NATO STANDARD

AEP-4818 Vol. V

ROBOTICS AND AUTONOMOUS SYSTEMS – GROUND (RAS-G) INTEROPERABILITY PROFILE (IOP): PAYLOADS PROFILE

Edition A Version 1
FEBRUARY 2023

NORTH ATLANTIC TREATY ORGANIZATION

ALLIED ENGINEERING PUBLICATION

Published by the
NATO STANDARDIZATION OFFICE (NSO)

INTENTIONALLY BLANK

NORTH ATLANTIC TREATY ORGANIZATION (NATO)

NATO STANDARDIZATION OFFICE (NSO)

NATO LETTER OF PROMULGATION

22 February 2023

;

1. The enclosed Allied Engineering Publication AEP-4818 Vol. V, Edition A, Version 1 ROBOTICS AND AUTONOMOUS SYSTEMS – GROUND (RAS-G) INTEROPERABILITY PROFILE (IOP): PAYLOADS PROFILE, which has been approved by the nations in the NATO ARMY ARMAMENTS GROUP (AC225 NAAG), is promulgated herewith. The agreement of nations to use this publication is recorded in STANREC 4818.

2. AEP-4818 Vol. V, Edition A, Version 1 is effective upon receipt.

3. This NATO standardization document is issued by NATO. In case of reproduction, NATO is to be acknowledged. NATO does not charge any fee for its standardization documents at any stage, which are not intended to be sold. They can be retrieved from the NATO Standardization Document Database (https://nso.nato.int/nso/) or through your national standardization authorities.

4. This publication shall be handled in accordance with C-M(2002)60.

Dimitrios SIGOULAKIS
Lieutenant General, GRC (A)
Director, NATO Standardization Office

INTENTIONALLY BLANK

RESERVED FOR NATIONAL LETTER OF PROMULGATION

INTENTIONALLY BLANK

RECORD OF RESERVATIONS

CHAPTER	RECORD OF RESERVATION BY NATIONS
Note: The reservations listed on this page include only those that were recorded at time of promulgation and may not be complete. Refer to the NATO Standardization Document Database for the complete list of existing reservations.	

INTENTIONALLY BLANK

RECORD OF SPECIFIC RESERVATIONS

[nation]	[detail of reservation]
Note: The reservations listed on this page include only those that were recorded at time of promulgation and may not be complete. Refer to the NATO Standardization Document Database for the complete list of existing reservations.	

INTENTIONALLY BLANK

TABLE OF CONTENTS

INTENTIONALLY BLANK

CHAPTER 1 SCOPE

1.1 PURPOSE

This document specifies interoperability concepts, architecture, and requirements associated with robotic system payloads. The capabilities addressed within this Interoperability Profile (IOP) relate primarily to payload interoperability with respect to payload operation, control, and status. Payload integration to the Unmanned Ground Vehicle (UGV) platform is addressed within this document and the RAS-G IOP Overarching Profile. To the degree possible, capabilities have been subset utilizing Interoperability Attributes to support the specification of payload system variations from simple payload systems to complex, integrated payload systems.

For the purpose of IOP Version 1 (V1), a limited number of payloads will be discussed. In future versions of this document, payloads and payload capabilities will be added as needed. In addition, this interoperability effort defines payloads as:

A robot payload is a physical device that interfaces to the robot using interoperable physical, power, and / or data interfaces, and is replaceable (modular) based on mission needs. A payload can be similar in nature to other devices that are integrated on a robotic vehicle, but a payload is not required for native UGV capabilities.

1.2 DOCUMENT OVERVIEW

This document provides the base concepts, architecture, requirements, and overview for defining the required interoperability of payloads. As shown in Figure 1: Payload IOP Relationships below, this IOP is tightly coupled with the RAS-G IOP SAE JAUS Profiling Rules, and the RAS-G IOP Communications Profile.

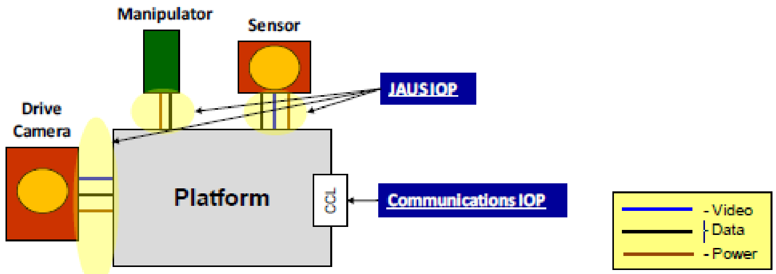


Figure 1: Payload IOP Relationships

The block diagram in the figure depicts a UGV platform with several integrated payload components: a teleoperation/driving camera, a manipulator, and a sensor. For this example, the RAS-G IOP SAE JAUS Profiling Rules would specify payload status/control message as applicable, to payload operations. The RAS-G IOP Communications Profile would specify the communications transport to/from integrated payload devices. This IOP is dedicated to payload interoperability with respect to data formats, metadata, and payload unique functionality.

1.3 DISCUSSION OF TECHNICAL TOPICS

1.3.1 Payload Classification

Within the IOP Composability Taxonomy (defined within the RAS-G IOP Overarching Profile), the payload branch is partitioned into Sensors, Emitters, and Actuators (see Figure 2: IOP Payload Composability Taxonomy below).

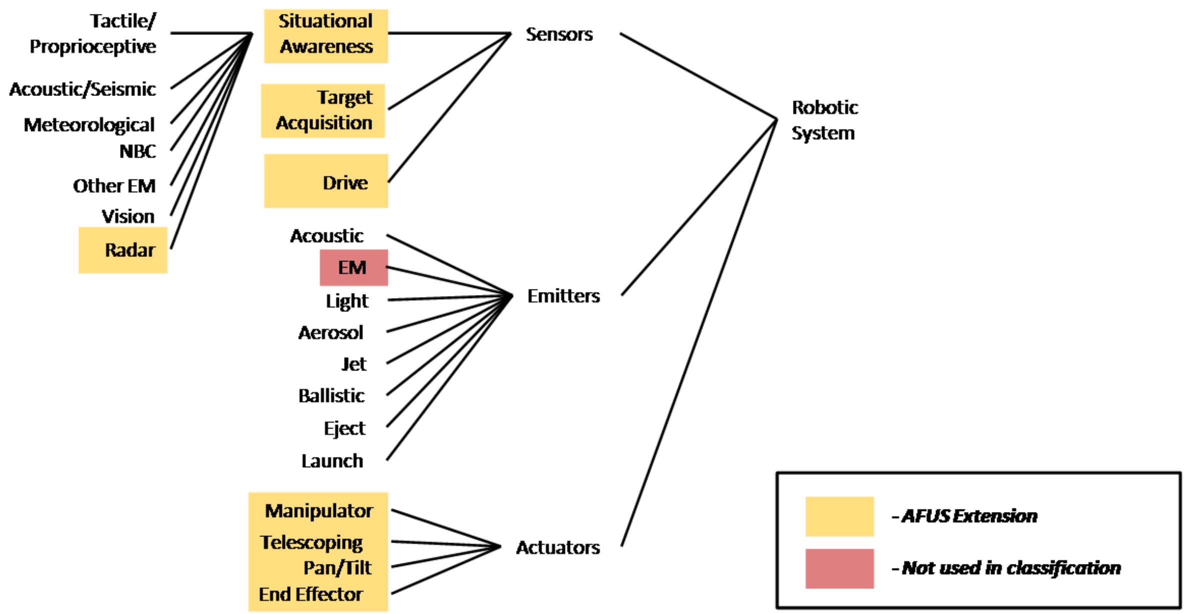


Figure 2: IOP Payload Composability Taxonomy

For the purposes of this IOP, the following payload definitions, extracted from the SAE AIR5665A, Architecture Framework for Unmanned Systems (AFUS) have been applied:

Sensor – Sensors codify information from the environment and can be used to reason about the environment. Typical sensor types include, but are not limited to, tactile, proprioceptive, seismic, acoustic, meteorological, chemical, biological, radiological, nuclear, visual, and range finding. All sensors fall into two categories, either passive or active. Passive sensors perform their detection without effecting or altering the environment (i.e. thermometer). Active sensors use some form of emission to detect the reflection or other effect that emission has on the environment (i.e. radar).

Emitter – An emitter is a device that can discharge a substance, object, or energy into the environment. Examples include radio, RADAR, LASER, loudspeaker, liquid jet or disruptor or sprayer, ballistic weapons, and launchers for various self-propelled devices. Most weapons fall into the class of emitters.

Actuator – An actuator is a mechanical device that can change shape in response to a signal. An actuator can be a simple device that has linear movement (prismatic) or Rotational movement (revolute) or it can be an articulated manipulator arm with many joints and links. The classic manipulator is an "arm" of a robotic system used to position an end-effector. Another common manipulator is a pan-tilt unit often used to position a directional sensor or emitter. At this time, all unpowered devices attached to a robot will also be classified as an actuator. (Examples include rakes, extensions, and bumpers.)

Within this IOP, payloads are organized in accordance with this taxonomy and also employ a loose class hierarchy, where interfaces and standards defined at upper levels are inherited in lower levels and further extended/restricted where applicable. A representation of this concept is depicted in Figure 3: Payload Classification below.

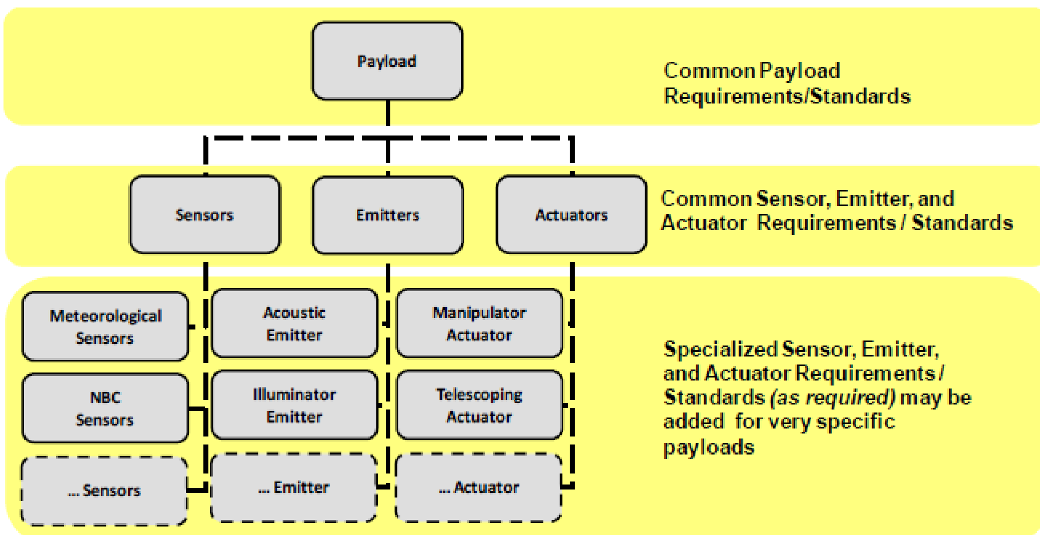


Figure 3: Payload Classification

As depicted in the figure, general interoperability standards and requirements applicable across the payload class are defined at the highest level: CHAPTER 4 PAYLOAD SYSTEM REQUIREMENTS. These standards retain applicability as payloads are traversed through the lower levels of the classification. The 5.1 SENSOR ATTRIBUTE, 6.1 EMITTER ATTRIBUTE, and 7.1 ACTUATOR ATTRIBUTE define standards and requirements specialized to each individual branch. As with the payload level of the classification, these standards retain their applicability within each of the individual branches. The decomposition within the classification continues to specialized attributes that cover unique payload products as necessary.

1.3.2 Compound and Complex Payloads

It is understood within the IOP that payloads can be compound or complex, and that certain payloads may span multiple categories. For example, a Reconnaissance, Surveillance, and Target Acquisition (RSTA) system could include multiple payloads, including multiple sensors, emitters, and possibly actuators.

Typically a RSTA solution will provide a defined interface with the operator for configuration, control, imagery, target reports, etc vs. requiring the operator to address each component of the RSTA separately. A compound payload will include associated, physically integrated capabilities where each payload requires the other payloads to provide a useful capability. A complex payload will include associated but independent capabilities where each payload is independent, where each capability does not rely on other payloads. The RAS-G IOP SAE JAUS Profiling Rules document defines other differences related to the logical structure differences.

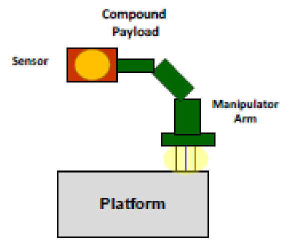


Figure 4: Compound Payload Example

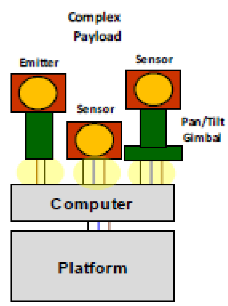


Figure 5: Complex Payload Example

Figure 4: Compound Payload Example shows an example of a Compound Sensor. The manipulator arm has a sensor mounted on top. Without the sensor, the arm serves no purpose, and without the arm, the sensor cannot be positioned in a useful manor. Figure 5: Complex Payload Example shows an example of a Complex Payload. This example has an Emitter (such as a speaker), a sensor (such as a chemical sensor), and a Compound Sensor (such as a pan-tilt-zoom camera). Each payload can function without the aid of the other payloads. All the payloads are tied together with a processor.

1.3.3 Control and Status Messages & JAUS Profiling

To the degree possible, and in accordance with the RAS-G IOP Overarching Profile, this IOP uses the SAE AS-4 Joint Architecture for Unmanned Systems (JAUS) standards to define the control and status messages transmitted between an Operator Control Unit (OCU) and the UGV payloads, as well as among on-board UGV payload subsystems.

The RAS-G IOP SAE JAUS Profiling Rules document provides guidance with respect to the profiling of the JAUS standard to define the manner in which JAUS messages are applied/interpreted as a means of limiting ambiguity and maximizing interoperability among disparate vendors.

1.3.4 Custom Messages

Similarly to the RAS-G IOP Overarching Profile, this IOP may require the specification of "custom" payload messages (documented within the RAS-G IOP Custom Services Messages and Transports) to provide mission capabilities scoped within the RAS-G IOP domain that are either not currently available in the SAE AS-4 JAUS standards or require SAE JAUS extension by the SAE AS-4 Committee. The specification and required usage of "custom" messages will be in accordance with the implementation requirements cited within the RAS-G IOP SAE JAUS Profiling Rules. The rules governing the development and usage of custom messages can be found in the RAS-G IOP Overarching Profile

1.3.5 Use of the Payloads Interoperability Profile

Robotic systems may include several payloads. Payloads are constantly being created or improved. It is suggested that each acquisition program carefully define what aspects of interoperability are required for each payload, and determine how many future capabilities may be needed in the "instantiation" of the Interoperability Profile for a particular program. The program manager may allow non-compliance to the IOP in certain cases; however steps should be taken to reduce non-compliance over time.

Each UGV program should determine what capabilities need to be integral to the robot. This integral capability would then be associated with the robotic platform, and may still be required to use interoperable messages as defined by the RAS-G IOP SAE JAUS Profiling Rules, but may not need to meet other payload interoperability requirements. In fact, a capability that is integrated into the platform is not classified as a payload. This is intended to allow a unique capability to be used on a system without complying with the payload interoperability profile, if that capability is integral to the platform and is determined by the program office to provide a non-modular capability.

The program should also determine how many additional, and possibly initially unused, interoperable payload interfaces to include. This would provide a path to adding unanticipated payloads to a robotic system later in the program. There are several strategies for implementing these requirements, which will be up to the program to decide on and implement.

The program may, at its discretion, incorporate the use of hardware and software adaptors, converters, or wrappers to allow a payload and a robotic platform to interoperate with each other. Allowable adaptations will be determined by the program, based on unique programmatic trade space and lifecycle plans.

CHAPTER 2 SOURCE DOCUMENTS

The following documents are referenced within this IOP and shall be used to implement the requirements contained within the IOP.

2.1 GOVERNMENT DOCUMENTS

ID	Version	Document
MIL-DTL-38999L	L	CONNECTORS, ELECTRICAL, CIRCULAR, MINIATURE, HIGH DENSITY, QUICK DISCONNECT (BAYONET, THREADED, AND BREECH COUPLING), ENVIRONMENT RESISTANT, REMOVABLE CRIMP AND HERMETIC SOLDER CONTACTS, GENERAL SPECIFICATION FOR
MIL-DTL-55116	1.0	MILITARY SPECIFICATION: CONNECTORS: MINIATURE AUDIO, FIVE-PIN AND SIX-PIN GENERAL SPECIFICATION FOR
MIL-STD-1913	1.0	DIMENSIONING OF ACCESSORY MOUNTING RAIL FOR SMALL ARMS WEAPONS
MIL-STD-810G	G	Environmental Engineering Considerations and laboratory test
MIL-PRF-62122-E	E	CABLE ASSEMBLY, INTER-VEHICLE POWER: PLUG, RECEPTACLE, AND ADAPTER
MIL-HDBK-454B	B	MILITARY HANDBOOK: GENERAL GUIDELINES FOR ELECTRONIC EQUIPMENT
	4.0	RAS-G IOP JAUS Profiling Rules
	1.0	RAS-G IOP Custom Service Messages and Transports
	1.0	RAS-G IOP Overarching Profile
	1.0	RAS-G IOP Communications Profile
	1.0	RAS-G IOP Applique Profile

Table1: Government Documents

2.2 NON GOVERNMENT DOCUMENTS

ID	Version	Document
AIR5665A	Rev A	AE Aerospace Information Report, Architecture Framework for Unmanned Systems (AFUS)
IEEE802.3-2008	1.0	Standards for Ethernet based LANs
AES42-2010	1.0	AES standard for acoustics - Digital interface for microphones
RFC2326	1.0	Network Working Group, Real-Time Streaming Protocol, 1998
RFC3550	1.0	Network Working Group, RTP: A Transport Protocol for Real-Time Applications, 2003
STANAG4074	1.0	NATO Slave Receptacle

Table2: Non Government Documents

CHAPTER 3 PAYLOAD ARCHITECTURE

The RAS-G IOP reference architecture, defined in the RAS-G IOP Overarching IOP with respect to the UGV platform and its payload(s) is presented in Figure 6: Payload Reference Architecture below

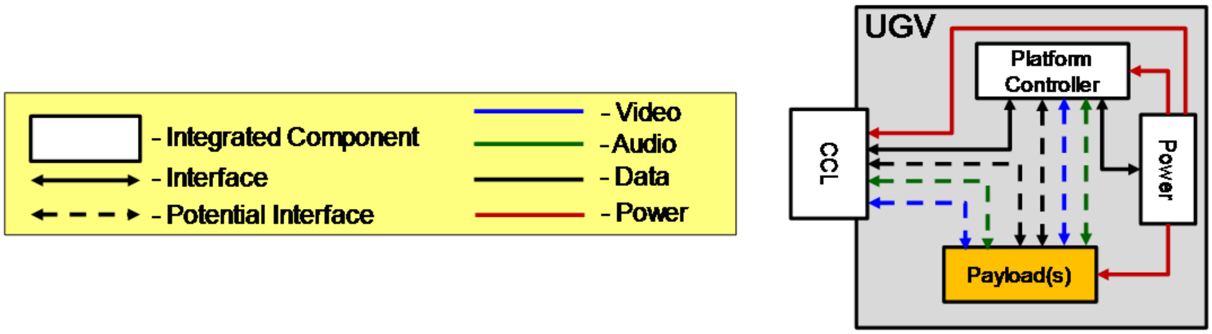


Figure 6: Payload Reference Architecture

As stated in Section 1, the payload(s) themselves are treated by this IOP as black boxes in that the IOP does not specifically mandate internal standards, computing platforms, operating systems, or other integral components within the payload. Rather the IOP defines interoperability with respect to payload integration to onboard elements as well as payload integration, through the Common Communications Link (CCL), to external systems and controllers.

CHAPTER 4 PAYLOAD SYSTEM REQUIREMENTS

This section identifies interoperability requirements with respect to standards and interfaces that are common across all payloads. Interoperability requirements specific to different payload classes are also defined in the Sensor, Emitter, and Actuator sections with attributes and associated requirements ranging from general to specialized. Requirements listed in this section are applicable to all payloads and requirements of a general attribute are inherited as applicable in lower levels. As an example, all "payloads" would inherit the requirements of the Common Payload Attribute, all "sensors" would inherit requirements from the Sensor Attribute, all "motion imagery cameras" would inherit requirements in Video Attribute, and "Camera Part Number XXX from Vendor Y" would further inherit the requirements from the Digital Video Attribute.

4.1 COMMON PAYLOAD ATTRIBUTE

Parent Attribute: IOP Usage

Any number of the following attributes can be chosen.

Attribute	Description
Sensor Attribute	UGVs have payloads which can collect data from the surrounding environment. In addition UGVs have sensors that collect data from the robot in order to report back to the operator health and other status information.
Emitter Attribute	UGVs have payloads which can affect their surrounding environment at a distance. These include Lights, Speakers, Laser Target Designators, and Weapons.
Actuator Attribute	Actuator payloads provide mechanical means of manipulation.
Platform Hardware Attribute	Allows for specification of platform hardware.
Self-Collision Avoidance Attribute	Provides the capability to communicate, control, and receive status from a self-collision avoidance system.

Table3: - Optional Select = any

4.1.1 Control and Status Messaging Requirement

SAE AS-4 JAUS messages provide the means for robotic controllers to connect to and control robotic systems, to include robotic system payloads.

V1.PAY-1 *Conformant implementations of this IOP shall use the SAE AS-4 JAUS message set as specified within these IOP documents and in accordance with the specified profiling rules.*

4.1.2 Payload Command, Control, and Status Messages

Payload command, control, and status messages specify the set of messages used to control a robotic system payload to perform a mission function(s). These messages support control of one or more integrated robotic system payloads. This section provides the interoperability messaging requirements relevant to controllers and robotic system payloads.

V1.PAY-2 *Unless specified otherwise, Payload command, control and status messages shall be implemented using the SAE AS-4 JAUS standards as profiled by the RAS-G IOP SAE JAUS Profiling Rules associated with any required (specified) Interoperability Attributes.*

4.1.3 Payload Custom Messages

Payload custom messages provide a mechanism to specify necessary payload command, control, and status messages that have not been defined within the specified SAE AS-4 JAUS standards. For the RAS-G IOP, all custom messages approved for use are defined within the RAS-G IOP Custom Services Messages and Transports. Custom messages are controlled within the RAS-G IOP activity and it is the intent of the DoD to seek standardization of these private messages within the applicable SAE AS-4 JAUS committees following adoption within the RAS-G community.

The RAS-G IOP will specify the use of SAE AS-4 JAUS messages to achieve interoperability and only employ custom messages when no JAUS message will suffice.

