The Evolution of the Rapid Integration Framework

Lessons Learned from the Army Crew Mission Station (CMS) Project

Army FACE™ TIM Paper by:

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Executive Summary

The project vision for the US Army's Crew Mission Station (CMS) is to define an enduring Open Systems Architecture (OSA) approach and management strategy capable of providing new capabilities to the UH-60 fleet in the shortest timeframe possible. This vision stemmed from a set of technical and business objectives expressed by the U.S. Army stakeholders.

The strategies to achieve these objectives included viewing the CMS system as a core system that could host future (currently unknown) capabilities. The lessons learned from the CMS lab and flight demonstrations, particularly the idea of defining the common hardware and software components that make up the core system to deploy capabilities on, led to the idea of establishing a set of requirements for a Rapid Integration Framework (RIF). Ideally, this framework will consist of proven software and hardware components for the core system and modular hosted capabilities that can be rapidly composed into Rapid Integration Platforms (RIP) that meet specific mission needs. Although the term was not defined at the time, the CMS system is a representative implementation of such a Rapid Integration Platform.

The information presented in this paper should be of interest to many FACE stakeholders since it highlights how the FACE Technical Standard and FACE Data Model concepts supported the modularity and reusability of component and software developed for the RIF and RIP.

Introduction

The U.S. Army's UH-60 Futures Team initiated the Crew Mission Station (CMS) project with the objective of providing computing resources and increased situational awareness (SA) for the non-rated crew members in the cabin of the utility Black Hawk. The project vision was to produce an enduring open systems architecture and management plan capable of providing new capabilities to the UH-60 fleet in the shortest timeframe possible. The project included a flight demonstration and flight test to verify the capabilities of the CMS system and the CMS architecture.

Throughout the development of the CMS, it was clear that such a system has many potential uses, and that the architectural requirements for such a system be should be developed to adapt to the widest variety of capabilities. The success of the CMS laboratory and flight demonstrations generated interest from other user communities within the Army and other branches of the DoD. This led the CMS team to consider how other aviation platforms could benefit from a "system" capable of rapidly hosting an even broader variety of capabilities, while still taking advantage of the Core/Hosted and other patterns developed on CMS. Such systems could share software and hardware components offering a greater level of portability through proven integration onto systems utilizing a common OSA. This common OSA, is now known as the Rapid Integration Framework (RIF).

The Army needs to constantly evolve to respond to new threats and emerging capabilities. The RIF will allow programs to "deliver performance at the speed of relevance" and "modernize key capabilities", which are key Modular Open Systems Approach (MOSA) aspects highlighted in the 2018 National Defense Strategy.

The CMS to RIF Evolution

The architectural decision to implement the CMS as a core system that hosts capabilities provided the initial glimpse into the concepts of a Rapid Integration Framework (RIF) and Rapid Integration Platform (RIP). The RIF is best defined as a technology agnostic, logical expression of high-level stakeholder requirements. The RIF defines the components, organization, relationships and key interfaces intended to address the government's business and technical objectives of an open, vendor neutral architecture capable of rapidly fielding new capabilities. A RIP is defined as a cyber-physical "entity" or system that is derived from and traceable to the RIF. RIP systems will be created to meet particular mission or platform requirements. Although neither term was defined at the time, the CMS system implementation could be considered the first Rapid Integration Platform, in that it was designed to rapidly host new capabilities.

Two previously published FACE Technical Interchange Meeting (TIM) papers, "Crew Mission Station (CMS) Comprehensive Architecture Strategy" and "The Impact of the FACE Technical Standard on the Crew Mission Station Objectives" highlighted the Business and Technical Objectives of the CMS system stakeholders. The approach taken to achieve the CMS objectives, along with how the FACE Technical Standard helped to meet the objectives were included in the papers. Many of the CMS objectives were translated into the guiding objectives for the RIF and RIP, including the high level objectives provided below:

- Provide the ability throughout system lifecycle to add new capabilities that are unknown at the time the system is initially installed on the aircraft
- Reduce duplicative development and improve reuse across platforms
- Improve Speed to Field through reduced integration and certification timelines and processes

Like CMS, the vision for the RIF/RIP is to provide a means of providing new capabilities to the war fighter in the shortest timeframe possible. The approach to meeting this vision and supporting other business and technical objectives centers on the strategy of defining the RIF as a set of requirements for a core system that hosts modular capabilities. Through the use of proven strategies such as Integrated Modular Avionics (IMA) and a product line approach, RIF aligned systems will have the capacity to expand and to allow for the rapid insertion of additional capabilities after the system is in the field.

