Dynamic Skip Fire Applied to a Diesel Engine for Improved Fuel Consumption and Emissions
动态停缸技术改善柴油发动机油耗和排放

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Mauro Scassa [2], Shino George [2], Marco Nencioni [2] and Thomas Koerfer [3]

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Prepared for

2019 Future Diesel Engine Summit China

March 27-28, 2019 Shanghai China

Agenda

- Diesel *Dynamic Skip Fire* (DSF®) Technology Overview
  柴油机动态停缸技术概述
- Motivation for Exploring DSF Benefits for Diesel Engines
  探索柴油发动机DSF技术效益的动机
- Description of Simulation Approach
  仿真模拟方法的描述
- Preliminary Simulation Results
  仿真模拟初步结果
- Summary and Conclusions
  总结和结论

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Tula Technology:

- A Controls/Software Company
- Develops Patented DSF® Technologies
  for Sophisticated Powertrain Controls
  to Help Engine Work Smarter

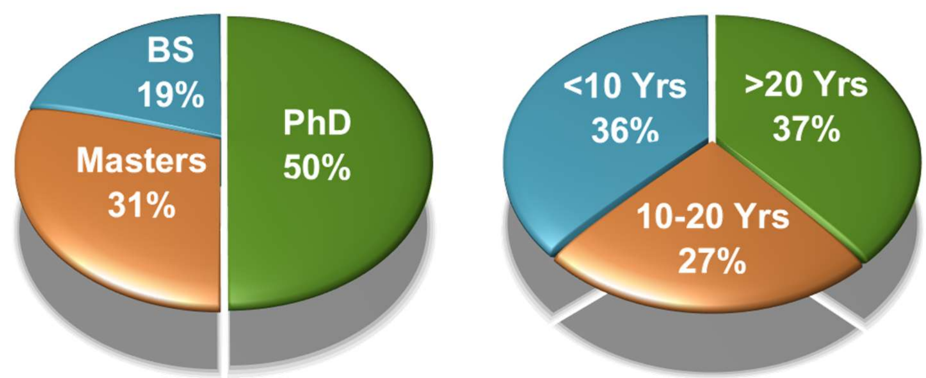
图拉科技公司

- 一家控制/软件公司
- 研发专利保护的动态停缸技术
  结合尖端的动力传动系统控制
  以帮助发动机更智能地工作

Tula Technology – The Company
图拉科技--公司

- Founded in 2008 in Silicon Valley, Tula has grown to 64 team members/图拉于2008年在硅谷成立, 现已发展到64名团队成员
- 110 issued patents/110项已颁发专利
  - Granted patent coverage in the US, China, Japan, Korea, Germany and India/在美国、中国、日本、韩国、德国和印度获得专利保护
  - 120+ patents pending/120+专利正在申请
- Investors include/投资者包括…
  - Financial (资本投资): Sequoia Capital (红杉资本), Sigma Partners, Khosla Ventures and Franklin-Templeton (弗兰克林-邓普顿)
  - Strategic (战略投资): General Motors (通用汽车), Delphi Technologies (德尔福科技)

Technical Staff
技术人员



Tula’s DSF Technical Integration Ecosystem

图拉的DSF 技术集成生态系统

TULA

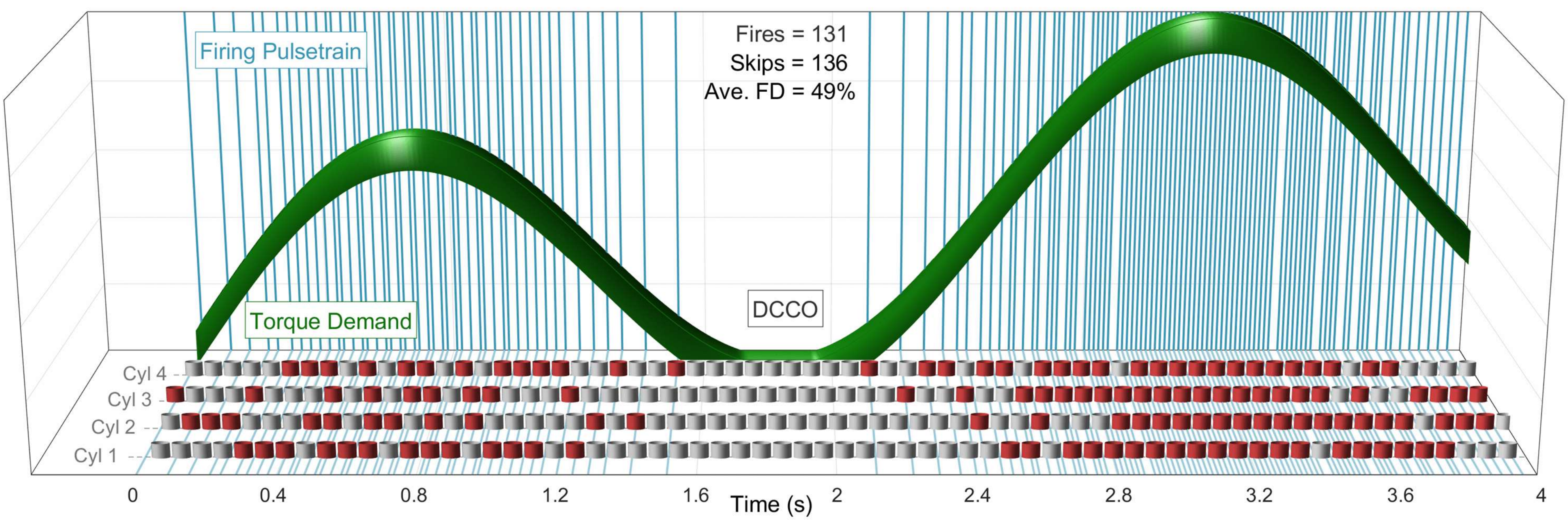
Delphi Technologies
BorgWarner
BOSCH
SCHAEFFLER
FEV
Valeo
EATON
Continental
富临精工 FULIN P.M.
iav automotive engineering
Jacobs Vehicle Systems®
GKN
WOLFFU AUTOMOTIVE TECHNOLOGY
faurecia
dSPACE
EXEDY
ETAS
LINAMAR Power to Perform
APTIV
The Ohio State University
TRC Transportation Research Center Inc.
A123 SYSTEMS
litens automotive group

What is *Dynamic Skip Fire?*
动态停缸是什么?

