Virtual Engine Calibration Optimization (VECO)

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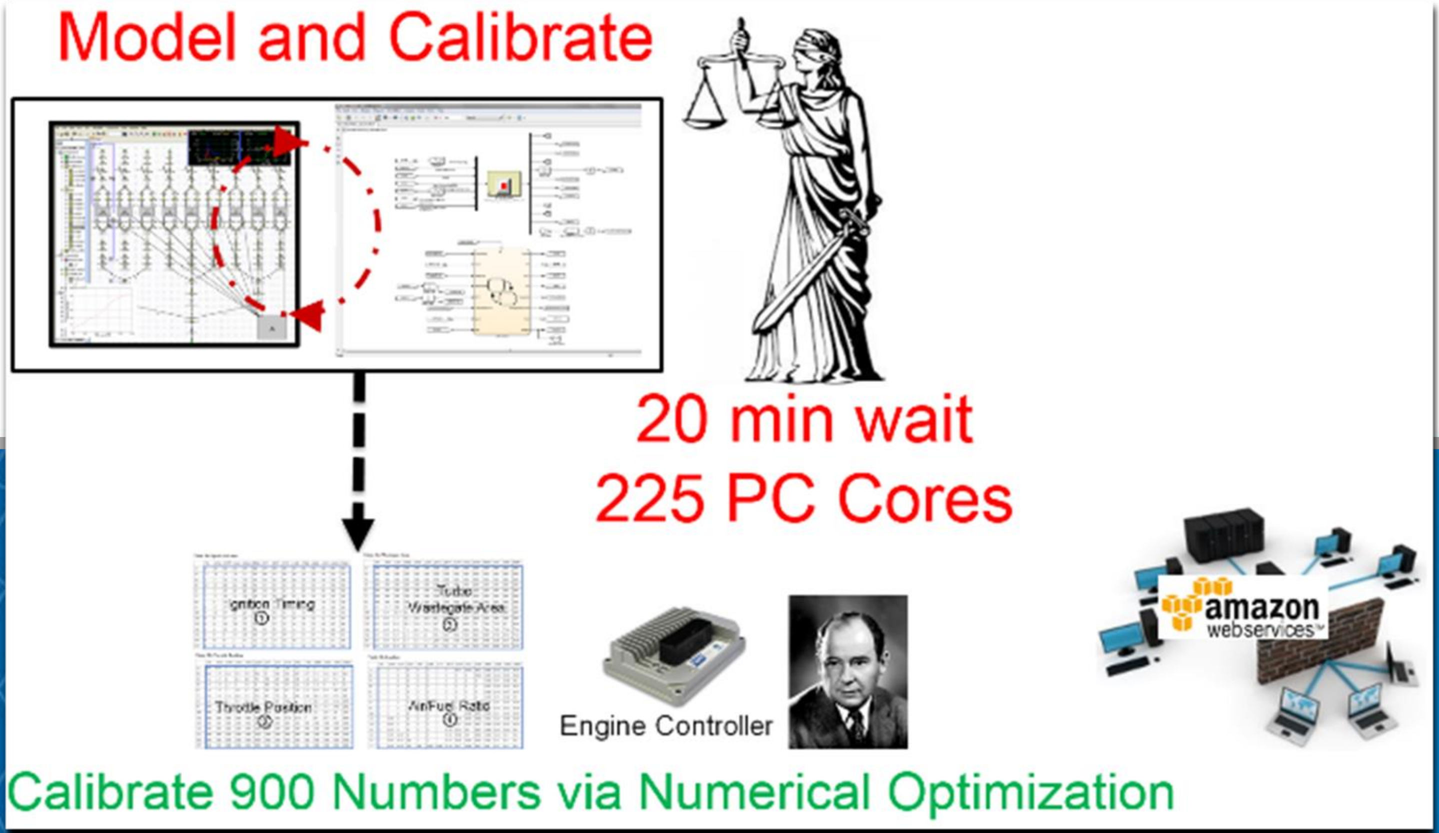
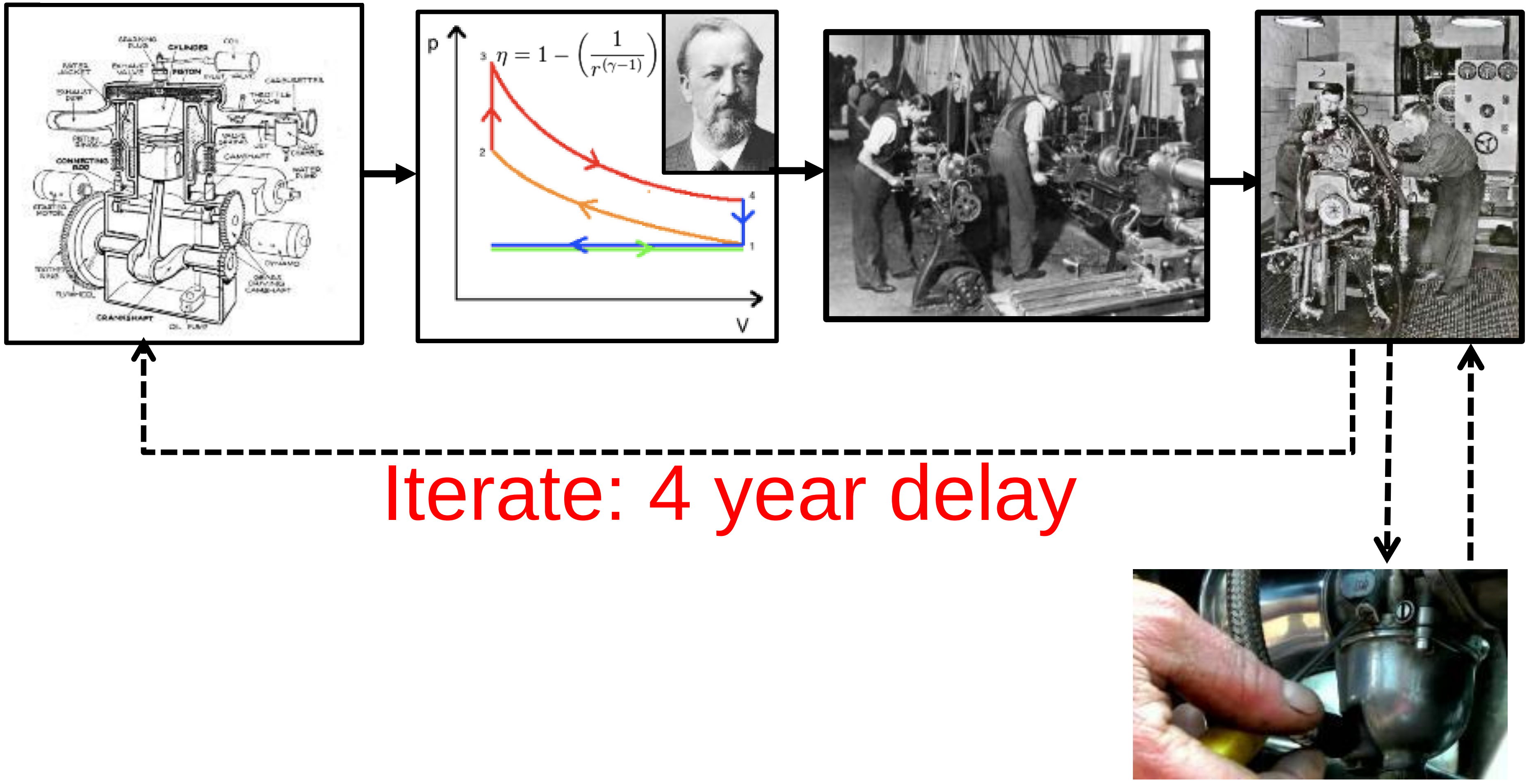


