Use of the FACE™ Technical Standards in SUMIT

Lessons Learned and Best Practices from GE Aviation and the U.S. Army in SUMIT

Air Force FACE™ TIM Paper by:

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Executive Summary

We present the application of Future Airborne Capability Environment (FACE) Technical Standards, Edition 2.1 on GE Aviation's recently completed demonstrations conducted under the U.S. Army Demonstration Program called Synergistic Unmanned Manned Intelligent Teaming (SUMIT). GE Aviation integrated their Mission Operation Management System (MOMS), consisting of several components including a multi-UAS operator station and team autonomy manager. GE's system was integrated into the U.S. Army's Future Open Rotorcraft Cockpit Environment (FORCE), consisting of a Future Vertical Lift helicopter simulation, multiple simulated unmanned assets, a FACE™ Portable Component Segment (PCS) Unit of Conformance (UoC) providing teaming data management, and a simulated battlespace. Major interfaces of the system were implemented as UoCs using FACE Transport Services Segment (TSS) communications. Novel elements included the integration of disparate TSS implementations using a paradigm translation strategy, extensive use of executable FACE UoC simulations for development, and the use of FACE platform data model views and TS interfaces in a Model/View/Controller Human Machine Interface (HMI) architecture.

SUMIT Program Overview

SUMIT is a multi-year Broad Agency Announcement (BAA) program conducted by the U.S. Army Aviation Development Directorate (ADD). The purpose of SUMIT is to advance human-autonomy teaming technologies from both a technology and system architecture standpoint. SUMIT technologies are specifically targeted at the Air Mission Commander (AMC) human machine interface (HMI) in a future manned vertical lift platform. This environment can prove particularly challenging[6], due to the integration of novel autonomy and HMI technology within a complex system architecture. The SUMIT BAA call included definitions for autonomy capabilities based on the Joint Common Architecture (JCA). Offerors were asked to provide technologies that could fulfill these capabilities. GE Aviation was awarded a contract under SUMIT, focusing on the key business drivers (KBDs) shown in Table 1:

Table 1: GE Aviation SUMIT Program Key Business Drivers

KBD	Description
Exploration of JCA Architecture	GE Aviation's SUMIT program goals included a candidate breakdown of system capabilities to be decomposed into separate system components using Department of Defense Architecture Framework (DoDAF) views, based on JCA capability descriptions provided in the BAA call and the SUMIT CONOPS. The U.S. Army considers these components as potential candidates to be eventually acquired and integrated separately from multiple industry/government sources in future programs.
Evaluate MOSA Standards (e.g., FACE Technical Standard)	GE Aviation's SUMIT program goals included employing a FACE Reference Architecture, Use of FACE Data Models, deploying UoCs aligned to the FACE technical standard, and FACE TS interfaces to meet the goals of a Modular Open Systems Approach (MOSA).
Apply Realistic Mission Processing Environment	GE Aviation's SUMIT program goals included the desire to evaluate how well future autonomy and HMI technologies could fit into a mission processing environment of an FVL platform composed of portable components from multiple vendors.
Effective Human-Autonomy Teaming HMI	SUMIT program goals included the creation of an autonomy and HMI capability that was effective in facilitating human/autonomy teaming.

FORCE is an Open Systems demonstration environment designed to allow integration of technologies in a mission environment. The FORCE system is installed in Huntsville, Alabama, and has been used for multiple evaluation activities for Manned-Unmanned Teaming (MUM-T) technologies. For the SUMIT program, the baseline FORCE elements are shown in Table 2:

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Table 2: SUMIT FORCE Key Elements

