DEVELOPMENT OF A WEAPON SYSTEM COMMUNICATION ARCHITECTURE FOR UNMANNED SYSTEMS

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I hereby declare that all information in this document has been obtained and presented in accordance with academic rules and ethical conduct. I also declare that, as required by these rules and conduct, I have fully cited and referenced all material and results that are not original to this work.

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ABSTRACT

DEVELOPMENT OF A WEAPON SYSTEM COMMUNICATION ARCHITECTURE FOR UNMANNED SYSTEMS

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Unmanned systems are taking increasingly the place of people in dangerous environments and in military missions day by day. Many military unmanned systems have been designed and manufactured worldwide. As a result of military use, the need to integrate existing and newly produced weapons into existing and newly produced unmanned systems continues. In the case of weapon integration into unmanned systems, there is a need for standardization to reduce costs, reduce integration time, simplify operations and minimize technical problems. In this study, which aims to standardize communication in unmanned systems, Joint Architecture for Unmanned Systems (JAUS) standard has been chosen as the mainstay of the study. The scope of the study was determined as guided tactical missiles. Taking into account the needs of the weapon systems included in the scope and the current structure of the Joint Architecture for Unmanned Systems (JAUS) standard, the weapon component and communication structure is defined as an extension to the Joint Architecture for Unmanned Systems (JAUS) standard.

Keywords: Joint Architecture for Unmanned Systems (JAUS), Unmanned Systems, Weapon Integration, Standardization, Tactical Guided Missiles

ÖZ

İNSANSIZ SİSTEMLER İÇİN BİR SİLAH SİSTEMİ İLETİŞİM MİMARİSİ GELİŞTİRİLMESİ

Yücel, Fırat Cem
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Tez Yöneticisi: Prof. Dr. Buyurman Baykal

Aralık 2019, 125 sayfa

İnsansız sistemler askeri alanda tehlikeli çevrelerde ve görevlerde insanların yerini her geçen gün daha fazla almaktadır. Dünya genelinde pek çok askeri insansız sistem tasarlanmakta ve üretilmektedir. Askeri alanda kullanımın bir sonucu olarak, mevcut ve yeni üretilen insansız sistemlere mevcut ve yeni üretilen silahların entegrasyonunun yapılması ihtiyacı süregelmektedir. İnsansız sistemlere silah entegrasyonu çalışmalarında, maliyetlerin düşmesi, entegrasyon süresinin azalması, çalışmaların kolaylaşması ve teknik sorunların en aza indirilmesi için standartlaşmaya ihtiyaç vardır. İnsansız sistemlerde silah entegrasyonunun iletişimsel açıdan standartlaşması yönünde yapılan bu çalışmada dayanak noktası olarak insansız sistemlerde haberleşmeyi standartlaştırmayı amaçlayan Joint Architecture for Unmanned Systems (JAUS) standardı seçilmiştir. Çalışmanın kapsamı güdümlü taktik füzeler olarak belirlenmiştir. Kapsama dahil olan silah sistemlerinin ihtiyaçları ve Joint Architecture for Unmanned Systems (JAUS) standardının mevcut yapısı göz önünde bulundurularak, Joint Architecture for Unmanned Systems (JAUS) standardına silah bileşeni ve haberleşme yapısı eklenti olarak tanımlanmıştır.

Anahtar Kelimeler: Joint Architecture for Unmanned Systems (JAUS), İnsansız Sistemler, Silah Entegrasyonu, Standardizasyon, Taktik Güdümlü Füzeler

To:

My Family

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Last and foremost, the author wishes to thank his mother Ms. Meliha Yücel and his father Mr. Hasan Yücel for their lifelong support and endless love.

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LIST OF ABBREVIATIONS

ABBREVIATIONS

GPS:	Global Positioning System
h:	Hexadecimal
IEC:	International Electrotechnical Commission
INS:	Inertial Navigation System
ISO:	International Organization for Standardization
JAUS:	Joint Architecture for Unmanned Systems
MIL-STD:	Military Standard
N/A:	Not Applicable
NATO:	North Atlantic Treaty Organization
RF:	Radio Frequency
SAE:	Society of Automotive Engineers
STANAG:	Standard Agreement
TDL:	Tactical Data Link
USB:	Universal Serial Bus

LIST OF SYMBOLS

SYMBOLS

Ψ, θ, and ϕ: Euler Angles

CHAPTER 1

INTRODUCTION

In the broadest sense, unmanned systems are critical robotics technologies that do not contain human elements unless they require missions on them, can be managed remotely or autonomously and perform predetermined tasks. Robotics technologies are becoming more common in the military field day by day. Robots as unmanned systems, including weapon integrated systems, especially in dangerous environments and missions, began to successfully take part in military forces in larger quantities instead of human beings [1].

Parallel to the use of unmanned systems in the military field, 1708 different types of unmanned aerial vehicles have been manufactured or developed by 540 company in 53 countries worldwide by July 2013 [2]. In 2002, The United States Senate set the goal of 30% of all military systems in The United States to remain unmanned by 2015 [3].

This transformation led to efforts to develop and standardize new communication technologies, interfaces and protocols [4]. Interoperability appeared as a key factor, since different technologies, interfaces and protocols increase technical difficulties and costs for design, manufacturing and maintenance [5]. That is why a comprehensive standardization named JAUS was developed to provide interoperability among unmanned systems. Joint Architecture for Unmanned Systems (JAUS) is a communication architecture developed for the systems referred to as unmanned systems in the literature.

JAUS was developed by the United States Department of Defense, subsequently it was transferred to the Society of Automotive Engineers (SAE) [6]. The purpose of developing the JAUS standardization is to ensure full communication protocol interoperability of components used in unmanned systems.

The United States Army began to make efforts to ensure that future war systems would include JAUS compliance [5]. The United States Army inventory includes unmanned systems that are currently JAUS-compliant or planned to be JAUS-compliant as a result of that JAUS is likely to provide interoperability between all types of unmanned vehicles [7].

Core service set [8], mobility service set [9], environment sensing service set [10], manipulator service set [11], mission spooling service set [12] and human machine interface service set [13] are defined in JAUS standard and standardized the communication architecture of the messages of the components on the related topics. However, neither weapon component definition nor any weapon integration work including weapon communication architecture have been conducted yet within the JAUS standard, although the JAUS standard includes an infrastructure to facilitate the integration of a weapon system.

Standardization of weapon interfaces in the plug & play concept is the future of weapon integration in order to reduce weapon integration costs [14].

Considering that unmanned systems are widely used and will be used even increasingly for military purposes, it can be foreseen that the necessity of weapon integration to unmanned systems operating in accordance with JAUS standard will emerge in the near future. Since the comprehensive standard JAUS is expected to become increasingly popular in this field, this study is carried out. Also, for this reason, ROKETSAN, which is rocket and missile systems designer and producer of Turkey, and Presidency of Defence Industries, which is affiliated to Presidency of the Republic of Turkey approved and supported this study which is adding weapon component and messages to the JAUS standard with the scope of tactical guided missiles.

1.1 Aim and Scope of the Study

This study was approved by ROKETSAN and Presidency of Defence Industries in order to be based on tactical guided missiles as an initial study for the addition of weapon architecture to the JAUS standard. This study aims;

- adding the weapon component as an extension to the JAUS standard, which has become an increasingly common standard in unmanned vehicles,
- modeling the architecture to provide a basis for possible future weapon integrations,
- building infrastructure for developing modular and interoperable hardware and software,
- reducing development and integration costs by ensuring standardization.

1.2 Why JAUS?

Table 1.1 Comparison of Interoperability Standards in the Domain shows the advantages and disadvantages of JAUS with respect to the other standards of interoperability in the domain.

Table 1.1 Comparison of Interoperability Standards in the Domain [15]

Standard	Acceptance level	Applicability level	Field of use
JAUS	Middle	High	All types of unmanned systems

Table 1.1 (continued)

NATO STANAG 4586	High	Low	Specific to unmanned aerial vehicles
NATO STANAG 7085	High	Low	Specific to image data
MIL-STD-1760	High	Low	Specific to weapons systems
AAST F-41	High	Low	Specific to control of unmanned undersea vehicles

The standard with which JAUS overlaps most is the NATO STANAG 4586, which is specifically focused on unmanned aerial vehicles [3]. It is widely accepted and has a great maturity, but its applicability is restricted to a very specific category of robotics. JAUS is the only interoperability standard applicable to all types of unmanned systems.

The scope of MIL-STD-1760 is limited by interoperability of weapon systems. However, it is also used in this study in order to analyze weapon system needs since it is an accepted and mature standard in the very specific field of weapon systems. Also, MIL-STD-1760 and MIL-STD-1553 which is used by MIL-STD-1760 as digital communication interface are referenced by the owner of the JAUS standard, Society of Automotive Engineers, for safe operation of weapons on unmanned systems [16]. Because MIL-STD-1760 has achieved success in reducing the number and the diversity of interfaces and thus increasing the interoperability of different weapons on many platforms [14].

As a result of the combination of the relatively wider range of use, the relatively higher level of applicability and the future potential for acceptance, extending JAUS in order to enable interoperable weapon integration in the plug and play concept is considered to be worth studying. Therefore, this study is carried out.

1.3 Research Question

In 1.1 Aim and Scope of the Study and 1.2 Why JAUS? parts, which started by searching for answers to the question of how to enable interoperable weapon integration in the plug and play concept in terms of the digital communication protocol for unmanned vehicles, the question has been turned into a more specific question by the conclusion that JAUS standard should be studied on the subject. Considering the explanations so far, the research question can be summarized and graphically illustrated in Figure 1.1 Research Question:

How can the JAUS standard be extended in order to enable interoperable weapon integration in the plug and play concept in terms of the digital communication protocol for tactical guided missile systems?

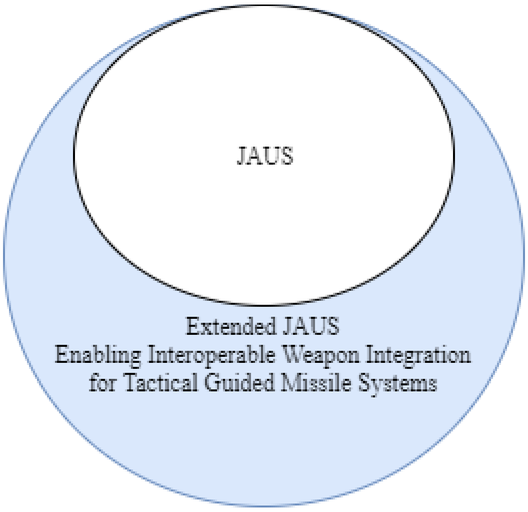

Figure 1.1 Research Question

1.4 Architectural Requirements / Drivers

Considering the explanations so far, the main architectural requirements / drivers shared in Table 1.2 Architectural Requirements / Drivers is derived from the main research question.

Table 1.2 Architectural Requirements / Drivers

Number	Architectural Requirement / Driver
1	The JAUS standard shall be extended in order to enable interoperable weapon integration.

Table 1.2 (continued)

2	The study shall be based on tactical guided missile systems as weapons.
3	The study shall define and cover only the digital communication protocol of the communication architecture between the host platform and the weapon.
4	The JAUS standard shall be extended in accordance with the present definitions of the standard.
5	The JAUS standard shall be extended based on the data sharing needs between the host platform and the weapon.
6	The design extending JAUS as a result of the study shall be applied in order to perform laboratory-level simulation tests.

Table 1.2 (continued)

7	Laboratory-level simulation tests of the design shall be based on the most basic, simplest and least challenging conditions in order to demonstrate feasibility at the basic level.
8	Laboratory-level simulation tests shall be performed with ROKETSAN tactical guided missile simulators.

1.5 Outline and Methodology of the Study

In CHAPTER 2 of this study, literature review on the subject is given. The literature review focuses on the JAUS standard and the needs of weapon systems within the scope of the study.

In CHAPTER 3 of this study, the requirements derived from architectural requirements / drivers for the design that satisfies the research question and then the design are shared.

In CHAPTER 4 of this study, the design that satisfies the research question is used for implementation. The implementation requirements derived from architectural requirements / drivers are set out. The implementation is made in accordance with these requirements. The principles of the implementation and the results of the implementation is shared.

In CHAPTER 5 of this study, the results of the study and the future work on the subject are discussed.

Considering this outline, the methodology that advances the study is shown in Figure 1.2 Methodology.

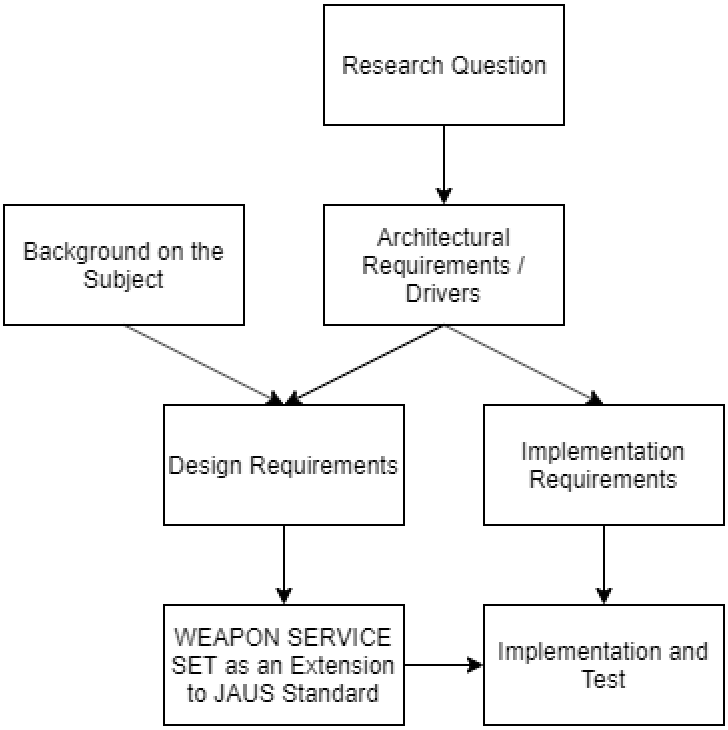

Figure 1.2 Methodology

CHAPTER 2

BACKGROUND

In this chapter, literature review on the subject is given. The literature review focuses on the JAUS standard and the needs of weapon systems within the scope of the study.

