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SBKF Modeling and Analysis Plan: Buckling Analysis of Compression-Loaded Orthogrid and Isogrid Cylinders

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Preface

The Shell Buckling Knockdown Factor (SBKF) Project, NASA Engineering and Safety Center (NESC) Assessment # 07-010-E, was established in March of 2007 by the NESC in collaboration with NASA's launch vehicle development programs. The SBKF Project has the goal of developing and experimentally validating improved (i.e., less conservative, more robust) shell buckling design factors (a.k.a. knockdown factors) and design technologies for launch vehicle structures.

Preliminary design studies indicate that implementation of these new knockdown factors can enable significant weight savings in these vehicles and will help mitigate some of NASA's future launch vehicle development and performance risks, e.g., reduced reliance on large-scale testing, high-fidelity estimates of as-built structural performance, increased payload capability, and improved structural reliability.

To this end, a series of detailed Project Reports are being published to document all results from the SBKF Project and include design trade studies, test article and test facility design, analysis and test data, technology development white papers and state-of-the-art assessments, and finally shell design guidelines to update and/or augment the existing NASA SP series publications for the design of buckling-critical thin-walled shell structures. A select group of significant results, in whole or in part, will be published as NASA Technical Memorandums (TM).

Any documents that are published as a part of this series, that refer to or report specific designs or design, analysis and testing methodologies are to be regarded as guidelines and not as NASA requirements or criteria, except as specified in formal project specifications.

Comments concerning the technical content of this NASA TM are welcomed.

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List of Figures

Nomenclature

F_u	applied force in the axial direction
L	cylinder length
R	cylinder radius
x, θ, z	axial, circumferential, and radial coordinate of a cylindrical coordinate system
u, v, w	axial, circumferential, and radial displacements
r_υ, r_v, r_w	rotations about the x, θ, z *axis*
P	axial load
P_{bif}	linear bifurcation buckling load
P_{cr}	buckling or limit load predicted from a geometrically nonlinear analysis
N_x, N_{xy}, N_y	axial, shear and circumferential stress resultants
Orthogrid design variables	See Figure 1
h	stiffener height measured from the inner mold line
b_r	circumferential stiffener (ring) spacing
b_s	axial stiffener (stringer) spacing
t	shell wall skin thickness
t_r	circumferential stiffener (ring) thickness
t_s	axial stiffener (stringer) thickness
H	total orthogrid panel thickness
Isogrid design variables	See Figure 2
a	stiffener side length
b	rib thickness
d	rib height
h	stiffener height measured from the skin inner mold line (d in the isogrid design handbook)
t	shell wall skin thickness
t_s	stiffener thickness (b in isogrid design handbook)
H	total isogrid panel thickness

Acronyms

CSS	NASA Langley Central Storage System
CxP	Constellation Program
KDF	Knockdown Factors
MAP	Modeling and Analysis Plan
NESC	NASA Engineering and Safety Center
OML	Outer Mold Line
PI	Principal Investigator
SBKF	Shell Buckling Knockdown Factor

Abstract

This document outlines a Modeling and Analysis Plan (MAP) to be followed by the SBKF analysts. It includes instructions on modeling and analysis formulation and execution, model verification and validation, identifying sources of error and uncertainty, and documentation. The goal of this MAP is to provide a standardized procedure that ensures uniformity and quality of the results produced by the project and corresponding documentation.

1.0 Overview

The Shell Buckling Knockdown Factor (SBKF) Project, NASA Engineering and Safety Center (NESC) Assessment #: 07-010-E, was established in March of 2007 by the NESC in collaboration with the NASA Constellation Program (CxP). The SBKF Project has the goal of developing and experimentally validating improved (i.e., less-conservative, more robust) analysis-based shell buckling design factors (a.k.a., knockdown factors (KDFs)) and developing design recommendations for launch vehicle structures.

