

AN ASSESSMENT OF MSC.NASTRAN RESIDUAL VECTOR METHODOLOGY FOR DYNAMIC LOADS ANALYSIS

**Christopher C. Flanigan
Mark C. Stabb, Ph.D., P.E.
Quartus Engineering Incorporated
San Diego, California USA**

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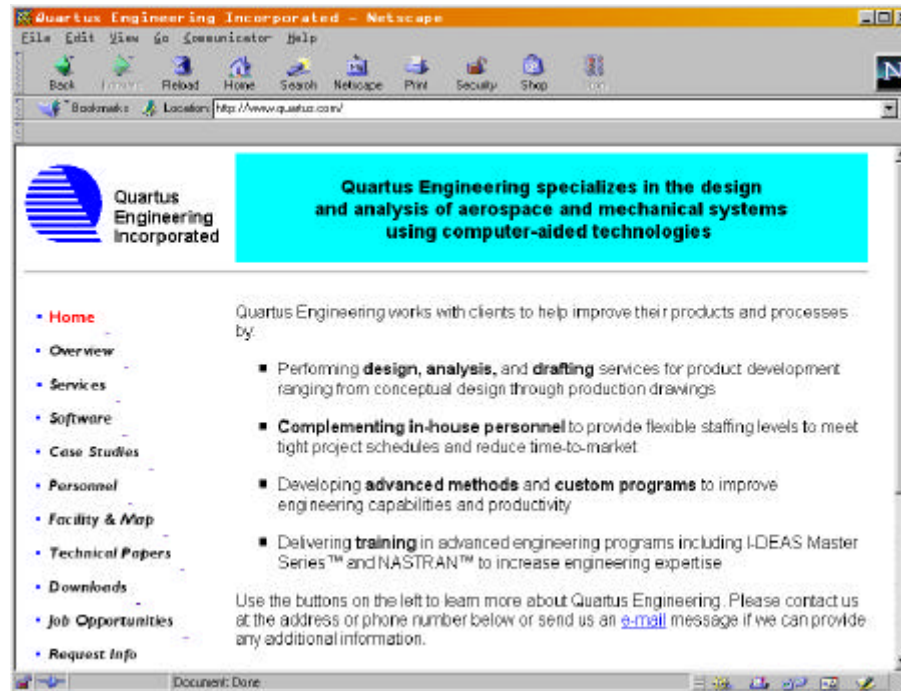
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AGENDA

- Introduction to problem
- Traditional approaches
- MSC.NASTRAN residual vector methodology
- Advantages
- Pitfalls
- DMAP alter
- Numerical example
- Conclusions and recommendations



