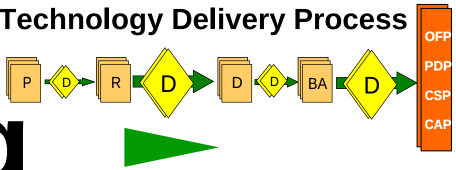
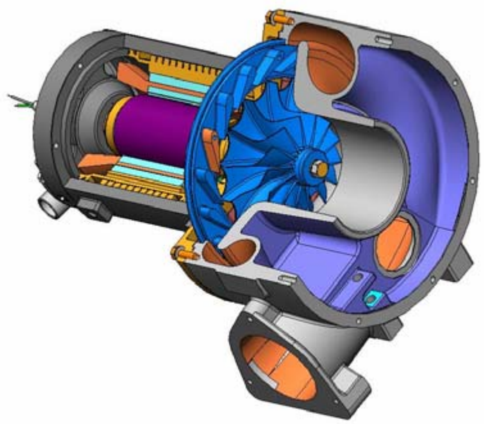
Technology Delivery Process



Turbo Compounding

A Technology Who’s Time Has Come



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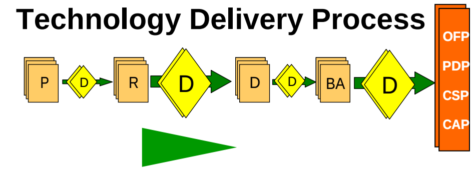
Carl T. Vuk

John Deere Moline Technical Center



OUTLINE

- History
- Rate Limiters
- Environmental Factors
- Electric Turbo Compounding
- System Architecture
- Drivers
- Analysis
- Testing
- Summary

Turbo Compounding History

- 1953 **Douglas DC-7 (Wright 3350 TC)**
- 1954 **Napier Nomad** (12 Cyl Diesel 2-stroke)
- 1968 **Mitsubishi** 10ZF (V10 2-stroke Diesel)
- 1981 Cummins NH
- 1983 Cummins V903 (Military Application)
- 1986 Cat 3406 & 11.3L
- 1988 Hino 8.82L
- 1990 DAF
- 1991 **Scania 11L** (Current Production)
- 1998 Cat 15L (21^{st} Century Truck)
- 2002 Isuzu Ceramic IDI (Experimental)
- 2002 **Volvo** (Current Production)

Napier Nomad
Circa 1955

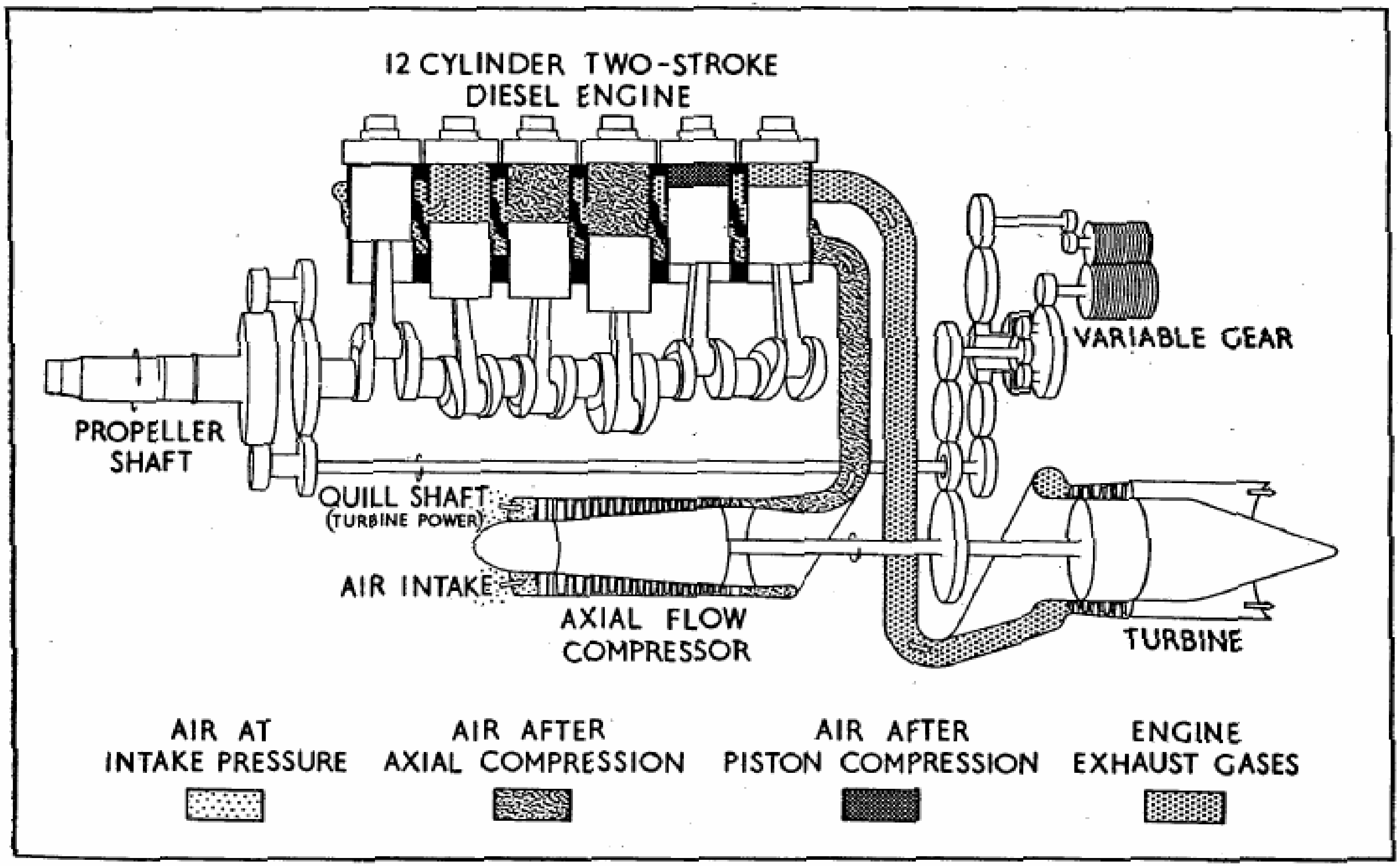
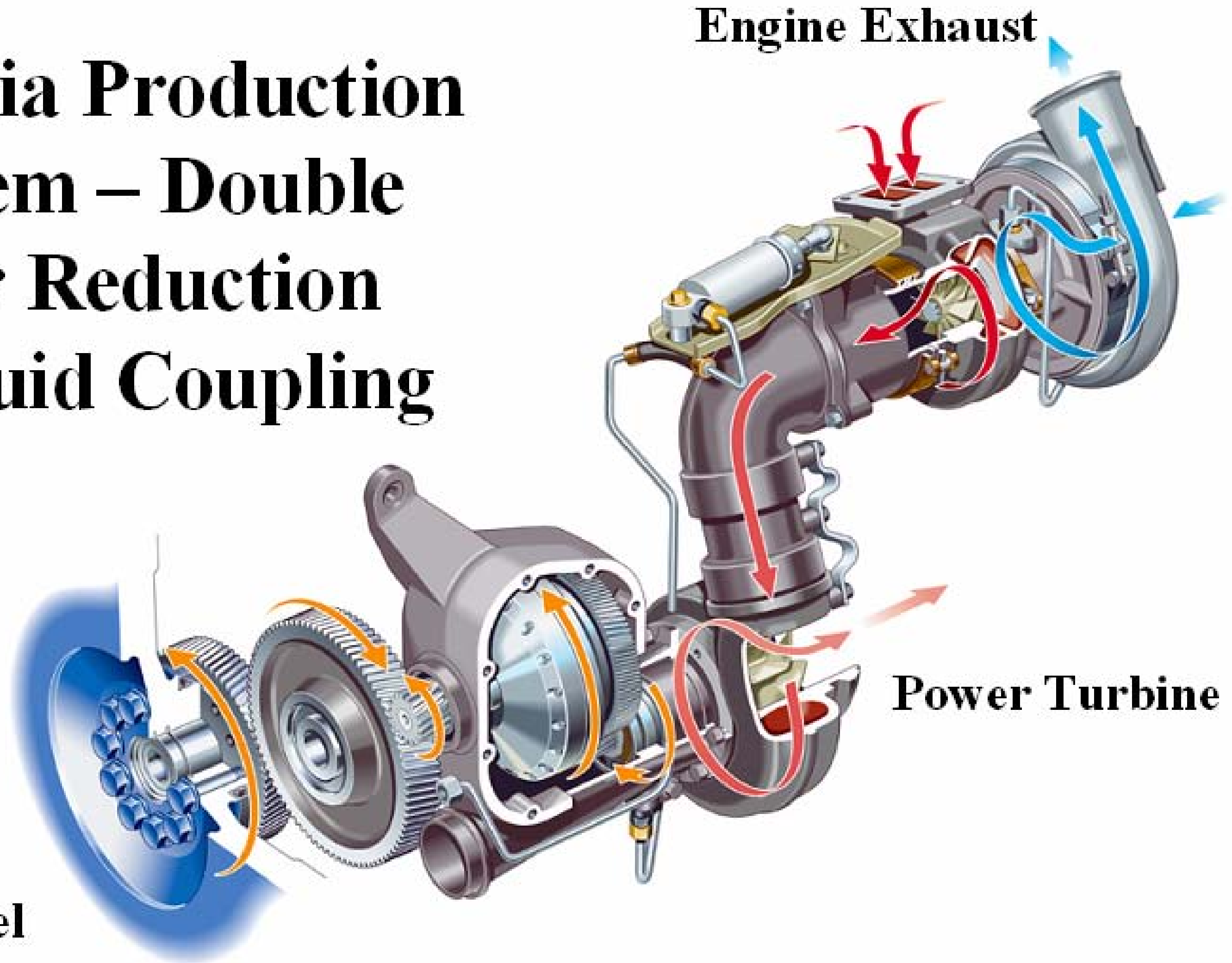