Shell buckling knockdown factors have been historically based on test data from laboratory-scale test articles obtained from the 1930s through the 1960s. The knockdown factors are used to account for the differences observed between the theoretical buckling load and the buckling load obtained from test. However, these test-based KDFs may not be relevant for modern launch-vehicle designs, and are likely overly conservative for many designs. Significant advances in structural stability theory, high-fidelity analysis methods, manufacturing, and testing are enabling the development of new, less conservative, robust analysis-based knockdown factors for modern structural concepts. Preliminary design studies indicate that implementation of new knockdown factors can enable significant weight savings in these vehicles and will help mitigate some of NASA's launch-vehicle development and performance risks, by reducing reliance on large-scale testing, and providing high-fidelity estimates of as-built structural performance, increased payload capability, and improved structural reliability.

To achieve its KDF development and implementation goals, the SBKF Project is engaged in several work areas including launch-vehicle design trade studies, subcomponent and component level design, analysis and structural testing, and shell buckling design technology development including analysis-method development, analysis benchmarking and standardization, and analysis-based KDF development. Finite-element analysis is used extensively in all these work areas. In particular, there are four main categories analyses conducted by SBKF and include: 1) high-fidelity structural simulations, 2) imperfection sensitivity studies, 3) test article design and analysis and 4) exploratory studies. Each of these types of analysis may have different analysis objectives and utilize different modeling approaches that depend on the results required to meet the Project needs. A description of the four main categories follows.

- <u>High-fidelity structural simulations</u>
  High-fidelity structural simulations are defined as simulations that can predict accurately the complex behavior of a structural component or an assembly of components (e.g., virtual structural test) and often require a significant level of modeling detail and knowledge of the structural system (e.g., its physical behavior and expected variability). Models are considered high-fidelity if results predicted with these models correlate with

test data to within a small range of variance and represent accurately the true physical behavior of the structure. The permissible amount of variance is determined based on the analysis requirements defined by the Project in accordance with the intended end use of the predicted data.

High-fidelity shell buckling analysis objectives considered by the SBKF Project often require the accurate prediction of stiffnesses, local and global deformations, strains, load paths and buckling-induced load redistribution, and buckling and failure loads and modes. To achieve these analysis goals, the models typically must accurately represent loading and boundary conditions, and expected or measured geometric and material variations (imperfections). It is expected that high-fidelity models developed by SBKF will predict effective axial stiffness (slope of the load versus end-shortening curve) within ±2%, buckling loads and point displacements (displacement measured at a point) within ±5%, and point strains within ±10%. However, if the displacements or strains of interest are in a high-gradient location, then the overall trend will be assessed for correlation.

- <u>Imperfection sensitivity studies</u>
  Imperfection sensitivity studies are used to assess the sensitivity of a structure's nonlinear response and buckling load to initial imperfections, such as geometric imperfections (imperfections in the shell wall geometry including out-of-roundness or local dimples), and loading and material non-uniformities. Geometric imperfections included in an analysis model can be based upon the measured geometry of test articles or flight hardware, or they can be defined analytically using eigenmode shapes or other perturbations.

  The SBKF Project is developing analysis-based SBKFs (KDFs) that are derived from imperfection sensitivity studies and several imperfection types are being investigated. First, a single dimple-shaped imperfection is being used as a "worst-expected" imperfection shape and is similar to the initial dimple that is observed in the shell wall at the onset of buckling. The dimple is created in the shell by applying a radially inward lateral load at the mid-length of the cylinder. The magnitude of the lateral load is held fixed and the active destabilizing load (e.g., axial compression) is then applied until buckling occurs in the shell. The magnitude of the lateral load is increased incrementally in subsequent buckling analyses until a minimum or lower-bound buckling load is achieved. A second imperfection type used includes actual measured geometry data from as-built launch-vehicle-like test articles and flight hardware. These measured geometric imperfections are included in the model by adjusting the original geometrically perfect finite-element mesh nodal coordinates to the perturbed imperfect geometry. Finally, the effects of loading imperfections are investigated by applying localized concentrated loads on the ends of the shell in combination with the geometric imperfections or separately. Loading imperfections can occur due to manufacturing/machining variabilities and/or fit-up mismatch at component interfaces.

