

PRINCIPLES AND PRACTICE OF AVIATION PSYCHOLOGY

Edited by

Pamela S. Tsang Wright State University

Michael A. Vidulich Air Force Research Laboratory



LAWRENCE ERLBAUM ASSOCIATES, PUBLISHERS Mahwah, New Jersey London

Contents

	Preface	xvii
	Foreword	xix
	Series Foreword	xxiii
	Abbreviations	XXV
1	Introduction to Aviation Psychology Pamela S. Tsang and Michael A. Vidulich	1
	The Changing Role of the Pilot	1
	Early Beliefs of the Pilot's Role in Aviation	1
	The Birth of Scientific Aviation Psychology	2
	The Modern Role of the Pilot	4
	Visualizing the Future Pilot	8
	The Roles of Basic and Applied Research in Aviation Psychology	9
	Basic and Applied Research in Meeting Future Needs	9
	The Role of Basic Research and Theory in Aviation Psychology	
	Practice	10
	Preview of the Chapters	12
	References	18
2	Perception and Attention During Low-Altitude	
-	High-Speed Flight	21
	Ralph Norman Haber and Lyn Haber	• •
	Aerodynamics of Motion: The Effects of Control Inputs on Flight Descriptions of the Position and Movements of Aircraft in Relation	23
	to Control Inputs	24
	Some Sample Maneuvers and Their Associated Time-to-Die and Free Time	26

