APPLICATION OF MSC/NASTRAN SUPERELEMENT DYNAMIC REDUCTION TECHNIQUES FOR THE VERTICAL LAUNCHING SYSTEM

TEJBIR ARORA* AND LILY BIRMINGHAM**
MARTIN MARIETTA AERO & NAVAL SYSTEMS
BALTIMORE, MD 21220

ABSTRACT

The MK 41 Vertical Launching System (VLS) is a large complex structure and its finite element model represents approximately 80,000 degrees of freedom (DOF's). The MSC/NASTRAN superelement method was used to model the VLS structure. In order to reduce the cost for the residual run, generalized dynamic reduction (GDR), Guyan reduction and component mode synthesis techniques were implemented. The VLS contains 8 modules and a standard module has 8 cells. As an aid to the analysis set (A-set) selection for the overall VLS model, a single cell model was studied. The results of this small model study are presented here. A comparison for the frequencies calculated using Guyan reduction with various A-sets versus using GDR is included. The optimized A-set for Guyan Reduction was identified based on the results. Subsequently, similar selection was used for every cell in the VLS model. This study provided the cost saving and the accuracy for optimizing the A-set selection for the VLS analysis.

* Staff Engineer, VLS Shock Analysis Group

** Group Engineer, VLS Shock Analysis Group

INTRODUCTION

The Navy's Vertical Launching System (VLS) provides a rapid-fire launch capability against air, surface, and underwater targets. The VLS is being installed in the U. S. Navy cruisers and destroyers. For the cruisers (USS Ticonderoga Class), there are two launchers, one in the forward section and the other in the aft section of the ship as shown in Figure 1. Each launcher contains 61 missiles as shown in Figure 2; 56 in 7 eight cell modules; and 5 in a strikedown module. Each missile is stowed vertically below deck in a sealed canister ready for launch from the ship. The strikedown crane, which can be elevated to deck level, is used for loading/unloading of the canistered missiles.

Dynamic analyses of the VLS was required to support the CG 53 Shock Trials conducted by the Navy in May/June 1987. The shock survivability analysis was performed using MSC/NASTRAN version 64A superelement (SE) techniques [3]. Two methods of analysis were implemented; the Dynamic Design Analysis Method (DDAM) [1] using Sol 63 and the direct transient analysis [2] using Sol 69. The VLS model consisted of approximately 80,000 physical DOF's. The primary SE's included in the VLS analysis were the ship bulkheads and keel, the ship deck, the VLS foundation, the eight-cell module, the five-cell module, and the canister/missile models. Six eight-cell module SE's were either identical to or an image of the primary SE. Many canister/missile models were also image SE's. It is a challenge handling a model this size in MSC/NASTRAN.

There are two methods of dynamic reduction available in MSC/NASTRAN [4]: Guyan Reduction and Generalized Dynamic Reduction (GDR). In the VLS analysis, the component modes analysis was performed for each SE

