THE APPLICATION OF REANALYSIS TECHNIQUES TO LARGE FINITE ELEMENT MODELS THROUGH MSC/NASTRAN DMAP

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In the past few years large finite element modeling of dynamics problems has become more and more common. This is not surprising since larger, more powerful computers are being brought into service and analysis complexity is usually a half step ahead of capability. If the dynamacist wants to make the most of the existing computing facilities he must find ways to simplify or reduce the size of the problems being worked. In the aircraft industry the normal approach is to reduce the structure of interest to an equivalent lumped mass and stiffness representation using beams and concentrated mass. This was and is still done for most aircraft lifting surfaces. When there is no convenient way to reduce a structure, the reduction can sometimes be accomplished in the solution phase. NASTRAN has two commonly used normal mode analysis reduction techniques, Guyan and Generalized Dynamic Reduction. Both approaches select a reduced set of coordinates that represent the total dynamic behavior of the structure analyzed. The solution is more efficient but it is only an approximation. The accuracy of the approximation is generally very good and a useable solution results. A different approach to dynamic reduction has been explored recently with excellent results. It is called the assumed mode reanalysis technique.

The assumed mode reanalysis technique has been around for quite a while; however, only recently has it been incorporated into MSC/NASTRAN using DMAP. Reanalysis is a perturbation technique where a "base" solution is used to extrapolate new solutions. The accuracy of the extrapolation depends on the size and number of differences between the two systems. The approach is best suited for repetitive or perturbational problems where a number of solutions are required. Some examples commonly encountered in the aircraft industry are test and analysis correlation, fuel weight parametrics, and external store carriage. The major restriction to the approach is that the gridpoints and their locations cannot change. If they must change, a new base run would be required for each configuration considered. Even with this restriction a significant percentage of the analysis performed can benefit from the approach. The theory behind reanalysis and its implementation using DMAP, along with several example problems is presented herin.

Reanalysis is based on a Rayleigh-Ritz approach where a set of initial modeshapes are recombined linearily to approximate the modified modeshapes. This is best illustrated by the matrix equation

$$\left[\phi_{NEW} \right] = \left[\phi_{OLD} \right] \{ q \}$$

where the q matrix or linear multiplier is unknown.

The q matrix is found by solving the eigenvalue equation

$$([K] - \lambda[M])q = 0$$

in modal coordinates. The structural coordinates of the perturbated system are converted to modal coordinates by pre and post multiplication of the modified structural mass and stiffness matrices by the base system modeshapes.

$$[K'] = \phi_{OLD}^T [K] \phi_{OLD}$$

$$[M'] = \phi_{OLD}^T [M] \phi_{OLD}$$

In the eigenvalue equation, (λ) represents the new frequencies and (q) represents a generalized modeshape that contains the participation factors of the base modeshapes in the new modeshape. The new modeshape is then generated by matrix multiplication of the q matrix and the base modeshapes. The efficiency of the approach is due to the solution being performed for a reduced set of generalized coordinates. The number of coordinates is equal to the number of base modeshapes retained from the original vibration analysis. The recommended procedure is to retain three times the number of modes of interest from the base vibration run. Typically very large dynamic problems involving many thousands of degrees of freedom can be approximated very accurately by 50 or so generalized coordinates. The eigenvalue solution efficiency would increase with model size if the number of generalized coordinates was held relatively constant.

Implementation in MSC/NASTRAN is fairly simple if solution 63 is used. A base run is made using the LANCZOS eigenvalue extraction method for three times the number of modes desired. A data base is automatically generated that contains everything necessary to perform the required operations. Figure 1 contains the DMAP statements necessary to implement reanalysis for subsequent submittals. The desired changes are then made to the bulk data and the deck is resubmitted with the DMAP changes included. The base modeshapes are first retrieved from the data base using the DBFETCH module. The pre and post multiplication of the new structural mass and stiffness is performed by the MPYAD module. The reduced system eigenvalues are extracted using the REIGL module. The new modeshapes are generated by matrix multiplication with the generalized modeshape using the MPYAD module. The final step is to overwrite the old A-set modeshape data block with the new modes using the MATMOD module. The modes contained in the data base are preserved by writing the new modeshapes to a seperate data base subset 2. This way subsequent solution operations operate off the new modeshapes instead of the old ones and the old ones are preserved for future use. This is the simplest application of reanalysis within MSC/NASTRAN. The process can be further streamlined through additiona DMAP changes, but solution generality is sacraficed. For the approach presented here, full data recovery and plotting are preserved.

