Lessons Learned During the Implementation of Aerial Refueling DMO

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ABSTRACT

Developing a virtual environment in which two trainers can network together and perform close proximity maneuvers such as aerial refueling (AR) missions is a new and complex task. The Air National Guard has worked closely with QuantaDyn Corporation to develop a solution and define standards to make the idea of Distributed Mission Operation (DMO) Aerial Refueling a reality. The solution uses an innovative relative positioning algorithm that maximizes positioning precision and minimizes network saturation. When aircraft trainers are networked together, the inherent latency in the network becomes a major factor. It takes a small amount of time for data to travel between trainers, during which both aircraft are moving at high speed, thus when the data arrives it is always a step behind. In order to compensate for this effect, dead reckoning is used to estimate the remote aircraft's position until new position data is received. While standard dead reckoning works well for most networked simulations, there can be position and orientation anomalies that may never be noticed unless the entities are in close proximity for a long duration. During the development of an AR DMO environment involving a Boom Operator Trainer and a Receiver Aircraft Trainer, a few of these anomalies and issues were encountered. These issues include: 1) a "surging" effect where the remote tanker aircraft would suddenly slow down giving the pilot a sense that their aircraft was surging forward; 2) the intricacies of developing dead reckoning algorithms suitable for relative positioning; and 3) the effects of relative versus absolute data packet time stamping on AR DMO. Several operational issues were also encountered including: 1) how to properly initialize networked trainers 2) how to define prerequisites for trainers to take part in AR DMO and 3) how to handle the uniquely detailed AR training environment across a network. This paper will discuss the obstacles both widely known and newly discovered that were encountered while building this unique network environment, as well as the solutions that were applied to allow for multiple trainers to network together and fly prolonged close proximity missions.

ABOUT THE AUTHORS

Michael Parker is a Staff Engineer at QuantaDyn Corporation and Lead Software Engineer for the Aerial Refueling DMO program. Mr. Parker has been working in modeling and simulation for five years and has spent the past two years focused on AR DMO. Mr. Parker has a B.S. Degree in Aerospace Engineering from Virginia Tech.

Ronald Kornreich is a retired USAF lieutenant colonel and fighter pilot, and is the Program Manager for Trainer Development within the ANG's Plans and Requirements Directorate. Much of his 38 years of government service has involved training in one capacity or another with 12 years in his present position. He has a B. S. Degree in Aerospace Engineering with a concentration in Nuclear Engineering from the University of Oklahoma. He is also a graduate of the Air War College and the Inter American Defense College. As Program Manager, Mr. Kornreich developed the Air National Guard's initial Distributed Mission Operations (DMO) roadmap and was the driving force behind the establishment of the Distributed Training Operations Center (DTOC) in Des Moines IA. The DTOC has developed into the USAF's premier facility for daily persistent DMO to include support for joint training as well. Mr. Kornreich also developed, and currently manages, the ANG's strategy for designing and developing simulator technology demonstrators as a part of larger strategy to provide state of the art capability to all ANG flight and mission aircrew. He is currently fielding a variety of trainers including the KC-135 Boom Operator Simulation System, the Advanced ANG Joint Tactical Air Controller Training System, C-130H Multi-Mission Crew trainer, desk top trainers for the MQ-9 Reaper and KC-135 boom operators, and a HH-60G procedures trainer.

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INTRODUCTION

Aerial refueling is a maneuver that takes frequent practice to maintain proficiency. It is one of the few missions that requires two or more aircraft to rendezvous and fly in close proximity to each other for extended periods of time and the only mission that requires two aircraft to physically connect and maintain contact during flight. Because of the complexities involved there is a strong emphasis placed on high quality training.

The use of simulators in lieu of aircraft can provide large flying hour cost reductions, save fuel and increase the service life of aircraft by reducing dedicated training sorties. Flight simulation can also provide training for dangerous scenarios, emergency or combat, without risk to aircrew or aircraft. Rarely, however, do we hear that flight simulation can result in *better* training. Distributed Mission Operations (DMO) capability has given the USAF an unprecedented training multiplier combining all of the aforementioned cost savings with the ability to provide a training resource, on demand, at any unit, at any time. Aircraft scheduling will no longer be a focused concern when providing training.

