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14. ABSTRACT  
THE OBJECTIVE OF THIS STUDY WAS TO DETERMINE AIRCRAFT LIGHTING THAT PROVIDE OPTIMUM VISIBILITY AND DEPTH PERCEPTION FOR THE BOOM OPERATOR AND VISIBILITY FOR THE RECEIVER PILOT TO MINIMIZE RISK DURING THE AERIAL REFUELING PROCESS FOR BOTH THE BOOM -RECEPTACLE AND THE PROBE-DROGUE METHODS. ANOTHER GOAL WAS TO PROVIDE A GUIDE TOWARD MEETING THESE REQUIREMENTS. THE STUDY ALSO WAS DESIGNED TO ADDRESS RECOMMENDED CURRENT NEAR-TERM AND FUTURE LIGHTING TECHNOLOGIES THAT COULD BE APPLIED TO EXISTING AND FUTURE PLATFORMS. SEE EXECUTIVE SUMMARY IN THE REPORT.

15. SUBJECT TERMS  
BDA - BOOM-TO DROGUE ADAPTER KIT AR - AERIAL REFUELING  
NVG- - NIGHT VISION GOGGLES  
PDL-- PILOT DIRECTOR LIGHTS  
UARRSI-- UNIVERSAL AR SLIPWAY INSULATION

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Final Report  
September 15, 2005**

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# 1. Executive Summary

This one-year study was completed by the University of Dayton Research Institute under USAF contract # F420-00-D-0028 dated 10 Aug 2004. The effort was performed under subcontract to Aerospace Engineering Spectrum (AES), Ltd. The tasks of this study were directed toward meeting the requirements set forth in the USAF statement of work.

The objective of this study was to determine aircraft lighting requirements that provide optimum visibility and depth perception for the boom operator and visibility for the receiver pilot to minimize risk during the aerial refueling process. Another goal was to provide a guide to meeting these requirements. The study also was designed to address/recommend current, near-term and future lighting technologies that could be applied to future and existing platforms.

Aerial refueling is highly dependent upon the participating operators' abilities to see and accurately locate the receiver aircraft and aircraft in formation, as well as the receiver aircraft pilot's capability to determine position relative to the tanker. Difficulties in these areas are exacerbated during low light or night aerial refueling operations. Lighting provides not only indication of relative location and facilitates communication but also highlights the critical visual cues needed for judging relative motion and for depth perception. This is true both for the boom/receptacle and for the probe/drogue refueling systems. This study focuses on tanker aircraft including the KC-135 and the KC-10, on the variety of receiver aircraft who participate in aerial refueling and on future tanker and receiver aircraft.

The recommendations of Paragraphs 10.1, 10.2, 10.3 and 10.4 contained in this report are based on assessments of the data gathered from a wide variety of sources, including input from users of aerial refueling lighting and markings. These sources can be categorized into three general areas. Each of these three areas and the sources used are as follows:

## Search and Familiarization

- a lighting manufacturing plant tour including lighting demonstrations and hardware examination,
- document and records search and review,
- team tutorials
- technical and operational briefings at Aerial Refueling Systems Advisory Group (ARSAG) conferences
- internal subject matter expertise (forty-five years' focused experience in aerial refueling),
- meetings with subject matter specialists regarding night vision goggles (NVG) including demonstration and use of latest NVG technology and equipment,

## Interviews

- interviews with pilots,
- interviews with boom operators,
- interviews with subject matter experts,
- discussions and exchanges among users and manufacturers in ARSAG's Lighting Panel,
- discussions and exchanges in ARSAG's Special Topics Meetings,
- direct inputs solicited from aerial refueling users regarding aerial refueling lighting and markings experiences and needs.

## Questionnaires

- receiver pilot questionnaires, and
- tanker operator questionnaires.

This project was specifically designed to gather and integrate aerial refueling information from as broad a range of individuals, aircraft, organizations, equipment, methods and technology as possible. It was a goal of this research to take advantage of recorded lessons learned from the past along with expressions of contemporaneous experiences and challenges, and subsequently offer ideas for potential future improvements through new technology and methods.

An examination was conducted of new lighting technology that could replace old/existing equipment and greatly enhance lighting and markings methods, hardware reliability and equipment life. Findings are reflected in the new concepts and recommendations presented in this report.

The value of the recommendations and potential solutions to problems offered herein are open to further examination as other factors including operational needs and budget issues are considered. This report also recommends the use of comparative evaluations when alternative or conflicting ideas are presented. Effective, accurate, appropriate and cost-effective evaluations can be conducted using scale model photography and aerial refueling simulators that can be modified for lighting and marking analyses. Two such simulator facilities currently exist at the United States Air Force Research Laboratories (AFRL) at Wright Patterson Air Force Base, Ohio. Discussions with AFRL personnel indicate these facilities that currently are programmed for other studies and research could be modified to allow comparative evaluations of lighting and marking concepts for both unaided and aided vision.

The two AFRL simulator facilities at WPAFB identified by this study, which potentially could be used in evaluating aerial refueling lighting and marking concepts, were classified into two aerial refueling phases. The first facility appears to best serve the initial tanker identity, approach to pre-contact, and traffic control aerial refueling Phase I (Global Phase).

The second facility provides some overlap in global capability but best lends its capabilities towards the pre-contact through the hook-up/disconnect phase of the aerial refueling operations, Phase II. (Close-Up Phase). Both of the facilities offer potential for receiver aircraft pilot and boom operator perspectives of low light aerial refueling operations. The second facility currently is designed for the boom/receptacle method of aerial refueling. It is understood that both facilities can be modified to the probe/drogue method of aerial refueling.

In addition to simulation facilities, the use of scale aircraft models and partial aircraft sections in a photographer's dark room also provides a quick and low cost initial method for evaluating a variety of lighting and markings issues.

## **RECOMMENDATIONS**

### **Tanker, General**

Complete underbody illumination of the tanker is critical to the receiver pilot in maintaining close formation with the tanker, especially under ambient low light level conditions. Additionally, air turbulence combined with tanker turns and tanker non-illuminated fuselage close formation references (normally available during daylight illumination conditions) are critical factors requiring a fully illuminated tanker underbody. This is true for receiver pilots of both boom/receptacle and probe/drogue aerial refueling systems. Matching airspeeds and maintaining a safe attitude in close proximity to the tanker requires close formation tanker references, particularly when the receiver pilot does not have a natural horizon for reference. Overall tanker underbody platform references are required for maintaining close tanker formation under all lighting conditions, day or by artificial light sources at night.

### **Formation Flood Lighting Underbody Surfaces**

All tanker underbody surfaces (wing, fuselage, horizontal tail, engine nacelles) and wing leading edge should have balance and symmetrical illumination for low light level conditions.

### **Light Source Visibility**

Light sources for surface lighting should not be visible to the receiver aircraft pilot in either the wing formation position or the refueling positions. This includes aerial refueling with wing mounted aerial refueling stores/pods (drogue or boom), centerline boom, BDA kit or centerline hose type systems.

### **Dimming Controls**

Each light source should be individually fully dimmable from full bright (adequate for all light conditions) to full off with failure mode detection. A master dimming control be provided which allows the operator a single dimming control of all tanker external lighting (except the boom nozzle light) to enhance the use of night vision goggles (NVG). Covert operations using infra-red light sources also should be dimmable.

## **Aerial Refueling Equipment and Critical Reference Illumination**

All light sources should provide sufficient illumination for all key aerial refueling references, i.e., wing stores, engine nacelles, booms, hoses, couplings drogues and other aircraft references, i.e., antennas, rivets, etc. for all ambient lighting conditions.

### **Underbody fuselage Strip Formation Illumination**

Provide a centerline bottom fuselage strip (currently an orange painted stripe) to extend from nose of tanker to the tail cone at 6:00 OC position on fuselage with active lighting (i.e., strip lighting with highly reliable LED's or electro-luminescent strip lighting). Also provide active lighting (similar to above) lateral strips spaced 10 feet apart along the underbody to extend from the tail cone to the nose of the aircraft. These stripes should be extended to center of aircraft body.

### **Tail Mounted Flood Light**

Provide the tanker's vertical tail or tail cone with redundant flood light sources for illuminating the top surface of the receiver aircraft and top surface of the aerial refueling boom and fuselage mounted hose. This light coverage should extend beyond a fully extended boom at 20° elevation and  $\pm 15^\circ$  lateral boom position. The light source should be a soft light (no direct filament visibility) with sand blasted lens (or equivalent). Operator controls should be equipped with a distinct position denticulated variable dimming control with a minimum of 10 positions of dimming. The operator dimming controller should be provided with lamp failure mode detection.

### **Anti-Collision Beacon and Strobe Light**

The tanker's rotating beacon/strobe lights (upper fuselage and lower fuselage) should be equipped with the capability to:

- A. be identified as a tanker and aerial refueling equipment (drogue, boom or dual) aerial refueling capability; and
- B. separate operator controls for upper or lower beacon and with full dimming controls to off.

Note: These separate controls allow appropriate lights to be dimmed or turned off so that their glare does not interfere with the vision of the receiver pilot and tanker operators while aerial refueling. During the aerial refueling operation, the lower rotating beacon/strobe light of the tanker and the top rotating beacon on the receiver aircraft must be turned off. During the operation, the lower rotating beacon on the receiver should be turned on so that the aerial refueling formation can be identified.

### **Vertical Stabilizer (Logo) Illumination**

The vertical stabilizer (both sides) of the tanker should be illuminated to assist in tanker identity. This light as all external lights are required to be fully dimmable from full on to full off as described above (individual and master controller).

## **Wing Tip Formation References**

Illuminated wing tip formation references are necessary for the receiver aircraft to maintain tanker formation prior to their departure to the refueling pre-contact position. The use of strip and formation lights have been typically used for this application.

## **Tanker Boom/Receptacle Method**

### **Nozzle Light**

The boom should be equipped with a redundant nozzle light for illuminating the boom nozzle at any boom telescoping position and for the use as a spot on the receiver aircraft surface in order to avoid contact with critical fuselage (no contact) areas, i.e., windshield, canopy, skin contours, protruding objects, antennas, externally mounted aerial refueling receptacle installations. This light also should provide illumination of the slipway/fuselage receptacle tape/paint markings and for locating the aerial refueling receptacle/slipway of the receiver aircraft.

The nozzle light should be located at a 6:00 OC position within the boom ice shield with the light filament source not visible to the receiver pilot. The coverage should be the equivalent to the KC-135 boom nozzle replacement light currently planned for a KC-135 retrofit, i.e., TCTO –1C-1351422 (a kit 1560 KO 180 480 AFL). The fixture should have as a minimum, the equivalent life of the KC-135 replacement nozzle light and a full variable dimming control (controlled by aerial refueling operator) from full bright to off with lamp failure mode detection.

### **Boom Telescoping Tube Envelope Markings**

The boom telescoping tube envelope should be provided with 360° circumference fluorescent markings illuminated by a light in the boom ice shield. These should be equivalent to the fluorescent markings (illuminated by a black light) in the KC-135/10 boom ice shield. These markings should be visible to both the boom operator and the receiver pilot prior to hook-up. Receiver pilots with forward-of-cockpit aerial refueling receptacles also should be able to see the markings after hook-up. These markings should be similar to the KC-135 and KC-10 boom marking indicating the boom telescoping tube center envelope with green markings, yellow indicating limit envelope, and red indicating out of envelope position. The markings should be compatible with night vision goggles (NVG) equipment. (Colors are not detectable with NVG.) Standardization of markings should be a primary consideration.

### **Pilot Director Lights**

Currently, the KC-135, KC-10, KCD-10 and some international KC-707 and KC-767 tankers are equipped with pilot director lights (PDL's). These PDL's are light strips located forward underbody of the tanker. These PDL's are used by pilots of receptacle-equipped receiver aircraft to aid the pilot in establishing proper position for hook-up and in maintaining proper position after hook-up. Prior to hook-up, the boom operator, from his position in the tanker, has control of the PDL's to direct the receiver pilot into position. After the receiver aircraft is in position, the boom operator guides the boom nozzle into the receiver aircraft receptacle to achieve a hook-up. After hook-up, the

PDL's become an automatic system that provides forward/aft and up/down position information.

With the KC-10, the PDL's also provide trend information. The KC-10 PDL's include several positive features that are not found on PDL's on the KC-135. These features include elongated letters, increased white background lighting and brighter color lighting of green (center of boom envelope), yellow/amber (caution approaching disconnect envelope), and red (pending disconnect envelope). These lights generally provide supplementary boom position information to the receiver pilot. These improvement features originally were incorporated on the KC/KE-707's international air forces' foreign military sales (FMS) tanker aircraft. Improvements were not made to the KC-135 PDL's to incorporate these features.

All future tanker aircraft designers should consider, as a minimum, the KC-707/KC-10 type director light improvements described above.

Receiver aircraft pilots may use a variety of primary visual references on the tanker underbody: the centerline TACAN antenna at ~FS-966 KC-135, rows of rivets, etc. These primary references are used in combination with the PDL's as formation aids before hook-up and in maintaining proper position on the boom after hook-up.

### **Alternative Solution for PDL's**

New ideas and concepts for improved equipment that could provide formation, receiver aircraft position and boom position signals should be evaluated and compared with the current equipment. New, easily read, accurate equipment could be positioned further aft on the tanker underbody and serve as a single reference to replace the current PDL's and the use of other references such as antenna and rows of rivets.

A combined formation/position (screen) system (CFPS) also should incorporate flush aircraft contour retraction features to avoid loss of efficiency due to dirt/sand contamination when not in use. The various models and simulators described in this report may be used to assess the value of such combined formation/position equipment.

### **Boom Operator Instrumentation Panel and Receiver Pilot Cockpit Three Position Status Lights**

The three position cockpit/operator station status lights currently used by both the boom operator and receiver pilot (blue = ready; yell/amber = contact made; red = disconnect) should be retained as standard for both the boom operator and the receiver pilot. Critical lights and boom position instrumentation should be in the boom operator's line of sight to the receiver aircraft.

### **Boom Load Indicator**

Investigate incorporating a boom nozzle load indicator in the boom operator's line of sight with crosshairs/load circles to ensure that telescoping boom loads are within normal operating load parameters and below limits.

### **Boom Interphone**

Provide tanker with through-the-boom inter-communication capability.

## **Tanker Drogue Method**

### **Receiver Closure Rate Warning Lights**

Methods should be investigated for warning receiver pilots that safe closure rate (prior to contact) is being exceeded. The CFPS described in Paragraph 1.12.1 above could be programmed to provide information for the centerline hose reel system.

### **External Tanker Status Lights (Drogue System)**

The three position status lights currently provide aerial refueling drogue system status to the probe equipped receiver pilot and the tanker operator: yellow/amber = ready (for hookup); green = fuel flowing; red = low/no hose response (no hydraulic), i.e., emergency hook-up only.

Provide the receiver pilot three-position status lights as described above. In some cases, a flashing yellow light that indicates inner and outer hose envelope position has been exceeded also should be provided. These lights should be visible to the receiver pilot from pre-contact to disconnect. Duplication of these status lights may be necessary depending on receiver pilot position before and after hook-up and throughout hose envelope position. The hose reel operator should be provided a duplicate set of these status lights on the hose drogue operator panel for each drogue system employed wing or fuselage. These lights should be provided with dimming controls from full bright to full off.

These three status lights should be NVG compatible and internationally standardized. Currently four or more variations of NVG-compatible designations are either proposed and/or incorporated on existing and new tanker aircraft. A single universal international designation should be adopted which best serves the receiver pilots. An evaluation of all current/proposed methods be conducted and a single NVG compatible standard be adopted and that configuration be illustrated and mandatory for all probe/drogue aerial refueling procedure technical orders, (ATP-56) STANAG 3971 and STANAG 3447, as the international standard.

### **Tanker Turn Indicator Light**

Investigate methods for alerting receiver pilot that tanker turn is imminent.

### **Boom-to-Drogue Adapter Kit (BDA Kit)**

Methods for providing BDA kit hose position and refueling status should be investigated. This status should be made available to both the receiver pilot and the boom operator.

### **Drogue/Coupling Lighting, Markings and Hose Markings Illumination**

Currently, most couplings and drogue canopies are either white or equipped with wide angle reflective white tape/paint. Some drogues and attached couplings are equipped with generators supplying electrical power to small incandescent lights attached to the drogue struts thus providing internal cone illumination. In some cases, tritium buttons are used in lieu of lights to identify the drogue internal cone.

Recently, external illumination by use of LED's to identify the external coupling/drogue hardware has been employed by tanker aircraft. This external lighting configuration of the coupling/drogue provides the receiver pilot valuable information as the receiver pilot moves from the wing formation position on the tanker to the pre-contact position behind the drogue.

As a minimum, the above lighting and marking configurations for both internal drogue cone and external coupling and drogue should be provided for all future tanker coupling/drogue aerial refueling systems.

### **Aerial Refueling Hoses**

The hose and hose markings provide the receiver pilot tanker closure rate and position information. In some aerial refueling hose installations, additional hose markings also may provide the receiver pilot center-of-envelope, inner and disconnect position limits.

Standard 10 foot spacing of hose markings with contrasting hose colors (black hose with white markings and white hose with black markings) is recommended. Hose inner/outer limits and center-envelope should be evaluated as optional standards in aerial refueling system lighting simulators. The white hose offers lighting visibility value over the black hose. Also, the white (1 ft) markings on the black hose become dirty, and it becomes difficult to illuminate and visually detect the white/black marking contrast. Lighting for wing mounted drogue stores/pods and hoses should be provided by forward tip of horizontal tail lights.

### **Existing Tankers Aerial Refueling Lighting Improvements**

#### **KC-135**

Four primary improvements recommended for the KC-135 aircraft are:

- 1) illuminate the aft empennage body from the wing root to the tail cone including underneath the horizontal stabilizer.
- 2) provide active lighting for the centerline orange fuselage stripe.
- 3) expedite the retrofit of the existing nozzle light with the nozzle light kit flight and service tested by USAF/AMC in the early 1990's. This light is now being implemented. All KC-135 aircraft are to receive the retrofit kits by end of August 2005 in accordance with TCTO-IC-135-1422 and A-kit 1560 KO-180 480 AFL.
- 4) improve boom position pilot director lights similar to those used on the KC-10 and KC-707 international tankers as described previously. Alternatively evaluate new concept of Paragraph 1.12 herein as a potential retrofit.

Other improvements to be considered include:

- A) tilting the boom position gauges near parallel to the operator window similar to the KC-707 international tanker configuration;
- B) Boom load alleviation indicator;

- C) vertical tail illumination (both sides); and
- D) all lights modified to have individual dimming controls for NVG compatibility.

### **KC-10A Tanker**

With few exceptions the KC-10A tanker may serve as a starting point for future tanker lighting and ergonomically efficient designs. Exceptions are the new concept for PDL's (Paragraph 1.12.1), active underbody centerline and lateral striping, and receiver aircraft closure warning light.

### **Receiver Aircraft, General**

This section of the recommendations covers lighting on the receiver aircraft that is pertinent to the tanker boom operator's and crew's view. It includes the receptacle/slipway and probe equipment.

