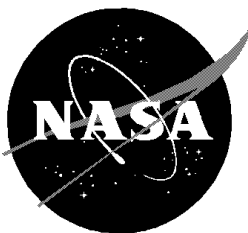


# Structural Integration Analyses Responsibility Definition for Space Shuttle Vehicle and Cargo Element Developers

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Space Shuttle Program

January 2001



National Aeronautics and  
Space Administration

**Lyndon B. Johnson Space Center**  
Houston, Texas

NSTS 37329

## DESCRIPTION OF CHANGES TO

Structural Integration Analyses Responsibility Definition

for

Space Shuttle Vehicle and Cargo Element Developers

CHANGE NO.	DESCRIPTION/AUTHORITY	DATE	PAGES AFFECTED
--	Basic issue/R37329-001	03/30/99	All
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REV B	General revision/R37329-0008	01/19/01	All

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.

NSTS 37329

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

JANUARY 19, 2001

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**DEFINITION OF ABBREVIATIONS AND ACRONYMS**

$\alpha$	Vehicle angle of attack
ASCII	American Standard Code for Information Interchange
ASE	Airborne Support Equipment
ATM	Acceleration Transformation Matrix
BRSS	Boeing Reusable Space Systems
CAD	Computer Aided Design
CADAR	Compatibility Analysis Data Acceptability Review
CAR	Compatibility Analysis Review
CATIA	Computer Aided Three-dimensional Interactive Application
CCR	Cargo Compatibility Review
CDR	Critical Design Review
CE	Cargo Element
CG	Center of Gravity
CI	Cargo Integration
CIR	Cargo Integration Review
CoFR	Certificate of Flight Readiness
CR	Change Request
DAC	Design Analysis Cycle
DLA	Design Loads Analysis
DOF	Degree(s) of Freedom
DTM	Displacement Transformation Matrix
EDO	Extended Duration Orbiter Pallet
ET	External Tank
EVA	Extravehicular Activity
FAWG	Flight Assignment Working Group
fps	Feet Per Second
FRD	Flight Requirements Document
FRR	Flight Readiness Review
FTP	File Transfer Protocol
G	Acceleration due to Gravity
GAS	Get-Away Special
Hz	Hertz
I/O	Input/Output
ICB	Integration Control Board

ICD	Interface Control Document
IDD	Interface Definition Document
IGES	Initial Graphics Exchange Specification
ISS	International Space Station
ISSP	International Space Station Program
JSC	Johnson Space Center
JST	Joint Structures Team
KSC	Kennedy Space Center
LMC	Lockheed Martin Corporation
LSDP	Loads and Structural Dynamics Panel
LTM	Loads Transformation Matrix
LWT	Light Weight External Tank
MIP	Mission Integration Plan
MLP	Mobile Launch Platform
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
OTM	Output Transformation Matrix which can include acceleration (ATM), displacement (DTM), and load (LTM) transformation matrices
OV	Orbiter Vehicle
PDR	Preliminary Design Review
PE	Performance Enhancement
PGHM	Payload Ground Handling Mechanism
PIH	Payload Integration Hardware
PILS	Payload Integration Library System
PIP	Payload Integration Plan
PSRP	Payload Safety Review Panel
PVLR	Pre-Verification Loads Review
RCS	Reaction Control System
RMS	Remote Manipulator System
ROEU	Remotely Operated Electrical Umbilical
ROFU	Remotely Operated Fluid Umbilical



SC	Support Contractor (United Space Alliance and Boeing Reusable Space Systems)
SIP	Standard Integration Plan
SLWT	Super Light Weight Tank
SRB	Solid Rocket Booster
SSD	Space Systems Division
SSP	Space Shuttle Program
SSV	Space Shuttle Vehicle
STD	Standards
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
UF	Uncertainty Factor
USA	United Space Alliance
USBI	United Space Boosters Incorporated
ADAR	Verification Analysis Data Acceptability Review
VAR	Verification Acceptance Review
VLA	Verification Loads Analysis

## 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 (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 (CE)	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 CE's 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.

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. Non returnable 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.

## **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 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).

## 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 Integration Engineering Office (NASA JSC, Mail Code MS2) and refers only to the Cargo Integration (CI) portion of the total Shuttle Program.

This document establishes a formal configuration management and control system for the SSP dynamic and quasi-static structural math models and forcing functions that are used for CI structural analyses. 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 two Sections: Section 2.0, which defines the SSP responsibilities, and Section 3.0, which defines the CE developer responsibilities and the following 17 Appendices:

- A. Responsibility Summary and Process Flow
- B. Current SSV Math Models and Forcing Functions
- C. Verification Loads Analysis (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. Pre-Verification Loads Review (PVL) Presenter's Outline

- I. CE Structural Math Model Data and Format Requirements
- J. Verification Acceptance Review Presenter's Outline
- 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 Cargo Element to Orbiter Clearance Requirements

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

- A. The SSP webpage address is: [SSPWEB.JSC.NASA.GOV](http://SSPWEB.JSC.NASA.GOV)

This webpage provides entry points to many of the other webpages as well as general information concerning the SSP. This includes the Shuttle manifests, schedules, libraries, and meetings.

- B. The SSP Integration Engineering Office (MS) webpage address is: [SSPWEB.JSC.NASA.GOV/webdata/mshome](http://SSPWEB.JSC.NASA.GOV/webdata/mshome)

The MS webpage provides access to Cargo Engineering schedules and charts, Integration Control Board (ICB) Change Requests (CRs), and the SSP CI Structures Home Page.

- C. The SSP Customer and Flight Integration Office (MT) webpage address is: [SSPWEB.JSC.NASA.GOV/ntdata/ssp/webdata/mt/mthome.htm](http://SSPWEB.JSC.NASA.GOV/ntdata/ssp/webdata/mt/mthome.htm)

The MT webpage provides access to the Flight Assignment Working Group (FAWG) webpage which provides long range manifest and launch date schedules for the SSP.

- D. The SSP CI Structures Home Page address is:  
[SSPWEB.JSC.NASA.GOV/webdata/mshome/struct/st-index.htm](http://SSPWEB.JSC.NASA.GOV/webdata/mshome/struct/st-index.htm)

This webpage contains information for each mission such as presentation charts, VLA schedules, and manifests. The webpage also serves as the SSP/International Space Station (ISSP) Joint Structures Team (JST) homepage 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 webpage.

- E. The SSP Payload Integration Library System (PILS) webpage address is: [SSPWEB.JSC.NASA.GOV/pils/](http://SSPWEB.JSC.NASA.GOV/pils/)

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

- F. The ICD 2-19001, Interface Definition Documents (IDDs), and CE unique Interface Control Documents (ICDs) can be accessed through:  
[www.unitedspacealliance.com/icd/](http://www.unitedspacealliance.com/icd/)

- G. The Structures Working Group (SWG) home page can be accessed through the CI Structures Home Page (Item D above). This page contains an SWG status report for each CE and the SWG Payload Design Guide.

- H. The NASA Technical Standards website can be accessed at <http://standards.nasa.gov/>

## 2.0 SSP RESPONSIBILITIES

The SSP, through the SSP Integration Engineering Office (NASA JSC, Mail Code MS2), 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 Reusable Space Systems (BRSS)) with SSP Structures Working Group (SWG) oversight.

### 2.0.1 Loads and Structural Dynamics Panel (LSDP)

The LSDP is the SSP Systems Integration 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 (SRB) 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-KSC, NASA-MSFC, Lockheed Martin Corporation (LMC), Cordant Technologies, United Space Boosters Incorporated (USBI), USA, and BRSS. Updated SI SSV system models and/or forcing function data are reviewed and approved by the LSDP.

### 2.0.2 Structures Working Group (SWG)

The SWG is responsible for SSP Cargo Integration (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 test 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 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.



## 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 liftoff, 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

BRSS, LMC, USBI, 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 Systems Integration 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 Systems Integration 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 System Integration models.

