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ALGEBRA OF TANKERS

THESIS

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ALGEBRA OF TANKERS

THESIS

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March 2006

ALGEBRA OF TANKERS

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Abstract

The Air Force's aerial refueling tanker aircraft provide essential support for deployment and employment of combat and combat support aircraft, by extending their endurance and enhancing fighting efficiency. As the lead command for air refuelers, Air Mobility Command (AMC) must frequently examine the capability of current and proposed tanker fleets to meet mission requirements due to limited tanker resources. Analysts in AMC primarily use the Combined Mating and Ranging Plans System to provide actual tanker/receiver aircraft schedules and flight plans that take into account numerous system constraints. However, this tool can take weeks to run. Even recently developed quick look tools, aimed at optimization of the fleet, can take 1/2 hour or more. Additionally, most of these more recent studies and tools focus on deployments and little attention has been given to the employment phase of missions. AMC lacks a quick look tool to quickly perform rough cut capacity analysis for tanker use and assess the feasibility of proposed employment of tankers.

To develop a feasibility quick look tool, the basic formulae for computing tankers missions must be understood. While the airlift community has defined million ton miles per day as their keystone metric, the tanker community -- concerned with being on time, on target, with fuel -- lacks such a definitive metric. This thesis describes fundamental algebraic relations that characterize employment of air refueling aircraft, employing rough cut capacity planning to determine feasibility of tanker employment with a given amount of resources. The Tanker Employment Model provides AMC with an efficient tool for quickly assessing tanker employment capabilities.

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I. Introduction

1.1 Background

Tanker history.

Air refueling is the in-flight transfer of fuel from a tanker aircraft to a receiver aircraft. It has a long history in the Air Force, beginning in 1923, when then Major "Hap" Arnold first demonstrated air refueling with an in-flight hose. It was on June 27, 1923, at an altitude of 500 feet above Rockwell Field on San Diego's North Island, that two U.S. Army Air Service airplanes linked by hoses performed the first aerial refuel (Smith, 1998: 1). Refueling efforts progressed in small increments up until World War II, when they were largely placed on hold during the war. In September 1947, General Carl Spaatz formed the Heavy Bombardment Committee to study methods of air delivery for bombers. One of their recommendations was to develop air-to-air refueling.

It was not until 1948 that the B-52 became the first aircraft designed with air refueling in mind (Smith, 1998:25). That same year, a commercial business, American Flight Refueling, Inc, created the "Boeing boom," which had "ruddervators" near the end of the nozzle end, to aid in steering the boom and could deliver up to 700 gallons per minute (Smith, 1998:26-27). In the summer of 1948, the Air Force stood up its first two refueling squadrons, the 43rd and 509th Air Refueling Squadrons (Smith, 1998:30-31). Also in 1948, another event advanced the role of refueling -- the probe and drogue system was developed. The new system allowed the tanker to trail a hose with a cone-shaped receptacle at its end; the receiver had a probe it inserted in the cone; valves opened and fuel flowed (Smith, 1998:32).

The following year, another significant event in the advancement of refueling occurred. On 7 August 1949, the first jet fighter refueled in air (Smith, 1998:32). By the end of 1949, six operational squadrons of modified aircraft were able to provide air refueling (Cox, 1991).

Even with these advancements, it was not until the Korean War that air refueling became vital to military operations. On 6 July 1951, the first combat mission using aerial refueling was executed. In addition, a new method was developed to only refuel the wing tip fuel tanks of fighters. However, even after three squadrons of the 136th Fighter Bomber Wing were equipped with the probe tanks for tip tank refueling as part of project HIGH TIDE, the project ended with the conclusion that refueling tip tanks was to be used for emergencies, and single-point refueling became the norm.

The first modern day refueler, the KC-135 Stratotanker, was ordered on 11 July 1954, and the first aircraft was produced by Boeing a little over a year later. Initially, the KC-135's primary mission was to support the B-52 intercontinental bomber (Cohen, 2000:3-4). However, the mission broadened from supporting strategic missions to tactical missions in 1964, when the first pre-strike refueling was performed on eight F-100s (Cohen, 2000:4).

By 1972, the number of KC-135s had grown from a fleet of 55 to 172 (Cohen, 2000:5). The Arab-Israeli War of 1973 convinced the Air Force to further increase the number of tankers. From 13 October through 24 October, Military Airlift Command delivered 23,395 short-tons of cargo to Israel. The vast majority of C-15 and C-141 used were forced to make refueling stops en route, increasing delivery times and increasing airport congestion at intermediate refueling stops (Cox, 1991).

Tankers finally came of age in 1991 during Operation DESERT STORM, flying nearly 14,000 combat sorties and offloading approximately 725 million pounds of fuel to 50,000 receivers (Cohen, 2000:6). In just 43 days, they serviced about 2,000 aircraft (GAO, 1993:1). Operation DESERT STORM used 300 U.S. tankers (and 40 from allied forces) to provide a ratio of approximately 1 tanker to every 6 receivers. The U.S. total included 260 Air Force KC-135/KC-10, and 35 from Marines and Navy (GAO, 1993:2.).

The importance of tankers was illustrated again in 1999. 1n 78 days from May to June, during Operation ALLIED FORCE, KC-135s flew 4,324 intratheater refueling sorties, offloading 188.1 million pounds to 17,751 receivers. An important lesson learned, however, was that limited beddown bases became a factor, causing tankers to fly further to get to refueling tracks. Burning more of their own fuel led to less offload fuel available, and thus, more tankers needed to accomplish the mission (Cohen, 2000:14-15).

Tankers continue to be a valuable resource in conflicts. As part of the Global War on Terrorism, Operations ENDURING FREEDOM (OEF) began in October, 2001, and two years later, Operations IRAQI FREEDOM (OIF) began in March, 2003. As of 18 November 2006, tankers had flown 7,136 sorties, delivering 425 million pounds of fuel to 34,912 aircraft for both operations (USAF Aim Points, 18 Nov). A sample of monthly tanker missions can be seen in Table 1, OIF/OEF Tanker Data for November 2005.

Table 1. OIF/OEF Tanker Data for November 2005

Operation	# OF AIRCRAFT RECEIVING	LBS OF FUEL OFFLOADED
OIF	1982	23,806
OEF	212	7,532

Source: USAF Aim Points, 17 Nov 05

Roles and Missions of Tankers.

Air refueling is one of the distinguishing characteristics that make the United States the predominant air power nation on the globe. It allows combat and support aircraft to strike targets deeper in enemy territory, extends the time fighter aircraft can protect friendly forces from attack by enemy aircraft, and supports the extension of the United States' military presence around the world (Capehart, 2000:1).

Air Refueling supports six distinct Air Force missions: Single Integrated Operations Plan (SIOP) (nuclear bombers), Global Attack (Air Expeditionary Forces, quick deployments, bombers, airlift, long range reconnaissance and intelligence), Air Bridge (an airborne line of communication linking the continental U.S. and a theater, or multiple theaters), Deployment (escort and air refuel of fighter aircraft during intertheater deployments), Theater (Airborne Warning And Control System (AWACS), Joint Surveillance Target Attack Radar System (JSTARS), Airborne Command Center (ABCC)), and Special Operations. In addition, air refueling is used in several for several other circumstances, including Emergency Air Refueling, Airlift, Aeromedical Evacuation, and Combat Search and Rescue (AFDD, 1999:14-19).

In general terms, an aircraft's ability to remain airborne is limited by its capacity to carry fuel. Air refueling removes this airborne time restriction through its two main enhancing roles: force-enhancement and force-multiplication. Force-enhancement is the more traditional role and is achieved through deployment of aircraft to any part of the world. The second role of force-multiplier is used in shorter range theater operations (Russina and Ruthsatz, 1999:2).

Additionally, tankers can be considered as both time enhancers and distance enhancers. As a time enhancer, tankers support operations that allow receiver aircraft to remain airborne without stopping to refuel. Depending on the weapon system, this may save many hours, which would otherwise be required for each landing and ground refueling needed to get from one point to another (Cohen, 2000:10). As a distance enhancer, the tanker offers a relative shortening of distance, as airborne forces are no longer married to routings that provide ground refueling stops. In addition, with fewer forward-deployed bases and limited receiver beddown locations, the tanker's worth increases rapidly. As the distance from point of departure to the target increases, more tankers are required (Cohen, 2000:11).

Tankers were originally designed to extend the range of heavy bombers supporting operations by U.S.-based strategic bombers. Today, the Air Force's approximately 600 tankers have adapted to support fighter, cargo and other support aircraft as well (AFDD, 1999:1). Support to these aircraft includes the deployment and employment of these aircraft during a conventional conflict. These conventional operations are far more complex and difficult to support versus heavy bombers because of shorter planning periods, rapidly changing priorities, crowded airspace, less predictable fuel requirements, lack of standardized refueling equipment, and continuous operations by thousands of aircraft (GAO, 1993:2).

When supporting aircraft other than bombers, tankers have two distinct but overlapping environments: airbridge operations -- supporting *deployment* of strategic airlift, bomber, and fighter assets into a theater of operations; and combat support operations -- supporting *employment* by providing needed fuel to "shooters" and support

aircraft in the combat zone (Cohen, 2000:2). Intratheater operations supporting employments within one theater are more dynamic and quick tempo than intertheater operations which support deployments between theaters, and often require emergency air refueling support. Intratheater operations generally are characterized by shorter distances and numerous refueling assets, making tankers more responsive to requests for emergency air refueling support. The preferred method of providing emergency fuel support is through a combination of aircraft waiting on ground and airborne aircraft (AFDD, 1999:20).

Strategic Planning.

All intratheater airpower operations are planned, tasked, and executed by the Air Operations Center (AOC) through three phases: aerospace assessment, planning, and execution. During the assessment phase, the commander conducts operational environment research and develop courses of action. The Air Refueling Control Team and Air Mobility Director (AMD) chief continually evaluate resource constraints, tanker utilization efficiency, and the overall operational effectiveness of tanker usage.

The planning phase begins with the commander providing broad planning guidance and objectives and a vision of what will constitute military success in the given contingency. Guidance from the commander will include air refueling apportionment decisions. One of the most important considerations during the planning phase is the availability of air refueling, as tanker availability can have an important impact on allocation for deep strike missions and for the timing and tempo of all airpower operations. When air refueling capability is limited, combat and combat support planners must work closely with air refueling planners to ensure accurate and realistic receiver

fuel requirements are met, in order to meet the commander's priorities. It is imperative that air refueling planners provide the best match between tanker capabilities and receiver mission requirements in order to maximize overall mission accomplishment (AFDD, 1999:8 – 42).

Another important consideration during planning is air apportionment of all aerospace forces. Air apportionment is the determination and assignment of total expected air effort by combinations of one or more of the following: percentages, the priority that should be devoted to the various air operations, and geographic areas for a given period of time. At this time, air refueling assets are matched against receiver requirements to ensure all objectives can be met as planned. During contingencies, competing priorities can limit the availability of air refueling support. At the operational level, commanders must apportion air refueling sorties among different airpower functions involved in the campaign. Apportionment of air refueling sorties should roughly follow the apportionment of combat and combat support sorties (AFDD, 1999:50-53).

A final consideration in aircraft allocation decisions is the number and type of assets to be used. For tankers, this entails matching the right air refueling capabilities against accurately forecasted air refueling requirements. Once receiver requirements are known, planners can match air refueling assets against those requirements. The most important consideration is to ensure that allocations are based on capabilities and not sheer numbers (AFDD, 1999:55).

During the final phase, the execution phase, the Joint Force Air Component Command will direct execution of the air tasking order and deconflict all aerospace forces and capabilities made available by the JFC (AFDD, 1999:38 – 42).

Tactical Planning.

Functionally aligned under the Combat Plans Division, the Tanker Plan Team plans, schedules and tasks the tankers that fall under the operations control of the JFACC. The fundamental objective of the Combat Plans' tanker planners is to produce a daily tanker plan supporting the Master Air Attack Plan using the appropriate Theater Battle Management System and to task theater tanker assets via the air tasking order. Three duties of the Tanker Plan Team are developing a concept of operations (CONOPS), coordinating airspace, and building a tanker plan (CWS 401, 2004:4).

When putting together a concept of operations supporting combat operations, the planning normally focuses on combat air patrol, strike, suppression of enemy air defenses, and close air support requirements. Each of these missions has their own requirements and considerations. For example, combat air patrol orbits are normally continuous, so tanker areas supporting these would be built first, followed by Airborne Element of the Theater Air Control System, which include platforms such as Airborne Warning and Control System and Airborne Battlefield Command and Control Center. Airborne Element of the Theater Air Control Systems use a standard fuel planning factor for support assets such as Joint Surveillance Target Attack Radar System (JSTARS), RC-135, and Airborne Warning And Control System: one tanker for every 8-hour support asset station time period (CWS 401, 2004:4-6).

Strike assets add complexity, since fuel planning is much more dependent on the type of strike mission. The master air attack plan must provide fuel offload, air refueling mission, and off tanker time. In addition, for packaged strike missions, planners can consider using tanker cells to provide pre/post fuel. To complicate further, boom/drogue cycle times are an important consideration for refueling, not just the amount of fuel available for offload (CWS 401, 2004:4-5).

Table 2 illustrates examples of basic planning factors for support to combat air patrol, suppression of enemy air defenses and close air support (CWS 401, 2004:6).

Table 2. Standard Fuel Planning

Standard fuel planning factors (1000 lbs per hour)					
CAP		Orbiting **SEAD**		**CAS** (FAC-A)	
F-15C	9.0	F-16CJ	6.0	A-10	5.0
F-16A/C	6.0	EA6B ****(Boom and drogue)**	9.0	F-16C	7.0

Source: CWS 401, 2004:5

In addition to considering the aircraft and mission of the receiving aircraft, there are many other factors critical to building the concept of operations, including aircrew availability, aircraft availability, and requirements for reliability tankers, ground alert air refueling capability, and spare tankers. Often, standard planning numbers are used for some of these considerations (CWS 401, 2004:4-6). Table 3 lists standard aircrew planning numbers.

Table 3. Standard Aircrew Planning

	KC-10	KC-135
Crew Ratio	2.0	1.5
Utilization Rate	1.5	1.5
Turn Time	5.0	4.0

Source: CWS 401, 2004:5

These numbers provide rough estimates only for planning aircrew, which may need to be adjusted. For example, these numbers may or may not include unit staff, which is not usually available to fly every day. In addition, ratios may need to be adjusted to meet planned operations requirements (CWS 401, 2004:4-6). Similar to aircrew planning, standard maintenance planning factors can be used: 80% Mission Capable Rate for KC-135 and 85% for KC-10. When planning, it is essential to remember these numbers are only a rough estimate, and can vary from day to day (CWS 401, 2004:4-6).

In addition to aircrew and aircraft availability, planners may include up to three additional tanker categories. The first is a reliability tanker, which provides an airborne alert capability, centrally located and at low enough altitude to be used by most receivers. The next is ground alert air refueling capability, which must be located close to the fight. Finally, there may be a Spare Tanker Requirement, used if another tasked tanker is unavailable to perform its mission (CWS 401, 2004:4-6).

After determining the scope of effort required to support combat operations, planners next determine tanker airspace requirements. Coordination is critical, as tankers are just one of many competing airspace requirements. Factors which determine the allocation of airspace include receiver requirements, threat conditions, and priority/criticality of airspace user. Likewise, many factors are considered when building tanker airspace. The following list is an example of key issues considered when building tanker airspace (CWS 401, 2004:6-7):

- Can receivers accomplish mission within given air refueling areas/tracks?
- What is minimum acceptable clearance from terrain?
- What is acceptable level of risk for tanker operations based on the threat?
- Is there a requirement for air refueling formation and can the formation be accomplished in the track/area?
- What is airspace flow plan in and out of AOR/air refueling areas?
- How will receivers and tankers enter and depart the air refueling areas AOR?
- What is radar coverage supporting the airspace plan?
- What are civilian/international airspace constraints?
- Will airspace need minor or major changes daily?
- If significant tanker airspace changes occur, airspace flow plan may not work

In addition to developing concept of operations and determining airspace requirements, the Tanker Planner Team also develops the tanker plan. Planners will first develop an offload capability matrix for each base and type of tanker aircraft, showing offload available (in 30 minute increments) broken down by air refueling area/track Next, they develop a receiver and tanker capability matrix by matching tanker and receiver compatibilities and listing tanker or receiver limitations (for example, the maximum altitude for air refueling). Several factors are considered prior to scheduling missions (CWS 401, 2004:10-12):

- Geographic location of tanker bases relative to refueling tracks
- Type of aircraft at each base
- Cell versus single ship operations
- Deconflicting arriving and departing tankers/receivers
- Deconflicting same time/track request
- Track saturation
- Best platform for each request
- Altitude constraints
- Air/ground alert tankers
- Boom versus drogue

Prior to planning mission, tanker theater set-up data must be confirmed to include (CWS 401, 2004:10-12):

- Operating base(s)
- Number of aircraft (UE)
- Utilization (UTE) Rate
- Normal maintenance turn times
- Accurate maximum takeoff fuel (varies with runway length, pressure altitude (PA), which is the altitude of a given atmospheric pressure in the standard atmosphere), temperature, etc)
- Burn rate
- Offload rates
- Airspace

Factors Affecting Tanker Planning.

The complexity of planning and scheduling tankers is not just limited to the varied missions and roles they fulfill. Additional intricacies lie in the number of tankers available, the configuration of the aircraft, types of refueling patterns, the number and formation of receiver aircraft, and terminology.

While the number of aircraft capable of being aerial refueled has increased, the number of tanker aircraft has decreased. Thirty-five years ago, there were approximately 800 KC-135. Today's Air Force refueling fleet is just over 600 aircraft and is primarily composed of KC-10A (59), KC-135E(133) and KC-135R (411) (HASC, 2004). Due to limited tanker aircraft compared to the number required during operations, not all refueling requests can be met simultaneously, if at all (Capehart, 2000:1-2).

Another variable influencing the use of tanker aircraft is the aircraft which receive the fuel. Almost all Air Force aircraft, as well as Navy and many foreign aircraft, can be refueled from the air. However, not all of them are able to receive fuel in the same manner. Some require probe and drogue systems, others must be refueled with booms. The two methods of refueling require different equipment; therefore, when necessary, tanker aircraft must be reconfigured whenever the mission changes. Additionally, the

two services use different types of fuel -- Air Force aircraft primarily use JP-8 fuel, and Navy aircraft primarily use JP-5.

When scheduling air refueling, two methods are considered: refueling via anchor area or along an air refueling track. In anchor areas, the tanker flies a racetrack pattern within defined airspace while waiting for receiver aircraft to arrive. Anchor air refueling is normally used for intratheater operations where airspace is confined or where receivers operate in a central location. For intertheater operations, the air refueling track is the preferred method for intertheater operations. In addition to the two methods, the tanker rendezvous can be accomplished two ways. The tanker can orbit at a designated point along the track awaiting the receiver's arrival, or the tanker and receiver can be preplanned to simultaneously arrive at a designated rendezvous point (AFDD, 1999:12).

Another complicating issue is that many missions require tankers to refuel their receivers while in a multiple-ship formation. Mission requirements may dictate several different types of tankers and multiple receiver types in the same formation. Formation refueling is one of the most demanding operations due to the number of aircraft in a confined block of airspace and because receiver aircraft may be constantly joining and leaving the formation. Cell formation operations may alleviate airspace constraints by allowing the same number of tankers to operate in less vertical airspace than if they were to operate individually (AFDD, 1999:12).

Adding to the complexity of scheduling is terminology. When working with other services and nations that may have their own culture, there is potential danger in the differences in procedure and terminology. Therefore, such operations require a standard set of tactics, terminology, and procedures. A final limitation to air refueling is airspace.

Standardized multinational cell formation procedures allow a variety of air refueling assets to operate in compressed space (AFDD, 1999:13).

1.2 Problem Motivation

Limited tanker aircraft available.

In 1984, a General Accounting Office (GOA) study concluded minimum number of tankers needed through 1990 would be equal to 1,000 tanker equivalents. A Congressional Budget Office report in 1985 used the same 1,000 KC-135A tanker requirement. Even then, the Air Force agreed to the number, but added that if there were an increase in world tensions, the figure would be low. Since then, tensions have increased as well as air refueling requirements, as predicted. The lack of air refueling aircraft is a serious problem with military's readiness. As early as 1991, Air Force acknowledged the 1,000 tanker figure was no longer valid (Cox, 1991).

With limited resources of tankers available, tankers usage must be planned carefully, and their use must be efficient. In Operations DESERT STORM, almost 40 percent of the fuel carried by tankers was unused, and combat sorties were limited by the inability of the K-135 to service more than one receiver at a time (Colella, 2001:105). However, inefficiency, starting at 41.5% unused during the first week of the war, dropped to 35% by the last week, while receivers jumped from 5,077 to 6,100 (GAO, 1993:6). Booms available – not fuel available – was the limiting factor and often required more tankers to be in the air than was dictated by fuel requirements alone (Colella, 2001:105).

A key lesson of Operation DESERT STORM is that the ability of air refueling operations to support combat missions is limited not only by the number of tankers but also by the efficiency of fuel transfer. Areas that contributed to inefficiencies in air

refueling operations included receiver requirements, tanker planning, refueling

equipment, communication, aerial refueling doctrine, and training (GAO, 1993:7).

A 1993 GOA report on tankers post DESERT STORM highlighted a need for

better planning tools (GAO, 1993:2). To improve the efficiency of air refueling

operations in future contingencies, GAO recommended the Secretary of Defense direct

the Secretary of the Air Force to ensure the development of needed improvements to the

automated tanker planning module fielded at the time, including examination of the

feasibility of substituting the existing AMC system for one under development by the Air

Combat Command (GAO, 1993:15).

Lack of simple planning tools.

To analyze transportation as a whole, the Transportation Command

(TRANSCOM) uses the Analysis of Mobility Platform to model and simulate systems for

analyzing the end-to-end transportation of unit equipment and sustainment through the

Defense Transportation System. Analysis of Mobility Platform has two suites, the Model

for Intertheater Deployment by Air and Sea (MIDAS), and the Enhanced Logistics

Intratheater Support Tool (ELIST and CONUS ELIST). MIDAS focuses on the

deployment of assets, and ELIST evaluates the feasibility of movement within theater;

however, its focus is more on the movement of personnel and equipment and the airlift

required (DTO, 2004:7-8).

The need for variety of planning scenarios create complex sets of questions whose

answers demand the use of powerful analytical tools dedicated to tankers. Among the

tools used are the Combined Mating and Ranging Planning System (CMARPS), and the

Air Refueling Control Model (ARCM). CMARPS is a computer program that helps

analyze, plan, and schedule deployment of tankers and receiver aircraft in support of immediate and anticipated military operations. Unfortunately, this tool can take many weeks to months to produce meaningful results due to the great number of scenarios that must be explicitly constructed (Barnes and others, 2004:619). ARCM is a linear optimization model designed to maximize the allocation of tanker according to the daily air tasking order. Using graphic user interface system, the model is more user friendly then CMARPS. However, ARCM is limited by its linear optimization design. With the use of a heuristic, the model will give an initial solution, which then be reviewed and validated before placing into the Theater Battle Management Core System (TBMCS).

