Waste Heat Recovery Utilizing Electric Turbocompounding

DOE Contract DE-SC05-99OR22735

DOE

Team Leader: Gurpreet Singh

Prgm Mngr: John Fairbanks

Tech Mngr: Carl Maronde

Caterpillar

PI: Ulrich Hopmann

2004 DEER Conference
Coronado, CA

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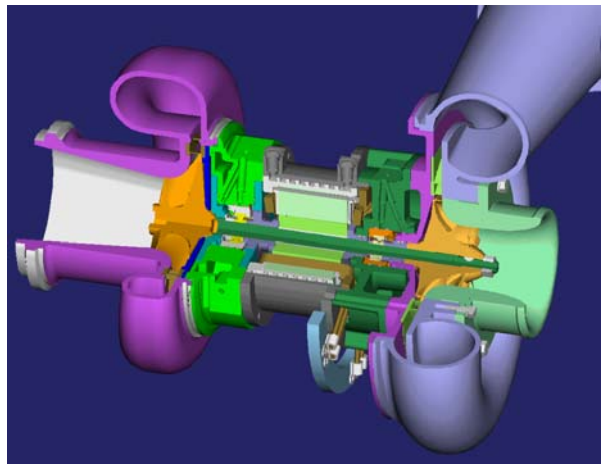
Agenda

- Program Objectives and Electric Turbocompound (ETC) System Background
- Update on Component Developments
  - Turbo-shaft generator and crankshaft motor
  - Air handling system
  - Control system
  - Component testing
- Cost/Value Study
- Next Steps and Summary

Diesel Electric Turbocompounding (ETC)



Primary Objectives:

- Demonstrate technical feasibility
- Improve fuel economy

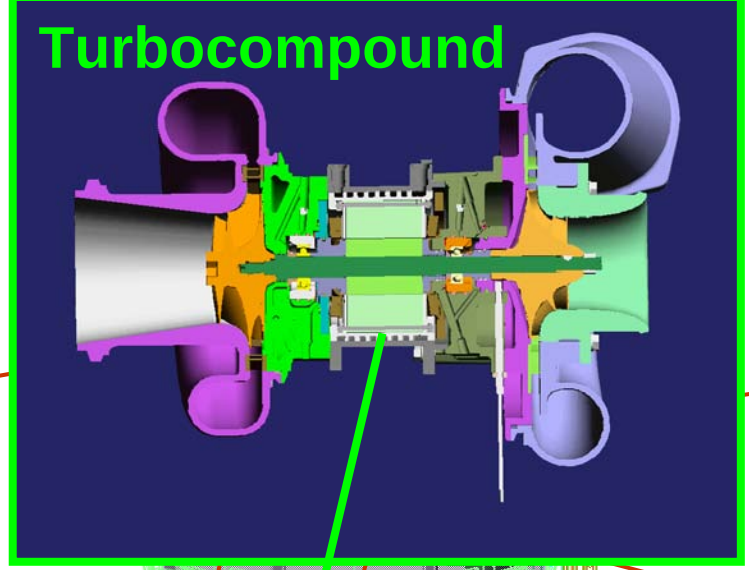
Program Goals and Milestones:

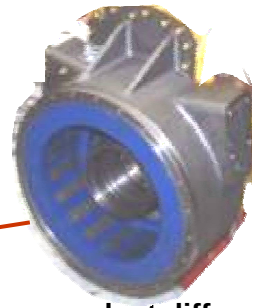
- Conceive and design optimum ETC system
- Develop and bench test turbomachinery
- Develop control system and strategy
- Rig test ETC hardware
- Lab engine test of ETC system

Modular HVAC

Variable speed compressor more efficient and serviceable

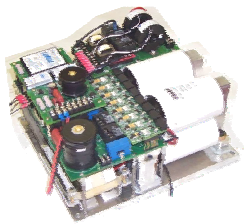
3X more reliable compressor no belts, no valves, no hoses leak-proof refrigerant lines instant electric heat





