SPACE STATION SOLAR ARRAY POINTING SYSTEM CONTROL/STRUCTURE INTERACTION STUDY USING CO-ST-IN FOR MODAL REDUCTION

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ABSTRACT

The control/structure interaction problem of orienting the Space Station Freedom (SSF) PhotoVoltaic arrays is solved to achieve desired system pointing performance using the Beta Gimbal Drive Mechanism. The vibration modes of the on-orbit SSF Stage Configuration 17 are calculated using MSC/NASTRAN finite element models which presently comprise a total of 250,000 degrees of freedom. In-house Direct Matrix Abstraction Programs and post-processors are developed for more efficient and accurate Craig-Bampton modal reduction with geometric stiffening and either modal displacement or modal acceleration data recovery. Structural Dynamic Research Corporation's CO-ST-IN post-processor is used to rank the vibration modes for control system analysis. The problem of solving an actual case of ranking modes using CO-ST-IN for large-scale SSF application is illustrated. Examples of calculated control system response including the effects of reduced flexible mode dynamics are shown.

INTRODUCTION

In controls analysis, one usually deals with a small set of linear/non-linear second-order uncoupled differential equations. On the other hand, in structural analysis one usually deals with a large set of linear coupled/uncoupled differential equations. Large-scale Finite Element Model (FEM) programs like MSC/NASTRAN (Reference 1) can be used to generate control models which may often have in excess of 100,000 equations . Therefore, full-scale MSC/NASTRAN models would seldom, if ever, be used in control-structure interaction studies. In cases where an MSC/NASTRAN model would be used, in all probability it would be a simple stick model. The number of vibration modes, and in turn the number of controls equations, would thus only be a handful.

However, starting with detailed structural FEMs one can derive a handful of linear differential equations of controls. This paper demonstrates a method of how this has been accomplished with existing MSC/NASTRAN models of the space station (Reference 2) in a cost-effective, fast and simple way.

METHODOLOGY

The first step in the process is to generate a system vibration mode model. This can be performed in two ways. When the system consists of one component, the modal model can be made directly from the system FEM. Alternatively, a system modal model can be synthesized from individual component modal models generated from component FEMs. The next step is to convert the structural modal model to a control system model using appropriate Direct Matrix Abstraction Programs (DMAPs). Finally, based on well defined controller inputs and outputs, the modes are ranked in order of importance.

SOFTWARE USED

The following software were used in the analysis:

- MSC/NASTRAN finite element program;
- S-PRO Substructure Processing Software System (Reference 3);
- CUPL-TRAN Software System for Coupling Substructures and Calculating Transient Response (Reference 4).
- CO-ST-IN Control Structure Interaction program (Reference 5);

CASE STUDY

System model generation and modal reduction

The Space Station Freedom (SSF) Stage Configuration (SC) 17 model that was analyzed is shown in Figure 1. It consists of the following ten individual component models which contain a total of 250,000 physical degrees of freedom:

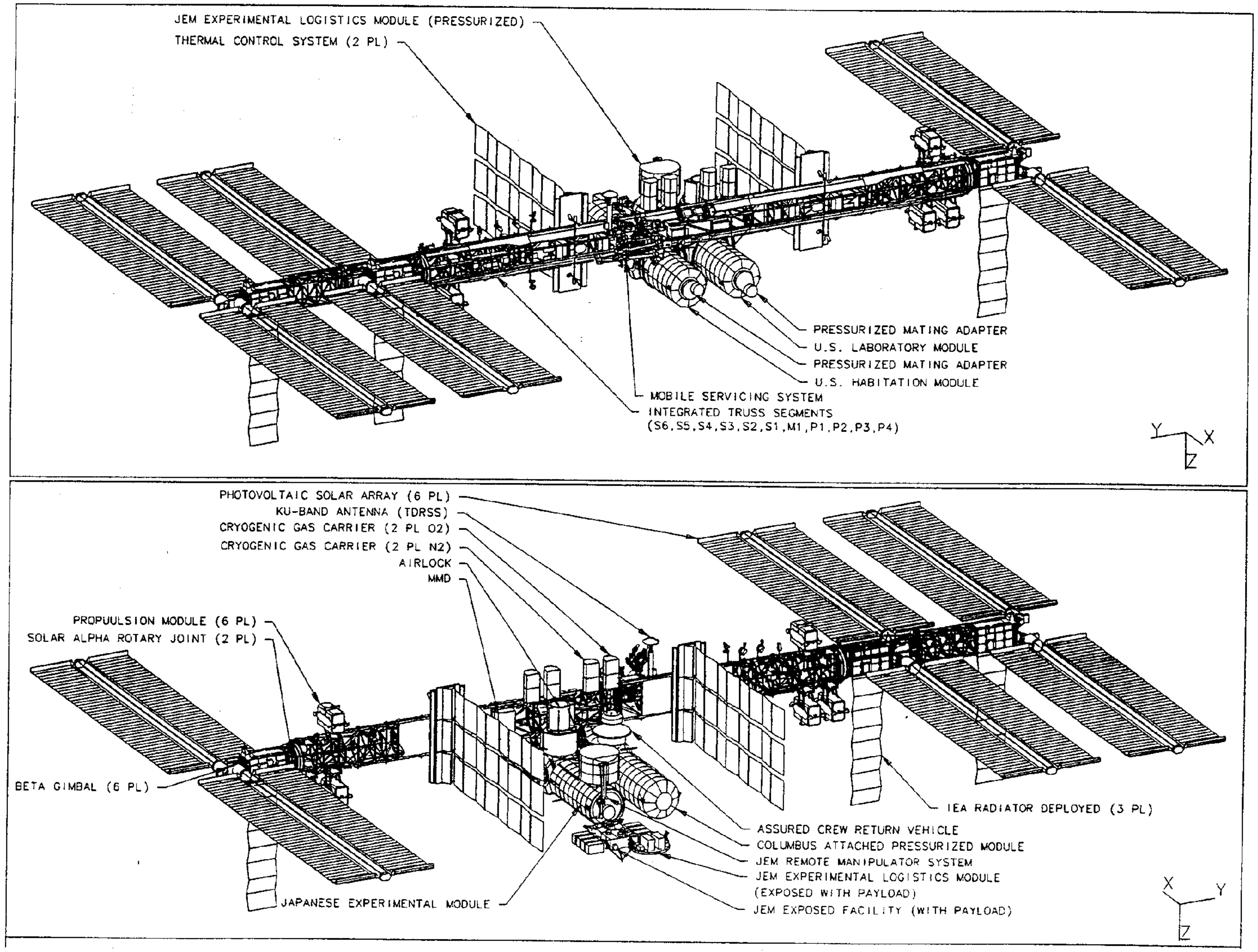

FIGURE-1: SPACE STATION FREEDOM ON-ORBIT SC-17 CONFIGURATION

Component 1: Center truss
Component 2: starboard inboard upper PhotoVoltaic (PV) array
Component 3: starboard outboard upper PV array
Component 4: starboard outboard lower PV array
Component 5: starboard inboard lower PV array
Component 6: port inboard upper PV array
Component 7: port inboard lower PV array
Component 8: port inboard Integrated Equipment Assembly (IEA)
Component 9: starboard inboard IEA
Component 10: starboard outboard IEA

There are four unique components and they are shown in Figures 2 through 6. The controller inputs and outputs are identified as data recovery points and are also shown in Figures 2 through 6. The component FEMs are translated to modal models. The modal models consist of:

[M] : diagonal mass matrix
[K] : diagonal stiffness matrix
[C] : diagonal damping matrix
[T1] : acceleration data recovery matrix
[T2] : velocity data recovery matrix
[T3] : displacement data recovery matrix

The characteristics of the component mode models are given in Table 1. The component mode models are of the fixed interface type and are based on a truncated number of vibration modes. This truncation serves as the first level of modal reduction. The inboard and outboard IEA modal models used a cutoff frequency of 15 Hz. The center truss and PV array models are based on modes below 7 Hz. The PV array exhibits high modal density and has in excess of 350 modes below 7.0 Hz. Based on strain energy modal selection (Reference 6), only 158 vibration modes were retained. This is the second level of modal reduction.

