Shell Buckling Knockdown Factor Project Overview and Status

Mark W. Hilburger, Ph.D.

SBKF Project Lead

Structural Mechanics and Concepts Branch

Research Directorate

NASA Langley Research Center

May 6, 2015

Outline

- Introduction
- Shell Buckling Knockdown Factor Project (SBKF)
  - Overview
  - Approach
- Project Highlights
  - Metallic Cylinder Testing
  - Benefits to the Space Launch Systems (SLS)
- Next Phase: Composite Structures
- Concluding Remarks

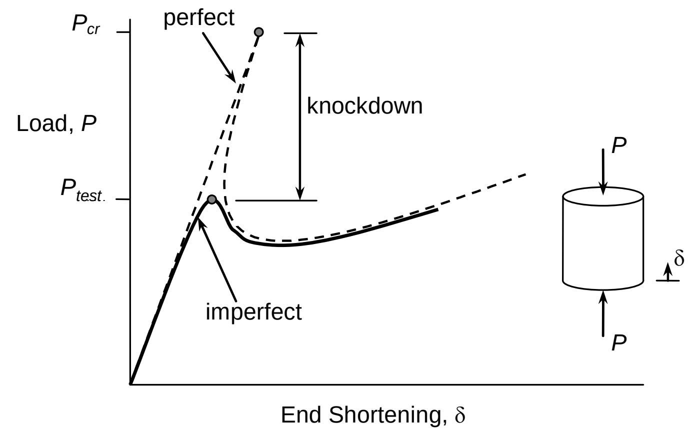
Introduction

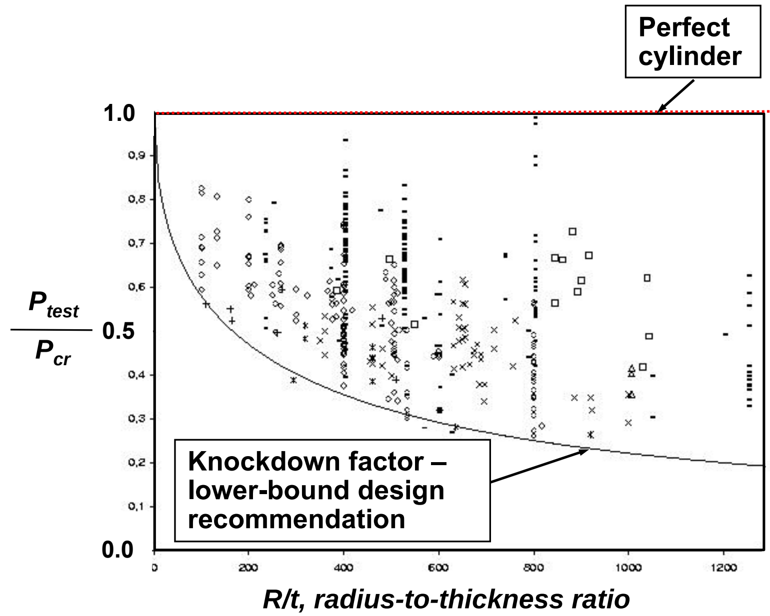
Background

- **Large amount of cylinder testing occurred in the 1920s-1960s to help understand shell buckling**
  - **Significant scatter in the buckling loads that were typically *less* than theoretical predictions**

