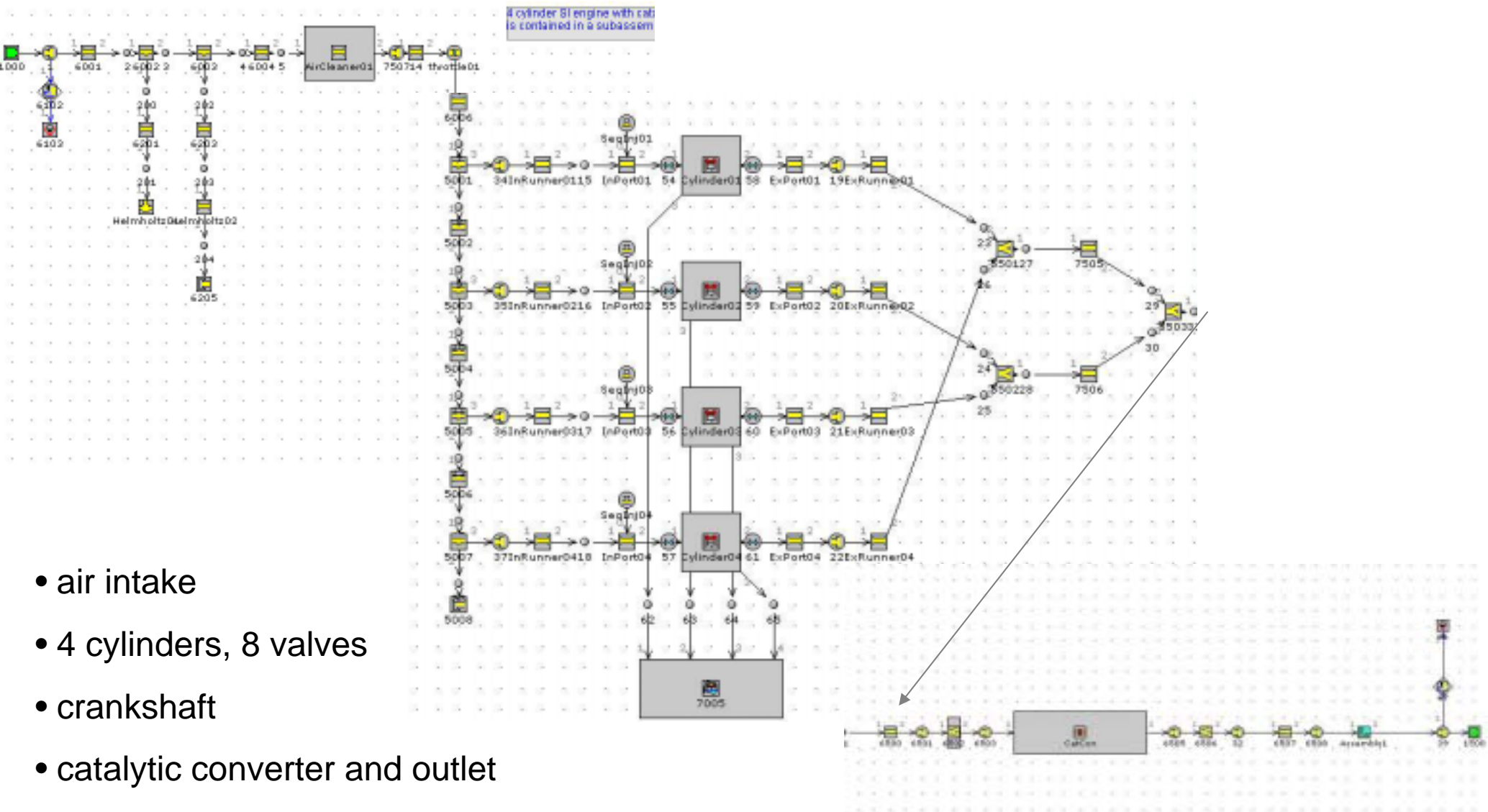




# Calibration of a 4-cyl engine model

Integration of modeFRONTIER with  
GTPower

- **Model definition (GTPower)**
- **Optimisation workflow (modeFRONTIER)**
- **Analysis of results**





- 4-stroke 4 cylinder 2.2L
- Bore: 93mm; stroke: 81mm; compression ratio: 8.9
- 2 valves per cylinder
- Port injection
- Combustion: Wiebe function (with spark trimming simulated by the 50% burn point parameter)
- In-cylinder heat transfer modeled by Woschni model



	Variable name	description	min	max
1	Tport	Intake port temperature [K]	300	500
2	Rlenght	Runners lenght [mm]	300	800
3	HrunM	Runners heat transfer multiplier	0.2	2
4	Hplenum	Plenum heat transfer multiplier	0.2	2
5	Elash	Exhaust valve lash [mm]	0.1	0.5
6	Etiming	Exhaust valve timing [ ° ]	100	150
7	Ilash	Intake valve lash [mm]	0.1	0.5
8	Itiming	Intake valve timing [ ° ]	200	260
9	Xmap	Scaling factor of Pressures ratio for lift-losses map	0.1	1.8
10	Ymap	Scaling factor of Lift for lift-losses map	1.2	2
11	Zmap	Scaling factor of Losses coefficients for lift-losses map	0.1	2



The screenshot shows the modeFRONTIER software interface. At the top, a GTPower model is visible with various components like pumps, valves, and an air cleaner. Below the model, the 'Edit Part: InPort01' dialog box is open. This dialog box contains a 'Template' dropdown set to 'Pipe', a 'Part' dropdown set to 'InPort01', and an 'Object' dropdown set to 'InPort'. There is an 'Edit Object' button. Below these fields is a table with parameters for the 'InPort' object.

