

# Virtual Engine Calibration Optimization (VECO)

Peter J Maloney, MathWorks Consulting

MathWorks

**AUTOMOTIVE CONFERENCE 2015**

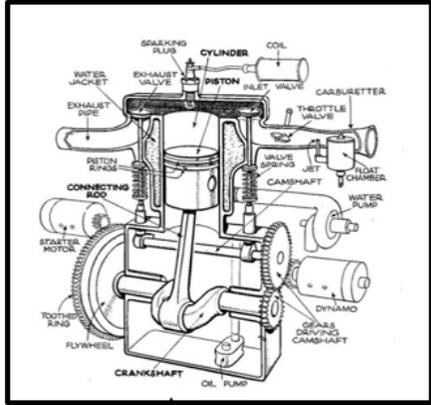


# Outline

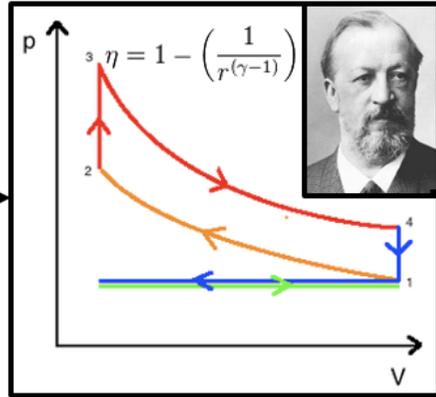
- Calibration After Engine Build Slows Design Iterations By About 4 Years
- 4 Year Design Iteration Delay Can Be Removed With
  - GT-POWER co-simulation (Simulink)
  - Direct optimization of engine calibration maps (StateFlow)
  - Rapid calibration development (Parallel Computing)

# What Was Engine Calibration?

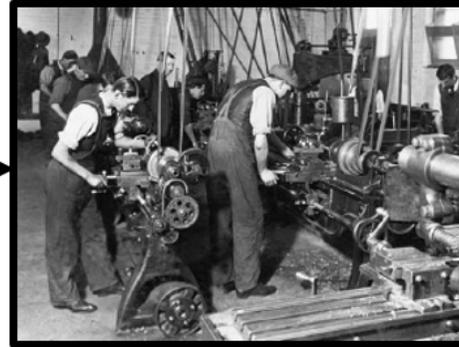
Sketch



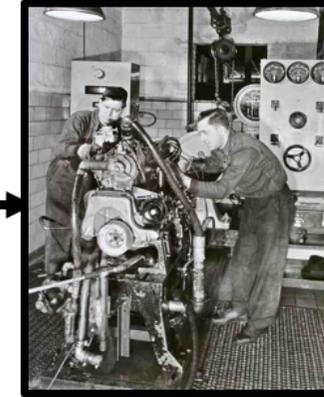
Model



Build



Test



Engine's Performance  
Cannot Be Judged  
Until It Is Calibrated

Iterate: 4 year delay



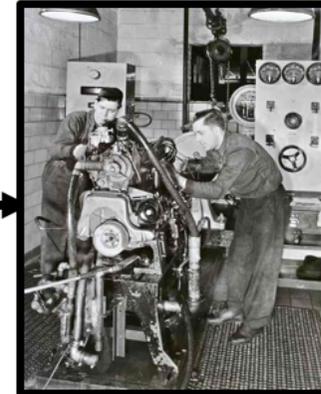
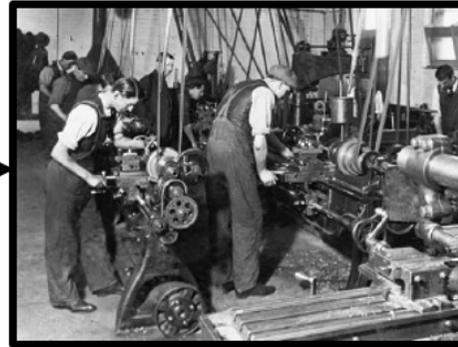
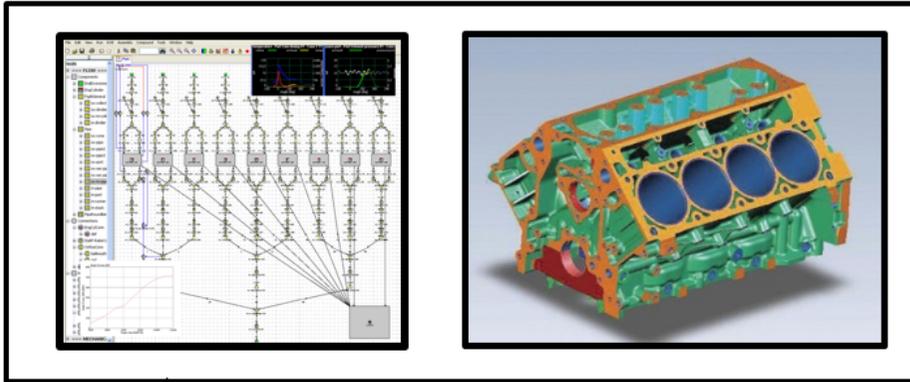
“Calibrate” By Adjusting A Few Screws