TABLE 1: CHARACTERISTICS OF COMPONENT MODE MODELS

COMPONENT	CONSTRAINT MODES	FLEXIBLE MODES	TOTAL MODES
Center Truss	12	156	168
Inboard IEA	30	20	50
Outboard IEA	48	22	70
PV Array	6	158	164

The system modal model is synthesized from the component models, and consists of 1173 modes below 7.0 Hz. Fourteen of these are zero frequency modes (system rigid body or mechanism type) and the rest are flexible modes. These 14 zero frequency modes correspond to six SSF rigid body modes, two Alpha Gimbal mechanism rotation modes and six Beta Gimbal mechanism rotation modes. The first 50 vibration mode frequencies, including the zero frequency modes, are listed in Table 2.

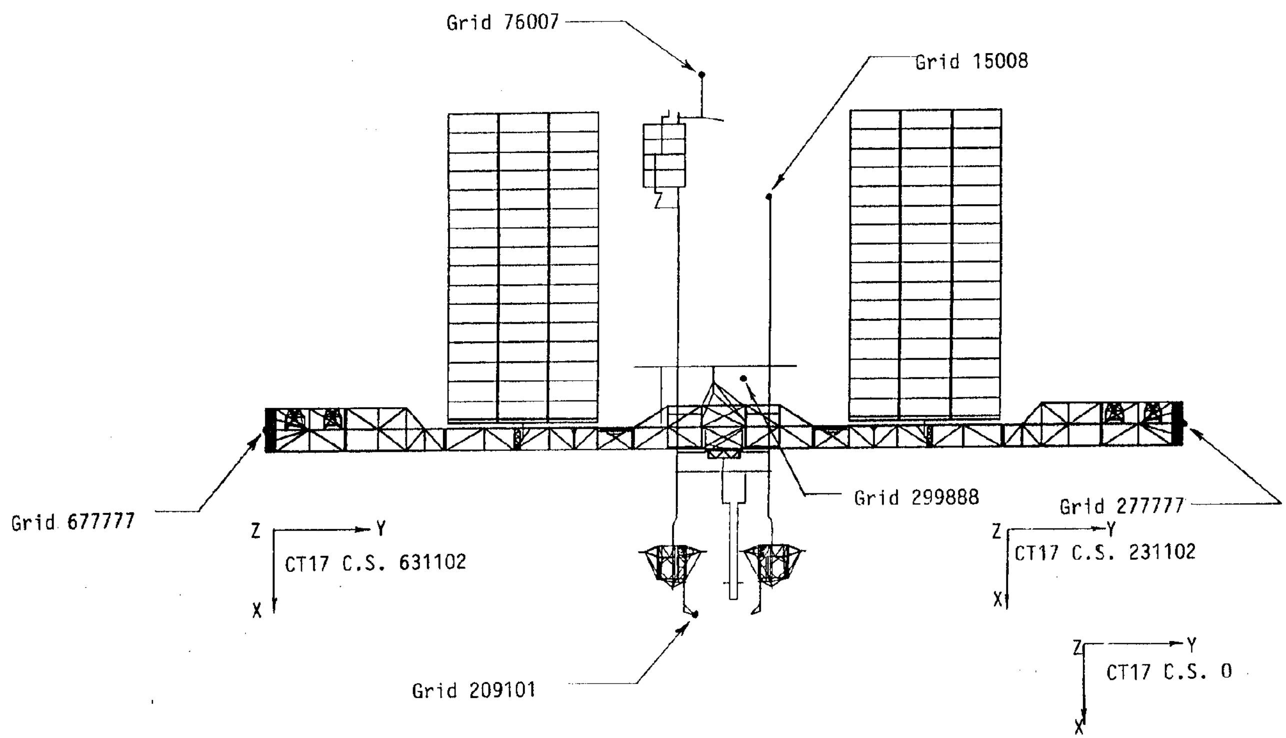

FIGURE-2: CENTER TRUSS FINITE ELEMENT MODEL

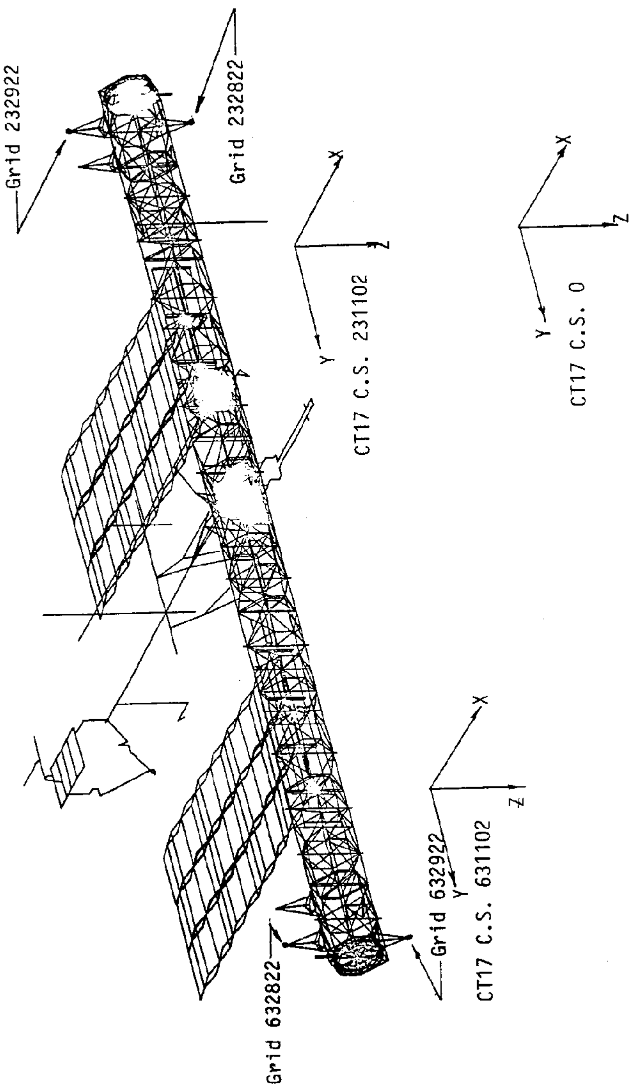

FIGURE-3: CENTER TRUSS FINITE ELEMENT MODEL

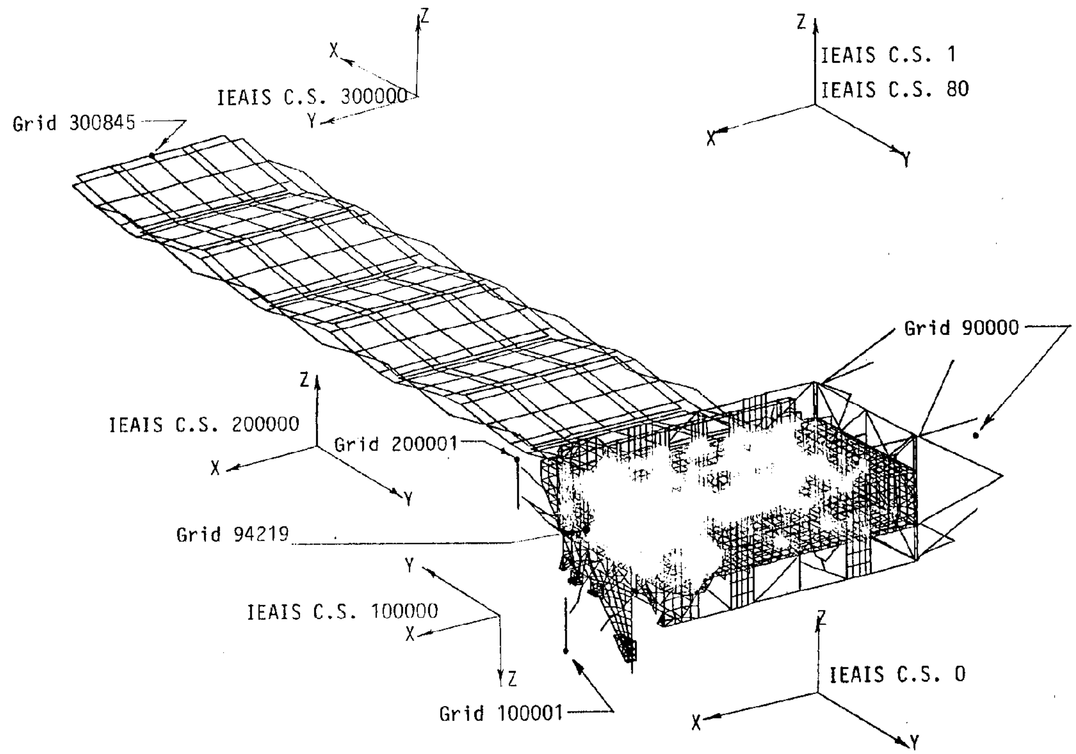

FIGURE-4: INBOARD IEA FINITE ELEMENT MODEL (TYPICAL)

