INTRODUCTION

The now rather familiar helicopter model was used to compare the method of static condensation vs. the method of component mode synthesis. The helicopter model has developed along with MSC/NASTRAN. Originally the conventional solution, rigid format 3, normal modes was used for the analysis. The model was redefined using the superelement technique, first as a single level substructing model and then into a multilevel substructuring model. Up to this point the Guyan method of static condensation was used to reduce the model from an original medium size static model to an acceptable size for normal modes analysis. With the development of the generalized dynamic reduction capability, the helicopter was reanalyzed using both superelements, generalized dynamic reduction and component mode synthesis.

Description of Model

The advanced attack helicopter during some period in the development stage is shown in Figure 1. The original static MSC/NASTRAN model is illustrated in Figure 2. The structure was modeled using CBARs for the formers and mast base, CØNRØDs and CSHEAR panels for the fuselage shell structure, and for major frames CRØDs and CQDMENs were used for detailed modeling. In addition, all structural and non-structural mass was lumped entirely into CØNM2 mass elements and RBE3, whiffletree elements, distributed the mass effects to the structure. The static analysis was performed using rigid format 2, statics with inertia relief.

The general statistics for the model are shown in Figure 3. As you may notice the model is fairly straight-forward for such a large structure. The model was originally designed to analysis only the monocoque structure, however, it grew to encompass almost every significant structural item except the control systems.

Guyan Reductions

The Guyan reduction model is shown in Figure 4. The analysis set grid points are defined by the engineer in what is hopefully a logical and descriptive manner. In this problem the A-set points (110 dynamic degrees of freedom) have been joined by PLOTELs (plot only elements) in order to obtain reasonable plots of the static condensation.

The following rules are about all the engineer has available to determine the A-set points.

Static Condensation (Guyan Reduction)

Separate free D.O.F's (u_f) into an omitted set (u_o) and an analysis set (u_a), by means of ØMIT cards or ASET cards.

1. Retain only a small fraction of the D.O.F.'s (typically 20% or less) in the analysis set, because the computer cost for static condensation increases rapidly with the size of the analysis set. Otherwise retain all of the D.O.F.'s

2. Retain D.O.F.'s with large concentrated masses in the analysis set.

3. Retain D.O.F.'s sufficient to describe the modes shapes.

The method may require several iterations for convergence for real engineering structures in order the meet the third requirement.

Superelement Element Model

At this time the prototype helicopter was in constant redesign. The wings were shortened, the horizontal moved from a low position to a T-tail configuration, the squirrel cheeks added for avionics, a new night vision system added to the nose and many more changes. In order to keep the model up to date and yet stay within a budget, the model was converted to a superelement configuration as shown in Figure 5.

Guyan Reduction in Superelements

The Guyan reduction method was still used in the analysis. In a superelement analysis the use of Guyan reduction is essentially a double reduction technique. First, the stucture is reduced to the residual structure as shown in Figure 6 (all the x's and circles).

Second, through the definition of A-set points, a Guyan reduction is performed reducing to the final dynamic degrees of freedom used for the analysis as indicated by the circles alone. Figure 7 shows the cost information of these configurations in the development of the models. Each configuration incorporated Guyan static condensation.

Generalized Dynamic Reduction

Following the development of GDR the helicopter model was reanalyzed using generalized dynamic reduction.

At MSC when a new capability such as GDR is developed, it is initially tested with small problems for functional capability, then large problems with closed form solutions are tested for accuracy studies such as rectangular plates. A moderately large problem from practice is then solved. The helicopter model is typical of many engineering structures in that it has complicated load paths, a mixture of element types, many localized modes of vibration, and in general is a "dirtier" numerical problem than a rectangular plate.

As only four superelements were of even moderate size in the helicopter model, GDR was applied to them only. The mass distribution of the smaller superelements such as the mast base and engine assemblies is lumped on only a few physical points. The auto-omit feature reduced the eigenvalue problem for these superelements to an acceptable size without GDR.

In superelements, massless points are automatically given the omit operation, both at the component level and in the system assembly phase.