Outline

- Calibration After Engine Build Slows Design Iterations By 4 Years
- 4 Year Design Iteration Delay Can Be Removed With Parallel Computing

What Was Base Engine Calibration?



Model and Calibrate

Build

Test

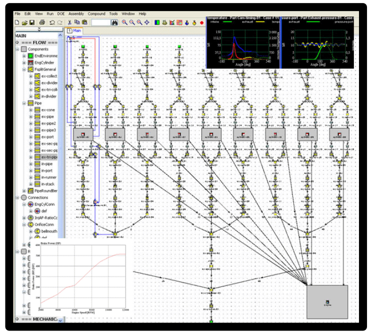
Iterate: 4 year delay

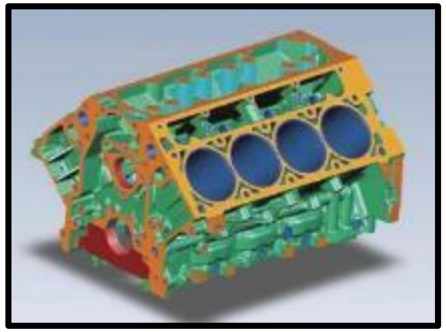
“Calibrate” By Adjusting A Few Screws

Engine’s Performance
Cannot Be Judged
Until It Is Calibrated

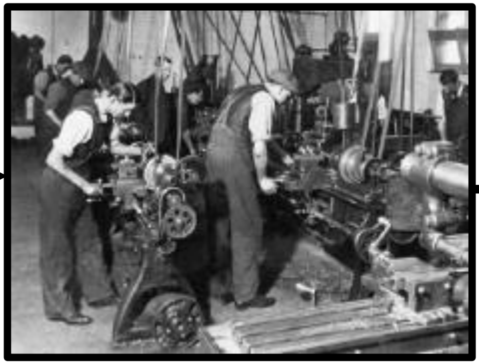
What Is Base Engine Calibration Now?

Model and Design





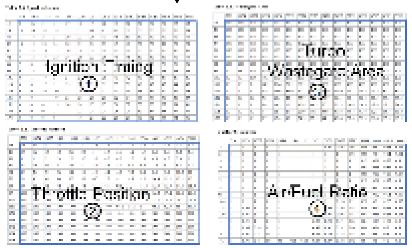
Build



Test

Iterate: 4 year delay

Engine's Performance Cannot Be Judged Until It Is Calibrated

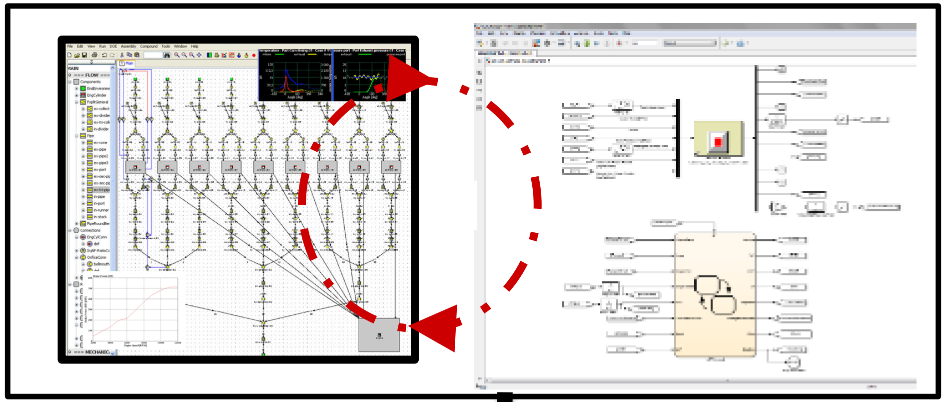


Engine Controller

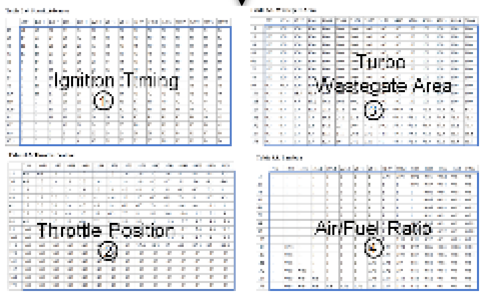
Calibrate By Adjusting 900 Numbers

How Do We Speed Up Engine Design?