In addition to the receiver aircraft aerial refueling lighting, side fuselage illumination also should be a major consideration along with anti-collision lights to assist other receiver aircraft and tanker crews in aircraft tracking and monitoring.

The following lighting/marking recommendations are provided in addition to those mentioned earlier for the tanker aircraft to insure that future and current receiver aircraft are equipped with adequate lighting intensity and reliable lighting/marking to insure safe and reliable aerial refueling.

### **Receptacle/Slipway Equipped Receiver Aircraft**

- A. Provide redundant slipway/receptacle lighting as a minimum equivalent to the UARRSI;
- B. Provide adequate lighting for areas on receiver aircraft in which protruding objects, aircraft engine nacelle contours and receptacle slipway installations are raised above aircraft contours that cannot be illuminated by the tanker lighting, i.e., tail mounted floodlight (TMF). Special consideration should be given for aircraft employing low observable paint;
- C. Provide symmetrical and balanced overwing/fuselage lighting;
- D. Outline windscreens with reflective paint/tape;
- E. Provide T-bar reflective markings and outline receptacle/slipway (UARRSI) with same;
- F. Provide separate on/off controls for upper and lower anti-collision (rotating beacon) light with full operator dimming controls;
- G. Provide fighter/attack aircraft with fuselage side mounted and critical formation strip lighting;
- H. Provide all external lights with full bright to full off dimming controls;
- I. Provide all future receiver aircraft with through-the-boom intercom capability; and

- J. Retrofit all aircraft currently not equipped with through-the-boom intercom communications.
- K. The use of receiver aircraft and tanker scale math models for aerial refueling receptacle installation and receiver aircraft exterior paint should be evaluated by engineers and operators in both photography laboratories and full scale simulators. These lighting evaluations should be accomplished prior to prototype aircraft development to avoid night aerial refueling restrictions to production aircraft.

### **Receiver Aircraft Probe Installations**

The following recommendations are for the probe equipped receiver aircraft. The receiver probe/fuselage light sources are designed to assist the receiver pilot in making the aerial refueling hook-up by illuminating the receiver's aircraft probe and the tanker's aerial refueling drogue/coupling, hose. They also should provide a redundant source of light for the aerial refueling store/pod, the fuselage hose exit and for other tanker references, i.e., engine nacelles. The receiver aircraft's aerial refueling probe nozzle light and/or fuselage light should provide this illumination for the BDA kit hose/drogue and boom telescoping tube.

### **Probe Equipped Receiver Aircraft**

- 1) Provide a probe and/or fuselage mounted floodlight on the receiver aircraft with redundant light sources (bulbs) to illuminate the following:
  - A. Probe nozzle (receiver aircraft)
  - B. Drogue/coupling (tanker)
  - C. Tanker hose/drogue markings
  - D. Aerial refueling store/pod (tanker)
  - E. Fuselage Drogue Exit (tanker)
  - F. BDA kit hose and boom telescoping tube (tanker)
  - G. Critical tanker formation references, i.e., engine nacelle, wing, fuselage (tanker)
- 2) Provide the receiver probe light with cockpit dimming control from full on to full off;
- 3) Provide the smaller fighter/attack aircraft with critical formation fuselage side-mounted strip lighting; and
- 4) Provide the anti-collision rotating beacon light with separate on/off controls and full dimming capability.

### **Night Vision Goggles (NVG) Compatibility and Covert Operations**

NVG compatibility is a major issue with some current tanker and receiver aerial refueling lighting sources not equipped with full bright to full off operator dimming

controls. Also, the colors used for status lights, pilot director lights and color coded boom telescope markings are not distinguishable with NVG equipment.

It is recommended that all tanker and receiver aircraft aerial refueling light sources should be dimmable to full off. The use of color (red, green, yellow) lighting to indicate aerial refueling status and formation position is ineffective with NVG; other forms of symbology and/or bright/dim flashing light techniques for transmitting critical information should be developed. Infra-red (IR) light sources should be provided for all formation, aerial refueling equipment, TMF, nozzle and PDL lights mentioned above for covert operations.

New methods and techniques for transmitting critical aerial refueling information should be evaluated in the aforementioned aerial refueling lighting simulators and/or scaled mock-ups.

### **Future Research Concepts Evaluations Methods**

Three techniques should be considered for evaluating and comparing potential aerial refueling lighting solutions/concepts and for evaluating new technologies:

- 1) The use of scale aircraft models and photography should be employed as a method for initial evaluations of the receiver pilot's geometric vision of tanker references/equipment and boom operator's vision requirements of receiver aircraft references/equipment.
- 2) The use of existing aerial refueling simulators modified for lighting/marketing evaluations will allow initial screening and selection of the best resolution of a given lighting issue. Some refining of any given solution may be possible depending on the simulator fidelity and image quality.
- 3) Initial development aircraft may be used for ground and flight test evaluation of aerial refueling lighting. Evaluation points may include the lighting direction, intensity and coverage for the production tanker or receiver.

The recommendations, solutions and new concepts described herein should be evaluated by the above methods to reduce program risk and provide cost effective solutions for safe night and day aerial refueling for both overt and covert operations.

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### 3. Short Bios and Primary Functions

**Dexter Kalt, Principle Investigator** has 45 years of experience in aerial refueling research. For over 30 years Mr. Kalt served as a fuel system and aerial refueling aerospace engineer for the Fuel and Aerial Refueling Systems for Aeronautical Systems Division (ASD) Fuels and Hazards Branch at Wright-Patterson Air Force Base. Mr. Kalt co-founded the Aerial Refueling Systems Advisory Group (ARSAG) 27 years ago and has served as Chairman and Executive Director of that inter-service, international organization. Presently Mr. Kalt is the president of Aerial Refueling Inc., and is a member of the Fuels/Materials group at the University of Dayton Research Institute. As a consultant Mr. Kalt has continued to assist the U.S. Air Force, U. S. Navy, and U.S. Army as well as U.S. and international military and commercial organizations as they experienced aerial refueling challenges. Mr. Kalt received a BSME from West Virginia University in 1959.

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## 4. Background

The purpose of this effort is to document the best ways to proceed in the development and evaluation of concepts for lighting system enhancements to improve both current and future aircraft mission capabilities, and maintenance support.

The scope of this study is to determine requirements that provide optimum visibility and depth perception for the tanker operator and visibility for the receiver pilot to minimize risk during the aerial refueling process. The study was also designed to address/recommend current, near-term, and future lighting technologies that could be applied to future and existing platforms.

Aerial refueling is highly dependent upon the participating operators' abilities to see and accurately locate the receiver aircraft and aircraft in formation, as well as the receiver aircraft pilot's capability to determine and maintain position relative to the tanker. Difficulties in these areas are exacerbated during low light or night aerial refueling operations. Lighting provides not only indication of relative location but also highlights the critical visual cues needed for depth perception and facilitates communication. This is true for both boom/receptacle and probe/drogue refueling systems. Primary focus of this effort is directed toward aerial refueling such as KC-135, KC-10, tanker-type aircraft and future aircraft.

This background is provided to describe tanker and receiver aircraft aerial refueling equipment for both boom/receptacle and probe/drogue aerial refueling systems. In addition to these two systems, a variation of the tanker drogue system is employed on the KC-135 boom; it is commonly referred to as the boom-to-drogue adapter (BDA) kit. Details of the two different aerial refueling systems and the tanker BDA kit are described in detail and photos are provided in Attachment 1.

### ***4.1. Aerial Refueling Equipment Description and Operation***

Photographs are contained in Attachment 1 for the following discussions.

#### **4.1.1. Boom Receptacle**

Transfer of fuel using the boom/receptacle aerial refueling system method requires two distinctive functions: the tanker boom operator conducts the hook-up functions while the receiver pilot flies formation on the tanker aircraft. The boom operator controls and maneuvers the flying boom. The boom is a solid apparatus (~28 ft. not extended, 47.4 ft. fully extended telescoping tube) long on the KC-135, and (~37 ft not extended to 58 ft. fully extended telescoping tube) long on the KC-10 that contains a telescoping fuel tube. It is attached underneath the empennage centerline near the tail of the tanker. The fuel nozzle is attached to the end of the telescoping tube which fits into the receiver aircraft's receptacle. Ruddevator control surfaces allow the boom operator to "fly" the boom. After the receiver pilot has stabilized the receiver aircraft in position, the boom operator extends the telescoping tube portion of the boom and its attached nozzle into the receiver aircraft receptacle.

Toggles within the receptacle latch onto the boom nozzle latching grooves thus forming a tight seal with the receptacle's sliding valve assembly elastomeric seal. This nozzle receptacle connection forms the fuel flow path between the tanker and receiver aircraft. When the boom nozzle is inserted into the receptacle sliding valve, a contact switch is closed sending an electronic signal to provide power to a hydraulic valve to close the receptacle's hydraulically actuated toggles. As the receiver's receptacle toggle latches are closed and locked onto the tanker's nozzle, a toggle latch switch closes and provides electrical power to the receiver aircraft electronic three-position switch (signal amplifier) through a set of induction coils, one half in the receptacle and the second half in the boom nozzle. An electrical signal pulse advances both the receiver aircraft signal amplifier and a similar signal amplifier in the tanker to the latched position.

A set of status lights (ready/contact-made/disconnect) reflect the tanker's signal amplifier position by illuminating the tanker contact-made light and the receiver aircraft nozzle latched light.

Either the tanker boom operator or the receiver pilot can unlatch the nozzle via a disconnect switch or by exceeding the boom disconnect envelope. Sustained fuel pressure in the receiver aircraft also may result in a disconnect. The receiver aircraft exceeding the boom disconnect envelope also will result in a disconnect. In addition to the KC-135 disconnect capability, the KC-10 boom system also employs an independent disconnect capability which by pneumatic pressure collapses the boom nozzle toggle latch groove seats.

In both the tanker and most receiver aircraft, the signal amplifier MIL-S-38449 Type 4 also provides through-the-boom intercom communication capability for both the tanker crew/boom operator and the receiver pilot.

Variations of the aerial refueling receiver aircraft boom/receptacle type or equipment currently are used throughout the United States Air Force and Navy and international military services. The Universal Aerial Refueling Receptacle Slipway Installation (UARRSI) is a modular package with quick removal features. Other receptacle/slipway installations include fixed integral airframe units and rollover units. Although these receptacles vary in installation design, the boom nozzle interface is common and compatible with the military standard MS-27604 boom nozzle envelop/interface employed on the KC-135 and KC-10 booms and the KDC-10 boom. Receptacle locations vary with each receiver aircraft. They include nose mounted, forward of windscreen, aft of canopy windshield and wing root mounted.

#### **4.1.2. Probe/Drogue Aerial Refueling**

The receiver pilot is in control during the probe/drogue method of aerial refueling (see Attachment 1). In this method the aerial refueling hose is unwound from the tanker's hose reel drum so that it trails from the tanker fuselage or wing(s). A coupling and drogue are attached to the end of the hose. The drogue is a cone- (basket-) shaped, collapsible apparatus that attaches to the coupling and serves to stabilize the motion of the hose. Additionally, it provides hose drag to achieve a horizontal hose trail position. The receiver pilot effects contact by maneuvering the aircraft into position so that the probe nozzle on the receiver aircraft is inserted into the tanker coupling. The connection is

secured by the coupling's spring loaded latches. An additional coupling latching force is provided by fuel pressure, i.e., 2lbs/psi fuel pressure (~200 lbs.). After fuel transfer, disconnect is effected by the receiver pilot by extending the hose to the full trail position until the nozzle exceeds the coupling latching force. Fuel pressure/flow is terminated at ~5 ft. of the hose full trail position. Also, fuel flow may be terminated by a fixed amount of fuel to be transferred and is controlled by the tanker operator.

The standard probe/drogue aerial refueling method may be employed on: 1) a tanker aircraft with a hose reel (wings and/or fuselage), e.g., KC-10 fuselage and wing; KC-135 wing and K/HC-130/MC-130 wing; or 2) a receiver aircraft equipped with aerial refueling (buddy store) hardware to transfer fuel to another aircraft and designated as a tanker. These types of drogue systems provide automatic hose tension throughout the hook-up and fuel transfer sequence.

### **4.1.3. Boom-to-Drogue Adapter Kit**

In contrast to these two systems, the boom-to-drogue adapter kit as described in Attachment 1 does not employ a hose self-tensioning system; it depends on the receiver aircraft probe to push the hose into a "C" shape (approximately half the hose length) as facilitated by the hose end trunnion (1/2 universal joint) just forward of the coupling and drogue. This BDA kit system provides for a very small geometric hose envelope for receiver movements after the hook-up is made. In most cases, the boom is positioned to the 30° elevation (below horizontal), zero azimuth and telescoping tube fully extended. The boom is not normally moved from this position and is maintained motionless throughout the aerial refueling. Fuel flow is manually initiated by advancing the signal amplifier to a "contact-made" condition after the boom operator's verification that a positive coupling between the tanker's coupling and receiver's probe nozzle has been established. Disconnect is accomplished by the receiver aircraft by moving the receiver aircraft to the initial hose trail position. Fuel flow is normally terminated by the tanker boom operator advancing the signal amplifier from "contact-made" to "disconnect."

The probe/drogue system for receiver aircraft carry a probe mast equipped with a standard nozzle IAW international standard STANAG 3447. The tanker is equipped with a drogue and coupling also IAW international standard STANAG 3447. Probe installations vary between each type of receiver aircraft, and are located in the nose area of the aircraft so that the receiver aircraft pilot can see the probe mast's nozzle.

Other important factors include monitoring the probe equipped receiver aircraft closure rate on the tanker drogue equipment, i.e., wing, fuselage hose reels and the BDA kit. The wing/fuselage hose reels require less attention than the KC-135 BDA kit. Closure on BDA kit drogue requires that the receiver achieve a very low closure rate due to the extremely small drogue/hose envelope. Also, the boom operator is required to initiate fuel flow procedures by observing the hose and receiver aircraft contact. Standard BDA kit procedures require no boom movement or tracking assistance prior to and during the hook-up/disconnect evolution. The boom operator's and flight engineer's duties do require boom/drogue deployment and verification of the full hose extension and operation. Relieving fuel pressure by retracting the boom telescoping tube after each BDA kit fuel transfer and wetting down the fuel seals periodically are additional tasks.

#### **4.1.4. Tanker Aerial Refueling References**

The receiver aircraft pilot uses references on various parts of the tanker, i.e., antenna, aerial refueling equipment, rows of rivets, etc. for formation and maintaining position on the tanker aircraft. During night aerial refueling, these references are illuminated by directed light sources and/or by reflected light. These light sources typically are provided by the tanker aircraft; however, with the probe/drogue method, the light sources may originate from the receiver aircraft probe mast and/or fuselage. Tanker lighting normally includes under-wing, underbody, engine nacelle and wing tip for formation flying. In some cases, illumination is provided under the horizontal stabilizer and on the aft fuselage.

##### **4.1.4.1 Boom/Receptacle Aerial Refueling Method**

Position-keeping and attitude for boom/receptacle aerial refueling generally is provided for the receiver aircraft pilot by the rows of rivets, antenna, centerline stripe and other tanker formation/station-keeping objects. The pilot director lights provide additional tanker position keeping information to receiver pilots, especially when the receptacle is located behind the pilot. The boom fluorescent markings (illuminated by a black light) in the boom ice shield are provided by the tanker boom and are a primary aid to receiver aircraft with receptacle located forward of the cockpit. The tanker boom operator uses the boom nozzle light to effect hook-ups and disconnects. The tanker tail-mounted flood light and over-fuselage/wing lighting of the receiver aircraft provide additional lighting for assisting the boom operators hook-up/disconnect functions. These light sources may include aerial refueling area lights, reflectors, slipway and receptacle lights, over-wing lighting and, in some cases, a tail-mounted floodlight on the receiver aircraft which illuminates the receptacle slipway and critical areas. In one case, an air spoiler located aft of the UARRSI provides for mounting light sources. These spoiler lights are directed for forward lighting onto the UARRSI and down the nose slope of critical aerial refueling raised fairing areas. Reflected light from both the tanker and the receiver aircraft illuminates the reflective paint/tape markings, i.e., UARRSI outline, T-bar lead-in markings, wind screen and other critical areas. In some cases, the T-bar lead-in markings are active by the use of electro-luminescent lighting.

##### **4.1.4.2 Probe/Drogue Aerial Refueling Method**

The probe/drogue receiver pilot uses a variety of visual indicators to aid in formation flying, position-keeping, and attitude information after the contact is made. These include wing stores/pods, engine nacelles, under-wing, under-fuselage, hose markings (black or white), hose exit from fuselage or store, centerline fuselage stripe, boom telescoping tube markings, wing/fuselage protruding antennas, rows of rivets, distinct wing and fuselage contours and intersections and markings and the aerial refueling drogue. Illumination for low light level and night aerial refueling is provided by direct light sources, reflected light, contrasting paint and colors, the receiver aircraft probe nozzle and fuselage lights, drogue (peanut) lights powered by ram air generators, drogue tritium buttons and other fuselage, wing, aerial refueling store nacelle light sources.

#### **4.1.5. Lighting Dimming Controls**

Most tanker and receiver aircraft of current vintage are provided with lighting controls for dimming from “full on” to “full off”. This provides both the receiver pilot and boom operator light levels consistent with ambient light and tolerable for aerial refueling task accomplishment. However, the receiver pilot identification of objectionable tanker light sources requiring dimming can be challenging even during radio communications.

