

## Introduction of the Solar Turbines Titan 250 Gas Turbine System

Design, Development and Validation Testing  
a New 22.4 MW Gas Turbine

VGB Fachtagung  
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Mannheim, Germany

Ulrich Stang  
Manager  
Turbine Aerodynamics

## Solar Turbines Inc.

- History

- Founded in 1927 As Prudden Airplane Company
- Full Transition to Industrial Gas Turbines in 1970's
- Caterpillar Subsidiary Since 1981
- 6000 Employees in 96 Countries Worldwide

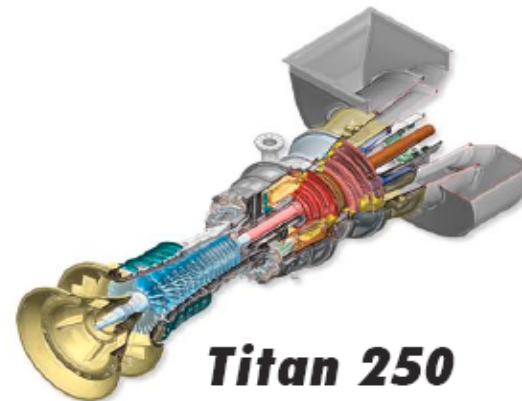
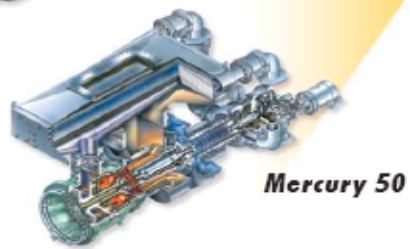
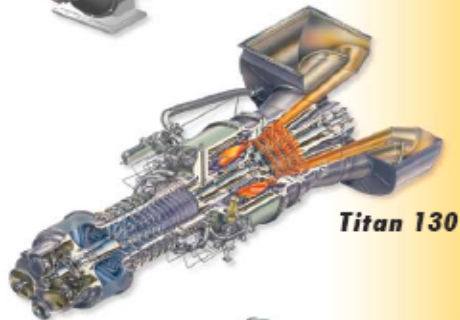
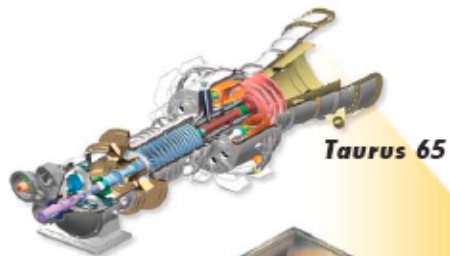
- Products

- Over 12,500 Units Installed Worldwide (3100 in EAME)
- Over 5,900 Compressor Sets and Mechanical Drive Units
- More than 1.2 Billion Operating Hours (350 Million in EAME)

- Titan 250 Timeline

- Program Kick-Off - 2004
- Hardware Delivered - 2008
- New Test Cell Commissioned - 2008
- First Light-Off – 2008
- Customer Delivery - 2009

