The Root of the C7R's Success is in its GENESIS

By Grant Browning

Corvette Racing has seen much success over the last 15 years with ten series championships and seven "24 Hours of Le Mans" class championships. Through the end of 2013, there had only been three major redesigns to the cars designated to represent Corvette Racing and GM in the sports car racing world. These were the C5.R, C6.R-GT1, and C6.R-GT2 respectively, and each was designed with enough potential to continue at the top of its class for its generation while competing with the highest level factory-backed sports car racing teams in the world. Each redesign was a step forward from the previous, and in 2013 it was time for the next step, as Pratt & Miller began designing what was to be the new representative of Corvette Racing, the C7.R (Figure 1).

Figure 1

At the start of the C7.R build, GENESIS structural optimization software was a tool we'd had at our disposal for two years, but until the C7.R design, was only used in individual component or subassembly designs or redesigns. Since our introduction to GENESIS, the implementation of optimization to drive our designs has grown. The C7.R was the first full car design where Pratt & Miller had the opportunity to implement optimization into every facet of car design, thus providing a direct comparison to the C6.R – GT2 an already very developed and very competitive car, to evaluate the influence GENESIS had.

As the build progressed and our seemingly over optimistic predictions began coming to fruition, the impact of optimization on the new car became obvious. The C7.R test car's torsional stiffness was 50% higher, while the overall weight of the structural components was more than 65lbs lighter. As track testing began, the positive feedback continued. From the Corvette Racing program manager, "Seems like the increased chassis stiffness has helped a lot of the strange chassis dynamics that we used to have. We don't see the rear moving around as much as we used to and the car recovers a lot better over curbs and bumps." Once the race season started and the cars began to see some real miles and racing incidents, the structural components continued to display their worth. In the second half of the season, the #3 Corvette, the car that was winning the championship at the time, was involved in a serious accident with another car — one that sent both drivers involved to the hospital and completely destroyed one of the chassis. (Figure 2)

Figure 2

Fortunately, our Corvette Racing crew was able the get the C7.R reassembled and ready for qualifying just two hours later. Now, after a full season of racing, the components are well proven and considering the overall weight savings, the torsional stiffness increase, and the resilience of the cars up to this point, we are very pleased with the results.

So how were these results achieved? To be pragmatic there are a lot of very smart and experienced designers and engineers involved in this race car program so, some degree of positive development is to be expected. But digging into numbers of the C7.R uncovers the substantial degree of advancement forged into this generational step. The influence of GENESIS was not only felt through direct simulations run on the C7.R, but also through the insight and understanding gained from our previous use. The reason that this secondary impact is substantial is because we do not just take optimized results straight from the software and use the efficient shapes as a basis to make physical parts; rather, we see GENESIS as not only a tool to generate ideas, but also as one that can produce new metrics for evaluating and understanding. GENESIS, in our hand, quickly became a tool that didn't simplified or speed our design process, but one that we pushed further to increase the potential for understanding and gain in our structural components and ultimately give us an advantage on the track.

Our process for implementing GENESIS has been refined over the last couple years and is typically used with topology optimizations, but it is similar for all our uses. Of course every case is a little different but our general process has matured into common steps (Figure 3).

