Dish Stirling Development

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DOE Program Review
April 17-19, 2007

CONCENTRATING•SOLAR•POWER
Sun♦Lab
Sandia National Laboratories, Albuquerque, NM
National Renewable Energy Laboratory, Golden CO

SES

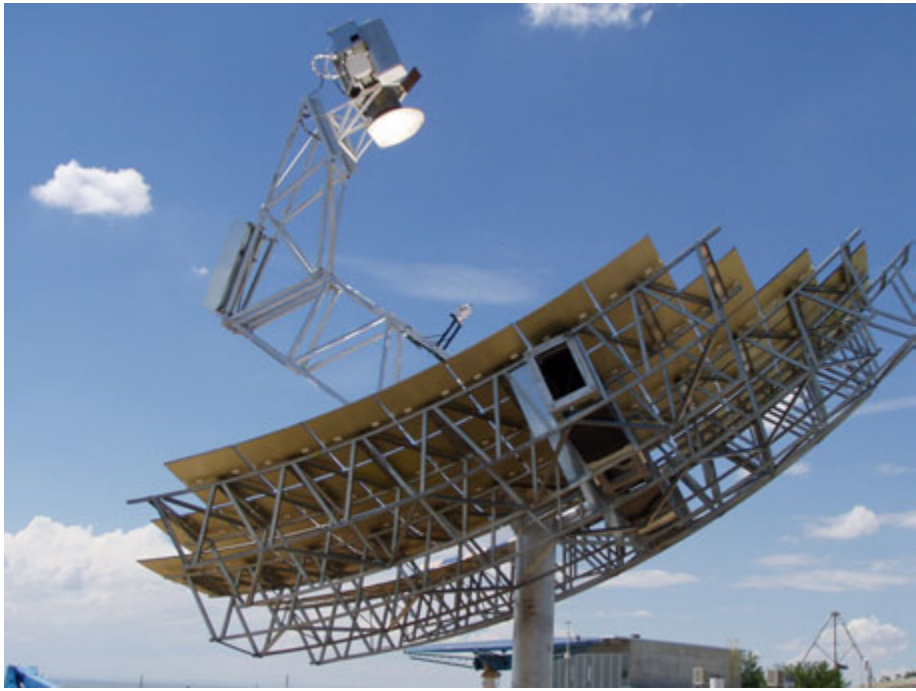
Sandia is a multiprogram laboratory operated by Sandia Corporation, a Lockheed Martin Company, for the U.S. Department of Energy under Contract DE-AC04-94-AL85000.

Project Background

- Dish Stirling most efficient solar conversions approach
  - 29.4% net conversion efficiency demonstrated
- Stirling Energy Systems to commercialize mature technology
  - Based on McDonnell Douglas successful designs
  - Substantial redesign for cost
  - Deployment model for utility scale plants
- PPA's in place for 800 to 1750MW
  - Two large plants in California
  - Allows jump to automated production
  - Production rate path to low cost

Project Description

- Support Stirling Energy Systems in Commercialization of dish-Stirling Technology
  - Operation of Model Power Plant
  - Reliability improvement
  - Next generation design support
  - Cost reduction
- Industry-led Technology Partnership
  - Substantial private financing
  - Presentation is on Sandia-Centric tasks
  - CRADA agreement protects SES data