Attribute	Unit	Object Value	Part Override
Diameter at Inlet End	mm	35	
Diameter at Outlet End	mm	35	
Length	mm	110	
Discretization Length	mm	[dxi]	
Surface Roughness	mm	0.25	
Wall Temperature	K	[Tport]	
Heat Conduction Object		ign	
Initial State Name		init	

Each parameter is defined indicating the variable name between [ ] in the definition of each part of the model



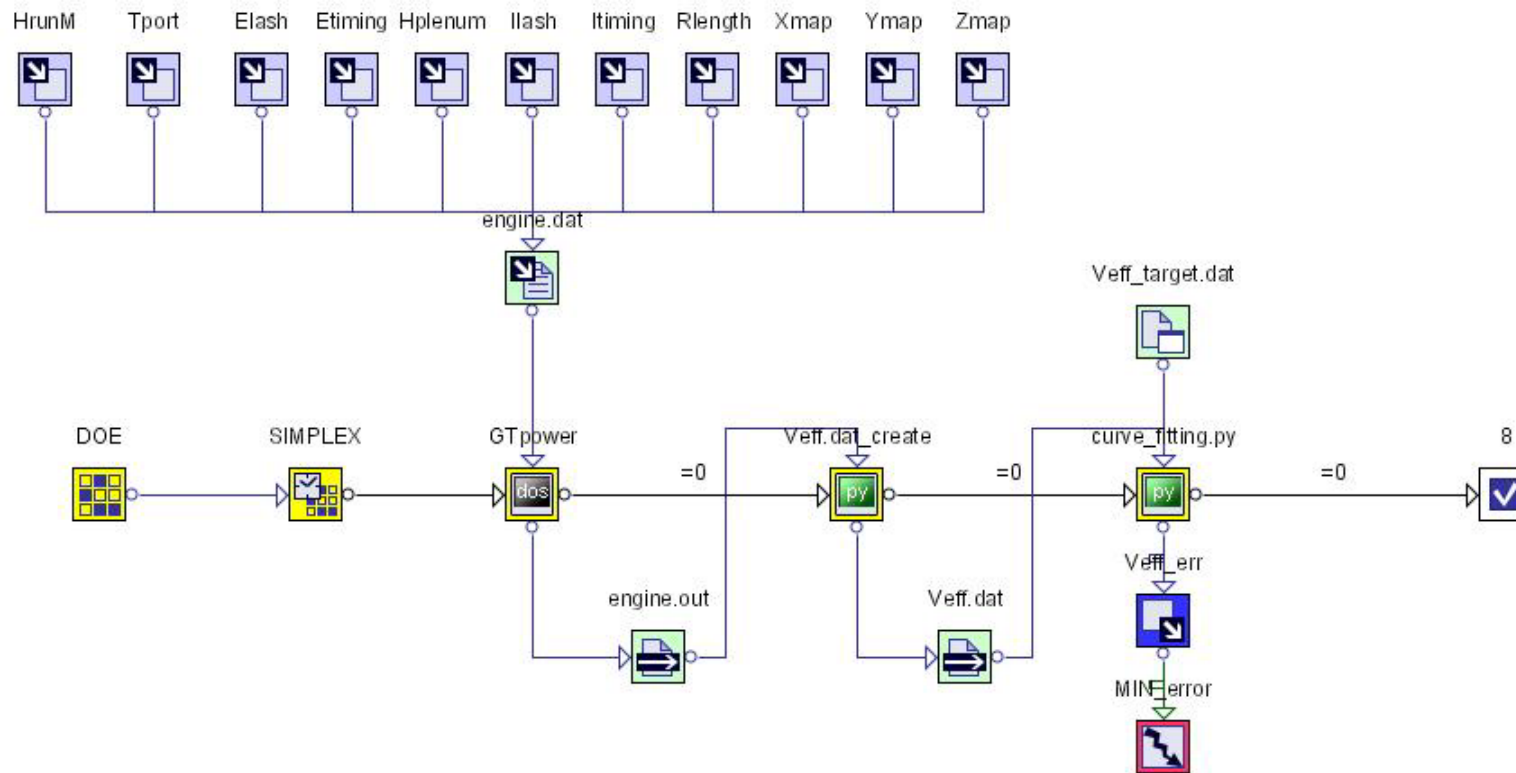
Parameter	Unit	Label	1 (on)	2 (on)	3 (on)	4 (on)	5 (on)
BDURINIT		SMWebe burn duration	16	16	16	16	16
DXE	mm	Discretization length exhaust	51	51	51	51	51
DXI	mm	Discretization length intake	37	37	37	37	37
ELASH	mm	Exhaust valve lash	0.3	0.3	0.3	0.3	0.3
ETIMING	Cam Angle	Exhaust Valve Timing	126	126	126	126	126
EXHINITP	bar	Initial exhaust pressure	1.22	1.22	1.22	1.22	1.22
EXHINITT	K	Initial exhaust temperature	1120	1120	1120	1120	1120
EXHTWALL	K	Initial exhaust wall temperatur...	1000	1000	1000	1000	1000
HPLENM		Heat Transfer Plenum Multip...	1	1	1	1	1
HRUNM		Runners Heat Transfer Multi...	1	1	1	1	1
HTMULT		Heat transfer multiplier used...	1	1	1	1	1
ILASH	mm	Intake valve lash	0.2	0.2	0.2	0.2	0.2
ITIMING	Cam Angle	Intake Valve Timing	239	239	239	239	239
MUFFINITP	bar	Muffler initial pressure	1.1	1.1	1.1	1.1	1.1
MUFFINITT	K	Muffler initial temperature	600	600	600	600	600
MUFTWALL	K	Muffler wall temperature	525	525	525	525	525
NCYC		Simulation duration	40	40	40	40	40
RLENGTH	mm	Runners lenght	500	500	500	500	500
RPM	RPM	Engine Speed	5500	5000	4500	4000	3500
THB50INIT		SMWebe anchor angle	10	10	10	10	10
THROTANG		Throttle angle	90	90	90	90	90

- The starting values of each parameter are defined by the CASE SETUP menu
- The engine speed is defined for 10 different rpm conditions
- All data are written by GTPower in **engine.dat** that becomes the modeFRONTIER input file



- The purpose is to **set the 11 model parameters** in order to **minimise the simulation error** with respect to the **experimental data** (relatively to volume efficiency vs rpm chart)
- For this goal, we use modeFRONTIER to define an **optimisation** case with **minimisation of volume efficiency error** as objective