The newest area of interest for further expansion of simulator training lies in the airborne air refueling (AAR) arena. In terms of complexity, AAR can be an order of magnitude more difficult to realistically model than standard single ship training. From the perspective of the boom operator, simulator training can be a more effective way to train while providing nearly unlimited access to every receiver aircraft platform in the inventory. Air Mobility Command (AMC) and the Air National Guard (ANG) are fielding state of the art devices that, for the first time, have the capacity for full spectrum training.

QuantaDyn Corporation, along with industry partners, has been successful in developing a robust and versatile aerial refueling DMO training solution. Work began in 2005, implementing DMO capability for the AETC Boom Operator Weapon System Trainer (BOWST) and the Air Nation Guard's Boom Operator Simulation System (BOSS) prototype. More recently a proof of concept program run by FlightSafety Services Corporation in 2010 to determine the feasibility of aerial refueling DMO between the KC-10 Weapon Systems Trainer and the KC-10 Boom Operator Trainer provided some breakthrough developments. In the past year, improvements have been made to DMO aerial refueling capability using a desktop Boom Operator Simulation System, the MicroBOSS. With each program providing additional development and refinement, aerial refueling training in a DMO environment is now possible.

"*Aerial Refueling in a DMO Environment*"

In 2009 the original requirements, challenges, and an approach for a robust solution for aerial refueling DMO were laid out in a paper entitled "*Aerial Refueling in a DMO Environment*" by Ronald Kornreich, William Dunn and Matt Richards. The paper laid out five key requirements to enable aerial refueling DMO using existing and proposed network infrastructure; 1) Entities must have very high positional accuracy; 2) There can be no network saturation; 3) The system must be latency resistant; 4) The solution must be compatible with new and legacy trainers; 5) When the boom is in contact it must be visually locked into the receptacle. One of the main challenges was how to deal with inherent network latency when positioning a remote entity. The close proximity of this mission requires very accurate and smooth positioning so a near flawless method to position all entities in the environment had to be developed. A Relative Position Measurement System (RPMS) based approach was proposed to take advantage of the fact that in a typical AR mission the aircraft are moving at slow speeds relative to each other. This approach combined with dead reckoning, a method used to estimate a remote entity's position in between updates, provided the foundation for the technical solution to accurately position two or more networked entities in close proximity moving at high speed without network saturation.

Dead Reckoning and DIS

When two trainers are networked together and transfer position, velocity and acceleration data packets, an element of latency is introduced. This latency is a result of the time it takes data packets to travel across cables from one trainer to another. When the trainers are on a local network this latency is relatively small, approximately 2-4 milliseconds. When the trainers are connected to a long haul network and data has to travel over many miles of cables the latency can grow to hundreds of milliseconds. Each frame of a simulation running at 60Hz occurs every 16.67 milliseconds. At refueling airspeeds of 275-290 knots, calibrated at the refueling altitude, an aircraft will travel 11-13ft during this time. If a frame is missed or when latency is not accounted for position steps in the magnitude of several feet can occur. During close proximity missions such as aerial refueling these steps are unacceptable. To smooth out these position steps a method called dead reckoning is used. Dead reckoning is a way for a trainer to estimate where a remote entity is located by extrapolating position and velocity using previous position, velocity and acceleration values. The dead reckoned position is used until a new position data packet is received from the remote entity. See Figure 1 below.

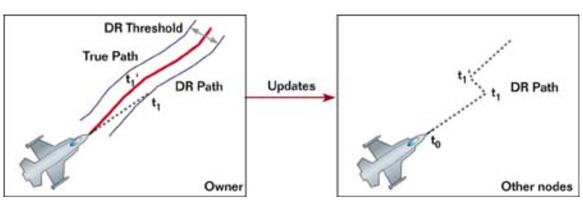

Figure 1. On the left a trainer's true path and illustrated threshold. On the right the dead reckoned position when a position update is received.

Dead reckoning is also used to reduce the amount of data sent across the network. Position data packets are only sent when the aircraft moves outside of a set threshold from its straight and level course. For example, when an aircraft is flying straight and level very few position updates are sent, however when an aircraft is maneuvering and constantly changing course, more position updates are sent as the aircraft repeatedly crosses the set threshold.

