Determination of damage area of spacecraft shields impacted by space debris at hypervelocity using an SPH mesh.

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Abstract. Space debris, are objects in Earth orbit consisting of small fragments from spent rocket stages and non-functional satellites. Accumulated in the lower earth orbit, these often cause considerable damage to the spacecraft orbiting around the earth. Hence it's necessary to develop ways to protect the newly placed spacecraft from the debris. The goal of the project was to determine the damage area of the pressure wall using the Smoothed Particle Hydrodynamic (SPH) meshing, a dynamic finite element modeling (FEM) method.

1. Introduction

Space debris is small objects in Earth orbit consisting of various parts of spacecraft and satellites left over during launch and operation. The pieces, many of which are very small and not traceable, travel at hypervelocity speeds above 3 km/s [1], and can cause significant impact damage to existing space vehicles. Protection of spacecraft is essential for a human presence in space. The current motivation for this project is derived from a NASA EPSCoR [1] research project dedicated to the development of a proof-of-concept portable Friction Stir Welder (FSW), which will be used to repair impact damage. Understanding the damage caused by the hypervelocity impacts is useful in developing FSW repair methods to the spacecraft. For manned spacecraft such as the International Space Station, the protection typically consists of one or more sacrificial shields protecting the pressure wall. This research continues previous research [2] in damage prediction for the sacrificial shield for new impact scenarios utilizing a new computational meshing technique called Smooth Particle Hydrodynamics (SPH).

2. Simulation, Results and Discussion

The overall approach was to model and validate hypervelocity impact damage on a Whipple bumper shield Figure (1) using a Lagrangian meshing technique [2]. The model successfully correlated results for a monolithic shield. The next step was to assess the damage area on a pressure wall which may require the formation of debris cloud after impacting the outermost shield Figure (1). However according to Depczuk and Schonberg several problems associated with the mesh tangling and distortion of regular Lagrangian mesh can be avoided by using the gridless SPH meshing technique [3]. In the SPH meshing technique the model is composed of particles shown in Figure (2). Velocity was defined in the direction of motion with an interpolation point and all properties defined on each particle. The software tool used for modeling was LS-PREPOST and later analyzed in non-linear finite element dynamic analyzer, LS-DYNA [4]. A FEM with SPH mesh having elastic and plastic material properties controlled by the Gruneisen equation [5] was used. Following an LS-DYNA example [5], the expected damage area was modeled using SPH, while the remaining shield used a Lagrangian mesh. The material property for the spherical impactor was Al 1100 O and Al 6061-T6 for the shield. SPH impact simulation results were initially correlated to NASA prediction Handbook [6] for sphere impacting a single shield. Parametric studies were then conducted using different impactor shapes and impactor velocities. Simulations were also conducted by placing a second shield.

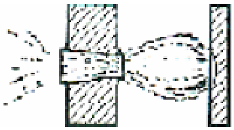

Figure1. Whipple shield and debris cloud [7]

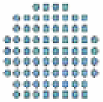

Figure 2. SPH mesh model

2.1Results

Five test cases were simulated with impactor velocities of 3.3 km/s and 7.2 km/s. Correlation case 1 impactor and shield used SPH mesh having 0.25mm spacing between particles. Because of memory limitations in case 2 the spacing between SPH particles was changed to 0.3 mm. Case 3 to 5 are a part of the parametric study which included a 2nd shield. In case 3 the corner nodes of the shield were constrained to check for variation in results with unconstrained cases 1 and 2. In case 4 and 5 cylindrical and cubic impactors of 7.8 by 3.6 mm diameter and 4.8 mm side were considered, respectively.

Table: 1

Comparison of hypervelocity impact results - range of hole diameters (mm)

Case	Shield	SIMULATION RESULTS		NASA EXPERIMENTAL RESULTS	
		3.3 km/s	7.2 km/s	3.3 km/s	7.2 km/s
Case 1	1st shield	9.21-10.25	11.04-13.15	7.87	13.20
Case 2	1st shield	9.64-11.58	11.15-12.54	7.87	13.2
Case 3	1st shield	9.57-11.93	10.02-12.00	7.87	13.2
	2st shield	3.0	3.0	2.54	0
Case 4	1st shield	8.5-12.95	9.46-11.18	-	-
	2st shield	No hole	3.0	-	-
Case 5	1st shield	10.14-13.33	10.83-14.49	-	-
	2st shield	No hole	1.0	-	-

2.2 Discussions

In Table 1, in case 1 the hole diameter (7.2 km/s, 11.04-13.15 mm) correlated with the NASA handbook (7.2 km/s, 13.20 mm). Changing the mesh spacing in case 2, the results (7.2 km/s, 11.15-12.54 mm) were similar to case 1. Similar results (3.3 km/s, 9.57-11.93 mm) were obtained by constraining the corner nodes in case 3 with respect to cases 1 and 2 (9.21-10.25 mm, 9.64-11.58 mm). The 2nd shield damage results (3.3 km/s, 3.0 mm) correlated with NASA handbook (3.3 km/s, 2.54 mm) results. Damage in case 4 and 5 using cylindrical and cubic impactors at 3.3 km/s was 8.5-12.95 mm and 10.14-13.33 mm respectively. Note that in cases 4 and 5 there was no penetration observed in the 2nd shield for impactor velocities of 3.3 km/s.

3. Conclusions

It is a necessity to protect spacecraft from debris impact, and repair the same. Assessment of the damage area can be accomplished through use of the SPH meshing technique in finite element simulations. To over come the space limitations a one quarter symmetry model is recommended. This study should also be extended to model a complete Whipple shield model, including the pressure wall. By a better understanding of hypervelocity damage, an enhanced space-bound Friction stir welder can be constructed.

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