#### 4.1.6. Tanker/Receiver Aircraft Equipment

The following tables list most of the United States tanker and receiver aircraft, their types, location and some lighting and communication equipment description:

Table 1. Tanker Aircraft Aerial Refueling Equipment

<i>No.</i>	<i>Tanker</i>	<i>Type Equipment</i>	<i>Operator/Observer Vision</i>	<i>Receptacle Receiver Capability and Thru-the-Boom (TTB) Communications Capability</i>	<i>Pilot Director (PDL) and Status Lighting</i>	<i>Lighting Equipment, Fuselage/Wing, etc.</i>
1.	KC-135	Centerline Flying Boom	Director Window View	Receptacle (Limited Models) (B-52 type) TTB	Position (PDL)	See Attachment 1, photos 1a – f.
2.	KC-10	Centerline Flying Boom	Direct Window View	UARRSI TTB	Command (PDL)	See Attachment 1, photos 2a – e.
3.	KDC-10	Centerline Flying Boom	Camera Vision	Unknown	Unknown	Not Shown
4.	KC-707 (IIAF)	Centerline Flying Boom	Direct Window View	None	Position (PDL)	Not Shown
5.	KC-747 IIAF	Centerline Flying Boom	Direct Window View	UARRSI TTB	Not KC-135/10 Type PDL	Not Shown
6.	KC-767	Centerline Flying Boom	Camera View	UARRSI Unknown	Store Status *	Not Shown
7.	KC-135	Drogue Wing Pods (Limited Number)	Direct Window View	N/A	N/A	Not Shown
8.	KC-135	BDA Kits	Direct Window View	N/A	Yes Status	Not Shown
9.	KC-10	Drogue Centerline Hose Reel	Direct Window View	N/A	POD Status	Not Shown
10.	KC-10	Drogue Wing Stores	Direct Window View	N/A	POD Status	Not Shown
11.	KC-130	Drogue Wing Stores	Direct Window View	UARRSI TTB	POD Status	Not Shown
12.	HC-130N/P	Drogue Wing Stores	Direct Window View	N/A	POD Status	Not Shown
13.	MC-130H	Drogue Wing Stores	Direct Window View	UARRSI TTB	POD Status	Not Shown
14.	KC-707 IIAF	Drogue Wing Stores	Direct Window View	N/A	POD Status	Not Shown
15.	KC-767	Drogue Fuselage Hose	Camera View	UARRSI TTB	POD Status	Not Shown
16.	KC-767	Drogue Wing Stores	Camera View	N/A	POD Status	Not Shown

Table 2. Receiver Aircraft Aerial Refueling Equipment Receptacle Type

No.	Receive Aircraft	Type Equipment	Equipment Location on Aircraft	Type Lighting & Dimming Control Slipway, Area, Other	Receptacle Lead In Markings	Thru-the-boom voice	Receiver Pilot Status Lights
1.	A-10	UARRSI	Nose centerline, flush contour	UARRSI, No, No	IT	Y	Yes/ signal amplifier
2.	B-1	UARRSI	Nose centerline, flush contour	UARRSI, No, No		Y	Yes/ signal amplifier
3.	B-2	Roll Over	Aft centerline, fuselage contour	Slipway, area, no			Yes/ signal amplifier
4.	B-52	Clam Shell Doors	Aft centerline, fuselage contour	Slipway, no, no		N	Yes/ signal amplifier
5.	C-5	Drop Door	Aft centerline, fuselage contour	Slipway, no, no		N	Yes/ signal amplifier
6.	C-130	UARRSI	Aft centerline, fuselage contour	Slipway, yes, no	2T	Y	Yes/ signal amplifier
7.	C-141	UARRSI	Aft centerline, fuselage externally mounted	Slipway, yes, no	2T	Y	Yes/ signal amplifier
8.	C-17	USRRSI	Aft centerline, fuselage, flush	Slipway, yes, TMF		Y	Yes/ signal amplifier
9.	E-3	Clam Shell Doors (B-52 type)	Aft centerline, fuselage, flush	Slipway, no, no		N	Yes/ signal amplifier
10.	E-4	UARRSI	Nose centerline fuselage above ski contour	Slipway, no, no	3T	Y	Yes/ signal amplifier
11.	E-6	UARRSI	Aft centerline, fuselage, flush	Slipway, unknown, no		Y	Yes/ signal amplifier
12.	E-707	UARRSI	Aft centerline, fuselage, flush	Slipway, yes, no.		Y	Yes/ signal amplifier
13.	F-15	Drop Door Fixed	Left wing root, flush	Slipway, unknown, unknown		N	Yes/ signal amplifier
14.	F-16	Drop Door Fixed (B-58 type)	Aft canopy centerline fuselage, flush	Slipway, no, TMF		Y	Yes/ signal amplifier
15.	F-22	Drop Door Fixed (B-58 type)	Aft canopy centerline fuselage, flush	Slipway, yes, TMF		Y	Yes/ signal amplifier
16.	F-117	Roll Over	Aft canopy centerline fuselage, flush	Slipway, yes, TMF			Yes/ signal amplifier
17.	KC-135 (SP)	Clam Shell Door	Aft cockpit centerline fuselage, flush	Slipway, no, no		N	Yes/ signal amplifier
18.	KC-10	UARRSI	Aft cockpit centerline fuselage, flush	Slipway, yes, no	3T	Y	Yes/ signal amplifier
19.	KC-767	UARRSI	Aft cockpit, centerline fuselage, above contour	UARRSI, no, no			Yes/ signal amplifier

Table 3. Receiver Aircraft Aerial Refueling Equipment Probe Type

No.	Receiver Aircraft	Type Equipment	Equipment Location on Aircraft	Type Lighting
1.	A-6	Non-retractable	Centerline fuselage nose	Probe light
2.	AV-8B	Extendable / telescoping	Left wing, external mounted	Probe light
3.	F-14	Fully retractable	Right fuselage nose	Probe (red lens)
4.	F-18	Fully retractable	Right fuselage nose	Probe light
5.	HH-53 (rotary wing)	Fully retractable	Right fuselage nose	Above cockpit variable control
6.	HH-60 K/L (rotary wing)	Fully retractable	Right fuselage nose	Above cockpit variable control
7.	HH-47 7D/E (rotary wing)	Non-retractable	Right fuselage nose	Above cockpit variable control
8.	S-3	Overhead cockpit centerline Fully retractable	Centerline overhead canopy	Probe light
9.	Tornado	Within fuselage or externally mounted pylon depending on country and model	Right or left mid fuselage depending on country and model	Probe light

#### **4.2. Tanker Identity and Aerial Refueling Sequence**

This section briefly describes the aerial refueling sequence of events from the initial tanker aerial refueling identity by the receiver aircraft to the completion of the aerial refueling process. Details of the AR sequence are contained in USAF Technical Order T.O. 1-1C-3.

The initial tanker aerial refueling identity communication is accomplished electronically via air-to-air TACAN, Radar, AWACS, GPS, TCAS, Weather, and radios etc. When the initial electronic methods are completed, visual methods may then be necessary. The use of the tanker rotating beacon/strobe, vertical tail (logo) surface illumination, as well as underbody illumination should provide the receiver pilot the visual tanker close in identity. In some cases, where radio communications are acceptable, the boom operator and/or tanker pilots may identify the receiver aircraft first and provide some position guidance to the receiver pilot of the tanker location.

When several tankers are in a given locale, but spaced by altitude, the receiver pilot is provided with electronic/pre-briefed altitude for which tanker and the receiver aircraft is assigned.

The tanker operator and receiver pilots depend on receiver aircraft fuselage/wing electro-luminescent strip lighting rotary beacon, formation lights, etc. for traffic monitoring/control.

The receiver aircraft's flight lead pilot controls the formation off the wing of the tanker and which receiver(s) aircraft receive tanker fuel first. Depending on the tanker aerial refueling equipment, fuselage boom or drogue, only one receiver of the formation will proceed to the centerline boom or drogue (on deck position) to obtain fuel and move to the opposite wing on completion of fuel transfer. In some cases, in order to fill up all the formation receiver aircraft in near equal amounts, the aerial refueling receiver rotation process cycle may be repeated more than once.

When the tanker carries wing mounted hose/drogue stores (pods), the compatible size receiver aircraft, i.e., fighters, attack type aircraft, two aircraft may be aerial refueling simultaneously. This reduces the number of repeat cycles of aerial refueling fuel transfer and reduces the fighters' time on the tanker.

A process called quick flow as described in USAF Technical Order 1-1C-1-3 allows the receiver aircraft to move quickly to the aerial refueling boom on deck position. This process differs from the normal process in that the receiver aircraft can be aerial refueled faster under employment conditions. After the designated receiver's aircraft moves from the wing formation position, the pilot positions the receiver aircraft to be aerial refueled into a pre-contact stabilized position behind the wing drogue/store/pod or centerline boom or drogue.

With the boom/receptacle method, once the receiver aircraft is stabilized, the pilot is directed by the boom operator into the contact position either by verbal direction or by director lights. Then, the boom operator effects the contact. This boom procedure is different for the probe/drogue aerial refueling method. After the receiver aircraft pilot has stabilized the aircraft (probe/drogue) in the pre-contact position, the pilot directly effects the drogue/coupling contact. The receiver then moves to a position in the system aerial refueling envelope, and the fuel transfer sequence is initiated. When the fuel transfer is completed, the receiver aircraft moves to the disconnect envelope (trailing drogue) position and the coupling and nozzle mechanically separate.

#### **4.2.1. Emergency Breakaway KC-10, KC-135**

Details for the emergency breakaway are contained in T.O. 1C-1-3.

When an emergency breakaway is called for, due to an emergency condition by either the tanker and/or receiver crew members, the following actions are taken:

1. Boom Operator
  - a. Radio/boom interphone: Tanker call sign
  - b. Radio/boom interphone: "Breakaway, Breakaway, Breakaway"
  - c. Flashes pilot director lights (manually for KC-135, automatically flashes on initiation for KC-10) and/or wing/fuselage drogue flashes red status light
2. Tanker Pilot/2<sup>nd</sup> Pilot
  - a. Turns on lower rotating beacon (bright)
  - b. Throttle to maximum power

- c. Straight ahead direction or climb if receiver aircraft verified cleared
- 3. Receiver Crew Member
  - a. Reduce power
  - b. Descends down and aft at a 30° boom axis incline
  - c. May turn on upper rotating beacon

## **5. History: General Aerial Refueling Lighting and Markings Background and History**

The information presented in this history of aerial refueling lighting and markings is based on the UDRI's subject matter expert's knowledge from the time period of June 1960 through June 2005. Dexter Kalt worked for the United States Air Force as a civilian engineer at Wright Patterson Air Force Base in Ohio from 1959 through 1992. Mr. Kalt co-founded the Aerial Refueling Systems Advisory Group in 1978, and since that time has served as Chairman and Executive Director of this inter-service, international organization, and has continued to assist the US Air Force, US Navy and US Army as well as US and international military and commercial organizations as they experienced aerial refueling challenges. During the past forty-five years, the Mr. Kalt has been involved in many aspects of aerial refueling. One area of special interest has been aerial refueling lighting and markings.

The US Air Force has signified the importance of and their interest in obtaining guidance and direction regarding aerial refueling lighting and markings for future tanker and receiver aircraft as well as for the existing tankers and receivers by contracting with the University of Dayton Research Institute for a study of the topic. The data collected in the study have been compiled into this report and the information utilized to produce a guidance document. Both boom/receptacle and probe/drogue lighting issues are identified in the contract's Statement of Work.

This history is offered as a background glimpse of aerial refueling lighting and markings. Its purpose is to illustrate the significant changes regarding the operational recognition and need for aerial refueling during low light level (night) conditions. This history also should assist the reader in understanding some of the deficiencies and inadequacies of the tanker/receiver lighting systems employed today and make the study data more understandable and more useful. It will discuss successes, failures and lessons learned. Technical and operational aspects of both boom/receptacle and probe/drogue methods of aerial refueling will be discussed. This history will illustrate the time and energy that have been expended to make aerial refueling safer and enhance interoperability. As a reflection of the primary writer's experience, the discussion will be limited to events after 1959.

Those involved in aerial refueling during the past several decades may recall that the development of aerial refueling lighting and markings has been characterized by an ineffective approach. Other factors often have taken precedence over aerial refueling lighting for both tankers and receiver aircraft. The need for aerial refueling lighting often has been recognized after the aircraft has been made operational. Retrofit of the F-4 fleet with a receptacle prism light is a prime example. It would have been difficult for designers and system managers to recognize that the ability to aerial refuel at night would become an absolute necessity for world-wide operations. Perhaps more thought and planning could have been applied to which parts of aircraft and aerial refueling hardware should or should not be illuminated. This was exemplified by the absence of a "total system" approach for the tanker and receiver aircraft. In many cases, the resolution of contract controversies was complicated by the absence of references in the Operational

Requirements Documents (ORD) or mission verification sections of the contract for night aerial refueling operations. Operational requirements documents usually mentioned only that the receiver aircraft is required to aerial refuel by the receptacle or probe method without reference to environmental conditions. Lighting on the receiver aircraft was not adequately addressed in that aerial refueling itself implied night aerial refueling operations and, therefore, aerial refueling lighting considerations.

In order to understand aerial refueling, it must be recognized that the aerial refueling system is neither a tanker alone nor is it a receiver alone. An aerial refueling system is that combination of a tanker and a receiver joined in mid-air so that the fuel systems built into each aircraft function as one system, an aerial refueling system. This understanding is basic to all phases of aerial refueling development including concept, design, test, training, maintenance and operations.

Most airframe designers are aware that all the technical disciplines, i.e., structural, electrical, aerodynamic, fuel systems, electronic, etc., employed in the design, manufacture and use of tanker and receiver aircraft are impacted by the incorporation of aerial refueling systems. Aerial refueling lighting and markings are not exempt from these considerations. Factors that impact the implementation of aerial refueling improvements are illustrated by the following discussion.

In some cases, a new receiver aircraft aerial refueling system is impacted due to the changing hardware location and technology it employs, i.e., aerial refueling equipment location of boom receptacle slipway and probe mast location on the receiver aircraft, low observable and non-gloss black paint, obstacles such as antenna placed in boom/drogue paths, installation fairings protruding above fuselage skin contours of aerial refueling installations. In addition to these factors, the receiver aircraft designer of the aerial refueling system may not have an adequate data base and description of the tanker aerial refueling system. This may be further complicated by the fact the tanker is out of production and data is just not available.

Development timing of the tanker and receiver aircraft are major factors impacting decisions involving tanker receiver lighting design improvements and retrofit programs.

The KC-135 boom-to-drogue adapter (BDA) kit was developed in 1960-63 as a platform for United States Air Force aerial refueling of its probe equipped aircraft and fighters as an interim system until the century series aircraft were phased out and all Air Force aircraft were equipped with boom/receptacles systems. The F-5, A-37 and F-102 probe aircraft were exempted from the requirement. The F-105D/F/G aircraft employed dual capabilities by direction. Phase out of the KC-135 BDA kit did not occur due to the need for a drogue system on the KC-135 aircraft for aerial refueling Navy, Marines and international fighters that have only probe aerial refueling equipment. The lessons learned with the F-105 probe/fuselage lighting with the interim KC-135 BDA kit were never applied or even considered for the Navy, Marines and international probe equipped receiver aircraft. Lighting problems have been recognized and highlighted by aerial refueling technical requirements and guidance documents, but these documents may not be contractually specified and/or enforced. In some instances, incidents and accidents may have been related to poor visibility at night, although that relationship has not always been established. Nevertheless, the essential nature of adequate aerial refueling

lighting and marking requirements has not been fully appreciated in the past. As evidence, we may cite the limited resources that have been allocated for improvement of the aerial refueling lighting (formation/under-body) references and pilot director light systems on the KC-135.

The development of the tail-mounted floodlight (TMF) for the KC-135 tanker was accomplished at Wright Patterson Air Force Base (WPAFB) under a small fund set aside for aerial refueling improvement projects. However, a year after the development and flight/service testing at both WPAFB and Edwards Air Force Base was completed, no retrofit funds for the KC-135 were appropriated. Only after an unplanned occurrence were F-16 TMF priority retrofit funds redirected and made available to initiate an in-house program at WPAFB to expend these funds in retrofitting the total KC-135 tanker fleet with a TMF to solve the F-16 night aerial refueling problem. As a result, many other receiver aircraft lighting problems were solved, as well. Retrofitting 800 (+) tankers with a TMF improved night aerial refueling safety and efficiency for thousands of receiver aircraft.

Involvement in new tanker platforms development under Foreign Military Sales (FMS) programs allowed USAF engineering to take advantage of lessons learned in small, inexpensive steps to improve aerial refueling lighting and other vision improvements including tilt-up boom position gauges. The USAF program offices and engineering provided lighting and marking guidance to the contractor for selected international aerial refueling programs. Guidance included improvements to their KC-707 tanker operator stations, to external night vision formation aids and to the receiver pilot director light (PDL) system. The improved director light system for a KC-707 international air force's FMS tanker aircraft was adopted later for the KC-10A tanker. In addition, improvements to an international KC-707 engine nacelle lighting and the F-14 receiver aircraft probe light were successfully flight tested during a night lighting evaluation.

The need for an improved KC-135 boom nozzle light was recognized as early as the 1960's and finally was developed in the late 1980's and tested in the early 1990's. The nozzle light kit has recently has been finalized for the KC-135 fleet retrofit.

During the development of the KC-10A tanker, designers and managers recognized the need for improved day and night capabilities. Considerable improvements were made in the area of lighting and ergonomics for the receiver pilot and for the boom operator. Improvements included underbody lighting and pilot director lights as well as a sit-up boom operator.

Today, operators and technical managers who have acquired the experience of several world conflicts recognize the vital role of aerial refueling in both deployment and employment operations. The ability to take on fuel in flight day and night is essential to all military aircraft including tankers, rotary wing aircraft, vertical take-off aircraft and now, unmanned aircraft are under consideration for aerial refueling. Environmental conditions including weather and night (low light levels) impact the design and test of both types of aerial refueling system methods and both the tanker and receiver aircraft.

The narration and events in this history illustrate that many aerial refueling lighting problems have continued to exist for many years. Due to the size of the KC-135 tanker

fleet, these lighting enhancements were not made; a cost/need justification analysis has given higher priority to other tanker needs.

### **5.1. Aided Lighting (Rotary Wing Aircraft) Use with NVG History**

Aerial refueling of rotary winged aircraft was developed at WPAFB during 1964 through 1966 utilizing the KC-130 tanker aerial refueling wing mounted stores modified with large drogues to provide adequate drag for the low speeds (95 to 130 KIAS) and altitudes (up to 10,000 ft) required for rotary winged receiver aircraft. The HH-3 aircraft was the first helicopter to be equipped with a long telescoping probe mast with a standard fighter MS probe nozzle. The use of the existing KC-130 tanker hose reel, hose and MA-2 coupling were utilized similar to the standard fighter probe/drogue equipment of the KC-130 tanker aircraft. The exception was the development of the considerably larger drogue and canopy to provide the necessary drag at the low airspeeds. Other tanker changes to accommodate the rotary winged aircraft included a reduced inner limit fuel flow envelope and associated status light adjustment. Also, the tanker wing stores were equipped with a bolt-on lower drogue exit fairing to protect the larger drogue canopy from airflow damage. This configuration provided the USAF HC-130 P/N tankers the capability to aerial refuel rotary wing aircraft.

The HH-53 followed the HH-3 development in ~1967; the HH-53 had a telescoping probe similar to that of the HH-3 helicopter. In the 1980's, the HH-60 was introduced into the United States Air Force inventory; it was equipped with a telescoping probe similar to that on the HH-3 and HH-53 helicopters.

In ~1987-88, the United States Army equipped the MH-47D with aerial refueling probes, and in 1992/93, the MH-60K/L with aerial refueling probes. Development tests with the two rotor MH-47D employing a 48 foot probe for rotor/drogue clearance was determined as not practical due to vibrations and supporting cable required to stabilize the very long, cantilevered probe mast. As a result, the US Army pursued a short non-retractable probe mast for the MH-47 dual rotor blade aircraft. The short probe mast required that the drogue/coupling and hose engage beneath the path of the forward rotor's blades.

One other service also became involved in helicopter aerial refueling; in 1983, the United States Marine Corps aerial refueled the RH-53D aircraft. US Air Force tankers included the C-130 P/N's; the Marine tankers were KC-130's. Currently, the MC-130H tanker is being developed by the US Air Force for aerial refueling rotary wing and tilt wing (V-22) aircraft.

