Ian Moir and Allan Seabridge

Third Edition

Aircraft Systems

Mechanical, electrical, and avionics subsystems integration

Aerospace Series
Editors Ian Moir, Allan Seabridge and Roy Langton

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Contents

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To Mike Woodhead
1944 to 2007
Professor of Systems Engineering at Loughborough University
An inspiration to all systems engineers and sadly missed

Foreword

The Aerospace and Defence industry has been at the forefront of systems engineering for many decades. The imperatives of commercial success and/or military need have compelled those in the Industry to seize the opportunities offered by taking a systems engineering approach to solve a variety of complex problems.

The insights offered by use of computer based modelling techniques, which have the capacity to represent multiple complex systems, their interdependencies, interactions and their inputs and outputs have propelled the exploitation of systems engineering by those in Aerospace and Defence. The approach is not confined to those mechanical and electrical systems for which stand alone systems models can be constructed. Rather, it is put to its best use when considering a major product or service as a system made up of many subsystems. For example, the optimisation of aircraft layout involving trade-offs between structural aspects, aerodynamic design, electronic and mechanical system performance as well as integrity can be achieved. Carried out in a balanced way, this can be the most powerful tool used by the Engineering teams in the process of defining a light, cheap to manufacture, reliable and high performance aircraft.

In stark terms, success or failure in the Aerospace and Defence sector is determined by the approach taken in the development of systems and how well or otherwise the systems or their interactions are modelled, understood and optimised. The most obvious output from such a process is the resulting system performance, for example how fast your aircraft can fly and what it can see using its radar. In addition however, the dimensions of cost and elapsed time to develop and build a system, together with its inherent reliability throughout its life, are also all critically dependent on effective systems engineering from the outset. Projects,

and sometimes entire businesses, will succeed or flounder on the basis of how well the systems engineering approach has informed decision making relating to the definition of responsibilities between, for example, customers and suppliers, industrial partners or members of an alliance or team. Effective systems engineering will help to expose where the natural boundaries are between areas of activity which in turn informs the definition of suitable contractual boundaries and terms and conditions of a contract. The ultimate benefit of this approach is more effective assignment of responsibilities, enduring contracts and, most importantly, safer systems.

The ultimate consequence of having a culture within an organisation that centres on Systems Engineering is that the inherent approach spills over into other aspects of the activity across the enterprise involved. Obvious benefits in manufacturing process optimisation sit alongside the creation of business information management systems and other tools each playing a part in the quest for an organisation to make the best use of its resources, skills and funding. All of this contributes to the drive for predictable business performance and business success.

This book exemplifies the need to apply a systems engineering approach to the aircraft systems as well as the avionics systems deployed by the aircraft and weapons systems in the performance of its military role. The performance and inter-relationship of all systems are paramount in meeting the air vehicle specification requirements, which in many future offensive air vehicles will be unmanned. The authors have described the Aircraft Systems that emerge from the application of Systems Engineering to show the benefits to individual systems performance and whole aircraft design and integration. Examples of solutions in commercial and military aircraft are

given, which complement the systems described in companion volumes.

The forthcoming More-Electric Aircraft and More-Electric Engine technologies as described in various places within this text herald the approach of innovative and highly integrated technologies for many of the aircraft systems that will serve both civil and military applications in the future. The book has much to recommend it as a place mark in time in relation to the ultimate maturity and application of these technologies.

Nigel Whitehead, Group Managing Director – Military Air Solutions, BAE SYSTEMS

Series Preface

The field of aerospace is wide ranging and covers a variety of products, disciplines and domains, not merely in engineering but in many related supporting activities. These combine to enable the aerospace industry to produce exciting and technologically challenging products. A wealth of knowledge is contained by practitioners and professionals in the aerospace fields that is of benefit to other practitioners in the industry, and to those entering the industry from University.

The Aerospace Series aims to be a practical and topical series of books aimed at engineering professionals, operators, users and allied professions such as commercial and legal executives with in the aerospace industry. The range of topics spans design and development, manufacture, operation and support of aircraft as well as infrastructure operations, and developments in research and technology. The intention is to provide a source of relevant information that will be of interest and benefit to all those people working in aerospace.

About the Authors

Ian Moir After 20 years in the Royal Air Force as an engineering officer, Ian went on to Smiths Industries in the UK where he was involved in a number of advanced projects. Since retiring from Smiths he is now in demand as a highly respected consultant. Ian has a broad and detailed experience working in aircraft avionics systems in both military and civil aircraft. From the RAF Tornado and Apache helicopter to the Boeing 777, Ian's work has kept him at the forefront of new system developments and integrated systems in the areas of more-electric technology and system implementations. He has a special interest in fostering training and education in aerospace engineering.