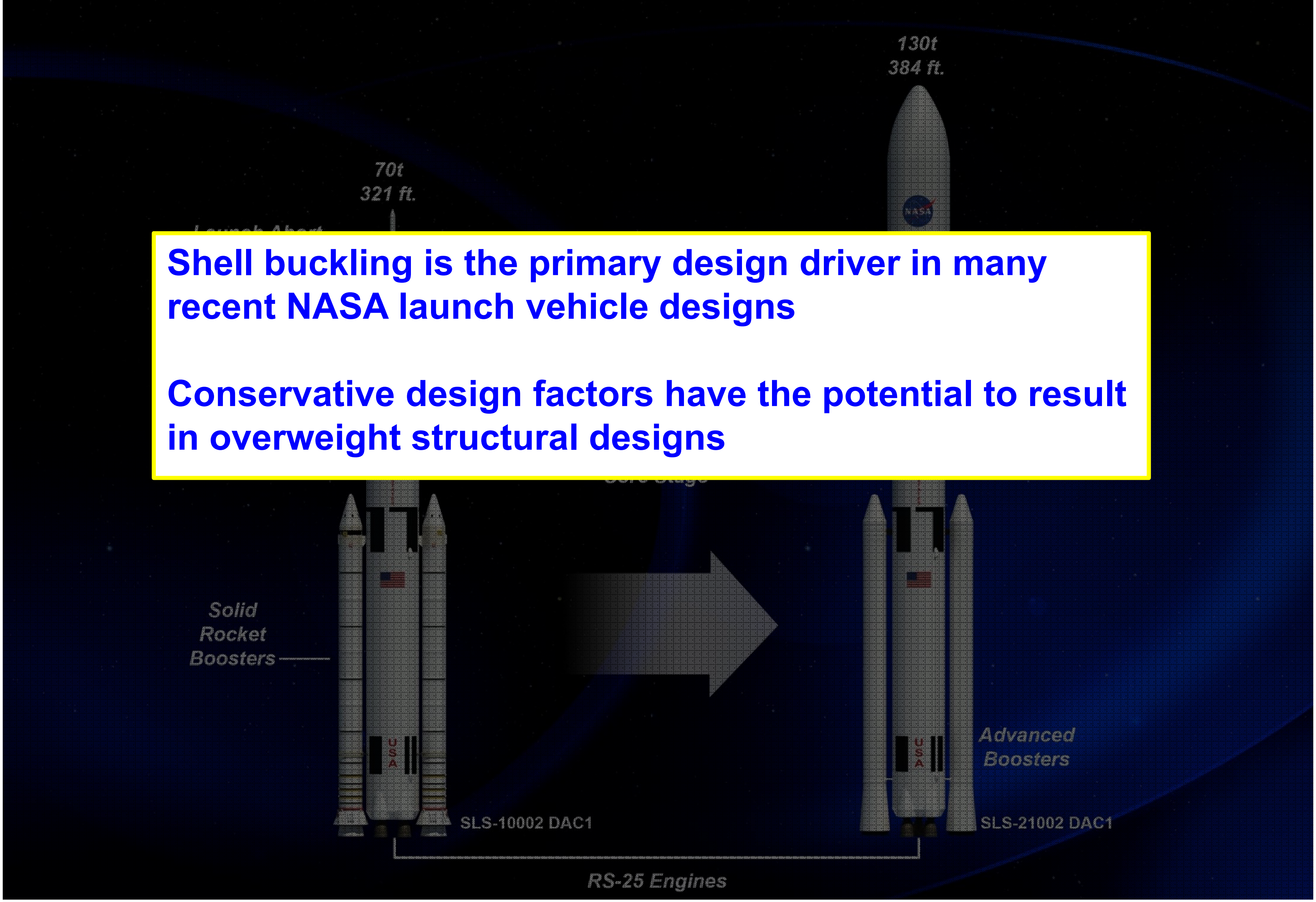
- **Differences between test and analysis are now primarily attributed to initial geometric imperfections (i.e., out-of-roundness)**

- **Standard practice is to apply a design knockdown factor to theoretical predictions of perfect cylinder**





SLS Architecture Reference Configuration



Shell buckling is the primary design driver in many recent NASA launch vehicle designs

Conservative design factors have the potential to result in overweight structural designs

NASA Shell Buckling Knockdown Factor Project

Shell Buckling Knockdown Factor Project (SBKF)

NASA Engineering and Safety Center (NESC) assessment

- 2007 – Present

Objective

- To develop and validate new analysis-based shell buckling knockdown factors (KDF) and design guidelines for launch-vehicle structures
  - Metallic cryotank and dry structures (2007 – 2016)
  - Composite dry structures (2015 - ?)

Expected outcome

- Reduce structural mass and mass-growth potential
- Enable new structural configurations
- Increase KDF fidelity to improve design trades and reduce design cycle time/redesigns

Developing New Design Factors

- Validated high-fidelity analyses are being used to generate the design data (virtual tests)

- Testing serves to validate the analyses

- New factors will account for the following:
  - Initial shell-wall geometric imperfections (out-of-roundness) and nonuniform loading (caused by end imperfections)
  - Modern launch-vehicle structural configurations and materials
  - Relevant launch vehicle loads
  - Joints

- Implementation
  - Engage the user community to review and refine a technology development and implementation plan

Project Highlights

- Metallic Cylinder Testing
- KDF Implementation on SLS

Metallic Cylinder Testing

Subscale and Full-Scale Cylinder Testing

- **Relevant metallic launch-vehicle-like structures**
- **State-of-the-art manufacturing, testing, and measurement techniques**