# What Is Typical Engine Calibration Now?

Model and Design

Build

Test



Iterate: 4 year delay

Engine's Performance Cannot Be Judged Until It Is Calibrated



Engine Controller

|  |  |   |
|--|--|---|
| <p>Table 1.1: Spark Advance</p> <p>Ignition Timing<br/>①</p>       | <p>Table 1.2: Wastegate Area</p> <p>Turbo Wastegate Area<br/>③</p> | <p>Table 1.3: Intake Cam Phase</p> <p>Intake Cam Phaser<br/>⑤</p>   |
| <p>Table 1.4: Throttle Position</p> <p>Throttle Position<br/>②</p> | <p>Table 1.5: Air/Fuel Ratio</p> <p>Air/Fuel Ratio<br/>④</p>       | <p>Table 1.6: Exhaust Cam Phase</p> <p>Exhaust Cam Phaser<br/>⑥</p> |

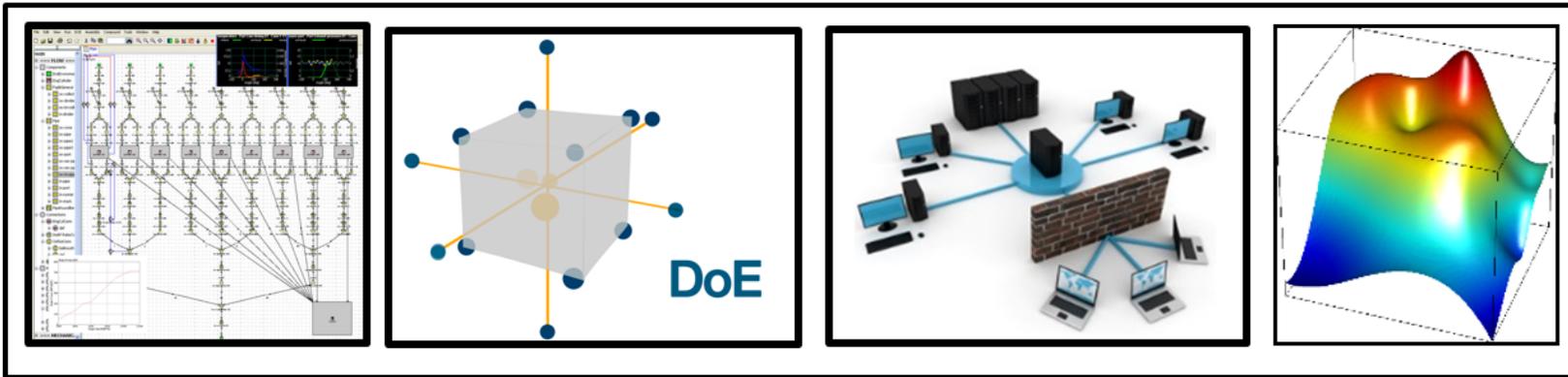


Engineer

Calibrate By Adjusting 1350 Numbers

# What Is Advanced Engine Calibration Now?

Model, Experiment, Fit, Optimize



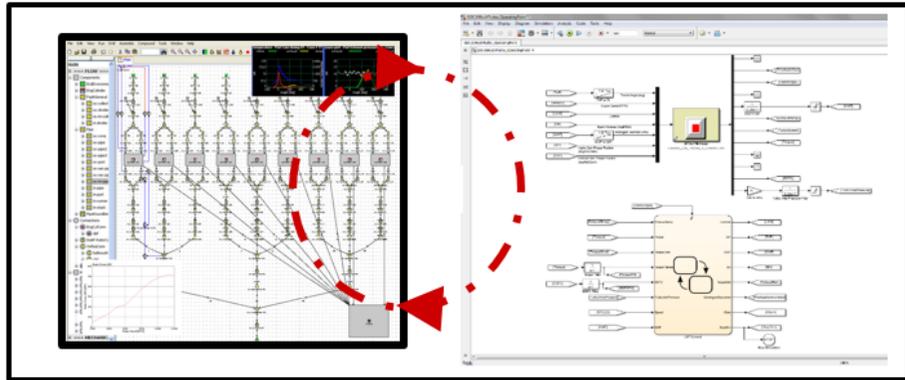
3 day wait on  
32 Core Cluster



|  |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |  |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |   |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |
|--|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|--|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|---|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|
| <p>Table 3.6. Spark Advance</p> <table border="1"> <tr><td>151</td><td>152</td><td>153</td><td>154</td><td>155</td><td>156</td><td>157</td><td>158</td><td>159</td><td>160</td></tr> <tr><td>161</td><td>162</td><td>163</td><td>164</td><td>165</td><td>166</td><td>167</td><td>168</td><td>169</td><td>170</td></tr> <tr><td>171</td><td>172</td><td>173</td><td>174</td><td>175</td><td>176</td><td>177</td><td>178</td><td>179</td><td>180</td></tr> <tr><td>181</td><td>182</td><td>183</td><td>184</td><td>185</td><td>186</td><td>187</td><td>188</td><td>189</td><td>190</td></tr> <tr><td>191</td><td>192</td><td>193</td><td>194</td><td>195</td><td>196</td><td>197</td><td>198</td><td>199</td><td>200</td></tr> </table> <p>Ignition Timing ①</p>       | 151 | 152 | 153 | 154 | 155 | 156 | 157 | 158 | 159 | 160 | 161 | 162 | 163 | 164 | 165 | 166 | 167 | 168 | 169 | 170 | 171 | 172 | 173 | 174 | 175 | 176 | 177 | 178 | 179 | 180 | 181 | 182 | 183 | 184 | 185 | 186 | 187 | 188 | 189 | 190 | 191 | 192 | 193 | 194 | 195 | 196 | 197 | 198 | 199 | 200 | <p>Table 3.7. Wastegate Area</p> <table border="1"> <tr><td>151</td><td>152</td><td>153</td><td>154</td><td>155</td><td>156</td><td>157</td><td>158</td><td>159</td><td>160</td></tr> <tr><td>161</td><td>162</td><td>163</td><td>164</td><td>165</td><td>166</td><td>167</td><td>168</td><td>169</td><td>170</td></tr> <tr><td>171</td><td>172</td><td>173</td><td>174</td><td>175</td><td>176</td><td>177</td><td>178</td><td>179</td><td>180</td></tr> <tr><td>181</td><td>182</td><td>183</td><td>184</td><td>185</td><td>186</td><td>187</td><td>188</td><td>189</td><td>190</td></tr> <tr><td>191</td><td>192</td><td>193</td><td>194</td><td>195</td><td>196</td><td>197</td><td>198</td><td>199</td><td>200</td></tr> </table> <p>Turbo Wastegate Area ③</p> | 151 | 152 | 153 | 154 | 155 | 156 | 157 | 158 | 159 | 160 | 161 | 162 | 163 | 164 | 165 | 166 | 167 | 168 | 169 | 170 | 171 | 172 | 173 | 174 | 175 | 176 | 177 | 178 | 179 | 180 | 181 | 182 | 183 | 184 | 185 | 186 | 187 | 188 | 189 | 190 | 191 | 192 | 193 | 194 | 195 | 196 | 197 | 198 | 199 | 200 | <p>Table 3.9. Intake Cam Phase Angle</p> <table