Standardizing Automated Air-to-Air Refueling
Considerations for a NATO Concept of Operations

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INTRODUCTION

Researchers have been studying the possibility of refueling aircraft without a human at the controls for nearly two decades. The aircraft in development are currently automated to fly a predetermined route based on a set of precise instructions. There is no remote pilot actively flying the aircraft with stick and rudder inputs. There is, however, an Air Vehicle Operator (AVO) positioned at a remote control station monitoring the health of the aircraft, standing by to issue updates to its mission as needed, and acting as the pilot in command for the Unmanned Air Vehicle (UAV), or even a set of UAVs. Air-to-air refueling (AAR) refers to the mid-air pairing of two manned aircraft with pilots at the controls physically flying the contact for refueling. When either one or both of those aircraft is replaced by an unmanned or automated aircraft, the process becomes automated air-to-air refueling (A3R), and the contact is made by a computer-controlled flight trajectory. In the United States, the Navy, the Air Force, the National Aeronautics and Space Administration (NASA), the Defense Advanced Research Projects Administration (DARPA), and their industry partners lead A3R development. In 2007, the DARPA/NASA Automated Aerial Refueling Demonstration (AARD) achieved a major milestone with the first automated (piloted but hands off) engagement of a probe and drogue system. Since then, research and development efforts have continued via the Air Force Research Laboratory's A3R program and the NAVAIR X-47B A3R demonstration, which culminated in the world's first contact between an automated unmanned aircraft and a manned tanker.

The NASA AARD program completing the first hands-off engagement. ***Credit NASA***

As the U.S. and other nations continue research and development of UAVs capable of in-flight refueling, the development of an operational system is near. The joint and allied community has spent decades standardizing the AAR mission of creating a mechanical interface (boom mating to a receptacle or probe mating to a drogue). As the community moves toward making A3R a reality, standardization is required to incorporate more complicated systems, such as relative positioning systems, data link systems, and remote AVOs. To achieve a level of interoperability comparable to manned AAR, we must begin the standardization process now.

Understanding this need, the international Aerial Refueling Systems Advisory Group (ARSAG) created a working group to develop recommended A3R procedures. Over the course of three years, the team drafted a concept of operations (CONOPS) and submitted it to the NATO Air-to-Air Refueling Working Group for consideration. Depending on national positions, information from the CONOPS could be included in the NATO AAR Allied Tactical Publication 3.3.4.2 (ATP 3.3.4.2).

A3R CONCEPTUAL OVERVIEW

In the draft CONOPS Systems Requirement Document (SRD), the team formulated baseline assumptions aimed at keeping the process basic, since the idea of A3R is still new to some readers. The procedures currently address single receiver and tanker operations. As system and process development matures, some assumptions can be removed or modified to enable increased complexity.

The overarching assumption is that, to the maximum extent possible, A3R procedures will accommodate current manned AAR standards and procedures. Therefore, the A3R CONOPS uses ATP 3.3.4.2 as a basis while detailing the differences or additional requirements pertaining to A3R. Second, the tanker and receiver pairing can be any combination of manned or unmanned aircraft. UAV has technical capabilities which are assumed to include some degree of autonomy to safely maintain flight and execute a maneuver by selecting from a finite set of predefined actions without supervision unless a human operator intervenes. In the case of manned aircraft, the aircraft may include capabilities for automated refueling, wherein the pilot selects the engagement process as an automated task.

Until unmanned A3R CONOPS are better understood, a key operational assumption is that an AVO gives approval for the UAV to proceed from one phase or position to the next. In this concept, the AAR process is automated within each step but is not a completely autonomous mission. In the future, A3R operations may make full use of autonomy and might need only one message to the AV: Tank. The AV will find the tanker, join, take fuel, depart the tanker, and report tanking complete to the AVO. However, the first step in realizing full autonomy is to exercise and prove the concept of automated operations.

With the AVO approving AV movement from one phase or position to another, it is important to highlight who has operational control of the mission in the air. For these procedures, the tanker aircrew, or AVO in the case of an unmanned tanker, retains control of the airspace around the tanker. The tanker crew or tanker AVO commands the receiving aerial vehicle (AV) (manned or unmanned) through the tanking procedures while the receiver AV crew or receiver AVO responds to the commands, monitors the event, and maintains override authority. These commands are relayed to the AVO, primarily through digital messaging over a datalink, but voice commands may be used to communicate between tanker operator and receiver operator. Enabling the exchange of key navigation and command and control messages requires establishing a datalink network between the tanker and receiver AV. The message content fully defines tanker type, precise position information, control messages, and datalink health status, described in more detail in the following paragraphs.

A3R POSITIONS

To keep procedures simple, a basic rendezvous (RV) procedure, RV Alpha (known to NATO crews and found in ATP 3.3.4.2), was selected. In the RV process, the tanker and receiver join up in flight prior to making contact and transferring fuel. RV Alpha was selected for A3R because of its flexibility and compatibility with unmanned operations. RV Alpha is based on an air traffic controller verbally providing flight vectors to a receiver to join a tanker in an established holding pattern. Because the A3R navigation systems are installed on the tanker and receiver, they know each other's precise location. Prior to beginning the rendezvous, the tanker and receiver ensure that they are established in each other's network. When commanded by the AVO, the receiver's flight computer acts as the airspace controller in RV Alpha and uses the navigation data received from the tanker to fly the air vehicle to an intercept with the tanker at a new position known as the Transition Point (TP).

