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NSTS 37329
Revision C

Structural Integration Analyses Responsibility Definition for Space Shuttle Vehicle and Cargo Element Developers

Space Shuttle Program

December 2007

National Aeronautics and
Space Administration

Lyndon B. Johnson Space Center
Houston, Texas

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DESCRIPTION OF CHANGES TO

Structural Integration Analyses Responsibility Definition

for

Space Shuttle Vehicle and Cargo Element Developers

CHANGE NO.	DESCRIPTION/AUTHORITY	DATE	PAGES AFFECTED
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REV A	General revision/R37329-002	01/05/00	All
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2	Update references and appendix B/S061755	12/06/01	25,B-2

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DESCRIPTION OF CHANGES TO (Concluded)

Structural Integration Analyses Responsibility Definition

for

Space Shuttle Vehicle and Cargo Element Developers

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Note: Date reflects latest approval dates of Change Requests received by the Payload Integration Library System.

Any proposed changes to this document must be submitted on a Space Shuttle Program (SSP) Integration Control Board (ICB) Change Request (CR) (SSP Forms 4040 and 4041) to the ICB Secretary. The CR must include a complete description of the change and the rationale to justify its consideration. All such requests will be processed in accordance with NSTS 07700, Volume IV, and dispositioned by the ICB Chair as a Space Shuttle Program Requirements Control Board Directive.

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STRUCTURAL INTEGRATION ANALYSES RESPONSIBILITY DEFINITION FOR SPACE SHUTTLE VEHICLE AND CARGO ELEMENT DEVELOPERS

DECEMBER 3, 2007

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DEFINITION OF ABBREVIATIONS AND ACRONYMS

α	Vehicle angle of attack
ASCII	American Standard Code for Information Interchange
ASE	Airborne Support Equipment
ATM	Acceleration Transformation Matrix
BEMSID	Boeing Electronic Messaging Services Identifier
BPN	Boeing Partners Network
B-SE	Boeing Space Exploration
CAD	Computer Aided Design
CADAR	Compatibility Analysis Data Acceptability Review
CAR	Compatibility Analysis Review
CATIA	Computer Aided Three-dimensional Interactive Application
CCP	Close Clearance Process
CD	Compact Disc
CDR	Critical Design Review
CE	Cargo Element
CG	Center of Gravity
CI	Cargo Integration
CIR	Cargo Integration Review
CLA	Coupled Loads Analysis
CMMAT	Critical Math Model and Analysis Tool
CMS	Component Modal Synthesis
CoFR	Certificate of Flight Readiness
CR	Change Request
DLA	Design Loads Analysis
DOF	Degree(s) of Freedom
DSD	Diagonal System Damping
DTM	Displacement Transformation Matrix
EAR	Export Administration Regulation
ET	External Tank
EVA	Extravehicular Activity
FAWG	Flight Assignment Working Group
FO&I	Flight Operations and Integration
FOICB	Flight Operations and Integration Control Board
fps	Feet Per Second
FRD	Flight Requirements Document
FRR	Flight Readiness Review
FTP	File Transfer Protocol

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G	Acceleration due to Gravity
GAS	Get-Away Special
GFE	Government Furnished Equipment
Hz	Hertz
I/O	Input/Output
ICB	Integration Control Board
ITAR	International Traffic-in-Arms Regulations
ICD	Interface Control Document
IDD	Interface Definition Document
IGES	Initial Graphics Exchange Specification
IP	Integration Plan
ISS	International Space Station
ISSP	International Space Station Program
JSC	Lyndon B. Johnson Space Center
JST	Joint Structures Team
KSC	John F. Kennedy Space Center
LSDP	Loads and Structural Dynamics Panel
LTM	Load Transformation Matrix
LWT	Lightweight External Tank
MB	Megabyte
MDP	Maximum Design Pressure
MIP	Mission Integration Plan
MLP	Mobile Launch Platform
MM	Math Model
MSFC	Marshall Space Flight Center
MUF	Manifest Uncertainty Factor
NASA	National Aeronautics and Space Administration
NASTRAN	NASA Structural Analysis System
NSTS	National Space Transportation System
ODS	Orbiter Docking System
OMS	Orbiter Maneuvering System
ORU	Orbiter Replacement Unit
OTM	Output Transformation Matrix which can include acceleration (ATM), displacement (DTM), and Load Transformation Matrices (LTM)
OV	Orbiter Vehicle
PDR	Preliminary Design Review
PE	Performance Enhancement
PGHM	Payload Ground Handling Mechanism
PIH	Payload Integration Hardware

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PILS	Payload Integration Library System
PIP	Payload Integration Plan
PMSF	Payload Model Submittal Form
PSRP	Payload Safety Review Panel
PVLR	Preverification Loads Review
RCS	Reaction Control System
RMS	Remote Manipulator System
ROEU	Remotely Operated Electrical Umbilical
ROFU	Remotely Operated Fluid Umbilical
RP	Reverse Proxy
SC	Support Contractor (United Space Alliance and Boeing Space Exploration)
SEI&I	Systems Engineering and Integration
SIP	Standard Integration Plan
SLWT	Super Lightweight Tank
SRB	Solid Rocket Booster
SSP	Space Shuttle Program
SSV	Space Shuttle Vehicle
STD	Standard
STS	Space Transportation System
SVP	Structural Verification Plan
SWG	Structures Working Group
TAEM	Terminal Area Energy Management
TDM	Technical Discipline Manager
TIM	Technical Interchange Meeting
TMP	Triple Matrix Product
UF	Uncertainty Factor
USA	United Space Alliance
VADAR	Verification Analysis Data Acceptability Review
VAR	Verification Acceptance Review
VLA	Verification Loads Analysis

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GLOSSARY

Abort Landings	Those landings that result from a Shuttle vehicle problem and includes Return to Launch Site aborts, abort once around, and other similar possibilities. The abort landing cases utilize the launch cargo bay manifest (not the planned landing cargo manifest).
Cargo	Also referred to as the Cargo System. This is the total complement of Cargo Elements (CEs) (one or more) including support equipment, that is carried on any one flight. In other words, everything contained within the Orbiter cargo bay plus other equipment, and hardware. This includes consumables located elsewhere in the Orbiter, which are user-unique and are not carried on board as part of the basic Orbiter.
Cargo Element	A system or sub-system that is stowed in the Orbiter cargo bay either mounted to the Orbiter using longeron and keel trunnions or mounted to a sidewall carrier (e.g. Get-Away Special (GAS) Beam) or to another cargo subsystem. This entity consists of the specific complement of instruments, Space equipment, and support hardware that is required to be carried into Space in order to achieve the CEs specific objectives.
Contingency Landings	Those cases in which a CE malfunction has occurred or an Orbiter on-orbit failure has occurred that requires return of the vehicle with a cargo bay manifest that is neither the launch nor the planned landing manifest. Examples of contingency landing configurations are when one CE has been deployed and another could not be deployed due to some failure (either CE related or with the Orbiter) or when a deployed satellite could not be retrieved and restowed into the cargo bay.

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Deployable CE	This is a CE that is removed from the Orbiter cargo bay while the Orbiter is in orbit. If the CE is eventually retrieved and restowed into the cargo bay, the CE is required to comply with all returnable payload requirements. If the CE is intended not to ever be retrieved and restowed, the CE is considered as “non returnable”.
Mixed Cargo	The term mixed cargo is used when more than one CE is carried in the Orbiter cargo bay. These CEs are generally under the cognizance and control of more than one user or discipline, and no overall mission manager has been designated. Mixed cargoes include all associated user-provided Airborne Support Equipment (ASE) required to operate the CEs in space.
Nominal Landing	The landing that is planned to occur after the completion of a successful mission. These are also referred to as the no failure landings or returnable CE landings.
Non Returnable CE	This is a CE that is not intended to ever be returned by the Shuttle Vehicle. Nonreturnable CEs must be designed to and compatible with abort landing requirements however.
Returnable CE	A CE which is planned for return from orbit by the Shuttle, whether it be on the mission on which it is launched, or on subsequent missions.

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PURPOSE

The purpose of this document is to define the various responsibilities related to the structural analyses that are performed in the Space Shuttle Program (SSP) Cargo Integration (CI) discipline. Responsibilities for the Cargo Element (CE) and Space Shuttle Vehicle (SSV) structural math models, forcing functions and integrated analyses are defined. This document also controls the integrated analysis protocols between the CE developers and the SSP. It defines the standard structural analytical services that are provided by the SSP; those services that the CE developer may wish to negotiate with the SSP as additional services; math model and response data transmittal protocols; and necessary math model data recoveries to perform the integrated analysis. The CE math model accuracy and verification requirements are controlled by the most current version of NSTS 14046 “Payload Verification Requirements” (Reference 1).

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1.0 INTRODUCTION

As a part of the Space Shuttle Program (SSP) Cargo Element (CE) integration process, a series of structural analyses will be performed to verify the structural compatibility of the CE with the Orbiter and with other CEs in the cargo bay manifest. This document defines the responsibilities of the participants in this effort. A summary of responsibilities and a generic process flow for CE hardware design and certification for flight on board the Space Shuttle Vehicle (SSV) is presented in Appendix A. For the purposes of this document, the SSP is represented by the Flight Operations and Integration (FO&I) Office (National Aeronautics and Space Administration (NASA) Lyndon B. Johnson Space Center (JSC), Mail Code MO) and refers only to the Cargo Integration (CI) portion of the total Shuttle Program.

This document describes the standard Verification Loads Analysis (VLA) process, standard and optional VLA outputs that are provided, and the structural math models and forcing functions (including dynamic and quasi-static) that are to be used for the VLA and to support the CE developer Design Loads Analysis (DLA).

This report is structured into these sections: Section 2.0, which defines the SSP responsibilities, and Section 3.0, which defines the CE developer responsibilities and the following Appendices:

A. Responsibility Summary and Process Flow

B. SSV Math Models and Forcing Functions

C. VLA Overview

D. CE Design Loads Report Contents

E. SSV Math Models and Forcing Functions Request Process

F. CE Data Requirements for Orbiter Compatibility Assessment

G. CE Computer Aided Design Model Requirements

H. Preverification Loads Review (PVLR) Presenter’s Outline

I. CE Structural Math Model Data and Format Requirements

J. Verification Acceptance Review Presenter’s Outline

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K. Structures Working Group and Structural Certification

L. Coupled Loads Analysis System Damping

M. SSV Structural Math Model and Forcing Functions Format Requirements

N. VLA Data Products Format Requirements

O. SSP Loads Indicator VLA Approach and Requirements

P. Loads Combination Equation

Q. SSP Latched CE to Orbiter Clearance Requirements

R. SC Standard Provision for VLA and CAD Data File Exchange

The following Web pages contain information that the CE developer will find useful. If access to the following Web pages cannot be achieved, please contact the SSP CI Structures Technical Discipline Manager (TDM).

A. The SSP Web page address is: SSPWEB.JSC.NASA.GOV

This Web Page provides entry points to many of the other Web Pages as well as general information concerning the SSP. This includes the Shuttle manifests, schedules, libraries, and meetings. This Web page (and all pages below it) are accessible to those on the JSC network or by login/password access.

B. The SSP FO&I Office (MO) Web page address is: SSPWEB.JSC.NASA.GOV/ntdata/ssp/webdata/mo/

This Webpage provides access to Cargo Engineering schedules and charts, and the SSP CI Structures Home Page. The MO Web page also provides access to the Flight Assignment Working Group (FAWG) Web page, which provides long-range manifest and launch date schedules for the SSP.

C. The configuration management and control system for CI SSV dynamic and quasi-static models and forcing functions used for CI structural analysis has been transferred from this document to NSTS 60534 “Cargo Integration Critical Math Model and Analysis Tools (CMMAT) Database.” The CMMAT database Web page can be accessed through (scroll down to “NSTS 60534”):

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SSPWEB.JSC.NASA.GOV/webdata/pdcweb/subdocs.htm

The CMMAT Web page provides information on the latest approved revision on each of the CI math models, forcing functions, and analysis tools. Points of contact for each tool are also provided. The CMMAT database is controlled through the Flight Operations and Integration Control Board (FOICB).

D. The SSP FO&I CI Structures Home Page address is: SSPWEB.JSC.NASA.GOV/webdata/mshome/struct/st-index.htm

This Web page contains information for each mission such as presentation charts, VLA schedules, and manifests. The Web page also serves as the SSP/International Space Station (ISSP) Joint Structures Team (JST) home page and provides interpretation letters for various topics that may be of interest to CE developers. Some of these letters may be incorporated as a formal SSP requirement at a later date. Charts and information for various Technical Interchange Meetings (TIMs) are also available through this Web page.

E. The SSP Payload Integration Library System (PILS) Web page address is: SSPWEB.JSC.NASA.GOV/pils/

This page contains the various Payload Integration Plans (PIPs), Mission Integration Plans (MIPs), Standard Integration Plans (SIPs), FRDs, and other SSP CI documents.

F. The ICD 2-19001, IDDs, and CE unique ICDs can be accessed through: WWW.UNITEDSPACEALLIANCE.COM/icd/

This Web page is in the public domain.

G. The Structures Working Group (SWG) home page can be accessed through the CI Structures Home Page (Item D above). This page contains information on structural verification requirements and the SWG Payload Design Guide.
MMPTDPUBLIC.JSC.NASA.GOV/es2/structures/index.htm
This page is in the public domain.

H. The NASA Technical Standards Web site can be accessed at STANDARDS.NASA.GOV NASA
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2.0 SSP RESPONSIBILITIES

The SSP, through the SSP Cargo Integration Office (NASA JSC, Mail Code MO2), has the overall responsibility for the CI structural analysis effort, including the SSV math models, forcing functions, and analytical practices and methodologies that are used to support the SSP structural analysis efforts. As such, the SSP has approval authority over the techniques used to develop the analysis results. The bulk of this work will be performed by the Support Contractor (SC) (United Space Alliance (USA) and Boeing Space Exploration (BSE)) with SSP SWG oversight.

2.0.1 Loads and Structural Dynamics Panel (LSDP)

The LSDP is the SSP Systems Engineering and Integration (SE&I) panel that is responsible for the SSV structural activities and supports the Systems Integration activities of the SSP. Systems Integration is concerned with the integrated SSV system including the External Tank (ET), Solid Rocket Boosters (SRBs) and the Orbiter. The LSDP is responsible for all structural activity associated with the SSV. This panel is chaired by NASA-JSC, and includes representatives from NASA-JSC, NASA-John F. Kennedy Space Center (KSC), NASA-Marshall Space Flight Center (MSFC), and the contractor community. Updated SE&I SSV system models and/or forcing function data are reviewed and approved by the LSDP.

2.0.2 Structures Working Group

The SWG has been delegated responsibility by the SSP Engineering Integration Office through Directive 149, NSTS 07700, Volume II, Book 2 for SSP CI structures activities including review and approval of CE developer’s compliance with the structural verification requirements that are specified in NSTS 14046 (Reference 1). The SWG is also responsible for review and approval of CE tests of verified structural math models, of new/revised CI SSV structural math models and forcing functions, and of structural analysis processes and techniques used to support the VLA. The SWG provides support to the Payload Safety Review Panel (PSRP) as requested. The SWG is responsible for informing the CE developers of potential changes to the SSV models and forcing functions. The SWG will review and approve all new or revised SSV models and forcing functions prior to their release to the CE developers and will work with the CE developers to resolve any problems or issues that arise from their use.

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2.1 Analysis Data Base Maintenance and Configuration Control

The SSP is responsible for analysis data base maintenance and configuration control of the CI SSV structural math models; VLA CE models; quasi-static data; and lift-off, landing, and on-orbit forcing functions. The SSP is responsible for developing and maintaining a database that contains the status of all models and forcing function data that are developed and issued to the various CE development organizations. The SSP shall document all SSV data provided to the CE developers. Each set of models, forcing functions, and quasi-static data shall be uniquely identified. SSV math models and forcing functions that are developed in support of the VLA shall be uniquely identified and documented as part of the VLA documentation.

2.1.1 SSV Dynamic Math Model Update Process

SSP SE&I contractors and NASA-KSC provide the Orbiter, ET, SRB, and Mobile Launch Platform (MLP) models, respectively. These models are maintained by each contractor or NASA center and the models are updated as required (mass data revisions, design changes, test results, analysis requirements, modeling upgrades, etc.).

Figure 2.1-1 illustrates the approach for the configuration control of the SSV SE&I Structural Math Models and Forcing Functions. Proposed or anticipated structural design changes to the various components of the SSV are reported to and reviewed by the LSDP. Once a change is approved, the revised math models are developed, integrated, and evaluated. The results are submitted to the LSDP for review, assessment, and approval.

The SSP SE&I contractor is responsible for performing element model checks and comparing old versus new model results as shown in Figure 2.1-2. The new models are assembled, and mode shape and frequency comparisons of old versus new model data are made. These data are reported to the LSDP, which is the focal point for the management of the SSP SE&I models.

Once the revised SE&I’s SSV models have been developed, CI personnel (SSP, SC, and SWG) will review the changes to determine if changes to the CI SSV models are warranted. If an update is determined to be necessary, additional analyses and benchmark studies will be performed to develop the CI structural math models that will be provided to the CE developers for DLA activities and to support the mission-specific VLAs. The SWG

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and SSP CI Office will review and approve the recommended CI SSV models. Final approval of these models will be through the SSP FOICB.

The SSP is responsible for assessing and benchmarking the impact of SSV model changes to the CE response environment. For this purpose, a pseudo CE model has been developed. SSV math models for pseudo CE studies contain three pseudo CE models that are located in the forward, mid, and aft portions of the cargo bay. Each pseudo CE has a rigid, strong back, massless frame. To this rigid frame, 35 masses with three Degrees of Freedom (DOF) each in the X, Y, and Z-directions are attached. Frequencies of these masses are tuned to 1, 2, 3, . . . 35 Hertz (Hz). Responses of these tuned DOFs are used in the evaluation of SSV model changes. However, the magnitudes of the pseudo payload response changes are not necessarily indicative of the unique CE response changes. In order to quantitatively assess potential impacts to CEs, several mission-specific Coupled Loads Analyses (CLAs) are benchmarked with the updated SSV models. Comparisons of the responses from the pseudo CE analysis and the CLAs aid in the SSP approval process. In addition, flight comparison analyses are performed to ensure that the analytical predictions are enveloping the measured flight data. Flight reconstruction and/or correlation analyses are also performed to ensure the accuracy of the analytical prediction methodology, math models, and forcing functions.

The SSP Cargo Integration Office and the SWG are responsible for determining whether the revised model shall be issued for use in CE loads analyses and/or to support the VLA process. Revised models shall be made available to the CE developer upon SSP approval. The SWG is responsible for informing the CE developers of potential changes to the SSV math model database and will work with the CE developers to resolve problems or issues that arise from their use.

The SSP is responsible for generating SSV lift-off and landing structural math models for CE DLAs and VLAs. These models are generated from detailed finite element math models of the Space Shuttle components. Models that are generated in response to a request from the CE developer contain a unique set of CE attach locations. Each individual model is identified by a unique model designation, such as CM1.0A12 or CM2.0A01. The first five digits specify the particular SSV model being used, and the last two digits are sequentially changed to individually designate and track the various CE model-specific interfaces and/or mission-specific SSV mass loading. The M6.0ZA model is the original Orbiter dynamic math model that was last updated in 1983 and is

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now obsolete, while the CM1.0A model is the latest CI Orbiter Math Model (CM1.0A = Cargo Orbiter Model Version 1.0, Revision A). The SSV math model and forcing function database is discussed in Appendix B.

2.1.2 SSV Transient Forcing Functions Update Process

Figure 2.1-2 illustrates the approach for the configuration control of the SSP transient forcing functions. Proposed or anticipated changes to the transient forcing functions are reported to and reviewed by the LSDP. Once a change is approved, the revised forcing functions are developed, integrated, and evaluated. These forcing functions are developed based on the LSDP-specified load criteria. The forcing functions are revised as required due to refined data from test and flight results or from criteria changes. These forcing function changes are presented to the LSDP for review and approval.

Once the revised SE&I's forcing functions have been developed, CI personnel will review the changes to determine if changes to the baselined CI forcing functions are warranted. If an update is determined to be necessary, additional analyses and benchmark studies will be performed to develop the forcing functions that will be provided to the CE developers for DLA activities and to support the mission-specific VLAs. The SWG and SSP Cargo Integration Office will review and approve the recommended CI forcing functions. Final approval of these forcing functions will be through the SSP FOICB.

The impact of SSV forcing function changes on the CE response environment will be assessed. The pseudo CE model is utilized in the evaluation of SSV forcing function changes (see section 2.1.1). The pseudo CE serves as an indicator for potential CE component reaction to changes in the SSV forcing functions. In addition, several mission-specific CLAs from previous missions are benchmarked with the updated SSV forcing functions. Comparisons of the responses from the pseudo CE analysis and the CLAs aid in the SSP approval process.

The SWG and SSP Cargo Integration Office are responsible for informing the CE developers of potential changes to the SSV forcing function database and will work with the CE developers to resolve problems or issues that arise from their use. A database that contains the status of all forcing function data that are developed and issued to the CE development organizations will be developed and maintained. Each lift-off and landing forcing function is uniquely identified through a numbering system. The SSV math model and forcing function database is discussed in Appendix B.

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2.1.3 SSV Quasi-Static Math Models

Quasi-static analysis is performed for the coupled cargo/Orbiter system for all mission events except for the lift-off, landing, and on-orbit transient events. Examples of quasi-static events include SRB pre- and poststaging; Orbiter maximum G loading; maximum dynamic pressure ascent; Terminal Area Energy Management (TAEM) pitch, roll, and yaw maneuvers; Orbiter thermal distortion, cargo bay pressure, and abort events. The database used to perform this analysis consists of event accelerations and Orbiter cargo bay deflections and stiffness.

SSV quasi-static structural math models will be generated to support the DLAs and VLAs. These models shall be generated from detailed finite element models of the Space Shuttle Orbiter. Models that are generated in response to a request from the CE developer contain a unique set of CE attach locations. Each individual model is identified by a unique model designation, such as CM1.0A12, where the first five digits specify the particular SSV model being used and the last two digits are sequentially changed to individually designate and track the various CE model specific interfaces and/or mission-specific SSV mass loading. Quasi-static math models are created from a constrained (at the ET/Orbiter interface) Orbiter stiffness math model.

2.1.4 SSV Quasi-Static Displacements

The SSV quasi-static displacement database shall be developed and maintained. Quasi-static deflection data shall be furnished for the various quasi-static analysis events. The data include deflections arising from mechanical and thermal loads. The on-orbit thermal deflection data is from the 5.4 loads cycle (Orbiter internal loads model 5.1) and is documented in Reference 2, SD73-SH-0069, “Structural Design Loads Data Book, Orbiter Internal Loads,” Volume 7D. Orbiter deflection data (for other than on-orbit thermal load conditions) is obtained from the 6.0 loads cycle, “Structural Design Loads Data Book, Volume 5, Orbiter Internal Loads,” STS 85-0169, dated September 1989 (Reference 3).

