Honeywell

Design and Development of e-Turbo™ for SUV and Light Truck Applications

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Acknowledgments

US DoE
John Fairbanks
Gurpreet Singh

Presentation Outline

- Base Integration of Turbocharger and Electrical Machinery in Suitable Sizes
  - Background/Benefits
  - Status from 2003 DEER Conference
  - Progress - Gen 1, 2 and 3 e -Turbo
  - Define Benefits/Issues “Go/No-Go” Criteria for Larger Turbos
- Variable Geometry Compressor to Realize Full Benefits of Electrical Assist
- Innovative Low Inertia Design to Reduce Demands of Electrical Power - to be Integrated with Electrical Machinery after Proof of Concept
- Integrated Control System Development for EGR, Electrical Machinery and VNT Vane Position

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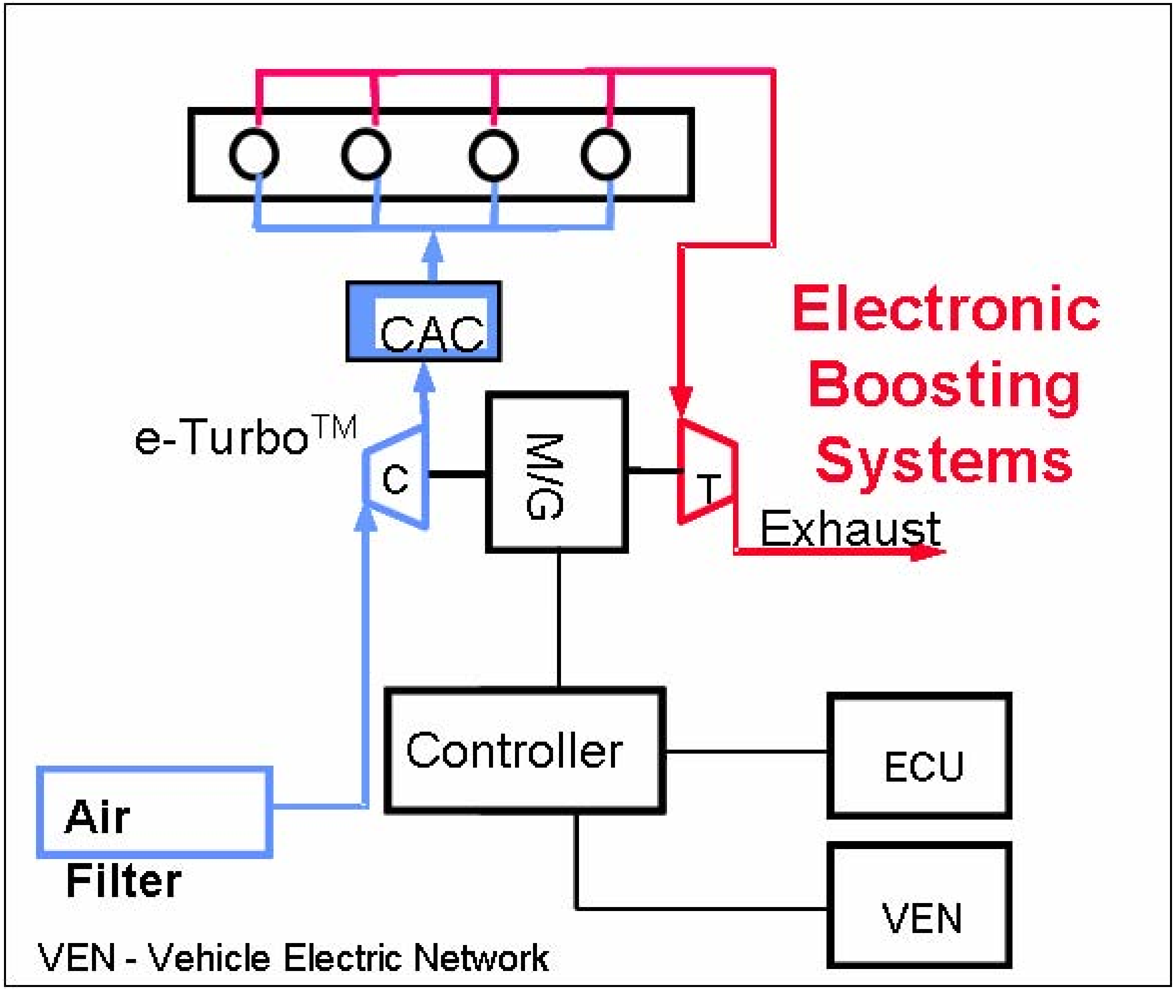
Background: e-Turbo™: Levels/Benefits

