AU/ACSC/2018

AIR COMMAND AND STAFF COLLEGE

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FUELING THE FIGHT: OPTIMIZING AIR REFUELING PROCEDURES FOR THE KC-135

by

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A Research Report Submitted to the Faculty

In Partial Fulfillment of the Graduation Requirements

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Maxwell Air Force Base, Alabama

December 2018

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Abstract

The KC-135 has been the backbone of the US Air Force's aerial refueling tanker fleet since 1957, and is projected to serve until the 2040s. The idea of fuel conservation was not at the forefront in its design process when the main concern was refueling strategic bombers that served as nuclear deterrents during the Cold War. The same idea, under the scope of fiscal responsibility, has come into sharper focus since that time. New technologies and operating procedures, coupled with the KC-135's projected longevity, warrant an examination of how it is currently employed with a goal of seeking more efficient and cost-effective methods of operation.

The research for this project used a problem/solution framework with adaptations from the quantitative analysis framework to investigate inefficiencies in KC-135 flying operations. It examined cost factors and employment methods, specifically with a focus on time spent conducting various operations such as taxiing and flying at specified air refueling airspeeds. The employment steps and fuel usage during those times were scrutinized for any opportunity to find efficiencies that could be amplified through an economy of scale for the entire fleet.

The findings showed potential for fuel savings. However, in the case of individual sorties, these savings were generally miniscule. For instance, 437lb of fuel saved by flying maximum endurance airspeed for a 15-minute rendezvous orbit versus the standard speed specified in the flight manual. It would only be by the adoption of new procedures throughout the KC-135 fleet that any significant fuel savings would be accrued. In conclusion, any advantages would be realized by a minimal cost of implementing changes in procedures, coupled with the effect gained by fleet-wide adoption of those procedures, causing even small savings to compound into meaningful values.

INTRODUCTION

Overview of the Study

The mission of the United States Air Force begins with the statement “fly, fight and win.”[1] Accomplishing the mission requires enormous energy, much of which comes from aviation fuel. It is a fundamental requirement for the power which allows the Air Force to fly, enables it to fight, and allows it to secure the win.

In fiscal year (FY) 15 the cost of fueling the fight stood at $6.8 billion with aviation fuel accounting for over 41 percent of the Department of Defense’s (DoD) total energy cost.[2] For FY 19 the Air Force has projected a grand total of 1.5 million flying hours shared between Active Duty, Air National Guard and Air Force Reserve at a total cost of $8.7 billion.[3] With such large numbers, it is not hard to imagine the role which optimization can play in cost reduction and conservation of this critical resource.

Efforts to optimize operations, increase efficiency, and be responsible shepherds of fiscal resources are supported at the highest levels. The Secretary of the Air Force has an identified goal of achieving a “10 percent improvement in aviation fuel efficiency by 2020.”[4] Additionally, The Secretary of Defense’s (SecDef) third primary line of effort laid out in the National Defense Strategy includes a “transition to a culture of performance where results and accountability matter” to ensure “effective stewardship of taxpayer resources.”[5] Delivered more bluntly, it is the SecDef’s intent to make more effective use of the people’s treasury, turned into lethality against the enemy.[6]

Following this intent, and working within the broader context of fiscal accountability and being effective stewards of tax dollars, forms the basis for this study. The narrower focus of the study is improving aviation fuel efficiency specifically with regard to the employment and operation of the Air Force's fleet of KC-135 Stratotankers.

Nature of the Problem

The problem lies in the confluence of two issues. First, the ever-present drive to save money, not only as a principle of fiscal soundness but by directives from the Secretaries of Defense and Air Force. The second is the operation of the KC-135, an aircraft designed in the 1950s when the idea of fuel conservation and its importance had not been focused through the lens of the 1973 Organization of Petroleum Exporting Countries (OPEC) oil embargo. These circumstances, coupled with the expectation of the KC-135's service life extending until 2040, warrant an examination of how it is currently employed with a goal of seeking more efficient and cost-effective operations. The KC-135 is an indispensable asset without which the US Air Force could neither achieve global reach nor project global power. It has been operating for over six decades and is projected to operate for another two, giving this research and any subsequently proposed investment time to pay dividends.

Purpose of the Study

The purpose of this study is to examine how changing KC-135 tactics, techniques and procedures (TTPs) could result in fuel savings. The focus will be two-fold. On the smaller scale, training missions where operating procedures can be examined in a more controlled environment, versus an operational setting where military necessity takes precedence, will be examined. On a grander scale, tanker management as an effect-providing resource within a large campaign or operation will be examined.

Previous cost-saving initiatives have been proposed, and some undertaken, by the Air Force and Air Mobility Command (AMC). As the KC-135 Lead Major Command (L-

MAJCOM), AMC is responsible for standardization of policy and direction for all of the Air Force's KC-135s. These previous initiatives have included the removal of paper flight manuals and publications in favor of a digital alternative known as an electronic flight bag, as well as changes to standard aircraft equipment configurations. Other ideas have been rejected as not cost-efficient, such as the addition of winglets to the KC-135 that would require a fuel cost of over $13.00 per gallon, a more than four-fold increase over current prices, to break even.[7] Still, others are being examined such as super-hydrophobic surface coatings that would repel contamination and reduce drag.[8]

Advancements in technology, changes in capabilities, and evolution of TTPs which have taken place over the KC-135's lengthy service, coupled with a demand for increased efficiency, warrant an examination of potential ways to optimize KC-135 aerial refueling missions and reduce operating costs for the fleet. It is the goal of this research to examine KC-135 mission planning and employment where changes can be easily made with minimal cost to reduce fuel consumption, translating directly into savings for the Air Force.

Research Question

The US Air Force's *Energy Flight Plan* plainly states, "Energy is a strategic imperative for the Air Force mission."[9] It further links the practice of efficiently shepherding the Air Force's energy resources directly to achieving an edge in ensuring operational supremacy.[10] In more quantifiable terms with respect to the entire Department of Defense (DoD), the Air Force accounts for slightly under 50 percent of DoD's total energy consumption, "with the vast majority of this spent on aviation fuel."[11] With this strategic imperative in mind, the research question for this study is, what solutions can the Air Force implement quickly and with minimal cost to reduce fuel consumption and commensurate costs associated with KC-135 refueling missions?

Definition of Terms

Aerial Refueling Anchor Pattern. Airspace that consists of a left-hand race track orbit with legs at least 50 nautical miles (NM) in length, normally separated by at least 20NM. Four anchor pattern turn points are designated to describe the anchor pattern.

Aerial Refueling Track. Airspace established to accommodate refueling operations along a prescribed route. It consists of an air refueling initial point (ARIP), the air refueling control point (ARCP), and an exit point. Navigation checkpoints between the ARCP and exit point are specified if required to facilitate navigation along the track.

Air Refueling Control Point (ARCP). The planned geographic point over which the receiver aircraft arrive in the observation/astern position stabilized behind the assigned tanker.

Air Refueling Control Time/Rendezvous Control Time (ARCT, RVCT). The planned time that the receiver and tanker will arrive over the designated Air Refueling Control Point (ARCP).

Air Refueling Initial Point (ARIP). A planned geographic point prior to the Air Refueling Control Point (ARCP) to which tankers and receivers time independently to arrive at the Air Refueling Control Time (ARCT).

Altitude Reservation (ALTRV). Pre-coordinated airspace approved by the Federal Aviation Administration (FAA) for utilization under prescribed conditions, normally employed for the mass movement of aircraft or other special user requirements which cannot otherwise be met.

Bleed Air. Pressurized air diverted from the compressor stage of a turbine engine for various purposes including engine starting or aircraft heating.

Rendezvous Delta (RV Delta, Point Parallel RV). A procedure that requires the receiver to maintain an agreed track, and the tanker to maintain the reciprocal track, offset a pre-determined distance, turning at an appropriate range so that the receiver arrives in a one to three mile trailing position behind the tanker. Normally used by large aircraft receivers.

Rendezvous Golf (RV Golf, En Route RV). A procedure that facilitates join up on a common track based on a scheduled Air Refueling Control Time (ARCT).

Runway Holding Position. Position on a taxiway, marked by a series of painted lines detailing where the aircraft must stop when clearance has not been issued to proceed onto the runway.