Once the revised System Integration'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 will review and approve the recommended CI SSV models. Final approval of these models will be through the SSP's Integration Control Board (ICB).

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 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 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 liftoff 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 M6.0ZA02 or CM1.0A12. 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 while

the CM1.0A model is the Cargo Integration High Fidelity Orbiter Math Model (CM1.0A = Cargo Orbiter Model Version 1.0, Revision A). The current SSV math models (and forcing functions) database are 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 System Integration'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 will review and approve the recommended CI forcing functions. Final approval of these forcing functions will be through the SSP's ICB.

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 is 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 liftoff and landing forcing function is uniquely identified through a numbering system. The current SSV forcing functions (and math models) database are discussed in Appendix B.

### 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 liftoff, 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 the Orbiter cargo bay deflections and flexibility.

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 includes 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 "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 2064 quasi-static conditions that are evaluated.

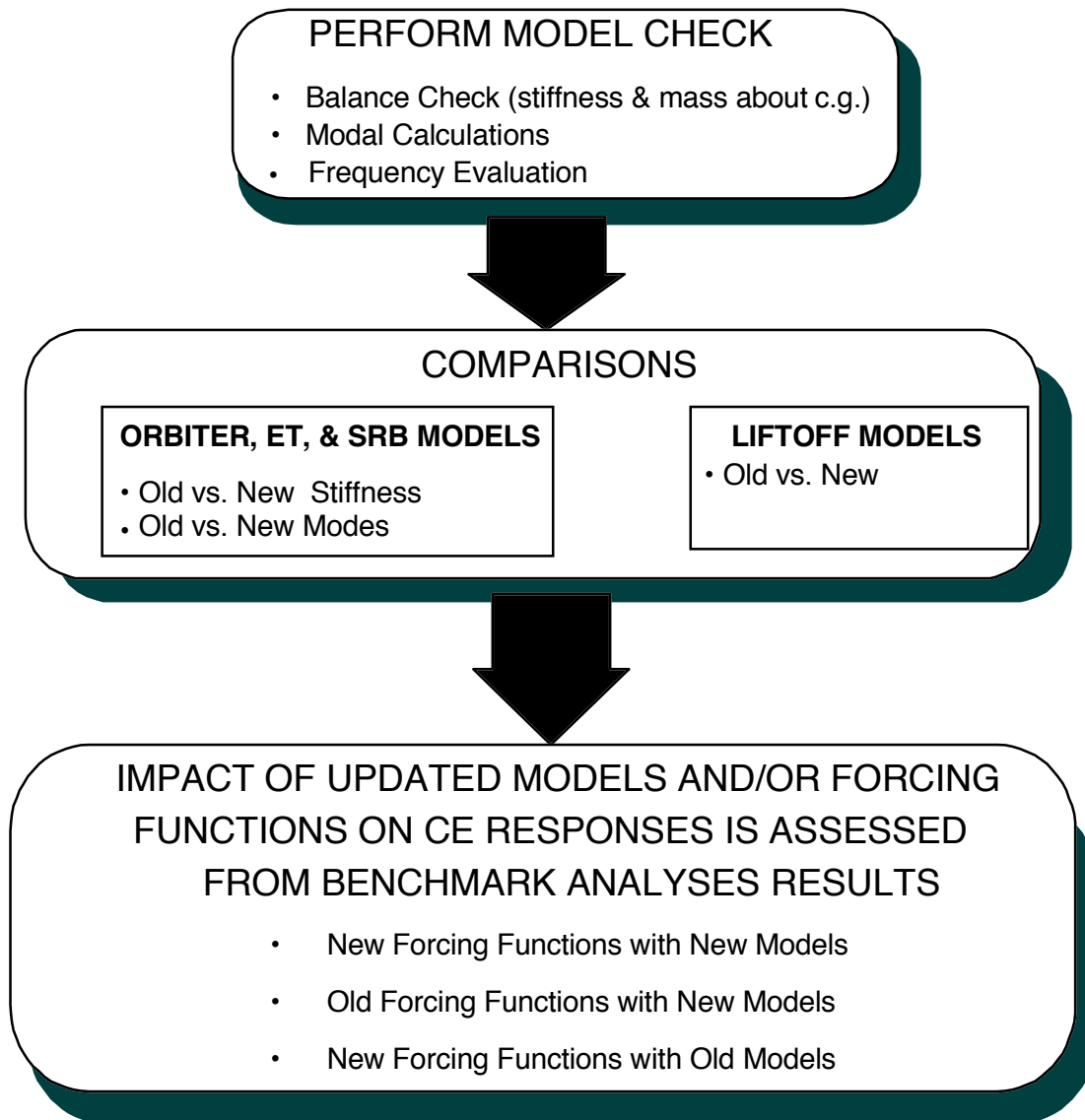


Figure 2.1-1 SSV Math Model and Forcing Function Evaluation

### SSV MATH MODEL & FORCING FUNCTION DATA BASE

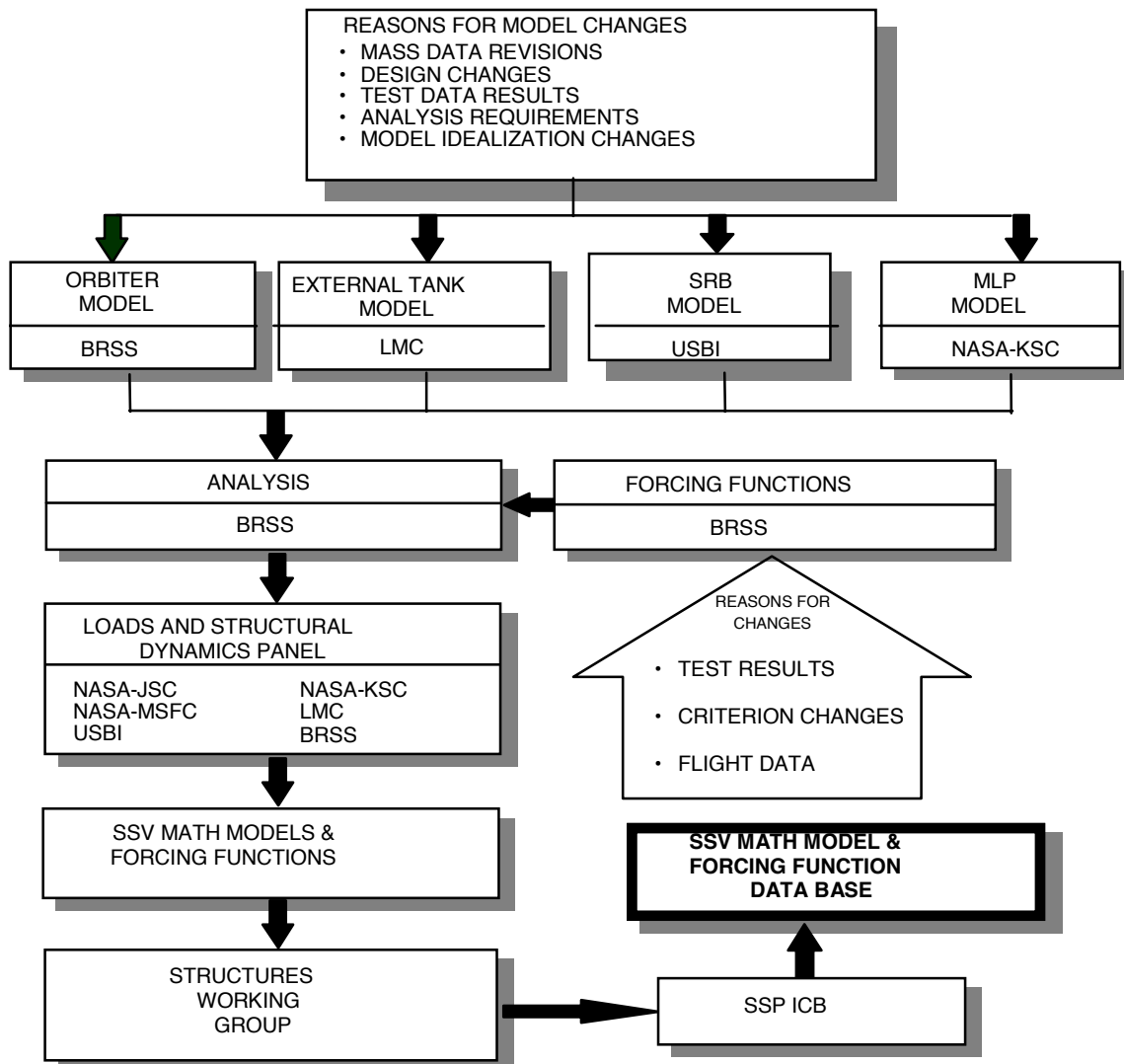


Figure 2.1-2 SSV Math Model and Forcing Function Configuration Control

The changes that were made to the quasi-static analysis to accommodate Performance Enhancements (PE) 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 CE's developer's latest DLA results and Computer Aided Design (CAD) models. 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. For International Space Station (ISS) missions, the SSV compatibility assessments are performed as part of the Design Analysis Cycles (DAC). For other missions, the compatibility assessments are performed on an "as needed" basis.

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/cargo element 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 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. 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 is expected to follow the close clearance process that is defined in Appendix Q or equivalent.

Where CE deflection data is 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 Technical Discipline Manager (TDM) shall be kept informed as to the benchmark results and shall have final approval authority over the use of analytical tools, methodologies, and computational platforms.

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.

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 liftoff and landing dynamic models will be utilized for generating the VLA mission-specific models with the correct 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 physical stiffness and mass matrices, 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. 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 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)

OTM sizes up to 1000 items for each CE are considered as 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 (VAR)

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 pertinent structural margins and/or load ratios versus allowable load. All pertinent open issues that may remain open after the VAR will be worked and resolved prior to launch.

### **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 (DLAs)**

The CE developer is responsible for performing all DLAs for the particular CE. These DLAs shall include the liftoff 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/roll back) 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. The SSV liftoff, landing, and quasi-static math models, liftoff 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. 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 must be performed 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. The CE models will be positioned such that the Orbiter CG will be within the allowable limits. 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 will be recommended by the SWG in consultation with the CE developer. The values of the UFs that will be recommended 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 Verification Loads Analysis (VLA). The CE developer should not assume that these values represent the values that the SWG will recommend 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. If it does, the SWG will normally specify a model UF of 1.0 to be used in the VLA. However, if the correlation is not in compliance with NSTS 14046 criteria, the SWG may assign a model UF to be used in the VLA or may reject the math model. There are no limitations as to the magnitude of the SWG recommended model UF to be used in the VLA. There are instances in which the SWG recommended 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 clearances of each of these points as part of each 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 Interface Control Document (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 is expected to follow the close clearance process that is defined in Appendix Q or equivalent.

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

