Joint Simulation Environment for United States Air Force Test Support

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ABSTRACT

Advances in integrated, multi-domain warfighting capabilities are challenging the ability of militaries to rapidly design, develop, field, support, test, and train next generation war fighting capabilities. Today's physical test ranges, in their present form, are inadequate to meet the testing and training needs of these future integrated weapon systems. Future test capabilities must be augmented with state-of-the-art modelling and simulation technologies to form a virtual range capable of meeting development, test, and training needs in a rapid and cost-effective manner. The United States Air Force, in concert with our Service partners, intends to develop an integrated modelling and simulation based virtual test range to address these challenges. The Joint Simulation Environment (JSE) leverages lessons learned from recent modelling and simulation activities in support of Joint Air Force and Navy testing. JSE seeks to advance the state of the art in modelling and simulation technologies applied to test, training, and experimentation. This paper will discuss JSE use in supporting Air Force objectives, challenges, way-forward, and potential NATO Partnership opportunities.

1.0 INTRODUCTION

The overall vision for the Air Force for the JSE capability is to improve developmental and operational test quality and efficiency, provide a stable and secure environment for cross-platform advanced training and tactics development, and better inform future acquisition decisions by improving the quality of integrated force analysis of alternative studies via multiple fidelity level experimentation and capability demonstration. Specific JSE objectives include:

(1) A government-owned, multi-platform advanced M&S capability that overcomes existing open-air range limitations, to include system availability, threat density, and safety and security concerns.
(2) An open architecture that enables composability and integration of models and simulations of varying levels of fidelity, to include blue and red aircraft operators-in-the-loop, threats, weapons, terrain and weather.
(3) Interoperability with other services and foreign partners within the JSE and extension to other required simulation environments.
(4) Opportunity for international testing and training/experimentation.

The overall goal of JSE is to enable smarter, faster acquisition by providing data in order to enable war fighter and acquisition decision makers to make risk-informed decisions in support of the recently published U.S. National Defense Strategy. *Dr. Eileen A. Bjorkman, Deputy Director of Test and Evaluation*

Air Force leadership recognized the need to provide a credible test environment to support current and future system testing, not currently possible on current test ranges due to a number of limiting factors. These factors include geographical constraints, technology limitations, electronic warfare limitations, frequency spectrum interference, operational limitations, and safety concerns. Reviewing these factors is instructive since they form or significantly contribute to the requirements foundation of the JSE for the Air Force.

2.0 JSE REQUIREMENTS

In 2017, the Chief of Staff of the Air Force (CSAF) directed the AF community to pursue a synthetic test capability designed to address current and future test and training deficiencies. The funding for this effort, provided by the AF to support the development activities and a lead execution organization (412th TW at Edwards AFB) within the test community, was established starting in Fiscal Year 2019. The Air Force Test and Evaluation Office (AF/TE) directed the team to develop and field a synthetic test capability by FY23 at both Edwards and Nellis AFBs. This effort links with the development of the synthetic test environment currently in development at Patuxent River NAS using a joint USN, USAF, and Intelligence Agency team.

The requirements development effort addresses three primary areas: (1) test limitations within today's physical test ranges, (2) anticipation of future capabilities and associated needs, and (3) balancing of cost and risk in achieving a useable and flexible design that can readily grow in time.

2.1 Limitations on today's test ranges

- Geographical constraints affect the ability of the live assets to properly set up the engagement, employ longer-range weapons, maneuver, or employ CONOPS/TTPs within larger mission fleets/forces against an air or ground threat system or integrated air defense system (IADS).
- Technology limitations limit the integration of live assets with modelling and simulation entities in the execution of test objectives. While the Test community has utilized synthetic environments for numerous years on the test ranges to augment a live force, significant technology-based obstacles exist that limit the effectiveness of the synthetic environment, such as the inability to replicate a dense threat environment employing complex signals in real time.
- Electronic Warfare Limitations include the replication of dense and complex electronic warfare environments in real time within a digital format. Achieving this computationally challenging environment through the use of complex fully digital signals would allow the simulation world to rapidly and cost-effectively scale the environment and be more representative of today's battlespace.
- Frequency Spectrum Interference limits today's test ranges in the type, and strength of electronic signals permissible on the range. This may include not only electronic warfare signals, but also IFF and RF communications that are not bound to range physical characteristics and may be adjacent to commercial frequency spectrums causing unintended electromagnetic spill over.
- Operational Limitations prevent the full range of possible engagements within a Mission Effects or Kill Chain. The most obvious limitation is the safety-driven limitation of the use of live weapons in close proximately to manned systems to complete the Kill Chain or engagement on a test range.
- Safety Concerns address not only the inability to utilize weapons, but also complex engagements of multiple aircraft aggressively manoeuvring in a confined airspace and with terrain considerations. Range safety is a primary concern when testing aircraft and routinely provide test limitations that can adversely affect test results.

The JSE seeks to remove or limit these constraints by developing a virtual test range to augment the existing physical ranges when testing systems or system of systems.

