Toward Next Generation Aerial Refueling Airplane Simulator Qualification

Michael Millington, Zack Kirkendoll, Brandon McCullough, Brian Morris, James Cook
CymSTAR, LLC
Tulsa, OK
michael.millington@cymstar.com, zack.kirkendoll@cymstar.com, brandon.mccullough@cymstar.com, brian.morris@cymstar.com, james.cook@cymstar.com

ABSTRACT

The current standard for aerial refueling simulator qualification is the Air Mobility Command (AMC) document "Aerial Refueling Airplane Simulator Qualification, Revision C" (ARASQ), dated 1 September 2009, initially modeled after the now outdated Federal Aviation Administration (FAA) advisory circular AC 120-40B, which has since been supplanted by FAA 14 Code of Federal Regulations (CFR) Part 60 (2016). Since the last revision 14 years ago, there have been significant changes to aircraft and simulation technology, training methodologies, and manufacturer data rights.

Modeling and simulation of aerial refueling is complex and requires objective criteria to validate the solution at a sufficient level to significantly reduce aircraft flying requirements through the qualification of simulators. There are significant nuances for technical qualification requirements between receiver and tanker (levels C and D) and boom operator (levels 1 and 2) simulators. The current ARASQ standard is insufficient for modern aircraft capabilities (KC-46A, KC-Y/Z), modern simulation and qualification methodologies, and next generation cost-effective lightweight lower-level training devices using technically mature commercialized technologies. Without next generation ARASQ, lightweight on-demand lower-level training devices cannot be leveraged for aerial refueling qualification or currency training as their simulation cannot be certified to prove there is no negative training.

This paper addresses next generation ARASQ innovative scientific research and analytical efforts to change the future of training warfighters. This paper will include discussing the qualification tests and tolerances for next generation technologies, such as non-traditional visual systems and other emergent technologies, including eXtended reality and haptics. This paper will discuss a pathway to expand qualification levels for lower-level training devices and the prerequisite trainer requirements and capability for distributed training participation and interoperability. Finally, alternative data sources (e.g., computational fluid dynamics) and their applicability will be addressed.

ABOUT THE AUTHORS

Michael Millington is a senior engineering architect at CymSTAR, LLC. Michael has been in the simulation industry for nearly 30 years in both military and commercial simulation, with a special emphasis on aerial refueling.

Zack Kirkendoll is an engineering architect at CymSTAR, LLC. Zack has been in the simulation industry for nearly 10 years, attaining broad experience in real-time aircraft simulation and training. Zack's current role is the C-5 Aircrew Training System (ATS) Program Engineer.

Brandon McCullough is the director of engineering at CymSTAR, LLC. Brandon has been in the simulation industry for over 20 years. Prior to his current position, Brandon was an expert in the aerial refueling simulation regime.

Brian Morris is a principal aerospace engineer at CymSTAR, LLC. Brian has been in the simulation industry for over 10 years and has integrated new and updated aerial refueling simulations into several training devices.

James Cook, Ph.D. is a principal aerospace engineer at CymSTAR, LLC. James has been in the simulation industry for over 10 years with an emphasis on Distributed Missions Operations (DMO). Prior to his current position, James conducted graduate research focused on rotorcraft, using computational fluid dynamics (CFD).

Toward Next Generation Aerial Refueling Airplane Simulator Qualification

Michael Millington, Zack Kirkendoll, Brandon McCullough, Brian Morris, James Cook
CymSTAR, LLC
Tulsa, OK
michael.millington@cymstar.com, zack.kirkendoll@cymstar.com, brandon.mccullough@cymstar.com, brian.morris@cymstar.com, james.cook@cymstar.com

INTRODUCTION

The Aerial Refueling Airplane Simulator Qualification (ARASQ) standard was created by Air Mobility Command (AMC) with SimTec & Kohlman Systems Research (KSR) in 1997 to objectively qualify simulators for the aerial refueling (AR) training task. The initial standard was templated from the FAA standard at the time, which was Advisory Circular (AC) 120-40B. **ARASQ allows for training credit to be earned in the simulator rather than the airplane, resulting in cost savings, increasing the number of AR qualified aircrews, and reducing flying hours and the load on the planes**. Since ARASQ's release, the FAA and EASA have released major revisions to their collective standards, while there have been just three (3) revisions to ARASQ, with the last being in 2009. There have been significant changes to aircraft and simulation technology, training methodologies, and manufacturer data rights in the intervening 14 years since that release. This paper will examine those changes and provide guidance on how ARASQ should be modernized for these changes.

