IMPACT in Action

Conducting multiple FACE™ development efforts aligned to DO-178C, DO-331, AC 20-148, and AR 70-62 for U.S. Army Airworthiness

The Open Group FACE™ & SOSA™ TIM Paper by

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Executive Summary

This paper introduces a new term; model based open systems approach (MBOSA). It also describes the use of TES-SAVi's AWESUM® MBOSA modeling tools on two significant U.S. Army advanced capabilities efforts scheduled to support U.S. Army aircraft flights in 2021.

This MBOSA is being refined and proven with these two-sets of modular open systems approach (MOSA) software suites that will be hosted on U.S. Army advanced aircraft, namely the Apache Attack and Black Hawk Utility aircraft.

The development efforts for these two programs have similar design requirements. They were for multiple FACE™ software applications operating on modular open systems hardware. The software is required to align to the FACE Technical Standard, Edition 3.0 (or latest edition), to be built to Radio Technical Commission for Aeronautics' (RTCA's) DO-178C Software Certification guidance using the DO-331 model-based supplement processes, and to the FAA's AC-20-148 guidance for reusable software components [ref.: 1,2,3,4]. These capabilities will be submitted to the U.S. Army for flight qualifications using Army Regulation AR 70-62 for U.S. Army Airworthiness [ref.: 5].

This MBOSA software lifecycle modeling process and TES-SAVi's AWESUM® MBOSA modeling tools support the lifecycle (*i.e.,* requirements development, architecture and software design – high level and low level, systems data and semantic modeling, and eventual auto-generation of embedded software code aligned with the FACE Technical Standard, auto-generation of tests with artifacts, and auto-generation of the complete set DO-178C life cycle documentation). These products are purposely designed to support FACE Verification and Airworthy Qualification efforts.

Introduction

The AWESUM® model-based open systems engineering approach (MBOSA) process is established. It is being refined and proven with two-sets of modular open systems approach (MOSA) software suites that are scheduled to support U.S. Army aircraft flights in 2021.

This paper describes the use of TES-SAVi's AWESUM® MBOSA tools on two significant U.S. Army advanced capabilities efforts which will be hosted on U.S. Army advanced aircraft, namely the Apache Attack and Black Hawk Utility aircraft.

Because these products are purposely designed for reuse, there is a strong possibility that they will be used on other Army aircraft, including Future Vertical Lift (FVL).

IMPACT

IMPACT is one of the many acronyms used to denote important funded research and development (R&D) efforts conducted within the U.S. Army's Aviation Directorate (ADD).

Improvements and Modernizations of Programs Affecting Capabilities and Technologies (IMPACT), conducted in the 2014 to 2015 timeframe, was one of a series of Science and Technology (S&T) research studies funded by the ADD [ref.: 6 – IMPACT]

The objective and intent of IMPACT were to prepare the U.S. military aviation community for using improved tools and processes to modernize the design and development capabilities for applications on its fleet of modern aircraft (Vision) [ref.: 7 – Vision].

The development processes for these next-generation aircraft must be prepared for the advanced capabilities that will be required to address tomorrow's complex battlespace environments. The battlespace requires both manned and unmanned teams (MuM-T) of aircraft operating within a dynamic mix of complex operational challenges (*e.g*., day/night, all weather, complex hostile terrain, over land, sea, *etc*.).

All of this will ensure that the U.S. military will "*own the environment*" through a collection of highly integrated advanced aircraft operating collectively with a set of interoperable advanced capabilities that is a system of airborne systems-of-systems [ref.: 8 – SA Net Centric Ops].

It is helpful to understand how in 2014 the U.S. Army organized its aircraft development efforts to understand the interrelated contracting collaborations of these role-specific aircraft activities. The U.S. Army Aviation is divided into two components: The PEO Aviation and the AMRDEC's Aviation Development Directorate (ADD) [now reorganized and re-named Combat Capabilities Development Command Aviation & Missile Center (CCDC-AvMC)].

The first organization, PEO Aviation, includes the Army's Platform Programs (*e.g.,* PM Apache, PM Cargo, PM Utility, PM UAS, and fixed-wing fleet programs). PEO Aviation, generalized for brevity, is focused on the Army's current fleet of aircraft, organized by roles, to *accomplish and dominate military missions* today and forward.

The latter organization now, CCDC-AvMC, is the complementary organization with a mission to *push the envelope* of the possible and *put-in-place* the ability to produce new advanced aircraft capabilities. It fulfills its mission for both tasks on the Enduring Fleet (was termed the Legacy Fleet) to *accomplish military missions* today; but also by creating additional reusable advanced aircraft capabilities for the next generation of aircraft currently being acquired, grouped as Future Vertical Lift (FVL). The CCDC-AvMC helps the U.S. military aviation community by setting in place the plans for tools and processes and funding S&T advanced studies for Unlimited Rights products for subsequent use by the Aviation Community of Developers. These CCDC-AvMC by-products will be *used to get us there and dominate the fight,* so that the U.S. Military can maintain our battlespace dominance both today and forward.

Together these two complementary organizations, the U.S. Army's Aviation PEO and its CCDC-AvMC, form *the largest and most dominant air force in the world*. They are given the mission to maintain the most innovative and capable military aviation fleet in the world, backed by the strong U.S. military funding.

In 2014 to 2015, the ADD funded IMPACT [ref.: 6 – IMPACT]. IMPACT was decomposed into a set of four sub-groups, led by the vision of Dr. William (Bill) Lewis and Mr. Layne Merritt, and organizationally managed by Mr. David Arterburn, from the University of Alabama in Huntsville. Each sub-group was comprised of two leads, one Government and an Industry or Academia co-lead. The four sub-groups were populated with teams of Subject Matter Experts (SMEs) from Industry or Academia, *approximately* 100 SME contributors in total. Together, in groups, they tasked themselves to identify issues blocking aviation development progress, flesh-out solutions, and in summary, suggest potential paths forward with improved tools and processes.