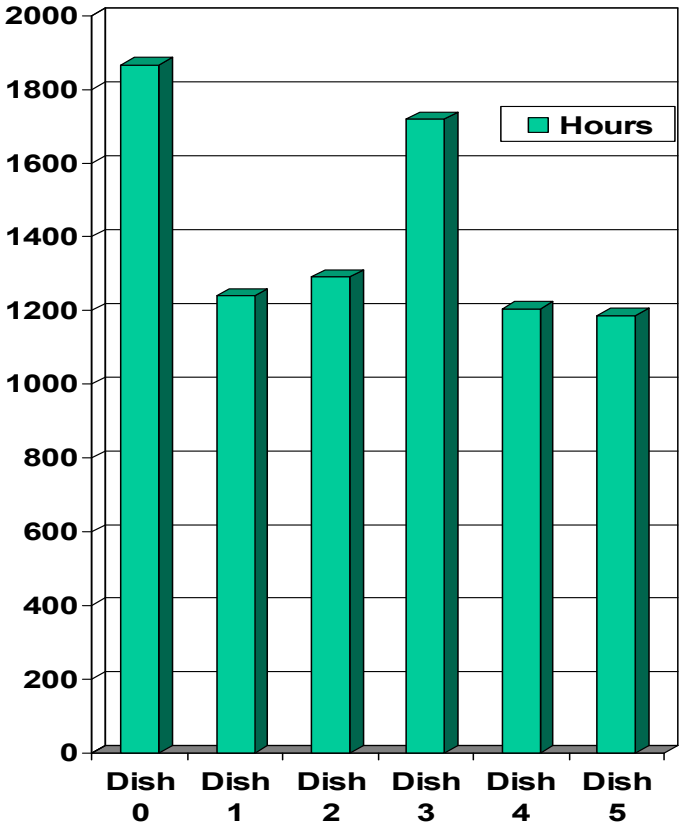
Goals and Objectives

- "Do what it takes to make SES successful"
  - Technology transfer
  - Design and analysis support
  - Aggressive reliability improvement program modeled on ADDS
  - Cost reduction design
  - Tours for investors and partners
- Baseline reliability
  - Understand what we have
- Lead reliability improvement program

FY06 Milestone Status

Baseline Reliability

- Delivered baseline reliability milestone report to DOE
- Classified primary fault issues
  - No “Show Stoppers”
  - Legacy hardware a consistent problem
- Developed processes for root cause analysis
  - XFRACAS commercial software
  - Tiger team approach
  - Automated web tools for monitoring performance
- SES currently staffing up in key areas
  - Systems engineering
  - Electronics/controls
- Performance Excellent
  - Over 30% gross efficiency (un-calibrated)
  - Over 25kW net per dish (calibrated)



