31ST OCTOBER, 2023

JIA SUN

FEV SVERIGE AB

GT-POWER SIMULATION OF OLSHAMMAR ENGINE

PREPARED FOR

OLSHAMMAR NEBULA AB

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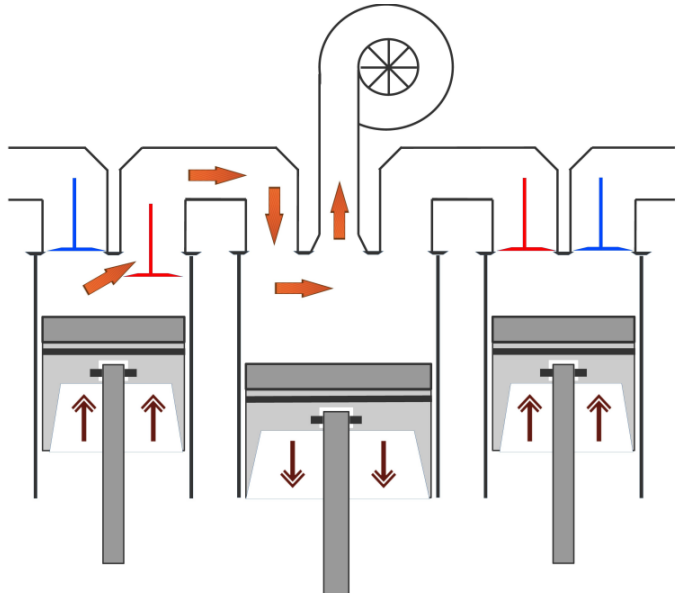
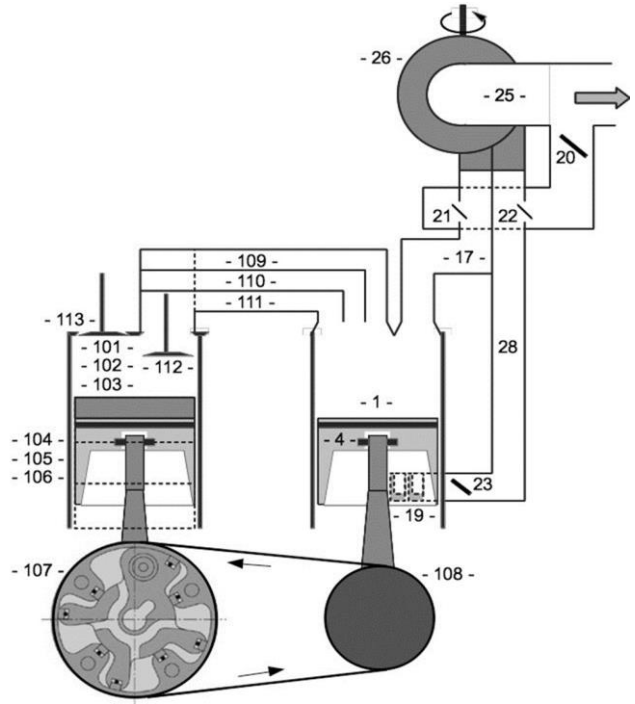
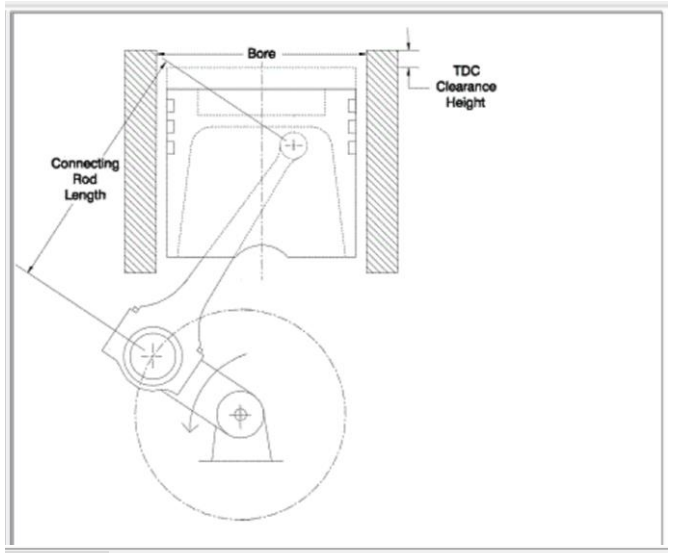




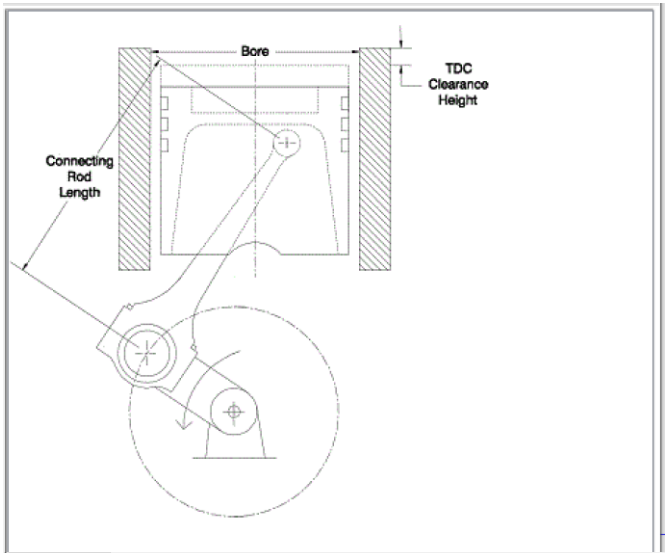
2 Cylinder Diesel Engine
Olshammar v.s. Baseline
BSFC & BP Results @1800 rpm

GT-Power Modelling
Geometry of Combustion Cylinder and Exh Piston



Main | Piston-to-Crank Offset | Crank-Slider Compliance

Attribute	Unit	Object Value
Bore	mm	131
Stroke	mm	158
Connecting Rod Length	mm	330
Compression Ratio		18.5
TDC Clearance Height	mm	0.5

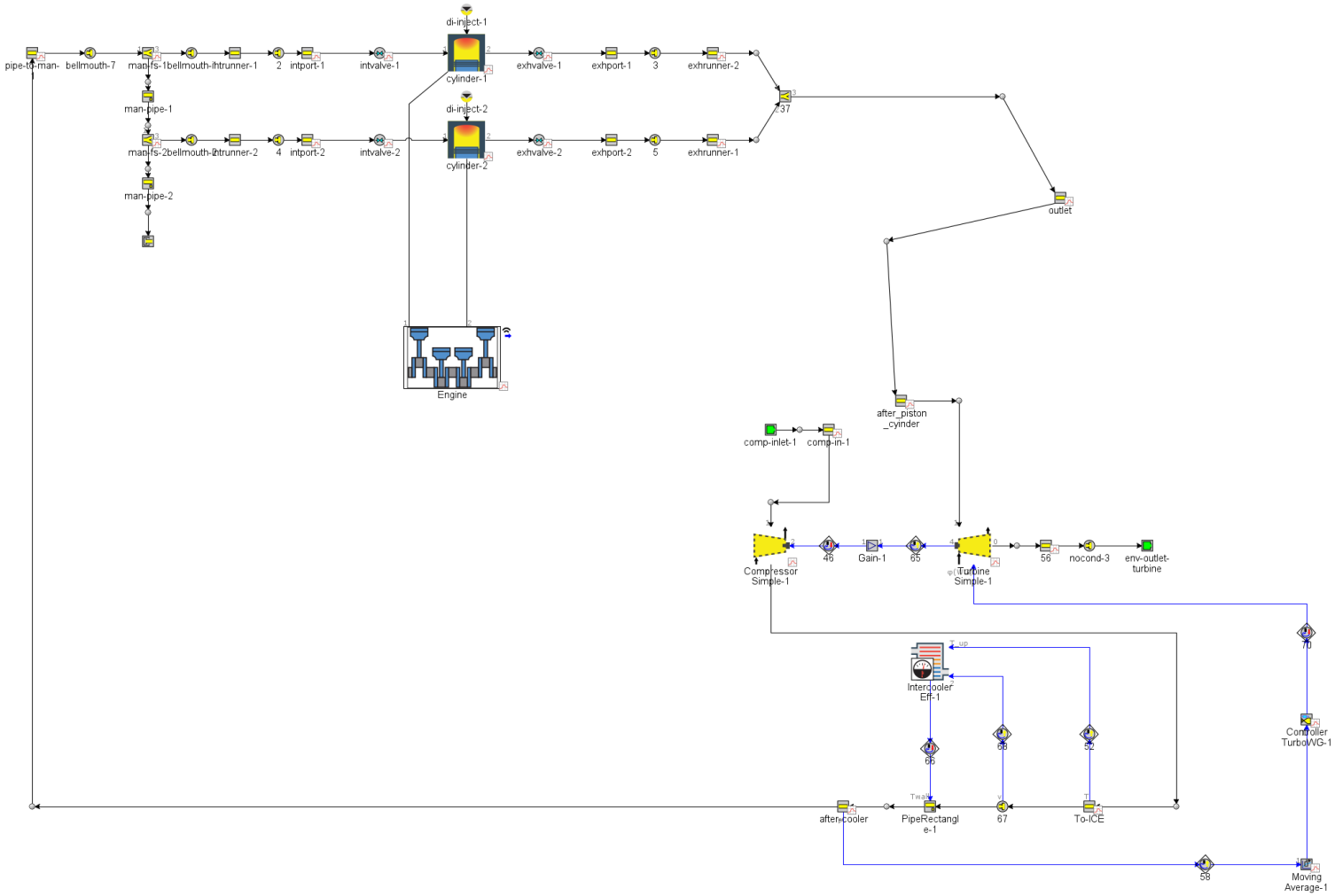


Main | Piston-to-Crank Offset | Crank-Slider Compliance

Attribute	Unit	Object Value
Bore	See Case S...	[Extra_Piston_Bore_Dia]
Stroke	See Case S...	[Extra_Piston_Stoke]
Connecting Rod Length	mm	360
Compression Ratio		18.5
TDC Clearance Height	mm	0.5

- Combustion cylinder is shown in figure left, where all parameters are fixed.
- Exh piston is shown in figure right, where bore and stroke are set as variables to optimize later.

GT-Power Model of Baseline 2 Cylinder Diesel Engine, Boost Pressure = 5.5 bar, @1800 rpm



Folder: 2Cylinder_DICI
GT-Baseline-2Cylinder_DICI-OPT-v01-5p5bar_updated.gtm

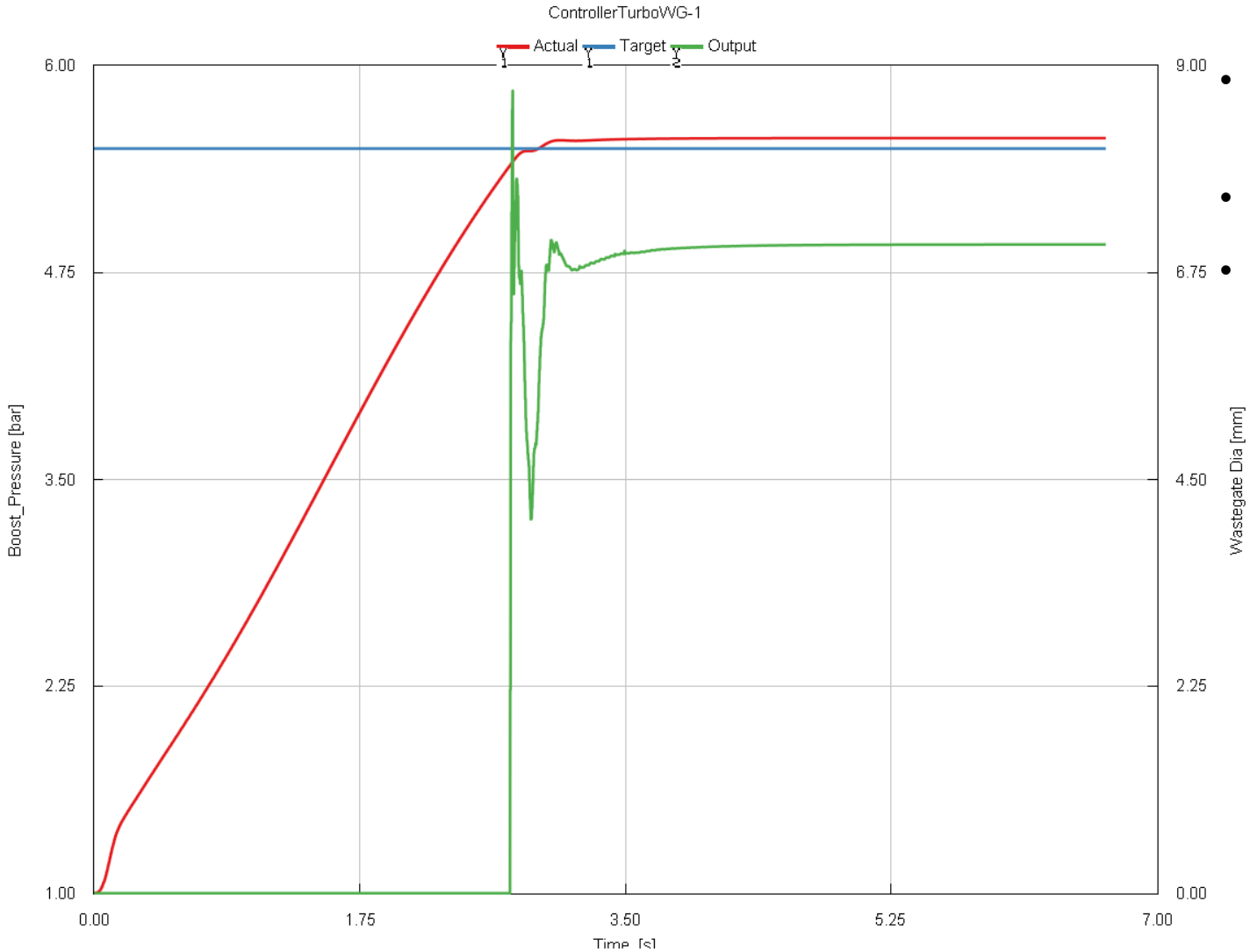
Parameters' optimization of Baseline 2 Cylinder Diesel Engine, Boost Pressure = 5.5 bar, @1800 rpm

Main

Parameter	Unit	Description	Case 1
Case On/Off		**Check Box to Turn Case On**	☑
Case Label		**Unique Text for Plot Legends**	
cylinder-offset	mm	Wrist Pin to Crank Offset	1
TargetBoostPressure	bar	Target	5.5
Agess		Aggressiveness Factor	0.9
exhport-dia	mm	Diameter at Inlet End	30
exhport-len	mm	Length	86
exhrunner-dia	mm	Diameter at Inlet End	42
exhrunner-len	mm	Length	96
orificedia	mm	Turbine Orifice Diameter	32
IntCTA	Crank Angle (4-stroke)	Cam Timing Angle	426
ExhCTA	Crank Angle (4-stroke)	Cam Timing Angle	241
intport-dia	mm	Diameter at Inlet End	49
intport-len	mm	Length	64
intrunner-dia	mm	Diameter at Inlet End	54
intrunner-len	mm	Length	110
RPM	RPM	Engine Speed	1800
Comb_Cylinder_Dia	mm	Bore	131
Comb_Cylinder_Stroke	mm	Stroke	158

- Parameters highlighted in red blocks are optimized in GT-Power.

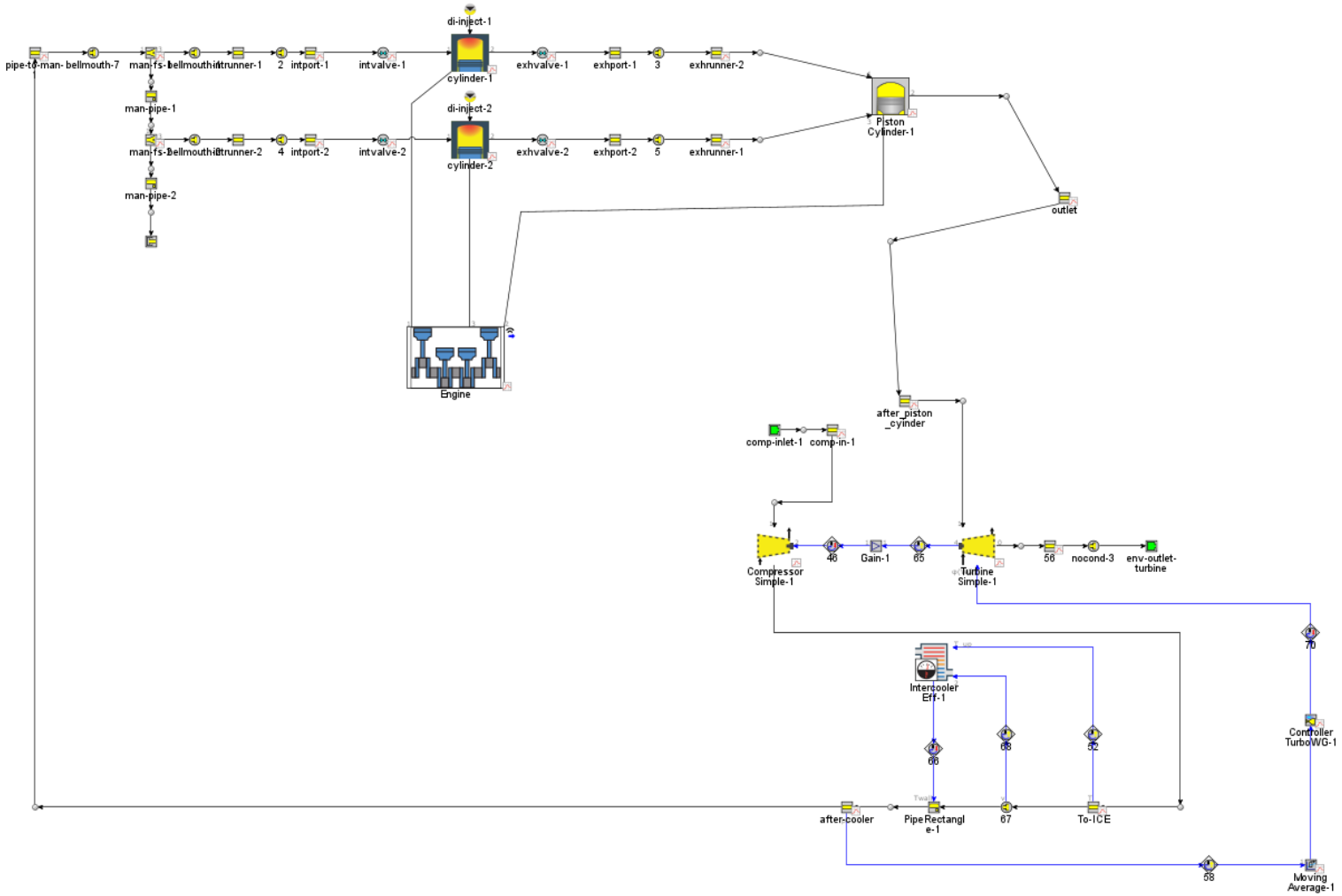
Optimized results of Baseline 2 Cylinder Diesel Engine, Boost Pressure = 5.5 bar, @1800 rpm



- Boost pressure reaches to the target pressure of 5.5 bar by using the wastegate controller.
- Green curve is the wastegate diameter.
- BSFC & Brake Power

Baseline bsfc [g/kW-h]	Baseline bp [kW]
224.0	209.3

GT-Power Model of Olshammar 2 Cylinder Diesel Engine with Exh Piston, Boost Pressure = 5.5 bar, @1800 rpm



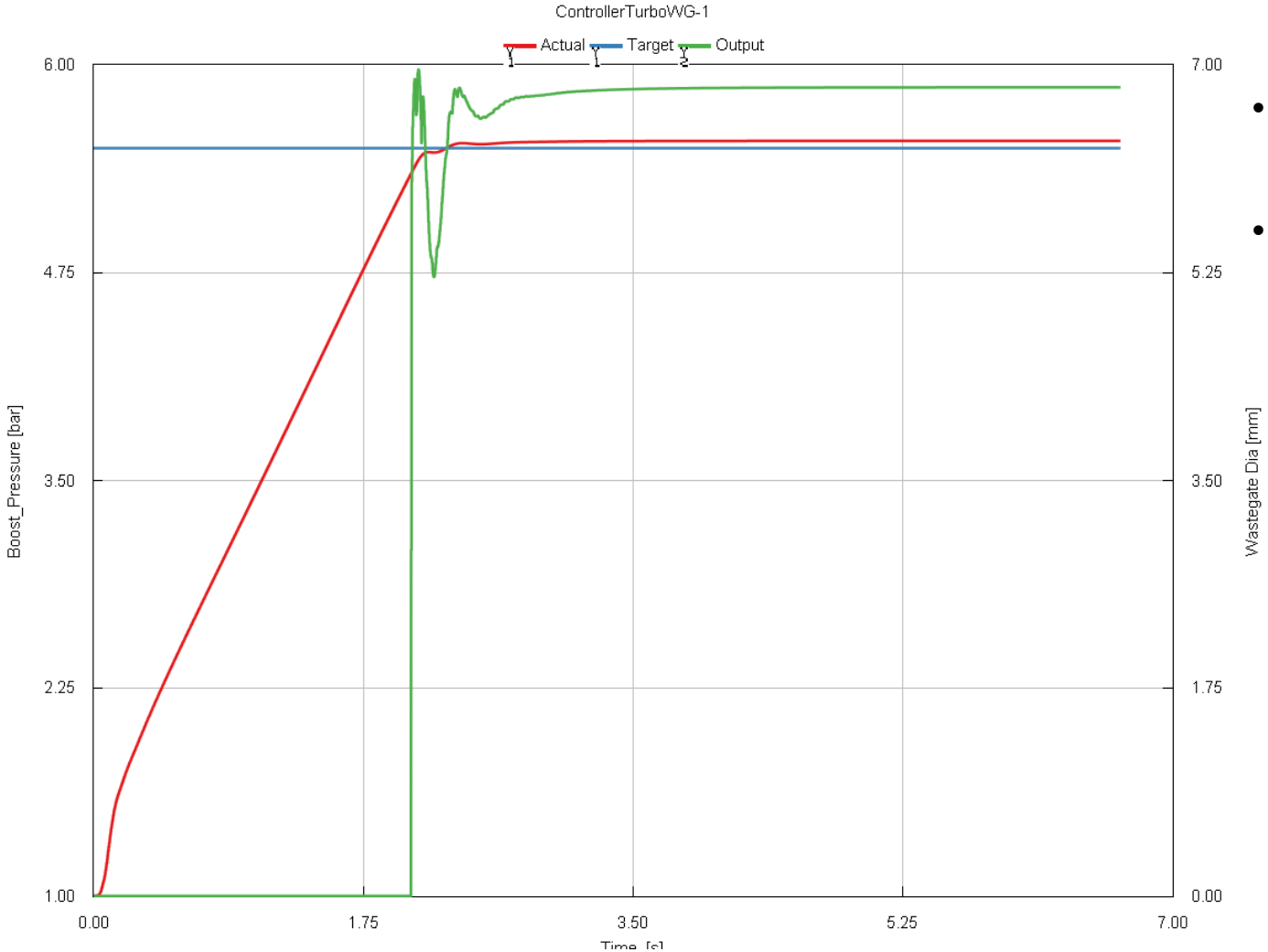
Folder: 2Cylinder_DICI
GT-ExtraPiston-2Cylinder_DICI-OPT-v02-5p5bar-updated.gtm

GT-Power Model of Olshammar 2 Cylinder Diesel Engine with Exh Piston, Boost Pressure = 5.5 bar, @1800 rpm

Parameter	Unit	Description	Case 1
Case On/Off		**Check Box to Turn Case On**	☑
Case Label		**Unique Text for Plot Legends**	
cylinder-offset	mm	Wrist Pin to Crank Offset	1
exhport-dia	mm	Diameter at Inlet End	31
exhport-len	mm	Length	77
exhrunner-dia	mm	Diameter at Inlet End	45
exhrunner-len	mm	Length	91
RPM	RPM	Engine Speed	1800
TargetBoostPressure	bar	Target	5.5
orificedia	mm	Turbine Orifice Diameter	25
IntCTA	Crank Angle (4-stroke)	Cam Timing Angle	430
ExhCTA	Crank Angle (4-stroke)	Cam Timing Angle	251
intport-dia	mm	Diameter at Inlet End	61
intport-len	mm	Length	53
intrunner-dia	mm	Diameter at Inlet End	65
intrunner-len	mm	Length	110
EXC_FI	deg	Firing Intervals	190
Extra_Piston_Stoke	mm	Stroke	59
Extra_Piston_Bore_Dia	mm	Bore	218
Cylinder_CR		Compression Ratio	18.5

- Parameters highlighted in red blocks are optimized in GT-Power.