The helicopter model does afford us the opportunity to use a reasonable size engineering problem. The procedure outlined in Figure 8 demonstrates the simplicity of GDR. For the helicopter all the original A-set D.O.F.'s for Guyan reduction were removed from the problem.

In Figure 9 an example of the requirements for GDR is shown. A set of cards such as these need to be included for each superelement using dynamic reduction. As mentioned previously, only the major superelements were reduced using GDR. Component modes are requested by placing METHOD cards in the case control for each superelement and referencing conventional EIGR cards.

Figure 10 lists the eigenvalues found using the Guyan method in superelemnt analysis, and the ratio of the eigenvalues found using GDR vs. Guyan reduction. All reduction methods are equivalent to placing constraints on the model. Therefore, the method with the lower natural frequencies is the more accurate answer. As shown all but one of the frequencies is less than or equal to the Guyan method. Several useful side effects have been incorporated into GDR, Figure 11.

Useful Side Effects

(PARAM,FIXEDB,-1)

During any stage of the development of a Nastran model, through the use of this parameter, the user is able to compute the uncoupled modes on any individual superelement. This can be a very valuable checkout tool; if the modes of a single superelement are not plausible the user can check that particular structure. The user has the option of fixing the boundary, freeing the boundary, or any combination, whichever best represents the structure, the test system, or the user's understanding of the problem.

(PARAM,SESEF,-1)

For each superelement its contribution to the total strain energy of each mode can be computer, helping the user identify each mode and evaluate the sensitivity of each component to changes necessary to improve the overall performance. One of our clients at a previous user's conference had requested this capability and we have found it to be very useful.

For any model and each superelement the user has a choice of four paths, as shown in Figure 12. Inherent in superelements is a static reduction to the boundaries, the user then has four choices.

1. Straight solution no further reduction; 4,5 - engines, 7 - gun; 8,9,11,13 - pylons, 0-residual.

2. Component modes calculations without GDR, 6 - mast base.

3. GDR only - which is rather academic we did not use this path.

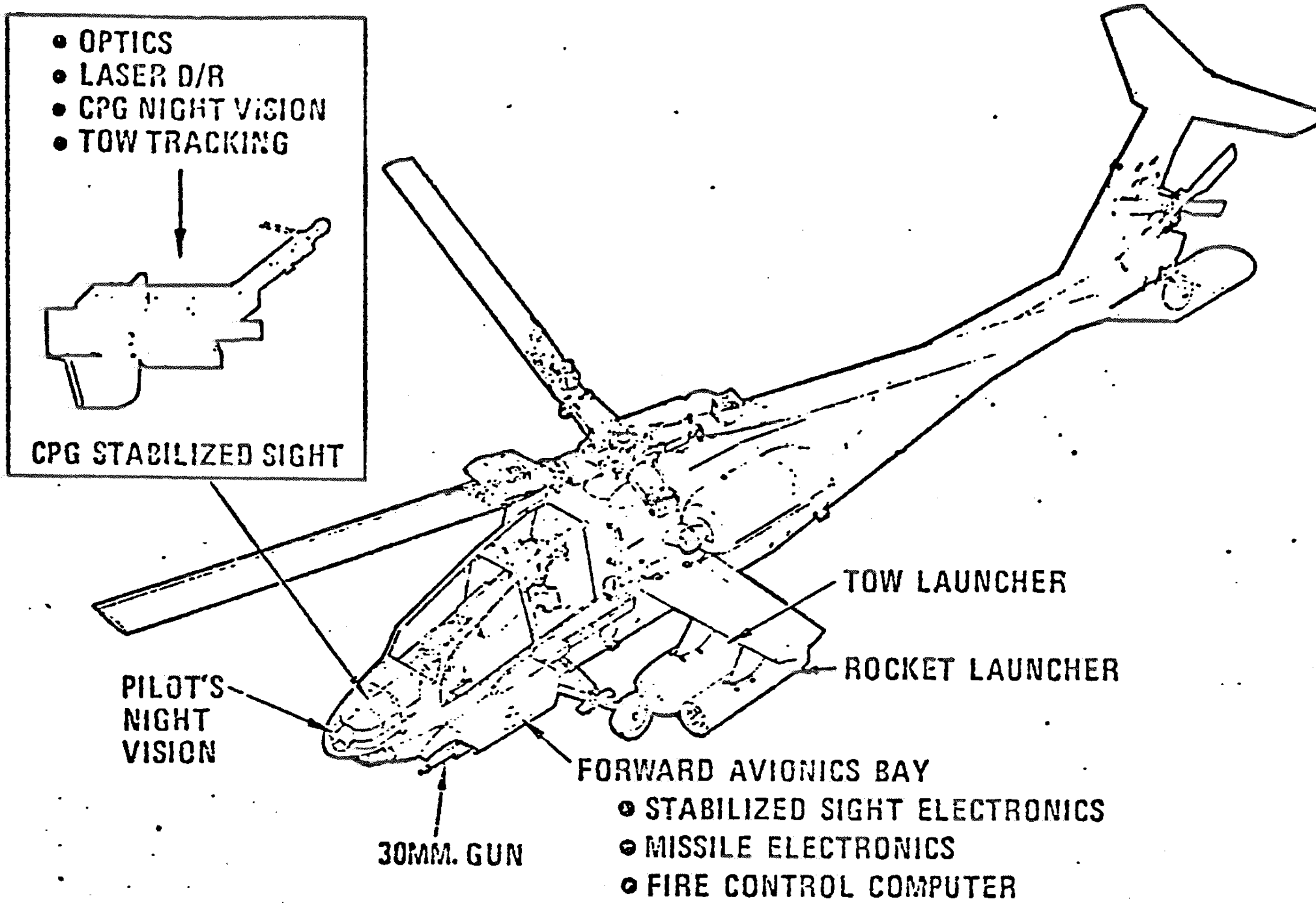
4. GDR and CM for large superelements; 1,2,3 and 10 body and empennage.