The finite element Orbiter internal loads model M6.0 was used to calculate deflections for the applied mechanical and thermal loads. The responses to 153 individual quasi-static load conditions were derived. These responses were then combined in various combinations with each other (thermal, mechanical, and pressure), and with the responses from the landing transient analyses, to arrive at a total of 1553 quasi-static conditions that are evaluated.

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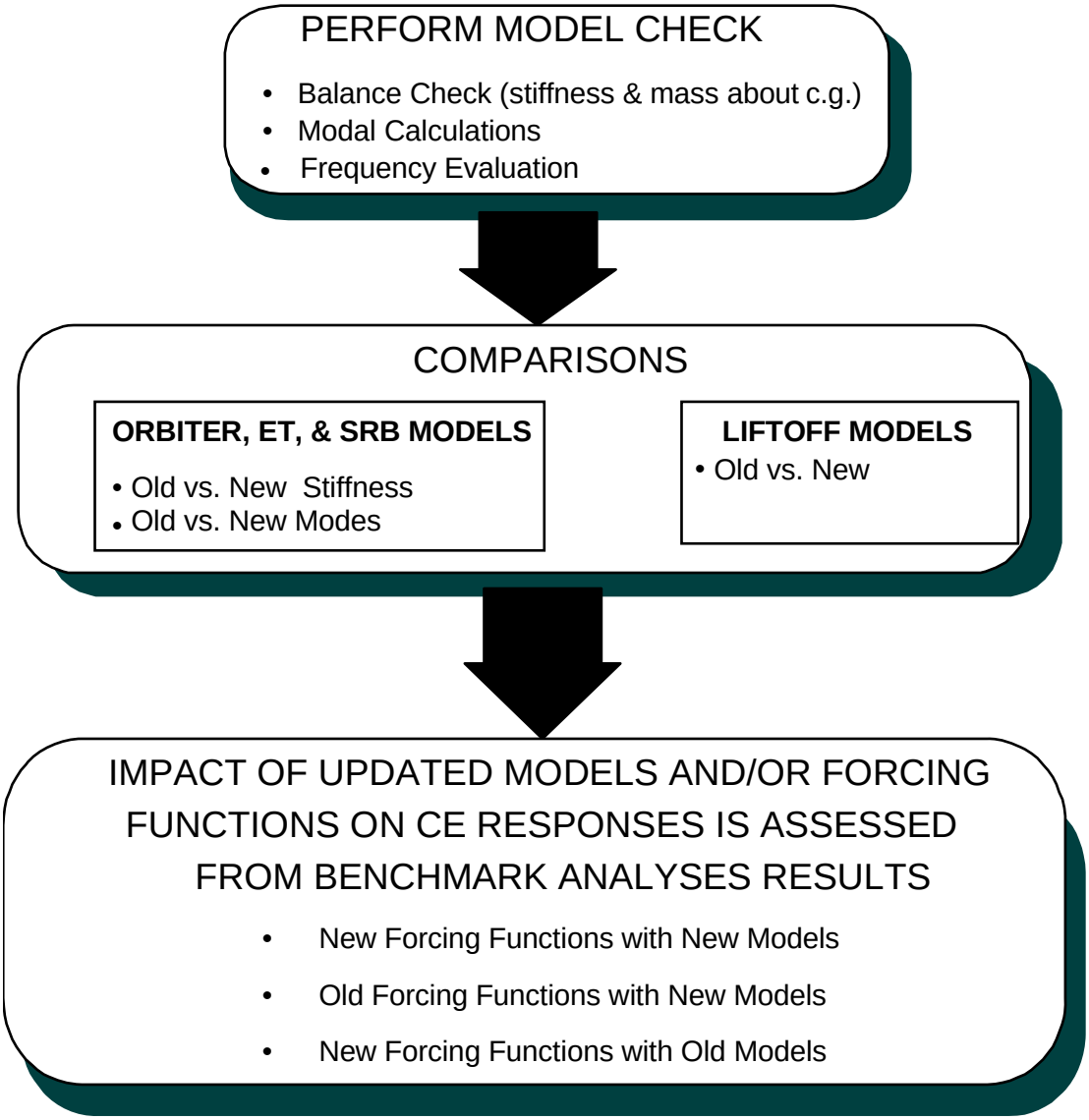

Figure 2.1-1.- SSV math model and forcing function evaluation.

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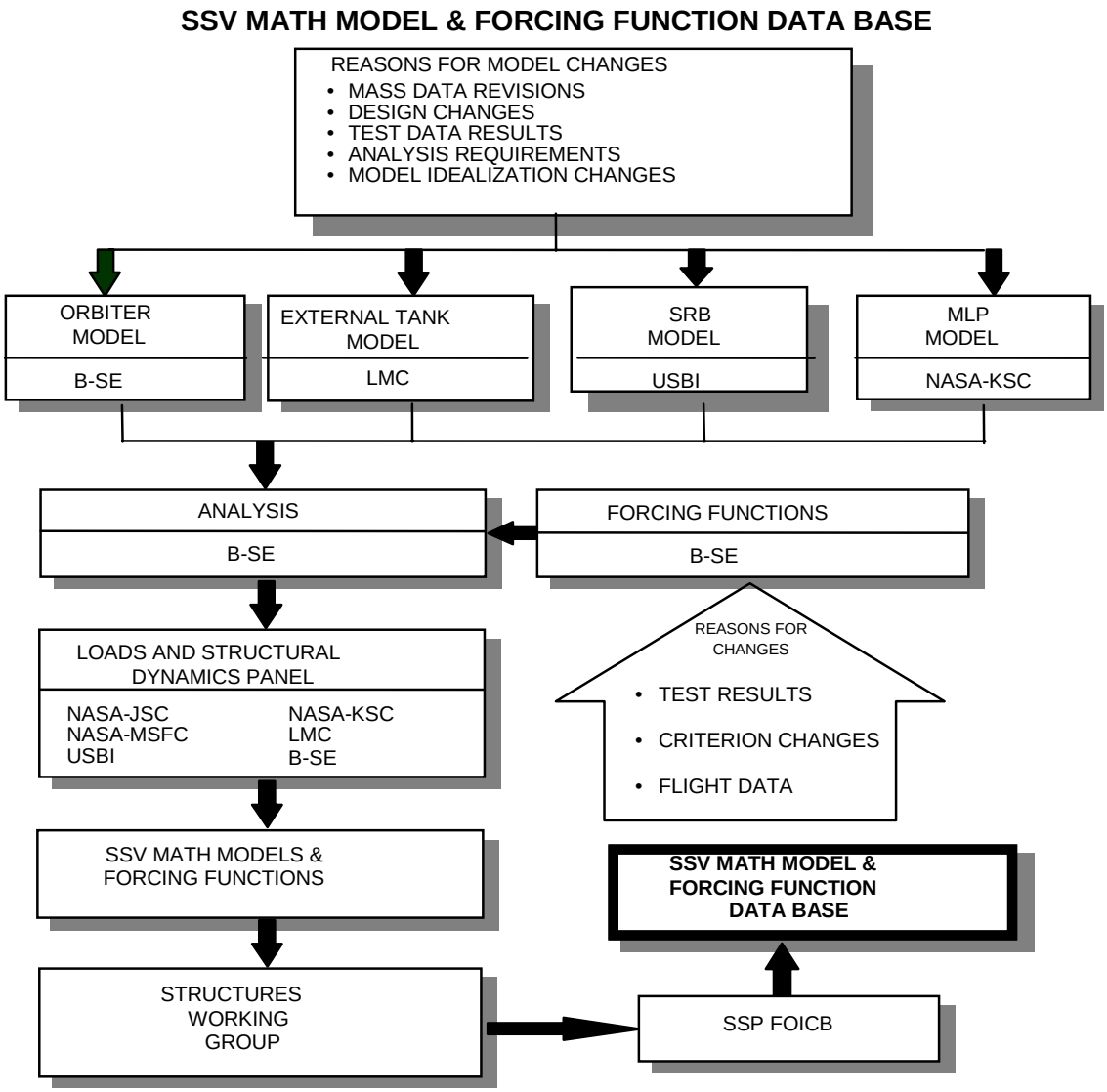

Figure 2.1-2.- SSV math model and forcing function configuration control.

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The changes that were made to the quasi-static analysis to accommodate Performance Enhancements (PEs) are described in Reference 4, BNA TM 270-400-98-026, "M6.0 Quasi-Static Conditions with Performance Enhancements Updates for Payload Loads Analysis."

2.1.5 CE Math Model Data Base

A database of all CE math models used in the VLAs shall be developed and maintained. This database will include all pertinent CE math model documentation.

2.2 COMPATIBILITY ASSESSMENT

The SSV compatibility assessment shall utilize the CEs developer’s latest DLA results and Computer Aided Design (CAD) models. Design loads analysis data from each CE developer shall be delivered to the SSP no later than L-13 months. If the CE is reflight hardware, then it is acceptable for the CE developer to submit an envelope of previous VLA results. The purpose of the compatibility assessment is to identify any issues that may cause CE to SSV hardware concerns such as relative motion and clearances so that those concerns can be addressed and resolved early in the CE design phase. The VLA will verify that the resolution is acceptable for the specific mission being analyzed.

Clearance assessments include grapple fixtures and other CE hardware protrusions that are near or are outside the 90-inch radius CE thermal and dynamic envelope, clearances with the Payload Ground Handling Mechanism (PGHM), cargo bay door/ radiators, mission kits, docking interfaces, and Extravehicular Activity (EVA) access and operational clearance envelopes. Orbiter/CE structural compatibility assessments include Orbiter/CE interface loads, Orbiter/CE interface relative displacements, and the dynamic clearance between the Orbiter and the CE hardware while the longeron and keel latches are closed. Grapple fixture EVA access and operational clearance envelopes are checked against the requirements that are specified in the applicable SSP requirements document (e.g., ICD 2-19001, NSTS 21000-IDD-ISS). The Orbiter interface loads capabilities and relative deflections are respectively defined in Appendices I and X of the SSP requirements document.

The CE shall remain inside the 90-inch radius thermal and dynamic envelope for all Orbiter flight conditions and avoid Orbiter

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intrusions into the envelope as defined in NSTS 21000-IDD-ISS and ICD 2-19001. The requirement for minimum acceptable dynamic clearance is 1.0-inch based on the CE and Orbiter thermal and dynamic relative motion. During latched CE flight events, the thermal and dynamic clearance shall be determined based on coupled loads and quasi-static analyses results and include all other parameters that affect clearances (e.g., CE and Orbiter manufacturing tolerances, CE thermal distortions, CE deflections due to acoustic excitation, CE deflections due to internal pressures, etc.). Data for CE to Orbiter tolerances from the CE developer shall be delivered with the DLA data at L-13 months. The minimum acceptable clearance requirement applies to all mission phases while the CE is latched in the Orbiter cargo bay. SSP approval of dynamic clearances less than 1-inch is determined on a case-by-case basis and is dependent on the thoroughness and completeness of the work performed by the CE developer. The CE developer shall follow the close clearance process that is defined in Appendix Q or equivalent.

Where CE deflection data are not provided, an assumed Orbiter/CE relative deflection of 3.0 inches will be used.

Clearances with the KSC payload canister used for ground transportation, clearances during cargo installation, and clearances during CE deployment/retrieval are not covered in these assessments.

2.3 VERIFICATION LOADS ANALYSIS (VLA)

The VLA is the final official cargo system coupled dynamic and quasi-static structural analysis that is conducted prior to launch. Thus the VLA is the final structural mission risk assessment tool. Results from this analysis are used for Orbiter, Payload Integration Hardware (PIH), CE, and CE/Orbiter interface structural integrity assessments to support the Verification Acceptance Review (VAR), the Certificate of Flight Readiness (CoFR) process, and the Flight Readiness Review (FRR). A mission-specific VLA is performed for the SSP-specified Orbiter cargo bay manifest as a standard service. An overview of the VLA process and template is presented in Appendix C.

The SSP is responsible for the successful execution of the VLA and is responsible for the analytical accuracy and quality of the VLA products. The VLA shall utilize proven structural analysis tools. Updates to software, incorporation of new software, and use of new computational platforms shall be benchmark tested before utilization. The SWG and the SSP CI Structures TDM shall be kept informed as to the benchmark results and shall have final

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approval authority over the use of analytical tools, methodologies, and computational platforms. Reference 24 provides requirements used by the SWG in reviewing VLA analytical tools. These requirements also apply to CE developer analysis tools that are used to perform sensitivity analyses from which results are provided to the SWG for justification of a particular math model or uncertainty factor for the elimination of a specific VLA configuration or contingency case.

The SWG is responsible for review and approval of the CE developer's math model compliance with the structural verification requirements that are specified in NSTS 14046 (Reference 1). The SWG also reviews and approves all new or revised VLA structural analysis processes and techniques used by the SC.

Upon receipt of the CE-provided math models and documentation, analytical checks will be performed to ensure that the model has been accurately received, that the minimum and maximum frequency requirements have been complied with, and that the CE math model is mathematically acceptable. The math model checks include, but are not limited to, weight and Center of Gravity (CG), strain energy, free-free modal analysis, and a modal analysis with the CE constrained at the Orbiter attach DOF. The results of these checks are compared to the comparable values that are contained within the CE developer provided documentation (see Appendix I). These checks do not address math model accuracy versus the flight hardware.

2.3.1 Analysis and Data Dump

The latest SSP baselined SSV lift-off and landing dynamic models will be utilized for generating the VLA mission-specific models with the FRD defined CE attach points for the mission-specific cargo bay manifest. Mission-unique SSV mass properties shall be used to develop the VLA math models. A quasi-static model with deflections shall also be generated. A copy of the VLA dynamic and quasi-static models and associated forcing functions can be provided to the CE developers upon request to the SSP. The SSV dynamic models can be provided in Rubin-MacNeal free-free/residual flexibility, and/or Craig-Bampton fixed modal form as documented in references 5 and 6.

If required, an on-orbit VLA will be performed as a standard service. These analyses shall be performed on an "as needed" basis depending on CE on-orbit configurations and operations.

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The latest baselined on-orbit Orbiter math model and CE model(s) that are provided by the CE developer(s) shall be used. The analyses shall be performed using SSP approved forcing functions based on mission plans and system requirements. System modal cutoff frequency for on-orbit analyses is configuration and operation specific and shall be coordinated with the SSP and SWG prior to the analysis. The analytical treatment of damping is described in Appendix L. Mathematical checks of all on-orbit math models shall be performed.

The standard VLA guidelines shall be complied with unless instructed otherwise in writing by the SSP CI Structures TDM and SWG. This includes SSV/CE system modal fidelity up to and including 35 Hz. The following standard analysis response outputs shall be provided and shall be documented for each VLA:

1. Maximum and minimum Orbiter/CE interface loads

2. Maximum and minimum relative deflections at selected CE points

3. Maximum and minimum net CG load factors for each CE

4. Maximum and minimum CE Output Transformation Matrix (OTM) recoveries

5. Orbiter/CE interface loads time histories (if requested)

6. CE generalized response time histories (if requested)

A total of 2000 OTM recovery items for each CE will be considered standard. Additional output data including additional OTM items and/or time history plots can be negotiated with the SC.

The quasi-static analyses shall be performed in all VLAs. A description of the analysis methodology, selection of critical load sets, and combinations of on-orbit thermal, reentry thermal (this is further subclassified as entry thermal, TAEM, and landing thermal), and mechanical conditions are documented in Reference 4. The analysis response output is the same as for the transient analysis. The CE dynamic math model is used in the quasi-static analysis.

2.3.2 Verification Acceptance Review

The Orbiter and Payload Integration Hardware (PIH) structural assessments and the Orbiter to CE relative motion clearance assessments will be presented at the VAR. This is to include all

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pertinent structural margins and/or load ratios versus allowable load. All issues that are identified as open work at the VAR shall be worked, resolved, and closed with the SSP by the responsible party prior to L-1 month. The SSP Cargo Integration Technical Working Groups are responsible to evaluate the structural assessments and prepare comments and questions for the VAR. Written notices will be provided if additional technical data or reports are required to further clarify the structural assessment summaries.

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3.0 CE DEVELOPER RESPONSIBILITIES

The CE developer has the overall responsibility for designing, developing, building, testing, verifying, operating, and ensuring the safety of the CE including all components that are mounted to it. The CE developer is also responsible for supporting the SSP analytical and physical integration activities. Prior to flight on the SSV, all CE structures will be demonstrated to be safe for flight by a combination of analysis and tests. The CE developer is responsible for coordinating all NSTS 14046 required structural verification activities (including documentation requirements) directly with the SSP SWG.

3.1 CE DESIGN LOADS ANALYSES

The CE developer is responsible for performing all DLAs for the particular CE. These DLAs shall include the lift-off and landing transient events, quasi-static, and on-orbit analyses as appropriate for the particular CE. The CE developer shall also consider other loading events (e.g., emergency landing, Orbiter towing, and Orbiter rollout/rollback) as defined in the SSP requirements document. The landing transient events shall include launch aborts, nominal, and contingency landings. As a nonstandard service, the SSP can perform DLAs for the CE developer. Requests for DLA services to be performed by the SSP shall be submitted directly to the SSP Cargo Integration Office. The SSP Cargo Integration Office shall review resources and negotiate directly with the request to determine the scope and schedule for the requested service.

The SSV lift-off, landing, and quasi-static math models, lift-off and landing forcing functions, and quasi-static data for one CE developer designated Orbiter cargo bay configuration will be provided to the CE developer as a standard service by the SSP. The process for a CE developer to request SSV math models and forcing functions is described in Appendix E. Additional SSV models and/or forcing functions that are required to address alternate CE cargo bay arrangements and/or CE configurations can be provided as an additional service and shall be submitted to the SSP Cargo Integration Office. Updated SSV model and/or forcing functions that arise from SSV model and/or forcing function database changes will be provided to the CE developer upon request as a standard service.

The CE developer is responsible for the validity of the DLA data. It is important to note that the quasi-static flight events typically result in the minimum Orbiter-to-CE clearances and thus

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must be analyzed or otherwise enveloped as part of the CE DLA efforts. If the CE position in the Orbiter cargo bay and/or the CE mix is not known, the CE should be placed in and analyzed for multiple cargo bay locations. CE attachment locations for DLAs shall be coordinated with the SSP prior to the official request for SSV math models and forcing functions.

It is expected that the CE developer will incorporate a “model Uncertainty” Factor (UF) during the CE design stage to cover potential changes due to subsequent changes in the CE and SSV math models and possible interactions with the actual flight manifest. The specific value of the UF to be used for a particular CE shall be specified and documented by the SWG in consultation with the CE developer. The values of the UFs that shall be specified by the SWG are dependent on the particular CE being developed, expertise of the particular CE developer, development schedule, and other similar considerations. Typical UF numbers are 1.50 for Preliminary Design Review (PDR) quality models and loads analysis, 1.25 for Critical Design Review (CDR) quality models and loads analysis, and 1.10 for post-CDR models that are test verified and being used to support DLAs prior to the VLA. The CE developer should not assume that these values represent the values that the SWG will specify for a particular CE.

After the math model has been correlated with the test data, the SWG will review the model correlation and determine if it complies with the NSTS 14046 criteria. Based on the level of compliance, the SWG will specify an appropriate UF to be used in the VLA. However, if the correlation is not in compliance with NSTS 14046 criteria, the SWG may reject the math model and require the CE developer to perform further correlation analyses, additional test cases, or sensitivity analyses as deemed appropriate to be compliant with NSTS 14046 requirements. There are no limitations as to the magnitude of the SWG specified model UF to be used in the VLA. There are instances in which the SWG specified a higher model UF for the VLA than had been used in the CE DLAs. The recommended model UFs that are contained within this paragraph are consistent with those recommended in paragraph 4.2.4.2 of NASA STD 5002 (Reference 12) and in D684-10019-1 “Space Station Structural Loads Control Plan” (Reference 22).

If the CE has structure that is within 3 inches of or outside of the 90-inch radius Orbiter cargo bay thermal/dynamic envelope, or is within 3 inches of any Orbiter protrusion into the 90-inch radius envelope, the CE developer shall monitor the CE-to-Orbiter

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clearances of each of these points as part of the DLA. This will require coordination with the SSP to ensure that the SSV models that are provided include the appropriate Orbiter grid points to support the clearance calculations. The CE developer shall also ensure that the CE-unique ICD accurately documents each occurrence. When deflection or clearance data is not provided, a 3.0-inch deflection will typically be assumed unless it is known that the structure is very flexible, in which case a larger, very conservative estimate will be made by the SSP.

The CE shall remain inside the 90-inch radius thermal and dynamic envelope for all Orbiter flight conditions and avoid Orbiter intrusions into the envelope as defined in NSTS 21000-IDD-ISS and ICD 2-19001. The requirement for minimum acceptable dynamic clearance is 1.0 inch based on the CE and Orbiter thermal and dynamic relative motion. During latched CE flight events, the thermal and dynamic clearance shall be determined based on coupled loads and quasi-static analysis results and include all other parameters that affect clearances (e.g., CE and Orbiter manufacturing tolerances, CE thermal distortions, CE deflections due to acoustic excitation, CE deflections due to internal pressures, etc.). The minimum acceptable clearance requirement applies to all mission phases while the CE is latched in the Orbiter cargo bay. All close clearance points shall be addressed in the Structural Verification Plan (SVP) and included in the math model verification activities (see Appendix K). SSP approval of dynamic clearances less than 1 inch is determined on a case-by-case basis and is dependent on the thoroughness and completeness of the work performed by the CE developer. The CE developer shall follow the close clearance process that is defined in Appendix Q or equivalent.

A DLA Report that documents the DLA and clearance calculation results shall be provided by the CE Developer to support the SSP Cargo Integration Review (CIR). The report delivery schedule will be documented in the PIP or MIP. The contents of the report are defined in Appendix D.

3.2 SSV COMPATIBILITY ASSESSMENT SUPPORT

An early SSV Compatibility Assessment may be performed prior to the flight scheduled CIR due to the Close Clearance Process documented in Appendix Q. Data requirements for either the early or standard compatibility assessment are defined in Appendix F. In order to assess the Orbiter-to-CE dynamic/thermal clearances, the CE developer shall provide definition (schematic and coordinates) of all CE structure that is within 3 inches of or

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outside of the 90-inch radius Orbiter cargo bay envelope, or is within 3 inches of any Orbiter protrusion into the 90-inch radius Orbiter cargo bay envelope. A CAD 3-D model for evaluating detail clearances between the CE and Orbiter structure and to support development of the CE-unique ICD is required. CAD model requirements are specified in Appendix G.

After the SSP Cargo Integration Office and the SC have received all data required to perform an early SSV Compatibility Assessment, a Compatibility Analysis Data Acceptability Review (CADAR) will be conducted. The SSP and SC shall provide to the CE developer a description of the data to be used for the assessment. Both SSP and CE developers are responsible for reviewing the data to be used in the assessments and providing corrections prior to the start of the assessment. After the early assessment has been performed, a Compatibility Analysis Review (CAR) shall be conducted to review the results and determine follow-on activities and actions.

The results of the in-template compatibility assessment are presented at the CIR meeting.