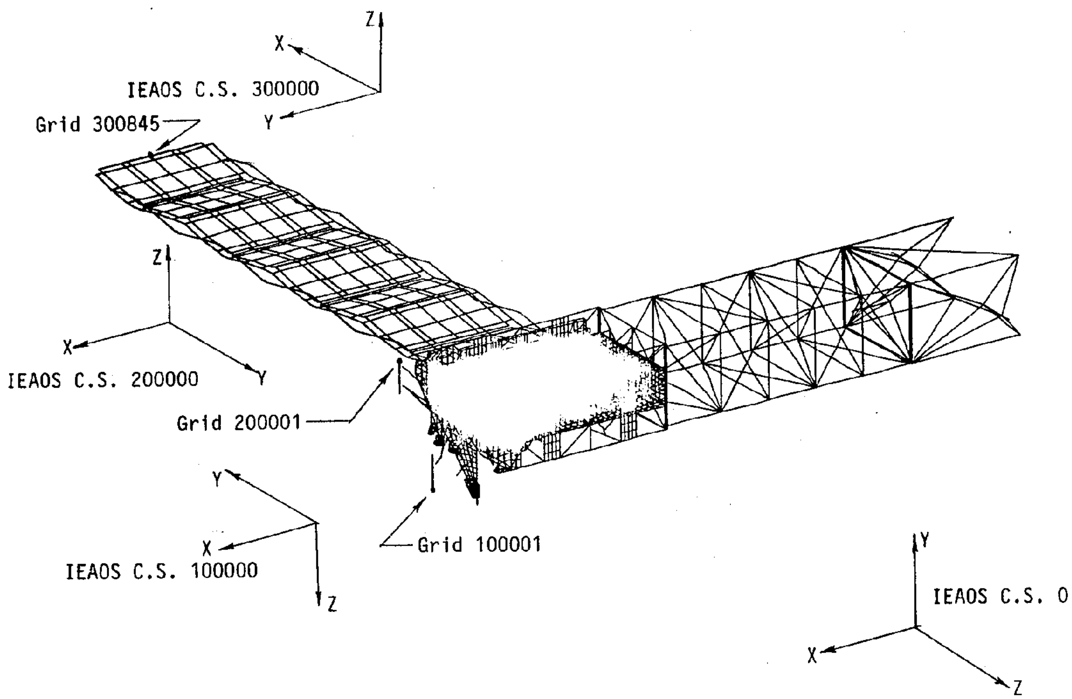

FIGURE-5: OUTBOARD IEA FINITE ELEMENT MODEL

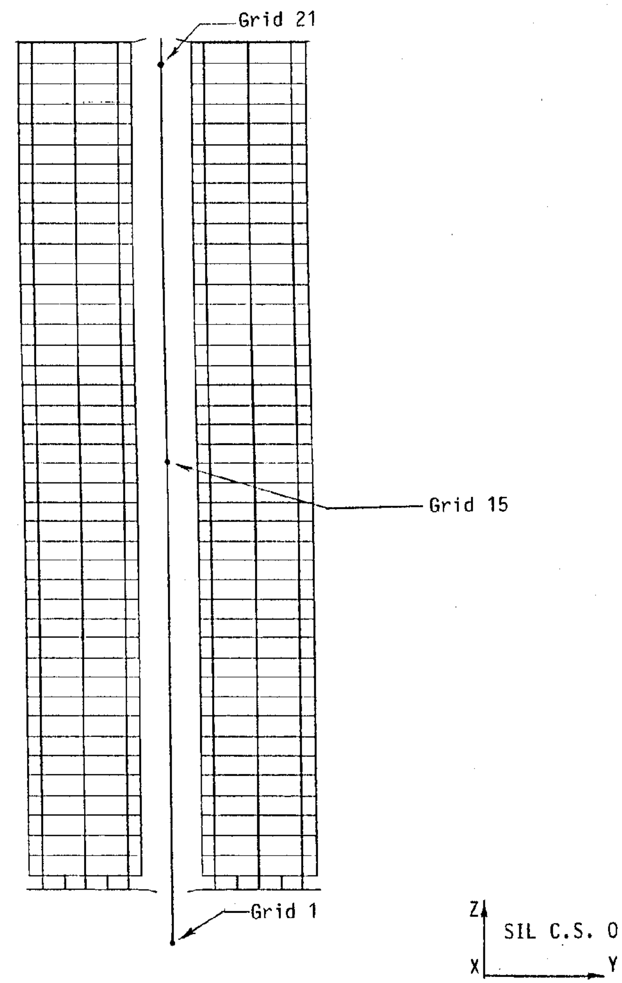

FIGURE-6: PV ARRAY FINITE ELEMENT MODEL (TYPICAL)

TABLE-2: FREE FREE FREQUENCIES OF SYSTEM MODEL

MODE NO.	EXTRACTION ORDER	EIGENVALUE	REAL EIGENVALUES RADIANS	CYCLES	GENERALIZED MASS	GENERALIZED STIFFNESS
1	1	-7.860360E-05	8.865867E-03	1.411047E-03	1.000000E+00	-7.860360E-05
2	2	-6.305416E-06	2.511059E-03	3.996474E-04	1.000000E+00	-6.305416E-06
3	3	-2.588430E-06	1.608860E-03	2.560580E-04	1.000000E+00	-2.588430E-06
4	4	-3.635860E-07	6.029809E-04	9.596739E-05	1.000000E+00	-3.635860E-07
5	5	-3.166890E-07	5.627513E-04	8.956465E-05	1.000000E+00	-3.166890E-07
6	6	-1.369511E-08	1.170261E-04	1.862529E-05	1.000000E+00	-1.369511E-08
7	7	-1.369511E-08	1.170261E-04	1.862529E-05	1.000000E+00	-1.369511E-08
8	8	-1.369511E-08	1.170261E-04	1.862528E-05	1.000000E+00	-1.369511E-08
9	9	-1.369490E-08	1.170252E-04	1.862514E-05	1.000000E+00	-1.369490E-08
10	10	-1.368562E-08	1.169855E-04	1.861883E-05	1.000000E+00	-1.368562E-08
11	11	-1.368409E-08	1.169790E-04	1.861779E-05	1.000000E+00	-1.368409E-08
12	12	3.821812E-07	6.182081E-04	9.839087E-05	1.000000E+00	3.821812E-07
13	13	6.554783E-05	8.096162E-03	1.288544E-03	1.000000E+00	6.554783E-05
14	14	1.197496E-04	1.094302E-02	1.741635E-03	1.000000E+00	1.197496E-04
15	15	2.501192E-01	5.001192E-01	7.959644E-02	1.000000E+00	2.501192E-01
16	16	2.509727E-01	5.009717E-01	7.973213E-02	1.000000E+00	2.509727E-01
17	17	2.525302E-01	5.025238E-01	7.997915E-02	1.000000E+00	2.525302E-01
18	18	2.642997E-01	5.141009E-01	8.182170E-02	1.000000E+00	2.642997E-01
19	19	3.016734E-01	5.492480E-01	8.741554E-02	1.000000E+00	3.016734E-01
20	20	3.079731E-01	5.549532E-01	8.832355E-02	1.000000E+00	3.079731E-01
21	21	4.577852E-01	6.765982E-01	1.076840E-01	1.000000E+00	4.577852E-01
22	22	4.578023E-01	6.766109E-01	1.076860E-01	1.000000E+00	4.578023E-01
23	23	4.800916E-01	6.928864E-01	1.102763E-01	1.000000E+00	4.800916E-01
24	24	4.804201E-01	6.931234E-01	1.103140E-01	1.000000E+00	4.804201E-01
25	25	4.806531E-01	6.932915E-01	1.103408E-01	1.000000E+00	4.806531E-01
26	26	4.813834E-01	6.938180E-01	1.104246E-01	1.000000E+00	4.813834E-01
27	27	5.259848E-01	7.252481E-01	1.154268E-01	1.000000E+00	5.259848E-01
28	28	5.266651E-01	7.257169E-01	1.155014E-01	1.000000E+00	5.266651E-01
29	29	5.267073E-01	7.257461E-01	1.155061E-01	1.000000E+00	5.267073E-01
30	30	5.268014E-01	7.258108E-01	1.155164E-01	1.000000E+00	5.268014E-01
31	31	5.268212E-01	7.258245E-01	1.155186E-01	1.000000E+00	5.268212E-01
32	32	5.268657E-01	7.258552E-01	1.155234E-01	1.000000E+00	5.268657E-01
33	33	5.695235E-01	7.546678E-01	1.201091E-01	1.000000E+00	5.695235E-01
34	34	5.992283E-01	7.740984E-01	1.232016E-01	1.000000E+00	5.992283E-01
35	35	6.025830E-01	7.762622E-01	1.235460E-01	1.000000E+00	6.025830E-01
36	36	6.111138E-01	7.817377E-01	1.244174E-01	1.000000E+00	6.111138E-01
37	37	6.130002E-01	7.829433E-01	1.246093E-01	1.000000E+00	6.130002E-01
38	38	6.154091E-01	7.844801E-01	1.248539E-01	1.000000E+00	6.154091E-01
39	39	8.710205E-01	9.332848E-01	1.485369E-01	1.000000E+00	8.710205E-01
40	40	8.726183E-01	9.341404E-01	1.486731E-01	1.000000E+00	8.726183E-01
41	41	9.247751E-01	9.616523E-01	1.530517E-01	1.000000E+00	9.247751E-01
42	42	9.249223E-01	9.617288E-01	1.530639E-01	1.000000E+00	9.249223E-01
43	43	9.770719E-01	9.884695E-01	1.573198E-01	1.000000E+00	9.770719E-01
44	44	9.770735E-01	9.884703E-01	1.573199E-01	1.000000E+00	9.770735E-01
45	45	1.050763E+00	1.025067E+00	1.631446E-01	1.000000E+00	1.050763E+00
46	46	1.054503E+00	1.026890E+00	1.634347E-01	1.000000E+00	1.054503E+00
47	47	1.055508E+00	1.027379E+00	1.635125E-01	1.000000E+00	1.055508E+00
48	48	1.055603E+00	1.027426E+00	1.635198E-01	1.000000E+00	1.055603E+00
49	49	1.081055E+00	1.039738E+00	1.654795E-01	1.000000E+00	1.081055E+00
50	50	1.081246E+00	1.039830E+00	1.654940E-01	1.000000E+00	1.081246E+00