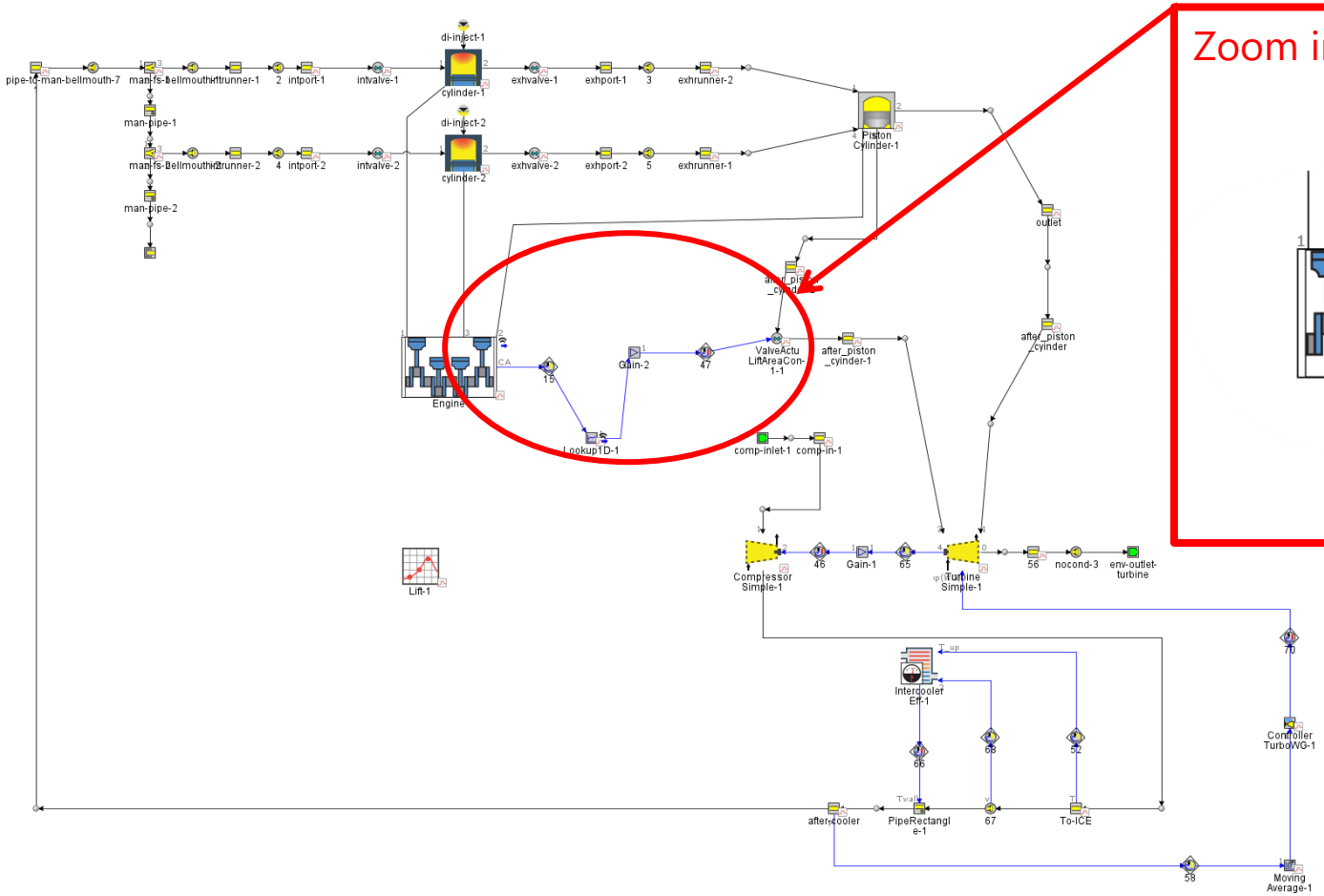
GT-Power Model of Olshammar 2 Cylinder Diesel Engine with Exh Piston, Boost Pressure = 5.5 bar, @1800 rpm



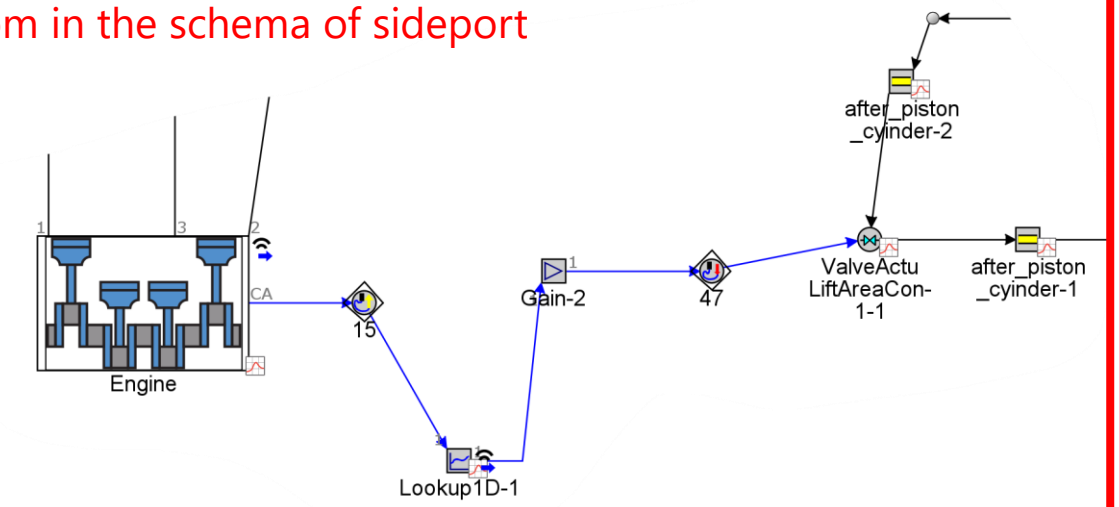
- Boost pressure reaches to the target pressure of 5.5 bar by using the wastegate controller.
- BSFC & Brake Power

Exh Piston bsfc [g/kW-h]	Exh Piston bp [kW]
212.5	239.5

GT-Power Model of Olshammar 2 Cylinder Diesel Engine, with Exh Piston & Sideport, Boost Pressure = 5.5 bar, @1800 rpm



Zoom in the schema of sideport

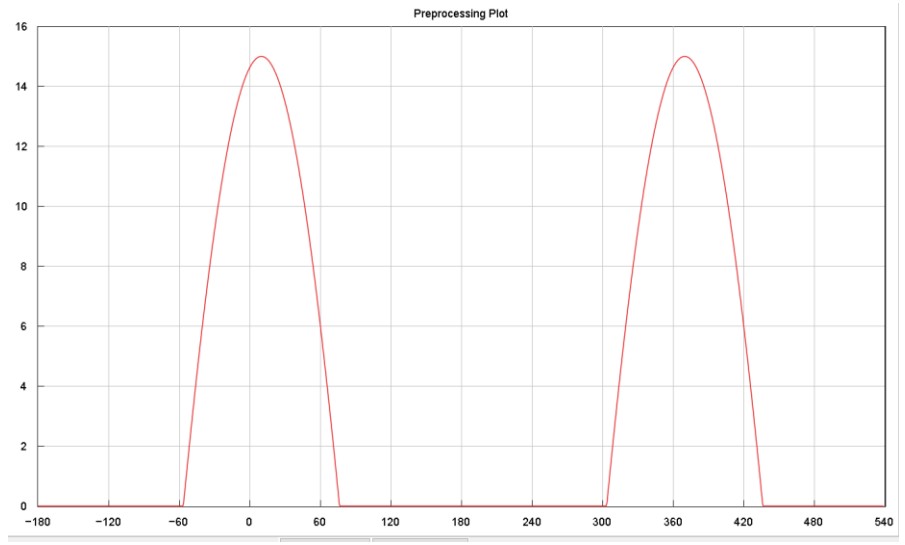


Folder: 2Cylinder_DICI

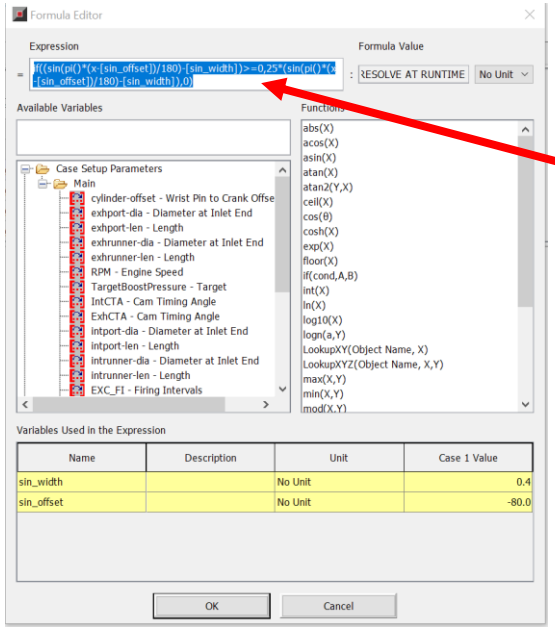
GT-ExtraPiston-Sideport-2Cylinder_DICI-v02_updated.gtm

GT-Power Model of Olshammar 2 Cylinder Diesel Engine, with Exh Piston & Sideport, Boost Pressure = 5.5 bar, @1800 rpm

- Modelling the valve lift curve to control sideport's opening, see figure right



- Formula used in GT-Power, see figure below



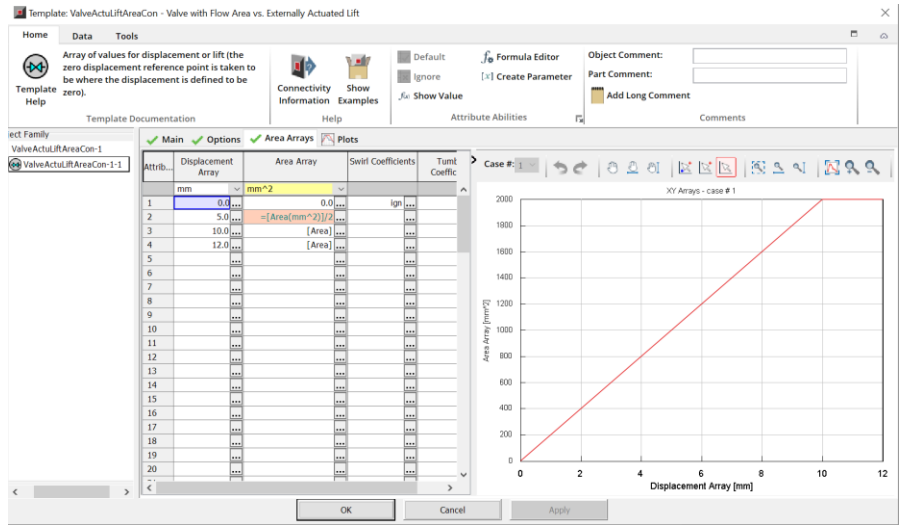
If (sin(pi()*(x-[sin_offset])/180)-[sin_width])>=0),

= 25*(sin(pi()*(x-[sin_offset])/180)-[sin_width]),

else

= 0

- ValveActuLiftAreaCon is used with a map of lift displacement and lift area

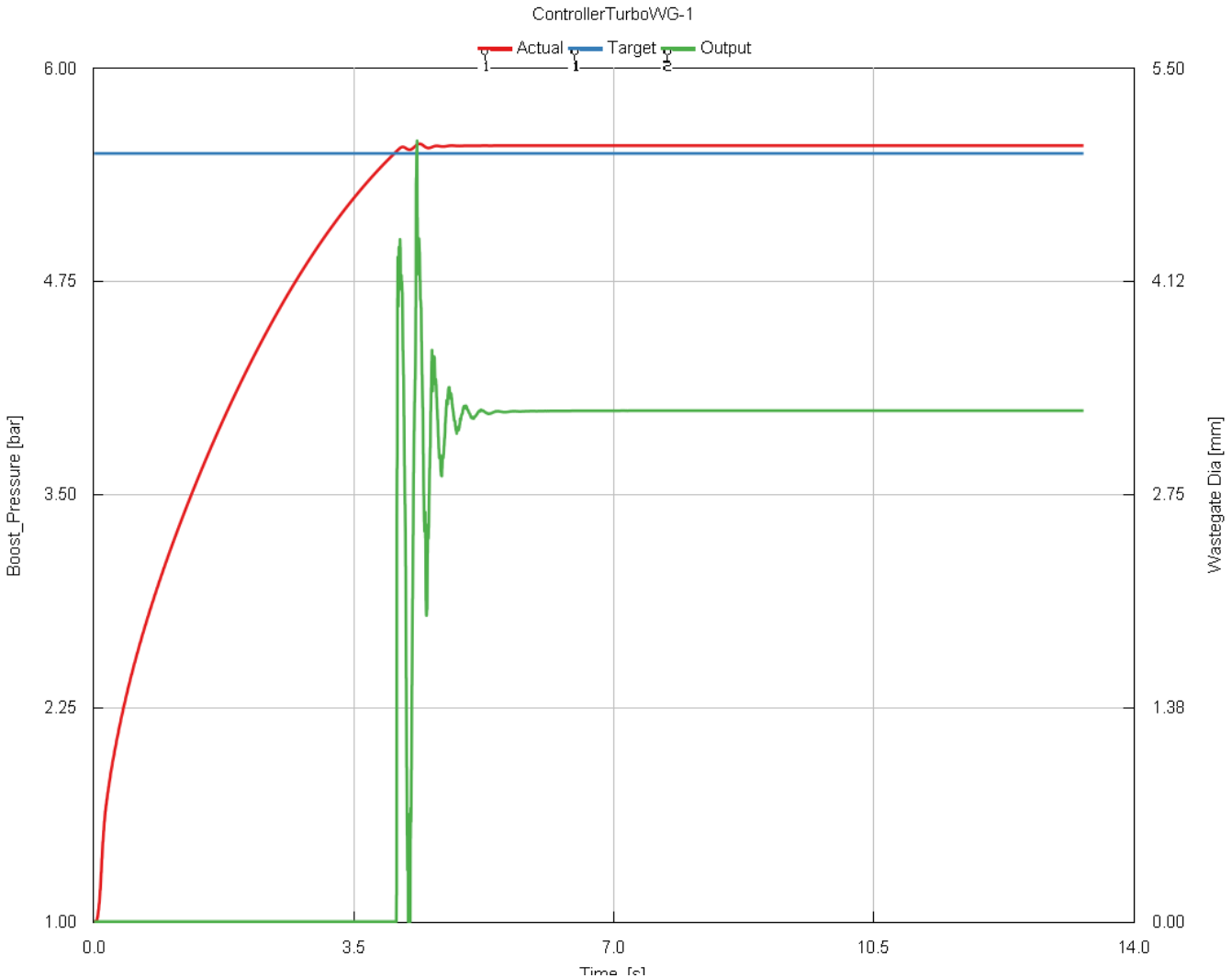


GT-Power Model of Olshammar 2 Cylinder Diesel Engine, with Exh Piston & Sideport, Boost Pressure = 5.5 bar, @1800 rpm

Parameter	Unit	Description	Case 1
Case On/Off		**Check Box to Turn Case On**	☑
Case Label		**Unique Text for Plot Legends**	
cylinder-offset	mm	Wrist Pin to Crank Offset	1
exhport-dia	mm	Diameter at Inlet End	31
exhport-len	mm	Length	77
exhrunner-dia	mm	Diameter at Inlet End	45
exhrunner-len	mm	Length	91
RPM	RPM	Engine Speed	1800
TargetBoostPressure	bar	Target	5.5
IntCTA	Crank Angle (4-stroke)	Cam Timing Angle	430
ExhCTA	Crank Angle (4-stroke)	Cam Timing Angle	254
intport-dia	mm	Diameter at Inlet End	61
intport-len	mm	Length	53
intrunner-dia	mm	Diameter at Inlet End	65
intrunner-len	mm	Length	110
EXC_FI	deg	Firing Intervals	190
Extra_Piston_Bore_Dia	mm	Bore	218
Cylinder_CR		Compression Ratio	18.5
Comb_Cylinder_Dia	mm	Bore	131
Comb_Cylinder_Stroke	mm	Stroke	158
Comb_CR		Compression Ratio	18.5
sin_offset			-80
orificedia	mm	Turbine Orifice Diameter	32
Area	mm^2	Area Array	2000
sin_width			0.4
Extra_Piston_Stoke	mm	Stroke	73

- Parameters highlighted in red blocks are optimized in GT-Power.

GT-Power Model of Olshammar 2 Cylinder Diesel Engine, with Exh Piston & Sideport, Boost Pressure = 5.5 bar, @1800 rpm



- Boost pressure reaches to the target pressure of 5.5 bar by using the wastegate controller.
- BSFC & Brake Power

Sideport bsfc [g/kW-h]	Sideport bp [kW]
207.9	249.0

Comparison of Baseline and Two Olshammar Engines
Boost Pressure = 5.5 bar, @1800 rpm

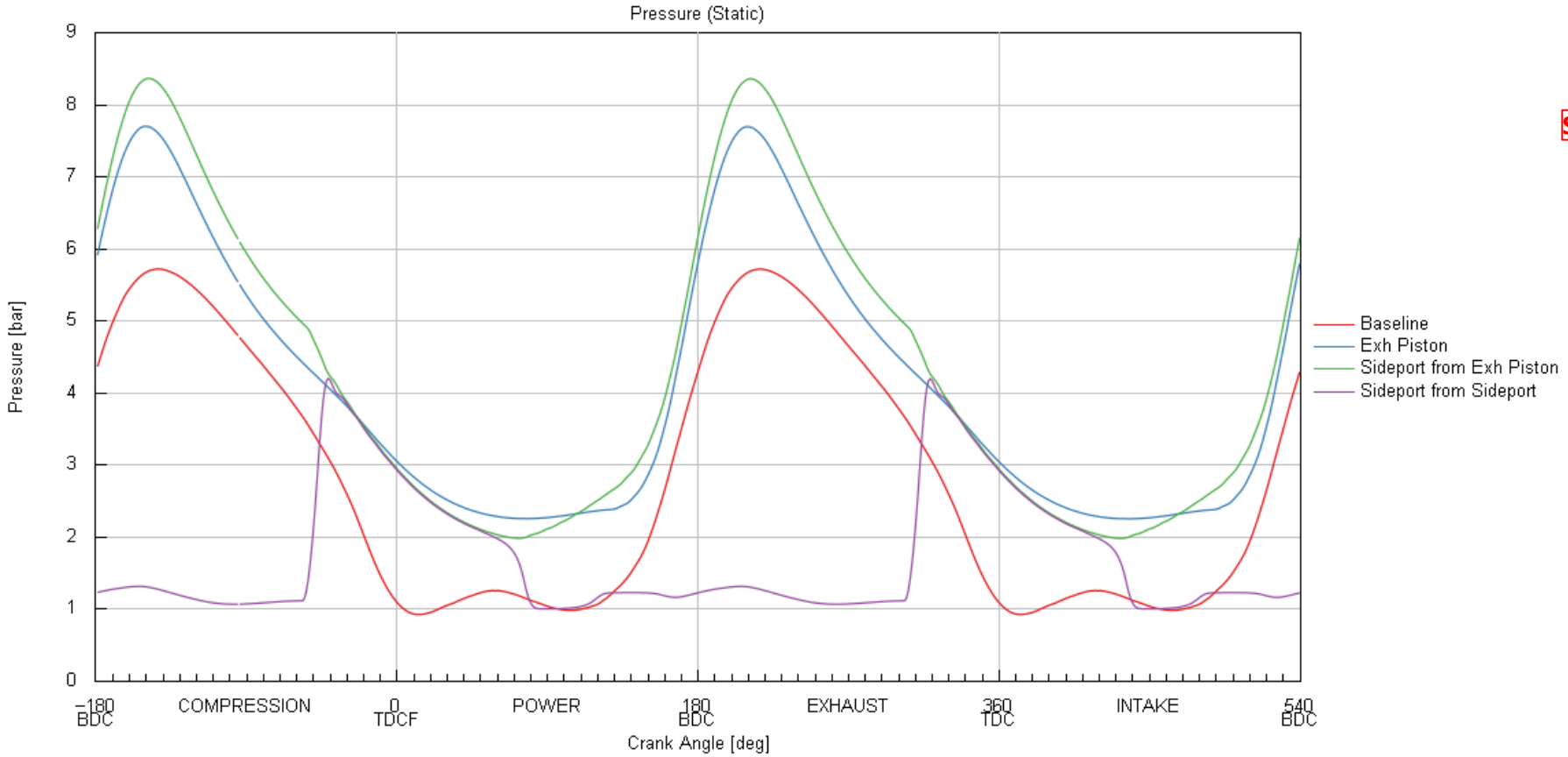
BSFC & Brake Power

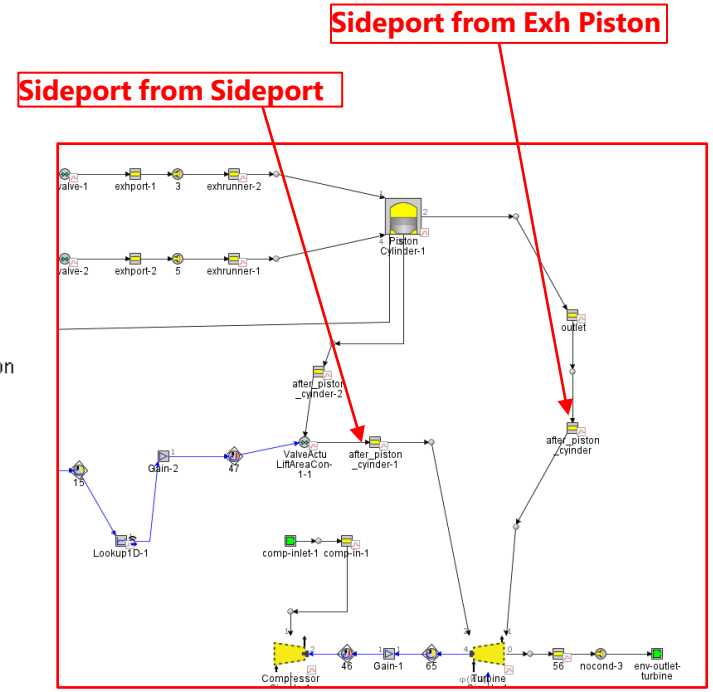
- Three engines are compared
  - 2-Cylinder Baseline Engine
  - 2-Cylinder Olshammar engine with exhaust piston
  - 2-Cylinder Olshammar engine with both exhaust piston and sideport

Baseline bsfc [g/kW-h]	Baseline bp [kW]	Exh Piston bsfc [g/kW-h]	Exh Piston bp [kW]	Sideport bsfc [g/kW-h]	Sideport bp [kW]
224.0	209.3	212.5	239.5	207.9	249.0
0%	0%	-5.14%	+14.4%	-7.20%	+19.0%

Comparison of Baseline and Two Olshammar Engines
Boost Pressure = 5.5 bar, @1800 rpm

Static pressure before turbine





DOE with varying RPM
Baseline and Two Olshammar Engines, Boost Pressure = 5.5 bar

- **BSFC & BP**
- **RPM = 800 - 2800**

2-Cylinder Baseline Engine

Folder: 2Cylinder_DICI
GT-Baseline-2Cylinder_DICI-OPT-v01-5p5bar_updated_DOE_RPM.gtm

#		Label	Weight	Dataset	Case	RPM	bsfc	bkw	inst_error_rel
Type						Factors	Responses		
Units						RPM	g/kW-h	kW	%
1	☑	Training	1.00000	DataSet1_Default	1 - Case - 1	800.000	221.769	36.9624	0.722157
2	☑	Training	1.00000	DataSet1_Default	1 - Case - 1	1300.00	208.694	185.922	0.0314769
3	☑	Training	1.00000	DataSet1_Default	1 - Case - 1	1800.00	224.006	209.320	-0.0115324
4	☑	Training	1.00000	DataSet1_Default	1 - Case - 1	2300.00	250.688	187.258	-0.00979583
5	☑	Training	1.00000	DataSet1_Default	1 - Case - 1	2800.00	293.074	152.494	-0.00828701

delta bsfc [%]	delta bp [%]
0	0
0	0
0	0
0	0
0	0

2-Cylinder Olshammar engine with exhaust piston

Folder: 2Cylinder_DICI
GT-ExtraPiston-2Cylinder_DICI-OPT-v02-5p5bar-updated_DOE_RPM.gtm

#		Label	Weight	Dataset	Case	RPM	bsfc	bkw	inst_error_rel
Type						Factors	Responses		
Units						RPM	g/kW-h	kW	%
1	☑	Training	1.00000	DataSet1_Default	1 - Case - 1	800.000	203.796	101.293	0.273733
2	☑	Training	1.00000	DataSet1_Default	1 - Case - 1	1300.00	200.273	194.736	0.0383435
3	☑	Training	1.00000	DataSet1_Default	1 - Case - 1	1800.00	212.457	239.498	-0.00799537
4	☑	Training	1.00000	DataSet1_Default	1 - Case - 1	2300.00	239.257	213.929	-0.00514495
5	☑	Training	1.00000	DataSet1_Default	1 - Case - 1	2800.00	284.147	173.184	-0.00382828

delta bsfc [%]	delta bkw [%]
-8.10%	+174.04%
-4.04%	+4.74%
-5.16%	+14.42%
-4.56%	+14.24%
-3.05%	+13.57%

2-Cylinder Olshammar engine with both exhaust piston and sideport

Folder: 2Cylinder_DICI
GT-ExtraPiston-Sideport-2Cylinder_DICI-v02_updated_DOE_RPM.gtm

#		Label	Weight	Dataset	Case	RPM	bsfc	bkw	inst_error_rel
Type						Factors	Responses		
Units						RPM	g/kW-h	kW	%
1	☑	Training	1.00000	DataSet1_Default	1 - Case - 1	800.000	203.091	98.8524	0.298642
2	☑	Training	1.00000	DataSet1_Default	1 - Case - 1	1300.00	198.603	190.046	0.123511
3	☑	Training	1.00000	DataSet1_Default	1 - Case - 1	1800.00	207.868	248.991	-0.00835132
4	☑	Training	1.00000	DataSet1_Default	1 - Case - 1	2300.00	233.938	223.303	-0.00450302
5	☑	Training	1.00000	DataSet1_Default	1 - Case - 1	2800.00	278.037	181.100	-0.00313387

delta bsfc [%]	delta bkw [%]
-8.42%	+167.44%
-4.84%	+2.22%
-7.20%	+18.95%
-6.68%	+19.25%
-5.13%	+18.76%

Comparison of Baseline and Two Olshammar Engines
Boost Pressure = 3.5 bar, @1800 rpm

GT-Power model is based on optimized parameters which are obtained from previous case with 5.5 bar boost pressure, @1800 rpm.

Only orifice diameter of the turbine may adjust to achieve best efficiency.

BSFC & Brake Power

- Three engines are compared
  - 2-Cylinder Baseline Engine
  - 2-Cylinder Olshammar engine with exhaust piston
  - 2-Cylinder Olshammar engine with both exhaust piston and sideport

Baseline bsfc [g/kW-h]	Baseline bp [kW]	Exh Piston bsfc [g/kW-h]	Exh Piston bp [kW]	Sideport bsfc [g/kW-h]	Sideport bp [kW]
230.0	134.8	219.0	154.7	215.2	160.3
0%	0%	-4.8%	+14.8%	-6.4%	+18.9%

Folder: 2Cylinder_DICI

GT-Baseline-2Cylinder_DICI-OPT-v01-3p5bar_updated.gtm
GT-ExtraPiston-2Cylinder_DICI-OPT-v02-3p5bar-updated.gtm
GT-ExtraPiston-Sideport-2Cylinder_DICI-v02-3p5bar_updated.gtm

Comparison of Baseline and Two Olshammar Engines
Boost Pressure = 2.5 bar, @1800 rpm

GT-Power model is based on optimized parameters which are obtained from previous case with 5.5 bar boost pressure, @1800 rpm.

Only orifice diameter of the turbine may adjust to achieve best efficiency.

BSFC & Brake Power

- Three engines are compared
  - 2-Cylinder Baseline Engine
  - 2-Cylinder Olshammar engine with exhaust piston
  - 2-Cylinder Olshammar engine with both exhaust piston and sideport

Baseline bsfc [g/kW-h]	Baseline bp [kW]	Exh Piston bsfc [g/kW-h]	Exh Piston bp [kW]	Sideport bsfc [g/kW-h]	Sideport bp [kW]
236.6	96.0	229.1	108.8	227.2	111.6
0%	0%	-3.17%	+13.3%	-4.0%	+16.1%

Folder: 2Cylinder_DICI

GT-Baseline-2Cylinder_DICI-OPT-v01-2p5bar_updated.gtm
GT-ExtraPiston-2Cylinder_DICI-OPT-v02-2p5bar-updated.gtm
GT-ExtraPiston-Sideport-2Cylinder_DICI-v02-2p5bar_updated.gtm

Summary of Engine with boost Pressure = 5.5/3.5/2.5 bar, @1800 rpm

GT-Power model is based on optimized parameters which are obtained from previous case with 5.5 bar boost pressure, @1800 rpm.