TBMCS is another tool used for daily tanker planning and is designed to cover planning for all aspects of a 24 hour air tasking order – including receivers and other missions not requiring air refueling. However, even the Air Force Mobility Weapons School for KC-135, a school for top rated tanker pilots, recommends using the auto planning feature of TMBCS only if already a "master of TBMCS and tanker planning." They continue on to say, "it's better to build the [air tasking order] mission from scratch than to clone previous days [air tasking order] missions" (CWS 401, 2004:12).

In an effort to improve the daily air tasking order mission planning, several individuals and groups have conducted studies and developed simpler tools, including Quick Look Tools and the Tanker Assignment Tool. The majority of these simple tools thus far have focused on the deployment aspect of tankers. In addition, while considerably simpler than CMARPS or ARCM, these tools are still complex and require detailed data. Employment tanker tools have come into focus in recent years. However, like their deployment counterparts, these tools also focus on detailed operations, not the

overarching relationships upon which planning are based. These planning tools, from

CMARPS to the simple tools will be discussed in the next chapter.

Current Employment Tanker Planning.

Unfortunately, current air refueling doctrine is potentially confusing, awkward,

and limited (Cohen, 2000:2). Additionally, Air Force doctrine has not been explicit in

planning factors either. There is limited amount written on tanker doctrine. Even in Air

Force Manual 1-1 (AFM 1-1), Vol. I, Basic Aerospace Doctrine, March 1992, only one

short paragraph is devoted to air refueling:

> "Sufficient air refueling capability must be available to exploit aerospace
> power's unique flexibility. The ability of aerospace power to concentrate
> force anywhere against any facet of the enemy may depend on sufficient
> air refueling capability."

AFM 1-1, Vol. II, is 300 pages, and intended to provided clarity and support the doctrinal

statements in Vol. I, and yet, only one page, buried within an essay on "Aerospace Force

Enhancement," is devoted to air refueling doctrine (Dougherty, 1996:43).

The organizational diagram in Figure 1 identifies the command and control

structure as described in AFDD 2-6.2, Air Refueling Doctrine. Simplicity, a fundamental

principle of war, is violated with throughout the diagram, with overlapping boxes and

intersecting lines. In addition, the descriptions of this command structure from AFDD 2-

6.2 add to the confusion. For example, five different organizations, Tanker/Airlift

Control Center, Air Mobility Operations Control Center, Air Mobility Division, Air

Refueling Control Team, and the air refueling plans section within the combat plans

division of the Air Operations Center, are responsible for planning, tasking, and

executing air refueling missions (Cohen, 2000:36).
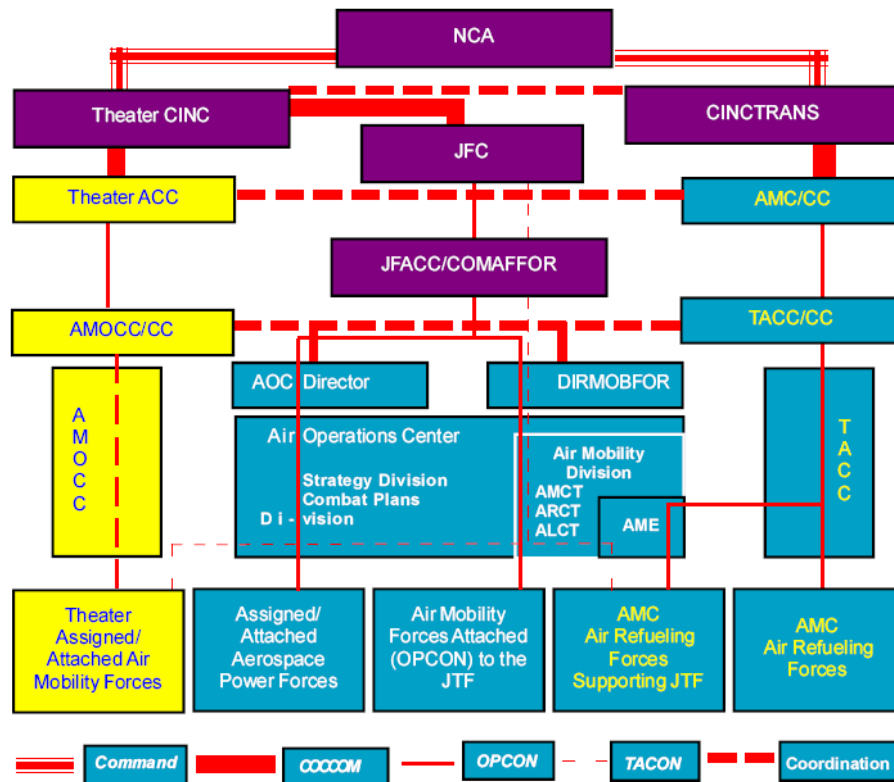
Figure 1. Command and Control Structure for Air Refueling (AFDD, 1999:34)

The lack of overarching Air Force doctrine for tankers, and the confusion for the limited amount that does exist, filters down to how the Air Force conducts training. In 1994, Air War College's wargaming exercise, CAMPEX, addressed tanker employment by saying, "Air Refueling… assumed to be present in adequate supply. Our experience in testing CAMPEX with previous classes showed that addition of these assets increased the complexity of the simulation without contributing to the outcome." Five years later, Air Command and Staff College war game, TROPIC THUNDER, made a similar claim. It is not surprising then, that the Air Force fights, and plans to fight, using the same inadequate assumptions with which it trains (Cohen, 2003:3).

The lack of training emphasis translates into real world readiness. A key example of this was Operation ALLIED FORCE. The Air Mobility Operations Control Center in USAFE coordinated movement of all Air Mobility Command (AMC) aircraft in Europe. With only a handful of air refueling experts in United States Air Forces in Europe, a major was the Chief of Tanker Plans. Furthermore, AMC was not actively engaged in determining tanker requirements for Operation ALLIED FORCE. The issues were exacerbated, since European Command (EUCOM) did not have a deliberate plan for a similar operation, so that the planners could modify and adapt to the task at hand. Additionally, the J-33 in EUCOM was to balance EUCOM's tanker requests with other priorities and validate them before forwarding to Transportation Command, AMC and the Tanker/Airlift Control Center to process the request. But with no tanker expertise in J-33, the philosophy was that the Commander in Charge knew best, and a blank check for requests was given (Cohen, 2003:32-33).

Tanker requirements should not drive an operation; however, an unlimited amount of assets can not be assumed either. Tanker employment during war and other contingencies, as it relates to doctrine, must be simplified and acknowledged that in a combat support role, the tanker is no longer a mobility asset, but a combat aircraft and shooter's best friend (Cohen, 2003:38).

1.3 Problem Statement

Air Mobility Command's Tanker Airlift Control Center is responsible for planning and scheduling all tanker operations in support of air operations. As the lead command for the Air Force's air refueling fleet, AMC frequently examines the capability of current and proposed tanker fleets along with their supporting manpower and resources

to meet wartime requirements. To provide tanker/receiver aircraft schedules and flight plans, analysts at AMC use a very detailed tanker planning tool called the Combined Mating and Ranging Planning System (CMARPS). The tool can take into account numerous system constraints, but it also takes a long time, a lot of data, and a lot of operational expertise to set-up properly for a given scenario. Futhermore, as problem complexity increases, the time to solve increases as well. Finally, CMAPRS is not well suited to quick turn analysis or gross feasibility checks.

Air Mobility Command lacks a simple, efficient tool for analysis of strategic tanker capabilities during the employment phase of military operations.

1.4 Research Objectives

Several theses (Capehart (2000), Tekelioglu (2001), Annaballi (2002), Miller (2005)) as well as a dissertation by Wiley (2001), have developed detailed MS Excel and java-based tools, which solve the tanker assignment problem in detail. However, the Air Force lacks standardized equations to define relationships of tanker refueling for deployments or employments. Additionally, while tanker requirements for force deployments can be determined via models, most estimates for employment refueling requirements are calculated via personalized, "back of the envelope" spreadsheets.

The objective of this research is to first create a standardized set of relationships estimating fuel and tail requirements for employment scenarios. Theses equations will then be modeled into an Excel-based tool, the tanker employment model.

1.5 Scope

A complete tanker planning model would address both the force-enhancement as well as the force-multiplier roles discussed previously. Two tools recently developed address many of these issues. The Tanker Assignment Problem (TAP) tool by Capehart (2000) addresses the deployment phase of the overall model, and addresses the employment planning process. The tanker employment model takes a step back from the Tanker Employment Tool developed by Miller (2005) and focuses on the overarching relationships considered during employments of tankers. This project focuses on answering the following questions:

1. Given system constraints/capacities and information on receiver employment missions, how many tankers will it take to meet receiver air refueling requirements?

2. Given system constraints/capacities, and a fixed number of tankers, how many receiver employment missions can be supported?

This problem involves assigning homogeneous vehicles, located at one 'super base', to meet the refueling needs of a receiver group. Time windows are an important aspect of tanker modeling – having aircraft, aircrew and base services available when receivers require fuel. To keep this tool on a strategic level, utilization factors are also introduced to account for availability of tankers, aircrew, and aircraft at specific time frames.

Factors effecting this problem include the aircraft fuel capacities and burn rates, air speed, mission distances and times, number of aircraft to be supported, the number of tankers available, the number of aircrew available (including crew duty limitations.) Other detailed factors such as time frames, wind, altitude, and crew duty limitations,

locations of tanker and receiver group origins and destinations, escort requirement for receivers, and formation size are not explicitly modeled.

1.6 Contributions of Research

This effort provides Air Mobility Command with a set of equations and a planning tool to quickly estimate the feasibility the tanker support planned for a deployment. Additionally, the equations proposed in this research can serve to bolster equations already available in Air Force Pamphlet (AFPAM) 10-1403 and introduces some novel tanker metrics.

1.7 Thesis Overview

The remainder of this thesis is organized as follows: Chapter 2 reviews the literature pertaining to tanker operations. Chapter 3 develops the methodology for conducting this research, and Chapter 4 presents the results. Finally, Chapter 5 discusses issues for further research and improvements that can be incorporated for into the tanker employment model.

II. Literature Review

2.1 Air Mobility Command Tanker Tools

Air Mobility Command has a need for a variety of planning scenarios for tankers which create complex sets of questions whose answers demand the use of powerful analytical tools. Among these tools are the Combined Mating and Ranging Planning System (CMARPS), Air Refueling Control Model, Quick Look Tools and the Tanker Assignment Problem tool.

CMARPS was built in 1982 and has continued to evolve to its present form, a deterministic computer planning system that assists analysts and warplanners in developing and scheduling the deployment of tankers and receivers during peacetime, crisis, contingency and wartime operations (Barnes and others, 2004:626). It determines when, where, and how much air refueling is required for most mission aircraft. CMARPS also determines fuel requirements, considering factors such as restricted airspace, threat exposure, deconfliction of routes in strike zones, and time over target. Next it is assigns tankers to meet fuel requirements, considering factors including minimizing the number of tankers used, minimizing tanker fuel consumption, regeneration of tankers, and abort base requirements. After assignments are made, CMARPS simulates aircraft mission using formulas for wings and fuel consumptions to generate a final mission schedule and flight plan (Capehart, 2000:5).

While CMARPS can assist in providing extensive, detailed, and accurate data for predicting receiver and tanker aircraft mission requirements, its complexities make quick and effective use difficult for even highly experienced users (Barnes and others,

2004:626). This tool can take many weeks to months to produce meaningful results due to the great number of scenarios that must be explicitly constructed (Barnes and others, 2004:219).

2.2 Tanker Scheduling Tools

To combat the problems and time requirements associated with CMARPS, AMC has sponsored research on aerial refueling for years. Two early attempts at solving the 'refueling problem' were research completed by Yamani (1986) and Hostler (1987). Yamani's research was limited to consideration of receiver groups which only required one waypoint and consideration of single aircraft that required two waypoints (Barnes and others, 2004:626). Hostler developed preemptive goal programming with three prioritization levels, using algorithms and an off shelf mixed integer program. He allowed a tanker to refuel at more than one point, but ignored various equipment on an aircraft, ignored the amount of offload carried by KC-10 versus the KC-135, and did not allow for different constraints on flight time for the various tanker types. Additionally, as a mixed integer linear program, an optiomal solution could not be guaranteed (Hostler, 1987).

In 1992, Hong created an optimal refueling position which minimizes the overall fuel consumption according to the optimal function. Hong's (1992) solution optimized refueling position and scheduling plan for air refueling. He designed optimal tracks of assigning tankers to receivers, and computes optimal refueling times and fuel weights with maximum total fuel consumption. Thus, Hong took maximum tankers required, maximum number of tankers available take-off bases, destination bases and post refueling bases, etc, into consideration (Hong, 1992:1299). Hong however, made many

assumptions. He assumed receiver take-off states (take off weights, fuels, take off times, take off bases and destination bases) were fixed; tanker take off states were determined by refueling scheduling plan; earth is perfect sphere; weather was neglected, only constant wind was considered; refueling was a period process; flight weight and their fuel consumption rates of tankers and receivers were allowed to vary; and after refueling the tanker landed at most appropriate base (Hong, 1992:1299-1300).

In one of the first attempts to provide a more responsive program than CMARPS, Russina and Ruthsatz (1999) developed a quick look tool (QLT). Their goals were to quickly estimate the number of tankers needed for a deployment and then determine how quickly that deployment could be achieved. The tool includes several simplifying assumptions, including constant flight speeds for all aircraft, refueling tanker must provide any escort duties, all tankers are identical, only one tanker could be assigned to a waypoint, the location of all waypoints and the amount of fuel required at the waypoint are assumed to be known constants and are part of the input data. Russina and Ruthsatz (1999) provide a means to schedule tanker aircraft to receiver groups; however, they did not model multiple locations for the tankers (Capehart, 2000:17). Although the tool was developed for tanker deployments, several of the assumptions and issues are directly applicable to future tanker employment models.

Capehart (2000), Wiley (2001), Tekelioglu (2001), and Annaballi (2002) built upon the efforts of Russina's and Ruthsatz's QLT, developing models to help efficiently utilize tankers specifically in their deployment missions. Capehart (2000) developed a Tanker Assignment Problem (TAP) tool, viewing the problem as an assignment problem and using a heuristic to solve. The Tanker Assignment Problem is an Excel based

spreadsheet model, coded with Visual Basic for Applications, to have multiple worksheets to input data regarding tanker resources and receiver data. Capehart was one of first to apply the tabu heuristic to solving the air refueling tanker assignment problem. Capehart built upon Russina and Ruthsatz (1999) by increasing tanker capability to multiple origins (Capehart, 2000:17). His model could be viewed as a deployment, with fighter aircraft needing tanker escort. (In reality, the escort is only needed over water, but was assumed to be needed between refueling points and the final leg.)

The tabu search employed for the Tanker Assignment Problem explores the solution space by swapping tankers assigned to a refueling point, by taking an existing tanker assigned to a refueling point and replacing it with another tanker within range to satisfy the needs of the receiver group at that refueling point. Tekelioglu (2001) extended the tabu search methodology of Capehart, to have all refueling points calculated up front based on maximum flying distance of the receiver groups. Additionally, Tekelioglu included the ability to reuse tankers and limit the total flight distance for tankers. However, he did not allow for the possibility of more than one refueling point per mission, nor for effects of altitude on speed or fuel burn, and only used distances based on fuel flow -- not accounting for air speed, wind, etc (Tekelioglu, 2001:11).

In 2002, Annaballi (2002) updated TAP by making it more operationally realistic and applying an ant colony heuristic to a vehicle routing problem (Annaballi, 2002:11). Ant colony heuristic is a distributive metaheuristic that combines an adaptive memory function with a local heuristic function to repeatedly construct possible solutions which can then be evaluated. Thus, Annaballi used multiple ant colony heuristics combined with a simple scheduling algorithm and modeled the Tanker Assignment Problem as a

Multiple Depot Vehicle Routing Problem, finally producing an Excel based spreadsheet also (Annaballi, 2002: ix). Adding increased functionality to the TAP model resulted in the model being more operationally realistic. In addition, Annaballi conducted some validation and verification of the TAP tool.

Wiley (2001) developed a JAVA-based tool for the Tanker Assignment Problem, using Group Theoretic Tabu Search, providing an ensemble of solutions to any instance of the Aerial Fleet Refueling Problem. The solution was composed of the following decisions: waypoints, the tankers that search each waypoint, and how much fuel the assigned tanker(s) should deliver to the waypoint (Barnes and others, 2004:622-624). Wiley eliminated the requirement for tankers to return to their base of origin, calculated refueling points to reduce the distance tankers had to travel, and allowed a tanker to service more than one refueling point. His model provides a very effective solution methodology for the Aerial Fleet Refueling Problem and improved on TAP; however, the research was limited to only the deployment aspect of receiving aircraft and tankers (Barnes and others, 2004:622-624). Therefore, although it improved on TAP, its applicability is still limited only to deployments.

2.3 Tanker Employment Scheduling Tools

More recent attempts to solve the air refueling issue have been directed at the employment side of tanker usage. Three models have been developed, and one graduate research project devoted to the subject. In 2005, Miller developed the Tanker Employment Tool, which focused on tanker employment. His model allowed for inputting attacking or patrolling sorties of various aircraft as well as the location of available tanker aircraft, using many of same issues and assumptions as Russina and

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Ruthsatz, with respect to time, air speed and travel, geographical position of airbase, crew duty limitation, take off fuel, fuel consumption (Russina and Ruthsatz, 1999:12). Miller treated his model as a capacitated facility location problem with sole sourcing constraints, and used tabu search to find a feasible allocation of tankers and sorties to anchor areas during employment. The primary objective was to partition the tankers and refueling points to anchor areas so that all receivers can be refueled during their attack operations. Additionally, there are secondary objectives to minimize the number of tankers required and the total flight distance for the tankers. A limiting factor of TET is that it does not account for many variables such as wind, altitude and crew duty limitations. Also, Miller assumed that aircraft beddown locations, sorties, and area of engagement are predefined (Miller, 2005).

The Air Refueling Control Model was also developed in 2005 as a linear optimization tool designed to allocate tankers optimally, ensuring requests are supported and flexibility for additional requests is maximized (Adams and Anderson, 2005). Because it is an integer program, there is always the possibility that the program won't solve. To mitigate the risk, the tool uses a heuristic that may not produce the true optimum. Thus, the model's output is only an initial solution, which must be reviewed and validated each day prior to input into the Theater Battle Management Core System.

Also in 2005, Macdonald compiled a "Handbook for Tankers." While not a tool in itself, it is a reference for factors vital to planning tankers. His research project serves as a foundation for tanker employment studies and modeling, but only begins the work of outlining broad relationships in tanker planning. With his efforts, Macdonald lays the foundations of capacity planning for tankers during employments (Macdonald, 2005).

The third tool is the AIRPLAN AAR Suite, developed by a retired Royal Air officer. Empson developed an excel-based software suite designed to aid decision making in choosing and optimizing the necessary mix of aircraft and support. His model incorporates four programs: Military Air Operations Planning program, Mixed Fleet Analysis program, Missions Database, and Air-to-Air Refueling (Airplan AAR, 2005). With the four programs, users are able to calculate the minimum number of crews and aircraft necessary for mission packages, enter and save preplanned missions, and size a tanker fleet required for an operation. Empson's model combines aspects from both deployment and employment planning. His model has various limitations, such as limited refueling points for deployment missions, assumed given beddown location, and no consideration for base support as a resource. Additionally, unlike either the Tanker Assignment Problem or the Tanker Employment Tool, the AIRPLAN AAR does not try to optimize the solution to tanker planning. Instead, it relies on the user to perform their own sensitivity analysis. Finally, the AIRPLAN AAR only models for one tanker and receiver type at a time. (Macdonald, 2005:45-49).

The tools developed thus far try to solve the tanker problem from an optimization standpoint. Thus far, no one has tackled the basic relationships involved in tanker planning. Furthermore, no attention has been given to capacity available for tanker planning.

2.4 Capacity Planning

Even with detailed operations planning and scheduling, which consider the volume and timing of output, the utilization of operations capacity and balancing output with capacity at desired levels need to be considered and fit together at various levels of

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planning (Adam, 1992:372). Aggregate planning is useful because it is general. A planner can devise a course of action, consistent with strategic goals and objectives, without having to deal with a lot of detail (Krajewski and Ritzman, 1998:575). However, planning in general has many different levels.

First, a business plan stating the organizational overall level of business activity for the next 6 to 18 months is developed by the top executives. The plan could be equated to the decision to employ tankers to support an operation. Next, aggregate production planning addresses the demand side of a firm's activities. In the case of tankers, receivers' demands could be considered at this point. Since a statement of desired output is only useful if it is possible, an aggregate capacity plan tests plausibility of planned output against current capacity. To meet the demand for individual products, a master production plan is developed and rough-cut capacity planning ensures that a proposed production schedule does not inadvertently overload any key department, work center, or machine, making the schedule unworkable (Adam, 1992:373-375).

After rough-cut capacity planning, the plans continually get more and more detailed, from material requirements planning to detailed capacity planning, and finally, shop floor control. The planning tools discussed thus far are for detailed planning, and could be correlated to Shop Floor Planning in the realm of Operational Management. Shop Floor Planning coordinates the weekly and daily activities to get a job done. However, there are several steps to operational management to get from a strategic overview of employment planning to get to the day to day air tasking order planning (Krajewski and Ritzman, 1998:575).

The aggregate plan links overall strategy and the detailed operations plans (Krajewski, 1998:574). One of the typical objectives of aggregate planning is the maximum utilization of the plant and equipment. In the case of tankers, the aircraft, aircrew and even base resources may be considered to be equipment. The overall process of aggregate planning is dynamic, as illustrated in Figure 2, and consists of basic steps which can be related to tanker planning. The first step in the planning process is to determine the demand requirements for each period of the planning horizon. (Number of receiver aircraft and the amount of fuel they require.) Planners can estimate these requirements in various ways, such as by using historical data or expert opinion.

The second step is to identify alternatives, relationships, constraints, and costs for the plans. (Alternatives could be refueling at ground bases, not flying the mission, shortening the mission, etc.) Relationships in operations management would involve the equation for the number of workers on the payroll in a given time period and the equation for inventory level in production plans. (Number of aircrew and maintenance capability.) Constraints can represent physical limitations or managerial policies associated with the aggregate plan. (MOG, boom versus drogue.) These constraints must be satisfied before an aggregate plan is considered acceptable (Krajewski and Ritzman, 1998:587-589).
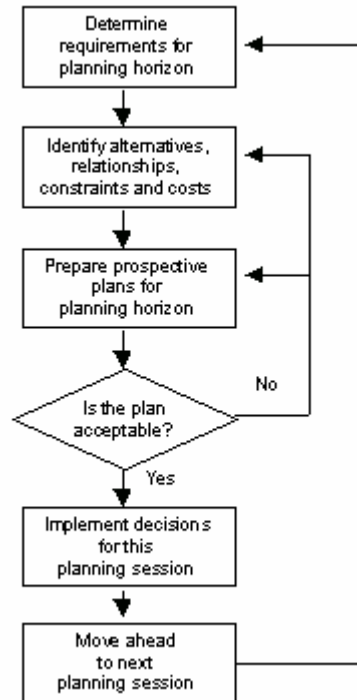
Figure 2. Planning Process for Aggregate Planning (Krajewski and Ritzman, 1998: 588)

The third step of aggregate planning is to prepare the aggregate data. Developing an acceptable plan is an iterative process. Once a plan is acceptable, then it can be implemented. The final step is implementing and updating the aggregate plan, which requires the commitment of top management (Krajewski and Ritzman, 1998:589-590).