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By the use of appropriate DMAPs, the NASTRAN modal model is converted to a CO-ST-IN control system analysis model. Table 3 gives the list of items selected for the data recovery matrices of this model. It should be noted that when generating the data recovery matrices using Rocketdyne's DMAPs at either the component or system level, there is a choice between using the modal acceleration or modal displacement method. This allows greater flexibility in the model formulation. The modal models did not have the applied force vectors which are typically used in structural loads analysis. This is because the actual forcing functions were applied in the control system model. Therefore, the data recovery item list has locations where external forces would be applied.

The ranking of the vibration modes is shown for two cases of controller inputs/outputs, as given in Tables 4 through 7. Table 4 gives the inputs and Table 5 gives the outputs for the case when disturbances and generalized displacements at SSF Reaction Control System RCS thruster, Space Shuttle Orbiter docking and crewmember Extra-Vehicular Activity (EVA) locations are considered along with those of the Alpha Gimbal, Beta Gimbal and station c.g. Tables 6 and 7 give the inputs and outputs for the case when disturbances and generalized displacements at only the Alpha Gimbal, Beta Gimbal and station c.g. are considered.

The vibration modes were ranked based on the approximate balanced singular value method. There are other methods in CO-ST-IN that may be used. The first 50 modes for each case are given in Tables 8 and 9. Modal reduction is achieved by retaining sufficient modes which are observable and controllable by the control system to represent the full-order system.

Controls study using reduced modes

As an integrated part of the control system model (Figure 7), the structural vibration mode shapes were formulated and divided into two matrices: input locations (including Alpha Gimbal and Beta Gimbal control torques and disturbances) and output measurements. The inertial angles and rates representing station motions can be determined by structural mode dynamics to study station vibration effects. Following this modelling approach, any disturbance applied to one location will perturb and interact with the rest of the locations and, in turn, the entire station.

Based on the above, a mathematical model of the PV array pointing control system was constructed using the SC-17 reduced-order structural dynamics model. A set of controller gains was designed for the Beta Gimbal control system, including both rigid body and flexible mode dynamics. Time domain simulations were executed to predict system transient response, control accuracy, and disturbance rejection capability. An example of the calculated SSF SC-17 response of the PV arrays to a typical Space Shuttle orbiter docking case is shown in Figures 8 and 9. Also, frequency domain analyses were performed to characterize system stability. A typical example of this is shown in Figure 10.

CONCLUSIONS

In the above control-structure interaction study, several MSC/NASTRAN DMAPs were used. Some of these were written in-house. This analysis requires a coordinated and well integrated effort of structural dynamics and control system engineers. While the structural dynamics engineer is familiar with the various hardware components, the controls engineer is familiar with parameters such as the controller measurements. The techniques described herein

TABLE 3: SYSTEM DATA RECOVERY ITEMS OF SC-17 CONFIG.(CONTD.)

ITEM	DESCRIPTION	DISP C.S.	POINT	DOF	DIRECTION (SS C.S.)
1	STATION C.G.	CT17 0	299888	1	X
2	STATION C.G.	CT17 0	299888	2	Y
3	STATION C.G.	CT17 0	299888	3	Z
4	STATION C.G.	CT17 0	299888	4	X'
5	STATION C.G.	CT17 0	299888	5	Y'
6	STATION C.G.	CT17 0	299888	6	Z'
7	RCS -Z (STARBOARD UPPER)	CT17 231102	232822	1	X
8	RCS +Z (STARBOARD LOWER)	CT17 231102	232922	1	X
9	RCS -Z (PORT LOWER)	CT17 631102	632822	1	X
10	RCS +Z (PORT UPPER)	CT17 631102	632922	1	X
11	ALPHA GIMBAL (CENTER TRUSS, STAR)	CT17 231102	277777	5	Y'
12	ALPHA GIMBAL (CENTER TRUSS, PORT)	CT17 631102	677777	5	Y'
13	DOCKING (PORT)	CT17 0	209101	1	X
14	DOCKING (PORT)	CT17 0	209101	2	Y
15	DOCKING (PORT)	CT17 0	209101	3	Z
16	DOCKING (PORT)	CT17 0	209101	4	X'
17	DOCKING (PORT)	CT17 0	209101	5	Y'
18	DOCKING (PORT)	CT17 0	209101	6	Z'
19	EVA (JEM-ES TIP STOP)	CT17 0	15008	6	Z
20	EVA (ESA TIP STOP)	CT17 70006	76007	6	Z
21	ALPHA GIMBAL (EPS TRUSS, STAR)	IEAIS 1	90000	4	Y'
22	BETA GIMBAL (EPS TRUSS, PVSIL)	IEAIS 100000	100001	6	Z'
23	BETA GIMBAL EPS TRUSS, PVSIU)	IEAIS 200000	200001	6	-Z'
24	TCS RADIATOR TIP (INBOARD, STAR)	IEAIS 300000	300845	3	-Z
25	BETA GIMBAL (EPS TRUSS, PVSOL)	IEAOS 100000	100001	6	Z'
26	BETA GIMBAL (EPS TRUSS, PVSOU)	IEAOS 200000	200001	6	-Z'
27	TCS RADIATOR TIP (OUTBOARD, STAR)	IEAOS 300000	300845	3	-Z
28	ALPHA GIMBAL (EPS TRUSS, PORT)	IEAIP 1	90000	4	-Y'
29	BETA GIMBAL (EPS TRUSS, PVPIU)	IEAIP 100000	100001	6	-Z'
30	BETA GIMBAL (EPS TRUSS, PVPIL)	IEAIP 200000	200001	6	Z'
31	TCS RADIATOR TIP (INBOARD, PORT)	IEAIP 300000	300845	3	Z
32	EVA (PORT TRUSS TIP)	IEAIP 80	94219	2	X
33	EVA (PORT TRUSS TIP)	IEAIP 80	94219	3	Z
34	BETA GIMBAL (PVSIL)	PVSIL 0	1	6	Z'
35	ARRAY CENTER (PVSIL)	PVSIL 0	15	6	Z'
36	ARRAY TIP (PVSIL)	PVSIL 0	21	1	X
37	ARRAY TIP (PVSIL)	PVSIL 0	21	2	Y
38	ARRAY TIP (PVSIL)	PVSIL 0	21	6	Z'
39	BETA GIMBAL (PVSIU)	PVSIU 0	1	6	-Z'
40	ARRAY CENTER (PVSIU)	PVSIU 0	15	6	-Z'
41	ARRAY TIP (PVSIU)	PVSIU 0	21	1	- X
42	ARRAY TIP (PVSIU)	PVSIU 0	21	2	-Y

TABLE-3: SYSTEM DATA RECOVERY ITEMS OF SC-17 CONFIG.(CONTD.)

