



RADAR, SONAR, NAVIGATION & AVIONICS 8

AVIATION WEATHER SURVEILLANCE SYSTEMS

advanced radar and
surface sensors for
flight safety and
air traffic
management



PRAVAS MAHAPATRA

The Institution of Electrical Engineers

Contents

Preface	xiii
Acknowledgments	xv
Abbreviations	xvii
Symbols	xxi
1 Introduction	1
1.1 Aviation and electronics: a symbiotic relationship	1
1.2 Phases in evolution of aircraft navigation	2
1.3 Modern aviation weather surveillance	4
1.4 Scope and organisation of the book	5
1.5 References	9
2 Basic background of aviation	11
2.1 Goal of aviation systems	11
2.2 Phases of aircraft flight	11
2.2.1 Terminal area operations	12
2.2.2 <i>En route</i> operations	14
2.3 Mechanics of aircraft flight	14
2.4 Aircraft navigation systems	21
2.4.1 <i>En route</i> navigation: dead-reckoning systems	23
2.4.2 <i>En route</i> navigation: position fixing systems	24
2.4.3 Aircraft landing guidance systems	25
2.5 Air traffic control and air traffic services	26
2.6 Radars in aircraft navigation and air traffic control	29
2.7 Aeronautical communication systems	32
2.8 Summary	34
2.9 References	35
3 Atmospheric effects on aviation	37
3.1 Weather as a factor in aviation	37

3.2 Overall effects of weather on aviation	37
3.2.1 Safety	37
3.2.2 Comfort	38
3.2.3 Schedule-keeping	39
3.2.4 Efficiency	40
3.2.5 Economy	40
3.2.6 Combination of factors	41
3.3 Atmospheric phenomena involving air motion	42
3.3.1 Wind shear	43
3.3.2 Turbulence	50
3.4 Hydrometeorological phenomena	57
3.4.1 Rain	59
3.4.2 Snow	60
3.4.3 Hail	61
3.5 Aircraft icing	61
3.6 Low visibility	67
3.7 Atmospheric electrical phenomena	69
3.8 Need for improved aviation weather information	72
3.9 Summary	74
3.10 References	75
Origins of harmful atmospheric effects on aircraft	79
4.1 General	79
4.2 Structure of atmosphere	79
4.3 Thunderstorms: nature, initiation and evolution	81
4.4 Thunderstorm parameters	85
4.5 Phenomena associated with thunderstorms	86
4.5.1 Divergence and convergence	87
4.5.2 Turbulence	89
4.5.3 Downburst	91
4.5.4 Cyclonic motion and tornadoes	91
4.5.5 Rain	93
4.5.6 Hail	93
4.5.7 Lightning, electric fields and atmospheric	95
4.5.8 Icing	97
4.5.9 Poor visibility	97
4.5.10 Overall thunderstorm scenario	98
4.6 Gust fronts and related phenomena	98
4.6.1 Characteristics	99
4.6.2 Outflow-induced waves and bores	101
4.7 Macrobursts and microbursts	105
4.7.1 Microburst types	106
4.7.2 Characteristics	108
4.7.3 Asymmetry	111
4.8 Other sources of atmospheric hazard	111

4.9 Summary	115
4.10 References	115
Requirements of systems for aviation weather surveillance	121
5.1 General	121
5.2 Types of weather surveillance systems for aviation	122
5.2.1 <i>In situ</i> and remote sensing	122
5.2.2 Ground-based, airborne and spaceborne sensors	124
5.3 Spatial coverage	125
5.4 Data update rates	129
5.5 Spatial resolution	130
5.6 Data processing and display systems	132
5.6.1 Stages in data processing	132
5.6.2 Display of aviation weather data	134
5.6.3 Requirements of data processing and display systems	135
5.7 Automated operation	137
5.8 Selection of primary sensors	138
5.8.1 Atmospheric parameters monitored for aviation	138
5.8.2 Primary sensors for modern aviation weather surveillance	139
5.9 Summary	140
5.10 References	141
Doppler weather radar as a primary aviation weather sensor	143
6.1 General	143
6.2 Basic aspects	144
6.2.1 Weather radar resolution	145
6.2.2 Mapping of weather fields	150
6.2.3 Scattering by raindrops and radar reflectivity of weather	154
6.2.4 Radar echoes from clear air	157
6.2.5 Weather attenuation of radar signals	158
6.2.6 Operating frequencies of weather radars	162
6.3 Conventional weather radar	164
6.3.1 Reflectivity measurement: radar range equation	165
6.3.2 Estimation of rain rates	172
6.3.3 WSR-57 radar	178
6.4 Motivation for developing modern weather sensors	180
6.5 Doppler weather radar: basics	181
6.5.1 Basic principle and limitation	182
6.5.2 Atmospheric wind tracers	183
6.6 Doppler weather radar: primary data products	185
6.6.1 Spectral moments of weather echo signals	186
6.6.2 Doppler weather radar system features and architecture	190
6.6.3 Computation of basic data products	194
6.6.3.1 Reflectivity	195
6.6.3.2 Mean radial velocity	197