### **3.2 SSV COMPATIBILITY ASSESSMENT SUPPORT**

A SSV Compatibility Assessment will be performed for all ISS Missions as part of the ISS Design Analysis Cycle. For non-Space Station missions, the SSV Compatibility Assessment will be performed on an "as needed" basis. Data requirements for the 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 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 Computer Aided Design (CAD) 3-D model for evaluating detail clearances between the CE and Orbiter structure and to support development of the CE-unique ICDs is required. CAD model requirements are specified in Appendix G.

After BRSS has received all data that is required to perform an SSV Compatibility Assessment, a Compatibility Analysis Data Acceptability Review (CADAR) will be conducted. BRSS will provide to the CE developer, USA, SSP and other interested personnel a description of the data to be used for the assessment. The non-BRSS recipients are responsible for reviewing the BRSS data and providing corrections prior to the start of the assessment. After the assessment has been performed, a Compatibility Analysis Review (CAR) will be conducted to review the results and determine follow-on activities and actions.

### **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 Pre-Verification Loads Review (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 DTMs) for each of these items to facilitate clearance assessments.

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 or on magnetic media in ASCII text format, 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 must be obtained prior to submitting the model for the VLA. The SWG requires written Structural Verification Plans (SVPs), testing plans, and model correlation reports to be submitted as described in Appendix K and NSTS 14046. 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 liftoff, 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 comanifested CEs and not just a single developer.

CE structural math model criteria and guidelines have been established 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. To this end, the SSP has established generic CE weight tolerances as follows: 200 pounds for across the bay CEs, 50 pounds per sidewall carrier beam, and 50 pounds for each payload/logistic rack. That is, the actual measured flight weight for an across the bay CE shall be within 200 pounds of the math model weight that was submitted for the VLA. If this tolerance is exceeded, then a revised math model may be required that is more representative of the actual flight configuration. The established generic center of gravity (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, and each rack. These tolerances can be expanded by CE-developer-performed sensitivity studies that are closely coordinated with 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. Should it be 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.

#### **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 (which should 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 Interface Definition Documents (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.

### 3.5.2 Interface Definition Documents (IDDs)

The Space Shuttle provides many interfaces and services to the CEs. The IDD documents 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 International Space Station (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. Since the CE hardware configuration could be different for liftoff, 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 Standards (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.

## 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 Payload Integration Library System (PILS) which can be accessed from the SSP Home Webpage (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

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. Shimizu, Michael W., et al, "STS Dynamic Math Models (M6.0ZA) for Payload Loads Analysis," BNA Document No. STS81-0641F, July 1988
17. TBD, "STS Cargo Integration Dynamic Math Models (CM1.0A) for Cargo Element Loads Analysis," BRSS Document No. TBD
18. Haugen, Earl A., "Liftoff Forcing Functions (LR2000 Series) for Payload Loads Analysis," BNA Document No. STS88-0609, April 1988
19. TBD, "Cargo Integration Liftoff Forcing Functions (CLO1000 Series) for Cargo Element Loads Analysis," BRSS TBD.
20. Shimizu, Michael W. and Sullivan, Andrew J., "Landing Forcing Function 7000 Series Data Base," BNA Document No. STS86-0020A, February 1988
21. Shimizu, Michael W., "STS Dynamic Math Model (M6.0VB) for On-orbit Payload Loads Analyses," Report No. SSD92D0594, August 1992
22. Boeing International Space Station Alpha Program Document D684-10019-1, "Space Station Structural Loads Control Plan," March 1994

## **APPENDIX A**

### **RESPONSIBILITY SUMMARY AND PROCESS FLOW**

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

#### **The NASA-JSC SSP Integration Engineering Office**

Responsible for the overall process leading to Cargo Element (CE) hardware certification for flight.

#### **The Loads and Structural Dynamics Panel**

Responsible for the review/assessment/approval of the source data utilized in forming the SSP System Integration Space Shuttle Vehicle (SSV) math models and forcing functions.

#### **The Structures Working Group**

Responsible for overall technical advice and support to the National Aeronautics and Space Administration-Lyndon B. Johnson Space Center (NASA-JSC) SSP Integration Engineering Office. Also responsible for providing technical support to the Payload Safety Review Panel and reviewing, assessing, and approving proposed revisions to the SSP Cargo Integration 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 Verification Loads Analysis (VLA).

#### **Cargo Element Developer**

Responsible for the CE structural integrity.

Responsible for providing Design Loads Analysis report to support the SSV compatibility review.

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

Responsible for providing test verified math models to support the Verification Loads Analysis.

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.

### **Boeing Reusable Space Systems**

Responsible for maintenance and configuration control of the SSV Cargo Integration 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.