- <u>Test article design and analysis</u>
  Test article design and analysis encompass unique requirements that differ significantly from those associated with the design of aircraft, spacecraft, or launch-vehicle structures. Aerospace structures are designed and evaluated to ensure that they are able to sustain the required loads, but they are not typically required to exhibit a specific controlling or critical failure mode (i.e., they are not typically designed such that a specific failure mode

has the minimum design margin). In contrast, test articles used in the SBKF Project are designed and evaluated to ensure that a particular failure mechanism is exhibited during a test so that the resulting test data may be used to validate modeling and analysis methods for predicting specific behaviors. In addition, the test articles are typically designed such that they lie within the same design space as the full-scale structure they represent and exhibit similar response characteristics.

- <u>Exploratory studies</u>
  Exploratory studies are typically quick assessments used to guide future detailed analysis tasks. Data from these exploratory studies are not intended for future use or as decisional data and are often only used by the analyst to make informed decisions on the direction of future work. Thus, rigorous quality control and reporting of these analysis studies is typically not required.

The specific class of analysis and corresponding analysis and data requirements shall be determined by the SBKF team leads and the analyst. The analysis approach shall be based on standard best practices, when possible, and shall be uniform across all related analysis activities to ensure consistency. However, deviations from standard practice may be required and/or new approaches may be necessary to meet the analysis objectives. In such circumstances, the analyst and team lead will work together to develop and validate any new approach required.

The SBKF Modeling and Analysis Plan (MAP) is defined in the following section. The objective of the SBKF MAP is to provide a uniform guideline on how to develop and execute the SBKF analysis tasks, and to provide a means by which assumptions, modeling techniques, and other information pertinent to the tasks are identified, documented, and archived in a complete and consistent way. In some instances, general guidelines are indicated to help the analyst think through the process of developing a specific analysis and in other cases, specific definitions or assumptions are provided and shall be used unless otherwise directed. The MAP includes sections on model and analysis definition, sources of input, assumptions, model verification and validation, and identifying sources of error and uncertainty. The use of this MAP shall help ensure consistency, quality, and accuracy of the analysis results. The final section of the MAP outlines the reporting requirements to be used by all analysts and will ensure consistent and thorough documentation of all analysis methods, assumptions, inputs, and results.

2.0 Modeling and Analysis Plan

2.1 Model and Analysis Definition

The analyst shall employ a hierarchical approach to model and analysis development in order to assess the effects of various modeling and analysis assumptions on the predicted response during the preliminary stages of model and analysis development. That is, the analyst will start with a simplified version of the problem and methodically increase the level of complexity. For example, the analyst shall assess the effects of different approaches for modeling stiffeners including the use of smeared stiffener properties, beam, and shell representations. Similar approaches shall be used to assess the effects of other structural details such as weld lands or other structural discontinuities, and boundary conditions. Once sufficient experience and knowledge has been acquired for a specific type of structure, the hierarchical approach may be streamlined or eliminated if it is determined that one modeling approach is found to give reliable results for a particular family of analysis cases. Similarly, the analyst shall conduct linear bifurcation buckling analyses before proceeding on to geometrically nonlinear quasistatic and/or transient dynamic analysis. It is advised that closed-form solutions be used as a solution benchmark when available. The analyst shall also conduct model convergence studies to ensure converged solutions. The convergence studies shall assess the effects of mesh refinement, element type, and modeling assumptions associated with boundary conditions and structural details. In addition, a convergence study shall be conducted on the solution methods, parameters, and tolerances. In particular, it is well known that the use of artificial solution damping in quasistatic analyses can have a significant effect on the nonlinear and buckling response of thin-walled structures and should be used with extreme caution or avoided, if possible. If used, the amount of artificial damping energy should be monitored and compared with the physically realistic energies. Additionally, other important solution parameters include structural damping, time step increment, and solution convergence tolerance. Additional guidelines on model verification and validation are provided later.

Examples of previous shell buckling analyses for testing and test article design are provided in References 1–3 and examples for imperfection sensitivity studies and determining lower bound knockdown factors are provided in References 4 and 5.

