NVH Optimization on NEC Supercomputers Using MSC/NASTRAN

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ABSTRACT

NVH (Noise, Vibration and Harshness) Optimization has now gained popularity in driving the automotive and aerospace design process using frequency response analysis of detailed full vehicle structural-acoustic models. Usual design targets include minimization of structure weight, the adjustment of fundamental eigenmodes and the minimization of acoustic pressure at selected interior locations. Typical NVH Optimization analyses require considerable computational resources, both in terms of cputime as well as memory. The availability of state-of-the-art high performance hardware coupled with software advances and improved methodology has made it possible to solve complicated NVH dynamic response problems very efficiently.

With the introduction of Adjoint Sensitivity Method in V70, MSC/NASTRAN has been increasingly used to perform large NVH Optimization analyses that were unimaginable with the Direct Method. The Adjoint Method usually requires a fraction of the computer resources to produce sensitivity coefficients as compared with the Direct Method. However, for extremely large NVH Analyses, the sensitivity calculations are very demanding in terms of cputime, especially in the context of vector machines. The calculation of sensitivity coefficients is done inside the DSADJ module of MSC/NASTRAN. For V70.5 and V70.7, NEC initiated a project with MacNeal-Schwendler Corporation to address the performance bottleneck in the DSADJ module of MSC/NASTRAN. The performance enhancements to the DSADJ module are available exclusively on NEC SX-4 and SX-5 Series Supercomputers for a limited time period.

The DSADJ module was totally redesigned to improve vectorization and to exploit the vector architecture of NEC SX-4 and SX-5 Series Supercomputers. In this paper, aerospace as well as automotive customer datasets are presented to demonstrate the performance improvements of the DSADJ module. Dramatic improvements in the DSADJ module resulting in approximately 8-9 fold performance improvement as compared with V70 were observed for NVH Optimization. With the tremendous improvements in the performance of the DSADJ module, and the fact that the eigenvalue analysis involved in NVH Optimization is inherently highly vectorized, NEC Supercomputers are ideally suited for running large NVH Optimization Analyses using MSC/NASTRAN.

1. Introduction

NVH (Noise, Vibration and Harshness) Analysis/Optimization is a key technology for the transportation industry [4,8]. MSC/NASTRAN is now increasingly being used to perform NVH Analysis and Optimization for predicting the vehicle tactile and acoustic responses in relation to the established targets for design considerations. Very significant performance improvements have been in MSC/NASTRAN for NVH Optimization using NEC Series Supercomputers. In this paper, two examples – one, automotive and another, aerospace datasets are presented. Performance improvements of 80-90% have been observed in the DSADJ module resulting in a reduction of the overall user cputime by almost 50%. The performance of MSC/NASTRAN V70.7 on NEC SX-4 and SX-5 systems is quite possibly the 'best in class' for NVH Optimization.

2. The Adjoint Method

A brief theoretical description of the Adjoint method can be found in [2,3]. The Adjoint method requires the computation of adjoint vectors equal in number to the number of retained responses in the optimization task. The adjoint method requires fewer operations, as compared with the direct method, whenever

$$nresp < ndv \times nlc$$

where, *nresp* is the number of retained responses, *ndv* is the number of design variables and *nlc* is the number of load cases. In a frequency response analysis, the number of load cases is the number of frequencies times the number of subcases. In the context of NVH optimizations, usually, a handful of pressure responses are monitored to control the sound levels when subjected to excitations over a broad frequency range and the design task involves a large number of design variables. This makes the product, $ndv \times nlc$, much larger than *nresp* clearly favoring the adjoint method over the direct method.

There are some restrictions, though. The adjoint method is applicable in MSC/NASTRAN only in cases where the grid responses are involved. For element response, an exact expression for the term $\{\partial f / \partial u\}$ is not available for some elements and responses. Please refer to [2] for a complete description of the criteria that must be satisfied for the adjoint method to be selected.

The adjoint method is based on a gradient approach. The calculation of the sensitivity coefficients is, therefore, the most computationally intensive portion of the adjoint method and is performed inside the DSADJ module of MSC/NASTRAN.

