# Vehicular Engine Design – Extra Material

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Chapter 1: The Internal Combustion Engine – An Introduction

Problem 1.1: Calculate Total Engine Displacement

Given the following dimensions of a four-stroke engine, calculate the total swept displacement of the engine. Determine whether it is more effective to increase bore or stroke to increase engine displacement.

\[
\text{Bore diameter} = 86\text{mm} \\
\text{Piston stroke} = 86\text{mm} \\
\text{Number of cylinders} = 4
\]

\[
\text{Displacement/Cylinder} = \frac{\pi (\text{Bore})^2 (\text{Stroke})}{4}
\]
It is more effective to increase engine bore, as total engine displacement rises as the square of this dimension.

**Problem 1.2: Calculate Engine Power for Engine Torque at Speed**

Given the same engine produces 179 N-m of torque at 4,800rpm, calculate the power at this engine speed:

\[
P(kW) = (T \cdot N - m) \cdot (N \text{ rpm})
\]

\[
P(kW) = (179 N - m) \cdot (4,800 \text{ rev/min}) \cdot \left(\frac{1 \text{ min}}{60 \text{ s}}\right) \cdot \left(\frac{2\pi}{\text{rev}}\right) \cdot \left(\frac{1kW}{1000N - m/s}\right) = 90kW
\]

**Problem 1.3: Calculate BMEP from Power**

Given the same four-stroke engine produces 90kW at 4,800rpm, calculate the brake mean effective pressure:

\[
BMEP = \left[\frac{\text{(brake power) \cdot (rev/cycle)}}{(D) \cdot (N)}\right]
\]

\[
BMEP = \left[\frac{(90kW) \cdot (2 \text{ rev/cycle})}{(2.0L) \cdot (4,800 \text{ rev/min})}\right] \cdot \left[\frac{60s}{1\text{min}}\right] \cdot \left[\frac{1,000 N - m/s}{1kW}\right] \cdot \left[\frac{1L}{0.001m^3}\right] \cdot \left[\frac{1Pa}{N/m^2}\right] = 1125kPa
\]
Problem 1.4: Calculate Volumetric Efficiency from Air Flow Rate

Given the same four-stroke engine with air density at sea level, calculate the volumetric efficiency:

$$\dot{m}_{actual} = 0.088 \text{ kg/s}$$
$$\rho_{ref} = 1.225 \text{ kg/m}^3$$

$$\eta_{vol} = \left[ \frac{\dot{m}_{actual}}{\dot{m}_{ideal}} \right] = \left[ \frac{\dot{m}_{actual}}{(\rho_{ref} \cdot \frac{(D \cdot (N \text{ rpm}))}{2 \text{rev/cycle}})} \right]$$

$$\eta_{vol} = \left[ \frac{0.088 \text{ kg/s}}{(1.225 \text{ kg/m}^3) \cdot \left( \frac{(2 \text{L}) \cdot (4,800 \text{ rpm})}{2 \text{rev/cycle}} \right)} \right] \cdot \left( \frac{1.0 \text{L}}{0.001 \text{m}^3} \right) \cdot \left( \frac{60 \text{s}}{1 \text{min}} \right) = 90\%$$

Chapter 2: Engine Maps, Customers and Markets

Problem 2.1: Choose a Desired Torque Curve for an Existing Market

Choose a desire torque curve shape, peak torque value, and peak torque engine speed for an existing market and justify the choices. Explain the impact of the following factors:

- Customer expectations
- Fuel choice
- Anticipated duty cycle
- Engine cost
Chapter 3: Engine Validation and Reliability

Problem 3.1: none

Chapter 4: The Engine Development Process

Problem 4.1: Compare Development Methodologies

Describe how your company’s development methodology differs from the example shown. Does the described company product more clean-sheet engines, or more engine application projects? How long is the Concept Study Phase, and is this considered part of the time to deliver a new engine? Does the size and cost of prototypes influence the method for the Prototype Development phase? How many iterations of prototype build are conducted prior to start of production? If a prototype is large and expensive, a company may favor simulation versus producing a prototype to validate loading and duty cycle. How important is NVH refinement to the chosen market and company brand?