Model Input and Computational Resource Requirements

Model development and analysis execution requires access to pre- and post-processing software as well as analysis codes. Access to modeling and post-processing codes such as Patran™ and Abaqus/CAE is needed to develop the analysis models and to interrupt results. Design geometry definitions of the cylinders to be included in the study are needed to develop the analysis models and shall be provided. Material definition and data including elastic modulus, Poisson's ratio, mass density, and failure allowables shall also be provided. Access to analysis codes that include Abaqus, Nastran™ and STAGS is needed, depending on the analysis being performed. Access to computing resources for modeling and analysis is also needed, including file storage space.

Sources of Input

The design information for orthogrid and isogrid designs shall be provided in the form of sets of geometric variable data (Figures 1 and 2). For orthogrid designs, skin thickness, t, ring spacing, b_r, ring thickness t_r, total orthogrid panel thickness, H, stringer spacing, b_s, and stringer thickness, t_s, shall be provided. For isogrid designs, skin thickness, t, isogrid edge length, a, rib thickness, b, and rib height, d, shall be provided. For all cylinders, the cylinder length and outer mold line (OML) radius will be provided. When weld lands are to be included, the weld land geometry (Figure 3), or a means to derive the weld land region geometry, shall be provided.

Assumptions

All materials will be treated as linear elastic isotropic at room temperature.

The amount of detail incorporated in a model, can limit the type of responses that can be predicted. For example, a smeared model where the effect of stiffeners is incorporated in the model by adjusting the elastic stiffness properties is unable to predict local or pocket buckling between stiffeners. Similarly, if details such as the tapered height of stiffener run-outs or mid-surface eccentricities are neglected, the local stiffness and load paths in the structure could be affected significantly. The amount of detail included in the model shall be determined by the analysis requirements and shall be supported by hierarchical and convergence studies as described previously.

Similarly, element type and element density (refinement) and solution procedure can have a significant influence on the predicted nonlinear and buckling behavior of thin-walled cylinders and should be investigated thoroughly during model convergence studies and documented in the final report.

Boundary conditions shall be determined based on the analysis requirements. In general clamped boundary conditions are used when modeling test articles or structures where relatively stiff boundary conditions are expected. Imperfection sensitivity studies typically consider both simply supported and clamped boundary conditions to assess the limiting cases.

Clamped boundary conditions are defined as follows: in a cylindrical coordinate system, x-θ-z, with the z-axis aligned with the cylinder axis, $u = v = w = r_{\upsilon} = r_v = r_w = 0$ are specified at one end of the cylinder, where r denotes rotation about the axis indicated by the subscript, and $v = w = r_{\upsilon} = r_v = r_w = 0$ and either u *or* F_u are specified to be equal to a constant value at the other end. If a load F_u is prescribed, then an additional constraint is used to impose a uniform displacement of all the edge nodes that the load is applied to.

Simply supported boundary conditions are defined as follows: in a cylindrical coordinate system, with the z-axis aligned with the cylinder axis, this assumption requires that $u = v = w = r_{\upsilon} = r_w = 0$ are specified at one end of the cylinder, and $v = w = r_{\upsilon} = r_w = 0$ and either u *or* F_u are specified to be equal to a constant value at the other end. If a load F_u is prescribed, then an additional constraint is used to impose a uniform displacement of all the edge nodes that the load is applied to.

2.2 Model Verification

Model verification is the process by which the analyst ensures that the model developed is done so in accordance with the design specifications and intended modeling assumptions, and shall be documented in a report in a checklist format. As suggested in NASA/TM–2004-213256 (Ref. 6), model verification shall include, at minimum, the following:

- Verify geometry
    - Perfect, imperfect
- Verify material property data
- Verify coordinate systems and element normal directions
- Verify loading (mechanical, thermal, etc.)
- Verify system of units
- Verify boundary conditions and constraints
- Verify implementation and adequacy of solution process/procedure, including selection of solution parameters and convergence criteria
- Verify solution convergence, conduct a mesh refinement study and assess sensitivity to element selection
- Compare analysis predictions to closed-form/analytic or other independent numerical solution if available

