THERMAL EFFICIENCY ENHANCEMENT OF GASOLINE ENGINE

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INTERNATIONAL

The Power of Dreams

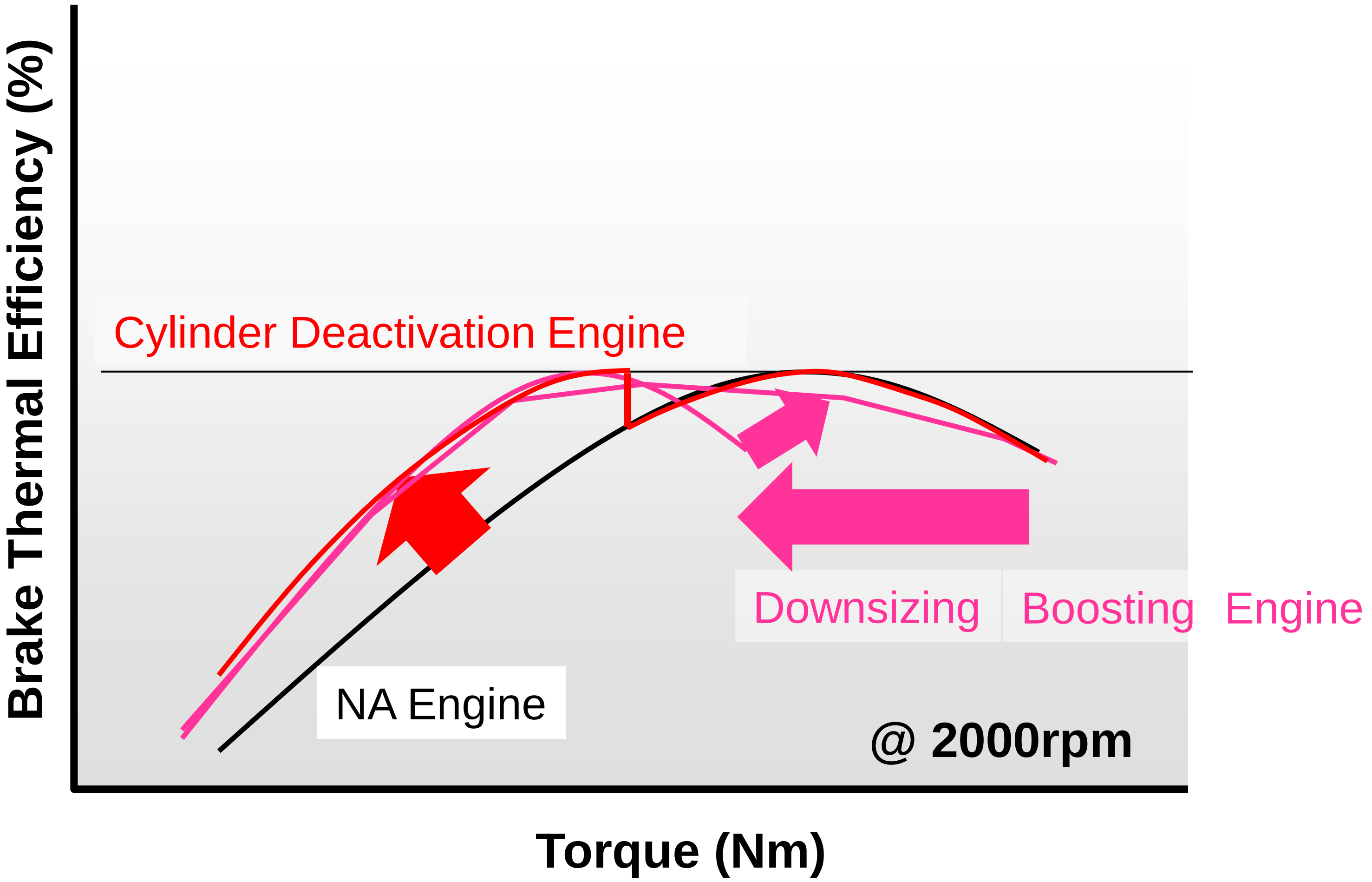
OUTLINE

3. How to Achieve Brake Thermal Efficiency 45%

<SAE_PAPER 2015-01-1263>

4. Conclusion

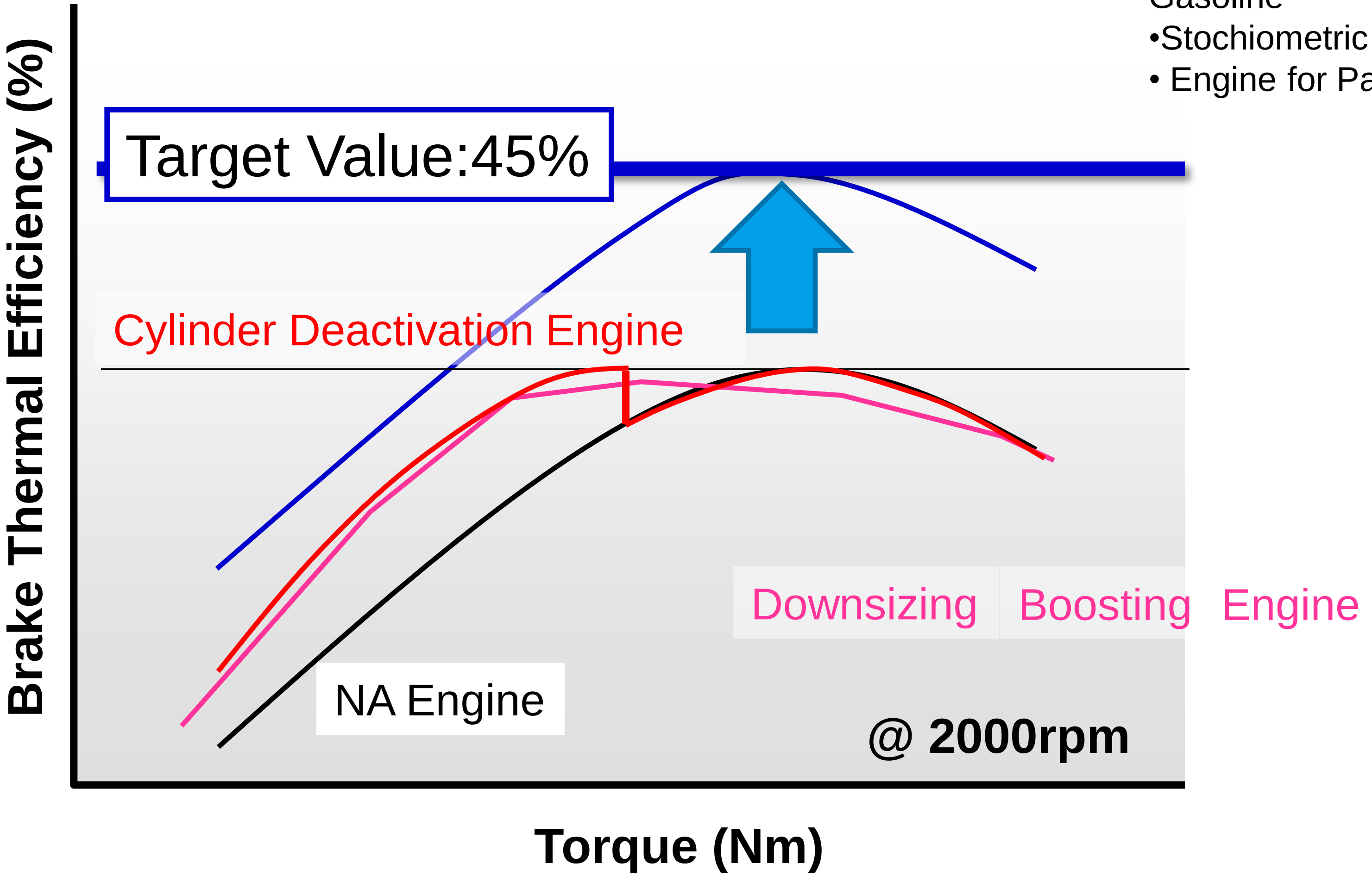
Intended Direction of This Research



Intended Direction of This Research

Aim of This Research：
Improvement of Maximum Brake Thermal Efficiency

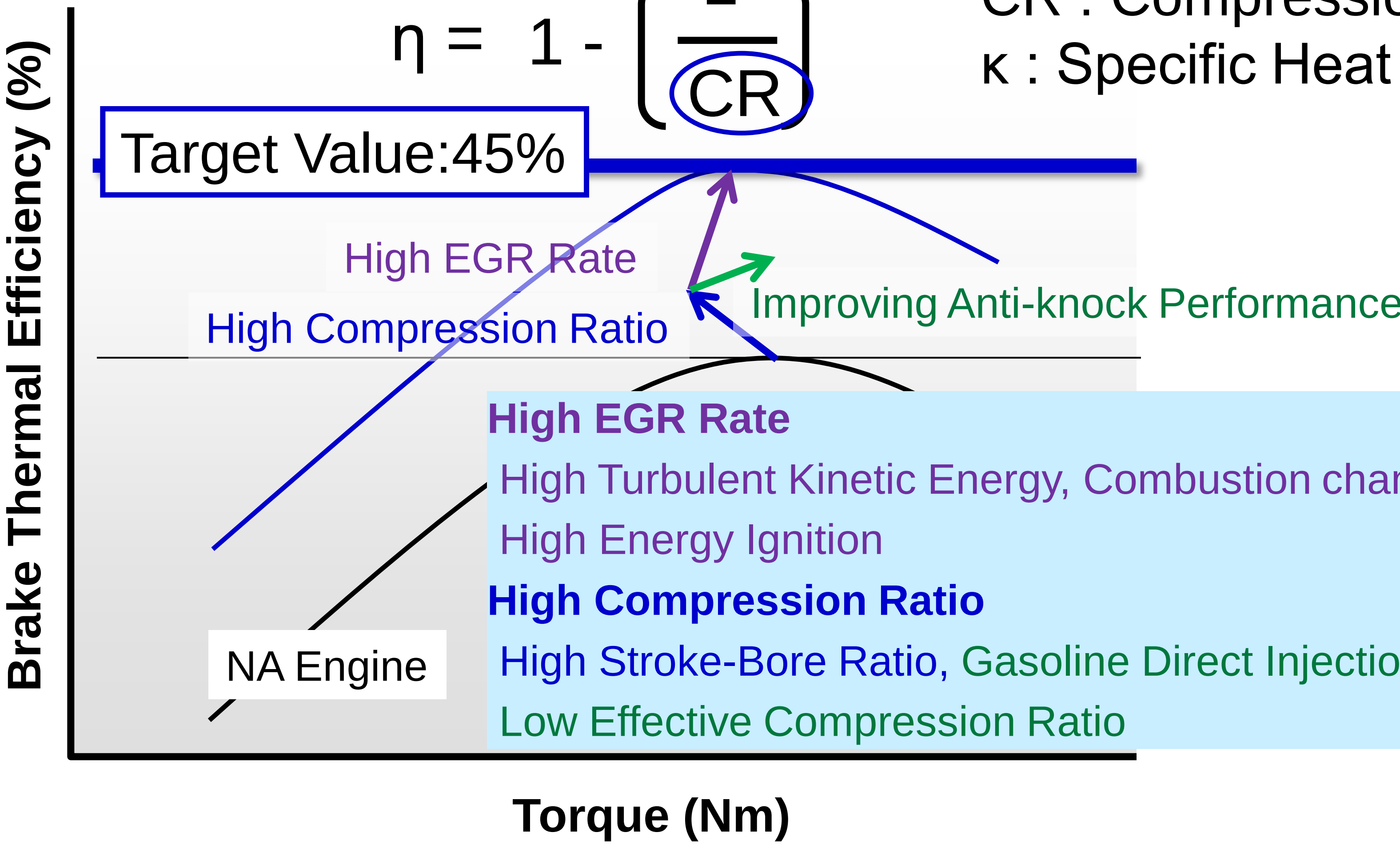
Under Following Condition
•91 Research Octane Number Gasoline
•Stochiometric Air/Fuel(A/F) Ratio
• Engine for Passenger Car



