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ROBOTICS AND AUTONOMOUS SYSTEMS – GROUND (RAS-G) INTEROPERABILITY PROFILE (IOP): APPLIQUÉ PROFILING RULES

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NATO LETTER OF PROMULGATION

22 February 2023

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CHAPTER 1 SCOPE

1.1 PURPOSE

This document is a normative attachment to the RAS-G Interoperability Profile (RAS-G IOP) Overarching Profile and provides specific rules, requirements, guidance, and consideration associated with the profiling of appliqué type robots and vehicles to achieve system level and platform level interoperability.

Robotic appliqué for the purposes of this document is defined as the application of sensors, hardware, and software to an existing manned platform to provide cost effective remote operation as well as semi or fully autonomous operational modes which enable optional manning of individual platforms and convoys as well as laying the groundwork for manned/unmanned teaming.

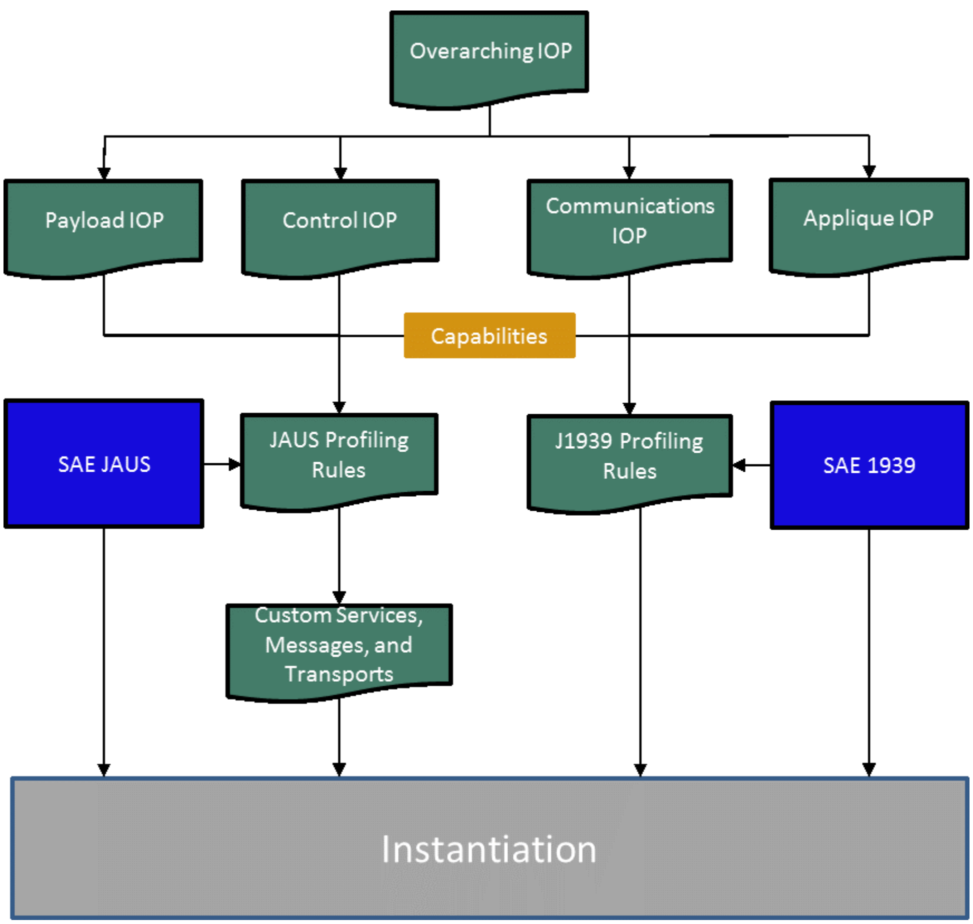

Figure1: Relationship of the RAS-G IOP Profiling Documents

CHAPTER 2 SOURCE DOCUMENTS

2.1 GOVERNMENT DOCUMENTS

Version	Document
1.0	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 Payloads Profile
D	MIL-STD-1275D CHARACTERISTICS OF 28 VOLT DC ELECTRICAL SYSTEMS IN MILITARY VEHICLES
F	MIL-STD-704F DEPARTMENT OF DEFENSE INTERFACE STANDARD: AIRCRAFT ELECTRIC POWER CHARACTERISTICS
E	MIL-STD-882E DEPARTMENT OF DEFENSE STANDARD PRACTICE: SYSTEM SAFETY

2.2 NON GOVERNMENT DOCUMENTS

Version	Document
AIR5665A	AE Aerospace Information Report, Architecture Framework for Unmanned Systems (AFUS)
IEEE 802.3-2008	Standards for Ethernet based LANs
SAE J1939	Serial Control and Communications Heavy Duty Vehicle Network
SAE J3016	Taxonomy and Definitions for Automated On-Road Vehicles
ISO 11898	Road Vehicles - Controller Area Network (CAN)

CHAPTER 3 KEY CONCEPTS AND INFORMATION

This section provides information on key document concepts, how to use this document to describe interoperability requirements, definitions, and other information.

3.1 DEFINITIONS

Term	Definition
Appliqué	The augmentation of a manned vehicle such that it can be remotely, autonomously, or semi-autonomously controlled. This document describes two categories of appliqué. **Delivered By-Wire Appliqué:** Augmentation of a vehicle which was designed for by-wire control upon acquisition. **Retrofit Appliqué:** Vehicle to be augmented has little or no ability (upon acquisition) to be actuated by-wire.
B-kit	Everything added to a platform after acquisition. Designed to enable capabilities not intended by the original equipment manufacturer (OEM). Wherever possible subsystem design should include Line Replaceable Units (LRU), where an LRU is an easily swappable functional unit. This drives the ability for various elements of the B-Kit to be swapped during operation or testing when a fault has occurred. This prevents excessive downtime where spare LRU's can be made available. Note: The B-Kit can be thought of as a single "kit", however in many cases its component elements will be highly distributed and integrated into the base vehicle platform, potentially with various B-kit elements acquired from different vendors. Whether there is a simple mountable kit, or distributed subsystems will be solely based on the specific implementation needs of program instantiations.
C-Kit	The C-Kit is a communication and user interface subsystem which is part of the B-Kit for some Appliqué use cases.
Compliance Bridge	Allows a system or subsystem not having been designed with IOP compliance in mind to interface in an IOP compliant way (as defined by the RAS-G IOP Overarching Profile). The bridge consists of everything required to attain compliance and may include physical, electrical, and/or logical elements.

Autonomy	**Semi-Autonomous:** A mode of operation of an unmanned system wherein the human operator and/or the unmanned system plan and conduct a mission and require various levels of human robot interaction. **Autonomous:** A mode of operation of an optionally or unmanned system wherein the system carries out a mission plan with little or no direct intervention or supervision on the part of a human after initial configuration of mission parameters.
Mobile Base Unit (MBU)	The Mobile Base Unit is a collection of software and hardware designed to exist as an interface between a Semi-Autonomy Kit (defined below) and a by-wire actuated vehicle. The MBU is contained within the B-Kit and has a RAS-G IOP compliant interface to a Vehicle Control Module (VCM, defined below). Further, the MBU has a RAS-G IOP Communication Profile compliant interface to an Operator Control Unit (OCU) via radio or tether.
Autonomy Kit Types	**Semi-Autonomy Kit (SAK):** A semi-autonomy kit is a combination of an MBU and any relevant mission payloads used for semi-autonomous control used for a particular mission application. **Autonomy Kit:** An autonomy kit consists of more and higher resolution sensors in addition to a much greater computational ability enabling advanced autonomy algorithms. This enhanced kit provides all required components for fully autonomous behaviors and mission profiles.
By-wire Kit	This kit is required for any vehicle which has not been designed for full by-wire control. Active safety functionality can be built into this kit (i.e. obstacle avoidance) should it be required and not available on the base platform.
Doer–Checker	A relationship between two ECU's where one (the doer) is primarily responsible for carrying out actuation commands without safety criticality, and the other (the checker) is responsible for ensuring safety criticality of all actuations performed by the doer.
Vehicle Control Module	**Delivered By-Wire:** This VCM variant is expected to be delivered with the vehicle by the OEM, or via an acquisition process pre-dating augmentation. It is an ECU which receives commands from the SAK via an MBU and directly