The goal, to identify the gaps in tools and processes needed to build the next generation of military aircraft, is now known as the Future Vertical Lift (FVL) Family of Systems (FoS). The results from IMPACT served as a list of improvement suggestions for possible additional Government funding.

Since IMPACT's 2015 publication, several organizations have leveraged IMPACT's published results. Using IMPACT's results as guidance, several organizations have begun to develop capabilities to fill the identified gaps. These gaps have been filled with improved model-based system engineering (MBSE) tools and improved processes to help build the next generation of military aircraft [ref.: 9 – Next Gen MBSE for CPS].

Today, aligning to ADD's original 2013 Vision [ref.: 7 – Vision] and with the IMPACT study's guidance [ref.: 6 – IMPACT], improvements are being made. The Vision and IMPACT report is being used to support the development and procurement of the FVL FoS, which includes both the Future Attack Reconnaissance Aircraft Competitive Prototype (FARA CP) and the Future Long Range Assault Aircraft (FLRAA). The Vision and IMPACT report are also being utilized in other funded S&T efforts [*e.g.,* VLC JMR Task 4 AV/MSA IDD, see page 9].

Tucson Embedded Systems, Inc. (TES) served as one of these IMPACT co-leads. TES was assigned to lead the Verification, Validation, and Accreditation (VV&A) team. TES also participated and contributed to the Model Based Tools sub-group.

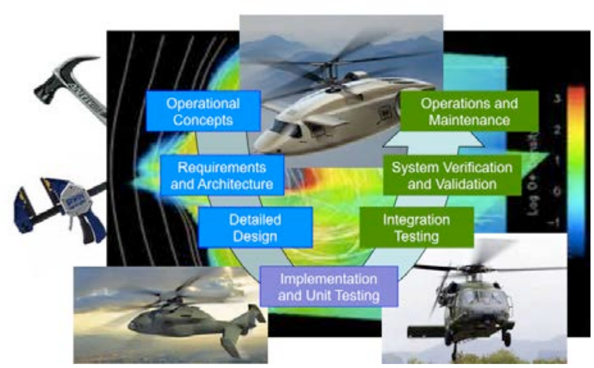

Figure 1 – IMPACT VV&A Report, 2015 [ref.: 6]

Leading up to the IMPACT study, TES had been serving as a Systems Engineering and Technical Assistance (SETA) contractor for the U.S. Army since 2003 on reusable common software solutions [PM-AS Common Software Initiative, (CSI)]. To support these SETA studies, TES has also been actively developing rapid integration capabilities using model-based tools for the U.S. Army Aviation Community's future needs. TES has published several technical papers [*e.g.,* IEEE, AHS, FACE organizations] on our progress and stepwise accomplishments toward the Vision described by the 2015 IMPACT study [ref.: 6 – IMPACT].

TES was awarded intellectual property on our MBOSA process in 2009 [ref.: 10, 11 – TES CDA and TES IP], and joined the Open Group's FACE Consortium in its inception year, 2010.

Within this FACE TIM paper, TES describes progress toward fielding capabilities developed based on the gaps and needs for improved tools and processes described in the IMPACT study [ref.: 6]. These capabilities were developed using industry-unique model-based open systems approach (MBOSA) tools and processes [https://tes-savi.com/awesum-products/]. These tools are now assisting the development of significant advanced capabilities efforts for the US Army Aviation fleet of aircraft.

Aviation Engineering Model-based Performances

The following sub-sections introduce past programs that have led us to these two advanced development efforts. Following that, two current efforts of domains of multiple FACE development efforts being performed will be described.

Past Performances that led to today's MBOSA engineering activities efforts

In this section, selected past program study efforts are introduced. Described is a series of efforts that have led TES to several key positions supporting development within the U.S. Army Aviation Community. These efforts have also supported and been applied to the Navy's NAVAIR group, the Air Force, and civilian Aerospace communities (*e.g.,* NASA JPL). The lessons learned served to ring-out the MBOSA processes currently being used on the following U.S. Army development efforts, which have FACE Technical Standard requirements.

Army's R2C2, now ARCM

ARCM (Airborne Radio Control Manager) is a past effort, and is the first of the two current program efforts showcased in this FACE TIM technical paper. Formally known as "R2C2", short for Reusable Radio Control Component is a FACE communications domain application. R2C2 is written to FAA's DO-178B Design Assurance Level (DAL) 'C', is aligned to the FACE Technical Standard Edition 2.1. R2C2 was the U.S. Army's *first* product to complete the Army's sanctioned FACE Verification Authority (FACE VA) process in July 2016. It was also aligned to the FAA's AC-20-148 guideline for reusable software components. R2C2 was developed following Army Guidelines [ref.: 12 – Handbook].

R2C2, now known as A2E2 ARCM [Aviation Architecture and Environment Exploitation (A2E2) for Airborne Radio Control Manager Software Application] is a set of four (4) FACE Units of Conformance (see figure – ARCM FACE diagram). This software suite and Capability Data Model are aligned to the FACE Technical Standard. It supports multiple US Aviation radios, 14 abstracted open communications capabilities sets, including over 500 radio functions. It represents a real-world implementation of radio control capabilities in the Army Aviation domain.

Under the new A2E2 ARCM contract, its design requirements have been updated to align with the Army's most current guidance, specifically: FACE Technical Standard Edition 3.1 DO-178C DAL 'C', and AR 70-62 [ref.: 1,2,4]. ARCM will be delivered to the U.S. Army's sanctioned FACE Verification Authority (Army FACE VA) and verified for correctness per the FACE Conformance Policy. Then the products will be sent to Flight Qualification to Combat Capability Development Command-Aviation/Missile Command System Readiness Directorate – Airworthiness (CCDC-AvMC SRD-AW) for the U.S. Army's Airworthiness efforts for integration and flight on an Army PM Office's Utility helicopter, UH-60M model.

