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Conceptual Design and Analysis of a Dynamic Scale Model of the Space Station Freedom

D. A. Davis, M. J. Gronet, M. K. Tan, and J. Thorne

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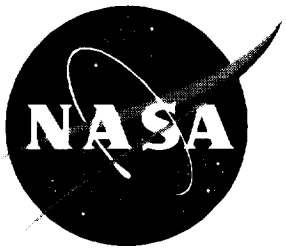

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List of Acronyms

BETA	Solar Array Beta Joint
BKHD	Bulkhead
CID	Component Identification
CSI	Controls- Structures Integration
DIAG	Diagonal Strut
DMAP	Direct Matrix Abstraction Program
DSA	Design Sensitivity Analysis
DSC	Design Sensitivity Coefficient
DSMT	Dynamic Scale Model Technology
DV	Design Variable
EVA	Extra-Vehicular Activity
FEM	Finite Element Model
FFP	Firm-Fixed Price
F.S.	Factor of Safety
GM	Generalized Mass
HZ	Hertz
IEA	Integrated Equipment Assembly
ITS	Integrated Truss Segment
JSC	Johnson Space Center
LaRC	Langley Research Center
LDWG	Loads and Dynamics Working Group
LESC	Lockheed Engineering & Sciences Company
LONG	Longeron Strut
MB	Mission Build
MDSSC	McDonnell Douglas Space Systems Company
MSC	MacNeal-Schwendler Corporation
MT	Mobile Transporter
MTC	Man-Tended Configuration
MTI	Module-Truss Interface Structure
MTS	Mobile Transporter System
NASA	National Aeronautics & Space Administration
NC	Numerically Controlled
NODE	Resource Node
OTHER	Miscellaneous Hardware

List of Acronyms Continued

PBM	Pressurized Berthing Mechanism
PDR	Preliminary Design Review
PID	Property Identification
PIT	Pre-Integrated Truss
PMAS	Propulsion Module Attachment Structure
SA	Solar Array
SARJ	Solar Alpha Rotary Joint
SC-7	Stage 7 Configuration
SE	Strain Energy
SID	System Identification
SQRT	Square Root
SSF	Space Station Freedom
STS	SARJ-Truss Interface Structure
SV	State Variable
TCS	Thermal Control System
TRRJ	Thermal Radiator Rotary Joint
US LAB	U.S. Laboratory Module
WP	Work Package

List of Symbols

Variables

A	Area
E	Modulus of Elasticity
f	Frequency
g	gravity
G	Shear Modulus of Elasticity
IY	Area Moment of Inertia
IZ	Area Moment of Inertia
J	Torsional Inertia
K	Stiffness
L	Length
m	Mass
M	Mass
P	Applied Load
W	Weight
X	Deflection
ϕ	Mode Shape
λ	Scale Factor
ρ	Density
ω	Frequency

Subscripts

cant	cantilevered
cr	critical
g	gravity
i	mode no.
j	property no.
n	normalized
orig	original

Acknowledgements

The authors wish to acknowledge the contribution of Dr. Edward Crawley of the Massachusetts Institute of Technology in the analysis of the requirements for a dynamic scale model of the Space Station Freedom. The authors also wish to acknowledge the cooperation of Bernard Bashkoff and Ludwig Abruzzo of the Grumman Space Station Program Support Division and Mike West of the Lockheed Engineering and Sciences Company who provided the SSF analytical models used in the study. In addition, the support and direction of Brantley Hanks, Mike Gilbert, Ray Kvaternik, Vic Cooley, and Rudeen Smith-Taylor of NASA/LaRC is also gratefully acknowledged.

1.0 EXECUTIVE SUMMARY

Historically, dynamic scale models have played a significant role in the design, development, and verification of aircraft, launch vehicles, and spacecraft[1,2]. At the NASA Langley Research Center, a series of successful scale model ground tests have been performed in support of the Nimbus, Saturn I, Apollo-Saturn V, Apollo-LEM, Titan III, Space Shuttle, and other programs. These tests provided valuable development and verification data at reduced cost, risk, and schedule time compared to testing the full-size vehicle. Whereas the full-scale hardware can usually be tested only once due to schedule constraints before launch, the subscale models can be tested over and over again, as in the case of the Space Shuttle. The scale model test data obtained has been used to gain a better understanding of complex dynamic phenomena and to validate analytical models.

The Space Station Freedom (SSF) program has challenging development and verification needs in that it is impractical to test the fully-assembled vehicle on the ground. The vehicle is simply too large and flexible to support and test in a simulated zero-g environment. There are also significant logistical problems in that the vehicle is built by a number of contractors associated with the three Work Packages (WP) and assembled in stages over a period of many years, making it difficult and costly to bring all of the components together at the same time and place for an integrated ground test. While ground tests of SSF segments in the launch configuration will be conducted, there are limited plans for dynamically testing coupled segments in the on-orbit configuration. Thus, the verification of the SSF on-orbit dynamics will rely primarily on analytical models and the data from a limited number of coupled-segment ground tests.

A unique opportunity exists to develop a subscale dynamic model of the SSF which can be used to address both operational and structural verification concerns. The model can be used to conduct system integration tests normally performed on all flight vehicles but which are impractical for the full-scale Space Station. In addition, a scale model can be invaluable for investigating observed on-orbit and ground test anomalies, and for performing growth and modification studies. A high-fidelity scale model of SSF can be used to correlate the on-orbit and launch analytical models to reduce model uncertainty and increase confidence in the structural load predictions. Subscale tests can also be performed on a component level to complement the limited full-scale ground testing planned and provide risk reduction.

This report presents the technical results of a conceptual design study for a high-fidelity scale model of the SSF that was performed under Contract NAS1-19241 (Task 17) for the NASA Langley Research Center.

1.1 INTRODUCTION

A series of lower-fidelity SSF scale models have been built as part of the Dynamic Scale Model Technology (DSMT) project at NASA/LaRC[3]. These models reflected the original 5 meter SSF truss design. The models were used to develop scaling techniques, advanced zero-g suspension devices, testing techniques, and related experiments which can be applied to future spacecraft ground test programs.

Due to the extensive astronaut Extra-Vehicular Activity (EVA) time and cost required to assemble the space station on-orbit, a redesigned truss configuration was introduced in 1992 to simplify the assembly process. The new configuration uses a new Pre-Integrated Truss (PIT) structure concept which allows pre-integrated segments of the space station structure to lifted into orbit, thereby minimizing on-orbit assembly. A total of 17 flights (not including re-supply flights) are required to assemble a permanently manned configuration in space by the year 2000.

The redesign of the SSF truss structure limited the ability of the existing DSMT model to support SSF verification. Therefore, the feasibility of developing a new PIT scale model needed to be addressed. As a result, NASA/LaRC funded a study to evaluate conceptual design options for a subscale dynamic test model which could be used to investigate the expected on-orbit structural dynamic characteristics of the space station early build configurations. The baseline option was designated as a "near-replica" model of the SSF Stage 7 pre-integrated truss configuration (SC-7) shown in Figure 1-1. "Near-replica" refers to the combination of both replica and dynamic similarity scaling wherein scaling compromises are made to reduce cost with minimal impact on performance.

All of the SSF data sources used during the conceptual design study are based on Preliminary Design Review (PDR) or Delta PDR designs and represent the most comprehensive and up-to-date documents available at the time the study was initiated. Each of the references contained detailed information with respect to the mature design of the integrated truss primary structure and the location of subsystems. The level of detail reflects what was available for the SSF PDR Load Cycle and provides a sufficient representation of the dynamics for the purposes of this scale model study.

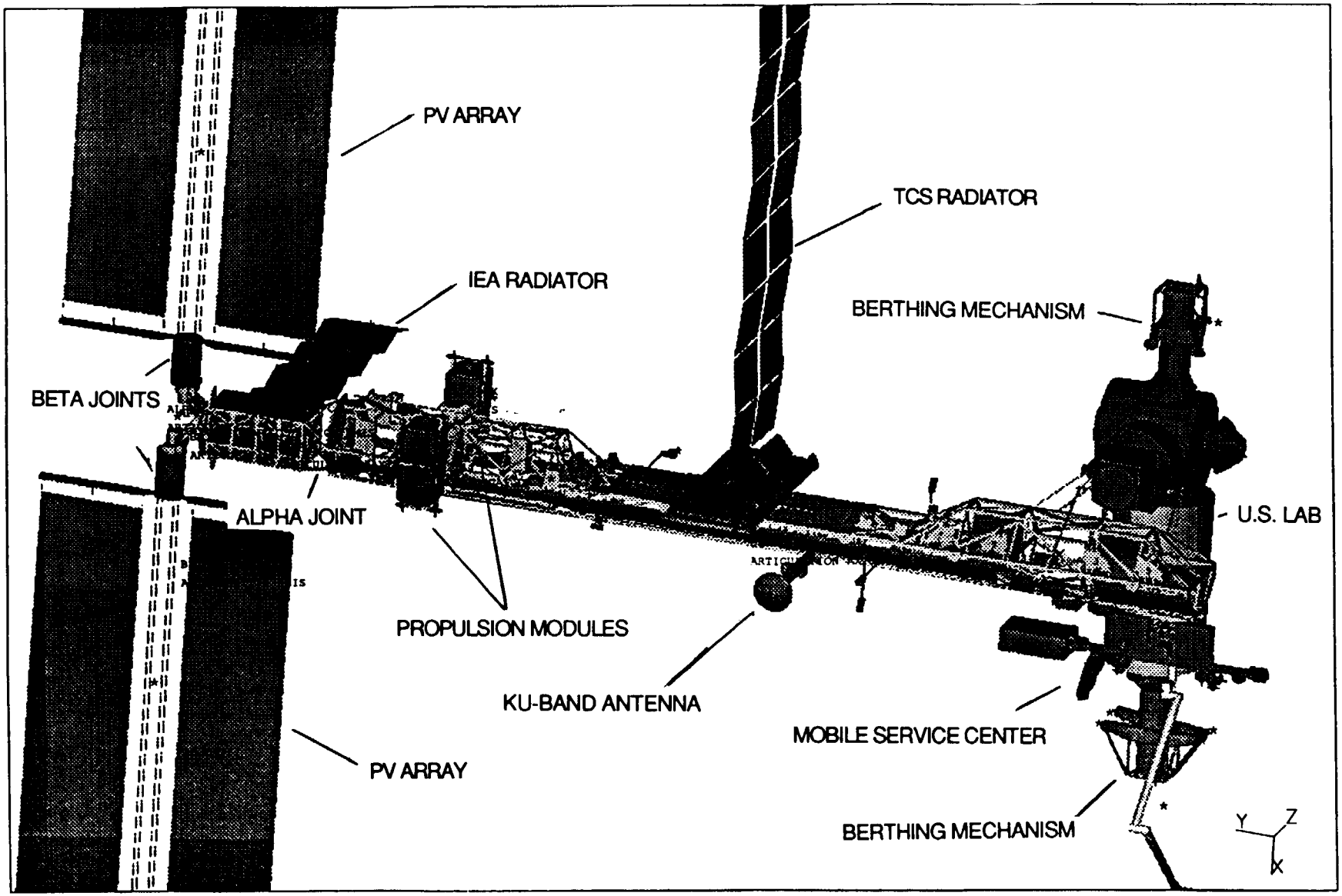


Figure 1-1 SC-7 IDEAS Solid Model Configuration

One of the initial studies performed in support of the scale model task was a model justification study performed by Dr. Ed Crawley of the Massachusetts Institute of Technology. The purpose of the study was to determine the role of a scale model in the SSF verification process. The results of the study showed that the strongest justification for a scale model in support of SSF verification is found in loads analysis and analytical modeling. The model could also be used to address current and future SSF operational concerns. It was concluded that in the long term, the development of a SSF PIT scale model could be a very valuable contribution to NASA and the Space Station Freedom Program.

1.2 APPROACH

The approach taken to develop conceptual design options for a dynamic scale model of SSF involved three sets of studies: (1) evaluation of the full-scale design and analysis databases, (2) conducting scale factor trade studies including fabrication of prototype hardware, and (3) performing design sensitivity studies. The most current databases on the Space Station Freedom early build configurations were evaluated first to obtain a thorough understanding of the SSF hardware prior to initiating the scale factor and design sensitivity studies. The SSF SC-7 configuration was selected for the scale model study since nearly all the major flight loads, micro-dynamics, assembly dynamics, operational timelines, and attitude control system stability issues can be addressed in the scale model program using this configuration.

The purpose of the scale factor trade study was to develop a fundamental understanding of the key scaling parameters that drive the design, performance, and cost of the SSF dynamic scale model. Scaling issues were evaluated to identify any "cliffs" or "show stoppers" associated with specific scale factor designs which might limit the trade space. The key scaling parameters evaluated were associated with gravity loads, handling loads, model suspension, hardware producibility, and facility issues. The findings resulting from this study form the technical basis for the selection of a scale factor size for a SSF scale model.

In a parallel effort to the scale factor trade studies, a design sensitivity study was conducted to establish a technical approach for developing lower-cost design alternatives for the scaled SSF hardware components. A flowchart illustrating the design study approach followed is shown in Figure 1-2. The approach is intended to provide a fundamental basis for making cost-effective, performance driven model fidelity decisions by identifying critical hardware component properties that drive dynamic performance. Knowledge of these critical properties enables the scale model

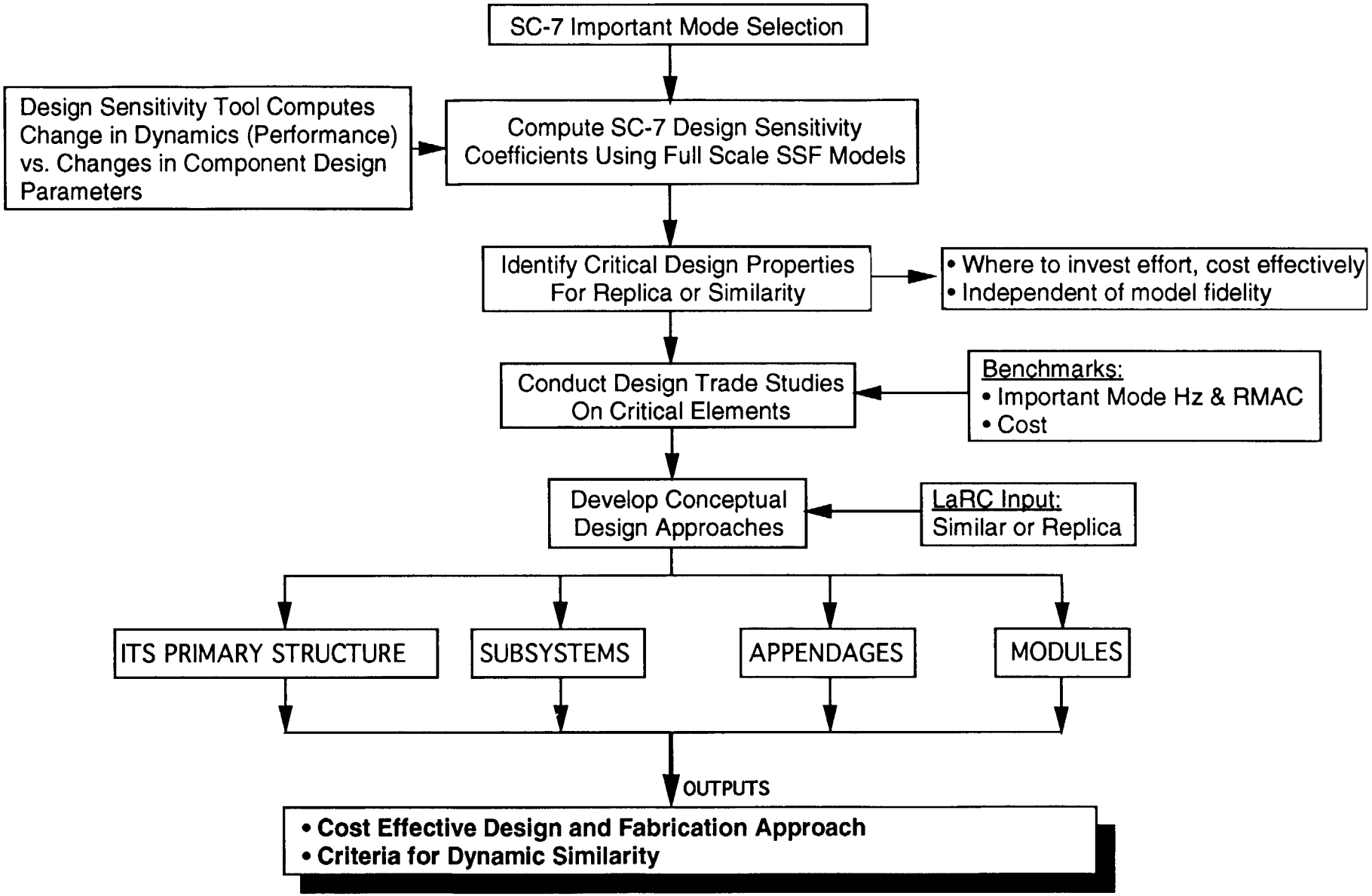


Figure 1-2 Design Study Flowchart

design effort to focus its limited resources on these components which require high-fidelity replication in order to match the scaled dynamics of the full-scale Space Station hardware.

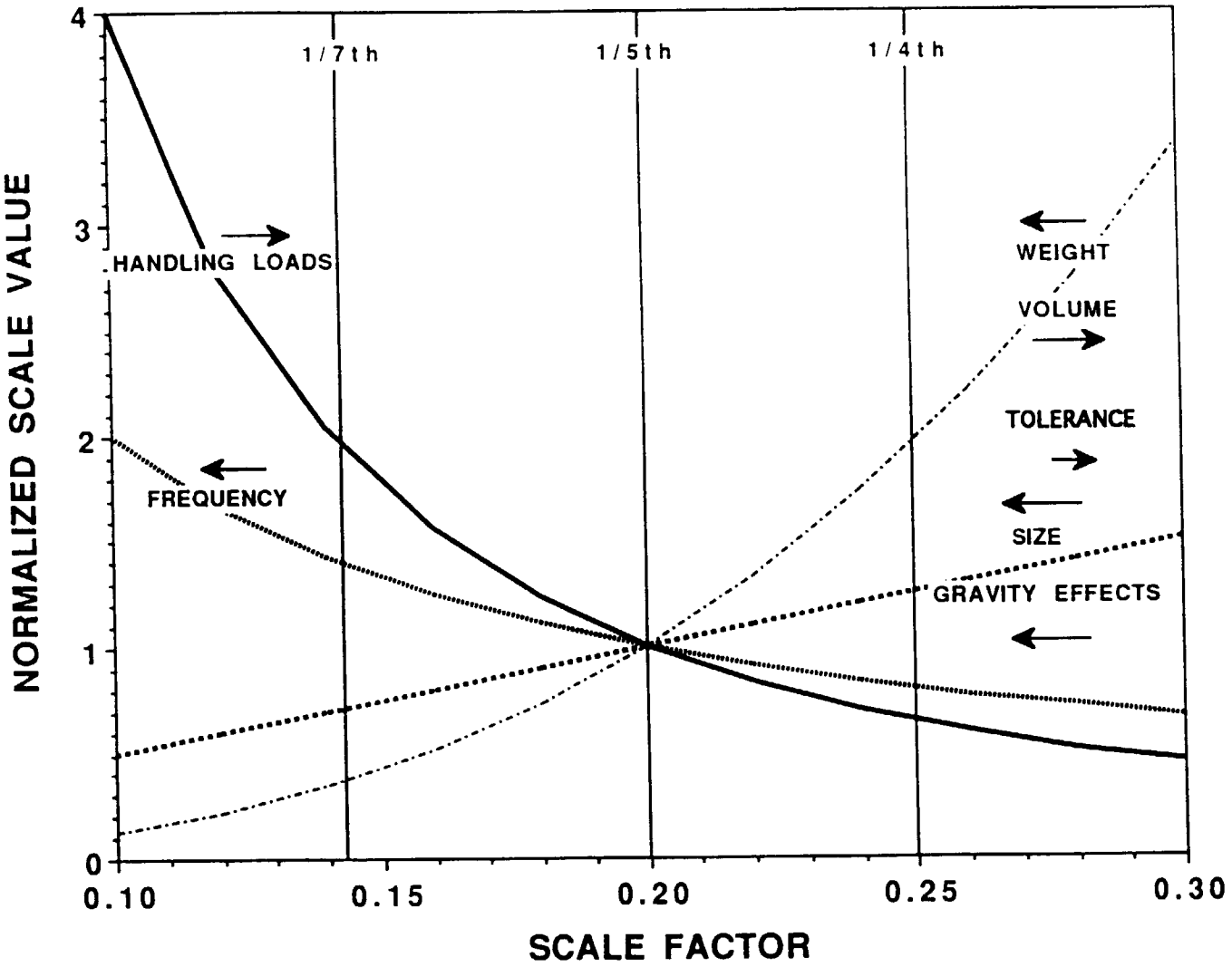
1.3 SUMMARY

A thorough review of the SSF SC-7 design drawing and Finite Element Model (FEM) was conducted in order to generate a comprehensive database identifying the SSF components and corresponding structural properties. A top level understanding of the various hardware components is essential for completing the scale factor trade study while knowledge of each individual property is required to successfully perform the design sensitivity study.

The scale factor trade study was successfully completed to form a technical basis for selection of a scale factor for the SC-7 dynamic scale model. Initially, a total of four scale model options were evaluated in the trade study; 1/4, 1/5, 1/7, and 1/10 scale. The proposed scale factor trade space was based on a review of the scale factors used for existing spacecraft scale models such as the 1/5-1/10 Hybrid-Scale DSMT model at NASA/LaRC and the 1/4 scale replica Space Shuttle model at NASA/JSC[4]. Early on in the trade study, it was concluded that a replica 1/10 scale factor was not a realistic model option and therefore it was deleted from the trade space.

The results obtained from fabricating the prototype bulkhead and strut hardware indicate there are no show-stoppers associated with producing 1/5 scale SSF primary structure hardware. Both the 1/4 and 1/5 scale factors are viable options in terms of hardware producibility based on the lessons learned during of the study. The small volume and length dimensions corresponding to 1/7 scale hardware however significantly reduce the likelihood of building an affordable model at this scale.

An overall summary of the scale factor trade study results is illustrated in Figure 1-3. The plot demonstrates the variations in scaled parameters versus scale factor for the 1/4, 1/5, and 1/7 scale options. The curves shown coincide with the key scaling parameters evaluated during scale factor trade study: size and tolerance (length), volume (producibility and fidelity), weight & gravity effects (robustness), handling loads, and frequency (suspension). The facility issue is not included in this summary as it will not be used in the scale factor selection (as directed by the LaRC technical monitor). All of the curves shown have been normalized to a value of 1.0 at 1/5 scale for comparison purposes. The arrow associated with each parameter indicates the preferred scaling direction for that quantity based on the results of the scale factor



	1/7th	1/5th	1/4th
SIZE	0.71	1.00	1.25
VOLUME	0.36	1.00	1.95
WEIGHT	0.36	1.00	1.95
1-G EFFECTS	0.71	1.00	1.25
HANDLING	1.96	1.00	0.64
FREQUENCY	1.40	1.00	0.80

Figure 1-3 Scale Factor Technical Performance Plot

trade study. The arrows indicate that the optimum size, gravity, weight, and frequency is achieved using the smaller 1/7 scale factor while scale-invariant handling loads and producibility concerns favor using the larger 1/4 scale factor.

The relative importance of each of the various performance parameters evaluated during the study needs to be considered before drawing a conclusion regarding which scale factor is best suited for a SSF subscale dynamic model. The most important requirement imposed on this study was to develop a high-fidelity "near-replica" scale model design which is best achieved with larger scale factors. This combined with the ability to couple the model with an existing 1/4 scale shuttle model favors selection of the larger 1/4 scale option. The increased fidelity associated with the 1/4 scale option outweighs the modest relative performance gains in gravity effects and suspension interaction realized with the smaller 1/5 and 1/7 scale designs. Therefore, the 1/4-scale size is recommended for the SSF subscale dynamic model.

The task of identifying SSF SC-7 critical structural elements which drive dynamic performance and thus may require high-fidelity replica scaling was accomplished by performing a design sensitivity study. By computing eigenvalue design sensitivity coefficients for each structural element physical property in the MSC/NASTRAN finite element model, a system level framework is provided for efficiently determining the relative scale model hardware fidelity required on an element property by property basis.

The database used to define the structural characteristics of the SSF SC-7 configuration consists of 1144 design sensitivity coefficients corresponding to the unique structural element properties in the finite element model. These properties relate only to structural stiffness, as mass effects were not considered. This resulted in a combined total of 11,440 coefficients for the ten important modes considered in the study. The important modes are predominantly first and second system level bending and torsion modes which characterize the overall dynamics of the SSF SC-7 configuration.

In order to evaluate the relative importance of each physical property, the Design Sensitivity Analysis (DSA) results were summed over all ten important modes and ranked in decreasing order. These ranked results when plotted in terms of cumulative sensitivity clearly show that over 90% of the total eigenvalue sensitivity of the structure is realized from only 118 unique design coefficients. These critical design parameters dominate the dynamic characteristics of the SSF structure and are the key to fabricating a cost-efficient scale model which captures the dynamic performance of the full-scale SSF. The remaining 1026 coefficients contribute only 10% of the total

sensitivity and therefore are prime candidates for dynamically similar designs. The recommended design approach for the non-critical component properties is to use lower fidelity dynamic similarity scaling which can yield significant time and cost savings. The design sensitivity analysis results provide a sound technical basis for making model fidelity decisions.

2.0 BASELINE CONFIGURATION DESCRIPTION

The Space Station Freedom on-orbit configuration baselined for the dynamic scale model design study is the Stage 7 Configuration, also referred to as the Man-Tended Configuration (MTC+). The SC-7 configuration is rich in dynamics as a result of the large module cluster masses attached at the port end of the truss structure along with low frequency appendages (Figure 2-1). At this Stage, nearly all the major flight loads, micro-dynamics, assembly dynamics, operational timelines, and attitude control system stability issues can be addressed in the scale model program.

The following Sections discuss the analytical models and design databases used to define the SSF SC-7 hardware design and dynamic characteristics. An overview of the hardware configuration is presented using the solid model database. A review of the finite element model listings and results provides further information on the dynamic complexity of SC-7. More detailed information on the overall structure and its design maturity was obtained by reviewing the design drawings supplied by the Work Package contractors.

2.1 DATABASE REFERENCES

The four SSF database references used to describe the SC-7 design are as follows:

1) WP-1, WP-2, and WP-4 MTC PDR Design Drawings
2) Delta PDR Design Review Handbooks For SSF WP-2
3) Updated IDEAS™ Solid Model of Stage-1 through Stage-7 Based on MDSSC Mass Properties List Dated April 30, 1992
4) Delta PDR MSC/NASTRAN Finite Element Model Used to Calculate On-Orbit Structural Design Loads

All the data sources are based on Preliminary Design Review or Delta PDR designs and represent the most comprehensive and up-to-date documents available at the time the scale model study was initiated. The two databases used most extensively for scale model design and analysis activities were the design drawings (1) and the finite element model (4). Both references contain detailed information concerning the mature design of the integrated truss primary structure and the location of subsystems.

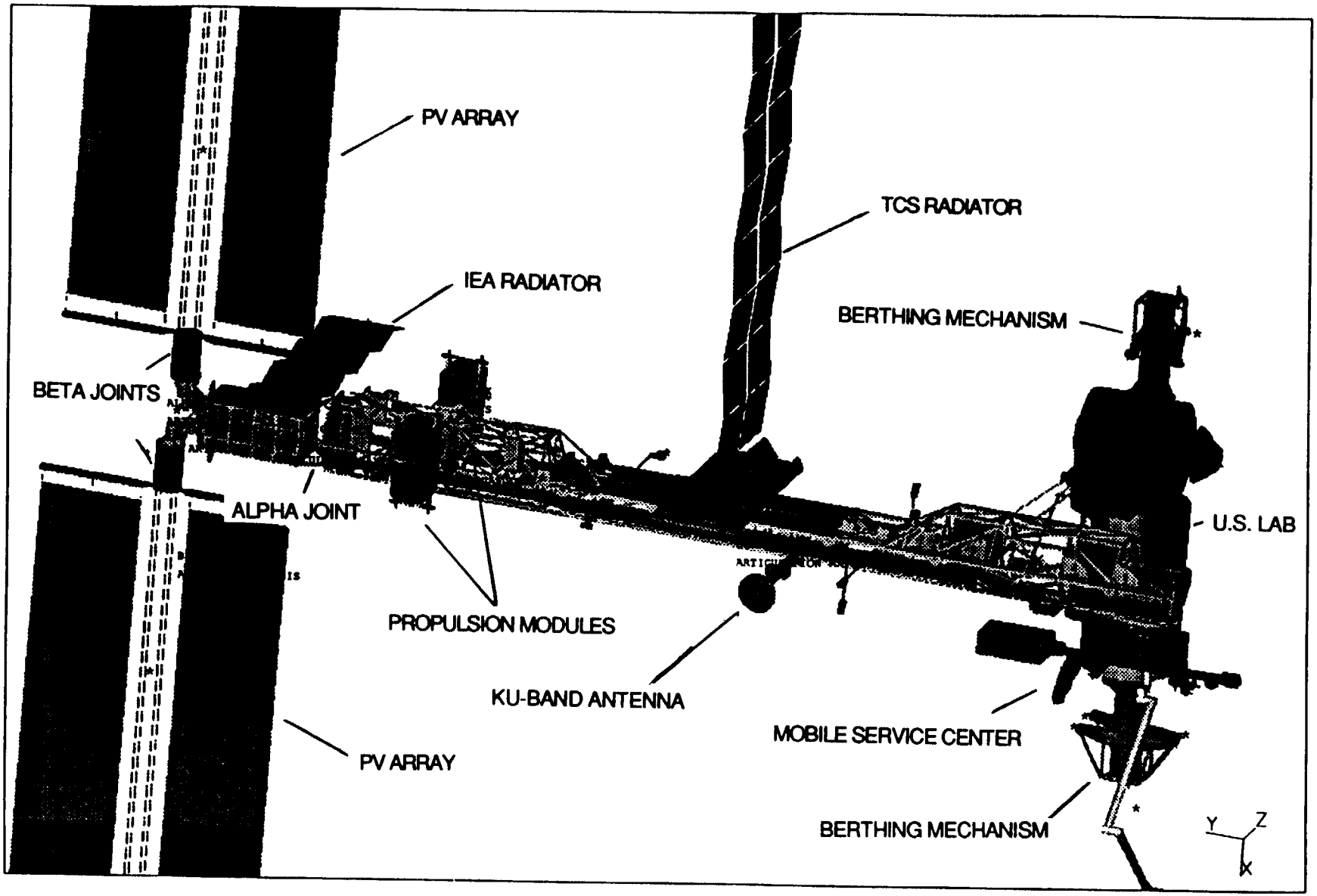


Figure 2-1 SC-7 IDEAS Solid Model Configuration

However, details on the secondary structure are somewhat lacking due to the fact that the design effort is still underway.

2.2 SOLID MODEL

The IDEAS™ solid model of SC-7 is basically a top level mass properties model showing the overall hardware locations of the primary structure and some of the larger secondary structure items. The model was primarily used for displaying the locations of the hardware components and served as an essential learning tool for understanding the overall component layout of the SC-7 configuration.

Figure 2-1 depicts the solid model of the SC-7 configuration consisting of five Integrated Truss Segments (ITS), associated secondary structure, a Solar Alpha Rotary Joint (SARJ), deployed solar arrays, TCS (Thermal Control System) radiator, IEA (Integrated Equipment Assembly) radiator, and KU-Band antenna appendages, a module cluster assembly, and a mobile service center. Figures 2-2 through 2-6 show the solid models of the S-4, S-3, S-2, S-1, and M-1 integrated truss segments, respectively. Several of the larger secondary structure components associated with each segment are identified in the figures. Note that segments M-1, S-2, and S-3 use the hexagonal bulkhead truss design while S-1 uses a half-hexagonal design in order to accommodate the rotating TCS radiator assembly. Also note that the S-4 segment structure is totally different from the others, using series of plates and panels to produce a rectangular cross-section rather than a hexagonal one. This was necessary to house the Integrated Equipment Assembly associated with the power generation system.

The relative location of the individual pre-integrated truss segments is shown in Figure 2-7 along with the corresponding Mission Build (MB) designations which refer to the shuttle flight assembly sequence. Table 2-1 contains the SSF assembly sequence of the major system components from Stages 1 through 7. This data is useful for tracking the configuration changes during the assembly process.

The mass properties breakdown of SC-7 by major subsystem is contained in Figure 2-8. The pie chart shows that the majority of the system mass is associated with the modules (41%), followed by the secondary structure (22%). The truss structure provides the primary stiffness and strength for the space station and accounts for 16% of the total mass. The remainder is divided between the mobile service center (which moves along the truss), the utility trays, and the solar array and radiator appendages.

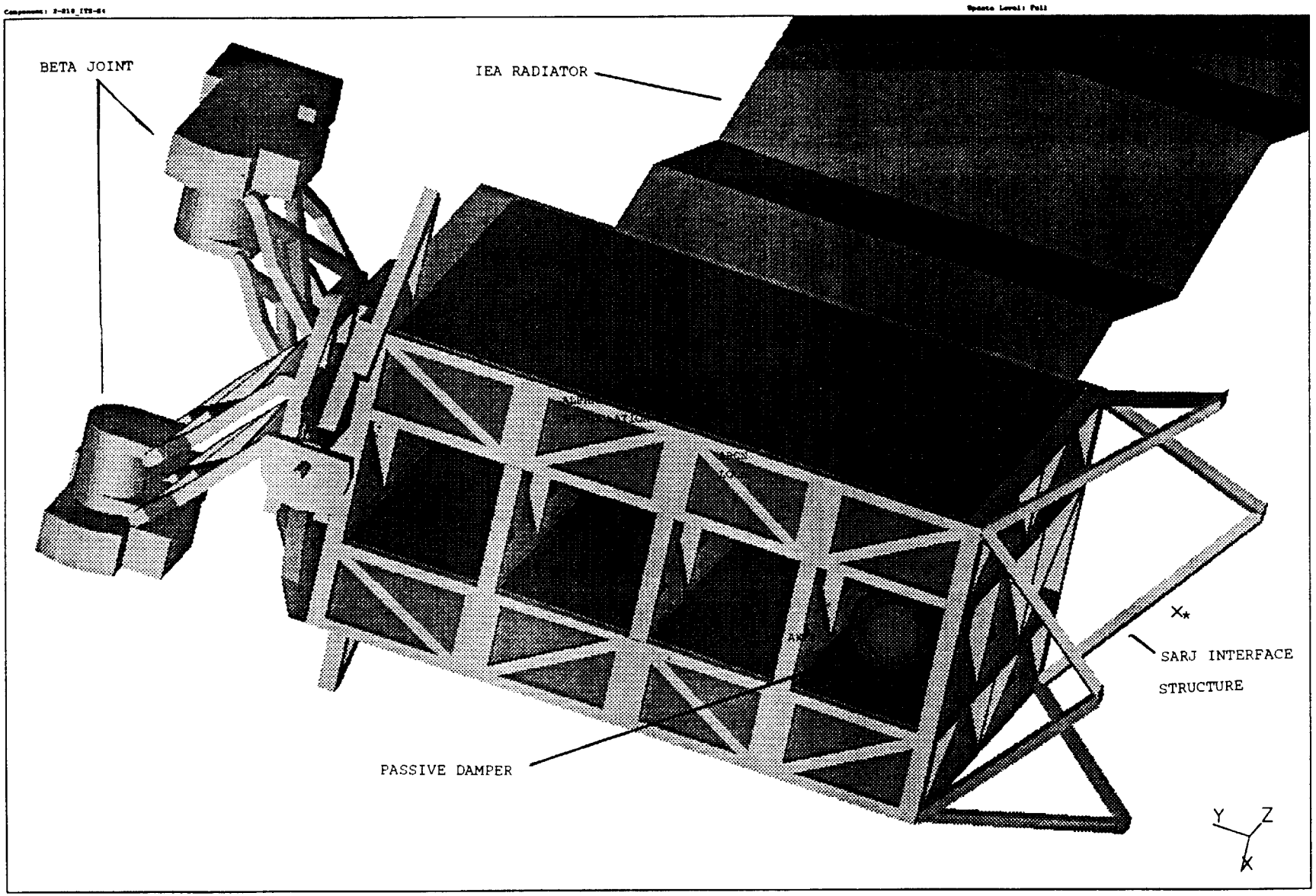


Figure 2-2 ITS S-4 Solid Model

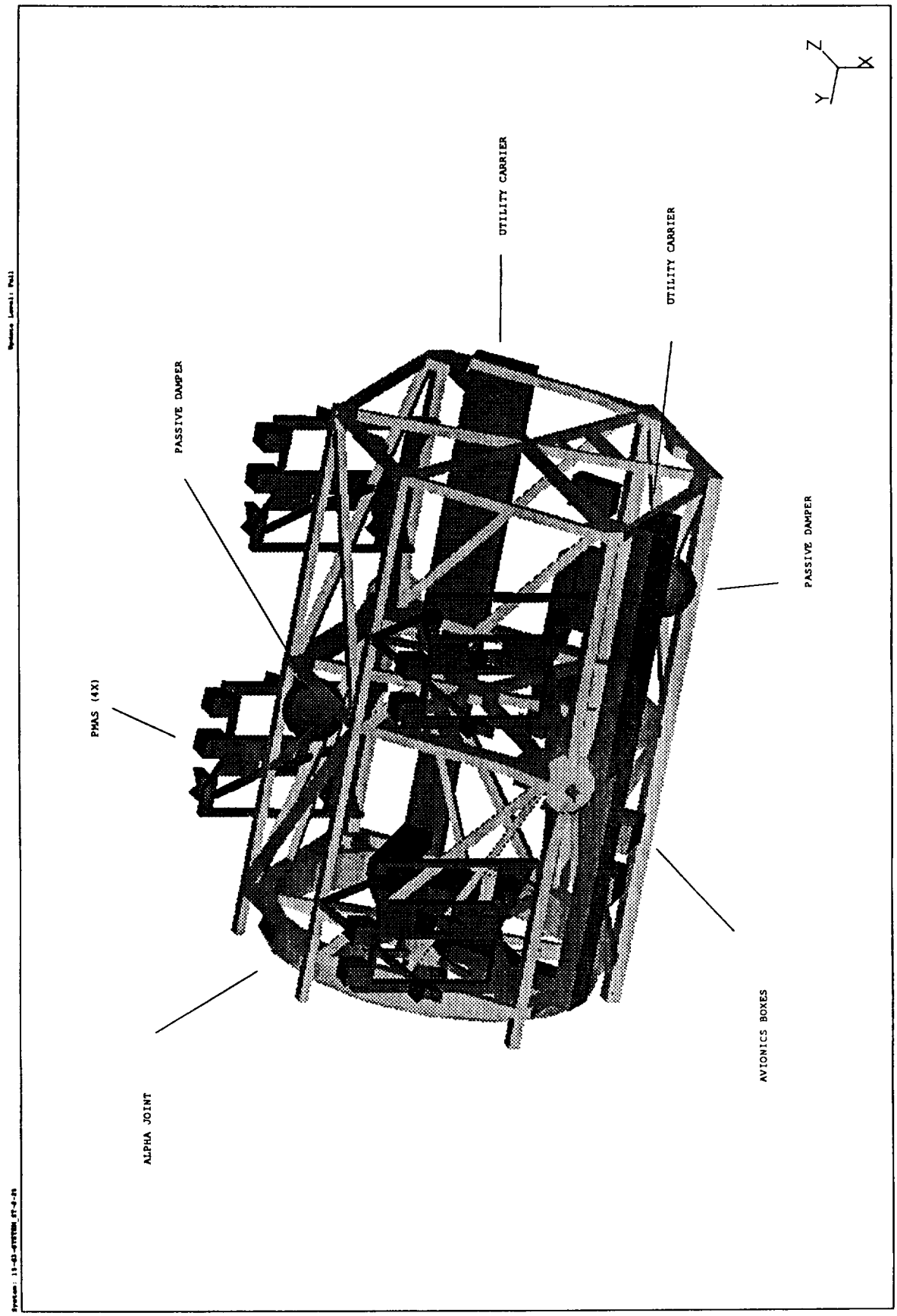


Figure 2-3 ITS S-3 Solid Model

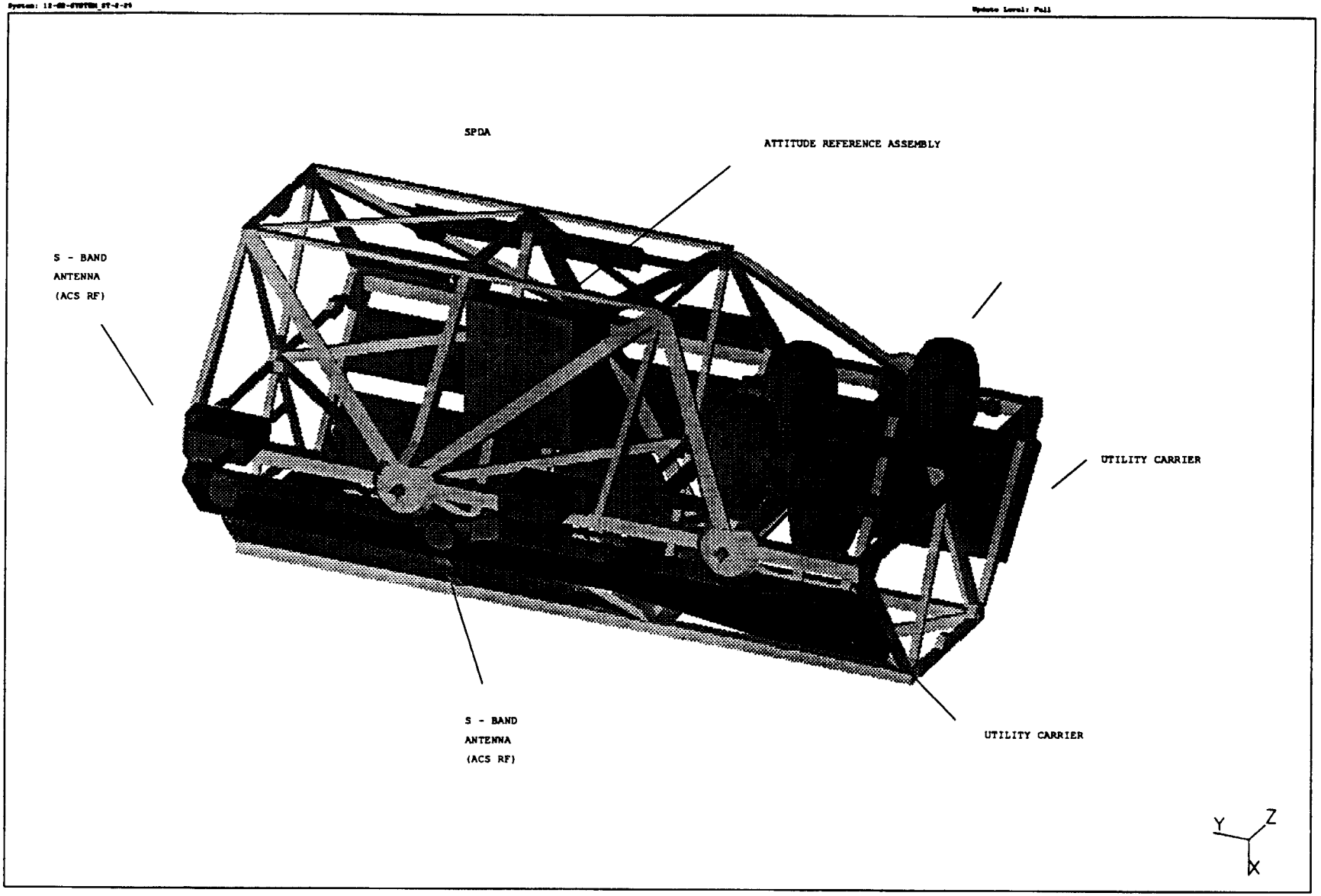


Figure 2-4 ITS S-2 Solid Model

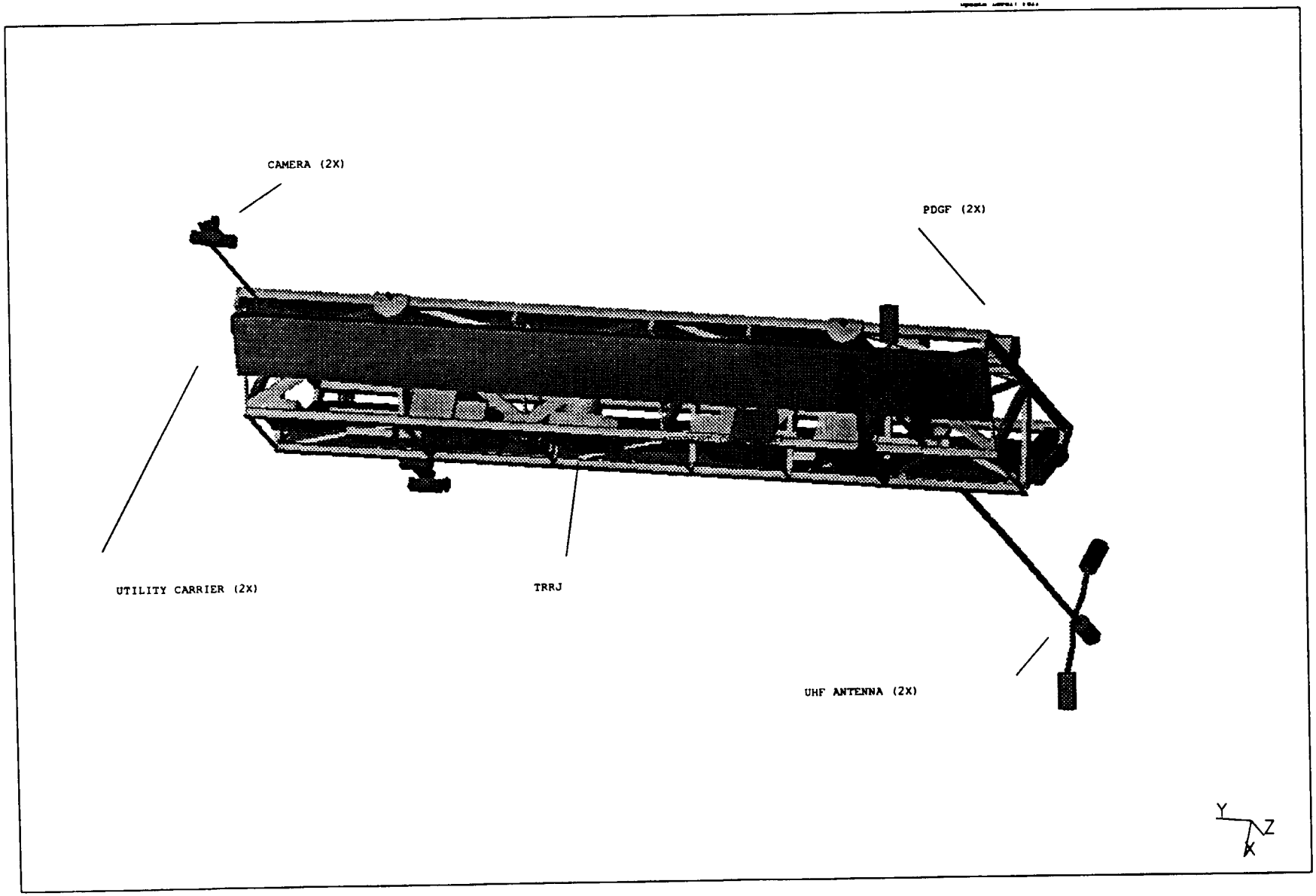


Figure 2-5 ITS S-1 Solid Model

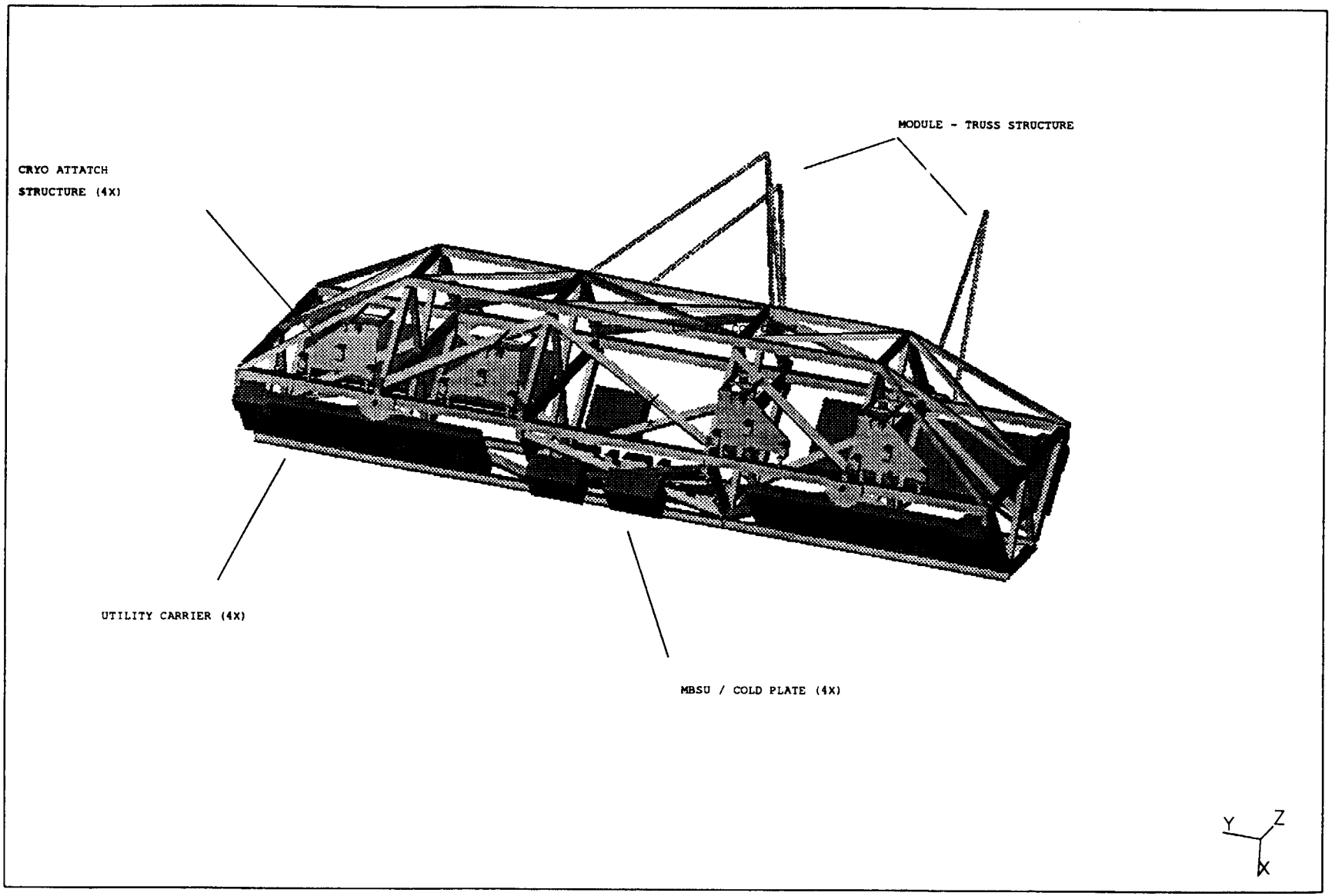
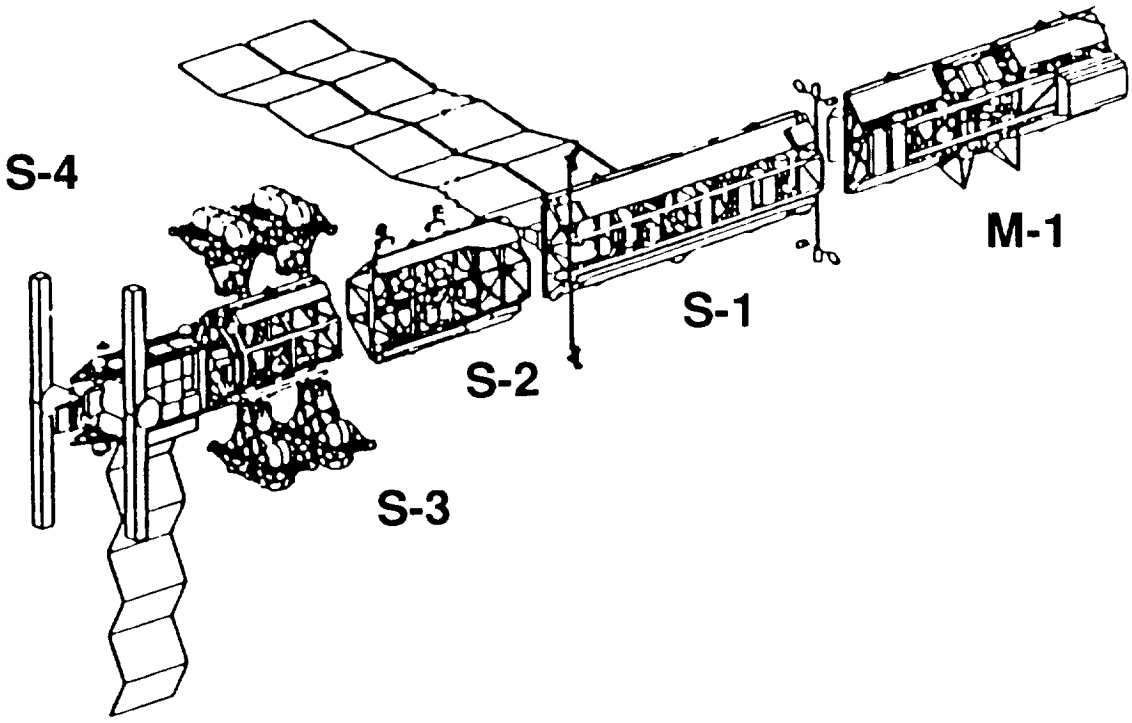


