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A Reference Architecture for Augmented Reality Maintenance Support

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A REFERENCE ARCHITECTURE FOR AUGMENTED REALITY MAINTENANCE SUPPORT

THESIS

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Abstract

The current method of preparing Airman to perform tasks in their designated Air Force Specialty is to provide coursework-based initial skills training and on-the job training (OJT) for that specialty. Full qualification for a single Air Force Specialty is estimated to average seven years with OJT consisting of seventy-five percent of that timeline. OJT primarily consists of mastering the use of the Technical Order (TO), a governing document that provides step-by-step task instruction that must be followed explicitly. Though TOs have transitioned to an electronic format, employment of the information has remained the same. A proven aid in instruction and task accomplishment is Augmented Reality (AR). A transition to an AR supported TO system has the potential to aid in training and performance in operational environments by providing multisensory support to Airmen. An AR platform may also expand the scope of Airmen beyond a single Air Force Specialty, providing capability that directly supports Agile Combat Employment concepts. This thesis presents a Model-Based Systems Engineering designed reference architecture for an AR maintenance support system. To provide a relevant example, the system architecture focuses on flightline aircraft maintenance training and operations.

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Daniel A. Cuellar

Table of Contents

List of Figures

List of Tables

A REFERENCE ARCHITECTURE FOR AUGMENTED REALITY MAINTENANCE SUPPORT

I. Introduction

Background

Over the past two decades technological and economic advancements have brought changes and challenges to the global power structure. With these advancements the United States position as the only military superpower is being challenged. Both Russia and China are exerting an unprecedented amount of pressure as near-peer adversaries on the global stage. Reports on current Russian and Chinese capabilities show a willingness and eagerness of the two countries to expand their influence across the globe and alter the scales of the world order to lean in their favor.

Russia has shown itself to be the more immediate threat due to its current military posturing, as we have seen with the annexation of Crimea and challenges to Ukraine's sovereignty. Fortunately, Russia is more susceptible to sanctions and other non-military, more diplomatic, maneuvering from the west due to their economy's heavy reliance on natural gas exports. However, their military capabilities and their inclination to demonstrate them act as leverage on the global stage.

China takes a more strategic stance when it comes to global matters. It has the world's second largest economy and is expected to overtake the U.S. as the largest economy by 2030. According to the publication, Competing with China on Technology and Innovation (Mori et al., 2019), China is undergoing a second industrial revolution with the Chinese government outspending the U.S. on research and development as far back as 2018. China is also taking large strides in intellectual property ownership with 40

percent of global patent applications in 2019, twice the number of applications filed in the U.S.. A RAND report, entitled “The U.S.-China Military Scorecard: Forces, Geography, and the Evolving Balance of Power, 1996–2017”, shows the trend of technological advances and modernization of Chinese Air, Space and Cyberspace forces. According to this report, many of the major advantages the U.S. traditionally had in these areas has evaporated, with a majority of the assessed operational areas being in parity or at a Chinese advantage with the U.S. Their economic and technological capability increases have enabled China to directly challenge the U.S. both diplomatically, as continuously shown at the United Nations, but also militarily, as displayed in the South China Sea.

Diverging from the focus on the Middle-East and recognizing the potential of these near-peer adversaries has led to major changes in The National Defense Strategy (NDS). The NDS, 2018, acknowledged direct competition and threats to U.S. dominance, particularly from Russia and China, and was tailored to initiate steps to combat the growing threats. Two key tenets in the U.S. strategic approach covered in the NDS are the expansion of American technological innovation and development of a more lethal military force. This is accomplished through the rebuilding of military readiness, restructuring practices for greater performance and affordability, and the modernization of key capabilities.

Modernization of key capabilities relies on two major components, forward force maneuver and posture resilience, and agile logistics. Both of these components are heavily reliant on strategic mobility assets to meet the intent outlined in the NDS. This means there will need to be a transition from the current military structure, which was

developed to support more-traditional warfare from garrisoned bases, to a more capable, decentralized, truly expeditionary force through Agile Combat Employment (ACE).

ACE concepts have been envisioned in the USAF since 2005 and is defined as the aggregation and integration of activities across the Air Force that enable "operational concepts and the capabilities that distinguish air and space power-speed, flexibility, and global perspective" (AFDD 2-4, 2005) (AFDN 1-21, 2021). One study suggests that the ideal time to restructure the USAF to fully adopt ACE concepts is following the drawdown of activities in the Middle-East. This presents the "opportunity to both reassess the size and shape of its forces and the policies it uses to govern them in light of potential future demands" (Balancing ACS Manpower, 2014). Part of the ACE concept is Adaptive Basing (AB). This concept allows the Air Force to operate from a network of integrated locations rather than a single forward location which, if attacked, could severely impact combat operations and cripple critical resources (Mills et al., 2020). AB calls for regular movement of aircraft across the network to avoid establishing prime targets. To support this, there may need to be a decoupling of flight line maintenance from the flying units they typically support and prepositioning of maintainers at various locations across the network. This means individual maintainers would likely need to draw upon larger skillsets to support multiple Air Force Specialties on an airframe.

Problem Statement

There is no system in place to support the expansion of the flightline maintainer's skill set. The current method of training places emphasis on learning a single Air Force Specialty that is typically aligned to a single subsystem on a single airframe. Initial Skills

Training, Career Development Courses, and on-the-job training are well established to support the single airframe, limited skillset system. The only personnel who have the authorization to go beyond this limitation are E-8s with a Superintendent designation of a 9 Skill-Level. Superintendents do not typically perform maintenance; their emphasis is maintaining Mission Capability rates to support training and operational needs. Additionally, only 2.5 percent of the Air Force can hold this rank according to 10 U.S. Code 517, which has an average time in service requirement of 18.4 years. The bulk of the maintainer corps consists of E-1s, including those in initial skills training, through E-5s. Individuals entering the force begin working on aircraft as early as six months after entering the Air Force. The Air Force should no longer limit the skillset of the maintainers E-7 and below if ACE aims to be successful. To support the AB concept there must be a deepening of maintainer skillsets that may go beyond single specialties and potentially single airframes.

Research Objectives

The objective of this research is to develop an open-ended reference architecture for an augmentation system that can be used by members of an Air Force Specialty to assist in the performance of both their specialty and external specialties. The current reference architecture assumes that this can be accomplished through a light weight, wearable, portable system comprised of optics, data storage, and hands-free navigation which is capable of supporting the operator by:

1) replacing current maintenance Technical Orders (TO) to include both hardcopy and tablet based TOs,

2) providing task data, including estimated time of completion, level of difficulty, skill level required, necessary tools, and necessary support equipment,

3) visually aiding identification of parts or work areas, including panels, systems, subsystem line replaceable units, connectors, fasteners, wiring, and

4) tracking training and performance that can be used to assess the efficacy of the system to provide appropriate aids to maintainers who are performing maintenance pertaining to multiple Air Force Specialties.

Ideally, such a system would be wirelessly tied to databases for acquiring updates to the task procedural information and individual user training information, but may also operate as a stand-alone unit when necessary.

Investigative Questions

The investigative questions posed below are to provide emphasis on the development of a framework that is malleable, is capable of supporting multiple Air Force Specialties, addresses the human factors that are associated with this type of augmentation system, and maintains long-term relevance. These include:

I. What are the use cases, major components and associated procedures that need to be addressed to develop a system of this type?

II. What human aspects are considered by this system to support increased functionality with minimal impairment?

III. How can the AR system be employed to affect training and operations in the United States Air Force?

Methodology

This research uses Model-Based Systems Engineering (MBSE) to describe and analyze the design space for a human augmentation system that provides training and assistance through instruction and real time cueing. This system is intended to be a resource that incorporates libraries of task walk-throughs to provide flightline maintainers the ability to provide support in both their primary Air Force Specialty and external Air Force Specialties to increase the capabilities of the individual to enable the ACE concepts.

The baseline requirements used for this system were captured during interviews with maintenance supervisors at the 149th Maintenance Squadron, Lackland AFB, Texas. In many cases, the use cases described during interviews provided the User Requirements of the system. Additional requirements and sub-requirements were developed to support areas not fully examined during the interviews or required further investigation after the interviews.

Having established the baseline requirements, the capabilities and operational aspects were developed and described using the Object-Oriented-Systems Engineering Method (OOSEM) and Department of Defense Architectural Framework guidance.

Assumptions

This research makes a few assumptions. The first assumption lies with the multi-capable airman concept. Multi-capable Airmen are defined as, "Airmen capable of accomplishing tasks outside of their core Air Force Specialty. Specifically, these personnel are often trained as a cross-functional team to provide combat support and

combat service support to ACE [Agile Combat Employment] force elements. They are enabled by cross-utilization training and can operate independently in an expeditionary environment to accomplish mission objectives within acceptable levels of risk (AFDN 1-21, 2021)." Because this definition allows room for interpretation, the assumption is that the concept of training as a cross-functional team can include all Air Force Specialties associated with a single airframe; through training, a cross-functional team can develop individuals capable of performing all aspects of maintenance on an airframe.

Another assumption is that maintainers will be able to easily utilize the technology. Good form, fit, and function are essential to support maintainers when performing tasks. If the use of the system becomes cumbersome it is less likely to be used.

Current airfield operations do not typically maintain wireless wide-area-networks, so an important assumption is that the proposed system must have some stand-alone capability. This means that the system may benefit from connectivity, but continuous connectivity is not a requirement for operation.

The greatest assumption is that the system will be adopted and utilized by individuals who are supporting more than a single Air Force Specialty. The limitations placed on the number of career fields that have access to this type of system also places limits on the system. By not establishing the libraries or walk-throughs from multiple career fields, the usefulness to the individual and the Air Force is likely to be diminished. If a system like this is adopted, a determination will need to be made as to if and when tasks should be expanded beyond those of a single Air Force Specialty.

Implications

The maintenance community has been looking for alternative maintenance methods for several years. The AR-based system described in this thesis has the promise to alter the way maintainers are trained and perform tasks. If appropriately enabled, it has the potential to allow individuals trained in a specific specialty on a specific airframe to perform tasks outside of their limited scope. This means that in an "emergency" situation, the Air Force will have the ability to flex personnel utilizing this system and leverage the additional capability. This can affect the way Airmen are trained at the schoolhouse during IST, during career development courses, and while performing OJT by introducing tasks and systems that are not captured in their traditional Air Force Specialty training. This system is also designed to allow remote monitoring of training by allowing external parties (Supervisor, Training Manager, or Quality Assurance Specialist) to review documented task training and task certification to compare with tasks that have been or are being performed by the maintainer. Providing Airmen with additional capabilities and the means to execute on those capabilities is critical if the Air Force is truly looking to field an agile force in the near future.

Preview

The proceeding chapters of this thesis provides a literature review, research methodology, research analysis results and the conclusion. Chapter II, the literature review, addresses topics covering MBSE, the method for developing reference architectures, hardware descriptions, potential physical impacts to users, aspects of training and support for future strategic concepts. Chapter III, the research methodology,

covers the methods used when performing the research and how the results will be captured. Chapter IV provides research analysis and results and a wide array of figures generated to support the reference architecture and answer the investigative questions. Finally, the conclusion will provide further insight on the results and potential areas of future research.

II. Literature Review

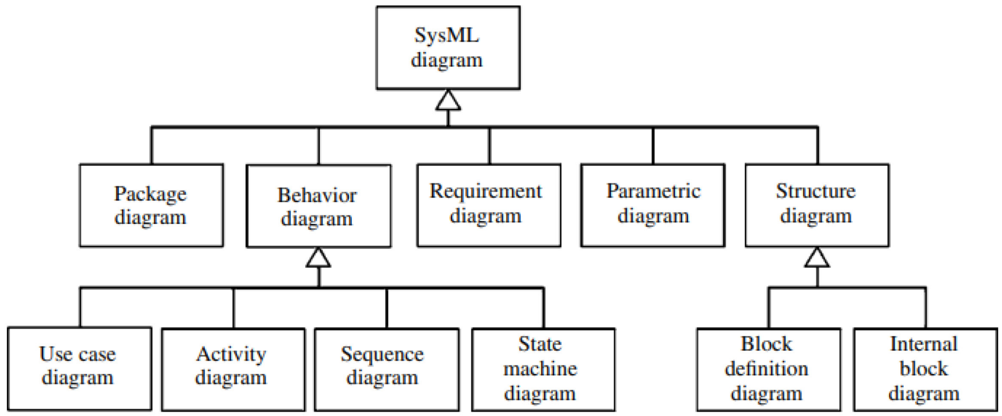
Chapter Overview

This chapter provides 1) details on the requirements and constraints for Department of Defense reference architectures, 2) baseline information on augmented reality (AR) systems and associated concepts, AR components, potential physiological effects of use and, 3) examples of how augmented reality can be employed to support future Air Force concepts.

Model-Based Systems Engineering (MBSE)

Modeling is typically carried out to characterize an existing system, evaluate and formulate mission and system concepts, capture system architecture and requirements flow, support systems integration and verification, support training, and to capture knowledge and system design evolution (Walden et al., 2015). MBSE is a collection of these models for a system or system-of systems. INCOSE defines MBSE as "The formalized application of modeling to support systems requirements, design, analysis, verification, and validation activities" (INCOSE Systems Engineering Vision 2020, 2007).

Utilizing SysML, a key modeling language utilized in MBSE, allocation relationships can be established between "functions to elements, allocation of logical to physical elements and other types of allocations (Walden et al., 2015)." The diagrams used in SysML are shown in Figure 1. The five main categories consist of the Package Diagram, Behavior Diagram, Requirements Diagram, Parametric Diagram and Structure Diagram.



(Friedenthal et al., 2015)

Figure 1. SysML Diagrams.

The Package Diagram is used to group models together under one package or category (Walden et al., 2015). The Behavior Diagram consists of four sub-diagrams, all of which are used to describe the use, function and process flow of an element or system. The sub-diagrams are the Use Case Diagram, which shows the high-level functionality, external interfaces and internal interfaces of a system, the Activity Diagram, which shows the sequential process or processes while identifying the inputs and outputs to each stage in the sequence, the Sequence Diagram, which shows the time-order of messages passed between system components and the State Machine Diagram which shows the transition of states during an activity based on defined entrance and exit criteria (Walden et al., 2015). The Requirements Diagram provides a means of capturing requirements and traceability within a modeled system (Walden et al., 2015). The Parametric Diagram identifies the network of constraints and their relationships within a system (Friedenthal et al., 2015). The Structure Diagrams includes the Block Definition Diagram (BDD) and the Internal Block Diagram (IBD). The BDD uses blocks to define system components or

functions in a hierarchical fashion while the IBD shows the interconnections internal to the system. These diagrams will be used throughout this document to define the system.

The Object-Oriented Systems Engineering Method (OOSEM) of MBSE was selected due to its versatility and ability to capture tailored, cradle to grave design elements and requirements. Based on the Integrated Systems and Software Engineering approach, this top-down method allows system designers to originate the design at the system specification level and determine the subsystems necessary to support the system; from that point, the subsystems can be decomposed further with increasing degrees of fidelity. Friedenthal explains in A Practical Guide to SysML (Friedenthal et al., 2015), that applying OOSEM "at the system-of-system level results in the specification and verification of one or more systems. Applying the process at the system level results in the specification and verification of system elements, and applying the process at the element level results in the specification and verification of components."

Reference Architecture

"Reference Architecture is an authoritative source of information about a specific area that guides and constrains the instantiations of multiple architectures and solutions (Reference Architecture Description, 2010)." The Office of the Assistant Secretary of Defense, Networks and Information Integration released the Reference Architecture Description to align designers and system developers when building reference architecture in or for the Department of Defense. The document provides guidance and constraints to establish standard criteria for architecture. These constraints include the use of the Department of Defense Architecture Framework (DoDAF), which is comprised of

the specified views or models that must be included to be considered a reference architecture. The DoDAF viewpoints used within this text are the Capability Viewpoints (CV), Operational Viewpoints (OV) and Systems Viewpoints (SV). CVs are used to describe current capability of the system and the potential evolution of the capabilities. OVs describe “tasks and activities, operational elements, and resource flow” in the model. SVs show internal and external system interfaces. CVs, OVs and SVs are not only necessary to be incompliance with the adopted DoDAF structure, but are also necessary to show the design, capability and potential viability of modeled system to designers and program offices in the DoD.

Hardware

The concept behind Augmented Reality systems is to blend the digital and physical world by providing overlaid “graphics, video streams, or holograms in the physical world” and the means to interface with them (Hololens 2-Overview, Features, And Specs: Microsoft Hololens, 2021). There are varying levels of AR system capability, all of which rely on depth cameras with differing sensing ranges. Sensing ranges are the areas where the depth camera can reliably detect objects and events with large sensing ranges allowing users to operate AR systems in larger, more open areas and short sensing ranges providing close proximity detection. Depth cameras are used to identify differences in depth in the physical world and use that data to create a digital three-dimensional replica of the surrounding scenery. This is done to provide the system and user with digital objects and surroundings to interface with.

Passive stereo depth cameras use at least two cameras and rely on comparing the features identified by the cameras to triangulate the estimated depth. This type of system is typically employed outdoors and in open areas due to some limitations in the cameras ability to differentiate between objects of the same color or texture (e.g., two walls that run perpendicular to each other may be recognized as a single surface).

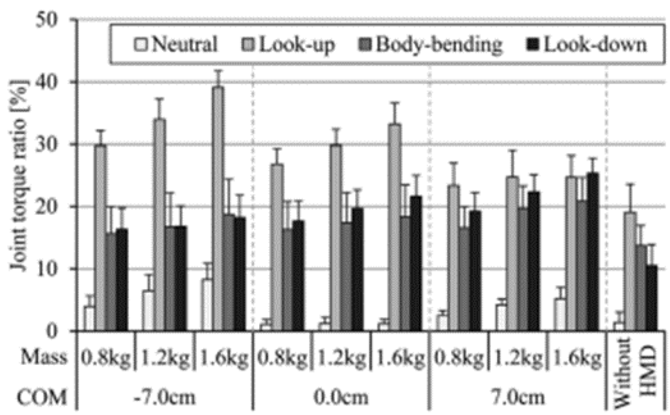
Active stereo depth cameras, much like the passive system, rely on more than one camera to triangulate the estimated depth, but also employ the use of structured light, the projection of known infrared patterns or grids to illuminate surface areas (Wagner, 2018). The distortion in the projected grid or pattern is then measured and the size, shape and position of objects in the environment are calculated. Active stereo depth cameras have a much shorter sensing range, which is useful for hands-free operation.

An active depth sensing technique that has been adopted due to its versatility is time-of-flight. Time-of-flight sensing directly measures the distance to objects using infrared lasers rather than using the triangulation technique. Time-of-flight devices measure the time or phase differences between energy transmission and energy reflection detection by a sensor. Time-of-flight depth cameras can run in “mixed modes” to support both short and long-range sensing.