Model and Calibrate



3 day wait
on 1 PC Core

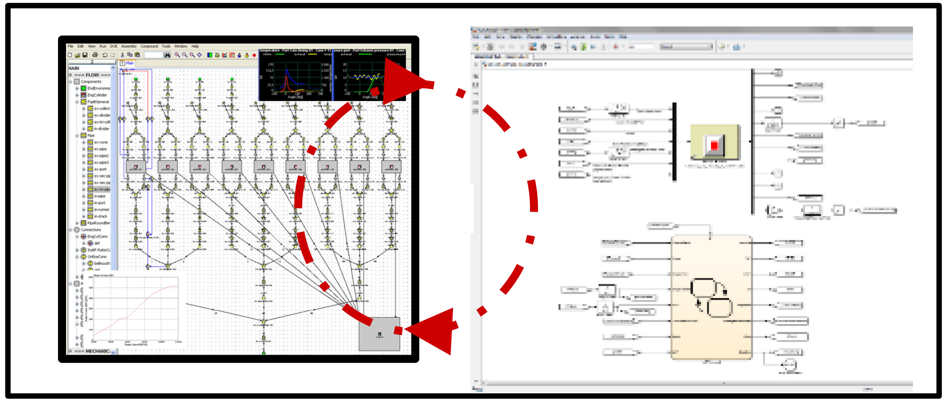


Engine Controller

Calibrate 900 Numbers via Numerical Optimization

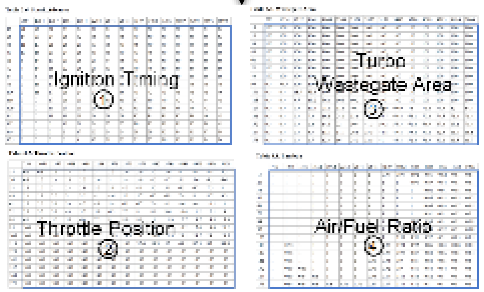
How Do We Speed Up Engine Design?

Model and Calibrate



20 min wait

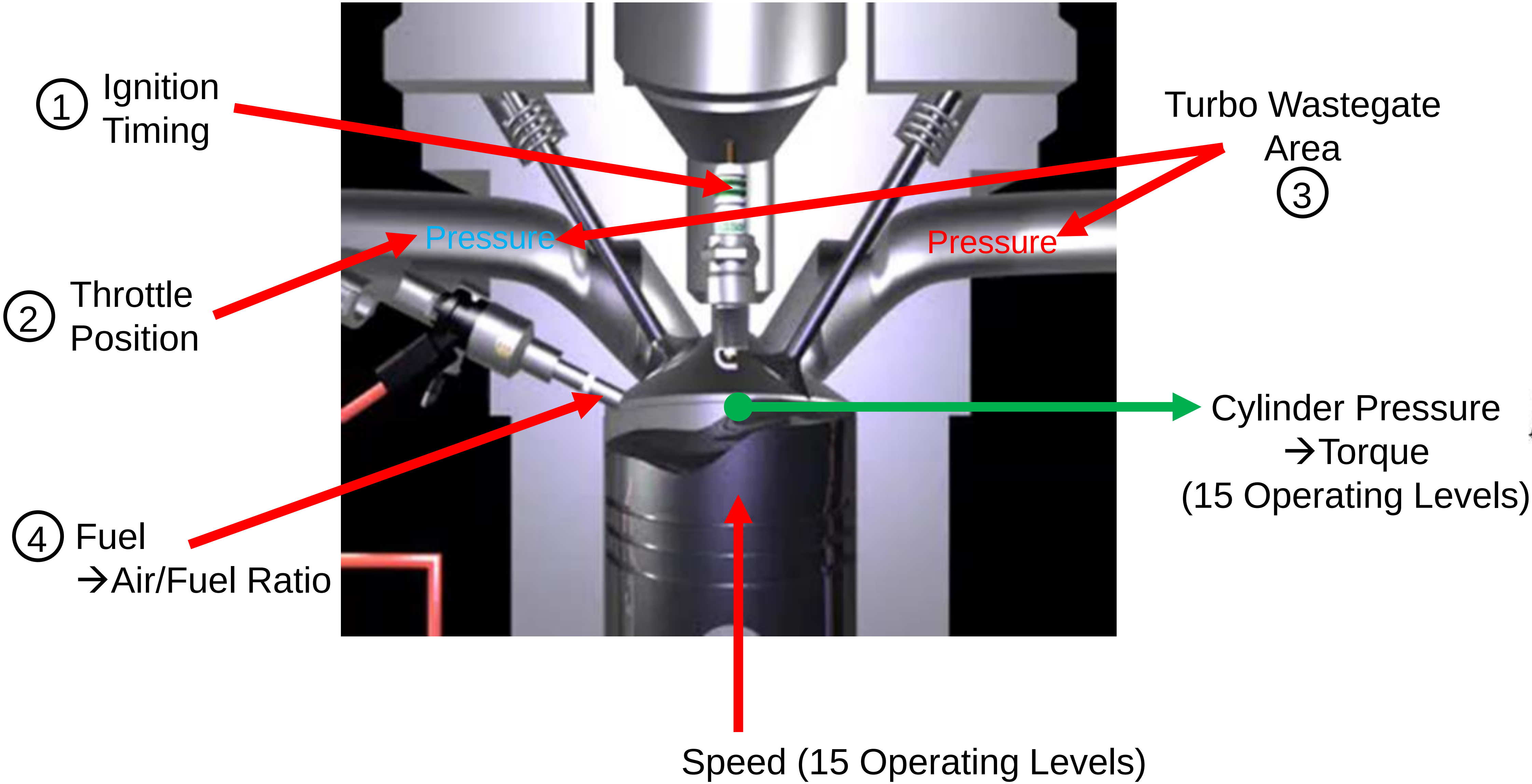
225 PC Cores



Engine Controller

Calibrate 900 Numbers via Numerical Optimization

Base Engine Calibration Problem Addressed by VECO



① Ignition Timing

② Throttle Position

④ Fuel
→Air/Fuel Ratio

Turbo Wastegate Area
③

Cylinder Pressure
→Torque
(15 Operating Levels)