### Design parameters

#### Input variables

11 parameters

#### Output variables

Volume efficiency error

### Design goals

Minimize Veff error

#### Sampling phase:

Random Doe – nr initial individuals: 12

#### Exploration phase:

SIMPLEX initial phase – NLPQLP refinement



The screenshot displays the modeFRONTIER interface. On the left, a workflow diagram shows a sequence of steps: 'SIMPLEX' (represented by a yellow box with a checkmark) followed by 'GTpower' (represented by a yellow box with a 'dos' icon). An arrow points from 'SIMPLEX' to 'GTpower'. Above 'GTpower', there is a box labeled 'engine.dat' with a document icon, and an arrow points from it to 'GTpower'. Below 'GTpower', an arrow points to a box labeled 'ei'. On the right, a text editor shows the contents of the 'engine.dat' file, which is a list of input parameters for a simulation. The parameters are listed with their units, default values, user values, and labels. Some parameters are highlighted in red, indicating they are user-defined variables. An orange arrow points from the 'engine.dat' box in the workflow to the corresponding line in the text editor.

```
893 BDURINIT=16 unitDef=0 unitUser=0 label="SIWebe burn duration"
894 DXE=51 unitDef=3 unitUser=3 label="Discretization length exhaust
895 DXI=37 unitDef=3 unitUser=3 label="Discretization length intake"
896 ELASH=<VAR name="Elash" format="0.00000"/> unitDef=3 unitUser=3
897 ETIMING=<VAR name="Etiming" format="0.00000"/> unitDef=179 unitU
898 EXHINITP=1.22 unitDef=25 unitUser=25 label="Initial exhaust pres
899 EXHINITT=1120 unitDef=32 unitUser=32 label="Initial exhaust temp
900 EXHTWALL=1000 unitDef=32 unitUser=32 label="Initial exhaust wall
901 HPLENM=<VAR name="Hplenum" format="0.00000"/> unitDef=0 unitUser
902 HRUNM=<VAR name="HrunM" format="0.00000"/> unitDef=0 unitUser=0
903 HTMULT=1 unitDef=0 unitUser=0 label="Heat transfer multiplier us
904 ILASH=<VAR name="Ilash" format="0.00000"/> unitDef=3 unitUser=3
905 ITIMING=<VAR name="Itiming" format="0.00000"/> unitDef=179 unitU
906 MUFFINITP=1.1 unitDef=25 unitUser=25 label="Muffler initial pres
907 MUFFINITT=600 unitDef=32 unitUser=32 label="Muffler initial temp
908 MUFTWALL=525 unitDef=32 unitUser=32 label="Muffler wall temperat
909 NCYC=40 unitDef=0 unitUser=0 label="Simulation duration"
910 RLENGTH=<VAR name="Rlength" format="0.00000"/> unitDef=3 unitUse
911 RPM=5000 unitDef=139 unitUser=139 label="Engine Speed"
912 THB50INIT=10 unitDef=0 unitUser=0 label="SIWebe anchor angle"
913 THROTANG=90 unitDef=0 unitUser=0 label="Throttle angle"
914 TPORT=<VAR name="Tport" format="0.00000"/> unitDef=32 unitUser=3
```

Row: 1 Co Len: 6749

		Name	Occurences
0	<input checked="" type="checkbox"/>	Tport	10
1	<input checked="" type="checkbox"/>	HrunM	10
2	<input checked="" type="checkbox"/>	Elash	10
3	<input checked="" type="checkbox"/>	Etiming	10

put Variables Output Variables

Each input parameters is indicated by modeFRONTIER inside **engine.dat** file with correspondent format



```
gtpower engine.dat
```

```
exit 0
```

This very simple UNIX command is used to run the GTPower model reading the parameters modified by modeFRONTIER



```
from java.lang import String as string
f = []
infile_name = CWD + '\\engine.out'
outfile_name = CWD + '\\Veff.dat'
keyword = "VOLEF(tot)  VOLEF(man)"
find = string.indexOf
infile= open(infile_name,'r')
while 1:
    line = infile.readline()
    if not line:
        break
    if find(line, keyword) <> -1:
        line = infile.readline()
        s = line.split()
        f.append(float(s[1]))
infile.close()
outfile=open(outfile_name,'w')
for i in range(len(f)):
    print f[i]
    outfile.write("%s\\n" % f[i])
outfile.close()
```

In engine.out GTPower output file, the data relative to Volumetric efficiency are found and reported in Veff.dat file



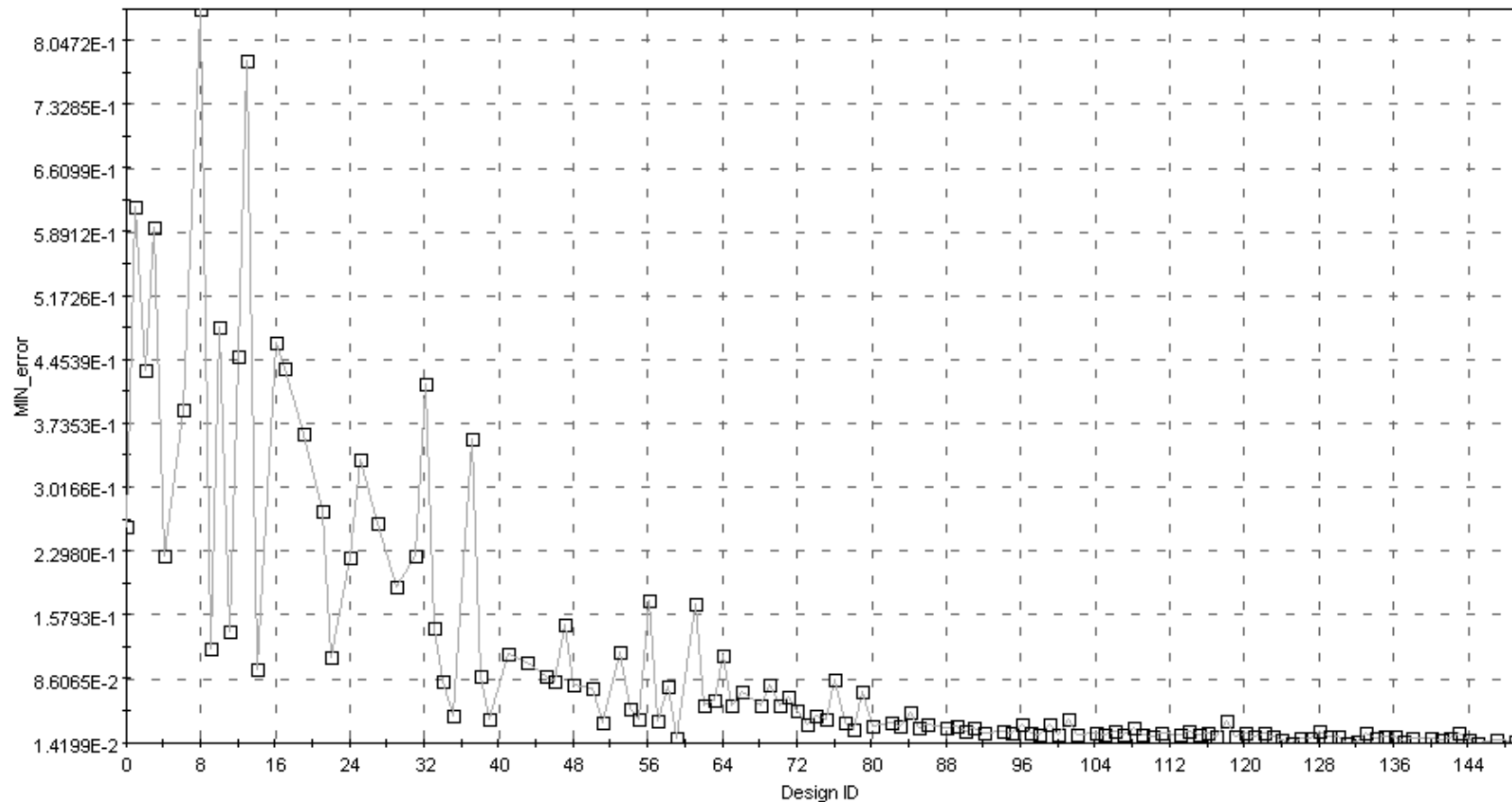
```
f = []
ft = []
target_file = CWD + '¥¥Veff_target.dat'
real_file = CWD + '¥¥Veff.dat'
# load TARGET data: one column file
infile = open(target_file,'r')
while infile:
    line = infile.readline()
    s = line.split()
    n = len(s)
    if n == 0:
        break
    ft.append(float(s[0]))
infile.close()
# load REAL data: one column file
infile = open(real_file,'r')
while infile:
    line = infile.readline()
    s = line.split()
    n = len(s)
    if n == 0:
        break
    f.append(float(s[0]))
infile.close()
```

```
# calculate absolute difference
d = []
dr = []
for i in range(len(ft)):
    d.append(abs(f[i]-ft[i]))
    dr.append(abs((f[i]-ft[i])/ft[i]))
# numerical integration: trapezoidal rule
integral = 0.0
for i in range(len(d)-1):
    integral = integral+(d[i]+d[i+1])/2.0
integral = integral/(len(d)-1)
print integral
outfile=open('error.dat','w')
outfile.write("%s¥n" % integral)
outfile.close()
```