FORCE Element	Description
UAS Assets	UAS Assets simulated using the Multiple Unified Simulation Environment (MUSE), with sensor camera simulated using Virtual Battlespace (VBS) IG channels over the Common Image Generator Interface (CIGI). Automatic target recognition simulation using CIGI
Scenario	Tactical scenarios using Virtual Battlespace 3 (VBS3) over DIS
Ownship Rotorcraft	Ownship FVL flight model and VBS IG for the out the window view
Mission Software	Software Simulations of UAS messaging at multiple levels of FACE, including PSSS (STANAG 4586) and UoCs (Teaming Data Manager and chat)

Each contractor under SUMIT performed integration into FORCE in order to demonstrate their technologies within the FORCE environment. In order to enable this integration in a flexible manner that could be performed within scope, the U.S Army's Government Furnished Information (GFI) for FORCE contractors included a FORCE Integration Guide describing various means that SUMIT contractors could use it to integrate their capabilities. This included descriptions of all available interfaces, including FACE platform data models describing low-level interfaces such as STANAG 4586 and Distributed Interactive Simulation (DIS) message formats. Additionally, the U.S. Army provided a well-defined FACE Domain Specific Data Model (DSDM) including a Teaming Data Manager (TDM) interface, which described UAS state reporting and control at an abstract level designed to hide communications details and UAS platform differences. All interfaces included an Interface Description Document (IDD) describing the data content and associated expected use cases.

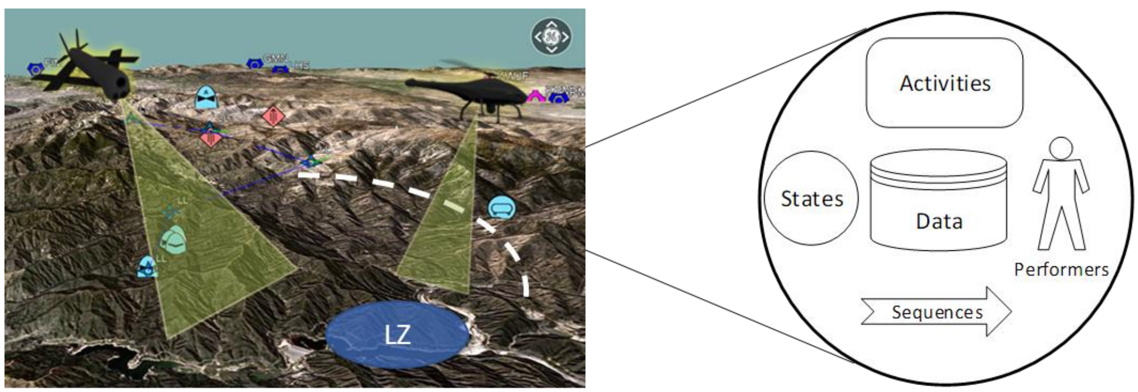
Multiple contractors chose the interfaces and methods by which they would integrate into FORCE and conduct the operator evaluations. The U.S. Army's goals for the integration were to evaluate how well MOSA approaches supported the various integration activities. As such, the SUMIT program provides an interesting example of a non-trivial usage of the FACE Reference Architecture for a representative MUM-T mission set.

GE Aviation's integration was focused on using the FACE Reference Architecture for as much of the system as could be achieved. As such, the TDM approach was chosen since it offered the opportunity to use a complex UoC aligned to the FACE Technical Standard for a key capability. Under SUMIT, GE Aviation developed the system architecture and implemented software components including an autonomy manager and operator HMI, which all made use of MOSA integration methods based on the FACE Technical Standard whenever possible. The system was installed in FORCE in April 2019 and used for eight operator evaluation events over a six-week period. This paper describes various key lessons learned during this process.

GE Aviation SUMIT Program Overview

GE Aviation's SUMIT components were defined by a process of developing a JCA architecture and associated teaming capabilities. In SUMIT, GE Aviation performed system architecture tasks intended to decompose the candidate JCA capabilities into components suitable for system/software development and instantiation. The architecture process was focused on using relevant Department of Defense Architecture Framework (DODAF)[5] views as the means of describing CONOPS and resulting capabilities. These views were refined through the creation of Objective Architecture (OA) and System Architecture (SA) to define system/software components. The DODAF decomposition process is shown in figure 1.

