A Proposal Standard for Distributed Aerial Refueling with Probe-and-Drogue

Michael Tillett, Hung Tran
CAE USA Inc.
Tampa, FL
michael.tillett@caemilusa.com; hung.tran@caemilusa.com

ABSTRACT

Advances in simulation technology and fidelity, specifically in the ability to network weapon system trainer (WST) devices together, have made it possible to move more live aircraft training to virtual training. Benefits of transferring more aircraft training to WSTs include increased freedom in system usage and engagements, reduced cost, and improved safety. Besides these benefits, the use of WSTs in networking training provides a valuable and cost-effective tool for training aircrews during mission operations that involve coordination between aircraft, such as aerial refueling (AR) training.

The Mobility Air Force (MAF) Distributed Mission Operations (DMO) standard is the protocol used by the U.S. Air Force for distributed Virtual Aerial Refueling (VAR) training. It provides a set of specifications defining the technical requirements for VAR. This standard enabled the capability of VAR over a distributed network using a flying boom refueling system. The U.S. Navy, as well as most North Atlantic Treaty Organization (NATO) countries, uses the probe-and-drogue (P&D) refueling system as the primary method to perform air refueling. For this reason, the ability to train VAR with a P&D system in a distributed environment would be a valuable training capability. Currently, the MAF DMO standard does not provide the technical direction and required interface on how to perform distributed VAR training using a P&D refueling system.

This paper proposes a complementary data structure to the MAF DMO standard to enable the capability of distributed VAR with P&D systems. Using this proposed standard, a simulation of a distributed VAR was successfully performed with a C-130J simulator as the aircraft tanker and a constructive CH-53 as the aircraft receiver. This paper will present the experiment results and discuss the crucial lessons learned from this effort. Finally, it will lay out the roadmap of how this proposed standard for VAR with P&D refueling systems can be implemented in the existing MAF DMO standard.

ABOUT THE AUTHORS

Michael Tillett is an Interoperability Software Engineer at CAE USA. He joined CAE USA 6 years ago where he has worked on DMO programs for C-130J and KC-135 programs. Michael holds a Bachelor of Science in Computer Engineering from University of South Florida.

Hung Tran is a Tactical Systems, Aircraft Sensors, and Interoperability Group Leader at CAE USA. He joined CAE USA more than 20 years ago and has worked on the modeling and simulation of several Electronic Warfare systems. Hung is also the lead designer of the Computer-Generated Forces currently used by several United States Air Force C-130J Weapons System Trainers. Hung holds a Bachelor of Science in Electrical Engineering from Polytechnique Montréal at University de Montréal in Quebec, Canada.

A Proposal Standard for Distributed Aerial Refueling with Probe-and-Drogue

Michael Tillett, Hung Tran
CAE USA Inc.
Tampa, FL
michael.tillett@caemilusa.com; hung.tran@caemilusa.com

INTRODUCTION

The U.S. Air Force (USAF) Distributed Mission Operations (DMO) concept is one of the most successful applications of modeling and simulation for distributed training. DMO is a USAF initiative to allow warfighters to train and maintain combat readiness by conducting mission rehearsal in a synthetic environment that is as realistic as possible. The ability of USAF to achieve training and mission rehearsal objectives is well established in the DMO program, and the distributed mission-training concept was designed to achieve these training objectives. It introduced high-fidelity training devices and the capability to link with other training devices connected to the same network.

The DMO Concept of Operations (CONOPS) objectives are specifically addressed in the USAF DMO implementation plan (USAF Distributed Mission Operations CONOPS White Paper. 20 October 2003). The DMO plan is subdivided into five air and space components (USAF Distributed Mission Operations Implementation Plan. 15 November 2004):

- Replicate and integrate Command and Control (C2) capabilities, including the Tactical Air Control System
- Replicate and integrate Intelligence, Surveillance, and Reconnaissance (ISR) and reconnaissance capabilities
- Replicate and integrate USAF force application capabilities
- Replicate and integrate USAF force projection capabilities
- Replicate and integrate Homeland Defense (HLD) capabilities

Aerial refueling (AR) capability is defined in the objective "Replicate and integrate USAF force projection capabilities" and represented an effective method of increasing the range of aircraft. It consists in transferring fuel from one aircraft to another during flight, enabling the receiver aircraft to remain airborne longer.

