AN ALTERNATE METHOD FOR MODE ACCELERATION DATA RECOVERY IN MSC/NASTRAN

ABSTRACT

An alternate method for mode acceleration data recovery has been developed for MSC/NASTRAN. Physical responses are recovered as a summation of their transient and steady-state contributions. The steady-state portion is calculated using static deflection analyses of the entire finite element model with inertial relief effects automatically included as required. The transient portion of the response is recovered from the modal responses of the truncated dynamic model.

The alternate method for mode accleration data recovery is substantially more efficient than MSC/NASTRAN's standard mode acceleration method for certain types of problems. In addition, data recovery is selective by employing the matrix method recovery module. Accuracy and efficiency comparisons are included. The alternate method has been implemented in MSC/NASTRAN using standard DMAP statements. Example problems are provided.

INTRODUCTION

Dynamic analysis using the modal superposition method is typically performed in three steps. First, a selected set of natural modes of the system are calculated and used to define the dynamic model in generalized modal coordinates. Next, the dynamic response caused by input disturbances is determined for each mode. Finally, physical responses are recovered from the modal responses and other information.

If all the modes of the system are not calculated, some information is truncated in the transformation from physical to modal coordinates. Typically, the truncated information represents the high frequency modes of the structure which will have only small dynamic excitation. In some cases, these high frequency modes can be ignored with little accuracy loss in the physical response calculation. Data recovery using only the kept normal modes is called the Mode Displacement method.

In many other cases, however, the high frequency modes are essential in accurately defining the steady-state portion of the transient response. This is especially true when accurate element loads, stresses, and displacements are required. In such cases, the mode displacement method produces inaccurate physical displacements and element loads.

A technique exists to improve the accuracy of physical response recovery in modal dynamic analyses. This technique, called the Mode Acceleration method, accounts for both the dynamic effects of the kept normal modes plus the static response of the high frequency modes. Physical responses are recovered as a combination of the transient and steady-state response. The transient response is determined from the normal mode set, and the steady-state response is calculated using the full finite element model. Thus, there is no information truncation in the steady-state calculations, and the transient response is based on the important low frequency modes.

There are several ways to implement the mode acceleration method of data recovery. MSC/NASTRAN has a general purpose mode acceleration method currently available, but the method can often be prohibitively expensive to use. The purpose of this paper is to present an alternate method for mode acceleration data recovery which is substantially more efficient than the standard method for certain types of problems.

In this paper, the discussion of modal dynamic analysis will be limited to transient analysis as presented in Figure 1. However, the alternate method of mode acceleration data recovery can be extended to other dynamic analyses (frequency response, random excitation, etc.)

CURRENT MODE ACCELERATION CAPABILITIES IN MSC/NASTRAN

MSC/NASTRAN currently supports both the mode displacement and the mode acceleration method. The mode displacement method can be used in either the standard (default) approach or the Matrix Method of Dynamic Data Recovery (DDRMM). In the standard method, physical displacements, velocities, and accelerations are recovered for every degree-of-freedom (DOF) in the finite element model. This can be very expensive, especially when only a fraction of the model requires data recovery. For such cases, the Matrix Method is substantially more efficient as it recovers only the requested responses. However, the Matrix Method is not available if mode acceleration data recovery is requested.

The mode acceleration method as implemented in MSC/NASTRAN recovers physical responses by forming new load vectors and improved displacement vectors. The new load vectors consist of the input disturbances plus the "inertia" and damping loads obtained from the modal responses.

$$p^1 = p - M\ddot{x} - B\dot{x}$$

Using the new load vectors, the improved displacement vectors are calculated by a static solution using the full finite element model.

$$[k]\{x^1\} = \{p^1\}$$

Physical velocities and accelerations are recovered via the mode displacement method.