Impacts To User

There are typical environmental issues and stressors that lead to reduced human performance, such as heat, humidity, limitations to visibility, task design, and physical workload. When outfitting humans with wearable equipment the goal should be to take these issues and many others into consideration to minimize impacts to free movement

and minimize fatigue (Redden, 2015). The system covered in this thesis utilizes a head-mounted display (HMD) which carries its own unique set of considerations. HMD use has been shown to have varying effects on people of all ages. In a study conducted in 2021 using the Timed Up and Go Test, an evaluation of a person's mobility, there were moderate to severe impacts to the posture when HMDs of varying masses were used. HMDs were shown to alter the pitch of the body when transitioning from a sitting position to a standing position (Almajid et al., 2021). Head movement has also been shown to be affected with head borne mass as low as 0.8 kg and increases in the difficulty of movement occur as the mass increases (Chihara, 2017). Figure 2 shows the varying joint torque ratios of the neck when performing movement with varying mass and the offset of the center of mass on the head from the rear of the head of -7.0 cm, center of head at 0.0 cm and forward on the head at 7.0 cm. The long-term degenerative physiological impacts of the increased torque and physical loading on the body, to include effects on posture, caused by HMDs requires further investigation (Knight et al., 2017).



(Chihara, 2017)

Figure 2. Neck Torque Ratios With varying Mass.

Training

In the United States Air Force, training in specific Air Force Specialties is conducted in two phases. These phases include the Initial Skills Training (IST), which consists primarily of introductory, book-based work and on-the-job training (OJT) which is the hands-on phase of learning that is generally directed by Technical Orders. Upon completion of IST an individual is awarded a 3 skill-level (also referred to as a 3-level). They then enter upgrade training (UGT) which consists of additional, more specialized, book-based studies and OJT. An individual with a 3-level is not authorized to perform maintenance without supervision; the individual will typically be assigned a trainer that supervises activities performed during OJT and annotates tasks the trainee has been trained and, in some instances, certified on. OJT and UGT are used throughout the maintainer's career for attaining a 5 skill-level (also referred to as a 5-level) and 7 skill-level (also referred to as a 7-level).

A RAND study estimated total training costs associated with IST to be twenty thousand dollars per trainee over a duration of twenty-three weeks with OJT costing forty thousand dollars per trainee annually. Though both are essential to producing productive military members, IST effectiveness has an estimated limitation of 20 percent maximum effectiveness in an operational environment with OJT, progressively, making up the additional 80 percent of effectiveness over seven years (Manacapilli et al., 2007). In the research report, "Effects of Training Task Repetition on Retention and Transfer of Maintenance Skill" (Hagman et al., 1980) it was determined that "task retention improved in terms of both speed and accuracy as the number of task repetitions performed during training increased." The cost per trainee annually and the degree of

overall effectiveness in an operational environment shows that OJT is the better investment in the current training structure and there is potential for significant cost savings if the duration for meeting 100 percent effectiveness can be truncated.

Augmented Reality (AR) is proving to be an invaluable tool in training environments outside of the military. It increases student confidence and motivation and leads to increased gains in learning outcomes. AR has also been shown to increase student engagement and decrease dependence on teachers (Bridges et al., 2019). The benefits can be linked to the multisensory learning approach that is used by these systems. The combination of visual, auditory, and kinesthetic senses has also been shown to improve memory. In Prasannakumar's working memory study (Prasannakumar, 2018), consisting of sixty students, the experimental group, consisting of thirty students, that received multisensory training consistently outperformed the control group, the remaining thirty students, in memory tests by a margin of 50 percent.

Another potential benefit of using an AR system and a capability that may prove invaluable in conducting training from geographically separated locations is the ability stream AR experiences. Streaming an AR experience involves sharing the augmented camera feed from an AR system to a peer device (Streaming an AR experience, 2022). This feed can happen in real-time or can be recorded and saved for later viewing.

Agile Forces

Near-peer adversaries have developed methods to degrade command and control amongst U.S. forces. This degradation can lead to situations where military command is reactive in nature. The proposed solutions to this issue are to decentralize command or to

technologically overcome the degradation (Phillips et al., 2020). Other solutions to this issue include adopting Agile Combat Employment (ACE) and/or Adaptive Basing (AB) principles. The intent of ACE is to create cross-functional capability within the Air Force that allows for “speed, flexibility, and global perspective” (Combat Support AFDD 2-4, 2005). The Posturing Responsive Forces tenet of ACE relies on structuring prepositioned forces and capability of personnel. This aligns with the AB concepts of operating through integrated basing and conducting flexible operations (Mills et al., 2020). AB can be employed in two ways, integrated basing and flexible operations.

Integrated basing is the concept of operating from multiple small bases rather than one large installation. The theory behind integrated basing is that multiple smaller installations provide more resilience than a single, highly protected base. Integrated basing would also allow for the rapid movement of assets to provide additional operations security (Mills et al., 2020).

The concept of flexible operations uses a similar framework to integrated basing where multiple bases are utilized rather than one large base in an area of responsibility. Where this concept differs is the focus on relocating aircraft amongst smaller bases to create operational resilience. For flexible operations to function properly, maintenance and weapons crews, together with appropriate logistics and support, will need to be located at multiple locations within the area of responsibility to provide aircraft support (Mills et al., 2020).

Summary

The intent of Chapter II was to provide further understanding on the hardware, function, use and application of AR systems, provide the foundational elements of building a reference architecture through MBSE and cover Agile concepts in the Air Force. This information supports the development of plausible solutions to the investigation questions posed in Chapter I and informs on the methodology, results and conclusion of this thesis.

III. Methodology

Chapter Overview

This thesis provides plausible solutions to the investigative questions outlined in Chapter I and a reference architecture for an augmented reality (AR) system to support the goals of aircraft maintenance. Chapter III describes the steps necessary to explore and develop the possible solutions to the questions posed.

Initial Interviews

To gather the information necessary to model an AR-based system that meets the basic need of providing aircraft maintenance support to maintainers, understanding the needs of the maintainer was essential. To further examine these needs, interviews were conducted with the 149th Aircraft Maintenance Squadron, located at Joint Base San Antonio, Lackland Air Force Base, San Antonio, Texas. These interviews elicited responses that provided the information necessary to determine baseline requirements and develop use cases. Interviews were conducted with personnel that were well versed in training, performing maintenance, and evaluating personnel. These individuals included the flightline avionics section Production Supervisor/Flightline Expediter and the 149th Aircraft Maintenance Squadron Quality Assurance Lead/Technical Order Distribution Office Non-Commissioned Officer in Charge.

The interviews included providing the participants the background information and affiliations of the interviewer, the area of study and the research topic. To focus on the maintenance aspect of their positions, the participants were then provided two scenarios to guide the discussion:

1. An Airman is in upgrade training performing a peacetime mission.
2. An Airman is untrained or does not meet the minimum skill level to perform a task, but must perform it due to mission needs.

Given these scenarios, and the thesis focus on a maintenance support, the participants were then asked a series of questions regarding an AR-based solution:

1. How do you envision this system operating?
2. What types of information and prompts should be displayed?
3. What do you envision this system providing?
4. What hardware do you associate with this solution?
5. How would this system be used?

The responses from the interview were captured and were converted to user requirements and use cases. The use cases created from the interview inputs were further developed into system and subsystem requirements which were used to develop the reference architecture.

Feedback Interviews

To ensure the requirements extracted from the interview met intent, feedback was required. The requirements were discussed with and validated by the individuals interviewed from the 149th Aircraft Maintenance Squadron. Further, these individuals aided the development of derived requirements and the expansion of use cases. The participants have been contacted throughout the development process to provide additional information on tasks, organizational structure, maintenance processes and to provide clarification on requirements. The participants have also been contacted to

provide feedback on the feasibility of the system and provide vector checks to ensure the proposed system meets intent and satisfies user needs.

Reference Architecture Development

The reference architecture was developed using the student version of the Dassault Systems, CATIA-Magic System of Systems Architect 2021x and the Magic Model Analyst 2021x plugin. The SysML modeling language and the Object-Oriented Systems Engineering Method were used to develop Block Definition Diagrams, Use Case Diagrams, Activity Diagrams, Internal Block Diagrams and tables that represent relationships among elements of the system.

The reference architecture also required the use of the Department of Defense Architectural Framework (DoDAF) to ensure compliance with the DoD Reference Architecture Description, 2010. The DoDAF Viewpoints in Table 1 were selected for inclusion in the reference architecture to represent the what, why, and how aspects of the AR system.

Summary

The methodology described in Chapter III was critical in the development of requirements and the reference architecture. The interviews and subsequent feedback allowed for the expansion of the imagination and the concentration of ideas used in this thesis. The DoDAF Viewpoints outlined in the methodology provide a holistic reference architecture approach that covers the “what”, “why”, and “how” of the system as well as the potential for future expansion of capability.

Table 1. Selected DoDAF Viewpoints And Models

Model	Description
CV-1: Vision	Addresses the enterprise concerns associated with the overall vision for transformational endeavors and thus defines the strategic context for a group of capabilities.
CV-2: Capability Taxonomy	Captures capability taxonomies. The model presents a hierarchy of capabilities. These capabilities may be presented in context of a timeline - i.e., it can show the required capabilities for current and future capabilities.
CV-4: Capability Dependencies	The dependencies between planned capabilities and the definition of logical groupings of capabilities.
OV-1: High Level Operational Concept Graphic	The high-level graphical/textual description of the operational concept.
OV-2: Operational Resource Flow	A description of the Resource Flows exchanged between operational activities.
OV-3: Operational Resource Flow Matrix	A description of the resources exchanged and the relevant attributes of the exchanges.
OV-4: Organizational Relationships Chart	The organizational context, role or other relationships among organizations.
OV-5a: Operational Decomposition Tree	The capabilities and activities (operational activities) organized in a hierarchal structure.
OV-5b: Operational Activity Model	The context of capabilities and activities (operational activities) and their relationships among activities, inputs, and outputs; Additional data can show cost, performers or other pertinent information.
SV-1: System Interface Description	The identification of systems, system items, and their interconnections.
SV-2: Systems Resource Flow Description	A description of Resource Flows exchanged between systems.

(Department of Defense Architecture Framework, 2010)

IV. Analysis and Results

Chapter Overview

Chapter IV provides a reference architecture for an augmented reality (AR)-based maintenance assistance system based on current maintainer requirements. This chapter addresses how the system supports maintenance and training through the human interface and how the system can be utilized to meet the Air Force's strategic need of becoming a more agile force.

This chapter begins by describing the user requirements captured in the initial interview. Additional requirements are derived from Use Cases, which were developed from subsequent interviews and interview participant feedback. Following the use case descriptions, the Department of Defense Architecture Framework (DoDAF) Capability Viewpoints and Operational Viewpoints outlined in Chapter III are covered. Aspects of the system architecture and the associated military standards are then discussed. Finally, the logical interfaces of an AR-based maintenance support system are covered in the Systems Viewpoints.

Initial Requirements

During the initial interviews two scenarios were provided to capture peacetime and wartime applications of an AR-based system for maintenance support. A series of questions were then asked to elicit responses used to develop use cases, user requirements and system requirements. The questions were:

1) How do you envision this system operating?

2) What types of information and prompts should be displayed?
3) What do you envision this system providing?
4) What hardware do you associate with this solution?
5) How would this system be used?

The responses to these questions provided the initial user requirements for the system. At the initial interview the participants also envisioned some of the hardware necessary to realize the system. The major components described were useful in developing the baseline system requirements. The derived user and system requirements are shown in Figure 3.

#	Name	Text
1	1 Maintenance System	Shall enhance maintenance capability with a wearable augmented reality system that provides visual and auditory technical order procedures while simultaneously assisting in visually identifying systems, sub-systems, line replaceable units (LRU), LRU retaining devices and LRU connections being serviced.
2	1.1 Database	
3	1.1.3 User Data	Shall maintain up-to-date user data
4	1.1.4 Updates	Shall maintain system updates
5	1.1.1 TO Data	Shall maintain up-to-date TO data
6	1.1.2 Connectivity	Shall have the bandwidth to transmit user information, headset SW updates. TOs/TO updates,
7	1.2 AR Headset	
8	1.2.5 Wearable	Shall be a headset Shall keep the hands free Shall not limit mobility
9	1.2.2 Power	Shall provide 8 hours of active use
10	1.2.3 Video	Shall display unit in-work and information from 1.2.7
11	1.2.1 Display	Shall fit over or work in conjunction with glasses
12	1.2.4 Audio	Shall provide audible instruction
13	1.2.7 Provides Information To User	Shall provides task TO step-by-step instruction, ETC, Skill req'd, consumables, tools, support equipment, system, subsystem, LRU, aircraft
20	1.2.6 Wireless	Shall update information at system checkout and turn-in

Figure 3. User and System Requirements

The combination of initial requirements and participant example scenarios provided enough information to begin developing use cases.

Use Cases

Use Case Diagrams are verbal and written scenarios which are converted to visual representations. To better show how adoption of an AR-based system could impact current and future flightline maintainers, a reference Use Case Diagram was created to depict the current method of conducting unscheduled aircraft maintenance on the flightline.

Figure 4 shows the Use Case Diagram for current or “as-is” unscheduled maintenance. The main point of this Use Case Diagram is to show the effort and manning roles necessary for performing unscheduled flightline maintenance in a structure that supports single Air Force Specialties performing single flightline maintenance activities. The diagram portrays the current key actors (represented by stick figures) and activities (represented by circular nodes) necessary to perform unscheduled flightline aircraft maintenance. The extend arrows between activities are meant to augment the originating or base activity while the included arrows point to an activity required for the originating or base activity to be considered complete. In this Use Case Diagram, the activity “Ensure minimum skill level for task is met” requires that the Air Force Specialty specific Training Business Area (TBA) or Career Field Education and Training Plan (CFETP) are referenced to ensure the skill level for that task is met by the individual performing the task. The activity “Unscheduled Aircraft Maintenance” is augmented by the tasks of performing corrective maintenance and performing fault isolation measures. Both of these activity augmentations require the use of technical orders while “Performing Corrective Maintenance” requires the use of tools.

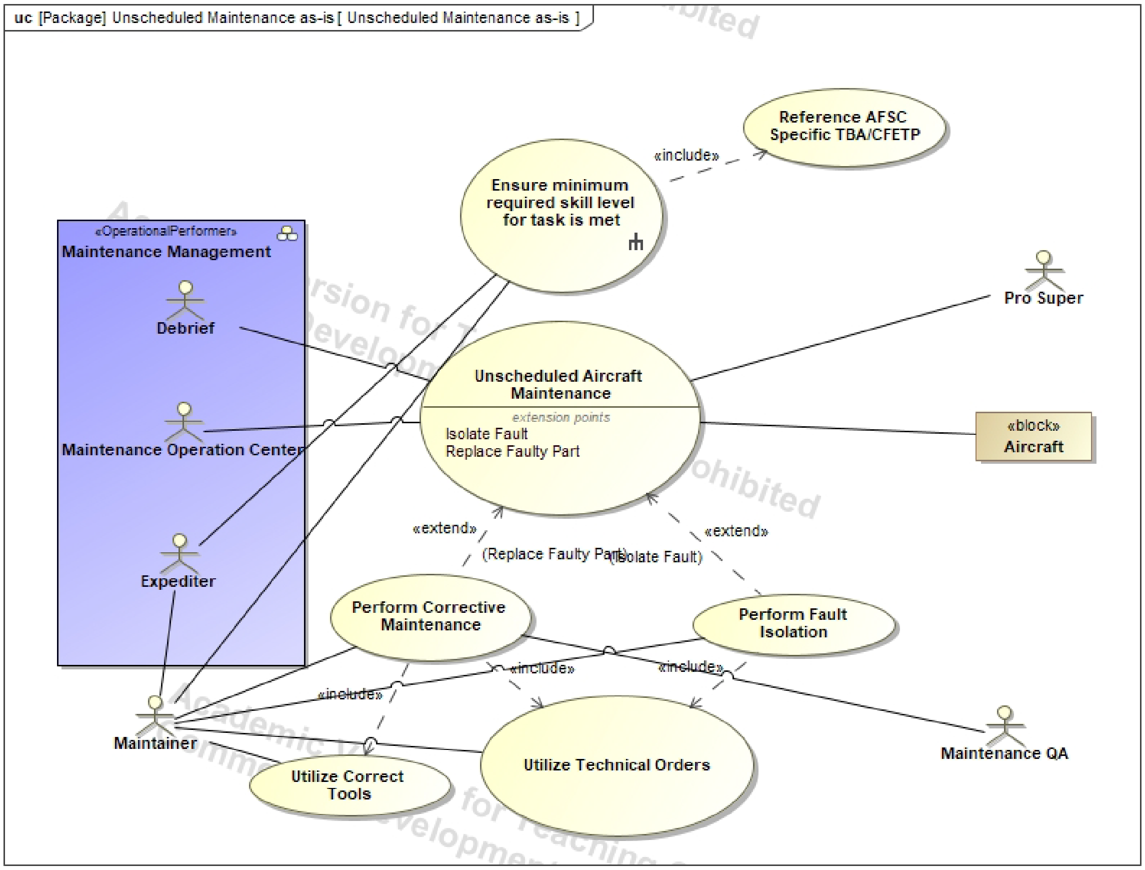


Figure 4. Use Case: Unscheduled Maintenance "As-Is"

In the event an AR-based maintenance system is employed, and roles are assessed to eliminate redundancy, it may be possible to eliminate or redefine the role of the Production Supervisor. The system would theoretically have the ability to assist maintainers on the entire aircraft so a Production Supervisor role may be absorbed by the Expediter. Figure 5 shows the AR-based maintenance system with the Production Supervisor role eliminated and the maintenance, fault isolation, and training use cases being supported by the AR-based maintenance system. Additionally, the Expediter still serves as the individual that assigns tasks to maintainers, but is no longer responsible for determining the capability and skill level of the maintainer. The AR-based maintenance

system also has the potential to eliminate the need for the maintainer to go to several different resource areas for information. The system is expected to provide the maintainer with their personal training information via downloaded TBA or CFETP data to the headset so they can be notified if they meet the qualifications to perform a task. Ideally, the maintainer will have skill levels of 5-level or 7-level as 3-level are not authorized to perform maintenance tasks unsupervised (3-levels require a 5-level or 7-level to accompany them when they are performing tasks). The maintainer would also use the AR-based system to access information on the correct tools necessary to perform a task, system and subsystem theory of operation, illustrated parts breakdown information, consumables, and required support equipment. The system will also provide step-by-step task instruction that conforms with requisite Technical Order information.