The Volume efficiency data read in Veff.dat file are compared to the target data, and the mean relative error is written in error.dat file



History Chart - MIN\_error on Designs Table

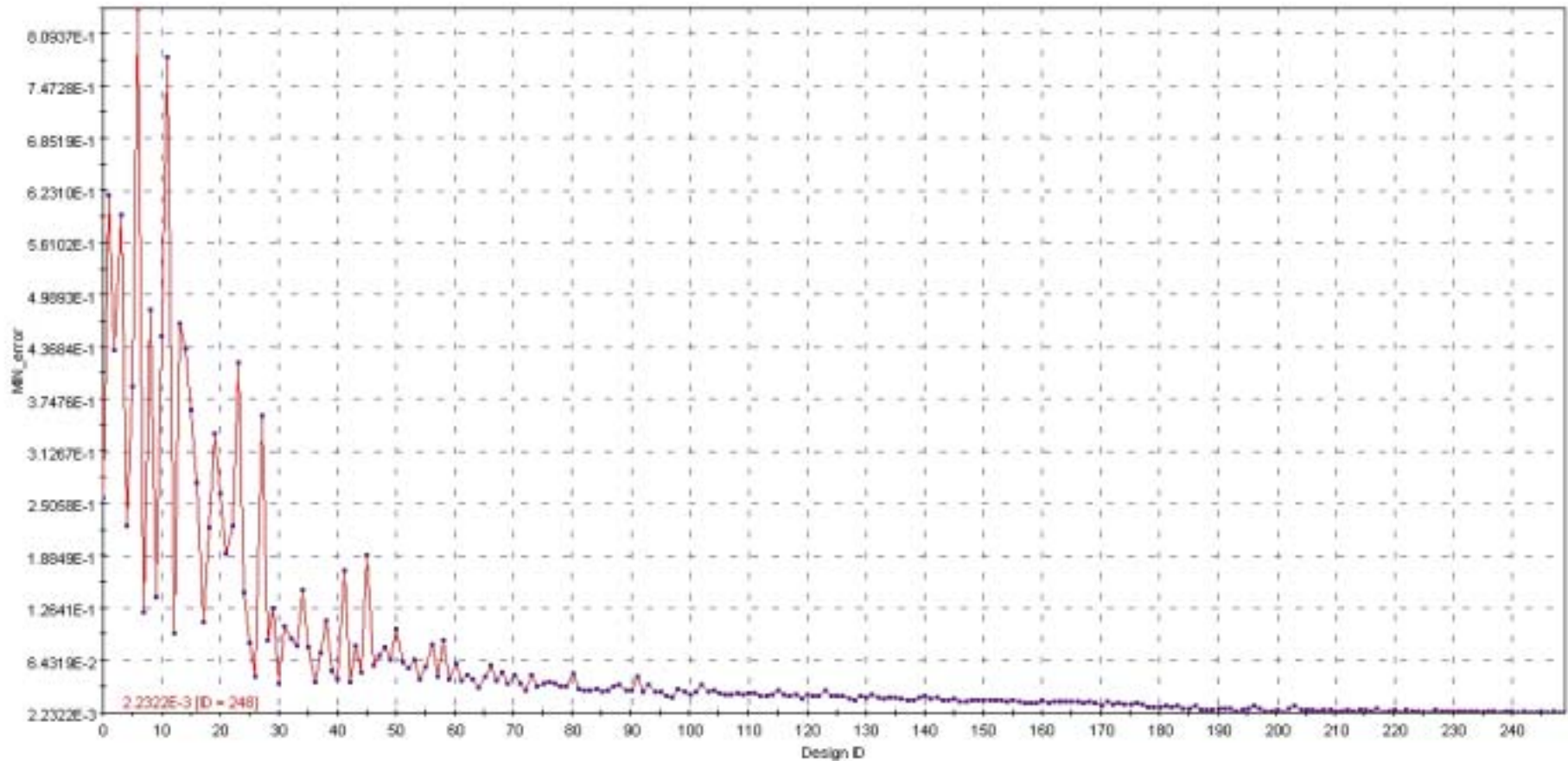


After 150 SIMPLEX iterations, the Veff error has been reduced from 30% to 1.4%

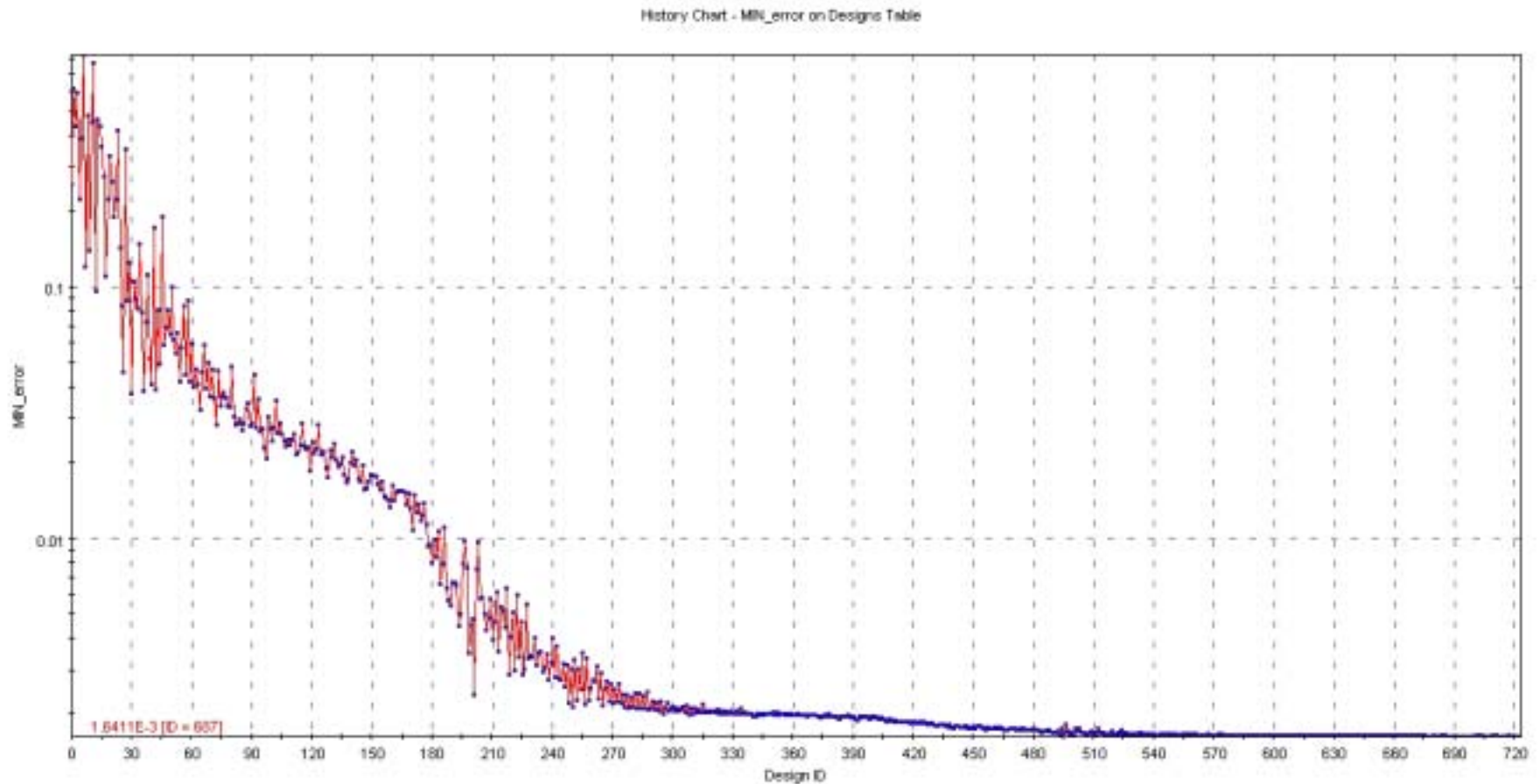




