Designation: F2545 – 07

Standard Guide for Unmanned Undersea Vehicle (UUV) Physical Payload Interface[1]

This standard is issued under the fixed designation F2545; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

INTRODUCTION

ASTM has prepared this series of standards to guide the development of autonomous unmanned underwater vehicles (UUVs). The standards address the key capabilities that a UUV system must possess in order to be considered autonomous and reconfigurable:

Autonomous—Capable of operating without operator input for extended periods of time. Implicit in this description is the requirement that the UUV's sortie accomplishes its assigned goal and makes the appropriate rendezvous for a successful recovery.

Reconfigurable—Capable of operating with multiple payloads.

The top level requirement is established that the UUV systems will consist of:

Payloads to complete specific system tasking such as environmental data collection, area surveillance, mine hunting, mine countermeasures, intelligence/surveillance/reconnaissance (ISR), or other scientific, military, or commercial objectives.

Vehicles that will transport the payloads to designated locations and be responsible for the launch and recovery of the vehicle/payload combination. While the payload will be specific to the objective, the vehicle is likely to be less so. Nevertheless, commonality across all classes of UUV with respect to such features as planning, communications, and post sortie analysis (PSA) is desirable. Commonality with regard to such features as launch and recovery and a common control interface with the payload should be preserved within the UUV class. In accordance with this philosophy, ASTM identifies four standards to address UUV development and to promote compatibility and interoperability among UUVs:

F2541 Guide for UUV Autonomy and Control,
F2545 Guide for UUV Physical Payload Interface,
F2594 Guide for UUV Communications, and
F2595 Guide for UUV Sensor Data Formats.

The relationships among these standards are illustrated in Fig. 1. The first two standards address the UUV autonomy, command and control, and the physical interface between the UUV and its payload. The last two ASTM standards address the handling of the most valuable artifacts created by UUV systems: the data. Since there are many possibilities for communications links to exchange data, it is expected that the UUV procurement agency will provide specific guidance relative to these links and the appropriate use of the UUV communications standard. In a similar manner, specific guidance is expected for the appropriate use of the UUV data formats.

F2541 Standard Guide for UUV Autonomy and Control—The UUV autonomy and control guide defines the characteristics of an autonomous UUV system. While much of this guide applies to the vehicle and how the vehicle should perform in an autonomous state, the relationship of the payloads within the UUV system is also characterized. A high level depiction of the functional subsystems associated with a generic autonomous UUV system is presented. The important functional relationship established in this guide is the payload's subordinate role relative to the vehicle in terms of system safety. The payload is responsible for its own internal safety, but the vehicle is responsible for the safety of the vehicle-payload system. Terminology is defined to provide a common framework for the discussion of autonomous systems. System behaviors and capabilities are identified that tend to make a system independent of human operator input and provide varying levels of assurance that the UUV will perform its assigned task and successfully complete recovery. A three-axis sliding scale is presented to illustrate the system's level of autonomy (LOA) in terms of situational awareness,

