Low Cost Heliostat Development

SunShot

Concentrating Solar Power

Program Review

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Presentation Outline

- Project
  - Description
  - Objectives & Goals
  - Innovation
  - Key Results
  - Heliostat Size Analysis
  - Heliostat Development
    - Drive
    - Controls
    - Reflector
  - Future Work

Project Description

- Phase I
  - Develop the methodology to determine minimal heliostat cost as a function of size
  - Design & prototype novel aspects of the heliostat
    - Azimuth drive
    - Reflector
    - Heliostat Controller
- Phase II
  - Make a final determination for heliostat size
  - Design, fabricate, and test a novel heliostat of that size

Project Objectives & Goals

There are three primary objectives:

1. Develop the means for determining the optimal size of a heliostat in terms of applied forces, moments, manufacturing learning curve effects, O&M, and optical efficiency.
2. Use those means to determine the appropriate heliostat size for a typical Az/El heliostat to minimize cost
3. Develop and demonstrate the performance of a novel, low-cost heliostat

Innovation

- Demonstrating a Methodology for Determining a Minimal-Cost Heliostat which point to smaller heliostats than promoted over many years

- Eliminating field wiring with an “Autonomous” heliostat

- Reducing the effects of cumulative fatigue damage in drives

Key Results

- Minimal-cost heliostat size is more dependant on fixed cost items (e.g., heliostat controller) than previously anticipated.
- Impulse loads (controls, aerodynamic, wind gusts) over a typical heliostat lifetime can greatly affect structural time-to-failure. More attention to balancing low factors of safety to reduce initial cost and higher factors of safety for lower lifecycle cost may be required.
- Current low-cost RF and PV technologies allow heliostat field wiring to be eliminated.

Heliostat Size Analysis

- Heliostats of various sizes have been built since the early 1970’s
- Each overall solar plant architecture brings some generic and some specific requirements
- The general trend has been to build larger and larger heliostats up until a few years ago
- The goal of this task is to create a methodology to ascertain a heliostat size that minimizes cost for a generic 100MW_e baseload central receiver plant

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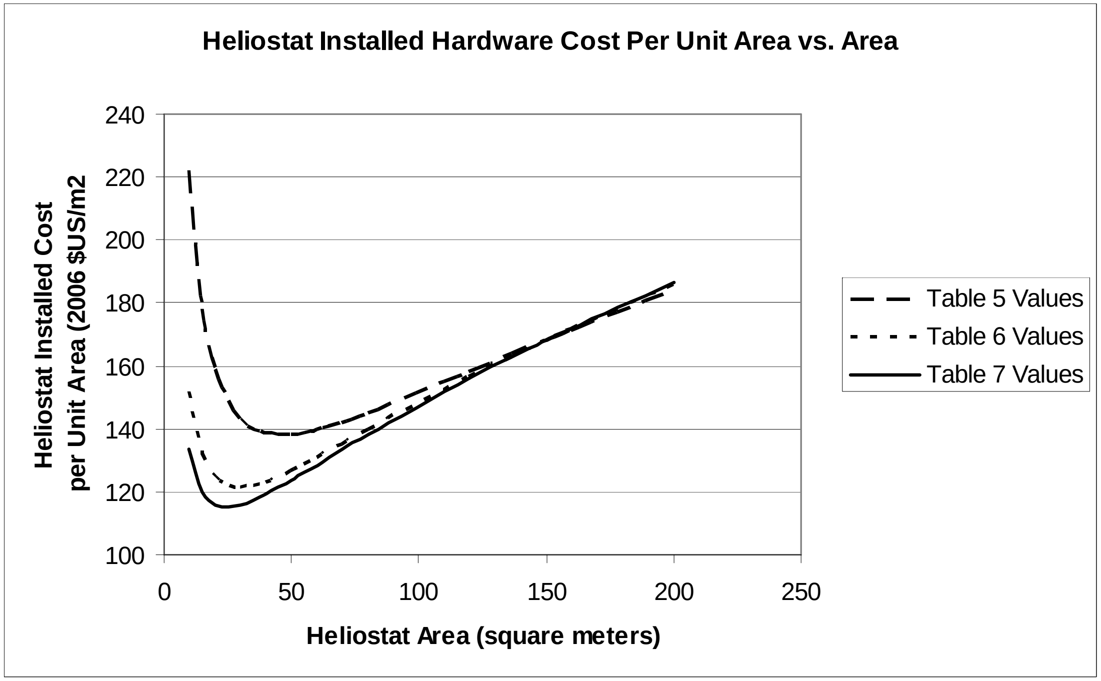
Analysis Approach

- Start by using previous studies and existing data that are recast into a few cost categories
  1. Hardware with costs that vary linearly with area (e.g., mirrors)
  2. Hardware with costs that vary with the three-halves power law (e.g., structure)
  3. Hardware with fixed costs no matter the heliostat size (e.g., control items)
  4. Hardware that does not neatly fit into one of the other categories (e.g., field wiring) - Optional
- Once the various heliostat elements are assigned to their category, and costs are determined as a function of area, calculate a cost for various heliostat sizes