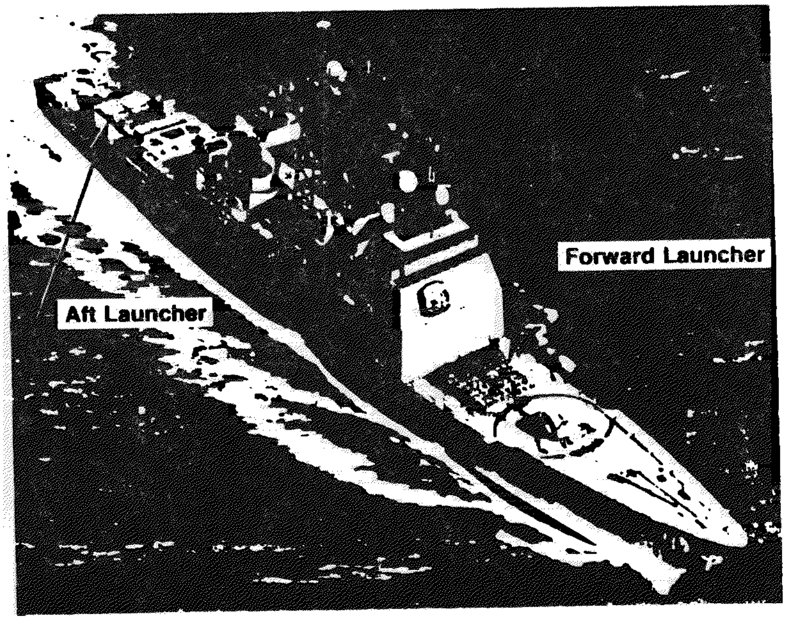


Figure 1 Launcher Location on CG 53

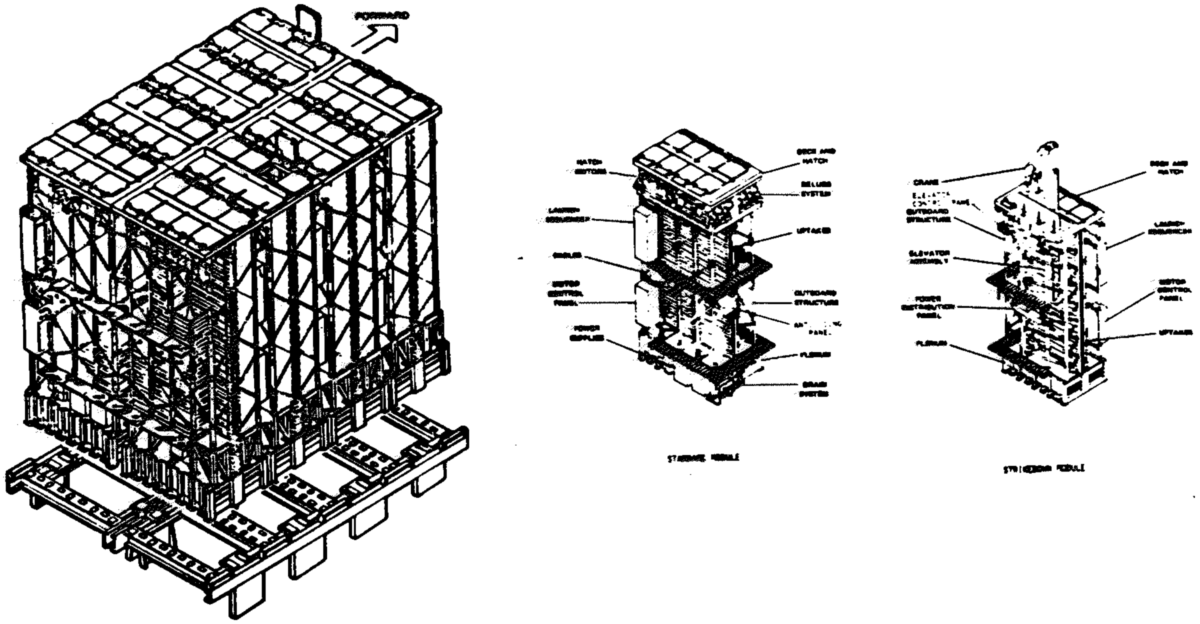


FIGURE 2 VLS 61- MISSILE LAUNCHER

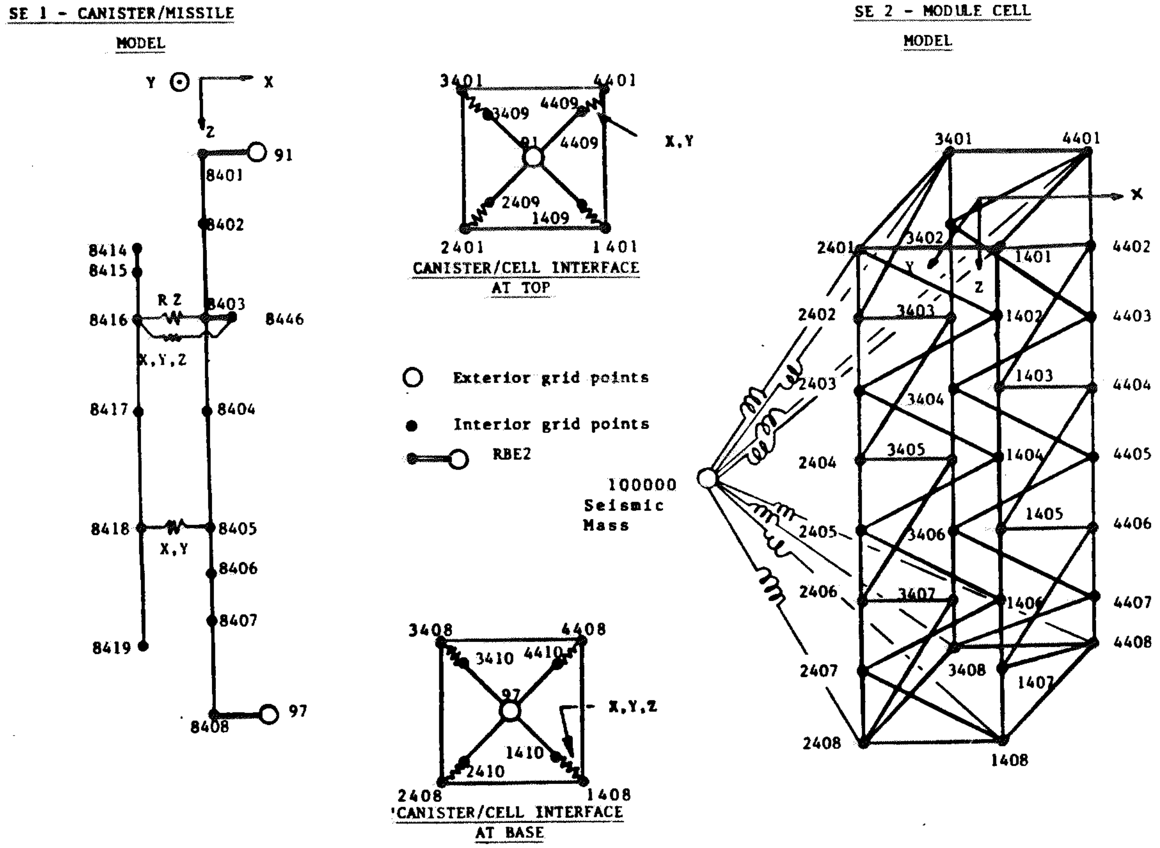
using GDR. Since there were up to 30 SE's for one launcher model, the residual structure model became very large and GDR method was inefficient [4]. Therefore, Guyan Reduction was selected for the residual structure. Guyan Reduction requires the user to select the dynamic analysis set (A-set) which controls the accuracy of the analysis. In order to optimize the A-set selection for the VLS residual run, several A-set selection studies were performed for small local models prior to the final analysis. This paper presents a study using the normal mode analysis.

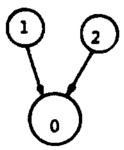
FINITE ELEMENT MODEL

A local model of a single cell out of one launcher module with one missile/canister was selected for the study. Figure 3 shows the finite element models for the missile/canister and the module cell. The missile and the canister were modeled as stick models with BAR elements. The missile elements were connected to the canister elements with elastic spring elements (ELAS2). The missile was supported in the canister at forward and aft shoes in the lateral (x and y) directions and at forward shoe in the vertical (z) direction. The cell model was a square structure model with BAR elements.

CANISTER TO CELL INTERFACE

The interface between the canister and the module cell was assumed similar to the module-to-canister interfaces for the whole VLS. The only vertical support for the canister is at the base. Since the canister fits in the square cell tightly, its top and base are supported in x and y directions at all four corners. The x and y interfaces between the canister and the module cell were modeled as elastic springs (ELAS2). Both top and bottom corners of the canister are connected to the center of the canister with RBE2 rigid





SUPERELEMENT TREE

FIGURE: 3 SINGLE CELL WITH CANISTER/MISSILE MODEL elements as shown in Figure 3 (GP 91 and 97). The top and base grid points (GP8401 and 8408) of the canister stick model are also connected rigidly with these exterior points.