Because the future of refueling tankers is still evolving, ARASQ must be a standard that can support the future requirements of the tanking community, which includes the future KC-Y and KC-Z/Next Generation Air-refueling System (NGAS). Current tankers and a potential KC-Y are now a known technological quantity, while the NGAS will be a drastically different tanking platform. One potential technology change is for an automated boom operator, known as Air to Air Autonomous Refueling (A3R). This new technology uses aerial refueling cameras and image processing algorithms to create shape models around receiver aircraft for identification and making AR contact. Additionally, the KC-46A platform introduced technologies that ARASQ does not fully account for, such as a unique fly-by-wire control system and a 3D camera system.

In addition to new aircraft technologies, there have been advances in simulation technologies, as well as new training methodologies. One of the most applicable technologies is eXtended Reality (XR) and its representative forms, including virtual reality, augmented reality, and mixed reality. This technology is fundamentally changing how operators approach training and has the potential for the creation of smaller, task specific trainers at a low cost. These purpose-built devices provide scalable, extensible, and immersive simulation environments accelerating the pace of training. Additional technological advancements include visual systems, haptics, and gamification of the training environment.

For XR to be qualified for aerial refueling, ARASQ must be updated to include qualification requirements for lower-level devices (LLDs). Currently, ARASQ only has two levels of qualification for both a full flight simulator (FFS) and a boom operator trainer. The lack of multiple qualification levels limits the overall training program's flexibility. Both the FAA and EASA have seven (7) levels of qualification, which range from desktop trainers, flight training devices (FTD), and full motion simulators. A multi-level qualification concept incorporated into ARASQ would enable training (and credit) on multiple levels of devices, thus minimizing time on the aircraft and FFS, resulting in significantly reduced resource need and cost throughout the training program. For example, the approximate total cost for one C-5 aircraft AR training event (receiver and tanker) is $2.9M and to procure a new traditional FFS costs upwards of $40M, while the total cost of an ARASQ-certifiable LLD capable of AR qualification and currency training is estimated to cost less than $500K. The lower initial procurement and utilization costs of LLDs enable high scalability and portability to allow training at the point of need, including a small footprint and low resource requirement.

The future of tanking is already being deployed and ARASQ should be refreshed to meet this new world. As the Air Force continues to evolve their tanker needs for the future, the Department of Defense needs a qualification standard that can evolve with them. A paradigm shift for aerial refueling training is rapidly approaching and the next generation of ARASQ is required to successfully meet these training objectives.

BACKGROUND AND RELATED WORK

The Original release and Revision (Rev.) A of ARASQ contained an inordinate amount of validation test points, between 200 for a tanker and receiver qualification and 350 for a boom operator training device. The Government soon realized that the amount of qualification testing was not aligned with other simulation qualification standards, which resulted in a revision to Rev. B. This release reduced the number of test points significantly, down to 100 tests for the tanker and receiver and under 100 for the boom operator training device. Rev. C's release included a restructuring of the document to divide tanker, receiver, and boom operator testing into separate chapters and a technical refresh to address missing test points and clarify existing ones. Along with the release of Rev. C, a new ARASQ companion document was released titled "Aerial Refueling Data Collection and Modeling Standard (ARDCMS)". This document details the flight test data collection and modeling requirements for proper AR modeling, provides flight test procedures, defines data parameters and minimum frame rates to be captured during flight test, and discusses best modeling practices.

The ARASQ standard is comprised of 5 primary chapters:

1. Qualification Guidance
2. Free Air Simulator Qualification Requirements
3. Receiver Simulator Qualification Requirements
4. Tanker Simulator Qualification Requirements
5. Boom Operator Simulator Qualification Requirements

Each chapter describes the requirements, both objective and subjective, for each qualification type. The free-air chapter is unique and only applicable if the simulator seeking ARASQ qualification is not currently qualified to another acceptable free-air standard, such as FAA 14 CFR Part 60 or EASA CS.FSTD(A). The free-air chapter only applies to tanker and receiver ARASQ qualifications, and not boom operator qualifications. Receiver and tanker qualifications are covered in Chapters 3 and 4, where the simulator standards, objective validation tests, and the functions and subjective tests are all detailed. For example, approximately 90 objective tests are required for receiver qualification. Example types of objective tests for receiver qualification include closures from Pre-Contact to Contact, boom limit sweeps, and breakaways. Chapter 5 focuses on the boom operator, rather than the aircraft pilots, and applies to boom training devices only. Example types of objective tests for boom qualification include boom sweeps, connects and disconnects, and closures to and from Contact. Figure 1 highlights the positions of interest for air refueling, which include Contact and Pre-Contact (Astern). The intent of qualification using ARASQ is to verify that refueling positions of interest have been modeled, tested, and validated in multiple conditions.