6.6.3.3	Doppler velocity spectrum width	199
6.6.3.4	Some general aspects of Doppler moment estimation	200
6.6.4	Display of basic products	201
6.6.5	Derivation of vector wind fields	204
6.7	Summary	208
6.8	References	212
Colour plates		215
7	Modern Doppler weather radars for aviation	245
7.1	General	245
7.2	WSR-88D system	246
7.2.1	Architecture	246
7.2.2	Parameters	247
7.2.3	System features	247
7.2.4	Data products	250
7.2.5	Performance	251
7.3	Range and velocity ambiguities	252
7.3.1	Nature of problem	252
7.3.2	Minimisation of range overlays	257
7.3.2.1	Low elevation angles	257
7.3.2.2	Middle elevation angles	257
7.3.2.3	High elevation angles	258
7.3.3	Velocity dealiasing	258
7.3.4	Advanced ambiguity resolution methods	258
7.3.5	Potential and futuristic methods	260
7.3.5.1	Spectral decomposition	260
7.3.5.2	Triple-PRF radar observation	261
7.3.5.3	Staggered PRT scheme	262
7.3.5.4	Random phase transmission	263
7.3.5.5	Systematic discrete phase coding	263
7.3.5.6	Single-pulse Doppler estimation	264
7.4	Other special considerations	264
7.4.1	Coverage	265
7.4.2	Siting for terminal area surveillance	266
7.4.2.1	Resolution	266
7.4.2.2	Range coverage	266
7.4.2.3	Low-altitude coverage	267
7.4.2.4	Zone of blindness	267
7.4.2.5	Range ambiguity and overlaid echoes	268
7.4.2.6	Airport configuration	268
7.4.2.7	Comparison of siting alternatives	269
7.4.3	Scanning strategies and modes	270
7.4.4	Data lag	274
7.4.5	Comparison with air route surveillance radar	274

7.5	Terminal Doppler weather radar (TDWR)	275
7.6	Airport surveillance radar with weather channel	281
7.7	Summary	284
7.8	References	285
Other sensors and systems for aviation weather		289
8.1	General	289
8.2	Wind profilers	290
	8.2.1 Conventional wind profiling	290
	8.2.2 Radar wind profilers	291
8.3	Radio-acoustic sounding systems (RASS)	302
	8.3.1 Basic system	302
	8.3.2 RASS augmentation for sensing aircraft icing conditions	304
8.4	Low-level wind shear alert system (LLWAS)	305
	8.4.1 Concept and basic configuration	306
	8.4.2 Enhanced system	307
8.5	Airborne wind shear detection	309
	8.5.1 <i>In situ</i> sensing	310
	8.5.2 Forward-looking remote sensing	311
8.6	Airborne turbulence measurement	316
8.7	Automated weather observing systems	317
8.8	Radiometric satellite observation	320
8.9	Airport visibility measurement	325
8.10	Summary	330
8.11	References	332
Integrated system approaches		337
9.1	General	337
9.2	Integrated terminal weather system	338
	9.2.1 Data integration	339
	9.2.2 Automated operation and fully processed output	340
	9.2.3 Performance enhancement, versatility and adaptability	341
	9.2.4 Predictive capability	341
9.3	Aviation gridded forecast system	342
9.4	Aviation weather products generator	343
9.5	Summary	348
9.6	References	349
Automatic detection and tracking of hazardous weather features		351
10.1	General	351
10.2	Basis of automated weather feature detection	352
10.3	Thunderstorm cells	353
10.4	Mesocyclones	356
10.5	Gust fronts	363
10.6	Storm outflows and microbursts	369
10.7	Summary	372
10.8	References	373

SPECIAL TOPICS IN AVIATION WEATHER SURVEILLANCE

11 Atmospheric turbulence and its detection by radar	375
11.1 General	375
11.2 Wind shear and turbulence in meteorological events	376
11.2.1 Thunderstorms	377
11.2.2 Thermal plumes	378
11.2.3 K-H waves	379
11.3 Detection of turbulence with Doppler radar	380
11.4 Statistical theory of turbulence	384
11.4.1 Correlation and spectral functions in the inertial subrange	388
11.4.2 Filtering by the radar's weighting function	391
11.4.3 Variance of point and average velocities	395
11.5 Doppler spectrum width and eddy dissipation rate	396
11.6 Eddy dissipation rates in thunderstorms	398
11.7 Avoiding turbulence	400
11.8 Summary	403
11.9 References	404
12 Lightning and aviation	407
12.1 General	407
12.2 Lightning, electric fields and atmospherics	407
12.3 Lightning-aircraft interaction	411
12.4 Weather conditions and lightning strikes to aircraft	418
12.5 Detection and surveillance of lightning phenomena	423
12.6 Lightning threats to aircraft: what else do we need to know?	425
12.7 Summary	425
12.8 References	426
13 Polarisation diversity radars	429
13.1 General	429
13.2 Description	429
13.3 Basic definitions	431
13.4 Propagation effects	432
13.5 Rainfall measurement	434
13.6 Hail detection	438
13.7 Automatic classification and quantification of precipitation	439
13.8 Status and prospects for aviation use	441
13.9 Summary	441
13.10 References	442
Index	445