ARSAG

AERIAL REFUELING SYSTEMS ADVISORY GROUP

Guidance Document

Aerial Refueling Probe/Drogue System

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[signed]
Dexter H. Kalt
ARSAG Executive Director

[signed]
Col Gomer C. Custer, USAF, ret.
ARSAG Secretary

[signed]
Rob Tipton, Lockheed Martin
Working Group Lead /
Working Group # 6

[signed]
Derek Ferwereda, NAVAIR
Document Manager

[signed]
Farhad H. Choudhury, NAVAIR
JSB Chair

[signed]
David A. Benson, AFLCMC/EZFA
JSB Deputy Chair

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9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES) **NAVAIR** **Farhad H. Choudhury** **NAVAIR PMA-201** **Hwy 547** **Lakehurst, New Jersey 08733**	10. SPONSOR/MONITOR'S ACRONYM(S) NAVAIR
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14. ABSTRACT

The ARSAG Aerial Refueling Probe / Drogue Guidance Document provides technical information and supporting data useful for development of probe/drogue aerial refueling (AR) systems on new or existing aircraft. Its focus is on the coupled tanker/receiver aircraft system, tanker AR fuel system, tanker AR drogue system integration, receiver aircraft probe system design/integration, and receiver aircraft fuel system. The document includes guidance and lessons learned that can impact safety and mission success when integrating probe/drogue AR systems onto a tanker or receiver aircraft. The document is applicable to manned and unmanned tankers and receivers, day/night operations, and AR training and to the KC-135 equipped with the Boom-to Drogue Adaptor (BDA) kit. The document may be provided to NATO JAPCC as a supplement to technical information in ATP 3.3.4.6 (STANAG 3447) and in conjunction with the Joint Services Specification Guides (JSSG)

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-		Initial Release

ARSAG Workshop / DOD Joint Standardization Board (JSB) for Aerial Refueling Systems

PROJECT INITIATION FORM (PIF)

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(To be filled out by the requester)		
Name of Individual:	Jennifer Ingmire	
Name of Organization:	NAVAIR	
POC Information:	Phone Number 301 342-9387	E-mail Jennifer.ingmire@navy.mil
2. PROJECT REQUEST		
(To be filled out by the requester)		
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Contents

1. Summary

This ARSAG Guidance Document addresses the background of the requirements, lessons learned and recommendations for future improvements for probe/drogue aerial refueling. Future revisions will be required to address all lessons learned and background of the requirements stated herein. This document should be used in conjunction with the Joint Services Specification Guides (JSSG) to ensure all aspects of probe/drogue AR are address in the design. This ARSAG Guidance Document provides users with additional information to supplement the requirements defined in ATP 3.3.4.6 (STANAG 3447) [Ref1].

This document provides additional technical information and supporting data useful for development of probe/drogue AR systems on new or existing aircraft. It focuses on the coupled tanker/receiver system, tanker AR fuel system, tanker AR drogue system integration, receiver probe system design/integration, and receiver fuel systems.

The guidance and lessons learned in this document discuss the safe integration of probe and drogue AR systems onto a tanker or receiver aircraft which can impact the safety and success of the AR process. The document is applicable for manned and unmanned tankers/receivers, day/night operations, operational and training AR (wet/dry hose), and receivers that will have operations with the KC-135 Boom-Drogue Adapter (BDA).

2. Acknowledgement

Name	Organization	Role in Document
Robert Tipton	Lockheed Martin	Group 6 Lead
Derek Ferwerda	NAVAIR	Document Owner
Steve McLaughlin	NAVAIR	Probe Loads Contribution
Harry Slusher	Boeing	Group 6 Participant
Steve Peake	Cobham	Hose Reel Design Guidance
Jennifer Ingmire	NAVAIR	Initial Preparation
Mark Burket	USAF	Group 6 Participant

3. References

The following specifications, standards, drawings, and handbooks form a part of this guide document to the extent specified herein.

1. ATP 3.3.4.6 (STANAG 3447), Air-to-Air Refueling Equipment: Probe-Drogue Interface Characteristics, Edition 5, dated 28 June 2016.

2. ATP 3.3.4.7 (STANAG 7215), AAR Signal Lights in Hose and Drogue Systems, Edition A Version 1, dated March 2013.

3. MIL-STD-1472G, Human Engineering, dated 11 January 2012.

4. MIL-H-4495D, Hose Assembly, Rubber, Aerial Refueling, dated 10 May 1985.

5. MIL-PRF-81975C, Amendment 2, Couplings, Regulated, Aerial Pressure refueling Type MA-2, Type MA-3, and Type MA-4, dated 29 October 2013.

6. MIL-PRF-57267, Coupling, Aerial Pressure Refueling Type MA-5, Dated 13 November 2017

7. Aerial Refueling Lighting Study Final Report, University of Dayton Research Institute, dated 15 September 2005 DTIC # AD1051415

8. MIL-N-25161C, Nozzle, Aerial Pressure Refueling, Type MA-2, dated 1 April 2010.

9. ARSAG Doc. 03-00-03R, Aerial Refueling Pressure Definitions and Terms, Design and Verification Guidance, dated 12 December 2010 DTIC NO. AD102580

10. STANAG Study 7218, Hose Color and markings for Drogue Aerial Refueling Systems

11. MIL-A-8865, Airplane Strength and Rigidity Miscellaneous Loads, date 20 May 1987

12. Joint Service Specification Guides (JSSG) 2009, Air Vehicle Subsystems

13. MIL-A-19736A, Air Refueling Systems, General Specification For, dated 5 August 1960

4. Associated documents

1. Joint Service Specification Guides (JSSG) 2001, Air Vehicle

2. Joint Service Specification Guides (JSSG) 2006, Aircraft Structures

3. ATP 3.3.4.2 Edition D, Air-to-Air Refueling

4. MIL-R-9126A, Reel, Fueling Hose, Aerial, Refueling, General Specification For, dated 3 July 1961

5. MIL-F-17874B, Fuel Systems, Aircraft, Installation and Test of, dated 20 August 1965

6. MIL-A-8865B, Airplane Strength and Rigidity Miscellaneous Loads, 20 May 1987

7. ARSAG Doc. 20-08-17, Aerial Refueling Boom/Receptacle Guide Document, dated 28 July 2017 DTIC NO. AD1048313

8. MIL-STD-464C, Department of Defense, Interface Standard, Electromagnetic Environmental Effects, Requirements for Systems, Dated 1 December 2020

