Air Force's Continuous Integration and Continuous Development with the FACE™ Technical Standard

FACE VV&A on the Hanscom MilCloud

Army FACE TIM Paper by:

Jeffrey W. Wallace, Ph.D., CMSP, Infinite Dimensions Integrations, Inc.

Sara J. Kambouris, Ph.D., Infinite Dimensions Integrations, Inc.

Stephen M. Simi, Tucson Embedded Systems, Inc.

Ed LeBouthillier, Tucson Embedded Systems, Inc.

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Table of Contents

Executive Summary

Verification, Validation, and Accreditation (VV&A) confirm the establishment of a well-formed development and integration process. Performing on the Air Force's R-EGI program, Infinite Dimensions, Inc. (IDI) and Tucson Embedded Systems, Inc. (TES) combined VV&A capabilities to support open systems development efforts aligned to the FACE Technical Standard in a continuous integration/continuous development (CI/CD) process hosted on the Hanscom MilCloud (HmC). US Air Force's Resilient-Embedded Global Positioning System/Inertial Navigation System (R-EGI), Virtual EGI Development and Testing, [RIK-OTA-16-ZAC-EGI] – is a program with software and architecture aligned to the FACE Technical Standard that includes rapid prototyping, cross-organizational developments, secure internet protocol (IP), and with hardware in the loop (HWIL) support.

The approach utilized for R-EGI may well change how cross-organizational teams collaborate. CI/CD has been shown to effectively speed capability development though the life cycle and improve product quality. The CI/CD can be replicated to support other development efforts aligned to the FACE Technical Standard.

This paper and the corresponding FACE Technical Interchange Meeting (TIM) capability demonstration should be of interest to both Stakeholders and cross-organizational integrate product teams (IPTs) of Systems/Software Developers of open systems products aligned to the FACE Technical Standard, and or other open systems approaches that have complex accreditation requirements.

Introduction

Next-generation aircraft capabilities will be developed by cross-organizations, combining skilled workforces to develop, deliver, qualify, and field increasing complex product with reduced schedule requirements [1]. Innovative approaches that garner collaborations are being developed and tested to support the development of open systems products. This paper describes how one approach, continuous integration continuous development (CI/CD), is helping to *challenge* and *push* the envelope of *business as usual*.

Military aircraft are qualified using one of a branch-specific approved process [2,3,4]

- AR 70-62 – Airworthiness Qualification of US Army Aircraft Systems
- MIL-HDBK-516B – Airworthiness Certification Criteria US Department of Defense (DOD)
- Joint Software System Safety Committee (JSSSC) Software System Safety Handbook

These processes all have similar Verification, Validation, and Accreditation (VV&A) guidelines in that the Product Supplier/Developer/System Integrator must sufficiently demonstrate that system and software high-level and low-level requirements are achieved and are traced to test results of review-approved tests [5,6,7,8,9,10]. In addition, newer defense contracts may also levy open systems standards requirements (like the FACE Technical Standard [11,12,13]) on a Product Supplier.

Several studies identified that the earlier problems are identified and corrected in the life cycle, the less cost and less impact on schedule the problems are easier to correct [14,15,16,17,18]. Correspondingly in order to reduce impact on cost and schedule, there is desire to "*collapse*" or "*shift-left*" the Life Cycle V model (see Figure 1), thereby bringing it forward in time and then paralleling the two efforts for requirements and development with the corresponding verification and validation efforts.

The term for such an environment, is continuous integration continuous development (CI/CD), where Developers have supporting automated verification and validation processes that allow them to test against supplied test suites, and check development efforts in a *test-fix* agile development cycle.

Several complimentary layers of model-based agile design, development and testing [17] now enhance the older approach of incremental development and collectively support Verification, Validation, and Accreditation (VV&A) efforts purposely aligned with Conformance and Accreditation requirements.