Speed (15 Operating Levels)

Calibrations Produced By VECO Process

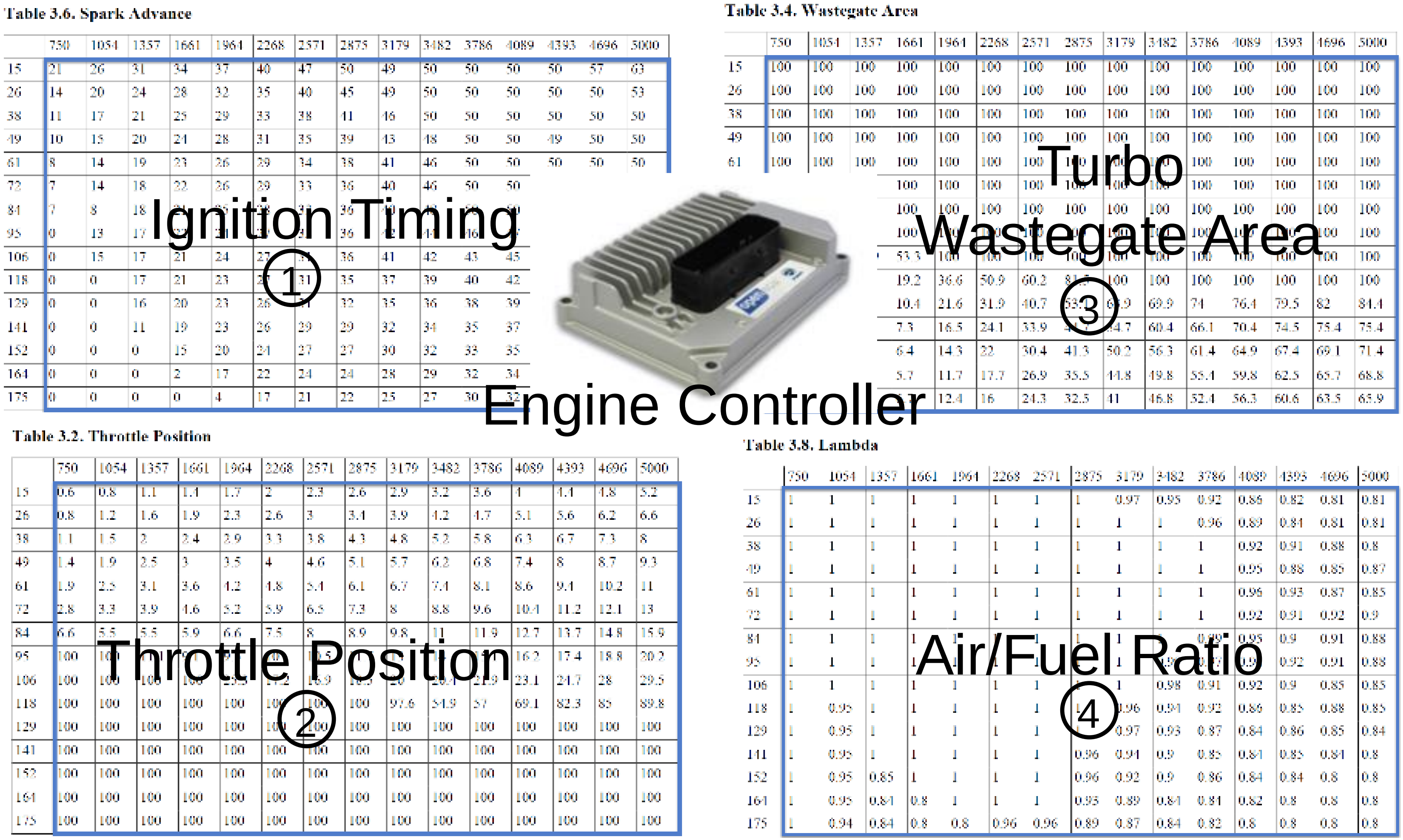


Table 3.6. Spark Advance

	750	1054	1357	1661	1964	2268	2571	2875	3179	3482	3786	4089	4393	4696	5000
15	21	26	31	34	37	40	47	50	49	50	50	50	50	57	63
26	14	20	24	28	32	35	40	45	49	50	50	50	50	50	53
38	11	17	21	25	29	33	38	41	46	50	50	50	50	50	50
49	10	15	20	24	28	31	35	39	43	48	50	50	49	50	50
61	8	14	19	23	26	29	34	38	41	46	50	50	50	50	50
72	7	14	18	22	26	29	33	36	40	46	50	50	[illegible]	[illegible]	[illegible]
84	7	8	18	[illegible]	[illegible]	[illegible]	[illegible]	36	40	[illegible]	[illegible]	50	[illegible]	[illegible]	[illegible]
95	0	13	17	[illegible]	[illegible]	[illegible]	[illegible]	36	[illegible]	41	46	[illegible]	[illegible]	[illegible]	[illegible]
106	0	15	17	21	24	27	[illegible]	36	41	42	43	45	[illegible]	[illegible]	[illegible]
118	0	0	17	21	23	27	31	35	37	39	40	42	[illegible]	[illegible]	[illegible]
129	0	0	16	20	23	26	[illegible]	32	35	36	38	39	[illegible]	[illegible]	[illegible]
141	0	0	11	19	23	26	29	29	32	34	35	37	[illegible]	[illegible]	[illegible]
152	0	0	0	15	20	24	27	27	30	32	33	35	[illegible]	[illegible]	[illegible]
164	0	0	0	2	17	22	24	24	28	29	32	34	[illegible]	[illegible]	[illegible]
175	0	0	0	0	4	17	21	22	25	27	30	32	[illegible]	[illegible]	[illegible]