Modeling Lessons Learned

1. On the helicopter model it was found that static reduction was adequate for the residual structure because of the high density of the boundary matrices causing high costs for GDR. We tried using GRD, however the results were not improved and the cost was more.

2. Second we found it necessary to include at least 6 D.O.F.s at each boundary in the A-set. On our first try without these six boundary D.O.F.'s the structural response appeared to have grounded boundaries. The RBE3 (whiffletree) was useful for this purpose. In this case, the D.O.F.'s are included on the RBE3 and the boundary points are be default omitted. Also the generalized coordinates should by included using A-set cards. However, if excessive generalized D.O.F.'s are computed they can be placed on SPC cards and removed from the final analysis.

3. An finally we found that the fixed boundary components are easier to understand than free or mixed boundary conditions.



(SEE "AVIATION WEEK" AUGUST 18, 1975)

ADVANCED ATTACK (YAH-64) HELICOPTER STRUCTURE

Figure 1

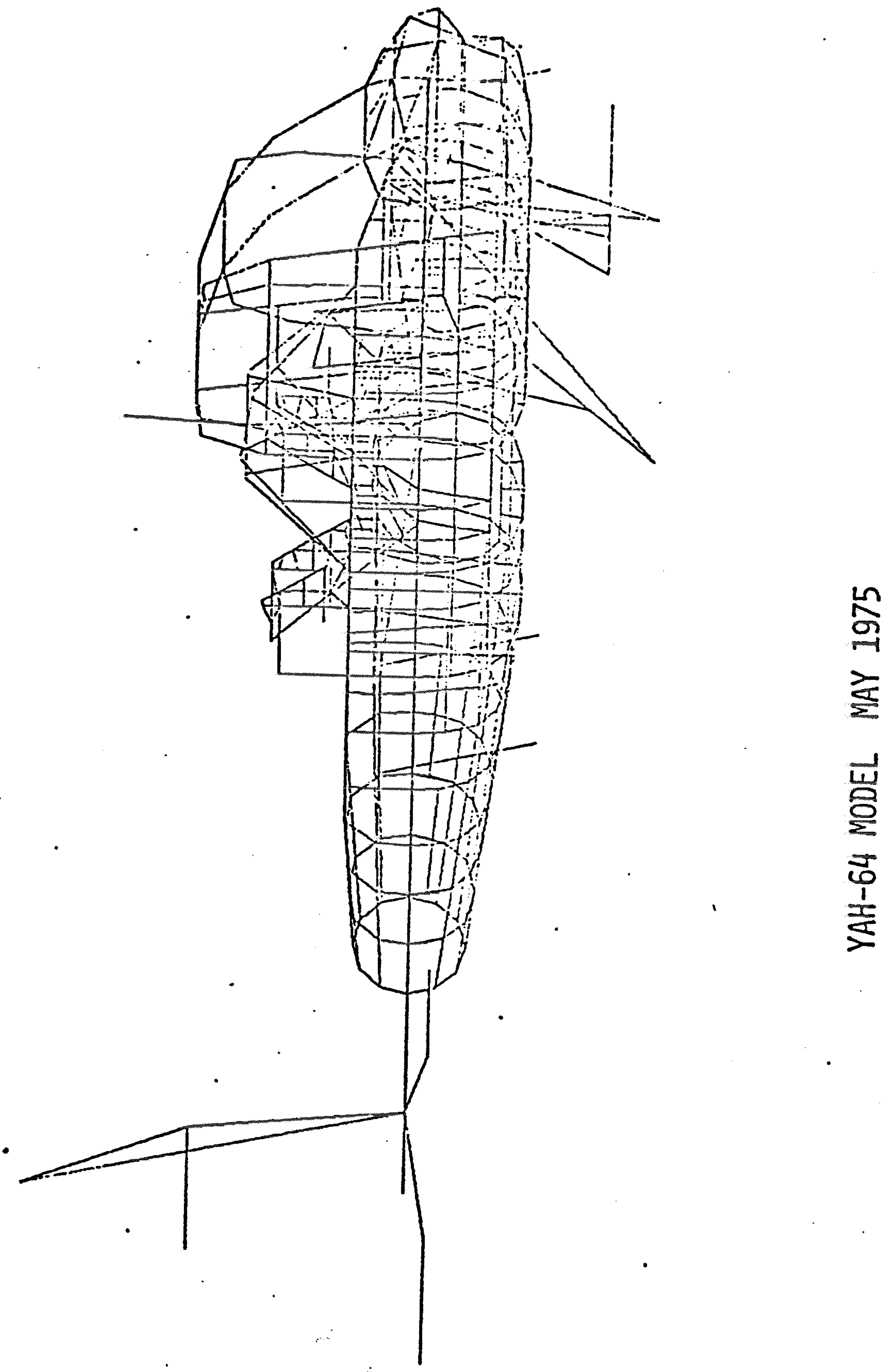


Figure 2

YAH-64 MATH MODEL STATISTICS

Number of Grid Points	695
Number of Degrees of Freedom	2800
Number of Finite Elements	2300
Number of Mass Points	100
Number of Vibration Modes of Interest	50