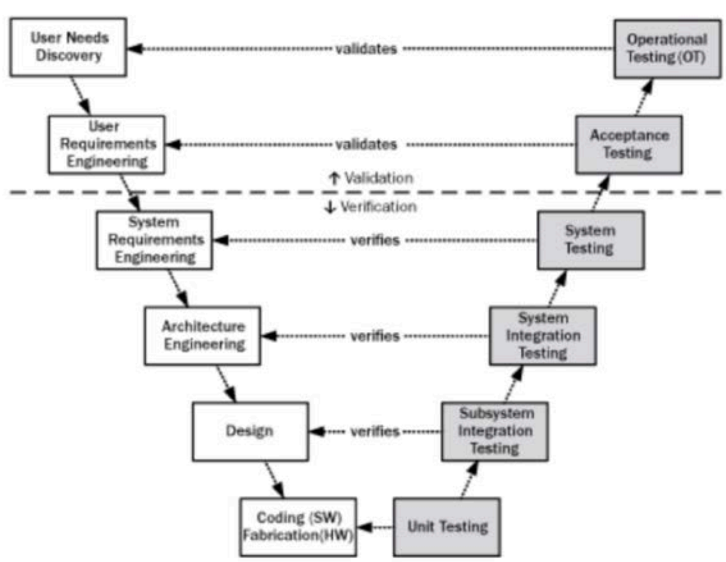
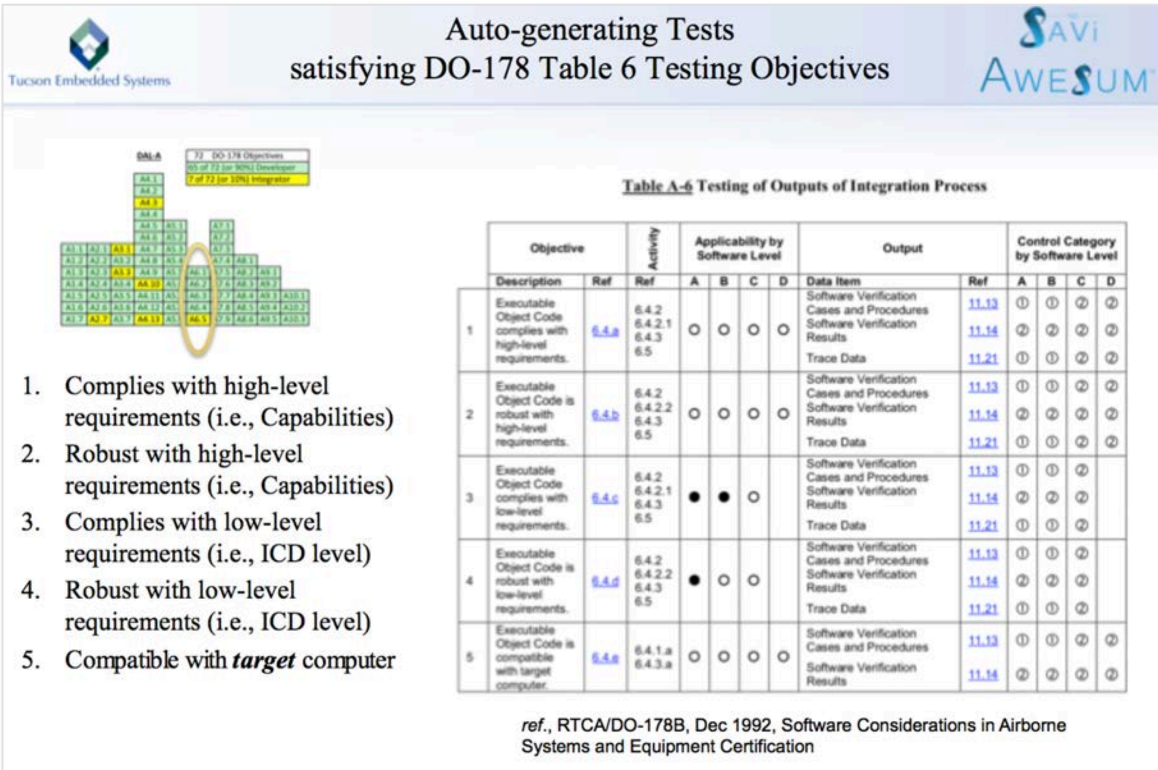


Figure 1 - Shift-Left Life Cycle Model [17]

When we look at Radio Technical Commission for Aeronautics' (RTCA's) DO-178C Software Considerations in Airborne Systems and Equipment Certification guidance [7,8], the Process Objectives described in Table A-6 – Testing of Outputs of Integration Process, and in Table A-7 – Verification of Verification Process Results can be supported by model-based automation (Figure 2).