V1.PAY-3 *Unless specified otherwise, Custom payload command, control and status messages shall be implemented in accordance with the RAS-G IOP Custom Services Messages and Transports.*

4.1.4 Transport

Transport requirements and interoperability attributes are defined within the RAS-G IOP Overarching IOP. Payloads shall conform to the transport requirements at the vehicle level. This could be accomplished via direct communication between a controller/subsystem and a payload or via a translator that can interface to a payload via a native protocol and to a controller/subsystem via the vehicle specified JAUS transport.

V1.PAY-4 *Unless specified otherwise, the payload transport shall be identical to the vehicle transport in accordance with the Transport Interoperability Attribute, described in section 4.2.7 of the RAS-G IOP Overarching IOP.*

4.2 PLATFORM HARDWARE ATTRIBUTE

Parent Attribute: Hardware Attribute

Any number of the following attributes can be chosen.

Attribute	Description
Mounting Attribute	Mounting of a payload.
Physical and Electrical Interfaces Attribute	Physical And Electrical Interface to a platform
Uninterrupted Power Supply Attribute	In cases of sudden loss of power, the UPS capability affords the system the ability to shut down without loss of data, or causing damage to any part of the system.
NATO Slave Receptacle Attribute	NATO Slave Receptacle
Payload Physical Specifications Attribute	Provides various physical specifications of a payload

Table4: - Optional Select = any

4.3 PHYSICAL MOUNTING

4.3.1 Mounting Attribute

Parent Attribute: Platform Hardware Attribute

Physical interfaces for mounting payloads/other to the vehicle are driven by both the automotive industry and the RAS-G IOP Payload's Profile attributes.

At least one of the following attributes must be chosen.

Attribute	Description
Physical Mounting Attribute	Physical mounting of a payload

Table5: - Mandatory Select = any

4.3.2 Physical Mounting Attribute

Parent Attribute: Mounting Attribute

The physical mounting requirements listed in this document describe which standards should be used. This does not ensure that a particular mounting will support a payload, provide stable mounting, or provide the proper vehicle dynamic characteristics.

It is up to the designers to ensure that these characteristics are met, and would pass testing, in a particular implementation.

Any number of the following attributes can be chosen.

Attribute	Description
Picatinny Rail Attribute	Mounting rail(s) of varying length
Optical Bench Attribute	A series of threaded holes placed in a rectangular grid of varying size

Table6: - Optional Select = any

4.3.3 Picatinny Rail Attribute

Parent Attribute: Physical Mounting Attribute

Use MIL-STD-1913 as the standard for the mounting rail for payloads. The platform program will specify the length of the rail, and is dependent on the intended use of the rail. The program will specify the quantity of rails on a platform, dependent on the intended use of the rails. The program will specify the location of each rail, dependent on the intended use of the rail.

4.3.3.1 Picatinny Rail Requirement

V1.PAY-5	*If the Picatinny Rail Interoperability Attribute is selected, the payload shall be capable of mounting to a rail in accordance to MIL-STD-1913.*

4.3.4 Optical Bench Attribute

Parent Attribute: Physical Mounting Attribute

The optical bench option is defined as a series of threaded holes placed in a rectangular grid. The grid is 1" by 1" spacing. The threaded holes are 1/4"-20 UNC (Unified National Coarse). The program will specify the size of the grid, the material used, and the depth of the holes, based on the requirements of the vehicle program. This optical bench set up is not intended to provide the same vibration damping, stability, and stiffness as an actual optical bench – it only provides a standard hole and layout for attachment of payloads. The platform program will specify the type of bolt head, based on the drivers available. (I.E. – Socket head cap)

4.3.4.1 Optical Bench Requirement

V1.PAY-6	*If the Optical Bench Interoperability Attribute is selected, the payload shall be capable of mounting to a plate that has 1" X 1" grid spacing, ¼-20 UNC threaded holes. Configuration, quantity, material characteristics, depth, and tolerances to be listed by the platform program.*

4.4 NATO SLAVE RECEPTACLE ATTRIBUTE

Parent Attribute: Platform Hardware Attribute

4.4.1 NATO Slave Receptacle Requirement

V1.PAY-7 *Systems requiring the use of the North Atlantic Treaty Organization (NATO) slave receptacle shall utilize connectors & cables that meet the specifications in MIL-PRF 62122-E and STANAG 4074.*

4.5 PHYSICAL AND ELECTRICAL INTERFACES ATTRIBUTE

Parent Attribute: Platform Hardware Attribute

This attribute provides requirements common to all physical and electrical interfaces defined within the Payloads IOP. Any specific type of connector or electrical interface must meet these requirements before adding any of its own requirements or specifics. This attribute groups electrical power and connector interface requirements. Broadly applicable requirements are provided in 3 categories: environmental, safety and availability, with additional requirements provided for data and power depending on the type of connectors chosen.

The following attributes are mandatory.

Attribute	Description
Electrical Power Attribute	This attribute provides baseline electrical power requirements that are intended to be used in conjunction with a chosen class of connectors.

Table7: - Mandatory Select = all

At least one of the following attributes must be chosen.

Attribute	Description
Power-Only Connector Attribute	Provides the capability to include connectors that only transmit power.
Data Connector Attribute	Provides the capability to have connectors that transmit data.

Table8: - Mandatory Select = any

Any number of the following attributes can be chosen.

Attribute	Description
Tethered Communications Attribute	Utilizes a tether for communication.

Table9: - Optional Select = any

4.5.1 Environmental Requirement

V1.PAY-8 *Any connector shall meet applicable standards for water, dust, and other environmental factors.*

4.5.2 Safety Requirement

V1.PAY-9 *Any chosen class or group of connectors shall provide a mechanism to prevent payloads of one voltage from being plugged into connectors with a wrong voltage type (for example, plugging a 12 V payload into a 48 V connector). This mechanism may utilize different keys, different connector types / size, or any other method to physically prevent a connector of one voltage level from being mated with a connector of a non-compatible voltage level.*

V1.PAY-10 *Any chosen class or group of connectors shall identify maximum permissible current draws using that connector.*

4.5.3 Availability Requirement

V1.PAY-11 *Any chosen class or group of connectors shall have multiple sources of availability, and shall preferably be based on openly available standards.*

4.6 ELECTRICAL POWER INTERFACES SECTION

4.6.1 Electrical Power Attribute

Parent Attribute: Physical and Electrical Interfaces Attribute

There will be several electrical power interfaces available for selection, and may be expanded in this IOP for payloads over time. Each robotic program will determine which power interfaces will be required. The purpose of specifying electrical power requirements is to limit the number of power standards that will exist in interoperability compliant standards. The ability of the platform to provide the necessary power and current, both steady state and peak, will need to be verified and is not inherently provided by the interoperability profile. It is reasonable to expect that a platform may meet a voltage requirement, but would be unable to support a current draw for an unexpected future payload capability, and thus may not be able to support the unexpected future payload capability.

Current power attributes include 12V, 24V, and 48V, summarized in the following table:

Power Interface	Nominal Voltage	Minimum Voltage	Maximum Voltage
12 V	12 VDC	10 VDC	14 VDC
24 V	24 VDC	20 VDC	28 VDC
48 V	48 VDC	36 VDC	60 VDC

Table 10: Power Attributes

System designers implementing the 48V Power Interface should refer to MIL-HDBK-454B for safety guidelines regarding high voltages, which begin to take effect at 30V.

The following attributes are mutually exclusive, exactly one must be chosen.

Attribute	Description
Power Interface 12V Attribute	This attribute provides the capability to use the 12V electrical power interface.
Power Interface 24V Attribute	This attribute provides the capability to use the 24V electrical power interface.
Power Interface 48V Attribute	This attribute provides the capability to use the 48V electrical power interface.

Table 10: - Mandatory Select = one

4.6.1.1 Stable Power Requirement

V1.PAY-12 *The Platform shall be able to support hot-swapping of all Payloads without any degradation of performance.*

V1.PAY-13 *The Platform shall be able to accommodate inrush current of three times the current limit for a period of at least 500 microseconds without damage or fault.*

4.6.2 Power Interface 12V Attribute

Parent Attribute: Electrical Power Attribute

The Power Interface 12V Attribute specifies a nominal 12 VDC interface. Power availability is based on the capabilities of the connector.

4.6.2.1 Power Interface 12V Requirement

V1.PAY-14 *Any power interface implementing this attribute shall provide / accept voltage on power contacts with a nominal voltage of 12 Volts DC, +/- 2 volts (10VDC-14VDC range). A power provider (i.e. platform) shall provide power at this voltage, and a power acceptor (i.e. payload) shall accept power at this voltage.*

4.6.3 Power Interface 24V Attribute

Parent Attribute: Electrical Power Attribute

The Power Interface 24V Attribute specifies a nominal 24 VDC interface. Power availability is based on the capabilities of the connector.

4.6.3.1 Power Interface 24V Requirement

V1.PAY-15	*Any power interface implementing this attribute shall provide / accept voltage on power contacts with a nominal voltage of 24 Volts DC, +/- 4 volts (20VDC-28VDC range). A power provider (i.e. platform) shall provide power at this voltage, and a power acceptor (i.e. payload) shall accept power at this voltage.*

4.6.4 Power Interface 48V Attribute

Parent Attribute: Electrical Power Attribute

The Power Interface 48V Attribute specifies a nominal 48 VDC interface. Power availability is based on the capabilities of the connector.

4.6.4.1 Power Interface 48V Requirement

V1.PAY-16	*Any power interface implementing this attribute shall provide / accept voltage on power contacts with a nominal voltage of 48 Volts DC, +/- 12 volts (36VDC-60VDC range). A power provider (i.e. platform) shall provide power at this voltage, and a power acceptor (i.e. payload) shall accept power at this voltage.*

4.7 POWER ONLY CONNECTORS SECTION

4.7.1 Power-Only Connector Attribute

Parent Attribute: Physical and Electrical Interfaces Attribute

Some connections on robotic platforms may exceed the amount of power supplied by the Data Connections. In order to connect higher power payloads for either larger, more powerful functionality (e.g. heavy lift arms) or for power generation and charging, a class of connectors that contains no data pins is specified.

This Payloads IOP defines standard Power Only Connections for use in interoperable payloads. Each robotic program will be able to select which connector interface(s) will be included. Payloads will be able to connect directly to the interoperability-based connectors, or use an adaptor or converter. If a data interface is required, any of the Data Connections can be utilized in conjunction with the Power Only Connection.

This attribute provides common information, definitions, and requirements for use of Power Only connectors used within the Payloads IOP. These connectors are military grade connectors that come with a variety of shell types, pin counts, environmental ratings, and other properties. At least one specific connector of this class must be selected when using this connector class, and all requirements from this attribute must be followed.

The following attributes are mutually exclusive, exactly one must be chosen.

Attribute	Description
Power-Only Connector Interface A	This interface uses a DIN (Deutsches Institut für Normung) VG95234 Connector, shell size 22 with insert 22-22 (Also referred to as 22-22 Contact Arrangement), consisting of 4 contacts.
Power-Only Connector Interface B	This interface uses a DIN (Deutsches Institut für Normung) VG95234 Connector, shell size 24 with insert 24-28 (Also referred to as 24-28 Contact Arrangement), consisting of 24 contacts.

Table 11: - Mandatory Select = one

4.7.2 Power-Only Connector Interface A

Parent Attribute: Power-Only Connector Attribute

This interface uses a DIN (Deutsches Institut für Normung) VG95234 Connector, shell size 22 with insert 22-22 (Also referred to as 22-22 Contact Arrangement), consisting of 4 contacts.
This connector is required to use a pinout as shown below.

Pin #	Signal
A	GND
B	GND
C	PWR
D	PWR

Table 13: Interoperability Power Only Connector Interface A Pinout

Figure 7: Interoperability Power Only Connector Interface A Diagram illustrates the connector and its usage. This Diagram shows the nominal keying of the connector, actual keying will vary based on the power interface selected.

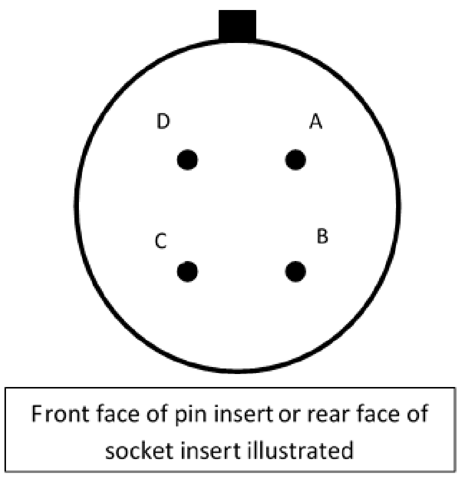


Figure 7: Interoperability Power Only Connector Interface A Diagram

4.7.2.1 Power Connector Interface A Requirement

V1.PAY-17 *This connector shall meet DIN (Deutsches Institut für Normung) VG95234, shell size 22 with insert 22-22, 4 contacts.*

V1.PAY-18 *The pinout and connector diagram found in the description of this requirement shall be used.*

V1.PAY-19 *The platform side shall consist of contact size 8 sockets in the receptacle. The payload side shall consist of contact size 8 pins in the plug.*

V1.PAY-20 *Both the payload side and platform side shall use 8 AWG wire (or equivalent circuit board wire traces) to support a maximum of a 74 amp current limit per power/ground pair. There are 2 total power / ground pairs for a total potential maximum current of 74A * 2 = 148A. Smaller current limits may be specified by programs using this requirement, based on design specifications.*

V1.PAY-21 *If using a 12 VDC nominal power interface (Power Interface 12V Attribute), key orientation X shall be chosen for the connector.*

V1.PAY-22 *If using a 24 VDC nominal power interface (Power Interface 24V Attribute), normal key orientation (N) shall be chosen for the connector.*

V1.PAY-23 *If using a 48 VDC nominal power interface (Power Interface 48V Attribute), key orientation Y shall be chosen for the connector.*

4.7.3 Power-Only Connector Interface B

Parent Attribute: Power-Only Connector Attribute

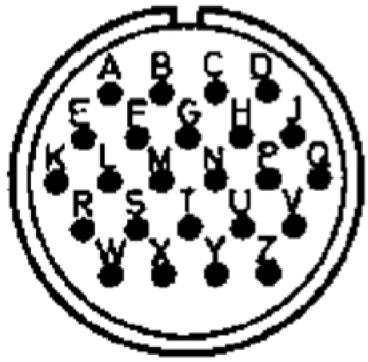
This interface uses a DIN (Deutsches Institut für Normung) VG95234 Connector, shell size 24 with insert 24-28 (Also referred to as 24-28 Contact Arrangement), consisting of 24 contacts.

This connector is required to use a pinout as shown below.

Pin #	Signal	Pin #	Signal	Pin #	Signal
A	GND	J	PWR	S	GND
B	GND	K	GND	T	PWR
C	GND	L	GND	U	PWR
D	PWR	M	GND	V	PWR
E	GND	N	PWR	W	GND
F	GND	P	PWR	X	PWR
G	GND	Q	PWR	Y	PWR
H	PWR	R	GND	Z	PWR

Table 14: Interoperability Power Only Connector Interface B Pinout

Figure 8: Interoperability Power Only Connector Interface B Diagram illustrates the connector and its usage. This Diagram shows the nominal keying of the connector, actual keying will vary based on the power interface selected.



Front face of pin insert or rear face of socket insert illustrated

Figure 8: Interoperability Power Only Connector Interface B Diagram

4.7.3.1 Power Connector Interface B Requirement

V1.PAY-24	*This connector shall meet DIN (Deutsches Institut für Normung) VG95234, shell size 24 with insert 24-28, 24 contacts.*
V1.PAY-25	*The pinout and connector diagram found in the description of this requirement shall be used.*
V1.PAY-26	*The platform side shall consist of contact size 16 sockets in the receptacle. The payload side shall consist of contact size 16 pins in the plug.*
V1.PAY-27	*Both the payload side and platform side shall use 16 AWG wire (or equivalent circuit board wire traces) to support a maximum of a 22 amp current limit per power/ground pair. There are 12 total power / ground pairs for a total potential maximum current of 22A * 12 = 264A. Smaller current limits may be specified by programs using this requirement, based on design specifications.*
V1.PAY-28	*If using a 12 VDC nominal power interface (Power Interface 12V Attribute), key orientation X shall be chosen for the connector.*
V1.PAY-29	*If using a 24 VDC nominal power interface (Power Interface 24V Attribute), normal key orientation (N) shall be chosen for the connector.*

V1.PAY-30 *If using a 48 VDC nominal power interface (Power Interface 48V Attribute), key orientation Y shall be chosen for the connector.*

4.8 DATA CONNECTIONS

Several data connections are currently used on robotic platforms in order to connect to payloads. It is anticipated that several data connections will continue to be used to support unique or proprietary payloads. This Payloads IOP defines standard data connections for use in interoperable payloads. Each robotic program will be able to select which connector interface(s) will be included. Payloads will be able to connect directly to the interoperability based connectors, or use an adaptor, converter, or wrapper (which may be only physical, or may include electronics and software).

4.8.1 Data Connector Attribute

Parent Attribute: Physical and Electrical Interfaces Attribute

The connectors referenced by this attribute are used to transmit data in an IOP system. This list may be expanded in the IOP over time.

The following attributes are mutually exclusive, exactly one must be chosen.

Attribute	Description
MIL-DTL-38999 Series III Connector Attribute	This is a class of connectors that are military grade and come with a variety of shell types, pin counts, environmental ratings, and other properties. Series III is a replacement for Series II specified by previous version of the IOP.
Mini38999 Connector Attribute	At least two companies have developed compatible connectors designed to be comparable to MIL-DTL-38999 series connectors, but with significant weight and size savings. These variants are currently offered by companies Glenair and Amphenol, and may be offered by other entities in the future.
MIL-DTL-38999 Series II Connector Attribute (Deprecated)	This is a class of connectors that are military grade and come with a variety of shell types, pin counts, environmental ratings, and other properties. Series II is now deprecated in favor of Series III.

Table 12: - Mandatory Select = one

4.8.1.1 Data Requirement

V1.PAY-31 *Any connector shall provide 8 pins appropriate for transmission of Gigabit Ethernet data compliant with IEEE 802.3-2008. These pins are designated by A+/A-, B+/B-, C+/C-, and D+/D- in connector pinouts.*

V1.PAY-32 *Any connector shall be capable of effectively handling high frequency data such as Gigabit Ethernet, including types of data like video, audio and platform telemetry and commands.*

4.8.1.2 Data Connector Power Requirement

V1.PAY-33 *Any connector shall provide at least one (1) power contact and one (1) ground contact. The contacts will be suitable to provide power sufficient for expected payload draws.*

V1.PAY-34 *Any connector's power contacts shall be chosen to minimize interference with transmission of data over the required Gigabit Ethernet lines.*

4.8.2 MIL-DTL-38999 Series III Connector Attribute

Parent Attribute: Data Connector Attribute

This attribute provides common information, definitions, and requirements for use of MIL-DTL-38999 Series III connectors used within the Payloads IOP. These connectors are military grade connectors that come with a variety of shell types, pin counts, environmental ratings, and other properties. At least one specific connector of this class must be selected when using this connector class, and all requirements from this attribute must be followed.

At least one of the following attributes must be chosen.

Attribute	Description
Connector Interface A Attribute	This interface uses a MIL-STD-38999 Series III connector with 13 pins and a B35 (11-35) insert.
Connector Interface B Attribute	This interface uses a MIL-STD-38999 Series III connector with 22 pins and a C35 (13-35) insert.
Connector Interface B - Configuration Lines Attribute	This interface uses a MIL-STD-38999 Series III connector with 22 pins and a C35 (13-35) insert. This connector provides configuration lines on the same pins as the AEODRS connector, but is NOT compatible with the actual similar connector defined in the AEODRS documentation.

Table 13: - Mandatory Select = any

4.8.2.1 MIL-DTL-38999 Series III Requirement

V1.PAY-35 *If using a 12 VDC nominal power interface (Power Interface 12V Attribute), key rotation A shall be chosen for the connector.*

V1.PAY-36 *If using a 24 VDC nominal power interface (Power Interface 24V Attribute), normal key rotation (N) shall be chosen for the connector.*

V1.PAY-37 *If using a 48 VDC nominal power interface (Power Interface 48V Attribute), key rotation B shall be chosen for the connector.*

4.8.3 Connector Interface A Attribute

Parent Attribute: MIL-DTL-38999 Series III Connector Attribute

This interface uses a MIL-STD-38999 Series III connector with 13 pins and a B35 (11-35) insert.

4.8.3.1 Connector Interface A Requirement

This connector is required to use a pinout as shown below. Figure 9: Interoperability Connector A Diagram illustrates the connectors and their usage. The Figure 9: Interoperability Connector A Diagram below shows the nominal keying of the connector – actual keying will vary based on the power interface selected.

Pin #	Signal	Pin #	Signal
1	GND	8	C+
2	A+	9	B-
3	A-	10	B+
4	D+-	11	PWR
5	D-	12	PWR
6	GND	13	NA
7	C-		

Table 17: Interoperability Connector A pinout

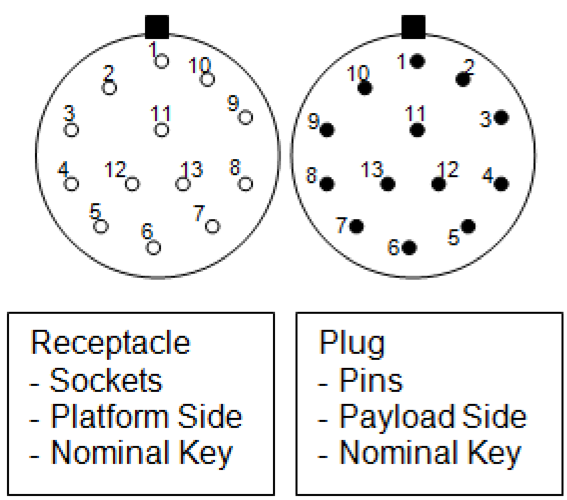


Figure 9: Interoperability Connector A Diagram

V1.PAY-38 *This connector shall meet MIL-DTL-38999L series III, 13-pin, B35 (11-35) insert.*

V1.PAY-39 *The pinout and connector diagram found in the description of this requirement shall be used.*

V1.PAY-40 *The platform side shall consist of 22D size sockets in the receptacle. The payload side shall consist of 22D size pins in the plug.*

V1.PAY-41 *Both the payload side and platform side shall use 22 AWG wire (or equivalent circuit board wire traces) to support a maximum of a 5 amp current limit per power/ground pair. There are 2 total power / ground pairs for a total potential maximum current of 5A * 2 = 10A. Smaller current limits may be specified by programs using this requirement, based on design specifications.*

4.8.4 Connector Interface B Attribute

Parent Attribute: MIL-DTL-38999 Series III Connector Attribute

This interface uses a MIL-STD-38999 Series III connector with 22 pins and a C35 (13-35) insert.