3. NVH Analysis

Nowadays, NVH Analysis involves frequency response analysis of detailed full vehicle structural-acoustic models. The full vehicle assembly includes engine, fuselage, wings passenger cabin and the landing gear in aerospace applications, while in the case of automotive analyses it includes tires, suspension, powertrain, body and the acoustic cavity. For typical automotive NVH analyses, modes are computed for the entire vehicle structure (including chassis and powertrain) as well as for the acoustic cavity. Both, tactile and acoustic responses to excitation are computed at the areas of interest. Tactile responses include vibrations in the seat track, toe pan and steering column, while acoustic responses include sound levels at specific locations in the acoustic cavity [4,5].

Typical full vehicle NVH simulations involve forces that may be external or internal to the vehicle [6]. External forces include road induced shake/noise and aerodynamic forces due to contact with the surrounding air. Internal forces include powertrain combustion reaction forces, powertrain unbalance forces, tire/wheel unbalance forces, driveline unbalance forces (axle etc.) and brake induced forces. Brake noise and vibration analysis is one of the topics of discussion in an upcoming paper [7].

4. NVH Optimization

The need for high quality design, quicker time to market and lower production costs have resulted in a great demand for NVH Optimization in the transportation industry. NVH Optimization tightly couples the modal frequency response analysis with structural design optimization. The fundamental bending and torsional modes are generally a major concern because of resonance. For this reason, better bending and torsional rigidity values are desirable for NVH, ride and handling performance. However, the task of controlling the transmission/amplification of low frequency vibrations along the structure (and air cavity) path often conflicts with the desire to minimize vehicle weight (for better fuel efficiency and lower material cost reasons). NVH Optimization is very effective for meeting the design targets using global optimization of full vehicle analysis. It automatically arrives at an optimal design that satisfies the user specified constraints and minimizes the Objective function (vehicle weight, RMS response etc.). Since NVH Optimization involves a solution strategy as well as an optimization, it is instrumental in automating full vehicle simulation and driving the design process.

5. Computational Demands for NVH Optimization

NVH Optimization analyses involves an eigenvalue analysis for the frequency response calculations and a sensitivity coefficients calculation during optimization phase. Usually, multiple design cycles are involved, implying that the eigenvalue analysis and sensitivity calculations are repeated for each design cycle. In the context of MSC/NASTRAN, the eiegenvalue analysis is performed inside the READ module while the Adjoint sensitivity calculations are done inside the DSADJ module. Both these modules are extensively used in NVH Optimization analyses. The READ module is intensively used due to the large models and the large number of frequencies requested by the analysts/designers. The DSADJ module is computationally intensive because of the model size and the large number of design variables and excitation frequencies involved. NVH Optimization, therefore, has huge computational requirements in terms of cputime, I/O as well as memory requirements. Detailed full vehicle models involving 2,500,000 dynamic degrees of freedom are routinely being analyzed and eigenvalue analysis typically involves 8,000 modes. Frequency ranges up to 500Hz are now becoming quite common. This type of analyses requires extremely powerful computers – NEC SX-4 and SX-5 Series Supercomputers are capable of meeting these computational requirements.

6. READ Module Performance on NEC Supercomputers

The full vehicle NVH analysis jobs usually execute a wide frequeny range normal modes solution. This solution is incorporated into the READ (Real Eigenvalue Analysis DMAP) module of MSC/NASTRAN. The preferred eigenvalue analysis solution for NVH analyses is the Lanczos method. The block, shifted, inverted Lanczos method, pioneered in the structural analysis community by MSC during the late 1980’s, is the *de facto* industry standard.

The NEC specific improvements to the Lanczos method are confined to the area of specific vector kernel functions. The vector operations imbedded into the aforementioned matrix operations, most notably the kernels used in the orthogonalization step in the Lanczos process, have significant effect on the performance of the Lanczos method in the READ module. NEC has put significant effort into providing highly tuned vector kernels that take advantage of the architecture of NEC machines.