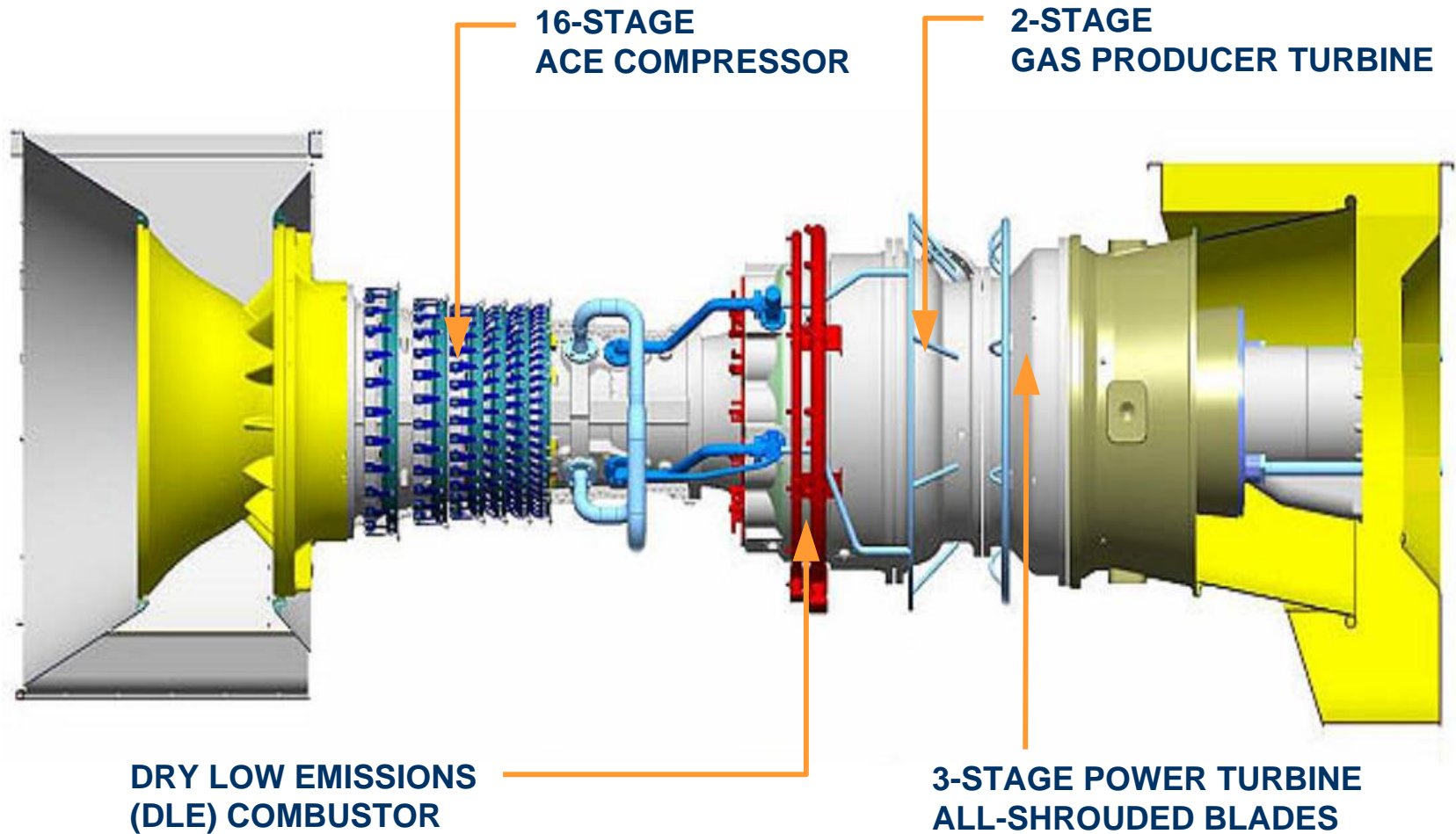
## Leveraging Proven Technology



### SYSTEM DESIGN GOALS

- Highest-Efficiency Gas Turbine in Class
- Design for Long-Life Industrial Applications
- Common Modular Design Throughout
- Minimum Package Footprint
- Advanced Aerodynamics, Optimized Cooling
- High Availability, Maximum Life-Cycle Benefits
- Wide Application Range for Compressors
- Packaged Generator Set for High Efficiency
- Simple Cycle and Heat Recovery Installations

Parameter	CS/MD	GS
Power Output	22,400 kW	21,745 kW <sub>e</sub>
Heat Rate	8993 kJ/kW-hr	9259 kJ/kW-hr
Efficiency	40.0% (shaft)	38.9% (generator)
Exhaust Flow	245664 kg/hr	
Exhaust Temperature	463 °C	
Pressure Ratio	24:1	
Power Turbine Speed	6,300 rpm (optimum) 7,000 rpm (maximum)	