	Objective		Activity	Applicability by Software Level				Output		Control Category by Software Level			
	Description	Ref	Ref	A	B	C	D	Data Item	Ref	A	B	C	D
1	Executable Object Code complies with high-level requirements.	6.4.a	6.4.2 6.4.2.1 6.4.3 6.5	○	○	○	○	Software Verification Cases and Procedures	11.13	①	①	②	②
								Software Verification Results	11.14	②	②	②	②
								Trace Data	11.21	①	①	②	②
2	Executable Object Code is robust with high-level requirements.	6.4.b	6.4.2 6.4.2.2 6.4.3 6.5	○	○	○	○	Software Verification Cases and Procedures	11.13	①	①	②	②
								Software Verification Results	11.14	②	②	②	②
								Trace Data	11.21	①	①	②	②
3	Executable Object Code complies with low-level requirements.	6.4.c	6.4.2 6.4.2.1 6.4.3 6.5	●	●	○		Software Verification Cases and Procedures	11.13	①	①	②	
								Software Verification Results	11.14	②	②	②	
								Trace Data	11.21	①	①	②	
4	Executable Object Code is robust with low-level requirements.	6.4.d	6.4.2 6.4.2.2 6.4.3 6.5	●	○	○		Software Verification Cases and Procedures	11.13	①	①	②	
								Software Verification Results	11.14	②	②	②	
								Trace Data	11.21	①	①	②	
5	Executable Object Code is compatible with target computer.	6.4.e	6.4.1.a 6.4.3.a	○	○	○	○	Software Verification Cases and Procedures	11.13	①	①	②	②
								Software Verification Results	11.14	②	②	②	②

Figure 2 - Automation of DO-178 Table 6 Test Objectives

Furthermore, a hardware agnostic open interface standard, like the FACE Technical Standard, allows an opportunity to align with AC 20-148 "Reusable Software Components" [1,6,18]. As such, design, development, and verification artifacts can be reused across dissimilar target architectures, illustrated in Figure 3.

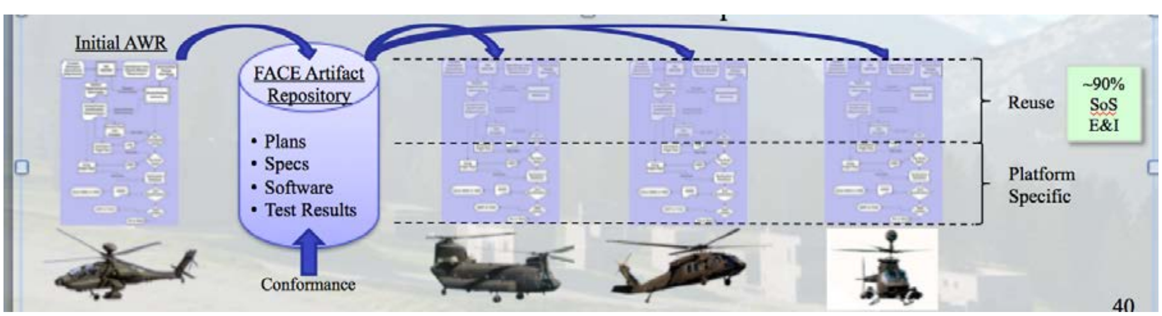


Figure 3 - Reusable Verification Components (RVC) across dissimilar target platforms (AC 20-148) [6]

The US Air Force's R-EGI program objectives afforded us the opportunity to apply a rich set of VV&A activities in an automated fashion and efficiently enhance cross-organizational development operations with an integrated product team (IPT). The following list describes and illustrates our efforts with some insightful findings.