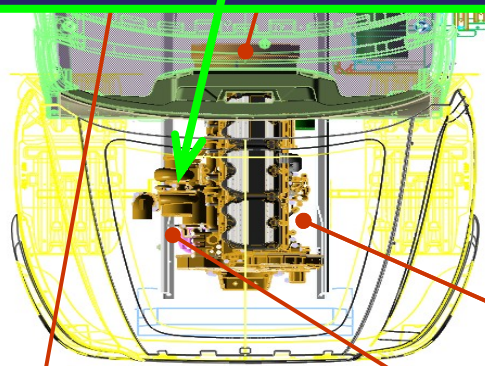
Starter Generator Motor

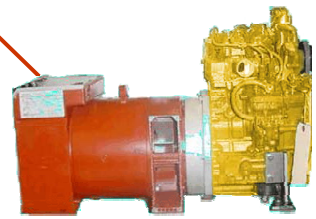
Beltless engine product differentiation improve systems design flexibility more efficient & reliable accessories



Shore Power and Inverter

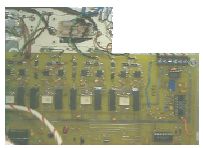
Supplies DC Bus Voltage from 120/240 Vac 50/60 Hz Input Supplies 120 Vac outlets from battery or generator power





Auxiliary Power Unit

Supplies DC Bus Voltage when engine is not running - fulfills hotel loads without idling main engine overnight



Down Converter

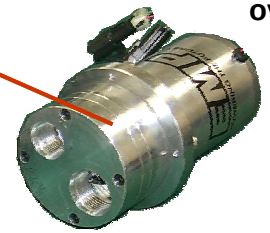
Supplies 12 V Battery from DC Bus

Compressed Air Module

Supplies compressed air for brakes and ride control

Electric Water Pump

Higher reliability variable speed faster warm-up less white smoke lower cold weather emissions



Electric Oil Pump

Variable speed
Higher efficiency

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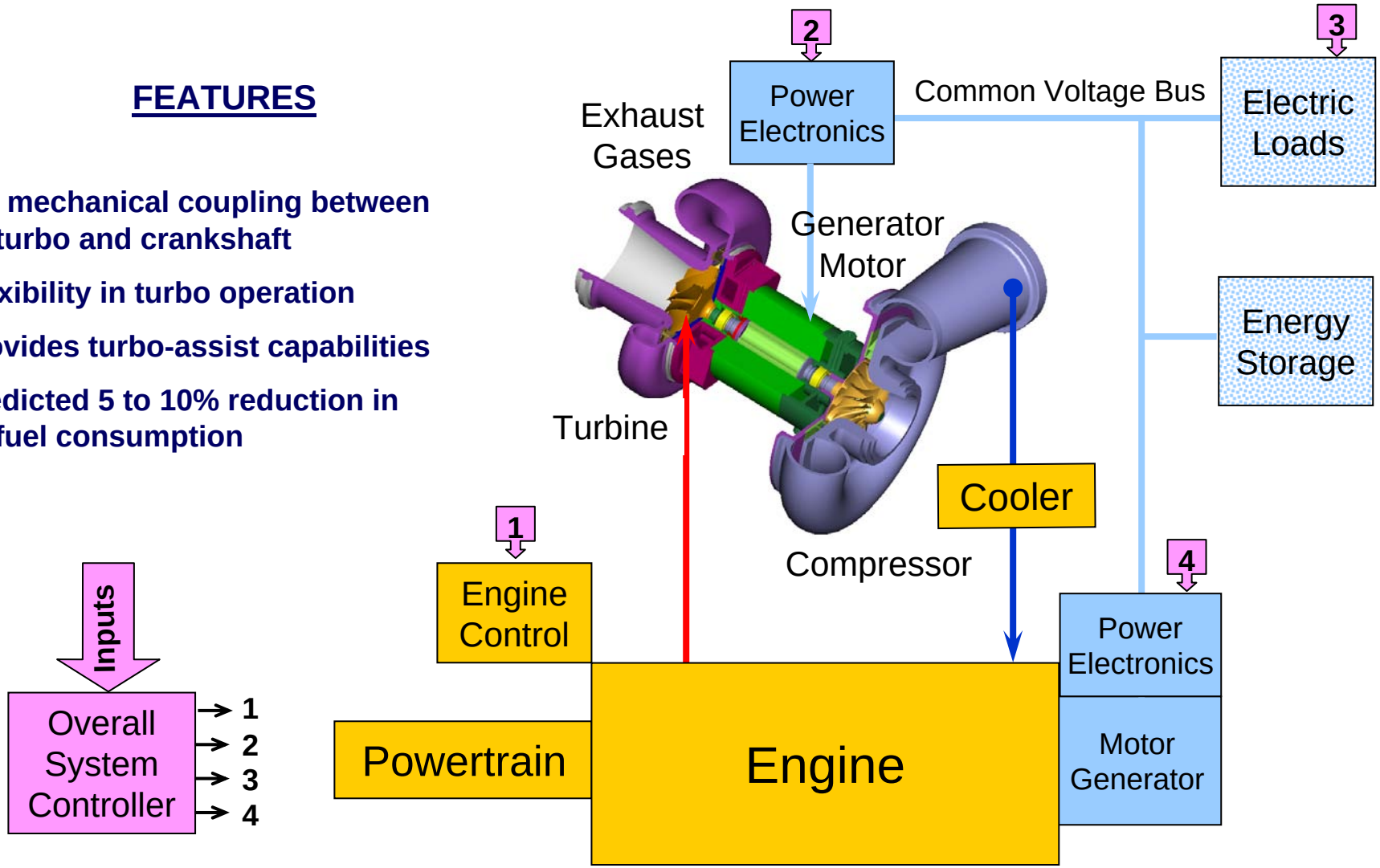
Working Principle