Including the role of an Architecture Maintainer, as described in the previous CMS TIM papers, will ensure RIF implementations avoid common pitfalls leading to vendor lock. Government authority over the RIF architecture, specifically its modularity and key interfaces, will ensure that the government's business and technical objectives will be achieved.

Elements Defining the RIF

The RIF combines a number of complementing strategies and approaches including IMA, Product Lines, Objective Architectures as defined in the Comprehensive Architecture Strategy (CAS), and MOSA. These techniques, along with the Army Common Operating Environment (COE) mandate to adopt the FACE Technical Standard for the Real Time Safety Critical Embedded (RTSCE) Computing Environment (CE) for Army Aviation, contributed to the architecting and design of a framework for a family of systems that can be rapidly developed and composed. The framework provides the OSA for the integration platform that hosts user capabilities for a system architecture that enables an innovative detailed design. It provides little "sandboxes" for technology or capability maturation e.g. smart displays, new maps, new bus types etc.

IMA

The concept of a core system and its hosted capabilities is directly derived from the Federal Aviation Administration (FAA) guidance on Integrated Modular Avionics found in RTCA DO-297. IMA provides a path to airworthiness for qualification of an IMA platform and independent qualification of IMA hosted applications that could be installed on that platform. The final qualification of the combined system is then easier, reducing the qualification efforts of the final integrated system.

Through the use of IMA, a platform consisting of the hardware and software needed to support additional capabilities can be developed and complete some level of qualification. In the RIF, this platform is called the Core System.

"Hosted Capabilities" that are developed to deploy to the Core System follow IMA's hosted application approach and can achieve their own level of qualification independent of the core system. The integration of the Hosted Capabilities onto the Core System should greatly reduce the qualification efforts when they are reused in subsequent combinations.

Designing capability software as both FACE Units of Conformance (UoCs) and IMA hosted applications should provide a greatly reduced test and qualification cycle, aiding in meeting the principal requirement of a Rapid Integration Platform.

MOSA

The Office of the Deputy Assistant Secretary of Defense for Systems Engineering website defines MOSA as an "integrated business and technical strategy to achieve competitive and affordable acquisition and sustainment of a new or legacy system or component over the system life cycle. MOSA implies the use of modular open systems architecture, a structure in which system interfaces share common, widely accepted standards, with which conformance can be verified." The RIF addresses the MOSA aspects highlighted in the 2018 National Defense Strategy aimed at delivering performance at the speed of relevance and modernizing key capabilities. Modularity is an important RIF consideration to ensure reusability and interchangeability of the core hardware and software components and of hosted capabilities. Modularity is also instrumental in having the ability to recompose proven components into additional RIP systems.

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CAS

"The Crew Mission Station (CMS) Comprehensive Architecture Strategy" TIM paper published in 2017 describes how the two architecture levels defined for the CMS Open System Architecture (OSA), were aligned to the emerging Comprehensive Architecture Strategy (CAS). The RIF concept evolved from the CMS OSA and includes the definition of architecture levels described in the CAS.

As shown in Figure 1, the CAS defines three levels of architectures: an enterprise level Reference Architecture (RefArch); Objective Architectures (ObjArch) for a Product Line or Family of Systems; and System Architectures (SysArch) for distinct systems. One of the tenets of CAS is that the architecture levels capture not only technical architectural requirements, but also the Key Business Drivers (KBD) and Key Architecture Drivers (KAD) that those requirements should trace to. The RIF includes documentation of the ObjArch level, meaning it provides a set of requirements and constraints to create a Family of Systems or product line. The current ObjArch within the RIF captures and documents the KBDs and KADs of the UH-60 customer and stakeholders, but will be expanded to include additional stakeholders as the RIF concept matures.