DSF in action
DSF演示

Dynamic Skip Fire Attributes
动态停缸特征

- **Determination of whether a cylinder's torque is required is made immediately prior to firing**
  在点火前的最后一刻做出一个气缸是否要贡献扭矩的决定
- **Firing Decisions are made on an event-by-event basis: *"Dynamic Downsizing"***
  点火与否由逐个点火机会决定："动态小型化"
- **Firing Density (FD) is chosen to optimize fuel consumption and/or others, subject to certain constraints**
  点火密度兼顾最佳油耗及其他限制因素



2019 Silverado V8 with Dynamic Fuel Management

具有动态燃料管理功能的2019 索罗德 V8

TULA

"…the most impressive thing about the engine is the new Dynamic Fuel Management system.
发动机最令人印象深刻的是新的动态燃油管理系统"

– Road Show by CNET

"…props to the Silverado's trick cylinder deactivation for putting the 6.2 ahead of a 3.5 liter in fuel economy, both with and without a trailer
…无论有没有拖车，**Silverado**的停缸技术使**6.2**升发动机的燃油效率高于**3.5** 升(无停缸技术的)发动机"

- Car and Driver

"Industry first individual cylinder deactivation system
行业首创的独立单缸停缸系统"

– Engine Technology International

"The (cylinder) shutdowns are so seamless, you can't tell how many are firing at any given time
关闭气缸的操作如此平顺, 你无法判断在任何给定的时间有多少缸在点火."

– Motor Trend

WARDS 10 Best Engines
沃德十佳发动机

"The 6.2L V-8 uses DFM to achieve a 1 mpg increase in fuel economy in the EPA city cycle and 2 mpg real world… Those MPG numbers are nothing to sneeze at, with the latter translating into more than a 13% gain in efficiency

***6.2**升 **V-8** 使用 **DFM** 在 **EPA** 城市循环里燃油效率提升了 **1mpg**, 实际道路测试实现了 **2mpg** 提升**.....**。没法对这些 **mpg** 数字不屑一顾, 因为 **2mpg** 在该车上相当于**13%** 以上的燃油效率提升."*

Technology Roadmap
技术路线图

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China VI Emission Standards for Heavy Duty Vehicles

中国重型车辆国六排放标准

TULA

Source: The International council on Clean Transportation (icct): www.theiccct.org

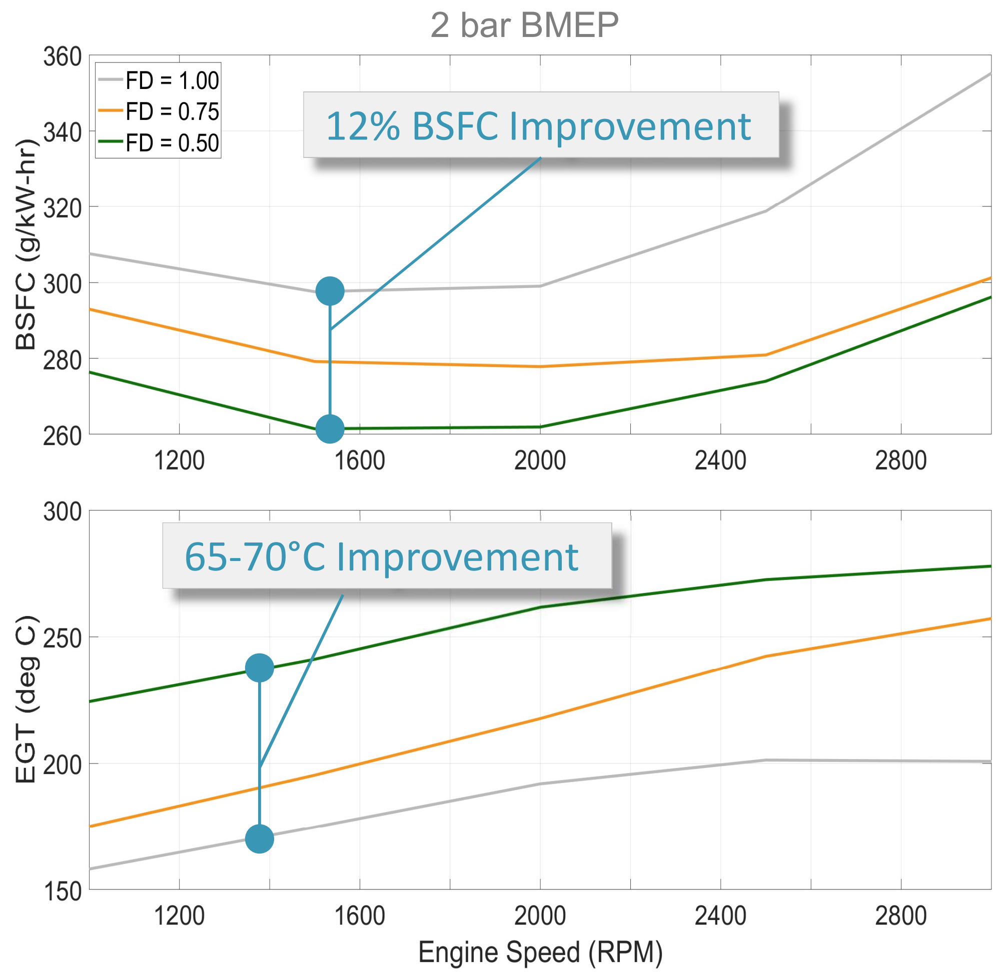
		China V/Euro V	Euro VI	China VI-a	China VI-b
Engine test cycle		ESC, ETC	WHSC, WHTC, WNTE		
Emission limits on transient cycle	**NO_x (g/kWh)**	2	0.46		
	PM (g/kWh)	0.03	0.01		
	PN (#/kWh)	No limit	6E+11		
PEMS test		No	Yes		
Emission limits for PEMS test	**NO_x (g/kWh)**	N.A.	0.69 (CF=1.5)		
	PN (#/kWh)	N.A.	No limit	No limit	1.2E+12 (CF=2.0)

- China VI emission standards mandate 77% reduction in NOx emissions from China V standards. More effective NOx aftertreatment system would be required to meet the new standards. More efficient exhaust gas thermal management technologies would become critical in ensuring high conversion efficiency of the NOx aftertreatment system to meet both emissions and fuel consumption requirements.
国六排放标准要求NOx排放从国五基准上降低77%。这就要求使用更有效的尾气后处理理系统。为了这些尾气后处理系统NOx转换率更高以同时满足排放和油耗标准，更省油的尾气热管理技术变得极为重要。

Advantages of Dynamic Skip Fire for Diesel Engines
柴油发动机动态停缸的优势

Diesel DSF offers two major benefits to diesel ICEs:
动态停缸可给柴油内燃机带来两大重要效益

- Improved fuel consumption
  改善油耗
  - Reduction in pumping loss
    降低泵气损失
  - Improvement in combustion
    提高燃烧效率
- Increased exhaust gas temperature
  提高尾气温度(可改善有害排放的控制)
  - Increased cylinder load
    单缸负载增加
  - Decel cylinder cut-off
    减速停缸