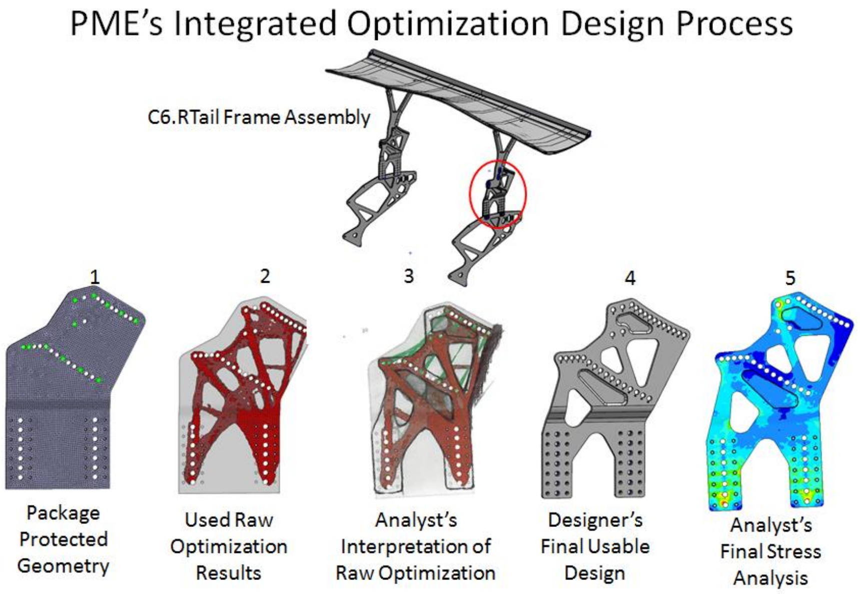


Figure 3

The process starts with a package protected volume. Sometimes this is a big brick using all the packaging space possible, and sometimes it's an existing part we'd like to pull extra weight out of. From there a set of load cases, constraints, and objectives will be input, and optimized results are produced by GENESIS. Next, the results will be critiqued, thoroughly understood, and interpreted by the analyst. We found these optimization and interpretation steps to be the most critical in successfully implementing GENESIS. From there, the analyst and designer (which is sometimes the same person) will review the interpretation of the results and produce a usable design. The final step is to run a FEA on the components, ensuring that stresses and stiffnesses are acceptable. In most situations, the last two steps are cycled through a few times to minimize weight within our acceptable stress limits.

Everything down the line (Figure 3) is based on the raw optimized results and these results are incredibly dependent on many variables. The first variable to address is the load cases. One might imagine that anyone implementing structural optimization would already have a handle on the load cases because they've been running structural FEA analysis to check stresses on components for some time prior. But in our experience, a model being optimized from scratch tends to be far more susceptible to overly focused load cases than a design that most likely took its shape because the designer thought it looked like it would do the job. Understanding these sensitivities and susceptibilities when using optimization as an idea generator is critical to avoiding oversights that can lead to failure or undesired behaviors. However, once these sensitivities are understood they can be utilized for what they are in order to gain knowledge and insight into a component and how it functions structurally. We regularly use a series of overly focused load cases to see how the optimized shape changes for each and to gain insight on how a different shape can influence our targeted responses. We would not use these responses as a design, these are just used as a metric for evaluation. Figure 4 shows the responses produced by optimizing a simplified chassis shape for focused load cases.