The standard mode acceleration method in MSC/NASTRAN is very general purpose and does yield more accurate displacements and element responses than the mode displacement method. However, it can be extremely expensive. All responses of the structure are recovered. In addition, a static solution (forward-backward substitution) occurs for each output time. The only way to decrease costs is to perform data recovery only at selected output times. However, this is often inconvenient and potentially misleading, as the times of maxima are usually not known until after data recovery has been performed. In addition, the costs of restarting a large transient analysis can be considerable.

ALTERNATE METHOD FOR MODE ACCELERATION DATA RECOVERY

The alternate mode acceleration method is based upon recovering the physical responses as a combination of the transient and steady-state contributions. The dynamic portion of the response is calculated from the elastic modes retained in the analysis. The steady-state portion of the response is determined from unit load static solutions and the externally applied loads. The mathematical derivation of the alternate mode acceleration method is presented in Figure 2.

The alternate method offers many advantages over the MSC/NASTRAN standard method. First, the static solutions are performed only once using a unit load applied to each loaded degree-of-freedom. The steady-state response at each output time is then just the unit load deflections times the applied loads. This multiplication is much faster than performing a forward-backward substitution at each output time. Secondly, the alternate method can be implemented with the Matrix Method module (DDRMM). This allows selective recovery of responses instead of having to recover the entire model. Finally, data recovery can be limited to selected output times as in the standard method.

The major disadvantage of the alternate method is that it requires a unit load static solution for each degree-of-freedom to which a load is applied during the transient analysis. For cases where only a few loads are applied, this represents no problem. However, the alternate method is impractical for gravity loads, pressure loads, or other cases where a large portion of the structure is externally loaded. MSC/NASTRAN's standard mode acceleration method should be used for such analyses.

The other restrictions at the present time are to exclude non-linear forces and to assume that damping loads are negligible. However, these restrictions could be removed by additional development of the alternate method presented in this paper.

IMPLEMENTATION OF THE ALTERNATE METHOD

The alternate method of mode acceleration data recovery has been implemented for modal transient analysis (SOL 31) using the matrix method module (DDRMM). Physical response recovery occurs in the following order:

- * Scan the load vector (PP) to determine which degrees-of-freedom were loaded;
- * Build a unit load matrix with one column for each loaded DOF;
- * Reduce the unit loads to the independent (L-set) DOF and solve the unit load static deflections;
- * Merge the mode shapes and unit load static deflections into an expanded data recovery matrix (PHIAHS);
- * Modify the modal response matrix (UHV) to include the modified elastic mode multipliers (QSTAR) and the non-zero applied loads (PPGNZ);
- * Perform mode acceleration data recovery of selected responses using the Matrix Method module (DDRMM)

This procedure has been implemented as a rigid format alter for modal transient analysis (SOL 31) using standard DMAP modules.

EXAMPLE PROBLEMS

Two example problems are presented to demonstrate the effectiveness of the alternate method for mode acceleration data recovery. The first problem is a large space truss beam with a rocket motor. Dynamic excitation is provided by the ignition of the rocket motor. A typical drawing of the system is shown in Figure 3.

For the modal transient analysis, the first five planar modes (including one rigid body mode) were calculated. 1200 integration steps were performed with data recovery occurring every two steps (600 output times). Data recovery was performed by three methods: 1) mode displacement method using DDRMM; 2) standard mode acceleration method; and 3) alternate mode acceleration method using DDRMM. The time to perform the data recovery varied considerably. The alternate mode acceleration method was more than three times faster than the standard mode acceleration method, while the mode displacement method was the fastest of the three methods. All three methods provided essentially the same answers, with less than .5% difference in the maximum bending moment in the truss. These results are summarized in Figures 4 and 5.

A second test problem consists of an Atlas launch vehicle (shown in Figure 6) at booster engine cutoff. This transient event starts at a steady-state deformed condition caused by the booster and sustainer engine thrust. As the booster engine thrust cuts off, the vehicle is excited both longitudinally and laterally. Since the vehicle starts at a steady-state static deformation, it is especially important to use the modal acceleration method to accurately recover the physical responses of the missile and spacecraft.