border="1"> <tr><td>151</td><td>152</td><td>153</td><td>154</td><td>155</td><td>156</td><td>157</td><td>158</td><td>159</td><td>160</td></tr> <tr><td>161</td><td>162</td><td>163</td><td>164</td><td>165</td><td>166</td><td>167</td><td>168</td><td>169</td><td>170</td></tr> <tr><td>171</td><td>172</td><td>173</td><td>174</td><td>175</td><td>176</td><td>177</td><td>178</td><td>179</td><td>180</td></tr> <tr><td>181</td><td>182</td><td>183</td><td>184</td><td>185</td><td>186</td><td>187</td><td>188</td><td>189</td><td>190</td></tr> <tr><td>191</td><td>192</td><td>193</td><td>194</td><td>195</td><td>196</td><td>197</td><td>198</td><td>199</td><td>200</td></tr> </table> <p>Intake Cam Phaser ⑤</p>   | 151 | 152 | 153 | 154 | 155 | 156 | 157 | 158 | 159 | 160 | 161 | 162 | 163 | 164 | 165 | 166 | 167 | 168 | 169 | 170 | 171 | 172 | 173 | 174 | 175 | 176 | 177 | 178 | 179 | 180 | 181 | 182 | 183 | 184 | 185 | 186 | 187 | 188 | 189 | 190 | 191 | 192 | 193 | 194 | 195 | 196 | 197 | 198 | 199 | 200 |
| 151  | 152 | 153 | 154 | 155 | 156 | 157 | 158 | 159 | 160 |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |  |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |   |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |
| 161  | 162 | 163 | 164 | 165 | 166 | 167 | 168 | 169 | 170 |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |  |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |   |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |
| 171  | 172 | 173 | 174 | 175 | 176 | 177 | 178 | 179 | 180 |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |  |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |   |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |
| 181  | 182 | 183 | 184 | 185 | 186 | 187 | 188 | 189 | 190 |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |  |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |   |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |
| 191  | 192 | 193 | 194 | 195 | 196 | 197 | 198 | 199 | 200 |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |  |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |   |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |
| 151  | 152 | 153 | 154 | 155 | 156 | 157 | 158 | 159 | 160 |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |  |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |   |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |
| 161  | 162 | 163 | 164 | 165 | 166 | 167 | 168 | 169 | 170 |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |  |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |   |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |
| 171  | 172 | 173 | 174 | 175 | 176 | 177 | 178 | 179 | 180 |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |  |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |   |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |
| 181  | 182 | 183 | 184 | 185 | 186 | 187 | 188 | 189 | 190 |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |  |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |   |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |
| 191  | 192 | 193 | 194 | 195 | 196 | 197 | 198 | 199 | 200 |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |  |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |   |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |
| 151  | 152 | 153 | 154 | 155 | 156 | 157 | 158 | 159 | 160 |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |  |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |   |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |
| 161  | 162 | 163 | 164 | 165 | 166 | 167 | 168 | 169 | 170 |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |  |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |   |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |
| 171  | 172 | 173 | 174 | 175 | 176 | 177 | 178 | 179 | 180 |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |  |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |   |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |
| 181  | 182 | 183 | 184 | 185 | 186 | 187 | 188 | 189 | 190 |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |  |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |   |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |
| 191  | 192 | 193 | 194 | 195 | 196 | 197 | 198 | 199 | 200 |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |  |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |   |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |
| <p>Table 3.2. Throttle Position</p> <table border="1"> <tr><td>151</td><td>152</td><td>153</td><td>154</td><td>155</td><td>156</td><td>157</td><td>158</td><td>159</td><td>160</td></tr> <tr><td>161</td><td>162</td><td>163</td><td>164</td><td>165</td><td>166</td><td>167</td><td>168</td><td>169</td><td>170</td></tr> <tr><td>171</td><td>172</td><td>173</td><td>174</td><td>175</td><td>176</td><td>177</td><td>178</td><td>179</td><td>180</td></tr> <tr><td>181</td><td>182</td><td>183</td><td>184</td><td>185</td><td>186</td><td>187</td><td>188</td><td>189</td><td>190</td></tr> <tr><td>191</td><td>192</td><td>193</td><td>194</td><td>195</td><td>196</td><td>197</td><td>198</td><td>199</td><td>200</td></tr> </table> <p>Throttle Position ②</p> | 151 | 152 | 153 | 154 | 155 | 156 | 157 | 158 | 159 | 160 | 161 | 162 | 163 | 164 | 165 | 166 | 167 | 168 | 169 | 170 | 171 | 172 | 173 | 174 | 175 | 176 | 177 | 178 | 179 | 180 | 181 | 182 | 183 | 184 | 185 | 186 | 187 | 188 | 189 | 190 | 191 | 192 | 193 | 194 | 195 | 196 | 197 | 198 | 199 | 200 | <p>Table 3.8. Lambda</p> <table border="1"> <tr><td>151</td><td>152</td><td>153</td><td>154</td><td>155</td><td>156</td><td>157</td><td>158</td><td>159</td><td>160</td></tr> <tr><td>161</td><td>162</td><td>163</td><td>164</td><td>165</td><td>166</td><td>167</td><td>168</td><td>169</td><td>170</td></tr> <tr><td>171</td><td>172</td><td>173</td><td>174</td><td>175</td><td>176</td><td>177</td><td>178</td><td>179</td><td>180</td></tr> <tr><td>181</td><td>182</td><td>183</td><td>184</td><td>185</td><td>186</td><td>187</td><td>188</td><td>189</td><td>190</td></tr> <tr><td>191</td><td>192</td><td>193</td><td>194</td><td>195</td><td>196</td><td>197</td><td>198</td><td>199</td><td>200</td></tr> </table> <p>Air/Fuel Ratio ④</p>               | 151 | 152 | 153 | 154 | 155 | 156 | 157 | 158 | 159 | 160 | 161 | 162 | 163 | 164 | 165 | 166 | 167 | 168 | 169 | 170 | 171 | 172 | 173 | 174 | 175 | 176 | 177 | 178 | 179 | 180 | 181 | 182 | 183 | 184 | 185 | 186 | 187 | 188 | 189 | 190 | 191 | 192 | 193 | 194 | 195 | 196 | 197 | 198 | 199 | 200 | <p>Table 3.8. Exhaust Cam Phase Angle</p> <table border="1"> <tr><td>151</td><td>152</td><td>153</td><td>154</td><td>155</td><td>156</td><td>157</td><td>158</td><td>159</td><td>160</td></tr> <tr><td>161</td><td>162</td><td>163</td><td>164</td><td>165</td><td>166</td><td>167</td><td>168</td><td>169</td><td>170</td></tr> <tr><td>171</td><td>172</td><td>173</td><td>174</td><td>175</td><td>176</td><td>177</td><td>178</td><td>179</td><td>180</td></tr> <tr><td>181</td><td>182</td><td>183</td><td>184</td><td>185</td><td>186</td><td>187</td><td>188</td><td>189</td><td>190</td></tr> <tr><td>191</td><td>192</td><td>193</td><td>194</td><td>195</td><td>196</td><td>197</td><td>198</td><td>199</td><td>200</td></tr> </table> <p>Exhaust Cam Phaser ⑥</p> | 151 | 152 | 153 | 154 | 155 | 156 | 157 | 158 | 159 | 160 | 161 | 162 | 163 | 164 | 165 | 166 | 167 | 168 | 169 | 170 | 171 | 172 | 173 | 174 | 175 | 176 | 177 | 178 | 179 | 180 | 181 | 182 | 183 | 184 | 185 | 186 | 187 | 188 | 189 | 190 | 191 | 192 | 193 | 194 | 195 | 196 | 197 | 198 | 199 | 200 |