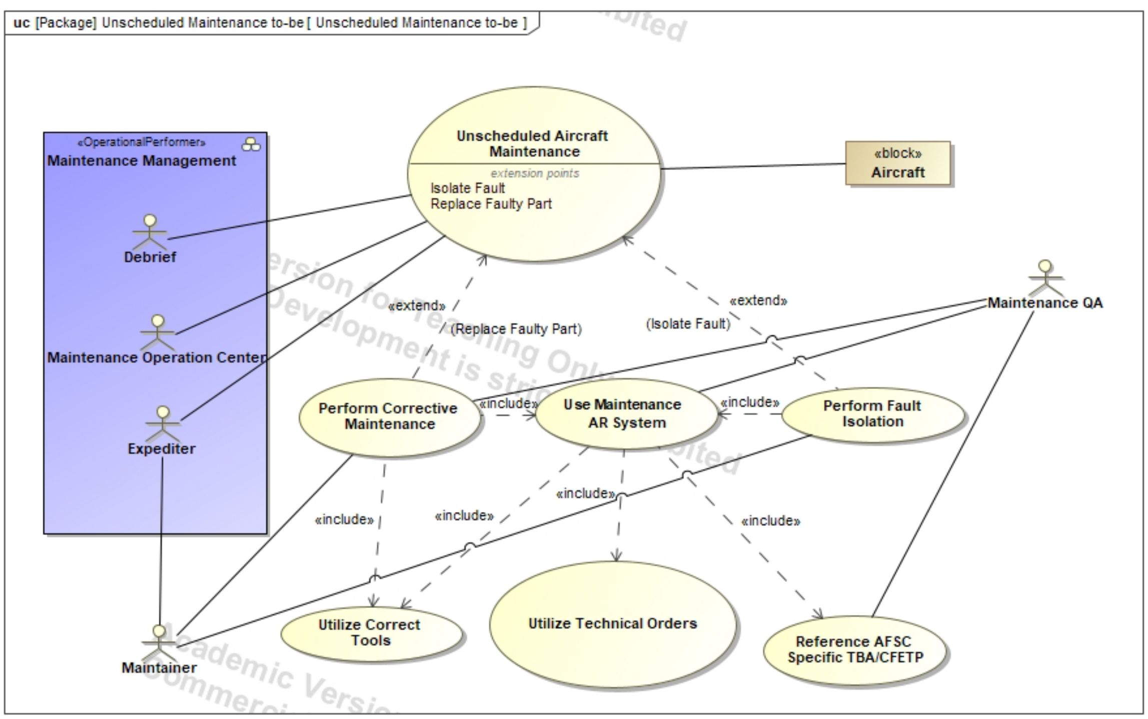


Figure 5. Use Case: Unscheduled Maintenance To-Be

The proposed AR-based maintenance system is not entirely stand-alone. Figure 6 depicts elements which directly affect the system. The actor added in this use case is the System Manager. The System Manager would be a blended role of the current Technical Order Distribution Officer, who manages the Technical Order program by ensuring they are current and accessible, and an information technology technician. The System Manager will need to manage updates to the AR-based system software and hardware components, manage interfaces with an electronic-based Career Field Education and Training Plan, maintain the system server and ensure a short-range wireless network is maintained for transmitting data between the headset and the database/server portions of the system. In the Maintainer AR System block shown in the Figure 6, the projected baseline capabilities of the system are introduced.

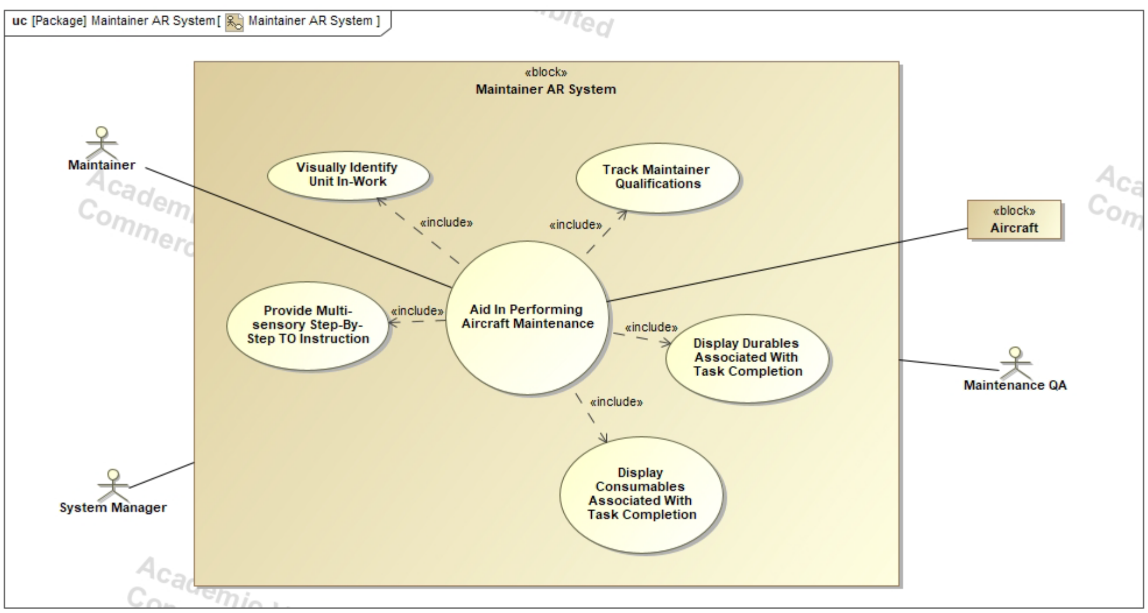


Figure 6. Use Case: Maintainer AR System Interfaces and Basic Utility

Maintenance training can be significantly altered with the adoption of an AR-based system. The multisensory aspect of AR systems has proven effective in short-term

and long-term memory retention (Bridges et al., 2019). Virtual reality and AR share many of the same benefits. Virtual reality-based training is being employed by the United States Air Force for aircraft flight simulators and the use of similar systems is being explored for maintenance. Figure 7 shows possible implications associated with adoption of an AR-based training system for maintainers. The diagram shows both maintenance and upgrade training, the method by which a maintainer becomes certified on tasks and increases skill level, using an AR-based system. The “Train On Airframe” node is used to represent the restructured schoolhouse technical training that has historically consisted of providing training in several Air Force Specialties to support maintenance on a single airframe. By providing AR-based step-by-step walk-throughs of tasks with video and audio support, the number of tasks an individual is capable of performing may be increased. In the diagram, the schoolhouse has been altered to reflect this change in training ideology. If the tasks an individual can perform expands outside of a single Air Force Specialty to all areas of an airframe, familiarization of an entire airframe should be emphasized during Initial Skills Training.

Figure 7 also shows many of the stakeholders that impact the training of a maintainer. The New Trainee is considered a prospective maintainer in Initial Skills Training or in 5-level upgrade training with upgrade training primarily taking place by use of the AR-based maintenance system with supervision from a flightline Maintenance Trainer (5-level or 7-level). The Weapon System Program Office (the organization responsible for the airframe) and the Maintainer AR-System Program Office (the organization responsible for the AR-based system) provide the technical data necessary to support technical training and to keep the AR-based system updated.

The role of Maintenance QA is to ensure maintenance is being conducted properly. Maintenance QA reviews any flagged items the system provides regarding the maintainer using the system and the tasks carried out by that maintainer.

The system outlined in this thesis compares the maintainer's accomplished training (trained/certified tasks) with the task carried out using the AR-based system. It also tracks and time stamps any selections in the system. This allows the system to recognize if the duration of any steps in the task were overly long or short (by comparing estimated times for completing each step). By tracking this data, the system can flag discrepancies to the System Manager and Maintenance QA personnel. This permits these personnel to identify discrepancies, interview the maintainer, and determine the reason for the disparity (e.g., a long task-step duration may be caused by incomplete or confusing instruction and the task-step may need to be further refined for clarity warranting a change in TOs or system software).

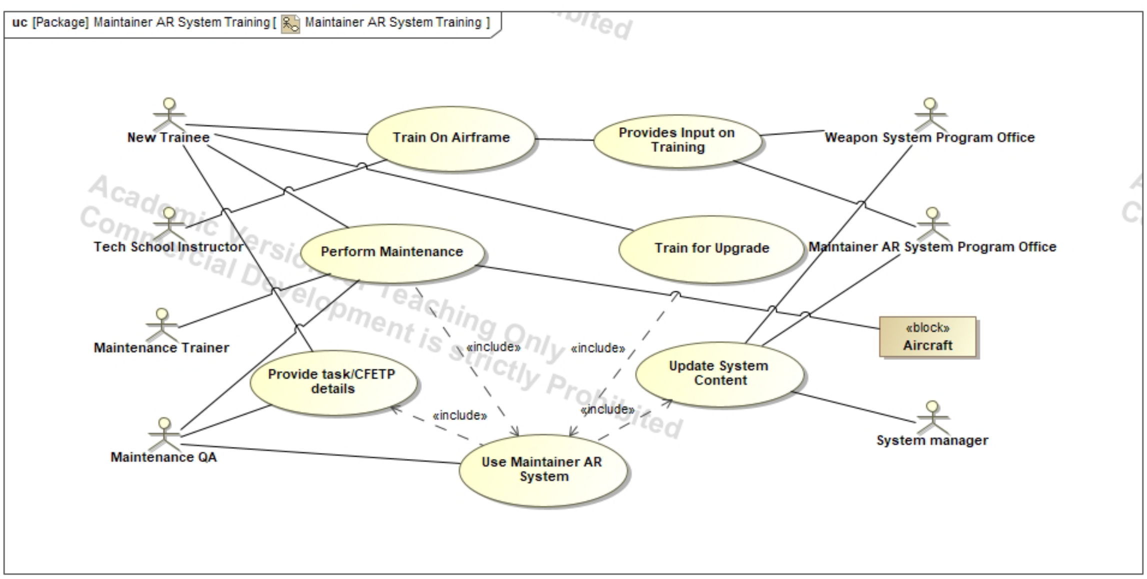


Figure 7. Use Case: Maintainer Training

The Use Case Diagram in Figure 8 provides a glimpse of potential impacts an AR-based maintenance system may have on strategic military goals. Employing Adaptive Basing, the Air Force concept of operating from several small bases in an area of responsibility and having the ability to move assets amongst those bases rapidly, requires a smaller, more capable maintenance force that can be pre-positioned or relocated as rapidly as the supported airframes. In current operations, fighter units typically deploy with multiple members of each Air Force Specialty that support an airframe. This type of large force movement requires extensive pre-planning and coordination of support mobility aircraft. An AR-based system that supports maintenance and training on an entire airframe would allow for a smaller maintenance footprint at many of the smaller bases with similar capability to the current, larger footprint. The intent of Figure 8 is to show that the ability to rapidly relocate aircraft relies on the force's ability to provide aircraft maintenance support to the rapidly relocated aircraft.

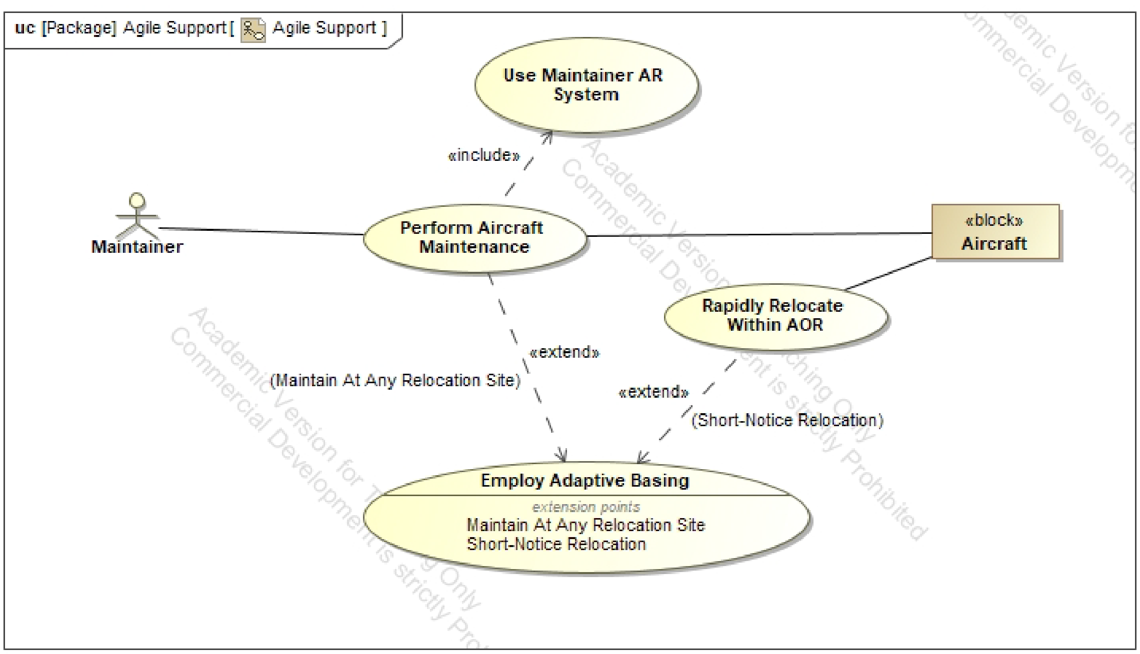


Figure 8. Use Case: AR-Based Solution to Meet Strategic Military Goals

DoDAF Viewpoints

The use cases provided a visual interpretation of system, user and some stakeholder interactions. The Department of Defense Architecture Framework (DoDAF) Viewpoints are used to provide further detail on the system structure, capability, requirements and interfaces in the form of an approved architecture structure (Department of Defense Architecture Framework, 2010). From the remainder of Chapter IV, the AR-based system will be referred to as the Maintainer AR System. The architect and stakeholders selected DoDAF Viewpoints from the Capability Viewpoint (CV), Operational Viewpoint (OV) and Systems Viewpoint (SV) areas to represent the Maintainer AR System use, interfaces and functionality. For descriptions of the Viewpoints selected please refer to Chapter III.

Capability Viewpoints

To address enterprise concerns associated with the Maintainer AR System and to provide an outline of projected capability, CV- 1 was selected. CV-1 outlines the vision of the system and includes stakeholders, stakeholder needs, system goals and projections of system capability.

The stakeholders associated with the Maintainer AR System are captured in Figure 9. Projected item-flows between the stakeholders and the Maintainer AR System are captured. A factor important to stakeholders is Mission Capability (MC) rate. MC rates are determined by calculating the number of aircraft available for at least one mission over a period of time. These rates are supported by Full Mission Capable (FMC) (can perform all mission requirements) and Partial Mission Capable (can perform at least

one, but not all mission requirements (Cohen, 2022)) aircraft. Adoption of the Maintainer AR System will likely rely on projecting increases in MC rates for the airframes the system is employed on and validation of those projections.

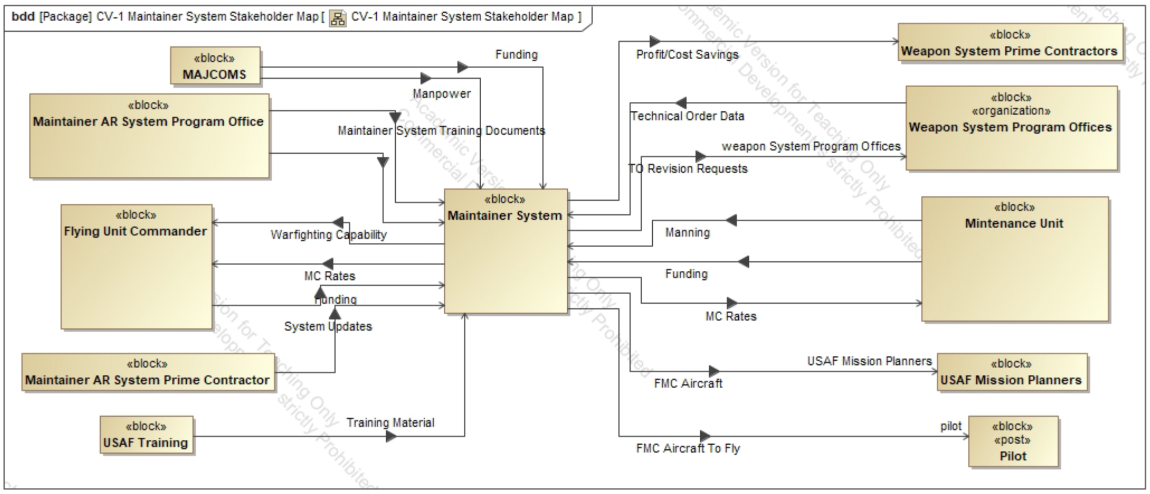


Figure 9. CV-1: Stakeholder Interfaces

Stakeholder needs are also addressed in CV-1. The purpose of providing the stakeholder needs is to gain strategic context on resources and potential resource constraints as well as context on what the stakeholders may require of the system and how those requirements may be levied on the system. Figure 10 shows some overlap of resources and needs amongst the various stakeholders.

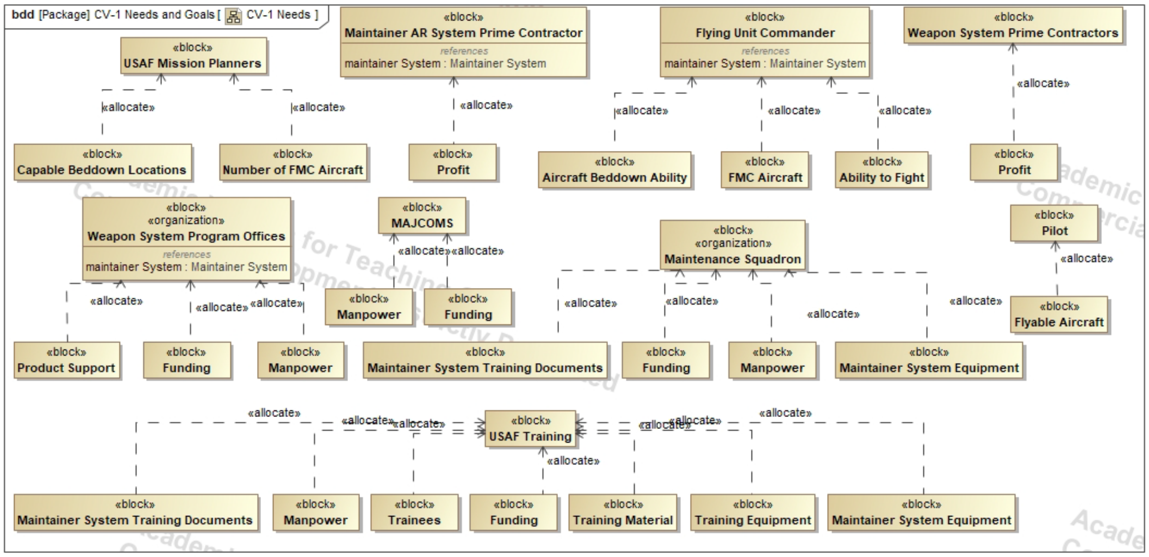


Figure 10. CV-1: Stakeholder Needs

The explicit declaration of system goals can assist in gaining buy-off from stakeholders. It provides the envisioned pathway for future growth of the system. The goals outlined in Figure 11 begin with the near-term goal of providing portable, multisensory, maintenance assistance to maintainers. It then evolves into expanding the maintenance task envelope beyond a single Air Force Specialty. This expansion leads to the goal of altering how students are trained during Initial Skills Training (IST) before being assigned to a maintenance unit. The final goal listed is the support of Agile concepts, more specifically, Adaptive Basing. The goals of the system are prioritized to provide realistic expectations at the current time. The prioritization can change at any time to meet mission and stakeholder needs.