Additionally, this product suite has been positioned for reuse on other U.S. Army aircraft [Aviation Platform Programs (*e.g.,* PM Apache, PM Cargo, PM UAS, and fixed-wing fleet)]. To do this, we have introduced special provisions for reuse into our design and development processes per the AC 20-148 RSC guidance [ref.: 4 – RSC]. The FACE Approach describes how to develop modular open standards software agnostic to hardware implementations; AC 20-148 informs developers and integrators how to use and reuse software components.

Army's MIS – Modular Integrated Survivability

Modular Integrated Survivability (known by the acronym MIS/ROSAS) is a software product suite aligned to the FACE Technical Standard that provides situational awareness in the domain of Aircraft Survivability Equipment (ASE). MIS is both a product suite and a virtual simulation environment. The Army's ADD lab funded the effort in the 2010 to 2015 timeframe to investigate the rapid development of reusable FACE products aligned with Army Airworthiness. TES' simulation suite models multiple aircraft platforms, and simulates their flight. The suite controls the operations of actual or simulated Aircraft Survivability Equipment (ASE) to illustrate enhanced situational awareness (SA) of the platform in flight in degraded visual environment conditions. ROSAS, short for Route Optimization for Survivability Against Sensors, was the follow-on Science and Technology (S&T) funded program of the MIS effort.

TES, with our tools and processes, developed the control software for the ASE, and flew the software in a virtual simulated environment. These products have been demonstrated at several FACE Technical Interchange Meetings (FACE TIMs) in the past.

Figure 2 - (top left) Industry-unique Virtual Platform Simulations capabilities with operations of actual or simulated integrated 3rd party military avionics, (top right) one of many Army/Military Simulation Platforms within our tool set, (bottom) TES-SAVi at FACE Air Force Demonstration, demonstrating to 3-star General Moore at Wrights-Patterson Air Force Base multiple simulation platforms operating actual embedded software on representative platform processors conducting missions rehearsals a virtual network-centric battle space.

These MIS S&T ASE development efforts served to position TES well to support a second domain of ASE FACE software development efforts funded by the PM-Apache Program Office. The PM-Apache next generation Aircraft Gateway Processor (AGP) known as AGx (x signifies neXt generation) External Interface Systems (AGx EIS) program effort is our second showcased program described in this FACE TIM paper.

Army's JCA – Joint Common Architecture

The JCA data model product was built using a Modular Open Systems Approach (MOSA), is aligned with the FACE technical reference architecture, supports software reuse across the Joint Multi-Role (JMR) fleet, and embraces automation. TES has supported contract efforts for the Army's PEO-Aviation during the first release of the JCA data model.

Air Force's R-EGI

R-EGI is a collaboration of several software modules aligned to the FACE Technical Standard. Collectively the software modules provide a "resilient" enhancement to separately collected input data (*e.g.*, EGI/IMU, EGI/GPS, and Link-16) each with quality of service metrics. That is, the multiple inputs are collected and run through a Kalman filter software capability resulting in an improved platform position being reported by a combination of the collective inputs.

For additional information on R-EGI, see [ref.: 13 – CI/CD, 14 – R-EGI BITS, 15 – Model-Based Code Gen.].

Army's SBIR FADEC

Another quick turn past performance involved a small business innovation research (SBIR) topic, Common Engine Controller for a Full-Authority Digital Engine Controller (FADEC), A18-080 delivered March 2019. The SBIR is based on modular open systems design and alignment to the FACE technical standard. Although the SBIR objective requested alignment to FACE Edition 3.0; the 3.0 eco-system wasn't available during the SBIR's 6-month period of performance (PoP).

The SBIR's objective was to design an open architecture, to data-model the architecture messages, and achieve alignment with the FACE Technical Standard. TES sub-contracted to Management Sciences, Inc (MSI) in the last 5 weeks of the Phase I PoP. Using AWESUM®, TES engineers designed, developed, and using the FACE Conformance Test Suite (FACE CTS) verified the SBIR FADEC data model and software and presented the results to the Army Improved Turbine Engines Program Office on schedule.

Subsequent to Army's SBIR final report and presentation, TES then used AWESUM® and converted the data model from 2.1 to 3.0, and auto-generated the FACE TSS software. The conversion and demonstration was performed and presented live during the BITS event at the FACE members meeting in April 2019.

For more information on SBIR FADEC, see [ref.: 16 – Three Use Cases]

DARPA's - Collaborative Operations in a Denied Environment

Collaborative Operations in a Denied Environment (CODE) is a series of 50+ software modules being developed under a DARPA funded US Air Force contract. The DARPA efforts came with guidance that contractors (Raytheon and Lockheed Martin) should employ open systems approaches using either OMS or FACE and to leverage the data model from an existing Government-funded product, e.g., Unmanned Systems (UxS) Control Segment (UCS) standard.

The CODE Auto-Router Service Unit of Portability (UoP) was selected by the CODE team as a standalone service. The Auto-Router's small number of interfaces served as a simple example for demonstration purposes. The CODE Auto-Router Service supports generation of air vehicle routes around a supplied set of obstacles as well as evaluates the validity of those routes. The CODE Auto-Router Service UoP was developed as a FACE™ Portable Components Segment (PCS).

For more information on DARPA's CODE, see [ref.: 16 – Three Use Cases]

VLC's JMR AV/MSA IDD – Task 4 efforts

TES is serving as Program Manager and supporting design efforts on the VLC JMR AV/MSA IDD. In this research effort, US Government (USG) desires to procure mission system capabilities separate from the procurement of the air vehicle for future acquisition projects. To achieve this goal, the USG acquired support from the Vertical Lift Consortium (VLC) to collaboratively develop an initial prototype interface specification consistent with the tenants of a MOSA. The VLC collaboration team was formed to include a diverse group of companies and subject matter experts (SMEs). The SMEs span aircraft developers, systems integrators, suppliers, and academic institutions to obtain the broadest possible consensus on the end products.