Aerial refueling lighting for the helicopters included a probe light. The KC-130/C-130's tankers employ aerial refueling system status lights (yellow, green, red) similar to those used by fighter aircraft refueling with the KC-130's, i.e., yellow/amber – ready for hook-up; green – fuel flowing; red- low hydraulics, dead hose, no hook-up. The tankers also utilized side door windows for crew members to provide signals to the receiver aircraft utilizing the same Altus lamps used for fighters. The horizontal stabilizer tip is a light source to illuminate the wing store and the hose.

The use of night vision goggle (NVG) equipment was introduced for aerial refueling operations by the US Air Force Special Operations Forces in the late 1960's. Currently, the United States Army, Air Force and Marines utilize the NVG equipment exclusive for night aerial refueling operations. Both training and night operations conducted by Special Operations Forces require that the tankers provide NVG compatible (friendly) aerial refueling lighting and infra-red (IR) lighting for covert operations.

## **5.2. Lessons Learned and Associated Documentation**

The above history is designed to provide lessons from the past and to fill the need to consider the background of aerial refueling light/markings through a significant period. It looks back in time to examine what has worked and to see what has been less than adequate for aerial refueling.

The events described below involving aerial refueling lighting, markings and paint schemes are presented in chronological order and by the type of aerial refueling system. They are representative of the types of aerial refueling lighting issues that have occurred over the past 45 years, they are recorded as recalled from the teams subject matter expert. They are intended to supplement this study by illustrating lessons learned that may be applied to the development of future tanker and receiver aircraft and to the potential upgrading of existing tankers and receiver aircraft.

## **5.3. Selected Events, 1960-2005, Aerial Refueling Lighting/Markings**

### **5.3.1. B-58 Receptacle/Slipway Light/ KC-135 tanker nozzle light**

Date: ~ 1960

Place: Over the Atlantic

Problem: A single light source failure B-58 slipway (no light redundancy) combined with a boom nozzle light failure (no light redundancy).

Result/Impact: Mission abort

Corrective Action: Small F-105 prototype slipway light flight evaluated and installed on B-58 slipway to provide redundancy and improved slipway lighting.

### **5.3.2. F-101 Probe Nozzle Light / KC/135 BDA kit**

Date: ~ 1960

Place: WPAFB, night flight test

Problem: Nozzle light direction.

Result/Impact: Obscures the vision of (blinds) the boom operator.

Corrective Action: Investigated light polarization, light angle may have been adjusted. Uncertain regarding retrofit.

### **5.3.3. KC-135 BDA Kit Lighting**

Date: 1961

Place: Seymour Johnson AFB, SAC/TAC operational compatibility testing

Problem: Poor visibility of BDA kit for use by receiver pilots of probe equipped USAF century series aircraft.

Result/Impact: Install flood light in KC-135 tail cone (tail mounted flood light, TMF).

Corrective Action: Light installed at improper angle, thereby rendered as not acceptable as installed, no follow-up on tanker. However, receiver fuselage light was retrofitted on F-105 (See item 5.3.4 below).

#### **5.3.4. KC-135 BDA kit lighting / F-105 probe**

Date: 1961-63

Place: WPAFB night flight test

Problem: Inadequate lighting of BDA kit (black) hose at night.

Result/Impact: Accident, hose wrapped around drogue, and on disconnect, drogue/coupling separated from hose and lodged in F-105 vertical stabilizer, probe fixed nozzle tip separated, shaft bent vertically down.

Corrective Action: 1) KC-135 BDA kit 9' hose changed from black to white; 2) light source with (clear lens) installed in forward upper nose surface of F-105 to illuminate BDA kit white hose and a portion of the boom telescoping tube, location/envelope restricted forward/aft angle to avoid boom operator/pilot "blinding", full variable dimming control provided, all aircraft retrofitted. These improved lighting capabilities for the F-105's which were verified by flight test for night operational aerial refueling. A later flight test evaluation also evaluated replacing the black drogue rubber, reverse airfoil, with a white one. Receiver pilots rated the change to white as a significant improvement to night aerial refueling with the BDA kit. This change never was retrofitted for the BDA kit.

High angle white glass beaded tape external/internal to drogue cone and coupling was retrofitted and replaced the original orange tape (poor reflecting properties). The white tape is similar to current highway signs.

#### **5.3.5. KC-135 BDA kit / F-105 Probe Nozzle Light**

Date: WPAFB flight test

Place: ~ 1961

Problem: F-105 probe nozzle light obscures the vision of (blinds) the boom operator.

Result/Impact: boom operator capabilities impeded.

Corrective Action: Re-design nozzle light, direction and provide full dimming rheostat control.

#### **5.3.6. A-37 Fuselage Mounted Probe Nozzle Light / KC-135 BDA kit**

Date: ~ 1965

Place: WPAFB, flight test development

Problem: Avoided problem by lessons learned from previous F-105 experience.

Result/Impact: No problem with nose mounted fuselage light.

Corrective Action: None required, initial design considered past experience of F-101 and F-105.

### **5.3.7. F-5 Probe Nozzle Light / KC-135 BDA Kit**

Date: ~ 1965-66

Place: Northrop / Edwards AFB

Problem: Avoided past problem by lessons learned.

Result/Impact: No problem experienced with probe mounted light and full dimming control.

Corrective Action: None required, initial design considered past experience of F-101 and F-105.

### **5.3.8. F-105 Prototype Receptacle Installation**

Date:

Place: WPAFB flight test

Problem: Initial slipway single light, no redundancy.

Result/Impact: Prototype installation found unacceptable.

Corrective Action: F-105D/F/G production provided light redundancy and full dimming control.

### **5.3.9. F-4 Receptacle Light / KC-135 Tanker**

Date: WPAFB flight test and in-service reports

Place: ~ 1968-69

Problem: No slipway, therefore, no lighting forward of receptacle area.

Result/Impact: Difficult hookups with receptacle, can't see receptacle at night.

Corrective Action: Retrofit of all F-4 aircraft with prism light forward of receptacle to illuminate receptacle face.

### **5.3.10. Universal Aerial Refueling Receptacle Slipway Installation (UARRSI) Lighting**

Date: 1964-75

Place: WPAFB In-house development

Problem: Past aerial refueling receptacles were not provided with adequate slipway/receptacle lighting, redundant light sources and variable lighting dimming controls.

Result/Impact: Initial design considered the need for adequate lighting and lighting redundancy to avoid mistakes of previous aerial refueling receptacle slipway aircraft installations.

Corrective Action: The UARRSI was provided with twelve light sources (six each side of slipway). A full scale mock-up was built prior to first prototype flight test article. The mock-up was ground tested and evaluated in a

simulated darkroom by numerous boom operators to insure full adequacy under several light source failures.

Installation design guides and specifications required receiver aircraft to provide full dimming to off controls. Flight testing in several receiver aircraft, E-4, B-1, A-10, C-130, etc. demonstrated that UARRSI lighting was fully acceptable.

Each side of the UARRSI is provided with two sets of three bulbs and offset for full slipway receptacle illumination. A total of 12 bulbs are shock mounted by an epoxy module.

### **5.3.11. Lead-in Markings for UARRSI and Other Receiver Aircraft Receptacle Slipway Installations**

Date: 1962 to present

Place: WPAFB, Edwards AFB, Special Requirements and Guidance Documents

Problem: Lead-in markings to the receptacle with reflective tape are necessary to provide safe entry into slipway receptacle equipped aircraft to assist in locating the receptacle during ambient low light level conditions and to avoid windscreen, canopy, raised installations, antennas, contour changes, etc. clear path to receptacle defined. The boom nozzle light was the primary light source for reflective tape until the implementation of the later developed KC-135/KC-10 tail mounted flood light (TMF) which now provides an improved direct light source for the reflective/contrast paint tape reflective properties.

Result/Impact: Without these markings, the potential exists for striking the receiver aircraft skin contours, antennas, wind screens, canopies and raised external aerial refueling receptacle fairings/housings.

Corrective Action: Currently, all receiver aircraft employ some form of “T-bar” markings, either passive reflective tape, paint, with contrasting background paint color and/or active strip lighting for identifying lead-in receptacle/slipway markings. A single “T-bar” for the A-10, a double “T-bar” for the F-16 and many other aircraft. The B-1 employs a triple “T-bar” marking. Also, windscreens and the UARRSI perimeter are outlined and identified with wide angle reflective tape.

### **5.3.12. Lead-In Area Lighting for Boom Receptacle/UARRSI Equipped Receiver Aircraft**

Date: 1970’s to present

Place: WPAFB/Edwards AFB

Problem: Boom operator depth perception at night and in low light levels. Prior to KC-135 TMF development, inadequate depth perception concerns were reported with several receiver aircraft by test boom operators, receiver aircraft having low observable paint, low reflective paint, etc. The F-16 is an example of requiring additional lighting to illuminate reflective tape

“T-bar” markings and other critical aircraft contours forward of the receptacle.

Result/Impact: Potential for striking receiver aircraft skin contours, antennas, wind screens, canopies and raised external aerial refueling receptacle fairings/housings.

Corrective Action: Provide active lighting to illuminate all critical surfaces in boom nozzle path to and around receptacle/slipway area including those mentioned above. The following are examples of critical area lighting currently provided on receiver aircraft.

- 1) tanker tail mounted flood (TMF) lights for boom equipped KC-135/10/707
- 2) receiver aircraft area lighting provisions/types: B-2, C-130, C-141, KC-10 lights with reflective mirrors, C-17 strip lighting, E-4 spoiler, F-16 TMF, etc.

### **5.3.13. External Aerial Refueling Tanker Lighting and Anti-Collision Strobe Lights**

Date: 1969 to present

Place: N/A

Problem: 1) improved tanker identity needed,  
2) separate controls for upper/lower anti-collision lights during aerial refueling.

Result/Impact:

- 1) reduce time required for receiver aircraft during tanker visual identity,
- 2) separate controls for upper and lower anti-collision lights to avoid lower tanker light “blinding” receiver pilot and upper receiver light “blinding” boom operator/tanker crew.

Corrective Action:

- 1) Provide illumination of vertical tanker stabilizer and underneath horizontal stabilizer, i.e., several commercial aircraft which have the vertical tail logo illuminated have been found to assist in tanker identity during aerial refueling. An example is the KC-707 drogue equipped tanker.
- 2) Retrofitted KC-135 tanker with new anti-collision lights incorporating strobe lights for identity.
- 3) Commercial aircraft converted to tanker aircraft require the upper and lower rotating beacon/strobe lights to be separately switched to off during aerial refueling. tanker – lower off; receiver – upper off.

**5.3.14. 1) Hose Visibility**  
**2) Coupling/Drogue Internal Cone/External Identification at Night**

Date: 1961 to present

Place: WPAFB/Others

Problem: 1) Hose visibility: Inability to see black hose of KC-135 BDA kit. Example: KC-135 BDA kit hose wrap as reported in items 5.4.3 and 5.4.4 above. Long aerial refueling hose (black with 1 foot wide white markings) trailing from fuselage are difficult to illuminate by tanker or receiver aircraft under certain tanker lighting geometry. A prototype fuselage right keel bay mounted 98 ft. hose and the KC-707 Omega centerline 80 ft. fuselage hose could not be illuminated past the tanker fuselage. The one foot wide white markings on black hose become dirty. White markings' contrast is deteriorated and is difficult to illuminate adequately for night identification by receiver aircraft from formation to pre-contact positioning.

Both tankers, therefore, employed white hoses with black markings as an initial prototype and production configuration.

2) The absence of reflective surfaces of both internal drogue cone and external drogue and coupling hardware, i.e., reflective surfaces with light source(s) or active lighting by remote generators.

Result/Impact: Poor positioning for receiver aircraft from formation to pre-contact to hook-up and maintaining hose position after hook-up.

Corrective Action/Lessons Learned and/or Verified:

1) All KC-135 BDA kit hoses were required to be white. Drogue/coupling interior cone and exterior cone were identified with white wide angle reflective tape with light sources, i.e., KC-135 TMF, receiver aircraft probe light with clear lens, pod (wing store) lights, fuselage lights and hose fuselage stowage and exit lights, etc.

2) Fuselage and wing mounted hoses, drogues, couplings and drogue canopies to be provided with reflective white tape, white canopy, internal and external reflective white tape on drogues/couplings. Provide white hose with black 1 ft. markings, white markings for black hoses to be illuminated by tanker and/or receiver aircraft light sources, i.e., tanker TMF, receiver probe and fuselage lights, pod (wing stores), hose fuselage exit light, fuselage lights, etc.

3) Provide active lighting for drogues/couplings which do not have available tanker airframe light sources.

Examples of current, active light technology available and currently employed are drogue peanut lights and external LED lights powered by coupling mounted ram air turbines (generators), i.e., KC-707 Omega, KC-10, KC-135 and KC-130 wing stores.

Tridium lights also have been utilized; however, depth perception concerns should be considered.

### **5.3.15. KC-135 Tail Mounted Floodlight (TMF)**

Date: Late 1970's, Early 1980's

Place: WPAFB, OH

Problem: Numerous receiver aircraft were requiring additional lighting to solve boom operator depth perception concerns.

Result/Impact: Expensive retrofit costs and aircraft night aerial refueling restrictions imposed resulting in mission impact, i.e., F-16.

Corrective Action: Initiated in-house development of KC-135 TMF, under KC-135 improved aerial refueling system (IARS) funds.

- A) Two L-1011 cargo lights were obtained from Grimes Co., Urbana, OH.
- B) Initial hanger aero stand initial feasibility was demonstrated with A-37 and A-7 aircraft and other fighter aircraft.
- C) Flight evaluation with 4950<sup>th</sup> Test Wing was initiated in house under Improved Aerial Refueling Systems (IARS) KC-135 improvement program.
- D) ASD 4950<sup>th</sup> Test Wing in-house fabrication of tail mounted floodlight (TMF) sting and kit utilizing initial feasibility light fixtures (two each) with variable position dimming control with distinct positive settings.
- E) Flight test conducted with KC-135 and A-7 receiver aircraft and test and operational boom operators evaluation with clear light lens with second back-up sand-blasted (spot) lens.
- F) Evaluation required that boom operator dimming control settings were compatible with receiver light intensity tolerance.
- G) Evaluation was not unanimous, therefore, it was determined unacceptable to boom operator and receiver pilot.
- H) De-fused (sandblasted) lens was not evaluated at WPAFB (4950<sup>th</sup> Test Wing) by a second flight.
- I) Reported to ASD General Officer as "Operation Successful, Patient Died."
- J) Follow-on testing was resumed at Edwards AFB with KC-135 TMF with the de-fused light lens and determined as highly successful with all receiver aircraft tested. Reported as "Best Aerial Refueling Improvement since Flying Boom" by boom operators.
- K) No KC-135 production retrofit funds were made available for retrofitting the KC-135 fleet, and no further action taken for nearly a year. The F-16 TMF priority funds were made available for a USAF in-house

follow-on effort for the KC-135 TMF production retrofit and KC-10 TMF concept adoption and production retrofit.

Following the development of the TMF, the KC-10 was equipped and the KC-707 Saudi Arabian Air Force tanker was equipped with the TMF.

### **5.3.16. KC-135 Boom Nozzle Light**

Date: 1960 to present

Place: Field reports

Problem: Premature light bulb (filament) failure due to: 1) vibration; 2) thermal shock; 3) short filament life; 4) BDA kit adapter valve impact nozzle light assembly; and 5) failure to detect bulb failure during pre-flight check. Required close observation and examination by aero stand to detect boom stowed nozzle light failure during daytime ambient lighting.

Result/Impact: Aerial refueling mission aborts.

Corrective Action: Existing tube assembly: 1) bulb shock absorber provided; 2) light tube shock mounts; 3) light warm-up to altitude to avoid thermal shock at low altitude temperatures; and 4) heavier, more robust bulb filaments utilized.

### **5.3.17. KC-135 Improved Boom Nozzle Light Direct Replacement Assembly development Initiated**

Date: 1988-2005

Place: WPAFB

Problem: Recognition of the poor reliability of the KC-135 nozzle light and attendant deficiencies and mission aborts:

- 1) no bulb redundancy (single failure results in aerial refueling mission abort),
- 2) no detection of bulb failure except by use of aero stand on ground prior to flight,
- 3) poor reliability of light,
- 4) improved light intensity and coverage desired.

Result/Impact: KC-135 improved aerial refueling systems (IARS) development funds made available for new nozzle development and in-house test initiated.

Corrective Action: New boom nozzle light developed with attendant capability and improvements:

- 1) direct replacement interface with existing nozzle light,
- 2) redundant halogen bulbs provided with inherent vibration/impact improvements,
- 3) in-flight failure detection of bulb failures by LED's on boom operator's panel ,
- 4) increased light intensity and light coverage,

5) full dimming control on boom operator's panel.

Flight/service tests successfully conducted 1991-92. Quantities of light kits adequate to retrofit all inventoried KC-135's were purchased from manufacturer by USAF/OC/ALC. Currently (August 2005) none installed on KC-135 fleet. However, TCTO kits to be field available by early September '05.

### **5.3.18. KC-135 Tanker Pilot Director Lights (PDL)**

Date: 1960's to present

Place: WPAFB, Flight Test and Field (in service), and other

Problem: KC-135 Pilot Director Light (PDL) reported as less than desirable or receiver pilot direction position information, especially during daylight conditions.

Result/Impact: Flight test conducted at WPAFB during late 1960's to evaluate reported concerns. Test findings/field reports revealed the following:

Nose wheel deflects dirt onto the lights, making them not visible, letters are not distinguishable, i.e., "Up", "Down", "Fwd" "Aft." Captain bars originally green faded to amber (same as amber caution position). Boom position info reflected by PDL after hook-up (boom/receiver aircraft) is not visible to the receiver pilot during certain lighting conditions.

Corrective Action: None taken to date for KC-135 (lessons were learned and improvements were made to tanker applications, i.e., KC-10, KC-707, (international) tankers as documented in Paragraph 5.4.19 below.

### **5.3.19. KC-707 International Tanker Aerial Refueling Pilot Director Lights**

Date: 1972-1973

Place: WPAFB Program Office FMS Case

Problem: Based on lessons learned from KC-135 PDL equip. ASD engineering recommended to program office/contractor, that the KC-707 international air force's aircraft should be provided with improved PDL (Paragraph 5.4.18 above) over KC-135 aircraft. Problems highlighted above and solutions be evaluated by a comparative PDL hangar mock-up.

Result/Impact: Recommendation was accepted.

Corrective Action: The proposed improved PDL lights were evaluated by both F-4 receiver pilots and engineers in a darkened hangar with simulated aerial refueling geometry, and F-4 receiver cockpit. The KC-707 improved lights compared side by side KC-135 existing PDL lights, proved to be a significant improvement over the KC-135 PDL. (See enclosed photos, 8 e.f.) The changes included:

- 1) significant increase of light intensity, i.e., reflectors/bulbs, etc. for background white and color lights,

- 2) elongated letters “fwd/aft” and “up/down”,
- 3) captain bars made a durable green color (fade resistant).

