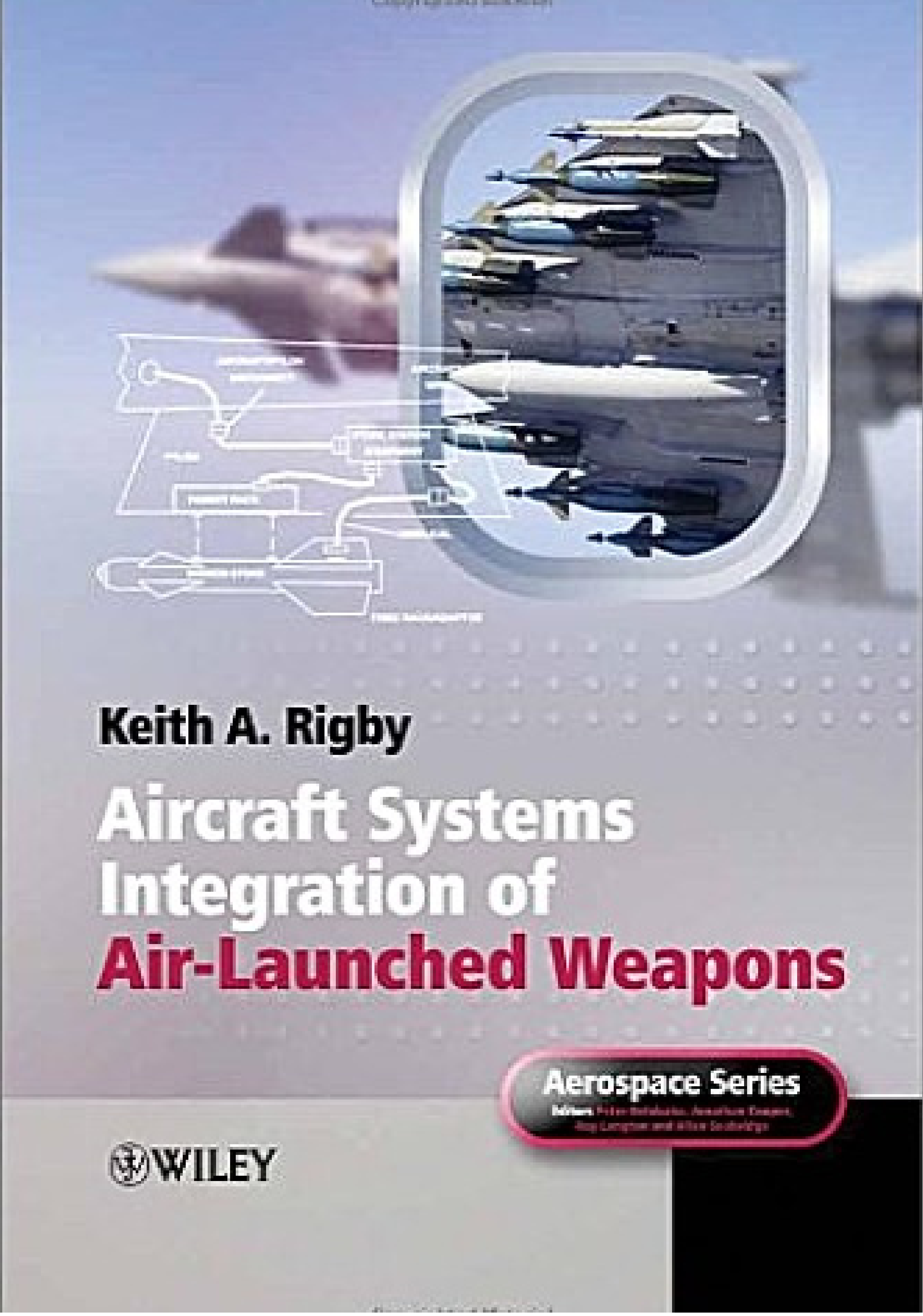

Keith A. Rigby
Aircraft Systems Integration of Air-Launched Weapons
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Contents

Series Preface

The Aerospace Series has concerned itself largely with the design of aerospace vehicles and their systems, comprehensively covering aspects of structural and system design in theoretical and practical terms. There has been reference to military aircraft types in the books of the Series, sometimes as developments of commercial aircraft for surveillance or transport roles, and other times as specific combat types. However, there has been no detailed consideration of one aspect that is quite specifically applicable to military types – the carriage and release of air launched weapons.