4.8.4.1 Connector Interface B Requirement

This connector is required to use a pinout as shown below. Figure 10: Interoperability Connector B Diagram illustrates the connectors and their usage. The Figure 10: Interoperability Connector B Diagram below shows the nominal keying of the connector – actual keying will vary based on the power interface selected.

Pin #	Signal	Pin #	Signal
1	A-	13	B-
2	C+	14	A+
3	C-	15	D-
4	Reserved	16	Reserved
5	PWR	17	GND
6	PWR	18	GND
7	PWR	19	GND
8	PWR	20	Reserved
9	PWR	21	D+
10	PWR	22	GND
11	Reserved		
12	B+		

Table 18: Interoperability Connector B pinout

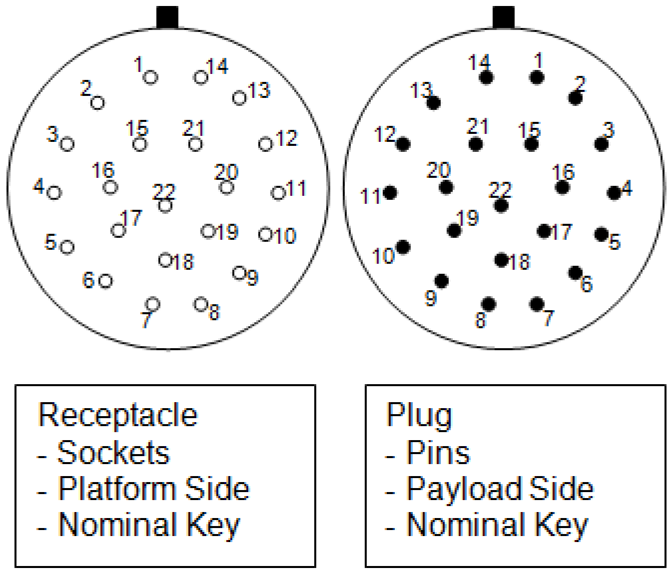


Figure 10: Interoperability Connector B Diagram

V1.PAY-42 *This connector shall meet MIL-DTL-38999L series III, 22-pin, C35 (13-35) insert.*

V1.PAY-43 *The pinout and connector diagram found in the description of this requirement shall be used.*

V1.PAY-44 *The platform side shall consist of 22D size sockets in the receptacle. The payload side shall consist of 22D size pins in the plug.*

V1.PAY-45 *Both the payload side and platform side shall use 22 AWG wire (or equivalent circuit board wire traces) to support a maximum of a 5 amp current limit per power/ground pair. There are 4 total power / ground pairs for a total potential maximum current of 5A * 4 = 20A. Note that there are 6 pins labelled power, but only 4 grounds – you cannot provide power on more than 4 power pins at one time. Smaller current limits may be specified by programs using this requirement, based on design specifications.*

4.8.5 Connector Interface B - Configuration Lines Attribute

Parent Attribute: MIL-DTL-38999 Series III Connector Attribute

This interface uses a MIL-STD-38999 Series III connector with 22 pins and a C35 (13-35) insert. This pinout (formerly known as the AEODRS Interoperability Connector Interface) uses some reserved lines from Connector Interface B as AEODRS configuration lines, but is not guaranteed to be compatible with the similar connector defined within AEODRS.

4.8.5.1 Connector Interface B - Configuration Lines Requirement

This connector is required to use a pinout as shown below. Figure 11: Interoperability Connector B - Configuration Lines Diagram illustrates the connectors and their usage. The Figure 11: Interoperability Connector B - Configuration Lines Diagram below shows the nominal keying of the connector – actual keying will vary based on the power interface selected.

Pin #	Signal	Pin #	Signal
1	A-	13	B-
2	C+	14	A+
3	C-	15	D-
4	CONFIG_D	16	CONFIG_C
5	PWR	17	GND
6	PWR	18	GND
7	PWR	19	GND
8	PWR	20	CONFIG_B
9	PWR	21	D+
10	PWR	22	GND
11	CONFIG_A		
12	B+		

Table 19: AEODRS Interoperability Connector Diagram

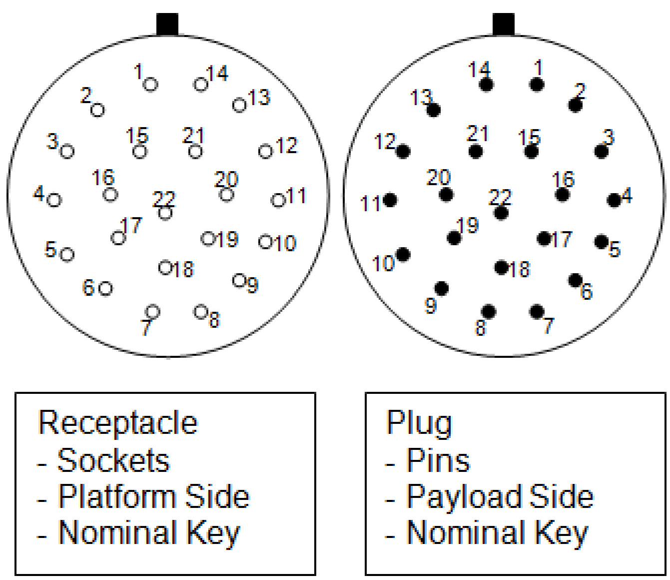


Figure 11: Interoperability Connector B - Configuration Lines Diagram

The pins CONFIG_A, CONFIG_B, CONFIG_C, and CONFIG_D represent a 4-bit configuration bus that is used to assign unique locations codes to a payload.

There are 16 possible values. CONFIG_A represents the highest order bit of a 4-bit location code value, and CONFIG_D represents the lowest order bit.

When this value is selected for a payload, the payload shall provide resistive pull-ups on the 4-bit configuration bus. When this value is selected for a platform, the platform shall either ground a configuration line to represent a 0 logical value, or leave the line floating to yield a logical value of 1. Figure 12: Configuration Line Logic Levels Simplified Example below shows this setup. Note that the example in Figure 12: Configuration Line Logic Levels Simplified Example is conceptual – an actual implementation will need to implement circuitry on both the payload and platform side to:

- Prevent payload internal voltage rails and logic pins from direct connector exposure
- Allow multiple payloads to share a single configuration bus ID
- Survive temporary exposure to the power rail
- Support multiple logic voltages
- Limit static power dissipation

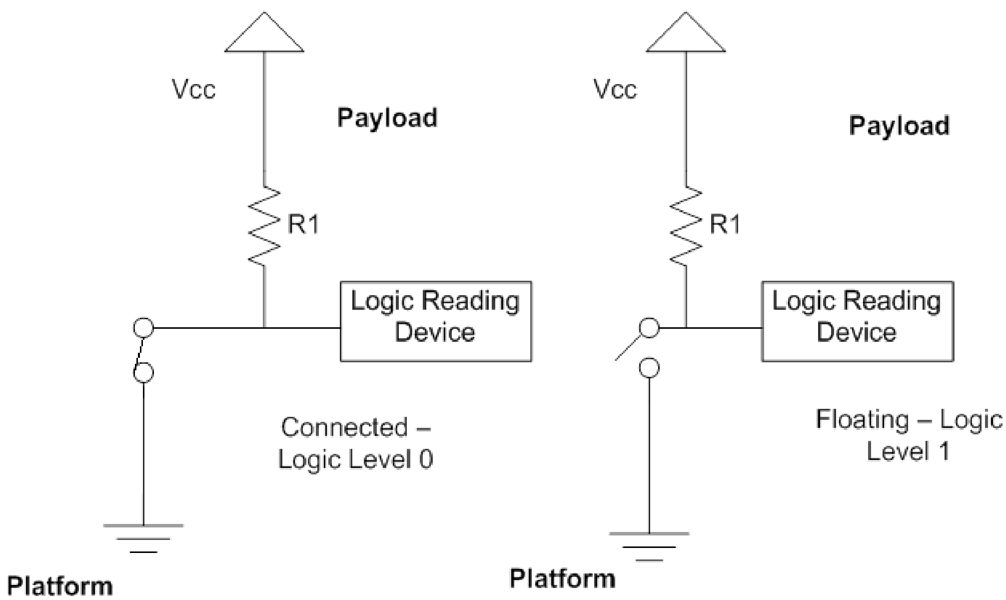


Figure 12: Configuration Line Logic Levels Simplified Example

Table 26: Configuration Line Location Codes below shows the 16 possible values that can be achieved using different configurations of the 4 configuration lines (LOW = line connected to platform ground, Not Connected = line is floating). These values can be used as location codes (uniquely identifying where a payload is plugged into on a platform) and can also support unique payload identification.

Location Code (hex)	CONFIG_A	CONFIG_B	CONFIG_C	CONFIG_D
0x00	LOW	LOW	LOW	LOW
0x01	LOW	LOW	LOW	Not Connected
0x02	LOW	LOW	Not Connected	LOW
0x03	LOW	LOW	Not Connected	Not Connected
0x04	LOW	Not Connected	LOW	LOW
0x05	LOW	Not Connected	LOW	Not Connected
0x06	LOW	Not Connected	Not Connected	LOW
0x07	LOW	Not Connected	Not Connected	Not Connected
0x08	Not Connected	LOW	LOW	LOW
0x09	Not Connected	LOW	LOW	Not Connected
0x0A	Not Connected	LOW	Not Connected	LOW
0x0B	Not Connected	LOW	Not Connected	Not Connected
0x0C	Not Connected	Not Connected	LOW	LOW
0x0D	Not Connected	Not Connected	LOW	Not Connected
0x0E	Not Connected	Not Connected	Not Connected	LOW
0x0F	Not Connected	Not Connected	Not Connected	Not Connected

Table 20: Configuration Line Location Codes

V1.PAY-46 *This connector shall meet MIL-DTL-38999L series III, 22-pin, C35 (13-35) insert.*

V1.PAY-47 *The pinout and connector diagram found in the description of this requirement shall be used.*

V1.PAY-48 *This connector shall implement configuration lines as found in the description of this requirement.*

V1.PAY-49 *The platform side shall consist of 22D size sockets in the receptacle. The payload side shall consist of 22D size pins in the plug.*

V1.PAY-50 *Both the payload side and platform side shall use 22 AWG wire (or equivalent circuit board wire traces) to support a maximum of a 5 amp current limit per power/ground pair. There are 4 total power / ground pairs for a total potential maximum current of 5A * 4 = 20A. Note that there are 6 pins labelled power, but only 4 grounds – you cannot provide power on more than 4 power pins at one time. Smaller current limits may be specified by programs using this requirement, based on design specifications.*

4.8.6 Mini38999 Connector Attribute

Parent Attribute: Data Connector Attribute

At least two companies have developed compatible connectors designed to be comparable to MIL-DTL-38999 series connectors, but with significant weight and size savings. These variants are currently offered by companies Glenair and Amphenol, and may be offered by other entities in the future.

4.8.6.1 Mini38999 Connector Requirement

This connector is required to use a pinout as shown below. Figure 13: Mini38999 Pinout (Pin Connector View, Socket Pin Numbers are Reversed) illustrates the connectors and their usage. The Figure 13: Mini38999 Pinout (Pin Connector View, Socket Pin Numbers are Reversed) below shows the nominal keying of the connector – actual keying will vary based on the power interface selected.

Pin #	Signal	Pin #	Signal
1	A+	13	B-
2	A-	14	D+
3	C-	15	D-
4	C+	16	CONFIG_C
5	CONFIG_D	17	GND
6	GND	18	PWR
7	GND	19	CONFIG_B
8	RESERVED	20	RESERVED
9	PWR		
10	PWR		
11	CONFIG_A		
12	B+		

Table 21: Mini38999 Connector Pinout

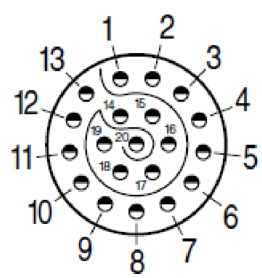


Figure 13: Mini38999 Pinout (Pin Connector View, Socket Pin Numbers are Reversed)

V1.PAY-51 *This connector used shall be the 805 series (Amphenol 2M805 series, Glenair Series 805 Mighty Mouse) with 15-220 insert arrangement (20 pins / sockets).*

V1.PAY-52 *The pinout and connector diagram found in the description of this requirement shall be used.*

V1.PAY-53 *This connector shall implement configuration lines as specified in the Mini38999 Connector attribute, but using the pins/sockets specified in the pinout for this connector.*

V1.PAY-54 *If using a 12 VDC nominal power interface (Power Interface 12V Attribute), key position B shall be chosen for the connector.*

V1.PAY-55 *If using a 24 VDC nominal power interface (Power Interface 24V Attribute), key position A shall be chosen for the connector.*

V1.PAY-56 *If using a 48 VDC nominal power interface (Power Interface 48V Attribute), key position C shall be chosen for the connector.*

V1.PAY-57 *The platform side shall consist of size 20HD sockets in the receptacle. The payload side shall consist of size 20 pins in the plug.*

V1.PAY-58 *Both the payload side and platform side shall use 20 AWG wire wire (or equivalent circuit board traces) to support a maximum of a 7.5 amp current limit per power / ground pair for a total potential maximum current limit of 3 * 7.5A = 22.5A. Smaller current limits may be specified by programs using this requirement, based on design specifications.*

4.8.7 MIL-DTL-38999 Series II Connector Attribute (Deprecated)

Parent Attribute: Data Connector Attribute

This attribute provides common information, definitions, and requirements for use of MIL-DTL-38999 Series II connectors used within the Payloads IOP. These connectors are military grade connectors that come with a variety of shell types, pin counts, environmental ratings, and other properties. At least one specific connector of this class must be selected when using this connector class, and all requirements from this attribute must be followed.

At least one of the following attributes must be chosen.

Attribute	Description
MIL-DTL-38999 Series II Connector Interface A Attribute (Deprecated)	This interface uses a MIL-STD-38999 Series II connector with a 13 pin 10-35 insert.
MIL-DTL-38999 Series II Connector Interface B Attribute (Deprecated)	This interface uses a MIL-STD-38999 Series II connector with a 22 pin 12-35 insert.

MIL-DTL-38999 Series II Connector Interface B - Configuration Lines Attribute (Deprecated)	This interface uses a MIL-STD-38999 Series II connector with a 22 pin 12-35 insert. This connector provides configuration lines on the same pins as the AEODRS connector, but is NOT compatible with the actual similar connector defined in the AEODRS documentation.

Table 22: - Mandatory Select = any

4.8.7.1 MIL-DTL-38999 Series II Requirement

V1.PAY-59 *If using a 12 VDC nominal power interface (Power Interface 12V Attribute), key rotation A shall be chosen for the connector.*

V1.PAY-60 *If using a 24 VDC nominal power interface (Power Interface 24V Attribute), normal key rotation (N) shall be chosen for the connector.*

V1.PAY-61 *If using a 48 VDC nominal power interface (Power Interface 48V Attribute), key rotation B shall be chosen for the connector.*

4.8.8 MIL-DTL-38999 Series II Connector Interface A Attribute (Deprecated)

Parent Attribute: MIL-DTL-38999 Series II Connector Attribute (Deprecated)

This interface uses a MIL-STD-38999 Series II connector with a 13 pin 10-35 insert

4.8.8.1 Series II Connector Interface A Requirement

This connector is required to use a pinout as shown below. Figure 14: Series II Interoperability Connector A Diagram illustrates the connectors and their usage. The Figure 14: Series II Interoperability Connector A Diagram below shows the nominal keying of the connector – actual keying will vary based on the power interface selected.
Table 23: Series II Interoperability Connector A pinout

Pin #	Signal	Pin #	Signal
1	GND	8	C+
2	A+	9	B-
3	A-	10	B+
4	D+-	11	PWR
5	D-	12	PWR
6	GND	13	NA
7	C-		

Table 23: Series II Interoperability Connector A pinout

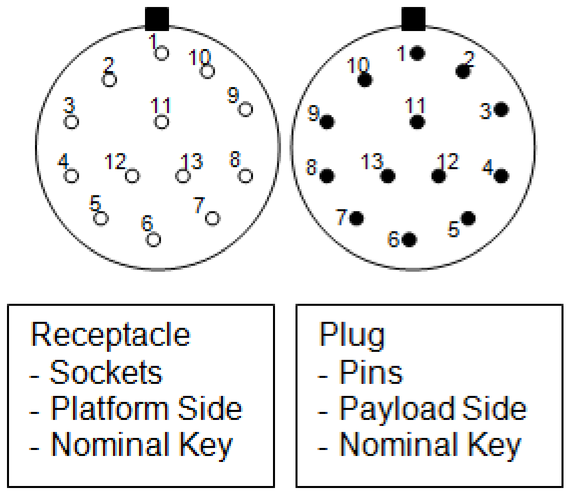


Figure 14: Series II Interoperability Connector A Diagram

V1.PAY-62 This connector shall meet MIL-DTL-38999L series II, 13-pin, 10-35 insert.

V1.PAY-63 The pinout and connector diagram found in the description of this requirement shall be used.

V1.PAY-64 The platform side shall consist of 22D size sockets in the receptacle. The payload side shall consist of 22D size pins in the plug.

*V1.PAY-65 Both the payload side and platform side shall use 22 AWG wire (or equivalent circuit board wire traces) to support a maximum of a 5 amp current limit per power/ground pair. There are 2 total power / ground pairs for a total potential maximum current of 5A * 2 = 10A. Smaller current limits may be specified by programs using this requirement, based on design specifications.*

4.8.9 MIL-DTL-38999 Series II Connector Interface B Attribute (Deprecated)

Parent Attribute: MIL-DTL-38999 Series II Connector Attribute (Deprecated)

This interface uses a MIL-STD-38999 Series II connector with a 22 pin 12-35 insert..

4.8.9.1 Series II Connector Interface B Requirement

This connector is required to use a pinout as shown below. Figure 15: Series II Interoperability Connector B Diagram illustrates the connectors and their usage. The Figure 15: Series II Interoperability Connector B Diagram below shows the nominal keying of the connector – actual keying will vary based on the power interface selected.

Pin #	Signal	Pin #	Signal
1	A-	13	B-
2	C+	14	A+
3	C-	15	D-
4	Reserved	16	Reserved
5	PWR	17	GND
6	PWR	18	GND
7	PWR	19	GND
8	PWR	20	Reserved
9	PWR	21	D+
10	PWR	22	GND
11	Reserved		
12	B+		

Table 24: Series II Interoperability Connector B pinout

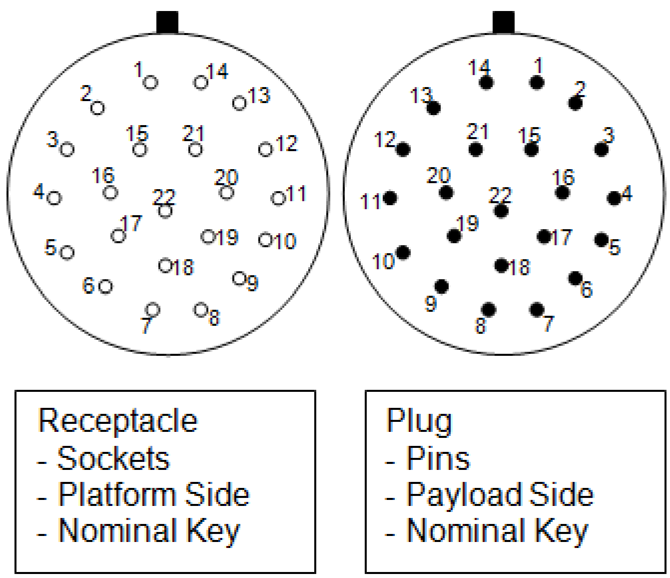


Figure 15: Series II Interoperability Connector B Diagram

V1.PAY-66 This connector shall meet MIL-DTL-38999L series III, 22-pin, 12-35 insert.

V1.PAY-67 The pinout and connector diagram found in the description of this requirement shall be used.

V1.PAY-68 The platform side shall consist of 22D size sockets in the receptacle. The payload side shall consist of 22D size pins in the plug.

V1.PAY-69 Both the payload side and platform side shall use 22 AWG wire (or equivalent circuit board wire traces) to support a maximum of a 5 amp current limit per

*power/ground pair. There are 4 total power / ground pairs for a total potential maximum current of 5A * 4 = 20A.*
Note that there are 6 pins labelled power, but only 4 grounds – you cannot provide power on more than 4 power pins at one time. Smaller current limits may be specified by programs using this requirement, based on design specifications.

4.8.10 MIL-DTL-38999 Series II Connector Interface B - Configuration Lines Attribute (Deprecated)

Parent Attribute: MIL-DTL-38999 Series II Connector Attribute (Deprecated)

This interface uses a MIL-STD-38999 Series II connector with a 22 pin 12-35 insert.

4.8.10.1 Series II Connector Interface B - Configuration Lines Requirement

This connector is required to use a pinout as shown below. Figure 16: Series II Interoperability Connector B - Configuration Lines Diagram illustrates the connectors and their usage. The Figure 16: Series II Interoperability Connector B - Configuration Lines Diagram below shows the nominal keying of the connector – actual keying will vary based on the power interface selected.

Pin #	Signal	Pin #	Signal
1	A-	13	B-
2	C+	14	A+
3	C-	15	D-
4	CONFIG_D	16	CONFIG_C
5	PWR	17	GND
6	PWR	18	GND
7	PWR	19	GND
8	PWR	20	CONFIG_B
9	PWR	21	D+
10	PWR	22	GND
11	CONFIG_A		
12	B+		

Table 25: Series II AEODRS Interoperability Connector Diagram

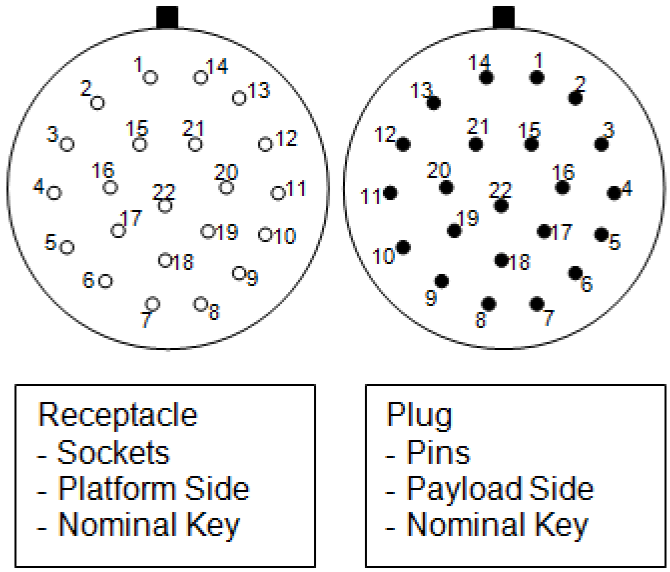


Figure 16: Series II Interoperability Connector B - Configuration Lines Diagram

The pins CONFIG_A, CONFIG_B, CONFIG_C, and CONFIG_D represent a 4-bit configuration bus that is used to assign unique locations codes to a payload. There are 16 possible values. CONFIG_A represents the highest order bit of a 4-bit location code value, and CONFIG_D represents the lowest order bit.