IMPACT in Action - Conducting multiple FACE™ development efforts using MBOSA

The USG requested support from the Vertical Lift Consortium (VLC) to collaboratively develop an interface definition that identifies the mechanical, electrical, signal/data, and functional interfaces between an air vehicle (AV) and its mission systems architecture (MSA) (architecture common to all variants).

This AV/MSA interface exists in the context of a three-part architecture consisting of two modules, the air vehicle (AV) and the mission system architecture (MSA), and the interface between them. The AV and MSA encapsulate functions and exhibit behaviors, and the interface consists of the physical/mechanical connections and the electrical and digital exchanges.

The results of these AV/MSA interface definition efforts are intended to support the development and procurement of the Future Vertical Lift (FVL) family of systems (FoS) to include the Future Attack Reconnaissance Aircraft Competitive Prototype (FARA CP) and the Future Long Range Assault Aircraft (FLRAA).

Current Aviation Efforts

Today, TES is working on two contracted efforts (other efforts are being worked under non-disclosure agreements). These efforts have rapid development and integration schedules, are to be designed with a MOSA, and have flight critical requirements. Accordingly, TES will design, develop, test, and deliver multiple FACE development products aligned to RTCA's DO-178C, using the DO-331 model-based supplement, the FAA's AC-20-148 reusable software component, and AR 70-62 for US Army Airworthiness standards [ref.: 1,2,3,4,5]. These products and corresponding life cycle artifacts are to be delivered to the Government with Unlimited Rights for all technical data. These products will be sent through the FACE Verification process, through the Army's flight qualification process, then integrated on aircraft for flight.

TES has been working with the U.S. Army since 2003 on common reusable software. We have developed industry unique MBOSA tools and processes that incorporate all of the U.S. Army Aviation complex design and development requirements. With these MBOSA modeling tools and processes, TES is developing two domains of advanced software capabilities aligned to FACE technical standard. These capabilities will be qualified for flight and will soon fly on military aircraft.

TES is using a proven, repeatable, and highly sustainable process. To accomplish this, we use TES-SAVI's AWESUM® MBOSA modeling tools and our in-house open systems design processes to develop significant products to stringent FACE and Army Airworthiness requirements.

Army's A2E2 ARCM – Communications Domain of Multiple FACE Developments

The U.S. Army's Aviation Architecture and Environment Exploitation (A2E2) funded the Airborne Radio Control Manager Software Application (ARCM), see Figure below[1].

Figure 3 - ARCM (was R2C2) Solution Space - Common Radio Control

[1] Figure is an adaptation of TES Capability Driven Architecture (CDA) - "*Method and Apparatus for Interfacing with Multiple Objects using an Object Independent Interface Protocol*", US Pat No 8,239,586, Tucson Embedded Systems' Capability Driven Architecture (TES' CDA). This figure has been adapted by the Open Group's FACE Consortium, and is being used as a primary figure to illustrate concept of benefit for using the FACE Technical Standard.

The ARCM capability suite provides voice, data, routing, and radio control capabilities for military communications for use within Army Aviation Platforms. The ARCM capability suite is composed of multiple independent sub-systems modules, namely:

- Radio Control (RC) Platform Device Services (PCS)
    - Harris AN/PRC-158 RT and the Raytheon ARC-231
- CM - Communications Manager is a FACE Component that provides a focal point and management of all communications through the Radio Control PCS. The CM also provides a central point of ARCM system status and provides this status to other components.
- MNP – Mission and Network Planning is a FACE component used to provide Unit Task Organization (UTO) and RMDS configuration data to other components.
- BDM – Bulk Data Manager is a FACE component that provides files such as UTO and RMDS through a FACE IOS interface to other components.

The ARCM capability suite will be designed with RTCA/DO-178C Software Considerations in Airborne Systems and Equipment Certification. This life cycle data is compiled into contracted DIDs format and mapped to DO-178 table objectives, illustrated in the Figure 4 below.

Figure four's legend identifies the level of effort defined by DO-178C Design Assurance Level – C (DAL-C). For DAL-C there are 62 Compliance Objectives. The 59 objectives identified in green are subject for reuse. That is all life cycle data artifact documentation, software code, and tests; needed to support the demonstration of these Compliance Objectives is subject to reuse. The 3 objectives identified in yellow, need to be demonstrated on the target computer hardware.

LOE - Level of Effort

LOE from DO-178C DAL 'C' perspective (ref. RTCA, DO-178C, 2011)

DAL-C

62	DO-178C Objective Compliance (of 71)
9	N/A for DAL-C
59	Reuse per AC 20-148
3	Compatible with the target computer
Blank	*Satisification is at applicant's discretion*

			A4.1						
			A4.2						
			A4.3						
			A4.4						
			A4.5	A5.1		A7.1			
			A4.6	A5.2		A7.2			
A1.1	A2.1	A3.1	A4.7	A5.3		A7.3			
A1.2	A2.2	A3.2	A4.8	A5.4		A7.4	A8.1		
A1.3	A2.3	A3.3	A4.9	A5.5	A6.1	A7.5	A8.2	A9.1	
A1.4	A2.4	A3.4	A4.10	A5.6	A6.2	A7.6	A8.3	A9.2	
A1.5	A2.5	A3.5	A4.11	A5.7	A6.3	A7.7	A8.4	A9.3	A10.1
A1.6	A2.6	A3.6	A4.12	A5.8	A6.4	A7.8	A8.5	A9.4	A10.2
A1.7	A2.7	A3.7	A4.13	A5.9	A6.5	A7.9	A8.6	A9.5	A10.3
Plans	Dev	V.Rqt	V.Des	V.Sw	V.Int	VofV	CM	QA	Cert.

