

Modal analysis identified deformation of the crankshaft.

# Getting It Right the First Time

In a corporate-wide initiative, Cummins Inc. refines designs early with Analysis Led Design to shorten development time, reduce costs and improve product performance.

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In developing complex mechanical products such as diesel engines, going through multiple build-and-test hardware prototype cycles to verify performance, stress and fatigue life is tremendously expensive and time-consuming. This issue can be addressed by evaluating and refining designs with analysis tools up front in development, so fewer test cycles will be needed later in development.

Five years ago, such a Simulation Driven Product Development approach was started at Cummins Inc., a corporation of complementary business units that design, manufacture, distribute and service engines and related technologies, including fuel systems, controls, air handling, filtration, emission solutions and electrical power generation systems. Applications include trucks, construction and mining equipment, agricultural machinery, electrical generators, fire trucks, recreational vehicles, buses, cars, SUVs and pickup trucks. The Cummins Analysis Led Design (ALD) strategy is a corporate-wide initiative to change the prevalent test-first culture; it has had a major impact at the company, with significant benefits that include shorter development time, lower costs and improved products.

ALD can shorten product development time by getting designs right the first time. Many Cummins-designed parts have extensive lead times because tooling needs to be created. Beyond this, traditional hardware testing can take weeks or even months to validate a design. Leveraging analysis early in the process can eliminate tooling changes and repetition of lengthy endurance testing, thus providing significant reductions in overall development time.



The Cummins QSK78 engine delivers more power than any other engine for gigantic haulers in the mining industry. The 18-cylinder, 12-ton super-engine is rated at 3,500 horsepower and stands almost eight feet high. Cummins also provides engines for agricultural and industrial equipment and heavy-duty pickup trucks.

Simulation also radically lowers the total cost of product development through less dependency on hardware tests and a reduced number of long-hour tests, which sometimes can last for days. At Cummins, some of this traditional endurance testing can cost in the range of \$50k to \$100k per test, so eliminating even a single cycle can result in significant savings. The intention is not to eliminate all testing but, rather, to use targeted component and assembly-level testing first to validate analysis models and then to validate the overall design with only a few long-hour tests of the entire engine. Savings also are achieved by eliminating redesigns, in which costs are lowered by reducing resources required to manage the design process (engineering, drafting, clerical time, etc.) as well as reducing retooling costs.

While shortening development time and lowering costs are important aspects of ALD, it can be argued that the most significant benefit of the approach is the ability to create improved products by considering a broad range of design alternatives. Simulation allows engineers to readily perform what-if studies and large-scale design of experiments in order to understand more fully the design space and trade-offs involved. Otherwise, once the first set of hardware is created, the design space narrows and designs are much harder to modify.

Various measures have been used within Cummins to help determine the effectiveness of ALD. In looking at test time and cost in one example, validation testing for a cylinder block traditionally required \$72k of rig testing and \$30k to \$80k for engine testing for a single block design. Each repetition costs the same amount: in the range of \$100k to \$150k. Testing usually took about one month, once hardware was available. Lead time for the tooling and part procurement took about 12 weeks.

Through the ALD initiative, engine testing has been removed as a requirement for some cylinder block

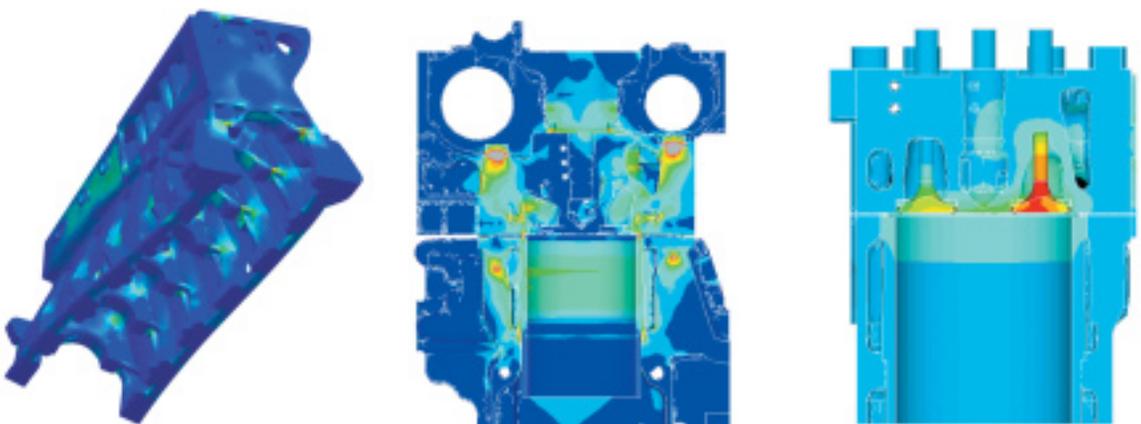


This customized Kenworth tanker truck has a Cummins 565-horsepower engine.