Research Methodology

This research will use the problem/solution framework with adaptations from the quantitative analysis framework as well. The problems being investigated are inefficiencies in KC-135 flying operations, specifically during air refueling training missions or the wholesale employment of the KC-135 as a weapons system within a larger operation, both leading to unnecessary fuel burn and financial expense. The paper will introduce energy cost factors and Air Force leadership directives mandating cost savings. It will also explain the fundamentals of aerial refueling as it applies to this research. The research itself will explore and analyze different employment methods for the KC-135, using quantitative data when available, that could result in potential fuel savings for the Air Force. Methods to be examined include a modified refueling rendezvous, the effect of adaptively planned air refueling speeds on fuel consumption, and automated versus manual refueling mission planning within large-scale operations.

Various alternatives will be examined centered about the execution of a typical refueling flight from engine start through the end of air refueling. Processes and performance factors will be studied to see if any advantages can be gained by making changes to the same. The goal of the research will be to find opportunities for changes which can be made with a minimal cost of implementation. Even marginal advantages, when implemented, can provide benefit and cost savings through an economy of scale in relation to the broad scope of the Air Force's mission. This research paper's goal is to present recommendations that can be implemented by AMC for the KC-135 fleet to save fuel and thus money for the Air Force and DoD.

LITERATURE REVIEW

Mandates and Cost Factors

Mandates

On January 6, 2017, the Assistant Secretary of the Air Force for Installations, Environment & Energy released *The U.S. Air Force Energy Flight Plan 2017 – 2036*. It was to serve as "a comprehensive approach to energy management to improve [the Air Force's] ability to manage supply and demand in a way that enhances both mission capability and readiness."[12] Within its contents were statistics that noted the Air Force accounted for 48% of DoD's total energy consumption costs, approximately 86% of which was spent on aviation fuel, totaling over $6.8 billion.[13]

The *Flight Plan* set out a desired energy-secure future-state goal, and laid out the way ahead towards three "Energy Strategic Goals:" improving resiliency, optimizing demand, and assuring supply.[14] It further tasked the Air Force operations community, as the largest consumer of energy, with the requirement to "explore opportunities within their policies, processes, and equipment" noting that operational decisions "play a primary role in determining Air Force energy requirements, and any improvements in optimizing energy use can have a significant impact on enhancing mission assurance through energy assurance."[15]

The second strategic goal, optimizing demand, specifically targets aviation fuel consumption, and is further broken down into areas of intent and expected outcome. Within these two areas, the intent includes increasing operational efficiency and enhancing capabilities, while the expected outcomes include "increased flexibility, range, and endurance in all operations" and decreased energy consumption without negative mission impacts.[16] This strategic level directive is reflected in AMC's guidance to its aircrews in a publication titled, *Birds Fly Free, AMC Doesn't - An Aircrew Guide for Efficient Fuel Use.* This guide essentially echoes the *Flight Plan* stating, "It is Air Force policy to conserve aviation fuel when it does not adversely affect training, flight safety, or operational readiness."[17]

According to the *Flight Plan*, the way forward towards optimizing demand involves, in part, "focusing on training and operational effectiveness through innovation and cost-effective investments" as well as the implementation of planning activities "to identify, evaluate, and/or prioritize opportunities to optimize energy demand, including changes in existing operations."[18] These methods form the key basis for this research whereby the search will be for increased efficiency through innovation by changing existing operating procedures with minimal cost-impact of implementation.

Cost and Planning Factors

The Office of the Secretary of Defense Comptroller, in conjunction with the Defense Logistics Agency (DLA), determines a standard fuel price (SFP) for a given FY for DoD customers including the Air Force. The SFP is determined prior to the FY in which it is used, and is based on an 18-month projection of future fuel prices, subject to change within the FY. It also takes into account the "budgeted cost of transporting, storing and managing the government fuel system, including war reserve stocks" and reflects whether the Defense Working Capital Fund gained or lost money during previous years.[19] DLA cautions that the SFP cannot be compared to "the price of fuel at the service station down the block" as it is not intended to be "comparable with similar fuels in the commercial marketplace."[20]

DLA SFPs for the past several fiscal years can be seen in the table 1, below. These prices will be used as a cost basis for this research. The FYs with asterisks represent an average price for the year as DLA adjusted the price one or more times to accommodate market fuel price changes. These prices represent bulk pricing for jet fuel and do not reflect higher costs that may be paid when military aircraft are refueled at commercial airports. Currently, the DLA SFP for JP-8 and Jet A-1 is $2.76/gal, while Jet A is $2.74/gal.[21] Both of these types of fuel are suitable for use in the KC-135.

Table 1. DLA Bulk Fuel Prices by Fiscal Year, Dollars per Gallon

Type of Fuel	FY13	FY14	FY15	FY16*	FY17*	FY18*
JP-8 & JET A-1	$3.73	$3.62	$3.70	$2.60	$2.21	$2.46
Jet A	$3.71	$3.60	$3.68	$2.58	$2.19	$2.44

For KC-135 mission planning purposes, fuel quantity is calculated in pounds rather than gallons or liters. This applies to fuel loading, consumption/burn rates, and amount transferred to receiver aircraft. Fuel density for planning purposes is 6.7lb/gal.

According to the aircraft flight manual, the KC-135 can nominally hold 31,275 gallons of fuel with variances for design tolerances of the bladder type fuel cells which line the body of the aircraft. Using 6.7lb/gal results in a total fuel capacity of 209,543lb. These numbers are maximum extremes and used only to frame a sense of the capacity of the aircraft. Limitations imposed by maximum gross weight and takeoff performance reduce the actual usable fuel loads for missions. Typical fuel loads of 60,000 and 120,000lb represent a normal range for training operations and will be used to examine data in this research.

KC-135 Background

The Air Force took delivery of its first KC-135 on June 28th, 1957, the same year Dwight Eisenhower was President, Elvis Presley was becoming a national celebrity and Jimmy Hoffa was arrested by the FBI.[22] 732 of the KC-135A Stratotankers were eventually built by Boeing Aircraft in Renton, Washington and delivered to the Air Force's Strategic Air Command.[23] Since its first iteration as an "A model" (KC-135A) the venerable tanker has undergone numerous airframe and systems upgrades; changes in crew duties and assignments; enhancements to aerial refueling procedures; and drastic evolutions in the TTPs used for its employment. The KC-135 has also witnessed a long succession of receiver aircraft from the B-58 and F-104 to the B-2 and F-22, each having its own peculiarities involved with aerial refueling. More than sixty years later, the current "R model" (KC-135R) is still the backbone of the US Air Force tanker fleet.[24]

The Air Force's current fleet of 414 KC-135 Stratotankers provides the core of its aerial refueling capability.[25] KC-135s provide fuel for combat aircraft, increasing their ability to gain and maintain air superiority or conduct global strike missions. The same tankers also enhance the ability of cargo aircraft to enable rapid global mobility, and increase the endurance of vital command and control (C2) and intelligence, surveillance and reconnaissance (ISR) aircraft. As an example of the enabling capability of aerial refueling, B-2 bombers based exclusively at Whiteman AFB, MO can fly anywhere in the world non-stop, strike multiple targets with precision munitions, and return home from grueling missions over thirty hours long. This feat would be impossible without multiple aerial refueling sorties supporting each B-2 mission.

Despite the KC-135's longevity and more than half a century of service, the final chapter of its story has not been written. A United States Government Accountability Office (US GAO) report required by the National Defense Authorization Act for FY 12 required the GAO to annually review production of the Air Force's new KC-46 Pegasus tanker through 2017. The report noted that "Aerial refueling is essential to global U.S. military operations;" highlighted the KC-135 as "the backbone of the nation's tanker forces;" and identified a "broad agreement that KC-46 schedule risk is a concern."[26] It further recognized the KC-46 acquisition program will only replace two-fifths of the existing KC-135 fleet and that the KC-135 fleet will likely remain in service to 2040.

Basic Concepts of Air Refueling

Successful air refueling, in its most basic form, involves the science of timing and art of flying. The science involves having two or more airplanes takeoff from various locations and arrive at a precise time, over a precisely defined point. This time is referred to as the air refueling control time or rendezvous control time (ARCT or RVCT). The location is referred to as the air refueling initial point or air refueling control point (ARIP or ARCP) depending on what procedural type of rendezvous is conducted.