When this value is selected for a payload, the payload shall provide resistive pull-ups on the 4-bit configuration bus. When this value is selected for a platform, the platform shall either ground a configuration line to represent a 0 logical value, or leave the line floating to yield a logical value of 1. Figure 17: Configuration Line Logic Levels Simplified Example below shows this setup. Note that the example in Figure 17: Configuration Line Logic Levels Simplified Example is conceptual – an actual implementation will need to implement circuitry on both the payload and platform side to:

- Prevent payload internal voltage rails and logic pins from direct connector exposure
- Allow multiple payloads to share a single configuration bus ID
- Survive temporary exposure to the power rail
- Support multiple logic voltages
- Limit static power dissipation

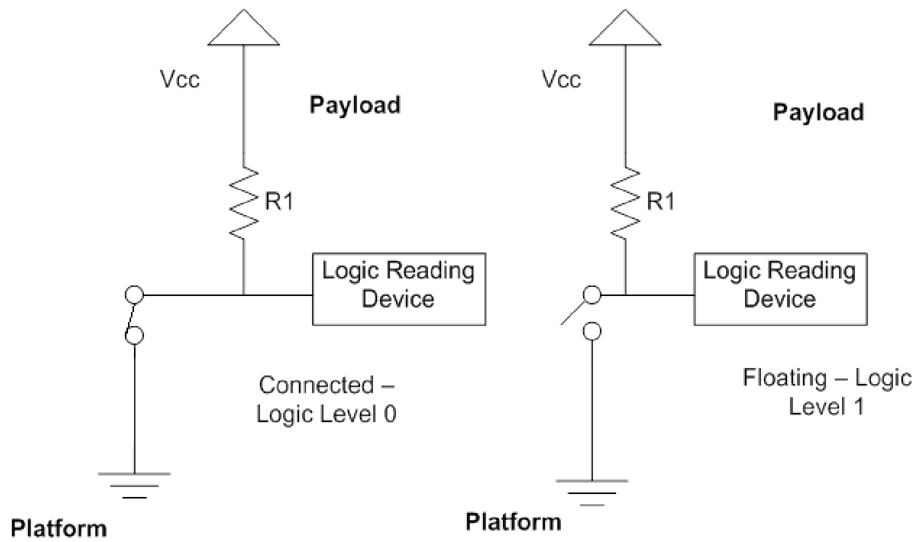


Figure 17: Configuration Line Logic Levels Simplified Example

Table 26 shows the 16 possible values that can be achieved using different configurations of the 4 configuration lines (LOW = line connected to platform ground, Not Connected = line is floating). These values can be used as location codes (uniquely identifying where a payload is plugged into on a platform) and can also support unique payload identification.

Location Code (hex)	CONFIG_A	CONFIG_B	CONFIG_C	CONFIG_D
0x00	LOW	LOW	LOW	LOW
0x01	LOW	LOW	LOW	Not Connected
0x02	LOW	LOW	Not Connected	LOW
0x03	LOW	LOW	Not Connected	Not Connected
0x04	LOW	Not Connected	LOW	LOW
0x05	LOW	Not Connected	LOW	Not Connected
0x06	LOW	Not Connected	Not Connected	LOW
0x07	LOW	Not Connected	Not Connected	Not Connected
0x08	Not Connected	LOW	LOW	LOW
0x09	Not Connected	LOW	LOW	Not Connected
0x0A	Not Connected	LOW	Not Connected	LOW
0x0B	Not Connected	LOW	Not Connected	Not Connected
0x0C	Not Connected	Not Connected	LOW	LOW
0x0D	Not Connected	Not Connected	LOW	Not Connected
0x0E	Not Connected	Not Connected	Not Connected	LOW
0x0F	Not Connected	Not Connected	Not Connected	Not Connected

Table 26: Configuration Line Location Codes

V1.PAY-70 This connector shall meet MIL-DTL-38999L series II, 22-pin, 12-35 insert.

V1.PAY-71 The pinout and connector diagram found in the description of this requirement shall be used.

V1.PAY-72 This connector shall implement configuration lines as found in the description of this requirement.

V1.PAY-73 The platform side shall consist of 22D size sockets in the receptacle. The payload side shall consist of 22D size pins in the plug.

*V1.PAY-74 Both the payload side and platform side shall use 22 AWG wire (or equivalent circuit board wire traces) to support a maximum of a 5 amp current limit per power/ground pair. There are 4 total power / ground pairs for a total potential maximum current of 5A * 4 = 20A. Note that there are 6 pins labelled power, but only 4 grounds – you cannot provide power on more than 4 power pins at one time. Smaller current limits may be specified by programs using this requirement, based on design specifications.*

4.9 TETHERED COMMUNICATIONS ATTRIBUTE

The Tethered Communications attribute provides the capability to communicate with a payload via a fiber optic or wire tether.

A fiber tether would need a fiber optic payload to convert electrical signals from the Ethernet message to light. That light would then travel through the fiber optic cable. The light would be converted back to electrical signals, which would create an Ethernet message with a similar fiber optic payload on the far end. A wired tether would physically connect the communications backbone of the two endpoints via metal wires (e.g. Ethernet).

Any number of the following attributes can be chosen.

Attribute	Description
Tether Spooler Attribute	Adds support for controlling and obtaining status from a tether's spooling mechanism

Table 27: - Optional Select = any

4.10 UNINTERRUPTED POWER SUPPLY ATTRIBUTE

The Uninterrupted Power Supply Attribute add the capability to accommodate systems that contain a UPS system. A UPS system's main purpose is to allow controlled vehicle shutdown in the event of dissipation or failure of main system power.

It is here treated as a Payload, but the system could be tightly integrated with or inseparable from the platform and maintain a logical IOP interface only.

4.10.1 Uninterrupted Power Supply Payloads Requirement

V1.PAY-75	*Payloads implementing the uninterrupted power supply capability shall do in accordance with the definition and rules specified in the RAS-G IOP SAE JAUS Profiling Rules, Uninterrupted Power Supply Attribute.*

4.11 PAYLOAD PHYSICAL SPECIFICATIONS ATTRIBUTE

Parent Attribute: Platform Hardware Attribute

When specified, payloads should be capable of reporting their physical specifications. This data will be used by other subsystems in order to provide self-collision avoidance, center of gravity management, power management, or other smart functions.

IOP V4 provides a custom Physical Specifications JAUS service for use in payloads and platforms.

4.11.1 Payload Physical Specifications (Payload Model)

V1.PAY-76	*Payloads implementing payload physical specifications shall do so by using the custom Physical Specifications Service in accordance with the definition and rules specified in the RAS-G IOP SAE JAUS Profiling Rules, Physical Specifications Interoperability Attribute.*

4.12 SELF-COLLISION AVOIDANCE ATTRIBUTE

Parent Attribute: Actuator Attribute

The Self-Collision Avoidance Attribute specifies the capability to support self-collision avoidance.

When specified, systems should be capable of providing self-collision avoidance of payloads. This service will be to prevent on-board collisions in situations where there are multiple manipulator arms or moving payloads that could negatively interact with other physical dynamic subsystems.

IOP V1 provides custom services for use in these situations.

4.12.1 Self-Collision Avoidance System Requirement

V1.PAY-77	*Payloads implementing self-collision avoidance shall do so in accordance with the definition and rules specified in the RAS-G IOP SAE JAUS Profiling Rules, Self-Collision Avoidance Attribute. Either the Centralized Self-Collision Avoidance Attribute or the Distributed Self-Collision Avoidance Attribute may be selected.*

CHAPTER 5 PAYLOAD SENSOR REQUIREMENTS

5.1 SENSOR ATTRIBUTE

The Sensor Interoperability Attribute provides capabilities to sense aspects inherent to a platform or the environment.

This section specifies common requirements associated with sensors in accordance with the IOP composability taxonomy. Common requirements are those requirements that are common to the sensor class. As of this version of the IOP, few sensor payloads have been defined; and for sake of clarity only applicable sections of the composability taxonomy have been included. Other sections of the taxonomy will be addressed, as applicable, in future revisions of this IOP.

5.1.1 Electrical and Mechanical Interfaces

As of this version of the IOP, there are no additional sensor specific electrical and mechanical interface requirements beyond the requirements specified in CHAPTER 4 PAYLOAD SYSTEM REQUIREMENTS. This section serves as a placeholder for future requirements and/or capabilities.

5.1.2 Protocols, Formats, and Measures

Protocols, Formats, and Measures characterize the outputs associated with sensor payloads. Interoperability requirements defined here provide for the ability to define a standardized interchange from a payload on a UGV to a controller or to an external system. Standards and requirements identified within this section are applicable to and inherited by other sensors defined in subsequent paragraphs.

Any number of the following attributes can be chosen.

Attribute	Description
Video Attribute	Provides a method for interacting with a video source, such as a digital or analog camera or video from another source.
Still Image Attribute	Provides the capability to configure and retrieve information from a still image source.
Range Sensor Attribute	Provides the capability for getting information back from a range sensor. This may be either a simple range finder (one range, like a ranging laser) or a more complex range finder (like a LIDAR unit with many returns per second over a large azimuth).
Microphone Attribute	Provides the capability to receive audio from a microphone device. It is assumed that the audio will be sent in a digital format. Multiple microphones may be represented using this attribute.

Chemical, Biological, Radiological, & Nuclear Sensor Attribute	The Chemical, Biological, Radiological, & Nuclear Sensor Attribute provides a method for interacting with a Chemical, Biological, Radiological, & Nuclear (CBRN) sensor source.
Thermal Sensor Attribute	A thermal sensor
Force/Torque Sensor Attribute	Provides a way to get force or torque information from one or more devices.
Acoustic Sensor Attribute	Provides a mechanism for controlling and obtaining data from an acoustic sensor.
Engagement Detection Attribute	The Engagement Detection Attribute provides a capability to identify and locate small weapons fire. The capability itself is agnostic of the underlying detection mechanism and specific sensor(s) used.
Magnetic Sensor Attribute	Provides a mechanism for controlling and obtaining data from an magnetic sensor.
Seismic Sensor Attribute	Provides a mechanism for controlling and obtaining data from a seismic sensor.
Global Contact Tracking Attribute	Provides a capability to identify and track objects moving in the environment. These objects may be limited to humans, vehicles, pedestrians, etc. based on the specific needs of the program. The actual method of detection and tracking, e.g. vision versus lidar or some combination, is left to the implementation

Table 28: - Optional Select = any

5.2 VIDEO ATTRIBUTE

Parent Attribute: Sensor Attribute

Video based sensors come in various forms. Some video data present information in color and others present information in monochrome. Others convey different meanings with hue, saturation, and value (e.g. infrared vs. LADAR) of each pixel. Some cameras can only turn when the vehicle is commanded to turn while others can be controlled independently from the UGV chassis.

At least one of the following attributes must be chosen.

Attribute	Description
Digital Video Attribute	The Digital Video Interoperability Attribute provides a method for interacting with a digital video source, such as a digital camera or digital video from another digital source.
Analog Video Attribute	Provides a method for interacting with an analog video source, such as an analog camera.

Table 29: - Mandatory Select = any

Any number of the following attributes can be chosen.

Attribute	Description
Pan Tilt Video Sensor Attribute	Provides the capability to configure, control, and find/connect to a video device (analog or digital) that has pan tilt capabilities (i.e. a PTZ camera).

Table 30: - Optional Select = any

5.3 DIGITAL VIDEO ATTRIBUTE

Parent Attribute: Video Attribute

A Digital Video Attribute may be selected to provide digital drive and motion imagery within the Video Interoperability Attribute. IOP compliant digital motion imagery sensors must support H.264 or H.262 video standards.

IOP compliant digital motion imagery sensors may support either Real-Time Streaming Protocol (RTSP) based or JAUS (RTP) based streaming control protocols. RTSP is an "application-level protocol for control over the delivery of data with real-time properties" [RFC 2326] such as video and audio. Any digital motion imagery sensor using RTSP shall implement the following at a minimum:

- Implement the minimal server implementation items described in RFC 2326, Section D.2
- Implement RTP [RFC 3550] as a valid transport for video data
- Include the Server header
- Implement the DESCRIBE method
- Generate SDP session descriptions as defined in RFC 2326 Appendix C

If using the RTP method, control shall be done as specified in RAS-G IOP SAE JAUS Profiling Rules, section 9.1.4. The transport protocol is RTP [RFC 3550].

IOP provides a multitude of video resolutions capable to be used on the platform ranging from very small (sqcif) to very large (whuxga). In order to ensure basic interoperability between platform and controller, a standard resolution, bit rate, and frame rate must be implemented by IOP-compatible payloads. At a minimum, IOP-compatible payloads must support a basic 4:3 resolution of 640x480. If a platform only supports 16:9 resolutions exclusively or resolutions with a pixel count greater than 640x480, it shall be acceptable to squeeze, stretch, or crop a video in order to fit the requirement. Additionally, IOP-compliant payloads must be capable of streaming digital video of at least 10 frames per second at 200 kbps. Video formats beyond these requirements are discretionary.

Systems that provide H.264 encoded video may implement one or more optional "Presets", which capture H.264 encoder parameter sets that are intended to be used under specific circumstances. The presets chosen may incorporate H.264 encoder

parameters as applicable, which are not specified by the IOP and shall be defined by the payload manufacturer.
Preset names and numerical designators shall be chosen from the following list:

- Enum 0: LowLatency
- Enum 1: SlowComms
- Enum 2: PersistentStare
- Enum 3: DriveVision
- Enum 4: Manipulation
- Enum 5: BestQuality
- Enum 12-15: ProgramSpecific

If the Presets option is selected, preset names shall be reported in response to QueryH264VideoEncodingCapabilities or QueryH264VideoEncodingConfiguration messages.

Systems utilizing H.264 shall implement the Baseline Profile, as defined in ITU-T H.264 Infrastructure of Audiovisual Services – Coding of Moving Video Annex A, at a minimum. In addition, systems utilizing H.264 shall support H.264 level 3 or higher, as defined by ITU-T H.264 Infrastructure of Audiovisual Services – Coding of Moving Video Annex A.

Additional suggested profiles to be supported are the Main and High profile. It is recommended that high quality video sources support level 4.1 or higher. Systems which support stereoscopic video, such as stereovision cameras, shall support the Stereo High Profile.

5.3.1 Payloads Digital Video Requirement

V1.PAY-78	*Payloads implementing the digital drive and motion imagery capability shall do so by implementing the digital video component in accordance with the definition and rules specified above and also in the RAS-G IOP SAE JAUS Profiling Rules, Digital Video Interoperability Attribute. The payload shall use one or more of the following:*
V1.PAY-79	*The payload shall support H.264 video standards along with the above described requirements at a minimum.*
V1.PAY-80	*The payload shall support H.262 video standards along with the above described requirements at a minimum.*

5.4 ANALOG VIDEO ATTRIBUTE

Parent Attribute: Video Attribute

An Analog Video Attribute may be selected to provide analog drive and motion imagery within the Video Interoperability Attribute. Interoperability compliant analog motion imagery sensors must support National Television System Committee (NTSC) video

standards. Analog cameras shall use the MIL-DTL-55116, 6 contact connector, with the pin out listed below.
This may be in conjunction with platform based microphone which will be defined under the Speaker section. The MIL-DTL-55116, 6 contact connector has been selected to remain consistent with the analog microphone / speaker connector.

Analog_Video_In
Protocol: NTSC
Signal Type: Analog Single Ended

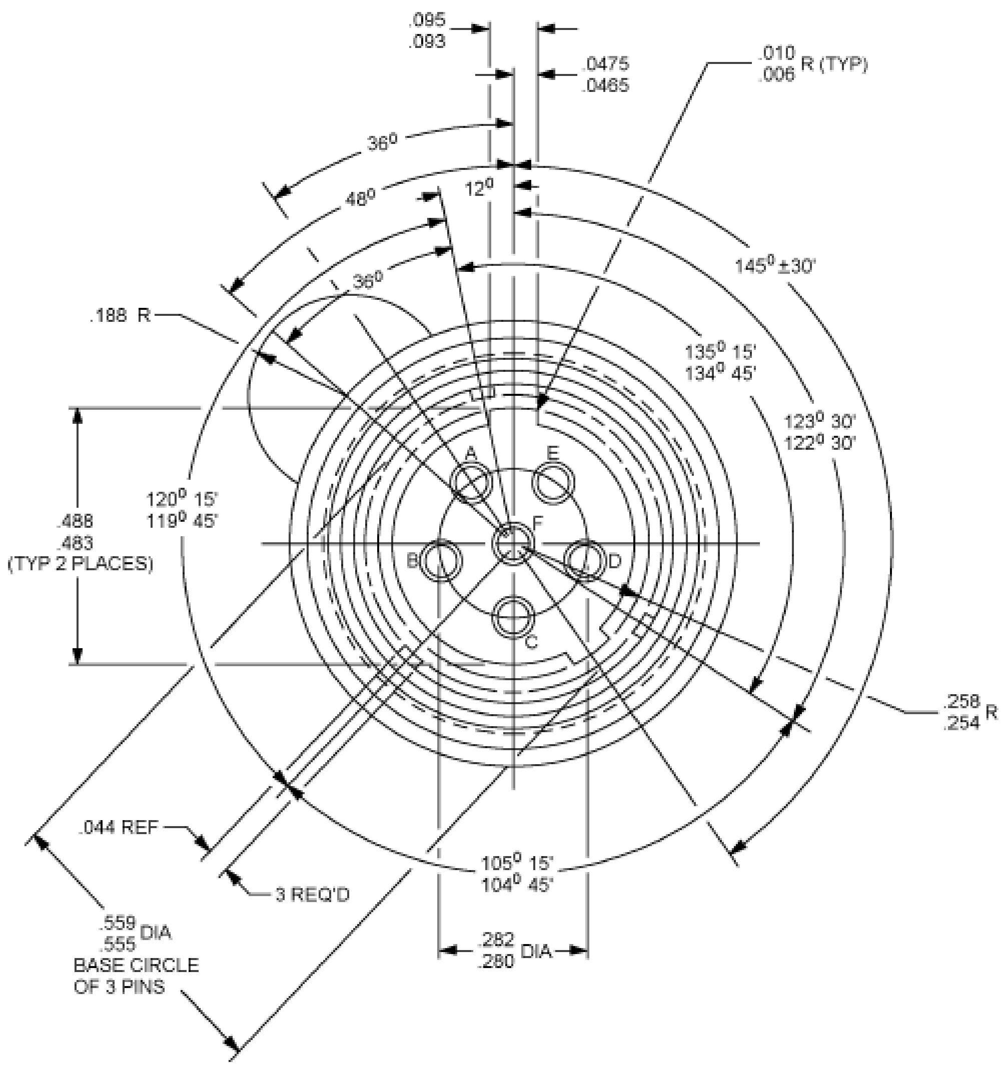


Figure 18: MIL-DTL-55116, 6 Contact Connector

Pin	Signal Name
A	Power_GND

B	Power_12V
C	Audio_In
D	Audio_GND
E	Video_In
F	Video_GND

5.4.1 Analog Drive and Motion Imagery Requirement

V1.PAY-81	*If the Analog Video Interoperability Attribute is selected, the connector shall meet the MIL-DTL-55116, 6 contact connector selected, with the pinout identified. Audio_In and Audio_GND pins are not necessary, but are left as an option for integrated microphone / camera payloads. Payloads using a common Power_GND and Video_GND should tie these signals together internally. Platforms may choose to keep these signals isolated or tie them together, based on need.*

5.5 PAN TILT VIDEO SENSOR ATTRIBUTE

Parent Attribute: Video Attribute

The pan, tilt, zoom (PTZ) camera is a compound payload comprised of a digital video sensor and a pan/tilt gimbal.

The PTZ camera sensor shall be realized via a Pan Tilt Video Sensor Interoperability Attribute defined within the RAS-G IOP SAE JAUS Profiling Rules.

5.5.1 Pan Tilt Video Sensor Payloads Requirement

V1.PAY-82	*Payloads implementing the PTZ camera sensor capability shall do so by using the Pan Tilt Video Sensor Interoperability Attribute in accordance with the definition and rules specified in the RAS-G IOP SAE JAUS Profiling Rules.*

5.6 STILL IMAGE ATTRIBUTE

Parent Attribute: Sensor Attribute

The Still Image Interoperability Attribute defines the capability to configure and retrieve information from a still image source. Multiple related still image sources (such as multiple cameras that all take still images on a single payload) may be represented.

IOP-compliant still imagery must support JPEG or JPEG2000 imagery standards for lossy compressed images, PNG for lossless compressed images, and BMP for uncompressed images.
IOP-compliant payloads must support a minimum 4:3 resolution of 640x480 (vga). If a platform only supports 16:9 resolutions exclusively or resolutions with a pixel count greater than 640x480, it shall be acceptable to squeeze, stretch, or crop an image in order to fit the requirement. Image formats beyond these requirements are discretionary.

5.6.1 Still Image Payloads Requirement

V1.PAY-83	*Payloads implementing the still imagery capability shall do so by implementing the still image component in accordance with the definition and rules specified in the RAS-G IOP SAE JAUS Profiling Rules, Still Image Interoperability Attribute, and will support JPEG or JPEG2000 image standards at a minimum.*
V1.PAY-84	*If using lossless compressed images, payloads shall support at least PNG standards.*
V1.PAY-85	*If using uncompressed images, payloads shall support at least BMP standards.*

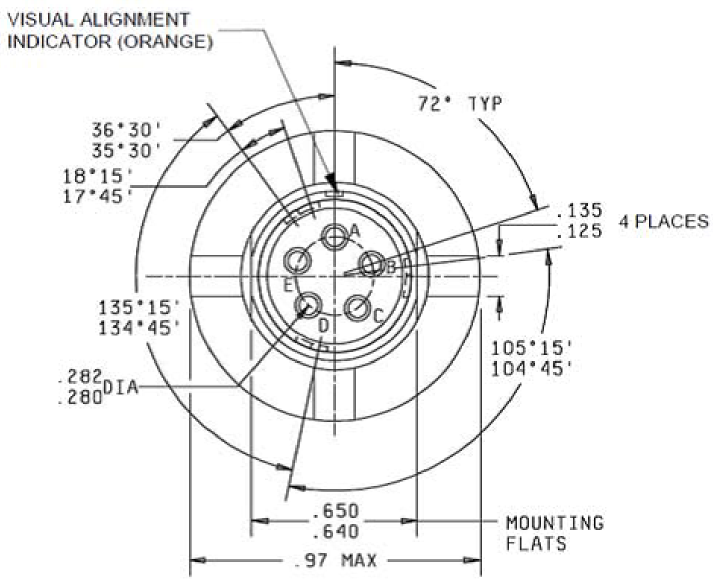
5.7 MICROPHONE ATTRIBUTE

Parent Attribute: Sensor Attribute

A platform based Microphone Attribute may be selected within the Sensor Interoperability Attribute. Audio data will be sent in digital format. If a Digital Microphone is used, the Audio Engineering Society (AES) 42-2010 standard will be used. Digital microphone physical interface has not been defined. Analog microphones should follow the standards below. Analog microphones should use the MIL-DTL-55116, 5 contact connector, with the pin outs listed below. This is in conjunction with platform based speakers which will be defined under the Speaker section. The MIL-DTL-55116, 5 contact connector has been selected to remain consistent with other robot standards currently in development. However, if the MIL-DTL-55116 is inappropriate for a particular platform, for example due to size constraints, programs may elect to specify a different connector.