The accuracy observed for the approach depends on the type of changes considered. Figure 2 graphically depicts some general guidelines observed for the method. The percent allowable change is for 2% accuracy in the modes of interest where the modes of interest are defined as the first third of the modes retained for reanalysis. The most difficult changes to accommodate are concentrated mass additions where no mass previously existed. About 30% of the total structural mass can be added at any one location before appreciable errors are noticed. Existing masses can be varied by 500% or more with good results. The same is true for stiffness changes. New elements are limited to 30% of a local maximum and existing elements can be pushed to 500% or more. The results presented are worst case. The objective is to provide a threshold value for change that the user can use directly. Applications involving larger variations are possible but the user is advised to verify the accuracy with a test case first. Since the new solution is formed by linear combination of the old solution modeshapes it is logical that changes like large new mass or stiffness additions that radically alter the modeshape cannot be approximated as well. Changes that tend to preserve the modeshape and shift the frequency can be predicted with a high degree of accuracy.

The technique has been used successfully in a variety of applications. Figure 3 summarizes the three general catagories; optimization, test and analysis correlation, and perturbation studies. Reanalysis has been used to calculate structural derivatives with respect to flutter. The approach used required a complete aeroelastic solution in addition to a structural solution for each derivative. The structural parameter of interest was varied independently to obtain the derivative for that parameter. The approach can become prohibitive if the structural model is large or if a lot of derivatives are required. Reanalysis reduces the vibration analysis time enough to make the approach feasible.

Test and analysis correlation has always involved a lot of trial and error guesswork. The engineer usually makes a number of vibration runs varying critical parameters to find the best overall match between frequencies or modeshapes. The value of reanalysis depends on the size of the model being correlated. For very large models long cycle times may force the engineer to settle for less than optimum results. Reanalysis allows models up to 64,000 degrees of freedom to be turned around in a fraction of the time previously required.

Perturbation studies are an integral part of aircraft design and analysis, especially in the advanced design stage. The designer always wants to know how one parameter affects another in search of the optimum design. The major worry for the dynamacist is flutter. They want to know how different fuel weights, control surface restraints or external store loadings affect flutter. Each configuration considered is a potential vibration analysis. In many cases all posible combinations are not analyzed due to the time and resources availiable. Reanalysis allows the engineer to do a more thorough job within the resources availiable.

The reanalysis technique presented here has been tested on the large finite element model depicted in Figure 4. The model was built to represent an integral fuel tank fuselage section that was being fatigue tested in the presence of fuel. The model contained approximately 20,000 degrees of freedom and primarily consisted of CQUAD4 plate elements. A number of different thickness tank wall skins were being tested and it was desireable to know the vibration characteristics of each configuration. A single vibration run on a VAX 8650 computer required over 7.75 hours of CPU time to obtain the lowest 40 modes using the LANCZOS method. The effect of increasing the tank floor thickness from .063 in. to .070 in. was evaluated using reanalysis in less than 15 CPU minutes on the same computer. The results obtained are summarized in Figure 5. The accuracy observed for the first six tank floor modes was within .2% of that calculated by rerunning the entire model. The problem reformulation and solution was completed in less than 7 CPU minutes with the remainder spent on modeshape processing, formatting, and I/O.