| 151  | 152 | 153 | 154 | 155 | 156 | 157 | 158 | 159 | 160 |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |  |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |   |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |
| 161  | 162 | 163 | 164 | 165 | 166 | 167 | 168 | 169 | 170 |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |  |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |   |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |
| 171  | 172 | 173 | 174 | 175 | 176 | 177 | 178 | 179 | 180 |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |  |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |   |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |
| 181  | 182 | 183 | 184 | 185 | 186 | 187 | 188 | 189 | 190 |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |  |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |   |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |
| 191  | 192 | 193 | 194 | 195 | 196 | 197 | 198 | 199 | 200 |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |  |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |   |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |
| 151  | 152 | 153 | 154 | 155 | 156 | 157 | 158 | 159 | 160 |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |  |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |   |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |
| 161  | 162 | 163 | 164 | 165 | 166 | 167 | 168 | 169 | 170 |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |  |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |   |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |
| 171  | 172 | 173 | 174 | 175 | 176 | 177 | 178 | 179 | 180 |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |  |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |   |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |
| 181  | 182 | 183 | 184 | 185 | 186 | 187 | 188 | 189 | 190 |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |  |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |   |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |
| 191  | 192 | 193 | 194 | 195 | 196 | 197 | 198 | 199 | 200 |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |  |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |   |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |
| 151  | 152 | 153 | 154 | 155 | 156 | 157 | 158 | 159 | 160 |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |  |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |   |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |
| 161  | 162 | 163 | 164 | 165 | 166 | 167 | 168 | 169 | 170 |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |  |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |   |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |
| 171  | 172 | 173 | 174 | 175 | 176 | 177 | 178 | 179 | 180 |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |  |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |   |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |
| 181  | 182 | 183 | 184 | 185 | 186 | 187 | 188 | 189 | 190 |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |  |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |   |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |
| 191  | 192 | 193 | 194 | 195 | 196 | 197 | 198 | 199 | 200 |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |  |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |   |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |

# How Do We Speed Up Engine Design?

## Model and Calibrate



18 day wait  
on 1 Core

|  |  |   |
|--|--|---|
| <p>Table 1.6. Spark Advance</p> <p>Ignition Timing<br/>①</p>       | <p>Table 1.8. Wastegate Area</p> <p>Turbo Wastegate Area<br/>③</p> | <p>Table 1.9 Intake Cam Phaser Angle</p> <p>Intake Cam Phaser<br/>⑤</p>     |
| <p>Table 1.2. Throttle Position</p> <p>Throttle Position<br/>②</p> | <p>Table 1.4. Lambda</p> <p>Air/Fuel Ratio<br/>④</p>               | <p>Table 1.11. Exhaust Cam Phaser Angle</p> <p>Exhaust Cam Phaser<br/>⑥</p> |



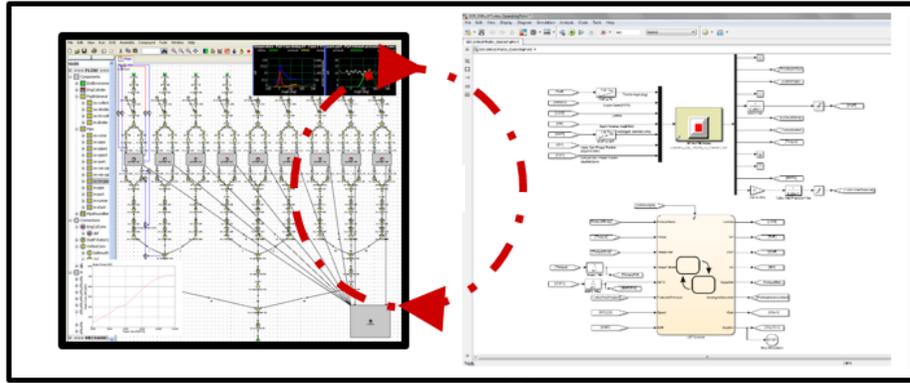
Engine Controller



Calibrate 1350 Numbers via Numerical Optimization

# How Do We Speed Up Engine Design?

## Model and Calibrate



2hr wait

225 Cores

|   |  |  |
|---|--|--|
| <p>Table 3.6. Spark Advance</p> <p>① Ignition Timing</p>      | <p>Table 3.8. Turbo Wastegate Area</p> <p>③ Turbo Wastegate Area</p> | <p>Table 3.7 Intake Cam Phaser Angl</p> <p>⑤ Intake Cam Phaser</p>   |
| <p>Table 3.2 Throttle Position</p> <p>② Throttle Position</p> | <p>Table 3.4 Lambda</p> <p>④ Air/Fuel Ratio</p>                      | <p>Table 3.5 Exhaust Cam Phaser Angl</p> <p>⑥ Exhaust Cam Phaser</p> |