In broad terms, this thesis will provide a tool to link strategic planning and basic strategic guidelines for planning tankers, and provide an intermediary step, or link, to detailed tactical tools, such as TET, TAP or CMARPS. This attempt is similar to Brigantic and Merril's linking strategic airlift capacity factors to tactical airlift planning tools.

2.5 Algebra of Airlift

In 2004, Brigantic and Merril described the fundamental algebraic relations that characterize the movement of cargo and passengers via strategic aircraft. Many of today's defense transportation systems use fundamental algebraic relationships that characterize the movement of cargo and passengers. Using relationships and appropriate input planning factors, Brigantic and Merril provide a means of computing a variety of important force closure metrics that assess the transportation feasibility of proposed peacetime operations, war plans, and other operations. The primary measure they dissected were the relations used to determine AMC's capstone metrics for airlift, the metric million ton-miles per day (MTM/D), a measure of unconstrained airlift capacity. (Brigantic and Merril, 2004:1,8)

2.6 Conclusion

The airlift mission is to deliver a certain amount of tonnage, cargo and passengers to a destination. While Brigantic and Merril describe many of the factors which go into planning these missions, the airlift problem is simple when compared to tankers. Airlift involves planning for only one airlift aircraft and its cargo. Tankers, however, must account for at least two aircraft types: the refueler and the receiving aircraft. Additionally, cargo airlift is used in one role only, to deliver their cargo and passengers, whether strategically or operationally. Tankers have a dual role as force enabler and force multiplier.

This chapter presented current tanker deployment and employment scheduling tools. Some of the tools uses and drawbacks were discussed as well. In addition, the

chapter provided an overview of aggregate planning and rough cut capacity planning. Finally, the chapter discussed the relationships in the planning of airlift. The following chapter applies some of these ideas to formulate the relations involved in tanker planning at a rough cut capacity level.

III. Methodology

3.1 Introduction

To obtain the approximate number of required tankers by airframe, planners will divide a tanker mission by a set number to ascertain how many receivers can be refueled. For instance, to determine the number of fighter sorties which can be refueled by a KC-10, the number of tankers is divided by 5.6 (18%); to determine the same for a KC-135, the number is divided by 4 or 5. (CWS 401, 2004:2-3). However, these round estimates do not take into account any variables such as available aircrew, in flight refuelings of the tanker, etc.. This chapter details the creation of basic algebraic formulas to calculate the strategic relationships involved in tanker planning, specifically, tanker employment.

In this chapter, the assumptions involved in rough cut capacity planning view are first discussed and the relationships are developed into formulas. Next, the use of Visual Basic for Applications and Excel are discussed. Finally, the chapter discusses how the tanker employment model will be tested and validated.

3.2 Assumptions

In tackling tanker planning from a strategic overview, many details are not incorporated. Three large assumptions are homogenous receivers, homogenous tankers, and tanker departure from and return to one 'super base'.

The primary concern with the tanker employment model is how much fuel is available by receivers as a whole. Therefore, it is not concerned with details regarding which type of aircraft is receiving the fuel. Thus, the tool treats receiving aircraft as one homogenous receiver group. If a group of F-16 and A-10 need to receive fuel, the

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calculations for required fuel can be individually calculated and then summed, or an average can be estimated.

Another gross assumption in the tanker employment model is that when determining required missions, one type of tanker aircraft will provide the fuel. This assumes no difference between boom and probe refueling or wingtip refueling, as well as other calculations outlined in the next section. Like the 'homogenous receiver,' if multiple tanker types and variously configured tankers are being considered, the calculations for fuel available could be summed for each various tanker, or an average can be estimated.

Finally, for the purpose of calculations, all tankers are assumed to fly from and return to one 'super base.' The super base assumption also includes that all aircraft and aircrew are in one super unit. Distance from the base is a primary factor in the tanker employment model. Therefore, if more than once departure/return base is required to calculate fuel available to receivers, an average of distances could be used. Additionally, sortie generation rates for base constraints include operating hours, fuel capacity, and maximum on ground, which could also be averaged if more than one base was being considered.

In addition to the three primary assumptions, the rough cut capacity view of the tanker employment model necessitates that many details are not incorporated into the calculations. Some of these factors include altitude flown, winds, and effects of gross weight on fuel consumption. While many details are not considered, they do not necessarily need to be for this tool, as rough cut capacity is the link to detailed operational planning which factors in these details.

3.3 Formula Construction

To begin constructing tanker employment equations, the offload required in pounds for each receiver aircraft is determined as follows,

$$\textit{offload required}_{ij} = \max \left[\textit{req fuel}, 0 \right] \text{ [lbs]} \qquad (1)$$

where i is the aircraft type, j is the receiver group, and

$$\textit{req fuel} = (\textit{sortie duration} \times \textit{avg fuel flow}) - \textit{total fuel} + \textit{dest reserve} \text{ [lbs]} \qquad (1a)$$

Sortie duration is the time from takeoff at a base to the next landing at a base, *total fuel* is the amount of fuel on the aircraft initially, and *dest reserve* is the amount of fuel desired in the event of emergencies. Average fuel flow can be found in applicable flight manuals and technical orders for receiver aircraft and are listed in Table 4. Of note, the fuel burn rates in the table are based on average/historical data.

Table 4. Fuel Burn Rates

Aircraft Type	Fuel Burn Rate (lbs/hr)	Aircraft Type	Fuel Burn Rate (lbs/hr)	Aircraft Type	Fuel Burn Rate (lbs/hr)
C-9	6,661	B-707	13,916	F-117	9,197
C-130	5,109	B-747	26,800	F-22A	13,154
C-141	13,768	B-767	10,552	F-15C	10,822
C-17	19,643	DC-8	13,916	F-15E	12,669
C-5	23,132	DC-10	20,616	F-18	5,829
KC-10	17,830	L-1011	17,219	F-16	5,854
KC-135R	10,718	MD-11	17,511	A/OA-10	4,160

Source: AFPAM 10 – 1403, 2003:17

Mission requirements will dictate the minimum amount of fuel required, but having additional fuel increases mission flexibility and can cover contingencies (Navrid, 2004:13).

The actual offload available from tanker aircraft is a function of take-off gross weights, take-off loads, take-off bases, destination bases and post refueling bases, etc. (Hong, 1992:1299). For strategic calculations, the offload available from tanker aircraft is a function of fuel available on the aircraft versus fuel used or fuel delivered. Specifically, the *offload available* can be calculated as

$$\text{offload available}_t = (\text{available fuel - fuel used - destination reserve}) \times \text{offload utilization} \quad (2)$$

where *t* is the type of tanker aircraft,

$$\text{available fuel} = \text{take off fuel} + \text{fuel received in air} \ [\text{lbs}] \quad (2.a)$$

and

$$\text{fuel used} = \left(\left(\frac{\text{dist to} + \text{dist from refuel pt}}{\text{air speed}} + \text{loiter time} \right) \times \text{fuel flow} \right) [\text{lbs}] \quad (2.b)$$

The *offload utilization* factor takes into account scheduling and operational realities driven by characteristics of real world receiver demand. For example, no receivers may actually require the fuel while the tanker is in the air and has fuel available. Also, while listed in the formulas, it is important to note that not all tankers can receive fuel in air. Currently, only the KC-10 and KC-135RT are able to refuel in air. Refueling tankers in the air increases the fuel available for offload, as the tanker does not need to be concerned with limiting fuel due to restrictions for taking off. Planners will add one tanker sortie for each tanker refueled in air (CWS 401, 2004:2-3).

Air speed is often calculated using either true air speed (TAS) or block speed. True air speed is the actual speed of an aircraft through the air mass in which it flies. Under zero wind conditions this is equal to the speed over the ground. Block speed is the true air speed of an aircraft in knots under zero wind conditions adjusted in relation to length of sortie to compensate for takeoff, climb out, letdown, instrument approach, and landing. The use of one over the other will depend upon whether takeoff or landing will be a factor during the time calculated. (See Table 5 for average block speeds for tanker aircraft.) Average block speeds for mobility aircraft are listed in AFPAM 10-1403, and in the applicable flight manuals for other types of receiver aircraft.

Table 5. Aircraft Block Speeds

Type	500 nm	1000 nm	1500 nm	2000 nm	2500 nm	3000 nm	3500 nm	4000 nm	4500 nm	5000 nm	5500 nm	6000 nm
KC-10	354	410	428	435	436	437	440	443	446	447	449	450
KC-135	348	401	419	425	426	426	430	433	435	437	438	439

Source: AFPAM 10 – 1403, 2003:13

Even with detailed planning methods, planners will often use an estimate of deliverable fuel, that factors in distance flown, as represented in Table 6.

Table 6. Tanker Offload Capabilities

Aircraft	Takeoff Gross Weight (lbs)	Takeoff Fuel Load (lbs)	Max Offload Available (lbs)			
			Mission Radius			
			500nm	1000nm	1500nm	2500nm
KC-135E	300,500	160,000	101,200	78,600	55,800	10,500
KC-135R/T	322,500	180,000	122,200	99,400	76,400	30,700
KC-10	587,000	327,000	233,500	195,200	156,000	78,700

Source: AFPAM 10 – 1403, 2003:17

The numbers in Table 6 are derived from historic data, estimating a 1 hour orbit

and therefore, represent maximum fuel only (AFPAM 10-1403, 2003:17). The takeoff

weight, and therefore takeoff fuel and offload available fuel, can be affected by

conditions of origin base, runway length, and weather conditions. The primary method of

decreasing weight to overcome these conditions is to decrease fuel on board (Capehart,

2000:11).

To deliver the maximum amount of fuel to the fight, tankers leverage three

capabilities. First, the more fuel a tanker departs home station with, the more it will have

when it reaches the planned aerial-refueling. (See Figure 3.) Second, the less fuel a

tanker burns en route to the flight, the more it can deliver. Finally, the faster a tanker can

offload fuel to a receiver, the less time the additional receivers spend burning fuel in the

refueling track (Navrid, 2004:13).
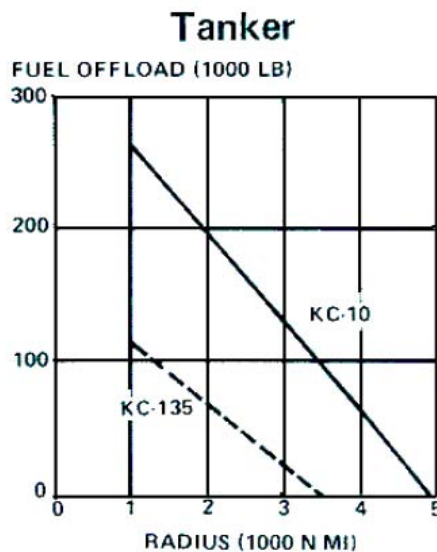
Figure 3. Fuel Weight to Fuel Burned Relationship

To determine the number of tankers required to deliver the amount of fuel required by receivers, Equation 1 is summed for all receivers, and combined with Equation 2, as

$$Number\ of\ tanker\ missions = \frac{\sum_{j=1}^{m}\sum_{i=1}^{n} off\ load\ required_{ij}}{off\ load\ available_{t}} \qquad (3)$$

where the double summation of the *offload required* is all quantities of aircraft, *i*, for all receiver groups, *j*, and the average *offload available* is the maximum deliverable fuel for each type, *t*, of tanker aircraft to be used. If a mix of tanker aircraft are used, a weighted average can be used based on the appropriate number of each type of tanker aircraft (AFPAM 10 – 1403, 2003:9).

In order to determine the amount of fuel capable of being delivered on a daily basis, a sortie generation capability will need to be calculated. The three capabilities, aircraft, aircrew, and base, use a time component from tanker missions in their calculations. The time required to determine the number of missions tanker aircraft can fly in one day are the *round trip flying time* (RTFT), *total ground time* (TGT) and *cycle time*.

The *round trip flying time* (RTFT) for the tanker aircraft for a given refueling employment cycle is first calculated. RTFT is a function of distance from base, time spent awaiting receivers and servicing them, and time to return to base. Therefore, RTFT is computed as

$$RTFT = \frac{leg\ dist\ to\ refuel}{block\ speed\ to\ refuel} + loiter\ at\ refuel\ pt\ +$$

$$\sum_{k=1}^{p} \left(\frac{leg\ dist\ to\ refuel_k}{TAS\ to\ refuel_k} + loiter\ at\ refuel\ pt_k \right) + \qquad (4)$$

$$\frac{leg\ dist\ return}{block\ speed\ return}\ \ [\text{hrs}]$$

where k is the number of refueling points, not including the first point, *dist* represents

distance, *distance/speed* is the time spent traveling and the *loiter at refuel* is the time

spent at the refueling point. The summation over k indicates the possibility of multiple

refueling points. The *loiter at refuel* could be time spent in orbit or on track awaiting

receiver aircraft and the time spent refueling the receiver aircraft, or time spent refueling

receiver aircraft at a designated place and time.

The time spent refueling will be a factor of the type of tanker aircraft, the type of

receiver aircraft, and the type of type of refueling equipment on the tanker aircraft. For

example, when refueling using a boom, tankers to transfer fuel at a maximum of 1,100

gallons per minute. That capability is reduced when using hose and drogue systems

installed on the wings of some KC-10 and KC-135s. A hose is only able to offload fuel

at a rate slightly half as fast as a boom. Despite having two hoses (one on each wingtip),

two receiver aircraft are still only able to transfer fuel at about the same rate as one boom

(Navrid, 2004:14.). Another example is the difference between receiver aircraft. A C-5

has the fastest offload, as 6 pumps can be used for refueling. An F-16, on the other hand,

can only take 2 pumps, and is therefore, slower.

It is important to note the intricate relations involving fuel consumption rates.

Travel distance, time and air speed rate are key factors in tankers refueling receiver

aircraft (Capehart, 2000:7). Aircraft fuel consumption is inversely proportional to

altitude flown, and proportional to air speed and gross weight. These factors combined create a dichotomy. Increasing the speed which an aircraft travels allows an aircraft to fly more quickly, and therefore, fly more missions, however increasing the speed also increases the fuel consumption rate. Therefore, when an aircraft flies faster, more fuel is consumed by the tanker on its way to meet the receiver, and thus, the tanker will have less fuel to deliver. A final factor effecting fuel consumption is wind conditions, since ground speed, the amount of time to traverse a distance, is affected by wind conditions, which can lengthen a flight and therefore, increase fuel consumption (Capehart, 2000:11).

The next time component considered is *total ground time* (TGT), the time required on ground to prepare an aircraft for another mission. Various factors in servicing the aircraft, including type and availability of refueling assets, personnel and equipment, will effect ground time. Additionally, if a reconfiguration between missions is required, several hours can be added to the ground time. Thus, planners often use different times other than the standard turn time provided in AFPAM 10-1403 for KC-135 and KC-10.

$$TGT = aircraft\ servicing\ [\text{hrs}] + reconfiguration\ [\text{hrs}] \tag{5}$$

Combining Equation 4 and Equation 5, the total *cycle time* for one tanker aircraft can be computed as:

$$cycle\ time = RTFT + TGT\ [\text{hrs}] \tag{6}$$

which is the total time it takes to complete one mission and before the aircraft can depart on the next mission.

Once the time components are calculated, the sortie generation capability of the unit is determined in order to compute the number of missions that tanker aircraft can complete in one day. The sortie generation capability rates considered are based on tanker capabilities, aircrew capabilities, and base capabilities. Computation of these capabilities will allow a calculation of the deliverable fuel in terms of volume per day.

To begin sortie generation capability calculations, the *tanker generation capability* is an indication of how many missions a tanker unit can complete in a day. The maximum number of times that one aircraft can be generated in one day is the hours in a day divided by the cycle time from Equation 6. The *tanker generation capability* rate for a unit is a function of the number of tanker aircraft available and *cycle time*:

$$\# \ avail \ tankers = assigned \ tankers - NMC \ tankers - other \ tankers \qquad (7)$$

Assigned tankers, for this tanker employment model, are the number of aircraft bedded down at a location. *NMC* tankers are those unable to fly, either due to being broken, undergoing preventative maintenance, etc. Finally, *other tankers* cover those aircraft required for ground alert and spare aircraft (CWS 401, 2004:4-6).

Based on historical factors, planners will often use a percentage for maintenance reliability times the number of unit aircraft to estimate the number of available tankers (CWS 203, 2004:4-6). Reliability rates vary not only by aircraft, but also by specific model capability as well. For example, the KC-135E reliability differs from the KC-135RT. Generally however, planners will use 80% reliability for KC-135 and 85% reliability for KC-10 (CWS 203, 2004:4-6).

Thus, using Equations 6 and 7, a *tanker generation capability* is computed as,

$$tanker\ generation\ capability = \frac{\#\ avail\ tanker\ \times\ 24\ \text{hrs/day}}{cycle\ time} \times\ aircraft\ utilization \quad (8)$$

This *tanker generation capability* is a measure of how many missions can be flown in one day, based solely on the aircraft availability. *Aircraft utilization*, like *offload utilization,* takes into account scheduling and operational realities. An aircraft may be available to fly; however, there is no guarantee that a mission will need to be flown at that time.

Of note, shorter regeneration time increases the *tanker generation capability* rate, referred to as UTE. However, the increased utilization will increase the amount of periodic maintenance required, thus lessening the total number of available aircraft (CWS 203, 2004:5-9). Additionally, if aircraft are used for prolonged, higher rates of activity, there will be an increased need for more aircraft and support personnel to accomplish the same tasks (AFDD 2-6, 1999:55).

Historically, a greater limiting factor than tanker availability for sortie generation is aircrew availability (AFDD 2-6, 1999:62). The *aircrew sortie generation capability* rate is similar to the tanker sortie generation capability rate, in that it is a measure of how personnel availability affects the number of missions tanker aircraft can complete in one day. The rate is a function of crew availability and crew rest cycle. Personnel availability can be computed as

$$\#\ avail\ crew = assigned\ crews\ \text{-}\ non\ available\ crews \quad (9)$$

Assigned crews are the number of crews assigned to the tanker unit and *non available crews* incorporate crews who are unavailable either to not being mission

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qualified, in Duty Not Involving/Including Flying status, or on leave or on temporary duty status (MacDonald, 2005:27). Crew qualifications can include the type of equipment the aircraft is configured for, as well as the type of mission, such as refueling special forces.

The crew rest cycle is determined by Air Force regulations involving the maximum time an operator can be on duty in any 24 hour period, as well as the maximum amount of time they are allowed to fly on consecutive days (AFI 11-202v3, 2005:69). The basic limits are as follows:

- Max Flight Duty Period for basic crew, 16 hours (18 with command approval)
- Max Crew Duty Time for basic crew, 20 hours
- Max Flying Time
  - 56 hours per 7 consecutive days
  - 125 hours per 30 consecutive days
  - 330 hours per 90 consecutive days

One method of extending available duty times is to use augmented crews, where a basic crew is supplemented by additional aircrew members to permit in-flight rest periods. If an augmented crew is used on a mission, the flight and crew duty day are extended as follows:

- Max Flight Duty Period for augmented crew, 24 hours
- Max Crew Duty Time for augmented crew, 20 hours

The cumulated maximum flying hours, however, do not change.

Thus, the *aircrew generation capability* is computed using Equations 4 and 9, and the minimum crew rest cycle, as follows:

$$aircrew\ generation\ capability = \frac{\#\ crew\ avail \times min\ crew\ time}{RTFT} \times aircrew\ utilization \quad (10)$$

where

$$min\ crew\ time = min\left[\frac{flight\ duty\ period}{cycle\ time}, \frac{crew\ duty\ time}{24\ hours}, \frac{time\ frame}{RTFT}\right][\text{hrs}] \quad (10a)$$

Aircrew utilization is similar to the other utilization factors thus far, and added to model characteristics of the real world receiver demand. As before, even if a crew is available to fly and has the requisite time window to fly, there may be no mission required at that given time.

An example using Equation 10 and 10a of the *aircrew generation capability* rate using the restrictions for *time frame/RTFT* as the *min crew time* and the minimum crew time for 30 days (125 hours per 30 consecutive days) would be calculated as

$$aircrew\ availability\ interval = \frac{\dfrac{\#\ crew\ avail \times 125\ \text{hrs}/\text{mon}}{30\ \text{days}}}{RTFT} \times aircrew\ utilization$$

Although not directly used for calculations of aircraft required, an important consideration for planners is the Aircrew/Aircraft Ratio, calculated as (CWS 203, 2004:19)

$$aircrew/aircraft\ ratio = \frac{aircrews\ required}{aircraft\ required}$$

(11)

Tanker aircrew units are currently manned at ratios between 1.17 to 1.36, but may only deploy with 1.0 – 1.5 crew ratio depending on the nature of the operation (AFDD 2-

6, 1999:62). A recent Tanker Requirement Study for Fiscal Year 2005 (TRS-05) recommends a 1.75 crew ratio for KC-135 versus the 1.36 for Active Duty, and 1.27 for Air Reserve Component standards in 2004 (CWS 203, 2004:20).

The last sortie generation capability rate is *base generation capabilities*, which factors into how many aircraft can be serviced either at once or per day, and therefore, how many aircraft can fly in one day as determined by base limitations. The *base generation capability* is calculated as

$$base\ generation\ capability = \frac{MOG \times operating\ hours}{TGT} \times queuing\ factor \qquad (12)$$

MOG is the maximum aircraft on ground per station. There are various types of *MOG*, including working, parking, or fuel *MOG*. There are a variety of factors affecting the number of aircraft which can be serviced at once, such as equipment, personnel, ramp space, net weight restrictions, other facility limitations, and command and control constraints. A primary factor affecting the number of aircraft which can be serviced in one day is the amount of fuel available to be loaded onto the tanker each day. The *operating hours* indicates the amount of time the airfield is open, and will also vary from base to base, often for regional political reasons or the amount of daily operations required. Finally, a *queuing factor* is once again added to schedule real world considerations. Bases ready to accommodate servicing tankers may not have planes to service.

When planning for deployments, often standard numbers are provided. The estimate used for KC-10 is 2.0 crew ratio and 5.0 hr turn times, and for KC-135, 1.5 crew ratio and 4.0 turn time (CWS 401, 2004:4–6). Additionally, for both types of aircraft, a

1.5 is used as the tanker availability interval, which is referred to as the UTE rate. (CWS 203, 2004:1).

With the three sortie generation capability rates defined, an overall sortie generation capability rate, called *flow capability*, can be calculated, using the minimum of each of the previous capability rates in Equations 8, 10, and 12, as

$$flow\ capability = \min\left[tanker\ gen\ cap, crew\ gen\ cap, base\ gen\ cap\right] \quad (13)$$

where *tanker gen* is *tanker generation capability*, *crew gen cap* is *aircrew generation capability* and *base gen cap* is *base generation capability*.