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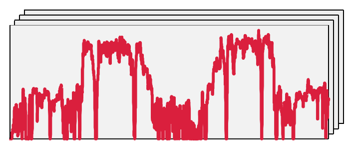
2.0L Light Duty Diesel DSF Simulation
轻型柴油机动态停缸的仿真

Baseline Engine & Exhaust A/T System Assumptions:
基准发动机&尾气后处理系统的假设：

ENG	2.0 L, I-4 Diesel, Spec. RP 60 kW/L HP- & LP- EGR, Single-stage VNT
EAS	Cc(DOC & SDPF) & Uf SCR

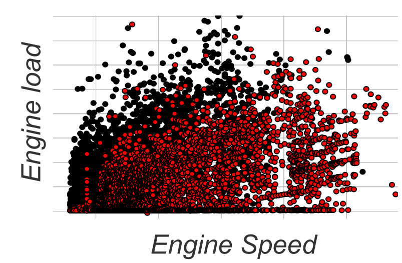
Simulation Steps:
仿真模拟步骤：

1. Driving cycle:
- WLTP cycle
- RDE cycle

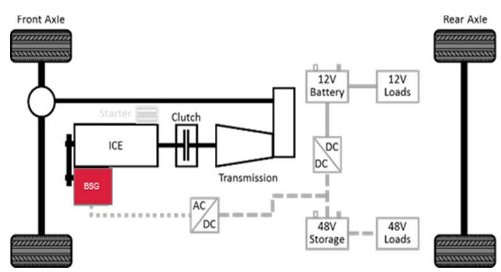


2. Vehicle Mass:
- Mid-size SUV
- C-Seg Compact

3. Gear Shift Schedule:
CO_2 Optimal vs Aggressive



4. PWT Electrification:
48V BSG system (P0)

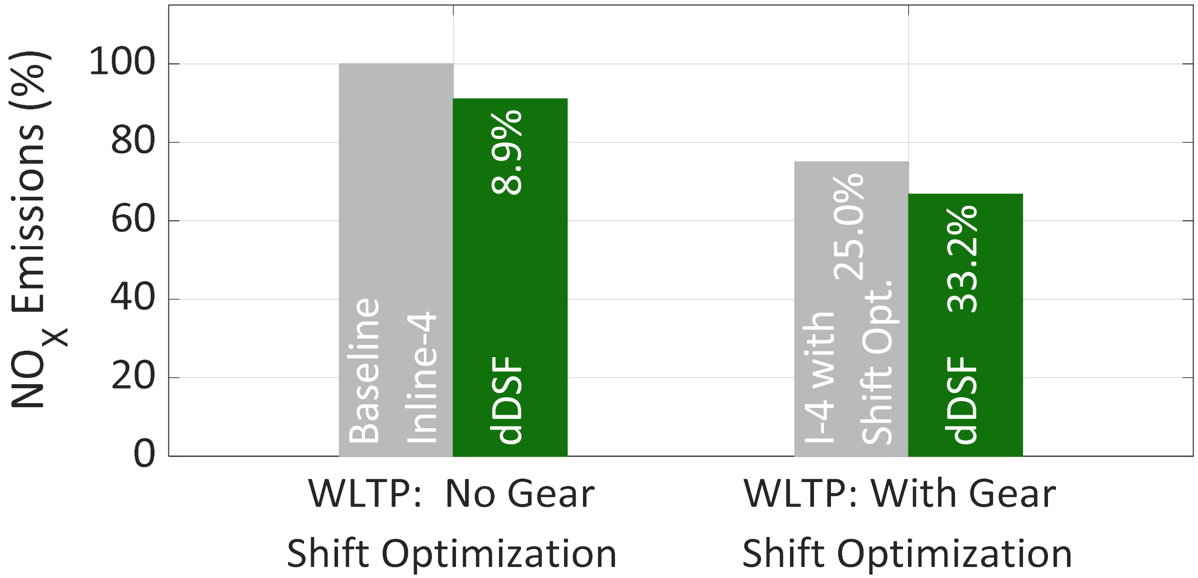


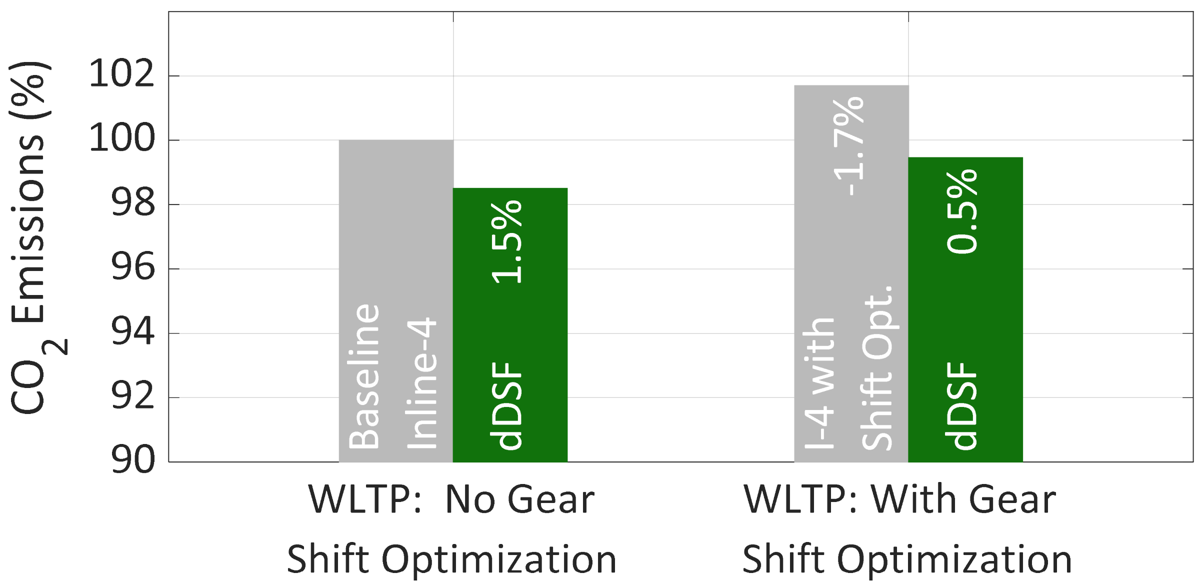
Cylinder Deactivation Strategy:
停缸策略：

- Low pressure exhaust spring (LPES) trapping
- Dynamic skip fire
- NVH limit derived from light duty vehicle