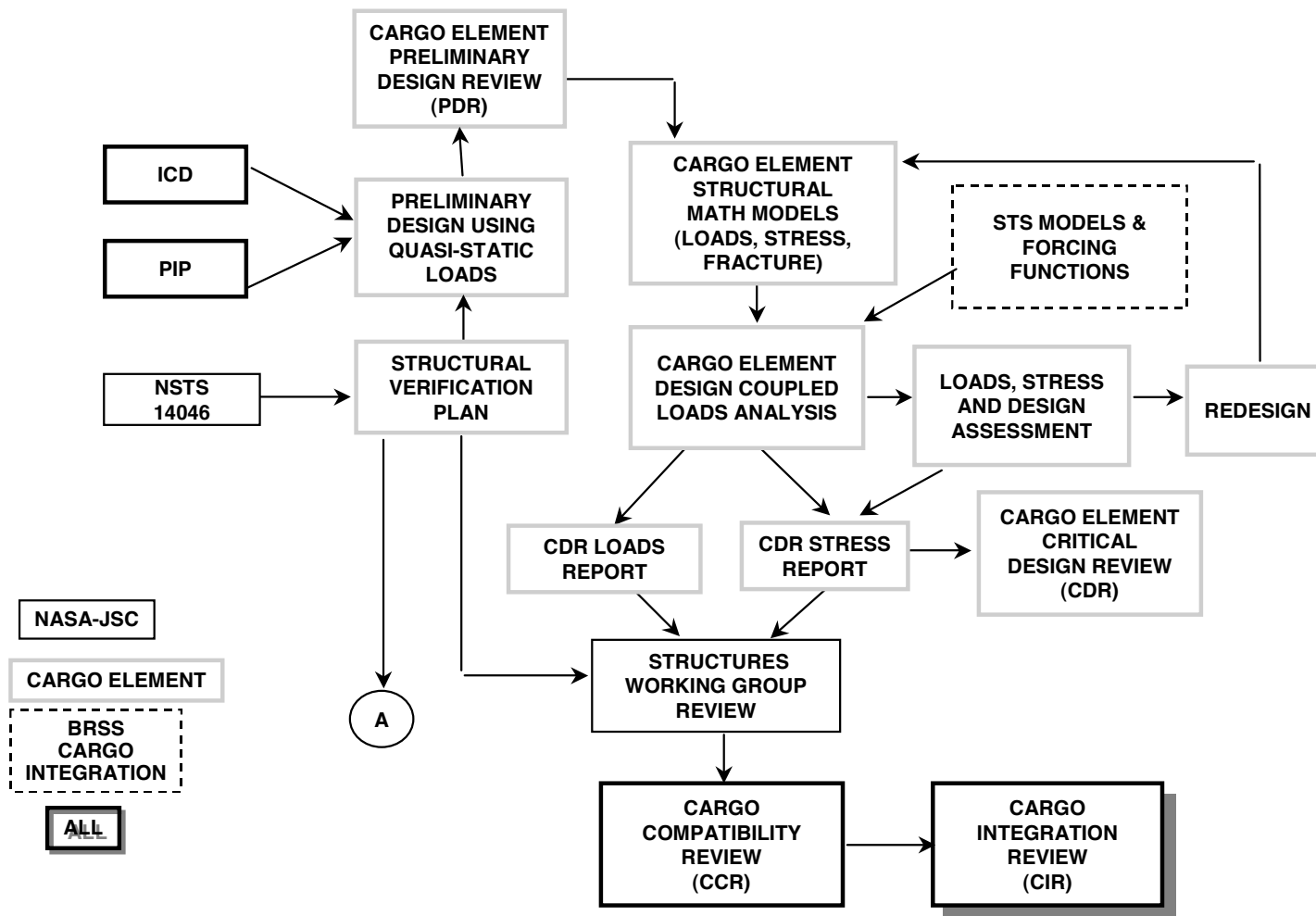
Responsible for the performance of the SSV compatibility assessment based upon the CE developer provided Design Loads Analyses and CAD models.

Responsible for performing the Verification Loads Analyses 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.

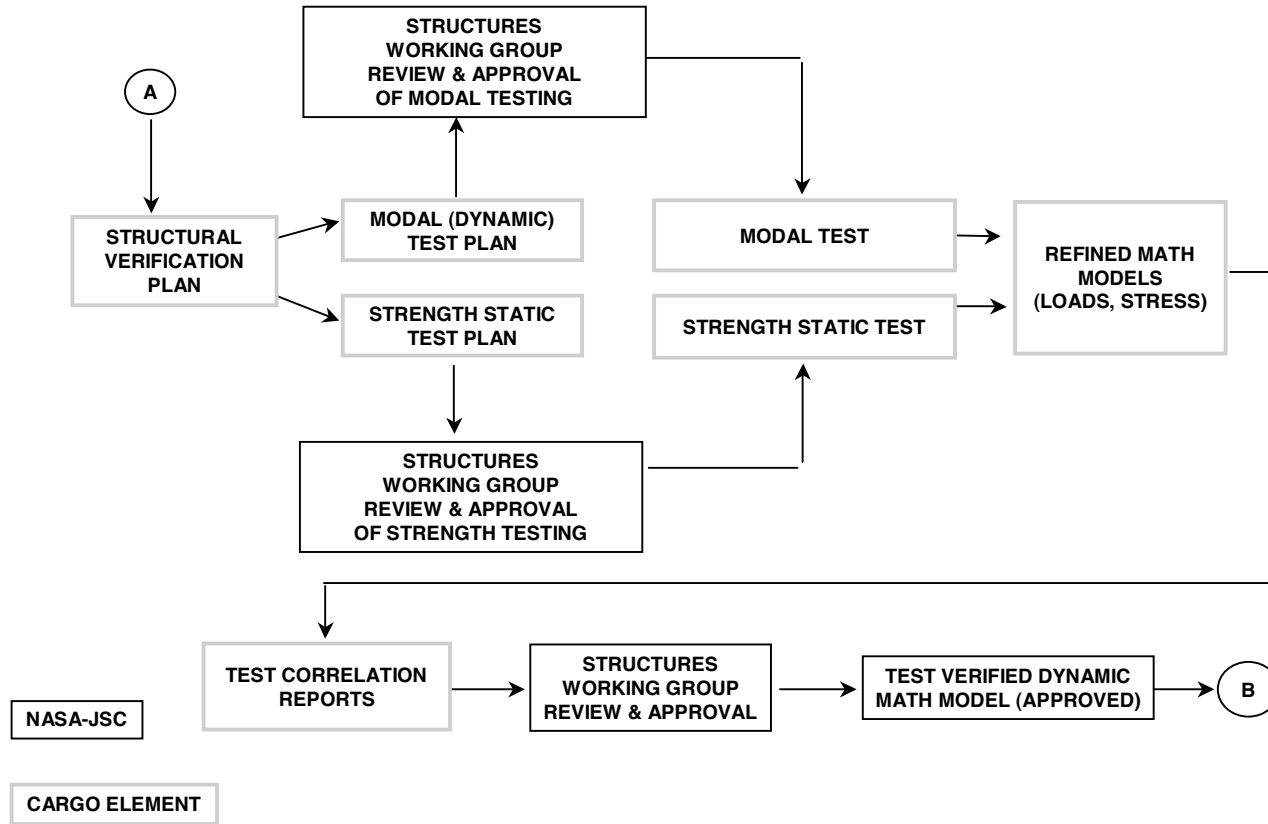
The following three flow charts depict the typical CE design, verification, and VLA process.