Currently, the U.S. military employs two main AR technologies: boom-and-receptacle and probe-and-drogue (P&D):
- The flying boom is a gimballed, telescopic probe that a boom operator in coordination with the pilot inserts into the refueling receptacle on the receiving aircraft. The boom is retractable when it not in use.
- The P&D air-to-air refueling technique uses a trailing hose with the basket on the end. The P&D system is more complex than the flying boom system. It consists of three disparate dynamics parts: probe, drogue, and hose drum. The receiving aircraft pilot guides the probe of their aircraft into the basket to connect with the hose of the tanker. The trailing hose is retractable when not in use.

Both air-to-air refueling (AAR) techniques are complex and require significant training. To enable the distributed virtual air refueling (VAR) training, simulators must be designed to comply with a common standard. The Mobility Air Force (MAF) DMO standard is the protocol used by the U.S. Air Forces for Distributed Aerial Refueling training. It provides a set of specifications defining the technical requirements for VAR. However, the MAF DMO standard specified only interoperability interface requirements for a flying boom refueling system. Currently, the MAF DMO standard does not provide the technical direction and required interface on how to perform distributed VAR training using a P&D refueling system.

Generally, USAF's fixed-wing aircraft refuel with the flying boom. USAF's helicopter, and all U.S. Navy and Marine Corps aircraft refuel using the P&D system. The latter is true also for NATO countries and other U.S. allies. Therefore, given the lack of interoperability standards to support VAR training over DMO that used the P&D system is critical. In summary, the future existence of a standard to support DMO VAR training with P&D refueling system will represent a valuable training asset.

This paper consists of two main parts: 1) propose and describe a complementary data structure to the existing MAF DMO standard to enable the VAR using the P&D system, and 2) prototype implementation of this proposed standard and assess its effectiveness.

AIR-TO-AIR REFUELING TRAINING TRANSFER FROM AIRCRAFT TO SIMULATOR

Background

Distributed VAR training saves millions in flying hour dollars per year. For example, a tanker, such as KC-135, burns over 4000 lbs. of JP-8 (jet propellant) per hour. Flying a 4-hour sortie will burn approximately 1600 lbs. of fuel. Additionally, AR missions require extensive support to complete the mission. From ground crews to personnel who service, maintain, and marshal the aircraft, all add cost to AR training. VAR training capability enabled the USAF to reduce flying hours by shifting AR training to simulators (Carretta & Dunlap, 1998). Therefore, the possibility to train VAR over a DMO network represents a significant cost benefit because VAR training not only saves money, but it also requires far less support than live training.

Training transfer represents the process from which the knowledge and skills acquired through the training are applied to the real situation (Allen, Hays, & Buffardi, 2001; Noble, 2002). The fidelity of the equipment used for training and the environment from which the training is performed are closely linked to the training transfer. Therefore, poor equipment fidelity usually leads to negative training transfer. In the case of VAR, training is usually conducted using flight simulators, because they provide several advantages, including a safe training environment and significant reduction in the cost of training. The fidelity of a simulator consists of three fundamental elements: physical, cognitive, and operational. Physical fidelity refers to the level to which the simulator replicates the real aircraft cockpit. Physical fidelity includes visual, sound, and motion (Allen et al, 1986). Cognitive fidelity represents the ability of a simulator training environment to replicate the cognitive skills required in the cockpit (Lee, 2009). Lastly, the operational fidelity represents the level at which the simulator is able to replicate the look and feel of a real cockpit (Allen et al., 1986). To conduct effective VAR training, the simulators must be designed to satisfy all three elements of fidelity.

The main objective of first-generation simulators designed to conduct training was to perform the VAR training as a stand-alone system. This stand-alone training is useful, but also has its limitations because this type of VAR training is usually conducted using a synthetic environment (SE) with the capability of generating constructive entities that perform the role of either aircraft tanker or aircraft receiver. For this type of training, pilot students “fly” the simulator and learn to perform the task of either receiving fuel from the synthetic aircraft tanker or giving fuel to the synthetic aircraft receiver. The use of a synthetic aircraft tanker or synthetic aircraft receiver for VAR training is limited because synthetic aircraft are usually designed to fly almost perfectly. Therefore, this type of training does not provide the required fidelity for a high level of training transfer.

VAR training could also be approached by connecting simulators to a local network. This would provide higher fidelity training because the simulators are being controlled by humans rather than computers (as in an SE). This training approach is simple and easy to maintain, and the interoperability between simulator participants within the same training exercise is possible via a private software interface. However, the use of a private interface presents a critical issue. Each company manufactures their simulators using their company-owned private interface, creating an inherent incompatibility with other manufacturers’ simulators. Consequently, only simulators manufactured by the same company can participate in the same training scenario.