2.0L LD Diesel Transient Cycle Investigation
轻型柴油机瞬态循环模拟

Simulated Tailpipe NO_x and CO_2 Emission Benefits for dDSF Technology
动态停缸技术在尾气NO_x和CO_2 排放效益的仿真结果





- dDSF provides simultaneous reductions in NO_x and CO_2 emissions
  动态停缸可同时降低NO_x和CO_2 的排放
- Significant tailpipe NO_X reduction from:
  尾气NO_x排放的显著改善来自于
  - Lower engine-out NO_X
    原气NO_x 的降低
  - Increased NO_X conversion efficiency in catalyst supported by higher exhaust gas temperature
    因尾气温度带来的后处理系统内NO_x转换率的提高

7.7L MHD Diesel DSF Simulation
中型柴油机动态停缸的仿真

Baseline Engine Assumptions:
基准发动机假设：

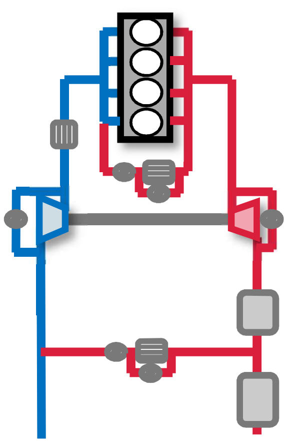
ENG

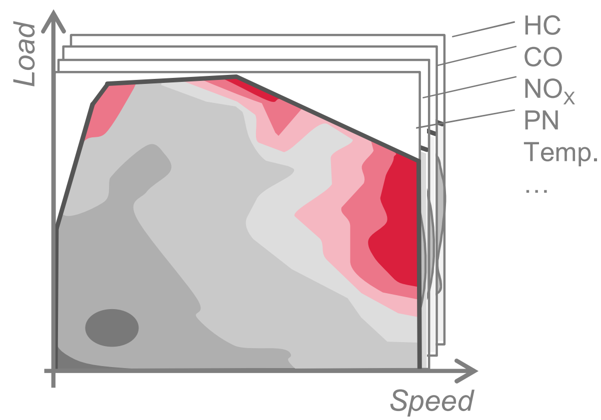
- 7.7L I-6 MHD Diesel
- 17.6 Compression Ratio
- HP-EGR
- 2400 bar Max Inj Pressure
- Single stage, Wastegate Turbo

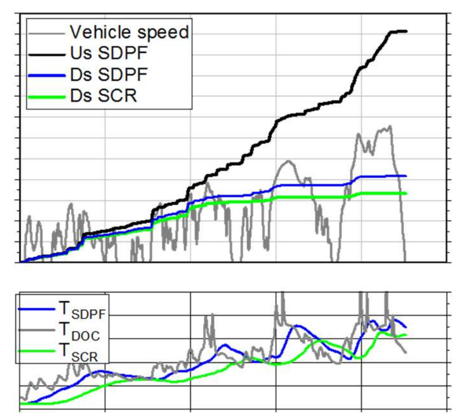
Cylinder Deactivation Strategy:
停缸策略：

- Low pressure exhaust spring (LPES) trapping
- Dynamic skip fire
- Constant EGR rate
- Stringent NVH limit and minimal NVH limit