Figure 3

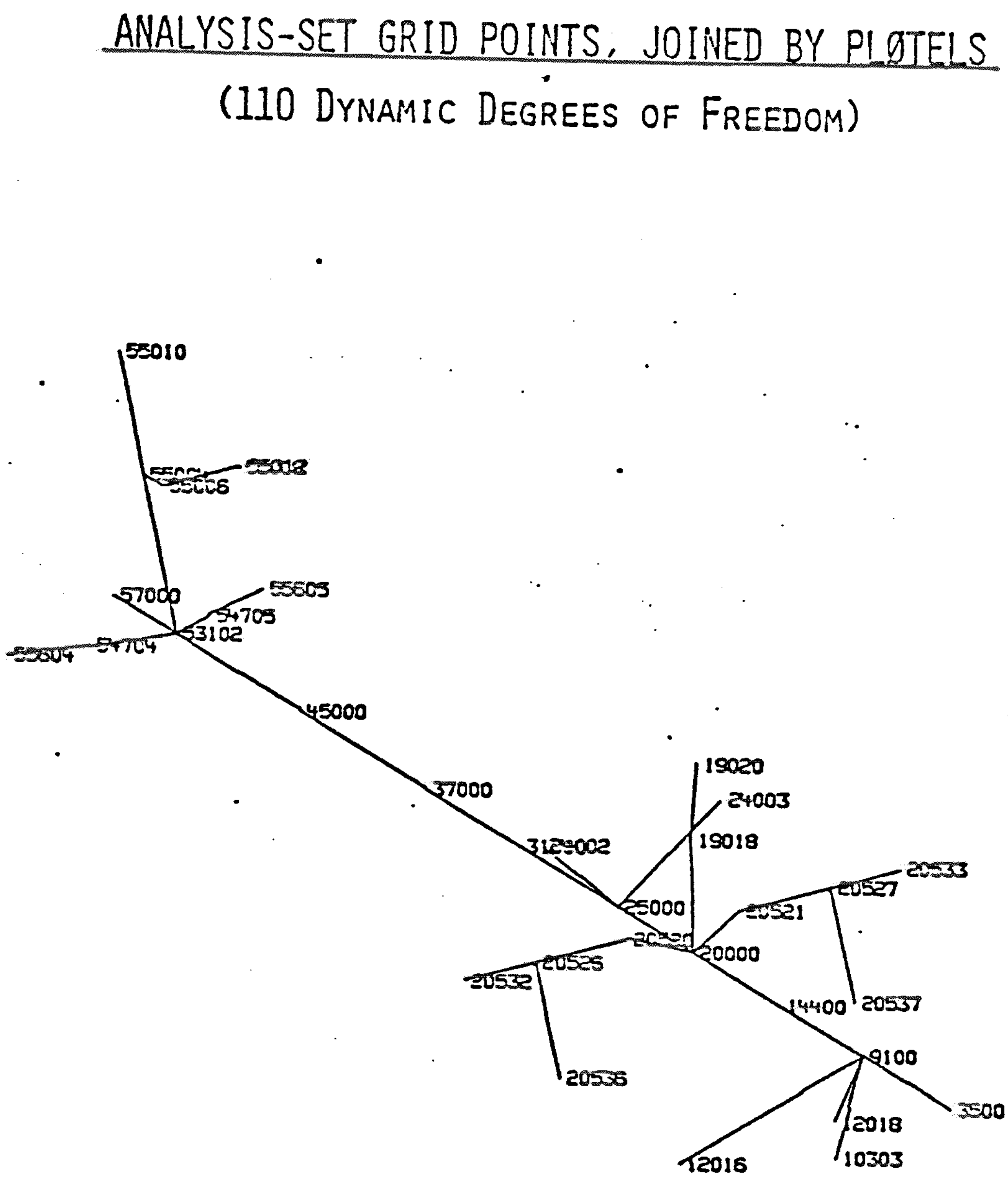

ANALYSIS-SET GRID POINTS, JOINED BY PLØTELS
(110 DYNAMIC DEGREES OF FREEDOM)
55010
55012
55006
57000
55605
54705
53102
55604
54704
45000
37000
3129002
19020
24003
19018
25000
20533
20527
20521
20000
20526
20532
14400
20537
9100
20536
3500
12018
12016
10303