FEATURES

- No mechanical coupling between turbo and crankshaft
- Flexibility in turbo operation
- Provides turbo-assist capabilities
- Predicted 5 to 10% reduction in fuel consumption



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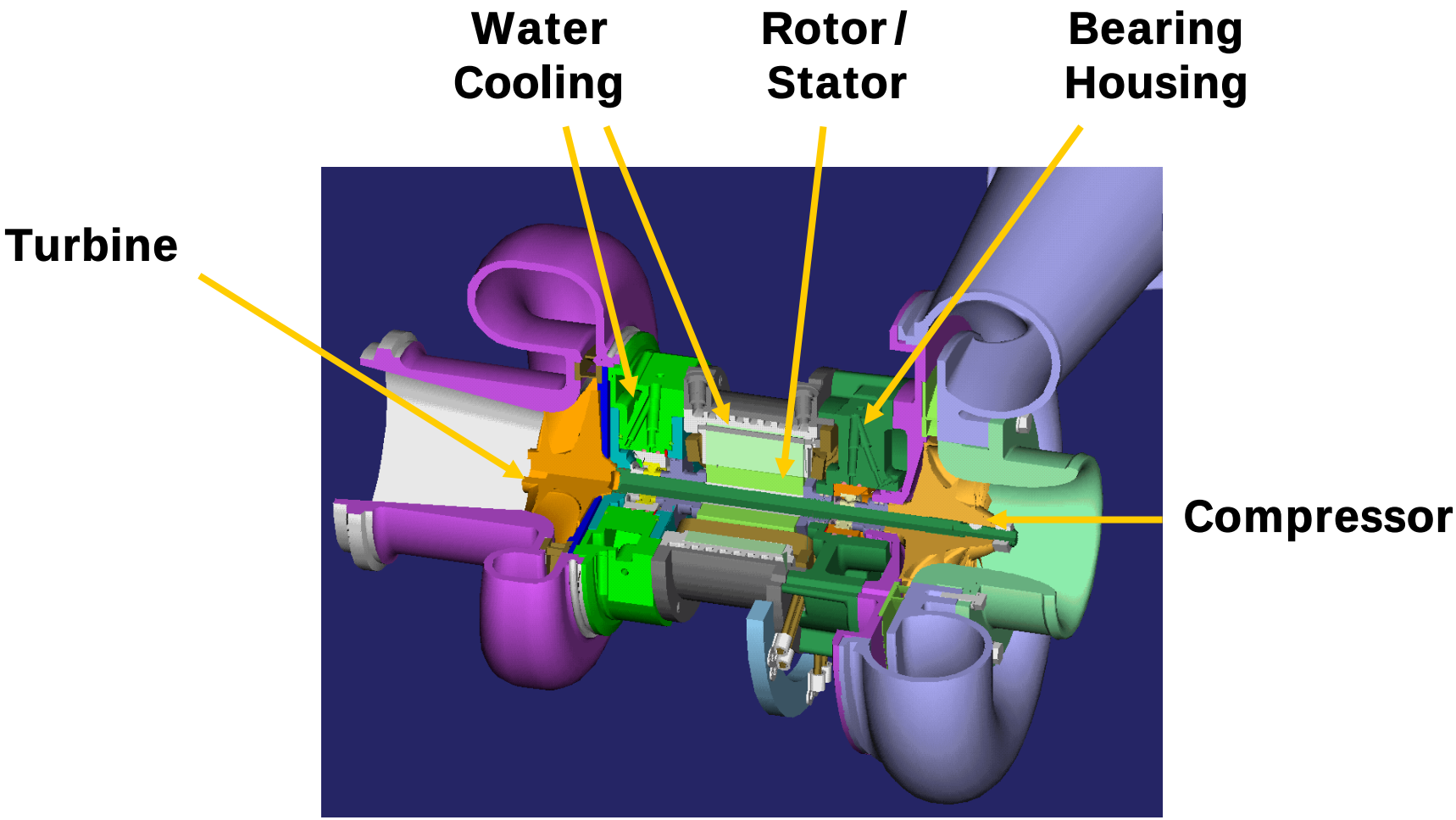
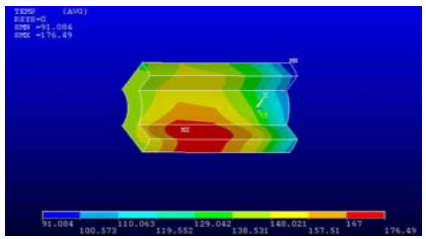
- Program Objectives and ETC System Background
- **Update on Component Developments**
  - **Turbo-shaft generator and crankshaft motor**
  - **Air handling system**
  - **Control system**
  - **Component testing**
- Cost/Value Study
- Next Steps and Summary

