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**George C. Marshall Space Flight Center**  
Marshall Space Flight Center, Alabama 35812

EV30

MSFC TECHNICAL STANDARD

DESIGN PRODUCT PACKAGES FOR  
LAUNCH VEHICLE INTEGRATION  
HANDBOOK

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## FOREWORD

This document defines the Design Product Packages required to perform Level 2 Vehicle and Launch System Design Integration activities. Additionally, this document describes the intent, usage, format, content, and management of those datasets in the context of both analytical and physical launch vehicle integration activities.

The NASA Office of Primary Responsibility (OPR) for this document is Marshall Space Flight Center (MSFC), EV30, Structural Design and Analysis Division.

Proposed changes and/or comments to this document shall be submitted to EV30.

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## 1. SCOPE

This document applies to launch vehicle design integration and to the elements (stages and/or Ground Systems) comprising the Integrated Launch System and Flight Vehicle. It is applicable to the Computer-Aided Design (CAD) Products and the associated data. This data is used to define launch vehicle design integration with the elements (stages and/or Ground Systems) comprising an Integrated Launch System and Flight Vehicle. This document provides guidance to the participating design organizations in the preparation of Design Product Packages so that only the required/pertinent design information is conveyed. Doing so allows rapid and accurate integration of the design, minimizes the unnecessary and burdensome overhead associated with transferring and/or translating extremely large CAD datasets, and facilitates the “cleanest”, most practical management of the configuration.

Furthermore, this document describes many of the customer/client relationships involved in the physical and analytical integration of the launch system. This allows for greater insight regarding the Design Product Package requirements, better comprehension of system integration and flight performance analysis, improves communication across disciplines and organizations, and provides illustration of the techniques used to improve system design efficiency and design cycle time (at a vehicle or stage level).

The Design Product Packages defined in this document are:

- a. Outer Mold Line (OML) Product. See Section 5.
- b. Lightweight Viewable Visualization Dataset. See Section 6.
- c. Interface Detail Product (IDP). See Section 7.
- d. Interface Control Model (ICM). See Section 8.
- e. Guidance, Navigation, and Control (GN&C) Alignment Package. See Section 9.

## 2. DOCUMENTS

### 2.1 Applicable Documents

The following documents include specifications, models, standards, guidelines, handbooks, and other special publications. The documents listed in this paragraph are applicable to the extent specified herein. Unless otherwise stipulated, the most recently approved version of a listed document shall be used. In those situations where the most recently approved version is not to be used, the pertinent version is specified in this list.

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## 2.2 Reference Documents

<u>ASME Y14.41M</u>	Digital Product Definition Data Practices
<u>ASME Y14.5M</u>	Dimensioning and Tolerancing
<u>NASA-STD-0007</u>	NASA Computer Aided Design (CAD) Interoperability Standard
<u>MSFC-STD-3528</u>	Computer Aided Design (CAD) Standard

## 3. DEFINITIONS

See Appendix A for a list of *Acronyms and Abbreviations*.

A *Glossary of Terms* is also presented in Appendix B for all nomenclature pertaining to CAD, Design Integration, etc.

## 4. DESIGN PRODUCT PACKAGES (OVERVIEW)

### 4.1 Background

Modern CAD systems have facilitated significant gains in the speed, accuracy, and efficiency of the structural/mechanical design process. These gains have reduced risk and contingencies associated with the design by allowing greater visualization and understanding of the design, faster, more accurate prediction of mass properties, and the parameterization of the design for operational, functional, or assembly optimization.

While CAD technology has improved many aspects of the design process, the integration, utilization, and management of large CAD datasets can be extremely cumbersome. CAD datasets can become so large that integration at the Next Higher Assembly (NHA) severely hampers design cycle time, i.e., the CAD datasets are so large that extraction of the pertinent data required for NHA integration takes longer than the integration activity(s). These effects are exacerbated when integrating multiple datasets, such as those found in a Launch Vehicle/System.

Therefore, Design Product Packages when utilized within a collaborative design effort increases design productivity, improves design cycle time and reduces superfluous exchange of CAD data. These Product Package definitions yield maximum utility for both the source and destination (NHA) activities.



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## 4.2 Definition of a Design Product Package

A Design Product Package is a CAD model, or collection of CAD models, and where applicable, additional supporting data (such as dimensions, tolerances, direction cosines, notes, etc.), that are used in lieu of a comprehensive full detail CAD dataset with associated metadata representing the design. The most straightforward example would be a single “envelope model” that becomes the functional equivalent of a multipart assembly.

The advantages of Design Product Packages are as follows:

- a. Most Effective Management of the Configuration at the NHA
- b. Minimize CAD Resources/Translation Time
- c. Mask Company Proprietary Information Embedded in the Comprehensive Dataset
- d. Improve Design Cycle Turnaround/Efficiency
- e. Accomplish Rapid Changes
- f. Allows for Rapid Dissemination of Salient Parameters for Analytical Integration
- g. Better Synchronization of the Design Configuration with Analysis Activities

Therefore, a Design Product Package may be defined as the minimal CAD dataset necessary to convey design information at the NHA or integration level.

## 5. OUTER MOLD LINE (OML) PRODUCT

### 5.1 Background/Usage

The OML Product is the most widely used CAD model in Vehicle Design Integration. The OML Model is a single surface “envelope” representing the stage element (devoid of all internal components). Usage of the single surface envelope model results in rapid integration into the NHA and provides disciplined control of the configuration. The stage (or element) design integration function is responsible for ensuring that the single surface model(s) accurately represent the comprehensive CAD dataset.

Predominately used by aerodynamics disciplines as the basis for most aerodynamics related analyses, the OML model is also used in vehicle assembly drawings, envelope drawings, thermal heating analyses, venting analyses, pad and launch accessory design, logistics flow diagrams, stacking simulations, Interface Control Documents (ICDs), layouts, and various project level documents where views of the vehicle are required.

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Preliminary Aerodynamic analyses occur early in the design cycle and must be completed before any other disciplines can begin. Typical aerodynamics disciplines that also use the OML include Computational Fluid Dynamics (CFD), Experimental (wind tunnel testing), Aero-acoustics, Aero-elasticity, Aero-thermal, Lift-off Acoustics, Re-entry, Break-up Analyses, and Range Safety/Debris Field Analyses. Therefore, each stage element's OML product must be submitted and integrated into the launch configuration before any downstream work can begin.

**Because the OML product is so essential to downstream design and analysis activities, requirements regarding the OML fidelity (surface detail) and CAD modeling techniques must be adhered to in order to ensure rapid integration/dissemination.** The following paragraphs define those requirements.

## 5.2 OML Product as Design Definition

- a. To the extent possible, the OML product is used as the design definition (as outlined above).
- b. The OML CAD model should be submitted in the project defined CAD format as well as in either Initial Graphics Exchange Specification (IGES) or Standardized Exchange of Product (STEP) formats.
- c. The OML product may be constructed using either a "Top Down" or "Integrated" approach. Whichever approach is used, the element level OML products submitted are viewed as the design definition.
  - (1) In the "Top Down" approach, the OML is established before the integrated design is complete, or base-lined. Therefore, this OML serves as a design template for the element design. The overall fidelity is lower than in the integrated approach, due to incomplete or immature design information. This approach is a good starting point early in the program when small scale details are scarce; however, it is highly recommended that this approach be reconciled with the integrated approach as soon as the design matures sufficiently. This is especially true in areas of the OML that are aerodynamically sensitive (acoustics, stability, etc.).
  - (2) The "Integrated" approach yields the most accurate results. This method requires coordination and understanding throughout the design team. Automated generation techniques and/or shared responsibility throughout the design team can lessen the serial time required as compared to a single person preparing the OML after the detailed design is complete (or ready to baseline).
  - (3) Regardless of the approach utilized manual inspection of the OML surfaces is still necessary for completeness, and to ensure that all Thermal Protection System (TPS), and/or close-out structures are shown. Where the TPS design is immature, the element

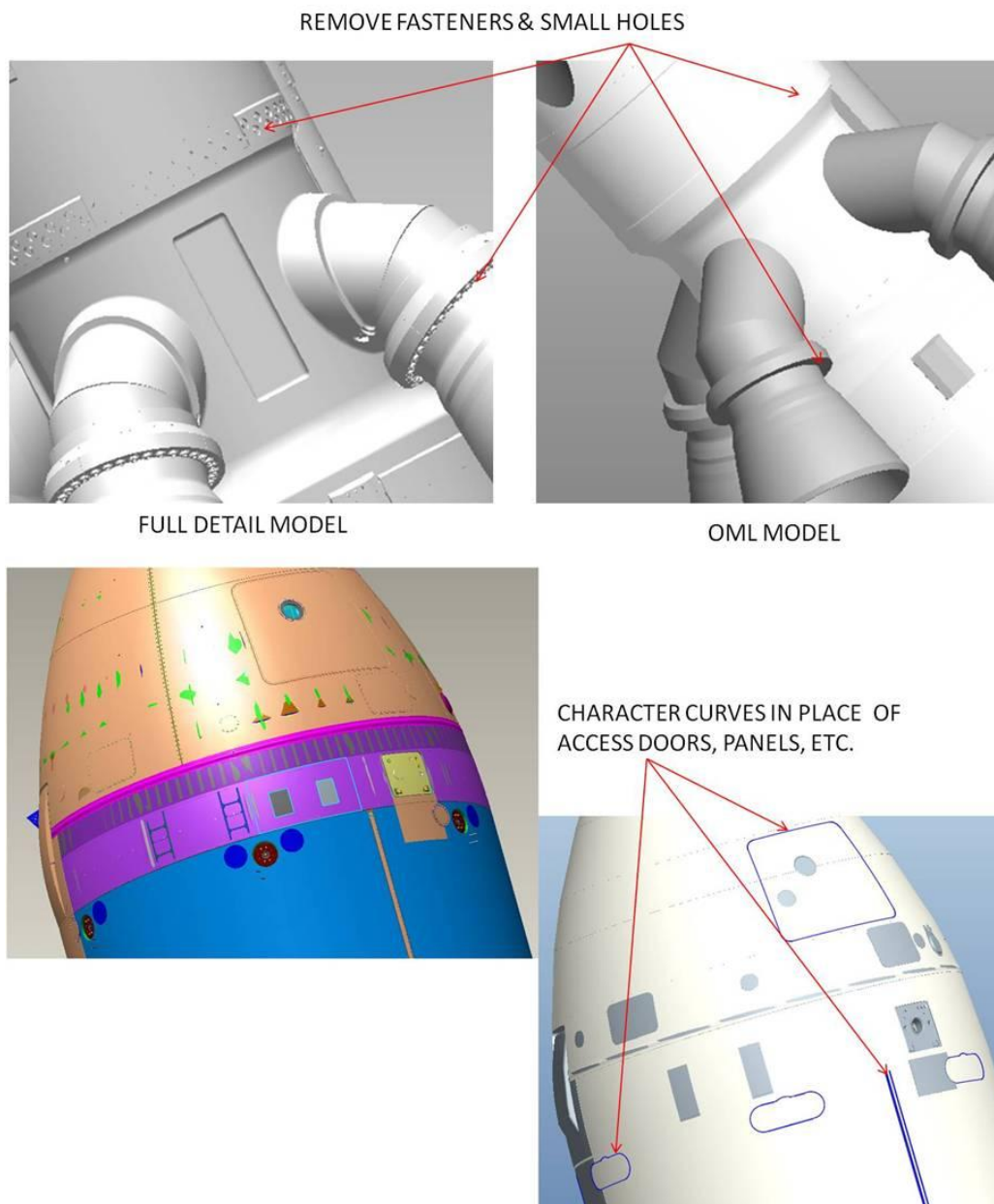
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may consult with Vehicle Design Integration and Integrated Aerodynamics Analysis for a configuration to include on the Integrated Vehicle OML.