3.3 VLA CE DYNAMIC MATH MODELS

The VLA is performed to verify that the structural integrity of each CE, all PIH, and the Orbiter are adequate for the specific mission. This analysis is performed for the specific-flight configuration and thus, it is the responsibility of the CE developer to clearly and accurately report any deviation from the actual flight configuration (both internal to the cargo bay and internal to the CE). The CE developer is responsible for presenting the pertinent CE information at the PVLR. This review establishes the VLA ground rules and is used to assure that the planned VLA will support all parties' needs. Appendix H presents an outline of the expected PVLR presentation.

In order to assess the Orbiter-to-CE dynamic/thermal clearances, the CE developer will provide definition (schematic and coordinates) of all CE structure that is within 3 inches of or outside of the 90-inch radius Orbiter cargo bay envelope, or is within 3 inches of any Orbiter protrusion into the 90-inch radius Orbiter cargo bay envelope. This data is required to ensure that the appropriate DOFs are retained in the SSV math model to facilitate clearance assessments. The CE structural math models must also include physical DOFs (or Displacement Transformation Matrixes (DTMs)) for each of these items to facilitate clearance assessments.

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The CE developer is responsible for delivering the CE dynamic math models for the VLA in accordance with the mission-specific USA defined VLA schedule. All CE model data shall be provided electronically as described in Appendix I.

CE math model fidelity and completeness are the responsibility of the CE developer. Test verified CE math models are required for the VLA. “Test verified” in this context means that the SWG has approved the CE structural math model for use in the VLA. This written approval from the SWG must be obtained prior to submitting the model for the VLA. The SWG requires written SVPs, testing plans, and model correlation reports to be submitted as described in Appendix K and NSTS 14046. Dynamic model correlation report shall be submitted no later than 4 months prior to VLA model delivery date. The math model correlation criteria are specified in NSTS 14046. If the correlation criteria are not fully complied with, the SWG may specify a model UF that will be applied to the VLA results by the SSP, and the CE developer will be required to perform the VLA hardware assessment/certification with the model UF included. It is important to note that the total CE math model must be test verified, which includes the primary structure and all secondary structural items (e.g., racks and other significant mass items) that have significant dynamic characteristics below 50 Hz. (See paragraph 5.1.1.3.2, NSTS 14046 for more details.) Since the CE hardware configuration could be different for lift-off, on-orbit, nominal landing, and contingency landings, each unique CE configuration structural math model must comply with the NSTS 14046 requirements and be approved as “test verified” by the SWG. All contingency configurations of each CE must be assessed during the VLA unless the SWG provides prior written authorization to remove a specific configuration. Logistics CEs with a large number of deployable payloads should contact the SWG very early in the development process to determine what analytical studies will have to be performed to assess the large number of contingency cases. Note that a large number of contingency cases will impact all co-manifested CEs and not just a single developer.

The SSP has established CE structural math model criteria, and guidelines to assure that consistent and adequate data relative to the actual flight manifest will be supplied to the SSP for use in performing the VLA and for assessing the results.

The following generic CE weight tolerances are applicable for all VLAs:

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a. +/- 200 pounds for across the bay CEs
b. +/- 50 pounds per sidewall carrier beam
c. +/- 50 pounds for externally mounted integrated Orbital Replacement Unit (ORU) assembly or externally mounted payload
d. +/- 50 pounds for each payload/logistic rack

If the actual measured flight weight for any payload or component is not within its tolerance listed above, then a revised math model may be required that is more representative of the actual flight configuration.

The generic CG tolerance is one (1.0) inch root-sum-square of the X, Y, and Z CG differences for each across the bay CE, each sidewall-mounted CE, externally-mounted integrated ORU assembly, and each payload/logistic rack.

Expansion of these tolerances may be possible but will require the CE developer to perform sensitivity studies that are closely coordinated with and approved by the SWG.

The SWG and the CE developer will investigate the differences between the VLA math model and the actual flight hardware and determine if the differences invalidate the VLA. If it is deemed necessary, the CE developer will be requested to update the CE math model for use in additional assessments. The updated math model will be compared to the VLA model by the CE developer and reviewed by the SWG to determine if the CE dynamic characteristics have changed. Typically, this will be done by reviewing the modal effective mass, cross-orthogonality and frequency comparisons for the two models. If the SWG determines that the VLA integrity has been compromised, another VLA will be performed using revised CE math models that are more representative of the flight article.

Any deviation from the standard VLA practice (as documented herein) must have prior written approval from the SSP. Significant additional analysis caused by late or incomplete CE input data or CE driven changes to VLA output data requirements shall be performed as an additional service. Nonstandard analyses which require significant additional effort such as nonlinear analyses, unique analysis methodology applications, or special CE math model processing or development shall be identified to the SSP as early as possible and by 18 months prior to launch at the latest. These nonstandard analyses may be considered as additional service items.

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3.4 VERIFICATION ACCEPTANCE REVIEW (VAR)

At the VAR, the CE developer has the responsibility to report the results of the CE structural assessment for the subject mission.
The VAR is an SSP review of CE structural assessments which shall be 100% complete. This includes (but is not limited to) all structural margin assessment and any open issues concerning the CE hardware relative to the mission. This assessment shall be based upon the VLA results combined with CE thermal effects, random vibration effects, CE acoustic response, CE manufacturing tolerance effects, etc. Also, an on-orbit relatch assessment and Orbiter failed open vent door thermal assessment may be required. A discussion of the required CE structural assessments to support the VAR is presented in Appendix C. The VAR presenter's outline is presented in Appendix J.

3.5 SSP REQUIREMENTS DOCUMENTATION

There are several SSP documents that the CE developers and CE structural analysts must be cognizant of and use for designing, verifying, and certifying their CEs. The top-level agreements between the CE developer organization and the SSP are documented in the PIP or MIP. These agreements define the responsibilities and schedules for performing the DLAs and VLAs along with any additional service tasks that are agreed to. Other significant requirement documents include the IDDs, NSTS 14046, and the NASA Standards (STDs).

3.5.1 Payload Integration Plans and Mission Integration Plans

The PIP or MIP represents the CE and SSP agreement on the responsibilities and tasks that are directly related to the integration of the CE into the Space Shuttle. PIPs are used for non-Space Station missions and MIPs are used for Space Station missions. These documents identify the nonstandard services that have been agreed to for the particular CE. The PIP or MIP provides the management roles and responsibilities and defines the technical activities, interfaces, and schedule requirements for accomplishing the integration, launch, flight operations, and postlanding operations of the CE. Section 6.1 of the PIP or MIP identifies the structural activities that have been agreed to for the particular CE.

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3.5.2 Interface Definition Documents

The Space Shuttle provides many interfaces and services to the CEs. The IDDs define and control the design of interfaces between the Orbiter and the CE. These documents provide information concerning available attach locations within the Orbiter cargo bay; preliminary design load factors for the various Orbiter flight loading events; thermal, pressure, acoustic, and random vibration environments; and other required information. Questions regarding any of these documents should be referred to the SSP or SWG personnel. The CE developer is expected to fully comply with the latest version of each of these documents. These interfaces and services are physical as well as functional and are defined in the following documents:

a.	NSTS-21000-IDD-ISS, “International Space Station (ISS) Interface Definition Document,” which is intended to be used by ISS across the Orbiter cargo bay CEs (Reference 7).
b.	Interface Control Document (ICD) 2-19001, “Shuttle Orbiter/Cargo Standard Interfaces,” which is intended to be used by non ISS across the Orbiter cargo bay CEs (Reference 8).
c.	NSTS-21000-IDD-SML, “Shuttle Orbiter/Small Payload Accommodation Interfaces,” which is intended to be used by all CEs that are mounted to Orbiter sidewall carriers (Reference 9).
d.	NSTS-21000-IDD-MDK, “Middeck Interface Definition Document,” which is intended to be used by all CEs that are mounted inside the Orbiter crew cabin (Reference 10).

3.5.3 NSTS 14046, Payload Verification Requirements Document

CE verification is considered a primary step toward certification of that CE for flight. It is the responsibility of the CE developer to verify compatibility of CE physical and functional interfaces with the applicable interface agreements. The SSP intends to provide the CE developer maximum flexibility in determining the manner or method to be used to accomplish this verification. All CE physical and functional compliance must be accomplished prior to installation of the CE into the Orbiter cargo bay. CE structural verification requirements are specified within the NSTS 14046, Payload Verification Requirements Document. All CEs must comply with the requirements that are specified within the latest version of NSTS 14046, including all sidewall-mounted CEs, all across the bay CEs (including all ISS CEs), and CEs that are mounted or installed in the crew cabin.

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Since the CE hardware configuration could be different for lift-off, on-orbit, nominal landing, and contingency landings, each unique CE configuration must comply with the NSTS 14046 requirements. All structural verification plans, test plans, correlation reports, etc., shall be submitted directly to the SSP and the SWG for review and approval. Submittals that are included within design review documentation, safety packages, or that are submitted to other entities will not be considered as satisfying NSTS 14046 structural verification requirements. The schedule for each submittal is included within Appendix K along with the recommended contents.

3.5.4 NASA Standards

Several NASA STDs concerning structures have been developed and approved and are listed as References 11 through 15. The NASA STDs provide a NASA-wide common basis for recommended engineering practices and test programs that provides consistency across NASA and its contractors. These NASA STDs are consistent with SSP requirements and practices and are included as applicable documents in the SSP requirement documents.

NASA-STD-5001 defines the factors of safety that are to be used for all CEs to be flown on the SSV. Since different factors of safety are specified for different materials, load sources, etc, a process for combining loads from these different sources is necessary. The SSP approved process for combining loads is defined in Appendix P.

3.5.5 Safety Critical Mechanical Systems Requirements

The CE developer is responsible for compliance with the safety critical mechanical systems requirements. A mechanical system is defined as safety critical if its failure to function or premature function will lead to a critical or catastrophic hazard as defined in NSTS 1700.7B. The PIP, NSTS 18798, “Interpretation of NSTS Payload Safety Requirements,” and NSTS 14046 contain the various requirements that must be complied with. The CE safety critical mechanical systems verification requirements are specified within NSTS 14046.

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REFERENCES

The following list of documents is applicable as of the publication date. The CE developer is responsible for complying with the latest SSP requirements as specified in the following documents and any subsequent updates. The latest revision of SSP documents can be obtained from the PILS which can be accessed from the SSP Home Web page (e.g., http://sspweb.jsc.nasa.gov).

1. "Payload Verification Requirements," NSTS 14046, Latest Revision

2. "Structural Design Loads Data Book, Orbiter Internal Loads," Volume 7D, SD73-SH-0069

3. "Structural Loads Data Book, Volume 5, Orbiter Internal Loads," STS 85-0169, dated September 1989

4. Ali, A. M. and Sharma, R., "M6.0 Quasi-Static Conditions with Performance Enhancements Updates for Payload Loads Analysis," BNA TM 270-400-98-026

5. MacNeal, Richard H., "A Hybrid Method of Component Mode Synthesis," Computers and Structures, Volume 1, pp. 581-601, Pergamon Press, 1971

6. Craig, Jr., Roy R. and Bampton, Mervyn C. C., "Coupling of Substructures for Dynamic Analysis," AIAA Journal, Volume 6, No. 7, pp. 1313-1319, July 1968

7. NSTS-21000-IDD-ISS, "International Space Station Interface Definition Document," Latest Revision

8. ICD 2-19001 "Shuttle Orbiter/Cargo Standard Interfaces," Latest Revision

9. NSTS 21000-IDD-SML, "Shuttle Orbiter/Small Payload Accommodation Interfaces," Latest Revision

10. NSTS 21000-IDD-MDK, "Middeck Interface Definition Document," Latest Revision

11. NASA-STD-5001, "Structural Design and Test Factors of Safety for Spaceflight Hardware," June 21, 1996

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12. NASA-STD-5002, “Load Analyses of Spacecraft and Payloads,” June 21, 1996

13. NASA-STD-5003, “Fracture Control Requirements for Payloads Using the Space Shuttle,” October 7, 1996

14. NASA-STD-7001, “Payload Vibroacoustic Test Criteria,” June 21, 1996

15. NASA-STD-7002, “Payload Test Requirements,” July 10, 1996

16. Item deleted

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20. Shimizu, Michael W. and Sullivan, Andrew J., "Landing Forcing Function 7000 Series Data Base," BNA Document No. STS86-0020A, February 1988

21. Foist, Brian and Tong, Hana, “SSV Dynamic Math Model (CM2.0A) for On-orbit Loads Analysis,” Boeing Technical Memorandum SCB0.SJF0.2001.053, November 2001

22. Boeing International Space Station Alpha Program Document D684-10019-1, “Space Station Structural Loads Control Plan,” March 1994

23. Walls, William T., “Stud Hang-Up Liftoff Forcing Functions (CLO1013-CLO1030) for Space Shuttle Vehicle Cargo Element Loads Analysis,” Boeing NASA Systems Houston Technical Memorandum CINS–TM-04-027, May 14, 2004

24. NASA/JSC Memorandum MO2-04-018, “Requirements for Software Tools Used in the Space Shuttle Program (SSP) Cargo Integration Verification Loads Analysis (VLA) Process,” August 10, 2004

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APPENDIX A

RESPONSIBILITY SUMMARY AND PROCESS FLOW

This appendix presents a summary of the Cargo Integration (CI) structural analysis responsibilities and process flow.

The NASA-JSC SSP Flight Operations and Integration Office

Responsible for the overall process leading to Cargo Element (CE) hardware certification for flight. This includes responsibility for the Verification Loads Analysis (VLA) process.

Final approval authority for any deviation from VLA template schedule (see appendix C) and/or VLA approved processes.

Responsible for oversight of the Structures Working Group (SWG).

Responsible for the Close Clearance Process (CCP) defined in Appendix Q.

Responsible for Certification of Flight Readiness (CoFR) endorsement for all SSP CI activities for any given flight.

The Loads and Structural Dynamics Panel

Responsible for the review/assessment/approval of the source data utilized in forming the Space Shuttle Program (SSP) Systems Engineering and Integration (SE&I) Space Shuttle Vehicle (SSV) math models and forcing functions.

The Structures Working Group

Responsible for overall technical support to the National Aeronautics and Space Administration-Lyndon B. Johnson Space Center (NASA-JSC) SSP Flight Operations and Integration Office.

Responsible for providing technical support to the Payload Safety Review Panel (PSRP) and reviewing, assessing, and approving proposed revisions to the SSP CI SSV math models and forcing functions.

Responsible for technical oversight relative to the CE developers' compliance with all SSP verification requirements. Responsible for the final approval of the CE Developer test verified structural math model and the determination of model uncertainty factors to be used in the VLA.

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Cargo Element Developer

Responsible for the CE structural integrity.

Responsible for providing DLA report to support the SSV compatibility review.

Responsible for providing structural verification plan, test plans, and test correlation reports to the SWG in a timely manner. See Appendix K for contents and schedule requirements for the various submittals.

Responsible for providing test-verified math models per the format requirements of Appendix I to support the VLA.

Responsible for CE structural assessment to be presented at the Verification Acceptance Review (VAR).

United Space Alliance

Responsible for scheduling and managing the VLA process, including chairing VLA meetings and identifying and tracking action items.

Boeing Space Exploration

Responsible for maintenance and configuration control of the SSV CI math models and forcing functions.

Responsible for delivery of pertinent SSV math models and forcing functions to the CE developers.

Responsible for assigning unique identification numbers to each SSV math model and/or forcing functions that are provided to the CE developers and maintaining a database for tracking each model.

Responsible for maintaining the CE math model database including all pertinent CE math model documentation.

Responsible for the performance of the SSV compatibility assessment based upon the CE developer provided DLA and Computer Aided Design (CAD) models.

Responsible for performing the VLA and disseminating the data.

Responsible for SSV and Payload Integration Hardware structural assessment to be presented at the VAR. This includes hardware-to-envelope and hardware-to-hardware clearance assessments.

The following three flow charts depict the typical CE design, verification, and VLA process.

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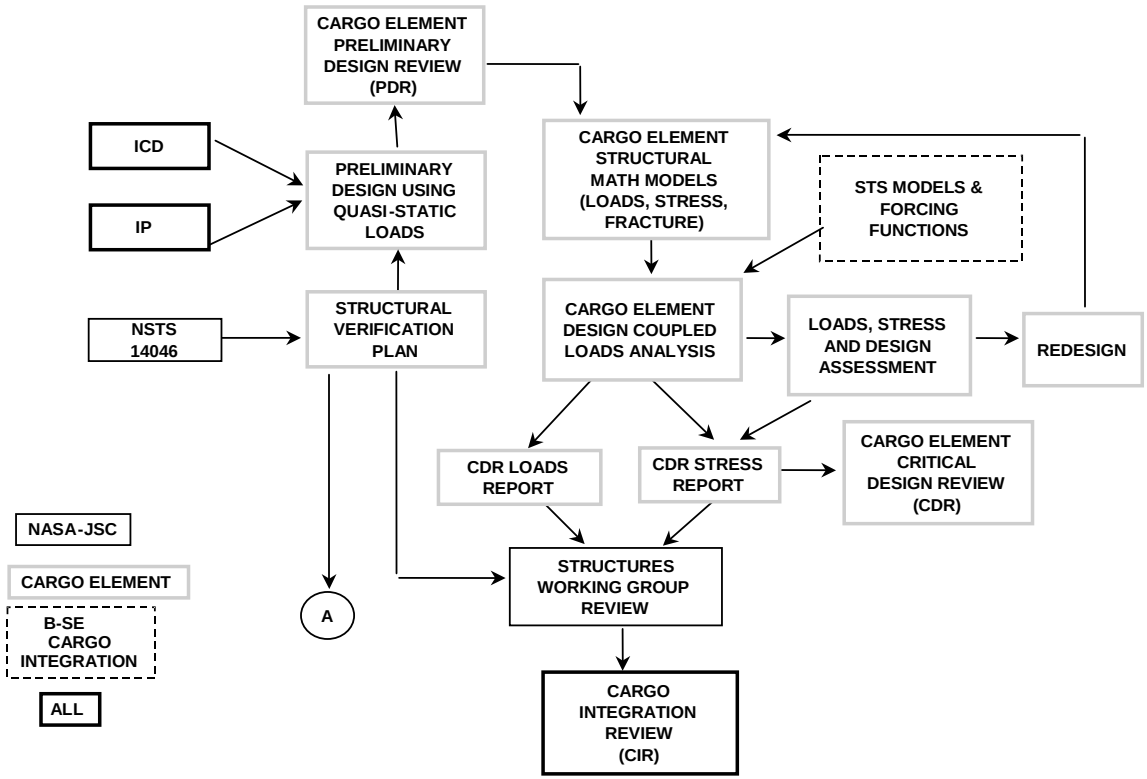
STRUCTURAL DESIGN AND LOADS- DESIGN



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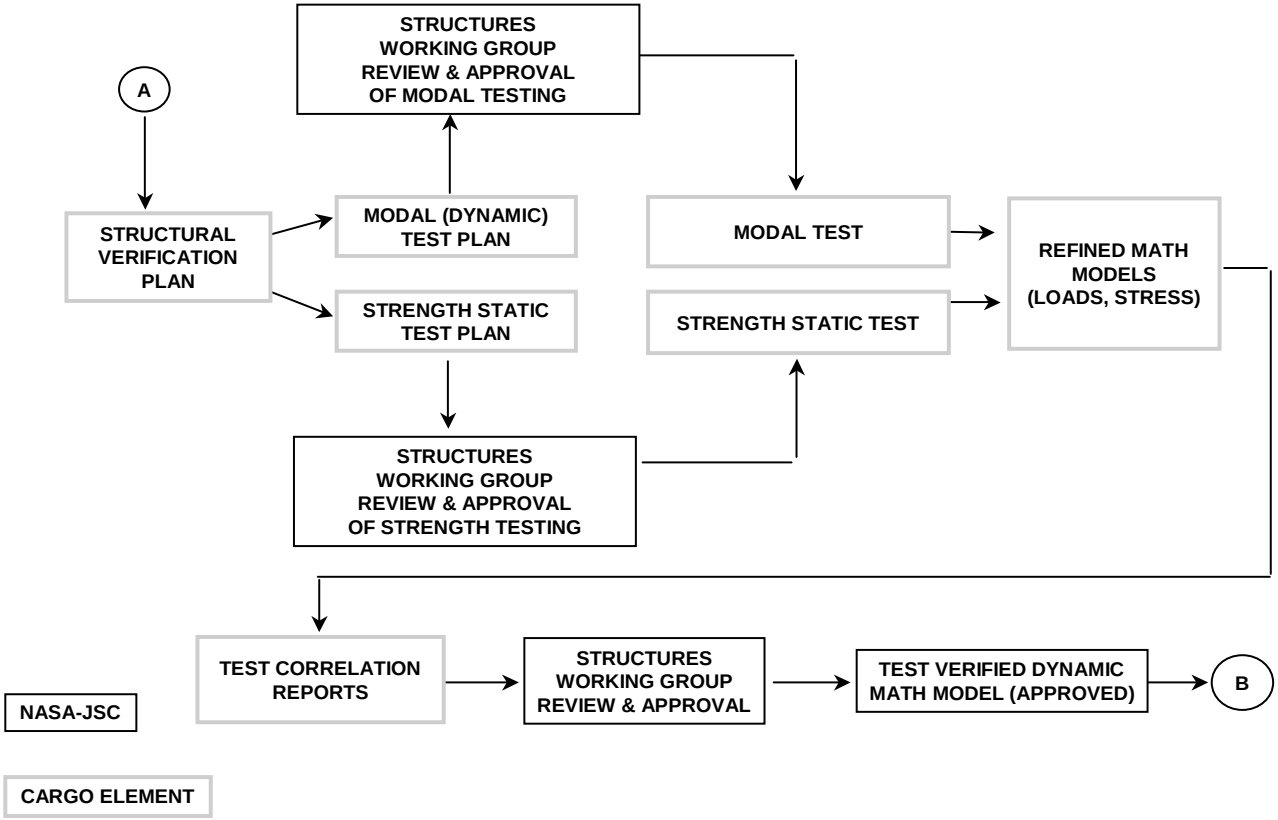
STRUCTURAL DESIGN AND LOADS - TESTING



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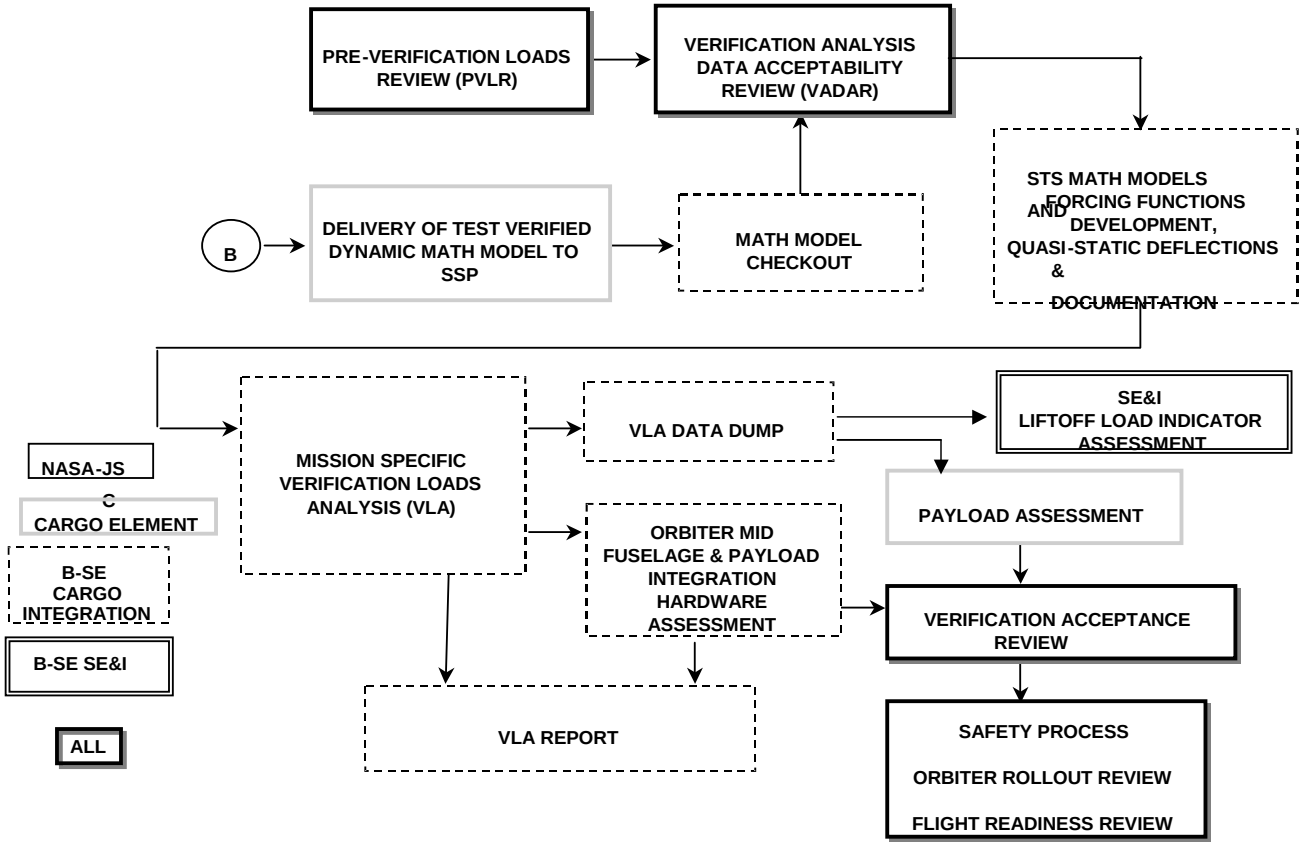
STRUCTURAL DESIGN AND LOADS -VERIFICATION



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APPENDIX B

SPACE SHUTTLE VEHICLE MATH MODELS AND FORCING FUNCTIONS

Cargo Integration (CI) Space Shuttle Vehicle (SSV) math models and forcing functions are configuration controlled through the Flight Operations and Integration Control Board. Information on the most current revision of all models and forcing functions is stored in NSTS 60534 “Cargo Integration Critical Math Model and Analysis Tools (CMMAT) Database.”