2.2 Anticipation of future system test needs

Next generation testing will encompass not only advanced systems and weaponry, but also the need for systems to work in close coordination (between US and NATO partners) within an information-based system of systems. Information technologies will provide broadband, high-speed connectivity that will enable shared information-based applications to support improved detection, tracking, identification, and weapon delivery solutions. A future synthetic test range may be the only viable means to test a future information-based system/system-of-system kill chain. Viability implies not only the ability to test the technologies, but to do so in a cost-effective, risk-mitigated, and complete (full kill chain) manner. Future test needs may include:

- Battlespace Density/Complexity: The synthetic range must be able to produce large numbers of assets of varying complexity to properly "feed" the System-Under-Test (SUT) in a credible battlespace environment to support the necessary and appropriate test conditions. These feeds are a combination of virtual and constructive entities from a variety of simulation capabilities in a distributed environment.
- Geo-Specific Place/Time Testing: The synthetic range must be able to replicate geo-specific terrain on any test range or in any area of the world. This capability must include not only the support of non-imaged sensors, but also image-based sensors including cultural features and threats/targets-of-interest to the test community. An additional requirement is to replicate this geo-specific place within varying time spans from current year to any number of future projected years.
- Representation of Future Rapid and Adaptive Threat Capabilities: The synthetic range must be able to produce a realistic representation of future threats and the resulting interaction with the System Under Test (SUT). Stapleton observed that we do not realistically represent technologies within our tests often substituting current technologies in place of future technologies that are not well understood, or similarly, future effects that are not well understood. This pattern is often repeated with regard to our future threat representations, resulting in unrealistic own and opposing forces pairings under unrealistic engagement conditions. As more systems increasingly rely upon easily upgradable software this trend becomes more pervasive in our testing. [1]
- Multi-Domain Integration: The synthetic range must be able to produce the ability to test the kill chain across multiple domains including air, space, sea, land, and cyber. The synthetic test range must address the multi-domain aspects of future systems and their associated war fighting capabilities. Additionally, the nature of a multi-domain, multi-national, complex array of sensors distributed across the air, space, and cyber domains presents a daunting test challenge. New approaches and methodologies are required to address the complexity challenge such as those suggested by Sheard. [2]
- Future Kill Chain: The synthetic range must be able to produce the ability to test the kill chain from detection (on-board or off-board ISR sources) through tracking, through identification (ID), to targeting, and through Battle Damage Assessment (BDA). Enabling a cross discipline kill chain involves moving from air/space/sea/land/cyber target detection via advanced sensors, data processing, data mining, networking, cueing, track formation and sustainment, track correlation, track fusion including ID from diverse information sources, rapid decision-making with support from automation, and Artificial Intelligence. While it is possible to deconstruct a test into sub-objectives, the entire kill chain must be testable within a synthetic range.
- Collaboration: A future kill chain may elect to combine steps within today's kill chain reducing the need to share the information across network spaces or it may elect to enable many spectrally diverse sensors located on various platforms and in effect expand the kill chain collaboration. This collapse and expansion might occur dynamically during the prosecution of a mission and be accelerated by automation. Support platforms/sensors or nodes owned by US or US Partners (NATO) must work in collaboration within this dynamic battlespace. Additionally, US/US Partners must communicate and dynamically and rapidly share raw and/or processed information. The Command and Control (C2) aspects of a future fight will require a higher degree of decision-making collaboration that must keep pace with a highly dynamic and time constrained modern battlespace while addressing collaboration barriers (such as language). A synthetic range must be able to support the testing of these challenges from providing credible sensor modelling, to connectivity, to addressing rapid and dynamic decision-making requirements.

- Automation: Future warfighting systems will continue to see improved automation requiring test capabilities to support various levels of autonomy from pilot assisted autonomy to complete machine-to-machine autonomy requiring no human intervention. These varying levels of automation located throughout the kill chain provide significant challenges to the tester with or without a synthetic test range.
- Geo-Specific Weather: While a physical range cannot control the weather, a synthetic range can provide dynamic and varying weather conditions within the testing environment. A synthetic range must provide the ability to produce and alter weather conditions within the test environment that correlates non-imaged and imaged sensors, networks, and nodes.
- Electronic Warfare (EW): A synthetic range can avoid the EW issues found on physical ranges. The synthetic EW signal is not observable by our enemies (not propagated in physical space), does not infringe on commercial spectrums, and can be readily modifiable as desired. There are four principle challenges for Modelling and Simulation today when employing EW techniques: (1) Generating and propagating signal complexity in real time in a dense EW environment, (2) Scaling EW signals in space, (3) Verification and Validation of the EW signals and their effect within the environment, and (4) properly modelling the Electronic Attack and Electronic Protection interactions given the available fidelity in today's models.
- Security: A synthetic range must address security concerns as various programs interoperate within a common operational battlespace. Multi-Level-Security (MLS) concerns are central to the development and operation of the test range. MLS concerns are addressed early in the design and potential solutions will only consider proven and previously approved approaches.