Audio_In
Protocol: N/A
Signal Type: Analog Single Ended
Voltage Range (V): -2 to 2
Current Range (mA): 0-250

The analog Microphone connector shall use the receptacle side of the interface. The pinout designations looking into the receptacle side are outlined in the figure below.



Pin #	Signal Name
A	Power_GND
B	Audio_Out1
C	Audio_Out2
D	Audio_In
E	Power_24V

Figure 19: The MIL-DTL-55116, 5 Contact Connector Analog Microphone Pinout

At a minimum, IOP-compliant microphones must support a sample rate of 11kHz, and a bitrate of at least 10 kbps. The use of any specific, required codec is selected on a per-program basis.

IOP compliant audio may support either Real-Time Streaming Protocol (RTSP) based or JAUS based RTP streaming control protocols. RTSP is an "application-level protocol for control over the delivery of data with real-time properties" [RFC 2326] such as video and audio. Any audio sensor using RTSP shall implement the following at a minimum:

- Implement the minimal server implementation items described in RFC 2326, Section D.2
- Implement RTP [RFC 3550] as a valid transport for video data
- Include the Server header
- Implement the DESCRIBE method
- Generate SDP session descriptions as defined in RFC 2326 Appendix C

If using the RTP method, control shall be done as specified in RAS-G IOP SAE JAUS Profiling Rules, section 9.1.12. This transport protocol method is RTP [RFC 3550].

5.7.1 Microphone Payloads Requirement

V1.PAY-86 *Payloads implementing the microphone capability shall do so by implementing the microphone component in accordance with the definition and rules specified in the RAS-G IOP SAE JAUS Profiling Rules, Microphone Interoperability Attribute.*

V1.PAY-87 *If the MIL-DTL-55116, 5 contact connector is selected, the connector will meet the pinout identified to remain consistent with other Interoperability efforts. Audio_Out pins are not necessary for microphone, but are labeled for consistency with the Speaker Connector. If the MIL-DTL-55116, 5 contact connector is not selected, the program must select a connector that meets the physical needs of the platform.*

5.8 RANGE SENSOR ATTRIBUTE

Parent Attribute: Sensor Attribute

Successful UGV navigation requires detailed knowledge of the surrounding area. Static and dynamic obstacles and other terrain features can impede UGV mobility if not detected. Laser range finder sensors can help in this regard by providing distance information. These distance vectors can also aid in aiming weapons.

The Range Sensor Interoperability Attribute provides the capability for getting information back from a range sensor. This may be either a simple range finder (one range, like a ranging laser) or a more complex range finder (like a LIDAR, RADAR, or Ground-Penetrating RADAR unit with many returns per second over a large azimuth). Multiple related range sensors (such as multiple LIDARs on a single payload) may be represented using this attribute.

Any number of the following attributes can be chosen.

Attribute	**Description**
Ground-Penetrating Radar Attribute	Specialized range finder using radar pulses to image the subsurface

Table 31: - Optional Select = any

5.8.1 Range Sensor Payloads Requirement

V1.PAY-88 *Payloads implementing the range finder sensor capability shall do so by implementing the range finder component in accordance with the definition and rules specified in the RAS-G IOP SAE JAUS Profiling Rules, Range Sensor Interoperability Attribute Option.*

5.9 GROUND-PENETRATING RADAR ATTRIBUTE

Parent Attribute: Range Sensor Attribute

There are no specialized IOP requirements for GPRs. Implementation of GPR functionality should be achieved using existing IOP support for Range Sensor. It should be noted, however, that larger GPR units have considerable power draw. Consequently, the 12 and 24 volt busses provided in Power Attributes A or B may not be sufficient. In such cases, Power Attribute C should be considered.

5.9.1 Ground-Penetrating Radar Requirement

V1.PAY-89	*Payloads implementing the Ground-Penetrating Radar capability shall do so by implementing the range finder component in accordance with the definition and rules specified in RAS-G IOP SAE JAUS Profiling Rules, Range Sensor Interoperability Attribute.*

5.10 THERMAL SENSOR ATTRIBUTE

Parent Attribute: Sensor Attribute

The Thermal Sensor Interoperability Attribute specifies sensors that typically include video and image cameras that can detect radiation in the infrared range of the electromagnetic spectrum. Its most typical use is in sensing temperature variations in order to generate images. The data format will be in the same format as the previously described motion and still imagery data.

Generally, the resolution of a thermal sensor is lower than that of a standard RGB camera, and thusly, the resolution requirements of a thermal sensor image are also lower. For IOP compliance, a thermal sensor must be able to generate an image or video of at least 160x120 pixels (qqvga). Higher resolutions are discretionary. Video frames per second and bit rate will be defined in a future IOP release.

5.10.1 Thermal Sensor Requirement

V1.PAY-90	*Payloads implementing the thermal sensor capability shall do so by implementing the appropriate imagery component in accordance with the definition and rules specified in the RAS-G IOP SAE JAUS Profiling Rules. The formats will be the same as those presented in the Video Attribute (for thermal motion imagery) and the Still Image Attribute (for thermal still imagery) in this document.*

5.11 FORCE/TORQUE SENSOR ATTRIBUTE

Parent Attribute: Sensor Attribute

While the SAE JAUS Manipulator Service Set offers per-joint force/torque sensing, there is currently no JAUS end effector-based sensor for measuring forces/torques at the tool point. IOP includes a custom-service modeled after existing End Effector sensors.

Furthermore, a generalized force-sensor suitable for mounting directly on the vehicle for bump/impact and/or vibration sensing is included.

Force sensing shall be realized at the tool point, or on any general system location by using the custom services defined in the RAS-G IOP SAE JAUS Profiling Rules document.

5.11.1 Force/Torque Sensor Payloads Requirement

V1.PAY-91	*Payloads implementing force sensing at the tool point shall do so by using the custom Manipulator End Effector Force/Torque Sensor Service in accordance with the definition and rules specified in the RAS-G IOP SAE JAUS Profiling Rules, Manipulator End Effector Force/Torque Sensor Interoperability Attribute.*
V1.PAY-92	*Payloads implementing generalized force sensing for bump/impact and/or vibration sensing shall do so by using the custom Force Torque Sensor Service in accordance with the definition and rules specified in the RAS-G IOP SAE JAUS Profiling Rules, Force Torque Sensor Interoperability Attribute.*

5.12 ACOUSTIC SENSOR ATTRIBUTE

Parent Attribute: Sensor Attribute

The Acoustic Sensor Attribute provides a mechanism for controlling and obtaining data from an acoustic sensor.

5.12.1 Acoustic Sensor Payloads Requirement

V1.PAY-93	*Payloads implementing the acoustic sensor capability shall do so by implementing the acoustic sensor in accordance with the definition and rules specified in the RAS-G IOP SAE JAUS Profiling Rules, Acoustic Sensor Attribute.*

5.13 ENGAGEMENT DETECTION ATTRIBUTE

Parent Attribute: Sensor Attribute

The Engagement Detection Attribute provides a capability to identify and locate small weapons fire. The capability itself is agnostic of the underlying detection mechanism and specific sensor(s) used.

5.13.1 Engagement Detection Payloads Requirement

V1.PAY-94 *Payloads implementing the engagement detection capability shall do so by implementing the engagement detection component in accordance with the definition and rules specified in the RAS-G IOP SAE JAUS Profiling Rules, Engagement Detection Attribute.*

5.14 MAGNETIC SENSOR ATTRIBUTE

Parent Attribute: Sensor Attribute

The Magnetic Sensor Attribute provides a mechanism for controlling and obtaining data from a magnetic sensor.

5.14.1 Magnetic Sensor PayloadsRequirement

V1.PAY-95 *Payloads implementing the magnetic sensor capability shall do so by implementing the magnetic sensor in accordance with the definition and rules specified in the RAS-G IOP SAE JAUS Profiling Rules, Magnetic Sensor Attribute.*

5.15 SEISMIC SENSOR ATTRIBUTE

Parent Attribute: Sensor Attribute

The Seismic Sensor Attribute provides a mechanism for controlling and obtaining data from a seismic sensor.

5.15.1 Seismic Sensor Payloads Requirement

V1.PAY-96 *Payloads implementing the seismic sensor capability shall do so by implementing the seismic sensor in accordance with the definition and rules specified in the RAS-G IOP SAE JAUS Profiling Rules, Seismic Sensor Attribute.*

5.16 GLOBAL CONTACT TRACKING ATTRIBUTE

Parent Attribute: Sensor Attribute

The Global Contact Tracking Attribute provides a capability to identify and track objects moving in the environment. The service itself is agnostic of the underlying detection mechanism and specific sensor(s) used.

5.16.1 Global Contact Tracking Payloads Requirement

V1.PAY-97 *Payloads implementing the tracking capability shall do so in accordance with the definition and rules specified in the RAS-G IOP SAE JAUS Profiling Rules, Global Contact Tracking Interoperability Attribute.*

CHAPTER 6 PAYLOAD EMITTER REQUIREMENTS

6.1 EMITTER ATTRIBUTE

This section specifies common requirements associated with emitters in accordance with the IOP composability taxonomy. Common requirements are those requirements that are common to the emitter class.

6.1.1 Electrical and Mechanical Interfaces

As of this version of the IOP, there are no additional Emitter specific electrical and mechanical interface requirements beyond the requirements specified in CHAPTER 4 PAYLOAD SYSTEM REQUIREMENTS. This section serves as a placeholder for future requirements and/or capabilities.

6.1.2 Protocols, Formats, and Measures

Protocols, Formats, and Measures characterize the outputs associated with emitter payloads. Interoperability requirements defined here provide for the ability to define a standardized interchange from a controller or external system to a payload on a UGV. Standards and requirements identified within this section are applicable to and inherited by other emitters defined in subsequent paragraphs.

As of this version of the IOP, there is no specific emitter protocol, format, or measure requirements. This section serves as a placeholder for future requirements and/or capabilities.

The following attributes describe each of these emitters.

Any number of the following attributes can be chosen.

Attribute	Description
Illumination Attribute	Provides the capability to interact with lights.
Speaker Attribute	Provides the capability to send audio that gets annunciated over a speaker. Multiple speakers may be represented using this attribute.
Debris Blower Attribute	Provides the capability to blow debris.

Table 32: - Optional Select = any

6.2 ILLUMINATION ATTRIBUTE

Parent Attribute: Emitter Attribute

If selected, the Illumination Interoperability Attribute provides the capability to interact with lights.

The IOP does not call out lighting interface standards at this time, but the use of industry standards is encouraged.

6.2.1 Illumination Payloads Requirement

V1.PAY-98	*Payloads implementing the lights capability shall do so by implementing the Illumination Attribute or Camera Lights Attribute, respectively, in accordance with the definition and rules specified in the RAS-G IOP SAE JAUS Profiling Rules depending on whether the lighting source is associated with a camera or not.*

6.3 SPEAKER ATTRIBUTE

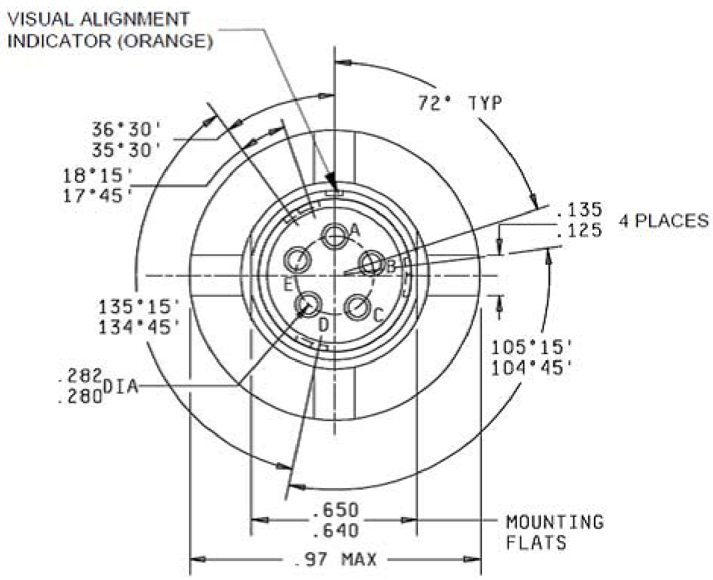
Parent Attribute: Emitter Attribute

The Speaker Interoperability Attribute provides the capability to send audio that gets annunciated over a speaker. It is assumed that the audio will be sent in a digital format and converted to an analog signal if required by the speaker. Multiple speakers may be represented using this attribute.

Analog speakers should use the MIL-DTL-55116, 5 contact connector, with the pin outs listed below. This is in conjunction with platform based microphones which will be defined under the Microphone section. The MIL-DTL-55116, 5 contact connector has been selected to remain consistent with other robot standards currently in development. However, if the MIL-DTL-55116 is inappropriate for a particular platform, for example due to size constraints, programs may elect to specify a different connector. The speaker device may amplify the output as required.

Audio_Out
Protocol: N/A
Signal Type: Analog Stereo
Voltage Range (V): -2 to 2
Current Range (mA): 0-250

The analog Speaker connector shall use the receptacle side of the interface. The pinout designations looking into the receptacle side are outlined in the figure below.



Pin #	Signal Name
A	Power_GND
B	Audio_Out1
C	Audio_Out2
D	Audio_In
E	Power_24V

Figure 20: The MIL-DTL-55116, 5 Contact Connector Analog Speaker Pinout

At a minimum, IOP-compliant annunciated audio broadcasted via speaker must be received digitally at a sample rate of 11kHz, and a bitrate of at least 10 kbps. The use of any specific, required codecs is selected on a per-program basis.

IOP compliant audio may support either Real-Time Streaming Protocol (RTSP) based or JAUS based streaming control protocols. RTSP is an "application-level protocol for control over the delivery of data with real-time properties" [RFC 2326] such as video and audio. Any audio sensor using RTSP shall implement the following at a minimum:

- Implement the minimal server implementation items described in RFC 2326, Section D.2
- Implement RTP [RFC 3550] as a valid transport for audio data
- Include the Server header
- Implement the DESCRIBE method
- Generate SDP session descriptions as defined in RFC 2326 Appendix C

If using the JAUS method, control shall be done as specified in RAS-G IOP SAE JAUS Profiling Rules, Speaker Push Interoperability Attribute. The transport protocol for the JAUS method is RTP [RFC 3550].

6.3.1 Speaker Requirement

V1.PAY-99	*Payloads implementing the speakers capability shall do so by implementing the speaker attribute in accordance with the definition and rules specified in the RAS-G IOP SAE JAUS Profiling Rules, Speaker Pull Interoperability Attribute.*

V1.PAY-100	*If the MIL-DTL-55116, 5 contact connector is selected, the connector will meet the pinout identified to remain consistent with other Interoperability efforts. Audio_In pins are not necessary for speaker, but are labeled for consistency with the Microphone Connector. If the MIL-DTL-55116, 5 contact connector is not selected, the program must select a connector that meets the physical needs of the platform.*

6.4 DEBRIS BLOWER ATTRIBUTE

Parent Attribute: Emitter Attribute

When specified, debris blowing payloads shall be capable of being controlled through a custom JAUS service for Debris Blower. This service will be used by other subsystems in order to provide control or management of debris blower capabilities, speed, azimuth, elevation, and status.

6.4.1 Debris BlowerPayloads Requirement

V1.PAY-101	*Payloads that blow debris shall do so by using the custom Debris Blower Service in accordance with the definition and rules specified in the RAS-G IOP SAE JAUS Profiling Rules, Debris Blower Attribute.*

CHAPTER 7 PAYLOAD ACTUATOR REQUIREMENTS

7.1 ACTUATOR ATTRIBUTE

This section specifies common requirements associated with actuators in accordance with the IOP composability taxonomy. Common requirements are those requirements that are common to the actuator class.

7.1.1 Electrical and Mechanical Interfaces

As of this version of the IOP, there are no additional actuator specific electrical and mechanical interface requirements beyond the requirements specified in CHAPTER 4 PAYLOAD SYSTEM REQUIREMENTS. It is important to note, however, that many complex actuator and manipulator systems require high power draw. Consequently, the 12 and 24 volt busses provided in Power Attribute A or B may not be sufficient. In such cases, Power Attribute C should be considered.

7.1.2 Protocols, Formats, and Measures

Protocols, Formats, and Measures characterize the outputs associated with actuator payloads. Interoperability requirements defined here provide for the ability to define a standardized interchange from a controller or external system to a payload on a UGV. Standards and requirements identified within this section are applicable to and inherited by other actuators defined in subsequent paragraphs.

7.1.3 Manipulator Taxonomy

Within this IOP, manipulators have been further classified into robotic arms, pan tilt manipulators, and end effectors. Additional manipulator types may be added in future revisions of this IOP.

At least one of the following attributes must be chosen.

Attribute	Description
Robotic Arm Control Attribute	Provides the capability to communicate, control, and receive status from a robotic arm.
Pan Tilt Manipulator Attribute	Defines requirements common to all pan-tilt manipulator related services.
End Effector Attribute	Adds support for the capability to control and/or receive status from an end-effector

Table 33: - Mandatory Select = any

Any number of the following attributes can be chosen.

Attribute	Description
Self-Collision Avoidance Attribute	Provides the capability to communicate, control, and receive status from a self-collision avoidance system.

Table 34: - Optional Select = any

7.2 ROBOTIC ARM CONTROL ATTRIBUTE

Parent Attribute: Actuator Attribute

Robotic Arm payloads provide a means to manipulate objects. Types include lower arms that extend underneath the UGV platform and upper arms that rest on top of a UGV chassis. The arm is often positioned via a commanded desired position of the end effectors (e.g. grasper) using inverse kinematics. For many UGVs however, the operator often controls robotic arm links/joints independently. In addition, torques/forces provided by the motors are limited and the robotic arm may not be able to lift certain heavy objects that, if attempted, may cause the UGV to rollover. Therefore, feedback to the operator is often essential.

Any number of the following attributes can be chosen.

Attribute	Description
Basic Manipulator Attribute	Defines a basic manipulator controlled using open loop control.
Mast Actuator Attribute	Provides the capability to communicate, control, and receive status from a mast actuator.

Table 35: - Optional Select = any

7.3 BASIC MANIPULATOR ATTRIBUTE

Parent Attribute: Robotic Arm Control Attribute

The basic manipulator is a component that provides for simple control of linear and revolute joints. With respect to JAUS, this is realized through joint effort control.

7.3.1 Basic Manipulator Payloads Requirement

V1.PAY-102	*Payloads implementing the basic manipulator capability shall do so by implementing the Basic Manipulator Attributes in accordance with the definition and rules specified in the RAS-G IOP SAE JAUS Profiling Rules.*

7.4 MAST ACTUATOR ATTRIBUTE

Parent Attribute: Robotic Arm Control Attribute

The telescoping mast is a special case manipulator used to control a single linear motion.

7.4.1 Mast Actuator Payloads Requirement

V1.PAY-103	*Payloads implementing the telescoping mast capability shall do so by implementing the Mast Actuator Interoperability Attribute in accordance with the definition and rules specified in the RAS-G IOP SAE JAUS Profiling Rules.*

7.5 PAN TILT MANIPULATOR ATTRIBUTE

Parent Attribute: Actuator Attribute

Pan tilt manipulators are a specific type of manipulator designed for panning and tilting, typically with a device attached such as a camera.

7.5.1 Pan Tilt Manipulator Payloads Requirement

V1.PAY-104	*Payloads implementing the basic pan tilt capability shall do so by implementing the Pan Tilt Manipulator Interoperability Attribute in accordance with the definition and rules specified in the RAS-G IOP SAE JAUS Profiling Rules.*

7.6 END EFFECTOR ATTRIBUTE

Parent Attribute: Actuator Attribute

An end effector is a specialized tool attached either directly to a platform or to a joint (typically the last one) of an actuator system. An end effector generally manipulates the environment or platform in some way such as gripping an object, cleaning a sensor, or stabilizing a platform.

Any number of the following attributes can be chosen.

Attribute	Description
Basic End Effector Attribute	Provides the capability to communicate, control, and receive status from an end-effector.
Complex End Effector Attribute	Provides the capability to define a complex end effector beyond a simple one degree of freedom.
Surrogate UAV Attribute	Provides a capability to identify, launch, and recover a surrogate UAV associated with the host platform.
Tether Spooler Attribute	Adds support for controlling and obtaining status from a tether's spooling mechanism

Table 36: - Optional Select = any

7.7 BASIC END EFFECTOR ATTRIBUTE

Parent Attribute: End Effector Attribute

The Basic End Effector Interoperability Attribute defines a simple one degree of freedom end effector. While traditional simple end-effectors such as a basic two fingered gripper are supported, this Attribute can be used to control any end-effectors types that are limited to a single degree of freedom. Examples include cutters, drills, digging tools (buckets), and welding torches.

7.7.1 Basic End Effector Payloads Requirement

V1.PAY-105	*Payloads implementing the basic end effector capability shall do so in accordance with the definition and rules specified in the RAS-G IOP SAE JAUS Profiling Rules, Basic End Effector Interoperability Attribute.*

7.8 COMPLEX END EFFECTOR ATTRIBUTE

Parent Attribute: End Effector Attribute

A complex end effector is an end effector with capabilities that go beyond the basic open / close capabilities of a basic end effector covered by the 7.7 BASIC END EFFECTOR ATTRIBUTE. A complex end effector may have multiple degrees of freedom (for example, a hand-like device) and is more similar to a manipulation device than a simple one degree of freedom end effector device.

The following attributes are mandatory.

Attribute	Description
Basic Manipulator Attribute	Defines a basic manipulator controlled using open loop control.

Table 37: - Mandatory Select = all

7.8.1 Complex End Effector Requirement

V1.PAY-106	*Payloads implementing the complex end effector capability shall do so by implementing the Complex End Effector Attribute in accordance with the definition and rules specified in the RAS-G IOP SAE JAUS Profiling Rules.*

7.9 SURROGATE UAV ATTRIBUTE

Parent Attribute: End Effector Attribute

The Surrogate UAV Attribute provides a capability to identify, launch, and recover a surrogate UAV associated with the host platform. The UAV could be tethered or untethered. In the most basic configuration, the surrogate is expected to follow the host platform at a specified relative altitude. The means of following is left to the implementation; example approaches include active control or being pulled by a tether.