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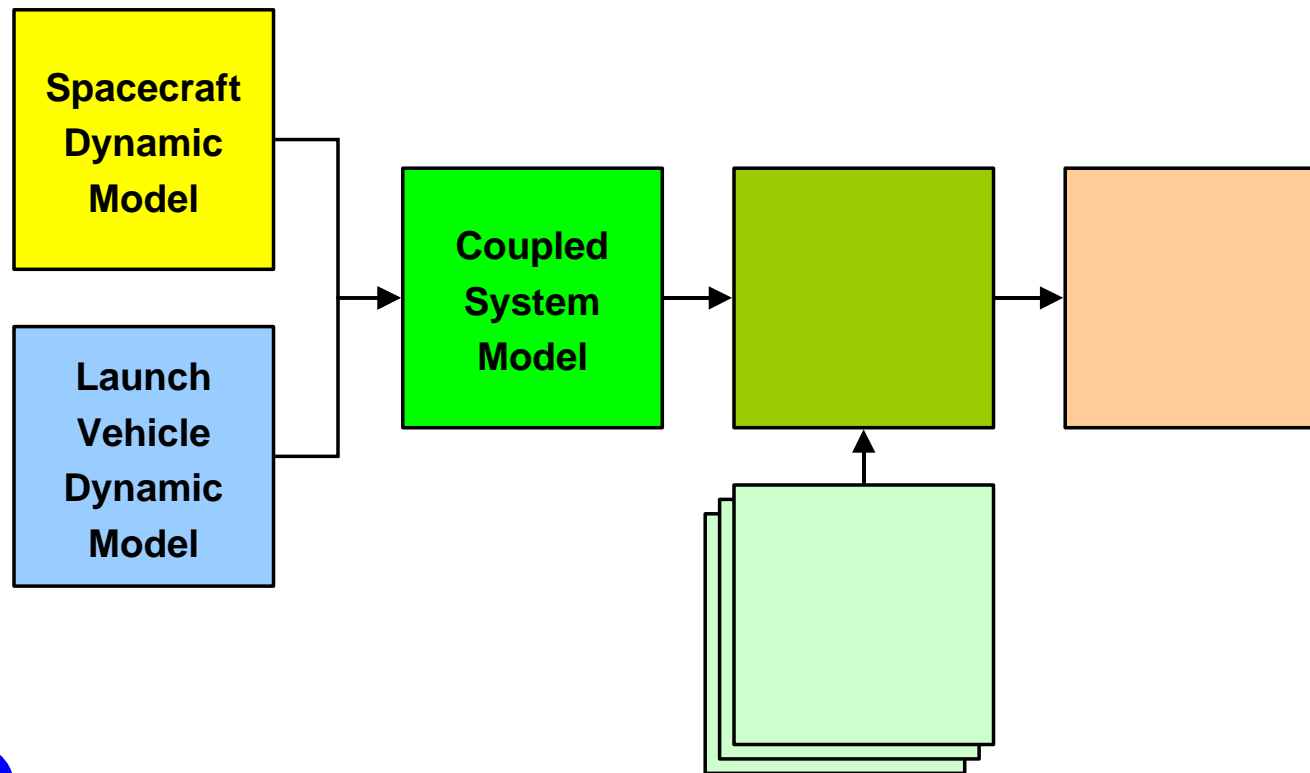


COUPLED LOADS ANALYSIS PREDICTS SYSTEM RESPONSES

- High performance systems
 - Maximize payload (minimize weight)
- Significant interaction
 - Payload affects launch vehicle
- Complex environments
 - Steady state and dynamic terms
- *Need accurate methods to predict coupled system responses*



CLA PROCESS USES MODAL SYNTHESIS & TRANSIENT ANALYSIS



MODAL APPROACH FOR TRANSIENT RESPONSE AND DATA RECOVERY

- Calculate modes to user-specified frequency
- Modal equations of motion

$$\phi^T m \phi \ddot{q} + \phi^T c \phi \dot{q} + \phi^T k \phi q = \phi^T p$$

- Transient analysis to calculate modal responses
 - Many methods (“exact”, Newmark-Beta, Runge-Kutta)
- Recover physical responses from modal results

$$x \approx \phi q \quad \dot{x} \approx \phi \dot{q} \quad \ddot{x} \approx \phi \ddot{q}$$