2.3 Balancing Cost and Risk

Achieving a viable synthetic test range design and implementation approach requires the architect to balance available modelling and simulation technologies with development and sustainment cost and risk. The AF budget established cost numbers for the development effort. The AF development team elected to balance the design of the JSE in the following manner:

- Use of an existing prototype: The JSE for broad AF use must expand capabilities from an existing environment developed jointly by the Navy and AF to support broad operational testing activities. The Joint Navy, AF, and Intelligence community team constructed this first environment, led by the Navy, at Patuxent River Naval Air Station (NAS) located in Maryland, United States. Using a working protoype allows the team to continue development and the Air Force to leverage these prior investments while mitigating development risk.
- Limited Development: The Air Force elected to limit environment development where practical by reusing models/components within the existing environment. The current reuse is over 60% within the environment. Sixty percent (60%) of the models the Air Force intends to use are already developed and in use within the community of interest. Of the remaining development items, 20% are currently in development, with the remaining items scheduled to start development in FY20.
- The System-Under-Test (SUT) will generally contain rehosted Operational Flight Program (OFP) code supplied by the appropriate System Program Office. The developing contractor must work with the Government JSE team to integrate the SUT with the JSE environment. These costs and risks are appropriately aligned with the System Program Office and Prime Weapon System Contractor.
- Development of an Information Broker that is responsible for the proper message exchanges supporting the necessary timing, scheduling, routing, and other services is critical to ensuring the synthetic test range operates as designed. For the next iteration of the JSE, this Information Broker is known as the Information Exchange Services Matrix (IESM). The IESM is information/domain

agnostic and can be utilized for not only test, but also training and experimentation uses. The IESM is the subject of a separate paper produced by the MITRE Corporation.

- Distributed Operations: There is a desire within the test and training community to connect geographically distributed sites, cost-effectively enabling larger and more diverse testing and training including cross-service components. This requirement is not contained within the initial JSE development effort, but the synthetic range design will provide design accommodations to ensure the range can support distributed operations in the near future. This requirement is balancing cost and development risk by early accommodation of distributed operation needs in the design coupled with early prototyping.
- Blending of Commercial and Government Off-The-Shelf (COTS/GOTS) products while limiting new development to only those critical capabilities without which the JSE cannot succeed: This risk-managed approach allows JSE to establish an early baseline from which to measure development progress while balancing risk and cost. While the JSE is government-owned, its composable nature allows for the addition of commercial and even proprietary components as required. All solutions must provide specific metadata that provides the needed conceptual and technical transparency of the solution needed to ensure integration into the infrastructure, interoperability of the simulations, and composability of the concepts. [4]
- Development with the goal of NATO Allies collaborative development and use: Foundational architecture and software decisions allow the sharing of capability with US allies supporting an objective of collaborative development and use for Test and Training applications. This approach fundamentally changes the technological decisions for the development of the JSE.

Collaboration comes in many forms. The sharing of ideas provides an idea trade space from which to formulate a longer-term collaborative implementation plan. Collaboration can include the cooperative design of common components that provide a foundation for interoperability. In addition, collaboration can result in the joint development of critical components that enable allies to employ operationally relevant CONOPS vis-a-vie integrated or integratable simulation environments.

3.0 JSE ARCHITECTURE APPROACH

The approach selected by the Air Force to utilize and further contribute in developing the synthetic environment begins by defining three regions. Region A is the region where the System-Under-Test (SUT) resides and any other entity or component critical to the testing of the SUT. Entities in Region A have direct interaction with the SUT. Region B entities can have a direct influence on the SUT and may or may not directly interact with the SUT under limited circumstances. Region C entities provide context to the broader scenario and do not directly interact with the SUT.

The idea captured in the development of Regions A, B, and C follows best practices for system engineering. In systems engineering, there is great interest in achieving precise detail in high resolution and fidelity in our system within the system borders (Region A). There are other systems that the SUT has to interact with, but at a lesser fidelity (lesser impact to the SUT performance) (Region B). Finally, there is the context that provides the additional input and may influence our system, but is not influenced by our system (Region C). [3]

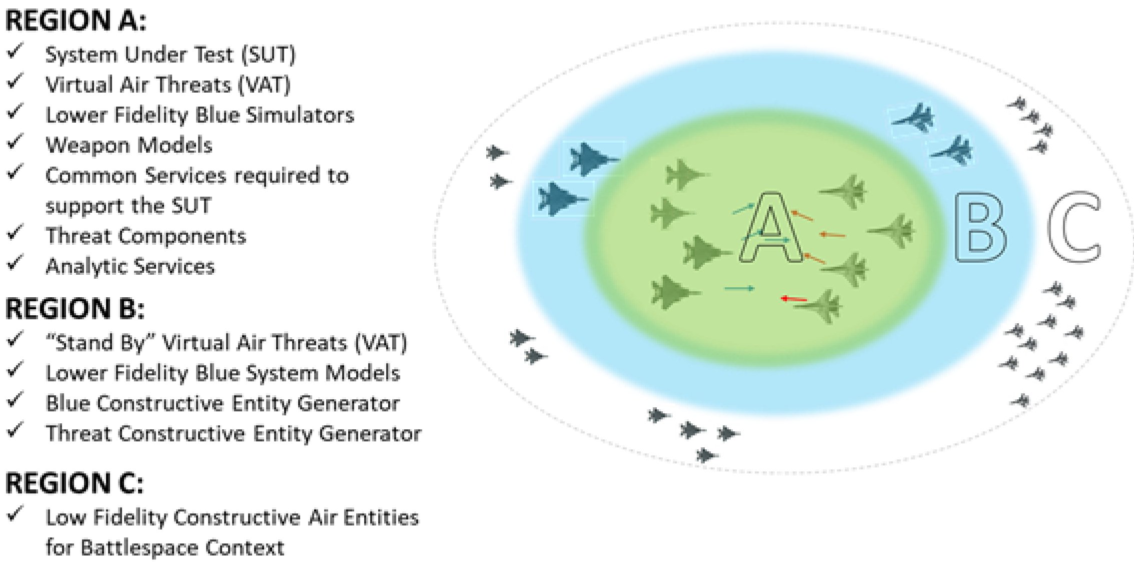

Figure 1: JSE Test Region Description

3.1 Composition of the JSE Architecture

The JSE Architecture approach is to decompose the environment into a limited number of components from which to enable multiple and concurrent development streams. Each component contains a specific suite of requirements necessary to enable select functionality within the environment. The major components will include:

