Stirling Energy Systems, Inc.

Solar Dish Stirling Systems Report

For NREL CSP Technology Workshop

March 7, 2007

Creating a

brighter future

for humanity through

SOLAR ENERGY

Stirling Energy Systems, Inc. SES

Agenda

- ✓ Technology Overview
- ✓ Current Test & Development Program
- ✓ Major Deployment Plans
- ✓ How DOE Can Help

Technology Overview

Model Power Plant Video

Stirling Energy Systems, Inc. SES

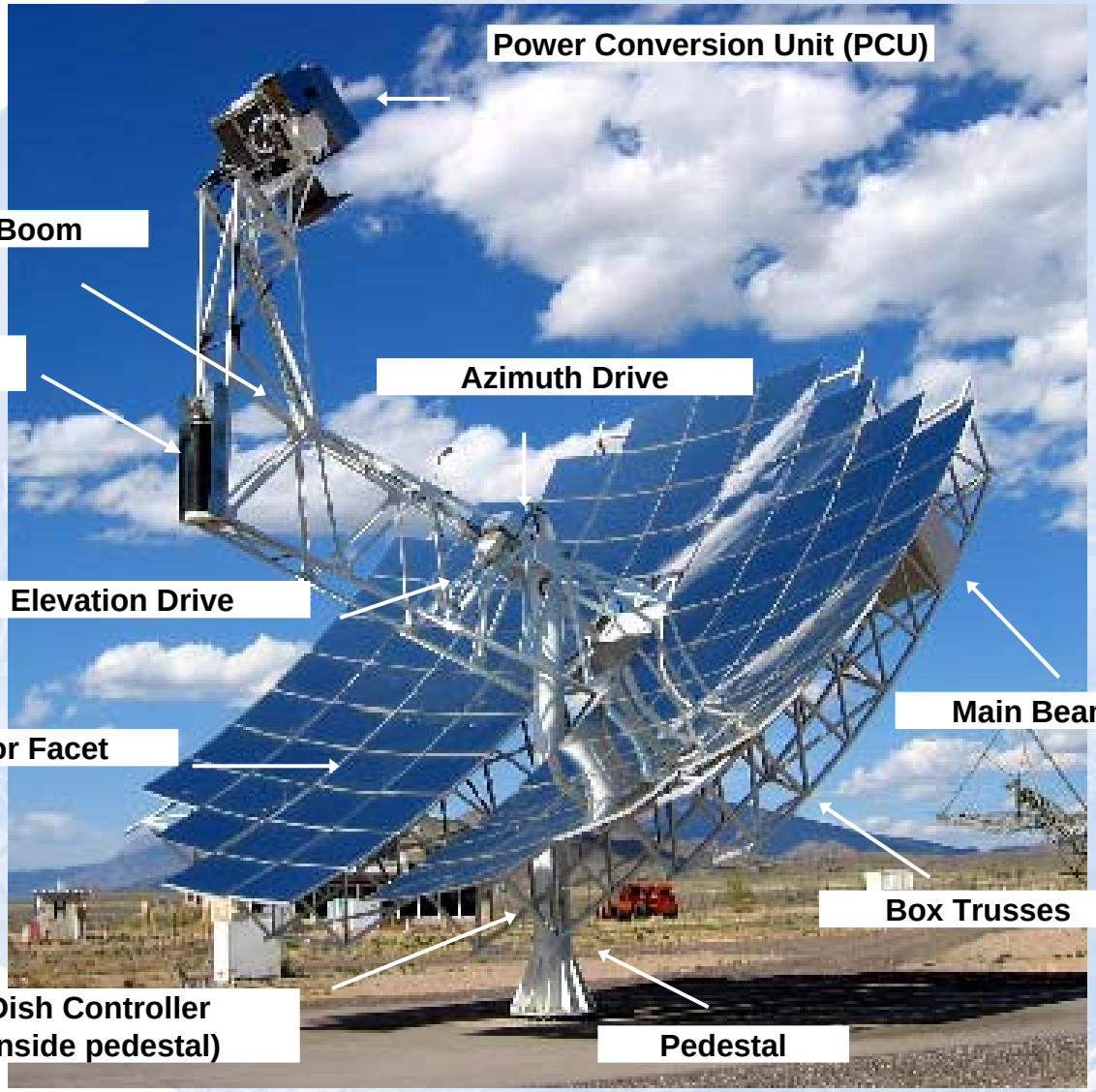
Click frame to start video