Only orifice diameter of the turbine may adjust to achieve best efficiency.

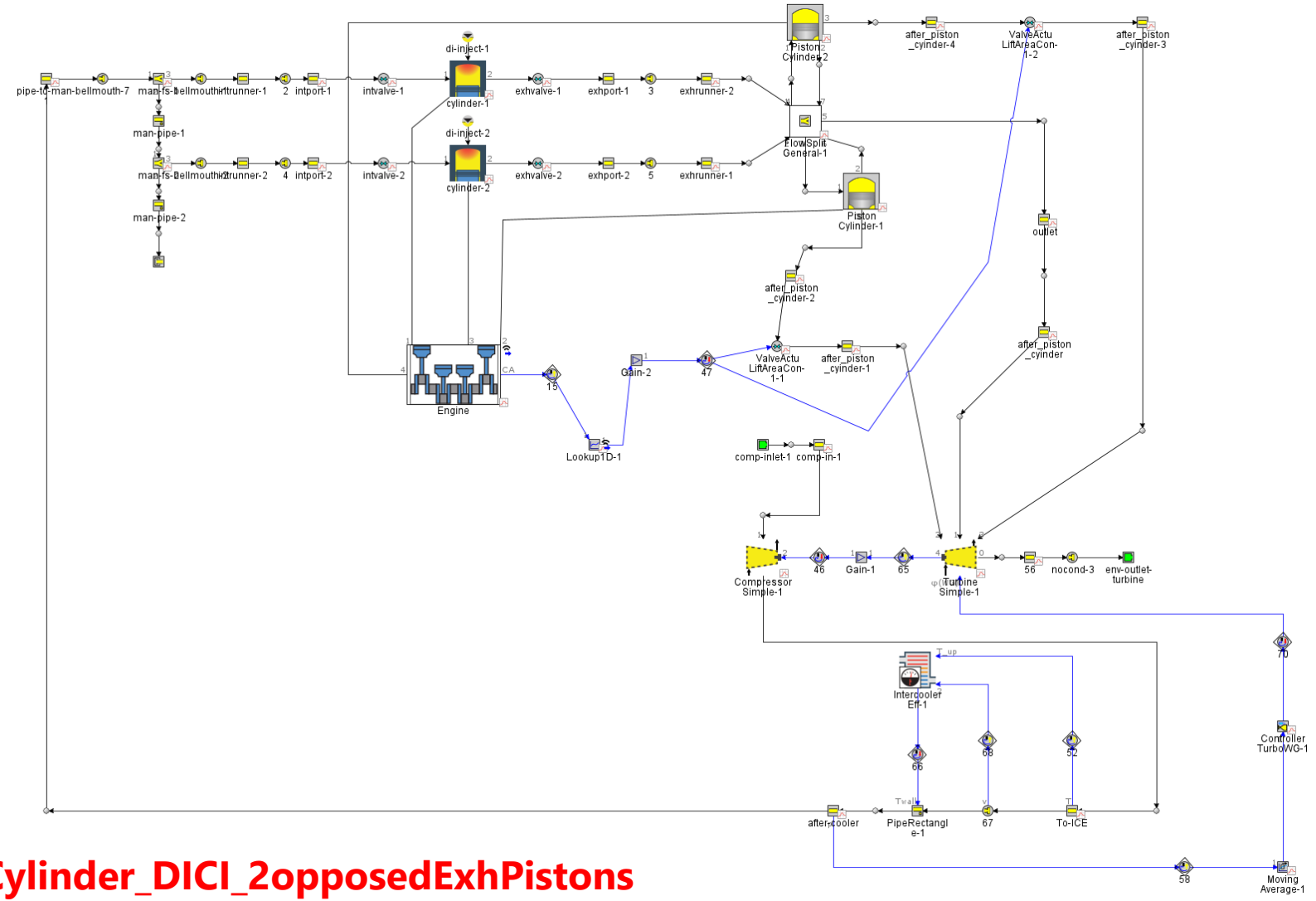
Booster Pressure	Baseline bsfc [g/kW-h]	Baseline bp [kW]	Exh Piston bsfc [g/kW-h]	Exh Piston bp [kW]	Sideport bsfc [g/kW-h]	Sideport bp [kW]
5.5 bar	224.2	209.3	212.5	239.5	207.9	249.0
	0%	0%	-5.14%	+14.4%	-7.2%	+19.0%
3.5 bar	230.0	134.8	219.0	154.7	215.2	160.3
	0%	0%	-4.8%	+14.8%	-6.4%	+18.9%
2.5 bar	236.6	96.0	229.1	108.8	227.2	111.6
	0%	0%	-3.17%	+13.3%	-4.0%	+16.1%

2 Cylinder Diesel Engine

Olshammar 2 opposed exhaust pistons v.s. Baseline

BSFC & BP Results @1800 rpm

GT-Power Model of 2 Cylinder Diesel Engine with 2 opposed exhaust pistons
Boost Pressure = 5.5 bar, @1800 rpm



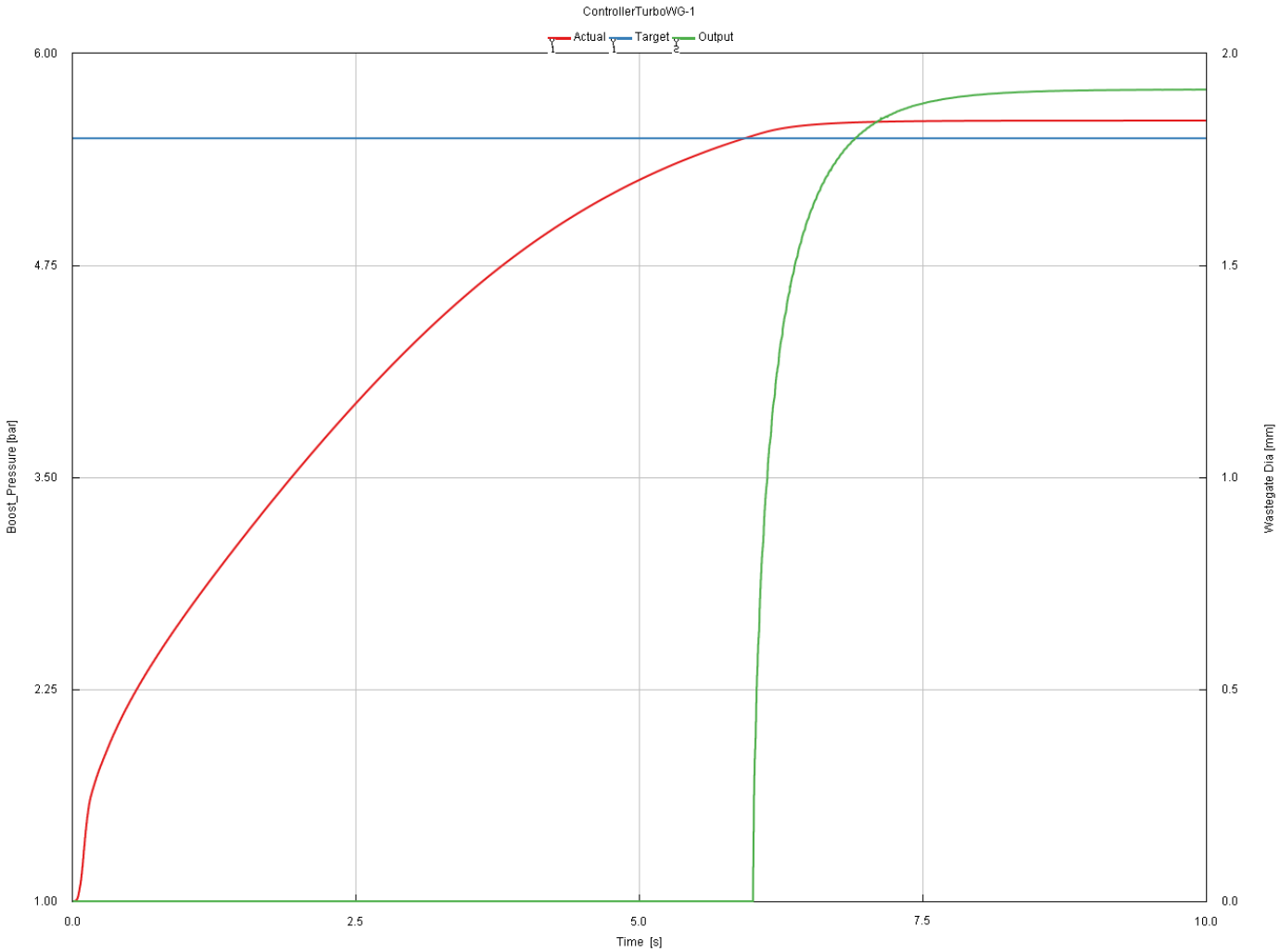
Folder: 2Cylinder_DICI_2opposedExhPistons
GT-2opposedExhPistons-2Cylinder_DICI-v01_updated.gtm

Parameters' optimization of 2 Cylinder Diesel Engine with 2 opposed exhaust pistons Boost Pressure = 5.5 bar, @1800 rpm

Parameter	Unit	Description	Case 1
Case On/Off		**Check Box to Turn Case On**	☑
Case Label		**Unique Text for Plot Legends**	
cylinder-offset	mm	Wrist Pin to Crank Offset	1
exhport-dia	mm	Diameter at Inlet End	31
exhport-len	mm	Length	77
exhrunner-dia	mm	Diameter at Inlet End	45
exhrunner-len	mm	Length	91
RPM	RPM	Engine Speed	1800
TargetBoostPressure	bar	Target	5.5
IntCTA	Crank Angle (4-stroke)	Cam Timing Angle	430
ExhCTA	Crank Angle (4-stroke)	Cam Timing Angle	254
intport-dia	mm	Diameter at Inlet End	61
intport-len	mm	Length	53
intrunner-dia	mm	Diameter at Inlet End	65
intrunner-len	mm	Length	110
Cylinder_CR		Compression Ratio	18.5
Comb_Cylinder_Dia	mm	Bore	131
Comb_Cylinder_Stroke	mm	Stroke	158
Comb_CR		Compression Ratio	18.5
Area	mm^2	Area Array	2000
sin_width			0.4
Extra_Piston_Stoke	mm	Stroke	42
EXC_FI	deg	Firing Intervals	182
Extra_Piston_Bore_Dia	mm	Bore	221
orificedia	mm	Turbine Orifice Diameter	33
sin_offset			-60

- Parameters highlighted in red blocks are optimized in GT-Power.

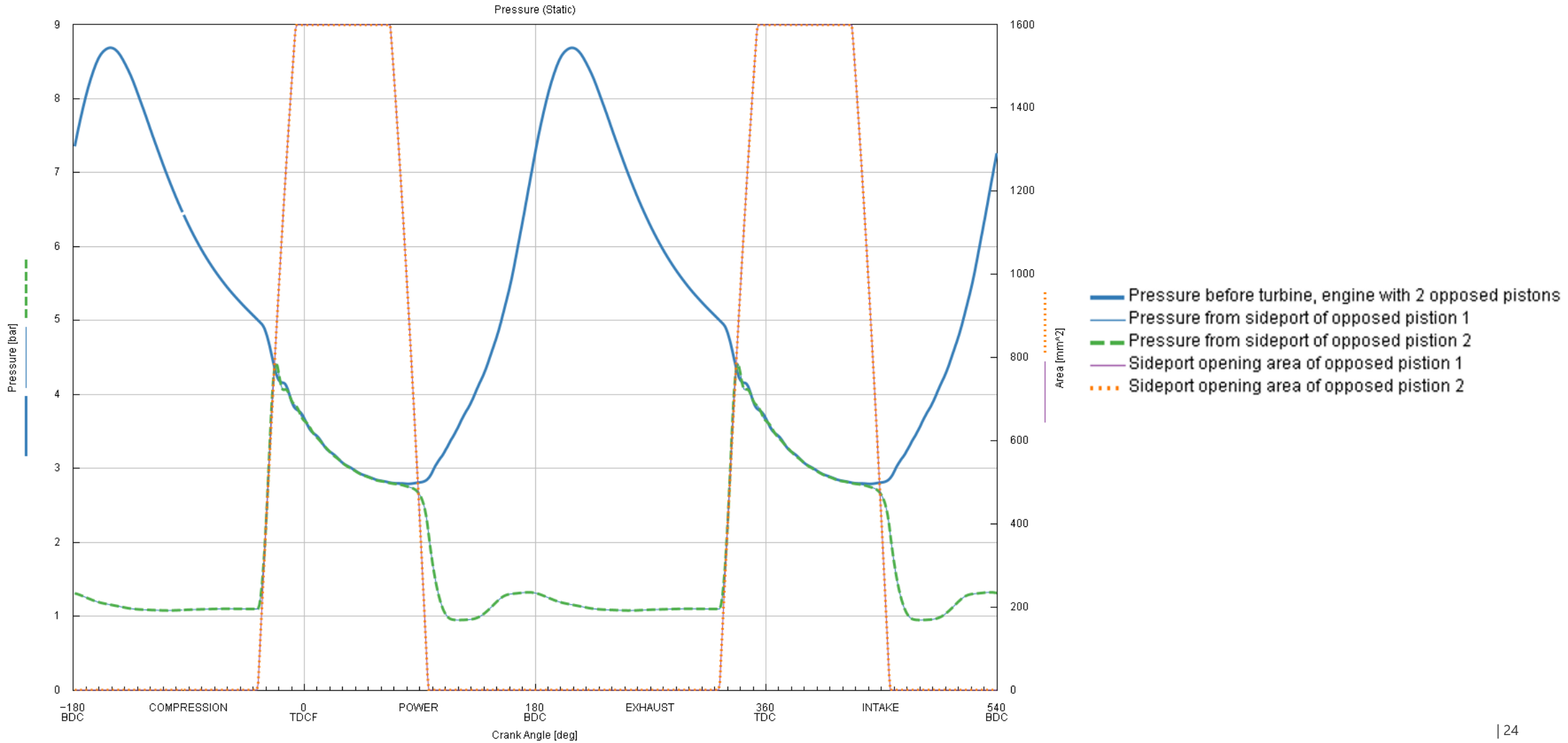
Optimized results of 2 Cylinder Diesel Engine with 2 opposed exhaust pistons, Boost Pressure = 5.5 bar, @1800 rpm



- Boost pressure reaches to the target pressure of 5.5 bar by using the wastegate controller.
- BSFC & Brake Power

Baseline bsfc [g/kW-h]	Baseline bp [kW]
224.0	209.3
2 Opposed Extra Pistons bsfc [g/kW-h]	2 Opposed Extra Pistons bp [kW]
205.6	249.5
-8.2%	+19.2%

2 Cylinder Diesel Engine with 2 opposed exhaust pistons
Boost Pressure = 5.5 bar, @1800 rpm



DOE with varying RPM
Baseline and Two Olshammar Engines, Boost Pressure = 5.5 bar

- **BSFC & BP**
- **RPM = 800 - 2800**

2-Cylinder Baseline Engine

#		Label	Weight	Dataset	Case	RPM	bsfc	bkw	inst_error_rel	delta bsfc [%]	delta bp [%]
Type						Factors	Responses				
Units						RPM	g/kW-h	kW	%		
1	☑	Training	1.00000	DataSet1_Default	1 - Case - 1	800.000	221.769	36.9624	0.722157	0	0
2	☑	Training	1.00000	DataSet1_Default	1 - Case - 1	1300.00	208.694	185.922	0.0314769	0	0
3	☑	Training	1.00000	DataSet1_Default	1 - Case - 1	1800.00	224.006	209.320	-0.0115324	0	0
4	☑	Training	1.00000	DataSet1_Default	1 - Case - 1	2300.00	250.688	187.258	-0.00979583	0	0
5	☑	Training	1.00000	DataSet1_Default	1 - Case - 1	2800.00	293.074	152.494	-0.00828701	0	0

Folder: 2Cylinder_DICI
GT-Baseline-2Cylinder_DICI-OPT-v01-5p5bar_updated_DOE_RPM.gtm

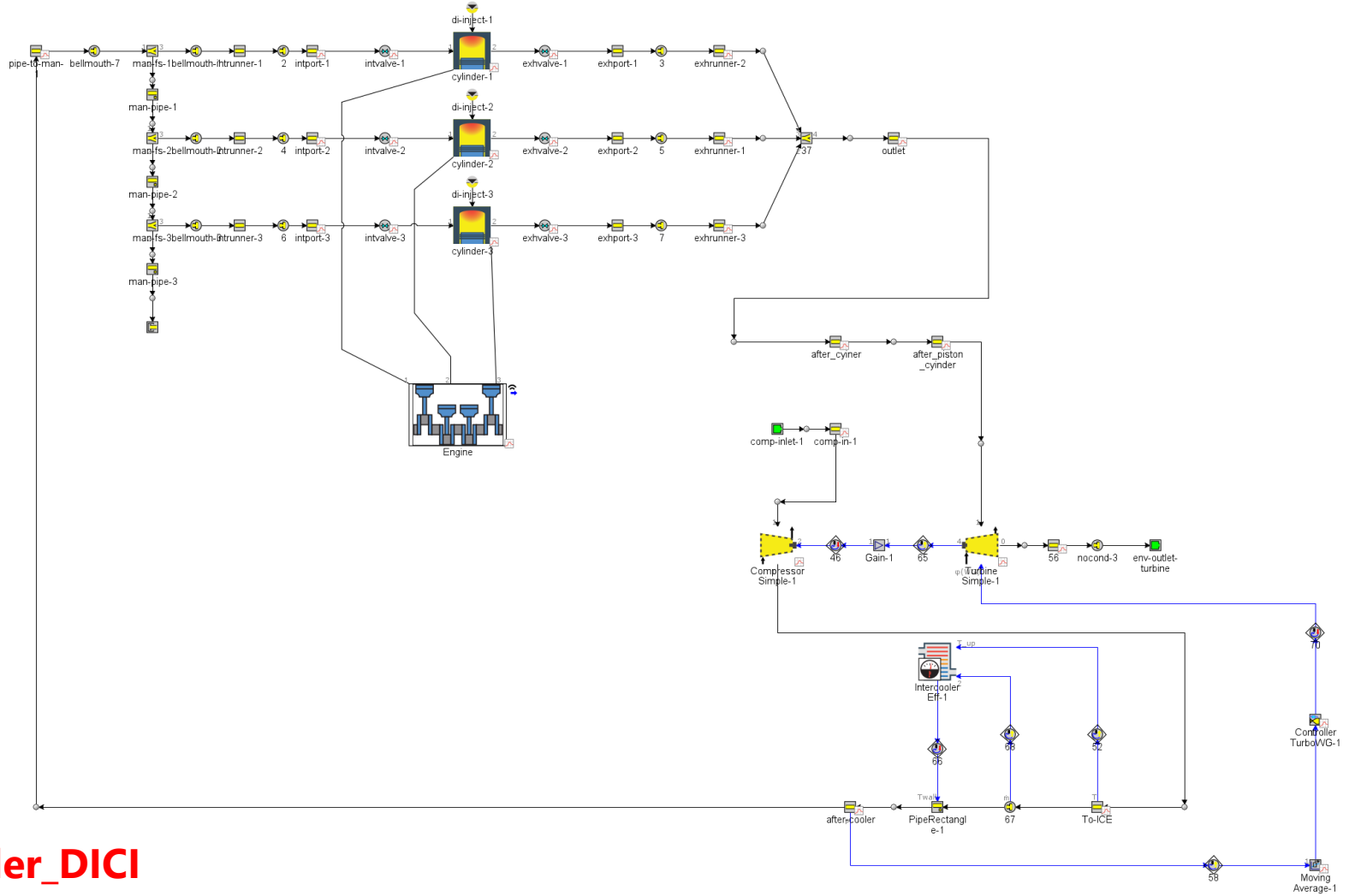
2-Cylinder Olshammar engine with 2 opposed pistons

#		Label	Weight	Dataset	Case	RPM	bsfc	bkw	inst_error_rel	delta bsfc [%]	delta bkw [%]
Type						Factors	Responses				
Units						RPM	g/kW-h	kW	%		
1	☑	Training	1.00000	DataSet1_Default	1 - Case - 1	800.000	202.660	77.2126	0.470044	-8.6%	+108.9%
2	☑	Training	1.00000	DataSet1_Default	1 - Case - 1	1300.00	197.653	147.936	0.343978	-5.3%	-20.4%
3	☑	Training	1.00000	DataSet1_Default	1 - Case - 1	1800.00	205.630	249.635	-0.0193192	-8.2%	+19.3%
4	☑	Training	1.00000	DataSet1_Default	1 - Case - 1	2300.00	233.148	220.331	-6.37913E-4	-7.0%	+17.7%
5	☑	Training	1.00000	DataSet1_Default	1 - Case - 1	2800.00	279.117	178.393	-1.46249E-4	-4.8%	+17.0%

Folder: 2Cylinder_DICI_2opposedExhPistons
GT-2opposedExhPistons-2Cylinder_DICI-v01_updated_DOE_RPM.gtm

3 Cylinder Diesel Engine
Olshammar v.s. Baseline
BSFC & BP Results @1800 rpm

GT-Power Model of Baseline 3 Cylinder Diesel Engine, Boost Pressure = 5.5 bar, @1800 rpm



Folder: 3Cylinder_DICI

GT-Original-3Cylinder_DICI-OnlyBSFC-v04_Optimized_updated.gtm

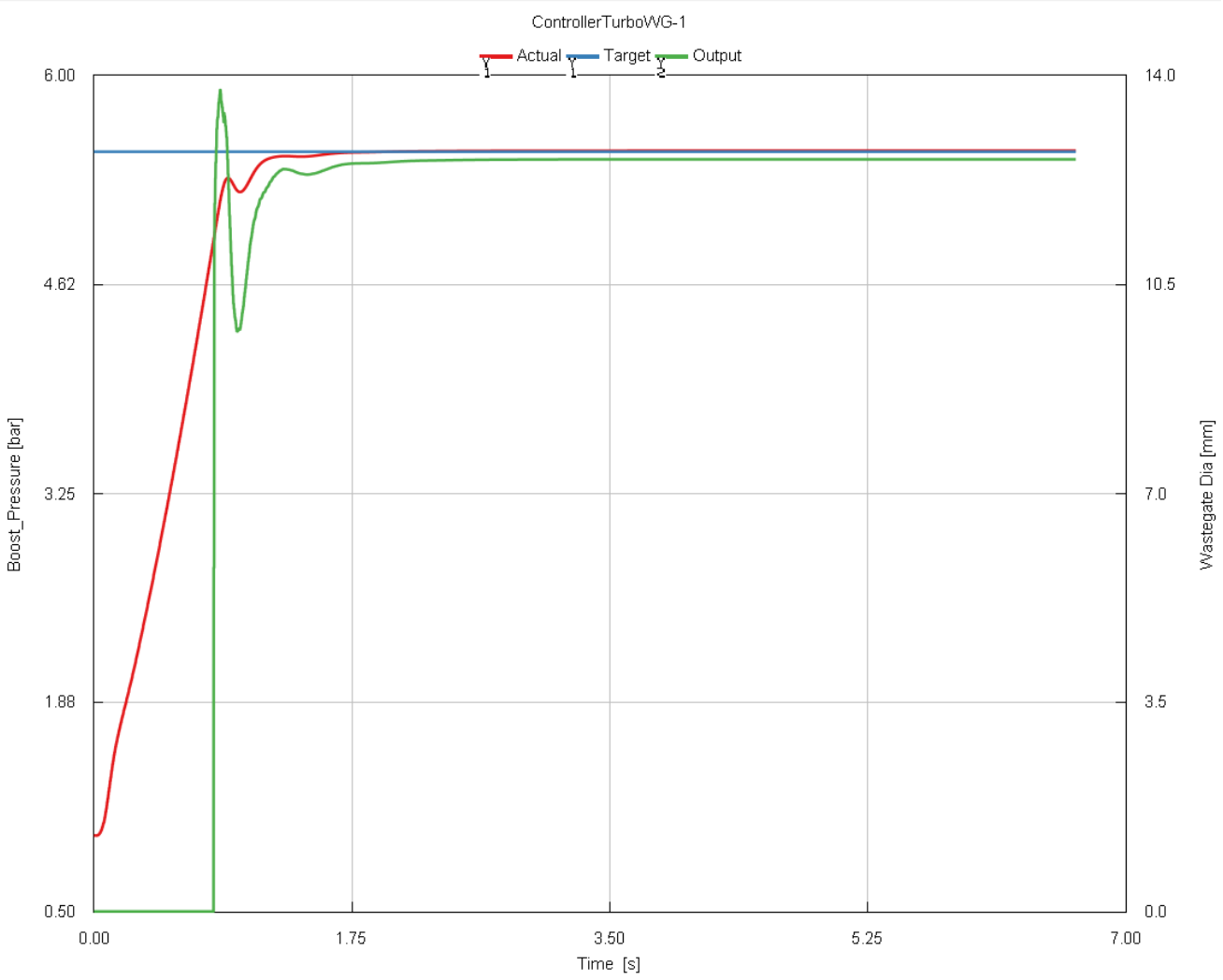
Parameters' optimization of Baseline 3 Cylinder Diesel Engine, Boost Pressure = 5.5 bar, @1800 rpm

Main

Parameter	Unit	Description	Case 1
Case On/Off		**Check Box to Turn Case On**	☑
Case Label		**Unique Text for Plot Legends**	
cylinder-offset	mm	Wrist Pin to Crank Offset	1
exhport-dia	mm	Diameter at Inlet End	33
exhport-len	mm	Length	97
exhrunner-dia	mm	Diameter at Inlet End	37
exhrunner-len	mm	Length	129
RPM	RPM	Engine Speed	1800
TargetBoostPressure	bar	Target	5.5
orificedia	mm	Turbine Orifice Diameter	23
IntCTA	Crank Angle (4-stroke)	Cam Timing Angle	433
ExhCTA	Crank Angle (4-stroke)	Cam Timing Angle	246
intport-dia	mm	Diameter at Inlet End	51
intport-len	mm	Length	60
intrunner-dia	mm	Diameter at Inlet End	49
intrunner-len	mm	Length	113
Dia_Before_Turbine	mm	Diameter at Inlet End	70
Length_Before_Turbine	mm	Length	160

- Parameters highlighted in red blocks are optimized in GT-Power.

