

# Optimization of shock isolation frames with triangular grid stiffeners for weight reduction

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**Abstract.** Based on the demand of impact attenuation and weight reduction for launch vehicles' separation system, three types of aluminum alloy circular shock isolation frames with triangular grid stiffeners have been designed, optimized and analyzed for load-bearing capability. According to the real geometric configuration, the finite element models of the shock isolation frames have been established through FEM parametric modelling based on Python and Abaqus. Combined with the Downhill Simplex algorithm on Isight, the three parameterized models have been optimized with the aim of load-bearing and weight reduction. The optimization results showed that the three optimized frames had the weight reduction of 5.29 kg, 5.94 kg and 6.64 kg compared with the original configurations respectively. Moreover, because of the limitation of skin thickness, the decisive factor affecting the optimization results was the limitation of structural buckling coefficient.

## 1. Introduction

Currently, most payloads of large space launch vehicles were separated by pyrotechnic separation devices [1-3] which would result in great impact loads [4-6]. With the wide application of precision electronic equipments on payloads and launch vehicles, the demand for impact reduction continued to be more and more prominent. Therefore, the shock attenuation design for the pyrotechnic separation system has gradually become a research focus in the aerospace engineering [7-10].

Generally, there were three ways for reducing separation shock responses: 1) shock attenuation design of impact source; 2) shock attenuation design of impact load path based on stress wave propagation theory; 3) shock isolation design of impact objects.

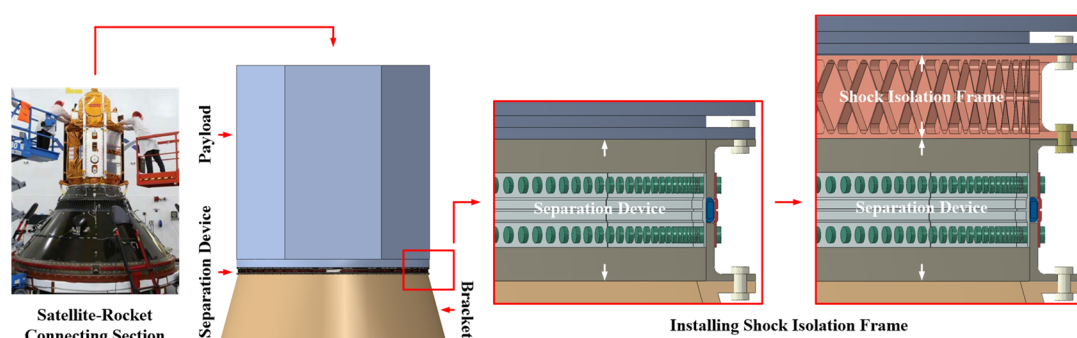


Figure 1. The satellite-rocket connecting section with a shock isolation frame.

In view of the above-mentioned second type of impact reduction scheme, a feasible method was to install a shock isolation frame with special geometric configuration between the separation device and the payload, as shown in figure 1, which would cause the diffraction of the stress wave induced by separation shock loads to attenuate during passing.

As a part of the rocket body structure, the shock isolation frame needed to meet the requirements of load-bearing capacity and weight limit. For large circular frames with complex geometric configuration, it was time-consuming and difficult to optimize their load-bearing capacity by means of conventional optimization methods. Thus, a parameterized finite element modeling method based on Python/Abaqus and an optimization method based on Isight have been developed in this research, which realized the load-bearing and weight reduction optimization of three kinds of shock isolation frames.

## 2. Geometric configurations of shock isolation frames

The three circular shock isolation frames with triangular grid stiffeners to be optimized, as shown in figure 2, had two, three and four grid layers respectively. The configuration design of triangular grid stiffeners was based on the stress wave propagation theory with the expectation that when stress wave passed through circular frames with triangular grid stiffeners, the transmitted energy would be attenuated because of the wave reflection. In this study, the load-bearing capacity optimization of this structure was carried out, and the mechanical property was expected to be obtained, so as to lay the foundation for further impact reduction researches.

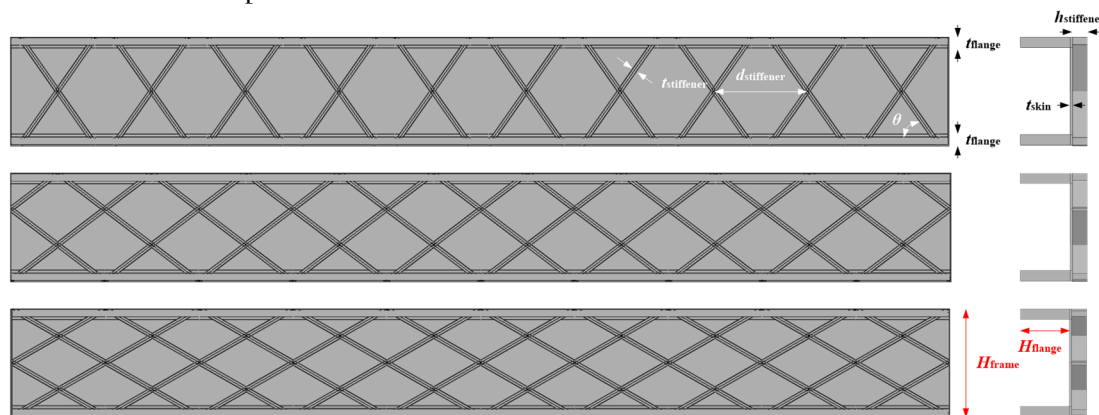


Figure 2. Three types of shock isolation frames.

