Virtual Engine Calibration Optimization (VECO)

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MathWorks
AUTOMOTIVE CONFERENCE 2015

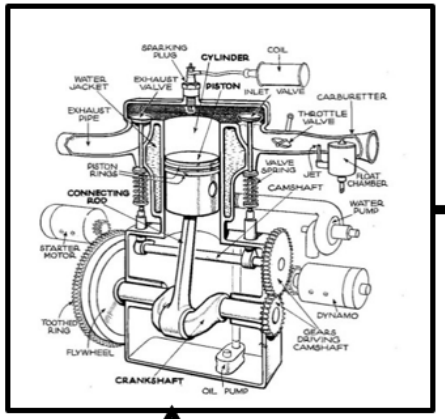
Outline

- Calibration After Engine Build Slows Design Iterations By About 4 Years

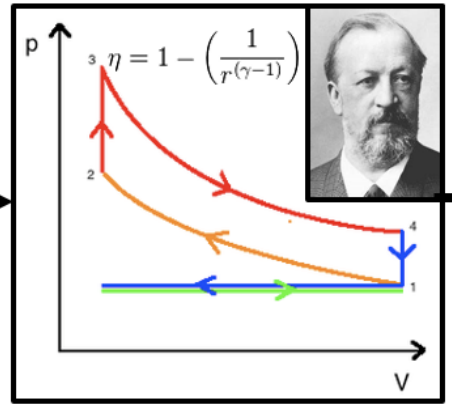
- 4 Year Design Iteration Delay Can Be Removed With
  - GT-POWER co-simulation (Simulink)
  - Direct optimization of engine calibration maps (StateFlow)
  - Rapid calibration development (Parallel Computing)

What Was Engine Calibration?