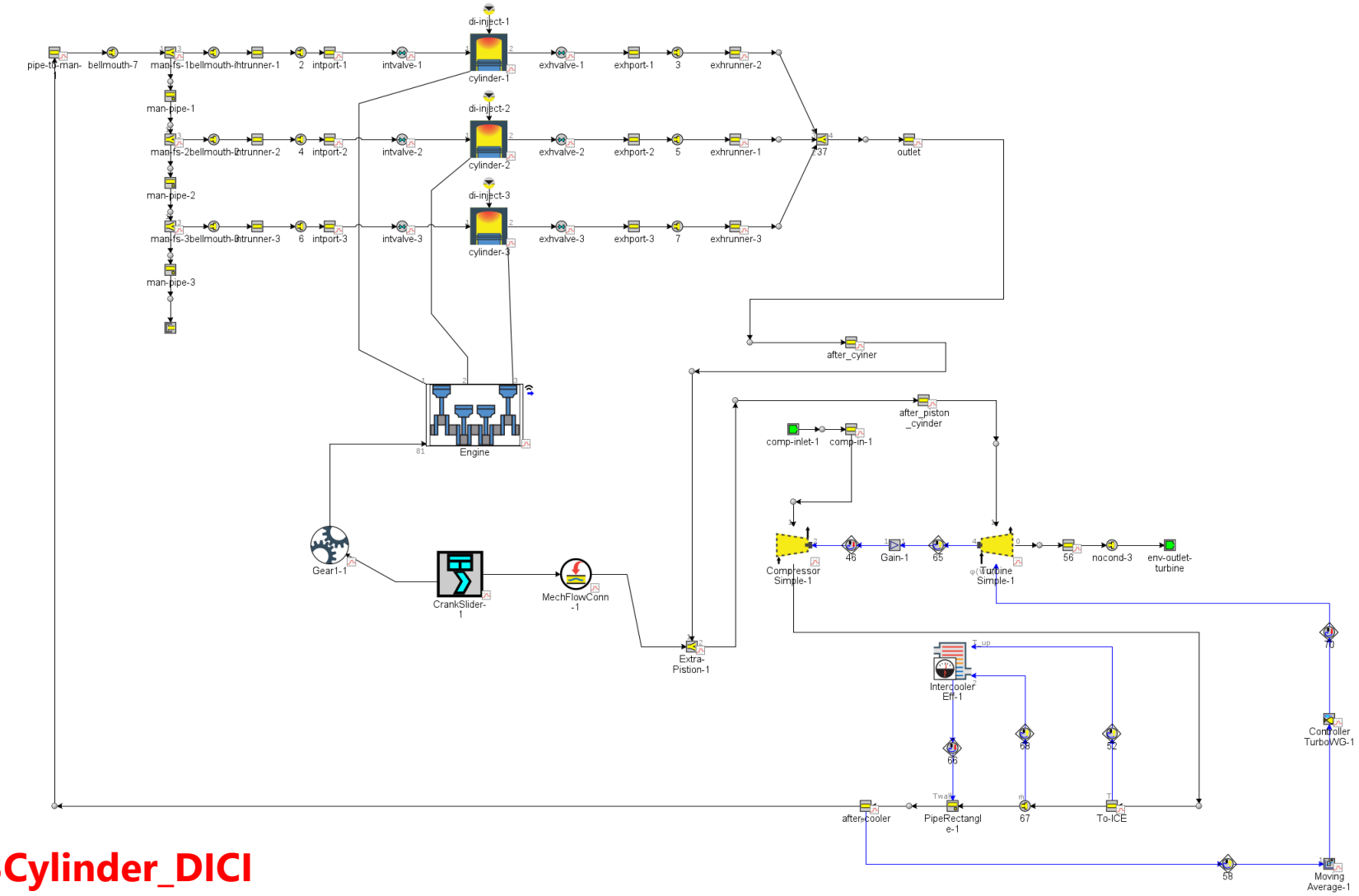
Optimized results of Baseline 3 Cylinder Diesel Engine, Boost Pressure = 5.5 bar, @1800 rpm



- Boost pressure reaches to the target pressure of 5.5 bar by using the wastegate controller.
- BSFC & Brake Power

Baseline bsfc [g/kW-h]	Baseline bp [kW]
235.2	302.9

GT-Power Model of Olshammar 3 Cylinder Diesel Engine with Exh Piston, Boost Pressure = 5.5 bar, @1800 rpm



Folder: 3Cylinder_DICI

GT-Opt-ExtraPiston-3Cylinder_DICI-v04_updated.gtm

GT-Power Model of Olshammar 3 Cylinder Diesel Engine with Exh Piston, Boost Pressure = 5.5 bar, @1800 rpm

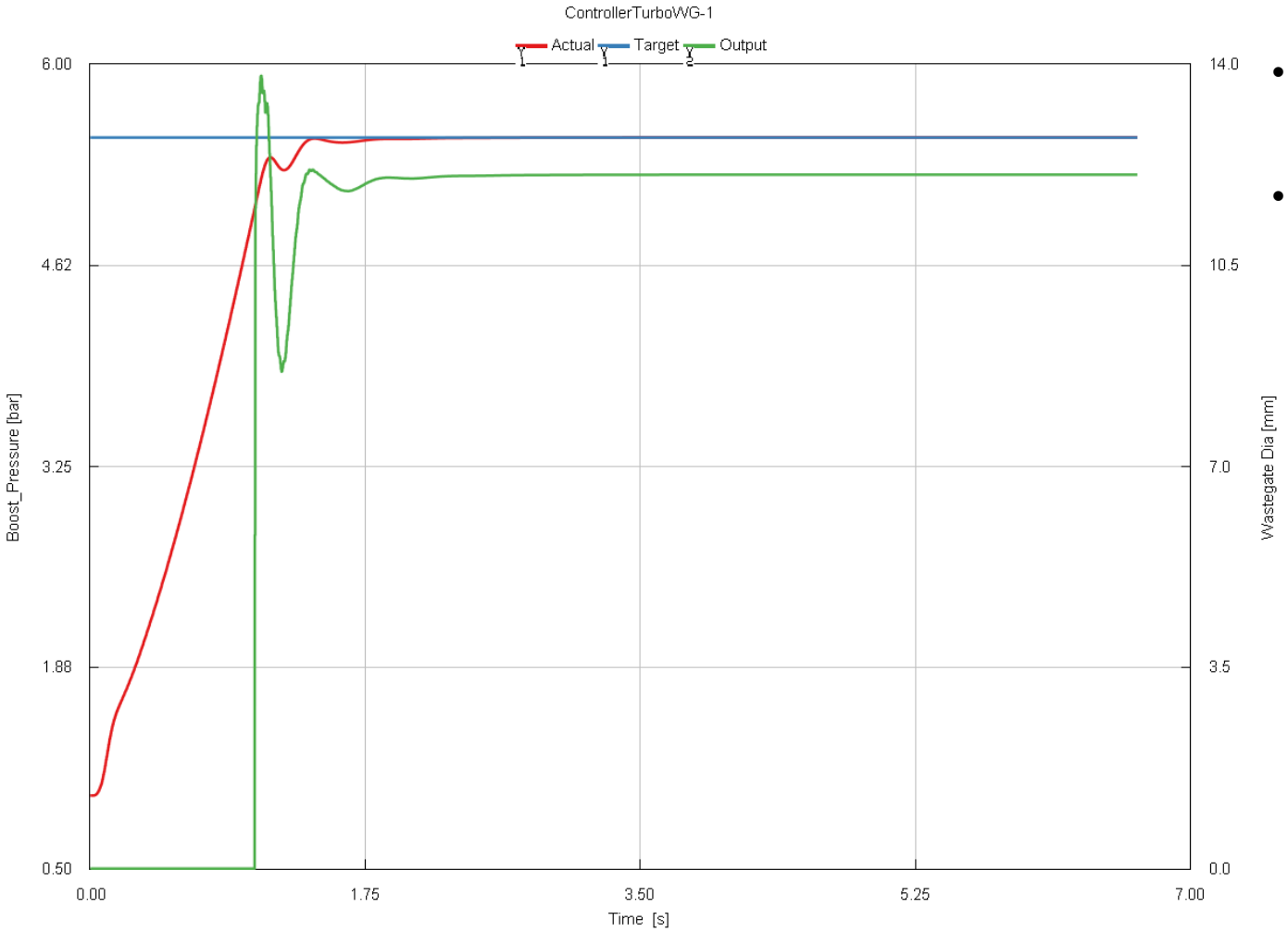
Main | Design of Experiments | All

Main

Parameter	Unit	Description	Case 1
Case On/Off		**Check Box to Turn Case On**	☑
Case Label		**Unique Text for Plot Legends**	
cylinder-offset	mm	Wrist Pin to Crank Offset	1
exhport-dia	mm	Diameter at Inlet End	31
exhport-len	mm	Length	80
exhrunner-dia	mm	Diameter at Inlet End	44
exhrunner-len	mm	Length	93
RPM	RPM	Engine Speed	1800
TargetBoostPressure	bar	Target	5.5
orificedia	mm	Turbine Orifice Diameter	25
IntCTA	Crank Angle (4-stroke)	Cam Timing Angle	430
ExhCTA	Crank Angle (4-stroke)	Cam Timing Angle	246
intport-dia	mm	Diameter at Inlet End	50
intport-len	mm	Length	74
intrunner-dia	mm	Diameter at Inlet End	50
intrunner-len	mm	Length	109
Dia_Before_Turbine	mm	Diameter at Inlet End	70
Length_Before_Turbine	mm	Length	160
Piston_Stroke	mm	Stroke	60
piston-bore	mm	Bore	180
piston-start-angle	deg	Crank (Throw) Initial Angle	-91

- Parameters highlighted in red blocks are optimized in GT-Power.

GT-Power Model of Olshammar 3 Cylinder Diesel Engine with Exh Piston, Boost Pressure = 5.5 bar, @1800 rpm



- Booster pressure reaches to the target pressure of 5.5 bar by using the wastegate controller.
- BSFC & Brake Power

Exh Piston bsfc [g/kW-h]	Exh Piston bp [kW]
225.0	322.0

Comparison of Baseline and Olshammar Engine
Boost Pressure = 5.5 bar, @1800 rpm

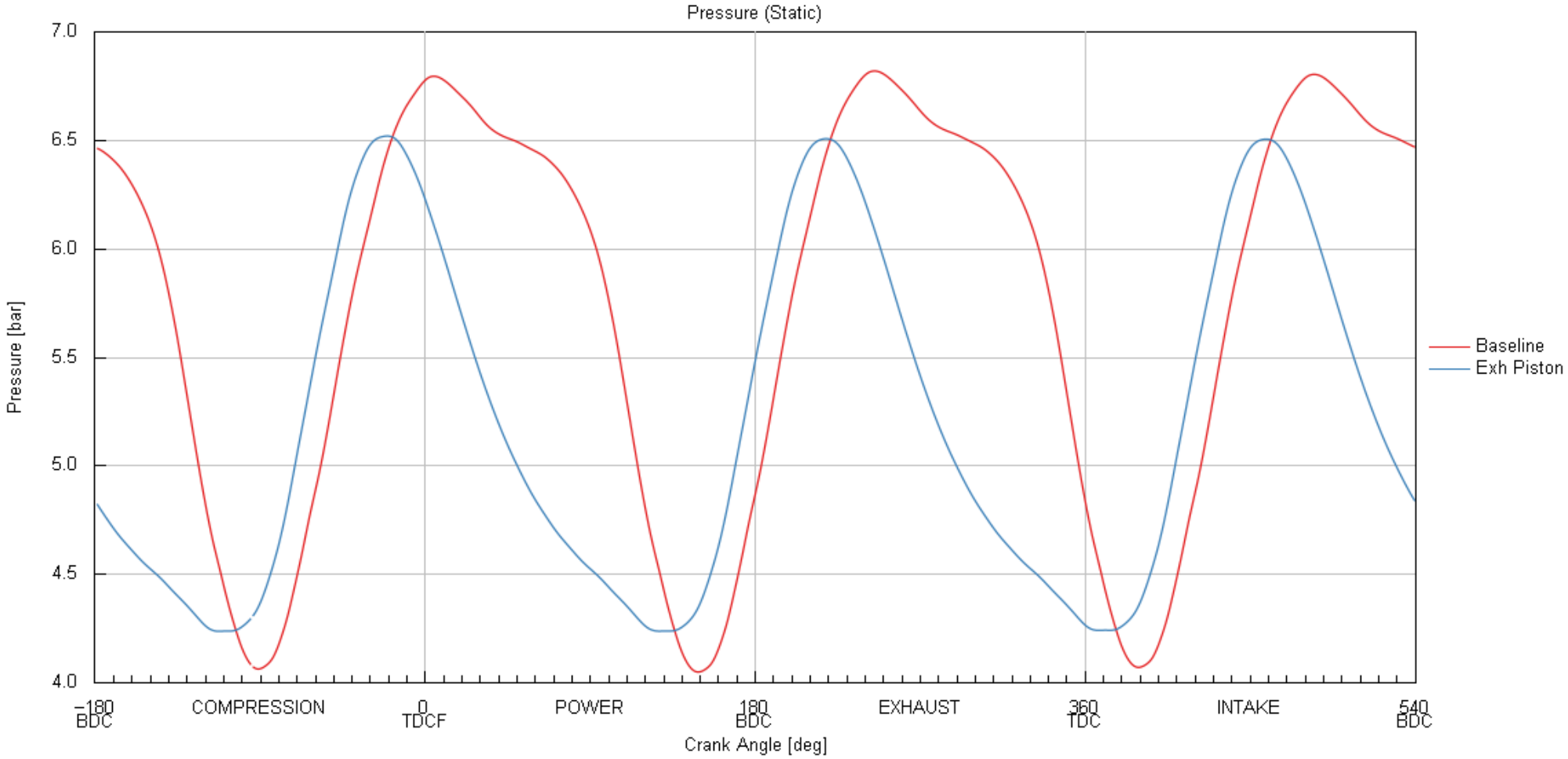
BSFC & Brake Power

- Two engines are compared
  - 3-Cylinder Baseline Engine
  - 3-Cylinder Olshammar engine with exhaust piston

Baseline bsfc [g/kW-h]	Baseline bp [kW]	Olshammar bsfc [g/kW-h]	Olshammar bp [kW]
235.2	302.9	225.0	322.0
0%	0%	-4.34%	+6.3%

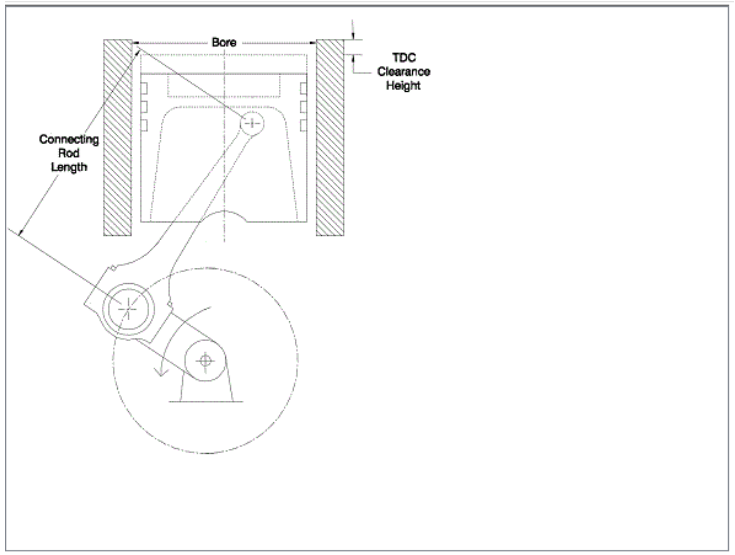
Comparison of Baseline and Olshammar Engine
Boost Pressure = 5.5 bar, @1800 rpm

Static pressure before turbine

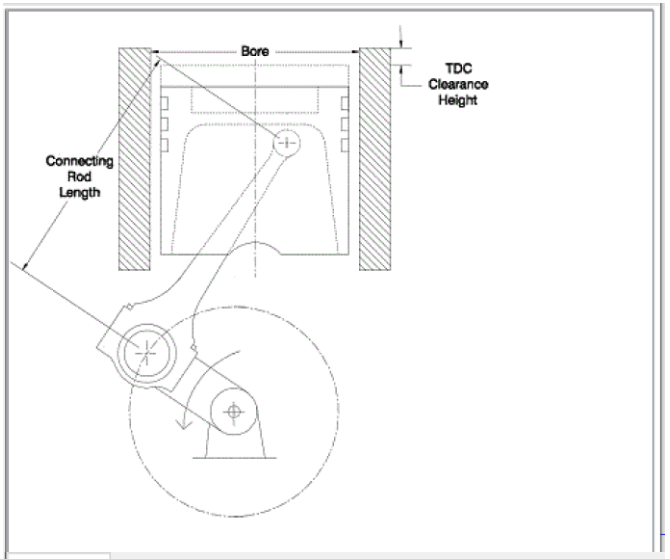


2 Cylinder Petrol Engine
Olshammar v.s. Baseline
BSFC & BP Results @4000 rpm

GT-Power Modelling
Geometry of Combustion Cylinder and Exh Piston



Attribute	Unit	Object Value
Bore	mm	86
Stroke	mm	86.07
Connecting Rod Length	mm	175
Compression Ratio		9.5
TDC Clearance Height	mm	1

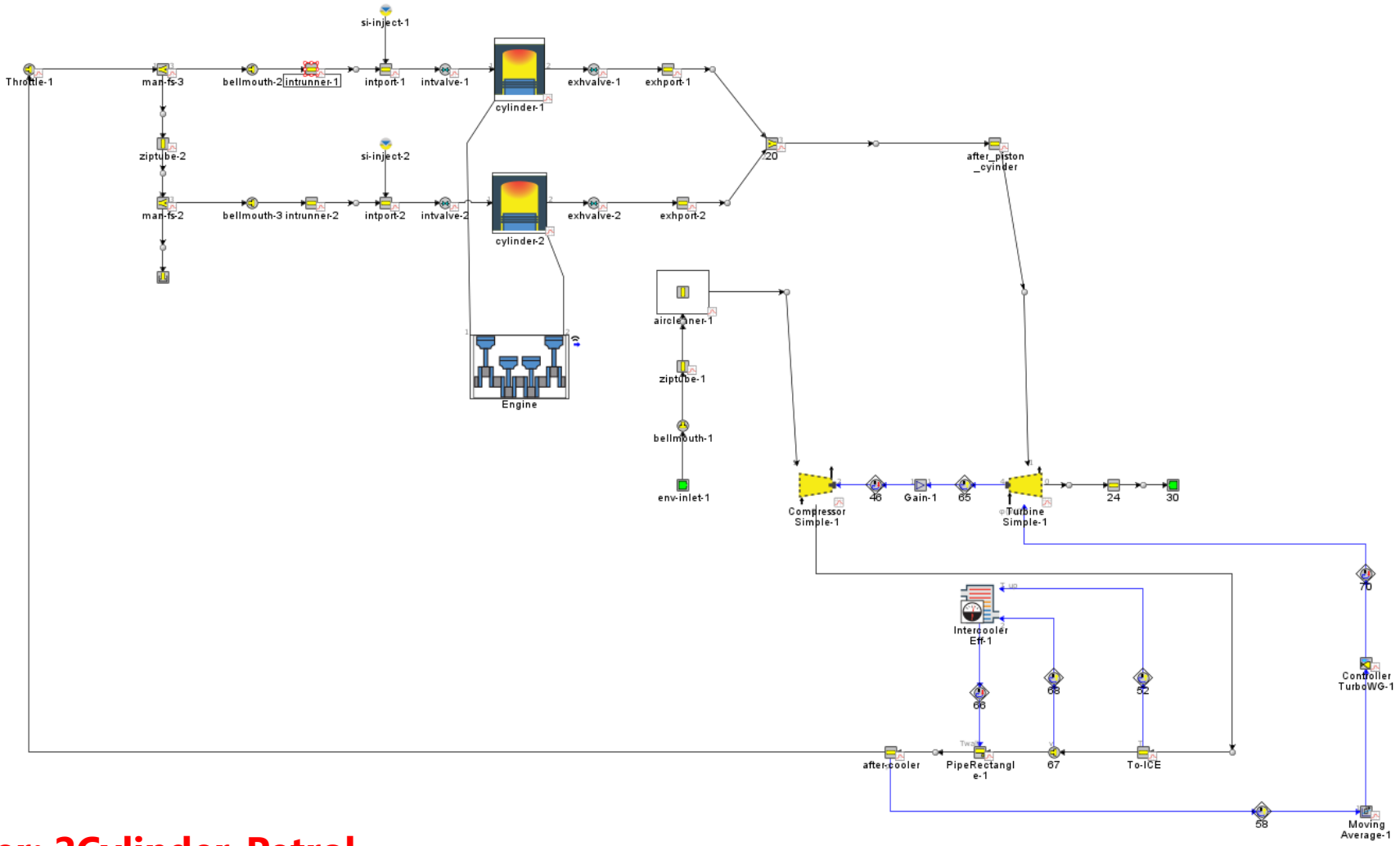


Main | Piston-to-Crank Offset | Crank-Slider Compliance

Attribute	Unit	Object Value
Bore	See Case S...	[Extra_Piston_Bore_Dia]
Stroke	See Case S...	[Extra_Piston_Stoke]
Connecting Rod Length	mm	360
Compression Ratio		18.5
TDC Clearance Height	mm	0.5

- Combustion cylinder is shown in figure left, where all parameters are fixed.
- Exh piston is shown in figure right, where bore and stroke are set as variables to optimize later.

GT-Power Model of Baseline 2 Cylinder Petrol Engine, Boost Pressure = 3.5 bar, @4000 rpm



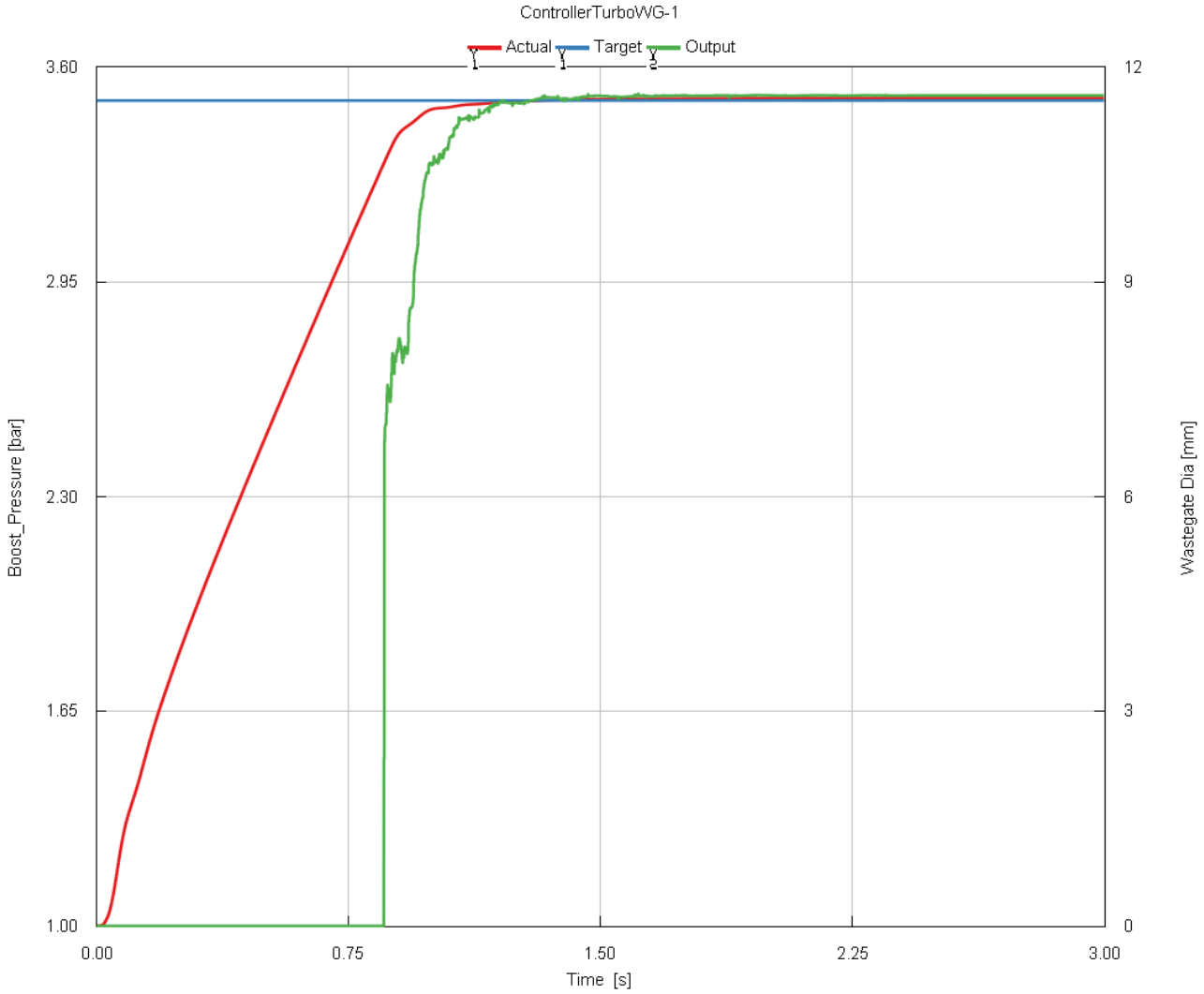
Folder: 2Cylinder_Petrol
Baseline-2Cylinder_SI-v01_Opt_updated.gtm

Parameters' optimization of Baseline 2 Cylinder Petrol Engine, Boost Pressure = 3.5 bar, @4000 rpm

Parameter	Unit	Description	Case 1
Case On/Off		**Check Box to Turn Case On**	☑
Case Label		**Unique Text for Plot Legends**	
TargetBoostPressure	bar	Target	3.5
Agess		Aggressiveness Factor	0.9
orificedia	mm	Turbine Orifice Diameter	31
RPM	RPM	Engine Speed	4000
throttle	mm	Hole Diameter	70
IntCTA	Crank Angle (4-stroke)	Cam Timing Angle	463
ExhCTA	Crank Angle (4-stroke)	Cam Timing Angle	240
intport_Dia	mm	Diameter at Inlet End	41
intport_Len	mm	Length	60
exh_Dia	mm	Diameter at Inlet End	42
exh_Len	mm	Length	93
after_piston_Dia	mm	Diameter at Inlet End	53
after_piston_Len	mm	Length	186

- Parameters highlighted in red blocks are optimized in GT-Power.