In this book, the author takes a systems engineering view of the weapon and platform as an integrated whole for both manned and unmanned aircraft. The importance of considering the integration of the weapon with the airframe and with the aircraft systems is stressed as it is vital to the achievement of a safe and successful launch with a high probability of target destruction. This aspect of integration is important to the introduction of precision weapons with a high degree of accuracy to reduce the incidence of collateral damage, as well as making best use of costly weapons.

It is important for engineers and designers to visualise the totality of a system in order to gain an understanding of all that is involved in the establishment of requirements and the certification process to arrive at a coherent design of vehicle and infrastructure. Understanding the impact of external weapons installation on aircraft performance and handling, and the needs of the weapon for navigation and attitude information, is key to understanding how to aim, fuze and release a weapon for maximum effect. This understanding enables developments in new aircraft types and new weapon types to be understood and adapted so that the most effective weapon system can be selected and developed for a particular aircraft in order to respond to changing threats.

This book is a comprehensive treatise on the subject of air launched weapons and will be of great value to all design engineers, support engineers, air crew and armourers working on armed military aircraft. The message is reinforced by the introduction of a worked example of integration of a smart weapon with the airframe. It also provides a good background to people who have an interest, professional or casual, in the design of aircraft weapon systems. It is worth noting that the book carefully avoids any areas of security classification, thereby making the book accessible to a wide audience.

Peter Belobaba, Jonathan Cooper and Allan Seabridge

Preface

For any military conflict where Western air forces are involved, the public is accustomed to media coverage of weapons being targeted against the enemy. Whether this is an Air-to-Ground missile being aimed at a particular window in a building or a smart bomb destroying a strategically located bridge, the public understand that in modern warfare precision weapons can provide surgical attack capabilities whilst minimising collateral damage and harm to non-combatants.

However, the terminal accuracy of a guided weapon significantly depends on its priming prior to release. Simply, the launch aircraft and weapon together form a complex system where the performance of each component is interdependent on the performance of the other.

It is unusual for a weapon to be designed specifically for operation with a single aircraft type; it will generally be designed to provide a particular military capability when operated with a range of aircraft. The Weapon Design Organisation will generally define an idealised set of requirements to be placed on the launch aircraft such that if they are satisfied, the weapon can achieve its specified performance. However, although the Weapon Design Organisation has responsibility for the design, development and certification of the weapon, generally, it is the Aircraft Design Organisation that has responsibility for the design, development and certification of the total aircraft and for certification of the aircraft/weapon combination. As the aircraft may not be able to satisfy the set of ideal requirements placed on it by the weapon, the terminal performance of the weapon may be degraded.

Whenever a weapon has to be integrated with an aircraft, there will be a need for the Aircraft and Weapon Design Organisations to collaborate to satisfy the needs of the Government agency (the Contracting Agency) which contracts for the integrated capability. Whilst this may bring many organisational interaction challenges, the pure engineering activities which need to be undertaken are many and complex.

For the purposes of this book, weapons integration is divided into systems integration activities and aeromechanical activities (e.g. covering aerodynamics, structures and the airborne environment). Whilst all activities must be undertaken to realise the certified integrated product, this book concentrates on the aircraft systems integration aspects of air-launch weapons integration. However, this still covers a complex series of activities which are multi-disciplinary in nature and which it is unlikely that a single engineer in an organisation would have a deep understanding of all.