### 5.3 Preparation of the OML Model

- a. The OML is an accurate single surface, water-tight contiguous body representing the nominal “as-designed” hardware in the launch and/or flight configuration. The model should include all TPS and close-out assemblies. Small fasteners should be omitted and small holes should be filled. See FIGURE 1 for salient features of the Vehicle OML. Note that the surface must be contiguous so that downstream surface simplification (for CFD grid generation), and the computation of volumes and areas may be rapidly accomplished.

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**FIGURE 1. OML Characteristics**

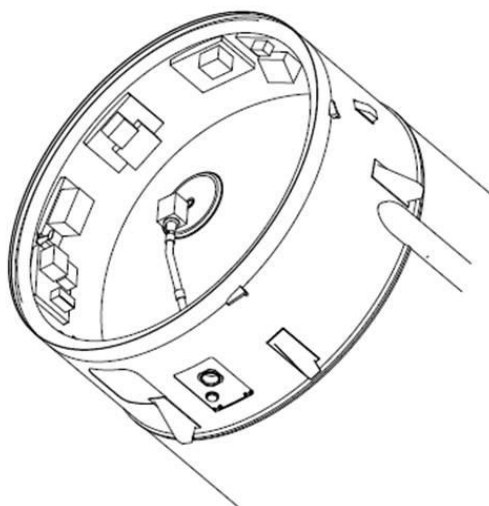
- b. Cavity regions (volumes between stage elements, or volumes subjected to venting, but are otherwise removed from the ascent flow-stream) should be simplified. For these regions it is only necessary that the general shape and volume of the cavity region be replicated. Machined webs, ribs, bosses, orthogrid patterns, small lines, etc. may be omitted. Internals may be represented by a simulated volume. Submission of the internal simulated volume

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should accompany the OML submission. See FIGURE 2 for portrayal of typical cavity regions and treatment thereof.

Approximate Cavity Region



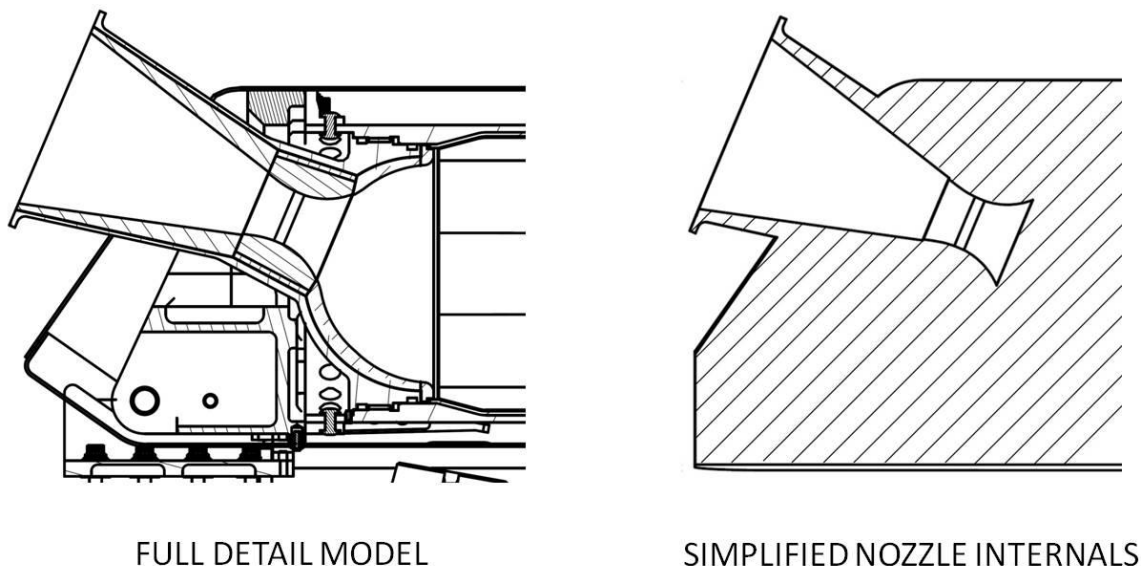
Full Detail CAD



**FIGURE 2. Cavity Region OML (Typical)**

- c. Engine and solid rocket motor nozzles should be hollow to just inside the throat of the nozzle; additional detail forward the throat is not required (FIGURE 3).
- d. Separable assemblies, or assemblies that are jettisoned during flight, but are otherwise part of the continuous OML solid, should include a datum feature or surface denoting the parting line of separation.
- e. The OML model should be constructed in the element coordinate frame (ecf) and the coordinate frame should be included for assembly purposes. See Figure 9 showing typical vehicle level elements and coordinate frames.
- f. Operational Interfaces, such as access doors, umbilical panels, service panels, etc., should be identified, as practical, in order to assist Ground System design efforts where the OML is used as a template for integrated design. In these cases, the inclusion of character surfaces/lines representing doors, etc. is warranted. This should be coordinated with the Interface Control Model submission. See Section 8 for additional details.

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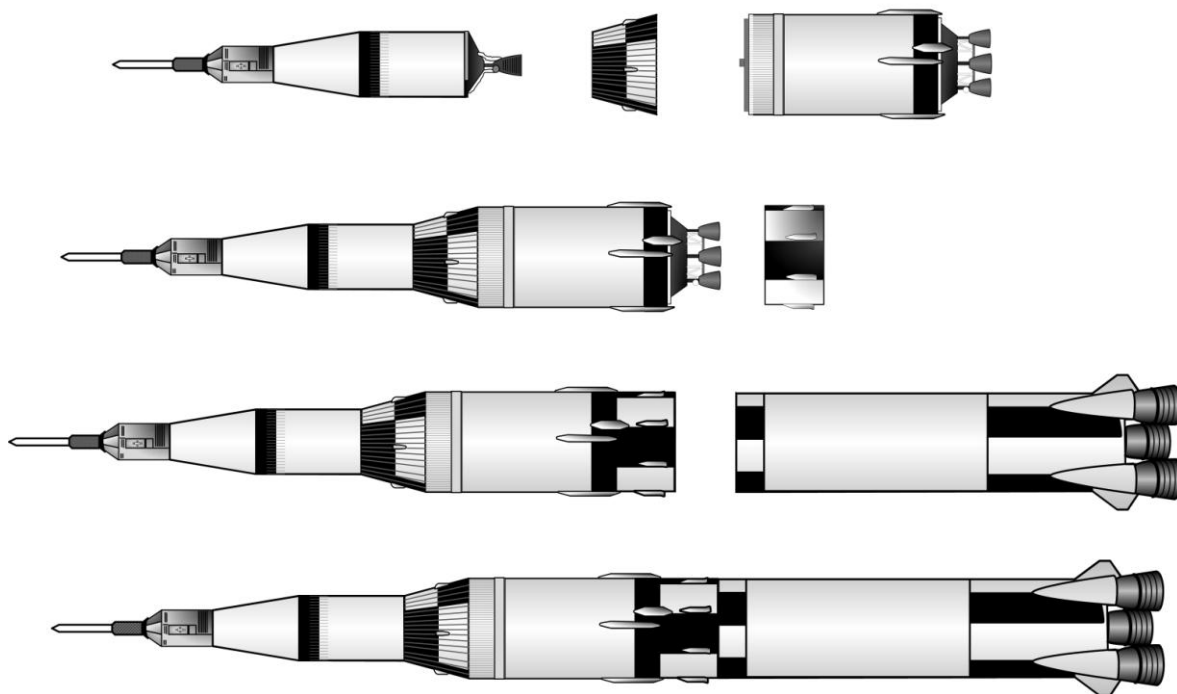


**FIGURE 3. Nozzle OML Detail**

#### 5.4 Component Cavity Regions for Venting Analysis

- a. Component cavity regions are volumes adjacent to the ascent flow field, but are otherwise removed from the flow stream. Examples of these volumes are inter-tank regions, the volumes under the Reaction Control System (RCS) pods, Systems Tunnel, Booster Tumble Motors (BTM), etc., and areas behind jettisoned panels. These volumes are closed off for the ascent aerodynamics analyses and require separate analysis.
- b. Component Cavity regions should be included with the OML product, but should be separate and distinct. The volume to which the cavity is vented should be obvious (external to vehicle or larger internal cavity).
- c. Similar to the volumes between stage elements, fine detail is not required for the Component Cavity regions; it is only necessary to generally replicate the volume and topology. See Figure 3.
- d. Where panels/fairings are jettisoned during ascent, exposing a payload or spacecraft, the resulting exposed surfaces should be treated as a separate OML using a reduced fidelity replication. Refer to Section 5.3. FIGURE 4 shows a typical jettisoned fairing arrangement.