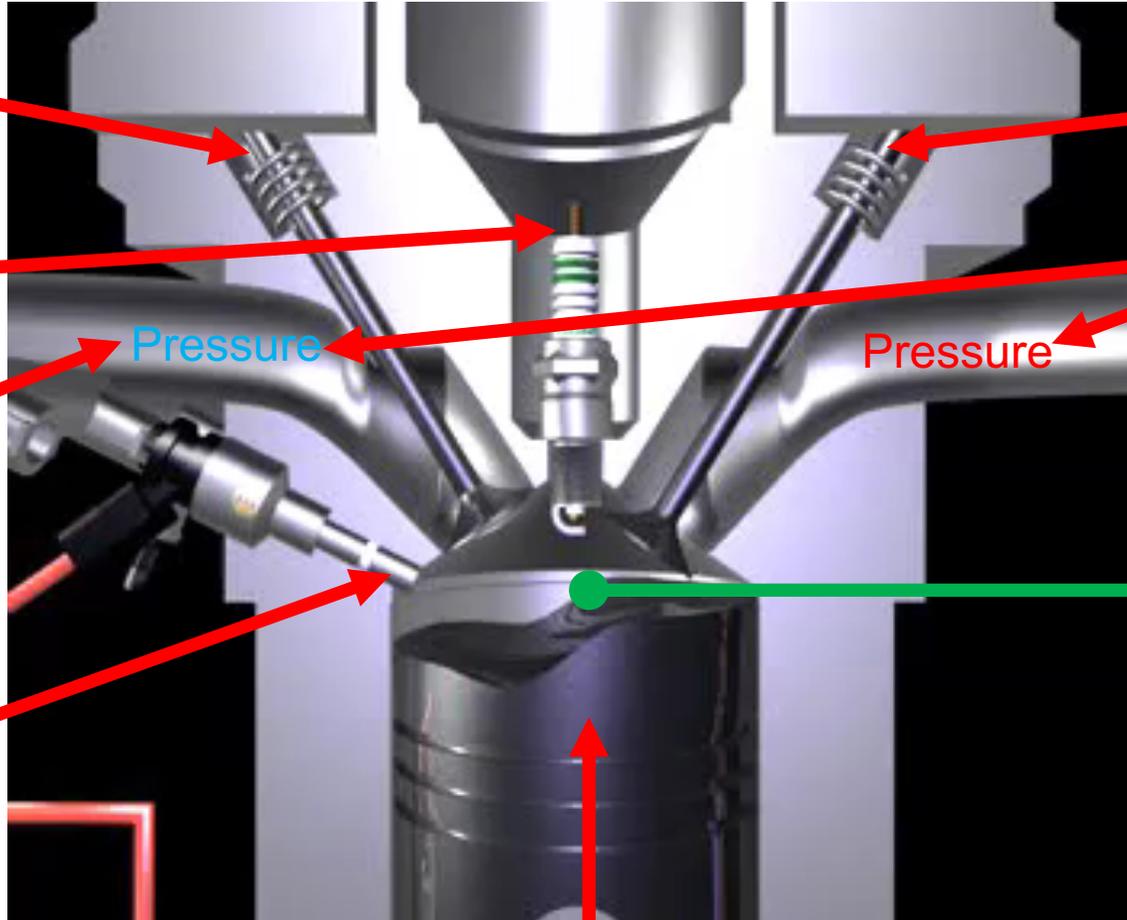


Engine Controller



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 → NO<sub>x</sub>

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   | 11   | 15   | 19   | 22   | 24   | 27   | 31   | 36   | 40   | 44   | 48   | 50   | 50   | 50   |
| 84  | 7   | 8    | 11   | 14   | 17   | 21   | 25   | 29   | 33   | 36   | 40   | 44   | 48   | 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    | 0.92 | 0.9  | 0.92 | 0.9  |
| 84  | 1   | 1    | 1    | 1    | 1    | 1    | 1    | 1    | 1    | 1    | 1    | 0.95 | 0.89 | 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    | 1    | 0.96 | 0.94 | 0.9  | 0.85 | 0.84 | 0.85 | 0.84 |
| 152 | 1   | 0.95 | 0.85 | 1    | 1    | 1    | 1    | 1    | 0.96 | 0.92 | 0.9  | 0.86 | 0.84 | 0.84 | 0.8  |
| 164 | 1   | 0.95 | 0.84 | 0.8  | 1    | 1    | 1    | 1    | 0.93 | 0.89 | 0.84 | 0.84 | 0.82 | 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  | 2.3  | 2.8  | 3.3  | 3.8  | 4.3  | 4.8  | 5.3  | 5.8  | 6.3  | 6.8  | 7.3  | 7.8  | 8.3  |
| 61  | 1.9 | 2.4  | 2.9  | 3.4  | 3.9  | 4.4  | 4.9  | 5.4  | 5.9  | 6.4  | 6.9  | 7.4  | 7.9  | 8.4  | 8.9  |
| 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 | 100  | 11.1 | 9.1  | 9.5  | 10   | 10.5 | 11.7 | 13   | 14   | 15.1 | 16.2 | 17.4 | 18.8 | 20.2 |
| 106 | 100 | 100  | 100  | 100  | 25.3 | 17.1 | 15   | 20   | 20.4 | 21.9 | 23.1 | 24.7 | 28   | 29.5 |      |
| 118 | 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    | 5    | 12   | 25   | 41   | 41   | 48   | 48   | 49   | 45   | 48   |
| 49  | 10  | 2    | 5    | 5    | 5    | 5    | 5    | 5    | 4    | 4    | 4    | 4    | 4    | 4    | 4    |
| 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   | 14   | 13   | 0    | 46   | 46   | 50   | 50   | 50   | 50   | 48   |
| 95  | 0   | 0    | 3    | 9    | 8    | 14   | 11   | 11   | 7    | 7    | 50   | 50   | 50   | 50   | 49   |
| 106 | 0   | 0    | 0    | 0    | 5    | 10   | 0    | 0    | 1    | 5    | 50   | 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    | 0    | 49   | 50   | 50   | 36   | 45   | 49   | 50   |