Figure 4

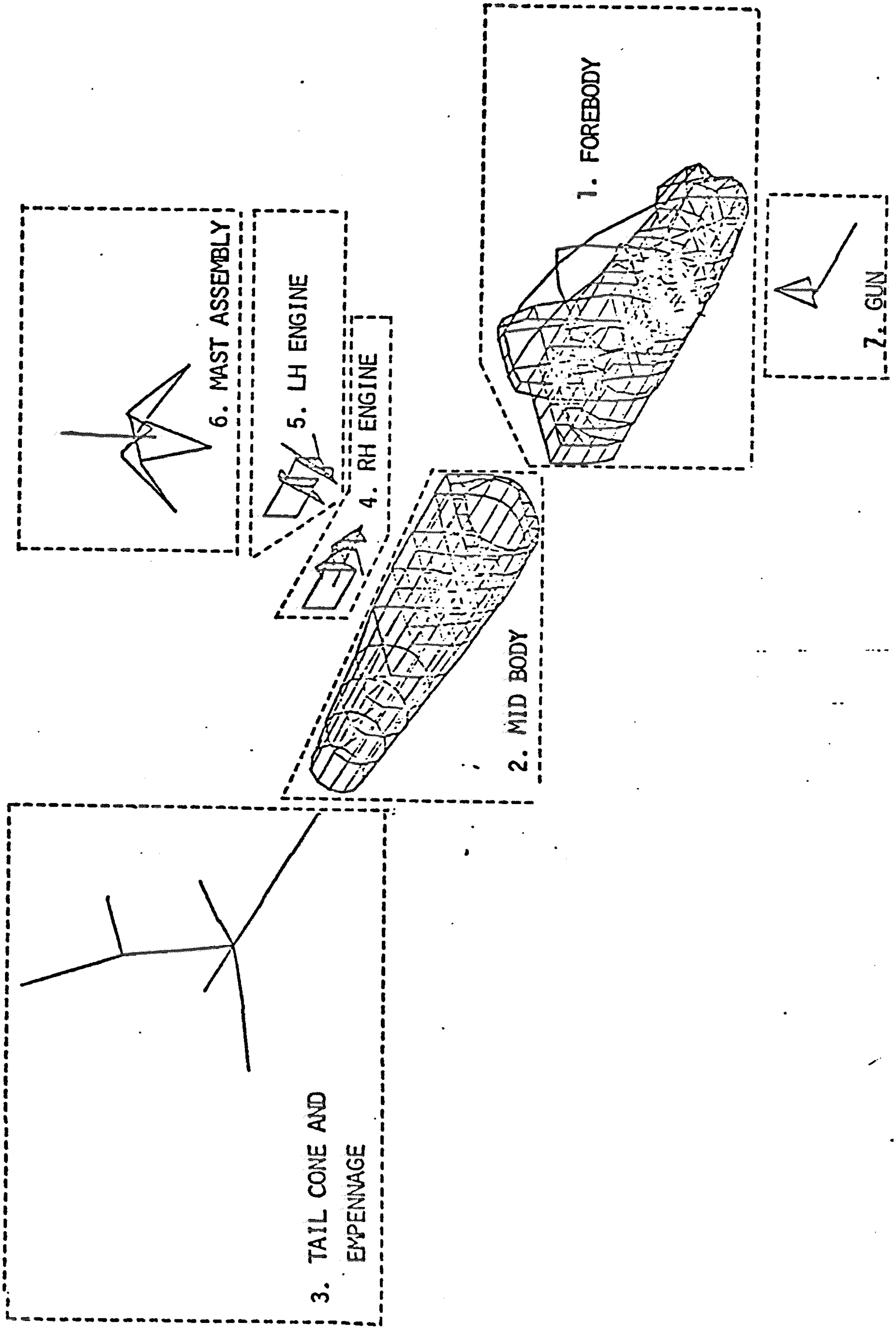