Solar Tracking

Stirling Energy Systems, Inc. SES

SES Solar Dish Assembly

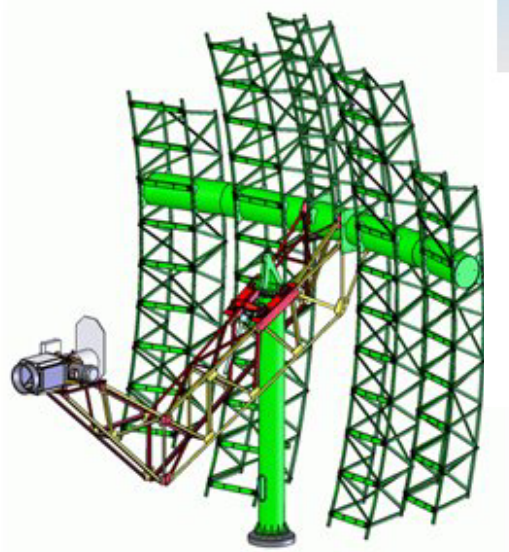
Stirling Energy Systems, Inc. SES

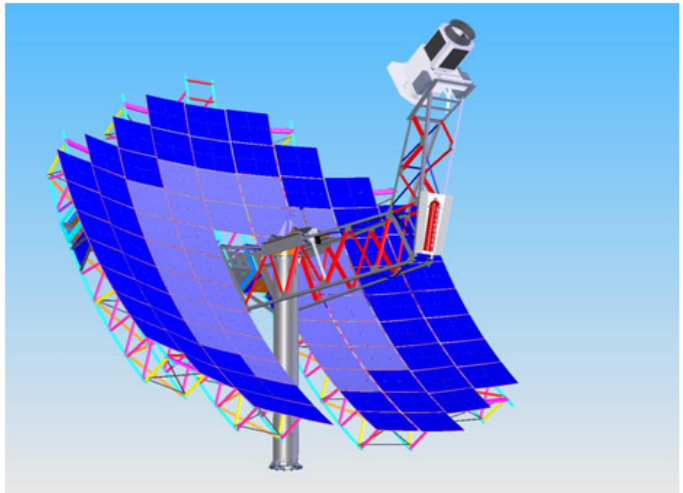


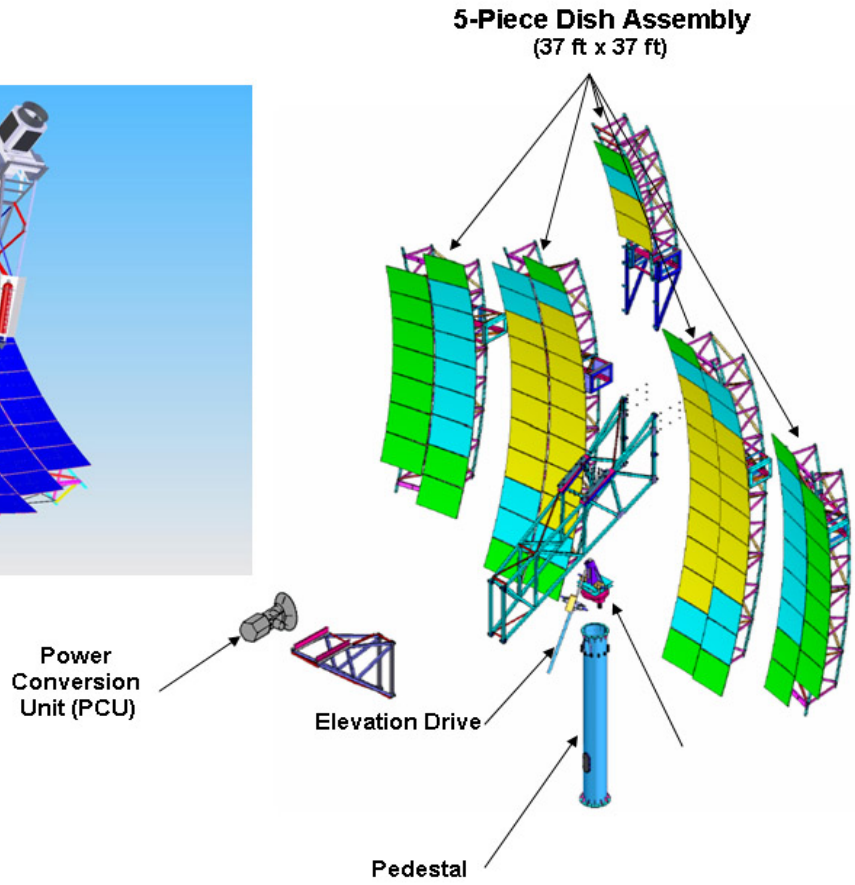
The SES Solar Dish Assembly

Stirling Energy Systems, Inc. SES

SunCatcher is modular for ease of assembly and maintenance

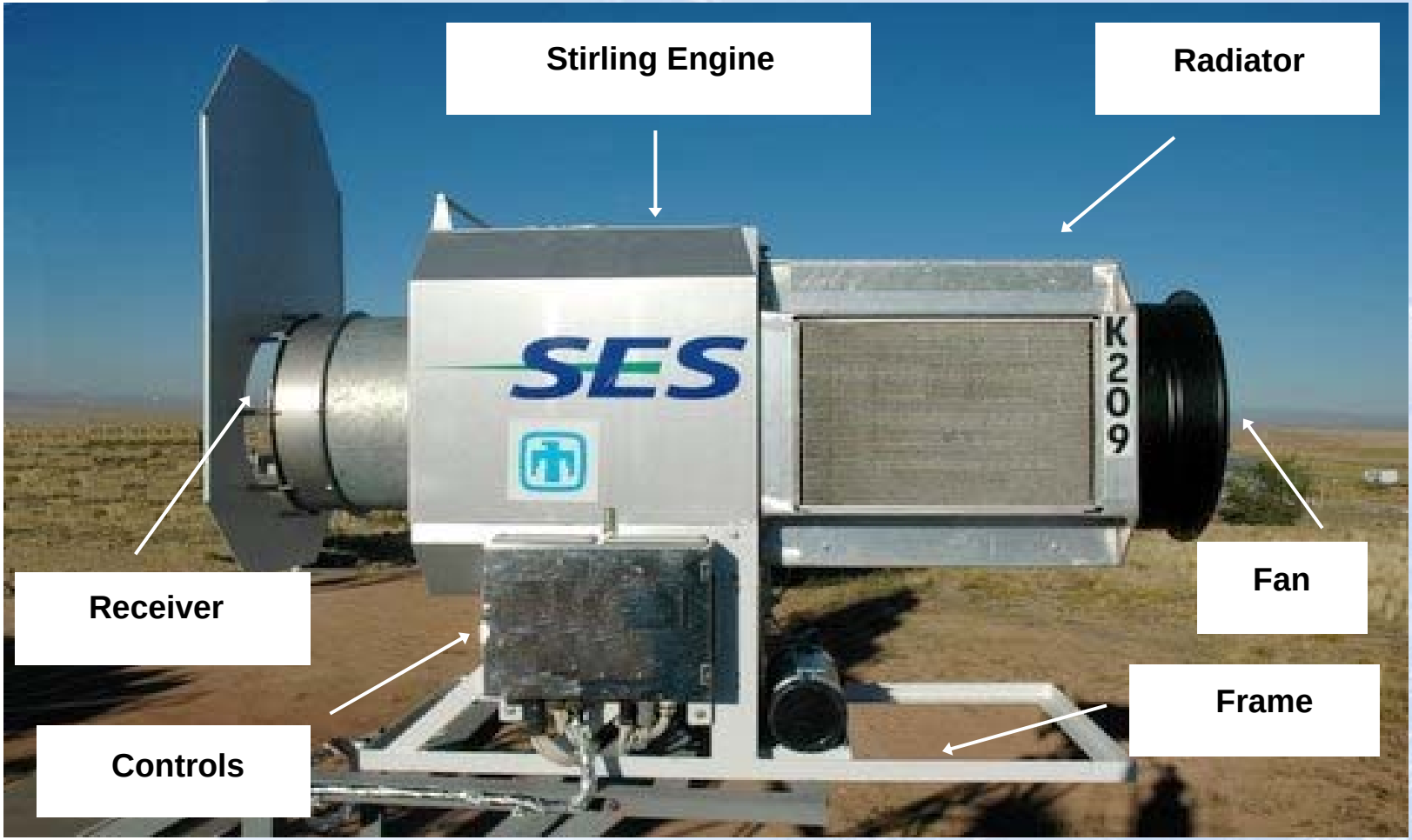






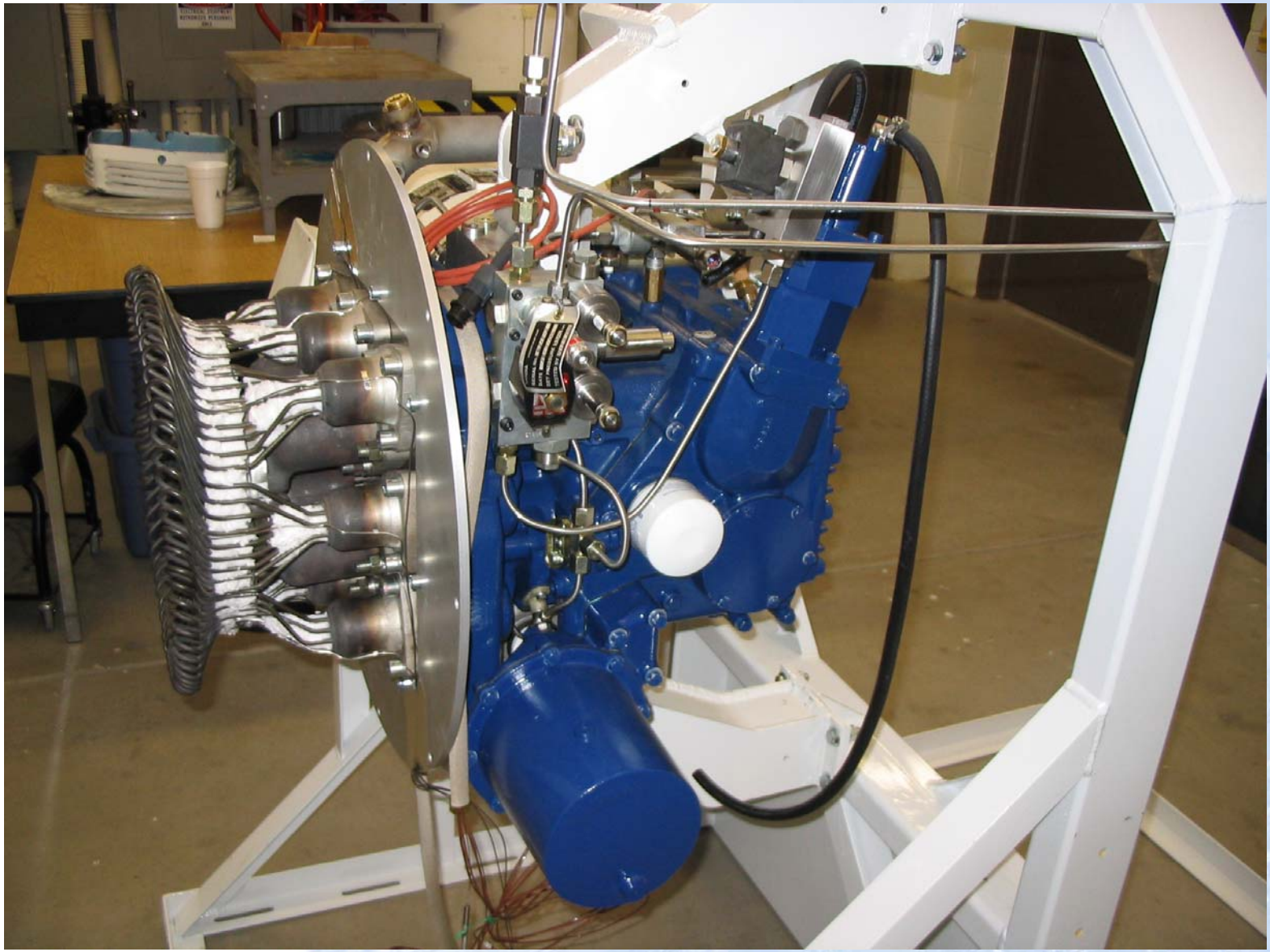
Power Conversion Unit (PCU)