Intended Direction of This Research

$$\eta = 1 - \left(\frac{1}{CR}\right)^{\kappa - 1}$$

η : Thermal Efficiency
CR : Compression Ratio
κ : Specific Heat Ratio



High EGR Rate

High Turbulent Kinetic Energy, Combustion chamber shape

High Energy Ignition

High Compression Ratio

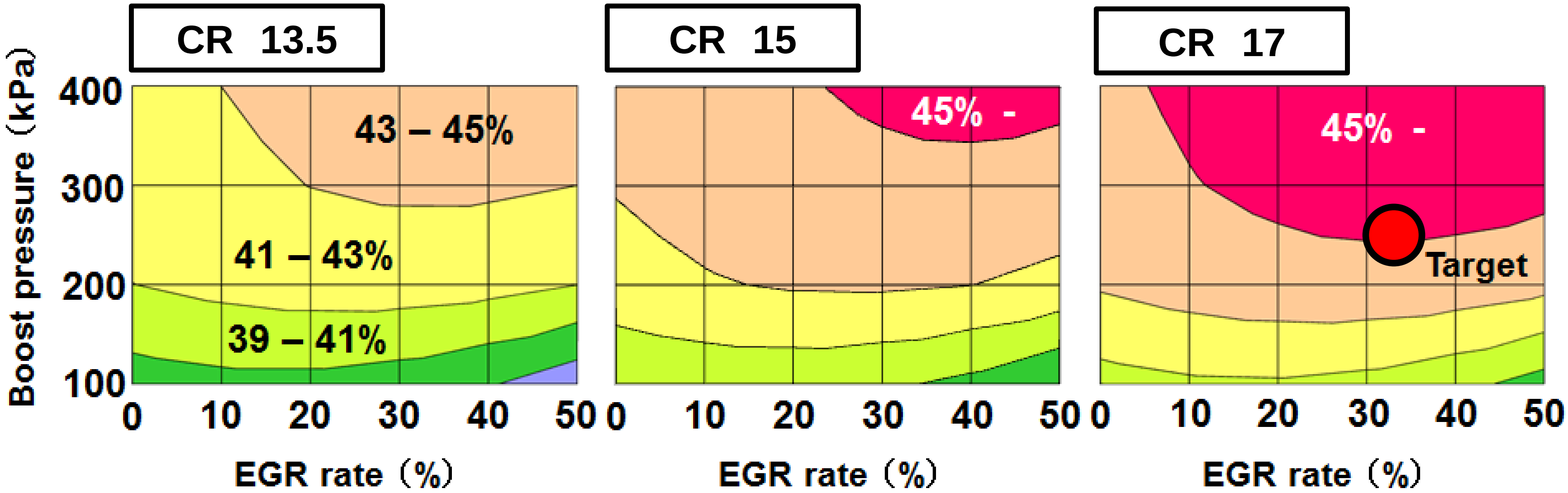
High Stroke-Bore Ratio, Gasoline Direct Injection

Low Effective Compression Ratio

How to Achieve Target Thermal Efficiency

Estimated Efficiency
by Past Test Result and 1D Simulation

L4 2000cc
Ne=2000rpm



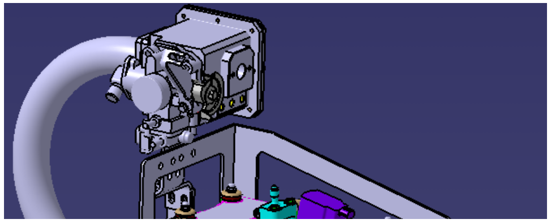
- Compression ratio (CR) : 17 or over
- Ignition timing : MBT
- EGR rate : 30% or more
- Boost pressure : 200 kPa or more

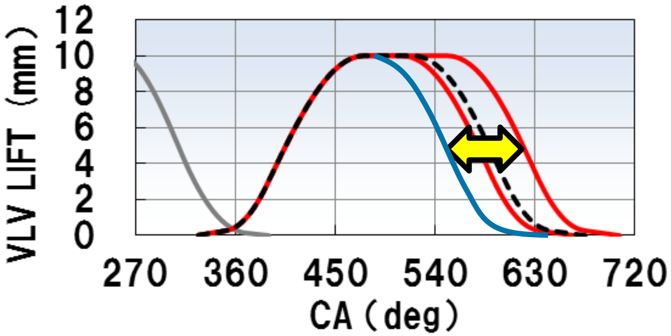
*FMEP: Mass-production L4 engine
*Ignition timing: MBT

Test System : Single-cylinder Engine

Engine specifications

Engine type	DOHC 4-valve Single-cylinder
Compression Ratio (CR)	13.5 -- 20.0
Inlet Valve Close @1mm	40,54,64,74,84° ABDC
Bore, Stroke (mm)	Φ81 , 96.6 -- 121.5 -- 162
S/B	1.2 -- 1.5 -- 2.0
Displacement Volume (cm^3)	499 -- 626 -- 835
Intake Port	Tumble Port
Air Supply	Super-charger
EGR Supply	LPL - EGR
Fuel Supply	PI / DI





Inlet Valve Open@1mm

-10deg ATDC (Fixed)

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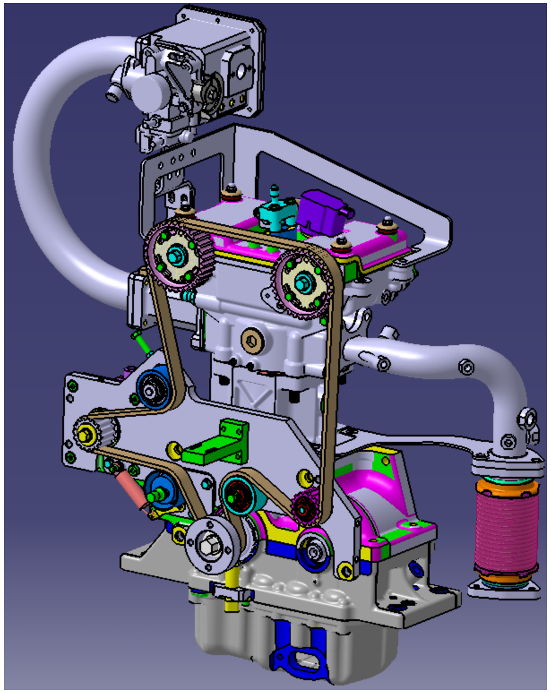


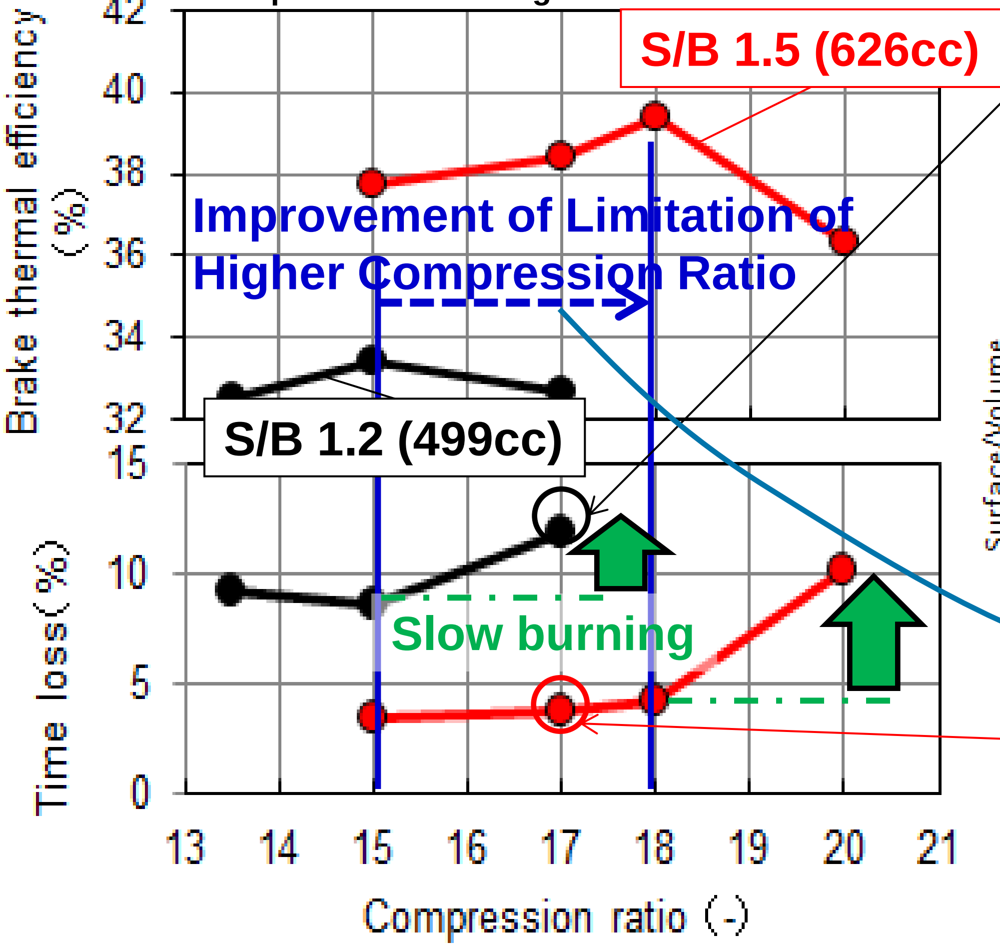
Stroke was changed by

- Crankshaft
- Connecting Rod
- Cylinder Sleeve

Countermeasure of High Compression Ratio
1 Stroke-Bore (S/B) ratio

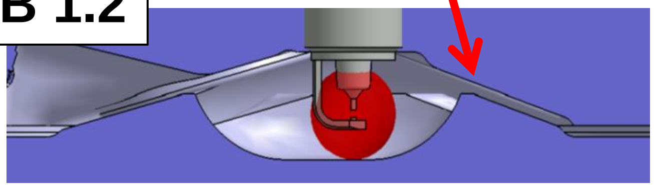
2000 rpm, IMEP 520 kPa, MBT、Port injection

