Mazda Balances Performance and Weight In a Steel Car Body

Isight streamlines and automates complex CAE optimization study

The Mazda CX-5 was the focus of a weight-reduction design optimization investigation.

Steel has remained the dominant material in car bodies for over a century by keeping pace with the evolving automobile. Improved corrosion-resistance, more refined mechanical properties, higher-strength characteristics, and advanced manufacturing technologies have kept steel at the top in terms of content in the average vehicle on the road—about 60% by weight today.

Yet weight remains a primary concern for automotive companies, due to its far-reaching effects on fuel efficiency. Other materials such as aluminum, magnesium, and composites are being increasingly considered as potential replacements for parts once made from steel. Although steel's proven reliability means it's likely to remain the primary ingredient in car bodies for some time to come, automobile manufacturers are now approaching the limits of how lightweight a steel car body can be. To fully understand and build within those limits, they are turning to sophisticated computer-aided engineering (CAE) tools that help them optimize their designs, provide the quality their customers demand, and meet ever more stringent mileage goals, emissions standards, and crash test regulations cost-effectively.

In a recent collaboration, the Vehicle Development Division and the Technical Research Center of Mazda Motor Corporation (Hiroshima City, Japan) developed a multidisciplinary methodology for design optimization (MDO) of a steel body structure based on the company's CX-5 car model. "Optimization technology is essential for solving the problem of how to balance improved performance against reduction in weight," says Takehisa Kohira, technical specialist at Mazda.

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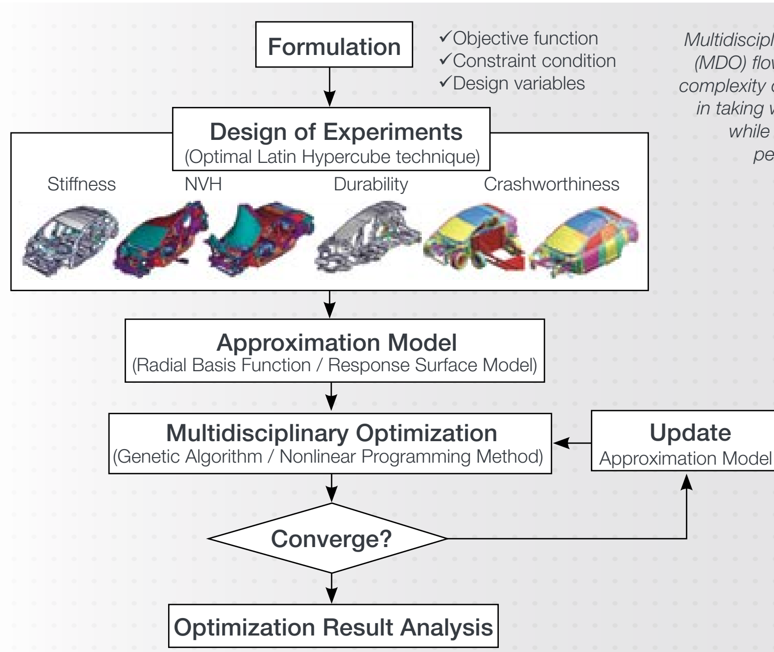
The team's goal was to identify the lightest gauge (sheet metal thickness) combination of steel parts that would allow them to reach four target performance values—stiffness, NVH quality, durability, and crashworthiness—for the top-hat structure of the CX-5. The group employed a variety of CAE tools to model such diversity of the whole-car-body behavior—including Abaqus, LS-DYNA, Nastran, and others. "CAE helps us improve our designs, increase the accuracy of our analyses, and build fewer prototypes," says Kohira. Abaqus finite element analysis (FEA) evaluated strength, durability of body components, and thermal stress of powertrain components in vehicle development.

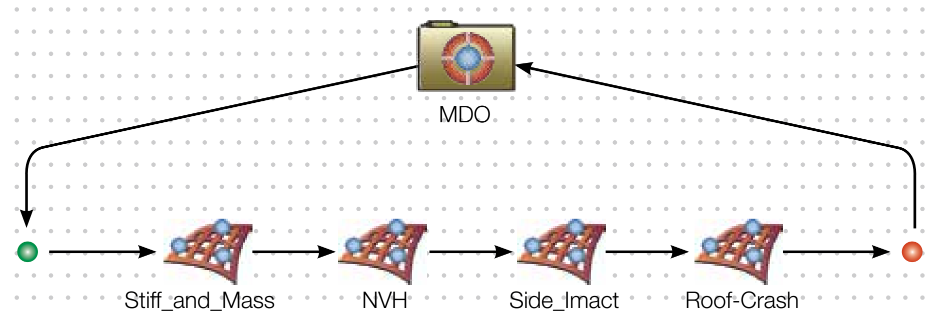
Creating an overarching analysis system that would first optimize vehicle body behavior in each of the four target areas, and then identify a final design that brought all these 'best' characteristics together at the lightest possible weight, was a complex analysis challenge.



Multidisciplinary Design Optimization (MDO) flow chart demonstrates the complexity of the challenges involved in taking weight out of a car design, while retaining a number of key performance characteristics.