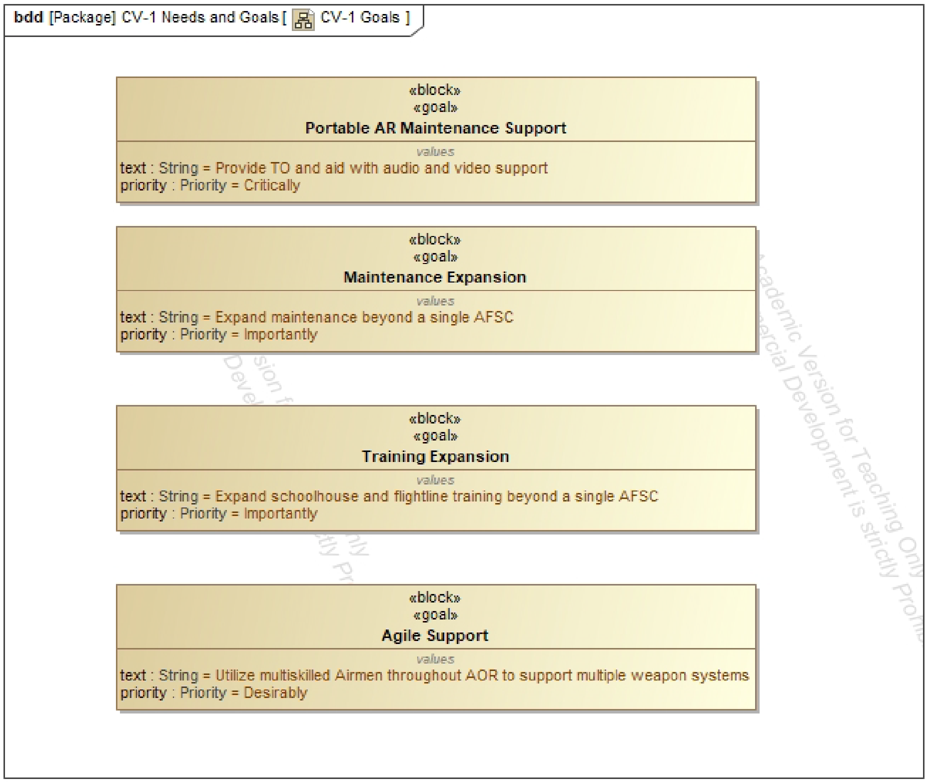


Figure 11. CV-1: System Goals

To compliment the goals of the system, projected timelines to meet the goals are established. The Maintainer AR System adoption and implementation of strategic goals works in the phased approach detailed in Figure 12 (timelines are notional). Phase 1: Limited Distribution Evaluation, consists of low-rate initial production (LRIP) of the system with limited distribution. This will allow selected maintenance units to train on and use the Maintainer AR System to aid human-system integration and provide feedback on system software and hardware for system refinement. During this phase, the system is only meant to support the goal of providing Portable AR Maintenance Support.

Phase 2: Full Distribution Expanded Maintenance & Training consists of full-rate production of the system which includes the updates from Phase 1 and expansion of maintainer maintenance beyond the confines of a single Air Force Specialty. To be

synchronized with maintenance, Phase 2 may also include the investigation and execution of expanding upgrade training tasks in the CFETP. Phase 2 may also consist of developing training plans for IST to support airframe system familiarization and to further skill expansion beyond a single Air Force Specialty.

Phase 3: Full Spectrum Maintenance & Training is the full adoption of the concept of providing maintenance and training for an entire airframe. This phase supports the employment of Adaptive Basing concepts through use of the Maintainer AR System.

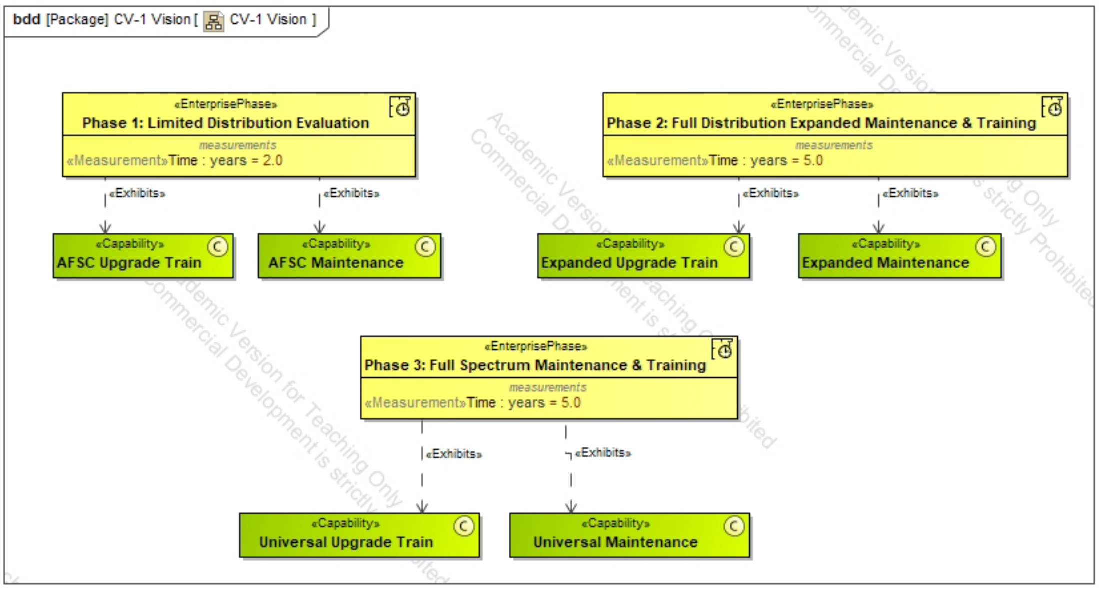


Figure 12. CV-1: Vision

The capabilities of the system are expanded on in CV-2- Capability Taxonomy. The capabilities associated with the Maintainer AR System in Figure 13 show near-term and long-term potential. Two capabilities requiring clarification are “To Perform Maintenance” and “Maintain”. The capability “To Perform Maintenance” represents the act of following step-by-step instructions to perform a task. The “Maintain” capability represents the act of keeping aircraft systems maintained.

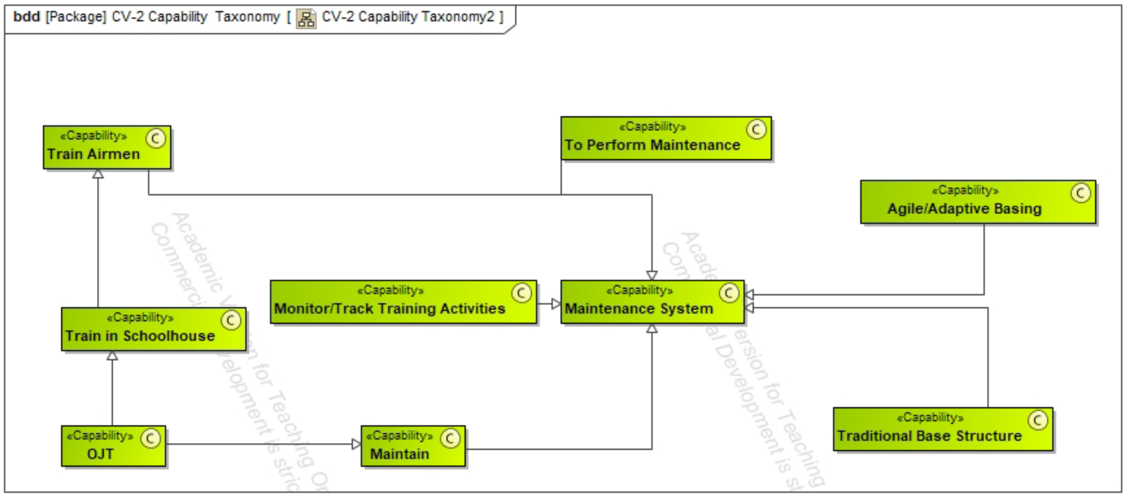


Figure 13. CV-2 Capability Taxonomy

To understand the progressive development of the capabilities of a system, the capability dependencies must be described. Figure 14 is a depiction of the dependent relationships of the potential capabilities of the Maintainer AR System. CV-4 includes the capabilities to support the current maintenance structure as well as capability expansions that support Adaptive Basing concepts.

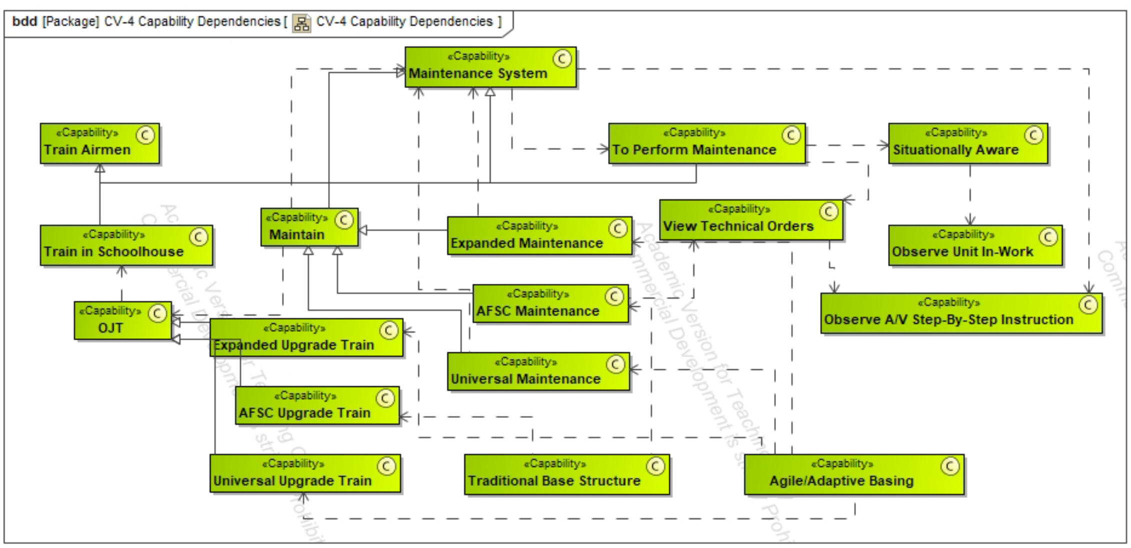


Figure 14. CV-4: Capability Dependencies

Operational Viewpoints

The DoDAF OVs are used to "describe the tasks and activities, operational elements, and resource flow exchanges required to conduct operations (Department of Defense Architecture Framework, 2010)." The following OVs will cover the operational concept, the resource flows, organizational relationships and the operational activities of the Maintainer AR System.

The high-level concept of the Maintainer AR System is depicted in Figure 15. It showcases a notional scenario where a maintainer is provided F-15 Strike Eagle maintenance support through an AR headset. The AR headset also interfaces with a database on a server to store pertinent data.

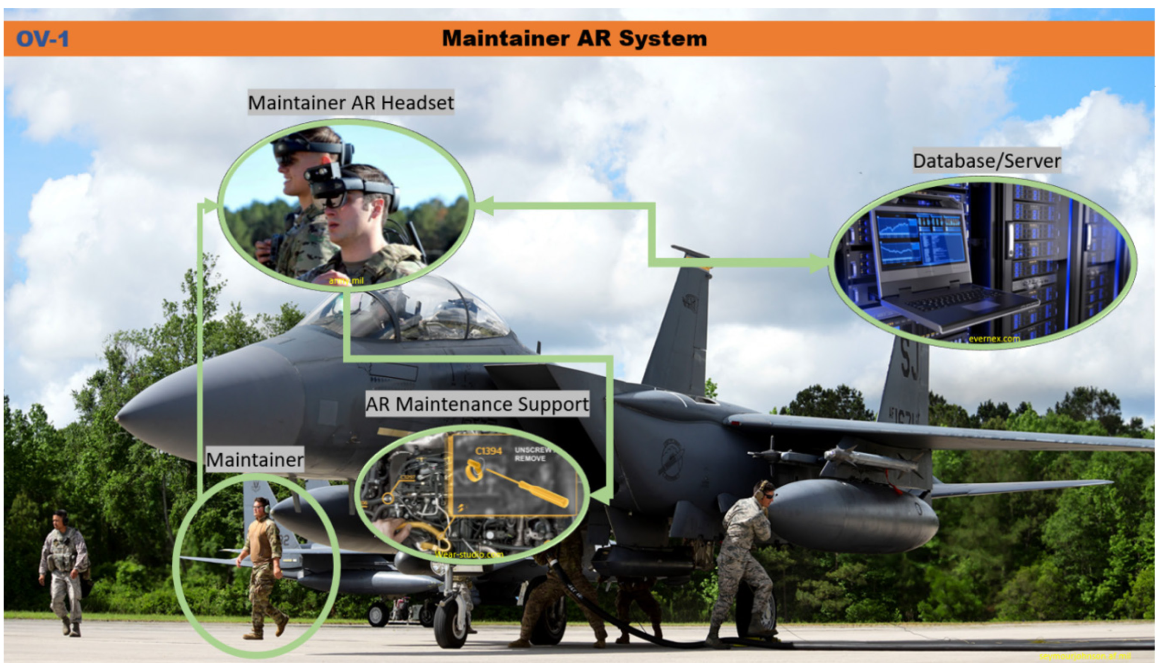


Figure 15. OV-1: Maintainer AR System High-Level Operational Concept

The high-level operational concept only provides a glimpse of the interfaces necessary to perform unscheduled maintenance. The "to-be" process of performing

upgrade training and maintenance with the Maintainer AR System, from an operational standpoint, is captured in OV-2 as shown in Figure 16. The process begins with the Pilot recognizing an aircraft fault during flight. The fault information is then passed on to Debrief. Debrief validates the fault and passes the information to the Maintenance Operation Center (MOC) who manages maintenance activities across all aircraft on the flightline. The MOC then passed the repair notification to the Expediter who manages and assigns the work on specific aircraft. The assigned maintainer utilizes the Maintainer AR System interfaces to assist with performing the maintenance task. Training is also enabled in CV-2, providing the ability to track the task being completed and comparing it to the individual maintainer's completed training as captured in the CFETP. If the Maintainer AR System identifies a mismatch in completed training and the task performed, i.e., the individual performs the task without being signed-off as trained or certified, an error flag is recorded and later uploaded to the database on the server where it can be brought to the attention of Quality Assurance personnel. The OV-3, located in Appendix A, is a matrix depicting the item flows described in the OV-2.

Two OV-4 viewpoints were created to show the fundamental differences between the "as-is" and "to-be" organizational structures. Figure 17 provides the "as-is" format of the organizational structure which includes maintenance, training, program office and flying organizations. The image depicts three separate paths for the different Air Force Specialties. On a single airframe there can be more than eight different specialties that perform maintenance functions, but Figure 17 only depicts three which are represented by AFSC 1, AFSC 2 and AFSC 3.

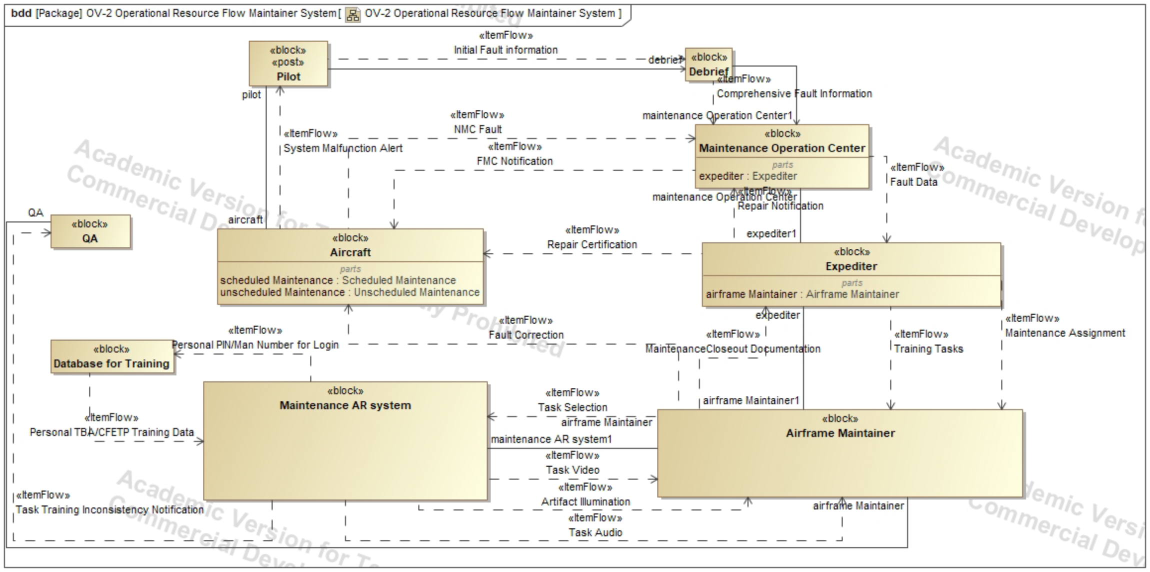


Figure 16. OV-2: Maintenance and Upgrade Training Operational Resource Flow

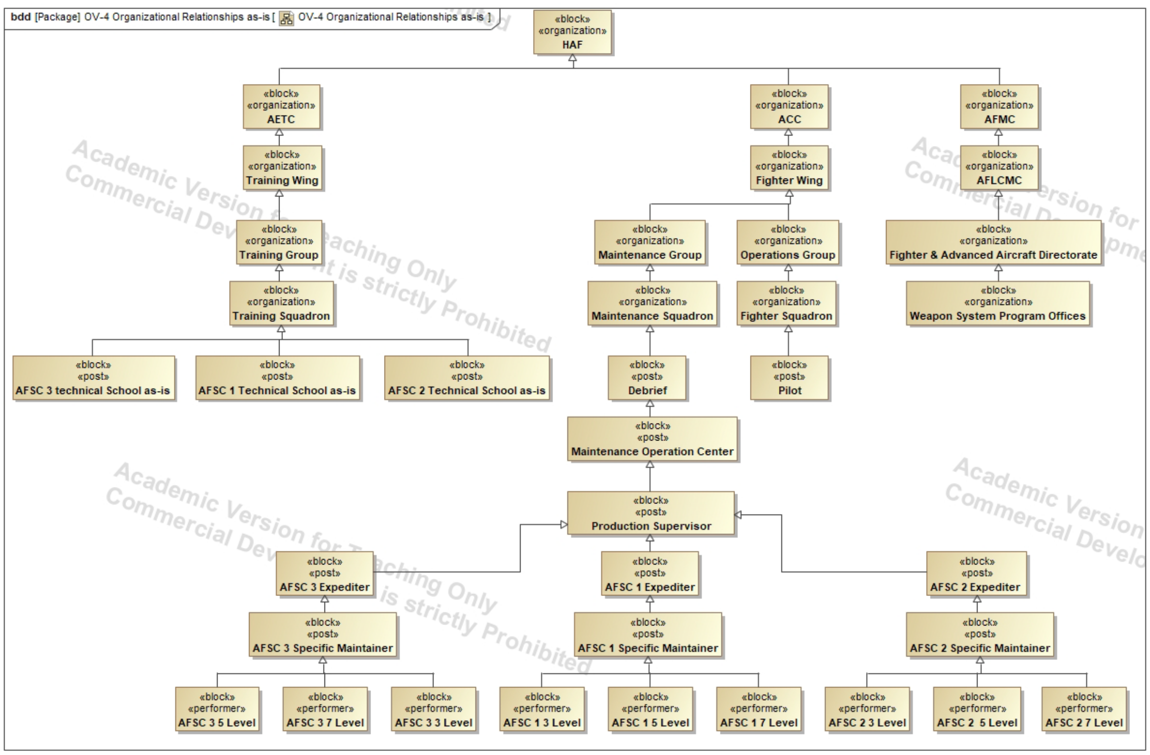


Figure 17. OV-4: Organizational Relationships "As-Is"