History Chart - MIN\_error on Designs Table



After a total of 250 SIMPLEX iterations, the Veff error has been reduced to 0.23%



And after a total of 750 SIMPLEX iterations, the Veff error has been reduced to 0.16%



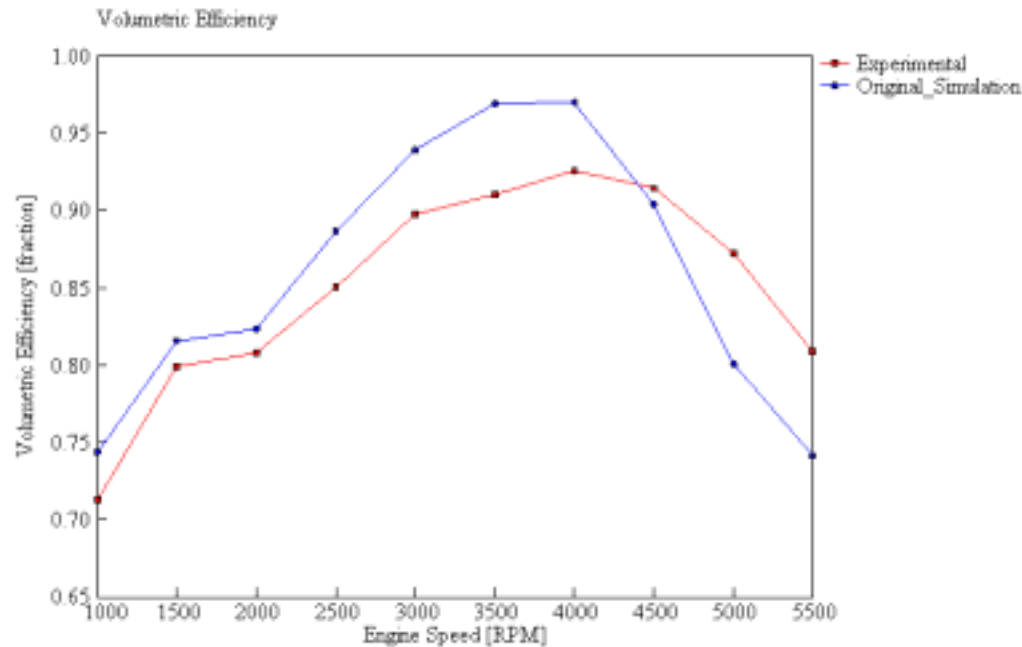


comparison between target data and simulation (Veff vs RPM)

