# Weight Optimization of a rubber using Altair Optistruct and Hyperstudy

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## Abstract

Weight reduction at even the component level can add up to significant fuel economy gains. This paper presents a process for optimizing the weight of a rubber bushing under compression. Most studies on hyper-elastic material involve shape optimization to attain a certain performance for stiffness. In this case, the bushing performance is evaluated with Altair Optistruct to solve the non-linear, quasi-static problem, and optimized using Altair HyperStudy. The finite element model is evaluated with four shape variables. This process resulted in a weight savings of 5% while maintaining the stiffness characteristic of the bushing under a 1cm compression.

## Introduction

Rubber bushings are widely available in all shapes and sizes, depending their use. Rubber bushings are often used as vibration isolators to prevent energy transfer from one part to another. Rubber as a material is ideal for such use because it can withstand large deformations without experiencing permanent damage. These characteristics exceed linear elastic theory resulting in large deformations and non-linear elastic behavior. When designing rubber bushings, the static load-displacement curve must be considered, in order to attain the desired stiffness, but engineers find meeting this requirement while reducing weight a difficult task due to geometrical and material non-linearity. To assist in this task, shape optimization has been used and studied [1] to achieve a certain static, as well as, dynamic stiffness response of different types of isolators. This paper presents the results of an axis-symmetric rubber bushing that is submitted to axial, quasi-static compression with the goal of weight reduction, through shape optimization, while maintaining its stiffness characteristics. The optimization was conducted through a finite element model using Optistruct as the solver and HyperStudy for the optimization.

## FEA Model

The rubber bushing model (Figure 1) is comprised of an upper and lower plate encasing the rubber bushing. The upper plate contains a shaft along the center, to which an enforced displacement of 1cm is applied through a rigid element while fully constraining the lower plate. To solve this model a large displacement, non-linear, static load case was setup in Optistruct. To accurately capture the non-linearity of the material, the loading of the bushing has to be done incrementally by solving the non-linear equilibrium equation using Newton's Method. Given a smooth solution, a quadratic rate of convergence can be achieved, which is a robust method for non-linear solutions. There are many hyper-elastic models that can accurately describe rubber materials by describing elastic energy as a function of deformation [2]. For this paper, the Arruda-Boyce model was used, which is defined as follows:

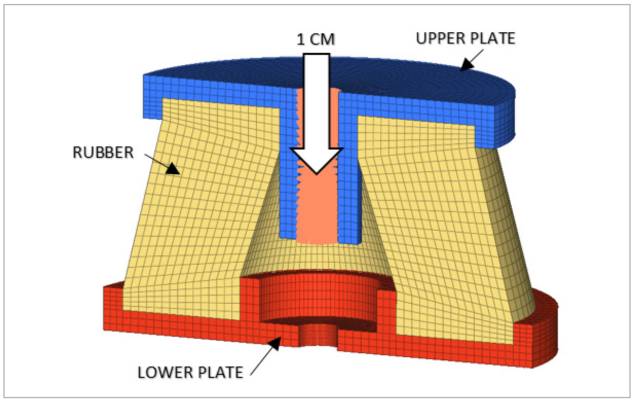


Figure 1 – Cross section of Rubber Bushing

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$$U = \mu \sum_{i=1}^{5} \frac{C_i}{\lambda_m^{2i-2}} \left(\bar{I}_1^i - 3^i\right) + \frac{1}{D}\left[\frac{J_{el}^2-1}{2} - Ln(J_{el})\right] \quad (1)$$

With:

$$C_1 = \frac{1}{2}, C_2 = \frac{1}{20}, C_3 = \frac{11}{1050}, C_4 = \frac{19}{7000}, C_5 = \frac{519}{673750} \quad (2)$$

U = strain energy

μ = initial shear modulus

$\lambda_m$ = locking stretch

$$D = \frac{2}{K} \text{ (K is the bulk modulus at small strain)} \quad (3)$$

where D is zero for an incompressible material.

When performing the Finite Element Analysis (FEA), material parameters for the above strain energy potential can be determined by fitting experimental data obtained from tensile, compression, and pure shear physical tests of the rubber material through a non-linear least square optimization method [3]. For this particular model, the experimental data used shown in Figure 2, which is directly defined in Optistruct through a MATHE card (hyper-elastic material model card)

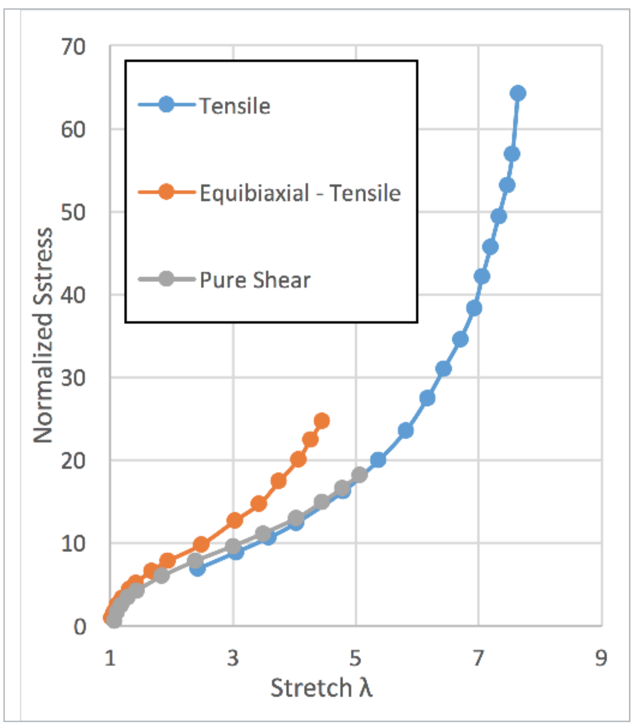


Figure 2 – Material Data from Tensile, Equibiaxial Tensile, and Pure Shear Testing

