



Diesel Engine Waste Heat Recovery Utilizing Electric Turbocompound Technology

**Ulrich Hopmann
Caterpillar Inc.**

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Caterpillar Engine Research
Diesel & Emissions Technology

Outline



- ✍ **Turbocompounding System**
- ✍ **Design**
- ✍ **Turbomachinery Performance**
- ✍ **Component & System Analysis**
- ✍ **Summary**

Primary Objectives

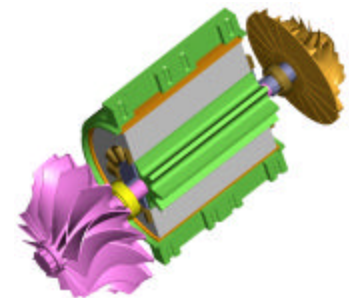


-  **Demonstrate Technical Feasibility**
-  **Improve Fuel Economy**
-  **Reduce Emissions**
-  **Improve Driveability**

Specific Program Milestones



- † ETC Concept
- † Turbomachinery
- † Electrical Machinery
- † Control System and Strategy
- † Rig Test and Engine Test



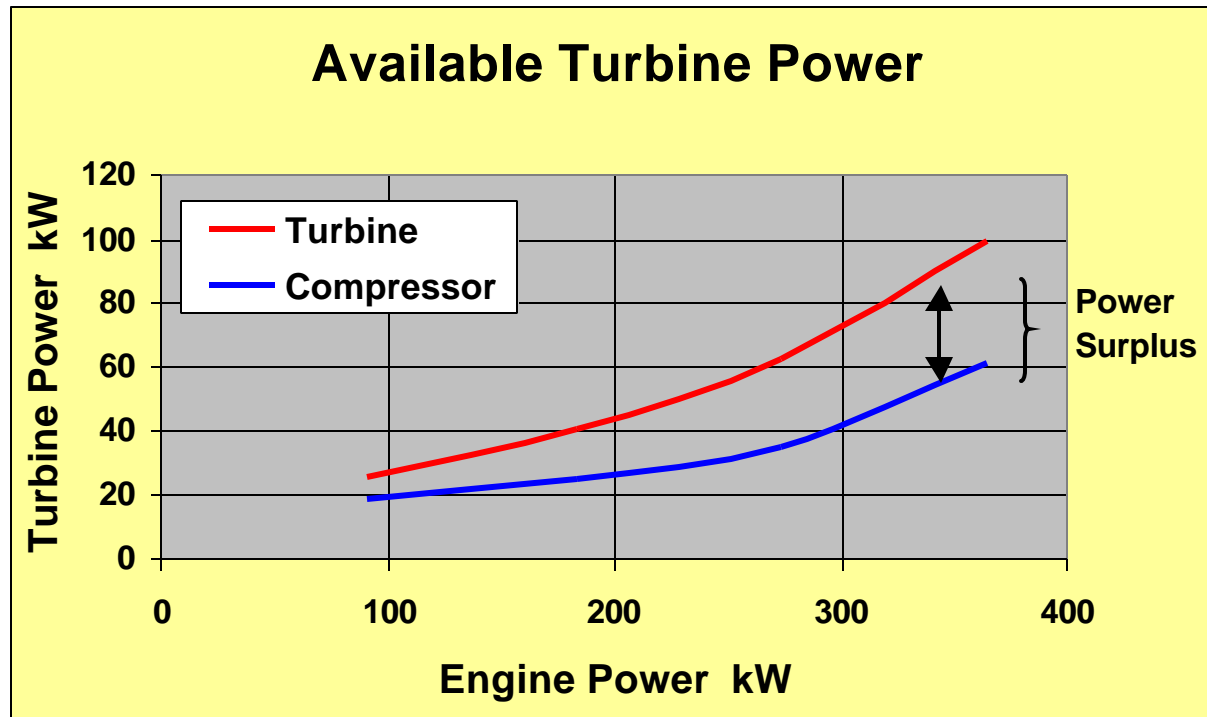
What is Turbocompounding?