There is one SSV lift-off structural math model that is used to support Cargo Element (CE) Design Loads Analyses (DLAs) and Verification Loads Analyses (VLAs). The lift-off structural model is documented in Reference 17, Report Technical Memorandum SCB0.SJF0.2001.031 Revision A, "Space Shuttle Vehicle Dynamic Math Models (CM1.0A) for Cargo Element Loads Analysis” and uses the Super Lightweight Tank (SLWT) and the latest CI Orbiter structural dynamic math model. This model is also referred to as the CI model. The ET model is the verification cycle SLWT, which represents the new flight hardware. The previous Orbiter models M6.0ZA, M6.0ZB and M6.0ZC are now obsolete and shall not be used.

The lift-off forcing functions are applicable for all CE weights and include the effects of a three-sigma Solid Rocket Booster (SRB) ignition overpressure and also the effects of 1, 2, and 3 SRB stud hang-ups. The first 12 lift-off forcing functions addressing the SRB ignition overpressure for the CI model are documented in Reference 19, Technical Memorandum SCB0.SJF0.2001.030 Revision A, “Liftoff Forcing Functions (CLO1000 Series) for Space Shuttle Vehicle Cargo Element Loads Analysis.” The remaining 18 forcing functions, addressing the 1, 2, and 3 stud hang-up cases, are documented in Reference 23, Technical Memorandum CINS–TM-04-027, “Stud Hang-Up Liftoff Forcing Functions (CLO1013-CLO1030) for Space Shuttle Vehicle Cargo Element Loads Analysis.”

In order to ensure that the full lift-off response envelope is assessed, the complete set of lift-off forcing functions must be included in the CE developer’s analysis. Any deviation from this requires prior written approval from the Structures Working Group (SWG) and Space Shuttle Program (SSP).

The CI Orbiter structural math model (CM1.0A) will be used for all quasi-static and landing loads analysis.

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The landing forcing functions are dependent on the Orbiter/cargo system weight, mass moment of inertia, and center of gravity (CG). Landing forcing functions are documented in Reference 20, STS86-0020A, "Landing Forcing Function 7000 Series Data Base."

Landing load conditions have been selected to adequately characterize the landing transient loading environment for CEs in the Orbiter cargo bay. There are seven sets of landing forcing functions that are provided for Orbiter/CE response analysis. These are:

a. Maximum nose gear loading
b. High α - main gear landing
c. Low α - main gear landing
d. High α - main gear landing with $+Y_0$ crosswind
e. Low α - main gear landing with $+Y_0$ crosswind
f. High α - main gear landing with $-Y_0$ crosswind
g. Low α - main gear landing with $-Y_0$ crosswind

where α is the Orbiter's angle of attack during main gear impact.

For returnable CEs nominal landing cases, a sink speed criteria of 9.6 feet per second (fps) shall be used to calculate conditions 2 through 7. Nonreturnable CEs will be analyzed using a sink speed criterion of 7.2 fps for conditions 2 through 7. Abort and contingency landing cases will also be performed using the 7.2 fps landing sink speed criteria.

The empty cargo bay on-orbit Orbiter dynamic math model is documented in Reference 21, Boeing technical memorandum SCBO.SJFO.2001.53, "SSV Dynamic Math Model (CM2.OA) for On-orbit Loads Analysis." This model is based on the CM1.0A baseline CI math model with OV-103 mass distribution and with the cargo bay doors rotated to the full open position. All standard frame attach Degrees of Freedom (DOF) necessary to couple bridge fittings and sidewall-mounted payloads to the Orbiter, as well as DOF serving as on-orbit analysis force application points, have been included in this model.

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APPENDIX C

VERIFICATION LOADS ANALYSIS OVERVIEW

The following paragraphs describe the Verification Loads Analysis (VLA) Generic Template and the various activities that occur during that timeframe. The generic VLA template timeline is shown in Table C-1 for the various events that will occur. The mission-specific VLA template will be published and maintained by the Support Contractor (SC) and may differ from the generic template. Planned multicycle VLAs will utilize the Space Shuttle Program (SSP) Loads Indicator VLA Approach that is described in Appendix O. The first cycle of a planned multicycle VLA will utilize the template described in the following paragraphs with the second and subsequent cycles being highly condensed from the generic template.

The process for supporting the VLA starts several months prior to the Preverification Loads Review (PVLR) and ends with the closure of action items resulting from the Verification Acceptance Review (VAR). Prior to the start of this process, the various Cargo Element (CE) structural analysts will be working closely with the Structures Working Group (SWG) to ensure that the NSTS 14046 payload verification requirements are met. To support the Cargo Integration Review (CIR) and the PVLR, the SSP requires a copy of the latest CE Design Loads Report at L-13 months. For reflight items, the CE design loads report can be an envelope of previous VLA loads data, but must still be submitted at the L-13 month timeframe. Preliminary thermal deflections, manufacturing tolerances, and documentation shall be delivered for each CE to the SSP SC as part of the design loads report delivery. Details on specific items that should be contained within that report are defined in Appendix D. The data contained within the design loads report is used to perform CE-to-Orbiter interface loads and clearance assessments for the planned flight manifest. Results of this assessment identify potential interface loads or clearance problems that must be closely monitored during the VLA.

The PVLR is conducted approximately 2.5 months prior to math model delivery. The PVLR is conducted so that the participants can discuss the VLA process, determine the status of each CE math model, identify VLA output data products required by each CE developer for their final structural assessment, define data transmittal procedures, and finalize the schedule of activities leading to the VAR. By the end of the PVLR, all CEs and their

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location in the cargo bay, and all VLA contingency landing manifests and landing sink rates have been finalized. The PVLR Presenter's Outline, which describes the recommended contents of the CE developer presentation, is included as Appendix H.

At or prior to the specified math model delivery date, test-verified CE structural math models and associated CE data, including thermal deflections, manufacturing tolerances, and documentation shall be delivered for each CE to the SC. All items that are identified in Appendix I must be provided at this time. If a CE changes configuration during flight, a math model will be required for each CE configuration.

Thus math models for lift-off, abort landing, contingency landings, normal landing, and on-orbit configurations may be required to support a particular VLA. All CE models, whether they are across the Orbiter's cargo bay or sidewall-mounted (primary or secondary) are due at this time. The model delivery date shown in Table C-1 assumes that a standard template VLA will be performed using the standard diagonal system damping approach. If this is not the case, the PVLR would have established a unique template, and the dates documented within the PVLR minutes would apply. VLA templates for non-linear loads analysis will be longer and require earlier math model deliveries than for a standard VLA. If a delivered math model does not comply with the NSTS 14046 payload verification requirements, SWG personnel will review the model and determine a model Uncertainty Factor (UF) that shall be included in the VLA results. The SSP will specify a Manifest Uncertainty Factor (MUF) that shall be included in the VLA results. Planned multicycle VLAs will utilize the SSP Load Indicator VLA Approach that is described in Appendix O. Each CE developer shall be required to certify that the CE structure has positive margins of safety with the VLA results, including all SWG, USA, and SSP-specified UFs and MUFs. In some cases, additional parametric analyses will be performed to determine the effect of potential errors in non-test verified math models.

At L-7 months, the Verification Analysis Data Acceptability Review (VADAR) will be conducted between the SSP, the SC, and the CE developers. This telecon will be conducted after all CE models have been received and validated by B-SE. Specific cargo bay configurations, math models, forcing functions, CE data, analysis methods, and response data recoveries that are planned for the VLA will be clearly identified by the SC. Each CE developer shall either concur with the SC-provided data or provide updated data prior to or during the VADAR. After

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completion of this review, formal authorization will be provided by USA to begin the VLA. Any changes to CE models, output products, manifests, etc., that occur after the VADAR shall have an impact to the VLA and must be coordinated with USA as soon as practical. By the end of the VADAR, all data to be provided for the VLA data dump, as well as the data recipients, data formats, and means of data delivery have been finalized and agreed to by all parties. Those agreements will be documented in formal minutes that will be distributed to all participants.

The VLA output data (this event is referred to as the VLA Data Dump) will be provided to the CE developers in the data transmittal formats, media, and contents as defined in Appendix N or, when modified, in the PVLR or VADAR minutes. The Boeing Space Exploration (B-SE) VLA results will be formally documented and will be published prior to the VAR at L-4.5 months.

The CE developer is responsible for computing CE loads and deflections due to cargo bay vibro-acoustics, pressure differentials, trunnion friction, CE thermal distortions, etc., and combining them as appropriate with the VLA results. The CE developer shall include in this assessment loads from all sources (e.g., low frequency transient, quasi-static, thermal, pressure, acoustics, random vibration, preloads, and friction) for all mission segments during which the CE hardware is attached to the Orbiter. The CE developer is also responsible for verifying that the CE thermal/dynamic envelope (including pressure, thermal, misalignment, and manufacturing tolerance effects) does not exceed the constraints as specified in the unique CE ICD, ICD-2-19001, NSTS 21000-IDD-ISS or NSTS 21000-IDD-SML as appropriate.

The CE developer shall notify the SSP and the SC as soon as possible after learning about any CE changes that would either invalidate the CE math model or exceed the specified tolerances for CE weight and center of gravity (CG) (see section 3.3 for details).

The CE developer is responsible for performing an Orbiter restow latch load assessment if a mission scenario exists where it may be necessary to relatch a deployable CE (due to an aborted mission or planned return of a CE from orbit). The force that is required to pull the trunnions down into the latches must be combined with other flight loads and assessed against the strength capability of the Orbiter and CE structure. In addition, the force that is required throughout the latching motion must be within the latch’s capability. In order to determine the relatching force, the manufacturing tolerances of

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the Orbiter and CE plus the on-orbit thermal deformation of the Orbiter and CE must be taken into account. The torque imparted to the CE in latching an out-of-plane longeron trunnion can cause the longeron trunnions to deflect in the $+/-Y_0$ direction and can cause the keel trunnion to deflect in the $-Z_0$ direction. These deflections must be considered when evaluating allowable trunnion and keel deflection limits. The procedure for evaluating these effects is described in Reference 7, NSTS 21000-IDD-ISS "International Space Station Interface Definition Document," which is applicable for International Space Station (ISS) CEs and Reference 8, ICD 2-19001 "Shuttle Orbiter/Cargo Standard Interfaces," which is applicable for non-ISS CEs. Determinately
mounted CEs require no additional force for relatching but will still impose some latch to CE relative motion.

The cargo bay vent doors are normally closed at the start of entry and do not begin to open until after peak aerodynamic heating has occurred. However, the CE developer is required to make a thermal assessment of the CE and all CE-supplied hardware considering a vent failed in the open position and remaining open throughout entry. The CE developer shall verify that this condition will not cause the CE to present a hazard to the Orbiter. A preliminary safety assessment shall be submitted to SSP and shall be made assuming a conservative, worst case condition which has the CE located directly in front of the ingested air plume with respect to the X_0 direction. A more detailed discussion of venting effects is described in NSTS 21000-IDD-ISS for ISS CEs or ICD 2-19001 for non-ISS CEs.

The VAR is conducted to review and approve the results of the SSP SC and CE structural assessments. Each CE developer shall certify during this review that all margins of safety for the CE, considering all in-flight cargo bay configurations including contingencies and aborts, are positive and that the structure is safe for all flight phases. This assessment and certification shall include all applicable UFs and MUFs. All CE assessments are to be completed and reported at the VAR. The VAR presenter's outline that describes the recommended contents of the CE developer's presentation is provided in Appendix J. VAR charts will be due at L-3.5 months with the actual meeting held 10 days later. This schedule allows the SSP Technical Working Groups to evaluate the structural assessments and prepare comments and questions for the VAR. If additional technical data or reports are required to further clarify the structural assessment summaries, written notice will be provided to the CE developer to address at the VAR meeting. If the items identified during this review are not addressed at the VAR, action items with specific due dates will be assigned. All VAR actions shall be

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closed no later than 1 month prior to launch. If circumstances arise where CE assessments cannot be completed to support the VAR, the CE shall contact USA and the SSP Flight Operations and Integration Office prior to the VAR to discuss the issue, resolution paths, and resolution schedule. The VAR meeting is an input to the SSP structural flight verification process and provides the data that will be used to support the SSP Flight Readiness Review (FRR) process.

The normal SSP Certification of Flight Readiness (CoFR) Reviews and FRR processes begin approximately 2.5 months prior to launch. The intervening time between the structures VAR and these reviews is allocated to resolve and complete all residual action items from the VLA. Open actions that extend into the CoFR or FRR process are treated as a threat to launch and shall receive considerable SSP management attention and assistance in closing the issue. Thus it is required to have all structures issues closed prior to the start of these reviews.

Table C-1 summarizes the significant VLA milestones and dates leading to flight and the appendix that contains additional information on the item.

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Table C-1
VLA generic template (single load cycle)

MILESTONE	DATE*	APPENDIX
CE Design Loads Analysis Report	L – 13.8	D
Preverification Loads Review (PVLR)	L – 10.0	H
All CE Math Models Delivered	L – 7.5	I
Verification Analysis Data Acceptability Review (VADAR)	L – 7.0	
VLA Data Dump	L – 5.5	N
VLA Report	L – 4.5	
VAR Charts Due	L - 3.5	J
VAR meeting	L - 3.2	
CoFR/FRR Start	L - 2.5	
Launch	L – 0	

* Months before launch

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APPENDIX D

CE DESIGN LOADS REPORT CONTENTS

The Cargo Element (CE) Payload Integration Plan (PIP) or Mission Integration Plan (MIP) requires that the CE developer supply a CE Design Loads Report. This report is to be delivered to the Space Shuttle Program (SSP) Support Contractor (SC) as specified in Table C-1 of Appendix C or the mission-unique Verification Loads Analysis (VLA) schedule that is published by United Space Alliance (USA). This document is required to support the Cargo Integration Review (CIR). The report provides the data from which a preliminary assessment of CE capability and Orbiter/CE compatibility can be made. As a minimum the Design Loads Report should contain the following:

a. Define the cargo bay manifest that was analyzed and the Space Shuttle Vehicle (SSV) math models and forcing functions or load cases that were used.

b. CE mass properties that include comparisons between the model and current mass properties data. Mass properties data should define the maturity level of the data being provided. The mass properties comparison shall compare mass, Center of Gravity (CG), locations, and inertia terms.

c. CE-to-Orbiter quasi-static and dynamic point-to-point relative displacements for all CE items that are within 3 inches (statically) of the 90-inch radius envelope, within 3 inches of Orbiter hardware that protrudes into the 90-inch radius envelope, or outside the 90-inch radius envelope.

d. Shuttle/CE longeron trunnion interface loads, relative displacements and loads due to trunnion out-of-planarity (misalignment).

e. Shuttle/CE keel trunnion interface loads and relative displacements.

f. Trunnion-to-Orbiter relative deflections due to CE thermal distortion and CE internal pressure relative to cargo bay.

g. Trunnion length manufacturing tolerances or measurement data.

h. Manufacturing tolerances of points used in CE-to-Orbiter relative displacement calculations, or measurement data.

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If the CE developer does not conduct a mission-specific design loads cycle, documentation shall be provided to the SSP designating which previous design loads report or previous flight VLA data is to be used for the CIR review.

The actual organization of the document may be according to the author's desires. However, the following items are requested by the SSP to be contained in the Design Loads Report.

REQUESTED DESIGN LOADS REPORT CONTENTS

1. INTRODUCTION
   1.1. Provide an organizational chart of those developing or analyzing the CE/instrument, NASA Center sponsoring the CE, the company organization, titles, mail address, electronic mail address, telephone numbers, and FAX numbers of the individuals involved.
   1.2. Provide pictorials of the CE and its major components. Coordinate systems and transformations to Orbiter reference coordinates are to be included.
   1.3. Tabulate the CEs mass properties.

2. CE DYNAMIC MATH MODEL DESCRIPTION
   2.1. Describe and provide the modal frequencies, free-free eigenvalues, Shuttle constrained eigenvalues, etc.
   2.2. Describe and provide the model checks performed for each CE (e.g., strain energy, etc.)
   2.3. List the SC provided SSV model number, forcing functions, and documentation reference used in the CE Design Loads Analysis (DLA).
   2.4. List any other load cases and documentation used in the CE DLA.
   2.5. Describe the cargo bay manifest arrangement used for the DLA.
   2.6. Describe the process that was used to develop the design loads and sources of input parameters (e.g., load factors).

3. UNIQUE ANALYSIS REQUIREMENTS
   3.1. Describe any unique analysis, non-linear analyses, interface friction, stick/slip analyses, or CE unique damping schedules that were performed.
   3.2. Describe any unique loading environments which were analyzed including Reaction Control System (RCS), On-Orbit configuration changes, Remote Manipulator System (RMS) operations, and crew induced loads.

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3.3. Describe any contingency configurations, (e.g., landing with failed CE latches, mechanism failure to retract/tilt, doors or covers failed open, etc.) which were analyzed to comply with SSP safety requirements.
3.4. Describe which of the above analyses are recommended for inclusion in the VLA.

4. ANALYSIS RESULTS (Provide loads and deflections as flight regime consistent data as appropriate (e.g., lift-off, ascent quasi-static, descent quasi-static, on-orbit, and landing)).
4.1. Transient Analysis Results
4.1.1. Lift-off analysis
4.1.2. Landing analysis (includes nominal, contingencies, emergency, and abort)
4.1.3. On-orbit analysis
4.2. Quasi-static Analysis Results
4.3. Provide a summary of the Orbiter/CE interface loads.
4.4. Provide a summary of the CE stress analyses that has been performed and the resulting Margins of Safety. The stress analysis margin tables shall include the following: item description, material, allowable used, factors of safety used, failure mode, and margin of safety. References shall be provided to actual stress analyses for each margin calculation.
4.5. Describe each structural item that is within 3 inches (statically) of the 90-inch radius envelope, within 3 inches of Orbiter hardware that protrudes into the 90-inch envelope, or outside the 90-inch radius envelope. Provide CE-to-Orbiter dynamic and quasi-static point-to-point relative deflection results for each item.
4.6. Provide the quasi-static and dynamic relative deflections of the CE at the trunnions and the points identified in 4.5 above.
4.7. Describe all uncertainty factors (UFs) that were used and how they were applied. If no UF was utilized in the CE DLA, the documentation that is submitted to Boeing Space Exploration (B-SE) shall specify a UF that is recommended by the CE developer and concurred to by the Structures Working Group (SWG) to be applied for the Orbiter/CE interface loads and relative deflection compatibility assessment. The CE structural math model maturity, mass properties maturity, extent of test-verified hardware, manifest uncertainty, and usage (or lack of usage) of the currently baselined SSV structural math models and forcing functions shall be considered in determining the recommended Uncertainty Factor (UF).

5. ACRONYM LIST

6. REFERENCES

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APPENDIX E

SPACE SHUTTLE VEHICLE MATH MODELS AND FORCING FUNCTIONS REQUEST PROCESS

The process and requirements for requesting Space Shuttle Vehicle (SSV) math models and forcing functions for a Cargo Element (CE) design loads analysis is as follows:

1. Requests for SSV math models and forcing functions originate with the CE development organization and should be scheduled per the appropriate Integration Plan (IP).

2. The formal request shall be made to the current Space Shuttle Program (SSP) Support Contractor (SC) point of contact:

   Ms. Erica E. Bruno,
   United Space Alliance (USA) USH-700D
   telephone 281-280-6945
   electronic mail address:
   “erica.e.bruno@usa-spaceops.com”.

   An advance copy should also be sent to the Boeing point of contact:

   Mr. M. Kaouk
   Boeing Space Exploration
   telephone 281-226-4721
   electronic mail address:
   “mo.kaouk@boeing.com”

   A courtesy copy should also be sent to the current chairman of the SSP Structures Working Group (SWG):

   Vincent Fogt/NASA/JSC ES6
   telephone 281-483-6391
   electronic mail address is
   “Vincent.A.Fogt@nasa.gov”

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3. Data delivery schedules are coordinated and agreed to between the CE development organization and the SSP SC. USA will provide written authorization to Boeing Space Exploration (B-SE) to proceed once the delivery schedule is baselined and agreements have been reached regarding the SSV math models and forcing functions development requirements. Authorization will not be provided until all necessary information has been provided to B-SE.