The art of air refueling relies on pilot skill and use of precise airspeed and closure rate control. These skills are used to bring the tanker and receiver aircraft into close vertical proximity, physically connecting the two to complete the fuel offload. This execution comes with an understated warning that "flying two airplanes in close vertical proximity is not safe."[27]

Mission timing, whether it be from an Air Tasking Order, an Air Operations Center flight plan or local agreement between tanker and receiver aircraft units, defines the ARCT. The type of mission; training requirements of the tanker and/or receiver aircrews; availability of specialized navigational equipment; weather conditions; and constraints and restraints of airspace design all drive the type of airborne rendezvous conducted to join the aircraft together into an air refueling formation by the time they reach the ARIP or ARCP.

The airborne rendezvous is the maneuver used to join the tanker aircraft with its mated receiver into an air refueling formation. Rendezvouses vary by who directs the process and by the physical maneuvering used to affect the rendezvous or join up as it is alternatively called. Two of the most common types of rendezvous used will be examined for the purpose of this research. These are the Point Parallel Rendezvous (Rendezvous Delta) and En Route Rendezvous (Rendezvous Golf).

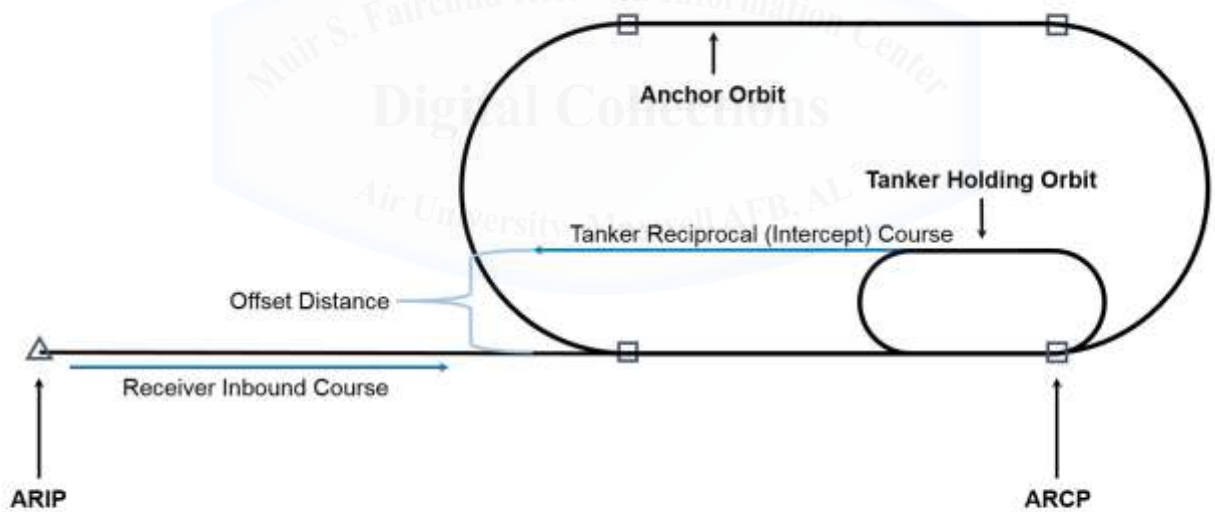

Figure 1. Air refueling anchor area set up for Rendezvous Delta

Rendezvous Delta

The Point Parallel or Rendezvous Delta procedure "requires the receiver to maintain an agreed track and the tanker to maintain the reciprocal track, offset a predetermined distance."[28] It is especially useful during emission control (EMCON) restricted procedures when the operating environment or special instructions requires EMCON be employed to minimize each aircraft's signature for detection avoidance. It is also useful as a backup if an initially planned En Route Rendezvous was missed. In general, it is the procedure used when the tanker arrives in the air refueling area ahead of the receiver.[29]

Figure 1, above, shows a typical RV Delta scheme of maneuver within a larger air refueling anchor area. The receiver plans to arrive at the ARIP such that it will be able to continue to arrive at the ARCP by the ARCT. The tanker plans to arrive at the ARCP 15 minutes prior to the ARCT, establish a holding pattern and await the receiver's arrival at the ARIP. The tanker departs its holding pattern along a reciprocal (intercept) course toward the receiver at a calculated offset distance and turns in front of the receiver so that the formation arrives over the ARCP at the ARCT.

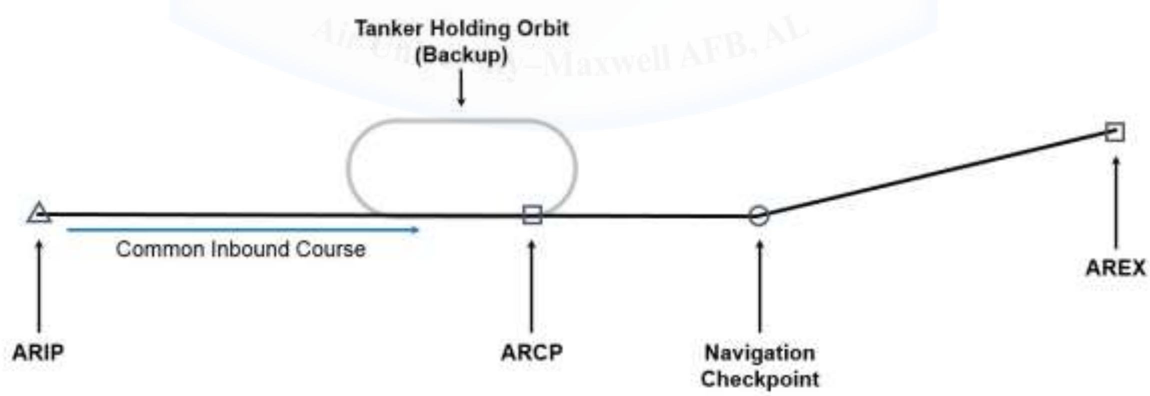

Figure 2. Air refueling track set up for Rendezvous Golf

Rendezvous Golf

The Rendezvous Golf or En Route Rendezvous procedure is used when join up is to be achieved en route to the air refueling track (or area) "by making good a scheduled time" over a set point.[30] It is useful for joining a block of airspace known as an "altitude reservation" which is essentially an established air corridor for the mass movement of aircraft. An En Route Rendezvous is arguably more efficient than a Point Parallel Rendezvous, and the research will advocate a hybridized approach for efficiency.

Figure 2, above, shows a typical RV Golf scheme of maneuver along an air refueling track. During the rendezvous, both the tanker and receiver will plan to be overhead the ARIP at the ARCT. The depicted tanker holding pattern would be for backup purposes if the initial rendezvous did not take place at the ARIP. In that event, a new ARCT is set, and the rendezvous occurs at the ARCP.

Mission Planning Factors

KC-135 mission planning covers the spectrum from detailed tactical level planning to larger operational level endeavors. At the tactical level, it focuses on a single mission's timing and profile. At a larger operational level, it includes fuel planning for theater-level air campaigns. Here, the overall tanker plan may integrate other USAF and Sister-Service tankers, as well as tankers from allied and coalition partners. Regardless of the scale of mission planning, opportunities to examine fuel efficiency exist.

Tactical Level Planning

Refueling mission planning at the tactical level typically involves creating a profile for a single sortie or formation of tankers to takeoff, refuel their receivers, accomplish required crew training, and land. One of the easiest targets for fuel savings are the rendezvous procedures previously described and the way they are executed. Within the rendezvous itself, both the orbit pattern and specified airspeeds are targets for optimization. Procedures for the execution of the RV Delta and Golf are described in a North Atlantic Treaty Organization (NATO) Standard Allied Tactical Publication (ATP) titled ATP-3.3.4.2.

Orbit Pattern and Timing

ATP-3.3.4.2 directs the tanker "to attempt to arrive at least 15 min before the ARCT and, normally, establish a left-hand holding pattern using the ARCP as an anchor point."[31] There are valid reasons for using this procedural timing method such as accounting for potential early receiver arrival, when executing missions in an EMCON restricted environment or when executing the mission as part of a larger operation where overall timing flexibility or synchronization is required. However, in many cases, this procedure is used by default without consideration for the fuel consumption while executing it as prescribed by ATP-3.3.4.2. Modifications can be made to the default RV Delta procedure orbit to save fuel without compromising mission accomplishment or training.