Figure 4 – Dashboard for RTCA's DO-178C DAL 'C' Process Objectives

Systems requirements are traced down to high-level software requirements [e.g., written the SRS (DI-IPSC-81433A)], and low-level requirements [*e.g.,* written in the SwDD (DI-IPSC-81435A)]. The program developed module level SRS and SwDD for each ARCM sub-system module named in the listing above.

Additionally, ARCM capability suite is designed and aligned with the FACE Technical Standard. As such FACE requirements are levied on the system and its subsystem modules, and captured in SSS and corresponding SRSs and SwDDs and traces to software verification case, procedures and results. A summary is presented in the SAS.

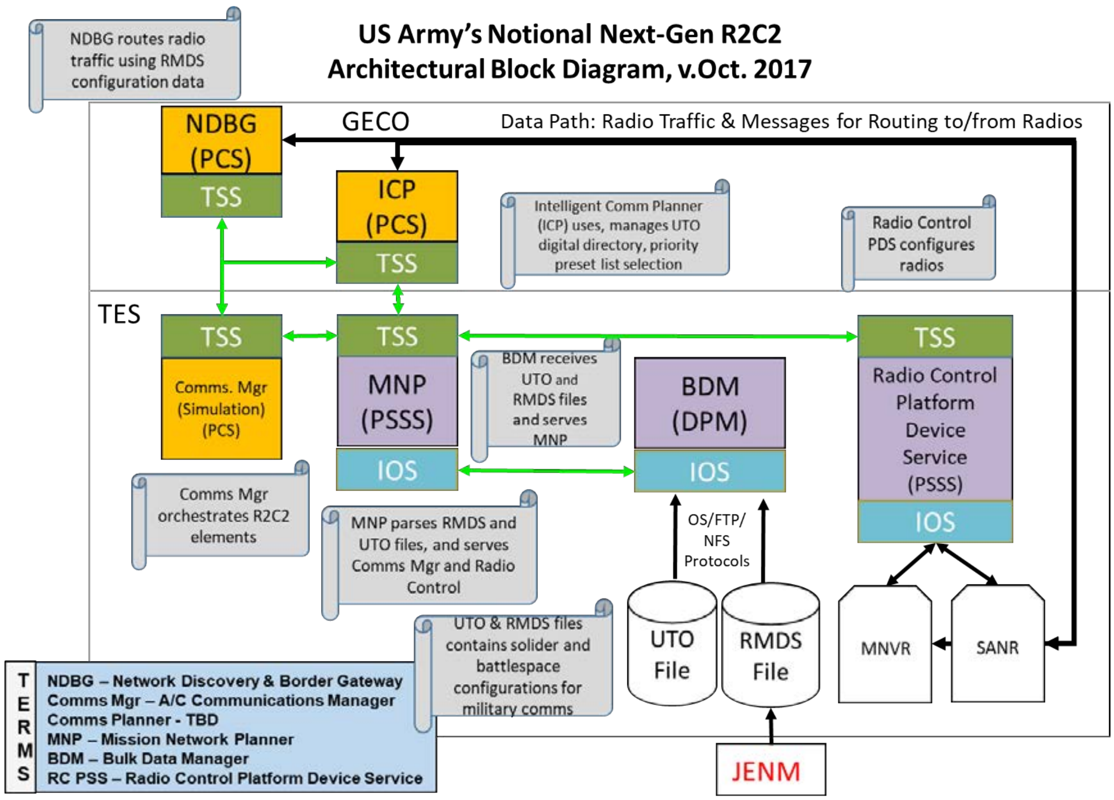

Figure 5 - ARCM (was R2C2) Software Capability Architectural Block Diagram

Army's PM Apache AGx EIS – ASE Domain of Multiple FACE Developments

U.S. Army's Apache program office has contracted Leonardo Electronics, Inc. (LEI) and Tucson Embedded Systems, Inc. (TES) to co-develop the next generation Aircraft Gateway Processor (AGP) known as AGx (x signifies neXt generation).

The AGx is a computer-based integration hub for Aircraft Survivability Equipment (ASE). The integration hub is designed to perform data fusion on applicable ASE sensor systems and provide prioritized tactical indications.

The initial targeted Platforms are the U.S Army's Apache AH-64D and AH-64E attack helicopter models (see illustrations below). The AGx system is designed following MOSA principles for potential reuse on other Army Aviation platforms with integration capabilities aligned to the FACE Technical Standard.

Figure 6 – PM Apache Attack Helicopters

The AGx software is split into two major subsystems. The External Interfaces System (EIS) is aligned to FACE Technical Standard and provides a FACE Transport Service Segment (TSS) interface to hardware and sensor systems. As noted, all software will be submitted and evaluated for Conformance using a sanctioned FACE Verification Authority. These sensors and devices include:

- APR-39A Radar Warning Receiver
- APR-39DV2 Radar Warning Receiver
- AN/APR-48B MRFI (Modernized Radar Frequency Interferometer)
- AAR-57 Common Missile Warning System (including Improved Countermeasure Dispensers) and CIRCM
- AVR-2A Laser Detecting Set
- AVR-2B Laser Detecting Set
- ALQ-144A Infrared Jammer (note this is a LEI development activity)
- ALQ-136 Radio Frequency Jammer (note this is a LEI development activity)

The EIS, developed as multiple FACE Units of Conformance (UoCs), is logically decomposed into the following modules: Seven (7) FACE PSSS's (RWR APR-39A PSSS, RWR APR-39DV2 PSSS, LWR AVR-2A PSSS, LWR AVR-2B PSSS, MWS AAR-57 PSSS, Aircraft Interfaces PSSS, and Ethernet Interfaces PSSS), plus four (4) FACE Services (*e.g.*, HMFM, Logging, Lifecycle Management, and Configuration Management) with a distributed FACE IOSS.

