High Confidence Performance Prediction to Improve the Vehicle Development Process

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ABSTRACT

Ford is increasingly using CAE tools to speed up the product development process and replace hardware prototypes while bringing new products to market. The use of an analytical prototype allows performance to be predicted in advance of hardware proveout. Many design iterations can be performed, thus producing a world class vehicle. The accuracy of these predictions for a given attribute, and how the resultant design recommendations are integrated with other attributes has remained a major issue for the CAE community. During the recent development of a new vehicle all CAE disciplines (Safety, NVH, Durability, Vehicle Dynamics, etc.) were successfully combined to "sign-off" a design based entirely on CAE.

This paper explains how the Durability and NVH CAE attributes employed MSC/NASTRAN to produce high confidence results as part of an integrated process which allowed the vehicle to be verified for the Global and local performance at approximately 3 years to job 1.

1.0 Introduction.

The Automotive industry is changing drastically. Many companies are re-organizing, re-engineering, downsizing, and above all changing their approach to engineering vehicles. The reasons for these changes are numerous; increased competition, new market requirements, greater customer focus, vastly improved information technology, outdated business practices, etc. To be successful in the coming century the company must challenge and beat the intensifying competition; understand, exceed and drive the new markets; surpass heightened customer expectations; install and fully utilize the most advanced information technology; replace the old business practices with new aggressive global strategies; and, finally, do all this profitably.

Automotive companies are focussing on the processes of delivering a new or updated high quality vehicle to the market faster and cheaper. Analytical processes like CAE are extensively used upfront to develop a robust quality product. Ford is one of the leading automotive companies in employing CAE tools effectively to speed up the product development process. CAE tools have been around for many years and have been used successfully on many vehicle programs within Ford. Ford has leadership in the tools, methods and computational infrastructure. Almost all functional areas within Ford understand how CAE can be applied to the vehicle design. These facts mean Ford can support total commitment to CAE.

During the recent development of a new vehicle all CAE disciplines (Durability, NVH, Safety, etc.) were successfully combined to "sign-off" a design based entirely on CAE. This paper briefs the vehicle development process in general, and explains how the Durability and NVH CAE attributes used MSC/NASTRAN to produce high confidence results to predict performance vehicle.

2. Development Process.

Based on overall company product planning strategy, the market segment for the new vehicle will be identified and a viable business plan to support the market entry developed. The vehicle level targets are developed early in the program to support the vehicle design. These targets have to be both competitive in performance and affordable in this market segment.

For this vehicle, most of the durability and safety targets are set based on the worldwide Corporate requirements and federal regulations and the process is straight forward. Setting the targets for vehicle refinement such as interior noise, ride, handling, which will please the customer and ultimately impact the purchase decision, is complex. These targets are set based on a process that consists of the following major steps:

- Develop customer desires through customer drive evaluations and focus groups. Use total vehicle Quality Function Deployment, (QFD) to identify important customer wants that relate to the performance of the vehicle. This information is used to develop a customer driven ranking of the important vehicle characteristics.
- Develop functional image targets (subjective) relative to the best-in-class (BIC) vehicle. Once the customer wants and the associated vehicle attributes related to vehicle performance are established, the competitive image vehicles can be selected in this market segment. Through customer/expert drive evaluations and future

projections of BIC vehicle performance, the functional image targets are developed.

- Convert functional image targets to objective engineering metrics to develop objective vehicle level targets. Extensive benchmarking testing on the road and in the lab, is conducted to define the objective performance of the image vehicle. The future improvement trend in this market segment is studied and projected. The vehicle targets will be established according to this benchmarking data which represents the competitive image vehicle performance in the current market and the projected future improvement.

To give an example of this process, vehicle NVH targets are defined for all the major NVH attributes. These include road NVH, wind noise, powertrain NVH. The natural frequencies of various systems play a critical role in determining the overall NVH performance of a vehicle. It is very important to ensure that these resonant frequencies are well separated from each other as well as from the excitation frequencies. Modal alignment Charts help to systematically establish natural frequency targets for various systems. To aid the design and engineering process, the vehicle level objective targets are cascaded to the major systems of body, chassis and powertrain to establish system targets. The system targets are further cascaded down to sub-system and component targets, to provide component design engineers specific guidelines for their component design.