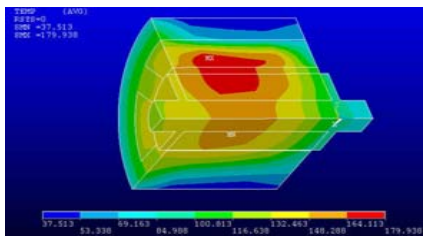
Final Design

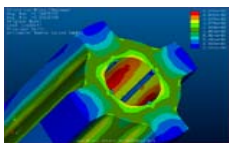


Final Design

Turbo Shaft M/G

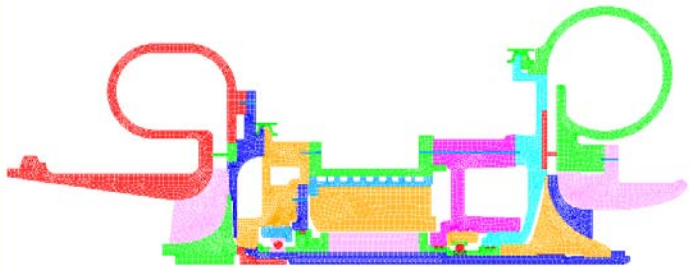


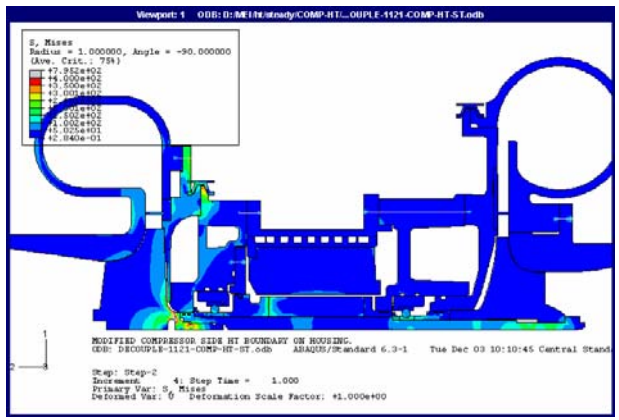




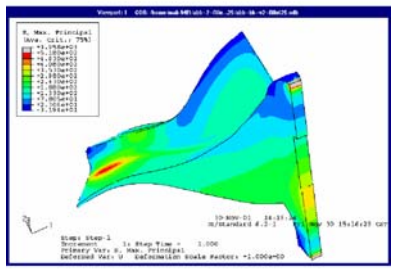
Voltage: Voltage: 340 V
Power: 40 kW / 60kW
Rotor Length: 70 mm