	actuates vehicle sub-systems including any relevant passive/active safety components. **Retrofit Appliqué** A VCM variant developed as part of a by-wire kit upgrade to allow an autonomy kit to interface with a vehicle which was not designed for by-wire control. It is a doer and is not ultimately responsible for safety criticality. The level of complexity of this VCM is much greater as a great deal of design and integration must be performed on the base platform to make a non-inherently by-wire vehicle ready for actuation by an autonomy kit.
Safety Checker	Required for a Retrofit Appliqué approach. This ECU module is the checker in the doer/checker relationship. The safety checker is responsible for ensuring that actuations undertaken by the VCM doer (in Retrofit Appliqué) are correct and intended. This module also monitors vehicle sub-systems which may have the ability to act independently of the VCM. An example of such an independent system might be a highly integrated brake systems equipped with automated emergency braking. The safety checker must be in the loop with all such active sub-systems so that their safety can be assured from a system level. This module is required in Retrofit Appliqué due to the complexity of integration required to make a non-by-wire vehicle controllable by an autonomy kit. When this task is performed the inherent safety of the vehicle as delivered by the OEM can no longer be relied upon and must be separately ensured.

Table1: Definitions

3.2 SYSTEM CONTEXT

An appliqué approach suggests the goal of turning a manned platform into an optionally or fully unmanned system. In the optionally manned case, an augmented vehicle may allow an operator(s) to accomplish tasking which would otherwise be distracting to the core traditional driving task, such as being freed to maintain greater situational awareness without the need to constantly manage every aspect of vehicle dynamics (preventing many cases of roll-over for example). It is via the use of add-on kits that that this enhanced functionality is achieved. This strategy has the advantage of utilizing existing manned platforms. This greatly extends the number of mission profiles available to a commander for a given vehicle type without the need to completely re-engineer the entire vehicle force structure from the ground up.

There are two primary categories into which a particular appliqué system implementation may fall: Delivered By-Wire and Retrofit Appliqué.

1. As seen in Figure2: Delivered By-Wire Appliqué Reference Architecture below, a delivered by-wire appliqué implementation platform manufacturers deliver a vehicle which is already capable of being electronically actuated. Thus a separate drive-by-wire kit development isn't necessary.
   The task then is to develop only those parts of the system for which a human driver would be required, in-other-words the creation of a virtual driver. It is expected that eventually most vehicles will fall into this category as full drive-by-wire systems become a commercial norm.

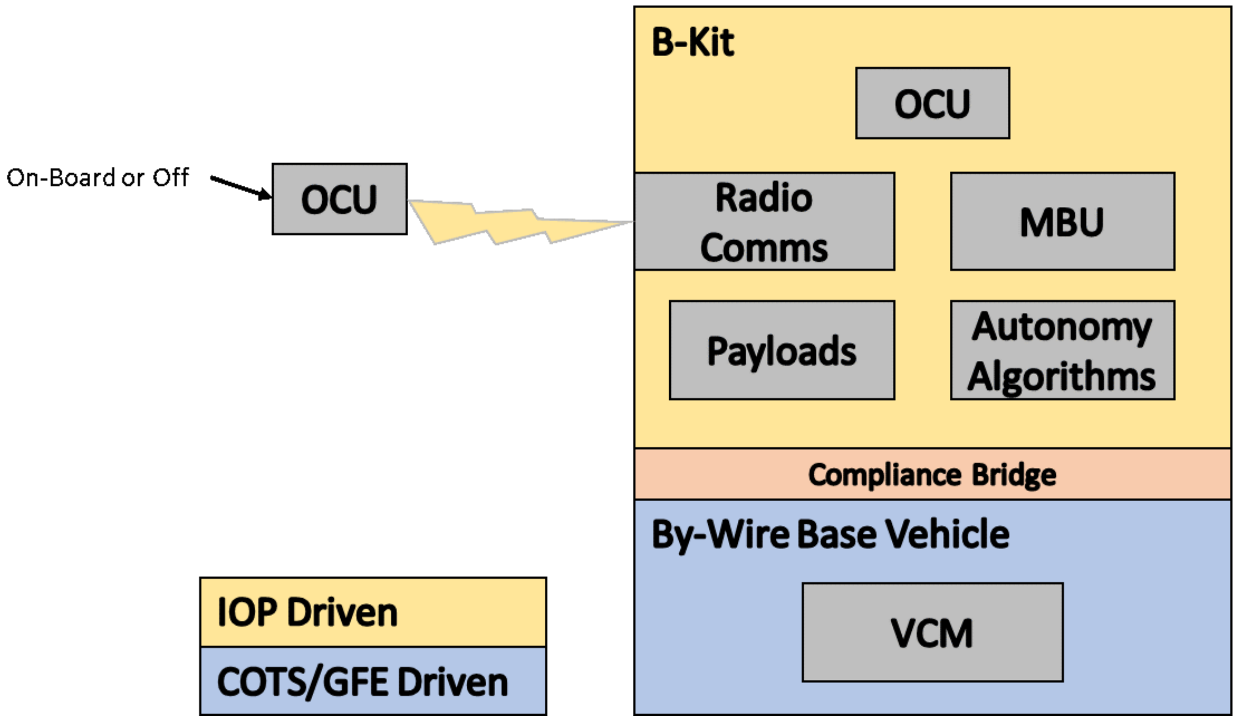

Figure2: Delivered By-Wire Appliqué Reference Architecture

2. As seen in Figure3: Retrofit Appliqué Reference Architecture below, a retrofit appliqué implementation has the goal to take a platform with limited (or no) capability of being electrically actuated and providing an add-on drive-by-wire capability in addition to the virtual driver as found in the Delivered By-Wire case. This approach has the benefit of being able to upgrade a great many vehicles already acquired, thereby greatly reducing costs while full by-wire commercially available platforms remain an outlier.

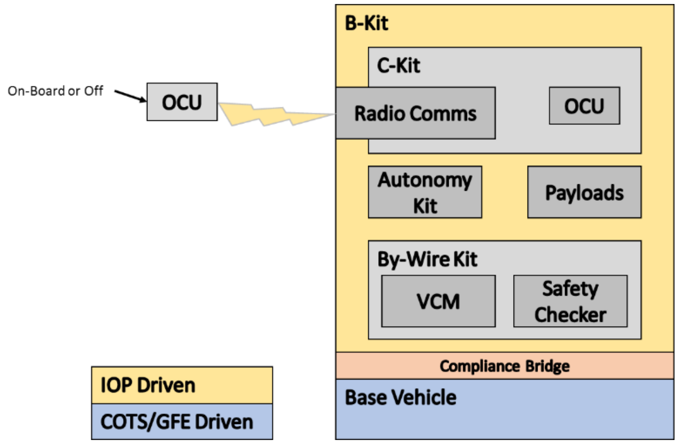

Figure3: Retrofit Appliqué Reference Architecture

Figure4: Example Leader-Follower Instantiation below shows an example instantiation of a Retrofit type using US Army current heavy vehicle fleet systems not originally designed for by-wire control or autonomous behaviors. This example is instructive as it provides for a great deal of flexibility for where and how system elements are integrated, adding advanced capability to current generation vehicles, and making use of low-cost COTS hardware.