ITEM	DESCRIPTION	DISP C.S.	POINT	DOF	DIRECTION (SS C.S.)
43	ARRAY TIP (PVSIU)	PVSIU 0	21	6	-Z'
44	BETA GIMBAL (PVSOL)	PVSOL 0	1	6	Z'
45	ARRAY CENTER (PVSOL)	PVSOL 0	15	6	Z'
46	ARRAY TIP (PVSOL)	PVSOL 0	21	1	X
47	ARRAY TIP (PVSOL)	PVSOL 0	21	2	Y
48	ARRAY TIP (PVSOL)	PVSOL 0	21	6	Z'
49	BETA GIMBAL (PVSOU)	PVSOU 0	1	6	-Z'
50	ARRAY CENTER (PVSOU)	PVSOU 0	15	6	-Z'
51	ARRAY TIP (PVSOU)	PVSOU 0	21	1	X
52	ARRAY TIP (PVSOU)	PVSOU 0	21	2	-Y
53	ARRAY TIP (PVSOU)	PVSOU 0	21	6	-Z'
54	BETA GIMBAL (PVPIU)	PVPIU 0	1	6	-Z'
55	ARRAY CENTER (PVPIU)	PVPIU 0	15	6	-Z'
56	ARRAY TIP (PVPIU)	PVPIU 0	21	1	X
57	ARRAY TIP (PVPIU)	PVPIU 0	21	2	-Y
58	ARRAY TIP (PVPIU)	PVPIU 0	21	6	-Z'
59	BETA GIMBAL (PVPIL)	PVPIL 0	1	6	Z'
60	ARRAY CENTER (PVPIL)	PVPIL 0	15	6	Z'
61	ARRAY TIP (PVPIL)	PVPIL 0	21	1	X
62	ARRAY TIP (PVPIL)	PVPIL 0	21	2	Y
63	ARRAY TIP (PVPIL)	PVPIL 0	21	6	Z'

TABLE-4: CASE 1 COSTIN INPUT MEASUREMENTS

INPUT	RECOVERY ITEM	DESCRIPTION	DIRECTION (SS C.S.)
1	1	STATION C.G.	X
2	2	STATION C.G.	Y
3	3	STATION C.G.	Z
4	4	STATION C.G.	X'
5	5	STATION C.G.	Y'
6	6	STATION C.G.	Z'
7	34 - 22	BETA GIMBAL (PVSIL)	Z'
8	23 - 29	BETA GIMBAL (PVSIU)	Z'
9	44 - 25	BETA GIMBAL (PVSOL)	Z'
10	26 - 49	BETA GIMBAL (PVSOU)	Z'
11	29 - 54	BETA GIMBAL (PVPIU)	Z'
12	59 - 30	BETA GIMBAL (PVPIL)	Z'
13	21 - 11	ALPHA GIMBAL (STAR)	Y'
14	-28 -12	ALPHA GIMBAL (PORT)	Y'
15	8	RCS +Z (STARBOARD, LOWER)	X
16	7	RCS -Z (STARBOARD, UPPER)	X
17	10	RCS +Z (PORT, UPPER)	X
18	9	RCS -Z (PORT, LOWER)	X
19	13	DOCKING (PORT)	X
20	14	DOCKING (PORT)	Y
21	15	DOCKING (PORT)	Z
22	16	DOCKING (PORT)	X'
23	17	DOCKING (PORT)	Y'
24	18	DOCKING (PORT)	Z'
25	19	EVA JEM	Z
26	20	EVA ESA	Z
27	32	EVA PORT TRUSS TIP	X
28	33	EVA PORT TRUSS TIP	Z

TABLE-5: CASE 1 COSTIN OUTPUT MEASUREMENTS

OUTPUT	RECOVERY ITEM NO.	DESCRIPTION	DIRECTION (SS C.S.)
1	34	BETA GIMBAL RESOLVER (PVSIL)	Z'
2	-39	BETA GIMBAL RESOLVER (PVSIU)	Z'
3	44	BETA GIMBAL RESOLVER (PVSOL)	Z'
4	-49	BETA GIMBAL RESOLVER (PVSOU)	Z'
5	-54	BETA GIMBAL RESOLVER (PVPIU)	Z'
6	59	BETA GIMBAL RESOLVER (PVPIL)	Z'
7	21	ALPHA GEMBAL (STAR)	Y'
	VEL		
8	-28	ALPHA GIMBAL (PORT)	Y'
	VEL		
9	1	STATION C.G.	X
10	2	STATION C.G.	Y
11	3	STATION C.G.	Z
12	4	STATION C.G.	X'
	VEL		
13	5	STATION C.G.	Y'
	VEL		
14	6	STATION C.G.	Z'
	VEL		
15	35	SOLAR ARRAY CENTER (PVSIL)	Z'
16	-40	SOLAR ARRAY CENTER (PVSIU)	Z'
17	45	SLOAR ARRAY CENTER (PVSOL)	Z'
18	-50	SOLAR ARRAY CENTER (PVSOU)	Z'
19	-55	SOLAR ARRAY CENTER (PVPIU)	Z'
20	60	SOLAR ARRAY CENTER (PVPIL)	Z'
21	36	SLOAR ARRAY TIP (PVSIL)	X
22	37	SLOAR ARRAY TIP (PVSIL)	Y
23	38	SLOAR ARRAY TIP (PVSIL)	Z'
24	41	SOLAR ARRAY TIP (PVSIU)	X
25	-42	SOLAR ARRAY TIP (PVSIU)	Y
26	-43	SOLAR ARRAY TIP (PVSIU)	Z'
27	46	SOLAR ARRAY TIP (PVSOL)	X
28	47	SOLAR ARRAY TIP (PVSOL)	Y
29	48	SOLAR ARRAY TIP (PVSOL)	Z'
30	51	SOLAR ARRAY TIP (PVSOU)	X
31	-52	SOLAR ARRAY TIP (PVSOU)	Y
32	-53	SOLAR ARRAY TIP (PVSOU)	Z'
33	56	SOLAR ARRAY TIP (PVPIU)	X
34	-57	SOLAR ARRAY TIP (PVPIU)	Y
35	-58	SOLAR ARRAY TIP (PVPIU)	Z'
36	61	SOLAR ARRAY TIP (PVPIL)	X
37	62	SOLAR ARRAY TIP (PVPIL)	Y
38	63	SOLAR ARRAY TIOP (PVPIL)	Z'
39	-24	TCS RADIATOR TIP (INBOARD,STAR)	Z
40	-27	TCS RADIATOR TIP (OUTBOARD, STAR)	Z
41	31	TCS RADIATOR TIP (INBOARD, PORT)	Z