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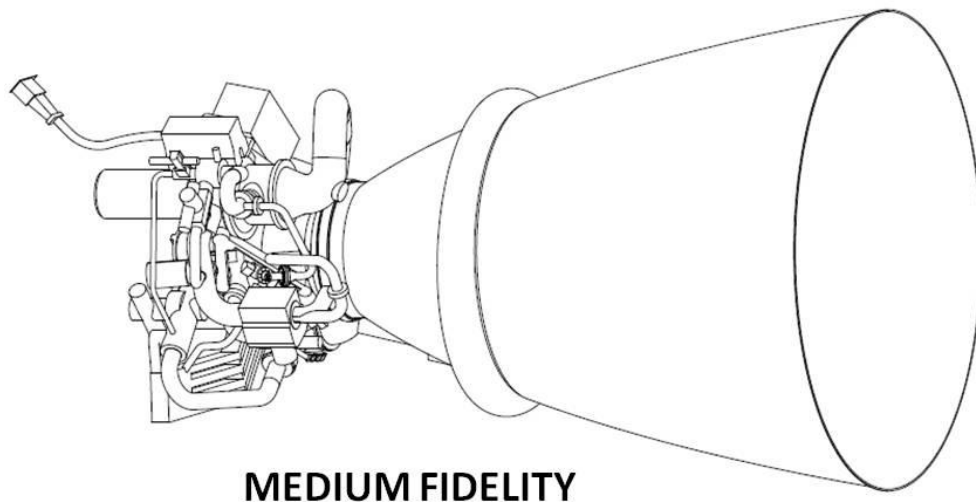
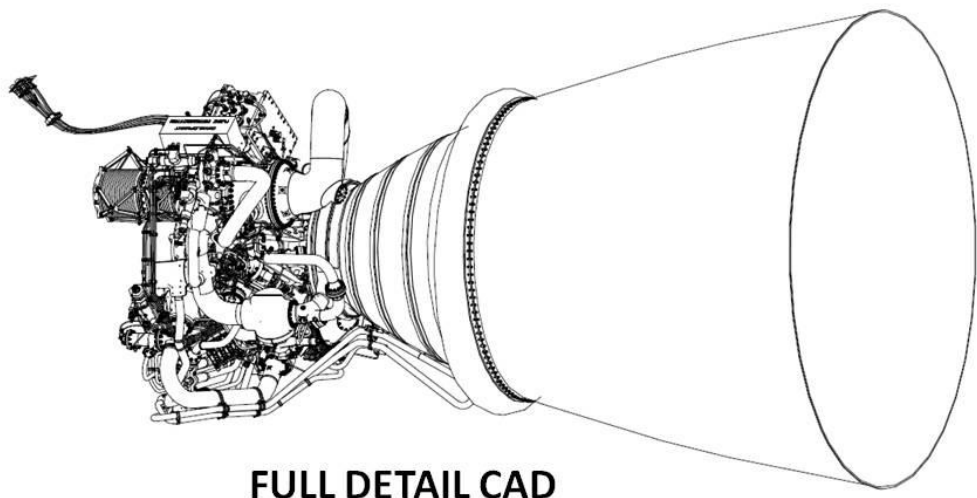
**FIGURE 4. Stage Flight OMLs**

### 5.5 Engine OML

- a. An engine OML is often the most cumbersome of all vehicle integration products because it is highly detailed, contains many complicated parts and geometries, and various integration/analysis functions have differing fidelity requirements for their analyses. Typically, the engine assembly function generates a simplified representation of the Engine Assembly which suffices for their internal purposes. Generally, this product is still too complicated for vehicle integration purposes and is typically not “water-tight” and contiguous. Therefore, the following paragraphs are presented as an approach to most successfully managing engine integration functions and best providing a product suitable for downstream integration purposes.
- b. Like all OML models used for vehicle integration, the engine OML should be a single surface, water-tight, contiguous body representing the as-built configuration of the engine. It should contain all shields/TPS/etc., but small lines and ducts may be omitted. Generally, details smaller than two inches may be ignored. However, the engine OML should have sufficient fidelity to distinguish all major components. Note that this model may still be too complicated for analysis purposes; this model is used for assembly illustration, volume simulation, etc., and is used as the basis for the greater simplifications required to perform analyses. The “OML Seed Model” should be provided by the Engine design integration function.

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- c. To the extent possible, the engine OML seed model serves as the design definition for the engine and will be used as such by integration functions and ground systems.
- d. FIGURE 5 illustrates a succession of engine related models used for integration and analysis purposes. Note that various analyses have various fidelity requirements. A greater degree of coordination is required for the engine related models used for integration and analysis. Generally, it is more efficient for the Vehicle Integration function to perform any downstream simplifications required for analysis purposes, but the initial “high fidelity” engine OML Model should be provided by the engine design integration function, and it should be considered the source definition for that article.



**FIGURE 5. Engine OML Models**



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## 5.6 Ground Systems and Ground Support Equipment (GSE)

- a. GSE design integration is performed using a simplified model of the design consisting of a single part that represents the basic envelope. The simplified model of the GSE design may consist of various versions representing configuration or extent changes (for example a retracted configuration and an extended configuration). Simplified models with only positional changes and no configuration or extent changes do not require separate versions for each position. Primary position and position changes are controlled by coordinate system features with a default orientation of X pointing right, Y pointing up, Z pointing out of screen.
- b. GSE design simulations are performed using design models and these models will be de-featured by the analyst and stored as separate models.
- c. GSE design space claim models (i.e., volume simulators, keep out zones, etc.) are used at the beginning of GSE design integration to advertise initial location and layout. Space claim models are basic in shape and envelop the basic size and extent of operation. Space claim models are replaced with GSE design integration models as GSE design matures.
- d. To the extent possible, The element and integrated vehicle OMLs, together with the ICM, are utilized as the basic template for ground system design. This is especially true prior to release of the ICDs. Refer to Paragraphs 5.0 (OUTER MOLD LINE PRODUCT) and 7.0 (INTERFACE DETAIL PRODUCT) for additional detail regarding use of these products by ground system design.

## 6. LIGHT-WEIGHT VIEWABLE DATASET

### 6.1 Background/Usage

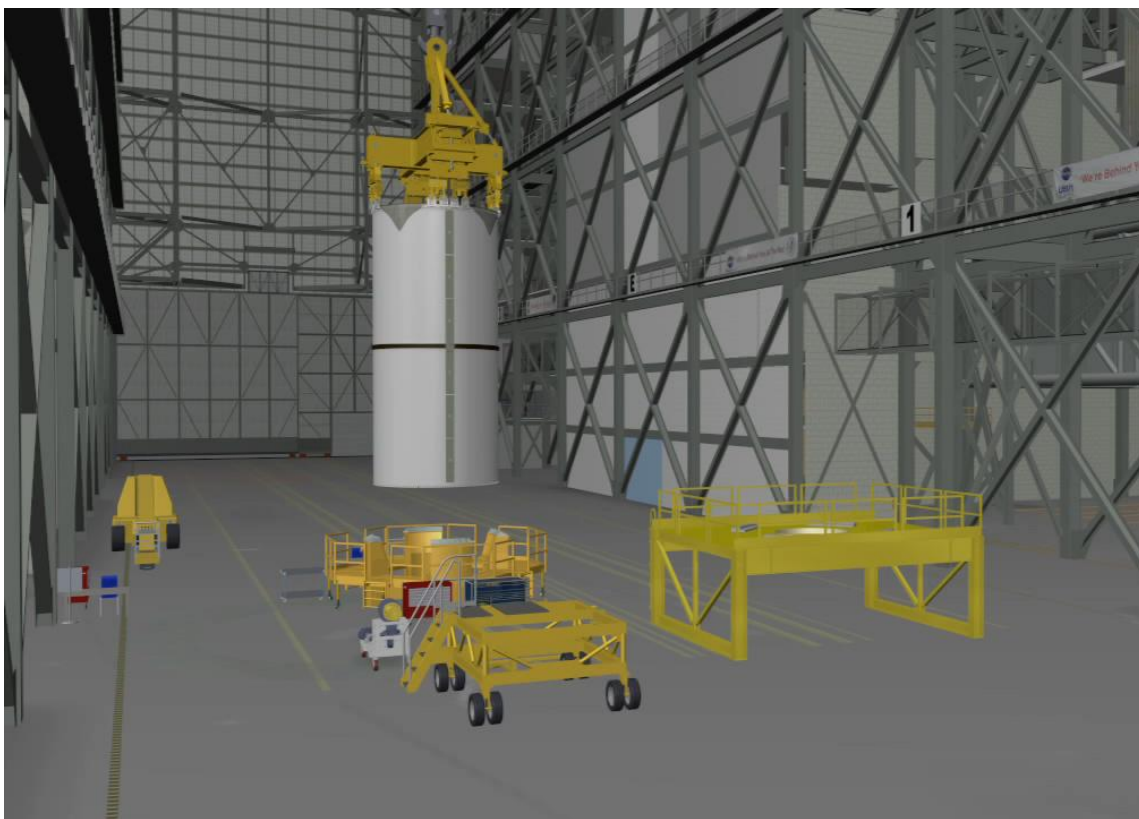
Light-weight Viewables are CAD derived products that are used to view CAD graphical data with a standard personal computer and web downloadable software. Light-weight Viewables can be used by those with little or no CAD experience and/or without access to CAD software/licenses. This is accomplished because the “viewable” contains only the graphic portion of the CAD data. Thus, additional computer memory and higher processing speeds are not required. This makes the design data available to anyone needing to view the CAD data and reduces the need for access to the native CAD data. Several key uses/applications are noted below (in no particular order):