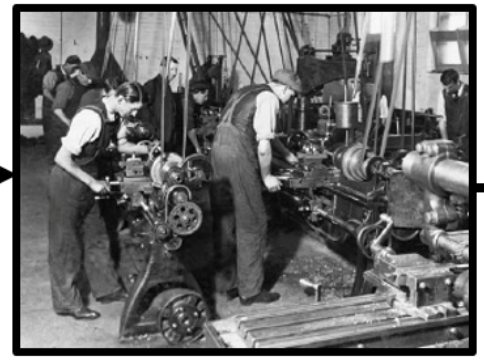
Sketch



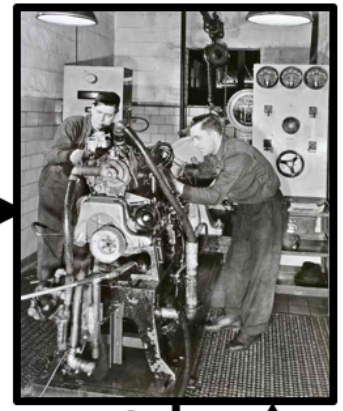
Model



Build

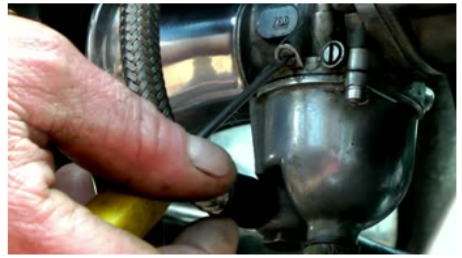


Test



Engine's Performance Cannot Be Judged Until It Is Calibrated

Iterate: 4 year delay



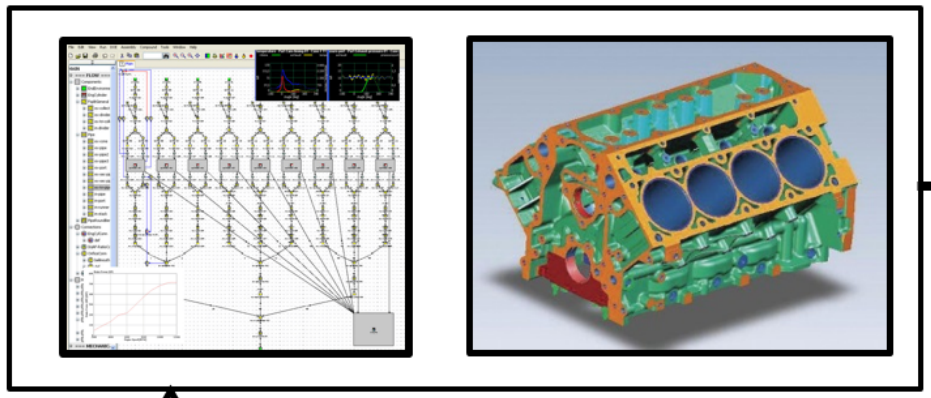
"Calibrate" By Adjusting A Few Screws

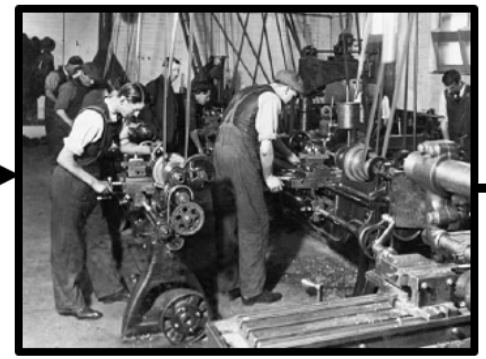
What Is Typical Engine Calibration Now?

