ in 316TiSteel casing. The calculations are performed with the REACTOR software package, which implements a numerical solver of the balance equations, taking into account the behavior of materials and the fulfillment of the boundary conditions.
3. The numerical simulation

The geometric model shown in figure 1 together with the finite-difference grid is a hollow cylinder of 40 cm diameter and a wall thickness of 0.5 cm. In the center, there is a rod of 4.9 cm diameter and a shell of 1 cm thickness. It also contains six evenly spaced rods of 2.9 cm diameter and 1 cm thick shell.

The impactor is a standard 6 cm long bolt M12 made of steel 20. The impact speed is 11.17 km/s. The impact occurs on the side of the bolt. Two cases are considered. The first one is a collision with the reactor filled with water, the second one is a collision with the empty reactor.

![Figure 1](image1.png)

Figure 1. Geometric Model. The reactor is filled with water (a); the hollow reactor (b).

Figure 2 shows a sequence of frames illustrating the process of interaction of the bolt with the reactor in the first case.

Note that at given interaction speeds, the steel bolt is completely destroyed. The rods located near the area of interaction of the bolt with the body receive minor damage to their shells. The remaining rods are not damaged, because the fragmentation cloud is inhibited by the fluid. The reactor vessel in the area of the impact is broken and receives significant deformations. The violation of the shell tightness will lead to termination of the reactor’s operating mode.

The impact of the steel bolt on the unfilled reactor leads to catastrophic consequences. Frames showing the evolution of the fragment cloud formation and their effect on the fuel cells are shown in figure 3.

As in the first case, the bolt is completely destroyed when it hits the reactor vessel. Almost all fuel rods are damaged, some of them critically, namely, the tightness of the shells of the fuel elements is broken. A cloud of fragments pierces many through holes in the reactor vessel. The damage to the reactor is catastrophic.

4. Conclusions

The results of a series of calculations showed that a model reactor filled with water, when interacting with artificial junk in the form of an M12 bolt at a speed of 11.17 km/s, received damage that put it out of action, while the unfilled reactor received catastrophic destruction.
Figure 2. Visualization of the simulation in the first case at several time moments.

Figure 3. Visualization of the simulation in the second case at several time moments.
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