4.1 MS and AS Drawings

1. MS 24354 - Drogue Cone, Nozzle and Reception Coupling – type MA-2 Flight-Pressure Refueling System, Assembly of

2. MS 24356 - Nozzle, Type MA-2, Flight Pressure Refueling (ASG)

3. MS 24359 – Nozzle, Probe mast – Type MA-2, Flight Pressure Refueling Nozzle, Outline Dimensions for (ASG)

4. MS 24360C-2 – Ring, Lock Flight Pressure Refueling Nozzle (CRES)

5. MS 24358 - Fitting Hose end – Type MA-2, Flight Pressure Refueling, Reception coupling, Outline Dimensions For

6. MS 24361 – Ring, Split – Type MA-2, flight Pressure Refueling, Reception Coupling

7. MS 24362 – Sleeve – Type MA-2, flight Pressure Refueling, Reception coupling

8. SAE-AS29513 - Packing, Preformed, Hydrocarbon Fuel Resistant, O Ring

5. Abbreviations and Terminology

AR	Aerial Refueling
AAR	Air-to-Air Refueling
CAD	Cartridge Activated Device
DTIC	Defense Technical Information Center
FOD	Foreign Object Debris/Damage
RAT	Ram Air Turbine
TFOA	Things Falling Off Aircraft
A/C	Aircraft
PSIG	Pounds Per Square Inch Gauge
UDRI	University of Dayton Research Institute

Hose Reel System:	a) Extends/retracts and stows the hose/drogue. b) Provides hose tension to prevent hose slack when the receiver A/C makes contact. c) Provides tension as the receiver A/C moves while engaged.
Hose:	Provides a fuel path to the coupling.
Wet Hose:	A hose filled with fuel
Dry Hose:	A hose void of fuel
Hose End Coupling:	Tanker interface for the receiver aircraft probe nozzle. Contains mechanically latching feature for the receiver aircraft probe nozzle and permits fuel flow between the tanker and receiver aircraft.
Drogue:	Provides drag for the hose reel system and hose/coupling stability.
Probe/ mast:	Receiver aircraft structural component used to facilitate a clear, visible, and unobstructed interface with the tanker aircraft drogue and coupling.
Nozzle:	Receiver aircraft interface to the tanker. Mounts to the end of the probe mast and permits fuel flow between the tanker and receiver.
Multipoint:	A tanker simultaneously refueling two or more receivers.
Fuel Transfer Range:	The amount of deployed hose that will permit fuel transfer without interruptions. This range is bounded by the inner fuel transfer limit (inner limit) and the outer fuel transfer limit (outer limit). Also known as the Refueling Range.
Astern Position:	The stabilized formation position behind the AR equipment (approximately 5ft. directly aft of the drogue) with zero rate of closure.
Exit Tunnel:	The passageway for the AR hose and drogue to exit the tanker aircraft.

6. Requirements Guidance

This document describes lessons learned associated with the integration of probe & drogue AR systems on tanker and receiver aircraft and the critical factors that directly impact the safety and success of the AR process. Affected systems include the tanker fuel system, hose reel (or equivalent), hose/drogue, receiver probe, and receiver aircraft fuel system.

The tanker/receiver aircraft interface takes place at the coupling and nozzle which are used to mate the two aircraft and transfer fuel. ATP 3.3.4.6 (STANAG 3447) [Ref 1] is the requirement standard for NATO probe & drogue AR.

6.1 Tanker Aerial Refueling Systems

6.1.1 Tanker Fuel Systems

The tanker AR fuel system is comprised of the fuel containment tanks, pumps, plumbing, valves, surge control devices, and other dedicated fuel system components located on the tanker airframe up to the tanker drogue AR system unit.

The tanker AR fuel systems should be designed to control fuel pressure and function satisfactorily during receiver aircraft initial contact, while the receiver aircraft is connected (with a wet and dry hose), during fuel transfer to the receiver aircraft, and during receiver aircraft disconnect conditions.

The tanker AR fuel system should not be adversely affected by the fuel pressure resulting from the normal operation of the air vehicle's fuel system or any other AR system. This is an integration, operational, and safety requirement. Damage or breakage to any AR system must not interfere with the proper operation of the air vehicle's fuel system or any other AR system installed on the air vehicle.

6.1.1.1 Tanker Offload Rates

The primary offload rate requirement will most likely be driven by the tanker operational customer(s) (potential receivers). Consideration should be given to the type of receivers to be refueled, number of aerial refueling pumps, number of receivers receiving fuel at one time (multipoint refueling), and the fuel system of the tanker. Large receiver aircraft fuel systems are generally able to accommodate higher on load rates (up to 600 gpm or more). Suggested refueling times based on receiver fuel tank capacity are stated in JSSG-2009 paragraph F.3.4.6.2.1.2

6.1.1.2 Tanker Offload Pressures

The tanker steady state AR fuel system delivery pressure to the receiver should not exceed 55 psig, in accordance with ATP 3.3.4.6 (STANAG 3447) [Ref 1]. This should be achieved by the performance of the AR pumps and pressure regulation system onboard the tanker. A tanker AR fuel system which achieves the required 55 psig offload pressure limit should not replace the hose end pressure regulation capability contained within the MA-3, MA-4, or MA-5 coupling. Any one of these hose end couplings will provide the receiver aircraft surge protection and fuel delivery pressure regulation of 50 +/-5 psig, not to exceed 60, as outlined in MIL-PRF-81975 3.8.1.1 [Ref 5] and MIL-PRF-57267 [Ref 6].