## 3. Optimization models of shock isolation frames

Based on Python and Abaqus, three kinds of parameterized finite element shell models of shock isolation frames with loads and boundary conditions have been established, as shown in figure 3. The total number of triangular grid stiffeners in single row ( $N_{\text{stiffener}}$ ), degree of triangular grid stiffeners' bevel ( $\theta$ ), grid stiffeners' spacing ( $d_{\text{stiffener}}$ ), height of grid stiffeners ( $h_{\text{stiffener}}$ ), thickness of grid stiffeners ( $t_{\text{stiffener}}$ ), thickness of skin ( $t_{\text{skin}}$ ) and thickness of flange ( $t_{\text{flange}}$ ) could be adjusted. The material used in all analysis models was aluminum alloy, and its properties were shown in table 1.

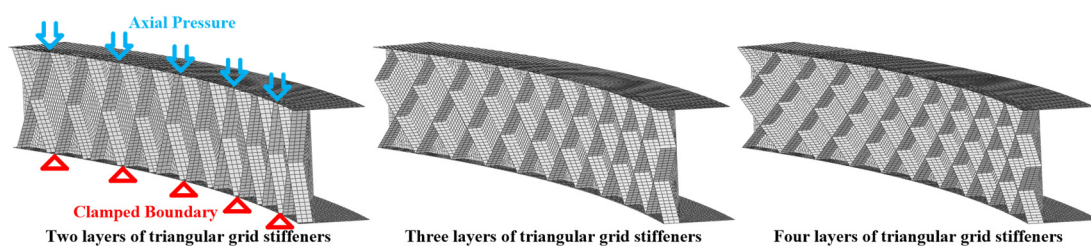


Figure 3. Parameterized finite element models of shock isolation frames.

It was difficult to establish the parameterized geometric models of circular frames with triangular grid stiffeners directly. In this study, flat plate models were set up firstly, and then the mesh nodes were offset by Python to obtain the parameterized models consistent with the real circular shock isolation frames. In order to improve the optimization efficiency, the parameterized models were circular frames of ten triangular stiffeners in single row with symmetric boundary conditions.

Table 1. Material properties of shock isolation frames.

Material	Density(Kg/m <sup>3</sup> )	Young's modulus(GPa)	Poisson's ratio
Aluminum alloy	2700	70	0.33

Table 2. Optimization parameters setting.

Optimization parameters	Setting		
	2 layers	3 layers	4 layers
$N_{\text{stiffener}}$	[50, 210]	[50, 315]	[50, 420]
$d_{\text{stiffener}}$	[30.0, 250.0]mm	0.0	0.0
$h_{\text{stiffener}}$		[3.0, 15.0]mm	
$t_{\text{stiffener}}$		[2.0, 5.0]mm	
$t_{\text{skin}}$		[1.5, 3.0]mm	
$t_{\text{flange}}$		[2.0, 7.0]mm	
$\sigma_{\text{Max}}$		$\leq 300\text{MPa}$	
$C_1$		$\geq 1.5$	
Initial Simplex Size		0.1	
Maximum Iterations		40	
Mass		Minimum	

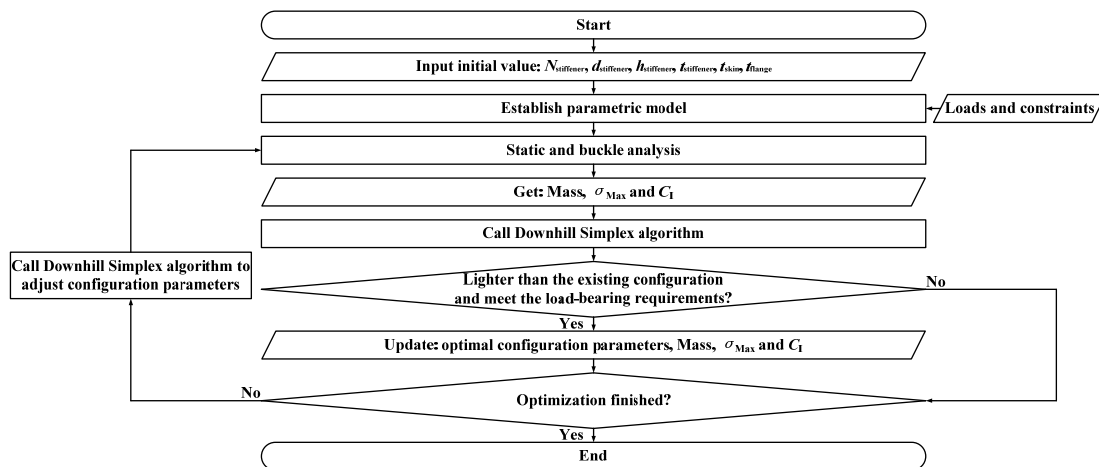


Figure 4. The optimizing process.