✍ Utilization of Power Surplus of the Exhaust Turbine

✍ Back to Engine Crank Shaft

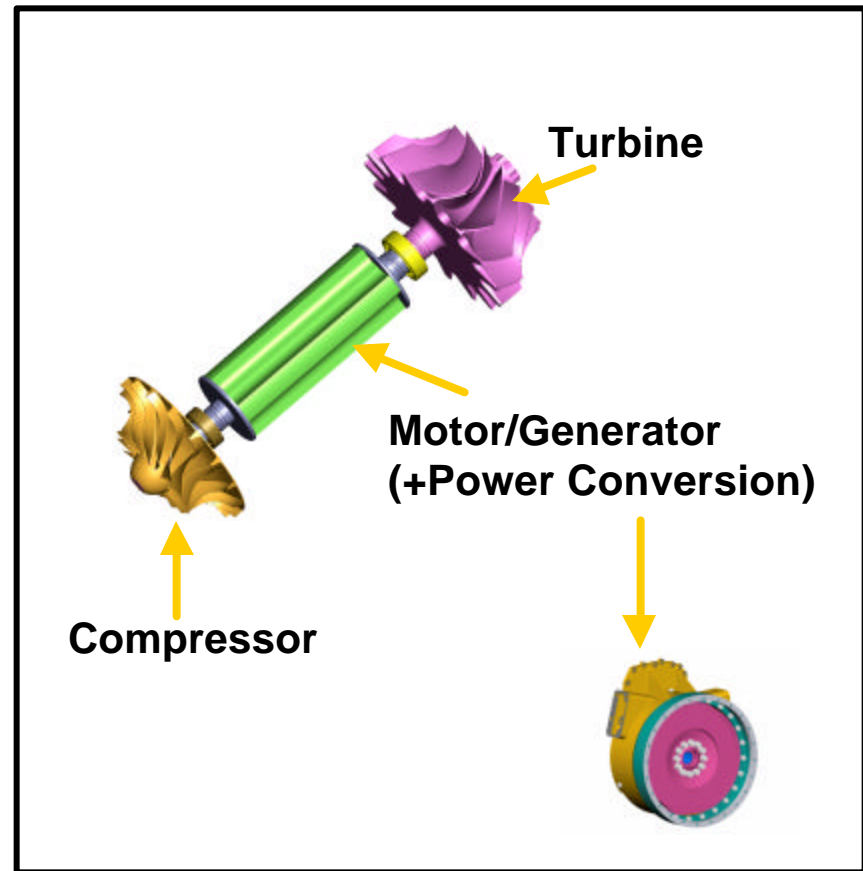
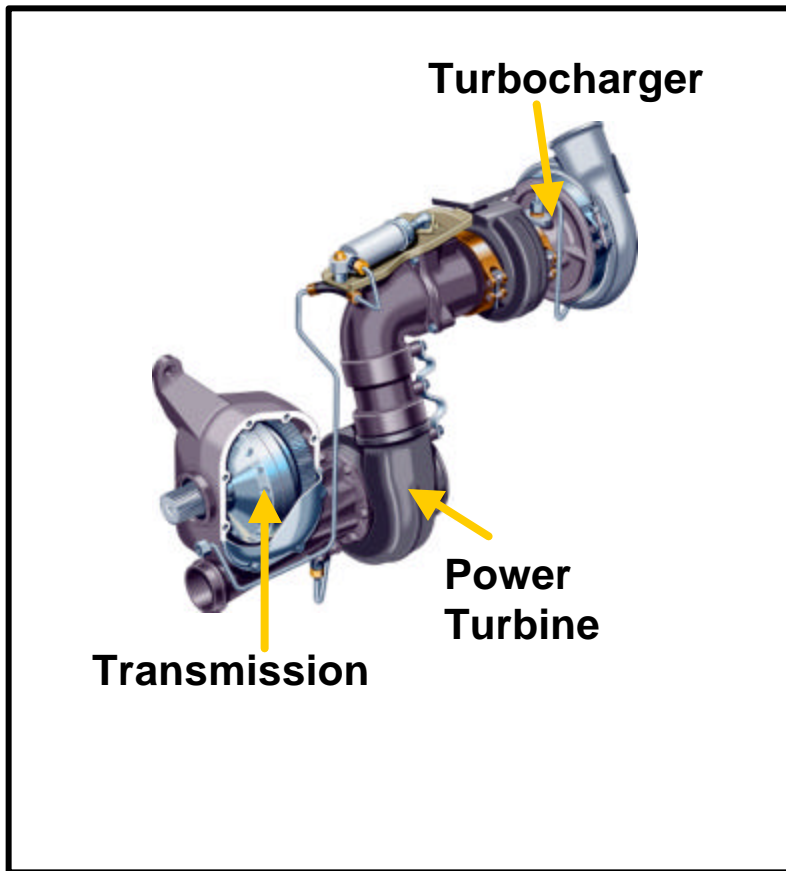
✍ Drive Accessories