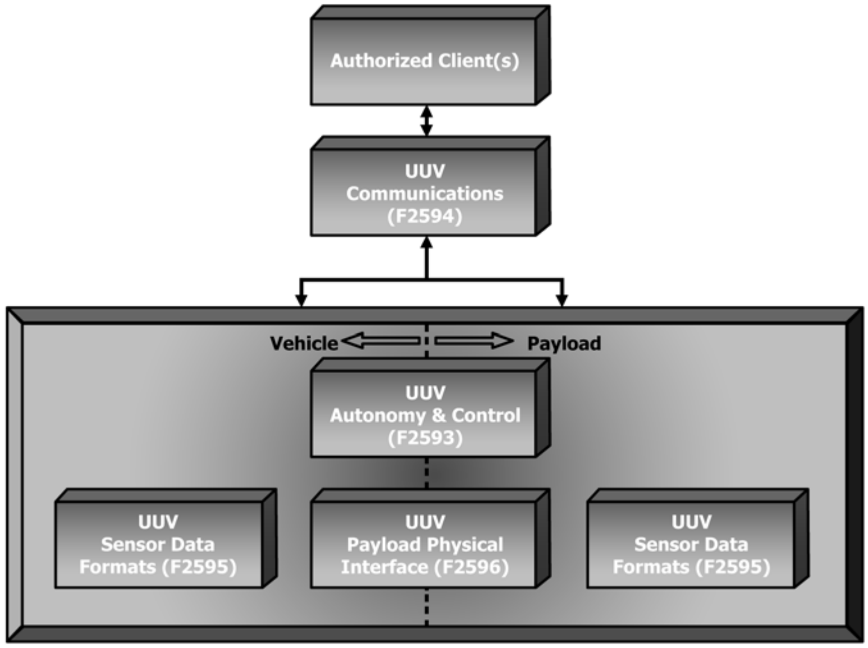

FIG. 1 Notional System Interfaces and Governing Standards

decision-making/planning/execution, and external interaction. The control interface (messages exchanged between the vehicle and the payload) is described and instantiations of this interface for the various classes of UUV are presented in associated appendices.

F2545 Standard Guide for UUV Physical Payload Interface—The UUV physical payload interface guide is a physical and functional interface standard that guides: the mechanical and electrical interface between the vehicle and the payload, and the functional relationship between the vehicle and the payload. Inasmuch as a single physical interface standard cannot address all classes of UUVs, this guide describes the physical interfaces in the body of the guide and provides appendices to guide the instantiation for each of the classes. This guide reinforces the relationship between the vehicle and the payload and confirms the permission-request responsibility of the payload and the permission granted/denied authority of the vehicle.

F2594 Standard Guide for UUV Communications—The UUV communications standard guides the development of offboard communications between the UUV system and the authorized clients, that is, those agents designated by the UUV operational authorities with responsibility for programming, operating, or maintaining a UUV, or a combination thereof. An authorized client may also represent an end user of UUV and payload mission data. Such a standard is required to provide for UUV interoperability with multiple authorized agents and to provide the authorized agents with interoperability with multiple UUVs (preferably across the different classes of UUVs). Optical, RF and acoustic methods of communication are considered. While RF communication is a matured communications mode and existing standards are referenced and adopted for offboard surface communication, underwater acoustic communication (ACOMMS) is an evolving field and interoperability between the different ACOMMS systems is also evolving. Typical ACOMMS systems and protocols are described with typical applications related to bandwidth and range. General comments are provided for optical communication as the use of this mode of communication may evolve in the future.

F2595 Standard Guide for UUV Sensor Data Formats—The UUV sensor data formats guide provides the UUV and payload designer with a series of commonly accepted data formats for underwater sensors. These formats provide the opportunity for two-way interoperability. Their use facilitates the UUV system's ability to process historical environmental data for mission planning purposes. Likewise, use of these formats facilitates the end users' ability to catalog, analyze, and produce recommendations based on current field data. Fig. 1 suggests that both vehicle-specific data as well as payload sensor data should be stored in these data formats.

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[1] This guide is under the jurisdiction of ASTM Committee F41 on Unmanned Undersea Vehicle (UUV) Systems and is the direct responsibility of Subcommittee F41.03 on Mission Payload Interface.

Current edition approved Aug. 1, 2007. Published September 2007. DOI: 10.1520/F2545-07.

1. Scope

1.1 This guide covers the interface requirements for physical payload interface for Unmanned Undersea Vehicles (UUVs). In its initial release, the purpose of this standard is to specify the physical, electrical, and operational interfaces between the host UUV and the modular payload sections. This guide provides specific requirements for the 21-in. heavyweight UUV body. Future iterations of this standard will add requirements for additional bodies.

1.2 The desired system is based on the qualitative features defined in this guide and the quantitative requirements as specified in individual performance specifications. Quantitative measures are beyond the scope of this guide. The resulting system is a combination of both.

1.3 This guide is intended to provide the developer with parameters necessary to integrate various combinations of system components and mission payload packages into the UUV, but at the same time not specify particular products. The established standard evaluates several autonomous vehicle architectures, performs a functional decomposition, and identifies key aspects that are common throughout. Through this process, a common architecture standard can be adopted that covers the family of unmanned undersea vehicles (UUVs) and the integration of emerging technologies.

1.4 This guide should be tailored to each application.

1.5 This guide does not attempt to specify a particular version of a commercial product or tool, but it does show examples that might conform. This guide does not address specific system functionality required of UUVs, but focuses on architectural matters.