The VV&A of FACE Applications on the Hanscom MilCloud (HmC)

The VV&A performed on our R-EGI CI/CD development environment includes these steps:

- Accreditation – ***Run*** CI/CD development efforts through the FACE Conformance Test Suite (CTS)
- Verification – ***Run*** the BALSA architecture support tests to ensure that added R-EGI development efforts have not compromised BALSA functionality. These executable tests are available as a part of the BALSA source distribution.
- Verification – ***Review*** the product development to ensure the software conforms to standards
- Validation – ***Run*** R-EGI and examine error statistics
- Platform Integration – ***Re-run*** R-EGI on small board computer (SBC) target

Accreditation – Run CI/CD development efforts through the FACE Conformance Test Suite (CTS)

The FACE Conformance Test Suite (CTS) demonstrates alignment to the FACE Technical Standard of candidate Software Supplier data models and source code artifacts. Although only part of the entire FACE Conformance program, the CTS serves as an initial and important step within the conformance process.

Other verification efforts aimed at FACE UoCs include reviewing the product development design artifacts to ensure the software design is aligned to the FACE Technical Standard (see Verification below). Note: If a Program requires product Conformance to an edition of the FACE Technical Standard, the Authors suggest that you contact a Sanctioned FACE VA early in the process. Early coordination with a VA will help serve to ensure your software design is aligned to the FACE Technical Standard early in the process and help limit cost of rework and time for alignment design corrections.

Users of the CTS configure the test suite corresponding to the Software Supplier software profiles [see Figure 4 and refer to reference [13] – FACE Software Supplier Getting Started Guide, Appendix A – Obtaining the FACE UoP Supplied Data Model Data Model and Testing using the Conformance Test Suite].

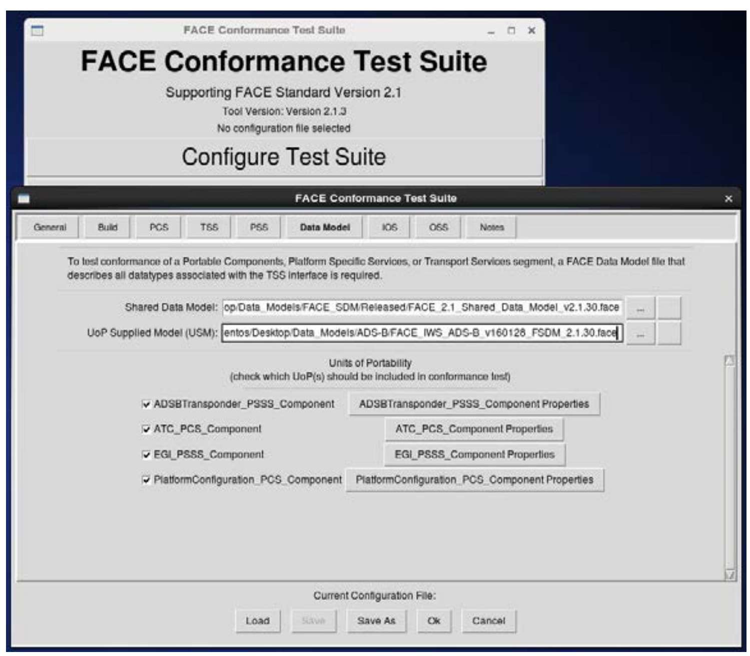


Figure 4 - Example CTS Configuration Dialog

The R-EGI program developed pre-configured scripts for our software suite. These scripts contain the data needed to populate the CTS dialogs and execute conformance tests. We prepared scripts to launch the CTS, load saved configuration files, and run the CTS using the latest branch R-EGI software baseline. This automation helps ensures that the latest R-EGI software baseline continuously meets requirements of the FACE Technical Standard.

Verification – Run the BALSA architecture support tests to ensure that added R-EGI development efforts have not compromised BALSA functionality

The R-EGI baseline was built upon the Basic Avionics Lightweight Source Archetype (BALSA) FACE implementation architecture v2.1. The Consortium’s intent was to leverage BALSA as an implementation example, and have it used it as a “starting point” from which Software Developers using the FACE Technical Standard will layer on additional functionality, allowing them to create enhanced software capabilities aligned to the FACE Technical Standard.

The BALSA source distribution code is available to Consortium-only members, includes the following set of BALSA architecture support tests. This software can be obtained using links to BALSA provided below in Table 1. These operational functional tests, are *summarized* by the titles listed below, help verify and demonstrate that Software Supplier’s implementations have not compromised baseline BALSA operations.