When the tanker aircraft is equipped with an onboard pressure regulation system (not including the hose end coupling), the hose reel operator should be able to monitor inflight fuel delivery pressure to the receiver aircraft probe nozzle. Should failure of that pressure regulation system occur it may be detected by the operator and necessary precautions be taken to avoid exceeding the design pressure limits of the receiver aircraft.

The tanker AR fuel delivery system can generate pressure surges and cause damage to receiver aircraft. These surges can be caused by rapid pump startup and will not be suppressed by a regulated MA-3, 4, or 5 coupling. Tanker surge protection such as surge boots may be required to protect the tanker and receiver AR fuel systems.

The fuel pressure within the drogue system, prior to engagement, should not negatively affect the receiver's ability to latch. This pressure condition should be achieved following a normal disconnect and prior to the receiver attempting another contact. Historically a time of 3 seconds has been used to achieve this pressure condition, however; operational procedures and system design may drive different a time. Traditionally static head pressure exceeding 10psig (in the coupling) at receiver A/C engagement will negatively impact the receiver's ability to latch the coupling.

A pressure regulated coupling can assist in reducing pressure surges generated by the receiver aircraft's fast-closing valves. Failure of the pressure regulation features of MA-3, 4, or 5 couplings cannot be detected in flight. Ground support equipment is necessary to detect whether the coupling's pressure regulation feature is operating correctly. Repair or replacement of a coupling requires ground maintenance time.

The combination of an onboard pressure regulation system having failure detection features and a hose end coupling having pressure regulation and surge protection features reduces the risk to the receiver aircraft from: a) overpressure generated by the tanker aircraft, and b) surges produced by the receiver aircraft's fast-closing valves.

Pressure regulated couplings increase pressure drop across the coupling. Increased pressure drop reduces the pressure downstream of the coupling and must be considered in the system design to avoid a reduction in fuel flow rates

6.1.2 Tanker Formation Aids and Lighting

The tanker should provide the necessary aids/cues under all natural lighting (day/night/transition) conditions for safe rendezvous and to adequately assist the receiver aircraft crew to achieve stable formation flying. Exterior lighting should not blind or distract the air vehicle crew member(s) of the receiver or the tanker aircraft during the aerial refueling process. Independent variable intensity dimming control should be provided for all exterior lighting, with the exception for the anti-collision beacons, from "full intensity" to completely "off" to ensure safe and effective operations during aerial refueling. In addition, all upper fuselage beacons shall have on/off control that is independent of the lower fuselage beacons.

Tanker formation aids and lighting guidance, past lessons learned, and recommendations are located in the USAF sponsored Lighting study performed by the University of Dayton Research Institute (UDRI) [Ref 7].

6.1.3 Tanker Drogue Systems

Tanker drogue systems typically consists of a hose reel (or equivalent), a refueling hose, a hose end coupling and a drogue. Variations of drogue systems may include hose reels powered by hydraulic systems (aircraft integrated or dedicated hydraulic system actuated with a RAT), electric systems, or mechanical tensioning systems.

The Drogue System should be designed to regulate (or boost) fuel delivery pressure as needed and provide a stable target that permits safe and effective contacts by the receiver aircraft. This includes alleviating undesirable movement of the hose and drogue during free flight, initial contact, coupled flight, and disconnect. Hose/drogue movement during free flight should not go unstable or divergent under tanker maneuvers with hose trailed (hose empty and hose full of fuel). Such tanker maneuvers include side slips, rudder and elevator doublets and flying in light to moderate turbulence.

NOTE: The Boom-Drogue Adaptor Kit (BDA) is a 9-foot hose system that has been adapted to the KC-135 Boom as an interim measure to attain interoperability with probe-equipped aircraft. There is no hose reel to assume the excess hose slack upon engagement, which can lead to unique loading scenarios, very limited disconnect envelopes, and additional challenges to receiver aircraft training. Consequently, this is not recommended for new AR systems.

6.1.3.1 Static Discharge

The tanker drogue and aerial refueling systems must be installed in a manner to pass an electrical discharge, caused by the tanker/receiver connection, into the tankers airframe. All tanker systems, including the tanker drogue system, shall meet their operational performance requirements when subjected to a 300 kilovolt discharge between the tanker drogue system coupling and the receiver aircraft probe nozzle.

6.1.3.2 Electromagnetic Environmental Effects

The tanker drogue and aerial refueling system including the hose reel (or equivalent), pod, drogue, and other system(s) used during aerial refueling should be protected from electromagnetic environmental interferences from any tanker system.

6.1.3.3 Drogue System Fuel Transfer Range

The fuel transfer range of the drogue system is the amount of deployed hose that will permit fuel transfer without interruption. This range is bounded by the inner fuel transfer limit (inner limit) and the outer fuel transfer limit (outer limit).

At the outer fuel transfer limit, the drogue system should automatically initiate fuel transfer to a connected receiver aircraft when the hose is pushed in a predefined distance from the hose's full trail position. An outer fuel transfer limit of 5 feet from the deployed hose's full trail position has been demonstrated to be adequate to minimize pressure disconnects and facilitate safe and effective AR.

At the inner fuel transfer limit, the drogue system shall automatically terminate fuel transfer to the receiver aircraft when the hose is pushed in a predefined distance from the hose's full trail position. The inner fuel transfer limit placement should take into consideration proximity of the receiver aircraft at the inner fuel transfer limit to any portion of the tanker airframe.

6.1.3.4 Drogue System Status

The tanker should provide the receiver aircraft aircrew information regarding the status of the drogue system. Any indication system which relies upon providing status information via visual signals to the receiver aircraft aircrew should be visible from the astern position to the inner refueling limit. The position of the receiver throughout the refueling range should be considered when locating the drogue system status lights. Rotor wing receivers typically position themselves upward and outward when compared to fixed wing receivers. The signals should be visible to all intended receivers. Multipoint system should operate independently; however, a breakaway should be for all receivers. Lighting signal layouts and logic should be as defined in ATP 3.3.4.7 (STANAG 7215) [Ref 2].

6.1.3.5 Location

Tanker drogue systems may be located within the fuselage or in a separate pod mounted along the tanker centerline, each side of the fuselage for redundancy, or underneath the wing. Potential receivers must be considered when deciding the location of the hose reel system. Large receivers may have spatial clearance problems when operating from wing mounted drogue systems and generally exhibit better handling qualities on the tanker centerline.