Ignition Timing
①

Table 3.4. Wastegate Area

	750	1054	1357	1661	1964	2268	2571	2875	3179	3482	3786	4089	4393	4696	5000
15	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
26	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
38	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
49	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
61	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
[illegible]	[illegible]	[illegible]	100	100	100	100	100	100	100	100	100	100	100	100	100
[illegible]	[illegible]	[illegible]	100	100	100	100	100	100	100	100	100	100	100	100	100
[illegible]	[illegible]	[illegible]	[illegible]	100	100	100	100	100	100	100	100	100	100	100	100
[illegible]	[illegible]	[illegible]	[illegible]	53.3	100	100	100	100	100	100	100	100	100	100	100
[illegible]	[illegible]	[illegible]	[illegible]	19.2	36.6	50.9	60.2	81.5	100	100	100	100	100	100	100
[illegible]	[illegible]	[illegible]	[illegible]	10.4	21.6	31.9	40.7	[illegible]	[illegible]	69.9	74	76.4	79.5	82	84.4
[illegible]	[illegible]	[illegible]	[illegible]	7.3	16.5	24.1	33.9	[illegible]	[illegible]	60.4	66.1	70.4	74.5	75.4	75.4
[illegible]	[illegible]	[illegible]	[illegible]	6.4	14.3	22	30.4	41.3	50.2	56.3	61.4	64.9	67.4	69.1	71.4
[illegible]	[illegible]	[illegible]	[illegible]	5.7	11.7	17.7	26.9	35.5	44.8	49.8	55.1	59.8	62.5	65.7	68.8
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	12.4	16	24.3	32.5	41	46.8	52.4	56.3	60.6	63.5	65.9

Turbo
Wastegate Area
③

Engine Controller

Table 3.2. Throttle Position

	750	1054	1357	1661	1964	2268	2571	2875	3179	3482	3786	4089	4393	4696	5000
15	0.6	0.8	1.1	1.4	1.7	2	2.3	2.6	2.9	3.2	3.6	4	4.4	4.8	5.2
26	0.8	1.2	1.6	1.9	2.3	2.6	3	3.4	3.9	4.2	4.7	5.1	5.6	6.2	6.6
38	1.1	1.5	2	2.4	2.9	3.3	3.8	4.3	4.8	5.2	5.8	6.3	6.7	7.3	8
49	1.4	1.9	2.5	3	3.5	4	4.6	5.1	5.7	6.2	6.8	7.4	8	8.7	9.3
61	1.9	2.5	3.1	3.6	4.2	4.8	5.4	6.1	6.7	7.4	8.1	8.6	9.4	10.2	11
72	2.8	3.3	3.9	4.6	5.2	5.9	6.5	7.3	8	8.8	9.6	10.4	11.2	12.1	13
84	6.6	5.5	5.5	5.9	6.6	7.5	8	8.9	9.8	11	11.9	12.7	13.7	14.8	15.9
95	100	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	16.2	17.4	18.8	20.2
106	100	100	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	21.9	23.1	24.7	28	29.5
118	100	100	100	100	100	100	100	100	97.6	54.9	57	69.1	82.3	85	89.8
129	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
141	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
152	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
164	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
175	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100

Throttle Position
②

Table 3.8. Lambda

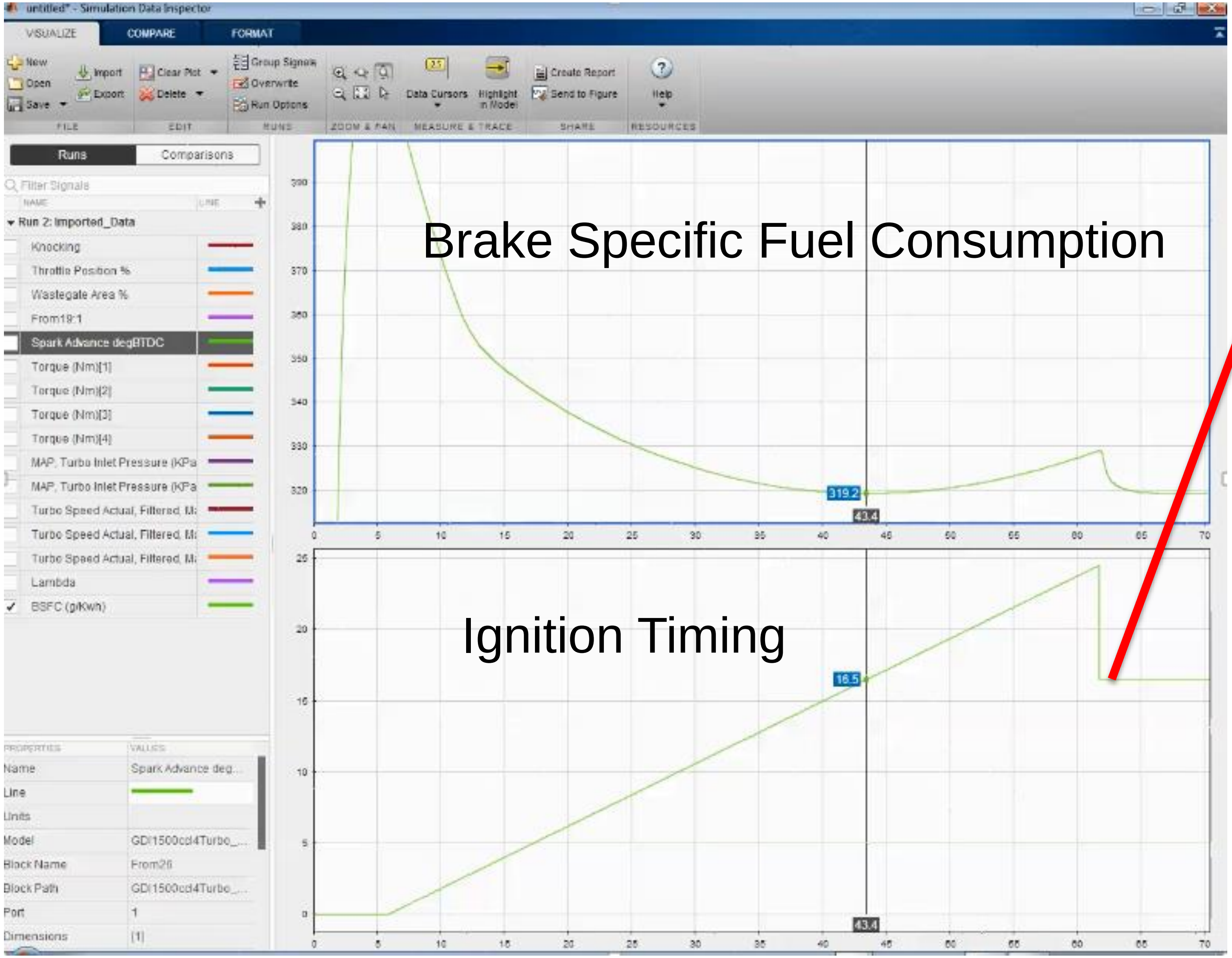
	750	1054	1357	1661	1964	2268	2571	2875	3179	3482	3786	4089	4393	4696	5000
15	1	1	1	1	1	1	1	1	0.97	0.95	0.92	0.86	0.82	0.81	0.81
26	1	1	1	1	1	1	1	1	1	1	0.96	0.89	0.84	0.81	0.81
38	1	1	1	1	1	1	1	1	1	1	1	0.92	0.91	0.88	0.8
49	1	1	1	1	1	1	1	1	1	1	1	0.95	0.88	0.85	0.87
61	1	1	1	1	1	1	1	1	1	1	1	0.96	0.93	0.87	0.85
72	1	1	1	1	1	1	1	1	1	1	1	0.92	0.91	0.92	0.9
84	1	1	1	1	1	1	1	1	1	[illegible]	0.99	0.95	0.9	0.91	0.88
95	1	1	1	1	1	1	1	[illegible]	1	[illegible]	[illegible]	[illegible]	0.92	0.91	0.88
106	1	1	1	1	1	1	1	[illegible]	1	0.98	0.91	0.92	0.9	0.85	0.85
118	1	0.95	1	1	1	1	1	[illegible]	0.96	0.94	0.92	0.86	0.85	0.88	0.85
129	1	0.95	1	1	1	1	1	[illegible]	0.97	0.93	0.87	0.84	0.86	0.85	0.84
141	1	0.95	1	1	1	1	1	0.96	0.94	0.9	0.85	0.84	0.85	0.84	0.8
152	1	0.95	0.85	1	1	1	1	0.96	0.92	0.9	0.86	0.84	0.84	0.8	0.8
164	1	0.95	0.84	0.8	1	1	1	0.95	0.89	0.84	0.81	0.82	0.8	0.8	0.8
175	1	0.94	0.84	0.8	0.8	0.96	0.96	0.89	0.87	0.84	0.82	0.8	0.8	0.8	0.8