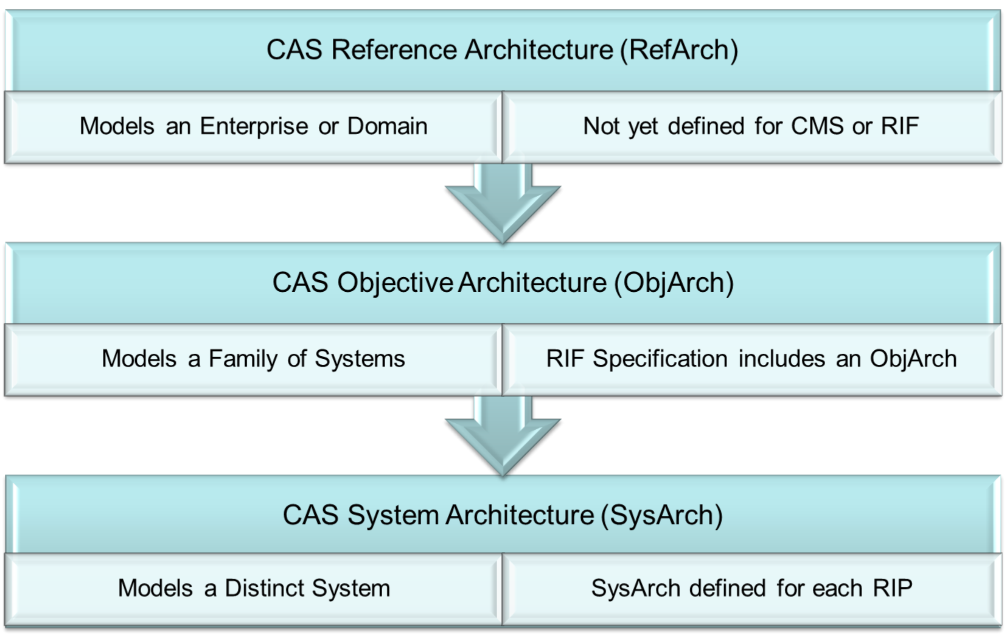

Figure 1 CAS Architecture Levels related to the RIF

By including an ObjArch, the RIF represents a level around which to identify and exploit opportunities for commonality that reflect a product line approach for both hardware and software. The RIF defines a set of core hardware and software components, software services, as well as a common data model to manage component interfaces. The testable requirements and constraints contained in the RIF bind and control subsequent architectures and implementations and provide the mechanisms to promote consistency, cohesiveness and commonality. The RIF extends the recommended elements of a CAS ObjArch by including the allocation of User Level Capabilities to system components. This allocation aids in the creation of capability software that is portable between all systems meeting the RIF.

Referring back to Figure 1, the next CAS architecture level, the SysArch, serves to model a distinct system. Design and implementation choices will be made from the RIF options to create a RIP SysArch for a particular platform or program. Each RIP SysArch will be an optimization of the RIF, adding architectural requirements and architectural mechanisms to the RIF in order to address additional stakeholder concerns and technical objectives. The goal of the RIP SysArch is to provide a System Integrator and Capability Suppliers with a specification for a system architecture from which they will generate the Core System and/or Hosted Capability Designs. It serves as the 'Design-to Architecture' for a RIP.

FACE Technical Standard

The FACE Technical Standard is included as the software architecture element of the RIF architecture specification. The inclusion of the FACE Technical Standard in the RIF architecture and design was both helpful in answering several of the technical and business objectives expressed by the stakeholders and an objective itself. The FACE Technical Standard provides a segmented architecture with key interfaces, and is supported with mandates ensuring wide use. The modularity and segmented nature of the architecture described in the FACE Technical Standard was ideally suited to support the system design and the FACE interfaces were heavily leveraged to provide the required key interfaces between the core and hosted capabilities in the RIF. The RIF extends the FACE approach to include modularity and behavioral decisions made by the RIF Architecture Maintainer. These decisions provide a more restrictive environment than the FACE Technical Standard, and allow for greater portability and reuse within the RIF.