2.3 Model Validation

Model validation is the process by which the analyst ensures that the model developed satisfies the intended purpose. At this stage, the analyst shall demonstrate that the model and its associated data are accurate representations of the real physics needed to meet the analysis objectives. This process shall include, at minimum, the following:

- Validate idealization/modeling assumptions
- Validate material modeling assumptions
- Validate interface conditions
- Validate connection modeling assumptions
- Validate contact modeling assumptions (if present)
- Validate generalized imperfection treatment (if present)

In general, the modeling and analysis approaches used in the SBKF Project are based on validation efforts conducted during previous research activities (Refs. 7–9) and benchmarking studies on relevant stiffened metallic cylinders conducted by SBKF (Ref. 10). The goal of the previous validation studies was to determine the required model fidelity and inputs to predict accurately the buckling behavior of compression-loaded cylindrical shells. It was found necessary to include in the computational model initial geometric imperfections, non-uniform loading conditions, elastic boundary conditions, and, in some cases, thickness imperfection of the as-built test article to produce an accurate representation of the buckling behavior of these thin-walled, unstiffened cylinders. The goal of the benchmarking studies was to assess different commercially available finite element analysis codes for conducting buckling simulations, and to develop a series of user guidelines. SBKF team leads involved in the previous benchmarking studies shall provide guidance to the analysts on the development of these models to ensure that appropriate modeling approach and best practices are considered. Additionally, the analysts are advised to review the validation results and benchmarking study references identified herein as they become available. In particular, results should be cross-checked for similarity in behavior. If it is determined that the analysis results generated from models covered in this MAP are significantly different from those reported in the validation or benchmarking studies, a note in the final report shall be provided, along with any comments on the potential ramifications of using said results.

2.4 Sources of Error and Uncertainty

Sources of error and uncertainty are inherent in any modeling and analysis effort and can result from the data used and assumptions made to construct a model and from assumptions made in selecting and implementing an approach for analyzing a model of the physical system. Geometry definitions for the cylinder designs considered in the SBKF Project are expected to be well defined, but due to naturally occurring variations in actual geometry and material properties, and boundary conditions and loads, some amount of uncertainty will always exist in the analysis model and in the analysis predictions. Similarly, simplifying assumptions are typically necessary when developing a computational model and will introduce some amount of error.

Sources of Error

Errors are introduced in the analysis predictions due to the use of assumptions. Assumptions made during data processing and interpretation, and in simplifying the modeling of structural details are examples. Models that use smeared properties and/or discrete beams to represent stiffener response in regions of a global model may provide reasonable prediction of the global response, including proper load path prediction, but cannot be used to predict local responses such as local skin pocket buckling (e.g., model with smeared skin properties), stiffener rolling and buckling (e.g., stiffeners modeled with beam element versus shell elements), or local bending at weld land regions.

Sources of Uncertainty

Uncertainty is introduced by the information and data that are used to generate the models to perform the analyses. Example inputs that may contribute to uncertainty include material data, and the distribution and magnitude of loads and variations in geometry. The use of material property information from a source whose pedigree is not known introduces uncertainty.

3.0 Reporting

During the KDF analysis effort, analysis and results information will be documented for each design or family of designs that is analyzed. This documentation will be in the report format outline provided in SBKF_Report_Template-Analysis-2012.09.26.doc (or newest available), and will be submitted to the Principal Investigator (PI) and other SBKF personnel identified by the PI at the completion of the analysis task for review and concurrence. Report information shall include a brief summary of the problem definition, the modeling approach and rationale, model verification and validation, results, list of files, sources of error and uncertainty, and any other information that the analyst deems important to document their work fully. The analyst is encouraged to reference the MAP whenever possible to minimize repetition. Details of the minimum reporting requirements are briefly described in the following sections.