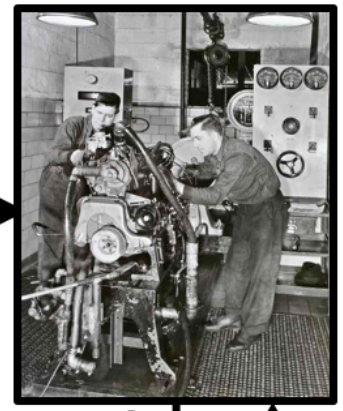
Model and Design

Build

Test



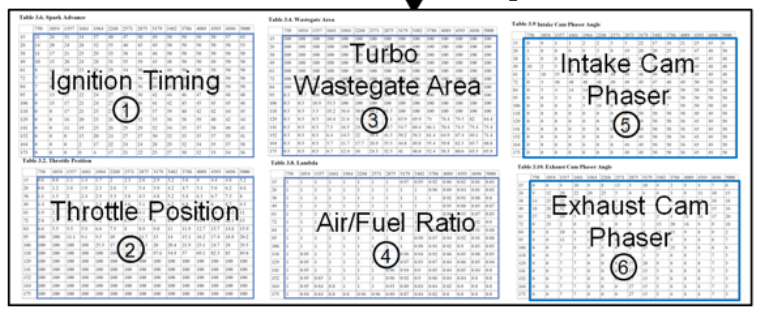




Engine's Performance Cannot Be Judged Until It Is Calibrated

Iterate: 4 year delay

Engine Controller

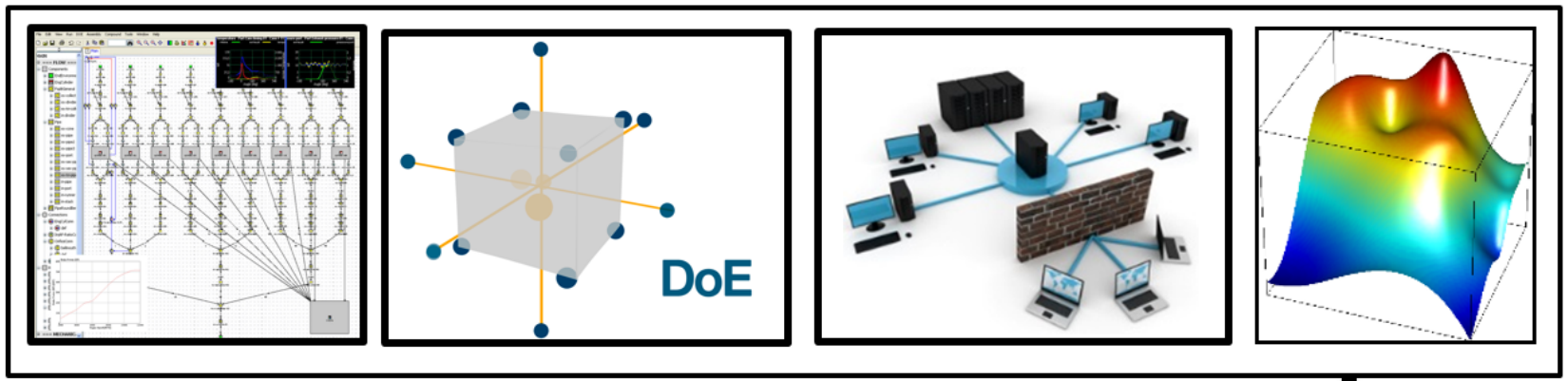


Engineer

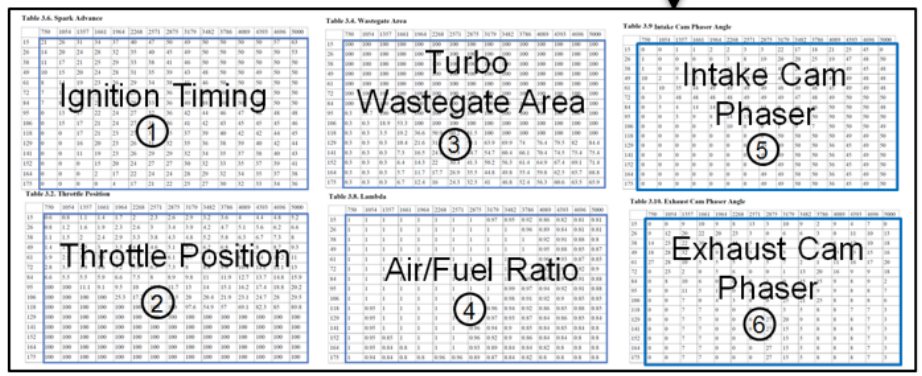
Calibrate By Adjusting 1350 Numbers

What Is Advanced Engine Calibration Now?

Model, Experiment, Fit, Optimize



Engine Controller

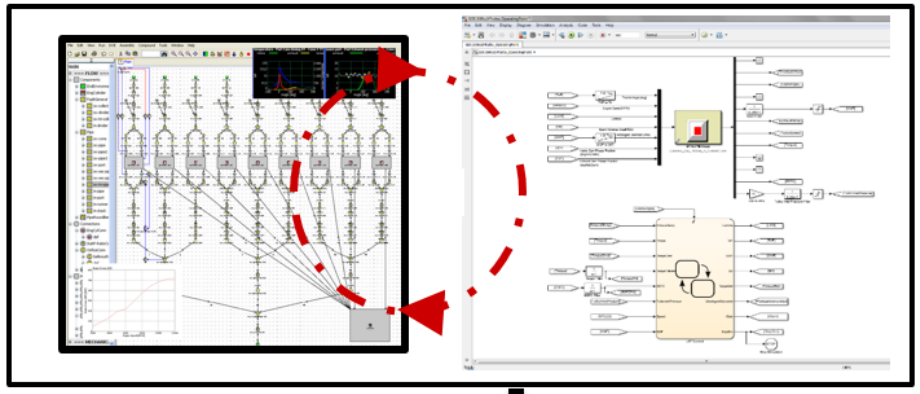


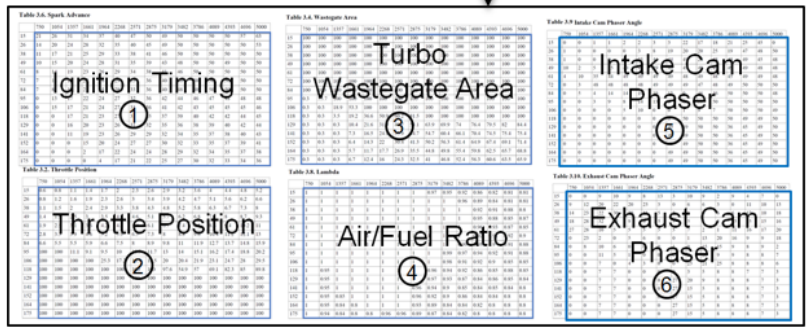
3 day wait on
32 Core Cluster

Calibrate 1350 Numbers via DoE, RSM, Numerical Optimization

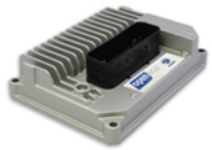
How Do We Speed Up Engine Design?