Air/Fuel Ratio
④

15 Engine Speeds
X
15 Engine Torques
X
4 Variables

900 Calibration Values

Example VECO At One Operating Point



Run 2: Imported_Data

- Knocking
- Throttle Position %
- Wastegate Area %
- From18:1
- Spark Advance degBTDC
- Torque (Nm)[1]
- Torque (Nm)[2]
- Torque (Nm)[3]
- Torque (Nm)[4]
- MAP, Turbo Inlet Pressure (KPa
- MAP, Turbo Inlet Pressure (KPa
- Turbo Speed Actual, Filtered, M
- Turbo Speed Actual, Filtered, M
- Turbo Speed Actual, Filtered, M
- Lambda
- ✓ BSFC (g/Kwh)

PROPERTIES	VALUES
Name	Spark Advance deg...
Line	🟩
Units	
Model	GDI1500cc14Turbo_...
Block Name	From26
Block Path	GDI1500cc14Turbo_...
Port	1
Dimensions	[1]

Brake Specific Fuel Consumption

Ignition Timing

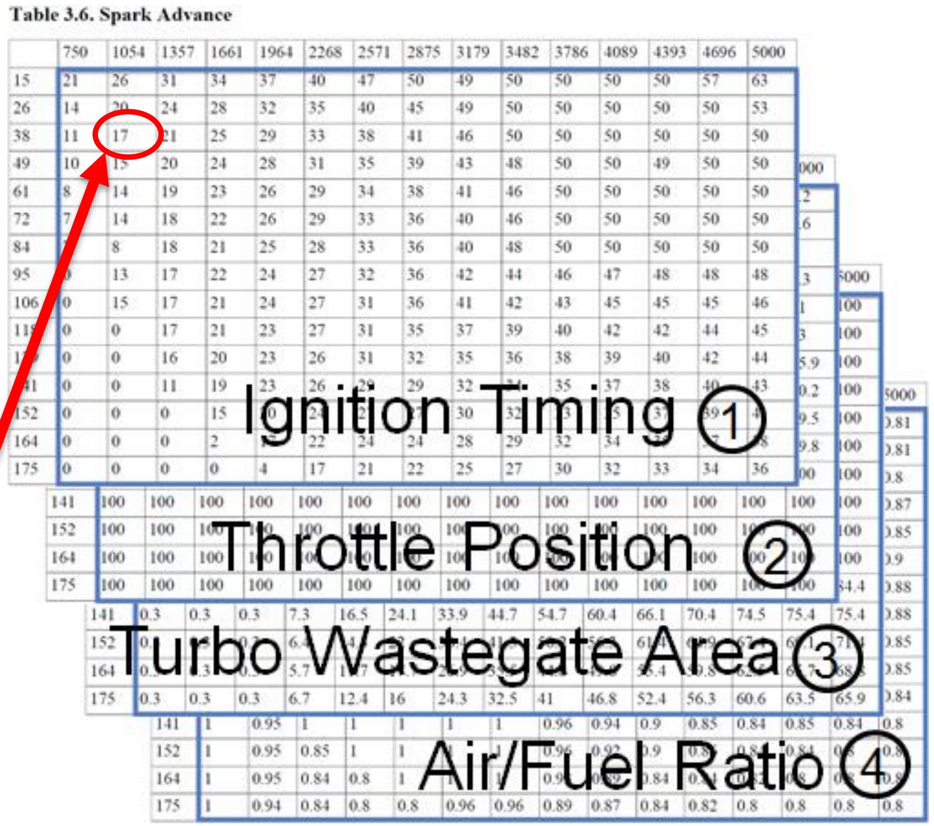


Table 3.6. Spark Advance

	750	1054	1357	1661	1964	2268	2571	2875	3179	3482	3786	4089	4393	4696	5000
15	21	26	31	34	37	40	47	50	49	50	50	50	50	57	63
26	14	20	24	28	32	35	40	45	49	50	50	50	50	50	53
38	11	17	21	25	29	33	38	41	46	50	50	50	50	50	50
49	10	15	20	24	28	31	35	39	43	48	50	50	49	50	50
61	8	14	19	23	26	29	34	38	41	46	50	50	50	50	50
72	7	14	18	22	26	29	33	36	40	46	50	50	50	50	50
84	[illegible]	8	18	21	25	28	33	36	40	48	50	50	50	50	50
95	[illegible]	13	17	22	24	27	32	36	42	44	46	47	48	48	48
106	0	15	17	21	24	27	31	36	41	42	43	45	45	45	46
[illegible]	0	0	17	21	23	27	31	35	37	39	40	42	42	44	45
[illegible]	0	0	16	20	23	26	31	32	35	36	38	39	40	42	44
[illegible]	0	0	11	19	23	26	29	29	32	[illegible]	35	37	38	40	43
152	0	0	0	15	[illegible]	[illegible]	[illegible]	[illegible]	30	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
164	0	0	0	2	[illegible]	22	24	24	28	29	32	34	[illegible]	[illegible]	[illegible]
175	0	0	0	0	4	17	21	22	25	27	30	32	33	34	36

Ignition Timing ①

141	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
152	100	100	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	100	[illegible]	[illegible]
164	100	100	100	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	100	[illegible]	[illegible]
175	100	100	100	100	100	100	100	100	100	100	100	100	100	[illegible]	[illegible]

Throttle Position ②

141	0.3	0.3	0.3	7.3	16.5	24.1	33.9	44.7	54.7	60.4	66.1	70.4	74.5	75.4	75.4
152	[illegible]	[illegible]	[illegible]	6.4	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
164	[illegible]	[illegible]	[illegible]	5.7	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
175	0.3	0.3	0.3	6.7	12.4	16	24.3	32.5	41	46.8	52.4	56.3	60.6	63.5	65.9