The TP is 1,000 ft. below and 1,500 ft. in trail of the tanker and is used by the AVO to assess the AV's relative navigation performance prior to commanding the AV any closer to the tanker. Throughout the tanking operation, the AVOs of the tanker and receiver (if both are unmanned) monitor the position of each other and the messaging sent to each AV. If the tanker is manned, the crew monitors position and messaging as well.

The X-47B readies for engagement behind the Omega KDC-707 tanker. ***Credit http://www.omegaairrefueling.com***

When the AVOs are satisfied that the systems of the tanker and receiver are performing as required, the receiver AV can be commanded to depart the TP and proceed to either a position in echelon with the tanker or astern of the contact position. If the tanker has no ongoing refueling operations and the receiver AV uses

Artist rendering of KQ-X in pre-contact position.
Credit DARPA (Defense Advanced Research Project Agency)

a probe and drogue, then the AV can be commanded directly to the tanker's astern (approaching) position of any refueling station (left, right, or center), followed by the contact position. If refueling operations are underway, the AV can be commanded to echelon left to wait its turn. When refueling is completed, the AVO commands the AV to echelon right and then to depart the tanker and continue with the mission.

A3R COMMANDS AND MESSAGING

Since the goal is to seamlessly integrate manned and unmanned operations, A3R will use the existing standardized voice command and control (C2) messages and procedures translated into data link messages an AV's computer can understand.

C2 messages are identified as originating from the tanker or receiver. Using this philosophy and the process described above for control of the airspace and AVs, a message set can cover all operational scenarios. For example, the tanker sends the command "Cleared to tanking position X" where "X" is an approved tanking position, such as echelon left. Upon receipt of the command, the AV responds with a "Wilco," and after successfully achieving the position, sends "Established in echelon left." However, if the AV is already in echelon left, and the tanker command is erroneously sent, the AV responds with "Unable, action already complete." It is incumbent on AVOs to monitor all data link messages and voice communications between the other segments and their respective AVs. At any time, AVOs can override a command sent by the tanker (for safety or other reasons) by sending the correct message. It is also important to note that the AV's responses to C2 messaging, both acknowledgements and actions, are automatic and near instantaneous. Therefore, operators need to be aware of the consequences of commands they issue. The ability to exchange these messages in a quick and timely manner demands a strict set of interoperability guidelines for processing requirements (accuracy, latency) and message structure.

CONTINGENCIES

An important part of automated systems is the ability to respond to off-nominal scenarios. Whether automated or command-based, these responses must be clearly defined and integrated to the process ahead of time. The A3R CONOPS document refers to these responses as contingency responses, and defines a number of them. The most familiar to manned operations is the breakaway maneuver. Either the tanker or receiver AVO can call for a breakaway, at which point the AV separates from the receiver or tanker in both altitude and range to maintain safe flight while the reason for the breakaway is evaluated. Due to the relative navigation and messaging demands of A3R, data link integrity is the key to maintaining safe flight.

If at any time the data link is lost, a lost link contingency maneuver is executed with the receiver descending 1,000 ft. and turning 30 degrees from the tanker's last known position. Some scenarios are unique to boom receptacles, like a boom flight control malfunction or tension disconnect. Others, like fuel leakage, are common to both boom mating and probe mating. The goal in all of these contingencies is to maintain safe flight while safely separating from the other AVs.

SUMMARY

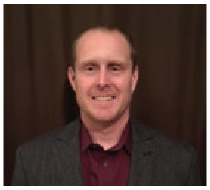
NATO nations have worked hard to achieve interoperability in our current AAR systems, and the interoperability challenges that A3R presents are no less demanding. The procedures introduced in this article are a starting point for standardizing how to conduct A3R, but much more needs to be done. This is no longer a simple mechanical interface. Significant data will be exchanged for each engagement.

A3R requires the use of precision navigation, sensors, and AAR systems combined with a networked data link. Therefore, platforms need to share a specific set of precision navigation, informational, and system status data for successful A3R. At a minimum, requirements for accuracy, integrity, continuity, and availability of the underlying sensors and systems must be defined to enable accurate calculation of a system's own precise location in a reference coordinate frame. All datalink message format and content needs to be defined in a NATO standard. In addition, clearing tanker and receiver pairings for A3R requires significantly more data compared to today's systems.

Overall, the path to operational A3R will be made easier if we begin standardizing the equipment and airworthiness requirements, as well as the procedures, now!

A Calspan Learjet conducts station-keeping exercises as part of the AFRL AAR program.
Credit Calspan

ABOUT THE AUTHORS



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Mark Pilling *is a retired Naval Flight Officer with over 3,500 hours in P-3, F/A-18, T-45, and EA6-B aircraft, and an additional 250 hours in Pioneer UAV as both a mission commander and internal pilot. After retirement in 2003, he joined SAIC as a Program Manager and Senior System Analyst. Mr. Pilling was instrumental in the X-47B demonstration program, assisting in the development, integration, and testing of the carrier-based command and control systems and the tanker-based A3R system. He continues developing and testing advanced aerial refueling system concepts with his support of the Navy's Fuel Containment and Unmanned Carrier Aviation program offices.*

Phillip "PD" Weber *is a Defence Analyst at Coherent Technical Solutions, working on a variety of projects aimed at increasing the effectiveness and lethality of the Carrier Air Wing. A retired career Naval Flight Officer, he served as a Radar Intercept Officer in the F-14A, B, and D, where he completed three operational tours, a tour as an F-14 instructor, a test squadron tour as the F-14 project head, and a command tour. He is also a graduate of the Royal Air Force Command and Staff College. After retirement, Mr. Weber was an advisor to the Republic of China Air Force's operational test squadron. He supports NAVAIR with the X-47B demonstration and the Unmanned Carrier Aviation program.*

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