Turbocompounding



Mechanical vs. Electrical



Outline



 Turbocompounding System

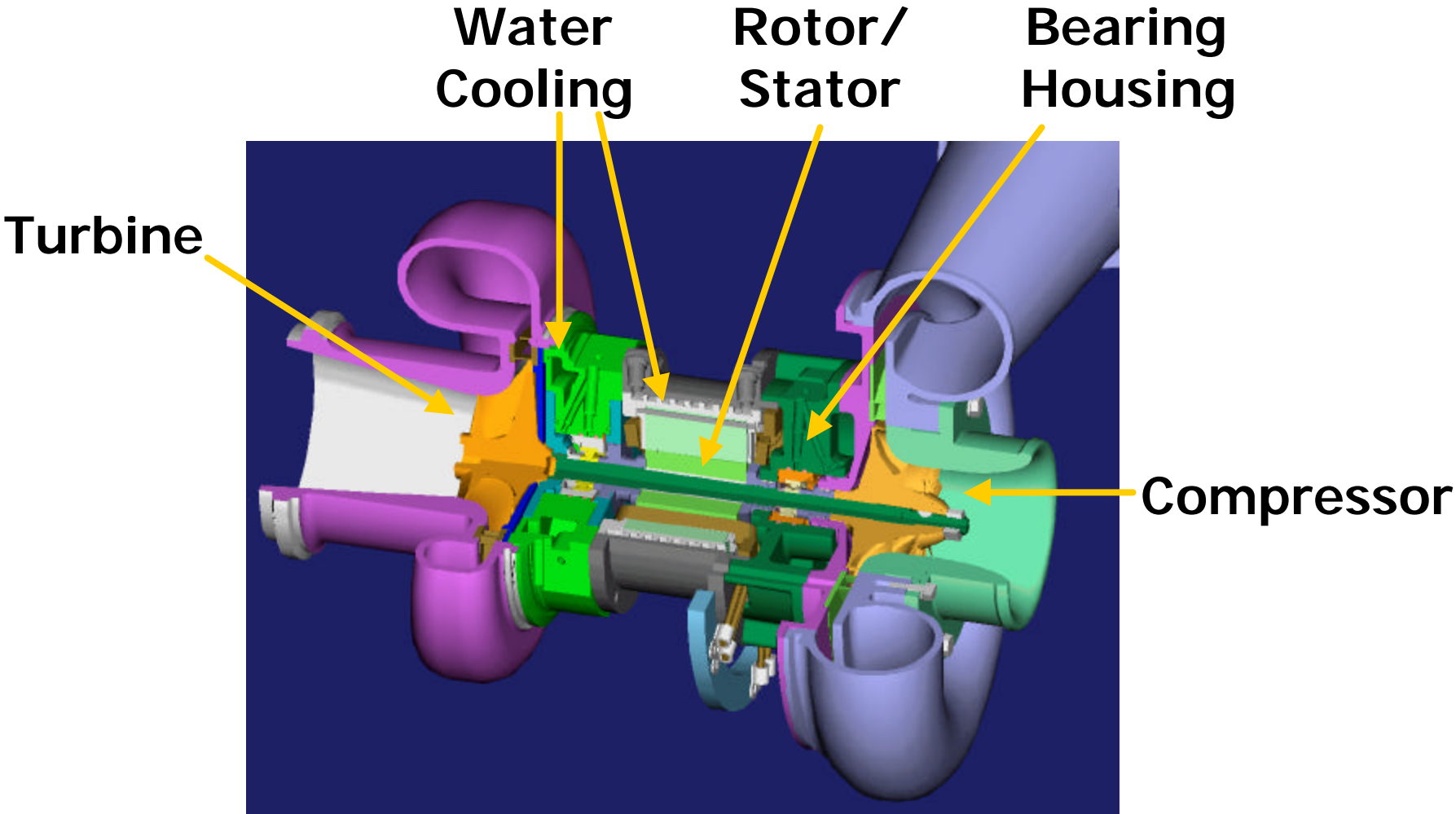
 **Design**

 Turbomachinery Performance

 Component & System Analysis

 Summary

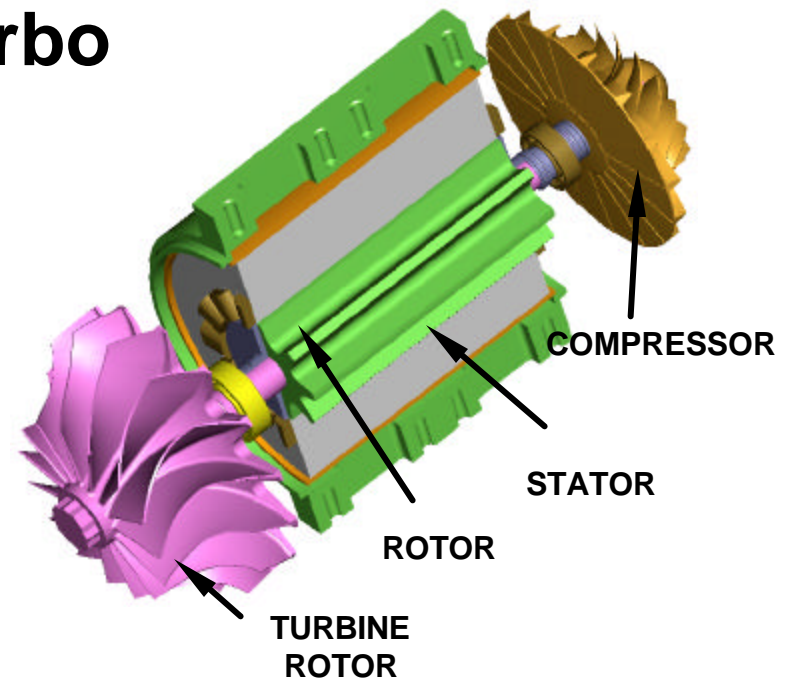
Cross Section of ETC Turbocharger



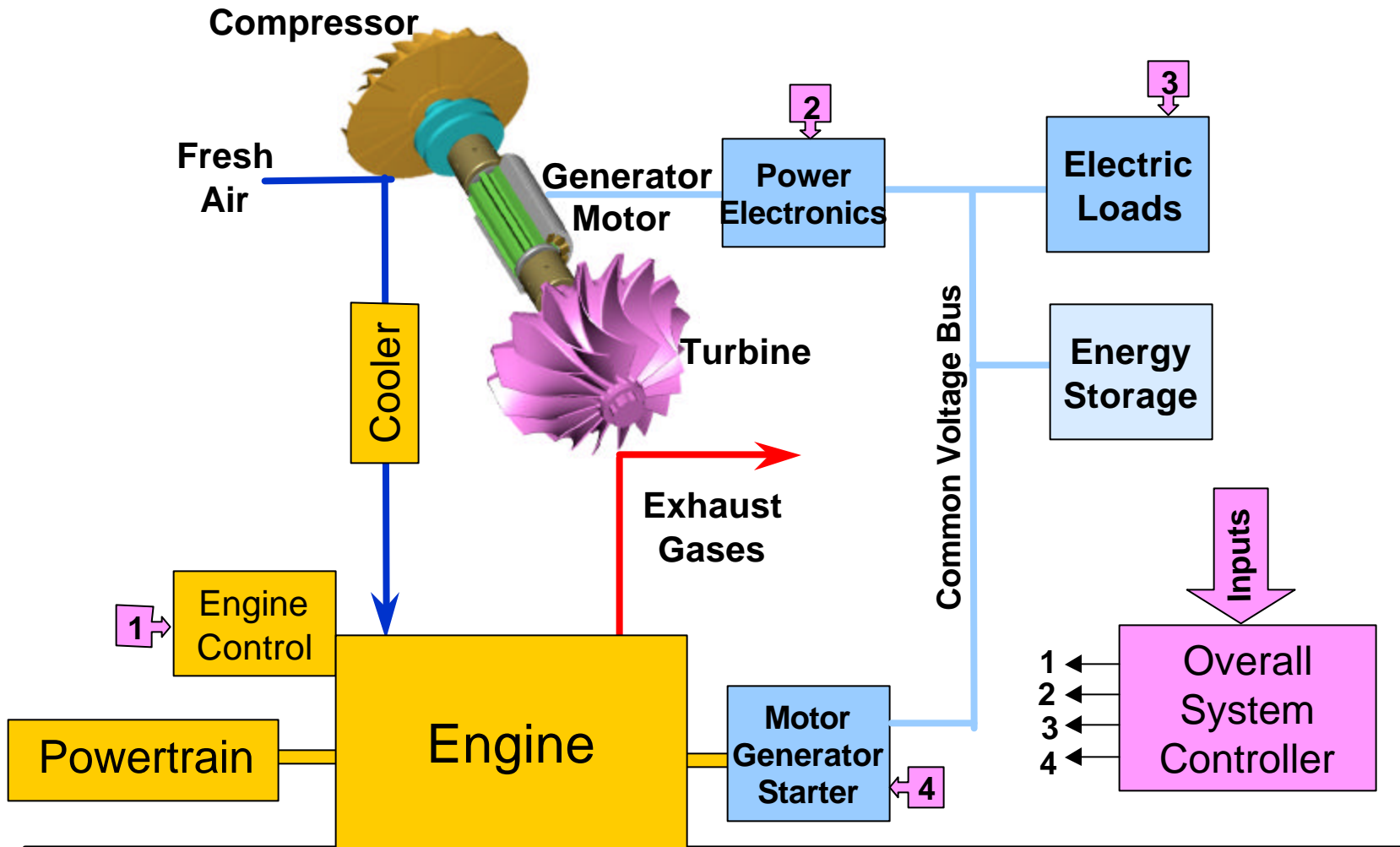