Interoperability Standard for Virtual Aerial Refueling

The MAF DMO standard is the protocol used by the U.S. Air Forces for distributed aerial refueling training (Szulinski & Soroorche, 2005). It provides a set of specifications defining the technical requirements for VAR. This standard enabled the capability of VAR over a distributed network using a flying boom refueling system. Presently, there is no interoperability standard defining technical specifications to conduct distributed VAR using P&D refueling system. A VAR interoperability standard specified for the flying boom system cannot be used for the P&D refueling system because the modeling of two refueling system is incompatible physically and operationally as illustrated in Table 1. For this reason, it is necessary to have a VAR interoperability standard that will be compatible physically and operationally with the P&D refueling system. The main objective of this paper is to propose a data structure, software interface, and operational requirements to complement the MAF DMO standard by filling the gap in specifications to conduct VAR training using a P&D refueling system.

Table 1. Comparison of Flying Boom and P&D Refueling Systems (adapted from Thomas et al. 2014)

Flying Boom	Probe-and-Drogue
Larger size, weight, and cost	Light and compact
Fuel one receiver at the time	Fuel multiple receivers possible
Controllable via flap	Passive, susceptible to aerodynamic disturbances
Not suitable for helicopter	Low speed drogues can be used to refuel helicopters

AERIAL REFUELING OVER A DMO NETWORK

In order to accomplish VAR, both the tanker and receiver require a common interface so they can interoperate. Furthermore, all required data needs to be on the network to support visually seeing the aircraft and their articulations, feeling the wake field, and most importantly, transfer fuel. While networks today have an increased capacity to transmit and receive communication data, multiple training exercises passing data at 60 Hz can easily bog down the system—especially if simulators are located at different sites. Data needs to be organized in a manner that allows the simulator to render the other simulators correctly and interact together in a seamless environment.

When interoperating different simulators together, there are common issues that occur frequently due to simulators handling things slightly different. In most cases, the difference will just cause minor issues that would not be detrimental in training. Such issues, like models not being all in the same relative location (little high/low, forward/aft), are not a large concern except in close flight, such as when air refueling. When completing P&D AR, additional concerns, such as the location of the drogues, shape of the hose, contact, fuel flow, and aero effect, must be considered. In order to resolve these issues, simulators on the same network must employ the same interoperability standard and interface.

PREVIOUS WORKS (MAF DMO)

The majority of MAF DMO development effort is performed through working groups, which started working on VAR capability over 9 years ago. At that time, the USAF was focused on AAR via flying boom system to support training Air Mobility Command's (AMC) big cargo planes, such as the C-17, being refueled by KC-10 and KC-135 tankers. The development process was conducted as a collaborative network between the USAF MAF stakeholder (C-17, KC-10, and KC-135 platforms) and industry working groups. Based on the training needs of each training platform, VAR standards were defined, discussed, and voted on. After a rough outline of how the standards should operate was decided, the working group conducted interoperability analysis and network integration, followed by a prototyped design that focused on design feasibility to meet the training needs of the customer. After the prototype was complete, simulator-upgrade efforts were performed and lessons learned contributed to further revisions of the standard (Schwindt & Engler, 2014).

The DMO standards that were developed through MAF DMO working groups are mainly to support the flying boom refueling system, which covers most of U.S. Air Force's aircraft. However, the standards do not cover all aircraft from other military branches, nor does it cover NATO aircraft, which use the P&D refueling system. Nonetheless, the lessons learned from training exercises using the flying boom refueling system can be useful to the P&D refueling as well. They also provided an infrastructure for how to transfer fuel information as well as the wake field information, which can be leveraged into the P&D standard. Recently, the MAF DMO working groups are focusing on the two most critical aspects of VAR over the MAF DMO network: relative location and dead reckoning. The relative location issue is related to the visual model of the simulated tanker as perceived by the simulated receiver and vice versa, the visual model of the simulated receiver as perceived by the simulated tanker. The dead reckoning is fundamentally related to the iteration rate of the equations of motion. Because these two issues are critical to the performance of the VAR training over the MAF DMO network, the following sections provide detail on the solution adopted by the MAF DMO working groups.