Figure 2-6 ITS M-1 Solid Model



MISSION BUILDS

MB-1 = S-3 & S-4
MB-2 = S-2
MB-3 = S-1
MB-4 = M-1

Figure 2-7 Integrated Truss Segment (ITS) Nomenclature

Table 2-1 SSF SC-7 Solid Model Assembly Sequence

System	Component	Stage 1	Stage 2	Stage 3	Stage 4	Stage 5	Stage 6	Stage 7
Primary Structure	ITS-S4	Primary Structure	Primary Structure	Primary Structure	Primary Structure	Primary Structure	Primary Structure	Primary Structure
	ITS-S3	Primary Structure	Primary Structure	Primary Structure	Primary Structure	Primary Structure	Primary Structure	Primary Structure
	ITS-S2		Primary Structure	Primary Structure	Primary Structure	Primary Structure	Primary Structure	Primary Structure
	ITS-S1			Primary Structure	Primary Structure	Primary Structure	Primary Structure	Primary Structure
	ITS-M1				Primary Structure	Primary Structure	Primary Structure	Primary Structure
	MTS					On M-1	On M-1	On M-1
Appendages	PV Arrays (2)	Stowed	Deployed	Deployed	Deployed	Deployed	Deployed	Deployed
	IEA Radiator	Stowed	Deployed	Deployed	Deployed	Deployed	Deployed	Deployed
	TCS Radiator			Stowed	Stowed	1 Finger Deployed	2 Fingers Deployed	2 Fingers Deployed
	TDRSS-Antenna			S1 - 3rd Blkhd from Inbd End	S1 - 3rd Blkhd from Inbd End	S1 - 3rd Blkhd from Inbd End	S1 - 3rd Blkhd from Inbd End	S1 - 3rd Blkhd from Inbd End
Modules	Cupola					On Resource Node - Aft End	On Resource Node - Aft End	On Resource Node - Aft End
	PBM-A					On Resource Node - Aft End	On Resource Node - Aft End	On Resource Node - Aft End
	PBM-B							On Resource Node - Fwd End
	Resource Node 2					On M-1	On M-1	On M-1
	Airlock							On Resource Node
	US Lab Stage6						On Resource Node	
	US Lab Stage7							On Resource Node
Mobile Service Center (MSC)	Mobile Transport†	S-3 - Inboard End	S-2 - Inboard End	S-1 - Inboard End	M-1 - Inboard End	M-1 - Inboard End	M-1 - Inboard End	M-1 - Inboard End
	UBM	On MT	On MT	On MT	On MT			
	SSRMS†			S-1 - Inboard End	S-1 - Inboard End	S-1 - Inboard End	On MBS	On MBS
	MT Batteries†				M-1 - Inboard End, Aft Face	M-1 - Inboard End, Aft Face	M-1 - Inboard End, Aft Face	On Mobile Transporter
	CETA Device A				Middle of M-1 Forward Face	Middle of M-1 Forward Face	Middle of M-1 Forward Face	Middle of M-1 Forward Face
	CETA Device B				Middle of M-1 Forward Face	Middle of M-1 Forward Face	Middle of M-1 Forward Face	Middle of M-1 Forward Face
	MBS						On Mobile Transporter	On Mobile Transporter
	SPDM							On MMD
	MMD on MBS							On MBS
Secondary Structure	RCS Module-A		S-3 - Inboard End	S-3 - Inboard End	S-3 - Inboard End	S-3 - Inboard End	S-3 - Inboard End	S-3 - Inboard End
	RCS Module-B		S-3 - Inboard End	S-3 - Inboard End	S-3 - Inboard End	S-3 - Inboard End	S-3 - Inboard End	S-3 - Inboard End
	Gas Cond Assy-A				M-1 - Inboard End	M-1 - Inboard End	M-1 - Inboard End	M-1 - Inboard End
	Gas Cond Assy-B				M-1 - Inboard End	M-1 - Inboard End	M-1 - Inboard End	M-1 - Inboard End

† = Component Relocated During Configuration Buildup

ITEM	FULL SCALE (LBS)
ITS-S4	**16809**
TRUSS STRUCTURE	8507
SECONDARY STRUCTURE	5889
IEA RADIATOR	1528
SARJ	884
ITS-S3	**7888**
TRUSS & AV BOXES	3995
SECONDARY STRUCTURE	778
SARJ	1769
UTILITY TRAYS	1347
ITS-S2	**12572**
TRUSS STRUCTURE	4043
SECONDARY STRUCTURE	3729
CMG'S	2395
UTILITY TRAYS	2405
ITS-S1	**18965**
TRUSS STRUCTURE	7363
SECONDARY STRUCTURE	5784
TRRJ	1197
KU ANTENNA	595
UTILITY TRAYS	4026
ITS-M1	**27385**
TRUSS STRUCTURE	11400
SECONDARY STRUCTURE	10333
MTS	1076
UTILITY TRAYS	4576
MODULES	**89443**
PV ARRAYS	**6079**
TCS RADIATOR	**8469**
PROP MODULES	**15075**
MOBILE CENTER	**16165**
TOTAL WEIGHT =	**218,851**

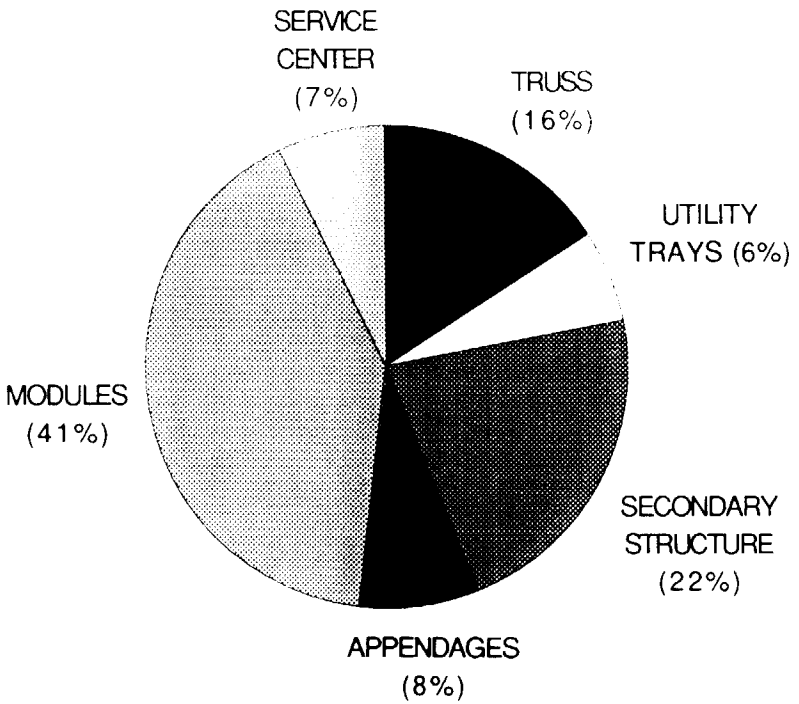


Figure 2-8 SC-7 Solid Model Mass Properties

2.3 FINITE ELEMENT MODEL

The finite element model used to analyze the SC-7 hardware design was the MSC/NASTRAN[5] Delta PDR model used by Lockheed Engineering & Sciences Co. (LESC) at NASA/JSC to calculate on-orbit structural design loads in support of the Loads and Dynamics Working Group (LDWG). This finite element model was used extensively during the suspension analysis and component design sensitivity analysis phases of the scale model study. The model received from LESC contained component mode models for the IEA radiator and solar arrays which have high modal densities. Since the major focus of the scale model study did not require detailed analysis of the higher modes of these two appendage components, the component mode models were replaced with equivalent beam representations in MSC/NASTRAN resulting in a single bulk data deck. This change was implemented in order to simplify the analysis and increase computational efficiency.

A mesh plot of the resulting SC-7 finite element model used is shown in Figure 2-9. The model is composed of 2683 nodes and 4564 elements resulting in approximately 16,000 active degrees-of-freedom. An eigensolution produces 56 free-free modes below 3 Hz. The design of the relatively mature truss primary structure is well defined in the model along with some of the larger secondary structures such as the Propulsion Module Attachment Structure (PMAS) and cryo attachment structure. The SARJ is also modeled in significant detail.

There is essentially no design detail corresponding to the majority of the secondary structure which is simply modeled as lumped masses. The modules and mobile service center components are modeled using equivalent beam representations with minimal detail. In general, the fidelity of this model lends itself to studies focusing on the dynamic characteristics of the SSF truss primary structure and key subsystems. The level of detail reflects what was available for the SSF PDR Load Cycle and provides a sufficient representation of the dynamics for the purposes of this scale model study.

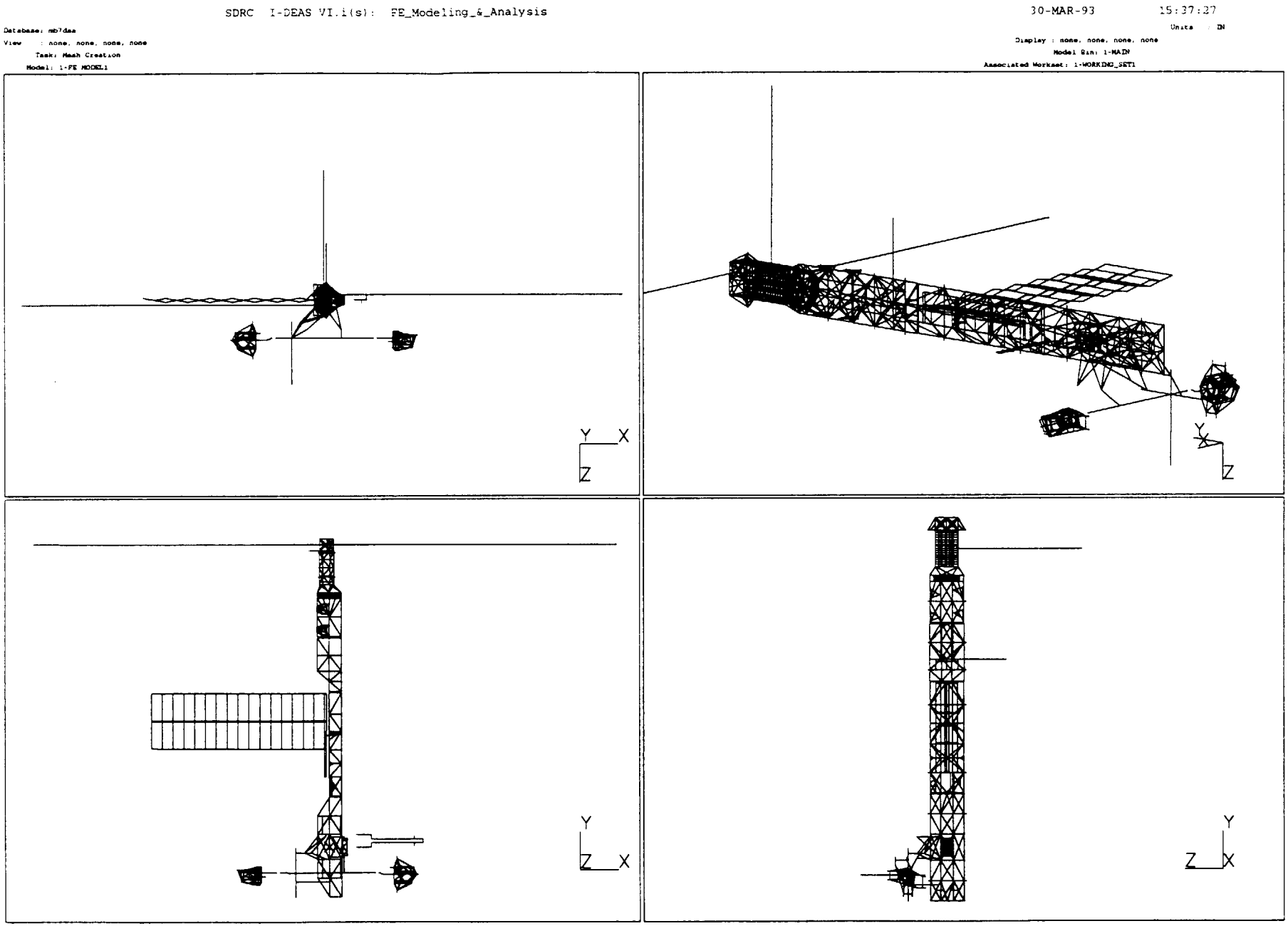


Figure 2-9 SC-7 Finite Element Model

3.0 SCALE FACTOR TRADE STUDIES

The primary purpose of the scale factor trade study was to develop a fundamental understanding of the key scaling parameters that drive the design, performance, and cost of the SSF dynamic scale model. Scaling issues were evaluated both in relative and absolute terms in order to identify any "cliffs" or "show stoppers" associated with specific scale factor designs which limit the trade space. The findings resulting from this study form the technical basis for the selection of a scale factor size for a SSF scale model. Merits of other equally important criteria such as cost and program resources should also be considered when making the final scale factor selection.

This Section begins with a brief overview of the scaling laws used to perform the scaling analysis followed by a description of the proposed scale factor options. The remainder of the section focuses on evaluating and comparing each of the key scaling parameters associated with gravity loads, handling loads, model suspension, hardware producibility, and facility issues. The results of the study are then summarized in a scale factor performance plot.

3.1 SCALING LAWS

A fundamental understanding of the scaling laws associated with both similarity and replica scaling is needed to efficiently design a "near-replica" scale model of the Space Station Freedom. Replica scaling can be considered a subset of the more general method of similarity scaling. Similarity scaling is classically used to design wind tunnel models for investigating aerodynamic and aeroelastic behavior. In similarity scaling, the equations of motion are non-dimensionalized and the characteristics which are to be scaled are expressed in terms of non-dimensional parameters. The dimensionless parameter of interest can be properly scaled, given that the other non-dimensional ratios are preserved. For example, in aeroelastically scaling a cantilever wing with a tip mass, the frequencies and mode shapes can be scaled if the mass, inertia, and stiffness distributions are preserved. In this similarity example, the scale factors for time, length, and mass may be selected independently, while the rest of the model properties are derived from these primary scale factors. By way of contrast, in replica scaling only one of these scale factors may be chosen independently, and all of the other model properties are derived from dimensionless

ratios. One advantage gained in using replica scaling is that much of the non-linear behavior present in the full-scale spacecraft will also exist in the subscale model[6].

In replica scaling, the non-dimensional ratio that is normally selected is the length (size) scale factor, λ. This is the independent ratio used for deriving the replica scale parameters needed for the SSF scale model. The other two primary factors, mass and time, cannot be selected independent of the length scale factor and therefore are fixed once λ is determined. Figure 3-1 lists the fundamental replica scale factors as a function of λ along with an example set of computed scale factors for a 1/5 scale design. These replica scale factors are derived from the non-dimensional equations of motion using energy techniques[7]. The important parameters to note are length, volume, frequency, mass, and unscaled effects which correspond to the scale factors evaluated during the scale model trade study. The prominent unscaled effects include gravity loads, handling loads, and suspension related issues.

In reality, a scale model of the Space Station Freedom will never be an exact replica design as there will always be areas in the structure which cannot be fully replicated for some reason (e.g., cost, manufacturing limitations, etc.). Also, secondary components in the structure often behave essentially as rigid masses in which case the cost of duplicating the design detail in replica scale is not justified. For these cases, using a dynamically similar scaling approach having overall size and mass scale factors consistent with the replica design can result in a considerable cost savings without compromising overall dynamic performance. Combining replica and similarity scaling in this manner results in what is referred to in this study as a "near-replica" design.

3.2 SCALE MODEL OPTIONS

Four scale model options were initially considered for the SSF dynamic scale model trade study. These options correspond to a range of replica scale factors varying from 1/10 to 1/4 scale as illustrated in Figures 3-2 and 3-3. The outline drawings of the scaled SC-7 configurations shown in the figures are drawn to scale in order to demonstrate the relative size ranges of the four options. There is also a summary table presented in Figure 3-2 which contains the overall scaled dimensions and weights of the four model options. The scaled SC-7 length and weight range from 38.6 feet and 3420 lbs for the larger 1/4 scale model to 15.5 feet and 219 lbs for the smaller 1/10 scale model.

• PRIMARY SCALE FACTORS (SUB = λ * FULL)

PARAMETER	SCALE FACTOR	1/5 SCALE
LENGTH	λ	0.200
MASS	λ^3	0.008
TIME	λ	0.200
MODULUS (E)	1.	1.000
DENSITY (ρ)	1.	1.000

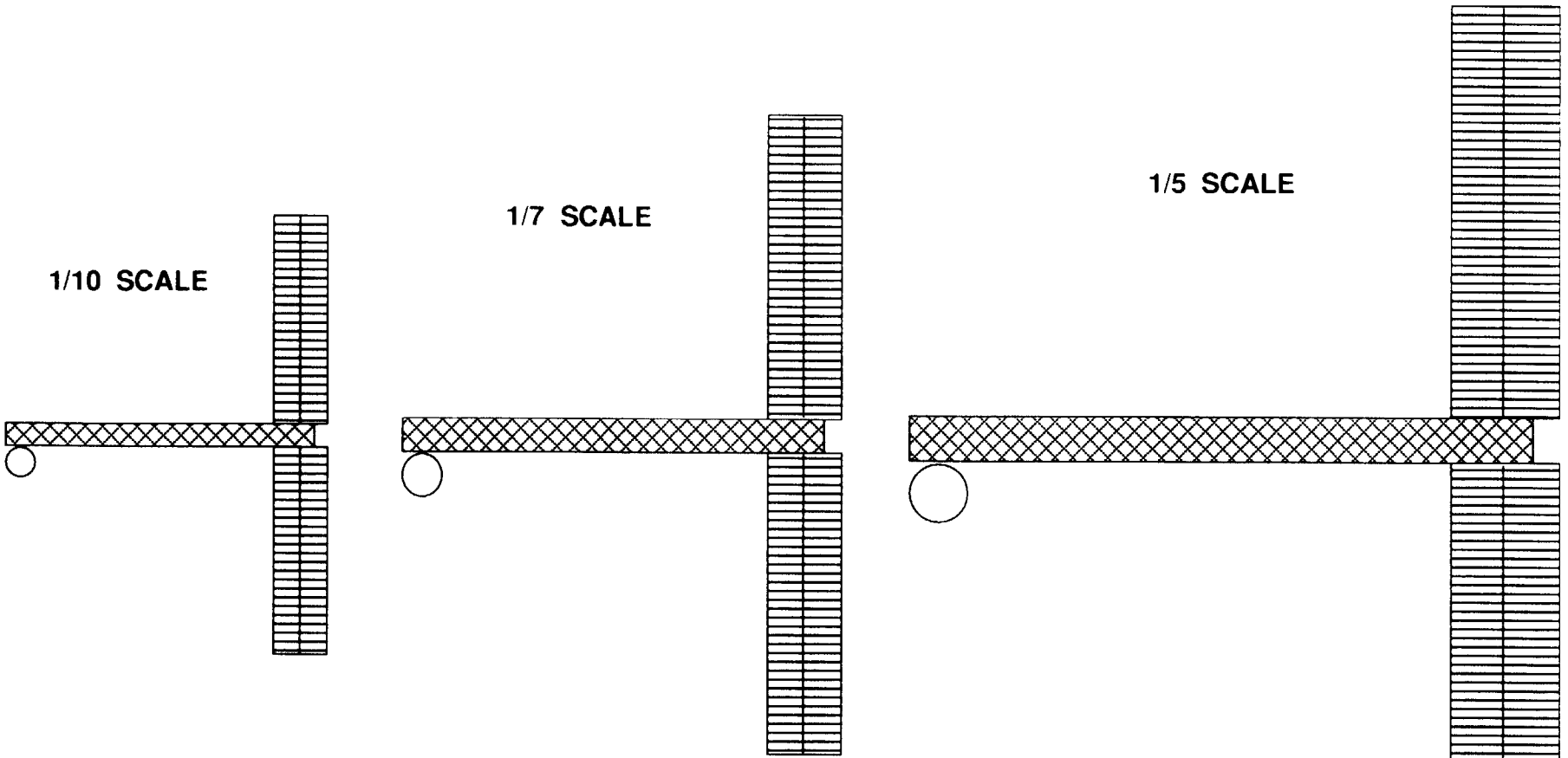
• UNSCALED EFFECTS

PARAMETER	SCALE FACTOR	1/5 SCALE
GRAVITY EFFECTS	λ	0.200
GRAVITY	1.	1.000
HANDLING	λ^{-2}	25.00
SUSPENSION	?	?
AIR	?	?

• DERIVED SCALE FACTORS

PARAMETER	SCALE FACTOR	1/5 SCALE
AREA	λ^2	0.040
VOLUME	λ^3	0.008
DISPLACEMENT	λ	0.200
VELOCITY	1.	1.000
FORCE	λ^2	0.040
TORQUE	λ^3	0.008
STRESS	1.	1.000
FREQUENCY	λ^{-1}	5.000
LINEAR ACCEL	λ^{-1}	5.000
DAMPING	1.	1.000
AREA INERTIA	λ^4	0.0016
MASS INERTIA	λ^5	0.0003

Figure 3-1 Replica Scaling Laws



Distance (feet)	FULL SCALE	REPLICA 1/4th	REPLICA 1/5th	REPLICA 1/7th	REPLICA 1/10th
Truss Length	154.5	38.6	30.9	22.1	15.5
Truss Width-X	11.1	2.8	2.2	1.6	1.1
Truss Width-Z	14.2	3.6	2.8	2.0	1.4
Array Tips	229.0	57.3	45.8	32.7	22.9
Weight (lbs)	218,851	3,420	1,751	638	219

Figure 3-2 1/10, 1/7, 1/5 Scale Model Options

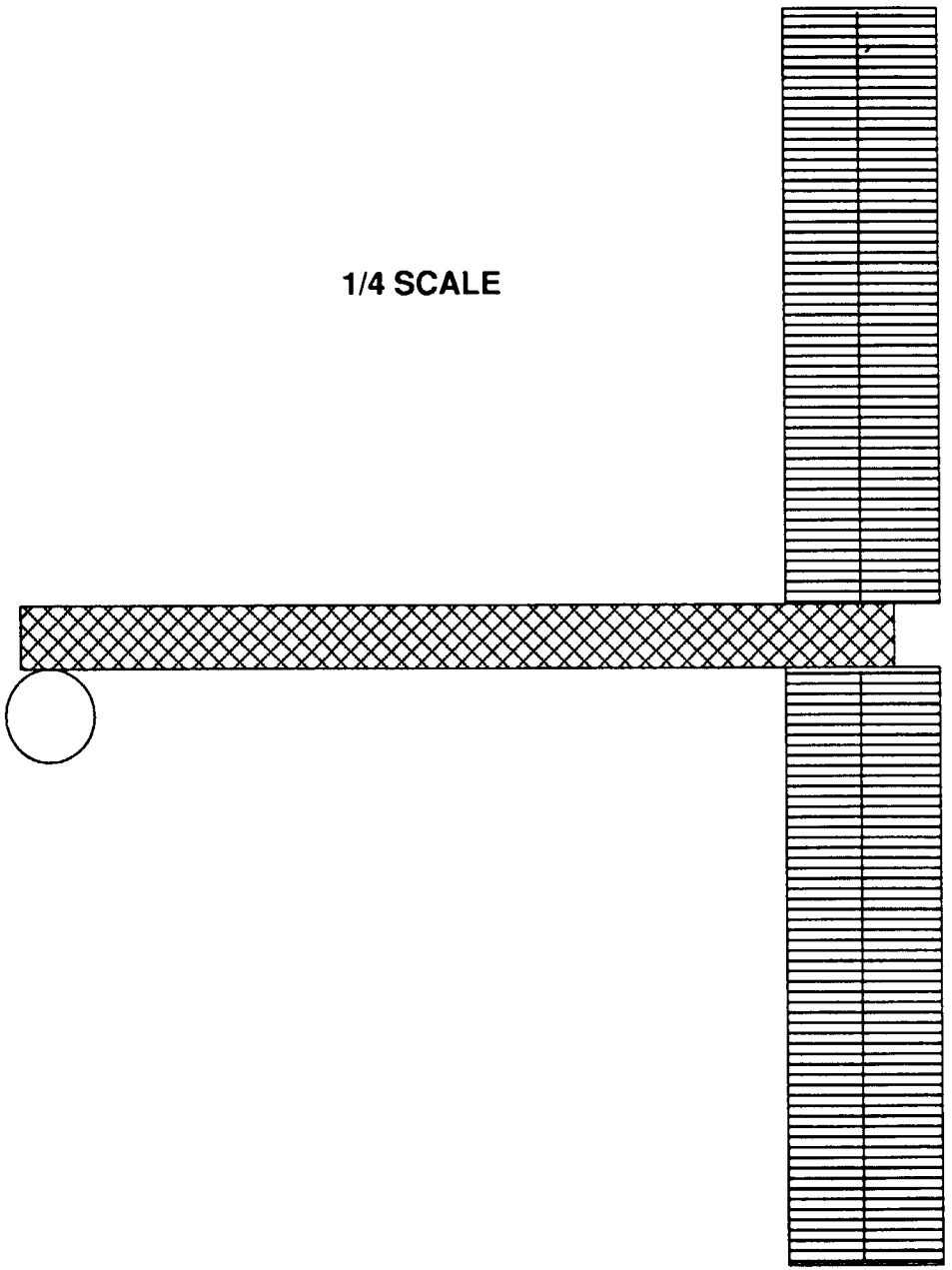


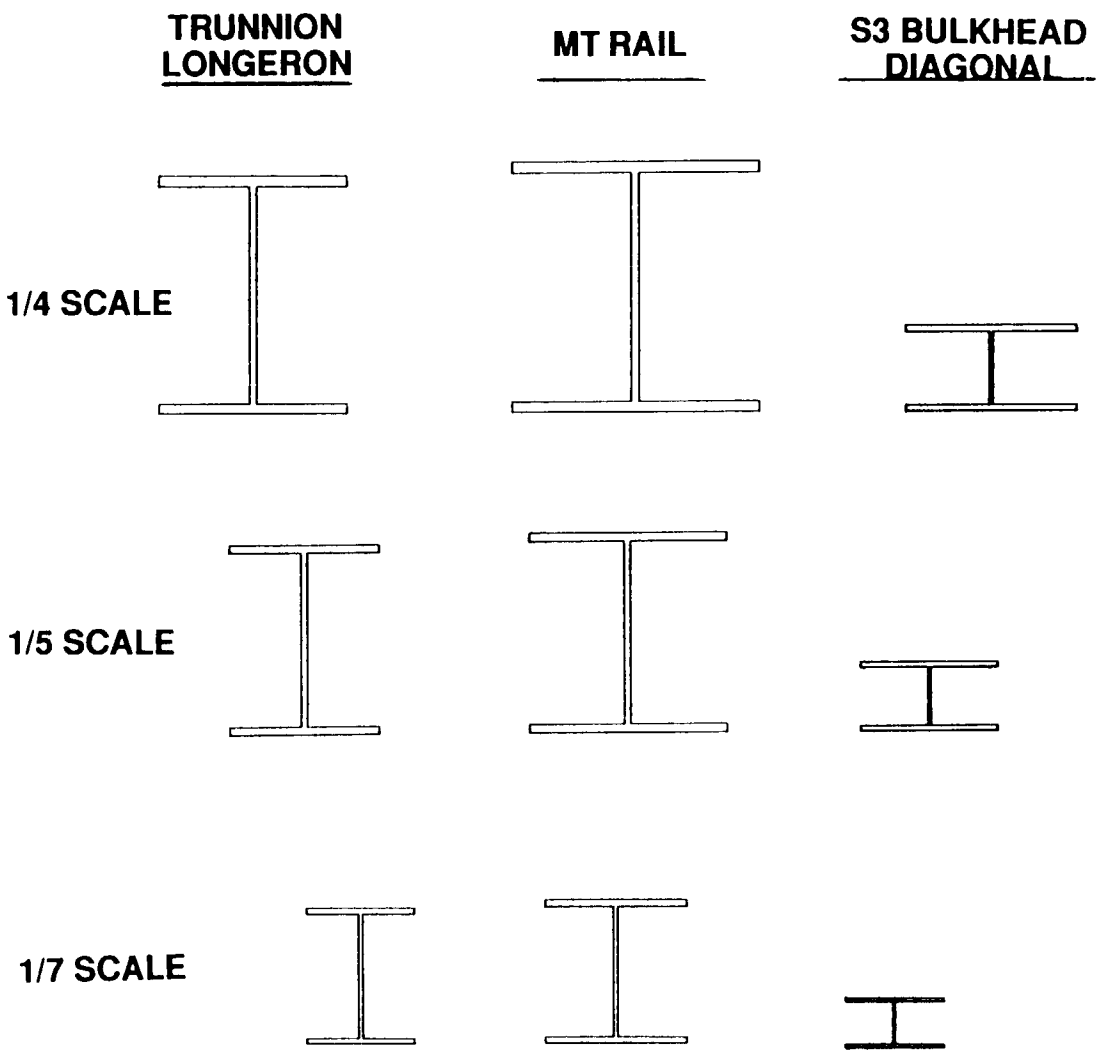
Figure 3-3 1/4 Scale Model Option

The approach used for defining the proposed scale factor trade space was based on a review of the scale factors used for existing spacecraft scale models such as the 1/5-1/10 Hybrid-Scale DSMT model at NASA/LaRC and the 1/4 scale replica Space Shuttle model at NASA/JSC. The 1/10 scale option bounded the problem on the small end of the spectrum since replica designs of this size or smaller are extremely costly to manufacture. On the larger side, the 1/4 scale option was a practical upper limit based on overall size and weight considerations, including facility space. There was a strong justification for including the 1/4 scale option in the trade space based on the existence of the 1/4 scale shuttle model used extensively by the Space Shuttle program. Since the Space Shuttle will play a vital role in the on-orbit assembly of SSF, a 1/4 scale SSF model could be combined with the 1/4 shuttle model to study coupled loads events such as assembly dynamics, docking, and berthing which are extremely difficult to quantify analytically.

Early on in the trade study, it was concluded that a replica 1/10 scale factor was not a realistic model option and therefore it was deleted from the trade space. A review of SSF primary truss I-beam dimensions revealed significant manufacturing and assembly issues associated with fabricating delicate components at 1/10 scale. Figure 3-4 shows cross-sectional drawings of trunnion longeron, Mobile Transporter (MT) rail, and bulkhead diagonal I-beams scaled using the 1/4, 1/5, and 1/7 scale options along with a table summarizing the resulting dimensions. The I-beam cross-sections are drawn actual size to illustrate the true dimensions. Each of these beams are part of the truss primary structure with the MT rail being one of the larger beams in the structure and the diagonal being one of the smaller beams. Inspection of the scaled I-beams dimensions reveal potential producibility issues associated with building even 1/7 scale replica components. The precision machining of I-beams with web thicknesses approaching 10 mils which would be required for a replica 1/7 scale model could be extremely difficult and costly. More detailed information regarding manufacturing issues is presented in Section 3.5.

3.3 UNSCALED EFFECTS

In order to correlate SSF scale model dynamic results with full-scale SSF on-orbit dynamic behavior, proper implementation of the similarity scaling laws would require that the SSF scale model be tested in a zero-g, vacuum environment with free-free boundary conditions. There are several parameters which require analysis since they cannot be properly scaled when testing the model in earth's 1-g atmosphere. The significant ones for the purposes of this study are gravity loads (Section 3.3.1) and suspension effects (Section 3.3.2). Since there are few large planar surfaces on the



I-BEAM	DIMENSIONS (INCHES) A	B	C	D
1/4 TRUNNION LONG.	0.045	1.375	0.058	1.100
1/4 MT RAIL	0.045	1.450	0.063	1.450
1/4 BKHD DIAGONAL	0.020	0.500	0.038	1.000
1/5 TRUNNION LONG.	0.036	1.100	0.046	0.880
1/5 MT RAIL	0.036	1.160	0.050	1.160
1/5 BKHD DIAGONAL	0.016	0.400	0.030	0.800
1/7 TRUNNION LONG.	0.026	0.786	0.033	0.629
1/7 MT RAIL	0.026	0.829	0.036	0.829
1/7 BKHD DIAGONAL	0.011	0.286	0.022	0.571

A = WEB THICKNESS
B = DEPTH
C = FLANGE THICKNESS
D = FLANGE WIDTH

Figure 3-4 Primary Truss I-Beam Cross-Sections (Actual Size)

SSF model to generate significant aerodynamic drag, testing in a vacuum is not required.

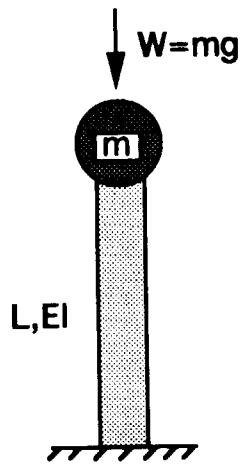
Gravity effects are referred to as "unscaled" because gravity should scale as linear acceleration (λ^{-1}) but in reality gravity cannot be scaled and therefore remains a constant 1-g regardless of the scale factor. The presence of 1-g gravity loads generates concerns regarding primary structure loads, appendage buckling margins, appendage static deflections (sag), and appendage destiffening. The presence of the suspension system which supports the model can also perturb the models free-free dynamic behavior. Each of these concerns are individually addressed in the sections to follow.

An additional unscaled parameter which is unrelated to gravity but is still independent of scale factor is handling loads. This unscaled effect also needs to be considered when evaluating scale factors, and is addressed in Section 3.3.3.

3.3.1 Gravity Loads

The most important unscaled effect which needs to be evaluated is that resulting from the presence of gravity loads on the scale model. Gravity effects scale by the structural Froude number which scales linearly as λ. The Froude number can be thought of as a measure of the relative importance of gravity when compared with the inertial accelerations of the model. One way to interpret this number is that if a 1/4 scale model is tested in 1-g, the influence of the gravity forces is equivalent to testing the full scale model in 1/4-g. Thus, the desire to minimize gravity effects drives the scale factor smaller, and in the limit, an infinitely small scale model in 1-g would have the same gravitational influence as the full scale model in zero-g. This means that of three model options being considered, the 1/7 scale option would result in the least amount of gravity effects and would give the best simulation of a zero-g environment.

One of the principle issues which arise due to the presence of gravity loads is scale model structural integrity or model "robustness". Figure 3-5 demonstrates the effect of gravity induced loads on model robustness using the column buckling equation for a simple cantilevered beam as an example. Assuming a massless beam supporting a lumped mass at its tip, an unscaled 1-g load results in an axial compressive force (W) in the beam as shown. Substituting the proper replica scale factors in place of the buckling equation variables results in a scale factor of λ for the W/P_{cr} expression. Therefore, a structural component having a full-scale W/P_{cr} ratio of 0.4 would have a corresponding W/P_{cr} ratio of only 0.1 if built at 1/4 scale. This results in a factor of four



Column Buckling Ratio: $\frac{W}{P_{cr}} = \frac{4mgL^2}{\pi^2 EI}$

(Fixed-Free)

Scaled Buckling Ratio: $\frac{W}{P_{cr}} = f(\lambda) = \frac{(\lambda_m * \lambda_g)\,\lambda^2}{\lambda^4} = \frac{\lambda_m * \lambda_g}{\lambda^2}$

For True Scaling: $\lambda_m * \lambda_g = \lambda^3 * \frac{1}{\lambda} = \lambda^2$ ------> $\frac{W}{P_{cr}} = 1.0$

For Unscaled Gravity: $\lambda_m * \lambda_g = \lambda^3 * 1.0 = \lambda^3$ ------> $\frac{W}{P_{cr}} = \lambda$

CRITICAL BUCKLING RATIO SCALES AS λ IN 1-G ENVIRONMENT RESULTING IN INCREASED MODEL ROBUSTNESS WITH SMALLER SCALE FACTORS

Figure 3-5 Unscaled Gravity Effects (Column Buckling)

increase in the critical buckling margin relative to full-scale which translates into improved model robustness with decreasing scale factor.

In comparison, if gravity could be truly scaled as λ^{-1} consistent with replica scaling laws, the corresponding scale factor for the buckling expression would be 1.0 which says that the robustness of a scale model in a true scaled environment is independent of scale factor. The reason for this is shown in Figure 3-5 were it can be seen that weight (m*g) scales only as λ^2 for a true scaled model versus λ^3 for a scale model in 1-g. This factor of λ difference is the scaling of weight induced loads is the reason why scale models become more robust with decreasing scale factor. Therefore, a 1/7 scale model would result in greater model robustness relative to the other two scale options under consideration.

In terms of model robustness, the SSF scale model components which are at most risk in a 1-g environment are the low frequency primary appendages which could buckle when aligned with the gravity vector. The SSF appendages most vulnerable are the flexible, low-frequency solar arrays, TCS radiator, and IEA radiator whose orientations with respect to gravity are dependent on the model test configuration. The most probable test configuration for a SSF scale model from a facilities and suspension point of view is one with the solar arrays parallel with the ground (perpendicular to gravity), the IEA radiator oriented vertically upward (Alpha = -90°), and the TCS radiator appendages either parallel to ground or rotated 90° as shown in Figure 3-6. In this configuration, the component with the highest likelihood of buckling is the IEA radiator. For the flexible appendages oriented horizontally (solar arrays and TCS radiator), it is a foregone conclusion that suspension devices will be required to off load gravity and minimize static sag. Section 3.3.2 discusses in detail the issues associated with properly suspending these appendages.

In order to address the appendage buckling issue, a graph of Pg/Pcr versus frequency for a uniform cantilevered beam representative of the IEA radiator was generated as shown in Figure 3-7. Curves depicting 10, 15, and 20 foot beam lengths were plotted along with a horizontal line indicating a Factor of Safety (F.S.) of two for buckling. Three data points corresponding to actual 1/4, 1/5, and 1/7 scale IEA radiator frequencies (1-g vertical) are plotted to evaluate absolute appendage buckling as a function of scale factor. The frequencies shown include the effect of gravity destiffening which occurs when appendages are oriented vertically upward in a 1-g environment. The results show that the buckling ratios for all three scale factors are below the F.S. = 2 line, indicating that primary appendage absolute buckling is not a driver when selecting a scale factor. However, greater factors of safety are achieved with the smaller 1/7 scale option.

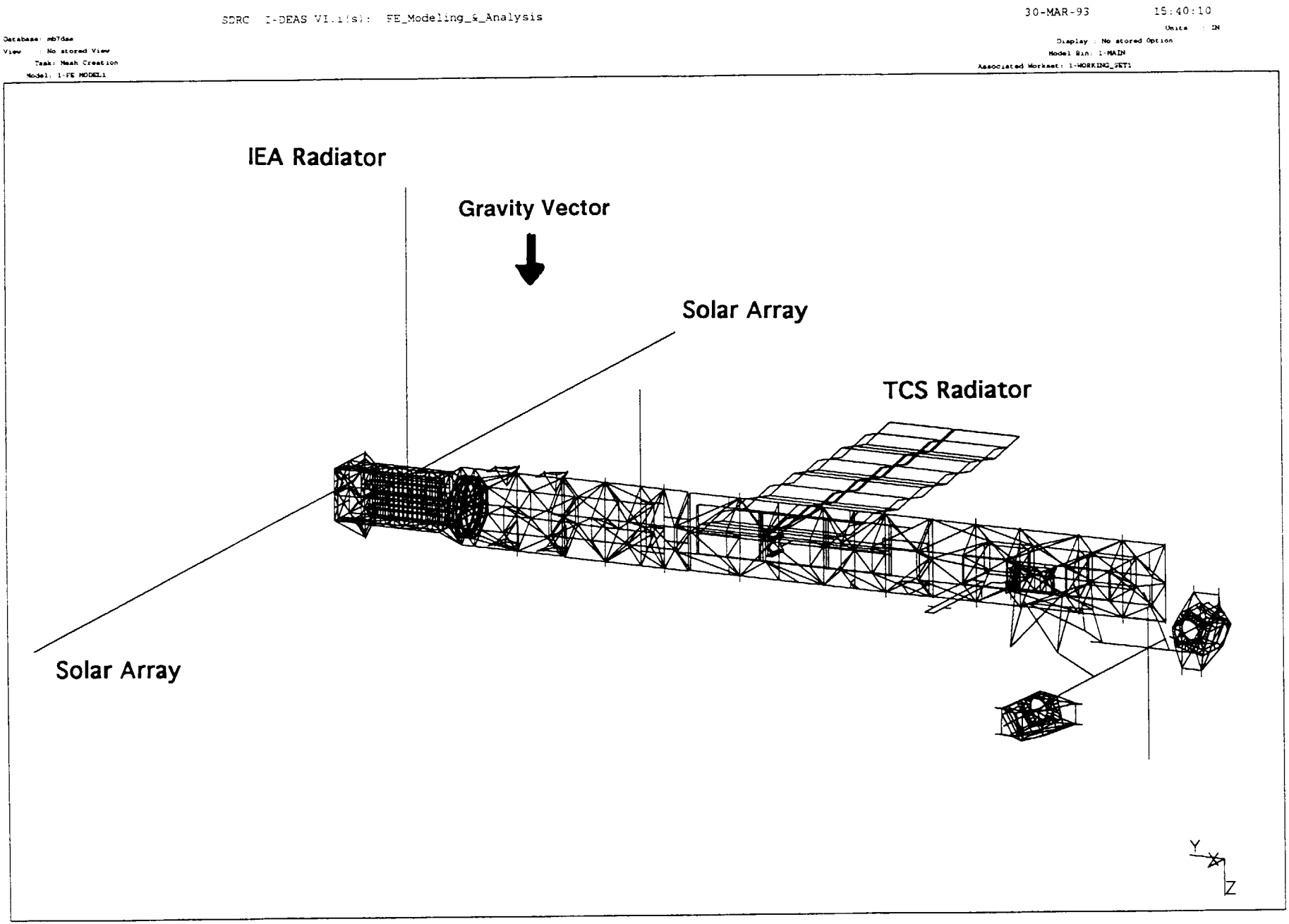


Figure 3-6 Proposed SC-7 Test Orientation Relative to Gravity Vector

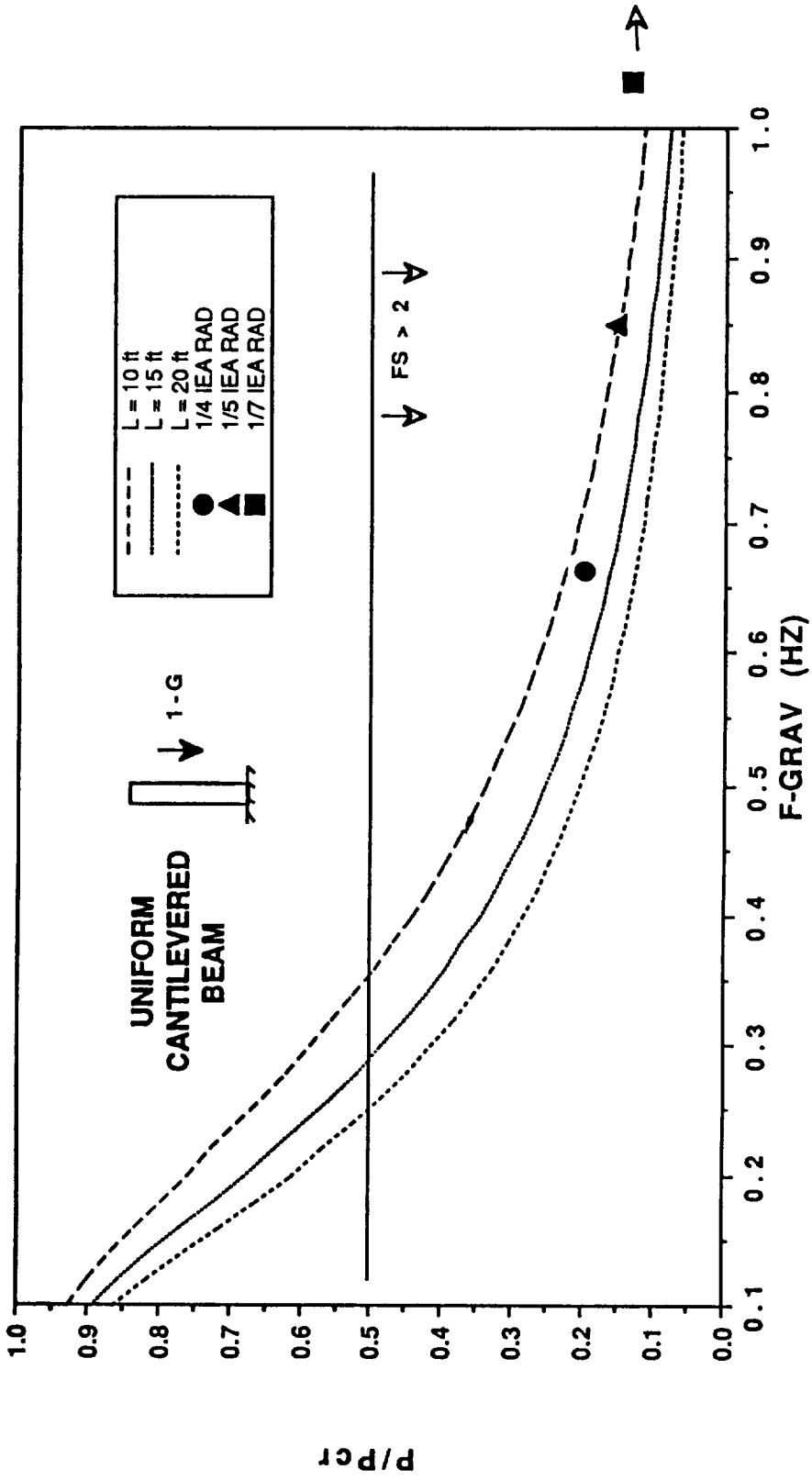


Figure 3-7 Gravity Induced Appendage Buckling

A simple closed form equation was developed using Galerkin's Method to approximate the gravity destiffening effect on a uniform cantilevered beam oriented vertically upward in a 1-g environment[8]. This is the classical flagpole problem. The frequency of the beam first bending mode in 1-g can be approximated as a function of the corresponding zero-g frequency and the beam length as shown below.

$$\omega_{1\text{-}g} = \sqrt{\omega_o^2 - \frac{cg}{L}}$$

where: $\omega_{1\text{-}g}$ = frequency in 1-g (rad/sec)
ω_o = frequency in 0-g (rad/sec)
c = 1.557
g = 386.06 in/sec^2
L = beam length (in)

The coefficient c has been analytically verified by conducting MSC/NASTRAN modal analyses with and without geometric stiffness due to gravity pre-stress. This basic equation form can also be used to calculate the gravity stiffening effect which occurs when the cantilevered beam is loaded in tension due to gravity (simply change the minus sign to a plus sign in the above equation).