Electric Turbocompound Features



- ✍ **No Mechanical Coupling between Turbo and Crank Shaft**
- ✍ **Allows Flexibility in Turbo Operation**
- ✍ **Provides Turbo-Assist Capabilities**



ETC System Schematic



Outline



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ETC - Turbomachinery

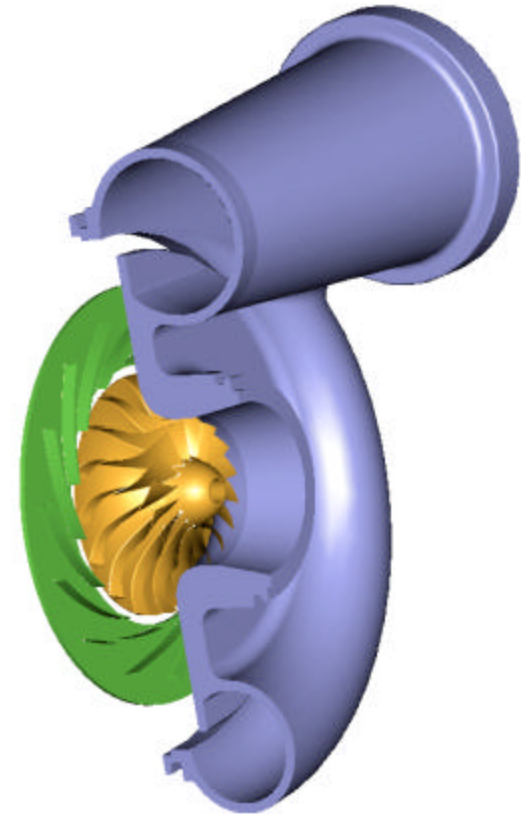


- ✍ **Overall Turbo Efficiency > 65%**
- ✍ **Engine Exhaust Temperature = 650° C**
- ✍ **Airflow = 0.63 kg/s**
- ✍ **Altitude Capability of 10,000 ft without Derating of Engine**

ETC - Compressor



- ✍ **PR = 3.1**
- ✍ **Efficiency = 82%**
- ✍ **Proven Design**
- ✍ **Vaned Diffuser**
- ✍ **Speed = 66,500 rpm**