Subsequent flight tests proved the KC-707 international air force’s aircraft lights by USAF receiver F-4 pilot as superior to KC-135 PDL. Follow-on programs for the KC-707 Saudi Arabian AF tanker and the KC-10 adopted these improvements. The KC-135 PDL lights have not been improved to date.

Advanced tankers are understood to adopt the above changes not verified to date. No new concepts for PDL systems are known to be proposed to date.

### **5.3.20. KC-707/F-14 Aerial refueling lighting improvements**

Date: 1974-77

Place: Patuxent River MD, Navy Flight Test Center

Problem: F-14 aerial refueling at night restricted, operational impact. Due to F-14 windscreen/canopy obstructions, cannot see tanker reference outboard engine nacelle and 1080 store/pod and probe nozzle without changing head position, i.e., with a single view.

Result/Impact: Night aerial refueling operations were restricted.

Corrective Action: Light placed on inboard side of wing 1080 aerial refueling store to illuminate outboard engine nacelle. Red lens removed from F-14 probe nozzle light and replaced with clear lens. Corrections flight tested satisfactorily and restrictions for night aerial refueling were removed.

### **5.3.21. Boom-to-drogue adapter kit follow-on lighting recommendations**

Date: 1980’s

Place: Aerial Refueling Systems Advisory Group (ARSAG) conference

Problem: Navy aircraft aerial refueling probes designed to aerial refueling from KC-130’s hose reels were not re-designed for night compatibility with the KC-135 BDA kit, i.e., removing red lens, re-directing nozzle light and/or providing additional fuselage light to illuminate the BDA kit white hose.

Result/Impact: Continual reports of poor visibility of KC-135 tanker equipped with BDA kit. References were reported at ARSAG meetings by Navy/Marine receiver pilots. Aft fuselage underneath tanker was referred to as “a black hole.” Also, pilots recommended corrective action: No lighting changes were made to the KC-135 or BDA kit since the wide-angle reflective white tape and white hose implemented in the early 1960’s. Production F-18’s do employ aerial refueling probe nozzle clear lens vs. red lens as the F-14 aircraft currently employ. Focus was placed on providing KC-135’s with wing mounted aerial refueling stores (pods) due to other physical envelope limitations of the KC-135 BDA kit. Only limited KC-135’s now

are equipped with wing mounted stores, and no plans to improve the KC-135 and BDA kit which is currently projected for USAF inventory for ~30 more years.

Corrective Action: None taken to date.

**5.3.22. Aerial Refueling Lighting/Markings Signal Specifications and Guide/Lessons Learned Documents**

Date: 1960-2005

Place: US Air Force, ASC  
US Navy, NASC

Problem: Existing aerial refueling lighting requirements and guide documents may not be adequate (See list below).

Result/Impact: Poor future tanker/receiver aerial refueling lighting.

Corrective Action: USAF study of aerial refueling lighting initiated September 2004. Prepare new guide document for aerial refueling lighting and marking criteria. This document should include guidance for aerial refueling lighting, markings and signal systems. It should be used for new tanker and receiver aircraft and should contain guidance for both boom/receptacle and probe/drogue aerial refueling methods.

**Aerial Refueling Specifications Regarding Lighting, Markings and Signal/Communications Systems**

<u>Status</u>	<u>Specification No.</u>	<u>Title</u>
Inactive	MIL-F-38363	Fuel System, Aircraft, General Specification For
Active	MIL-A-19736A	Aerial Refueling Systems, General Specification For (US Navy)
Active as Guide Only	MIL-L-6503H	Lighting Equipment, Aircraft General Specification For (Installation of)
Inactive	MIL-S-38449C	Signal and Signal-Intercommunication Amplifiers, Universal, Aerial Refueling
Active	MIL-H-4495D	Hose Assembly, Rubber, Aerial Refueling
Inactive	MIL-A-87166	Aerial Refueling Receiver Subsystems
Active	AFGS-87166A	Amendment 3, Aerial Refueling Receiver Subsystems
Active	ARP694B (SAE-A-20B Exterior) (Jan '04)	Aerial Refueling Lights – Design Criteria
Active	ARP 4392 (SAE-A-20B Exterior) (June '93)	Lighting, Aircraft Exterior, Night Vision Imaging System (NVIS) Compatible
Active	MIL-STD-3009 (Supersedes MIL-L-85762A)	Lighting, Aircraft, Night Vision Imaging System (NVIS) Compatible

### **5.3.23. B-1 Aerial Refueling UARRSI Marking Configuration Selection**

Date: 1984

Place: Edwards AFB (see Attachment 1, photo 13g)

Problem: Lead-in nose markings evaluation of two contending configurations:

- 1) proposed configuration T.B.D. Co.,
- 2) triple "T-bar" configuration.

Result/Impact: Conduct night evaluation in weight and balance hangar with full scale boom model, elevated stands (simulated boom operator position) and B-1A aircraft of competing marking configurations. Utilize test and operational boom operators for the evaluation.

Specify critical lead-in aerial refueling markings for the production B-1 aerial refueling installation.

Corrective Action: Full scale (actual aircraft) evaluation was completed by operational/test boom operators with unanimous preference for the triple "T-bar" configuration. A light (pearl) gray color was chosen for the markings. The B-1 windshield also was outlined with the tape/paint. All production model B-1 aircraft were provided with this configuration.

## 6. Data Collection Approach

This project included a variety of data collection methods. In all cases data were gathered and analyzed within the categories of tanker boom, tanker drogue, receiver receptacle, and receiver probe. This document uses these categories in not only the data collection approach, but in other sections such as Recommendations to aid in explanation of findings.

A wide variety of sources were used to gather information for this research. These sources can be categorized into three general areas: search and familiarization, interviews, and questionnaires. Sources and their respective categories are as follows:

### Search and Familiarization

- a lighting manufacturing plan tour including lighting demonstrations and hardware examination,
- document and records search and review,
- team tutorials
- technical and operational briefings at Aerial Refueling Systems Advisory Group (ARSAG) conferences
- internal subject matter expertise (forty-five years' focused experience in aerial refueling),
- meetings with subject matter specialists regarding night vision goggles (NVG) including demonstration and use of latest NVG technology and equipment,

### Interviews

- interviews with pilots,
- interviews with boom operators,
- interviews with subject matter experts,
- discussions and exchanges among users and manufacturers in ARSAG's Lighting Panel,
- discussions and exchanges in ARSAG's Special Topics Meetings,
- direct inputs solicited from aerial refueling users regarding aerial refueling lighting and markings experiences and needs.

### Questionnaires

- receiver pilot questionnaires, and
- tanker operator questionnaires.

In all cases methods were used to gather information relevant to current and future considerations for aerial refueling lighting systems. The first category was one of search and familiarization. In this method, various means were used to gather information relevant to aerial refueling. The team sought out opportunities to collect information

relevant to lighting issues for aerial refueling. In addition, the contractor team was provided with training from our internal subject matter expert, Dexter Kalt. A second method for collecting information involved user interviews. Interviews were conducted to assist in pulling together specific issues and situations surrounding the aerial refueling process. Some of these interviews were more formal in nature, while others were opportunistic. These interviews provided context for the data received from the other data collection methods. Finally, Questionnaires were developed to identify issues with lighting during aerial refueling maneuvers. These questionnaires provided a wealth of information from the user community. The following sections provide additional detail on each of these data collection methods.

## **6.1. Search and Familiarization**

### **6.1.1. Search**

The initial means of collecting information for this project was through surveying literature for latest information on: 1) DoD Standards, handbooks, and guidelines relevant to aerial refueling lighting and markings; 2) Photos, movies, and diagrams to illustrate refueling tasks from the pilot's and operator's perspectives; 3) Relevant human performance research; 4) Possible aerial refueling incidents attributable to lighting issues; and, 5) Lighting and marking technologies. The following list identifies some of the information sources used for this effort:

- URL's 1000+ visited and reviewed - saved 106,
- Mishaps -14
- AF docs ~40+/-
- Technical documents >400
- NVIS - 135 files
- Formation - 13 files
- Human Factors articles on Aerial Refueling – 16

One specific area was identified as requiring extensive consideration – refueling during reduced lighting and covert operations. During reduced artificial tanker lighting and covert operations, users need visual aids to perform the refueling task. Due to these conditions it is becoming increasingly important for aerial refueling systems to include lighting compatible with use of Night Vision Goggles (NVG). Therefore, familiarity with both NVG systems and Night Vision Imaging System (NVIS) equipment was important for the team. To increase their knowledge in this evolving field, the team collected information about NVG and NVIS as well as contacted a laboratory at the Air Force Research Laboratory (AFRL) that performs research and development work on the latest version of panoramic night vision goggles. Technical reports were provided by NVG, NVIS experts Ms. Sharon Dixon and Mr. Jeff Craig, and a meeting was held at AFRL/HECV (AFRL Battlespace Visualization Branch) to discuss NVGs. Following this meeting scientists at HECV provided numerous useful documents to supplement our literature review; provided contact information for individuals willing to participate in

our study; answered questions regarding NVG technology; and, expressed a sincere willingness to work with us in a variety of ways

On another occasion, a data collection effort was made to AFRL/HECV. During this trip a heuristic evaluation was conducted on the visual effects of using a white hose with Night Vision Goggles. The SIRE laboratory served as the setting for the evaluation. F4949G Binocular NVGs were used for the evaluation. Four people, including two AFRL NVG specialists and two aerial refueling lighting study analysts tested various conditions of light on and through the white hose while using the NVGs. Three conditions were tested: 1) no specific light, 2) a dim light, and 3) a bright floodlight. The evaluation was specifically aimed at looking for blooming effects due to the white hose. Blooming effects were not noted during the evaluation. Further measurements were made with both a white and black hose. A report of these measurements are contained in Attachment 6.

### **6.1.2. Team Familiarization and Training**

In addition to familiarization methods, team training with aerial refueling concepts continued throughout the project. Three examples of training and familiarization efforts are illustrated below.

At the beginning of this project, two classroom training sessions were provided for UDRI technical team members on the subjects of aerial refueling components, procedures, and technologies. The sessions were extremely informative, and allowed the team members to come up to speed with terms and technologies related to aerial refueling.

A second example of how the team trained and familiarized themselves throughout the project included review of materials used to train aerial refueling procedures. These training materials provided a thorough explanation of the pre-defined processes and procedures from a user's perspective. Training materials were acquired and reviewed for aerial refueling in the C-141, C-17, C-5, F-14, F-16, F-18, KC-135, KC-10, and international KC-707 tankers. These materials included background information on how the human operators are taught to perform refueling tasks.

The ARLS team familiarized themselves with advanced lighting designs and concepts in a variety of ways including a visit to the Honeywell facility in Urbana, Ohio. Candice Colley and Richard Kemp provided information regarding lighting advancements, and provided a visit through their facility to demonstrate how lighting is tested for various factors such as heat, cold, and lighting qualities including NVG compatibility. Lighting analysis included discussion of tail mounted flood lights, nozzle lights, pilot director lights, and underbody/wing lights. Advanced lighting concepts such as Light Emitting Diodes (LEDs) and strip lighting were also discussed.

## **6.2. Interviews**

As a part of the data collection activities, several trips and teleconferencing interviews were made to collect information from users. These trips included collecting questionnaire data, they also incorporated interviews with the user population. Interviews were conducted at Springfield Ohio Air National Guard Base (OANG),

Rickenbacker (OANG, Patuxent River Naval Research Center (NRC), and Oceana Naval Air Station (NAS). Each of these interview opportunities is further defined below.

In the first few months of the project an interview session was conducted at Springfield OANG. The team interviewed eight F-16 receiver pilots. Questions were asked regarding the effectiveness of lighting. Response data was recorded, analyzed and transcribed.

A second interview session was conducted at Rickenbacker OANG. The team interviewed five KC-135 tanker operators and collected completed questionnaires. The operators provided feedback on both boom and drogue tanker configurations. During this trip the team also watched a video highlighting various aspects of the refueling process. Response data from the interviews was recorded, analyzed and transcribed for further evaluation.

Team members traveled to Patuxent River Naval Air Research Center to collect initial data on the Probe aspects of refueling. The purpose of the trip was to interview F-14 and F-18 receiver pilots, and to have them complete the Receiver Pilot Questionnaire for the Lighting Study. Questionnaires were emailed to Navy contacts for distribution to the pilots prior to our arrival. At Pax River eight pilots were interviewed, and the respective Receiver Pilot Questionnaires were completed. Plans for this trip initially included interviewing pilots at both Pax River and Oceana NAS. However, due primarily to weather, the team interviewed two F-14 receiver pilots by phone at Oceana. They also completed the questionnaires that were sent to them via e-mail.

To further information collection process, during two ARSAG meetings in, a structured interview was conducted with a helicopter pilot to collect rotary wing probe receiver unique requirements, in addition to his filled out questionnaire. Additionally, impromptu discussions were held with other experts in formal ARSAG meetings regarding lighting issues.

Finally, in March the team refined the structured interview questions. The interview guide was revised to identify questions to be asked in subsequent interviews (both on this program and on future efforts). These revised interview guides relate to the portions of the refueling task that require complex cognitive analysis on the part of the user. The intent of these questions is to tap into this complex cognitive process in more depth. See Attachment 5 for the Cognitive Task Analysis interview guide.

### **6.3. Questionnaires**

An important part of the data collection effort was to construct and administer questionnaires to tanker operators and receiver pilots for the purpose of: 1) Substantiating current requirements and identify any additional requirements; 2) Identifying improvements for current systems; 3) Identifying current unsatisfactory lighting features requiring immediate attention, and 4) Proposing enhancements to future tanker and receiver airframe lighting/marketing systems.

Questionnaires were used as one of the primary means of collecting information about aerial refueling lighting needs from the user community. An 8-page questionnaire was developed within the first few months of the effort for collecting data from receiver

pilots and tanker operators. The document went through two major iterations (based on feedback from the team members), and a final version was generated. Throughout the effort questionnaires were distributed to users during each data collection trip. This included trips to Rickenbacker AFB (Tanker Boom and BDA kit), Springfield AFB (Receiver Receptacle), and Patuxent River NRC (Tanker Drogue); and, questionnaires were provided to Oceana NAS (Receiver Probe). Based on comments from these tanker and receiver pilots, the questionnaires were revised and the final version was used for the remainder of the study. See Attachment 3

In the early spring the questionnaire was placed on the Aerial Refueling Systems Advisory Group (ARSAG) website. This is a site sponsored by the ARSAG not-for-profit organization. The organization is not affiliated with the USAF or DoD; however, its members are clearly very interested in aerial refueling and the lighting associated with these aircraft systems. The USAF Tanker Modernization Squadron Program Office and the UDRI contracted team used the site as a vehicle allowing people in this community to readily find and download the questionnaire. It provided a great medium for distributing the questionnaire. Responses were sent directly to the UDRI team.

A database was developed for accommodating all questionnaire data from this study. Information from the questionnaire database was organized in order to answer specific questions regarding this project. The organizational method focused on summarizing findings and identifying gaps in data (See Attachment 4). Specific formats for summary charts were identified and chart creation began.

#### **6.4. Review and Analysis**

With regard to each of the data collection efforts identified above, once data were collected they were reviewed, compiled, and analyzed for inclusion this report. Data were examined for determining lighting recommendations and for "holes" or "gaps" that indicate where additional data needed to be collected (i.e., from pilots or boom operators of specific aircraft, or to clarify specific lighting issues). Once these gaps were identified the team sought methods for collecting information to satisfy these needs in the analysis. Approximately six months before the end of the project a preliminary list of considerations was prepared and submitted to GRR for initial review.

## 7. Results from Interviews

Interviews were conducted at Springfield Air National Guard Base, OH on November 16, 2004, Rickenbacker Air National Guard Base, OH on November 23, 2004, and at a meeting of the Aerial Refueling Systems Advisory Group (ARSAG) on February 8, 2005. All individuals interviewed were experienced within their respective profession (i.e., receiver aircraft pilot, tanker operator). Participants for the Springfield Air National Guard interview consisted of F-16 pilots. Participants for the Rickenbacker Air National Guard interview consisted of tanker operators. The participant for the ARSAG interview was a helicopter receiver pilot of the U.S. Army. Data collected from the Springfield Air National Guard Base primarily addressed issues that receiver pilots may face when refueling from boom equipped tanker aircraft. The data collected from the Rickenbacker Air National Guard interviews addressed issues that tanker operators may encounter during aerial refueling. Data collected from the ARSAG interview addressed issues that helicopter receiver pilots may encounter during aerial refueling.

Interviews provided valuable insights on major refueling issues with regard to lighting. These insights were subsequently used to assist in evaluation and interpretation of data collected from questionnaires and to generate the recommendations contained in this report. The following subsections provide some of the highlights gathered during the interviews. These sections provide bulleted points of interest captured during the interviews. Comments are interpreted and paraphrased.

### **7.1. Boom Operator/Probe Interview Results**

- New boom nozzle lights are very helpful (they are a dual bulb halogen light, and very reliable). The light was flight tested in the 1990's (the nozzle light is needed even when the tail light is out). The nozzle light is rheostat controlled. Marker lights have indication of on/off.
- Day time with clouds (white-out conditions) with clouds on the bottom (below the aircraft) present the most difficult refueling conditions.
- Night time and twilight (dusk) refuels are more difficult for the receiver pilot than for the boom operator.
- Looking outside of the plane and looking inside the plane at the gauges is a problem due to light/dark adaptation. It is a problem of focusing eyes (maybe a problem of light intensity difference). This problem can occur at any point during the refuel process. The boom operator often wears sunglasses to help with the light/dark problem.
- The paint used on the F-22 makes the area near the receptacle seem flat, and the tail-mounted floodlight helps. When a good fuselage picture is presented, there is a better range of motion for the boom operator. When certain lights are on, the boom operators get a better idea of where the receiver aircraft is.
- The boom operator depends on the lights on the tanker aircraft as well as the lights on the receiver aircraft.
- There is a red spotlight in the tanker that can be hand-held light a map light. The boom operators don't see the red light, but some receiver pilots use it to help with refueling.