1.6 The values stated in inch-pound units are to be regarded as standard.

1.7 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. Referenced Documents

2.1 *ASTM Standards:*[2]

F2541 Guide for Unmanned Undersea Vehicles (UUV) Autonomy and Control (Withdrawn 2015)[3]

F2594 Guide for Unmanned Undersea Vehicle (UUV) Communications

F2595 Guide for Unmanned Undersea Vehicle (UUV) Sensor Data Formats

2.2 *Government Standards:*[4]

NAVSEA 5855688 Mk 48 Shell Joints Male/Female

NAVSEA 8293251 System Specification for the Mission Reconfigurable Unmanned Undersea Vehicle System (MRUUVS)

3. Terminology

3.1 *Definitions:*

3.1.1 *application software, n*—high-level software that is unique to the application for which the processor exists and represents the major cost driver of long-term development costs.

3.1.2 *application software interface, n*—boundary between the application software and the software execution platform.

3.1.3 *autonomy module, n*—in accordance with Guide F2541, a higher-level controller that interfaces with external systems (that is, mission downloads, mission retasking from platforms, and so forth).

3.1.3.1 *Discussion*—The mission controller tracks obstacle and terrain avoidance inputs and may update or replan the UUV sortie based upon sensor input to meet mission plans and objectives.

3.1.4 *conformance, n*—degree by which a design conforms to a particular standard.

3.1.5 *device drivers, n*—low-level software that manages the input and output to the various external devices in support of the application software.

3.1.6 *distributed architecture, n*—allows for local control of processes and local processing of data, which eliminates the need for passing large amounts of data across networks.

3.1.6.1 *Discussion*—A distributed architecture also allows for the removal or update of a particular function without changes to the rest of the system. The functionality of Forward Look Sonar (FLS) might change, but as long as the output remains constant, there is no need for any additional changes to the system.

3.1.7 *emerging payload, n*—payload capabilities that have not been defined at this time.

3.1.7.1 *Discussion*—Section 1.3 of the UUV Master Plan[5] describes research and development (R&D) enabling technologies.

3.1.8 *event driven, adj*—type of architecture in which individual components announce data that they wish to share with other components.

3.1.8.1 *Discussion*—The reporting of the FLS sensor with specific target data is an example of an event-driven architecture. The FLS can send specific messages that cause an action for the vehicle controller.

3.1.9 *heterogeneous, adj*—implies that several styles of architecture may be required and are allowed by this standard.

3.1.10 *hierarchical, adj*—implies a layered order of control.

3.1.10.1 *Discussion*—For example, a master controller controlling a lower layer of processors.

3.1.11 *interoperability, n*—ability of two or more systems to exchange information and use the information that has been exchanged mutually.

[2] For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

[3] The last approved version of this historical standard is referenced on www.astm.org.

[4] Available from Naval Sea Systems Command (NAVSEA), 1333 Isaac Hull Ave., SE, Washington, DC 20376, http://www.navsea.navy.mil.

[5] Navy Unmanned Undersea Vehicle (UUV) Master Plan, November, 2004.

3.1.12 *middleware, n*—software layer between the application software and the hardware, which is connectivity software that consists of a set of enabling services that allow multiple processes running on one or more machines to interact across a network and is essential to migrating cross-platform applications to client/server applications and providing for communication across heterogeneous platforms.

3.1.12.1 *Discussion*—This technology has evolved during the 1990s to provide for interoperability in support of the move to client/server architectures.

3.1.13 *modular, adv*—supports a wide range of payloads and sensors.

3.1.14 *modularity, n*—system shall be modular to support a wide range of payloads and sensors.

3.1.14.1 *Discussion*—A major attribute of the proposed architecture is its ability to support a wide range of missions thus requiring a modular system. Modular code allows for functions developed from one platform to be rehosted on another, thus enhancing the portability of the system.

3.1.15 *open architecture, n*—architecture open to the inclusion of many formally standardized components and products (hardware and software).

3.1.15.1 *Discussion*—It allows the developer to obtain components from a variety of sources, thus creating competition and lowering costs. The term "open system" also implies components and product modularity and that upward compatibility has been given a high priority. Open systems allow for solutions of common problems across platforms and reduce training and logistics costs.