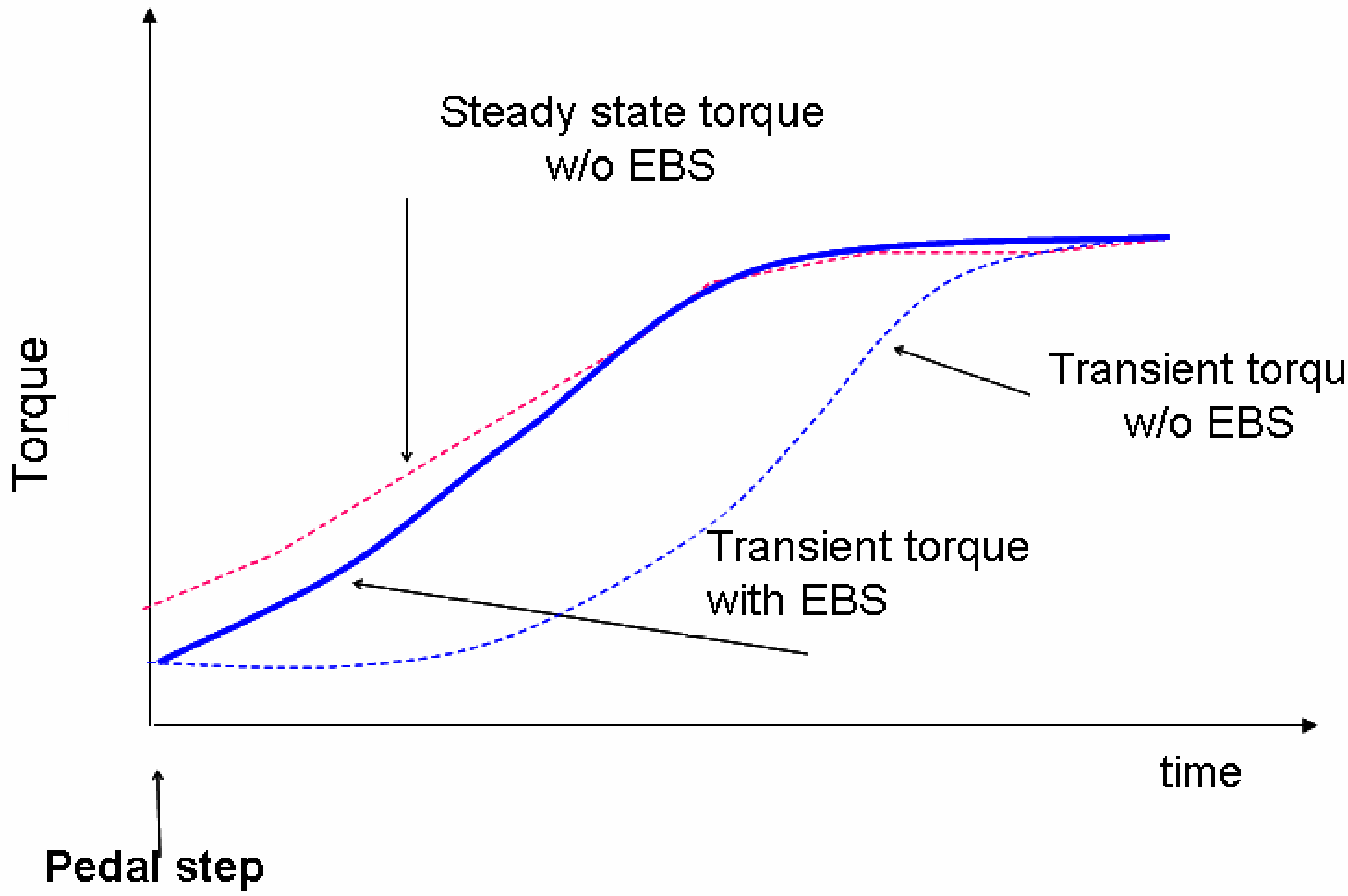


Three Levels of System Benefits

- **Performance - Eliminate Turbolag**
- **Aggressive Engine Downsizing**
- **Air Management System - Synergy with EGR, Fuel Injection, Aftertreatment, Vehicle Power Demands**

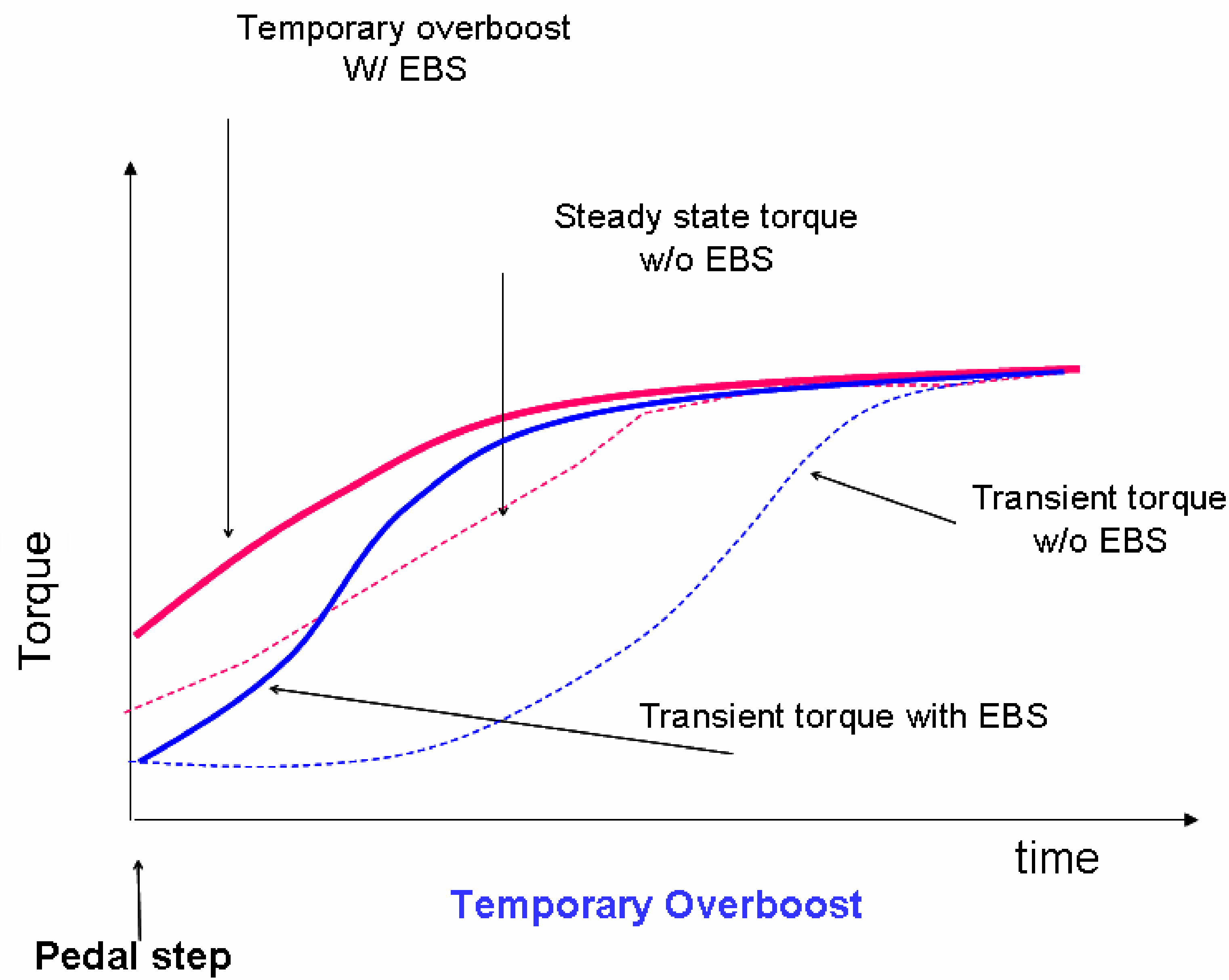
M/G - Supplier Developed 12 V DC Input 2 kW Induction Motor/Generator
Controller - Supplier Developed

Performance Benefits Level I - Eliminate Turbo-lag



Transient Time-to-Boost Improvement

Performance Benefits – Level II Engine Rightsizing



Temporary Overboost

Status from 2003 - Critical "Go/No-Go" Criteria

- High-speed motor/controller system to provide up to 1.4kW mechanical power at speeds up to 175kRPM total system efficiency > 60%.
- Turbocharger bearing system to carry the extra mass and length while still retaining acceptable shaft rotor-dynamic behavior up to 225kRPM.
- Turbocharger and motor cooling system to protect the motor from the extreme turbocharger thermal environment as well as from self-heating.
- Compressor aerodynamics to deliver the extra boost without suffering from surge ("stall") during the transient.