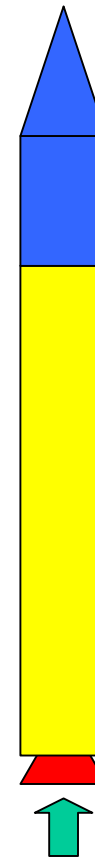
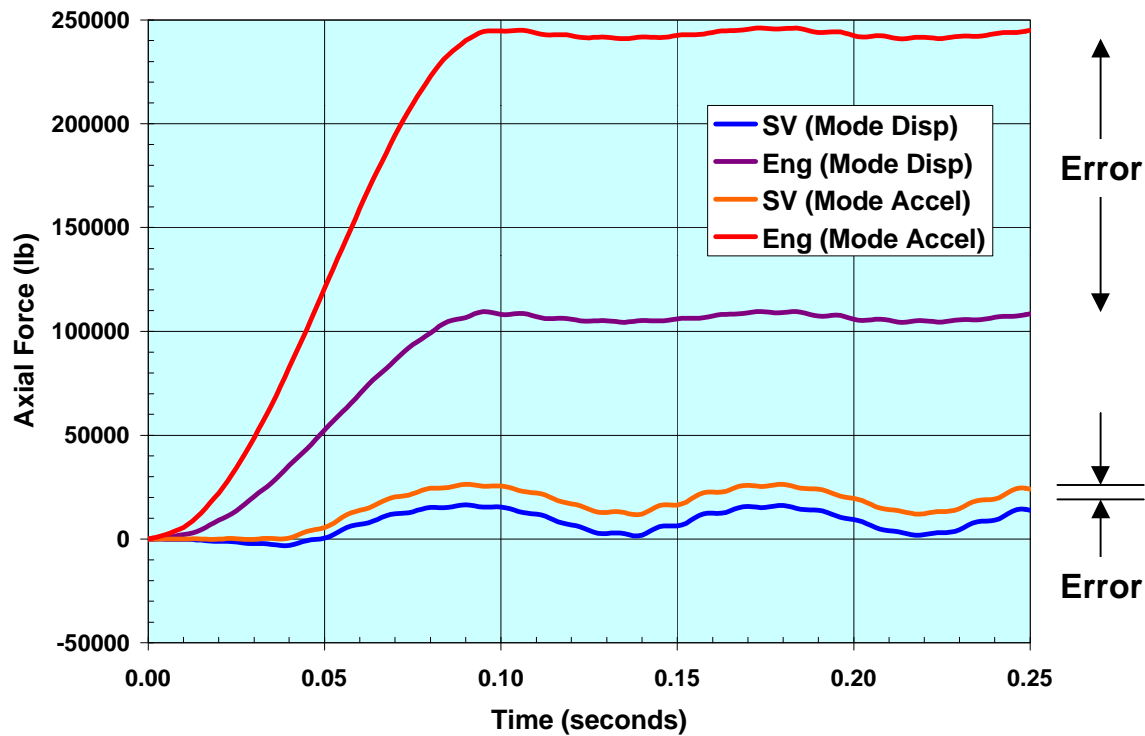
DATA RECOVERY IS CRITICAL FOR ACCURATE LOADS AND STRESSES

- **Modal approximation (truncation)**
 - Subset of available modes
 - High frequency modes truncated
- **Small effect on accelerations and velocities**
 - Retain sufficient modes to represent dynamic response
- **May not accurately represent displacements and displacement-dependent responses**
 - Forcing functions include large steady-state forces
 - Retained modes not sufficient to represent static shapes



Introduction

NUMERICAL EXAMPLE OF MODAL TRUNCATION



MODE ACCELERATION METHOD USED TO IMPROVE ACCURACY

- **NASTRAN (traditional)**

$$\mathbf{x} = \mathbf{k}^{-1}(\mathbf{p} - \mathbf{m}\phi\ddot{\mathbf{q}} - \mathbf{c}\phi\dot{\mathbf{q}})$$

- **Alternate form 1**

$$\mathbf{x} = \mathbf{k}^{-1}\mathbf{p} - \phi_{el}\lambda_{el}^{-1}\ddot{\mathbf{q}}_{el} + \phi_{rb}\mathbf{q}_{rb}$$

- **Alternate form 2**

$$\mathbf{x} = \phi\mathbf{q} + \mathbf{R}$$

$$\mathbf{R} = \mathbf{k}^{-1}\mathbf{p} - \phi\mathbf{K}^{-1}\phi^T\mathbf{p}$$



TRADITIONAL METHODS HAVE ADVANTAGES AND DISADVANTAGES

- **NASTRAN traditional method**
 - **Readily available (PARAM,MODACC,0)**
 - **Computationally intensive (CPU, disk space)**
 - **Does not support upstream superelements**
- **Alternate forms**
 - **Computationally efficient**
 - **Requires special codes**
 - **DMAP sequences**
 - **Stand-alone codes**



RESIDUAL VECTOR METHOD ADDED TO MSC.NASTRAN

- **Introduced in Version 70**
 - Occasional bugs in initial release
 - Bugs eliminated in V70.5 and V70.7 (hopefully)
- **General approach**
 - Calculate modes to frequency cutoff
 - Calculate residual vectors caused by “unit” loads
 - Append residual vectors to eigenvectors
 - Calculate “all” modes ($N = h + p$)
 - Use “all” modes in transient analysis and data recovery



IMPORTANT OPERATIONS IN RESIDUAL VECTOR METHOD

- Calculate “residual load”

$$\hat{\mathbf{p}} = \mathbf{p} - \mathbf{m}\phi\mathbf{M}^{-1}\phi^T\mathbf{p}$$