Changes to orbit procedure timing are made possible primarily due to modernized navigational equipment incorporating Global Positioning System (GPS) technology. The use of the GPS constellation of satellites allows for precision timing in airborne navigation. When the KC-135 entered service with the Air Force, no man-made satellites were orbiting the Earth. The Soviet Union was still preparing Sputnik, the world's first satellite, for its launch in October of 1957. Airborne navigation was the responsibility of a navigator assigned as a primary crewmember for all KC-135 aircrews before a fleet-wide upgrade of KC-135s incorporating GPS receivers into the aircraft's navigation systems. Today, there remains a limited number of KC-135 navigators who occupy a niche roll for designated special operations missions. However, most missions are flown with aircrews consisting of only two pilots and one boom operator.

The 15-minute orbit time of the RV Delta easily accommodated any timing variances when calculations were done manually by a navigator onboard both the tanker and receiver aircraft. With GPS navigation and timing, unless specific mission or training requirements dictate otherwise, there is no need to plan or fly the entire 15-minute orbit pattern. Tankers can be planned to arrive overhead the ARCP precisely at the ARCT via a direct path similar to an RV Golf.

Any risk to the mission by modifying existing procedures is minimal. The largest liability is losing the flexibility of the 15-minute buffer should a receiver arrive early for the refueling. However, the benefit gained from deleting the 15-minute orbit from a rendezvous can save approximately 2,000 pounds of fuel depending on the tanker's gross weight and orbit altitude.

Table 2. Tanker Orbit Fuel Burn

15 Minute Standard Tanker Orbit Flight Level 210, 275 KIAS	
Aircraft Gross Weight	Fuel Burn
185,000lbs	2222lbs
250,000lbs	2537lbs

Specific data for normal aircraft gross weights in a standard orbit are in table 2, below.

Modified Half-Orbit

In some circumstances, it may not be practical to eliminate the orbit, such as arrival time differences of the tanker and receiver or a rushed flight profile requiring additional time to complete checklist items prior to air refueling. Additionally, the geographic orientation and

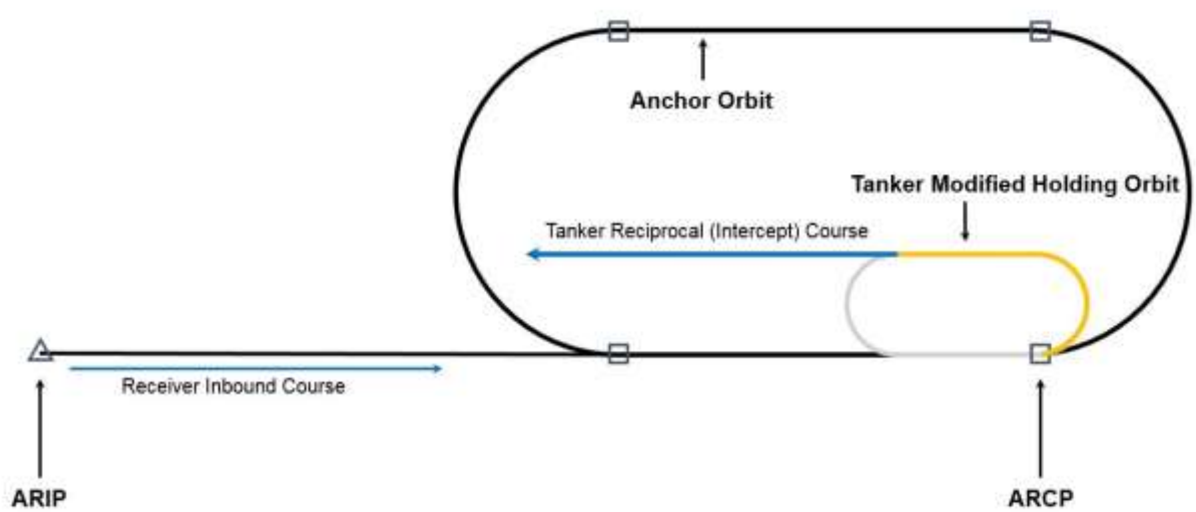

Figure 3. Modified RV Delta tanker half-orbit

layout of the air refueling track or anchor versus the relative approach path to the ARCP by the tanker may require additional time for the tanker to maneuver to align itself to fly the proper course outbound to intercept the receiver as it flies inbound.

In such circumstances, a shortened half-orbit can be used to allow for extra time or maneuvering airspace. An example in figure 3, above, would have the tanker fly only the gold highlighted portion of its orbit and not the gray portion. The half-orbit pattern could be intercepted anywhere along its path as long as the tanker is able to achieve its required offset to intercept the receiver on its inbound course. Adopting this procedure requires more precise timing than the standard 15-minute orbit as the half-orbit would allow only 5 minutes to complete the maneuver – 2 minutes in the turn and a 3-minute outbound leg. The result would be a 67% savings from the standard 15-minute orbit based on a 10-minute time savings.

Orbit Airspeeds

During the 15 minutes of an RV Delta orbit, the tanker is planned to fly the lower of 275 Knots Indicated Airspeed (KIAS) or .78 Mach while awaiting its receiver.[32] This speed does not take into account aircraft gross weight or altitude in relation to aircraft performance and fuel consumption. It roughly correlates to a maximum endurance speed for a fully loaded tanker flying in the higher twenty thousand foot altitude range. Coincidentally, this would have suited KC-135s awaiting in their orbits for the arrival of B-52s during the days of Strategic Air Command when the tanker's number one role was to support nuclear-armed manned strategic bombers arrayed against the Soviet Union. Today's mission, and the technology available for the tanker to continually fly optimized airspeeds, is much different.

Fuel burn for a standard 15-minute orbit at 275 KIAS is presented in table 2, above, for two different aircraft gross weights representing normal fuel loads between sixty and one hundred twenty thousand pounds. By comparison, the same data is presented in table 3, below,

Table 3. Orbit Fuel Burn at 275 KIAS vs Max Endurance

15 Minute Standard Tanker Orbit Flight Level 210		
Aircraft Gross Weight	Fuel Burned	
	275 KIAS	Max Endurance
185,000lbs	2222lbs	1785lbs
250,000lbs	2537lbs	2366lbs

showing fuel consumption for those same conditions with a 275 KIAS orbit with additional data for fuel consumption flying at maximum endurance speed during the orbit.[33]

If mission requirements dictated the need for a 15-minute orbit, flying it at maximum endurance airspeed rather than the standard 275 KIAS would result in fuel savings with no compromise to mission execution. The benefit of flying maximum endurance increases as the aircraft gross weight decreases due to the reduction in power, corresponding with lower gross weights, needed to maintain a lower airspeed. In other words, there is an inverse relationship between tanker gross weight and fuel savings accrued by flying maximum endurance airspeed. The lighter the aircraft, the more fuel is saved.

The primary risks are a lowered airspeed buffer between maximum endurance and the initial buffet airspeed where the aircraft begins to stall, as well as crew comfort concerns. The lowered airspeed buffer is not a factor during normal weather conditions and flight profiles. Using the standard 275 KIAS during turbulent weather, where airspeed buffer provides a safety margin, would resolve the problem. However, it is unlikely that refueling would occur at all under such conditions due to safety. Crew comfort concerns are a result of the decreased cabin airflow at the lower engine power settings due to less available bleed air, resulting in what could be frigid conditions in the aircraft.

Slight modifications to rendezvous procedures could result in significant fuel savings if adopted across the enterprise. An added benefit would be the minimal cost of implementing these changes. An immediate change could be made by AMC issuing a *Flight Crew Information File* message to the KC-135 fleet. The brunt of the cost would be absorbed in the next regular update of aircraft flight manual publications. As this is a regularly occurring process, there would be no need for a special update which would incur additional cost.

Operational Level Planning

Operational level planning can see individual KC-135 missions incorporated into a combined large-force exercise such as the recently concluded Trident Juncture hosted by NATO, or a theater-wide air campaign to support a combatant commander’s objectives. One broad area within operational level planning is the placement of air refueling tracks and anchors within the area of operations. This includes their associated ingress and egress procedures and any required airways between a series of refueling areas. Another area of operational planning is the scheduling of receiver aircraft against available tankers within these refueling areas. This process must be integrated into the overall joint air planning cycle and take into account physical compatibility of tankers and receivers, as well as command approval for joint or coalition aircraft refueling, and any political sensitivities that might restrict certain receivers taking fuel from certain tankers despite their physical compatibility.