- a. Range Safety/Debris Field Analyses
- b. Logistics and Transportation

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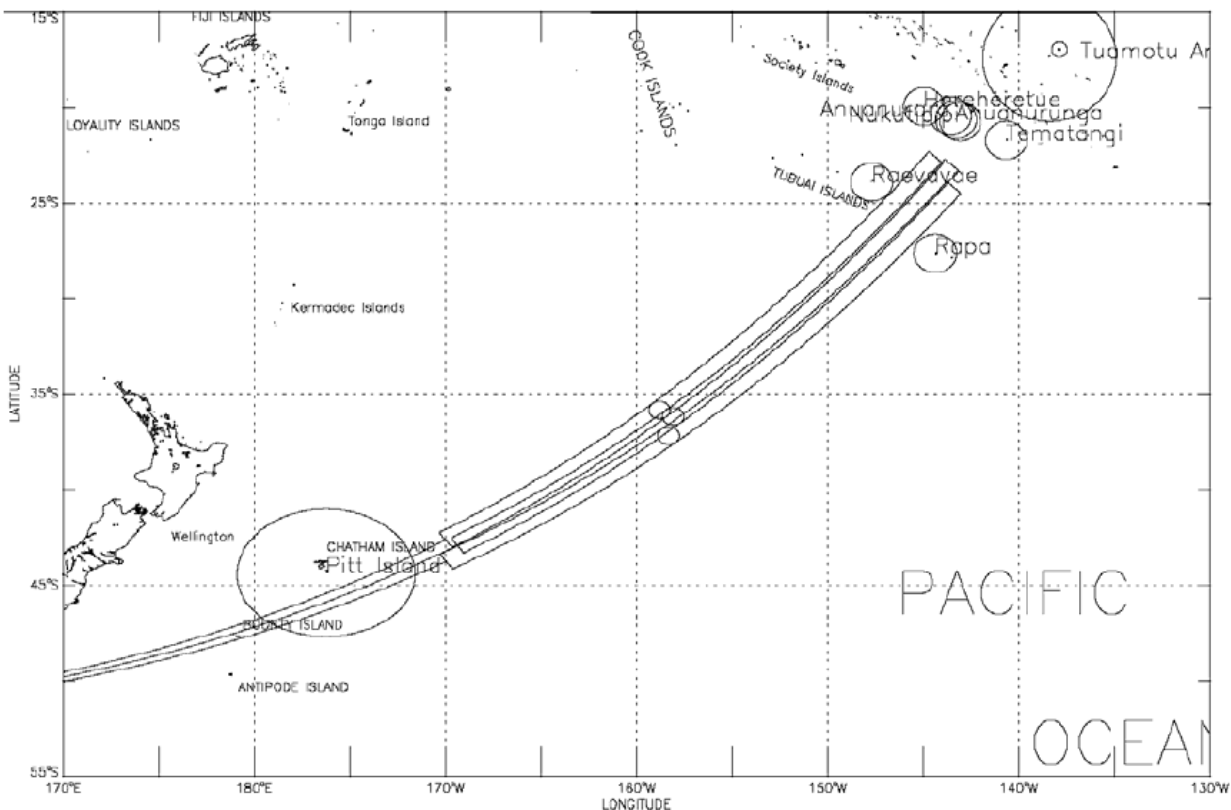
- c. Stacking/Assembly Choreography/Simulations
- d. Human Factors Analyses
- e. Multi-CAD/Multi-Software Compatible
- f. Public Relations Imagery
- g. Part Identification/Nomenclature
- h. Import into Native CAD to Augment Detail

FIGURE 6 depicts stacking and assembly simulations in the Vehicle Assembly Building (VAB). Figure 7 depicts a debris footprint derived from “break-up” aerodynamic modeling.



**FIGURE 6. SRB Stacking Simulation in the VAB using Light-weight Viewables.  
Note the VAB Infrastructure**

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**FIGURE 7. Debris Footprint of a Typical Break-up and Re-entry**  
**Note: Lightweight Viewables are used to interrogate the design for likely segmentation.**

## 6.2 Preparation of the Lightweight Viewable

Several common formats associated with third party viewing software are prevalent in the mainstream CAD arena. The preferred formats for design integration deliveries, Creo View .pvz files (desired) or JT (.jt), are compatible with Viewable packages from other CAD software manufacturers. These formats can also be imported into a native CAD format to augment detail, such as when a mating assembly should be shown for reference.

### 6.2.1 Content

Each light weight viewable should be published to include the following (when available):

- a. Surface Boundary Representations (BREPs)
- b. Datum Features for alignment of multi-CAD viewables.

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- c. Annotations
- d. View Orientations and View States
- e. Layers
- f. Descriptive Name Parameter

The viewable origin should be located at the appropriate vehicle or element level structural coordinate system.

### 6.3 Delivery

Visualizations should be provided with each design integration product delivery. If based on another product delivery (OML, IDP, etc) it should be published off the exact delivery. If the light weight visualization product is stand alone or an accompanying file (providing differing or supplement design information), it should be referenced back to a specific element configuration (for traceability).

## 7. INTERFACE DETAIL PRODUCT (IDP)

### 7.1 Background/Usage

- a. An Interface Detail Product, or IDP, is defined as a collection of CAD files, and any additional dimensional data, notes, etc., associated with a specific interface. The IDP is used (primarily) in the development of ICDs, but can be used in the production of assembly drawings if so desired. The IDP is not a formally controlled product but its submission is required; its contents are used by the program to gauge ICD maturity and to develop the views/data necessary for ICD documentation.
- b. It is assumed that each independent side of the interface is working to collaboratively develop the interface with the opposing side; and that an integration authority is delegated to resolve/reconcile any discrepancies between the two and document the resolution in an ICD. Once documented in the ICD, the ICD becomes the controlling authority. Again, the Element IDP submissions are not formally controlled through Configuration Management (CM); the ICD is the controlling document. Where an un-delegated or un-assigned interface exists, Vehicle Design Integration shall assume those responsibilities.
- c. The idea behind an IDP is for each design participant (or “side” of an interface) to simultaneously submit to the integration function a “minimal” CAD data/design package targeted especially for its intended usage (as ICD graphical views or drawings); each package is then reviewed and reconciled (by all design parties and the ICD Book-

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managers) for compliance with mating assemblies contained in the opposing side of the interface and system requirements.

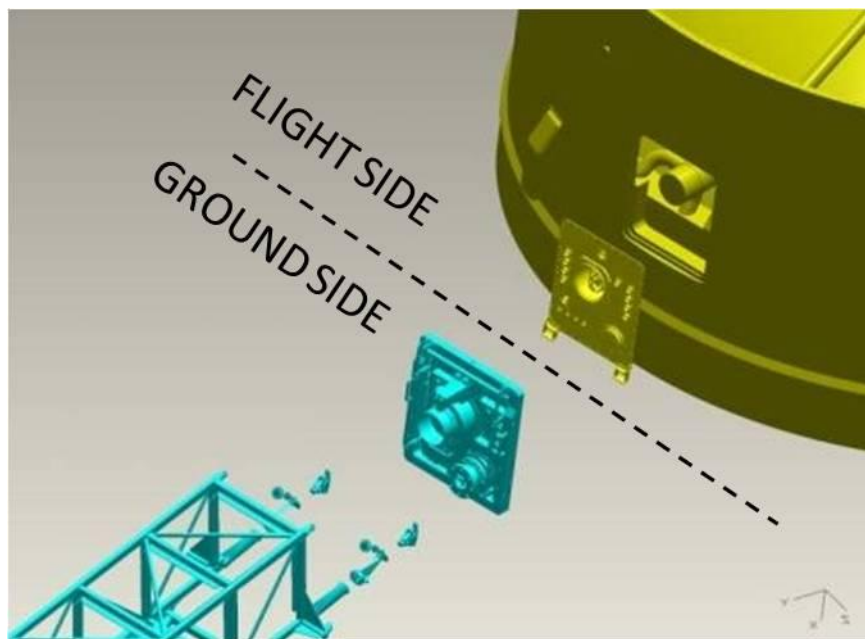
- d. Since the IDPs only represent a small percentage of the comprehensive CAD dataset, IDP packages can be reviewed and reconciled faster and more efficiently by the design participants (submitters) and the integration function. Another virtue of the IDPs is that they are an “extraction” of the comprehensive CAD dataset and stand alone from the associations and dependencies that exist within the native design environment; the integration function and/or the design authority can modify CAD files in order to establish interface control, and/or resolve differences, and/or render generic, and/or publish the graphical views in an ICD document or drawing.
- e. The following paragraphs elaborate on the specifics of IDP submissions and the preparation thereof.

## 7.2 Preparation of the IDP

- a. By definition, the IDP contains only the CAD files necessary to construct the ICD views. The IDP CAD dataset should be located in vehicle or element coordinates. The IDP package is typically compressed into a single zip format file and submitted to a server location specified.
- b. Each participant (or side) of the interface should submit an IDP to the integration authority (delegated or otherwise).
- c. In addition to the CAD file submissions, the IDP should contain drawings and/or layouts specifying the dimensions, tolerances, form control, salient notes, schematics, vender parts, etc. for that particular interface. Prior to completion of the piece part drawings (which typically specifies this type of information) as much of this information should be communicated to the integration authority and ICD book manager as possible. Where detailed dimensional data, and/or notes, and/or specifications are un-available or un-resolved, a “place-holder” for that information should be given.
- d. IDP submissions and schedules are given by the ICD book manager.
- e. Refer to FIGURE 8 for a typical IDP CAD file collection and the views generated from them.
- f. An ICD should be as generic as possible. To the extent possible, an IDP should not reflect “background detail” that is subject to change. Where practical, all parties (IDP submitters, the integration authority, and ICD book-manager) should endeavor to construct and arrange ICD views so that only the information required to capture the ICD is shown and superfluous detail is omitted.