Another important aspect of the READ module performance is the appropriate setting of application parameters. MSC offers a set of parameters specific to the Lanczos method that can significantly improve performance. The optimal setting of parameters such as MAXSET (block size), FBSMEM (storage area reserved for the solution phase of Lanczos) and MASSBUFF (size of mass matrix buffer), is the result of careful and extensive performance tuning by NEC.

In conclusion, the READ module performance as a cornerstone of NVH analysis is very good on NEC Series Supercomputers.

7. DSADJ Module Performance on NEC Supercomputers

The DSADJ module computes the design sensitivity coefficients using the Adjoint method [2]. These computations involve a series of matrix-vector products, vector updates and coordinate transformations that are very computationally intensive for NVH optimization tasks. The performance of the DSADJ module is, therefore, crucial for NVH Optimizations where extremely large models are subjected to a wide range of excitation frequencies. The following sections discuss the performance enhancements to the DSADJ module and the motivation for undertaking this project.

7.1. Motivation for the DSADJ Enhancement Project

Prior to the release of MSC/NASTRAN V70 in spring 1998, MSC/NASTRAN was simply not able to handle extremely large NVH Optimization problems using the Direct method due to excessive disk requirements and cputime. But, with the introduction of the Adjoint method (DSADJ Module), MSC/NASTRAN V70 has been increasingly used to perform large NVH Optimization analyses that were unimaginable with the old Direct Method. However, the original implementation of the DSADJ module in MSC/NASTRAN V70 demonstrated poor performance, especially on vector machines, primarily due to poor vectorization. In fact, the DSADJ module accounted for more than 50% of the total User cputime (typically tens of thousand seconds) for typical NVH Optimization problems.

To address this performance issue, NEC initiated the DSADJ Performance Enhancement Project. The DSADJ module was redesigned to improve vectorization and to exploit the vector architecture of NEC SX-4 and SX-5 Series Supercomputers. Some of the NEC exclusive DSADJ enhancements are listed in Section 7.2. These efforts resulted in performance improvements ranging from 80-90% for the DSADJ module and the reduction of the overall User cputime by almost 50% (section 9). NEC's enhancements to the DSADJ module will be available exclusively on NEC SX-4 and SX-5 for a limited time period.

7.2. NEC Exclusive DSADJ Enhancements

The DSADJ module was totally reengineered to improve vectorization and to exploit the vector architecture of NEC SX-4 and SX-5 Series Supercomputers. This was a major undertaking effort on the part of NEC in collaboration with the MacNeal-Schwendler Corporation. This project involved a rigorous QA procedure and took almost 10 man-months before final integration into MSC/NASTRAN V70.7.

Modest DSADJ enhancements were first introduced in MSC/NASTRAN V70.5 on NEC SX-4. The DSADJ performance enhancement project was completed in V70.7 resulting in approximately ten-fold performance improvement in the DSADJ module as compared with V70. Some of the major enhancements in V70.7 are enumerated below:

- Perform element level operations on strings rather than on a term-by-term basis.
- Exploit the sparsity pattern of elemental matrices.
- Handle multiple solution vectors simultaneously.
- Use lumped mass formulation, if possible.
- Perform extremely efficient coordinate transformations that operate on an element level rather than on a node-by-node level. Process multiple solution vectors for coordinate transformations as well.
- Reduce the number of matrix-vector products by almost 50% for typical models.

The details of the above enhancements are proprietary in nature, and cannot be discussed here. The improvements in performance due to the above enhancements are demonstrated in section 9 for an Aerospace application as well as an Automotive NVH Optimization analysis.

8. NEC SX-4 and SX-5 Series Supercomputers

NEC has provided state-of-the-art supercomputing products since 1983. The SX-4 Series was first delivered in the 4th quarter 1995. The newest model range is the SX-5 Series. The SX-4 and SX-5 Series, which are parallel vector supercomputers, provide solutions for a broad range of application requirements involving intensive computation, very large main memory, very high performance main memory and very high input-output rates. Both, SX-4 and SX-5 are constructed using air-cooled CMOS VLSI technology. CMOS enables low costs for system acquisition, low operational power consumption, and high system reliability through stable chip technology. Each processor board contains a vector unit and a scalar unit.