- Calculate residual vectors

$$\hat{\mathbf{u}} = \mathbf{K}^{-1}\hat{\mathbf{p}}$$

- Orthogonalize residual vectors wrt eigenvectors
- Append residual vectors to eigenvectors

$$\Phi = \{\phi \quad \hat{\mathbf{u}}\}$$



IMPORTANT OPERATIONS IN RESIDUAL VECTOR METHOD

- Calculate augmented stiffness and mass matrices

$$\bar{K} = \Phi^T k \Phi \quad \bar{M} = \Phi^T m \Phi$$

- Eliminate linearly dependent terms
 - Cholesky decomposition of \bar{M}
 - Eliminate DOF with null pivot ratios
- Calculate “all” modes
 - Original modes unchanged
 - Residual stiffness and mass in “new” modes



RESIDUAL VECTOR METHOD EASY TO USE

- **PARAM,RESVEC,YES**
 - Activates residual vector method
- **PARAM,RESVINER,YES**
 - Required if structure has rigid body modes (inertia relief)
 - Also requires SUPORTi statements
- **PARAM,RESVSO,YES**
 - Orthogonalize residual vectors wrt eigenvectors (default)
- **PARAM,RESVSLI,YES**
 - Remove linearly dependent shapes (default)



RESIDUAL VECTOR METHOD HAS MANY ADVANTAGES

- **Easy to use**
 - Standard MSC.NASTRAN (no alters required)
- **Accurate**
 - Theoretically comparable to mode acceleration method
- **Efficient**
 - Supports “matrix method” data recovery (DDRMM)
- **Compatible with superelements**
 - Single level and multi-level superelement trees



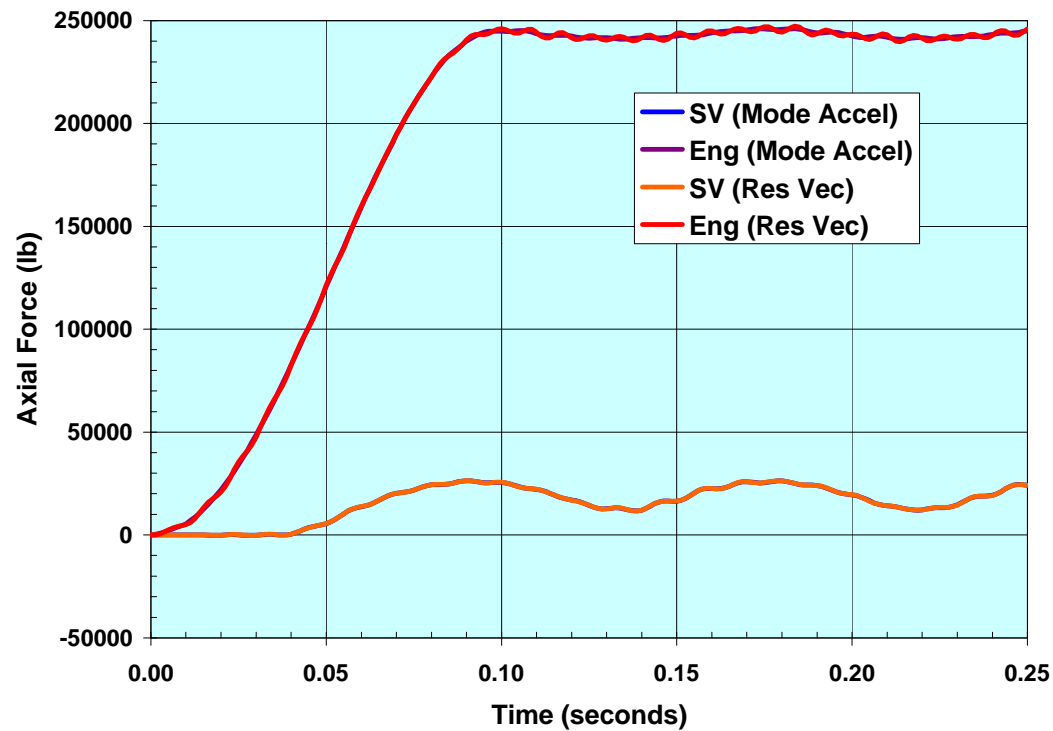
RESIDUAL VECTOR METHOD HAS POTENTIAL PITFALLS

- **Acceleration (inertia) effects**
 - PARAM,RESVNER is “NO” by default
 - May cause loss of accuracy if large acceleration loads
 - Special concern for upstream superelements
- **High frequency responses modified**
 - Residual modes may have significant dynamic response
 - Different answers than traditional mode accel. methods
- **Errors if residual vectors truncated**
 - PARAM,HFREQ or PARAM,LMODES
 - No warning messages!



