Structural Design Optimization in Mobile Devices

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Abstract
Design optimization tools have conventionally been used in the automotive and aerospace industry. In the mobile devices business, given the short development cycle and limited design space, optimization techniques have not been extensively explored. Typically an analyst iteratively explores various design options using computer simulation and extensive testing. This process can be quite involved and might not necessarily lead to the optimal design. The work presented herewith discusses the use of OptiStruct for design optimization, shape and topology optimization in specific, in the design of smartphones. A quasi-static test that is representative of the drop performance is used for optimization. It has been shown that design optimization can prove to be extremely powerful if used early in the design phase when there is greater design flexibility.

Introduction
The mobile devices industry has recently gotten extremely competitive and companies are being challenged to push the boundaries of their hardware design. The use of new materials for superior industrial design, larger screens, and lighter devices while meeting the reliability standards is driving the mechanical architectural definition. Moreover, with shorter design cycles and narrowing cost margins there has been greater emphasis on virtual testing using computer simulation. Traditionally an analyst would use FEA to iterate over a design until a feasible design solution is reached. Given the limitations to manually exploring the complete design space, the solution is not necessarily the optimal. In the absence of an optimization tool, the design cycles can be long and inefficient. Unlike the auto and aerospace industry where optimization techniques have been extensively used, its been fairly unexplored in the mobile devices domain. Given the limited design space to work with in a mobile device there is a natural concern about the value it can bring.

The focus of this paper is to demonstrate an approach to apply shape and topology optimization techniques in the design of a smartphone. A Samsung Galaxy device is used as an example for this study.

Process Methodology
A smartphone typically consists of two major structural components, front and rear housing. Figure 1 shows an exploded view of the Galaxy phone used for the following study. The phone has a plastic overmolded magnesium die-cast front housing and a polycarbonate rear housing. The lens-display module is adhered to the front housing. The PCB and the battery are constrained to the rear housing, which is screwed to the front housing.

One of the critical tests to determine the reliability of a mobile device is the drop test. The device is dropped in various orientations and the deformation of the internal components is monitored through simulation. Weaknesses in the housing design usually reflect in the drop performance of these components. The PCB strains near the solder joints and display glass strain are two of the high risk areas. The objective of this study is to address these weaknesses using optimization techniques. Given that the explicit drop simulation analysis can not be directly used for optimization, a quasi-static load case is proposed that simplifies the problem. Figure 2 shows how the optimization step can be introduced within the existing design process flow.
It has been observed that the drop reliability of a phone correlates to its stiffness, higher the stiffness higher is its reliability. In order to increase the overall system stiffness, the focus here is to maximize the stiffness of front and rear housings independently. The housings are subjected to a quasi-static 3-point bend and torsional load (Figure 3). In the 3-point bend test the top and bottom screw bosses are constrained and a distributed load of 30N is applied at the center of the housing. In the torsion test, the bottom screw bosses are constrained and a 500Nm moment is applied at a reference node connecting the top screw bosses. The objective is to minimize the compliance (or total strain energy) of the part for a given load. A weighted compliance formulation is used to combine the output of the two load cases in a single objective function.
The production design of a Galaxy phone is used for this study. Given the existing maturity of its design features, the design space for topology optimization had to be recreated (Figure 4a). In Figure 4b, the design space is indicated by the blue region. To ensure manufacturability of the optimized part, minimum and maximum member size constraints are specified.

The corresponding front housing part is shown in Figure 4c. This is a magnesium die-cast part (yellow region) with a plastic overmold (pink region). For the shape optimization problem, the dimensions of the rib features are defined as design variables. 17 design variables, like the rib x-y thickness, z height and the floor thickness, are defined using HyperMorph. Bounds are set for these variables based on the geometric feasibility of the part and also ensuring that there is no interference with adjacent components. The objective in both these runs is to maximize the stiffness of the housing for the same mass as the baseline design. As discussed in the next section, the optimization run gave improved results when the mass constraint is marginally relaxed.