vii

c

	Sources of Information That Specify Ground Clearance	32
	Visual Information From the Surface of the Terrain	33
	Vestibular Information Arising From Changes in G-Forces	39
	Symbolic Information From Flight Instruments and Displays	40
	Information Acquired Before the Flight	42
	Perceptual Processes: How a Pilot Perceives Ground Clearance	44
	Automatic and Controlled Perceptual Processes	44
	Perceiving a Change in Altitude AGL	46
	Perceiving Absolute Altitude AGL	50
	Perceiving the Velocity Vector in Straight and Level and in	
	Turning Flight	51
	Perceiving Ground Track	55
	Perceiving Distance to Objects in Front of the Plane	56
	Integration of Tasks and Priorities in Low-Altitude Flight	57
	Factors That Affect the Difficulty of Flight Tasks	58
	Factors That Affect the Duration of Tasks	59
	Free Time	62
	A Training Program to Integrate Low-Altitude Tasks With All Other	
	Mission Tasks	64
	Conclusion	65
	References	66
	Acknowledgments	68
		70
3	Spatial Orientation	69
3	Spatial Orientation Laurence R. Young	69
3	Spatial Orientation Laurence R. Young Sensory Bases for Spatial Orientation	69 72
3	Spatial Orientation Laurence R. Young Sensory Bases for Spatial Orientation Visual System	69 72 72
3	Spatial Orientation Laurence R. Young Sensory Bases for Spatial Orientation Visual System Vestibular System	69 72 72 73
3	Spatial Orientation Laurence R. Young Sensory Bases for Spatial Orientation Visual System Vestibular System Other Proprioceptive Sensors	69 72 72 73 80
3	Spatial Orientation Laurence R. Young Sensory Bases for Spatial Orientation Visual System Vestibular System Other Proprioceptive Sensors Auditory Spatial Orientation	72 72 73 80 81
3	Spatial Orientation Laurence R. Young Sensory Bases for Spatial Orientation Visual System Vestibular System Other Proprioceptive Sensors Auditory Spatial Orientation Multisensory Interaction	72 72 73 80 81 82
3	Spatial Orientation Laurence R. Young Sensory Bases for Spatial Orientation Visual System Vestibular System Other Proprioceptive Sensors Auditory Spatial Orientation Multisensory Interaction Spatial Disorientation Illusions	72 72 73 80 81 82 84
3	Spatial Orientation Laurence R. Young Sensory Bases for Spatial Orientation Visual System Vestibular System Other Proprioceptive Sensors Auditory Spatial Orientation Multisensory Interaction Spatial Disorientation Illusions Illusions Attributable Primarily to the Semicircular Canals	72 72 73 80 81 82 84 84
3	Spatial Orientation Laurence R. Young Sensory Bases for Spatial Orientation Visual System Vestibular System Other Proprioceptive Sensors Auditory Spatial Orientation Multisensory Interaction Spatial Disorientation Illusions Illusions Attributable Primarily to the Semicircular Canals Ancillary Effects on SD Illusions	72 72 73 80 81 82 84 84 84
3	Spatial Orientation Laurence R. Young Sensory Bases for Spatial Orientation Visual System Vestibular System Other Proprioceptive Sensors Auditory Spatial Orientation Multisensory Interaction Spatial Disorientation Illusions Illusions Attributable Primarily to the Semicircular Canals Ancillary Effects on SD Illusions Illusions Attributable Primarily to the Otolith Organs	72 72 73 80 81 82 84 84 84 91
3	Spatial Orientation Laurence R. Young Sensory Bases for Spatial Orientation Visual System Vestibular System Other Proprioceptive Sensors Auditory Spatial Orientation Multisensory Interaction Spatial Disorientation Illusions Illusions Attributable Primarily to the Semicircular Canals Ancillary Effects on SD Illusions Illusions Attributable Primarily to the Otolith Organs Visual Illusions	72 72 73 80 81 82 84 84 84 84 91 91
3	Spatial Orientation Laurence R. Young Sensory Bases for Spatial Orientation Visual System Vestibular System Other Proprioceptive Sensors Auditory Spatial Orientation Multisensory Interaction Spatial Disorientation Illusions Illusions Attributable Primarily to the Semicircular Canals Ancillary Effects on SD Illusions Illusions Attributable Primarily to the Otolith Organs Visual Illusions Motion Sickness	72 72 73 80 81 82 84 84 84 89 91 94 99
3	Spatial Orientation Laurence R. Young Sensory Bases for Spatial Orientation Visual System Vestibular System Other Proprioceptive Sensors Auditory Spatial Orientation Multisensory Interaction Spatial Disorientation Illusions Illusions Attributable Primarily to the Semicircular Canals Ancillary Effects on SD Illusions Illusions Attributable Primarily to the Otolith Organs Visual Illusions Motion Sickness Causes of Motion Sickness	69 72 72 73 80 81 82 84 84 84 84 89 91 94 99
3	Spatial OrientationLaurence R. YoungSensory Bases for Spatial OrientationVisual SystemVestibular SystemOther Proprioceptive SensorsAuditory Spatial OrientationMultisensory InteractionSpatial Disorientation IllusionsIllusions Attributable Primarily to the Semicircular CanalsAncillary Effects on SD IllusionsIllusions Attributable Primarily to the Otolith OrgansVisual IllusionsMotion SicknessCauses of Motion SicknessSimulator Sickness	72 72 73 80 81 82 84 84 84 89 91 94 99 100 101
3	Spatial Orientation Laurence R. Young Sensory Bases for Spatial Orientation Visual System Vestibular System Other Proprioceptive Sensors Auditory Spatial Orientation Multisensory Interaction Spatial Disorientation Illusions Illusions Attributable Primarily to the Semicircular Canals Ancillary Effects on SD Illusions Illusions Attributable Primarily to the Otolith Organs Visual Illusions Motion Sickness Causes of Motion Sickness Simulator Sickness Drug Treatment	69 72 72 73 80 81 82 84 84 84 84 89 91 94 99 100 101 102
3	Spatial Orientation Laurence R. Young Sensory Bases for Spatial Orientation Visual System Vestibular System Other Proprioceptive Sensors Auditory Spatial Orientation Multisensory Interaction Spatial Disorientation Illusions Illusions Attributable Primarily to the Semicircular Canals Ancillary Effects on SD Illusions Illusions Attributable Primarily to the Otolith Organs Visual Illusions Motion Sickness Causes of Motion Sickness Simulator Sickness Drug Treatment	69 72 72 73 80 81 82 84 84 84 84 99 91 94 99 100 101 102 102
3	Spatial Orientation Laurence R. Young Sensory Bases for Spatial Orientation Visual System Vestibular System Other Proprioceptive Sensors Auditory Spatial Orientation Multisensory Interaction Spatial Disorientation Illusions Illusions Attributable Primarily to the Semicircular Canals Ancillary Effects on SD Illusions Illusions Attributable Primarily to the Otolith Organs Visual Illusions Motion Sickness Causes of Motion Sickness Simulator Sickness Drug Treatment Space Flight Launch	69 72 72 73 80 81 82 84 84 84 89 91 99 100 101 102 102 103
3	Spatial Orientation Laurence R. Young Sensory Bases for Spatial Orientation Visual System Vestibular System Other Proprioceptive Sensors Auditory Spatial Orientation Multisensory Interaction Spatial Disorientation Illusions Illusions Attributable Primarily to the Semicircular Canals Ancillary Effects on SD Illusions Illusions Attributable Primarily to the Otolith Organs Visual Illusions Motion Sickness Causes of Motion Sickness Simulator Sickness Drug Treatment Space Flight Launch Early-On Orbit	69 72 72 73 80 81 82 84 84 84 84 99 100 101 102 102 103 103
3	Spatial Orientation Laurence R. Young Sensory Bases for Spatial Orientation Visual System Vestibular System Other Proprioceptive Sensors Auditory Spatial Orientation Multisensory Interaction Spatial Disorientation Illusions Illusions Attributable Primarily to the Semicircular Canals Ancillary Effects on SD Illusions Illusions Attributable Primarily to the Otolith Organs Visual Illusions Motion Sickness Causes of Motion Sickness Simulator Sickness Drug Treatment Space Flight Launch Early-On Orbit Extravehicular Activity	69 72 72 73 80 81 82 84 84 84 84 91 94 99 100 101 102 102 103 103 103