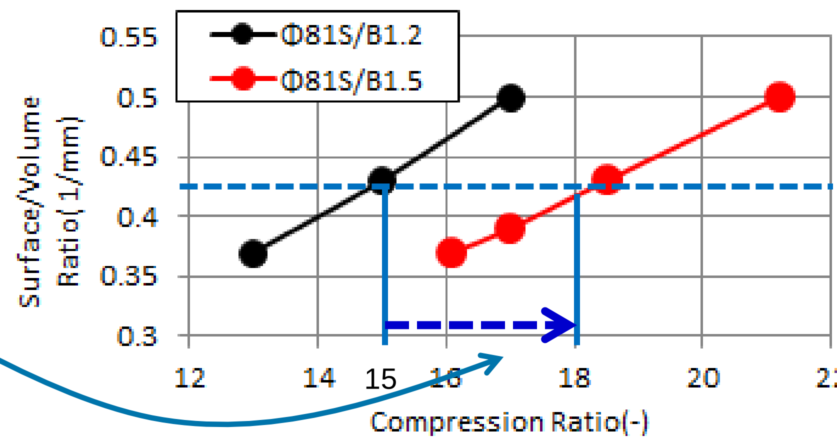
***Thermal efficiency calculation FMEP,PMEP : Equivalent to L4 engine**



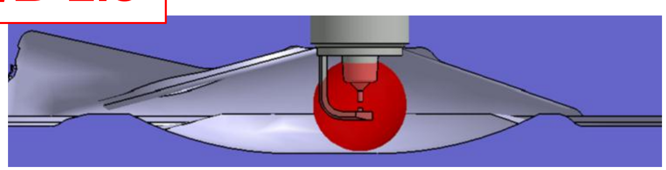
Slow burning occurred by narrow area of combustion chamber