Stirling Energy Systems, Inc. SES



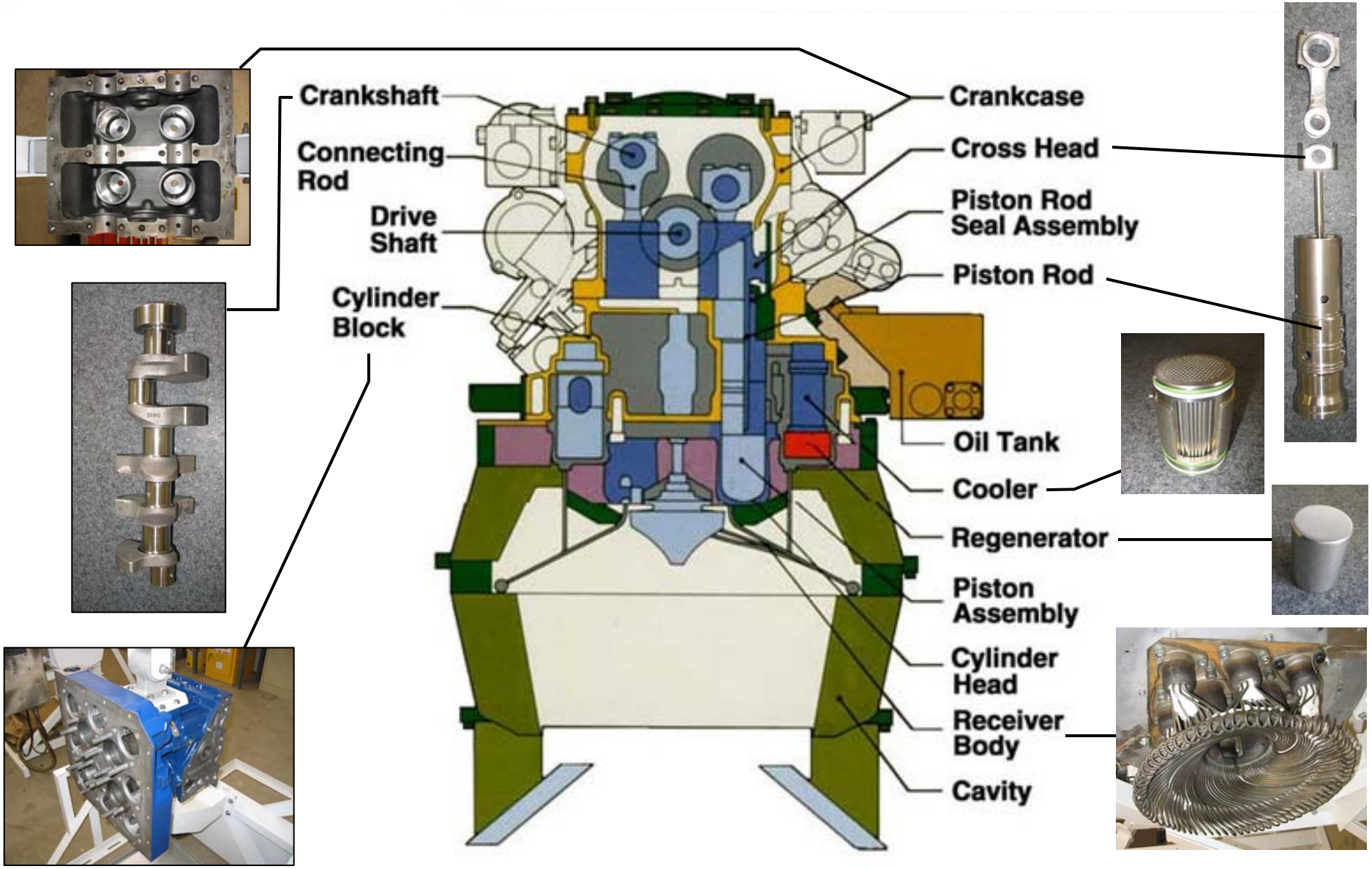
Stirling Engine

Stirling Energy Systems, Inc. SES



Stirling Engine Schematic

Stirling Energy Systems, Inc. SES



Dish Controls Enclosure

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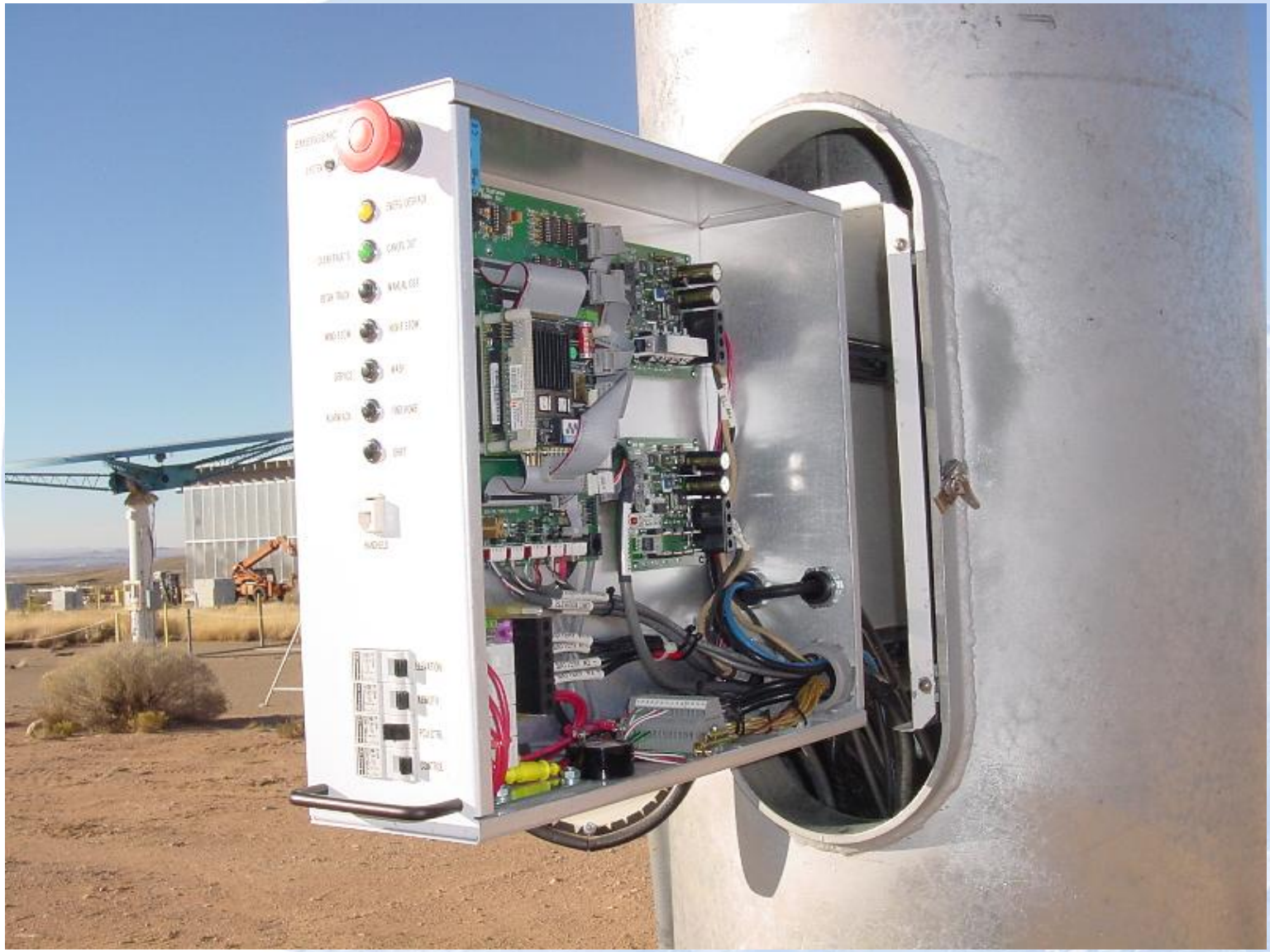

Current Test & Development Program

Pathway to Commercialization

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Past… Today
"Technology"

"PATHWAY"

"Bridging the Gap"

"Commercialization"

Starting Point

- ✓ 20 Year History
- ✓ Development units
  - HB, NV, SA, SNL
- ✓ Model Power Plant
  - 6 Systems
  - SES Supply Chain

Commercialization Program

- ✓ Product Commercialization
- ✓ Supply Chain Development
- ✓ Development Projects
  - Model Power Plant
  - 1 MW Pilot Project
- ✓ Company Infrastructure

Goals

- ✓ US & International Markets
- ✓ Supply Chain—US Based with Global Reach
- ✓ Ultra-Low Cost Systems
- ✓ High Volume Manufacturing
- ✓ Advanced Systems

Commercialization Program is the pathway to fulfilling production contracts

SES Model Power Plant Operating at Sandia

Stirling Energy Systems, Inc. SES

- ✓ Located at the NSTTF
- ✓ Proving Ground & Showcase
- ✓ On-Going System Testing
  - Performance
  - Reliability
  - Systems Integration
- ✓ SES and Sandia Scientists & Engineers Teamed Together

MPP – A Slice Out of Large-Scale Solar Plant

Site Has Been Visited By Some VIPs

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Sec. Bodman told us how impressed he was to see tangible results from all the years of DOE spending – “the key now is to get this technology deployed”.

Proven Technology

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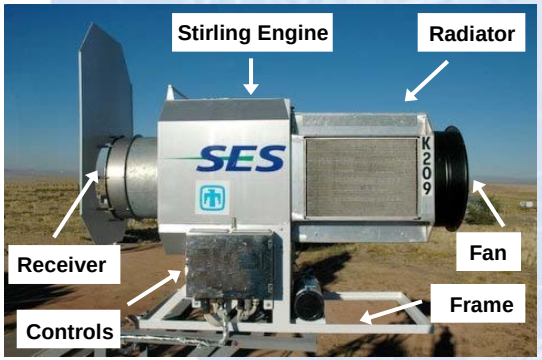
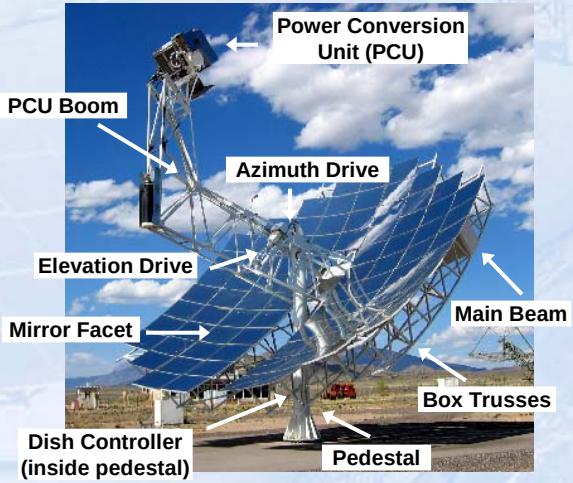
- ✓ Developed by leading solar industry pioneers: Kockums, McDonnell Douglas, Southern California Edison, the Department of Energy, and Sandia National Laboratories
- ✓ Proven track record of 20+ years of R&D and testing at a total cost of over $400 million
- ✓ World's most efficient solar generation technology: converting sunlight into grid-quality electricity

Operating History

Power Conversion Unit:
161,000 hrs On-Sun & Test Cell



Dish Concentrator:
100,000 hrs On-Sun



Complete System:
36,000 hrs On-Sun

Equivalent Daily Solar Operation:

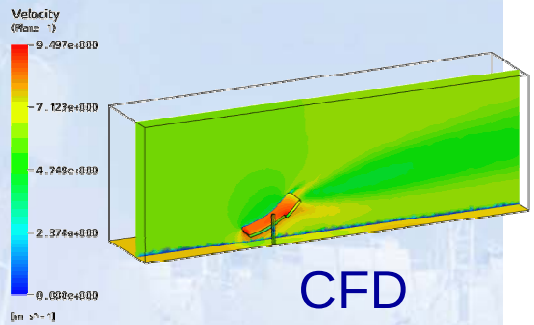
45 years ***28 years*** ***10 years***

SES And Sandia Have Developed And Used A Number of Powerful Analytical Tools This Past Year