- Strip lighting is needed around the boom operator area in order to give the receiver pilot more light, although this may put too much light near the receiver pilot's lights.
- On some occasions, the boom operators may put the pilot director lights on to help give the pilots an additional reference point. In these situations, the boom operators won't direct the pilot with the lights, but they will leave them on. This is not a standard method, although seems helpful.
- Boom operators have used the tail mounted floodlights on very low settings when refueling probe and drogue aircraft.
- The F-117 needs wing lights for silhouette and depth perception and motion. They are needed fore and aft, up and down—in order to provide an outline of the fuselage.
- The majority of the boom operator's job (e.g., 90%) deals with judging the area between the receiver aircraft and the tanker "the closure" and the movement of the receiver aircraft.
- The boom operators cannot currently increase the intensity of the tail mounted floodlights without blinding the receiver pilots.
- The C-17 is the easiest aircraft to refuel because of its tail-mounted flood light and illuminated strips around the receptacle.
- Intensity needs to be variable for all lighting.
- Before a receiver aircraft can assume the pre-contact position, the pilot must first turn off the strobe lights and navigation lights and turn on the receptacle lights. The engine nacelle lights will be turned off or down in intensity. The boom operator will instruct the receiver pilot to change the lights accordingly.
- A rheostat controls the receptacle light so that the intensity can be changed.
- Research is needed to determine if a two-dimensional display can work for the boom operators, who are working in a three-dimensional environment.
- It may be helpful to add a backlight (orange) to the boom operator gauges. Panel lights should be improved because they overheat.
- To help with the light/dark adaptation/focusing problem it may be helpful to incorporate an orange backlight, but it shouldn't be so intense that it could blind or distract the boom operator. This could be a problem when the boom operators begin using NVG.
- During a refuel with an F-15E the receiver pilot accidentally activated the control for the flares, the switch for the flare is next to the receptacle controls. This type of accidental confusion should be avoided.
- Boom operators need reference points in order to determine the relative motion of the receiver aircraft.
- Reflections off the receiver's windscreen are a problem.
- Pilots of probe and drogue aircraft need to be trained to communicate with boom operators when it is necessary during refuel.
- With regard to lighting failure, in the past refuel would continue as long as either the boom nozzle light or the receiver aircraft's receptacle light was working.

- There is a problem with communicating over the boom intercom. The problem seems to be with the individual receiver aircraft and not the tanker (intensity/loudness problem).
- The boom nozzle light is absolutely critical.

## **7.2. *Receptacle Interview Results***

- The KC-135 has two engine nacelle lights mounted on the fuselage. These lights are used by the KC-135 pilot to determine if icing has occurred. They are white and high intensity. The lights offer no benefit for receiver pilots in the observation position. In fact, they're considered detrimental, as they can be blinding to the receiver pilot. For the receiver pilot on the boom, the nacelle lights offer a point of reference.
- Receiver pilots routinely ask the tanker pilot to dim or turn off the nacelle lights before getting into formation, but their request is rarely satisfied. It is not certain why this is the case, it may be that the nacelle lights cannot be independently dimmed or turned off, or it may be that regulations prohibit the tanker pilot from doing so.
- Lighting only visible when using night vision goggles, should be dual mode (i.e., it must have the ability to be switched from regular lighting, overt operation, to night-vision only, covert operation). This is because night vision goggles are often not suitable for use during inclement weather.
- The receiver aircraft in the observation position depends on visual cues to stay in position. These cues include the tanker's wing tip and vertical tail. Each pilot must also see adjacent aircraft, this can be difficult with aircraft that do not have strip lighting. These cues will change when a receiver aircraft drops down from the wing and gets in position at the boom for refueling. When going to the boom, a receiver pilot will primarily focus on the boom, with secondary attention going to the tanker's outline.
- A receiver pilot uses the director lights during the fueling operation to maintain the correct position relative to the tanker. These are the only lights that are important to the receiver pilot during the refueling operation. Before hookup, the boom operator will manually control the lights to instruct the receiver pilot on position. After hookup the director lights are in "automatic mode," and reflect the position of the boom in real-time. After hookup the receiver pilot uses the director lights as feedback for maintaining proper position.
- The director lights work well at night, but can be very difficult or impossible to see during daytime operations. It is especially problematic when the receiver pilot is facing the sun. If the director lights cannot be seen, the boom operator will attempt to transmit commands to the receiver pilot via radio communication. The director lights should be much brighter during daytime refueling and dimmed during nighttime refueling.
- During daytime refueling the pilot uses the tip of the TACAN antenna for alignment purposes.
- It would be helpful if the KC-135 had strip lighting on the wing tips, the vertical tail, and the fuselage.

- The worst refueling/flying conditions are flying in clouds on a moonless night. When flying in these conditions the lights on the tanker become even more important than normal. The refueling pilots need to be able to make out the shape of the tanker when flying in observation positions (on wing). The pilots also need to be able to see the tanker fuselage when flying in observation position (on/above the wing).

### **7.3. Probe Helicopter Interview Results**

- There are differences in the tanker rendezvous procedures for helicopters and jets. Most helicopter missions are special operations. Special operators missions have a strict time schedule and must be precisely times (+/- 30 second flexibility). The helicopters will fly approximately 300-500 feet off the ground, and the tanker will perform an overtaking rendezvous. The tanker and the helicopter need to be moving in the same direction at the ARCT. The tanker will overtake the helicopter and fly above it while navigating the same route. The tanker will slow its speed down to approximately 125 knots. The tanker is required to make visual contact with the helicopter by a certain time, or it must break off its approach.
- While in the observation position the second helicopter pilot (in the probe seat) will examine the tanker to make sure that fuel is not coming out of the wrong places, and that the hose is alright.
- Most special operations have no communication. The C-130 and helicopter communicate through light signals. There are indicator lights on the back of the refueling pod (old version was amber, green, and red lights to communicate status; new version uses a combination of lights to communicate).
- It is important to make sure that the correct combination of lights for “caution” is lit. It is also important to make sure that the pod hydraulic is getting power.
- While in the pre-contact position the helicopter is approximately 10 – 15 ft behind the drogue (this can be very bumpy due to turbulence). The pilot needs to physically see where the hose is trailing.
- For disconnect the first thing that the pilot will look at is where the refuel pod comes out from behind the flaps. They also pay attention to the distance for disconnect, and for up/down they want to be above that for disconnect. Once these are referenced, the pilot will make an approach to the drogue. The pilot will focus on the tanker wings and cross check laterally. They will not focus on the drogue.
- Once the pilot has made contact with the drogue they move up and outside so that they are looking straight down at the fuel dump tube on the end of the wing. This gives the pilot a primary visual cue (which gives them their lateral out).
- The “vertical” is primarily measured by the “Batman ears,” and if the pilot is in the correct position they can see the triangular tops of the engine nacelle.

- Forward and aft are measured by the markings on the hose, so there is a continuous check with the dump tube, the “Batman ears”, and the hose markings.
- On the MH-47 there are two IR search lights in the front pylons which provide cues to the pilot.
- The entire environment can be illuminated by the IR light, so additional light sources usually are not needed.
- Almost all helicopter pilots use NVG. Due to mission purposes, helicopter refuel is always conducted at night.
- The C-130 has an IR strobe light and that can be seen for miles with NVG. Both the tanker and the helicopter can see each other (usually).
- The tridium lights are very visible to the naked eye, but the same effect is not achieved with NVG. It is possible to see the tridium lights when wearing NVG.
- It is preferred that the crews on the KC-10 and KC-135 turn all of their normal lights off and use their IR strobe lights for crash avoidance.
- Some helicopters don’t have any lighting for aerial refueling (the “Jolly Green” Giant, the “Super Jolly” MH-53).
- NVG need improvement (Gen IV).
- The pilots that use NVG learn to use monocular cues. For the majority of the refueling process (while wearing NVG) they are in optimum range for acuity (10 ft – 100 ft they have binocular vision).
- The C-130 is a 3-6 man aircraft. The crew’s goal is to fly the plane as flat as possible. The C-130 loadmaster is in the back of the aircraft watching the refuel. The loadmaster can give the helicopter the breakaway signal and pull the hose in. The loadmaster needs to be able to see the helicopter better, but this pilot doesn’t know what to do to improve things for the loadmaster.
- The helicopter needs at least one hour worth of fuel onboard before it needs refueling (or at the time of refueling).
- There is usually a backup tanker on each refuel mission.
- The helicopters do stack up in the observation position.
- The hose gets scuffed up and it becomes difficult to see the hose markings.

#### **7.4. Information requirements for aerial refueling phases**

Interviews were conducted for the primary purpose of obtaining details about lighting issues and to determine their total information requirements. Analysis of interview notes identified the need to construct a graphical representation of these data for illustrating and determining lighting criticality. Results from the interviews, therefore, were compiled based on the phases of the aerial refueling process. Major phases of the process were identified with the primary information requirements associated with that phase. Within these areas, the user community identified areas where information was not always available during aerial refueling. This analysis has been captured and is presented in Table 4.

Table 4. Data collected from interviews regarding information shortfalls.

<b>PHASE</b>	<b>INFORMATION REQUIRED (Partial)</b>	<b>INFORMATION NOT ALWAYS AVAILABLE (Partial)</b>
<b>Rendezvous</b>	<ul style="list-style-type: none"> <li>• Identify tanker vs other A/C</li> <li>• Available systems (drogue, boom, etc.)</li> </ul>	<ul style="list-style-type: none"> <li>• Cannot always identify tanker vs other A/C</li> <li>• No indication of available systems</li> </ul>
<b>Join-up</b>	<ul style="list-style-type: none"> <li>• Tanker orientation</li> <li>• Location of other A/C</li> </ul>	<ul style="list-style-type: none"> <li>• Tanker orientation and location of other A/C may not be known during covert ops</li> </ul>
<b>Formation</b>	<ul style="list-style-type: none"> <li>• Distance from other A/C</li> <li>• Ownship attitude, speed</li> </ul>	<ul style="list-style-type: none"> <li>• Unable to see other A/C in covert ops</li> <li>• Unable to use tanker for ownship attitude reference in covert ops</li> </ul>
<b>Departure from formation to pre-contact</b>	<ul style="list-style-type: none"> <li>• Position of other A/C</li> <li>• Location / orientation of tanker</li> <li>• Location of drogue or boom</li> </ul>	<ul style="list-style-type: none"> <li>• Same as above</li> <li>• May not be able to see drogue from the side</li> </ul>
<b>Pre-contact</b>	<ul style="list-style-type: none"> <li>• Ownship attitude</li> <li>• Closure rate</li> <li>• Location and movement of drogue/boom</li> <li>• Tanker maneuvers / orientation</li> </ul>	<ul style="list-style-type: none"> <li>• Ownship attitude difficult to determine w/ tanker aft fuselage dark</li> <li>• Closure rate difficult to determine with tanker aft fuselage dark</li> <li>• Tanker maneuvers difficult to determine with aft fuselage dark</li> </ul>
<b>Contact</b>	<ul style="list-style-type: none"> <li>• Hose markings</li> <li>• Tanker maneuvers / orientation</li> </ul>	<ul style="list-style-type: none"> <li>• Hose markings may not be visible with NVGs</li> <li>• Tanker maneuvers difficult to determine without NVGs because of no light on aft fuselage</li> </ul>
<b>Refuel</b>	<ul style="list-style-type: none"> <li>• Hose markings</li> <li>• Tanker maneuvers / orientation</li> </ul>	<ul style="list-style-type: none"> <li>• Same as above</li> </ul>
<b>Disconnect</b>	<ul style="list-style-type: none"> <li>• Hose markings</li> <li>• Position of other A/C</li> </ul>	<ul style="list-style-type: none"> <li>• Hose markings may not be visible with NVGs</li> <li>• Other A/C may not be visible in covert ops</li> </ul>
<b>Separation</b>	<ul style="list-style-type: none"> <li>• Position of other A/C</li> </ul>	<ul style="list-style-type: none"> <li>• Position of other A/C may not be visible during covert ops</li> </ul>

## **8. Results from Questionnaires**

Number of respondents to the questionnaire was very high. The UDRI team received 40 total responses to the questionnaires, 24 receiver pilots, and 16 tanker operators. Estimates are that approximately 75% of the questionnaires distributed were completed and returned (a very high response rate). More importantly, the responses received were more than adequate to address the types of aerial refueling lighting interface issues being faced by the tanker and receiver communities.

Results from questionnaire data is divided into two major sections, the Receiver Pilot Questionnaire results and the Tanker Questionnaire results. The Receiver Pilot Questionnaire addressed the concerns that the receiver pilot might have regarding tanker aircraft. The Tanker Boom Operator Questionnaire addressed the concerns the tanker operator might have regarding the receiver aircraft. Each of these major sections will be further divided into three sections that focus on three different groupings of questions. The Receiver Pilot section is subdivided into the Common, Receptacle, and Probe subsections. Questions within the Common subsection address common issues that receiver pilots may have encountered when refueling from both drogue and boom equipped tankers. Questions within the Receptacle subsection address issues that receiver pilots may have encountered when refueling from a boom equipped tanker. Questions within the Probe subsection address issues that receiver pilots may have encountered when refueling from a drogue equipped tanker.

Tanker respondents: 16

Receiver respondents: 24

Total respondents: 40

The Tanker section is divided into the Common, Boom, and Drogue subsections. Questions addressed within the Common subsection focus on issues that are common to both the boom operator and to aircrews that operate boom receptacle and probe/drogue systems. Questions within the Boom subsection address issues that boom operators may encounter when refueling receiver aircraft equipped for the boom-receptacle method. Questions within the Drogue subsection address issues that an aircrew or boom operator may encounter when refueling receiver aircraft equipped for probe-drogue connections.

### ***8.1. Receiver Pilot***

#### **8.1.1. Common Issues**

##### **Tanker Location and Identification.**

Respondents identified various methods to locate and identify tanker aircraft, but air-to-air TACAN, visual contact, and radar were the three major methods they used.

##### **Lighting & Markings.**

Respondents indicated that there were some problems with tanker markings, lighting, and status lights. Specific emphasis was placed on the markings for the KC-135 and KC-

10 tanker aircraft. Respondent suggestions included making tanker lighting compatible with night vision devices and adjustable/dimmable (full dimming), equipping the boom/basket with a light, and lighting the hose via the pod. Some respondents stated that the underbody stripe and engine nacelles were also problem areas that required improvement. Some respondents indicated that there are obstructions that obscure the receiver's view of the formation references on the tanker aircraft. Respondents also indicated that some of the formation references are visible during day light conditions, but are not visible during night conditions.

### **Tanker Rendezvous.**

Respondents indicated that there were problems with identifying the appropriate tanker aircraft to rendezvous with. Some respondents noted that on occasion they have rendezvoused with a tanker aircraft only to discover that it was not the correct tanker. Respondents also indicated that it could be difficult to rendezvous with the correct tanker aircraft when there are multiple tankers flying within the same area.

### **Glare and low sun angles.**

Findings suggest that low sun angles are a problem for receiver pilots. Low sun angles can make it difficult for the receiver pilot to see the necessary references to keep formation or maintain the appropriate refueling envelope.

### **Hose Markings.**

Respondents indicated that the distance of the hose and the hose markings are important references. The hose markings allow the receiver pilot to gauge the rate of closure and keep the hose retracted to the proper length. Respondents also pointed out that the hose markings are fairly visible in day, night, twilight, and night vision goggle conditions.

### **Night Vision Devices.**

Some respondents indicated that they use night vision goggles (NVG) during aerial refueling. The night vision goggles can help them see the necessary tanker lights and markings.

## **8.1.2. Tanker Boom Receptacle Issues**

### **Pilot Director Lights.**

The findings indicated that some of the respondents used the Pilot Director Lights (PDL) while others did not. The respondents that did use the PDL indicated that they also cross reference the PDL with other tanker markings and references. Some participants indicated that the PDL were adequate for refueling, while other respondents indicated the PDL need improvement. Respondents also indicated that the illumination from the PDL is not constant. In some instances the PDL can be too bright for refueling and in other instances the PDL are not bright enough. Suggested improvements for the PDL included making the lights brighter for day aerial refueling and dimming the lights

for night and covert refuels. Of the individuals that responded, most indicated they wanted the PDL to give them information regarding their position rather than commands about where they should be.

### **8.1.3. Probe Issues**

#### **Boom-to-Drogue Adapter kit.**

There are some problems with receiver pilots of probe-equipped aircraft receiving verbal instructions from boom operators when refueling with tankers equipped with BDA kits. Problems include having too much communication on non-standard communication channels and the boom operator moving the boom while the receiver pilot is refueling.

#### **Hose Markings (see above Hose Markings section).**

Respondents indicated that they did have some difficulty seeing the hose and drogue during night refueling. Respondents suggested improving the markings and lighting for the hose and drogue so that the receiver pilot can follow them. Respondents also stated that the probe light on the receiver aircraft should to stay lit/failure free so that aerial refueling is not interrupted. Most respondents indicated that it was important for the drogue to be illuminated during night and twilight conditions. It was suggested that adding tritium buttons or white reflective tape to the hose and drogue might help improve drogue illumination.

## **8.2. Tanker Operator**

### **8.2.1. Common Issues**

#### **Lighting & Markings.**

According to the findings night lighting and markings are a problem for nighttime refueling. Respondents indicated that the major problem is that there is either too much lighting or not enough lighting for aerial refueling. Essentially insufficient lighting conditions can cause depth perception problems for the boom operator, however, conditions in which there is too much lighting can result in blinding the receiver pilot. One respondent pointed out that the underbody lights require constant adjustment to avoid blinding the receiver pilot. Respondents also indicated that it would be helpful to both the boom operator and the receiver pilot if both the tanker and the receiver aircraft had the ability to easily adjust or dim the exterior lighting. The findings indicate that boom operators do use reference markings on both the tanker (e.g., nacelle lighting, tail mounted flood lights) and the receiver aircraft (e.g. tail lights, wingtip lights, receptacle lights) to assist them in aerial refueling. Respondents also suggested that additional lights and markings might better assist them in performing their aerial refueling duties.

## **8.2.2. Boom Issues**

### **Boom Nozzle Light.**

Respondents indicated that there was some concern with the boom nozzle light bulb. Many respondents indicated that they checked the status of the boom nozzle light bulb while the tanker aircraft is still on the ground. In spite of this check they may still encounter a boom nozzle light bulb failure while in flight, and they may not be aware of the failure until they are ready to refuel a receiver aircraft. Respondents also suggested that the boom nozzle light have some redundancy (i.e., a backup light bulb), and that the boom operator instrument panels provide the boom operator with an indicator for light bulb failures.

### **Visual Information.**

The findings suggest that in general, the boom operators are able to acquire the visual information they need to perform their job. However, improvements to the boom operator station would assist them in better performing their job. Some respondents suggested improvements including making interior and exterior lighting compatible with night vision equipment. Further refinements can be realized by making the interior and exterior lighting adjustable, and replacing the current boom operator panel with a Heads Up Display (HUD). This is so that the boom operator will not need to divide his attention between the refueling taking place outside the tanker and the instrument panel inside the boom operator station.

### **References.**

Respondents indicated that it would be helpful to them to equip receiver aircraft with adjustable/dimmable exterior lighting. Respondents also indicated that additional lighting on the top of receiver aircraft would provide them additional cues to improve their depth perception.

### **Glare and low sun angles.**

According to the findings low sun angles do cause a problem for boom operators. Respondents stated that low sun angles can be so troublesome that when necessary, in these conditions they will either instruct the tanker pilot to change headings or instruct the receiver pilot to maintain their position until the glare/low sun angle is no longer a problem.

## **8.2.3. Drogue Issues**

### **Tail Mounted Floodlight.**

Most respondents indicated that they did use the tail-mounted floodlight when refueling probe equipped receiver aircraft.

### **Boom-to-Drogue Adapter Kit.**

According to the findings and respondent comments it may be beneficial to the boom operator to improve the viewing and lighting of the boom-to-drogue adapter (BDA) kit. Respondents indicated that it is difficult to see the receiver aircraft as it approaches for contact. Respondents also stated that the view was so troublesome that they were not able to see the refueling process at all, and had to rely on “feel” and communication with the receiver pilot in order to perform the refuel.