S/B 1.2

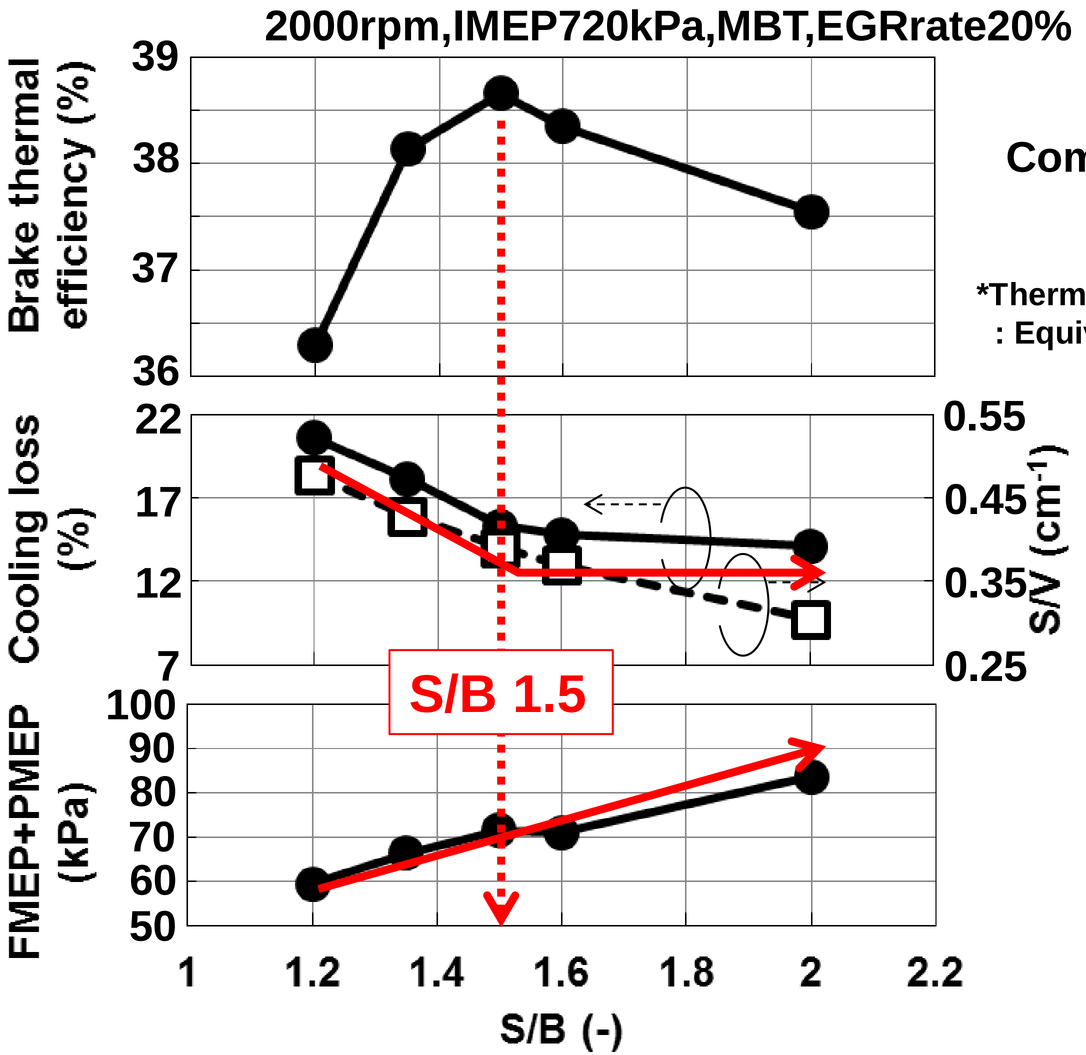




S/B 1.5



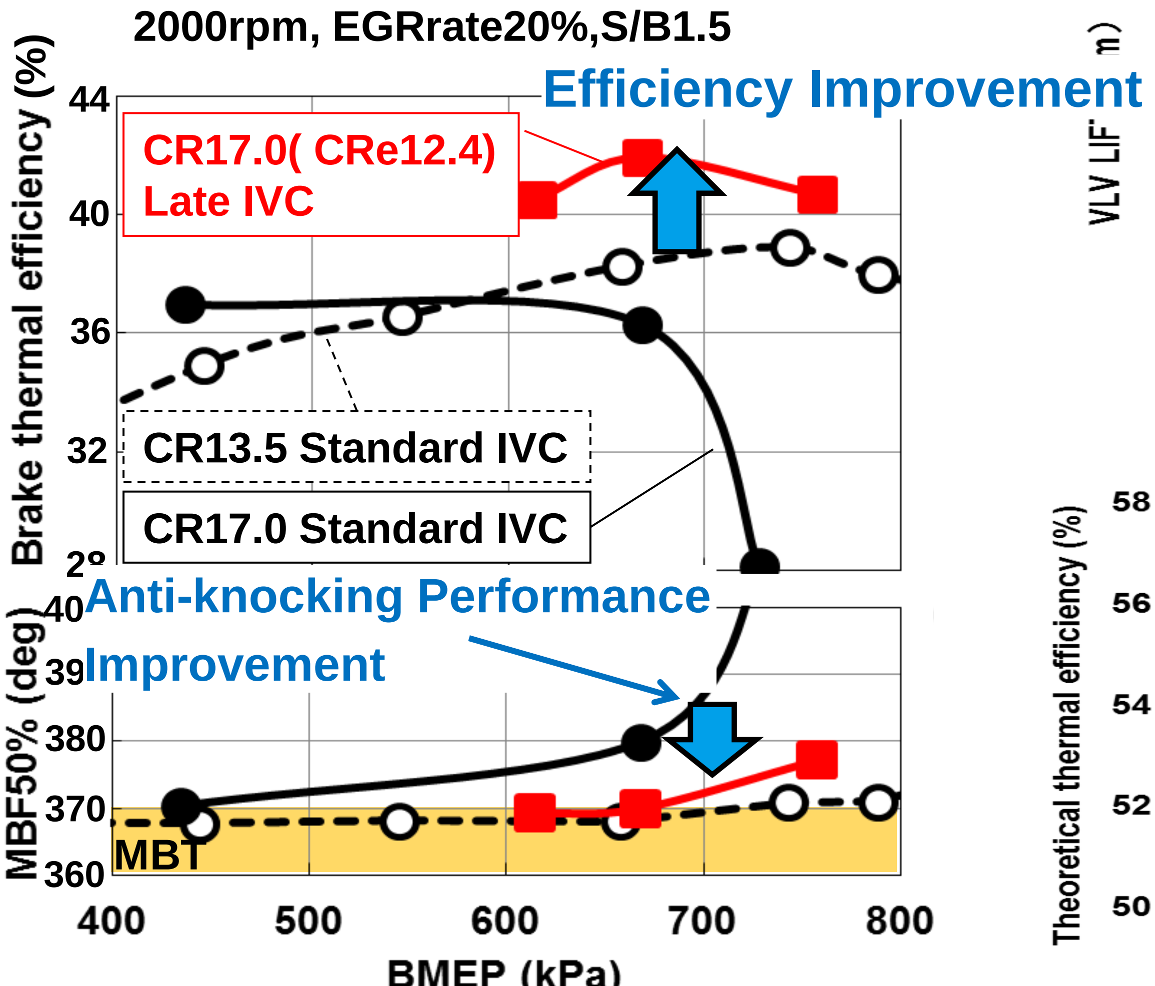
Influence of S/B to thermal efficiency

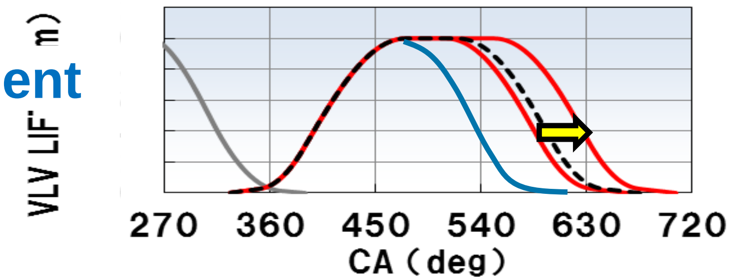


Compression Ratio = 13.5

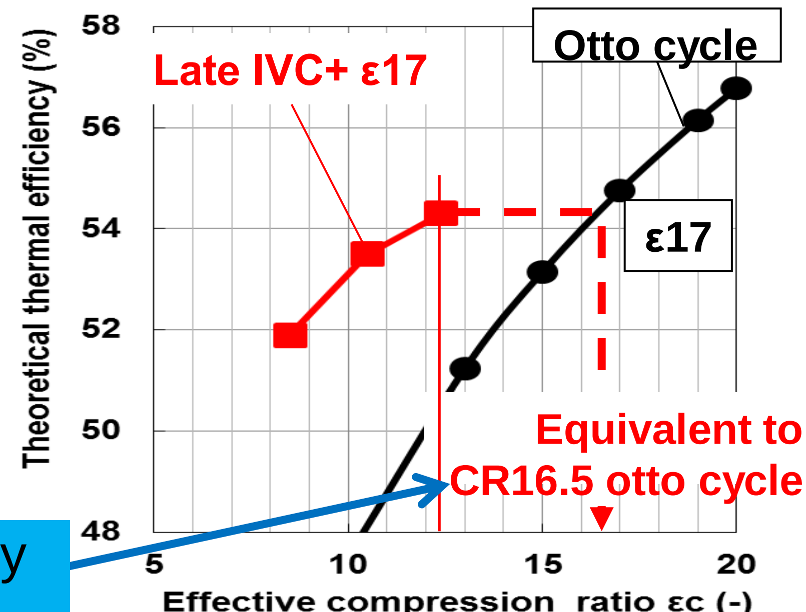
*Thermal efficiency calculation FMEP,PMEP
: Equivalent to L4 engine

Countermeasure of High Compression Ratio
2 Effective Compression Ratio (Late Intake Valve Close)





Standard IVC=580deg
Late IVC=614deg

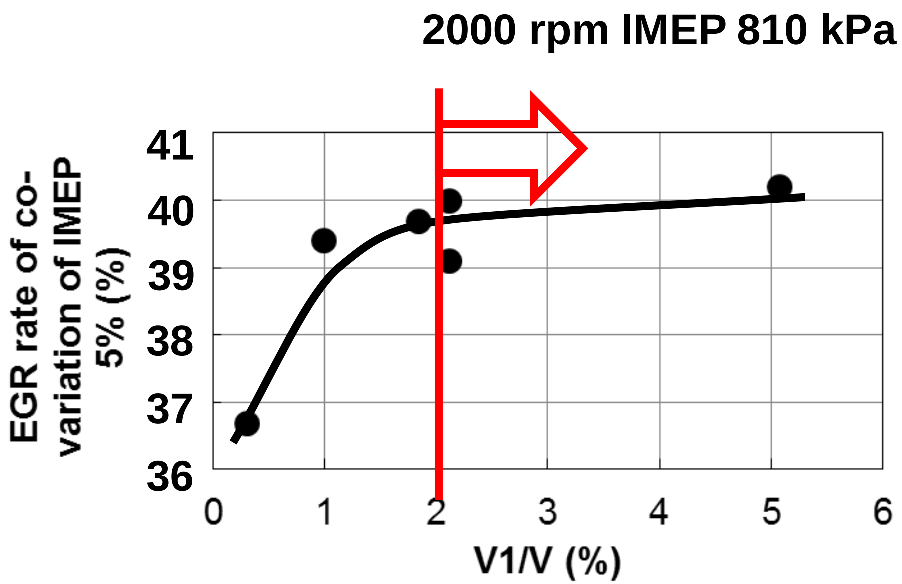


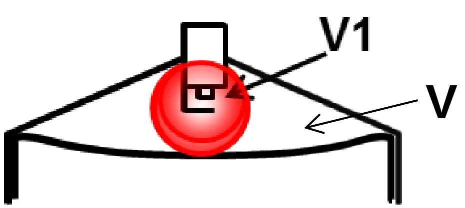
Theoretical Thermal Efficiency
Equivalent to CR16.5

Countermeasure for High EGR Ratio
1 Flame Kernel Formation

Space Near Spark Plug Gap

- V1 > 2% of Combustion Chamber Volume at TDC



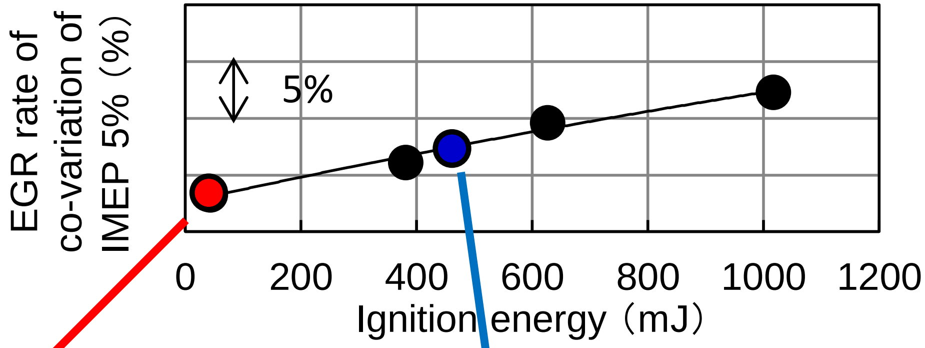


V: Combustion chamber volume at TDC
V1: Volume of virtual sphere centering on Ignition-plug electrode with inflating to touch surface of piston or cylinder head

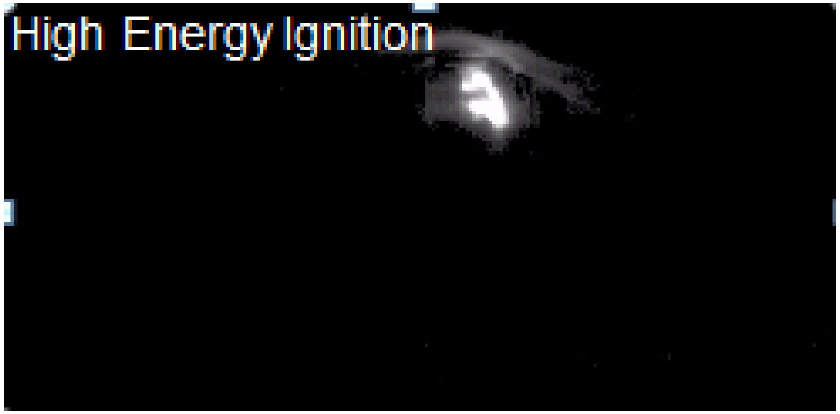
Countermeasure for High EGR Ratio
1 Flame Kernel Formation

High Energy Ignition

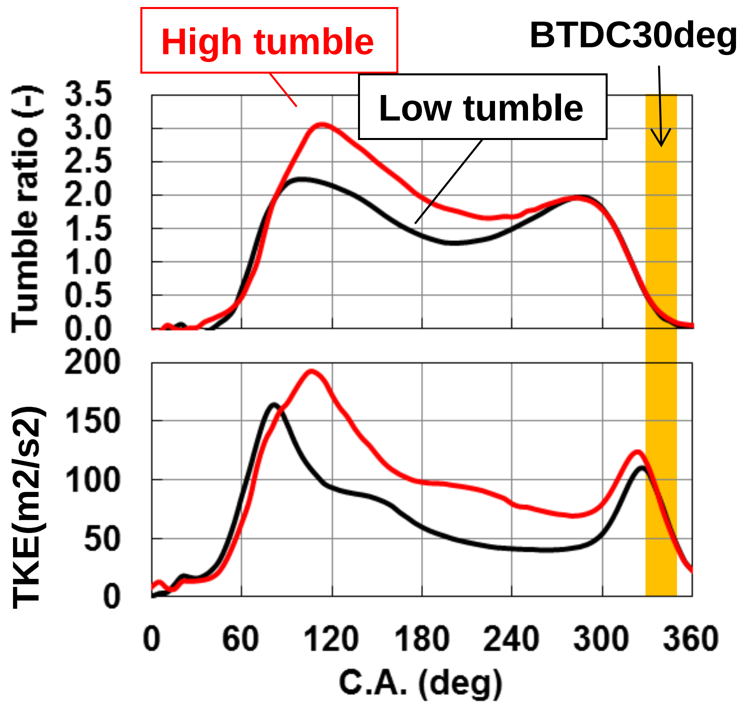
- Ignition Energy Extends EGR Limit
- Ignition Energy Set to 450mJ
  - Wear of Spark Plug
  - Power comsumption



2000 rpm, IMEP 520 kPa, EGR Rate=20%, ε = 9.5



Countermeasure for High EGR Rate
2 High Turbulent Intensity - 3D Simulation Result



Formation of High Tumble Flow

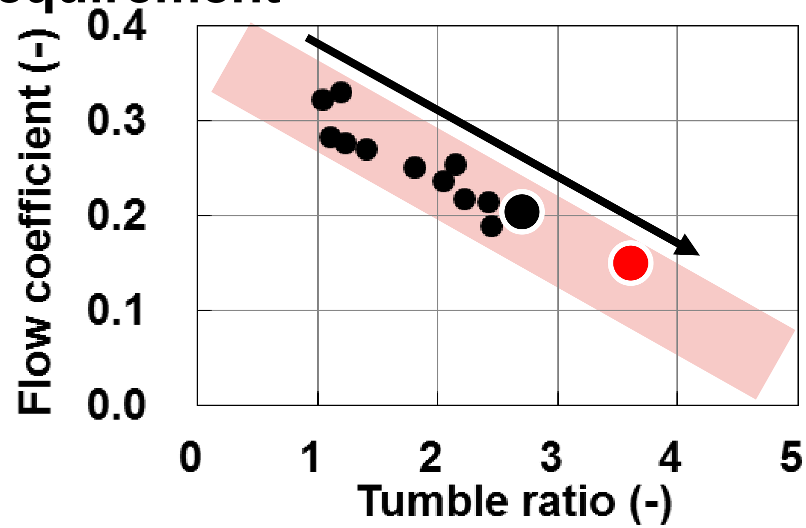
Holding Tumble Flow

Increase Turbulent Kinetic Energy(TKE)