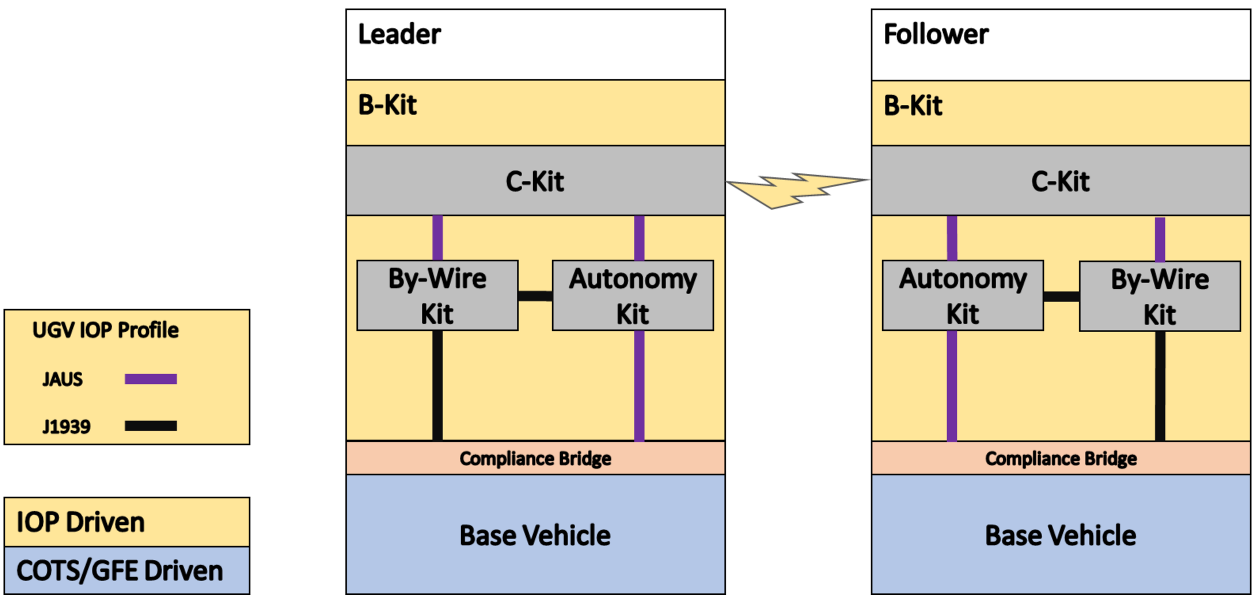

Figure4: Example Leader-Follower Instantiation

3.2.1 Communications

Communications within an appliqué system use the attributes as specified in the RAS-G IOP Communications Profiling Document. Figure5: Communications Architecture below shows a notional system diagram of how communications between an OCU/other and the augmented vehicle occurs. The Common Communications Link (CCL) is not limited to point-to-point (as shown) but can be architected in any manner acceptable according to the RAS-G IOP Communications Profiling Document (i.e. mesh/other).

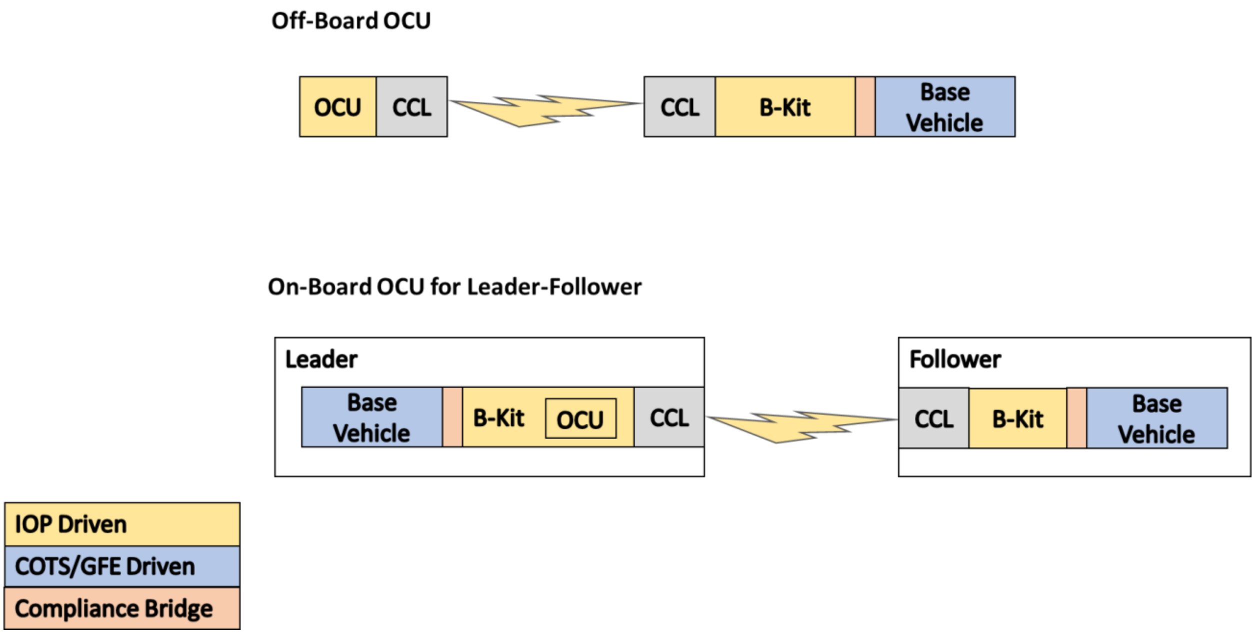

Figure5: Communications Architecture

CHAPTER 4 APPLIQUÉ ATTRIBUTES

4.1 APPLIQUÉ CORE ATTRIBUTE

All appliqué type vehicles will follow the RAS-G IOP Appliqué Attribute as specified by the following sections each containing attributes that aid in describing the interoperable interfaces. Where possible, references to the other RAS-G IOP Profiling documents will be cited.

Appliqué augmented systems have the unique problem of being driven by the automotive industry, the military robotics industry, and vehicles produced specifically for military applications. As such, attributes set forth herein shall take this into consideration. When designing an appliqué system, care should be taken to separate IOP compliant subsystems from non-compliant parts of the overall system to enable easier creation of IOP compliant LRU's. Compliance, and how to deal with compliant/non-compliant interfacing is defined within the RAS-G Overarching Profile document (section titled "Non-compliance").

Any non-compliant portion of the system may be interfaced to a compliant portion of the system via wrapping or adapting the necessary physical, electrical, and software interfaces. Adoption of a standard into the IOP is an alternative, but may not meet the version of the IOP the system is being designed to. There is no guarantee that an adopted interface will be added to a future version of the IOP.

4.1.1 Compliant/Non-compliant Interfacing Requirement

V4.Appliqué-1	*All non-compliant physical, electrical, and logical interfaces shall be wrapped or adapted as specified in the RAS-G IOP Overarching Profile document.*

4.2 CCL ATTRIBUTE

Communications interfaces on the vehicle will be driven by both the automotive industry and the RAS-G IOP Communications Profiling attributes. The RAS-G IOP will not specify the communications on the vehicle that are delivered by the vehicle manufacturer. Instead the RAS-G IOP will specify attributes for communications on the vehicle that drive the design of the appliqué kits. A compliance bridge between the communications is necessary to translate from the IOP compliant side of the augmented vehicle to the non-compliant side.

4.2.1 Applique Communications Requirement

V4.Appliqué-2	*Appliqué kits shall provide communications interfaces compliant with the RAS-G IOP Communication Profile.*

4.3 PHYSICAL AND ELECTRICAL INTERFACES ATTRIBUTE

Physical interfaces for electrical connections and power profiles for the vehicle are driven by both the automotive industry and the RAS-G IOP Payload's Profile attributes. If power for the appliqué kits is to be provided by the vehicle, the power will need to be conditioned to meet one of the power profiles as specified in the IOP via the included compliance bridge.

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.

Table 2: - Mandatory Select = all

4.3.1 Physical And Electrical Interfaces Requirement

V4.Appliqué-3	*Electrical connections and power profiles should be profiled as specified in the most current RAS-G IOP Payloads Profile specification.*

4.4 ELECTRICAL POWER 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 as specified in the most current RAS-G IOP Payloads Profile specification.

Any number of the following attributes can be chosen.