	Reentry	106
	Postflight Disturbances	106
	Major Factors Contributing to SD	107
	Night Flying	107
	Shifting Reference Frames and Instrument Flying	107
	Flight Maneuvers and Head Movements	107
	Workload and Capacity	108
	Methods to Minimize SD	108
	Training to Deal With Spatial Disorientation	108
	Cockpit and Instrument Design to Minimize SD	109
	References	109
4	Mental Workload and Situation Awareness:	
	Essential Concepts for Aviation Psychology Practice <i>Michael A. Vidulich</i>	115
	Defining Mental Workload and Situation Awareness	116
	Types of Theoretical Concepts	118
	Models and Measures of Mental Workload and Situation	
	Awareness	121
	Secondary Task Measurement of Mental Workload	122
	Memory Probe Measurement of Situation Awareness	129
	Is There a Relationship Between Mental Workload and	
	Situation Awareness?	133
	Future Directions for Mental Workload and Situation Awareness:	
	Research and Applications	137
	Meta-Measures and Their Uses	137
	Real-Time Human Engineering	138
	Conclusion	140
	References	142
5	Aviation Displays	147
	Christopher D. Wickens	
	Display Principles	148
	Principle of Information Need	148
	Principle of Legibility	149
	Principle of Display Integration/Proximity Compatibility Principle	149
	Principle of Pictorial Realism	152
	Principle of the Moving Part	152
	Principle of Predictive Aiding	153
	Principle of Discriminability: Status Versus Command	154
	Summary and Conclusion	155
	Classic Navigation: The Historic Perspective	155
	Present Navigational Display Environments	157
	Display Integration: The Navigational Display	158
	Ground Proximity warning System (GPWS)	100