Designs Successfully Establish Feasibility

Fundamental e-Turbo Technical Challenges

Design Criterion	Target	Why	Previous Design	Improved Design
Speed Limit	> 225 Krpm	Aerodynamic performance	< 190,000 rpm • Unstable bearing • Weak motor rotor	Successful
Motor Torque at low speed	0.25 Nm	Boost at low engine speed	< 0.15 Nm	Successful
High speed power	1200-1400 W	Boost performance	< 1000 W	Successful
Motor speed at target power	> 175,000 rpm	Boost up to 2000 rpm engine speed	< 150,000 rpm	Successful
Controller Efficiency	> 70%	Electrical power impact	25-50%	Close
Motor temperature	Normal duty cycle Survival at all "off" conditions	Duty cycle requirements	• Limited usage • Failure at severe "off" conditions	Successful

Technical Feasibility Demonstrated

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Progress with Gen 1, 2 & 3 e-Turbo

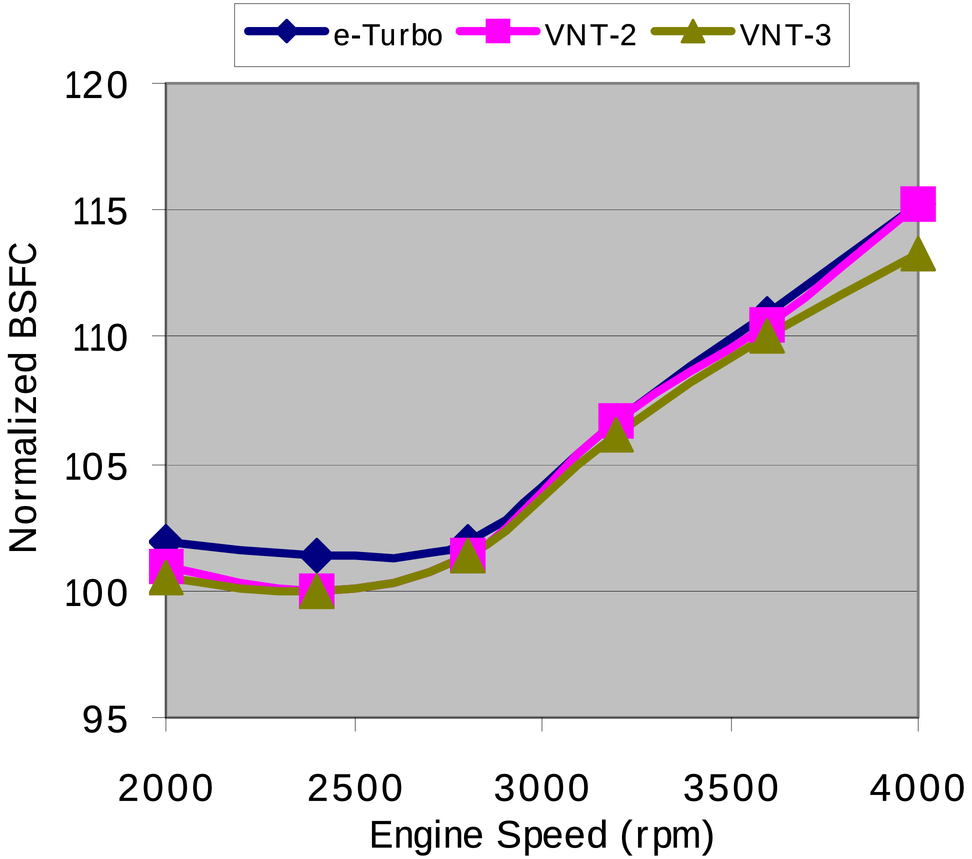
Progress with turbomachinery design and electrical machinery integration continues

Three areas of results reported

- Steady state efficiency and torque
- Transient torque
- Electrical power generation