Product Line Approach

As mentioned, the Rapid Integration Framework is an ObjArch that defines the architecture for a "core system" capable of hosting user level capabilities. It is essentially a product line architecture that provides the key interfaces for development of new capabilities and rapid integration of existing capabilities with minimal impact to legacy Operational Flight Programs (OFPs) or legacy architectures. Items developed to the RIF's product line requirements will be easier to integrate than items not using these interfaces.

The RIF is the mechanism to provide consistency, cohesiveness and commonality (if desired) and should be an architecture from which many Rapid Integration Platforms, using differing technologies can be developed. This will allow a Product Line approach for Rapid Integration Platforms. Development efforts that conform to the RIF will result in a product line of hardware and software components that can be integrated into RIP systems across the fleet.

The "common" requirements and the common hardware and software components from the CMS system used in the flight demo and Limited User Evaluation (LUE) served as the basis for documenting the RIF. The resulting product line architecture is characterized by modularity and defined variation points, which allow the RIF to be tailored into specific implementations.

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The product line architecture of the RIF actually supports three levels of product lines:

- Rapid Integration Platform: A Rapid Integration Platform will be the actual "cyber-physical" product or system, consisting of hardware and software, resulting from the Product Line architecture defined by the RIF. There could be a RIP product lines based on aircraft type.
- Components making up a RIP: Some components of the Rapid Integration Platform that fit into the Rapid Integration Framework could be or become product lines themselves
- Capabilities hosted by a RIP

CMS Lessons Learned applied to the RIF and RIP

The initial CMS system design, with its accompanying open architecture and management plan, was the starting point to begin identifying potential requirements for the RIF and RIP specifications.

Separation of the Core System, Hosted Capabilities and Integration

The RIF concepts are directly lifted from the successful strategies that were tested and proven during the CMS project, particularly the decision to divide the requirements, designs, and software for the CMS System, into three categories:

- **A Core System**, provides the common hardware and software needed to integrate the Hosted Capabilities supporting User Level Capabilities. The Core System concept equates to a RIP, and will encompass Core Capabilities like a computational infrastructure, Input/Output (I/O) resources, an operating system, and a data transport for those capabilities. Ideally, these hardware and software core capabilities will be tested and proven to work together so that they can be rapidly assembled into RIPs. The RIP will include the interfaces to the Core Capabilities for the support of Hosted Capabilities. The RIP will be an IMA platform.

- **Hosted Capabilities**, developed to specifically support one or more User Level Capabilities (ULCs), A ULC is defined as the functionality provided to or used by the actual end user of the system. Hosted Capabilities, on the other hand, provide the computational aspects, display of data, and handling of user inputs related to the bringing of new ULCs onto the aircraft. Hosted capabilities will be customer dependent and could constitute an additional series of independent product lines. Hosted Capabilities use the interfaces provided by the Core Capabilities of the RIP. Hosted Capabilities will be developed as IMA software and be installed on an IMA platform, the RIP, which is composed of Core Capabilities. Examples of the Hosted Capabilities that were planned and/or actually implemented throughout the CMS project: moving map, mission flight planning, fuel planning and an E-Reader for viewing documents and files.

- The Integration of the Hosted Capabilities into the Core System, including “glue code”, configuration files, and device specific interfaces that connect the Core Subsystem and the Hosted Capabilities as well as providing an integrated presentation to the crew. The system architecture will limit the Integration Software to configuration files and other IMA components in order to limit the airworthiness impacts of adding new Hosted Capabilities.

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User Level Capabilities and the "Ships Wheel" Diagram

There are a number of capabilities that RIF aligned systems will provide to the user; these are the User Level Capabilities. The combination of the Core System and the Hosted Capabilities enables these User Level Capabilities.