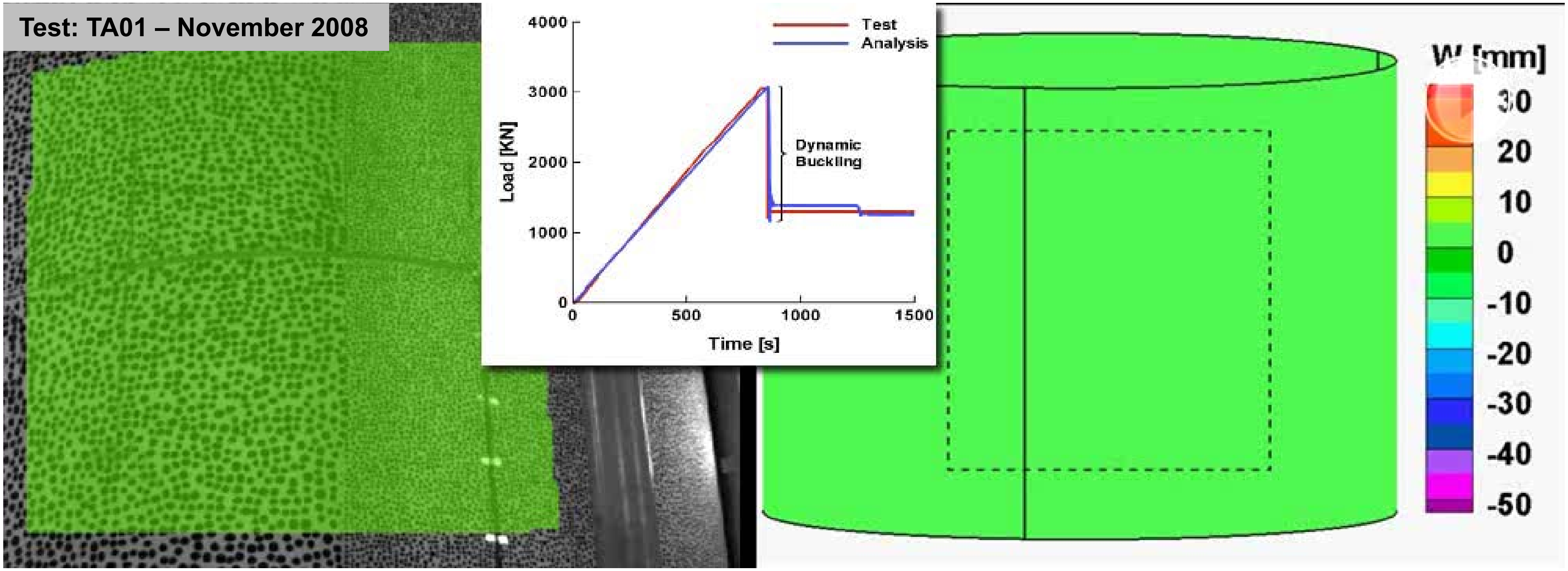
Subscale (8-ft diameter) launch-vehicle cylinders

7 of 9 complete

Full-scale (27.5-ft diameter) launch-vehicle cylinders

2 of 2 complete

Predicted and Measured Buckling Response



- **Test and analysis results correlate well:**
  - **Buckling loads predicted within 5% - 10%**
  - **Physics of buckling initiation and propagation predicted accurately**
  - **Validated high-fidelity analysis methods can be used to derive analysis-based design factors**

KDF Implementation on SLS

Boeing Testimonials* and Return on Investment

- The Boeing Company (Boeing) has utilized our preliminary set of KDFs in the design of the Block 1 SLS Core Stage
- Testimonials from Boeing management state that the new KDFs enabled
  - 2,000 lb - 3,000 lb mass savings in the SLS Core Stage tanks (5% - 8%)
  - Reduced material costs by \$300K - \$400K per launch by using thinner plate material (machining cost reduction also expected, but not captured here)
  - Reductions in design and analysis cycle time by eliminating the need for detailed structural optimization of weld lands
  - Contributed significantly to on-time PDR
- Return on investment (ROI) rough order of magnitude (ROM) based on mass savings only
  - Assume 3,000 lb mass savings in Core Stage tanks
  - Assume core stage gear ratio = 5.5
  - Assume \$10K/lb payload