IEEE standard 1278.1a-1998 for "Distributed Interactive Simulation - Application Protocols" has been employed to define, package, and send the relevant data packets across the network to enable networked training. The IEEE DIS standard currently does not specify the data packets that are required to be transferred during a networked aerial refueling mission so part of the work on this project involved creating new standards that will eventually be incorporated into the next iteration of the DIS standard.

The Relative Position Approach

The Relative Position Measurement System (RPMS) was developed to gather flight test data from aerial refueling missions. See Figure 2.

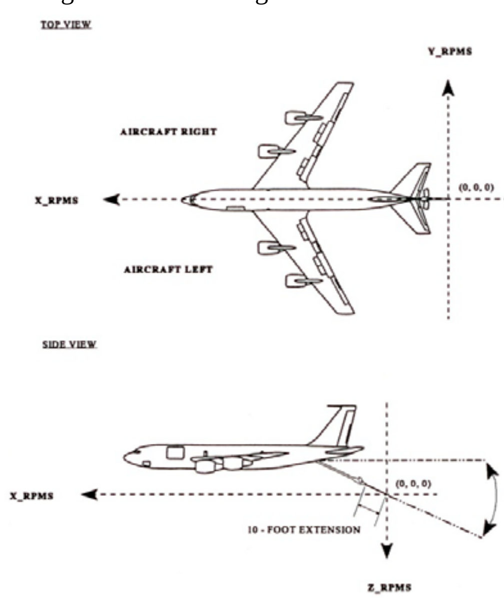

Figure 2. RPMS Coordinate System as shown on a KC-135.

The RPMS coordinate system defines its origin at the theoretical ideal contact position behind the tanker. This point corresponds to the boom tip when the boom is at -30° elevation, 0° Azimuth and 10 feet extension. This same measurement system is employed in AR DMO. The tanker entity is the position lead and is placed using typical Earth Centered Earth Fixed (ECEF) coordinates and is dead reckoned using standard dead reckoning routines. A receiver aircraft is placed relative to the tanker and is dead reckoned using relative position, velocity and acceleration.

The Receptacle Relative Coordinate System (RRCS) is a coordinate system defined for use in AR DMO training. It has its origin located at the bottom of the receiver's fuel receptacle. Positive X is towards the front of the nose, positive Y is towards the right wing, positive Z is down. See figure 3. This coordinate system is locked to the receiver and pitches, rolls, and yaws with the receiver aircraft. The boom tip is positioned using the RRCS coordinate system.

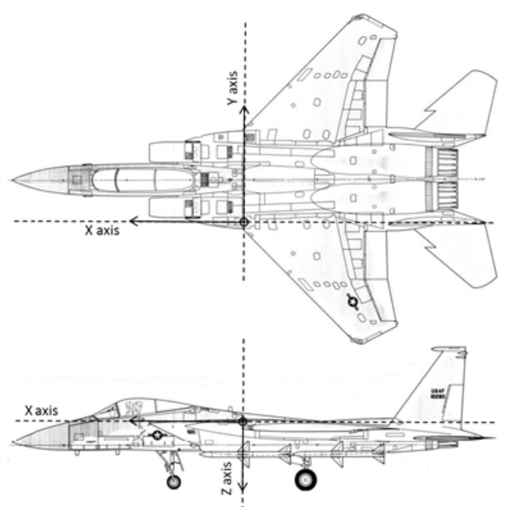

Figure 3. The Receptacle Relative Coordinate System as shown on an F-15.

Other than the tanker entity, all positions, velocities, and accelerations are relative, and therefore much lower than their absolute counterparts: latitude, longitude, altitude, body velocity, and body acceleration.

IMPLEMENTATION TECHNICAL AND OPERATIONAL

Using the approach outlined in "*Aerial Refueling in a DMO Environment*", AR DMO capability has been installed onto several trainers including new and legacy systems. During the implementation process two technical issues were encountered that had not previously been identified. The first was a positional surge in the forward direction of the tanker entity. The second was network saturation caused by frequent position updates.