Fig. 8 – Diagram of Nomad engine

Two-Stage Mechanically Coupled System

Scania Production System – Double Gear Reduction w/Fluid Coupling



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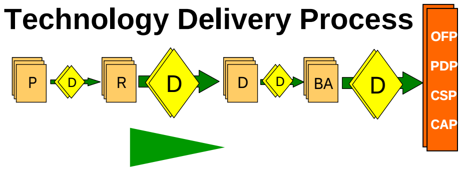
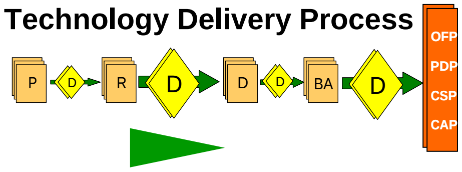
Technology Limiters

Technology Delivery Process



- System Complexity
  - High Ratio Gear Trains
  - Torsional Couplers
  - Impact on Turbocharger and Engine
  - Machine Placement
- Control Issues
- Costs

Technology Delivery Process



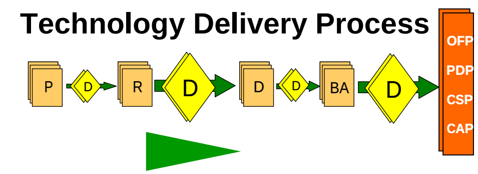
Factors Favoring TC

- Increasing Fuel Costs
- Availability of Low Cost Controls
- Availability of Cost Effective Power Electronics (Automotive Hybridization)
- EGR Requirements for NOx Control
- High Pressure Ratio VG Turbos

Electric Turbo Compounding

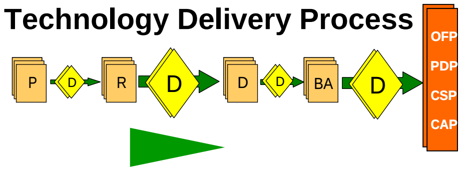
- Simple Architectures Possible
  - Flexible Placement
  - Isolated Coupling
- Integrated Electronic Control
- High Efficiency
- Modest Cost

TurboCompounding Drivers



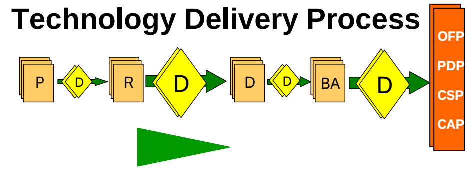
- Improved Fuel Economy - 10+%
- Increased Power Density - 20+%
- Emissions & After Treatment Benefits
- High Exhaust Pressure Requirement – EGR
- Maturation of Electrification Technology

Technology Delivery Process



Emissions Impact

- Increased Output Directly Impacts Specific Emissions
- Power Turbine Reduces Net Impact of Retarded Injection Timing
- Improved Transient Response Lowers Emissions
- Electrical Output Can Power Emissions Control Devices