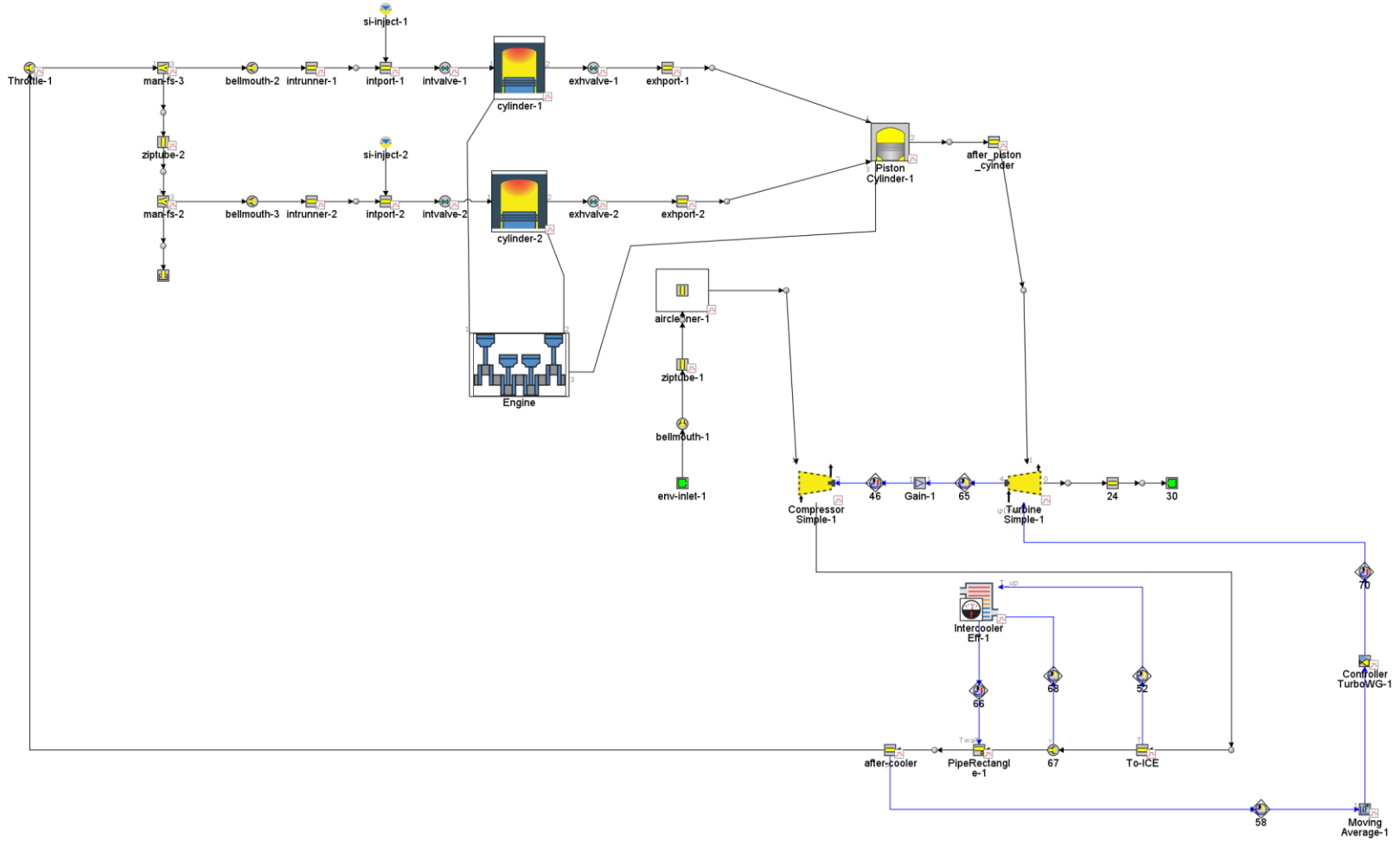
Optimized results of Baseline 2 Cylinder Petrol Engine, Boost Pressure = 3.5 bar, @4000 rpm



- Boost pressure reaches to the target pressure of 3.5 bar by using the wastegate controller.
- BSFC & Brake Power

Baseline bsfc [g/kW-h]	Baseline bp [kW]
211.2	152.8

GT-Power Model of 2 Cylinder Petrol Engine with Exh Piston , Boost Pressure = 3.5 bar, @4000 rpm

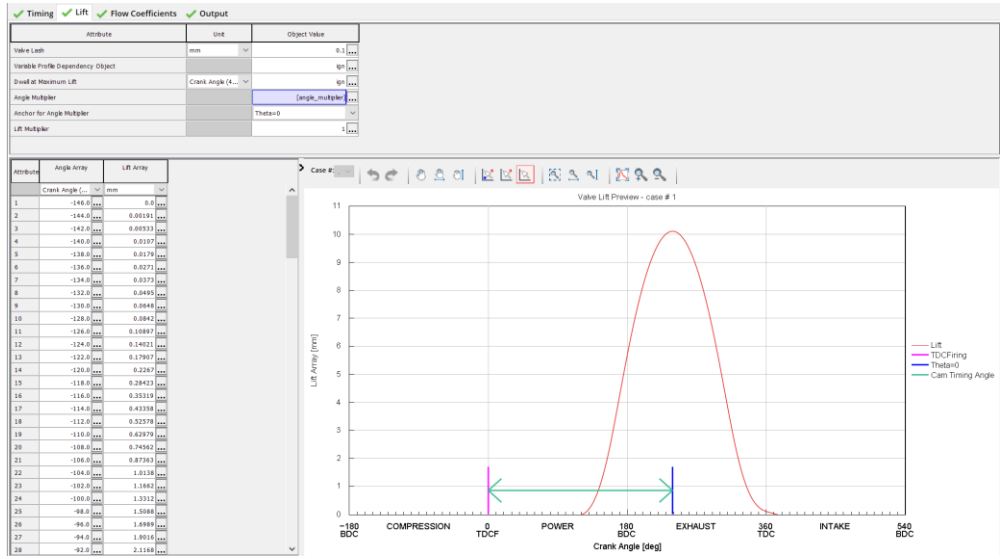


Folder: 2Cylinder_Petrol
ExhPiston-2Cylinder_SI-v02_Opt_Opt_EVODuration_updated.gtm

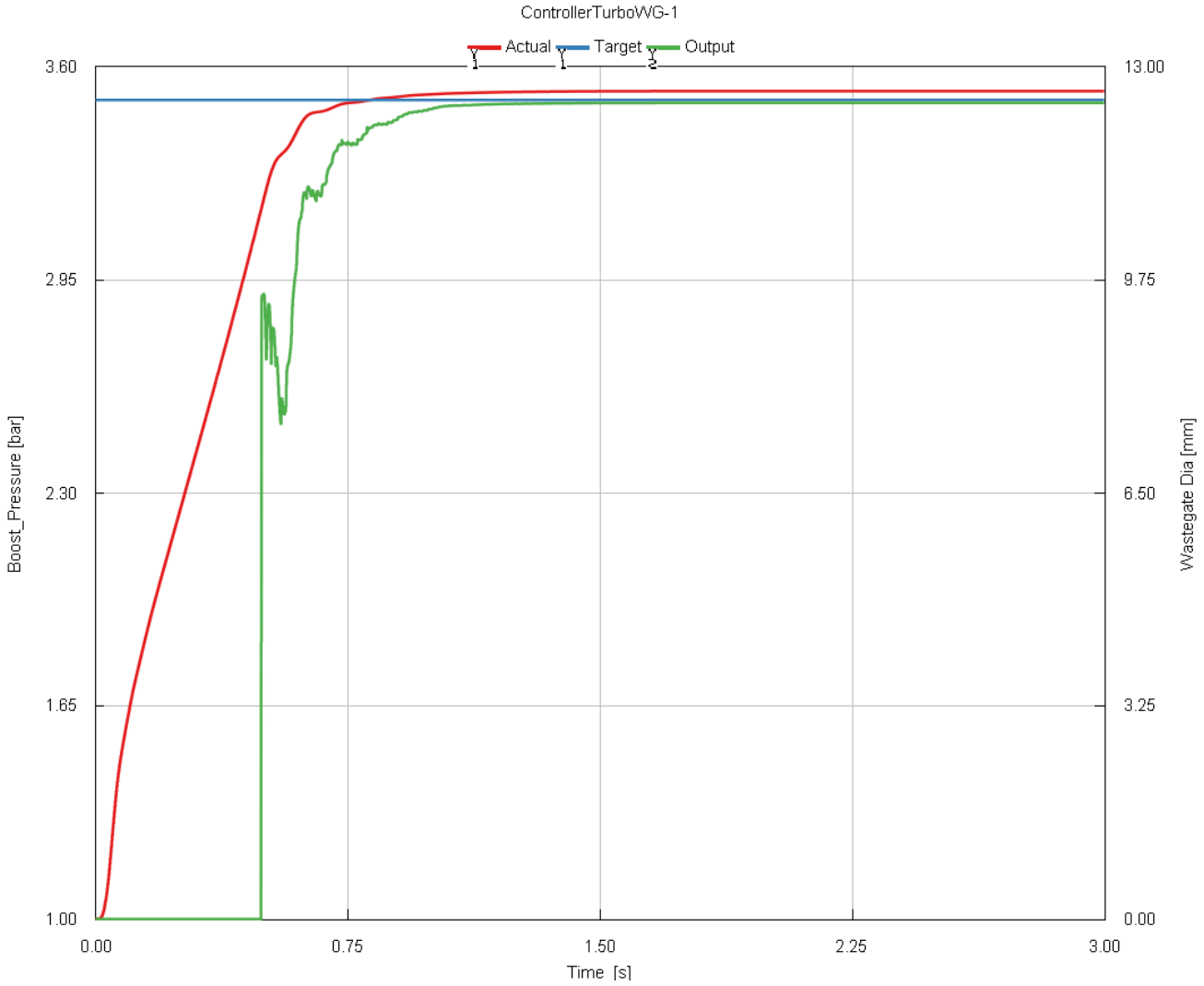
Parameters' optimization of 2 Cylinder Petrol Engine with Exh Piston , Boost Pressure = 3.5 bar, @4000 rpm

Parameter	Unit	Description	Case 1
Case On/Off		**Check Box to Turn Case On**	☑
Case Label		**Unique Text for Plot Legends**	
TargetBoostPressure	bar	Target	3.5
Agess		Aggressiveness Factor	0.9
orificedia	mm	Turbine Orifice Diameter	24
RPM	RPM	Engine Speed	4000
throttle	mm	Hole Diameter	70
intCTA	Crank Angle (4-stroke)	Cam Timing Angle	459
intport_Dia	mm	Diameter at Inlet End	69
intport_Len	mm	Length	114
ExhPiston-Bore_Dia	mm	Bore	150
ExhPiston-Stroke	mm	Stroke	61
ExhPiston-CR		Compression Ratio	45
FI	deg	Firing Intervals	156
intrunner_Dia	mm	Diameter at Inlet End	40
intrunner_Len	mm	Length	408
exh_Dia	mm	Diameter at Inlet End	37
exh_Len	mm	Length	45
after_piston_Dia	mm	Diameter at Inlet End	41
after_piston_Len	mm	Length	189
angle_multiplier		Angle Multiplier	0.91664064
ExhCTA	Crank Angle (4-stroke)	Cam Timing Angle	238.71094

- Parameters highlighted in red blocks are optimized in GT-Power.
- Parameter 'angle_multiplier' is a scaling factor used to vary EVO duration.



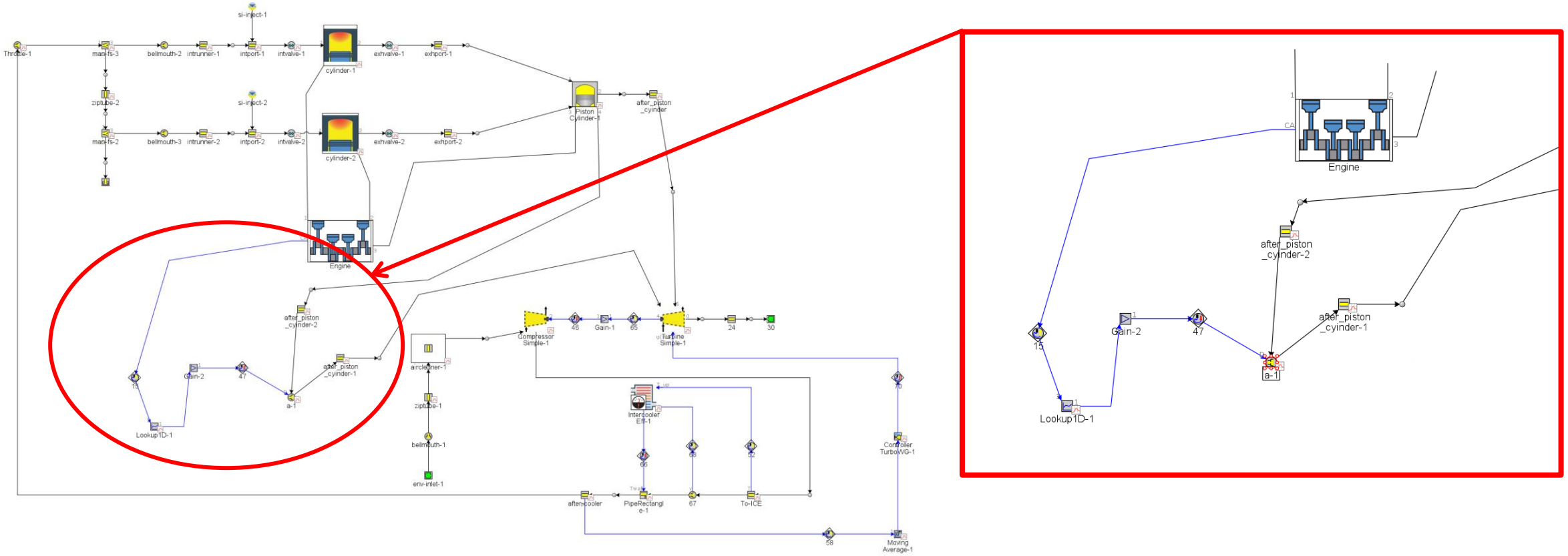
Optimized results of 2 Cylinder Petrol Engine with Exh Piston , Boost Pressure = 3.5 bar, @4000 rpm



- Boost pressure reaches to the target pressure of 3.5 bar by using the wastegate controller.
- BSFC & Brake Power

Exh Piston bsfc [g/kW-h]	Exh Piston bp [kW]
199.8	163.4

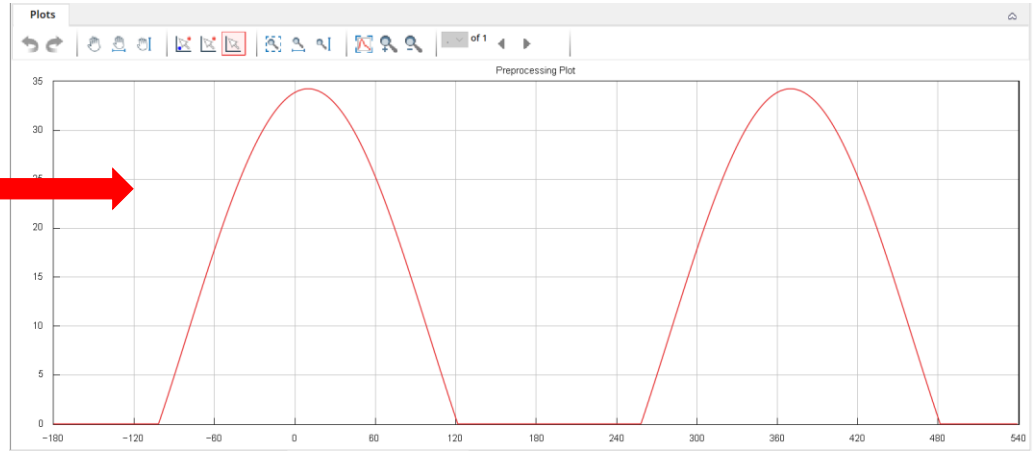
GT-Power Model of 2 Cylinder Petrol Engine with Exh Piston & Sideport, Boost Pressure = 3.5 bar, @4000 rpm

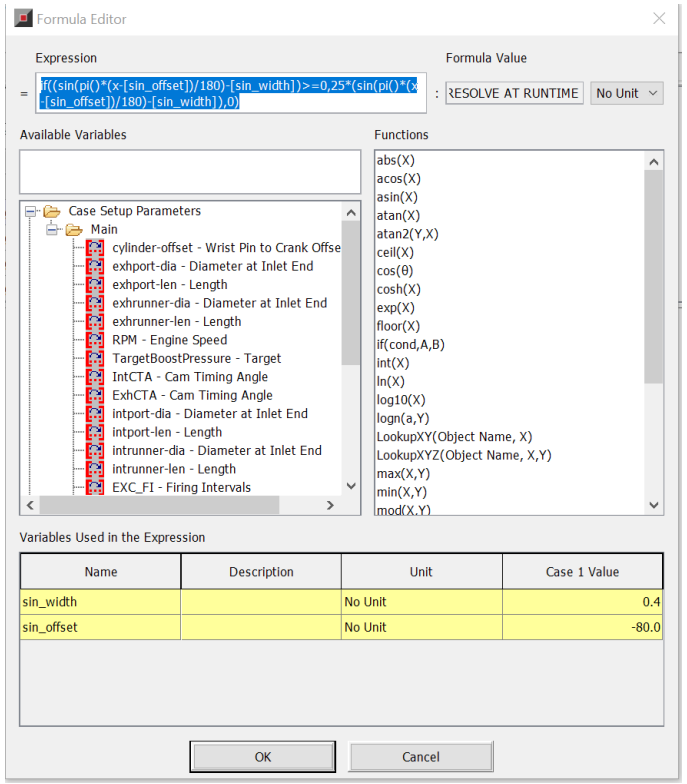


Folder: 2Cylinder_Petrol
Sideport-2Cylinder_SI-v03_OrificeConn_Opt_updated.gtm

GT-Power Model of Olshammar 2 Cylinder Petrol Engine with Exh Piston & Sideport, Boost Pressure = 3.5 bar, @4000 rpm

- Modelling the valve orifice diameter curve to control sideport's opening, see figure right
- Formula used in GT-Power, see figure below





If (sin(pi()*(x-[sin_offset])/180)-[sin_width])>=0),

= 25*(sin(pi()*(x-[sin_offset])/180)-[sin_width]),

else

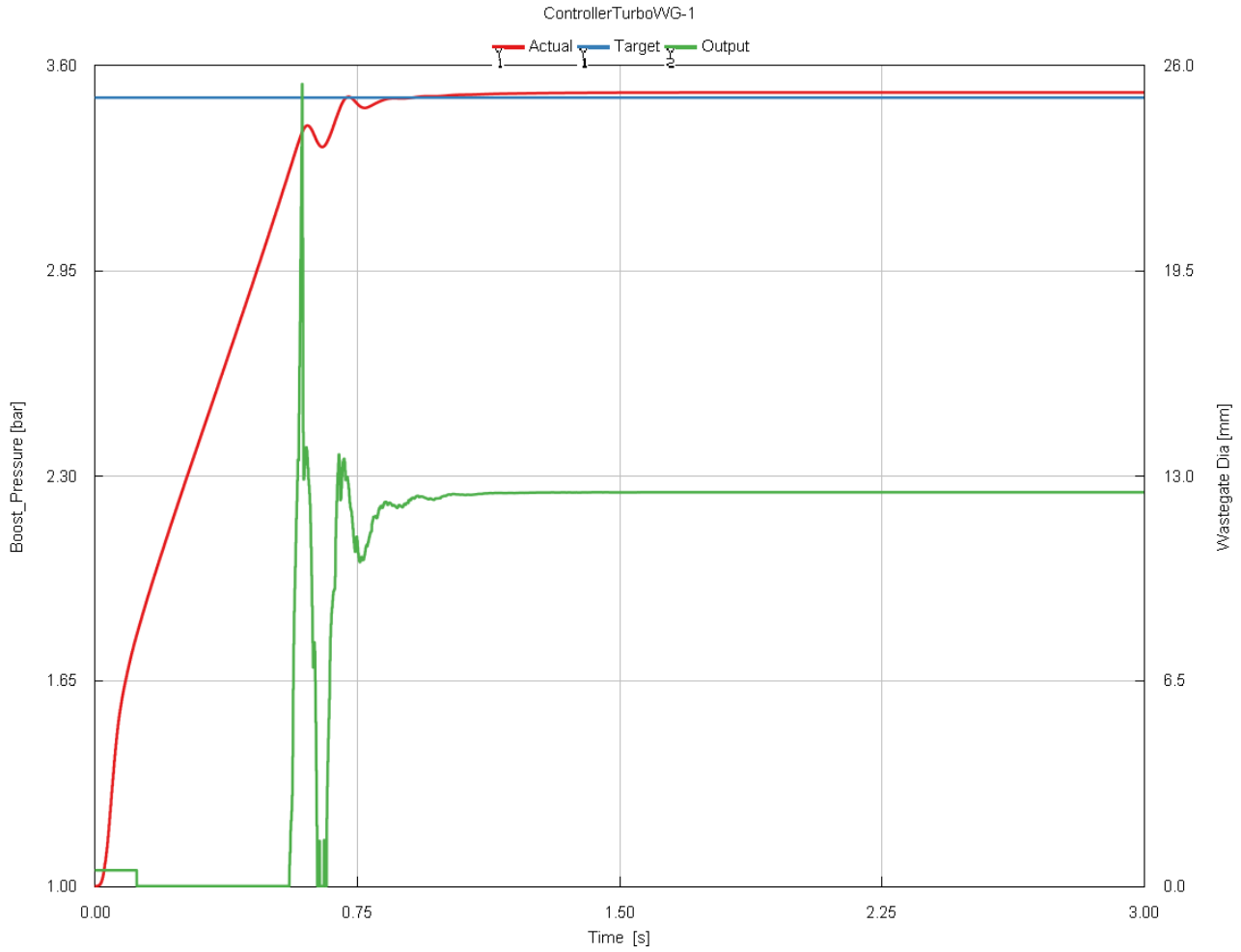
= 0

Parameters' optimization of 2 Cylinder Petrol Engine with Exh Piston & Sideport, Boost Pressure = 3.5 bar, @4000 rpm

Parameter	Unit	Description	Case 1
Case On/Off		**Check Box to Turn Case On**	☑
Case Label		**Unique Text for Plot Legends**	
TargetBoostPressure	bar	Target	3.5
Agess		Aggressiveness Factor	0.9
orificedia	mm	Turbine Orifice Diameter	28
RPM	RPM	Engine Speed	4000
throttle	mm	Hole Diameter	70
intCTA	Crank Angle (4-stroke)	Cam Timing Angle	471
exhCTA	Crank Angle (4-stroke)	Cam Timing Angle	242
intport_Dia	mm	Diameter at Inlet End	62
intport_Len	mm	Length	74
ExhPiston-CR		Compression Ratio	45
FI	deg	Firing Intervals	147
sin_offset			-99
sin_width			-0.36923572
exh_Dia	mm	Diameter at Inlet End	39
exh_Len	mm	Length	35
intrunner_Dia	mm	Diameter at Inlet End	36
intrunner_Len	mm	Length	469
after_piston_Dia	mm	Diameter at Inlet End	22
after_piston_Len	mm	Length	109
ExhPiston-Bore_Dia	mm	Bore	163
ExhPiston-Stroke	mm	Stroke	61
area_gain		Gain	6.8
angle_multiplier		Angle Multiplier	0.9716013
after_piston_sideport_Dia	mm	Diameter at Inlet End	33

- Parameters highlighted in red blocks are optimized in GT-Power.

Optimized results of 2 Cylinder Petrol Engine with Exh Piston & Sideport, Boost Pressure = 3.5 bar, @4000 rpm



- Boost pressure reaches to the target pressure of 3.5 bar by using the wastegate controller.
- BSFC & Brake Power

Sideport bsfc [g/kW-h]	Sideport bp [kW]
190.7	177.6

Comparison of Baseline and Two Olshammar Petrol Engines
Boost Pressure = 3.5 bar, @4000 rpm

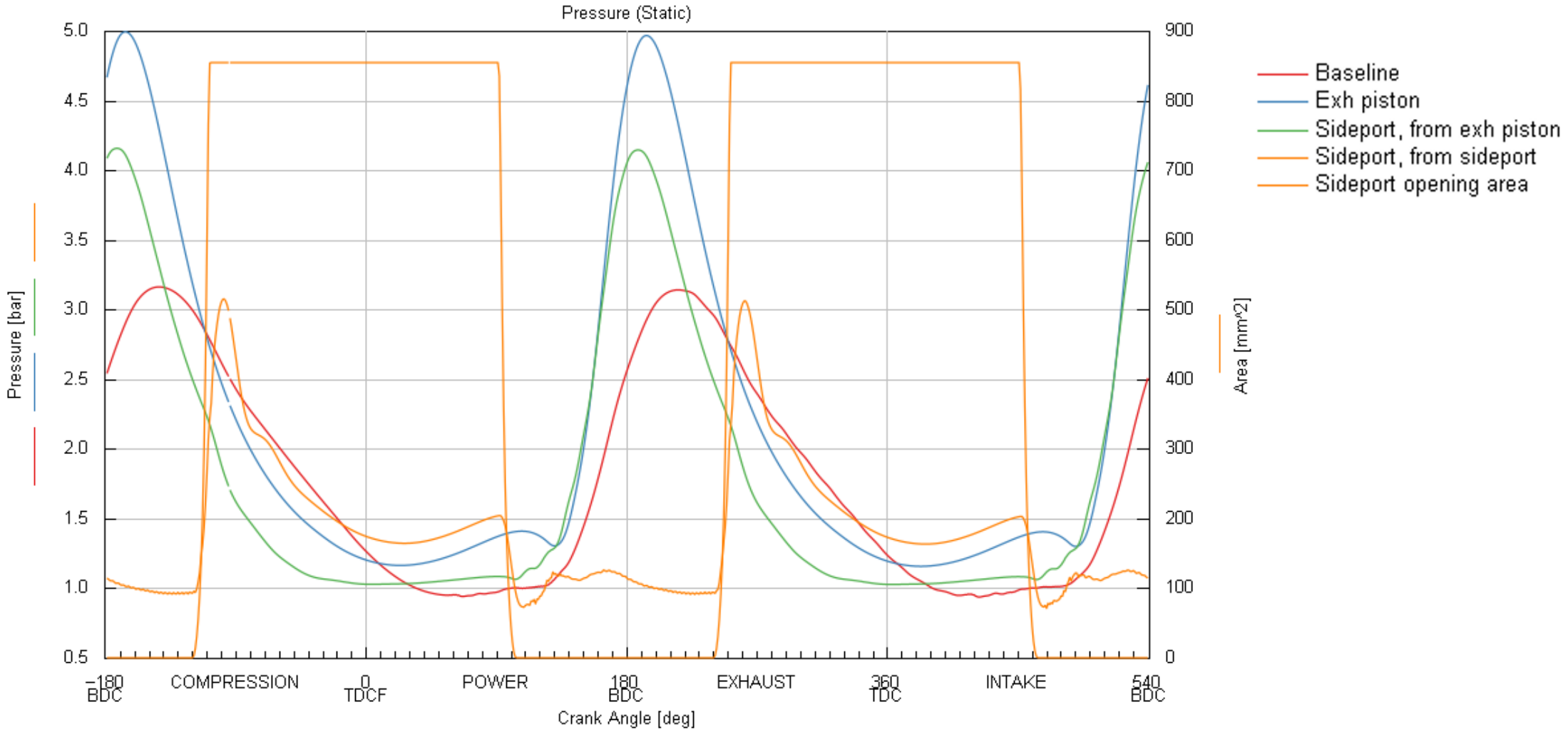
BSFC & Brake Power

- Three engines are compared
  - 2-Cylinder Baseline Engine
  - 2-Cylinder Olshammar engine with exhaust piston
  - 2-Cylinder Olshammar engine with both exhaust piston and sideport