Model and Calibrate





18 day wait
on 1 Core

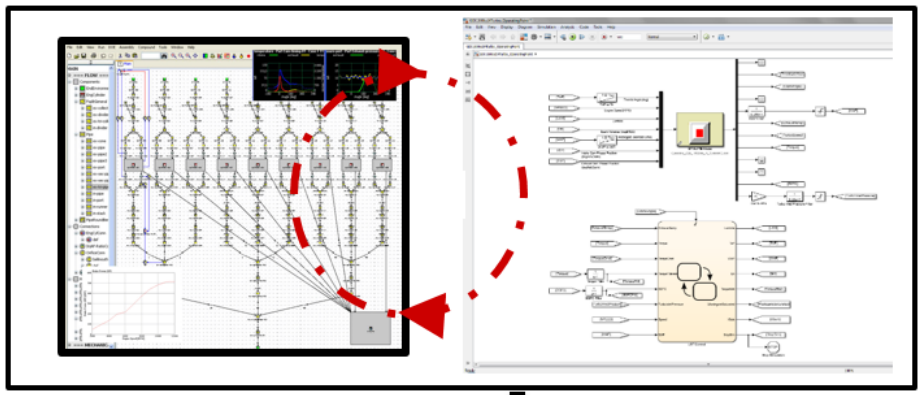


Engine Controller

Calibrate 1350 Numbers via Numerical Optimization

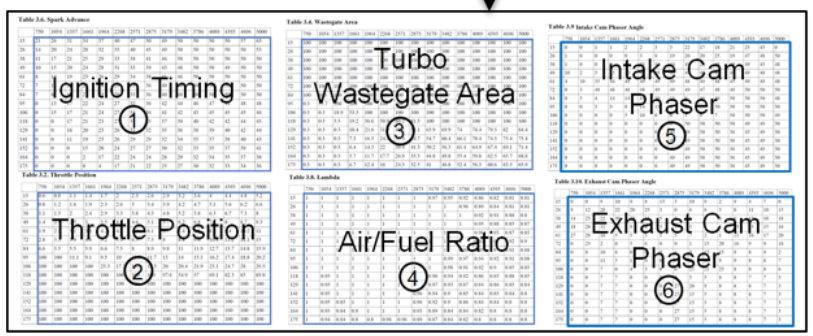
How Do We Speed Up Engine Design?