2.1 Hardware.

Typically, vehicles are currently developed using prototype build phases over a 3-year period. Depending on the size of the vehicle program many very costly vehicles may be built. These vehicles are used to assess the total vehicle performance of all attributes for all driving conditions. They are also used to iterate the design to compare its functional performance. This conventional hardware approach is labor-intensive, time consuming and costly. At Ford currently CAE is used in conjunction with the prototypes to speed up the development process. However, processes are underway to put more emphasis on CAE whereby prototypes can be reduced or completely eliminated.

3. How CAE Leads the Design.

With improved CAE predictive capability, as demonstrated on previous vehicle programs, the vision of replacing hardware prototypes with a CAE "analytical prototype" could be reality sooner than we think. In the design process the performance of the full vehicle, subsystems and components are evaluated by CAE and compared with the targets. Several iterations are usually required to achieve the targets. Trade-off among performance, weight, cost, manufacturing and other design requirements must be made to establish the optimized vehicle design. CAE plays the leading role in achieving functional, weight and cost targets.

During the early development phases of an all new program at Ford, CAE was employed to evaluate different architectures and to drive the design to meet all its functional, cost and weight targets. This was achieved prior to any prototype builds.

This resulted in 2 major improvements:

1. Significantly reduce the development time required to deliver the vehicle.
2. Reduce the number of prototypes by 50%.

4. Integrated CAE Approach.

With the reliance on CAE being clear in the PD process all the different attributes of the CAE community must have an integrated approach to guide the vehicles' design. The modelling requirements for the different attributes of NVH, Safety and Durability differ extensively in terms of complexity, mesh refinement, and time to complete. For a total vehicle assessment all attributes must be evaluated. A common set of design recommendations must be used to drive the design; what is good for durability must satisfy the safety performance too.

In the development of this vehicle the following cornerstones were used to achieve an integrated CAE approach:

1. A common model is developed based on a complete set of design data at a given date by all attributes working together.
2. Each attribute tailors the model to suit the specific attributes needs to give the best quality results.
3. Multi-function optimization is performed on the common model to minimize weight while maintaining the functional performance of all attributes.
4. Regular reviews are held to consolidate the design recommendations for consistency across all attributes.

5. Typical Analyses.

In this section typical examples are presented to demonstrate how the integrated CAE approach aided the vehicles' design and development.

5.1 NVH Example

Based on the preliminary BIW and trimmed body modal analysis, it was determined that the initial vehicle performance was short of the functional targets set based on competitive benchmarking. Typically, Static Stiffness - 30% short of target; Dynamic Frequency - 3 Hz short of target.

CAE was used utilized to identify the reasons for not meeting the functional targets and to suggest the design changes needed to achieve the same.

5.1.1 Analysis Approach.

MSC/NASTRAN [1] was used to determine the static and dynamic characteristics of the model. Based on the results, Design Sensitivity Coefficients for the overall torsional and bending stiffness were calculated. The DEQATN card was used to define a synthetic response based on the method used to compute the stiffnesses. Eigenvalue sensitivity coefficients were used for the overall torsional and bending frequencies.

An optimization problem was formulated using the DSA coefficients. The objective function was weight minimization and the performance constraint were the static and dynamic characteristics. The design variable was panel thicknesses. Before, identifying the feasible design space, across attribute team was formed to incorporate the requirements of safety, durability,

vehicle dynamics. NVH, packaging and manufacturing. This team was responsible for defining the upper and lower bounds for the design variables based on all the different attribute requirements (both global and local). This integrated team approach ensured that all the optimized gages were acceptable based on corporate design standards. This optimization problem was analyzed on the CRAY C-90. The optimization resulted in two different scenarios: (1) all the performance criterias met the functional targets but with weight penalty,
(2) the Static performances met the target and the dynamic frequencies improved while considerable weight was saved.

It was obvious that the latter scenario was appealing based on the fact that weight was taken out to improve the performance significantly. A detailed investigation of the optimizer projections resulted in the following conclusions:

a. The stiffnesses of the major load carrying members were increased

b. Certain components, like the A-pillar inner were downgaged which was desirable for head impact requirements

c. Some key areas like the front and rear shock towers had to be locally reinforced with laser welded blanks

d. Improved bead patterns were needed to stop local panel resonances at high frequencies.

This typical NVH problem of improving function and reducing weight was solved using the powerful capabilities of MSC/NASTRAN, to the extent that the current vehicle performance meets all targets.

The eigenvalue analysis yielded the natural frequencies, which helped in establishing the modal alignment strategy. The DSA coefficients provided a invaluable insight into the components that were responsible for the static & dynamic characteristics. In absence of a representative hardware, (which is frequently the case in the auto industry) the power of CAE tools to predict the performance based on math models is paramount.