Note: TES will be supplying (with Restricted Rights) its self-funded internally developed research and development (IRAD) FACE Common Operating Environment (FACE COE) upon which these products will operate.

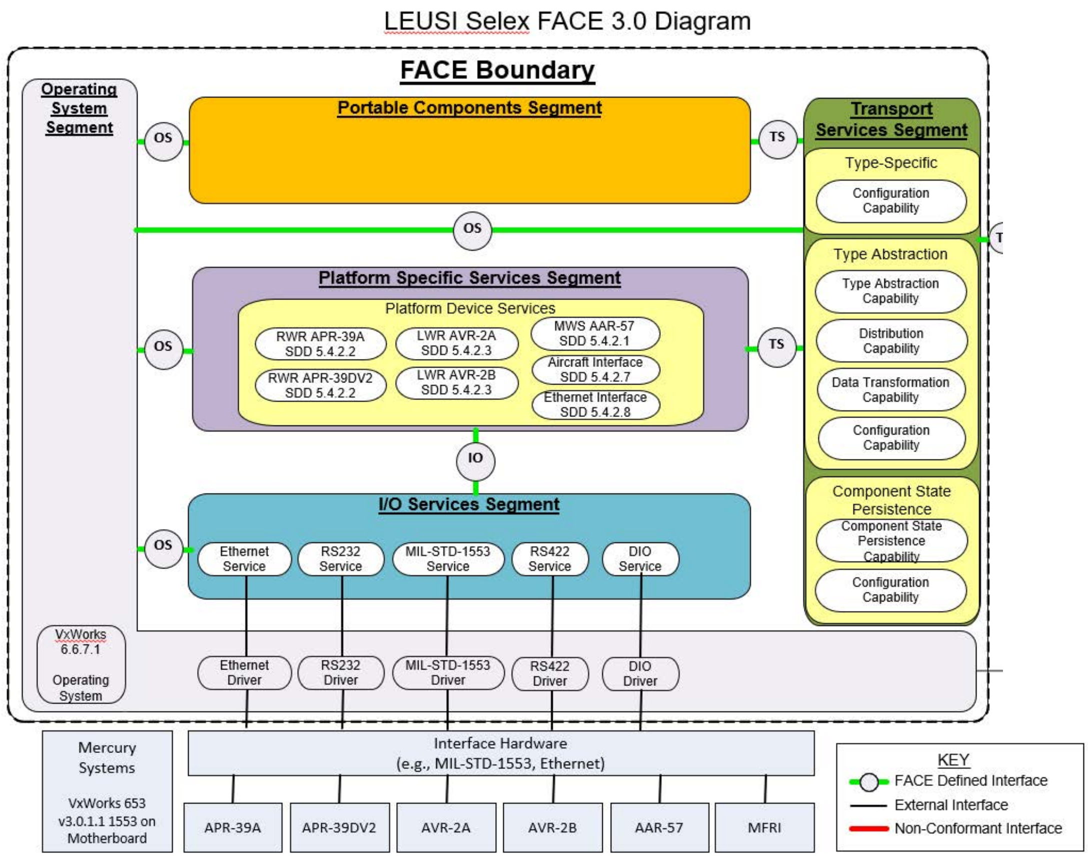

Figure 7 - AGx FACE Software Components, this figure developed with Leonardo Electronics US, Inc.

The AGx FACE Software will be sent to a sanctioned FACE Verification Authority (FACE VA) and through the Mission Equipment Development & AH-64E Modifications Apache Airworthiness Division –Systems Readiness Directorate-Airworthiness (MED-AWD SRD-AW).

TES' MBOSA Proven Process

TES-SAVi's AWESUM® CDA process [patent - "Method and Apparatus for Interfacing with Multiple Objects using an Object Independent Interface Protocol", US Pat No 8,239,586, Tucson Embedded Systems' Capability Driven Architecture (TES' CDA).], is embedded within the AWESUM® MBOSA modeling tool suite. It embraces the tenets of RTCA's DO-331 model-based supplement to DO-178 model based systems engineering [ref.: 3 – DO-331], and collects and organizes systems model descriptions sufficiently detailed to auto-generate the software product artifacts used by both FACE Conformance and Verification activities and Army Airworthiness qualification efforts [ref.: 5 – AR 70-62]. These include:

- Embedded Control Software (for the model system/device)
- Tests [high-level requirements (HLR) and low-level requirements (LLR) with tracing], and
- Life Cycle Documentation

TES' MBOSA aligns these artifacts for submissions to:

- Conformance (*e.g.,* a sanctioned FACE Verification Authority)
- Certification (*e.g.,* DO-178) [ref.: 2 – DO-178C], and
- Airworthy qualification processes (*e.g*., Military AWR, AR-70-62) [ref.: 5 – AR 70-62]

AWESUM® produces software life cycle data artifacts, aligned to DO-178C Life Cycle Data. These products are *intentionally tailored* to support FACE Verification and Conformance efforts with tracing to FACE Technical Standard requirements and FACE external interface artifacts described by the FACE data models, per the FACE™ Conformance Policy.

RTCA's Software Considerations in Airborne Systems and Equipment Certification (DO-178C), 2011 guidance [ref.: 2 – DO-178C], sections 3.0 and 11.0 Software Life Cycle Data, lists and describes 22 artifacts (11.1, PSAC, … , 11.22 Parameter Data Item File). These must be delivered for airborne certification and qualification efforts.

TES' MBOSA engineering development process is aligned with DO-178C guidance, with modifications to support the additional FACE Technical Standard Edition 3.1 requirements, and additional modifications to allow for software porting and reuse across different hardware target platforms. The reuse modifications comply with the FAA's Reusable Software Components, AC 20-148 [ref.: 4 – AC 20-148]. TES' processes follow model-based methods using our TES-SAVi AWESUM® MBOSA modeling tool suite. AWESUM® produces artifacts, including embedded control software aligned to the FACE Technical Standard, data models, tests, and documentation.