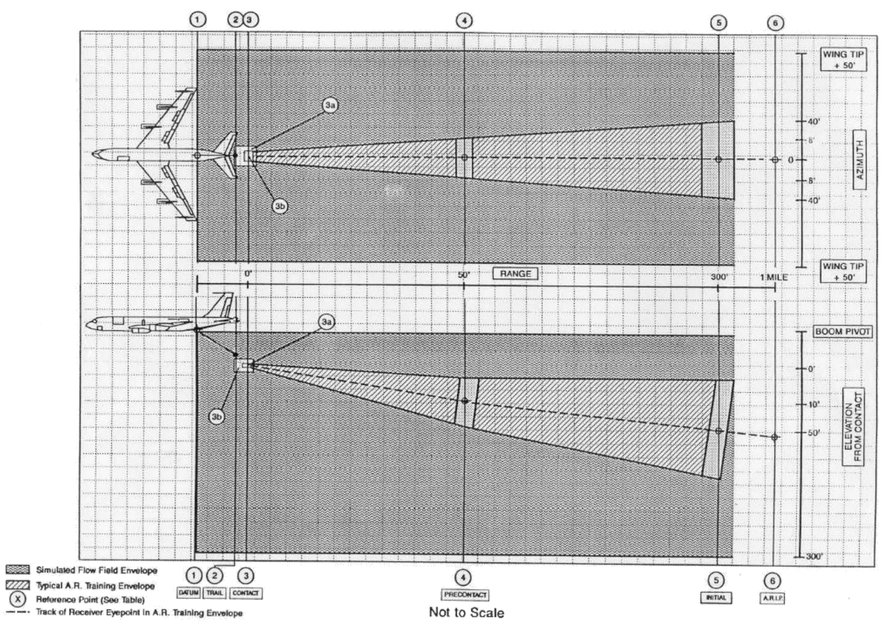

Figure 1: Air Refueling Positions of Interest.

The authors have contributed to the updates of ARASQ since Revision A. Mr. Millington and Mr. McCullough both helped to refine the validation testing objectives of ARASQ and improved overall requirement wording in their respective roles at Thales Training and Simulation, Inc. and Kohlman Systems Research from 1999 to Revision B release in 2001. As the standard became utilized by additional training platforms in the 2000s, CymSTAR was subcontracted to update the standard again to incorporate user community feedback, improve testing methodologies and validation test tolerances, and restructure the document into chapters to make tanker, receiver, and boom trainer requirements more distinct.

STANDARDIZATION UPDATES

General Updates

ARASQ will benefit from general updates to bring it in alignment with other regulatory standards of today, specifically FAA 14 CFR Part 60 and EASA CS FSTD(A).300. This alignment will focus on the look and feel of the document along with the contents of the subjective and objective requirements. Other items to be addressed include creating a consistent usage of terminology (such as Astern vs. Pre-Contact), updates for future tankers, a compliance matrix requirement, and guidance for auto-tolerancing (in accordance with ARINC 436).

Specific Updates

The authors have compiled a list of recommended changes, most of which are corrections to small errors or inconsistencies within ARASQ. These changes include test numbering consistency (e.g., 5.1 vs. 5.a), inclusion of drogue refueling, additional guidance on weight configurations, clarification on the test driver guidance section (1.4.11) and requirements for relative position validation.

NEW TECHNOLOGIES

Since 2009 and the release of Rev. C, there have been significant changes to aircraft and simulation technologies. This section will review applicable new technologies and in the SUBSYSTEMS section provide information on how they could be incorporated successfully into ARASQ.

Advanced Fly-by-Wire Flight Control Systems

The KC-46A incorporates a fly-by-wire control system for the boom controls, known as BCLAWS (Boom Control Laws). BCLAWS does not use traditional fixed flight control rigging, but rather self-calibrates upon startup, which creates a non-deterministic system between control input and surface output. For example, based on the forces acting upon the boom at startup, a zero-deflection control input could result in variable, non-zero boom rudder surface outputs. Flight test data has shown offsets of up to 2 degrees. Given the closed loop nature of BCLAWS, this offset is somewhat irrelevant as BCLAWS will deflect the boom rudders to the deflection needed to maintain the prescribed boom roll attitude. ARASQ assumes a traditional flight control system for the boom (a deterministic relationship between control input and surface output), which does not accommodate for non-traditional solutions with regards to the flight control surface tolerances. The KC-46A boom control system also utilizes multiple gimbals within the control stick, which makes it challenging to determine the exact forces that are required for a given control stick input.