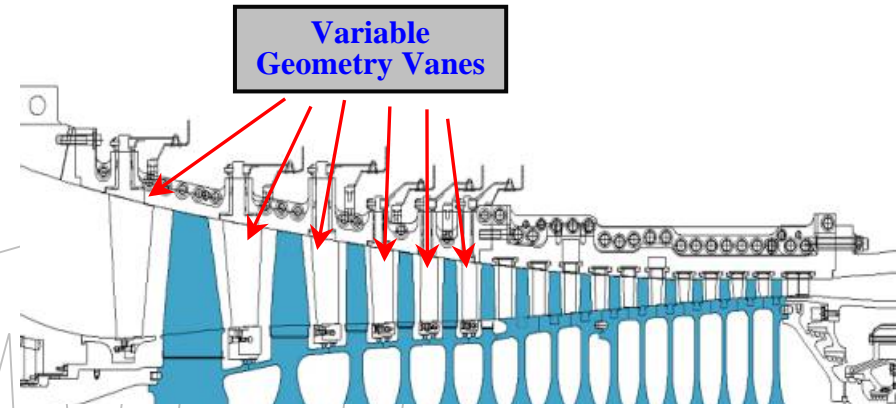




## COMPRESSOR FEATURES

### PERFORMANCE

- “Clean Sheet” Design
- 16-Stages of High-Efficiency Aerodynamics
  - 2 Stages More Than Titan 130
  - Built on Taurus 65 Success
- 6 Stages of Variable Guide Vanes
  - Optimized Airflow For Full Operating Range
- Sets New Standard for Compressor Efficiency
  - Within Experience Base
  - Unsurpassed Attention to Detail
- Multi-Stage CFD Code
  - Validated by Rig Testing
  - Mercury 50, Centaur 50 and Taurus 65
- Optimized for Wide Range of Operation
- Low-Loss, Minimum Distortion Inlet
- Compressor- Discharge and Inter-Stage Bleed



Variable  
Geometry Vanes

### COMPRESSOR (IGV-EGV)

- N = 10500 RPM
- W = 67.7 kg/s
- PR = 24:1

### INLET

- $\Delta p/p = .75\%$
- Blockage < 1.5%
- Minimum Distortion

### DIFFUSER

- $\Delta p/p = 1.6\%$
- $C_p > .70$
- $Ma < .10$
- $\alpha = +/- 3.0 \text{ deg}$



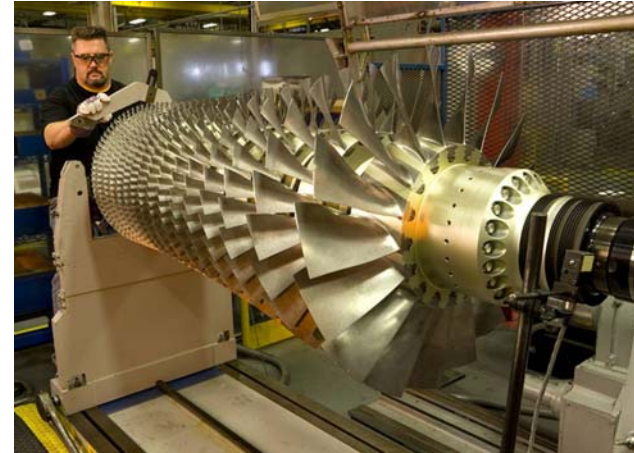
## COMPRESSOR FEATURES

### DURABILITY

- Welded Drum Design for Rigidity, Long Life
- Modular Annular Design
- Bearing Support Optimized - Rotor Dynamics
- Extensive Vibration Analyses
- Latest Variable Guide Vane Bushing Design
  - Based on In-House Corrosion Testing
  - Prevent Lock-up in Field

### MAINTAINABILITY

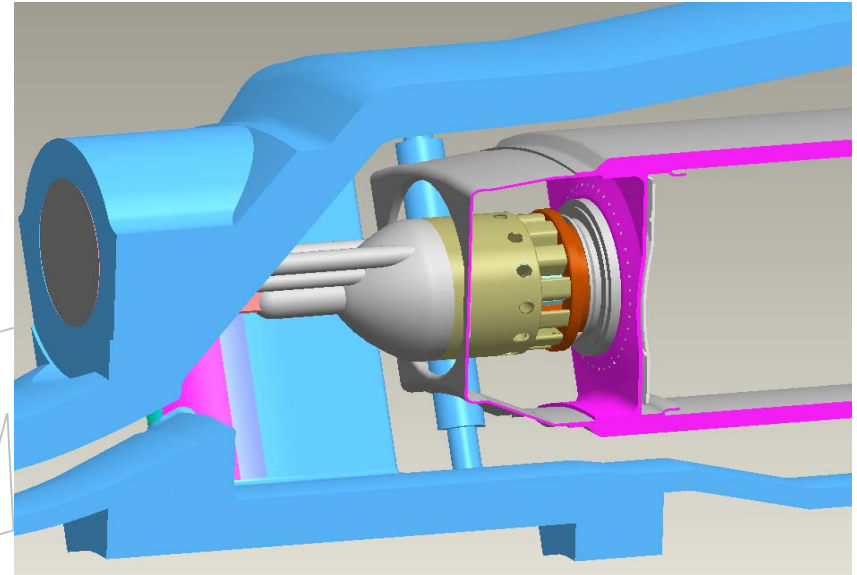
- Designed for Long Life and Maintainability
- Anti-Corrosion Aluminide Coating (Stages 1-12)
- In-Situ Two-Plane Trim Balancing
- All Airfoils Individually Field Replaceable
- 4-Piece Compressor Case (Mars, Titan 130)