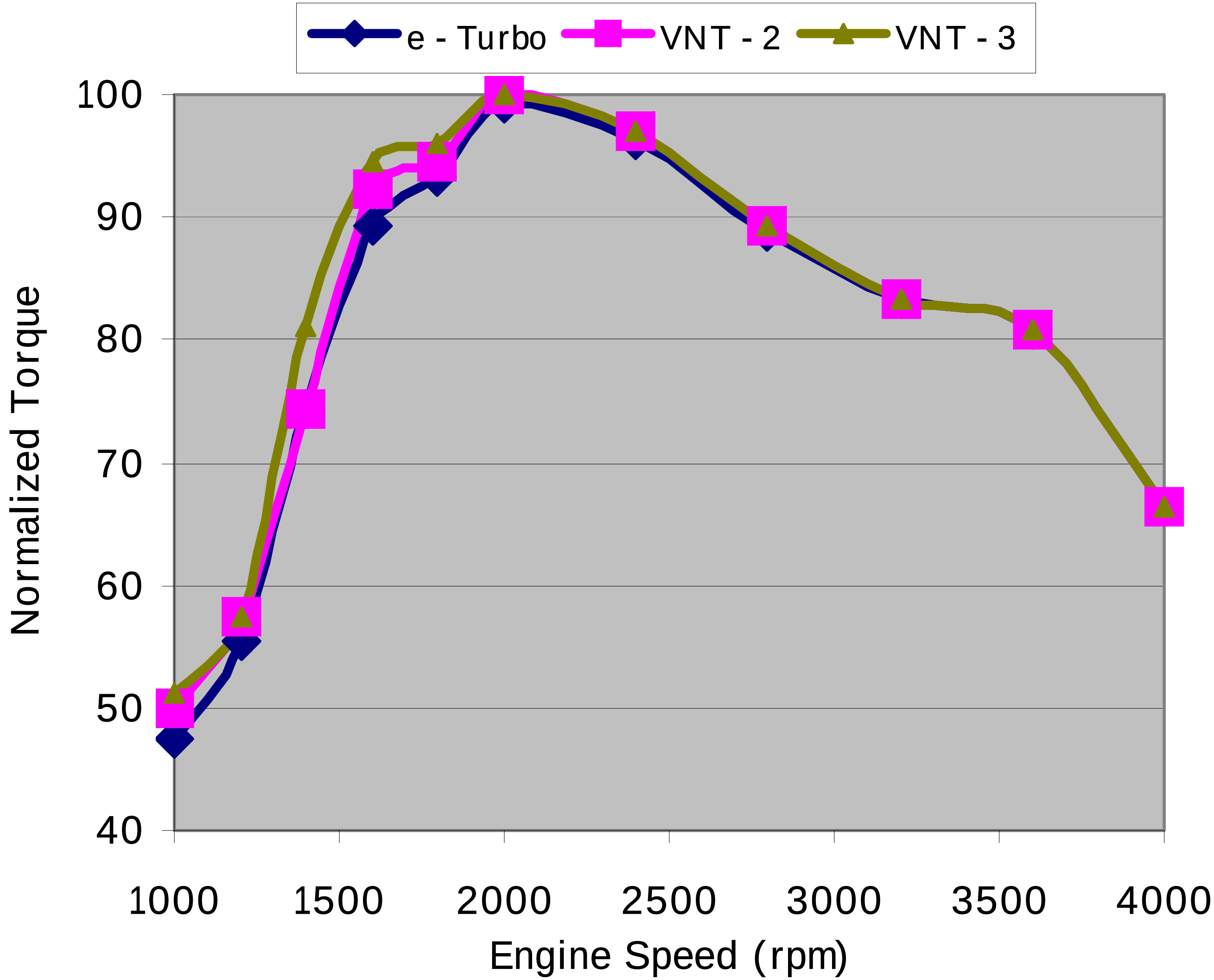
Steady-State Efficiency

- Engine efficiency w e -Turbo off: - 2% @ 2000-2800rpm
- Because engine delta P is higher
- Phenomenon more sensitive when engine speed decreases



e-Turbo™ efficiency slightly lower

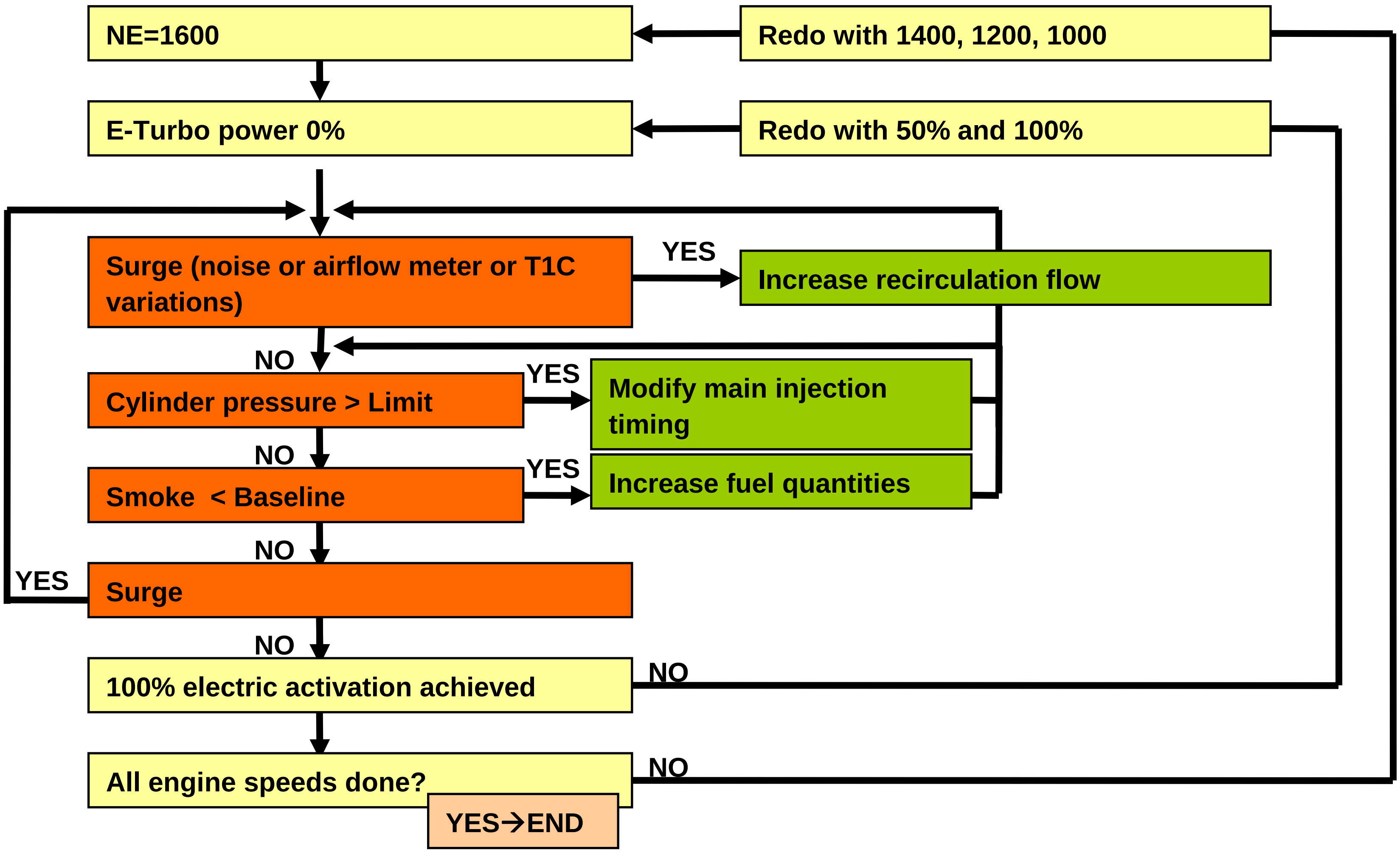
Steady-State Torque w/o Electric Activation