Turbocharger Structure

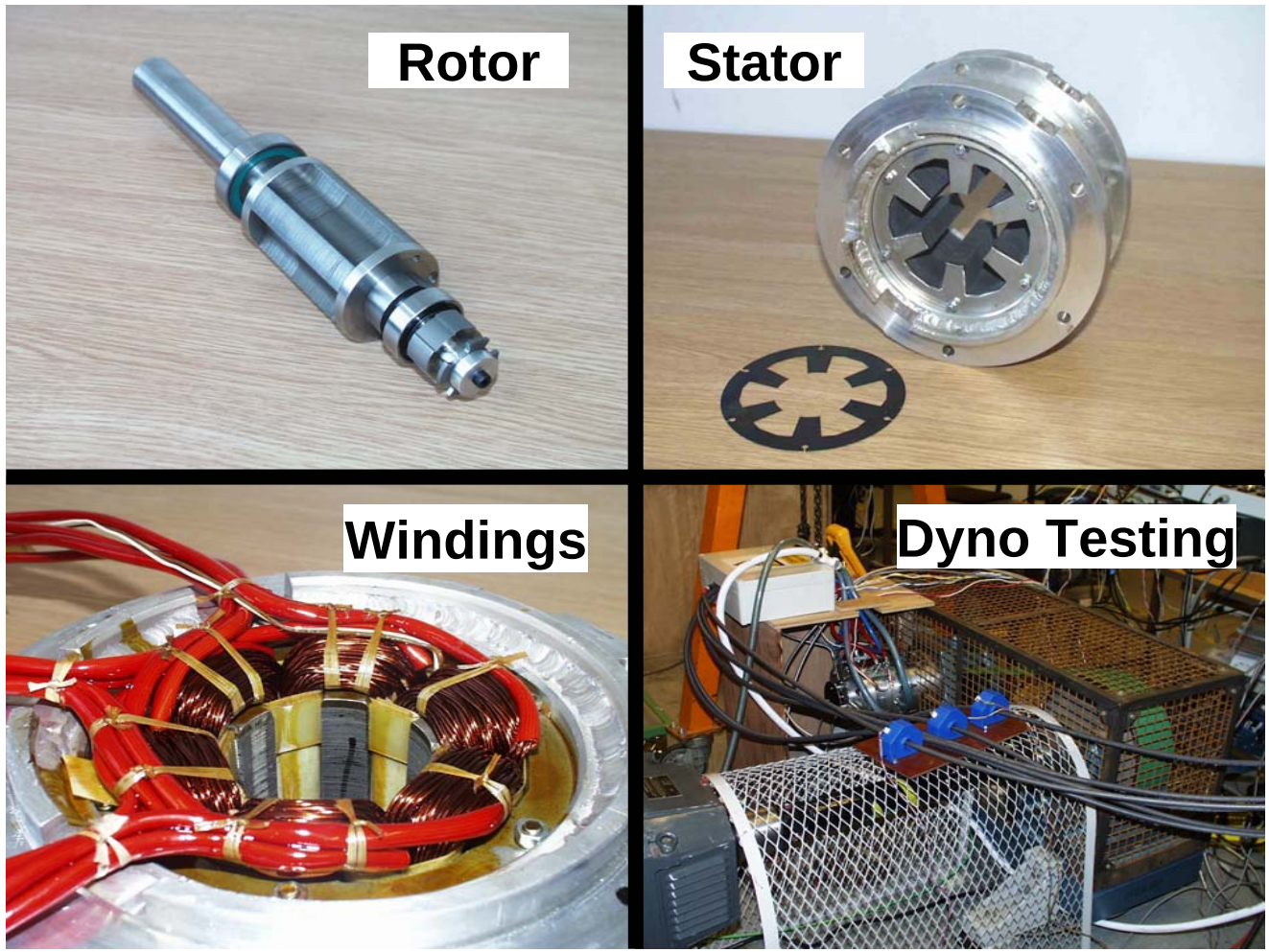




Aero Components

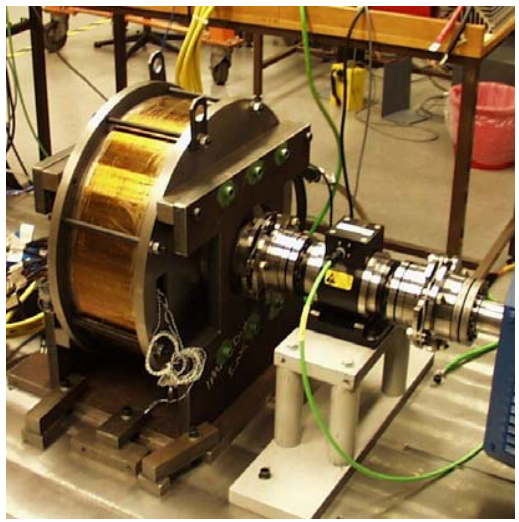


Turbo Shaft – Generator/Motor

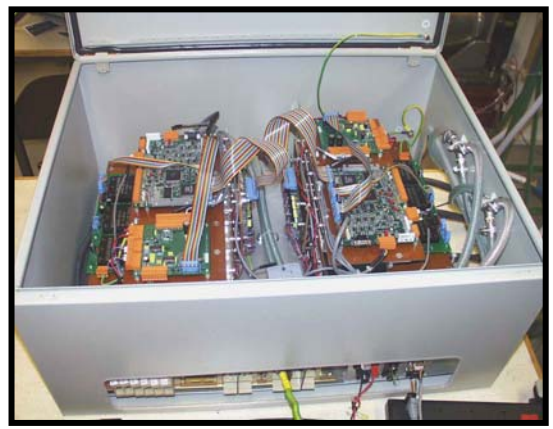


Crank Shaft - Motor/Generator

Flywheel Housing with
Crank Shaft M/G



340 Vdc Crank Shaft M/G



Electronics

Compressor and Turbine

Compressor Scroll and Compressor Wheel with Diffuser

Design Point