The table below shows the magnitude of the frequency change in the IEA radiator due to the presence of gravity (destiffening). The full-scale radiator is approximately 600 inches in length and has a first cantilevered frequency of 0.185 Hz in a zero-g condition. The results clearly show that gravity has a more pronounced effect on lower frequency appendages.

Scale factor	$f_{1\text{-}g}$ (Hz)	f_o (Hz)	Δ%
1/4	0.668	0.740	-9.7
1/5	0.854	0.925	-7.7
1/7	1.224	1.295	-5.5

In the SSF primary structure, buckling loads which result from suspending the model in a 1-g environment also need to be quantified as part of evaluating absolute model robustness as a function of scale factor. The maximum buckling loads generated in a suspended scale model need to be verified in order to ensure that positive factors of safety exist for each scale factor option. Since the gravity induced loads in the structure are a direct function of both the number of cables used and their attachment locations, it was determined that a minimum of eight cables attached to the large

masses and structural hard points are required to off-load a SSF scale model. Since the load calculation is an output of model suspension analyses, the primary structure buckling question will be discussed in the Suspension Issues Section where results of a preliminary model suspension analysis are documented.

In summary, the desire to minimize unscaled gravity effects (Froude number) in order to approximate the zero-g SSF on-orbit environment drives the scale factor choice smaller. Of the three scale factor proposed, the 1/7 model option would be least influenced by gravitational effects and would have the greatest robustness relative to gravity induced loads. In terms of appendage buckling, all three of the proposed scale factor options appear to be acceptable based on the full-scale SSF appendage designs.

3.3.2 Suspension Issues

Since a scale model of the SSF cannot be tested in a zero-g environment, advanced suspension systems are required to off-load gravity and simulate free-free boundary conditions analogous to the on-orbit environment[9,10]. The areas of particular concern associated with suspending a scale model in the presence of gravity are dynamic coupling of suspension and flexible body modes, primary structure member loads, and appendage static sag. Each of these topics is addressed in terms of relative scaling sensitivity in the following paragraphs.

The suspension coupling issue relates to the separation in frequency between the suspension system "rigid body" modes and the scale model flexible body modes. Since the model is tested suspended in a 1-g field, it is important to insure proper frequency separation between the suspension and flexible body modes in order to minimize dynamic coupling and simulate free-free boundary conditions. Current technology exists to drop suspension modes as low as 0.10 Hz independent of the model size and weight. Therefore, the degree of frequency separation is driven solely by the scaled flexible body frequencies. Since frequency scales inversely with scale factor (λ^{-1}), building a smaller scale factor model results in higher scaled flexible body frequencies and thus reduced dynamic interaction with the suspension system.

A general rule of thumb is to maintain a factor of ten separation between suspension and flexible modes in order to prevent coupling. For the SSF full-scale design, the lowest flexible frequency is a solar array bending mode at approximately 0.12 Hz which would scale to 0.48 Hz for a 1/4 scale design and 0.84 for a 1/7 scale option. Neither of these scaled frequencies satisfy the factor of ten rule of thumb, but in relative

terms the 1/7 scale factor would be the preferred option in terms of reduced dynamic coupling.

The second suspension related issue to be addressed is primary structure member loads that result from off-loading the model using suspension devices. The key trade is between maximum member loads and the number of support points (suspension devices). The member loads can be predicted by performing a 1-g static suspension analysis using the full-scale model and then scaling the appropriate loads to compute subscale load margins. A hard cable static suspension analysis was conducted using the SSF Delta PDR SC-7 finite element model referenced in Section 2.3. In order to simplify the analysis, the solar arrays and IEA radiator equivalent beam models were replaced by concentrated masses in the math model.

The load distribution in a structure suspended in 1-g is directly related to the number and location of the suspension system cable attachment points. Parametric studies are required to determine the optimal cable attachment points on the model that minimize local member loads and reduce the likelihood of a structural failure. The general approach to minimizing member loads is to off-load all of the large masses and attach cables only at structural hard points. After several design iterations, a final analysis was performed using eight cable attachment locations on the truss and module assembly and one at the tip of the TCS radiator (Figure 3-8). It is a given that cables will also be needed to off-load the solar array appendages which were not included in the suspension analysis. Since the primary failure mode for a truss structure suspended in 1-g is local strut buckling, worst case full-scale buckling margins were computed for several hundred unique SSF primary structure strut members.

Results of the static analysis indicate that all of the *full-scale* buckling margins computed for the primary truss structure are positive with exception of the Module-Truss Interface structure (MTI) and an ITS-M1 diagonal member. This means that with further refinement to the suspension locations, a full-scale SSF could theoretically be suspended in 1-g without incurring primary truss buckling failures. Using the derived scaling factor of λ for strut buckling, subscale buckling margins were computed for 1/4, 1/5, and 1/7 scale models assuming a factor of safety of two. The net result was positive buckling margins for all three model options with no suspension induced strut buckling failures for the SC-7 configuration. Since buckling scales linearly with scale factor, greater margins are realized using smaller scale factors (i.e. 1/7). In absolute terms, the model suspension loads are not a driver in scale factor selection.

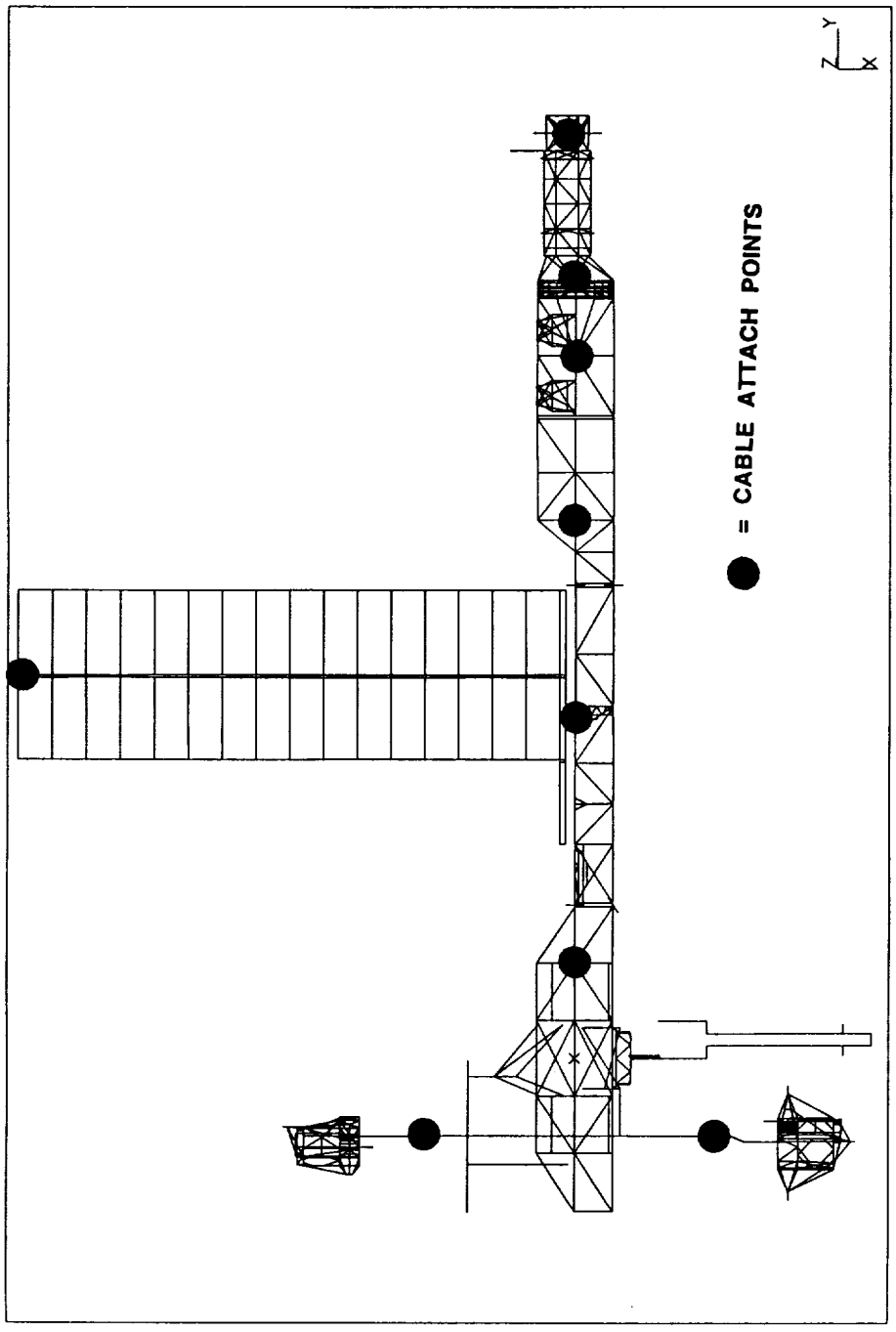


Figure 3-8 Preliminary SC-7 Suspension Analysis Cable Attachment Points

The final suspension related issue which requires analysis is appendage static sag due to gravity loading. Large tip deflections can occur on low frequency appendages oriented perpendicular to gravity. These, in turn, result in excessive root loads and non-linear behavior if the appendages are not properly supported by the suspension system. The appendages of concern for the proposed SSF test configurations are the solar arrays and the TCS radiator (Figure 3-6).

Analyses were performed using a simple cantilevered beam to quantify the maximum appendage static sag as a function of appendage frequency for three proposed suspension configurations (Figure 3-9). The lowest scaled appendage frequency for the 1/4, 1/5, and 1/7 scale model options is 0.48 Hz. This is based on a 1/4 scale solar array whose full-scale first bending mode is approximately 0.12 Hz. Similar frequencies for the 1/5 and 1/7 scale options are 0.60 Hz and 0.84 Hz, respectively.

Inspection of the curves in Figure 3-9 shows that static sag is reduced at higher frequencies. The worst case static sag is approximately 0.6 inches for a 1/4 scale solar array (0.48 Hz) off-loaded using only a single suspension device. The static sag corresponding to the other scale factor options and suspension configurations are significantly less. Therefore, it can be concluded that a single suspension device can effectively off-load a 1/4 to 1/7 scale model appendage. Therefore, appendage static sag is not a strong discriminator for the scale factor options.

In summary, each of the suspension related issues evaluated (dynamic coupling, member loads, and appendage static sag) yielded improved scaling performance with decreasing scale factor. From a static loads perspective (member loads and static sag), all three scale factor options result in positive load margins with the 1/7 scale option yielding the greatest margins. From a dynamics point of view , the 1/7 scale option is preferred since it is more representative of a free-free condition due to reduced dynamic coupling with the suspension modes.

3.3.3 Handling Loads

Another unscaled effect to be considered is hardware handling loads. Usually when considering the effects of transportation and handling loads on the selection of the scale factor, it is assumed that these loads vary with the mass of the model in a way which results in more robust models as scale decreases. However, it is important to note that even though the task of handling the assembled model generally gets easier as its overall size and weight are reduced, certain types of handling loads such as accidental loads, impact loads, and machining loads are independent of model size and thus remain constant at all scale factors. For these scale-invariant loads, special

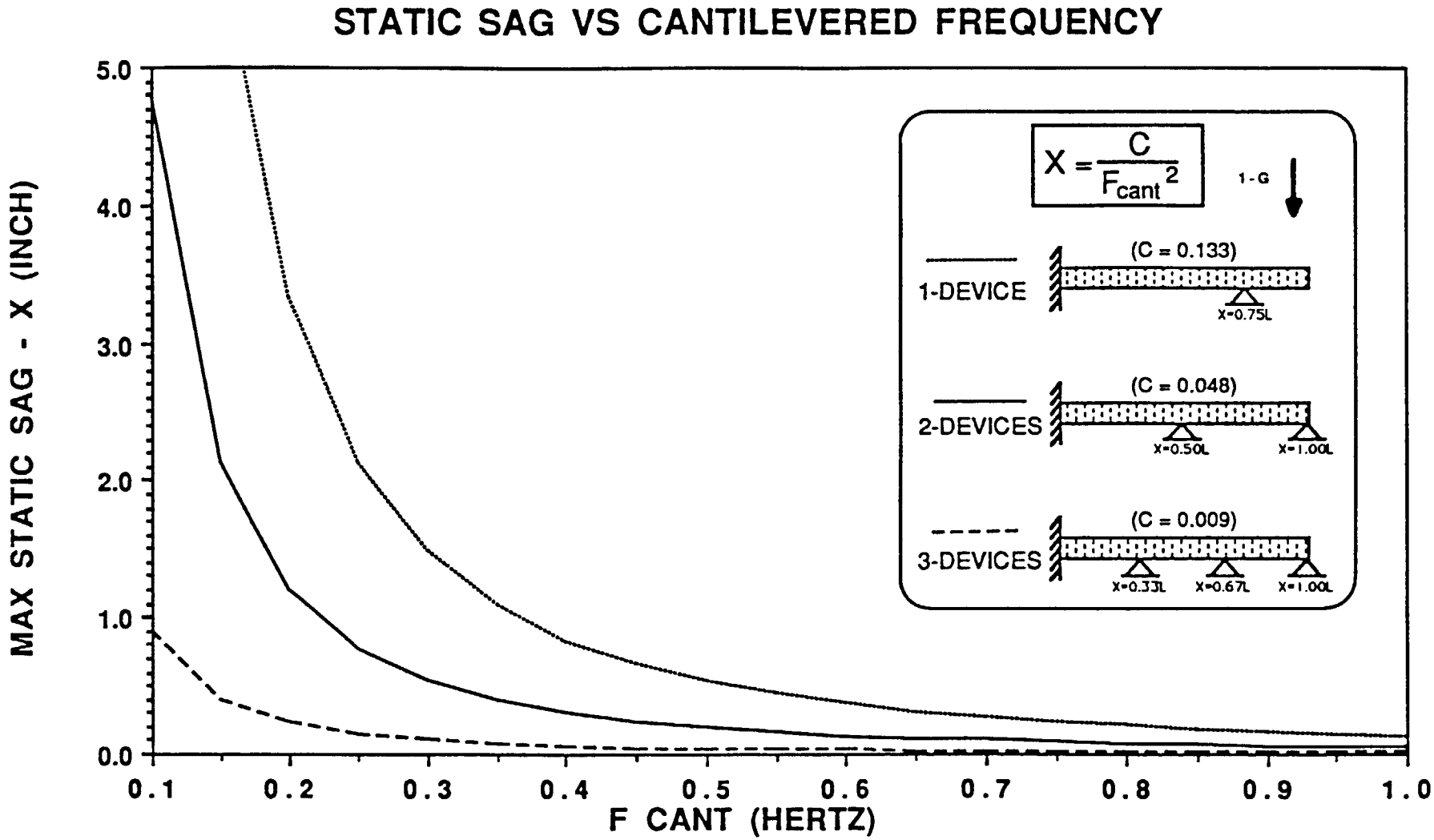


Figure 3-9 Horizontally Configured Appendage Suspension Options

allowances must be made to protect fragile components with thin cross-sections from damage, such as the replica SSF truss I-beams shown in Figure 3-4.

In scale modeling, the sensitivity to accidental forces increases as the scale factor gets smaller by the relationship λ^{-2}. This translates to a 1/7 scale model component being three times more sensitive (fragile) to scale-invariant loads than one built at 1/4 scale. Considering the high parts count associated with the SSF design along with the fact that the scale model is likely to be assembled and disassembled several times in different configurations over the life of the program, the issue of handling loads tends to drive the scale factor up toward larger scale models. Some of the risks associated with handling loads can be alleviated by employing more robust simulated components in the place of the fragile replicated components. Extreme care must be taken when making these kind of changes in a SSF scale model in order to ensure that the dynamic characteristics of the "near-replica" design are not compromised.

Based on the SSF scale model primary structure design detail evaluated to date, handling loads such as impact and transportation are not considered to be strong drivers in the selection of a scale factor. On the other hand, concerns regarding machining loads required to fabricate small replica parts could dictate that a larger scale factor be used. Regardless of which scale factor is chosen, potential handling problems will have to be evaluated on an individual component basis.

3.4 FACILITY ISSUES

The proposed location for suspending a SSF scale model at NASA/LaRC is in the Building 1293 high bay facility currently used by the DSMT and Controls-Structures Integration (CSI) projects. The facility is equipped with a space frame (80 foot vertical clearance) and a gantry (60 foot vertical clearance) for suspending testbeds requiring simulated free-free boundary conditions. Brief studies were conducted to assess the facility issues associated with using the Building 1293 high bay.

The scaling parameters which most often drive facility requirements are overall model size and weight. In general, there are no major facility issues associated with suspending a 1/7 or 1/5 scale SC-7 model in the Building 1293 high bay. The scaled sizes and weights are such that they can be suspended from the gantry or space frame with little or no facility modifications required. On the other hand, the size and weight of a 1/4 scale model would require significant modifications to the existing gantry structure. Therefore, the best option for a 1/4 scale model would be to suspend it from the space frame. This would more than likely require removal of the gantry to

accommodate the model. Figure 3-10 shows an overhead view of a 1/4 scale SC-7 configuration positioned in the high bay. As drawn, the 1/4 scale model would consume a majority of the available lab floor space creating a conflict with other testbeds in the lab. Overall, each of the three scale model options could potentially be suspended in the Building 1293 high bay though the 1/4 scale design would require some facility modifications.

3.5 PRODUCIBILITY

Producibility issues relate to the relative cost and technical feasibility associated with fabricating scale model hardware. Producibility is closely tied to the volume and length parameters which determine the overall dimensions and tolerances of a scaled design. These parameters relate directly to scale model fidelity (i.e. replica detail). As the scaled volume and length of a model decrease, the degree of reproducible design detail also decreases resulting in costly "miniaturized" components and fasteners which have to be tailor-made. In order to achieve the highest degree of replication possible, the largest scale factor permissible should be selected.

In many instances, manufacturing limitations and component assembly issues drive the replica scale factor size larger. Choosing too small of a scale factor can result in a scale model design that looks feasible on paper but in reality is extremely complex and costly to produce. Early in the SSF scale model trade study, it was recognized that hardware producibility issues are an important driver in the selection of a scale factor. Therefore, a preliminary evaluation of SSF scale model producibility issues was conducted by designing and fabricating prototype truss hardware. A trade study was also performed to assess the pros and cons of several proposed truss joint designs.

3.5.1 Prototype Hardware

The key components which make up the SSF truss primary structure are bulkheads, trunnion longerons, MT rail longerons, upper longerons (secondary longerons), lower longerons (secondary longerons) , and diagonal struts as illustrated in the Figure 3-11. These components, which all have I-beam cross-sections, provide the majority of the structural stiffness and strength in the SSF model. Prototype hardware was fabricated for the three most common components contained the truss primary structure: bulkheads, trunnion longerons, and MT rail longerons. Figure 3-12 shows the specific components used in the study which are the ITS-S3 End Bulkhead, Trunnion Longeron Strut , and MT Rail Longeron Strut.

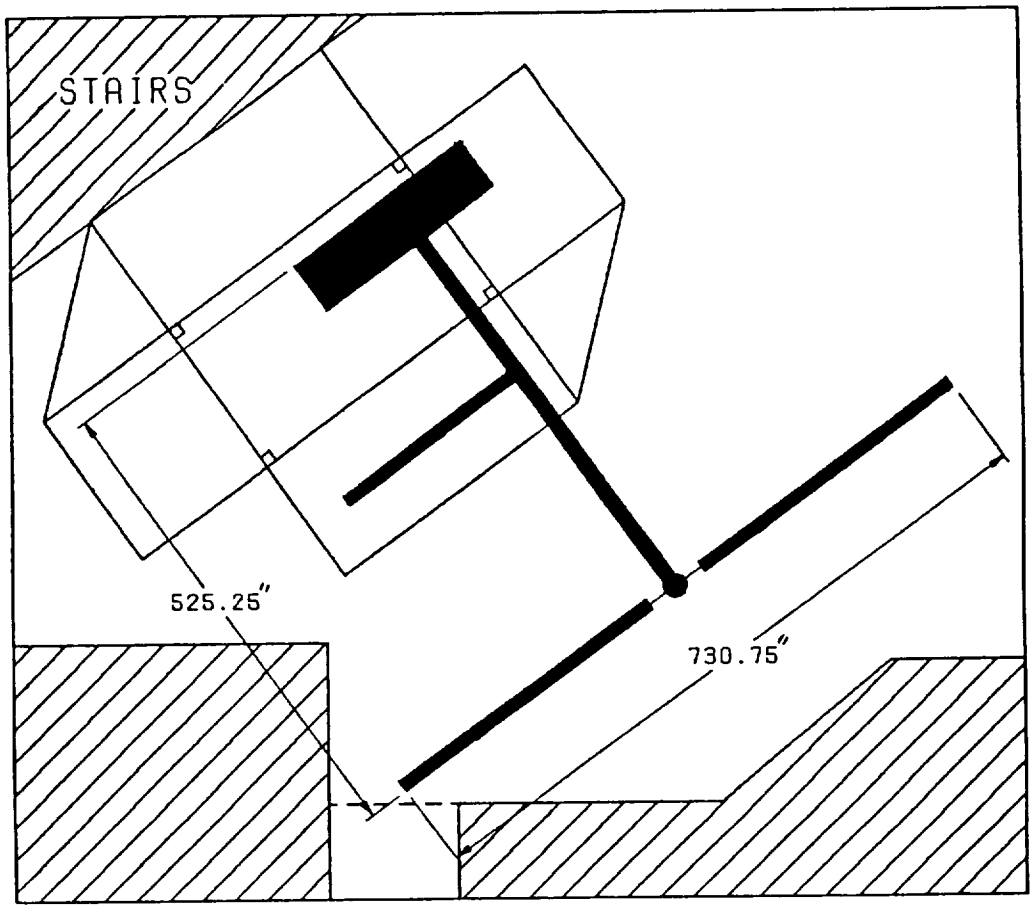


Figure 3-10 1/4 Scale SC-7 Model in NASA/LaRC B-1293 High Bay Facility

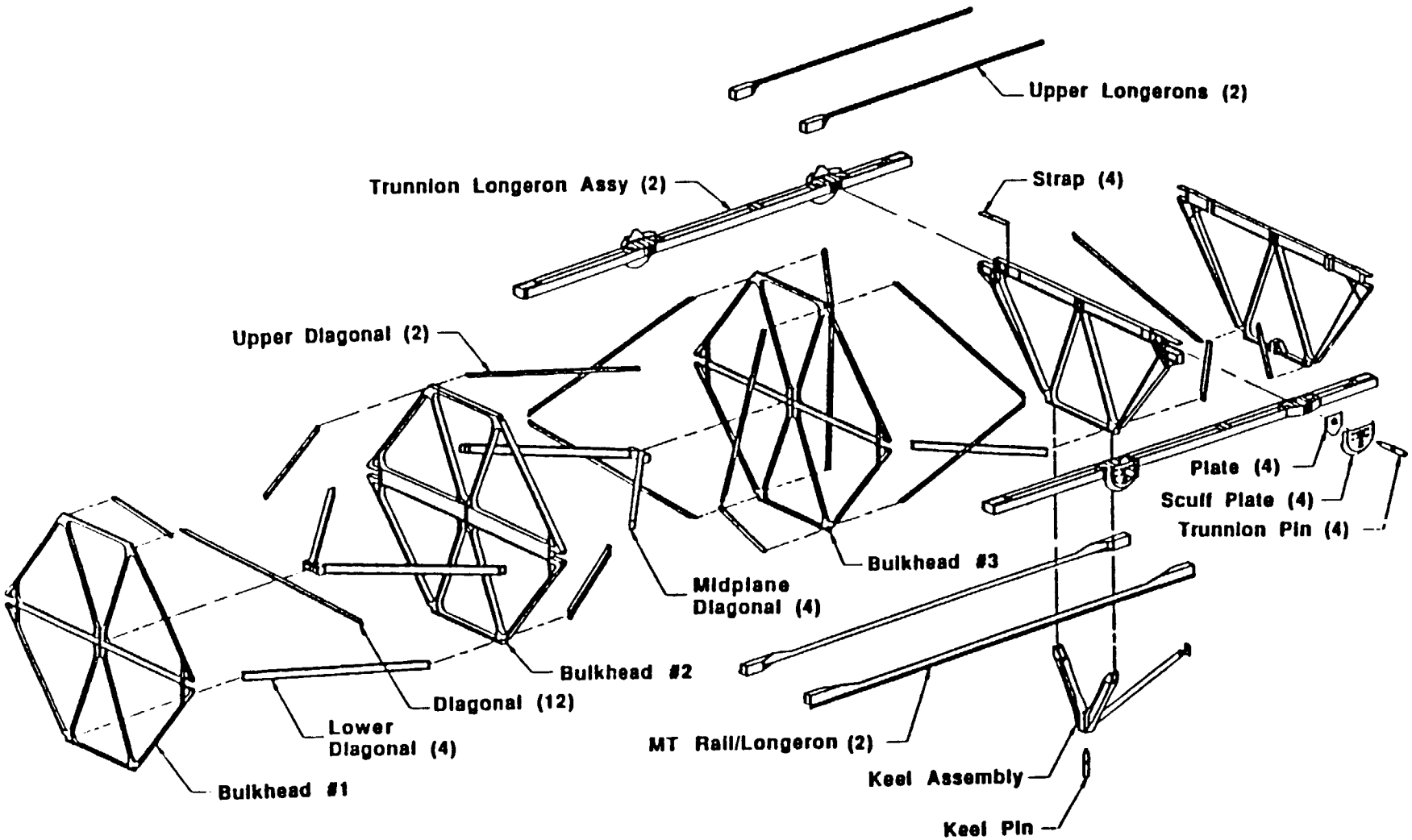


Figure 3-11 ITS Primary Structure Components

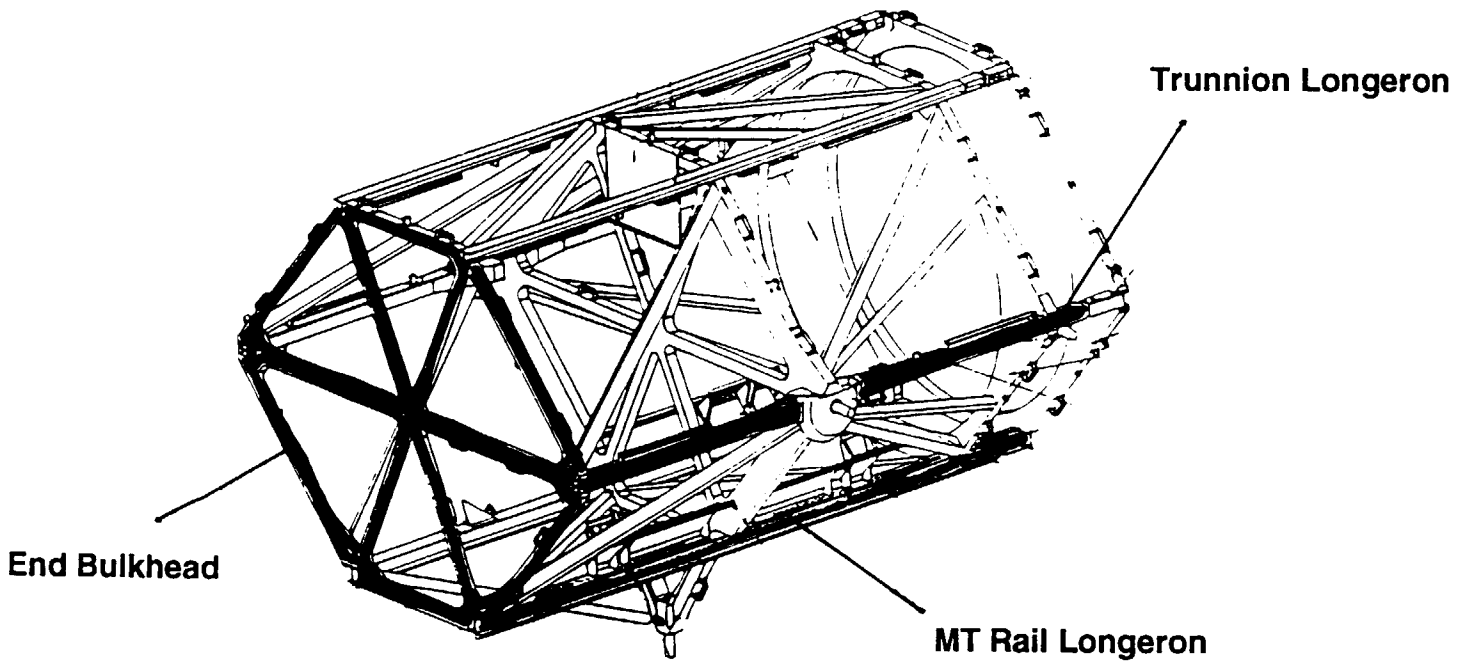


Figure 3-12 ITS-S3 Prototype Hardware Components

Due to the limited funds available for this study, it was decided to fabricate only 1/5 scale prototype hardware. Precision machining of 1/7 scale I-beams having web thicknesses approaching 10 mils could be extremely difficult and costly. The decreased volume and length dimensions corresponding to 1/7 scale hardware significantly reduce the likelihood of building an affordable model at this scale. Machining larger 1/4 scale dimensions is overall less challenging compared to 1/5 scale dimensions therefore there was no benefit to fabricating 1/4 scale hardware at this stage of the study.

Prototype drawings of the 1/5 scale bulkhead and struts were sent out to four machine shops for Firm-Fixed Price (FFP) cost quotes. Out of the four vendors, two decided not to submit bids based on the minimum wall thicknesses called out on the drawings. The other two vendors did submit fixed price bids but the risk associated with machining the thin wall sections was reflected in the proposed costs and schedules.

3.5.1.1 End Bulkhead

A drawing of the prototype 1/5 scale ITS-S3 End Bulkhead sent to each vendor is shown in Figure 3-13 along with the as-built dimensions. In terms of overall size, the 1/5 scale bulkhead is very close to the size of a 1/5:1/10 multiple scale DSMT batten frame as shown in Figure 3-14. The major differences between the prototype bulkhead and a replica bulkhead are the prototype unit was not lightweighted at the joints nor were the corner radii at the longeron joints properly scaled. A photograph of the fabricated bulkhead component which was NC machined from a 1.25 inch stock aluminum plate is shown in Figure 3-15.

The feedback from the machine shop responsible for fabricating the End Bulkhead was extremely favorable. Anticipated breakage of thin wall sections due to machining loads never occurred and no major problems were encountered during fabrication. The bulkhead was delivered head of schedule requiring only one-half of the original time allocated for the job.

3.5.1.2 Longeron Struts

The as-built cross-section dimensions of the Trunnion Longeron and MT Rail Longeron prototype hardware are shown in Figure 3-4 which was presented earlier in Section 3.2. Prior to fabricating the prototype struts, a trade study was performed to determine the best method for fabricating these components at 1/5 scale. The two approaches considered were machining and extrusion as summarized in Figure 3-16.

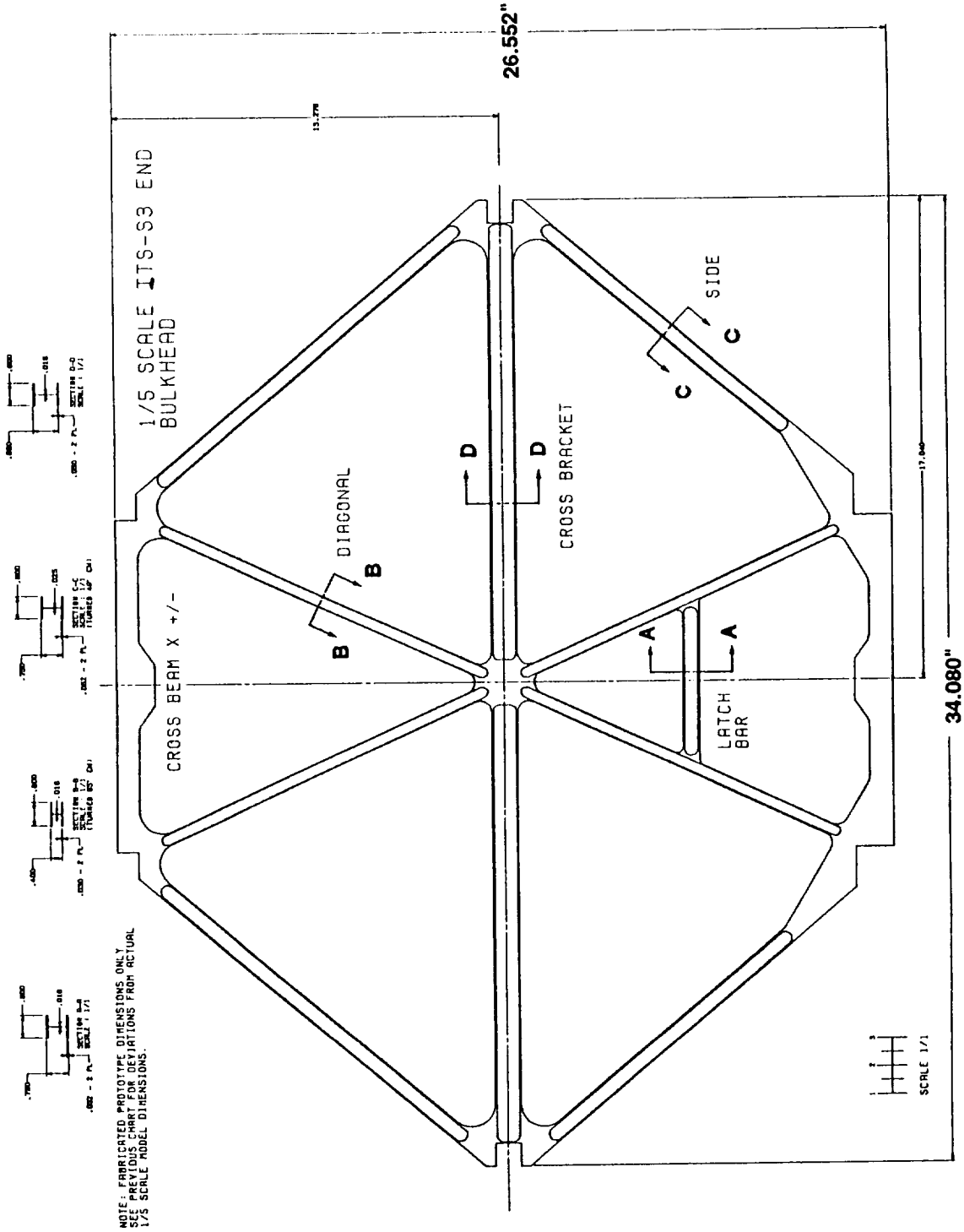


Figure 3-13 Prototype 1/5 Scale ITS-S3 End Bulkhead Drawing

STRUT	QTY	X-SEC	DIMENSIONS (INCHES)			
			A	B	C	D
LATCH BAR	1	I-BEAM	0.025	0.750	0.052	0.800
DIAGONAL	4	I-BEAM	0.016	0.400	0.030	0.800
CROSS BRACE	2	I-BEAM	0.025	0.880	0.050	0.800
SIDE	4	I-BEAM	0.025	0.750	0.052	0.800

A = WEB THICKNESS

B = DEPTH

C = FLANGE THICKNESS

D = FLANGE WIDTH

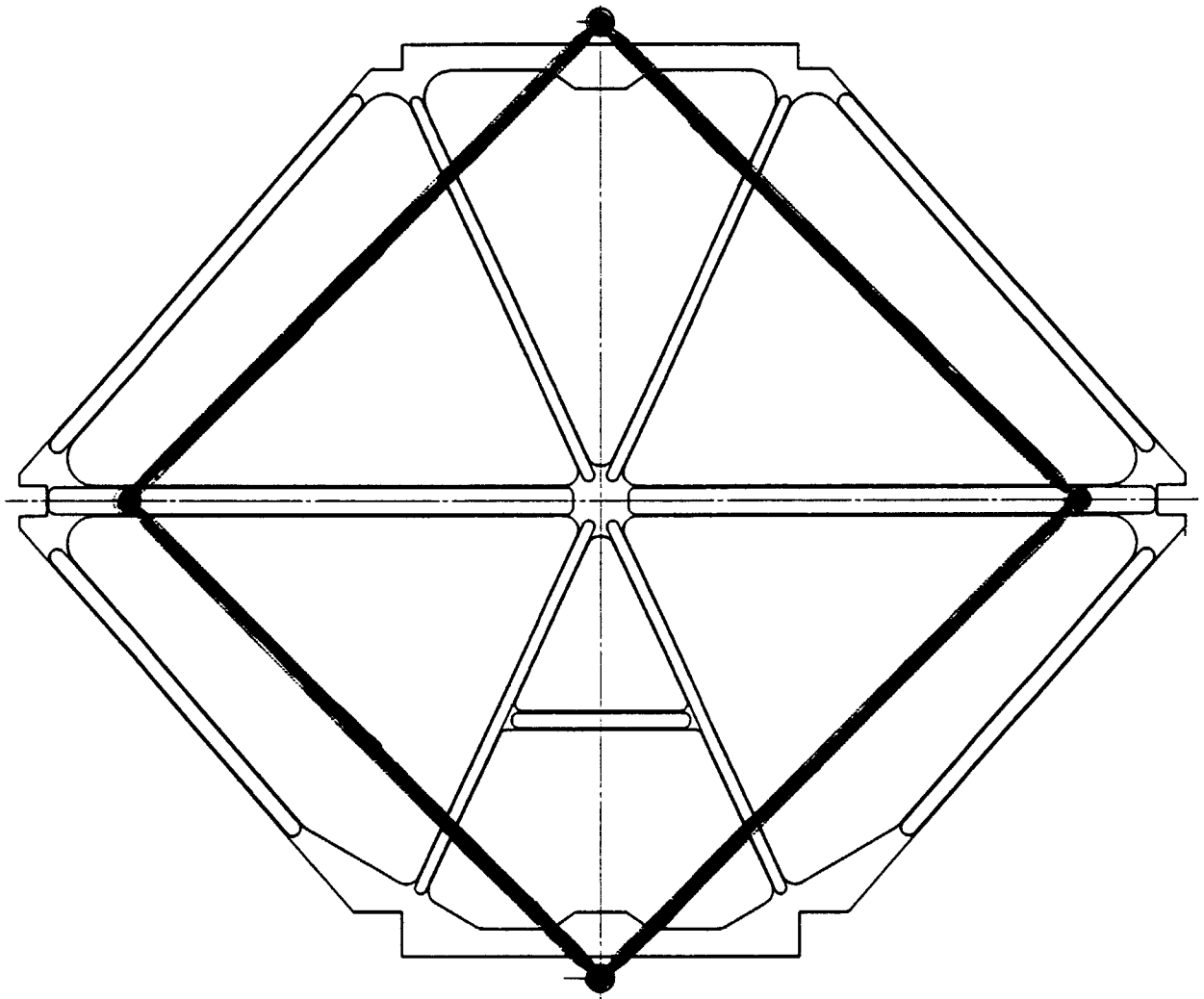


Figure 3-14 ITS-S3 End Bulkhead vs. DSMT Batten Frame

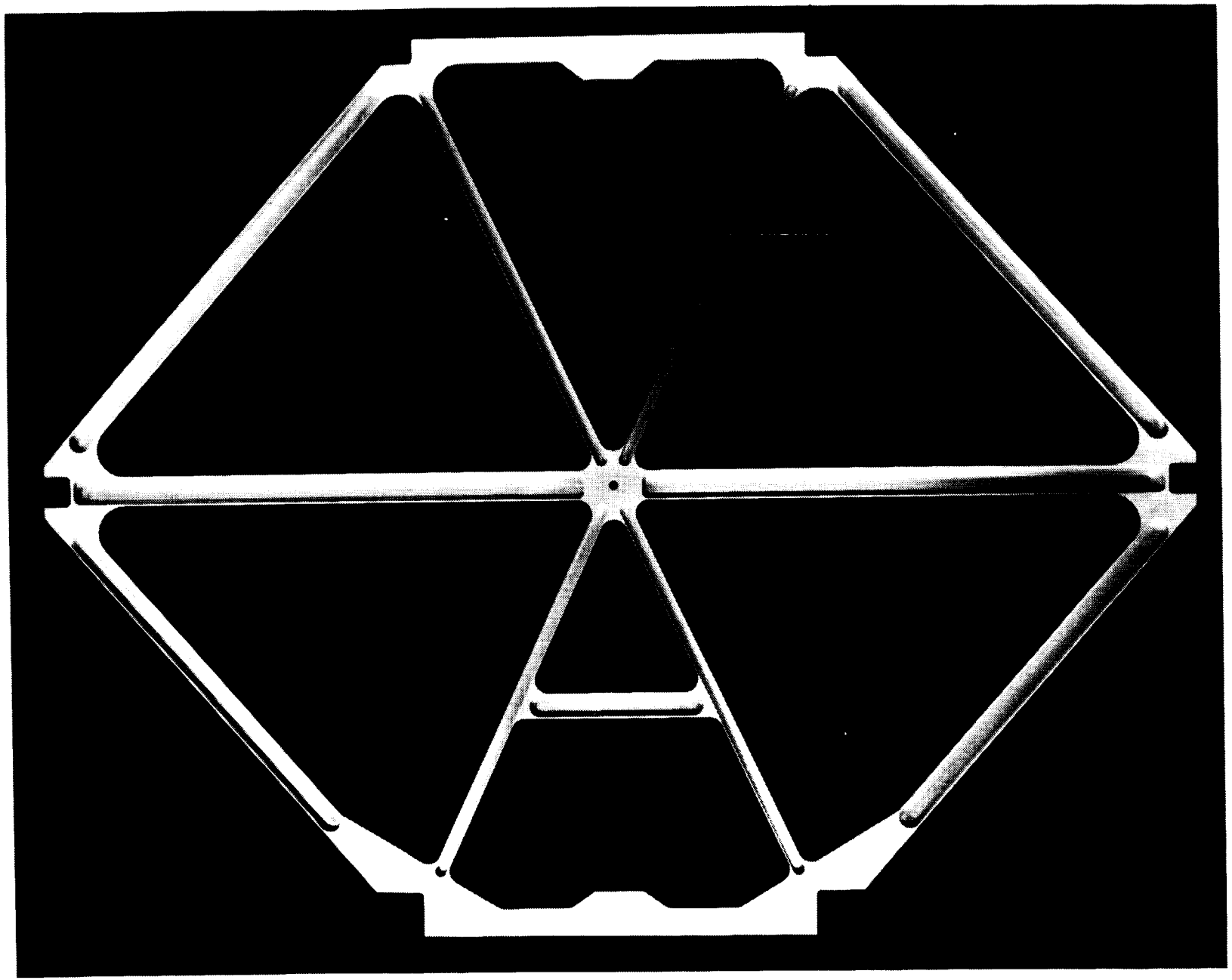
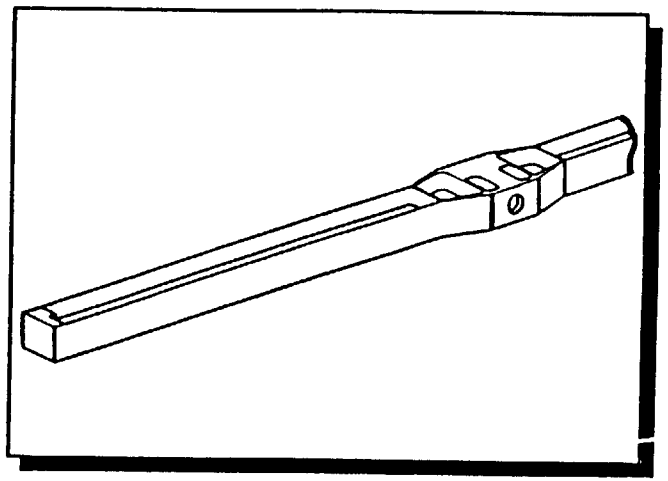
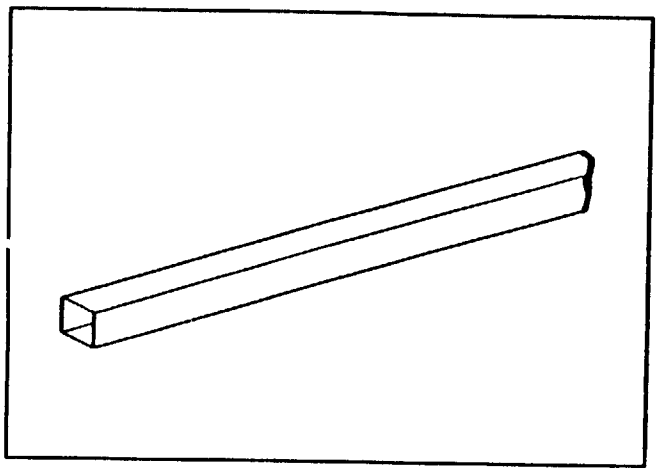


Figure 3-15 Prototype 1/5 Scale ITS-S3 End Bulkhead





MACHINING:

- LESS COSTLY FOR SMALL QTY
- ALLOWS CUSTOM FEATURES
- REDUCED PARTS COUNT
- HIGHER TOLERANCE/COST RATIO
- HIGHER SURFACE FINISH/COST RATIO
- NOT MATERIAL SENSITIVE
- DIFFICULT TO FABRICATE DEEP I-BEAMS
- CANNOT FABRICATE CLOSED SECTIONS
- LENGTH LIMITED

EXTRUSION:

- LESS COSTLY FOR LARGE QTY
- NOT LENGTH LIMITED
- CLOSED SECTIONS ARE OBTAINABLE
- MINIMUM SECTION THICKNESS = 10-40 MILS
- NO CUSTOM FEATURES ALLOWED
- LOWER TOLERANCE/COST RATIO
- LOWER SURFACE FINISH/COST RATIO

Figure 3-16 Strut Fabrication Approaches

The major advantages associated with machining the struts is the ability to incorporate custom features which reduces parts count while the disadvantages are deep I-beams can be difficult to fabricate and closed sections cannot be fabricated. In comparison, closed sections can be obtained with extruded struts but the fact that no custom features are allowed along with limitations on minimum section thicknesses makes the extrusion process unacceptable. As a result, machining was selected as baseline for fabricating scaled I-beams struts in the SSF model. This is the same approach baselined for the full-scale SSF strut hardware.

Similar to the bulkhead hardware, no significant producibility problems were discovered during fabrication of the two prototype struts and all of the vendor feedback was favorable. One potential issue was identified with regard to the lengths of the machined struts. The milling machine table size dictates the maximum strut length which can be machined within an acceptable straightness tolerance therefore producibility issues could arise if significantly long struts are desired. The prototype struts fabricated for this study were only approximately 12 inches in length and therefore were not a problem for the vendor. Any potential problems which do occur in the future will have to evaluated on a individual component basis.

The results obtained from fabricating the prototype hardware indicate there are no show-stoppers associated with producing 1/5 scale SSF primary structure hardware. Both the 1/4 and 1/5 scale factors are viable options in terms of hardware producibility based on the lessons learned during of the study. The small volume and length dimensions corresponding to 1/7 scale hardware however significantly reduce the likelihood of building an affordable model at this scale. A detailed technical and cost developmental effort would be needed to determine the feasibility of a 1/7 scale design.

3.5.2 Joint Design Options

A significant portion of the SSF design complexity and parts count is attributable to the joints located in the integrated truss segments. The full-scale SSF trunnion pin joint design shown in Figure 3-17 illustrates the complexity of the design. Being able to develop a simplified primary structure joint design for the SSF "near-replica" scale model without compromising structural performance could lead to a large cost savings. This is especially true since there are over 140 unique joints in the primary structure. To address the joint design issue, a preliminary trade study was conducted which identified several joint design concepts and compared the relative merits of each option.