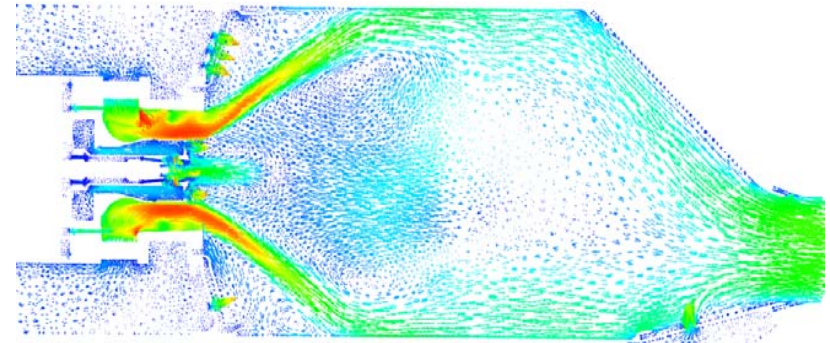
### COMBUSTOR FEATURES

#### PERFORMANCE

- Proven SoLoNOx Technology
- Canted Diffuser for Optimized Airflow
- Optimized Outer Dome For Good Swirler Flow
- Extensive CFD Used to Design
  - Diffuser
  - Liner
  - Injector
- Emissions (NOx/CO/UHC) ppm
  - Natural Gas: 15/25/10
  - Liquid Fuel: 60/30/15
  - Associated Gas (900–1600 WI) / 25/50/10
- Operating Range
  - 40 thru 100% Load
  - -29°C to 49°C (Gas/Liquid)



CFD Predictions of Internal Flow field





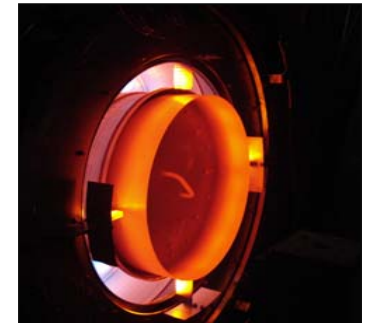
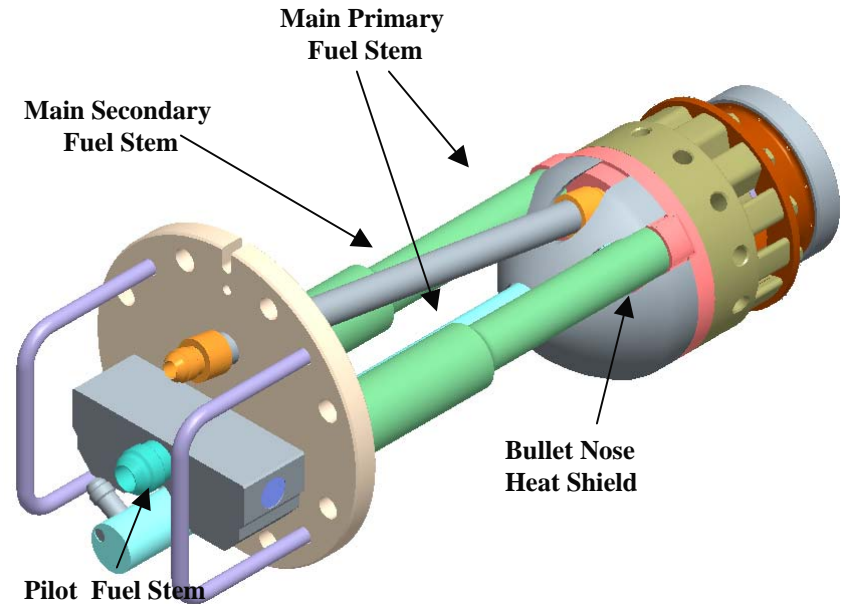
## COMBUSTOR FEATURES