BALSA Architecture Support Tests

- Configuration Systems Logging Test
- INI File Media Adapter Test
- File Media Adapter Test
- Configuration Library INI Files Test
- Shared Memory Test
- XML File Configuration Test
- Timestamp Test
- Types Packing/Unpacking Test
- BufferQueue Test
- IMU/GPS/Ephemeris Test
- ADS-B encoder/decoder and results Test

Table 1 - Obtaining BALSA FACE Implementation Architecture software

BALSA aligned to FACE Technical Standard, v2.1 (FACE Consortium access-only, protected product suite) https://www.opengroup.us/face/BITS/protected/documents.php?action=show&dcat=&gdid=18659
BALSA v3.0; aligned to FACE Technical Standard v3.0 (FACE Consortium access-only, protected product suite) https://www.opengroup.us/face/steering/intworkshop/protected/documents.php?action=show&dcat=&gdid=19089

In addition to these built-in BALSA architecture support tests, additional testing was added to verify Software Supplier enhanced functionality. R-EGI added the Navigation Position Estimator capability and its corresponding test capability.

The R-EGI test bed automatically executes these BALSA + R-EGI enhanced tests whenever changes to baseline code is checked into the R-EGI program's version control system. The R-EGI program's version control system is user whitelisted and safely and securely located on AFRL Hansom MilCloud (HmC). This R-EGI CI/CD process ensures that new functionality and new development efforts haven't compromised previous baseline functionality. Pass/fail results are logged within the test suite environment.

Verification – Review the product development to ensure the software conforms to standards

As introduced with CTS accreditation efforts above, an accompanying FACE Verification activity involves analysis of software design artifacts to ensure developed products are aligned with standards (e.g., FACE, and DO-178C [8] Process Objective Table 4 – Verification of Outputs of Software Design Process).

Figure 5 - Verification via Inspection of Work Product Outputs

The R-EGI program is composed of skilled workforce from cross-organizations forming a collaborative integrated product team (IPT). The IPT is executing an agile type development process, using the HmC to develop, VV&A, and demonstrate operations of R-EGI work products. Although R-EGI program contracted team members to perform on co-dependent tasks; during execution, the IPT collaborations blurred the demarcation of individual organizational tasks. These cross-task collaborations helped ensure a proper hand-off between organizational tasks, helped ensure that quality work products transitioned among tasks, and did not delay or compromise life cycle and task workflows. IPT served to review and analyze work products that effect flow-down efforts (e.g., organizations helped others get "up-to-speed" with FACE Technical Standard requirements).

Our findings interestingly challenged the current culture of *business as usual* practices established within the aviation communities; practices where companies typically compete against each other *versus* assist each other. The R-EGI program's cross-organizational agile environment forced IPT organization's members to review and modify the product developed by other team members.

For example, it is well known the level of knowledge and expertise for FACE data modeling is limited and varied across today's aviation companies. Within the R-EGI program, one organization served and helped verify and identified model design issues back to another IPT developer. Partial resolution was addressed, the product was then passed back into the workflow, which flowed-down to and included two other IPT organizations. The product revisions were reviewed and deemed that they made the model functional, but not correct. The issue was again identified through the R-EGI program manager. The immediate inquiry from PM back to the Verifier, was why did the Verifier not just not make the corrections? The short answer was/is that in *today's* competitive culture, you just don't change another organization's work product (unfortunately, you often don't ever help them).

We observed first-hand how this R-EGI CI/CD environment challenges cross-organizational roles and responsibilities, and helps promote IPT collaborations that produce rapid developments with real-time VV&A efforts, resulting in improved product delivered faster.

For example, an actual exchange via email was...

> "*The pathing looks correct and the generated messages are now much more succinct. One other thing I noticed in today's drop, in Laser_Scanner platform entity there is a Characteristic Composition "Point" with Min elements 1 and Max elements -1. Thank you*"

Therefore, the R-EGI CI/CD environment augmented automation with collaborative practices enhancing VV&A efforts and improving product development.

Validation – Run R-EGI and examine error statistics

As illustrated in software architecture diagram Figure 5, 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 a 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.