- Representation of own systems in high fidelity
- Representations of opposing systems in high fidelity
- Consistent representation of the environment
- Consistent representation of interactions between these systems in high fidelity
- Representations of own systems in lower fidelity to provide a credible test environment
- Representations of opposing systems in lower fidelity to provide a credible test environment
- Administrative, Infrastructure, Data Collection, Analysis Tools, and other Exercise supporting services

As the JSE designs and implements common services, it would be wise to consider the NATO objectives of interoperable forces. NATO forces must be developed within the collaborative employment and operation in combat theatres. It follows that collaborative test and training is required to meet these objectives. The development of common services includes the development of RF/IR environments, RF-based communication, weapon models/effects, electronic warfare effects, cyber effects, and space models/effects. The intent of the JSE is to allow the end user to alter edge services as required, but to develop an agnostic suite of common services to support a fair fight. JSE is utilizing RF/IR environment services from legacy system software, upgrading the code structure and modelling language to meet today's standards. The US Air Force has developed numerous higher fidelity communication models that will form the basis of the common communication models. The US AF and USN agreed upon the development of a Weapon Server Common Environment (WSCE) framework as a joint framework to house weapon models. This effort is led by the US Navy and supports the training community. Electronic warfare effects are generally a function of the specific system and model features of the SUT. These effects are categorized and validated through

Laboratory or Open-Air Range testing. Cyber effects generally follow the same approach as electronic warfare requiring laboratory or range testing to validate an effect for simulation use. Finally, space models run the gambit from commercial space to military space systems. JSE is focusing on the use of Space in support of the air system that would generally include communication and navigation models.

A final note, given the object oriented and/or composable nature of the JSE, models can be rapidly replaced within the architecture (as an edge service), as long as edge service simulations comply to the JSE distributed simulation architecture. This flexibility forms the basis for reuse across the community providing useable and tailorable capability across multiple domains.

3.2 JSE in Operation for Air Force Test

The JSE Operational view is show in Figure 2. The following descriptions define the JSE key "service" components. Services contained within the Information Broker, the IESM, which support the agnostic operation of the broker itself, are labelled as "core" services. Services that ensure a fair fight are "common services." Services that allow the user to set up and execute the simulation are "exercise services." Services that provide entity or domain specific characteristics are "edge services".