2.1 Joint Architecture for Unmanned Systems (JAUS)

2.1.1 History

In the United States, the Office of the Under-Secretary of Defense for Acquisition, Technology and Logistics, set up a group of people to work on standardization for interoperability of both previous and future unmanned vehicle components under Joint Robotics Program in 1998. The standard used to be called JAUGS (Joint Architecture for Unmanned Ground Systems), later it expanded to all unmanned vehicle types. In 2005, JAUS was transferred to the Society of Automotive Engineers, aerospace standards section [3]. Now the group also consists of academic members and government officials. Owing to its input range, JAUS has a significant reputation amongst people interested in unmanned vehicle systems.

2.1.2 Basic Principles of JAUS

In order to achieve the interoperability goal, JAUS is built on five basic principles given in Figure 2.1 Basic Principles of JAUS [6]. In order to comply with these five independence principles, the JAUS standard defines the components that can be used in unmanned vehicles, their communication methods and message structures. Thus, JAUS has a component-based message transmission structure.

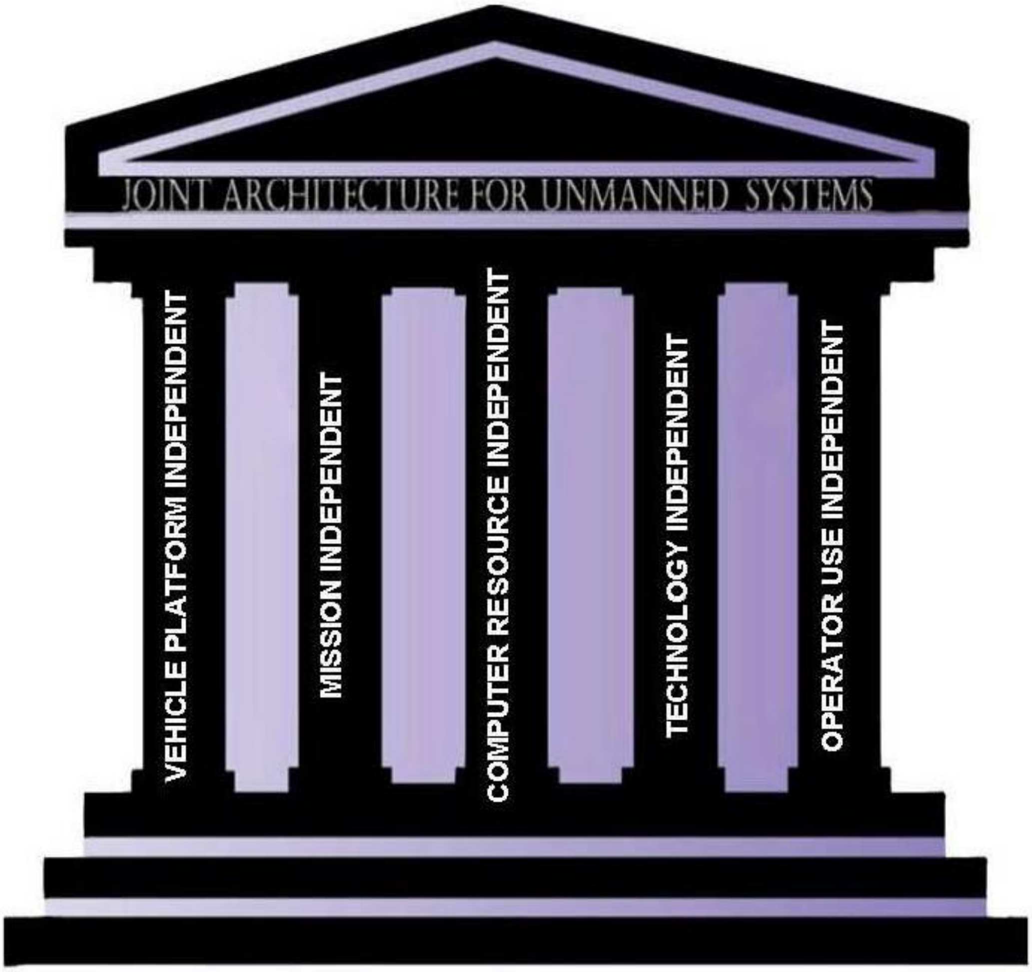

Figure 2.1 Basic Principles of JAUS [6]

2.1.2.1 Vehicle Platform Independence

Unmanned vehicles are used in a variety of missions. As far as interoperability is concerned, vehicle platform independence principle means there are no certain obligations about platforms.

2.1.2.2 Mission Independence

JAUS does not expect a system to execute a specific mission. Unmanned systems might execute different types of missions. Mission independence principle allows systems to execute any specific mission or multiple missions.

2.1.2.3 Computer Resource Independence

Computer resource independence principal means that JAUS does not depend on any certain structural information. The platform is able to be composed of any type of hardware. Therefore, if the computer resources are sufficient to interact with JAUS messages, it is accepted as compatible.

2.1.2.4 Technology Independence

Technology independence principal assures that both the messages and transportation methods that form JAUS are detached from all former or future standards. Giving different technology options allows the developer to use any preferred method.

2.1.2.5 Operator Use Independence

Operator use may cause unintended results or obstruct beneficial results. In order to execute a mission in the best way possible, JAUS needs to be operator use independent.

2.1.3 Basic JAUS Definitions

It can be seen how elements are organized in JAUS system in Figure 2.2 JAUS System Diagram [17]. A system comprises one subsystem or more. The subsystems are logically grouped to work cooperatively. A subsystem comprises one node or more. A node comprises variable number instances of variable number of components.

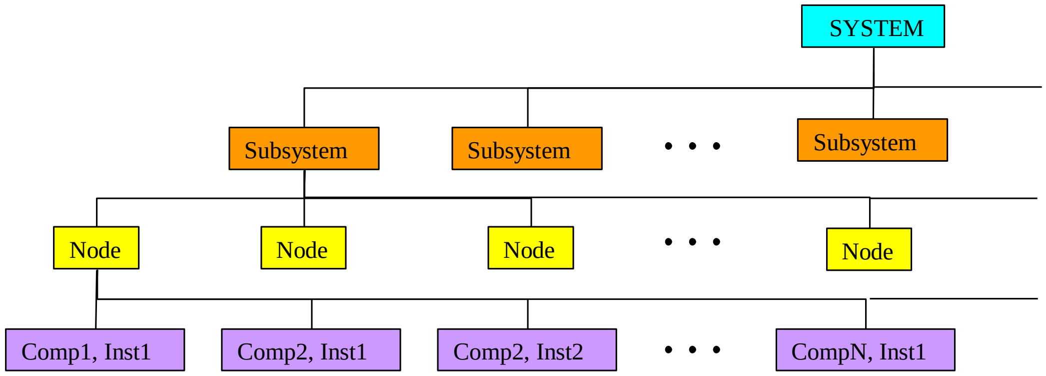

Figure 2.2 JAUS System Diagram [17]

JAUS communication network organization can be seen in Figure 2.3 JAUS Communication Network Diagram [17]. Subsystems communicate via communicator elements. Nodes communicate via node manager elements.

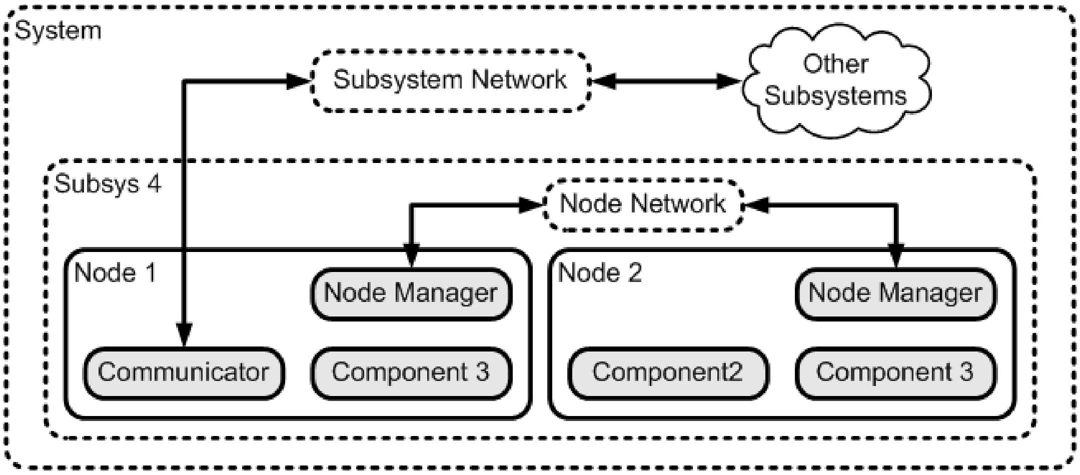

Figure 2.3 JAUS Communication Network Diagram [17]

Subsystems are separate elements that contains different numbers of computer nodes and software components. They execute their functions. All nodes and components need to be compatible with JAUS.

A node consists of all hardware and software needed to complete the task. It assists computing skills. A vision processor is an example of a node in a subsystem. It is possible to connect several nodes using different techniques such as serial networks.

A component is hierarchically the lowest level. Provide an identified service, a component is a connected software; basically, a process. Plural examples of components can run on the same node.

Owing to numerous configurations that can be created, interfaces boundaries are not limited. This is an important explanation about JAUS flexibility.

2.1.4 Message Definitions

For all the unmanned system developers to speak the same language, certain rules have been set about JAUS message transmissions and protocols.

2.1.4.1 Textual Data Representation

Textual data must be compatible with ISO/IEC 885 [18].In this study, the definitions were made accordingly.

2.1.4.2 Numerical Data Representation

JAUS numerical data types are;

- Byte (8-bit unsigned integer),
- Short Integer (16-bit signed integer),
- Integer (32-bit signed integer),
- Long Integer (64-bit signed integer),
- Unsigned Short Integer (16-bit unsigned integer),
- Unsigned Integer (32-bit unsigned integer),
- Unsigned Long Integer (64-bit unsigned integer),
- Float (IEEE 32-bit floating-point number),
- Long Float (IEEE 64-bit floating-point number).

In this study, the numerical data definitions were made in accordance with JAUS definitions.

2.1.4.3 Platform Orientation

Ψ, θ, and ϕ are the terms that are used to orient the unmanned vehicle. Putting on the XYZ coordinate system to a vehicle, X axis must point forward and Z must point downward as shown in Figure 2.4 JAUS Platform Axis System [18] illustrating global platform orientation definition. X axis must be aligned northward direction and Z axis must be aligned throughout gravity vector.

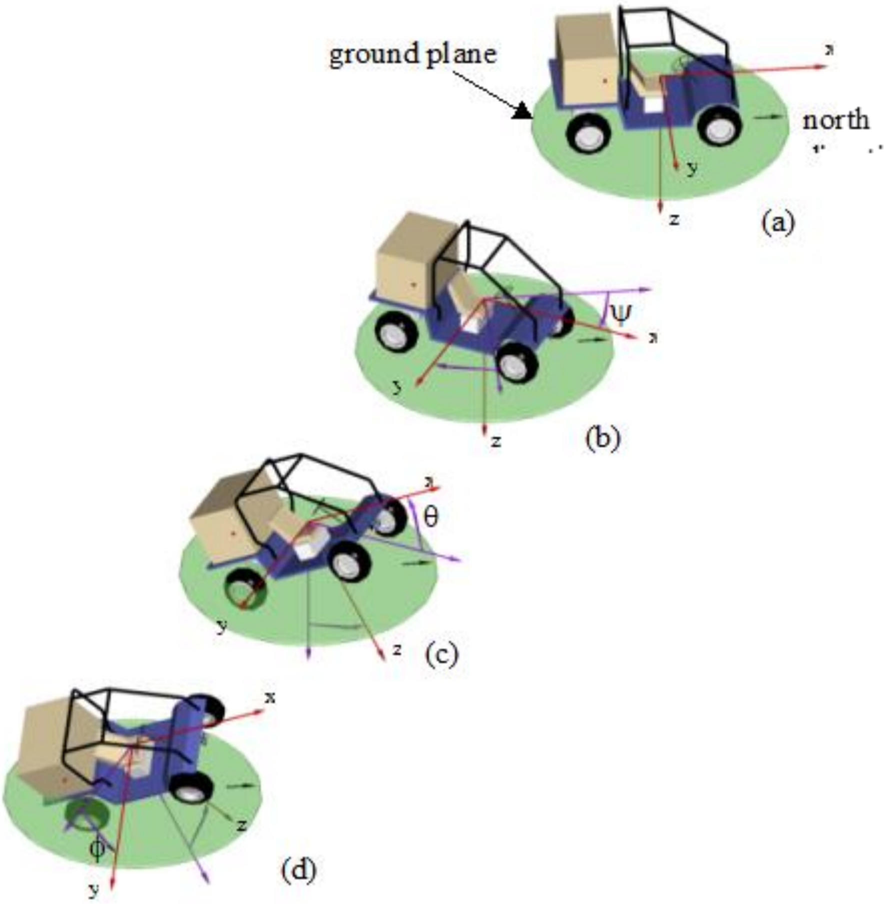

Figure 2.4 JAUS Platform Axis System [18]

2.1.5 Message Specification

JAUS provides interoperability owing to well-defined message usage. All the events happening in JAUS is a result of messages. Hence, JAUS is message transmitting architecture with a component-based structure.

2.1.5.1 Message Classes

Messages are segmented in JAUS with their identifier ranges as shown below for both receiving and transmitting processes:

- Command Class Messages (Offset range from 0000h to 1FFFh): Start, change or control an action.
- Query Class Messages (Offset range from 2000h – 3FFFh): This is a command for a reply from other components. Inform class messages are created as a reply.
- Inform Class Messages (Offset range from 4000h – 5FFFh): Inform class messages transmits information between components such as status reports, geographic position, state information.
- Experimental Class Message (Offset Range from D000h to FFFFh): Experimental class messages try new messages that are not specified in JAUS. It aims the experimental messages to be a part of the next generation version of JAUS. While an experimental class message is being tried, a standard JAUS command code will be assigned for it. The number of these experimental messages must be kept least as possible.