Simulation Process:
仿真模拟过程：

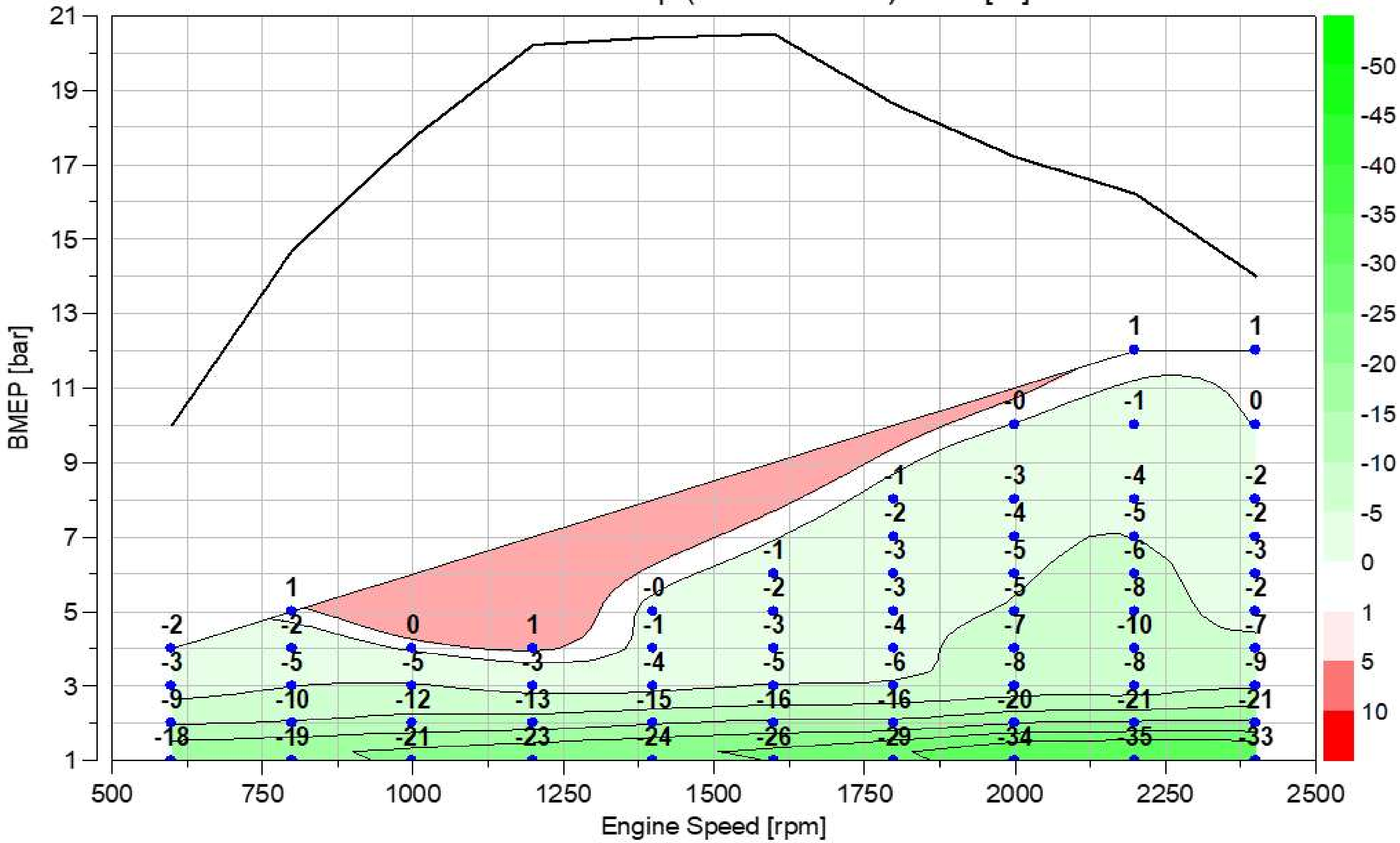






7.7L MHD Diesel Steady State Investigation
中型柴油机稳态模拟

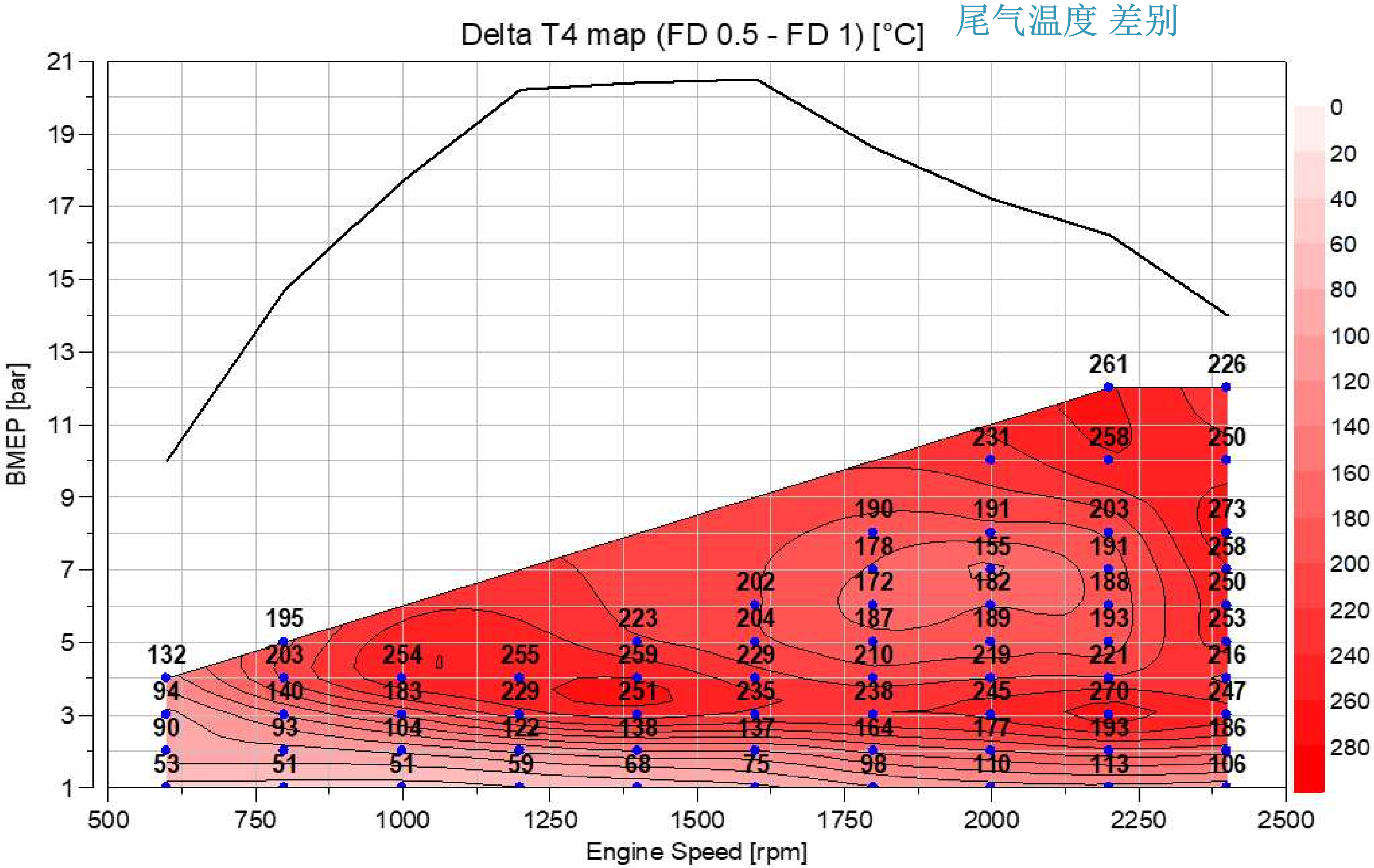
BSFC 差别



- This graph shows the difference in BSFC when comparing 6-cylinder versus 3-cylinder operation
上图比较在6缸与3缸操作时BSFC的差别

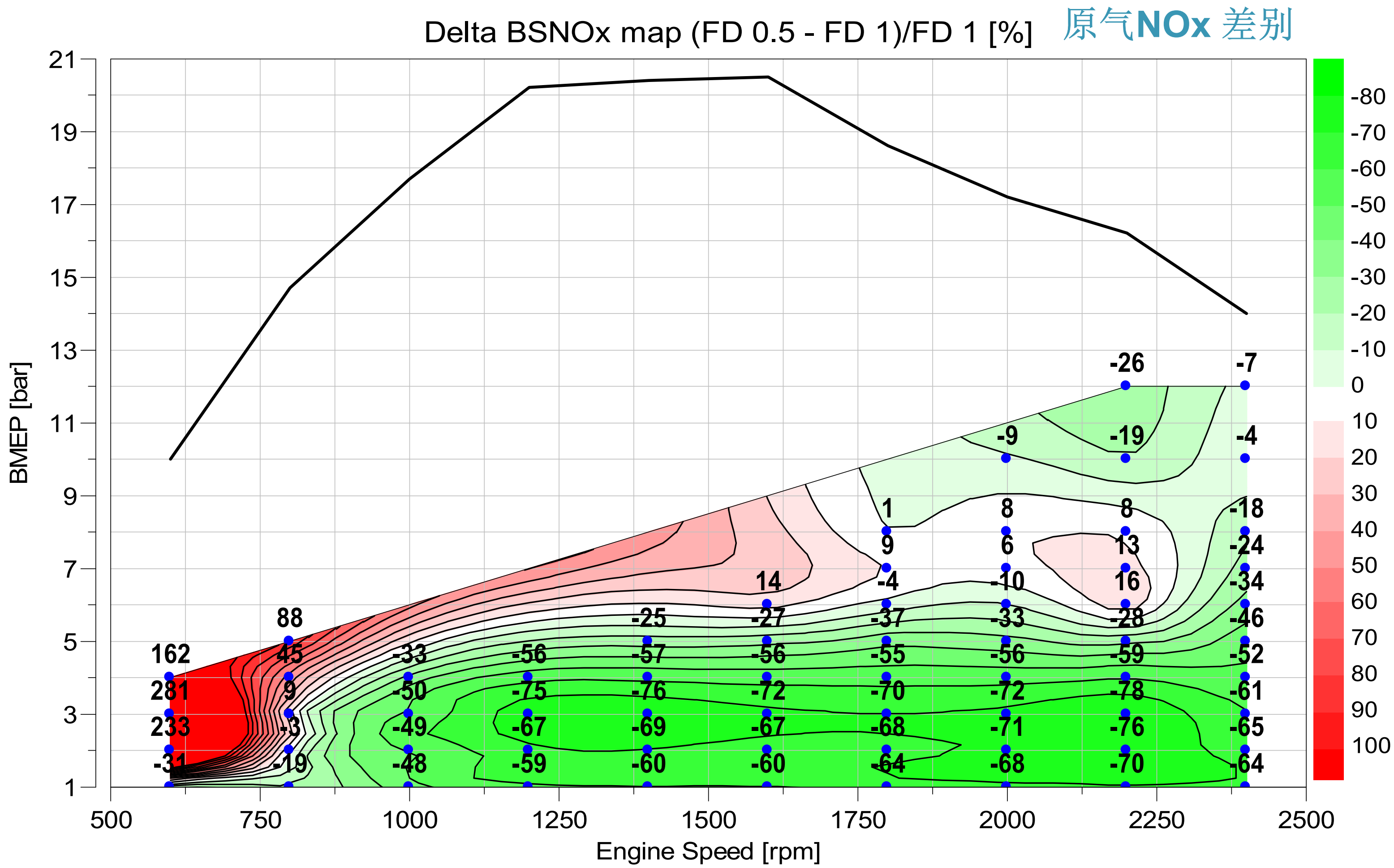
7.7L MHD Diesel Steady State Investigation
中型柴油机稳态模拟