Another application of reanalysis that has been studied in detail is aircraft external store carriage. A typical configuration is illustrated in Figure 6. The reanalysis technique was used to vary the mass of the store from zero to a predetermined maximum. Three approaches were used with identical results in all cases. For the first case the base run contained a bare pylon and stores were added later by reanalysis. For the second case the base run contained the maximum store weight and mass was subsequently removed using reanalysis. For the third case the base run contained a mid weight store and mass was either added or removed during reanalysis to cover the full weight range. Figure 7 shows the flutter trends obtained by reanalysis and full analysis. The frequencies and modeshapes obtained in all cases were identical. The resulting flutter speeds were also the same. The model used for the store weight variations was much smaller than the previous example. It contained approximately 500 degrees of freedom and a factor of 6 reduction in processing time was observed. The expectation that effeciency would increase with model size was also confirmed.

The reanalysis procedure outlined in Figure 1 is the simplest form to incorporate in MSC/NASTRAN. There is a considerable amount of information contained in the base run solution that can be used to improve the efficiency of the entire process. The USET table contains the various MSC/NASTRAN internal sets. If this information is known in advance some operations can be bypassed when reformulating the new structural mass and stiffness matrices. Additional data blocks listed in Figure 8 can also be utilized to shortcut the problem reformulation. For example, the optimum bandwidth sequencing is already determined, the grid point geometry and element connectivity can be reused, the MPC transformations are still valid, and the AUTOSPC set has already been formed. The amount of change to utilize this information in a standard rigid format vibration solution is prohibitive. It is best to write an independent DMAP procedure specifically designed with reanalysis in mind. If this is done, the MODTA module in MSC/NASTRAN becomes a very big contributor to the entire process.

The module appears to have been written with reanalysis in mind. It compares new and old element summary tables and generates differential mass and stiffness matrices representing only the changes. The differential mass and stiffness matrices can then be modalized by pre and post multiplication with the base modeshapes and added directly to the generalized mass and stiffness from the base run. The flow chart in Figure 9 illustrates the alternate procedure. The approach reconstructs the modified generalized structural representation many times faster than the approach presented in Figure 1. Some solution generality was sacrificed in the process. Printing and plotting were preserved but some modeling restrictions were introduced.

The restrictions are; no general elements, no ASET or OMIT cards, no Q-set or scalar points, no Guyan or Generalized Dynamic Reduction allowed, and only the LANCZOS eigenvalue extraction technique may be used. Additional performance increases have been realized by only regenerating a subset of the full modeshape. This reduced the size of the data blocks being processed and resulted in additional CPU time savings.

Even further reductions in computation times can be achieved by custom tailoring a reanalysis procedure for a specific application. External store carriage on aircraft falls into this catagory. For external store parametrics it is possible to generate a set of unit generalized mass matrices that can be multiplied by scalar constants and recombined to simulate any store mass desired. Figure 10 illustrates the specific reanalysis procedure designed for stores. Regeneration of the structural matrices from bulk data has been completely replaced by a scalar multiplication of a matrix. The overall process is extremely efficient; however, it is limited to concentrated mass parametrics.

DMAP procedures have been written and tested for the alternate approach outlined in Figure 9 and the mass parametric method described in Figure 10. Both DMAP solutions were tested on a 20,000 degree of freedom model to determine the reductions in CPU time possible. Figure 11 summarizes the factor reductions observed for the two methods. For general reanalysis, if full modeshape regeneration is required, the process is about 30 times faster. If a reduced subset of the full modeshape is acceptable, the factor jumps to around 60. For concentrated mass parametrics the first phase is around 80 times faster since all stiffness considerations are dropped. Any additional parametrics on the same configuration can be accomplished with a factor reduction of 750. Once the initial unit mass matrices are formulated, the solution time is independent of the original model size. It only depends on the number of generalized coordinates retained in the analysis. As long as the solution can be approximated by a relatively small number of modes or generalized coordinates, the solution times will be small. For external store variations the reanalysis approach to mass parametrics has been shown to be accurate as well.

Reanalysis can be a powerful tool for perturbation type problems. It has been shown to have specific applications with real benefits for each application. The approach is not limited to vibration only. The direct transient solution using the modal approach is another canidate for reanalysis. Optimization is another area which could benefit. The approach is not restricted to MSC/NASTRAN. It could easily be applied to other finite element procedures.