Allan Seabridge was until recently the Chief Flight Systems Engineer at BAE SYSTEMS at Warton in Lancashire in the UK. In over 30 years in the aerospace industry his work has latterly included the avionics systems on the Nimrod MRA 4 and Lockheed Martin Lightning II (Joint Strike Fighter) as well as a the development of a range of flight and avionics systems on a wide range of fast jets, training aircraft and ground and maritime surveillance projects. Spending much of his time between Europe and the US, Allan is fully aware of systems developments worldwide. He is also keen to encourage a further understanding of integrated engineering systems. An interest in engineering education continues with the design and delivery of systems and engineering courses at a number of UK universities at undergraduate and postgraduate level.

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List of Abbreviations

A 429	ARINC 429 Data Bus
A 629	ARINC 629 Data Bus
A 664	ARINC 664 100Mbits/sec Fast Switched Ethernet
AC	Advisory Circular (FAA)
AAWWS	Airborne Adverse Weather Weapons System (Apache)
AC	Advisory Circular (FAA)
AC	Alternating Current
ACE	Actuator Control Electronics
ACM	Air Cycle Machine
ACMP	AC Motor Pump
ACT	Active Control Technology
A/D	Analogue to Digital
ADM	Air Data Module
ADP	Air Driven Pump
ADU	Actuator Drive Unit
ADV	Air Defence Variant (Tornado)
AFCS	Automatic Flight Control System
AFDC	Autopilot Flight Director Computer (B777)
AFTI	Advanced Fighter Technology Integration (F-16)
AIAA	American Institute of Aeronautics & Astronautics
Aj	Jet Pipe Area
AMAD	Airframe-Mounted Accessory Drive
AMB	Active Magnetic Bearing
Amp or A	Ampere
AoA	Angle of Attack
APB	Auxiliary Power Breaker
APU	Auxiliary Power Unit
ARINC	Air Radio Inc
ART	Actuator Remote Terminal (B-2 flight control system)
ASCB	Avionics Standard Communications Bus
ASI	Airspeed Indicator

ASIC	Application Specific Integrated-Circuit
ASM	Air Separation Module
AS/PCU	Air Supply/Pressurisation Control Unit (B777)
ATA	Air Transport Association
ATC	Air Traffic Control
ATF	Advanced Tactical Fighter
ATM	Air Transport Management
ATP	Advanced Turbo-Prop
ATR	Air Transport Radio
AUW	All-Up Weight
AVM	Airplane Vibration Monitoring
B	Blue (as in blue hydraulic system)
BAES	BAE SYSTEMS
Batt	Battery
BC	Bus Controller (MIL-STD-1553B)
BCF	Bromo-Chloro-diFluoro-Methane
BCRU	Battery Charger Regulator Units (regulated TRUs used on the A380)
BIT	Built-In Test
BOV	Blow Off Valve
BPCU	Bus Power Control Unit
BSCU	Brake System Control Unit
BTB	Bus Tie Breaker
BTMU	Brake Temperature Monitoring Unit
C	Centigrade
C	Centre
C	Collective
CAA	Civil Aviation Authority
CANbus	Commercial-Off-The-Shelf data bus (originally designed by Bosch for automobile applications)
CASA	Construcciones Aeronauticas Socieda Anonym
CBLTM	Control-By-LightTM (Raytheon proprietary fibre optic bus)

CCA	Common Cause Analysis
CCB	Converter Control Breaker (B777)
CCR	Common Computing Resource (B787)
CDA	Concept Demonstration Aircraft
CDR	Critical Design Review
CDU	Cockpit Display Units
CG	Centre of Gravity
CHRG	Charger
CMA	Common Mode Analysis
CNS	Communications, Navigation, Surveillance
COTS	Commercial Off-The-Shelf
CPIOM	Common Processor Input/Output Module (A380 avionics IMA)
CSAS	Control Stability Augmentation System
CSD	Constant Speed Drive
CT	Current Transformer
CTC	Cabin Temperature Control
CTOL	Conventional Take-Off & Landing
CV	Carrier Variant
DATAC	Digital Autonomous Terminal Access Communication (forerunner to ARINC 629)
D/A	Digital to Analogue
DC	Direct Current
DECU	Digital Engine Control Unit
Def Stan	Defence Standard
Dem/Val	Demonstration/Validation
DFCC	Digital Flight Control Computer (AFTI F-16)
DTD	Directorate of Technical Development
DTI	Department of Trade & Industry
DVO	Direct Vision Optics
E1	E1 Electrical Channel (A380)
E2	E2 Electrical Channel (A380)