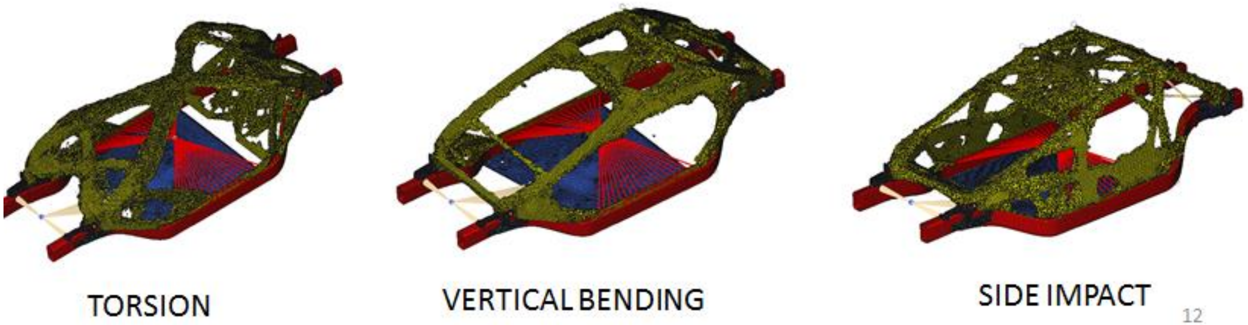
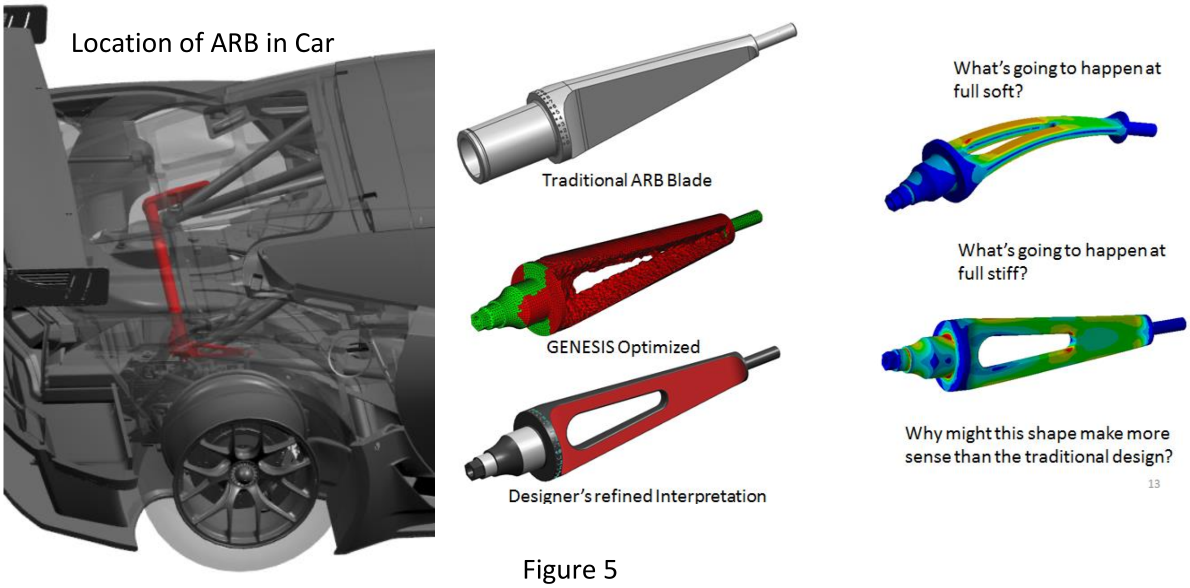


Figure 4

We found that understanding these responses is also important when weighing the importance of load cases. One example of why looking at these focused responses separately is important can be illustrated with the chassis of a race car. Torsional stiffness is the target objective in a chassis, while yield stress is only a constraint that must be met, yet torsional stiffness load cases are in the realm of 20X lesser than maximum stress load cases. The mismatch of load cases creates an optimization run that always biases the design toward the max stress load cases even though optimizing for torsion may be the intent. This method of gaining an understanding instead of just producing a base shape to design from can create the cognizance required to catch these types of issues.

This leads us into interpreting the results. It is important to understand why a result was produced before it can be useful. If there is not a good reason an acquired result either does or does not make logical sense then more information is likely required to give this comprehension. Not understanding "why" leads to components that fail or behave differently than expected in practice, even though they are, most likely, doing exactly what was asked of them. An example of an anti-roll bar (ARB) blade result and its understanding is shown in Figure 5.



What's going to happen at full soft?

What's going to happen at full stiff?

Why might this shape make more sense than the traditional design?

Figure 5

As we asked the questions stated in Figure 5 we came to the following conclusions. At full stiff, the center of the blade does not have much load going through it because it's on the neutral axis. At full soft, the center of the blade does affect the stiffness, but that will only result in a larger range of adjustability. This should allow for a higher max stiffness and lower min stiffness at a lower weight for the same packaging area. So, if we can keep the blade and bar combo stresses within our acceptable limits at max deflection, then this design could feasibly produce some advantages.

The C7.R combined many of these approaches, including some overall knowledge gained simply by regularly using GENESIS and always trying to understand the results. A more detailed example these approaches being implementation can be seen on the uprights — always a very critical and high-valued component. Since the uprights are the structural components that the car's wheels attach to, they see all kinds of loading and temperature swings, in addition, they provide a large portion of the controllable unsprung mass. Both the front and rear uprights were produced with the same modified process, but we'll just look at the fronts in detail and then show the results of both. To some degree, this follows our general optimization design process, only the first optimization cycle is producing the design space for the second, as seen in Figure 6.