This book aims to give an insight into the various aspects of aircraft systems integration including consideration of the various subsystems required for the successful control of a weapon, systems engineering principles as applied to an integration programme, safety and certification, and provides a worked example of the integration of a smart weapon with an aircraft. By covering the broad scope of aircraft systems integration of air-launched weapons, it is intended that engineers at every level in their career will find something useful, be it a revision of previous knowledge, gaining an insight into the future direction of weapons integration or understanding the extent of weapons integration activities for those new to the discipline.

Acknowledgments

As with any textbook, there will always be people who have helped the author by sourcing material, checking draft manuscripts and supplying images to illustrate the content. This book is no exception. I would therefore like to thank all those people in the United Kingdom and United States who have helped in some way, but especially the following.

Paul Ellis, Pierre Miles and Rod Robinson who provided invaluable comments on the various draft manuscripts; and Chris Ryding, Nick Guard, Geoffrey Lee and Thiery Wurtz for use of their photographs. There are also those individuals within BAE Systems Military Air & Information and elsewhere who supported the production and vetting of the final manuscript and secured permission to use other copyright images.

A large amount of material in the book has drawn on the work of the many experienced weapons integration practitioners that have contributed to standardisation efforts within the Society of Automotive Engineers Aircraft Systems & Systems Integration Committee and the various NIAG studies. There are far too many to mention by name, but you know who you are. Thank you all.

List of Abbreviations

°C	Degrees Celsius
1PPS	One Pulse Per Second
3-DOF	Three Directions of Freedom
6-DOF	Six Directions of Freedom
A	Ampere
AC	Alternating Current
ACMI	Air Combat Manoeuvring Instrumentation
ADO	Aircraft Design Organisation
AEIS	Aircraft/Store Electrical Interconnection System
AGE	Aerospace Ground Equipment
AIM	Air Intercept Missile
AIR	Aerospace Information Report
AL	Application Layer
ALWI	Aircraft, Launcher and Weapons Interoperability
ALWI-CI	Aircraft, Launcher and Weapons Interoperability – Common Interface
ANSI INCITS	American National Standards Institute International Committee for Information Technology Standards
AOP	Allied Operating Procedure
API	Application Programme Interface
APOS	Application to Operating System Interface
AS	Aerospace Standard
ASAAC	Allied Standard Avionic Architecture Council
ASI	Aircraft Station Interface
ASRAAM	Advanced Short-Range Air-to-Air Missile
AWFL	Airworthiness Flight Limitations
BC	Bus Controller
BIT	Built-In Test
BPSK	Bipolar-Phase Shift Key

C of D	Certificate of Design
C/A	Course Acquisition
C/N_0	Carrier to Noise Ratio
CCIP	Continually Calculated Impact Point
CEP	Circular Error Probability
CLARA	Common Launch Acceptability Region Approach
CMM	Critical Monitor Message
COTS	Commercial Off-the-Shelf
CSI	Carriage Store Interface
CSSI	Carriage Store Station Interface
D	Direct Interface (1D, 2D, 3D and 4D)
dB	Decibel
dBHz	Decibel-hertz
dBic	Decibels relative to an ideal, circularly-polarised isotropic antenna
dBK^{-1}	Decibels per Kelvin
dBW	Decibels (relative to 1 W)
dc	Direct Current
DC	Direct Current
DDP	Declaration of Design and Performance
Def Stan	Defence Standard
DMC	Display Mission Computer
DO	Design Organisation
DoD	Department of Defense
DoDAF	Department of Defense Architecture Framework
DRL	Data Requirements List
EBR-1553	Extended Bit Rate 1553
EMC	Electromagnetic Compatibility
F	Noise Figure
FAA	Federal Aviation Administration
FFA	Functional Failure Analysis
FMECA	Failure Modes Effect Criticality Analysis
FOM	Figure of Merit
FTA	Fault Tree Analysis
g	Gain
GASIF	Generic Aircraft–Store Interface Framework
G_e	Effective Gain
GHz	Gigahertz
GOA	Generic Open Architecture
GPS	Global Positioning System
GR	Ground Attack/Reconnaissance
GRAM	GPS Receiver Application Module
GSM	Generic System Manager
GWR	Guided Weapon Release
HB1	High Bandwidth 1
HDBK	Handbook
HE	High Explosive