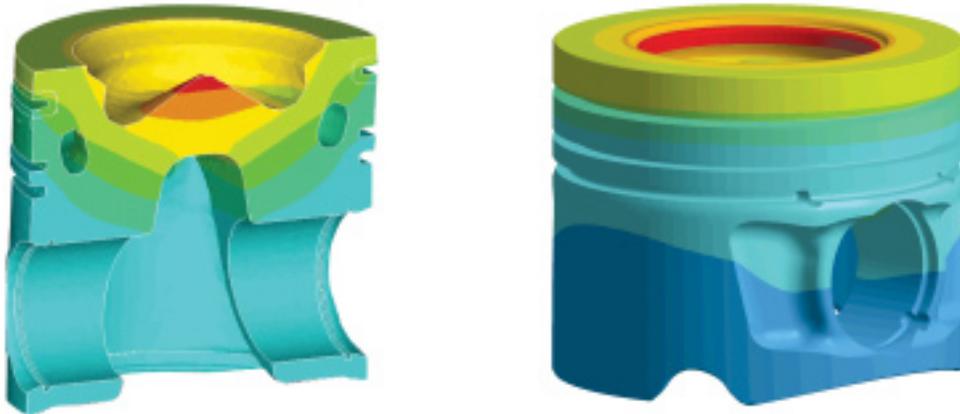
validations. Now when a new heavy-duty engine design is being developed, a series of repetitions are done through simulation until the entire block meets the design limits. This requires the time of one analyst for about a month of work, or approximately \$7k. Once the hardware is procured, rig testing is completed on the initial pass — a first for this type of design. The result is that a minimum \$30k of engine testing is eliminated. Also, redesigns are eliminated that, most likely, would have occurred over many more weeks or months and at an additional cost of \$100k (\$72k of rig and \$30k of engine testing), which does not include the significant additional expense of prototype hardware.

There are several reasons why ALD has been successful at Cummins: It is a top-down initiative that was driven by upper management, appropriate resources were allocated, and an infrastructure was established to support the initiative.

From the beginning of the program, top management has been a strong proponent of ALD. Cummins' chief technical officer coined the acronym ALD, and he has continued to push the initiative. The progress of ALD has



In the development of Cummins diesel engines, engineers use the ANSYS Mechanical software to determine (left to right) cylinder block deformation and stresses, cylinder head assembly stresses and temperature distribution in the cylinder head and valves.



Thermal analysis shows temperature distribution for a diesel engine piston.

been monitored continually and reported in quarterly messages by Tim Solos, Cummins CEO. At the executive levels, there has never been a question about whether to reduce testing and increase analysis but rather how to best accomplish this objective with limited resources.

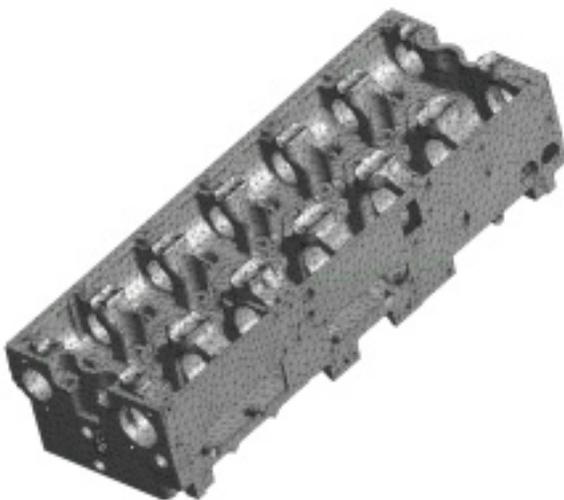
Along with driving ALD, Cummins management provided resources to do more analysis. Shortly after the ALD initiative was started, a technical center was set up (Cummins Research and Technology, or CRT, in India). This analysis center focuses solely on design, computational fluid dynamics (CFD) and structural analysis in supporting all Cummins business units.

Infrastructure to support ALD at Cummins has taken two forms: Engineering Standard Work (ESW) processes

and Six Sigma tools. ESW defines the work, tools and limits required to release a part for production. This became a natural focus for ALD as Cummins examined where testing was being reduced and where analysis was being increased. Six Sigma has been an invaluable support for ALD in validating new tools and methods to ensure that analysis can be used to replace testing. So, ALD is the initiative, ESW is the process to ensure that all necessary work is completed and Six Sigma is the set of tools used to determine that the appropriate work is included.

In performing the underlying work for ALD, the Structural and Dynamic Analysis group within the Cummins Corporate Research and Technology organization is responsible primarily for developing tools and methods as well as conducting analyses to ensure that structural components meet both reliability and durability requirements. The group partners with key software vendors in efforts to develop improved simulation tools, and one of the primary relationships is with ANSYS, Inc. In fact, the relationship has been the benchmark set for subsequent partnerships. Technology from ANSYS has become the primary finite element tool within all Cummins business units for conducting static structural, thermal, transient thermal, modal, harmonic and other analyses. This partnership with ANSYS has resulted in joint development of advanced features in continuing to meet analysis needs at Cummins.

Any culture shift is difficult, requiring vision, leadership, planning and tangible benefits. The ALD initiative, in particular, has driven considerable change and has proven to be of tremendous value at Cummins. While significant progress has been made, there is room for expansion, and Cummins will continue to evaluate new and improved technologies, processes and strategies in using simulation to further strengthen its position in the diesel engine industry. ■



Coarse mesh of detailed geometry for an inline six-cylinder head created using the ANSYS Workbench platform