۰,۰

	The Traffic Alert and Collision Avoidance System (TCAS)	161
	Conclusions: Cockpit Hazard Warning Systems	162
	Hazard Alerting: The Alarm Issue	162
	Display Overlay, Integration, and Clutter	164
	Procedural Displays: Text, Instrumentation, Checklists	169
	Advanced Display Technology: 3-D Displays	171
	Information-Processing Mechanisms	173
	Aviation Tasks: The Task-Viewpoint Interactions	175
	3-D Displays: Conclusions and Solutions	178
	Advanced Technology: See-Through Displays:	
	The HUD and the HMD	181
	The Head-Up Display	182
	The Helmet-Mounted Display	185
	Automation and Displays	186
	Display Implications of Aircraft Automation and Autopilots	186
	Harnessing Automation for Improved Displays	189
	Conclusion	192
	References	192
	Acknowledgments	200
6	Aeronautical Decision Making: Metaphors, Models,	
	and Methods	201
	David O'Hare	
	Gamblers, Daredevils, Aces, and Romantics	202
	What Is Aeronautical Decision Making (ADM)?	203
	The Decision Maker as Faulty Computer	204
	The Decision Maker as Rational Calculator	208
	The Vigilant Decision Maker	200
	Training Rational Decision Making	210
	Effects of Technology on Rational Decision Making	213
	The Adaptive Decision Maker	215
	The Decision Maker as Character Defective	217
	The Decision Maker as Enquiring Expert	220
	Expertise in ADM	223
	The Decision Maker as Organizational Cog	228
	Conclusion	230
	References	232
	Acknowledgments	237
7	Dilat Actions and Tasks: Solastion Execution	
1	and Control	220
	christopher D. Wickens	437
	Task Choice and Task Management	220
	Cocknit Task Management	239
	Cockpu tusk munugement	241

1

CONTENTS

, т

	Concurrent Activities	245
	Aviation Control	245
	Aviation Control	249
	Control Order and Lag	252
	Gain and Instability	250
	Simplifications	257
	Positive Feedback	257
	Adaptive Flight Control	259
	Flight Control and Task Management	260
	Conclusion	260
	References	260
8	Pilot Control	265
	Ronald A. Hess	
	The Aircraft Control Problem	265
	Pilot Models	268
	Chapter Overview	269
	The Feedback Paradigm in Pilot Control	269
	Mathematical Preliminaries and Inner-Loop Pilot Control	269
	Outer-Loop Pilot Control	279
	Historical Perspectives	284
	Human Sensors, Control Effectors, and Information Processors	286
	Control-Theoretic Models of Pilot Control Behavior	287
	Isomorphic Models	287
	An Algorithmic Model	296
	Utility of Control-Theoretic Pilot Models	298
	An Example Pilot/Vehicle Analysis	300
	The Task and Pilot Model	300
	The Input to the Pilot/Vehicle System	304
	Predicted Pilot/Vehicle Performance and Handling Qualities	304
	Automation and Pilot Control	307
	Concluding Remarks	308
	References	308
0	Automation and Human Parformance in Aviation	311
1	Raia Parasuraman and Evan A Ryrne	511
	Rogeround	211
	Factors Contributing to Effective Human Automation Interaction	212
	Factors Contributing to Effective Human-Automation Interaction	312
	Aviation Automation	313
	Aviation Automation	314
	Definition	314
	Irenas in Aviation Automation	315
	A wodel for types and Levels of Human Interaction	2 47
	With Automation	317
	Automation-Related Incidents in Aviation	320
	Accident Investigation	320

xi

	"Fail Silent" Problems and Unforeseen Limits	321
	Misuse of Automation	322
	Misunderstanding or Lack of Understanding of System	326
	Human Performance in Automated Systems	327
	Situation Awareness	328
	Decision Biases	330
	Trusts in Automation	330
	Mental Workload	335
	Adaptive Automation	338
	Characteristics of Adaptive Systems	338
	Techniques for Adaptive Automation	339
	Benefits of Adaptive Automation	341
	Computational and Formal Methods for Studying	
	Human-Automation Interaction	344
	Standard and Fuzzy Signal Detection Theory	345
	Expected-Value Models	346
	Other Formal Models	347
	Conclusion	348
	References	349
	Acknowledgments	356
10	Pilot Selection Methods	357
	Thomas R. Carretta and Malcolm James Ree	
	What Is Pilot Selection and Why Is It Important?	358
	Overview of Pilot Selection Process	358
	Are Effective Pilots "Selected" or "Trained?"	359
	Validity and Validation Studies	359
	What Is Validity?	359
	What Is a Validation Study?	360
	Common Methodological Issues in Pilot Selection	362
	Misunderstanding Constructs	362
	Lack of Statistical Power	363
	Failure to Cross-Validate	364
	Misinterpretation of Correlations and Regression	365
	Recommendations for Researchers and Practitioners	369
	Military Pilot Selection	370
	Historical Overview	370
	Recent Validation Studies	371
	Current Research	378
•	Commercial Pilot Selection	383
	The Future of Pilot Selection Methods	386
	General Cognitive Ability	386
	Flying Knowledge and Skills	387
	Incrementing the Validity of g	387
	Conclusion	388