# STRUCTURAL DESIGN AND LOADS - DESIGN

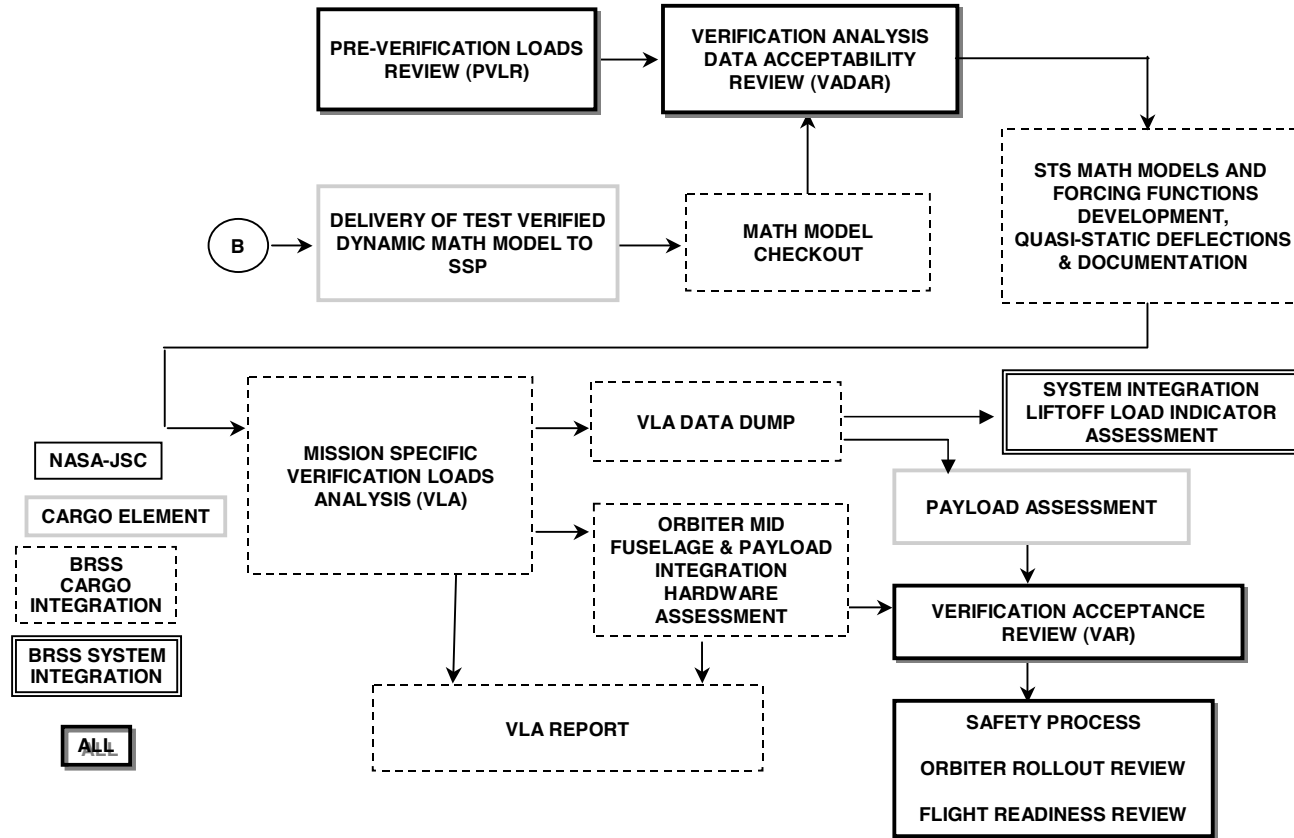




## STRUCTURAL DESIGN AND LOADS - TESTING



## STRUCTURAL DESIGN AND LOADS - VERIFICATION



## APPENDIX B

### CURRENT SPACE SHUTTLE VEHICLE MATH MODELS AND FORCING FUNCTIONS

There are currently two Space Shuttle Vehicle (SSV) liftoff structural math models that are used to support Cargo Element (CE) Design Loads Analyses (DLAs) and Verification Loads Analyses (VLAs). The model to be employed is dependent upon which External Tank (ET) is being used for the particular mission. One model uses the Lightweight External Tank (LWT) that has been used to support Shuttle flights since 1989. This model is documented in Reference 16, Report No. STS81-0641F, "STS Dynamic Math Models (M6.0ZA) for Payload Loads Analysis." The second liftoff structural model is documented in Reference 17, Report No. TBD, "STS Cargo Integration Dynamic Math Models (CM1.0A) for Cargo Element Loads Analysis" and uses the Super Lightweight Tank (SLWT) and the new High Fidelity Cargo Integration Orbiter structural dynamic math model. The second model is also referred to as the Hi Fi model. The ET model is the verification cycle SLWT which represents the new flight hardware. There is approximately a 7500-pound reduction in the SLWT inert structural weight as compared to the LWT. The previous M6.0ZB and M6.0ZC Orbiter performance enhancement models are now obsolete and shall not be used.

The liftoff forcing functions are developed for a specific SSV model, such as M6.0ZA or CM1.0A, and are applicable for all CE weights. The liftoff forcing functions for the LWT are documented in Reference 18, STS88-0609, "Liftoff Forcing Functions (LR2000 Series) for Payload Loads Analysis." The liftoff forcing functions for the Hi Fi Orbiter model are documented in Reference 19, Report No. TBD "Cargo Integration Liftoff Forcing Functions (CLO1000 Series) for Cargo Element Loads Analysis." It is important to note that these two sets of forcing functions are not interchangeable. That is, the LR2000 forcing functions cannot be applied to the CM1.0A math model nor can the CLO1000 forcing functions be applied to the M6.0ZA math model.

In order to ensure that the full liftoff response envelope is assessed, the complete set of liftoff forcing functions must be included in the CE developer's analysis. Any deviation from this requires prior written approval from the SWG and SSP.

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

The landing forcing functions are dependent on the cargo/Orbiter 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:

1. Maximum nose gear loading
2. High  $\alpha$  - main gear landing
3. Low  $\alpha$  - main gear landing
4. High  $\alpha$  - main gear landing with  $+Y_0$  crosswind
5. Low  $\alpha$  - main gear landing with  $+Y_0$  crosswind
6. High  $\alpha$  - main gear landing with  $-Y_0$  crosswind
7. Low  $\alpha$  - main gear landing with  $-Y_0$  crosswind

where  $\alpha$  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, Report No. SSD92D0594, "STS Dynamic Math Model (M6.0VB) for On-orbit Payload Loads Analysis." This model is based on the M6.0 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.

## APPENDIX C

### VERIFICATION LOADS ANALYSIS (VLA) OVERVIEW

The following paragraphs describe the Verification Loads Analysis (VLA) Generic Template and the various activities that occur during that time frame. 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) (United Space Alliance (USA) and Boeing Reusable Space Systems (BRSS)) and may differ from the generic template. Planned multi-cycle VLAs will utilize the SSP Loads Indicator VLA Approach that is described in Appendix O. The first cycle of a planned multi-cycle VLA will utilize the VLA activities that are 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 Pre-Verification 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 Compatibility Review (CCR), the Cargo Integration Review (CIR) and the PVLR, the SSP requires a copy of the latest CE Design Loads Report. 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 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 location in the cargo bay, and all VLA contingency landing manifests and landing sink rates have been finalized. The PVLR Presenter's Outline, that 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 liftoff, 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 linear VLA will be performed using the standard diagonal system damping approach. If this is not the case, the PVLRL would have established a unique template and the dates contained within the PVLRL 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 UF that will be included in the VLA results. The SSP will specify a manifest uncertainty factor (MUF) that will 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 will 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.

Just prior to actually starting the VLA, the Verification Analysis Data Acceptability Review (VADAR) telecon will be conducted between the SSP, USA, BRSS, and the CE developers. This telecon will be scheduled after all CE models have been received and validated at BRSS. 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 completion of this review, formal authorization will be provided to begin the VLA. Any changes to CE models, output products, manifests, etc., that occur after the VADAR will be 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.

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 PVLAR or VADAR minutes. The BRSS VLA results will be formally documented and will be published prior to the VAR.

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).

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 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 BRSS and CE structural assessments. Each CE developer will 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 will include all applicable UFs and MUFs. If items are identified during this review that require additional work or if the CE has not yet completed the evaluations, action items will be assigned. The VAR presenter's outline that describes the recommended contents of the CE developer's presentation is provided in Appendix J. The VAR meeting is intended to complete the SSP structural flight verification process and to provide 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 receive considerable SSP management attention and assistance in closing the issue. Thus it is highly desirable 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.