Initial Results

- Use cost data from the Sandia Heliostat Cost Reduction Study (June 2007)
- Recast the published costs into the three cost categories
- Create the cost equations as a function of area so that the cost per unit area is $167.50 for a 148m^2 heliostat
- Create an installed cost per unit area curve versus heliostat area
- Reallocate costs between categories and calculate changes



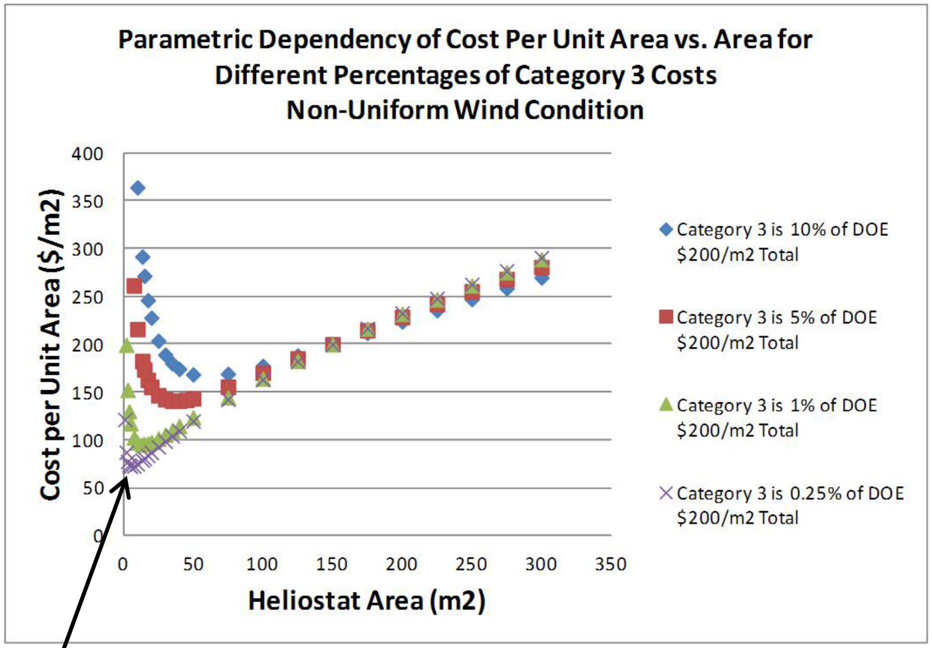
Initial Minimum Calculated at 20-40m^2

Latest Results

- Parametric approach uses the three basic cost categories
- Determines total field cost as a fixed cost and a cost that varies with the number of heliostats:

  $C_T(N) = F + BN$.
- Determines heliostat cost (B) in terms of fixed cost and costs that are a function of loads.

  $B = f + kA_H^{3/2}$
- Fundamental relationships of costs can be examined without detailed information on component costs, using a total cost per unit area for a given design (e.g., baseline $\$200/m^2$ for 150 m^2).
- Provides insight into area dependence and how reducing Category 3 costs can help achieve lower overall heliostat costs



Shows effect of reducing fixed heliostat costs

Minimum near $10m^2$ with "low" heliostat controller costs

Heliostat Size Analysis Publications

1. Text published late 2012:

   Lovegrove, Keith and Wes Stein, *Concentrating solar power technology - Principles, developments and applications.* 2012. Woodhead Publishing Series in Energy No. 21.

   Chapter 17 presents size analysis based on openly available cost data

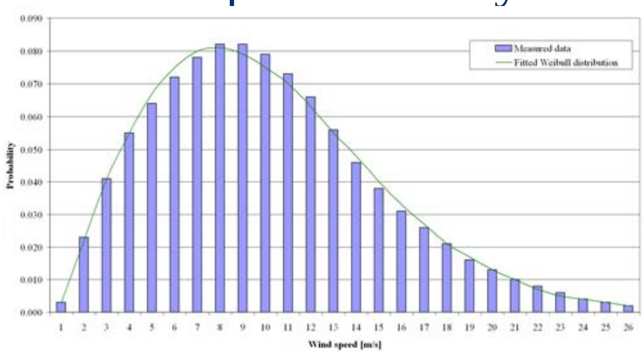
2. SubmittedTechnical Paper to ISES Journal, *Solar Energy*:

   Parametric Determination of Heliostat Minimum Cost Per Unit Area

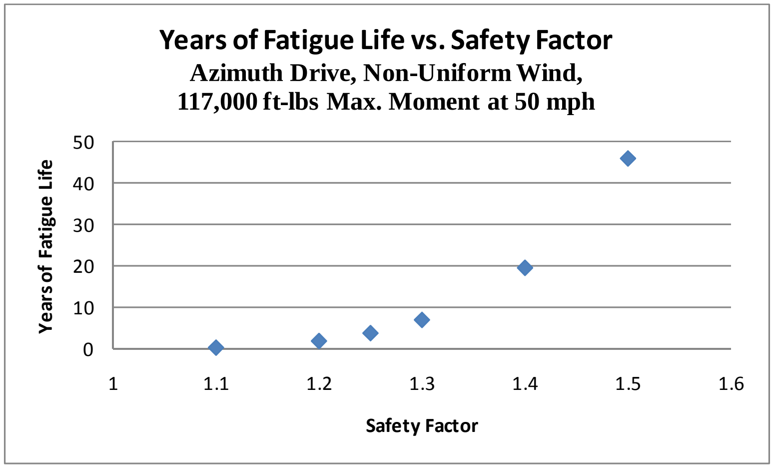
Heliostat Development - Drive

Dynamic Loading Issues

- Utilized a new approach that relates cumulative fatigue damage to wind loads using the Weibull distribution of wind speed for a given site
- This shows that low design safety factors will not achieve 30 year life.
- The analysis determines fatigue life for quasi-static loads as a function of design safety factor and will thus aid in designing heliostats with improved life cycle costs.



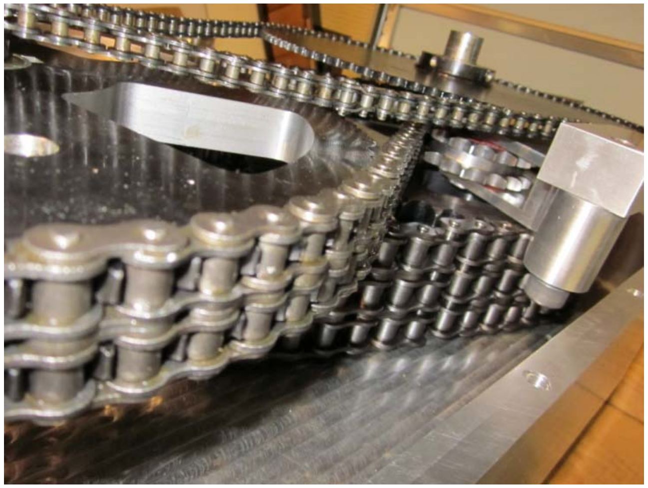
Wind Speed Distribution (Iuga, European Wind Energy Data)



Heliostat Development - Drive

Dynamic Loading Issues

- Showed that dynamic coupling with conventional heliostats having relatively low damping coefficients (e.g., of the order of 0.1), are severe, with these loads about 5 to 7 times higher than the static loads.
- The azimuth chain drive used in our heliostats has inherent "soft" loading from the chain tensioners.
- This lends itself to new designs that reduce the load and allow the damping coefficient to be "tuned" with a classical spring-damper approach



The HiTek 27m^2 3-Stage Azimuth Chain Drive

Heliostat Development - Controls

- Phase I analysis and prototyping results pointed toward the autonomous controller as feasible and lower in overall cost
- Two pathways are being developed
  - Baseline – PV, battery, RF communication, rotary encoders, motors, and power management designed in from the start to minimize PV and battery size
  - Advanced – PV, battery, and motors with the aim to eliminate much of the conventional control and wireless communications electronics

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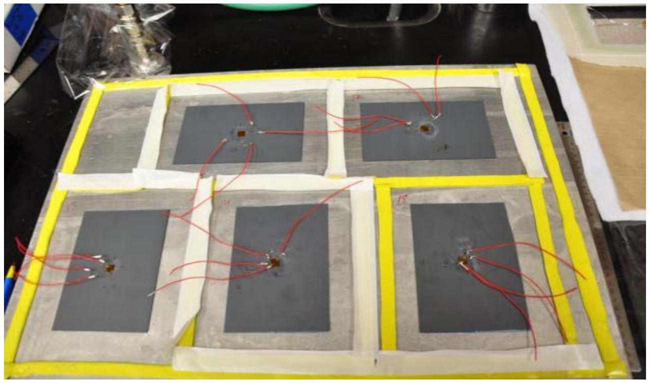
Heliostat Development - Reflector

- The concept was to fabricate an integrated mirror/mirror support structure that loaded a thin glass mirror in compression to allow for less mirror support structure. We first demonstrated the concept around 2000.

- Instrumented coupons with newly available resins showed residual compressive loads over 10ksi in 1mm thick glass
- While technically successful, the composite structure costs were ultimately too high for a "low-cost" solution
- The fall back position is to go back to a conventional metal/glass arrangement



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Phase 2 - Future Work

- Design, Fabricate & Test the Baseline Drive System
- Design, Fabricate & Test an Azimuth Chain Drive with Enhanced Impulse Damping
- Design, Fabricate & Test the Autonomous Heliostat Controller
- Integrate a complete prototype heliostat
- Perform on-sun tracking tests and document performance