尾气温度 差别



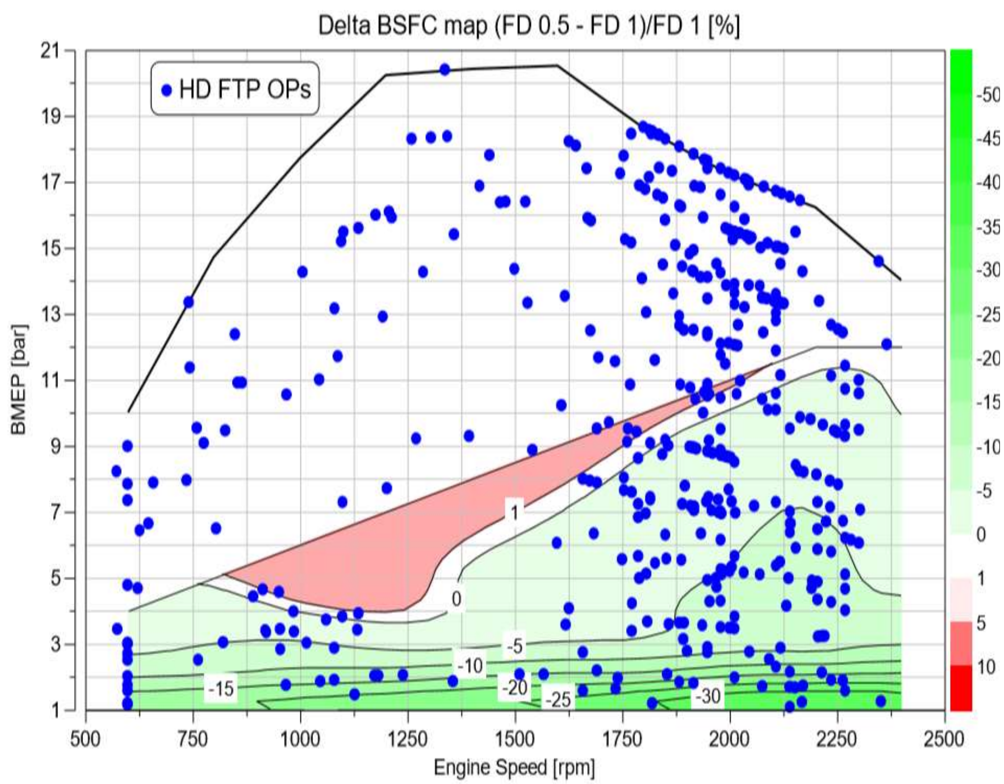
- This graph shows the impact on exhaust gas temperature when comparing 6-cylinder versus 3-cylinder operation
  上图比较在6缸与3缸操作时对尾气温度的影响