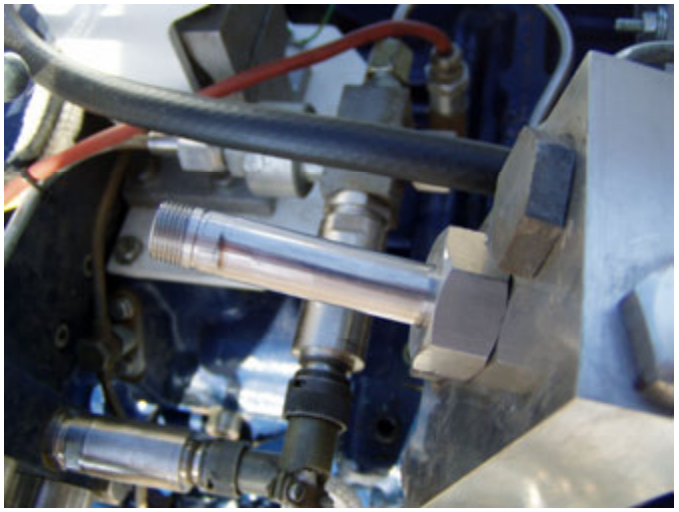
Total System Hours Over 8500

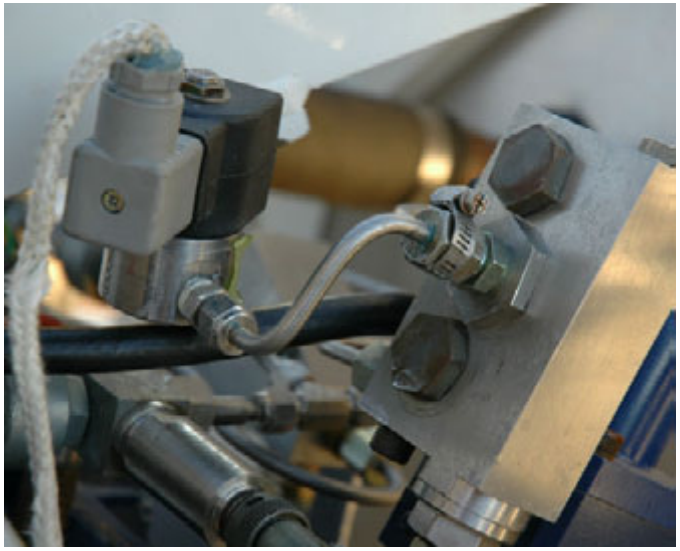
Progress: Incident Tracking

- Failure Reporting, Analysis and Corrective Action System (FRACAS)
  - Reliasoft "XFRACAS" software implemented
    - Web-based
    - Technician training
- Web-based data mining tools developed
  - Real-time data extraction
  - Critical to fault resolution
- Ownership of issues established
  - Issues prioritized based on criticality criteria
  - Team leaders own problems
  - Management interest and tracking

Progress: Compressor Valve

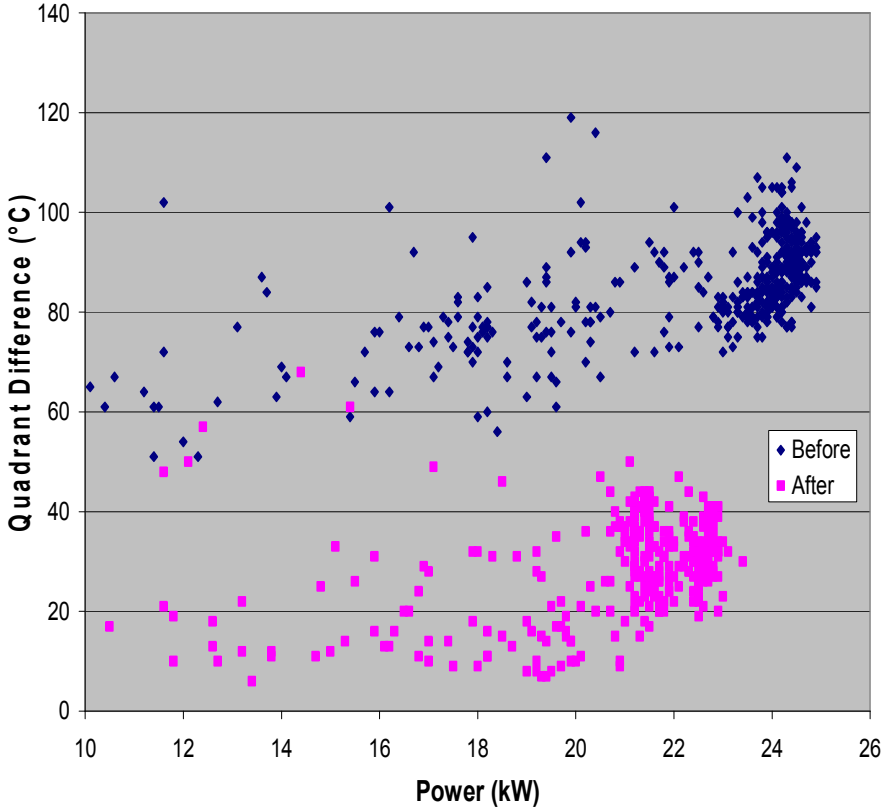
- Greatest problem area in 2005
  - Inconsistent gas control system valve operation
    - Sticking open
    - Sticking closed
    - Abnormal wear
- Sandia-led attack
  - Careful characterization led to clear engineering specification
  - Low-cost valve replacement
  - Reduced valve size by 150x
- No compressor valve faults last 12 months!
- Qualifying additional high volume US manufacturers
- Integrated compressor valve blocks ordered
- Additional Gas Management System work underway