The dynamic model consisted of the first 45 modes ranging in frequency from 0 to 75 HZ. The non-zero modal initial conditions were calculated and incorporated using techniques described in Reference 3. 2000 integration steps were performed with output every other step.

Physical responses were recovered for selected accelerations and element loads using the three methods employed for the first test problem. The alternate method was nearly eight times faster than the standard method for mode acceleration data recovery. In addition, the mode acceleration method provided more accurate element loads than did the mode displacement method. These results are summarized in Figures 7 and 8.

CONCLUSIONS

An alternate method for mode acceleration data recovery has been developed for MSC/NASTRAN. The alternate method is substantially more efficient than the current mode acceleration method for certain types of problems. The alternate method as implemented is as accurate as the standard method for cases where damping is negligible.

BIBLIOGRAPHY

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2) MacNeal, Dr. R. H., et.al., "The NASTRAN Theoretical Manual", NASA publication SP-221(03), March 1976

3) Flanigan, C. C., "Methods for Calculating and Using Modal Initial Conditions in MSC/NASTRAN", 1980 MSC/NASTRAN Conference on Finite Element Methods and Technology, MacNeal-Schwendler Corporation, March 1980

NOMENCLATURE

m = Physical Mass
k = Physical Stiffness
b = Physical Damping
p = Applied Load
x = Physical Displacement
M = Generalized Mass
K = Generalized Stiffness
q = Generalized Displacement
ζ = Critical Damping Ratio
ϕ = Modal Eigenvector
ω^2 = Modal Eigenvalues
ψ = Unit Load Static Deflections
p_i = Unit Applied Loads

EQUATIONS OF MOTION

Equations of motion in physical coordinates

$$[m]\{\ddot{x}\} + [b]\{\dot{x}\} + [k]\{x\} = \{p\}$$

Using the modal transformation:

$$\{x\} = [\phi]^T\{q\}$$

the equations of motion in modal coordinates are:

$$[\phi]^T[m][\phi]\{\ddot{q}\} + [\phi]^T[b][\phi]\{\dot{q}\} +$$

$$[\phi]^T[k][\phi]\{q\} = [\phi]^T\{p\}$$

or

$$[M]\{\ddot{q}\} + [B]\{\dot{q}\} + [K]\{q\} = [P]$$

Solve for $\ddot{q}$, $\dot{q}$, and q by numerical integration.

Figure 1. Equations of motion for a modal transient analysis

DERIVATION OF ALTERNATE METHOD

Rewriting equations of motion:

$$M\ddot{q} + 2M\zeta\omega\dot{q} + M\omega^2 q = \phi^T p$$

Separate into rigid body (r) and elastic (n) partitions:

$$\begin{bmatrix} M_{rr} & 0 \\ 0 & M_{nn} \end{bmatrix}\begin{Bmatrix} \ddot{q}_r \\ \ddot{q}_n \end{Bmatrix} + 2\begin{bmatrix} 0 & 0 \\ 0 & M_{nn}\zeta\omega_{nn} \end{bmatrix}\begin{Bmatrix} \dot{q}_r \\ \dot{q}_n \end{Bmatrix} + \begin{bmatrix} 0 & 0 \\ 0 & M_{nn}\omega_{nn}^2 \end{bmatrix}\begin{Bmatrix} q_r \\ q_n \end{Bmatrix} = \begin{Bmatrix} \phi_r^T \\ \phi_n^T \end{Bmatrix} p$$

Back transforming to physical coordinates:

$$x = \phi q = \phi_r q_r + \phi_n q_n$$

$$= \phi_n\left(M_{nn}\omega_{nn}^2\right)^{-1}\left[\phi^T p - M_{nn}\ddot{q}_n - 2M_{nn}\zeta\omega_{nn}\dot{q}_n\right] + \phi_r q_r$$