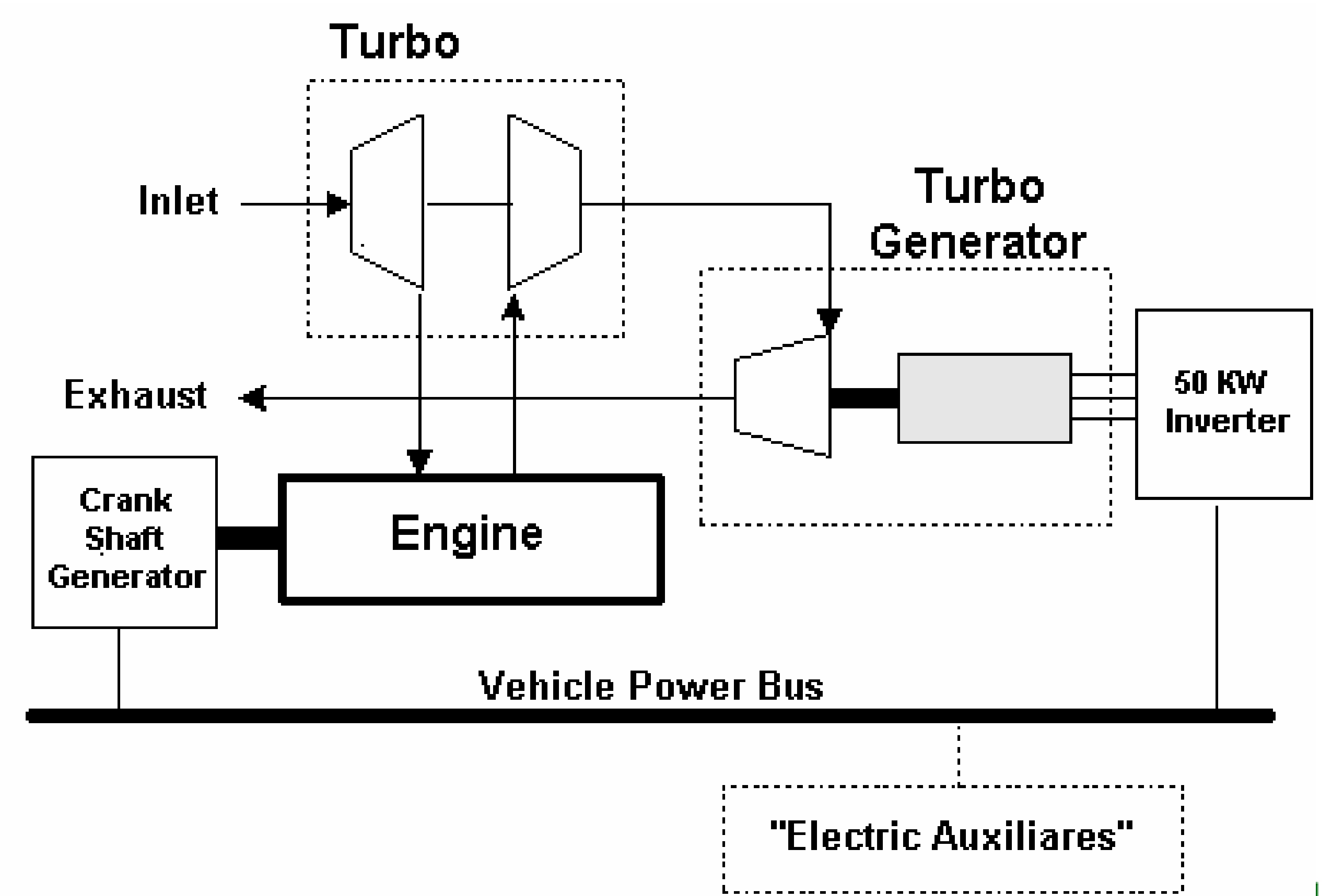


Power Density Growth Enablers

- Turbo Chargers (1970 – 1990)
- After Cooling (1975 – 2005)
- High Performance Pistons (1985 – 2005)
- **Turbo Compounding** (2008 - ….)

TC System Schematic

Electrically Coupled Deere System



Turbo Generator on Gas Stand

Technology Delivery Process

P D R D D D BA D

OFP
PDP
CSP
CAP

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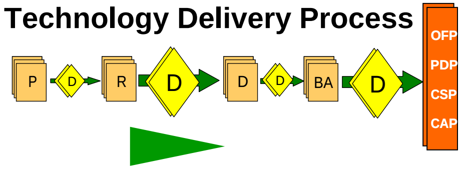
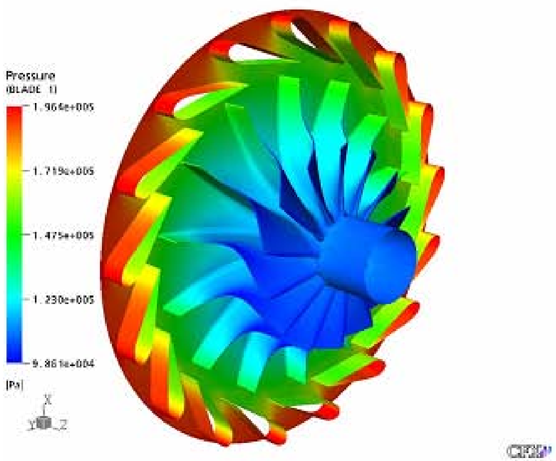
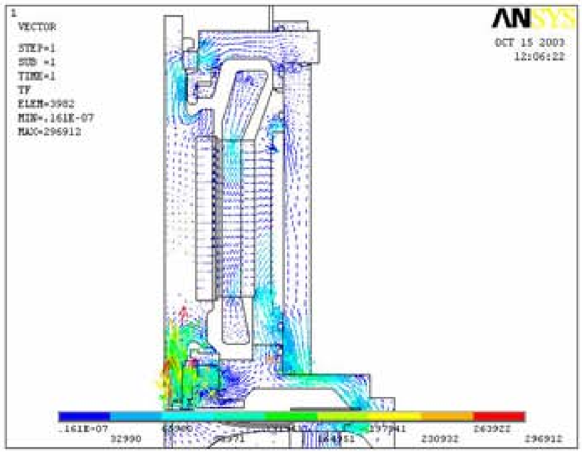
Analysis