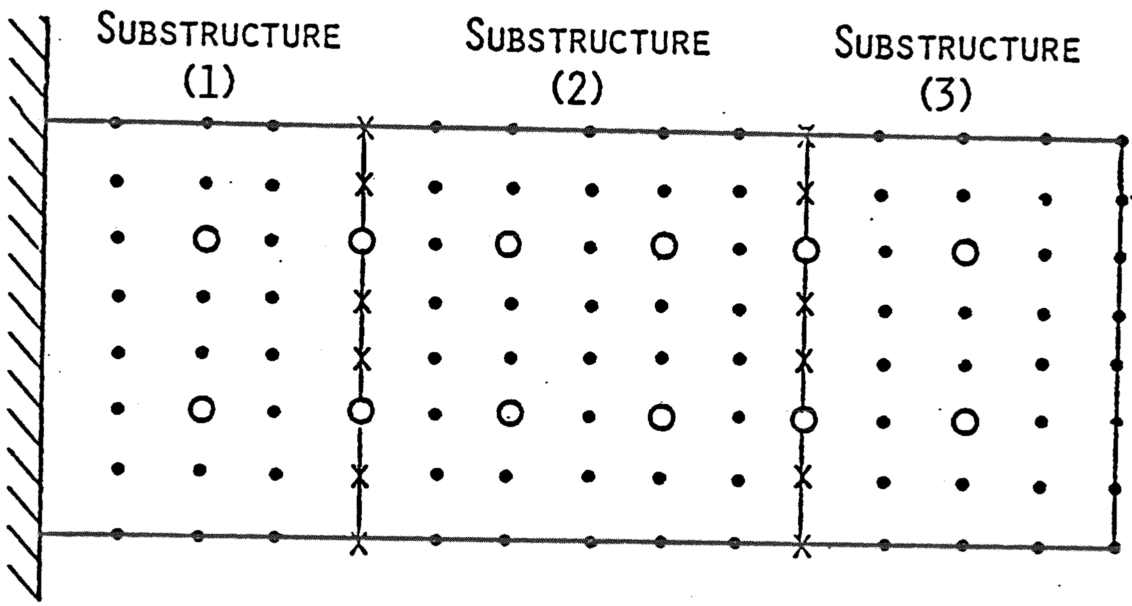