| 141 | 0   | 0    | 0    | 0    | 0    | 0    | 0    | 0    | 49   | 50   | 50   | 36   | 45   | 49   | 50   |
| 152 | 0   | 0    | 0    | 0    | 0    | 0    | 0    | 0    | 49   | 50   | 50   | 36   | 45   | 49   | 50   |
| 164 | 0   | 0    | 0    | 0    | 0    | 0    | 0    | 0    | 49   | 49   | 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 | 0.5  | 10   | 10   | 10   | 10   | 10   | 10   | 10   | 10   | 10   | 10   | 10   | 10   | 10   |
| 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 | 60.3 | 81.5 | 100  | 100  | 100  | 100  | 100  | 100  | 100  |
| 129 | 0.3 | 0.3  | 0.3  | 10.4 | 21.6 | 31.9 | 43   | 58.1 | 63.9 | 69.9 | 74   | 76.4 | 79.5 | 82   | 84.4 |
| 141 | 0.3 | 0.3  | 0.3  | 7.3  | 16.5 | 24   | 33.9 | 47   | 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   | 26   | 5    | 5    | 4    | 2    | 6    | 6    | 6    | 10   | 18   |
| 49  | 18  | 28   | 32   | 32   | 29   | 29   | 5    | 5    | 5    | 5    | 2    | 1    | 11   | 16   | 17   |
| 61  | 27  | 28   | 10   | 5    | 5    | 5    | 5    | 5    | 5    | 7    | 2    | 1    | 11   | 16   | 17   |
| 72  | 0   | 23   | 2    | 0    | 5    | 6    | 0    | 0    | 1    | 13   | 20   | 16   | 9    | 9    | 18   |
| 84  | 0   | 8    | 10   | 6    | 6    | 6    | 0    | 0    | 1    | 15   | 15   | 9    | 8    | 9    | 2    |
| 95  | 0   | 0    | 11   | 5    | 10   | 10   | 10   | 10   | 10   | 9    | 9    | 8    | 8    | 8    | 7    |
| 106 | 0   | 0    | 7    | 0    | 0    | 3    | 0    | 0    | 0    | 25   | 8    | 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    | 0    | 10   | 20   | 9    | 8    | 8    | 7    | 3    |
| 141 | 0   | 0    | 7    | 7    | 0    | 0    | 0    | 0    | 10   | 27   | 15   | 8    | 8    | 7    | 3    |
| 152 | 0   |      |      |      |      |      |      |      |      |      |      |      |      |      |      |





# 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?