Relative location

In order to provide the correct relative location, MAF DMO utilizes consumer and producer truths. Each device will make measurements between the centers of their model to a point of interest: for the tankers, the boom pivot point and, for the receivers, the receptacle location. The tanker (or receiver) will broadcast to the DMO network an Entity State Protocol Data Unit (PDU) with an offset containing that measurement, which is referred to as "producer truth." The receiving simulator will then shift the tanker (or receiver) by the difference of the producer truth and their local measurement (consumer truth). The shifting allows each aircraft to know exactly where a given point on the other aircraft is, allowing the simulations to ensure correct relative location. The importance of relative location correction is that both devices need to visually see the other aircraft(s) in the correct location, along with the flight models agreeing on the location. It would be a critical problem if the receiver thinks it is in the perfect location for contact, but the tanker thinks the receiver too far forward, which would cause issues in the bow wave effect on the tanker (Ryan, Oliver, & Hill, 2009).

As illustrated in Figure 1, the receiver and boom both believe their view is correct, but due to issues with their visual models being slightly different sizes and their model origins being in different locations, they see the scenario quite differently. The receiver has the model origin for the tanker farther forward and higher up, and the visual model has the tanker slightly longer. The boom has a shorter visual model for the receiver and has the model origin closer towards the refueling receptacle. Due to discrepancy, the receiver thinks he still needs to move forward and up, but the boom sees the receiver needing to move aft and down. By the boom correcting for the error in producer and consumer truth, the boom can see the receiver is near contact.