The SX-4 Series include a wide range of models ranging from the Compact models to the Single-node (a maximum of 32 CPUs and 8 Gigabytes main memory) and Multi-node configurations (a maximum of 512 CPUs and 128 Gigabyte main memory). The System Peak performance of each processor is 2 GigaFLOPS, resulting in a System Peak performance of 64 GigaFLOPS for a Single-node model and 1 TeraFLOPS for a Multi-node system. A Single-node model is shown in Figure 1.

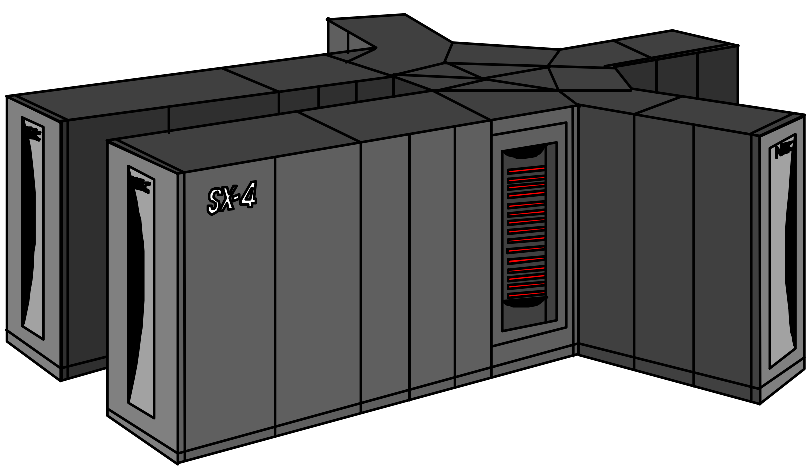


Figure 1: SX-4 Single-node Model

The SX-5 Series is the newest member of the family of parallel vector supercomputers from NEC and includes a wide range of models ranging from cabinet models to Single-node models (a maximum of 16 CPUs and 128 Gigabytes main memory) and Multi-node configurations (a maximum of 512 CPUs and 4 Terabytes main memory). The System Peak performance of each processor in SX-5 is 8GigaFLOPS, resulting in a System peak performance of 128 GigaFLOPS for a Single-node SX-5 and 4 TeraFLOPS for the top-of-the-line SX-5 Multi-node system. The SX-5 Single-node model is shown in Figure 2.