3.1.16 *operating system, n*—low-level software that, once booted, manages all other software (this management involving such things as multitasking, memory sharing, I/O interrupt handling, error and status reporting, and so forth).

3.1.17 *payload control support equipment (PCSE) or shipboard deployed equipment (SDE), n*—provides off-vehicle control, check-out, programming and data retrieval of the payload.

3.1.18 *payload controller, n*—provides a level of local control over mission-specific payload sensors and payload data recoding. Will interface with the Autonomy Module.

3.1.18.1 *Discussion*—As missions and payloads become more sophisticated, responsibilities between payload and mission controllers may evolve, and the control architecture needs to be flexible enough to accommodate growth.

3.1.19 *portability, n*—ease with which application software and data can be transferred from one application platform to another.

3.1.20 *scalability, n*—ability to provide functionality up and down a graduated series of application platforms that may differ in speed and capacity.

3.1.21 *vehicle controller, n*—provides real-time, autonomous guidance, navigation, and control of the UUV using a predefined sortie plan and provides supervisory and execution authority on vehicle-related functions.

4. Requirements

4.1 *Definition*—The vehicle payload shall consist of a modular payload section and all required support and test equipment. Fig. 2 shows the major payload interfaces.

4.2 *Payload Section Characteristics*—The following sections detail the required interface characteristics of the vehicle payload relative to physical requirements and interface specifications and protocol. Environmental requirements imposed on the payload section shall be in accordance with (IAW) NAVSEA 8293251. Performance characteristics shall be unique to the specific mission payload section.

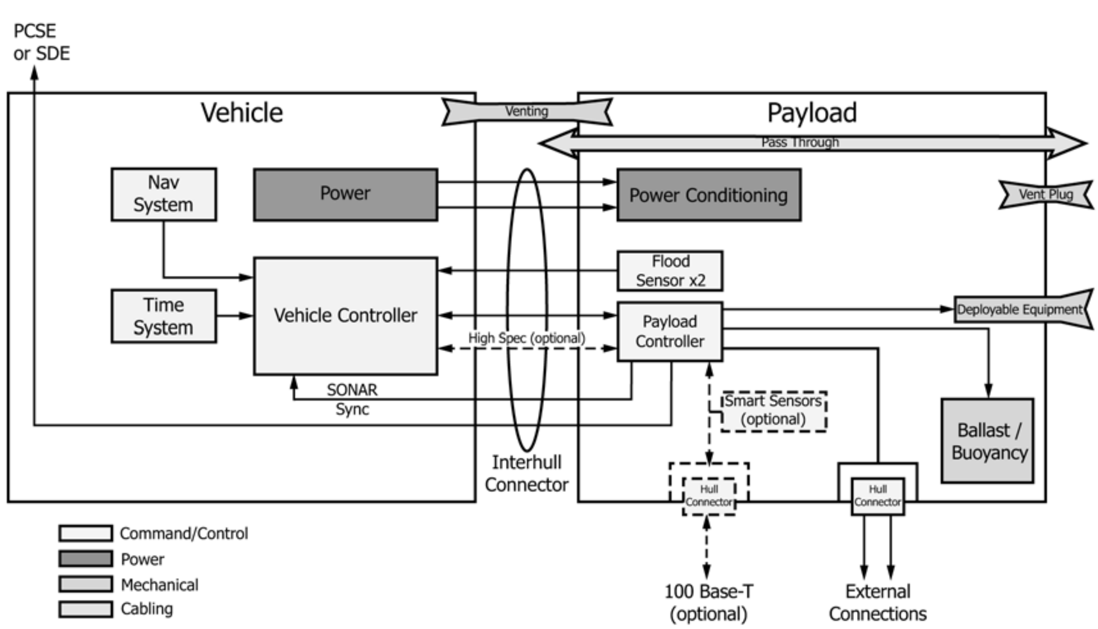

FIG. 2 Payload Interfaces

4.3 *Physical Characteristics*—This section identifies the physical characteristics for the modular payload section. The payload shall be provided as a stand-alone hull section. Readily removable bulkheads shall be provided at each hull joint to provide containment of the internal volume during payload section change-out. Containment bulkheads shall be capable of at least a 15-psi differential between the payload section and the mating vehicle sections. A relief valve shall be provided in the bulkhead to ensure venting of internal volume prior to bulkhead failure in the event of over pressurization. If wet volume is required, payload bulkheads shall be capable of meeting full UUV host operational depth requirements.