**Table C-1**  
**VLA Generic Template**

MILESTONE	DATE*	APPENDIX
CE Design Loads Analysis Report	L - 13.0	D
Pre-Verification Loads Review (PVLRL)	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	
Verification Acceptance Review (VAR)	L - 3.5	J
CoFR/FRR Start	L - 2.5	
Launch	L - 0	

\* Months before launch

## 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 SC as specified in Table C-1 of Appendix C or the mission-unique Verification Loads Analysis (VLA) schedule that is published by USA. This document is required to support the Cargo Compatibility Review (CCR) and 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 SSV math models and forcing functions that were used
- b. CE mass properties
- 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 that is outside the 90-inch radius envelope.
- d. Shuttle/CE longeron trunnion interface loads and relative displacements
- e. Shuttle/CE keel trunnion interface loads and relative displacements

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.
  - 1.3. Tabulate the CE's mass properties.

2. CE DYNAMIC MATH MODEL DESCRIPTION
  - 2.1. Describe the modal frequencies, free-free eigenvalues, shuttle constrained eigenvalues, etc.
  - 2.2. List the Support Contractor (SC) (United Space Alliance (USA) and Boeing Reusable Space Systems (BRSS)) provided Space Shuttle Vehicle (SSV) model number and document used in the CE Design Loads Analysis (DLA).
  - 2.3. List the SC provided forcing functions and document used in the CE DLA.
  - 2.4. Describe the cargo bay manifest arrangement used for the DLA.
  - 2.5. If coupled and quasi-static loads analysis results were not used for the CE design, 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.
  - 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 must be included in the VLA.
4. ANALYSIS RESULTS (Provide loads and deflections as flight regime consistent data (e.g., liftoff, ascent quasi-static, descent quasi-static, on-orbit, and landing)).
  - 4.1. Transient Analysis Results
    - 4.1.1. Liftoff 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.
  - 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 that is 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 BRSS shall specify a UF that is recommended by the CE developer 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 UF.

5. ACRONYM LIST

6. REFERENCES

## 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 as per the Payload Integration Plan (PIP) or Mission Integration Plan (MIP).
2. The formal request should be made to Ms. Erica E. Bruno, United Space Alliance USH-700D, telephone 281-280-6945, facsimile 281-212-6045, electronic mail address "erica.e.bruno@usahq.unitedspacealliance.com". An advance copy should also be sent to Mr. C. T. Rodgers, Boeing Reusable Space Systems (BRSS). He may be contacted at telephone 714-372-2801, facsimile 714-934-5009, or "chris.t.rodgers@boeing.com" via electronic mail. A courtesy copy should also be sent to NASA/JSC ES2/Vincent Fogt, telephone 281-483-6391; facsimile 281-244-5918. Mr. Fogt's electronic mail address is "Vincent.A.Fogt1@jsc.nasa.gov".
3. Data delivery schedules are coordinated and agreed to between the CE development organization, United Space Alliance (USA), and BRSS. USA will provide either written or verbal authorization to BRSS 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 BRSS.
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 BRSS. Urgent requests must be coordinated with USA such that ongoing or planned SSV math model development tasks and schedules can be modified.
5. A two-week template is required for additional quasi-static deflection data or for only landing forcing functions development and transmittal.

6. Media and format requirements for the data transmittal are coordinated with the CE development organization. The standard data format for SSV math models and forcing functions is defined in Appendix M.
7. The requested data are generated, transmitted to the requesting organization, and the appropriate documentation is published.

The request for SSV math models and forcing functions must 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-RSS will verify that the specified locations are viable, based on ICD-2-19001 or NSTS 21000-IDD-ISS constraints.
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 math model 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), Extended Duration Orbiter (EDO) pallet, 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 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 BRSS for these mission equipment items to assess mission compatibility with the Orbiter.

Where direct recoveries of these items are not feasible from the DLA, an Output Transformation Matrix will be provided to facilitate the recoveries.

6. Format of the Shuttle math models (Physical, 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.
8. Media transmittal type and format shall be specified and is negotiable based upon the CE development organization's and BRSS's capabilities. Some options are 9-track magnetic tapes, magnetic cartridge tapes, electronic transmission, and temporary guest accounts on mainframe computers.
9. The CE desired data delivery date shall be specified. The final delivery date will be negotiated based upon the amount of math model requests in work at the time and other approved priority and nonpriority tasks in the SC request queue. Under no circumstances will a Shuttle math model 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.

**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 M6.0ZA CM1.0A

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: Physical Craig-Bampton Rubin-MacNeal Other(explain)

Landing category (returnable or non-returnable): \_\_\_\_\_

Media transmittal type (e.g., 9-track tape, electronic,  
magnetic cartridge): \_\_\_\_\_

(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 three inches of the 90-inch radius Orbiter cargo bay thermal/dynamic envelope, within three 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.



## 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, email, 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 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 SSV math models and forcing functions utilized in the transient and quasi-static analysis.
5. Description of the methodology used to perform the Orbiter/CE coupled quasi-static and dynamic loads analyses. Describe the combination method being used for combining random and transient loads.
6. Sidewall mounted CEs orientation (port/starboard), weight, 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 maximum (both positive and negative) sidewall carrier-to-Orbiter interface loads. Event consistent and time uncorrelated translational and rotational

transient (liftoff/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: liftoff (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 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 case identification, uncertainty factor, preload, and friction coefficients utilized. If trunnion temperatures above  $-130^{\circ}$  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.

13. Definition of the deflections of CE secondary structure (such as meteoroid/debris shields) with potential clearance issues, as defined in 2.0 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 section 2.0.

## APPENDIX G

### CARGO ELEMENT COMPUTER AIDED DESIGN MODEL REQUIREMENTS

The following three files are required when Cargo Element (CE) Computer Aided Design (CAD) data, (e.g., 2-D Drawings, 3-D models, figures, data listings) are submitted to Boeing Reusable Space System (BRSS). 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 email address), sender's company name and address.
2. STEP FILE -- (in ASCII format) to provide 3-D model geometry. IGES FILE can be accepted when the CE developer CAD system does not support the generation of a STEP file. STEP/IGES files are required for CE developers only.
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 iso view (with hidden lines removed) from its native system or CE drawing is acceptable.

(It is recommended that each STEP and/or IGES file has 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.

Note: BRSS currently uses I-DEAS Master's Series Version 5.0.

For CE developers sending 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: BRSS/Huntington Beach currently uses CATIA Version 4.2.1 R1  
on AIX/Workstations.

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

1. Electronic Data transfer (Local Area Network, Internet  
connection, Ethernet, etc.):
  - 1.1. Internet connection: (The following IP address is  
authorized and accessible:)  
Sphinx.cal.boeing.com (or  
141.102.208.157 for UNIX  
environment)  
userid: userxfer  
passwd: mongoose  
(then, cd to /pub/remote/payload)

Note: It is highly recommended to send data files via the  
Internet due to the existing BRSS system which  
consists of a high volume of disk space and fast  
response time overall. The model provider should  
contact BRSS while the file is being sent. This  
public File Transfer Protocol (FTP) remote site is  
outside the BRSS firewall and all model files will be  
automatically deleted after 2 weeks.

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

## 2. Data transfer by tape:

### 2.1. 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

### 2.2. IBM/PC

- a) Floppy Disk requirement: 3.50 inch (1.44 MB).
- b) Floppy Disk format: IBM DOS/MS-DOS

### Space Station Analysis Coordinate System

Space Station on-orbit CAD models shall be provided in the Space Station 3D Analysis Coordinate Axis System. The broken down/CE model files shall comply with the same axis system.

### 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.

### BRSS/Huntington Beach Contacts

Due to continuous software updates, it is suggested that BRSS be contacted prior to the CE developer developing and sending CAD models. For additional information concerning CAD model requirements or BRSS CAD capabilities, please contact the following personnel:

1. For Catia/Unigraphics translation - Y. C. Yang (714) 372-2939 (yuan.c.yang@boeing.com)

3. For Pro-E/I-deas translation - Y. C. Yang (714) 372-2939  
(includes STEP, IGES, GIF, UNV, VRML and any other solid  
conversion/translation)
4. For on-orbit Space Station - Richard.Wong@West.Boeing.com  
(714) 372-2846

## APPENDIX H

### PRE-VERIFICATION LOADS REVIEW (PVL R) PRESENTER'S OUTLINE

The following topics should be thoroughly discussed in the presentation material presented at the Pre-Verification Loads Review (PVL R), as appropriate for the particular Cargo Element (CE). 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.