While the KC-Z/NGAS tanker is still many years away, all indications show it is will be a very different aircraft from the current widebody tanker fleet. Current concepts show an advanced blended wing body design that is increasingly stealthy and capable of avoiding threats in a potential combat zone. Given these design concepts, the NGAS will almost certainly be an advanced computer-controlled aircraft that uses a non-traditional flight control system, like a B-2 aircraft.

Non-traditional Visual Systems

The KC-46A uses a remote aerial refueling station incorporating cameras and 3D technology for visual rendering, known as the Remote Vision System (RVS), rather than a direct line of sight to refueling aircraft utilized by previous tankers. ARASQ visual requirements do not currently account for such a system, as the standard was written to address technologies that existed at the time, such as traditional collimated visual systems that simulate a direct line of sight. The Airbus A330 Multi-Role Tanker Transport (MRTT) also uses a similar visual system for the Air Refueling Operator (ARO) station.

Simulation and training system adoption of non-traditional visual systems include XR and Head Mounted Displays (HMDs). These headsets are used in various configurations, adjusting the amount of virtual space and augmented reality content, based on the training task and device qualification level sought. This approach allows for a more immersive training experience with a significantly reduced hardware footprint.

Automation

Both the KC-46A and MRTT are currently testing automated boom operator tasks using a system termed automatic air-to-air refueling (A3R). The MRTT has this system approved for daylight operations. While the system is automated, the boom operator can retake control of the system if needed. This system will fundamentally change a boom operator's tasking, and ARASQ will need to provide guidance on how to address this scenario. Additionally, the usage of automated drone aircraft for aerial refueling missions is quickly approaching, and the impacts of this would need to be studied and result in ARASQ adaptation.

Computational Fluid Dynamics (CFD)

CFD is not necessarily a new technology, but recent advances in computational power and programming have made it possible to execute CFD modeling in real-time within a simulator. CFD will be discussed as a possible alternative data source in the ALTERNATIVE DATA SOURCES section.

Haptics

While qualification standards exist for full motion systems and actual aircraft cockpit hardware, the continued integration of LLDs and XR has resulted in technological advancement for various haptic systems. For example, an LLD with a minimal footprint could utilize a dynamic seat or "buttkicker" system to provide movement cues without a full motion base. XR setups that utilize physical interfaces for switches and knobs also have options for haptic feedback, increasing the realism of the simulation.

Gamification

Gaming experience has become increasingly commonplace, especially among the younger generation of pilots and operators who grew up in the digital age learning differently than the methods employed by traditional training systems. Gamification, which is the application of game playing elements, such as integrated rule descriptions, virtual instruction, or automated objective grading, increases user knowledge retention and recall. Gamification has been shown to increase learning motivation and engagement resulting in improved instruction and training options (Zainuddin, 2020). These approaches provide an efficient, effective, and low-cost option as part of a holistic training ecosystem. This is particularly useful for LLDs, which could provide self-paced, on-demand instruction while still utilizing a structured lesson plan and grading system.

New and Future Technology Adoption

To account for the above technologies and future technologies, ARASQ will need to provide an additional section for adopting new technologies that outpace the regulations. This new section will need to contain guidance on how the new technology can be used on training devices and how the technology will be accepted. The Trainer Device Manufacture (TDM) can submit its recommendations on the type of tests and tolerances that would be required for qualification. The certifying authority and the TDM would need concurrence on this acceptance plan. The key is for ARASQ to be adaptable for future technologies.

For example, if a TDM today wants to use a new technology (e.g., XR) that ARASQ does not currently consider, there is no official recourse. The intent of this new section in ARASQ is to allow the TDM to propose a certification plan for the new technology within the ARASQ framework.

LOWER-LEVEL DEVICES (LLDs)

A training and simulation technological advancement gaining momentum in the commercial simulator realm is the usage of less expensive, more efficient LLDs to accelerate the pace of training. The operating costs and utilization rates of full motion simulators continue to escalate, so low cost, scalable, task-specific training options have become a much larger component to a holistic training program. However, ARASQ does not currently have provisions for any LLDs, and only lists two levels of qualification for each AR training device type; therefore, ARASQ will need to be updated for the usage of LLDs.

Other fixed-wing regulatory documents outline more devices and qualification levels. For example, the FAA has four (4) levels of FFS qualification, while Flight Training Devices (FTD) have four (4) further levels of qualification (Levels 4 thru 7). EASA similarly describes four (4) levels of FFS, two (2) levels of FTD, three (3) levels of Flight and Navigation Procedures Trainers (FNPT), and one level for Basic Instrument Training Devices (BITD), for a total of ten distinct levels.