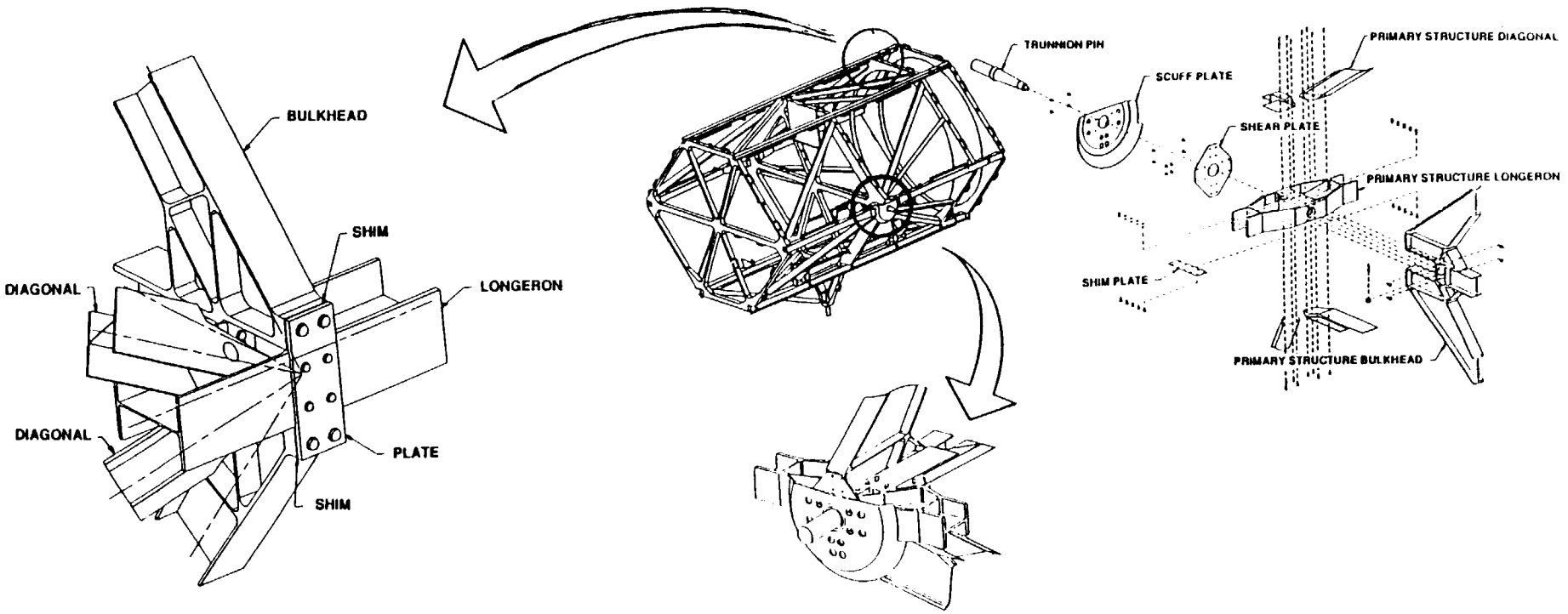


Figure 3-17 Full-Scale SSF Joint Designs

A total of seven joint concepts were evaluated in terms of cost, structural integrity, parts count, ease of disassembly, proof testing, tolerance stackup, and the need for special fixturing. All of the designs identified are based on three fundamental types of connections, welded joints, bonded joints, and mechanical joints. A summary of preliminary study results is shown in Figure 3-18. A sample of how a welded joint might look like compared to a mechanical joint is illustrated in Figure 3-19.

The three welding processes (arc welding, brazing, and soldering) result in joints with significantly reduced parts count and tolerance stackup which are key to developing a simplified joint design. Unfortunately, the thermal distortion issues associated with welding thin walled sections along with the need for detailed proof testing of each joint assembly are major drawbacks which outweigh the benefits. Using a bonded joint also results in reduced parts count and tolerance stackup compared to mechanical fasteners but the uncertainty associated with the structural integrity of the bonded connection makes the concept less appealing. In addition, special surface treatment and cleaning processes along with proof testing are required for bonded joints.

The preferred truss joint in terms of structural integrity, ease of disassembly, proof testing, and special fixturing needs is a mechanical joint. Several variations of the mechanical joint could be used such as mechanical fasteners, gusset plates with mechanical fasteners, or mechanical fasteners combined with bonding. The only drawback with the mechanical joint is the large parts count and tolerance stackup compared to the other concepts which could result in a higher relative cost. It is recommended that a development effort be initiated to reduce the technical risk and cost uncertainty associated with each of the joint concepts before making the final selection.

3.6 SCALE FACTOR TRADE SUMMARY

A scale factor performance plot is presented in Figure 3-20 which graphically summarizes the variations in scaled parameters versus scale factor for the 1/4, 1/5, and 1/7 scale options. The curves shown coincide with the key scaling parameters evaluated during this trade study: size and tolerance (length), volume (producibility and fidelity), weight & gravity effects (robustness), handling loads, and frequency (suspension). The facility issue is not included in this summary as it will not be used in the scale factor selection (as directed by the LaRC technical monitor). All of the curves shown have been normalized to a value of 1.0 at 1/5 scale for comparison purposes. The arrow associated with each parameter indicates the preferred scaling direction for

JOINING PROCESS	COST	JOINT STRUCTURAL INTEGRITY	REDUCED PARTS COUNT	DISASSEMBLY CAPABILITY	NO INSPECTION/ PROOF TEST	REDUCED TOLERANCE STACKUP	NO SPECIAL FIXTURING REQ'D
WELDING	?	√	√			√	
BRAZING	?	√	√			√	
SOLDERING	?		√			√	
MECHANICAL FASTENERS	?	√		√	√		√
GUSSET PLATES W/ MECH FASTENERS	?	√		√	√		√
BONDING	?		√			√	
MECH FASTENERS & BONDING	?	√		?	√		√

Figure 3-18 Joint Design Trade Study

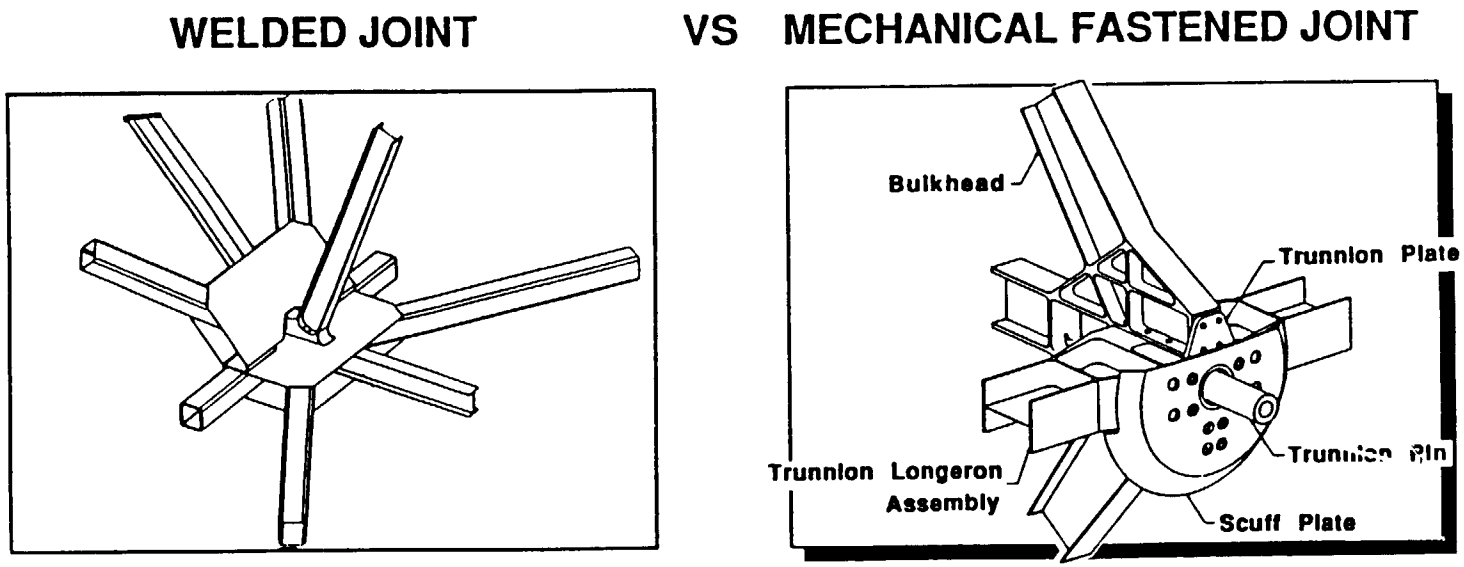
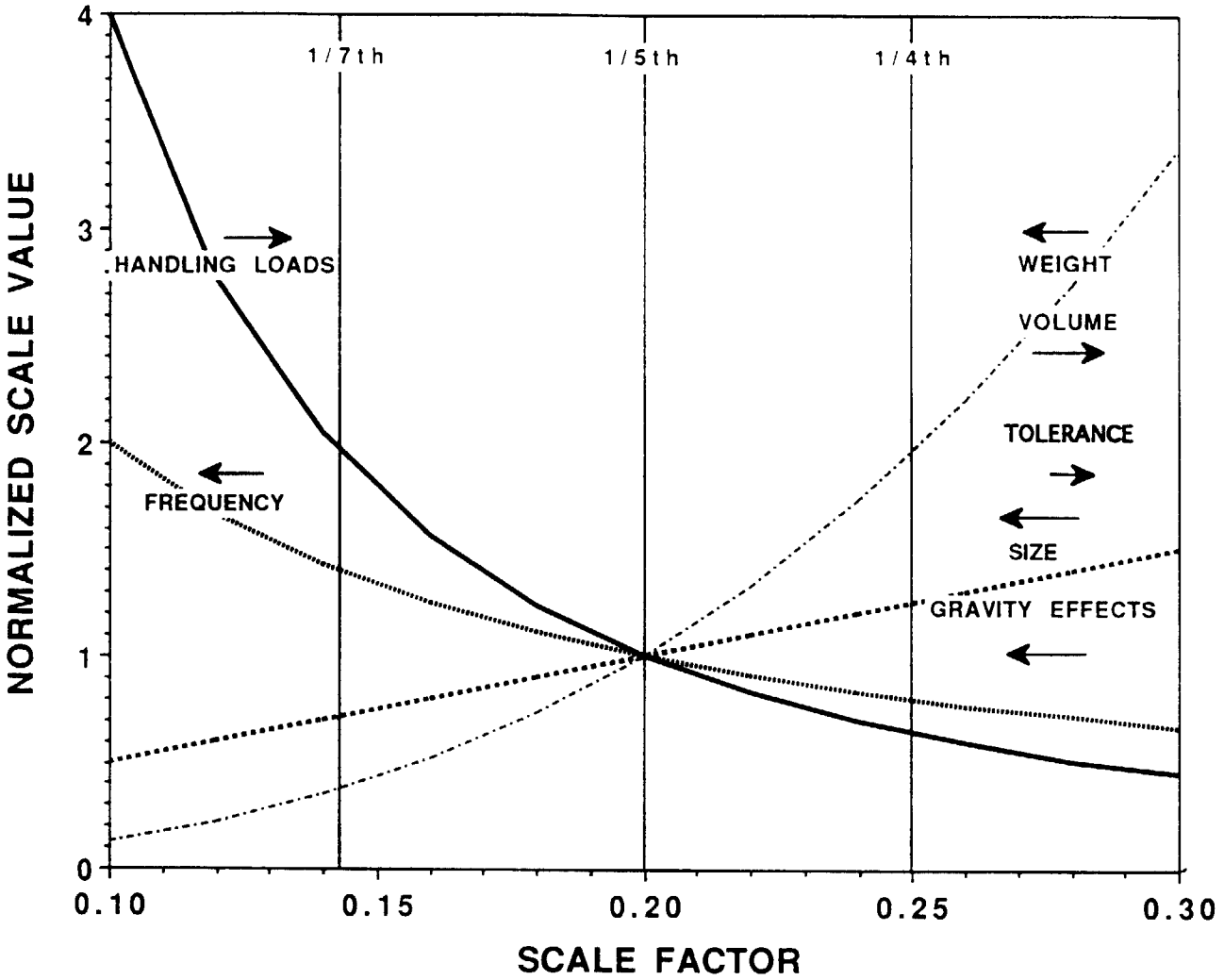


Figure 3-19 Welded Joint vs. Mechanical Fastened Joint



	1/7th	1/5th	1/4th
SIZE	0.71	1.00	1.25
VOLUME	0.36	1.00	1.95
WEIGHT	0.36	1.00	1.95
1-G EFFECTS	0.71	1.00	1.25
HANDLING	1.96	1.00	0.64
FREQUENCY	1.40	1.00	0.80

Figure 3-20 Scale Factor Technical Performance Plot

that quantity based on the results of the scale factor trade study. The arrows indicate that the optimum size, gravity, weight, and frequency is achieved using the smaller 1/7 scale factor while scale-invariant handling loads and producibility concerns favor using the larger 1/4 scale factor.

The relative importance of each of the various performance parameters presented herein needs to be considered before drawing a technical conclusion regarding which single scale factor is best suited for a SSF subscale dynamic model. The most important requirement imposed on this study was to develop a high fidelity "near-replica" scale model design. The capability to successfully replicate full-scale hardware in a high fidelity model is directly related to increased scale factor. In addition, the ability to couple the model with an existing 1/4 scale shuttle model favors using the larger 1/4 scale option. Based on these finding, the increased fidelity associated with the 1/4 scale option outweighs the modest relative performance gains in gravity effects and suspension interaction realized with the smaller 1/5 and 1/7 scale designs. Therefore, the recommended scale factor size for a SSF subscale dynamic model based on technical merit is the 1/4 scale option.

4.0 DESIGN SENSITIVITY STUDIES

In a separate, parallel effort to the scale factor trade studies, design sensitivity studies were conducted to establish a technical approach for developing lower-cost design alternatives for the SSF hardware components. The approach is intended to provide a fundamental basis for making cost-effective, performance driven model fidelity decisions by identifying critical hardware component properties that drive dynamic performance. Knowledge of these critical properties enables the scale model effort to focus its limited resources on these components which require high fidelity replication.

For non-critical components, such as secondary structure components which behave essentially as rigid masses, the cost and time associated with duplicating high fidelity design detail in replica scale can be saved. By using a dynamically similar scaling approach having overall size, stiffness, and mass scale factors consistent with the replica design, a considerable cost savings can be realized without compromising overall dynamic performance. Relaxing the design tolerances for the non-critical components is one example. Another is the significant reduction in total parts count through commonality. Several components having different geometric cross-section properties but similar stiffness properties can be simulated with a single component design reducing the number of unique parts. Concerns associated with scale-invariant loads such as machining and handling loads are also minimized by substituting for fragile high fidelity designs with more robust dynamic similar designs.

The two basic metrics which dictate whether replica or dynamic similarity scaling should be used for the structural component properties in the dynamic scale model are cost and design (performance) sensitivity as illustrated in Figure 4-1. Design sensitivity is used to indicate the degree of hardware fidelity required to preserve dynamic performance. The figure shows that hardware components with high sensitivities may require replication independent of cost whereas significant savings can be achieved by dynamically simulating hardware components having low sensitivities. Since non-linear characteristics and material damping are not included in the finite element representation of the Space Station, components with known highly non-linear behavior or high damping characteristics should be considered strong candidates for replication unless a strong argument can be made in favor of simulation.

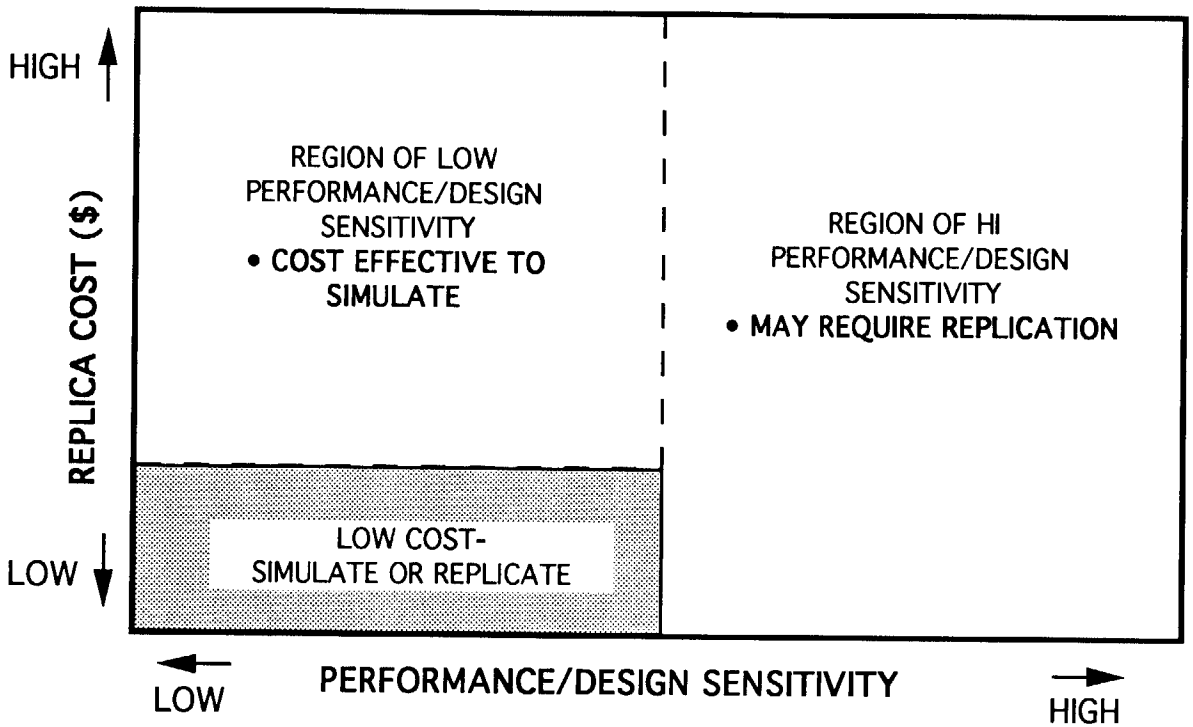


Figure 4-1 Design Fidelity as a Function of Cost and Performance Sensitivity

The task of identifying critical structural elements which drive dynamic performance and thus may require high-fidelity replica scaling is performed using the eigenvalue Design Sensitivity Analyses (DSA) capability present in MSC/NASTRAN[11]. By computing design sensitivity coefficients for the physical properties of each structural element in the full-scale model, a system level framework is provided for determining the relative scale model hardware fidelity required on an element property by property basis.

A flowchart describing the fundamental design study approach developed for the SSF SC-7 dynamic scale model is shown in Figure 4-2. The first step in the process is the selection of the global system modes associated with the full-scale model. These global modes, also referred to as important modes, describe the overall dynamic characteristics of the primary structure and are used in the design sensitivity analysis. Accurate dynamic scaling of these important modes is essential for developing a true "near-replica" scale model. The criteria used to select the important mode set is described in Section 4.1.

Once the important modes are selected, a design sensitivity analysis can be performed in order to compute the design sensitivity coefficients corresponding to each element physical property in the SSF SC-7 model. These coefficients relate a change in dynamic performance (i.e. frequency) to the change in a component physical property. A unique set of coefficients are computed for each important mode. Using these DSA coefficients, the critical design properties which drive dynamic performance are determined. The scope of the study documented in this report extends to the completion of the design sensitivity analysis, which is presented in Section 4.2.

With the critical component design properties defined, design trade studies can be conducted to assess producibility and cost issues associated with replica scaling of these components. The final step in the process would be to develop conceptual design approaches for all of the major hardware components comprised of the ITS primary structure, subsystems, appendages, and modules. This includes both the critical and non-critical components. Before proceeding to the detailed design phase, the recommended design fidelity (replica or similar) for each component based on the design sensitivity analysis would be reviewed by NASA/LaRC. The end product is a systematic, performance-driven approach for developing cost-effective hardware designs which result in a "near-replica" dynamic scale model of Space Station Freedom.

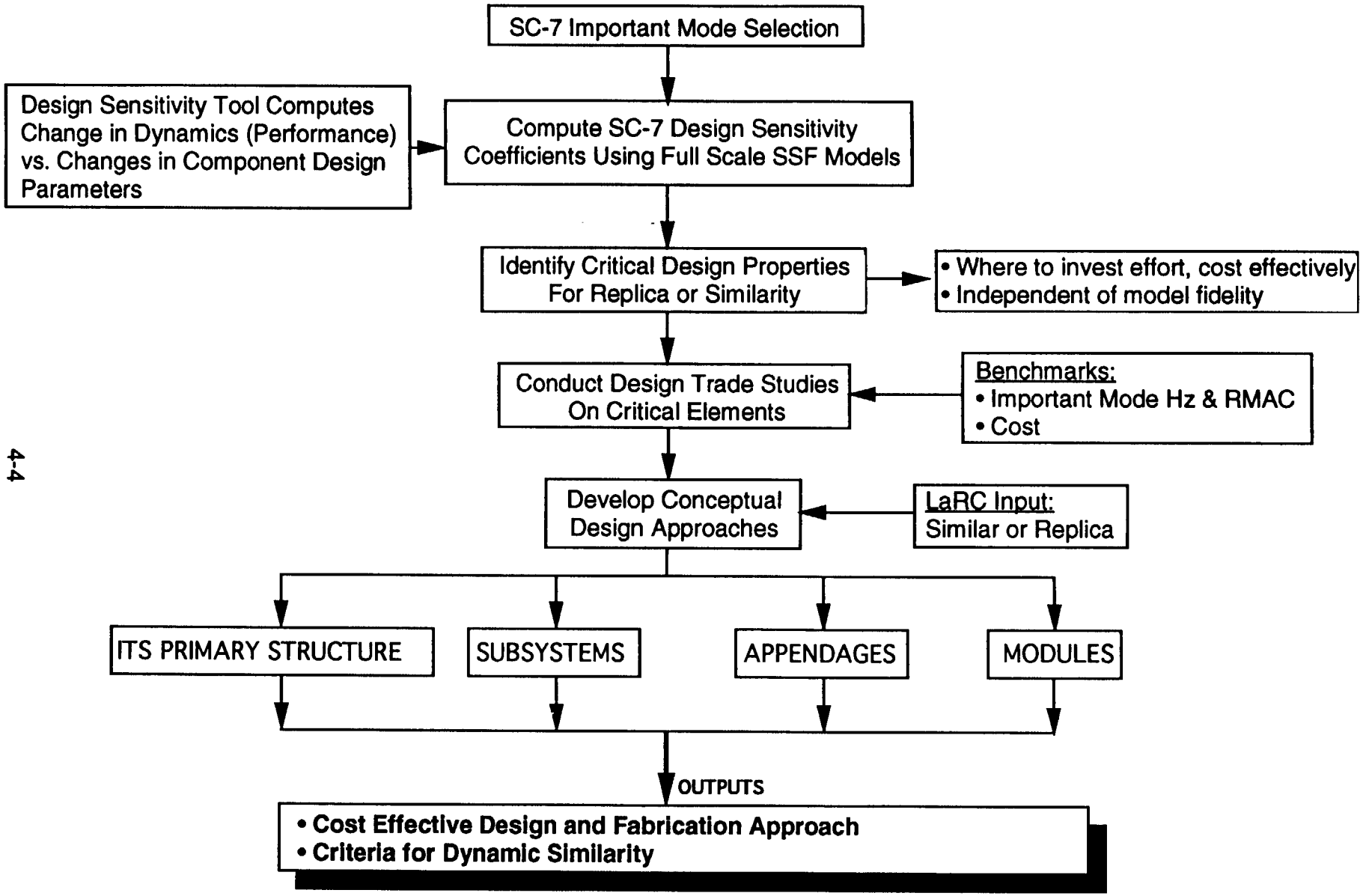


Figure 4-2 Design Study Flowchart

4.1 IMPORTANT MODES

Developing an accurate "near-replica" dynamic scale model of SSF requires that the global modes and frequencies of the subscale FEM model match the global modes and frequencies of the full-scale FEM model. These global modes, also referred to as important modes, define the overall dynamic behavior of the structure and are a key part of the design sensitivity analysis. By matching the global modes of the full-scale FEM model, the scale model will have the same dynamic characteristics as the full-scale SSF.

Modes in the SSF model which are classified as global modes are characterized by highly coupled ITS primary structure, appendage, and module motion along with modal participation of the larger subsystem components such as the PMAS. Modes which exhibit only localized component motion are referred to as local modes and can also be designated as important modes depending on the performance and functional requirements of the model. In the SSF model, no such local modes were identified and therefore only global modes were used in the important mode set.

A modal analysis of the SSF SC-7 Delta PDR finite element model referenced in Section 2.3 was performed from 0 to 3 Hz in order to identify the important modes. A total of 56 modes (6 free-free and 50 elastic) were computed from which ten important modes were extracted. Use of equivalent beam models for the high fidelity solar array and IEA appendages resulted in a significantly reduced modal density which simplified the analysis without affecting the global modes of the structure.

4.1.1 Selection Criteria

The selection criteria used to identify the important modes of the SSF SC-7 full scale model were relative Generalized Mass (GM), elemental Strain Energy (SE), and visual inspection of the animated mode shapes. Modes with large generalized mass, significant elemental strain energy in the ITS structure, and visually confirmed to have system level motion throughout the structure were selected as important modes. No one single criteria alone was used to identify an important mode.

The generalized mass for each of the flexible body modes ($\phi_N^T M \phi_N$) was computed using flexible mode shapes (ϕ) normalized to have a maximum displacement of 1.0 (ϕ_N). The resulting generalized mass values were then re-normalized with respect to the largest GM value in the mode set to obtain relative GM percentages (GM%). A mode exhibiting a large GM% is considered a prime candidate for selection as an important mode since large GM% values are usually indicative of system level motion.

One exception to this rule is local modes of components with large masses such as the module cluster assembly on SSF. These local modes can have large generalized mass values without significant global motion in the ITS structure.

The second selection criteria, ITS elemental strain energy percentage (SE%), was computed by dividing the strain energy distribution in each mode into four discrete groups; ITS primary structure, subsystems , appendages, and modules. Modes having sizable SE% in the ITS primary structure are considered potential important modes but only when combined with a large GM%. Strain energy results evaluated independent of generalized mass can be misleading since many of the local appendage modes have a significant amount of strain energy concentrated in the ITS-to-appendage interface structure which is classified as part of the ITS primary structure. These modes are localized and therefore should not be confused with global system modes.

4.1.2 Modal Ranking

Table 4-1 shows the SC-7 modes ranked by decreasing relative generalized mass percentage. The percentage of strain energy in the ITS primary structure along with a brief description the mode shape is also shown for each mode. Low ranked modes with GM% values less than 2% and ITS SE% values less than 20% are definitely not global modes and therefore are excluded from consideration. The GM% and SE% results are summarized in bar chart form in Figure 4-3 to more easily compare the GM% and ITS SE% values computed for each mode. The combination of large GM% and ITS SE% values is an indicator of a global mode.

A total of ten important modes were ultimately selected for the design sensitivity analysis as shown in Table 4-2. These modes are predominantly first and second system level bending and torsion modes which characterize the overall stiffness and mass properties of the SSF SC-7 configuration. Finite element mode shape plots of each important mode are contained in Appendix A for reference. In should be pointed out that important mode 49 possesses a significant amount of module cluster motion relative to the other nine modes and borders on being classified as a local module mode while modes 30 and 31 also selected as important modes contain significant motion in the PMAS subsystem.

It is interesting to note that the top two ranked modes based on GM% (modes 40 and 28) along with the seventh ranked mode (mode 45) were not selected as important modes. Inspection of these modes revealed them to be local module cluster modes with large rigid body GM% in the module components but only a small amount of SE% in the ITS structure. The remaining modes not selected as important modes were all

Table 4-1 SC-7 Modes Ranked By Relative Generalized Mass

RANK	MODE NO.	FREQ (HZ)	RELATIVE GM%	ITS SE%	DESCRIPTION
1	40	1.501	100.0	7.9	Modules 92% SE
2	28	0.876	76.4	15.1	Modules 70% SE
3	49	2.383	74.0	15.6	Modules/(ITS: B-2)
4	31	0.926	32.9	38.3	PMAS/ITS: T-1
5	30	0.913	22.9	40.0	PMAS/ITS:B-1-X,T-1
6	27	0.803	21.6	42.6	ITS: B-1-X,(B-1-Z)
7	45	1.915	17.8	20.1	Modules 68% SE
8	47	2.138	14.0	60.8	ITS: B-2-Z,(B-2-X)
9	36	1.195	11.4	58.1	ITS: B-1-X,B-1-Z
10	20	0.573	9.3	72.5	ITS: B-1-Z
11	17	0.499	8.5	60.9	ITS: T-1
12	37	1.204	7.6	62.2	ITS: B-1-X,B-1-Z
13	53	2.732	7.4	29.1	ITS: T-1, (B-2-Z)
14	44	1.881	3.1	11.9	Solar Array
15	51	2.705	3.0	17.1	Solar Array
16	26	0.741	2.7	17.9	Solar Array
17	48	2.270	2.7	16.7	TCS Radiator
18	18	0.535	2.6	0.5	Mobile Transport
19	19	0.555	2.6	0.5	Mobile Transport
20	25	0.698	2.6	9.7	Solar Array
21	32	0.979	2.5	14.3	Solar Array
OTHER MODES W/ LARGE ITS SE%					
27	7	0.103	2.0	52.0	TCS Radiator
30	56	2.970	2.0	35.0	TCS Radiator
31	9	0.118	1.8	22.5	Solar Array
32	14	0.285	1.8	59.7	TCS Radiator
35	21	0.643	1.7	25.1	TCS Radiator
36	41	1.539	1.7	48.3	PMAS
39	34	1.106	1.3	46.0	TCS Radiator
42	43	1.760	1.2	20.6	TCS Radiator
50	42	1.583	0.4	84.8	KU Mount

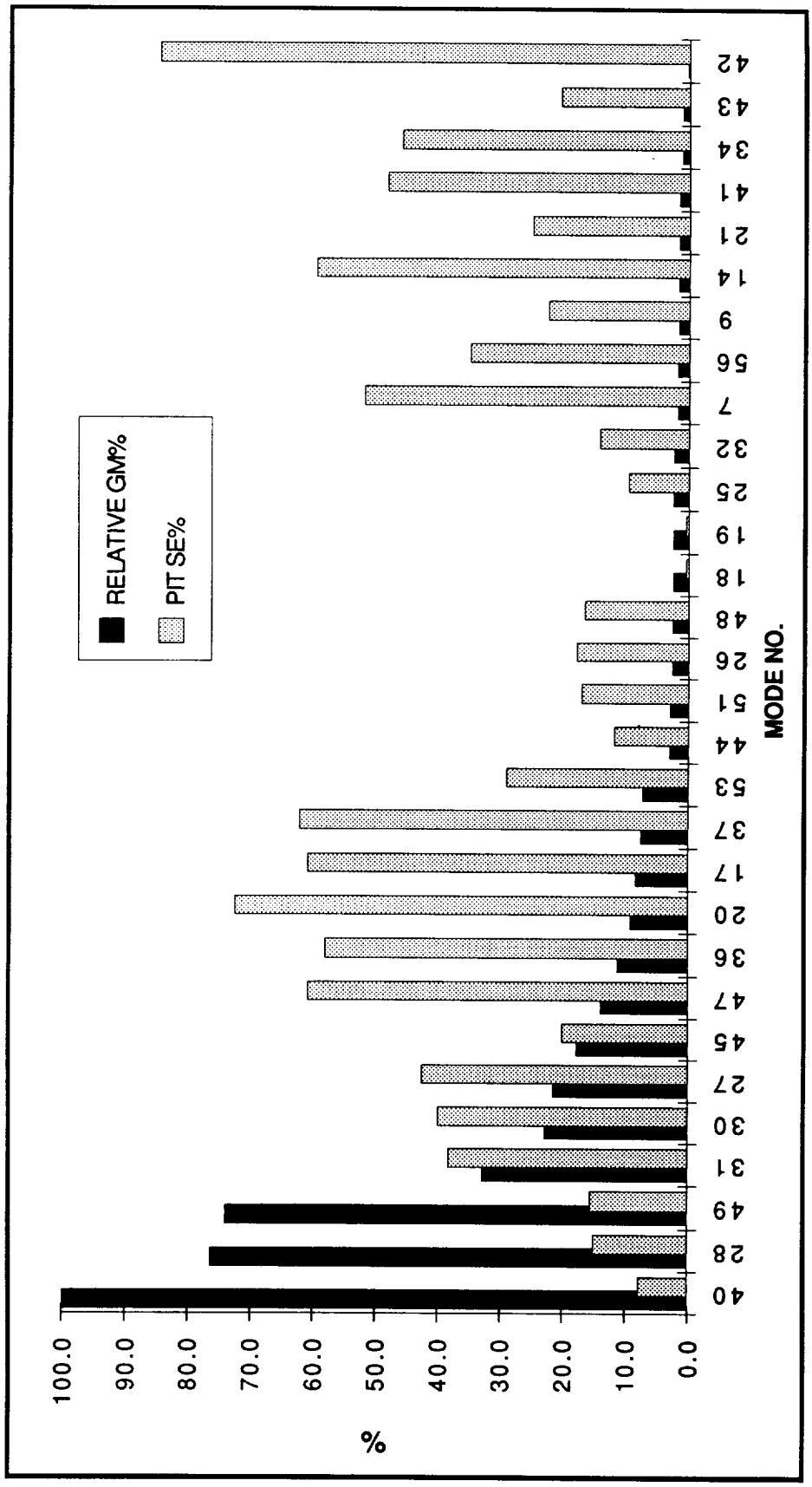


Figure 4-3 Relative Generalized Mass and PIT SE% vs. Mode Number

Table 4-2 SC-7 Important Modes

MODE NO.	FREQ (HZ)	RANK	RELATIVE GM%	ITS SE%	DESCRIPTION
17	0.499	11	8.5	60.9	ITS: T-1
20	0.573	10	9.3	72.5	ITS: B-1-Z
27	0.803	6	21.6	42.6	ITS: B-1-X,(B-1-Z)
30	0.913	5	22.9	40.0	PMAS/ITS:B-1-X,T-1
31	0.926	4	32.9	38.3	PMAS/ITS: T-1
36	1.195	9	11.4	58.1	ITS: B-1-X,B-1-Z
37	1.204	12	7.6	62.2	ITS: B-1-X,B-1-Z
47	2.138	8	14.0	60.8	ITS: B-2-Z,(B-2-X)
49	2.383	3	74.0	15.6	Modules/(ITS: B-2)
53	2.732	13	7.4	29.1	ITS: T-1, (B-2-Z)

local appendage modes with small relative GM% values. As a final check, the important modes selected in this study were found to be in agreement with those selected by the SSF LDWG.

4.2 DESIGN SENSITIVITY ANALYSIS

The design sensitivity analysis capability in MSC/NASTRAN provides a means for computing eigenvalue derivatives corresponding to the design variables in a finite element model. For the SSF scale model design study, the design variables are the physical properties which relate to the stiffness of the hardware components. Through the use of design sensitivity analysis, the task of identifying the most critical structural element properties in the SSF finite element model can be accomplished much more efficiently.

4.2.1 Theory

The method incorporated in MSC/NASTRAN to compute eigenvalue derivatives is Haug's and Arora's design space approach[12] which utilizes linear stiffness perturbation theory to estimate the derivatives. The estimated derivatives are computed in a cost efficient manner by making linear approximations to nonlinear functions. These derivatives, commonly referred to as Design Sensitivity Coefficients (DSC), are based on the following first order variation to the eigenvalue problem :

$$\{\phi^o\}^T [M^o] \{\phi^o\} \Delta\lambda = \{\phi^o\}^T ([\Delta K] - \lambda^o [\Delta M]) \{\phi^o\}$$

where $\{M\}$ = g-set mass matrix
$\{K\}$ = g-set stiffness matrix
λ = eigenvalue
ϕ = eigenvector

The $()^o$ symbol denotes the value of the current design point. Design sensitivities associated with other response quantities such as mode shapes and buckling load factors can also be computed using a similar approach.

The design sensitivity coefficients computed in MSC/NASTRAN define the relationship between State Variables (SV) and Design Variables (DV) which for this study are the eigenvalues and physical properties of the SSF model, respectively. The relationship can be expressed simply as:

$$DSC\ (ij) = \Delta SV(i) / \Delta DV(j)$$

where i = mode no.
j = physical property no.

The eigenvalue design sensitivity coefficients output using MSC/NASTRAN define the change in modal frequency (Hertz) due to a 100% (doubling) change in the magnitude of a design variable. The larger the DSC value for a particular component property, the more sensitive the eigenvalue is to changes in that property. Even though the coefficients are expressed in terms of a 100% design variable change, the actual design sensitivity calculations in MSC/NASTRAN are performed using only a 2% perturbation consistent with small perturbation theory.

Using the design sensitivity coefficients as defined , the modified frequency (HZ_{NEW}) of a mode can be estimated as a function of the change in the design variable (ΔDV). The equation is written as:

$$HZ_{NEW}\ (i) = HZ_{ORIG}\ (i) + \Sigma DSC(ij) * \Delta DV\ (j)$$

where HZ_{ORIG} denotes the original design point frequency[13]. This equation is extremely useful for quantifying the combined effect of varying several design parameters at once. It should be noted that when a modified frequency resulting from design variable changes is computed, the accuracy of the result is valid only for small changes. Whenever the effect of large design variable changes on frequency is desired, the FEM model should be exercised to obtain the correct solution independent of linear perturbation theory.

A more meaningful way of expressing the frequency change is in terms of percent frequency change ($\Delta HZ\%$) rather than an absolute frequency. This is accomplished by rewriting the equation as:

$$\Delta HZ\%\ (i) = \Sigma DSC(ij) * \Delta DV\ (j) / HZ_{ORIG}\ (i) * 100$$

The component properties in the SSF model which result in the largest relative frequency change per unit perturbation (ΔDV) are considered the critical properties in terms of influencing overall dynamic performance.

As previously stated, linear approximations to nonlinear functions are required to generate design sensitivity coefficients, therefore the coefficients should be considered accurate only for small design variable changes. As a test case, a simple

10 bay truss model was used to measure the error associated with using linear approximations to estimate design sensitivities.

Using a 2% design variable change for every component stiffness property in the model, the estimated frequency change based on design sensitivity analysis was 1.000% compared to a theoretical frequency change of only 0.995% (SQRT K/M = SQRT 1.02). The frequency error is fairly negligible for a ΔDV of only 2% but as the assumed perturbation is increased, the difference between the estimated change which is a linear function and the theoretical change which is a parabolic function increases as illustrated in Figure 4-4. For a ΔDV value of 10%, the estimated frequency change based on DSA is 5.00% versus a theoretical change of only 4.88% (SQRT 1.10). The limitations of design sensitivity analysis should be realized for large changes to the design variables. When in doubt, design variable changes should be incorporated directly into the FEM and new eigenvalues computed to assess the model sensitivity independent of DSA.

Knowledge of the total sensitivity associated with all the design variable changes in a design sensitivity analysis is extremely useful in verifying the results. For example, if the total frequency change resulting from a +10% ΔDV to each element property does not equate to 5.000%, the analyst knows that some contributing design sensitivity coefficients have either been ignored or incorrectly computed. This check is especially important for the SSF SC-7 FEM which has design sensitivity coefficients corresponding to more than 1100 unique physical properties.

The design sensitivity coefficients computed for the physical properties of the SSF model are solely a function of changes to the element stiffness properties in the model. Since a perturbation to the area property (ΔA) of an element having mass density (ρ) will result in a corresponding mass change ($\Delta M = \Delta A \rho L$), special DMAP coding was inserted into the MSC/NASTRAN runstream to cause sensitivities associated with mass property changes to be ignored. This enables stiffness sensitivities associated with each unique physical property in the model to be calculated independent of mass effects, as many mass effects can otherwise be compensated for in the design of the SSF scale model.

4.2.2 FEM Database

The database used to define the structural characteristics of the SSF SC-7 configuration consists of 361 unique physical property cards in the MSC/NASTRAN model. Design sensitivity coefficients corresponding to the individual physical properties (design variables) listed on each physical property card are required to

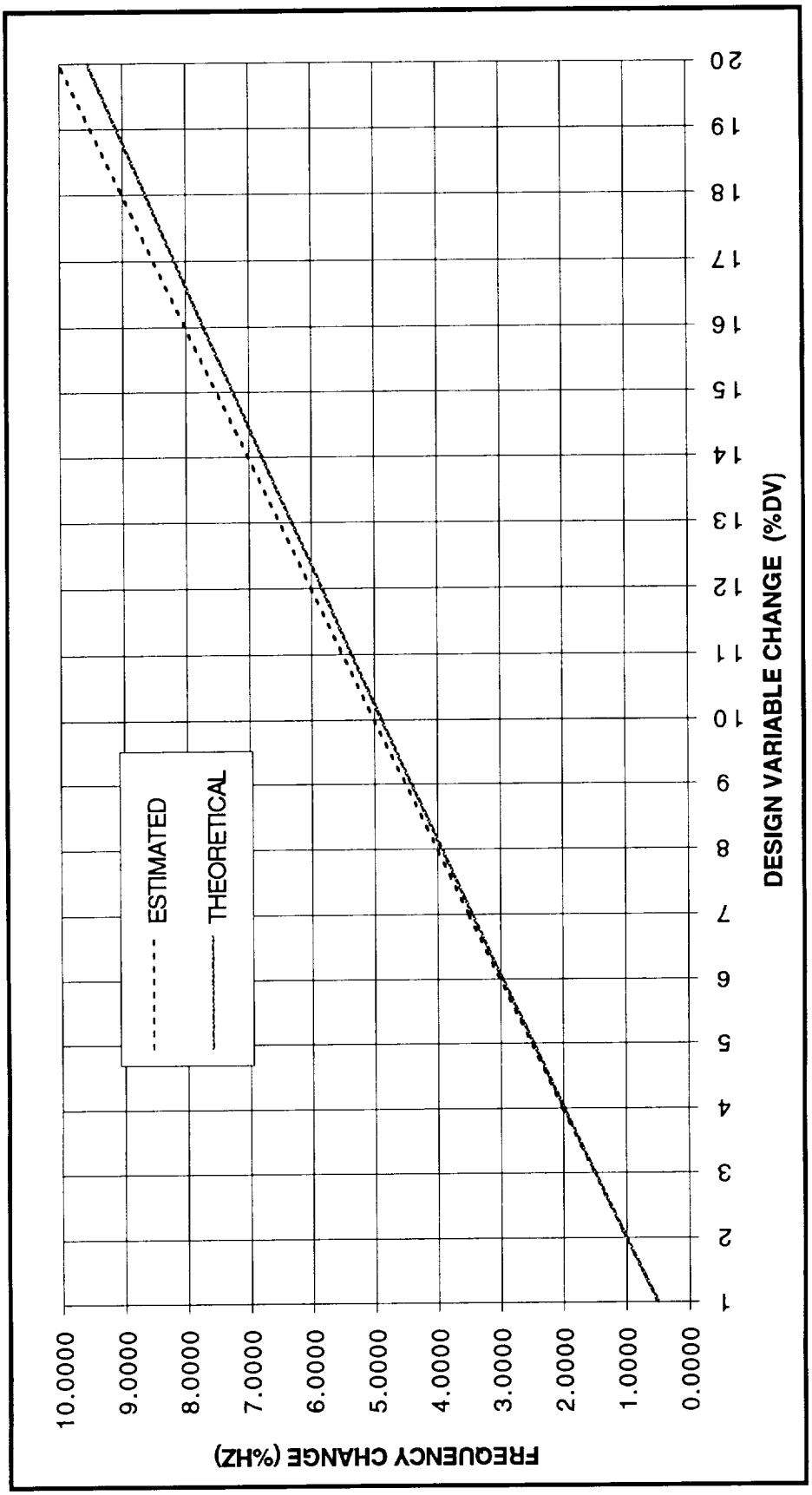


Figure 4-4 Estimated vs Theoretical Frequency Change

account for the total eigenvalue sensitivity of the structure. The finite element model uses PBEAM, PBAR, PSHELL, PCOMP, and PELAS cards to define the element properties. These property cards are referenced by the CBEAM (beam element), CBAR (bar element), CELAS1 (scalar spring element), CQUAD4, (quadrilateral shell element), and CTRIA3 (triangular shell element) element cards in the model.

The number of physical property cards contained in the model as a function of element type is summarized below. The large number of PBAR cards (259) reflects the fact that the majority of the truss-dominated SSF structure is modeled using simple bar elements.

ELEMENT TYPE	NO. PROPERTY CARDS
PBAR	259
PBEAM	2
PSHELL/PCOMP	8
PELAS	92
	$\Sigma = 361$

The fundamental design variables used in determining design sensitivity coefficients for the 261 PBAR and PBEAM cards are the cross-sectional area (A), area moments of inertia (IZ, IY), and torsional inertia (J) properties. Other properties such as area product of inertia and shear stiffness factor were determined to be higher order effects in the SSF model and are therefore ignored. Computing four design sensitivity coefficients for each of the PBAR and PBEAM cards resulted in a total of 1044 unique coefficients associated with the beam and bar elements.

For the PELAS property cards, only a single design variable is entered on each card which resulted in a total of 92 design sensitivity coefficients generated for these spring elements. The design variable on the card defines the scalar stiffness value for the element.

The design sensitivity coefficients required for the eight PSHELL and PCOMP physical property cards were computed using a slightly different procedure due to the complexity of the shell elements. Rather than computing the design sensitivities based on perturbations to the individual design variables, the total sensitivity associated with each plate element was obtained by computing design sensitivity coefficients corresponding to the material properties, E (Young's modulus) and G (shear modulus). The total sensitivity derived by combining the design sensitivity coefficients based on perturbations to E and G is equivalent to summing the constitutive sensitivities computed for each design variable contained on the physical property card. Using this

approach, a set of eight design sensitivity coefficients (E+G) describing the plate elements was obtained.

A sample listing of the MSC/NASTRAN DVAR and DVSET input cards used to compute the design sensitivity coefficients is shown in Table 4-3. The data entries differ slightly depending on the type of element being used. Therefore, the MSC/NASTRAN User's Manual[5] should be referenced for a detailed description of the input data required for each element type.

A total of 1144 design sensitivity coefficients per important mode were ultimately computed for the complete SSF SC-7 physical properties database. This resulted in a combined total of 11,440 coefficients for the ten modes analyzed. Post processing these coefficients in an orderly manner requires evaluating each coefficient on an individual basis and in terms of hardware component type.

4.2.3 SSF Hardware Components

In order to systematically analyze all of the design sensitivity information contained in the 1144 coefficients per mode, the structural elements in SSF model were separated into individual hardware component categories as shown in Figure 4-5. A total of 21 components were grouped into four categories; ITS primary structure (5) , subsystems (7), modules (5) , and appendages (4). The ITS primary structure components, which constitute the majority of the design detail in the SSF model, were further partitioned into individual bulkhead and strut members. The large number of elements in the individual S4, S3, S2, S1 truss segments coupled with their mature design state justify the need for additional refinement.

As part of the process of cross-referencing the 361 element physical properties in the model with the hardware components, a listing of the element types used to model each of the components was created. Bar elements, which are by far the most common element used in the model, are used in every hardware component while beam elements are only used to model parts of the SARJ. Shell elements are found in each of the ITS-S4, SARJ, TCS radiator, Thermal Radiator Rotary Joint (TRRJ) and berthing mechanism components. Spring elements are used extensively in the module cluster assembly to model connections between the individual modules. These elements are also used to represent the stiffness of the ITS segment to segment attachment systems.