However, surrogate UAVs can be associated with more advanced functionality through additional Attributes, allowing for behaviors like independent control, leader/follower, and loiter patterns.

7.9.1 Surrogate UAV Payloads Requirement

A Surrogate UAV may be launched and recovered from a host platform, supporting either a tethered or untethered relationship.

V1.PAY-107	*Payloads implementing the surrogate UAV capability shall do so in accordance with the definition and rules specified in the RAS-G IOP SAE JAUS Profiling Rules, Surrogate UAV Interoperability Attribute.*

7.10 TETHER SPOOLER ATTRIBUTE

Parent Attribute: End Effector Attribute

A tether is a line that connects a UGV to an OCU or payload that can range from something simple like a chain or rope to a material capable of transmitting communications like an optical fiber or a wire. There are at least two use cases where an UGV may operate while connected to a tether:

- **Optical Fiber/ Wire Communications:** the UGV communicates over an optical fiber or wire which must be spooled in or out based on the movement of the mobility platform

- **Winch-based Recovery:** a winch mechanism is used to extricate an UGV that has become stuck in difficult terrain or recover another object/payload from the environment

The Tether Spooler Attribute provides support for controlling and displaying status from a spooling mechanism for a tether.

7.10.1 Tether Spooler Payloads Requirement

V1.PAY-108	*Systems implementing logical control of a tether's spooling mechanism shall do so by implementing the Tether Spooler Attribute in accordance with the definition and rules specified in the RAS-G IOP SAE JAUS Profiling Document.*

ANNEX A ACRONYMS AND ABBREVIATIONS

AFUS	Architecture Framework for Unmanned Systems
AEP	Allied Tactical Publication
AWG	American Wire Gauge
CBRN	Chemical, Biological, Radiological, and Nuclear
CCL	Common Communications Link
GPR	Ground Penetrating Radar
IEEE	Institute of Electrical and Electronics Engineers
IOP	Interoperability Profile
ISO	International Organization for Standardization
JAUS	Joint Architecture for Unmanned Systems
JPEG	Joint Pictures Expert Group
LASER	Light Amplification by Stimulated Emission of Radiation
MIL-DTL	Military Detail Specification
MIL-STD	Military Standard
MISB	Motion Imagery Standards Board
NTSC	National Television System Committee
PTZ	Pan, Tilt, Zoom
PUI	Product Unique Identifiers
RADAR	Radio Detection And Ranging
RAS-G	Robotics and Autonomous Systems - Ground
RS JPO	Robotic Systems Joint Project Office
RSTA	Reconnaissance, Surveillance, and Target Acquisition
SAE	Society of Automotive Engineers
UGV	Unmanned Ground Vehicle
UNC	Unified National Coarse
V0	Version 0 (zero)
V1	Version 1 (one)

INTENTIONALLY BLANK

ANNEX B PLANNED EXPANSIONS

The RAS-G Interoperability Profile (IOP) Payloads Profile is expanded based on several factors, which are collected and explained in the annual RAS-G Interoperability Profile (IOP) Capabilities Plan. As new payloads are required, the profiles for using those payloads are added to the Payloads Profile.

In addition, this Appendix serves to record other, more generic, information that has been identified for capture in future versions of the Payloads Profile. In many cases a selection was not done because of a lack of complete information, and the IOP Working Groups did not want to make selections based on incomplete information. This list will update for each version of the IOP, and should not be considered a complete list.

B.1 PICATINNY RAIL (MIL-STD-1913)

- Required tolerances for payload attachment
  - Should it depend on the payload and the payload function?
- Material
  - Is there any benefit to allowing alternate (lighter) materials in order to allow reduced weight for payloads that don't require metal rails?
- Quantity of rails
  - Should there be a minimum number of rails?
  - Should a minimum number of rails be based on robot class?
  - Should the number of rails be dictated by the program?
- Location of rails
  - Should rail locations on the platform be specified?
  - Should rail locations be dictated by the program?

B.2 OPTICAL BENCH

- Required tolerances for the payload attachment for both size and location
  - Should it depend on the payload and the payload function?
  - Should the bolt/hole gage be specified? (ASME/ANSI B1.3M)
  - Should the bolt/hole grade be specified? (SAE J429)
  - Should a standard tolerance class be specified? (ANSI/ASME B1.1-1989)
- Hole depth
  - Should there be a minimum hole depth be specified?
  - Should the hole depth be dictated by the program?
  - Should the hole depth be dictated by the type of payload?
- Bolt length
  - Should there be a minimum / maximum bolt length, or is it reasonable to assume a selection of sizes will be available?

- Material
  - Should there be minimum material performance specified?
  - Should the material be dictated by the program?
  - Should the material be dictated by the type of payload?
- Optical Bench Configuration
  - Should there be minimum requirements on the optical bench layout?
  - Should payload types have minimum requirements on the optical bench layout?

B.3 ELECTRICAL POWER

- Voltage
  - Are other voltage standards required?
- Current
  - Are other current standards required?
- Power
  - Are other power standards required?
  - Should power be regulated by the platform or the payload?
  - Should power be regulated by the source or the sink?
- "Clean" Power and "Dirty" Power
  - Should there be a split between a "clean" and a "dirty" power source?
  - What tolerances should be required for voltage supplied?
  - What tolerances should be required for voltages accepted?
  - What tolerances should be required for current supplied?
  - What tolerances should be required for current accepted?
- Power only connector
  - It has been determined that there should be a connector that supplied power only, with no data, for higher power applications. What parameters should be used to select that connector?
    - Proposed language: A power only connector has also been specified for IOP Vx. The connector will meet MIL-DTL-38999L series II 4-pin 10-4 insert, with nominal rotation keyway. The platform side will consist of XX size sockets in the receptacle. The payload side will consist of XX pins in the plug. Both sides will use XX AWG wire to support a XX amp current requirement. Select (2) 16 AWG or (4) 20 AWG
- Battery plug standard
  - Identify the standard battery connector plug and the data formats for battery status
    - DWG # SC-C-179495 connector
    - SMBus v1.1 and SBData v1.1

B.4 INTERFACE A

- Additional Information
  - Is any additional information required to clarify this standard?
  - Are there any concerns with this standard?

B.5 INTERFACE B AND C

- Additional Information
  - Is any additional information required to clarify this standard?
  - Are there any concerns with this standard?

B.6 ADDITIONAL ELECTRICAL CONNECTORS

- Are additional connectors required?
  - There may be common, generalized, or specialized connectors. Not all connectors need to be valid for all payloads.-
- Future connectors for discussion
  - MIL-DTL-83513 (Micro D)
  - MIL-C-24308 / MIL-C-39029 (Subminiature D with high current lines)
  - Small, data only connectors
  - Payload specific connectors

B.7 COMMON SENSOR

B.7.1 Other

- Proprioception
  - How can we accomplish self-avoidance with moving payloads
  - Can we pass physical payload models to the platform to accomplish this goal?

B.8 GENERALIZED SENSOR

B.8.1 Drive / Motion Imagery

- Interoperability standards similar in scope to RAS-G IOP exist for the unmanned aerial systems (UAS) industry and for the physical security hardware / security camera industry. Applicable standards include the Motion Imagery Standards Board (MISB) Motion Imagery Standards Profile for UAS and the Open Network Video Interface Forum (ONVIF - Physical Security Hardware / Security Cameras)
- Digital
  - H.264 is currently specified. What other details are required?
  - Video resolution / bandwidth / etc… may be details that are required.
  - Methods of transport and standards

  - Should IOP incorporate a "MISB Compatibility Attribute" that serves as an indicator of payload support for at least the minimum requirements for digital video defined in the MISP?
  - Should IOP incorporate an "ONVIF Compatibility Attribute" that serves as an indicator of payload support for at least the minimum requirements defined for digital video in the ONVIF Specification Set?
- Analog
  - NTSC is currently specified. What other details are required?
  - Are analog video connectors required?
- Messaging / JAUS
  - Are there additional message parameters required?
  - Session details (session announcement, media types, etc.) for each RTSP digital video stream are transmitted via a Session Description Protocol (SDP) file. Certain types of media viewer software (e.g., VLC Media Player) require the SDP file to be transmitted separately from the media stream itself. Should a new JAUS message be created to initiate transmission of the SDP file separate from the media stream in order to support additional streaming media players?"
  - Are new messages needed to enable compatibility with MISB-oriented systems or systems of systems?
  - Are new messages needed to enable use of ONVIF-compliant cameras or other hardware? Would a translator suffice for conversion of JAUS messages and service sets to their corresponding ONVIF messages and service sets?"

B.8.2 Still Imagery

- JPEG and JPEG2000 are currently specified. What other details are required?
- Messaging / JAUS
  - Are there additional message parameters required?

B.8.3 CBRN Sensor

- Encapsulation of APT-45 reports. Is a converter for AEP-45 required?
- Are CBRN connectors required?
- Messaging / JAUS
  - Does the sensor supports configuration parameter?
  - How should spectral measurements be formatted?

B.8.4 Microphone

- Digital format is not identified. What format and bit rate should be used? (AAC, AC’07, G.711, Other?)
- What else should be specified?

B.8.5 Range Sensor

- What other details are required?
- Can we add geospatial format requirements or 2-D/3-D point requirements?

B.8.6 Thermal Sensor

- Currently follows the motion and still imagery standards. What other details are required?

B.8.7 Pan, Tilt, Zoom Camera

- Follows JAUS controls.
  - Are other formats required? (Pelco D, Pelco P, etc...)

B.8.8 Ground Penetrating Radar (GPR)

- What industry standards should be used?
- What messages are required for use?
- What other details are required?

B.9 GENERALIZED EMITTER

B.9.1 Lights

- What other details are required?
- Do we need to clarify that lights tightly associated with a camera should not be defined using the Light attribute, instead using the light commands associated with a camera?

B.9.2 Speakers

- Digital format is not identified. What format and bit rate should be used? (AAC, AC'07, G.711, Other?)
- Should frequency range be specified, or dictated by the program?
- What else should be specified?

B.10 GENERALIZED ACTUATOR

B.10.1 Basic Manipulator

- What other details are required?

B.10.2 Basic Pan Tilt Manipulator

- What other details are required?

B.10.3 Telescoping Mast

- What other details are required?

B.10.4 Advanced Manipulator

- What additional messages are required to utilize various advanced manipulators?
- What other details are required?

B.10.5 Input Devices for Coordinated Manipulators

Dual/multiple arm manipulator controls systems have existed for some time within the medical community. These systems are large and targeted towards medical applications. Similar type products that are more portable, innovative and aimed at mobile robotic applications are just coming onto the market.

Both types of systems mimic human motion through their input devices and translate this to the robotic arms being controlled. As well, there are some experimental systems out there that are using other types of inputs, for example hand gestures combined with AI, in order to control the dual/multiple arms. At this time, the number of devices available for production is small. Further study is required for future versions of the IOP.

ANNEX C FURTHER TUTORIAL OF SAE AS-4 MESSAGES FOR PAYLOADS

SAE AS-4 Joint Architecture for Unmanned Systems (JAUS) is a set of standard messages. Many of the payloads use these messages to set values, report values, and to inform what services are available. A detailed description of the JAUS interoperability profiles can be found in the RAS-G IOP SAE JAUS Profiling Rules. This appendix is designed to explain how the JAUS messages can be used by payloads, and to assist in identifying gaps in existing messages for future updates to SAE AS-4 and the RAS-G IOP documentation.

C.1 APPENDIX – FUNCTION OF JAUS PAYLOADS MESSAGES – SENSORS

Drive and Motion Imagery Sensors – *Defined by RAS-G IOP Payloads Profile, Section 5.3*

<u>Common Data Fields</u>
Valid Frame Sizes: 128x96 (sqcif), 176x144 (qcif), 352x288 (cif), 704x576 (4cif), 1408x1152 (16cif), 160x120 (qqvga), 320x240 (qvga), 640x480 (vga), 800x600 (svga), 1024x768 (xga), 1600x1200 (uxga), 2048x1536 (qxga), 1280x1024 (sxga), 2560x2048 (qsxga), 5120x4096 (hsxga), 852x480 (wvga), 1366x768 (wxga), 1600x1024 (wsxga), 1920x1200 (wuxga), 2560x1600 (woxga), 3200x2048 (wqsxga), 3840x2400 (wqsxga), 6400x4096 (whsxga), 7680x4800 (whuxga), 320x200 (cga), 640x350 (ega), 852x480 (hd480), 1280x720 (hd720), 1920x1080 (hd1080)

Available Digital Formats: AVI, MJPEG, H.262, H.263, H.263+, MPEG-4 Visual (MPEG-4 Part 2), MPEG-4 AVC (MPEG-4 Part 10 or H.264)

<u>Common Messages Between Services</u>
Confirm Sensor Configuration – This message is used to notify the setting component that the requested sensor’s configuration has been set to the specified values. If a specified configuration from a set message is found to be invalid, this message shall contain an error code and description of the configuration setting that was deemed invalid. For each error code listed in the below sections, a corresponding human-readable message is also generated explaining why a specified configuration is invalid.

(Note: all query messages must contain a SensorID field to set which sensor is being queried)

<u>Visual Sensor Service (Common Between Imagery Sensor Services)</u>

This service provides access to the basic capabilities and configuration of a visual sensor. Both the digital and analog video services described below inherit from this service, and are able to use the described messages.

Messages:

Query Visual Sensor Capabilities -- This message causes the receiving service to reply with a Report Visual Sensor Capabilities message.

Query Visual Sensor Configuration -- This message causes the receiving service to reply with a Report Visual Sensor Configuration message.

Query Sensor Geometric Properties Configuration -- This message causes the receiving service to reply with a Report Sensor Geometric Properties message.

Set Visual Sensor Configuration – This message is used to set the configuration of the visual sensors associated with the service. The available configuration settings are based off of each sensor's capabilities as described in the Report Visual Sensor Capabilities message. This message shall cause the receiving service to reply to the sender with a Confirm Sensor Configuration message. If the specified configuration is invalid, the confirm message will contain a Visual Sensor Error Record.

Field Name	**Unit**	**Function**
SensorID	Single Value	The ID of the sensor to be set on the platform
State	Single Value	Set the current state of the visual sensor 0: Active (default) 1: Standby 2: Off
Zoom Mode	Single Value	Sets the available zoom modes of the visual sensor 0: Mixed (default) 1: Analog Only 2: Digital Only 3: No Zoom
Zoom Level	Percentage	The percent of the maximum zoom level of the visual sensor Range: 0 to 100 %
Focal Length	Meter	The effective focal length of the visual sensor Range: 0.0 to 2.0 meters

Horizontal/Vertical Field of View	Radian	The vertical and horizontal field of view of the visual sensor Range: -pi to +pi radians
Focus Mode	Single Value	Sets the ability of the visual sensor to either automatically or manually focus 0: Auto focus (default) 1: Manual focus
Focus Value Mode	Percentage	The percent of maximum of changes in focus position based on the entire focal range of the visual sensor Range: 0 to 100 %
White Balance	Single Value	Sets the white balance of the visual sensor 0: Auto (default) 1: Daylight 2: Cloudy 3: Shade 4: Tungsten 5: Fluorescent 6: Flash
Imaging Mode	Single Value	Sets the imaging mode of the visual sensor 0: Color (default) 1: Grayscale 2: Infrared 3: Lowlight
Exposure Mode	Single Value	Sets the exposure mode of the visual sensor 0: Auto (default) 1: Manual 2: Shutter Priority 3: Aperture Priority
Metering Mode	Single Value	Sets the metering mode of the visual sensor 0: Auto (default) 1: Center Weighted 2: Spot
Shutter Speed	Seconds	Sets the shutter speed of the visual sensor Range: 0 to 60 seconds
Aperture	Single Value	Sets the aperture value of the visual sensor in f-stop values (f/#) Range: 0.1 to 128
Light Sensitivity	Single Value	The light sensitivity level of the visual sensor in ISO film speed equivalent 0: Auto (default)

		1: ISO 100 2: ISO 200 3: ISO 400 4: ISO 800 5: ISO 1600 6: ISO 3200
Image Stabilization	Single Value	Sets whether the image stabilization feature of the visual sensor is enabled 0: Off 1: On

Table 38: Visual Sensor Configurations

Report Visual Sensor Capabilities -- This message is sent to the requesting service upon receipt of a Query Visual Sensor Capabilities message. This message is identical to the Set Visual Sensor Configuration message, however, the message has changed to a bit field to show the specification of all allowable values on the platform, and it replies with whether a particular option offered by this service is capable to be set by the requesting service. For example, if an image stabilization option is unavailable, this message would reply stating that this option is unavailable and cannot be set.

Report Visual Sensor Configuration – This message is sent to the requesting service upon receipt of a Query Visual Sensor Configuration message. This message is identical to the Set Visual Sensor Configuration message, but instead, replies with the current values on the receiving platform.

There are three possible use cases for this message:

1. The sensor has no knowledge of its geometric properties.
2. The sensor is rigidly mounted to the vehicle and the position and orientation with respect to the vehicle coordinate system is known.
3. The sensor is mounted to a manipulator in which the JAUS ID, joint number, and sensor offset are described.

This message makes use of the unit quaternion previously described in the Manipulator appendix.

Field Name	**Unit**	**Function**
SensorID	Single Value	The ID of the sensor to be set on the platform
Sensor Position (3-dimension array)	Array of Meters	An array describing the position of the sensor on a platform with respect to the platform's coordinate system Range: -30 meters to +30 meters
Sensor Unit Quaternion (4-dimension array)	Array of Values	An array containing the unit quaternion specifying the axis and angle of rotation

		used to establish the orientation of the sensor coordinate system with respect to the vehicle coordinate system Range: -1 to +1
Subsystem/Node/Component ID	Single Values	The JAUS address of the manipulator where the sensor is located
Joint Number	Single Value	The joint number to which the given sensor is attached
Sensor ID	Single Value	The ID of the sensor that was set on the platform
Visual Sensor Error Code	Single Value	Contains error codes that represent problems with setting values related to the visual sensor: 0: Unknown sensor ID 1: Invalid Sensor State 2: Invalid Zoom Mode 3: Invalid Zoom Value 4: Invalid Focus Mode 5: Invalid Focus Value 6: Invalid White Balance 7: Invalid Imaging Mode 8: Invalid Exposure Mode 9: Invalid Metering Mode 10: Invalid Shutter Speed 11: Invalid Aperture Value 12: Invalid Light Sensitivity 13: Invalid Image Stabilization 14: Invalid Horizontal FOV 15: Invalid Vertical FOV 16: Multiple Invalid Parameters 255: Unknown Error

Table 39: Visual Sensor Responses

Digital Video Service

This service provides access to the capabilities and configuration of the digital video sensor, and allows the controlling component to set the digital video sensor to a particular operational profile. This service does not handle the actual transmission of the video stream. This service provides the ability to start, stop, and pause a video stream.

Messages:

Query Digital Video Sensor Capabilities – This message causes the receiving service to reply with a Report Digital Video Sensor Capabilities message.

Query Digital Video Sensor Configuration -- This message causes the receiving service to reply with a Report Digital Video Sensor Configuration message.

Set Digital Video Sensor Configuration – This message is used to set the configuration of the digital video sensor associated with the service. The receiving platform shall respond with a Confirm Sensor Configuration message. If the set configuration is invalid for the provided Sensor ID, the confirm message shall contain an error record for the given ID, otherwise, valid configuration settings shall be set.

Field Name	**Unit**	**Function**
SensorID	Single Value	The ID of the sensor to be set on the platform
Minimum/Maximum Bit Rate	Single Value	Allows the service to set a minimum and maximum bit rate for the digital video stream in kilobits per second (default is 200 kbps)
Frame Rate	Single Value	Allows the service to set the frame rate of the video stream in frames per second (default is 25 fps)
Frame Size	Single Value	Allows the service to set the resolution of the video stream. Possible resolutions listed under common data fields as "Valid Frame Sizes"
Digital Format	Single Value	Allows the service to set the video compression format of the video stream. Possible formats listed under common data fields as "Available Digital Formats"

Table 40: Digital Video Sensor Configurations

Control Digital Video Sensor Stream – This message is used to control the playback state of the digital video stream.

Field Name	**Unit**	**Function**
SensorID	Single Value	The ID of the sensor to be set on the platform
StreamState	Single Value	Allows three playback states to be set: Play, Pause, and Stop

Table 41: Digital Video Sensor Stream Control

Report Digital Video Sensor Capabilities – This message is used to report the sensors' capabilities upon receipt of a Query Digital Video Sensor Capabilities message. This message is identical to the Set Digital Video Sensor Capabilities message above in addition to a Minimum and Maximum Frame Rate field.

Report Digital Video Sensor Configuration – This message is sent in response to a Query Digital Video Sensor Configuration message. It is identical to the Set Digital Video Sensor Capabilities message above.

Confirm Sensor Configuration

Field Name	**Unit**	**Function**
SensorID	Single Value	The ID of the sensor to be set on the platform
Digital Video Error Code	Single Value	Contains error codes that represent problems with setting values related to the range sensor: 0: Unknown sensor ID 1: Invalid Minimum Bit Rate 2: Invalid Maximum Bit Rate 3: Invalid Minimum Frame Rate 4: Invalid Maximum Frame Rate 5: Invalid Frame Size 6: Invalid Format 7: Multiple Invalid Parameters 255: Unknown Error

Table 42: Digital Video Sensor Configuration Error Responses

Analog Video Service

This service provides access to the capabilities and configuration of the analog visual sensor. This does not cover the actual transmission of the video stream.

Query Analog Video Sensor Capabilities – This message causes the receiving service to reply with a Report Analog Video Sensor Capabilities message.

Query Analog Video Sensor Configuration -- This message causes the receiving service to reply with a Report Analog Video Sensor Configuration message.

Set Analog Video Sensor Configuration – This message is used to set the configuration of the specified sensor (using the Sensor ID).

Field Name	**Unit**	**Function**
SensorID	Single Value	The ID of the sensor to be set on the platform
Analog Format	Single Value	Allows the analog video format of the stream to be set: 0: NTSC-M (default) 1: NTSC-J 2: PAL-N 3: PAL-M 4: SECAM-L 5: SECAM-B/G

Table 43: Analog Video Sensor Configuration

Report Analog Video Sensor Capabilities – This message is sent in response to a Query Analog Video Sensor Capabilities message.

It is identical to the Set Analog Video Sensor Configuration message above, however, the message has changed to a bit field to show the specification of all allowable values on the platform, and the Analog Format field is renamed Supported Analog Formats.

Report Analog Video Sensor Configuration – This message is sent in response to a Query Analog Video Sensor Configuration message. It is identical to the Set Analog Video Sensor Configuration message above.