When ARASQ was written, the concept of using an LLD for aerial refueling was not feasible given the technology constraints at the time. Even by 2009 when ARASQ was last revised, LLDs were not as widely used or accepted, due to offering a much-reduced scope of functionality.

EASA has recently released guidance for the incorporation of XR technology in some LLDs (EASA, 2023). One of the devices seeking this EASA approval was an FNPT for a Robinson R22 helicopter produced by Loft Dynamics (Loft Dynamics, 2023). This device features a small motion base along with an HMD. This new guidance from EASA will assist in updating ARASQ for the qualification of technologically advanced LLDs. This could include a similar type of device (small motion base with an HMD), aimed specifically at aerial refueling training for the tanker, receiver, or boom operator perspective. Recommendations for haptic adoption will need to be included in an update to ARASQ.

While the misalignment between the two primary simulator authorities for LLD qualifications presents a challenge, we recommend the EASA model as the best fit for ARASQ. The EASA format presents cleaner, more distinguishable lines of demarcation in the various training device types and how they can be qualified for training. For example, the EASA model offers four (4) unique device types that can be integrated into a full training suite of devices, rather than a training program dependent upon one training device, such as an FFS. The recommendation for ARASQ is to include FFS Levels C and D, FTD Levels 1 and 2, FNPT Levels I and II, and a single BITD level. With the ability to qualify multiple levels of training devices, from a basic trainer to an FFS, training programs can provide more efficient and effective training while remaining cost effective. The usage of LLDs enables the opportunity to create a synergy of training devices. For example, if a full flight simulator is ARASQ certified, its software codebase can be used on the LLDs to create a standardized suite of training devices.

SUBSYSTEMS

The major subsystems of a simulator are distinctly addressed by ARASQ. As previously noted, ARASQ was derived from previous revisions of the FAA's simulator standard, so many of the validation tests and tolerances need to be refreshed to align with current revisions of FAA and EASA standards. ARASQ qualification for a tanker or receiver is typically in addition to another free air qualification, such as 14 CFR Part 60. In this case, most of the subsystem test requirements are satisfied by the free air qualification and thus should not be required to be duplicated in ARASQ. If the device is NOT qualified in free air to an accepted standard, then the simulator must also satisfy the requirements of the Free Air chapter (Chapter 2) of ARASQ. Boom operator trainers do not have such a free-air requirement and therefore the objective test requirements do contain subsystem requirements.

Visual Requirements

Table 1 lists the existing visual requirements of ARASQ that should be updated for conformity with other regulations.

Table 1: Visual Requirements.

Chapter	Table	Table Subsection	Description	Change
2	2-1	3	Visual	Conform with FAA requirements
2	2-1	4.a	Transport Delay	Conform with FAA requirements
3	3-1	3	Visual	Conform with FAA requirements Make 3.h individual requirements
4	4-1	3	Visual	Conform with FAA requirements Make 3.h individual requirements
5	5-1	3	Visual	Conform with FAA requirements Make 3.h individual requirements
5	5-1	4.a	Transport Delay	Conform with FAA requirements

The recommended changes address the staleness of the visual requirements as they pertain to traditional visual systems. For example, the visual requirements listed in subsection 3 of Table 2-1 of ARASQ list five (5) basic tests, whereas the new requirements from the FAA require a minimum of 14 tests. While all 14 tests are not related to AR, such as the visual ground segment, the relevant tests will need to be incorporated. Additionally, both FAA and EASA regulatory documents provide advanced guidance on transport delay testing that needs to be added to ARASQ. This change provides clarity for computer-controlled aircraft (CCA) using aircraft black boxes, CCA using emulated black boxes, and aircraft using software or rehosted avionics.

The recently issued EASA information paper titled "FSTD Special Conditions for the use of Head Mounted Displays (HMD) combined with a motion platform with reduced envelope" (EASA, 2023) provides initial guidance on the use of headsets and XR with a small motion system. One area of note in this information paper is the HMD visual display density requirements, which will relate to the ability to sufficiently visualize the AR entity models.

The updated ARASQ sections for LLDs will need to include guidance for traditional and non-traditional visual systems. The XR/HMD visual system guidance is recommended to follow the technical requirements provided by EASA. For example, the field of view and geometry requirements are updated, and six (6) new tests are required for the visual systems utilizing XR. Similarly, additional non-traditional guidance will need to be provided for flatscreen and curved displays using 3D glasses.