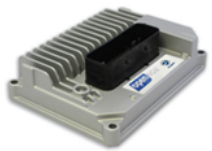
Model and Calibrate



2hr wait

225 Cores

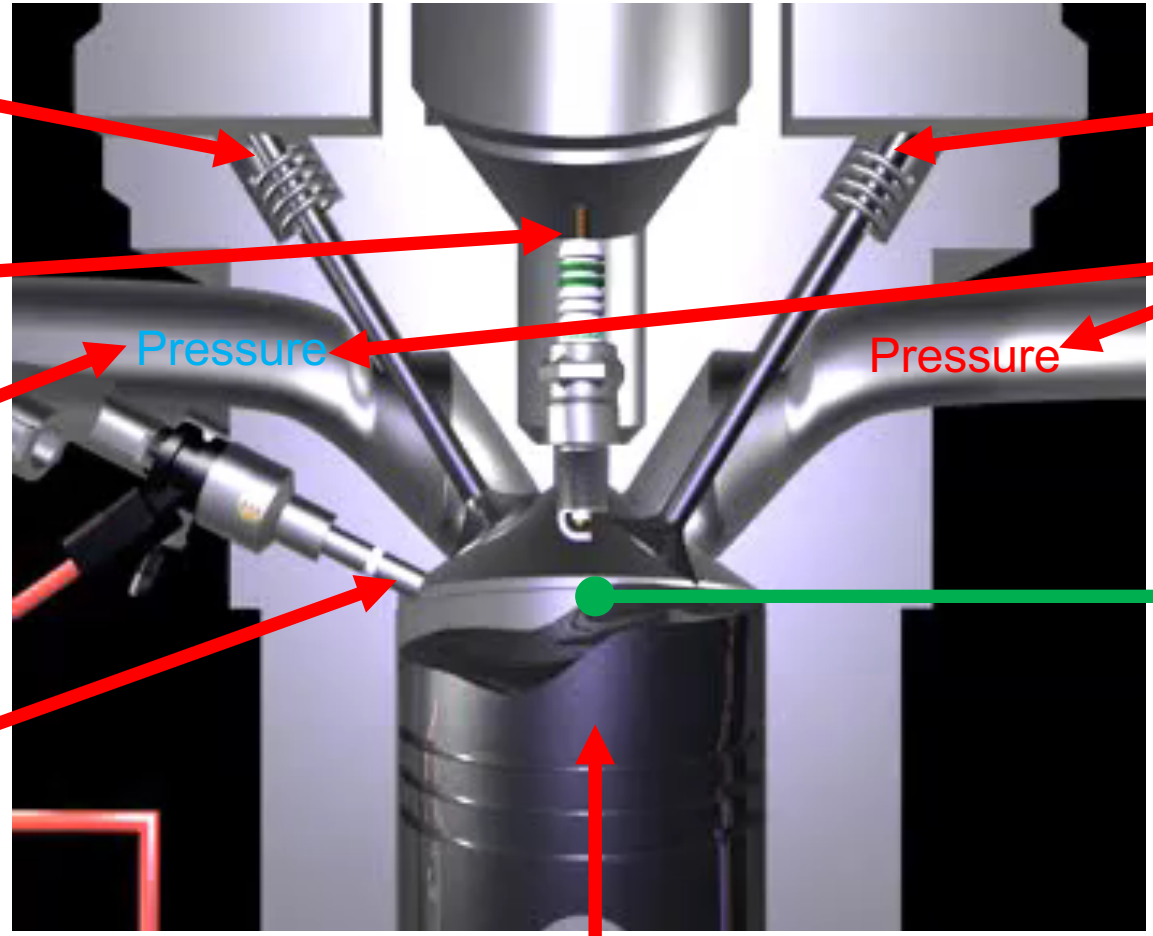




Engine Controller

Calibrate 1350 Numbers via Numerical Optimization

Base Engine Calibration Problem Addressed by VECO



Intake Cam Phasing
5

1 Ignition Timing

2 Throttle Position

4 Fuel
→Air/Fuel Ratio

Exhaust Cam Phasing
6 →NOx

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	13	17	21	25	28	33	36	40	45	50	50	50	50	50
84	7	8	17	21	24	27	32	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	29	29	32	34	35	37	38	40	43
152	0	0	0	15	20	24	27	27	30	32	33	35	37	39	41
164	0	0	0	2	17	22	24	24	28	29	32	34	35	37	38
175	0	0	0	0	4	17	21	22	25	27	30	32	33	34	36

Ignition Timing ①

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	0.97	0.92	0.92	0.9
84	1	1	1	1	1	1	1	1	1	1	1	0.96	0.95	0.91	0.88
95	1	1	1	1	1	1	1	1	1	0.99	0.97	0.94	0.92	0.91	0.88
106	1	1	1	1	1	1	1	1	1	0.98	0.91	0.92	0.9	0.85	0.85
118	1	0.95	1	1	1	1	1	1	0.96	0.94	0.92	0.86	0.85	0.88	0.85
129	1	0.95	1	1	1	1	1	1	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	0.93	0.89	0.84	0.84	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

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	1.8	2.5	3	3.5	4	4.6	5.1	5.7	6.2	6.8	7.3	7.8	8.7	9.3
61	1.9	2.3	2.9	3.6	4.2	4.8	5.5	6.1	6.7	7.4	8.1	8.8	9.5	10.2	11
72	2.8	3.5	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	100	11.1	9.1	9.5	10	10.8	11.7	13	14	15.1	16.2	17.4	18.8	20.2
106	100	100	100	100	25.3	17.2	18.2	19.5	20	20.4	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 3.9 Intake Cam Phaser Angle

	750	1054	1357	1661	1964	2268	2571	2875	3179	3482	3786	4089	4393	4696	5000
15	0	0	1	1	2	2	3	3	22	17	18	21	25	45	0
26	1	0	0	0	0	3	8	19	20	20	25	19	47	48	50
38	1	0	0	0	0	25	44	44	49	48	48	49	49	45	48
49	10	2	5	25	44	49	49	49	48	49	49	45	49	48	48
61	4	10	35	44	49	49	49	49	48	49	48	45	49	49	48
72	0	3	48	48	48	48	49	49	49	47	48	49	50	50	50
84	0	5	4	14	14	49	49	49	49	46	46	50	50	50	48
95	0	0	3	9	8	14	14	49	49	49	50	50	50	50	50
106	0	0	0	0	5	10	0	0	1	0	7	50	50	50	49
118	0	0	0	0	0	0	0	0	50	50	50	50	49	49	50
129	0	0	0	0	0	0	0	49	49	50	50	36	45	49	50
141	0	0	0	0	0	0	0	49	49	50	50	36	45	49	50
152	0	0	0	0	0	0	0	49	49	50	50	36	45	49	50
164	0	0	0	0	0	0	0	49	49	50	50	36	45	49	50
175	0	0	0	0	0	0	0	49	49	50	50	36	45	49	50

Intake Cam Phaser ⑤

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
72	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
84	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
95	0.3	15.7	100	100	100	100	100	100	100	100	100	100	100	100	100
106	0.3	0.3	18.9	53.3	100	100	100	100	100	100	100	100	100	100	100
118	0.3	0.3	3.5	19.2	36.6	50.9	60.2	81.5	100	100	100	100	100	100	100
129	0.3	0.3	0.3	10.4	21.6	31.9	42.2	56.1	63.9	69.9	74	76.4	79.5	82	84.4
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	0.3	0.3	0.3	6.4	14.3	22	30.4	41.3	50.2	56.3	61.4	64.9	67.4	69.1	71.4
164	0.3	0.3	0.3	5.7	11.7	17.7	26.9	35.5	44.8	49.8	55.4	59.8	62.5	65.7	68.8
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