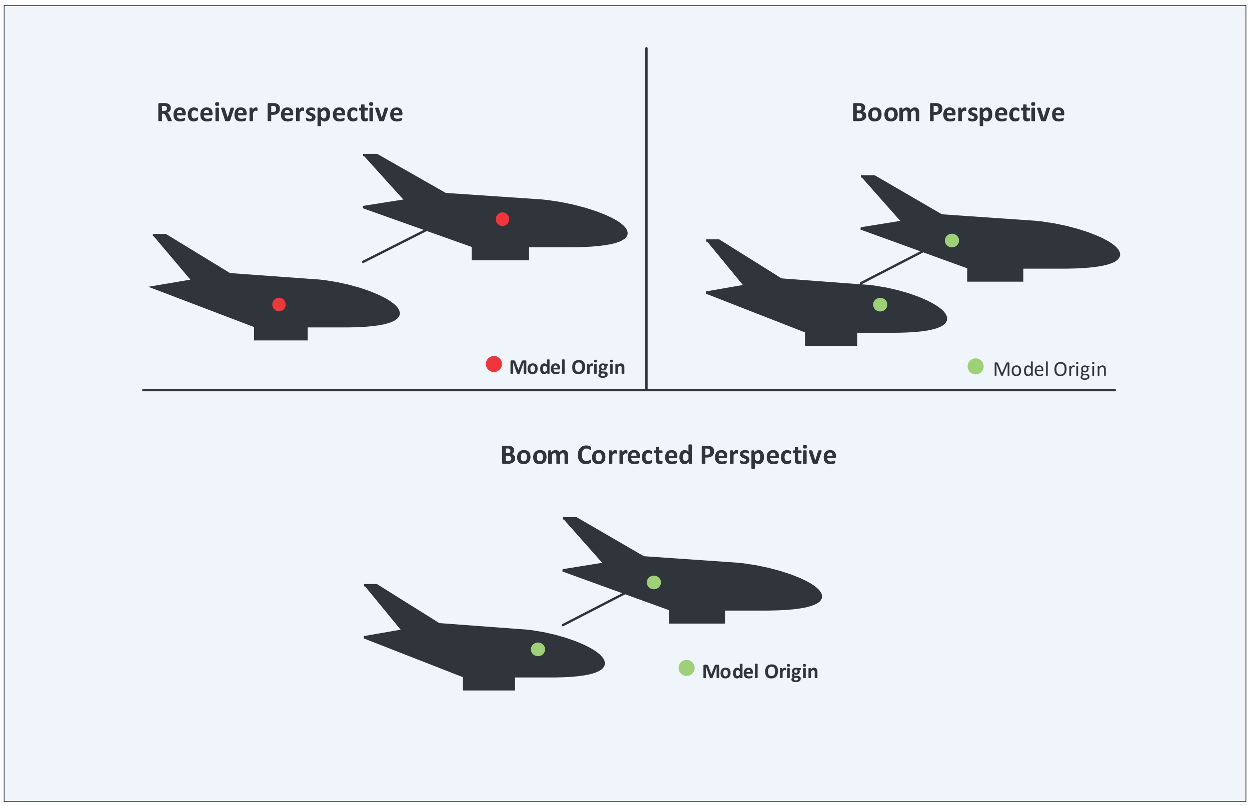

Figure 1. Relative Location Diagram

Dead Reckoning
Normal dead reckoning in the Distributed Interactive Simulation (DIS) version 7 (v7) standard requires a position threshold of 1 meter and an orientation threshold of 3 degrees. However, when the simulators are flying in close proximity, a jittering or drastic shift in orientation was observed. To resolve this, the MAF DMO working group created “Adaptive Thresholds,” so that when the aircraft are close to each other, the position threshold is changed to 0.01 meters and orientation threshold to 0.01 degrees. By tightening the thresholds, the aircrafts participating in the VAR mission should not see any large jumps in the visual when an updated Entity State PDU is received. Having accurate and up-to-date kinematic information is required to provide a seamless visual experience to the trainees (Tramposh & Schwindt, 2018).

IMPLEMENTATION OF THE PROPOSED VIRTUAL AIR REFUELING STANDARD

The proposed standard is based on DIS v7. To accomplish P&D VAR, we utilized the Entity State, Collision, and Data PDU. Each part will be described in detail below. As we describe the use of each PDU, we will reference the enumerations that are defined in SISO-REF-10 in parenthesis.

Entity State PDU

To describe the receiver and tanker, we utilized the Articulated Part Variable Parameter Record (VPR), Entity Association VPR, Offset VPR, Pilot-Controlled External Lighting VPR (created and defined by MAF DMO), Hose and Drogue External Lighting VPR (created and defined by MAF DMO), and the AR Max Fuel Flow Rate VPR (created and defined by MAF DMO). Throughout the following section, we will reference enumerations that are defined in SISO-REF-10. We will use the description followed by, in parenthesis, the value defined.

For the tanker, the drogue's position is described using the Articulated Part Record. The types utilized are Centre Refueling Drogue (8160), Port Refueling Drogue (8192), and Starboard Refueling Drogue (8224). The metrics used are X (5), Y (7), and Z (9), which describe the position of the drogue relative to the refueling pods; azimuth (11) and elevation (13), which describe the drogue's orientation; and extension (3), which describes the hose length. By passing all of this information on the drogue, the receiver has the information required to know where it is with relation to the refueling pods. The Offset Record will be sent with an enumeration of Right Pod Point (104), which is defined as the point at the center of the pod where the Drogue will be (0, 0, 0). It will be assumed the left drogue should be at the same point as the right, just using –Y instead. Using this information, the receiver can compute exactly where the drogue is relative to the point that the receiver sends out as its location. The tanker will also fill out the Pilot-Controlled External Lighting and the Hose and Drogue External Lighting Records. Lights provide important information to other aircraft, such as when the tanker is ready for contact. While in contact, the tanker will also send an Entity Association Record with the receiver aircraft. The Association Type will be set to Refueling Operation (61), Own Station Location set to Air Refueling Probe (22), Physical Connection Type set to Refueling Drogue (8), and Group Member Type set to Formation Leader (3).

For the receiver, the probe is described using the Articulated Part Record. If the receiver has a Refueling Probe Door, a part will be added using the type of Refuel Probe Door (9024) with a metric of Position (1), with 0.0 being fully closed and 1.0 being fully opened. If the receiver has an extendable probe, it will be described using Type of Refueling Probe (9760) and a metric of Extension (3). The Offset Record will be sent with an enumeration of Refueling Probe Point (103), which is defined as the end of the non-extending probe (probe with 0 extension and door fully opened). Using both the probe articulation data and the offset record, the tanker will be able to calculate the probe tip location to be used when flying the drogue in contact. The receiver will send out the Pilot Controlled External Lighting Record. While in contact, the receiver will also send an Entity Association Record with the tanker aircraft. The Association Type will be set to Refueling Operation (61), Own Station Location set to either Port Side Refueling Drogue (19), Starboard Side Refueling Drogue (20), or Center Refueling Drogue (21), Physical Connection Type set to Refueling Drogue (8), and Group Member Type set to Formation Member (4). While in contact, the receiver will also send the AR Max Fuel Flow Record. The tanker uses the AR Max Fuel Flow to know how much fuel the receiver can take based on the fuel pressure the tanker is sending.

