Critical Challenges of Math-Based Engineering

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In the coming century, I believe the basis of automotive leadership will be a global agility to market customized vehicles that meet (and preferably exceed) customer requirements.

I further believe that this vision of industry leadership can only be achieved through technical leadership.

And one of the most essential elements of technical leadership, in my view, is a well-defined product development process fully integrated with a well-developed math-based engineering analysis capability.

So this morning I thought I’d take this opportunity to present my vision of the 21st-century product development process.

The most important commodity in this process is information.

The most important tool is an enterprise-wide, math-based system that extends beyond the company to encompass operating customers, suppliers, and a network of virtual partners.

And the most important capability will be the ability to integrate existing information and use it to generate new information that will cascade throughout a dynamic development process.

With these prerequisites in mind, a typical vehicle development process would work as follows:

Beginning with marketing data, customer preferences will be captured by the enterprise network and will influence vehicle requirements. Designers will use this information to begin developing the engine, body architecture, chassis, and subsystem elements, using “templates” based on engineering data from prior vehicle programs. This data will include geometric descriptions, engineering performance requirements, and fabrication and processing specifications. The passenger compartment and exterior styling will be free-form, with design flexibility enhanced by new high-performance materials. Design of the vehicle and its various subsystems and components will be largely concurrent and will involve the participation of internal and external groups.

Product development and engineering evaluation will be rapid because the basis of the design will be stored in the enterprise database as analysis models, while new parts will be generated automatically from new geometry. These models will merely need to be scaled and conformed to the necessary shape and integrated into the complete vehicle architecture. The database will also contain associated material properties, manufacturing specifications, and even experimentally determined ranges of performance to speed engineering analysis.

Once a full digital model is created, it will only be necessary to build a few test pieces, scale models, and full-size prototypes using rapid prototyping methods to confirm the final design. And once confirmed, the manufacturing systems will be established using automated, highly
flexible fabrication and assembly equipment. A complete family of vehicles will be produced in a single facility simply by reprogramming the equipment for each unique style. Sounds great. Sounds like we know exactly where we’re headed.

And we do know where we’re headed.

The industry has been focused on math-based development and manufacturing for a long time.

The problem is that we lack a clear roadmap.

How do we get from where we are today to where we need to go?

I’m sure many of you have seen the Automotive Research Center’s recently issued Delphi forecast on modeling and simulation. In reviewing it, I wasn’t at all surprised to learn that people in our industry don’t believe math-based tools are well integrated into today’s development processes. Too often, these tools remain an adjunct to development, much like testing.

An even more depressing finding of the survey was that it may be ten years or more before we can implement our vision.

Evidently, the view is fairly widespread that the auto industry is a long way from anything approaching Boeing’s math-based design of the 777.

Of course, designing and validating a jumbojet on a computer is in some ways a lot easier than creating a digital automobile that can be readily translated to the physical world. For one thing, time and cost constraints are vastly different.

But the auto industry is definitely making progress.

We’ve been routinely modeling important vehicle processes, such as structural behavior, engine and drivetrain performance, and occupant dynamics for some time. And more recently, we’ve begun to model integrated systems and even full vehicle simulations.

We’ve also been working hard to move our modeling and simulation programs up front in the development process.

One of the most critical modeling areas for our industry has always been vehicle crashworthiness.

At General Motors, we pioneered computational methods for crashworthiness analysis in the late ‘60s, and we’ve been modeling occupant dynamics and restraint systems since the ‘80s. But even as we’ve progressed, the design problem has become more challenging – as
customers demand more efficiency with greater safety, manufacturers struggle to balance vehicle mass against safety constraints. It’s no easy matter to juggle these paradoxical demands.

Today, we rely on both hardware testing and math-based tools to develop and assess crashworthy structures and occupant protection features. But our long-term goal is to do the majority of the development work and validation on the computer.

Before we can do that with a high degree of confidence, there are many capabilities that need to be developed or enhanced. Just to name a few: We need validated models of barrier tests and crash dummies for all regions of the world. We require better airbag simulations. We need to be able to model foam and other interior trim materials, as well as complex phenomena such as sheet metal tearing and fuel system behavior, during impacts. We also need simulations of vehicle rollover crashes and pedestrian impacts. And we require methods to more accurately model impact trauma, such as injuries to the chest, thorax, and lower legs.