The placement of air refueling areas is dictated by military necessity taking into account threats, assets that require support, and de-confliction with other airspace requirements. Therefore, what may be fuel-efficient may not be operationally sound. As such, this area will not be examined for optimization.

Tanker/Receiver Scheduling

However, the scheduling of tankers, receivers, and all air refueling missions required to support a complex campaign or large force exercise, does present opportunities for examination in both the training and operational settings. This fact was brought into painful focus during Operation Unified Protector (OUP) when NATO forces intervened in Libya under the aegis of the United Nations. There were tankers and receivers participating from several NATO countries during OUP, and not all players were physically compatible. The situation grew so complex that air planners developed an "OUP tanker matrix" to delineate who could refuel with whom. Tanker crews would carry these matrices on flights in the event of a dynamic re-tasking to avoid a situation where a command and control agency would send an incompatible receiver to a tanker or vice-versa.[34] This was later identified as a "key lesson" by air operations center planners during OUP citing, "the difficulty in cross-referencing tanker and receiver data from the paper copy ATP-3.3.4.2."[35]

A non-compatible tanker/receiver pairing executed during operations wastes a tremendous amount of fuel as well as negatively impacting mission accomplishment. Much has improved since OUP to address compatibility issues. However, the scheduling of tankers and receivers still relies in large part on a tried and true manual processes. One example involves a white-board, dry-erase markers, and many iterations of inputs from different individuals. Figure 4, below, shows how tankers were scheduled against receivers to cover one day of operations in the Central Command area of responsibility (CENTCOM AOR).

Each of the black outlined squares is filled with information representing an air refueling request in a particular area, at a certain time, against a particular receiver-set, with a requested offload. It was up to members of the Air Refueling Control Team to draw lines connecting

Figure 4. Tanker scheduling white-board at 609th Combined Air Operations Center

available tankers with receivers while taking into account transit times between air refueling areas, all compatibility issues between aircraft, and whether the tanker could support the offload request with its remaining fuel load. This manual process is time consuming and plays out through the entire day's air tasking cycle. It is subject to a myriad of human errors and has the side-effect of centralizing information creating a choke-point where all concerned parties must go to be involved in the process.

Computerized Scheduling

Fortunately, this manual process used by CENTCOM's 609th Combined Air Operations Center (CAOC) has gone by the wayside. Eric Schmidt, of Google fame, visited the CAOC and "was shocked to discover the Air Force used a 7-ft. dry-erase board to plan the elaborate daily process of refueling aircraft involved in the campaign against Islamic State."[36] Teaming with the Defense Innovation Unit Experimental (DIUx) agency they developed the *Jigsaw* program to replace the white-board. The result cut an 8-hour manual planning process into 4 hours, reduced the chance for error and resulted in saving “millions of pounds of tanker gas over the course of the year.”[37]

Figure 5. Computerized tanker scheduling (old white-board in background)

Each Geographic Combatant Command has an Air Operations Center (AOC) that could adopt this program, transitioning away from the white-board towards a seamless unified solution. Additionally, there are numerous large force exercises (LFEs) heavily reliant on aerial refueling to accomplish their training objectives. Many of these use the traditional white-board scheduling method or rely on spreadsheet products to schedule aerial refueling. Adopting *Jigsaw* would serve the same benefit for these LFEs as it has for the 609th CAOC. The benefit of a computerized solution removes the complexities of compatibility matrices, manual fuel and transit time calculations, as well as provides process visibility to any party that requires it.

Mission Profile Segments

Every air refueling mission flown goes through a linear series of events from the aircraft engines being started until the fuel offload is complete. These events will be organized chronologically and examined for opportunities to alter processes and procedures that could result in fuel savings.

Engine Start

The first action that burns fuel for any KC-135 mission is the engine start. In most cases, the aircraft's onboard auxiliary power unit (APU) is used to provide a pressurized flow of bleed air to start the engines. In its normal operating mode, the APU consumes approximately 250 pounds of fuel per hour.[38] The step to start the APU is located in the sequentially executed "starting engines and before taxi" checklist. When the checklist sequence reaches the point to start the aircraft engines, proficient crews are still waiting for the APU to complete its own start cycle and provide bleed air for engine starting. Thus, there is negligible opportunity to save fuel with APU operations prior to starting engines.

Taxi

Taxiing is the movement of the aircraft along designated pathways on an airfield called taxiways. The KC-135 flight manual directs its crew to start all four engines while parked, prior to taxiing. After the engine start checklist has been completed, chocks removed, and ground crew cleared off, the jet is taxied under the power of all four engines to the runway for takeoff. Using all engines to taxi presents the first opportunity for possible fuel saving in a KC-135's mission profile.

Unlike the military, airlines are extremely cost-sensitive and take extraordinary steps to save fuel (money) when the opportunity arises. Delta Airlines, for example, encourages their pilots “to use a single engine taxi to limit fuel use” rather than starting all engines to taxi (most passenger airliners have two engines versus four on the KC-135).[39] Nothing prevents the KC-135 from doing something similar and using two versus four engines for taxiing. However, a single-engine taxi is not feasible for the KC-135, even at light gross weights, as only one of two hydraulic systems would be pressurized, leaving essential components unpowered. The two-engine taxi option is briefly mentioned in the flight manual but only under a time-critical scramble response scenario approved by the local commander.[40]

Taxiing without all engines operating does present specific risks to the mission. Though these risks are not easily quantifiable with hard data, they must be considered in the overall picture. A mission failure resulting from a two-engine taxi scenario, such a subsequent failure to start one of the remaining engines, would render moot any fuel savings for the sortie. Multiple mission failures over a span of time would negate any savings accrued by the fleet. The primary risks of taxiing with two engines is reduced crew situational awareness resulting from splitting attention between the tasks of taxiing and engine starting. Reduced crew situational awareness can be partially mitigated by training the boom operator to either assist in accomplishing the engine start procedure or monitoring the process as a safety-observer, allowing the pilot team to devote more attention to taxiing.[41]

Another risk occurs in the starting of the engines themselves should they not start properly or catch fire during the start sequence. Were these situations to occur while the aircraft was parked for engine start, maintenance troops conducting the launch could intervene. A failed engine start while taxiing, at best would result in a significant delay, at worst a canceled mission. An engine fire would obviously result in a canceled mission and objectives not met.

There are certain mission profiles where the KC-135 would benefit from taxiing with all four engines running. Taxiing at a high gross weight would be one example where the thrust of all engines would make moving far easier and arguably safer by reducing the individual thrust needed on each engine and thus, the associated jet blast. However, under most fuel loads, two operating engines provide enough thrust at safe power levels to move the airplane and taxi.

If safe thrust requirements are met, the primary driving factor to start all four engines versus two for the taxi would be the distance to cover from parking to the runway holding position. The KC-135 flight manual allots 5 minutes and 2,500 pounds (lb) of fuel without variance as a standard planning factor for the "Start Engines, Taxi, Takeoff and Accelerate" phase.[42] However, actual timing can vary widely depending on parking location at the airport, traffic priority and density, taxi path over busy intersections or crossing runways where delays could occur, weather conditions, etc.

Two examples of opposite extremes are found at General Mitchell International Airport and Joint Base Pearl Harbor Hickam (JBPHH). At General Mitchell Int'l, the total taxi distance can be less than 1,000 feet from the parking spot to a runway holding position.[43] However, taxiing from JBPHH's ramp to the runway can easily be 9,715 feet (1.84 statute miles) and hindered by the movement of other traffic.[44]

At General Mitchell Int'l, taxiing conservatively at 10 knots will put the airplane at the runway holding position within a minute. Whereas at JBPHH, taxiing briskly at 20 knots will still take 4.8 minutes to reach the holding position with uninterrupted progress. This is a best-case scenario for JBPHH that does not account for typical delays taxiing across another runway along the route, nor any delays for commercial air traffic which takes precedence over military traffic. These delays could easily increase the taxi time to 10 minutes. Given that each engine takes approximately 60 to 90 seconds to start makes a two-engine taxi scenario at General Mitchell Int'l impractical but creates a potential opportunity to save fuel at JBPHH.