Progress: Hardware Improvements

- Alignment
  - Sandia-developed alignment strategy
  - Substantial performance improvement (60-80% decrease in head delta T)
- Oil leaks
  - Developed modified oil galley assembly approach
  - Provide redesign support
- Electrical
  - Rework old controls to improve workmanship
  - Analog filters improve digital stability
- Instrumentation
  - Developed methods for consistent thermocouple installation
  - Understanding and improving motor position sensors
  - Controls characterization



MPP Operation

- Over 8500 hours operation
  - Routine unattended operation
  - Stakeholder demonstrations
  - Development and qualification testing
- Substantially improved dish performance
  - Reflectivity
  - Mirror slope error
  - Alignment
  - Can overpower engine in Albuquerque conditions
  - Up to 27kW new output
  - Little cost increase

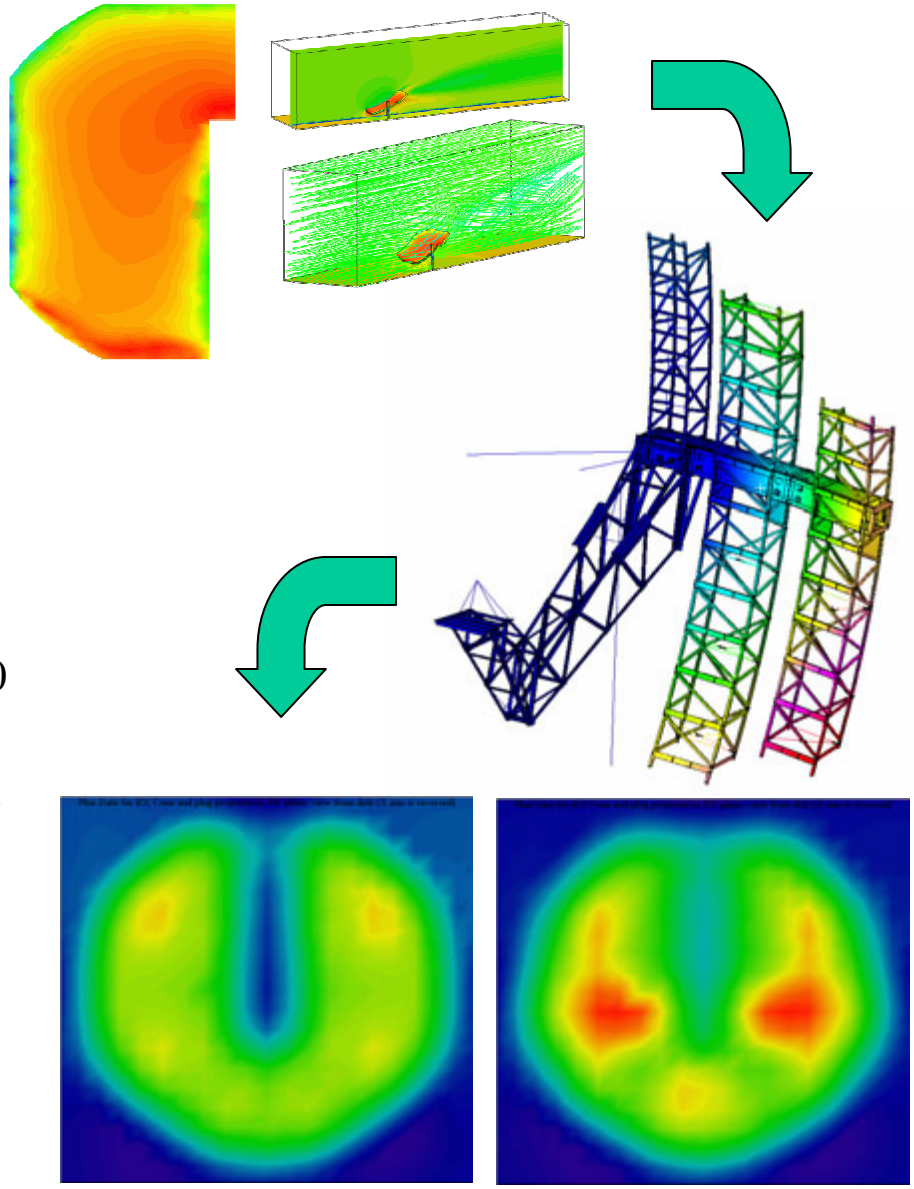
Progress: Design Support

- Integral with reliability improvement
  - Reliability issues are designed out (Some known issues will continue until redesign implemented)
  - Cost reduction efforts must be monitored to prevent inadvertent system degradation
  - Better design processes will lead to analytically-verified designs
- Sandia experience and capabilities critical support to SES for rapid next-generation development