3.1 Problem Definition

This section shall provide an overview describing the modeling and analysis effort, including the objectives, requirements and the corresponding approach. The description of the physical structure (e.g., cylinder) and all details necessary to develop the finite element model shall be included. References may be used when available. The following information shall be summarized:

1. Objectives of analysis (general statement)
2. Analysis requirements (specific data/results the analysis will provide)
3. Design (or series of designs) designation
4. Source of design (reference)
5. Cylinder geometry and construction type (isogrid, orthogrid, (see Figures 1 and 2, respectively), etc.)
    a. Stiffener pattern dimensions
    b. Location of stiffeners (interior, exterior)
    c. Cylinder length
    d. Cylinder OML radius
    e. Cylinder geometry parameter values (see Figures 1 and 2)
6. Weld lands
    a. Number, location
    b. Geometry of weld land and taper regions (see Figure 3)
7. Coordinate system and boundary conditions (include figure with coordinate system and boundary conditions)
8. Other details

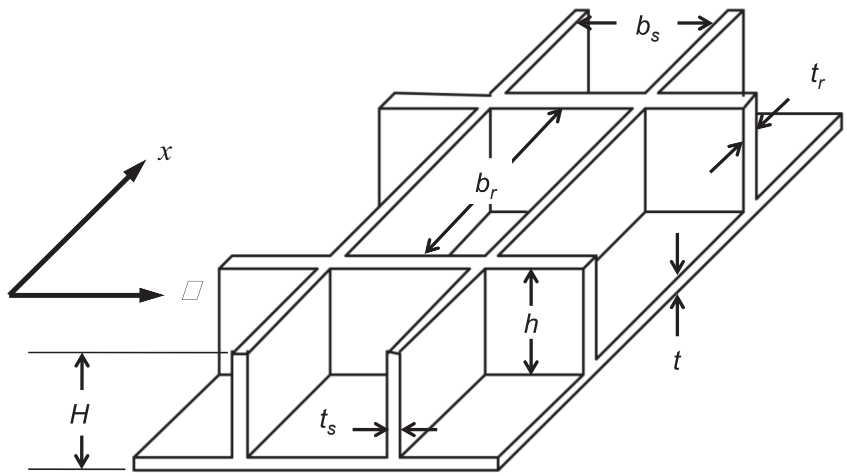


Figure 1. Orthogrid geometry and design variables.