The notional, "To-Be", organizational structure captured in Figure 18 has many of the same organizations as the "As-Is" structure captured in Figure 17. The major

differences lie within the AETC branch of the diagram and the Maintenance Group branch of the diagram. The AETC branch shows the trainees are no longer broken out into individual Air Force Specialties, but are trained to work on an entire airframe; thus, they participate in airframe familiarization training. This is done to prepare the maintenance trainee to performing maintenance on the entirety of an airframe. The block titled "System X Familiarization Training" was added to provide another example of non-Air Force Specialty specific training that may take place. The maintenance activity below the MOC in the Maintenance Group branch of the organizational chart has also changed significantly. There is no longer a need for the Production Supervisor as the role has been absorbed by the Expediter. The maintainer's responsibility has also changed by transitioning from an Air Force Specialty specific area to the entire airframe.

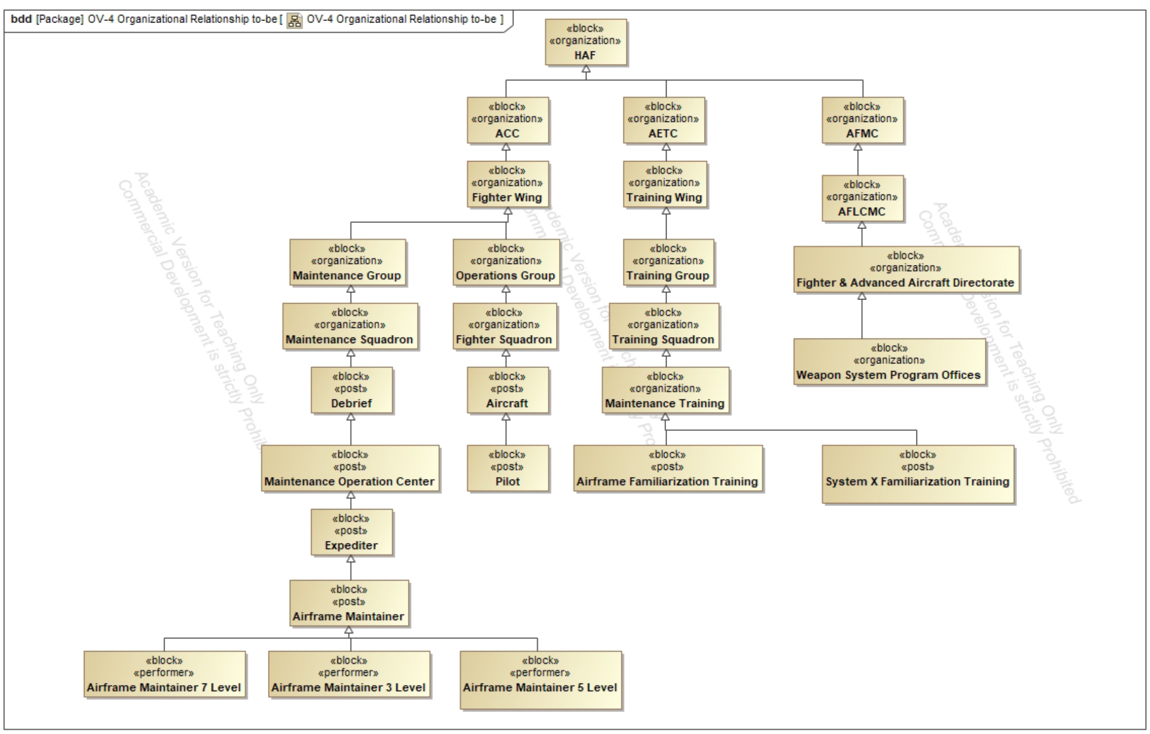


Figure 18. OV-4: Organizational Relationships "To-Be"

OV-5a, shown in Figure 19, and OV-5b, shown in Figure 20, cover the operational activities of the system. For the OV-5a, the roles of Debrief, MOC and the Expediter have been combined into the role of Maintenance Management; this was done because many of the responsibilities carried out by these entities consist of relaying fault information. The OV-5a is further decomposed in the OV-5b.

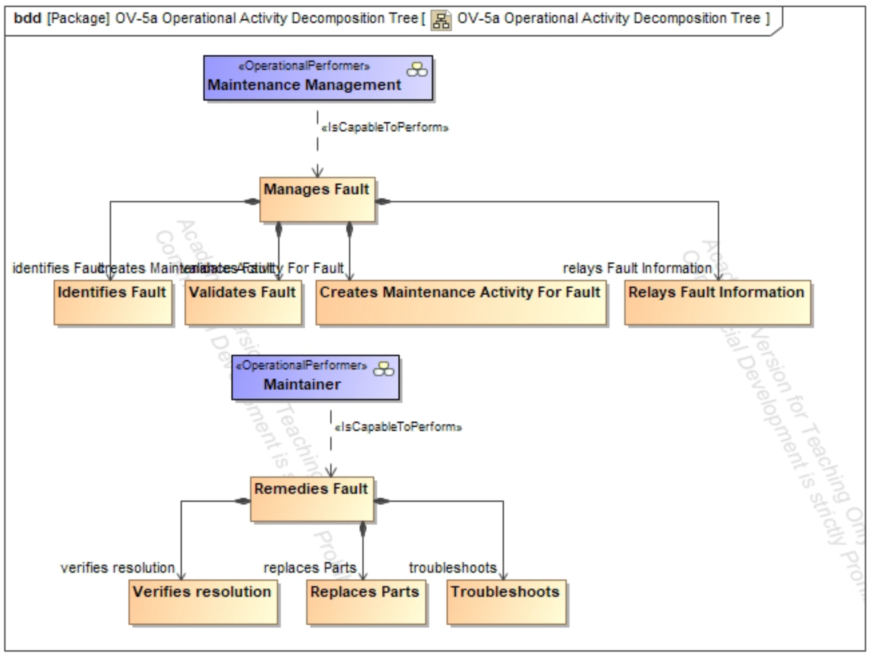


Figure 19. OV-5a: Maintenance Operational Activity Decomposition

Figure 20 is a breakdown of the activities carried out by the two major components of the Maintainer AR System, the Database on the Server and the AR Headset along with human user (maintainer) interface. The diagram shows the dependencies between the components and the human user for system functionality.

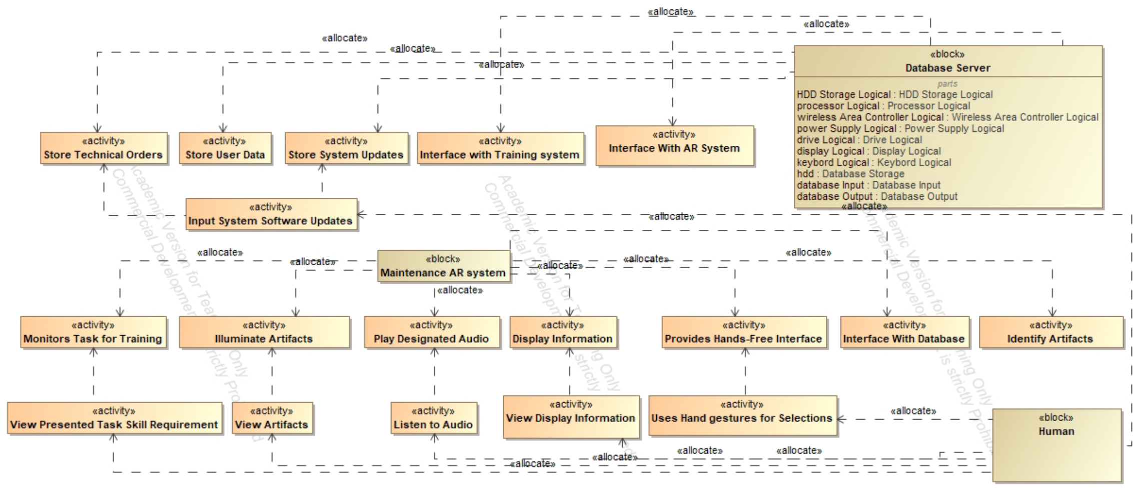


Figure 20. OV-5a: Maintainer AR System Operational Activity Decomposition

The Activity Diagram in Figure 21 includes the aircraft and the pilot. Though the aircraft is the unit in-work and the pilot conveys the initial fault information to Debrief, the fault is not acted upon as a maintenance activity until it is validated by Debrief. The Maintenance Management role is captured, but it is also broken down into the individual roles, i.e., Debrief, MOC, and Expediter, which are contained within it. The Maintainer role references the Maintainer AR System during initialization and performance of the maintenance task. The OV-5b covers aspects of the maintenance activity, including steps associated with identifying and validating faults, clearing the “Red X”, and returning the aircraft serviceable.

The activity model depicting the operation of the Maintainer AR System has been broken down into three sections: Operator/Headset Interface as shown in Figure 22, AR Headset System Utilities and I/O as shown in Figure 23, and Database/Server Operation as shown in Figure 24. The diagram can be viewed in its entirety in Appendix B.

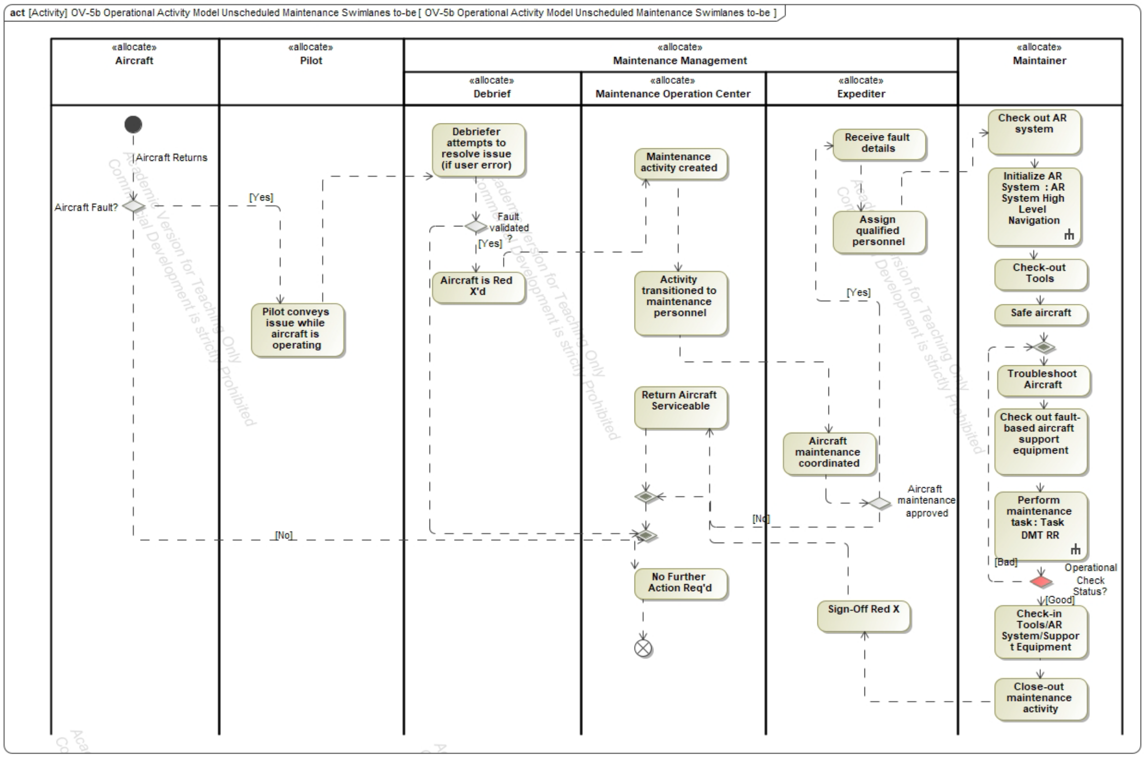


Figure 21. OV-5b: Maintenance Operational Activity Model

The Maintainer AR System consists of three parts, the headset, the database/server and the charging dock. Upon initialization of the system, the headset establishes a connection with the database/server and begins downloading any updates. The maintainer then provides login information to download individualized information from the database/server to the headset. The maintainer then selects the airframe they are working on to access the system, the subsystem, and the line replaceable unit (LRU) information including theory of operation and illustrated parts breakdowns. The maintainer navigates through the selections with hand movements and gestures. The maintainer can also elect to perform maintenance which consists of the Remove/Replace activity, Remove activity, and Install options. By selecting Remove/Replace the user is provided the step-by-step instructions (both visually and audibly) to remove and replace

an LRU. The purpose of the separate Remove and Install selections is to provide instruction on either removing an LRU without replacing it or installing an LRU in an aircraft that had parts removed previously, but not installed (this can happen when LRUs are unavailable through supply). For any maintenance selection, the estimated time of completion, level of difficulty, and skill level required are provided. The maintainer also has the option to view required tools, support equipment, and consumables. Once the maintenance task is completed, all data associated with the task (selections, step durations, task duration, etc.) is packaged as a Task File and prepared for transmission to the database/server. Once all tasks are completed and the user selects the option of logging out of the headset the Task File will be transmitted to the database/server for storage. The database/server then stores the data in the maintainer's file and the maintainer is logged out.

To update the system, the System Manager uploads updates to the database/server. The Activity Diagram in Figure 24 contains an Accept Event Action titled "Update Database". The purpose of this node is to allow for an external input to the database/server. It is activated by signal, "External User Uploads Updates" which can consist of any input from a drive or keyboard. This upload is then stored in the partitioned area that aligns with the type of update it is (system, Technical Order, etc.).

