

# Enhancing Computational Efficiency in Modal Transient Analysis through Nastran Restart Method

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**Abstract-** Vehicle operation occurs in a highly dynamic environment, necessitating the use of dynamic simulation methods for accurate durability analysis. In the automotive sector, predicting structural life and damage during the design phase is essential to meet warranty requirements and ensure long-term reliability. To replicate real-world loading conditions, the industry employs torture track recipes—specialized test tracks designed to simulate extreme road conditions. Data collected from these tests, in the form of time-domain road excitations, is used for digital validation of vehicle structures. Given the limitations of current computational resources, simulating vehicle durability tests and performing structural fatigue life assessments require efficient methodologies and advanced CAE tools. Modal transient analysis in MSC Nastran offers a practical solution for evaluating time-dependent dynamic responses of vehicle structures, particularly the Body-in-White (BIW). This paper presents an effective and resource-conscious approach to vehicle dynamic durability analysis using the restart method in modal transient analysis. Although this technique has been validated across multiple programs, this paper presents two case studies to demonstrate its feasibility and accuracy in stress analysis and fatigue damage prediction. Also the automation script is designed to initiate the cold start run, followed by the automatic execution of multiple restart runs. The results confirm that the restart method significantly reduces runtime while maintaining analytical fidelity, making it a viable option for modern automotive durability simulations.

**Keywords:** Vehicle durability analysis, Dynamic simulation, Modal transient analysis, MSC Nastran, Restart method, Body-in-White (BIW).

## I. INTRODUCTION

The monocoque body is widely used in modern car design, which endures complex loads during driving. It has to bear not only inertial loads such as drive and brake, but also complex load of powertrain vibration and road excitation. How to consider practical situation in the new car design stage becomes a critical part[1].

Modal transient analysis is a dynamic simulation technique used to evaluate the time-dependent response of structures subjected to transient loading conditions. Unlike direct transient analysis, which solves the full system equations at every time step, modal transient analysis leverages the structure's natural modes of vibration—obtained through a prior modal (eigenvalue) analysis—to reduce computational effort and improve efficiency. This method is particularly effective for systems where the response is dominated by a limited number of modes, such as in aerospace, automotive,

and civil engineering applications. By expressing the system's response as a combination of these modes, engineers can capture essential dynamic behaviour with significantly reduced computational cost.

Modal transient analysis is commonly used to simulate events such as shock loads, impact, or time-varying forces like those from road or track inputs. It is especially valuable when multiple load cases or long-duration simulations are required, making it a practical choice for both design validation and optimization.

However, when dealing with large models and repeated analyses, computational efficiency becomes critical. MSC Nastran's restart capability allows users to reuse modal analysis results in subsequent transient or frequency response analyses, significantly reducing computation time. This paper outlines the methodology, implementation, and best practices for using the restart method effectively.

## II. METHODOLOGY

The four basic components of a dynamic system are mass, energy dissipation (damper), resistance (spring), and applied load. As the structure moves in response to an applied load, forces are induced that are a function of both the applied load and the motion in the individual components. The equilibrium equation representing the dynamic motion of the system is known as the equation of motion.

This equation, which defines the equilibrium condition of the system at each point in time, is represented as

$$m\ddot{u}(t) + b\dot{u}(t) + ku(t) = p(t) \dots \dots \dots (1)$$

The left hand side of the equation shows internal forces acting on the structure and right hand side shows external excitation load. The resulting equation is a second-order linear differential equation representing the motion of the system as a function of displacement and higher-order derivatives of the displacement.

An accelerated mass induces a force that is proportional to the mass and the acceleration. This force is called the inertia force,  $m\ddot{u}(t)$ . Viscous Damping The energy dissipation mechanism induces a force that is a function of a dissipation constant and the velocity. This force is known as the viscous damping force,  $b\dot{u}(t)$ . The damping force transforms the kinetic energy into another form of energy, typically heat, which tends to reduce the vibration. Elastic Force The final induced force in the dynamic system is due to the elastic resistance in the system and is a function of the displacement and stiffness of the system. This force is called the elastic force or occasionally the spring force,  $ku(t)$ . The applied load on the right-hand side of Eq. 1 is defined as a function of time. This load is independent of the structure to which it is applied.