With recalibration, baseline torque level is recovered

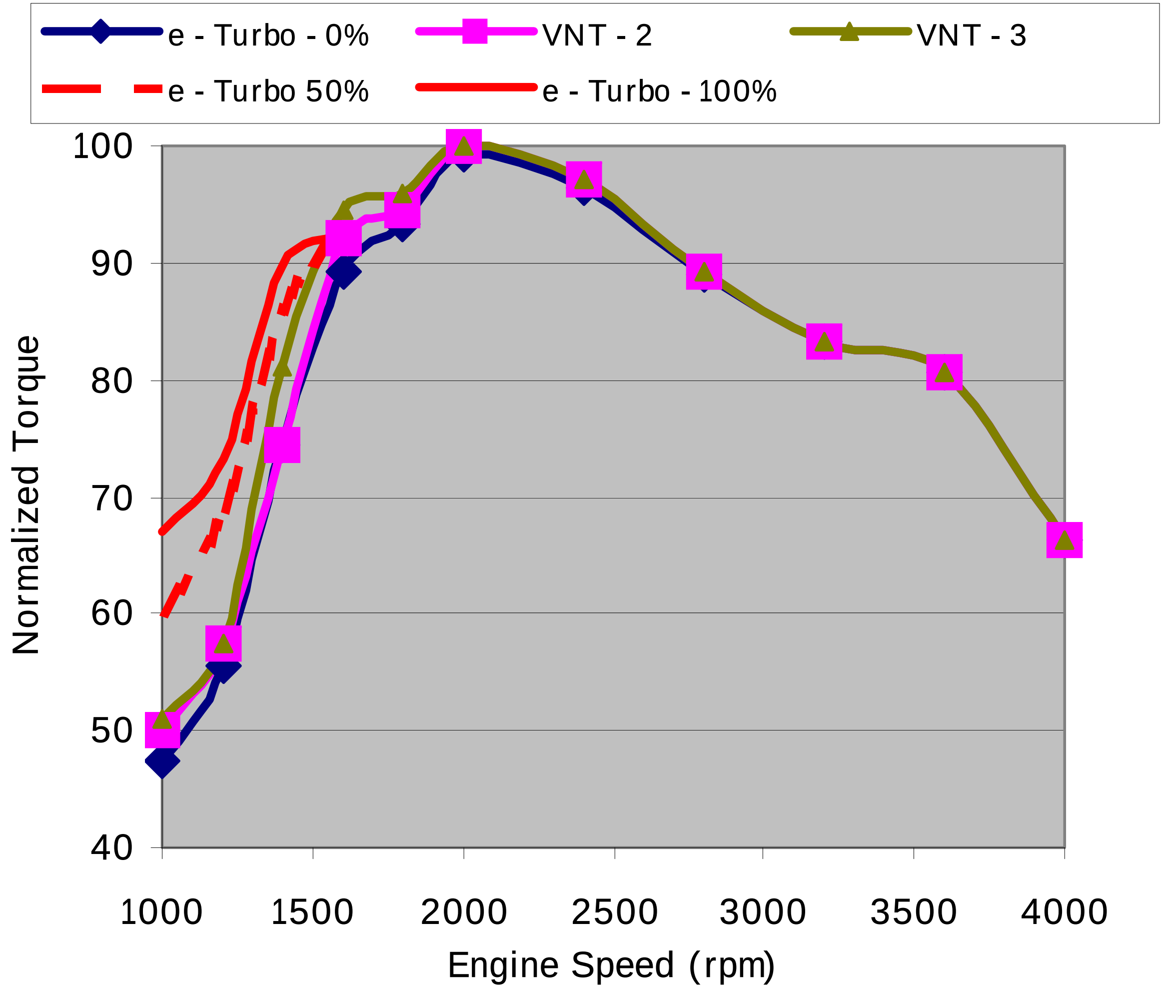
Recalibration Methodology

- **e-Turbo™ activation provides more air to the engine. So, to get overtorque, this higher airflow needs a fuel recalibration:**