4. Six weeks are required for the development and delivery of a full SSV math model and forcing functions data package after authority to proceed is received by B-SE. Urgent requests must be coordinated with USA such that ongoing or planned SSV MM development tasks and schedules can be modified.

5. A 2-week template is required for additional quasi-static deflection data or for only landing forcing functions development and transmittal.

6. Requests for updated math models and forcing functions can be expedited when a payload developer provides a summary of changes such as attach points, mass properties, and clearance points.

7. Media and format requirements for the data transmittal are coordinated with the CE development organization. The standard data format for SSV MMs and forcing functions is defined in Appendix M.

8. The requested data are generated, transmitted to the requesting organization, and the appropriate documentation is published. See Appendix R regarding SC standard provision for Verification Loads Analysis (VLA) data file exchange.

The request for SSV lift-off/landing math models and forcing functions shall contain the following information:

1. Identification of sill longeron and keel trunnion attach locations (coordinates in the Orbiter coordinate system). Identification of primary and stabilizer trunnion locations. B-SE will verify that the specified locations are viable, based on ICD-2-19001 or NSTS 21000-IDD-ISS constraints.

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2. Alternate or potential longeron and keel locations (if any) accounting for trunnion spacing unknowns, manifest location uncertainty, or the desire to analyze the same CE in a tandem or triplet manifest configuration in the cargo bay.

3. Mass properties of the CE and CE chargeable equipment (weights and Center of Gravity (CG) referenced to the Shuttle Orbiter coordinate system).

4. Definition (schematic and coordinates) of CE structure that is located within 3 inches of the 90-inch radius thermal/dynamic envelope, within 3 inches of any Orbiter protrusion into the envelope, or that protrudes outside the envelope such that appropriate Degrees of Freedom (DOF) may be retained in the Shuttle MM to facilitate clearance assessments.

5. Definition, if known, of special mission equipment or mission kits such as the Remote Manipulator System (RMS), Orbiter Docking System (ODS), Remotely Operated Electrical/Fluid Umbilical (ROEU/ROFU), etc., and whether these items should be coupled to the Orbiter math model or provided separately. If to be provided separately, the format must be specified. The ROEU/ROFU, if required by the CE developer, shall be provided as a separate model if the Rubin-MacNeal format is used for the SSV math model. The coordinates of the ROEU/ROFU interface to the CE shall be specified. The SSP requires that response data be calculated (net load factors, Orbiter interface loads, relative deflections, etc.) and provided to B-SE for these mission equipment items to assess mission compatibility with the Orbiter.

   Where direct recoveries of these items are not feasible from the Design Loads Analysis (DLA), an Output Transformation Matrix (OTM) will be provided to facilitate the recoveries.

6. Format of the Shuttle math models (Craig-Bampton or Rubin-MacNeal free-free) shall be specified.

7. Specification of returnable or nonreturnable CE type such that the appropriate landing forcing functions can be provided. Contingency configurations shall be considered for additional landing analyses and shall be specified in the request with the appropriate mass properties.

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8. Media transmittal type and format shall be specified and are negotiable based upon the CE development organization's and B-SE's capabilities. Some options are Compact Disks (CDs) electronic transmission, and temporary guest accounts on mainframe computers. See Appendix R regarding SC standard provision for VLA data file exchange.

9. The CE desired data delivery date shall be specified. The final delivery date will be negotiated based upon the amount of MM requests in work at the time and other approved priority and nonpriority tasks in the SC request queue. Under no circumstances will a Shuttle MM begin to be developed without a complete list of requirements.

10. A single point of contact shall be specified from the CE development organization to facilitate coordination of requirements, schedules, and data transfer. Please include full name, telephone and facsimile numbers, and electronic mail address with the request.

Any request for SSV on-orbit SSV math models must contain the same information as for the lift-off/landing SSV math model with the exception of paragraphs 3, 4, and 7.

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SSV MATH MODELS AND FORCING FUNCTIONS REQUEST FORM

Requesting Organization: _____

Complete mailing address _____

Full name of point of contact _____

Phone and fax numbers _____

Electronic mail address _____

Desired data delivery date: _____

Orbiter Model to be Delivered CM1.0A (liftoff/landing) CM2.0A (on-orbit)

Cargo Element (CE) weight in pounds _____

CE center of gravity: X_0 _____ Y_0 _____ Z_0 _____

Primary longeron X_0 attach locations: _____ Alternate: _____

Stabilizer longeron X_0 attach location: _____ Alternate: _____

Keel X_0 attach locations: _____ Alternate: _____

Specify any special mission equipment: _____
(e.g., RMS, ODS, ROEU, ROFU)

Specify how the special mission equipment models are to be provided (e.g., coupled with Orbiter or stand alone separate models)

_____

ROEU/ROFU CE interface coordinates: X_0 _____ Y_0 _____ Z_0 _____

Shuttle math model format: Craig-Bampton Rubin-MacNeal Other(explain)

Landing category (returnable or non-returnable): _____

Media transmittal type (e.g., CD, electronic, FTP site): _____

(If electronic, provide necessary data) _____

NOTES:

1. All locations are to be provided in inches and Orbiter coordinate system.

2. Detailed definition (schematic and coordinates) of all CE structure that is located within 3 inches of the 90-inch radius Orbiter cargo bay thermal/dynamic envelope, within 3 inches of any Orbiter protrusion into the envelope, or that protrudes outside the envelope shall be provided. If the CE does not have any such structure, include a statement that it does not.

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APPENDIX F

CARGO ELEMENT DATA REQUIREMENTS FOR ORBITER COMPATIBILITY ASSESSMENT

In order for the Space Shuttle Program (SSP) Structures team to perform an Orbiter/Cargo Element (CE) structural compatibility assessment, the CE developer must deliver the CE current design coupled quasi-static and dynamic loads analyses report and/or data. If a formal report is not available, the data must be provided with traceability, such as a cover letter or memorandum. Other data that must be provided include the following:

1. Points of contact (name, telephone, address, e-mail, fax) from the CE developer organization for providing and answering questions regarding Computer Aided Design (CAD) models and design loads analysis results/reports.

2. The CE 3-D CAD model that includes all existing Extravehicular Activity (EVA) aids, umbilicals, grapple fixtures, and other surface-mounted hardware items with identification for ground or on-orbit installation. The CAD model requirements are defined in Appendix G. Any item that is located within 3 inches of the 90-inch radius thermal/dynamic envelope, within 3 inches of any Orbiter hardware protrusion into the envelope, or that protrudes outside of the envelope must be fully and accurately represented in the CAD model.

3. The CE math model description that identifies the model pedigree and uncertainty factors used in the analysis.

4. References for all Space Shuttle Vehicle (SSV) math models and forcing functions utilized in any transient and quasi-static analysis.

5. Description of the methodology used to perform the Orbiter/CE coupled quasi-static and dynamic loads analyses. Description of any other methodology used to perform Orbiter/CE analyses. Describe the combination method being used for combining random and transient loads.

6. Sidewall-mounted CEs orientation (port/starboard), weight, Center of Gravity (CG), and interface attachment to the sidewall carrier defined in the Orbiter coordinate system. The CE minimum natural frequency as cantilevered from the sidewall carrier. Event consistent and time uncorrelated (if available) maximum (both positive and negative) sidewall carrier-to-Orbiter interface loads. Event consistent and

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time uncorrelated (if available) translational and rotational transient (lift-off/landing), and random vibration net load factors with the appropriate random/transient combinations.

7. Physical description of the CE primary, stabilizer, and keel trunnion (length, diameter, surface finish, material, etc.), and thermal and manufacturing tolerances.

8. Definition of the CE primary, stabilizer, and keel trunnion Orbiter interface locations and the coupled Degrees of Freedom (DOF) in the Orbiter coordinate system for all cargo bay configurations considered in the analysis.

9. Description of the analyses performed, broken out by individual flight regime if appropriate: lift-off (including random vibration), landing (normal/abort/contingency/ emergency), acoustic, quasi-static, and on-orbit conditions, including all appropriate thermal, mechanical, and compartment pressure case combinations.

10. Event consistent and time uncorrelated (if available) maximum (both positive and negative) CE primary, stabilizer, and keel trunnion Orbiter interface loads for the lift-off and landing transient flight events and the in-flight “quasi-static” regimes with definition of the load case, uncertainty factor, preload, and friction coefficients utilized. If trunnion temperatures above -130° Fahrenheit were used to determine the friction coefficients, provide information and documentation of any thermal analysis that was performed to determine and justify a warmer temperature.

11. Primary, stabilizer, and keel trunnion Orbiter relative deflections of the uncoupled DOF for the lift-off and landing transient flight events and the in-flight quasi-static regimes. Relative deflections between the CE trunnions and the Orbiter should be categorized as motion together and motion apart. When deflection data is not provided, a 3.0-inch deflection will typically be assumed.

12. Relative deflections of the CE structure (having a radius greater than 87.0 inches) with respect to the CE 90-inch radius thermal and dynamic envelope. Relative deflections of potentially flexible CE structures (such as antennae) which reside inside the 87.0-inch static radius are similarly required. If the CE structure to Orbiter point-to-point dynamic clearance has been calculated, these data should also be provided (for example, CE structure to Orbiter top centerline cargo bay door latches). When deflection data is not provided, a 3.0-inch deflection will typically be assumed unless it is known that the structure is very flexible, in which case a larger, very conservative estimate will be made.

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13. Definition of the deflections of CE secondary structure (such as meteoroid/debris shields) with potential clearance issues, as defined in item 2 above, due to dynamic, quasi-static and random vibration environments.

14. Provide CE manufacturing tolerances and thermal distortion and internal pressure deflections for each item defined in item 2.

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APPENDIX G

CARGO ELEMENT COMPUTER AIDED DESIGN MODEL REQUIREMENTS

All International Space Station (ISS) Cargo Element (CE) developers are required to submit Computer Aided Design (CAD) models to the ISS CAD Modeling Team via the Lyndon B. Johnson Space Center (JSC) File Transfer Protocol (FTP) server. To request access to the JSC FTP server for CAD model deliveries, contact NASA-JSC/OM2, Linda Jack, at (281) 244-7172 or Linda.s.jack@nasa.gov. All models delivered are translated into various formats and made available to the appropriate users.

All other CE developers (non-ISS) are required to submit the following three files when submitting CAD data (e.g., 2-D Drawings, 3-D models, figures, data listings) directly to Boeing Space Exploration (B—SE). Each file must include the CE name and assembly parts number.

1. READ-ME FILE -- Provide general information about the contents of files, sending system, person to contact (phone number and e-mail address), sender's company name and address.

2. STEP FILE -- (in American Standard Code for Information Interchange (ASCII) format) to provide 3-D model geometry. Initial Graphics Exchange Specification (IGES) FILE can be accepted when the CE developer CAD system does not support the generation of a STEP file.

3. GIF, VRML, STL or HPGL FILE -- For visualization purpose. If file is not available, a fax or hard copy of the CE (solid) model in isometric view (with hidden lines removed) from its native system or CE drawing is acceptable.

   (It is recommended that each STEP and/or IGES file have a maximum size of 50 Megabytes (MB). Models that are broken down into several files by the CE developer shall use the same CAD coordinate system. Instructions for reassembling the models must be provided.)

For CE developers sending I-DEAS (3-D) geometry model:

1. Model data file can be electronically transferred (see below).

2. The model data can be provided in I-DEAS' UNIVERSAL file (.unv) or archive file (.arc) format.

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Note: B-SE currently utilizes I-DEAS Master's Series Version 7.2.

For CE developers sending Computer Aided Three-Dimensional Interactive Application (CATIA) (solid) models or direct solids translated into CATIA:

1. File requirement: Use CATEXP (drop=yes, refer=no).

   Output to sequential file, and CATAIX to "ISO08859-1" code page format.
   Solids in the database shall be nonisolated.
   Maximum individual file size: 30 MB (Data + Index)

2. Tape/CD format: The CATEXP output file shall be included on the tape.
   CATEXP.OUT on AIX platforms.
   The tape/CD label shall include a list of the sequential files and shall identify the platform from which the CATEXP was done: VM or MVS (EBCDIC), or AIX (ASCII).

Note: B-SE currently utilizes CATIA Version 4.2.3 on HP Workstations.

The method for transferring data files shall be compatible with one of the following:

1. Electronic Data transfer (Local Area Network, Internet connection, Ethernet, etc.):

   1.1. Internet connection: Data file exchange can be hosted on the CE developer FTP site or hosted through the Support Contractor (SC) standard provision for data file exchange. If hosted at a CE developer site, the developer must provide an FTP address, userid, and password at least 2 weeks before the data file delivery. See Appendix R for further information about the SC standard provision.

   1.2. E-mail connection: Data files can be sent as an electronic message attachment to the following address: glen.p.glassford@boeing.com. There is a 5-MB maximum file size limit for this method of data transfer.

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2. Data transfer by tape:

UNIX Workstation (SGI, SUN, IBM, HP):

a) Tape requirement: CACHE tape - 4 or 8 MM - cartridge or 1/4 inch - cartridge

b) Tape or CD format: UNIX TAR.

c) Floppy Disk requirement: 3.5 inch Disk Backup, or TAR on IBM RS/6000

Orbiter Coordinate System/Unique Cargo Element Coordinate System

All CAD models that are intended for use with the Orbiter (e.g., launch, nominal landing, and/or contingency landing configurations) shall be provided in the Orbiter Coordinate System. If a unique Cargo Element Coordinate System is used, its correlation to the Orbiter Coordinate System must be specified in the read-me file and/or contained within the provided CE drawings.

B-SE Contacts

Due to continuous software updates, it is suggested that SSP SC, B-SE, be contacted prior to the CE developer developing and sending CAD models. For additional information concerning SSP CAD model requirements or B-SE CAD capabilities, please contact Glen Glassford (281) 226-5736 (glen.p.glassford@boeing.com) for any of the following items:

1. For Catia/Unigraphics translation

2. For Pro-E/I-deas translation (includes STEP, IGES, GIF, UNV, VRML and any other solid conversion/translation)

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APPENDIX H

PRE-VERIFICATION LOADS REVIEW PRESENTER'S OUTLINE

The following topics shall be thoroughly discussed in the presentation material presented at the Preverification Loads Review (PVLR), for each Cargo Element (CE) manifested on the flight. In the case of previously flown CEs, identify all differences between this flight and the previous flight.

1. **INTRODUCTION**
   Describe the CE and the various functions that comprise the CE. Describe the load paths through the structure. Provide an organizational chart of those developing and analyzing the CE that includes the supporting NASA Center, the Development Company, titles, telephone and FAX numbers, and electronic mail addresses. Provide a list of acronyms and their definitions associated with the CE. Identify all Government Furnished Equipment (GFE) that is mounted to the CE.

2. **CARGO ELEMENT MATH MODEL VERIFICATION**
   Summarize the approach used for static and dynamic math model verification per the latest version of NSTS 14046, "Payload Verification Requirements." Note that this summarization shall be based on the Space Shuttle Program (SSP) Structures Working Group (SWG) approved Structural Verification Plan (SVP). For new CEs, SVPs shall be submitted to the SSP SWG at the Preliminary Design Review timeframe. For reflown or structurally modified CEs, SVPs shall be submitted by L-18 months. Summarize all test results and the correlation of the dynamic math model with test data. Provide references to report numbers in the presentation.

3. **CE DYNAMIC MATH MODEL DESCRIPTION**
   Provide a brief description of the math models that will be provided for the Verification Loads Analysis (VLA). Describe the format, size, free-free eigenvalues, Shuttle interface constrained eigenvalues, etc. Specify whether the Orbiter retention latch masses will be added to the sliding Orbiter interface Degrees Of Freedom (DOF) and values that will be added. Provide a comparison of the current mission weight and Center of Gravity (CG) (preferably based upon measurements) to that of the math model being supplied. Define the CE manufacturing tolerances and the thermal displacement data. Identify any model uncertainty factors required to account for errors due to unverified models or

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specified by the SWG. Provide the SWG approval memo number in the presentation if available. Describe the Component Modal Synthesis (CMS) method to be used to develop the dynamic math model for the VLA. If the method is not an approved method as documented in Appendix I, indicate where the method is in the approval process with the SWG. Also, describe any mechanisms that will be included in the math model.

4. CLOSE CLEARANCE POINTS

For clearance analysis purposes, additional recoverable physical DOF shall be included in the CE math models. These shall include all CE structural items that are within 3 inches of the 90-inch radius thermal and dynamic envelope, within 3 inches of Orbiter structure that intrudes into the 90-inch radius thermal and dynamic envelope, or that protrude outside the 90-inch radius thermal and dynamic envelope. Describe all close clearance points and the special efforts that have been taken to verify the math model responses for those points.

5. UNIQUE ANALYSIS REQUIREMENTS

Describe any unique analysis requirements for the VLA, including nonlinear analyses, interface friction, stick/slip analyses, CE unique damping schedules, additional modal response recoveries above the standard 35 Hertz cutoff, etc.

Describe any unique loads environments which must be analyzed in the VLA including Reaction Control System, Remote Manipulator System operations, Extravehicular Activity (EVA) crew induced loads, etc. Describe any contingency configurations (e.g., landing with failed CE internal interfaces) that must be analyzed to meet Space Shuttle safety requirements.

6. DATA REQUIREMENTS

Describe the VLA data recoveries (e.g., accelerations, displacements, and internal loads) necessary to develop the CE structural assessment to show compatibility with mission loads. Specify requirements for the data dump content, such as maximum/minimum listings, time histories, transmittal media, double precision data requirements, etc.

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APPENDIX I

CARGO ELEMENT STRUCTURAL MATH MODEL DATA AND FORMAT REQUIREMENTS

1. The integration of the Cargo Element (CE) and Orbiter structural math models require complete CE model data that are compatible with the Orbiter math models. All CE models provided for use in the Verification Loads Analysis (VLA) shall be test verified and approved by the Space Shuttle Program (SSP) Structures Working Group (SWG) according to the structural verification requirements specified in NSTS 14046.

2. The CE structural math models shall satisfy the following requirements to assure compatibility with the Orbiter math models:

   2.1. All numerical math model data shall be transmitted using at least 14 significant decimal digits of precision.

   2.2. All data shall be transmitted electronically using File Transfer Protocol (FTP) or other electronic file transfer methods. Alternate transfer methods shall be precoordinated with the SSP Support Contractor (SC).

   2.3. When using electronic transmission, all documentation shall be provided with the model files. An official hard copy of the documentation shall also be provided to the SSP SC. Information about file names, contents, and formats shall be included in the documentation.

   The SSP SC can either access a special account on the CE customer’s computer system or the CE customer can transfer the data using SC’s standard provision for VLA data file exchange. See Appendix R for more information.

   To use an account on a CE customer’s computer system, the CE customer must give the SSP SC the Internet address of the computer system, the name of the account, and the password. When a CE model is available, the CE customer contacts the SSP SC and provides the file names of the CE model. The SSP SC accesses the account by logging on through FTP and copies the files to the SC’s system.

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If the CE customer cannot provide an account for the SSP SC, the standard provision for VLA data file exchange can be used (see Appendix R). The CE customer can then transfer the data to the SSP SC's computer system and contact the SSP SC to provide the necessary information concerning the data transfer.

2.4. All matrices shall be in either SSP SC or MSC NASA Structural Analysis System (NASTRAN) OUTPUT4 format (see SC format in paragraph 2.7 below). This data shall be provided in American Standard Code for Information Interchange (ASCII) format and not in binary format. Note that all zero matrix terms will be explicitly written when using the SC version of NASTRAN (i.e., no packed matrices).

2.5. The physical Degrees of Freedom (DOFs) used for the CE mass and stiffness matrices, and for trunnion displacement, clearance item displacement, and Orbiter interface force Output Transformation Matrix (OTM) shall be in the Orbiter coordinate system as defined in Section 3.1.1 of ICD-2-19001, NSTS 21000-IDD-ISS.

2.6. The CE structural attachment point locations in the cargo bay shall be explicitly stated in the Orbiter coordinate system in the accompanying documentation.

2.7. The SSP SC OUTPUT4 format in terms of FORTRAN formatting where the matrix data is written by columns is as follows:

Record	Format	Data
1	(I6, 2A4)	IHD, NAME1
2	(3I6)	NR, NC, NT
3	(12X, 1P5D24.16)	(A(J), J=1, NR)
.	.	.
.	.	.
Repeat for each data block.		
.	(I6, 2A4)	IHD, NAMEN
.	(3I6)	NR, NC, NT
.	(12X, 1P5D24.16)	(A(J), J=1, NR)
.	.	.
LAST	(I6)	IEND

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Where:

IHD	-111
NAME1	Eight Character Data Block Name of First Matrix
NAMEN	Eight Character Data Block Name of the Nth Matrix
NR	Number of Rows
NC	Number of Columns
NT	Matrix Form 1 – Square 2 – Rectangular 3 – Symmetric
IEND	-999 (write once after the last data block in the file)

3. CE models shall comply with the following general requirements:

   3.1. The CE structural attachment point requirements are specified in Section 3.3.1 of ICD-2-19001 or NSTS 21000-IDD-ISS.

   3.2. CE math models that will have a keel attachment to the cargo bay forward of X_0 = 1191.0 inches require physical interface attachment DOF to be located at Z_0 = 305.0 inches. CE models that will have a keel attachment to the cargo bay aft of X_0 = 1191.0 inches require the keel physical interface attachment DOF at Z_0 = 308.4 inches. CEs that have potential keel attachments to the cargo bay both forward and aft of X_0 = 1191.0 inches require keel physical attachment DOF at both Z_0 = 305.0 inches and Z_0 = 308.4 inches.

   3.3. All CE math model longeron attachment DOF shall have the Z_0 = 414.00 regardless of whether deployable or nondeployable retention latches are used.

   3.4. CE math models shall contain modes up to 50 Hz as a minimum (up to 70 Hz modal content is highly desired) for the CE model constrained at the fixed Orbiter interface DOF unless the SWG specifies a higher frequency content.

4. The CE mathematical models and documentation shall include the following elements:

   4.1. The documentation shall include a date, title, and unique letter/report number for tracking purposes.

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4.2. A stiffness (K) matrix and an associated mass (M) matrix shall be provided. The maximum number of DOF for a Shuttle CE math model is limited by analysis cost and cycle time considerations to 800. Exceptions to this limit shall be coordinated with the SSP SC. The stiffness and mass matrices shall be provided in one of two formats listed below in Sections 4.2.1 and 4.2.2. Exceptions to these formats shall be coordinated with the SSP Flight Operations and integration (FO&I) Office, the SSP SC, and the SWG. If delivered models do not meet the following requirements and have not been precoordinated, they cannot be used. This will require the CE developer to submit new models using an approved method and will delay the VLA.