We’re now working with a number of universities to improve the robustness of our current simulations. For instance, as part of GM’s new satellite laboratory, we have a project underway here at the University of Michigan to develop a math model to characterize heat loss to the airbag fabric. And we’re working with the University of Iowa to develop human neck and thorax models that can be integrated into our programs.

Another modeling area that is of intense interest to the auto industry is computational fluid dynamics. At General Motors, we use CFD codes for many aspects of vehicle design and analysis. To improve external aerodynamics. To optimize engine performance and emissions. And to optimize underhood cooling.

We’ve also applied our CFD codes to improving vehicle heating, ventilation, and air-conditioning systems. In fact, we used our code to design the HVAC system in the new Chevy Malibu.

And our newest application is modeling water flow over the vehicle windshield and side windows. We’ve been able to identify optimal designs for the A-pillar gutter to improve driver visibility in the rain.

Although we employ CFD analyses today in conjunction with testing, we’ve begun to move them further upstream in the development process, applying them to new vehicle programs where the information has the most value. Some of the major issues to be addressed in code development are improving model accuracy, developing methods for automatic grid generation, and increasing the flexibility of the codes through modularization.
We’ve also begun to intensively apply math-based methods to eliminate noise, vibration, and harshness from the vehicle. With lighter and more efficient body structures and powertrains, tools to predict NVH performance have gained increasing importance.

Today, there are a fair number of reasonably well-developed analytical tools for handling low- and high-frequency noise and vibration issues. And we’re working on new techniques, such as statistical energy analyses, to model mid-level frequencies.

Statistical methods also show promise to enable engineers to predict variation in NVH performance based on assumptions about the vehicle design – which would be very useful in the early phases of development. These techniques might eventually allow us to “tune” the noise and vibration characteristics of a particular vehicle design to achieve a “sporty” or “luxury” feel.

So, as in other areas, one of the key pushes in the noise and vibration arena is to move math-based tools forward in the design cycle. And this is especially critical as the industry collaborates more closely with suppliers on component and subsystem development.

One way to speed math-based development is to bring in test data from previous vehicles – because there is going to be significant carryover structure for subsystems and components. As we work on enhancing our computational capabilities, too often we tend to forget about what we still have to gain from the testing community. And this is a mistake. There is a significant opportunity to advance the development of the math model by making use of previous test data to fill short-term data gaps.

At GM, we’re currently collaborating with Sandia National Laboratory to understand how to do good noise and vibration tests and reconcile testing data to math-based simulations. We’re also working with suppliers on the most effective ways to integrate subsystem and component design into our noise and vibration modeling.

Integration is a key issue. The real power of computer simulation is using it to do things we couldn’t do before. One area where we’ve found this to be especially true has been integrated chassis control. GM’s new stability control system, StabiliTrak™, was developing using a GM simulation program that incorporates models of the suspension, steering, braking, a simplified powertrain model, and roadway surface models.

This simulation was employed in every phase of development and validation, and helped us create a system that’s been rated by industry observers as the best and most affordable in the world. In fact, we like to think of our simulation program as a “virtual proving ground” because we were able to test many of StabiliTrak’s capabilities in software before any metal was cut. It also allowed us to greatly cut development time.
The simulation has proven to be so useful that we’re currently developing a user friendly, PC version for our platform engineers, so they’ll have easy access to the program from early development right to the test site.

And speaking of virtual, another major area of emphasis for us is virtual reality-based visualization. One of our most effective technologies to evaluate potential designs is our VisualEyes V-R system. With VisualEyes™, our engineers can see and experience a product almost as fast as it can be transferred from the mind to the computer.

In fact, I’ve been told about one engineer who wanted to observe the engine block during a crash simulation, so he stuck his head through the car’s outer skin to watch. His approach obviously wouldn’t have been possible with hardware. And it certainly gives new meaning to looking at a problem from a different angle, doesn’t it?