Chapter 5: Determining Displacement

Problem 5.1: none

Chapter 6: Engine Configuration and Balance

Problem 6.1: Choose Engine Configuration

Choose an industry and describe why a certain engine configuration is dominant, and why a certain fuel type is dominant. Consider the following:

- Customer expectations
Problem 6.2: Calculate Compression Ratio

Calculate the static compression ratio given the engine dimensions below. Calculate with and without the head gasket thickness to determine if it is a significant contribution.

\[ \text{Bore diameter} = 86 \text{mm} \]
\[ \text{Piston stroke} = 86 \text{mm} \]
\[ \text{Head gasket thickness} = 1.4 \text{mm} \]
\[ \text{Volume of combustion chamber} = 50 \text{cm}^3 \]

\[
V_{cyl} = \frac{\pi (\text{Bore})^2 (\text{Stroke})}{4}
\]
\[
V_{cyl} = \left[ \frac{\pi (86\text{mm})^2 (86\text{mm})}{4} \right] \times \left[ \frac{1\text{cm}}{10\text{mm}} \right]^3 = 500 \text{cm}^3
\]

\[
V_{gasket} = \frac{\pi (\text{Bore})^2 (\text{thickness})}{4}
\]
\[
V_{gasket} = \left[ \frac{\pi (86\text{mm})^2 (1.4\text{mm})}{4} \right] \times \left[ \frac{1\text{cm}}{10\text{mm}} \right]^3 = 8.1 \text{cm}^3
\]

\[
\text{Compression Ratio} = \frac{V_{cc} + V_{cyl}}{V_{cc}}
\]
\[
\text{Compression Ratio} = \frac{(50\text{cm}^3 + 8.1\text{cm}^3) + 500\text{cm}^3}{(50\text{cm}^3 + 8.1\text{cm}^3)} = 9.6
\]
The head gasket thickness makes a significant contribution to the calculation of compression ratio.

Chapter 7: Cylinder Block and Head Materials and Manufacturing

Problem 7.1: Choose Engine Configuration

Choose an industry and describe reasons to choose block and head materials and manufacturing methods. Consider the following:

- Component cost, including materials and manufacturing method
- Anticipated duty cycle
- Engine center of gravity effect on vehicle
- Thermal conductivity

Chapter 8: Cylinder Block Layout and Design Decisions

Problem 8.1: Calculate Minimum Deck Height, Minimum Clearance Piston-to-Crankshaft

Calculate the minimum deck height for a single cylinder engine at TDC, and minimum piston-to-crankshaft clearance at BDC, assuming the following dimensions. Now increase stroke length 6mm and recalculate deck height and piston clearance. What changes must be made?

\[
\text{Piston stroke} = 86\text{mm} \\
\text{Connecting rod length} = 136.3\text{mm} \\
\text{Piston crown height} = 30\text{mm} \\
\text{Piston skirt length} = 28\text{mm}
\]
The deck height will need to get taller or the piston crown height will need to get smaller with increasing stroke. To ensure minimum piston-to-crankshaft clearance is maintained, the connecting rod will need to be made longer, the piston skirt length will need to get shorter, or the crankshaft counterweight radius will need to decrease. None of these changes are easy to make once an engine is designed.

\[ \text{Clearance margin} = 2\text{mm} \]

\[ \text{Crankshaft counterweight radius} = 60\text{mm} \]

\[
\text{Min deck height} = \frac{\text{Stroke}}{2} + \text{Conrod length} + \text{Piston crown height}
\]

\[
\text{Min deck height} = \frac{86\text{mm}}{2} + 136.3\text{mm} + 30\text{mm} = 209.3\text{mm}
\]