Attribute	Description
Clean Power Attribute	This attribute provides "clean" electrical power as defined in MIL-STD-704.
Base Vehicle Power Attribute	Base Vehicle Power Attribute This attribute provides standard military ground vehicle 28V electrical power as defined in MIL-STD-1275.

Table 3: - Optional Select = any

4.4.1 Appliqué Electrical Power Interface Requirement

V4.Appliqué-4	*Appliqué systems shall use one of the power profiles specified in the most current RAS-G IOP Payloads Profile specification.*

4.5 CLEAN POWER ATTRIBUTE

Appliqué kits frequently have much greater needs for "clean" power than base vehicles are able to supply. For an explanation of what constitutes "clean" power, see B.1 "CLEAN" POWER SYSTEMS.

4.5.1 Clean Electrical Power Interface Requirement

V4.Appliqué-5	*Provided clean electrical power should be profiled as specified in the most current version of MIL-STD-704.*

4.6 BASE VEHICLE POWER ATTRIBUTE

Military ground vehicles typically supply 28V (24V nominal) as the prime automotive power network, therefore this attribute is provided as the unaltered standard power interface.

4.6.1 Base Vehicle Electrical Power Interface Requirement

V4.Appliqué-6	*Provided clean electrical power should be profiled as specified in the most current version of MIL-STD-1275.*

4.7 CORE SOFTWARE AND LOGICAL ATTRIBUTE

Logical communications are defined to the extent possible using SAE JAUS service oriented architecture and SAE J1939 serial control and communications heavy vehicle network. The IOP has extended and profiled both the SAE JAUS and SAE J1939 through the RAS-G IOP JAUS Profile, RAS-G IOP J1939 Profile, and the RAS-G IOP Custom Services, Messages and Transports documents.

The automotive domain has heavily invested in low-cost, real-time, fault-tolerant data buses for safety critical applications (CAN et.al.). As a consequence, those wishing to interface COTS automotive embedded hardware may be greatly aided by use of the RAS-G IOP J1939 Profile. While the IOP does not primarily concern itself with implementation or system safety, the choice to use J1939 for safety critical real-time system interfaces provides the potential to leverage the decades of work which has gone into stabilizing automotive safety and control.

Heavy vehicle platforms which are to be augmented with appliqué kits will make use of the SAE J1939 and ISO 11898, which defines the physical layer for CAN networks, CAN standards and utilize the whitelisted RAS-G IOP J1939 Profile available to qualified applicants at the sole discretion of the United States Army. The process for obtaining this whitelisted profile will be outlined in a later added Appendix C.

The IOP will only specify logical interfaces on the IOP compliant side of the system.

4.7.1 Logical Interfaces Requirement

V4.Appliqué-7	*The logical interfaces within the system shall be provided utilizing SAE JAUS as profiled within the RAS-G IOP JAUS Profile and RAS-G IOP Custom Services, Messages, and Transports documents.*

4.7.2 J1939 Logical Interfaces Requirement

V4.Appliqué-8	*Interfaces within the system where appropriate shall be provided utilizing SAE J1939 as profiled within the white-listed RAS-G IOP J1939 Profile.*

4.8 MANAGEMENT ATTRIBUTE

This attribute provides the current reference implementation for Appliqué E-Stop integration. For the future direction of this capability, see FUTURE DIRECTIONS FOR APPLIQUÉ INTEROPERABILITY.

4.8.1 Emergency Stop Appliqué Requirement

V4.Appliqué-9	*E-Stop should be profiled as specified in the most current UGV IOP Controls Profile specification.*

4.9 PHYSICAL MOUNTING OPTIONS

4.9.1 Mounting 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
Vehicle Manufacturer-Specified Mounting Attribute	Physical mounting specified by vehicle manufacturer.

Table 4: - Mandatory Select = any

4.9.2 Physical Mounting Attribute

Parent Attribute: Mounting Attribute

4.9.2.1 Physical Mounting Requirement

V4.Appliqué-10	*Physical mounting of a payload/other or other specified structure should comply with Physical Mounting Requirements as specified in the most current RAS-G IOP Payloads Profile specification.*

4.9.3 Vehicle Manufacturer-Specified Mounting Attribute

Parent Attribute: Mounting Attribute

4.9.3.1 Vehicle Manufacturer-Specified Mounting Requirement

V4.Appliqué-11	*Vehicle manufacturer may specify physical mounting requirements.*

4.10 V4 ADDITIONS AND ASSUMPTIONS

Additions to V4 for appliqué systems were identified via current program needs.

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ANNEX A FUTURE DIRECTIONS FOR APPLIQUÉ INTEROPERABILITY

Versions 2 and 3 of the IOP Appliqué profile included technical discussion pertaining to the various types of robotic systems and the safety implications. It is anticipated that during FY2019 there will published a new MIL-STD with the sole focus of capturing topics related to safety in (semi)autonomous systems. For this reason V4 of the Appliqué document no longer contains these topics with the expectation that V5 will refer to the forthcoming standard directly. Naturally the topics are preserved in previous versions for reference.

As program offices begin to increasingly adopt subsystems compatible with IOP best practices, it will become increasingly less likely to require Appliqué methods. This is the case as a result of both government and industry agreeing on modular open system architectures which enable refit of primary vehicles systems with a plug-and-play approach with a level playing field between OEM and aftermarket vendors.

With the above stated legacy vehicles (requiring full Appliqué methods) will likely remain in use for some decades to come if for no other use than for Research, Development, Test, and Evaluation (RDT&E). For this reason future versions of the IOP Appliqué Profile should focus on bridging the interface gap between new IOP Compliant programs of record and legacy vehicles used for RDT&E to insure ease of transfer of sub-systems and modular payloads to enhance newly fielded vehicles over time without need for non-recurring engineering (greatly easing the transition from lab to field).

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ANNEX B DISCUSSION OF TECHNICAL TOPICS AND LESSONS LEARNED FOR FUTURE CONSIDERATION

The following sections are included to introduce technical considerations and lessons learned related to appliqué systems – as well as to propose vehicle categorizations to aid in the further definition of appliqué system requirements.

B.1 "CLEAN" POWER SYSTEMS

B.1.1 Introduction to Clean Power Systems

The below represent excerpts from the white paper: "Clean Power Considerations for IOP Applique" written by Bruce Bradford.

The purpose of a power standard is to ensure compatibility between elements of a power generation and distribution system and the equipment utilizing it. A power standard sets bounds on transients despite loads of varying types, while also protecting all loads connected during fault conditions. Regardless of these requirements the definition of clean and dirty power is subjective and application specific.

For medium and large alternator powered Army ground vehicles, power quality is standardized by MIL-STD-1275 "Characteristics of 28 Volt DC Electrical Systems in Military Vehicles" (24V nominal).

For nominal 24V systems (based on 12V batteries in series or series/parallel combinations) 1275 specifies both normal operating conditions and limits of abnormal conditions power loads or "utilizing equipment" must survive without damage.

Army tracked and wheeled vehicles specify MIL-STD-1275 to enable sharing common equipment such as radio and the NATO slave receptacle. It is not the historical standard for "dirty power" and is clean enough for tank/automotive systems which suffer large voltage transient drop-outs when cranking. The voltage ranges and transient conditions present in 1275 has resulted in more robust (also larger and heavier) electronics

Power systems designed to MIL-STD-1275 must maintain operation of electronics during engine starting, starting of large loads (such as pumps and fans), and protection of sensitive electronics from conducted emissions from other parts on the same power bus.

Another standard of note is: MIL-STD-704 "Aircraft Electric Power Characteristics" which is often discussed as a "cleaner" alternative to 1275. MIL-STD-704 discusses 28V power systems which naturally is of interest to developers of ground vehicle systems.