FIGURE 1

MSC/NASTRAN IMPLEMENTATION
SOL 63 VERSION 65

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804  DBFETCH   PHIA,,,,/V,Y,SOLID/0//DBSET2 $

804  MPYAD     PHIA,KXX,/KXX1/1 $
804  MPYAD     KXX1,PHIA,/KHH/0 $

804  MPYAD     PHIA,MXX,/MXX1/1 $
804  MPYAD     MXX1,PHIA,/MHH/0

804  REIGL     KHH,MHH,DYNAMICS,CASES/LAMA,PHIZ,MI,
               EIGVMAT/V,N,READAPP/S,N,NEIGV $

804  MPYAD     PHIA,PHIZ,/PHIX $

804  MATMOD    PHIX,,,,,/PHIA,/13 $

                    .
                    .

816  DBSTORE   PHIA,LAMA//2/0/DBSET2 $

                    .

818  DBFETCH   PHIA,LAMA,,,/2/0//DBSET2 $

                    .

840  DBFETCH   PHIA,LAMA,,,/2/0//DBSET2 $

                    .
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FIGURE 2

REANALYSIS ACCURACY LIMITS

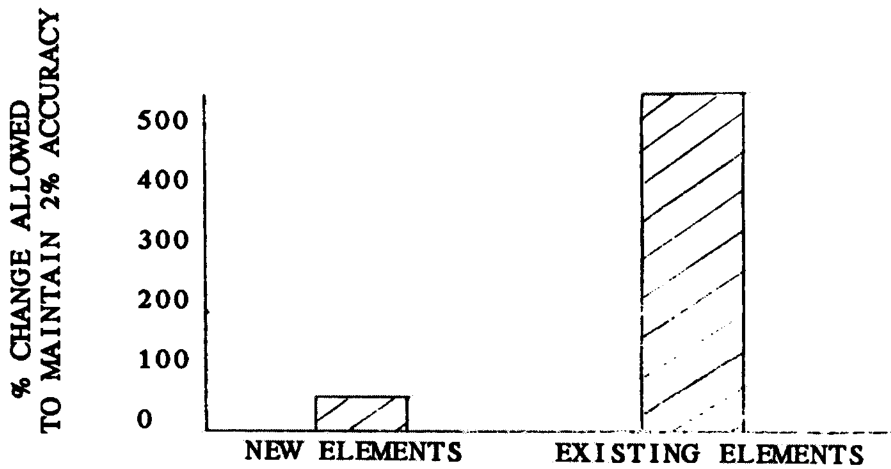

FIGURE 3

REANALYSIS APPLICATIONS

1) OPTIMIZATION

   a. Structural

   b. Aeroelastic

2) TEST-ANALYSIS CORRELATION

3) PERTURBATION STUDIES

   a. Flutter Sensitivity

   b. Design Modifications

   c. Trend Studies

FIGURE 4

REPRESENTATIVE FUSELAGE TANK MODEL

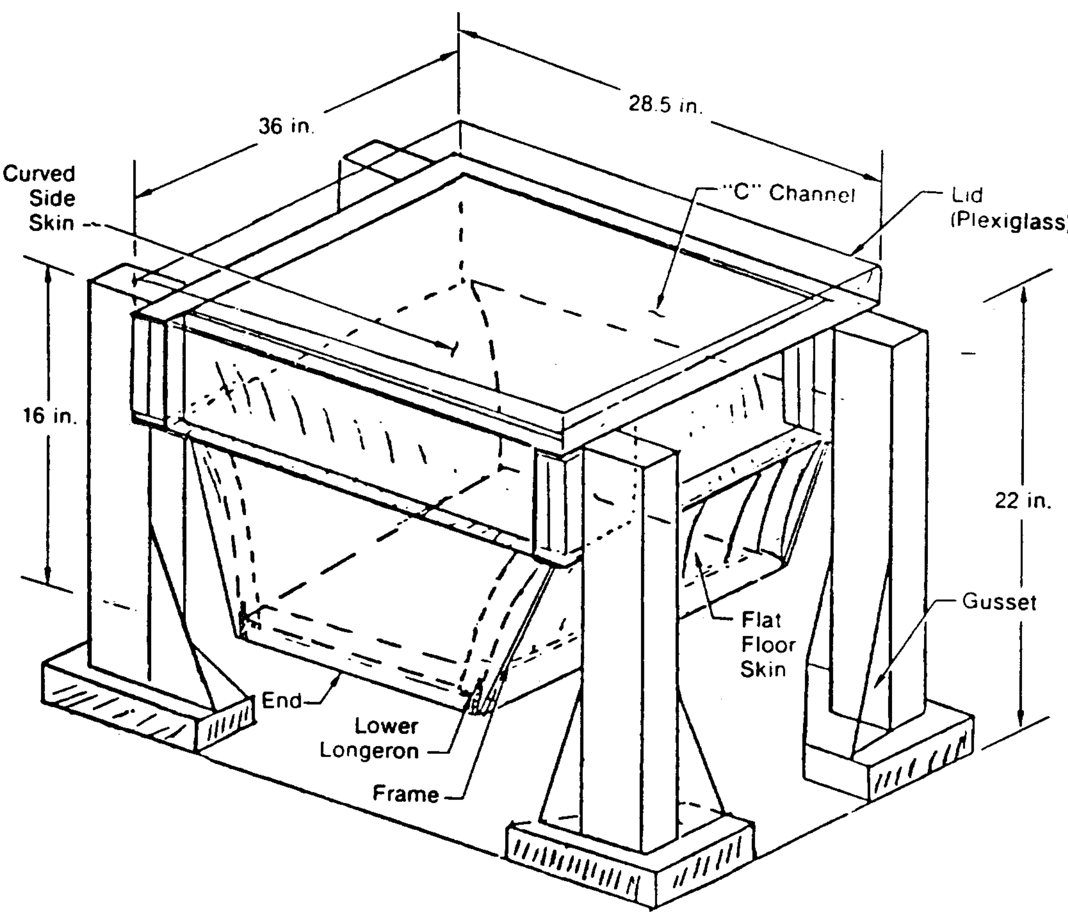

Figure 19. Representative Tank Section (Task VI)

FIGURE 5

REANALYSIS RESULTS FOR A 10%
INCREASE IN TANK FLOOR THICKNESS

MODE	ANALYSIS	REANALYSIS	ANAL/REANAL
2	136.4	136.8	.997
6	218.3	218.9	.997
9	285.4	285.7	.999
11	324.6	324.7	.999
13	390.0	390.5	.999
14	397.1	397.0	1.000