Figure 2: DoDAF Decomposition Process



Software components were primarily described as data models aligned to the FACE Technical Standard based on a shared GFI Domain Specific Data Model (DSDM) for the MUM-T domain, with additions as needed for autonomy or HMI-centric components not described in the GFI. The DSDM and extensions also included entities describing a Shared World Model with elements such as Geospatial Data, Mission Data, Team Status Data, and Situational Awareness Data. Using this model, a common set of UoCs aligned to the FACE Technical Standard provided data management services to mission processing components appropriate to their needs.

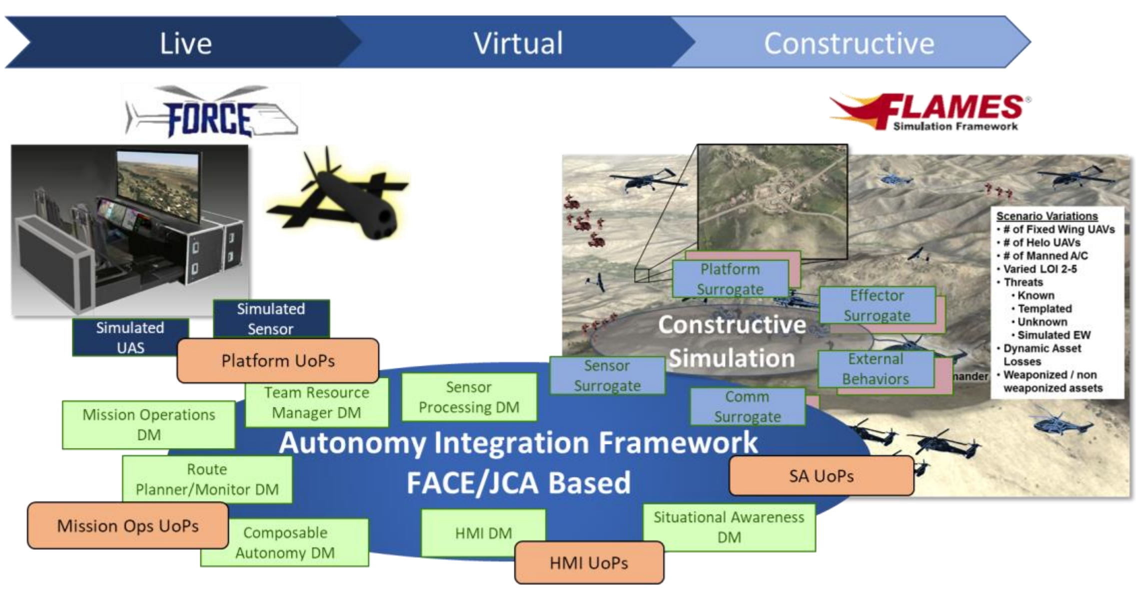
The SUMIT architecture GE Aviation created was not a complete description of all autonomy described by JCA. The scope was such that the architecture was constrained to fulfill the CONOPS derived from the scenario vignettes being performed by the Air Mission Commander (AMC) operators. As such, the architecture provided a series of vertical slices of capability required for the employment of the UAS assets in the vignettes. Within these constraints, FACE platform data models of the required or provided data for the various system components, and behavioral descriptions of their operation, were the primary output for the system instantiation activities.

Executable Simulation of FACE Capabilities

For SUMIT development, GE Aviation utilized executable simulation of FACE TS interfaces extensively. In system architecture and development activities, executable simulation is a technique whereby interfaces at the system boundary are populated with dynamic data such that the components of the system interoperate in a realistic manner. For FACE UoCs, the system boundary is often well defined, consisting of the relevant requested and provided FACE platform data model views that components use. The collection of UoC components, operating over a TSS forms the processing required for the mission system to do its job.