Characteristic	**MIL-STD-1275E**	**MIL-STD-704F**
Steady State Voltage	20.0V to 33.0V	22.0V to 29.0V
Operational Transients* Negative	18.0V for 500ms (recovery in 600ms)	18.0V for 12.5ms (recovery in 82.5ms)
Operational Transients* Positive	100.0V for 50ms (recovery in 500ms)	50.0V for 12.5ms (recovery by 100ms)
Power Line Spikes	+/- 250V (for up to 100us)	Not Defined
Engine Starting Voltage Drop**	12V for 1s 16V for 30s	12V for 1s***
Ripple Voltage	2Vpp****	1.5Vpp
Abnormal Condition Under/Over Voltage	Not Defined	*****

Table 5: MIL-STD-1275E vs MIL-STD-704F

*Transients allowed during "normal operations" which exclude engine starting and fault conditions. These result from the time delay between activation (resulting in negative voltage dips) and deactivation of another electrical load (resulting in positive voltage rise) and the time for the voltage regulation system to bring the power line voltage back to normal.

**A challenge so great that electrical systems have historically not been expected to operate through it but rather not be damaged and then should fully and automatically recover back to normal operations quickly.

***This dip is expected to occur during Auxiliary Power Unit start-up (usually most electronics are turned off at this point). No dip is allowed after Auxiliary Power Unit has been started while main engine is being started.

****Was 2V peak to peak in older versions, but now is regulated by the MIL-STD-461 test for CS101

*****Allows under-voltages down to zero volts for up to 7 seconds, which is the slowest "trip time" of all MIL SPEC circuit breakers, and allows over-voltages due to a generator failure up to 50 volts for 500 milliseconds at which time the generator should be shutdown.

B.1.2 Worst Case Conditions for Ground Vehicle Power Systems

Traditional Worst Case (analog electronics)

Cranking Engine after Cold-Soak:

As the engine oil gets colder, its viscosity gets thicker, and the engine gets harder to crank. The "let-go" current of the starter motor will be greater in the cold, and the resulting voltage drop out from the battery powering the starter motor will be extreme. The huge voltage drop out will activate the power-on-reset and reboot all of the electronics, but together they will exercise their routine system power up and initialization sequence as has been developed and integrated in their systems integration laboratories and are usually quite robust.

Modern Worst Case (digital electronics, networked vehicles)

Power Surges of Intermediate Size:

Digital electronics will suffer more from the intermediate sized power surges, those that will reboot some but not all of the electronics. In fact given the part to part variation of power components in the power supplies, there is no guarantee that the same power surge will result in the same electronic units among different vehicles of the same design will be reset. This combination may vary again over temperature and over the life of the system. There are many combinations of drop-outs and their impact to a system consisting of many digital electronic units. The reality here is that it is very difficult to design a recovery sequence for systems that can detect which electronics have dropped out, and then automatically bring the system fully back on-line.

External Ramifications:

If the applique participates in an external network, rebooting some, but not all of its electronics, may result in unexpected system behavior in the greater formation because the affected system may appear to be "online", but in fact be in a fault condition. Additional network complexity will be required for diagnostics of the network and handshaking among the network nodes.

B.1.3 Overview of Army Ground Vehicle Power Challenge Mitigations

Army ground vehicle systems have added advanced capabilities in recent years which have resulted in novel engineering approaches to mitigating some of the power system issues enumerated above.

B.1.3.1 Battery Backup

An early use for an appliqué/retrofit battery backup system is shown in Figure 6: Digital Control Unit . The motivating risk mitigated by the battery backup was engine cranking after cold soak. This activity caused a power drop which could force a reboot of the system (in turn shutting off fuel) thus aborting the starting sequence.

A solution is to provide power to the system via a local secondary battery protected from the main batteries. This idea is to maintain input voltage for the system during engine cranking, however a potential undesired side effect if a battery exists in the crew compartment it could theoretically vent hydrogen in a failure mode.

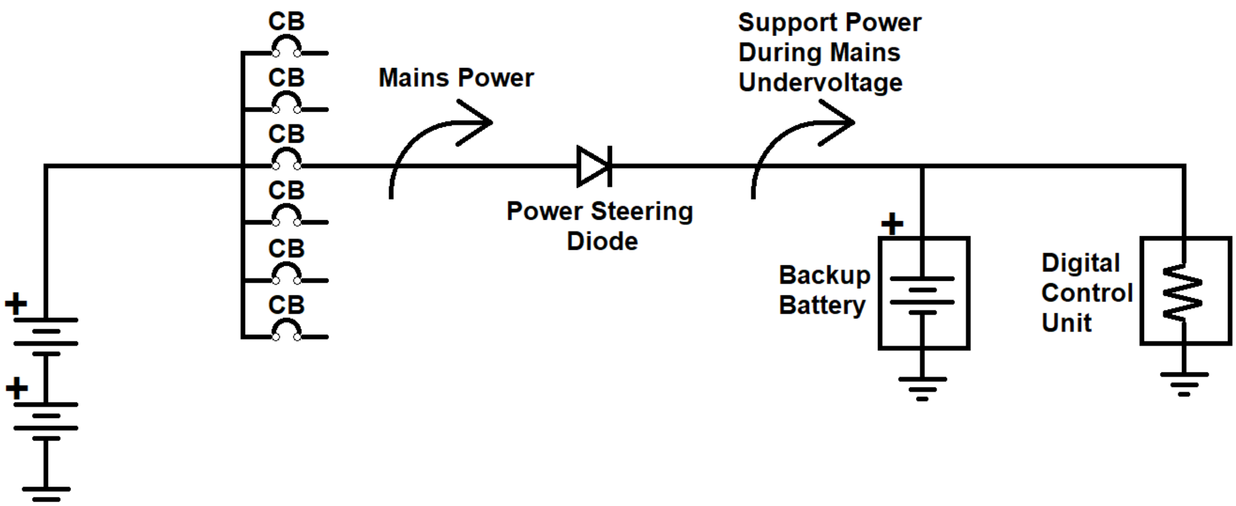

Figure 6: Digital Control Unit

B.1.3.2 Battery Switching System

In addition to other motivations, the side effects seen in the Battery Backup in Figure 6: Digital Control Unit were mitigated by implementing a battery switching system as seen in Figure7: Battery Switching System. This system consists of six 12V batteries in a series parallel configuration and includes a large power contactor that can be controlled to reconfigure the battery pack in response to varying need including engine starting, battery recharging, and silent watch. When the normally closed contactor is open, this creates a clean side (MIL-STD-704F without an engine starting surge, but could also be MIL-STD1275E without the surge) and dirty side (MIL-STD-1275E including the engine starting surge).

The battery pack is configured to allow both the single battery pack configuration of all six battery modules (typically closed, which provides charging of all six batteries as well as full battery capacity to support silent watch power demand), or during engine starting the relay could be opened to split the battery pack into a 4 battery group which supplies power to the engine starting motor and a 2 battery group which could deliver clean power to the vehicle electronics that will not suffer the large voltage drop out induced by the starting motor.

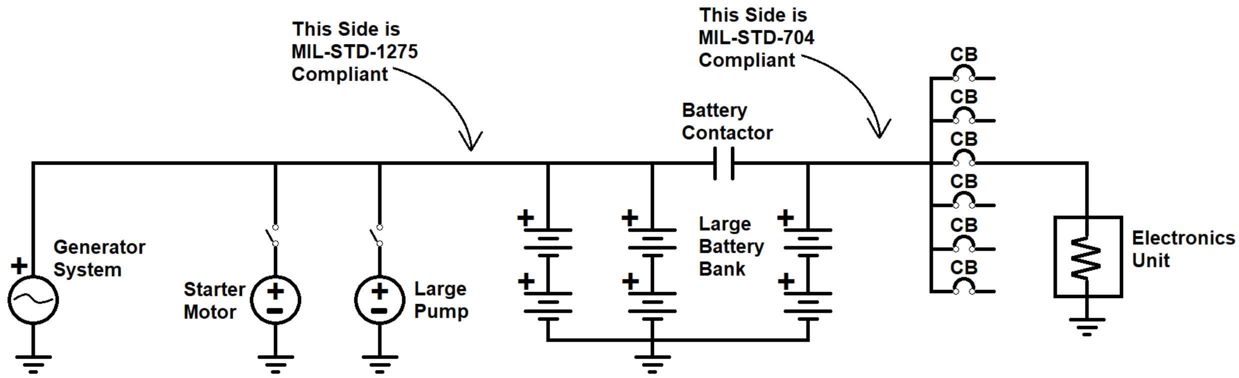

Figure7: Battery Switching System

This strategy works because the engine starting cycle was of short duration (not draining the 2 separate battery groups to significantly different states of charge) and most always ended with a battery recharging capability immediately after the engine is started. This has the benefit of preventing electronics from rebooting during cranking after silent watch (on a low battery state of charge), but also when starting the engine after an extended cold soak.