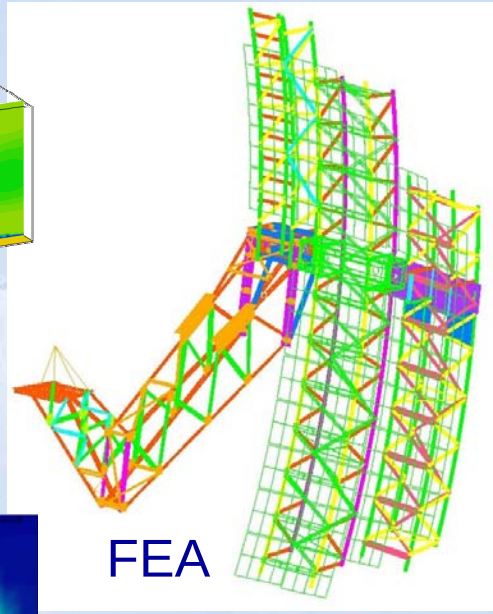
Design Tools

Stirling Energy Systems, Inc. SES

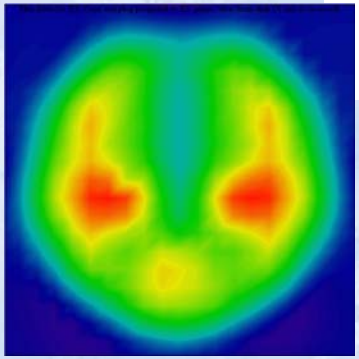
- ✓ **Systems Design Tool**
  - CFD Wind load model
  - FEA structural model
  - CIRCE2 optical model
  - MathCad user interface
- ✓ **Provides Structural Designer with True Metric**
  - Deflection impact on flux distribution
- ✓ **Results**
  - Close to 4,000 pound weight reduction
  - Stiffer net structure
  - Understanding of residual deflections
- ✓ **Empirical Validation of Tools**
  - Fluxmapper
  - Deflection measurements



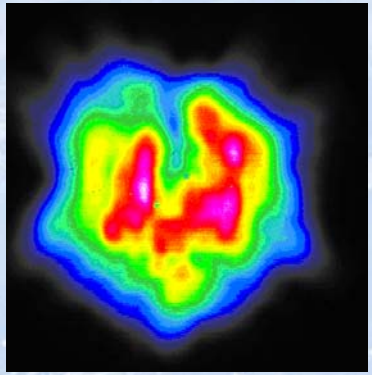
CFD



FEA



CIRCE



Flux Mapper

Systems Design Tools

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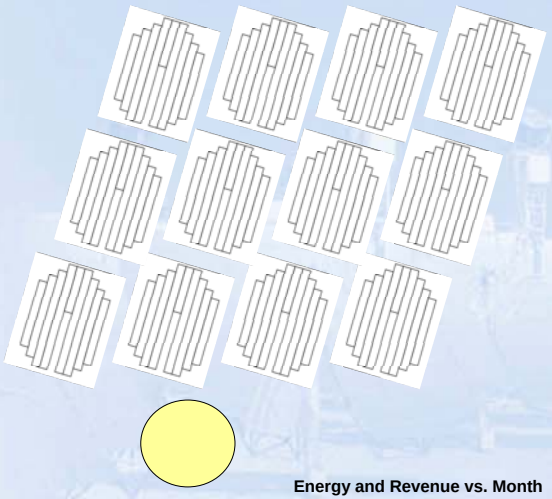
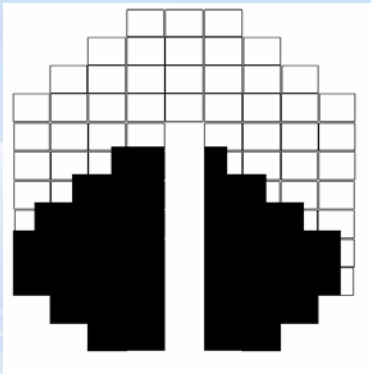
- ✓ **Field Layout Optimization**

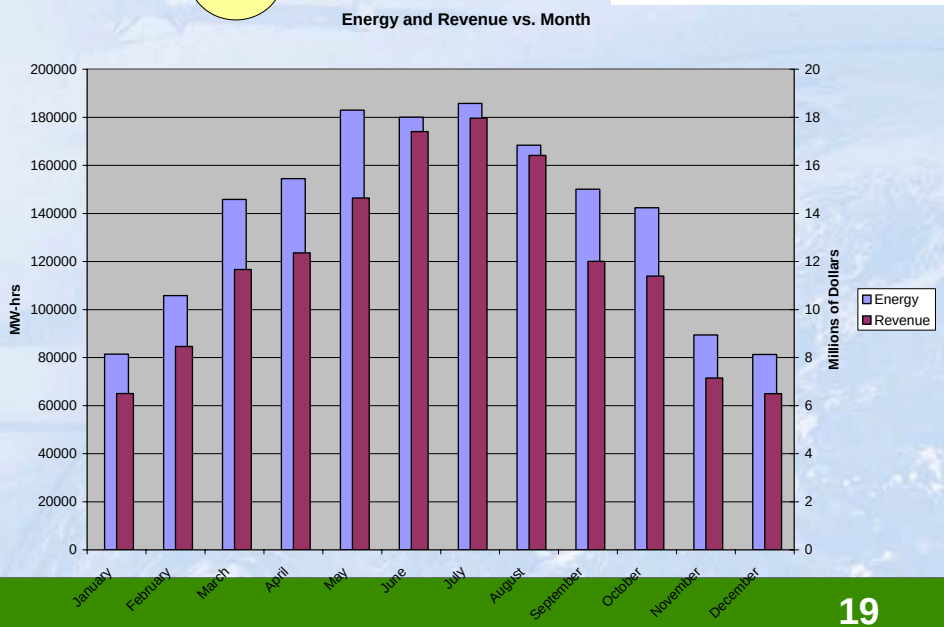
- ✓ **New Features**
  - Row stagger
  - TOD and TOY electricity value
  - Edge effects

- ✓ **Shading Model**
  - True dish shape
  - Incorporates real shading performance degradation
  - Input TMY2 or 15-minute Solar 2 data

- ✓ **Results**
  - Shade shape validated with hardware
  - Stagger notably detrimental







Dish Alignment Tools

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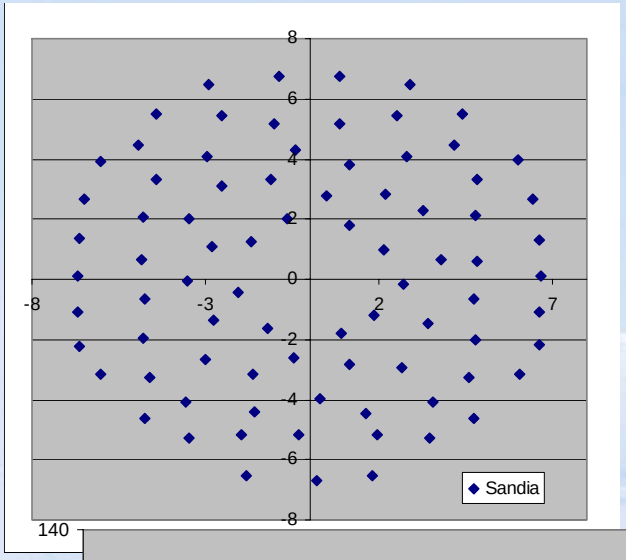
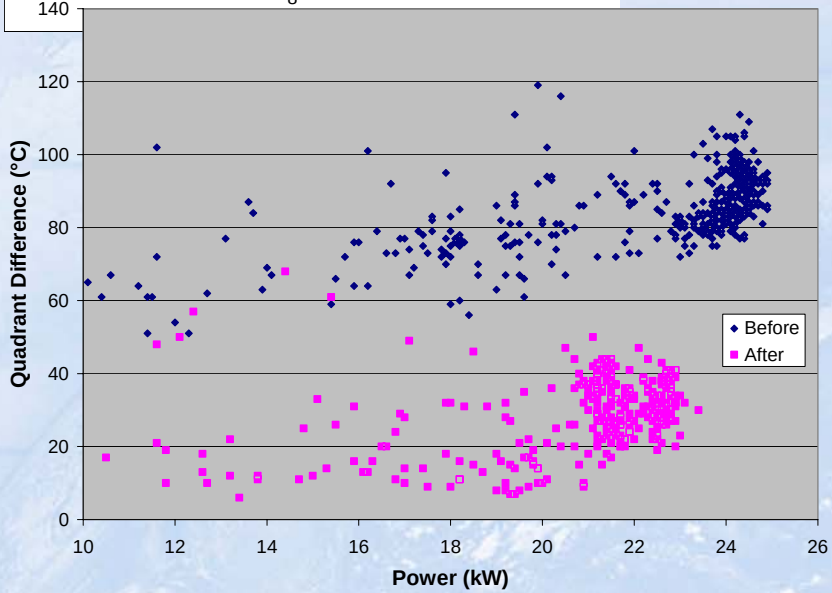
- ✓ **Approach**
  - Optimize aimpoint using molecular dynamics-like code
  - Avoid compromising aperture
- ✓ **Results**
  - Power improvement
    - Increase output even without new aperture installed
    - 1 to 1.5 percentage points performance improvement
    - No additional cost
  - Uniformity
    - Reduced quadrant difference from near 100C to 20C
    - Increases operating "headroom"
  - Aperture effects
    - Aperture 7.5" diameter, compared to MDAC at 9.5"
    - Expect 0.5kW$_e$ additional output

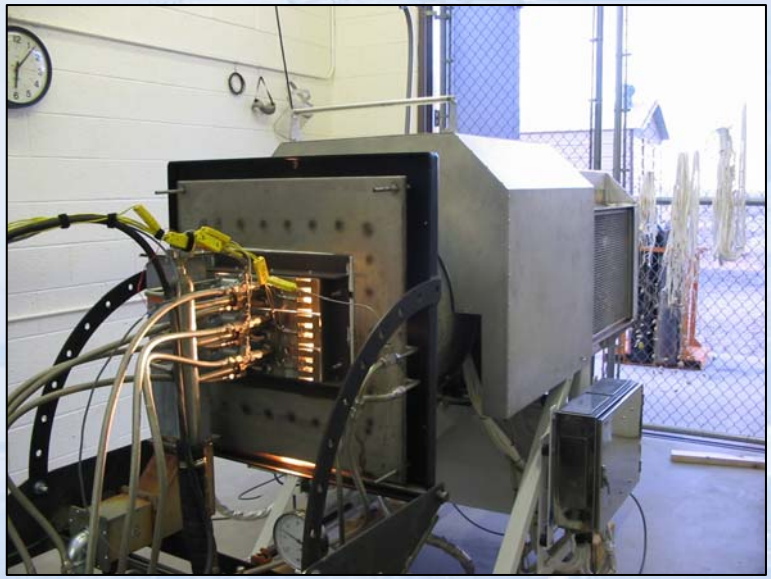




Development Facilities

Stirling Energy Systems, Inc. SES

- ✓ Model Power Plant – Sandia Site
- ✓ Engine Test Facility
  - Assembly and documentation development
  - Lamp bank testing (short term)
  - Gas fired testing (long term cyclic)
- ✓ Electronics Lab: SES Controls Simulator
  - Critical to next-generation software development
- ✓ Sandia National Laboratories
  - Materials
  - Manufacturing
  - Failure analysis
  - Lightening protection
  - Facilities



FRACAS Implementation Underway

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Failure Reporting Analysis and Corrective Action System

XFRACAS Also Includes..