Even if a message is not specified in the standard, a developer can use it as an experimental message. Nevertheless, it should not be used to overcome standard JAUS messages. The fields other than the experimental field of the header must be created according to JAUS definitions.

In this study, experimental class messages used in order to define new messages. In this way, command, query and inform class messages are defined in accordance with JAUS architecture.

2.1.5.2 Message Composition

In each message, there is a header and data fields. The header's format is common. So, particular fields of the header contain information about how to process a message, or how data is encoded or decoded. The details of the message header can be seen in Figure 2.5 JAUS Message Header [18].

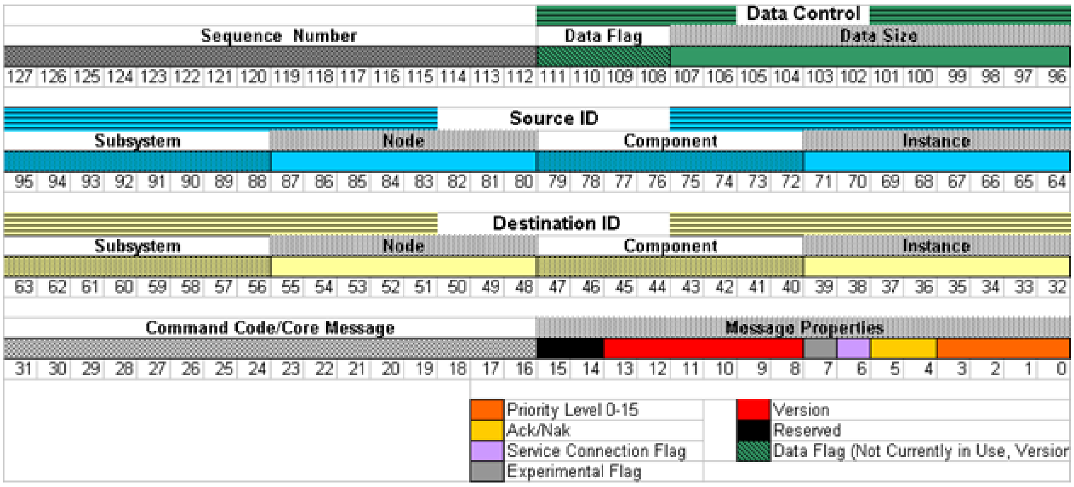

Figure 2.5 JAUS Message Header [18]

Header is evaluated as an unsigned integer. Encoding and decoding algorithm, data size, property of the message, usage necessity and message dispatch take part in the header. All messages must contain a header.

2.1.5.3 Message Routing

Source and destination information in the header indicates how messages are routed. Source and destination are complexes which comprise identifier elements [18]. Identifiers are indicated as xxx: xxx: xxx: xxx where xxx is a number. Subcomponent identifier, node identifier, component identifier and instance identifier are represented in the fields respectively. The identifier numbers differ from 0 to 255.

Owing to the usage of byte-wide identifiers numbering scheme, maximum 256 different identifier variations is consented by JAUS. There are also some restrictions regarding identifier fields such as: 0 is never used as a valid identifier, 255 is always used as a broadcast identifier, other 254 identifiers are valid and assignable.

2.2 Weapons and Weapon Systems

By a general definition, a weapon is a tool used in order to destroy, damage or defeat an enemy [19]. A sword which is a primitive weapon fits this definition. However, obviously, the subject of this thesis is modern weapons, which need data sharing over communication interfaces, such as missiles. Detailed definitions explaining the weapons within the scope of this study and usage concepts explaining communication interface needs of these weapons are given below.

By a general definition, a weapon system is an integrated, mostly computerized, system in order to control and operate weapons. These systems can be divided into mainly two groups, namely strategic weapon systems and tactical weapon systems [20].

2.2.1 Strategic Weapon Systems

By a general definition, a strategic weapon system is a weapon system used in order to hit a target at the center of its armed, financial or governmental power [21].

2.2.2 Tactical Weapon Systems

By a general definition, a tactical weapon system is a weapon system which is integrating tactical weapons, which are used for relatively short ranges with relatively quick results in order to offend or defend [22]. Dissimilar to strategic weapon systems in use in a limited number of countries, tactical weapon systems are common.

2.2.2.1 Tactical Guided Missile Systems

By a general definition, a missile is a rocket-powered weapon developed to transfer a detonating warhead with high precision at high speed and nearly all missiles include a kind of guidance and control technique [23]. Whence missiles are usually mentioned as guided missiles which adjust their course subsequent to launching [24]. According to their range and intended use, missiles are classified as tactical or strategic like other weapon systems. This study is based on tactical guided missiles.

Tactical guided missiles use guidance methods, namely command, inertial, active, semi active, passive or a combination of these [25]. Inertial guidance works on the principle of calculating the position of the missile in space through the gyroscope and directing it to the target. This leads to the need for the missile to know its position and target position.

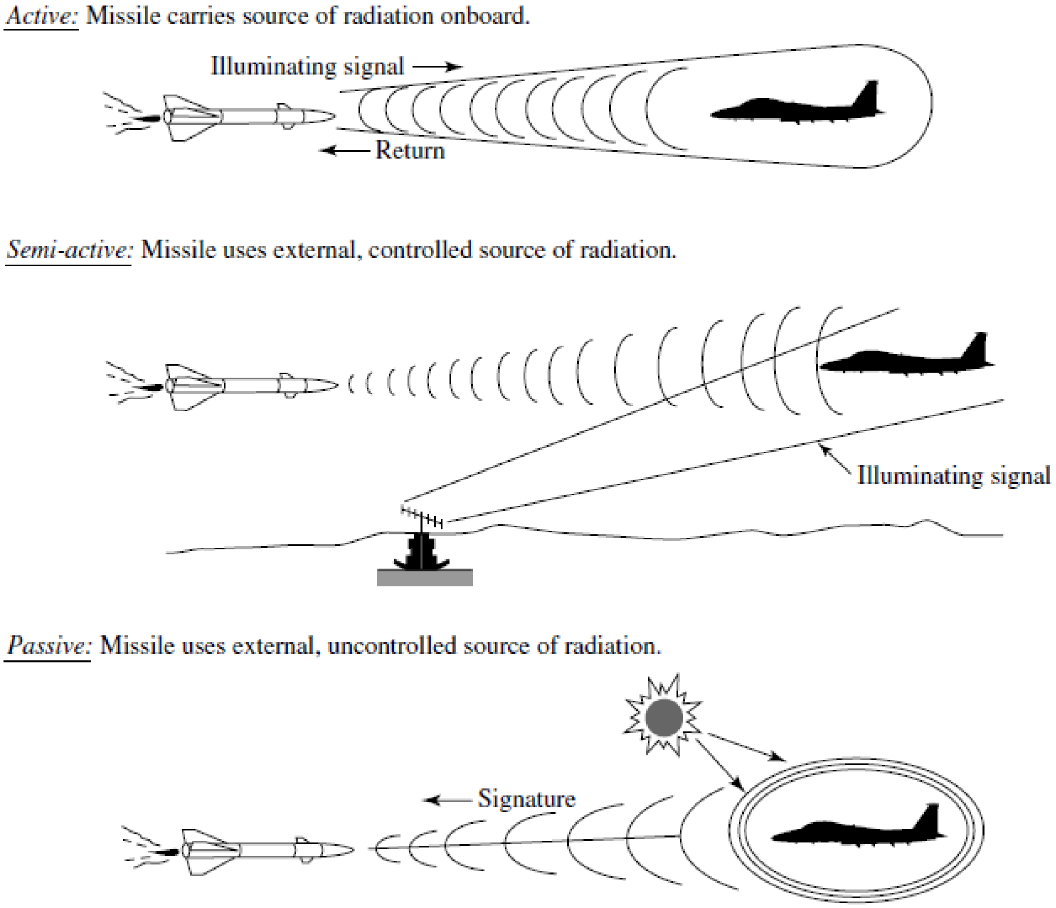

Figure 2.6 Active, Semi-Active and Passive Guidance [26]

Figure 2.6 Active, Semi-Active and Passive Guidance [26] shows how active, semi-active and passive guidance methods works. For command guidance method, missile guidance and target tracking are fully commanded externally.

When all information about non-inertial guidance method is evaluated together, the needs for a seeker to be used in missiles and to be controlled before and after launching emerge [27]. Tactical guided missiles have two axis, namely yaw and pitch, gimballed seekers which can rotate in order to extend field of view or strapdown seekers which are fixed to missile body in order to achieve non-inertial guidance methods [28]. Thus, the following seeker control and monitor needs arise:

- Two axis rotation control and monitor for rotating, slaving for stabilization, tracking target and zeroizing,
- Tracking control and monitor,
- Laser designation control and monitor for controlled source of radiation [29].

For designation, the appropriate NATO standard agreement is STANAG 3733 Laser Pulse Repetition Frequencies Used for Target Designation and Weapon [30]. In this study on NATO compliant or supported standards such as JAUS and MIL-STD-1760, STANAG 3733 is taken as reference to ensure compliance.

2.3 MIL-STD-1760E Department of Defense Interface Standard Aircraft/Store Electrical Interconnection System

The MIL-STD-1760 standard describes application needs and electrical interfaces from a military air vehicle to its carriage stores which is mostly weapons in order to reduce interface variations, costs and technical problems [31].

2.3.1 Interfaces

Figure 2.7 MIL-STD-1760E Primary Interface Signal Diagram [31] and Figure 2.8 MIL-STD-1760E Auxiliary Power Interface Signal Diagram [31] show the interfaces defined in MIL-STD-1760. MUX A and MUX B constitute a dual redundant MIL-STD-1553 differential serial data bus with one megabaud speed which is used for main communication bus including data-sharing and control between air vehicles and weapons [32]. This study extending JAUS standard with the weapon communication architecture between unmanned systems and weapons corresponds to the communication on MIL-STD-1553 bus in the way described in MIL-STD-1760.

MIL-STD-1760 also defines data needed on the interface between military platform and weapon as a data entity list [31]. This data list is used in the study considering the scope of the study by grouping logically and mainly include below functions:

- The platform describes itself to the weapon.
- The weapon describes itself to the platform.
- The platform controls the weapon.
- The platform monitors the status of the weapon.

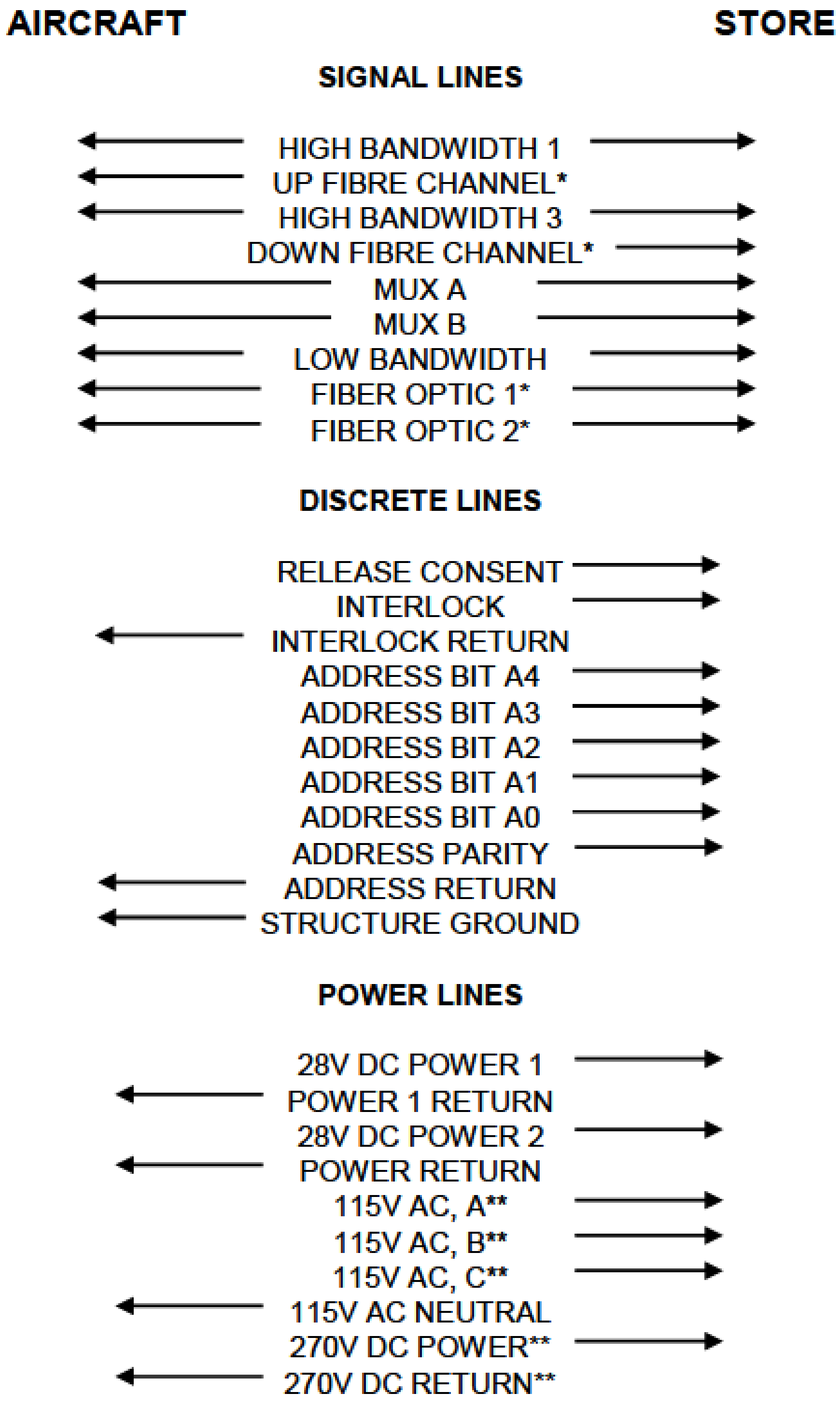

Figure 2.7 MIL-STD-1760E Primary Interface Signal Diagram [31]