GE Aviation created an executable simulation environment by integrating custom-developed UoC component models executing within a constructive simulation based on a Commercial Off-the-Shelf (COTS) constructive scenario execution framework called FLAMES (Ternion's **FL**exible **A**nalysis and **M**ission **E**ffectiveness **S**ystem (FLAMES®),[4]). We chose FLAMES for its ability to construct accurate scenarios representing mission elements such as platforms, sensors, effectors, and associated behaviors in both the air and ground domain that satisfied the Army SUMIT vignettes. Custom models in these scenarios were developed to implement FACE UoC platform data model interfaces for the software components at the system boundary, providing dynamic TSS data in a realistic manner for component development and integration. These scenarios integrated into the COTS FLAMES tools with these models allow a fully featured TSS aligned with the FACE Technical Standard with dynamic data to be used by individual developers, or for system level integration as needed. The resulting technology integration framework is illustrated in Figure 2.

Figure 2: Executable Simulation Environment



The TDM TS interfaces were entirely simulated within this environment for GE Aviation's development effort. The system was able to generate teamed assets providing the data needed to simulate the TDM UoC interfaces including state reporting, weapons and sensors state and commands, waypoint following, payload schedules, camera views, and ATR detections. FORCE integration was primarily a process of replacing the simulated TDM UoC with the FORCE provided TDM UoC.

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Using this FACE Reference Architecture for executable simulation proved to be a beneficial way to speed development. Multiple subcontractors at various sites assisted in the rapid creation of the needed simulation components. In these cases, the ability to decouple the components through FACE interfaces worked well, and demonstrated the benefits of this portable component approach to a development team consisting of multiple contractors working on a distributed system architecture.

GE Aviation's FACE TS based executable simulation approach provided key benefits to the overall FORCE integration effort. This approach helped reduce the time needed for integration from potentially months for other similarly complex systems, to approximately one week. While the team did encounter some integration issues, these were primarily related to sim realism, not to FACE TS interface issues.

Automation of FACE TSS Capabilities

GE Aviation employed an automated approach to implementing the required TSS capabilities needed for SUMIT. As mentioned, the U.S. Army supplied a FACE DSDM with the views required to interface to the FORCE TSS. The two primary FACE UoCs were the TDM (consisting of approximately 30 view types), and Chat (consisting of approximately 20 view types). Other aspects of the mission system, such as sensor observations and Common Operating Picture (COP) management, were not provided as FACE UoCs by FORCE. Rather, GE Aviation added these as augmentation to make a more complete distributed mission processing environment. In addition, FACE platform data models were defined between the components that realized the autonomy and HMI, as derived from the original JCA architecture definition activity.

The TDM and Chat interfaces were provided as a FACE data model in FACE 2.1 format[1]. The U.S. Army's TSS implementation used a TSS implementation consisting of code generated for the Basic Avionics Lightweight Source Archetype (BALSA) to create the required TS capabilities and interfaces for the Chat and TDM UoCs. GE Aviation imported the FACE model into Enterprise Architect (EA) using a UML profile describing FACE 2.1 data models and used in-house model transformation tool chains to support TSS capability automation.

To instantiate a working system to be integrated in FORCE, a set of TSS capabilities was essential. Automation was a key part of creating the required elements[2]. The primary required TSS capabilities GE Aviation identified for FORCE integration are discussed in Table 3:

Table 3: SUMIT FORCE Key TSS Capabilities

TSS Capability	Description
Data Transport	Serialization, deserialization, and message distribution using required patterns
Paradigm Translation	Interface between a multicast messaging paradigm containing platform data serialized by a BALSA TSS implementation and GE's own TSS implementation
High Level Language FACE TSS APIs	Generate FACE TSS APIs and associated implementations for use by applications in C or C++
Data Logging	FACE TSS data logged for analysis by FORCE evaluation team