The implementation of AR DMO not only involved technical challenges but also required the definition of procedures to enable this new technology to provide adequate training. There were five procedural challenges that were encountered. 1) How to properly initialize the mission across two or more trainers, 2) How to define prerequisites for trainers with different aerial refueling capabilities, 3) How to let instructors and students in multiple networked trainers communicate, 4) How to properly handle important cues such as lighting, control surface movement and 5) How to develop logic to simulate each aircraft's aerial refueling signaling system.

With the solutions developed and applied during the implementation of a close proximity networked training environment, networked aerial refueling training is now possible. The following pages will explain the obstacles encountered and the lessons learned in overcoming these challenges.

Technical Challenges

During the course of developing and installing the software and hardware needed to enable AR DMO there were two main technical challenges that arose. The first was a periodic positional surge of the tanker entity seen from the receiver aircraft trainer.

Tanker Surging

The tanker surging issue can be described as follows: As the tanker is flying straight and level, it periodically moves backwards approximately 10 feet over the course of half a second. This movement is smooth without any sudden jumps and gives the receiver aircraft pilot a sense that they are artificially accelerating. The receiver position is sent to remote trainers as a relative position offset from the RPMS origin attached to the tanker. When the tanker position surges, the relative position of the receiver also changes and therefore the surging is seen by both the tanker and receiver trainers.

The cause of this surging is the use of relative time stamping when latency is present in the network. Both entities are dead reckoned, the local entity dead reckons to determine when a position update should be sent, and the remote entity dead reckons to determine its position until a new position update is received. When the local entity determines that a new position update must be sent, it packages the data and sends it across the network, resulting in latency. When the position data is sent from the local trainer at time *t* it is current. When it arrives at the remote trainer at time $t + t_l$, where t_l is the network latency, the position data is no longer current. Occasionally, the dead reckoned position on the remote trainer will have extrapolated past the new position update causing the tanker entity to surge backwards to the newly received position. See Figure 4.

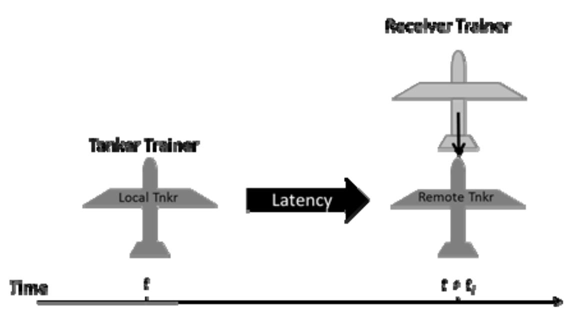

Figure 4. At time *t* a position update is sent. Network latency is introduced. At time t+t_l the dead reckoned position has extrapolated past the newly received position, thus the tanker entity smoothly moves back to the new position, causing a surging effect.

In order to resolve this issue, the networked simulation must use absolute time in which both trainers' time is determined from a single time source. In this case, the time source originates from the boom operator trainer DMO computer and the systems are synced via IRIG-B cards installed in both trainers' DMO computers. After the switch is made to absolute time, latency is no longer a variable and can be calculated by taking the difference between the timestamp on the data packet when it is sent and the timestamp on the data packet when it is received. This known value for latency is included in the time delta for the dead reckoning algorithm to properly determine the extrapolated position of the remote tanker. Running the simulation using absolute time fully alleviates the tanker position surging. An alternative solution to installing expensive IRIG cards for each networked AR trainer requires a clever dead reckoning algorithm which would be able to compensate for the unknown duration of network latency. This solution is in development and will be explained in a following paper that will outline the proposed standards for implementing networked AR training using DMO infrastructure.

Handling unique Equations of Motion

When developing a high fidelity flight trainer, it is common practice to modify the equations of motion to make the trainer fly to match flight test data and/or a pilot's "golden hand." These equations of motion algorithms allow the trainer to numerically integrate position and velocity each frame based upon the current and previous acceleration and calculate a highly accurate position for the aircraft. Dead reckoning algorithms essentially do the same thing although they extrapolate based on a constant acceleration with the assumption that acceleration does not change significantly as a function of time between position updates. As mentioned earlier, dead reckoning is performed on both the local trainer and the remote trainer. On the local trainer dead reckoning is performed in order to determine when a position update should be sent. A position threshold value is set and each time a position update is sent dead reckoning begins. Once the dead reckoned position has diverged from the actual position by the threshold value, a new position update is sent. If the dead reckoning equations and the equations of motion do not match, the positional divergence occurs much more rapidly and causes position updates to be sent at a more frequent rate, thus impacting network saturation. Another result of this issue is a lower fidelity dead reckoned position for the remote entity which can cause a positional step when a new update is received.