B.1.3.3 Auxiliary Power Unit

Inclusion of the auxiliary power unit into the prime power generation circuit can be similar to the battery switching option, but rather than combining and splitting between two battery banks the APU is used in place of the second battery bank. This also creates a clean side (MIL-STD-704F) and dirty side (MIL-STD-1275E) when the contactor is open. In this case, the contactor would be of the normally open type to support smart battery charging (i.e. open the contactor to stop charging when a battery monitor reports that charging is complete). The contactor would be closed when the APU is off to support power distribution from the main generator or the battery pack. Depending on the vehicle mission, the APU may be the primary source of clean power, or may be reserved for stationary or silent watch operations. Some vehicle architectures may need the APU running all the time for cooling purposes. So there are many options and alternative configurations that would be useful.

While we have been focusing on Army ground systems (with applique electronics) here, it is helpful to review aircraft configurations with an APU. As seen in Figure8: Aircraft Auxiliary Power Unit in rotary wing aircraft, the APU is started first (from its own very small battery). The APU then generates both electrical power to bring up the rest of the system and a separate power source for actually starting the engine (which can be air powered or hydraulically powered). Fixed wind aircraft often have the APU external to the system, where it can be wheeled up to the aircraft on the ground as a support unit. Much can be learned about these architectures from future study.

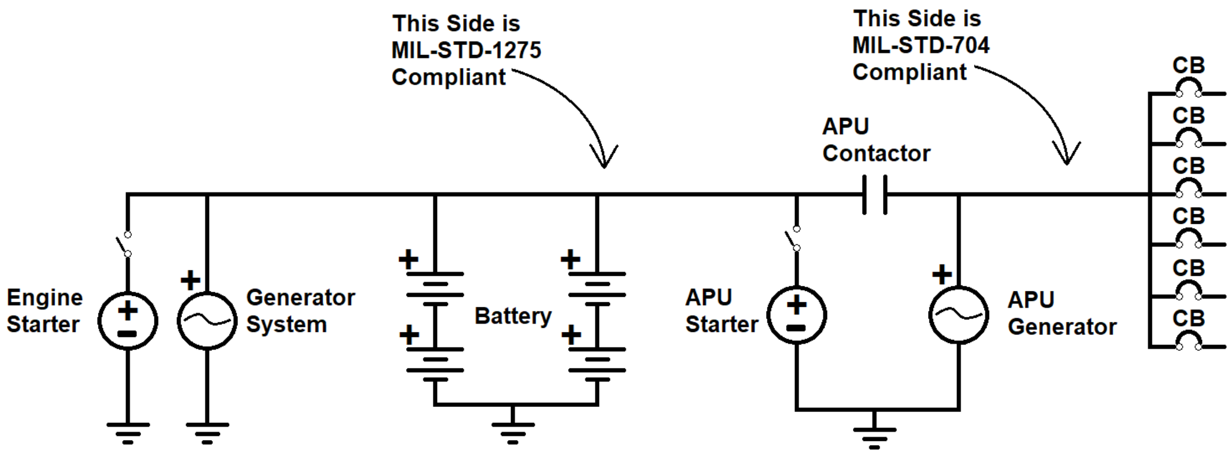

Figure8: Aircraft Auxiliary Power Unit

B.1.3.4 Non-Interrupt-Able Power Supply

A non-interrupt-able power supply (NIPS) is a system designed to be in the path between a vehicles prime power and select loads such as an appliqué subsystem. An example of such a strategy is shown in Figure 9: Autonomy Power Unit intended to mitigate loss of power to the autonomy electronics such that a safety critical function can be assured in the event of an identified failure mode. In this case, the non-interrupt-able power source is included in the Autonomy Power Unit (not to be confused with an auxiliary power unit APU). This autonomy APU packages together the NIPS with applique power distribution and conversion circuits. In the normal (non-failure mode) operation the NIPS does not act, but when a failure mode is detected the NIPS is activated as part of a coordinated strategy: the NIPS maintains power to the autonomy equipment and a safety checker computer while the safety strategy is exercised. The NIPS must be sized to accommodate the power needs and duration of the expected safety strategy mitigation. In this case, the autonomous vehicle can be commanded to come to a controlled stop (steering braking and parking brake). The autonomy APU accomplishes the same benefit to the electronics as the backup battery and steering diode but is smart enough for the NIPS to be inactive in normal modes, avoiding the side effects of the steering diode.

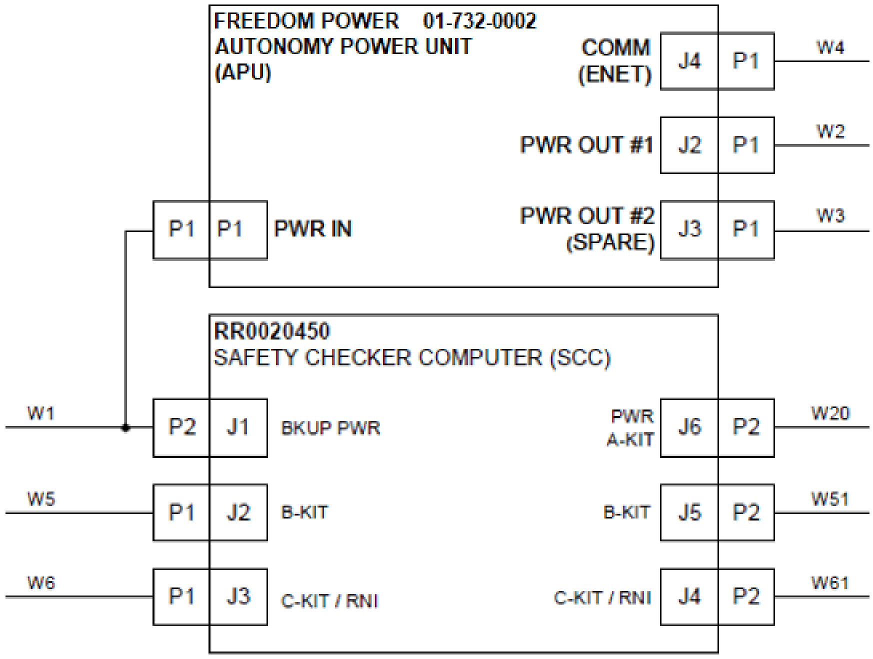

Figure 9: Autonomy Power Unit

B.1.4 Choosing an Applique Interface Power Standard

When comparing the benefits and criticisms of the MIL-STD-1275E to MIL-STD-704F there is a shift in burden and impact to the internal power supply (generally requiring a much larger input power “hold-up” capacitor) which impacts the size and weight of the electronic LRU's that packages the internal power supply. 1275 demands robust power loads (as displays, computers, sensors, etc.) which places a burden on the LRU designs and typically results in larger and heavier designs. 704 places the burden on the electrical power generation and distribution system for tighter voltage regulation, which tends to result in smaller and lighter LRU designs.

The difficulty of adding auxiliary power systems after acquisition is directly proportional to the size of the base vehicle platform under consideration. This is the case because the smaller the vehicle the more difficult it becomes to add weight and complexity of any kind. Thus it follows that clean power in particular (as not being a capability in-and-of itself per se) should be a strong consideration in the primary design of small, or strongly space constrained platforms (under armor for instance).

B.1.5 Options for Applique Power Interfaces

The strengths and weaknesses of the different options can be compared and contrasted as shown in the table below.