Neglecting damping and rearranging:

$$x = \phi_n\left(M_{nn}\omega_{nn}^2\right)^{-1}\phi_n^T p - \phi_n\left(\omega_{nn}^2\right)^{-1}\ddot{q}_n + \phi_r q_r$$

$\phi_n\left(M_{nn}\omega_{nn}^2\right)^{-1}\phi_n^T$ is the steady-state response due to unit loads

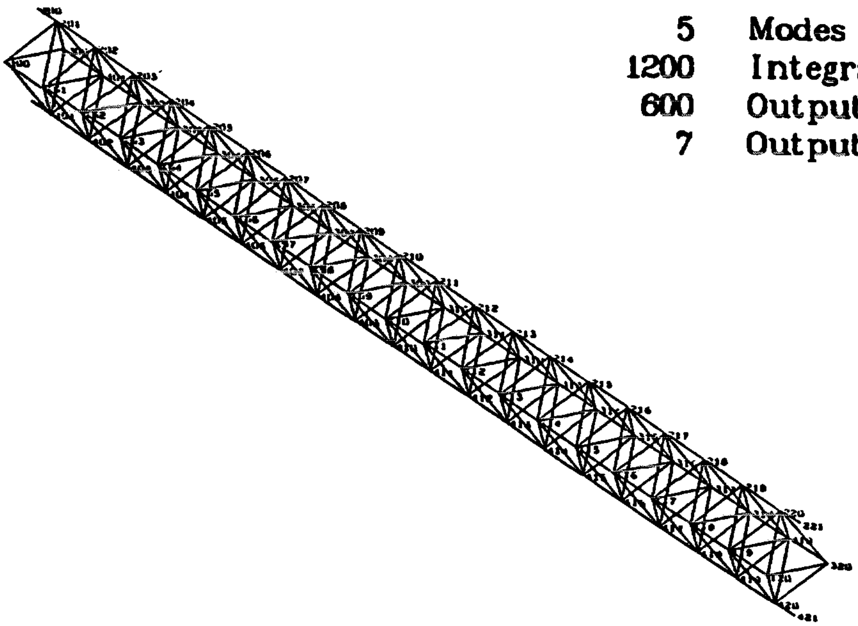
$$\psi = \phi_n\left(M_{nn}\omega_{nn}^2\right)^{-1}\phi^T = k^{-1}p_1$$

Equation for alternate mode acceleration data recovery:

$$x = \psi p - \phi_n\left(\omega_{nn}^2\right)^{-1}\ddot{q}_n + \phi_r q_r$$

Figure 2. Derivation of the equations for the alternate method of mode acceleration data recovery