  - Systems viewpoint
  - Field experience
  - Sandia people on design review boards

Progress: Design Support

Integrated Design Tools

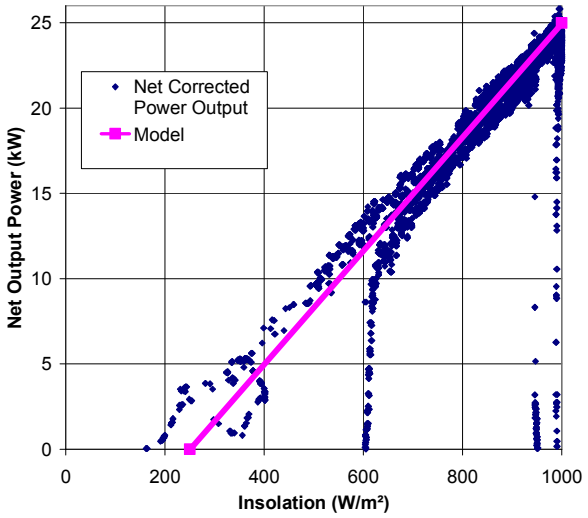
- Integrate CFD, FEA, and Sandia Optical Analysis
  - Developed understanding of key structural interactions
  - Sandia proposed integrating tools to define optical impact of design changes
  - Modeling and integration by SES and their engineering consultants
  - Eliminate "deflection budget fallacy"
- Successful integration
  - Validated with MPP physical and optical measurements
  - Redesign reduced rotating weight by about 4000 pounds
  - Resulting structure stiffer, reducing flux hotspots that impact performance *and* reliability
  - Located source of subtle optical distortions
- Excellent example of Labs-Industry leveraged teamwork
- Structural team success hinged on this model

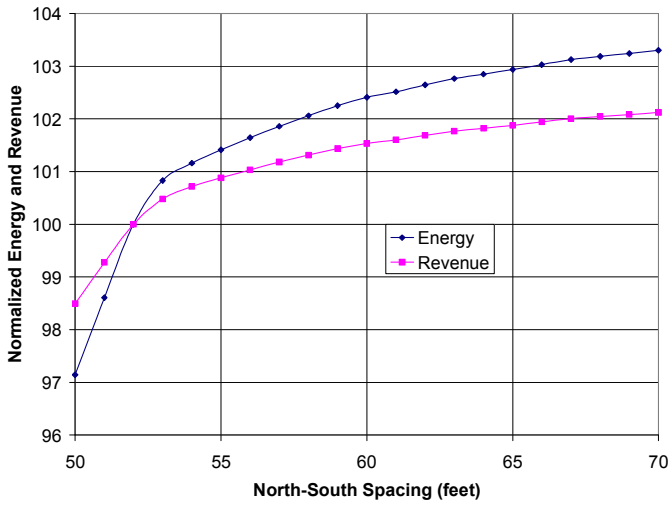


Progress: Design Support

Field Systems Model

- Integrated performance and revenue stream model
- Evaluate field spacing impacts
  - Dish-to-dish shading
  - Dish layout including stagger
  - TMY2 or other environmental data
  - Site slope
  - Incorporates measured data effects
- Rolled out to SES
  - Used in developing 1MW installation layout
- ASME paper 2007