Legend: Parameters = green boxes and Constraints = orange boxes

Steady-State Torque with Electric Activation

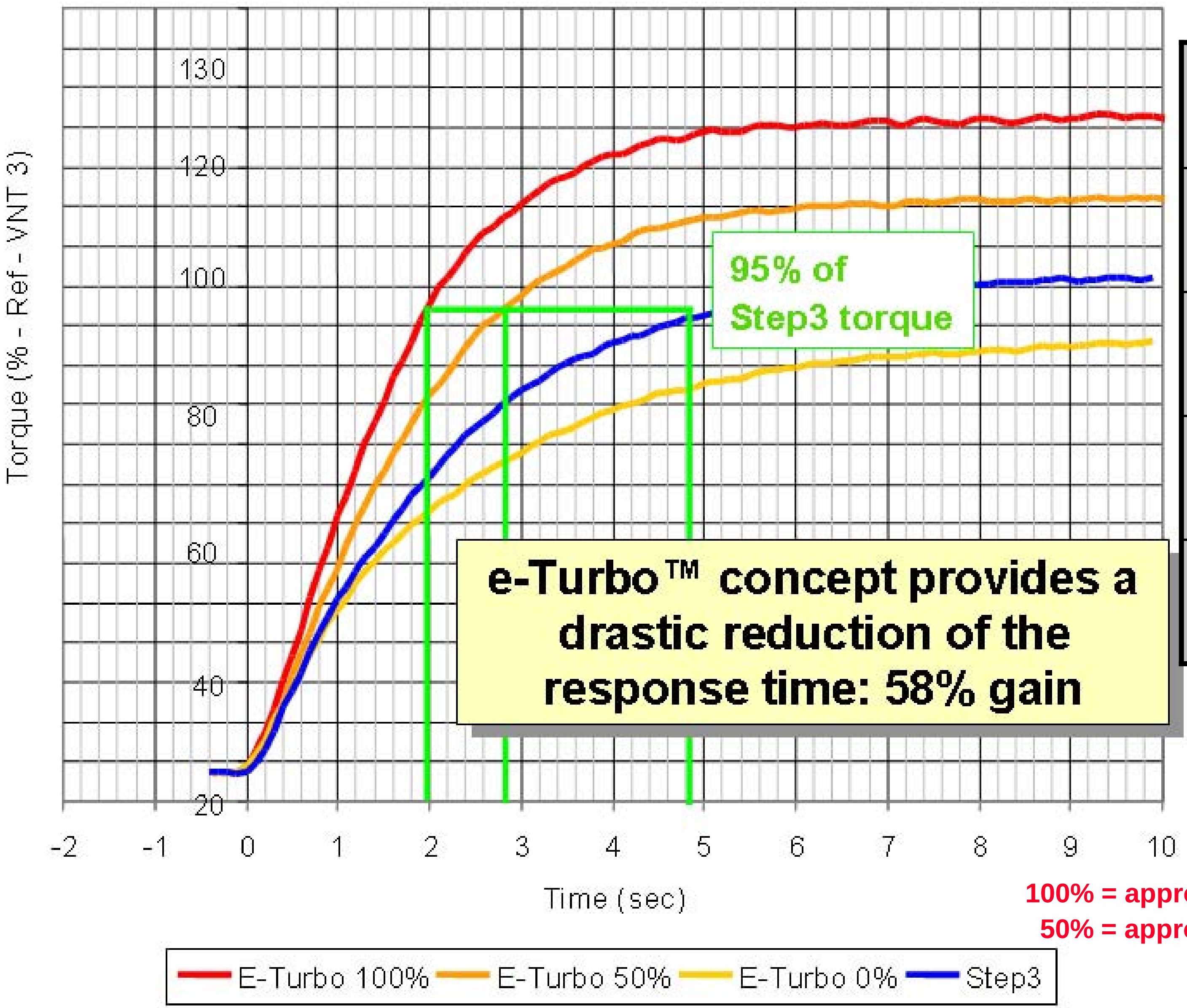


-Electric activation provides a high increase of torque:

33-27-12% more than Step 3 at 1000, 1200, and 1400rpm

43-32-21% more than e-Turbo™ off (0%)

Transient Response @1250 rpm

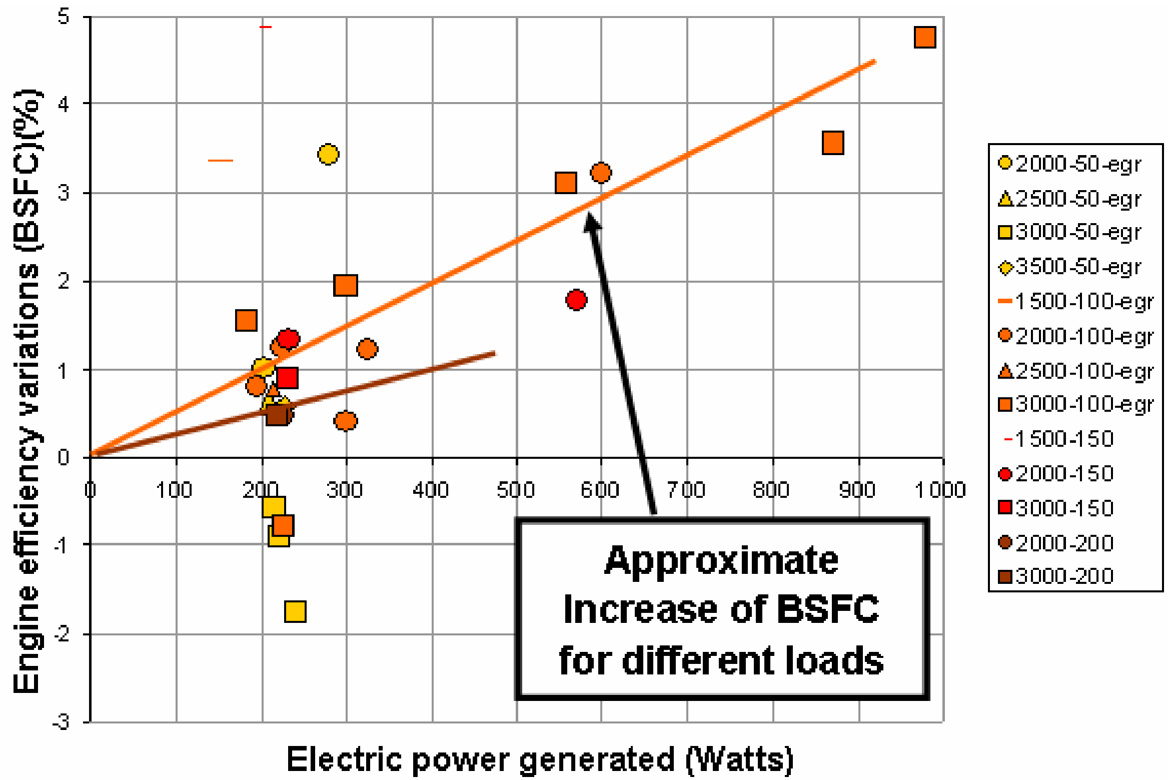


	Ref: Step3	Ref: E-Turbo 0%
E-Turbo 100%	2,0s 58%	1,7s 74%
E-Turbo 50%	2,8s 42%	2,3s 65%
E-Turbo 0%		6,6s 0%
Step3	4,8s 0%	3,4s 48%

100% = approx. 1200 W (mechanical watts)
50% = approx. 650 W (mechanical watts)

Electric Power Generation

- **Efficiency effects**
  - **The BSFC increases less if exhaust enthalpy is high**
  - **Between 2000-3000rpm:**
    - **+1% for 400W @ 200Nm**
    - **+2% for 400W @ 100Nm**
- **No major impact on NOx, HC, CO emissions**
- **Unable to quantify the BSFC variation when load and fuel flow are low**
- **Unable to generate if exhaust enthalpy is too low (example 2000-25Nm)**



- Generating electricity is possible if load isn't too low
- Cost around 1% of BSFC to generate 200W @ 2000rpm-100Nm
- It has no effect on emissions

Rough Comparison with Alternator

- **250W of electrical power output**
- **Alternator efficiency: 67-61-59% @ 1000-2000-3000rpm**
- **e-Turbo™ approximate results: from previous slide**

Operating point		*Increase of BSFC (%)*	
rpm	*load (Nm)*	*w alternator*	*w e-Turbo*
1000	25	14,3	No power
1000	50	7,1	No power
1000	100	3,6	No power
2000	25	7,8	No power
2000	50	3,9	better
2000	100	**2,0**	**better**
2000	200	**1,0**	**better**
3000	25	5,4	better
3000	50	2,7	better
3000	100	**1,3**	**same**
3000	200	**0,7**	**same**