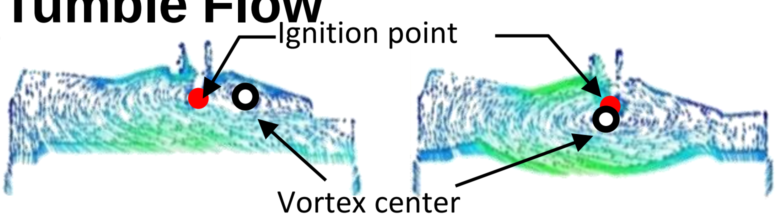
Combustion

Higher Tumble Ratio Worsens Flow Coefficient

>>Higher Boosting Efficiency Requirement



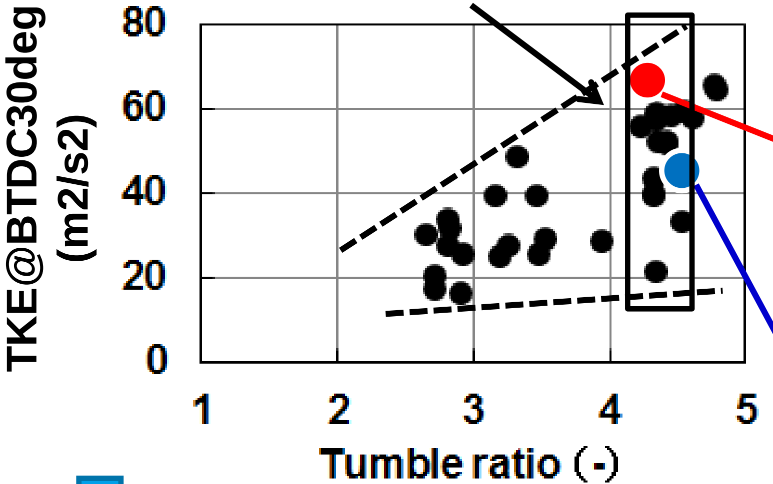
Piston Shape for Keep Tumble Flow



(a) Flat piston (b) Bowl-shaped piston

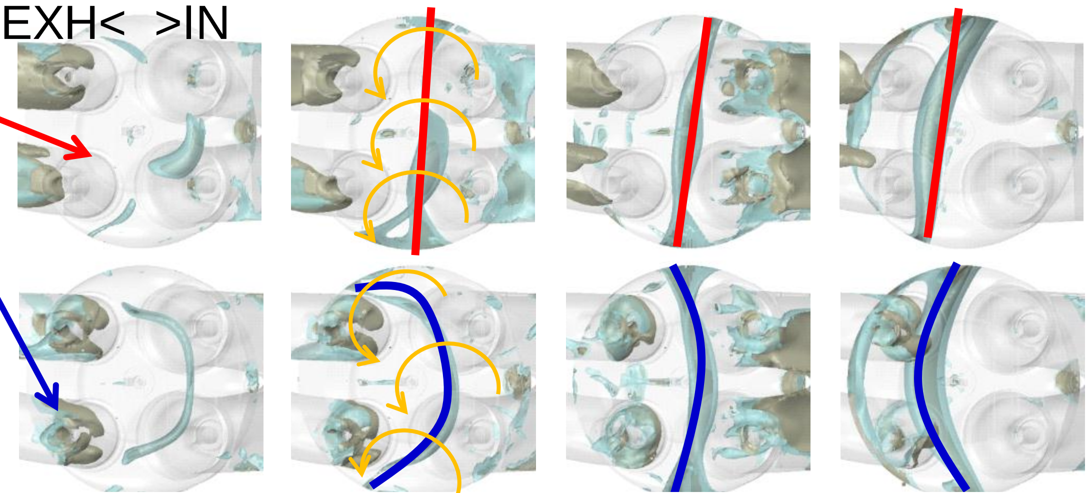
Countermeasure for High EGR Rate
2 High Turbulent Intensity - 3D Simulation Result