#### 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." Summarize all test results and the correlation of the dynamic math model with test data. Provide report numbers in the presentation, if possible.

#### 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 specified by the Structures Working Group. Provide the SWG approval memo number in the presentation if available.

#### 4. CLOSE CLEARANCE POINTS

For clearance analysis purposes, additional recoverable physical DOF shall be included in the CE math models. These must 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 non-linear 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 crew induced loads, etc. Describe any contingency configurations (e.g., landing with failed CE latches) 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 format, such as maximum/minimum listings, time histories or shock spectra plots, transmittal media, double precision data requirements, etc.

## 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 must 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 should be transmitted electronically using File Transfer Protocol (FTP) or other electronic file transfer methods. Alternate transfer methods must be pre-coordinated with the Support Contractor (SC)(United Space Alliance (USA) and Boeing Reusable Space Systems (BRSS)).
  - 2.3. When using electronic transmission, all documentation must be provided with the model files. An official, hard copy of the documentation shall also be provided. Information about file names, contents, and formats shall be included in the documentation.

The SC can either access a special account on the CE customer's computer system or the CE customer can transfer the data to an 'anonymous' account on the SC's computer system. Many CE customers have set up accounts for the SC on their systems.

To use an account on a CE customer's computer system, the CE customer must give the 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 SC and provides the file names of the CE model. The SC accesses the account by logging on through FTP and copies the files to the SC's system.

If the CE customer cannot provide an account for the SC, the SC can provide an 'anonymous' FTP account on the SC's computer system. The Internet address will be provided on an "as-needed" basis. The CE customer can then transfer the data to the SC's computer system and then shall contact the SC to provide the necessary information concerning the data transfer.

- 2.4. All matrices should be in either SC or MSC NASTRAN OUTPUT4 format (see SC format in paragraph 2.7 below). This data shall be provided in ASCII format and not in binary format. Note that all zero matrix terms must be explicitly written (i.e., no packed matrices).
- 2.5. The physical degrees of freedom (DOF) used in the CE model should be in the Orbiter coordinate system as defined in Section 3.1.1 of ICD-2-19001, NSTS 21000-IDD-ISS, or the CE documentation must include the transformation from the CE coordinate system to the Orbiter coordinate system.
- 2.6. The CE structural attachment point locations in the cargo bay must be explicitly stated in the Orbiter coordinate system in the accompanying documentation.
- 2.7. The SC OUTPUT4 format in terms of FORTRAN formatting where the matrix data is written by columns 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)

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.

- 4.2. A stiffness (K) matrix and an associated mass (M) matrix must be provided. The maximum number of DOF for a Shuttle CE math model is limited by analysis cost and cycle time considerations to 400. Exceptions to this limit shall be coordinated with USA. 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 USA.
- 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). In addition to the generalized stiffness and mass matrices, the CE must provide the coordinate transformation matrix (containing normal modes and constrained modes) including only those rows corresponding to DOF at which physical responses are required.
- 4.3. The model must contain physical DOF or a transformation matrix to recover physical DOF in the X, Y, Z,  $\Theta_x$ , and  $\Theta_z$  directions at each longeron bridge attach point and in the X, Y, Z,  $\Theta_x$ , and  $\Theta_y$  directions at each keel bridge attach point.
- 4.4. The extra DOF that are needed for Orbiter to CE relative displacement and relative rotation computations at the trunnions must be included. In addition, for the stabilizing longeron and keel trunnion DOF that attach to a retention latch which slides in the Orbiter  $X_0$  direction, the appropriate physical DOF must be provided so the CE retention latch mass can be added in the coupled loads analysis.
- 4.5. For clearance analysis purposes, additional recoverable physical DOF shall be included in the CE math models. 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 Output Transformation Matrices (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 will be incorporated into the analysis as NASTRAN TCURVE cards.
- 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.
  - 4.8.5. The units for all numerical data must be specified. The English system (inch-pound-second) is the preferred system of units. Other systems of units are acceptable provided that the documentation contains the CE recommended conversion factors to convert the supplied data into the preferred (English) system of units.
  - 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.

5. Prior to performing the VLA, a PVLR will be conducted between the SSP, SWG, USA, BRSS and CE developers to establish formal agreements on analysis input data requirements, products, and schedules.
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 liftoff 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.



## 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.

#### 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 Pre-Verification Loads Review (PVLAR) 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 PVLAR. 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.

#### 4. SUMMARY OF VERIFICATION LOADS

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. Address 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. List each uncertainty factor 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. 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. Additional items that must be evaluated include the effects of Orbiter cargo bay vent impingement on the CE and the restow capability of a CE that must be returned for landing.

## **APPENDIX K**

### **STRUCTURES WORKING GROUP AND STRUCTURAL CERTIFICATION**

Reference JSC Memo ES42-90-30M, dated April 1990, Structural Certification of Space Shuttle Payloads.

The above referenced Lyndon B. Johnson Space Center (JSC) Memo was written due to the confusion that Cargo Element (CE) Developers had concerning the process for complying with the Space Shuttle Program (SSP) structural verification requirements. It discusses the Structures Working Group's (SWG) expectations of the CE developers in the certification/validation process and describes the meetings, reviews, and data submittals that are required as part of that process. The following text follows the JSC Memo approach but has been revised to reflect today's requirements and expectations.

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 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 will 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). The detailed information that should be provided in the SVP is described under the Documentation heading.

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 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 should 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 will submit strength and dynamic test results and model correlation reports. The dynamic test results and model correlation report must be submitted far enough in advance of the Pre-Verification Loads Review (PVLRL) 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 can also reject the model.

6. The CE developer will 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 PVLAR. 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 PVLAR.
9. The CE developer will submit the test verified CE dynamic math model (or models) according to the requirements of this document and NSTS 14046. USA will 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 to review the CE structural analysis prior to approving the hardware certification. This review would be necessary, for example, for CEs that are not being developed under contract, or the sponsorship, of one of the NASA centers.
11. The CE developer will 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 (SVP)

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.
- 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.
- 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.
- 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.
- d. Description and sketches of test set-up, 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 set-up 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.
- 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 set-up, 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.
  - (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.

## 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 (and probably highly nonlinear). Detailed modeling of such a complex process is not practical. Instead, damping is approximated through analytical assumptions. Hopefully, a measure of the conservatism of these assumptions can be supported by the CE dynamic test results. However, the analytical system damping assumption that is generally used is made at the SSV/CE(s) system modal level, a level at which no damping test data has ever been obtained.

The standard Space Station 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  $\zeta$  is the system level percent critical damping value (e.g.,  $\zeta = 0.01$  is one percent of critical) and  $\omega$  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.,  $\zeta = 0.0025$  or one quarter of a percent critical). Conversely, the CE developer may wish to take advantage of the measured higher damping (e.g.,  $\zeta = 0.05$ ) 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 PVLAR.

#### Liftoff 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 liftoff

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.

### 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, to some extent, 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 can have significant impact on the analytical results.

## APPENDIX M

### SSV STRUCTURAL MATH MODEL AND FORCING FUNCTIONS FORMAT REQUIREMENTS

#### STRUCTURAL MATH MODEL DATA FORMAT

All structural math model matrices developed by the SC, for transmittal to the CE customers, are written in NASTRAN OUTPUT4 format. This data is provided in ASCII format and all zero matrix terms are explicitly written (i.e., no packed matrices).