- Pressure Ratio (t-s) 3.1
- Efficiency (t-s) 82%, max. 85%

Turbine Scroll and Turbine Rotor with Nozzle

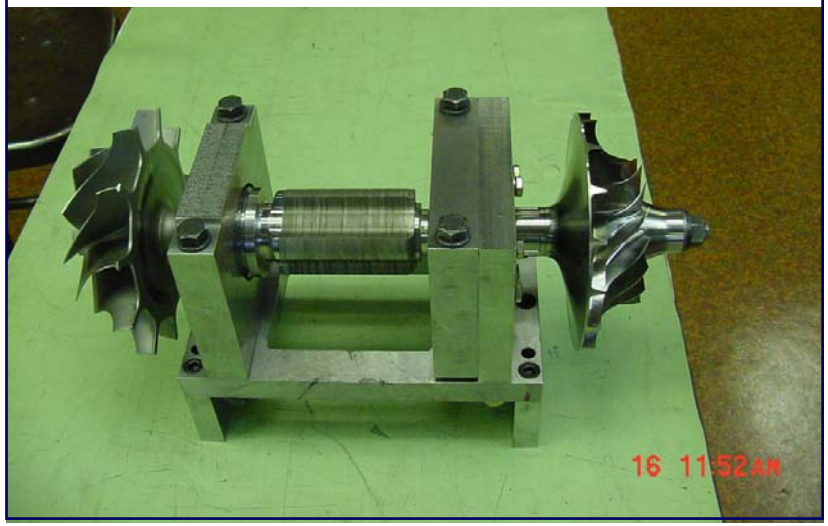
Design Point

- Pressure Ratio (t-s) 3.7
- Efficiency (t-s) 84%, max. 85%

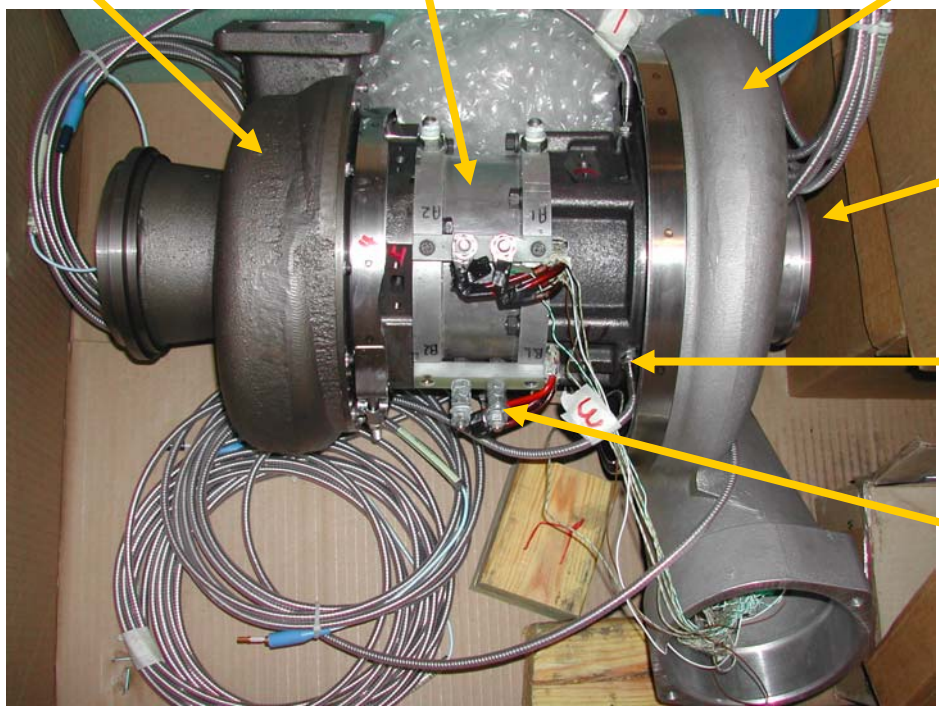
Turbo Shaft & Bearing Housing

Turbo Shaft w/ Ball Bearings

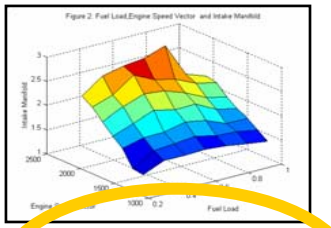
Rotor Assembly with Balancing Fixture