Depending on the operating point:

-e-turbo™ unable to generate

-e-turbo™ better than an alternator

-e-turbo™ as good as an alternator

*** The variations of BSFC are lower than the noise in fuel consumption measurements**

Conclusions - Electric Assist

1. Steady-state torque increase
   - 43% @ 1000rpm (compared to e-Turbo™ off)
   - Could be higher if lambda value was lower

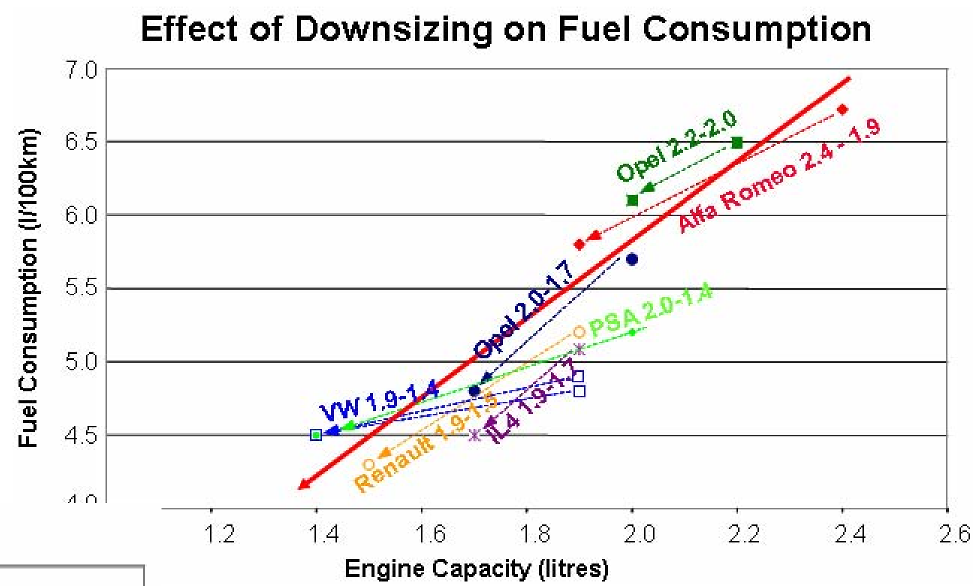
2. Better time to torque
   - Gain of around 70% between 1000-1500rpm (compared to e-Turbo™ off)
   - Could be higher if lambda value was lower

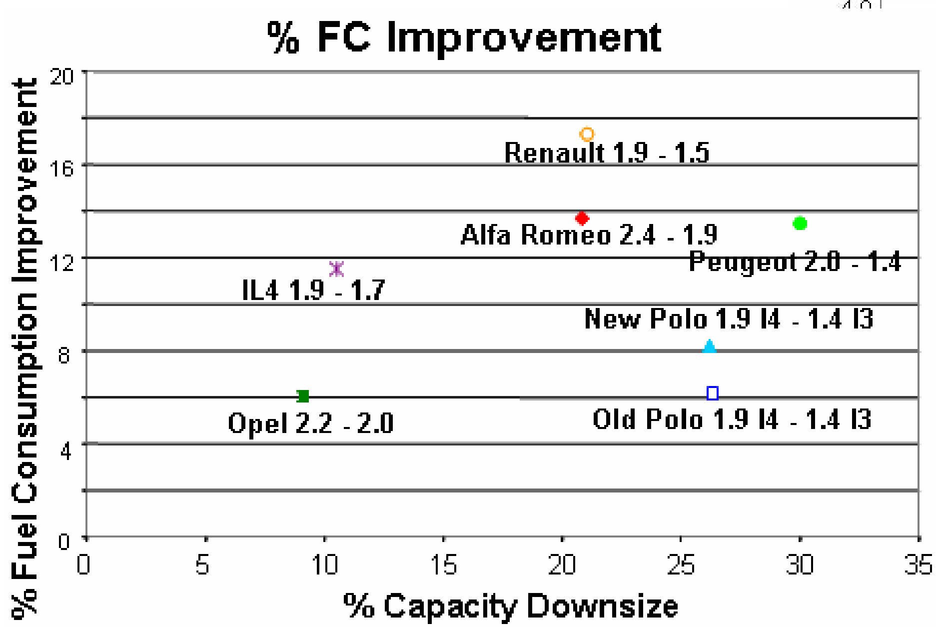
3. Electrical power generation ability
   - Seems to have a better efficiency than an alternator
   - However, generation is limited to certain conditions