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- g. IDP CAD submissions should be stand alone datasets with no external relationships to the parent CAD product.



**FIGURE 8. Typical IDP CAD file collection.**

### 7.3 IDP Reconciliation Process

- a. After each side of an interface submits an IDP, the integration authority and ICD book-manager will review the submissions for completeness. After that, the CAD models are mated with the opposing side and a manual inspection takes place to ensure that the mating assemblies align.
- b. Each side of the interface is then graded relative to completeness and alignment. This information is reported to the ICD book-manager, at which point the ICD book-manager may schedule meetings to resolve any discrepancies.
- c. Where follow-on meetings are required, the available expertise may be utilized on an as needed basis to reconcile difference and thus establish the ICD. For the development of integration guidelines and activities relevant to materials selection, specifications, and nondestructive evaluation captured by integrated CAD data, MSFC Materials and Processes Laboratory will be called.

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## **8. INTERFACE CONTROL MODEL**

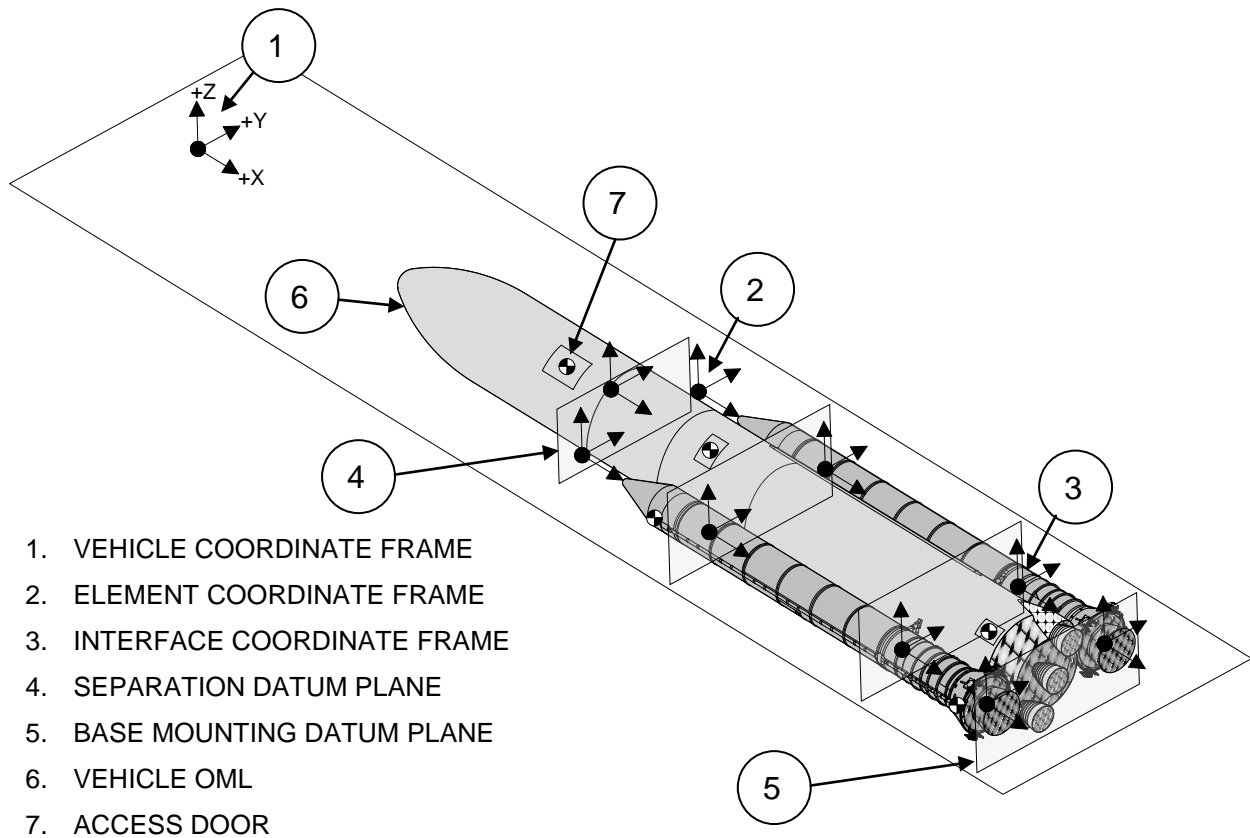
### **8.1 Background/Usage**

The Interface Control Model (or ICM) is a three dimensional CAD product used as a design template by both ground systems designers and vehicle design integration. Used in conjunction with the OML, the ICM contains only the very basic/minimal interface attributes (datums, planes, points, etc.) required to identify the location of an external interface (element-to-element or element-to-ground).

The ICM fills an important need early in the design. Before the ICDs are base-lined, the ICM allows Ground System designers to have a “template” for locating the launch accessories. This is especially important since the locations of interfaces are a function of the stacked vehicle, and not necessarily that of a particular element.

Hence, the ICM is an initial step toward developing the ICDs, and is a convenient tool which allows designers to rapidly and accurately locate the interfaces. And since the ICM product is a compilation of element data, this is the most efficient way to authenticate and synchronize vehicle level interfaces. See FIGURE 9 for representative ICM details.

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**FIGURE 9. Typical ICM Details**



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## 8.2 Preparation of the ICM

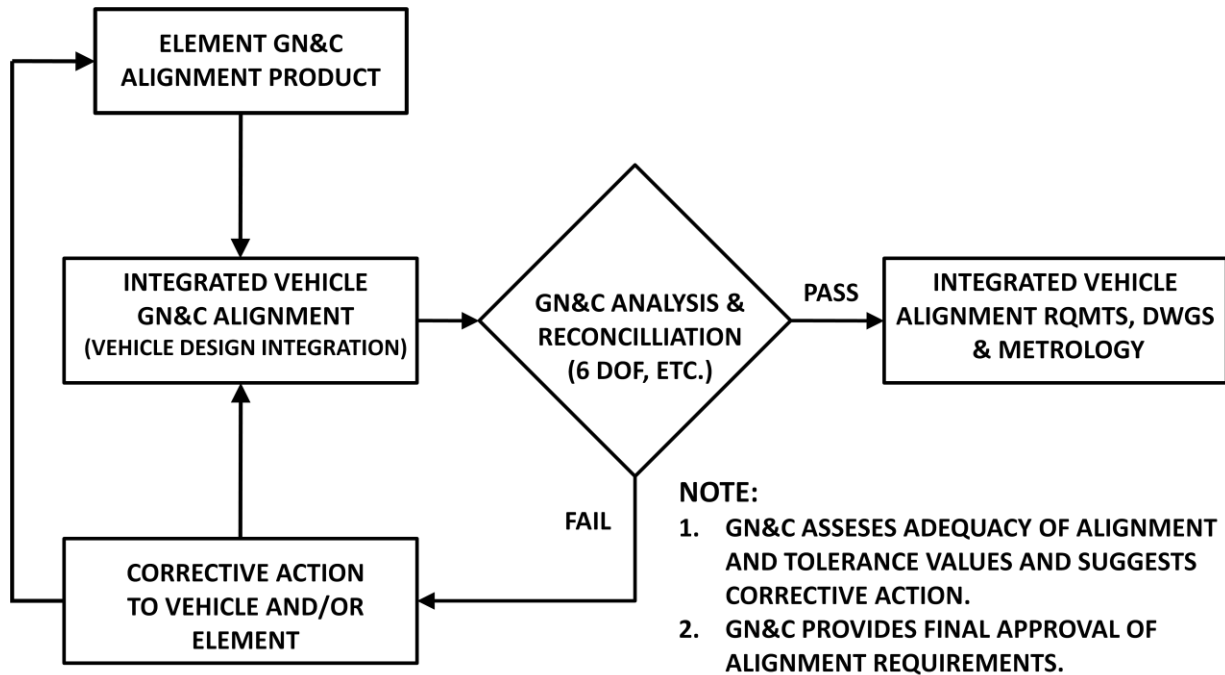
- a. The ICM should only contain the geometry necessary to locate the interface in three dimensional space relative to the elements coordinate frame.
- b. The ICM should be submitted by each element and ground systems for reconciliation by the design integration function.
- c. The ICM should be submitted along with the OML and should be coordinated with it for maximum utility.

## 9. GUIDANCE, NAVIGATION, AND CONTROL (GN&C) ALIGNMENT PACKAGE

### 9.1 Background/Usage

- a. The GN&C Alignment Package is used to ensure that Guidance, Navigation, and Control (GN&C) components (sensors and effectors) and attributes (vectors, points, coordinate frames, etc.) are located within sufficient bounds so as to provide adequate control response during flight.
- b. The nominal (or perfect form) location of GN&C components are found in the element CAD dataset and drawings. However, mounting and manufacturing conditions exist which must be accounted for. Likewise, the dimensional relationships and alignments between various GN&C components across element boundaries must be considered. Therefore, all GN&C component and attribute locations must be reconciled (by Vehicle Design Integration) with respect to vehicle and element tolerance conditions (i.e., in the context of an off-nominal vehicle).
- c. The GN&C component locations are used as inputs to various flight simulation programs (along with trajectory information, thrust profile, wind data, aerodynamics, etc.). The component locations and tolerances can thus affect flight control and performance. Should a component or attribute location affect flight performance, the location of that component within the element may be adjusted to suit performance needs. Similarly, a component/attribute location may require verification relative to the vehicle's "as built" configuration to assure the alignment is acceptable. See FIGURE 10 for a representation of this process.
- d. The following paragraphs describe which CAD products and numerical values should be submitted by the element as part of a GN&C Alignment Package.