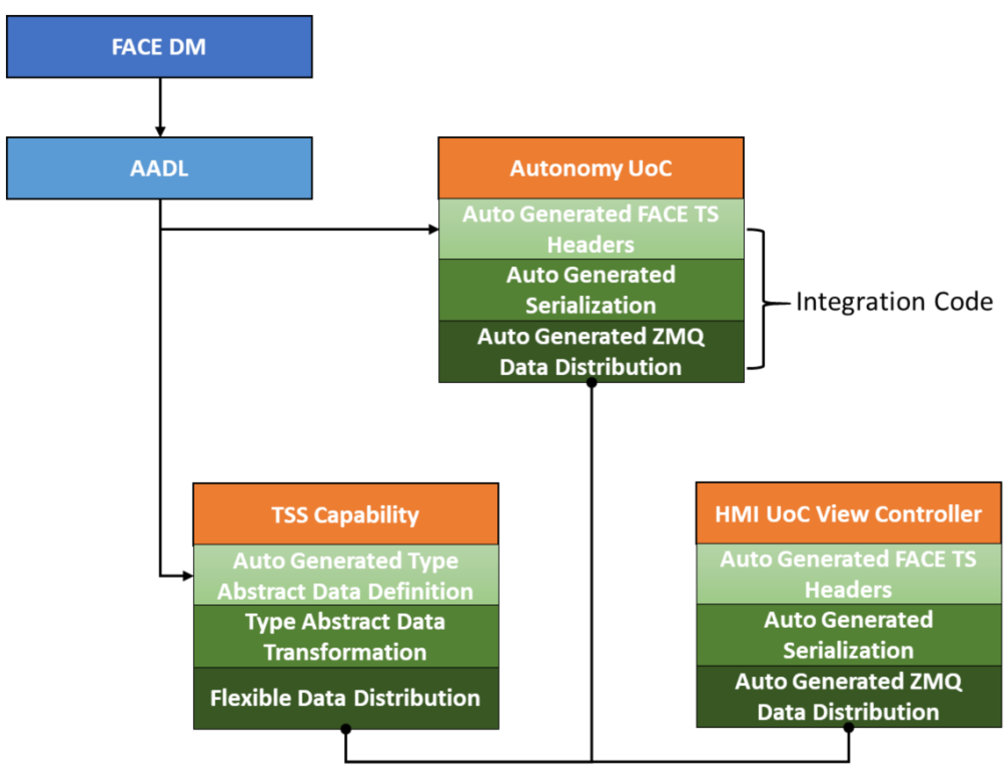
The automation approach used by GE's tool chain was to create an Architecture Analysis and Design Language (AADL) platform level data description model that drives automation of TSS capabilities. This type of abstract data type representation was used by GE's code generators, and by runtime components as needed to accomplish automation needs. The TSS capabilities needed for FORCE integration were provided by this approach, as shown in Table 4:

Table 4: FORCE Key TSS Capabilities Implementation

TSS Capability	Description
Distribution	Auto-generation of serialization and deserialization methods for data. Autogeneration of implementation of connections on underlying transport APIs
Configuration	Storage/retrieval of data definitions and other configuration data required to perform other TSS capabilities
Transport Protocol Module	Bridge component driven from data representation, handling serialization transformation between the BALSA TSS implementation and GE's TSS, and transport API configurations to bridge data to/from differing socket implementations
Transport Service Interface	Auto-generation of type-specific FACE TS Interfaces and associated type-specific data structures, linkable to distribution implementation
Data Store	Logging component within TSS driven from type abstract representation handling deserialization to human-readable CSV files

Figure 3 illustrates how the platform model used by GE Aviation's TSS automation environment is used to automate various TSS capabilities:

Figure 3: FACE TSS Automation



There were many benefits of this degree of automation of TSS capabilities. The Platform data models provided by UoCs changed as the program progressed, and new interfaces were constantly being added or modified as the implementation of FORCE, autonomy components, and the HMI changed over time. FORCE IDD revisions that occurred during the program did not cause significant development delays because of the degree of automation. In addition, GE Aviation was able to refactor major interfaces between the operator HMI and the autonomy components as the system became more capable, again with relatively little impact to development schedules.