Technology Delivery Process

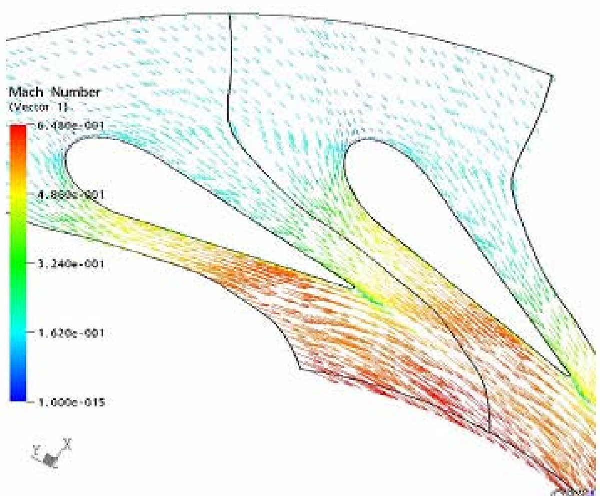




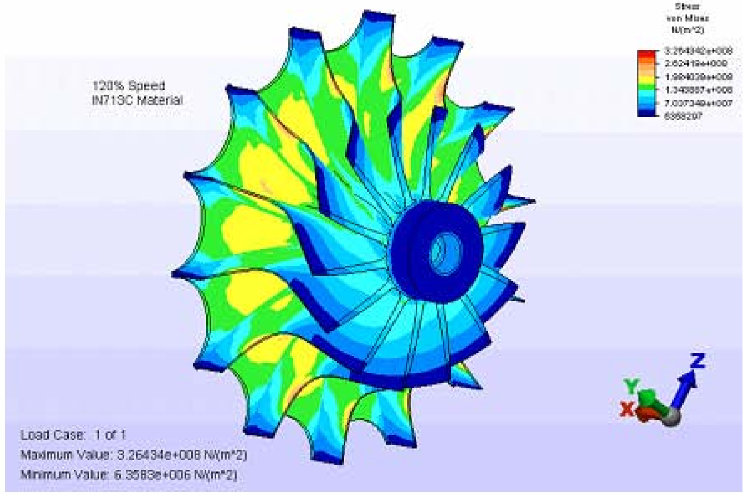
Pressure Distribution



Heat Flux



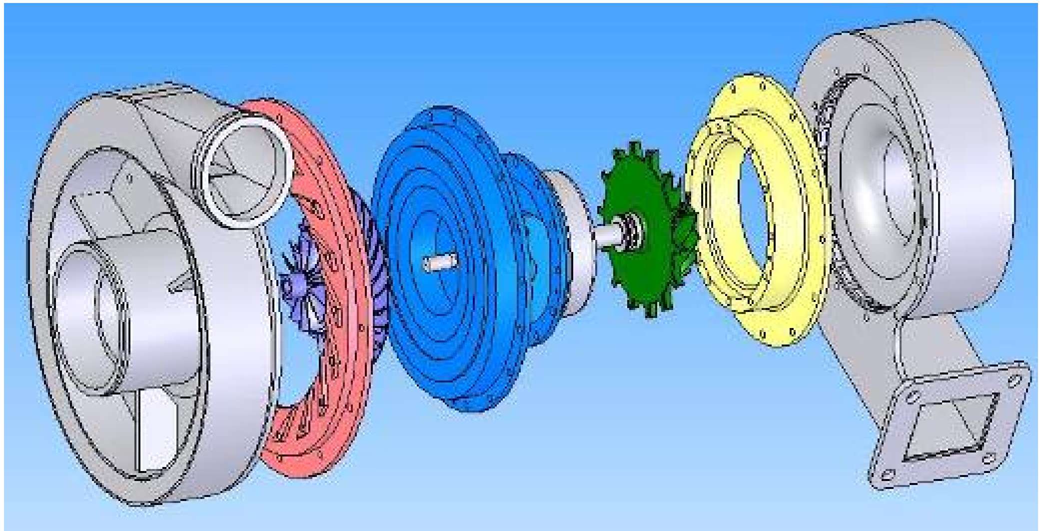
CFD - Flow Around Vanes

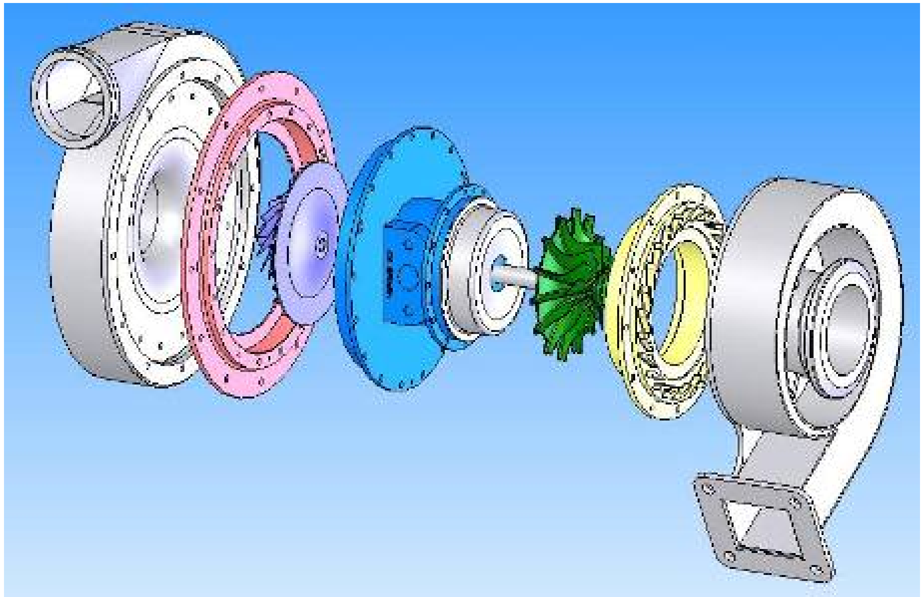


Blade Stresses

RE

Turbocharger Assembly