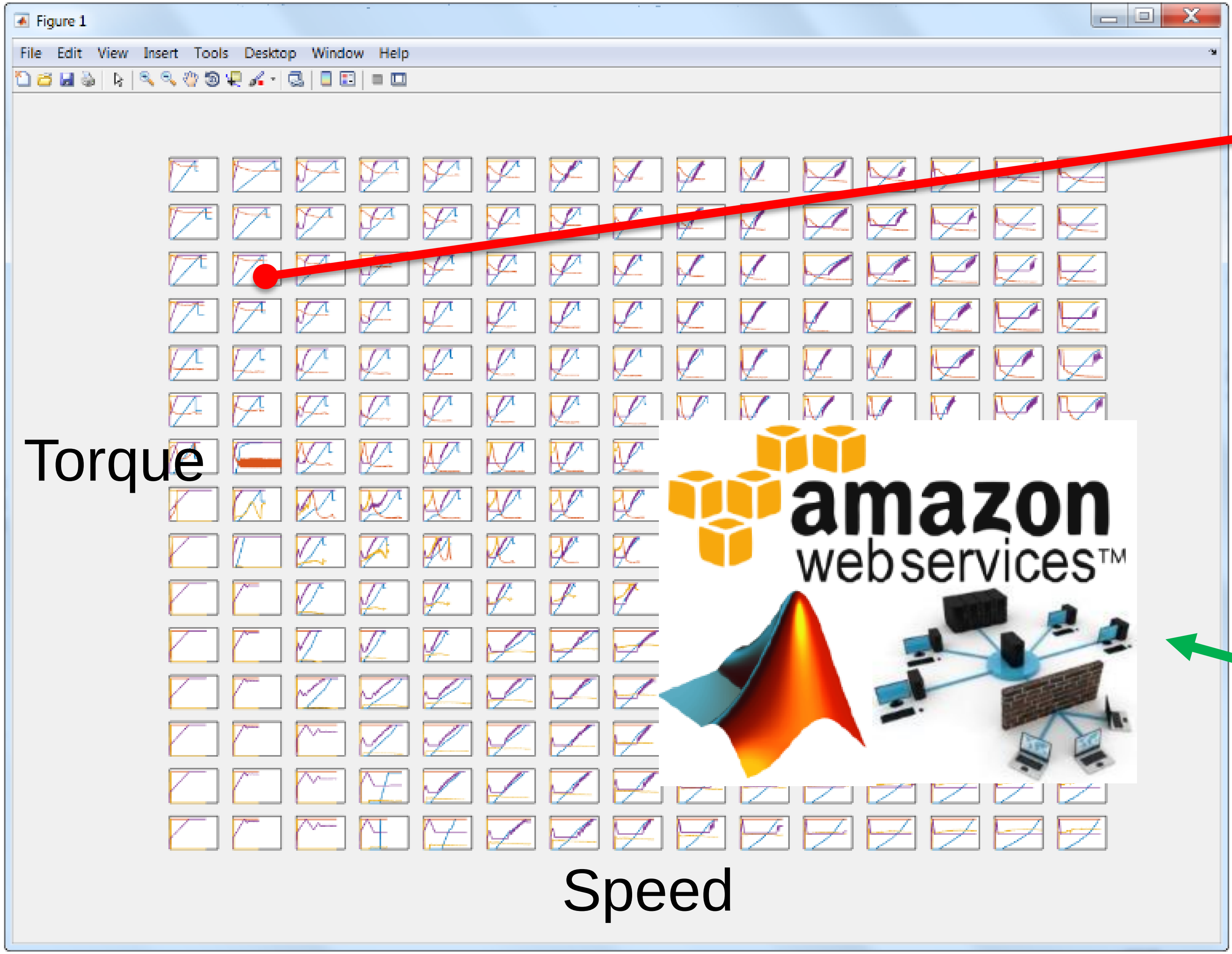
Turbo Wastegate Area ③

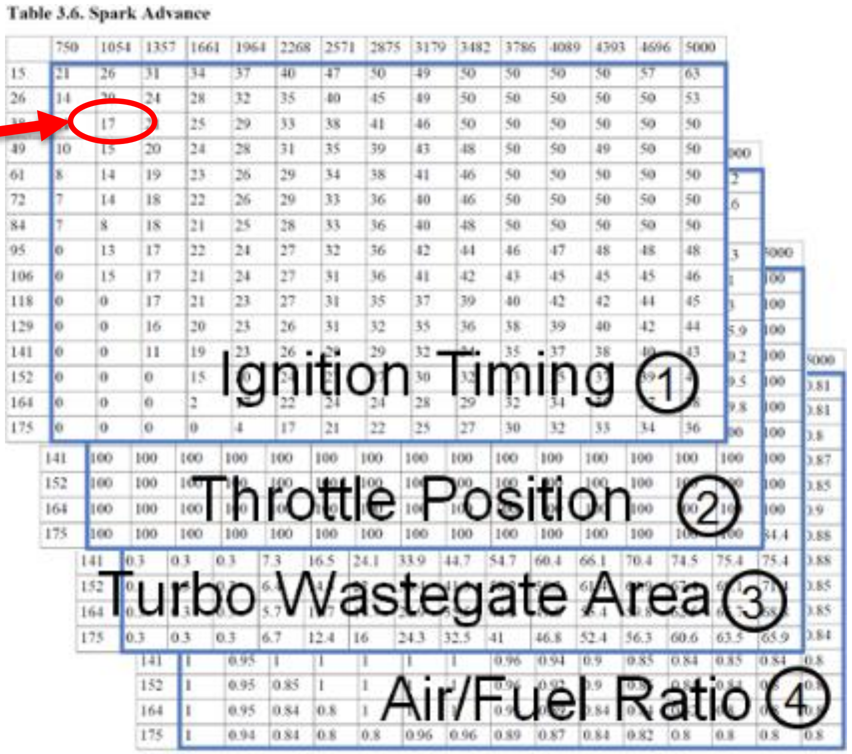
141	1	0.95	1	1	1	1	1	0.96	0.94	0.9	0.85	0.84	0.85	0.84	0.8
152	1	0.95	0.85	1	1	[illegible]	[illegible]	0.96	0.92	0.9	[illegible]	[illegible]	0.84	[illegible]	[illegible]
164	1	0.95	0.84	0.8	1	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
175	1	0.94	0.84	0.8	0.8	0.96	0.96	0.89	0.87	0.84	0.82	0.8	0.8	0.8	0.8

Air/Fuel Ratio ④

1.5L SI DOHC I4 GDI
Dual VCP Turbo
Application Example

Parallel Computing Used for 225x Speed-Up





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	750	1054	1357	1661	1964	2268	2571	2875	3179	3482	3786	4089	4393	4696	5000
15	21	26	31	34	37	40	47	50	49	50	50	50	50	57	63
26	14	20	24	28	32	35	40	45	49	50	50	50	50	50	53
38	[illegible]	17	[illegible]	25	29	33	38	41	46	50	50	50	50	50	50
49	10	15	20	24	28	31	35	39	43	48	50	50	49	50	50
61	8	14	19	23	26	29	34	38	41	46	50	50	50	50	50
72	7	14	18	22	26	29	33	36	40	46	50	50	50	50	50
84	7	8	18	21	25	28	33	36	40	48	50	50	50	50	50
95	0	13	17	22	24	27	32	36	42	44	46	47	48	48	48
106	0	15	17	21	24	27	31	36	41	42	43	45	45	45	46
118	0	0	17	21	23	27	31	35	37	39	40	42	42	44	45
129	0	0	16	20	23	26	31	32	35	36	38	39	40	42	44
141	0	0	11	19	23	26	[illegible]	29	32	[illegible]	35	37	38	[illegible]	43
152	0	0	0	15	[illegible]	[illegible]	[illegible]	[illegible]	30	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
164	0	0	0	2	[illegible]	22	24	24	28	29	32	34	[illegible]	[illegible]	[illegible]