Examining the situation at JBPHH more closely, using 10 minutes for taxiing and 3 minutes to start the two remaining engines while the APU is still running to provide bleed air for engine start, yields the fuel burn statistics in table 4, below.[45] This assumes engine start times in the slower end of the normal 60 to 90-second window, reducing the fuel-efficient time when taxiing with two engines running.[46] Note that the two remaining engines must be started individually as the single running APU does not provide enough bleed air to start both engines at

Table 4. Fuel Burn during Taxi Scenario

10 Minute Total Taxi Time					
Euipment Operating/ Configuration	Fuel Burn	Time Operated	Total Fuel Burn	Total Fuel Burn for Scenario	Fuel Savings
4 Engines running	53.3lb/min	10min	533lbs	533lbs	144.2lbs
2 Engines running	26.7lb/min	7min	186.9lbs	388.8lbs	
4 Engine equivalent (2 running, 2 started)	53.3lb/min	3min	159.9lbs		
APU Operation	4.2lb/min	10min	42lbs		

the same time.

The net result from the 10-minute taxi scenario at JBPHH using two engines to taxi, and starting the remaining engines while taxiing, can save 144.2lb of fuel. This may seem trivial when considering fuel loads of one hundred thousand pounds or more, but when applied through an economy of scale against the number of sorties flown from JBPHH, the savings can mount steadily. For instance, AMC's Fuel Efficiency Office tracked five hundred twenty-two KC-135 sorties launched from JBPHH in FY 17.[47] Given that number, using a two-engine taxi as standard procedure could result in a savings of over 75,000lb of fuel per FY.[48] When examined in the scope of operations for the entire KC-135 fleet at all operating locations where taxi times are a factor the potential for fuel savings grows even larger.

Table 5. F-16 Aerial Refueling Data Specific to a KC-135 Tanker

KC-135 AAR MISSION PLANNING AND INFLIGHT DATA (BOOM)

NOTE: For foreign national receivers, before planning/conducting AAR activity, see Chapter 2, para 2.6.5 and Figure 2-5.

CURRENT AS OF: 11 Oct 16			RCVR RV SPEED IAS	OVERRUN IAS/MACH	PPM / # PUMPS	RENDEZVOUS					RV VIS SINGLE / MULTI	BOOM INTERPHONE	BOOM TRIM SETTING	FLOOD LIGHT SETTING	REVERSE A/R CAPABLE	LIMITS
TYPE RCVR	BUDDY CRUISE IAS/ MACH	OPTIMUM AAR ALT/IAS/MACH				UHF	VHF	HF	A/A TAC X	A/A TAC Y						L R U D
K/NF/Q/F-16A-F/I	315	300 / 315 / 0.81	335	335 / 0.90	2000 / 2 (10)	X	X		X	X	RDR LOCK	X	0	7-10		10 - 10 25 - 40

(10) Use one A/R pump with receivers configured with external tanks.

<u>*Aerial Refueling*</u>

The KC-135 conducts aerial refueling with a wide array of USAF and foreign receiver aircraft. Each has its peculiarities, mostly documented as notes, cautions, and warnings in the ATP-3.3.4.2. These operational idiosyncrasies can vary even among the same type of receiver depending on the model, equipment configuration or country which operates the aircraft. Regardless, every compatible receiver is assigned operating limits for aerial refueling. Among these is the receiver's optimum aerial refueling airspeed. Some aircraft have an acceptable speed band like the F-15, but most have a single airspeed listed. As an example, the data for F-16 refueling against a KC-135 is presented in table 5, above.[49]

The crew aboard the KC-135 performs a "Preparation for Air Refueling" checklist before conducting the refueling rendezvous. One checklist item directs the crew to establish radio contact with their receiver 15 minutes prior to the planned ARCT and exchange information in accordance with ATP-3.3.4.2. guidelines. These items include: receiver call sign, tanker call sign, type of rendezvous, current altitude, Mode 3 code as required, altimeter setting if not standard, and a "nose cold, switches safe" check for fighters as required.[50] Nowhere in the exchange is the air refueling airspeed confirmed. It is expected that crews will fly the standard speeds from the ATP-3.3.4.2. However, a closer examination of the air refueling airspeeds for each receiver type may result in opportunities for fuel savings.

F-16 Aerial Refueling

The KC-135 can accommodate a wide range of speeds for air refueling, from 200 KIAS with the C-130 Hercules to 320 KIAS with the B-1 Lancer.[51] Thus, it has the ability to work within a large speed range to accommodate particular receiver needs. The F-16 Fighting Falcon, as USAF's most numerous fighter with 941 in the total active inventory, serves as the exemplar for a fighter-type receiver.[52] For the different models of F-16s, the optimum airspeed is listed as 315 KIAS without variance. However, this does not mean every F-16 is physically limited to fly 315 KIAS for every refueling. The actual airspeed can be determined by the pilot in command for the given aircraft loadout, operating altitude, and prevailing conditions. The ability to deviate from standard speeds can potentially save fuel for both the tanker and the receiver aircraft.

F-16 Refueling Planning Factors

Any deviation from an established/published airspeed does carry risk. However, the ATP-3.3.4.2. lists optimum refueling airspeeds and altitudes as seen in table 5, above. Thus, those values are neither exclusive nor mandatory. Rather, they are generally accepted as most favorable. To pursue the F-16 example further, air refueling can usually be conducted at 300 KIAS versus the published 315 KIAS.[53] This seemingly small airspeed change reduces fuel consumption for both the tanker and receiver as less thrust is required to maintain the lower

Table 6. Fuel Consumption at 300 versus 315 KIAS

Example Fuel Burn per hour at 315 versus 300 KIAS		
315 KIAS	300 KIAS	Difference
10,724 lb/hr	9,947 lb/hr	777lb

airspeed. The difference in fuel consumption for the KC-135 can be seen in table 6, below.[54]

A more detailed estimate of fuel conservation can be made using the following data points and other typically observed values. During training scenarios, F-16s commonly present themselves as two or four-ship formations for aerial refueling. During the rendezvous, until completion of aerial refueling, the tanker maintains the appropriate refueling airspeed. Once the formation requests clearance to join with the tanker, the rendezvous can take 5 minutes until the first receiver is in contact taking fuel.

The F-16 has a nominal 7,000lb internal fuel capacity and a typical fuel onload during aerial refueling in the 4,000lb range.[55] Using these data points and the ATP-3.3.4.2. specified fuel onload rate of 2,000lb/min gives 2 minutes per receiver for fuel transfer under ideal circumstances.[56] Additional time is spent “cycling” each receiver aircraft from the “awaiting air refueling position” position off the tanker’s left wing, to the boom for fuel transfer, and then to the “post-refueling position” off the tanker’s right wing.[57] For a four-ship F-16 formation, the total time spent can easily reach the 10 to 15-minute mark depending on conditions and pilot and/or boom operator proficiency.

AMC Refueling Data

AMC’s Fuel Efficiency Office maintains a database that captures various data points with respect to KC-135 missions. These data include type and number of receiver aircraft as well as total fuel offloaded per mission.[58] This data is not exhaustive, nor is it without error as it relies on manual input by individual aircrews for certain points. However, it is informative. Examining refueling data for F-16s from AMC’s MAF Ops database (mobility air forces, operations database), in conjunction with parameters previously mentioned, allows for the analysis of potential fuel savings actions.

In FY 16, the database recorded eight hundred twenty-one KC-135 sorties, refueling F-16s belonging to the Air National Guard.[59] The total fuel offloaded during those sorties was 17,830,200lb in the course of 4,498 receiver refuelings with 3,525 aircraft. It should be noted that the number of receiver refuelings does not necessarily equate to the number of aircraft refueled. A single receiver can return to the same tanker during a training scenario for more fuel, thus having two separate aerial refueling events. Using the numbers from the database in conjunction with known offload rates and common timing factors allows further extrapolation of potential fuel savings using a reduced air refueling speed of 300 KIAS versus the ATP-3.3.4.2. 315 KIAS optimum speed.

Table 7, below, uses the data to determine a total time spent during FY 16 where KC-135s were flying at the refueling speed to accommodate F-16 receivers. The total offload and known transfer rate are used to determine actual time for the physical transfer of fuel from the tanker to all receivers. It uses the number of KC-135 refueling sorties as a basis for the number of initial rendezvous conducted. This is conservative as there are some scenarios where all receivers can depart from the tanker only to return after their training is complete to onload more fuel for the next mission leg.