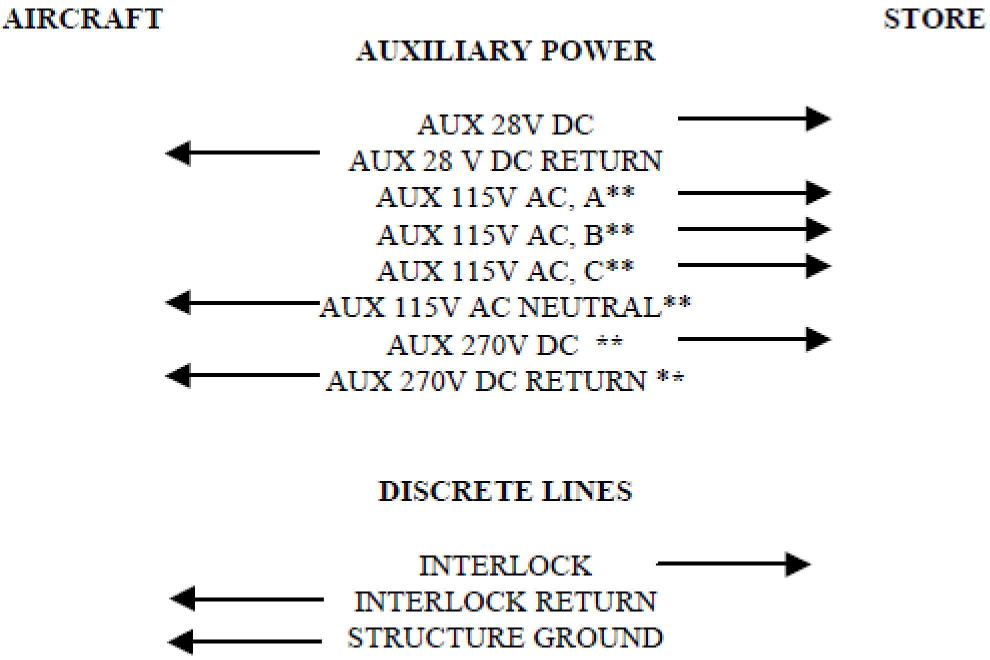

Figure 2.8 MIL-STD-1760E Auxiliary Power Interface Signal Diagram [31]

2.3.2 Axis Definitions

Figure 2.9 Earth Axis System [31], Figure 2.10 Platform Body Axis System [31], Figure 2.11 Earth Platform Alignment [31], Figure 2.12 Weapon Axis System [31] and Figure 2.13 Weapon Platform Moment Arm Axis System [31] show axis definitions in the MIL-STD-1760 standard. These definitions are compatible with the JAUS axis definitions and referenced in the related message fields defined in this study.

2.3.2.1 Earth Axis System

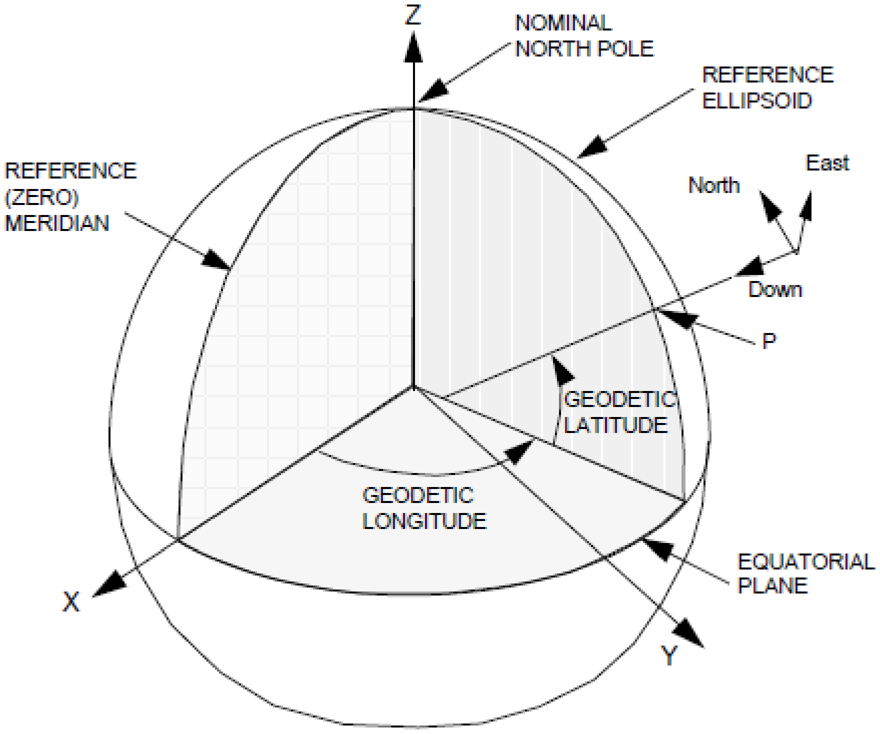

Figure 2.9 Earth Axis System [31]

2.3.2.2 Platform Axis System

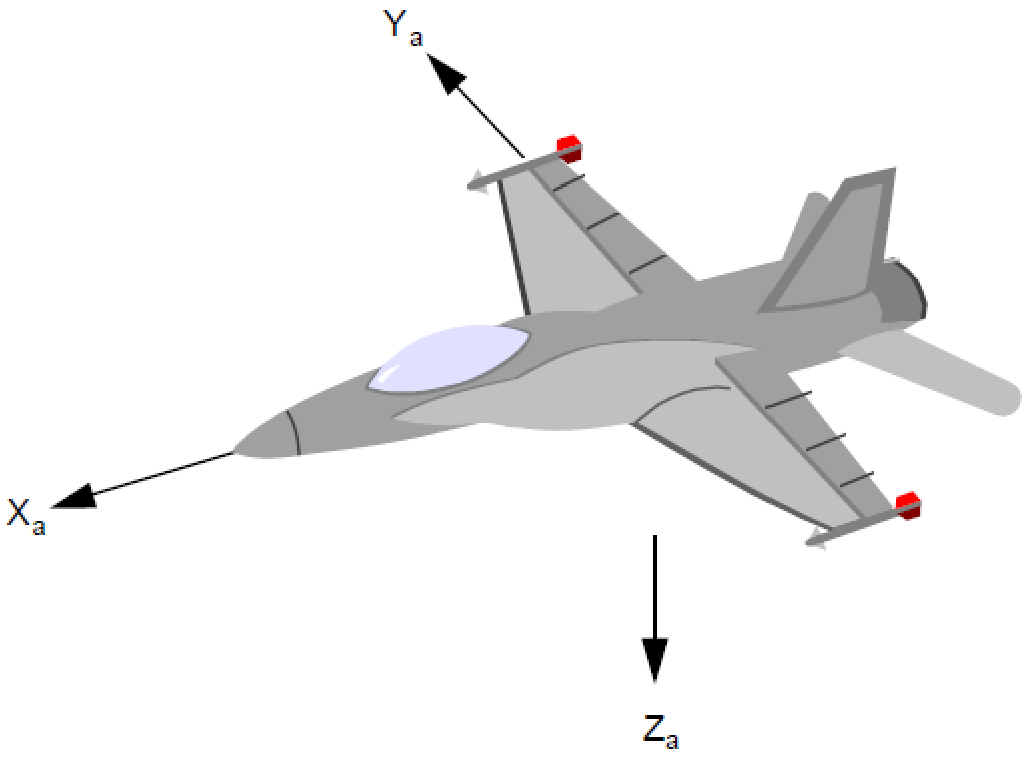

Figure 2.10 Platform Body Axis System [31]

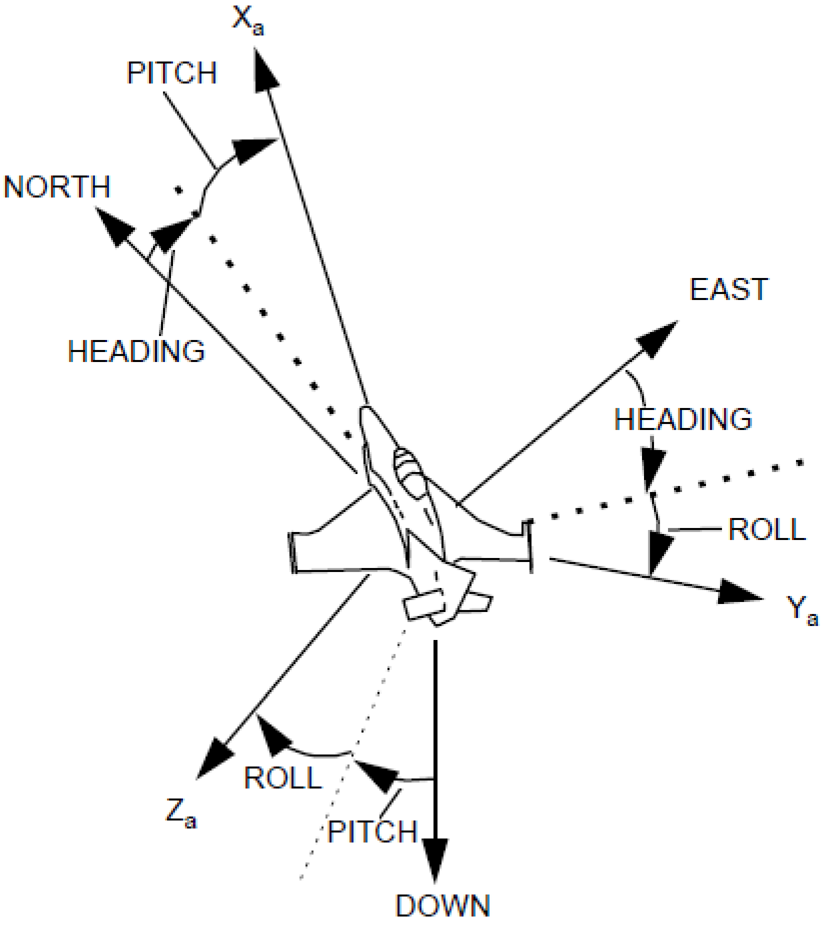

Figure 2.11 Earth Platform Alignment [31]

2.3.2.3 Weapon Axis System

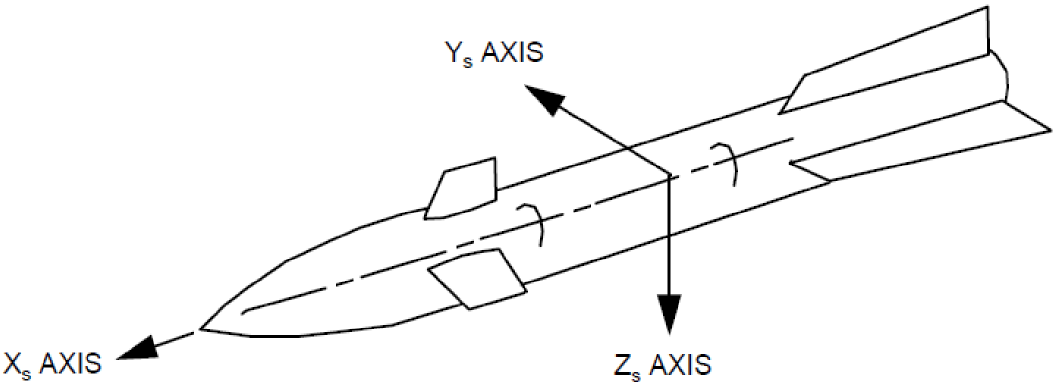

Figure 2.12 Weapon Axis System [31]

2.3.2.4 Moment Arm Axis System

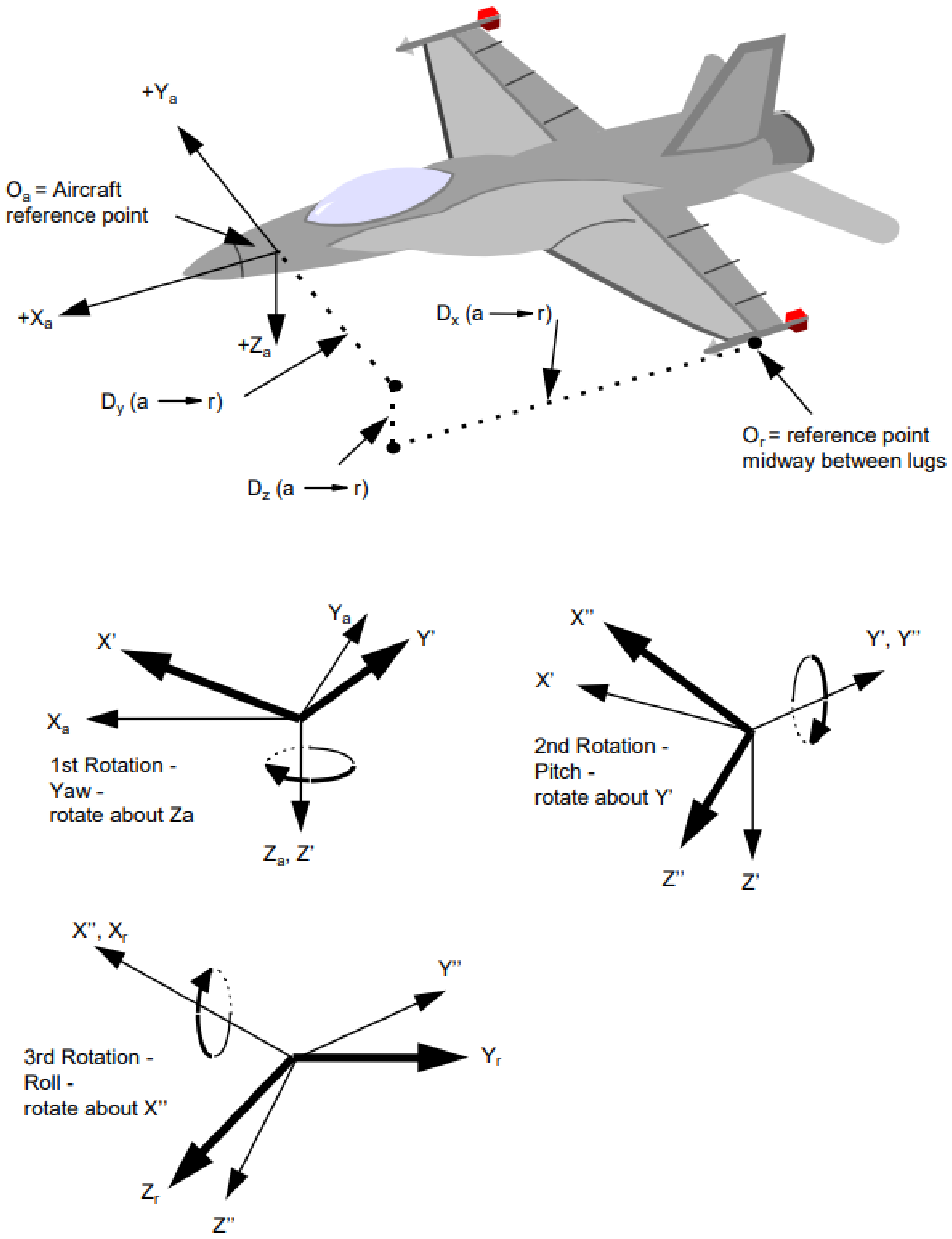

Figure 2.13 Weapon Platform Moment Arm Axis System [31]

2.4 Transfer Alignment and Moment Arm

Transfer alignment, that can notably make better weapon control and guidance performance, is the operation of initializing and fine-tuning inertial navigation system of a weapon using information coming from the navigation system of host platform [33]. The guidance performance of a weapon essentially depends on the high accuracy transfer alignment of the host platform information, namely location, speed, acceleration, orientation angles, angular rate [34].