ROI = 3,000 lb /5.5 x \$10K/lb = \$5.45M savings per launch

** Boeing SLS Core Stage Design Technical Lead Engineer*

Composite Structures

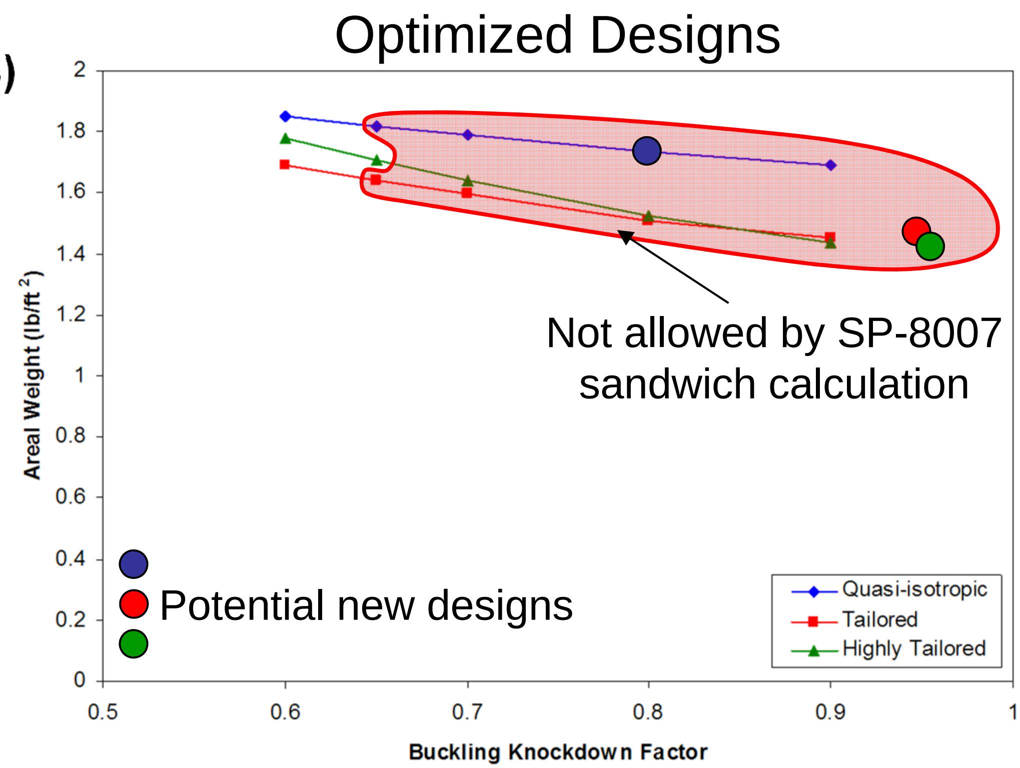
Status

Engaged in a detailed planning phase

- Trade studies to identify design space
- Preliminary test planning
  - Considering 2.5-m to 4-m diameter cylinders
  - Assessing fabrication options
  - Assessing test facility options
- Looking for collaboration opportunities
  - Test article fabrication
  - Cylinder and cone geometry measurements

Preliminary Design and Imperfection Sensitivity Study

- **Ares V Interstage, honeycomb-core sandwich composite**
- **Design optimization**
  - **Given facesheet layup and knockdown factor, optimize for facesheet and core thicknesses**
  - **Three facesheet layups**
    - **Quasi-isotropic (25% axial plies)**
    - **Tailored (43% axial plies)**
    - **Highly tailored (60% axial plies)**
  - **0.6 ≤ KDF ≤ 0.9**
    - **500 lb - 1,000 lb (7%-15%) weight savings on Interstage**



Composite Cylindrical Test Articles

- **8-ft dia. honeycomb-core sandwich composite cylinder**
  - Nonreimbursable SAA with Northrop Grumman Corporation
  - Out-of-autoclave construction
  - Single piece (unsegmented)
  - Testing Oct. 2015

Image courtesy of Northrop Grumman

- **13-ft dia. fluted-core sandwich composite cylinder**
  - Nonreimbursable SAA with Boeing
  - Segmented in-autoclave construction

Fluted-core cross section

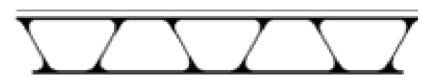


Image courtesy of Boeing

Concluding Remarks

- **SBKF is using validated high-fidelity models to derive new analysis-based shell buckling knockdown factors for launch vehicles**
  - **NASA has implemented new knockdown factors on the SLS core stage**
  - **Demonstrated savings in mass, design cycle time, and cost**

- **Currently ramping up the SBKF Composites work**

- **We welcome your comments and participation**

- **Questions or Comments?**