Modal transient response (SOL 112) is an alternate approach to computing the transient response of a structure. This method uses the mode shapes of the structure to reduce the size, uncouple the equations of motion (when modal or no damping is used), and

make the numerical integration more efficient. Since the mode shapes are typically computed as part of the characterization of the structure, modal transient response is a natural extension of a normal modes analysis.

As a first step in the formulation, transform the variables from physical coordinates  $\{u\}$  to modal coordinates  $\{\xi\}$  by

$$\{u(t)\} = [\Phi] \{\xi(t)\} \dots \dots \dots (2)$$

The mode shapes  $[\Phi]$  are used to transform the problem in terms of the behavior of the modes as opposed to the behavior of the grid points. Equation represents an equality if all modes are used; however, because all modes are rarely used, the equation usually represents an approximation. To proceed, temporarily ignore the damping, resulting in the equation of motion

$$[M]\{\ddot{u}(t)\} + [K]\{u(t)\} = \{P(t)\} \dots \dots \dots (3)$$

If the physical coordinates in terms of the modal coordinates (Eq. (2) is substituted into Eq. (3)), the following equation is obtained:

$$[M][\Phi]\{\ddot{\xi}(t)\} + [K][\Phi]\{\xi(t)\} = \{P(t)\} \dots \dots \dots (4)$$

This is now the equation of motion in terms of the modal coordinates. At this point, however, the equations remain coupled. To uncouple the equations, premultiply by  $[\Phi]^T$  to obtain

$$[\Phi]^T [M] [\Phi] \{\ddot{\xi}\} + [\Phi]^T [K] [\Phi] \{\xi\} = [\Phi]^T \{P\} \dots \dots \dots (5)$$

Where:  
 $[\Phi]^T [M] [\Phi]$  = modal (generalized) mass matrix  
 $[\Phi]^T [K] [\Phi]$  = modal (generalized) stiffness matrix  
 $[\Phi]^T \{P\}$  = modal force vector

The final step uses the orthogonality property of the mode shapes to formulate the equation of motion in terms of the generalized mass and stiffness matrices that are diagonal matrices. These matrices do not have off-diagonal terms that couple the equations of motion. Therefore, in this form, the modal equations of motion are uncoupled. In this uncoupled form, the equations of motion are written as a set on uncoupled SDOF systems as

$$m_i \ddot{\xi}_i(t) + k_i \xi_i(t) = p_i(t) \dots \dots \dots (6)$$

Where:

- $m_i$  = i-th modal mass
- $k_i$  = i-th modal stiffness
- $p_i$  = i-th modal force

Note that there is no damping in the resulting equation. If the damping matrix exists, the orthogonality property of the modes does not, in general, diagonalize the generalized damping matrix [B]. In the presence of a matrix, the modal transient approach solves the coupled problem in terms of modal coordinates using the direct transient numerical integration approach[2].

Thus equation is similar to the direct transient method except that they are in terms of modal coordinates. Since the number of modes used in a solution is typically much less than the number of physical variables, the direct integration of the modal equations is not as costly as with physical variables. During the truncation of modes, higher frequency modes will be lost and thus it affects the dynamic solution directly. In order to retain the impact of lost modes, the residual modes are computed which enhances the solution. As a step of enhancing the accuracy of dynamic solution, modal augmentation methods are preferred in which residual modes are adapted in this case. The residual vectors play an important role in improving the data lost during the structural modes consideration[3].

The best approach is to always include enough normal modes to capture the dynamics of the problem, and rely on the residual vectors to help account for the influence of the truncated modes on the quasistatic portion of the response. Residual

vector card (RESVEC = YES) is inserted in case control section to compute the residual modes in f06 file (Output file of MSC Nastran).