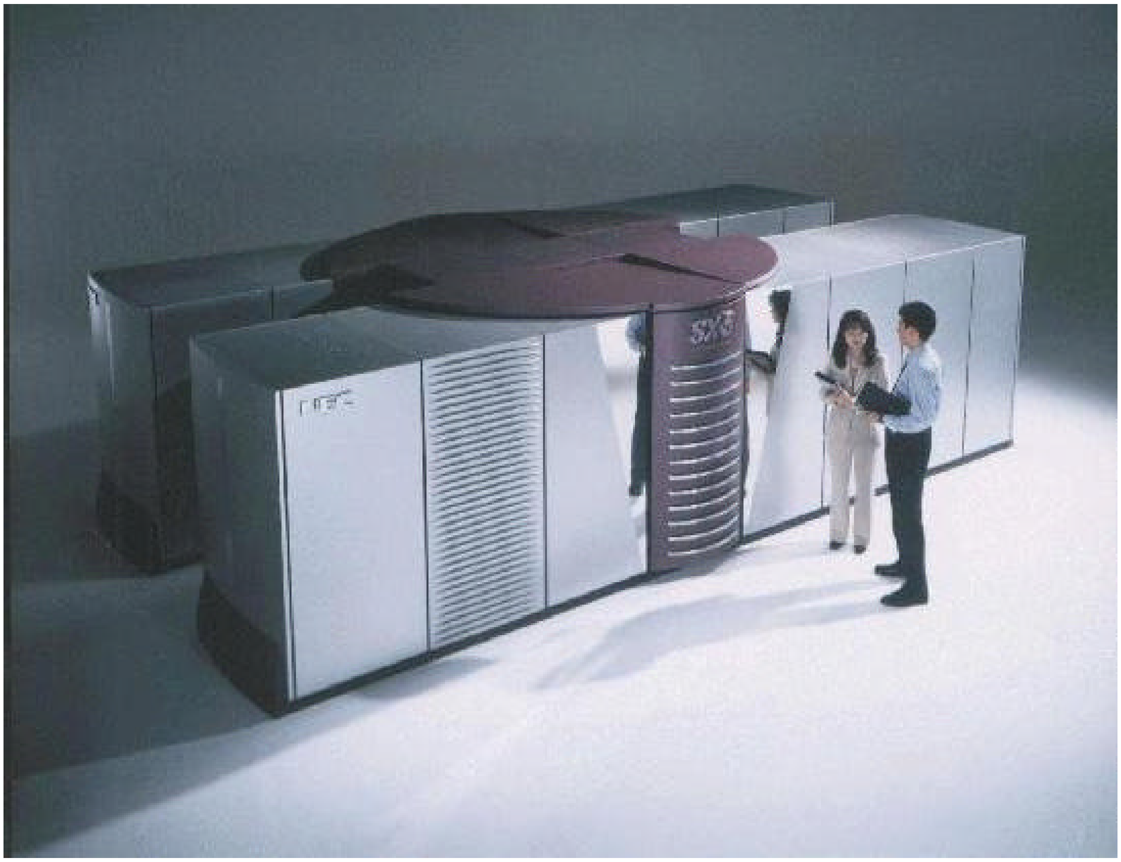


Figure 2: SX-5 Single-node Model

9. Performance Studies

Two customer datasets are presented to demonstrate the performance improvements in MSC/NASTRAN V70.7 due to NEC enhancements to the DSADJ module. The first example is from an aerospace user, while the second one is a typical NVH Optimization dataset from a major automotive user. Performance comparisons are made between MSC/NASTRAN V70, V70.5 and V70.7 (all using the Adjoint method) for NEC SX-4. In this paper, we have not attempted to compare the Adjoint method with the Direct method. This comparison was made in an earlier paper [2].

9.1 Visual Sensor

The critical performance criteria of a sensor is its ability to track targets while excited by external loads, usually random vibration loads. The critical parameter is sensor jitter, or the motion of energy as it is passes through the sensor's optical path. Rotation and translation of the components within the optical path, i.e., the telescope or prism, affect the energy focus when it arrives at the focal plane array. If the image on the focal plane array is fuzzy, the sensor jitter is high and hence tracking capabilities are impaired. The overall motion of the optical path was accounted for by writing a multi point constraint equation (MPC) that sums up the total motion of the optical path including optical power factors.

The finite element model shown in Figure 3 is a dual gimballed visual sensor. The sensor is gimballed about the pitch axis and the roll axis to provide for optimal tracking motion. The sensor consists of the following components: the base including gussets to increase stiffness and inner race of roll bearing; the roll housing including the outer race of roll bearing, end caps, and outer race of pitch bearing; and the pitch shaft including the inner race of pitch bearing, telescope and counterweights. In addition, a "mock" optical path of the sensor is modeled including the focusing optics, prism, and focal plane array. The optical components are assumed to be rigid.

MSC/NASTRAN Design Sensitivity and Optimization was used to minimize the transfer function between a 1 G sinusoidal acceleration applied at the base of the sensor and the over all sensor jitter. Because the response of a linear system to a gaussian white random vibration input is the magnitude of the transfer function squared multiplied by the input, this approach worked well to minimize the sensor jitter RMS response to a base input random vibration loading that is constant across the range of excitation frequencies. Constraints were also imposed that the weight could not exceed 8.5 units and that the first two eigenvalues must be greater than 400,000 $(rad/sec)^2$ (100.66 Hz.).