E3	E3 Electrical Channel (A380)
EAI	Engine Anti-Ice
EAP	Experimental Aircraft Programme
EASA	European Aviation Safety Authority
EBHA	Electrical Backup Hydraulic Actuator (A380)
EC	European Community
ECAM	Electronic Crew Alerting & Monitoring
ECS	Environmental Control System
EDP	Engine Driven Pump
EE	Electrical Equipment (as in EE Bay)
EEC	Electronic Engine Controller
E2PROM	Electrically Erasable Programmable Read Only Memory
EFA	European Fighter Aircraft
EFAB	Extended Forward Avionics Bay
EFIS	Electronic Flight Instrument System
EFPMS	Engine Fuel Pump and Metering System
EGT	Exhaust Gas Temperature
EHA	Electro-Hydrostatic Actuator
EICAS	Engine Indication & Crew Alerting System
ELCU	Electronic Load Control Unit
ELMS	Electrical Load Management System (B777)
EMA	Electro-Mechanical Actuator
EMP	Electrical Motor Pump
EMI	Electro-Magnetic Interference
EPC	External Power Contactor
EPMS	Electrical Power Management System (AH-64C/D Apache)
EPROM	Electrically Programmable Read Only Memory
EPU	Emergency Power Unit
ERA	Electrical Research Agency
ESS	Essential
ESS	Environmental Stress Screening
ETOPS	Extended Twin OperationS
EU	Electronics Unit

EU	European Union
EUROCAE	European Organisation for Civil Aviation Equipment
EXT or Ext	External
FAA	Federal Aviation Authority
FAC	Flight Augmentation Computer
FADEC	Full Authority Digital Engine Control
FAR	Federal Aviation Regulations
FBW	Fly-By-Wire
FC	Flight Control
FCC	Flight Control Computer
FCDC	Flight Control Data Concentrator
FCMC	Fuel Control and Monitoring Computer (A340-500/600)
FCP	Fuel Control Panel
FCPC	Flight Control Primary Computer
FCS	Flight Control System
FCSC	Flight Control Secondary Computer
FDC	Fuel Data Concentrator (A340-500/600)
FCU	Fuel Control Unit
FHA	Functional Hazard Analysis
FITEC	Farnborough International Technology Exploitation Conference (1998)
FLIR	Forward Looking Infra Red
FMC	Flight Management Computer
FMEA	Failure Modes & Effects Analysis
FMES	Failure Modes & Effects Summary
FMGEC	Flight Management Guidance & Envelope Computer (A330/A340)
FMQGS	Fuel Management & Quantity Gauging System (Global Express)
FMS	Flight Management System
FOB	Fuel On Board
FQIS	Fuel Quantity Indication System
FQPU	Fuel Quantity Processor Unit (B777)
FSCC	Flap/Slat Control Computers (A380)

FSD	Full Scale Development
FSDG	Fan Shaft Driven Generator
FSEU	Flap Slats Electronics Unit (B777)
ft	Feet
FTA	Fault Tree Analysis
G	Green (as in green hydraulic system)
G or Gen	Generator
GA	General Aviation
G&C	Guidance & Control
GCB	Generator Control Breaker
GCU	Generator Control Unit
GE	General Electric (US)
GEC	General Electric Company
GLY	Galley
GND	Ground
gpm	Gallons per minute
GPS	Global Positioning System
GPU	Ground Power Unit
GR	Ground Reconnaissance
HISL	High Intensity Strobe Lights
HP	High Pressure
HPSG	High Pressure Starter Generator
hp	Horse Power
HUMS	Health & Usage Management System
Hyd	Hydraulic
Hz	Hertz
IAP	Integrated Actuator Package
IC	Integrated Circuit
IDEA	Integrated Digital Electric Airplane
IDG	Integrated Drive Generator

IDS	InterDictor Strike (Tornado)
IEE	Institution of Electrical Engineers
IEEE	Institute of Electrical & Electronic Engineers
IFE	In-Flight Entertainment
IET	Institute of Engineering & Technology (formerly IEE)
IFPC	Integrated Flight & Propulsion Control
IFSD	In-Flight ShutDown
IMA	Integrated Modular Avionics
IMechE	Institution of Mechanical Engineers
INS	Inertial Navigation System
INV	Inverter
I/O	Input/Output
IPN	Iso-Propyl Nitrate
IPT	Integrated Product Team
IPU	Integrated Power Unit
IR	Infra Red
IRS	Inertial Reference System
ISA	International Standard Atmosphere
ISA	Instruction Set Architecture
JAA	Joint Airworthiness Authority
JAR	Joint Aviation Regulation
JET A	JET A Aviation Fuel (also known as JET A-1)
JET B	JET B Aviation Fuel
J/IST	Joint Strike Fighter/Integrated Subsystems Technology
JP-4	Aviation fuel used by the US Air Force
JP-5	Aviation fuel used by the US Navy
JSF	Joint Strike Fighter (F-35 Lightning II)
K	Kelvin
kg	Kilogram
kN	Kilo Newton
kPa	Kilo Pascal