Confirm Sensor Configuration

Field Name	**Unit**	**Function**
SensorID	Unsigned Short Integer	The ID of the sensor that was set on the platform
Analog Video Error Code	Unsigned Byte	Contains error codes that represent problems with setting values related to the range sensor: 0: Unknown sensor ID 1: Invalid Format 255: Unknown Error

Table 44: Analog Video Sensor Error Responses

Still Imagery -- *Defined by RAS-G IOP Payloads Profile, Section 5.6*

Still Image Service
This service provides access to the capabilities and configuration of a still image camera, and provides for the ability to obtain images from the camera. This service, along with the Events service, can be used to report images at a specified rate, and can be used to simulate video.

Query Still Image Sensor Capabilities – This message causes the receiving service to reply with a Report Still Image Sensor Capabilities message.

Query Still Image Sensor Configuration – This message causes the receiving service to reply with a Report Still Image Sensor Configuration message.

Query Still Image Data – This message causes the receiving component to reply to the requestor with a Report Still Image data message. The message must set the requested coordinate system.

Set Still Image Sensor Configuration – This message is used to set the configuration of the still image sensor associated with the service. The receiving platform shall respond with a Confirm Sensor Configuration message. If the set configuration is invalid for the provided Sensor ID, the confirm message shall contain an error record for the given ID, otherwise, valid configuration settings shall be set.

Field Name	Unit	Function
SensorID	Single Value	The ID of the sensor to be set on the platform
Frame Size	Single Value	Contains error codes that represent problems with setting values related to the range sensor: 0: Unknown sensor ID 1: Invalid Format 255: Unknown Error
Still Image Format	Single Value	Allows the service to set the compression format of the still images. The following are options: JPEG, GIF, PNG, BMP, TIFF, PPM, PGM, PNM, NEF (Nikon RAW), CR2 (Canon RAW), DNG (Adobe RAW)

Table 45: Still Imagery Sensor Configuration

Report Still Image Sensor Configuration – This message is sent in response to a Query Still Image Sensor Configuration message. It is identical to the Set Still Image Sensor Configuration message above.

Report Still Image Sensor Capabilities – This message is sent in response to a Query Still Image Sensor Capabilities message. It is identical to the Set Still Image Sensor Configuration message above; however, the message has changed to a bit field to show the specification of all allowable values on the platform, and the "Frame Size" field is renamed to "Supported Frame Sizes" and the "Still Image Format" field is renamed to "Supported Image Formats".

Report Still Image Data – This message is sent in response to a Query Still Image Data message. Along with the still image raw data, this message sends information describing the still image's data.

Field Name	Unit	Function
SensorID	Single Value	The ID of the sensor to be set on the platform
Coordinate System	Single Value	Allows the service to set the coordinate system; either the native coordinate system of the still image camera or the vehicle's coordinate system
Time Stamp	Time Value	The time stamp of the current frame in pseudo-format: Day (1-31):Hour(0-23):Minute(0-59):Second(0-59):Millisecond(0-999)
Image Frame	Count_field (size of current image frame) as Single Value	Allows the service to set the compression format of the still images. The following are options: JPEG, GIF, PNG, BMP, TIFF, PPM, PGM, PNM, NEF (Nikon RAW), CR2 (Canon RAW), DNG (Adobe RAW)

Table 46: Still Imagery Sensor Responses

Field Name	**Unit**	**Function**
SensorID	Single Value	The ID of the sensor that was set on the platform
Still Image Error Code	Single Value	Contains error codes that represent problems with setting values related to the range sensor: 0: Unknown sensor ID 1: Invalid Frame Size 2: Invalid Format 3: Multiple Invalid Parameters 255: Unknown Error

Table 47: Still Imagery Sensor Error Responses

Chemical, Biological, Radiological, Nuclear (CBRN) Sensor – *The IOP Payload Profile has not yet been defined.*
JAUS messages representing CBRN Sensors defined by RAS-G IOP CustomServices, Section 4.6.

Microphone –
Defined on RAS-G IOP Payloads Profile, Section 5.7

<u>Digital Audio Service</u>
This service provides a means of configuring a digital audio stream such as from a microphone or other similar device. The transport of the digitized audio stream is not covered by this service, and may use existing audio networking standards such as RTSP.

Messages:

Query Digital Audio Capabilities – This message causes the receiving service to reply with a Report Digital Audio Capabilities message. The requesting service can specify what sensor to be queried, or all supported sensors can be queried.

Query Digital Audio Configuration – This message causes the receiving service to reply with a Report Digital Audio Configuration message. The requesting service can specify what sensor to be queried, or all supported sensors can be queried.

Report Digital Audio Capabilities – This message reports the full set of capabilities for one or more sensors.

Field Name	Unit	Function
SensorID	Single Value	The ID of the sensor that was set on the platform
Bitrate Minimum/Maximum	Kilobits per Second	The minimum and maximum bandwidth values supported by the sensor. (default = 192 kbps)
Sample Rate Minimum/Maximum	Samples per Second	The minimum and maximum bitstream sample rate supported by the sensor. (default = 44100 Hz)
Supported Digital FormatsD	Bit Field	A setting of "1" for any of the following bits reports that the corresponding digital format is supported. Bit 0: LPCM/PCM (default) Bit 1: AIFF Bit 2: WAV Bit 3: ALAC (Apple Lossless) Bit 4: FLAC Bit 5: RealAudio Bit 6: WMA9 Lossless Bit 7: TrueAudio Bit 8: DolbyDigital Bit 9: DTS Bit 10: MP2 Bit 11: MP3 Bit 12: AAC-MPEG2 Bit 13: AAC-MPEG4 Bit 14: Vorbis Bit 15: WMA Bit 16: Speex Bits 28-31: Reserved for vendor use
Supported Bit Depths	Bit Field	TA setting of "1" for any of the following bits reports that the corresponding bit depth is available for the audio stream. Bit 0: 8 bits Bit 1: 10 bits Bit 2: 12 bits Bit 3: 14 bits Bit 4: 16 bits Bit 5: 20 bits Bit 6: 24 bits Bit 7: 32 bits Bits 13-15: Reserved for vendor use
Supported Quality Levels	Bit Field	A setting of "1" for any of the following bits reports that the corresponding digital audio quality is available for the audio stream. Bit 0: Best Bit 1: Better Bit 2: Good s Bit 3: Average (default) Bit 4: Less Bit 5: Poor Bit 6: Worst

Table 48: Digital Audio Configuration

Report Digital Audio Configuration – This message is similar to the Report Digital Audio Capabilities message, however, it reports the current configuration settings for one or more audio sensors based on its capabilities.

Set Digital Audio Configuration – This message is similar to the Report Digital Audio Configuration message, however, it allows the requesting service to set the configuration settings of one or more audio sensors on the receiving service. Additional messages include the setting of the sensor's sensitivity, and the ability to set minimum and maximum bitrates to allow for Variable Bit Rate (VBR) streams.

Set Digital Audio Configuration Response – This message is sent by the receiving service in response to a Set Digital Audio Configuration message. The message responds with one of four enumerations:

Range Sensor-- *Defined by RAS-G IOP Payloads Profile, Section 5.8*

<u>Range Sensor Service</u>
The range sensor service provides information from proximity sensors. This service outputs a location of various data points with a certain measure of accuracy, and may be comprised of multiple physical sensors or other technologies. Data from the range sensor can be reported in both a compressed and uncompressed format.

The data points are measured in the particular sensor's native coordinate system and are expressed in terms of range, bearing, and inclination. Range is the distance, in meters, along the line from the origin of the sensor's native coordinate system to the specified point. Bearing is the angle, in radians, that the line from the sensor's origin to the specified point makes about the sensor's z-axis in the right handed sense. Inclination is the angle, in radians, that the line from the sensor origin to the specified point makes about the sensor's y-axis in the right handed sense.

Messages:

Query Range Sensor Capabilities -- This message causes the receiving service to reply with a Report Range Sensor Capabilities message.

Query Range Sensor Configuration -- This message causes the receiving service to reply with a Report Range Sensor Configuration message.

Query Sensor Geometric Properties -- This message causes the receiving service to reply with a Report Sensor Geometric Properties message.

Query Range Sensor Data -- This message causes the receiving service to reply with a Report Range Sensor Configuration message. The requesting service must specify which coordinate system the data should be reported in: either the sensor's native coordinates system or, if supported, the vehicle coordinates system.

Set Range Sensor Configuration – This message is used to set the robotic platform range sensors to some configuration. The configuration is based on each range sensor's capabilities as described in the Report Range Sensor Capabilities message. This message shall reply with a Confirm Range Sensor Configuration message. If the specified configuration is invalid, the confirm message shall contain an error record for the given Sensor ID.

Field Name	**Unit**	**Function**
SensorID	Single Value	The ID of the sensor to be set on the platform
Vertical/Horizontal Field of View Start and Stop Angles	Radian	The desired vertical and horizontal fields of view starting and stopping angles as measured in radians about the sensor's fixed coordinate system's Y and Z-axes
Update Rate	Hertz	The desired update rate of the sensor Range: 0 to 1000 Hertz
Minimum/Maximum Range	Meter	The desired minimum and maximum range of data points reported Range: 0 to 1,000,000 meters
Sensor State	Single Value	The desired enumerated sensor state. 0: Active 1: Standby 2: Off

Table 49: Range Sensor Configuration

Report Range Sensor Configuration – This message is sent in response to a Query Range Sensor Configuration message. This message's format is identical to the Set Range Sensor Configuration message described above.

Report Range Sensor Capabilities -- This message is sent in response to a Query Range Sensor Capabilities message. This message's format is identical to the Set Range Sensor Configuration message described above with some additional messages:

Field Name	**Unit**	**Function**
Sensor Name	String	A human-readable string representing the name of the sensor
Supported Compression	Single Value	A list of the sensor's supported data compression algorithms: No compression (default), DEFLATE, bzip2, and LZMA

Coordinate Transformation Supported	Single Value	True or False setting representing whether the range sensor supports coordinate transforms

Table 50: Range Sensor Responses

The message has also changed to a bit field to show the specification of all allowable values on the platform.

Report Range Sensor Data – This message is sent by the receiving platform upon receipt of a Query Range Sensor Data message. This message reports a list of detected data points for a given time. Data is only reported for sensors which are in the active state.

Field Name	**Unit**	**Function**
SensorID	Single Value	The ID of the sensor to be set on the platform
Data Error Code/Error Message	Single Value	An enumeration and human-readable string representing some error message: 0: Sensor not active 1: Invalid Compression Format 255: Unknown Error
Report Coordinate System	Single Value	Enumeration representing platform's coordinate system 1: Native (default) 2: Vehicle
Time Stamp	Time Value	The time stamp of the current frame in pseudo-format: Day (1-31):Hour(0-23):Minute(0-59):Second(0-59):Millisecond(0-999)
Point ID	Single Value	An assigned number of a particular data point
Range/Validity	Meter	The distance between the range sensor and the data point, and a true/false value representing whether the current distance is considered valid Range: 0 to 1,000,000 meters
Range Error RMS	Meter	The root mean square error of the distance between the range sensor and data point Range: 0 to 100,000 meters
Bearing/Validity	Radian	The bearing between the range sensor and the data point, and a true/false value representing whether the current bearing is considered valid
Bearing Error RMS	Radian	The root mean square error of the bearing between the range sensor and data point Range: 0 +pi radians

Inclination/Validity	Radian	The inclination between the range sensor and the data point, and a true/false value representing whether the current inclination is considered valid Range: -pi to +pi radians
Inclination Error RMS	Radian	The root mean square error of the inclination between the range sensor and data point Range: 0 +pi radians

Table 51: Range Sensor Error Responses

Report Range Sensor Compressed Data -- This message is sent by the receiving platform upon receipt of a Query Range Sensor Compressed Data message. This message reports a list of detected data points for a given time. Data is only reported for sensors which are in the active state. This message differs from the Report Range Sensor Data message in that this data has undergone compression by the specified algorithm. From the aforementioned message, this message makes use of the following fields: Sensor ID, Error Code, Error String, and Time Stamp. Additionally, this message includes a Data Compression field signifying the method used to compress the data. Possible compression formats include None (default), DEFLATE, bzip2, and LZMA. The final field of this message contains a compressed version of the entirety of a Report Range Sensor Data message.
Report Sensor Geometric Properties – This message is used to report information about the geometric properties of a sensor with respect to the vehicle. This message is described previously under the Visual Sensor Service section of this appendix.
Confirm Sensor Configuration

Field Name	**Unit**	**Function**
SensorID	Single Value	The ID of the sensor that was set on the platform
Range Sensor Error Code	Single Value	Contains error codes that represent problems with setting values related to the range sensor: 0: Unknown sensor ID 1: Invalid Horizontal Field of View 2: Invalid Vertical Field of View 3: Invalid Update Rate 4: Invalid Sensor Range 5: Invalid Sensor State 6: Multiple Invalid Parameters 255: Unknown Error

Table 52: Range Sensor Settings Error Responses

Thermal Sensor – *Defined by RAS-G IOP Payloads Profile, Section 4.3.7*
The Thermal Sensor does not have any specialized JAUS messages. Instead, it makes use of the Drive and Motion Imagery requirements (described in section 4.3.2 of the RAS-

G IOP Payloads Profile) for thermal motion imagery, and the Still Imagery Requirements (section 4.3.3) for thermal still imagery.

Pan, Tilt, Zoom Camera – *Defined by RAS-G IOP Payloads Profile, Section 4.3.8*
This Requirements Definition makes use of two previously described attributes. Receiving of the video data makes use of either the Digital or Analog Video Sensor attributes described previously (section 4.3.2, RAS-G IOP Payloads Profile), and controlling of the manipulator where the PTZ camera is located is handled by the Basic Pan Tilt Manipulator attribute (section 8.10.2, RAS-G IOP Payloads Profile).

C.2 APPENDIX – FUNCTION OF JAUS PAYLOADS MESSAGES – EMITTERS

Lights – *Defined by RAS-G IOP Payloads Profile, Section 6.2*

Illumination Service
This service provides the operator the means to control lights on a UGV.

Messages:

Set Illumination – This message allows the controlling component to set the on/off state of various lights available on the UGV. As described by RAS-G IOP JAUS Profiling Rules 4.4.7.2, the following UGV lights may be controlled:

- Headlights: Forward-facing light(s) used to illuminate the driving path of a vehicle as it moves forward. Depending on platform, this may also represent any lights associated with the forward drive camera.
- Left/Right Turn Signal: Lights that indicate to the observer behind the vehicle that the vehicle is about to or is turning left or right. On could indicate either a solid or blinking state. Can be disabled if turn signals are not available on the platform.
- Running Lights: Lights that are used while a vehicle is running for purposes other than signaling or driving (i.e., lighting for safety).
- Brake Lights: Rear-facing lights that indicate whether that a vehicle is applying a resistive linear force in order to slow the vehicle down. Can be disabled if brake lights are not available on the platform.
- Variable Lights: Lights that have varying intensities ranging between 0 (off) and 15 (full intensity). Light intensities are scaled based on each light's capabilities. There are four options for variable lights. Variable Light 1 is used for a variable light source associated with a forward drive camera (different than a simple on/off light declared as headlights). Variable Light 2 is used for a variable light source associated with a rear driving camera. Variable Lights 3 and 4 are currently undefined, but available for future use.
- IR Light Source: An infrared light source associated with the currently controlled drive camera.

Query Illumination State – This message causes the receiving service to reply with a Report Illumination State message.

Query Illumination Configuration – This message causes the receiving service to reply with a Report Illumination Configuration message.

Report Illumination State – This message replies to the requesting service with the current state of each light on the platform. This message is identical to the Set Illumination message described previously.

Report Illumination Configuration – This message replies to the requesting service listing which of the possible lights are available on the platform. This message is identical to the Set Illumination message; however, it responds with a "true/false" indicating if a particular light is available for control.

Speakers – *Defined by RAS-G IOP Payloads Profile, Section 6.3*

Digital Audio Annunciator Service

This service extends the Digital Audio Service to allow a client to specify an RTSP stream as an audio source. This service is expected to connect, decode, and play the specified stream presumably over one or more speakers. Supported codecs are defined by this message. Playback volume can also be set via the sensitivity value of the parent Digital Audio Service.

Messages

Query Digital Audio Stream Source – This message causes the receiving service to reply with a Report Digital Audio Stream Source message. The requested sensor being queried can be set, or a setting of zero can be used to request the source of all supported sensors on the receiving service.

Set Digital Audio Stream Source – This message is used to specify the stream source to play. The specified stream must *not* require a DNS lookup to resolve.

Field Name	Unit	Function
SensorID	Single Value	The ID of the sensor to be set on the platform
StreamURL	String	URL of the source of the stream. This URL should not require a DNS to resolve, that is, an IP address shall be substituted for a host name.
Repeat	Single Value	Specifies behavior for RTSP streams that have a finite play time. Enum 0: Play Once Enum 1: Repeat Until New Stream is Specified

Table 53: Digital Audio Stream Source Configuration

Report Digital Audio Stream Source – This message reports the stream that is currently being played for each queried sensor. The available fields are identical to the Set Digital Audio Stream Source message. An empty StreamURL implies that no stream is currently being played.

C.3 APPENDIX – FUNCTION OF JAUS PAYLOADS MESSAGES – ACTUATORS

Basic Manipulator – *Defined by RAS-G IOP Payloads Profile, Section 7.1*
Primitive Manipulator Service
This service provides a low-level interface to a manipulator arm. Upon being queried, the service will reply with a description of the manipulator's specification parameters, axes range of motion, and axes velocity limits. Motion of the arm can also be accomplished via the Set Joint Effort message available in this service.

Messages:
Query Manipulator Specifications – This message requests the robotic platform to reply with a Report Manipulator Specifications message.
Query Joint Effort – This message requests the robotic platform to reply with a Report Joint Effort message.
Set Joint Effort – This message, sent by the requesting platform, allows the user to independently control each joint offered by the platform in an open loop fashion. The sent command states the percentage level of effort that each joint actuator should apply.

Field Name	Unit	Function
Joint Effort	Percentage	Percent of maximum effort for particular joint. Clockwise or counterclockwise motion determinant by platform. Range from -100 percent to 100 percent.

Table 54: Joint Effort Message

Report Manipulator Specifications – This message is generated and sent by the robotic platform upon receipt of a Query Manipulator Specifications message. This message contains a multitude of various fields each representing some feature of the manipulators on the robotic platform. Some fields may be optional, and can be provided by the platform if those particular features exist on the platform.
As is referenced, the vehicle coordinate system is defined as attached to the vehicle frame. Typically, the X-axis faces the forward direction, the Z-axis points downwards, and the Y-axis is defined according to a right-handed vector coordinate system.
As defined, revolute joints are joints that revolve around an axis, and prismatic joints are joints that linearly actuate along an axis.
For images of the manipulator and vehicle coordinate systems, please refer to *SAE JAUS Manipulator Service Set AS6057*

Field(s)	Unit	Optional?	Function
Manipulator Coordinate System X,Y,Z value	Meter		The base X, Y, and Z-coordinate of origin of manipulator measured with respect to vehicle coordinate system. Range from -30m to 30m.

a,b,c,d component of unit quaternion q	Single Value		Quaternion q = d + ai + bj + ck defines the orientation of the manipulator base coordinate system with respect to the vehicle coordinate system. Options: -1 or +1

Table 55: Manipulator Coordinate System Record – Entire Block Optional

Field(s)	**Unit**	**Optional?**	**Function**
Joint 1 Offset	Meter		The distance between this joint and the following joint. Range between -10m and +10m
Joint Minimum/Maximum Value	Radian	X	The minimum and maximum allowed revolution of the joint. Range: -8pi rad to +8pi rad (Note: these fields are omitted for joints that rotate continuously without limit)
Max Speed	Radian per second	X	Maximum movement speed of the joint. Range: 0 rad/s to +10pi rad/s
Max Torque	Newton Meters	X	Maximum allowed torque of joint. Range: 0 N m to 5000 N m

Table 56: Revolute Joint Offset Record

Field(s)	**Unit**	**Optional?**	**Function**
Joint 1 Angle	Radian		The angle between the link of the previous joint and the current joint. Tange between –pi rad to +pi rad
Joint Minimum/Maximum Value	Meter		The minimum and maximum allowed actuation of the joint. Range between -10 m and +10 m
Max Speed	Meter per second	X	Maximum movement speed of the joint. Range: -5 m/s to +5 m/s
Max Force	Newton	X	Maximum allowed force of joint. Range: 0 N to 5000 N

Table 57: Prismatic Joint Angle Record

Field(s)	**Unit**	**Optional?**	**Function**
Link Length	Meter		The distance between the two joint axes. Range between –10 m to +10 m

Twist Angle	Radian		The angle between the up-and-down origin of the joint and the upward arm measured in a right-hand sense. Range between -pi rad to +pi rad
Joint Offset	Meter		Perpendicular distance between two links on the joint. Range: -10 m to +10 m
Joint Minimum/Maximum Values	Radian	X	Identical to Joint Minimum/Maximum Value described above.
Max Speed	Radian per second	X	Identical to Max Speed described above.
Max Torque	Newton meter	X	Identical to Max Torque described above.

Table 58: Revolute Joint Specification Record

Field(s)	**Unit**	**Optional?**	**Function**
Link Length	Meter		The distance between the two joint axes. Range between –10 m to +10 m
Twist Angle	Radian		The angle between the up-and-down origin of the joint and the upward arm measured in a right-hand sense. Range between -pi rad to +pi rad
Joint Angle	Radian		The angle between the link of the previous joint and the current joint. Range between –pi to +pi
Joint Minimum/Maximum Values	Radian		Identical to Joint Minimum/Maximum Value described above.
Max Speed	Radian per second	X	Identical to Max Speed described above.
Max Force	Newton	X	Maximum allowed force of joint. Range: 0 N to 5000 N

Table 59: Prismatic Joint Specification Record

Report Joint Effort -- This message is generated and sent by the robotic platform upon receipt of a Query Joint Effort message. This message simply replies with the selected manipulator's Joint Effort percentage as described above under Set Joint Effort.

Basic Pan Tilt Manipulator– *Defined by RAS-G IOP Payloads Profile, Section 7.3.1*
Common Messages Between Services
Query Pan Tilt Specifications -- This message requests the robotic platform to reply with a Report Pan Tilt Specifications message.
Report Pan Tilt Specifications -- This message is generated and sent by the robotic platform upon receipt of a Query Pan Tilt Specifications message. This message contains descriptions of various aspects of the robotic platform.