To resolve this issue it is necessary to match the dead reckoning equations to the equations of motion. One way to achieve this is to modify and recompile the standard dead reckoning equations. This time intensive effort involves researching the equations of motion and modifying the dead reckoning algorithms on every trainer on the network.

Another approach would be to break down the equations of motion into a set of coefficients corresponding to the specific numerical integration technique. These coefficients would be sent out during the scenario initialization and would be used by all trainers to dead reckon the position of a remote trainer. Using this approach allows all trainers involved to accurately dead reckon the position of any remote entity in the exercise without having to modify a trainer offline.

Operational Challenges

A robust aerial refueling DMO system not only involves robust technical solutions but also intuitive operational solutions. A networked system that can be easily used for proper training missions is essential.

Mission Initialization

The largest training value for aerial refueling is during three phases of an AR mission: rendezvous, approach and contact. One key to running a successful AR training mission is the ability to initialize the scenario to a specific mission phase. This minimizes the time spent on flight phases that provide minimal AR training value, such as take off and flying to a specific AR track and waiting for the receiver aircraft to arrive. In order to accomplish this, a common initialization routine must be established across all trainers on the network. All trainers must be initialized properly and be fully aware of the environment which they are in. When dealing with different trainers, it is likely that each one will have a different initialization routine. There are, however, three main blocks of information that are needed to initialize any trainer: 1) ownship position, heading and velocity; 2) remote entity aircraft type, position, heading and velocity and 3) environmental characteristics and time of day.

The boom operator trainer is designated the initialization master. When all parties have joined the networked training environment, the boom operator trainer will send the initialization command. When this occurs, all relevant initial conditions (IC) data is calculated, packaged and sent to all entities on the network by the boom operator trainer. In order to streamline this process a new IC PDU has been built. Table 1 lists the data included in this new PDU.

Table 1. Data included in IC PDU

Data	Description	Variable Type
Tanker Position	lat, lon, alt	double, double, float
Tanker Body Velocity	x,y,z	float, float, float
Tanker Heading	true heading	float
Tanker Aircraft Type	descriptive number	integer
Receiver Position	lat, lon, alt	double, double, float
Receiver Body Velocity	x,y,z	float, float, float
Receiver Heading	true heading	float
Receiver Aircraft Type	descriptive number	integer
Time of Day	hours, minutes	integer, integer
Environmental Characteristics	descriptive number	word

The aircraft type for both tanker and receiver is necessary in order for the trainer to properly load the correct visual model for a remote entity. A standard set of integers which correspond to aircraft type is used to perform this action across a wide variety of trainers. The environmental characteristics include such data as clouds, visibility, and turbulence. This data is sent through the use of bit masks which allows one bit to represent a true or false value for each environmental characteristic.

AR DMO Prerequisites

In order to perform valuable high fidelity AR training, all trainers involved must have minimum AR training capabilities. These capabilities are separated into five levels and are outlined in the paper mentioned earlier, "*Aerial Refueling in a DMO*

Environment". The AR capability levels can be seen in Table 2. The factors that are of major concern in aerial refueling training and simulation are proper visual model database, visual model fidelity, and the aerial refueling system model.

Owning the proper aircraft model database is very important. If a KC-135 boom operator trainer is networked with an F-16 pilot trainer, the boom operator trainer must have the proper F-16 visual model and the pilot trainer must have the proper KC-135 visual model. When moving to larger scale networked training with several entities on the network, each trainer must be capable of loading the proper visual model for each remote entity. A database including over 20 visual models would be expected.

During aerial refueling both the boom operator and receiver aircraft pilot spend a great deal of time looking at the other aircraft, which may only be 30-50ft away. At this proximity, it is easy to see the details on an aircraft very clearly. On a visual system the models are built by shaping many polygons to form the skin of the aircraft and then overlaying textures to match the look of the aircraft. The longer you look at a visual model, the easier it is to see its flaws; circular engine intakes are not circles, they are polygons, a cylindrical fuselage is made up of many polygons, the marking on the wing of the aircraft is blurry and so on. These flaws can be distracting in a training environment and must be eliminated.