Figure 3: Quasi-static test cases for the optimization problem

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Figure 4: (a) Production rear housing geometry. (b) Rear housing geometry for topology optimization. (c) Production front housing geometry with shape optimization variables.
Results & Discussions

The simulations are run on an 8cpu Intel i7 machine. On an average it took about 30mins for the optimization run. To put this into perspective, a 1.5msec phone drop simulation usually takes 6hr on a similar system. Figure 5a compares the topology optimized design of the rear housing with the production design. As expected, the optimized design has very different rib arrangement but the stiffness is significantly higher (40% in bending and 74% in torsion).

Figure 5b indicates the z dimensional changes to the shape optimized front housing. The housing floor is marginally thinner than the baseline design and is offset by 0.5mm towards the display. The optimized design is 1.6gm (10%) heavier than the baseline design but is 65% and 85% stiffer in bending and torsion respectively. Without the additional weight, the optimized design is about 30% stiffer.

The system level impact of the optimized housings is determined by swapping the part in the baseline model and running a drop simulation. Specific drop orientations are identified that expose the display and PCB to high strains. The contour plot of the PCB strain in one of the critical oblique drops is shown in Figure 6a. The percentage reduction in peak strain at the BGA packages with the optimized rear housing design is

Figure 5: (a) Comparison of rear housing baseline design and optimized design from OptiStruct. (b) Optimized front housing with the shape changes in z.

Figure 6: (a) Contour plot of PCB strains in a phone drop simulation. (b) % improvement in strain at major BGAs with the optimized design for 3 drop orientations.
shown in Figure 6b. In most orientations there is a 15-20% drop in strain. The strain at some BGAs is higher than the baseline design because some essential PCB support features are eliminated during the optimization, but this can easily be addressed. It should also be noted that the PCB is not tightly coupled to the rear housing, and therefore its increased stiffness can only have a limited impact on the PCB strains.

The impact of the optimized front housing is measured by the reduction in display strains. The contour plot of display strain for the baseline and the optimized design is compared in Figure 7 for two drop orientations. The gray region indicates areas of high strain that are at risk of cracking. The optimized design significantly reduces the peak strain (upto 50%) as well as the effective area of high strain on the display.

![Figure 7: Contour plot of display strains in two drop orientations. Comparison of baseline design with the shape optimized front housing. Gray regions are above failure strain threshold.](image)

In order to demonstrate the benefit of shape optimization, another simulation is run where the front housing material in the baseline model is changed from magnesium to aluminum. This is a common practice when trying to improve the reliability of a product. The component level stiffness of the aluminum housing is the same as the optimized magnesium design of Figure 5b. But as shown in Figure 8 the system level performance of the Aluminum housing is not as good as the shape optimized design. This confirms that shape optimization can be effective in addressing specific weaknesses in a design that cannot be achieved by changing the material modulus.

![Figure 8: Display strains in two drop orientations compared for Magnesium and Aluminum front housings in the baseline design.](image)

**Conclusion**

The work presented in this paper demonstrates the impact that optimization techniques can have in designing a robust and reliable mobile device. As an example, the front and rear housings of a Samsung Galaxy phone are optimized for shape and topology respectively. At a component level, there is a 40-85% increase in stiffness of the housings in a 3-point bend and torsion test. In a drop simulation, the optimized
front housing reduces the peak display strain by up to 50%, along with the area of high strain. The topology optimized rear housing provides up to 20% reduction in PCB strain at the BGA packages.

Topology optimization can have a much greater impact when used early in the architectural definition rather than on a mature design. One of the key challenges with topology optimization is to ensure the manufacturability of the housing geometry. OptiStruct allows for the definition of certain design constraints but there are some aspects like the alignment of rib features that cannot be enforced. In such cases, the optimized design can be used as an initial reference to lead the designer towards a more robust design.

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