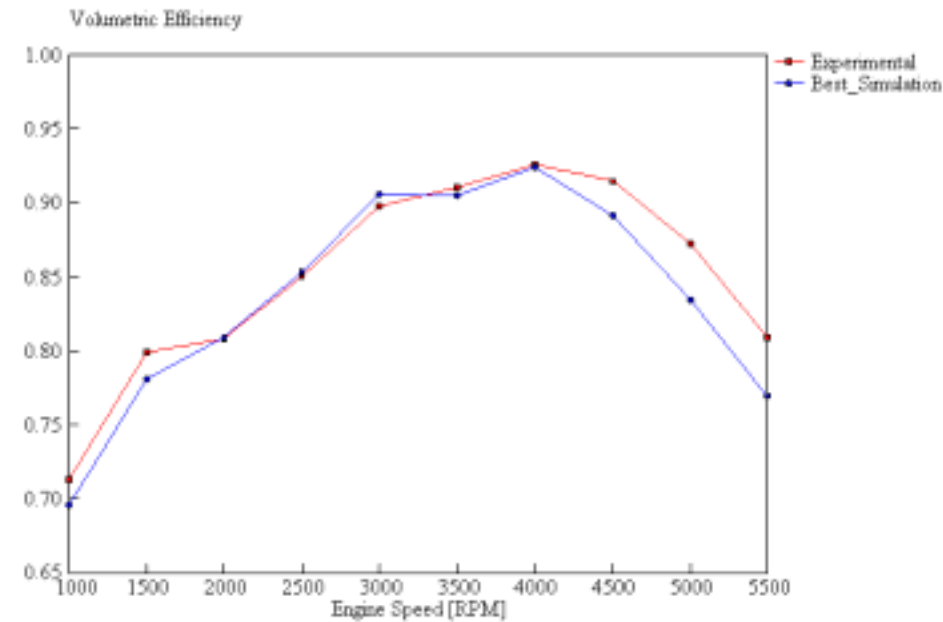
4 Cylinder Engine

NeoGa

GT-SUITE v6.0 05-JUL-05 12:46:54



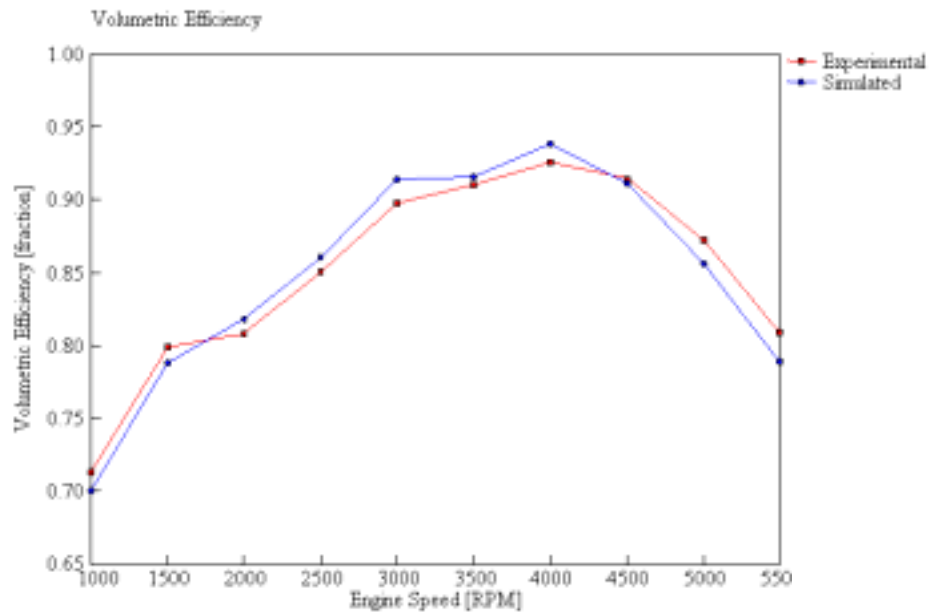
Initial guess: Mean error=30%



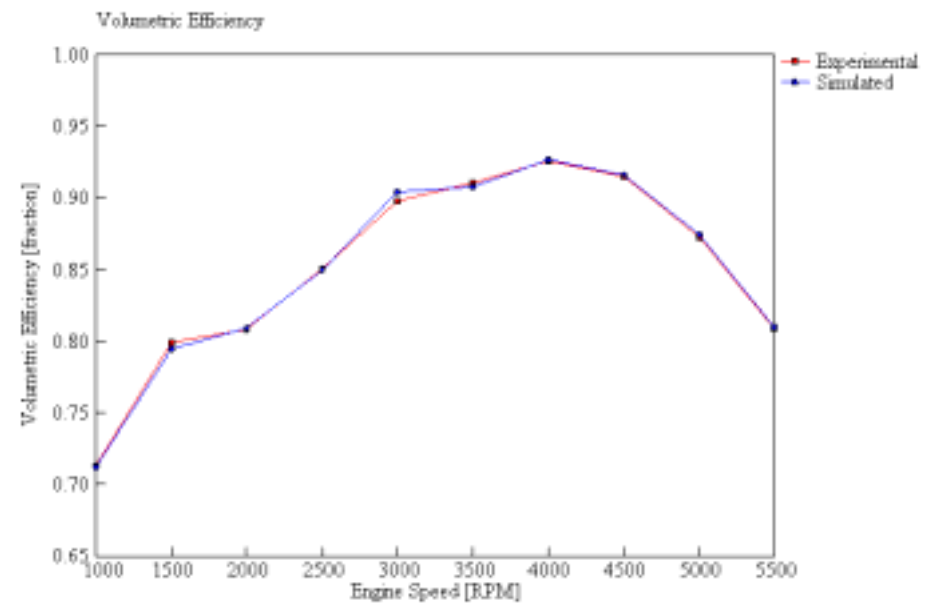
Optimised (150 run) : Mean error=1.42%



comparison between target data and simulation (Veff vs RPM)