FIGURE 6

TYPICAL EXTERNAL STORE CONFIGURATION

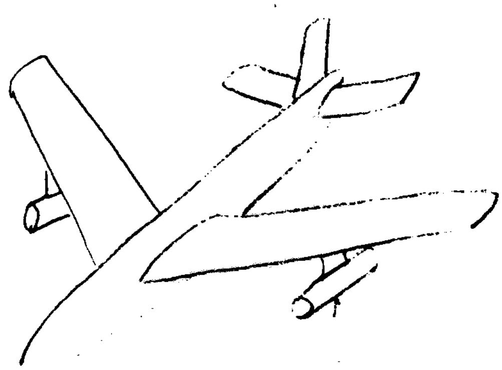

FIGURE 7

STORE FLUTTER SPEED TRENDS AS PREDICTED BY EXACT AND REANALYSIS METHODS

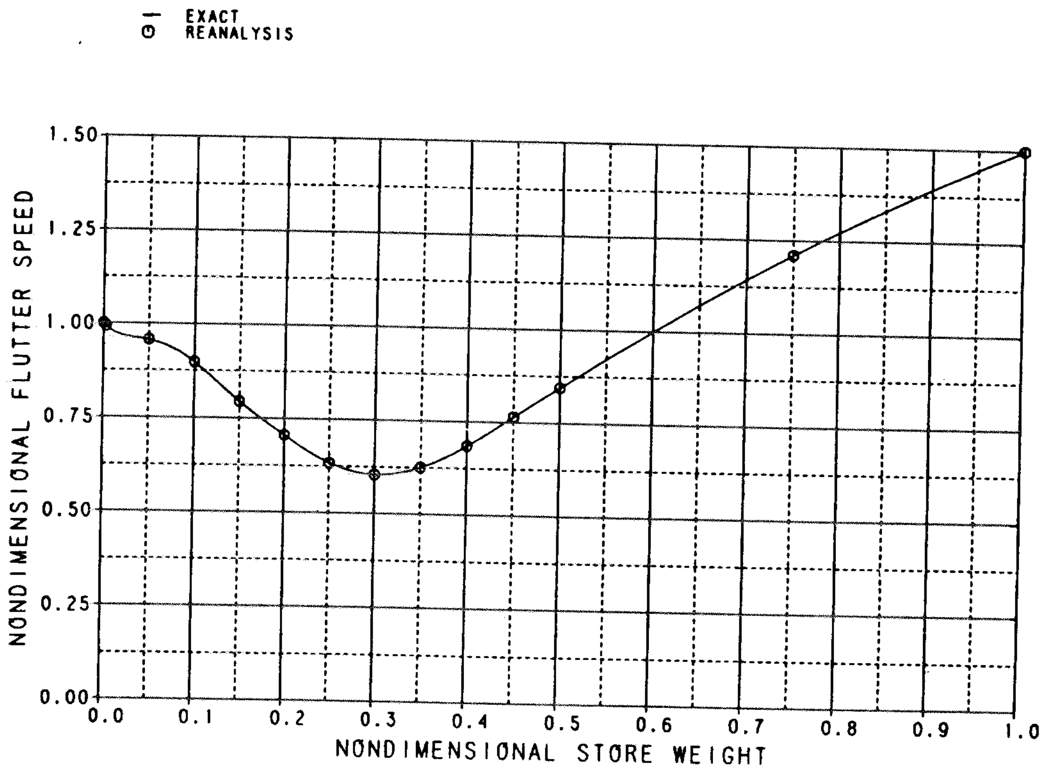

FIGURE 8

INFORMATION USEABLE FOR REANALYSIS FROM THE INITIAL BASE RUN

DATA BLOCK	PURPOSE
GM	Multi Point Constraint Transformation
EQEXIN	Optimum Internal Grid Sequence Order
USET	MSC/NASTRAN Internal Sets + Autospc Constraints
GEOM1	Grid Point Data
LAMA	Base Run Generalized Mass And Stiffness
PHIA	Base Run Modeshapes