This minimum rate will represent how many tankers missions can be flown in one day from the base. Once calculated, the *flow capability* can be used to determine the volume available per day, which is calculated as

$$max\ volume = flow\ capability \times avg\ offload\ available\ \left[\text{lbs}\right] \quad (14)$$

where *average offload* is an average capability of the tanker aircraft. The *average offload* can be determined using various methods. One method would be to take the historical average based upon Equation 2. Another method would be to determine the radius of air covered during employments and use an average from Table 6.

Another use for the *flow capability* is to determine fuel delivery feasibility. By using Equation 3 and Equation 13 the feasibility of delivering a given volume of fuel can be examined. Thus, the condition for testing if the planned missions for one day can be flown is as follows:

$$number\ of\ tanker\ missions \overset{?}{\leq} flow\ capability \quad (15)$$

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If the inequality of Equation 14 is true, then there will be excess capacity, and planners have the option of either decreasing the flow interval or increasing the number of receivers requiring fuel. If able to decrease the *sortie generation rate*, planners can either decrease the number of available aircraft or aircrew, which in turn means fewer resources are required. (Changes to base generation capability rate would likely not result in tangible benefits, but could be considered as well.) Another possibility is that planners can add additional receiver sorties or lengthen the receiver sorties already planned, increasing the number of receivers requiring fuel to use the excess capacity. If the Equation 14 is not true, then

$$\text{number of tanker missions} > \textit{flow capability}$$

and there is inadequate fuel delivery capability. Again, planners have two options. First, they can decrease the number of tanker missions required by either decreasing the number of sorties flown, or the length of the sorties scheduled. The second option is to increase the *flow capability*. By examining Equation 13, planners can determine whether more aircraft or more aircrews are required, or if the base resources can be adjusted to accommodate more aircraft.

When determining the number of missions required, one consideration must be the total offload versus "booms in the air," that is, the number of aircraft used, and whether operations will emphasize total offload capability for only a few receivers or a rapid refueling capability for multiple receivers. If total offload capability is more important (such as for heavy receivers), fewer numbers of tankers with larger fuel loads

should be planned. If the mission emphasis is on frequent, rapid refueling to multiple

receivers (such as multiple fighter strike packages), it is more effective to use a larger

numbers of tankers maximizing the number of available 'booms in the air' (AFDD 2-6,

1999:55).

In addition to considering volume per day, fuel efficiency can be calculated by

using offload available calculations from Equation 2, and actual fuel offloaded.

Efficiency is thus calculated as

$$efficiency = \frac{fuel\ offload\ available\ -\ fuel\ offloaded}{fuel\ offload\ available} \times 100 \qquad (16)$$

The basic relationships for daily fuel availability defined by these equations can

be modeled into a simple, user friendly, tanker employment model. Excel was selected

as the platform for the tanker employment model, in order to use Visual Basic with

Applications and create input based upon userforms.

3.4 Visual Basic for Applications

Visual Basic with Applications (VBA) is Microsoft's common scripting language

used in a variety of Microsoft Office applications, as well other applications from other

vendors. One feature of VBA is the ability to create userforms – custom dialog boxes

which allow for easy data entry.

Three reasons were instrumental in selecting to use VBA in Excel to develop the

tanker employment model. First, AMC desired an easy to use tool (as the current tool,

CMARPS is widely known for being difficult to learn and use). Secondly, Excel is one

of the standard software applications in many offices, so many Air Force members have

some familiarity with the Excel platform. Last, many of the tanker tools recently developed were also Excel based projects coded in VBA.

3.5 Validation and Testing

For completeness, it would be ideal to compare the results obtained with this tool with those obtained by a commercial or AMC application. However, no such model or program exists to draw a comparison. Additionally, the most beneficial use of a rough cut capacity model is its ability to aid in planning for future production – in this case, future employments. For this reason the tanker employment model will be tested by inputting data from an air tasking order and adjusting the utilization parameters to match the expected outcome from the model to the actual data. Once a set of parameters have been determined for the utilization parameters, the parameters will be used on data from more air tasking orders to measure the accuracy of the forecast. These results are also analyzed by a knowledgeable source for their reasonableness and usefulness.

Additionally, the other value to the tanker employment model is the ability to adjust not only the utilization parameters, but the resources as well, to determine the effect on available fuel and required missions. Thus, the tanker employment model allows adjustments to the number of aircraft and aircrew being employed and base capabilities, so that sensitivity analysis can be performed. The next chapter reports the results of model testing.

IV. Results and Analysis

4.1 Introduction

An Excel-based tool was developed to assist tanker planners in preparing for employments. The tanker employment model calculates fuel required, fuel available, and sortie generation capability in order to determine the number of tanker missions required to fuel a receiver group. To test the ability of the tanker employment model to be used in this capacity, the validity of the tanker employment model was first examined. Next, data from real world scenario was used to determine the accuracy of using this tool for forecasting. Finally, and example of sensitivity analysis is included to demonstrate the tool's use in rough cut capacity analysis.

4.2 Model Validation and Verification

The first tests performed on the tanker employment model were for validation and verification. Verification involves testing an apparently correct model specifically to find and fix modeling errors. It refers to the processes and techniques that the model developer uses to assure that his or her model is correct and matches any agreed-upon specifications and assumptions (Carson, 2002:52). Verification began on the tanker employment model during the research phase. As the tanker employment model was being developed until the final testing phase, the tanker employment model was presented to subject matter experts from AMC and other experienced tanker planners for continuous feedback into construction of the relationships between variables and to identify and remove any coding errors. This constant feedback shaped the algebraic relationships that were used to create the Excel tool. (Complete coding for the Excel tool

is located in Appendix A.) Once the tool was finalized, numerical work in the form of comparing results of simple calculations with CMARPS was performed.

Since CMARPS is a complex program and requires extensive training to be able to operate, analysts from the AMC/A-59 office performed the calculations necessary to compare CMARPS output with the output from the tanker employment model. Using data from a previously generated scenario (see Table 7), the analysts generated three runs in CMARPS by adjusting the distance to a refueling track. The distances selected were chosen to approximate 250, 500, and 1,000 nm initial distance to the track. Of note, CMARPS adjusts the air speed and fuel burn rate throughout the tanker mission. The values listed in Table 7 are an average only, and were used to compare with the tanker employment model, which does not allow for these values to change during the mission.

Table 7. Data from CMARPS, Generated Scenario

Take Off Fuel (lbs)	187000	187000	187000
Distance to Track (nm)	262	581	1059
Refuel in Air (lbs)	0	0	0
Time on Track (min)	135	135	135
Return Distance (nm)	271	568	1038
Air Speed (nm/hr)	430	430	430
Avg Fuel Burn (lbs/hr)	12457	12457	12457
Offloaded Fuel (lbs)	50000	50000	50000
Reserve Fuel (lbs)	24000	24000	24000

Results from the CMARPS test runs are listed in Table 8. The results from CMARPS are compared with the results from putting these values into the tanker employment model. The tanker employment model is designed to provide a rough analysis of tanker employment, and therefore does not factor in all variables. It is designed therefore, to provide an optimistic amount of fuel available for offload. Thus, it

is not surprising to see output from the tanker employment model yield more fuel then

CMARPS calculates in the first two distances, 262 and 581 nm.

Table 8. Results of CMARPS to Model Comparison of Generated Scenario

Distance to Track (nm)	262	581	1059
CMARPS Offload avail (lbs)	117400	104300	85500
Model Offload avail (lbs)	122645	108044	77336
Actual Difference (lbs)	5245	3744	-8164
Percent Difference	5%	4%	-10%

The estimated available fuel for the third run, where the distance to refuel track

was 1,059 nm, was lower for the tanker employment model. The difference could likely

be due to the averaged air speed and fuel burn rate. In particular, as the tanker's weight

decreases due to less fuel on board, the fuel burn rate will decrease. A decrease in fuel

burn rate will increase the amount of fuel available. Overall, all three runs were within

10,000 pounds of fuel, which according to AMC/A-59, provided acceptable results,

thereby verifying the tanker employment model.

The next step was to test the validity of the tanker employment model. Validation

occurs when the model developer and people knowledgeable of the real system or work

review and evaluate how a model works, and ensure that the model represents the real

system to a sufficient level of accuracy (Carson, 2002:52). To validate this tanker

employment model, the help of the AMC/A-59 office was again employed. An actual air

tasking order from a deployed base with KC-135s was randomly selected to test. Using

this air tasking order, the nine sorties flown that day were inputted into CMARPS. (Data

from the sorties is in Table 9.) One sortie was an exact duplicate of another, thus, only

the data on eight sorties are displayed. Again, like the verification runs on CMARPS, the fuel burn rate and air speed rates listed in the Table 7 are averages from the flown sorties. Additionally, to run the same information in the tanker employment model, the fuel remaining at the end of the sortie was inputted into the tanker employment model as the reserve fuel. Finally, most of the sorties flown on the air tasking order traveled to more than one refueling track. To keep data consistent for entry into the tanker employment model, all distances flown while traveling to the tracks were summed to calculate the total distance to the refueling track. Similarly, all times at the track were summed to calculate the total time on track.

It is worthy of noting that the time difference between CMARPS and the tanker employment model for entering the data and calculating the results was minimal. However, the training to learn how to enter data into CMARPS is extensive and time consuming. Additionally, when comparing the data for the eight sorties from CMARPS, the tanker employment model found anomalies twice. In both cases, the data had been entered erroneously into CMARPS and the data had to be examined and reentered.

Once the air tasking order sorties were inputted into CMARPS and the results calculated, the information from Table 9 was entered into the tanker employment model. The results from CMARPS and tanker employment model runs are in Table 10. Although the air tasking order was randomly selected, it afforded the opportunity to input sorties with a variety of profiles. Three missions (5, 6, and 8) had to travel over 1,000 miles to the refueling track, all but two (1 and 2) had less than 1 hour on the refueling track, and all but the 7th sortie had to fly to multiple tracks, with one of those sorties (1) traveling to four tracks.

Table 9. Data from Multiple Sorties on One Day

Sortie Number	1	2	3	4	5	6	7	8
Initial Onload (lbs)	199630	199630	199630	199630	199630	199630	199630	199630
Refuel in Air	0	0	0	0	0	0	0	0
Dist to refuel (nm)	858	713	936	833	1028	1149	625	1195
Time on Track (min)	117	258	66	61	28	60	25	64
Return Distance (nm)	304	302	418	802	542	306	417	416
Air Speed (nm/hr)	420	420	420	420	420	420	420	420
Avg Fuel Burn (lbs/hr)	10700	10700	10700	10700	10700	10700	10700	10700
Return fuel (lbs)	39600	60300	80300	49200	53700	58200	69600	93000
Sortie Length (hr:min)	5:00	7:09	4:44	5:34	4:37	4:54	3:19	5:18
Number of Tracks	4	2	3	3	2	3	1	3

Table 10. Results from CMARPS to Model Comparison, Multiple Sorties

Sortie Number	1	2	3	4	5	6	7	8
CMARPS Fuel Offloaded (lbs)	102000	57000	62000	86000	90000	82000	88000	42000
Model Offload avail (lbs)	113059	59368	66684	89450	99335	85788	99095	46362
Model to CMARPS actual diff	11059	2368	4684	3450	9335	3788	11095	4362
Model to CMARPS % diff	10.8%	4.2%	7.6%	4.0%	10.4%	4.6%	12.6%	10.4

All but two of these sorties (1 and 7) were within AMC/A-59's acceptable outcome of the two models being within 10,000 pounds. One sortie which did not meet the 10,000 pound acceptable difference was the seventh sortie, which only had one refueling track, which lasted only 25 minutes. With a relatively short distance to the refuel track, only 625 nm, the entire sortie lasted only 3 hours and 19 minutes. The fuel available for offload, as calculated by the tanker employment model, was 11,095 pounds greater than CMARPS. One factor which likely accounted for a greater amount from the tanker employment model was the air speed inputted. This air speed was the average of true air speeds. With the shorter sortie time, a better approximation for air speed would have been the block air speed, which accounts for ground times, thereby decreasing the average air speed. While the other sorties are also affected by ground times, the increased sortie times help to average out the effect on the block air speed versus true air speed used in the calculations.

The other sortie which did not meet the 10,000 lb standard was the first run, which had a difference of 11,059 pounds. On this run, the tanker aircraft refueled at four different tracks, offloading a total of 102,000 pounds. (Table 11 lists information regarding distances traveled to the refueling point, time spent on track, and amount of fuel offloaded at each track, for each of the sorties.) This sortie was the only sortie to refuel four tracks, and the only to offload over 100,000 pounds. The fuel available for offload, as calculated by the tanker employment model, was 11,059 greater than CMARPS. A factor which may have contributed to the greater amount from the tanker employment model was the maneuvers during the refuel.

The other six missions, seven including the duplicated mission, produced results
from the tanker employment model that were within 10,000 pounds of CMARPS
calculations. As with the verification, numbers produced by the tanker employment
model were optimistic, but provide the planner with a rough cut analysis of fuel capacity
for the tankers to offload. Planners need to adjust for various factors, as seen in the
verification phase and the accounting of fuel burn rate at long distances, as well as in the
validation phase and the judgment to use Block Speed versus true air speed for shorter
distances. But overall, the verification and validation phases indicate the tanker
employment model is able to provide an optimistic amount of fuel available for offload.

Table 11. CMARPS Data on Refuel Points

Sortie Number	1	2	3	4	5	6	7	8
Number of Tracks	4	2	3	3	2	3	1	3
Dist to Refuel (nm)								
refuel pt 1	625	623	624	467	890	789	625	626
refuel pt 2	97	90	164	213	138	134		279
refuel pt 3	76		148	153		226		290
refuel pt 4	60							
Time on track (min)								
refuel pt 1	23	95	26.1	32	14	15	25	25
refuel pt 2	36	163	15	16	14	24.1		14
refuel pt 3	25		25	13.1		21		25
refuel pt 4	33							
Fuel Offloaded (1,000 lbs)								
refuel pt 1	40	15	42	36	24	14	88	14
refuel pt 2	14	42	0	14	66	36		14
refuel pt 3	36		20	36		32		14
refuel pt 4	12							

4.3 Air Tasking Order Comparison

Once the overall validity was established, the tanker employment model was tested using data from a situational report. (Situational reports summarize the actually mission flown versus the planned missions on the air tasking order.) The data from one day's flying was loaded into the tanker employment model, and the output was compared to the flying data. The utilization factors were then adjusted to attempt to match the fuel offloaded as calculated by the tanker employment model, to that as recorded on the situation report. Finally, the new parameters for the utilization factors were used to compare the remaining days from the monthly situational reports to determine if the parameters were accurately calculated, in essence, testing to see if the model could be used to forecast the fuel used on the other days.

The data from actual air tasking orders and situational reports are classified; however, the unclassified data is summarized in Table 12.

Table 12. Data from One Day in Air Tasking Order

Aircraft Assigned	15
Crews Assigned	23
(NMC/PMC) Aircraft	3
Ground Alert Aircraft	1
Actual Sorties	13
Base Fuel Capacity	4900000 gal
Sortie Duration	79 hrs
Total Actual Offload	1042900 lbs

Since real world data collected does not conform exactly to the tanker employment model's data requirements, several assumptions were made:

First, the model is only capable of determining refueling requirements from a single receiver group. Furthermore, while the type of tanker aircraft is known, distances to and from the air refueling point were not recorded. Thus, to determine the average fuel offload, the daily fuel offloaded (from the air tasking order), was divided by the number of missions flown for the day.

Similarly, sortie duration for each individual mission is unknown. Therefore, the average sortie duration was calculated using the total sortie duration for the day divided by the number of missions flown for the day.

Distance to refueling track was taken as a weighted average. The two operations supported by this air tasking order had tracks varying in distances. The first operation's tracks were 450 – 600 nautical miles away. The second operation's tracks were 1,100 nautical miles away. Thus, the average of the first operation's distance (525 nm) was applied to all tankers supporting that mission, and weighted against the tankers supporting the second operation at 1,000 nm.

Next, to determine the number of aircraft available, the number of aircraft which were non mission capable, partial mission capable, and on alert were subtracted from the number assigned. This calculation assumes that the partial mission capable aircraft could not perform the mission, although this is not always the case.

Since no data is provided on the availability of aircrew, it was assumed that all assigned aircrew were available. Furthermore, since the deployments to the location are for more than 90 days, the 90 day flying hour restriction was used for the time frame. (Per regulations, aircrew are not allowed to fly more than 330 hours in a 90 day period.)

For the air tasking order, ground time was not usually a factor, since very few aircraft were prepared for a second mission on the same day. However, for the tanker employment model, the standard 3.25 hours was used as a ground time with the assumption no cargo was loaded or offloaded (AFPAM 10-1403, 2003: 14).

The final assumption was regarding base generation capability. Since the tanker units were flying from and returning to the base they were assigned to, there was no limit placed on MOG. Thus, it was assumed the maintenance personnel would be available from the tanker's unit to prepare the aircraft, all refuel could be accomplished via fuel trucks, ground refueling stations, etc.

Using the data from Table 12, the assumptions previously listed, and utilization factors set to 1, the tanker employment model calculated 1,368,406 pounds of fuel available per day. Per the situational report, 1,042,000 pounds were actually delivered, a difference of 31 percent. With the initial calculations complete, the utilization factors were next adjusted in the tanker employment model to obtain the 1,042,000 fuel offload.

A simple analysis on the utilization factors was performed by adjusting the four utilization factors: fuel offload, and aircraft, aircrew and base. The utilization factors range between zero and one and are used to reflect queuing effects, thus allowing the tool to be "calibrated" to estimate aggregate tanker demand. For example, aircraft utilization adjusts for the fact that just because an aircraft is generated does not mean there is a mission for it to fly. Offload utilization is used to adjust for a tanker having offload fuel available, but with no receivers that may need the fuel at the time. Therefore, these factors take into account scheduling and operational realities driven by the characteristics of real world receiver demand.

By adjusting each utilization factor, real world effects can be factored into the tanker employment model. For example, utilization factors of one would likely indicate all tanker and receiver missions fly at the same times. On the other hand, a low utilization near zero would indicate that missions for both tankers and receivers mission timing do not align, or do not align to fit aircraft, aircrew, and base support available to support the missions.

Using these results from the air tasking order, each of the four utilization factors (fuel offload, aircraft, aircrew and base) were adjusted to 1.0, 0.75, 0.50, and 0.25, to ascertain their effects on the maximum available fuel. (Zero was not tested, since the tanker employment model relies on the minimum capability. Zero utilization would mean no capability, and therefore, no missions to fly nor fuel to offload.) The complete listing of offload available for each of the combinations can be found in Appendix B. Figures 4, 5, 6 and 7 depict the results of the changing utilization factors, specifically for an Offload Utilization of 1.0, 0.75, 0.50 and 0.25, respectively. In Figures 4, 5, 6 and 7, the fuel offload utilization is held constant, and the aircraft utilization is plotted against the changes to aircrew and base utilizations.
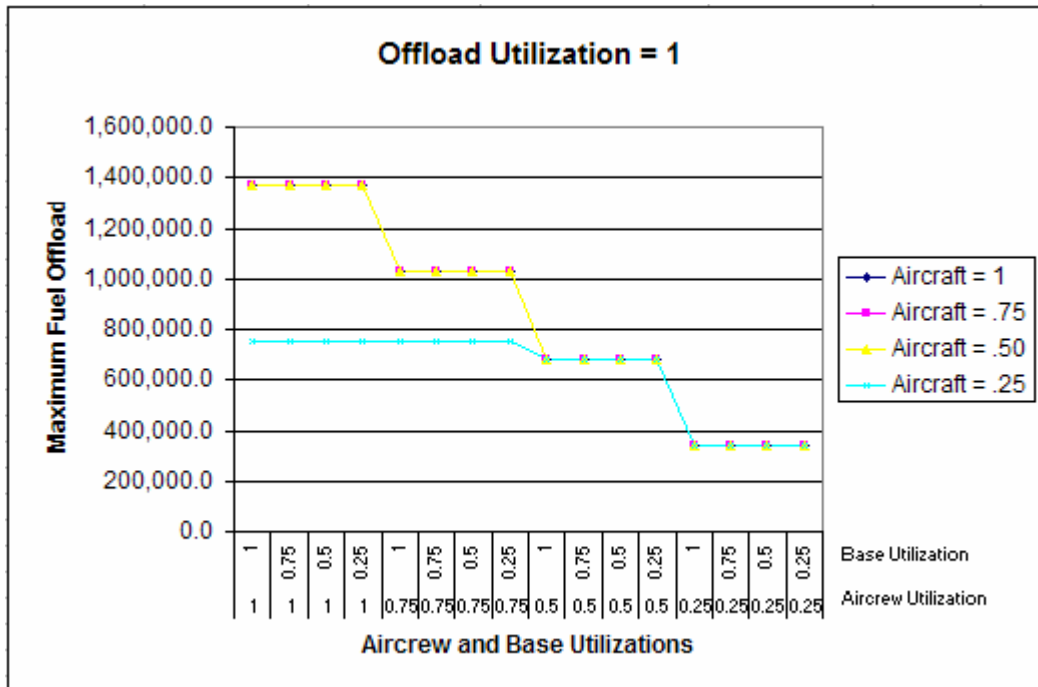
Figure 4. Fuel Availability, Offload Utilization = 1.0

Of interest, not until aircraft utilization factor is at 0.25 does aircraft utilization factor affect the amount of fuel available. Also, changes to base utilization factor never affects the offload capability in this example. Thus, if tankers were the only mission flown from the base, the base's capacity could be reduced. Additionally, as shown in Figures 6 and 7, when the offload utilization is below 0.5, the maximum fuel available is far less then the 1,042,000 pounds required by the days tasking order. Therefore, the discussion will focus on Figures 4 and 5.