EXAMPLE 1 – SPACE TRUSS



5	Modes
1200	Integration Steps
600	Output Times
7	Output Requests

Figure 3. Example 1 was a space truss beam with a rocket motor

EXAMPLE 1 ACCURACY COMPARISON

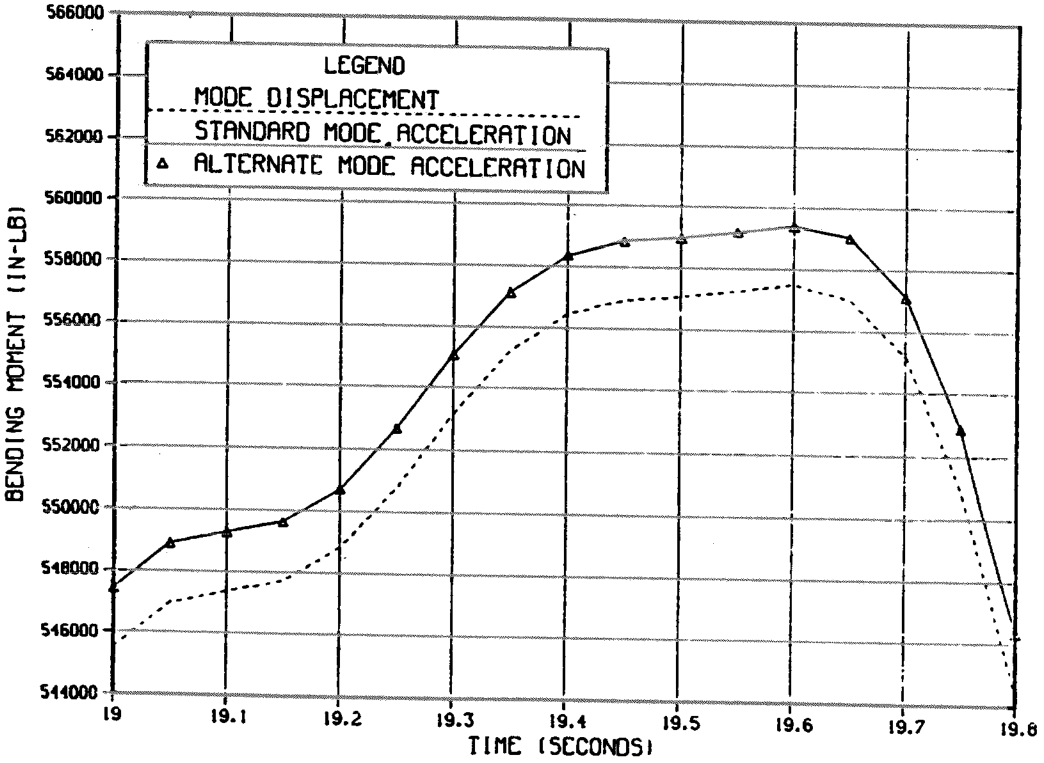


Figure 4. Accuracy comparison of data recovery methods for Example 1

EXAMPLE 1 DATA RECOVERY TIME

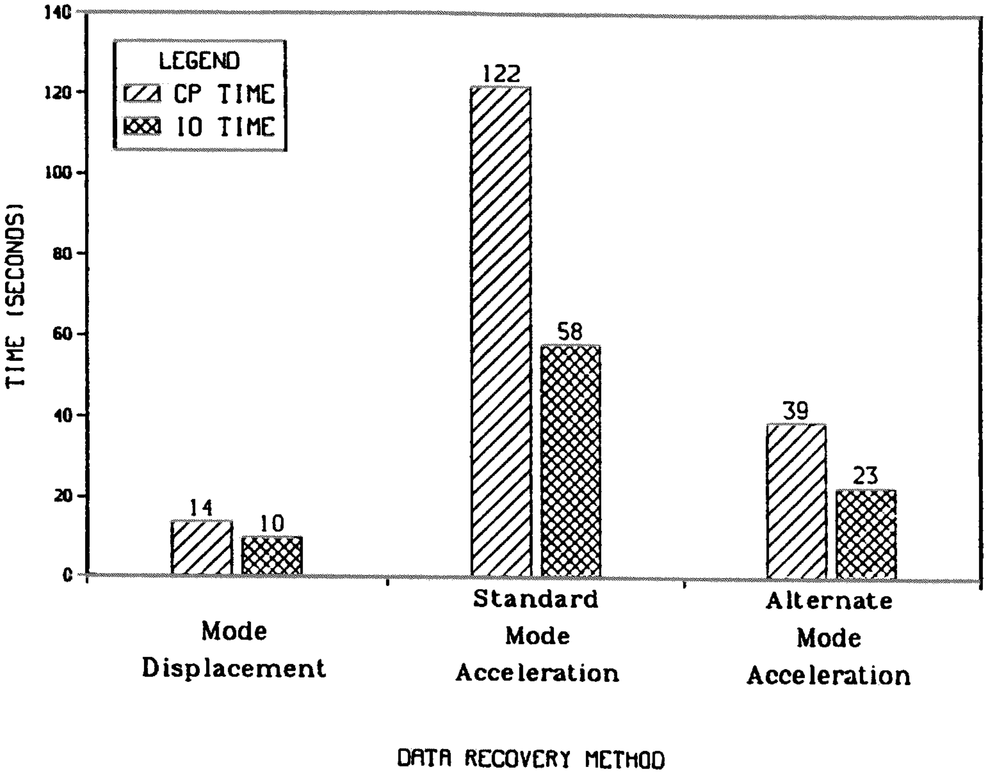
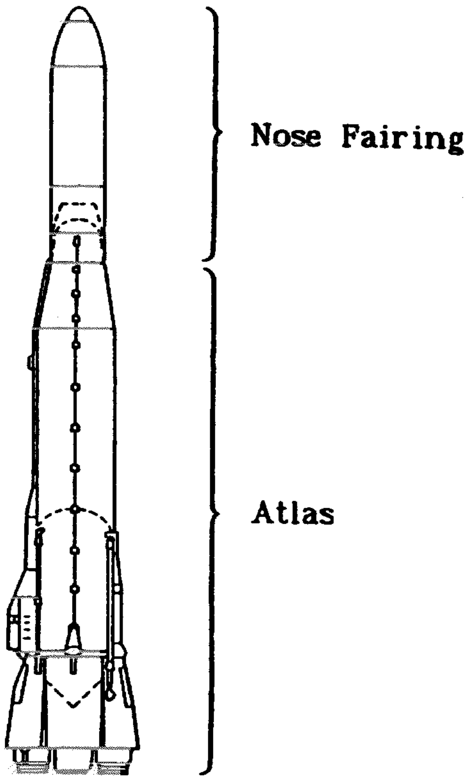