The model has the following statistics:

Table 1: Visual Sensor Statistics

Number of grids:	2335
Number of elements:	2129
Number of subcases:	1
Number of excitation frequencies:	101
Number of design variables:	13
Number of responses:	91

Table 2 compares the performance of MSC/NASTRAN V70.7 as compared with V70.5 and V70. The cputime spent in the DSADJ module has reduced by almost 90% in V70.7 as compared with V70 and the overall User cputime has reduced by more than 50%. This is a relatively small problem, but it gives an indication of the performance improvements that can be expected with MSC/NASTRAN V70.7 on NEC platforms.

Table 2: Performance Improvements for Visual Sensor

NASTRAN Version	NEC Platform	User Cputime	System Cputime	DSADJ Module Cputime	% Improv. in DSADJ
MSC/NASTRAN V70	SX-4	1,615	92	1,091	-
MSC/NASTRAN V70.5	SX-4	1,589	98	1,040	4.7 %
MSC/NASTRAN V70.7	SX-4	644	57	102	90.6 %

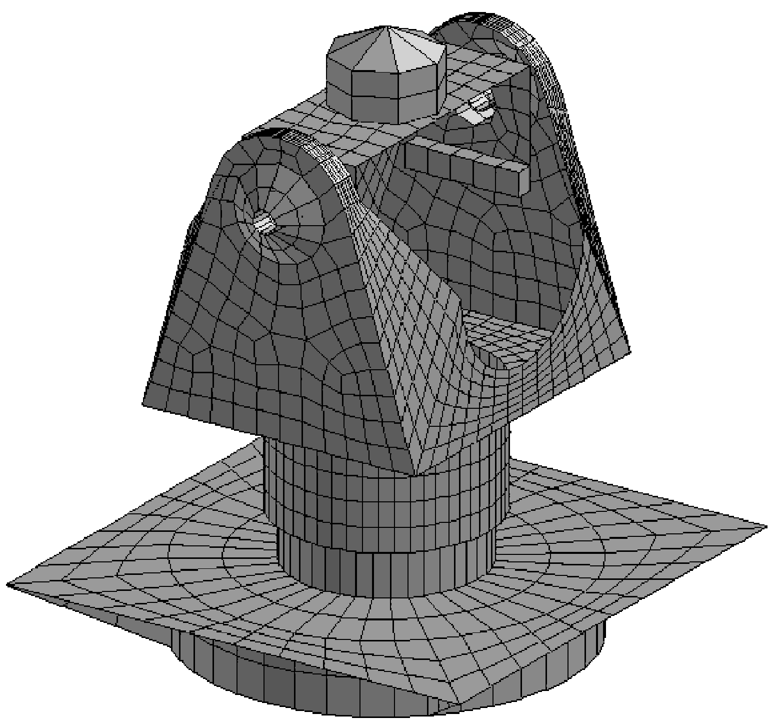
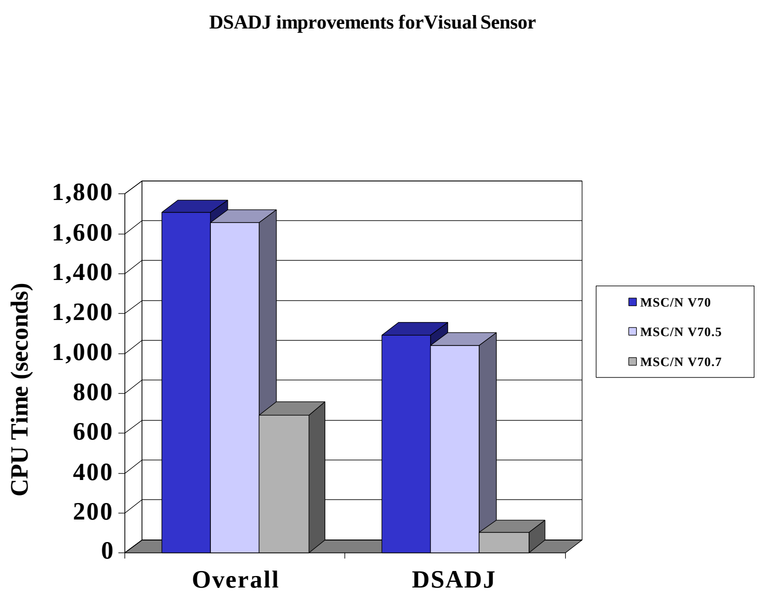


Figure 3. Visual Sensor Model.