Table 3.10. Exhaust Cam Phaser Angle

	750	1054	1357	1661	1964	2268	2571	2875	3179	3482	3786	4089	4393	4696	5000
15	0	0	9	10	9	8	13	3	10	9	2	9	4	7	0
26	9	12	20	22	20	23	3	0	6	6	3	0	11	10	13
38	14	23	22	30	26	1	5	5	5	5	6	6	12	10	18
49	18	28	32	19	1	5	5	5	5	5	5	5	15	15	16
61	27	28	10	5	5	5	5	5	7	2	1	11	16	17	20
72	0	23	2	0	5	6	0	0	1	13	20	16	9	9	18
84	0	8	10	6	0	0	1	0	15	15	9	8	9	2	
95	0	0	11	5	0	0	0	0	0	9	9	8	8	7	
106	0	0	7	0	4	3	0	0	25	21	25	8	8	8	6
118	0	0	7	7	0	0	0	0	3	5	8	8	7	7	3
129	0	0	7	7	0	0	0	27	20	9	8	8	8	7	3
141	0	0	7	7	0	0	0	27	15	5	8	8	8	7	3
152	0	0	7	7	0	0	0	27	15	5	8	8	8	7	3
164	0	0	7	7	0	0	0	27	15	5	8	8	8	7	3
175	0	0	7	7	0	0	0	27	15	5	8	8	8	7	3