Field(s)	Unit	Optional?	Function
Pan Tilt Coordinate System X,Y,Z value	Meter		The X, Y, and Z-coordinate of origin of pan tilt manipulator measured with respect to vehicle coordinate system. Range from -30m to 30m.
a,b,c,d component of unit quaternion q	One		Quaternion q = d + ai + bj + ck defines the orientation of the pan tilt manipulator coordinate system with respect to the vehicle coordinate system. Options: -1 or +1
Joint 1 minimum/maximum value	Radian		The minimum and maximum allowed revolution of either the pan or tilt joint. Range: -8pi rad to +8pi rad
Joint 1 maximum speed	Radian per second		The allowed maximum revolution speed of either of the pan or tilt joint. Range: 0 rad/s to 10pi rad/s
Joint 2 minimum/maximum value	Radian		The minimum and maximum allowed revolution of either the pan or tilt joint. Range: -8pi rad to +8pi rad
Joint 2 maximum speed	Radian per second		The allowed maximum revolution speed of either of the pan or tilt joint. Range: 0 rad/s to 10pi rad/s

Table 60: Manipulator Coordinate System Record – Entire Block Optional

Primitive Pan Tilt Service
The Primitive Pan Tilt Service is a low-level interface to a pan tilt mechanism. Upon being queried, the service will reply with a description of the pan tilt manipulator's minimum and maximum allowable values and maximum velocity for each of the two joints. Additionally, each joint's position and orientation of the pan tilt base coordinate system relative to the vehicle coordinate system is also sent. Motion of the pan tilt mechanism can be accomplished via the Set Pan Tilt Joint Effort message

Messages:
Query Pan Tilt Joint Effort -- This message requests the robotic platform to reply with a Report Pan Tilt Joint Effort message.
Report Pan Tilt Joint Effort – This message is generated and sent by the robotic platform upon receipt of a Query Pan Tilt Joint Effort message. This message contains two fields that represent the current speed of each joint as a scaled percentage of each joint's maximum speed.

Field Name	**Unit**	**Function**
Joint 1 (pan) effort Joint 2 (tilt) effort	Percentage	Percent of maximum effort for particular joint. Clockwise or counterclockwise motion determinant by platform. Range from -100 percent to 100 percent.

Table 61: Manipulator Joint effort message

Set Pan Tilt Joint Effort – This message allows for low-level open loop control of the two joint actuators on a pan tilt mechanism. Identically to the Report Pan Tilt Joint Effort message above, the speed of each joint is set independently by using the percentage of the maximum speed of each joint.
Telescoping Mast -- *Defined by RAS-G IOP Payloads Profile, Section 7.4.1*
The telescoping mast does not make use of a unique JAUS message and instead relies on the standard Primitive Manipulator Service described above. The details of this implementation are outlined in section 7.4.1 of the Payloads Profile document.

ANNEX D PRELIMINARY INVESTIGATION FOR WEAPONS CONTROL

Although not covered in this Version of the IOP, forward-looking capabilities necessitate standardization of the interfaces for weapon systems mounted on unmanned ground vehicles. In this section, we present some initial research into this area in an attempt to provide guidance on subsequent revisions to the IOP. As weaponization of Unmanned Air Systems (UAS) has now progressed beyond research and demonstration programs, best practices from UAS as well as manned systems is used as a starting point.

D.1 FUTURE WEAPONS PAYLOADS

While programs should not be limited by the IOP on the weapon systems they deploy, attempting to document standard interfaces for an infinite variety of weapons is not realistic. However, there are existing classes of weapon systems that can be used in order to classify weapon payloads, their needs, and their status information. These weapon classes are: Direct fire ballistic weapons, Indirect fire ballistic weapons, Direct fire guided or course-correcting weapons, and Indirect fire guided or course-correcting weapons. Each of these classes are discussed in the following sub sections.

D.1.1 Direct fire ballistic weapons

Direct fire refers to the launching of a projectile directly at a target within the line-of-sight of the firer. These weapons are ballistic in nature because there is no ability to control their flight path once they have been initiated. This class includes standard "small arms" weapon systems, such as pistols, machine guns, and heavy machine guns, as well as larger chain guns and cannons. These payloads require real-time line of sight to the target to verify the target is valid, and the path of the rounds is clear to fire through, according to the Rules of Engagement. In most cases, these weapons will be integrated into gimbals or turrets, and these gimbals or turrets will often have integrated optics used for providing real-time video for target acquisition, tracking, and engagement. The optics are aligned, via boresighting and zeroing operations, to the weapon system in order to increase the accuracy of firing and the overall safety of operation associated with more controlled and precision fires.

Another aspect of these systems that differentiates them from others is their ability to support continuous firing. While it is possible to operate them in single shot or fixed length burst modes, and initial systems have adopted this as a safety mitigation, the weapon systems are inherently capable of, and under certain failure conditions, will continuously fire until all ammunition is spent. As a result of the continuous nature of many weapons in this class, the inputs to this system must also be continuous to sustain firing. As a result, upon any loss of signal, the systems must at a minimum cease firing, but may also require additional actuation of safety mechanisms to mitigate failure modes that could manifest themselves during periods of communications loss.

Currently some medium and large caliber versions of these system support "smart" rounds that have programmable fuses, such as 30mm precision air burst rounds. These rounds are not guided or course-correcting, as they still fly along the pre-determined ballistic trajectory, but they do provide additional levels of effects control that should be accounted for in this IOP. While the programming of the rounds must be integrated into the payload, the source of the information for programming the rounds could be external, depending on the level of automation in the fire control systems and the source of the targeting information.

D.1.1.1 Potential payload inputs

To effectively employ direct fire ballistic weapons, the following information may be necessary:

- Desired azimuth and elevation speed commands
- A redundant arming sequence
- A redundant firing sequence that requires the system to be in an armed state
- Desired firing mode, such as single shot, controlled burst length, and full auto
- Desired ammunition type, for dual and multi-feed weapons or multi-weapon systems
- Desired firing rate, for variable rate weapons
- Camera controls for the integrated optics
- Platform data, such as roll, pitch, and yaw, to replace or augment integrated inertial sensors in the system
- A slew-to-cue interface, to allow other sensors on the platform or in the unit to command the payload’s motion to a specific position
- A means to specify no traverse and no fire zones
- A means to specify parameters to the munition fuzes, such as distance to target or mode of operation

D.1.1.2 Potential payload outputs

To enhance the capabilities of direct fire ballistic weapons, the following information may be necessary:

- Current azimuth, elevation, and range to target, to support handoff from the weapon payload to other systems
- Current mode of operation, such as joystick controlled, stabilized, or tracking
- Weapon status, such as rounds count, weapon and ammo types, armed status, and firing status
- Current inhibits, such as no traverse zones, no fire zones, and system errors

D.1.2 Indirect fire ballistic weapons

Indirect fire is aiming and firing a projectile without relying on a direct line of sight between the gun and its target, as in the case of direct fire. Aiming is performed by calculating azimuth and elevation angles, and may include correcting aim by observing the fall of shot and calculating new angles. These weapons are ballistic in nature because there is no ability to control their flight path once they have been initiated. This class of weapons will overlap with the direct fire ballistic weapons and indirect fire guided or course-correcting weapons depending on the munitions employed. As such, where there are differences in the requirements for implementation, the desired ammunition and mission for a particular system should be taken into account to employ the proper controls without excessive additional sensors or protocols.

This class of weapons includes crew served weapons as small as the M2 machine gun and MK19, as the enhanced fire control capabilities of a weapons payload can allow for accurate indirect fires from these systems, to medium and large caliber chain guns and cannons, based on the availability of penetrating and air burst munitions. This class also includes typical indirect fire systems such as mortars and artillery systems. Conceptually speaking, a Paladin with the appropriate appliqué kit and ammo loadout would fall into this category.

With manned versions of these systems, the operators are required to verify that the target area is valid, typically by a forward observer, and that the line of fire is clear, typically by the vehicle commander. For unmanned weapon payloads, these same protocols should be retained, but their implementations may be different. As outside factors necessitate fewer Soldiers available to oversee system operations, a single Soldier could take on the FO and Weapons operator roles. Conceptually, the FO could be a UXV with "eyes on" the target area and a real-time feed going back to the weapons payload operator. The operator would also have a real-time feed looking down the line of bore of the weapon. After verifying both are clear, and the target coordinates are correct, the weapons operator could fire the system. Due to the dependence on multiple video feeds, this method of employment may still be further in the future, and there is nothing in this IOP to preclude a Soldier as the FO using a conventional radio to provide fire missions and situational awareness of the target area, which then get entered manually or digitally transferred by the weapons operator to carry out the fire mission.

D.1.2.1 Potential payload inputs

To effectively employ indirect fire ballistic weapons, all of the inputs to a direct fire system should be made available. In addition, indirect fire systems would benefit from the following:

- Coordination across multiple platforms for coordinated fires, to replicate current section and battery engagement
- A link to a forward observer, either manned or unmanned, for target area SA

D.1.2.2 Potential payload outputs

To effectively employ indirect fire ballistic weapons, all of the inputs to direct fire system should be made available. In addition, indirect fire systems would benefit from the following: No Additional Elements at this Time.

D.1.3 Direct fire guided or course-correcting weapons

While direct fire ballistic munitions cannot be controlled once they leave the weapon system, guided or course-correcting munitions are more advanced and offer the capability to modify the mission in flight. This class of systems is already very large, and continues to grow as technology becomes smaller. It includes externally commanded, such as single-shot course correction or laser riding, and self-guided, such as Javelin with integrated detection and tracking, munitions and missiles. Again, this is a case where the weapon system payload should contain all of the specific mechanisms for controlling its specific ammunition type, but the IOP will cover the methods of getting the correct information to and from the payload.

D.1.3.1 Potential payload inputs

To effectively employ direct fire guided or course-correcting weapons, all of the inputs to a direct fire system should be made available. In addition, direct fire guided or course-correcting systems would benefit from the following:

- A means to specify a target prior to launch
- A means to specify or change a target after launch (if capable)
- A means to confirm a target prior to launch
- A means to confirm a target after launch (if capable)
- A means to initiate "special commands" specific to the munition or missile, such as a wrapper function or message
- A means to command detonate the munition or missile in flight (if capable)
- A means to abort the mission in flight (if capable)

D.1.3.2 Potential payload outputs

To effectively employ direct fire guided or course-correcting weapons, all of the outputs from a direct fire system should be made available. In addition, direct fire guided or course-correcting systems would benefit from the following:

- A means to acknowledge a specific target prior to launch
- A means to acknowledge a specific target after launch
- A means to send out "special feedback" specific to the munition or missile, such as a wrapper function or message
- A means to confirm command detonation
- A means to confirm mission abort
- A means to confirm mission complete, either at launch for fire and forget or at impact/detonation for rounds with continued data links

D.1.4 Indirect fire guided or course-correcting weapons

While indirect fire ballistic munitions cannot be controlled once they leave the weapon system, guided or course-correcting munitions are more advanced and offer the capability to modify the mission in flight.

This class includes many of the same seeker technologies and capabilities as the direct-fire variants, but they must acquire their target in-flight as the weapon system does not have "eyes on" the target. Again, this class is dependent on a second system for identifying and maintaining a visual and geographical lock on the target area.
In one concept, a UXV may be operating as a forward observer and designating a target with a laser. This FO system must continue to track the target until another mission is commanded or it is destroyed. Another UXV with an indirect weapon system is then told to engage the target, the necessary information is provided to get the munition or missile in the window required to find the laser, and then launch.

D.1.4.1 Potential payload inputs

To effectively employ indirect fire guided or course-correcting weapons, all of the inputs to an indirect fire ballistic system and a direct fire guided or course correcting system should be made available. In addition, direct fire guided or course-correcting systems would benefit from the following:

Forward observer status, such as tracking, locked, off mission

D.1.4.2 Potential payload outputs

To effectively employ indirect fire guided or course-correcting weapons, all of the outputs from an indirect fire ballistic system and a direct fire guided or course correcting system should be made available. In addition, direct fire guided or course-correcting systems would benefit from the following:

A means to request and command a forward observer for the mission, if not done by a central coordination system

D.2 INTERFACES FOR STANDARDIZATION

Allowing remotely fired weapons on unmanned systems requires strict adherence to systems engineering principles to ensure safety. While it is beyond the scope of the IOP to mandate a particular system architecture, it is convenient to document a notional subsystem decomposition so that relevant interfaces, standards, and safety concerns can be documented. The following diagram provides a primitive breakdown of subsystems roles to support subsequent discussion, and should not be construed as a requirement or limitation on system design.

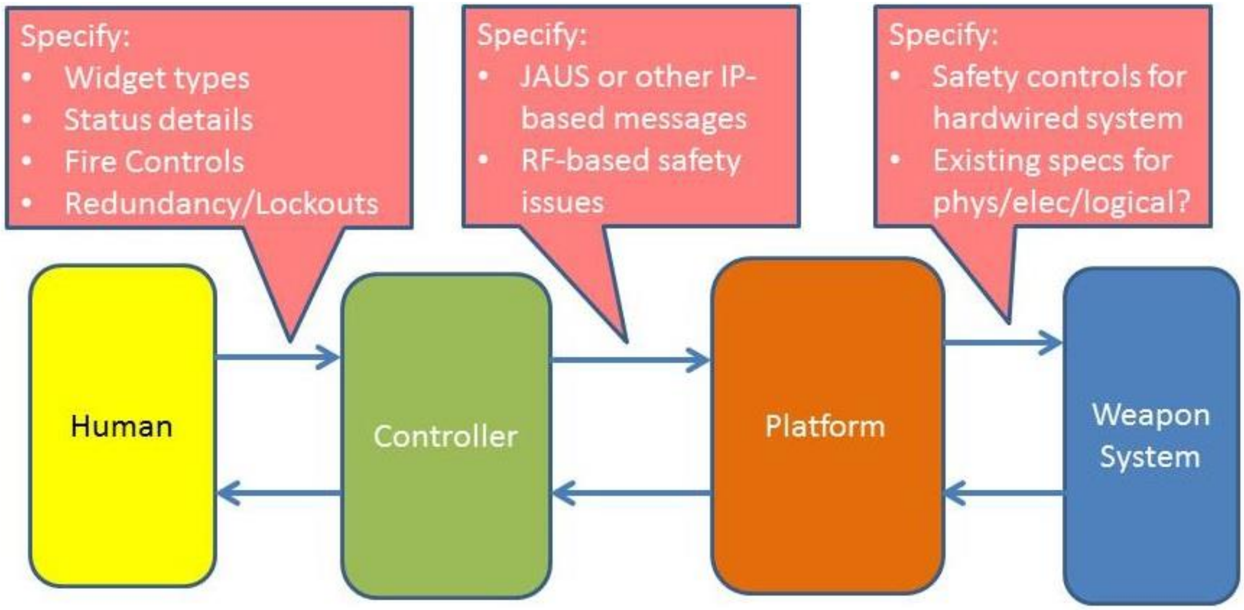


Figure 21: Interfaces for Standardization

While these interfaces may share safety critical factors, interfaces between each subsystem element pose their own unique challenges. The types of data exchanged among these interfaces for classes of weapon systems has already been addressed in section 10.1, so this section will focus on the physical interfaces for mechanical coupling, power, and communications.

- Platform to Weapon System: This interface considers the weapon system as an IOP payload mounted on the host platform. Due to the wide variety of available weapons payloads, it also makes sense to break this interface down into classes based on weapon system size. The table below shows the categories and expected parameters of each.

Class	Weight	Power	Communications	Mount drawing	Stiffness
Ultra-Light	<100lbs	<5A @ 28VDC	Gigabit Ethernet	Modified pintel mount	xx @ 30Hz
Light	<250lbs	<10A @ 28VDC	Gigabit Ethernet	Modified pintel mount	
Medium-Light	<600lbs	<50A @ 28VDC	Gigabit Ethernet	Modified pintel mount	
Medium	<4000lbs	<400A @ 28VDC	Gigabit Ethernet	Modified pintel mount	
Heavy Cannon	<10000lbs		Gigabit Ethernet		
Heavy Artillery	<10000lbs		Gigabit Ethernet		

Table 62: Weapon System Class Responses

- Human to Controller: This interface includes HMI and ergonomic issues. Software controls must give the operator sufficient situational awareness to understand the state of the weapon systems and to make a determination as to the safety of firing the weapon. In addition, the user interface and TTPs must eliminate the chance of accidentally activating the weapon. To that end, the human-to-controller interface specifications should require persistent operator engagement of certain switches (such as a dead-man) as part of the protocol to move, arm and subsequently fire the weapon. Since these interfaces are not unique to unmanned systems, the IOP development team expects to adopt existing standards to address most of these issues.
- Controller to Platform: While some programs may permit or expect a physical connection between the controller and platform, e.g. fiber-optic spool, the most common configuration will be command and control via an RF-radio. This poses an extra challenge for safety critical systems, which often use redundancy and multiple signals to ensure operator intent. Well-designed messages or datagrams and system architectures will be required, to fully address the safety aspects. As this need exists and is currently being addressed by a number of fielded unmanned air systems and research projects on armed unmanned ground vehicles, the IOP development team expects to adopt or refine existing standards and best-practices from these programs.

D.3 EXISTING STANDARDS

A number of existing standards and best-practice documents must be considered when finalizing the IOP interoperability requirements for weapons control:

- Universal Systems Interoperability Profile (USIP) 5.1, 01 August 2012: This document is maintained by the OUSD AT&L and has three sections: IP 6.1 Weapons, IP 7.1 Weapons Data Link, and IP 8.1 Unmanned Systems Cooperative Engagements. While written primarily for air systems, the guidance is generally applicable to all domains. The document relies heavily on existing standards for physical and electrical interfaces, referencing MIL-STD-1760, 1553, and MIL-DTL-38999 throughout. In addition, several SAE standards are used, including AIR6027 Safety Considerations for Store Arming and Release. This document also outlines the message set being used in the UAS community as part of the Universal Control Segment (UCS) architecture. These messages address several short comings with STANAG 4586, the more common command-and-control interface message set used for air systems.
- AIR 6027 Safety Considerations for Store Arming and Release: This document is maintained by the SAE by the AS-1B committee composed of industry, academic, and Government partners. The purpose of AIR 6027 is to "provide designers of armed unmanned systems with guidelines that may be applied to ensure safe integration and operation of weapons on unmanned platforms."

Consequently, the document stops short of mandating any particular safety solutions, but does make several recommendations that can be ported to remote weapons firing over lossy data links. These safety recommendations include measures to detect possible data errors in datagrams, as well as validation by an entirely independent signal.

- MIL-STD-1760 Aircraft/Store Electrical Interconnection System: This standard focuses primarily on the electrical and logical interfaces between a weapons store and a host platform. Because of its heavy focus on complex, air-launched weapon systems, this document may not be sufficiently applicable to the ground domain. However, the use of redundant signaling, including three independent control signals (DC#2/Safety Enable, Release Consent/Safety Enable, and Subaddress 11 Critical Control Message SA11R) should be considered for adoption by the IOP as part of the host-to-weapon system interface.
- UAI-PSICD-R03 Universal Armament Interface Platform to Store ICD: The UAI represents a continuation of MIL-STD-1760, and consequently may be too domain specific to provide guidance to the IOP interfaces.
- STANAG 4586: A NATO standard similar in scale and intent to SAE JAUS, with primary emphasis on unmanned air vehicles. While weapons control and release has long been part of the standard, it appears to be in transition as a result of the Universal Control Segment (UCS) Architecture activities. The UCS messages for weapons control should be considered, rather than messages from 4586.

D.4 SAFETY CONSIDERATIONS

The need for safe weapon store and release from an unmanned platform is clear. Considerable ground work has been done to document best-practices, particularly in AIR 6027. However, this document does not recommend any specific safety solution, particularly when dealing with RF radios that could be noisy or lossy. The IOP development team believes this to be a critical area for subsequent standardization in the ground domain.

System safety can be considered in (at least) two ways. First, proper assessment and operation of the hardware and software throughout the lifecycle of the system must be ensured. Measurements such as Mean Time Between Failures, Risk Assessment Processes, and other engineering best practices should be specified and enforced throughout system design, implementation, integration, and testing. Existing standards such as MIL-STD-882 provide guidance for classification of error types, and assessment of associated risks. While such assessments are critical to the safety of the system, they are best specified by the individual programs and therefore considered out-of-scope for the IOP. On the other hand, risks associated with physical, electrical, and logical interfaces do fall under the purview of the IOP and must be mitigated appropriately.

While the exact requirements are not yet determined and left for future IOP development, the IOP team believes there are three mandates which must be followed through subsequent publications:

1. **All interfaces must be validated by two independent signals.** For example, a command to fire a weapon from a human operator might be accomplished by pressing a soft key on the input device, but such an action is valid only when the accompanying dead-man switch is held. Such an action might trigger a JAUS message (datagram) over an RF radio, but such a message is only considered valid when a second radio is transmitting the 'armed' state. Finally, the host may translate the JAUS message to a 1553 Critical Control Message to the weapon to fire, but such a message is only considered valid while the Safety Enable discrete signal is activated.
2. **JAUS messages (datagrams) transmitted over an RF signal should be designed to compensate for bit errors.**. For example, a single "fire" message with a single on/off Boolean could be susceptible to transmission errors in a single bit, resulting in an accidental discharge. The UCS message set mitigates this risk in two ways: 1) By requiring the 'fire' signal to equal a predetermined 32-bit key rather than a single bit; and 2) By requiring a successful 'fire' message to be received a minimum number of times during a predetermined time span. Such solutions should be considered for the SAE JAUS custom messages as well.
3. **The protocol (order of operations) for all interfaces must be sufficiently complex and rigidly enforced to prevent an accidental discharge.** While good interface design generally reduces the workload on a human operator, the critical nature of remotely firing a weapon mandates a multi-step protocol. It is insufficient for a user interface to present the user with a means of discharging a weapon without rigidly enforcing each step. For example, the interface may require that the user switch modes through a serious of button presses or password inputs to engage the weapon, then arm the weapon through a physical key switch, and finally fire the weapon through a different input mechanism. This protocol (engage, arm, fire) should be enforced at each level of the interface, such that requesting to fire a weapon that has not been previously armed should be ignored by the weapons system or reported as an error.

D.5 LESS THAN LETHAL WEAPONS

In addition to the lethal weapons listed as possible systems for integration on ground vehicles in the near-term, less-than-lethal (non-lethal) devices may also be considered. Such devices include but are not limited to dazzlers, pepper spray, tear gas, flash bangs, water cannons, and Active Denial Systems (heat ray). Applications generally include crowd control and other non-combat operations.

Due to the reduced risk of lethal accidents, it may be tempting to lower the interface requirements mandated in Section 10.4. It could be argued that reducing the safety constraints on such systems lowers the overall development and acquisition costs.

At this time, however, the IOP development team believes that the risks associated with an unintended discharge out-weigh any potential cost and/or development time savings. Consequently, it is expected that less-than-lethal payloads will be treated the same as a lethal weapon payload, thereby necessitating the same interfaces and level of scrutiny.
Reference: Bailey, Johnathan B. A., Field Artillery and Firepower, Naval Institute Press, 2004

INTENTIONALLY BLANK

AEP-4818 Vol. V (A)(1)