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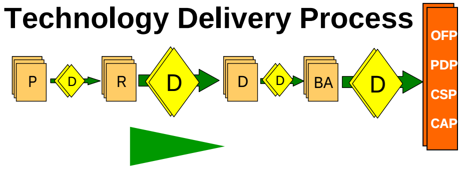
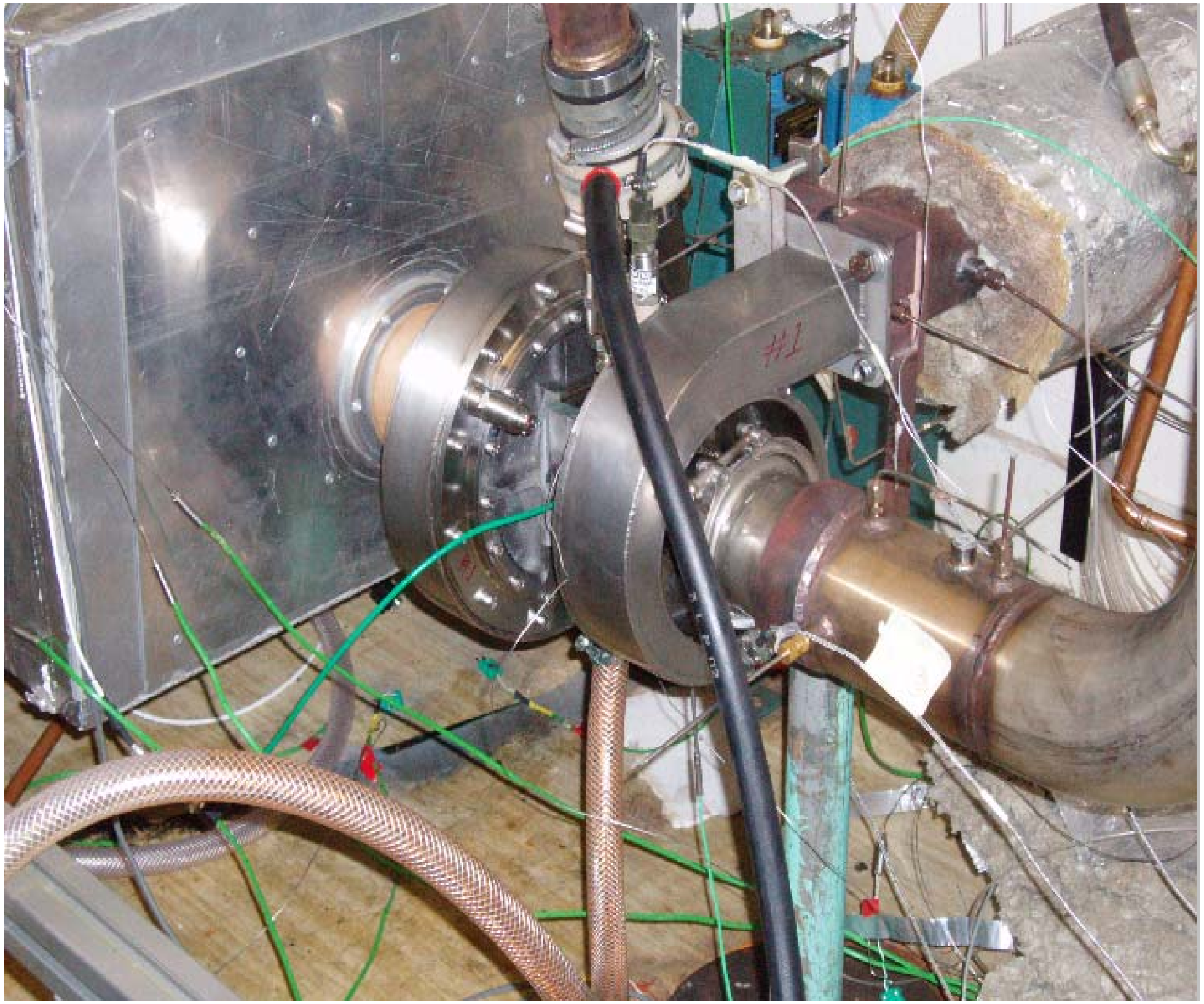
Advanced TurboCharger





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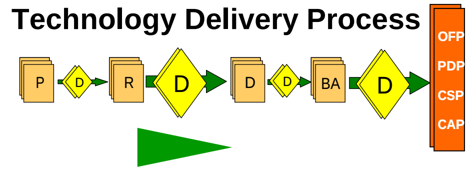
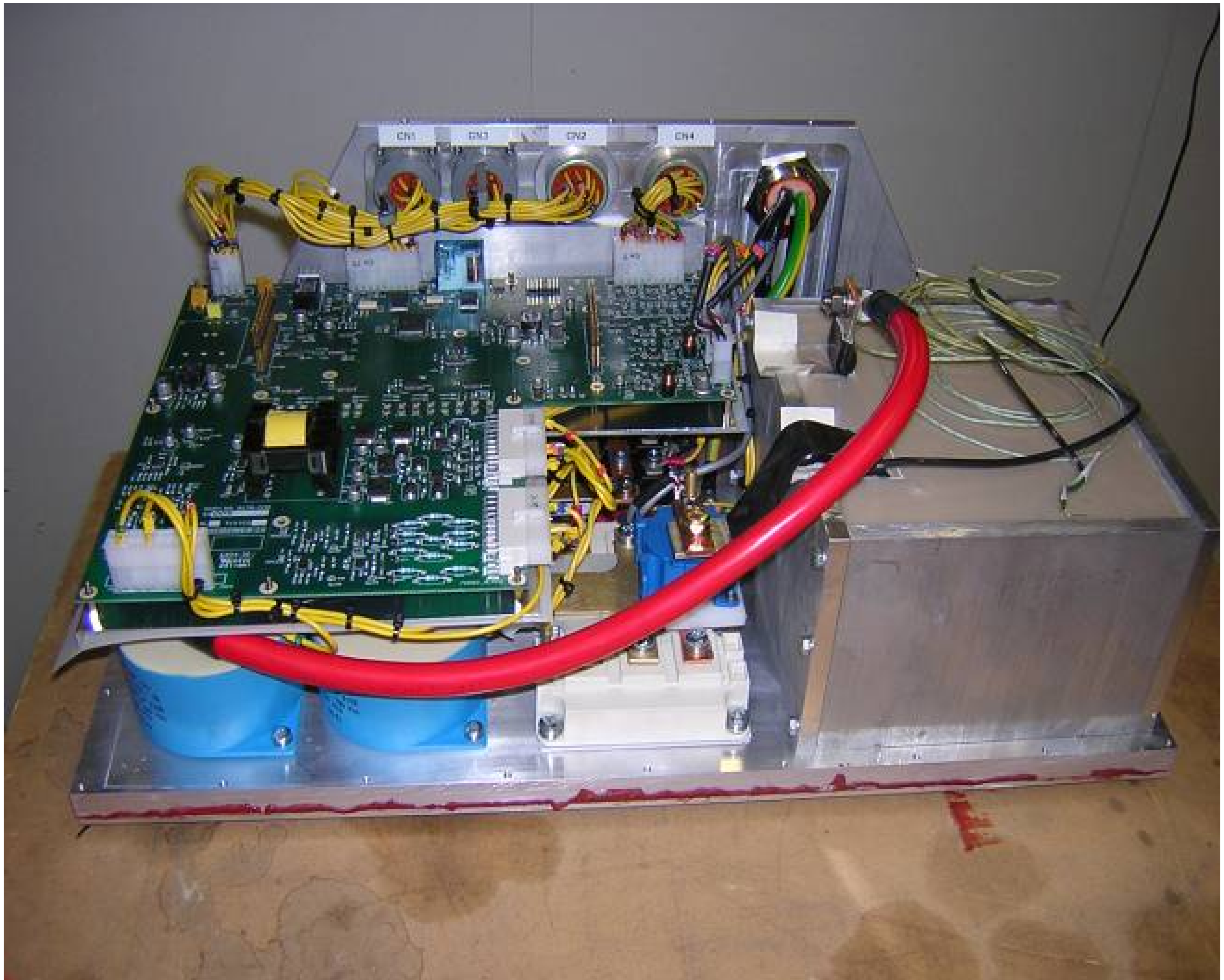