Baseline bsfc [g/kW-h]	Baseline bp [kW]	Exh Piston bsfc [g/kW-h]	Exh Piston bp [kW]	Sideport bsfc [g/kW-h]	Sideport bp [kW]
211.2	152.8	199.8	163.4	190.7	177.6
0%	0%	-5.4%	+6.7%	-9.7%	+16.0%

Comparison of Baseline and Two Olshammar Petrol Engines
Boost Pressure = 3.5 bar, @4000 rpm

Static pressure before turbine



DOE with varying RPM
Baseline and Two Olshammar Petrol Engines, Boost Pressure = 3.5 bar

- **BSFC & BP**
- **RPM = 2000 - 5000**

2-Cylinder Baseline Engine

Folder: 2Cylinder_Petrol
Baseline-2Cylinder_SI-v01_Opt_updated_DOE_RPM.gtm

#		Label	Weight	Dataset	Case	RPM	bsfc	bkw	inst_error_rel
Type						Factors	Responses		
Units						RPM	g/kW-h	kW	%
1	☑	Training	1.00000	DataSet1_Default	1 - Case - 1	2000.00	212.862	44.7276	0.357844
2	☑	Training	1.00000	DataSet1_Default	1 - Case - 1	3000.00	207.979	102.143	0.0424471
3	☑	Training	1.00000	DataSet1_Default	1 - Case - 1	4000.00	211.066	153.116	-0.00188300
4	☑	Training	1.00000	DataSet1_Default	1 - Case - 1	5000.00	218.872	183.743	0.00246748

delta bsfc [%]	delta bp [%]
0.0%	+0.0%
0.0%	+0.0%
0.0%	+0.0%
0.0%	+0.0%

2-Cylinder Olshammar engine with exhaust piston

Folder: 2Cylinder_Petrol
ExhPiston-2Cylinder_SI-v02_Opt_Opt_EVODuration_updated_DOE_RPM.gtm

#		Label	Weight	Dataset	Case	RPM	bsfc	bkw	inst_error_rel
Type						Factors	Responses		
Units						RPM	g/kW-h	kW	%
1	☑	Training	1.00000	DataSet1_Default	1 - Case - 1	2000.00	202.144	72.0751	-0.00805200
2	☑	Training	1.00000	DataSet1_Default	1 - Case - 1	3000.00	197.412	116.408	-0.00802834
3	☑	Training	1.00000	DataSet1_Default	1 - Case - 1	4000.00	199.758	163.433	-0.00775207
4	☑	Training	1.00000	DataSet1_Default	1 - Case - 1	5000.00	206.667	160.775	9.40822E-4

delta bsfc [%]	delta bkw [%]
-5.04%	+61.14%
-5.08%	+13.97%
-5.36%	+6.74%
-5.58%	-12.50%

2-Cylinder Olshammar engine with both exhaust piston and sideport

Folder: 2Cylinder_Petrol
Sideport-2Cylinder_SI-v03_OrificeConn_Opt_updated_DOE_RPM.gtm

#		Label	Weight	Dataset	Case	RPM	bsfc	bkw	inst_error_rel
Type						Factors	Responses		
Units						RPM	g/kW-h	kW	%
1	☑	Training	1.00000	DataSet1_Default	1 - Case - 1	2000.00	205.762	72.7902	0.0236801
2	☑	Training	1.00000	DataSet1_Default	1 - Case - 1	3000.00	188.323	120.443	0.0198628
3	☑	Training	1.00000	DataSet1_Default	1 - Case - 1	4000.00	190.662	177.586	-0.00464092
4	☑	Training	1.00000	DataSet1_Default	1 - Case - 1	5000.00	199.989	181.186	-2.60340E-4

delta bsfc [%]	delta bkw [%]
-3.34%	+62.74%
-9.45%	+17.92%
-9.67%	+15.98%
-8.63%	-1.39%

DOE with varying boost pressure 2.5 – 4.0
Baseline and Two Olshammar Petrol Engines, @ 4000 rpm

- **BSFC & BP**
- **RPM = 4000**

Folder: 2Cylinder_Petrol
Baseline-2Cylinder_SI-v01_Opt_updated_DOE_BoostPressure.gtm

2-Cylinder Baseline Engine

#		Label	Weight	Dataset	Case	TargetBoostPressure	bsfc	bkw	inst_error_rel	delta bsfc [%]	delta bp [%]
Type						Factors	Responses				
Units						bar	g/kW-h	kW	%		
1	☑	Training	1.00000	DataSet1_Default	1 - Case - 1	2.50000	214.885	109.022	-0.00342495	0.0%	+0.0%
2	☑	Training	1.00000	DataSet1_Default	1 - Case - 1	3.00000	212.702	131.186	-0.00249640	0.0%	+0.0%
3	☑	Training	1.00000	DataSet1_Default	1 - Case - 1	3.50000	211.066	153.116	-0.00188300	0.0%	+0.0%
4	☑	Training	1.00000	DataSet1_Default	1 - Case - 1	4.00000	209.736	174.431	-0.00146476	0.0%	+0.0%

Folder: 2Cylinder_Petrol
ExhPiston-2Cylinder_SI-v02_Opt_Opt_EVODuration_updated_DOE_BoostPressure.gtm

2-Cylinder Olshammar engine with exhaust piston

#		Label	Weight	Dataset	Case	TargetBoostPressure	bsfc	bkw	inst_error_rel	delta bsfc [%]	delta bkw [%]
Type						Factors	Responses				
Units						bar	g/kW-h	kW	%		
1	☑	Training	1.00000	DataSet1_Default	1 - Case - 1	2.50000	210.217	111.887	-0.00759416	-2.17%	+2.63%
2	☑	Training	1.00000	DataSet1_Default	1 - Case - 1	3.00000	203.766	137.909	-0.00767356	-4.20%	+5.12%
3	☑	Training	1.00000	DataSet1_Default	1 - Case - 1	3.50000	199.758	163.433	-0.00775207	-5.36%	+6.74%
4	☑	Training	1.00000	DataSet1_Default	1 - Case - 1	4.00000	197.168	188.636	-0.00761368	-5.99%	+8.14%

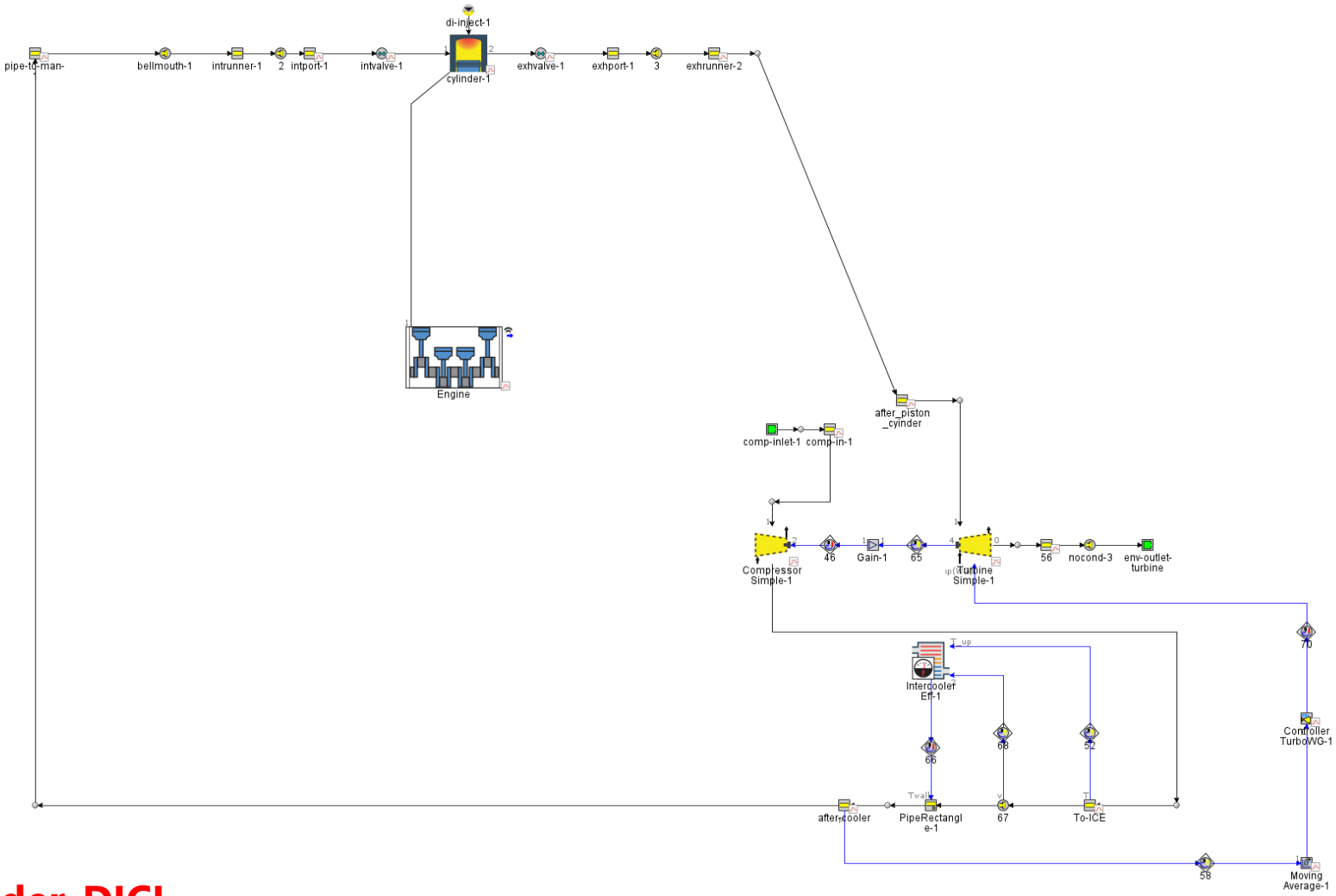
Folder: 2Cylinder_Petrol
Sideport-2Cylinder_SI-v03_OrificeConn_Opt_updated_DOE_BoostPressure.gtm

2-Cylinder Olshammar engine with both exhaust piston and sideport

#		Label	Weight	Dataset	Case	TargetBoostPressure	bsfc	bkw	inst_error_rel	delta bsfc [%]	delta bkw [%]
Type						Factors	Responses				
Units						bar	g/kW-h	kW	%		
1	☑	Training	1.00000	DataSet1_Default	1 - Case - 1	2.50000	199.236	122.604	-0.00442553	-7.28%	+12.46%
2	☑	Training	1.00000	DataSet1_Default	1 - Case - 1	3.00000	193.940	150.432	-0.00457900	-8.82%	+14.67%
3	☑	Training	1.00000	DataSet1_Default	1 - Case - 1	3.50000	190.662	177.586	-0.00464092	-9.67%	+15.98%
4	☑	Training	1.00000	DataSet1_Default	1 - Case - 1	4.00000	188.503	204.213	-0.00463012	-10.12%	+17.07%

1 Cylinder Diesel Engine
Olshammar v.s. Baseline
BSFC & BP Results @1800 rpm

GT-Power Model of Baseline 1 Cylinder Diesel Engine, Boost Pressure = 5.5 bar, @1800 rpm



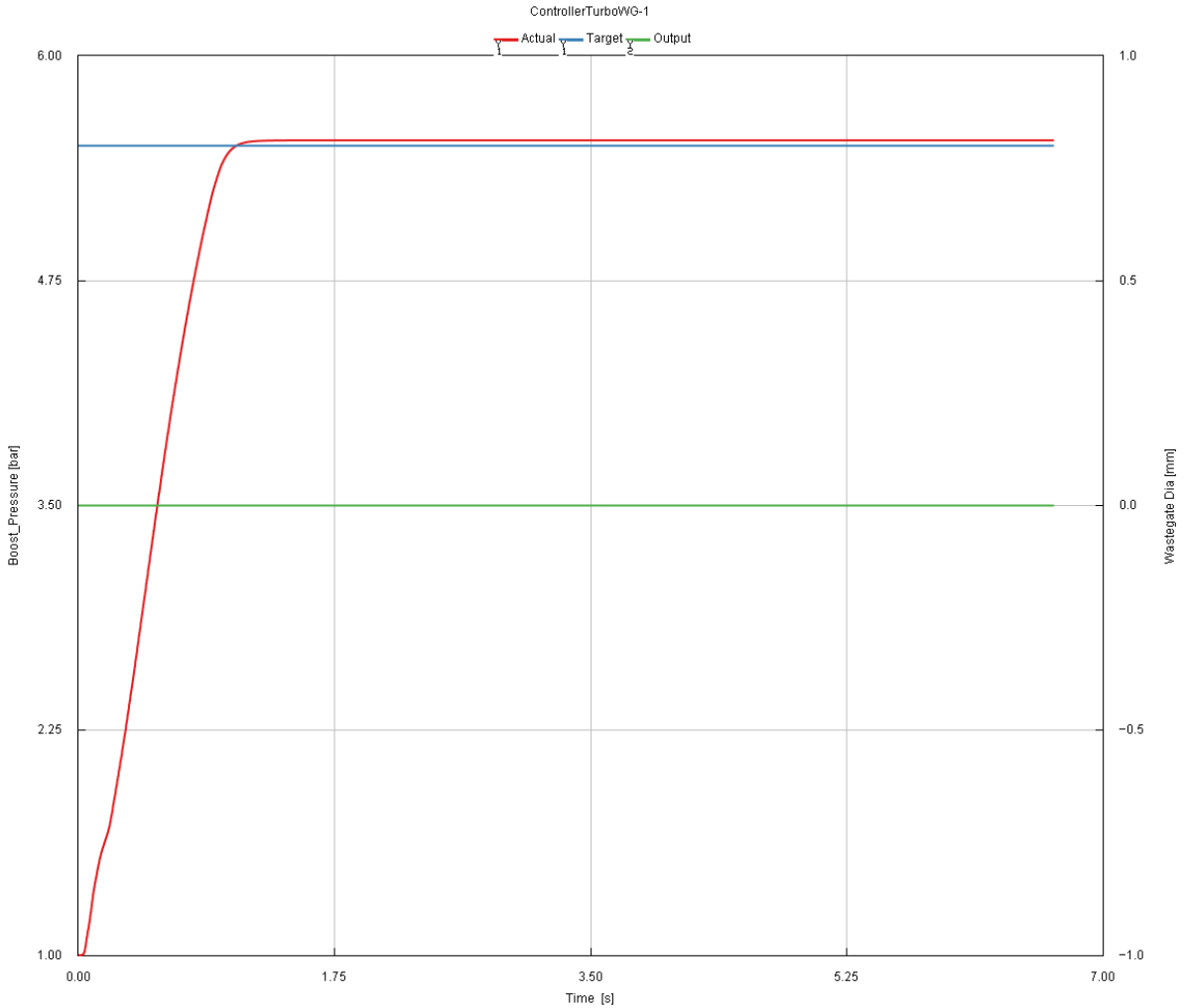
Folder: 1Cylinder_DICI
GT-Baseline-1Cylinder_DICI-OPT-v01-5p5bar_Optimized.gtm

Parameters' optimization of Baseline 1 Cylinder Diesel Engine, Boost Pressure = 5.5 bar, @1800 rpm

Parameter	Unit	Description	Case 1
Case On/Off		**Check Box to Turn Case On**	☑
Case Label		**Unique Text for Plot Legends**	
cylinder-offset	mm	Wrist Pin to Crank Offset	1
TargetBoostPressure	bar	Target	5.5
Agess		Aggressiveness Factor	0.9
exhport-dia	mm	Diameter at Inlet End	36
exhport-len	mm	Length	97
exhrunner-dia	mm	Diameter at Inlet End	67
exhrunner-len	mm	Length	130
orificedia	mm	Turbine Orifice Diameter	31
IntCTA	Crank Angle (4-stroke)	Cam Timing Angle	446
ExhCTA	Crank Angle (4-stroke)	Cam Timing Angle	254
intport-dia	mm	Diameter at Inlet End	48
intport-len	mm	Length	64
intrunner-dia	mm	Diameter at Inlet End	59
intrunner-len	mm	Length	137
RPM	RPM	Engine Speed	1800
Comb_Cylinder_Dia	mm	Bore	131
Comb_Cylinder_Stroke	mm	Stroke	158
man_Dia	mm	Diameter at Inlet End	67
man_Len	mm	Length	95
after_dia	mm	Diameter at Inlet End	82
after_Len	mm	Length	57

- Parameters highlighted in red blocks are optimized in GT-Power.

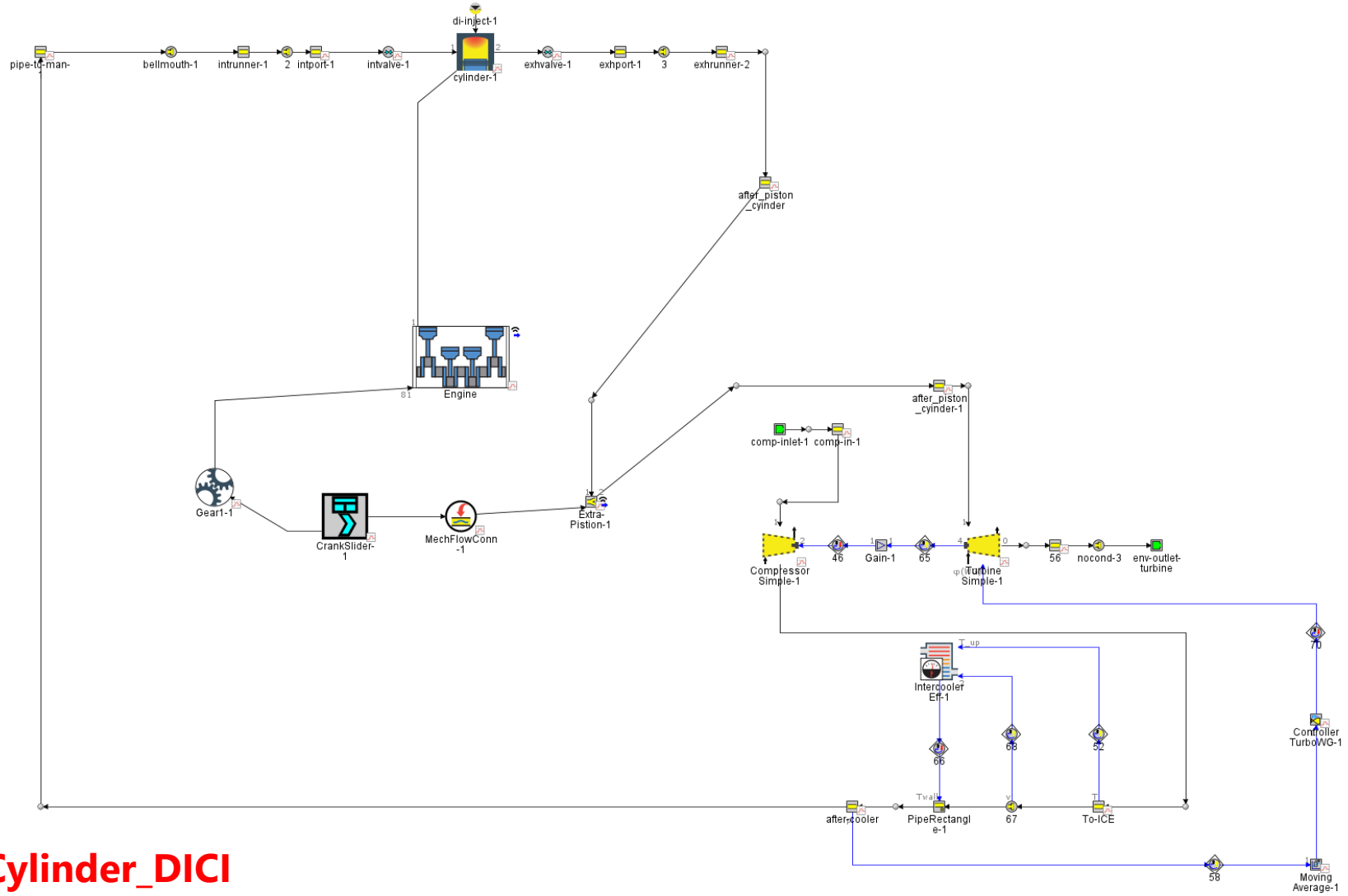
Optimized results of Baseline 1 Cylinder Diesel Engine, Boost Pressure = 5.5 bar, @1800 rpm



- Boost pressure reaches to the target pressure of 5.5 bar by using the wastegate controller.
- BSFC & Brake Power

Exh Piston bsfc [g/kW-h]	Exh Piston bp [kW]
215.9	116.3

GT-Power Model of Baseline 1 Cylinder Diesel Engine with Exh Piston, Boost Pressure = 5.5 bar, @1800 rpm



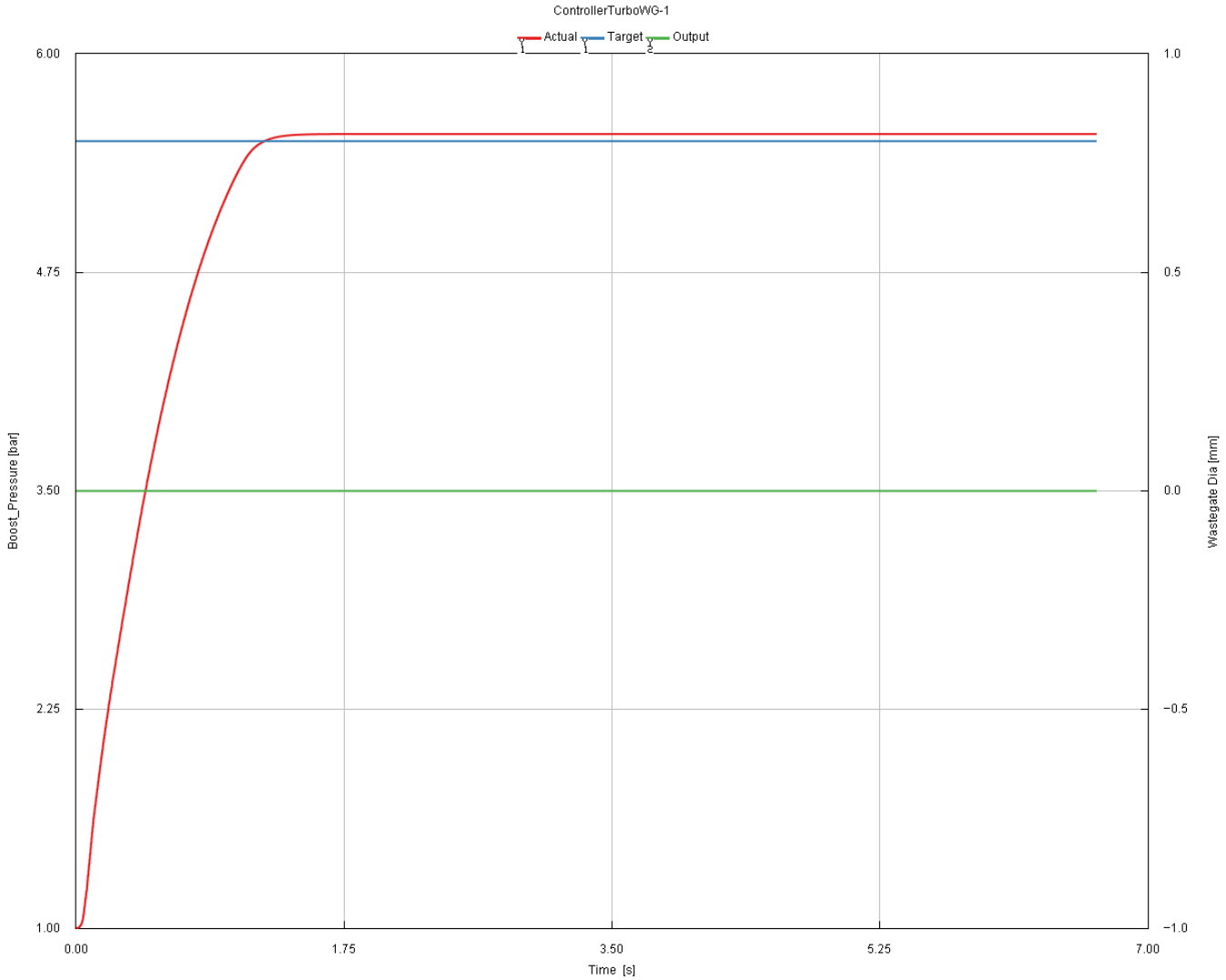
Folder: 1Cylinder_DICI
GT-ExhPiston-1Cylinder_DICI-OPT-v01-5p5bar_Optimized.gtm

Parameters' optimization of Baseline 1 Cylinder Diesel Engine with Exh Piston, Boost Pressure = 5.5 bar, @1800 rpm

Parameter	Unit	Description	Case 1
Case On/Off		**Check Box to Turn Case On**	☑
Case Label		**Unique Text for Plot Legends**	
cylinder-offset	mm	Wrist Pin to Crank Offset	1
TargetBoostPressure	bar	Target	5.5
Agess		Aggressiveness Factor	0.9
exhport-dia	mm	Diameter at Inlet End	60
exhport-len	mm	Length	74
exhrunner-dia	mm	Diameter at Inlet End	68
exhrunner-len	mm	Length	92
orificedia	mm	Turbine Orifice Diameter	28
IntCTA	Crank Angle (4-stroke)	Cam Timing Angle	448
ExhCTA	Crank Angle (4-stroke)	Cam Timing Angle	246
intport-dia	mm	Diameter at Inlet End	69
intport-len	mm	Length	76
intrunner-dia	mm	Diameter at Inlet End	41
intrunner-len	mm	Length	111
RPM	RPM	Engine Speed	1800
Comb_Cylinder_Dia	mm	Bore	131
Comb_Cylinder_Stroke	mm	Stroke	158
man_Dia	mm	Diameter at Inlet End	83
man_Len	mm	Length	141
after_dia	mm	Diameter at Inlet End	61
after_Len	mm	Length	54
piston-start-angle	deg	Crank (Throw) Initial Angle	118
piston-bore	mm	Bore	126
after_piston_Dia	mm	Diameter at Inlet End	88
after_piston_Len	mm	Length	67

- Parameters highlighted in red blocks are optimized in GT-Power.