Assembled ETC Turbocharger



ETC Control System

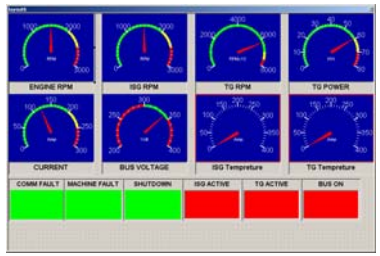


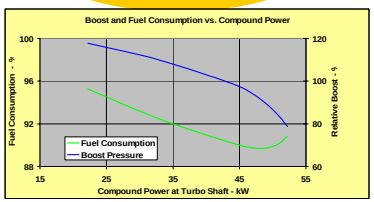
Map Boost / Speed / Load

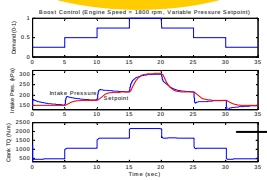
Boost at Optimum Fuel Consumption

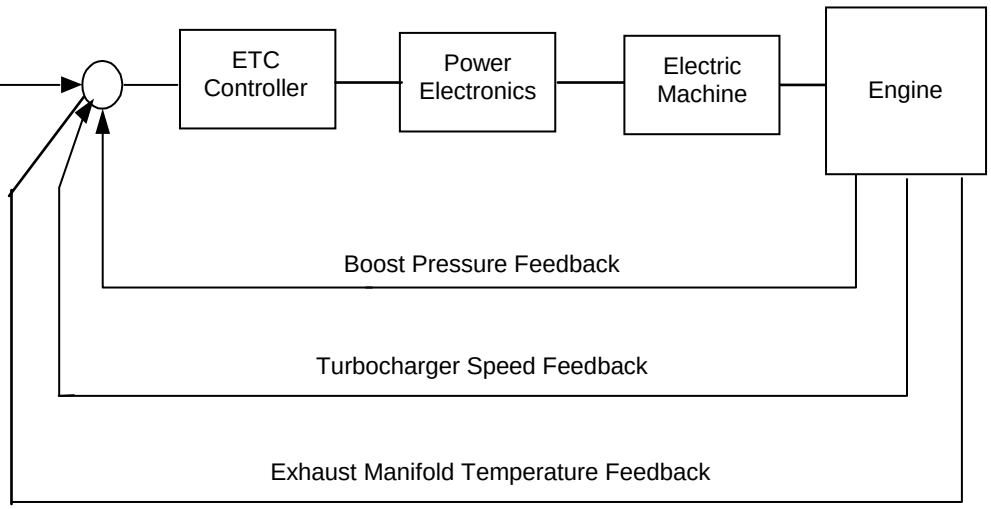
Set Point for Transient Behavior

- System Simulation in Simulink
- Controller Implemented in dSpace
- Virtual Instrumentation Capabilities