- ✓ Tracking of part repair/replacement and serialized system configuration management
- ✓ Integration with reliability analysis engines including part life calculations, system reliability and reliability growth analyses
- ✓ Interactive graphical interface.
- ✓ Web-based- easy access, collaboration and deployment to multiple sites.
- ✓ Reliability data/history repository
- ✓ Framework for FMEA and failure analysis.
- ✓ Flexible and scalable enterprise system.

CFD Modeling of Multi-Dish Array

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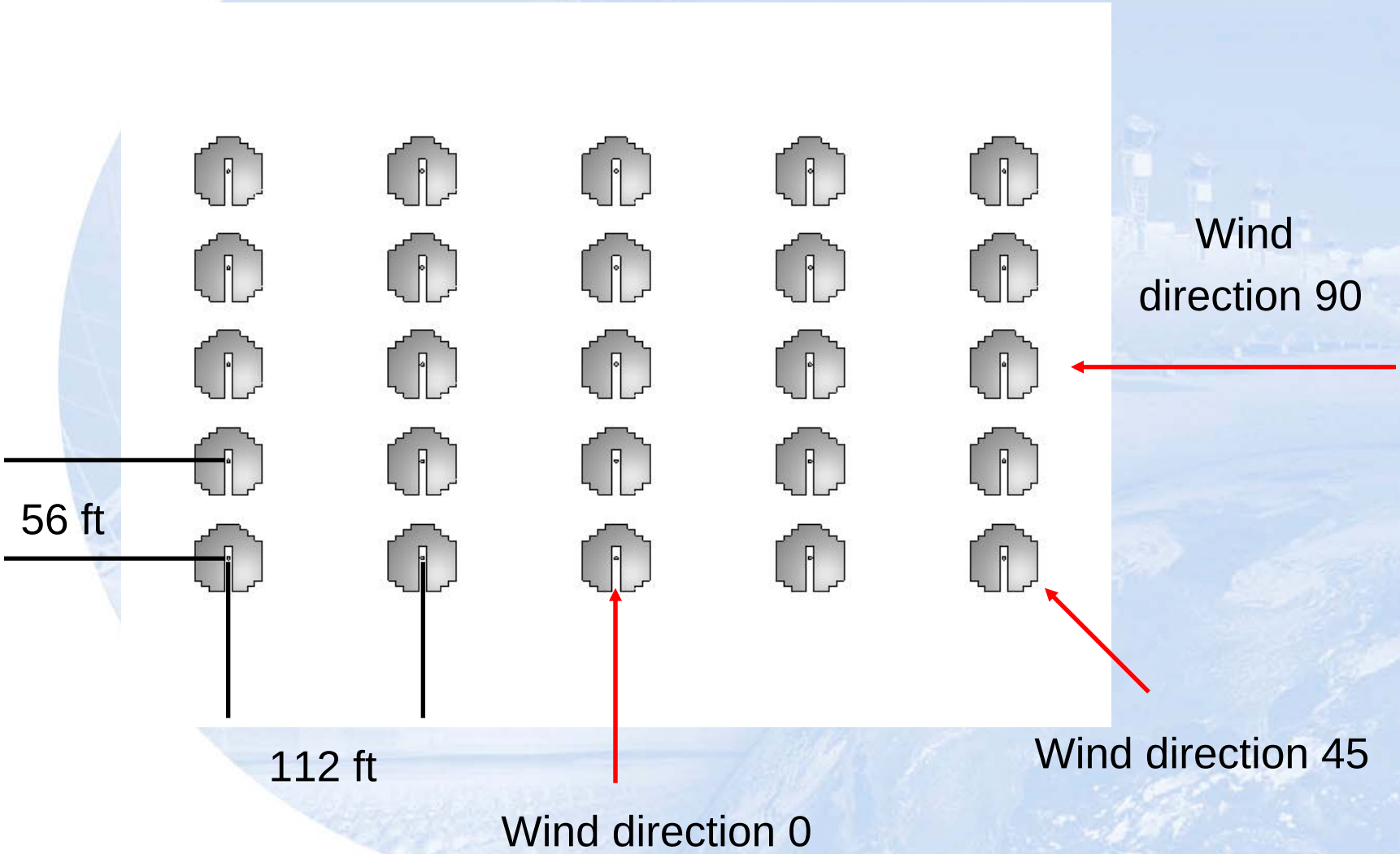
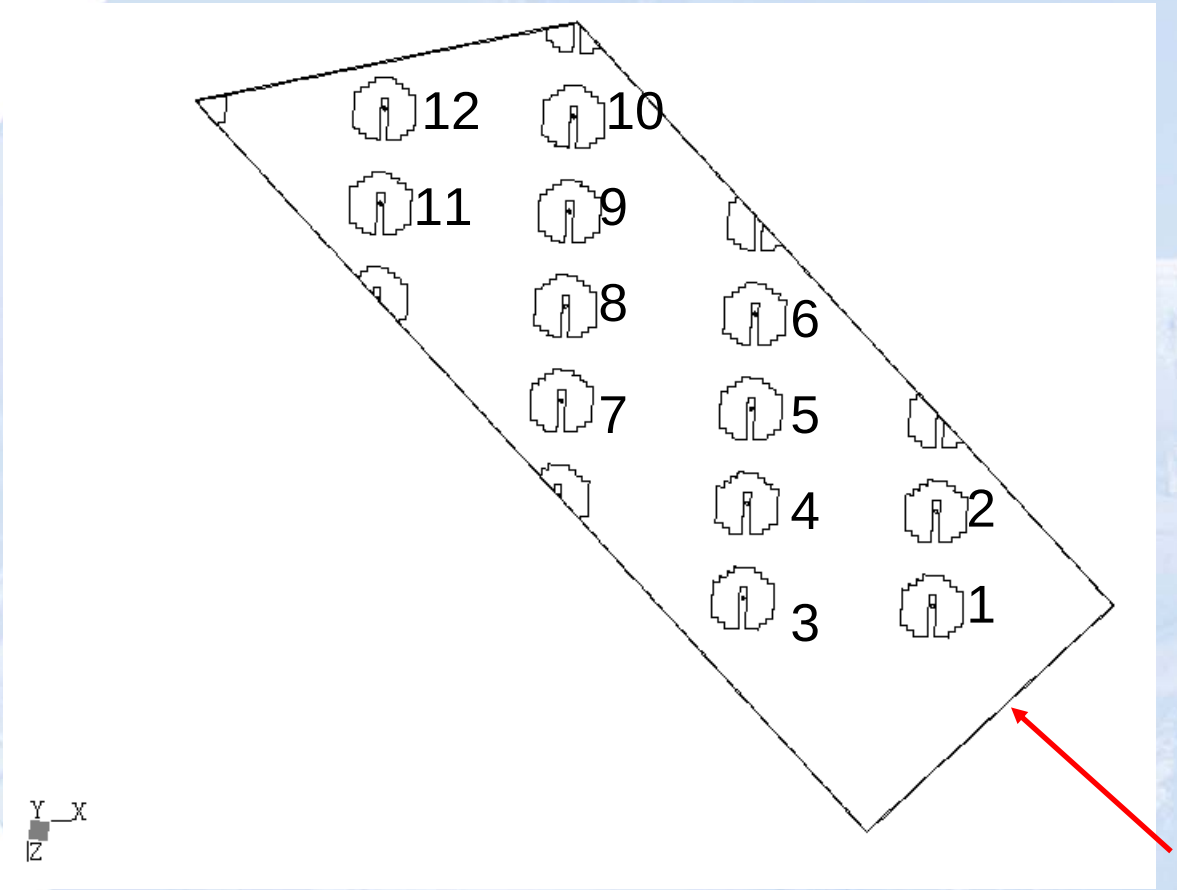
Top View of the 5-by-5 Field