1. FOREBODY
2. MID BODY
3. TAIL CONE AND EMPENNAGE
4. RH ENGINE
5. LH ENGINE
6. MAST ASSEMBLY
7. GUN

Figure 5

THE DOUBLE GUYAN REDUCTION



• D.O.F.'S REMOVED DURING FIRST GUYAN REDUCTION

X EXCESS BOUNDARY D.O.F.'S REQUIRED TO JOIN SUBSTRUCTURES AND REMOVED DURING THE SECOND GUYAN REDUCTION

O DYNAMIC DEGREES OF FREEDOM

SOLUTION IDENTICAL TO SINGLE REDUCTION, ONLY CHANGE IS IN ORDER OF OPERATIONS

Figure 6

TOTAL COST COMPARISONS

	Relative Cost Units	
	Guyan Reduction	Substructures (Double Guyan Reduction)
Total Solution One Shot	1940	2070
Minor Structural Change	1940	760

Figure 7

GENERALIZED DYNAMIC REDUCTION PROCEDURE CAN BE USED WITH SUPERELEMENTS

- USE A SEPARATE DYNRED CARD FOR EACH SUPERELEMENT (SELECT IN CASE CONTROL)
- USE SEQSETi TO IDENTIFY GENERALIZED COORDINATES
- ALSO PUT GENERALIZED COORDINATES ON ASET OR ASET1 CARDS

Figure 8

NEW DYNAMIC REDUCTION PROCEDURE

EXAMPLE OF BULK DATA DECK SET-UP

DYNRED	SID	FMAX	NIRV	NIT	IDIR	NCMAX	NCDES	AUTØSEL
DYNRED	2	20.0						YES

NCMAX: LEAVE BLANK

SPØINT	ID1	"THRU"	ID2					
SPØINT	10001	THRU	10050					

SEQSET1	SEID	ID1	"THRU"	ID2				
SEQSET1	10	10001	THRU	10050				

ASET1	C	ID1	"THRU"	ID2				
ASET1	0	10001	THRU	10050				

ID2 - ID1 + 1 = NCMAX

NCMAX > 1.5 * (NUMBER OF MODES BELOW FMAX)

SUPERELEMENT DMAPS ONLY

ID1 NOT RESTRICTED

Figure 9

ACCURACY OF GRD VS. GUYAN FREQUENCIES

MODE NO.	GUYAN	GDR / GUYAN
1	0.0	0
2	0.0	0
3	0.0	0
4	0.0	0
5	0.0	0
6	0.0	0
7	4.239	.9988
8	5.376	.9995
9	6.253	1.0000
10	6.360	.9999
15	7.707	.9998
20	10.596	1.0005
30	17.380	.9969

Figure 10

USEFUL SIDE EFFECTS

1. UNCOUPLED MODES OF EACH SUPERELEMENT (PARAM, FIXEDB, -1)

   IF UNCOUPLED MODES NOT PLAUSIBLE, DELAY SYSTEM ASSEMBLY UNTIL BUGS FOUND.