FIGURE 9

ALTERNATE REANALYSIS APPROACH

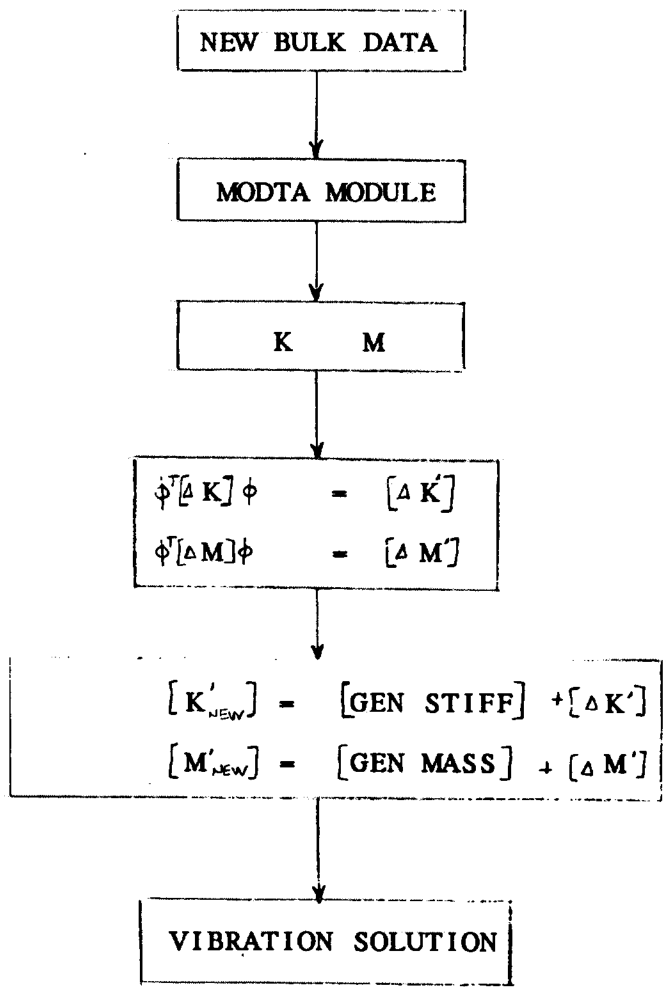

FIGURE 10

REANALYSIS FOR AIRCRAFT EXTERNAL STORES

STRUCTURE PLUS STORE		STRUCTURAL MASS MINUS STORE		STORE MASS MINUS STRUCTURE

$$\phi^T \begin{bmatrix} x & x & x \\ x & 1 & x \\ x & x & x \end{bmatrix} \phi = \phi^T \begin{bmatrix} x & x & x \\ x & 0 & x \\ x & x & x \end{bmatrix} \phi + \phi^T \begin{bmatrix} 0 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 0 \end{bmatrix} \phi$$

$$[M'_T] = [M'_A] + [M'_S]$$

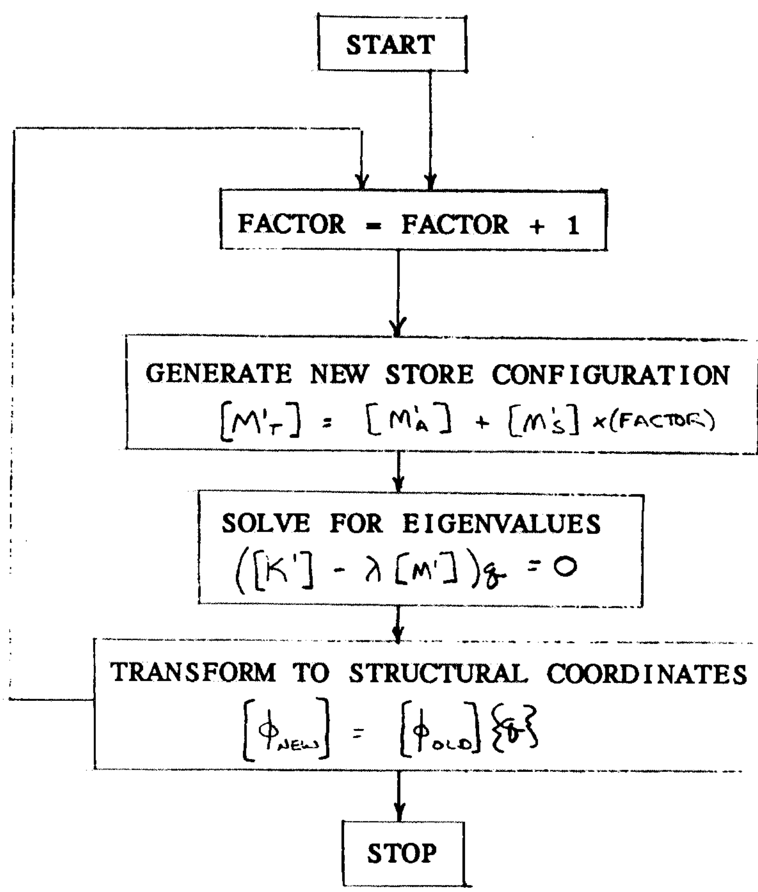

FIGURE 11

REANALYSIS PERFORMANCE ON A

20,000 DEGREE OF FREEDOM MODEL

	CPU SEC.	ANAL/REANAL
BASE RUN	26289.0	1.0
REANALYSIS WITH FULL MODESHAPE	863.0	30.4
REANALYSIS WITH PARTIAL MODESHAPE	446.0	58.9
MASS PARAMETRIC (FIRST PASS)	338.0	77.8
MASS PARAMETRIC (SUBSEQUENT PASS)	35.0	751.1