The results tabulated in Table 2 are represented in the following barchart.



9.2 NVH Optimization of Van Body

This second example is a very large finite element model that is considered representative of a state of the art design task. The model shown in Figure 4 was provided by an automotive customer and its statistics are shown in Table 3.

This model is a B-I-W car body consisting of mostly 2-D shell elements. The analysis involves a typical NVH Optimization, wherein the Modal Frequency response is performed followed by a minimization of the RMS value of responses. The starting value of the Objective function was 9,000 units and the user requested that the analysis be performed for 1 design cycle only.

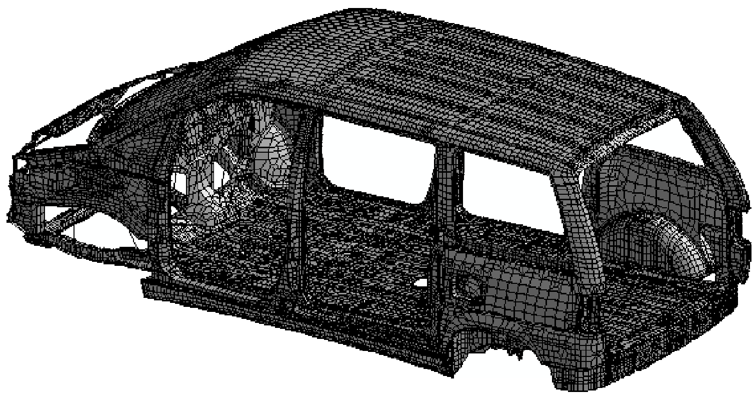


Figure 4. Van Body Model (courtesy of PSA Peugot).

Table 3: Statistics for Van Body Model

Number of grids:	102,891
Number of elements:	91,378
Number of degrees of freedom:	569,839
Number of subcases:	1
Number of frequencies:	705
Number of modes:	269
Number of design variables:	111
Number of responses:	618