Within CMS, the concepts of User Level Capabilities, Hosted Capabilities, and a Core System is depicted by the Ships Wheel diagram, which was leveraged for the RIF.

The Core System combined with Hosted Capabilities lead to the realization of the User Level Capabilities, thus expressing the complete set of functionality encapsulated by all components that provide the user with a function, the relationship is shown in Figure 2.

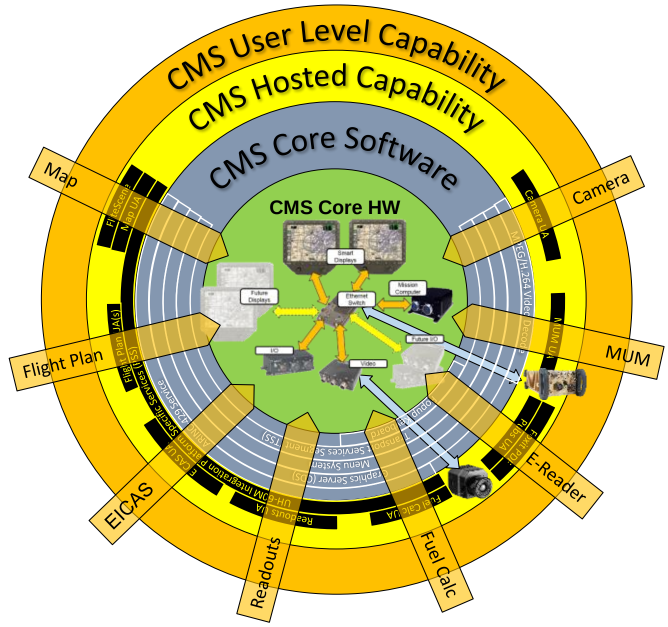

Figure 2 Core Software and Hosted Capabilities provide User Level Capabilities

Key Interfaces between the Core System and Hosted Capabilities

To facilitate the addition of new Hosted Capabilities and ULCs, CMS was designed to expose a set of key interfaces, selected from existing widely used standards, like the FACE Technical Standard and ARINC 661 in order to maximize the probability of component reuse. The RIF adopted these key interfaces, which include:

- A common Operating System Interface
- An interface for sharing data between capabilities
- An interface for the rendering of a user interface
- An interface for the receipt of user commands through a common set of controls
- Interfaces for commonly used data buses.

The FACE Technical Standard provided many of these key interfaces. The modularity and segmented nature of the architecture described in the FACE Technical Standard and the defined interfaces were ideally suited to support the vision and meet the objectives for the RIF.

Core Software in FACE Segments

Figure 3 depicts how Core Software is represented in the FACE Segments.