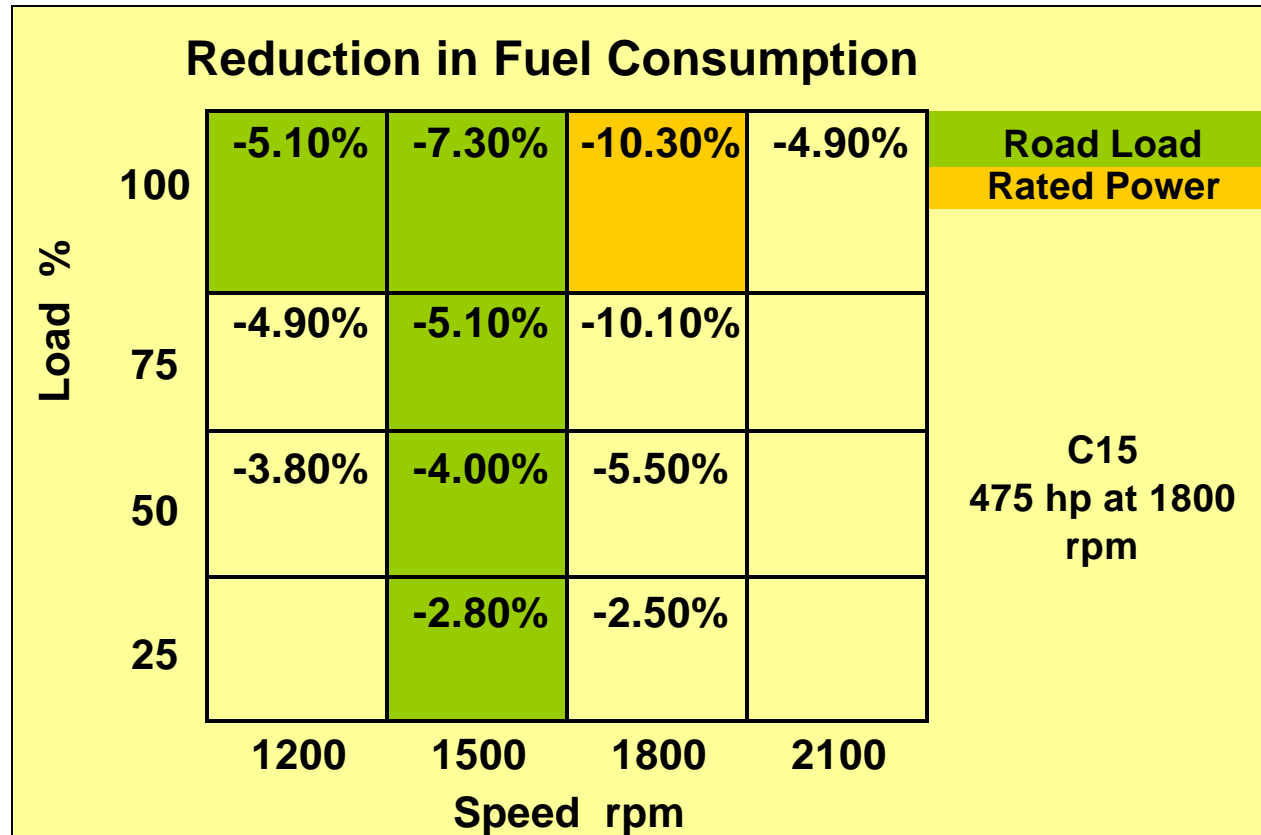
ETC - Turbine



- ✍ **Radial Turbine, Vaned Nozzle**
- ✍ **Efficiency = 84%**
- ✍ **PR = 3.5**



Engine Simulation of ETC System



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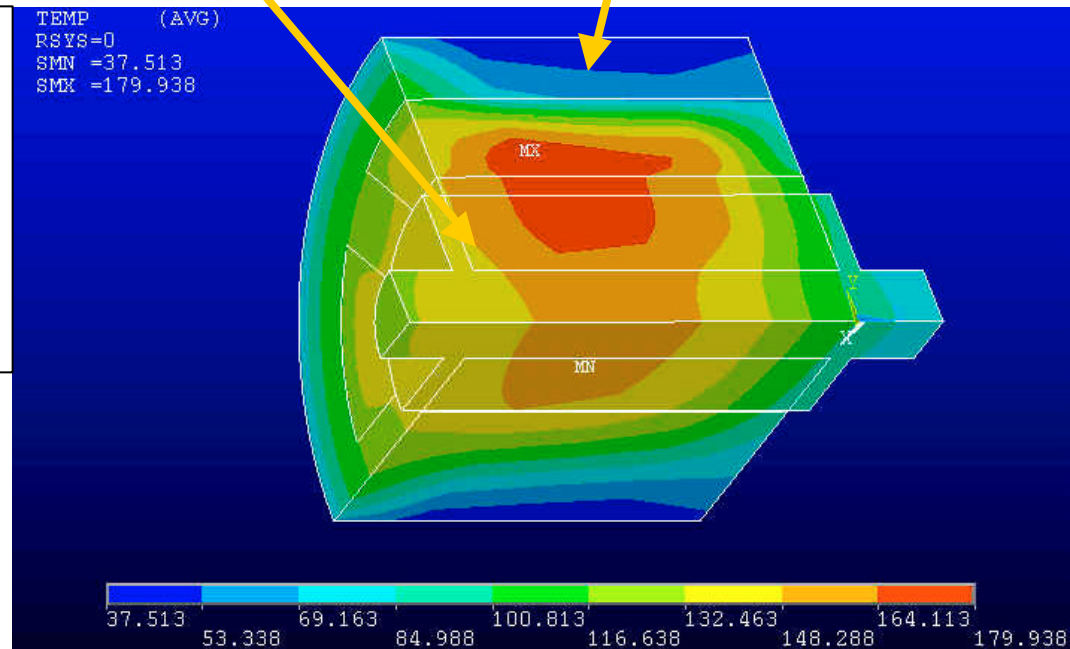
Heat Transfer - Generator