A useful guide that describes combining these processes and standards is the "Developer's Handbook for Airworthy, Reusable FACE Units of Conformance", Carter, Simi, Tompkins; 2014, US Army AMRDEC-SED [ref.: 12 – Handbook].

TES' MBOSA modeling tool suite also produces a unique Capability Interface Description (CID), based on the systems and semantic data model interface, *i.e.,* FACE data model. The CID is a combination of three data item descriptions. The combination accommodates higher-order non-language specific interface characteristics (ICD) with lower-level language-specific design (IDD & DBDD). This provides the specificity required for generating the implementation of message traffic software (*i.e.,* FACE TSS) and platform systems integration. The CID is the combination of ICD, IDD and DBDD, and is written in accordance with DI-IPSC-81436A (IDD), DI-IPSC-81437A (DBDD), and DI-SESS-81876, MIL-STD-3046 (ICD).

The CID meets DO-178C objectives identified in the Plan for Software Acceptance Compliance (PSAC). It draws upon guidance from DoD-STD-2167A—Defense System Software Development Best Manufacturing Practices, the Developer's Handbook for Airworthy Reusable FACE Units of Conformance, and the FAA's AC-20-148 Reuse Guidelines documentation.

The CID describes the interface characteristics of one or more systems, subsystems, Hardware Configuration Items (HWCIs), Computer Software Configuration Items (CSCIs), manual operations, or other system components.

The CID is a companion to three higher-order lifecycle documents, specifically the SSDD, SRS, and SSS. It therefore serves to communicate and control interface design decisions. Correspondingly, this CID has been traced to the SSDD, SRS, and SSS. Trace Data establishes the associations between life cycle data contents. Trace data within the CID demonstrates bi-directional association between:

- System requirements allocated to software and high-level requirements (SSS to SRS)
- High-level requirements and low-level requirements (SRS, SSDD)
- Low-level requirements and Source Code (SSDD to language-specific implementation)

In short, the CID is a textual description of the product's aggregated data models. It includes document hotlinks to assist Integrators navigation through this voluminous and important integration document. The CID is a useful dictionary of significant data products created during the development process, which is a product of TES' MBOSA.

This CID is delivered with other life cycle artifacts to support FACE Verification efforts. The other artifacts developed to support FACE Verification efforts include:

- Software Requirements Data (11.9),
- Design Description (11.10), with traces to the FACE Conformance Verification Matrix (FACE CVM) to support FACE Verifications efforts,
- Software Verification Cases and Procedures (11.13),
- Software Verification Results (11.14), and
- Trace Data (11.21)

TES, in close consultation with the Army's Airworthiness authority, has developed Life Cycle documentation templates, which are used within our TES-SAVi AWESUM® MBOSA tool suite. These templates guide our systems/software engineers through these complex life cycle processes. *For more information* see [ref.: 17].

Additional Benefits of TES AWESUM® MBOSA modeling tools and processes

As mentioned previously, using DO-331 model based processes with a “sufficiently” described model, one has the ability to auto-generate the embedded software control, corresponding tests, and life cycle artifact design and verification documentation. TES’ MBOSA has significant benefits -- it supports six additional process objectives illustrated and listed below; making it more DAL “B-like’.

During the DAL ‘C’ design activities, low-level requirements and tests are modeled using the AWESUM® model based tools suite. The model and tool suite is then used to generate software code, and tests with design and verification documentation. These artifacts correspond to the 6 low-level requirements Compliance Objectives (see Figure 8 below), which allows the source code to be verifiable (A3.3). These are significant process benefits, which serve to make the aircraft safer and the modeled product more robust.

LOE - Level of Effort

*** Upscope benefit using TES' MBSE DO-331- LOE becomes DO-178C DAL 'B-like'*

62	DO-178C Objective Compliance (of 71)
9	N/A for DAL-C
62	Reuse per AC 20-148 (59->62)
6	Compatible with the target computer (3->6)
Added	6 - Design and Test, using DO-331 MBSE (62->68)

DAL-C

			A4.1						
			A4.2						
			*A4.3						
			*A4.4						
			A4.5	A5.1		A7.1			
			A4.6	A5.2		A7.2			
A1.1	A2.1	A3.1	A4.7	*A5.3		A7.3			
A1.2	A2.2	A3.2	A4.8	A5.4		A7.4	A8.1		
A1.3	A2.3	*A3.3	A4.9	A5.5	A6.1	A7.5	A8.2	A9.1	
A1.4	A2.4	A3.4	*A4.10	A5.6	A6.2	A7.6	A8.3	A9.2	
A1.5	A2.5	A3.5	*A4.11	A5.7	A6.3	A7.7	A8.4	A9.3	A10.1
A1.6	A2.6	A3.6	A4.12	A5.8	A6.4	A7.8	A8.5	A9.4	A10.2
A1.7	A2.7	A3.7	A4.13	A5.9	A6.5	A7.9	A8.6	A9.5	A10.3
Plans	Dev	V.Rqt	V.Des	V.Sw	V.Int	VofV	CM	QA	Cert.

Figure 8 - Dashboard of DO-178C DAL “C” Ob A4.3, A4.4, A4.10, and A5.3) added as a

6 additional Compliance Objectives using TES' DO-331 mbse approach

A3.3 High-level requirements are compatible with the target computer
A4.3 Low-level requirements are compatable with the target computer
A4.4 Low-level requirements are verifiable
A4.10 Software architecture is compatible with target computer
A4.11 Software architecture is verifiable
A5.3 Source Code complies is verifiable

As illustrated below in Figure 9, TES' MBOSA is aligned with tenets of the FACE Technical Standard, and follows the FAA's Advisory Circular for Reusable Software Components [ref.: 1 – FACE, 4 – AC 20-148].