Location of pod mounted and fuselage hose reels must consider vortices and air flow off of the tanker during hose retraction, extension, at the trail position, throughout the fuel transfer range, and the impacts to the receiver aircraft during aerial refueling. The receiver aircraft should not have to compensate (i.e. crab) while engaged with the drogue during aerial refueling. Aerial refueling hose and drogue stability during extension and retraction must be evaluated to ensure that the drogue does not contact the tanker aircraft, excluding the drogue system exit tunnel. In addition, hose/drogue stability at the full trail position must be evaluated to ensure a stable drogue is provided for the receiver aircraft under both clear air, during light to moderate turbulence, and with a wet and dry hose.

6.1.3.6 Hose Response

To ensure safe and positive engagement, tanker drogue systems should consider receiver aircraft closure rates up to 10 ft/sec in accordance with MIL-A-19736 [Ref 13]. High closure rates can lead to hazardous conditions including receiver aircraft underruns and hose whips/sine waves. Slow closure rates (e.g. below 2 ft/sec) have posed significant challenges for achieving positive engagement, due to receiver aircraft bow wave influence, drogue high restoring force design, and the inability to overcome coupling latch forces. Drogue system response should not be so sensitive that the drogue pulls away from the receiver aircraft at contact (sail away) but should be responsive enough to maintain hose tension.

Drogue system response must remain adequate during receiver aircraft maneuvering while in contact throughout the full hose travel range (from full trail to retract). Drogue system response should not result in the drogue prematurely disengaging from the probe during normal receiver aircraft maneuvering within the full hose travel range.

Adequate drogue system response should be achievable throughout the identified AR envelope (airspeed and altitude) and include both wet and dry hoses. Inadequate drogue system response can result in excessive loads on the hose and receiver aircraft probe, create a hose whip/sine wave, cause inadvertent disconnects, and hose and probe failure.

6.1.3.7 Hose Jettison

Failure to retract the hose or a failure of the drogue coupling assembly may require the hose to be jettisoned. The drogue system should allow jettison capability at any hose extension and flight condition. Mission profiles, landing environment, and airspeed limitations due to drag on the drogue are all things to consider when deciding on the jettison method. Clean separation of the hose from the tanker aircraft is required. The hose should not strike the tanker aircraft, structure or control surfaces.

Established jettison methods include a guillotine to cut the hose and a quick disconnect that detaches when sufficient load is applied. The guillotine method utilizes an explosive Cartridge Activated Device (CAD) to actuate a cutting mechanism to sever the hose in flight. The design requirements of the CADs are such that the guillotine method is highly reliable. A quick disconnect method, when commanded, allows the hose reel to unwind beyond full trail, disengages the hose from the drum, and relies on drogue drag for safe separation of the hose and drogue from the tanker. To prevent fuel from leaking into the fuselage or pod, the jettison function should include a means to safely contain the residual fuel in the tanker drogue system.

Design of the jettison system should prevent an inadvertent jettison resulting from a single failure within the drogue system. Inadvertent jettison should also be prevented by design in accordance with MIL-STD-1472 [Ref 3] or equivalent.

The designer must consider the customers' needs and requirements when choosing whether or not a hose jettison is required and if so which type best suits the need. The hose jettison function is a safety and airworthiness feature that allows the operator to control when and where the hose is jettisoned. The hose is jettisoned when the hose/drogue is unable to be retracted, becomes aerodynamically unstable, leaking fuel, and/or becomes a risk to the aircraft structure and control surfaces.

6.1.3.8 Hose Design

Hose design requirements are stated in MIL-H-4495 [Ref 4].

The hose length should provide a stable hose and drogue at full trail, adequate clearance between the tanker and receiver aircraft and adequate receiver aircraft handling qualities throughout all required relative positions to achieve AR. Hose diameter and length will dictate pressure drop and delivery flow rate. These factors must be considered when determining the necessary hose length for the tanker aircraft.

The hose system should allow the receiver aircraft and tanker crews to readily determine deployed hose length and position within the refueling range. Historically hose markings every 10 feet have been used to achieve this. ARSAG Joint Standardization Board (JSB) Workshop and NATO Study 7218 [Ref 10] are evaluating criteria for hose markings and colors.

6.1.3.9 Coupling and Drogue Design

AR drogues interface with AR couplings and should provide an aerodynamically stable target for probe equipped receiver aircraft.

The coupling performance requirements are defined in MIL-PRF-81975 [Ref 5] and MIL-PRF-57267 [Ref 6]. MA-3/4/5 couplings provide hose end pressure regulation. For the selection of the most effective coupling, consideration should be given to AR system delivery pressures, desired fuel flow rates, and refuel times for both normal operating and failure conditions. Other factors should include pressure regulation systems on board the tanker and ground support equipment required to verify MA-3/4/5 coupling's pressure regulation features are operational prior to flight.

If MA-2 couplings (no pressure regulation) are utilized, upstream regulation is required to achieve system performance and compatibility with targeted receiver aircraft based on fuel flow/pressure delivery and surge pressure characteristics. If MA-3 couplings are utilized as the sole source of pressure regulation and surge alleviation, single failure conditions should be considered for the proper operation of the system.

Although MIL-PRF-81975[Ref 5] allows 25 cc spillage per engagement, the design intent of the system should be to ensure a sealed surface prior to engagement of the poppet resulting in zero leakage during initial coupling/nozzle engagement. Fuel spillage on disengagement is permitted in accordance with the component specification; however, there should be no system leakage before or during refueling operations.

The drogue should be constructed of robust materials to withstand the abuse of missed contacts and large off-center disconnects (both vertical and horizontal). In addition, the drogue should be designed to minimize the potential to liberate Foreign Object Damage (FOD). It is documented that FOD from the drogue can cause serious damage to the receiver aircraft.