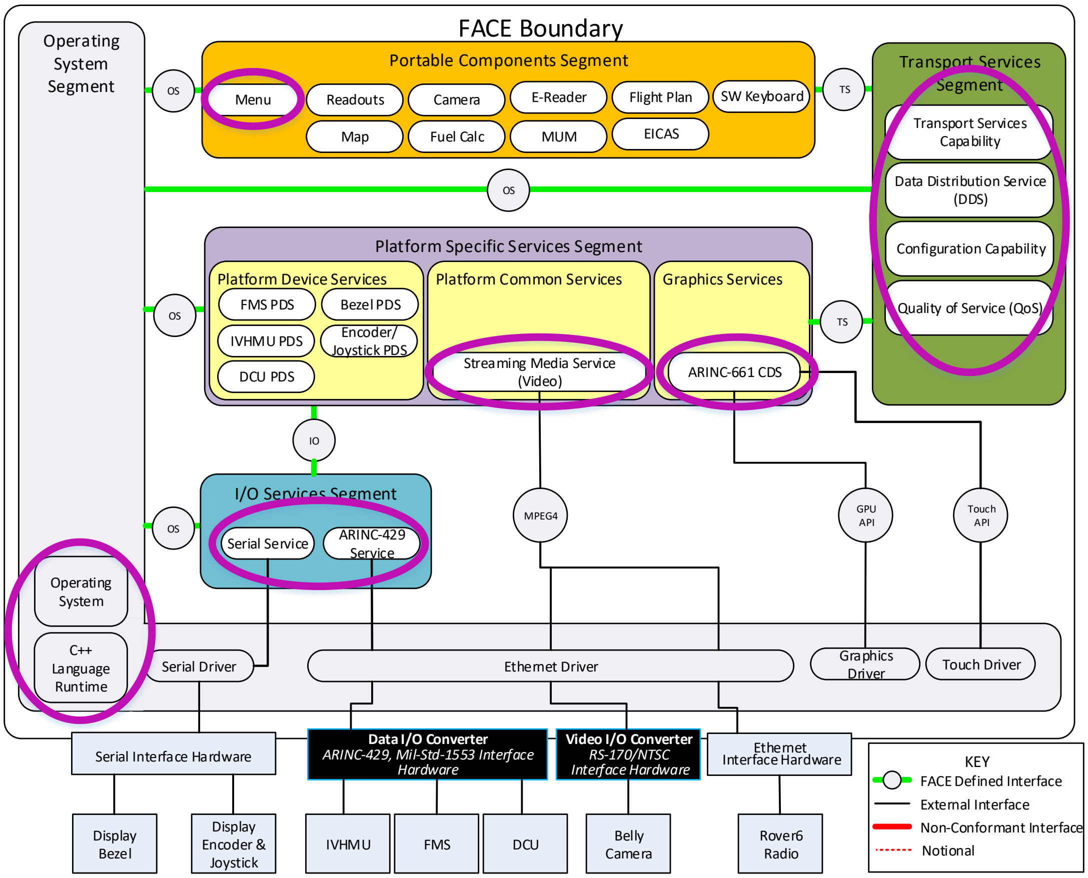

Figure 3 Core Software in FACE Segments

The FACE Technical Standard defines many of the RIF Core Capabilities within the Common Services and Graphic Services sub-segments of the Platform Device Services Segment. Other Core Capabilities are provided for in the FACE Technical Standard through entire segments dedicated to that capability. These include:

- Transport Services Segment
- Input / Output Services Segment
- Operating System Segment

Where the RIF expands on the FACE Technical Standard

The modularity and segmented nature of the architecture described in the FACE Technical Standard and the FACE defined interfaces were ideally suited to support the vision and meet the objectives for the RIF. To facilitate the addition of new Hosted Capabilities and ULCs, the Core Capabilities were designed to expose a set of key interfaces, which were purposefully selected from well-known standards to meet OA goals. The FACE Technical Standard provided many of these key interfaces, including:

- The FACE Technical Standard defines a common Operating System interface, the Operating System Segment (OSS) Interface Application Programming Interface (API), and provides a Safety Profile, which supports the interfaces to the most widely adopted Real-time Operating System (RTOSs) used in avionics today.

- The FACE Technical Standard defines a Transport Service (TS) for the sharing of information between independently developed components.

- The FACE Technical Standard provides for the use of the ARINC-661 standard used within commercial avionics as a means for multiple independent components to share a display.

- The FACE Technical Standard provides for an I/O Service (IOS) Interface that abstracts the IO device drivers, allowing CMS to easily adapt to new hardware when necessary.

The FACE Technical Standard plays a key role in the software architecture for the RIF, but the RIF includes key business and technical objectives specific to the RIF. These objectives are expanded on to include to include additional prescribed modularity, The RIF further extends the FACE approach through UoC behavioural decisions and a Domain Specific Data Model (DSDM). These decisions are controlled by the RIF Architecture Maintainer, and provide a more restrictive environment than the FACE Technical Standard, and should allow for greater portability and reuse within the RIF.

From a CAS perspective, the FACE Technical Standard by itself does not constitute a complete architectural solution for the RIF, since it focuses primarily on providing the requirements to facilitate software portability and interoperability. As such, it does not include the standardization of any hardware aspects and only supports, but does not explicitly define, the functional allocation needed for complete architecture solution. The RIF leverages the FACE Technical Standard's ability to support a range of functional allocations and includes the allocation of User Level Capabilities to system components. This allocation aids in the creation of portable capability software.