> *Kalman filter is a linear quadratic estimation (LQE), is an algorithm that uses a series of measurements observed over time, containing statistical noise and other inaccuracies, and produces estimates of unknown variables that tend to be more accurate than those based on a single measurement alone, by estimating a joint probability distribution over the variables for each timeframe.* [Wikipedia]

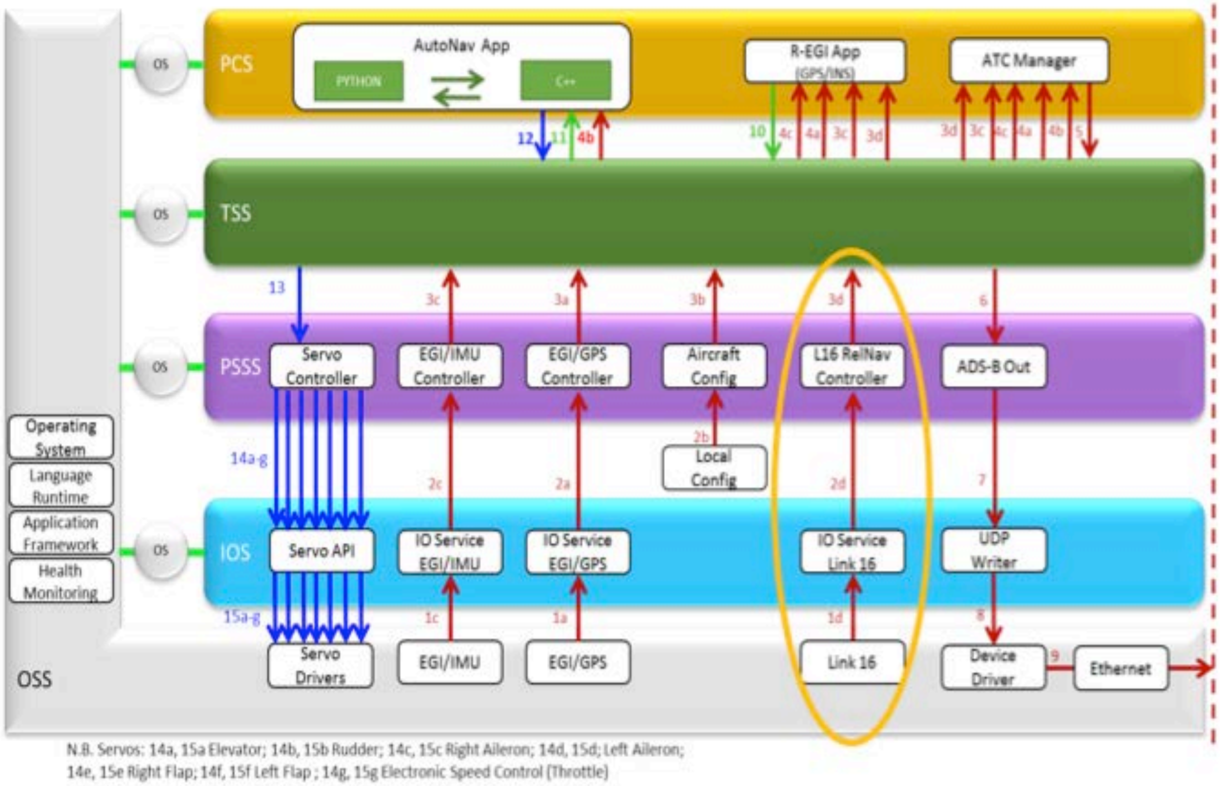


Figure 6 - Diagram of R-EGI Modules

To ensure that the R-EGI multi-module FACE Units of Conformance (UoCs) were operational at the module and integrated systems levels, and to demonstrate that the integrated system meets its intended use, automated validation tests were developed. These integration tests are performed using R-EGI test data [e.g., ViaSAT Terminal Operational Environment Simulator (TOES)]. The R-EGI CI/CD checkout, build, and collective test results processes are shown in Figure 7.