Optimized results of Baseline 1 Cylinder Diesel Engine with Exh Piston, Boost Pressure = 5.5 bar, @1800 rpm



- Boost pressure reaches to the target pressure of 5.5 bar by using the wastegate controller.
- BSFC & Brake Power

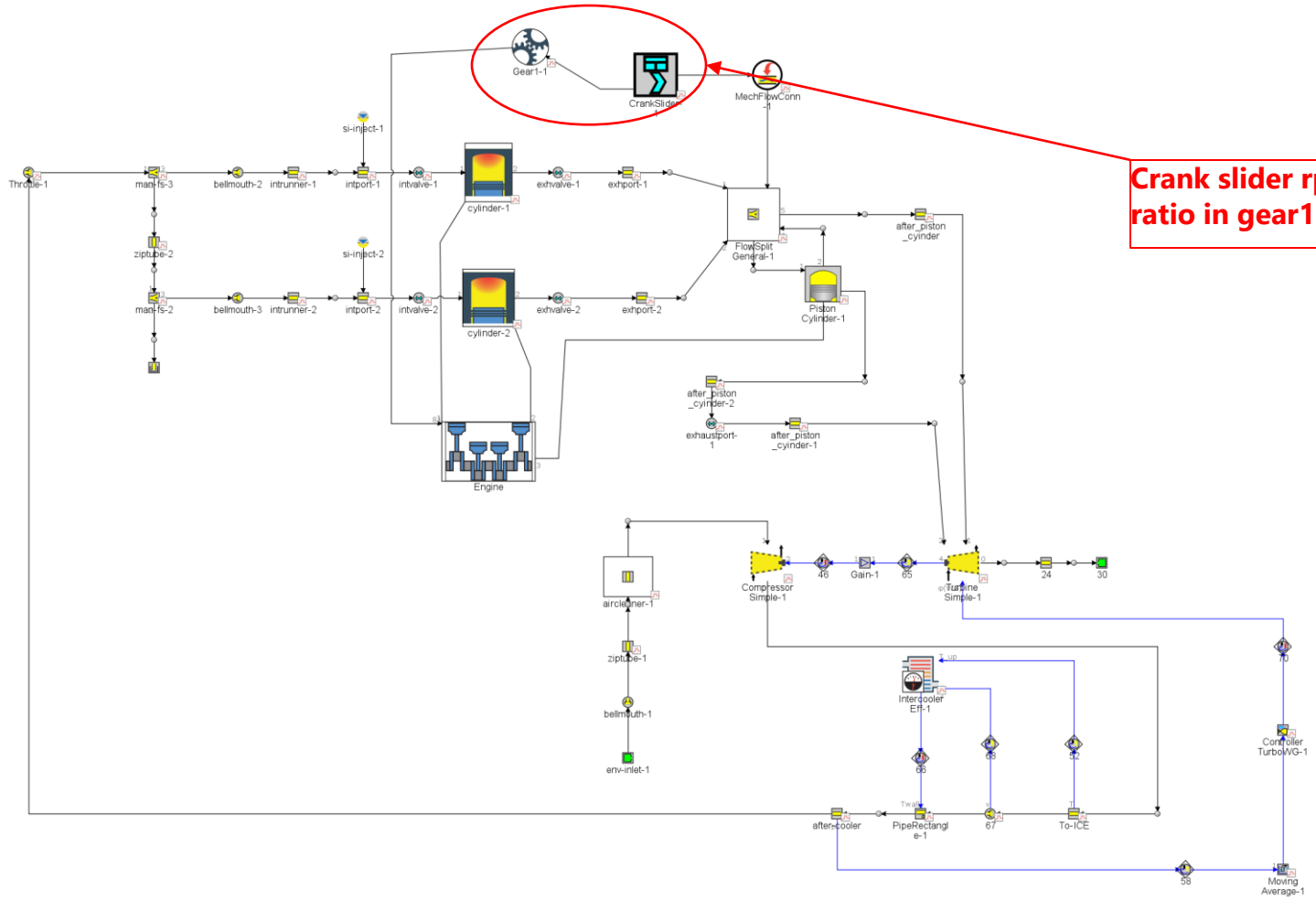
Exh Piston bsfc [g/kW-h]	Exh Piston bp [kW]
234	110.8

2 Cylinder Petrol Engine

Olshammar 2 extra pistons v.s. Baseline

BSFC & BP Results @4000 rpm

GT-Power Model of 2 Cylinder Petrol Engine with 2 extra pistons, Boost Pressure = 3.5 bar, @4000 rpm



Crank slider rpm is twice as the engine rpm through setting gear ratio in gear1-1 to be 2.0.

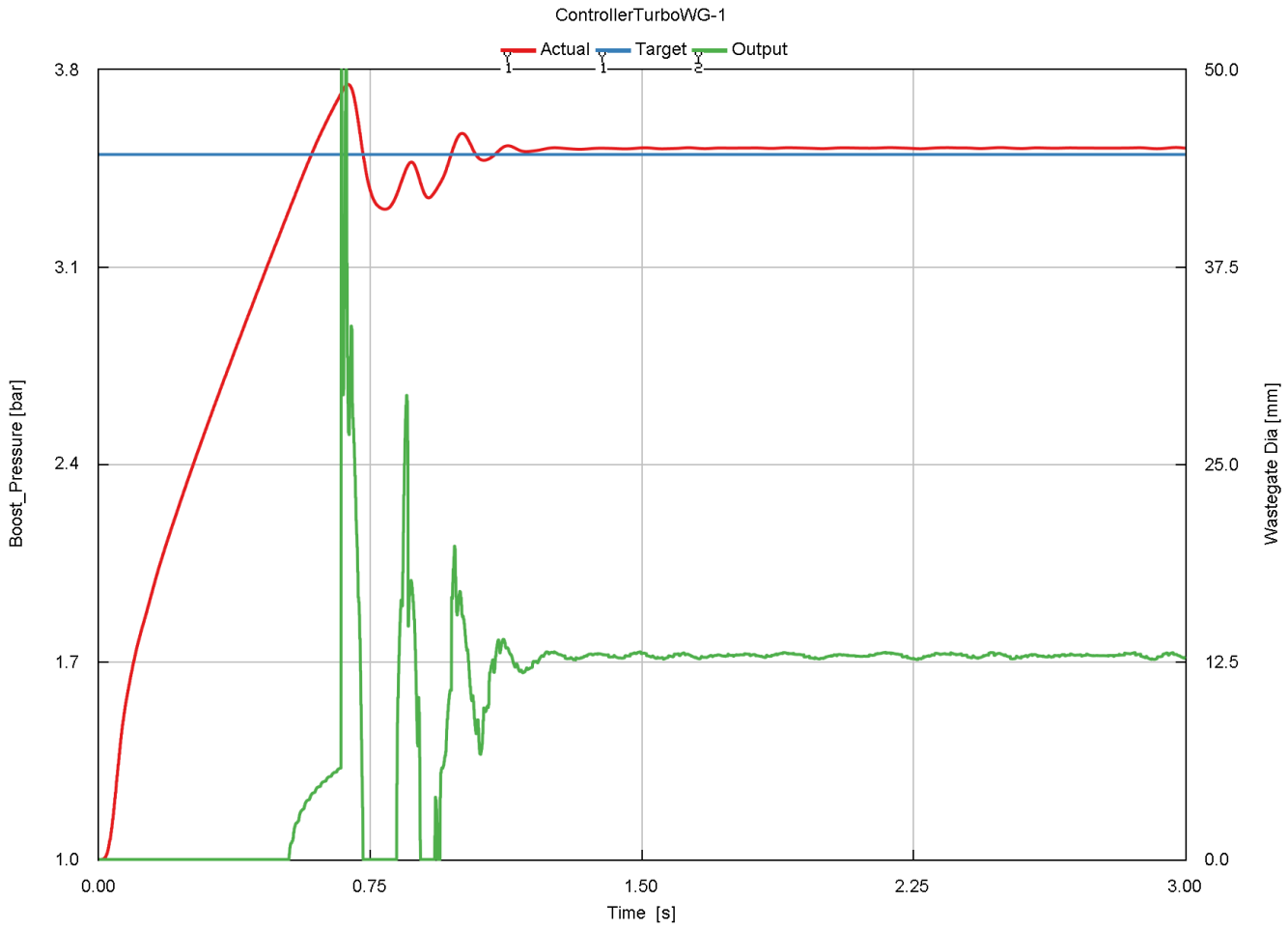
Folder: 2Cylinder_Petrol_2extrapistons
ExhPiston-2Cylinder_SI-v03_SideportAndExtraPiston_Design607_Optimized_Design606.gtm

Parameters' optimization of 2 Cylinder Petrol Engine with 2 extra pistons, Boost Pressure = 3.5 bar, @4000 rpm

Parameter	Unit	Description	Case 1
Case On/Off		**Check Box to Turn Case On**	☑
Case Label		**Unique Text for Plot Legends**	
TargetBoostPressure	bar	Target	3.5
Agess		Aggressiveness Factor	0.9
orificedia	mm	Turbine Orifice Diameter	29
throttle	mm	Hole Diameter	70
intCTA	Crank Angle (4-stroke)	Cam Timing Angle	466
intport_Dia	mm	Diameter at Inlet End	71
intport_Len	mm	Length	88
ExhPiston-Bore_Dia	mm	Bore	152
ExhPiston-Stroke	mm	Stroke	65
ExhPiston-CR		Compression Ratio	45
FI	deg	Firing Intervals	153
intrunner_Dia	mm	Diameter at Inlet End	40
intrunner_Len	mm	Length	408
exh_Dia	mm	Diameter at Inlet End	36
exh_Len	mm	Length	33
after_piston_Dia	mm	Diameter at Inlet End	24
after_piston_Len	mm	Length	189
angle_multiplier		Angle Multiplier	0.9910915
exhCTA	Crank Angle (4-stroke)	Cam Timing Angle	245
RPM	RPM	Engine Speed	4000
piston-start-angle	deg	Crank (Throw) Initial Angle	176
piston-bore	mm	Bore	43
after_piston_sideport_Dia	mm	Diameter at Inlet End	30
piston_stroke	mm	Stroke	49
angle2		Crank Angle Array	250
angle1		Crank Angle Array	80

- Parameters highlighted in red blocks are optimized in GT-Power.

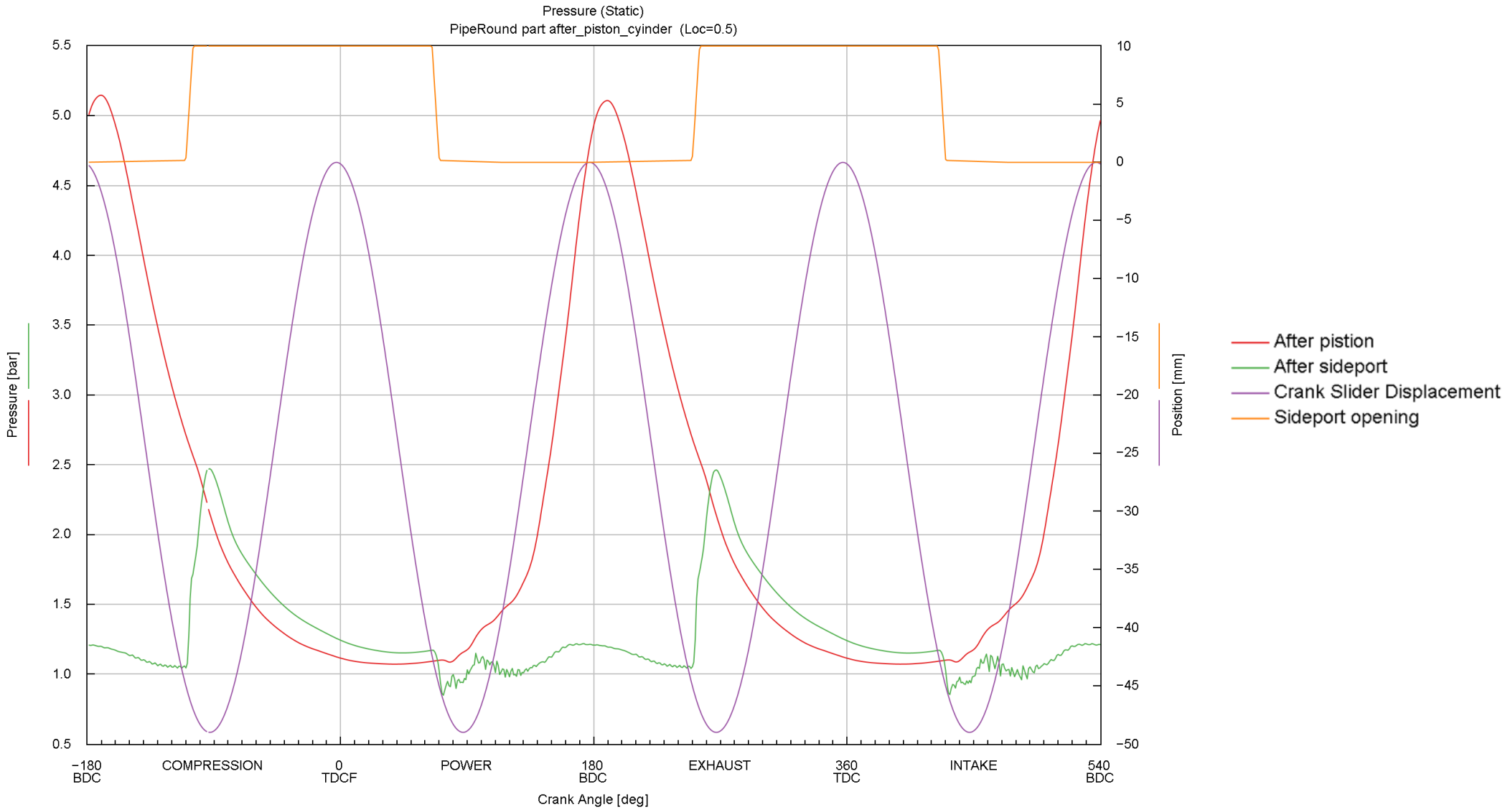
Optimized results of 2 Cylinder Petrol Engine with 2 extra pistons, Boost Pressure = 3.5 bar, @4000 rpm



- Booster pressure reaches to the target pressure of 3.5 bar by using the wastegate controller.
- BSFC & Brake Power

Baseline bsfc [g/kW-h]	Baseline bp [kW]
211.1	153.1
2 Extra Pistons bsfc [g/kW-h]	2 Extra Pistons bp [kW]
192.7	175.5
-8.7%	+14.6%

2 Extra Pistons Petrol Engine
Boost Pressure = 3.5 bar, @4000 rpm

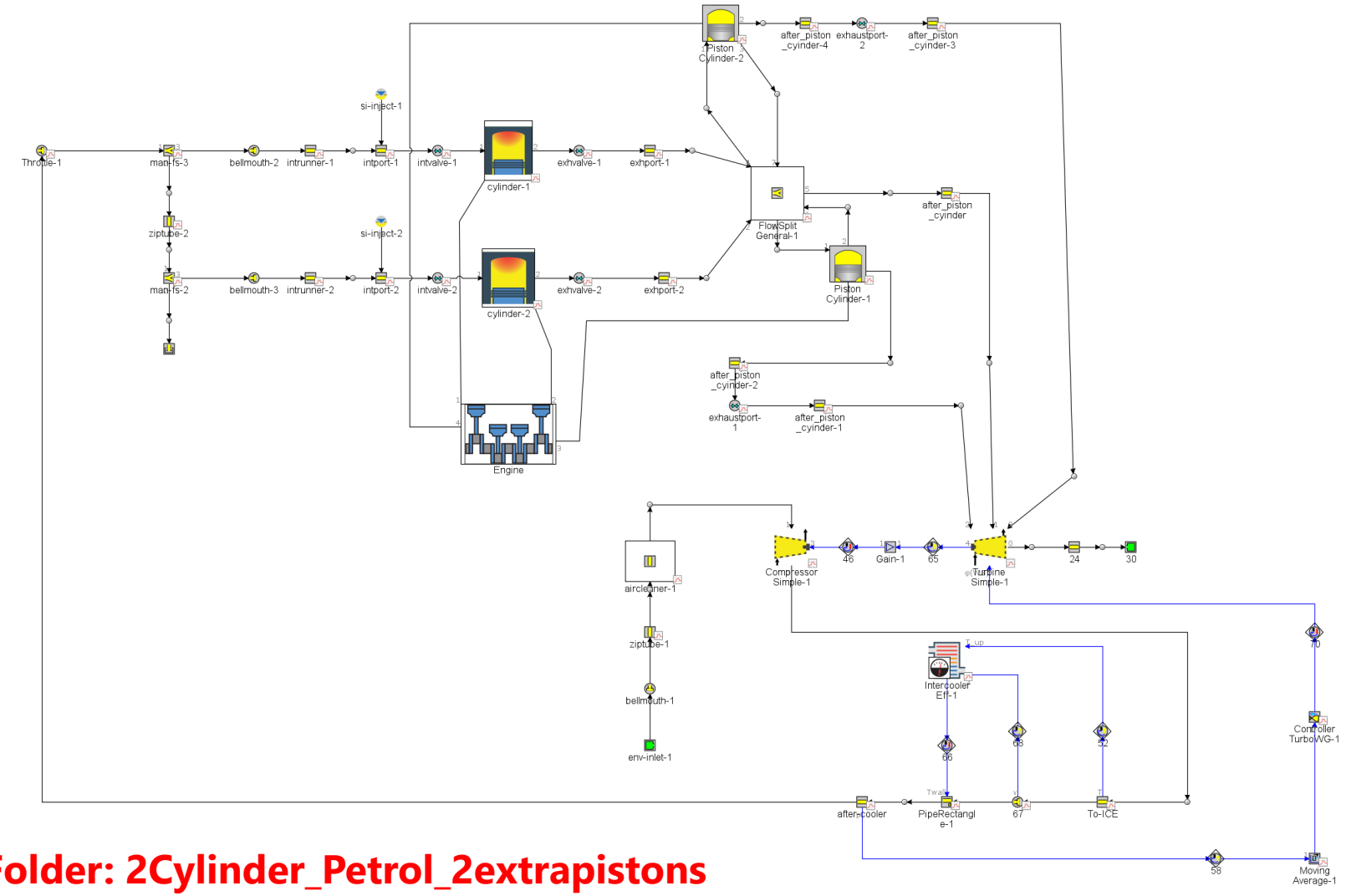


2 Cylinder Petrol Engine

Olshammar 2 opposed exhaust pistons v.s. Baseline

BSFC & BP Results @4000 rpm

GT-Power Model of 2 Cylinder Petrol Engine with 2 opposed exhaust pistons
Boost Pressure = 3.5 bar, @4000 rpm



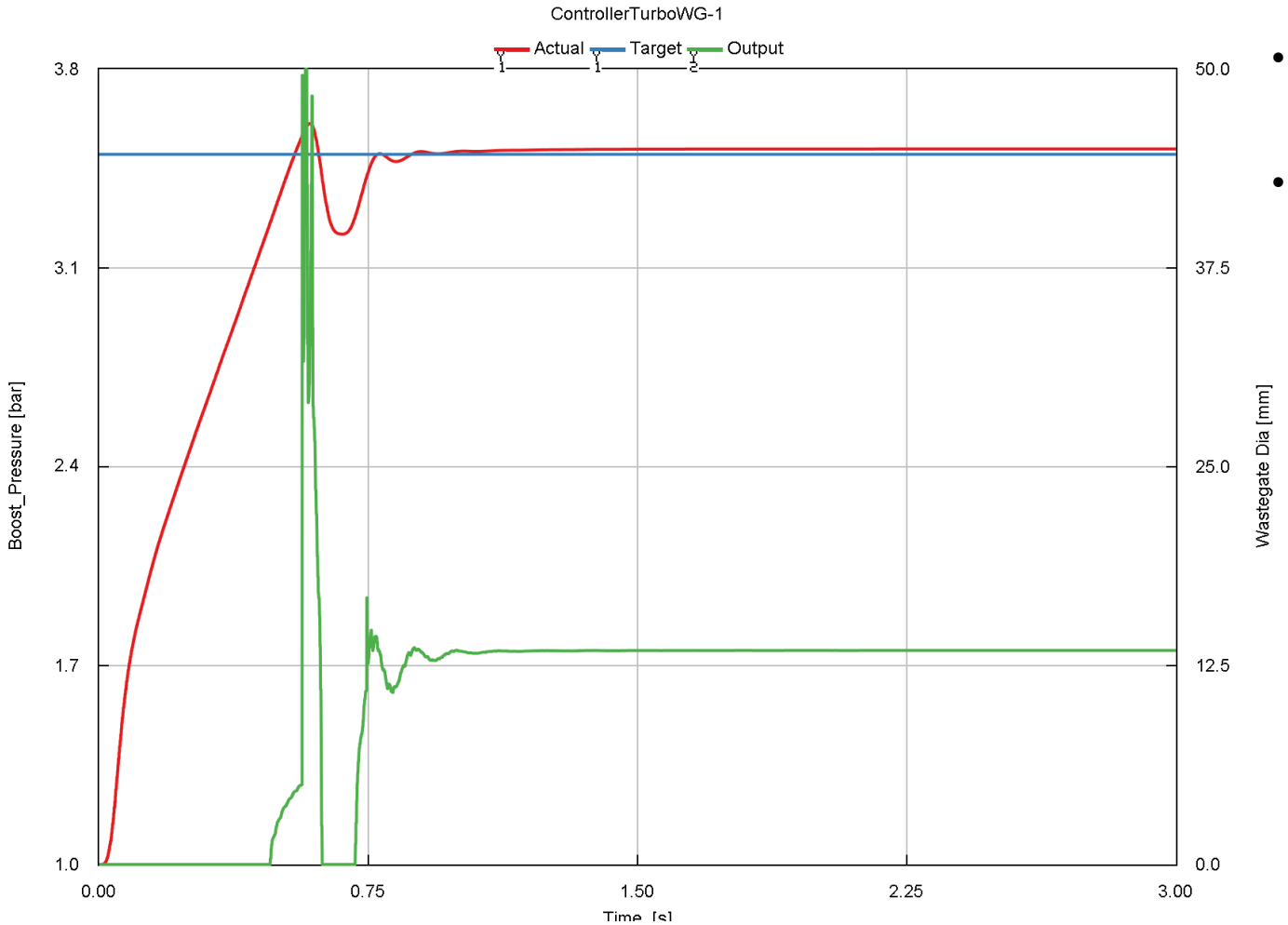
Folder: 2Cylinder_Petrol_2extrapistons
ExhPiston-2Cylinder_SI_TwoOpposedExhPistons_v01.gtm

Parameters' optimization of 2 Cylinder Petrol Engine with 2 opposed exhaust pistons Boost Pressure = 3.5 bar, @4000 rpm

Parameter	Unit	Description	Case 1
Case On/Off		**Check Box to Turn Case On**	☑
Case Label		**Unique Text for Plot Legends**	
TargetBoostPressure	bar	Target	3.5
Agess		Aggressiveness Factor	0.9
orificedia	mm	Turbine Orifice Diameter	29
throttle	mm	Hole Diameter	70
intCTA	Crank Angle (4-stroke)	Cam Timing Angle	466
intport_Dia	mm	Diameter at Inlet End	71
intport_Len	mm	Length	88
ExhPiston-CR		Compression Ratio	45
intrunner_Dia	mm	Diameter at Inlet End	40
intrunner_Len	mm	Length	408
exh_Dia	mm	Diameter at Inlet End	36
exh_Len	mm	Length	33
after_piston_Dia	mm	Diameter at Inlet End	24
after_piston_Len	mm	Length	189
angle_multiplier		Angle Multiplier	0.9910915
exhCTA	Crank Angle (4-stroke)	Cam Timing Angle	245
RPM	RPM	Engine Speed	4000
piston-start-angle	deg	Crank (Throw) Initial Angle	176
piston-bore	mm	Bore	43
after_piston_sideport_Dia	mm	Diameter at Inlet End	30
piston_stroke	mm	Stroke	49
angle2		Crank Angle Array	250
angle1		Crank Angle Array	80
ExhPiston-Stroke	mm	Stroke	42
ExhPiston-Bore_Dia	mm	Bore	158
PhaseShift	deg	Firing Intervals	0
FI	deg	Firing Intervals	155

- Parameters highlighted in red blocks are optimized in GT-Power.