The RIF also encapsulates specific business and technical objectives that the FACE Technical Standard supports and can adapt to, but does not explicitly define. Capturing architectural requirements and their associated allowable architecture "mechanisms" in the RIF and flowing these down as guidance and constraints for RIP system architectures provides a means to trace back to the business and technical objectives of the stakeholders.

Conclusion

The successful demonstration and flight testing of the CMS system proved the CMS system design, with its accompanying open architecture and management plan, could provide an enduring method to provide additional capabilities to the UH-60 crew more rapidly than is currently possible. The lessons learned from CMS were used to define a generic framework that could benefit other aviation or ground platforms.

The potential RIF Family of Systems will be able to easily share software components to rapidly integrate new combinations of Hosted Capabilities. In addition, future RIP systems that support the same interfaces (or to which those interfaces can be adapted) will be able to readily accept the software developed for other RIP systems. The RIF concept is still maturing and the RIF specification will evolve as more stakeholders become involved and as RIP systems are designed and implemented. The 2018 Army TIM demo collaboration aligned to the RIF is already taking the concept in directions not envisioned by the CMS team.

The inclusion of the FACE Technical Standard in the RIF/RIP architecture and design was both helpful in answering several of the technical and business objectives expressed by the stakeholders and an objective itself. The modularity and segmented nature of the architecture described in the FACE Technical Standard was ideally suited to support the RIF and RIP requirements and the FACE interfaces were heavily leveraged to provide the required key interfaces between the core and hosted capabilities in the CMS system design.

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(Please note that the links below are good at the time of writing but cannot be guaranteed for the future.)

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About the Author(s)

Christopher J. Edwards has been working in the avionics industry for over 20 years, primarily on cockpit systems for military aircraft. In those years, he has served in leadership roles in Software, Requirements, System Design, PVI development, Qualification Testing, and Project Management. Mr. Edwards has been the primary author of the FACE Conformance Certification Guide and the Problem Report/Change Request (PR/CR) Process and a contributor to several other documents in both the Technical Working Group (TWG) and Business Working Group (BWG). Mr. Edwards currently serves as a co-lead of the FACE TWG Conformance Verification Matrix Subcommittee, a co-lead on the FACE EA PR/CR Process, the facilitator of the FACE Verification Authority Community of Practice and is the Lead Systems Engineer for the CMS Project.

Steven P. Price has been working in avionics and embedded software for 30 years. He's worked on several different graphic user interfaces including cockpit systems. He's been a leader in the design and implementation of some of these systems, along with being involved with the testing of some of these systems. Currently Mr. Price is one of the Software Engineers for CMS, and the principal developer of the CMS Menu System. He is a FACE Verification Authority Subject Matter Expert (SME).

Deborah H. Mooradian has supported the Navy and Army as a civilian contractor for the past nine years. Her FACE experience includes managing the FACE Academia efforts and representing the PMA 209 Aviation Architecture Team (AAT) in the FACE Business Working Group and Enterprise Architecture Standing Committee. She has been a key author of the FACE Business Guide, FACE Contract Guide, and FACE Overview Document, contributor to the FACE EA PR/CR documents, and author of numerous technical reports on various Open Architecture (OA) topics. In addition to FACE OA activities, Ms. Mooradian also participated on the DASN RDT&E Navy Open Architecture Enterprise Team and current MOSWG. In 2017, she shifted support to the Army's CMS program and the PEO AVN SPL project, which includes contributing to the Comprehensive Architecture Strategy.

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The Open Group Future Airborne Capability Environment (FACE) Consortium, was formed as a government and industry partnership to define an open avionics environment for all military airborne platform types. Today, it is an aviation-focused professional group made up of industry suppliers, customers, academia, and users. The FACE Consortium provides a vendor-neutral forum for industry and government to work together to develop and consolidate the open standards, best practices, guidance documents, and business strategy necessary for acquisition of affordable software systems that promote innovation and rapid integration of portable capabilities across global defense programs.

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