6.1.3.10 Coupling and Drogue Dimensions

The envelope dimensions for the coupling and drogue design as well as stay out zones are defined in ATP 3.3.4.6 (STANAG 3447) [Ref 1]. The dimensions are defined to ensure geometric compatibility between the tanker drogue/coupling and the receiver aircraft probe.

The coupling and drogue (including ribs, canopy, etc.) stay out zones are in place to avoid snag hazards, damage to critical components, engine FOD, and Things Falling Off Aircraft (TFOA).

The mating dimensions for the coupling are also defined in ATP 3.3.4.6 (STANAG 3447) [Ref 1]. These dimensions are critical to ensure that the AR event can be accomplished without any fuel leakage or probe nozzle to coupling hang-up or snagging. Probe/nozzle to drogue hang-up/snagging can result in damage to the receiver aircraft probe/nozzle, damage to the coupling thereby impacting future refueling events, and a damaged or broken hose.

The drogue canopy supporting struts guide the receiver aircraft probe into the coupling. They should be smooth and radiused to prevent damage (gouging) to the receiver aircraft probe nozzle sealing lip which makes the fuel seal with the tanker coupling. (See Paragraph 7.2.5.1 Figure 1 Point C.)

6.1.3.11 Drogue Drag/Hose Catenary

The hose catenary curve, with the hose at full trail, should be considered as an important variable for safe and effective AR operations. Consideration should be given to targeted receiver aircraft, airspeed/altitude envelope, tanker airflow characteristics for given location of the tanker drogue system, hose length, hose mass (wet & dry), and hose/drogue drag when assessing the suitability of hose catenary for safe and effective AR.

A hose which extends parallel to the pod or aircraft exit (i.e. straight back) due to a high drag drogue is not acceptable and does not provide the receiver aircraft pilot depth perception nor hose marking visibility. Conversely, a hose which hangs too steeply from the pod or aircraft exit is also not acceptable. A hose which droops to the point where there is significant contact with the pod/aircraft hose exit tunnel can impact hose reel performance and cause hose whips/sine waves. An aerial refueling hose that contacts the exit tunnel either laterally or vertically can increase friction to the extent that the hose reel take-up function is impaired and a hose whip may be produced at the hose exit. High upward tanker flow can force the aerial refueling hose against the upper hose exit tunnel with high friction force, sufficient enough to result in poor hose take-up response.

6.1.3.12 Drogue/Hose Stability

Drogue stability is defined as exhibiting predictable movement that is resistant to sudden or extreme change in position. At full trail, vertical or lateral oscillations should not exceed one half the diameter of the drogue canopy and disturbances should damp out to 1/3 amplitude within 3 cycles. Little to no receiver aircraft pilot compensation should be required.

The drogue should be inherently stable such that it is not negatively affected by turbulence or aircraft maneuvering. The drogue should be stable throughout the AR envelope in zero to low turbulence conditions and throughout the extended range of the hose in both wet and dry conditions.

Drogue movement should not be excessive in any direction when extending from or retracting towards the tanker aircraft. The drogue should not contact the tanker airframe (including pod/pylon/ wing structure) on extension or retraction at any point within the specified AR envelope of the tanker system.

The drogue/coupling should not spin about the coupling swivel ball assembly or hose/coupling connection. at any airspeed or hose trail position. The coupling swivel ball assembly and hose/coupling connection should not be mechanically restricted from rotation. Mechanical restrictions may induce drogue loads onto the hose during receiver aircraft maneuvers and missed off-center drogue connections.

The drogue/hose should remain stable throughout the identified AR envelope and include both wet and dry hoses. Hose stability tests should be conducted with the hose in free flight (no receiver aircraft coupled). These tests should be conducted at all airspeeds/altitudes with both a wet and dry fuel hose and at various tanker gross weights. These tests should consist of elevator and rudder doublets and side slips of the tanker aircraft.

6.2 Receiver Aircraft Systems

6.2.1 Receiver Aircraft Fuel System

The receiver aircraft AR fuel system is comprised of pumps, plumbing, fuel level control valves, shutoff valves, surge control devices, probe, nozzle, fuel tanks, vent systems, and other dedicated fuel system components.

The receiver aircraft AR fuel system should not be adversely affected by fuel pressure resulting from the normal operation of the air vehicle's fuel system or any other AR subsystem (hydraulic, pneumatic, electric, etc.). Damage or breakage to any AR system must not interfere with the proper operation of the air vehicle's fuel system or any other AR system installed on the air vehicle. A check valve, typical for fighter aircraft, or motor-operated valve, normally in larger transport aircraft, is placed downstream of the AR probe/nozzle. The purpose of this valve is to prevent any siphoning of fuel in the event of a failed (bent) or broken probe/nozzle or mast.

6.2.1.1 Receiver Aircraft On-Load Rates

AR time is an operational requirement from which the rate at which the receiver aircraft takes on fuel is derived. The receiver aircraft's mission should dictate how much time is allowed for the receiver aircraft to perform AR operations. Factors that should be considered, but are not limited to, the number of receivers in the AR cell, the time required to be able to make a successful engagement with the coupling, and whether single point versus multipoint refueling procedures will be employed. In addition to the fuel pumping capacity of the tanker AR subsystem, the receiver aircraft AR subsystem design will affect how long it will take to refuel a receiver aircraft.

Typically, a rate is not specified, rather requirements are written such that the receiver aircraft should be refueled from 10% capacity to full (top off) or a mission defined fuel capacity in a required time. When specifying receiver aircraft time to refuel, it is imperative to state what tank loading configurations are applicable. Operational requirements may dictate refueling times. A chart suggesting refueling times based on receiver fuel tank capacity is in JSSG-2009 paragraph F.3.4.6.2.1.2 [Ref 12].

6.2.1.2 Receiver Aircraft Fuel Pressure

Receiver aircraft fuel systems should be designed to operate with an operating fuel pressure of 60 psig to accommodate typical tanker supply pressure fluctuations.

The receiver aircraft fuel system should prevent fuel surges from exceeding the system proof pressure for any fuel shutoff condition, including a single failure within the receiver fuel system. Minimum proof pressure requirements are typically two times operating pressure; however, experience has shown that some systems may require higher proof pressure values to accommodate unique surge characteristics, reference ARSAG document number 03-00-03R [Ref 9].