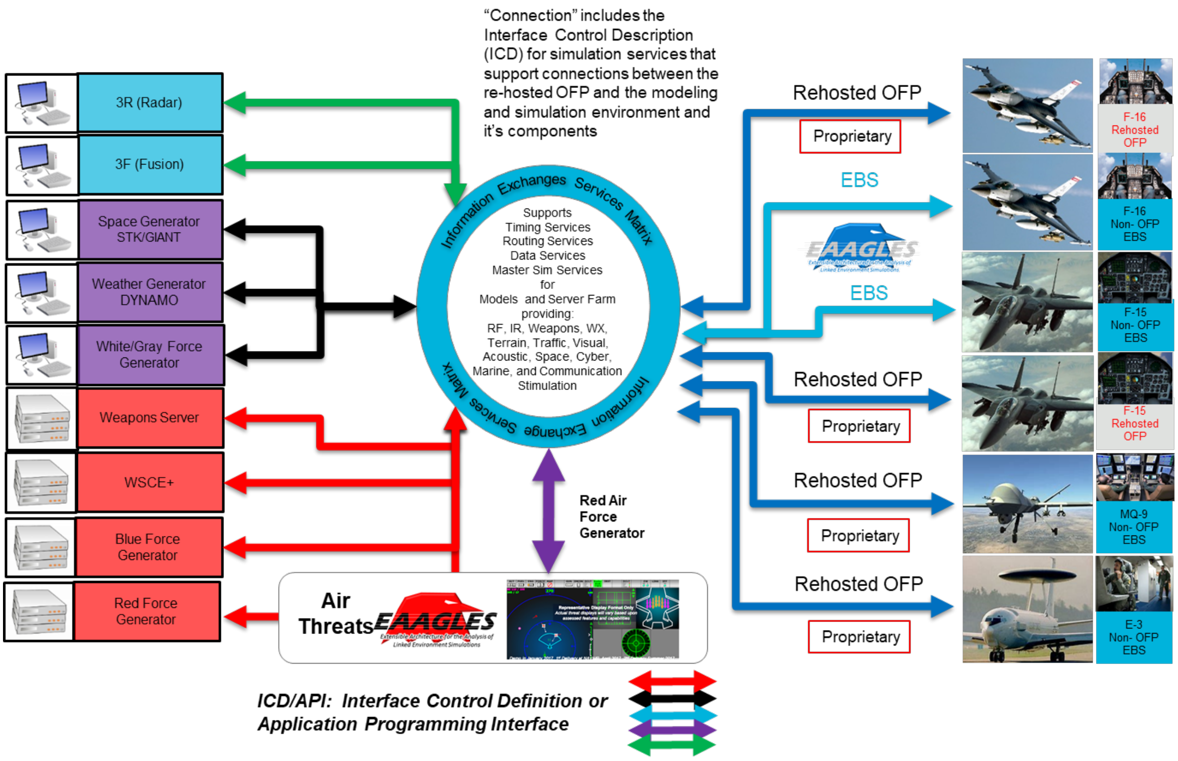

Figure 2. JSE Operational View for Air Force Testing

Following these definitions, simulation applications representing weapon systems are considered edge Services. The IESM broker provides core services to the simulation environment and interfaces with common and edge services. Common services include RF and IR environments, weather, munition models, communication models, etc. Other services (which are analytical, infrastructure, or exercise support related) include analytical services, data and interface repositories, standards repositories, and operational missions/use cases, etc.

Figure 2 illustrates the various edge services within the JSE. The core services, contained within the IESM allow the various services within the JSE to operate in a manner that is seamless to the user. The intent of the exercise services are to allow a JSE user to plan a mission using the appropriate operationally relevant mission planning tools. Once planned, a blueprint is formed that can be passed to a simulation engineer to support the orchestration of the simulation environment by assigning needed functionality to available components/services. This operation is transparent to an operational user, but critical to a tester or trainer to ensure the proper fidelity to support the test or training requirement is available and aligned with the simulation assets/services. After orchestration, test or training personnel execute the mature blue print. Collected data is analysed for test or training purposes.

While Figure 2 illustrates a “clean” design in which the community builds simulation components according to the design, implementation within the existing infrastructure provides a more realistic view of maturation of the JSE over time. Many training systems within the current training portfolio utilize rehosted Operational Flight Program (OFP) code in representing the system. These legacy systems utilize system OFP wrapped with a simulation interface to interoperate with the training environment. The JSE must provide a means to integrate new and legacy OFP and non-OFP simulators of numerous fidelities into a seamless battlespace. The JSE interface documents and services must address the information exchanges required between the system edge services and the battlespace common services to form a coherent unified battlespace suitable for test and training support. Figure 3 provides an illustration of these components while highlighting the need for Interface Control Descriptions (ICDs) to manage message interactions between these diverse services.

Finally, the environment must provide an integration path for additional edge and/or common services such as Space, Cyber, Communication, and Weapons. These services are likely to be a mixture of both common services and application unique edge services when the SUT or Training requirements demand. As with many common services, JSE seeks to accommodate multiple configurations with Government-Off-The-Shelf (GOTS), Commercial-Off-The-Shelf (COTS), and Industry proprietary solutions (unique edge services). This is a potential collaboration area between NATO partners.

3.3 Putting the Pieces Together

The JSE will start with an established prototype using work performed by the team in support of other activities conducted at Patuxent River NAS with NAVAIR. The expansion of the prototype capabilities leverages work performed by the MITRE Corporation in establishing the Information Exchange Services Matrix (IESM) while maturing other critical components. The prototype facilities at MITRE, the Simulation Analysis Facility located at Wright Patterson AFB, a test facility located at Edwards AFB, and the use of laboratory space at Nellis AFB will allow the team to continue development while remaining linked to the original prototype activities with the Navy at Patuxent River. This cross AF and Navy link, coupled with the continued threat model development by the Intelligence agencies provide ample mature components to populate the prototype as it matures. Figure 3 provides additional detail of the major components addressed in the prototype to allow the development activity to mature in support of test objectives.

Of particular interest is the maturation and integration of Region “A” Edge Services (Aircraft System models using rehosted OFP and higher fidelity simulators) coupled with common services (RF Environment, IR Environment, Line-Of-Sight (LOS), Weather, Weapons, and Electronic Warfare (EW)) driven by core services (via the IESM) through defined interfaces (ICDs/APIs). Additional Region “A/B” Edge Services include the use of the Next Generation Threat Simulation (NGTS) and other IADs models to provide a broad, complex, and dense test environment. See Figure 3.

One of the first challenges in maturing the prototype is the design and population of the ICD between the various edge services (Rehosted OFP, higher fidelity simulators) and the IESM. The Rehosted OFP aircraft simulation requires the tracking and/or fusion algorithms fed in at the appropriate rates with the appropriate formatted data to ensure proper operation. Failure to meet these real-time requirements will render the test and/or training results invalid. This Quality of Service (QoS) requirement provides a speed and fidelity requirement that the IESM must meet in every time step important to the operation of the rehosted OFP within the system model. These requirements are captured by the IESM during the design and orchestration phases and result is the selection of higher speed services and networks. The IESM is designed to address multiple simultaneous channels of varying QoS to support the simulation.