HOTAS	Hands on Throttle and Stick
HOW	Hand-Over Word
HRI	Hazard Risk Index
HUD	Head-Up Display
Hz	Hertz
IAD	Interface Agreement Document
ICAO	International Civil Aviation Organisation
ICD	Interface Control Document
ICN	Interface Change Note
ICWG	Interface Control Working Group
IER	Interface Exchange Requirements
IIR	Imaging Infra-Red
IMB	Interface Management Board
IMM	Interface for Micro Munitions
IMU	Inertial Measurement Unit
INCOSE	International Council on Systems Engineering
IR	Infra-Red
IRIS-T	Infra-Red Imaging System Tail/Thrust Vector-Controlled
IRS	Integration Requirements Specification
IRS-CM	Integration Requirements Specification – Compliancy Matrix
IRST	Infra-Red Search and Track
IRS-VP	Integration Requirements Specification – Validation Plan
ITEA	Integrated Test, Evaluation and Acceptance
J/S	Jammer to Signal Ratio
JICWG	Joint Interface Control Working Group
JSP	Joint Service Publication
K	Kelvin
kg	Kilogram
kHz	Kilohertz
kts	Nautical Miles per Hour
kΩ	Kilohm
LAN	Local Area Network
LAR	Launch Acceptability Region
LGB	Laser Guided Bomb
LOAL	Lock-On After Launch
LOBL	Lock-On Before Launch
LSB	Least Significant Bit
LSP	Least Significant Part
m	Metre
mA	Milliampere
MAA	Modular Avionics Architecture
MAR	Military Aircraft Release
MASS	Master Armament Safety Switch
Mbits/s	Megabits per Second
MDA®	Model Driven Architecture
MDT	Mass Data Transfer

MHz	Megahertz
MiDEF	Mission Data Exchange Format
MIL-STD	Military Standard
MMHI	Micro Munition Host Interface
MMSI	Miniature Mission Store Interface
MOS	Module to Operating System Interface
ms	Millisecond
MSB	Most Significant Bit
MSCI	Miniature Store Carriage Interface
MSCS	Miniature Store Carriage System
MSI	Mission Store Interface
MSL	Module Support Layer
MSP	Most Significant Part
Mux	Multiplex Data Bus
NATO	North Atlantic Treaty Organisation
NIAG	NATO Industrial Advisory Group
NIU	Network Interface Unit
NUAI	NATO Universal Armament Interface
OFP	Operational Flight Programme
OS	Operating System
OSI	Open Systems Interconnection
OSL	Operating System Layer
P(Y)	Precision Code
PIM	Platform Independent Model
P_k	Probability of Kill
PPS	Precise Positioning Service
PRN	Pseudo Random Noise
PSI	Platform Specific Implementation
PSICD	Platform–Store Interface Control Document
PSM	Platform Specific Model
PTTI	Precise Time and Time Interval
PVT	Position, Velocity and Time
QoS	Quality of Service
REAC	Reaction Time
RF	Radio Frequency
RT	Remote Terminal
RTS	Release To Service
S&RE	Suspension & Release Equipment
SAE	Society of Automotive Engineers
SCM	Store Control Message
SDB II	Small Diameter Bomb II
SDM	Store Description Message
SIL	Systems Integration Laboratory
SMM	Store Monitor Message
SMP	Stores Management Processor