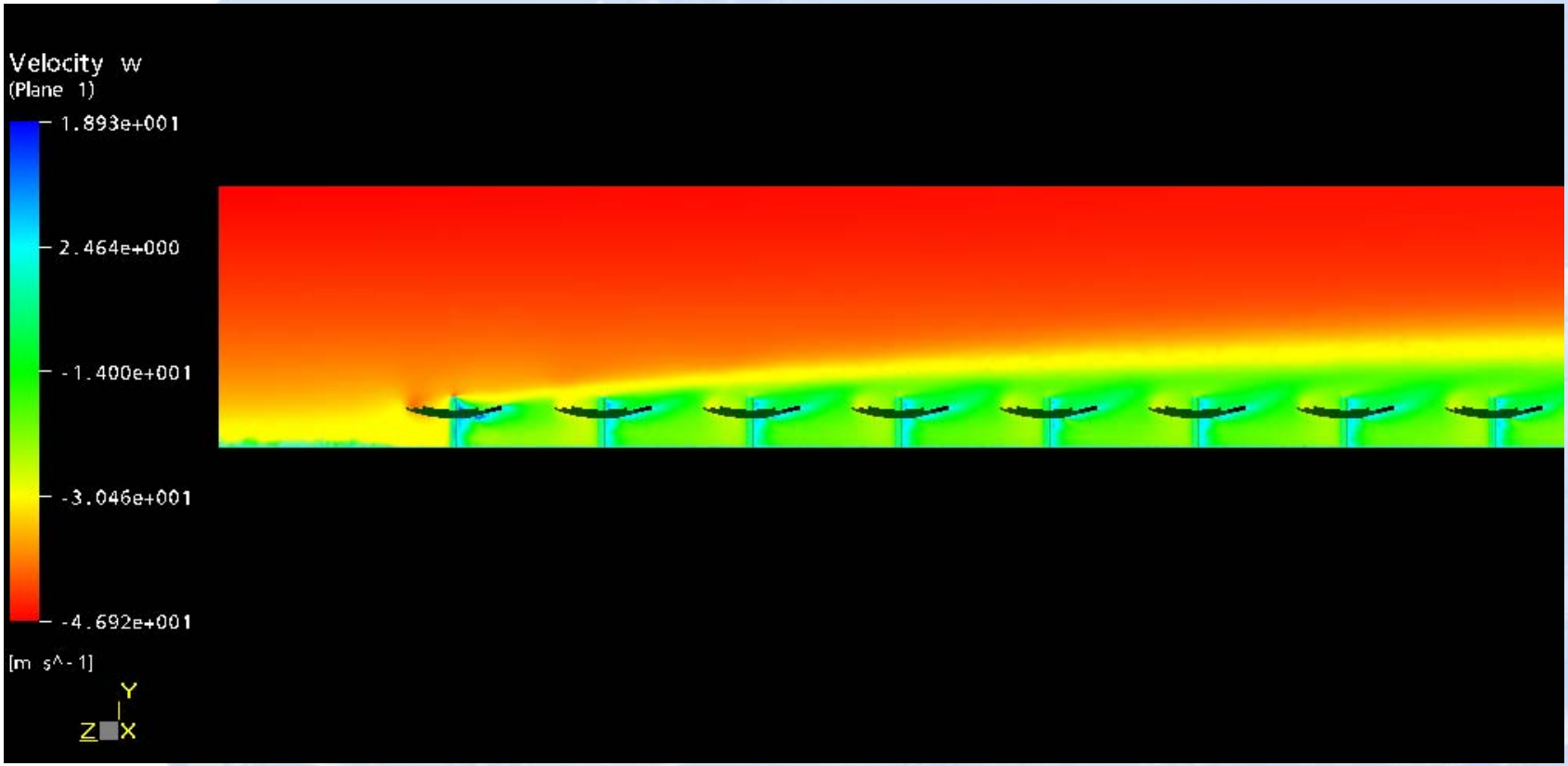
CFD Model and Dish Numbering For 45 Degrees Wind Direction



Flow direction

Symmetry condition imposed on the side boundaries

Flowfield Development, 0 Degree Wind Direction

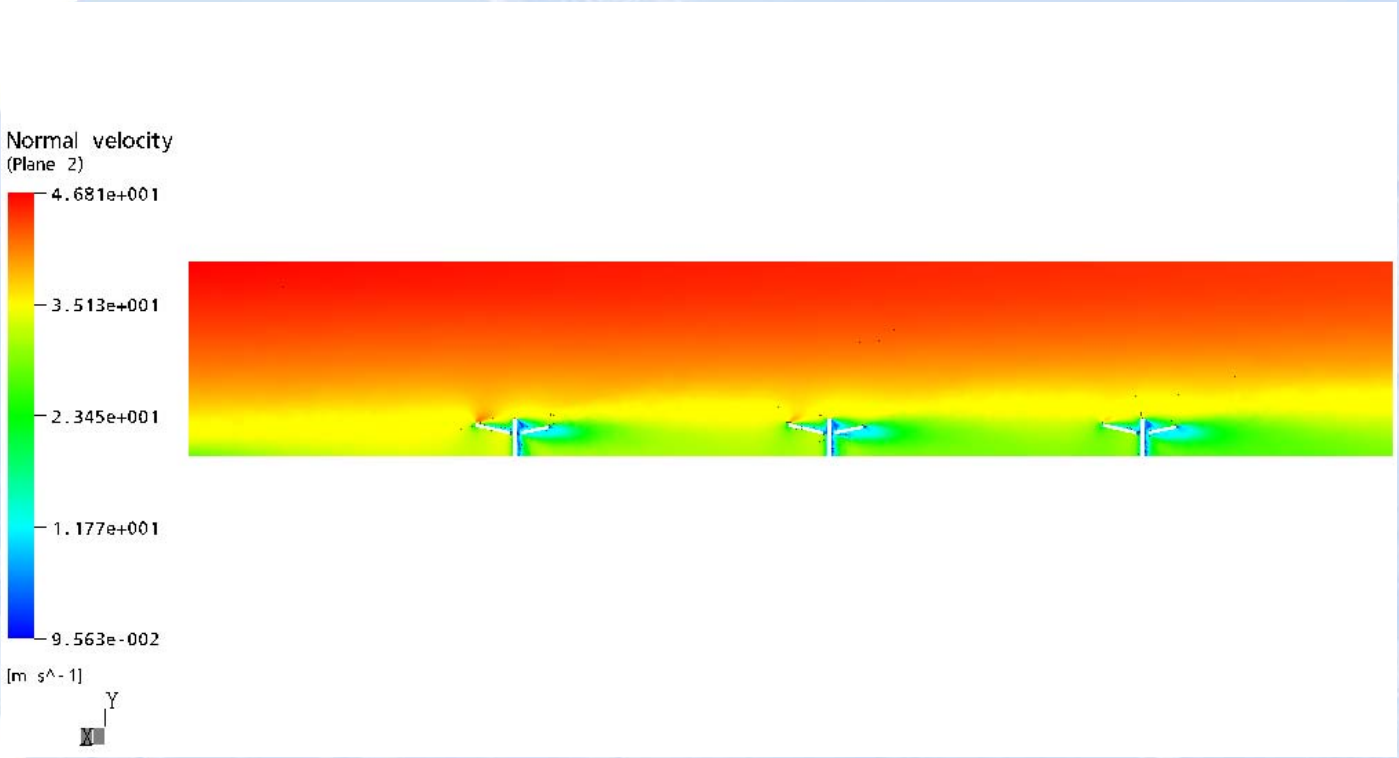


Notice that only the first dish is affected by the full wind load and the remaining dishes only encounter the wake flow of the first dish.

Flowfield Development, 45 Degrees Wind Direction

Stirling Energy Systems, Inc. SES

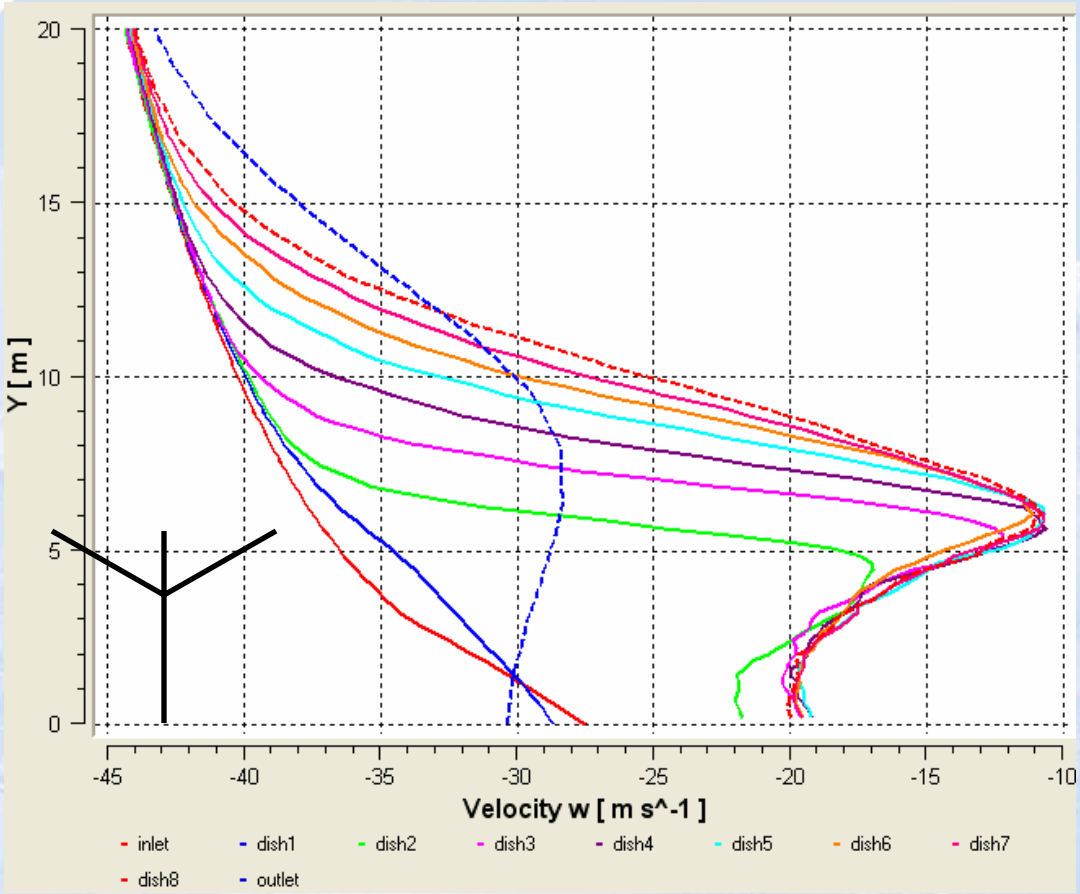
Flow at the plane of dishes 1, 5, and 9



Note that only the first row is affected by the full wind load. The edge of the wake is very close to the remaining dishes leading to higher loading than in previous cases.