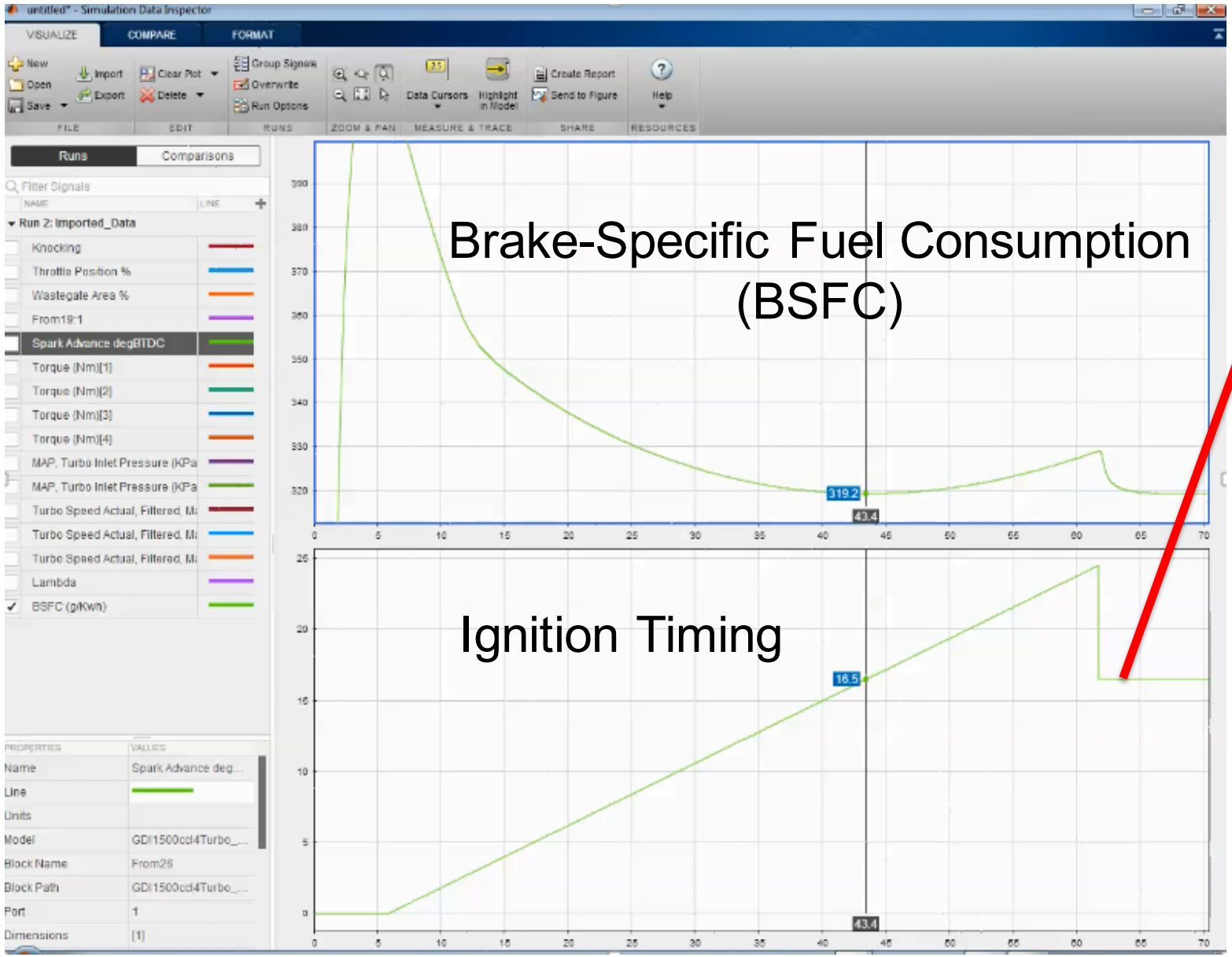
Exhaust Cam Phaser ⑥

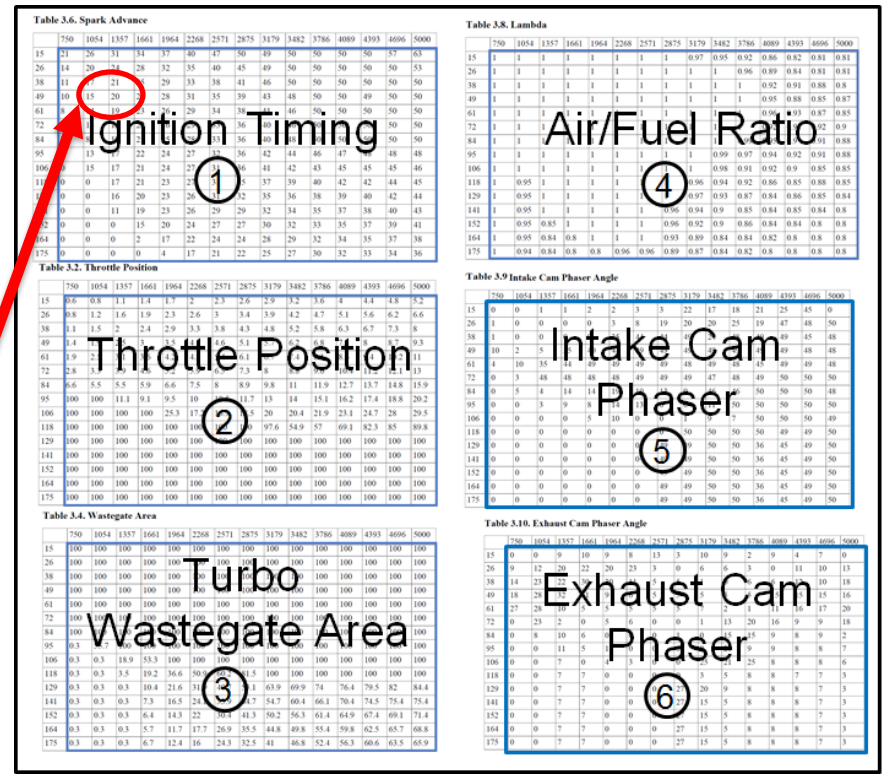
Engine Controller

15 Engine Speeds
X
15 Engine Torques
X
6 Variables

1350 Calibration Values

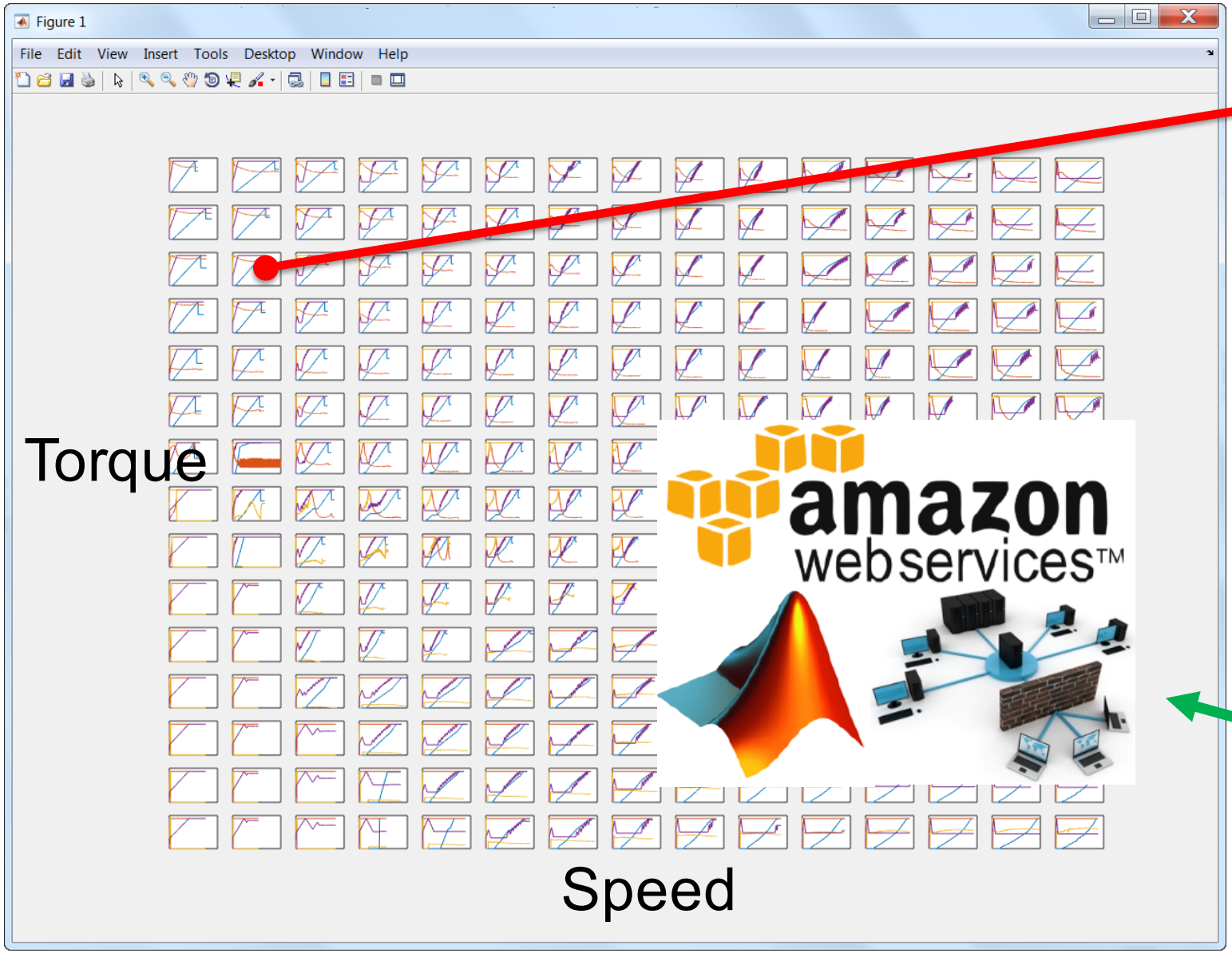
Example VECO At One Operating Point