TABLE-6: CASE 2 COSTIN INPUT MEASUREMENTS

INPUT	RECOVERY ITEM	DESCRIPTION	DIRECTION (SS C.S.)
1	1	STATION C.G.	X
2	2	STATION C.G.	Y
3	3	STATION C.G.	Z
4	4	STATION C.G.	X'
5	5	STATION C.G.	Y'
6	6	STATION C.G.	Z'
7	34 - 22	BETA GIMBAL (PVSIL)	Z'
8	23 - 29	BETA GIMBAL (PVSIU)	Z'
9	44 - 25	BETA GIMBAL (PVSOL)	Z'
10	26 - 49	BETA GIMBAL (PVSOU)	Z'
11	29 - 54	BETA GIMBAL (PVPIU)	Z'
12	59 - 30	BETA GIMBAL (PVPIL)	Z'
13	21 - 11	ALPHA GIMBAL (STAR)	Y'
14	-28 -12	ALPHA GIMBAL (PORT)	Y'

TABLE-7: CASE 2 COSTIN OUTPUT MEASUREMENTS

OUTPUT	RECOVERY ITEM NO.	DESCRIPTION	DIRECTION (SS C.S.)
1	34	BETA GIMBAL RESOLVER (PVSIL)	Z'
2	-39	BETA GIMBAL RESOLVER (PVSIU)	Z'
3	44	BETA GIMBAL RESOLVER (PVSOL)	Z'
4	-49	BETA GIMBAL RESOLVER (PVSOU)	Z'
5	-54	BETA GIMBAL RESOLVER (PVPIU)	Z'
6	59	BETA GIMBAL RESOLVER (PVPIL)	Z'
7	21	ALPHA GEMBAL (STAR)	Y'
	VEL		
8	-28	ALPHA GIMBAL (PORT)	Y'
	VEL		
9	1	STATION C.G.	X
10	2	STATION C.G.	Y
11	3	STATION C.G.	Z
12	4	STATION C.G.	X'
	VEL		
13	5	STATION C.G.	Y'
	VEL		
14	6	STATION C.G.	Z'
	VEL		

TABLE-8: RANKING OF MODES PER CASE 1 CONTROLLER SUMMARY

MODES ORDERED ON THE BASIS OF THE INFINITY NORM:

ORD #	MOD #	GRP #	FREQ(RAD/S)	WEIGHTING FACT	REL WEIGHTING	CUM WEIGHTING
1	1	1	0.00000E+00	0.10000E+35	0.00000E+00	0.00000E+00
2	2	2	0.00000E+00	0.10000E+35	0.00000E+00	0.00000E+00
3	3	3	0.00000E+00	0.10000E+35	0.00000E+00	0.00000E+00
4	4	4	0.00000E+00	0.10000E+35	0.00000E+00	0.00000E+00
5	5	5	0.00000E+00	0.10000E+35	0.00000E+00	0.00000E+00
6	6	6	0.00000E+00	0.10000E+35	0.00000E+00	0.00000E+00
7	7	7	0.00000E+00	0.10000E+35	0.00000E+00	0.00000E+00
8	8	8	0.00000E+00	0.10000E+35	0.00000E+00	0.00000E+00
9	9	9	0.00000E+00	0.10000E+35	0.00000E+00	0.00000E+00
10	10	10	0.00000E+00	0.10000E+35	0.00000E+00	0.00000E+00
11	11	11	0.00000E+00	0.10000E+35	0.00000E+00	0.00000E+00
12	12	12	0.00000E+00	0.10000E+35	0.00000E+00	0.00000E+00
13	13	13	0.00000E+00	0.10000E+35	0.00000E+00	0.00000E+00
14	14	14	0.00000E+00	0.10000E+35	0.00000E+00	0.00000E+00
15	18	18	0.51410E+00	0.50426E+01	0.20240E+00	0.20240E+00
16	15	15	0.50012E+00	0.16079E+01	0.64540E-01	0.26694E+00
17	45	45	0.10251E+01	0.14845E+01	0.59585E-01	0.32653E+00
18	33	33	0.75467E+00	0.11928E+01	0.47879E-01	0.37441E+00
19	55	55	0.10469E+01	0.11804E+01	0.47379E-01	0.42179E+00
20	39	39	0.93328E+00	0.11378E+01	0.45669E-01	0.46745E+00
21	40	40	0.93414E+00	0.11303E+01	0.45369E-01	0.51282E+00
22	57	57	0.11158E+01	0.11232E+01	0.45083E-01	0.55791E+00
23	56	56	0.11087E+01	0.77674E+00	0.31177E-01	0.58908E+00
24	17	17	0.50252E+00	0.72511E+00	0.29105E-01	0.61819E+00
25	34	34	0.77410E+00	0.63815E+00	0.25615E-01	0.64380E+00
26	35	35	0.77626E+00	0.53782E+00	0.21588E-01	0.66539E+00
27	38	38	0.78448E+00	0.49161E+00	0.19733E-01	0.68512E+00
28	37	37	0.78294E+00	0.38581E+00	0.15486E-01	0.70061E+00
29	36	36	0.78174E+00	0.38462E+00	0.15438E-01	0.71605E+00
30	73	73	0.15370E+01	0.35493E+00	0.14247E-01	0.73029E+00
31	58	58	0.11969E+01	0.28321E+00	0.11368E-01	0.74166E+00
32	26	26	0.69382E+00	0.24627E+00	0.98850E-02	0.75155E+00
33	105	105	0.20481E+01	0.21557E+00	0.86525E-02	0.76020E+00
34	208	208	0.38337E+01	0.19947E+00	0.80063E-02	0.76821E+00
35	22	22	0.67661E+00	0.19918E+00	0.79949E-02	0.77620E+00
36	92	92	0.18814E+01	0.18255E+00	0.73272E-02	0.78353E+00
37	74	74	0.15753E+01	0.17924E+00	0.71946E-02	0.79072E+00
38	114	114	0.24956E+01	0.16679E+00	0.66947E-02	0.79742E+00
39	23	23	0.69289E+00	0.16540E+00	0.66390E-02	0.80406E+00
40	85	85	0.17142E+01	0.14121E+00	0.56678E-02	0.80972E+00
41	21	21	0.67660E+00	0.13535E+00	0.54328E-02	0.81516E+00
42	225	225	0.41521E+01	0.13348E+00	0.53578E-02	0.82051E+00
43	113	113	0.24187E+01	0.13165E+00	0.52842E-02	0.82580E+00
44	91	91	0.17721E+01	0.12753E+00	0.51191E-02	0.83092E+00
45	209	209	0.38557E+01	0.12653E+00	0.50788E-02	0.83600E+00
46	71	71	0.14608E+01	0.11623E+00	0.46651E-02	0.84066E+00
47	221	221	0.39469E+01	0.11015E+00	0.44213E-02	0.84508E+00
48	20	20	0.55495E+00	0.10960E+00	0.43991E-02	0.84948E+00
49	200	200	0.37250E+01	0.10814E+00	0.43406E-02	0.85382E+00
50	180	180	0.33941E+01	0.10286E+00	0.41285E-02	0.85795E+00

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TABLE-9: RANKING OF MODES PER CASE 2 CONTROLLER SUMMARY

MODES ORDERED ON THE BASIS OF THE INFINITY NORM:

ORD #	MOD #	GRP #	FREQ(RAD/S)	WEIGHTING FACT	REL WEIGHTING	CUM WEIGHTING
1	1	1	0.00000E+00	0.10000E+35	0.00000E+00	0.00000E+00
2	2	2	0.00000E+00	0.10000E+35	0.00000E+00	0.00000E+00
3	3	3	0.00000E+00	0.10000E+35	0.00000E+00	0.00000E+00
4	4	4	0.00000E+00	0.10000E+35	0.00000E+00	0.00000E+00
5	5	5	0.00000E+00	0.10000E+35	0.00000E+00	0.00000E+00
6	6	6	0.00000E+00	0.10000E+35	0.00000E+00	0.00000E+00
7	7	7	0.00000E+00	0.10000E+35	0.00000E+00	0.00000E+00
8	8	8	0.00000E+00	0.10000E+35	0.00000E+00	0.00000E+00
9	9	9	0.00000E+00	0.10000E+35	0.00000E+00	0.00000E+00
10	10	10	0.00000E+00	0.10000E+35	0.00000E+00	0.00000E+00
11	11	11	0.00000E+00	0.10000E+35	0.00000E+00	0.00000E+00
12	12	12	0.00000E+00	0.10000E+35	0.00000E+00	0.00000E+00
13	13	13	0.00000E+00	0.10000E+35	0.00000E+00	0.00000E+00
14	14	14	0.00000E+00	0.10000E+35	0.00000E+00	0.00000E+00
15	55	55	0.10469E+01	0.15865E-01	0.24905E+00	0.24905E+00
16	249	249	0.46289E+01	0.35577E-02	0.55849E-01	0.30490E+00
17	105	105	0.20481E+01	0.32084E-02	0.50367E-01	0.35526E+00
18	15	15	0.50012E+00	0.31982E-02	0.50206E-01	0.40547E+00
19	92	92	0.18814E+01	0.25220E-02	0.39592E-01	0.44506E+00
20	45	45	0.10251E+01	0.20766E-02	0.32599E-01	0.47766E+00
21	73	73	0.15370E+01	0.20034E-02	0.31450E-01	0.50911E+00
22	20	20	0.55495E+00	0.18174E-02	0.28530E-01	0.53764E+00
23	49	49	0.10397E+01	0.13397E-02	0.21032E-01	0.55867E+00
24	52	52	0.10399E+01	0.13343E-02	0.20947E-01	0.57962E+00
25	54	54	0.10399E+01	0.13331E-02	0.20927E-01	0.60054E+00
26	53	53	0.10399E+01	0.13330E-02	0.20926E-01	0.62147E+00
27	51	51	0.10399E+01	0.13329E-02	0.20924E-01	0.64240E+00
28	50	50	0.10398E+01	0.13327E-02	0.20920E-01	0.66332E+00
29	411	411	0.80469E+01	0.11032E-02	0.17319E-01	0.68063E+00
30	159	159	0.31915E+01	0.10606E-02	0.16650E-01	0.69728E+00
31	38	38	0.78448E+00	0.86949E-03	0.13650E-01	0.71093E+00
32	17	17	0.50252E+00	0.74523E-03	0.11699E-01	0.72263E+00
33	99	99	0.20149E+01	0.65519E-03	0.10285E-01	0.73292E+00
34	18	18	0.51410E+00	0.58021E-03	0.91083E-02	0.74203E+00
35	180	180	0.33941E+01	0.48776E-03	0.76570E-02	0.74968E+00
36	643	643	0.11623E+02	0.44853E-03	0.70411E-02	0.75672E+00
37	32	32	0.72586E+00	0.44279E-03	0.69511E-02	0.76368E+00
38	33	33	0.75467E+00	0.44212E-03	0.69405E-02	0.77062E+00
39	278	278	0.53496E+01	0.44138E-03	0.69289E-02	0.77755E+00
40	31	31	0.72582E+00	0.42701E-03	0.67033E-02	0.78425E+00
41	30	30	0.72581E+00	0.42638E-03	0.66934E-02	0.79094E+00
42	29	29	0.72575E+00	0.42405E-03	0.66568E-02	0.79760E+00
43	28	28	0.72572E+00	0.42313E-03	0.66425E-02	0.80424E+00
44	27	27	0.72525E+00	0.42241E-03	0.66311E-02	0.81087E+00
45	303	303	0.58432E+01	0.38450E-03	0.60360E-02	0.81691E+00
46	71	71	0.14608E+01	0.37278E-03	0.58519E-02	0.82276E+00
47	74	74	0.15753E+01	0.36411E-03	0.57159E-02	0.82848E+00
48	192	192	0.34767E+01	0.32520E-03	0.51050E-02	0.83358E+00
49	404	404	0.79818E+01	0.28451E-03	0.44664E-02	0.83805E+00
50	227	227	0.43806E+01	0.28188E-03	0.44247E-02	0.84247E+00

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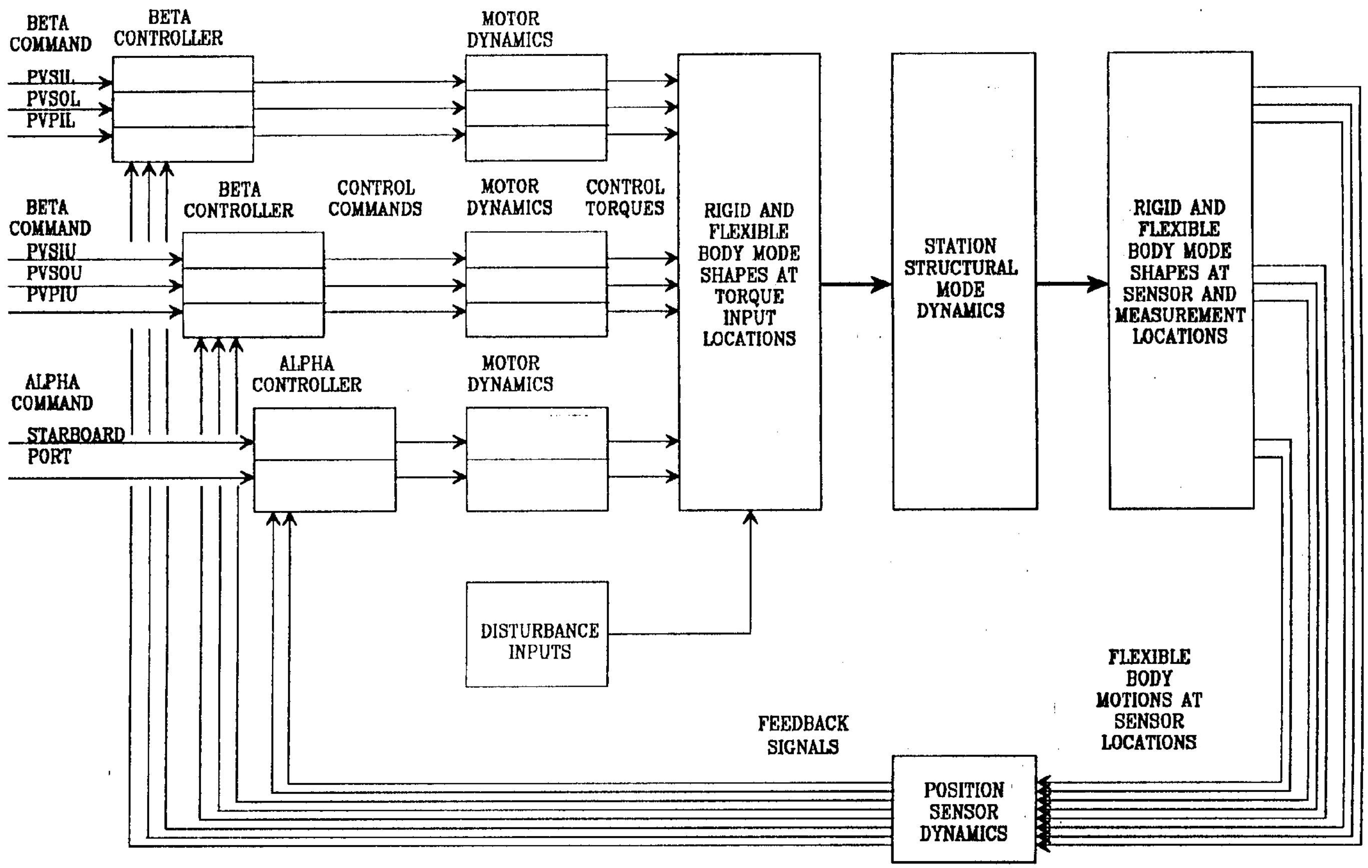