Table 4-3 Sample Design Sensitivity Analysis Input Cards

NASTRAN FORMAT						
DVAR	*BID*	*LABEL*	*DELTAB*	*VID*		
DVSET	*VID*	*TYPE*	*FIELD*	*PREF*	*ALPHA*	*PID1*

PELAS: Scalar Spring Element						
DVAR	101	K		101		
DVSET	101	PELAS	3			1000
PBAR: Bar Elemen						
DVAR	201	A		201		
DVSET	201	PBAR	4			2000
DVAR	202	IZ		202		
DVSET	202	PBAR	5			2000
DVAR	203	IY		203		
DVSET	203	PBAR	6			2000
DVAR	204	J		204		
DVSET	204	PBAR	7			2000
PBEAM: Beam Element						
DVAR	301	A		301		
DVSET	301	PBEAM	-7			3000
DVAR	302	IZ		302		
DVSET	302	PBEAM	-8			3000
DVAR	303	IY		303		
DVSET	303	PBEAM	-9			3000
DVAR	304	J		304		
DVSET	304	PBEAM	-11			3000
PSHELL/PCOMP: Shell Element						
DVAR	401	E		401		
DVSET	401	PSHELL	3	4002		4000
DVAR	402	G		402		
DVSET	402	PSHELL	3	4003		4000

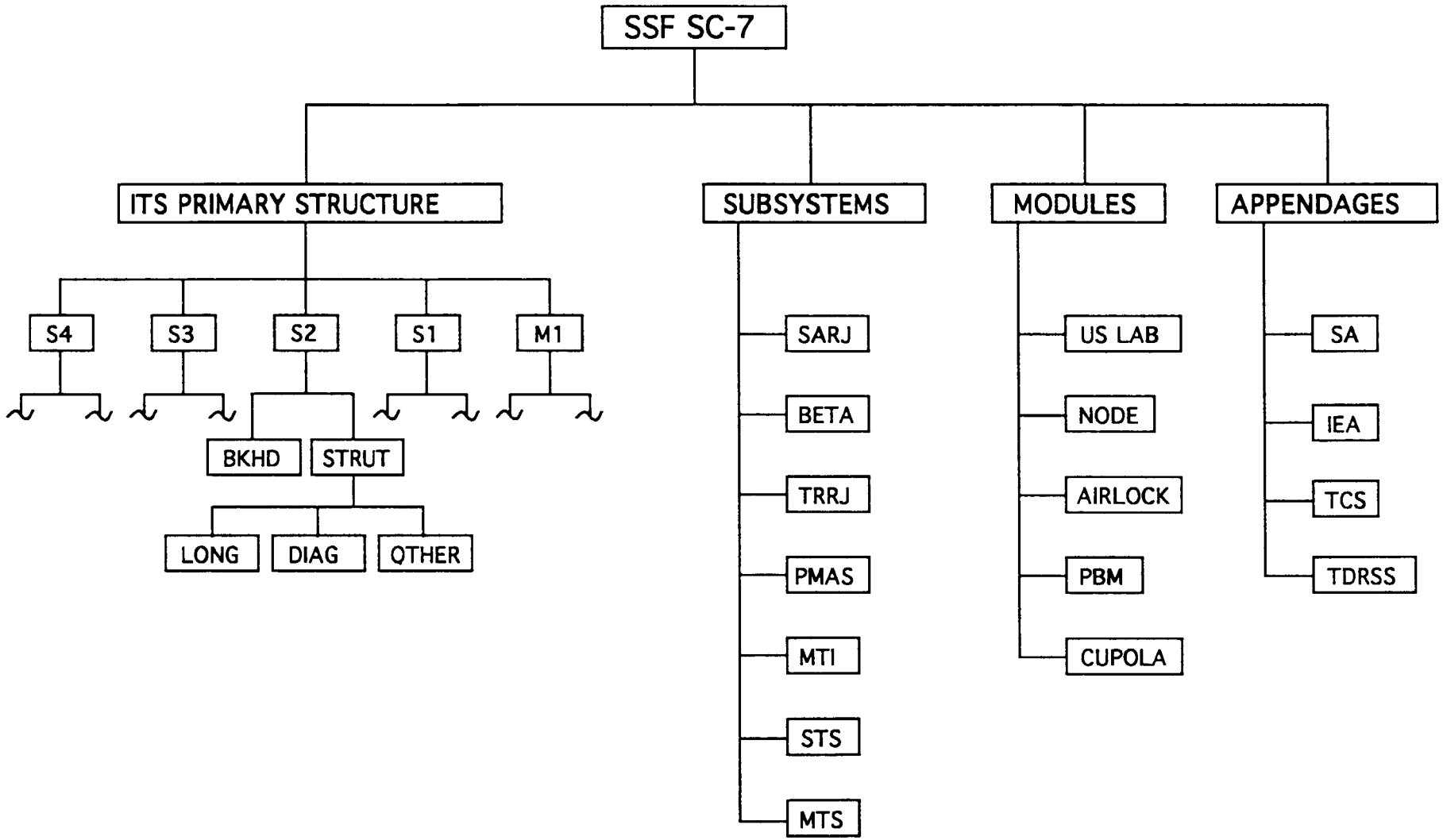


Figure 4-5 SSF SC-7 Component Tree

4.2.4 Design Sensitivity Results

In order to perform a consistent evaluation of the design sensitivity data for each of the ten important modes, the coefficients originally expressed in terms of absolute frequency change were converted into percent frequency change (ΔHZ%) results using an assumed ΔDV value of +10%. Normalizing the data in terms of percentage changes yields DSA results which are equally weighted for each of the individual modes. This way the results can be combined to obtain total and average sensitivities for the ten modes.

The ΔDV value of +10% used in the frequency change calculation was arbitrarily selected and should not be confused with the +2% perturbation used in MSC/NASTRAN to compute the eigenvalue derivatives. The actual ΔDV used in the frequency change calculations does not effect the final results of this study since the process of identifying critical hardware properties in the SSF SC-7 model is based solely on evaluating relative sensitivities. The ΔDV is simply a scalar value which defines the total frequency change expected for a mode. From Figure 4-4, it can be seen that the total expected frequency change for an assumed system level ΔDV of 10% based on design sensitivity analysis is 5.000%.

The 1144 design sensitivity coefficients computed for each of the ten important modes were added together then compared with the expected value of 5.000% in order to assess the accuracy of the analysis. The results of this comparison are shown in Table 4-4. For the first five important modes, computed coefficients sum to exactly 5.000% indicating that all of the design sensitivity for these modes has been fully captured. The combined sensitivities for the five higher frequency modes are all slightly under the total expected sensitivity of 5.000% with the largest deviation being only -0.12%. Since the observed residuals are negligible, no attempt was made to explain the missing sensitivity.

The total summed frequency sensitivity computed for the ten modes was 49.71% compared with the predicted total of 50.00%. This equates to a total combined delta frequency of only -0.29%. These results clearly demonstrate that the design sensitivity coefficients computed for the subset of 1144 physical properties selected from the SSF SC-7 FEM fully describe the eigenvalue sensitivity of the model, accounting for 99.4% of the total sensitivity.

A list describing the physical properties used in the design sensitivity analysis is included in Appendix B. Each coefficient is individually referenced by a Design Sensitivity Coefficient Number (DSC NO.), a System ID (SID), a Component ID (CID),

Table 4-4 Total Design Sensitivity For 10 Important Modes

IMP MODE NO.	DSC SUM (%HZ)	TOTAL DSA (%HZ)	Δ DSC
17	5.00	5.00	0.00
20	5.00	5.00	0.00
27	5.00	5.00	0.00
30	5.00	5.00	0.00
31	5.00	5.00	0.00
36	4.91	5.00	-0.09
37	4.88	5.00	-0.12
47	4.99	5.00	-0.01
49	4.99	5.00	-0.01
53	4.94	5.00	-0.06
TOTAL =	**49.71**	**50.00**	**-0.29**

99.4% of Total Design Sensitivity Computed

a Property ID (PID), and a brief description of the hardware component it represents. The total ten mode sensitivity (DSC %HZ) corresponding to each physical property is ranked in descending order based on the component list shown in Figure 4-5.

The coefficients corresponding to the 92 scalar spring element properties (K) and the eight shell element properties (E+G) are summarized in terms of component type in Appendix B. This is the reason why only 1057 physical properties are listed in the appendix instead of 1144. The 92 spring properties can be expressed in terms of only eight hardware components while the eight shell properties describe only five components.

4.2.4.1 Summary Results

A top level component summary of the DSA results is shown in Tables 4-5a and 4-5b for each important mode along with averaged values for the ten modes. Table 4-5a presents the sensitivity results in terms of percent frequency change (%HZ) corresponding to a ΔDV of +10% while Table 4-5b expresses the results in terms of a percentage of the total sensitivity. The %HZ notation is used to differentiate absolute frequency changes in percent (Figure 4-5a) from the percentage of total frequency change (Figure 4-5b). For example, a sensitivity of 1.00 %HZ for a mode could also be expressed as 20% of the total sensitivity for that mode (1.00 %HZ out of 5.00 %HZ). The %HZ format is intended to provide a physical insight to the results while the percent of total data expresses the relative sensitivity of each component independent of frequency. All of the component DSA summaries are presented in both formats.

The summary results indicate that the ITS primary structure and subsystems account for 72% of the total sensitivity in the SSF SC-7 model with the modules and appendages accounting for the remaining 28%. This is not surprising since the majority of the SSF structure is comprised of truss and subsystems. Note that mode 49 is dominated by the module components consistent with earlier findings. If this mode had not been selected as an important mode, the total sensitivity in the modules would have been only 9% instead of 14%. More detailed observations with respect to the structural sensitivities can be obtained by evaluating the results on an individual component basis as shown in Tables 4-6 through 4-9.

4.2.4.2 Subsystem Component Results

Table 4-6a and 4-6b contain the ITS primary structure DSA results summarized as a function of cross-sectional area, bending inertia, and torsional inertia for the bulkheads (BKHD), longeron struts (LONG) , diagonal struts (DIAG), and other miscellaneous

Table 4-5a DSA Overall Component Summary (Freq Change %HZ)

	17	20	27	30	31	36	37	47	49	53	AVE
ITS	3.06	3.59	2.04	1.93	1.87	1.84	1.25	2.72	0.76	1.31	**2.04**
SUBSYSTEMS	0.33	1.18	1.86	2.11	2.37	1.86	2.26	1.06	0.90	1.54	**1.54**
MODULES	0.04	0.09	0.74	0.78	0.51	0.55	0.71	0.36	3.25	0.13	**0.72**
APPENDAGES	1.57	0.14	0.36	0.18	0.25	0.66	0.66	0.85	0.08	1.96	**0.67**
TOTAL =	**5.00**	**5.00**	**5.00**	**5.00**	**5.00**	**4.91**	**4.88**	**4.99**	**4.99**	**4.94**	**4.97**

Table 4-5b DSA Overall Component Summary (% of Total)

	17	20	27	30	31	36	37	47	49	53	AVE
ITS	61%	71%	41%	38%	38%	38%	25%	55%	15%	26%	**41%**
SUBSYSTEMS	7%	24%	37%	42%	47%	38%	46%	21%	18%	31%	**31%**
MODULES	1%	2%	15%	16%	10%	11%	15%	7%	65%	3%	**14%**
APPENDAGES	31%	3%	7%	4%	5%	13%	14%	17%	2%	40%	**14%**
TOTAL =	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**

Table 4-6a DSA ITS Summary (Freq Change %HZ)

		17	20	27	30	31	36	37	47	49	53	AVE
AREA (A)	BKHD	1.08E-01	1.30E-01	1.01E-01	6.75E-02	6.18E-02	9.37E-02	5.31E-02	1.32E-01	3.82E-02	8.65E-02	**0.09**
	LONG	8.75E-01	2.75E+00	6.81E-01	1.52E-01	6.98E-02	6.98E-01	5.26E-01	1.36E+00	8.31E-02	2.99E-01	**0.75**
	DIAG	1.03E+00	4.17E-01	1.49E-01	1.18E-01	8.35E-02	2.91E-01	1.80E-01	6.29E-01	7.39E-02	2.44E-01	**0.32**
	OTHER	7.96E-03	7.94E-03	1.73E-02	3.25E-03	2.32E-03	1.67E-02	6.96E-03	1.15E-02	2.62E-02	1.76E-03	**0.01**
	TOTAL	**2.02**	**3.31**	**0.95**	**0.34**	**0.22**	**1.09**	**0.77**	**2.13**	**0.22**	**0.64**	**1.17**
BENDING INERTIA (IZ, IY)	BKHD	1.75E-01	7.43E-02	1.54E-01	1.22E-01	1.12E-01	2.88E-01	1.56E-01	1.51E-01	1.62E-01	1.73E-01	**0.16**
	LONG	6.23E-01	1.11E-01	5.92E-01	1.33E+00	1.45E+00	2.98E-01	2.09E-01	3.06E-01	1.32E-01	4.28E-01	**0.55**
	DIAG	1.65E-01	6.37E-02	2.28E-01	8.30E-02	5.31E-02	1.30E-01	7.36E-02	8.71E-02	1.79E-01	4.83E-02	**0.11**
	OTHER	4.74E-02	1.11E-02	9.99E-02	3.25E-02	1.76E-02	1.52E-02	2.05E-02	1.69E-02	6.87E-02	6.65E-03	**0.03**
	TOTAL	**1.01**	**0.26**	**1.07**	**1.57**	**1.63**	**0.73**	**0.46**	**0.56**	**0.54**	**0.66**	**0.85**
TORSION INERTIA (J)	BKHD	1.00E-03	2.00E-04	1.90E-03	6.00E-04	3.00E-04	4.00E-04	9.00E-04	1.00E-03	6.00E-04	7.00E-04	**0.00**
	LONG	3.20E-03	0.00E+00	5.70E-03	1.47E-02	1.54E-02	7.00E-04	1.00E-03	1.90E-03	4.00E-04	7.00E-03	**0.01**
	DIAG	5.00E-04	0.00E+00	1.00E-04	1.00E-04	1.00E-04	1.00E-04	0.00E+00	2.00E-04	1.00E-04	1.00E-04	**0.00**
	OTHER	2.45E-02	2.66E-04	3.29E-04	2.97E-04	1.01E-03	1.03E-03	6.33E-04	4.27E-03	3.86E-04	2.84E-03	**0.00**
	TOTAL	**0.02**	**0.00**	**0.01**	**0.02**	**0.02**	**0.00**	**0.00**	**0.01**	**0.00**	**0.01**	**0.01**
SPRING ELEMENTS		**0.01**	**0.02**	**0.01**	**0.00**	**0.00**	**0.01**	**0.01**	**0.02**	**0.00**	**0.00**	**0.01**
PLATE ELEMENTS		**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.01**	**0.01**	**0.00**	**0.00**	**0.00**	**0.00**
COMBINED TOTAL:		***3.06***	***3.59***	***2.04***	***1.93***	***1.87***	***1.84***	***1.25***	***2.72***	***0.76***	***1.31***	***2.04***

Table 4-6b DSA ITS Summary (% of Total)

		17	*20*	*27*	*30*	*31*	*36*	*37*	*47*	*49*	*53*	AVE
AREA (A)	BKHD	2%	3%	2%	1%	1%	2%	1%	3%	1%	2%	**2%**
	LONG	17%	55%	14%	3%	1%	14%	11%	27%	1%	6%	**15%**
	DIAG	21%	8%	3%	2%	2%	6%	4%	13%	1%	5%	**6%**
	OTHER	0%	0%	0%	1%	1%	0%	0%	1%	1%	0%	**1%**
	TOTAL	**40%**	**66%**	**19%**	**7%**	**5%**	**22%**	**16%**	**44%**	**4%**	**13%**	**24%**
BENDING INERTIA (IZ, IY)	BKHD	4%	1%	3%	2%	3%	6%	3%	3%	3%	4%	**3%**
	LONG	12%	2%	12%	26%	29%	6%	4%	6%	3%	8%	**11%**
	DIAG	3%	2%	5%	2%	1%	3%	2%	2%	4%	1%	**2%**
	OTHER	1%	0%	2%	1%	0%	0%	0%	0%	1%	0%	**1%**
	TOTAL	**20%**	**5%**	**22%**	**31%**	**33%**	**15%**	**9%**	**11%**	**11%**	**13%**	**17%**
TORSION INERTIA (J)	BKHD	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	**0%**
	LONG	1%	0%	0%	0%	0%	0%	0%	0%	0%	0%	**0%**
	DIAG	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	**0%**
	OTHER	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	**0%**
	TOTAL	**1%**	**0%**	**0%**	**0%**	**0%**	**0%**	**0%**	**0%**	**0%**	**0%**	**0%**
SPRING ELEMENTS		**0%**	**0%**	**0%**	**0%**	**0%**	**0%**	**0%**	**0%**	**0%**	**0%**	**0%**
PLATE ELEMENTS		**0%**	**0%**	**0%**	**0%**	**0%**	**0%**	**0%**	**0%**	**0%**	**0%**	**0%**
COMBINED TOTAL:		*61%*	*71%*	*41%*	*38%*	*38%*	*38%*	*25%*	*55%*	*15%*	*26%*	*41%*

hardware (OTHER). The sensitivities associated with the spring and plate elements in the ITS structure are also shown. This refined breakdown of the ITS primary structure components in comparison to the subsystems, modules, and appendages is necessary due the relative importance of the truss structure in the scale model design. The mature state of the truss design along with the design detail contained in the FEM make this refinement possible.

Inspection of the ITS primary structure DSA results in Table 4-6b reveals the longeron struts to have the largest design sensitivities in the ITS structure, accounting for 26% of the total model sensitivity. These longeron struts are definitely critical components in the scale model design. Diagonal struts are second in importance in the ITS having a lesser total sensitivity value of only 8%. Additional evaluation of the ITS primary structure results show the torsional inertia properties, plate elements, and spring elements make up less than 1% of the total sensitivity and therefore are not critical properties requiring high fidelity designs in the scale model.

The design sensitivities corresponding to each of the seven subsystem components are summarized in Tables 4-7a and 4-7b. The potential critical components are the PMAS, SARJ, and MTI whose coefficients account for 13%, 8%, and 6% of the total model sensitivity, respectively. The Solar Array Beta Joint (BETA), TRRJ, Mobile Transporter System (MTS), and SARJ-Truss Interface Structure (STS) components can be designed using dynamically similar scaling due to their negligible sensitivities.

Review of the module component summary in Tables 4-8a and 4-8b shows that the majority the module sensitivity is attributed to the Pressurized Berthing Mechanism (PBM) component which accounts for 8% of the total sensitivity in the model. The U.S. Lab Module (US LAB) and the Resource Node (NODE) each account for 3% of the model sensitivity which is directly attributable to their interface stiffness properties since these components are modeled as equivalent bar elements having limited fidelity. There is no sensitivity associated with the Airlock and Cupola so these components can be dynamically simulated in the scale model. With the exception of the PBM, the module components in the FEM have very little design detail and behave essentially as rigid masses in the SSF global modes.

Appendage design sensitivity results are displayed in Tables 4-9a and 4-9b. The Solar Array (SA) is responsible for 9% of the total sensitivity of the SSF structure followed by 4% for the TCS Radiator and 1% for the IEA Radiator. The TDRSS antenna, also referred to as the KU-band antenna, does not influence the dynamics of the global modes and therefore is not an important feature in the scale model.

Table 4-7a DSA Subsystems Summary (Freq Change %HZ)

	17	*20*	*27*	*30*	*31*	*36*	*37*	*47*	*49*	*53*	*AVE*
SARJ	0.00	0.04	0.07	0.06	0.04	0.79	1.43	0.21	0.02	0.05	**0.27**
BETA	0.00	0.00	0.02	0.01	0.01	0.01	0.02	0.01	0.00	0.05	**0.01**
TRRJ	0.00	0.00	0.00	0.00	0.00	0.05	0.02	0.08	0.00	0.03	**0.02**
PMAS	0.25	0.00	0.71	1.63	2.07	0.11	0.20	0.28	0.06	1.30	**0.65**
MTI	0.08	0.24	0.93	0.39	0.23	0.72	0.29	0.39	0.73	0.08	**0.41**
STS	0.00	0.02	0.01	0.01	0.01	0.17	0.29	0.06	0.00	0.01	**0.06**
MTS	0.00	0.88	0.12	0.01	0.01	0.01	0.01	0.03	0.09	0.02	**0.12**
TOTAL =	**0.33**	**1.18**	**1.86**	**2.11**	**2.37**	**1.86**	**2.26**	**1.06**	**0.90**	**1.54**	**1.54**

Table 4-7b DSA Subsystems Summary (% of Total)

	17	*20*	*27*	*30*	*31*	*36*	*37*	*47*	*49*	*53*	*AVE*
SARJ	0%	1%	1%	1%	1%	16%	30%	4%	0%	1%	**6%**
BETA	0%	0%	0%	0%	0%	0%	0%	0%	0%	1%	**0%**
TRRJ	0%	0%	0%	0%	0%	1%	0%	2%	0%	1%	**1%**
PMAS	5%	0%	15%	33%	41%	2%	4%	6%	1%	26%	**13%**
MTI	2%	5%	19%	8%	5%	16%	6%	7%	15%	2%	**8%**
STS	0%	0%	0%	0%	0%	3%	6%	1%	0%	0%	**1%**
MTS	0%	18%	2%	0%	0%	0%	0%	1%	2%	0%	**2%**
TOTAL =	**7%**	**24%**	**37%**	**42%**	**47%**	**38%**	**46%**	**21%**	**18%**	**31%**	**31%**

Table 4-8a DSA Module Summary (Freq Change %HZ)

	17	*20*	*27*	*30*	*31*	*36*	*37*	*47*	*49*	*53*	*AVE*
US LAB	0.01	0.05	0.09	0.08	0.07	0.28	0.28	0.12	0.27	0.02	0.13
NODE	0.01	0.00	0.27	0.23	0.12	0.02	0.14	0.06	0.84	0.01	0.17
AIRLOCK	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00
PBM	0.02	0.04	0.38	0.47	0.32	0.25	0.29	0.18	2.13	0.10	0.42
CUPOLA	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
TOTAL =	**0.04**	**0.09**	**0.74**	**0.78**	**0.51**	**0.55**	**0.71**	**0.36**	**3.25**	**0.13**	**0.72**

Table 4-8b DSA Module Summary (% of Total)

	17	*20*	*27*	*30*	*31*	*36*	*37*	*47*	*49*	*53*	*AVE*
US LAB	0%	1%	2%	2%	1%	6%	6%	2%	5%	0%	**3%**
NODE	0%	0%	5%	5%	2%	0%	3%	1%	17%	0%	**3%**
AIRLOCK	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	**0%**
PBM	1%	1%	8%	9%	7%	5%	6%	4%	43%	3%	**8%**
CUPOLA	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	**0%**
TOTAL =	**1%**	**2%**	**15%**	**16%**	**10%**	**11%**	**15%**	**7%**	**65%**	**3%**	**14%**

Table 4-9a DSA Appendage Summary (Freq Change %HZ)

	17	*20*	*27*	*30*	*31*	*36*	*37*	*47*	*49*	*53*	*AVE*
SA	1.30	0.11	0.34	0.14	0.22	0.20	0.40	0.26	0.03	1.08	0.40
IEA	0.15	0.01	0.00	0.03	0.03	0.14	0.07	0.02	0.00	0.23	0.07
TCS	0.12	0.02	0.02	0.01	0.00	0.32	0.19	0.57	0.05	0.65	0.20
TDRSS	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
TOTAL =	**1.57**	**0.14**	**0.36**	**0.18**	**0.25**	**0.66**	**0.66**	**0.85**	**0.08**	**1.96**	**0.67**

Table 4-9b DSA Appendage Summary (% of Total)

	17	*20*	*27*	*30*	*31*	*36*	*37*	*47*	*49*	*53*	*AVE*
SA	26%	3%	7%	3%	4%	4%	8%	6%	1%	22%	**9%**
IEA	3%	0%	0%	1%	1%	3%	1%	0%	0%	5%	**1%**
TCS	2%	0%	0%	0%	0%	6%	5%	11%	1%	13%	**4%**
TDRSS	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	**0%**
TOTAL =	**31%**	**3%**	**7%**	**4%**	**5%**	**13%**	**14%**	**17%**	**2%**	**40%**	**14%**

4.2.4.3 Element Property Results

The previous summary charts have been extremely useful in making overall observations with regard to which components in the model have large sensitivities and might require high fidelity designs and which components can be dynamically simulated to reduce design and fabrication costs. What the tables don't reveal are the specific critical element properties within each component which dominate the sensitivity results and thus should be replicated. Just because a component is deemed important doesn't necessarily mean that every element property in the component requires replica scaling. The sensitivities corresponding to the 1144 element properties need to evaluated on an individual basis to determine the specific element properties which are critical for designing a "near-replica" scale model of SSF.

In order to evaluate the relative importance of each physical property, the DSC %HZ results contained in Appendix B were ranked in decreasing order and plotted as shown in Figure 4-6. These results correspond to the combined sum of all ten important modes. Only the 662 largest coefficients are shown since coefficients ranked lower than 622 position are over four orders of magnitude below the highest ranked coefficient and thus are not critical to the scale model design. There are 21 coefficients within one order of magnitude of the largest coefficient (4.11 %HZ) and 143 coefficients within two orders of magnitude.

A useful diagram for understanding the relative contribution of each coefficient to the total sensitivity of the important modes is the cumulative frequency change vs. ranked coefficient plot shown in Figure 4-7. This figure clearly shows that 45 %HZ out of the total possible sensitivity of 50 %HZ is obtained from only 118 design coefficients. These 118 physical properties dominate the dynamic characteristics of the SSF structure and capture 90% of the total design sensitivity in the SSF model. The remaining 1026 coefficients contribute only 10% of the total sensitivity and therefore are prime candidates for dynamically similar designs.

The top 118 ranked component physical properties are summarized in Appendix C. The reference system used to define the properties is identical to the one described for Appendix B. The total sensitivity for each property summed over the ten modes is listed in terms of percent frequency change (DSC %HZ) along with the corresponding ranking. The largest single sensitivity of 4.11 %HZ belongs to the scalar spring elements used to model the radial port berthing mechanism and endcone in the module cluster. This is followed next by the area property of the module support beams (3.82 %HZ) which are the interface between the module assembly and the ITS

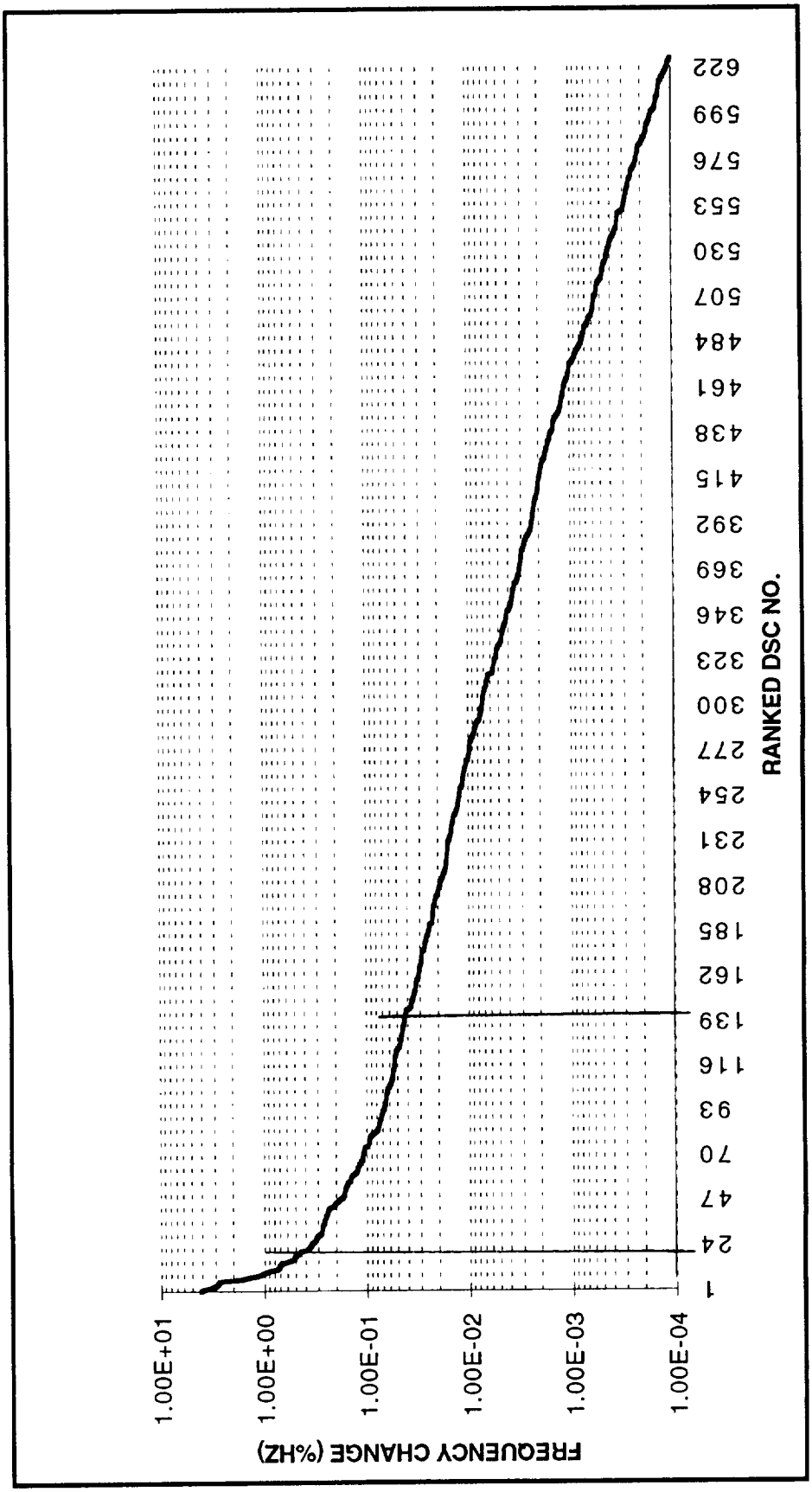


Figure 4-6 Ranked Design Sensitivity Coefficients

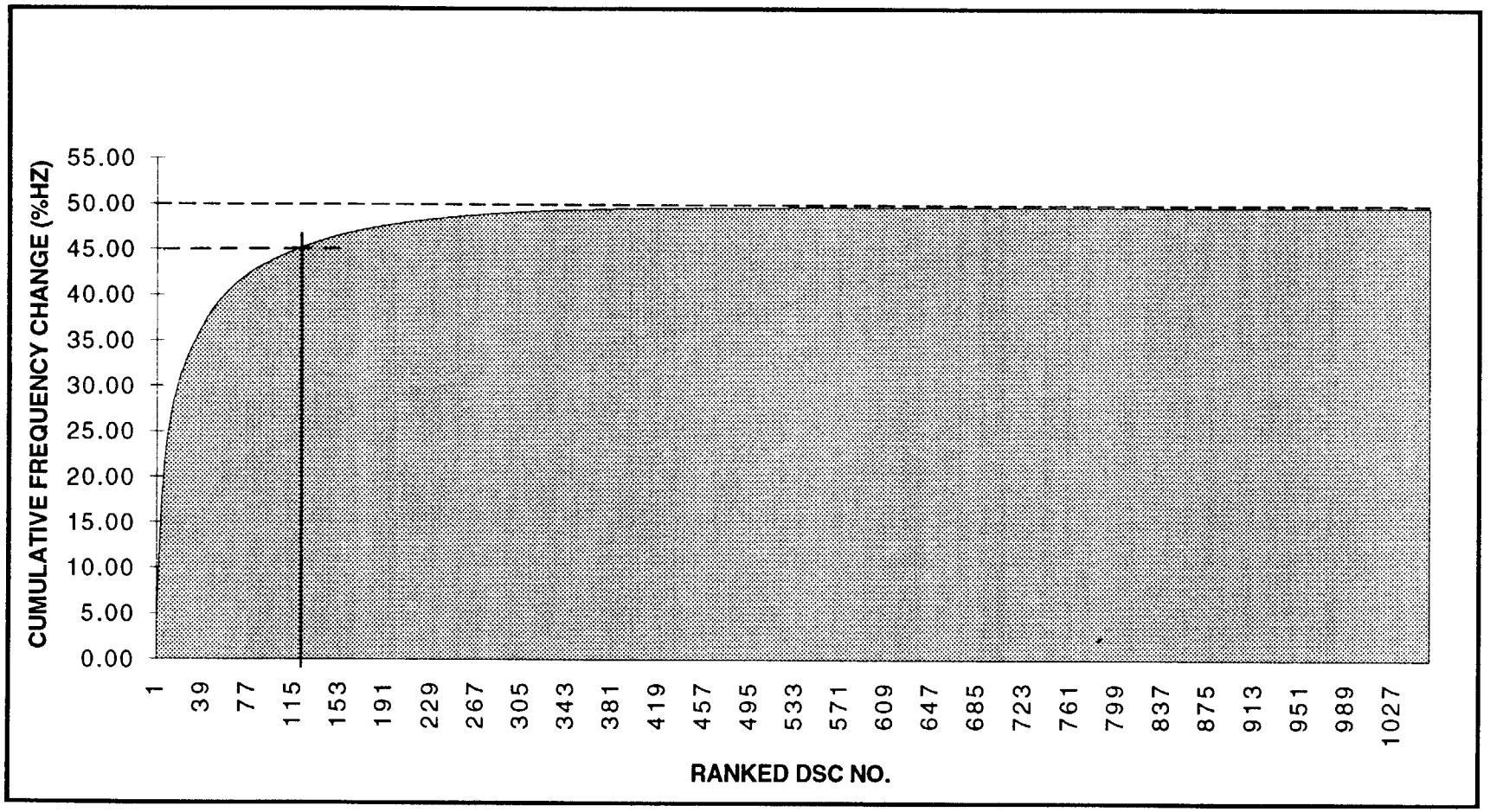


Figure 4-7 Cumulative Design Sensitivity

primary structure. The top 21 coefficients which are within one order of magnitude of the largest sensitivity are shown as shaded entries in the Appendix C.

Many of the 118 coefficients in Appendix C correspond to the same hardware components in the SSF model. Accordingly, the 118 sensitivity values were summarized in terms of critical component properties in the SSF structure which require high fidelity replica designs in order to fabricate a "near-replica" dynamic scale model. A total of 13 critical hardware components were identified as shown in Table 4-10. The critical properties for each of these 13 components account for 42 %HZ out of the total design sensitivity of 50 %HZ. This equates to 84% of the total eigenvalue sensitivity for the ten important modes.

The 13 critical hardware components are ranked in order of relative importance based on total percent frequency change as illustrated in Figure 4-8 and tabulated in Table 4-10. The cross-sectional area of the MT rail and trunnion longerons located in ITS primary structure is the highest ranked component property (7.11 %HZ) followed closely by the area and bending inertias of the PMAS subsystem (6.44 %HZ) which is ranked second. The ITS secondary and trunnion longerons bending inertias are ranked third in importance (4.70 %HZ). One other component property in the ITS primary structure, the face and side diagonal strut areas, is also designated as critical. The ITS longeron and diagonal struts are the backbone of the SSF truss structure and it should be expected that these components require high fidelity designs as part of a dynamic scale model.

Other subsystem components identified as critical in addition to the PMAS are the MTI, SARJ/STS, and MTS Arm which are ranked 6th, 8th, and 12th, respectively. The three module components which drive dynamic performance are the PBM, MPLM/NODE interface stiffness, and LAB/NODE interface stiffness. There are also three appendage components which appear on the critical component list. They are the SA, TCS radiator, and the IEA radiator which require high fidelity designs for the bending inertia properties.

In conclusion, the design sensitivity analysis results provide a sound technical basis for making model fidelity decisions. The design of a "near-replica" dynamic scale model of SSF should focus on the 118 critical component properties listed in Appendix C and summarized in Table 4-10. These critical properties are the key to fabricating a cost-efficient scale model which captures the dynamic performance of the full-scale SSF.

Table 4-10 Critical Hardware Components

ITS PRIMARY STRUCTURE

COMPONENT	PROPERTY	TOTAL DSC (%HZ)	RANK
MT RAIL & TRUNNION LONGERONS	A	7.11	1
SECONDARY & TRUNNION LONGERONS	IY & IZ	4.70	3
FACE/SIDE DIAGONALS	A	2.99	7

SUSBSYSTEM

COMPONENT	PROPERTY	TOTAL DSC (%HZ)	RANK
PMAS	A, IY, & IZ	6.44	2
MTI	A	3.82	6
SARJ / STS	A, IY, & IZ	2.87	8
MTS ARM	IZ	0.70	12

MODULES

COMPONENT	PROPERTY	TOTAL DSC (%HZ)	RANK
PBM	K	4.11	4
MPLM/NODE INTERFACE	K	1.66	10
LAB/NODE INTERFACE	K	1.12	11

APPENDAGES

COMPONENT	PROPERTY	TOTAL DSC (%HZ)	RANK
SA	IY & IZ	4.07	5
TCS	IY & IZ	1.76	9
IEA	IY & IZ	0.68	13
	TOTAL =	**42.03**	**13**

C-2

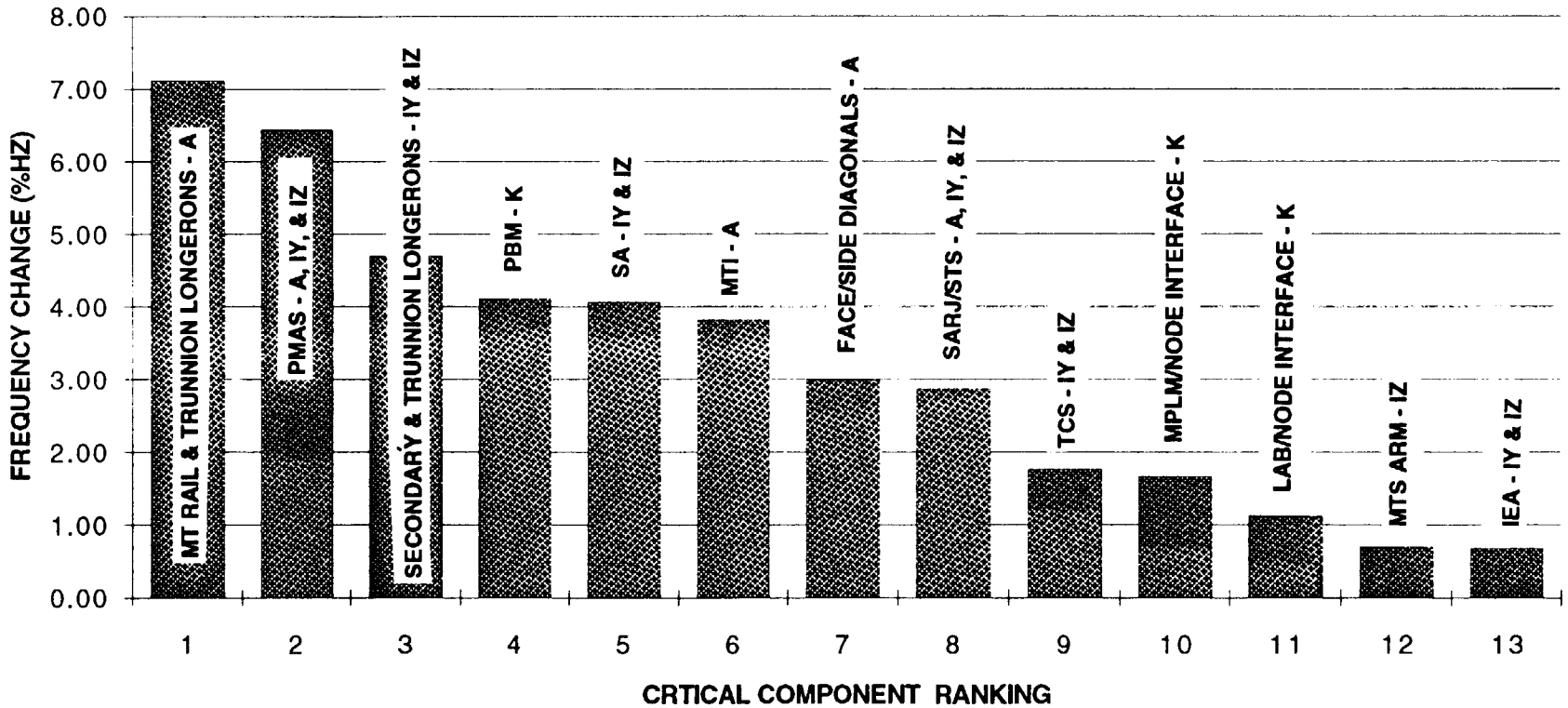


Figure 4-8 Relative Importance of Critical Hardware Components

The recommended general design approach for the remaining component properties not shown in Table 4-10 or Appendix C is to use lower fidelity dynamic similarity scaling which can yield significant time and cost savings. For example, a strut whose area is critical but whose inertia is not could be designed with a more cost-effective and producible cross-sectional shape. Through commonality, a substantial reduction in parts count can be realized for the non-critical components. Special cases may exist were additional design detail is required for specific non-critical components based on the needs of the scale model program. These cases need to be examined on an individual basis and designed accordingly.

The DSA data is only intended to serve as a tool for evaluating the relative sensitivities of the FEM component properties and directing the focus of the scale model conceptual design effort. Since the design sensitivities results are approximations based on small design variable changes, the dynamic performance of the scale model component designs should be verified by rerunning the finite element model with the new design properties incorporated.

5.0 REFERENCES

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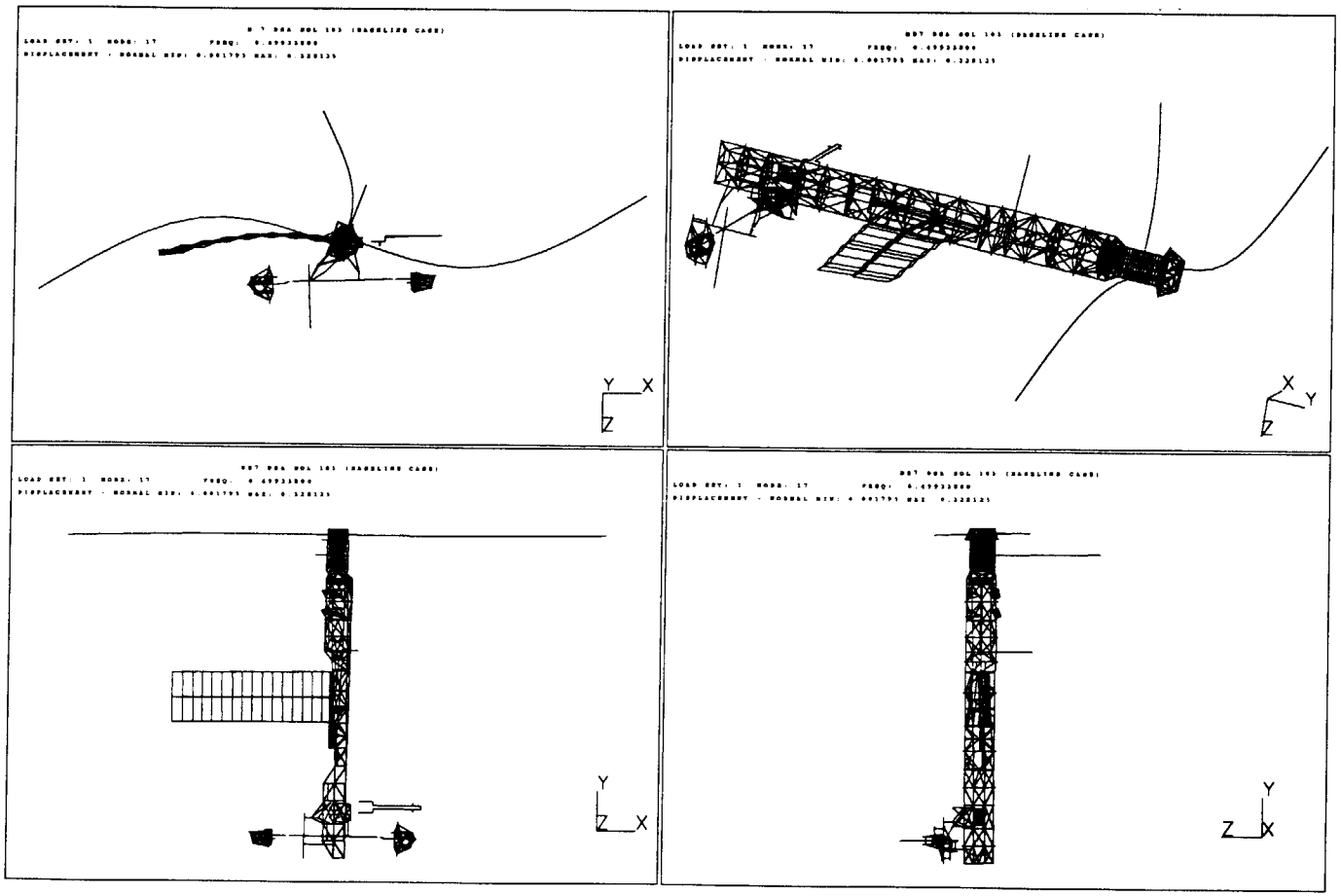
APPENDIX A

MODE SHAPE PLOTS OF IMPORTANT MODES

SC-7 FEM MODE SHAPE PLOT
(Mode 17 - 1st Torsion)

Lockheed



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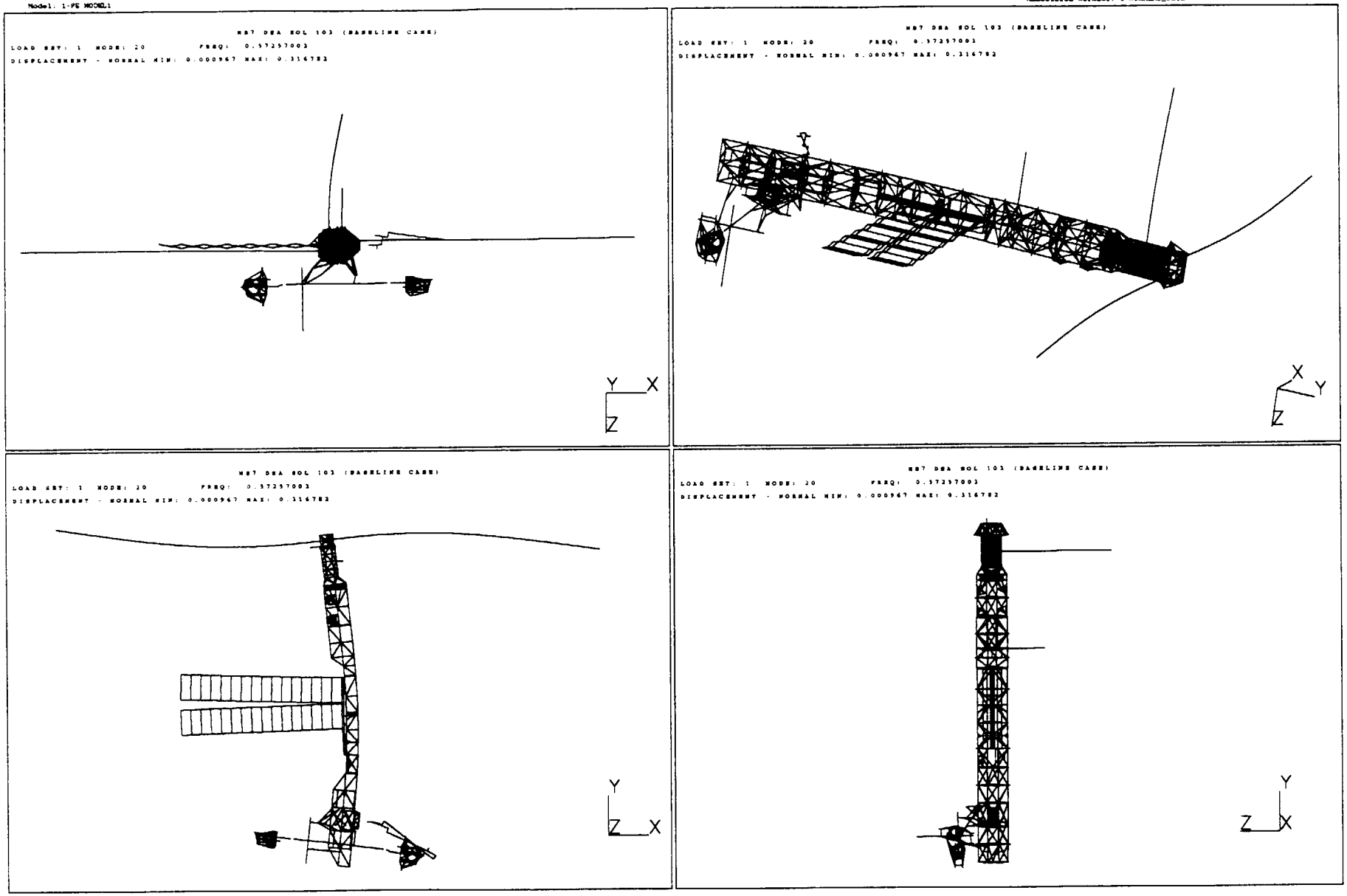

A-3

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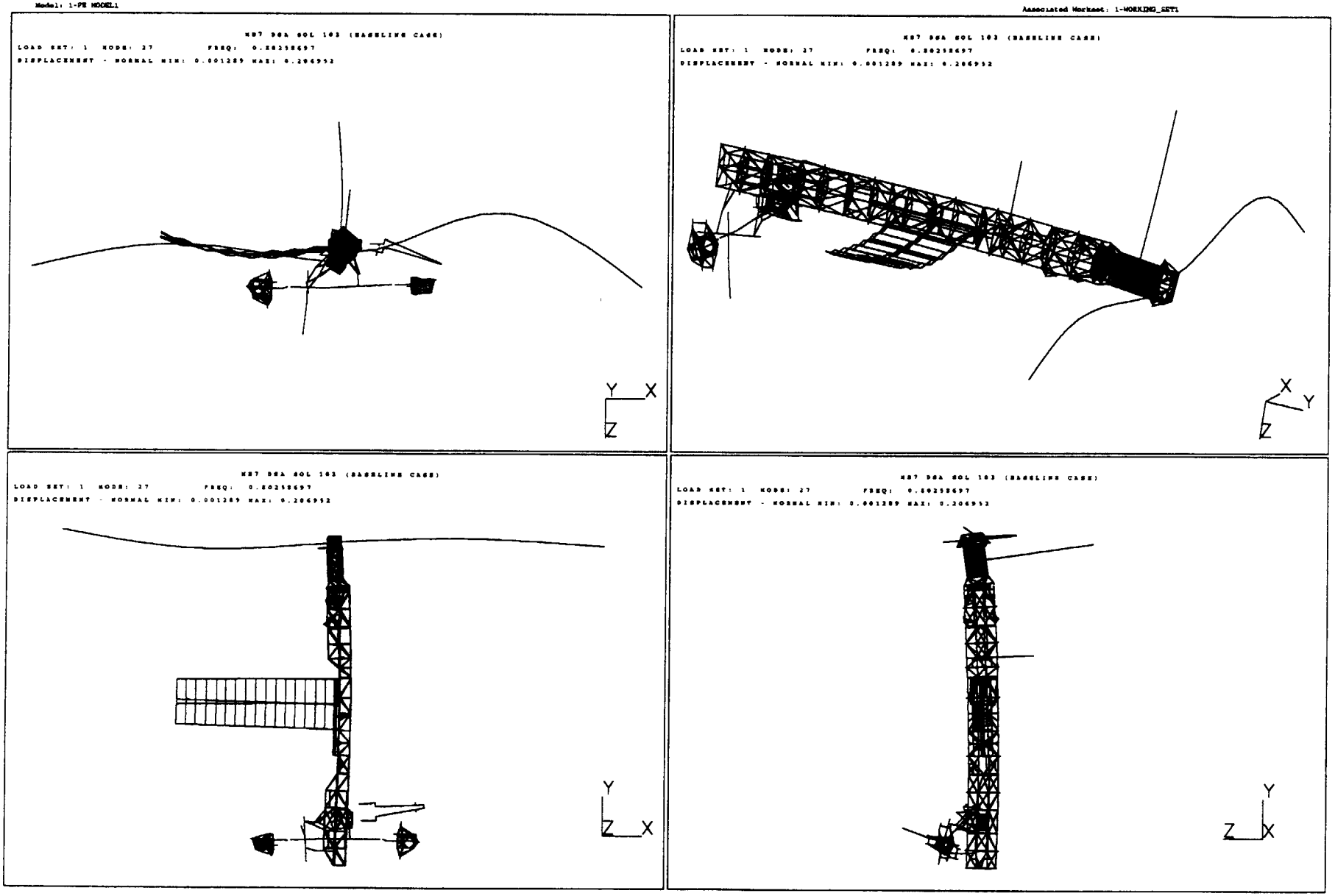