7.7L MHD Diesel Steady State Investigation
中型柴油机稳态模拟

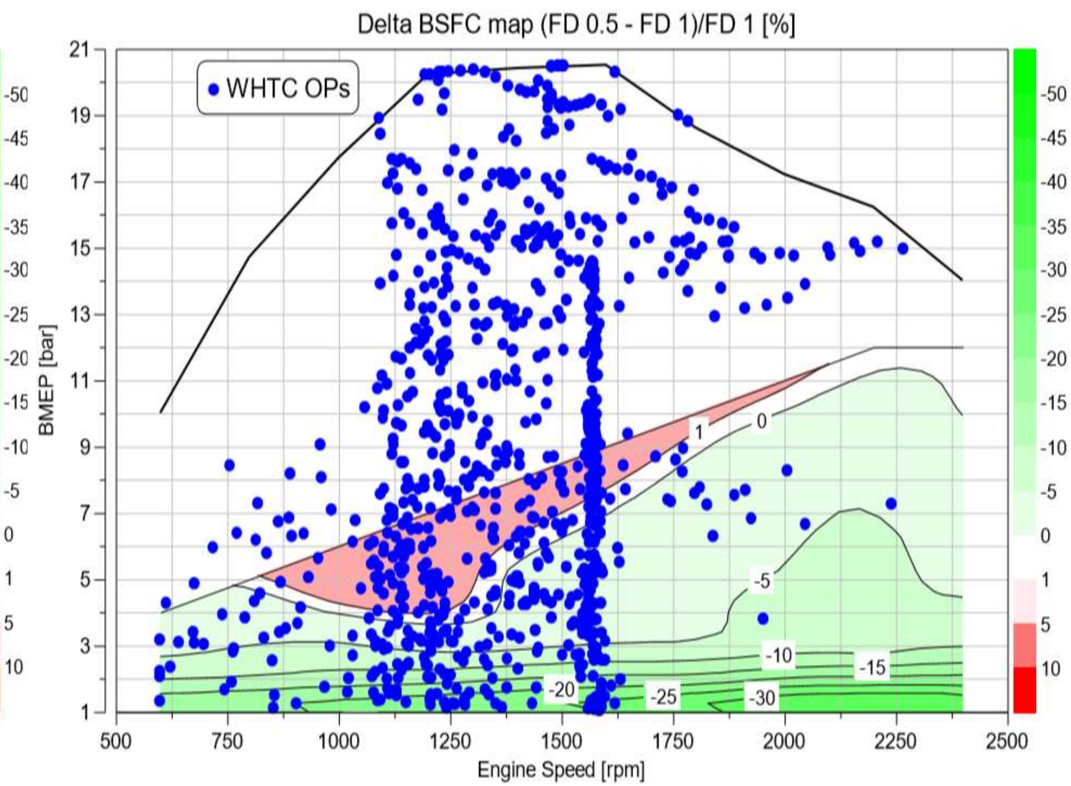


- This graph shows the impact on engine-out NO_x emissions when comparing 6-cylinder versus 3-cylinder operation
  上图比较在6缸与3缸操作时对原气NO_x排放的影响

7.7L MHD Diesel Transient Cycle Investigation
中型柴油机瞬态循环模拟



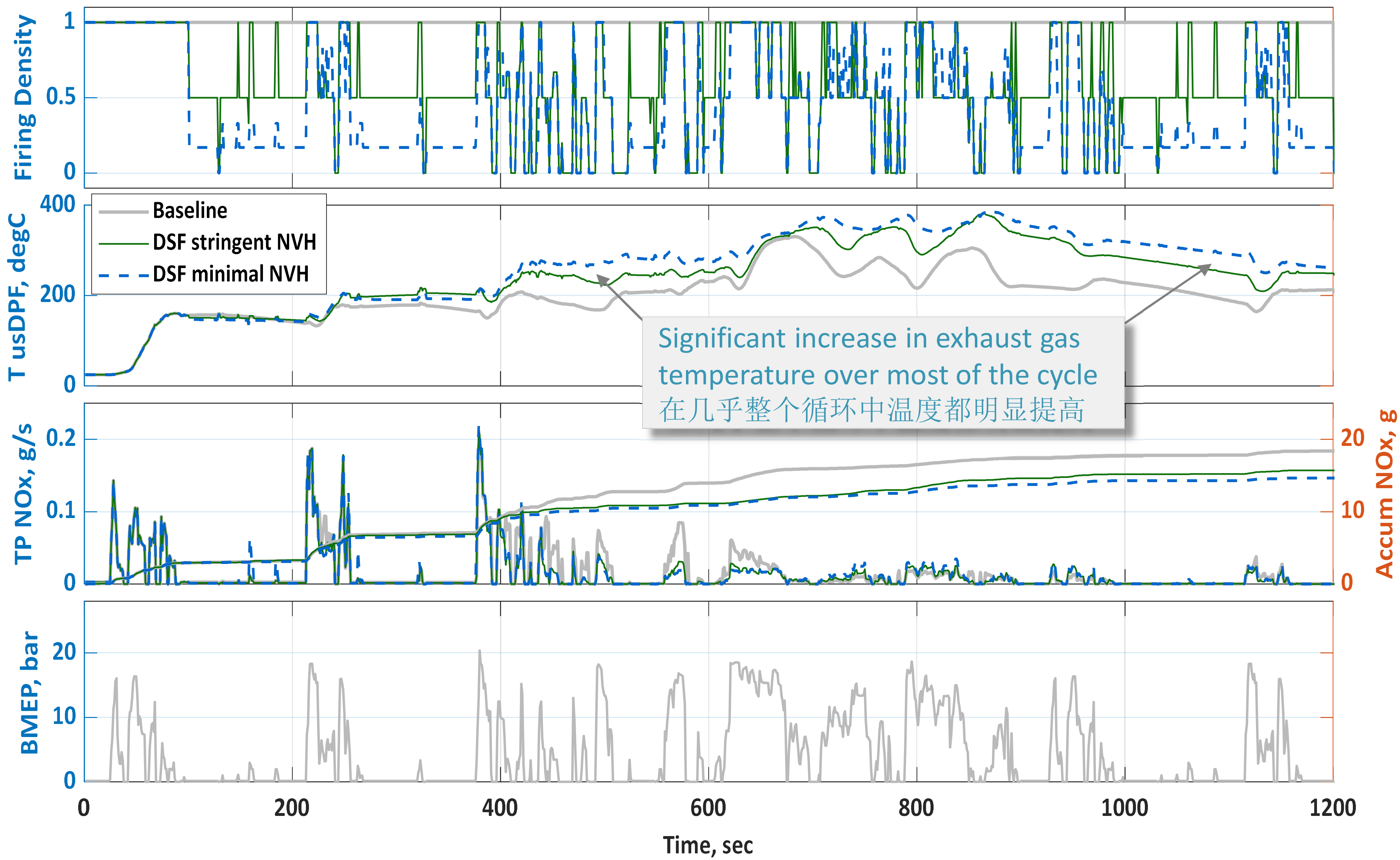
HD FTP drive cycle operating points on Delta BSFC map
重型FTP驾驶循环操作点在BSFC差别图上的显示