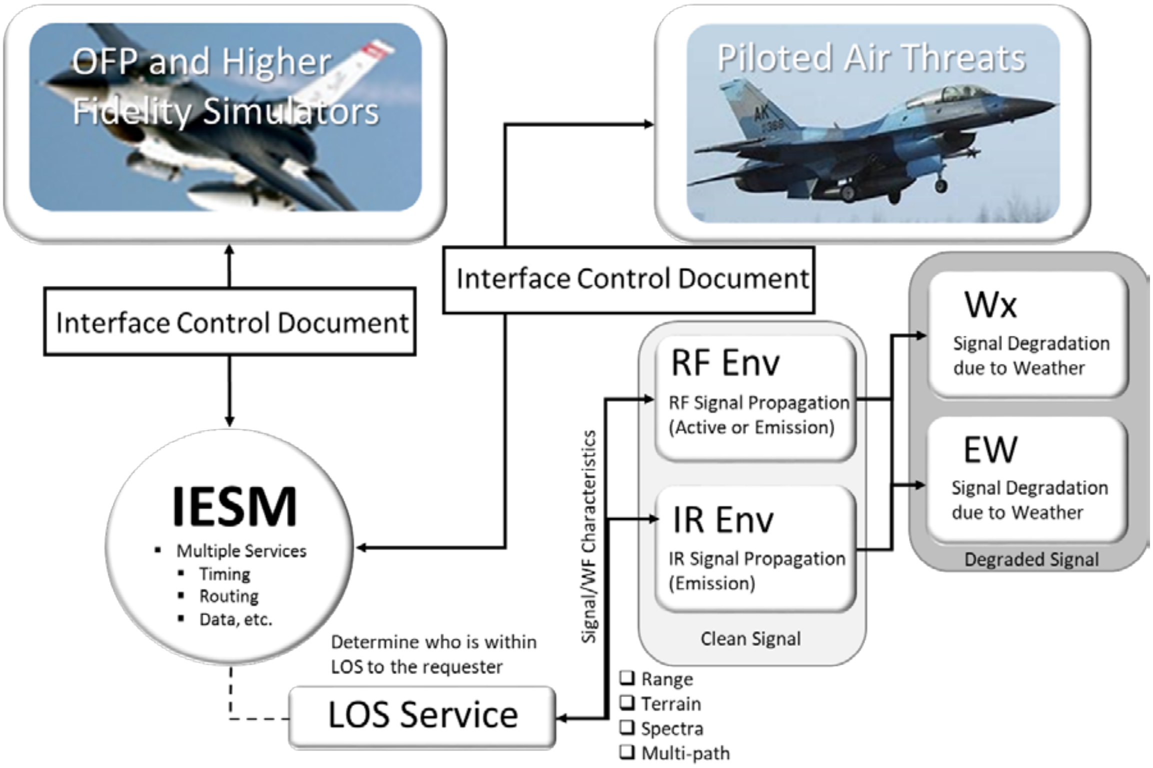

Figure 3. JSE Architectural view

The ICDs are part of the infrastructure within ICD repositories. The AF intends to define Government Simulation Interfaces (GSI) for the JSE that meet AF test needs. While the Government standards will allow the JSE to supply these standards to any Government Program Office in an unrestricted manner, they do no guarantee that all ICDs will be non-proprietary. The Government fully expects some Prime Weapon System Contractors (PWSCs) will establish propriety ICDs for their various rehosted OFP system models with the claim that the data fields contained within the ICD provide critical insight into the aircraft system model itself warranting the proprietary claim. As JSE balances cost and risk during development, it must also consider existing legacy solutions in the design.

The Government intends to allow the distribution of the GSI libraries to the Program Offices to support the distributed development of numerous aircraft system models using rehosted OFP that are compliant with the JSE. This provides a long-term business case for the Government supporting edge service development within the program offices while the Government supports a reusable, composable, common, and Government owned simulation environment suitable for all program use. The use of a Government owned environment levels the playing field by ensuring assessments contain transparent, well-understood, and government developed and controlled common services.

4.0 MODEL/ENVIRONMENT VERIFICATION AND VALIDATON

4.1 Establishing the Verification and Validation Foundation for Modelling and Simulation

The crux of using a Modelling and Simulation environment for test purposes relies upon its credibility with the decision-making test body. By its very nature, Modelling and Simulation generally utilizes assumptions to focus modelling efforts on features and functions within the system/environment believed to be critical in supporting the test objectives. This approach serves multiple purposes including focusing limited dollars and effort on areas that are believed to be critical drivers in assessing test objectives while balancing cost and risk in developing only as much functionality and fidelity as required to support a credible test activity. The decisions into which features and functions are critical to a test form the central issue in building a JSE. How much fidelity is required and for what test objective/purpose? There comes a point where adding too much functionality or fidelity is not only unnecessary, but can be detrimental to an analysis by confounding critical factors and making the design of experiments, and resulting analysis, unnecessarily complex.

The JSE seeks to utilize proven Operations Research (OR) based analytical techniques and practices coupled with state-of-the-art tools and infrastructure. JSE will leverage the practice of executable architectures to allow the design/user to assess information exchanges within the requirement analysis space verifying that these data exchanges will satisfy the information exchange requirements. This is an early and critical step as part of the Verification and Validation activities the JSE must support.

4.2 Message Exchange Characterization

The JSE team is assessing various tool capabilities to determine the best tool(s) to support environment needs. One of the critical decisions, that must be carefully weighed and balanced, is to how much detail and to what depth the exchange messages/requirements are defined within the executable architecture. Trades include (1) Open loop or Closed loop or both, (2) Basic equations for sensor detection or complex equations including switches and filtering, (3) Message exchange content, (4) Message exchange context within the use case or mission-based use case, and (5) Sensor model characteristics pertinent to the exchange, etc. This can be a long and detailed list with numerous branches in describing information exchanges. The difficult task is deciding how much detail is enough, where to trim the many possible exchange conditions (branches), and the criteria as to when and how you decide to trim the branches.