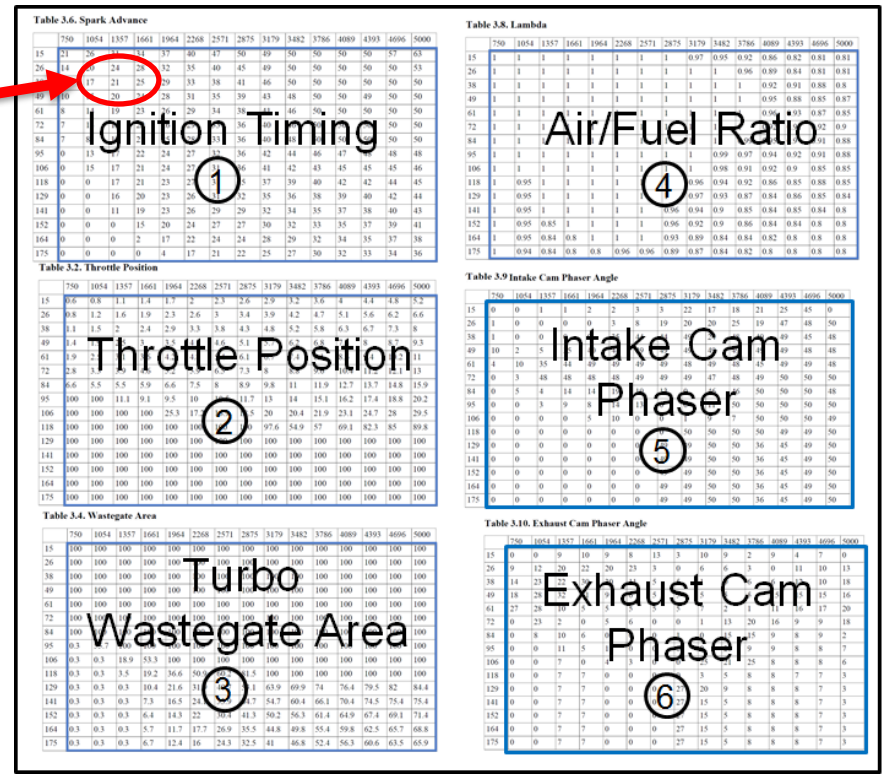




1.5L SI DOHC I4 GDI Dual VCP Turbo Application Example

Parallel Computing Used for 225x Speed-Up





Automated Base Engine Calibration Maps In 2hrs!

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?