Among the target behaviors being examined, stiffness—both static and dynamic—involved primarily linear calculations. NVH analysis, on the other hand, entailed complex multi-physics problems that considered both the physical interaction of frame components and whole-body vibration. Crashworthiness, which is nonlinear to different degrees depending on whether it is front, rear, or side impact, presented the most complexity. "Side-crash analysis concerns only the bending/buckling domain, which can be predicted with an approximation model," says Kohira. "However, front- and rear-crash involve strong nonlinearity due to both buckling and axial compression of a multitude of parts, so the optimization of weight versus performance was particularly complex for these analyses."

To bring all the data together into a 'best-performance' body structure design, the team employed a variety of Design of Experiments (DOE) techniques and approximation models, manually conducting tradeoffs between the different behaviors. The car body's various performance targets were considered as constraints, and the design variables were thickness of material of each body component. "Our end goal was always the minimization of body weight," says Kohira. "But working to achieve that goal through manual data organization and comparison was taking a great deal of time."



Isight process automation and design optimization software enabled Mazda to set up their MDO challenge within an automated workflow that reduced analysis setup and runtime considerably.

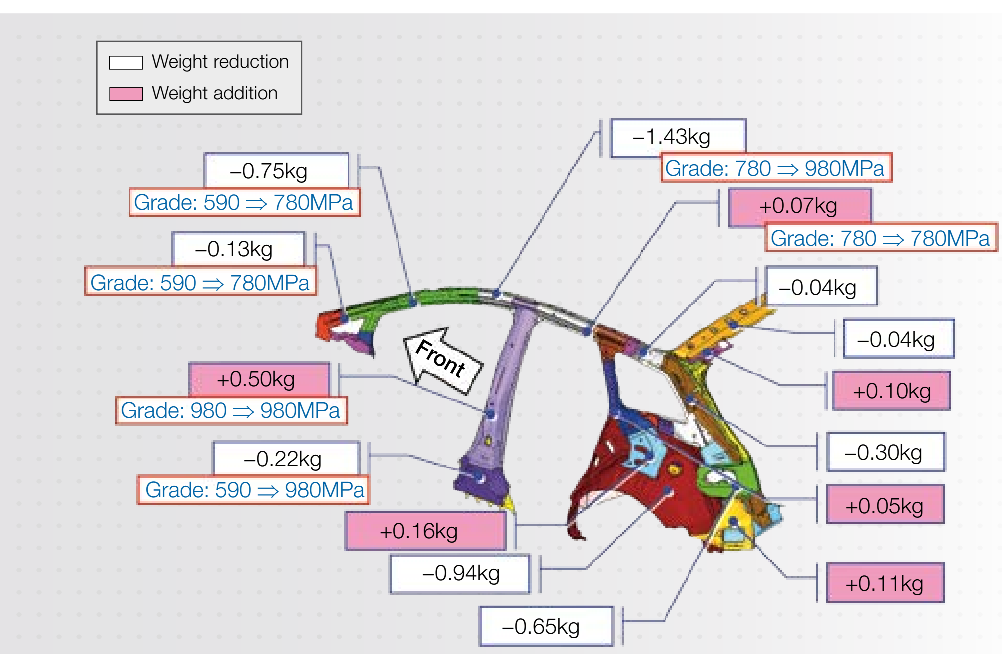
Then the team turned to Isight for process automation and design exploration. "Once we started using Isight, we could more readily understand the limitations of our designs after our DOE studies, which made it easier for us to make decisions," says Kohira. "We could see the design space more clearly and better visualize our results."

Isight helped the engineers integrate all their CAE software into customized, 'drag and drop' workflows that would run all their performance tradeoff sequences automatically. "By using Isight, we could confirm and numerically validate our designers' ideas and be confident in the validity of our designs," says Kohira.

An interesting effect of applying Isight to the car body optimization problem was the ability to categorize body components based on their importance relative to the performance of the whole structure. "During the optimization process, in most cases parts that had a low contribution to performance became thinner," says Kohira. "On the other hand, some of the parts that had a large contribution to performance needed to become thicker and heavier. Optimization with Isight enabled us to balance out these opposing needs while still lightening the overall weight."

The result? The team achieved their goal of a 3.4 percent reduction in weight over the previous design of the CX-5. Their multidisciplinary design optimization protocol is now being used in Mazda's SKYACTIV-BODY technology development program, which is aimed at improving vehicle fuel efficiency through engine and transmission development along with lightweight bodies and chassis.

Going forward, the Mazda team plans to adapt their Isight-automated MDO system to aluminum, CFRP (carbon fiber reinforced plastic), and other materials. "We have refined our steel designs about as far as they can go at this point," says Kohira. "Future designs will incorporate increasing proportions of a number of materials in addition to steel, but we now have the technology in hand to manage even greater complexity."



Left. Initial analysis image of the portion of Mazda CX-5 body side frame assembly showing weight reduction (white labels) and weight addition (pink labels) that resulted from optimizing performance over a number of behavior parameters.

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