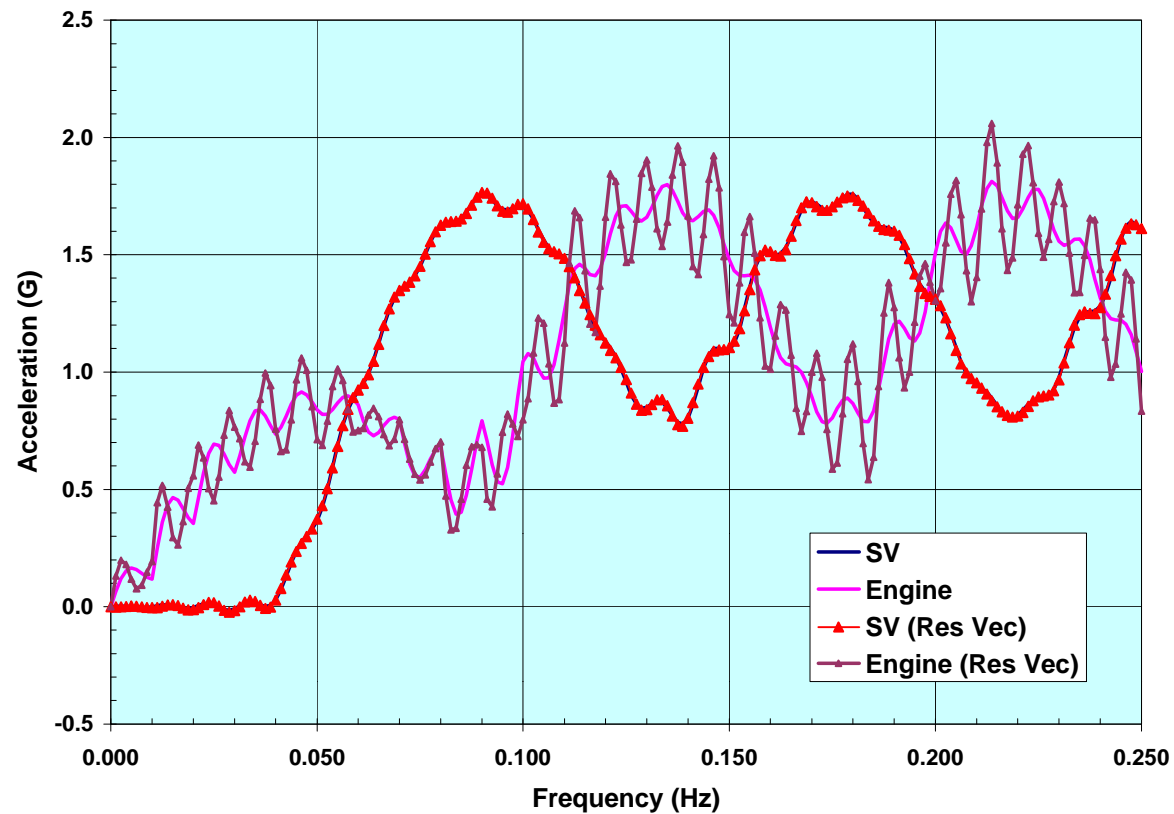
Residual Vector Methodology

NUMERICAL EXAMPLE OF RESIDUAL VECTOR METHOD



Residual Vector Methodology

RESIDUAL MODES CAN CAUSE HIGH FREQUENCY RESPONSES



WHAT IS CORRECT ANSWER?