*

ŧ

	References Acknowledgments	389 396
		-
11	Training	397
	John Patrick	
	Trends and Contexts of Pilot Training	398
	Increasing Automation	399
	Crew Coordination	401
	Stages of Training Development	402
	Analyzing Tasks and Identifying Training Needs	405
	Traditional Task Analysis	407
	Analysis of Incidents and Errors	409
	Training Objectives	412
	Training Design	414
	Development of Expertise and Transfer	414
	Transfer Principles	416
	Design of Simulations	419
	Design of Practice	422
	Evaluation of Training	428
	Conclusion	429
	References	430
12	Flights of Fancy: The Art and Science of	
	Flight Simulation	435
	Mary K Kaiser and Leffery A Schroeder	100
	The Dymoge of Flight Simulation	127
	Training Selection and Testing	43/
	Passage and Development	430
	Fidelity of Flight Simulators	439
	Validating Simulator Fidelity How Cood Is Cood France 2	439
	Flight Simulators A Drief History	440
	Fight Simulators: A Brief History	442
	Larly Lijoris	442
	A Systematic Approach The Modern Fre	442
	Vieual Systems	445
	Visual Systems	443
	Modeling the Visual Information of the Flight Emvironment	444
	Motion Systems	440
	Notion Systems	455
	How Motion Systems Work	455
	The Platform Motion Debate	434 452
	Recommendations for Further Work	430 465
	Future Fancies	
	References	
		40/

xiii

13	Applying Crew Resource Management Theory and	X
	Methods to the Operational Environment	473
	Paul J. Sherman	
	One Flight Segment, Several Incidents	473
	Crew Resource Management—Its Theoretical and	-
	Applied Genesis	476
	The Paradigm Shift	476
	The Systems Perspective: Modeling Group Inputs, Processes, and	
	Outputs	477
	The Model as Applied to Aviation: Characteristics and	
	Model Dynamics	478
	Applying the IPO Model to Flight-Deck Team Training	481
	Early Approaches to Improving Team Performance on the	
	Flight Deck	483
	Refinement of CRM Training	483
	Measuring CRM Training Efficacy	485
	Attitude Measurement and its Use in CKM Iraining Developments Englishing Export Patience in the Simulaton and	485
	on the Line	180
	Further Refinement of CRM Concepts	407
	The Growth of Systemic Evaluation Methods	493
	Applying Current Thinking to the Flight Observation	494
	Automation on the Flight Deck—Another Potential Source of	
	Safety Threats	497
	Automation and Aircrews	497
	Group Communication and Coordination Effects	498
	Automation as Crew Member	499
	Incorporating Automation Issues Into CRM Training	500
	Concluding Remarks	501
	References	501
	Acknowledgments	506
14	Assessing Cognitive Aging in Piloting	507
	Pamela S. Tsang	
	About the Age 60 Rule	508
	Cognitive Demands of Piloting and Aging	509
	Attention Switching	510
	Attention Sharing	512
	The Expertise Advantage	517
	Characterizing Expertise	517
	The Paradoxical Relationship Between Age and Expertise	518
	Circumventing Intrinsic Processing Limitations	520
	Methodological Issues	522
	Metrics of Pilot Performance and Experience	522

i

,

i

CONTENTS

.

Cross-Sectional and Longitudinal Methods for Assessing Age Effects	524
Confounds of Age and Experience	525
Generalizing Laboratory Findings to Real-World Operations	527
Summary	529
Manifestation of Aging in Simulator Performance and	
Accident Data	529
Flight Simulator Performance	529
Accident Data	532
Toward a Better Understanding of the Interplay Between Aging	
and Piloting	535
Does Age Affect Piloting?	535
The Paramount Role of Experience/Expertise	536
An Empirical Approach	536
Conclusion	538
References	540
Contributors	
Author Index	553
Subject Index	573

1