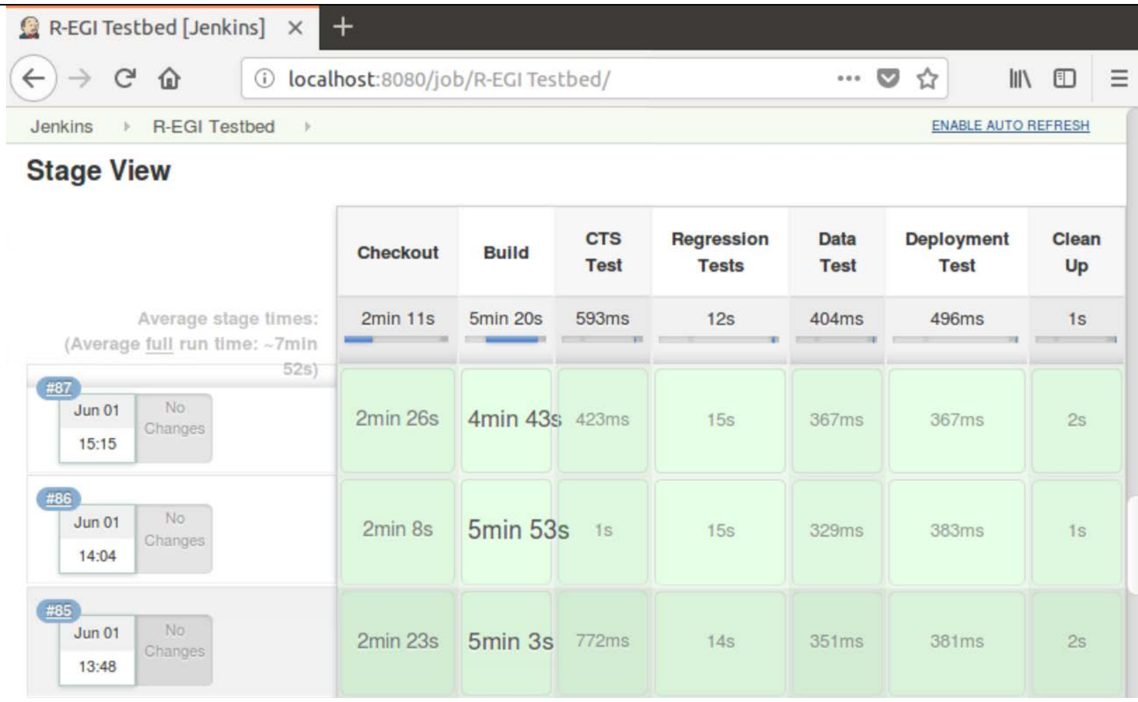


Figure 7 - R-EGI CI/CD checkout, build, and collective test results processes

Platform Integration – Re-run R-EGI on small board computer (SBC) target

In addition to all of the above test processes, and as part of the CI/CD process, the R-EGI development code is deployed and tested on single board computer (SBC) target architectures. These tests occur whenever code changes are checked in.

The targeted runtime system is based on the INTEGRITY-178 tuMP, a real-time operating system (RTOS) from Green Hills Software. Running on and verifying operations of the deployment in this manner increases the operational fidelity by demonstrating performance on the actual targeted platform. It also increases the test readiness level (TRL) of the R-EGI development from TRL 4-5 to TRL 6. Additionally, it demonstrates hardware agnostic platform independence of the developed software.

With operational testing performed on a target, several DO-178 verification objectives, e.g., A-6.5, are demonstrated in an automated fashion (*c.f.*, Figures 2 and 3 above).

Summary – VV&A of AFRL's R-EGI performed on AFRL's Hanscom milCloud CI/CD development environment

Performing on the Air Force's Resilient-Embedded Global Positioning System/Inertial Navigation System (R-EGI) program, Infinite Dimension, Inc. (IDI) and Tucson Embedded Systems, Inc. (TES) combined VV&A capabilities to support open systems development efforts in a continuous integration/continuous development (CI/CD) process hosted on the AFRL's Hanscom MilCloud (HmC). These efforts were purposely aligned to the FACE Technical Standard, and the VV&A capabilities embraced the FACE Technical Standard.

The approach speeds capability development and improves collaboration of cross-organizational teams throughout the life cycle. We observed that the R-EGI model-based agile design, development, testing using CI/CD environment improved product quality and reduced development schedule, by addressing design and implementation issues early in the life cycle. Automation helped the development and verifications processes with a test-fix processes that may have saved months of man-hours of efforts.