One major observation from the integration and evaluation was GE Aviation's recommendation that FORCE use a TSS implementation with better Quality of Service (QoS) than that provided by multicast sockets. Some of the UoCs implemented interfaces consisting of a series of sequential messages, such as a flight plan consisting of multiple waypoints. When using multicast, the UDP network protocol provided limited message reliability, resulting in non-deterministic operation of the system. To address this would require one of two approaches: design the UoC to offer a reliability or retry mechanism, or employ a QoS offering better guarantees of message delivery.

FACE HMI Capabilities

Under SUMIT the JCA descriptions of HMI capabilities were used to guide the implementation of the AMC operator HMI. Under JCA, HMI is a specific component of the system, managing the HMI as a subsystem. Other system capabilities that require a human interface are designed to interface with the HMI capabilities. JCA defines HMI capabilities using the taxonomy in Table 5:

Table 5: JCA HMI Capability Definitions

HMI Capability	Description
User Input Management	System components, including devices and software, designed to interface with the human operator input. For GE Aviation's HMI, these included touchscreen, joystick, and HMI software interfaces to these devices, and HMI mechanisms around these such as gesture recognition.
User Output Management	System components, including devices and software, designed to interface with the human operator output. For SUMIT, this included the touch screen display, GPU, CPU, video, and software components that formatted data to these devices.
HMI Presentation Management	System components designed to control priority and information display to the operator. For SUMIT, these included window management, priority alerting functions, and declutter.
HMI Content Management	System components designed to collect and format output for the operator. For SUMIT, these included HMI pages (views), HMI view controllers, and HMI content managers.

These components are realized in a system instantiation on a FACE software architecture in different ways. Components with platform device interfaces (such as HMI input) have PSSS implementations and supply their data over TSS. Graphics components can make use of the FACE Graphics Services to define portable components with allowable graphical interfaces (OpenGL SC). HMI presentation and content management components will generally be PCS UoCs dedicated to the HMI functions of the system.

GE Aviation's HMI implementation made extensive use of FACE platform data model views and the associated FACE TS interfaces in order to create HMI content, presentation, and user output management capabilities. To use FACE abstraction as much as possible, GE adopted the Presentation Abstraction Control variant of the Model/View/ Controller (MVC) architecture pattern[3] with the following general methodology:

- *Abstractions (Models)* were capabilities of the system, with interfaces described by FACE data models via the TSS. These primarily fulfilled HMI content manager JCA capabilities. In some cases, no specific content management was needed by the HMI, it merely subscribed to the FACE views it required. In other cases, components had specific views needed by their operation, such as a view designed to 'ask the operator to approve an engagement'.
- *Presentation (Views)* were specific graphical elements designed for operator display or operator data input (i.e., widgets, graphics, and screen layouts). Views were designed to meet the specific look and feel of the HMI, and to work together as needed to create an intuitive and easy to use operator interface.