FIGURE-7: SC-17 SOLAR ARRAY POINTING CONTROL SYSTEM BLOCK DIAGRAM

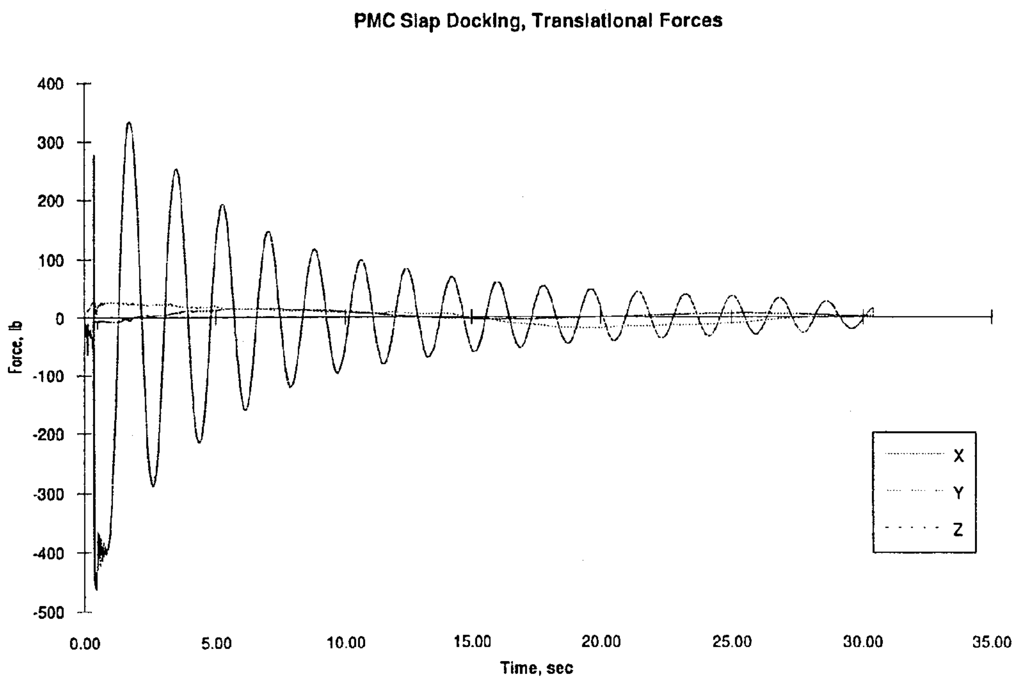

FIGURE 8: TYPICAL FORCING FUNCTIONS

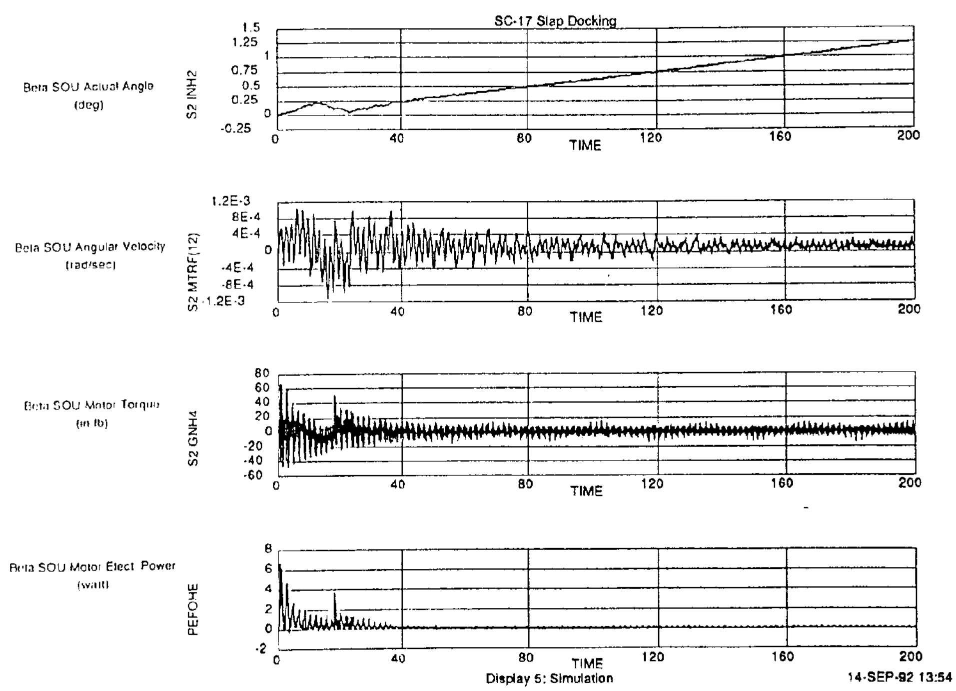

FIGURE 9: TYPICAL TIME HISTORY RESPONSES

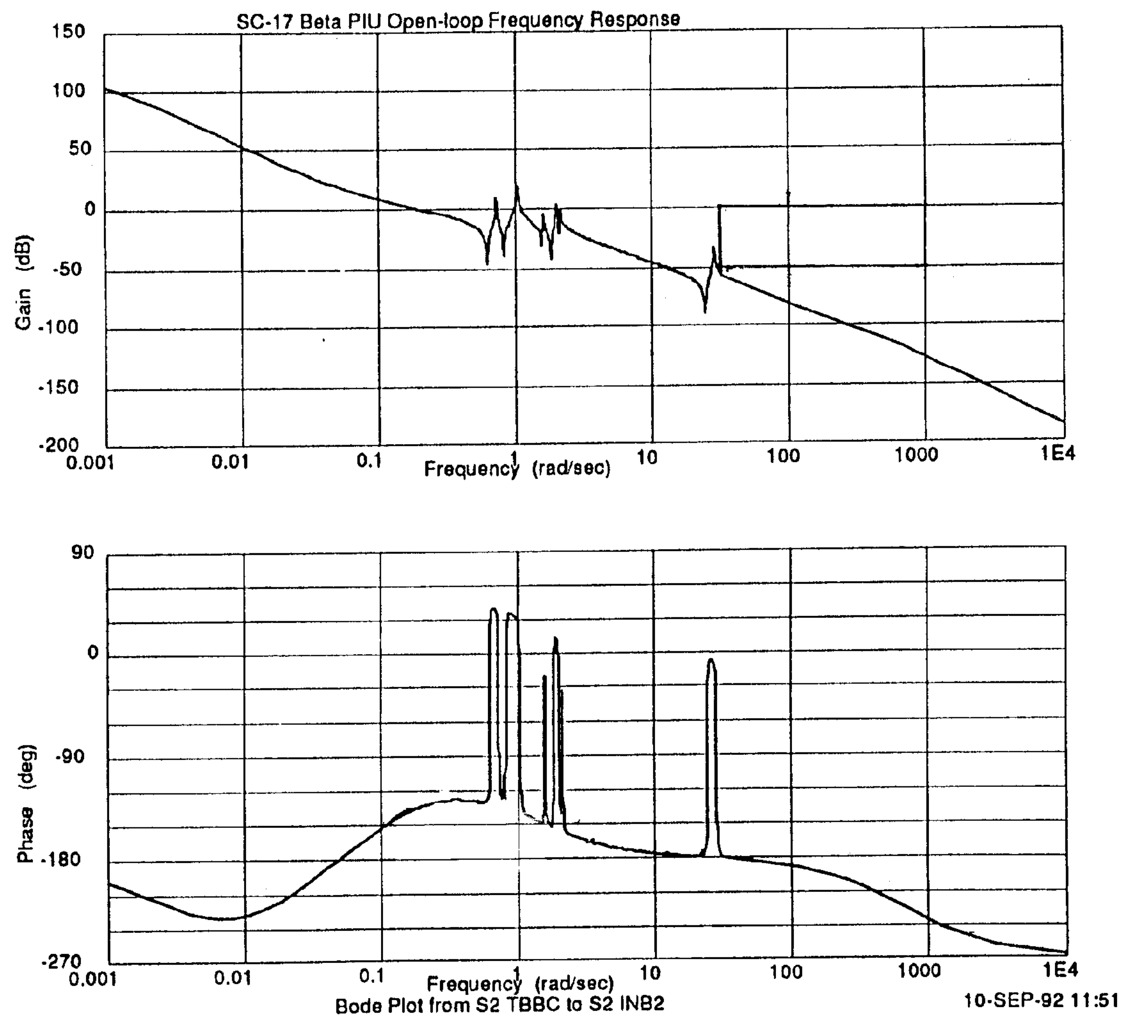

FIGURE 10: TYPICAL FREQUENCY RESPONSE

have been used at the Rocketdyne Division of Rockwell International for control/structure interaction analysis on the SSF program.

Modal reduction was performed at three levels in this study. It is the last level where CO-ST-IN was used that made use of a control/structural system interface for large NASTRAN models.

Using the reduced component mode dynamic model with data recovery matrices, control/structure interaction studies can be performed along with structural loads analysis based on the same math models. This would reduce the duplication of effort in creating a separate controls model to account for the system vibration modes, and thus cut down significantly the total time needed to do the two analyses. Additionally, the use of flexible vibration modes from the component mode analysis results in a more accurate representation of the higher frequency dynamics of the system than can be obtained from lower fidelity stick models.

ACKNOWLEDGEMENT

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