Figure 5. Fuel Availability, Offload Utilization = 0.75
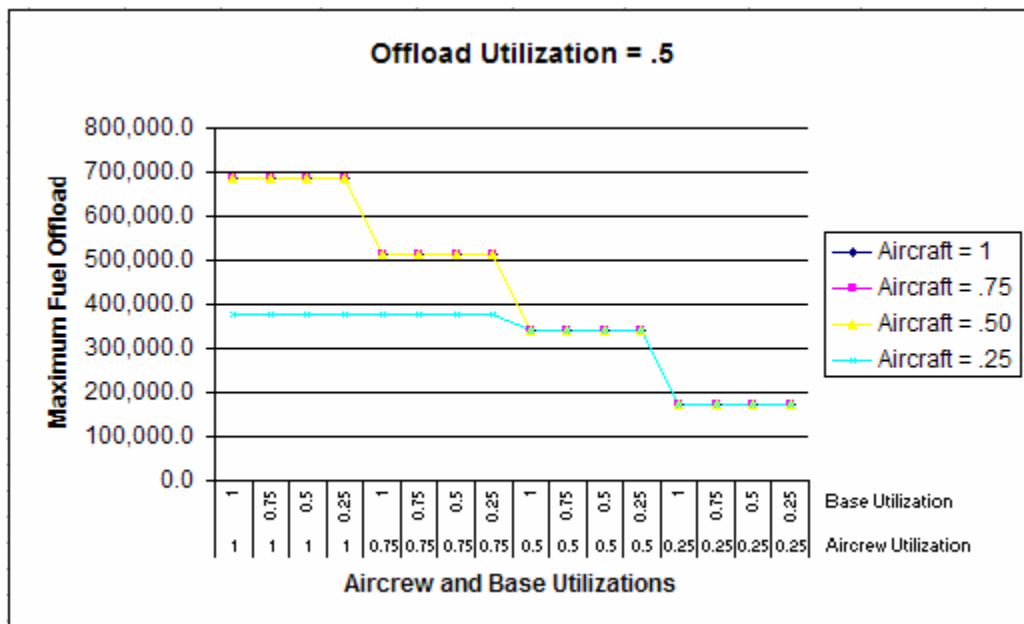
Figure 6. Fuel Availability, Offload Utilization = 0.5
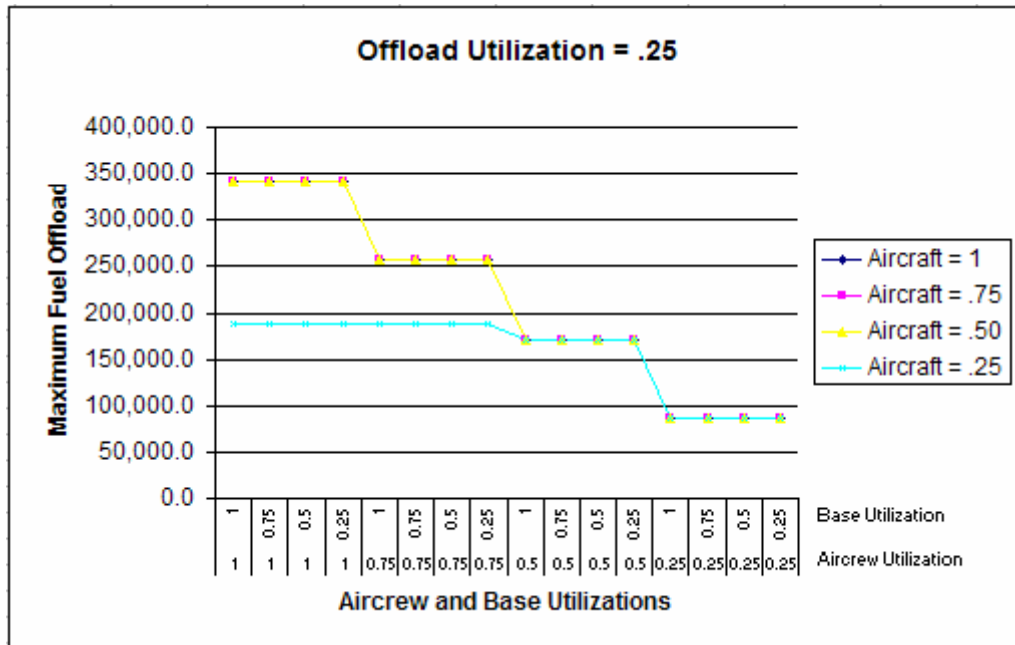
Figure 7. Fuel Availability, Offload Utilization = 0.25

By observing Figures 4 and 5, it can be seen that when the Offload Utilization is between 0.75 and 1.0, the amount of fuel available is near the required amount. Thus, using a similar method of adjusting utilization factors again, the factors were adjusted to reach a more precise amount. This time, each of the utilization factors were adjusted to 1.0, 0.95, 0.90 and 0.85 and the results computed. (Complete results can be found in Appendix C.) The results are graphed for offload utilization equal to 1.0, 0.95, 0.90 and 0.85 in Figures 8, 9, 10 and 11, respectively. Similar to the first set of utilization calculations, changes to the aircraft and base utilization at these levels do not affect the amount of fuel available for offload. With these combinations, the results for offload utilization equal to 1.0 and 0.95 are too high, thus the focus will be on Figures 10 and 11. In addition, the figures indicate there are several utilization factor combinations which give answers near the actual 1,043,900 pounds of fuel per day.
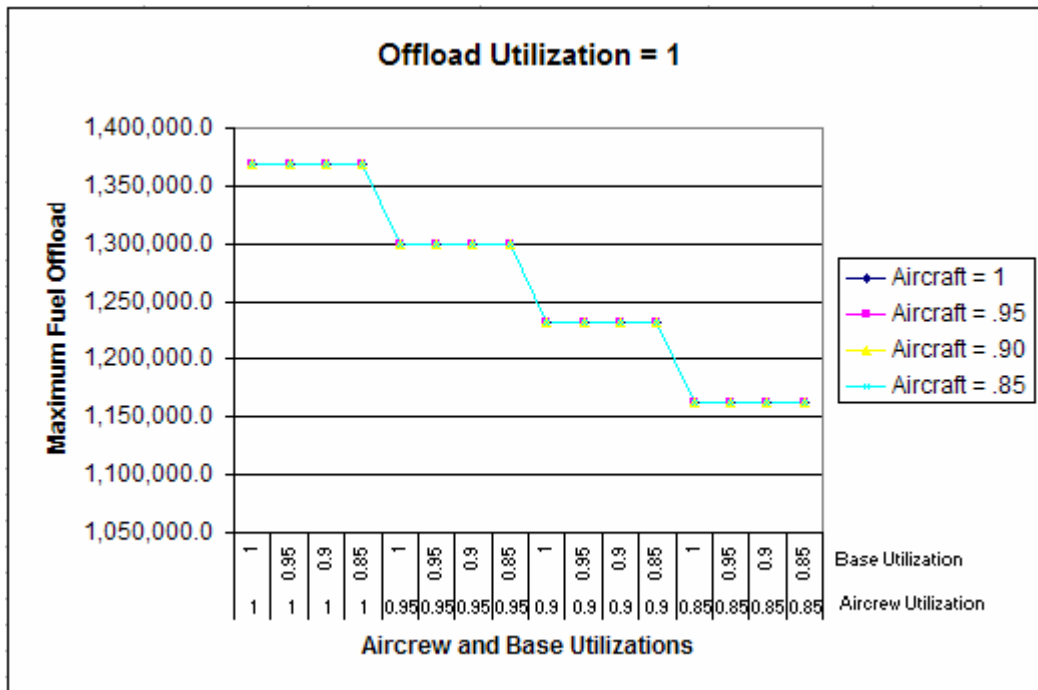
Figure 8. Fuel Availability, Offload Utilization = 1.0
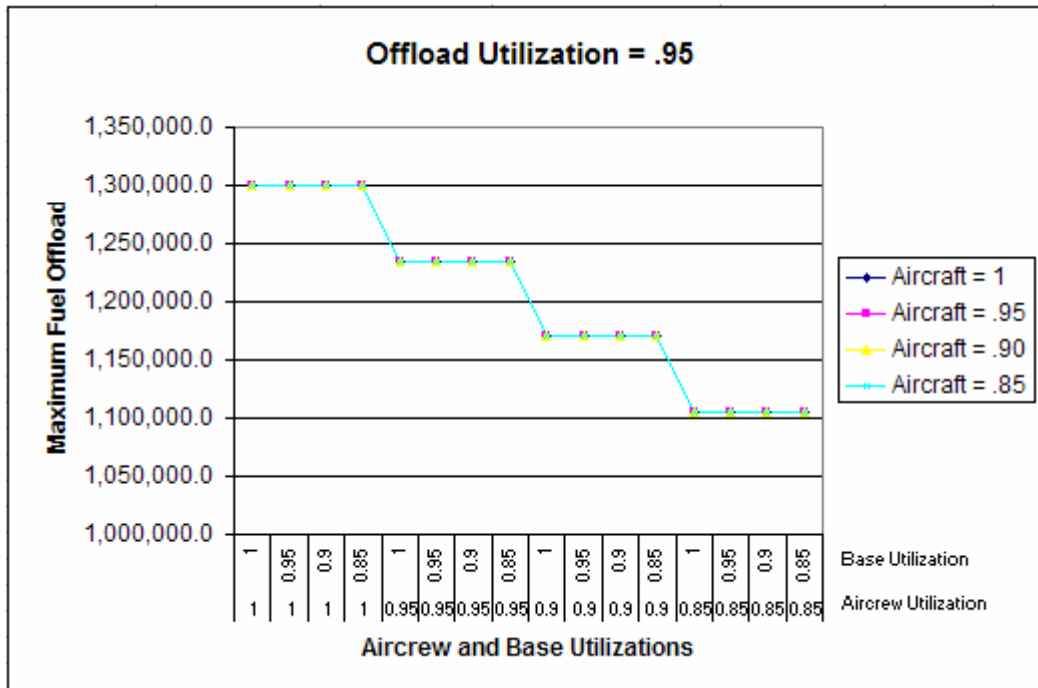
Figure 9. Fuel Availability, Offload Utilization = 0.95
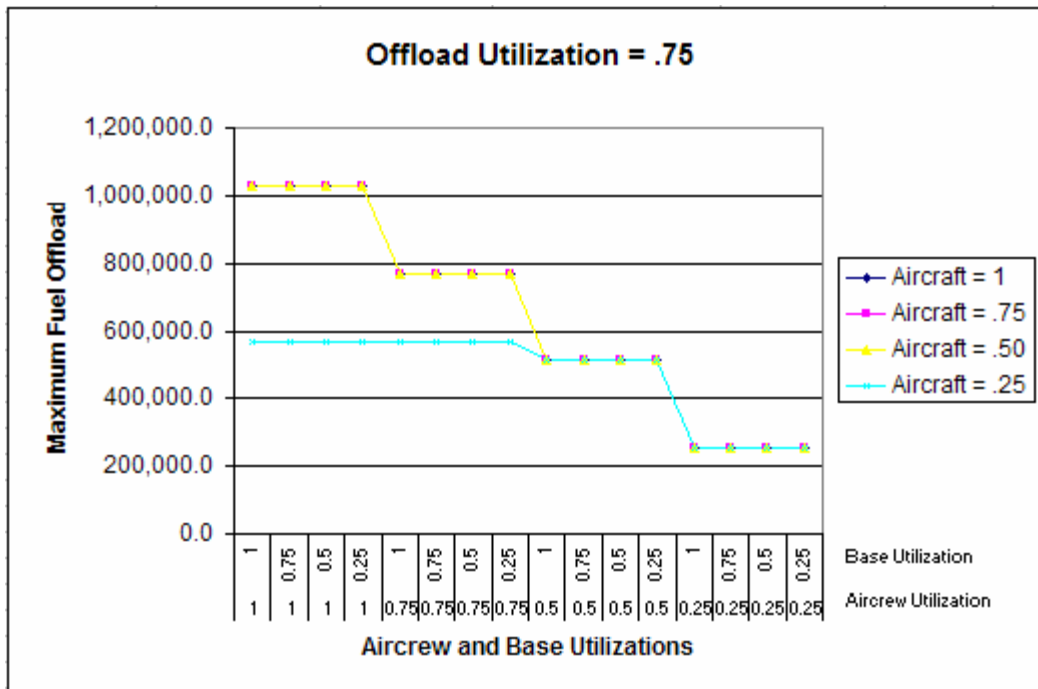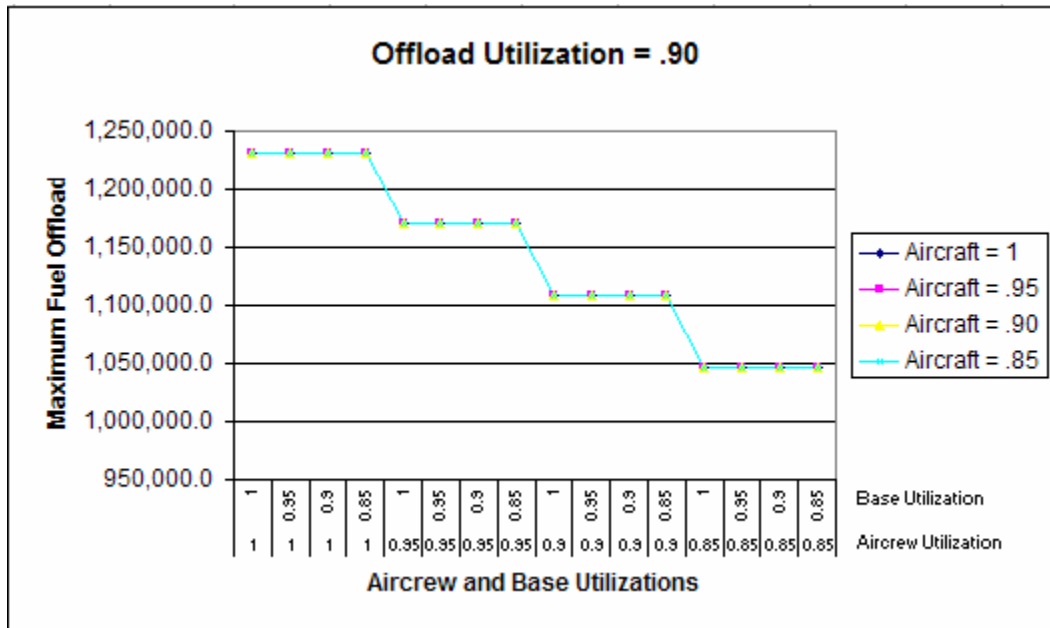
Figure 10. Fuel Availability, Offload Utilization = 0.90
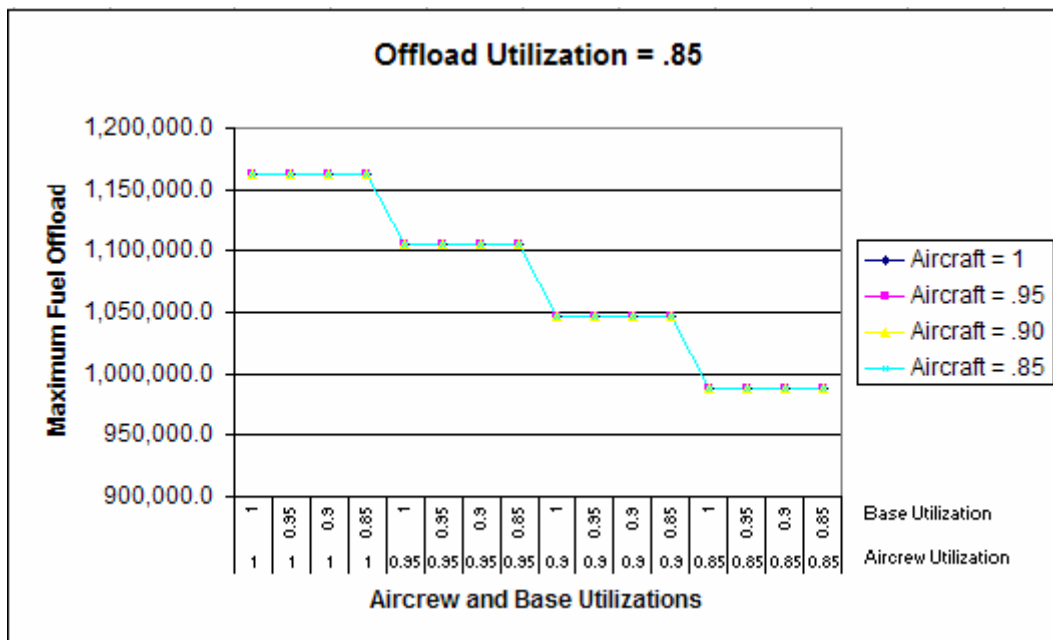
Figure 11. Fuel Availability, Offload Utilization = 0.85

Using the second set of utilization factors (0.85 to 1.0), the closest amount of fuel available for offload is 1,046,831 pounds. This amount of fuel available can be obtained from the tanker employment model and the data from Table 12 by adjusting the utilization factors in several combinations. When the offload utilization factor is 0.90 and the aircrew utilization is 0.85, the other two utilization factors can be anything and the result will be 1,046,831 pounds of fuel available. Likewise, when the offload utilization factor is 0.85 and the aircrew utilization is 0.90, the other two utilization factors can be anything and the result will be 1,046,831 pounds. For the next step, utilizations factors of offload = 0.90, aircrew = 0.85, aircraft = 1 and base = 1 were arbitrarily selected from the choices.

With the utilization factors determined, the data from the situation report for each day was entered into the tanker employment model. (Data and results are listed in Appendix C.) The same assumptions from the first step -- assumptions regarding average offload, sortie duration, aircrew and aircraft availabilities, ground times, base capacity, etc -- were used again in this phase. The comparison between the actual amount offloaded with the forecasted available amount for offload is graphed in Figure 12.
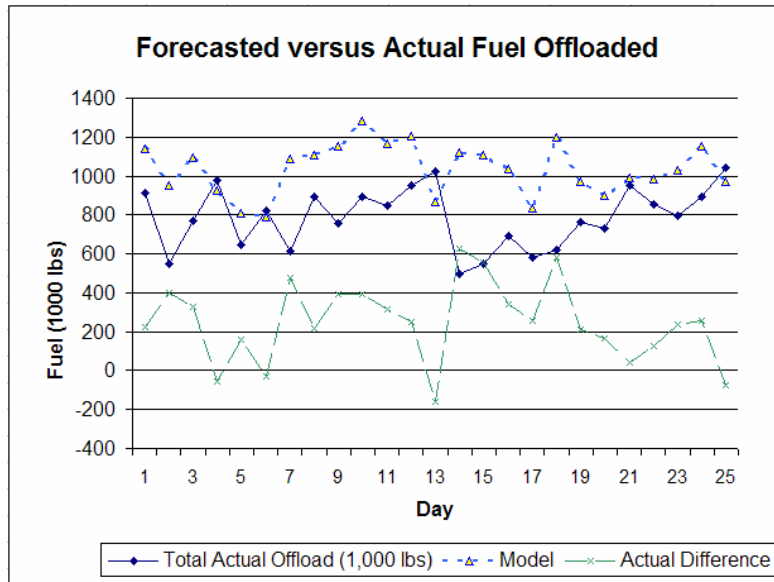
Figure 12. Forecasted versus Actual Fuel Offloaded

The amount of fuel forecasted varies from -154,000 to 625,000 pounds over the actual amount. With the exception of four days, the tanker employment model predicted there would be more fuel available then what was actually offloaded. However, none of the predictions were within AMC's 10,000 pound acceptable range. Since none of the amounts were within range, the tanker employment model would not be good as a strict forecasting tool. The additional fuel predicted by the model was not unexpected, as the tanker employment model's relationships are designed to calculate the maximum fuel available. The results indicate that the tool is able to be used to provide an upper bound to the amount of fuel which is available.

The fluctuation seen between various days may account for other disparate results as well. When entering the daily data from the situation report, several assumptions had to be made. The largest of these assumptions was that each sortie flew the same profile mission – the same distances, time on track, airspeed and fuel burn rate. The chances of each day being similar enough to use one set of data appears unlikely, given the wide

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range of results. Thus, the next step in analyzing the tanker employment model is to demonstrate its use for planning purposes.

4.4 Using the Model for Planning and Sensitivity Analysis

The main purpose behind the tanker employment tool is to provide planners with the ability to calculate a rough cut capacity analysis for fuel availability for employed tankers. A common objective of aggregate planning is to achieve the maximum use from plants and equipment. In the case of tankers, the aircraft, aircrew and even base resources may be considered to be equipment. Thus, when planning tanker employments, planners can use the tanker employment model to aide in determining adequate resources.

If planners knew in advance the type of daily requirements for fuel that receivers would have, they could use the tanker employment model to aide in capacity considerations. The fewer resources a unit deploys with creates many benefits for the military. The additional resources left at the home unit can be used for training or for other deployments. A reduction of resources also results in a smaller logistics footprint, saving money on items such as transportation and supply costs. Additionally, countries may have host nation agreements limiting the number of personnel, or the size of the deployed location, thus, the fewer resources required, the easier it is to meet the host nation agreement.

If planners estimated the average distance to refueling track (based on established tracks or through working with the Combined Air Operations Center and Tanker/Airlift Control Center) and the average amount of fuel the receivers will require, they can estimate the number or resources required. For example, using part of the data from the

CMARPS generated scenario in Table 7, and part of the data from the day in the air tasking order from Table 12, the following data was estimated for an employment scenario.

Table 13. Combined Data from Generated Scenario and Air Tasking Order

Initial Fuel Load (lbs)	187000
Distance to Track (nm)	581
Time at Track (min)	135
Air Speed (nm/hr)	430
Avg Fuel Burn (lbs/hr)	12457
Reserve Fuel (lbs)	24000
Offloaded Fuel (lbs)	50000
Aircraft Assigned	15
Crews Assigned	23
(NMC/PMC) Aircraft	3
Ground Alert Aircraft	1
Base Fuel Capacity (gal)	4900000
Base Operating Hours (hrs)	24

Using the data from Table 13, the tanker employment model generated the results listed in Table 14. (Data was calculated setting all utilization factors to 1.)

Table 14. Results from Combined Data

Offload Available per Tanker (lbs)	104423
Aircraft Gen Capability	36.8
Aircrew Gen Capability	17.8
Base Gen Capability	110.8
Maximum Daily Fuel Avail (lbs)	1879614

According to the tanker employment model, the deployed tanker unit would be able to deliver a maximum of 1,879,614 pounds of fuel a day. If planners knew that only five receiver groups would require fuel per day, and therefore, only 250,000 pounds of fuel would be required per day, they could adjust the aircraft, aircrew, or base resources

to more efficiently meet the requirement. Figures 13 through 17 depict the changes in each of these resource, aircraft, aircrew and base, and how it effects the maximum daily amount of fuel available.
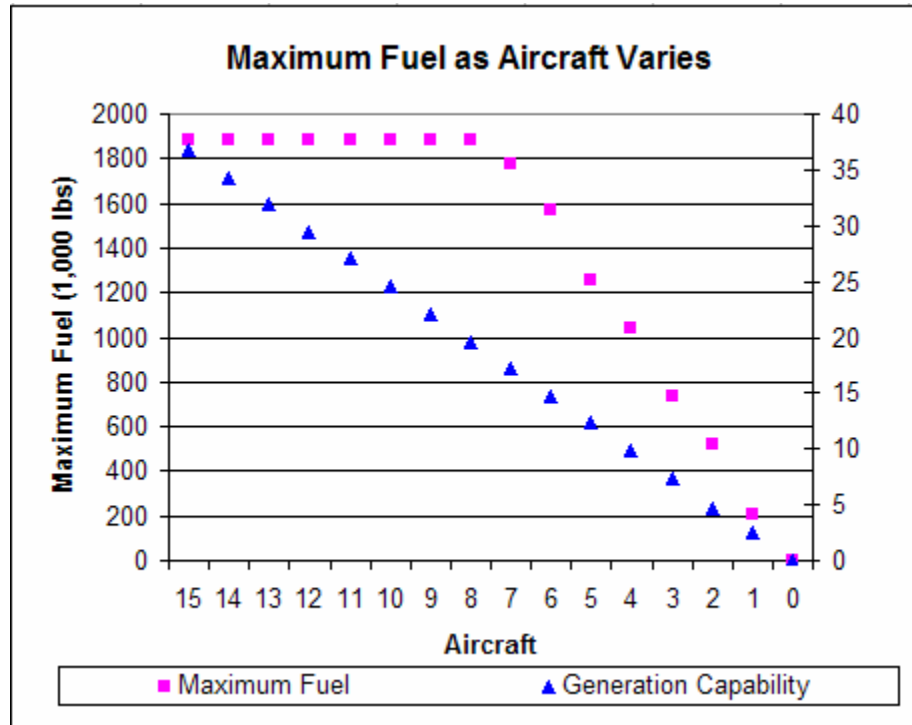
Figure 13. Maximum Fuel Available as Aircraft Vary

Figure 13 illustrates that since aircrew generation capability initially was 17.8, changes in the number of aircraft deployed do not affect the maximum fuel available until the aircraft generation capability drops below 17.8. In this example, the drop occurs if seven aircraft are deployed instead of eight. Therefore, all other things being equal, a unit could deploy with 9 aircraft and achieve the same results as 15.