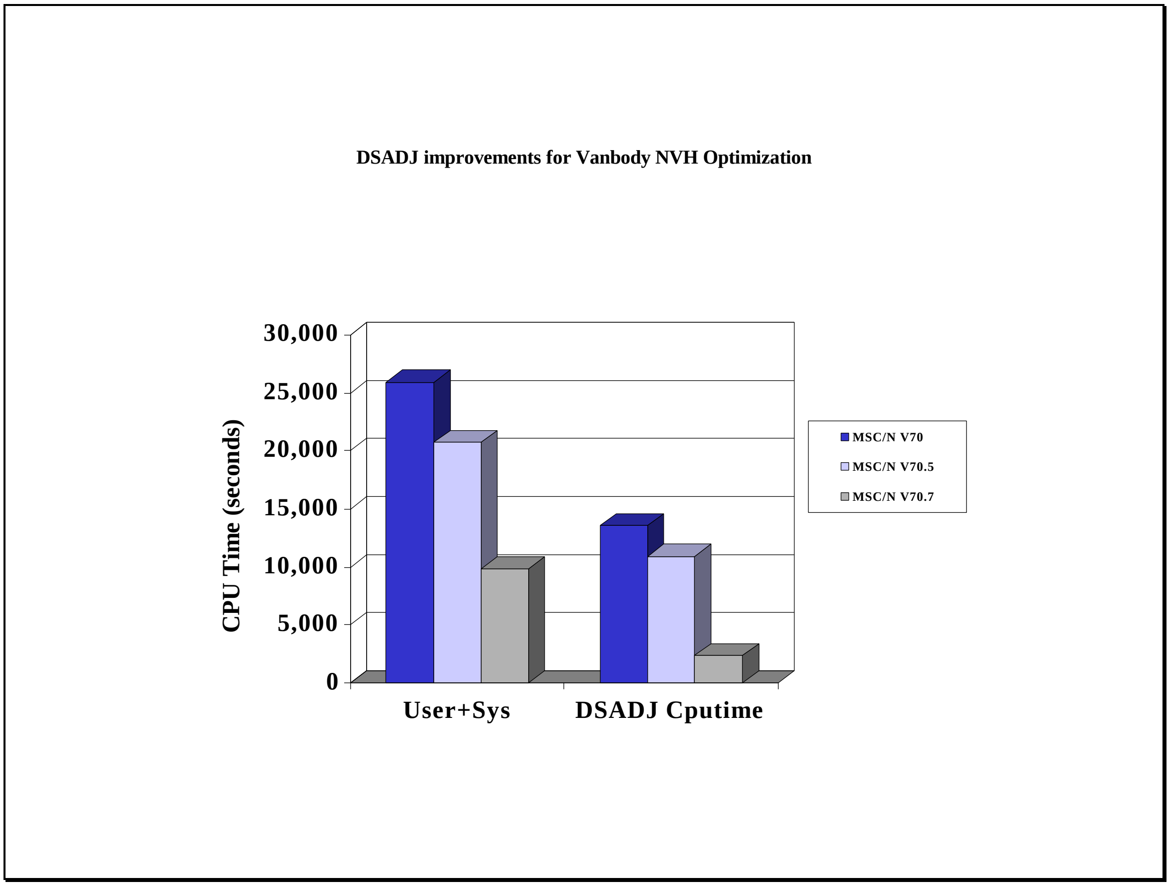
From Table 4, it is evident that the performance of MSC/NASTRAN V70.7 on SX-4 is twice as fast as MSC/NASTRAN V70.5. The cputime spent in the DSADJ module has reduced by almost 85% in MSC/NASTRAN V70.7 as compared with MSC/NASTRAN V70. This is primarily because of better vectorization and longer vector lengths for operations performed inside the DSADJ module. The net effect is that the overall User cputime has reduced from 6.7 hours using MSC/NASTRAN V70 to 5.2 hrs with MSC/NASTRAN V70.5 and only 2.6 hrs using MSC/NASTRAN V70.7. The turnaround time (elapsed or real) time has also been reduced by more than a factor of two.

Table 4: Performance Improvements for Van Body

NASTRAN Version	**NEC Platform**	**Real Cputime**	**User Cputime**	**System Cputime**	**DSADJ Module Cputime**	**% Improv. in DSADJ**
MSC/N V70	SX-4 (non-dedicated)	45,798	24,038	1,857	13,562	-
MSC/N V70.5	SX-4 (non-dedicated)	46,377	18,922	1,806	10,910	19.6%
MSC/N V70.7	SX-4 (dedicated)	13,810	9,390	473	2,378	82.5%

This analysis required 18 Gbytes of Hiwater Disk, 433 Gbytes of I/O, 13.8 Gbyte of SCRATCH Dbset and 5 Gbyte of SCR300. Clearly, this problem is intractable without the availability of the adjoint method and is still only accessible to powerful computers with extensive available disk space and fast I/O and an efficient implementation of MSC/NASTRAN. The availability of High Performance Input Output (HPIO) library on NEC SX-4 was instrumental in achieving extremely fast I/O and in reducing the elapsed cputime.

The results tabulated in Table 4, are represented in the following barchart.



10. Concluding Remarks

The enhancements to the DSADJ module have resulted in a dramatic improvement in performance of MSC/NASTRAN V70.7 on NEC SX Series Supercomputers for design sensitivity and optimization. Performance improvements ranging from 80-90% were observed in the DSADJ module for real-life Aerospace and Automotive examples. The overall cputime for the complete solution has been reduced by approximately 50%. Aerospace applications involving grid responses are ideal candidates for improved performance. As far as Automotive applications are concerned, the performance of MSC/NASTRAN V70.7 on NEC Series Supercomputers is quite possibly the 'best in class' for NVH Optimization.

11. Acknowledgments

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12. Disclaimer

MSC supported NEC in the theoretical aspects and integration of DSADJ enhancements in MSC/NASTRAN. However, nothing in this paper should be interpreted as an endorsement by the second author or MSC of NEC systems relative to other computer vendors that MSC supports.

13. References

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