Motion Requirements

Table 2 lists the existing motion requirements of ARASQ that should be updated for conformity with other regulations and with additional clarity.

Table 2: Motion Requirements.

Chapter	Table	Table Subsection	Description	Change
2	2-1	2	Motion	Conform with FAA requirements
2	2-1	4.a	Transport Delay	Conform with FAA requirements
3	3-1	2	Motion	Conform with FAA requirements
3	3-6	4.a	Buffets	Add clarity on test conditions
4	4-1	2	Motion	Conform with FAA requirements
4	4-6	5.a	Buffets	Add clarity on test conditions
5	5-1	2	Motion	Conform with FAA requirements
5	5-5	2.a, 2.b, 2.c	Motion	Conform with FAA requirements
5	5-5	2.d	Motion	Add clarity on test conditions
5	5-5	4.a	Transport Delay	Conform with FAA requirements

The recommended changes address the staleness of the motion requirements. For example, the Leg Balance test is no longer required by the FAA and has been replaced by a repeatability test. The lack of specifics regarding the characteristic buffet conditions will also need to be addressed. For example, Table 3-6, Test 4.a states the flight condition as "Air Refueling" and that the "Test should be performed at optimum AR airspeed and altitude".

The motion requirements will need to be expanded to address LLDs, smaller motion bases, and haptics. The recent guidance issued by EASA noted above (EASA, 2023) provides a reference point for the update.

Controls Requirements

Table 3 lists the existing controls requirements of ARASQ that should be updated for conformity with other regulations and for CCA controls.

Table 3: Controls Requirements.

Chapter	Table/Section	Table Subsection	Description	Change
2	Table 2-1	1.a, 1.b	Controls Tests	Conform with FAA requirements
2	Section 2.2.3	N/A	Control Dynamics	Conform with FAA requirements
5	Table 5-5	1.a	Control Characteristics	Update for CCA controls

The recommended changes above detail the most recent changes to 14 CFR Part 60 (2016). The FAA updated the tolerance and guidance for evaluating the dynamic control checks, such as adding an "or 0.05s" to the tolerance for $T(P_x)$.

As noted in the NEW TECHNOLOGIES section, the KC-46A BCLAWS presented a challenge for ARASQ as the controls function in ways ARASQ did not anticipate. Therefore, the controls evaluation section for boom qualification will need to be updated to test this system, as well as future similar systems. This section will also enable an aircraft OEM to use supplemental and/or alternate tests to validate the characteristics of the system. The controls requirements will need to be expanded to address LLDs.

Sound Requirements

Table 4 lists the existing sound requirements of ARASQ that should be updated for conformity with other regulations.

Table 4: Sound Requirements.

Chapter	Table	Table Subsection	Description	Change
2	2-1	1.j, 1.k, 1.l	Sound	Update for clarity and add SOC
2	2-1	4.b	Sound Tests	Update Tolerances and Comments
3	3-1	1.j, 1.k, 1.l	Sound	Update for clarity and add SOC
3	3-6	5.a	Sound	Update Tolerances and Comments
4	4-1	1.j, 1.k, 1.l	Sound	Update for clarity and add SOC
5	5-5	1.j, 1.k, 1.l	Sound	Update for clarity and add SOC
5	5-5	4.b	Sound Tests	Update Tolerances and Comments

The sound requirements of ARASQ were defined in a way that left many decisions to the TDM for what to model and include in validation testing. The ARASQ update will need to refine the test condition requirements. Also, the FAA updated guidance and tolerances for recurrent sound testing that will also need to be incorporated. The sound requirements will need to be expanded to address LLDs.

DISTRIBUTED MISSION OPERATIONS TRAINING

With the advent of the new training technologies, methodology and curriculum for training students has also evolved. One such training advancement has been distributed training, known as Distributed Mission Operations (DMO), where training devices are linked through a military network and perform missions as a joint unit.

Aerial refueling is one of the more complex exercises that can be performed in Mobility Air Force (MAF) DMO exercises and has the potential to become part of Combat Air Force (CAF) DMO exercises as well. It is important that AR aerodynamic effects are accurately modeled for DMO training to be effective. Typically, stand-alone aerial refueling capabilities are first implemented, tested, and accepted on a stand-alone training device (with ARASQ), and later Virtual Aerial Refueling (VAR) capabilities are added as part of MAF DMO implementation. DMO implementations typically take advantage of the existing AR aerodynamic model that has already been validated, thus ensuring that if the ARASQ objective validation tests are within tolerance, then the VAR exercises will operate to the same level of fidelity, when DMO has been correctly implemented.