A boom operator trainer is the only known simulation where the entire training task is spent concentrating on close-up views of aircraft models. This being the case, very high fidelity models must be used. Models with tens of thousands of polygons smooth out the frame of the aircraft and photographic quality textures make the model look true to life. Along with the visual fidelity of the models, physical fidelity plays a large part in the overall quality of the model. The size and shape of the nose of the aircraft, engine intakes, wings, windows, and glare shields all must be drawn to the true dimensions of the aircraft. The articulated parts including the ailerons, spoilers, rudder, and elevators, must be the correct size and shape and function properly as they help to give visual cues to the pilot and boom operator when either aircraft is making flight control inputs. The lights on both the tanker and receiver aircraft are also very important. They are used by the pilot and boom operator to visually locate each other. During refueling, lights are used to illuminate parts of the receiver aircraft and boom. Thus all models must have a full set of working lights that are used in AR missions.

The heart of aerial refueling is transferring fuel. Each aircraft is equipped with a signal system which switches the aerial refueling system between three modes, ready, contact/toggles latched, and disconnected. When the tanker and receiver refueling systems are in contact/toggles latched mode, fuel can be pumped from the tanker to the receiver. To model this process, there must be a physical model that can detect when the boom tip is in the receptacle, a logical model to stimulate the signal systems on both aircraft, and another physical model to transfer fuel and distribute fuel weight on both aircraft. If all of the prerequisites are met, high fidelity AR training can take place.

Communication over a Network

The ability for the instructors and students to communicate during a mission is vital to training. Communication before a mission allows the proper initialization of a selected scenario and will make sure all initialization routines are complete before the training begins. During a mission, radio communication is used by the boom operator to guide the receiver pilot into position. Both the pilot and boom operator use their radios to exchange important information throughout the mission and if there is an emergency, specific procedures are initiated over radio. After a training session is completed the instructors and students can use radios to discuss the exercise, do a partial debrief, and coordinate a disconnect from the network.

Table 2. Levels of AR Capability and Fidelity

Level	Description	Training Objectives	Receiver Training Device System Requirements	Data Transfer Requirements
0	No AR Training	None	No AR specific capabilities	No AR specific data transfer requirements
1	AR Familiarization	• Visual rendezvous training • Pre-contact positioning training	• Basic tanker visual model (boom articulation not required) with basic aircraft exterior lighting • Comm/Nav simulation compatible with rendezvous and communication	• High fidelity positioning data • Exterior lighting data • Full DMO compatible digitized voice for all communications systems
2	Limited DMO AR Training	• Contact positioning training • Simulated contact training • Emergency separation training	• Detailed tanker visual model with articulating boom and pilot director lights • Receptacle door control simulation • AR related external light controls, i.e., receptacle lights, slipway lights, etc.	• Boom azimuth and elevation data • Pilot director light data • Receptacle door data • AR specific lighting intensities
3	Partial DMO AR Training	• Basic contact training • Fuel transfer training	• Geometrically compliant tanker model with fully articulating boom, fuel tube (with multiple segments) and fuel nozzle, tail mounted AR floodlight, and boom nozzle light • Geometrically compliant and fully articulating boom drogue adaptor (BDA) model with defined segments (U.S. Navy & NATO) • Fuel management system model capable of fuel on-load via AR • Boom interphone communication • Basic AR malfunction simulations	• Fuel tube extension data • Fuel tube bending data • Tanker AR lighting intensity and direction • BDA positioning data • Fuel quantity transfer data • Point-to-point digitized voice communication data through the boom interphone link • Basic malfunction activation data

4	Full DMO AR Training	• Full contact training
		• Full boom/nozzle interaction training
		• Full transfer of forces through the boom
		• Flying qualities changes (while in contact) due to weight and balance changes
		• EMCON communications
			• Force and moment transfer due to impacts and connectivity
			• Full mass (fuel) transfer effects on flight performance
			• Tanker generated wake and turbulence effects on flight performance
			• Special effects
			    o Fuel spray
			    o Damage simulation
			    o Audio cues
			• Advanced AR malfunction simulations and damage response
				• Contact forces while connected
				• Impact location and severity data
				• Temperature compensated fuel mass transfer data
				• Special effects related data
				• Advanced malfunction data and secondary effects data
				• EMCON signals