Following MAF DMO's lead, when the tanker and receiver are closer than 500 meters, both aircraft will switch to Adaptive Threshold (Position Threshold set to 0.01 meters and Orientation Threshold set to 0.01 degrees). By having the tighter thresholds, all devices in the refueling scenario will have the best data and should not see large steps in the visual model due to the increased traffic of the Entity State.

Collision PDU

The Collision PDU will be used to describe contact between the tanker and receiver. The receiver aircraft will be the one that has the best view of both the drogue and the refueling probe. They will be the first to notice if the two are not lining up. For this reason, the receiver will be the one to adjudicate contact. When contact occurs, the receiver will send a Collision PDU with a Collision Type of 5. When the receiver determines that the drogue is no longer in contact with the probe, it will send a Collision Type of 55. The receiver sends the collision PDUs to let the tanker know contact has occurred, fuel flow is possible, and the drogue needs to start following the probe position.

Data PDU

The Data PDU is used to pass information about Fuel Flow and Wakefield Effects. Both sets of data will be sent by the tanker.

The Wake Field Effects Data PDU (created and defined by MAF DMO) will be sent by the tanker whenever it is in Adaptive Threshold and will have the Receiving Entity ID set to ALL_SITES (0xFFFF), ALL_APPLIC (0xFFFF), and ALL_ENTITIES (0xFFFF). The Wake Field Effect Data PDU is a Data PDU with seven Fixed Datum Records as defined in Table 2. As the title of the Data PDU suggests, this packet has the information required for the receiver to calculate the wake field, which is generated by the tanker. This data corresponds with some of the flight data collected that the simulator would use. While the receiver may not use all of the information, as the fidelity increases, the information provided should meet the simulators' need. For example, a heavier tanker will cause a different effect on the receiver, which is captured in Aerial Refueling Airplane Simulator Qualification (ARASQ) data.

Table 2. Wake Field Effects Data PDU Definition

Field Name	Description	Data type
Angle of Attack ID	Datum ID – 270106	Unsigned Integer (32-bit)
Angle of Attack	Set to the Tanker's Angle of Attack in radians	Floating Point (32-bit)
Sideslip Angle ID	Datum ID – 270107	Unsigned Integer (32-bit)
Sideslip Angle	Set to the Tanker's Sideslip Angle in radians	Floating Point (32-bit)
Gross Weight ID	Datum ID – 270110	Unsigned Integer (32-bit)
Gross Weight	Set equal to the Tanker's Gross Weight in kilograms	Floating Point (32-bit)
Engine #1 Thrust ID	Datum ID – 270111	Unsigned Integer (32-bit)
Engine #1 Thrust	Set equal to the Tanker's #1 Engine Thrust in newtons	Floating Point (32-bit)
Engine #2 Thrust ID	Datum ID – 270112	Unsigned Integer (32-bit)
Engine #2 Thrust	Set equal to the Tanker's #2 Engine Thrust in newtons	Floating Point (32-bit)
Engine #3 Thrust ID	Datum ID – 270113	Unsigned Integer (32-bit)
Engine #3 Thrust	Set equal to the Tanker's #3 Engine Thrust in newtons	Floating Point (32-bit)
Engine #4 Thrust ID	Datum ID – 270114	Unsigned Integer (32-bit)
Engine #4 Thrust	Set equal to the Tanker's #4 Engine Thrust in newtons	Floating Point (32-bit)

The Fuel Flow Data PDU (created and defined by MAF DMO) will be sent by the tanker whenever it is in contact with the receiver and will have the Receiving Entity ID set to the receiver's Entity ID. The Fuel Flow Data PDU is a Data PDU with three Fixed Datum Records as defined in Table 3. As the title of this Data PDU suggests, this packet contains the amount of fuel being transferred from the tanker to the receiver. The whole point of flying AR is to transfer fuel; as such, it is important that both the tanker and receiver agree on the amount of fuel being transferred. If the receiver were to show that it is taking fuel prior to the tanker being properly configured, it would lead to negative training transfer.

