Structural deformation of sandwich composite heliostats

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Introduction

• The sun emits energy at an extremely high and relatively constant rate.

  o If all of this energy could be converted into usable forms on earth, it would be more than enough to supply the world’s energy demand.

• This demand significantly encouraged the development of solar power generation technologies.
Introduction

Central tower concentrating solar power (CSP) systems
Central Tower CSP System

• This emerging technology holds much promise for countries with plenty of sunshine and clear skies.

• Its electrical output matches well the shifting daily demand for electricity.

A huge obstacle prevents the expansion of these systems

COST
Central Tower CSP System

**Heliostats** contribute around 50% to the plant’s cost (*Kolb et al., 2007*)

- Heliostats are the most crucial cost element of central tower CSP systems
Heliostat Cost Reduction Opportunities

Impact of heliostat primary elements on the total cost (Kolb et al., 2011)
Heliostat Cost Reduction Opportunities

- Focusing on large-scale heliostats:
  - **Heavyweight** mirror support structure (Steel)

(high-torque drive)

Less structural weight

Less drive torque

Less heliostat cost

How can we accomplish this weight reduction??
Sandwich Composites

• Sandwich composites are becoming an essential part of today’s materials.

• They offer various advantages including:
  ❖ Lightweight.
  ❖ High fatigue strength.
  ❖ Corrosion resistance.
  ❖ Faster assembly.
Honeycomb Sandwich Composites

- High stiffness to weight ratios.
- formed by adhering two thin-face sheets to a low-density honeycomb core.
- The honeycomb core is capable of withstanding transverse normal and shear loads, while the faces handle both compressive and tensile loads due to bending.

Honeycomb sandwich structure (Abbadi et al., 2009)
Research Question

How can **honeycomb sandwich composites** be utilized to develop a robust, lightweight heliostat mirror support structure that is capable of withstanding wind loads at various tilt angles??
Method
Fluid-Structure Interaction (FSI)
Stage 1: Heliostat Structure Modelling

Stage 2: Modelling the Flow of Air around the Heliostat Structure

Stage 3: Fluid-Structure Interaction
Considering a typical heliostat configuration, the full structure of the heliostat have been visualized.

Existing ATS 150 Heliostat
(Mancini, 2000; Kolb et al., 2007)
Stage 1:  Heliostat Structure Modelling

Stage 2:  Modelling the Flow of Air around the Heliostat Structure

Stage 3:  Fluid-Structure Interaction
Fluid Domain

Solver Settings

> Steady state
> Pressure-based solver
> SST K-ω model
Stage 1: Heliostat Structure Modelling

Stage 2: Modelling the Flow of Air around the Heliostat Structure

Stage 3: Fluid-Structure Interaction
Importing Pressure Loads from Fluid Solver to Mechanical Solver

One-way FSI
Honeycomb sandwich composite material properties

Mechanical properties’ calculation
(Nast 1997; Gibson and Ashby 1997)

\[
E_1 = \frac{t^3 (1 + \sin \varphi)}{12 a^3 \cos \varphi \left[ \frac{\cos \varphi}{3} - \frac{1 + \cos \varphi}{8} (1 - \nu^2) \right]} E
\]
\[
E_2 = \frac{t^2 \cos \varphi}{(1 + \sin \varphi) a^3 \sin^2 \varphi (1 - \nu^2)} E
\]
\[
E_3 = \frac{2 t}{a \cos \varphi (1 + \sin \varphi)} E
\]
\[
G_{12} = \frac{t^2 (1 + \sin \varphi)}{a^3 (1 - \nu^2) \cos (6.25 - 6 \sin \varphi)} E
\]
\[
G_{13} = \frac{10 t}{9 a \cos^3 \varphi (1 + \sin \varphi)} G
\]
\[
G_{23} = \frac{2 t}{a \cos \varphi (1 + \sin \varphi)} G
\]
\[
v_{12} = \frac{\sin^2 \varphi (1 + \sin \varphi)^2}{12 a^3 \cos^2 \varphi \left[ \frac{\cos \varphi}{3} - \frac{1 + \cos \varphi}{8} (1 - \nu^2) \right]}
\]
\[
v_{23} = \frac{t^2 \cos^2 \varphi}{2 a^2 \sin^2 \varphi (1 - \nu^2)} \nu
\]
\[
v_{13} = \frac{t^2 (1 + \sin \varphi)^2}{24 a^2 \cos \varphi \left[ \frac{\cos \varphi}{3} - \frac{1 + \cos \varphi}{8} (1 - \nu^2) \right] \nu}
\]
\[
\rho_{\text{honeycomb}} = \frac{3}{2 a \cos \varphi (1 + \sin \varphi)} \rho
\]
Validation
Validation of CFD model

Drag coefficient

Lift coefficient
Validation of FEA model

Modal frequency results
Results and Discussion
Figure 7. Pressure distribution on the heliostat at wind speed of 20 m/s

(a) $\theta = 90^\circ$  (b) $\theta = 60^\circ$

(c) $\theta = 30^\circ$  (d) $\theta = 0^\circ$

(e) $\theta = -30^\circ$  (f) $\theta = -60^\circ$

(g) $\theta = -90^\circ$

Figure 8. Displacement distribution of the heliostat surface at wind speed of 20 m/s for different tilt angles

(a) $\theta = 90^\circ$  (b) $\theta = 60^\circ$

(c) $\theta = 30^\circ$  (d) $\theta = 0^\circ$

(e) $\theta = -30^\circ$  (f) $\theta = -60^\circ$

(g) $\theta = -90^\circ$
\[ \tan(\pm 3.6 \, \text{mRad}) = \frac{\text{Displacement}}{\frac{1}{2} (\text{Heliostat chord length})} \]

The maximum allowable deflection = ±21.3 mm.

Simplified interpretation of the wind load displacement requirement (Björkman, 2014).
Highly stressed regions

Back surface

(θ=30°)
20% Weight Reduction

<table>
<thead>
<tr>
<th>Material Type</th>
<th>Total Weight of Mirror Support (tonnes)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Steel-based heliostat</td>
<td>1.5</td>
</tr>
<tr>
<td>Composite material-based heliostat</td>
<td>1.2</td>
</tr>
</tbody>
</table>

Honeycomb sandwich composite-based heliostat
Thank you