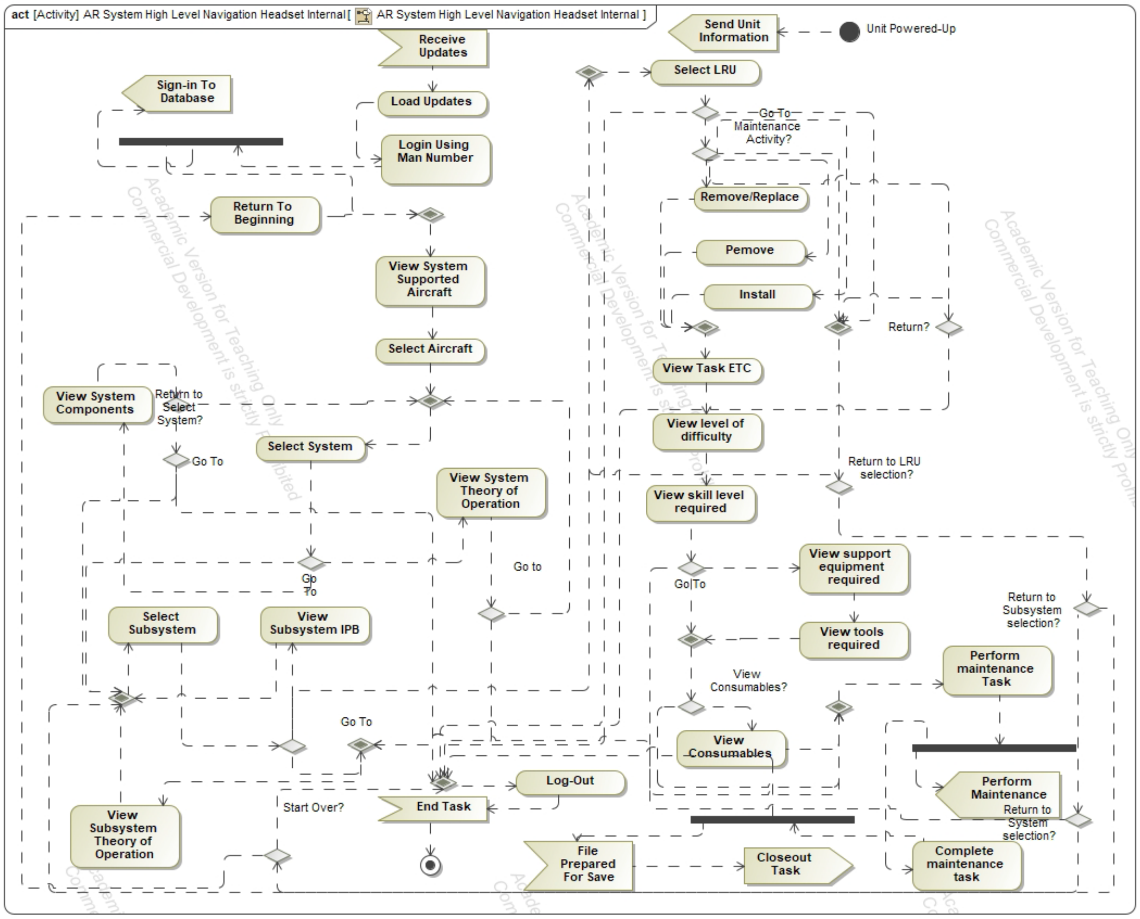


Figure 22. Maintainer AR System Operator/Headset Interface

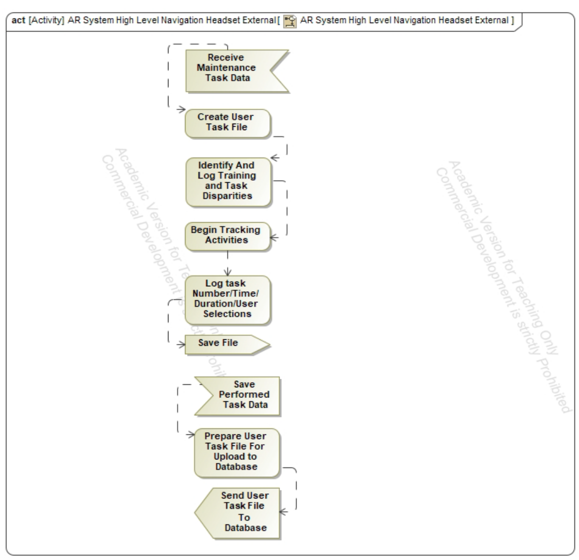


Figure 23. Maintainer AR System Headset System Utilities and I/O

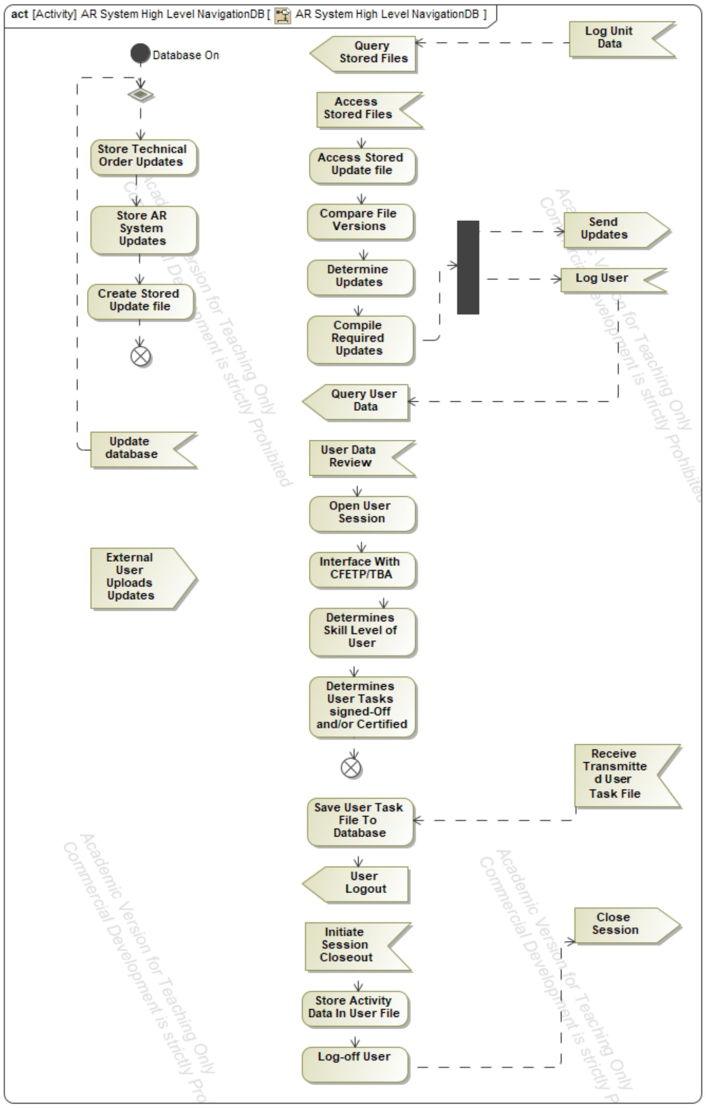


Figure 24. Maintainer AR System Database/Server Operation

Systems Viewpoints

Prior to covering the DoDAF Systems Viewpoints, component selection for the Maintainer AR System headset must be addressed. This is necessary because 1) there are military standard constraints placed on hardware used for military purposes and 2) the logical structure and interfaces of the system are covered in SV-1 and SV-2. Table 2 is a list of major logical components selected for the Maintainer AR System and their

descriptions. Table 3 covers many of the applicable military specifications and standards associated with this type of system.

Table 2. AR Headset Logical Components

#	Logical Component	Description
1	Display	The display is the component that projects the image in an AR system. The resolution of the display plays a major role in how the human perceives the presented digital imagery (virtualrealitypop.com). One of the highest resolutions on the market today is 2048 X 1080 pixels(softwwaretestinghelp.com). This resolution is necessary when rendering digital overlays that consist of small text.
2	Optical Combiner	The optical combiner is the component that is viewed by the user with both the real-world image and the digital overlay. An optical waveguide, a type of optical combiner, provides a large eye box which is necessary to allow for minimal individual user adjustment. (virtualrealitypop.com)
3	Depth Camera	Depth cameras determine object distance. The time-of-flight depth cameras are best suited for providing near and far range depth which is ideal for the varying flightline settings. The time-of-flight depth camera is also one of the best methods of detecting hand gestures and movement which is essential for making selections on the headset. (medium.com)
4	Digital Camera	The digital camera is used to provide a reference point for the depth camera overlays (medium.com) and has the potential to provide training and maintenance assistance to personnel that are geographically separated through video communication.
5	Eye Tracker	The eye tracker provides the video system with the details of where the eye is focused to provide high-quality image rendering in that area.
6	Audio System	The audio system is used to provide the audible instruction to the user. It must be powerful enough to be heard through hearing protection or be integrated into hearing protection.
7	Battery	The battery will be lithium based to support keep the system light-weight and minimize issues associated with added weight placed on the head (Chihara, 2017). Most lithium options on the market provide enough power for

		three hours of active use. To keep the weight low extra batteries can be carried and the ability to hot-swap (the swapping of batteries with no interruption to system operation) the battery can be employed.

Table 3. Associated Military Specifications and Standards

MIL-STD/MIL-PRF	Title	Description
MIL-PRF-32432A	MILITARY COMBAT EYE PROTECTION SYSTEM (11-SEP-2018)	This specification covers the Military Combat Eye Protection (MCEP) system. This document covers both prescription and non-prescription wearers. MCEP provides protection from dust, flying debris, and ballistic hazards both in training and on the battlefield while maintaining compatibility.
MIL-PRF-32383	BATTERIES, RECHARGEABLE, SEALED, GENERAL SPECIFICATION FOR (16 JUN 2011)	This specification covers sealed rechargeable batteries designed to power portable communications electronics devices used by the US military.
MIL-STD-1472H	HUMAN ENGINEERING (15-SEP-2020)	This standard establishes general human engineering design criteria for military systems, subsystems, equipment and facilities. Specific head mounted display standards are located in section 5.2.2.16, Head and Helmet Mounted Displays.

The system interface descriptions are captured in Figure 25, Figure 26 and Figure 27, and can be viewed in a single diagram in Appendix C. The diagrams depict necessary system and subsystem logical interfaces for the Maintainer AR System to operate. Figure 25 focuses on the headset's internal and external interfaces. The headset external interfaces include the AR Display which provides digital overlays creating the AR

environment, the Dock/Battery Charger which interfaces with the battery, the Headset Wireless Data Transmitter/Receiver, which interfaces with the database/server and Selections which is how the maintainer makes selections using hand movements and gestures.

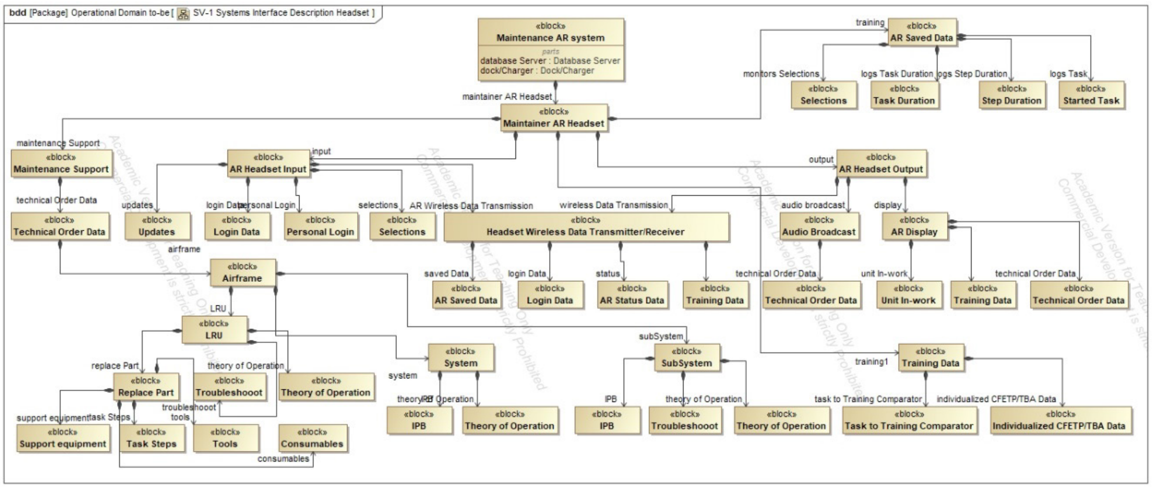


Figure 25. SV-1: System Interface Description, Headset

The database/server has the same wireless interfaces as the headset. It also provides an input for the System Manager through a keyboard and drive and provides a means for viewing data through the Database Display.

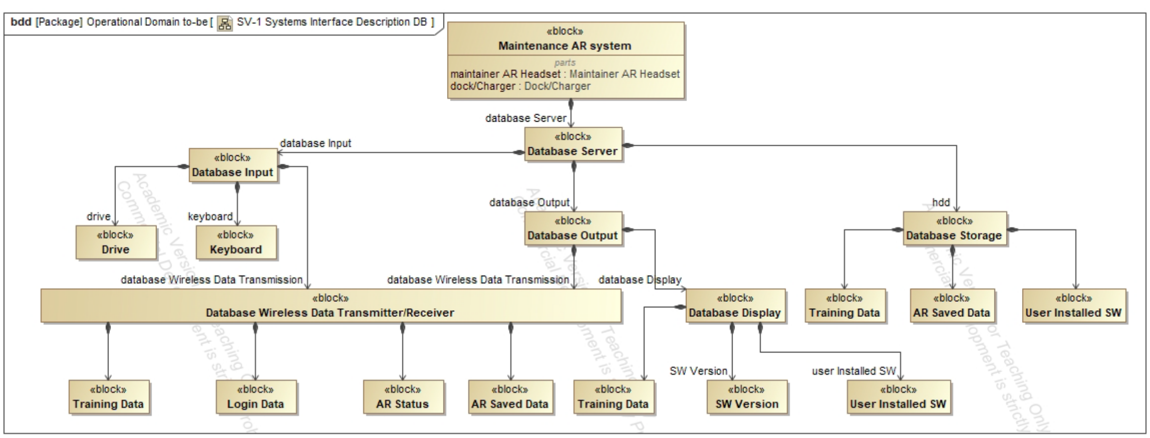


Figure 26. SV-1: System Interface Description, Database/Server

An area that has not been addressed is the power needs of the system. The headset of this system is wireless so batteries are needed. Figure 27 shows the battery management system as a headset dock and charging station. This is portrayed this way to provide the option of performing a battery hot swap on the system. A requirement of this system is to provide eight hours of use. To accomplish this a large battery may be used or a hot swap of batteries can take place. A hot swap is the ability to swap an external, main system battery without interrupting the operation of the system. This would require an on-board, permanent battery on the headset that would provide very short-term power to the system during the swap; the on-board battery would theoretically be charged by the docking station with a separate charger for the external batteries.

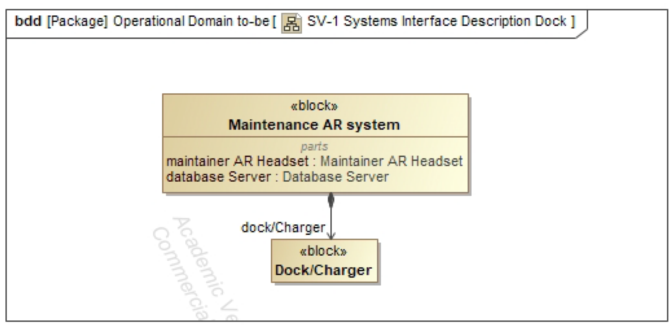


Figure 27. SV-1: System Interface Description, Dock/Charger

SV-2 captures the resource flow within the logical design of the Maintainer AR System. The system is broken down into the three sections described in SV-1. The ports show the direction of resource flow and the resources assigned to that port. Figure 28 details the major logical components of the system and their interfaces.

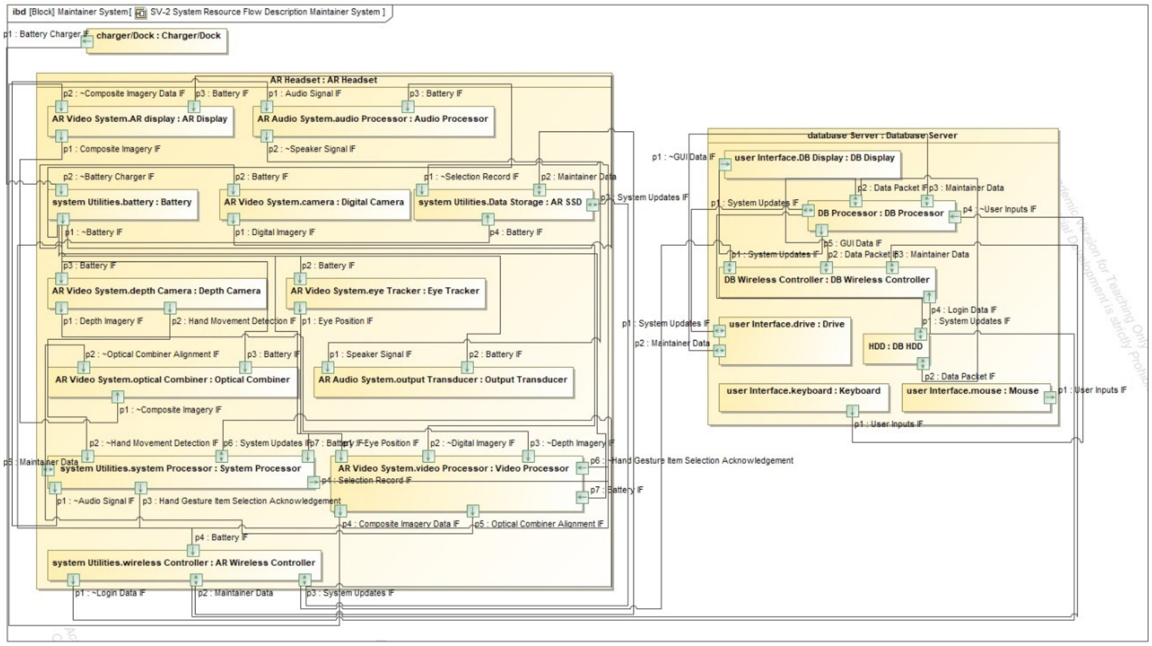


Figure 28. SV-2: Maintainer AR System Resource Flow Description

Figures 29 and 30 are exploded views of the components captured in Figure 27. These diagrams detail the logical sub-components interfaces of the Maintainer AR System.

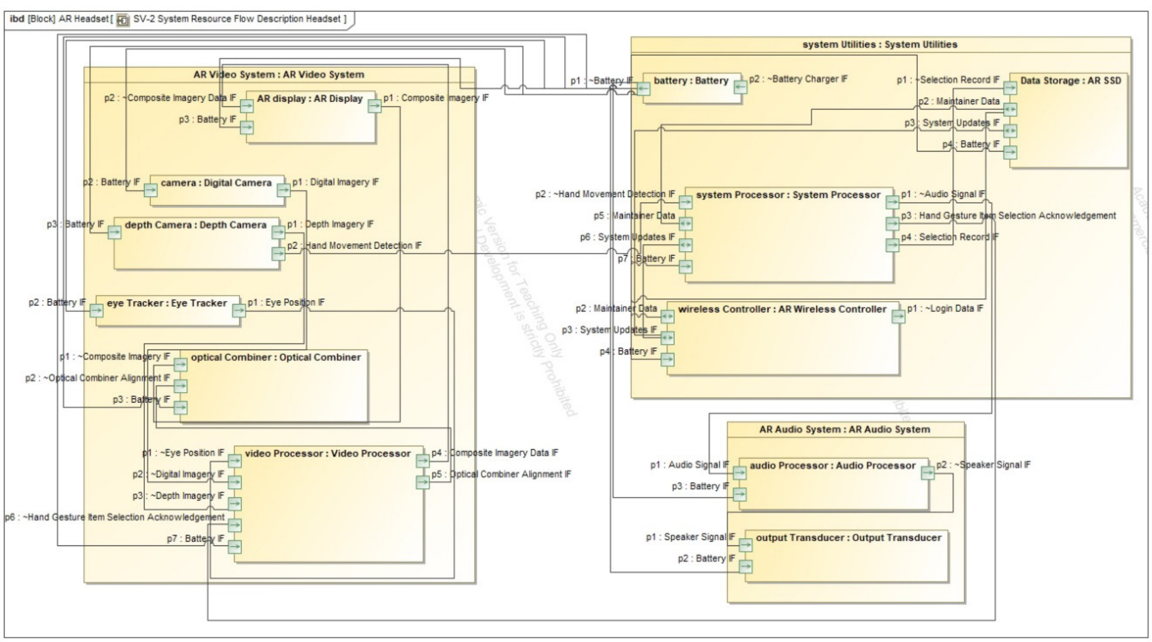


Figure 29. SV-2: System Resource Flow Description, Headset

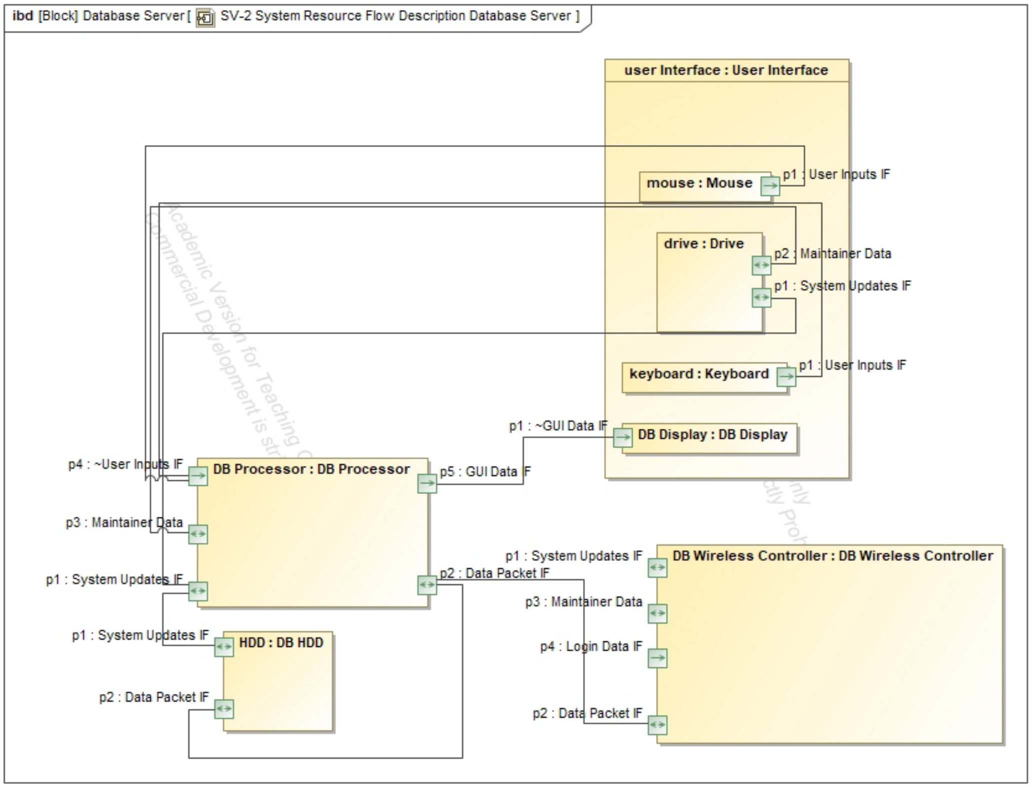


Figure 30. SV-2: System Resource Flow Description, Database/Server

Summary

This chapter presented baseline requirements, use cases and interfaces at both an organizational and system level. These areas were emphasized to show the user needs, how the system was designed to meet those user needs and the possible effects adoption and employment of a system of this type may have on Air Force organizations and strategic planning.