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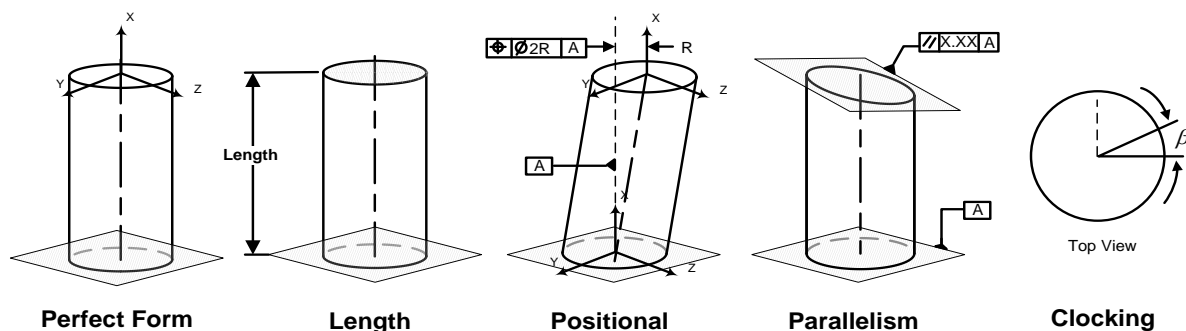


**FIGURE 10. GN&C Alignment Plan/Process**

## 9.2 GN&C Related Element Attributes (Gross Element Tolerances)

### 9.2.1 Stage Element Gross Tolerances

The Stage Element “gross” dimensional tolerances should be reported as shown by example in FIGURE 11. These interface datum surfaces shall be used by Vehicle Design Integration to reconcile the worst case component/attribute location relative to the off-nominal vehicle stack, and to publish the off-nominal vehicle stack envelope. This product should be coordinated with the stage element OML product. This product only includes manufacturing and assembly effects; this does not include any environmental or loading effects.



**FIGURE 11. Stage Element Gross Tolerances.**

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### 9.2.2 Ground Systems

Ground Systems shall submit the worst case tolerance conditions for launch platform alignment. This is to include all phases of assembly and operation including transportation to the launch site and re-leveling (if applicable).

### 9.2.3 Environmental and Operational Effects

The superimposed effects from any operational or environmental conditions (loading, self weight, tanking, thermal, etc.) on the integrated vehicle shall be addressed by each stage element and ground systems. This should be reported similar to 9.2.1 (above).

### 9.3 GN&C Components and Attributes in Perfect (Nominal) Form

a. GN&C components and attributes include, but are not limited to, the following:

- (1) Thrust Producing Devices/Thrust Vectors
- (2) Servo-actuator and Engine Attachments
- (3) Flight Computer/Inertial Navigation Unit/Global Positioning System (GPS) Antennas
- (4) Propellant Tanks
- (5) Rate Gyro Assemblies
- (6) Nominal Element Coordinate Frame
- (7) Gimbal Points/Gimbal Angles
- (8) Any additional Instruments/Sensors associated with GN&C

Mass properties as a function of propellant remaining and thrust histograms are provided by other organizations.

- b. Elements should submit simplified envelope models of all GN&C components in their nominal location. This should be a standalone submission and contain only the three dimensional (3D) CAD parts necessary to define the components. These components should be located in the element structural coordinate frame.
- c. **All components and attributes should have an affixed coordinate frame. The component/attribute coordinate frame should be included with the submitted CAD data.** Where practical, the coordinate frame should be located so that it can be measured while installed on the vehicle. Where an attribute (such as a gimbal point) cannot be

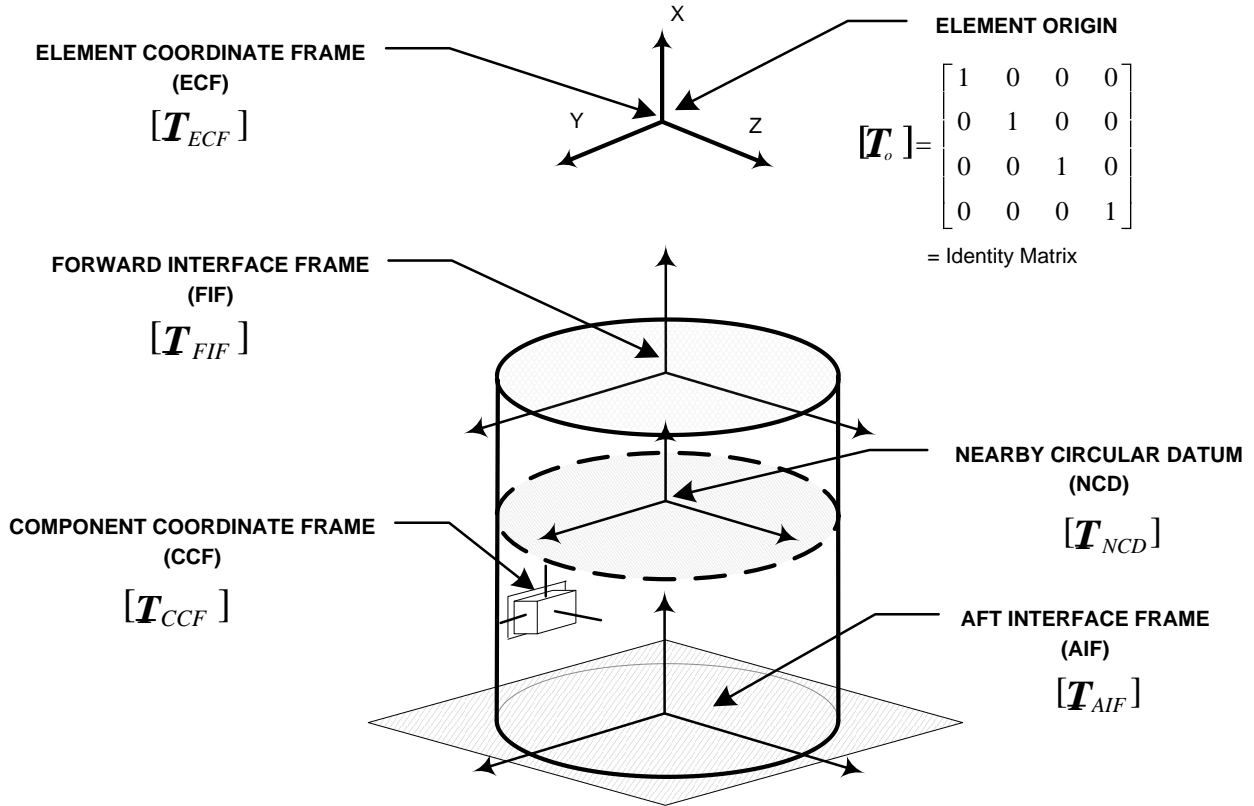
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directly measured, consideration should be given to the accuracy to which it can be determined.

- d. Each coordinate frame representing a component or attribute should be so labeled in the model tree. Identifying nomenclature should be obvious so as to readily identify the component of interest and avoid confusion (for example, RGA\_CSYS denotes the nominal Rate Gyro Assembly Coordinate System, GP\_CSYS denotes Gimbal Point, etc.).
- e. In addition to the components and attributes outlined above, a nearby reference datum in close proximity to that component or attribute should be identified. The nearby datum surface should also have an affixed coordinate frame. This nearby datum will be used when reconciling component mounting tolerance error with respect to an off-nominally stacked vehicle. The nearby datum surface and coordinate frame should be included with the CAD submission. Refer to paragraph 9.4a for more detail regarding use of the nearby datum.
- f. Data submissions should correspond to a recognized Vehicle Configuration.
- g. Refer to FIGURE 12 for general nomenclature and representation of the various coordinate frames and datum surfaces. Note that the 4 x 4 matrix shown denotes both rotation and translation; the first three rows and columns denote the Direction Cosine Matrix (DCM).

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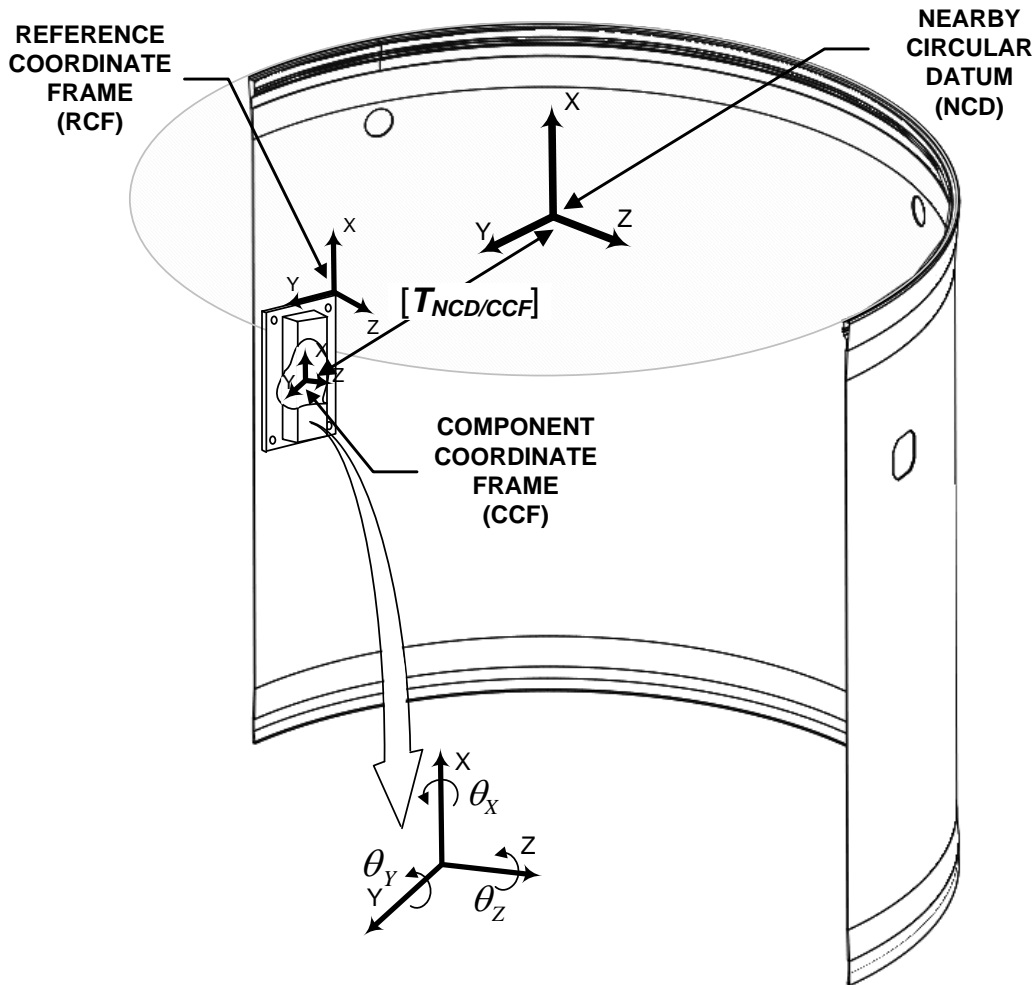
**FIGURE 12. Element and component coordinate frames and transformations in perfect form.**