Restarts in Linear Transient may be used to continue modes calculations from a previous run without repeating the earlier computations. This is accomplished by extending the usage of the restart parameter to SOLs 109 and 112. In order to use this feature in SOLs 109 and 112, ensure that the model and the constraints, as well as the subcase setup in the restart run, are the same as those in the previous run. The user may, however, specify different TSTEP and DLOAD requests in the Case Control and also different TSTEP and dynamic loading entries in the Bulk Data compared to the previous run[2]. In this way we can save repeated modes calculation time for different track excitation loading. Even though we used the dynamic condensation technique to reduce the runtime of the full vehicle model, the mode calculation for the entire BIW structure still takes approximately 10 to 15 hours of run time for each track loading, depending on the number of nodes and elements. In such cases restart method is very useful for effective run time of analysis.

### III. WORKFLOW OVERVIEW

In a modal transient analysis (SOL 112), the sequence begins with the calculation of the structure's normal modes by invoking the normal modes analysis (SOL 103). Therefore, for each track excitation load case, the analysis starts by computing the normal modes of the structure. To avoid recalculating the modes repeatedly, the restart option in MSC Nastran can be utilized. The key benefit of restart is to saving analysis time along with file handling required during analysis.

So normal modes analysis of the BIW structure can be solved separately as cold start run. And same analysis can be used as restart for transient response analysis.

#### Cold Start Run - Modal Analysis (SOL 103)

A normal modes analysis deck setup is required for a cold start run. Since this cold run will be used to calculate the transient response of the structure,

certain precautions must be taken. To improve the accuracy of the transient response, residual vector calculations should be included in the normal modes analysis itself. These residual modes are determined based on the excitation load points and their directions. However, normal modes analysis does not require excitation loads. To address this limitation, MSC Nastran provides the RVDOF card, which can be defined in the normal modes analysis deck to incorporate residual vectors.

This approach enables us to match the number of normal and residual modes, along with their corresponding frequency values, to those obtained from a standard transient analysis. However, when calculating fatigue damage using the restart option, discrepancies may occasionally arise compared to regular runs. One observed issue is the sign reversal of modal displacement vectors for certain modes, which can lead to variations in the modal stress history channels and, consequently, in the fatigue damage results.

This sign flipping occurs because eigenvectors can mathematically have either sign without affecting the validity of the solution. Since this change is mathematically acceptable, it is not flagged during the solution process. To address this issue effectively, a reliable alternative is to define dummy dynamic loads directly in the cold start run, rather than relying on the RVDOF1 command. These dummy loads later can be replaced with the actual track excitation loads during the transient response analysis.

Further to submit restart runs, it is essential to save the .DBALL, .IFPDAT, and .MASTER files from cold start run. These files can be preserved by enabling the SCR=YES option when initiating the run.

#### **Restart Run – Transient Response Analysis (SOL 112)**

Once the cold start run is prepared with the required files, a transient analysis restart run can be initiated. In modal transient analysis, approximately 90% of the total runtime is consumed by mode calculations. By using the restart approach, this time can be saved for subsequent transient track load cases. To initiate a restart run in MSC Nastran, the following command

should be included before the Executive and Case Control sections:

```
$  
ASSIGN MASTER= 'Cold_Start_File_Name.MASTER'  
RESTART VERSION=1, KEEP
```

```
$  
Before putting restart run make sure that consistency in model geometry and boundary conditions remains the same, as well as the subcase setup in the restart run be the same as those in the cold start run. In this restart run we can define different dynamic load, modal damping and time increment steps as required. In this way we can solve multiple track load transient response analysis more effectively. Once the restart run is completed, modal stress output from cold start run and modal displacement vector from transient restart run can be feed to fatigue solver for damage calculations
```

## **IV. PRACTICAL CONSIDERATIONS**

Implementing the restart method in modal transient analysis offers significant computational efficiency, but it requires careful planning and setup to ensure accurate and reliable results. The following practical considerations are taken into account while doing the analysis:

- **Cold Start Run Preparation** - Ensure that the cold start run includes all necessary output files like .DBALL, .IFPDAT, and .MASTER.
- **Residual Vector Handling** - Residual modes are sensitive to excitation load points and directions so dummy loads were defined in cold start run mimicking the transient load definition.
- **Restart Run Configuration** - Used the RESTART command before the Executive and Case Control sections and ensured that the version ID used in the restart run matches the one in the F04 file from the cold start run.
- **Verification and Validation** - Performed comparative studies using multiple program files to ensure that fatigue damage results are consistent across different configurations with respect to regular approach method.

### **Case Study**

We applied the restart method in modal transient analysis of the BIW (Body-in-White) structure to

assess fatigue damage. To verify and validate the results of the restart approach, this study was extended across multiple programs. The results of this analysis are presented in the figure below.

This approach shows a high degree of similarity in the modal displacement vector and fatigue damage when compared to a regular transient analysis. A comparison of the results is shown in the figure below.

The restart method in Modal Transient Analysis for program-A

[SOL 112 Regular Approach Without Restart]							[Cold Start SOL 103 + Restart SOL 112]						
TIME	TYPE	T1	T2	T3	R1	R2	TIME	TYPE	T1	T2	T3	R1	R2
0.0	M	0.0					0.0	M	0.0				
2.00000E+02	M	-2.874839E-02					2.00000E+02	M	-2.874839E-02				
4.00000E+02	M	-1.345138E-02					4.00000E+02	M	-1.345138E-02				
6.00000E+02	M	-2.772037E-02					6.00000E+02	M	-2.772037E-02				
8.00000E+02	M	-6.520003E-02					8.00000E+02	M	-6.520003E-02				
1.00000E+03	M	-6.320003E-02					1.00000E+03	M	-6.320003E-02				

Fig 1: modal displacement vector of regular approach (LH) and restart approach (RH) for Program-A

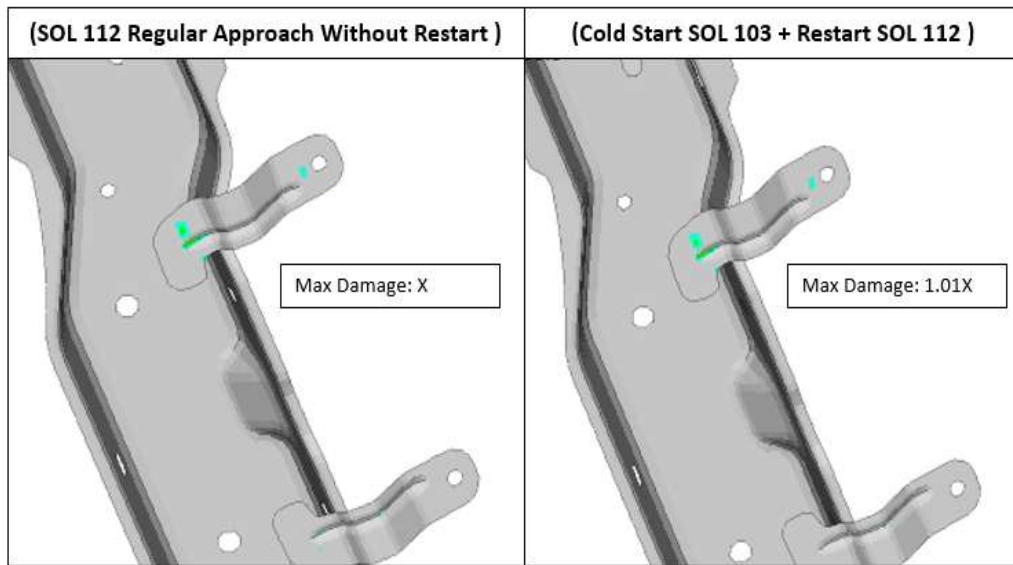


Fig 2: Fatigue damage plot of regular approach (LH) and restart approach (RH) for Program-A