2. STRAIN ENERGY DISTRIBUTIONS (PARAM, SESEF, 1)

MODE	PERCENT OF STRAIN ENERGY			
	NOSE	MIDBODY	TAIL CONE	ETC.
7	50	10	10	
8	10	60	10	
9	10	10	70	
⋮	⋮	⋮	⋮	
30	.	.	.	

UNAMBIGUOUS METHOD FOR NAMING MODES, IDENTIFYING MOST SENSITIVE COMPONENT FOR CHANGES.

Figure 11

REDUCTION PATHS

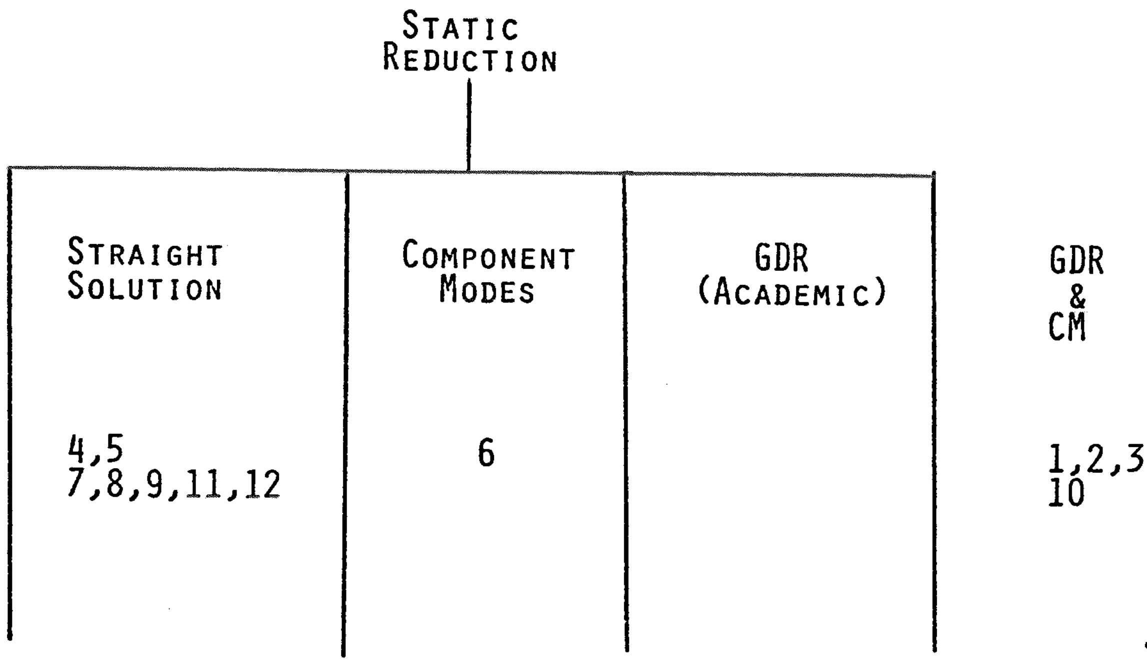


Figure 12

MODELING LESSONS LEARNED

1. ON THIS CLASS OF STRUCTURE STATIC REDUCTION IN RESIDUAL STRUCTURE ADEQUATE, BECAUSE OF HIGH DENSITY OF BOUNDARY MATRICES.

2. FOR THE ASET, INCLUDE AT LEAST 6 DOF'S AT EACH BOUNDARY. THE RBE3 ("WHIFFLETREE") IS USEFUL FOR THIS PURPOSE. ALSO INCLUDE GENERALIZED COORDINATES. BY DEFAULT, OMIT BOUNDARY POINTS.

3. FIXED-BOUNDARY COMPONENTS EASIER TO UNDERSTAND THAN FREE- OR MIXED BOUNDARY COMPONENTS.

Figure 13