4.2.1. The stiffness and mass matrices may be expressed in the physical coordinate system.

4.2.2. The stiffness and mass matrices may be expressed in Craig-Bampton fixed mode generalized form (see Reference 6) or other SWG approved Component Modal Synthesis (CMS) method. The following guidance pertains to the CE mechanisms that remain unconstrained after the CE is coupled with the Orbiter: The CE model shall retain in the physical partition, DOFs that, upon constraint, will constrain only those mechanisms. Those DOFs shall be expressed in the orbiter coordinate system.

4.3. The CE mass and stiffness matrices must contain physical DOFs corresponding to the nominal Orbiter interface (tied DOFs). If latch masses are to be added to the CE model by the SSP SC, the CE mass and stiffness matrices must also include appropriate physical DOFs to accommodate these latch masses.

4.4. Non-interface (untied) DOFs at all Orbiter attach locations must be included in an OTM or among the physical DOFs in the CE mass and stiffness matrices to facilitate SSP SC calculation of Orbiter interface relative displacements and relative rotations. The Y_0-rotation DOF is not required at longeron attach points and the Z_0-rotation DOF is not required at keel attach points.

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4.5. For clearance analysis purposes, additional recoverable physical DOF shall be included in an OTM such that output physical displacements are expressed in the Orbiter coordinate system. These must include all CE structural items that are expected to be within 3 inches of the 90-inch radius thermal and dynamic envelope, within 3 inches of Orbiter structure that intrudes into the 90-inch radius thermal and dynamic envelope, or that protrude outside the 90-inch radius thermal and dynamic envelope.

4.6. CEs which utilize the Remotely Operated Electrical Umbilical (ROEU) or the Remotely Operated Fluid Umbilical (ROFU) shall retain the ROEU or ROFU physical interface DOF in physical coordinates, in the CE math model.

4.7. The CE developer may provide OTMs. Orbiter interface load recovery items must be included and clearly identified in the OTMs to provide a check on OTM usage. The OTM recovery method must be specified in writing by the CE developer. Simple and direct recovery methods are preferred. The number of recovery items is negotiable per flight per mission manifest. An electronic text file may be provided containing descriptions of the items to be recovered. These descriptions of up to 60 characters per OTM item will be incorporated into the analysis output as OTM item labels.

4.8. The following math model data must be provided in writing by the CE developer and included with the math model transmittal:

4.8.1. Row and column descriptions of all provided matrices.

4.8.2. Row/columns pertaining to DOF in the physical coordinate system shall be identified with node point and component numbers.

4.8.3. Reference coordinates in the Orbiter coordinate system must be provided for all physical DOF.

4.8.4. Plots of the finite element model showing Orbiter attach points, attach point numbering, and the Orbiter coordinate system axes shall be provided.

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4.8.5. The units for all numerical data must be specified. The English system (Length: inch, Force: lbf, Time: second, Mass: slinch or snail [lbf/(in/s^2)]) shall be used for the mass and stiffness matrices, and for trunnion displacement, clearance item displacement, and Orbiter interface force OTM items.

4.8.6. A modal analysis of the dynamic model constrained at the Orbiter attachment DOF shall be performed. As a minimum, the modal frequencies up to and including 50 Hz from this analysis shall be provided. It is preferred that all modal frequencies up to 70 Hz be provided.

4.8.7. A free-free modal analysis of the dynamic model shall be performed and all rigid body and flexible body frequencies below 50 Hz should be included within the documentation that is provided.

4.8.8. Results of a force equilibrium check about the CE Center of Gravity (CG) shall be provided using the free-free stiffness matrix. A written summary of a mass summation check about the CE CG shall be contained in the documentation. The model's CG location in the Orbiter coordinate system shall be provided in the model documentation.

4.8.9. Sketches of the CE with labeled critical components and locations (in Orbiter coordinates) shall be provided to aid the loads and clearance analysis process.

4.8.10. CE trunnion and clearance point manufacturing tolerances and thermally induced displacement data shall be provided as part of the CE math model transmittal for the calculation of trunnion preloads for indeterminately constrained CEs and for clearance assessments.

Thermal displacement data in Orbiter coordinates is required for longeron trunnion to latch Y_0 relative displacements, keel trunnion to latch Z_0 relative displacements and other clearance points. These data shall be provided in the documentation.

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5. The Payload Model Submittal Form (PMSF) is required to be completed and submitted with the CE math models for the VLA. There are two separate PMSF program configurations, one for across-the-bay CEs and one for sidewall-mounted CEs.

   The current version of the PMSF program and User's Manual are posted on the Structures Home Page under General Information at:
   http://sspweb.jsc.nasa.gov/webdata/mshome/struct/st-index.htm

   The current version of the PMSF should always be downloaded from the web site prior to submittal. For help with PMSF, contact the SSP SC Point of Contact:

   Ms. Santha Susarla
   Boeing Space Exploration
   Telephhone 281-226-5648
   electronic mail santha.v.susarla@boeing.com

   All model deliveries will be made to the above SSP SC Point of Contact.

6. For nonstandard analyses involving special analysis methods, deviations from standard analysis parameters, special CE model processing, on-orbit dynamic loads analyses and/or the modeling and analysis of nonlinearities, the required additional test verified CE model data and analysis requirements must be coordinated with the SSP as early as possible and no later than 18 months prior to the scheduled launch date. A Technical Interchange Meeting (TIM) between the CE developer and the SSP will be required to discuss and agree to these nonstandard analyses and schedules.

7. CE on-orbit math model fidelity requirements for Orbiter attached CEs, which change from their lift-off and landing configurations, are configuration dependent. The CE on-orbit math models must contain sufficient detail to accurately characterize Orbiter/CE system modes up to 20 Hz. On-orbit CE math models are required to be test verified per NSTS 14046 requirements.

8. For Reaction Control System (RCS), Orbiter Maneuvering System (OMS), and dynamic crew loads analyses, CE math model OTMs and associated limit load constraints representing critical load elements shall be provided to facilitate the selection of loads, flight control and operations compatible flight control parameters, and flight rules.

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APPENDIX J

VERIFICATION ACCEPTANCE REVIEW PRESENTER'S OUTLINE

The following topics should be thoroughly discussed in the presentation material presented at the Verification Acceptance Review (VAR). In the case of a reflight, only differences between this flight and the previous flight should be identified and discussed. In the case of multiple cycles, comparisons of current cycle results to the first cycle results with the Manifest Uncertainty Factor (MUF) shall be provided. For certain ISS logistics flights, additional VAR requirements may be outlined at the Preverification Loads Review (PVLR) and/or Verification Analysis Data Acceptability Review (VADAR).

1. **INTRODUCTION**
   Provide a general description of the Cargo Element (CE) structure, including any reflown hardware. Clearly identify all composites, bonded, beryllium, or shatterable materials. Provide a comparison of the measured weight and Center of Gravity (CG) as compared to the math model that was analyzed in the Verification Loads Analysis (VLA).

2. **MATH MODEL VERIFICATION**
   If the subject was not completely addressed at the PVLR or additional work has been done, describe the dynamic and static math model verification testing and final correlation results. Identify all differences between the final math model and the math model that was used in the VLA. Provide an assessment of what each difference means to the Orbiter interface. If the final math model verification occurred after the VADAR, provide an assessment of the differences between the VLA and final math models. If the final math model verification is still to occur, a detailed schedule for this activity must be presented along with a plan for assessing the differences between the VLA and the final math models.

3. **STRENGTH VERIFICATION TESTING**
   Describe any strength testing that was not addressed at the PVLR or in the approved Structural Verification Plan (SVP). Compare the test load levels to the final verification loads and show how compliance with the latest version of NSTS 14046, Payload Verification Requirements, was achieved. If additional strength testing will be performed, provide a detailed schedule and assessment plan.

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4. SUMMARY OF VERIFICATION LOADS

Include in the presentation a completed Table J-1 for the appropriate Interface Control Document (ICD) (CORE ICD, IDD-ISS or IDD-SML). Table J-1 will help to summarize the loads environments that were evaluated in the strength assessment including lift-off and landing transients; vibroacoustic; ascent, descent, and on-orbit quasi-static cases; friction; thermal; Orbital Maneuvering System (OMS) or Reaction Control System (RCS) firings; Remote Manipulator System (RMS) operations; Extravehicular Activity (EVA) crew induced loads; etc. Table J-1 also includes the effect of the Orbiter vent impingement pressure environment and the failed opened Orbiter vent door contingency on the CE. For each referenced environment, specify the source of that environment if it is not the listed reference. List each uncertainty factor in the presentation and how it was incorporated into the assessment.

5. STRUCTURAL ASSESSMENT

Describe how the final structural certification with the VLA results was accomplished, (e.g., new stress analyses, comparison to design loads, comparison to test allowable loads). Indicate whether worst case or time consistent loads and whether load factors or internal element loads were used. Provide a summary Margins of Safety Table for the primary structure and subsystems and include the minimum Margin of Safety in Table J-1. Provide a table showing the structural life assessment of the primary and secondary structure. Identify material, critical load case, failure mode, and factor of safety (yield or ultimate) for each margin. Also, identify cases for which positive margins were obtained by using plasticity, by changing uncertainty factors, and by using time or case consistent loads. Additional items that shall be evaluated include the effects of Orbiter cargo bay vent impingement on the CE, emergency landing loads, and the restow capability of a CE that must be returned for landing. Address any Government Furnished Equipment (GFE) on the CE and how the GFE was structurally verified either by unique analysis or comparison of loads to the GFE certification.

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TABLE J-1
SUMMARY OF VERIFICATION LOADS AND STRUCTURAL ASSESSMENT

Flight event	ICD Section/IDD Section [1]		IDD-SML section	Assessment Reference	Loads Assessment Results [2]
misalignment/preload	para. 3.3.1.1.1	para. 3.3.1.1.1.1	N/A		
restow/relatch	para. 3.3.1.2	para. 3.3.1.1.2	N/A		
Friction	para. 4.1.1.1	para. 4.1.1.1	N/A		
emergency landing loads	para. 4.1.3.5	para. 4.1.1.3.3	para. 4.1.3.5		
Fracture control	para. 4.1.3.7	para. 4.1.1.3.5	para. 4.1.3.7		
Acoustics	para. 4.1.5	para. 4.1.1.5	para. 4.0.4.2.3		
Random Vibration	para. 4.1.6.2	para. 4.1.1.6	para. 4.1.6.2		
pyro-technic shock	para. 4.1.9	para. 4.1.2	para. 4.1.9.2		
crew induced loads	para. 4.1.10	para. 4.1.3	N/A		
Ferry Flight loads	para. 4.1.11	para. 4.15	para. 4.1.11		
RCS	para. 4.3.1	para. 4.3.1	N/A		
OMS	para. 4.3.3	para. 4.3.2	N/A		
prelaunch accelerations	para. 4.3.2	para. 4.3.3	N/A		
Towing	para. 4.3.4	para. 4.3.3.1	para. 4.3.4		
Orbiter rollout/rollback	para. 4.3.6	para. 4.3.4	para. 4.3.6		
Failed open vent door	para. 6.1.4.2.1	para. 6.1.4.1.1	para. 6.1.4.2.2		
Thermal limits	table 6.1.4.1-1	table 6.1.4.1.1.1-1	table 6.1.4.1-1		
Pressure Environment:	---	---	---		
Prelaunch	table 6.2.1.1-1 Note 2	table 6.2.1.1-1 Note 2	table 6.1.4.1-1 Notes 2 and 3		
Ascent	para. 10.6.1.2	para. 10.6.1.2	para. 10.6.1.2		
Entry	para. 10.6.1.3	para. 10.6.1.3	para. 10.6.1.3		
Vent impingement	para. 10.6.4	para. 10.6.4	para. 10.6.1.4		
ODS on-orbit venting	para. 10.6.5	para. 10.6.5	para. 10.6.1.5		
Plume impingement (OMS, RCS and VRCS)	paras. 11.2.1, 11.2.2, 11.2.3	para. 11.2.1.1 (ref. JSC 26507)	N/A		
RMS structural loads	para. 14.4.5	para. 14.4.5	N/A		
RMS minimum frequency	para. 14.4.5.4	para. 14.4.5.2	N/A		
RMS contact (0.11 fps)	para. 14.8	para. 14.8	N/A		
Liftoff (combined w/acoustic, misalignment, friction, etc.)	VLA	VLA	VLA or para. 4.1.3 if above 35 Hz		
Landing (combined with thermal)	VLA	VLA	VLA or para. 4.1.3 if above 35 Hz		
Quasi-static loads and deflections	VLA	VLA	VLA		

Notes:
[1] If alternate sources of data are used, source must be stated
[2] List minimum Margin of Safety and identify part

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APPENDIX K

STRUCTURES WORKING GROUP AND STRUCTURAL CERTIFICATION

The following list of meetings, reviews, and data submittals, which require the support of the CE developer, is provided to assist the developer in complying with the SSP and SWG requirements. The list is in somewhat sequential order. Although not all items will apply to all CEs, the list will be applicable to most primary and secondary CEs. For unique cases, the SWG may require additional information, documentation, and/or testing. All Structural Verification Plans (SVPs), test plans, correlation reports, etc., shall be submitted directly to the SSP Flight Integration and Operations Office and the SWG for review and approval. Submittals that are included within design review documentation, safety packages, or that are submitted to other entities will not be considered as satisfying NSTS 14046 structural verification requirements.

MEETINGS AND REVIEWS

1. The CE developer should support the Payload Integration Plan (PIP) or Mission Integration Plan (MIP) review meetings(s) to negotiate the structurally related sections of the PIP or MIP. The important structures sections are 5.1, 6.1, 15, and 16.

2. The CE developer shall perform a review of the CE SVP with the SWG. The purpose of this review is to determine whether the SVP meets the requirements of NSTS 14046 and this document. For simple or reflown CEs, the required information may be submitted in report or view chart format.

   Issues will be resolved via a teleconference. For a new CE, it is desirable to have a face-to-face meeting. This can be accomplished as a splinter to a PIP or MIP meeting or a Flight Safety Review. A preliminary review will occur by the Phase 0 Safety Review or CE Preliminary Design Review (PDR). The final mutually agreed to written SVP will be submitted by the Phase 1 Safety Review or CE Critical Design Review (CDR) and no later than 18 months prior to flight. The detailed information that should be provided in the SVP is described under the Documentation heading.

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3. For those CEs, payloads, or components for which random vibration and/or acoustic loads are expected to be a significant source of loading and/or resulting deflections, the SVP and all dynamic structural documents (e.g., dynamic test plans, dynamic model correlation report, etc.) shall include the appropriate data for those dynamic loads and deflections as well as the standard low frequency transient data. See NASA STD-7001 for the applicable acoustic and random vibration test criteria. In the subsequent paragraphs, “dynamic” includes low frequency transient, random vibration, and acoustics.

4. The CE developer is responsible for the submittal of strength/static and dynamic structural test plans for review by the SWG. The test plans must be submitted at least 2 months (60 days) prior to the tests to allow the SWG sufficient time to review the plans and the CE developer time to incorporate any suggested changes. The information which shall be provided in the strength/static math model verification test plan and in the dynamic math model verification test plan are described under the Documentation heading.

5. The CE developer shall submit strength and dynamic test results and model correlation reports. The dynamic test results and model correlation report shall be submitted 4 months (120 days) prior to delivery of CE math model for the VLA to allow sufficient time for SWG comments to be addressed. The SWG initial review of the test results will take about 4 weeks. The SWG may require follow-up discussions with the CE developer and additional data submittals. Further analyses may also be required to investigate model uncertainties in the event that the tests were not completely successful. If the dynamic model correlation does not comply with the NSTS 14046 specified correlation criteria, the SWG may assign a model Uncertainty Factor (UF) that must be used in all subsequent structural analyses. The SWG reserves the right to reject the model if the model is found to be noncompliant with NSTS 14046 requirements.

   The static test results and model correlation report shall be submitted 4 months (120 days) prior to deliver of VLA data (data dump) to the CE to allow sufficient time for SWG comments to be addressed. The SWG initial review of the test results will take about 4 weeks. The SWG may require follow-up discussions with the CE developer and additional data submittals. Further analyses may also be required to

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investigate model uncertainties in the event that the tests were not completely successful. If the static model correlation does not comply with the NSTS 14046 specified correlation criteria, the SWG may assign a model uncertainty factor (UF) that must be used in all subsequent structural analyses. The SWG reserves the right to reject the model if the model is found to be noncompliant with NSTS 14046 requirements.

6. The CE developer shall submit the latest CE design loads cycle report per the mission-unique VLA schedule or the Appendix C VLA template if a mission-unique schedule has not been published.

7. The CE developer shall support the SSP's Orbiter compatibility assessment as described in Appendix F. The goal is to assess the Orbiter's capability to meet CE structural interface requirements. The assessment covers Orbiter/CE interface loads, deflections, and clearances. The assessment is based on data submitted in the CE design loads report.

8. The CE developer shall support the PVLR. At this meeting, the CE developer is required to present an overview of the CE structural dynamic math model and its verification. The developer must define any unique analysis and/or output data requirements from the VLA (e.g., load transformation matrices and component accelerations) to support structural certification of the CE. See Appendix H for details of the presentation that should be presented at the PVLR.

9. The CE developer shall submit the test-verified CE dynamic math model (or models) according to the requirements of this document and NSTS 14046. The SSP shall establish the math model delivery schedule which will be published in memos and electronic mail as well as being available through the SSP Structures Home Page. The generic CE math model VLA delivery schedule is listed in Table C-1 of Appendix C.

10. The CE developer may be required to submit a formal stress analysis or portions thereof. It may be necessary for the SWG and the Space Shuttle Program (SSP) Flight Operations and Integration (FO&I) Office to review the CE structural analysis prior to approving the hardware certification. This review would be necessary, for example, if negative margins are reported on critical interfaces that have not been previously discussed in open technical forums or discussed with the SWG.

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11. The CE developer shall support the Verification Acceptance Review (VAR). The purpose of this meeting is to review the CE structural certification based on the results of the Verification Loads Analysis. See Appendix J for details of the presentation that shall be presented at the VAR.

In addition to the above meetings, the CE developer is also required to support Interface Control Document (ICD) meetings and the Flight Safety Reviews. NSTS 13830, "Implementation Procedures for NSTS Payloads System Safety Requirements," lists the structural information that must be included in the Safety Data Packages.

DOCUMENTATION REQUIREMENTS

The following described documents are required to be submitted to the SWG and/or the SSP as part of the CE structural verification and certification process.

1. Structural Verification Plan

   The following information shall be provided in the CE SVP:

   a. Brief description and sketches of CE structure. Include information on materials and any nonstandard manufacturing processes.

   b. Proposed method for strength verification based on the options defined in the latest version of NSTS 14046. Include proposed factors of safety, stress analysis methodology (i.e., hand or computer analysis), verification approach for the finite element model that will be used for stress calculations, and the proposed strength testing. Rationale shall be provided if no strength testing is planned.

   c. Description of special materials (e.g., composites, beryllium, and glass) and the corresponding special measures which will be taken to verify their strength according to the NSTS 14046 requirements.

   d. Material allowables which will be used for the strength analysis.

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e. Derivation of design loads for primary structure, secondary structure, and components or experiments. Include thermal, friction, acoustic, random vibration, emergency landing, and on-orbit loads if applicable. Describe planned coupled and quasi-static loads analyses to support the design cycle. Identify UFs to be used in the design cycle.

f. Proposed method for dynamic math model verification. Rationale shall be provided if no dynamic testing is planned.

g. Summary and schedule of all loads and stress analyses, planned tests (includes strength, pressure, dynamic, random vibration, and acoustic tests), and math model correlation activities.

h. Description and sketches of all portions of the CE that may have clearances to Orbiter hardware of less than 3 inches static and/or 1.0-inch dynamic. Describe what special measures will be taken to verify these items deflections and dynamic motion. These special measures could include instrumentation of close-clearance points in the testing, the addition of local modes of the close-clearance points in the modal testing target mode set or other such procedures. Describe how the process described in Appendix Q will be implemented for each close clearance point.

2. Strength/Static Verification Test Plan

The following information shall be included in the CE strength/ static verification test plan:

a. Description and sketches of the CE structure, identification of materials that are used, and a description of any nonstandard manufacturing processes that are used.

b. Comparison of the test article, including boundary conditions, to the flight article. Explain and provide justification as to why any differences are acceptable for static testing.

c. Describe the derivation of the static test loads and their comparison to the design/flight loads.

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d. Description and sketches of test setup, including load application techniques, load magnitudes and locations, instrumentation layout, and data recording system.

e. Provide the pretest analysis for deflections, internal loads and stresses of the test configuration to predict critical deflections, and stress regions for test measurement locations.

f. Planned correlation analysis to verify the static math model.

3. Dynamic Verification Test Plan

For the purposes of this test plan and the Dynamic Test and Math Model Correlation Report that follows, the term “dynamic” includes low frequency transient, random vibration, and acoustics. The following information shall be included in the CE dynamic verification test plan:

a. Description of test article in relation to the flight article. Include summary of dummy masses and components that will not be included in test.

b. Comparison of test and flight article mass properties.

c. Description and sketches of test setup including:

(1) Description and sketches of the instrumentation location on the test article and test fixture.
(2) Description of and rationale for selection of excitation method, levels, and application points.

d. Description of test article boundary conditions.

(1) For the test article support structure, provide evidence that the support structure does not participate in the test frequency range. Otherwise, describe how a “test verified” model of the support structure will be obtained, as well as how it will be instrumented during the CE modal test.
(2) For “free-free” test, describe how the interface modes will be verified. Describe the suspension system and predicted suspension modes.

e. Summary of steps which will be taken to investigate linearity.

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f. Derivation of test specimen math model which will be used for correlation analysis.

g. Summary of pretest analysis and results including:

(1) Identification of the target modes and the rationale for their selection.
(2) Description and plots of the target mode shapes.
(3) Assessment of the test fixture/test article interaction including work done in correlating the test fixture itself.
(4) Comparison of the test article modes installed in the test fixture with the flight article modes.
(5) Evaluation of the instrumentation locations including a comparison of the full model modes to the modes from the model reduced to the instrumentation locations (cross-orthogonality comparison).

h. Description of the planned correlation analysis.

4. Dynamic Test and Math Model Correlation Report

The following information shall be included in the CE dynamic math model correlation report:

a. A complete summary of the test results, including:

(1) Description and plots of measured modes, including auto-orthogonality calculations.
(2) Orthogonality checks between the test mode shapes and analytically derived modes.
(3) Outcome of linearity checks with sample plots of reciprocity and/or response to varying force levels.
(4) Discussions of problems encountered during testing, changes made to test setup, and updates to the target mode set.

b. A description of the changes made to the math model for correlation purposes.

c. Comparisons of measured modes to updated math model results, including:

(1) Frequency data comparisons.
(2) Qualitative comparisons such as side-by-side plots, computer animations, spike plots, or others as appropriate.

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(3) Quantitative comparisons such as cross-orthogonality, Modal Assurance Criteria, strain energy, effective mass, modal superposition analysis, and others as appropriate.
(4) Comparison of trunnion stiffnesses to those measured in the static test, if available. Otherwise, this comparison should be included in the Static Test Report.

d. Description, data, and plots to support the usage of a unique damping schedule for the CE, if planned to be used in the VLA.