Figure 2.14 Relative Movements of a Weapon Inertial Navigation System at an Air Vehicle Wing Station [34] shows the relative movements of the reference INS or INS/GPS systems of the host vehicle and the aligning INS of the weapon as an example. There are increasing errors between the reference INS or INS/GPS systems of the host vehicle and the aligning INS of the weapon calculations due to the movement of non-rigid body. Also, inertial navigation systems on weapons have typically poor quality relative to the ones on the host platform. As a result of this, synchronized periodic transfer alignment make better calculation errors and increase weapon control and guidance performance.

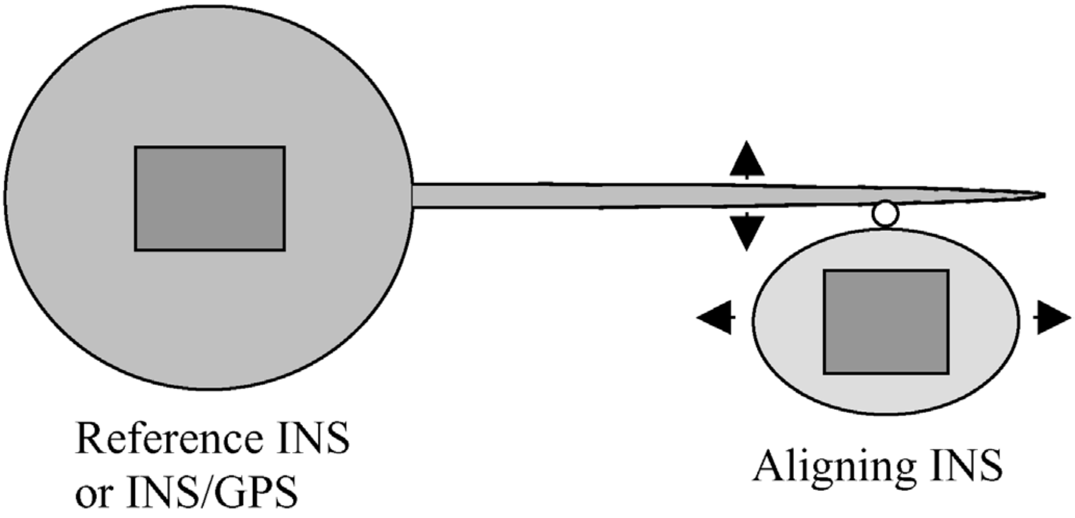

Figure 2.14 Relative Movements of a Weapon Inertial Navigation System at an Air Vehicle Wing Station [34]

Transfer alignment operation also needs to be corrected by moment arm vector which is composed of the relative distance and the relative orientation between INS or INS/GPS systems of the host vehicle and the aligning INS of the weapon [33]. Because, INS or INS/GPS systems of the host vehicle and the aligning INS of the weapon have different measuring points and different results while turning.

To sum up, transfer alignment and moment arm information need to be shared by weapons in order to achieve full performance.

2.5 Tactical Data Links

2.5.1 History

During the Vietnam War, the United States suffered from serious difficulties in terms of tactical communication [35]. Therefore, the need to develop faster, higher capacity and tamper-resistant digital communication systems has emerged. Operational deficiencies of analog communication have shown itself and with the experience gained, the importance of secure, fast data transmission and digital communication that will provide this transmission has been understood. In the 1970s, the necessity of technologies that would ensure effective, safer and more reliable communication on the battlefield was realized and new tactical data links were developed by starting intensive studies in this direction. Link 1, Link 11, Link 22 and Link 16 are some examples of the basic tactical data links developed.

2.5.2 Explanation

Tactical data links are interoperability standards. However, they are much more extensive than the technical interoperability standards compared in the introduction. When tactical data links are examined, military discipline as an academic discipline, defense science, strategic needs, tactical needs and scenarios are included [36]. Therefore, a study to be conducted in relation to tactical data links is very comprehensive. In this study, while a relatively simple network structure between the host platform and the weapon is being studied, tactical data links cover many elements in the field of combat and very comprehensive needs. For example, Figure 2.15 A Sample Tactical Communication Architecture [37] shows the diversity of military, strategic, operational needs and elements that need to communicate in combat environments. The complexity resulting from these diversities is incompatible with the subject of this study. These standards have also high level of confidentiality. For example, MIL-STD-6016 Tactical Data Link (TDL) 16 Message Standard which is one of the most popular and successful data link standards, consists of 11410 pages and it is also classified [37].

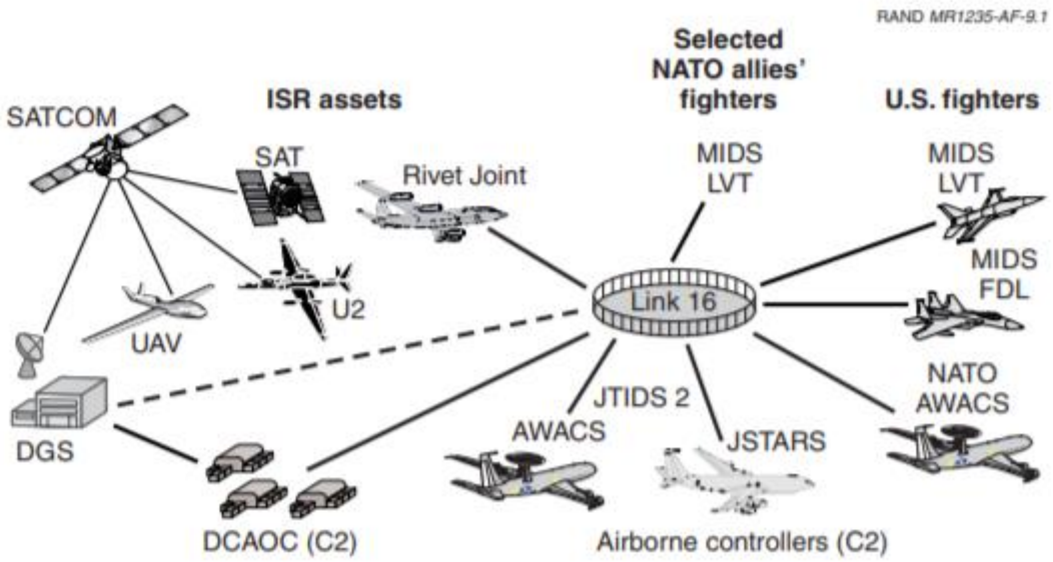

Figure 2.15 A Sample Tactical Communication Architecture [38]

Reconciliation of tactical data link standards with other technical interoperability standards can be meaningful in another context in terms of some specific points. However, due to the complexity of the tactical data links and the high level of confidentiality associated with these standards, they could not be used in this study directly. They are only mentioned in CHAPTER 5 in order to guide the future studies.

CHAPTER 3

WEAPON SERVICE SET AS AN EXTENSION TO JAUS STANDARD

In this chapter, the requirements derived from architectural requirements / drivers for the design that satisfies the research question and then the design are shared.

3.1 Weapon Service Set Design Requirements

Weapon Service Set design requirements are derived from 1.4 Architectural Requirements / Drivers which are derived from 1.3 Research Question, considering the needs of the literature review in CHAPTER 2. Weapon Service Set design requirements are given in Table 3.1 Weapon Service Set Design Requirements.

Table 3.1 Weapon Service Set Design Requirements

Number	Weapon Service Set Design Requirements
DESIGN1	A message set named Weapon Message Set shall be designed as an extension suggestion to the JAUS standard in order to enable interoperable weapon integration.

Table 3.1 (continued)

DESIGN2	Weapon Message Set shall be designed based on the needs of tactical guided missile systems as weapons.
DESIGN3	Weapon Message Set shall define digital communication protocol between the host platform and the weapon.
DESIGN4	Weapon Message Set shall include an input set which consists of the command class and query class messages from the host platform to the weapon.
DESIGN5	Weapon Message Set shall include an output set which consists of the report class messages from the weapon to the host platform.

Table 3.1 (continued)

DESIGN6	Input set shall include a command class message meeting the need that the platform describes itself to the weapon. (See 2.3 MIL-STD-1760E Department of Defense Interface Standard Aircraft/Store Electrical Interconnection System.)
DESIGN7	Input set shall include a command class message meeting the need that the platform controls the weapon. (See 2.3 MIL-STD-1760E Department of Defense Interface Standard Aircraft/Store Electrical Interconnection System.)
DESIGN8	Input set shall include a command class message meeting the need that the platform transfers its alignment to the weapon. (See 2.4 Transfer Alignment and Moment Arm.)

Table 3.1 (continued)

DESIGN9	Input set shall include a command class message meeting the need that the platform sets moment arm on the weapon. (See 2.4Transfer Alignment and Moment Arm.)
DESIGN10	Input set shall include a command class message meeting the need that the platform sets target on the weapon. (See 2.2.2.1 Tactical Guided Missile Systems.)
DESIGN11	Input set shall include a command class message meeting the need that the platform controls the weapon seeker. (See 2.2.2.1 Tactical Guided Missile Systems.)

Table 3.1 (continued)

DESIGN12	Input set shall include a query class message meeting the need that the weapon describes itself to the host platform. (See 2.3 MIL-STD-1760E Department of Defense Interface Standard Aircraft/Store Electrical Interconnection System.)
DESIGN13	Input set shall include a query class message meeting the need that the platform monitors the status of the weapon. (See 2.3 MIL-STD-1760E Department of Defense Interface Standard Aircraft/Store Electrical Interconnection System.)
DESIGN14	Input set shall include a query class message meeting the need that the platform monitors the target set on the weapon. (See 2.2.2.1 Tactical Guided Missile Systems.)

Table 3.1 (continued)

DESIGN15	Input set shall include a query class message meeting the need that the platform monitors the weapon seeker. (See 2.2.2.1 Tactical Guided Missile Systems.)
DESIGN16	Output set shall include a report class message meeting the need that the weapon describes itself to the host platform. (See 2.3 MIL-STD-1760E Department of Defense Interface Standard Aircraft/Store Electrical Interconnection System.)
DESIGN17	Output set shall include a report class message meeting the need that the platform monitors the status of the weapon. (See 2.3 MIL-STD-1760E Department of Defense Interface Standard Aircraft/Store Electrical Interconnection System.)

Table 3.1 (continued)

DESIGN18	Output set shall include a report class message meeting the need that the platform monitors the target set on the weapon. (See 2.2.2.1 Tactical Guided Missile Systems.)
DESIGN19	Output set shall include a report class message meeting the need that the platform monitors the weapon seeker (See 2.2.2.1 Tactical Guided Missile Systems.)
DESIGN20	Weapon Service Set shall use experimental class message code range as an extension to the JAUS standard.
DESIGN21	Weapon Service Set messages shall use types based on the messages containing the same or similar type of data in the current JAUS standard for all fields.

Table 3.1 (continued)

DESIGN22	Weapon Service Set messages shall use units based on the messages containing the same or similar type of data in the current JAUS standard for all fields.
DESIGN23	Weapon Service Set messages shall use interpretations based on the messages containing the same or similar type of data in the current JAUS standard for all fields.

The traceability between 1.4 Architectural Requirements / Drivers and 3.1 Weapon Service Set Design Requirements is given in Table 3.2 Architectural Requirements / Drivers – Weapon Service Set Design Requirements Traceability Matrix. Since only architectural requirements / drivers from number 1 to number 5 are design requirements / drivers, design traceability has been created only for these five requirements / drivers.

Table 3.2 Architectural Requirements / Drivers – Weapon Service Set Design Requirements Traceability Matrix

Architectural Requirement / Driver Number	Weapon Service Set Design Requirement Number
1	DESIGN1 DESIGN4 DESIGN5
2	DESIGN2
3	DESIGN3 DESIGN4 DESIGN5
4	DESIGN2 DESIGN20 DESIGN21 DESIGN22 DESIGN23

Table 3.2 (continued)

5	DESIGN6 DESIGN7 DESIGN8 DESIGN9 DESIGN10 DESIGN11 DESIGN12 DESIGN13 DESIGN14 DESIGN15 DESIGN16 DESIGN17 DESIGN18 DESIGN19

3.2 Weapon Message Set

The design within the scope of this study and meeting 3.1 Weapon Service Set Design Requirements is given as Weapon Message Set below. Input Set consists of the command and query class messages from the host platform to the weapon. Output Set consists of the report class messages from the weapon to the host platform.

3.2.1 Input Set

3.2.1.1 Code D000h: Set Platform Description

Table 3.3 Set Platform Description Message Format shows Set Platform Description Message which is defined for the platform description data sharing need described in 2.3 MIL-STD-1760E Department of Defense Interface Standard Aircraft/Store Electrical Interconnection System section. This message is used by the platform in order to describe itself to the weapon. Type, Units and Interpretation fields are based on the messages containing the same or similar type of data in the current JAUS standard.