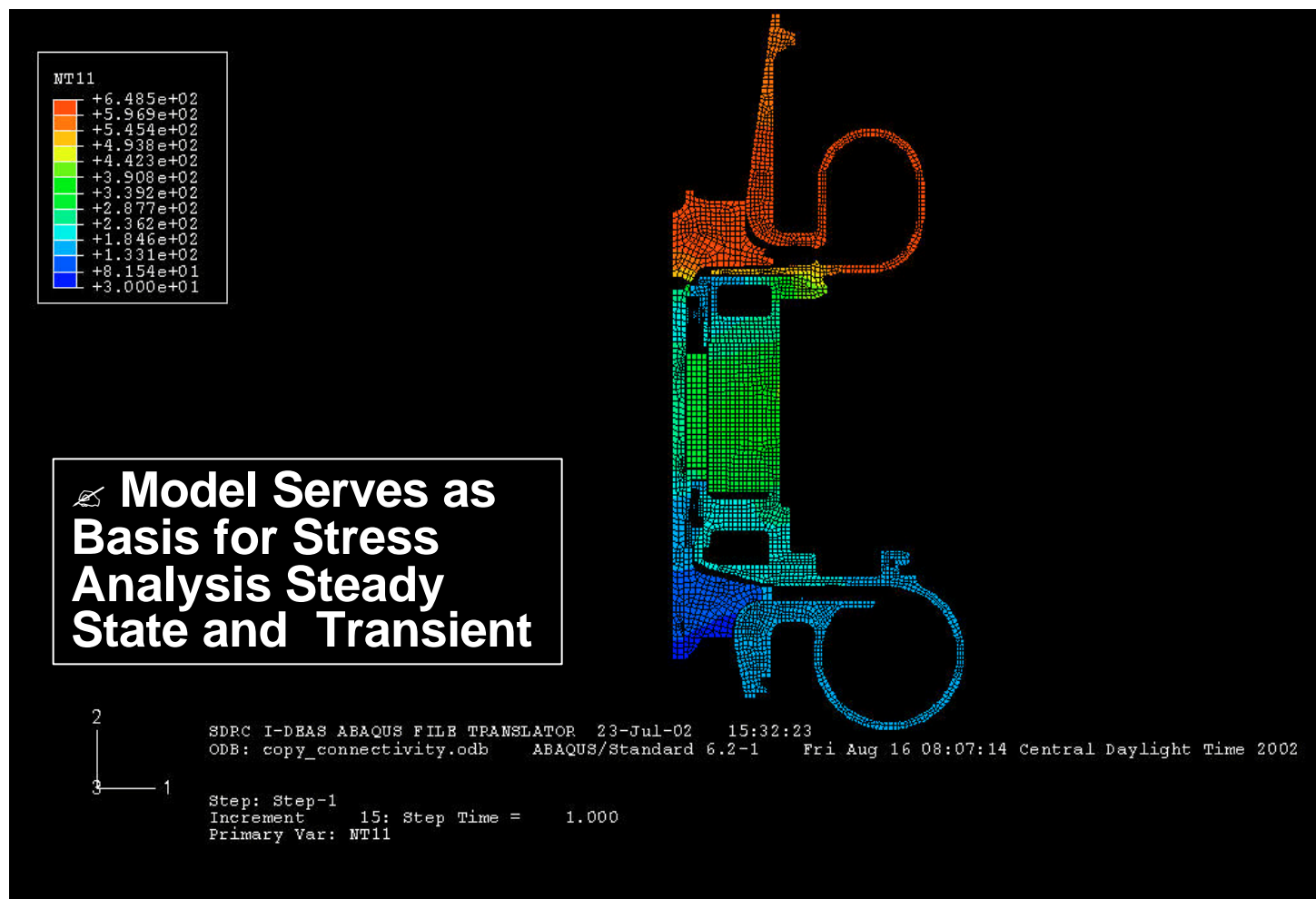
Stator

Rotor

**Motor/Generator
at maximum
power = 60 kW**



Heat Transfer - Turbocharger



Rotor Dynamics



Rotor Dynamics Analysis Determined Shaft Assembly Layout:

- ✍ **Shaft Geometry**
- ✍ **Bearing and Damping Selection**
 - ✍ **Angular Contact Ball Bearing**
 - ✍ **O-Ring and Oil Damping**
- ✍ **Acceptable Dynamic Response**