A similar concept is illustrated when adjusting base resources, including the base's maximum fuel capacity, the operating hours, or the MOG. Because the base generation capability is so much higher then the aircrew's, 110.8 versus 17.8, the

resources must be drastically reduced to effect maximum fuel delivery. (Figures 14

through 16 illustrate the changes in the various base resources.)
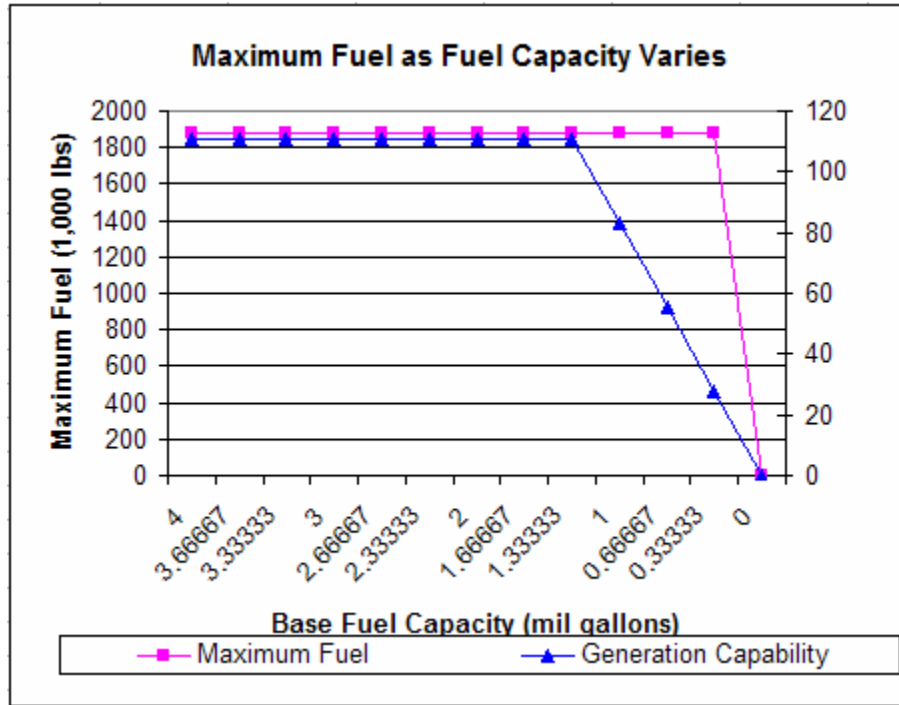
Figure 14. Maximum Fuel as Fuel Capacity Varies
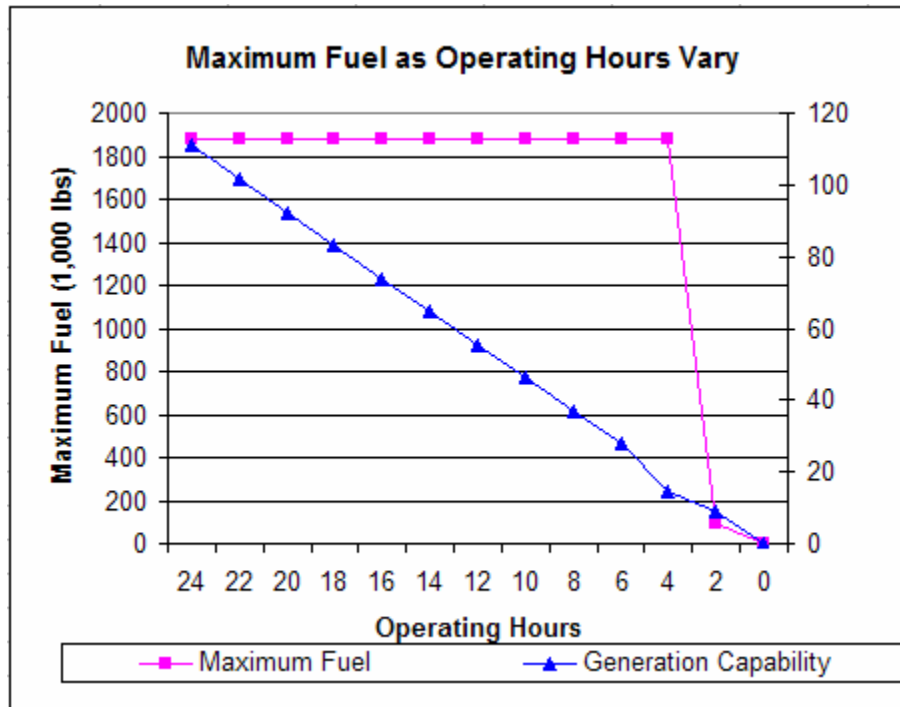
Figure 15. Maximum Fuel as Operating Hours Vary
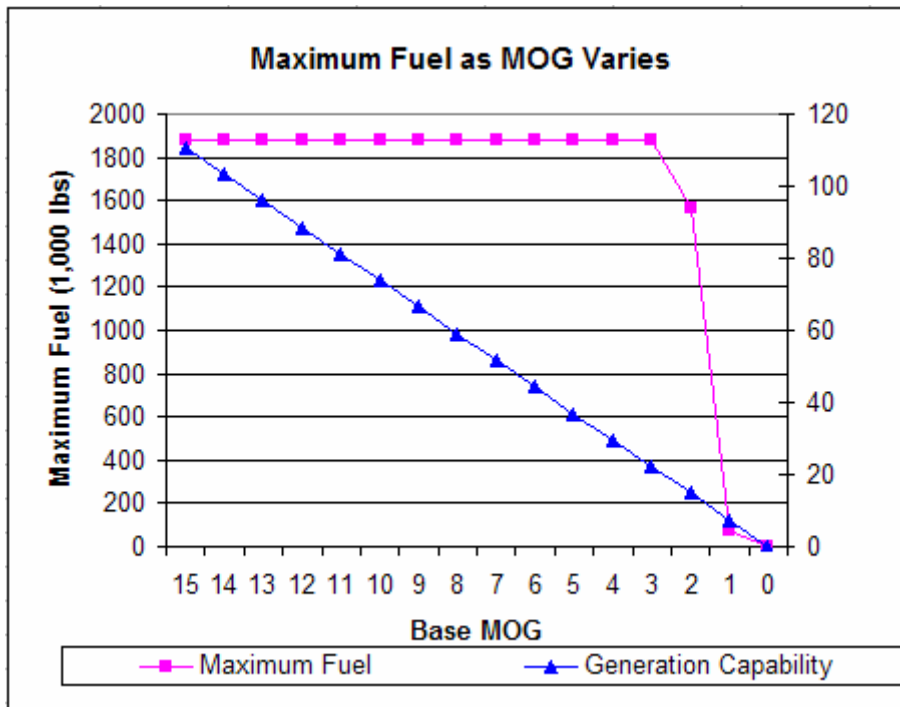
Figure 16. Maximum Fuel as MOG Varies

Finally, when viewing the changes to deployed aircrew, the changes to the aircrew and the effects on the maximum fuel delivery become profound. For every one less aircrew deployed, the maximum amount of available fuel decreases (see Figure 17). Thus, to increase or decrease the maximum fuel available, changes in the aircrew will make the most profound impact.
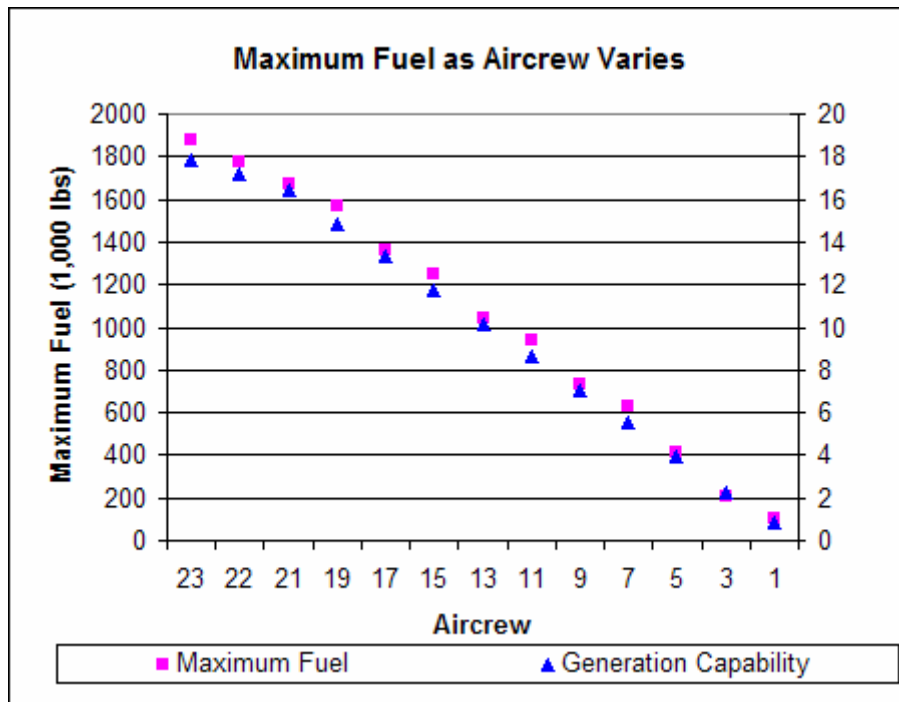
Figure 17. Maximum Fuel Available as Aircrew Vary

All of the changes to resources illustrated in this example assume a perfect world. Often planners will incorporate room for known issues. For example, at any given time, the mission capable rate for aircraft is only 85%. Therefore, in this case, planners would want to ensure they have at least three aircraft planned to be non mission capable at any time. Additionally, planners may know they need to have at least one aircraft on alert at all times. This would increase the number of required aircraft as well. However, if

known, or estimated, these factors can be incorporated into the tanker employment model from the beginning.

4.5 Conclusion

Using equations developed in Chapter 3, a tanker employment model was built to calculate the offloaded fuel available on a mission per mission basis. With the assistance of AMC/A-59 office, the tanker employment model was verified and validated by comparing outputs from CMARPS and the tanker employment model. To test the robustness of the verification and validation, data from both a generated scenario and an actual air tasking order were entered into the two models. In both sets of data, the tanker employment model performed within acceptable range of CMARPS, demonstrating its effectiveness in providing a quick, easily understood tool to planners for rough cut capacity analysis of fuel available for offload by employed tankers.

It was demonstrated, that tanker employment tool is not a good forecasting tool, as it can not accommodate the day to day variations of tanker missions. However, the tool can be useful for providing upper limit capacity to the amount of daily fuel available, if utilization factors can be determined from either historical data or expert opinion. Additionally, the tanker employment model aides in planning the effect of changes in various resources, including aircrew, aircraft, and various base resources, to changes to the fuel available for tankers to offload to receiver aircraft.

Almost every computer in the Air Force is loaded with Excel as part of the Microsoft Office suite. Therefore, the tool is extremely portable. Also, the employment of userforms, and the multitude of instructions sheets built into the tanker employment

model increase the usability, allowing anyone to use the tool with minimum training, even minimum planning experience.

4.6 Limitations

While useful as a rough cut capacity planning tool, the tanker employment model has several limitations. First, and greatest, is that the tanker employment model provides an optimistic quantity of fuel available for tankers to offload. Due to the equations being rigid, and focused on one set of sorties at a time, the tanker employment model does not handle fluctuation in air tasking orders well. If a planner would like to plan for days with widely varying missions, they would need to enter each set of mission types into the tanker employment model, and calculate to find the worst case scenario – the largest amount of fuel required – and then plan around those factors for an employment.

A final note on the tanker employment model is that the use of the utilization factors is deterministic instead of stochastic. Rarely will exact same missions, both for tanker aircraft and receiver aircraft, be flown in the exact same way. Additionally, aircraft break for a variety of reasons, and aircrew are unavailable for a variety or reasons. The tool could be more realistic by taking into account the 'fog of war' by allowing the planner to input a range of utilization factors. The tool could then randomly generate the utilization within those factors.

V. Conclusions and Recommendations

5.1 Introduction

This chapter discusses conclusions and contribution produced by this research and suggestions for future research.

5.2 Conclusions

Scheduling tankers during employments is a complex task due to high volume of demand and stricter constraints. Because of the complexities involved, optimally solving the tanker scheduling problem takes extensive time. CMARPS is an excellent tool for solving the problem optimally, but takes in-depth training, in addition to extensive time, for solving larger problems.

In the search for good solutions to the tanker problem, many studies have been accomplished in the field of tanker deployments, including Capehart (2000), Tekelioglu (2001), Wiley (2001), and Annaballi (2002). More recently, Miller (2005) has researched tanker employments. However, this research is the first to look at the tanker scheduling, and in particular tanker employment, from a rough cut capacity view point.

This thesis has demonstrated that a basic set of equations can be developed to model the offloaded fuel available on a mission per mission basis. The tanker employment model was written in Visual Basic for Applications within Excel, for portability within the Air Force. Additionally, the tanker employment model's user interface is very simple, easy to understand, with instructions interlaced through the tanker employment model. In addition, the reference sheets in the tanker employment model are able to be modified, updated and adapted by each user.

5.3 Contributions

After successful verification and validation of the tanker employment model, the model was tested as a rough capacity type of planning model and as a forecasting tool. While the results indicated the tanker employment model would not be a suitable forecasting tool for day to day operations, the tanker employment model was shown to be beneficial as a rough cut capacity planning tool and as a predictor of optimal fuel available.

Therefore, this research has provided AMC with a tool capable of quickly answering the two original research questions:

1. Given system constraints/capacities and information on receiver employment missions, how many tankers will it take to meet receiver air refueling requirements?

2. Given system constraints/capacities, and a fixed number of tankers, how many receiver employment missions can be supported?

5.4 Recommendations for Future Research

The tanker employment model provides a rough capacity analysis of tanker employment calculations very quickly and easily. However, in researching calculation for an optimistic solution, there were several areas sacrificed for simplicity. Additionally, there are potential changes to the tanker employment model which will enhance the robustness, which could bring the rough cut capacity estimates to more closely align to an optimal solution instead of an optimistic solution.

One limitation of the tanker employment model is the deterministic nature of the model does not mimic the real world. An appropriate area to explore stochastic changes to the tanker employment model would be to modify the function of the utilization factors. Designed to help the tanker employment model effects of the real world, changing the inputs of the utilization factors would allow the probabilistic nature of real world to factor in to the model.

Currently, the tanker employment model can consider any amount of required fuel, but it can only calculate the fuel needs of one receiver group. Expanding this userform's capabilities will expand the robustness of the tanker employment model. Similar to the limitation on calculating the refueling needs of one receiver group, a user can input any amount of fuel available, but can only calculate the tanker offload availability for one particular tanker type, flying one set mission. Possible expansion to the fuel available from the tanker could include consideration for fuel flow from booms versus probe and chutes, different mission profiles, and changes in fuel burn rate and airspeed as the tankers offload fuel.

Although much of today's Air Force has a working knowledge of Excel, the code could be modified to Java to allow for increased manageability. Java is platform independent and is object oriented. Currently reference sheets are included as part of the tanker employment model; however, Java code could be written to import receiver group data, thereby lessening the need for users to reference some of the information.

Another feature which could be added would be the ability to refuel at more than one base. Currently, the tanker employment model is set for resources from one set base, with a given capacity for MOG and fuel resources.

Another expansion to the tanker employment model is to research the effects of Special Operations on tanker requirements. Often, aircraft used in special operations have different requirements for refueling, such as flying altitude, black out conditions, and unusual terrain. Each of these factors could be explored to determine their effect versus normal tanker refueling operations.

Finally, the tanker employment model can be expanded to include more capabilities of maintenance actions and resources. The field of maintenance capacity includes personnel resources as well as equipment resources. Each of these types of resources have constraints associated. For example, maintenance personnel often have specialized training which affects the numbers availability to fix maintenance problems, let alone personnel issues such as being unavailable due to temporary duty, training, or illness. Likewise, equipment is also constrained by numbers assigned, as well as maintenance of the equipment itself.

In addition to expanding the tanker employment model, more tests could be run on determining the impact of utilization factors for comparison and forecasting. Due to limited access to real world air tasking orders and situation reports, the tanker employment model was not tested to compare bases with similar mission and tanker aircraft. While the tanker employment model proved unsuitable for forecasting day to day changes in fuel availability, there may be merit in testing utilization factor consistency across bases with similar aircraft composition and missions.

Appendix A. VBA Coding and User Forms

MAIN MODULE

Fuel Burn Rates

Aircraft Type	Fuel Burn Rate (Lbs/Hr)
A/OA-10	4,160
B-707	13,916
B-747	26,800
B-767	10,552
C-130	5,109
C-141	13,768
C-17	19,643
C-5	23,132
C-9	6,661
DC-10	20,616
DC-8	13,916
F-117	9,197
F-15C	10,822
F-15E	12,669
F-16	5,854
F-18	5,829
F-22A	13,154
KC-10	17,830
KC-135R	10,718
L-1011	17,219
MD-11	17,511

Source: Air Force Pamphlet 10-1403

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Figure 18. Reference Sheet, Fuel Burn

Receiver Planning Factors
(Data format in work)

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TYPE ACFT	MAX FUEL (10,000) Internal	External	# Bags	PPH BURN RATE Low	Med	Hi	PLN AIRSPEED Med/Hi	MAX Dist to AAR	MAX ON LOAD	OPT AAR ALT
A-6E	15.9	2	3 (5)	8	6	5	435T - 0.8M	450NM	10-14K	150-200
A-10	10.7	4.0-	2 (3)	5.3	4.5	4	310T – 0.5M	500NM	5.5K	100-200
AC-130H	40	-	-	8	6.2	-	240T – 300T	800NM	30K	80-150
AC-130U	40	-	-	7	6	5	240T – 300T	1500NM	30K	80-150
AMX-B/R	6.2	1.0/1.9	2or2	5.3	4.2	3.8	420T - 0.7M	500NM	6K	150-220
AV-8B	7.7	2	2 (4)	8	5.8	5	480T - 0.8M	400NM	7.0K	150-240
B-1B	220	-	-	39	18	16	500T - 0.85M	4400NM	190K	160-220
B-2	180+	-	-	17	14	12	420T – 0.7M	4000NM	150+	240-270
B-52	305	4.7	2	26.5	22	15	360T - 0.8M	6400NM	270K	240-310
C-5	332	-	-	30	25	24	420T - 0.8M	2000+	90K+	180-260
C-17	184/274	+37.5	+2	24	22	17	420T - 0.8M	2000+	90K+	120-310
C-135/707 (all)	85-155	-	-	14	12	11	200I - 275I	4000NM	60/100K	200-260
C-141	153	-	-	15	13.5	12	420T - 0.85M	2000+	120K	200-260
CV-22	13.5	-	-	9	7	6	275T – 275I	700NM	10K	100-180
E-3A/C	160	-	-	15	14	13	200I - 0.72M	2500NM	100K	200-260
E-3D/F	155	-	-	15	14	13	200I – 0.72M	2500NM	90K	200-260
E-4	343	-	-	26	24	22	460T - 0.9M	5000NM	240K	200-260
F-22	18	2 (4)	11.8	8.6	7.6	250I – 0.85M	700NM	18K	No Data	Burn Rates: 40K'/30K'/20K'
F-22	18	0 (4)	8.6	6.3	5.5	250I – 0.85M	450NM	14K	No Data	Burn Rates: 40K'/30K'/20K'
F-117	18.2	-	9	7.5	6.5	500T - 0.85M	450NM	14K	180-260	
GR-7 (AV-8)	7.7	2 (4)	8	5	4	480T - 0.8M	400NM	7.7K	150-250	
Jaguar (all)	7.8	3/2wng	8	6.4	5.8	450T – 0.8M	450NM	7K	100-180	
Joint Strike Fighter	18.3	2 (2)	6	5.5	5.4	250I - 0.85M	1000NM	18K	No Data	Burn Rates: 40K'/30K'/20K'
Joint Strike Fighter	18.3	0 (2)	5.1	4.7	4.4	250I - 0.85M	750NM	15K	No Data	Burn Rates: 40K'/30K'/20K'
M2000C (A-A)	7	1-Feb	8	6	5	470T – 0.9M	400NM	8K	220-270	
M2000DK (Gnd Attk)	8.2	1-Feb	9	7	6	470T – 0.9M	400NM	9K	150-230	
MC-130H	60	-	6.2	5.3	4.8	260T – 300T	3600NM	55K	80-160	
MC-130P	60-82	-	6.2	5.3	4.8	210I – 300T	3600NM	55K	80-160	
MIR F-1 CR/CT	7.6	1-Feb	6	5	4	475T – 0.9M	400NM	7K	150-220	
Rafale	9.4	2or2(4)	9	6.5	5	480T – 335I	750NM	9K	200-290	
RC-135S (Cobra Ball)	155	-	16	13	12.5	420T – 0.84	4000NM	100K	200-260	
RC-135VW (RJ)	155	-	15.4	12.4	12	420T – 0.84	4000NM	100K	200-260	
RC-135U (Cbt Sent)	155	-	17	15	14	400T – 0.78	3500NM	100K	180-250	
S-3	13.1	1	2.8	2.6	2.4	210T – 440T	1200NM	6.0K	120-200	
SHARF (Sea Harrier)	7.7	2 (4)	8	5	4	480T - 0.8M	400NM	7.0K	150-250	
Tornado F-3 (ADV)	11.2	2-3(4)	8	6.4	5.8	450T – 0.85M	750NM	11	150-230	2.2K Bags also used
Tornado (all others)	11.2	2+2or4	8	6.4	5.8	450T – 0.85M	750NM	11	150-230	2.2K Bags also used

Source: All data derived from multiple unclassified internet sources; CAPES Course Nellis AFB; "Janes" data, PFPS, and aircraft T.O. data

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Figure 19. Reference Sheet, Receiver Information