Table 3.3 Set Platform Description Message Format

Field #	Name	Type	Units	Interpretation
1	Country Code Character 1	Byte	N/A	The convenient country code specified in ISO 3166 standard using only upper-case alphabetic characters of ISO/IEC 8859 standard character set

Table 3.3 (continued)

2	Country Code Character 2	Byte	N/A	The convenient country code specified in ISO 3166 standard using only upper-case alphabetic characters of ISO/IEC 8859 standard character set
3	Platform Identity Character 1	Byte	N/A	Using ISO/IEC 8859 standard character set provided that alphabetic characters are upper-case

Table 3.3 (continued)

4	Platform Identity Character 2	Byte	N/A	Using ISO/IEC 8859 standard character set provided that alphabetic characters are upper-case
5	Platform Identity Character 3	Byte	N/A	Using ISO/IEC 8859 standard character set provided that alphabetic characters are upper-case
6	Platform Identity Character 4	Byte	N/A	Using ISO/IEC 8859 standard character set provided that alphabetic characters are upper-case

Table 3.3 (continued)

7	Platform Identity Character 5	Byte	N/A	Using ISO/IEC 8859 standard character set provided that alphabetic characters are upper-case
8	Platform Identity Character 6	Byte	N/A	Using ISO/IEC 8859 standard character set provided that alphabetic characters are upper-case
9	Platform Identity Character 7	Byte	N/A	Using ISO/IEC 8859 standard character set provided that alphabetic characters are upper-case

Table 3.3 (continued)

10	Platform Identity Character 8	Byte	N/A	Using ISO/IEC 8859 standard character set provided that alphabetic characters are upper-case
11	Platform Identity Character 9	Byte	N/A	Using ISO/IEC 8859 standard character set provided that alphabetic characters are upper-case
12	Platform Identity Character 10	Byte	N/A	Using ISO/IEC 8859 standard character set provided that alphabetic characters are upper-case

Table 3.3 (continued)

13	Platform Identity Character 11	Byte	N/A	Using ISO/IEC 8859 standard character set provided that alphabetic characters are upper-case
14	Platform Identity Character 12	Byte	N/A	Using ISO/IEC 8859 standard character set provided that alphabetic characters are upper-case
15	Platform Identity Character 13	Byte	N/A	Using ISO/IEC 8859 standard character set provided that alphabetic characters are upper-case

Table 3.3 (continued)

16	Platform Identity Character 14	Byte	N/A	Using ISO/IEC 8859 standard character set provided that alphabetic characters are upper-case
17	Platform Identity Character 15	Byte	N/A	Using ISO/IEC 8859 standard character set provided that alphabetic characters are upper-case
18	Platform Identity Character 16	Byte	N/A	Using ISO/IEC 8859 standard character set provided that alphabetic characters are upper-case

Table 3.3 (continued)

19	Weapon Station Number	Byte	N/A	Weapon station number to which the weapon is attached
20	Pylon/Bay Identity	Byte	N/A	Pylon or bay to which the weapon is attached Using ISO/IEC 8859 standard character set provided that alphabetic characters are upper-case

3.2.1.2 Code D001h: Transfer Platform Alignment

Table 3.4 Transfer Platform Alignment Message Format shows Transfer Platform Alignment Message which is defined for the transfer alignment data sharing need described in 2.4 Transfer Alignment and Moment Arm section. Axis definitions for the message data is defined in 2.1 Joint Architecture for Unmanned Systems (JAUS) and 2.3 MIL-STD-1760E Department of Defense Interface Standard Aircraft/Store

Electrical Interconnection System. This message is used by the platform in order to transfer its alignment data to the weapon. Type, Units and Interpretation fields are based on the messages containing the same or similar type of data in the current JAUS standard.

Table 3.4 Transfer Platform Alignment Message Format

Field #	Name	Type	Units	Interpretation
1	Timestamp	Unsigned Integer	N/A	Bits 0-9: milliseconds, range 0...999 Bits 10-15: Seconds, range 0...59 Bits 16 – 21: Minutes, range 0...59 Bits 22-26: Hour (24-hour clock), range 0...23 Bits 27-31: Day, range 1...31

Table 3.4 (continued)

2	Platform Latitude	Integer	Degrees	Scaled Integer Lower Limit = -90 Upper Limit = 90
3	Platform Longitude	Integer	Degrees	Scaled Integer Lower Limit = -180 Upper Limit = 180
4	Platform Geodetic Altitude	Integer	Meters	Scaled Integer Lower Limit = -10,000 Upper Limit = 35,000
5	Platform Height Above Ground Level	Integer	Meters	Scaled Integer Lower Limit = -10,000 Upper Limit = 35,000

Table 3.4 (continued)

6	Platform Barometric Altitude	Integer	Meters	Scaled Integer Lower Limit = -10,000 Upper Limit = 35,000
7	Platform True Heading	Short Integer	Radians	Scaled Integer Lower Limit = $-\pi$ Upper Limit = π
8	Platform True Ground Track	Short Integer	Radians	Scaled Integer Lower Limit = $-\pi$ Upper Limit = π
9	Platform Magnetic Heading	Short Integer	Radians	Scaled Integer Lower Limit = $-\pi$ Upper Limit = π

Table 3.4 (continued)

10	Platform Pitch	Short Integer	Radians	Scaled Integer Lower Limit = -π Upper Limit = π
11	Platform Roll	Short Integer	Radians	Scaled Integer Lower Limit = -π Upper Limit = π
12	Platform Velocity X	Integer	Meters per Second	Scaled Integer Lower Limit = -65.534 Upper Limit = 65.534
13	Platform Velocity Y	Integer	Meters per Second	Scaled Integer Lower Limit = -65.534 Upper Limit = 65.534

Table 3.4 (continued)

14	Platform Velocity Z	Integer	Meters per Second	Scaled Integer Lower Limit = -65.534 Upper Limit = 65.534
15	Platform Heading Rate	Short Integer	Radians per Second	Scaled Integer Lower Limit = -32.767 Upper Limit = 32.767
16	Platform Ground Track Rate	Short Integer	Radians per Second	Scaled Integer Lower Limit = -32.767 Upper Limit = 32.767
17	Platform Pitch Rate	Short Integer	Radians per Second	Scaled Integer Lower Limit = -32.767 Upper Limit = 32.767

Table 3.4 (continued)

18	Platform Roll Rate	Short Integer	Radians per Second	Scaled Integer Lower Limit = -32.767 Upper Limit = 32.767
19	Platform Acceleration X	Integer	Meters per second squared	Scaled Integer Lower limit = -20 m/sec2 Upper limit = +20 m/sec2
20	Platform Acceleration Y	Integer	Meters per second squared	Scaled Integer Lower limit = -20 m/sec2 Upper limit = +20 m/sec2
21	Platform Acceleration Z	Integer	Meters per second squared	Scaled Integer Lower limit = -20 m/sec2 Upper limit = +20 m/sec2

3.2.1.3 Code D002h: Set Moment Arm

Table 3.5 Set Moment Arm Message Format shows Set Moment Arm Message which is defined for the moment arm data sharing need described in 2.4 Transfer Alignment and Moment Arm section. Axis definitions for the message data is defined in 2.1 Joint Architecture for Unmanned Systems (JAUS) and 2.3 MIL-STD-1760E Department of Defense Interface Standard Aircraft/Store Electrical Interconnection System. This message is used by the platform in order to set moment arm data on the weapon. Type, Units and Interpretation fields are based on the messages containing the same or similar type of data in the current JAUS standard.

Table 3.5 Set Moment Arm Message Format

Field #	Name	Type	Units	Interpretation
1	Platform-Reference X Axis Offset	Integer	Meters	X coordinate of origin of weapon coordinate system measured with respect to platform coordinate system Scaled Integer Lower limit = -30 m Upper limit = +30 m

Table 3.5 (continued)

2	Platform-Reference Y Axis Offset	Integer	Meters	Y coordinate of origin of weapon coordinate system measured with respect to platform coordinate system Scaled Integer Lower limit = -30 m Upper limit = +30 m

Table 3.5 (continued)

3	Platform-Reference Z Axis Offset	Integer	Meters	Z coordinate of origin of weapon coordinate system measured with respect to platform coordinate system Scaled Integer Lower limit = -30 m Upper limit = +30 m
4	Platform-Reference Axis Yaw Difference	Short Integer	Radians	Scaled Integer Lower Limit = - π Upper Limit = π

Table 3.5 (continued)

5	Platform-Reference Axis Pitch Difference	Short Integer	Radians	Scaled Integer Lower Limit = - π Upper Limit = π
6	Platform-Reference Axis Roll Difference	Short Integer	Radians	Scaled Integer Lower Limit = - π Upper Limit = π

3.2.1.4 Code D003h: Control Weapon

Table 3.6 Control Weapon Message Format shows Control Weapon Message which is defined for controlling weapon data sharing need described in 2.3 MIL-STD-1760E Department of Defense Interface Standard Aircraft/Store Electrical Interconnection System section. This message is used by the platform in order to control the weapon. Type, Units and Interpretation fields are based on the messages containing the same or similar type of data in the current JAUS standard.

Table 3.6 Control Weapon Message Format

Field #	Name	Type	Units	Interpretation
1	Weapon Station Number	Byte	N/A	
2	Critical Control 1	Byte	N/A	Bit 0: Fire, Launch, or Release Bit 1: Jettison Bit 2: Commit to Separate Weapon or Munition on Station Bit 3: Execute Arming Bit 4: Preset Arming Bit 5: Select Store Bit 6: Initiate Interruptive Built-In-Test Bit 7: Release / Launch Mode

Table 3.6 (continued)

3	Critical Control 2	Byte	N/A	Bit 0: Erase Command / Authority Bit 1: RF Jam Command / Authority Bit 2: RF Emission Activate Command / Authority Bit 3: Control Surface Pre-Launch Inhibit Bit 4: Abort Release / Launch Bit 5: Activate Non-Safety Critical Release Functions Bit 6-7: Reserved

3.2.1.5 Code D004h: Set Target

Table 3.7 Set Target Message Format shows Set Target Message which is defined for the target data sharing need described in 2.2 Weapons and Weapon Systems section. Axis definitions for the message data is defined in 2.1 Joint Architecture for Unmanned Systems (JAUS) and 2.3 MIL-STD-1760E Department of Defense Interface Standard Aircraft/Store Electrical Interconnection System. This message is used by the platform in order to set target data on the weapon. Type, Units and Interpretation fields are based on the messages containing the same or similar type of data in the current JAUS standard.

Table 3.7 Set Target Message Format

Field #	Name	Type	Units	Interpretation
1	Target Latitude	Integer	Degrees	Scaled Integer Lower Limit = -90 Upper Limit = 90
2	Target Longitude	Integer	Degrees	Scaled Integer Lower Limit = -180 Upper Limit = 180

Table 3.7 (continued)

3	Target Geodetic Altitude	Integer	Meters	Scaled Integer Lower Limit = -10,000 Upper Limit = 35,000
4	Target Height Above Ground Level	Integer	Meters	Scaled Integer Lower Limit = -10,000 Upper Limit = 35,000
5	Target Barometric Altitude	Integer	Meters	Scaled Integer Lower Limit = -10,000 Upper Limit = 35,000
6	Target Approach True Heading	Short Integer	Radians	Scaled Integer Lower Limit = $-\pi$ Upper Limit = π

Table 3.7 (continued)

7	Target Approach Pitch	Short Integer	Radians	Scaled Integer Lower Limit = -π Upper Limit = π
8	Target Velocity X	Integer	Meters per Second	Scaled Integer Lower Limit = -65.534 Upper Limit = 65.534
9	Target Velocity Y	Integer	Meters per Second	Scaled Integer Lower Limit = -65.534 Upper Limit = 65.534
10	Target Velocity Z	Integer	Meters per Second	Scaled Integer Lower Limit = -65.534 Upper Limit = 65.534

3.2.1.6 Code D005h: Control Weapon Seeker

Table 3.8 Control Weapon Seeker Message Format shows Control Weapon Seeker Message which is defined for controlling weapon seeker data sharing need described in 2.2 Weapons and Weapon Systems section. Axis definitions for the message data is defined in 2.1 Joint Architecture for Unmanned Systems (JAUS) and 2.3 MIL-STD-1760E Department of Defense Interface Standard Aircraft/Store Electrical Interconnection System. This message is used by the platform in order to control the weapon seeker. Type, Units and Interpretation fields are based on the messages containing the same or similar type of data in the current JAUS standard.

Table 3.8 Control Weapon Seeker Message Format

Field #	Name	Type	Units	Interpretation
1	Seeker Mode Command	Byte	N/A	Enumeration 0: Idle 1: Rotate Manually 2: Slave 3: Track 4: Zeroize 5 – 255: Reserved

Table 3.8 (continued)

2	Gimbal Yaw Manual Rotating Rate	Short Integer	Radians per Second	Scaled Integer Lower Limit = -32.767 Upper Limit = 32.767
3	Gimbal Pitch Manual Rotating Rate	Short Integer	Radians per Second	Scaled Integer Lower Limit = -32.767 Upper Limit = 32.767
4	Gimbal Yaw Slave Position	Short Integer	Radians	Scaled Integer Lower Limit = - π Upper Limit = π
5	Gimbal Pitch Slave Position	Short Integer	Radians	Scaled Integer Lower Limit = - π Upper Limit = π

Table 3.8 (continued)

6	Move Tracking Point	Byte	N/A	Enumeration 0: No movement 1: Move Tracking Point Up 2: Move Tracking Point Down 3: Move Tracking Point Left 4: Move Tracking Point Right 5 – 255: Reserved

Table 3.8 (continued)

7	Laser Code Character 1	Byte	N/A	The selected laser code specified in STANAG 3733 using ISO/IEC 8859 standard character set
8	Laser Code Character 2	Byte	N/A	The selected laser code specified in STANAG 3733 using ISO/IEC 8859 standard character set

Table 3.8 (continued)

9	Laser Code Character 3	Byte	N/A	The selected laser code specified in STANAG 3733 using ISO/IEC 8859 standard character set
10	Laser Code Character 4	Byte	N/A	The selected laser code specified in STANAG 3733 using ISO/IEC 8859 standard character set

3.2.1.7 Code D1000h: Query Weapon Description

This message is defined for the weapon description data sharing need described in 2.3 MIL-STD-1760E Department of Defense Interface Standard Aircraft/Store Electrical Interconnection System section. This message is used by the platform in order to allow the weapon to describe itself. There is no need to define data in this message.