### DURABILITY

- Modular Annular Design
- Augmented Backside Cooled (ABC) Liner
- Simple Supported Pins
  - Reduce Dome Stress
- Independently controlled fuel flows
  - Main Primary, Main Secondary, Pilot
- Extensive Experience with HAST-X Material
- Modal Frequencies Per Design Criteria
- Injector Barrel Features Helmholtz Resonator
  - Oscillation Abatement

### MAINTAINABILITY

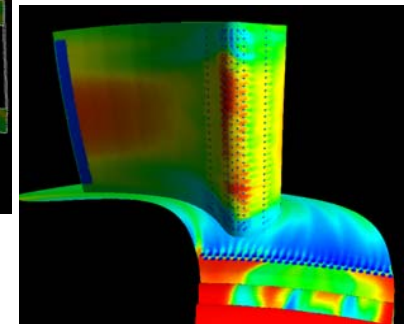
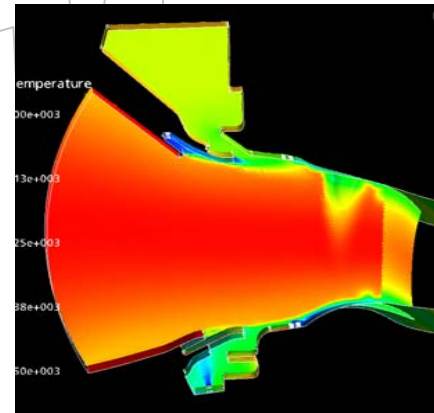
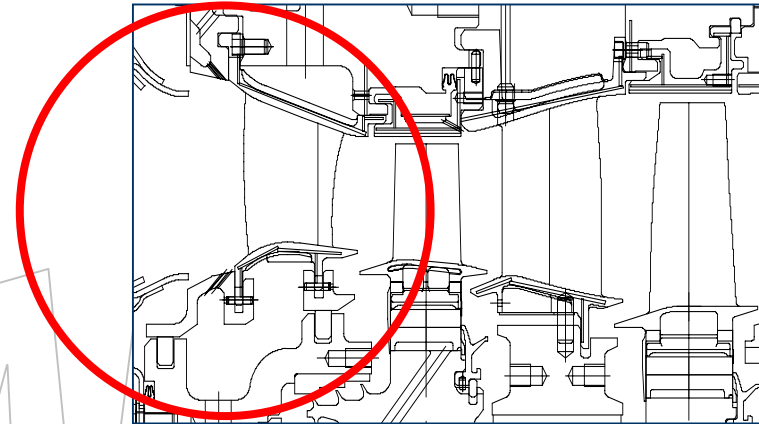
- Designed for Long Life and Maintainability
- 14 Radial-Inflow Injectors – Offset Stems
  - Proven Taurus 65 Experience
  - Easy Installation
  - Field Replaceable and Repairable



## GAS PRODUCER TURBINE

### PERFORMANCE

- Two-Stage Design, Similar to Titan 130
- Leveraged Taurus 65 Experience
- High Aspect Ratio Airfoils
- Optimized Work Split, High Stage Loading
  - Designed for Uncooled 2<sup>nd</sup> Blade
- Jump Cooling Experience Applied
- Extensive Application of Advanced CFD
  - Airfoil Design
  - Combustor Interface
  - Cooling Support
- Passive Tip Clearance Control