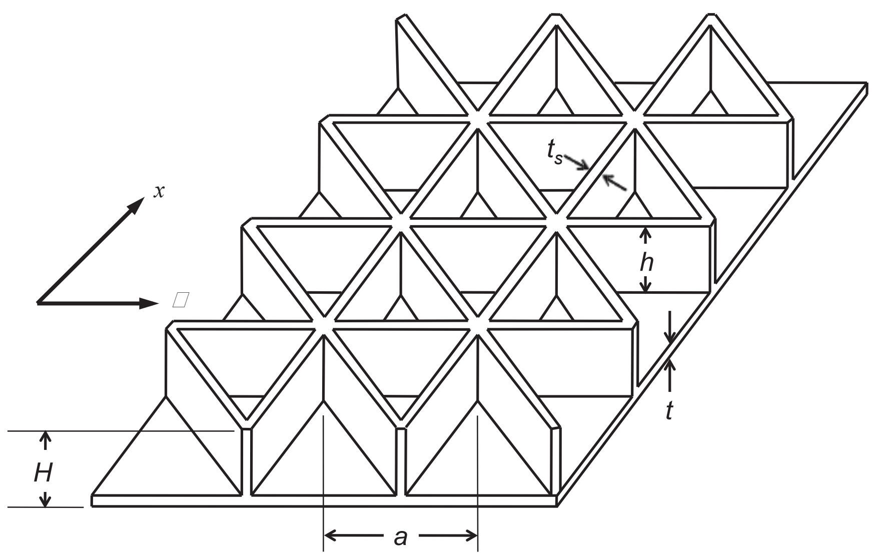
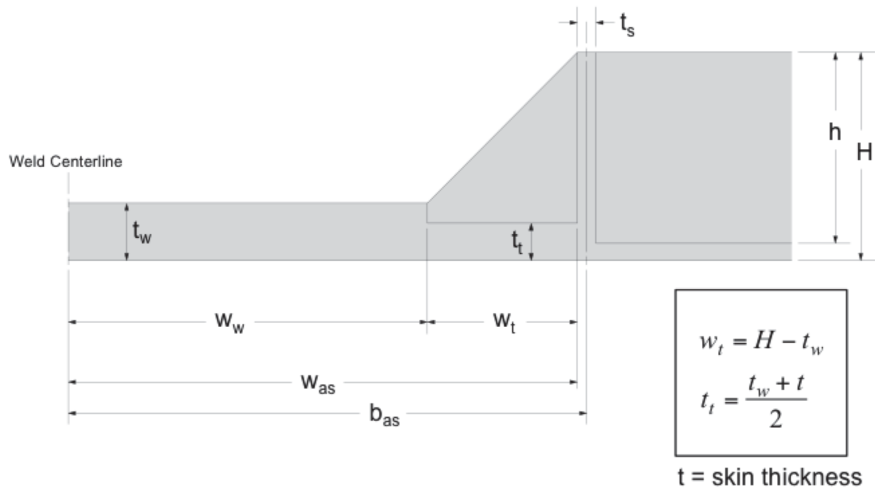
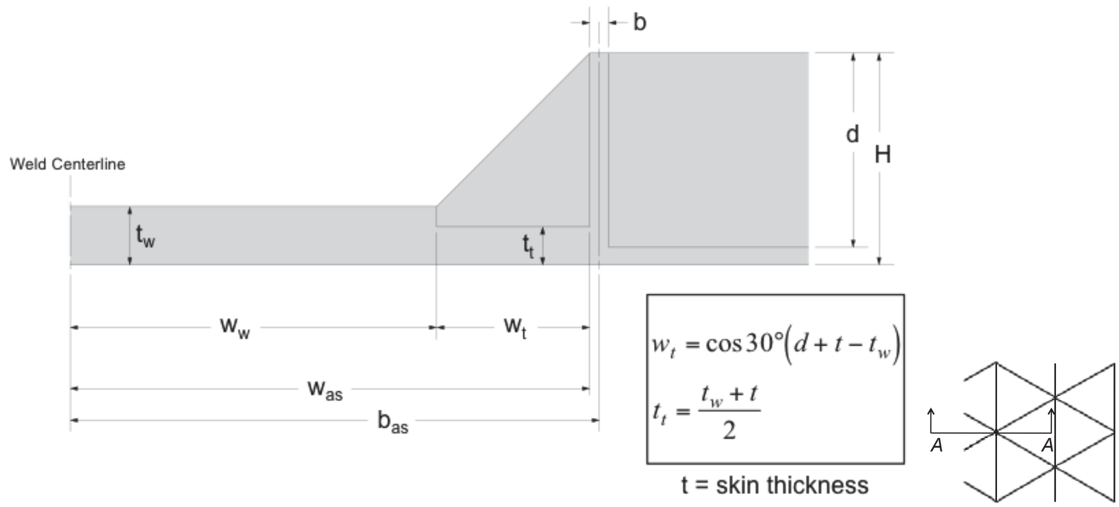


Figure 2. Isogrid geometry and design variables.



a) Orthogrid.



b) Isogrid.

Figure 3. Weld land geometry (assumes a 45-degree stiffener taper).

3.2 Modeling Approach and Rationale

This section shall document the model definition, modeling assumptions and the rationale for the modeling approach. Included in this section shall be a full description of the model, including material and element property information, as well as general information about the analysis software and solution procedure. The following information shall be provided:

1. Analysis software (including version, indicate any special user-defined subroutines, executables or scripts that were used)
2. Machine name and architecture used for conducting the analysis
3. As-modeled geometry parameters (list all that are different from the nominal parameters defined in the "Problem Definition" section, and indicate the reason for the difference)
4. Model type (smeared, beam/shell, shell)
    a. Element types used and why they were selected

    b. Description of element implementation if different from default. Describe changes to default implementation and rational for the changes.
5. Any other assumptions (e.g., ignored taper of stiffeners or other comments on modeling approach)
6. Coordinate system(s) used
7. Property sets used
    a. For each property set, give name and all values specified in the property definition (thickness, offset, etc.).
8. Location of reference surfaces, inner mold line, OML, mid-plane, etc. for each detail (skin, stiffener)
9. Mesh description
    a. Total number of nodes and elements
    b. Mesh discretization of features (number of elements in height of stiffeners, skin bay, etc.)
10. Applied loads/displacements
11. Boundary condition and constraint definitions
12. Type(s) of analyses performed
    a. Purpose for each analysis (expected results data)
    b. Solution parameters for each analysis
13. Estimated time required to create the model
14. Sources of error
15. Sources of uncertainty