Information needed for representing visual appearance of remote entities, position, contact and fuel flow, and aerodynamic effects are communicated among VAR participants. Training devices are synchronized using GPS time, so that positions can be dead reckoned to reduce jitter and discrepancies in position to negligible levels. During a VAR event, data for remote DMO entities are stored in the same global variables used for ARASQ data or local constructive entity data. Regardless of the source of the data, the same global variables and routines are used for processing it and distributing information to dependent subsystems, thus ensuring consistent behavior in DMO events, ARASQ tests, and local training as long as the data are correctly transferred into global variables. See Figure 2, for example, which illustrates the flow of tanker data processed by a trainer that is participating as a receiver. During DMO acceptance testing, pilots and boom operators verify that the aerodynamics model has been correctly implemented in DMO, and that the training device behaves consistently with aircraft behavior.

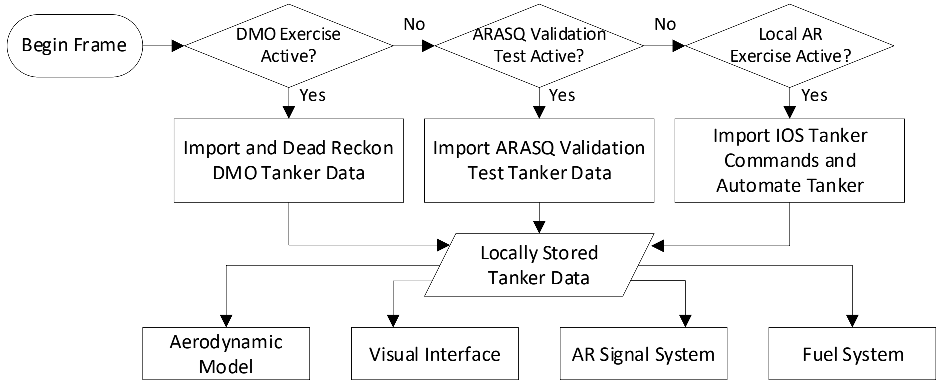

Figure 2: Flow of Tanker Information for a DMO Exercise, ARASQ Validation Test, and Local AR Training Scenario.

ARASQ will need to be updated to include a section on DMO. This section will need to describe the prerequisites to be included in ARASQ for executing a VAR DMO training mission. The prerequisites are: 1) Each DMO participant has an AR simulation that is individually qualified in stand-alone operation using ARASQ, and 2) Participants in the DMO training mission are validated by the SIMCERT authority. The second requirement can be divided into two parts. The first part, certification testing, individually tests a single training device's compliance with DMO requirements, including message formatting, kinematic data, time synchronization, Earth model usage, and VAR data. The second part, acceptance testing, is collaborative and verifies that various training devices properly interact with each other. In acceptance testing, aircraft handling, boom contact, visual scene jitter, and consistent relative positioning between the tanker and receiver are verified.

Since each aspect of VAR is tested objectively and subjectively during DMO testing, with exception of aerodynamic modeling that is identical as when executed in stand-alone training, ARASQ validation tests for DMO applications are not necessary and would present significant complications. These would include implementing control of participating training devices remotely, synchronizing automated testing trim and test stages, and integrating multiple training devices into an autotest system. More significantly, in DMO, the ARASQ validation test results would become interdependent with the behavior of the paired distributed training device, presenting a significant obstacle in reliably tuning flight characteristics and indeterminate. Finally, given that it can take months to tune all ARASQ tests, coordinating the time necessary for tuning and testing multiple devices participating in each test would be prohibitively costly for no measurable improvement in modeling of the AR environment.

ALTERNATIVE DATA SOURCES

As military contractors and aircraft OEMs continue to merge, there are fewer avenues to acquire the flight test data necessary to build a qualifiable training device. Flight test data is the primary data required for ARASQ and can be very expensive and schedule-intensive to acquire. This data collection effort can take years of planning before the actual flight test data collection begins. The execution phase of the flight test effort is generally reasonable but is followed by months of data post-processing and analysis. Aircraft flight test data is still the gold standard for modeling purposes, despite the challenges in obtaining it and occasional data accuracy, resolution, and instrumentation flaws. Additionally, the licensing fees to use the flight test data can be significant, which impacts the procurement and upgrade costs of a trainer. For LLDs, these additional costs can make the trainers instantly cost-prohibitive.