**Minimum Piston to Crank Clearance at BDC**

\[ C_{\text{max}} = L - p - \frac{S}{2} - R - \text{margin} \]

\[ \text{Min clearance piston} - \text{to} - \text{crankshaft} \]

\[ = \text{Conrod length} - \text{Piston skirt} - \frac{\text{stroke}}{2} - \text{counterweight radius} - \text{margin} \]

\[
\text{Min clearance piston} - \text{to} - \text{crankshaft} = 136.3\text{mm} - 28\text{mm} - \frac{86\text{mm}}{2} - 60\text{mm} - 2\text{mm}
\]

\[ = 3.3\text{mm} \]
Problem 8.2: Choose a Cylinder Liner Technology

Choose an engine architecture that is common in your industry, and describe the reasons why a particular cylinder liner technology is used. What impact will the liner choice have on overall engine dimensions? What impact will this have on engine block architecture and manufacturing methods? What impact will this have on head gasket design? Consider the following:

- Engine Cost
- Engine Weight
- Engine Configuration
- Engine Cooling and Duty Cycle
- Ability to Service Rebuild engine
- Material for engine block

Problem 8.3: Estimate Cooling Flow Requirements

Estimate cooling flow requirements for the cylinder block, assuming a 50/50 mix of water and Ethylene Glycol, and a 5°C increase in coolant temperature. Recalculate using only water, and describe the reason to use a mix.

\[
LHV \text{ of gasoline} = 43.5 \text{ MJ/kg}
\]

\[
c_{p,\text{coolant}} = 3.62 \text{ kJ/kg} \cdot \text{°C}
\]

\[
c_{p,\text{water}} = 4.19 \text{ kJ/kg} \cdot \text{°C}
\]

\[
\rho_{\text{coolant}} = 1038 \text{ kg/m}^3
\]

\[
\rho_{\text{water}} = 1000 \text{ kg/m}^3
\]

\[
BSFC \text{ at 4,800rpm} = 0.250 \frac{\text{kg}}{\text{kW} \cdot \text{hr}}
\]

\[
\text{Engine power} = 90 \text{kW}
\]

\[
Q_{\text{coolant}} = \frac{q_{\text{heat}}}{c_p \Delta t_{\text{coolant}} \rho_{\text{coolant}}}
\]
While using only water in the cooling system improves the ability to absorb heat, it is insufficient at the extremes of operating temperature. Adding Ethylene Glycol or Propylene Glycol improves operating range by raising the boiling point, and lowering the freezing point. However, adding Ethylene Glycol increases the viscosity of the coolant by up to 50%, which increases pumping losses.

Chapter 9: Cylinder Head Layout and Design

Problem 9.1: Calculate Intake Valve Geometry

Determine the initial size for the intake valve and stem for a 4-valve per cylinder head.

Bore diameter, piston diameter = 86mm

\[
\frac{D_{\text{intake}}}{D_{\text{piston}}} \approx 0.35 \text{ } \rightarrow \text{ } 0.42
\]

\[
D_{\text{intake}} = D_{\text{piston}} \times 0.4 = 34.4\text{mm intake head diameter}
\]

\[
\frac{D_{\text{intake}}}{D_{\text{stem}}} \approx 0.58 \text{ } \rightarrow \text{ } 7.0
\]

\[
D_{\text{stem}} = \frac{D_{\text{intake}}}{0.58} = 6.0\text{mm intake valve stem diameter}
\]
Problem 9.2: Calculate Intake Valve Performance

Determine the value maximum lift, valve curtain area, and discharge coefficient given:

Measure effective flow area = 620mm²

\[ \text{Max. Intake Valve Lift } \approx \frac{L_{V,\max}}{D_{\text{intake}}} \approx 0.25 - 0.31 \]

\[ L_{V,\max} = D_{\text{intake}} \times 0.28 = 34.4mm \times 0.28 = 9.6mm \text{ max lift} \]

\[ \text{Valve Curtain Area } = (\pi \times D_{\text{intake}}) \times L_{V,\max} = (\pi \times 34.4mm) \times 9.6mm = 1037mm² \]

\[ \text{Discharge Coefficient } = C_D = \frac{A_e}{(\pi \times D_{\text{intake}}) \times L_{V,\max}} = \frac{622mm²}{1037mm²} = 0.6 \]