V. Conclusions and Recommendations

Overview

This chapter explains the intent of the researched reference architecture, how the architecture answers to the investigative questions and potential future work associated with this research.

Significance of Research

Chapter I began by discussing the rapidly changing world and the need for the United States to take measures to assure dominance in conflicts involving peer and near-peer threats (National Defense Strategy, 2018). This requires the modernization of the equipment and processes necessary to make and win wars. Modernization within the Air Force has been selectively applied and generally equates to creating aircraft with greater stealth and perceived lethality. The modernization of Air Force infrastructure goes beyond securing the newest, fastest, stealthiest system, it requires investment in the areas susceptible to current and near-term threats. In an effort to develop a system that supports flightline aircraft maintainers in the performance of their duties, limitations within the current maintenance structure were identified. Air Force Doctrine Note 1-21 acknowledges many of these limitations and others placed on the Air Force and calls for the reexamination of operational processes to enable flexibility under Agile Combat Employment (ACE). The outlined structure, designed to meet strategic goals, calls for multi-capable airmen in the force.

This reference architecture was created as a modernization effort. It was built to address the technology gap between the maintainer and the systems the maintainer

supports. The research began by studying the current method of performing maintenance on the flightline and developing a potential near-term solution that can support increased efficiency in performing maintenance tasks. The research evolved into designing a system that has the capability of creating multi-capable Airman and a more agile Air Force.

Investigation Results

This thesis was created to design an open-ended reference architecture for an augmented reality (AR)-based flightline maintenance support system and provide answers to the investigative questions. The structure of this section is the presentation of the investigative question followed by the researched solution.

I. What are the use cases, major components and associated procedures that need to be addressed to develop a system of this type?

The use cases for this system are covered in the Use Cases section in chapter IV. The use cases were created from the interview participant's descriptions of the current maintenance method and potential maintenance methods based on the perceived benefits of adopting a system of this type. The use cases cover conducting maintenance, conducting training, and supporting strategic goals in the Air Force that revolve around agility and multi-capable Airmen.

The major components of the system were first addressed in the department of Defense Architectural Framework, 2010, Operational Viewpoint (OV)-5a (Figure 20) and further explained in Table 2 and the logical breakouts and interfaces covered in Systems Viewpoint (SV)-1 and SV-2 (Figures 25-30). They consist of the Database/Server, the AR

headset and the Dock/Charger. Many of the logical systems, subsystems and components are also covered in SV-1 and SV-2.

The associated procedures associated with the operation of this system are captured in the Activity Diagram in Appendix B as well as Figures 22-24. These are the Activity Diagrams that show how the maintainer interfaces with the AR Headset and how the AR Headset interfaces with the Database/Server.

The procedures associated with adopting and implementing a system of this type are captured in the Capability Viewpoints (CV) and OVs sections of Chapter IV. These areas cover a phased approach to adopting the system, the needs and goals of the system, the stakeholders that need to be involved during development and sustainment and some stakeholder interdependencies.

II. What human aspects are considered by this system to support increased functionality with minimal impairment?

The human aspects of this system that support functionality with minimal impairment are primarily covered in MIL-STD-1472H, which provides extensive requirements for Head Mounted Displays, but also in the wearable, wireless, hands-free aspects and requirements of the system. The ensemble of logical hardware selected for the headset was selected with guidance from MIL-STD-1472H with emphasis on displaying information in high resolution and providing the ability to navigate through system selections with hand gestures and hand movement.

III. How can the AR system be employed to affect training and operations in the United States Air Force?

OV-4, captured in Figure 17 and Figure 18, shows significant differences in the As-Is and To-Be organizational and training structures in the Air Force. In the figures the training transitions from Air Force Specialty specific training to training on an entire airframe. Airframe training is accomplished through planned transitions in capability covered in CV-2 (Figure 12), which rely on building the infrastructure that addresses and satisfies the dependencies depicted in Figure 14, CV-4.

Recommendations for Future Research

The reference architecture in this thesis carries many assumptions that were not captured in Chapter I. Three main areas that require further investigation are 1) the actual hardware components of the system, 2) the most efficient or effective method of performing aircraft maintenance and 3) the phases, timelines and detailed procedural aspects required to support Agile concepts.

Selecting Components. The hardware required to make an AR-based system of this type is commercially available and many of the components outlined in this document have already been built into systems that exist on the market. Determining the necessary hardware for the system can go in multiple directions: each component can be selected and integrated to develop the system from the ground up, a commercial off-the-shelf (COTS) system with the necessary hardware components can be selected, or a hybrid of a COTS system with additional selected hardware components integrated can be created. The determination of which path to take will involve funding, stakeholder buy-off and end-system capability.

Maintenance Method. The current Air Force Specialty-based method of being trained on and performing maintenance on an aircraft subsystem may not be the most effective method of performing maintenance and it certainly does not support the multi-capable Airman concept. This document describes the concept of transitioning from the Air Force Specialty-based method of maintenance and training to creating a multi-capable Airman whose maintenance and training encapsulates an entire airframe. These methods of performing maintenance are not the only solutions available. Having multi-capable Airmen provides additional options for training and performing maintenance. Additional methods that may be investigated include airframe system/subsystem experts and universal maintainers.

Airframe system/subsystem experts can be described as becoming a flightline expert on a system or subsystem on all airframes in the Air Force arsenal. An example of this may be an engine expert. With the assistance of an AR-based system, a maintainer may be able to work on propeller engines from airframes like a C-130 to the thrust vectored jet engines on F-22s.

The truly multi-capable Airman would follow the concept of a universal maintainer. The universal maintainer would be trained in the use of tools and electronic diagnostic equipment and would not be trained on any specific airframe. The universal maintainer would rely heavily on an AR-based system for instruction to perform any flightline maintenance task and would not be an expert on any system.

The best method for performing maintenance may be one that was described, a hybrid of the maintenance methods described or may be an additional method that was not identified in this thesis. Finding the most efficient and effective method that supports

Air Force agility will likely be the best way forward. An investigation of these methods and the associated implications will need to be examined to determine what the best solution is and answer the question: How many Airmen are needed to support an aircraft under the selected maintenance method in peacetime and in times of war?

Phased Adoption. The phases and timelines provided in CV-2 of this thesis are entirely notional and require further investigation to build realistic plans and timelines that meet stakeholder needs. To develop a realistic phased approach, a few items will need to be examined. First, the hardware of the system and the acquisition approach will need to be determined. This will impact the rate the systems can be produced and/or released to the field. If a COTS system is utilized rather than building a system from the ground up it will drastically effect development, production and fielding timelines. Second, the maintenance method will need to be determined. The phased approach relies on maintenance and training and the selected maintenance method will have an impact in both of these areas. If the airframe-based method is chosen over the universal maintenance method the technical training may be longer due to the focus on creating an airframe expert. This may also affect the procedures displayed on the AR-based system as well as the associated coding and testing procedures.

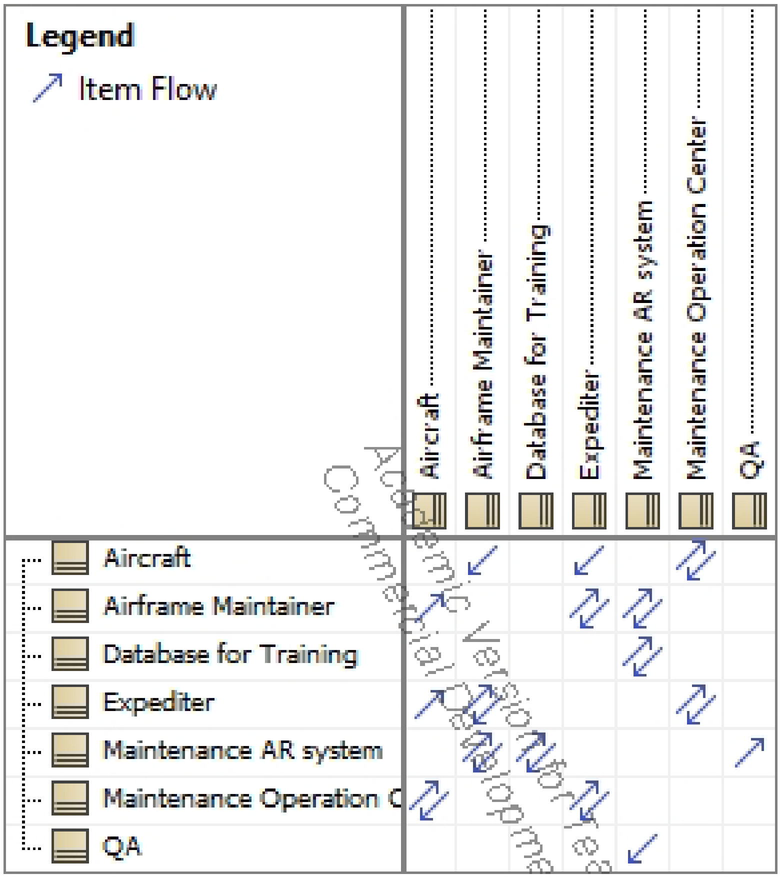
The third step is to determine the steps the Air Force is taking to enable Agile concepts. Determining the areas the Air Force is placing emphasis in may effect funding, development and fielding of an AR-based system. Additionally, it may be worthwhile to investigate how the Air Force plans to support ACE concepts and determine if the timelines defined for developing capability in differing areas align. If the plan is to use Adaptive Basing and have Airmen in place to perform maintenance using parts created

through additive manufacturing, will the infrastructure be in place to support the Airmen and the mission? Do any critical aspects of the ACE concepts or the support infrastructure lead or lag the AR assisted multi-capable Airman deployment timelines? Investigating these areas will aid in developing a roadmap that supports maintenance and training in the near-term and enable the mid or long-term goals of meeting strategic objectives in the Air Force.

Summary

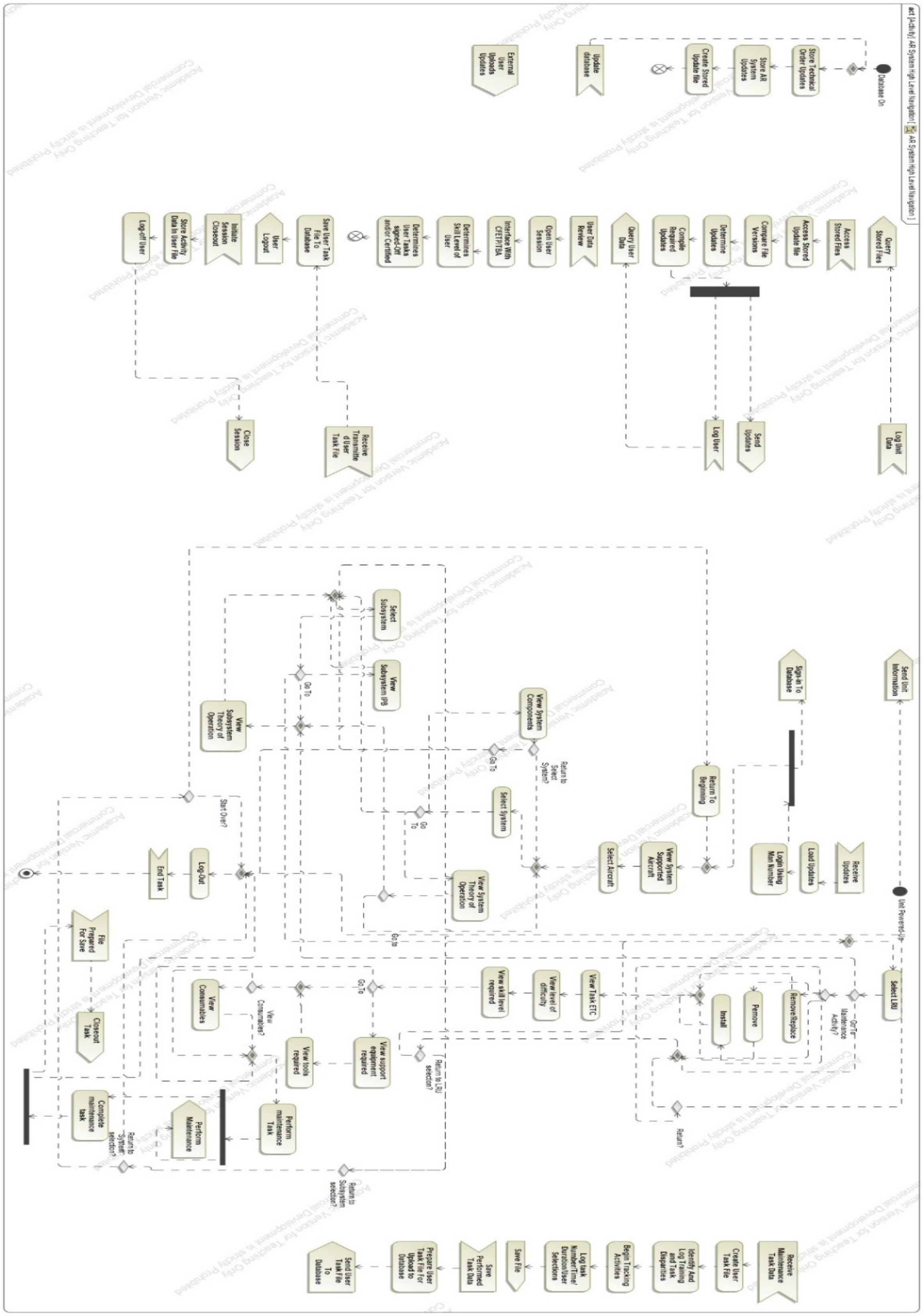
This thesis was created from a need. The AR-based system covered in this document was created using the direction and feedback from aircraft maintainers that have identified processes and procedures within maintenance and the maintenance structure that require modification to better support aircraft repair and mission capability rates. The individuals interviewed had the experience and foresight to assist in requirements development and provided potential use cases for this system. The DoDAF compliant, Object-Oriented Systems Engineering Method approach used to create the reference architecture in this thesis provides a foundation for an AR-based system that has the potential to meet current and future maintainer, mission capability and Air Force needs.