Power Electronics



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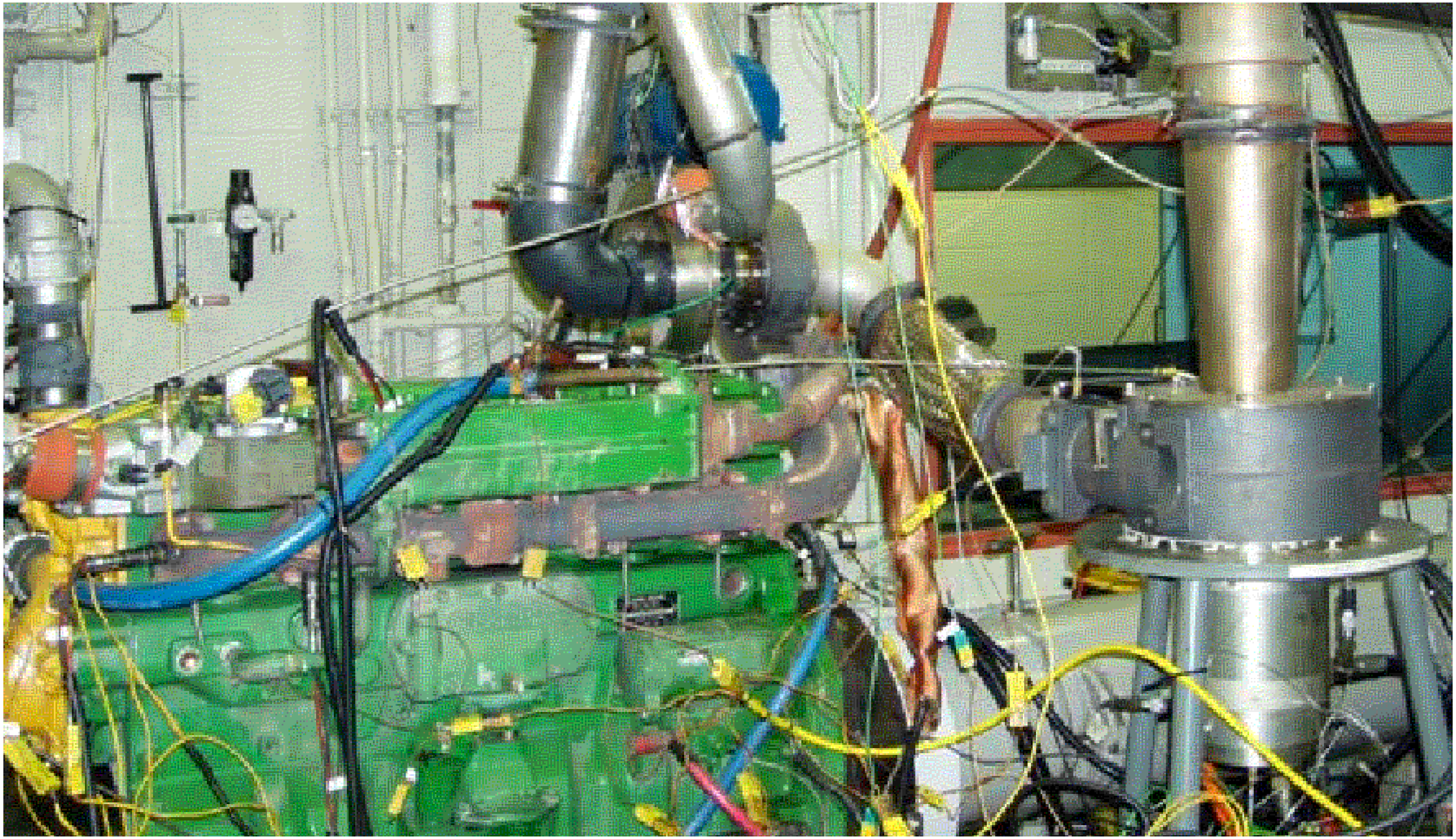
Engine Testing