The fuel system architecture must be considered when designing for surge protection/control. Managing the closure speed of the fuel level control valves (slower) and adding surge suppression devices to the fuel system can mitigate excessive surge pressures within the system. Recent fuel level control valves have been designed and manufactured with zero allowable leakage. When tankers equipped with MA-3/4/5 hose end regulators are coupled with receiver aircraft equipped with “no leak” fuel level control valves, resulting system fuel pressures may exceed the receiver aircraft operating pressure. This scenario coupled with a pressure relief valve set between 60-65 psig in the receiver aircraft may produce an unstable, high frequency, chatter condition. This valve instability has shown to produce high surge pressures within the receiver aircraft greater than the design proof pressure. In contrast to these “no leak” valves, past legacy valves have had allowable leakage ranging from 15-200 cc/min. When used in receiver aircraft coupled with tankers that are unable to adequately regulate hose end pressure at very low flow rates, the “leaky” fuel level control valves may help maintain pressure below the design proof pressure of the receiver aircraft.

6.2.2 Receiver Aircraft Exterior Lighting

Exterior lighting should not blind or distract the air vehicle crew member(s) of the receiver or the tanker aircraft during the aerial refueling process. Independent variable intensity dimming control should be provided for all exterior lighting, with the exception for the anti-collision beacons, from “full intensity” to completely “off” to ensure safe and effective operations during aerial refueling. In addition, all upper fuselage beacons shall have on/off control that is independent of the lower fuselage beacons.

The receiver aircraft should provide the necessary lighting to illuminate the last 12 inches of the probe, and the primary tanker formation aid and/or refueling pod. The light should not blind the tanker operators when aerial refueling. Additional probe illumination guidance is located in the UDRI Lighting study [Ref 7].

6.2.3 Aerial Refueling Probes

The type of probe installation (fixed, telescopic and retractable) shall be determined for the air vehicle. A retractable probe includes those that are fully retractable and those that are semi retractable. The type of probe should be selected based on mission performance requirements for the air vehicle. The probe should be of sufficient length to avoid drogue strut/canopy interference when the drogue is partially or fully inflated. Partial drogue inflation may occur due to receiver aircraft bow wave.

Aerodynamic effects of the probe throughout the flight envelope may impact the performance, noise, vibration, and handling qualities of a receiver aircraft. For fixed probes, consideration should be given to both fitted and removed configurations; for telescopic or retractable probes, or combination telescope/retractable consideration should be given to both extended and retracted configurations.

Components associated with telescopic and/or retractable probes should prevent leakage. Probe stowage compartments should provide for collection and drainage of fluids.

6.2.3.1 Static Discharge

The probe and probe nozzle must be installed in a manner to safely pass an electrical discharge, caused by the tanker/receiver connection, into the airframe. All receiver aircraft systems shall meet their operational performance requirements when subjected to a 300 kilovolt discharge between a tanker drogue system coupling and the receiver probe nozzle.

6.2.3.2 Probe Actuation

The primary actuation (extension and retraction) method for telescopic or retractable probes should be determined as either manual, electrical, hydraulic, or pneumatic. The actuation method should be functional throughout the receiver AR envelope.

An emergency method to actuate (extend and retract) the probe should also be provided in the event the primary actuation method fails.

The system should provide indication to the aircrew that the probe is positively locked in the extended and in the retracted position.

Typically, retractable probes have the capability to extend and lock the extended position or retract and lock in the stowed position in 5-20 seconds. An actuation which is too rapid can cause excessive forces within the actuation mechanism while an actuation time that is too long can impact the total aerial refueling time for the air vehicle operational mission.

6.2.3.3 Probe Location

The integration of an AR probe onto an air vehicle should include operational and safety considerations.

6.2.3.3.1 Pilot Visibility

The probe nozzle tip should be visible to the receiver aircraft pilot (and co-pilot, if applicable) for observing the hookup with the drogue and coupling without requiring the receiver aircraft pilot (and co-pilot, if applicable) to change their visual reference on the tanker under all ambient lighting conditions. The recommended visible portion of the probe mast is a minimum of 12 inches, measured from the nozzle tip.

The probe, in its extended or partially extended state should not prevent or degrade the pilot’s (and co-pilot’s, if applicable) vision during landing or other critical flight phases such as observing the drogue system status signals and other formation aids.

The pilot (and co-pilot, if applicable) should have an unobstructed view of each targeted tanker’s drogue AR subsystem status lights, hose exit area, its formation references, and underbody under all ambient lighting conditions throughout the aerial refueling event.

6.2.3.3.2 Clearance to Structure, Cockpit Canopy and Air Data System

The clearance around the probe should be designed to provide an unobstructed path for the drogue/coupling of the targeted tanker AR subsystem to approach and contact the probe nozzle. The probe clearance should comply with ATP 3.3.4.6 (STANAG 3447) [Ref 1]. For telescopic, retractable, and fixed probes, the clearance should apply in all normal refueling conditions and could be considered in emergency refueling conditions. In addition, for flush mounted probe retractable masts all attaching doors, lights, clamps, actuators, latch devices, etc. should be within the stay out limits defined in ATP 3.3.4.6 (STANAG 3447) [Ref 1].

Drogues, used to refuel rotary-wing air vehicles, are typically larger than the minimum clearances specified in ATP 3.3.4.6 (STANAG 3447) [Ref 1]. Probe clearance for these receiver aircraft should account for this larger drogue size in both normal and emergency conditions (probe not fully extended) when operational requirements dictate a need. The size of the rotary wing aircraft drogue may dictate a probe location undesirable for other critical design factors.

Inadequate probe clearance can prevent coupling engagement or damage tanker AR subsystems, which may pose a Foreign Object Damage (FOD) hazard to the receiver aircraft.

In addition to the clearances defined in ATP 3.3.4.6 (STANAG 3447) [Ref 1] the area around the probe mast and the probe mast profile should be free of any protrusions that provide a potential to “catch” or “snag” on the coupling and drogue during the probe/coupling engagements, disengagements and missed (overrun) engagement attempts.