Velocity Profiles, 0 Degree Wind Direction

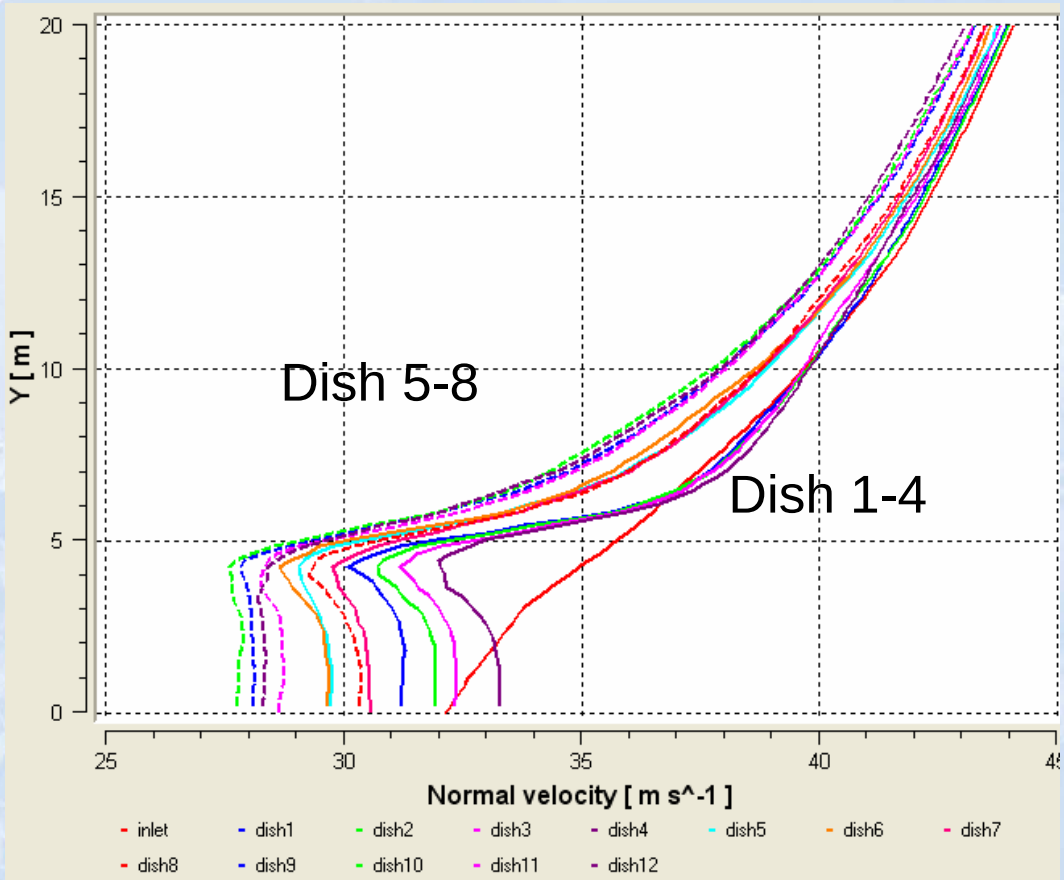
Stirling Energy Systems, Inc. SES



Note that the velocity profiles for dishes 3-8 are very similar, i.e. the boundary effect is limited to the first two rows

Velocity Profiles – 45 Degrees Wind Direction

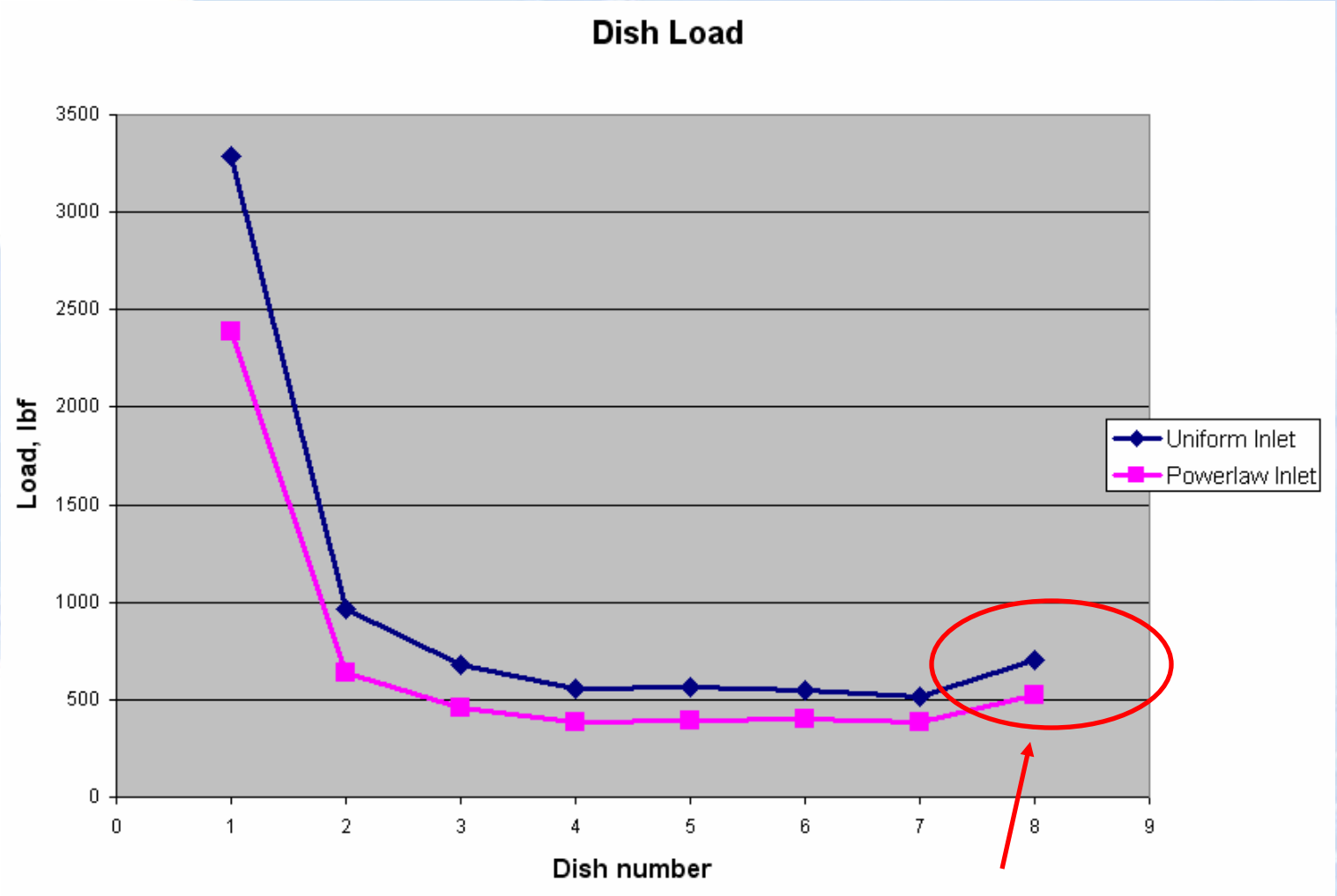
Stirling Energy Systems, Inc. SES



Exposed dishes (1-4) show slightly higher speeds than protected dishes (5-12)
Dish 4 however shows the highest speed due to venturi effect.