Technology Delivery Process

P D R D D D BA D

OFP PDP CSP CAP



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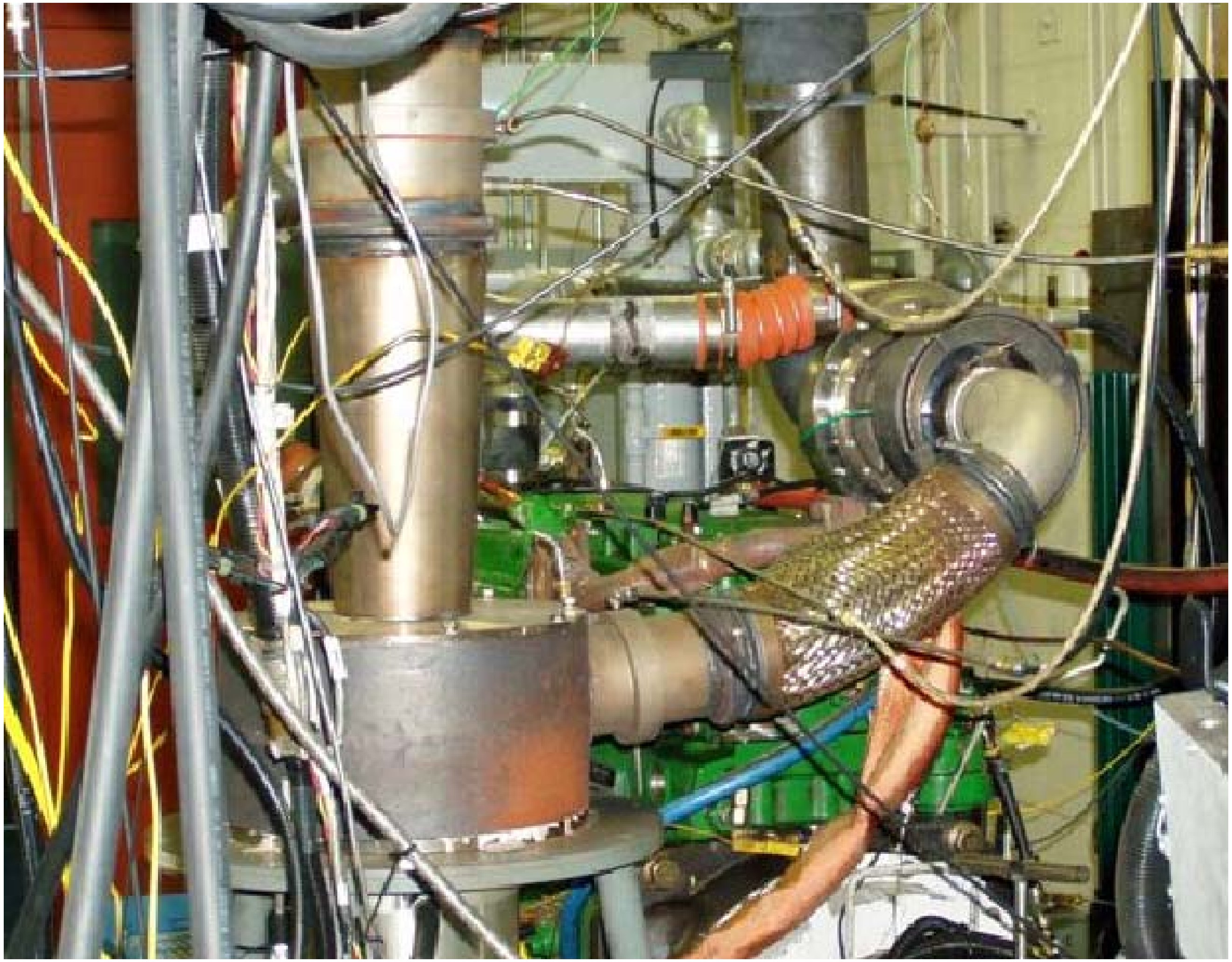
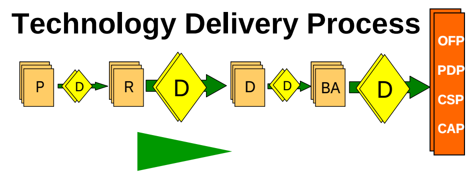
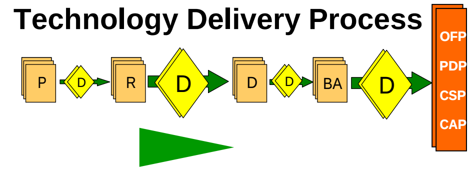
Engine Testing





System Parameters

- 50 kW Turbo Generator
- 340V DC Output
- Wastegate Control For Overspeed Protection
- 50 kW Motor/Generator
- No Energy Storage
- Integrated Control Engine/Turbo Generator
- Advanced High Pressure Ratio Turbocharger

