

CONTENTS

Chapter	Page
PREFACE	vii
SYMBOLS	xiii
I DEVELOPMENT OF THE EQUATIONS	
1.1 Introduction	1
1.2 Properties of the electrically conducting fluid	1
1.3 Magnetohydrodynamic equations	4
1.4 Formulas for signal voltage	7
1.5 Selection of an instrument	11
II MAGNETIC FIELD BALANCE	
2.1 Introduction	13
2.2 Balance for instruments with DC primary field	13
2.3 Balance for instruments with AC primary field	14
III TYPICAL IONIZED GAS FLOWS AND INSTRUMENTATION APPLICATIONS	
3.1 Introduction	17
3.2 Discussion of plasma sheath	17
3.2.1 Parameters influencing the plasma sheath	18
3.2.2 Parameters characterizing the plasma sheath	18
3.3 Magnetohydrodynamic power generation	20
3.4 Wakes of projectiles at hypersonic speeds	21
3.5 Plasma of rocket exhausts	22
3.6 Ionization in shock tubes	23
3.7 Arc plasma generators	23
IV PLASMA PROPERTIES MEASURED BY INDUCTIVE FLOW INSTRUMENTS	
4.1 Introduction	28
4.2 Average σU transducers	28
4.3 Electrical conductivity/velocity profile instruments	28
4.4 Flow angle indicator	29
4.5 Average electron collision frequency	30
4.6 Velocity measurement and turbulence indicator	31

CONTENTS

Chapter		Page
V	AVERAGE AND PROFILE σU TRANSDUCERS	
5.1	Measuring the influence function	34
5.2	Average σU transducers	35
5.2.1	Additional design features	35
5.2.2	Example of an average σU transducer	37
5.3	Electrical conductivity/velocity profile transducer	38
5.3.1	Requirements on the influence function	38
5.3.2	Vector analogy	40
5.4	Three different coil geometries for σU profile transducers	42
5.4.1	<i>E</i> -Lamination transducer with multiple sensing coils	42
5.4.2	Three-signal concentric coil arrangement	44
5.4.3	Nine-signal coil arrangement	44
5.4.4	Results of a test with the three-signal transducer	48
VI	TRANSDUCERS FOR ROCKET EXHAUSTS, ARC PLASMA JETS AND AXISYMMETRIC REENTRY VEHICLES	
6.1	Description of the transducer	50
6.2	Influence function in cylindrical coordinates	51
6.3	Interpretation of the radial average	53
6.4	Axial gradients	54
6.5	Calibration procedure for internal flow	57
6.5.1	Measurement of calibration constant	57
6.5.2	Measurement of influence function	58
6.5.3	Eddy current experiment	60
6.6	Calibration procedure for external flow	61
VII	TRANSDUCERS FOR TRANSIENT FLOWS; SHOCK TUBES AND BALLISTIC RANGES	
7.1	Introduction	65
7.2	Theory	65
7.2.1	Calibration using a conducting rod	67
7.2.2	Integration circuit	69
7.2.3	Calibration using a thin, electrically conducting disc	70
7.3	Design features	72
7.4	Conductivity measurements at R_m greater than unity	74
VIII	FLOW ANGLE INDICATOR	
8.1	Introduction	77
8.2	Dependence of the signal on flow angle relative to the transducer	77
8.3	Description of transducers and test apparatus	81
8.4	Experimental results	81
8.4.1	<i>E</i> -Lamination transducer	81
8.4.2	Pancake coil geometry	83
8.5	Zero angle of attack sensor	84

CONTENTS

Chapter		Page
IX	AVERAGE ELECTRON COLLISION FREQUENCY INSTRUMENT	
9.1	Introduction	87
9.2	Electrical conductivity tensor	87
9.3	Voltage induced in the sensing coil	89
9.3.1	Signal from <i>E</i> -Lamination transducer	90
9.3.2	Signal from pancake-coil transducer	91
9.3.3	Signal for flow normal to reference axis of transducer	92
9.4	Measurement of collision frequency	92
9.5	Summary	93
X	TURBULENCE AND VELOCITY	
10.1	Introduction	94
10.2	Theoretical background	95
10.2.1	Formula for the sensing coil voltage	95
10.2.2	Estimate of signal magnitude	95
10.3	Apparatus and typical results	95
10.4	Discussion of results	99
10.5	Turbulence indicator	101
XI	STEADY MAGNETIC FIELD INSTRUMENTS FOR STEADY FLOWS	
11.1	Introduction	105
11.2	Detectors	105
11.2.1	Fluxgate magnetometers	105
11.2.2	Hall effect detector	107
11.2.3	Comparison of fluxgate and Hall detector for flight applications	107
11.3	Relation of signal to plasma properties	108
11.4	Design features	109
11.4.1	Transducer geometry and circuit diagram	109
11.4.2	Refinements to the instrument	111
11.5	Design for MHD generators and accelerators	113
11.6	Summary	114
XII	OTHER DIAGNOSTIC INSTRUMENTS	
12.1	Introduction	115
12.2	Interlocked toroids for closed systems	115
12.3	Radio frequency transducers	116
12.3.1	Relevant parameters	116
12.3.2	Analysis of infinite solenoid	116
12.3.3	Analysis of single loop	121
12.3.4	Radio frequency bridges	126
12.3.5	Phase angle and impedance change; a combination electrical and velocity transducer	130
12.3.6	Solenoid with sensing coil	131
12.3.7	Conductivity from change in phase angle	132

CONTENTS

Chapter	Page
12.3.8 Impedance change due to plasma	134
12.3.9 Conductivity measurement from power dissipation	137
12.3.10 Change in resonant frequency	142
12.3.11 Relation of Q to electrical conductivity	144
12.3.12 Summary of RF methods	147
12.4 Langmuir probes	147
12.4.1 Conventional Probe Theory	147
12.4.2 Probe Theory for Moving Plasma	152
12.4.3 Modified Langmuir Probes	154
12.5 Electromagnetic flow meters with electrodes	155
12.6 Measurement of electrical conductivity using electrodes	155
12.7 Microwaves as a diagnostic tool	155

APPENDICES

A DESCRIPTION OF MHD PROFILE METER AND TRANSITION INDICATOR FOR A REENTRY VEHICLE

A.1 Design guidelines	163
A.2 Block diagram of instrument	165
A.3 Transducer assembly	168
A.4 Performance of instrument	168

B DESIGN FEATURES OF AXIAL FLOW TRANSDUCER FOR ROCKET EXHAUST

AUTHOR INDEX 175

SUBJECT INDEX 179

TABLE OF CONSTANTS AND CONVERSION FACTORS *inside*

TABLE OF MAGNETOHYDRODYNAMICS AND PLASMA FORMULAE *front cover*
inside
back cover