5. Static Test and Strength Math Model Correlation Report

The following information shall be included in the Static Test and Strength math model correlation report:

a. A complete summary of the test results, including:

(1) Description and plots of measured deflections and stresses
(2) Outcome of linearity checks with sample plots due to varying force levels
(3) Discussions of problems encountered during testing and changes made to the test set-up

b. A description of the changes made to the math model for correlation purposes.

c. Comparisons of measured deflections and stresses to the updated math model results demonstrating that the updated math model can accurately predict critical deflections, internal loads, and stresses.

d. Comparison of the test load levels to the final verification loads and show how compliance with NSTS 14046 was achieved.

e. Static correlation of the dynamic math model trunnion stiffnesses to the measured values.

f. Comparison of measured to updated math model results for each CE close clearance point where measured during testing.

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APPENDIX L

COUPLED LOADS ANALYSIS SYSTEM DAMPING

This appendix defines the analytical treatment of Space Shuttle Vehicle/Cargo Element (SSV/CE) system damping that will generally be used in the CE design coupled load analyses and in the Verification Loads Analysis (VLA).

It should be noted that the damping phenomenon is very complex. Detailed modeling of such a complex process is not practical. Instead, damping is approximated through analytical assumptions. The analytical system damping assumption that is generally used is made at the SSV/CE(s) system modal level.

The standard Space Shuttle Program (SSP) analytical practice for damping has been to employ Diagonal System Damping (DSD) which is defined at the free-free SSV/CE system modal level. Damping is defined as "percent of critical" with each system model Degree of Freedom (DOF) being assigned a $2\zeta\omega$ damping value, where ζ is the system level percent critical damping value (e.g., ζ = 0.01 is one percent of critical) and ω is the pertinent eigenvalue square root.

The CE developer is responsible for making a technical assessment as to whether the analytical damping assumptions that are used in the CE coupled design loads analyses and the VLA result in conservative CE load analyses. For example, some CE component modes could be measured in modal testing that demonstrate very low damping (e.g., ζ = 0.0025 or one quarter of a percent critical). Conversely, the CE developer may wish to take advantage of the measured higher damping (e.g., ζ = 0.05) for some specific modes. In all cases, the CE developer should discuss the CE damping, relative to the general analytical assumptions, with the SWG and be prepared to discuss the subject at the PVLR.

Lift-off System Damping

Unless unique damping is required for a given CE(s), DSD will be applied to the SSV/CE(s) system modes. DSD for a lift-off analysis is defined as one percent of critical damping for system modes up to 10 Hz and two percent of critical damping for system modes above 10 Hz.

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Landing System Damping

Unless unique damping is required for a given CE(s), DSD will be applied to the SSV/CE(s) system modes. DSD for a landing analysis is defined as one percent of critical damping for all system modes.

On-orbit System Damping

Unless unique damping is required for a given CE(s), one percent of critical DSD shall be used unless otherwise specified by the SWG.

Component Specific Damping

If it is necessary to apply unique damping to a given CE(s), this unique damping will be transformed up to the SSV/CE(s) system modal level using the Triple Matrix Product (TMP) procedure. DSD damping will be applied to the remaining SSV/CE(s) system modes and also transformed up to the entire SSV/CE system modal level via TMP. The two resulting system level damping matrices will be combined (added) at the system modal level. All off-diagonal terms in the resulting system damping will be retained in all transient analyses. This procedure will result in a set of coupled system equations which requires the use of a more computationally intensive solution method. Some of these methods (if not most) do not converge as rapidly (versus integration time step size) and will therefore require convergence testing.

Note: It is important to understand that assignment of 1 percent critical damping at the CE modal level is not equivalent to assignment of 1 percent critical damping at the SSV/CE(s) system modal level. The damping assumptions are different and will result in different analytical transient response levels. Although SSV/CE systems are treated as lightly damped (1 percent to 2 percent being typical), the assumptions made in the damping definition have significant impact on the analytical results.

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APPENDIX M

SSV STRUCTURAL MATH MODEL AND FORCING FUNCTIONS FORMAT REQUIREMENTS

STRUCTURAL MATH MODEL DATA FORMAT

All structural math model matrices developed by the Support Contractor (SC), for transmittal to the Cargo Element (CE) customers, are written in Space Shuttle Program (SSP) SC OUTPUT4 format. This data is provided in American Standard Code for Information Interchange (ASCII) format, and all zero matrix terms are explicitly written (i.e., no packed matrices).

The OUTPUT4 format in terms of FORTRAN formatted Input/Output (I/O), where the matrix data is written by columns, is as follows:

Record	Format	Data
1	(I6, 2A4)	IHD, NAME1
2	(3I6)	NR, NC, NT
3	(12X, 1P5D24.16)	(A(J), J=1, NR)
.	.	.
.	.	.
Repeat for each data block.		
.	(I6, 2A4)	IHD, NAMEN
.	(3I6)	NR, NC, NT
.	(12X, 1P5D24.16)	(A(J), J=1, NR)
.	.	.
LAST	(I6)	IEND

Where:

IHD	-111
NAME1	Eight Character Data Block Name of First Matrix
NAMEN	Eight Character Data Block Name of the Nth Matrix
NR	Number of Rows
NC	Number of Columns
NT	Matrix Form 1 – Square 2 - Rectangular 3 – Symmetric
IEND	-999 (write once after the last data block in the file)

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Matrix descriptions (i.e., Degree of Freedom (DOF) maps) which provide grid number, coordinate, and DOF information for each matrix can be read with a (25A4) format.

Quasi-static orbiter deflection data is provided as card image data. The standard data format is as follows:

Header cards with condition number (20A4)
Deflection data cards (I8,6F12.8) (Node No., Dx, Dy, Dz, Rx, Ry, Rz)

Units: Dx, Dy, Dz in inches
Rx, Ry, Rz, in Radians

An optional format for the development of quasi-static deflection data is SSP SC OUTPUT4. This format is available upon request.

FORCING FUNCTIONS DATA FORMAT

The lift-off and landing forcing functions are provided by the SC in a NASTRAN DLOAD format. This format involves four types of data cards: **DLOAD**, **TLOAD1**, **DAREA**, **DELAY** (lift-off only), and **TABLED1**. The forcing function is depicted as a dynamic loading consisting of a linear combination of force time histories.

Note: The DELAY card, contained in all 30 CLO1000 series lift-off forcing functions, has not been utilized in any previous Shuttle lift-off or landing forcing functions.

The **DLOAD** card is the entry point for the forcing function. It can be referenced by a “set identification number” (SID). The DLOAD card provides an overall scale factor (S) to the forcing function as well as identifying each of the time histories with a “load set identification number” (L_i) and applying a separate scale factor (S_i) to each time history. Each S_i references a separate TLOAD1 card.

Each **TLOAD1** card has its own “set identification number” (SID) which refers back to an individual Li on the DLOAD card. Each TLOAD1 card contains an identification number (L) for a DAREA card, an identification number (M) for a DELAY card, and an identification number (TF) for a TABLED1 card.

Each **DAREA** card has a SID, which refers back to one specific TLOAD1 card. Each DAREA card also specifies which grid (P) and

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DOF (C) the particular force time history is to act on. Each DAREA card also supplies an additional factor (A) for each time history.

Each **DELAY** card has a SID, which refers back to one specific TLOAD1 card. Each DELAY card supplies an additional factor (τ) which alters the input to the tabular function $F(t-\tau)$, supplied by the TABLED1 card.

Each **TABLED1** card contains a "table identification number" (ID) which refers back to a specific TLOAD1 card, and a description of a force time history (F(t)). This description consists of pairs of data (X_i, Y_i) which represent select time values (X_i) and corresponding force values (Y_i) of the particular force time history.

The above discussion can be summarized as follows:

Equation $\quad \text{ForcingFunction} = S \sum [S_i * A * F(t)]$

Cards $\quad$ **DLOAD** **DAREA** **TABLED1**

A description of each data card, which was paraphrased from the NASTRAN User's Manual, is provided below. The data on these cards are all formatted in fields of 8 characters with the exception of the data presented in the DLOAD card, which is in fields of 16 characters.

INPUT DATA CARD **DLOAD** Dynamic Load Combination (Superposition)

Description: Defines a dynamic loading condition for transient response problems as a linear combination of load sets defined TLOAD1 cards.

Format and Example:

1	2	3	4	5	6
DLOAD	SID	S	S1	L1	+abc
DLOAD	17	1.0	.01	1	+A
+abc	S2	L2	- etc. -		
+A	-2.0	2			

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Field	Contents
SID	Load set identification number (Integer > 0)
S	Scale Factor (Real)
S_i	Scale Factors (Real)
L_i	Load set identification numbers defined via TLOAD1 card (Integer > 0)

Remarks: 1. The load vector being defined by this card is given by

$$\{P\} = S\sum_i S_i \{P_{Li}\}$$

INPUT DATA CARD **TLOAD1** Transient Response Dynamic Load

Description: Defines a time-dependent dynamic load of the form

$$\{P(t)\} = \{A * F(\tau)\}$$

for use in transient response problems.

Format and Example:

1	2	3	4	5	6	7	8	9	10
TLOAD1	SID	L	M		TF				
TLOAD1	5	7	9		13				

Field	Contents
SID	Set identification number (Integer > 0)
L	Identification number of DAREA card set which defines A (Integer > 0)
M	Identification number of DELAY card set which defines τ (Integer > 0)
TF	Identification number of TABLED1 card which gives $F(\tau)$ (Integer > 0)

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INPUT DATA CARD **DAREA** Dynamic Load Scale Factor

Description: This card is used in conjunction with the TLOAD1 data cards and defines the point where the dynamic load is to be applied with the scale (area) factor A.

Format and Example:

1	2	3	4	5	6	7	8	9	10
DAREA	SID	P	C	A					
DAREA	3	6	2	8.2					

Field	Contents
SID	Identification number of DAREA set (Integer > 0)
P	Grid or scalar point identification number (Integer > 0)
C	Component number (1-6 for grid point)
A	Scale (area) factor A for the designated coordinate (Real)

INPUT DATA CARD **DELAY** Dynamic Load Time Delay

Description: This card is used in conjunction with the TLOAD1 data cards and defines the time delay term τ in the equations of the loading function.

Format and Example:

1	2	3	4	5	6	7	8	9	10
DELAY	SID	P	C	T					
DELAY	5	21	6	4.25					

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Field	Contents
SID	Identification number of DELAY set (Integer > 0)
P	Grid or scalar point identification number (Integer > 0)
C	Component number (1-6 for grid point)
T	Time delay τ for the designated coordinate (Real)

INPUT DATA CARD **TABLED1** Dynamic Load Tabular Function

Description: Defines a tabular function for use in generating time-dependent dynamic loads.

Format and Example:

1	2	3	4	5	6	7	8	9	10
TABLED 1	ID								+abc
TABLED 1	32								+ABC
+abc	X_1	Y_1	X_2	Y_2	X_3	Y_3	X_4	Y_4	
+ABC	-3.0	6.9	2.0	5.6	3.0	5.6	ENDT		

Field	Contents
ID	Table identification number (Integer > 0)
X_i, Y_i	Tabular entries (Real)

Remarks:

1. The end of the table is indicated by the existence of the string "ENDT" in either of the two fields following the last entry.

2. Each TABLED1 mnemonic infers the use of a specific algorithm where X_i represents a time value (seconds) and Y_i a force value (translations=lb. moments=in-lb.) The table look-up is performed using linear interpolation within the table and linear extrapolation outside the table using the last two end points at the appropriate table end.

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APPENDIX N

VERIFICATION LOADS ANALYSIS DATA PRODUCTS FORMAT REQUIREMENTS

1. Verification Loads Analysis (VLA) Data Products Format Requirements for Data Dump

   1.1. Transient analysis output

      1.1.1. Maximum/minimum search of orbiter/Cargo Element (CE) interface loads and relative displacements. Time history available upon request (File Transfer Protocol (FTP), Compact Disk (CD), or the Support Contractor (SC) standard provision in Appendix R).
      1.1.2. Maximum/minimum search of relative displacements at selected points. Orbiter-to-CE and/or CE-to-CE. Time history available upon request (FTP, CD, or the SC standard provision in Appendix R).
      1.1.3. Maximum/minimum search of net load factors for each CE. Time history available upon request (FTP, CD, or the SC standard provision in Appendix R).
      1.1.4. Maximum/minimum search of CE Output Transformation Matrix (OTM) recoveries.
      1.1.5. CE 90-inch dynamic envelope assessment results available upon request.
      1.1.6. CE generalized responses available upon request (FTP, CD, or the SC standard provision in Appendix R).
      1.1.7. Output data by special request.
      1.1.8. All minimum/maximum searches shall be Text format with carriage control (a typical output is attached to this Appendix). All time histories and generalized responses shall be in Space Shuttle Program (SSP) SC OUTPUT4 format (see below in Sec. 1.3).

   1.2. Quasi-static analysis output

      1.2.1. Maximum/minimum search of CE/Orbiter interface loads and relative displacements.
      1.2.2. Maximum/minimum search of relative displacements at selected points.
      1.2.3. Maximum/minimum search of CE OTM recoveries.
      1.2.4. CE 90-inch radius thermal/dynamic envelope assessment upon request.
      1.2.5. Output data by special request.

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1.2.6. CE case consistent data is available upon request (FTP, CD, or the SC standard provision in Appenidx R).

1.2.7. All minimum/maximum searches shall be Text format with carriage control.

1.3. The SSP SC OUTPUT4 format in terms of FORTRAN formatting where the matrix data is written by columns is as follows:

Record	Format	Data
1	(I6, 2A4)	IHD, NAME1
2	(3I6)	NR, NC, NT
3	(12X, 1P5D24.16)	(A(J), J=1, NR)
.	.	.
.	.	.
Repeat for each data block.		
.	(I6, 2A4)	IHD, NAMEN
.	(3I6)	NR, NC, NT
.	(12X, 1P5D24.16)	(A(J), J=1, NR)
.	.	.
LAST	(I6)	IEND

Where:
- IHD -111
- NAME1 Eight Character Data Block Name of First Matrix
- NAMEN Eight Character Data Block Name of the Nth Matrix
- NR Number of Rows
- NC Number of Columns
- NT Matrix Form
  - 1 – Square
  - 2 – Rectangular
  - 3 – Symmetric
- IEND -999 (write once after the last data block in the file)

1.4. Data dump file exchange can be hosted on a CE developer FTP site or hosted through the SC standard provision for VLA data file exchange. If hosted at a CE developer site, the developer must provide an FTP address, userid, and password at least 2 weeks before the data dump. See Appendix R for further information about the SC standard provision.

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2. VLA Data Products Format Requirement for Documentation

2.1. VLA documentation shall include the following:

2.1.1. Space Shuttle Vehicle (SSV) math models and matrix maps, description of lift-off and landing forcing functions.
2.1.2. CE math models, CE weight Center of Gravity (CG), and attachment information.
2.1.3. Methodology of transient and quasi-static analyses.
2.1.4. Detailed description of quasi-static uncombined and combined cases, load condition numbering system, flight regime map.
2.1.5. Orbiter capability assessment results, including clearance assessments.
2.1.6. Payload integration and orbiter hardware assessment results.
2.1.7. Minimum/maximum search data for all interface loads, relative displacements, and net load factors.

2.2. The documentation shall be in Portable Document Format (PDF).

3. Alternative VLA Data Products Formats can be negotiated between the CE Developer and the SSP SC. These must be negotiated, agreed to, and documented prior to the Verification Analysis Data Acceptability Review (VADAR).

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Table N-1 IUS/ORBITER I/F LOADS

STS-93 Verification Loads Analysis
Max/Min Search of Liftoff Transient SUBCASE 1
TIME SECONDS
FORCE LBS

	DESCRIPTION	MINIMUM VALUE	MINIMUM TIME	MINIMUM CASEID	MAXIMUM VALUE	MAXIMUM TIME	MAXIMUM CASEID	ABSOLUTE VALUE	ABSOLUTE TIME	ABSOLUTE CASEID
1	IF LD IUS/AXAF X=1116.2 Y= 94.0 Z=414.0 X DIR	-2753.483	7.008	lr5156v	1304.854	6.966	lr5123v	2753.483	7.008	lr5156v
2	IF LD IUS/AXAF X=1116.2 Y= 94.0 Z=414.0 Z DIR	-7852.603	8.130	lr5188v	14282.811	7.564	lr5274v	14282.811	7.564	lr5274v
3	IF LD IUS/AXAF X=1210.6 Y= 94.0 Z=414.0 X DIR	-74748.837	7.246	lr5178v	-1847.478	7.248	lr5194v	74748.837	7.246	lr5178v
4	IF LD IUS/AXAF X=1210.6 Y= 94.0 Z=414.0 Z DIR	-8726.410	8.316	lr5084v	4955.770	8.653	lr5194v	8726.410	8.316	lr5084v
5	IF LD IUS/AXAF X=1220.4 Y= 91.1 Z=408.2 Y DIR	-0.018	7.154	lr5156v	0.055	7.286	lr5138v	0.055	7.286	lr5138v
6	IF LD IUS/AXAF X=1271.6 Y= 91.1 Z=408.2 Y DIR	-3884.594	7.208	lr5123v	2541.535	7.290	lr5123v	3884.594	7.208	lr5123v
7	IF LD IUS/AXAF X=1281.4 Y= 94.0 Z=414.0 Z DIR	-6751.824	8.334	lr5084v	4087.205	8.653	lr5194v	6751.824	8.334	lr5084v
8	IF LD IUS/AXAF X=1116.2 Y= -94.0 Z=414.0 X DIR	-2946.458	7.278	lr5156v	1553.682	7.302	lr5156v	2946.458	7.278	lr5156v
9	IF LD IUS/AXAF X=1116.2 Y= -94.0 Z=414.0 Z DIR	-8529.101	8.016	lr5084v	15210.733	7.342	lr5156v	15210.733	7.342	lr5156v
10	IF LD IUS/AXAF X=1210.6 Y= -94.0 Z=414.0 X DIR	-74502.557	7.236	lr5123v	-2009.957	3.596	lr5178v	74502.557	7.236	lr5123v
11	IF LD IUS/AXAF X=1210.6 Y= -94.0 Z=414.0 Z DIR	-8712.610	8.372	lr5129v	4336.016	8.614	lr5188v	8712.610	8.372	lr5129v
12	IF LD IUS/AXAF X=1220.4 Y= -91.1 Z=408.2 Y DIR	-0.056	7.158	lr5194v	0.017	3.338	lr5175v	0.056	7.158	lr5194v
13	IF LD IUS/AXAF X=1271.6 Y= -91.1 Z=408.2 Y DIR	-2385.566	8.370	lr5129v	4318.091	7.298	lr5194v	4318.091	7.298	lr5194v
14	IF LD IUS/AXAF X=1281.4 Y= -94.0 Z=414.0 Z DIR	-6692.263	8.380	lr5129v	3687.491	8.614	lr5188v	6692.263	8.380	lr5129v
15	IF LD IUS/AXAF X=1116.2 Y= 0.0 Z=305.0 X DIR	-2697.021	7.222	lr5156v	1409.713	7.246	lr5156v	2697.021	7.222	lr5156v
16	IF LD IUS/AXAF X=1116.2 Y= 0.0 Z=305.0 Y DIR	-10099.884	7.532	lr5129v	11775.164	7.702	lr5156v	11775.164	7.702	lr5156v

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Table N-2 IUS/ORB I/F REL. DISPLACEMENTS

STS-93 Verification Loads Analysis
Max/Min Search of Liftoff Transient SUBCASE 2
TIME SECONDS
RD DIS IN.OR RAD

	DESCRIPTION	..... MINIMUM			..... MAXIMUM			..... ABSOLUTE		
		VALUE	TIME	CASEID	VALUE	TIME	CASEID	VALUE	TIME	CASEID
1	IF RD IUS/AXAF X=1116.2 Y= 94.0 Z=414.0 Y DIR	-0.405	7.884	lr5194v	0.522	7.244	lr5084v	0.522	7.244	lr5084v
2	IF RD IUS/AXAF X=1116.2 Y= 94.0 Z=414.0 RX DIR	-0.006	6.976	lr5084v	0.005	7.218	lr5129v	0.006	6.976	lr5084v
3	IF RD IUS/AXAF X=1116.2 Y= 94.0 Z=414.0 RZ DIR	-0.009	6.990	lr5123v	0.004	6.966	lr5123v	0.009	6.990	lr5123v
4	IF RD IUS/AXAF X=1210.6 Y= 94.0 Z=414.0 Y DIR	-0.183	8.332	lr5194v	1.416	8.554	lr5274v	1.416	8.554	lr5274v
5	IF RD IUS/AXAF X=1210.6 Y= 94.0 Z=414.0 RX DIR	-0.012	8.644	lr5194v	0.016	8.503	lr5194v	0.016	8.503	lr5194v
6	IF RD IUS/AXAF X=1210.6 Y= 94.0 Z=414.0 RZ DIR	-0.040	7.246	lr5178v	0.000	7.250	lr5194v	0.040	7.246	lr5178v
7	IF RD IUS/AXAF X=1281.4 Y= 94.0 Z=414.0 X DIR	-0.411	7.246	lr5178v	-0.053	2.495	lr5178v	0.411	7.246	lr5178v
8	IF RD IUS/AXAF X=1281.4 Y= 94.0 Z=414.0 Y DIR	-0.819	7.232	lr5123v	0.370	7.320	lr5156v	0.819	7.232	lr5123v
9	IF RD IUS/AXAF X=1281.4 Y= 94.0 Z=414.0 RX DIR	-0.013	8.623	lr5188v	0.026	8.376	lr5129v	0.026	8.376	lr5129v
10	IF RD IUS/AXAF X=1281.4 Y= 94.0 Z=414.0 RZ DIR	-0.026	7.298	lr5138v	0.000	7.252	lr5194v	0.026	7.298	lr5138v
11	IF RD IUS/AXAF X=1116.2 Y= -94.0 Z=414.0 Y DIR	-0.473	7.970	lr5129v	0.464	7.718	lr5274v	0.473	7.970	lr5129v
12	IF RD IUS/AXAF X=1116.2 Y= -94.0 Z=414.0 RX DIR	-0.005	8.438	lr5120v	0.006	7.968	lr5129v	0.006	7.968	lr5129v
13	IF RD IUS/AXAF X=1116.2 Y= -94.0 Z=414.0 RZ DIR	-0.004	6.966	lr5123v	0.011	7.168	lr5156v	0.011	7.168	lr5156v
14	IF RD IUS/AXAF X=1210.6 Y= -94.0 Z=414.0 Y DIR	-1.328	8.340	lr5129v	0.179	7.334	lr5156v	1.328	8.340	lr5129v
15	IF RD IUS/AXAF X=1210.6 Y= -94.0 Z=414.0 RX DIR	-0.016	7.110	lr5084v	0.012	8.647	lr5194v	0.016	7.110	lr5084v
16	IF RD IUS/AXAF X=1210.6 Y= -94.0 Z=414.0 RZ DIR	0.001	3.598	lr5178v	0.039	7.236	lr5123v	0.039	7.236	lr5123v

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Table N-3 IUS-AXAF NET LOAD FACTORS

STS-93 Verification Loads Analysis
Max/Min Search of Liftoff Transient SUBCASE 3
TIME SECONDS
NLF-IUS COORD.