After establishing the parameterized finite element models, the weight reduction of the shock isolation frames was optimized by the Downhill Simplex algorithm on Isight. It should be noted that part of the geometric quantities in figure 2 were interrelated. Therefore, not all these quantities could be set as optimization parameters, such as  $N_{\text{stiffener}}$ ,  $\theta$  and  $d_{\text{stiffener}}$  were interrelated. The optimization parameters were set as shown in table 2, among which,  $\sigma_{\text{Max}}$  was the maximum Von Mises stress,  $C_1$  was the critical buckling coefficient and the overall height of the frame ( $H_{\text{frame}}$ ) and the inner side flange ( $H_{\text{flange}}$ ) were set to constant values. The specific optimization process was illustrated in figure 4.

#### 4. Results and discussion

The optimal configurations for weight reduction of three types of shock isolation frames have been obtained, and the geometric parameters and the analysis results were shown in table 3. Compared with the initial configuration, the three optimized configurations reduced weight by 5.29 kg, 5.94 kg and

6.64 kg, respectively. The stress and buckle analysis results of the three optimal configurations under axial compressive load were illustrated in figure 5 and figure 6.

According to the above optimization and analysis results, the decisive factor restricting the optimization was the requirement of the critical buckling coefficient. Due to the limitation of the skin thickness, the shock isolation frames with triangular grid stiffeners would probably lose their stability firstly under the axial compressive load.

Table 3. Optimization results.

$N_{\text{layer}}$	$N_{\text{stiffener}}$	$\theta$	$d_{\text{stiffener}}$ (mm)	$h_{\text{stiffener}}$ (mm)	$t_{\text{stiffener}}$ (mm)	$t_{\text{skin}}$ (mm)	$t_{\text{flange}}$ (mm)	$\sigma_{\text{Max}}$ (MPa)	$C_1$	Mass (kg)
2	193	35°	65.8	3.1	2.0	1.5	2.0	159	1.52	90.71
3	229	49°	0	3.1	2.2	1.5	2.0	164	1.54	115.87
4	280	52°	0	3.0	2.1	1.5	2.0	164	1.52	146.16

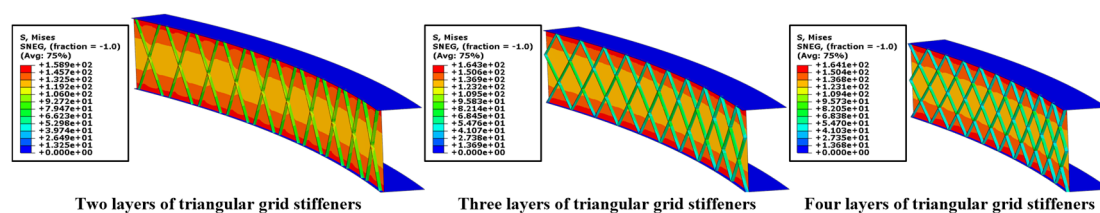


Figure 5. Stress analysis results of optimized configuration.

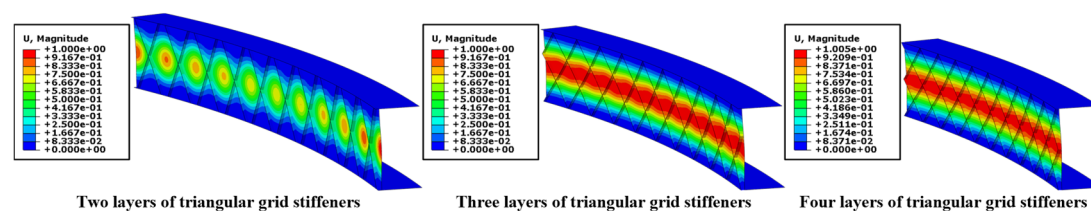


Figure 6. Buckle analysis results of optimized configuration.

## 5. Summary

By means of the FEM parameterized modelling method based on Python/Abaqus and the optimization algorithm on Isight, the parametric finite element models of three types of circular shock isolation frames with triangular grid stiffeners have been established, optimized and analyzed for weight reduction. The weight reduction optimizing configurations of three types of circular shock isolation frames with triangular grid stiffeners have been obtained, which were 5.29 kg, 5.94 kg and 6.64 kg less than the initial configurations respectively. Further analysis showed that the main limiting factor of the optimization was the critical buckling coefficient due to the thickness limitation of the skin.

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