Option	Strengths	Weaknesses
Battery Backup System for Sensitive Loads	• Backup battery holds up sensitive loads as needed • Easier to add by device	• Battery added to Army logistics • Discharges in silent watch modes, causing cycling • B/U battery does not fully charge due to diode drop
Power Conditioning Unit with NIPS	• Switching power supplies regulate transients and holds up during cranking	• More expensive • Long lead times
Battery Switching System	• Separates clean and dirty busses with contactor • Protects clean side during activation of a dirty load	• Must be designed into platform • May require more batteries
Aux Power Unit(APU)	• Can run electronics on APU alone • Enhanced silent watch • Thermal management	• Must be designed into platform • Acoustic/thermal signatures

Table 6: Options for Applique Power Interfaces

ANNEX C DATA DICTIONARY

In order to identify Appliqué program needs a data dictionary of what information, status, and control might need to be exchanged has been compiled. The data dictionary is a starting point for profiling any standard message sets that would be adopted by the Appliqué IOP, and should be implementation agnostic.

Relevant areas investigated include, but are not limited to, exchange of information and control of:

- Platform information
  - Vehicle parameters
  - Towed platform information
- Diagnostics and health
- Software/hardware information
- Actuator state
- Navigation
  - Planning
  - Path representation
- Active safety modules
- Units of measure
- Behaviors

C.1 VEHICLE PARAMETERS

Message Name	Short Description
Vehicle type	Vehicle types are predefined vehicle parameter groups that may have several vehicle information values already defined.
Vehicle reference frame	The vehicle reference frame is located at the center of the rear axle or tandem axle. Origin for Z is on the ground.
Minimum turning radius	The minimum radius the vehicle can turn in either left or right directions [m].
Maximum longitudinal acceleration	Query value for maximum longitudinal acceleration. The maximum capable longitudinal acceleration for the vehicle at curb weight [m/s^2].
Maximum longitudinal deceleration	The maximum capable longitudinal deceleration for the vehicle at curb weight [m/s^2].
Maximum lateral acceleration	The maximum capable lateral acceleration for the vehicle at curb weight [m/s^2].

Minimum forward longitudinal velocity	The minimum controllable forward longitudinal velocity for the vehicle at curb weight [m/s].
Maximum forward longitudinal velocity	The maximum capable forward longitudinal velocity for the vehicle at curb weight [m/s].
Minimum reverse longitudinal velocity	The minimum controllable reverse longitudinal velocity for the vehicle at curb weight [m/s].
Maximum reverse longitudinal velocity	The maximum capable reverse longitudinal velocity for the vehicle at curb weight [m/s].
Maximum steering curvature change rate	The maximum steering curvature change rate for the vehicle [1/m*s].
Maximum steering wheel angle left	The maximum steering wheel angle left [deg].
Maximum steering wheel angle right	The maximum steering wheel angle right [deg].
Maximum steering curvature left	The maximum steering angle to the left for the vehicle [1/m].
Maximum steering curvature right	The maximum steering angle to the right for the vehicle [1/m].
Wheelbase	The wheelbase is the measurement between the center of the front and center of tandem on same side of the vehicle [m].
Track width	The distance between the tire centers for an axle [m]. May be defined for each axle on the vehicle.
Nominal ground clearance	The amount of space between the base of the vehicle tire and the underside of the chassis at curb weight [m].
Length	The overall vehicle length measured from forward most point of vehicle to rearward most point of vehicle [m].
Width	The overall vehicle width measured from the outer most protruding fixture on the left and right sides [m].
Length to forward most point of vehicle	The distance from the origin in the vehicle reference frame of the vehicle to the outer surface of the forward most point of the vehicle [m].
Length to rearward most point of vehicle	The distance from the origin in the vehicle reference frame of the vehicle to the outer surface of the rearward most point of the vehicle [m].
Number of axles	The number of axles on the vehicle [-].
Center of gravity (x,y,z)	The center of gravity of the vehicle at curb weight measured from the origin in the vehicle reference frame (x,y,z) [m],[m],[m].
Vehicle mass	The mass of the vehicle at curb weight [kg].
Payload mass	The mass of the payload on the vehicle [kg].

Payload overhang length	The length of the payload that overhangs from the vehicle [m]. Adding the vehicle length and the payload overhang length will give the total length of the vehicle.
Payload overhang width	The width of the payload that overhangs from the vehicle [m]. Adding the vehicle width and the payload overhand width will give the total width of the vehicle.
Query payload overhang height	Query payload overhang height.
Payload center of gravity (x,y,z)	The center of gravity of the payload measured from the origin in the vehicle reference frame (x,y,z) [m], [m], [m].
Minimum braking distance	The minimum braking distance to bring the vehicle to a complete stop from an initial longitudinal velocity of 80 kph at curb weight [m].
Adjusted ground clearance delta	The change in ground clearance due to pressure delta w.r.t cross country setting and other conditions [m].
Tire pressure status	The tire pressure status for a specific axle. (low, normal, over inflated) [-].
Clearance height	The overall vehicle height measured from the top of the vehicle to the ground for clearance purposes [m].
Approach angle	The maximum angle (from the ground) that a hill or obstacle can have and that the front of the vehicle can still clear [deg].
Departure angle	Query departure angle. The maximum angle (from the ground) that a hill or obstacle can have and that the rear of the [deg] vehicle can still clear [deg].
Break-over angle	The angle between the vehicle's tires and the middle of its underside [deg].

C.2 TRAILER PARAMETERS

Message Name	**Short Description**
Trailer status	Specifies if a trailer is attached to the vehicle [-].
Trailer type	The type of trailer.
Trailer reference frame	Located at the center of the rear axle or tandem axle.
Trailer wheelbase	The wheelbase is the measurement from the front of the trailer and the center of the axle or tandem axle. Standard ISO 11992 Geometric Data [m].
Trailer track width	The distance between the tire centers for an axle [m]. May be defined for each axle on the trailer.
Trailer nominal ground clearance	The amount of space between the base of the trailer tire and the underside of the trailer at curb weight [m].

Adjusted ground clearance delta	The change in ground clearance due to pressure delta w.r.t cross country setting and other conditions [m].
Trailer height	The overall trailer height measured from the top of the vehicle to the ground for clearance purposes [m].
Trailer length	The length is measured from the trailer origin to the most rearward surface [m].
Trailer width	The overall trailer width measured from the outer most protruding fixture on the left and right sides [m].
Trailer number of axles	Number of ales on trailer [-].
Trailer center of gravity (x,y,z)	The center of gravity of the trailer at curb weight measured from the origin in the trailer reference frame (x,y,z) [m], [m], [m].
Trailer approach angle	The maximum angle (from the ground) that a hill or obstacle can have and that the front of the trailer can still clear [deg].
Trailer departure angle	The maximum angle (from the ground) that a hill or obstacle can have and that the rear of the trailer can still clear [deg].
Trailer break-over angle	The angle between the trailer's tires and the middle of its underside [deg].
Trailer unloaded mass	The mass of the trailer without payload [kg].
Trailer payload center of gravity (x,y,z)	The center of gravity of the payload measured from the origin in the trailer reference frame (x,y,z) [m], [m], [m].
Trailer payload overhang length	Trailer payload overhang length [m].
Trailer payload overhang width	Trailer payload overhang width [m].
Trailer payload overhang height	Trailer payload overhang height [m].
Trailer payload mass	Trailer payload mass [kg].

C.3 TRAILER HITCH PARAMETERS

Message Name	**Short Description**
Coupling point location for trailer (x,y,z)	The hitch ball mount location measured from the origin of the trailer reference frame (x,y,z) [m], [m], [m].
Coupling point location for vehicle (x,y,z)	The coupling point location measured from the origin of the vehicle reference frame (x,y,z) [m], [m], [m].