5.2 Durability Example Process.

The next example is in the durability area where the CAE and testing engineers came together to develop a durable car.

The durability analysis on a new vehicle is performed considering stress, fatigue life, and optimization. The stress and fatigue life analysis are performed using MSC/NASTRAN and an internal Ford Motor Company code named FLAP (Fatigue Life Analysis Procedure.) [2, 3] The new Ford Motor Company requirement of 150,000 customer miles while emphasizing quality and meeting weight targets make the analyses quite a challenge.

To perform our durability analyses, we needed loads on the body that will accurately represent the loads on Ford's rough road proving ground. A road load vehicle is instrumented and measurements are taken while the vehicle is driven around the track. These measured loads are then combined with an analytical vehicle model and load-time histories are produced at every suspension attachment point to the body.

The load-time histories produced contain over one million load cases, many more than we are able to analyze with a full body finite element model. Many of the load cases are not important for stress and fatigue life calculations. We therefore, reduce the load time histories using FLAP to give us the loads for just the important events from the track. This usually consists of approximately 2000 load cases that are to be used for stress calculations and 10,000 load cases that are used for fatigue life calculations.

The stress calculations are performed on the full body finite element model (approximately 200,000 elements). A unit load finite element analysis using inertia relief in MSC/NASTRAN is used to obtain the unit load stresses. Using FLAP [4] (which performs superposition), the unit load stress files along with the stress load file are combined to give us the maximum stresses for all 2000 load cases in the file. These stresses can be quickly post-processed to view all the maximum stresses for the entire durability track. Iterations on the finite element model can then be performed to improve the high stress locations which helps us lead in the design process.

Before the fatigue life calculations are performed, possible critical elements are selected from the full body finite element model. Due to computer resource limitations, the fatigue lives are not calculated for all the elements in the model. Only the elements with the highest principal stress ranges are used for the fatigue calculations. These elements are obtained from the FLAP procedure which determines each element's principal stress range by performing superposition using the MSC/NASTRAN unit load stresses and the road load file.

Once the elements are selected, the fatigue life calculations can commence. The fatigue load file (approx. 10,000 load cases) and the unit load stresses are combined using FLAP to produce stress time histories for all the possible critical elements. The stress time histories are rainflow counted, and along with the appropriate material strain-life curve, the fatigue lives are calculated. The elements that do not meet our target fatigue life criteria are then post processed to view the magnitudes and locations. Design iterations can then be performed to improve low fatigue life areas.

After all the major design changes are made to improve the high stress and low fatigue life areas, we perform material thickness optimization using an internal Ford code named STOPFAT [5] along with MSC/NASTRAN optimization. This helps us minimize the weight of the vehicle without sacrificing the structural integrity. STOPFAT determines the maximum allowable stress that each PID can experience to give us our target fatigue life. The program then produces the input deck for MSC/NASTRAN optimization. The optimization procedure is run, and the optimized thicknesses for each PID are determined. These results are used in conjunction with NVH and safety requirements for cross attribute optimization.

The two examples outlined above are only a small part of how MSC/NASTRAN aided during the vehicle development process. Other key areas of its use include:

- Non-linear sol 106 of seat belt pulls, tow hook, shipping and ocean load analysis
- Forced response analysis of full vehicle NVH predictions
- Time domain impact analysis
- Acoustic analysis of interior cavities

6. Validation of the Processes.

The current automotive culture is hardware biased, and always looks for testing validation. The CAE predictions for this vehicle are based on methodologies and guidelines which are well proven and validated on previous vehicle programs. Correlation studies such as Modal Assurance

Criteria, durability route testing, crash testing and component modal analysis are used as a continual part of the interactive development process. This installed high confidence in the cross-functional team of Design and Release, development and CAE engineers who signed off the vehicle based entirely on CAE predictions.

7. Conclusions.

This paper has clearly demonstrated the effective use of CAE to develop the vehicle where there was reduced reliance on hardware. This enables quicker turnaround time for design sections leading to a better quality product, reduced prototype testing and costs, and decreased total development time.

In almost all of the analyses for all attributes MSC/NASTRAN was successfully used to enable the vehicle to be signed off by a cross-functional team early in the development phase. Overall, the corporation who successfully uses the integrated CAE approach outlined in the paper will enjoy significant competitive advantage in speed-to-market.

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