3.2.1.8 Code D1003h: Query Weapon Status

This message is defined for monitoring weapon data sharing need described in 2.3 MIL-STD-1760E Department of Defense Interface Standard Aircraft/Store Electrical Interconnection System section. This message is used by the platform in order to allow the weapon to inform the platform about weapon status. There is no need to define data in this message.

3.2.1.9 Code D1004h: Query Target

This message is defined for the target data sharing need described in 2.2 Weapons and Weapon Systems section. This message is used by the platform in order to allow the weapon to verify that mission critical target data is received correctly. There is no need to define data in this message.

3.2.1.10 Code D1005h: Query Weapon Seeker Status

This message is defined for monitoring weapon seeker data sharing need described in 2.3 Weapons and Weapon Systems section. This message is used by the platform in order to allow the weapon about the weapon seeker status. There is no need to define data in this message.

3.2.2 Output Set

3.2.2.1 Code D200h: Report Weapon Description

Table 3.9 Report Weapon Description Message Format shows Report Weapon Description Message which is defined for the weapon description data sharing need described in 2.3 MIL-STD-1760E Department of Defense Interface Standard Aircraft/Store Electrical Interconnection System section. This message is used by the weapon in order to describe itself to the platform. Type, Units and Interpretation fields are based on the messages containing the same or similar type of data in the current JAUS standard.

Table 3.9 Report Weapon Description Message Format

Field #	Name	Type	Units	Interpretation
1	Country Code Character 1	Byte	N/A	The convenient country code specified in ISO 3166 standard using only upper-case alphabetic characters of ISO/IEC 8859 standard character set

Table 3.9 (continued)

2	Country Code Character 2	Byte	N/A	The convenient country code specified in ISO 3166 standard using only upper-case alphabetic characters of ISO/IEC 8859 standard character set
3	Weapon Type	Unsigned Short Integer	N/A	Indicator of the weapon type code value as assigned by the control point for weapon nomenclature

Table 3.9 (continued)

4	Weapon Variant	Byte	N/A	Indicator of the weapon variant code value as assigned by the control point for weapon nomenclature
5	Weapon Identity Character 1	Byte	N/A	Using ISO/IEC 8859 standard character set provided that alphabetic characters are upper-case
6	Weapon Identity Character 2	Byte	N/A	Using ISO/IEC 8859 standard character set provided that alphabetic characters are upper-case

Table 3.9 (continued)

7	Weapon Identity Character 3	Byte	N/A	Using ISO/IEC 8859 standard character set provided that alphabetic characters are upper-case
8	Weapon Identity Character 4	Byte	N/A	Using ISO/IEC 8859 standard character set provided that alphabetic characters are upper-case
9	Weapon Identity Character 5	Byte	N/A	Using ISO/IEC 8859 standard character set provided that alphabetic characters are upper-case

Table 3.9 (continued)

10	Weapon Identity Character 6	Byte	N/A	Using ISO/IEC 8859 standard character set provided that alphabetic characters are upper-case
11	Weapon Identity Character 7	Byte	N/A	Using ISO/IEC 8859 standard character set provided that alphabetic characters are upper-case
12	Weapon Identity Character 8	Byte	N/A	Using ISO/IEC 8859 standard character set provided that alphabetic characters are upper-case

Table 3.9 (continued)

13	Weapon Identity Character 9	Byte	N/A	Using ISO/IEC 8859 standard character set provided that alphabetic characters are upper-case
14	Weapon Identity Character 10	Byte	N/A	Using ISO/IEC 8859 standard character set provided that alphabetic characters are upper-case
15	Weapon Identity Character 11	Byte	N/A	Using ISO/IEC 8859 standard character set provided that alphabetic characters are upper-case

Table 3.9 (continued)

16	Weapon Identity Character 12	Byte	N/A	Using ISO/IEC 8859 standard character set provided that alphabetic characters are upper-case
17	Weapon Identity Character 13	Byte	N/A	Using ISO/IEC 8859 standard character set provided that alphabetic characters are upper-case
18	Weapon Identity Character 14	Byte	N/A	Using ISO/IEC 8859 standard character set provided that alphabetic characters are upper-case

Table 3.9 (continued)

19	Weapon Identity Character 15	Byte	N/A	Using ISO/IEC 8859 standard character set provided that alphabetic characters are upper-case
20	Weapon Identity Character 16	Byte	N/A	Using ISO/IEC 8859 standard character set provided that alphabetic characters are upper-case

Table 3.9 (continued)

21	Maximum Interruptive Built-In-Test Time	Integer	Seconds	The maximum time duration that the weapon may be nonoperational while conducting interruptive Built-In-Test commanded by the platform Scaled Integer Lower limit = 0 sec Upper limit = 6000 sec

Table 3.9 (continued)

22	Weapon Configuration Identifier Character 1	Byte	N/A	Specific configuration information about the weapon, such as the software version installed Using ISO/IEC 8859 standard character set provided that unused characters shall be set to SPACE (hexadecimal 20) character

Table 3.9 (continued)

23	Weapon Configuration Identifier Character 2	Byte	N/A	Specific configuration information about the weapon, such as the software version installed Using ISO/IEC 8859 standard character set provided that unused characters shall be set to SPACE (hexadecimal 20) character

Table 3.9 (continued)

24	Weapon Configuration Identifier Character 3	Byte	N/A	Specific configuration information about the weapon, such as the software version installed Using ISO/IEC 8859 standard character set provided that unused characters shall be set to SPACE (hexadecimal 20) character

Table 3.9 (continued)

25	Weapon Configuration Identifier Character 4	Byte	N/A	Specific configuration information about the weapon, such as the software version installed Using ISO/IEC 8859 standard character set provided that unused characters shall be set to SPACE (hexadecimal 20) character

Table 3.9 (continued)

26	Weapon Configuration Identifier Character 5	Byte	N/A	Specific configuration information about the weapon, such as the software version installed Using ISO/IEC 8859 standard character set provided that unused characters shall be set to SPACE (hexadecimal 20) character

Table 3.9 (continued)

27	Weapon Configuration Identifier Character 6	Byte	N/A	Specific configuration information about the weapon, such as the software version installed Using ISO/IEC 8859 standard character set provided that unused characters shall be set to SPACE (hexadecimal 20) character

Table 3.9 (continued)

28	Weapon Station 1 Identifier Code	Unsigned Short Integer	N/A	A binary code assigned by the control point for weapon nomenclature for the munition located on Station 1 of a weapon
29	Weapon Station 2 Identifier Code	Unsigned Short Integer	N/A	A binary code assigned by the control point for weapon nomenclature for the munition located on Station 2 of a weapon

Table 3.9 (continued)

30	Weapon Station 3 Identifier Code	Unsigned Short Integer	N/A	A binary code assigned by the control point for weapon nomenclature for the munition located on Station 3 of a weapon
31	Weapon Station 4 Identifier Code	Unsigned Short Integer	N/A	A binary code assigned by the control point for weapon nomenclature for the munition located on Station 4 of a weapon

Table 3.9 (continued)

32	Weapon Station 5 Identifier Code	Unsigned Short Integer	N/A	A binary code assigned by the control point for weapon nomenclature for the munition located on Station 5 of a weapon
33	Weapon Station 6 Identifier Code	Unsigned Short Integer	N/A	A binary code assigned by the control point for weapon nomenclature for the munition located on Station 6 of a weapon

Table 3.9 (continued)

34	Weapon Station 7 Identifier Code	Unsigned Short Integer	N/A	A binary code assigned by the control point for weapon nomenclature for the munition located on Station 7 of a weapon
35	Weapon Station 8 Identifier Code	Unsigned Short Integer	N/A	A binary code assigned by the control point for weapon nomenclature for the munition located on Station 8 of a weapon

Table 3.9 (continued)

36	Power-Up Time	Integer	Seconds	Time duration that the weapon needs to have power applied in order to ensure full communication in accordance with the weapon's system specification or interface control document Scaled Integer Lower limit = 0 sec Upper limit = 6000 sec

3.2.2.2 Code D203h: Report Weapon Status

Table 3.10 Report Weapon Status Message Format shows Report Weapon Status Message which is defined for monitoring weapon data sharing need described in 2.3 MIL-STD-1760E Department of Defense Interface Standard Aircraft/Store Electrical Interconnection System section. This message is used by the weapon in order to inform the platform about the weapon status. Type, Units and Interpretation fields are based on the messages containing the same or similar type of data in the current JAUS standard.

Table 3.10 Report Weapon Status Message Format

Field #	Name	Type	Units	Interpretation
1	Weapon Station Number	Byte	N/A	

Table 3.10 (continued)

2	Weapon State 1	Byte	N/A	Bit 0: Fired, Launched or Released Bit 1: Jettisoned Bit 2: Committed to Separate Weapon or Munition on Station Bit 3: Armed Bit 4: Arming Preset Bit 5: Store Selected Bit 6: Store in Interruptive Built-In-Test Bit 7: Weapon to be released / launched.

Table 3.10 (continued)

3	Weapon State 2	Byte	N/A	Bit 0: Erase on / Authorized Bit 1: RF jam on / authorized. Bit 2: RF Emission on / Authorized. Bit 3: Control Surface Pre-Launch Movement Inhibited Bit 4: Weapon in Abort State Bit 5: Non-Safety Critical Release Functions Activated Bit 6-7: Reserved

3.2.2.3 Code D204h: Report Target

Table 3.11 Report Target Message Format shows Report Target Message which is defined for the target data sharing need described in 2.2 Weapons and Weapon Systems section. Axis definitions for the message data is defined in 2.1 Joint Architecture for Unmanned Systems (JAUS) and 2.3 MIL-STD-1760E Department of Defense Interface Standard Aircraft/Store Electrical Interconnection System. This message is used by the weapon in order to verify that mission critical target data is received correctly. Type, Units and Interpretation fields are based on the messages containing the same or similar type of data in the current JAUS standard.

Table 3.11 Report Target Message Format

Field #	Name	Type	Units	Interpretation
1	Target Latitude	Integer	Degrees	Scaled Integer Lower Limit = -90 Upper Limit = 90
2	Target Longitude	Integer	Degrees	Scaled Integer Lower Limit = -180 Upper Limit = 180

Table 3.11 (continued)

3	Target Geodetic Altitude	Integer	Meters	Scaled Integer Lower Limit = -10,000 Upper Limit = 35,000
4	Target Height Above Ground Level	Integer	Meters	Scaled Integer Lower Limit = -10,000 Upper Limit = 35,000
5	Target Barometric Altitude	Integer	Meters	Scaled Integer Lower Limit = -10,000 Upper Limit = 35,000
6	Target Approach True Heading	Short Integer	Radians	Scaled Integer Lower Limit = $-\pi$ Upper Limit = π

Table 3.11 (continued)

7	Target Approach Pitch	Short Integer	Radians	Scaled Integer Lower Limit = -π Upper Limit = π
8	Target Velocity X	Integer	Meters per Second	Scaled Integer Lower Limit = -65.534 Upper Limit = 65.534
9	Target Velocity Y	Integer	Meters per Second	Scaled Integer Lower Limit = -65.534 Upper Limit = 65.534
10	Target Velocity Z	Integer	Meters per Second	Scaled Integer Lower Limit = -65.534 Upper Limit = 65.534

3.2.2.4 Code D205h: Report Weapon Seeker Status

Table 3.12. Report Weapon Seeker Status Message Format shows Report Weapon Seeker Message which is defined for monitoring weapon seeker data sharing need described in 2.2 Weapons and Weapon Systems section. Axis definitions for the message data is defined in 2.1 Joint Architecture for Unmanned Systems (JAUS) and 2.3 MIL-STD-1760E Department of Defense Interface Standard Aircraft/Store Electrical Interconnection System. This message is used by the weapon in order to inform the platform about the weapon seeker status. Type, Units and Interpretation fields are based on the messages containing the same or similar type of data in the current JAUS standard.

Table 3.12 Report Weapon Seeker Status Message Format

Field #	Name	Type	Units	Interpretation
1	Seeker Mode	Byte	N/A	Enumeration 0: Idle 1: Rotate Manually 2: Slave 3: Track 4: Zeroize 5 – 255: Reserved

Table 3.12 (continued)

2	Gimbal Yaw Position	Short Integer	Radians	Scaled Integer Lower Limit = - π Upper Limit = π
3	Gimbal Pitch Position	Short Integer	Radians	Scaled Integer Lower Limit = - π Upper Limit = π
4	Laser Code Character 1	Byte	N/A	The selected laser code specified in STANAG 3733 using ISO/IEC 8859 standard character set

Table 3.12 (continued)

5	Laser Code Character 2	Byte	N/A	The selected laser code specified in STANAG 3733 using ISO/IEC 8859 standard character set
6	Laser Code Character 3	Byte	N/A	The selected laser code specified in STANAG 3733 using ISO/IEC 8859 standard character set

Table 3.12 (continued)

7	Laser Code Character 4	Byte	N/A	The selected laser code specified in STANAG 3733 using ISO/IEC 8859 standard character set

CHAPTER 4

IMPLEMENTATION

In this chapter, the information given about the implementation made with ROKETSAN tactical guided missiles within the scope of this study is limited due to confidentiality. No technical details have been shared that would violate confidentiality. Confidential details of the study have been identified in an internal document of ROKETSAN [39].

In this chapter, the design that satisfies the research question is used for implementation. The implementation requirements derived from architectural requirements / drivers are set out. The implementation is made in accordance with these requirements. The principles of the implementation and the results of the implementation is shared.

4.1 How to Implement Core Service Set for Weapon Components

JAUS Core Service Set consists of the basic messages that have to be accepted by all components [8]. However, components do not have to take specific actions on each input message while JAUS Core Service Set requires that all components accept these messages [40]. Because the expected behaviors of the weapons depend on the specifications and needs of the weapons and the platforms. Thus, weapon integrators have to determine the component behaviors by considering these specifications and needs and maintain the JAUS Core Service Set compatibility.