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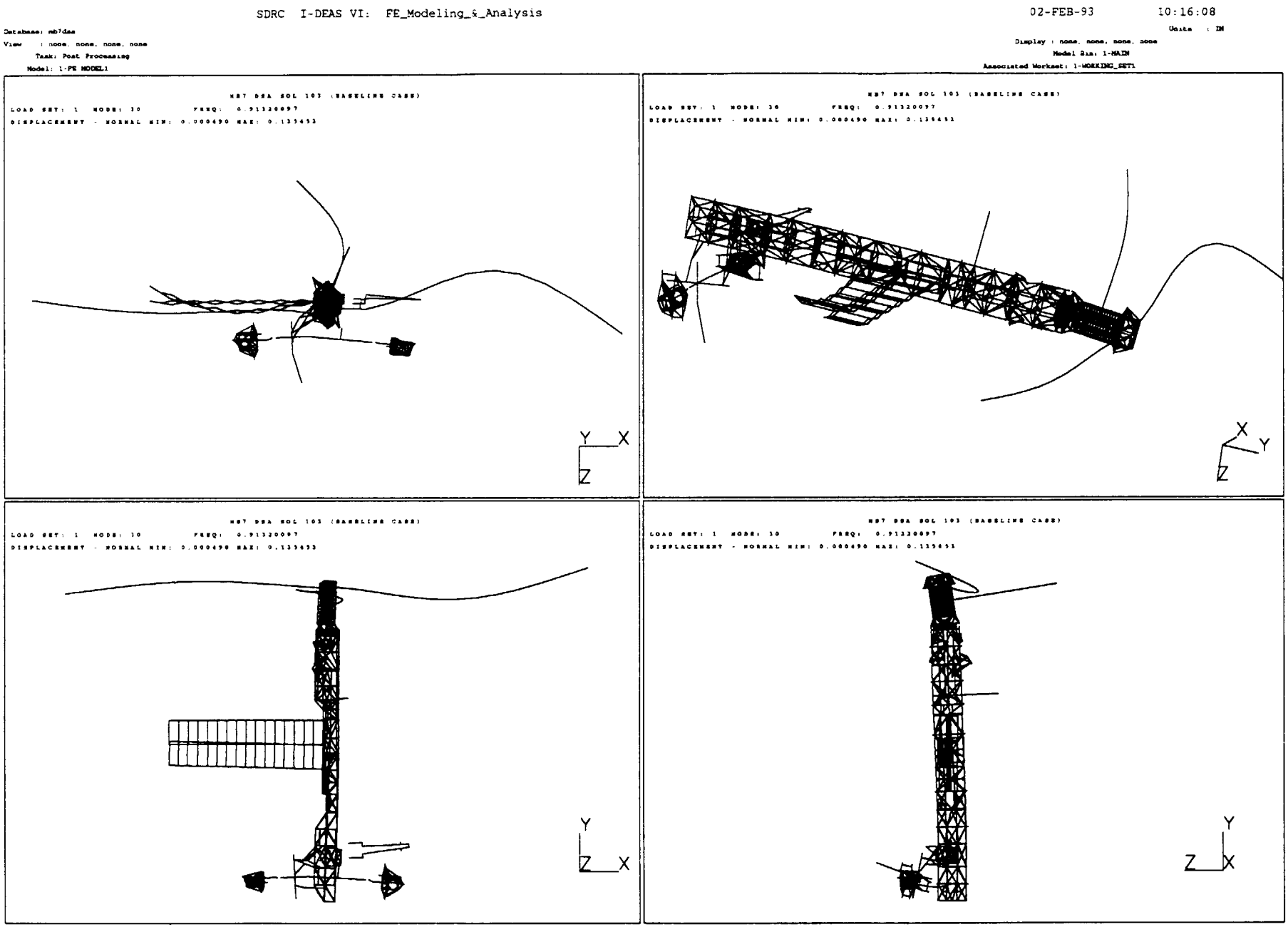
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DISPLACEMENT - NORMAL MIN: 0.000490 MAX: 0.135451
MB7 DSA SOL 103 (BASELINE CASE)
LOAD SET: 1 MODE: 30 FREQ: 0.91320097
DISPLACEMENT - NORMAL MIN: 0.000490 MAX: 0.135451
MB7 DSA SOL 103 (BASELINE CASE)
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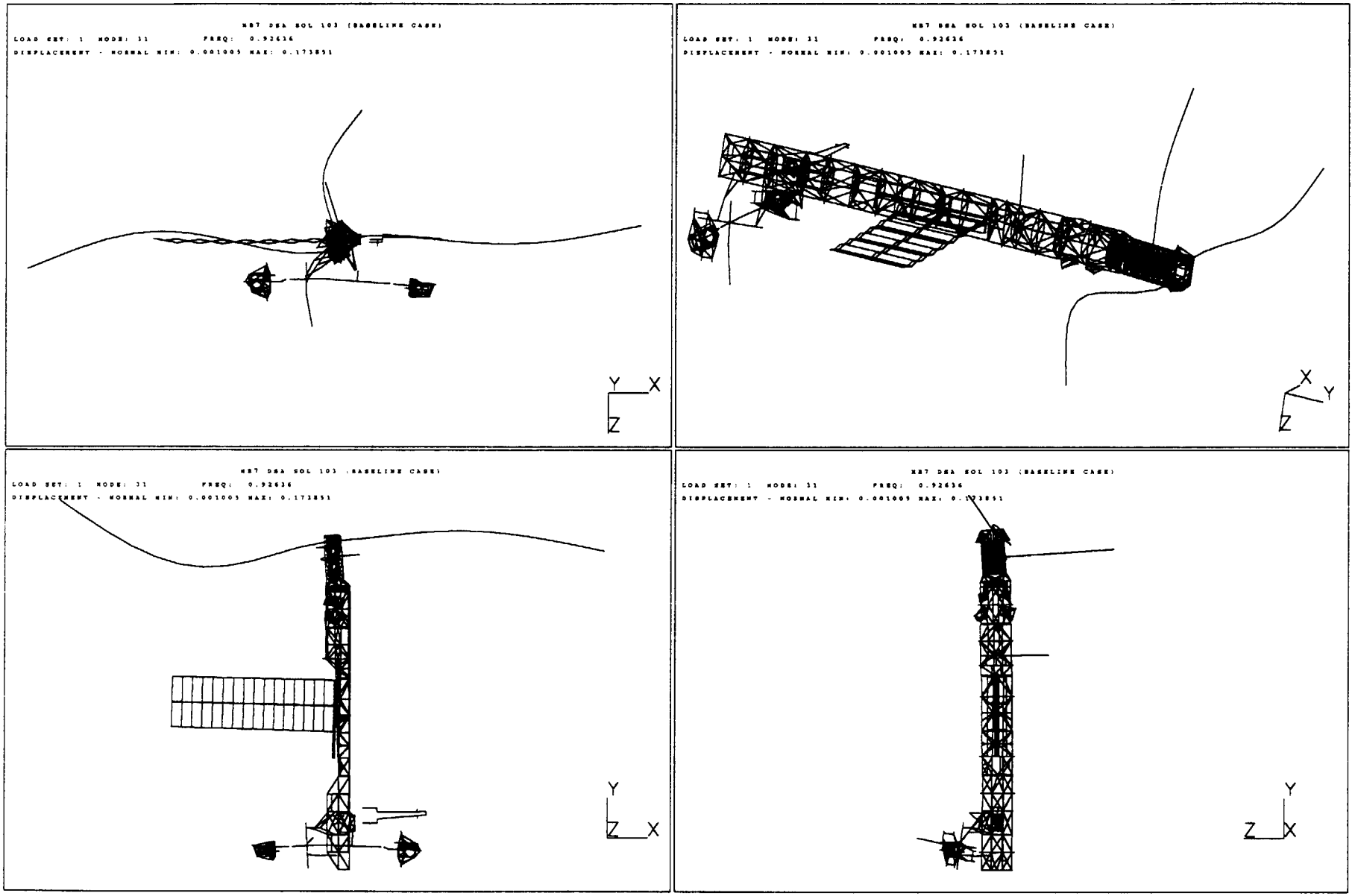

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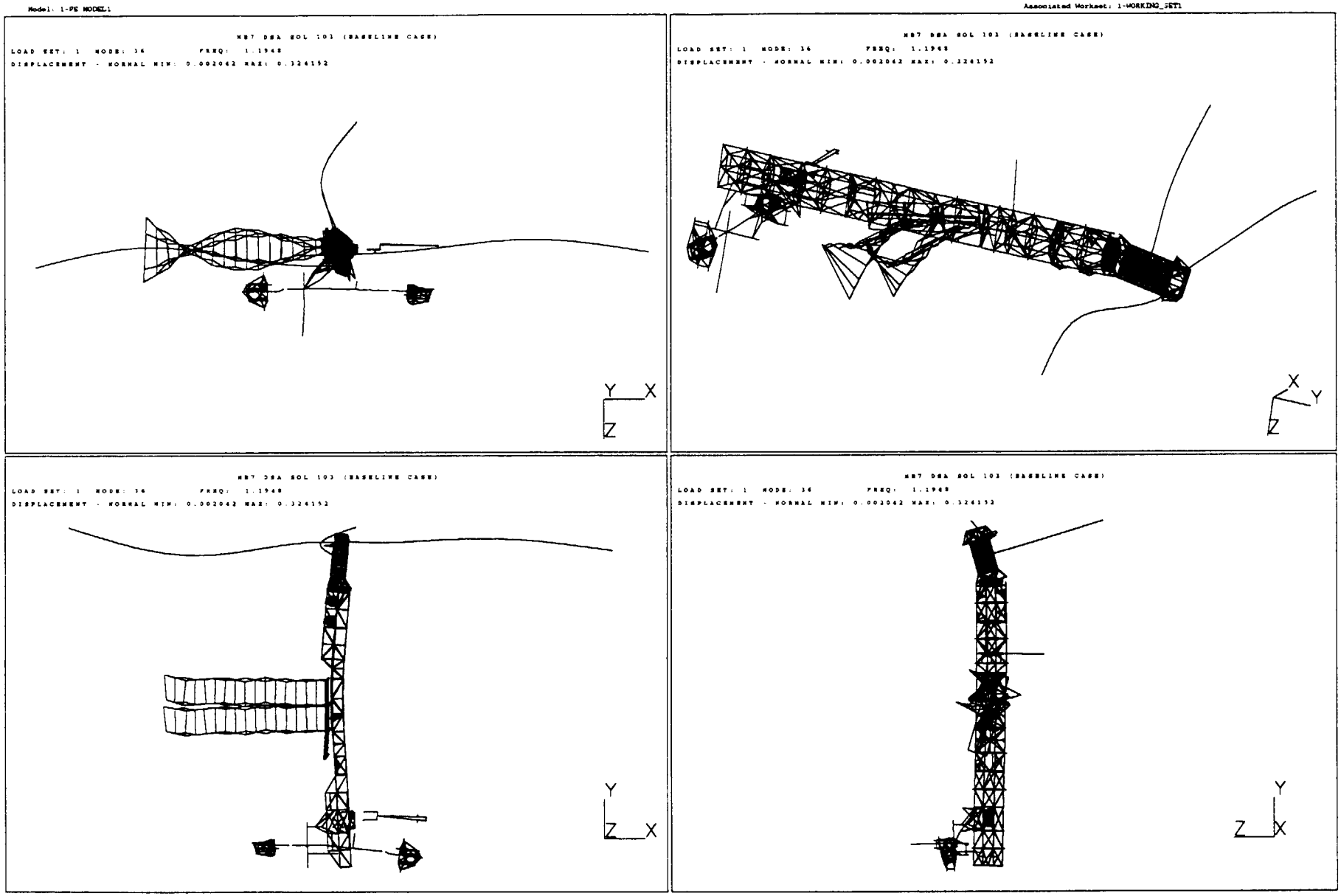

A-7

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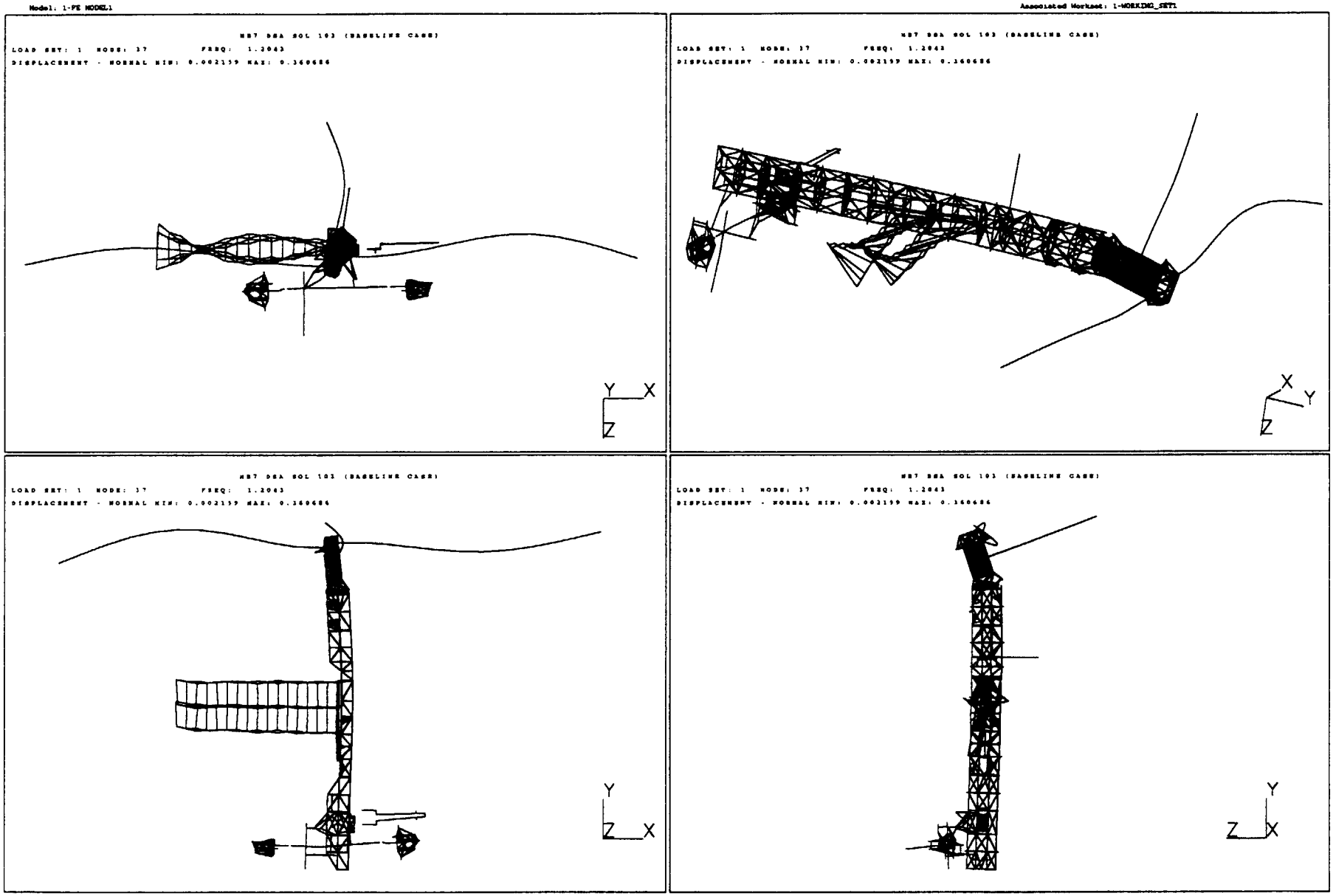

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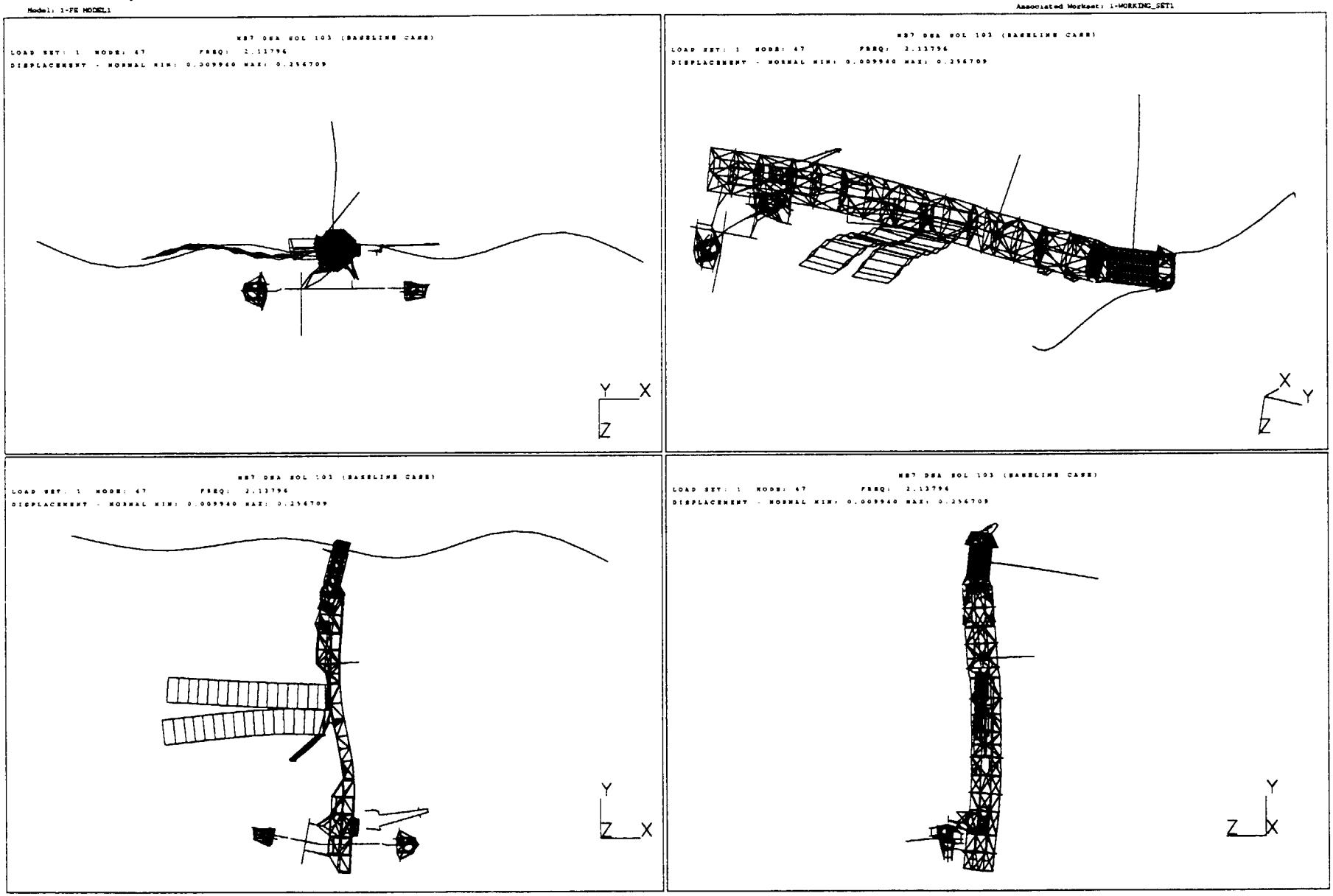

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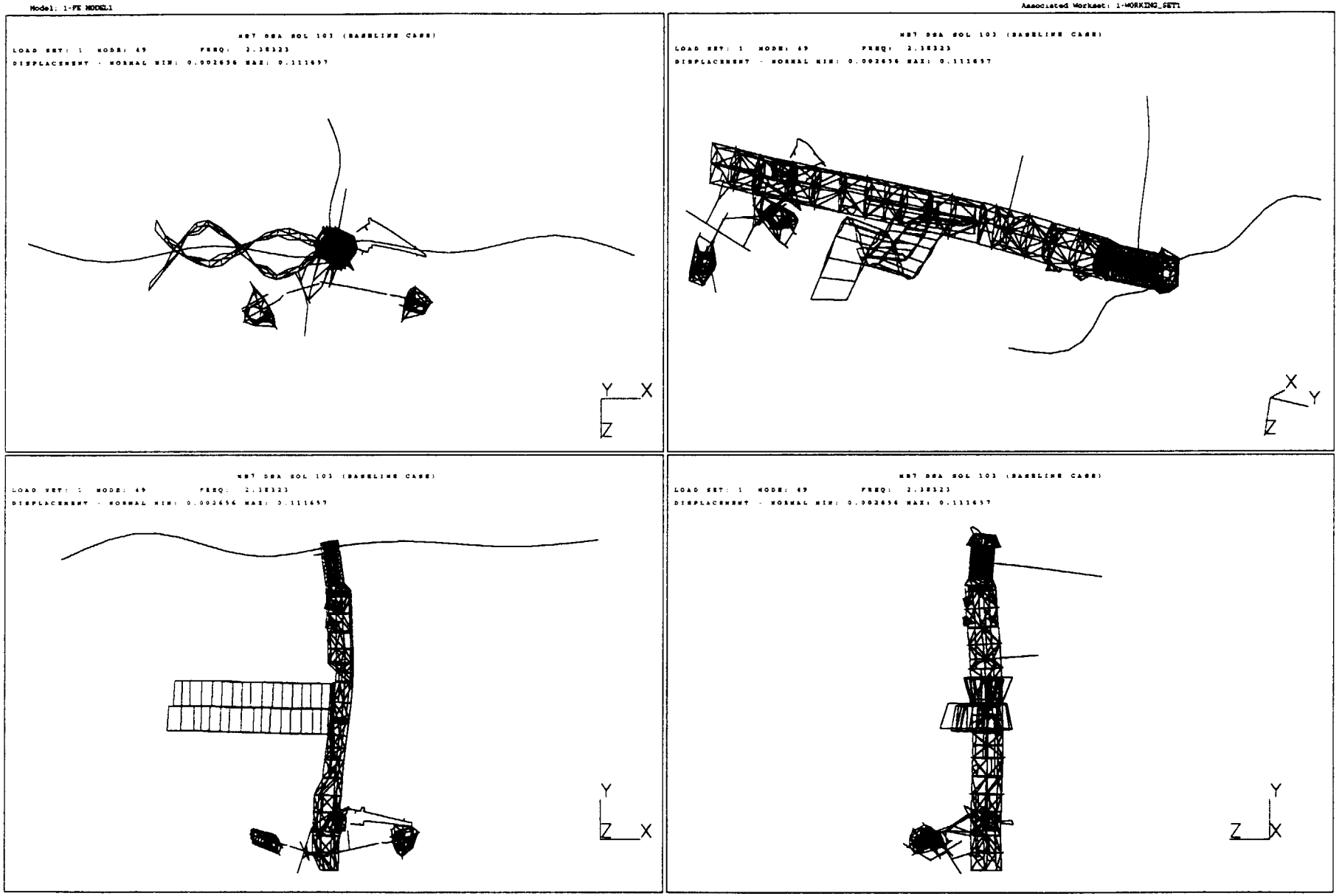
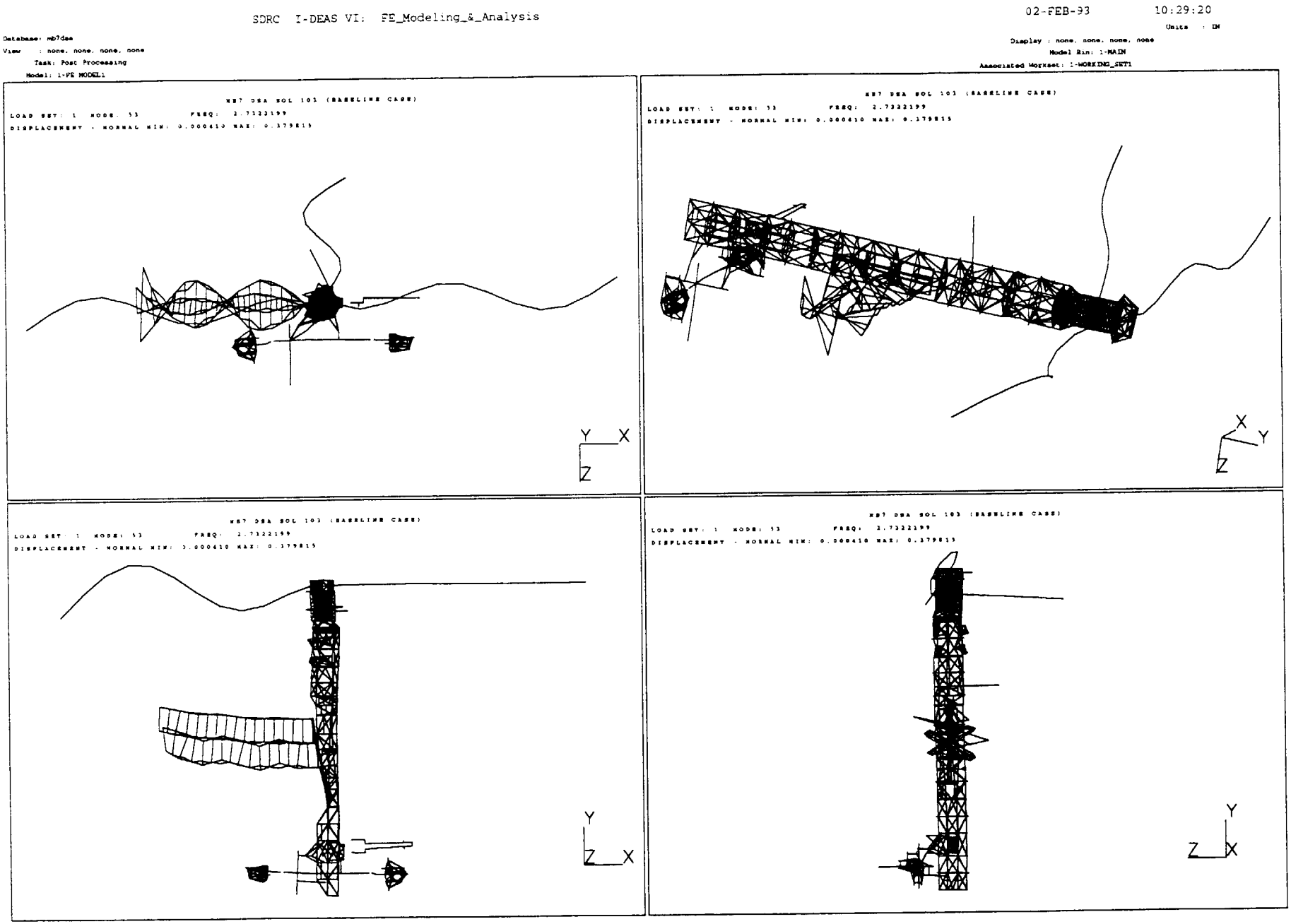
Model Bin: 1-MAIN
Associated Workset: 1-WORKING_SET1



MODE 49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02-FEB-93 10:29:20
Units : IN
Database: mb7dae
View : none, none, none, none
Task: Post Processing
Model: 1-FE MODEL1
Display : none, none, none, none
Model Bin: 1-MAIN
Associated Workset: 1-WORKING_SET1
MB7 DSA SOL 103 (BASELINE CASE)
LOAD SET: 1 MODE: 53 FREQ: 2.7322199
DISPLACEMENT - NORMAL MIN: 0.000410 MAX: 0.379815
Y X Z
X Y Z
Y Z X
Y Z X

MODE 53

APPENDIX B

DESIGN SENSITIVITY COEFFICIENT DATABASE

DATABASE ABBREVIATIONS

SID = SYSTEM ID
CID = COMPONENT ID
PID = PHYSICAL PROPERTY ID
PBAR= PHYSICAL PROPERTY CARD REFERENCE NO.

SID	SYSTEM
APP	Appendage
ITS	Integrated Truss Structure
M1	ITS-M1 Primary Structure
MOD	Module
S1	ITS-S1 Primary Structure
S2	ITS-S2 Primary Structure
S3	ITS-S3 Primary Structure
S4	ITS-S4 Primary Structure
SUB	Subsystem

CID	COMPONENT
AIR	Airlock
BETA	Solar Array Beta Joint
BKHD	Bulkhead
CUP	Cupola
DIAG	Diagonal Strut
IEA	IEA Radiator
LAB	U.S. LAB Module
LONG	Longeron Strut
MTI	Module-Truss Interface Structure
MTS	Mobile Transporter
NODE	Resource Node
OTHER	Miscellaneous Hardware
PBM	Pressurized Berthing Mechanism
PMAS	Propulsion Module Attach Structure
SA	Solar Arrays
SARJ	Solar Alpha Rotary Joint
STRUT	Miscellaneous Strut
STS	SARJ-Truss Interface Structure
TCS	TCS Radiator
TDRSS	TDRSS Antenna
TRRJ	Thermal Radiator Rotary Joint

PID	PROPERTY
A	Cross-Sectional Area
E & G	Material Properties E & G
IY	Area Moment of Inertia
IZ	Area Moment of Inertia
J	Torsional Inertia
K	Scalar Spring Stiffness

DESIGN SENSITIVITY COEFFICIENT DATABASE

(SUM OF DSC DATA FOR 10 IMPORTANT MODES)

DSC NO.	SID	CID	PID	DESCRIPTION	PBAR	DSC (%HZ)
53	S4	-	E & G	ITS-S4 PLATE ELEMENTS	PCOMP	2.85E-02
33	S4	BKHD	A	INTERNAL BULKHEAD	F00600A	2.62E-02
21	S4	STRUT	A	LONGERON	F00300A	1.52E-02
25	S4	BKHD	A	BULKHEAD -Y	F00400A	1.33E-02
41	S4	STRUT	A	SIDE DIAGONAL	F00900A	9.73E-03
26	S4	BKHD	IZ	BULKHEAD -Y	F00400I1	6.47E-03
46	S4	STRUT	IZ	SIDE BEAM	F00928I1	5.76E-03
45	S4	STRUT	A	SIDE BEAM	F00928A	3.16E-03
27	S4	BKHD	IY	BULKHEAD -Y	F00400I2	2.70E-03
42	S4	STRUT	IZ	SIDE DIAGONAL	F00900I1	1.51E-03
47	S4	STRUT	IY	SIDE BEAM	F00928I2	1.43E-03
34	S4	BKHD	IZ	INTERNAL BULKHEAD	F00600I1	1.32E-03
29	S4	BKHD	A	BULKHEAD -Y	F00401A	1.23E-03
1	S4	BKHD	A	BULKHEAD +Y	F00001A	8.75E-04
23	S4	STRUT	IY	LONGERON	F00300I2	8.11E-04
35	S4	BKHD	IY	INTERNAL BULKHEAD	F00600I2	6.64E-04
2	S4	BKHD	IZ	BULKHEAD +Y	F00001I1	5.90E-04
28	S4	BKHD	J	BULKHEAD -Y	F00400J	5.63E-04
22	S4	STRUT	IZ	LONGERON	F00300I1	5.43E-04
5	S4	BKHD	A	BULKHEAD +Y	F00002A	4.91E-04
43	S4	STRUT	IY	SIDE DIAGONAL	F00900I2	4.76E-04
30	S4	BKHD	IZ	BULKHEAD -Y	F00401I1	3.64E-04
36	S4	BKHD	J	INTERNAL BULKHEAD	F00600J	3.34E-04
24	S4	STRUT	J	LONGERON	F00300J	2.77E-04
32	S4	BKHD	J	BULKHEAD -Y	F00401J	2.52E-04
4	S4	BKHD	J	BULKHEAD +Y	F00001J	2.16E-04
37	S4	BKHD	A	INTERNAL BULKHEAD	F00601A	2.12E-04
38	S4	BKHD	IZ	INTERNAL BULKHEAD	F00601I1	2.09E-04
6	S4	BKHD	IZ	BULKHEAD +Y	F00002I1	2.09E-04
3	S4	BKHD	IY	BULKHEAD +Y	F00001I2	1.42E-04
31	S4	BKHD	IY	BULKHEAD -Y	F00401I2	1.17E-04
44	S4	STRUT	J	SIDE DIAGONAL	F00900J	1.10E-04
39	S4	BKHD	IY	INTERNAL BULKHEAD	F00601I2	1.06E-04
48	S4	STRUT	J	SIDE BEAM	F00928J	8.76E-05
50	S4	OTHER	IZ	SECONDARY STRUCTURE	F01200I1	3.35E-05
51	S4	OTHER	IY	SECONDARY STRUCTURE	F01200I2	2.73E-05
7	S4	BKHD	IY	BULKHEAD +Y	F00002I2	2.73E-05
49	S4	OTHER	A	SECONDARY STRUCTURE	F01200A	2.19E-05
8	S4	BKHD	J	BULKHEAD +Y	F00002J	1.30E-05
19	S4	OTHER	IY	TRUNNION BRAKE (BKHD +Y)	F00102I2	8.15E-06
52	S4	OTHER	J	SECONDARY STRUCTURE	F01200J	7.73E-06

DSC NO.	SID	CID	PID	DESCRIPTION	PBAR	DSC (%HZ)
40	S4	BKHD	J	INTERNAL BULKHEAD	F00601J	3.53E-06
17	S4	OTHER	A	TRUNNION BRAKE (BKHD +Y)	F00102A	1.83E-06
18	S4	OTHER	IZ	TRUNNION BRAKE (BKHD +Y)	F00102I1	9.21E-07
20	S4	OTHER	J	TRUNNION BRAKE (BKHD +Y)	F00102J	8.32E-07
15	S4	OTHER	IY	TRUNNION PIN (BKHD +Y)	F00101I2	1.29E-09
13	S4	OTHER	A	TRUNNION PIN (BKHD +Y)	F00101A	8.80E-10
11	S4	OTHER	IY	KEEL PIN (BKHD +Y)	F00100I2	7.89E-10
9	S4	OTHER	A	KEEL PIN (BKHD +Y)	F00100A	3.10E-10
14	S4	OTHER	IZ	TRUNNION PIN (BKHD +Y)	F00101I1	1.99E-10
10	S4	OTHER	IZ	KEEL PIN (BKHD +Y)	F00100I1	6.33E-11
12	S4	OTHER	J	KEEL PIN (BKHD +Y)	F00100J	3.70E-27
16	S4	OTHER	J	TRUNNION PIN (BKHD +Y)	F00101J	2.74E-27
72	S3	LONG	IY	TRUNNION LONGERON	P31006I2	2.76E+00
75	S3	LONG	IZ	SECONDARY LONGERON	P31008I1	4.94E-01
76	S3	LONG	IY	SECONDARY LONGERON	P31008I2	3.50E-01
71	S3	LONG	IZ	TRUNNION LONGERON	P31006I1	2.45E-01
82	S3	DIAG	A	FACES 2,3,5,6 DIAGONAL	P31011A	1.67E-01
70	S3	LONG	A	TRUNNION LONGERON	P31006A	1.65E-01
90	S3	DIAG	A	SARJ BRACE	P31013A	1.41E-01
100	S3	BKHD	IY	TRUN BKHD SIDES	P31032I2	1.23E-01
58	S3	BKHD	A	END BKHD SIDES	P31002A	9.35E-02
78	S3	LONG	A	MT RAIL	P31009A	8.24E-02
74	S3	LONG	A	SECONDARY LONGERON	P31008A	6.40E-02
60	S3	BKHD	IY	END BKHD SIDES	P31002I2	5.47E-02
66	S3	BKHD	A	END BKHD DIAGONALS	P31004A	4.77E-02
73	S3	LONG	J	TRUNNION LONGERON	P31006J	4.26E-02
62	S3	BKHD	A	END BKHD X BEAMS	P31003A	2.92E-02
86	S3	DIAG	A	FACES 1,4 / PMAS LEGS	P31012A	2.68E-02
84	S3	DIAG	IY	FACES 2,3,5,6 DIAGONAL	P31011I2	1.86E-02
64	S3	BKHD	IY	END BKHD X BEAMS	P31003I2	1.69E-02
104	S3	BKHD	IY	TRUN BKHD X BEAMS	P31033I2	1.46E-02
68	S3	BKHD	IY	END BKHD DIAGONALS	P31004I2	1.43E-02
79	S3	LONG	IZ	MT RAIL	P31009I1	1.23E-02
108	S3	BKHD	IY	TRUN BKHD DIAGONAL	P31034I2	1.19E-02
98	S3	BKHD	A	TRUN BKHD SIDES	P31032A	1.11E-02
80	S3	LONG	IY	MT RAIL	P31009I2	1.07E-02
88	S3	DIAG	IY	FACES 1,4 / PMAS LEGS	P31012I2	9.91E-03
83	S3	DIAG	IZ	FACES 2,3,5,6 DIAGONAL	P31011I1	9.33E-03
87	S3	DIAG	IZ	FACES 1,4 / PMAS LEGS	P31012I1	7.97E-03
54	S3	BKHD	A	END BKHD CRS BEAM	P31001A	7.60E-03
106	S3	BKHD	A	TRUN BKHD DIAGONAL	P31034A	3.47E-03
92	S3	DIAG	IY	SARJ BRACE	P31013I2	3.46E-03
77	S3	LONG	J	SECONDARY LONGERON	P31008J	3.11E-03
56	S3	BKHD	IY	END BKHD CRS BEAM	P31001I2	3.06E-03
96	S3	BKHD	IY	TRUN BKHD CRS BEAM	P31031I2	1.90E-03

DSC NO.	SID	CID	PID	DESCRIPTION	PBAR	DSC (%HZ)
94	S3	BKHD	A	TRUN BKHD CRS BEAM	P31031A	1.88E-03
102	S3	BKHD	A	TRUN BKHD X BEAMS	P31033A	1.84E-03
91	S3	DIAG	IZ	SARJ BRACE	P31013I1	1.42E-03
99	S3	BKHD	IZ	TRUN BKHD SIDES	P31032I1	1.18E-03
103	S3	BKHD	IZ	TRUN BKHD X BEAMS	P31033I1	5.86E-04
59	S3	BKHD	IZ	END BKHD SIDES	P31002I1	5.34E-04
93	S3	DIAG	J	SARJ BRACE	P31013J	4.23E-04
107	S3	BKHD	IZ	TRUN BKHD DIAGONAL	P31034I1	3.98E-04
63	S3	BKHD	IZ	END BKHD X BEAMS	P31003I1	3.66E-04
67	S3	BKHD	IZ	END BKHD DIAGONALS	P31004I1	2.89E-04
101	S3	BKHD	J	TRUN BKHD SIDES	P31032J	2.84E-04
61	S3	BKHD	J	END BKHD SIDES	P31002J	1.30E-04
55	S3	BKHD	IZ	END BKHD CRS BEAM	P31001I1	8.49E-05
85	S3	DIAG	J	FACES 2,3,5,6 DIAGONAL	P31011J	8.13E-05
116	S3	OTHER	IY	TRUNION PIN FITTINGS	P31043I2	4.94E-05
95	S3	BKHD	IZ	TRUN BKHD CRS BEAM	P31031I1	4.23E-05
65	S3	BKHD	J	END BKHD X BEAMS	P31003J	1.87E-05
57	S3	BKHD	J	END BKHD CRS BEAM	P31001J	1.84E-05
89	S3	DIAG	J	FACES 1,4 / PMAS LEGS	P31012J	1.80E-05
114	S3	OTHER	A	TRUNNION PIN FITTINGS	P31043A	1.31E-05
105	S3	BKHD	J	TRUN BKHD X BEAMS	P31033J	1.22E-05
81	S3	LONG	J	MT RAIL	P31009J	7.45E-06
69	S3	BKHD	J	END BKHD DIAGONALS	P31004J	7.18E-06
97	S3	BKHD	J	TRUN BKHD CRS BEAM	P31031J	4.93E-06
110	S3	OTHER	A	TRUNNION PIN	P31041A	2.82E-06
109	S3	BKHD	J	TRUN BKHD DIAGONAL	P31034J	2.30E-06
115	S3	OTHER	IZ	TRUNNION PIN FITTINGS	P31043I1	6.21E-08
111	S3	OTHER	IZ	TRUNNION PIN	P31041I1	9.28E-09
112	S3	OTHER	IY	TRUNNION PIN	P31041I2	6.71E-10
117	S3	OTHER	J	TRUNNION PIN FITTINGS	P31043J	1.52E-10
113	S3	OTHER	J	TRUNNION PIN	P31041J	2.78E-28
150	S2	LONG	A	TRUNNION LONGERON	P40041A	6.74E-01
170	S2	DIAG	A	SIDE FACE DIAGONAL	P40061A	3.43E-01
158	S2	DIAG	A	BOT FACE DIAGONAL	P40051A	2.69E-01
166	S2	LONG	A	MT RAIL -Z SIDE	P40053A	2.59E-01
152	S2	LONG	IY	TRUNNION LONGERON	P40041I2	2.41E-01
162	S2	LONG	A	MT RAIL +Z SIDE	P40052A	1.51E-01
142	S2	LONG	A	TOP (-X) LONGERON	P40031A	1.08E-01
127	S2	BKHD	IZ	BKHD 1,3,5 CRS-BEAM	P40013I1	9.50E-02
118	S2	BKHD	A	BKHD 1,3,5 SIDES/X	P40011A	6.41E-02
119	S2	BKHD	IZ	BKHD 1,3,5 SIDES/X	P40011I1	5.19E-02
120	S2	BKHD	IY	BKHD 1,3,5 SIDES/X	P40011I2	4.68E-02
154	S2	DIAG	A	MID-PLANE DIAGONAL	P40042A	4.47E-02
151	S2	LONG	IZ	TRUNNION LONGERON	P40041I1	4.45E-02
146	S2	DIAG	A	TOP FACE DIAGONAL	P40032A	4.26E-02

DSC NO.	SID	CID	PID	DESCRIPTION	PBAR	DSC (%HZ)
168	S2	LONG	IY	MT RAIL -Z SIDE	P400532	3.62E-02
160	S2	DIAG	IY	BOT FACE DIAGONAL	P400512	3.03E-02
171	S2	DIAG	IZ	SIDE FACE DIAGONAL	P400611	2.90E-02
138	S2	BKHD	A	BKHD 2,4 CRS-BEAM	P40023A	2.83E-02
122	S2	BKHD	A	BKHD 1,3,5 DIAGONALS	P40012A	1.98E-02
123	S2	BKHD	IZ	BKHD 1,3,5 DIAGONALS	P400121	1.76E-02
176	S2	OTHER	IY	MID-PLANE LONG STIFF	P400812	1.65E-02
124	S2	BKHD	IY	BKHD 1,3,5 DIAGONALS	P400122	1.44E-02
128	S2	BKHD	IY	BKHD 1,3,5 CRS-BEAM	P400132	1.43E-02
167	S2	LONG	IZ	MT RAIL -Z SIDE	P400531	1.38E-02
143	S2	LONG	IZ	TOP (-X) LONGERON	P400311	1.26E-02
159	S2	DIAG	IZ	BOT FACE DIAGONAL	P400511	1.14E-02
140	S2	BKHD	IY	BKHD 2,4 CRS-BEAM	P400232	9.57E-03
172	S2	DIAG	IY	SIDE FACE DIAGONAL	P400612	9.51E-03
126	S2	BKHD	A	BKHD 1,3,5 CRS-BEAM	P40013A	8.73E-03
130	S2	BKHD	A	BKHD 2,4 SIDES/X	P40021A	6.35E-03
147	S2	DIAG	IZ	TOP FACE DIAGONAL	P400321	5.54E-03
132	S2	BKHD	IY	BKHD 2,4 SIDES/X	P400212	5.40E-03
163	S2	LONG	IZ	MT RAIL +Z SIDE	P400521	4.69E-03
144	S2	LONG	IY	TOP (-X) LONGERON	P400312	3.68E-03
134	S2	BKHD	A	BKHD 2,4 DIAGONALS	P40022A	3.60E-03
179	S2	OTHER	IZ	MID-PLANE TRANS STIF	P400821	3.47E-03
164	S2	LONG	IY	MT RAIL +Z SIDE	P400522	2.80E-03
148	S2	DIAG	IY	TOP FACE DIAGONAL	P400322	1.62E-03
175	S2	OTHER	IZ	MID-PLANE LONG STIFF	P400811	9.93E-04
155	S2	DIAG	IZ	MID-PLANE DIAGONAL	P400421	9.92E-04
136	S2	BKHD	IY	BKHD 2,4 DIAGONALS	P400222	8.66E-04
180	S2	OTHER	IY	MID-PLANE TRANS STIF	P400822	7.67E-04
153	S2	LONG	J	TRUNION LONGERON	P40041J	6.97E-04
188	S2	OTHER	IY	TRUNION PINS	P402102	4.29E-04
186	S2	OTHER	A	TRUNION PINS	P40210A	3.31E-04
139	S2	BKHD	IZ	BKHD 2,4 CRS-BEAM	P400231	3.31E-04
141	S2	BKHD	J	BKHD 2,4 CRS-BEAM	P40023J	2.08E-04
174	S2	OTHER	A	MID-PLANE LONG STIFF	P40081A	1.81E-04
156	S2	DIAG	IY	MID-PLANE DIAGONAL	P400422	1.77E-04
131	S2	BKHD	IZ	BKHD 2,4 SIDES/X	P400211	1.56E-04
121	S2	BKHD	J	BKHD 1,3,5 SIDES/X	P40011J	1.34E-04
182	S2	OTHER	A	TRUNNION PIN	P40110A	9.39E-05
184	S2	OTHER	IY	TRUNNION PIN	P401102	6.00E-05
169	S2	LONG	J	MT RAIL -Z SIDE	P40053J	4.87E-05
135	S2	BKHD	IZ	BKHD 2,4 DIAGONALS	P400221	4.19E-05
161	S2	DIAG	J	BOT FACE DIAGONAL	P40051J	3.13E-05
129	S2	BKHD	J	BKHD 1,3,5 CRS-BEAM	P40013J	2.97E-05
173	S2	DIAG	J	SIDE FACE DIAGONAL	P40061J	1.86E-05
187	S2	OTHER	IZ	TRUNNION PINS	P402101	1.82E-05
133	S2	BKHD	J	BKHD 2,4 SIDES/X	P40021J	1.81E-05

DSC NO.	SID	CID	PID	DESCRIPTION	PBAR	DSC (%HZ)
178	S2	OTHER	A	MID-PLANE TRANS STIF	P40082A	9.82E-06
177	S2	OTHER	J	MID-PLANE LONG STIFF	P40081J	8.03E-06
125	S2	BKHD	J	BKHD 1,3,5 DIAGONALS	P40012J	6.23E-06
181	S2	OTHER	J	MID-PLANE TRANS STIF	P40082J	2.82E-06
145	S2	LONG	J	TOP (-X) LONGERON	P40031J	2.70E-06
183	S2	OTHER	IZ	TRUNNION PIN	P40110I1	1.87E-06
137	S2	BKHD	J	BKHD 2,4 DIAGONALS	P40022J	7.92E-07
165	S2	LONG	J	MT RAIL +Z SIDE	P40052J	3.59E-07
157	S2	DIAG	J	MID-PLANE DIAGONAL	P40042J	2.23E-07
149	S2	DIAG	J	TOP FACE DIAGONAL	P40032J	7.48E-08
189	S2	OTHER	J	TRUNNION PINS	P40210J	2.60E-08
185	S2	OTHER	J	TRUNNION PIN	P40110J	2.73E-09
230	S1	LONG	A	MT RAIL	P51080A	3.15E+00
218	S1	LONG	A	TRUNION LONGERON BAYS1-5	P51060A	9.99E-01
234	S1	DIAG	A	SIDE DIAGONAL	P51090A	9.10E-01
222	S1	LONG	A	TRUNION LONGERON BAY 6	P51066A	3.25E-01
219	S1	LONG	IZ	TRUNION LONGERON BAYS1-5	P51060I1	2.36E-01
226	S1	DIAG	A	TOP FACE DIAGONAL	P51070A	2.29E-01
228	S1	DIAG	IY	TOP FACE DIAGONAL	P51070I2	7.38E-02
190	S1	BKHD	A	BKHD 1,4,5,7- TOP BEAM	P51010A	6.67E-02
248	S1	BKHD	IY	BKHD 3 TOP CROSS BEAM	P53101I2	4.95E-02
206	S1	BKHD	A	BKHD 1,2,4,5,6,7-X BEAM	P51030A	4.55E-02
231	S1	LONG	IZ	MT RAIL	P51080I1	4.42E-02
236	S1	DIAG	IY	SIDE DIAGONAL	P51090I2	3.65E-02
235	S1	DIAG	IZ	SIDE DIAGONAL	P51090I1	3.62E-02
227	S1	DIAG	IZ	TOP FACE DIAGONAL	P51070I1	3.56E-02
252	S1	BKHD	IY	BKHD 3 BOTTOM CROSS BEAM	P53103I2	3.42E-02
259	S1	OTHER	IZ	BAY 6 SECONDARY BEAMS-A	P56100I1	3.04E-02
198	S1	BKHD	A	BKHD 1,3,4,5,7 SIDES	P51020A	2.87E-02
220	S1	LONG	IY	TRUNION LONGERON BAYS1-5	P51060I2	2.85E-02
208	S1	BKHD	IY	BKHD 1,2,4,5,6,7-X BEAM	P51030I2	2.06E-02
251	S1	BKHD	IZ	BKHD 3 BOTTOM CROSS BEAM	P53103I1	1.99E-02
255	S1	BKHD	IZ	BKHD 3 CRADLE BEAM	P53104I1	1.59E-02
261	S1	OTHER	J	BAY 6 SECONDARY BEAMS-A	P56100J	1.25E-02
223	S1	LONG	IZ	TRUNION LONGERON BAY 6	P51066I1	1.20E-02
210	S1	BKHD	A	BKHD 1,4,5,7 - DIAGONAL	P51040A	9.46E-03
232	S1	LONG	IY	MT RAIL	P51080I2	7.65E-03
196	S1	BKHD	IY	BKHD 2,6 - TOP BEAM	P51012I2	7.36E-03
247	S1	BKHD	IZ	BKHD 3 TOP CROSS BEAM	P53101I1	7.04E-03
271	S1	BKHD	IZ	BKHD 2,3,5 BRACES	P59075I1	6.59E-03
216	S1	BKHD	IY	BKHD 2,6 - DIAGONAL	P51042I2	6.32E-03
254	S1	BKHD	A	BKHD 3 CRADLE BEAM	P53104A	5.66E-03
224	S1	LONG	IY	TRUNION LONGERON BAY 6	P51066I2	5.53E-03
191	S1	BKHD	IZ	BKHD 1,4,5,7- TOP BEAM	P51010I1	5.21E-03
192	S1	BKHD	IY	BKHD 1,4,5,7- TOP BEAM	P51010I2	5.19E-03