Reminder: Benefits of Engine Rightsizing not Included in the Previous Discussion

European Production Models

Same Vehicle





10-30% Downsizing

6-17% Fuel Economy Improvement

Credits RICARDO

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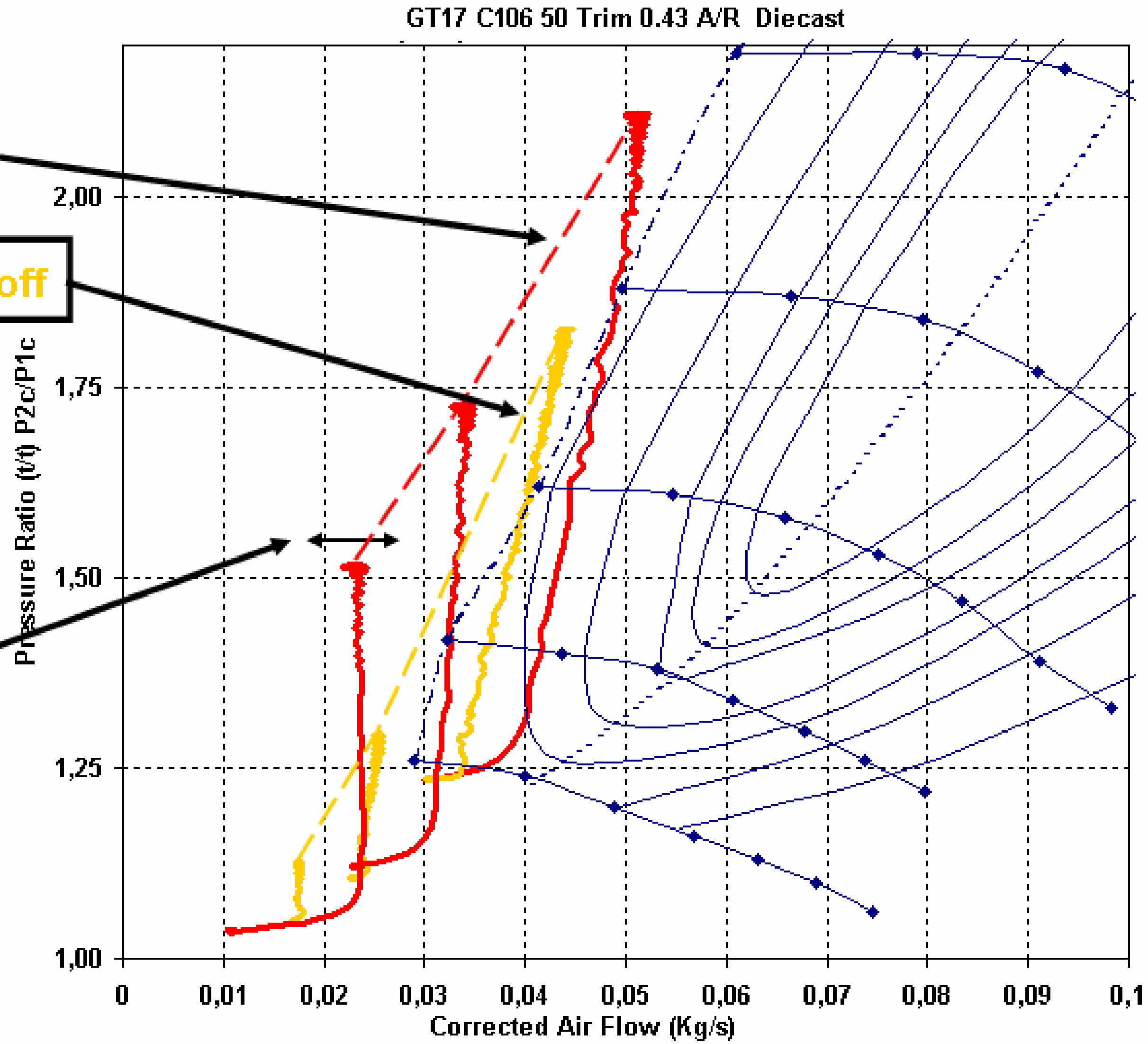
Flow Stability at Low Speeds

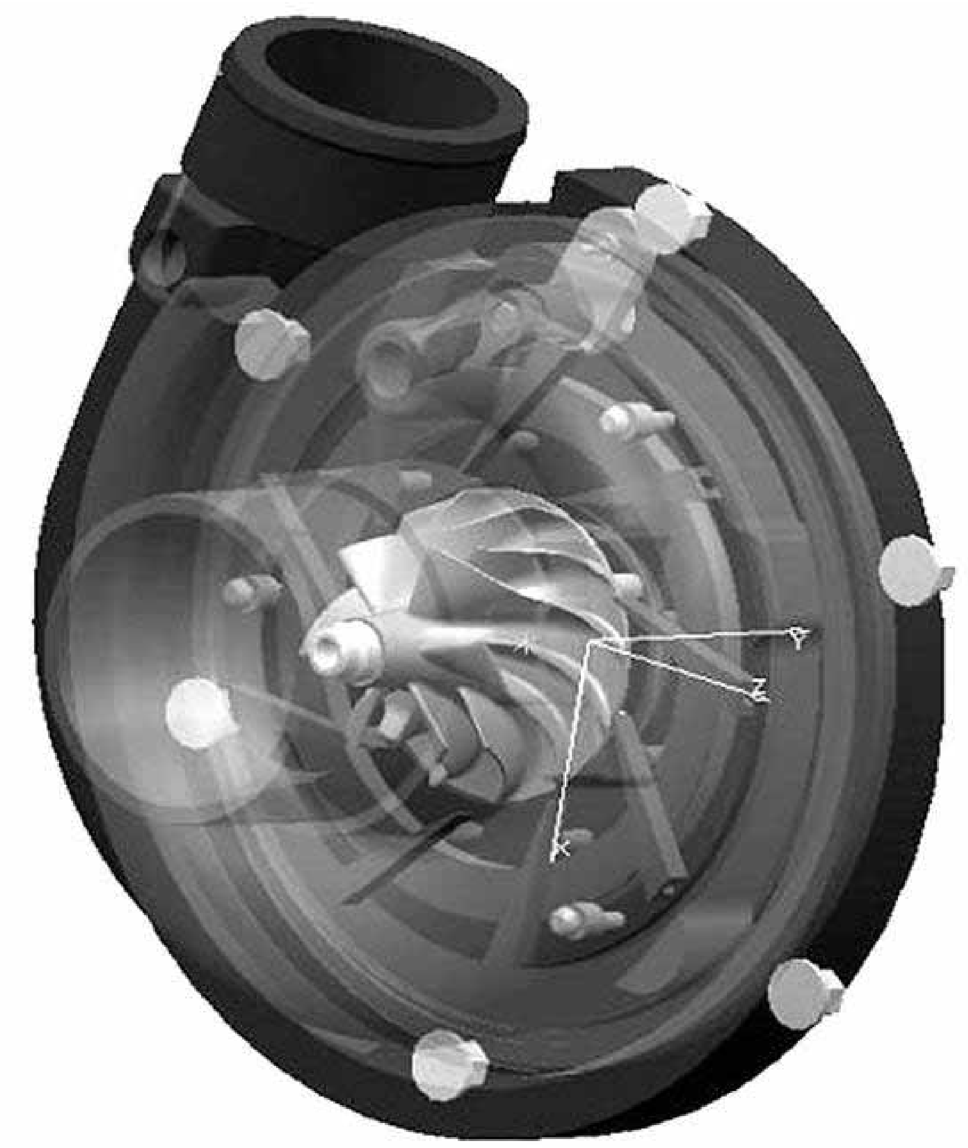
Lugline 100% or 1200W

Lugline 0% or e-Turbo™ off

Surge sometimes appears (oscillations of airflow)



Variable Geometry Compressor Concept



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Work in Progress

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