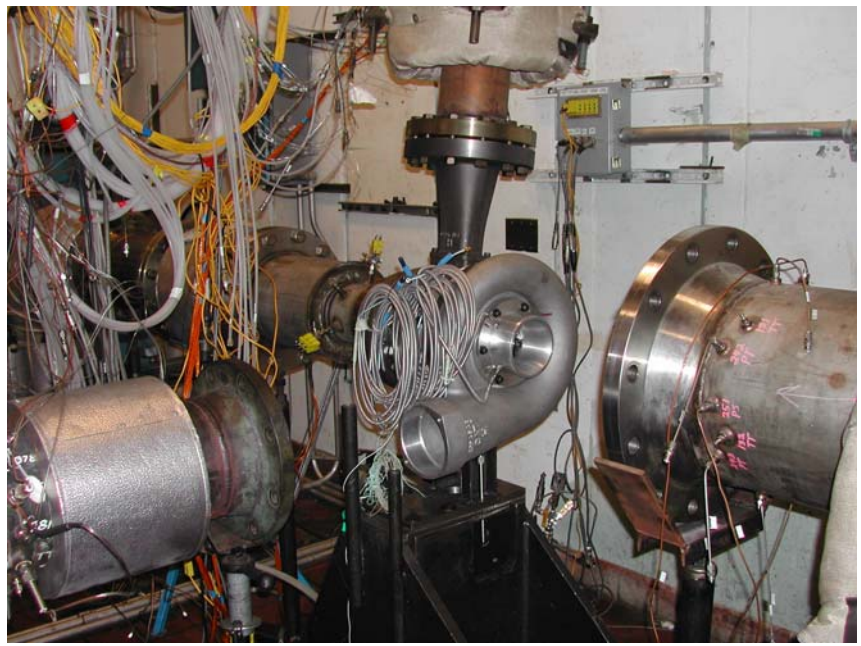






Component Testing

- Turboshaft and crankshaft motor/generator (M/G) have been tested on separate test rigs
- Measured peak efficiency of crankshaft M/G at target level
- ETC turbocharger is being tested on gas stand
  - Rotor dynamics check
  - Compressor map
  - Turbine map
- Engine test planned for October 2004



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Cost/Value Study

Value of ETC Technology

- 3 to 5% bsfc reduction

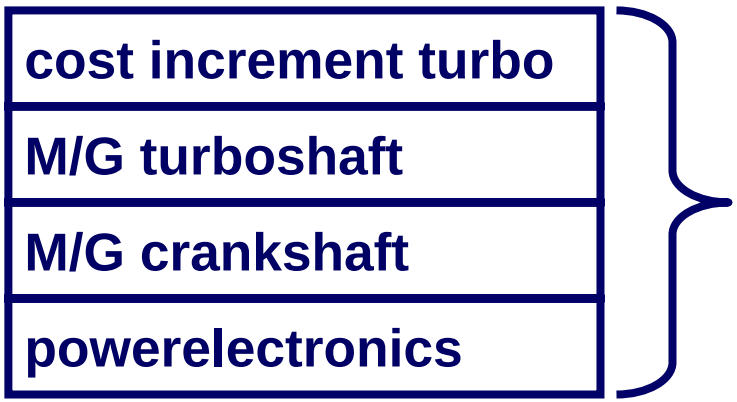
Program is based on MY 2000 engine

- No need for waste gate
- Enhanced braking power through
  - Higher boost
  - Regenerative braking with crank m/g

- Turbo assist capabilities
- Control A/F ratio (gas engines)
- Improved cold startability
- Altitude capability

System – Cost/Value: Example On-Highway Truck

- ETC system cost



  - System cost: $ 2000 to $ 3400
  - Powerelectronics account for half the cost

- Customer Benefit
  - Payback period between 13 (best case) and 38 months

Next Steps for ETC Development

- Complete test of ETC turbocharger in gas-stand lab-setting
- Complete engine testing with ETC system
- Assess ETC on low emission engine
  - Packaging
  - Aerodynamics
  - Cost effective design
  - Reliability/durability demonstration

Summary

- Turbocharger and ETC system have been designed and analyzed
- Performance predictions indicate 3 to 5% fuel economy improvement for cycle, 10% at key operating point
- Opportunity for reduced emissions and improved drivability
- E-Machine hardware testing completed
- Cost/Value analysis shows high customer value