One of the significant challenges in integrating diverse simulation components and/or environment generators is the harmonization of the components relevant to detail and resolution. Without proper harmonization, JSE does not end up with valid results or a “fair fight” as some models will not properly process the erroneous data. As an example, the sensor model of a radar might include differing forms of the radar range equation, filtering, differing characterization of the radar modes, signal processing, etc. These differences may affect the common services and how messages are treated as they propagate within the environment. Design of the JSE services must provide enough flexibility to not only support the message exchanges, but account for known and likely variances in the edge service providers and consumers of those messages. [5]

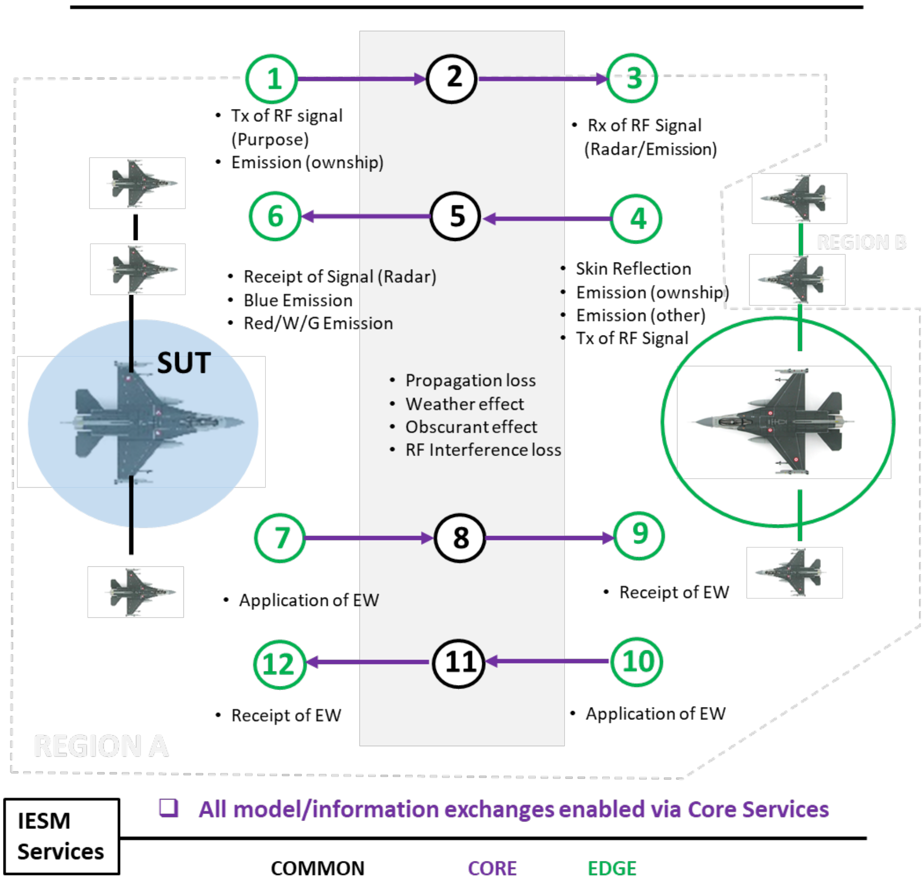

Figure 4. JSE RF Exchange Example

Figure 4 describes the type of exchanges present in a typical engagement: 1. The edge service representing the system under test computes the Tx of the RF signal to detect/track the opposing system. 2. Using the core services provided by the IESM, the edge services call the common service to calculate propagation loss, weather effects, etc. 3. The common services provide the resultant Rx and RF signals to the edge service representing the opposing system. 4. The skin reflection from the opposing system is computed by the common service but the resulting track is evaluated at the appropriate edge service. 5. The resulting signals are modified accordingly by the common services and the results are exchanged with the SUT. 6. The SUT receives the modified signals and computes the detection/tracking characteristics for the SUT. 7. Based on the results, the SUT decides to apply EW means and invokes the common services to modify the emission accordingly. 8. The common service applies the appropriate effects/computations to the EW RF signal as it propagates through space. 9. The opposing system, via the common services, receives the modified EW signal and determines the effect of that signal on the system in the local appropriate edge service. 10. The opposing system, via the edge service, applies EW against the SUT and invokes common services. 11. The common services modify the EW signal to account for RF propagation, weather, etc. 12. The SUT receives the modified RF EW Signal via the common services and, through its services, determines the effect of the EW signal on the SUT.

Ideally, JSE would have the radar modelling characteristics for the generation and detection of an RF signal. Typically, a form of the radar range equation is modelled with additional considerations for processing choices or other unique aspects of the radar characteristics and resulting performance. JSE will utilize an RF environment to account for RF signal loss when propagated through space. Additional atmospheric parameters would include weather effects (moisture, etc.), Obscurants (smoke, etc.), and RF interference loss from other RF energy propagating in the atmosphere. Receipt of the RF signal at the threat source would account for these losses and present RF parameters to the threat for RF signal detection and to present the necessary parameters to form an RF skin return (radar cross section) to support a detection calculation by the transmitting radar. Where these calculations actually occur in the JSE is a function of numerous considerations including the existing architecture of some of the system models, computational complexity, enterprise view of the desired long-term architecture, anticipated required fidelity, and impact to existing models and product lines within the community. The RF exchange example in figure 4 above will likely evolve as the IESM architecture matures.