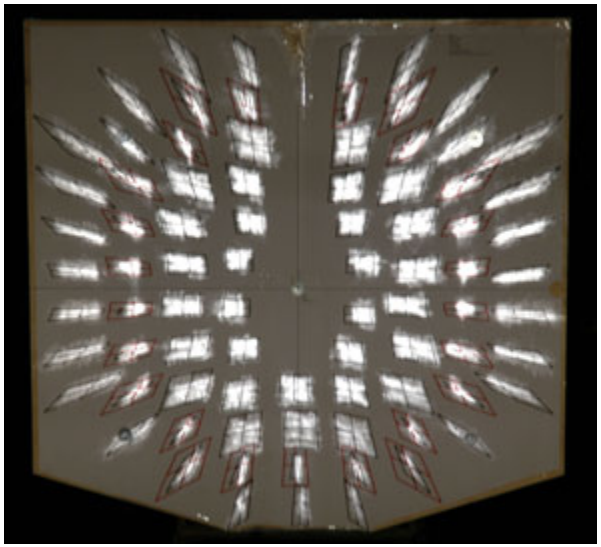


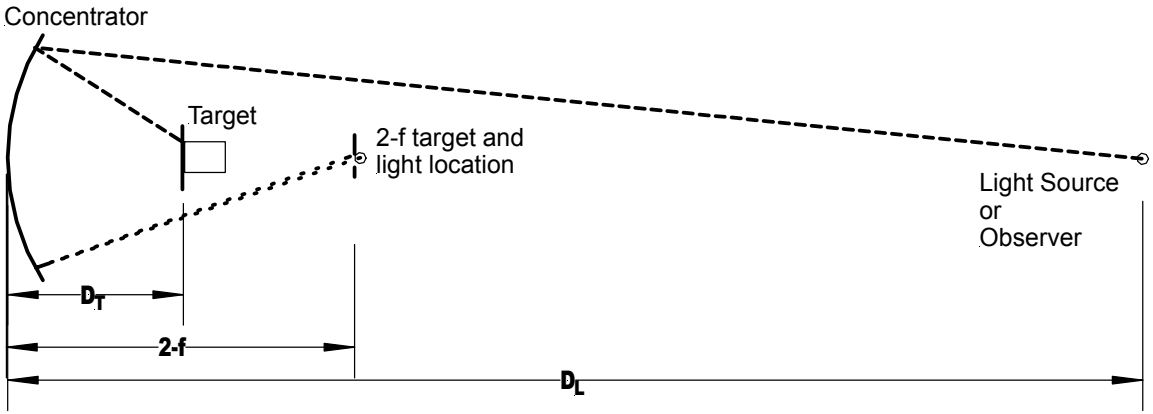


Progress: Design Support

Alignment Tool Development

- Sandia/SES/Schuff Steel collaborative effort
- High rate production tools needed
  - On-site assembly plant
  - In-field re-alignment for repairs
  - Substantially faster approach proposed
- Machine vision camera system
  - Field trials underway
  - Software development for automation
  - Extensive Sandia alignment experience critical