Figure 5. The alternate method was much faster than MSC/NASTRAN's method for mode acceleration data recovery

EXAMPLE 2 - LAUNCH VEHICLE



468	Degrees-of-freedom
45	Modes
2000	Integration Steps
5	Output Requests

Figure 6. An Atlas launch vehicle provided a larger test case for example 2

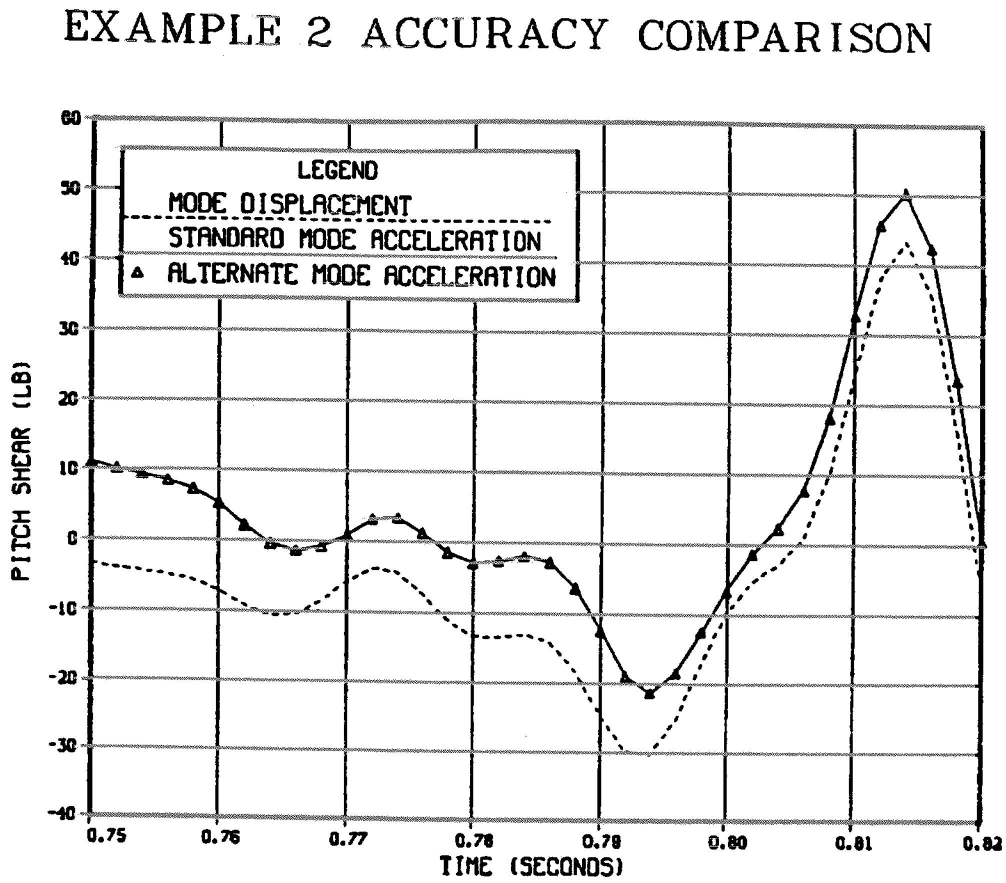


Figure 7. Accuracy comparison of data recovery methods for Example 2

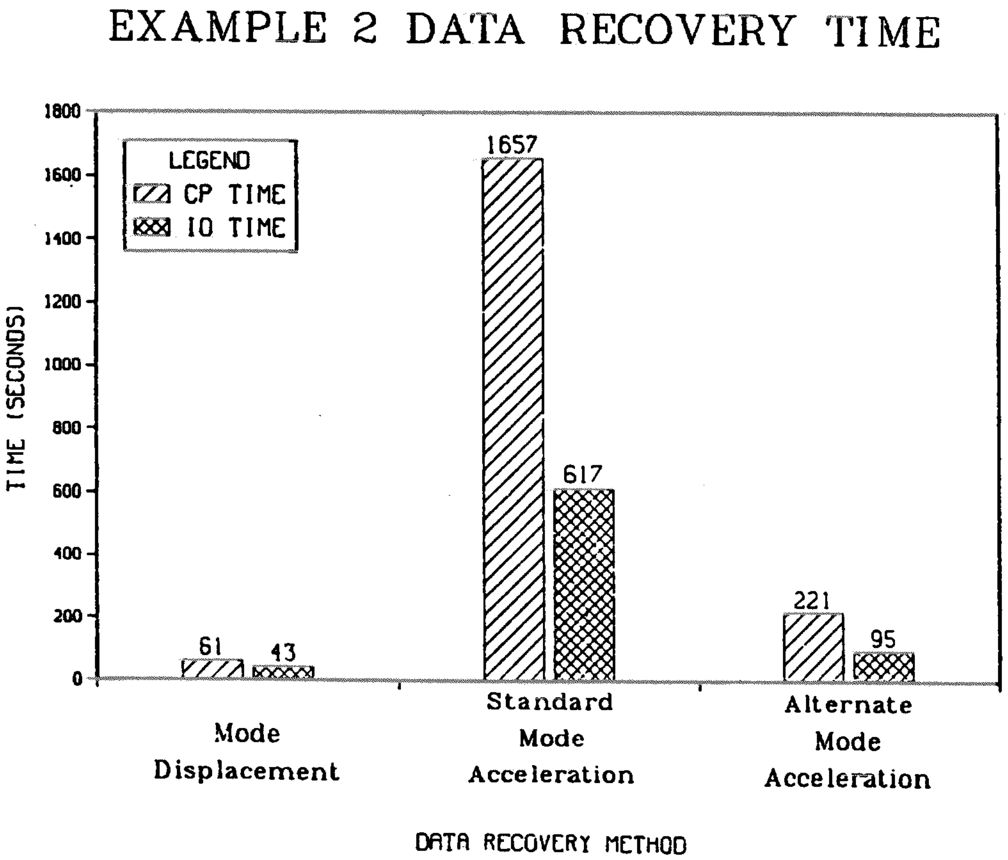


Figure 8. The alternate method was nearly eight times faster than MSC/NASTRAN's standard mode acceleration method