Standard DIS protocol is used to pass radio communication packets over the network. A trainer's local communications model typically allows for communication between the student or students and one or more instructors. There are two ways to enable networked radio communication. The first is to modify the existing radio model to allow for the transmission and reception of DIS packets. If the current radio model does not have the ability to allow DIS protocol then a radio transmitter model must be built into the DMO computer which gathers communication data from the radio model and sends it out over the network. A radio receiver model must also be built to gather DIS communication packets from the network and send them to the existing radio model.

Articulated Parts

The visual cues that boom operators gather from receiver aircraft let the boom operator anticipate aircraft movement and enhance perceived depth perception. For example, if a boom operator sees the receiver aircraft's elevator deflect upward he can anticipate that the nose of the aircraft is going to pitch up and move the boom accordingly to avoid damage. Aircraft control surfaces and maneuvers are also used as a form of communication when radios are not in use. A receiver rocking its wings indicates to the boom operator that the receiver has an emergency fuel situation.

To handle the wide range of articulated parts encountered on multiple receiver aircraft a list of common control surfaces is used. The local trainer publishes only the articulated parts it has and sends out position data for each part. DIS standards include definitions for most common control surfaces. A remote trainer goes through the list of common control surfaces which can be seen in Table 3, checks if the remote entity has a part and if so, receives the data attributed to the position of that control surface. All values range from ±90° and have 1 degree of freedom.

Table 3. List of Common Control Surfaces on receiver aircraft relevant to aerial refueling.

List of Common Control Surfaces
Left Aileron
Right Aileron
Left Spoiler
Right Spoiler
Left Rudder
Right Rudder
Left Elevator
Right Elevator
Left Speed Brake
Right Speed Brake

These values are then used to position the control surfaces on the remote entity's visual model.

The boom, fuel tube, ruddevators, boom nozzle, hose and drogue also must be modeled as articulated parts. There is no standard definition for these parts so new definitions were added to the current DIS list of articulated parts. See Table 4.

Table 4. New List of new articulated parts along with respective degrees of freedom. There can be several hose segments the number will depend on the visual model.

Part	DOF
Boom	Pitch, Yaw
Fuel Tube	X
Boom Nozzle	X
Left Ruddevator	Pitch
Right Ruddevator	Pitch
Hose segment	X,Y,Z,Roll,Pitch,Yaw
Drogue	X,Y,Z,Roll,Pitch,Yaw

Tanker and Receiver Lights

Aircraft lights play an important role in aerial refueling. They help the boom operator and receiver pilot locate each other during rendezvous, provide illumination to help guide the boom into the receptacle, and assist in signaling emergency situations such as breakaway.

Receiver aircraft can have up to five sets of lights consisting of steady and flashing light points and variable intensity flood lights. The tanker has additional lighting on the boom, tail, engine nacelles and underbody that provide variable intensity flood lighting to assist the boom operator and pilot to perform their mission.

To handle the multiple lights of various types a standard profile was established to accurately transfer lighting data. The light points that are either steady or flashing, i.e. wingtip lights and navigation lights, are represented by a combination of a bit and a byte. The bit represents the on/off value and the byte represents the analog intensity value of the light. The light pools are represented by a byte value that represents the analog intensity value.

The most important lights involved in aerial refueling are the Pilot Director Lights. See Figure 5. These lights on the underbody of the tanker let the boom operator guide the receiver pilot into position and while connected give the receiver pilot a representation of where their aircraft is in the refueling envelope, allowing minor adjustments forward, aft, up and down to stay in an ideal position. A high fidelity boom operator trainer will have the pilot director lights modeled to illuminate the correct combination of lights based on the boom position and fuel tube extension. There are a total of ten lights: five forward and aft indicators and five up and down indicators.