4.3.1 *Size:*

4.3.1.1 *Volume*—The mission payload module shall be configured to achieve all sortie goals and maintain a volume allocation of 5 ft^3.

4.3.1.2 *Diameter*—The payload shall have an maximum outer diameter (OD) diameter of 20.940 in. that shall include all protective coatings (not including alignment and locating components), and shall fit into a true right circular cylinder of 21.035 in. diameter. Payload equipment is allowed to extend beyond this diameter during operations; however, the payload shall be capable of fully stowing all deployable equipment to within this diameter.

4.3.1.3 *Weight*—The payload shall not exceed a maximum weight of 400 lb.

4.3.2 *Buoyancy and Trim:*

4.3.2.1 *Longitudinal and Transverse Moments*—The maximum longitudinal moment while operating submerged shall be 1000 in.-lb (0.77 in. longitudinal CG-CB separation for a 100 in. payload). The maximum transverse moment at all times shall be 80 in.-lb (0.06 in. transverse CG-CB separation for 100 in. long payload).

4.3.2.2 *Lateral Moment*—The payload CG must always remain below the CB to produce a stable righting moment. Payload minimum righting moment shall be 6.5 in.-lb/inch of payload length and a maximum of 13 in.-lb/inch of payload length. For example, a 100 in. long payload must have a righting moment of 650 to 1300 in.-lb (this is equivalent to a 0.5 to 1.0 vertical separation between the CB and CG for 100-in. long neutrally buoyant payload displacing 1300 lb).

4.3.2.3 *Buoyancy*—The payload section shall be designed to be within 5 lb of neutral buoyancy during vehicle submerged transit operations (payload non-operating) in water density of 63.3 lb/ft^3. It shall be assumed that the host vehicle ballasting system can accommodate any change in displacement resulting from submerged transit operations in other densities. The payload shall be designed to be within 30 lb of neutral buoyancy at all other times (payload operations, surfaced operations with masts deployed, payload drop operations, and so forth).

4.3.3 *Hull, Mechanical and Electrical (HM&E), Connectors and Vent Plugs:*

4.3.3.1 *Joint Bands and Joint Convention*—Joint bands and joint conventions shall be compatible with the NAVSEA 5855688 Mk 48 joint design in accordance with drawing NAVORD 2509404 where Detail A defines the aft joint and Detail B defines the forward joint.

4.3.3.2 *Connections:*

(1) Inter-Hull Section Connector Service Loops—Inter-hull section connections shall be in accordance with the higher level vehicle specification. Shell section to shell section connections can be either cabled or blind mated. If cabled, all connections should have service loops that permit section-to-section separation of 18 in. while the connections are still mated. In addition, connections should be either unique or keyed at each section interface so as to prevent incorrect mating. If blind mate connections are used, NAVSEA 8293251 defines location and allowable misalignments. The connection design shall include features that ensure live contacts cannot be accidentally contacted.

(2) External Connections—If the payload contains equipment that can be programmed or collects and stores data, the payload shall contain an external serial port and data upload port to support pre- and post-sortie checkout and sortie data downloads and uploads. These connections shall be dry connections only, but designed to withstand the full operating pressure of the host UUV. The payload shall support the provision of main bus voltage and current through an external connection to enable the payload to be operated with the vehicle assembled, but using 'shore' vice vehicle power. Location and type of ports shall support ease of maintenance and operation and if possible, all ports shall be located in the same vicinity on the hull.

4.3.3.3 *Leak Detection*—Allocation shall be provided for two leak detection sensors to be housed in the payload section and utilize payload connector pinouts. One leak detect shall be located at either end of the payload and utilize separate lines for each sensor. Sensor output shall be supplied to the vehicle controller for status and subsequent action. The payload may be equipped with additional leak detect sensors that are monitored by the payload controller only.