Table 3. Fuel Flow Data PDU Definition

Field Name	Description	Data type
Fuel Flow Rate ID	Datum ID – 270115	Unsigned Integer (32-bit)
Fuel Flow Rate	Set to the fuel flow in kilograms per minute	Floating Point (32-bit)
Fuel Temperature ID	Datum ID – 270116	Unsigned Integer (32-bit)
Fuel Temperature	Fuel temperature in degrees Centigrade	Floating Point (32-bit)
Fuel Pressure ID	Datum ID – 270117	Unsigned Integer (32-bit)
Fuel Pressure	Fuel pressure in Pascal	Floating Point (32-bit)

SIMULATION SCENARIO

In order to evaluate the feasibility of the P&D standard, training objectives were set to measure the validity of the standard. First, a tanker and receiver aircraft should be able to fly a rendezvous to meet up for a refueling mission. The tanker should be able to trail the hoses, and the receiver simulation should be able to receive the information and fly to contact based on that information. When contact is achieved, both tanker and receiver should acknowledge contact, allowing fuel to pass from the tanker to the receiver. While in contact, the drogue location should be reflected by the actions of the receiver (as the receiver climbs and gets closer to the tanker, hose will retract, and the drogue's relative location to the pod should change). When disconnect occurs, again both tanker and receiver should acknowledge the drogue is no longer connected to the probe, and the drogue should fall off the probe and begin to be driven purely off aero effects. By accomplishing each of those objectives, a tanker and receiver should be able to complete meaningful training using P&D.

To validate the proposed P&D DMO standard described in the previous section, the data structure and interface were implemented on a C-130J tanker simulator and a CH-53 helicopter synthetic receiver. Both aircraft were programmed to perform a "Head-on offset Rendezvous" air-to-air procedure. When the receiver approached the tanker from behind, the drogue would be trailed. When the receiver aircraft saw the hose fully deployed, it would progress towards contact and, after successfully making contact, climb to the contact position. After contact was maintained and stable, the receiver would be commanded to proceed back to the astern position.

Figure 2. Receiver Aircraft at Astern and Contact Position

When the scenario was initialized, the aircraft proceeded to fly towards the rendezvous. As soon as the tanker observed the receiver at its 10 o'clock, it proceeded with the 180 turn to acquire the same track as the receiver. After achieving the same track as the receiver, the tanker began to slow down towards 115 knots, which is the refueling speed for a CH-53. As the receiver saw the tanker abeam, the receiver proceeded to get into the observation position. The tanker then trailed the left-side hoses. When the hoses were fully deployed, the receiver was commanded to the astern position as shown in Figure 2. When the receiver successfully made it to the astern position, we considered "performing a rendezvous" a success.

Next, the scenario commanded the receiver to proceed to the contact position. Using its internal knowledge of the probe tip location and the location calculated for the drogue through the DIS PDUs, the receiver slowly closed in on contact. When the receiver calculated the probe was within the drogue, the receiver sent out a Collision PDU dictating that contact had been made and then started climbing towards the contact position as shown in Figure 2. As the receiver climbed towards the contact position, we were able to see the drogue following the probe location that the tanker calculated for the receiver. When the receiver had successfully made it to the contact position and the drogue was still attached to the end of the probe, the simulation considered making contact a success.

Lastly, the scenario commanded the receiver back to the astern position. As the receiver backed out, it continued calculating the drogue location relative to the probe. When the receiver calculated that it had moved aft enough so the drogue was no longer securely on the probe, it sent out a Collision PDU dictating there was no longer contact between the refueling probe and the drogue. At that point, we saw the drogue "fall" off the probe and began to react only to the aerodynamic drag. When the receiver had successfully made it back to the astern position and the drogue was no longer reacting to the probe position, the simulation considered disconnection a success.

RESULTS AND DISCUSSION

With the proposed standard, data from the aircraft tanker and the refueling drogue system were broadcasted over the network and the tanker and receiver simulation were able to complete AAR mission. This technique provided enough information for the receiver aircraft to fly into the contact position and to disconnect when the refueling operation was completed. As higher fidelity is required, there are limitations with the shape of hose that is not currently being passed. The receiver has to be the one to decide what the hose is doing based on the location of the drogue and the hose extension. While this may support normal AR, it may not meet the requirements for more advanced situations. Additional information about the hose shape may be required to be sent (possibly in the Wake Field Data PDU or in a new VPR) to the receiver simulation.