### **Lighting & Markings.**

Respondents indicated that although markings on fuselage mounted and wing mounted hose reels might be visible during the day the markings may be difficult to see at night. Respondents also indicated that it might be beneficial to standardize the hose markings across tanker aircraft.

## **9. Additional Supporting Evidence**

### **9.1. Aerial Refueling Equipment Photo Gallery**

The aerial refueling photo gallery shown in Attachment 1 provides a pictorial representation of both the boom/receptacle aerial refueling system method and the probe/drogue method. The boom/receptacle method requires two distinctive functions: the hook-up functions, performed by the tanker boom operator and formation on the tanker, performed by the receiver pilot. For the probe/drogue method the receiver pilot is in control. In this method, the aerial refueling hose is unwound from the tanker's hose reel drum so that it trails from the tanker fuselage or wing(s). The probe nozzle on the receiver aircraft is inserted into the tanker coupling. Photographic representations of these two methods of refueling further illustrate the processes further.

### **9.2. Aerial Refueling Lighting/Markings Block Diagrams**

Early in the study KC-135 block diagrams were created. The block diagrams were intended to:

- illustrate the magnitude of the contracted task,
- explain the complexity of the task,
- demonstrate the need to integrate the tanker and receiver as a single overall system,
- identify and prioritize the aerial refueling tasks,
- aid in developing a schedule for the tasks,
- identify lighting issues from past experiences,
- aid in developing interview questions and in preparing questionnaires for data collection, and
- serve as the foundation for the study.

The block diagrams, shown in Attachment 2, also served to coordinate and educate all the members of the lighting/markings study team regarding issues with existing tanker and receiver aircraft. The diagrams functioned as a departure milestone for the study.

### **9.3. Questionnaires (Receiver & Tanker)**

The purpose of the receiver questionnaire, shown in Attachment 3, was to collect aerial refueling data from the perspective of the receiver pilot. This questionnaire consisted of 21 questions. Responses were presented in binary, rating, and short answer formats. Questions addressed issues and problems that receiver pilots might encounter when refueling from boom equipped and drogue equipped tanker aircraft. Issues included: locating and identifying tanker aircraft, tanker markings and status lights, tanker dimming controls, use of the Pilot Director Lights, the effectiveness of the Pilot Director Lights for specific weather conditions, using the BDA kit adapter and the appropriate formation references, illuminating the drogue, drogue markings, visibility of tanker status lights for hose/drogue systems under specific conditions.

The purpose of the tanker questionnaire, also provided in Attachment 3, was to collect aerial refueling data from the perspective of the boom operator. This questionnaire consisted of 22 questions. Responses were presented in binary, rating, and short answer formats. Questions addressed issues and problems that boom operators might encounter when refueling receptacle equipped and probe equipped receiver aircraft. Issues addressed included: night lighting and markings on receiver aircraft, and dimming receiver aircraft lighting, tanker nozzle light redundancy, and dimming the interior tanker lights, tail mounted flood light use when refueling with a BDA kit (KC-135), viewing and lighting when using the BDA kit, improved viewing and lighting of the receiver aircraft.

#### **9.4. Questionnaire Summaries (Receiver & Tanker)**

The Receiver Pilot Questionnaire Summary, provided in Attachment 4, is a summary of the data collected from the receiver pilot questionnaire. The summary is divided into five sections: Common, Receptacle, Probe, Demographic, and Unassigned.

The questions within the Common subsection address issues that receiver pilots may have encountered when refueling from either boom or drogue equipped tankers. The following are examples of the types of issues that were addressed by the questionnaire: locating and identifying tanker aircraft, tanker markings and status lights, tanker dimming controls.

The questions within the Receptacle subsection address issues that receiver pilots may encounter when they fly a receptacle-equipped aircraft and refuel from a boom equipped tanker aircraft. The following are examples of the types of issues that were addressed by the questionnaire: use of the Pilot Director Lights, the effectiveness of the Pilot Director Lights for specific weather conditions.

The questions within the Probe subsection address issues that receiver pilots may encounter when they fly a probe-equipped aircraft and refuel from a drogue equipped tanker. The following are examples of the types of issues that were addressed by the questionnaire: problems with the tanker, using the BDA kit adapter and the appropriate formation references, illuminating the drogue, drogue markings, visibility of tanker status lights for hose/drogue systems under specific conditions, and tanker status lights.

The demographic section briefly addresses the respondents' experience with different receiver aircraft and their refueling experience with different tanker aircraft.

Attachment 4 also addresses the Tanker Questionnaire summary. The Tanker Questionnaire Summary is a short description of the data collected from the Tanker Questionnaire. The summary is divided into five sections: Common, Boom, Drogue, Demographic, and Unassigned.

The questions within the Common subsection address issues that are common for both boom operators and aircrews that operate drogue-refueling systems. The following are examples of the types of issues that were addressed by the questionnaire: night lighting and markings on receiver aircraft, and dimming receiver aircraft lighting.

The questions within the Boom subsection address issues that boom operators may encounter when refueling receptacle equipped receiver aircraft. The following are

examples of the types of issues that were addressed by the questionnaire: tanker nozzle light redundancy, and dimming the interior tanker lights.

The questions within the Drogue subsection address issues that a boom operator may have encountered during refueling when a BDA-kit is attached to the boom. The following are examples of the type of issues that were addressed by the questionnaire: tail mounted flood light use when refueling with a BDA kit (KC-135), viewing and lighting when using the BDA kit, improved viewing and lighting of the receiver aircraft.

The demographic section briefly addresses the respondents' experience with different tanker aircraft and their refueling experience with different receiver aircraft.

### **9.5. CTA Interview Guidelines**

Interviews conducted for this study revealed that the cognitive skills associated with this task were quite complex both for the tanker operator as well as the receiver operator. A set of guidelines was developed to assist in evaluation of the interview results. These guidelines were further expanded into a set of question probes and interview guidelines to assist in future interviews. These cognitive task analysis interview guidelines are provided in Attachment 5 of this document. They are included here as a tool for future research interviews in the area of aerial refueling.

### **9.6. Results of Hose Tests for NVG Usage**

Attachment 6 provides the results from tests conducted at AFRL/HEC with regard to the reflectivity of both a black and a white hose. These tests were conducted at AFRL/HEC at no cost to this program. These evaluations provided valuable information with regard to both white and black hose reflectivity when using NVG.

### **9.7. Existing Simulators and Areas for Potential Evaluation at Simulation Facilities**

Defining requirements associated with aerial refueling lighting upgrades or future systems requires careful analysis and thoughtful consideration. Many tools are available to conceptualize potential design trade-offs and their ability to meet necessary requirements. Typically, in aerial refueling lighting these tools have included mock ups, prototypes, and initial development aircraft. Advances in modeling and simulation over the past few years has allowed for complex models of the aircraft and its lighting to be joined with the environment and its lighting. Existing modeling and simulation facilities can provide meaningful information for early conceptual aerial refueling lighting designs. Two of these facilities exist at Wright-Patterson AFB, Ohio. The Air Force Research Laboratory, Air Vehicles Directorate (AFRL/VACD), Aerospace Vehicles Technology Assessment and Simulation (AVTAS) offers one of these facilities, the other is the Synthesized Immersion Research Environment (SIRE) laboratory in AFRL, Human Effectiveness Directorate, Warfighter Interface Division (AFRL/HECP). Capabilities of these two facilities are provided in Attachment 7 along with a table outlining areas for potential evaluation at these or other simulation facilities.

## **9.8. *Aerial Refueling Lighting Guide***

The Aerial Refueling Lighting Study Guide (ARLS-G), see Attachment 8, is designed to cover external lights and marking considerations on the tanker and receiver aircraft used to perform serial refueling. Lighting and ergonomics at the boom operators position is also included for completeness in the acquisition of visual inputs required to carry out the task of aerial refueling. The Guide is intended to be used for future aircraft but includes examples from existing aircraft for clarification purposes and is grouped first by common guidelines, then those for tankers, and third, for receiver aircraft.

## **10. Recommendations (Issues, Solutions & Future Research)**

The recommendations contained in Paragraphs 10.1, 10.2, 10.3 and 10.4 are based on assessments of the data obtained during this study through literature reviews, questionnaires, interviews, lighting manufacturing plant tours, research, 45 years of past aerial refueling lighting experience and an examination of new lighting technology. Methods for implementing the recommendations are included.

The value of the recommendations and potential solutions to problems offered herein are open to further examination as all factors including operational needs and budget issues are considered. Comparative evaluations may be conducted when alternative ideas are offered. Effective, accurate, appropriate and cost-effective evaluations can be conducted using scale model photography and aerial refueling simulators that can be modified for lighting and marking analyses. Two such simulator facilities currently exist at the United States Air Force Research Laboratories (AFRL) at Wright Patterson Air Force Base, Ohio. Discussions with AFRL personnel indicate these facilities that currently are programmed for other studies and research could be modified to allow comparative evaluations of lighting and marking concepts for both unaided and aided vision.

The two AFRL simulator facilities at WPAFB identified by this study, which potentially could be used in evaluating aerial refueling lighting and marking concepts, were classified into two aerial refueling phases. The first facility appears to best serve the initial tanker identity, approach to pre-contact, and traffic control aerial refueling Phase I (Global Phase).

The second facility provides some overlap in global capability but best lends its capabilities towards the pre-contact through the hook-up/disconnect phase of the aerial refueling operations, Phase II. (Close-Up Phase). Both of the facilities offer potential for receiver aircraft pilot and boom operator perspectives of low light aerial refueling operations. The second facility currently is designed for the boom/receptacle method of aerial refueling. It is understood that both facilities can be modified to the probe/drogue method of aerial refueling.

In addition to simulation facilities, the use of scale aircraft models and partial aircraft sections in a photographer's dark room also provides a quick and low cost initial method for evaluating a variety of lighting and markings issues.

### ***10.1. Tanker, General***

Complete underbody illumination of the tanker is critical to the receiver pilot in maintaining close formation with the tanker, especially under ambient low light level conditions. Additionally, air turbulence combined with tanker turns and tanker non-illuminated fuselage close formation references (normally available during daylight illumination conditions) are critical factors requiring a fully illuminated tanker underbody. This is true for receiver pilots of both boom/receptacle and probe/drogue aerial refueling systems. Matching airspeeds and maintaining a safe attitude in close

proximity to the tanker requires close formation tanker references, particularly when the receiver pilot does not have a natural horizon for reference. Overall tanker underbody platform references are required for maintaining close tanker formation under all lighting conditions, day or by artificial light sources at night.

#### **10.1.1. Formation Flood Lighting Underbody Surfaces**

All tanker underbody surfaces (wing, fuselage, horizontal tail, engine nacelles) and wing leading edge should have balance and symmetrical illumination for low light level conditions.

#### **10.1.2. Light Source Visibility**

Light sources for surface lighting should not be visible to the receiver aircraft pilot in either the wing formation position or the refueling positions. This includes aerial refueling with wing mounted aerial refueling stores/pods (drogue or boom), centerline boom, BDA kit or centerline hose type systems.

#### **10.1.3. Dimming Controls**

Each light source should be individually fully dimmable from full bright (adequate for all light conditions) to full off with failure mode detection. A master dimming control be provided which allows the operator a single dimming control of all tanker external lighting (except the boom nozzle light) to enhance the use of night vision goggles (NVG). Covert operations using infra-red light sources also should be dimmable.

#### **10.1.4. Aerial Refueling Equipment and Critical Reference Illumination**

All light sources should provide sufficient illumination for all key aerial refueling references, i.e., wing stores, engine nacelles, booms, hoses, couplings drogues and other aircraft references, i.e., antennas, rivets, etc. for all ambient lighting conditions.

#### **10.1.5. Underbody Fuselage Strip Formation Illumination**

Provide a centerline bottom fuselage strip (currently an orange painted stripe) to extend from nose of tanker to the tail cone at 6:00 OC position on fuselage with active lighting (i.e., strip lighting with highly reliable LED's or electro-luminescent strip lighting). Also provide active lighting (similar to above) lateral strips spaced 10 feet apart along the underbody to extend from the tail cone to the nose of the aircraft. These stripes should be extended to center of aircraft body.

#### **10.1.6. Tail Mounted Flood Light**

Provide the tanker's vertical tail or tail cone with redundant flood light sources for illuminating the top surface of the receiver aircraft and top surface of the aerial refueling boom and fuselage mounted hose. This light coverage should extend beyond a fully extended boom at 20° elevation and ±15° lateral boom position. The light source should be a soft light (no direct filament visibility) with sand blasted lens (or equivalent). Operator controls should be equipped with a distinct position denticulated variable

dimming control with a minimum of 10 positions of dimming. The operator dimming controller should be provided with lamp failure mode detection.

### **10.1.7. Anti-Collision Beacon and Strobe Light**

The tanker's rotating beacon/strobe lights (upper fuselage and lower fuselage) should be equipped with the capability to:

- A. be identified as a tanker and aerial refueling equipment (drogue, boom or dual) aerial refueling capability; and
- B. separate operator controls for upper or lower beacon and with full dimming controls to off.

Note: These separate controls allow appropriate lights to be dimmed or turned off so that their glare does not interfere with the vision of the receiver pilot and tanker operators while aerial refueling. During the aerial refueling operation, the lower rotating beacon/strobe light of the tanker and the top rotating beacon on the receiver aircraft must be turned off. During the operation, the lower rotating beacon on the receiver should be turned on so that the aerial refueling formation can be identified.

### **10.1.8. Vertical Stabilizer (Logo) Illumination**

The vertical stabilizer (both sides) of the tanker should be illuminated to assist in tanker identity. This light as all external lights are required to be fully dimmable from full on to full off as described above (individual and master controller).

### **10.1.9. Wing Tip Formation References**

Illuminated wing tip formation references are necessary for the receiver aircraft to maintain tanker formation prior to their departure to the refueling pre-contact position. The use of strip and formation lights have been typically used for this application.

## ***10.2. Tanker Boom/Receptacle Method***

### **10.2.1. Nozzle Light**

The boom should be equipped with a redundant nozzle light for illuminating the boom nozzle at any boom telescoping position and for the use as a spot on the receiver aircraft surface in order to avoid contact with critical fuselage (no contact) areas, i.e., windshield, canopy, skin contours, protruding objects, antennas, externally mounted aerial refueling receptacle installations. This light also should provide illumination of the slipway/fuselage receptacle tape/paint markings and for locating the aerial refueling receptacle/slipway of the receiver aircraft.

The nozzle light should be located at a 6:00 OC position within the boom ice shield with the light filament source not visible to the receiver pilot. The coverage should be the equivalent to the KC-135 boom nozzle replacement light currently planned for a KC-135 retrofit, i.e., TCTO –1C-1351422 (a kit 1560 KO 180 480 AFL). The fixture should have as a minimum, the equivalent life of the KC-135 replacement nozzle light and a full

variable dimming control (controlled by aerial refueling operator) from full bright to off with lamp failure mode detection.

### **10.2.2. Boom Telescoping Tube Envelope Markings**

The boom telescoping tube envelope should be provided with 360° circumference fluorescent markings illuminated by a light in the boom ice shield. These should be equivalent to the fluorescent markings (illuminated by a black light) in the KC-135/10 boom ice shield. These markings should be visible to both the boom operator and the receiver pilot prior to hook-up. Receiver pilots with forward-of-cockpit aerial refueling receptacles also should be able to see the markings after hook-up. These markings should be similar to the KC-135 and KC-10 boom marking indicating the boom telescoping tube center envelope with green markings, yellow indicating limit envelope, and red indicating out of envelope position. The markings should be compatible with night vision goggles (NVG) equipment. (Colors are not detectable with NVG.) Standardization of markings should be a primary consideration.

### **10.2.3. Pilot Director Lights**

Currently, the KC-135, KC-10, KCD-10 and some international KC-707 and KC-767 tankers are equipped with pilot director lights (PDL's). These PDL's are light strips located forward underbody of the tanker. These PDL's are used by pilots of receptacle-equipped receiver aircraft to aid the pilot in establishing proper position for hook-up and in maintaining proper position after hook-up. Prior to hook-up, the boom operator, from his position in the tanker, has control of the PDL's to direct the receiver pilot into position. After the receiver aircraft is in position, the boom operator guides the boom nozzle into the receiver aircraft receptacle to achieve a hook-up. After hook-up, the PDL's become an automatic system that provides forward/aft and up/down position information.

With the KC-10, the PDL's also provide trend information. The KC-10 PDL's include several positive features that are not found on PDL's on the KC-135. These features include elongated letters, increased white background lighting and brighter color lighting of green (center of boom envelope), yellow/amber (caution approaching disconnect envelope), and red (pending disconnect envelope). These lights generally provide supplementary boom position information to the receiver pilot. These improvement features originally were incorporated on the KC/KE-707's international air forces' foreign military sales (FMS) tanker aircraft. Improvements were not made to the KC-135 PDL's to incorporate these features.

All future tanker aircraft designers should consider, as a minimum, the KC-707/KC-10 type director light improvements described above.

Receiver aircraft pilots may use a variety of primary visual references on the tanker underbody: the centerline TACAN antenna at ~FS-966 KC-135, rows of rivets, etc. These primary references are used in combination with the PDL's as formation aids before hook-up and in maintaining proper position on the boom after hook-up.

### **10.2.3.1. Alternative Solution for PDL's**

New ideas and concepts for improved equipment that could provide formation, receiver aircraft position and boom position signals should be evaluated and compared with the current equipment. New, easily read, accurate equipment could be positioned further aft on the tanker underbody and serve as a single reference to replace the current PDL's and the use of other references such as antenna and rows of rivets.

A combined formation/position (screen) system (CFPS) also should incorporate flush aircraft contour retraction features to avoid loss of efficiency due to dirt/sand contamination when not in use. An example of a CFPS is described in the technology section of this document. The various models and simulators described in this report may be used to assess the value of such combined formation/position equipment.

### **10.2.4. Boom Operator Instrumentation Panel and Receiver Pilot Cockpit Three Position Status Lights**

The three position cockpit/operator station status lights currently used by both the boom operator and receiver pilot (blue = ready; yell/amber = contact made; red = disconnect) should be retained as standard for both the boom operator and the receiver pilot. Critical lights and boom position instrumentation should be in the boom operator's line of sight to the receiver aircraft.

#### **10.2.4.1. Boom Load Indicator**

Investigate incorporating a boom nozzle load indicator in the boom operator's line of sight with crosshairs/load circles to ensure that telescoping boom loads are within normal operating load parameters and below limits.

### **10.2.5. Boom Interphone**

Provide tanker with through-the-boom inter-communication capability.

## ***10.3. Tanker Drogue Method***

### **10.3.1. Receiver Closure Rate Warning Lights**

Methods should be investigated for warning receiver pilots that safe closure rate (prior to contact) is being exceeded. The CFPS described in Paragraph 1.12.1 above could be programmed to provide information for the centerline hose reel system.