The data assumes a 4-ship formation of F-16s as the standard for each initial rendezvous with 1.5-minute separation between each receiver onloading fuel. The time for the first receiver to make contact with the tanker is included in the 5-minute initial rendezvous. This equates to 4.5 minutes for each 4-ship formation to cycle through the appropriate formation positions and maneuvers to onload fuel (1.5 minutes between the first and second, second and third, and third and fourth receivers for a total of 4.5 minutes). This estimate is conservative as it uses the total number of receivers as a basis and not the total number of refuelings. It calculates the time spent only for the initial rendezvous of the formation and not subsequent rendezvouses of individual receivers or portions of the formation that are accounted for in the number of refuelings.

Tallying the data gives 16,985 minutes or 283.08 hours that KC-135s were refueling ANG F-16s in FY 16, and shows a potential savings of nearly 220,000lb of fuel by flying 300

Table 7. FY 16 Notional Fuel Consumption Comparison for ANG F-16 Sorties

FY 2016 ANG F-16 Refueling Data			
Planning Factors			
Total Fuel Offloaded	17,830,200lb	Fuel offload rate	2,000lb/min
Refueling Sorties	821	Avg offload per receiver	4,000lb
Number of Receivers	3525	Time to conduct initial RV	5 min
Number of Refuelings	4498	Time between receivers	1.5 min
Timing Calculations			
Total time conducting initial RV	*821 sorties * 5 min per RV*		4,105 min
Total time offloading fuel	*total offloaded / 2,000lb/min*		8,915 min
Time between receiver formation members	*assumes 4-ship formation*		3,965 min
		Total Time Spent at Refueling Speed	16,985min
Fuel Burned at 300 KIAS @ 9,947 lb/hr = 2,815,797 lb		Fuel Burned at 315 KIAS @ 10,724 lb/hr = 3,035,750 lb	
Fuel Savings 219,953lb			

KIAS versus 315 KIAS.

Examining data for FY 17–18, using the same parameters for FY 16, shows a total offload of 13,692,000 for FY 17 and 12,807,400 for FY 18. Carrying out the same calculations on these numbers gives notional fuel savings tallied in table 8, below.

Data Caveats

The fuel savings listed in table 7, above, is conservative for the reasons listed previously, as well as because of the way the data was considered due to nature of the database and data

Table 8. FY 16–18 Notional Fuel Savings for ANG F-16 Sorties

	Total Offload (lb)	KC-135 Sorties	F-16 Receivers	Total Time Refueling (min)	Fuel Savings (lb/FY)
FY 16	17,830,200	821	3,525	16,985	219,953
FY 17	13,692,000	732	2,880	13,746	178,011
FY 18	12,807,400	734	2,778	13,199	170,927
Total	**44,329,600**	**2,287**	**9,183**	**43,930**	**568,891**

gathering mechanism itself. The data within the MAF Ops database is not structured to allow queries by receiver aircraft type, only by wing. This is not an issue where a wing has only one aerial refueling-capable aircraft assigned. With other wings that have multiple types of KC-135 compatible aircraft assigned, such as the 53rd Wing at Eglin AFB or 57th Wing at Nellis AFB, there is no way to discern whether a refueling was conducted with an F-16 or an F-22. Thus, these wings were excluded. ANG F-16 units were selected as their parent wings have no other air refueling-capable aircraft assigned.[60]

Adding further complication, sometimes a tanker will refuel receivers from more than one unit during the same sortie. Thus, F-16s from the 169th Fighter Wing can be counted in the same sortie as F-15s from the 53rd Wing. Instances where more than one receiver unit was listed against a single tanker sortie were discounted.

Finally, much of the data is entered by hand and prone to human error. The KC-135 is capable of reporting limited data through automated internal aircraft systems such as takeoff and landing times. However, data fields populated with receiver unit information and actual fuel offloads are manually entered by an operator sitting at a computer accessing the MAF Ops website after a mission has been completed.

ANALYSIS, CONCLUSIONS AND RECOMMENDATIONS

The purpose of this research was to examine what procedures could be changed or implemented to KC-135 operations at minimal cost that would result in fuel savings and subsequent cost savings for the Air Force. This was viewed through the lens of the KC-135's long operational life-span of over sixty years where evolutions in technology could provide opportunities for efficiency. Today's fiscally constrained environment, the burden of cost-factors and impetus from Service-directed initiatives would provide the driving force for cost saving initiatives. Analysis of the research focuses on two broad areas where opportunities for optimization might exist. These areas are mission planning, and mission execution.

Mission Planning Analysis

Mission planning examined items from the tactical level through the operational level. Focus at the tactical level was on the effect of aerial refueling airspeeds for the KC-135 and rendezvous execution procedures, specifically for the Rendezvous Delta.

The normal orbit for the Rendezvous Delta is 15 minutes, to be flown at the lower of 275 KIAS or .78 Mach while awaiting the receiver aircraft. It was found that by modifying the 15-minute orbit to a technique of arriving at the ARCP, or anywhere along the outbound intercept leg, there would be a 67% reduction in the time spent versus the normal orbit. This has a direct relationship to the amount of fuel consumed. The average savings versus a normal orbit would be 1480 – 1690lb using the aircraft gross weights from table 2. Another method of fuel savings was flying the entire orbit using maximum endurance speed for the KC-135 versus the standard 275 KIAS/.78 Mach. However, this only resulted in a savings in the range of 171 – 437lb for a 15-minute orbit.

In both cases the numbers are driven largely by aircraft gross weight. The heavier the tanker the more fuel that will be saved using the modified orbit by reducing the rendezvous time. Conversely, the lighter the tanker, the greater the fuel savings by reducing the speed to maximum endurance during the rendezvous orbit. This is because the gap between maximum endurance airspeed and the standard orbit speed decreases the heavier the tanker is as heavier aircraft have a higher endurance airspeed.

Operational level planning considered theater-wide tanker operations where optimizations would come from more efficient overall force management. A new software program developed by the Defense Innovation Unit Experimental agency called *Jigsaw* was implemented in the CENTOM AOR and "has helped save millions of pounds of tanker gas over the course of the year."[61] This solution had the largest impact of all items examined. However, because *Jigsaw* was designed with the specific needs of the 609th CAOC in mind, it will need adaptation to the specific requirements of other combatant command AOCs or to meet the needs of tanker scheduling for large force exercises.

Mission Execution Analysis

Mission execution examined areas of an individual tanker's typical mission profile where fuel savings could be realized by modification to existing procedures. The two areas that were focused on were taxiing and aerial refueling.

The basis for the examination of taxi procedures stems from airline industry standards of engine-out taxiing, whereas the KC-135 taxis with all engines running as a standard. Because of the time involved in starting the additional engines, it was found that not all taxi scenarios would benefit from engine-out taxiing. However, at locations where there is a significant taxi-time a fuel savings could be realized. An estimated 144lb of fuel could be saved during a 10-minute taxi. This number, coupled with a high traffic volumes seen at busy airfields such as at Joint Base Pearl Harbor Hickam, could result in saving over 75,000lb of fuel per year at that location alone. The savings would be larger when incorporating other bases where significant taxi times are a factor.

Aerial refueling was examined with the F-16 as it is the most numerous fighter in the Air Force inventory. The focus was on the airspeed used for refueling and fuel consumption by the tanker at the speeds examined. A change in airspeed from the published 315 KIAS to 300 KIAS saves 777lb of fuel per hour for the typical tanker gross weight used in the scenario. This number multiplied by the sum total of all air refuelings conducted by F-16s assigned to the ANG could have resulted in a fuel saving of just under 220,000lb for FY 16.

This savings only represents F-16s assigned to the ANG as previously mentioned, and does not account for Active Duty or Air Force Reserve F-16s that would make the number even greater. Additionally, the examination of air refueling airspeeds only considered the F-16, and not the numerous other aircraft in the Air Force, Navy and Marine Corps inventories that are refueled by the KC-135. Each receiver aircraft could be examined to see if they have the ability to refuel at lower speeds than published making DoD-wide savings even larger. However, an undertaking on such a large scale would have to entail some form of airworthiness certification for each type of receiver as different speed regimes are explored. It is only because the author has refueled numerous F-16s over the course of fifteen years that it was known an alternative airspeed of 300 KIAS is reasonably achievable.