Chapter 10: Block and Head Development

Problem 10.1: None

Chapter 11: Engine Bearing Design

Problem 11.1: None, example in text
Chapter 12: Engine Lubrication

Problem 12.1: Describe a Lubrication System

Describe a lubrication system in an existing engine, and note its strengths and weaknesses. Was an open or closed lubrication circuit chosen, wet sump or dry sump? Which oil viscosity is chosen and why? Is a piston jet or oil cooler chosen, why or why not? What style of oil pump is used, and where is it driven from? Any special consideration for engine installation in multiple different vehicles? What oil pan construction was chosen?

Chapter 13: Engine Cooling

Problem 13.1: Describe a Cooling System

Describe a cooling circuit in an existing engine, and note its strengths and weaknesses. Which type of cooling circuit is used, and how does this impact engine packaging in the vehicle? What type of cylinder liner is used? What is the order of the coolers in the vehicle (intercooler, oil cooler, radiator, power steering cooler) and why? What type of coolant pump is used and why (radial flow, axial flow, mechanical or electric)? Where is the radiator cap placed, and are there special provisions made to bleed air from the system?

Chapter 14: Gaskets and Seals

Problem 14.1: Calculate Average Contact Stress and Design Margin

Determine the average sealing contact stress and design margin for a graphite head gasket in a single cylinder application. Is the design margin sufficient, and what steps can be taken to improve it? What other design considerations should be factored into the design?

\[ \text{Bore diameter} = 100\text{mm} \]
In order to increase the design margin to greater than 1.0, the fastener clampload would need to increase to 60kN, or an additional fastener would need to be added. Alternately, the outer diameter of the gasket could be reduced to 134mm in diameter.

In an application such as a head gasket, internal pressure is applied due to combustion, which will reduce the average sealing contact stress. Additionally, differential thermal expansion may change the fastener clampload. Finally, the tightening strategy chosen may reduce the actual clampload per fastener to less than designed, if high variability is present.

### Chapter 15: Pistons and Rings

### Problem 15.1: Choose a Piston and Ring Configuration

Choose an existing engine application and select an appropriate piston and ring package. What piston material is used? What impact does the cylinder liner material have on ring selection? What piston crown geometry is chosen, and how is this driven by fuel choice? How does piston ring geometry and ring tension affect engine friction and emissions?
Chapter 16: Cranktrain (Crankshafts, Connecting Rods, and Flywheel)

Problem 16.1: Select Crankshaft and Connecting Rod Arrangement

Describe an existing engine arrangement and explain why the crankshaft and connecting rod configurations were chosen. Is a one-piece or assembled crankshaft used, was a one-piece or assembly connecting rod used? How does the number of cylinders, bearing choice, and design of the lubrication system, affect these choices? Describe the accessories driven by the cranktrain and how power is transferred to the rest of the driveline. What effect does rod/stroke ratio (λ) have on overall engine packaging, and connecting rod loading?

Problem 16.2: See additional examples in extended Chapter 16.

Chapter 17: Camshafts and the Valve Train

Problem 17.1: Choose a Valvetrain Configuration for an Engine Upgrade

Choose an existing engine, and decide how best to upgrade the power output, while limiting changes primarily to the cylinder head assembly. How would you most economically increase the engine performance? Change from Overhead Valve (OHV) to Overhead Camshaft (OHC), increase the number of valves, change the valve train lift arrangement to increase stability at higher engine speeds? Describe how number of valves per cylinder and valve train arrangement impacts valve acceleration and load. What changes would be required to the valve train drive system?