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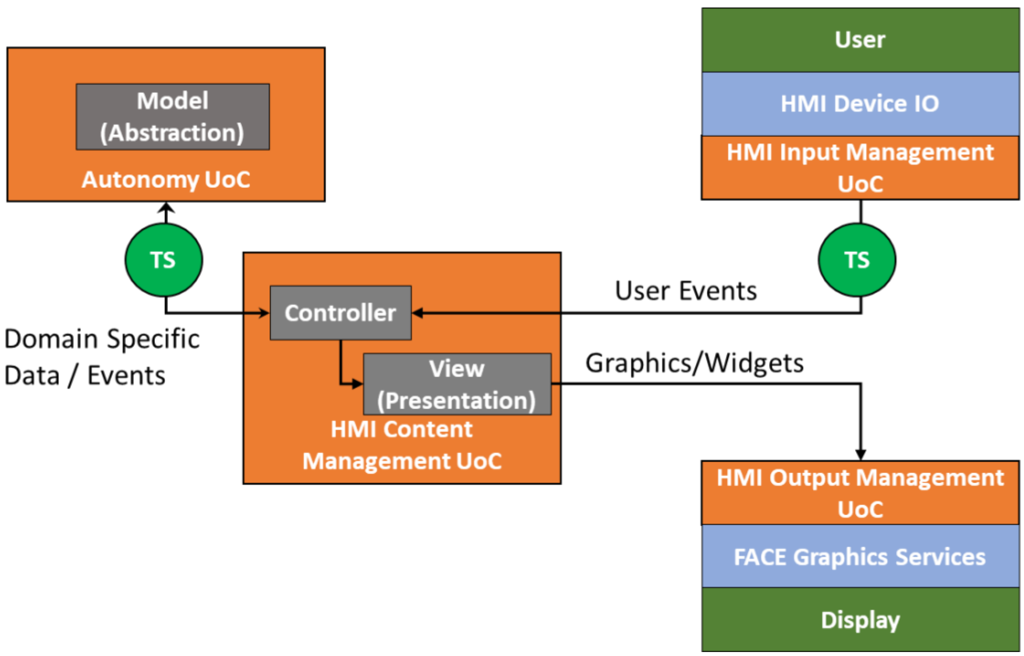
- *Controllers* were software components responsible for mapping model output data to the view elements, or to gather operator input data from view elements. These components were integrated with the views, and mapped HMI-specific constructs to FACE UoC TS interfaces.

Using this approach, FACE TS interfaces offer a natural way for UoCs to access HMI capabilities required to perform their function. Operator interactions can be described as FACE platform data views provided to or received from the operator with HMI specifics abstracted within HMI content management UoCs. The MVC architecture integrated with FACE UoCs deployed in GE's SUMIT system is shown in Figure 4.

Figure 4: MVC Architecture as FACE UoCs



Using this architectural pattern, the system architecture for the GE Aviation HMI was loosely coupled, abstract, extensible, and maintainable. HMI components communicated with other system components via the TSS, consistent with other software components of the system. In general, the autonomy components of the system were completely abstracted from any specific graphics, widgets, or HMI specific constructs, and just provided their data or reacted to FACE TS interfaces. Figure 5 illustrates the allocation of various system capabilities in GE Aviation's SUMIT HMI:

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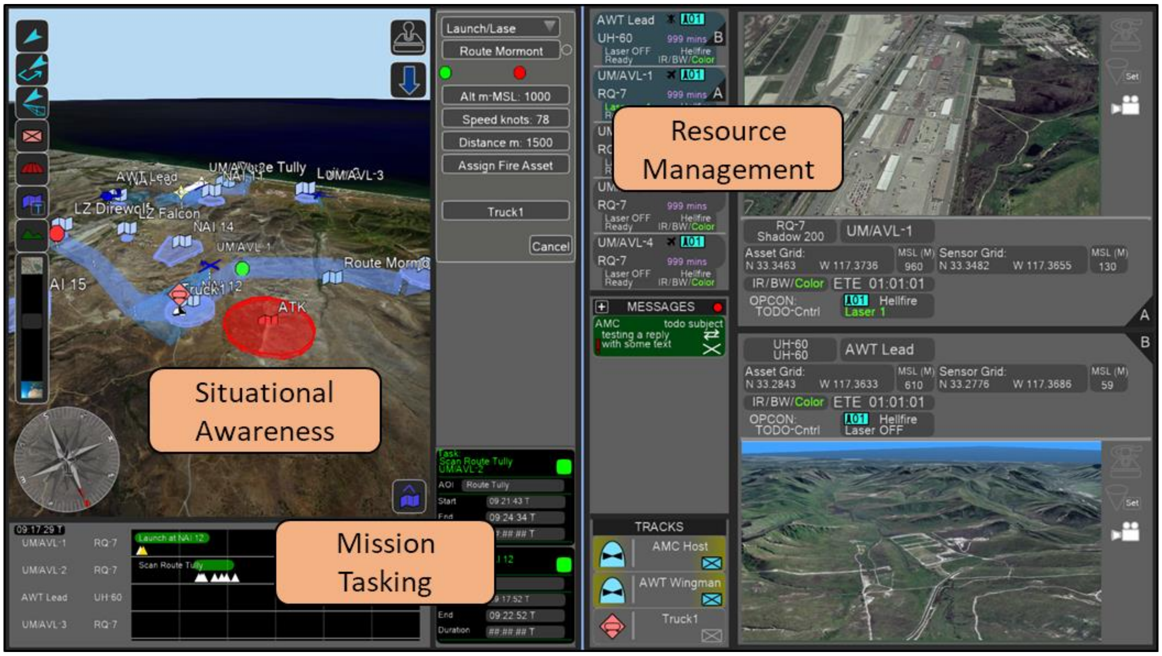
Figure 5: JCA Capabilities Represented via FACE in GE SUMIT HMI