Same Tumble Ratio, TKE Varied



High TKE:<Stable>
Small Change In Center Axis of Tumble Flow

EXH< >IN

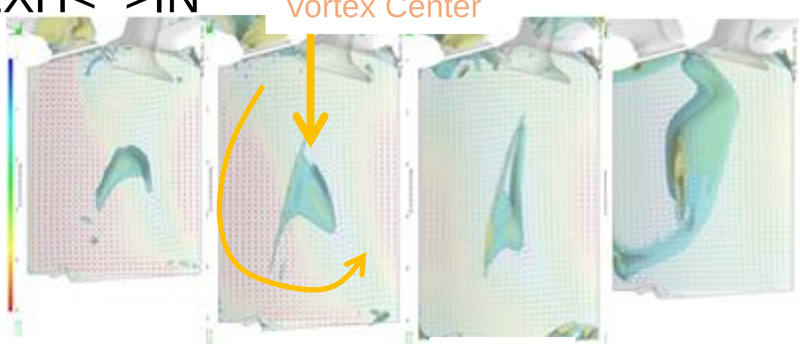


BTDC 240deg | BTDC 210deg | BTDC 180deg | BTDC 120deg

Low TKE:<Unstable>
Large Change In Center Axis of Tumble Flow

View from top of combustion chamber

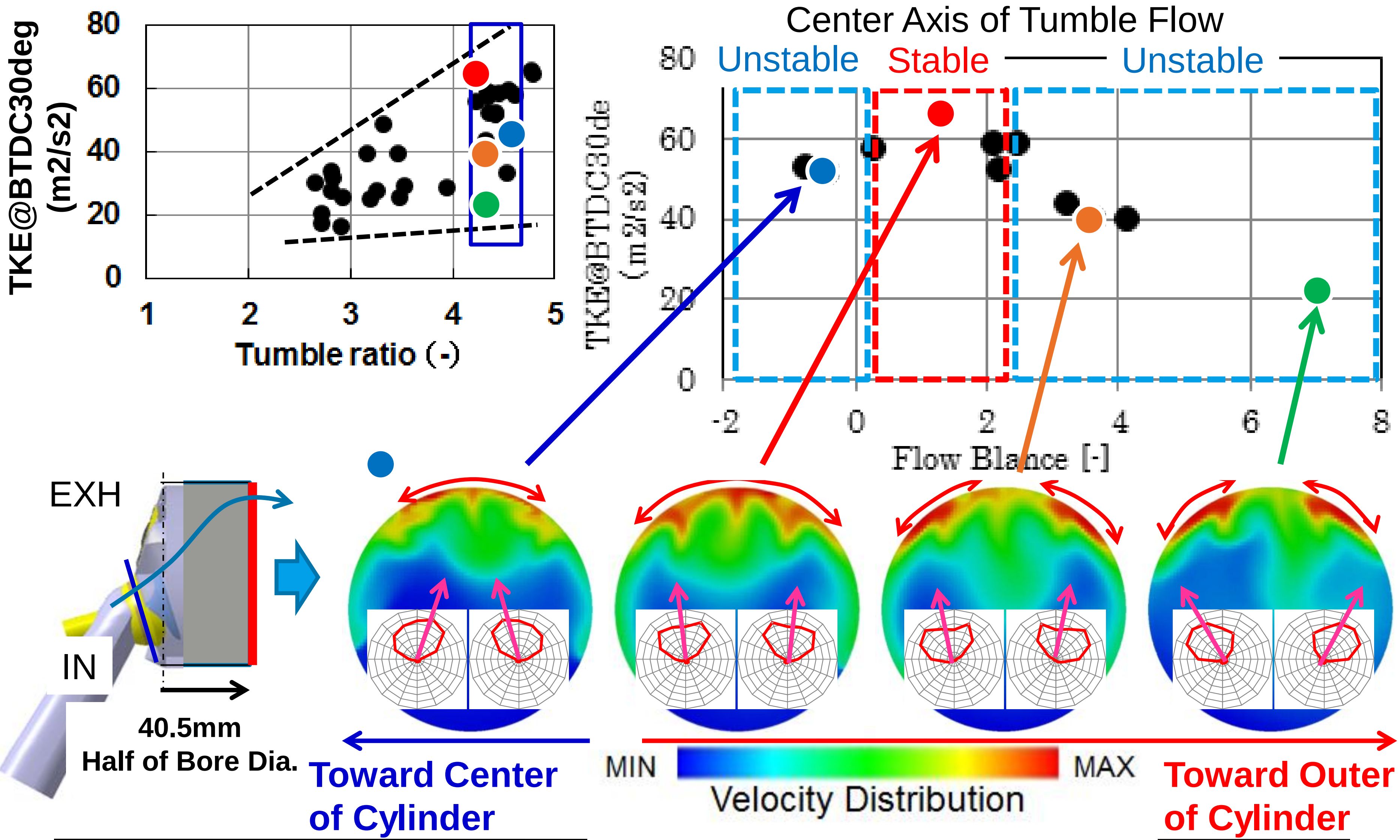
EXH< >IN



BTDC 240deg | BTDC 210deg | BTDC 180deg | BTDC 120deg

Stable Center Axis of Tumble Flow Make Higher TKE

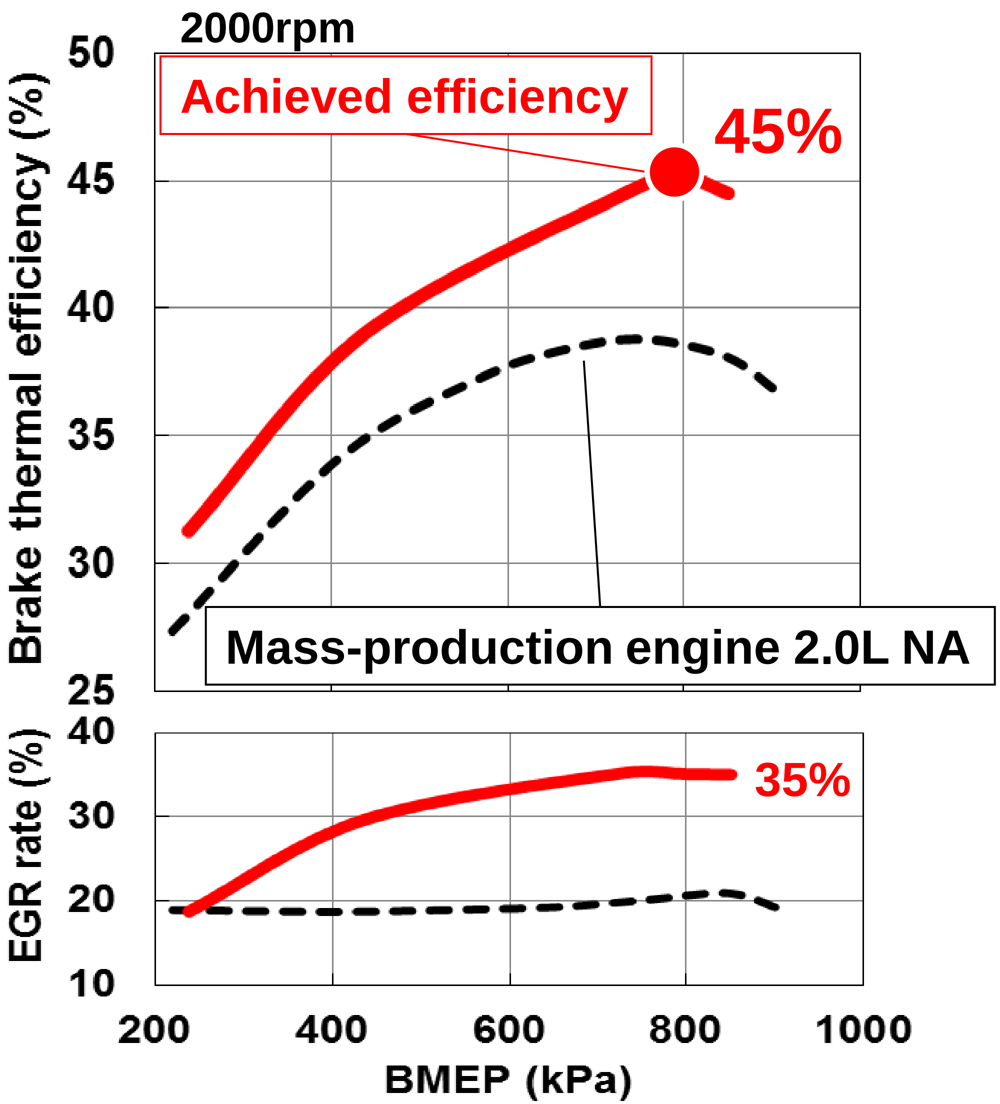
Countermeasure for High EGR Rate
2 High Turbulent Intensity - 3D Simulation Result



Brake Thermal Efficiency Achieved : Single Cylinder Engine

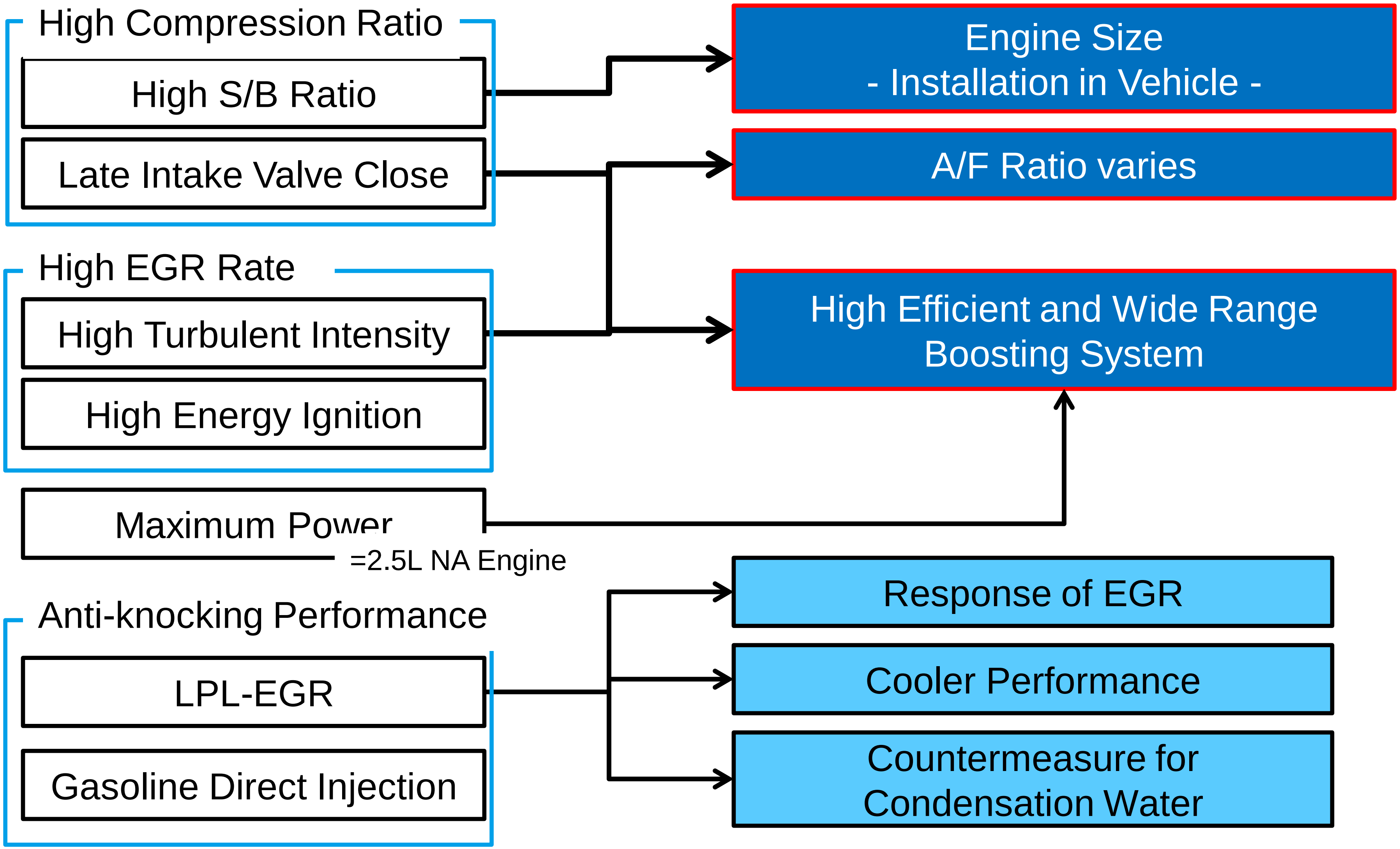
Engine specifications

Engine type	DOHC 4-valve
Bore, Stroke (mm)	Φ81 , 162
S/B	1.5
Displacement volume (cm^3)	626
Compression ratio	17.0
Effective compression ratio	12.4
Intake port	Tumble port
Piston shape	Bowl shape
Ignition energy	450 mJ
Air supply	Super-charger
Fuel supply	DI