Mirror Loading, 0 Degree Wind Direction

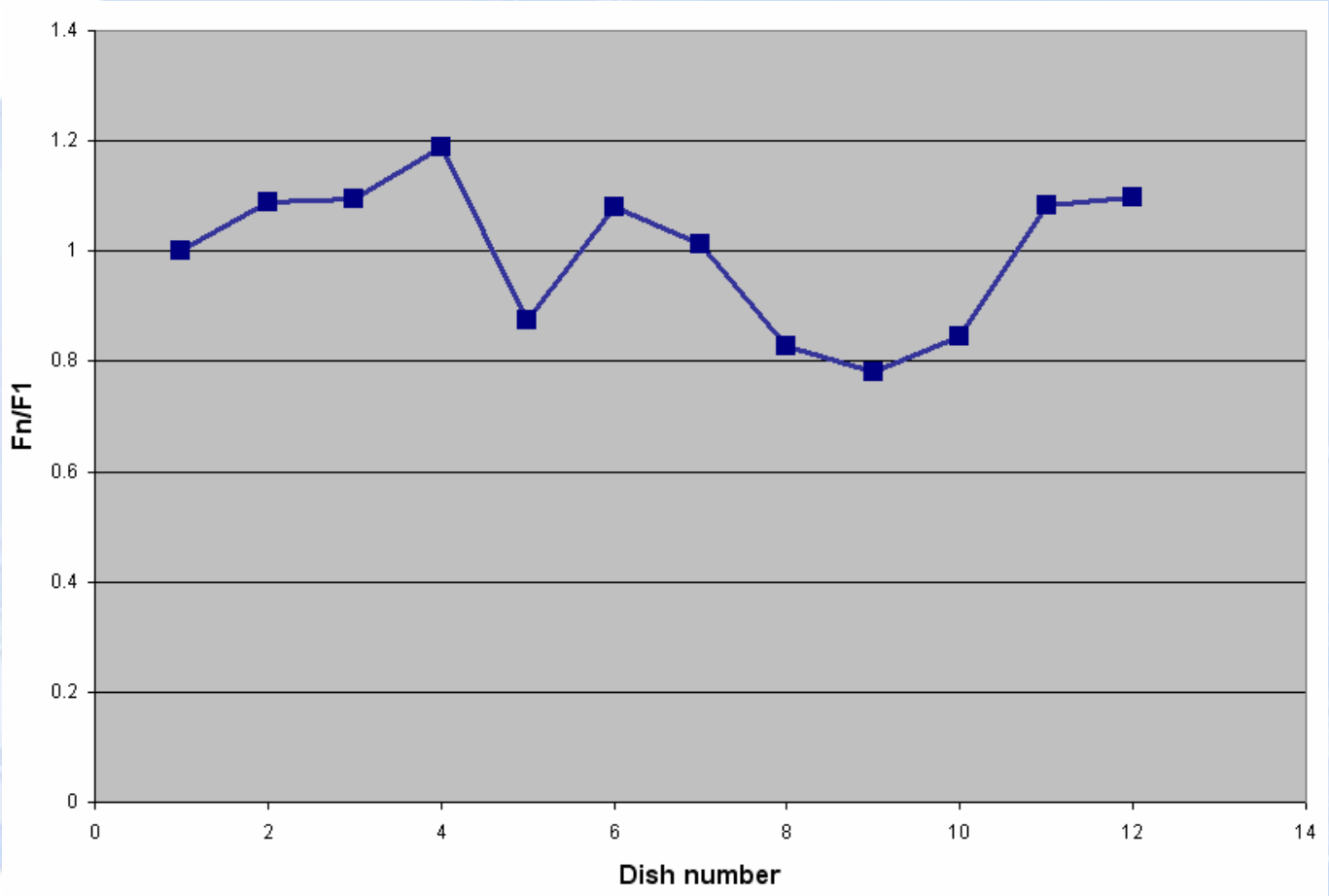
Stirling Energy Systems, Inc. SES



Increase in load due to unobstructed wake

Mirror Loading – 45 Degrees Wind Direction

Stirling Energy Systems, Inc. SES



Mirror loading on the interior dishes is not reduced

Major Deployment Plans

Two Major Solar Contracts Under Development

Stirling Energy Systems, Inc. SES

- ✓ For Up To 1,750 MW Of Peak Capacity
- ✓ Both Projects In Southern California
- ✓ One With Southern California Edison (SCE)
- ✓ Other With San Diego Gas & Electric (SDG&E)
- ✓ Details On Next Slides …

SCE Contract Overview

Stirling Energy Systems, Inc. SES

- ✓ Capacity = 500 MW with Expansion Option to 850 MW
- ✓ 20,000 – 34,000 Solar Dish Stirling Systems
- ✓ 20-Year Power Purchase Agreement
- ✓ Sited in the Mojave Desert East of Barstow
- ✓ Construction Scheduled for 2009-12 or 14

SDG&E Contract Overview

Stirling Energy Systems, Inc. SES

- ✓ Capacity = 300 MW with Options to 900 MW
- ✓ 12,000 – 36,000 Solar Dish Stirling Systems
- ✓ 10% of Total Load and 25% Of Peak Load
- ✓ 20-Year Power Purchase Agreement
- ✓ Sited in the Imperial Valley near El Centro
- ✓ Construction Scheduled for 2008 - 2014

Solar Generating Facility

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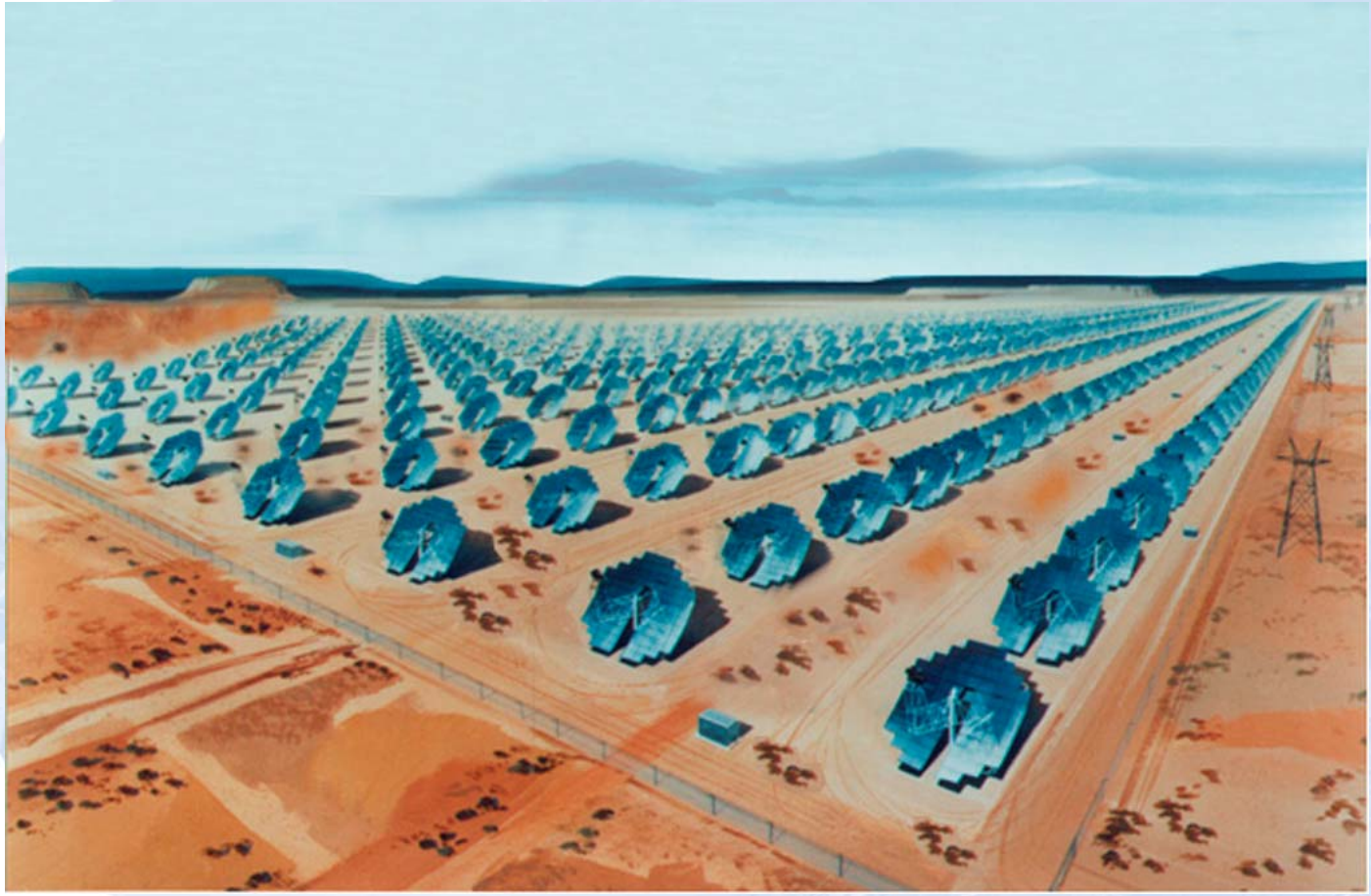

How DOE Can Help

Opportunity for Big Success

Stirling Energy Systems, Inc. SES

- ✓ After Investing Hundreds of Millions of Dollars in R&D, Opportunity Now To Focus on Second "D" in R D & D
- ✓ The Next 2 Years Are Key
  - Substantial Efforts Necessary To Transition To HVM
  - Every Change, No Matter How Small, Requires Careful Engineering and Systems Analysis – and Testing
- ✓ The SNL/SES Teaming Model Has Been Very Effective
  - Makes Maximum Use Of DOE Dollars
  - Utilizes the NSTTF For The Purpose It Was Designed For -- Solar Thermal Testing

The MPP at SNL Is Our Principal Laboratory

Expanding the SNL/SES Teaming Effort Helps Ensure Success

Stirling Energy Systems, Inc. SES

- ✓ SES Continues To Expand Its Engineering Team Dramatically, Both At SNL and in Phoenix and California
- ✓ SES Will Be Adding 2 New-Generation Dishes To MPP This Year & 2 More Of LRIP Configuration in 2008
- ✓ Additional SNL Resources Will Support
  - Expanded Engine Testing,
  - Controls Development,
  - Reliability Analyses,
  - Component & System Testing, &
  - Validation of Large-Scale Field Installation Processes

Success For The Entire CSP Program

NREL Can Help As Well

Stirling Energy Systems, Inc. SES

- ✓ Mirror Testing
- ✓ Resource Studies – New On-Site Solar & Wind Measurement Programs
  - At Key Sites In the Mojave Desert, Imperial Valley, Southern Nevada, Arizona, New Mexico, and Texas
  - (TMY2-Type Data, Augmented By Satellite Data)
- ✓ Advanced Optical Materials Development

Larger Scope, Longer Term DOE Support To Keep U.S. CSP At Forefront

Stirling Energy Systems, Inc. SES

For Dish-Engine Systems, This Means:

- ✓ Advanced Components
  - Continuous Improvements In:
    - Performance
    - Reliability
    - Life
    - Reduced Cost
- ✓ Larger Dish for Centralized Power Plants
- ✓ Smaller Dish Development Efforts For Distributed, Off-Grid Systems

Building On Successes To Date

& Advancing The State-of-the-Art

Examples of Dish Advanced R&D Programs

Stirling Energy Systems, Inc. SES

- ✓ Improved Receivers for Stirling Engines
  - Lower Cost
  - Higher Temperature/Efficiency
- ✓ New Advanced Mirror Systems
  - Self-Cleaning (or Resistant To Soiling)
  - Lower Cost
- ✓ Energy Storage Systems for Distributed Generators
- ✓ New, Improved Drives
  - Azimuth
  - Elevation
- ✓ Advanced Materials Research