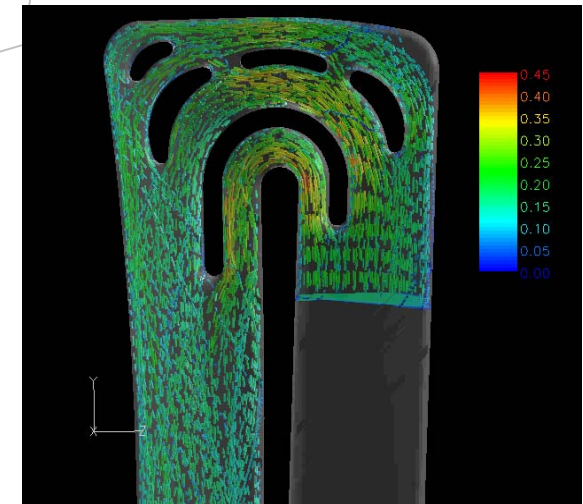
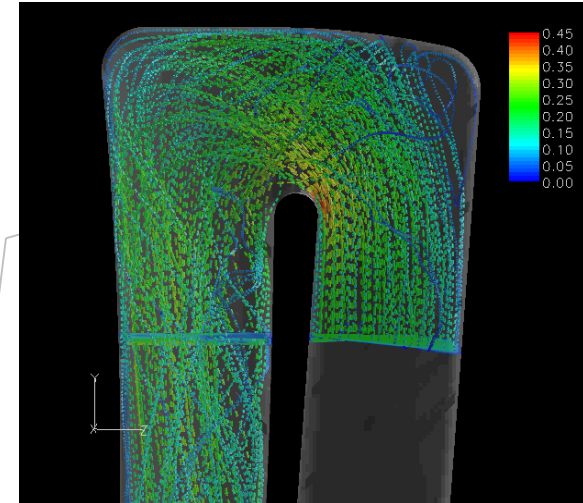
## GAS PRODUCER TURBINE

### DURABILITY

- Advanced 1<sup>st</sup> Stage Nozzle and Blade Cooling
  - Showerhead Film Cooling
- 2<sup>nd</sup> Nozzle Cooled for Minimum Performance Impact
  - Internal Convection Cooling
- Optimized Cooling Passages (Advanced CFD)
- Under-platform Dampers
- Advanced Materials
  - Nozzles - MAR-M-247
  - Blades - SCRY-4
  - TBC Pt-Al Coatings (1<sup>st</sup> Stage Airfoils)

### MAINTAINABILITY

- In-Situ Repair and Replacement Capability
- Borescope Access
- 2-Plane Trim Balance in Field
- Low-Speed Turning Gear (Cool down)
  - Avoid Rotor-Lock-up Issues

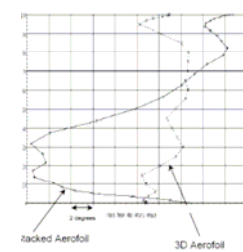
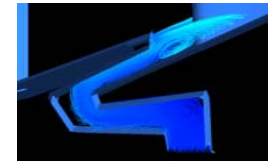
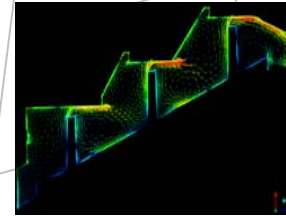
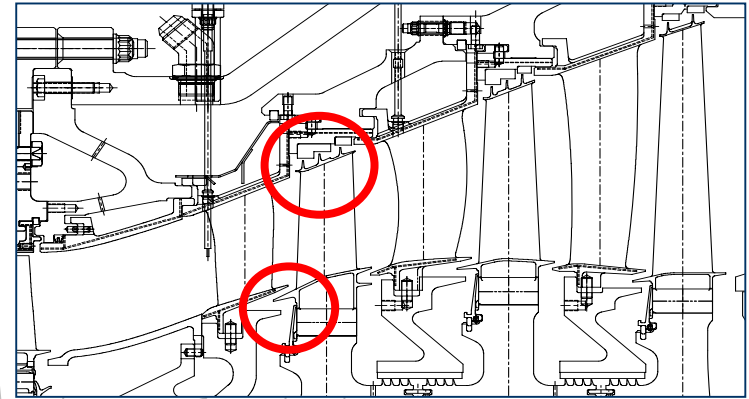


*With Turning Vanes*

## POWER TURBINE

### PERFORMANCE

- Three-Stages
- Low RPM Design (6300 / 7000)
- Moderate Endwall Slope
- All Blades Shrouded
  - Reduced-Leakage Geometry
  - Increased Knife-Count
- High Efficiency, 3-D Airfoils
- Optimized Axial Gaps
- High Fidelity, Detailed CFD Models Used
  - Tip Gap Analysis
  - Purge Cavity Effects Captured
  