DSC NO.	SID	CID	PID	DESCRIPTION	PBAR	DSC (%HZ)
260	S1	OTHER	IY	BAY 6 SECONDARY BEAMS-A	P56100I2	4.27E-03
199	S1	BKHD	IZ	BKHD 1,3,4,5,7 SIDES	P51020I1	3.62E-03
194	S1	BKHD	A	BKHD 2,6 - TOP BEAM	P51012A	3.15E-03
240	S1	OTHER	IY	TRUNION PINS-A	P51410I2	3.01E-03
202	S1	BKHD	A	BKHD 2,6 - SIDES	P51022A	3.00E-03
256	S1	BKHD	IY	BKHD 3 CRADLE BEAM	P53104I2	2.96E-03
250	S1	BKHD	A	BKHD 3 BOTTOM CROSS BEAM	P53103A	2.93E-03
272	S1	BKHD	IY	BKHD 2,3,5 BRACES	P59075I2	2.76E-03
221	S1	LONG	J	TRUNION LONGERON BAYS1-5	P51060J	2.66E-03
211	S1	BKHD	IZ	BKHD 1,4,5,7 - DIAGONAL	P51040I1	2.50E-03
212	S1	BKHD	IY	BKHD 1,4,5,7 - DIAGONAL	P51040I2	2.36E-03
200	S1	BKHD	IY	BKHD 1,3,4,5,7 SIDES	P51020I2	2.05E-03
246	S1	BKHD	A	BKHD 3 TOP CROSS BEAM	P53101A	2.00E-03
204	S1	BKHD	IY	BKHD 2,6 - SIDES	P51022I2	1.68E-03
258	S1	OTHER	A	BAY 6 SECONDARY BEAMS-A	P56100A	1.66E-03
195	S1	BKHD	IZ	BKHD 2,6 - TOP BEAM	P51012I1	1.03E-03
270	S1	BKHD	A	BKHD 2,3,5 BRACES	P59075A	9.79E-04
244	S1	OTHER	IY	TRUNION PINS-B	P51430I2	9.12E-04
229	S1	DIAG	J	TOP FACE DIAGONAL	P51070J	7.89E-04
203	S1	BKHD	IZ	BKHD 2,6 - SIDES	P51022I1	7.34E-04
205	S1	BKHD	J	BKHD 2,6 - SIDES	P51022J	4.54E-04
225	S1	LONG	J	TRUNION LONGERON BAY 6	P51066J	3.78E-04
207	S1	BKHD	IZ	BKHD 1,2,4,5,6,7-X BEAM	P51030I1	3.34E-04
197	S1	BKHD	J	BKHD 2,6 - TOP BEAM	P51012J	3.31E-04
214	S1	BKHD	A	BKHD 2,6 - DIAGONAL	P51042A	2.22E-04
253	S1	BKHD	J	BKHD 3 BOTTOM CROSS BEAM	P53103J	1.61E-04
267	S1	OTHER	IZ	BAY 6 SECONDARY BEAMS-C	P56102I1	1.44E-04
263	S1	OTHER	IZ	BAY 6 SECONDARY BEAMS-B	P56101I1	1.32E-04
193	S1	BKHD	J	BKHD 1,4,5,7- TOP BEAM	P51010J	1.32E-04
265	S1	OTHER	J	BAY 6 SECONDARY BEAMS-B	P56101J	8.38E-05
257	S1	BKHD	J	BKHD 3 CRADLE BEAM	P53104J	6.88E-05
237	S1	DIAG	J	SIDE DIAGONAL	P51090J	5.03E-05
242	S1	OTHER	A	TRUNION PINS-B	P51430A	4.84E-05
269	S1	OTHER	J	BAY 6 SECONDARY BEAMS-C	P56102J	4.42E-05
249	S1	BKHD	J	BKHD 3 TOP CROSS BEAM	P53101J	4.00E-05
262	S1	OTHER	A	BAY 6 SECONDARY BEAMS-B	P56101A	2.78E-05
233	S1	LONG	J	MT RAIL	P51080J	2.73E-05
239	S1	OTHER	IZ	TRUNION PINS-A	P51410I1	2.32E-05
217	S1	BKHD	J	BKHD 2,6 - DIAGONAL	P51042J	1.38E-05
215	S1	BKHD	IZ	BKHD 2,6 - DIAGONAL	P51042I1	1.16E-05
268	S1	OTHER	IY	BAY 6 SECONDARY BEAMS-C	P56102I2	1.13E-05
238	S1	OTHER	A	TRUNION PINS-A	P51410A	1.05E-05
201	S1	BKHD	J	BKHD 1,3,4,5,7 SIDES	P51020J	1.05E-05
213	S1	BKHD	J	BKHD 1,4,5,7 - DIAGONAL	P51040J	8.84E-06
273	S1	BKHD	J	BKHD 2,3,5 BRACES	P59075J	5.50E-06
266	S1	OTHER	A	BAY 6 SECONDARY BEAMS-C	P56102A	5.31E-06

DSC NO.	SID	CID	PID	DESCRIPTION	PBAR	DSC (%HZ)
243	S1	OTHER	IZ	TRUNION PINS-B	P51430I1	4.84E-06
209	S1	BKHD	J	BKHD 1,2,4,5,6,7-X BEAM	P51030J	4.37E-06
264	S1	OTHER	IY	BAY 6 SECONDARY BEAMS-B	P56101I2	3.36E-06
245	S1	OTHER	J	TRUNION PINS-B	P51430J	4.15E-08
241	S1	OTHER	J	TRUNION PINS-A	P51410J	8.47E-27
418	M1	LONG	A	BAY 1 TRUNION LONGERON	P61091A	5.12E-01
398	M1	LONG	A	BAY 1 MT RAIL	P61081A	3.10E-01
422	M1	LONG	A	BAY 2 TRUNION LONGERON	P61092A	2.76E-01
500	M1	DIAG	IY	BAY 5 -X SIDE DIAGONAL	P61135I2	2.60E-01
427	M1	LONG	IZ	BAY 3 TRUNION LONGERON	P61093I1	2.04E-01
448	M1	DIAG	IY	BAY 3 (-X) SIDE DIAGONAL	P61103I2	1.94E-01
494	M1	DIAG	A	BAY 1 -X SIDE DIAGONAL	P61131A	1.83E-01
446	M1	DIAG	A	BAY 3 (-X) SIDE DIAGONAL	P61103A	1.73E-01
402	M1	LONG	A	BAY 2 MT RAIL	P61082A	1.44E-01
470	M1	DIAG	A	BAY 2 TOP FACE DIAGONAL	P61121A	1.42E-01
324	M1	BKHD	IY	BKHD 3 CROSS BEAM	P61034I2	1.26E-01
423	M1	LONG	IZ	BAY 2 TRUNION LONGERON	P61092I1	1.04E-01
332	M1	BKHD	IY	BKHD 4 SIDES -X	P61041I2	1.04E-01
344	M1	BKHD	IY	BKHD 4 CROSS BEAM	P61044I2	9.56E-02
396	M1	LONG	IY	BAY 4 TOP LONGERON	P61074I2	9.28E-02
395	M1	LONG	IZ	BAY 4 TOP LONGERON	P61074I1	8.67E-02
359	M1	BKHD	IZ	BKHD 5 BOTTOM BEAM	P61053I1	7.57E-02
508	M1	OTHER	IY	BAY 5 END "V"	P61145I2	7.41E-02
432	M1	LONG	IY	BAY 4 TRUNION LONGERON	P61094I2	7.16E-02
516	M1	OTHER	IY	BAYS 2,4 INNER BOX	P61710I2	7.04E-02
482	M1	DIAG	A	BAY 4 BOT/TOP FACE DIAGONAL	P61124A	6.94E-02
478	M1	DIAG	A	BAY 3 BOTTOM FACE DIAGONAL	P61123A	6.64E-02
514	M1	OTHER	A	BAYS 2,4 INNER BOX	P61710A	6.56E-02
462	M1	DIAG	A	BAY 3 (+X) SIDE DIAGONAL	P61113A	6.47E-02
426	M1	LONG	A	BAY 3 TRUNION LONGERON	P61093A	6.39E-02
490	M1	DIAG	A	BAY 3 TOP FACE DIAGONAL	P61126A	6.35E-02
346	M1	BKHD	A	BKHD 4 DIAGONALS	P61045A	6.27E-02
507	M1	OTHER	IZ	BAY 5 END "V"	P61145I1	6.18E-02
466	M1	DIAG	A	BAY 4 (+X) SIDE DIAGONAL	P61114A	6.02E-02
474	M1	DIAG	A	BAY 2 BOTTOM FACE DIAGONAL	P61122A	5.89E-02
348	M1	BKHD	IY	BKHD 4 DIAGONALS	P61045I2	5.73E-02
483	M1	DIAG	IZ	BAY 4 BOT/TOP FACE DIAGONAL	P61124I1	5.59E-02
316	M1	BKHD	IY	BKHD 3 SIDES +X	P61032I2	5.55E-02
458	M1	DIAG	A	BAY 2 (+X) SIDE DIAGONAL	P61112A	5.51E-02
312	M1	BKHD	IY	BKHD 3 SIDES -X	P61031I2	5.46E-02
367	M1	BKHD	IZ	BKHD 5 DIAGONAL	P61055I1	5.38E-02
447	M1	DIAG	IZ	BAY 3 (-X) SIDE DIAGONAL	P61103I1	5.38E-02
438	M1	DIAG	A	BAY 1 (-X) SIDE DIAGONAL	P61101A	5.07E-02
406	M1	LONG	A	BAY 3 MT RAIL	P61083A	4.64E-02
399	M1	LONG	IZ	BAY 1 MT RAIL	P61081I1	4.62E-02

DSC NO.	SID	CID	PID	DESCRIPTION	PBAR	DSC (%HZ)
390	M1	LONG	A	BAY 3 TOP LONGERON	P61073A	4.36E-02
428	M1	LONG	IY	BAY 3 TRUNION LONGERON	P61093I2	4.33E-02
386	M1	LONG	A	BAY 2 TOP LONGERON	P61072A	4.18E-02
407	M1	LONG	IZ	BAY 3 MT RAIL	P61083I1	4.16E-02
484	M1	DIAG	IY	BAY 4 BOT/TOP FACE DIAGONAL	P61124I2	4.11E-02
424	M1	LONG	IY	BAY 2 TRUNION LONGERON	P61092I2	4.02E-02
336	M1	BKHD	IY	BKHD 4 SIDES +X	P61042I2	3.43E-02
523	M1	OTHER	IZ	BAY 5 "V" SUPPORT BRACE	P61730I1	3.36E-02
411	M1	LONG	IZ	BAY 4 MT RAIL	P61084I1	3.27E-02
338	M1	BKHD	A	BKHD 4 BOTTOM BEAM	P61043A	3.22E-02
342	M1	BKHD	A	BKHD 4 CROSS BEAM	P61044A	3.04E-02
450	M1	DIAG	A	BAY 4 (-X) SIDE DIAGONAL	P61104A	2.88E-02
468	M1	DIAG	IY	BAY 4 (+X) SIDE DIAGONAL	P61114I2	2.84E-02
326	M1	BKHD	A	BKHD 3 DIAGONALS	P61035A	2.58E-02
430	M1	LONG	A	BAY 4 TRUNION LONGERON	P61094A	2.47E-02
442	M1	DIAG	A	BAY 2 (-X) SIDE DIAGONAL	P61102A	2.41E-02
394	M1	LONG	A	BAY 4 TOP LONGERON	P61074A	2.39E-02
436	M1	LONG	IY	BAY 5 TRUNION LONGERON	P61095I2	2.24E-02
518	M1	OTHER	A	BKHD 3,4 "INNER RING"	P61720A	2.23E-02
282	M1	BKHD	A	BKHD 1 CROSS BEAM	P61014A	2.22E-02
515	M1	OTHER	IZ	BAYS 2,4 INNER BOX	P61710I1	2.20E-02
279	M1	BKHD	IZ	BKHD 1 BOTTOM -X BEAM	P61013I1	2.11E-02
451	M1	DIAG	IZ	BAY 4 (-X) SIDE DIAGONAL	P61104I1	2.11E-02
340	M1	BKHD	IY	BKHD 4 BOTTOM BEAM	P61043I2	1.94E-02
440	M1	DIAG	IY	BAY 1 (-X) SIDE DIAGONAL	P61101I2	1.85E-02
419	M1	LONG	IZ	BAY 1 TRUNION LONGERON	P61091I1	1.82E-02
330	M1	BKHD	A	BKHD 4 SIDES -X	P61041A	1.75E-02
311	M1	BKHD	IZ	BKHD 3 SIDES -X	P61031I1	1.65E-02
328	M1	BKHD	IY	BKHD 3 DIAGONALS	P61035I2	1.62E-02
334	M1	BKHD	A	BKHD 4 SIDES +X	P61042A	1.61E-02
452	M1	DIAG	IY	BAY 4 (-X) SIDE DIAGONAL	P61104I2	1.61E-02
392	M1	LONG	IY	BAY 3 TOP LONGERON	P61073I2	1.60E-02
274	M1	BKHD	A	BKHD 1 SIDES	P61011A	1.59E-02
479	M1	DIAG	IZ	BAY 3 BOTTOM FACE DIAGONAL	P61123I1	1.56E-02
278	M1	BKHD	A	BKHD 1 BOTTOM -X BEAM	P61013A	1.51E-02
355	M1	BKHD	IZ	BKHD 5 SIDES +X	P61052I1	1.45E-02
408	M1	LONG	IY	BAY 3 MT RAIL	P61083I2	1.39E-02
366	M1	BKHD	A	BKHD 5 DIAGONAL	P61055A	1.38E-02
322	M1	BKHD	A	BKHD 3 CROSS BEAM	P61034A	1.31E-02
420	M1	LONG	IY	BAY 1 TRUNION LONGERON	P61091I2	1.26E-02
339	M1	BKHD	IZ	BKHD 4 BOTTOM BEAM	P61043I1	1.22E-02
464	M1	DIAG	IY	BAY 3 (+X) SIDE DIAGONAL	P61113I2	1.13E-02
331	M1	BKHD	IZ	BKHD 4 SIDES -X	P61041I1	1.12E-02
502	M1	OTHER	A	BAY 1 END "V"	P61141A	1.12E-02
294	M1	BKHD	A	BKHD 2 SIDES +X	P61022A	1.11E-02
286	M1	BKHD	A	BKHD 1 X DIAGONALS	P61015A	1.10E-02

DSC NO.	SID	CID	PID	DESCRIPTION	PBAR	DSC (%HZ)
310	M1	BKHD	A	BKHD 3 SIDES -X	P61031A	1.09E-02
520	M1	OTHER	IY	BKHD 3,4 "INNER RING"	P617201 2	1.04E-02
499	M1	DIAG	IZ	BAY 5 -X SIDE DIAGONAL	P611351 1	9.85E-03
323	M1	BKHD	IZ	BKHD 3 CROSS BEAM	P610341 1	9.79E-03
412	M1	LONG	IY	BAY 4 MT RAIL	P610841 2	9.66E-03
404	M1	LONG	IY	BAY 2 MT RAIL	P610821 2	9.10E-03
347	M1	BKHD	IZ	BKHD 4 DIAGONALS	P610451 1	8.76E-03
439	M1	DIAG	IZ	BAY 1 (-X) SIDE DIAGONAL	P611011 1	8.49E-03
351	M1	BKHD	IZ	BKHD 5 SIDES -X	P610511 1	8.45E-03
410	M1	LONG	A	BAY 4 MT RAIL	P61084A	8.33E-03
356	M1	BKHD	IY	BKHD 5 SIDES +X	P610521 2	7.51E-03
463	M1	DIAG	IZ	BAY 3 (+X) SIDE DIAGONAL	P611131 1	7.42E-03
275	M1	BKHD	IZ	BKHD 1 SIDES	P610111 1	7.27E-03
354	M1	BKHD	A	BKHD 5 SIDES +X	P61052A	7.14E-03
455	M1	DIAG	IZ	BAY 5 (-X) SIDE DIAGONAL	P611051 1	7.14E-03
314	M1	BKHD	A	BKHD 3 SIDES +X	P61032A	7.11E-03
431	M1	LONG	IZ	BAY 4 TRUNION LONGERON	P610941 1	6.98E-03
318	M1	BKHD	A	BKHD 3 BOTTOM BEAM	P61033A	6.97E-03
467	M1	DIAG	IZ	BAY 4 (+X) SIDE DIAGONAL	P611141 1	6.92E-03
335	M1	BKHD	IZ	BKHD 4 SIDES +X	P610421 1	6.67E-03
456	M1	DIAG	IY	BAY 5 (-X) SIDE DIAGONAL	P611052 1	6.29E-03
403	M1	LONG	IZ	BAY 2 MT RAIL	P610821 1	5.58E-03
388	M1	LONG	IY	BAY 2 TOP LONGERON	P610721 2	5.52E-03
315	M1	BKHD	IZ	BKHD 3 SIDES +X	P610321 1	5.49E-03
471	M1	DIAG	IZ	BAY 2 TOP FACE DIAGONAL	P611211 1	5.11E-03
380	M1	BKHD	IY	BKHD 1 CROSS BEAM-A	P610641 2	4.52E-03
435	M1	LONG	IZ	BAY 5 TRUNION LONGERON	P610951 1	4.47E-03
444	M1	DIAG	IY	BAY 2 (-X) SIDE DIAGONAL	P611021 2	4.38E-03
372	M1	BKHD	IY	BKHD 1 SIDES-A	P610611 2	3.91E-03
363	M1	BKHD	IZ	BKHD 5 CROSS BEAM	P610541 1	3.85E-03
358	M1	BKHD	A	BKHD 5 BOTTOM BEAM	P61053A	3.77E-03
495	M1	DIAG	IZ	BAY 1 -X SIDE DIAGONAL	P611311 1	3.60E-03
379	M1	BKHD	IZ	BKHD 1 CROSS BEAM-A	P610641 1	3.06E-03
400	M1	LONG	IY	BAY 1 MT RAIL	P610811 2	2.93E-03
357	M1	BKHD	J	BKHD 5 SIDES +X	P61052J	2.80E-03
350	M1	BKHD	A	BKHD 5 SIDES -X	P61051A	2.46E-03
459	M1	DIAG	IZ	BAY 2 (+X) SIDE DIAGONAL	P611121 1	2.33E-03
492	M1	DIAG	IY	BAY 3 TOP FACE DIAGONAL	P611261 2	2.23E-03
443	M1	DIAG	IZ	BAY 2 (-X) SIDE DIAGONAL	P611021 1	2.23E-03
287	M1	BKHD	IZ	BKHD 1 X DIAGONALS	P610151 1	2.22E-03
480	M1	DIAG	IY	BAY 3 BOTTOM FACE DIAGONAL	P611231 2	2.17E-03
472	M1	DIAG	IY	BAY 2 TOP FACE DIAGONAL	P611211 2	2.16E-03
327	M1	BKHD	IZ	BKHD 3 DIAGONALS	P610351 1	2.08E-03
362	M1	BKHD	A	BKHD 5 CROSS BEAM	P61054A	2.03E-03
306	M1	BKHD	A	BKHD 2 DIAGONAL	P61025A	1.91E-03
298	M1	BKHD	A	BKHD 2 BOTTOM BEAM	P61023A	1.83E-03

DSC NO.	SID	CID	PID	DESCRIPTION	PBAR	DSC (%HZ)
291	M1	BKHD	Z	BKHD 2 SIDES -X	P61021I1	1.70E-03
460	M1	DIAG	Y	BAY 2 (+X) SIDE DIAGONAL	P61112I2	1.59E-03
498	M1	DIAG	A	BAY 5 -X SIDE DIAGONAL	P61135A	1.55E-03
290	M1	BKHD	A	BKHD 2 SIDES -X	P61021A	1.54E-03
486	M1	DIAG	A	BAY 5 BOTTOM FACE DIAGONAL	P61125A	1.47E-03
320	M1	BKHD	Y	BKHD 3 BOTTOM BEAM	P61033I2	1.42E-03
368	M1	BKHD	Y	BKHD 5 DIAGONAL	P61055I2	1.37E-03
383	M1	BKHD	Z	BKHD 1 DIAGONALS-A	P61065I1	1.28E-03
519	M1	OTHER	Z	BKHD 3,4 "INNER RING"	P61720I1	1.24E-03
343	M1	BKHD	Z	BKHD 4 CROSS BEAM	P61044I1	1.20E-03
476	M1	DIAG	Y	BAY 2 BOTTOM FACE DIAGONAL	P61122I2	1.13E-03
283	M1	BKHD	Z	BKHD 1 CROSS BEAM	P61014I1	1.12E-03
504	M1	OTHER	Y	BAY 1 END "V"	P61141I2	1.12E-03
454	M1	DIAG	A	BAY 5 (-X) SIDE DIAGONAL	P61105A	1.02E-03
475	M1	DIAG	Z	BAY 2 BOTTOM FACE DIAGONAL	P61122I1	1.02E-03
360	M1	BKHD	Y	BKHD 5 BOTTOM BEAM	P61053I2	9.98E-04
319	M1	BKHD	Z	BKHD 3 BOTTOM BEAM	P61033I1	9.41E-04
415	M1	LONG	Z	BAY 5 MT RAIL	P61085I1	8.50E-04
280	M1	BKHD	Y	BKHD 1 BOTTOM -X BEAM	P61013I2	7.49E-04
371	M1	BKHD	Z	BKHD 1 SIDES-A	P61061I1	7.35E-04
416	M1	LONG	Y	BAY 5 MT RAIL	P61085I2	7.01E-04
276	M1	BKHD	Y	BKHD 1 SIDES	P61011I2	6.50E-04
517	M1	OTHER	J	BAYS 2,4 INNER BOX	P61710J	6.48E-04
391	M1	LONG	Z	BAY 3 TOP LONGERON	P61073I1	5.76E-04
364	M1	BKHD	Y	BKHD 5 CROSS BEAM	P61054I2	5.74E-04
496	M1	DIAG	Y	BAY 1 -X SIDE DIAGONAL	P61131I2	5.73E-04
365	M1	BKHD	J	BKHD 5 CROSS BEAM	P61054J	5.71E-04
284	M1	BKHD	Y	BKHD 1 CROSS BEAM	P61014I2	5.29E-04
378	M1	BKHD	A	BKHD 1 CROSS BEAM-A	P61064A	5.23E-04
303	M1	BKHD	Z	BKHD 2 CROSS BEAM	P61024I1	4.63E-04
506	M1	OTHER	A	BAY 5 END "V"	P61145A	4.55E-04
370	M1	BKHD	A	BKHD 1 SIDES-A	P61061A	4.21E-04
352	M1	BKHD	Y	BKHD 5 SIDES -X	P61051I2	3.97E-04
414	M1	LONG	A	BAY 5 MT RAIL	P61085A	3.94E-04
307	M1	BKHD	Z	BKHD 2 DIAGONAL	P61025I1	3.35E-04
345	M1	BKHD	J	BKHD 4 CROSS BEAM	P61044J	3.11E-04
302	M1	BKHD	A	BKHD 2 CROSS BEAM	P61024A	2.91E-04
374	M1	BKHD	A	BKHD 1 BOTTOM BEAM-A	P61063A	2.87E-04
382	M1	BKHD	A	BKHD 1 DIAGONALS-A	P61065A	2.76E-04
434	M1	LONG	A	BAY 5 TRUNION LONGERON	P61095A	2.46E-04
384	M1	BKHD	Y	BKHD 1 DIAGONALS-A	P61065I2	2.45E-04
512	M1	OTHER	Y	TRUNION PINS	P61310I2	2.44E-04
491	M1	DIAG	Z	BAY 3 TOP FACE DIAGONAL	P61126I1	2.25E-04
387	M1	LONG	Z	BAY 2 TOP LONGERON	P61072I1	2.20E-04
299	M1	BKHD	Z	BKHD 2 BOTTOM BEAM	P61023I1	2.12E-04
288	M1	BKHD	Y	BKHD 1 X DIAGONALS	P61015I2	1.76E-04

DSC NO.	SID	CID	PID	DESCRIPTION	PBAR	DSC (%HZ)
511	M1	OTHER	IZ	TRUNION PINS	P61310I1	1.71E-04
296	M1	BKHD	IY	BKHD 2 SIDES +X	P61022I2	1.67E-04
295	M1	BKHD	IZ	BKHD 2 SIDES +X	P61022I1	1.48E-04
304	M1	BKHD	IY	BKHD 2 CROSS BEAM	P61024I2	1.40E-04
277	M1	BKHD	J	BKHD 1 SIDES	P61011J	1.32E-04
453	M1	DIAG	J	BAY 4 (-X) SIDE DIAGONAL	P61104J	1.24E-04
292	M1	BKHD	IY	BKHD 2 SIDES -X	P61021I2	1.17E-04
433	M1	LONG	J	BAY 4 TRUNION LONGERON	P61094J	1.06E-04
503	M1	OTHER	IZ	BAY 1 END "V"	P61141I1	1.02E-04
333	M1	BKHD	J	BKHD 4 SIDES -X	P61041J	1.01E-04
369	M1	BKHD	J	BKHD 5 DIAGONAL	P61055J	9.96E-05
325	M1	BKHD	J	BKHD 3 CROSS BEAM	P61034J	9.69E-05
300	M1	BKHD	IY	BKHD 2 BOTTOM BEAM	P61023I2	9.57E-05
313	M1	BKHD	J	BKHD 3 SIDES -X	P61031J	9.31E-05
501	M1	DIAG	J	BAY 5 -X SIDE DIAGONAL	P61135J	9.28E-05
353	M1	BKHD	J	BKHD 5 SIDES -X	P61051J	8.68E-05
429	M1	LONG	J	BAY 3 TRUNION LONGERON	P61093J	8.26E-05
488	M1	DIAG	IY	BAY 5 BOTTOM FACE DIAGONAL	P61125I2	7.14E-05
305	M1	BKHD	J	BKHD 2 CROSS BEAM	P61024J	6.37E-05
373	M1	BKHD	J	BKHD 1 SIDES-A	P61061J	5.48E-05
510	M1	OTHER	A	TRUNION PINS	P61310A	5.27E-05
349	M1	BKHD	J	BKHD 4 DIAGONALS	P61045J	5.24E-05
308	M1	BKHD	IY	BKHD 2 DIAGONAL	P61025I2	4.66E-05
376	M1	BKHD	IY	BKHD 1 BOTTOM BEAM-A	P61063I2	3.88E-05
361	M1	BKHD	J	BKHD 5 BOTTOM BEAM	P61053J	3.67E-05
465	M1	DIAG	J	BAY 3 (+X) SIDE DIAGONAL	P61113J	3.28E-05
317	M1	BKHD	J	BKHD 3 SIDES +X	P61032J	3.05E-05
449	M1	DIAG	J	BAY 3 (-X) SIDE DIAGONAL	P61103J	2.76E-05
425	M1	LONG	J	BAY 2 TRUNION LONGERON	P61092J	2.63E-05
293	M1	BKHD	J	BKHD 2 SIDES -X	P61021J	2.13E-05
469	M1	DIAG	J	BAY 4 (+X) SIDE DIAGONAL	P61114J	1.91E-05
375	M1	BKHD	IZ	BKHD 1 BOTTOM BEAM-A	P61063I1	1.90E-05
487	M1	DIAG	IZ	BAY 5 BOTTOM FACE DIAGONAL	P61125I1	1.79E-05
413	M1	LONG	J	BAY 4 MT RAIL	P61084J	1.58E-05
509	M1	OTHER	J	BAY 5 END "V"	P61145J	1.42E-05
437	M1	LONG	J	BAY 5 TRUNION LONGERON	P61095J	1.06E-05
409	M1	LONG	J	BAY 3 MT RAIL	P61083J	9.38E-06
526	M1	OTHER	A	TRUNION PINS	P62010A	9.08E-06
289	M1	BKHD	J	BKHD 1 X DIAGONALS	P61015J	8.22E-06
522	M1	OTHER	A	BAY 5 "V" SUPPORT BRACE	P61730A	6.53E-06
381	M1	BKHD	J	BKHD 1 CROSS BEAM-A	P61064J	6.44E-06
329	M1	BKHD	J	BKHD 3 DIAGONALS	P61035J	5.80E-06
481	M1	DIAG	J	BAY 3 BOTTOM FACE DIAGONAL	P61123J	5.49E-06
297	M1	BKHD	J	BKHD 2 SIDES +X	P61022J	4.73E-06
521	M1	OTHER	J	BKHD 3,4 "INNER RING"	P61720J	3.72E-06
485	M1	DIAG	J	BAY 4 BOT/TOP FACE DIAGONAL	P61124J	2.94E-06

DSC NO.	SID	CID	PID	DESCRIPTION	PBAR	DSC (%HZ)
341	M1	BKHD	J	BKHD 4 BOTTOM BEAM	P61043J	2.83E-06
337	M1	BKHD	J	BKHD 4 SIDES +X	P61042J	2.76E-06
457	M1	DIAG	J	BAY 5 (-X) SIDE DIAGONAL	P61105J	2.59E-06
321	M1	BKHD	J	BKHD 3 BOTTOM BEAM	P61033J	2.09E-06
441	M1	DIAG	J	BAY 1 (-X) SIDE DIAGONAL	P61101J	1.71E-06
285	M1	BKHD	J	BKHD 1 CROSS BEAM	P61014J	1.68E-06
397	M1	LONG	J	BAY 4 TOP LONGERON	P61074J	1.62E-06
525	M1	OTHER	J	BAY 5 "V" SUPPORT BRACE	P61730J	1.36E-06
493	M1	DIAG	J	BAY 3 TOP FACE DIAGONAL	P61126J	1.28E-06
461	M1	DIAG	J	BAY 2 (+X) SIDE DIAGONAL	P61112J	1.19E-06
393	M1	LONG	J	BAY 3 TOP LONGERON	P61073J	1.18E-06
513	M1	OTHER	J	TRUNION PINS	P61310J	1.16E-06
445	M1	DIAG	J	BAY 2 (-X) SIDE DIAGONAL	P61102J	1.06E-06
385	M1	BKHD	J	BKHD 1 DIAGONALS-A	P61065J	1.05E-06
497	M1	DIAG	J	BAY 1 -X SIDE DIAGONAL	P61131J	7.87E-07
421	M1	LONG	J	BAY 1 TRUNION LONGERON	P61091J	6.41E-07
389	M1	LONG	J	BAY 2 TOP LONGERON	P61072J	6.24E-07
405	M1	LONG	J	BAY 2 MT RAIL	P61082J	4.87E-07
401	M1	LONG	J	BAY 1 MT RAIL	P61081J	4.66E-07
309	M1	BKHD	J	BKHD 2 DIAGONAL	P61025J	3.96E-07
505	M1	OTHER	J	BAY 1 END "V"	P61141J	3.83E-07
281	M1	BKHD	J	BKHD 1 BOTTOM -X BEAM	P61013J	3.43E-07
301	M1	BKHD	J	BKHD 2 BOTTOM BEAM	P61023J	1.64E-07
473	M1	DIAG	J	BAY 2 TOP FACE DIAGONAL	P61121J	6.76E-08
524	M1	OTHER	IY	BAY 5 "V" SUPPORT BRACE	P617302	5.91E-08
477	M1	DIAG	J	BAY 2 BOTTOM FACE DIAGONAL	P61122J	5.33E-08
377	M1	BKHD	J	BKHD 1 BOTTOM BEAM-A	P61063J	3.56E-08
417	M1	LONG	J	BAY 5 MT RAIL	P61085J	2.96E-08
489	M1	DIAG	J	BAY 5 BOTTOM FACE DIAGONAL	P61125J	2.01E-08
528	M1	OTHER	IY	TRUNION PINS	P620102	2.02E-09
527	M1	OTHER	IZ	TRUNION PINS	P620101	8.43E-10
529	M1	OTHER	J	TRUNION PINS	P62010J	2.81E-28
530	ITS	-	K	MB INTERFACES	CELAS1	7.18E-02
533	SUB	SARJ	IY	SARJ BKHDS RING JST	P310512	7.13E-01
587	SUB	SARJ	E & G	SARJ PLATE ELEMENTS	PSHELL	5.08E-01
545	SUB	SARJ	IY	SARJ BKHDS RING OFFSETS	P310542	3.11E-01
537	SUB	SARJ	IY	SARJ BKHDS SIDES	P310522	2.70E-01
535	SUB	SARJ	A	SARJ BKHDS SIDES	P31052A	1.56E-01
548	SUB	SARJ	IZ	SARJ BKHDS RING	P310561	1.12E-01
551	SUB	SARJ	A	TRUNDLE BEAM	A20110A	1.08E-01
539	SUB	SARJ	A	SARJ BKHDS X BEAMS	P31053A	7.59E-02
556	SUB	SARJ	IZ	RACE RING	A201301	5.25E-02
557	SUB	SARJ	IY	RACE RING	A201302	5.25E-02
560	SUB	SARJ	IZ	T-RING	A201401	5.25E-02
561	SUB	SARJ	IY	T-RING	A201402	5.25E-02

DSC NO.	SID	CID	PID	DESCRIPTION	PBAR	DSC (%HZ)
536	SUB	SARJ	IZ	SARJ BKHDS SIDES	P31052I1	3.25E-02
577	SUB	SARJ	IY	UTA RIBS (TRING SIDE)	A20203I2	3.24E-02
581	SUB	SARJ	IY	UTA RIBS (RACE SIDE)	A20204I2	2.67E-02
547	SUB	SARJ	A	SARJ BKHDS RING	P31056A	2.64E-02
552	SUB	SARJ	IZ	TRUNDLE BEAM	A20110I1	2.22E-02
555	SUB	SARJ	A	RACE RING	A20130A	2.20E-02
559	SUB	SARJ	A	T-RING	A20140A	2.20E-02
549	SUB	SARJ	IY	SARJ BKHDS RING	P31056I2	1.60E-02
541	SUB	SARJ	IY	SARJ BKHDS X BEAMS	P31053I2	1.09E-02
576	SUB	SARJ	IZ	UTA RIBS (TRING SIDE)	A20203I1	7.21E-03
544	SUB	SARJ	IZ	SARJ BKHDS RING OFFSETS	P31054I1	6.93E-03
573	SUB	SARJ	IY	DLA/MOTORS	A20170I2	4.74E-03
580	SUB	SARJ	IZ	UTA RIBS (RACE SIDE)	A20204I1	3.23E-03
575	SUB	SARJ	A	UTA RIBS (TRING SIDE)	A20203A	3.08E-03
550	SUB	SARJ	J	SARJ BKHDS RING	P31056J	2.97E-03
579	SUB	SARJ	A	UTA RIBS (RACE SIDE)	A20204A	1.17E-03
543	SUB	SARJ	A	SARJ BKHDS RING OFFSETS	P31054A	1.08E-03
569	SUB	SARJ	IY	DLA/MOTORS	A20160I2	9.95E-04
531	SUB	SARJ	A	SARJ BKHDS RING JST	P31051A	7.49E-04
540	SUB	SARJ	IZ	SARJ BKHDS X BEAMS	P31053I1	5.78E-04
564	SUB	SARJ	IZ	DLA/MOTORS	A20150I1	4.34E-04
546	SUB	SARJ	J	SARJ BKHDS RING OFFSETS	P31054J	3.51E-04
538	SUB	SARJ	J	SARJ BKHDS SIDES	P31052J	1.59E-04
566	SUB	SARJ	J	DLA/MOTORS	A20150J	1.31E-04
578	SUB	SARJ	J	UTA RIBS (TRING SIDE)	A20203J	4.93E-05
582	SUB	SARJ	J	UTA RIBS (RACE SIDE)	A20204J	4.81E-05
532	SUB	SARJ	IZ	SARJ BKHDS RING JST	P31051I1	4.73E-05
542	SUB	SARJ	J	SARJ BKHDS X BEAMS	P31053J	3.44E-05
568	SUB	SARJ	IZ	DLA/MOTORS	A20160I1	3.32E-05
565	SUB	SARJ	IY	DLA/MOTORS	A20150I2	2.53E-05
585	SUB	SARJ	IY	UTA (BOTH SIDES)	A20210I2	3.37E-06
584	SUB	SARJ	IZ	UTA (BOTH SIDES)	A20210I1	3.10E-06
534	SUB	SARJ	J	SARJ BKHDS RING JST	P31051J	2.04E-06
586	SUB	SARJ	J	UTA (BOTH SIDES)	A20210J	4.12E-07
553	SUB	SARJ	IY	TRUNDLE BEAM	A20110I2	3.28E-07
572	SUB	SARJ	IZ	DLA/MOTORS	A20170I1	9.38E-08
563	SUB	SARJ	A	DLA/MOTORS	A20150A	1.96E-08
583	SUB	SARJ	A	UTA (BOTH SIDES)	A20210A	7.92E-09
571	SUB	SARJ	A	DLA/MOTORS	A20170A	5.34E-09
567	SUB	SARJ	A	DLA/MOTORS	A20160A	2.40E-09
570	SUB	SARJ	J	DLA/MOTORS	A20160J	2.93E-16
558	SUB	SARJ	J	RACE RING	A20130J	0.00E+00
562	SUB	SARJ	J	T-RING	A20140J	0.00E+00
554	SUB	SARJ	J	TRUNDLE BEAM	A20110J	0.00E+00
574	SUB	SARJ	J	DLA/MOTORS	A20170J	0.00E+00

DSC NO.	SID	CID	PID	DESCRIPTION	PBAR	DSC (%HZ)
596	SUB	BETA	A	BETA JOINT DIAG SUPPORT	F04000A	7.13E-02
617	SUB	BETA	IZ	BETA JOINT -X	F07042I1	2.46E-02
606	SUB	BETA	IY	BETA JOINT +X	F06042I2	1.24E-02
618	SUB	BETA	IY	BETA JOINT -X	F07042I2	6.46E-03
613	SUB	BETA	IZ	BETA JOINT -X	F07041I1	4.58E-03
605	SUB	BETA	IZ	BETA JOINT +X	F06042I1	4.57E-03
592	SUB	BETA	A	BETA JOINT SIDE BULKHEAD	F00201A	2.37E-03
597	SUB	BETA	IZ	BETA JOINT DIAG SUPPORT	F04000I1	1.98E-03
602	SUB	BETA	IY	BETA JOINT +X	F06041I2	1.72E-03
588	SUB	BETA	A	OB BETA JOINT BULKHEAD	F00200A	1.15E-03
614	SUB	BETA	IY	BETA JOINT -X	F07041I2	8.95E-04
601	SUB	BETA	IZ	BETA JOINT +X	F06041I1	8.26E-04
621	SUB	BETA	IZ	BETA JOINT -X	F07044I1	5.89E-04
610	SUB	BETA	IY	BETA JOINT +X	F06044I2	2.60E-04
594	SUB	BETA	IY	BETA JOINT SIDE BULKHEAD	F00201I2	1.75E-04
622	SUB	BETA	IY	BETA JOINT -X	F07044I2	1.28E-04
609	SUB	BETA	IZ	BETA JOINT +X	F06044I1	1.22E-04
593	SUB	BETA	IZ	BETA JOINT SIDE BULKHEAD	F00201I1	7.70E-05
589	SUB	BETA	IZ	OB BETA JOINT BULKHEAD	F00200I1	4.97E-05
590	SUB	BETA	IY	OB BETA JOINT BULKHEAD	F00200I2	3.36E-05
612	SUB	BETA	A	BETA JOINT -X	F07041A	2.98E-05
598	SUB	BETA	IY	BETA JOINT DIAG SUPPORT	F04000I2	2.26E-05
600	SUB	BETA	A	BETA JOINT +X	F06041A	1.79E-05
591	SUB	BETA	J	OB BETA JOINT BULKHEAD	F00200J	1.14E-05
595	SUB	BETA	J	BETA JOINT SIDE BULKHEAD	F00201J	8.26E-06
616	SUB	BETA	A	BETA JOINT -X	F07042A	6.14E-06
604	SUB	BETA	A	BETA JOINT +X	F06042A	4.48E-06
620	SUB	BETA	A	BETA JOINT -X	F07044A	3.51E-06
608	SUB	BETA	A	BETA JOINT +X	F06044A	2.73E-06
619	SUB	BETA	J	BETA JOINT -X	F07042J	6.08E-09
607	SUB	BETA	J	BETA JOINT +X	F06042J	6.01E-09
615	SUB	BETA	J	BETA JOINT -X	F07041J	5.51E-09
603	SUB	BETA	J	BETA JOINT +X	F06041J	1.02E-09
623	SUB	BETA	J	BETA JOINT -X	F07044J	1.33E-22
611	SUB	BETA	J	BETA JOINT +X	F06044J	5.98E-23
599	SUB	BETA	J	BETA JOINT DIAG SUPPORT	F04000J	0.00E+00
626	SUB	TRRJ	IY	TARJ CRADLE-A	P53105I2	4.61E-02
643	SUB	TRRJ	J	TRRJ BOTTOM	P59060J	3.73E-02
636	SUB	TRRJ	A	TARJ CRADLE-D	P53108A	2.42E-02
641	SUB	TRRJ	IZ	TRRJ BOTTOM	P59060I1	1.89E-02
638	SUB	TRRJ	IY	TARJ CRADLE-D	P53108I2	1.72E-02
624	SUB	TRRJ	A	TARJ CRADLE-A	P53105A	1.65E-02
630	SUB	TRRJ	IY	TARJ CRADLE-B	P53106I2	1.48E-02
628	SUB	TRRJ	A	TARJ CRADLE-B	P53106A	1.22E-02
647	SUB	TRRJ	J	TRRJ TOP	P59061J	9.16E-03

DSC NO.	SID	CID	PID	DESCRIPTION	PBAR	DSC (%HZ)
645	SUB	TRRJ	IZ	TRRJ TOP	P59061I1	4.20E-03
633	SUB	TRRJ	IZ	TARJ CRADLE-C	P53107I1	3.71E-03
632	SUB	TRRJ	A	TARJ CRADLE-C	P53107A	2.74E-03
629	SUB	TRRJ	IZ	TARJ CRADLE-B	P53106I1	2.26E-03
625	SUB	TRRJ	IZ	TARJ CRADLE-A	P53105I1	2.07E-03
637	SUB	TRRJ	IZ	TARJ CRADLE-D	P53108I1	1.76E-03
648	SUB	TRRJ	E & G	TRRJ PLATE ELEMENTS	PSHELL	1.69E-03
642	SUB	TRRJ	IY	TRRJ BOTTOM	P59060I2	1.19E-03
640	SUB	TRRJ	A	TRRJ BOTTOM	P59060A	1.08E-03
634	SUB	TRRJ	IY	TARJ CRADLE-C	P53107I2	7.05E-04
644	SUB	TRRJ	A	TRRJ TOP	P59061A	2.68E-04
646	SUB	TRRJ	IY	TRRJ TOP	P59061I2	2.16E-04
635	SUB	TRRJ	J	TARJ CRADLE-C	P53107J	4.43E-05
627	SUB	TRRJ	J	TARJ CRADLE-A	P53105J	4.11E-05
639	SUB	TRRJ	J	TARJ CRADLE-D	P53108J	1.34E-05
631	SUB	TRRJ	J	TARJ CRADLE-B	P53106J	1.15E-05
659	SUB	PMAS	IY	PMAS SUPPORT STRUCTURE	P31884I2	2.91E+00
658	SUB	PMAS	IZ	PMAS SUPPORT STRUCTURE	P31884I1	7.46E-01
654	SUB	PMAS	IZ	PMAS SUPPORT STRUCTURE	P31882I1	7.01E-01
651	SUB	PMAS	IY	PMAS SUPPORT STRUCTURE	P31880I2	4.48E-01
653	SUB	PMAS	A	PMAS SUPPORT STRUCTURE	P31882A	3.72E-01
657	SUB	PMAS	A	PMAS SUPPORT STRUCTURE	P31884A	2.54E-01
663	SUB	PMAS	IY	PMAS SUPPORT STRUCTURE	P31885I2	2.42E-01
667	SUB	PMAS	IY	PMAS SUPPORT STRUCTURE	P31887I2	2.03E-01
649	SUB	PMAS	A	PMAS SUPPORT STRUCTURE	P31880A	1.61E-01
662	SUB	PMAS	IZ	PMAS SUPPORT STRUCTURE	P31885I1	1.19E-01
665	SUB	PMAS	A	PMAS SUPPORT STRUCTURE	P31887A	1.05E-01
655	SUB	PMAS	IY	PMAS SUPPORT STRUCTURE	P31882I2	7.69E-02
668	SUB	PMAS	J	PMAS SUPPORT STRUCTURE	P31887J	5.79E-02
650	SUB	PMAS	IZ	PMAS SUPPORT STRUCTURE	P31880I1	5.47E-02
678	SUB	PMAS	IZ	PMAS SUPPORT STRUCTURE	P31899I1	4.31E-02
679	SUB	PMAS	IY	PMAS SUPPORT STRUCTURE	P31899I2	2.10E-02
661	SUB	PMAS	A	PMAS SUPPORT STRUCTURE	P31885A	1.85E-02
666	SUB	PMAS	IZ	PMAS SUPPORT STRUCTURE	P31887I1	1.39E-02
675	SUB	PMAS	IY	PMAS SUPPORT STRUCTURE	P31890I2	1.21E-02
676	SUB	PMAS	J	PMAS SUPPORT STRUCTURE	P31890J	1.05E-02
677	SUB	PMAS	A	PMAS SUPPORT STRUCTURE	P31899A	4.16E-03
674	SUB	PMAS	IZ	PMAS SUPPORT STRUCTURE	P31890I1	2.25E-03
664	SUB	PMAS	J	PMAS SUPPORT STRUCTURE	P31885J	1.94E-03
673	SUB	PMAS	A	PMAS SUPPORT STRUCTURE	P31890A	1.94E-03
660	SUB	PMAS	J	PMAS SUPPORT STRUCTURE	P31884J	1.84E-03
671	SUB	PMAS	IY	PMAS SUPPORT STRUCTURE	P31888I2	4.76E-04
670	SUB	PMAS	IZ	PMAS SUPPORT STRUCTURE	P31888I1	4.72E-04
652	SUB	PMAS	J	PMAS SUPPORT STRUCTURE	P31880J	4.23E-04
656	SUB	PMAS	J	PMAS SUPPORT STRUCTURE	P31882J	2.73E-04