- **Residual vectors are valid**
 - **Statically complete**
 - **Add information to high frequency regime**
- **Residual vector dynamics not significant if sufficient modes retained**
 - **2x times the frequency content of the forcing functions**
- **Frequency separation infeasible or impossible for many applications**
 - **Space Shuttle (35-50 Hz limit)**
 - **Transition from traditional methods**
 - **Independent verification and validation**



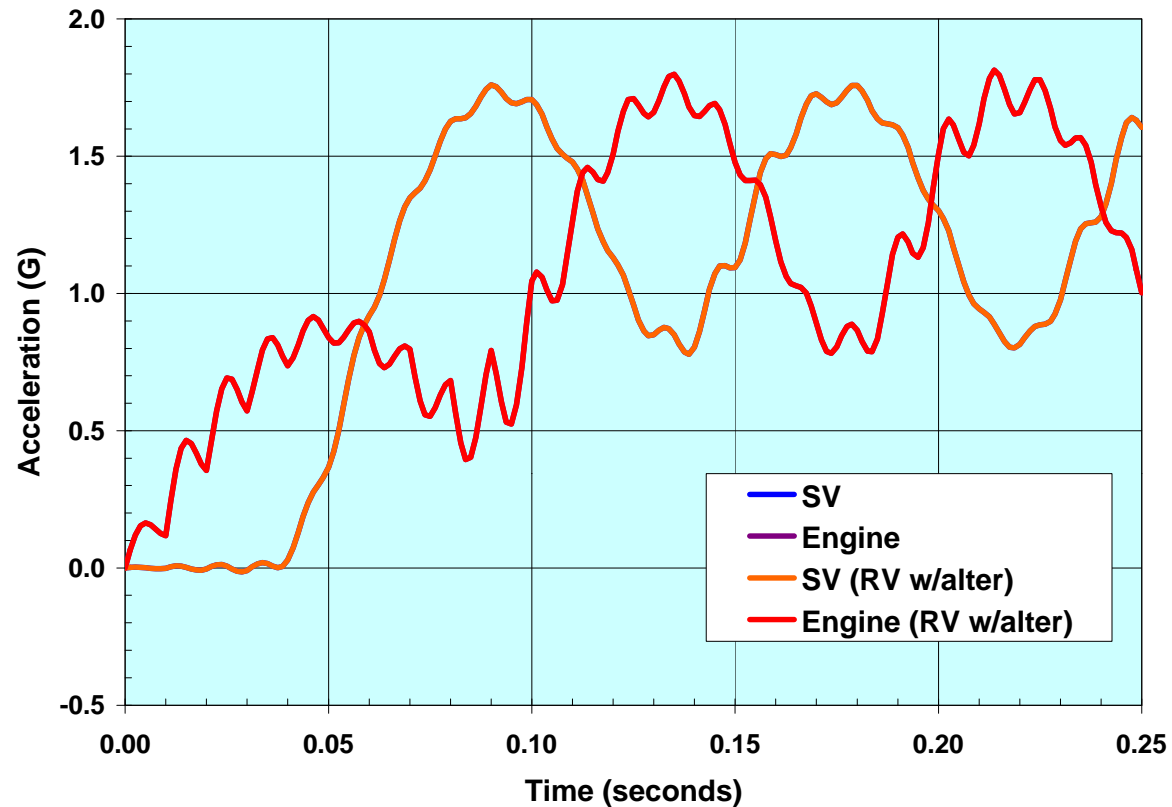
DMAP ALTER PROVIDES SPECIAL RESIDUAL VECTOR DATA RECOVERY

- **Standard residual vector through modal transient**
- **Modify UHT (modal transient responses)**
 - **Separate UHT into residual vectors and standard modes**
 - **Calculate displacement of residual vectors by static**
 - **Set residual vector velocities and accelerations to zero**
 - **Reassemble UHT**
- **Results comparable to traditional mode acceleration methods**



DMAP Alter

DMAP ALTER ELIMINATES HIGH FREQUENCY DYNAMICS



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Conclusions and Recommendations

MSC.NASTRAN RESIDUAL VECTORS PROVIDE POWERFUL CAPABILITIES

- **Accurate and efficient**
 - Comparable to traditional mode acceleration methods
- **Easy to use**
 - Incorporated in standard MSC.NASTRAN V70 and beyond
- **Be aware of differences and pitfalls**
 - Must retain all modes for transient analysis and data
 - Potential for high frequency dynamic responses
 - What is right answer?
- **DMAP alter to provide “traditional” results**