SMS	Stores Management System
SNR	Signal-to-Noise Ratio
SoD	Statement of Design
SPEAR	Selected Precision Effects At Range
SPS	Standard Positioning Service
SRR	System Requirements Review
STANAG	Standardisation Agreement
SV	Space Vehicle
T	Output Noise Temperature
t	Temperature
T_0	Ambient temperature
T_{antenna}	Antenna noise temperature
TC	Transfer Control
TC	Transfer Connection
TD	Transfer Data
TEACASE	Thermal Effects on Airborne Conventional Armament Stores and Equipment
TLE	Target Location Error
TLM	Telemetry Data Word
TM	Transfer Monitor
TMP	Time Mark Pulse
t_{n}	Noise temperature
TOO	Target of Opportunity
TRM	Technical Reference Model
TTFF	Time to First Fix
™	Trade Mark
UAI	Universal Armament Interface
UAS	Unmanned Air System
UAV	Unmanned Air Vehicle
UK	United Kingdom
UML	Unified Modelling Language
UPC	Unique Planning Component
US	United States (of America)
UTC	Universal Time Co-ordinated
V	Volt
VC	Virtual Channel
W	Watt
WBS	Work Breakdown Structure
WCP	Weapon Control Panel
WDO	Weapon Design Organisation
WGS-84	World Geodetic System – 1984
WOWS	Weight-Off-Wheels Switches
WSSU	Weapon Station Switching Unit
XOS	Extended Operating System
xUML	Executable Unified Modelling Language
μs	Microsecond

1

Introduction to Weapons Integration

1.1 Introduction

One of the key differences between civilian and military aircraft is that many military aircraft have the ability to carry and release weapons. From the earliest days of aviation where the pilot would drop simple bombs by hand, engineers have striven to develop the capability to accurately deliver weapons against targets reliably and safely. Today, for a successful target engagement, it is essential for the aircraft and weapon to be integrated such that the full capabilities of the weapon can be exploited. The release of a weapon whether it is a forward-fired missile or a downward ejected store such as a fuel tank, from either an externally mounted pylon or from an internal bay, creates issues such as the ability to achieve safe separation and the ability of the aircraft structure to withstand the imparted loads. The complexity of weapons integration is increased when the requirements for priming and aiming are considered. The integration of weapons onto aircraft therefore requires a multi-disciplinary set of capabilities within the integration organisation.

The generic term for any mission payload carried on an external pylon or an internal bay on a non-permanent basis is a ‘store’. The family of stores includes weapons, fuel tanks, countermeasure pods and so on. Whilst many of the stores would only be released from the aircraft under emergency conditions (e.g. in the event of an engine failure during take-off), weapons are designed to be released as a matter of course.

This book gives an introduction to the subject of weapons integration, primarily from the viewpoint of aircraft electrical and computing systems integration, and explores the systems integration problem space, outlining the importance of systems integration and the contribution of industry standards in achieving an integrated aircraft and weapons capability.

The following sections outline the contents of the main chapters of this book and then introduce the various aspects of weapons, the subsystems they employ and the contributions

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these make to a successful target engagement. By gaining an understanding of weapons, the subject of their integration with the launch platform can be explored.

1.2 Chapter Summaries

1.2.1 The Systems Integration Process

As with any system design, a structured, top-down approach is essential. However, for weapons integration, the higher level requirements will also include aeromechanical aspects such as the desired release envelope, carriage life, the number of weapons that can be carried, influences of other weapon and store types to be carried on the same sortie, and so on. In a series of chapters, the book will outline the basic systems engineering process employed in a typical weapons integration programme. This will include the definition of an appropriate set of requirements and their partitioning to subsystems, through systems implementation, to qualification and certification. The types of requirements that should be considered will be discussed and the benefits of minimising the number of initial requirements and the need to avoid ‘over engineering’ of requirements will be explained.

The need to consider safety from the outset and its place in the overall systems integration process will also be covered as will the individual responsibilities of the aircraft and weapon design organisations (WDOs).