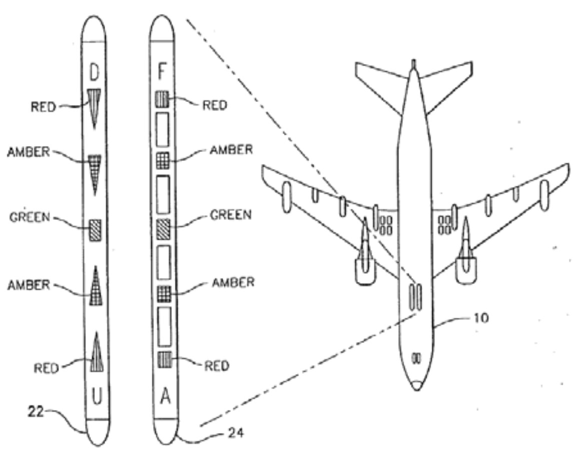

Figure 5. Pilot Director Lights on underbody of tanker.

These ten lights are represented by one bit for each light's on and off value and two bytes to represent the analog intensity value of both the forward/aft lights and the up and down lights.

Modeling the Aerial Refueling Signal System

Every aircraft capable of aerial refueling is equipped with an aerial refueling signal system. This system is triggered by boom/receptacle contact, a disconnect signal, toggles latching and ready/reset commands. It also enables the receiver aircraft and tanker aircraft to switch between different modes so that fuel pumps and specific aerial refueling systems can engage properly. In order for this system to work between two different trainers a standard logic profile was established to model the interaction between the two signal systems and define the data that must be transferred. The process involves a series of checks that finally put both systems in the same state. A typical contact is described as follows. Both the boom operator and receiver pilot set their respective systems into ready mode. The receiver flies into contact position. When the boom operator makes a contact, the tanker sends a contact request data packet to the receiver. If the receiver's system is functioning normally, the receiver sends back a toggles latched data packet to the tanker. When the tanker receives this command, it then sends the boom in contact data packet to the receiver. Both systems then transition to the contact/toggles latched mode which allows fuel flow. Once the preplanned amount of fuel has been transferred the boom operator triggers disconnect that sends a disconnect data packet to the receiver. The receiver then unlatches the toggles and sends a toggles unlatched data packet. Both systems are now in the disconnect mode and are ready to be reset and make another contact.

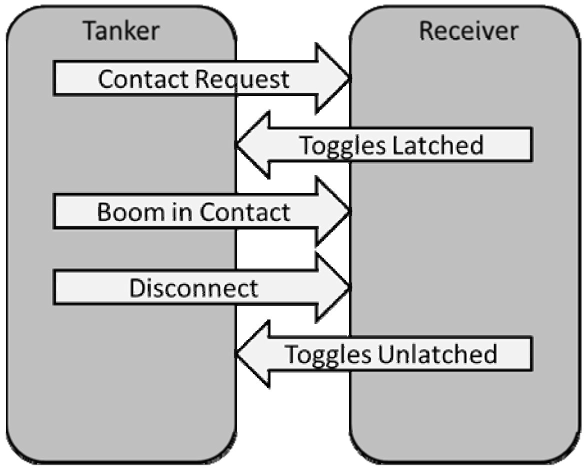

Figure 6. Illustration of data packet transfer for aerial refueling signal system model.

This process boils down to four true or false data packets that are sent back and forth. The contact request, the toggles latched, the boom in contact flag and the disconnect flag. See Figure 6 for an illustration of this process. Since the signal systems vary from one aircraft to another these generic flags are a simple way to transfer the vital information that can be used by any AR signal system model.

CONCLUSION

Over the course of several years of development and implementation, a practical solution for aerial refueling over a DMO network has been created. The technical challenges along the way have been put to rest through the use of newly developed algorithms and by identifying hardware requirements. To use a networked training system to its full potential operational standards and trainer capability, prerequisites must be put into place so that any trainer with aerial refueling and DMO capability can easily connect to a DMO network and perform high fidelity training.

NEXT STEPS

Currently, algorithms are in development that will eliminate the need for expensive IRIG boards. Effort is also being put towards identifying the prerequisites and defining the standards that will be incorporated into the next iteration of the IEEE/SISO standards for DIS. The third and final paper to this series will discuss the final solution and layout the guidelines and standards that make aerial refueling over a DMO network possible.

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