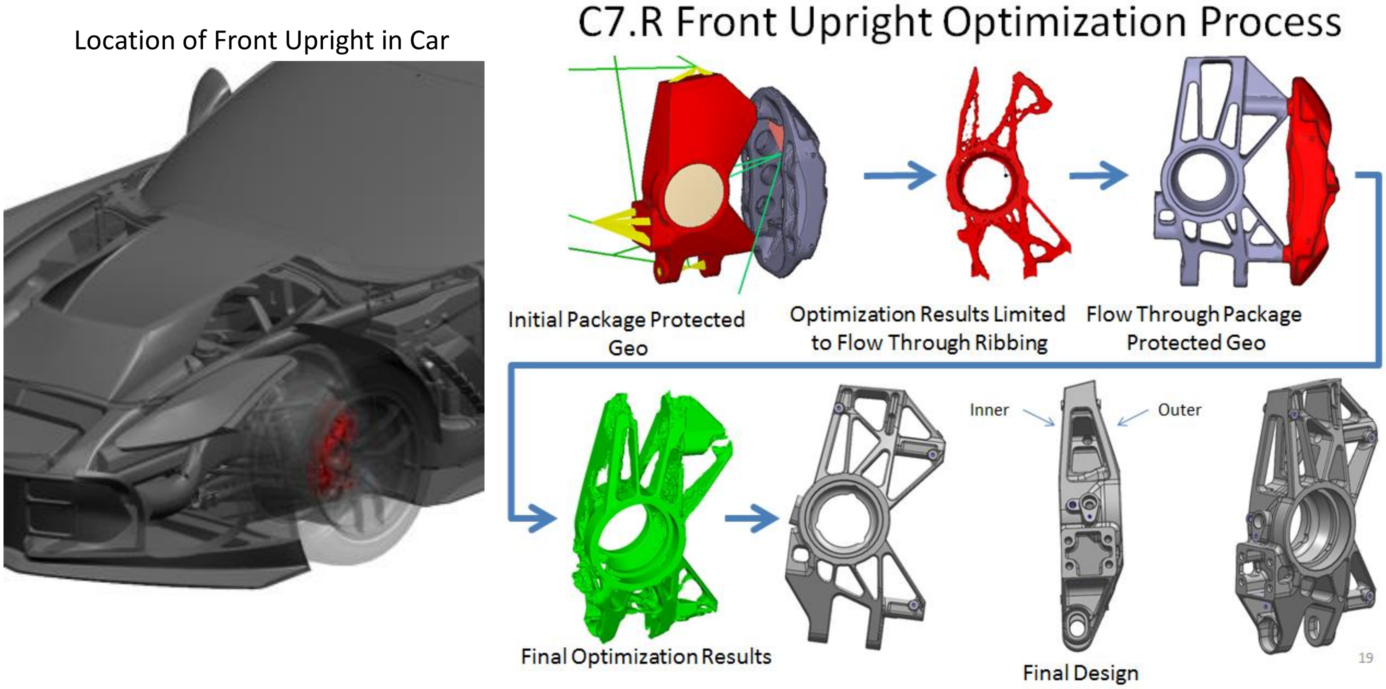

Location of Front Upright in Car

Figure 6

The purpose for using this process is that we require an upright that allows air to flow from the inner side of the upright to the outer side in order to cool the brakes. If an unrestricted optimization were to run, the inner and outer faces would be solid, blocking any flow through. We overcame this with a fabrication constraint, which through our normal process, got us to a result that was then used as the package protected area for the final optimization run. From there the design process continues as represented in Figure 3. Figures 7 and 8 depict not only the C7.R uprights and their weights, but also the C6.R GT1 and GT2 uprights for an idea of the gains made through the generation changes.