It also pretty effectively demonstrates that the applications for virtual-reality technology are almost limitless.

Even as we work to improve our math-based capabilities to design near-term products, we’re also thinking about how to use modeling and simulation technologies to speed the “game changers” along.

As GM and the industry attempt to push the envelop for clean, efficient, safe, and affordable vehicles, we’re turning to computational methods to help us visualize new types of vehicle configurations that are based on promising new technologies.

And we’re collaborating on the development of these models at our new satellite laboratory here at U of M. The goal is to devise optimization techniques to synthesize vehicle configurations for hybrid vehicles and associated powertrain components such as fuel conversion devices, energy storage units, and advanced transmission devices. The project will also focus on determining optimal subsystem size and parameters, and advanced energy management and control strategies.

As the modeling gains sophistication, we also anticipate that more detailed internal combustion engine models developed here at the satellite lab by the Advanced Powertrain Systems Division will be integrated into the simulation. And a third step will be to add the capability to model lightweight structural designs, since hybrid configurations can significantly affect loads on the vehicle body structure, and change the number and location of subsystems and components.

All of the modeling arenas I’ve briefly touched on this morning are critical to our business. But there are two important issues that cut across every one of them.
Those issues are: Speed and accuracy.

Unfortunately, fast continues to mean simple. And fast and simple generally mean less accurate. So we are caught between a rock and a hard place. We have simple models that don’t generate enough useful information. And accurate models that take so long to develop that they don’t really affect the product.

How do we bridge this gap?

In the early history of engineering, the engineer was an integrator of information. Engineering practice consisted primarily of integrating simple mathematical formulas and tests across a broad range of disciplines to design useful products. Computational methods made it possible to significantly extend the range of these simple math models. In fact, they enabled engineers to remove many engineering approximations and solve the field equations for complex problems. This additional accuracy was accompanied by increased complexity of use and understanding. And increased specialization. Today, we continue to refine computer-aided engineering in highly specialized disciplines. The goal within each of the separate disciplines is to achieve greater accuracy at comparable computing cost.

In order for computer modeling and analysis to become a more effective piece of the vehicle design equation, we need to “re-invent” the math-based engineering approach so that it more closely resembles that early “integrated” engineer. The emphasis must be on providing greater capability for design synthesis that incorporates engineering and manufacturing criteria.

And the development of these methods should be driven by engineering and development costs and the requirements of the development cycle, rather than by technology evolution.

Any engineering tool that is to be used in the design of a product should be chosen to fit into the time scale appropriate for that product. For an automobile, whose success in the market is strongly influenced by the timing of its entry, the time available for engineering is critical. What we need are tools that can perform a full system synthesis early in the design, yet which provide a smooth transition to the subsystem level of vehicle development.

Probably the greatest limiting factor to math-based analysis today is the amount of time required to generate the code. It’s not the 20-to-40 hours it takes to execute the model that we need to worry about. It’s the long wait for the input model. If we could cut model generation time to a fraction of the current practice, we wouldn’t have to worry about complexity. We could use the most complicated models available today and still accelerate our development processes.

This is one of the things we need to do, if we hope to achieve a 24-month or less vehicle development cycle. It’s absolutely essential that we be able to analyze information rapidly.
And it’s also absolutely critical that we have some understanding of how to make robust decisions, even faced with inconsistent levels of accuracy from different disciplines.

So we need to concentrate on how to generate useful information early.

And we need to recognize that the development process is dynamic – it will continually evolve as the global, agile enterprise evolves. The next modeling method is just down the road. And it may not be finite element-based; it may be a technique performed at the molecular level.

For the auto industry, the “need for speed” is changing the way we do our business. And one of the most important changes is to a 100-percent math-based process. The ability to make this change may even spell the difference between thriving or just surviving in the next century.

So for General Motors, simulation, analysis, and visualization remain critical areas for collaboration and leveraging.

At GM, we know where we need to go. And we have a roadmap for getting there: We’re going to work with universities, government laboratories, and industrial business partners to chart the future of math-based engineering for our industry.

Thank you.