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#### 9.4 GN&C Components and Attributes in Toleranced Form

- a. Elements should submit the worst case off-nominal location of each of the components/attributes included (FIGURE 13). This should be expressed as a bilateral deviation from the nominal (perfect form) component or attribute location. The components deviation should be referenced to a nearby datum having a value at or near the vehicles outer diameter at that station. The nearby datum surface shall be identified by name and station location, and shall be consistent with the submissions (above). The purpose of this submission is to capture the localized mounting effects and tolerance build-up associated with that component or attribute so that it may be analyzed with respect to the integrated vehicle in tolerance form.
- b. The bilateral tolerances shall be given in directions consistent with the vehicle's axial direction (vehicle x), clocking (rotation) about the x-axis, and tilts (a combination of rotations about vehicle z and vehicle y). Refer to FIGURE 13 for the conventions and a schematic associated with the Off-Nominal Component mounting effects. Rotations are assumed to be small (i.e., non-Euler sequences).
- c. Units for reporting component deviations should be in inches and degrees.

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Off-Nominal Reporting Conventions		
Description	Deviation	Symbol
Clocking	X-Axis Rotation	$\theta_x$
Tilt	Rotation about Y and/or Z Axes	$\theta_y, \theta_z$
Axial	X-Axis Translation	$\Delta x$
Radial	Translation in YZ Plane	$\Delta R = \sqrt{\Delta Y^2 + \Delta Z^2}$

**Note:**  $\Delta x$ ,  $\Delta y$ ,  $\Delta z$ , are defined as deviations of the component coordinate frame relative to the nearby circular datum (NCD). Therefore, these deviations define a tolerance zone.

**FIGURE 13. Schematic component and attribute tolerance deviations.**

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## 9.5 Launch Platform Design Characterization

- a. Ground Systems shall dimensionally characterize the Mobile Launch Platform (MLP) relative to the planar accuracy of the launch mounts, and the degree to which the MLP deflects (including asymmetries). Ground Systems shall characterize any non-recovery of deflections in the launch system due to hysteresis, friction, damping, etc., from the time the vehicle is stacked through any and all non-flight operational phases (roll out, parking, roll back, wind loading, re-fueling, etc.). Ground Systems shall include provisions to ascertain the vehicles location on the pad throughout all operational phases.
- b. The data for this product shall be submitted in report form with associated figures, drawings, etc., as required.

## 9.6 Vehicle Level GN&C Tolerance Reconciliation/Reporting

Note: All items in section 9.6 are performed by the Vehicle Design Integration function.

- a. The Vehicle Design Integration function should compile Element and Ground Systems GN&C tolerance and dimensional parameter submissions for the recognized Vehicle Configuration. Vehicle Design Integration shall transform component and attribute data (located in element coordinate reference frames) to the appropriate Vehicle Coordinate Frame (VCF) for each particular mission phase (prelaunch, flight, and reentry). See FIGURE 14 for portrayal of example mission phases.
- b. Under the direction of the GN&C authority, Vehicle Design Integration should assign all names, conventions, etc., associated with GN&C attributes. The GN&C and Vehicle Design Integration authority will assign statistical distributions to the location of all component, attribute, and stage element tolerances, as required.
- c. Vehicle Design Integration should compile nominal (perfect form) and localized off-nominal component and attribute locations in the appropriate vehicle flight phase configuration, and combine this data with the effects of off-nominal element gross tolerances with respect to the applicable vehicle flight coordinate frame.
- d. Vehicle Design Integration should superimpose the effects from any operational or environmental conditions (loading, tanking, thermal, etc.) on the integrated vehicle and the integrated vehicle's control related dimensional attributes.
- e. Vehicle Design Integration should account for any non-recovery of loads, dimensional variation, and/or hysteretic effects associated with roll out and/or wind loading.
- f. Vehicle Design Integration should reconcile the accuracies to which the vehicle can be dimensionally characterized during stacking and assembly, and determine the appropriate remedial actions should a particular dimensional parameter require adjustment.

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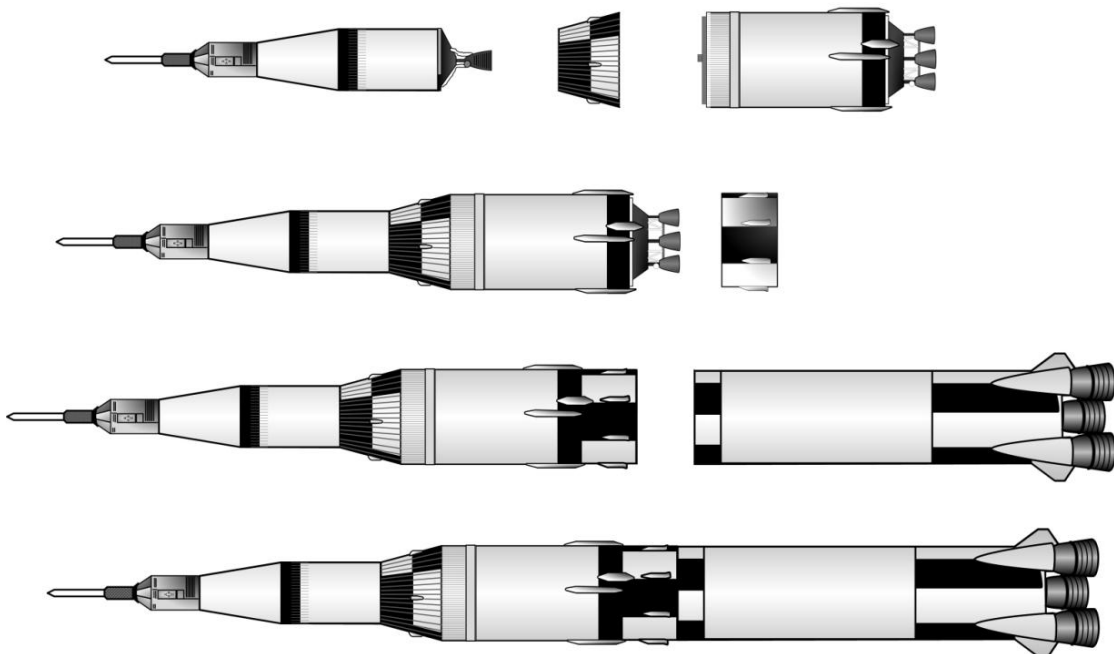
g. **Reporting of Dimensional Data Associated with GN&C Alignments and Vehicle Tolerances.** The following paragraphs provide a list of design products to be used as the source documentation for associated GN&C Alignment Verification purposes.

- (1) **Integrated Vehicle Envelope Drawing:** This drawing (also called the OML) is the perfect form envelope drawing for the integrated vehicle. This drawing depicts all surface features and identifies element interface locations. Along with this drawing are 3-D CAD models of the integrated vehicle and constituent elements. These models are the “shell” models associated with the comprehensive CAD dataset; these models do not include components or internal detail.
- (2) **Integrated Vehicle Static Envelope Drawing:** This drawing depicts the compilation of the stage element (gross) tolerance reports for the stacked vehicle. This drawing is used to reference the departure of theoretically perfect element datum references and coordinate frames to an off-nominal stack configuration.
- (3) **Integrated Vehicle Dynamic Envelope Drawing:** This drawing depicts the effects of wind loading, roll-out loads, and wind induced oscillations (WIO) on the integrated vehicle and launch platform. The drawing lists both absolute and relative deflections at various points along the vehicle and tower axis for each load case.
- (4) **Integrated Vehicle Component Alignment Drawing:** This drawing depicts the nominal and off-nominal (toleranced) location of the salient GN&C components and attributes in the context of the element, the integrated vehicle, and the staged flight configurations. This drawing reports tolerance values and considers thermal and environmental effects. This drawing also references any and all reference datums, alignment queues, and/or fiducial components that are required to ascertain the proper alignment and/or assembly of the component articles in the element/vehicle.
- (5) **Integrated Vehicle Alignment Drawing:** This drawing depicts the nominal and off-nominal (toleranced) location of the salient stage level GN&C alignment attributes in the context of the integrated vehicle, the staged flight configurations, and ground systems. It also locates all associated datums relative to the flight controller and mass centers. This drawing reports tolerance values and considers thermal and environmental effects. This drawing also references any and all alignment queues, reference datums, and/or fiducial components that are required to ascertain the proper alignment and/or assembly of the stage elements and ground systems.

**Note:** The Component Alignment Drawing reports the alignment of individual components within the element and integrated stack. The Integrated Vehicle Alignment Drawing aligns the elements and ground systems.