ANALYSIS APPROACH

This paper presents a single cell study using the normal mode analysis. GDR is considered to give excellent accuracy of normal modes [4]. This study started with two analyses using GDR for the one cell module: one without the SE breakdown and the other with the SE breakdown. SE 1 (canister/missile) has approximately 100 DOF's and SE 2 (cell structure) has approximately 300 DOF's.

The boundary conditions had to be determined for each SE in the calculations. Reference [5] recommends using "natural" boundary conditions for the component modes runs. Benfield and Hruda [6] recommended that for component mode synthesis "either free-free or constrained boundary condition may be selected, except for one condition: if an interface of a component is fixed, then the corresponding interface of the connected component must be free". In this paper, several SE boundary conditions were used. The eigenvalue analysis of SE 1 and SE 2 involved a GDR followed by the extraction of eigenvalues with the modified Givens Method (MGIV) which is the most efficient method [4]. Table 1 describes the boundary conditions used for component modes solutions for the three cases of GDR. Table 2 gives the frequencies and CPU time comparison for component modes for the three cases.

Modes for the residual structure shown in Figure 3 were obtained by using MSC/NASTRAN SOL 63 with non-superelement GDR and three cases

Table 1 Boundary Conditions For Superelement Component Modes

Component	Boundary Conditions					
	Case					
	I		II		III	
	RBE2	CSET	RBE2	CSET	RBE2	CSET
SE1	91(123456) 97(123456)	- -	91(126) 97(123456)	- -	91(126) 97(123456)	- 97(45)
SE2	91(123456) 97(123456)	91(12) 97(12345)	91(126) 97(123456)	91(12) 97(12345)	91(126) 97(123456)	- 97(45)

Table 2 Component Modes Frequencies For SE 1 And SE 2

Mode	Frequency (HZ)					
	Case I		Case II		Case III	
	SE 1	SE 2	SE 1	SE 2	SE 1	SE 2
CPU Sec	6.522	9.121	6.301	9.859	6.573	8.595
1	28.96	39.40	22.56	39.40	12.73	39.78
2	30.51	39.40	23.20	39.40	12.80	39.78
3	46.44	39.21	46.39	99.21	39.07	101.32
4	66.56	39.21	49.96	99.21	46.35	101.32
5	70.82	103.65	70.53	103.65	49.96	103.69
6	84.53	129.16	81.25	129.17	80.39	137.11
7		137.11	92.02	137.11	88.94	139.49
8		148.49		148.49	95.32	148.50
9		149.42		149.42		149.42

Table 3 Frequency Comparison Between Non-Superelement GDR And Superelement GDR

GDR Case	Total CPU Sec	Frequency (HZ)										
		1	2	3	4	5	6	7	8	9	10	11
		Y	X	X	Y	X	Z	Y	Z	X	Z	X
NONSE	11.951	21.88	22.46	39.33	39.65	46.38	49.48	67.79	81.17	90.68	97.13	98.69
I	25.763	21.89	22.46	39.33	39.65	46.39	49.54	67.80	81.54	-	97.12	99.42
II	25.057	21.88	22.46	39.33	39.65	46.38	49.48	67.80	81.17	90.68	97.15	99.52
III	25.068	21.88	22.46	39.33	39.65	46.40	49.48	67.86	81.18	90.71	97.15	99.70

of superelement GDR. The MGIV method of eigenvalue extraction was selected. The cut-off frequency described on DYNRED and EIGR cards was 100 HZ. Table 3 gives the comparison of frequencies between the non-superelement GDR case versus superelement GDR cases. All three cases (I - III) gave nearly identical eigenvalues up to 91 HZ. Case I showed one fore-aft mode missing whereas other two cases did not show any missing modes. In the ship shock environment, the vertical response is considered most critical for VLS. Therefore, one missing mode in fore-aft direction was considered not significant. Also the frequency (91 HZ) of the missing mode was high considering that the VLS launcher fundamental frequencies lie in the range of 20 to 40 HZ.