WHTC drive cycle operating points on Delta BSFC map
WHTC驾驶循环操作点在BSFC差别图上的显示

7.7L MHD Diesel Transient Cycle Investigation
中型柴油机瞬态循环模拟

Exhaust Gas Temperature Comparison over HD FTP Cycle
重型FTP循环中尾气温度的比较



7.7L MHD Diesel Transient Cycle Investigation
中型柴油机瞬态循环模拟

Simulated Tailpipe NO_x and CO_2 Emission Benefits for dDSF Technology
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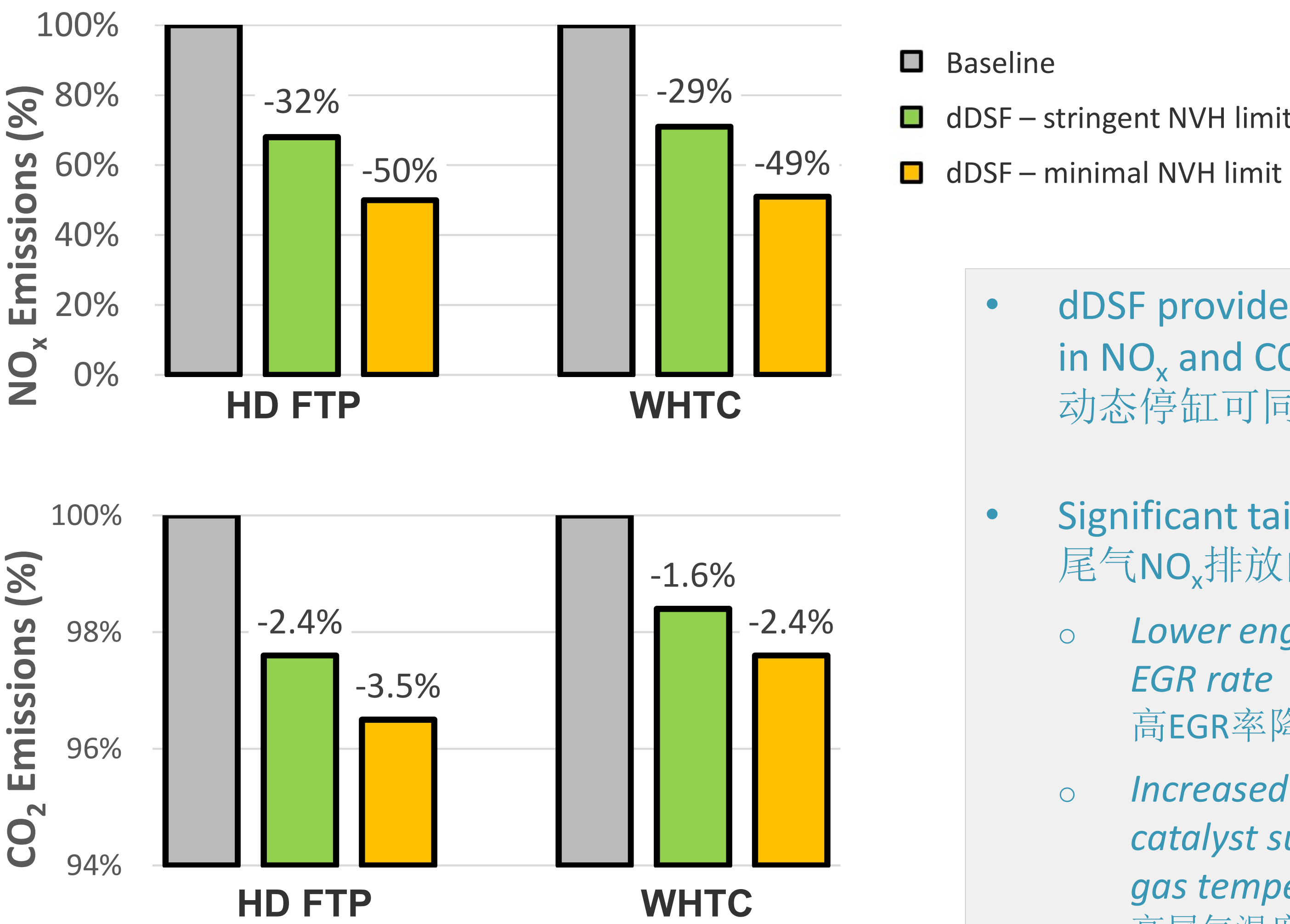
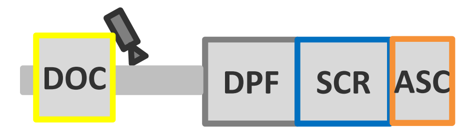


Exhaust AT System Assumption:
尾气后处理系统假设：



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- Significant tailpipe NO_x reduction from:
  尾气NO_x排放的显著降低来自于：
  - *Lower engine-out NO_x due to higher EGR rate*
    高EGR率降低了原气NO_x的排放
  - *Increased NO_x conversion efficiency in catalyst supported by higher exhaust gas temperature*
    高尾气温度提高了后处理器内NO_x转换率

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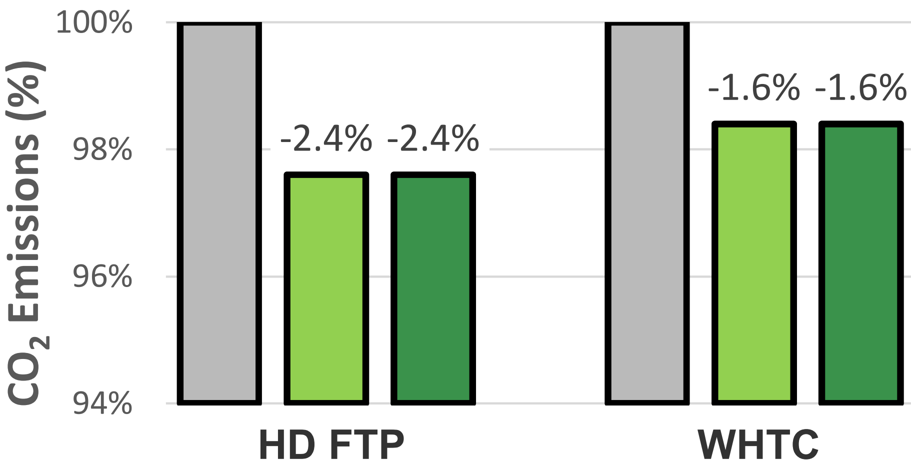
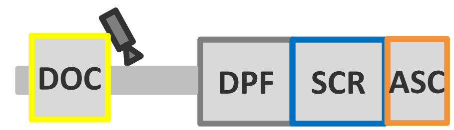
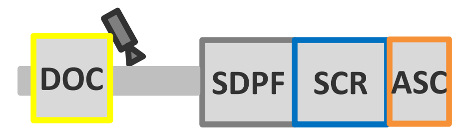


Exhaust AT System (EAS #1)
尾气后处理系统 #1



Exhaust AT System (EAS #2)
尾气后处理系统 #2



- Tailpipe NO_x benefit with dDSF technology can be affected by exhaust aftertreatment system assumption due to the system's sensitivity to exhaust temp profile
  尾气后处理系统的假设会影响动态停缸技术在尾气NO_x排放上的效益，这是因为后处理系统的效率对尾气温度较敏感

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Tula Offers technology of industry leading value in improving fuel consumption and emissions
图拉在降低排放和改善油耗方面提供具有行业领先价值的技术

- Tula's DSF offers significant CO_2 and NO_x reductions for diesel engines at a compelling cost
  图拉的动态停缸技术在柴油发动机上可显著降低CO_2和NO_x排放, 且成本低廉

- Tula's DSF technology can be applied to Light-Duty, Medium-Duty and Heavy Duty diesel engines to help meet China-VI emission standards
  图拉的动态停缸技术可在轻型，中型及重型柴油发动机上帮助达到国六排放标准

- Tula welcomes opportunities to work with OEM's and Tier 1's to integrate DSF onto target engine and vehicle platforms
  图拉期待与汽车制造商和一级供应商合作的机会，将DSF整合到目标发动机和车辆平台上

Thank you for your kind attention
谢 谢

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