Conclusion

The choice to use FACE Technical Standards, Edition 2.1 in GE's effort under the SUMIT program was driven by two factors – the U.S. Army's desire to explore a MOSA system architecture approach, and by GE's experience and expertise with pre-existing FACE infrastructure. Both the U.S. Army and GE believed the use of FACE Technical Standards, Edition 2.1 would be beneficial to SUMIT. SUMIT contractors had a choice to adopt FACE standards as an interface strategy only, or to adopt a FACE reference architecture as a means to capture much more of the overall service-oriented systems architecture and engineering effort. GE's effort used FACE standards as much as possible, not because it was prescribed, but because it was effective.

The many ways in which the FACE Technical Standard, Edition 2.1 was used in SUMIT proved particularly valuable to the program's achievement of its goals. On a limited development scope, GE Aviation and the U. S. Army were able to:

- Use a MOSA model and FACE data models, UoCs, and TS interfaces to define and successfully integrate and demonstrate the primary interfaces between FORCE and GE Aviation's integrated Mission Operations Management System.
- Use executable representations of FACE UoCs to accelerate development of major subsystem technologies required for autonomously assisted MUM-T.
- Demonstrate that a JCA architecture for both autonomy and HMI components, realized via FACE data models and TSS interfaces, can successfully provide abstraction between capabilities, potentially allowing such capabilities to be acquired using Open Standards and MOSA approaches in the future.

There is much more work ahead to refine the tools, architectural approaches, and FACE platform software capabilities to make a robust platform for future mission capabilities, especially in domains as challenging as autonomy, decision aiding, and operator HMIs. The authors believe these approaches hold great promise to solve these development and acquisition challenges.

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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)

Mark Snyder is a Senior Staff Engineer with GE Aviation Systems, where he leads software development for MOSA activities, specializing in HMI, Simulation, and Service Oriented Architectures for military and commercial aerospace applications. His 30-year career in aerospace includes 9-years active duty in the US Air Force concentrating on C4ISR systems and simulation. He also spent 5 years at Honeywell, where he was a key developer of moving map and flight deck software flying on business and regional jets worldwide. At Quantum3D, he led the development of IDataTM, a COTS HMI Development Tool Suite deployed on multiple civil and military aircraft programs including the Gulfstream G650, B-2 Bomber, Predator UAV Ground Station, Royal Navy MCSP Mission Operator Station, C-130 Harvest Hawk, and many others. He was the lead architect on GE Aviation's contribution to the SUMIT program

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About The Open Group FACE™ Consortium

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.

Further information on FACE Consortium is available at www.opengroup.org/face.

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