Appendix A: OV-3

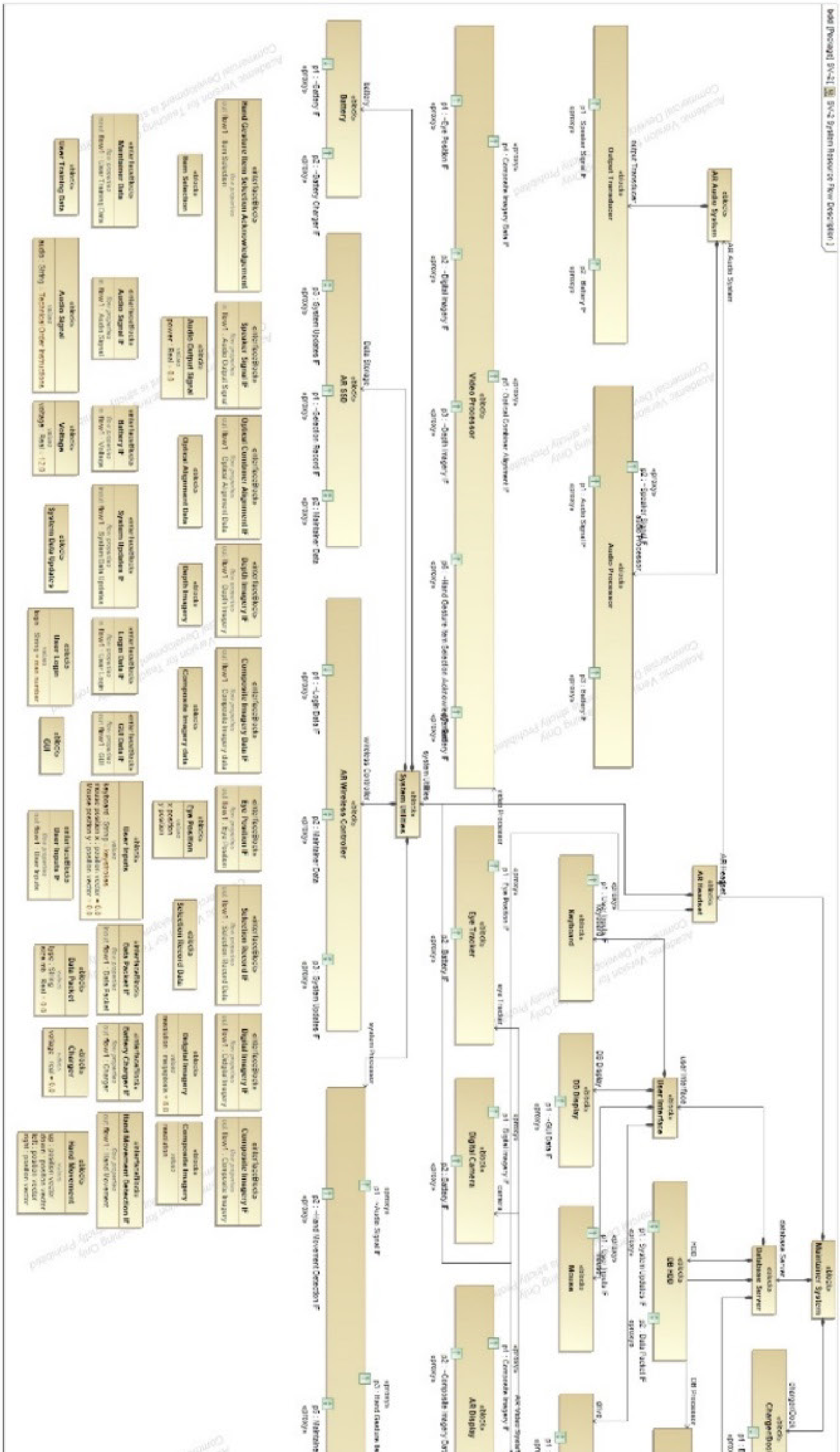


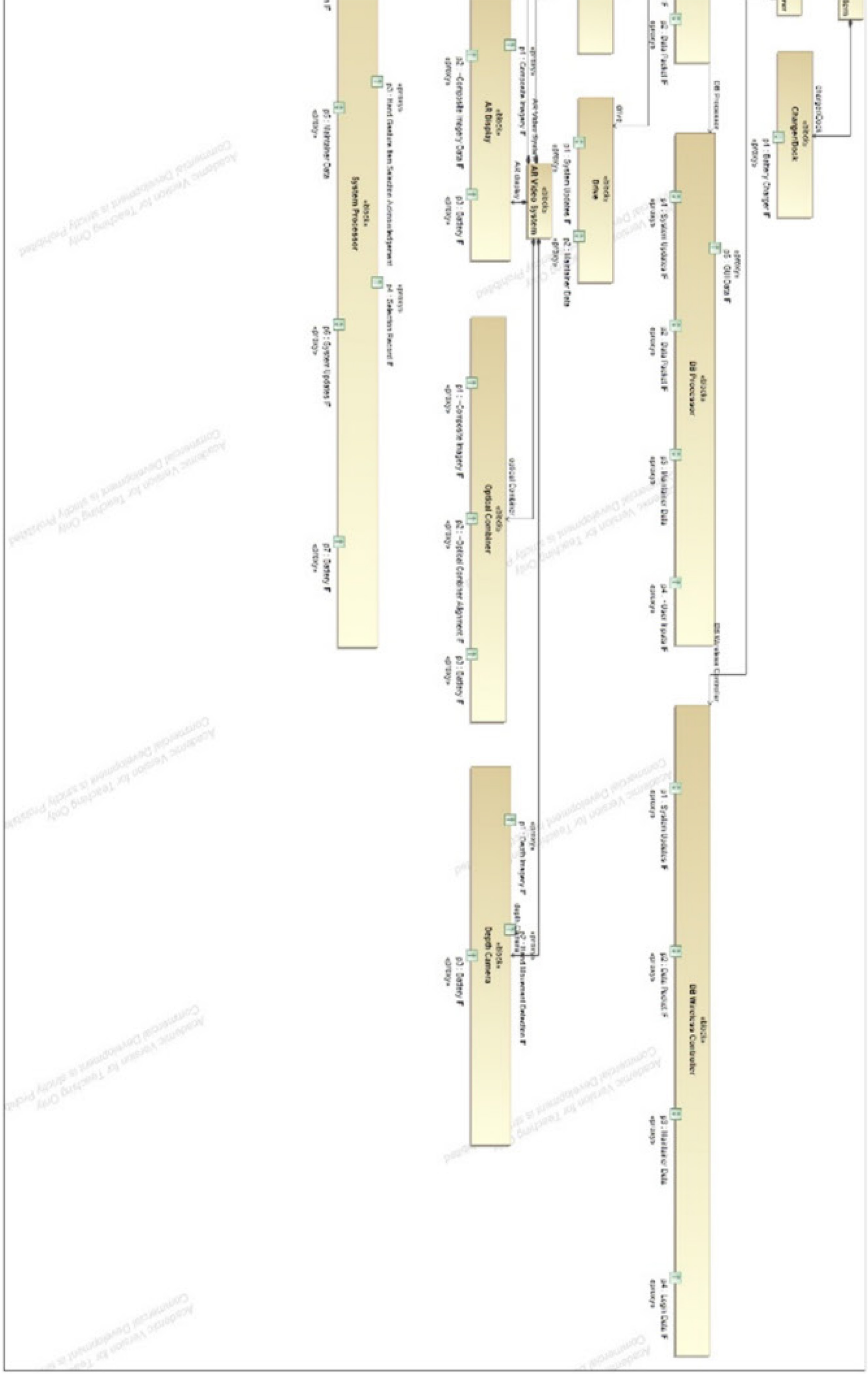
OV-3 is supplemental to OV-2 and shows the Item Flow interfaces in an operational environment. The Item Flows are defined in OV-2.

Appendix B: Maintainer AR System Operational Activity Diagram



Appendix C: System Resource Flow Description





Bibliography

10 US Code 517: Authorized Enlisted End Strength. Members in Pay Grades E-8 and E-9. (2021). Retrieved December 12, 2021, from https//uscode.house.gov

Air Force Doctrine Document 2-4. Combat Support. (2005). Retrieved December 12, 2021, from https://www.globalsecurity.org/military/library/policy/usaf/afdd/2-4/afdd2-4-draft.pdf

Air Force Doctrine Note 1-21. Agile Combat Employment. (2021) Retrieved December 12, 2021, from https://www.doctrine.af.mil/Operational-Level-Doctrine/AFDN-1-21-Agile-Combat-Employment/

Air Force Doctrine Publication 4-0. Combat Support. (2020). Retrieved December 12, 2021, from https://www.doctrine.af.mil/

Air Force Test and Evaluation Guide. (2019, February 8). Retrieved December 12, 2021, from https://www.dau.edu/guidebooks/Shared%20Documents/Air%20Force%20Test%20and%20Evaluation%20Guide%20-%208%20February%202019.epub

Almajid, R., Tucker, C., Keshner, E., Vasudevan, E., & Wright, W. G. (2021). Effects of Wearing a Head-Mounted Display During a Standard Clinical Test of Dynamic Balance. *Gait & Posture*, *85*, 78–83. https://doi.org/10.1016/j.gaitpost.2021.01.020

Amorim, J. A., Matos, C., Cuperschmid, A. R. M., Gustavsson, P. M., & Pozzer, C. T. (2013, December 13). *Augmented Reality and Mixed Reality Technologies: Enhancing Training and Mission Preparation with Simulations*. DIVA. Retrieved

February 8, 2022, from http://www.diva-portal.org/smash/record.jsf?pid=diva2%3A679031

Beginner's Guide to Depth (updated). Intel® RealSense™ Depth and Tracking Cameras. (2020, May 8). Retrieved February 8, 2022, from https://www.intelrealsense.com/beginners-guide-to-depth/

Boyton, K. (2019). [Photograph F-15E Maintenance]. Air Fore Completes Test of Combat Support Innovation. https://www.seymourjohnson.af.mil

Bridges, S. A., Robinson, O. P., Stewart, E. W., Kwon, D., & Mutua, K. (2019). Augmented Reality: Teaching Daily Living Skills To Adults With Intellectual Disabilities. *Journal of Special Education Technology*, *35*(1), 3–14. https://doi.org/10.1177/0162643419836411

Brucato, J. (2014). Enabling Enterprise Optimization Strategies Through Object-Process Methodology. *2014 5th IEEE Conference on Cognitive Infocommunications (CogInfoCom)*. https://doi.org/10.1109/coginfocom.2014.7020410

Cohen, R. (2022). US Air Force Fleet's Mission-Capable Rates Are Stagnating. Here's The Plan To Change That. *Air Force Times.* https://www.airforcetimes.com/

Dickerson, C. E., & Mavris, D. (2013). A Brief History Of Models And Model Based Systems Engineering And The Case For Relational Orientation. *IEEE Systems Journal*, *7*(4), 581–592. https://doi.org/10.1109/jsyst.2013.2253034

Dickson, B. (2018, June 11). *How Eye Tracking Will Enhance The AR And VR Experience*. TechTalks. Retrieved February 8, 2022, from https://bdtechtalks.com/2018/06/11/ar-vr-eye-tracking-foveated-rendering/

Dobbins, J., Shatz, H. J., & Wyne, A. (2019, January 28). *Russia Is A Rogue, Not A Peer; China Is A Peer, Not A Rogue*. RAND Corporation. Retrieved December 12, 2021, from https://www.rand.org/pubs/perspectives/PE310.html

DoDAF Viewpoints and Models. (n.d.). Retrieved November 19, 2021, from https://dodcio.defense.gov/Library/DoD-Architecture-Framework/dodaf20_viewpoints/

Friedenthal, S., Moore, A., & Steiner, R. (2015). *A Practical Guide to SysML: The Systems Modeling Language*. Morgan Kaufmann Object Management Group/Elsevier.

Goldstein, P. (2021, July 29). *Air Force Turns To VR, AR For Training And Maintenance*. Technology Solutions That Drive Government. Retrieved February 8, 2022, from https://fedtechmagazine.com/article/2020/04/air-force-turns-vr-ar-training-and-maintenance

Hagman, J. D., & Katz, M. S. (1980, April 30). *Effects Of Training Task Repetition On Retention And Transfer Of Maintenance Skill.* ERIC. Retrieved December 12, 2021, from https://eric.ed.gov/?id=ED203201

Hedili, M. K., Soner, B., Ulusoy, E., & Urey, H. (2019). Light-Efficient Augmented Reality Display With Steerable Eyebox. *Optics Express*, *27*(9), 12572. https://doi.org/10.1364/oe.27.012572

Heginbotham, E., Nixon, M., Morgan, F. E., Heim, J. L., Hagen, J., Li, S. T., Engstrom, J., Libicki, M. C., DeLuca, P., Shlapak, D. A., Frelinger, D. R., Laird, B., Brady, K., & Morris, L. J. (2015, September 14). *China's Military Modernization Increasingly Challenges U.S. Defense Capabilities In Asia*. RAND Corporation.

Retrieved December 13, 2021, from https://www.rand.org/pubs/research_reports/RR392.html

Hololens 2-Overview, Features, And Specs: Microsoft Hololens. -Overview, Features, and Specs | Microsoft HoloLens. (2021, February 11). Retrieved February 8, 2022, from https://www.microsoft.com/en-US/hololens/hardware

Hong, J.-Y., Lee, C.-K., Lee, S., Lee, B., Yoo, D., Jang, C., Kim, J., Jeong, J., & Lee, B. (2017). See-Through Optical Combiner For Augmented Reality Head-Mounted Display: Index-Matched Anisotropic Crystal Lens. *Scientific Reports*, *7*(1). https://doi.org/10.1038/s41598-017-03117-w

Jeong, J., Lee, J., Yoo, C., Moon, S., Lee, B., & Lee, B. (2019). Holographically Customized Optical Combiner For Eye-Box Extended Near-Eye Display. *Optics Express*, *27*(26), 38006. https://doi.org/10.1364/oe.382190

Knight, J. F., & Baber, C. (2005, December 5). *Assessing The Physical Loading Of Wearable Computers*. Retrieved January 5, 2021, from https://www.researchgate.net/publication/7002550_Assessing_the_physical_loading_of_wearable_computers

Korff, A., Weilkiens, T., & Lamm, J. G. (2020, October 19). *Tools for Forging the Functional Architecture*. Functional Architectures for Systems. Retrieved December 12, 2021, from http://fas-method.org/content/publications/

Kress, B. C., & Chatterjee, I. (2021). Waveguide Combiners for Mixed Reality Headsets: A Nanophotonics Design Perspective. *Frontiers in Optics and Photonics*, 41–74. https://doi.org/10.1515/9783110710687-004

Lamm, J. G., & Weilkiens, T. (2013). Method for deriving functional architectures from use cases. *Systems Engineering*, *17*(2), 225–236. https://doi.org/10.1002/sys.21265

Manacapilli, T., Bailey, A., Beighley, C., Bennett, B. E., & Bower, A. (2007, March 26). *Finding The Balance Between Schoolhouse And On-The-Job Training*. RAND Corporation. Retrieved December 12, 2022, from https://www.rand.org/pubs/monographs/MG555.html

MIL-PRF-32383, Performance Specification: Batteries, Rechargeable, Sealed, General Specification For (16 Jun 2011). EverySpec Standards. (n.d.). Retrieved February 15, 2022, from http://everyspec.com/MIL-PRF/MIL-PRF-030000-79999/MIL-PRF-32383_35531/

MIL-PRF-32432A, Performance Specification: Military Combat Eye Protection (MCEP) System (11-sep-2018). EverySpec Standards. (n.d.). Retrieved February 15, 2022, from http://everyspec.com/MIL-PRF/MIL-PRF-030000-79999/MIL-PRF-32432A_55832/

MIL-STD-1472H, Department of Defense Design Criteria Standard: Human Engineering (15-sep-2020). EverySpec Standards. (n.d.). Retrieved February 15, 2022, from http://everyspec.com/MIL-STD/MIL-STD-1400-1499/MIL-STD-1472H_57041/

Mills, P., Drew, J. G., Ausink, J. A., Romano, D. M., & Costello, R. (2014, June 26). *Balancing Agile Combat Support Manpower To Better Meet The Future Security Environment*. RAND Corporation. Retrieved August 15, 2021, from https://www.rand.org/pubs/research_reports/RR337.html

Mills, P., Leftwich, J. A., Drew, J. G., Felten, D. P., Girardini, J., Godges, J. P., Lostumbo, M. J., Narayanan, A., Van Abel, K., Welburn, J. W., & Wirth, A. J. (2020, April 16). *Building Agile Combat Support Competencies To Enable Evolving Adaptive Basing Concepts*. RAND Corporation. Retrieved August 15, 2021, from https://www.rand.org/pubs/research_reports/RR4200.html

Mori, S., Chase, M. S., & Iida, M. (2019, October 10). *Bolstering The Alliance Amid China's Military Resurgence*. Carnegie Endowment for International Peace. Retrieved August 15, 2021, from https://carnegieendowment.org/2019/10/10/bolstering-alliance-amid-china-s-military-resurgence-pub-80020

Phillips, H., Taylor, T., & Vincent, R. (2020). *Fighting Today's Peer/Near-Peer Fight With Today's Technology*. DTIC. Retrieved December 12, 2021, from https://apps.dtic.mil/sti/citations/AD1108171

[Photograph of AR assisted mechanic work]. (2020). MR, VR, and AR in Manufacturing and Logistics: an Ultimate Way to Increase Productivity. https://cdc.gov

[Photograph of server room]. (n.d.). https://evernex.com

[Photograph of soldier with AR headset]. (2021). https://army.mil

Prasannakumar, S. (2018). Improving Working Memory in Science Learning Through Effective Multisensory Integration Approach. *International Journal of Mind, Brain & Cognition*, *9*(1-2).

Redden, E. S. (2015). Environmental Conditions and Physical Stressors. In G. B. Larkin (Ed.), *APA Handbook of Human Systems Integration* (pp. 193–209). essay, American Psychology Association.

Reference Architecture Description - U.S. Department Of Defense (2010, June). Retrieved December 12, 2021, from https://dodcio.defense.gov/Portals/0/Documents/Ref_Archi_Description_Final_v1_18Jun10.pdf

Streaming an AR Experience. Apple Developer. (2022) Retrieved March 6, 2022, from https://developer.apple.com/documentation/arkit/streaming_an_ar_experience

Summary of the 2018 National Defense Strategy. https://dod.defense.gov/Portals/1/Documents/pubs/2018-National-Defense-Strategy-Summary.pdf. (2018). Retrieved August 10, 2021, from https://dod.defense.gov/Portals/1/Documents/pubs/2018-National-Defense-Strategy-Summary.pdf

Systems Engineering Vision 2020. (2007). Retrieved August 10, 2021, from http://www.ccose.org/media/upload/SEVision2020_20071003_v2_03.pdf

Teng-teng Zhang. (2012). Architecture Analysis and Design Language & Harmony System Engineering Process. *2012 IEEE/AIAA 31st Digital Avionics Systems Conference (DASC)*. https://doi.org/10.1109/dasc.2012.6383102

Thomas, B. E., & Brian E. (2021, June 3). *The Parts of an Augmented Reality System*. Coruzant Technologies. Retrieved February 8, 2022, from https://coruzant.com/virtual-reality/the-parts-of-an-augmented-reality-system/

Vergun, D. (n.d.). *Near-Peer Threats At Highest Point Since Cold War, DOD Official Says*. U.S. Department of Defense. Retrieved December 13, 2021, from https://www.defense.gov/News/News-Stories/Article/Article/2107397/near-peer-threats-at-highest-point-since-cold-war-dod-official-says/

Wagner, D. (2018, April 25). *Depth Cameras for Mobile AR: From IPHONES to Wearables and Beyond*. Medium. Retrieved February 8, 2021, from https://medium.com/@DAQRI/depth-cameras-for-mobile-ar-from-iphones-to-wearables-and-beyond-ea29758ec280

Walden, D. D., Roedler, G. J., Forsberg, K., Hamelin, R. D., & Shortell, T. M. (2015). *Systems Engineering Handbook: A Guide for System Life Cycle Processes and Activities*. Wiley.

Zhang, L., & Matsumaru, T. (2016). Near-Field Touch Interface Using Time-Of-Flight Camera. *Journal of Robotics and Mechatronics*, *28*(5), 759–775. https://doi.org/10.20965/jrm.2016.p0759

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14. ABSTRACT

The current method of preparing Airman to perform tasks in their designated Air Force Specialty is to provide coursework-based initial skills training and on-the job training (OJT) for that specialty. Full qualification for a single Air Force Specialty is estimated to average seven years with OJT consisting of seventy-five percent of that timeline. OJT primarily consists of mastering the use of the Technical Order (TO), a governing document that provides step-by-step task instruction that must be followed explicitly. Though TOs have transitioned to an electronic format, employment of the information has remained the same. A proven aid in instruction and task accomplishment is Augmented Reality (AR). A transition to an AR supported TO system has the potential to aid in training and performance in operational environments by providing multisensory support to Airmen. An AR platform may also expand the scope of Airmen beyond a single Air Force Specialty, providing capability that directly supports Agile Combat Employment concepts. This thesis presents a Model-Based Systems Engineering designed reference architecture for an AR maintenance support system. To provide a relevant example, the system architecture focuses on flightline aircraft maintenance training and operations.

15. SUBJECT TERMS

Augmented Reality, Maintenance Support, Adaptive Basing, Multi-Capable Airmen, Aircraft Maintenance, Maintenance Training

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