4.2 How to Implement Weapon Service Set

The JAUS standard defines functional components with message architecture but does not impose any specific configuration and exactly how the messages are used

[17]. Namely, the JAUS standard provides interoperability with JAUS-defined messages shared between JAUS-defined components. Therefore, in general, imposing strict rules of implementation do not conform to the spirit and the characteristics of the standard. However, it is useful to present a sample usage scenario for the weapon service set implementation as a guideline, not as a strict application rule, considering the needs of the weapon systems analyzed in this study and sorting logically the messages defined in this study.

Figure 4.1 Weapon Service Set Sequence Diagram reveals a sample usage scenario. In this scenario;

- platform describes itself to weapon,
- platform asks weapon to describe itself,
- weapon describes itself to platform,
- platform transfers alignment to weapon synchronously,
- platform monitors status of weapon and weapon seeker periodically,
- platform sets moment arm data, target data and controls weapon and weapon seeker when necessary.

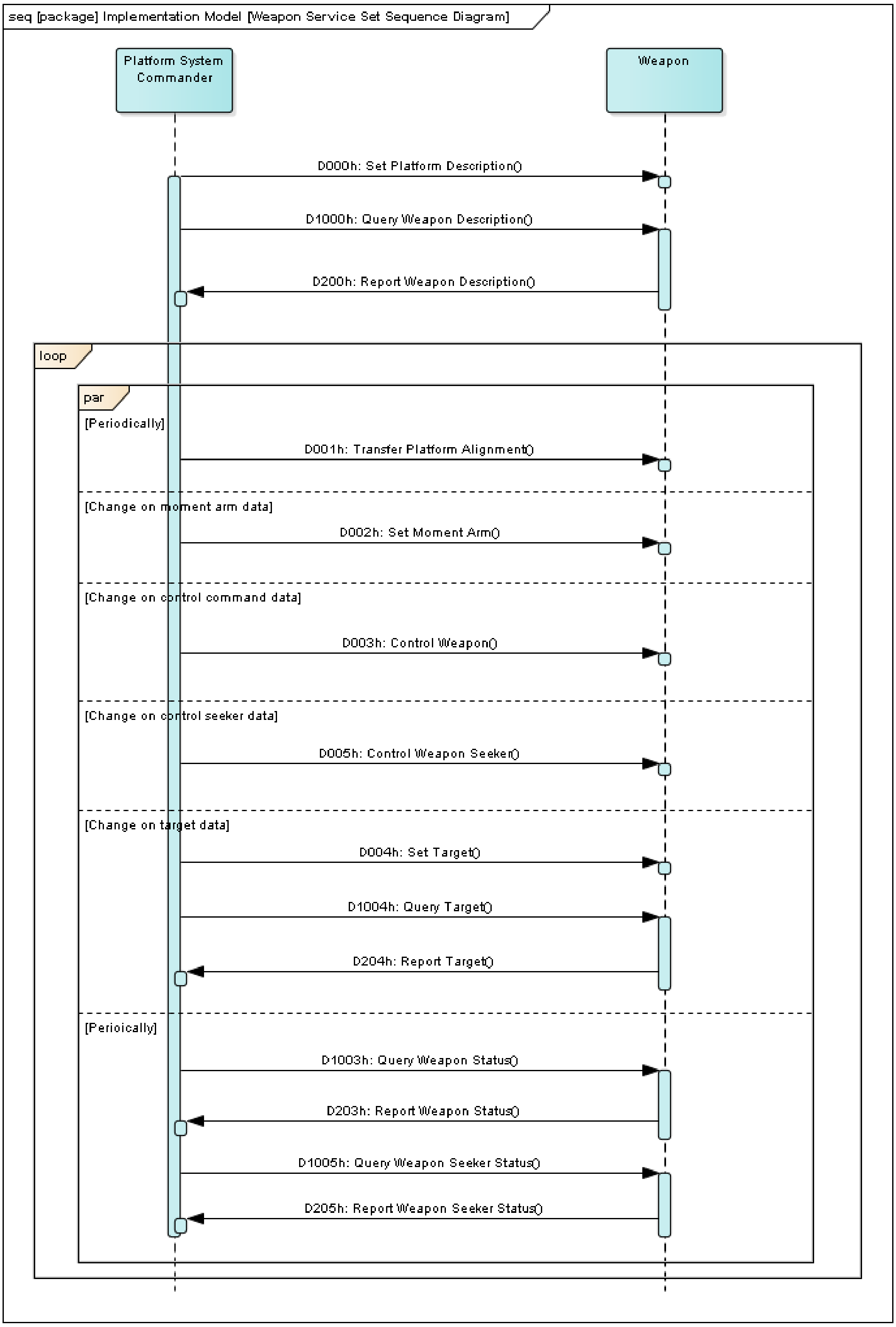

Figure 4.1 Weapon Service Set Sequence Diagram

4.3 Implementation Requirements

Implementation requirements are derived from 1.4 Architectural Requirements / Drivers which are derived from 1.3 Research Question, within the scope of the study. Implementation requirements are given in Table 4.1. Implementation Requirements.

Table 4.1 Implementation Requirements

Number	Implementation Requirements
IMPLEMENTATION1	A message set named Weapon Message Set shall be designed as an extension suggestion to the JAUS standard in order to enable interoperable weapon integration.
IMPLEMENTATION2	A laboratory-level simulation test shall be conducted in order to ensure the applicability of this design
IMPLEMENTATION3	In the simulation tests the target shall be assumed to be stationary.
IMPLEMENTATION4	In the simulation tests the platform shall be assumed to be stationary.

Table 4.1 (continued)

IMPLEMENTATION5	A Platform System Commander shall be included in the test setup.
IMPLEMENTATION6	The Platform System Commander shall use Weapon Service Set defined in this study in order to control the weapon.
IMPLEMENTATION7	A JAUS Compatibility Node shall be included in the test setup.
IMPLEMENTATION8	The JAUS Compatibility Node shall make ROKETSAN Tactical Guided Missile Weapon Simulator JAUS compatible by converting current MIL-STD-1553 interface into WEAPON SERVICE SET.
IMPLEMENTATION9	A ROKETSAN Tactical Guided Missile Weapon Simulator shall be included in the test setup.

Table 4.1 (continued)

IMPLEMENTATION10	The Weapon Simulator shall consist of launcher simulator and missile simulator(s).
IMPLEMENTATION11	The Weapon Simulator shall behave like weapon in order to simulate one successful firing activity through its digital communication protocol.
IMPLEMENTATION12	A Data Acquisition System shall be included in the test setup.
IMPLEMENTATION13	The data acquisition system shall observe WEAPON SERVICE SET and MIL-STD-1553 interfaces in order to determine the success of the test activity.
IMPLEMENTATION14	The Platform System Commander shall work in accordance with Figure 4.1 Weapon Service Set Sequence Diagram.

Table 4.1 (continued)

IMPLEMENTATION15	The JAUS Compatibility Node shall work in accordance with Figure 4.1 Weapon Service Set Sequence Diagram.
IMPLEMENTATION16	WEAPON SERVICE SET interface between The Platform System Commander and The JAUS Compatibility Node shall be ethernet interface in accordance with the JAUS standard.

The traceability between sections 1.4 Architectural Requirements / Drivers and 4.3 Implementation Requirements is given in Table 4.2 Architectural Requirements / Drivers – Implementation Requirements Traceability Matrix. Since only architectural requirements / drivers with number 3, 6, 7 and 8 are implementation requirements / drivers, implementation traceability has been created only for these four requirements / drivers.

Table 4.2 Architectural Requirements / Drivers – Implementation Requirements Traceability Matrix

Architectural Requirement / Driver Number	Implementation Requirement Number
3	IMPLEMENTATION6 IMPLEMENTATION8 IMPLEMENTATION11 IMPLEMENTATION13
6	IMPLEMENTATION1 IMPLEMENTATION2 IMPLEMENTATION5 IMPLEMENTATION6 IMPLEMENTATION7 IMPLEMENTATION8 IMPLEMENTATION9 IMPLEMENTATION10 IMPLEMENTATION11 IMPLEMENTATION12 IMPLEMENTATION13 IMPLEMENTATION14 IMPLEMENTATION15 IMPLEMENTATION16

Table 4.2 (continued)

7	IMPLEMENTATION3 IMPLEMENTATION4
8	IMPLEMENTATION8 IMPLEMENTATION9 IMPLEMENTATION10 IMPLEMENTATION11

4.4 Implementation Tests

4.4.1 Test Setup

See Figure 4.2 Test Setup for the test setup established in accordance with 4.3 Implementation Requirements. There is one executable software item on Platform System Commander node. There is another executable software item on JAUS Compatibility node. JAUS Compatibility Node software is responsible for making Weapon Simulator JAUS-compatible in terms of WEAPON SERVICE SET. Platform System Commander is responsible for controlling the weapon using WEAPON SERVICE SET. The software items are developed by using C++. Data Acquisition System is responsible for recording all the data on WEAPON SERVICE SET and MIL-STD-1553 interfaces with time tags.

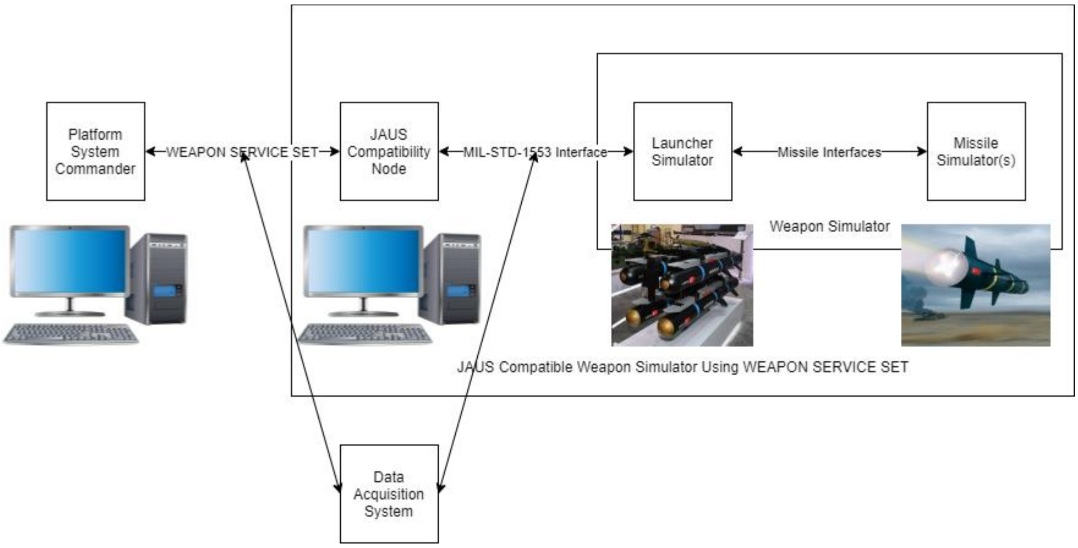

Figure 4.2 Test Setup

4.4.2 Test Procedure

The test procedure for the test performed in order to ensure the applicability of WEAPON SERVICE SET design at laboratory-level is given below.

1. 4.4.1 Test Setup is established.
2. 4.4.1 Test Setup is powered up.
3. JAUS Compatibility Node software is run.
4. Platform System Commander software is run.
5. It is observed that the setup finishes the test activity in accordance with Figure 4.1 Weapon Service Set Sequence Diagram over JAUS Compatibility Node software and Platform System Commander software.
6. 4.4.1 Test Setup is powered down.
7. The data record on Data Acquisition System is examined whether the setup finishes the test activity in accordance with Figure 4.1 Weapon Service Set Sequence Diagram.
8. The test activity is ended.

4.4.3 Test Results

It was observed that all steps were successfully applied in the test activity following 4.4.2 Test Procedure. Confidential details of the test results have been identified in an internal document of ROKETSAN [39]. The data record on Data Acquisition System shows;

- the setup finishes the test activity in accordance with Figure 4.1 Weapon Service Set Sequence Diagram,
- the WEAPON SERVICE SET design which is the main subject of this study is applicable to tactical guided missiles within the scope of this study.

CHAPTER 5

CONCLUSION AND FUTURE WORK

Weapon integration into unmanned systems, which are taking increasingly the place of people in dangerous environments and in military missions, is studied in this thesis work. In this context, interoperable standardization of communication protocol between the weapon and the host platform is discussed considering that the future concept of weapon integration is the plug and play concept. In accordance with this concept, thesis work is advanced on the JAUS standard, which aims to ensure full communication interoperability for unmanned systems. The scope of the study is determined as tactical guided missiles. Within the scope of the thesis, the message set and protocol, which shall enable interoperable weapon integration in the plug and play concept in terms of the digital communication for tactical guided missile systems between the weapon and the host platform, are defined as an extension suggestion to the JAUS standard. The resulting design is shared in the thesis. In addition to this, in this ROKETSAN-supported study, ROKETSAN tactical guided missile simulators is used to show that the design is applicable at the basic level laboratory tests.

It is clear that the scope of this study, which is an entry level study on the subject, should be extended with future studies. In this way, integration of weapons to unmanned systems can be done automatically in the plug and play concept in terms of the digital communication, just like USB sticks that can easily be operated automatically in almost any computer today. As concrete benefits of this improvement, integration costs, integration times, technical difficulties shall generally be reduced and weapon integration to unmanned systems shall be easier.

To summarize, the contribution of this study to the literature is to establish a communication architecture and protocol extending the JAUS standard that can be implemented based on tactical missile systems in the plug and play concept of weapon integration for unmanned systems and to demonstrate the feasibility of this architecture and protocol at a basic level.

The following issues can be studied in the future to improve this work:

- Extending scope with other weapon types.
- Extending scope with weapons and conditions in which determinism and timings are more important than in the scope of this study. In this case, limitations such as data rate, delays, need for real-time communication should also need to be considered.
- Studying the compatibility of other electrical signals like power and discrete signals needed by weapon systems beyond the digital communication architecture presented in this study.
- Studying safety issues about with the communication architecture presented in this study.
- Extending scope with tactical and combat-level interoperability standards.

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