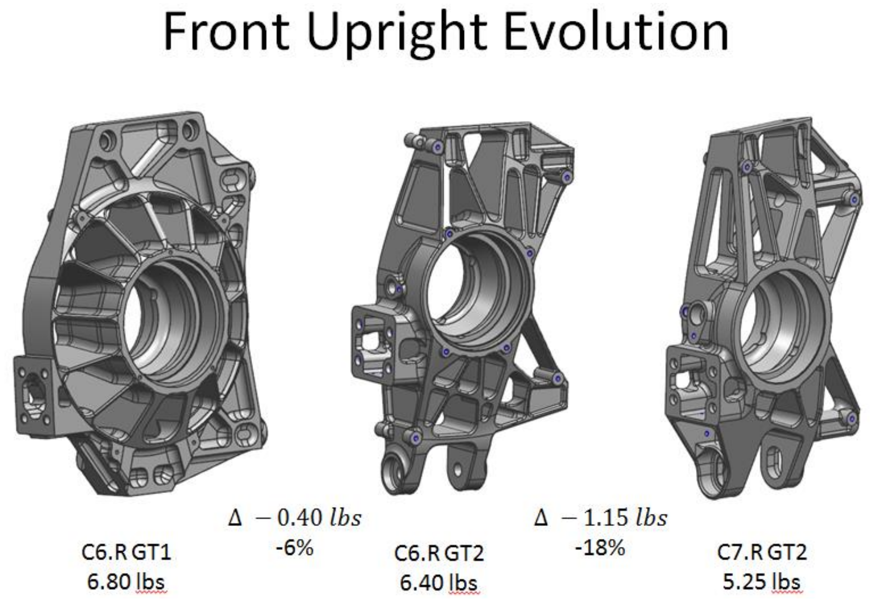


Figure 7

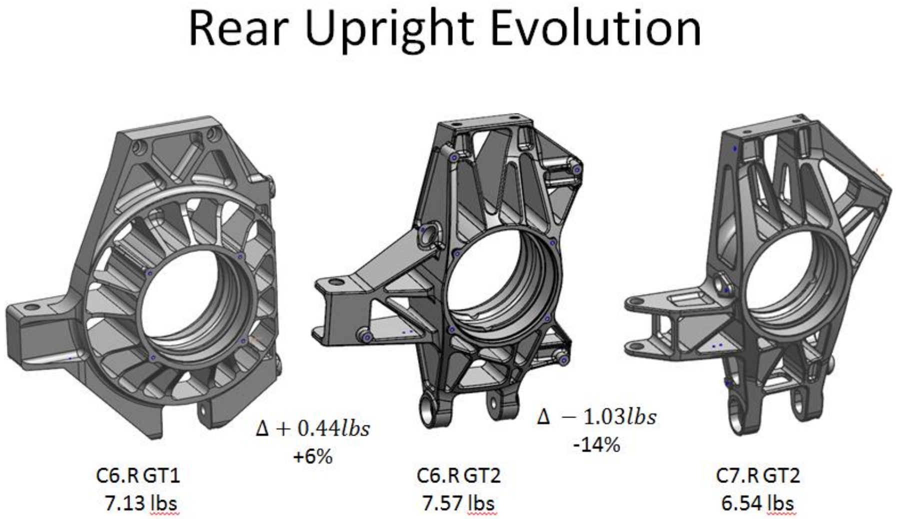
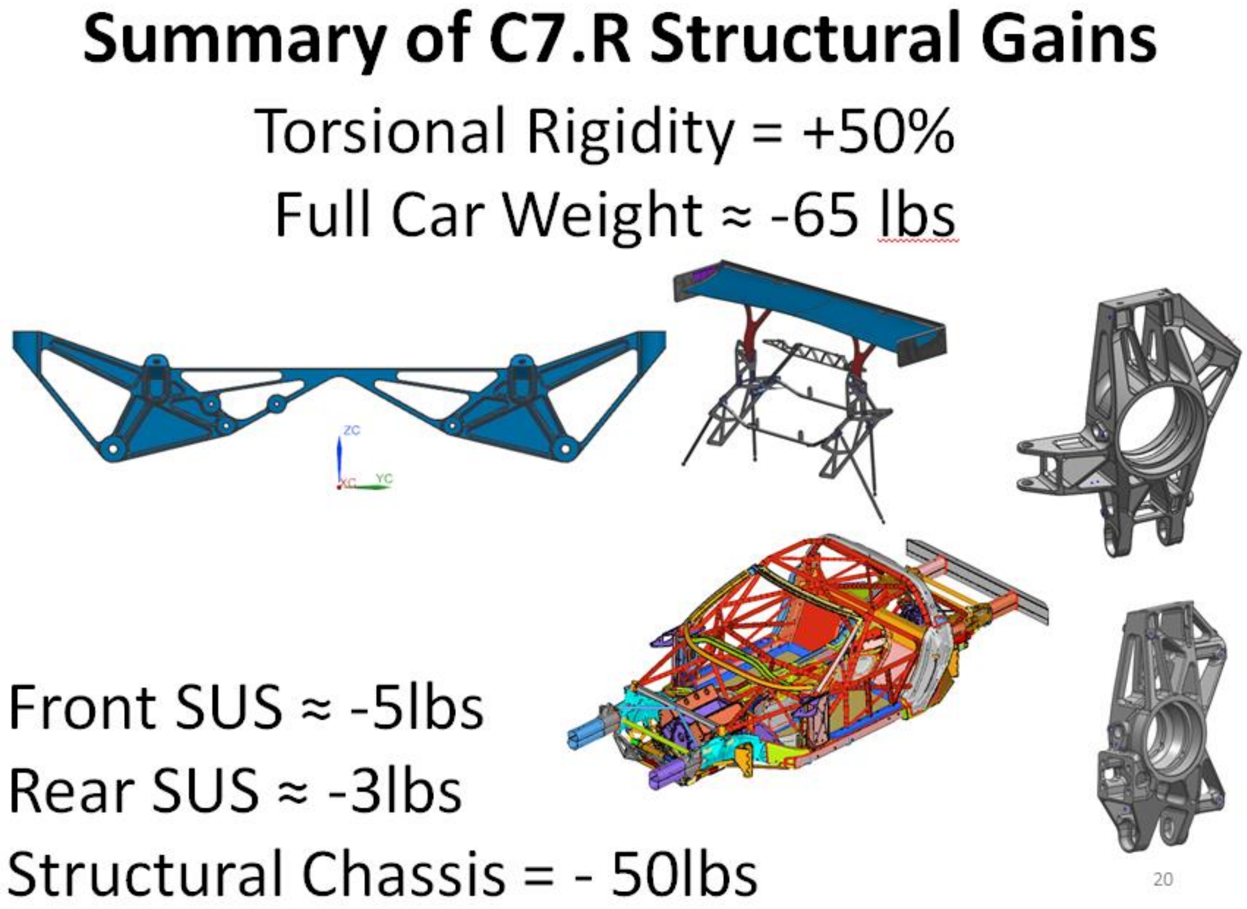


Figure 8

GENESIS has been an invaluable tool that has yielded substantial growth in structural development. A breakdown summary of some weight and stiffness gains throughout the C7.R race car are an excellent example of this point and can be seen in Figure 9. When we transitioned into using GENESIS optimization software, our initial expectations were that GENESIS would be a quicker way to get to our final designs by cutting down on the iterative process between FEA analysis and design revisions and improve those final designs. Once we recognized the further potential of GENESIS as a tool, we expanded our uses far beyond our initial intentions into not only an idea generator but also a vehicle which produces an increased level of understanding in load cases, structural responses, and a better universal familiarity of efficient structural patterns. When weighing the benefits and costs after exploring these additional facets we willingly abandoned the possibility of simplifying or streamlining the design process and instead pushed for more considerable gains in weight, stiffness, and understanding, that could yield advantages on the track, in exchange for the practical investment in further time and complexity.



Summary of C7.R Structural Gains

Torsional Rigidity = +50%

Full Car Weight ≈ -65 lbs

Front SUS ≈ -5lbs

Rear SUS ≈ -3lbs

Structural Chassis = - 50lbs

Figure 9