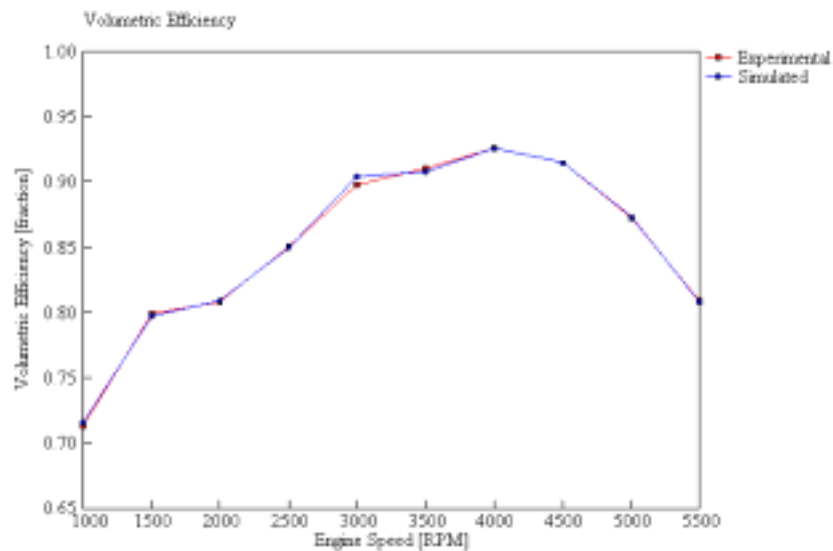
Optimised (200 run) : Mean error= 1.12%



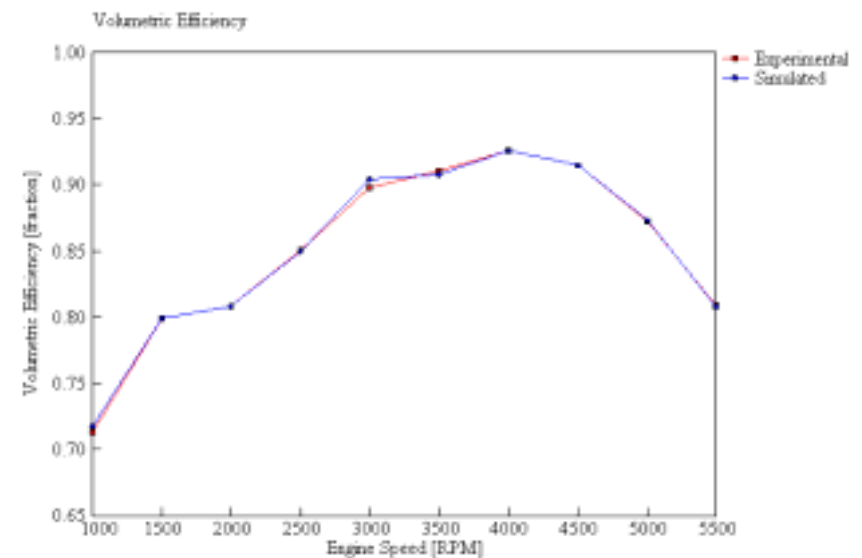
Optimised (250 run) : Mean error= 0.24%



comparison between target data and simulation (Veff vs RPM)



Optimised (500 run) : Mean error= 0.18%



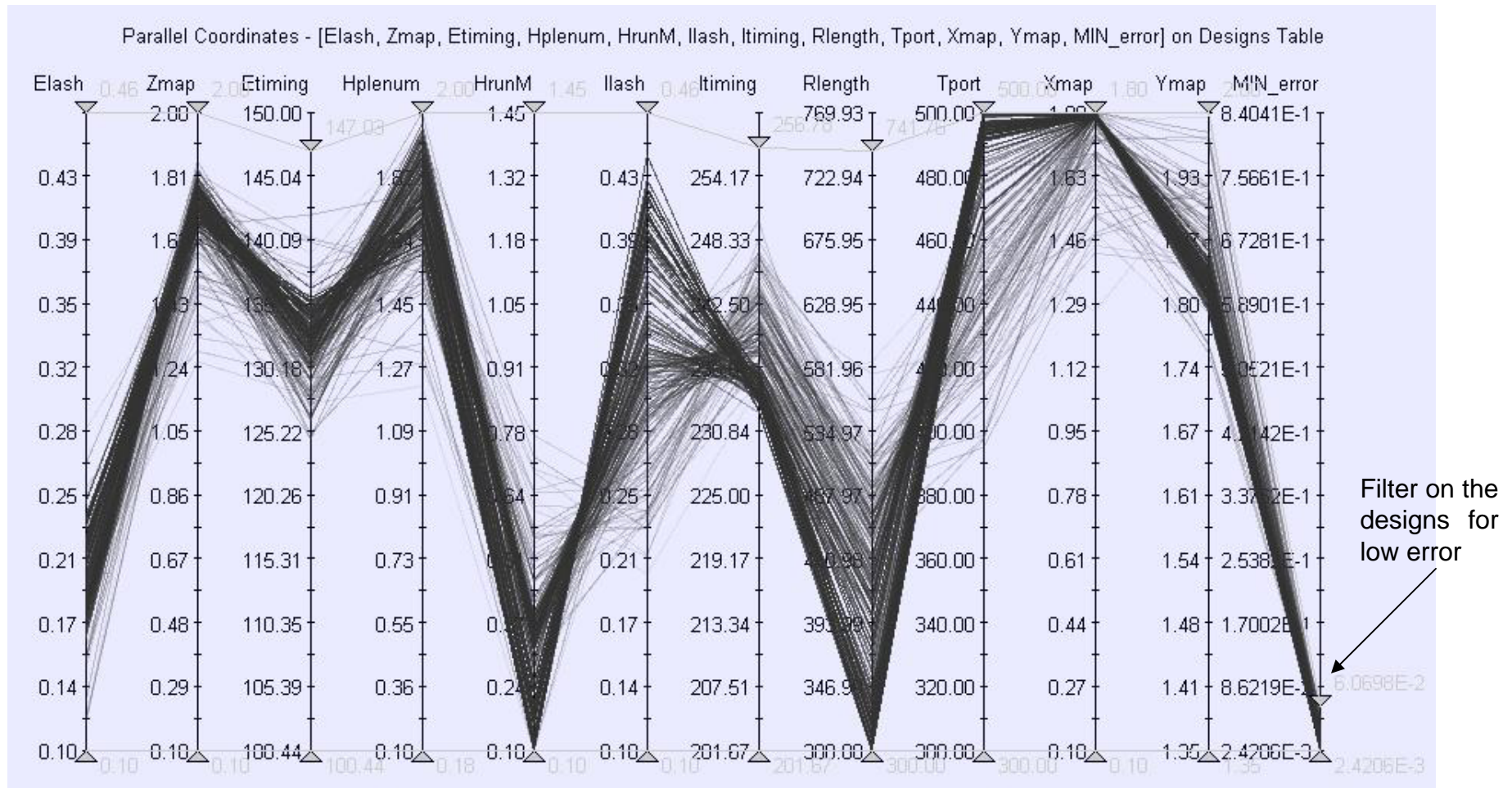
Optimised (750 run) : Mean error= 0.16%



A positive number reveals a direct correlation, a negative reveals an inverse correlation, 0 indicates that the variables are not correlated