Block Speeds

Aircraft Type	Mach	500 nm	1000 nm	1500 nm	2000 nm	2500 nm	3000 nm	3500 nm	4000 nm	4500 nm	5000 nm	5500 nm	6000 nm
C-9	0.78	344	397	414	420	421	-	-	-	-	-	-	-
C-130	0.49	242	266	272	273	272	271	-	-	-	-	-	-
C-141	0.74	332	380	396	401	401	401	404	407	409	410	-	-
C-17	0.76	335	384	400	405	406	406	409	412	-	-	-	-
C-5	0.77	341	393	410	415	416	416	420	422	424	426	428	429
KC-10	0.81	354	410	428	435	436	437	440	443	446	447	449	450
KC-135	0.79	348	401	419	425	426	426	430	433	435	437	438	439
B-707	0.8	351	405	424	430	431	432	435	438	-	-	-	-
B-747	0.84	363	422	442	450	451	452	456	459	461	463	465	466
B-767	0.81	354	410	428	435	436	437	440	443	446	447	-	-
DC-8	0.8	351	405	424	430	431	432	435	438	440	442	-	-
DC-10	0.83	360	418	438	445	446	447	451	454	456	458	-	-
L-1011	0.81	354	410	428	435	436	437	440	443	446	447	-	-
MD-11	0.83	360	418	438	445	446	447	451	454	456	458	460	461

For speed of combat, please reference the applicable flight manual speeds

Source: Air Force Pamphlet 10-1403

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Figure 20. Reference Sheet, Block Speed

Option Explicit

```
    Public OffloadReq As Long, OffloadAvail As Long, MissionReq As Long, RTFT As
Double, _
        CycleTime As Double, AircraftInt As Double, AircrewInt As Double, _
        TotalGroundTime As Double, BaseInt As Double, MaxFuelAvail As Long, _
        CurrentFuel As Long, TankerFuelUsed As Double, CurrentTime As Variant, _
        ReturnToForm As Integer, TrackRTFTEnter As Integer, ShowMain As Integer,
ShowRTFT As Integer

Sub Instructions()
' Opens the first page of instructions, which gives a broad overview of the program
' Allows the user to advance to more detailed instructions or return to the starting sheet
    InstructionsPg1.Show
End Sub

Sub ToMainForm()
' Calls the form which the user will enter and calculate all data
    TankerFuelUsed = 0
    MainInput.Show
End Sub

Sub ReturnToMainForm()
' Places the main sheet in the background again and returns to the main form
    ThisWorkbook.Worksheets("Tanker Employment").Activate
' Using ReturnToForm, selects which form to return the user to
    Select Case ReturnToForm
        Case 1
            ShowMain = 1
            InputFuelReqData.Show
        Case 2
            ShowMain = 1
            InputFuelAvailData.Show
        Case 3
            MainInput.Show
        Case 4
            ShowMain = 1
            ShowRTFT = 1
            InstructionsRTFT.Show
        Case Else
            ThisWorkbook.Worksheets("Tanker Employment").Activate
    End Select
End Sub

Sub ToBeginningSheet()
' Calls the form which the user will enter and calculate all data
    ThisWorkbook.Worksheets("Tanker Employment").Activate
End Sub
```

```
Function RoundNear(varNumber As Variant, varDelta As Variant) As Variant

' by Dejan Mladenovic, <<http://advisor.com/doc/08884>> accessed 31 Jan 05
' Rounds varnumber to the nearest multiple of varDelta

  Dim varDec As Variant
  Dim intX As Integer
  Dim varX As Variant

  varX = varNumber / varDelta
  intX = Int(varX)
  varDec = CDec(varX) - intX

  If varDec >= 0.5 Then
    RoundNear = varDelta * (intX + 1)
  Else
    RoundNear = varDelta * intX
  End If
End Function
```

MAIN FORM

Figure 21. Userform, Main Input

Private Sub CmdInstructions_Click()
' Calls the form to give instructions to the user
    InstructionsPg1.Show
End Sub

Private Sub CmdPrint_Click()
    MainInput.PrintForm
End Sub

Private Sub CmdTotalGroundTime_Click()
    Dim Result As Integer

' Calls form to enter total ground time

    InputGroundTimeData.Show

    With TotalGroundTimeBox
        TotalGroundTimeBox = TotalGroundTime
    End With
End Sub

Sub InputTotalGroundTime()

End Sub

```vba
Sub CheckInputsMaxFuel()
' Ensures Offload Available and the aircraft, aircrew and stations intervals have been
entered
   With OffloadAvailBox
     If .Value = "" Or Not IsNumeric(.Value) Then
        MsgBox "A numerical number for Offload Available is required to calculate the
Maximum Fuel Available."
        .SetFocus
        BoxCheck = 1
      Exit Sub
     End If
     OffloadAvail = OffloadAvailBox
     If OffloadReq < 0 Then
        MsgBox "That Offload Available should be a nonnegative value in order to
calculate the Maximum Fuel Available."
        .SetFocus
        BoxCheck = 1
      Exit Sub
     End If
   End With
   With AircraftIntBox
     If .Value = "" Or Not IsNumeric(.Value) Then
        MsgBox "A numerical number for Aircraft Sortie Generation rate" & _
          " is required to calculate the Maximum Fuel Available."
        .SetFocus
        BoxCheck = 1
        Exit Sub
     End If
     AircraftInt = AircraftIntBox
     If OffloadReq < 0 Then
        MsgBox "That Aircraft Sortie Generation rate should be a " & _
          "nonnegative value in order to calculate the Maximum Fuel Available."
        .SetFocus
        BoxCheck = 1
      Exit Sub
     End If
   End With
   With AircrewIntBox
     If .Value = "" Or Not IsNumeric(.Value) Then
        MsgBox "A numerical number for Aircrew Sortie Generation rate" & _
          " is required to calculate the Maximum Fuel Available."
        .SetFocus
        BoxCheck = 1
        Exit Sub
     End If
```

```vba
      AircrewInt = AircrewIntBox
      If OffloadReq < 0 Then
         MsgBox "That Aircrew Sortie Generation rate should be a " & _
            "nonnegative value in order to calculate the Maximum Fuel Available."
         .SetFocus
         BoxCheck = 1
         Exit Sub
      End If
   End With
   With BaseIntBox
      If .Value = "" Or Not IsNumeric(.Value) Then
         MsgBox "A numerical number for Base Sortie Generation rate" & _
            " is required to calculate the Maximum Fuel Available."
         .SetFocus
         BoxCheck = 1
         Exit Sub
      End If
      BaseInt = BaseIntBox
      If OffloadReq < 0 Then
         MsgBox "The Base Sortie Generation rate should be a " & _
            "nonnegative value in order to calculate the Maximum Fuel Available."
         .SetFocus
         BoxCheck = 1
         Exit Sub
      End If
   End With
End Sub


Sub CheckInputsMissionReq()
' First checks to ensure offload required and offload available data has been entered
   With OffloadReqBox
      If .Value = "" Or Not IsNumeric(.Value) Then
         MsgBox "Please enter a numeric value for the Offload Required."
         .SetFocus
         BoxCheck = 1
         Exit Sub
      End If
      OffloadReq = OffloadReqBox
      If OffloadReq < 0 Then
         MsgBox "Please enter a nonnegative value for the Offload Required."
         .SetFocus
         BoxCheck = 1
         Exit Sub
      End If
   End With
```

```
With OffloadAvailBox
    If .Value = "" Or Not IsNumeric(.Value) Then
      MsgBox "Please enter a numeric value for the Offload Available."
      .SetFocus
      BoxCheck = 1
      Exit Sub
    End If
    OffloadAvail = OffloadAvailBox
    If OffloadAvail < 0 Then
      MsgBox "Please enter a nonnegative value for the Offload Available."
      .SetFocus
      BoxCheck = 1
     Exit Sub
    End If
  End With
End Sub
```

INSTRUCTIONS
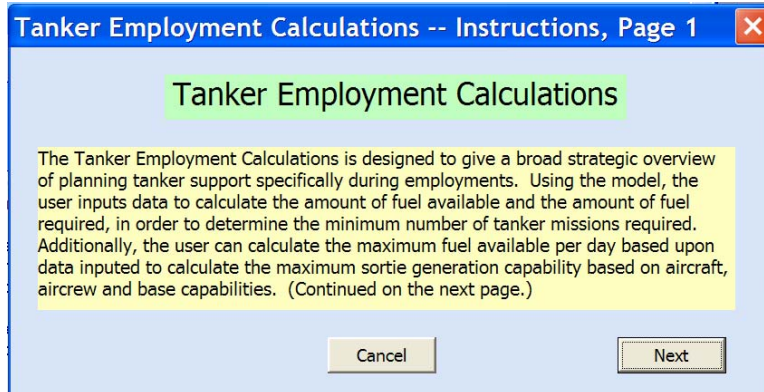
Figure 22. Userform, Main Instruction, Page 1

Option Explicit

Private Sub CancelCmd_Click()
    Unload Me
End Sub

Private Sub NextCmd_Click()
    Unload Me
    InstructionsPg2.Show
End Sub
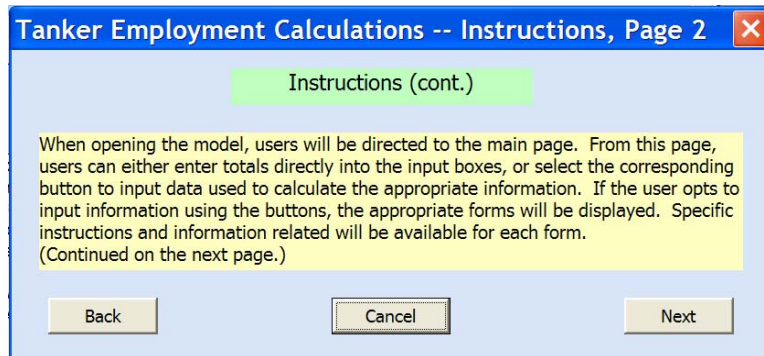
Figure 23. Userform, Main Instruction, Page 2

Option Explicit

Private Sub CancelCmd_Click()
    Unload Me
End Sub

Private Sub CommandButton1_Click()

```
      Unload Me
      InstructionsPg1.Show
End Sub

Private Sub NextCmd_Click()
      Unload Me
      InstructionsPg3.Show
End Sub
```
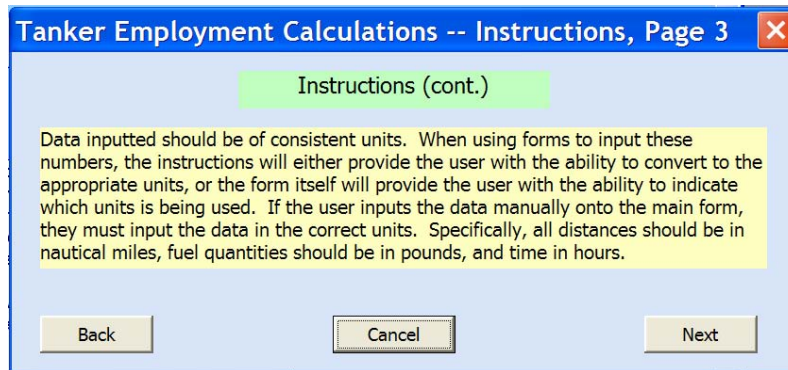

Figure 24. Userform, Main Instruction, Page 3

```
Option Explicit

Private Sub BackCmd_Click()
      Unload Me
      InstructionsPg2.Show
End Sub

Private Sub CancelCmd_Click()
      Unload Me
End Sub

Private Sub NextCmd_Click()
      Unload Me
      InstructionsPg4.Show
End Sub
```
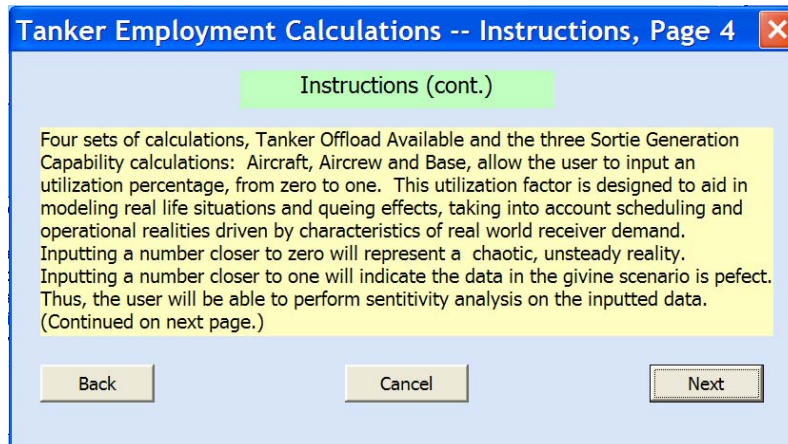
Figure 25. Userform, Main Instruction, Page 4

```
Option Explicit

Private Sub BackCmd_Click()
    Unload Me
    InstructionsPg3.Show
End Sub

Private Sub CancelCmd_Click()
    Unload Me
End Sub

Private Sub NextCmd_Click()
    Unload Me
    InstructionsPg5.Show
End Sub
```
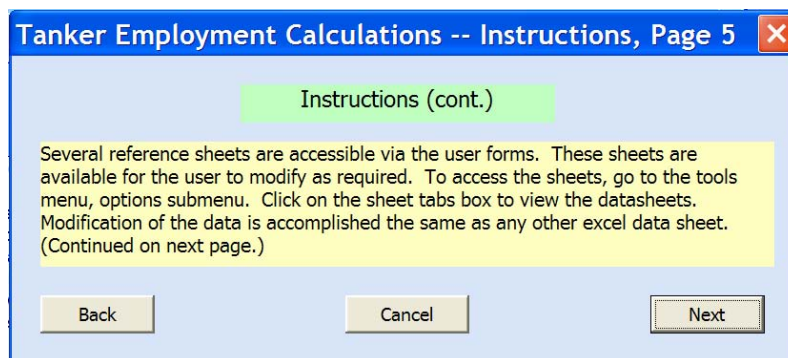

Figure 26. Userform, Main Instruction, Page 5

```
Private Sub BackCmd_Click()
    Unload Me
    InstructionsPg4.Show
```

```
End Sub

Private Sub CancelCmd_Click()
    Unload Me
End Sub

Private Sub NextCmd_Click()
    Unload Me
    InstructionsPg6.Show
End Sub
```
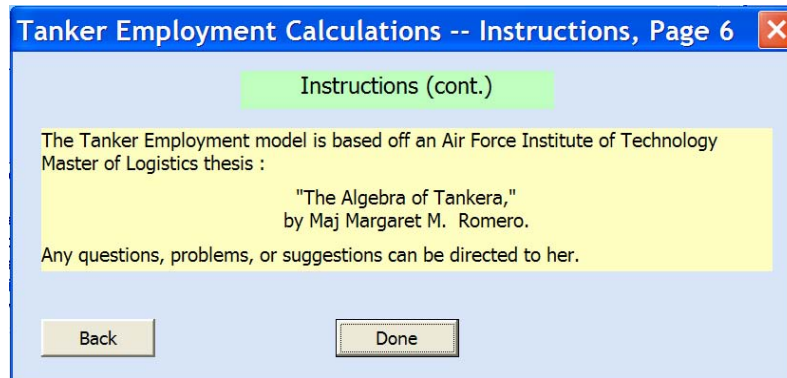

Figure 27. Userform, Main Instruction, Page 6

```
Option Explicit

Private Sub BackCmd_Click()
    Unload Me
    InstructionsPg4.Show
End Sub

Private Sub CancelCmd_Click()
    Unload Me
End Sub
```

INPUTFUELREQDATA

Figure 28. Userform, Input Data for Required Fuel

Option Explicit
    Dim TempSortieDuration As Variant, TempAvgFuelBurn As Long, _
        TempTotalFuel As Long, TempReserve As Long, TempNumber As Long, _
        TempOffload As Variant, BoxCheck As Integer

Private Sub CmdCancel_Click()
    Unload Me
    End
End Sub

Private Sub CalculateCommandButton_Click()
' Calls subroutine to check if inputs are valid
    BoxCheck = 0
    Call CheckInputs
    If BoxCheck = 1 Then
        Exit Sub
    End If
'Calculate Offload Required and places the value in the box for users to review
    TempOffload = (TempSortieDuration * TempAvgFuelBurn) - TempTotalFuel +
TempReserve
    OffloadReq = TempOffload * TempNumber
    OffloadReqBox = OffloadReq

95

```
End Sub

Private Sub CancelCommandButton_Click()
    Unload Me
    If ShowMain = 1 Then
        MainInput.Show
    End If
End Sub


Private Sub ClearCmd_Click()
'Resets all variables used in form
    TempSortieDuration = 0
    TempAvgFuelBurn = 0
    TempTotalFuel = 0
    TempReserve = 0
    TempNumber = 0
'Clears form by closing then reopening it
    Unload Me
    InputFuelReqData.Show
End Sub


Private Sub cmdViewFuelFlow_Click()
' Initializes ReturntoForm to return to this form
    ReturnToForm = 1
' Activates the worksheet with the chart
    InputFuelReqData.Hide
    MainInput.Hide
    ThisWorkbook.Worksheets("Fuel Flow").Activate
    With AvgFuelBurnBox
        .SetFocus
    End With
End Sub

Private Sub cmdViewReceiverInfo_Click()
' Initializes ReturntoForm to return to this form
    ReturnToForm = 1
' Activates the worksheet with the appropriate chart
    InputFuelReqData.Hide
    MainInput.Hide
    ThisWorkbook.Worksheets("Receiver").Activate
    With TotalFuelBox
        .SetFocus
    End With
End Sub

Private Sub InstructionsCmd_Click()
```

' Opens form for instructions for Inputting data for Required Fuel
   InstructionsFuelReq.Show
End Sub

Sub CheckInputs()
' Checks to ensure users inputs are numeric, and appropriate (converting minutes to hour
if needed)
' Assigns users inputs to temporary variables to calculate receivers' required fuel
   With SortieTimeBox
      If .Value = "" Or Not IsNumeric(.Value) Then
         MsgBox "Please enter a numeric value for the duration time of the sortie."
         .SetFocus
         BoxCheck = 1
         Exit Sub
      End If
      TempSortieDuration = SortieTimeBox
      If TempSortieDuration < 0 Then
         MsgBox "Please enter a nonnegative value for the duration time of the sortie."
         .SetFocus
         BoxCheck = 1
         Exit Sub
      End If
   End With
   If HoursOption = False And MinutesOption = False Then
      MsgBox "Please indicate if sortie duration is in hours or minutes."
      BoxCheck = 1
      Exit Sub
   ElseIf MinutesOption = True Then
      TempSortieDuration = TempSortieDuration \ 60
   End If
   With AvgFuelBurnBox
      If .Value = "" Or Not IsNumeric(.Value) Then
         MsgBox "Please enter a numeric value for the FuelFlow."
         .SetFocus
         BoxCheck = 1
         Exit Sub
      End If
      TempAvgFuelBurn = AvgFuelBurnBox
      If TempAvgFuelBurn < 0 Then
         MsgBox "Please enter a nonnegative value for the Average Fuel Burn Rate."
         .SetFocus
         BoxCheck = 1
         Exit Sub
      End If
   End With
   With TotalFuelBox

```
        If .Value = "" Or Not IsNumeric(.Value) Then
          MsgBox "Please enter a numeric value for the Total Fuel Loaded."
          .SetFocus
          BoxCheck = 1
          Exit Sub
        End If
        TempTotalFuel = TotalFuelBox
        If TempTotalFuel < 0 Then
          MsgBox "Please enter a nonnegative value for the Total Fuel Loaded."
          .SetFocus
          BoxCheck = 1
          Exit Sub
        End If
    End With
    With DestinationReserveBox
        If .Value = "" Or Not IsNumeric(.Value) Then
          MsgBox "Please enter a numeric value for the Destination Reserve fuel desired."
          .SetFocus
          BoxCheck = 1
          Exit Sub
        End If
        TempReserve = DestinationReserveBox
        If TempReserve < 0 Then
          MsgBox "Please enter a nonnegative value for the Destination Reserve fuel
desired."
          .SetFocus
          BoxCheck = 1
          Exit Sub
        End If
    End With
    With NumReceiverBox
        If .Value = "" Or Not IsNumeric(.Value) Then
          MsgBox "Please enter a numeric value for the Number of Receiver Aircraft."
          .SetFocus
          BoxCheck = 1
          Exit Sub
        End If
        TempNumber = NumReceiverBox
        If TempReserve < 0 Then
          MsgBox "Please enter a nonnegative value for the Number of Receiver Aircraft."
          .SetFocus
          BoxCheck = 1
          Exit Sub
        End If
    End With
End Sub
```

```
Private Sub ReturnCmd_Click()
'Returns the user to the main form, saving the data by hiding the form
    InputFuelReqData.Hide
    If ShowMain = 1 Then
        MainInput.Show
    End If
End Sub
```

INPUTFUELREQ INSTRUCTIONS
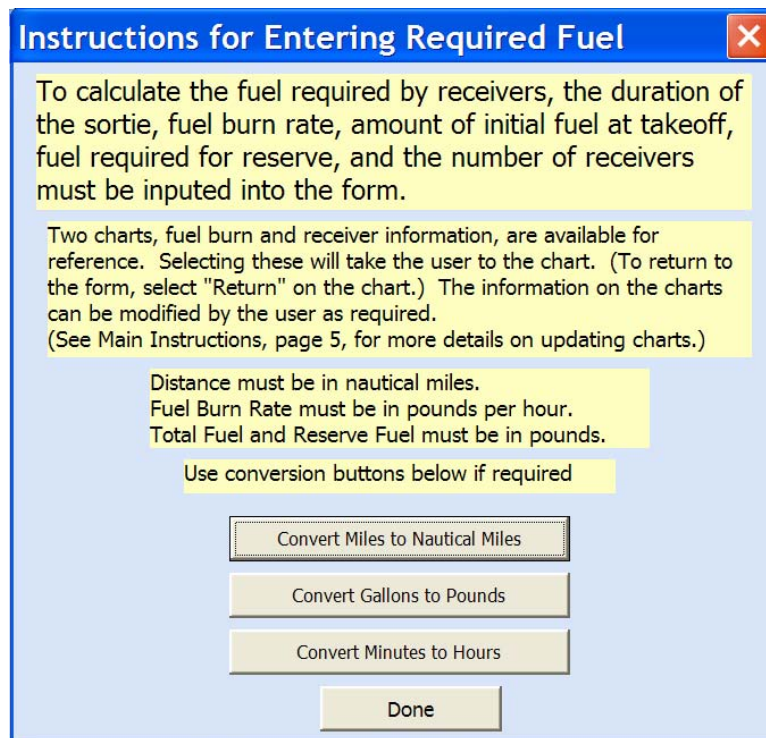
Figure 29. Userform, Require Fuel Instructions

```
Option Explicit

    Dim Miles As Variant, NauticalMiles As Long, Gallons As Variant, Pounds As Long
    Dim Hours As Long, Minutes As Variant

Private Sub CmdCancel_Click()
    Unload Me
End Sub

Private Sub GallonConversionCmd_Click()
' Opens input box to allow user to input gallons and returns the number of pounds
    Gallons = InputBox("Enter the number of gallons to convert to pounds:", _
        "Gallons to Pounds Conversion")
```

```
        If Gallons = "" Or Not IsNumeric(Gallons) Then
            MsgBox "You must enter a numerical value to be converted."
            Exit Sub
        End If
        Pounds = Gallons * 6.799
        MsgBox "The number of Pounds is " & Pounds
End Sub

Private Sub MileConversionCmd_Click()
' Opens input box to allow user to input miles and returns the number of nautical miles
        Miles = InputBox("Enter the number of miles to convert to nautical miles:", _
            "Miles to Nautical Mile Conversion")
        If Miles = "" Or Not IsNumeric(Miles) Then
            MsgBox "You must enter a numerical value to be converted."
            Exit Sub
        End If
        NauticalMiles = Miles * 0.868976242
        MsgBox "The number of Nautical Miles is " & NauticalMiles
End Sub

Private Sub MinuteConversionCmd_Click()
' Opens input box to allow user to input miles and returns the number of nautical miles
        Minutes = InputBox("Enter the number of minutes to convert to hours:", _
            "Minutes to Hours Conversion")
        If Minutes = "" Or Not IsNumeric(Minutes) Then
            MsgBox "You must enter a numerical value to be converted."
            Exit Sub
        End If
        Hours = Minutes \ 60
        MsgBox "The number of Hours is " & Hours
End Sub
```