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## Shape Variables

In order to generate the different shape design variables, the rubber bushing model was modified through HyperMesh using the HyperMorph capability to map morphing domains to a geometry. Figure 3 shows the four shape variables used for the optimization.

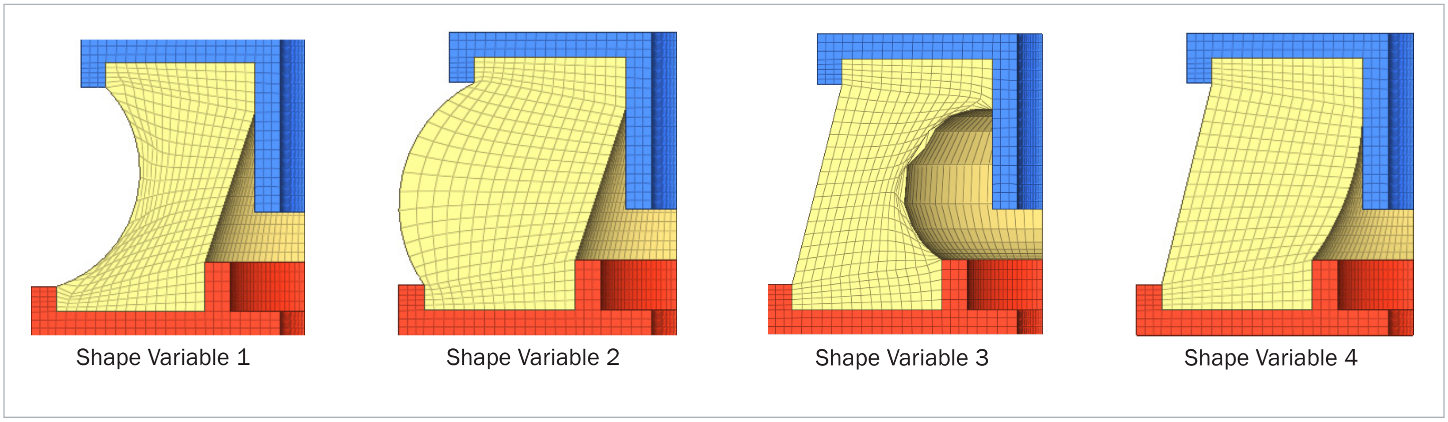


Figure 3 – Shape Design Variables applied with factor = 1

These shapes were saved as nodal perturbations and exported in a template format, which can be recognized by HyperStudy. Each shape variable to be considered has a factor range of 0 to 1.0.

Using HyperStudy the base input deck was parametrized to contain these shape variables, and a baseline model was run for the original shape. From the baseline results, responses are created to track the resultant force exerted by the rubber, the total displacement, and the total volume of the rubber, which were found to be 285.6 N, 1 cm, and 577.37 cm3 respectively. Figure 4 displays the deformed cross section for the baseline rubber bushing.

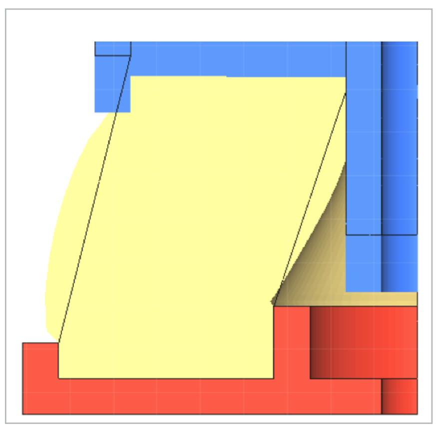

Figure 4. A self-excited system example using AcuSolve

## Optimization Parameters

Within HyperStudy, an optimization study is setup based on the parametrized, baseline model. The objective is to minimize the volume of the rubber bushing. Because the evaluation is based on the bushing's performance while compressed by 1cm, the resultant force exerted by the rubber was constrained at its baseline value of 285.6 N. Although there are several optimization methods available with HyperStudy, the Adaptive Response Surface Method (ARSM) was chosen for this case. ARSM works by building response surfaces which are then updated based on responses from different iterations. The optimum is then checked against the simulation until convergence is satisfied, otherwise the response surface keeps updating. The chart below (Figure 5) shows the different phases in the ARSM process:

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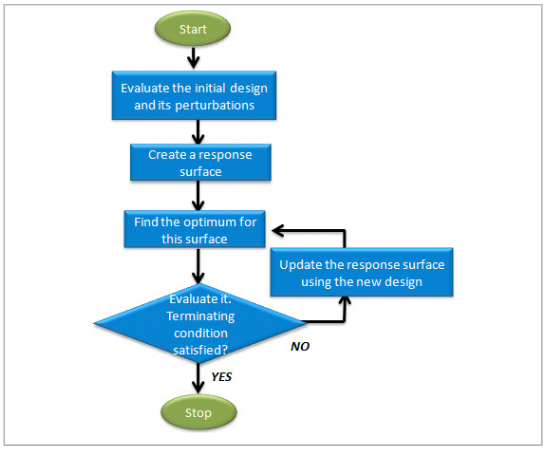


Figure 5 - ARSM Optimization Process [4]

# Results

In order to speed up solving time, Optistruct along with HyperStudy were run on a cluster. The optimizer went through nine iterations before finding an optimum. Table 1 displays the results obtained through HyperStudy with the shape variable factors and responses. It can be observed that a 5% weight reduction can be achieved while keeping the same stiffness under the 1 cm compression. Figure 6 shows what the final optimized shape is for the rubber bushing.

| Iteration | Shape 1 | Shape 2 | Shape 3 | Shape 4 | Force (N) | Disp. (cm) | Volume (cm3) |
|---|---|---|---|---|---|---|---|
| 1 | 0.000 | 0.000 | 0.000 | 0.000 | 285.60 | 1.00 | 577.37 |
| 2 | 0.000 | 0.165 | 0.000 | 0.000 | 283.43 | 1.00 | 575.67 |
| 3 | 0.083 | 0.000 | 0.000 | 0.000 | 285.32 | 1.00 | 565.14 |
| 4 | 0.000 | 0.000 | 0.165 | 0.000 | 287.81 | 1.00 | 599.84 |
| 5 | 0.000 | 0.000 | 0.000 | 0.165 | 287.65 | 1.00 | 579.01 |
| 6 | 0.100 | 0.000 | 0.000 | 0.027 | 285.43 | 1.00 | 562.75 |
| 7 | 0.200 | 0.000 | 0.000 | 0.085 | 284.70 | 1.00 | 547.80 |
| 8 | 0.190 | 0.000 | 0.000 | 0.185 | 285.85 | 1.00 | 550.36 |
| 9 | 0.201 | 0.000 | 0.000 | 0.185 | 285.67 | 1.00 | 548.69 |

Table 1 – Summary of Design Variables and Responses for each optimization iteration

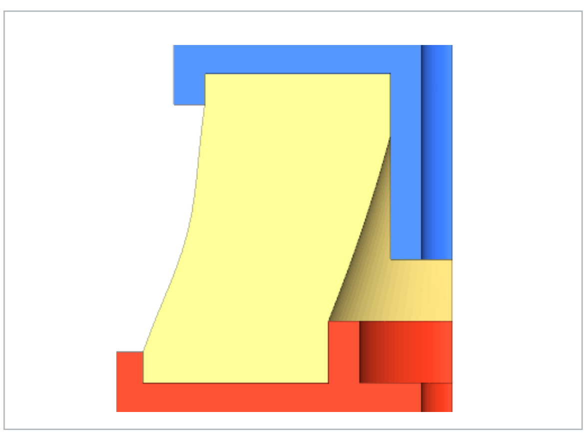

Figure 6 – Final optimized shape with factor of 0.201 and 0.185 for shapes 1 and 4 respectively

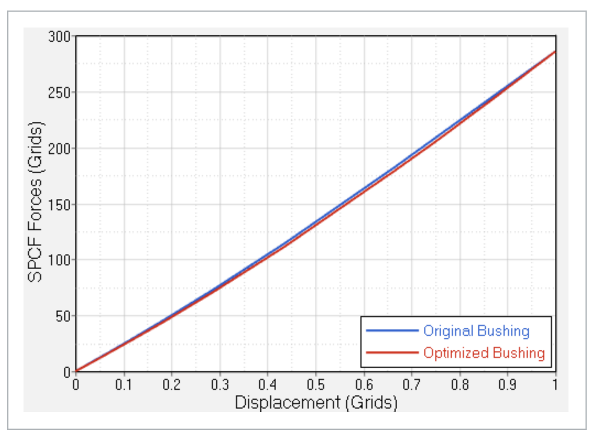


Figure 7 – Resultant Force vs Displacement plot at compression point

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## Closing Remarks

Based on this study, shape optimization can be beneficial for optimizing hyper-elastic materials. Although the model used was rather simple, this process can be applied for more complex systems with other non-linear factors such as adding contact definition if the rubber were to come in contact with the upper and lower plates or even self-contacting due to material folding. In terms of performance, there is a slight drop in stiffness comparing the original to the optimized shape as seen on Figure 7, but attains the same stiffness at the full 1cm compression.

In conclusion, a full process has been presented to perform weight optimization on a hyper-elastic rubber bushing yielding 5% weight reduction with same performance.

References

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[4] Figure obtained from https://connect.altair.com/CP/kb-view.html?f=2&kb=100995