Once the top-level integration requirements have been defined, there is a need to decompose these into more detailed requirements and to then partition these to the aircraft subsystems. This segmentation process may use software-based requirements management tools as these will, in due course, assist in the validation and verification of the system implementation against the requirements. This partitioning exercise depends on the actual aircraft system architecture and will therefore differ between aircraft, with the requirements being partitioned to individual aircraft subsystems, which could be implemented in both hardware and software. Each requirement placed on the aircraft’s subsystems will need to be proven for correct implementation, and the subsystems will then be progressively built up into an overall integrated system that provides the required military capability. This will include the testing of the system and its components in a Systems Integration Laboratory (SIL). Employing either weapon simulators or inert weapons with operational electronics, integration testing will test that all the aircraft subsystems are working together to control the weapon. Any problems which are identified would then need to be corrected during an iteration of the system design and implementation.

The typical individual responsibilities of the aircraft and WDOs will also be discussed.

1.2.2 Stores Management System Design

The first electrical systems to control the release of stores were based on relays that when energised would switch the current to the bomb rack, causing it to open. The relays were operated by the Bomb Aimer pressing the release button, thereby routing a current to the relay coils. From a safety and certification viewpoint, it is essential that an aircraft only releases a store when intended. This appears to be an obvious requirement, but it is the primary driver in the design of the armament system of an aircraft.

This requirement forced the design of systems with multiple breaks in the bomb rack firing chain such that a single failure, on its own, could not cause weapons to be released inadvertently. This basic principle is often referred to as the 'no single failure' criteria as no single failure can cause an unintended release of a store when not intended. A second 'availability' principle is often also quoted such that no single failure shall prevent a release when intended.

In a modern military aircraft, the simplicity of the first electrical systems has been replaced by a subsystem in its own right which is generally referred to as the Stores Management System (SMS). The SMS manages the weapon load-out and controls the safe arming, release, jettison and operation of any store loaded on the aircraft, including the generation of the high-integrity data messages required by modern smart weapons to ensure their safe operation. This increased level of functionality and the need to ensure that weapons are only released or jettisoned when required are the primary drivers in SMS design, adding complexity to the hardware implementation and introducing the need for embedded safety critical software. Chapter 4 will explore the SMS design considerations and outline common system architectures that are found in modern military aircraft. Design considerations for aircrew training for Air-to-Ground weapons delivery will also be discussed.

1.2.3 The Global Positioning System

The accuracy to which weapons can be delivered on target is a key requirement of most new weapon programmes. Since the first Gulf War in 1991, there has been an increased use of navigation technology such as the United States' Global Positioning System (GPS) to assist in the terminal guidance of weapons. This increased use of GPS receivers in guided weapons has enabled the continued potency of legacy aircraft. The integration of such so-called smart weapons brings with it special problems for the aircraft systems integrator. Chapter 4 will also outline the basic operation of GPS and discuss a number of aircraft system design issues that need to be considered when integrating such weapons.

1.2.4 Weapon Initialisation and Targeting

Different weapons demand different methods of targeting. Targeting a weapon, be it an Air-to-Ground weapon or an Air-to-Air missile, can be very complex and place great demands on the performance of the aircraft systems. For the accurate targeting of a smart weapon, it is essential that the aircraft and weapon axis reference systems are initialised to provide a common reference, thereby removing position and velocity errors. The chapter on weapon initialisation and targeting will discuss weapon initialisation and examine the different ways in which weapons are targeted covering the accurate delivery of ballistic bombs, the flexibility of targeting for smart weapons and the sensor types and target prosecution strategies of Air-to-Air missiles. Training for the delivery of Air-to-Air missiles will also be discussed.

1.2.5 The Role of Standardisation in Weapons Integration

From the earliest days of guided weapons, weapon designers have defined their interfaces to optimise the requirements against technologies that have been available. This has led to a plethora of different interfacing systems existing on aircraft.