6.2.3.3.3 Location Relative to Engine Inlet

Special considerations need to be accounted for when locating the probe with respect to the engine inlet. Airflow into the engine may be impacted by the tanker drogue, throughout the AR process, resulting in performance loss of the receiver aircraft and possible engine flame out. In addition, FOD and fuel spray may be ingested into the air vehicle engine during the AR event potentially resulting in loss of engine. Probe tip locations forward of engine inlet ducts should take into account the risk of FOD ingestion and local aerodynamic effects produced by the tanker drogue.

The probe should not interfere with the air flow field around the receiver aircraft such that it adversely affects the proper operation of the engine(s). These considerations must take into account a coupled drogue and probe.

The fuel spray that typically occurs at disconnect should not be ingested into the engine(s).

6.2.3.3.4 Location Relative to Air Data Ports and Probes

The probe or drogue should not interfere with the air flow field around the air vehicle such that it adversely affects the proper operation of air data ports and probes.

The fuel spray that typically occurs at disconnect should not impinge on the air data ports and probes.

6.2.3.3.5 Deployed Probe Nozzle Angle of Installation

The installation of the deployed probe nozzle should aim to be horizontal when at the nominal receiver aircraft AoA for aerial refueling and the nozzle centerline should be in line with the probe centerline such that the nozzle centerline aligns with the tanker trailed drogue/coupling centerline. Consideration should be given to the receiver aircraft pitch angle variations due to weight, various store/weapon configurations, and airspeed throughout the AR envelope.

6.2.3.3.6 Aerodynamics/Bow Wave Effect

Receiver aircraft bow wave, or altered airflow across the nose of the aircraft, can result in the tanker drogue not engaging the coupling at an angle parallel to the receiver aircraft nozzle. The drogue drag may be insufficient to allow a complete coupling engagement with an angular offset to the receiver aircraft nozzle. The incomplete nozzle/coupling engagement will result in no fuel transfer and potentially massive fuel leakage.

Tanker drogues which have a high restoring force to normal trail position, when influenced by the bow wave of the receiver aircraft nose configuration (e.g. F-14, Tornado), are prone to this condition.

6.2.4 Aerial Refueling Probe Nozzle

The AR probe nozzle, attached to the forward end of the probe mast, is defined by the performance requirements stated in MIL-N-25161 [Ref 8] and the interface requirements stated in ATP 3.3.4.6 (STANAG 3447) [Ref 1].

MIL-N-25161 [Ref 8], specification for the MA-2 nozzle, states that nozzles shall be either Type 1 or Type 2. Type 1 nozzles are capable of off-center disconnects up to 15 degrees' maximum and Type 2 nozzles are capable of off-center disconnects up to 22-1/2 degrees' maximum. This flexibility resides within the nozzle assembly and reduces the probability of MA-2 nozzle hang-up in the tanker's drogue and coupling during severe off-center disconnects thereby reducing the chance of probe nozzle damage. Type 1 nozzles are obsolete and should not be used, especially with BDA kits, helicopter aircraft, and when the tanker aircraft drogue system envelope is small and off center disconnects are common. There may be type 1 nozzles being used on older weapon systems worldwide.

Although MIL-N-25161 [Ref 8] allows 25 cc spillage per engagement, the design intent of the engaged nozzle and coupling should be to ensure a sealed surface prior to engaging the coupling poppet resulting in zero leakage during initial coupling/nozzle engagement. The sealed surface is achieved when the nozzle sleeve lip, point C in figure 1, engages the coupling sealing surface. Fuel spillage/leakage on disengagement is permitted in accordance with the component specification; however, there should be no system leakage before or during refueling operations.

The nozzle interface dimensions are defined in MS24356 and MS25359.

6.2.5 Probe Structural Load Criteria

In general, the probe installation should be designed with sufficient structural strength to withstand engagements at up to 10 ft/sec. These loads can vary depending on the tanker system. For example, if the KC-135 Boom-Drogue-Adapter kit (BDA) subsystem is a targeted subsystem, the lack of a hose reel (or equivalent) take up capability creates higher loads at contact, while in connect, and on disengagement than seen on tankers with hose reel take up systems.

Probe and drogue AR can be a dangerous mission where overload events can and will happen as a result of a tanker system failure or pilot error. For this reason, it is desirable to design the static/ultimate load margins such that a failure mode carries the least possible residual risk to the receiver aircraft. While refueling system designs do look to provide the most robust system and provide as much fail safe capability as reasonably possible (via flexible probe masts, flex tip nozzles and more reliable hose reel (or equivalent)), the overall failure chain needs to be preserved so that in the event of an overload, failures occur at known and repeatable locations within the AR system. For probe and drogue AR systems, in general, the preferred failure mode from the <u>most desirable</u> to the <u>least desirable</u>:

a) Structural fuse “weak link” failure (just aft of nozzle attachment point when designed to the requirements of Paragraph 6.2.5.3)

b) Probe mast or probe linkage failure

c) Receiver aircraft probe backup structural failure

d) Tanker AR system failure (coupling, hose, hose reel (or equivalent), or hose reel attachment)

By adhering to this basic design philosophy, the designer ensures that the smallest size FOD is generated in an overload event, and allows for the potential for that FOD to be retained by the tanker system to prevent further damage to the receiver aircraft. This is important because many single engine and propeller driven aircraft are subject to catastrophic risks as a result of FOD generated during AR. Limiting size and promoting retention of this FOD reduces the risk to these receiver aircraft. The result is that a structural fuse section near the tip of the probe is the desired failure point in the event of a system overload, and the structural margins throughout the AR system should be designed accordingly. While this does reduce the risk to any potential “mishap receiver aircraft”, it must be noted that this philosophy does bring about the risk of the receiver aircraft’s nozzle being stuck in the tanker’s coupling, “downing” the subject hose from refueling additional receiver aircraft on that mission. This is a risk that must be balanced against the potential loss of receiver aircraft.