4.3.3.4 *Pass-Through and Service Loop Allocation*—Pass-through and service loop volume shall be provided to accommodate the passage of electrical, fiber optic, and ballast piping across the length of the payload section, as required. Sufficient service loops of these pass-through function connectors shall be supplied to enable the connectors to be mated while the vehicle and payload sections are unassembled. The cross-sectional area required for pass-through should be assumed to be 2 by 3 in. This volume allocation within the payload section may be routed as desired to accommodate payload section component placement.

4.3.3.5 *Power*—Power delivery to the payload section shall be controlled by a relay located in the vehicle. The relay can be enabled or disabled by the vehicle controller or by operator command to the vehicle controller. Under normal shutdown conditions, appropriate commands and times shall be provided to the payload to enable an orderly shutdown of payload operations. In the event of emergency vehicle shutdown, immediate and uncontrolled removal of payload section power may occur. The payload section shall be capable of withstanding such a shutdown condition without hardware failure and be capable of restarting. As an objective, the payload shall be capable of accepting alternate power supply through an external connection in addition to the main vehicle electrical interface. If this capability is provided, appropriate circuitry and safeguards shall be provided to protect personnel and equipment from overcurrent or overvoltage conditions. Payload section recorded data shall be preserved within the payload in the event of a sudden loss of power (see Data Storage, 4.3.4.11).

(1) Bus Voltage—The vehicle shall provide the payload with a single bus voltage. Bus voltage shall be between 80 V dc and 100 V dc.

(2) Current and Power Load—Two supply lines shall be provided to the payload. Each line shall have a maximum current draw of 7 A. Maximum continuous payload current shall be less than 12.5 A. The maximum continuous power supplied by the vehicle energy system to the payload section shall be 1000 W.

(3) Power Regulation—Power supplied to the mission payload section will have a voltage ripple of less than 3.5 % RMS.

4.3.3.6 *Heating/Cooling*—The payload section design shall provide sufficient methods to heat or cool internal vehicle payload systems or components housed in the payload section to enable continuous operation while in water. There shall be no provisions for transfer of internal vehicle atmosphere between the vehicle and the payload section. The payload's cooling system shall enable the payload to be operated in air for 30 min at 104°F ambient temperature. Cooling blankets or external forced air cooling is permitted to meet this requirement in a laboratory environment.

4.3.3.7 *Vent Plug*—The payload section shall contain a vent plug that enables the payload section to be purged and backfilled separately from the remainder of the vehicle. The vent plug fitting shall be a standard fitting.

4.3.3.8 *Electro-Magnetic Interference and Electro-Magnetic Compatibility (EMI/EMC)*—EMI and EMC requirements for the mission payload shall conform to the limits set forth in NAVSEA 8293251.

4.3.4 *Functional Characteristics:*

4.3.4.1 *Payload Operations and Control*—The payload shall have a payload controller that provides the primary command and control interface to the vehicle controller. The Payload Controller (PC) shall provide interface and control of all payload section related equipment. The PC shall monitor and record payload section health and status during all payload section operating states. The PC shall have the capability of receiving mission or preset data from the Vehicle Controller (VC) or the Payload Control Support Equipment (PCSE)/Shipboard Deployed Equipment (SDE) to configure sensors or to provide specific operational guidelines prior to vehicle launch. The PC or its subsystems, or both, shall provide the capability to upload or access mission data via the PCSE or SDE without compromising the watertight integrity of the vehicle. Access ports, connectors, or any method utilized to obtain mission data shall not allow venting of the internal payload atmosphere if operated aboard a submarine.

4.3.4.2 *Physical Control Interface*—The payload controller shall provide an interface to the vehicle controller and an external interface. The following sections identify specific requirements for these interfaces.

(1) Internal—The command and control interface between the vehicle controller and the PC shall be compatible with 100 base T Ethernet as a minimum. Sensor data may require a separate higher-speed data interface. Interface protocol and requirements shall be as defined in 4.3.5.

(2) External—The payload shall have an external 100 base T Ethernet connection to provide a command and control interface with PCSE or Shipboard Deployed Equipment (SDE) during pre-launch and post sortie activities. This should support the capability for the external equipment to communicate with any 'smart' sensors (for example, Ethernet equipped sensors) without going through the payload controller. The payload shall also support high-speed offload of mission data. An additional external penetration may be provided to support this requirement.