The same one cell model with SE's was re-analyzed with Guyan Reduction for the residual structure. The A-set was varied until the minimum A-set was reached and the eigenvalues still approached those of GDR analysis. For processing of the residual structure with Guyan Reduction, the MGIV method of eigenvalue extraction was again selected. Several residual runs with different A-sets were made for the boundary conditions of the cases I, II, and III.

Tables 4, 5, and 6 provide the comparison for the different residual runs for the boundary conditions of Cases I, II, and III. In general, the CPU time required for the residual with Guyan reduction was 10% lower than the GDR residual for the single cell model. The size of the A-set can be reduced considerably as shown in the results in Tables 4, 5, and 6. Best results were obtained for boundary conditions of Cases II and III for frequencies up to 91 HZ. Three modes were missing in Case I. The frequencies of the missing modes were very high (above 90 HZ) and considered unimportant. Inclusion of rotational x and y DOF's for interior grid points in the A-set was

Table 4 Frequency Comparison Between Superelement GDR And Superelement Guyan Reduction Case I

Solution Case	A-SET	Total CPU Time (Sec)	Frequency (HZ) 1	2	3	4	5	6	7	8	9	10	11
			Y	X	X	Y	X	Z	Y	Z	X	Z	X
GDR	SPOINTS	25.763	21.89	22.46	39.33	39.65	46.39	49.54	67.89	81.54	—	97.12	99.42
Guyan R.													
Run 1	91(12), 97(123)	24.11	28.92	30.46	46.01	46.08	46.44	65.59	70.47	84.52	-	-	-
Run 2	91(45), 97(345)	24.13	21.91	22.49	39.74	40.06	46.46	65.16	68.06	81.79	-	-	-
Run 3	91(345), 97(12345)	24.14	21.90	22.47	39.40	39.74	46.41	49.54	67.84	81.56	-	-	-
Run 4	91(345), 97(345)	23.946	21.91	22.49	39.73	40.05	46.41	49.53	68.06	81.57			
Run 5	91(345), 97(345)*	24.431	21.91	22.49	39.73	39.06	46.41	49.54	68.06	81.57	-	-	-

Table 5 Frequency Comparison Between Superelement GDR And Superelement Guyan Reduction Case II

Solution Case	A-set	Total CPU Time (Sec)	Frequency (HZ) 1	2	3	4	5	6	7	8	9	10	11
			Y	X	X	Y	X	Z	Y	Z	X	Z	X
GDR	SPOINTS	25.057	21.88	22.46	39.33	39.65	46.38	49.48	67.80	81.17	90.68	97.15	99.52
Guyan R.													
Run 11	91(12) 97(12345)	23.125	21.88	22.46	39.33	39.65	46.38	49.48	67.81	81.17	90.72	-	99.52
Run 12	91(12) 97(345)	23.028	21.91	22.49	39.64	39.95	46.39	49.48	68.04	81.19	90.93	-	-
Run 13	91(45) 97(345)	23.242	21.91	22.49	39.72	40.05	46.41	49.48	68.06	81.20	91.06	-	-
Run 14	91(12) 97(123)	23.116	22.54	23.19	46.00	46.08	46.39	49.48	70.23	81.23	91.85	-	-
Run 15	91(-) 97(345)	23.098	21.91	22.49	39.72	40.05	46.41	49.48	68.06	81.20	91.06	-	-
Run 16*	91(12) 97(12345)	23.136	21.88	22.46	39.33	39.65	46.38	49.48	67.81	81.17	90.72	-	99.52

Table 6 Frequency Comparison Between Superelement GDR And Superelement Guyan Reduction Case III