It is estimated that development/verification processes that would typically take months of man-hours were reduced to a few hours using these model-based system engineering techniques and tools to support eco-system of the FACE Technical Standard. Additionally, several process iterations were performed on the R-EGI software components and FACE UoCs, saving development/verification times with each test-fix integration cycle [19]. Furthermore, the process ensured alignment to the FACE Technical Standard with each iteration [19].

The CI/CD can be replicated to support other development efforts aligned to the FACE Technical Standard, or other open systems approaches that have complex accreditation requirements.

This paper and the corresponding FACE TIM capability demonstration should be of interest to both Stakeholders and Systems/Software Developers of products aligned to the FACE Technical Standard, and/or other open systems approaches that have complex accreditation requirements.

For additional information on Infinite Dimension, Inc. (IDI) and its capabilities see [http://id-inc.us].

For additional information on Tucson Embedded Systems, Inc. (TES), TES-SAVi FACE Verification Authority (FACE VA), and TES-SAVi model-based tools that can be used for aligned with the FACE Technical Standard software developments and VV&A see [https://tes-savi.com].

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About the Author(s)

Jeffery W Wallace, Ph.D. CMSP, Infinite Dimensions, Inc., has over 25 years' experience in unmanned systems, interoperability, artificial intelligence, modeling and simulation (M&S), and high-performance computing – in a variety of academic, government, and industry positions. He worked with the Army, Navy, Air Force and Marines on various projects over the years. During the past 20 years, he worked as a government employee and as a CEO/CTO, he participated in the solution of many systems development and interoperability problems. Dr. Wallace helped reduce development and interoperability costs on several programs of record, often by a factor of four. Dr. Wallace has written over 40 technical papers and edited six books listed in the Library of Congress. He served as the general, or program, chair for numerous international conferences in unmanned systems, modeling and simulation (M&S), and high-performance computing. He led the team that created the first Certified M&S Professional examination.

Sara J Kambouris, Ph.D., Infinite Dimensions, Inc., is the Chief of Operations, and she is a facilitator for project management, engineering support, marketing and high-tech prototypes, team building and leadership, scientific and marketing data analysis, risk evaluation, and process improvement. Dr. Kambouris serves on the Integration Workshop Standing Committee.

Stephen M. Simi – serves as TES-SAVI's Vice-President and Program Manager for Military Aviation programs. Stephen has 30 years of experience designing and developing engineering and scientific applications and managing multiple programs. Since inception in 2010, Stephen has been very active in the FACE Consortium. He is serving as the Consortium's Integration Workshop Standing Committee (IWS) Vice-Chair, serves on the Steering Committee, Outreach, Conformance, and Airworthiness sub-committees; and has exhibited at every FACE Technical Interchange Meeting (TIM). 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 numerous technical publications and presented to the AHS, AOC, 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 has managed numerous US Army programs, VLC JMR Task 4 AV/MSA, JCA, MIS, R2C2, UC3, and MICD for TES, for the US Army Aviation, R-EGI with IDI for AFRL, and principal investigator and PM for SBIRs and BAAs. Stephen has a B.S. in Physical Sciences (Math, Computer Sciences, and Engineering) and a M.S. in Engineering from the University of Maryland. Before working for TES, Stephen served as the Director of Software Development, and Director of Software Business Development at world-renown optics company Breault Research. He also served, as a technical fellow at the MITRE CORPORATION for the US ARMY, The BOEING Company working on the International Space Station, was a college professor of Computer Science, and served various other organizations designing, developing, and testing engineering and scientific applications over his 30-year technical career.

Ed LeBouthillier – serves Tucson Embedded Systems, Inc. Military Aviation Division as a Senior Systems and Software Developer. He currently is performing within the R-EGI IPT as key developer in the R-EGI Link16 software development effort. Ed has a B.S. in Computer Science from the California Polytechnic University, Pomona. His 35-year career includes a variety of different industries including manufacturing, aerospace, communications, and medical.

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 the FACE Consortium is available at www.opengroup.org/face.

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