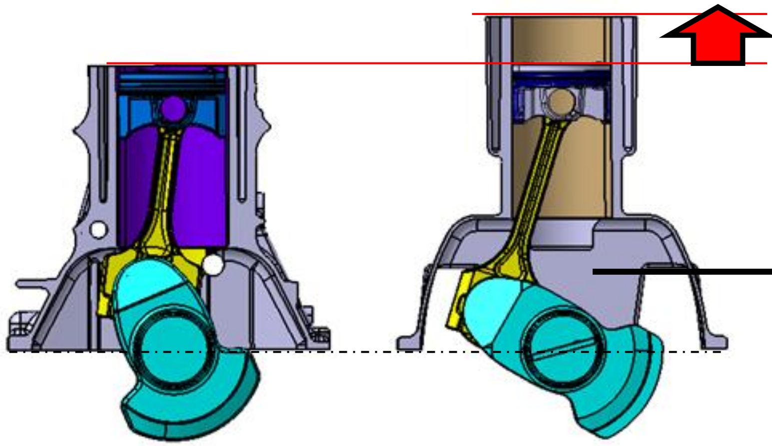


*Thermal efficiency calculation FMEP,PMEP
: Equivalent to L4 engine

Engine System Design



Engine Height Setting



Conventional
S/B Ratio1.2

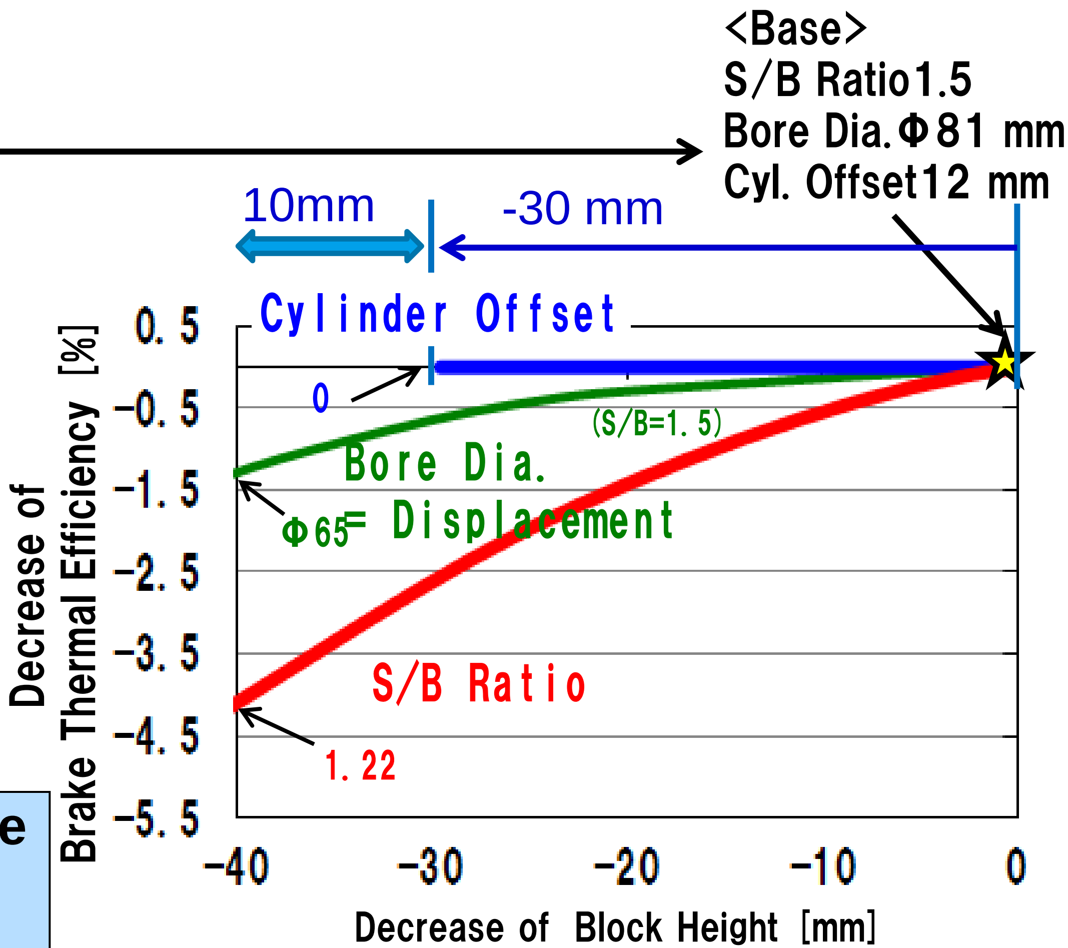
ηe45%
S/B Ratio1.5

S/B Ratio Changes from 1.2 to 1.5

- **Block Height Increase 40 mm**

Factors Affecting Block Height

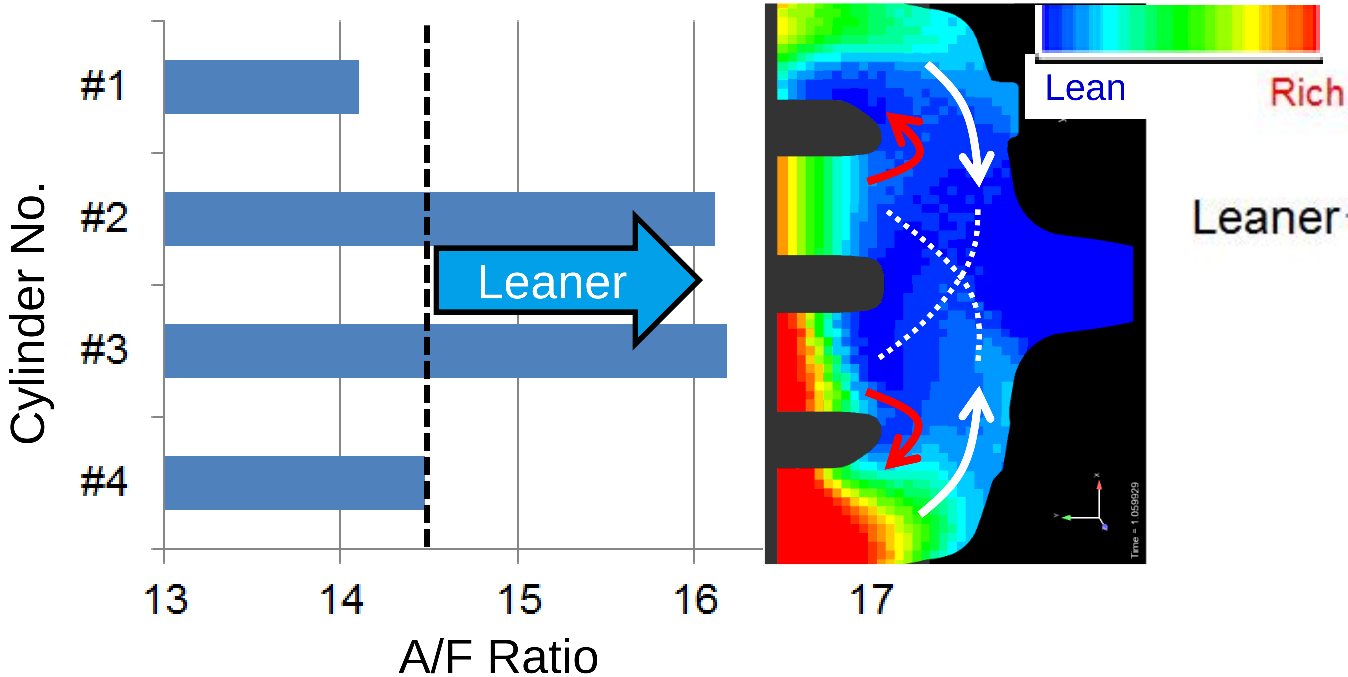
- **S/B Ratio**
- **Cylinder Offset**
- **Bore Diameter**

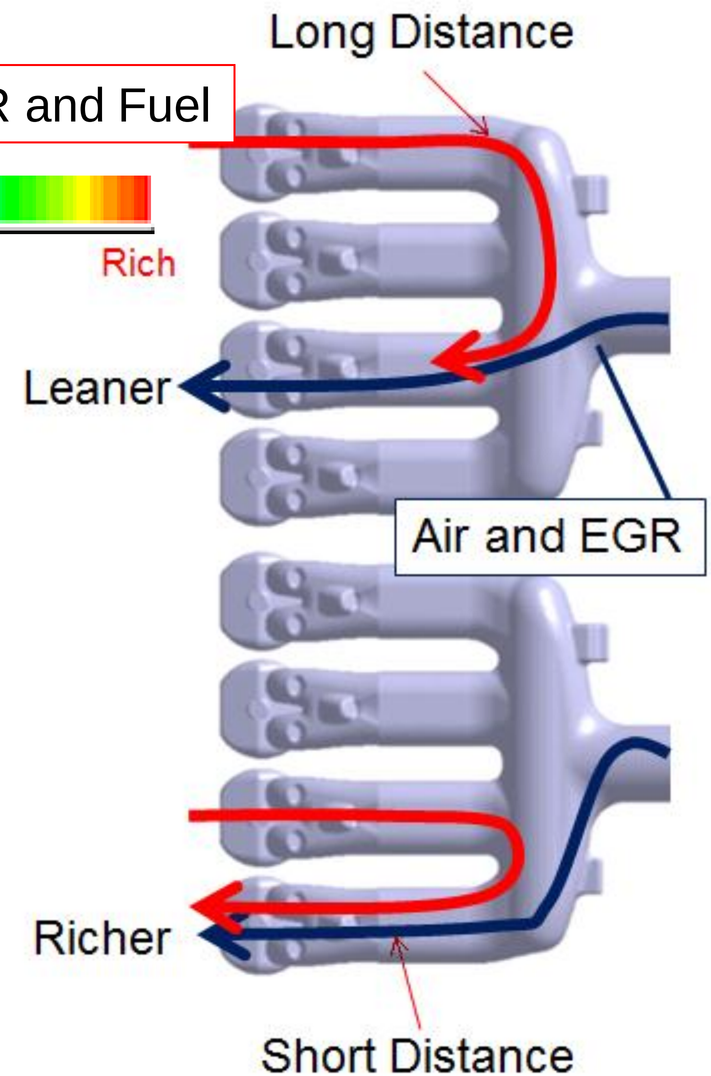


Eliminate Cylinder Offset to Give Priority to Efficiency-improving Benefit of S/B Ratio