175	0	0	0	0	4	17	21	22	25	27	30	32	33	34	36

Ignition Timing ①

141	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
152	100	100	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	100	[illegible]	[illegible]	[illegible]
164	100	100	100	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	100	100	[illegible]	[illegible]
175	100	100	100	100	100	100	100	100	100	100	100	100	100	[illegible]	100

Throttle Position ②

141	0.3	0.3	0.3	7.3	16.5	24.1	33.9	44.7	54.7	60.4	66.1	70.4	74.5	75.4	75.4
152	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
164	[illegible]	[illegible]	[illegible]	5.7	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
175	0.3	0.3	0.3	6.7	12.4	16	24.3	32.5	41	46.8	52.4	56.3	60.6	63.5	65.9

Turbo Wastegate Area ③

141	1	0.95	1	1	1	1	1	0.96	0.94	0.9	0.85	0.84	0.85	0.84	0.8
152	1	0.95	0.85	1	1	[illegible]	[illegible]	[illegible]	[illegible]	0.9	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
164	1	0.95	0.84	0.8	1	[illegible]	[illegible]	[illegible]	[illegible]	0.84	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
175	1	0.94	0.84	0.8	0.8	0.96	0.96	0.89	0.87	0.84	0.82	0.8	0.8	0.8	0.8

Air/Fuel Ratio ④

Automated Base Engine
Calibration In 20min!

Summary

- Engine Calibration Is a Major Bottleneck in Engine Design Process
- VECO Process For SI Engine Removes Base Calibration Bottleneck
- VECO Is Practical For Everyday Use Due To Parallel Computing

Questions?