One of the lessons learned from this exercise is obvious, that it is possible to conduct VAR using P&D. That said, we did not pass any velocity information for the drogue location. This caused the drogue position to “jump” from one relative location to another updated relative location. From our implementation, the receiver just assumed that the drogue was stuck to the probe until the tanker sent a Collision PDU for disconnect. That would prevent negative training while in contact but could cause issues when the drogue is in free flight. While the drogue was fully trailed and the tanker was in steady flight, there were no large noticeable changes in data (no jumps seen in drogue position). This could cause some issues when the receiver is watching the hoses trail/retract or possibly during turns. Solutions to this may include dead reckoning the drogues by including the velocity component for all drogue articulated parts. More work needs to be done to fully understand what would be required to provide a high-fidelity training environment for the receivers.

Future efforts would include implementing the standard on a full receiver simulator to see how the receiver visually sees the hose and drogue and to gain a better idea of what the limitations are given the lack of hose shape data being passed. Additional effort would also include compiling a list of P&D malfunctions and providing a technical approach on how best to implement them in the current framework or updating the framework to better meet the training needs of the students.

CONCLUSION

The USAF DMO vision is to allow warfighters to train as they would expect to fight. At the operational level, DMO will integrate live, virtual, and constructive systems into a realistic readiness-training environment. The use of flight simulators for training is generally considered a valuable complement to live training with aircraft, especially for training that requires the coordination of several simulators over a distributed network. The VAR interoperability standard proposed in this paper should provide an extension to the existing MAF DMO standard. In doing so, VAR training will not be limited to only the flying boom refueling system, enabling the P&D refueling system to be also employed for the VAR training.

The MAF DMO complementary standard presented in this paper will be submitted to the MAF DMO working group for consideration. This proposed standard will be subject for discussion by the working group and may require adjustments before it can become an official standard and recognized by the training community. Nevertheless, we are confident that it will make its way to become a valuable training asset. By adopting and releasing this proposed standard, the MAF DMO training community will have a framework to begin training with P&D refueling systems. While the proposed standard does not support all possible P&D refueling systems, it does provide a first step in creating a robust capability that can be expanded in future works.

REFERENCES

Allen, J. A., Hays, R. T., & Buffardi, L. C. (2001). Maintenance training simulator fidelity and individual differences in transfer of training. In R. Sweezey, & D. Andrews (Eds.), *Readings in training and simulation: a 30-year perspective* (pp. 272-284). Santa Monica, CA: Human Factors and Ergonomics Society. doi: 10.1177/001872088602800501

Allen, R., Park, G., & Cook, M. (2010). Simulator fidelity and validity in a transfer of-training context. *Transportation Research Record: Journal of the Transportation Research Board, 2185*, 40-47. doi:10.3141/2185-06

IEEE. (2012). IEEE Standard for Distributed Interactive Simulation -- Application Protocols. New York, NY: Institute of Electrical and Electronics Engineers, Inc.

Lee, A.T., (2009). Flight simulation virtual environments in aviation. Burlington, VT: Ashgate.

Noble, C. (2002). The relationship between fidelity and learning in aviation training and assessment. Retrieved from https://ntrs.nasa.gov/search.jsp?R=20020074981

Ryan, P., Oliver, W., & Hill, F. (2009). Aerial refueling in a real-time distributer simulation environment. *Simulation Interoperability Standards Organization (SISO) Conference Proceedings.*

Schwindt C., Engler D. (2014) Virtual Distributed Aerial Refueling Training. *Simulation Interoperability Workshop Proceeding*

SISO. (2018) Reference for Enumerations for Simulation Interoperability. Orlando, FL. Simulation Interoperability Standards Organization, Inc.

Thomas, P. R., Bhandari, U., Bullock, S., Richardson, T.S, du Bois, J.L. (2014). Advance in air to air Refueling. Progress in Aerospace Sciences. 71, 14-35.

Tramsposh, J., Schwindt, C. (2018). Lesson Learned from Distributed Virtual Air Refueling (VAR) Integration. *Interservice/Industry Training, Simulation, and Education Conference Proceeding (I/ITSEC).*

USAF Distributed Mission Operations CONOPS White Paper. 20 October 2003.

USAF Distributed Mission Operations Implementation Plan. 15 November 2004.

Carretta, T. R., Dunlap, R. D. (1998). Transfer of training effectiveness: 1986 to 1997. *United of Air Forces Research Library*.

Mobility Air Force Distributed Mission Operations (MAF DMO). Document No.: MAF-ENG-STD-006. 2016.

Szulinski, J., Sorroche, J. (2005). The US Air Force Distributed Mission Operations – A Premier Application of Distribute Modeling and Simulation in "Training the way we fight." RTO-MP-MSG-035.