The restart method in Modal Transient Analysis for program-B

[SOL 112 Regular Approach Without Restart]							[Cold Start SOL 103 + Restart SOL 112]						
TIME	TYPE	T1	T2	T3	R1	R2	TIME	TYPE	T1	T2	T3	R1	R2
0.0	M	0.0					0.0	M	0.0				
2.00000E+02	M	-2.908988E-02					2.00000E+02	M	-2.908988E-02				
4.00000E+02	M	-1.160571E-02					4.00000E+02	M	-1.160571E-02				
6.00000E+02	M	-2.805100E-02					6.00000E+02	M	-2.805100E-02				
8.00000E+02	M	-4.200407E-02					8.00000E+02	M	-4.200407E-02				
1.00000E+03	M	-7.010422E-02					1.00000E+03	M	-7.010422E-02				

Fig 3: modal displacement vector of regular approach (LH) and restart approach (RH) for Program-B

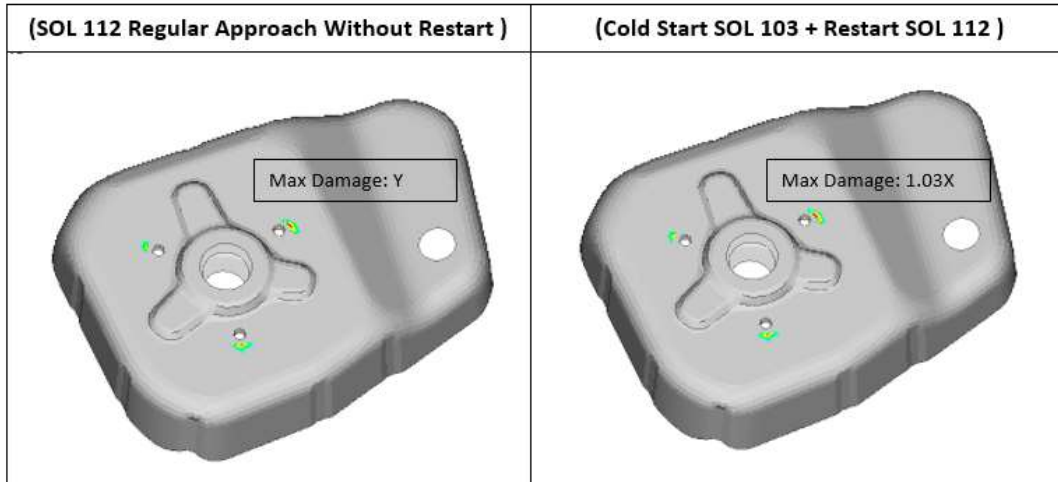


Fig 4: Fatigue damage plot of regular approach (LH) and restart approach (RH) for Program-B

### Future Scope

This study can be extended to include modal frequency response analysis of the structure, enabling more effective utilization of the capabilities offered by MSC Nastran. Furthermore, the entire process can be automated through scripting, minimizing manual intervention and simplifying file handling for end users.

2. MD/MSC Nastran 2010, "Dynamic Analysis User's Guide"
3. Sandeep P R, Dr. H G Hanumantharaju, Muralidhar K V, "Effect of residual modes on dynamically condensed spacecraft structure", e-ISSN: 2395-0056

## V. CONCLUSION

The restart method in Nastran is a valuable tool for engineers conducting modal transient analyses. When implemented correctly, it can lead to significant time savings and improved workflow efficiency. By using restart approach in modal transient analysis of BIW structure under different track loading can save simulation time up to 70%. Awareness of version-specific behavior and careful setup are essential for successful application.

## REFERENCES

1. Zhang, Z., Wu, C., Wu, Z., Lei, Y. (2021). Car Body Durability Analysis Based on Modal Superposition Method. In: Proceedings of China SAE Congress 2019: Selected Papers. Lecture Notes in Electrical Engineering, vol 646. Springer, Singapore.