C.4 SOFTWARE & HARDWARE INFO

Message Name	**Short Description**

A-kit software version number	A-kit software version number.
A-kit hardware version number	A-kit hardware version number.
A-kit manufacturer code	A-kit manufacturer code.
A-kit hardware manufactured date	A-kit hardware manufactured date.
A-kit IOP version number	A-kit IOP version number.
A-kit software flash date	A-kit software flash date.
B-kit software version number	B-kit software version number.
B-kit hardware version number	B-kit hardware version number.
B-kit manufacturer code	B-kit manufacturer code.
B-kit hardware manufactured date	B-kit hardware manufactured date.
B-kit IOP version number	B-kit IOP version number.
B-kit software flash date	B-kit software flash date.

C.5 ACTUATOR STATE

Message Name	**Short Description**
Transmission current gear	The gear currently engaged in the transmission or the last gear engaged while the transmission is in the process of shifting to the new or selected gear [-].
Steering wheel angle	The main operator`s steering wheel angle (on the steering column, not the actual wheel angle) [deg].
Brake application pressure	Gage pressure of compressed air or fluid in vehicle braking system measured at the brake chamber when brake shoe (or pad) is placed against brake drum (or disc) [kPa].
Brake primary pressure	Gage pressure of air in the primary, or supply side, of the air brake system [kPa].
Brake secondary pressure	Gage pressure of air in the secondary, or service side, of the air brake system [kPa].
Report brake secondary pressure	Report value for brake secondary pressure [kPa].
Steering wheel torque	Steering wheel torque [Nm].
Trailer hitch angle.	Trailer hitch angle [deg].
Tire mode.	Tire mode (CTIS) [-].
Steering wheel angle rate	Steering wheel angle rate [deg/s].
Steering actuator torque	Steering actuator torque [Nm].

Steering actuator position	Steering actuator position [m].
Steering actuator rate	Steering actuator rate [m/s].
Rain sensor status	Rain sensor status.
Brake pedal pressure	Brake pedal pressure.
Parking brake	Switch signal which indicates when the parking brake is set.
Set parking brake	Set value for parking brake actuation [-]. Command signal to influence the pneumatic pressure in the circuit or reservoir for the parking brake and/or the trailer supply.
Wiper fluid level	Wiper fluid level [-]. Values: low, not low
Accelerator pedal position	Accelerator pedal position. The ratio of actual position of the analog engine speed/torque request input device to the maximum position of the input device.
Engine desired throttle valve position	Engine desired throttle valve position. The desired position of the Throttle valve.

C.6 NAVIGATION DATA

Message Name	**Short Description**
Longitudinal acceleration	Longitudinal acceleration. Indicates the longitudinal acceleration of the vehicle [m/s^2].
Lateral acceleration	Indicates a lateral acceleration of the vehicle (the component of vehicle acceleration vector along the Y-axis) [m/s^2].
Wheel-based vehicle speed	Speed of the vehicle as calculated from wheel or tail shaft speed [m/s].
Yaw rate	Indicates the rate of rotation about the vertical axis (i.e. the z-axis) [deg/s].
Wheel speeds	High resolution measurement of the speed of the wheels [m/s].
Roll angle	The angle between the vehicle y-axis and the ground plane (i.e. rotation about the X-axis) [deg].
Roll rate	Query value for roll rate. Roll rate is the rate-of-change of the roll angle over time [deg/s].
Pitch angle	Pitch (rotation about the y-axis) of the vehicle as calculated by the navigation device(s) [deg].
Pitch rate	Pitch rate is the rate-of-change of the pitch angle over time, where the pitch angle vector is in the direction of travel of the vehicle [deg/s].

C.7 ADVANCED EMERGENCY BRAKING SYSTEM

Message Name	Short Description
Advanced emergency braking system state	Current operational state of advanced emergency braking system.
Collision warning level	To implement different HMI (human machine interface) concepts, e.g. visual only, visual/audible, different warning tones etc., the AEBS provides different levels of collision warning.
Relevant object detected for AEBS	Indication if the advanced emergency braking system (AEBS) is monitoring a relevant object.
Bend off probability of relevant object	Probability if monitored relevant object might start a turning maneuver, which could clear the travelling path of the host vehicle.
Time to collision with relevant object	The time to collision is the duration after which the predicted travelling paths of host vehicle and relevant object lead to a distance of 0m between both.

C.8 MILITARY LIGHTING COMMAND

Message Name	Short Description
Rear black out marker select	Rear black out marker select.
Front black out marker lamp select	Front black out marker lamp select.
Convoy lamp select	Convoy lamp select.
Convoy driving lamp select	Convoy driving lamp select.
Black out brake/stop lamp select	Black out brake/stop lamp select.
Night vision illuminator select	Night vision illuminator select.
Black out work lamp select	Black out work lamp select.
Black out intensity selection	Operators black out intensity selection.

C.9 VEHICLE PATH

Message Name	Short Description
Vehicle drive mode	Set value for vehicle drive mode. Three types of drive mode: direct control, waypoint, clothoid, and spline.
Set steering wheel request	Set value for steering request. Parameters [max torque, swa, max swa rate, swa control flag].
Set Steering Curvature	Set Steering Curvature [1/m]
Set speed request	Set value for speed request [speed, max acceleration] [km/h].
Set transmission gear request	Set value for transmission gear request [gear range, gear]. Gear requested by the operator, ABS, or engine.

Query clothoids	Query value for clothoids.
Report clothoids	Report value for clothoids.
Set clothoids	Set values for clothoids [-].
Set spline	Set values for splines [-].

C.10 SECONDARY CONTROLS

Message Name	Short Description
Set turn signal	Set value for turn signal.
Set hazard lights	Set value for hazard lights.
Set high/low beam	Set value for high/low beam.
Set reverse lights	Set value for reverse lights.
Set brake lights	Set value for brake lights.
Set horn state	Set value for horn state.
Set wiper	Set value for wiper.
Set front sensor cleaning fluid	Set value for front sensor wiper fluid.
Set rear sensor cleaning fluid	Set value for rear sensor wiper fluid.
Set door lock/unlock	Set value for door lock/unlock.
Set start/stop engine	Set value for start/stop engine.

C.11 HEALTH STATUS

Message Name	Short Description
A-kit heartbeat	Report value for A-kit heartbeat.
B-kit heartbeat	Report value for B-kit heartbeat.
A-kit health status	Report value for A-kit health status.
B-kit health status	Report value for B-kit health status.

C.12 BATTERY

Message Name	Short Description
Battery status	Report value for battery status.
Battery charge level	Report value for battery charge level.

C.13 ACTIVE SAFETY MODULES

Message Name	Short Description
Yaw stability control status	Report value for yaw stability control status.
Roll stability control status	Report value for roll stability control status.
ABS status	Report value for ABS status.
Road surface friction detection status	Report value for road surface friction detection status.
Traction control status	Report value for traction control status.
Lane keeping control	Report value for lane keeping control.

C.14 ENGINEDATA

Message Name	Short Description
Fuel level	Report value for fuel level.
Oil level	Report value for oil level.
Hydraulic brake level	Report value for hydraulic brake level.
Coolant level	Report value for coolant level.
Air intake temperature	Report value for air intake temperature.
Humidity	Report value for humidity.
Exhaust temperature	Report value for exhaust temperature.
Engine state	Report value for engine state.
Power mode	Report value for power mode.
Engine speed	Report value for engine speed.

C.15 PLATFORM MODE

Message Name	Short Description
Platform mode	Report value for platform mode. Mode - startup, shutdown, standby, ready, in use/busy, and reset.
Set platform mode	Set value for platform mode. Mode - startup, shutdown, standby, ready, in use/busy, and reset.

C.16 EMERGENCY STOP

Message Name	Short Description
Report emergency stop	Report emergency stop.
Set emergency stop	Set emergency stop.
Clear emergency stop	Clear emergency stop.

C.17 DRIVE MODE

Message Name	Short Description
Report drive mode	Mode -manual mode, remote control, teleoperation, leader/follower.
Set drive mode	Set value for drive mode.

C.18 TIME

Message Name	Short Description
Set system time	Set value for system time.
Report system time	Report value for system time.

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