- Flat Power Curve across Speed Range
- Highest Efficiency Solar PT





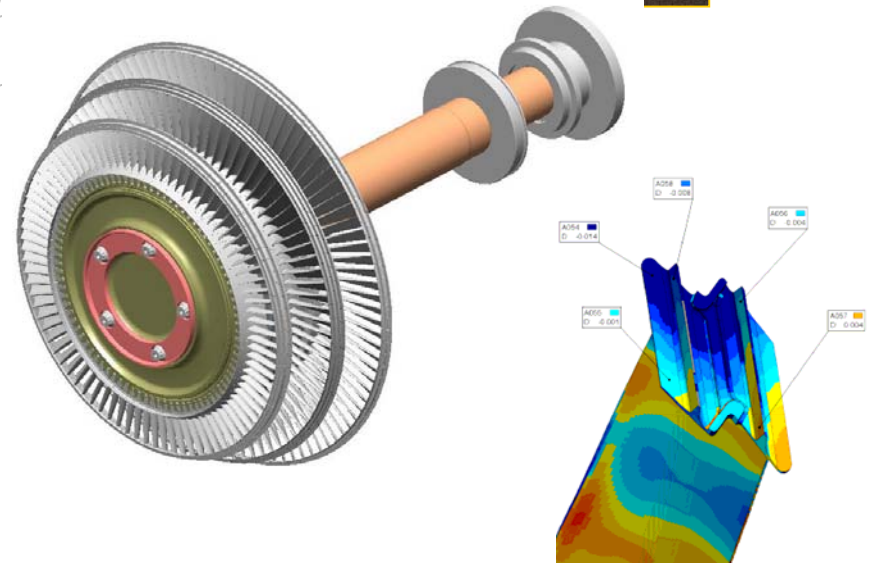
## POWER TURBINE

### DURABILITY

- Shrouded Blade Experience
  - Titan-130, Taurus-65
  - Low to Moderate AN<sup>2</sup> Levels
  - Clearances Set for Durability
- Extensive Experience with Materials
  - Nozzles : IN 939
  - Blades : IN792
- Vibration Testing on Shrouded Blades
- Proven, Reliable High-Time Bearings
  - Field-Retrofittable

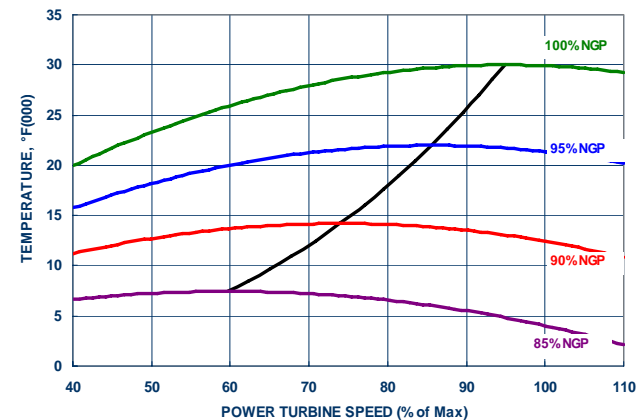
### MAINTAINABILITY

- Modular Design for Field Maintenance
  - Advanced Rail System
  - Dedicated Lubrication System
- Borescope Access



## VALIDATION

- New Test Cell Commissioned in 2008
- Test Program Initiated in Sep-08
  - >250 Hours of Operation
  - Advanced Instrumentation
- Start Power Minimized
  - Guide Vane Optimization
- Component Performance Validated
  - Compressor Mapping
  - Power Turbine Mapping
  - Load Modulation
- Emissions Verified



## SUMMARY

- Methodology
  - Lean, Interactive Processes
  - State-of-the-Art Design Tools
  - Experience From Prior Designs
  - Industry Design Experience
  - Maximum Commonality
- Design
  - Advanced Technology
  - Detailed Analyses
  - Highest Efficiency, Durable Components
  - Focus On Ease of Maintenance
- Validation
  - Attained Performance
  - Verification With Calibrated CFD
  - Extensive Engine Testing