DSC NO.	SID	CID	PID	DESCRIPTION	PBAR	DSC (%HZ)
669	SUB	PMAS	A	PMAS SUPPORT STRUCTURE	P31888A	2.62E-06
680	SUB	PMAS	J	PMAS SUPPORT STRUCTURE	P31899J	1.56E-25
672	SUB	PMAS	J	PMAS SUPPORT STRUCTURE	P31888J	2.01E-26
681	SUB	MTI	A	MODULE SUPPORT BEAMS	P69051A	3.82E+00
682	SUB	MTI	IZ	MODULE SUPPORT BEAMS	P69051I1	1.23E-01
683	SUB	MTI	IY	MODULE SUPPORT BEAMS	P69051I2	1.19E-01
684	SUB	MTI	J	MODULE SUPPORT BEAMS	P69051J	8.19E-08
686	SUB	STS	IZ	S4-to-SARJ (+Y END)	F00103I1	2.53E-01
687	SUB	STS	IY	S4-to-SARJ (+Y END)	F00103I2	1.65E-01
685	SUB	STS	A	S4-to-SARJ (+Y END)	F00103A	1.36E-01
688	SUB	STS	J	S4-to-SARJ (+Y END)	F00103J	3.32E-02
794	SUB	MTS	IZ	MT ARM	S00023I1	2.74E-01
786	SUB	MTS	IZ	MT ARM	S00021I1	1.55E-01
766	SUB	MTS	IZ	MT ARM	S00013I1	1.08E-01
782	SUB	MTS	IZ	MT ARM	S00020I1	9.12E-02
778	SUB	MTS	IZ	MT ARM	S00019I1	6.70E-02
791	SUB	MTS	IY	MT ARM	S00022I2	5.17E-02
779	SUB	MTS	IY	MT ARM	S00019I2	4.49E-02
767	SUB	MTS	IY	MT ARM	S00013I2	3.25E-02
795	SUB	MTS	IY	MT ARM	S00023I2	3.10E-02
798	SUB	MTS	IZ	MT ARM	S00024I1	3.09E-02
775	SUB	MTS	IY	MT ARM	S00018I2	2.98E-02
792	SUB	MTS	J	MT ARM	S00022J	2.69E-02
790	SUB	MTS	IZ	MT ARM	S00022I1	2.54E-02
800	SUB	MTS	J	MT ARM	S00024J	2.22E-02
796	SUB	MTS	J	MT ARM	S00023J	1.65E-02
771	SUB	MTS	IY	MT ARM	S00014I2	1.60E-02
784	SUB	MTS	J	MT ARM	S00020J	1.57E-02
689	SUB	MTS	A	MOBILE TRANSPORTER CART	C10001A	1.04E-02
725	SUB	MTS	A	MOBILE TRANSPORTER CART	C10010A	9.69E-03
709	SUB	MTS	A	MOBILE TRANSPORTER CART	C10006A	8.64E-03
788	SUB	MTS	J	MT ARM	S00021J	7.37E-03
735	SUB	MTS	IY	MOBILE TRANSPORTER CART	C10012I2	6.65E-03
727	SUB	MTS	IY	MOBILE TRANSPORTER CART	C10010I2	5.29E-03
693	SUB	MTS	A	MOBILE TRANSPORTER CART	C10002A	5.23E-03
774	SUB	MTS	IZ	MT ARM	S00018I1	4.62E-03
799	SUB	MTS	IY	MT ARM	S00024I2	4.59E-03
695	SUB	MTS	IY	MOBILE TRANSPORTER CART	C10002I2	4.41E-03
703	SUB	MTS	IY	MOBILE TRANSPORTER CART	C10004I2	4.16E-03
691	SUB	MTS	IY	MOBILE TRANSPORTER CART	C10001I2	4.13E-03
743	SUB	MTS	IY	MOBILE TRANSPORTER CART	C10014I2	4.11E-03
742	SUB	MTS	IZ	MOBILE TRANSPORTER CART	C10014I1	4.09E-03
721	SUB	MTS	A	MOBILE TRANSPORTER CART	C10009A	3.69E-03
787	SUB	MTS	IY	MT ARM	S00021I2	3.58E-03
741	SUB	MTS	A	MOBILE TRANSPORTER CART	C10014A	2.99E-03

DSC NO.	SID	CID	PID	DESCRIPTION	PBAR	DSC (%HZ)
731	SUB	MTS	IY	MOBILE TRANSPORTER CART	C10011I2	2.96E-03
734	SUB	MTS	IZ	MOBILE TRANSPORTER CART	C10012I1	2.45E-03
729	SUB	MTS	A	MOBILE TRANSPORTER CART	C10011A	2.31E-03
770	SUB	MTS	IZ	MT ARM	S00014I1	2.29E-03
694	SUB	MTS	IZ	MOBILE TRANSPORTER CART	C10002I1	2.27E-03
737	SUB	MTS	A	MOBILE TRANSPORTER CART	C10013A	2.00E-03
690	SUB	MTS	IZ	MOBILE TRANSPORTER CART	C10001I1	1.53E-03
783	SUB	MTS	IY	MT ARM	S00020I2	1.43E-03
768	SUB	MTS	J	MT ARM	S00013J	1.41E-03
744	SUB	MTS	J	MOBILE TRANSPORTER CART	C10014J	1.39E-03
702	SUB	MTS	IZ	MOBILE TRANSPORTER CART	C10004I1	1.22E-03
726	SUB	MTS	IZ	MOBILE TRANSPORTER CART	C10010I1	1.14E-03
738	SUB	MTS	IZ	MOBILE TRANSPORTER CART	C10013I1	1.13E-03
776	SUB	MTS	J	MT ARM	S00018J	1.06E-03
715	SUB	MTS	IY	MOBILE TRANSPORTER CART	C10007I2	7.26E-04
780	SUB	MTS	J	MT ARM	S00019J	6.47E-04
714	SUB	MTS	IZ	MOBILE TRANSPORTER CART	C10007I1	6.18E-04
719	SUB	MTS	IY	MOBILE TRANSPORTER CART	C10008I2	5.41E-04
701	SUB	MTS	A	MOBILE TRANSPORTER CART	C10004A	5.09E-04
718	SUB	MTS	IZ	MOBILE TRANSPORTER CART	C10008I1	4.71E-04
772	SUB	MTS	J	MT ARM	S00014J	4.34E-04
747	SUB	MTS	IY	MOBILE TRANSPORTER CART	C10015I2	4.16E-04
733	SUB	MTS	A	MOBILE TRANSPORTER CART	C10012A	3.54E-04
746	SUB	MTS	IZ	MOBILE TRANSPORTER CART	C10015I1	2.93E-04
754	SUB	MTS	IZ	MOBILE TRANSPORTER CART	C10017I1	2.85E-04
730	SUB	MTS	IZ	MOBILE TRANSPORTER CART	C10011I1	2.78E-04
750	SUB	MTS	IZ	MOBILE TRANSPORTER CART	C10016I1	2.28E-04
697	SUB	MTS	A	MOBILE TRANSPORTER CART	C10003A	1.94E-04
705	SUB	MTS	A	MOBILE TRANSPORTER CART	C10005A	1.91E-04
755	SUB	MTS	IY	MOBILE TRANSPORTER CART	C10017I2	1.86E-04
765	SUB	MTS	A	MT ARM	S00013A	1.73E-04
748	SUB	MTS	J	MOBILE TRANSPORTER CART	C10015J	1.59E-04
713	SUB	MTS	A	MOBILE TRANSPORTER CART	C10007A	1.56E-04
763	SUB	MTS	IY	MOBILE TRANSPORTER CART	C10019I2	1.40E-04
722	SUB	MTS	IZ	MOBILE TRANSPORTER CART	C10009I1	1.07E-04
717	SUB	MTS	A	MOBILE TRANSPORTER CART	C10008A	9.55E-05
745	SUB	MTS	A	MOBILE TRANSPORTER CART	C10015A	8.35E-05
720	SUB	MTS	J	MOBILE TRANSPORTER CART	C10008J	7.52E-05
762	SUB	MTS	IZ	MOBILE TRANSPORTER CART	C10019I1	7.31E-05
723	SUB	MTS	IY	MOBILE TRANSPORTER CART	C10009I2	7.16E-05
710	SUB	MTS	IZ	MOBILE TRANSPORTER CART	C10006I1	5.06E-05
752	SUB	MTS	J	MOBILE TRANSPORTER CART	C10016J	4.31E-05
706	SUB	MTS	IZ	MOBILE TRANSPORTER CART	C10005I1	4.11E-05
711	SUB	MTS	IY	MOBILE TRANSPORTER CART	C10006I2	4.07E-05
777	SUB	MTS	A	MT ARM	S00019A	3.81E-05
757	SUB	MTS	A	MOBILE TRANSPORTER CART	C10018A	3.29E-05

DSC NO.	SID	CID	PID	DESCRIPTION	PBAR	DSC (%HZ)
781	SUB	MTS	A	MT ARM	S00020A	3.27E-05
707	SUB	MTS	IY	MOBILE TRANSPORTER CART	C10005I2	3.20E-05
789	SUB	MTS	A	MT ARM	S00022A	1.86E-05
716	SUB	MTS	J	MOBILE TRANSPORTER CART	C10007J	1.78E-05
785	SUB	MTS	A	MT ARM	S00021A	1.75E-05
759	SUB	MTS	IY	MOBILE TRANSPORTER CART	C10018I2	1.60E-05
692	SUB	MTS	J	MOBILE TRANSPORTER CART	C10001J	1.53E-05
793	SUB	MTS	A	MT ARM	S00023A	1.27E-05
797	SUB	MTS	A	MT ARM	S00024A	1.10E-05
773	SUB	MTS	A	MT ARM	S00018A	1.06E-05
758	SUB	MTS	IZ	MOBILE TRANSPORTER CART	C10018I1	9.36E-06
696	SUB	MTS	J	MOBILE TRANSPORTER CART	C10002J	9.15E-06
736	SUB	MTS	J	MOBILE TRANSPORTER CART	C10012J	8.59E-06
751	SUB	MTS	IY	MOBILE TRANSPORTER CART	C10016I2	6.44E-06
769	SUB	MTS	A	MT ARM	S00014A	4.94E-06
749	SUB	MTS	A	MOBILE TRANSPORTER CART	C10016A	4.33E-06
698	SUB	MTS	IZ	MOBILE TRANSPORTER CART	C10003I1	4.24E-06
699	SUB	MTS	IY	MOBILE TRANSPORTER CART	C10003I2	3.12E-06
728	SUB	MTS	J	MOBILE TRANSPORTER CART	C10010J	3.04E-06
732	SUB	MTS	J	MOBILE TRANSPORTER CART	C10011J	1.68E-07
704	SUB	MTS	J	MOBILE TRANSPORTER CART	C10004J	1.30E-07
724	SUB	MTS	J	MOBILE TRANSPORTER CART	C10009J	1.25E-07
712	SUB	MTS	J	MOBILE TRANSPORTER CART	C10006J	4.96E-08
708	SUB	MTS	J	MOBILE TRANSPORTER CART	C10005J	4.18E-08
700	SUB	MTS	J	MOBILE TRANSPORTER CART	C10003J	5.36E-09
753	SUB	MTS	A	MOBILE TRANSPORTER CART	C10017A	2.17E-10
761	SUB	MTS	A	MOBILE TRANSPORTER CART	C10019A	1.45E-10
739	SUB	MTS	IY	MOBILE TRANSPORTER CART	C10013I2	1.66E-11
740	SUB	MTS	J	MOBILE TRANSPORTER CART	C10013J	0.00E+00
756	SUB	MTS	J	MOBILE TRANSPORTER CART	C10017J	0.00E+00
764	SUB	MTS	J	MOBILE TRANSPORTER CART	C10019J	0.00E+00
760	SUB	MTS	J	MOBILE TRANSPORTER CART	C10018J	0.00E+00
810	MOD	LAB	K	LAB/NODE INTERFACE	CELAS1	1.12E+00
802	MOD	LAB	IZ	LAB MODULE	M12200I1	7.83E-02
803	MOD	LAB	IY	LAB MODULE	M12200I2	2.98E-02
804	MOD	LAB	J	LAB MODULE	M12200J	2.38E-02
809	MOD	LAB	K	LAB-A TO LAB-B INTERFACE	CELAS1	1.94E-02
807	MOD	LAB	IY	CONNECTION	M12201I2	4.93E-03
805	MOD	LAB	A	CONNECTION	M12201A	2.50E-06
801	MOD	LAB	A	LAB MODULE	M12200A	1.68E-07
806	MOD	LAB	IZ	CONNECTION	M12201I1	4.02E-10
808	MOD	LAB	J	CONNECTION	M12201J	2.93E-11
831	MOD	NODE	K	MPLM/NODE INTERFACE	CELAS1	1.66E+00
820	MOD	NODE	IZ	CONNECTION	M12003I1	1.20E-02
821	MOD	NODE	IY	CONNECTION	M12003I2	2.35E-03

DSC NO.	SID	CID	PID	DESCRIPTION	PBAR	DSC (%HZ)
829	MOD	NODE	IY	RESOURCE NODE	M12005I2	2.25E-03
818	MOD	NODE	J	RESOURCE NODE	M12002J	2.02E-03
822	MOD	NODE	J	CONNECTION	M12003J	2.01E-03
830	MOD	NODE	J	RESOURCE NODE	M12005J	1.62E-03
817	MOD	NODE	IY	RESOURCE NODE	M12002I2	1.60E-03
816	MOD	NODE	IZ	RESOURCE NODE	M12002I1	3.36E-04
828	MOD	NODE	IZ	RESOURCE NODE	M12005I1	2.62E-04
819	MOD	NODE	A	CONNECTION	M12003A	1.91E-06
813	MOD	NODE	IY	RESOURCE NODE	M12001I2	1.37E-06
812	MOD	NODE	IZ	RESOURCE NODE	M12001I1	1.07E-06
814	MOD	NODE	J	RESOURCE NODE	M12001J	6.19E-07
826	MOD	NODE	J	RESOURCE NODE	M12004J	2.76E-07
825	MOD	NODE	IY	RESOURCE NODE	M12004I2	2.25E-07
815	MOD	NODE	A	RESOURCE NODE	M12002A	1.63E-07
827	MOD	NODE	A	RESOURCE NODE	M12005A	1.34E-07
824	MOD	NODE	IZ	RESOURCE NODE	M12004I1	1.18E-07
811	MOD	NODE	A	RESOURCE NODE	M12001A	9.91E-10
823	MOD	NODE	A	RESOURCE NODE	M12004A	3.98E-11
833	MOD	AIR	IZ	AIRLOCK	M12500I1	2.19E-02
834	MOD	AIR	IY	AIRLOCK	M12500I2	3.29E-03
835	MOD	AIR	J	AIRLOCK	M12500J	2.59E-04
832	MOD	AIR	A	AIRLOCK	M12500A	3.52E-09
1004	MOD	PBM	K	RADIAL PORT AND ENDCONE	CELAS1	4.11E+00
1006	MOD	PBM	K	PRESSURE TUNNEL	CELAS1	5.31E-02
1005	MOD	PBM	K	PDA-A & PDA-B INTERFACE	CELAS1	3.25E-03
906	MOD	PBM	IY	MODULE-B.M. (-X) CONNECT	M04321I2	2.61E-03
905	MOD	PBM	IZ	MODULE-B.M. (-X) CONNECT	M04321I1	2.00E-03
989	MOD	PBM	IZ	MODULE-B.M. (+X) CONNECT	M09321I1	1.19E-03
990	MOD	PBM	IY	MODULE-B.M. (+X) CONNECT	M09321I2	7.00E-04
910	MOD	PBM	IY	MODULE-B.M. (-X) CONNECT	M04331I2	4.57E-04
909	MOD	PBM	IZ	MODULE-B.M. (-X) CONNECT	M04331I1	3.83E-04
914	MOD	PBM	IY	MODULE-B.M. (-X) CONNECT	M04332I2	3.34E-04
913	MOD	PBM	IZ	MODULE-B.M. (-X) CONNECT	M04332I1	2.69E-04
918	MOD	PBM	IY	MODULE-B.M. (-X) CONNECT	M04333I2	2.58E-04
993	MOD	PBM	IZ	MODULE-B.M. (+X) CONNECT	M09331I1	2.43E-04
917	MOD	PBM	IZ	MODULE-B.M. (-X) CONNECT	M04333I1	2.01E-04
997	MOD	PBM	IZ	MODULE-B.M. (+X) CONNECT	M09332I1	1.72E-04
840	MOD	PBM	A	BERTHING MECH. (-X)	M00123A	1.38E-04
1001	MOD	PBM	IZ	MODULE-B.M. (+X) CONNECT	M09333I1	1.29E-04
911	MOD	PBM	J	MODULE-B.M. (-X) CONNECT	M04331J	1.14E-04
994	MOD	PBM	IY	MODULE-B.M. (+X) CONNECT	M09331I2	1.10E-04
842	MOD	PBM	IY	BERTHING MECH. (-X)	M00123I2	9.74E-05
998	MOD	PBM	IY	MODULE-B.M. (+X) CONNECT	M09332I2	8.13E-05
991	MOD	PBM	J	MODULE-B.M. (+X) CONNECT	M09321J	7.28E-05
915	MOD	PBM	J	MODULE-B.M. (-X) CONNECT	M04332J	6.97E-05

DSC NO.	SID	CID	PID	DESCRIPTION	PBAR	DSC (%HZ)
844	MOD	PBM	A	BERTHING MECH. (-X)	M00124A	6.60E-05
846	MOD	PBM	IY	BERTHING MECH. (-X)	M00124I2	6.58E-05
1002	MOD	PBM	IY	MODULE-B.M. (+X) CONNECT	M09333I2	6.33E-05
850	MOD	PBM	IY	BERTHING MECH. (-X)	M00125I2	5.70E-05
924	MOD	PBM	A	BERTHING MECH. (+X)	M05123A	5.45E-05
995	MOD	PBM	J	MODULE-B.M. (+X) CONNECT	M09331J	5.35E-05
926	MOD	PBM	IY	BERTHING MECH. (+X)	M05123I2	5.05E-05
866	MOD	PBM	IY	BERTHING MECH. (-X)	M00143I2	4.63E-05
919	MOD	PBM	J	MODULE-B.M. (-X) CONNECT	M04333J	4.58E-05
930	MOD	PBM	IY	BERTHING MECH. (+X)	M05124I2	4.09E-05
934	MOD	PBM	IY	BERTHING MECH. (+X)	M05125I2	3.53E-05
907	MOD	PBM	J	MODULE-B.M. (-X) CONNECT	M04321J	3.29E-05
999	MOD	PBM	J	MODULE-B.M. (+X) CONNECT	M09332J	3.27E-05
836	MOD	PBM	A	BERTHING MECH. (-X)	M00122A	3.02E-05
841	MOD	PBM	IZ	BERTHING MECH. (-X)	M00123I1	2.80E-05
928	MOD	PBM	A	BERTHING MECH. (+X)	M05124A	2.72E-05
865	MOD	PBM	IZ	BERTHING MECH. (-X)	M00143I1	2.22E-05
845	MOD	PBM	IZ	BERTHING MECH. (-X)	M00124I1	2.15E-05
1003	MOD	PBM	J	MODULE-B.M. (+X) CONNECT	M09333J	2.15E-05
949	MOD	PBM	IZ	BERTHING MECH. (+X)	M05143I1	2.02E-05
877	MOD	PBM	IZ	BERTHING MECH. (-X)	M04200I1	1.88E-05
857	MOD	PBM	IZ	BERTHING MECH. (-X)	M00128I1	1.76E-05
950	MOD	PBM	IY	BERTHING MECH. (+X)	M05143I2	1.74E-05
925	MOD	PBM	IZ	BERTHING MECH. (+X)	M05123I1	1.72E-05
929	MOD	PBM	IZ	BERTHING MECH. (+X)	M05124I1	1.19E-05
920	MOD	PBM	A	BERTHING MECH. (+X)	M05122A	1.18E-05
961	MOD	PBM	IZ	BERTHING MECH. (+X)	M09200I1	1.02E-05
902	MOD	PBM	IY	BERTHING MECH. (-X)	M04316I2	9.66E-06
837	MOD	PBM	IZ	BERTHING MECH. (-X)	M00122I1	8.90E-06
860	MOD	PBM	A	BERTHING MECH. (-X)	M00130A	8.90E-06
941	MOD	PBM	IZ	BERTHING MECH. (+X)	M05128I1	7.21E-06
856	MOD	PBM	A	BERTHING MECH. (-X)	M00128A	6.34E-06
870	MOD	PBM	IY	BERTHING MECH. (-X)	M00144I2	6.18E-06
861	MOD	PBM	IZ	BERTHING MECH. (-X)	M00130I1	5.94E-06
873	MOD	PBM	IZ	BERTHING MECH. (-X)	M00145I1	5.79E-06
874	MOD	PBM	IY	BERTHING MECH. (-X)	M00145I2	5.73E-06
944	MOD	PBM	A	BERTHING MECH. (+X)	M05130A	4.79E-06
869	MOD	PBM	IZ	BERTHING MECH. (-X)	M00144I1	4.35E-06
843	MOD	PBM	J	BERTHING MECH. (-X)	M00123J	4.33E-06
847	MOD	PBM	J	BERTHING MECH. (-X)	M00124J	3.95E-06
838	MOD	PBM	IY	BERTHING MECH. (-X)	M00122I2	3.89E-06
958	MOD	PBM	IY	BERTHING MECH. (+X)	M05145I2	3.75E-06
921	MOD	PBM	IZ	BERTHING MECH. (+X)	M05122I1	3.71E-06
954	MOD	PBM	IY	BERTHING MECH. (+X)	M05144I2	3.56E-06
898	MOD	PBM	IY	BERTHING MECH. (-X)	M04315I2	3.35E-06
940	MOD	PBM	A	BERTHING MECH. (+X)	M05128A	3.15E-06

DSC NO.	SID	CID	PID	DESCRIPTION	PBAR	DSC (%HZ)
945	MOD	PBM	IZ	BERTHING MECH. (+X)	M05130I1	3.13E-06
867	MOD	PBM	J	BERTHING MECH. (-X)	M00143J	3.08E-06
986	MOD	PBM	IY	BERTHING MECH. (+X)	M09316I2	2.61E-06
953	MOD	PBM	IZ	BERTHING MECH. (+X)	M05144I1	2.53E-06
854	MOD	PBM	IY	BERTHING MECH. (-X)	M00126I2	2.34E-06
927	MOD	PBM	J	BERTHING MECH. (+X)	M05123J	2.30E-06
957	MOD	PBM	IZ	BERTHING MECH. (+X)	M05145I1	2.18E-06
901	MOD	PBM	IZ	BERTHING MECH. (-X)	M04316I1	2.08E-06
849	MOD	PBM	IZ	BERTHING MECH. (-X)	M00125I1	2.00E-06
931	MOD	PBM	J	BERTHING MECH. (+X)	M05124J	1.96E-06
894	MOD	PBM	IY	BERTHING MECH. (-X)	M04314I2	1.84E-06
872	MOD	PBM	A	BERTHING MECH. (-X)	M00145A	1.74E-06
922	MOD	PBM	IY	BERTHING MECH. (+X)	M05122I2	1.61E-06
951	MOD	PBM	J	BERTHING MECH. (+X)	M05143J	1.55E-06
848	MOD	PBM	A	BERTHING MECH. (-X)	M00125A	1.54E-06
858	MOD	PBM	IY	BERTHING MECH. (-X)	M00128I2	1.52E-06
992	MOD	PBM	A	MODULE-B.M. (+X) CONNECT	M09331A	1.47E-06
890	MOD	PBM	IY	BERTHING MECH. (-X)	M04313I2	1.47E-06
859	MOD	PBM	J	BERTHING MECH. (-X)	M00128J	1.40E-06
878	MOD	PBM	IY	BERTHING MECH. (-X)	M04200I2	1.35E-06
908	MOD	PBM	A	MODULE-B.M. (-X) CONNECT	M04331A	1.35E-06
962	MOD	PBM	IY	BERTHING MECH. (+X)	M09200I2	1.31E-06
996	MOD	PBM	A	MODULE-B.M. (+X) CONNECT	M09332A	1.28E-06
863	MOD	PBM	J	BERTHING MECH. (-X)	M00130J	1.20E-06
864	MOD	PBM	A	BERTHING MECH. (-X)	M00143A	1.18E-06
912	MOD	PBM	A	MODULE-B.M. (-X) CONNECT	M04332A	1.15E-06
1000	MOD	PBM	A	MODULE-B.M. (+X) CONNECT	M09333A	1.13E-06
862	MOD	PBM	IY	BERTHING MECH. (-X)	M00130I2	1.03E-06
985	MOD	PBM	IZ	BERTHING MECH. (+X)	M09316I1	1.02E-06
916	MOD	PBM	A	MODULE-B.M. (-X) CONNECT	M04333A	1.01E-06
851	MOD	PBM	J	BERTHING MECH. (-X)	M00125J	9.66E-07
956	MOD	PBM	A	BERTHING MECH. (+X)	M05145A	9.43E-07
904	MOD	PBM	A	MODULE-B.M. (-X) CONNECT	M04321A	9.17E-07
982	MOD	PBM	IY	BERTHING MECH. (+X)	M09315I2	9.16E-07
886	MOD	PBM	IY	BERTHING MECH. (-X)	M04312I2	8.49E-07
938	MOD	PBM	IY	BERTHING MECH. (+X)	M05126I2	8.15E-07
948	MOD	PBM	A	BERTHING MECH. (+X)	M05143A	7.68E-07
933	MOD	PBM	IZ	BERTHING MECH. (+X)	M05125I1	7.26E-07
946	MOD	PBM	IY	BERTHING MECH. (+X)	M05130I2	6.86E-07
897	MOD	PBM	IZ	BERTHING MECH. (-X)	M04315I1	6.84E-07
947	MOD	PBM	J	BERTHING MECH. (+X)	M05130J	6.52E-07
942	MOD	PBM	IY	BERTHING MECH. (+X)	M05128I2	6.52E-07
932	MOD	PBM	A	BERTHING MECH. (+X)	M05125A	6.30E-07
882	MOD	PBM	IY	BERTHING MECH. (-X)	M04311I2	6.24E-07
943	MOD	PBM	J	BERTHING MECH. (+X)	M05128J	6.10E-07
853	MOD	PBM	IZ	BERTHING MECH. (-X)	M00126I1	5.92E-07

DSC NO.	SID	CID	PID	DESCRIPTION	PBAR	DSC (%HZ)
988	MOD	PBM	A	MODULE-B.M. (+X) CONNECT	M09321A	5.68E-07
963	MOD	PBM	J	BERTHING MECH. (+X)	M09200J	5.48E-07
978	MOD	PBM	IY	BERTHING MECH. (+X)	M09314I2	4.94E-07
868	MOD	PBM	A	BERTHING MECH. (-X)	M00144A	4.84E-07
879	MOD	PBM	J	BERTHING MECH. (-X)	M04200J	4.61E-07
839	MOD	PBM	J	BERTHING MECH. (-X)	M00122J	4.53E-07
935	MOD	PBM	J	BERTHING MECH. (+X)	M05125J	4.12E-07
974	MOD	PBM	IY	BERTHING MECH. (+X)	M09313I2	4.00E-07
893	MOD	PBM	IZ	BERTHING MECH. (-X)	M04314I1	3.51E-07
981	MOD	PBM	IZ	BERTHING MECH. (+X)	M09315I1	3.14E-07
952	MOD	PBM	A	BERTHING MECH. (+X)	M05144A	3.02E-07
889	MOD	PBM	IZ	BERTHING MECH. (-X)	M04313I1	2.59E-07
875	MOD	PBM	J	BERTHING MECH. (-X)	M00145J	2.44E-07
970	MOD	PBM	IY	BERTHING MECH. (+X)	M09312I2	2.31E-07
923	MOD	PBM	J	BERTHING MECH. (+X)	M05122J	2.09E-07
871	MOD	PBM	J	BERTHING MECH. (-X)	M00144J	1.94E-07
977	MOD	PBM	IZ	BERTHING MECH. (+X)	M09314I1	1.77E-07
966	MOD	PBM	IY	BERTHING MECH. (+X)	M09311I2	1.68E-07
937	MOD	PBM	IZ	BERTHING MECH. (+X)	M05126I1	1.62E-07
885	MOD	PBM	IZ	BERTHING MECH. (-X)	M04312I1	1.44E-07
955	MOD	PBM	J	BERTHING MECH. (+X)	M05144J	1.25E-07
959	MOD	PBM	J	BERTHING MECH. (+X)	M05145J	1.22E-07
973	MOD	PBM	IZ	BERTHING MECH. (+X)	M09313I1	1.08E-07
881	MOD	PBM	IZ	BERTHING MECH. (-X)	M04311I1	1.02E-07
969	MOD	PBM	IZ	BERTHING MECH. (+X)	M09312I1	5.85E-08
965	MOD	PBM	IZ	BERTHING MECH. (+X)	M09311I1	4.76E-08
876	MOD	PBM	A	BERTHING MECH. (-X)	M04200A	1.01E-08
852	MOD	PBM	A	BERTHING MECH. (-X)	M00126A	8.55E-09
936	MOD	PBM	A	BERTHING MECH. (+X)	M05126A	7.67E-09
960	MOD	PBM	A	BERTHING MECH. (+X)	M09200A	4.26E-09
900	MOD	PBM	A	BERTHING MECH. (-X)	M04316A	1.29E-09
984	MOD	PBM	A	BERTHING MECH. (+X)	M09316A	8.30E-10
896	MOD	PBM	A	BERTHING MECH. (-X)	M04315A	7.70E-10
892	MOD	PBM	A	BERTHING MECH. (-X)	M04314A	6.18E-10
980	MOD	PBM	A	BERTHING MECH. (+X)	M09315A	4.96E-10
976	MOD	PBM	A	BERTHING MECH. (+X)	M09314A	3.98E-10
888	MOD	PBM	A	BERTHING MECH. (-X)	M04313A	6.74E-11
972	MOD	PBM	A	BERTHING MECH. (+X)	M09313A	4.34E-11
884	MOD	PBM	A	BERTHING MECH. (-X)	M04312A	2.47E-11
968	MOD	PBM	A	BERTHING MECH. (+X)	M09312A	1.59E-11
880	MOD	PBM	A	BERTHING MECH. (-X)	M04311A	6.75E-12
964	MOD	PBM	A	BERTHING MECH. (+X)	M09311A	4.34E-12
903	MOD	PBM	J	BERTHING MECH. (-X)	M04316J	2.92E-22
987	MOD	PBM	J	BERTHING MECH. (+X)	M09316J	2.40E-22
979	MOD	PBM	J	BERTHING MECH. (+X)	M09314J	1.89E-24
895	MOD	PBM	J	BERTHING MECH. (-X)	M04314J	2.06E-25

DSC NO.	SID	CID	PID	DESCRIPTION	PBAR	DSC (%HZ)
899	MOD	PBM	J	BERTHING MECH. (-X)	M04315J	1.38E-25
983	MOD	PBM	J	BERTHING MECH. (+X)	M09315J	1.31E-25
891	MOD	PBM	J	BERTHING MECH. (-X)	M04313J	1.26E-25
975	MOD	PBM	J	BERTHING MECH. (+X)	M09313J	2.84E-26
855	MOD	PBM	J	BERTHING MECH. (-X)	M00126J	1.52E-26
939	MOD	PBM	J	BERTHING MECH. (+X)	M05126J	9.76E-27
883	MOD	PBM	J	BERTHING MECH. (-X)	M04311J	0.00E+00
887	MOD	PBM	J	BERTHING MECH. (-X)	M04312J	0.00E+00
967	MOD	PBM	J	BERTHING MECH. (+X)	M09311J	0.00E+00
971	MOD	PBM	J	BERTHING MECH. (+X)	M09312J	0.00E+00
1007	MOD	PBM	E & G	PBM PLATE ELEMENTS	PSHELL	0.00E+00
1012	MOD	CUP	K	CUPOLA	CELAS1	9.46E-05
1010	MOD	CUP	IY	CUPOLA	M12606I2	1.32E-05
1009	MOD	CUP	IZ	CUPOLA	M12606I1	9.51E-06
1011	MOD	CUP	J	CUPOLA	M12606J	3.68E-06
1008	MOD	CUP	A	CUPOLA	M12606A	2.08E-08
1015	APP	SA	IY	SOLAR ARRAYS	FB1I2	2.71E+00
1014	APP	SA	IZ	SOLAR ARRAYS	FB1I1	1.36E+00
1013	APP	SA	A	SOLAR ARRAYS	FB1A	2.50E-05
1016	APP	SA	J	SOLAR ARRAYS	FB1J	8.67E-23
1019	APP	IEA	IY	IEA RADIATOR	FB2I2	5.81E-01
1018	APP	IEA	IZ	IEA RADIATOR	FB2I1	9.55E-02
1017	APP	IEA	A	IEA RADIATOR	FB2A	2.03E-05
1020	APP	IEA	J	IEA RADIATOR	FB2J	2.43E-22
1022	APP	TCS	IZ	HRS BEAM SPINE- TRRJ CONN	T98101I1	4.46E-01
1053	APP	TCS	E & G	TCS PLATE ELEMENTS	PSHELL	3.62E-01
1050	APP	TCS	IZ	SCISSOR BEAMS	T98155I1	3.02E-01
1034	APP	TCS	IZ	MIDDLE SIDE SCISSOR BEAM	T98106I1	2.71E-01
1038	APP	TCS	IZ	UPPER SIDE SCISSOR BEAM	T98107I1	1.62E-01
1030	APP	TCS	IZ	LOWER SIDE SCISSOR BEAM	T98105I1	1.15E-01
1039	APP	TCS	IY	UPPER SIDE SCISSOR BEAM	T98107I2	1.09E-01
1035	APP	TCS	IY	MIDDLE SIDE SCISSOR BEAM	T98106I2	4.11E-02
1026	APP	TCS	IZ	HRS BEAM CROSS BRACE	T98102I1	3.47E-02
1031	APP	TCS	IY	LOWER SIDE SCISSOR BEAM	T98105I2	2.56E-02
1051	APP	TCS	IY	SCISSOR BEAMS	T98155I2	2.08E-02
1023	APP	TCS	IY	HRS BEAM SPINE- TRRJ CONN	T98101I2	1.61E-02
1024	APP	TCS	J	HRS BEAM SPINE- TRRJ CONN	T98101J	1.46E-02
1049	APP	TCS	A	SCISSOR BEAMS	T98155A	1.28E-02
1029	APP	TCS	A	LOWER SIDE SCISSOR BEAM	T98105A	1.04E-02
1033	APP	TCS	A	MIDDLE SIDE SCISSOR BEAM	T98106A	8.23E-03
1037	APP	TCS	A	UPPER SIDE SCISSOR BEAM	T98107A	5.06E-03
1052	APP	TCS	J	SCISSOR BEAMS	T98155J	2.14E-03
1027	APP	TCS	IY	HRS BEAM CROSS BRACE	T98102I2	1.90E-03
1046	APP	TCS	IZ	HRS BEAM OFFSET	T98123I1	5.65E-04
1028	APP	TCS	J	HRS BEAM CROSS BRACE	T98102J	5.35E-04

DSC NO.	SID	CID	PID	DESCRIPTION	PBAR	DSC (%HZ)
1040	APP	TCS	J	UPPER SIDE SCISSOR BEAM	T98107J	5.33E-04
1036	APP	TCS	J	MIDDLE SIDE SCISSOR BEAM	T98106J	4.06E-04
1032	APP	TCS	J	LOWER SIDE SCISSOR BEAM	T98105J	2.34E-04
1021	APP	TCS	A	HRS BEAM SPINE- TRRJ CONN	T98101A	1.40E-04
1042	APP	TCS	IZ	HRS BEAM OFFSET	T98122I1	1.40E-05
1043	APP	TCS	IY	HRS BEAM OFFSET	T98122I2	1.35E-05
1045	APP	TCS	A	HRS BEAM OFFSET	T98123A	4.58E-06
1025	APP	TCS	A	HRS BEAM CROSS BRACE	T98102A	3.07E-06
1041	APP	TCS	A	HRS BEAM OFFSET	T98122A	2.95E-06
1047	APP	TCS	IY	HRS BEAM OFFSET	T98123I2	4.96E-13
1044	APP	TCS	J	HRS BEAM OFFSET	T98122J	0.00E+00
1048	APP	TCS	J	HRS BEAM OFFSET	T98123J	0.00E+00
1056	APP	TDRSS	IY	TDRSS ANTENNA	P49001I2	3.57E-03
1055	APP	TDRSS	IZ	TDRSS ANTENNA	P49001I1	2.25E-05
1054	APP	TDRSS	A	TDRSS ANTENNA	P49001A	1.74E-12
1057	APP	TDRSS	J	TDRSS ANTENNA	P49001J	2.19E-22
					$\Sigma =$	**49.71%**

APPENDIX C

SUMMARY OF SSF CRITICAL COMPONENT PROPERTIES

Top 118 Ranked Component Physical Properties

ITS PRIMARY STRUCTURE:

BULKHEAD AREA

DSC NO.	SID	CID	PID	DESCRIPTION	DSC (%HZ)	RANK
58	S3	BKHD	A	END BKHD SIDES	0.09	78
190	S1	BKHD	A	BKHD 1,4,5,7- TOP BEAM	0.07	95
118	S2	BKHD	A	BKHD 1,3,5 SIDES/X	0.06	99
346	M1	BKHD	A	BKHD 4 DIAGONALS	0.06	103
					0.28	

BULKHEAD INERTIA

DSC NO.	SID	CID	PID	DESCRIPTION	DSC (%HZ)	RANK
324	M1	BKHD	IY	BKHD 3 CROSS BEAM	0.13	61
100	S3	BKHD	IY	TRUNNION BKHD SIDES	0.12	63
332	M1	BKHD	IY	BKHD 4 SIDES -X	0.10	74
344	M1	BKHD	IY	BKHD 4 CROSS BEAM	0.10	75
127	S2	BKHD	IZ	BKHD 1,3,5 CROSS-BEAM	0.10	77
359	M1	BKHD	IZ	BKHD 5 BOTTOM BEAM	0.08	86
348	M1	BKHD	IY	BKHD 4 DIAGONALS	0.06	108
316	M1	BKHD	IY	BKHD 3 SIDES +X	0.06	110
60	S3	BKHD	IY	END BKHD SIDES	0.05	112
312	M1	BKHD	IY	BKHD 3 SIDES -X	0.05	114
367	M1	BKHD	IZ	BKHD 5 DIAGONALS	0.05	115
					0.90	

DIAGONAL AREA

DSC NO.	SID	CID	PID	DESCRIPTION	DSC (%HZ)	RANK
234	S1	DIAG	A	SIDE DIAGONAL	0.91	11
170	S2	DIAG	A	SIDE FACE DIAGONAL	0.34	25
158	S2	DIAG	A	BOT FACE DIAGONAL	0.27	34
226	S1	DIAG	A	TOP FACE DIAGONAL	0.23	43
494	M1	DIAG	A	BAY 1 (-X) SIDE DIAGONAL	0.18	47
446	M1	DIAG	A	BAY 3 (-X) SIDE DIAGONAL	0.17	48
82	S3	DIAG	A	FACES 2,3,5,6 DIAGONAL	0.17	49
470	M1	DIAG	A	BAY 2 TOP FACE DIAGONAL	0.14	58

DSC NO.	SID	CID	PID	DESCRIPTION	DSC (%HZ)	RANK
90	S3	DIAG	A	SARJ BRACE	0.14	59
482	M1	DIAG	A	BAY 4 BOT/TOP FACE DIAGONALS	0.07	93
478	M1	DIAG	A	BAY 3 BOTTOM FACE DIAGONAL	0.07	96
462	M1	DIAG	A	BAY 3 (+X) SIDE DIAGONAL	0.06	98
490	M1	DIAG	A	BAY 3 TOP FACE DIAGONAL	0.06	102
466	M1	DIAG	A	BAY 4 (+X) SIDE DIAGONAL	0.06	105
474	M1	DIAG	A	BAY 2 BOTTOM FACE DIAGONAL	0.06	106
458	M1	DIAG	A	BAY 2 (+X) SIDE DIAGONAL	0.06	111
					2.99	

DIAGONAL INERTIA

DSC NO.	SID	CID	PID	DESCRIPTION	DSC (%HZ)	RANK
500	M1	DIAG	IY	BAY 5 -X SIDE DIAGONAL	0.26	35
448	M1	DIAG	IY	BAY 3 (-X) SIDE DIAGONAL	0.19	46
228	S1	DIAG	IY	TOP FACE DIAGONAL	0.07	88
483	M1	DIAG	IZ	BAY 4 BOT/TOP FACE DIAGONALS	0.06	109
447	M1	DIAG	IZ	BAY 3 (-X) SIDE DIAGONAL	0.05	116
					0.63	

LONGERON AREA

DSC NO.	SID	CID	PID	DESCRIPTION	DSC (%HZ)	RANK
230	S1	LONG	A	MT RAIL	3.15	3
218	S1	LONG	A	TRUNNION LONGERON BAYS 1-5	1.00	10
150	S2	LONG	A	TRUNNION LONGERON	0.67	15
418	M1	LONG	A	BAY 1 TRUNNION LONGERON	0.51	17
222	S1	LONG	A	TRUNNION LONGERON BAY 6	0.33	26
398	M1	LONG	A	BAY 1 MT RAIL	0.31	28
422	M1	LONG	A	BAY 2 TRUNNION LONGERON	0.28	30
166	S2	LONG	A	MT RAIL -Z SIDE	0.26	36
70	S3	LONG	A	TRUNNION LONGERON	0.17	50
162	S2	LONG	A	MT RAIL +Z SIDE	0.15	56
402	M1	LONG	A	BAY 2 MT RAIL	0.14	57
142	S2	LONG	A	TOP (-X) LONGERON	0.11	71
78	S3	LONG	A	MT RAIL	0.08	82
74	S3	LONG	A	SECONDARY LONGERON	0.06	100

DSC NO.	SID	CID	PID	DESCRIPTION	DSC (%HZ)	RANK
426	M1	LONG	A	BAY 3 TRUNNION LONGERON	0.06	101
					7.28	

LONGERON INERTIA

DSC NO.	SID	CID	PID	DESCRIPTION	DSC (%HZ)	RANK
72	S3	LONG	IY	TRUNNION LONGERON	2.76	5
75	S3	LONG	IZ	SECONDARY LONGERON	0.49	19
76	S3	LONG	IY	SECONDARY LONGERON	0.35	24
71	S3	LONG	IZ	TRUNNION LONGERON	0.25	39
152	S2	LONG	IY	TRUNNION LONGERON	0.24	41
219	S1	LONG	IZ	TRUNNION LONGERON BAYS 1-5	0.24	42
427	M1	LONG	IZ	BAY 3 TRUNNION LONGERON	0.20	44
423	M1	LONG	IZ	BAY 2 TRUNNION LONGERON	0.10	73
396	M1	LONG	IY	BAY 4 TOP LONGERON	0.09	79
395	M1	LONG	IZ	BAY 4 TOP LONGERON	0.09	81
432	M1	LONG	IY	BAY 4 TRUNNION LONGERON	0.07	90
					4.88	

OTHER AREA

DSC NO.	SID	CID	PID	DESCRIPTION	DSC (%HZ)	RANK
514	M1	OTHER	A	BAYS 2,4 INNER BOX	0.07	97
					0.07	

OTHER INERTIA

DSC NO.	SID	CID	PID	DESCRIPTION	DSC (%HZ)	RANK
508	M1	OTHER	IY	BAY 5 END "V"	0.07	87
516	M1	OTHER	IY	BAYS 2,4 INNER BOX	0.07	92
507	M1	OTHER	IZ	BAY 5 END "V"	0.06	104
					0.20	

SPRING ELEMENTS

DSC NO.	SID	CID	PID	DESCRIPTION	DSC (%HZ)	RANK
530	ITS	-	K	MB INTERFACES	0.07	89
					0.07	

SUBSYSTEMS:

BETA JOINT

DSC NO.	SID	CID	PID	DESCRIPTION	DSC (%HZ)	RANK
596	SUB	BETA	A	BETA JOINT DIAG SUPPORT	0.07	91
					0.07	

MTI

DSC NO.	SID	CID	PID	DESCRIPTION	DSC (%HZ)	RANK
681	SUB	MTI	A	MODULE SUPPORT BEAMS	3.82	2
682	SUB	MTI	IZ	MODULE SUPPORT BEAMS	0.12	62
683	SUB	MTI	IY	MODULE SUPPORT BEAMS	0.12	64
					4.06	

MTS

DSC NO.	SID	CID	PID	DESCRIPTION	DSC (%HZ)	RANK
794	SUB	MTS	IZ	MT ARM	0.27	31
786	SUB	MTS	IZ	MT ARM	0.16	55
766	SUB	MTS	IZ	MT ARM	0.11	70
782	SUB	MTS	IZ	MT ARM	0.09	80
778	SUB	MTS	IZ	MT ARM	0.07	94
					0.70	

PMAS

DSC NO.	SID	CID	PID	DESCRIPTION	DSC (%HZ)	RANK
659	SUB	PMAS	IY	PMAS SUPPORT STRUCTURE	2.91	4
658	SUB	PMAS	IZ	PMAS SUPPORT STRUCTURE	0.75	12

DSC NO.	SID	CID	PID	DESCRIPTION	DSC (%HZ)	RANK
654	SUB	PMAS	IZ	PMAS SUPPORT STRUCTURE	0.70	14
651	SUB	PMAS	IY	PMAS SUPPORT STRUCTURE	0.45	20
653	SUB	PMAS	A	PMAS SUPPORT STRUCTURE	0.37	22
657	SUB	PMAS	A	PMAS SUPPORT STRUCTURE	0.25	37
663	SUB	PMAS	IY	PMAS SUPPORT STRUCTURE	0.24	40
667	SUB	PMAS	IY	PMAS SUPPORT STRUCTURE	0.20	45
649	SUB	PMAS	A	PMAS SUPPORT STRUCTURE	0.16	53
662	SUB	PMAS	IZ	PMAS SUPPORT STRUCTURE	0.12	65
665	SUB	PMAS	A	PMAS SUPPORT STRUCTURE	0.11	72
655	SUB	PMAS	IY	PMAS SUPPORT STRUCTURE	0.07	84
668	SUB	PMAS	J	PMAS SUPPORT STRUCTURE	0.06	107
650	SUB	PMAS	IZ	PMAS SUPPORT STRUCTURE	0.05	113
					6.44	

SARJ

DSC NO.	SID	CID	PID	DESCRIPTION	DSC (%HZ)	RANK
533	SUB	SARJ	IY	SARJ BKHDS RING JST	0.71	13
587	SUB	SARJ	PLATE	SARJ PLATE ELEMENTS	0.51	18
545	SUB	SARJ	IY	SARJ BKHDS RING OFFSETS	0.31	27
537	SUB	SARJ	IY	SARJ BKHDS SIDES	0.27	33
535	SUB	SARJ	A	SARJ BKHDS SIDES	0.16	54
548	SUB	SARJ	IZ	SARJ BKHDS RING	0.11	67
551	SUB	SARJ	A	TRUNDLE BEAM	0.11	69
539	SUB	SARJ	A	SARJ BKHDS X BEAMS	0.08	85
556	SUB	SARJ	IZ	RACE RING	0.05	118
					2.31	

STS

DSC NO.	SID	CID	PID	DESCRIPTION	DSC (%HZ)	RANK
686	SUB	STS	IZ	S4-to-SARJ (+Y END)	0.25	38
687	SUB	STS	IY	S4-to-SARJ (+Y END)	0.17	51
685	SUB	STS	A	S4-to-SARJ (+Y END)	0.14	60
					0.56	

MODULES:

PBM

DSC NO.	SID	CID	PID	DESCRIPTION	DSC (%HZ)	RANK
1004	MOD	PBM	K	RADIAL PORT PBM & ENDCONE	4.10	1
1006	MOD	PBM	K	PRESSURE TUNNEL	0.05	117
					4.16	

NODE

DSC NO.	SID	CID	PID	DESCRIPTION	DSC (%HZ)	RANK
831	MOD	NODE	K	MPLM/NODE INTERFACE	1.66	7
					1.66	

LAB

DSC NO.	SID	CID	PID	DESCRIPTION	DSC (%HZ)	RANK
810	MOD	LAB	K	LAB/NODE INTERFACE	1.12	9
802	MOD	LAB	IZ	LAB MODULE	0.08	83
					1.20	

APPENDAGES:

SOLAR ARRAY

DSC NO.	SID	CID	PID	DESCRIPTION	DSC (%HZ)	RANK
1015	APP	SA	IY	SOLAR ARRAYS	2.71	6
1014	APP	SA	IZ	SOLAR ARRAYS	1.36	8
					4.07	

IEA RADIATOR

DSC NO.	SID	CID	PID	DESCRIPTION	DSC (%HZ)	RANK
1019	APP	EPS	IY	IEA RADIATOR	0.58	16
1018	APP	EPS	IZ	IEA RADIATOR	0.10	76
					0.68	

TCS RADIATOR

DSC NO.	SID	CID	PID	DESCRIPTION	DSC (%HZ)	RANK
1022	APP	TCS	IZ	HRS BEAM SPINE-TRRJ CONN	0.45	21
1053	APP	TCS	PLATE	TCS PLATE ELEMENTS	0.36	23
1050	APP	TCS	IZ	SCISSOR BEAMS	0.30	29
1034	APP	TCS	IZ	MIDDLE SIDE SCISSOR BEAM	0.27	32
1038	APP	TCS	IZ	UPPER SIDE SCISSOR BEAM	0.16	52
1030	APP	TCS	IZ	LOWER SIDE SCISSOR BEAM	0.11	66
1039	APP	TCS	IY	UPPER SIDE SCISSOR BEAM	0.11	68
					1.76	

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13. ABSTRACT (*Maximum 200 words*)

This report documents the conceptual design study performed to evaluate design options for a subscale dynamic test model which could be used to investigate the expected on-orbit structrual dynamic characteristics of the Space Station Freedom early build configurations. The baseline option was a "near-replica" model of the SSF SC-7 pre-integrated truss configuration. The approach used to develop conceptual design options involved three sets of studies: (1) evaluation of the full- scale design and analysis databases, (2) conducting scale factor trade studies, and (3) performing design sensitivitiy studies. The scale factor trade study was conducted to develop a fundamental understanding of the key scaling parameters that drive design, performance and cost of a SSF dynamic scale model. Four scale model options were estimated: 1/4, 1/5, 1/7, and 1/10 scale. Prototype hardware was fabricated to assess producibility issues. Based on the results of the study, a 1/4-scale size is recommended based on the increased model fidelity associated with a larger scale factor. A design sensitivity study was performed to identify critical hardware component properties that drive dynamic performance. A total of 118 component properties were identified which require high-fidelity replication. Lower fidelity dynamic similarity scaling can be used for non-critical components.

14. SUBJECT TERMS
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