The use of an executable architecture would allow the requirements team (as well as the V&V team) the ability to assess the completeness of the requirements necessary to support the modelling, simulation, and analysis objectives. Additionally, the executable architecture provides a coarse check on the modelling and simulation environment by comparing information-exchanges via use-cases. The executable architecture documents the requirement while providing a means to dynamically assess the execution of the information through the interfaces. Results from the execution of the simulation verify that the exchanges are properly documented in the architecture tool as part of the Operational and/or Developmental V&V activities conducted prior to testing.

4.3 Desired Features of an Executable Architecture

JSE will use commercially available executable architecture tools to support the development activity such as Enterprise Architect, Magic Draw and other SYSML/UML capable tools. The Air Force's intent is to describe the message interactions within the JSE by spectrum/band (RF, IR, Visual) as they relate to the various IESM Services (Core, Common, Edge, Exercise). These interactions will be developed and documented in the tools and then verified and validated against flight test, hardware in the loop (HITL), or anechoic chamber data as those components are developed and/or integrated and tested. From a prioritization perspective, Region "A" will take precedence over Regions "B" and "C." The use of executable architecture tools provides a means of developing, documenting, and testing not only the information exchanges, but the collection of information exchanges and corresponding required Quality of Service (QoS) necessary to populate the ICDs for the simulation. Reuse of the ICD's allows other Programs within the Air Force, other services, and partners to design their simulations against the ICDs and ensure interoperability with the JSE.

JSE also requires features tailored for the unique aspects of the architecture including the ability to link and track requirements based upon characteristics and features defined in the IESM. As previously described, the IESM decomposes the Information Broker into four service classes: Core, Common, Edge, and Exercise.

Recapping the previously described services, the core services are essential to all services and entities, are intricately linked, provide basic information broker functionality such as timing, routing, object declaration, object management, security, etc. Common Services ensure a fair fight and include RF, IR, Weather, Weapons, etc. Edge services provide functionality required by the JSE to support mission execution such as system representations, or unique components within the environment, etc. Finally, exercise services allow the user to define, configure, execute, and analyse the results from the environment. Exercise services would include mission planning, environment composition, orchestration, execution, and analysis.

Returning to Figure 4, and the information exchange example, the colors in the figure illustrate the various services involved in supporting an information exchange. In this example, timing, not shown in the figure, could readily be added in the form of quality of service (QOS) requirements. As written, the fighter aircraft shown within the figure are Edge Services and provide necessary war-fighting functionality to the test event. Common Services, represented in Black, illustrate the universal components required by all players within the environment to ensure a "fair fight". Common representations of universal services prevent inconsistencies in the representation of these services by establishing a single service to meet all entity needs.

The Violet color represents the routing paths required within the JSE for message exchanges and are Core Services. Core Services provide a variety of services as well as routing via information paths necessary to support Quality-Of-Service timing requirements. Conducting a complete test as illustrated in Figure 4 would be an example of an Exercise Service.

The ability to analyze not only the information exchanges, but also the Quality of Service required and provided within the executable architecture is an example of a custom requirement that the AF seeks within executable architecture tools. The Air Force intends to continue to drive the development of these tools to ensure the JSE needs are met while advancing its ability to rapidly characterize the performance of the environment in supporting Verification and Validation requirements for Test and Training.

5.0 DISCUSSION AND SUMMARY

The decision by test community leadership within the USAF and USN provides the community with an opportunity to advance the state-of-the-art in the design, integration, and application of a Virtual-Constructive real-time environment for test and training purposes. The leadership recognizes the limitations in today's physical test ranges in supporting current and future testing requirements in an environment that continues to expand its reliance on advanced sensors, datalinks, automation, and other technologies that do not readily lend themselves to live open-air-range testing. This recognition provides an opportunity to leverage significant investment already made in advancing Modelling and Simulation capabilities developing new capabilities only as required to meet Test and Training objectives. This risk-balanced approach avoids the pitfalls of many previous attempts to leverage Modelling and Simulation technologies by forming a composable environment that relies on proven technologies and established capabilities as opposed to constructing a complete a new environment fraught with development and cost risks.

JSE provides sharp contrast with previous efforts in another manner. JSE is a teaming activity leveraging the community investment in the JSE while accommodating individual service needs via a composable government-owned architecture and associated environment. The broader JSE Team provides a means to work across military service boundaries via that common architecture while allowing the military services to tailor the edge or exercise services as required. The core and common service are consistent and in fact, many of the edge and exercises services may remain consistent across the military services, but the key is that they do not have to do so. The military service partners have the inherent flexibility built into the architecture to tailor the architecture components depending upon their unique requirements and/or applications.

This paper has touched the basic tenants of the JSE. A complimentary paper by Dr. Andreas Tolk, the MITRE Corporation, provides an overview of the heart of the JSE, namely, the Information Exchange Services Matrix (or IESM). The IESM provides necessary services to the JSE allowing the various components within the JSE to function seamlessly with the ultimate objective of a complete integrated battlespace for Test and Training. [4] While the JSE today utilizes, the Global Reference Information Directory or GRID, the next generation of JSE development will expand the GRID to become the IESM.

In conclusion, the objective of this paper is to both produce knowledge for the reader and to solicit new ideas from the community to continue to advance modelling and simulation state-of-the-art for test and training applications by collaborating with our NATO Allies.

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