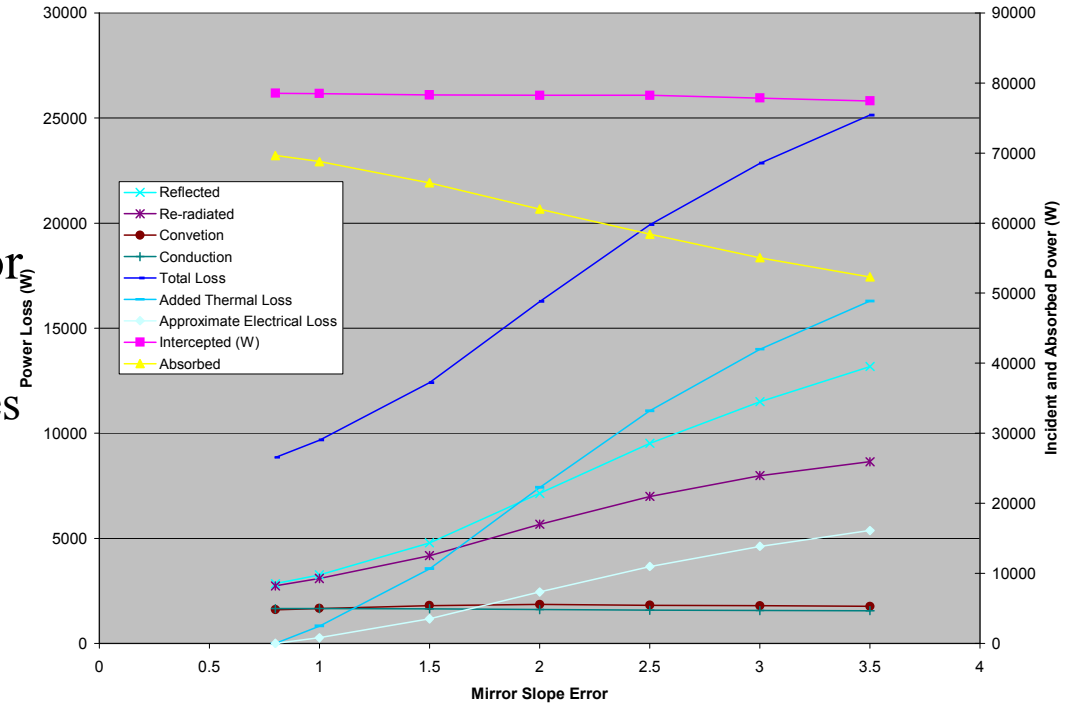




Progress: Design Support

Cost – Performance trade-offs

- Systems-level view
- Mirror Options
  - Evaluated impact of slope error
    - PCU aperture size
    - Receiver cavity thermal losses
  - Hard to pay for cheap mirrors
- Dish/System sizing
  - Design to max vs. averages
  - Evaluate engine performance



Progress: Design Support

Controls Characterization

- Develop understanding of present PCU controls
  - Vintage hardware and software
  - Incomplete documentation
  - Sandia-developed engine simulator basis provided
- Assist SES in characterizing and understanding dish controls
  - SES aggressively hiring controls team
  - Sandia experience with the WGA/SES dish controller critical

Sandia Plans for FY07

- Reliability Improvement continues priority#1
  - Teaming with new SES personnel
  - XFRACAS tool guides development
- Support controls team
  - Understanding of controls software
  - Continue cataloging fault areas
  - Suggest/develop algorithms for improved controls
  - Support engine controller modernization

Sandia Plans for FY07

- 40 unit support (next-generation prototypes)
  - Leverage experience
  - Aggressive schedule
  - Installation of prototypes at Sandia
- High volume production design support
  - Build design tools *with* SES team
    - Tool validation
    - Technology transfer: ESG
  - Build SES personnel technical capability
  - Consult, emphasize a systems view
    - Easy to compartmentalize
- Alignment tool development
  - Coordinate efforts with Schuff and SES
  - Field and Assembly building tools

Advanced Development

- Labs need to look beyond daily needs
- Next generation
  - Cost reduction
  - Performance enhancement
  - Life extension
- Key areas
  - Facet design
  - Advanced dish design
  - “Levelizer” receiver concepts
  - Maintenance predictive controls algorithms
  - Sensors and advanced controls concepts

Summary

- Reliability improvement processes impact every "facet" of system
  - System operation
  - Maintenance
  - Redesign
  - Deployment
  - Cost reduction
- MPP Daily operation improving
  - Addressing reliability issues
  - Evolving priorities
  - Excellent system performance
- Improved systems a strong focus
  - Near-term deployment a key to improved reliability
  - Prototypes at Sandia
- Successful labs-industry partnership
  - U.S. Industry-led teaming
  - Leverage DOE/Laboratory experience
  - Analytical and hardware improvements clear