DESCRIPTION		MINIMUM VALUE	MINIMUM TIME	MINIMUM CASEID	MAXIMUM VALUE	MAXIMUM TIME	MAXIMUM CASEID	ABSOLUTE VALUE	ABSOLUTE TIME	ABSOLUTE CASEID
1 NET X LOAD FACTOR--ON IUS/AXAF	G'S	0.152	7.248	lr5194v	3.032	7.338	lr5194v	3.032	7.338	lr5194v
2 NET Y LOAD FACTOR--ON IUS/AXAF	G'S	-0.252	7.532	lr5129v	0.293	7.704	lr5129v	0.293	7.704	lr5129v
3 NET Z LOAD FACTOR--ON IUS/AXAF	G'S	-0.796	8.140	lr5084v	0.961	8.428	lr5120v	0.961	8.428	lr5120v
4 RX ANGULAR ACCELERATION RAD/SEC2		-1.651	3.694	lr5178v	1.634	7.640	lr5218v	1.651	3.694	lr5178v
5 RY ANGULAR ACCELERATION RAD/SEC2		-1.610	8.647	lr5194v	1.306	7.094	lr5084v	1.610	8.647	lr5194v
6 RZ ANGULAR ACCELERATION RAD/SEC2		-0.800	11.000	lr5123v	0.781	10.840	lr5123v	0.800	11.000	lr5123v

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APPENDIX O

SSP LOADS INDICATOR VLA APPROACH AND REQUIREMENTS

The Space Shuttle Program (SSP) Loads Indicator Verification Loads Analysis (VLA) Approach performs several cycles of loads analysis and assessments as compared to the single cycle that is described in Appendix C. The need to perform several cycles can be due to poorly correlated math models being provided, cargo bay manifests being changed, weight and/or Center of Gravity (CG) tolerances being exceeded or other similar reasons. The first cycle of the SSP Loads Indicator VLA is very similar to the standard VLA that is described in Appendix C. The schedule for this first cycle may differ from that presented in Appendix C. All responses from the first cycle will have a Manifest Uncertainty Factor (MUF) applied, which is in addition to any model Uncertainty Factors (UFs) that are specified by the Structures Working Group (SWG). The MUF will be 1.10 for the lift-off and landing transient analysis and 1.05 for all quasi-static analyses. All Cargo Element (CE) developers will be required to provide the fully test-verified math models for the first cycle unless otherwise negotiated and agreed to with the SSP Cargo Integration (CI) SWG and the SSP Flight operations and Integration (FO&I) Office, along with extensive Output Transformation Matrices (OTMs) that includes all CE critical item responses. The SSP and Support Contractor (SC) will utilize the documented cargo bay manifest and Space Shuttle Vehicle (SSV) configuration in the mission Flight Requirements Document (FRD). All standard VLA and CE requested outputs will be generated and delivered to the CE developers for full assessment. Results from this assessment will be reported at the Verification Acceptance Review (VAR) and any negative margins or issues resolved. The CE developers shall contact the SSP and SC prior to making any hardware modifications that are based on the first cycle results. The SC will collect the maximums and minimums for all VLA outputs (including the MUF and applicable UFs) in a database for later comparisons.

The second and any subsequent cycles will be conducted similarly to the first VLA cycle but on a reduced time schedule. Each CE developer will be permitted to submit revised/updated math models and OTMs. The OTMs that are resubmitted for the second and subsequent cycles shall retain the initial cycle row order with null rows included for items that are no longer recovered in the second or subsequent cycle. This sequencing is required in order for the SC to compare results from the new analysis to the previous results. The CE developer can provide additional OTMs for those items that were not previously supplied. New math

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models and OTMs (i.e., for CEs that were added to the flight manifest) will be accommodated similar to a standard VLA. The SC will utilize the best-known cargo bay manifest and SSV configuration for the subsequent cycles.

As soon as the VLA results are available, the SC will develop a comparison table between the previous and the current VLA results for comparison purposes. The SC and CE developers will use this comparison data as a tool to evaluate the current VLA results. In general, if the results are within the previous VLA results, no additional assessment is required on the part of the CE developer. For those items in which the current results exceed the previous VLA results, the CE developer shall perform an assessment and determine whether the results are acceptable or not. A Final Acceptance Review (FAR) will be conducted prior to launch during which the CE developer will present the results from his assessments. The FAR is similar to the previously held VAR but only revised results are required to be presented and discussed. The SC shall present similar data for the Payload Integration Hardware, Orbiter vehicle, and other similar items.

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APPENDIX P

LOADS COMBINATION EQUATION

The loads combination equation is used to combine loads from different sources in a rational manner. The basic load combination equation is included in NSTS 07700, Volume X, Book 1 as paragraph 3.2.2.1.6, which is applicable for Orbiter hardware and NSTS 14046, Payload Verification Requirements, Revision E, as paragraph 5.1.1.1 which is applicable for payloads.

Factor of safety is defined in NSTS 1700.7B as being: "The factor by which the limit load is multiplied to obtain the ultimate load. The limit load is the maximum anticipated load or combination of loads, which a structure may be expected to experience. The ultimate load is the load that a payload must be able to withstand without failure." Thus the basic definition of the factor of safety (i.e., K) is the ultimate load (i.e., L_{Ult}) divided by the limit load (i.e., L_{limit}).

$$K = L_{Ult} / L_{limit} \qquad \text{(Equation P-1)}$$

Multiple values of factors of safety are often used for space vehicles to reflect the designers' varying confidence in different parts of the structure or for increased conservatism when the vehicle is manned. Different factors are typically used for flight and non-flight conditions. Different factors are typically used depending on the scope of structural development, qualification tests, and the design service life.

Since there are various sources of loads that are applied to a flight vehicle (e.g., mechanical {which includes aerodynamic and inertial}, thermal, pressure) a load combination equation is required to combine the different sources of loads in a rational manner. The general form of the load combination equation is:

$$K_E \Sigma L = K_M L_M + K_P L_P + K_T L_T \qquad \text{(Equation P-2)}$$

Where the K terms are safety factors and the L terms are loads. The subscript definitions are:

E = Effective
M = Mechanical (e.g., inertial, aerodynamic, etc)
P = Pressure
T = Thermal
Σ L = Summation of all loads

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When combining loads, those load components that are relieving do not have the full factor of safety applied. In some cases the relieving factors of safety are set to zero while in others they are set to 1.0. This will be discussed in more detail later. NSTS 14046 specifies a minimum effective factor of safety (i.e., K_E) of 1.40.

The mechanical factor of safety (i.e., K_M) that is applied to the mechanical load term (i.e., L_M) is dependent on the type of material that a part is made out of, whether the item will be structurally tested or not, and whether the load is additive to the load summation or relieving. If the load is relieving, the K_M factor is always set equal to 1.0. Table P-1 specifies the ultimate K_M factors that are used by the Space Shuttle Program (SSP) which are obtained from the NASA STD 5001 document.

TABLE P-1
ULTIMATE MECHANICAL FACTORS OF SAFETY

Material	Tested	Not Tested
Standard Metallic (e.g., aluminum, steel, etc.)	1.4	Note 1
Glass	3.0	5.0
Nonmetallic for nondiscontinuity areas	1.4 Note 2	Note 1
Nonmetallic for discontinuity areas	2.0	Note 1

Notes: 1. The SSP Structures Working Group (SWG) will determine the appropriate value based on the proposed usage.

2. The 1.4 value is applicable when a prototype verification approach is being used. This value becomes 1.5 when a protoflight verification approach is used.

The thermal factor of safety (i.e., K_T) values to be used are the same as the mechanical factors of safety defined in Table P-1. However if the thermal load is relieving, the SSP specifies that the K_T value to be used is 0.0. That is, no part of a relieving thermal load can be used in the load combination equation to reduce the load.

Usage of the pressure factor of safety term (i.e. K_P) is more complex than for the other two terms. If the pressure load is a

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relieving load, the K_P value that is to be used in the load combination equation is 1.0. Several hardware components have unique K_P values specified that shall be used in the load combination equation. These values are shown in Table P-2. If an item is not shown in Table P-2, the K_P value that shall be used is 1.5. The value is applied to the Maximum Design Pressure (MDP), which is defined in NSTS 1700.7B as being "the highest pressure defined by maximum relief pressure, maximum regulator pressure, or maximum temperature. Transient pressures shall be considered. Where pressure regulators, relief devices, and/or a thermal control system (e.g., heaters) are used to control pressure, collectively they must be two-fault tolerant from causing the pressure to exceed the MDP of the system."

TABLE P-2
ULTIMATE PRESSURE FACTORS OF SAFETY

Hardware Item	SSP K_P
Lines and fittings less than 1.5 inches in diameter and all flex lines	4.0
Lines and fittings greater than 1.5 inches in diameter	1.5
Pressure vessels and reservoirs	2.0
Actuating cylinders, valves, filters, switches, regulators, sensors, line-installed bellows and heat pipes	2.5
Doors, hatches and personnel compartments	2.0 Note 1
Glass	3.0

Note: 1. "For manned pressurized compartments, the hull shall be designed with an ultimate factor of safety of 2.0 applied to MDP and the maximum negative pressure differential that the hull may be subjected to during normal and contingency operations or as the result of two credible failures." From NSTS 1700.7B.

The process for using the loads combination equation (e.g., equation P-2) is as follows:

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1. Determine what material the part will be made out of and whether the part will comply with structural testing requirements. Use the appropriate value from Table P-1 for the mechanical and thermal factors of safety values. For nontested hardware, the SSP requires that the SWG review the intended application and specify the factors of safety values to be used.

2. If the mechanical load is found to be relieving to the load summation, set the value of K_M to 1.0.

3. If the thermal load is found to be relieving to the load summation, set the value of K_T to 0.0.

4. Determine if the part is one that is specified in Table P-2 that has unique values for the K_P term. If the part is listed in Table P-2, use the specified value for K_P. If it is not specified, use the value of 1.5 for K_P.

5. If the pressure load is found to be relieving to the load summation, set the value of K_P to 1.0.

6. Determine other sources of loads being induced into the structure (e.g., manufacturing, latching, torquing) and combine with the appropriate factors of safety. If the load is found to be relieving to the load summation, set the factor of safety to zero.

7. Determine the effective factor of safety (i.e., K_E) and determine if it is greater than the SSP specified minimum value of 1.4. Use K_E as calculated and the linear summation of the loads (i.e., Σ L) for hardware assessment if K_E is greater than 1.4. If the K_E value is less than 1.4, recalculate the load summation term as follows:

$$\Sigma L = (K_M L_M + K_P L_P + K_T L_T)(1.4)/K_E \quad \text{(Equation P-3)}$$

8. The load summation term is a “limit load” value and is to be used for designing, assessing, verifying, etc., the individual component item.

9. The worst-case combined loads depend upon the magnitude and direction of the component loads. For case- and time-consistent conditions, both the maximum positive load and the maximum negative load shall be evaluated based on the following six possibilities:

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A. L_E = Primary positive mechanical load (e.g., tensile) with associated pressure and thermal loads.
B. L_E = Primary negative mechanical load (e.g., compression) with associated pressure and thermal loads.
C. L_P = Primary positive pressure load (e.g., tensile) with associated mechanical and thermal loads.
D. L_P = Primary negative pressure load (e.g., compression) with associated mechanical and thermal loads.
E. L_T = Primary positive thermal load (e.g., tensile) with associated pressure and mechanical loads.
F. L_T = Primary negative thermal (e.g., compression) with associated pressure and mechanical loads.

Alternatively, a max-on-max, noncase-consistent, nontime-consistent maximum positive and maximum negative load conditions may be used to envelope all load cases.

References

P-1 NSTS 07700, Volume X - Book 1, Space Shuttle Flight and Ground System Specification

P-2 NSTS 14046, Payload Verification Requirements

P-3 NSTS 1700.7B, Safety Policy and Requirements for Payloads Using the Space Transportation System.

P-4 NASA-STD-5001, Structural Design and Test Factors of Safety for Spaceflight Hardware

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APPENDIX Q

SSP LATCHED CARGO ELEMENT TO ORBITER CLEARANCE REQUIREMENTS

Cargo Elements (CEs) are to remain within the 90-inch radius thermal and dynamic envelope while avoiding those areas where the Orbiter intrudes into the envelope as defined in Section 3.0 of ICD 2-19001 and NSTS-21000-IDD-ISS. CE hardware items that are statically within 3 inches of the 90-inch radius thermal and dynamic envelope or within 3 inches of any Orbiter intrusion into the 90-inch radius thermal and dynamic envelope are considered to have the potential for dynamic interference with the Orbiter. These items require monitoring in the design and Verification Loads Analysis (VLA) cycles and shall be documented in the CE unique Interface Control Document (ICD) as described in NSTS 37329.

The 1-inch minimum dynamic clearance requirement addresses the CE-to-Orbiter dynamic clearance during the lift-off, landing, and quasi-static flight regimes while the CE is latched within the cargo bay. All CE hardware items that do not comply with the minimum 1-inch dynamic clearance requirement shall be subject to strict review and monitoring by the Space Shuttle Program (SSP) according to the evaluation process described in Table Q-1.

In the event that the 1-inch minimum dynamic clearance is violated, the SSP shall evaluate and accept, on a case-by-case basis, a positive dynamic clearance provided it is verifiable. During the design phase, the CE developer shall make every effort to meet the 1-inch dynamic clearance. The items listed in Table Q-1 detail the generic evaluation process steps necessary to determine the mission risk and verify the dynamic clearance. SSP approval of dynamic clearances that are less than the required 1-inch is based upon the thoroughness and completeness of the evaluation and verification process. These activities are to be coordinated with the SSP Cargo Integration Structures Working Group (SWG) as part of the structural verification process as described in Appendix K. Final approval of clearances less than 1-inch will be made by the SSP only after all static measurements have been taken and the final VLA is completed.

Table Q-1 details three categories of CE-to-Orbiter clearances and the associated process steps required for their approval by the SSP. The first case, shown in column two, occurs when the CE-to-Orbiter dynamic clearance is less than the required minimum of 1 inch. The CE may or may not be protruding beyond the 90-inch radius thermal and dynamic envelope but is in very close proximity to Orbiter hardware. It is possible for this to occur

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even when the CE is within the 90-inch radius thermal and dynamic envelope because the Orbiter intrudes into the envelope at several locations as defined in Section 3.0 of ICD 2-19001 and NSTS-21000-IDD-ISS. Photographs of the close clearance hardware shall be provided to the SSP.

The second category, shown in column three, addresses the condition where the CE violates Section 3.0 of ICD 2-19001 and NSTS-21000-IDD-ISS by protruding beyond the 90-inch radius thermal and dynamic envelope, and the CE-to-Orbiter dynamic clearance is greater than the minimum required 1 inch. By protruding beyond the 90-inch radius thermal and dynamic envelope, the CE is in violation of ICD 2-19001 and NSTS-21000-IDD-ISS even though the dynamic clearance is greater than the required minimum of 1 inch. Table Q-1 lists the required activities for this situation.

The last condition, shown in column four of Table Q-1, occurs when the CE is within the 90-inch radius thermal and dynamic envelope and the dynamic clearance with Orbiter hardware is greater than the minimum required 1 inch. In this case, no additional effort is required unless there are CE hardware items statically within 3 inches of the 90-inch radius thermal and dynamic envelope or within 3 inches of any Orbiter intrusion into the 90-inch radius thermal and dynamic envelope. In addition, CE hardware items that are known to be extremely flexible, such as an antenna or a solar panel, shall be monitored according to column four as indicated by the footnote.

For the first two situations above, a Section 20 “Waivers; Deviations; and Exceedances” to the CE unique ICD is required. The last condition may or may not require a Section 20 depending on the static clearance.

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TABLE Q-1
CLOSE CLEARANCE EVALUATION PROCESS

ACTIVITY MATRIX	LESS THAN 1-INCH DYNAMIC CLEARANCE (HARDWARE TO HARDWARE)	DYNAMIC PROTRUSION BEYOND 90-INCH RADIUS ENVELOPE AND GREATER THAN 1-INCH DYNAMIC CLEARANCE (HARDWARE TO HARDWARE)	DYNAMIC MOTION WITHIN 90 INCH RADIUS ENVELOPE AND GREATER THAN 1-INCH DYNAMIC CLEARANCE (HARDWARE TO HARDWARE)
1. CE developer shall include definition of all CE close clearance points in Structural Verification Plan (SVP). • This activity requires the CE developer to identify all close clearance points in the CE SVP and to take the steps necessary to ensure the accuracy of the local deflections obtained from coupled and quasi-static loads analyses. Accurate CE deflections are critical in assessing the risk and acceptability of close clearances.	Required	N/A	N/A
2. CE developer shall provide “As Built” CE CAD model. • Requirement to deliver “As-Built” CE CAD model ensures that the CE CAD model reflects the CE flight hardware. Envelopes may conservatively represent some components but under no circumstances shall the CE flight hardware protrude beyond the outer mold line represented in the CE CAD model. Measurements of the CE flight hardware shall be performed to ensure that the “As-Built” CE CAD model complies with this standard. However, when possible, as-installed static measurements between the CE and Orbiter may replace CE H/W measurements.	Required	Required	Required

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3. CE developer shall include point-to-point relative displacement calculations of the CE hardware items with close clearances in the Design Loads Analysis (DLA). • Point-to-point relative displacement calculations provide the most accurate estimates of the CE-to-Orbiter relative motion. This requires the CE developer to identify all close clearance points when requesting an Orbiter math model so that the closest available points can be retained in the Orbiter math model.	Required	(Note 1)	(Note 1)
4. SSP to perform delta clearance assessments throughout the design and manufacturing processes as new data becomes available. • Delta clearance assessments are needed, for those areas with close clearances, as the specific hardware matures. These clearance updates will provide the SSP and CE developer with the information needed to manage potential clearance issues. The CE developer shall supply the appropriate data to support this activity.	Required	(Note 1)	(Note 1)

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5. CE developer shall demonstrate to the SSP that adequate manufacturing controls are in place to ensure that final assembly is within documented tolerances. • Implementation of manufacturing controls on CE hardware items with close clearances ensures that the CE flight hardware is built within design tolerances. The manufacturing control plan shall include intermediate measurements and final measurements of the CE flight hardware. These controls will provide an early warning of manufacturing outside of the design tolerances.	Required	N/A	N/A
6. SSP/B-SE to document close clearance in CE unique ICD. • Documenting close clearances in the CE unique ICD represents an agreement between the SSP and the CE developer of the close clearance. This agreement is contingent upon the CAD model and DLA data provided by the CE developer. If new data is provided an assessment is required in order to verify that the close clearance is still acceptable. The CE developer must supply the appropriate data to support this activity.	Required	Required	N/A
7. SSP and CE developer shall develop joint documentation freezing local configuration of the CE prior to ICD signing. Requires joint approval for any subsequent changes. • When close clearances exist, configuration control in the specific areas of concern is required to ensure that the clearances are not reduced by uncoordinated hardware changes.	Required	N/A	N/A

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8. SSP to perform Orbiter measurements in areas of concern. • This activity requires that Orbiter specific measurements of the local hardware of interest be obtained so those clearance assessments are based on Orbiter-specific flight hardware dimensions. However, when possible, as-installed static measurements between the CE and Orbiter may replace CE H/W measurements.	Required	N/A	N/A
9. Orbiter and CE develop shall perform safety assessments when early close clearances are identified. CE developer shall provide redesign plans to increase clearance. • Safety assessments shall identify the criticality of the affected hardware and the risk to the Orbiter and CE. Redesign plans shall include a description of the proposed design change together with the associated schedule and cost for implementing these hardware changes at two time points: 1) immediately following the early assessment and 2) at the time of the verified results (L-3.5 months). Safety assessments and redesign plans are required to define the impacts to the mission as a result of non-compliance with the clearance requirements.	Required	N/A	N/A

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10. CE developer shall provide “As Built” CE CAD model - including specific measurements of violating CE hardware. • Requirement that the specific CE flight hardware items with close clearances are measured ensures these specific points will be reflected to a higher degree of accuracy in the “As-Built” CE CAD model. The points to be measured shall be identified in coordination with SSP Cargo Integration Structures Working Group.	Required	N/A	N/A
11. SSP to perform point-to-point relative displacement calculations of CE hardware items with close clearances in VLA; the CE developer shall include the close clearances points in their math model. • Point-to-point relative displacement calculations provide the most accurate estimates of the CE-to-Orbiter relative motion and will be performed in the VLA. This requires that all clearance points be identified so that the closest available points can be retained in both the CE and Orbiter math models. The CE developer shall supply the appropriate data to support this activity.	Required	(Note 1)	(Note 1)
12. SSP and CE developer to perform postflight inspections of the Orbiter/CE respectively, in the vicinity of the hardware with close clearances. • Postflight inspections will determine if contact occurred and if the Orbiter/returned CE were damaged during the flight.	Required	N/A	N/A

N/A: Not Applicable (i.e., Activity is not required)
Note-1: Activity required if CE hardware is statically within three inches of the 90-inch radius thermal and dynamic envelope or within three inches of any Orbiter intrusion into the 90-inch radius thermal and dynamic envelope or known to be potentially very flexible.

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APPENDIX R

SC STANDARD PROVISION FOR VLA AND CAD DATA FILE EXCHANGE

Data file exchange can be hosted on a Cargo Element (CE) developer File Transfer Protocol (FTP) site or hosted through the Support Contactor (SC) standard provision for Verification Loads Analysis (VLA) data exchange. If hosted at a CE developer site, the developer must provide an FTP address, userid, and password at least 2 weeks before file transfer.

For file exchanges hosted through the SC standard provision, Boeing MessageCourier, each non-SC user must have a Boeing Electronic Messaging Services Identifier (BEMSID) and a Boeing Partners Network (BPN)/Reverse Proxy (RP) account. Userids and passwords obtained for use on the SC system cannot be shared with others.

Unlike regular e-mail that is available until the user deletes it, when a MessageCourier message expires, it is permanently deleted from the system. Unless the user saves the message on his computer using the “Download” button, the message title, body text, date, and distribution list are deleted from the system when the message expires. For future reference to the transmittal message, the message must be saved on the user’s computer.

Non-SC users send SC the following information 1 week in advance of file transfer: first name, last name, company name, e-mail address. Non-SC user will receive BPN userid and password by e-mail for BPN access at https://bpn.boeing.com. Once signed into BPN, Non-SC user selects MessageCourier link.

SC users access Boeing MessageCourier at https://webbits.web.boeing.com/apps/msgcourier/folder.do.

Note to UNIX users:
Attachments downloaded from MessageCourier may have spaces in their filenames. When uncompressing the files, a command formatted as follows can be used:
unzip “Data Delivery –Oct 27 2006-11 43 AM.zip”
Notice that the file name is enclosed in double quotes.

Important reminder:
All users must be aware of and meet the requirements of the International Traffic-in-Arms Regulations (ITAR) and the Export Administration Regulation (EAR). Data owners must follow their company’s procedures for control of sensitive company information.

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