A/F Ratio Varies

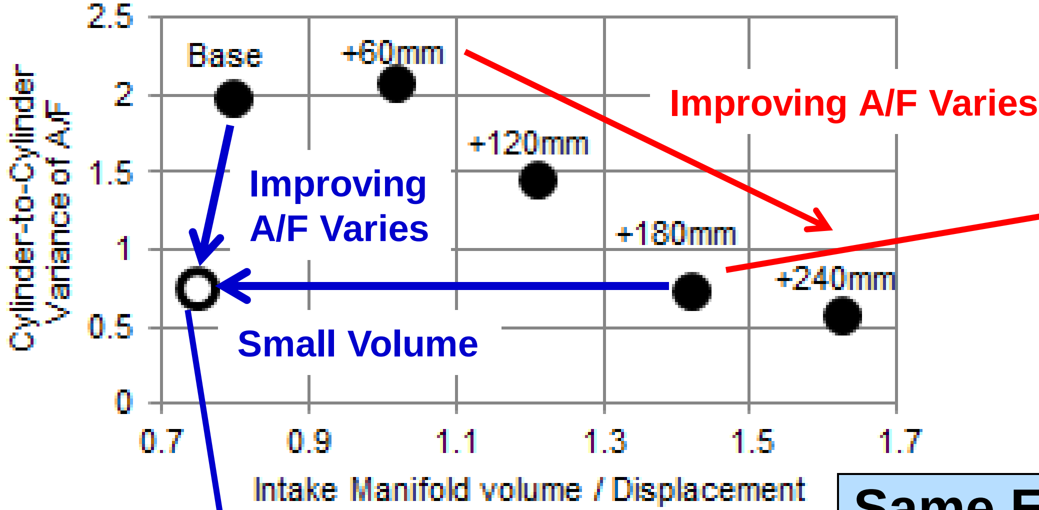
2000 rpm, IMEP 520 kPa, EGR 0%



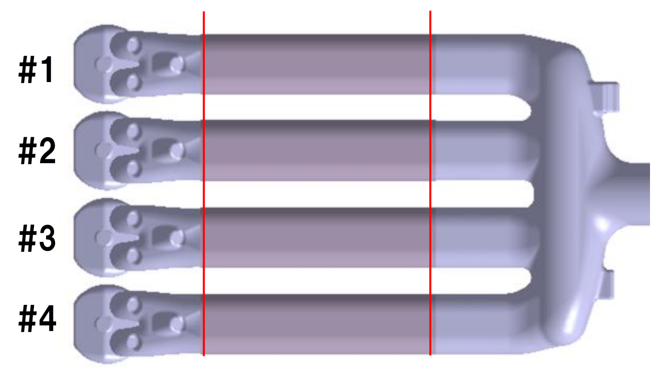


Miller Cycle Cause A/F Varies

A/F Ratio Varies / Countermeasure

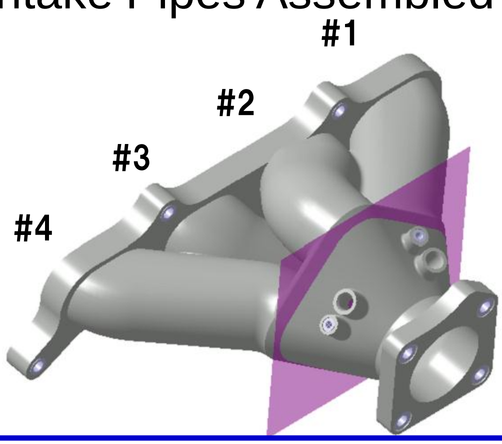


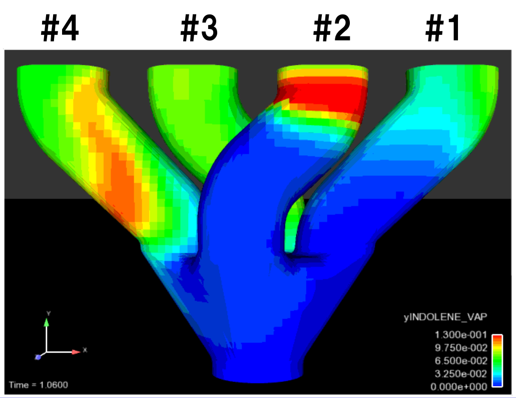
Extension of Intake Pipe

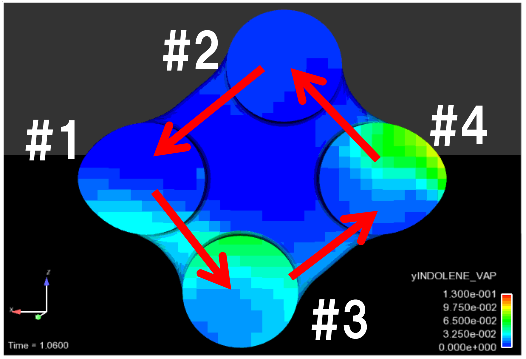


Same Effect on Less Intake Volume

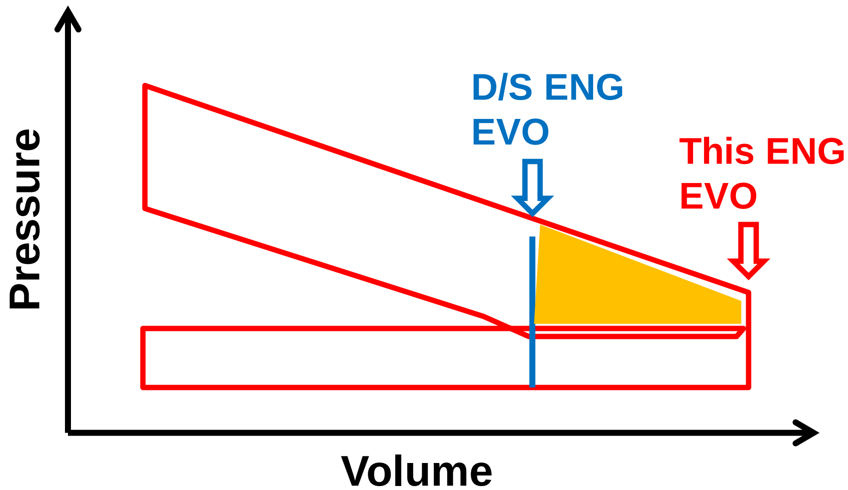
Intake Pipes Assembled in Firing Order



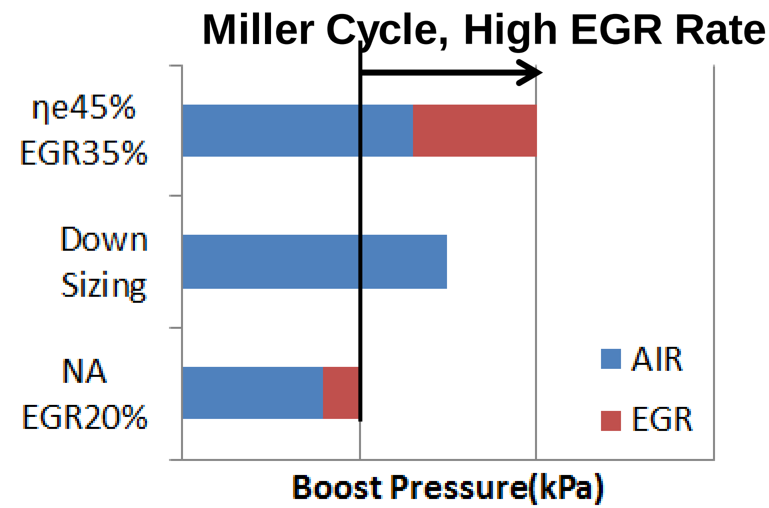




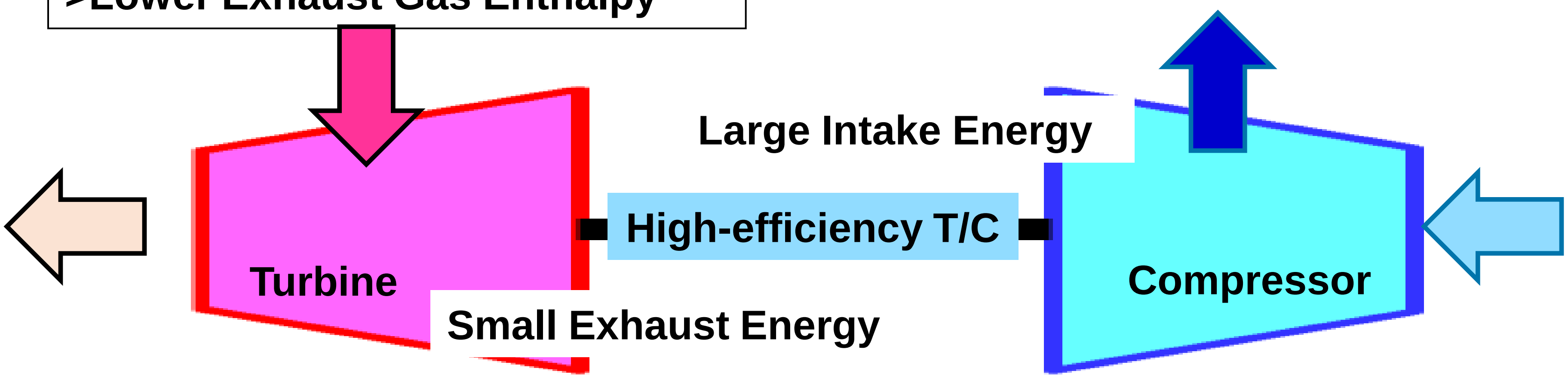
Examination of Boosting System Specifications



High EGR Rate and High Expansion Ratio
>Lower Exhaust Gas Enthalpy



Miller Cycle and High EGR Rate
>High Boost Pressure Is Required



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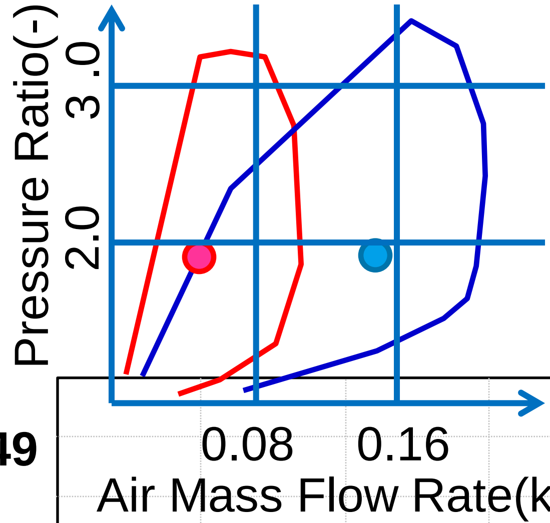
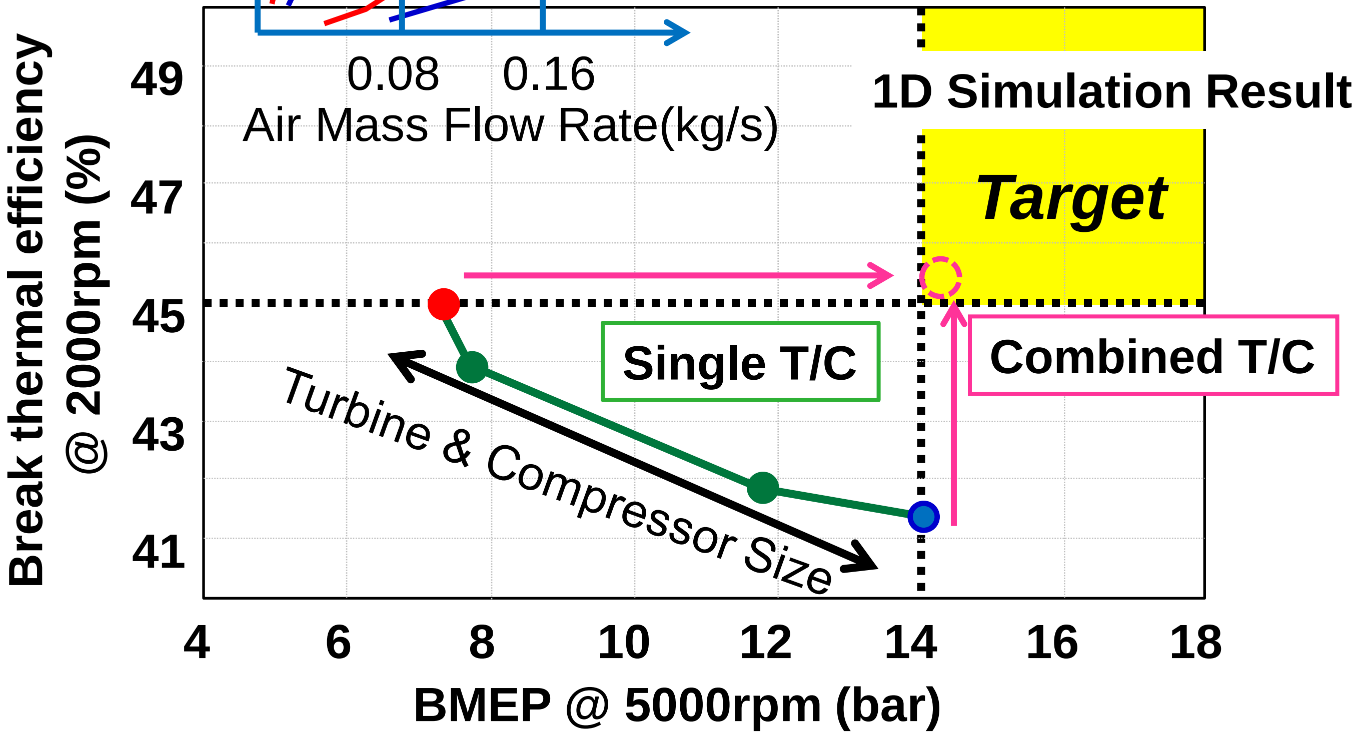


Single T/C Is Insufficient Engine Operation Point

- Combined Boosting System Is Required
  - T/C for Maximum Efficiency Point
  - T/C for Maximum Power Output Point



OUTLINE

3. How to Achieve Brake Thermal Efficiency 45%

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4. Conclusion

Conclusion

Specifications of 45% Brake Thermal Efficiency on Single Cylinder Engine

Higher Compression Ratio : Compression Ratio 17

- Late Intake Valve Close--- Effective Compression Ratio 12.4
- Long Stroke --- Stroke-Bore Ratio 1.5

Higher EGR Rate : EGR Rate 35%

- Ensuring Space around Ignition Point --- 2% Volume of TDC’s Combustion Chamber Volume
- High Energy Ignition --- 450mJ
- High Turbulent Kinetic Energy --- High Tumble Ratio Port, Keeping Tumble Flow Shape of Combustion Chamber

Multi Engine Application

Increased Engine Height Due to High Stroke-Bore Ratio

- 0 Cylinder Offset to Restrict Engine Height Increase to 10mm

Countermeasure for A/F varies caused by Late Intake Valve Close

- Firing Order Arranged Intake Manifold

High Efficiency and Wide range Boosting System is Needed

- Combined T/C

Conclusion

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Thank you for your kind attention.

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