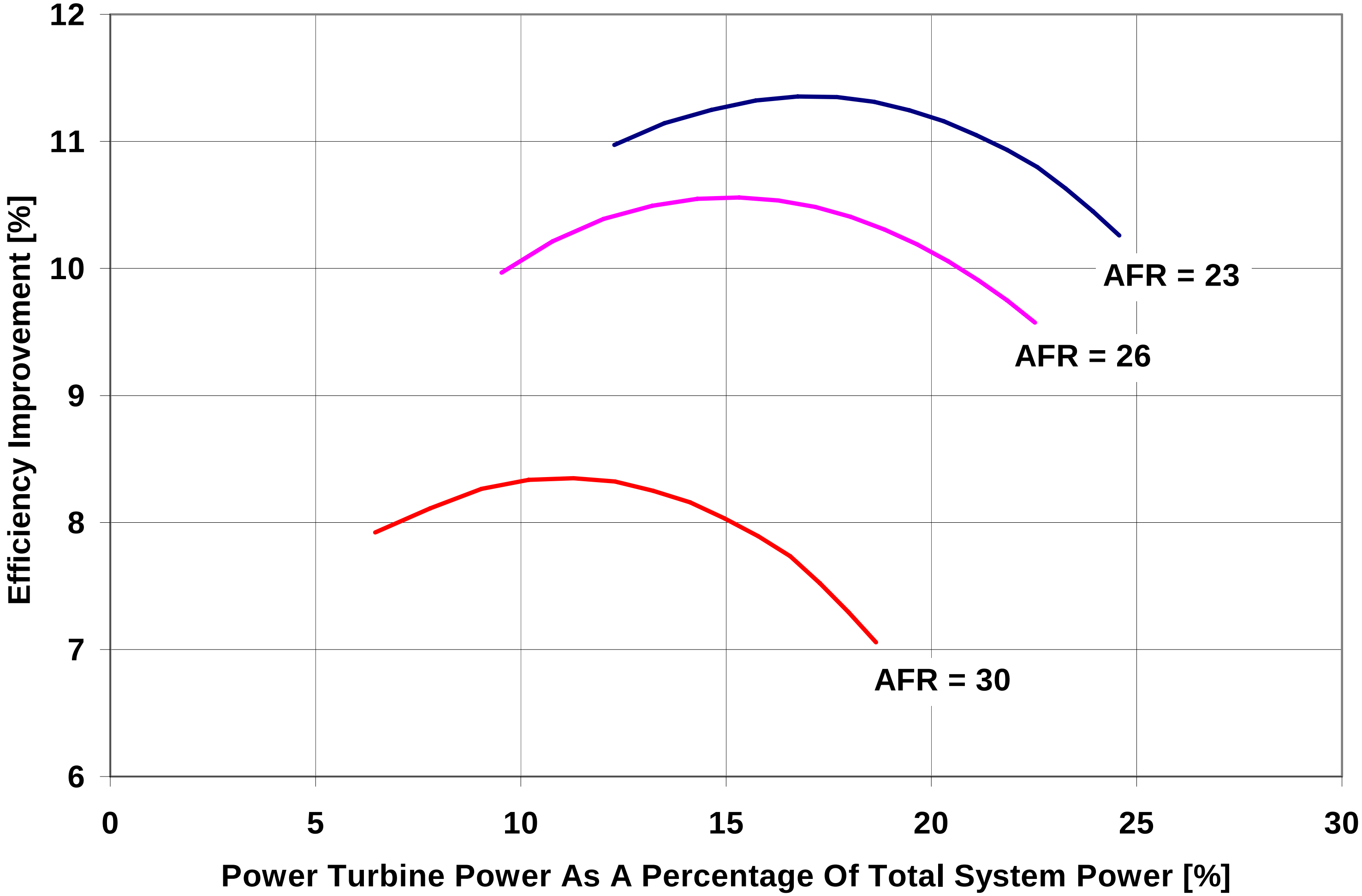


Efficiency Targets

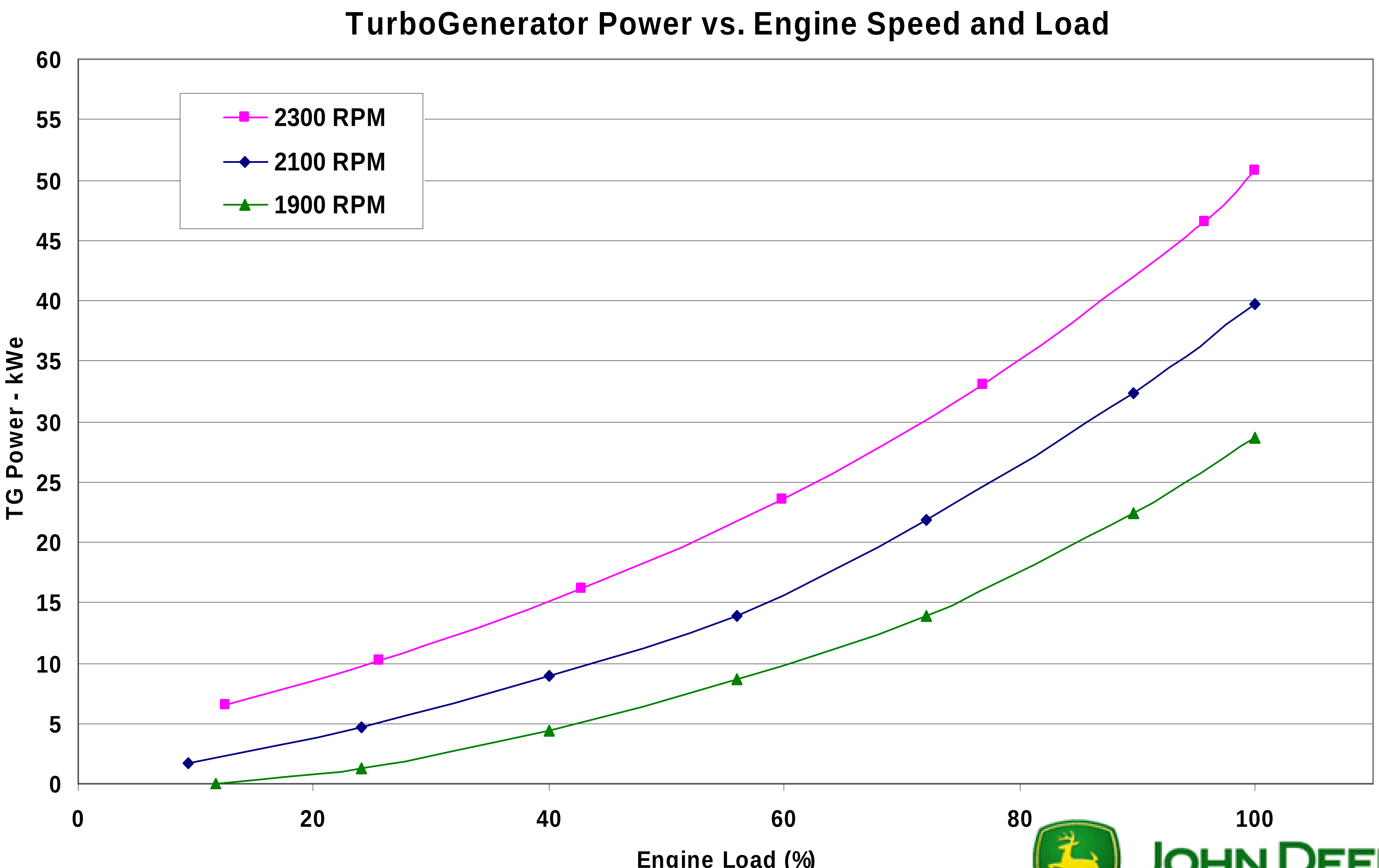
➢ Power Turbine	85%
➢ Turbo Generator w/Controller	95%
➢ Turbocharger Compressor	78%
➢ Turbocharger Turbine	85%
➢ Motor/Generator w/Controller	95%
➢ Engine w/TurboCompounding	46%

WAVE Performance Predictions

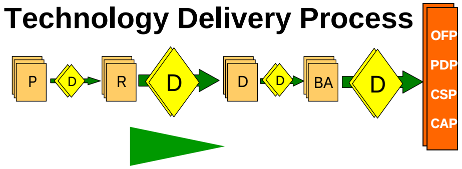
Turbocompound Effect On Performance



Engine Test Data



Technology Delivery Process



Application Selection Criteria

- Steady-State High-Duty Cycle Operation
- High Annual Usage
- Power Growth Requirement
- Vehicle Electrification Benefits

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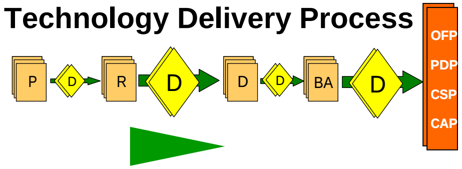
Potential Applications



9000 Tractor

8000 Tractor

Combine

Truck

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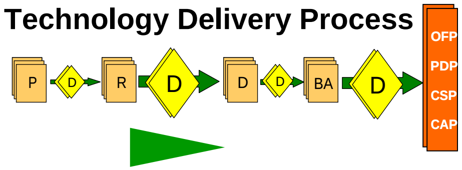
DoE Program Focus

Technology Delivery Process

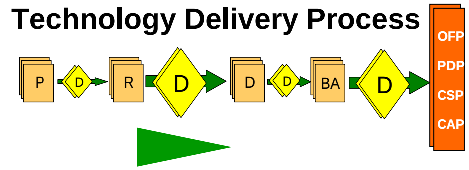


- Define Application Scope
- Develop and Evaluate Second Generation Hardware
- Integrate Turbo Compounding With Engine for Optimal Performance and Emissions

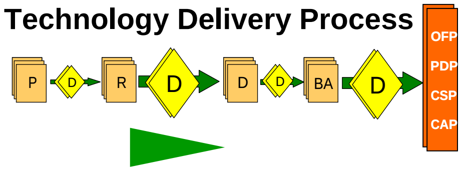
Summary

- Proven Technology
- Significant, Economy, Power, and Emissions Benefits
- Must be Integrated With Emissions Strategies and Vehicle Electrification
- Benefits in Specific Applications to be Defined

Acknowledgments



- Funding
  - John Deere Tech Council
  - DOE
- Engine Performance Testing
  - Todd Whiting



Questions ?