4.3.4.3 *Power Distribution*—Power distribution and sequencing of required sensors shall be managed to prevent interference or power consumption in excess of the allocated payload section energy budget.

4.3.4.4 *Payload Behaviors*—If required, the PC shall provide behaviors or activities to operate the payload section, request maneuvering of the vehicle, or optimize sensor performance based upon sensor parameters or status. The concept of operations (CONOPS) for each smart sensor shall be provided or performed by the PC.

4.3.4.5 *Sonar Systems*—The payload will allow for an external synchronization capability if equipped with a sonar projector, to allow sonar emission synchronization with vehicle sonar systems.

4.3.4.6 *Operation of Deployable Equipment*—The payload section, if equipped with any deployable equipment (sensor mast, package drop, and so forth), shall not deploy this equipment without a command to do so by the vehicle. (This command may originate in the vehicle, or may simply be passed through the vehicle from the onboard autonomous controller or an off-board authority.) The payload shall be capable of determining its ability to comply with the command from the vehicle, and inform the vehicle if it is unable to comply. The payload shall not be permitted to stow (as required) deployable equipment unless commanded to deploy by the vehicle, either due to completion of operations, or fault or hazard conditions being detected. All operations of deployable equipment, and the status and success or failure of those operations, shall be communicated to the vehicle.

(1) Emergency Retraction or Jettison—The payload shall be capable of either emergency retraction or jettison of any deployable equipment upon receipt of such a command from the vehicle.

4.3.4.7 *Off-Hull Communications*—The payload, if equipped with payload specific communication equipment, shall request and receive approval from the vehicle prior to any off-board communication transmissions. The payload may also request that payload section data be transmitted via the vehicle.

4.3.4.8 *Vehicle Maneuvering Operations*—If required, the payload shall be capable of requesting vehicle maneuvers. These requests shall consist of absolute position (waypoint) or course, speed, and depth (CSD) commands to the vehicle. The interaction between the vehicle, payload and autonomous control functions are discussed in the Guide F2541.

4.3.4.9 *Health Status*—The payload shall perform a built-in-test (BIT) functional checkout at power up and provide positive operating status or availability, or both, of all payload equipment to the vehicle. The payload shall continuously monitor it's own status, periodically inform the vehicle of any changes to status during the sortie, and immediately inform the vehicle of any fault conditions that are detected.

4.3.4.10 *Time Synchronization*—The payload shall be capable of synchronizing its time reference with that of the vehicle.

4.3.4.11 *Data Storage*—The payload shall be capable of storing critical sortie data in non-volatile memory. The storage capacity shall be sufficient to record all commands to and from the vehicle, all commands to and from internal payload equipment and sensors, health and status data, and all mission data collected by the payload sensors. (It is acceptable for the payload sensors to store the mission data, provided the means to forward this data to the payload controller, as well as to the external connection, is provided.)

4.3.5 *Signal Interface Requirements*—Interface requirements will be in accordance with Guide F2595.

5. Software Language

5.1 *Vendor Specified*—A common software language that is cross-platform compatible is desired. This would support the key aspects of portability, modularity, and scalability of this standard.

6. Operating System

6.1 *Vendor Specified*—To meet the demands of vehicle command and control, a real-time operating system (RTOS) is recommended.

7. Processors

7.1 Vendor defined.

8. Security

8.1 Director of Central Intelligence Directive 6/3, Protecting Sensitive Compartmented Information within Information Systems (DCID 6/3), defines levels of protection and necessary steps in developing a system. Depending on the level of security classification, Department of Defense Information Technology Certification and Accreditation (DITSCAP) and/or the Department of Defense Intelligence Information System (DODIIS) manuals provide additional guidance. Where mission drivers warrant, the UUV control architecture will need to satisfy information assurance requirements involving multi-level security classification information. The interface between vehicle Autonomy module and payload controller is the recommended interface at which UUV information assurance requirements can be accommodated through a combination of operating system, hardware, and middleware safeguards.

9. Keywords

9.1 physical payload interface; unmanned undersea vehicle; UUV