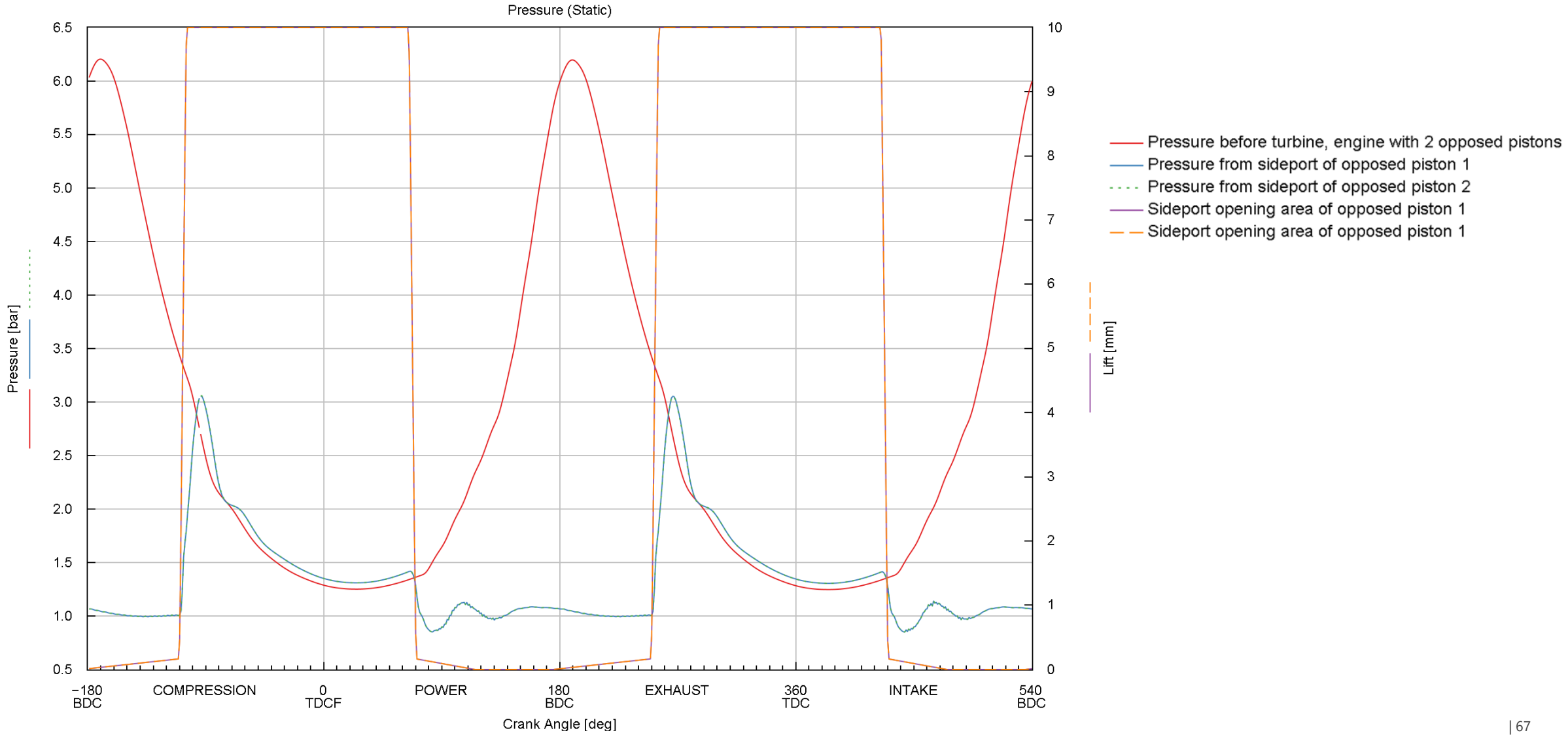
Optimized results of 2 Cylinder Petrol Engine with 2 opposed exhaust pistons, Boost Pressure = 3.5 bar, @4000 rpm



- Boost pressure reaches to the target pressure of 3.5 bar by using the wastegate controller.
- BSFC & Brake Power

Baseline bsfc [g/kW-h]	Baseline bp [kW]
211.1	153.1
2 Opposed Extra Pistons bsfc [g/kW-h]	2 Opposed Extra Pistons bp [kW]
189.7	178.2
-10.1%	+16.4%

2 Cylinder Petrol Engine with 2 opposed exhaust pistons
Boost Pressure = 3.5 bar, @4000 rpm



DOE with varying boost pressure 2.5 – 4.0 bar
Baseline and Two Olshammar Petrol Engines, @ 4000 rpm

- **BSFC & BP**
- **RPM = 4000**

2-Cylinder Baseline Engine

#		Label	Weight	Dataset	Case	TargetBoostPressure	bsfc	bkw	inst_error_rel	delta bsfc [%]	delta bp [%]
Type						Factors	Responses				
Units						bar	g/kW-h	kW	%		
1	☑	Training	1.00000	DataSet1_Default	1 - Case - 1	2.50000	214.885	109.022	-0.00342495	0.0%	+0.0%
2	☑	Training	1.00000	DataSet1_Default	1 - Case - 1	3.00000	212.702	131.186	-0.00249640	0.0%	+0.0%
3	☑	Training	1.00000	DataSet1_Default	1 - Case - 1	3.50000	211.066	153.116	-0.00188300	0.0%	+0.0%
4	☑	Training	1.00000	DataSet1_Default	1 - Case - 1	4.00000	209.736	174.431	-0.00146476	0.0%	+0.0%

Folder: 2Cylinder_Petrol
Baseline-2Cylinder_SI-v01_Opt_updated_DOE_BoostPressure.gtm

2-Cylinder Olshammar engine with 2 opposed exhaust pistons

#		Label	Weight	Dataset	Case	TargetBoostPressure	bsfc	bkw	inst_error_rel	delta bsfc [%]	delta bkw [%]
Type						Factors	Responses				
Units						bar	g/kW-h	kW	%		
1	☑	Training	1.00000	DataSet1_Default	1 - Case - 1	2.50000	199.776	123.218	-0.00548070	-7.0%	+13.0%
2	☑	Training	1.00000	DataSet1_Default	1 - Case - 1	3.00000	193.206	151.625	-0.00549771	-9.2%	+15.6%
3	☑	Training	1.00000	DataSet1_Default	1 - Case - 1	3.50000	189.701	178.200	-0.00535399	-10.1%	+16.4%
4	☑	Training	1.00000	DataSet1_Default	1 - Case - 1	4.00000	187.505	203.758	-0.00516920	-10.6%	+16.8%

Folder: 2Cylinder_Petrol_2extrapistons
ExhPiston-2Cylinder_SI_TwoOpposedExhPistons_v01_DOE_BoostPressure.gtm

2-Stroke, 2-Cylinder Diesel Opposed Piston Engine

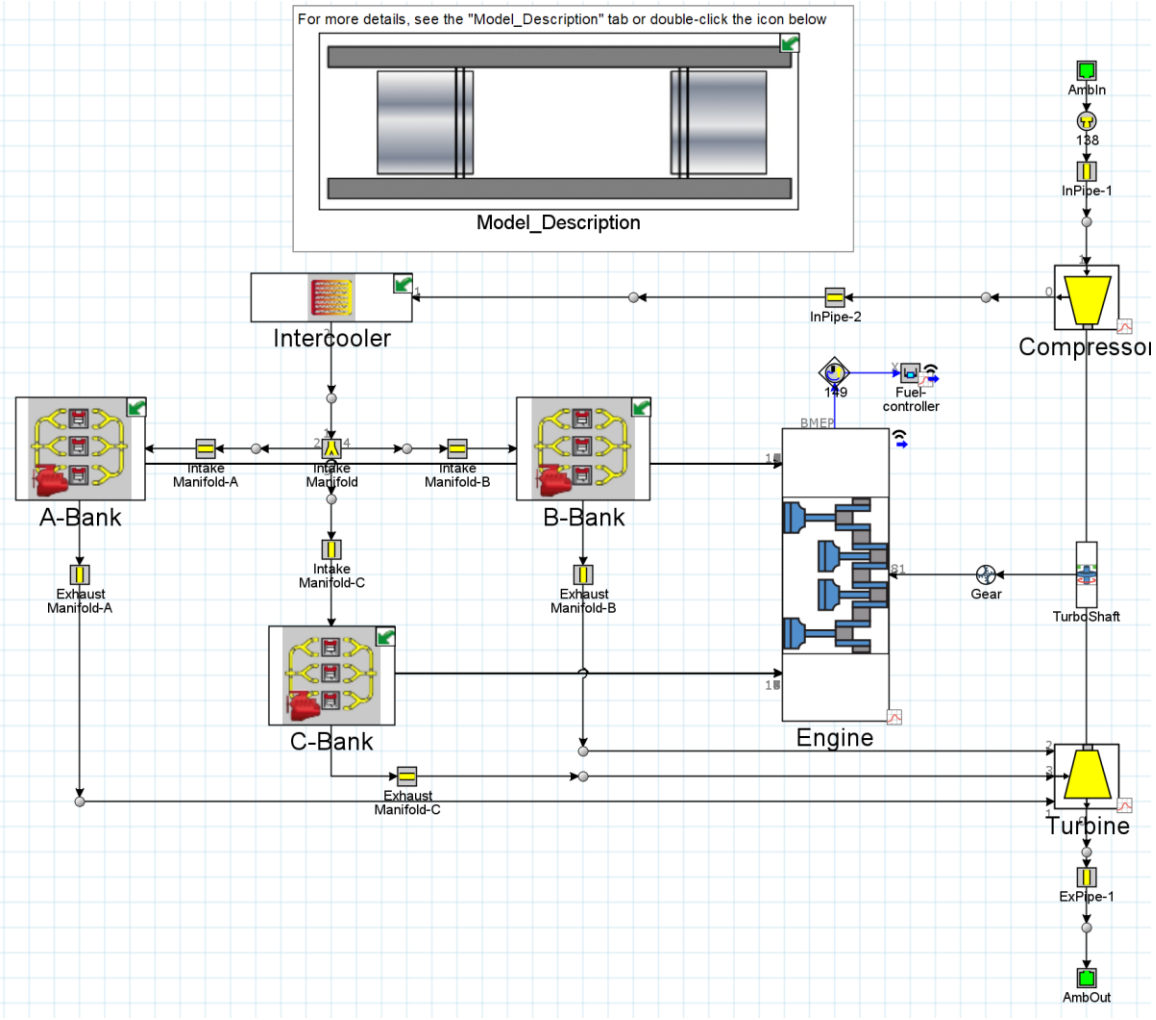
Opposed exhaust pistons v.s. Baseline

BSFC & BP Results @1400 rpm, BMEP = 5.5 bar

GT-Power model of 2-stroke, 2-cylinder diesel opposed piston engine, baseline BMEP= 5.5 bar, @1400 rpm

- The current model is simplified from GT-Power example, Napier Deltic CT18-42K engine.

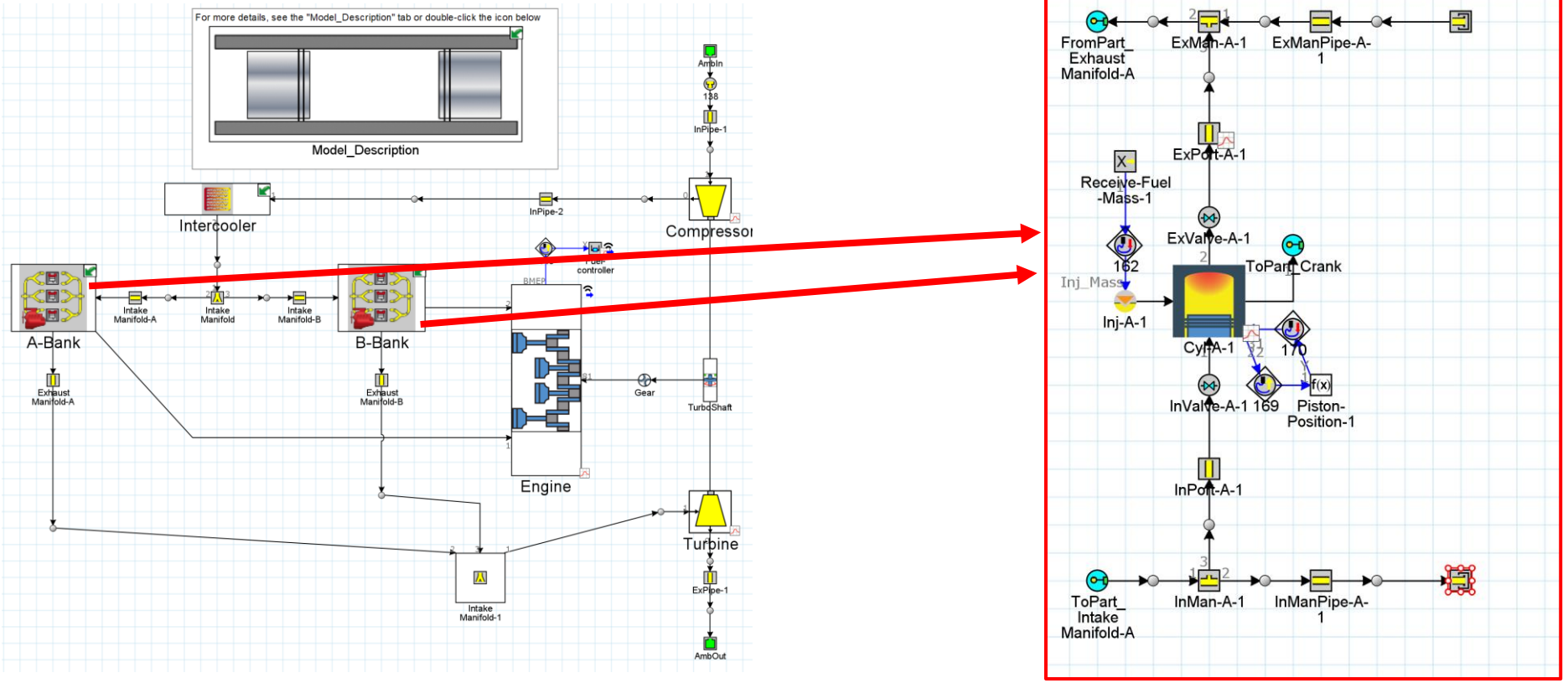
- The current model only includes A and B Banks, and each bank only has one opposed cylinder. This model is used as a baseline engine.



Deltic_CT18-42K_Opposed_Piston_Engine.gtm **in GT-Power example**

GT-Power model of 2-stroke, 2-cylinder diesel opposed piston engine, baseline BMEP= 5.5 bar, @1400 rpm

The current model only includes A and B Banks, and each bank only has one opposed cylinder. This model is used as a baseline engine.



Folder: Deltic_CT18-42k_Opposed_Piston_Engine
Deltic_CT18-42K_Opposed_Piston_Engine_Baseline.gtm

Parameters setup, 2-stroke, 2-cylinder diesel opposed piston engine, baseline BMEP= 5.5 bar, @1400 rpm

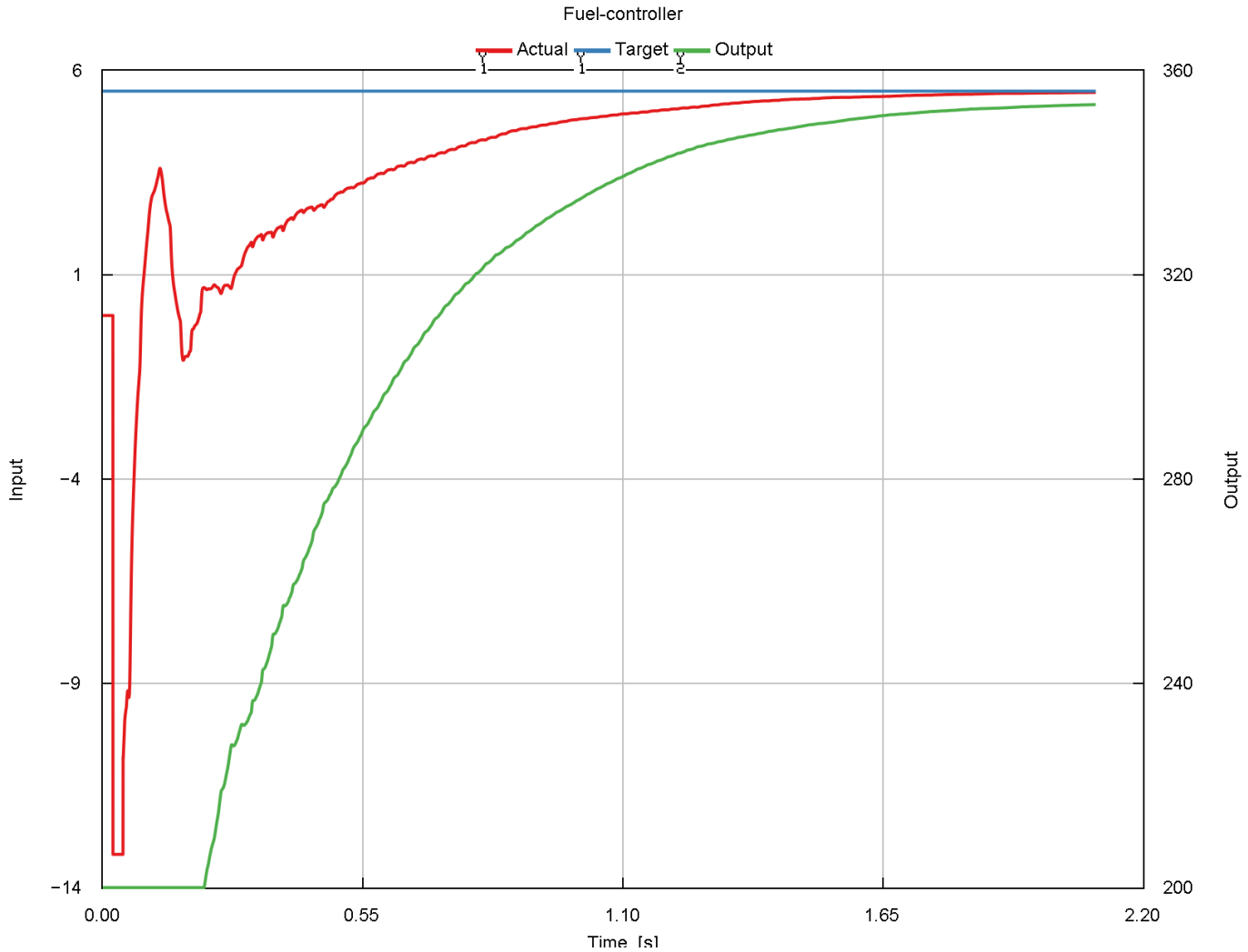
Engine parameters

Case Label		Unique Text for Plot Legends	1400 rpm 5.5 ...
Ambient-Pres	bar	Ambient Pressure	1
Ambient-Temp	K	Ambient Temperature	298
rpm	RPM	Engine Speed	1400
cycle-start		Start of Cycle (CA at IVC)	-105
dx-exh	mm	Exhaust Discretization Length	71
dx-int	mm	Intake Discretization Length	52
fuel-mass	mg	Initial Fuel Mass Per Cycle	200
gear-ratio		Turbo Compounding Gear Ratio	5.16
TuCo-Mech-Eff	fraction	Turbo Compounding Mechanical Effi...	0.7
BMEP-target		Target BMEP	5.5
BSFC-measured			243

Opposed piston parameters

Case Label		Unique Text for Plot Legends	1400 rpm 5.5 ...
bore	in	Bore	5.124803
stroke-nominal	mm	Nominal Stroke	368.3
CR-nominal		Nominal Compression Ratio	17.9
l_Int	mm	Intake Piston Connecting Rod Length	376.5
l_Exh	mm	Exhaust Piston Connecting Rod Length	376.5
a_Int	mm	Intake Piston Crank Radius	92.075
a_Exh	mm	Exhaust Piston Crank Radius	92.075
Alpha	deg	Exhaust Piston Lead Angle	20

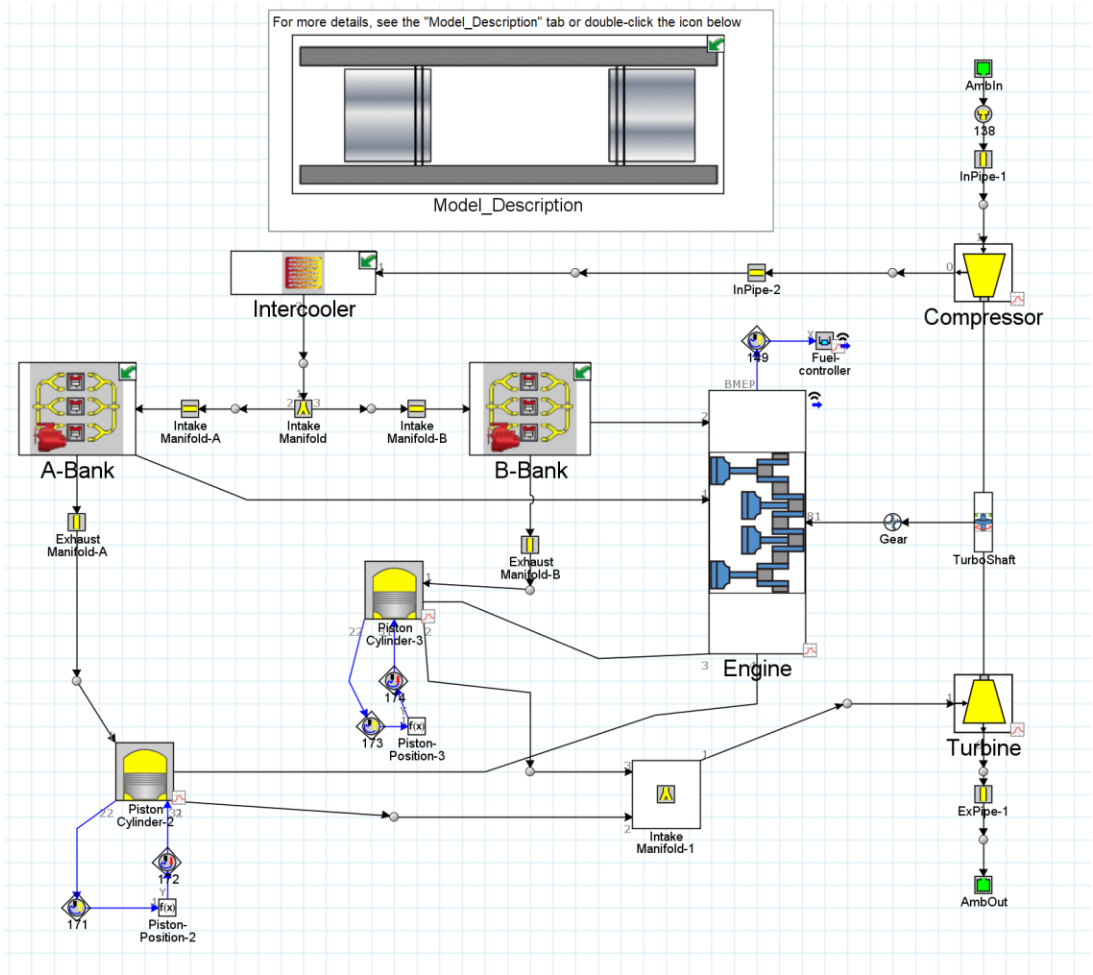
Results, 2-stroke, 2-cylinder diesel opposed piston engine, baseline
BMEP= 5.5 bar, @1400 rpm



Baseline bsfc [g/kW-h]	Baseline bp [kW]
474.6	125.1

GT-Power model of 2-stroke, 2-cylinder diesel opposed piston engine with opposed exhaust pistons
BMEP= 5.5 bar, @1400 rpm

- The current model is simplified from GT-Power example, Napier Deltic CT18-42K engine.
- The current model only includes A and B Banks, and each bank only has one opposed cylinder. This model is used as a baseline engine.
- Opposed exhaust pistons are connected to each bank to improve BSFC and BP.



Folder: Deltic_CT18-42k_Opposed_Piston_Engıne
Deltic_CT18-42K_Opposed_Piston_Engine_ExtraPiston.gtm

Parameters setup, 2-stroke, 2-cylinder diesel opposed piston engine with opposed exhaust pistons
BMEP= 5.5 bar, @1400 rpm

Engine parameters

Case Label		Unique Text for Plot Legends	1400 rpm 5.5 ...
Ambient-Pres	bar	Ambient Pressure	1
Ambient-Temp	K	Ambient Temperature	298
rpm	RPM	Engine Speed	1400
cycle-start		Start of Cycle (CA at IVC)	-105
dx-exh	mm	Exhaust Discretization Length	71
dx-int	mm	Intake Discretization Length	52
fuel-mass	mg	Initial Fuel Mass Per Cycle	200
gear-ratio		Turbo Compounding Gear Ratio	5.16
TuCo-Mech-Eff	fraction	Turbo Compounding Mechanical Effi...	0.7
BMEP-target		Target BMEP	5.5
BSFC-measured			243

Opposed piston's parameters

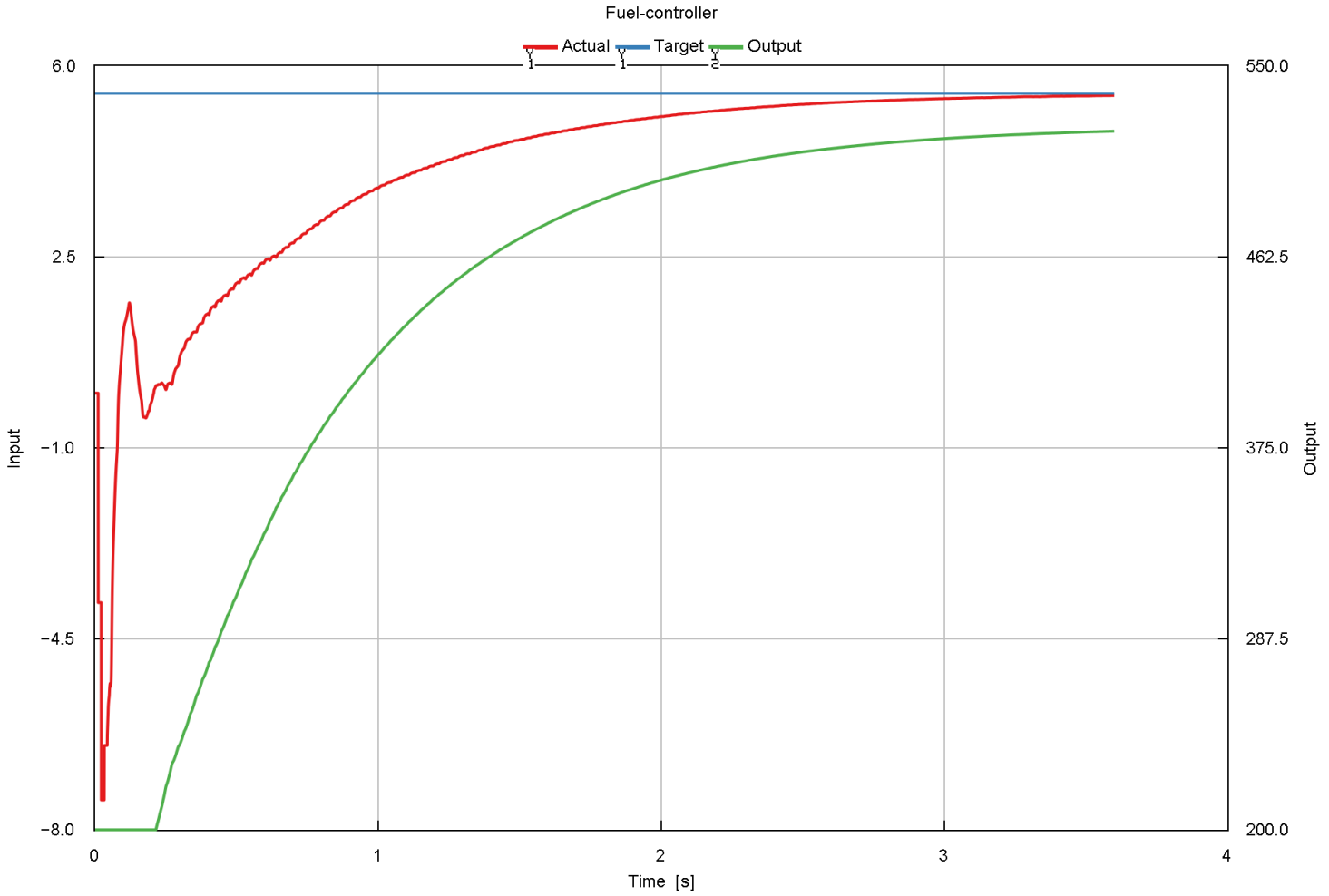
Case Label		Unique Text for Plot Legends	1400 rpm 5.5 ...
bore	in	Bore	5.124803
stroke-nominal	mm	Nominal Stroke	368.3
CR-nominal		Nominal Compression Ratio	17.9
l_Int	mm	Intake Piston Connecting Rod Length	376.5
l_Exh	mm	Exhaust Piston Connecting Rod Length	376.5
a_Int	mm	Intake Piston Crank Radius	92.075
a_Exh	mm	Exhaust Piston Crank Radius	92.075
Alpha	deg	Exhaust Piston Lead Angle	20

Opposed exhaust piston's parameters

a_Exh1		Exhaust Piston Crank Radius	50
a_Int1		Intake Piston Crank Radius	50
Alpha1		Exhaust Piston Lead Angle	20
l_Exh1		Exhaust Piston Connecting Rod Length	200
l_Int1		Intake Piston Connecting Rod Length	200
stroke-nominal1	mm	Nominal Stroke	600
bore1	mm	Bore	100

Results, 2 stroke, 2-cylinder diesel opposed piston engine with opposed exhaust pistons

BMEP= 5.5 bar, @1400 rpm



Baseline bsfc [g/kW-h]	Baseline bp [kW]
474.6	125.1
With exh pistons bsfc [g/kW-h]	**With exh pistons bp [kW]**
356.8	244.9
-24.8%	+95.8%

Disclaimer:
These results are very good, but they need to be verified.

31ST OCTOBER, 2023

JIA SUN

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