Conclusions

The key conclusions are two-fold. First, that new technologies exist that can be taken advantage of to increase fuel efficiency. Secondly, that optimization of existing procedures can also result in increased fuel efficiency. Thus, this research effectively concludes that as a result of the availability of new technologies, in concert with optimized procedures, opportunities exist to refine KC-135 operations and reduce the fleet's overall fuel usage.

Enhancements resulting from GPS technology providing precise navigational capabilities allow for greater precision in mission planning. This subsequently allows refueling rendezvous procedures to be shortened, thus saving fuel. Additionally, the consideration of flying more economical speeds during, or while awaiting, a rendezvous can further increase fuel savings.

Furthermore, flying airspeeds during refueling that are targeted for efficiency, rather than using rote speeds from a data table, also results in fuel savings for the mission.

The widespread adoption of existing methods from external organizations and new custom-developed technologies also offer opportunities for a fleet-wide reduction in fuel consumption. Fuel efficiency efforts spearheaded by the airline industry have proven the validity of engine-out taxiing as a method to save fuel when applied to an entire fleet of aircraft. This same concept is easily transferred to the Air Force's fleet of KC-135 tankers. Using a modern custom-made software application, versus a manual processes drawn on a white-board, has resulted in significant fuel savings for the CENTCOM AOR. This same technology could be adapted for use by AOCs across all combatant commands instead of remaining in CENTCOM's sole possession.

Recommendations

The recommendation from this research applies to the Air Force as a whole and to Air Mobility Command specifically. The Air Force has overall responsibility for its Air Operations Centers as a weapons system. AMC has the overall responsibility as the L-MAJCOM for the standardization of policy for the KC-135 fleet.

It is recommended that the Air Force examine the possibility of adopting DIUx's *Jigsaw* program for use by all of its AOCs for tanker scheduling. The results from its deployment in the CENTCOM CAOC saved "millions of pounds of tanker gas over the course of a year."[62] Since the program is already functional, and has proven its value, only minor adaptations should be needed to meet AOC-specific requirements of other geographic combatant commanders.

It is further recommended that AMC implement test programs to verify whether the data presented in this research will be borne out by facts when applied to actual operations. This should be accomplished by the development of procedures for an "Engine Start During Taxi" checklist. The parameters for when this checklist will be used as well as the actual checklist sequence of events would be the final products. This checklist could then be tested, at first, exclusively at a single airfield where extended taxi times are commonplace. The results of any fuel savings versus sortie cancellations due to the adoption of the procedures could be tallied to determine its efficacy or lack thereof.

Additionally, AMC should formalize procedures in the ATP-3.3.4.2, as well as the KC-135 flight manual, to reduce rendezvous timing for the Rendezvous Delta. This would be done by implementing the modified half-orbit as the standard versus a full 15-minute orbit, unless mission requirements dictate otherwise. If a full orbit is required, consideration should be given to flying it at maximum endurance airspeed. This change could be implemented at the next release of updates for those documents making the overall cost negligible.

Furthermore, AMC should re-examine all of the air refueling airspeeds published in the ATP-3.3.4.2 with the intent of optimizing them for fuel consumption. In conjunction with this, they should modify the existing "Preparation for Air Refueling" checklist to include a coordination item between the tanker and receiver pilots for air refueling airspeed. A step for tanker/receiver pilot coordination already exists in the checklist thus, the change would only add a single item.

These recommendations exist because of advancements in technology and new techniques which allow greater precision in mission planning and execution. They present unique opportunities for the KC-135 fleet because its sixty year tenure offers the opportunity to cast a critical eye on "how things have always been done" to see where the potential exists to bring a fresh perspective that can result in increased operational efficiency.

End Notes

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[32] Joint Air Power Competence Center, "United States ATP-3.3.4.2. (C) Standards Related Document (SRD)," 26 October 2018, 4-7.

[33] Data derived from calculations using "Portable Flight Planning System" (PFPS) software developed by Georgia Tech Research Institute. PFPS is the standard mission planning software used by KC-135 units.

[34] Personal experience as a KC-135 pilot and Mission Planning Cell chief during OUP.

[35] Joint Air Power Competence Center, "Air-to-Air Refuelling Consolidation – An Update," March 2014, 21.

[36] Lara Seligman, "Refueling Over Afghanistan? There's An App For That," *Aviation Week & Space Technology*, 30 November 2017.

[37] Ibid.

[38] The Boeing Company, Technical Order (T.O.) 1C-135(K)(I)-1 Change 18, *Flight Manual*, 1 November 2016, 1-118.

[39] Delta News Hub, "What does fuel efficiency mean to Delta?," Ashton Kang, 25 April 2016, https://news.delta.com/what-does-fuel-efficiency-mean-delta

[40] The Boeing Company, Technical Order (T.O.) 1C-135(K)(I)-1 Change 18, *Flight Manual*, 1 November 2016, 2-120.

[41] The boom operator is a KC-135 enlisted aircrew member whose job is to conduct aerial refueling, passenger handling and cargo loading/unloading.

[42] The Boeing Company, Technical Order (T.O.) 1C-135(K)(R)-1-1 Change 33, *Flight Manual Performance Data Appendix 1*, 1 November 2016, 1A11-5.

[43] KMKE home of 128th Air Refueling Wing, parking to RWY25L departure. Based on mapping software for distance measurements and the author's own experience.

[44] PHIK home of 203rd Air Refueling Squadron, parking to RWY8R departure. Based on mapping software for distance measurements and the author's own experience.

[45] Data based off 250lb/hr fuel consumption rate of APU and 800lb/hr for each engine's idle fuel consumption. Actual engine fuel usage would be higher for taxiing as idle power does not produce enough thrust to taxi, making figures conservative.

[46] By assuming slower engine start-up times, more time is spent starting additional engines and less time is spent taxiing with two engines.

[47] Air Mobility Command, Mobility Air Forces Operations (MAF Ops) online database, https://mafops.amc.af.mil/fueltracker (requires dot mil domain access)

[48] Calculated from fuel saved per sortie and sortie data from AMC MAF Ops database.

[49] Joint Air Power Competence Center, "United States ATP-3.3.4.2. (C) Standards Related Document (SRD)," 26 October 2018, 8-2.

[50] Joint Air Power Competence Center, "NATO Standard ATP-3.3.4.2 Air-to-Air Refuelling ATP-56 Edition C Version 1," November 2013, 2P-1.

[51] Joint Air Power Competence Center, “United States ATP-3.3.4.2. (C) Standards Related Document (SRD),” 26 October 2018, 8-2.

[52] “Aircraft Total Active Inventory,” *Air Force Association Magazine,* 100, no. 6 (June 2018): 48.

[53] This is from the author’s 15 years of experience refueling F-16s, habitually coordinating 300 KIAS as a refueling speed with the receivers as acceptable for their needs. This benefits fuel conservation and reduces aircraft turning radius to aid in remaining within airspace boundaries.

[54] Data from calculations using “Portable Flight Planning System” software developed by Georgia Tech Research Institute. 204,000lb gross weight aircraft at FL250.

[55] US Air Force. “F-16 Fighting Falcon Factsheet,” 23 September 2015, https://www.af.mil/About-Us/Fact-Sheets/Display/Article/104505/f-16-fighting-falcon/

[56] Joint Air Power Competence Center, “United States ATP-3.3.4.2. (C) Standards Related Document (SRD),” 26 October 2018, 8-2.

[57] Joint Air Power Competence Center, “NATO Standard ATP-3.3.4.2 Air-to-Air Refuelling ATP-56 Edition C Version 1,” November 2013, 1A-5, 1A-13.

[58] Air Mobility Command, Mobility Air Forces Operations (MAF Ops) online database

[59] AMC MAF Ops database was queried for KC-135 refueling missions with the following ANG units: 113th Wing, 114th Fighter Wing (FW), 115 FW, 138th FW, 140th Wing, 148 FW, 149 FW, 158 FW, 162nd Wing, 169 FW, 177 FW, 180 FW and 187 FW.

[60] “Air National Guard,” *Air Force Association Magazine*, 100, no. 6 (June 2018): 70.

[61] Lara Seligman, “Refueling Over Afghanistan? There’s An App For That.”

[62] Ibid.

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