### **10.3.2. External Tanker Status Lights (Drogue System)**

The three position status lights currently provide aerial refueling drogue system status to the probe equipped receiver pilot and the tanker operator: yellow/amber = ready (for hookup); green = fuel flowing; red = low/no hose response (no hydraulic), i.e., emergency hook-up only.

Provide the receiver pilot three-position status lights as described above. In some cases, a flashing yellow light that indicates inner and outer hose envelope position has been exceeded also should be provided. These lights should be visible to the receiver pilot from pre-contact to disconnect. Duplication of these status lights may be necessary depending on receiver pilot position before and after hook-up and throughout hose envelope position. The hose reel operator should be provided a duplicate set of these status lights on the hose drogue operator panel for each drogue system employed wing or fuselage. These lights should be provided with dimming controls from full bright to full off.

These three status lights should be NVG compatible and internationally standardized. Currently four or more variations of NVG-compatible designations are either proposed and/or incorporated on existing and new tanker aircraft. A single universal international designation should be adopted which best serves the receiver pilots. An evaluation of all current/proposed methods be conducted and a single NVG compatible standard be adopted and that configuration be illustrated and mandatory for all probe/drogue aerial refueling procedure technical orders, (ATP-56) STANAG 3971 and STANAG 3447, as the international standard.

### **10.3.3. Tanker Turn Indicator Light**

Investigate methods for alerting receiver pilot that tanker turn is imminent.

### **10.3.4. Boom-to-Drogue Adapter Kit (BDA Kit)**

The KC-135 boom when equipped with a boom-to-drogue adapter (BDA) kit does not provide for a set of these three status lights, since the BDA kit hose does not employ an automatic hose take-up system. The boom operator and pilot depend on the hose loop (C-shape) visual identity for a contact-made condition by visual observation. The fuel flow is manually controlled by the boom operator's verbal communication with the tanker second pilot who turns on the aerial refueling pumps. The only fuel flow indication the receiver pilot has is by the quantity/fuel gauges or boom operator voice/signal communications. Fuel flow termination is by either the receiver pilot's radio signal command or the boom operator observation and anticipation of an impending disconnect by the receiver aircraft's movement to the hose/drogue normal trail and disconnect position.. The boom operator is required to retract the boom telescoping tube to reduce the trapped fuel pressure to only static head pressure after each disconnect. Methods for providing BDA kit hose position and refueling status should be investigated. This status should be made available to both the receiver pilot and the boom operator.

### **10.3.5. Drogue/Coupling Lighting, Markings and Hose Markings Illumination**

Currently, most couplings and drogue canopies are either white or equipped with wide angle reflective white tape/paint. Some drogues and attached couplings are equipped with generators supplying electrical power to small incandescent lights attached to the drogue struts thus providing internal cone illumination. In some cases, tritium buttons are used in lieu of lights to identify the drogue internal cone.

Recently, external illumination by use of LED's to identify the external coupling/drogue hardware has been employed by tanker aircraft. This external lighting configuration of the coupling/drogue provides the receiver pilot valuable information as the receiver pilot moves from the wing formation position on the tanker to the pre-contact position behind the drogue.

As a minimum, the above lighting and marking configurations for both internal drogue cone and external coupling and drogue should be provided for all future tanker coupling/drogue aerial refueling systems.

### **10.3.6. Aerial Refueling Hoses**

Hose reel systems currently employ hoses of various lengths depending on the aircraft application, e.g., wing stores/pods, fuselage reels and the BDA kit. Wing store hoses and fuselage hose reel hoses may vary from 50 ft. to 85 ft. Some stores with metal hoses are only 35 feet long.

The KC-135 BDA kit is 9 feet in length and does not provide automatic hose take-up as do standard hose reel systems. Due to the absence of this hose take-up provision and hose system characteristics with the BDA kit, a white hose is required for safety purposes. Hose position (C-shape) identity illuminated by the receiver's probe light/fuselage light (when provided) and the tanker TMF requires a white versus a black hose. Hose positions are critical to the receiver pilot since the hose may wrap behind the drogue prior to disconnect, thus producing tanker and receiver aerial refueling equipment failure on disconnect. The white hose provides valuable position information for avoiding off-center disconnects associated with the very small hose envelope. Hose position also provides the boom operator coupling hook-up verification for fuel flow initiation during radio silent operations.

Both white and black hoses with contrasting black/white markings are used on current aerial refueling hose reel type systems (wing and fuselage). Marking stripes on these long hoses (50 to 85 feet) typically are spaced 10 feet apart and are 1 foot wide. A light near the hose stowage exit illuminates these hose markings. Also, a fuselage light aft of the tanker hose exit directed forward, to avoid receiver pilot direct vision, is used to illuminate a section of the hose. Also tanker elevator tip lights may provide a light source for wing mounted drogue stores/pods and hoses. Also tanker elevator tip lights may provide a light source for wing mounted drogue stores/pods and hoses.

The hose and hose markings provide the receiver pilot tanker closure rate and position information. In some aerial refueling hose installations, additional hose markings also may provide the receiver pilot center-of-envelope, inner and disconnect position limits.

Standard 10 foot spacing of hose markings with contrasting hose colors (black hose with white markings and white hose with black markings) is recommended. Hose inner/outer limits and center-envelope should be evaluated as optional standards in aerial refueling system lighting simulators. The white hose offers lighting visibility value over the black hose. Also, the white (1 ft) markings on the black hose become dirty, and it becomes difficult to illuminate and visually detect the white/black marking contrast.

Lighting for wing mounted drogue stores/pods and hoses may be provided by forward tip of horizontal tail lights.

#### **10.4. Existing Tankers Aerial Refueling Lighting Improvements**

##### **10.4.1. KC-135**

Four primary improvements recommended for the KC-135 aircraft are:

- 1) illuminate the aft empennage body from the wing root to the tail cone including underneath the horizontal stabilizer.
- 2) provide active lighting for the centerline orange fuselage stripe.
- 3) expedite the retrofit of the existing nozzle light with the nozzle light kit flight and service tested by USAF/AMC in the early 1990's. This light is now being implemented. All KC-135 aircraft are to receive the retrofit kits by end of August 2005 in accordance with TCTO-IC-135-1422 and A-kit 1560 KO-180 480 AFL.
- 4) improve boom position pilot director lights similar to those used on the KC-10 and KC-707 international tankers as described previously. Alternatively evaluate new concept of Paragraph 10.2.3.1. herein as a potential retrofit.

Other improvements to be considered include:

- A) tilting the boom position gauges near parallel to the operator window similar to the KC-707 international tanker configuration;
- B) Boom load alleviation indicator;
- C) vertical tail illumination (both sides); and
- D) all lights modified to have individual dimming controls for NVG compatibility.

##### **10.4.2. KC-10A Tanker**

With few exceptions the KC-10A tanker may serve as a starting point for future tanker lighting and ergonomically efficient designs. Exceptions are the new concept for PDL's (Paragraph 1.12.1), active underbody centerline and lateral striping, and receiver aircraft closure warning light.

#### **10.5. Receiver Aircraft, General**

This section of the recommendations covers lighting on the receiver aircraft that is pertinent to the tanker boom operator's and crew's view. It includes the receptacle/slipway and probe equipment.

In addition to the receiver aircraft aerial refueling lighting, side fuselage illumination also should be a major consideration along with anti-collision lights to assist other receiver aircraft and tanker crews in aircraft tracking and monitoring.

The following lighting/marketing recommendations are provided in addition to those mentioned earlier for the tanker aircraft to insure that future and current receiver aircraft

are equipped with adequate lighting intensity and reliable lighting/markings to insure safe and reliable aerial refueling.

### **10.5.1. Receptacle/Slipway Equipped Receiver Aircraft**

A. The below aerial refueling lighting and marking recommendations are primarily from the boom operator's perspective; they are designed to enhance his/her ability to accomplish the aerial refueling tasks through the aerial refueling process. These tasks include but are not limited to: 1) acquiring the receiver aircraft; 2) directing the receiver aircraft into the contact position; 3) securing the hook-up; 4) assisting the receiver aircraft pilot in maintaining the boom envelope throughout the initiation of disconnect including emergency break-away calls. The boom operator and other tanker crew members to monitor receiver aircraft traffic throughout the aerial refueling evolution.

The boom/receptacle aerial refueling method requires good depth perception for making the hook-up, maintaining the contact and avoiding striking the receiver aircraft throughout the aerial refueling procedure. Proper lighting and markings are critical for low/no ambient light conditions. Major tanker aerial refueling lighting considerations involve the boom nozzle light and the tanker tail mounted flood light. Likewise the receiver aircraft overwing/fuselage lighting around the aerial refueling receptacle/slipway, reflective tape/paint T-bar markings outline slipway receptacle lighting and other critical aircraft contours highlighted with contrasting paint/outlines, e.g. the windscreen. Factors which make the operator's task more difficult and reduce the effectiveness of the task include protruding antennas in the boom path, low observable paint, air turbulence, poor lighting, receptacle /slipways located in trough areas and receptacles located above the aircraft mold line (particularly externally-mounted receptacle/slipway).

- A. Provide redundant slipway/receptacle lighting as a minimum equivalent to the UARRSI;
- B. Provide adequate lighting for areas on receiver aircraft in which protruding objects, aircraft engine nacelle contours and receptacle slipway installations are raised above aircraft contours that cannot be illuminated by the tanker lighting, i.e., tail mounted floodlight (TMF). Special consideration should be given for aircraft employing low observable paint;
- C. Provide symmetrical and balanced overwing/fuselage lighting;
- D. Outline windscreens with reflective paint/tape;
- E. Provide T-bar reflective markings and outline receptacle/slipway (UARRSI) with same;
- F. Provide separate on/off controls for upper and lower anti-collision (rotating beacon) light with full operator dimming controls;
- G. Provide fighter/attack aircraft with fuselage side mounted and critical formation strip lighting;

- H. Provide all external lights with full bright to full off dimming controls;
- I. Provide all future receiver aircraft with through-the-boom intercom capability; and
- J. Retrofit all aircraft currently not equipped with through-the-boom intercom communications.
- K. The use of receiver aircraft and tanker scale math models for aerial refueling receptacle installation and receiver aircraft exterior paint should be evaluated by engineers and operators in both photography laboratories and full scale simulators. These lighting evaluations should be accomplished prior to prototype aircraft development to avoid night aerial refueling restrictions to production aircraft.

### **10.5.2. Receiver Aircraft Probe Installations**

The following recommendations are for the probe equipped receiver aircraft. The receiver probe/fuselage light sources are designed to assist the receiver pilot in making the aerial refueling hook-up by illuminating the receiver's aircraft probe and the tanker's aerial refueling drogue/coupling, hose. They also should provide a redundant source of light for the aerial refueling store/pod, the fuselage hose exit and for other tanker references, i.e., engine nacelles. The receiver aircraft's aerial refueling probe nozzle light and/or fuselage light should provide this illumination for the BDA kit hose/drogue and boom telescoping tube.

#### **10.5.2.1. Probe Equipped Receiver Aircraft**

- 1) Provide a probe and/or fuselage mounted floodlight on the receiver aircraft with redundant light sources (bulbs) to illuminate the following:
  - A. Probe nozzle (receiver aircraft)
  - B. Drogue/coupling (tanker)
  - C. Tanker hose/drogue markings
  - D. Aerial refueling store/pod (tanker)
  - E. Fuselage Drogue Exit (tanker)
  - F. BDA kit hose and boom telescoping tube (tanker)
  - G. Critical tanker formation references, i.e., engine nacelle, wing, fuselage (tanker)
- 2) Provide the receiver probe light with cockpit dimming control from full on to full off;
- 3) Provide the smaller fighter/attack aircraft with critical formation fuselage side-mounted strip lighting; and

- 4) Provide the anti-collision rotating beacon light with separate on/off controls and full dimming capability.

### ***10.6. Night Vision Goggles (NVG) Compatibility and Covert Operations***

NVG compatibility is a major issue with some current tanker and receiver aerial refueling lighting sources not equipped with full bright to full off operator dimming controls. Also, the colors used for status lights, pilot director lights and color coded boom telescope markings are not distinguishable with NVG equipment.

It is recommended that all tanker and receiver aircraft aerial refueling light sources should be dimmable to full off. The use of color (red, green, yellow) lighting to indicate aerial refueling status and formation position is ineffective with NVG; other forms of symbology and/or bright/dim flashing light techniques for transmitting critical information should be developed. Infra-red (IR) light sources should be provided for all formation, aerial refueling equipment, TMF, nozzle and PDL lights mentioned above for covert operations.

New methods and techniques for transmitting critical aerial refueling information should be evaluated in the aforementioned aerial refueling lighting simulators and/or scaled mock-ups.

### ***10.7. Future Research Concepts Evaluations Methods***

Three techniques should be considered for evaluating and comparing potential aerial refueling lighting solutions/concepts and for evaluating new technologies:

- 1) The use of scale aircraft models and photography should be employed as a method for initial evaluations of the receiver pilot's geometric vision of tanker references/equipment and boom operator's vision requirements of receiver aircraft references/equipment.
- 2) The use of existing aerial refueling simulators modified for lighting/markings evaluations will allow initial screening and selection of the best resolution of a given lighting issue. Some refining of any given solution may be possible depending on the simulator fidelity and image quality.
- 3) Initial development aircraft should be used for ground and flight test evaluation of aerial refueling lighting. Evaluation points may include the lighting direction, intensity and coverage for the production tanker or receiver.

The recommendations, solutions and new concepts described herein should be evaluated by the above methods to reduce program risk and provide cost effective solutions for safe night and day aerial refueling for both overt and covert operations.

### 10.7.1. Future Research Aerial Refueling Lighting Concepts for Evaluation via Scale Models, Photographers' Tunnels and Simulators,

#### Phase I and II Types.

The following table is included only as a potential guide and example of how the latest technology and/or concepts may be used in providing new and existing tankers and receiver aircraft improved lighting and reliability for aerial refueling. It also suggests the type of facility and/or simulator for lighting evaluations.

**Table 5. Future Research Aerial Refueling Lighting Concepts for Evaluation via Scale Models, Photographers' Tunnels and Simulators, Phase I and II Types.**

Tanker Aircraft				Receiver Aircraft			
No.	Light Source Identity and Other	Suggested Technology for Evaluation	Type Evaluation/ Facility Suggested	No.	Light Source Identity and Other	Suggested Technology for Evaluation	Type Evaluation/ Facility Suggested
1.T	Underbody references also new concepts as CSPA	Higher reliability LED's with IR	2. receiver pilot 3. receiver pilot	1R	Redundant Slipway/Receptacle	LED's and IR	3. boom operator
2.T	Wing Leading Edge & Engine Nacelle	High reliability LED's and IR	2. receiver pilot 3. receiver pilot	2R	Area lighting protrusions, contours, raised areas	LED's and IR	1. boom operator, 3. boom operator
3.T	Dimming Controls	Master dimming control for aircraft, aerial refueling lights and IR	1. all, 2. all, 3. all	3R	Balanced overwing/fuselage lighting	LED's and IR	1. boom operator, 3. boom operator
4.T	AR Store. & Critical Reference Illumination	Higher reliability LED's with IR	1. all, 2. all, 3. all	.4R	Windscreens (reflective paint/tape)	No change	1. boom operator, 3. boom operator
5.T	Bottom Fuselage Strip Formation	New technology electro-luminescent strip & IR	2. receiver pilot	5R	Markings, outline UARRSI	No change	1. boom operator, 3. boom operator
6.T	Tail Mounted Floodlight (TMF)	LED's and IR	3. boom operator	6R	On/ff, dimming controls upper/lower beacons/strobes	N/A	1. boom operator, 3. boom operator
7.T	Anti-Collision Strobe/Beacon	Tanker identity, hardware identity	2. receiver pilot	7R	Fuselage side strip lighting, (fighters and attack aircraft)	Electro-luminescent, LED's and IR	3. boom operator
8.T	Vertical Stabilizer (Logo)	LED's and IR	1. receiver pilot, 2. receiver pilot, 3. receiver pilot	8R	Full bright/full off dimming controls, all external lighting	N/A	3. boom operator
9.T	Wing Tip Formation References	LED's, electro-luminescent strip & IR	1. receiver pilot, 2. receiver pilot, 3. receiver pilot	9R	Through-the-boom intercom (future receivers)	Increase signal to noise ratio, eliminate noise to signal amplifier	N/A

Tanker Aircraft				Receiver Aircraft			
No.	Light Source Identity and Other	Suggested Technology for Evaluation	Type Evaluation/ Facility Suggested	No.	Light Source Identity and Other	Suggested Technology for Evaluation	Type Evaluation/ Facility Suggested
10.T	Nozzle Light	LED's and IR	2. boom operator 3. boom operator	10R	Through-the-boom intercom (retrofit existing)	Increase signal to noise ratio, eliminate noise to signal amplifier	N/A
11.T	Boom Telescoping Tube Envelope Markings	Add IR	2. receiver pilot 3. receiver pilot	11R	Probe/fuselage mounted floodlight (redundant)	LED's and IR	2.
12.T	Boom Op. Panel & Receiver Pilot Cockpit Status Lights	Improve viewing angle	1. boom operator 3. boom operator	12R	Receiver probe light w/ cockpit dimming	LED's and IR	2. receiver pilot, 3. receiver pilot
13.T	Pilot Director Lights/ New Concepts as CSPA	KC-10/KC-707 Equivalent LED's and IR	1. receiver pilot, 2. receiver pilot, 3. receiver pilot				
14.T	External Tanker Status Lights Drogue	Standardize with LED's & flashing/brightening concepts	1. receiver pilot, 2. receiver pilot, 3. receiver pilot				
15.T	Drogue/Coupling Markings & Hose Markings	LED's, solar BDA kit coupling/drogue	1. receiver pilot, 2. receiver pilot, 3. receiver pilot				
16.T	A R Lighting Improvements for KC-135 Existing Tankers	KC-707/KC-10 with LED's and IR	1. receiver pilot, 2. receiver pilot, 3. receiver pilot				
17.T	Through the Boom Communication	Increase signal to noise ratio	N/A				

## **11. Bibliography**

<\\prdivsfadm02\ZMADMIN\Aerospace Mechanics\Aerial Refueling Lighting Study\Final Report\AR Bibliography.doc>

## **12. Glossary of Aerial Refueling Terms**

<\\prdivsfadm02\ZMADMIN\Aerospace Mechanics\Aerial Refueling Lighting Study\Final Report\Glossary.doc>

## **13. AR Equipment Description CD's**

# **Attachment 1: Aerial Refueling Equipment Photo Gallery**

## **Attachment 2: Aerial Refueling Lighting/Markings Block Diagrams**

## **Attachment 3: Questionnaires (Receiver & Tanker)**

## **Attachment 4: Questionnaire Summaries (Receiver & Tanker)**

## **Attachment 5: CTA Interview Guidelines**

## **Attachment 6: Results of Hose Tests for NVG Usage**

## **Attachment 7: Existing Simulators and Areas for Potential Evaluation at Simulation Facilities**

# **Attachment 8: Aerial Refueling Lighting Study Guide**