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- h. **STACK METROLOGY PLAN:** The Vehicle Design Integration function works closely with the Elements and Ground Systems to develop the verifications required thus ensuring that the stacked vehicle conforms to the dimensions and relative alignments set forth by any of the above mentioned alignment drawings. This includes, but is not limited to, the types of measurement instruments and techniques used and should address when during the hardware assembly process the measurement occurs and any deviations that may occur (post measurement).



**FIGURE 14. Typical Mission Phases and Flight Configurations**

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## **APPENDIX A: ACRONYMS AND ABBREVIATIONS**

3-D	Three Dimensional
6-DOF	Six Degrees of Freedom
ACM	Alignment Control Model
ASME	American Society of Mechanical Engineers
BDM	Booster Deceleration Motor
BREPs	Boundary Representations
BTM	Booster Tumble Motor
CAD	Computer-Aided Design
CCF	Component Coordinate Frame
CFD	Computational Fluid Dynamics
CM	Configuration Management
CSYS	Coordinate System
DCM	Direction Cosine Matrix
ECF	Element Coordinate Frame
GN&C	Guidance, Navigation, and Control
GP	Gimbal Point
GPS	Global Positioning System
GSE	Ground Support Equipment
ICD	Interface Control Document
ICM	Interface Control Model
IDP	Interface Detail Product
IGES	Initial Graphics Exchange Specification
IU	Instrument Unit
MLP	Mobile Launch Platform
MMC	Maximum Material Condition
MSFC	Marshall Space Flight Center
NASA	National Aeronautics and Space Administration
NHA	Next Higher Assembly
NCD	Nearby Circular Datum
OML	Outer Mold Line
OPR	Office of Primary Responsibility
RCF	Reference Coordinate Frame
ReCS also RCS	Reaction Control System
RGA	Rate Gyro Assembly
RINU	Redundant Inertial Navigation Unit
RoCS	Roll Control System
SRM	Solid Rocket Motor
STD	Standard
STEP	Standardized Exchange of Product
TPS	Thermal Protection System
TVC	Thrust Vector Control
USM	Ullage Settling Motor

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VAB	Vehicle Assembly Building
VCF	Vehicle Coordinate Frame
VSP	Vehicle Support Post
WIO	Wind Induced Oscillations

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## **APPENDIX B: GLOSSARY OF TERMS**

Absolute Attribute	An Absolute (or True) attribute is a geometric attribute whose value or location is unambiguous. Lines and planar surfaces can only be described by a collection of points that fall within their definition.
Attribute	A geometric entity within the CAD dataset used to identify an important location, such as a centroid, instantaneous center, gimbal point, etc.. An attribute can be virtual, temporal, etc..
Active Flight Control Components/Subsystems	Those components and/or subsystems that actively participate in the vehicle's GN&C closed loop control system. This would include the controllable thrust producing devices (motors, engine, roll motors, reaction motors, etc.), sensing devices (rate gyro assemblies and the redundant inertial navigation unit), and thrust effecting devices (servo-actuators). These devices and/or subsystems provide the navigational and attitudinal control of the integrated and staged vehicle during all ascent phases.
Alignment Control Model (ACM)	A three dimensional CAD dataset with extracted GN&C components and attributes located in vehicle coordinates. This assembly model also includes pertinent alignment datums relative to GN&C, and interface "skeleton" representations for nearby referenced datums. Refer to Section 7.0 for additional detail.
Bilateral	A tolerance method using an equal plus and minus deviation from the specified nominal position.
Booster Deceleration Motor (BDM)	A small solid propellant motor used to decelerate a spent stage element.
Booster Tumble Motor (BTM)	A small solid propellant motor mounted on a stage element that aids in stage separation by rotating the booster away from the contact area.
Component Toleranced Location	A component (embedded within or attached to a stage element assembly) located off-nominally in an off-nominal stage element.
Coordinate Frame	An orthogonal reference frame defining the origin of a component in three dimensional space.
Direction Cosine Matrix (DCM)	A 3x3 Matrix which defines the relative orientation between two coordinate frames.
Dimensional Analysis	(Also called a tolerance analysis) is performed to ascertain the potential location and orientation of a component, attribute, or virtue within an assembly due to manufacturing and assembly variations (expressed as dimensional tolerances).

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Drawing Position	The theoretical location of a component or attribute (with or without tolerances) found by using analytical methods and dimensional analysis based on the drawings and/or models.
Element Gross Form Tolerances	A stage element's gross form tolerance is the as-manufactured overall form description. It includes, but is not limited to: (1) positional accuracy of the centerline, (2) parallelism between mating flanges, (3) planarity of mating flanges, and (4) clocking.
Euler Angle	Angle used to describe an objects orientation, implemented in three dimensional Euclidean space.
Feature of Size	One cylindrical or spherical surface, or a set of two opposed elements or opposed parallel surfaces, associated with a size dimension.
Fiducial	A component or target located in an optical path that is used determine location or alignment.
Geometric Attributes	The location/orientation of components or virtues, or virtual attributes (including tanks, center of gravity, coordinate system axes, gimbal points, thrust vectors, servo-actuator centerlines, etc.). Geometric attributes may be temporal (center of mass, thrust vector, etc.), subject to variation based on the assembly, and/or a function of some other parameter, such as pressure or usage.
Gravity Effects on Form	Under the effects of gravity, acceleration, or the weight of an additional stage element, the form characterization may differ from that of the unloaded structure.
Instrument Unit (IU)	Located at the top of the upper stage, the instrument unit houses the Redundant Inertial Navigation Unit (RINU). Prior to launch, the position of the RINU in the stacked vehicle is determined by a locational reference queue placed on the outer surface of the IU.
Metadata	Data that describes other data, providing information about an item's content.
MAV or MAVERIC	MAVERIC (Marshall Aerospace Vehicle Representation In C) is a low-to high-fidelity, three- or six degree-of-freedom (3-DOF/6-DOF) vehicle flight simulation program written primarily in the C programming language. The simulation can include trajectories, winds, vehicle flexibility, thrust profiles, etc.
Maximum Material Condition (MMC)	When a component is fabricated at either the maximum or minimum allowable tolerance condition, the component is said to have been manufactured at Maximum (or Minimum) Material Condition, or MMC.

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Measured Dimension	The location of a component or attribute based on a physical measurement(s) and possibly the characterization of a measurement datum(s). A measured dimension may differ from a true dimension due to measurement inaccuracy and/or inaccuracy in the characterization of the datum surfaces used to obtain the measurement.
Model Tree	Reference designators in hierarchical order, located in the CAD architecture, used for labeling features, virtues, datums, and attributes.
Non-actively Controlled Thrust Producing Devices	Those components which provide thrust for ullage settling (USM), stage deceleration (BDM), or stage tumbling (BTM). These devices provide a “one shot” force application via a non-controlled thrust vector for the above circumstances.
Perfect Form	Occurs when all components within the integrated vehicle are manufactured and assembled to the nominal (un-toleranced) dimension. Therefore, if all components are manufactured and assembled to their perfect (or nominal) form, the vehicle stack centerline will be perfectly straight, all coordinate system axes and mass properties will occur at their published (nominal) values, and all components will be located exactly in their nominal design location.
Rate Gyro (compassing) Assembly (RGA)	These are sensors are two axis sensors used to continually report the attitude of the vehicle during ascent. They sense vehicle pitch and yaw rates at their locations and are used for rigid body and body bending mode stabilization during first stage flight. (Gyrocompassing is a process by which an inertial measurement unit, or navigation platform, is operated for a time before launch to initialize its orientation and position by measuring the Earth’s rotation.)
Reaction Control System (ReCS)	A system of pulse modulated thrusters that are used to provide pitch and yaw control of the vehicle.
Redundant Inertial Navigation Unit (RINU)	The RINU is located in the instrument unit and provides angular and linear measurement data for the proper control of attitude, position, and velocity. Performance relies heavily upon initial position, accuracy of its gyrocompass alignment, the fidelity of its self-contained gravity model, the stability of its internal clock, and the accuracy and alignment of its inertial sensors.
Reference Coordinate Frame (RCF)	A measurable location on a component or element which is so designated on the source drawings.
Roll Control System (RoCS)	A system of pulse modulated hydrazine thrusters used for roll control of the vehicle.
Six degrees of freedom (6-DOF)	Three translations and three rotations.

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Thrust Vector	The line of action of the thrust vector at the point of application to the vehicle. This applies to all thrust effectors (Solid Rocket Motor (SRM) nozzle, engine nozzle, RoCS, ReCS, USM, BDM, and BTM). It is usually defined at the exit plane or throat of the thrust producing device.
Thrust Vector Control (TVC)	A system comprised of two electro-hydraulic servoactuators that are used to control the main propulsion thrust vector flight by gimbaling the motor or engine nozzle.
Toleranced Form	(Or off-nominal form) occurs when components are manufactured and/or assembled within acceptable tolerance bounds, but are otherwise imperfect.
Transform Matrix	A matrix that describes generalized positional variation (translation and rotation). See Appendix B.
True Dimension	(Or True Positional Value) is the dimension or location that falls within drawing (theoretical) and measured dimensional bounds when those methods are applied correctly. A true dimensional value may not always be measurable, and/or its value may be ambiguous. For instance, the vehicle in perfect form has a circular cross section with an easily defined centerline. However, the true vehicle cross section may have an elliptical or multi-lobed shape; this complicates determination of the vehicle's centerline.
Ullage Settling Motor (USM)	USMs are used to impart acceleration to a stage element just after stage separation in order to force liquid propellants toward the feed line pick-up points (rearward) to prevent cavitation.
Vehicle Support Posts (VSPs)	The four support posts locate the vehicle on the Mobile Launcher or launch pallet and are the basis for establishing the vehicle's nominal centerline. The four VSPs are nominally located within a planar accuracy of 0.010 inches, but the planarity may vary due to vehicle weight. Also referred to as Hold Down Posts, or HDPs.