Control System Simulation

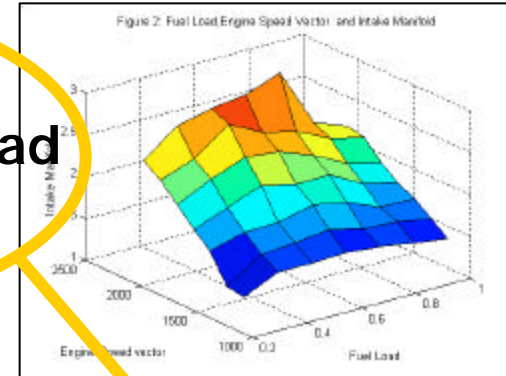


- ✍ **Simulation Model Constructed in Simulink**
- ✍ **Model Calibrated to Production Engine Test Data**
- ✍ **Turbocharger Maps Represent Selections for Electric Turbocompounding**
- ✍ **Boost Pressure is Primary Control Signal**
- ✍ **Model Being Used for:**
 - ✍ **Control System Stability Analysis**
 - ✍ **Control Algorithm Design**
 - ✍ **Transient System/Performance Behavior**

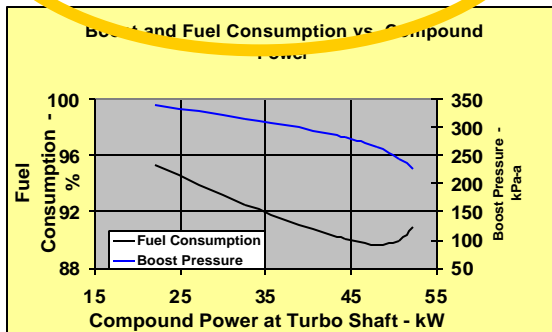
Boost Set Point Generation



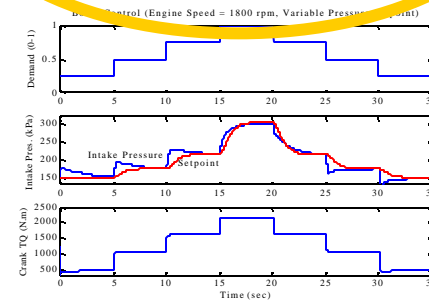
Map
Boost/Speed/Load



Boost at Optimum
Fuel Consumption



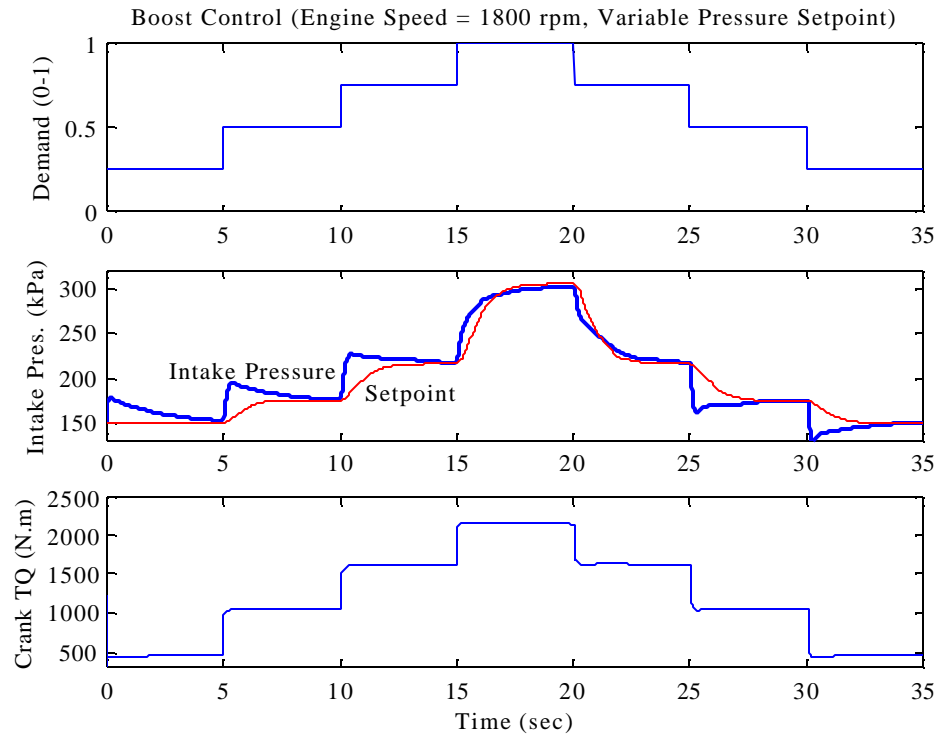
Set Point for
Transient Behavior



Boost Control



- ✍ Instantaneous Boost Pressure and Torque Response
- ✍ Reduced Emissions and Improved Driveability



Summary



- ✍ **Turbocharger and ETC - System are Designed and Analyzed**
- ✍ **Performance Predictions Indicate 5% - 10% Fuel Economy Improvement**
- ✍ **Opportunity for Reduced Emissions and Improved Driveability**