Active Project (2007)

Shell Buckling Knockdown Factors Project

NASA Engineering & Safety Center Program | Office Of The Chief Engineer (OCE)

ABSTRACT

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 former NASA Constellation Program (CxP) and now the Space Launch System (SLS) Program. 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.

ANTICIPATED BENEFITS

To NASA funded missions:

Reduction in mass of SLS launch vehicle due to less conservitive knockdown factors on cylindrical thin shell walls.

To other government agencies:

Benefits any new launch vehicle design for the DoD.

To the commercial space industry:

Benefits any new commerical launch vehicle design.

To the nation:

More mass to orbit potentially for the same cost when compared to older launch vehicles.

DETAILED DESCRIPTION

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-

Image Not Available

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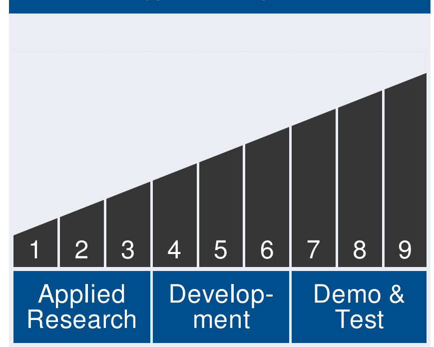
Technology Maturity



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.

High-fidelity structural simulations

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

Realized Benefits

1 Peer Reviewed Paper
1 Publication
1 Test Data and Report

Management Team

Program Director:
- Timmy Wilson

Project Manager:
- Clinton Cragg

Principal Investigator:
- Mark Hilburger

Co-Investigator:
- Marc Schultz

Technology Areas

Primary Technology Area:
Materials, Structures, Mechanical Systems and Manufacturing (TA 12)

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 SBKFwill 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.

Imperfection sensitivity studies

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.

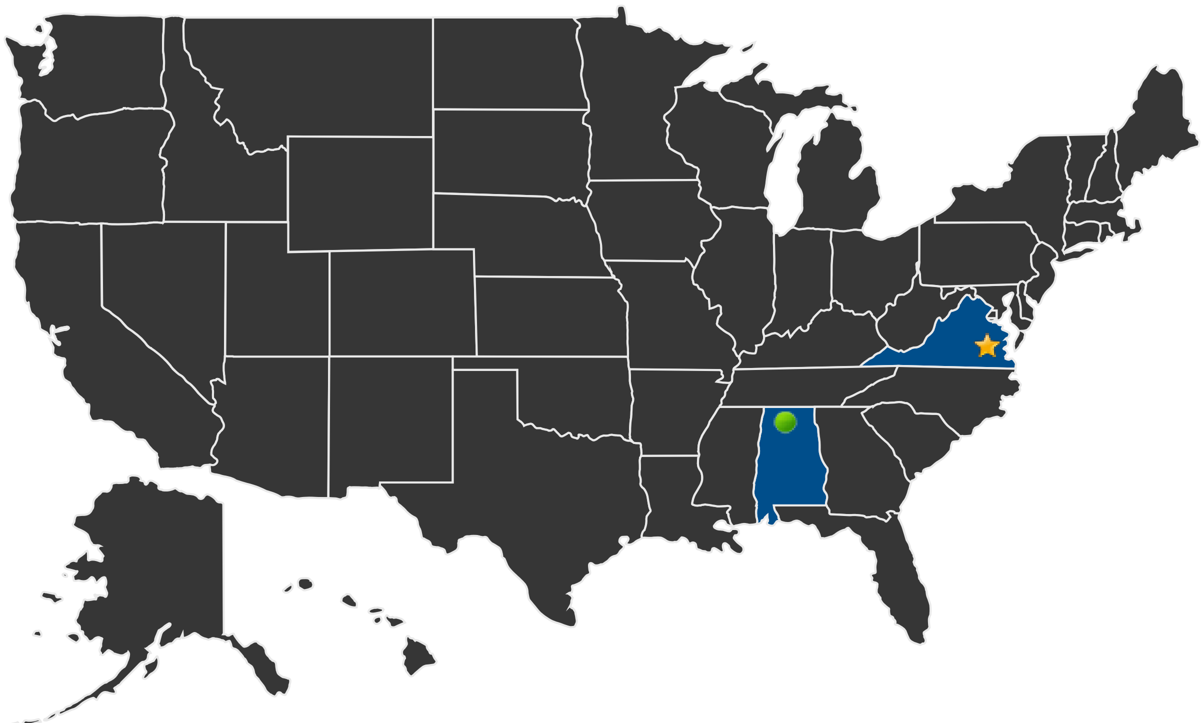
Test article design and analysis

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.

Exploratory studies
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.

U.S. LOCATIONS WORKING ON THIS PROJECT



U.S. States With Work

Lead Center:
Langley Research Center

Supporting Centers:

- Marshall Space Flight Center

Contributing Partners:

- Northrup Grumman
- The Boeing Company

PROJECT LIBRARY

Peer Reviewed Papers

- An experimental study of the compression response of fluted-core composite panels with joints
  - (http://www.elsevier.com/locate/compositesb)

Presentations

- Shell Buckling Knockdown Factor Project Overview and Status
  - (https://techport.nasa.gov:443/file/16720)

Publications

- SBKF Modeling and Analysis Plan:Buckling Analysis of Compression-Loaded Orthogrid and Isogrid Cylinders NASA/TM-2013-218037
  - (http://ntrs.nasa.gov)

Test Data and Reports

- Buckling Analysis of a Honeycomb-Core Composite Cylinder with Initial Geometric Imperfections NASA/TM?2013-217967
  - (http://ntrs.nasa.gov)

DETAILS FOR TECHNOLOGY 1

Technology Title

Knock Down Factors Modeling and Analysis

Technology Description

This technology is categorized as a hardware component or part for manned spaceflight

Analysis and modeling tools to determine knockdown factors for metallic and composite cylindrical shells.

Capabilities Provided

Lighter weight launch vehicles.

Potential Applications

Applicable to launch vehicle design.