	Elash	Zmap	Etiming	Hplenum	HrunM	lflash	ltiming	Rlength	Tport	Xmap	Ymap	MIN_error
Elash	1.00	-0.49	-0.30	-0.69	0.21	0.22	-0.41	0.11	-0.35	-0.54	-0.40	0.55
Zmap	-0.49	1.00	-0.04	0.66	-0.73	0.40	0.17	-0.47	0.72	0.65	0.29	-0.79
Etiming	-0.30	-0.04	1.00	-0.24	-0.15	-0.01	0.12	-0.05	0.06	0.02	0.34	-0.04
Hplenum	-0.69	0.66	-0.24	1.00	-0.26	0.17	0.01	-0.39	0.65	0.62	0.08	-0.62
HrunM	0.21	-0.73	-0.15	-0.26	1.00	-0.67	-0.19	0.65	-0.74	-0.64	-0.24	0.67
lflash	0.22	0.40	-0.01	0.17	-0.67	1.00	-0.46	-0.89	0.59	0.26	-0.24	-0.26
ltiming	-0.41	0.17	0.12	0.01	-0.19	-0.46	1.00	0.33	0.04	0.49	0.43	-0.42
Rlength	0.11	-0.47	-0.05	-0.39	0.65	-0.89	0.33	1.00	-0.63	-0.45	0.23	0.43
Tport	-0.35	0.72	0.06	0.65	-0.74	0.59	0.04	-0.63	1.00	0.73	0.00	-0.72
Xmap	-0.54	0.65	0.02	0.62	-0.64	0.26	0.49	-0.45	0.73	1.00	0.21	-0.87
Ymap	-0.40	0.29	0.34	0.08	-0.24	-0.24	0.43	0.23	0.00	0.21	1.00	-0.20
MIN_error	0.55	-0.79	-0.04	-0.62	0.67	-0.26	-0.42	0.43	-0.72	-0.87	-0.20	1.00

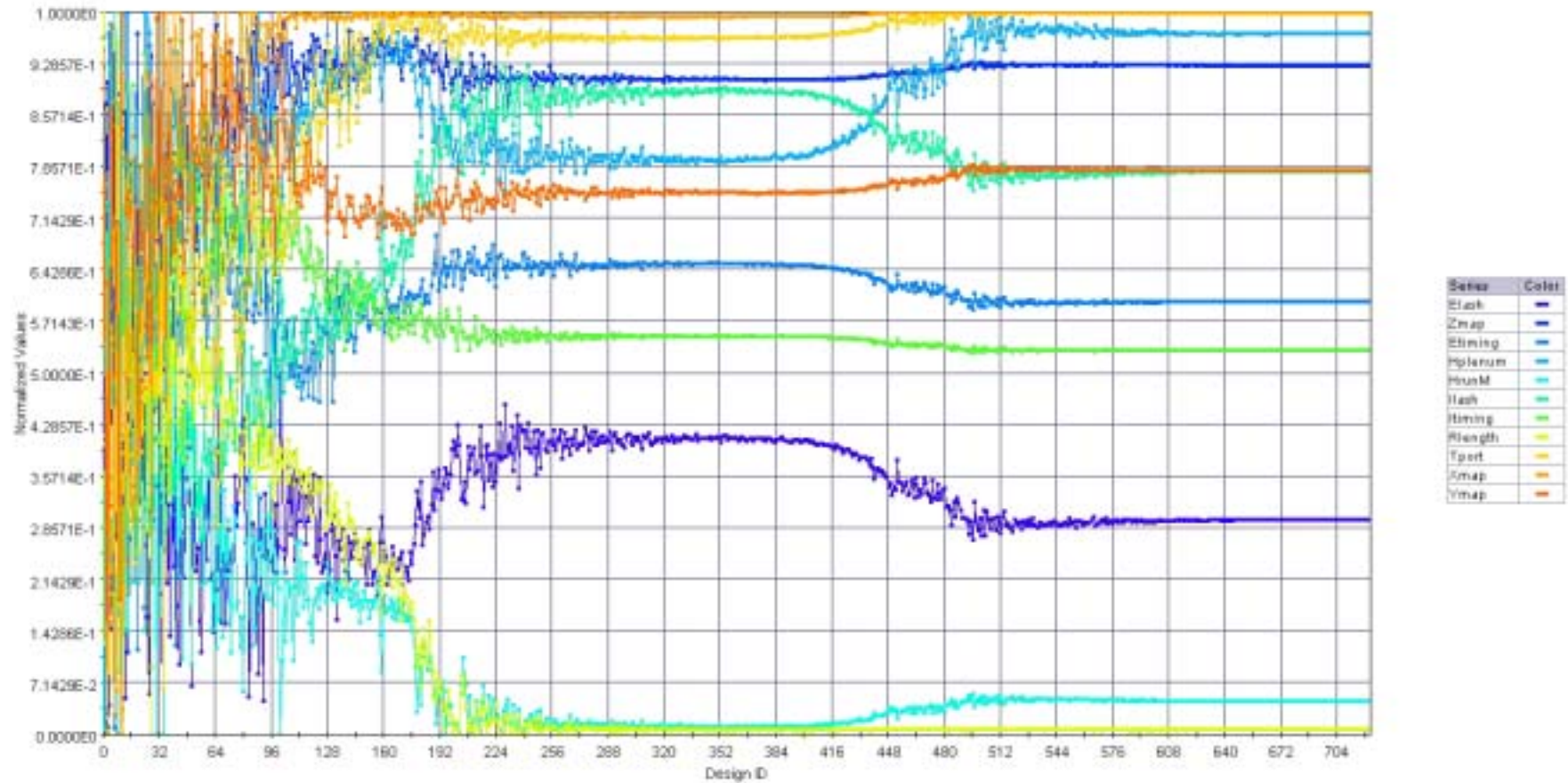
- 3 variables are **low** correlated with objective: Etiming, lflash, Ymap
- 5 variables are highly **inversely** correlated: Zmap, Hplenum, ltiming, Tport, Xmap
- 3 variables are highly **directly** correlated: Elash, HrunM, Rlength



To produce low value of error, most of designs have:

- **High** values for the variables: Zmap, Hplenum, Tport, Xmap
- **Low** values for the variables : Elash, HrunM, Rlenght







- modeFRONTIER has been used to set properly the parameters of a GTPower model, relative to a 4-cyl engine, in order to match the experimental data (inverse design)
- A Simplex optimisation strategy has allowed to reproduce the experimental Volume efficiency vs RPM chart with less than 0.2% of relative error
- Statistical analysis tools of modeFRONTIER has been used to find which are the most significant parameters for the calibration