6.2.5.1 Structural Fuse (Weak Link) Design and Load Conditions

A structural fuse is the best method of ensuring that the failure chain above is obtained in the final design. This can be done by utilizing a more traditional “weak link” that provides a system which results in a controlled structural failure which is readily replaceable and repairable. This can also be achieved via designing in a critical section in the probe mast where a failure will occur, but that usually requires replacement of the entire probe mast rather than the structural fuse. From here out, the term weak link will be used in this section but can be used to mean either application in practice.

When designing a weak link, the static and dynamic limit loads as stated in sections 6.2.5.3 and 6.2.5.4 should be applied as the limit and ultimate loads for the weak link section, with the limit loads for the remainder of the probe system established based on satisfactory margin over the weak link ultimate loads. In testing/analyzing these structures the locations identified in Figure 1 and described below should be used to apply the loads.

a) The static tensile loads shall be applied at the gage point on the toggle latching groove to the axis of the nozzle.

b) The static radial loads shall be applied to the nozzle sleeve 3.5 inches from the gage point in the toggle latching groove.

c) The static compression load shall be applied at the lip of the nozzle sleeve and parallel to the longitudinal axis of the nozzle.

d) All impact loads shall be at the very tip of the nozzle.

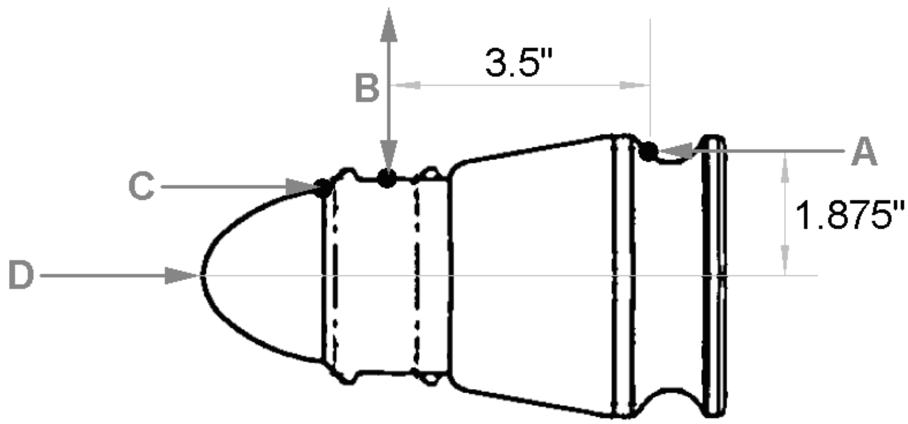


Figure 1: Probe Load Application Locations

6.2.5.2 Static Limit Loads

Probe Loads

Tensile	1,500 lbs.
Compression	2,500 lbs.
Radial	1,500 lbs.

Combined Loads

1,500 lbs. Tensile combined with 1,500 lbs. radial

2,500 lbs. Compression combined with 1,500 radial

6.2.5.3 Static Ultimate Load

Ultimate loads for the probe structure should be 150 percent of the limit loads.

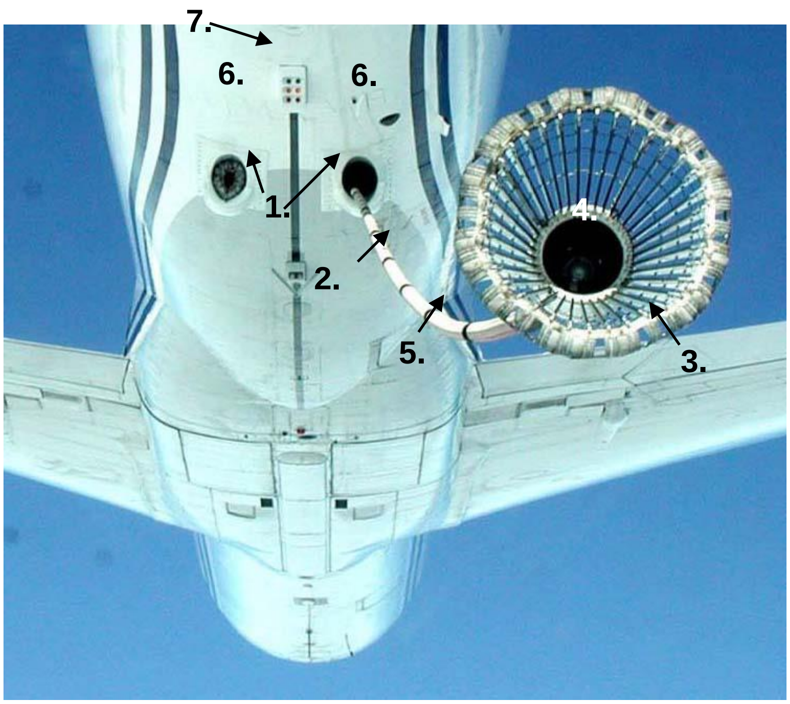
The ultimate load for the weak link should be 133 percent of the probe limit loads. The tolerance on the breaking load shall be +/- 5% of the critical nominal value(s).

6.2.5.4 Dynamic Load

The dynamic load for the probe structure should be those resulting from a closing speed of 10 ft./s. The effective weight at the tip of the probe should be 100 lbs. [Ref. 11].

Attachment 1: Coupled Receiver Aircraft with a Hose Reel Equipped Tanker

Attachment 2: Hose Deployed from a Hose Reel Equipped Tanker



1. **Hose Exits**
2. **Aerial refueling hose with 10 ft. Black Markings**
3. **Drogue, Collapsible**
4. **MA-4 Coupling (2 Regulators)**
5. **Catenary Hose Curve**
6. **Hose Reel Locations (Internal)**
7. **Status / Signal Light**

1. **Probe Mast**
2. **Probe Nozzle**

Attachment 3: Receiver Aircraft coupled with Boom-to-Drogue Adapter

1. **Boom-to-Drogue Adapter Connection**
2. **Nine-Foot Hose (Integrally stiffened)**
3. **Trunnion (one half universal joint)**
4. **MA-3 Coupling**
5. **Drogue Rubber Canopy**