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Introduction to Internal Combustion Engines

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Preface

This book aims to provide for students and engineers the background that is presupposed in many articles, papers and advanced texts. Since the book is primarily aimed at students, it has sometimes been necessary to give only outline or simplified explanations. However, numerous references have been made to sources of further information.

Internal combustion engines form part of most thermodynamics courses at Polytechnics and Universities. This book should be useful to students who are following specialist options in internal combustion engines, and also to students at earlier stages in their courses – especially with regard to laboratory work.

Practising engineers should also find the book useful when they need an overview of the subject, or when they are working on particular aspects of internal combustion engines that are new to them.

The subject of internal combustion engines draws on many areas of engineering: thermodynamics and combustion, fluid mechanics and heat transfer mechanics, stress analysis, materials science, electronics and computing. These disparate areas are drawn together in the first eight chapters, so that these chapters are best read in sequence. However, internal combustion engines are not just subject to thermodynamic or engineering considerations – the commercial (marketing, sales etc.) and economic aspects are also important, and these are discussed as they arise.

Chapter 1 provides an introduction, with definitions of engine types and operating principles. The essential thermodynamics is provided in chapter 2, while chapter 3 provides the background in combustion and fuel chemistry. The differing needs of spark ignition engines and compression ignition engines are discussed in chapters 4 and 5 respectively.

Chapter 6 describes how the induction and exhaust processes are controlled, and this leads to chapter 7, where turbochargers are discussed. The remaining chapters can be read in parallel with the earlier chapters. Some of the mechanical and materials aspects are discussed in chapter 8, while chapter 9 covers some experimental techniques. Finally, chapter 10 provides three case studies that should remain topical for some time.

This book is the product of information gained from numerous sources, and it would be invidious to acknowledge individuals. However, I should like to express my gratitude to Dr Neil Watson of Imperial College, London, and to Dr Neil Richardson of Jesus College, Oxford, for reading and commenting on the drafts. I must also express my thanks to the typists, in particular to Mrs Gill Oxley who typed most of the material.

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Autumn 1984

RICHARD STONE

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Notation

a	sonic velocity (m/s)
abdc	after bottom dead centre
atdc	after top dead centre
A	piston area (m ²)
A_c	curtain area for poppet valve (m ²)
A_e	effective flow area (m ²)
A_f	flame front area (m ²)
A_o	orifice area (m ²)
A/F	air/fuel ratio
bbdc	before bottom dead centre
bdc	bottom dead centre
bmep	brake mean effective pressure (N/m ²)
btdc	before top dead centre
BHP	brake horse power
c_p	specific heat capacity at constant pressure (kJ/kg K)
c_v	specific heat capacity at constant volume (kJ/kg K)
C_D	discharge coefficient
C_o	orifice discharge coefficient
C_p	molar heat capacity at constant pressure (kJ/kg K)
C_v	molar heat capacity at constant volume (kJ/kg K)
CI	compression ignition
CV	calorific value (kJ/kg)
dc	direct current
dohc	double overhead camshaft
D_v	valve diameter (m)
DI	direct injection (compression ignition engine)
E	absolute internal energy (kJ)
EGR	exhaust gas recirculation
f	fraction of exhaust gas residuals
ff	turbulent flame factor
fwd	front wheel drive
g	gravitational acceleration (m/s ²)

G	Gibbs function (kJ)
h	specific enthalpy (kJ/kg); manometer height (m)
h_d	mean height of indicator diagram (m)
H	enthalpy (kJ)
$imep$	indicated mean effective pressure (N/m ²)
I	current (A)
IDI	indirect injection (compression ignition engine)
jv	just visible (exhaust smoke)
k	constant
K	equilibrium constant
l	length, connecting-rod length (m)
l_b	effective dynamometer lever arm length (m)
l_d	indicator diagram length (m)
L	stroke length (m); inductance (H)
L_D	duct length (m)
L_v	valve lift (m)
LDA	laser Doppler anemometer
LDV	laser Doppler velocimeter
m	mass (kg)
$\dot{m}_a$	air mass flow rate (kg/s)
$\dot{m}_f$	fuel mass flow rate (kg/s)
m_r	reciprocating mass (kg)
M	mutual inductance (H)
MBT	minimum (ignition) advance for best torque (degrees)
n	number of moles/cylinders
N^*	rev./s for 2-stroke, rev./2s for 4-stroke engines
N'	total number of firing strokes/s ($\equiv n.N^*$)
Nu	Nusselt number (dimensionless heat transfer coefficient)
ohc	overhead camshaft
ohv	overhead valve
p	pressure (N/m ²)
p'	partial pressure (N/m ²)
$\bar{p}_b$	brake mean effective pressure (N/m ²)
Pr	Prandtl number (ratio of momentum and thermal diffusivities)
Q	heat flow (kJ)
r	crankshaft throw ($\equiv \frac{1}{2}$ engine stroke) (m)
r_v	volumetric compression ratio
R	specific gas constant (kJ/kg K)
R_0	molar (or universal) gas constant (kJ/kmol K)
Re	Reynolds number
s	specific entropy (kJ/kg K)
sfc	specific fuel consumption (MJ/kg)
SI	spark ignition
t	time (s)

tdc	top dead centre
T	absolute temperature (K); torque (N m)
T_0	absolute temperature of the environment (K)
U_1	laminar flame front velocity (m/s)
U_t	turbulent flame front velocity (m/s)
v	velocity (m/s)
v_p	mean piston velocity (m/s)
V	volume (m^3)
$\dot{V}_a$	volumetric flow rate of air (m^3/s)
V_s	engine swept volume (m^3)
wmmp	weakest mixture for maximum power
W	work (kJ)
$\dot{W}$	power (kW)
W_b	brake work (kJ)
W_c	compressor work (kJ)
W_f	friction work (kJ)
W_i	indicated work (kJ)
W_{REV}	work output from a thermodynamically reversible process (kJ)
W_t	turbine work (kJ)
WOT	wide open throttle
x	a length (m); mass fraction
α	cut off (or load) ratio
γ	ratio of gas heat capacities, c_p/c_v or C_p/C_v
ΔH_0	enthalpy of reaction (combustion) $\equiv -CV$
Δp	pressure difference (N/m^2)
$\Delta\theta_b$	combustion duration (crank angle, degrees)
ϵ	heat exchanger effectiveness = (actual heat transfer)/(max. possible heat transfer)
η	efficiency
η_b	brake thermal efficiency $\equiv \eta_o$
η_c	isentropic compressor efficiency
η_{Diesel}	ideal air standard Diesel cycle efficiency
η_{FA}	fuel-air cycle efficiency
η_i	indicated (arbitrary overall) efficiency
η_m	mechanical efficiency
η_o	arbitrary overall efficiency
η_{Otto}	ideal air standard Otto cycle efficiency
η_R	rational efficiency, W/W_{REV}
η_t	isentropic turbine efficiency
η_v	volumetric efficiency
θ	crank angle (degrees)
θ_0	crank angle at the start of combustion (degrees)
μ	dynamic viscosity ($\text{N s}/\text{m}$)
ρ	density (kg/m^3)

ρ_u	density of the unburnt gas (kg/m ³)
ϕ	equivalence ratio = (stoichiometric air/fuel ratio)/(actual air/fuel ratio) (<i>note that</i> sometimes the reciprocal definition is used in other publications)
ω	specific humidity (kg water/kg dry air); angular velocity (rad/s)