The reusable software can be recompiled and ported to dissimilar target computers that reside on dissimilar aircraft platforms. With automated scripts, we test and demonstrate the process objectives identified in yellow in Figures 4 & 8, and reuse the artifacts (planning, requirements, and design documentation, test cases and procedures) corresponding the to the DO-178C Compliance Objectives identified in green ~90% reuse.

This represents the goal and desire of FACE tenets for open reusable software. The DO-178C airborne certification process is optimized and aligned with the FAA's guidance for software reuse across dissimilar platforms/aircraft. This TES' MBOSA process represents a 90% artifact reuse.

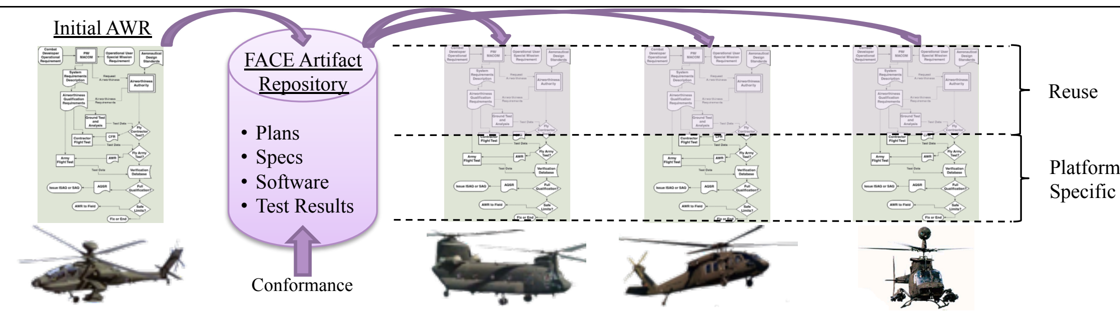

Figure 9 - Reusable Verification Components (RVC) across dissimilar target platforms (AC 20-148) [4]

Next Steps

TES-SAVi's AWESUM® is a commercially available product [https://tes-savi.com/awesum-products/]. TES' Military Aerospace Solutions (MAS) division members actively participate in the FACE Consortium, serve as leads on several FACE working groups, and provide FACE development engineering services [https://tes-savi.com/services/]. TES-SAVi FACE VA is a sanctioned FACE Verification Authority [https://tes-savi.com/services/].

TES is on schedule to develop FACE conformant software, which is scheduled for US Army aircraft (AH-64D & E models, and the UH-60M & V models) in 2021. The software will be verified by TES-SAVI's FACE VA (for the AGx EIS) and US Army's FACE VA (for the ARCM). ARCM will be submitted to the U.S. Army Airworthy authorities for flight qualification efforts, performed by Mission Equipment Development & AH-64E Modifications Apache Airworthiness Division –Systems Readiness Directorate-Airworthiness (MED-AWD SRD-AW). As noted the software shall be designed with considerations for reuse per AC 20-148 RSC guidance [ref.: 1 – FACE, 4 – AC 20-148].

Next Steps include additional direct and indirect development support for the FVL FoS' that await the military community. The initial aircraft include both the Future Attack Reconnaissance Aircraft (FARA) and the Future Long Range Assault Aircraft (FLRAA). TES will continue to support JMR developments including the JMR AV/MSA IDD and the FVL Architectural Framework (FAF).

Summary

TES has been working for the U.S. Army Aviation branches, PEO Aviation and CCDC-AvMC, on developing tools and processes for rapid development and integration of reusable software avionics systems since 2003, has been an active participant in the FACE Consortium since its inception in 2010, and a commercial MBOSA tool developer since 2013 – TES-SAVi.

This paper, *IMPACT in Action* showcased how TES has implemented an industry-unique MBOSA process, following the tenets of MBSE that are aligned with the MBOSA vision for Next-Generation Model-Based Systems Engineering Processes and Tools Supporting the Airworthiness efforts of Cyber Physical Systems (CPS) [Ref.: 6 – IMPACT, 9 – Next Generation MBSE]. It described how years of lessons learned are being leveraged to develop multiple FACE development efforts aligned with the FACE Technical Standard and Army's Airworthiness processes.

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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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Mr. Stephen Simi has worked within the advanced aviation industry for the U.S. Military and Space industry for the past 16 years at Tucson Embedded Systems, Inc. He currently serves as TES Vice President and Division Lead for Military and Aerospace Solutions (MAS) division, has lead and currently is leading many U.S. Army, Navy, Air Force, and NASA JPL program efforts for TES. He is partnered with many aviation industry organizations, helping the community to populate a growing list of FACE Conformant products [https://www.facesoftware.org]. Currently TES has helped developed 30% of these products.

Stephen has 33 years experience in Engineering, with 20 plus years at executive level. Stephen has a B.S. in Physical Sciences (Math, Computer Sciences, and Engineering) and a M.S. in Engineering from the University of Maryland. He is recognized as an industry innovator of agile technologies that can be applied to Joint forces across the common operating picture/battlespace of C4ISR assets, and an industry expert in lifecycle development of reusable software systems. He has authored over thirty technical publications and presented to the AHS, AOC, and AIAA/IEEE societies, to the FACE Consortium, and MITRE on areas of software development, reusable systems, and advanced modeling and simulations of those systems. Stephen currently manages US military programs for the US Army Aviation, US Air Force, and the Vertical Lift Consortium (VLC) Joint Multi-Role (JMR) program efforts; and aerospace programs for NASA JPL [https://www.linkedin.com/in/stephen-simi-94540226/].

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About The Open Group FACE™ Consortium

The Open Group FACE™ (Future Airborne Capability Environment) 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 the FACE Consortium is available at www.opengroup.org/face.

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