ARASQ does not currently provide for broad or sole utilization of alternative data sources, such as computational fluid dynamics or other theoretical data sources. With advancements in computational power, CFD can now be executed in a real-time environment at a sufficient execution rate for training the AR task. CFD methodology has the potential to produce a more holistic model of the turbulent airflow and interaction models. Quality shape models are required to achieve high fidelity CFD, which typically comes from the OEM. OEM shape models may be unavailable, which can result in the system designer generating less accurate shape models. Recently, the Air Force has funded some research into CFD and its ability to be used on training devices (see FA8621-21-C-0051) and has purchased some CFD-based lower-level familiarization trainers.

For LLDs, ARASQ will need to be updated to include the use of alternative data sources, similar to how the FAA and EASA both allow alternative data sources for LLDs. The exact qualification levels impacted will be addressed during the ARASQ update and discussion with the relevant SMEs, but the FNPTs and Level 1 FTD are good candidates for this. This would allow for qualitative familiarization training for lightweight trainers at a much lower cost. That said, nothing would prohibit the LLDs from using AR flight test data, if available. An LLD that uses and matches flight test data will also be accounted for in the ARASQ update. Note that an objectively qualified trainer (as opposed to a familiarization trainer) would allow for AR training credit to be obtained for qualification and currency training. For the alternative data source to be accepted, ARASQ will require additional supporting information that validates the proposed modeling.

For both FFSs and LLDs, an additional case study for investigation would be the scenario where there is aircraft data for a particular AR tanker and receiver pair, but no data available for additional pairings. For example, the KC-46A program was awarded circa 2013 and the simulators were completed circa 2016. However, the first AR flight test for ARASQ occurred in 2020 (and was delayed due to COVID) which tested only a KC-46A refueling a KC-46A. The flight test for additional AR pairs continues to slide into the future and is now scheduled for 2025. This scenario could have benefited from using alternative data sources for non-tested pairings once the alternative data source was validated by comparison to the available flight test data. ARASQ does have a provision for interim qualifications (1.10), but it is not robust enough to cover this scenario. Therefore, ARASQ will need to be updated to include this scenario and provide detailed guidance on the approval process.

Finally, an additional case in which CFD would be useful is a scenario where flight test data was collected, but there are gaps in the data. Gaps in collected data might occur due to poor flight test planning, issues with the collected data making it unusable, additional maneuvers/conditions of interest after initial test data collection, or for maneuvers considered risky but needed for training purposes. In CFD, it is extremely easy to run a few new cases with an existing model, in contrast with flight testing, which can be very expensive if aircraft must be instrumented again to collect data. CFD has the potential to save tens to hundreds of millions of dollars in reduced flight test costs (NASA, 2021).

CONCLUSIONS AND RECOMMENDATIONS

ARASQ is 25 years old and has transformed the way AR training and devices are qualified. However, since its inception, technology and training methods have evolved significantly and the next generation of ARASQ is needed. The first recommendation is to bring ARASQ into compliance with the other simulator regulatory documents and standards. The next recommendation is to update ARASQ for new technologies (current and future), such as XR. Guidance on DMO and the use of alternative data sources will also need to be added to ARASQ on. Finally, the recommendations for LLDs will allow AMC to develop a range of training devices, all of which will now have a pathway toward a specific level of qualification. This proposed suite of AR training devices will allow the USAF to train pilots and operators for AR more efficiently and effectively, at a reduced resource need and cost, and at scale. The goal for the next generation of AR training is to create a vendor and contractor agnostic standard to improve the quality of training being provided to the warfighter.

REFERENCES

European Aviation Safety Agency (EASA) (2018). Certification Specifications for Aeroplane Flight Simulation Training Devices ‘CS-FSTD(A)’ Issue 2.

European Aviation Safety Agency (EASA) (2023). FSTD Special Conditions for the use of Head Mounted Displays (HMD) combined with a motion platform with reduced envelope. *Information Paper*.

Federal Aviation Administration (FAA) (2016). 14 Code of Federal Regulations (CFR) Part 60 (2016).

Headquarters Air Mobility Command (AMC) (2009). Aerial Refueling Airplane Simulator Qualification (ARASQ) Revision C.

Headquarters Air Mobility Command (AMC) (2009). Aerial Refueling Data Collection and Modeling Standard (ARDCMS).

Loft Dynamics (2023). Robinson 22 FSTD Information. Retrieved June 15, 2023, from https://www.loftdynamics.com/flight-training-solutions/products/r22-simulator/

National Aeronautics and Space Administration (NASA) (2021). A Guide for Aircraft Certification by Analysis. NASA/CR-20210015404.

Zainuddin, Z., Chu, S. K. W., Shujahat, M., & Perera, C. J. (2020). The impact of gamification on learning and instruction: A systematic review of empirical evidence. Educational Research Review, 30, 100326.