Solution Case	A-set	Total CPU Time (Sec)	Frequency (HZ) 1	2	3	4	5	6	7	8	9	10	11
GDR	SPOINTS	25.068	21.88	22.46	39.33	39.65	46.40	49.48	67.86	81.18	90.71	97.15	99.70
Guyan R.													
RUN 21	91(12), 97(123)	23.167	22.54	23.19	46.0	46.08	46.40	49.48	70.33	81.25	91.96	-	-
RUN 22	91(12), 97(12345)	23.001	21.88	22.46	39.33	39.65	46.40	49.48	67.87	81.18	90.75	-	98.70
RUN 23	91(345), 97(345)	23.289	21.91	22.49	39.72	40.05	46.42	49.48	68.13	81.21	91.11	-	-
RUN 24	91(12), 97(345)	22.918	21.91	22.49	39.64	39.95	46.40	49.48	68.11	81.20	90.97	-	-

Note: A-set also includes following DOF's

- Seismic mass 1000000 (123)
- Spoints for component modes
- Interior grid point DOF's 1401 (123), 3401 (123), 1408 (123), 3408 (123)

* A-set did not include interior grid point DOF's

surprisingly important as shown in Table 4 for runs 2 through 5. Also, some DOF's for interior grid points when included in the A-set improved the eigenvalue solution for the residual run (runs 4 and 5).

For Case I, GP's 91 and 97 were rigidly attached to four corners at the top and the base of the canister in all six DOF's. Case I boundary conditions introduced rigid body rotations at the top of the canister. So it was important to include rotational DOF's in the A-set for the canister top. In Case II, the top of the cansiter was rigidly attached to GP 91 only in the x, y, and Rz directions. For this case, Run 11 shows it was not necessary to include rotational DOF's for GP 91 in the A-set. But it was necessary to include rotational (Rx, Ry) DOF's for GP 97. Although there was one mode missing for this case, the fundamental frequencies were close to the non-superelement solution.

Case III had mixed boundary conditions. The top interface between the two SE's was constrained whereas the base interface had free-free rotational x and y DOF's. The results for Case III were similar to those in Case II. There were two modes missing in Case III.

CONCLUSION

Local studies were extremely helpful in the A-set selection for the VLS residual model. Surprisingly, a few rotational DOF's which would have been excluded from the A-set normally, had high impact to the results and had to be included in the A-set. This was confirmed by different SE boundary conditions. An optimized A-set based on this study was later selected for all 61 cells in the launcher model. The final A-set size in the VLS analysis [1,2] was about 1400. Without the verification from the local model studies, this A-set size might have been doubled which would have increased the cost of the Givens method tremendously.

The cost saving of using Guyan reduction for VLS structure residual run was considerable. However, a careful A-set study was critical for the SE interfaces to assure the accuracy of Guyan reduction. It is highly recommended in a complex superelement model.

REFERENCES

1. "VLS Dynamic Design Analysis Method (DDAM) Pretest Report for CG 53 Shock Trials," BR101, Martin Marietta Baltimore Aerospace, December 1986.
2. "VLS Transient Analysis Pretest Report for CG 53 Shock Trials," BR110, Martin Marietta Baltimore Aerospace, February 1987.
3. "MSC/NASTRAN, Handbook for Superelement Analysis", edited by M.A. Gockel, the MacNeal-Schwendler Corporation, Los Angeles, California.
4. "MSC/NASTRAN, Handbook, for Dynamic Analysis", edited by M.A. Gockel, the MacNeal-Schwendler Corporation, Los Angeles, California.
5. "MSC/NASTRAN, Application Mannal", edited by Jerrard J. Joseph, Application Note - (Oct/Nov 1979), the MacNeal-Schwendler Corporation, Los Angeles, California.
6. Benfield, W.A. and Hruda, R.F., "Vibration Analysis of Structures by Component Mode Synthesis" AIAA Journal, Vol 9, No. 7, July 1971.