3.3 Model Verification

This section will describe the verification process (see Section 2.2 in this MAP). Describe all steps taken to verify that the model accurately represents the desired cylinder, and that the analysis was run correctly. The report shall include a checklist.

3.4 Model Validation

This section will describe the validation process and the success criteria applied (see Section 2.3 in this MAP). Describe why the analysis results are representative of the physical system being modeled and include comparisons/reference to previous test results or previous analysis data.

3.5 Results

This section shall be a compilation of the analysis results. The files containing the data shall be listed in the Files List section (Section 3.6), provided below. All data for X-Y plots shall be in Tecplot™ or comma-separated-variable (csv) format. Minimum documentation requirements for each analysis performed, are provided below:

1. Mesh convergence study results
    a. Type of analysis used
    b. Load case(s) used
    c. Meshes used
    d. Convergence criteria and metrics used to determine convergence
2. Linear bifurcation analyses
    a. Buckling load
    b. Buckling mode (rolled out contours)

    c. Time required for analysis
3. Nonlinear static and nonlinear transient
    a. Load vs. end shortening curve(s)
    b. Contour plots at critical load P_{cr} and as needed to show response characteristics, e.g., pocket and/or weld land buckling development (rolled out)
        i. *u*, *v* and *w* displacements
        ii. Stress resultants, N_x, N_y and N_{xy}
    c. Number of processors used
    d. Time required for analysis
4. For lateral perturbation analysis cases (in addition to 3a–3d above)
    a. Radial displacement vs. lateral load curve(s), with only lateral load applied at the point of lateral load application
    b. Radial displacement vs. end shortening curve(s)
        i. At point of lateral load application
        ii. At the center of selected panel sections and weld lands for cylinders with weld lands
    c. Critical load vs. lateral load
    d. Contour plots with lateral load only applied (same as above for critical load)
    e. Tabulated data of critical load for each lateral load
5. As necessary, depending on analysis type
    a. Calculated knockdown factor (P_{cr}/P_{bif})
    b. P_{cr} *and* P_{bif} used to calculate knockdown factor, and how determined
    c. Value of lateral load at load used to calculate knockdown factor

3.6 List of Files

File names of model, analysis and results information will be listed here, along with a brief description of the contents. This information shall also be placed in a "README" file and stored in the same folder/directory as the data files.

Model database:

Example-model.db – Patran™ database (v. 2012) that contains the model definition, which was created using the Abaqus preference. This database only contains a dummy load case, with the actual load case being directly edited into the Abaqus file.

Model input file:

example-analysis-buck.inp – Abaqus input file used for a linear bifurcation analysis of design example.

Results files:

example-results.plt – Tecplot™ input file for X-Y plots, including the following: end-shortening, load factor, load, lateral load, radial displacement at point of lateral load, etc.

3.7 Sources of Error and Uncertainty

This section shall be used to document assumptions, sources of error and uncertainty, and limitations. Limitations include, but are not limited to, those inherent in the analysis software, and limitations based on the range of design/loading variables considered and structural behaviors.

4.0 Configuration Management

All data and files shall be provided to the SBKF team by the due date for their review. All model files, once reviewed, shall be archived on the NASA LaRC Central Storage System (CSS), in addition to being stored on separate external drives provided by SBKF.

5.0 References

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14. ABSTRACT
This document outlines a Modeling and Analysis Plan (MAP) to be followed by the SBKF analysts. It includes instructions on modeling and analysis formulation and execution, model verification and validation, identifying sources of error and uncertainty, and documentation. The goal of this MAP is to provide a standardized procedure that ensures uniformity and quality of the results produced by the project and corresponding documentation.

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