The OUTPUT4 format in terms of FORTRAN formatted 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)

Matrix descriptions (i.e. 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 NASTRAN 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 12 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 it's own "set identification number" (SID) which refers back to an individual  $L_i$  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

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 ( $\tau$ ) 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:

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



Cards

**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			

<u>Field</u>	<u>Contents</u>
SID	Load set identification number (Integer > 0)
S	Scale Factor (Real)
S <sub>i</sub>	Scale Factors (Real)
L <sub>i</sub>	Load set identification numbers defined via TLOAD1 card (Integer > 0)

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

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

**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				

<u>Field</u>	<u>Contents</u>
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 $\tau$ (Integer > 0)
TF	Identification number of TABLED1 card which gives $F(\tau)$ (Integer > 0)



**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					

FieldContents

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  $\tau$  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					

<u>Field</u>	<u>Contents</u>
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 $\tau$ for the designated coordinate (Real)
<b>INPUT DATA CARD</b>	<b><u>TABLED1</u></b> 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 <sub>1</sub>	Y <sub>1</sub>	X <sub>2</sub>	Y <sub>2</sub>	X <sub>3</sub>	Y <sub>3</sub>	X <sub>4</sub>	Y <sub>4</sub>	
+ABC	-3.0	6.9	2.0	5.6	3.0	5.6	ENDT		

<u>Field</u>	<u>Contents</u>
ID	Table identification number (Integer > 0)
X <sub>i</sub> , Y <sub>i</sub>	Tabular entries (Real)
<u>Remarks:</u>	<ol style="list-style-type: none"> <li>The end of the table is indicated by the existence of the string "ENDT" in either of the two fields following the last entry.</li> <li>Each TABLED1 mnemonic infers the use of a specific algorithm where X<sub>i</sub> represents a time value (seconds) and Y<sub>i</sub> 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.</li> </ol>

## 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) or on tape).
    - 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 or on tape).
    - 1.1.3. Maximum/minimum search of net load factors for each CE. Time history available upon request (FTP or on tape).
    - 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 or on tape).
    - 1.1.7. Output data by special request.
    - 1.1.8. All minimum/maximum searches should be Text format with carriage control (a typical output is attached to this Appendix). All time histories and generalized responses should be in COSMIC NASTRAN 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.
    - 1.2.6. CE case consistent data is available upon request (FTP or tape).
    - 1.2.7. All minimum/maximum searches should be Text format with carriage control.

- 1.3. The OUTPUT4 format in terms of FORTRAN formatting where the matrix data is written by columns 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)

- 1.4. All data will be available in Support Contractor (SC) FTP server on or before the scheduled data dump date. Data might be made available in specific FTP address upon request.

## 2. VLA Data Products Format Requirement for Documentation

- 2.1. VLA documentation should document the following:

- 2.1.1. Space Transportation System (STS) math models and matrix maps, description of liftoff and landing forcing functions.  
2.1.2. CE math models, CE weight CG, and attachment information.

- 2.1.3. Methodology of transient and quasi-static analyses.
  - 2.1.4. Detail 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), and will be loaded into the USA Web site in the near future.
3. Alternative VLA Data Products Formats can be negotiated between the CE Developer and the Space Shuttle Program (SSP). These must be negotiated, agreed to, and documented prior to the Verification Analysis Data Acceptability Review (VADAR).

Table N-1 IUS/ORBITER I/F LOADS

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

SUBCASE 1

D E S C R I P T I O N	..... M I N I M U M .....			... .. M A X I M U M ....			.. A B S O L U T E .....		
	VALUE	TIME	CASEID	VALUE	TIME	CASEID	VALUE	TIME	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

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

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

SUBCASE 2

D E S C R I P T I O N	..... M I N I M U M .....			..... M A X I M U M .....			..... A B S O L U T E .....		
	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

Table N-3 IUS-AXAF NET LOAD FACTORS

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

SUBCASE 3

D E S C R I P T I O N		..... M I N I M U M .....			..... M A X I M U M .....			..... A B S O L U T E .....		
		VALUE	TIME	CASEID	VALUE	TIME	CASEID	VALUE	TIME	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



## 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 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 liftoff and landing transient analysis and 1.05 for all quasi-static analyses. All Cargo Element (CE) developers will be required to provide the best math models (preferably fully test verified) for the first cycle along with extensive Output Transformation Matrices (OTMs) that includes all CE critical item responses. The SSP and Support Contractor (SC) will utilize their best estimate as regards to the final cargo bay manifest and Space Shuttle Vehicle (SSV) configuration. 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 are requested to 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 much 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 must 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

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 will present similar data for the Payload Integration Hardware, Orbiter vehicle and other similar items.

## 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.,  $L_{Limit}$ ).

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

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:

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

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  
 $\Sigma L$  = Summation of all loads

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 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
Non-metallic for non-discontinuity areas	1.4 <sup>Note 2</sup>	Note 1
Non-metallic 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

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, then 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 <sup>Note 1</sup>
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:

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 non-tested 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 then 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.,  $\sum L$ ) for hardware assessment if  $K_E$  is greater than 1.4. If the  $K_E$  value is less than 1.4, then recalculate the load summation term as follows:
 
$$\sum L = (K_M L_M + K_P L_P + K_T L_T) (1.4)/K_E \quad (\text{Equation P-3})$$
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:

- 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, non-case consistent, non-time 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

## 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 Cargo Element (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 liftoff, 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 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. 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 Structures Working Group (SWG) as part of the structural verification process as described in Appendix K.

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 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. A deviation (section 20) to the CE unique ICD is required. 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.

**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)
<p>1. CE developer shall include definition of all CE close clearance points in Structural Verification Plan (SVP).</p> <ul style="list-style-type: none"> <li>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.</li> </ul>	Required	N/A	N/A
<p>2. CE developer shall provide "As Built" CE CAD model.</p> <ul style="list-style-type: none"> <li>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.</li> </ul>	Required	Required	Required

<p>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).</p> <ul style="list-style-type: none"> <li>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.</li> </ul>	Required	(Note 1)	(Note 1)
<p>4. SSP to perform delta clearance assessments throughout the design and manufacturing processes.</p> <ul style="list-style-type: none"> <li>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 assessments will be performed as new data becomes available. The CE developer shall supply the appropriate data to support this activity.</li> </ul>	Required	(Note 1)	(Note 1)
<p>5. CE developer shall demonstrate to the SSP that adequate manufacturing controls are in place to ensure that final assembly is within documented tolerances.</p> <ul style="list-style-type: none"> <li>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</li> </ul>	Required	N/A	N/A

<ul style="list-style-type: none"> <li>• measurements and final measurements of the CE flight hardware. These controls will provide an early warning of manufacturing outside of the design tolerances.</li> </ul>	Required	N/A	N/A
<p>6. SSP/BRSS to document close clearance in CE unique ICD.</p> <ul style="list-style-type: none"> <li>• 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.</li> </ul>	Required	Required	N/A
<p>7. SSP and CE developer shall develop joint documentation freezing local configuration of the CE. Requires joint approval for any subsequent changes.</p> <ul style="list-style-type: none"> <li>• 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.</li> </ul>	Required	N/A	N/A
<p>8. SSP to perform Orbiter measurements in areas of concern.</p> <ul style="list-style-type: none"> <li>• 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.</li> </ul>	Required	N/A	N/A

<p>9. CE developer shall perform impact loads and safety assessments.</p> <ul style="list-style-type: none"> <li>Impact loads and safety assessments are required to define the mission risks and the extent of the potential damage/hazards to the CE in the event of contact. This information is required in order to prioritize issue resolution options.</li> </ul>	Required	N/A	N/A
<p>10. CE developer shall provide "As Built" CE CAD model - including specific measurements of violating CE hardware.</p> <ul style="list-style-type: none"> <li>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 Structures Working Group.</li> </ul>	Required	N/A	N/A
<p>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 clearance points in their math model.</p> <ul style="list-style-type: none"> <li>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.</li> </ul>	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. <ul style="list-style-type: none"><li>• Postflight inspections will determine if contact occurred and if the Orbiter/returned CE were damaged during the flight.</li></ul>	Required	N/A	N/A
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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.