KT or kt	Knot
kVA	Kilo Volt-Ampere
L	Lift
L	Left
LAF	Load Alleviation Function
LAN	Local Area Network
LB or lb	Pound
LH	Left Hand
LHX or LH	Light Helicopter
LOX	Liquid Oxygen
LP	Low Pressure
LRM	Line Replaceable Module
LRU	Line Replaceable Unit
LVDT	Linear Variable Differential Transformer
M	Mach Number
m	Metre
mA	Milli Ampere
MA	Markov Analysis
MAC	Mean Aerodynamic Chord
MAU	Modular Avionics Unit (Honeywell EPIC system)
MBB	Messerschmit Bolkow Blohm
MCDU	Multipurpose Control & Display Unit
MDC	Miniature Detonation Cord
MCU	Modular Concept Unit
MDHC	McDonnell Douglas Helicopter Company (now Boeing)
MEA	More-Electric Aircraft
MEE	More-Electric Engine
MECU	Main Engine Control Unit
MEL	Minimum Equipment List
MFD	Multi-Function Display

MFOP	Maintenance Free Operating Period
MHz	Mega Hertz
MIL-H	Military Handbook
MLI	Magnetic Level Indicator
MIL-STD	Military Standard
ml	Millilitre
MLC	Main Line Contactor
MLI	Magnetic Level Indicator
mm	Millimetre
MR	Maritime Reconnaissance
m/s	Metres/second
MN	Mega Newton
MSOC	Molecular Sieve Oxygen Concentrator
MSOV	Modulating Shut-Off Valve
N	North Pole
NADC	Naval Air Development Center
NASA	National Space & Aerospace Agency
Nav	Navigation
NH or N2	Speed of rotation of engine HP shaft
Ni-Cd	Nickel-Cadmium
NGS	Nitrogen Generation System
HL or N1	Speed of rotation of engine LP shaft
NOTAR	NO TAil Rotor
NRV	Non-Return Valve
Nx	Lateral Acceleration
Ny	Longitudinal Acceleration
Nx	Normal Acceleration
OBOGS	On-Board Oxygen Generating System
OBIGGS	On-Board Inert Gas Generating System
OEM	Original Equipment Manufacturer
Ox	Pitch Axis

Oy	Roll Axis
Oz	Yaw Axis
P	Pressure
P	Pitch
POA	Power Optimised Aircraft (EC More-Electric Technology Programme)
Ps or Po	Ambient Static Pressure
Pc	Pressure Capsule
PCU	Power Control Unit
PDE	Power Drive Electronics (AFTI F-16)
PDU	Power Drive Unit
PDC	Power Distribution Center
PDR	Preliminary Design Review
PEM	Power Electronics Module
PEPDC	Primary Electrical Power Distribution Centre (A380)
PFC	Primary Flight Computer (B777)
PFCS	Primary Flight Control System (B777)
PMA	Permanent Magnet Alternator
PMG	Permanent Magnet Generator
PNVS	Pilot Night Vision System (Apache)
PRV	Pressure Reducing Valve
PRSOV	Pressure Reducing Shut-Off Valve
PSEU	Proximity Switch Electronics Unit (B777)
PSSA	Preliminary System Safety Analysis
psi	Pounds/Square Inch
Pt	Dynamic Pressure
PTFE	Poly-Tetra-Fluoro-Ethylene
PTU	Power Transfer Unit
PSU	Power Supply Unit
PWR	Power
‘Q’ feel	A pitch feel schedule used in aircraft flight control systems based upon $\frac{1}{2}\rho V^2$

R	Right
R	Roll
R & D	Research & Development
RAeS	Royal Aeronautical Society
RAF	Royal Air Force
RAT	Ram Air Turbine
RDCP	Refuel/Defuel Control Panel (Global Express)
RFI	Request For Information
RFP	Request For Proposal
RIU	Remote Interface Unit
RJ	Regional Jet
ROM	Read Only Memory
RPDU	Remote Power Distribution Units
RT	Remote Terminal (MIL-STD-1553B)
RTCA	Radio Technical Committee Association
RTZ	Return-To-Zero
RVDT	Rotary Variable Differential Transformer
S	South Pole
SAARU	Secondary Attitude Air data Reference Unit
SAE	Society of Automobile Engineers
SCR	Silicon Controlled Rectifier (Thyristor)
SDR	System Design Review
SEC	Spoiler Elevator Computer (A320)
SEPDB	Secondary Electrical Power Distribution Box (A380)
SEPDC	Secondary Electrical Power Distribution Centre (A380)
SFENA	Société Française d’Equipments pour la Navigation Aerienne
SFCC	Slat/Flap Control Computers (A330/A340)
SG	Specific Gravity (Density of water=1)
shp	Shaft horse Power
SIM	Serial Interface Module (A629)
SMP	Systems Management Processor (EAP)