INPUTFUELAVAILDATA

Figure 30. Userform, Input Data for Available Fuel

Option Explicit
    Dim TempTakeOffFuel As Long, TempAirRefuel As Long, TempDistanceTo As Long, _
        TempTimeAtRefuel As Long, TempDistanceFrom As Long, TempTAS As Long, _
        TempAvgFuelBurn As Long, TempReserve As Long, TempFuelUsed As Double, _
        BoxCheck As Integer, TempOffloadUte As Variant

Private Sub CalculateCommandButton_Click()
' Calls Subroutine to check inputs and assign users inputs to a variable
    BoxCheck = 0
    Call CheckInputs
    If BoxCheck = 1 Then
        Exit Sub
    End If
' Calculate Offload Available

```vba
   RTFT = ((TempDistanceTo + TempDistanceFrom) / TempTAS) +
TempTimeAtRefuel
   TrackRTFTEnter = 1
   TankerFuelUsed = RTFT * TempAvgFuelBurn
   OffloadAvail = (TempTakeOffFuel + TempAirRefuel - TankerFuelUsed -
TempReserve) * TempOffloadUte
   TempOffloadAvailBox = OffloadAvail

End Sub

Private Sub CancelCommandButton_Click()
   Unload Me
   If ShowMain = 1 Then
      MainInput.Show
   End If
End Sub

Private Sub ClearCmd_Click()
' Clears all values the users entered, but keeps the form open
   TempTakeOffFuel = 0
   TempAirRefuel = 0
   TempDistanceTo = 0
   TempTimeAtRefuel = 0
   TempDistanceFrom = 0
   TempTAS = 0
   TempAvgFuelBurn = 0
   TempReserve = 0
   TempFuelUsed = 0
   TempOffloadUte = 0
'Calls subproceedure to show form cleared
   Unload Me
   InputFuelAvailData.Show
End Sub

Private Sub cmdViewFuelFlow_Click()
' Initializes ReturntoForm to return to this form
   ReturnToForm = 2
' Activates the worksheet with the chart
   InputFuelAvailData.Hide
   MainInput.Hide
   ThisWorkbook.Worksheets("Fuel Flow").Activate
   With AvgFuelBurnBox
      .SetFocus
   End With
End Sub
```

```vba
Private Sub cmdViewTASTable_Click()
' Initializes ReturntoForm to return to this form
    ReturnToForm = 2
' Activates the worksheet with the chart
    InputFuelAvailData.Hide
    MainInput.Hide
    ThisWorkbook.Worksheets("Air Speed").Activate
    With TASBox
        .SetFocus
    End With
End Sub


Private Sub InstructionsCmd_Click()
' Opens form for instructions for Inputting data for Available Fuel
    InstructionsFuelAvail.Show
End Sub


Sub CheckInputs()
'Checks users inputs to ensure of proper format
'Assigns users inputs to temporary variables to calculate offload required
    With TakeOffFuelBox
        If .Value = "" Or Not IsNumeric(.Value) Then
            MsgBox "Please enter a numeric value for the Total Fuel Loaded."
            .SetFocus
            BoxCheck = 1
            Exit Sub
        End If
        TempTakeOffFuel = TakeOffFuelBox
        If TempTakeOffFuel < 0 Then
            MsgBox "Please enter a nonnegative value for the amount of Take Off Fuel."
            .SetFocus
            BoxCheck = 1
            Exit Sub
        End If
    End With
    With AirRefuelBox
        If .Value = "" Or Not IsNumeric(.Value) Then
            MsgBox "Please enter zero or another value for fuel Received in Air."
            .SetFocus
            BoxCheck = 1
            Exit Sub
        End If
        TempAirRefuel = AirRefuelBox
        If TempAirRefuel < 0 Then
            MsgBox "Please enter a nonnegative value for the Total Fuel Loaded."
            .SetFocus
```

```
            BoxCheck = 1
            Exit Sub
        End If
    End With
    With DistanceToBox
        If .Value = "" Or Not IsNumeric(.Value) Then
            MsgBox "Please enter a numeric value for the distance to the refuel point."
            .SetFocus
            BoxCheck = 1
            Exit Sub
        End If
        TempDistanceTo = DistanceToBox
        If TempDistanceTo < 0 Then
            MsgBox "Please enter a nonnegative value for the distance to the refuel point."
            .SetFocus
            BoxCheck = 1
            Exit Sub
        End If
    End With
    With OrbitTimeBox
        If .Value = "" Or Not IsNumeric(.Value) Then
            MsgBox "Please enter a numeric value for the time in orbit."
            .SetFocus
            BoxCheck = 1
            Exit Sub
        End If
        TempTimeAtRefuel = OrbitTimeBox
        If TempTimeAtRefuel < 0 Then
            MsgBox "Please enter a nonnegative value for the time in orbit."
            .SetFocus
            BoxCheck = 1
            Exit Sub
        End If
    End With
    If HoursOption = False And MinutesOption = False Then
        MsgBox "Please indicate if this is in hours or minutes."
        BoxCheck = 1
        Exit Sub
    ElseIf MinutesOption = True Then
        TempTimeAtRefuel = TempTimeAtRefuel \ 60
    End If
    With DistanceFromBox
        If .Value = "" Or Not IsNumeric(.Value) Then
            MsgBox "Please enter a numeric value for the return distance."
            .SetFocus
            BoxCheck = 1
```

```
        Exit Sub
     End If
     TempDistanceFrom = DistanceFromBox
     If TempDistanceFrom < 0 Then
        MsgBox "Please enter a nonnegative value for the return distance."
        .SetFocus
        BoxCheck = 1
        Exit Sub
     End If
  End With
  With TASBox
     If .Value = "" Or Not IsNumeric(.Value) Then
        MsgBox "Please enter a numeric value for the True Air Speed."
        .SetFocus
        BoxCheck = 1
        Exit Sub
     End If
     TempTAS = TASBox
     If TempTAS < 0 Then
        MsgBox "Please enter a nonnegative value for the True Air Speed."
        .SetFocus
        BoxCheck = 1
        Exit Sub
     End If
     If TempTAS > 630 Then
        MsgBox "Please recheck your air speed for the tanker." & vbCrLf & vbCrLf _
           & "Maximum speed for a KC-10 is 619 mph and for a KC-135 610 mph."
        .SetFocus
        BoxCheck = 1
       Exit Sub
     End If
  End With
  With AvgFuelBurnBox
     If .Value = "" Or Not IsNumeric(.Value) Then
        MsgBox "Please enter a numeric value for the FuelFlow."
        .SetFocus
        BoxCheck = 1
        Exit Sub
     End If
     TempAvgFuelBurn = AvgFuelBurnBox
     If TempAvgFuelBurn < 0 Then
        MsgBox "Please enter a nonnegative value for the Average Fuel Burn Rate."
        .SetFocus
        BoxCheck = 1
       Exit Sub
     End If
```

```vba
      End With
   With DestinationReserveBox
      If .Value = "" Or Not IsNumeric(.Value) Then
         MsgBox "Please enter a numeric value for the Destination Reserve fuel desired."
         .SetFocus
         BoxCheck = 1
         Exit Sub
      End If
      TempReserve = DestinationReserveBox
      If TempReserve < 0 Then
         MsgBox "Please enter a nonnegative value for the Destination Reserve fuel
desired."
         .SetFocus
         BoxCheck = 1
         Exit Sub
      End If
   End With
   With OffloadUtilizationBox
      If .Value = "" Or Not IsNumeric(.Value) Then
         MsgBox "Please enter a numeric value for the Offload Utilization."
         .SetFocus
          BoxCheck = 1
        Exit Sub
      End If
      TempOffloadUte = OffloadUtilizationBox
      If TempOffloadUte < 0 Or TempOffloadUte > 1 Then
         MsgBox "Please enter a number between 0 and 1 for the Offload Utilization."
         .SetFocus
          BoxCheck = 1
        Exit Sub
      End If
   End With
End Sub

Private Sub ReturnCmd_Click()
' Hides the form and returns to the main form, saving the values on the form
   InputFuelAvailData.Hide
   If ShowMain = 1 Then
      MainInput.Show
   End If
End Sub
```

INPUTFUELAVAIL INSTRUCTIONS

Figure 31. Userform, Available Fuel Instructions

Option Explicit

   Dim Miles As Variant, NauticalMiles As Long, Gallons As Variant, Pounds As Long
   Dim Hours As Long, Minutes As Variant

Private Sub CmdCancel_Click()
   Unload Me
End Sub

Private Sub GallonConversionCmd_Click()
' Opens input box to allow user to input gallons and returns the number of pounds
     Gallons = InputBox("Enter the number of gallons to convert to pounds:", _
       "Gallons to Pounds Conversion")
     If Gallons = "" Or Not IsNumeric(Gallons) Then
       MsgBox "You must enter a numerical value to be converted."
       Exit Sub

```vba
      End If
      Pounds = Gallons * 6.799
      MsgBox "The number of Pounds is " & Pounds

End Sub

Private Sub MileConversionCmd_Click()
' Opens input box to allow user to input miles and returns the number of nautical miles
      Miles = InputBox("Enter the number of miles to convert to nautical miles:", _
         "Miles to Nautical Mile Conversion")
      If Miles = "" Or Not IsNumeric(Miles) Then
         MsgBox "You must enter a numerical value to be converted."
         Exit Sub
      End If
      NauticalMiles = Miles * 0.868976242
      MsgBox "The number of Nautical Miles is " & NauticalMiles
End Sub

Private Sub MinuteConversionCmd_Click()
' Opens input box to allow user to input miles and returns the number of nautical miles
      Minutes = InputBox("Enter the number of minutes to convert to hours:", _
         "Minutes to Hours Conversion")
      If Minutes = "" Or Not IsNumeric(Minutes) Then
         MsgBox "You must enter a numerical value to be converted."
         Exit Sub
      End If
      Hours = Minutes \ 60
      MsgBox "The number of Hours is " & Hours
End Sub
```

INPUT FIRST RTFT

Figure 32. Userform, Input First Leg RTFT Data

```
Private Sub cmdContinueWithRTFT_Click()
    Dim Result As Integer
' Calls subroutine to check if inputs are valid
    BoxCheck = 0
    Call CheckInputs
    If BoxCheck = 1 Then
        Exit Sub
    End If
' Calls subroutine to calculate Round Trip Flying Time
    Call CalculateRTFT
' Prompts to see if user would like to add an additional leg to the trip
' If not, continues on to return leg
    Result = MsgBox("Do you want to add another leg to the mision?", _
        vbYesNo, "Add Additional Legs to the Mission?")
    If Result = 6 Then
    ' Sets the input row so that additional rows of info may be added on the data worksheet
        Unload Me
        InputAdditionalRTFTData.Show
    Else
        Unload Me
        InputFinalRTFTData.Show
    End If
'Unload the form
    Unload Me
```

```
End Sub

Sub CheckInputs()
' Checks to ensure users inputs are numeric
' Assigns users inputs to temporary variables used to calculate Round Trip Flying Time
   With DistanceBox
      If .Value = "" Or Not IsNumeric(.Value) Then
         MsgBox "Please enter a numeric value for the distance."
         .SetFocus
         BoxCheck = 1
         Exit Sub
      End If
      TempDistance = DistanceBox
      If TempDistance < 0 Then
         MsgBox "Please enter a nonnegative value for the distance."
         .SetFocus
         BoxCheck = 1
         Exit Sub
      End If
   End With
   With BlockSpeedBox
      If .Value = "" Or Not IsNumeric(.Value) Then
         MsgBox "Please enter a numeric value for the True Air Speed."
         .SetFocus
         BoxCheck = 1
         Exit Sub
      End If
      TempBlockSpeed = BlockSpeedBox
      If TempBlockSpeed < 0 Then
         MsgBox "Please enter a nonnegative value for the True Air Speed."
         .SetFocus
         BoxCheck = 1
         Exit Sub
      End If
   End With
   With TimeatPointBox
      If .Value = "" Or Not IsNumeric(.Value) Then
         MsgBox "Please enter a numeric value for the FuelFlow."
         .SetFocus
         BoxCheck = 1
         Exit Sub
      End If
      TempTimeatPoint = TimeatPointBox
      If TempTimeatPoint < 0 Then
         MsgBox "Please enter a nonnegative value for the Average Fuel Burn Rate."
         .SetFocus
```

```
            BoxCheck = 1
            Exit Sub
        End If
    End With
    If HoursOption = False And MinutesOption = False Then
        MsgBox "Please indicate if the time is in hours or minutes."
        BoxCheck = 1
        Exit Sub
    ElseIf MinutesOption = True Then
        TempTimeatPoint = TempTimeatPoint \ 60
    End If
'   With QEfficiencyBox
'    If .Value = "" Or Not IsNumeric(.Value) Then
'        MsgBox "Please enter a numeric value for the Receivers' Efficiency."
'        BoxCheck = 1
'        .SetFocus
'        Exit Sub
'    End If
'    TempQEfficiency = QEfficiencyBox
'    If TempQEfficiency < 0 Or TempQEfficiency > 1 Then
'        MsgBox "Please enter a number between 0 and 1 for the base's Receivers'
Efficiency."
'        BoxCheck = 1
'        .SetFocus
'        Exit Sub
'    End If
'    End With
End Sub

Sub CalculateRTFT()
'Calculate Round Trip Flying Time
    RTFT = (TempDistance / TempBlockSpeed + TempTimeatPoint) ' *
TempQEfficiency
End Sub

Private Sub CmdInstructions_Click()
    ShowRTFT = 0
    InstructionsRTFT.Show
End Sub
```

RTFT INSTRUCTIONS

Figure 33. Userform, RTFT Instructions

Option Explicit

Private Sub CmdCancel_Click()
    Unload Me
    If ShowRTFT = 1 Then
        InputFirstRTFTData.Show
    End If
End Sub

Private Sub cmdViewTASTable_Click()
' Initializes ReturntoForm to return to this form
    ReturnToForm = 4
' Activates the worksheet with the chart
    InstructionsRTFT.Hide
    InputFirstRTFTData.Hide
    MainInput.Hide
    ThisWorkbook.Worksheets("Air Speed").Activate
End Sub

Private Sub MileConversionCmd_Click()
' Opens input box to allow user to input miles and returns the number of nautical miles
        Miles = InputBox("Enter the number of miles to convert to nautical miles:", _

```
        "Miles to Nautical Mile Conversion")
    If Miles = "" Or Not IsNumeric(Miles) Then
        MsgBox "You must enter a numerical value to be converted."
        Exit Sub
    End If
    NauticalMiles = Miles * 0.868976242
    MsgBox "The number of Nautical Miles is " & NauticalMiles
End Sub
```

INPUTADDITIONALRTFTDATA

Figure 34. Userform, Input Additonal RTFT Legs

```
Option Explicit
    Dim TempDistance As Single, TempBlockSpeed As Single, TempTimeatPoint As
Variant, _
        BoxCheck As Integer, Result As Integer, _
        LegTime As Variant, FuelUse As Long, FuelBurn As Long
        ' TempQEfficiency As Variant

Private Sub CancelCommandButton_Click()
    If ShowMain = 1 Then
        MainInput.Show
    End If
    Unload Me
```

```vba
' Checks to see if the user would like to stop calculations on RTFT, or not enter data for
' an addition leg
    Result = MsgBox("Data for the final leg has not been entered yet.  Do you want to
complete the RTFT " & _
        "calculations?" & vbCrLf & vbCrLf _
        & "Select Yes to return to main form, No to proceed to inputting data for final leg",
_
        vbYesNo, "End RTFT Calculations?")
    If Result = 7 Then
        InputFinalRTFTData.Show
    End If
End Sub


Sub CalculateRTFT()
' Calculates current leg's Round Trip Flying Time and adds to previous legs times
    RTFT = (TempDistance / TempBlockSpeed + TempTimeatPoint + RTFT) ' *
TempQEfficiency
End Sub


Private Sub cmdContinueRTFT_Click()
    BoxCheck = 0
' Calls subroutine to see if each input is a non blank, non negative number, setting the
' variable BoxCheck to 1 if the input is not proper format
    Call CheckInputs
    If BoxCheck = 1 Then
        Exit Sub
    End If
' Calls subroutine to calculate Round Trip Flying Time
    Call CalculateRTFT
' Unload the form
    Unload Me
' Opens form to input data for return leg of Round Trip Flying Time
    InputFinalRTFTData.Show

End Sub


Private Sub CmdInputAdditionPoints_Click()
' Calls subroutine to check if inputs are valid
    BoxCheck = 0
    Call CheckInputs
    If BoxCheck = 1 Then
        Exit Sub
    End If
' Calls subroutine to calculate Round Trip Flying Time
    Call CalculateRTFT
' Resets form for additional inputs
```

```vba
   DistanceBox = ""
   BlockSpeedBox = ""
   TimeAtPointBox = ""
End Sub


Sub CheckInputs()
' Checks to ensure users inputs are numeric
' Assigns users inputs to temporary variables used to calculate Round Trip Flying Time
   With DistanceBox
      If .Value = "" Or Not IsNumeric(.Value) Then
         Result = MsgBox("Do you want to continue without adding an additional
refueling point?", _
            vbYesNo, "Manual Enter")
         If Result = 6 Then
            InputFinalRTFTData.Show
            Unload Me
         End If
      MsgBox "Please enter a numeric value for the distance."
         .SetFocus
         BoxCheck = 1
         Exit Sub
      End If
      TempDistance = DistanceBox
      If TempDistance < 0 Then
         MsgBox "Please enter a nonnegative value for the distance."
         .SetFocus
         BoxCheck = 1
         Exit Sub
      End If
   End With
   With BlockSpeedBox
      If .Value = "" Or Not IsNumeric(.Value) Then
         Result = MsgBox("Do you want to continue without adding an additional
refueling point?", _
            vbYesNo, "Manual Enter")
         If Result = 6 Then
            InputFinalRTFTData.Show
            Unload Me
         End If
      MsgBox "Please enter a numeric value for the True Air Speed."
         .SetFocus
         BoxCheck = 1
         Exit Sub
      End If
      TempBlockSpeed = BlockSpeedBox
      If TempBlockSpeed < 0 Then
```

```
              MsgBox "Please enter a nonnegative value for the True Air Speed."
              .SetFocus
              BoxCheck = 1
              Exit Sub
          End If
       End With
       With TimeAtPointBox
          If .Value = "" Or Not IsNumeric(.Value) Then
              Result = MsgBox("Do you want to continue without adding an additional
refueling point?", _
                 vbYesNo, "Manual Enter")
              If Result = 6 Then
                 InputFinalRTFTData.Show
                 Unload Me
              End If
              MsgBox "Please enter a numeric value for the FuelFlow."
              .SetFocus
              BoxCheck = 1
              Exit Sub
          End If
          TempTimeatPoint = TimeAtPointBox
          If TempTimeatPoint < 0 Then
              MsgBox "Please enter a nonnegative value for the Average Fuel Burn Rate."
              .SetFocus
              BoxCheck = 1
              Exit Sub
          End If
       End With
       If HoursOption = False And MinutesOption = False Then
          MsgBox "Please indicate if the time is in hours or minutes."
          BoxCheck = 1
          Exit Sub
       ElseIf MinutesOption = True Then
          TempTimeatPoint = TempTimeatPoint \ 60
       End If
'    With QEfficiencyBox
'       If .Value = "" Or Not IsNumeric(.Value) Then
'          MsgBox "Please enter a numeric value for the Receivers' Efficiency."
'          BoxCheck = 1
'          .SetFocus
'          Exit Sub
'       End If
'       TempQEfficiency = QEfficiencyBox
'       If TempQEfficiency < 0 Or TempQEfficiency > 1 Then
'          MsgBox "Please enter a number between 0 and 1 for the Receivers' Efficiency."
'          BoxCheck = 1
```

```
'          .SetFocus
'          Exit Sub
'      End If
'   End With
End Sub
```

INPUTFINALRTFTDATA

Figure 35. Userform, Input Final RTFT Leg Data

```
Option Explicit
    Dim TempDistance As Long, TempBlockSpeed As Long, BoxCheck As Integer, _
        LegTime As Variant, FuelUse As Long, FuelBurn As Long

Private Sub CancelCommandButton_Click()
    Unload Me
    If ShowMain = 1 Then
        MainInput.Show
    End If

End Sub

Private Sub cmdContinueRTFT_Click()
' Calls subroutine to check if inputs are valid
    BoxCheck = 0
    Call CheckInputs
    If BoxCheck = 1 Then
        Exit Sub
    End If
'Calls subroutine to calculate final leg for Round Trip Flying Time
    Call CalculateFinalRTFT
```

```vb
'Unload the form
    If ShowMain = 1 Then
        MainInput.Show
    End If
    Unload Me
End Sub
Sub CheckInputs()
' Checks to ensure users inputs are numeric
' Assigns users inputs to temporary variables used to calculate Round Trip Flying Time
    With DistanceBox
        If .Value = "" Or Not IsNumeric(.Value) Then
            MsgBox "Please enter a numeric value for the distance."
            .SetFocus
            BoxCheck = 1
            Exit Sub
        End If
        TempDistance = DistanceBox
        If TempDistance < 0 Then
            MsgBox "Please enter a nonnegative value for the distance."
            .SetFocus
            BoxCheck = 1
            Exit Sub
        End If
    End With
    With BlockSpeedBox
        If .Value = "" Or Not IsNumeric(.Value) Then
            MsgBox "Please enter a numeric value for the True Air Speed."
            .SetFocus
            BoxCheck = 1
            Exit Sub
        End If
        TempBlockSpeed = BlockSpeedBox
        If TempBlockSpeed < 0 Then
            MsgBox "Please enter a nonnegative value for the True Air Speed."
            .SetFocus
            BoxCheck = 1
            Exit Sub
        End If
    End With
End Sub

Sub CalculateFinalRTFT()
' Calculates current leg's Round Trip Flying Time and adds to previous legs times
    RTFT = (TempDistance \ TempBlockSpeed) + RTFT
End Sub
```

INPUTGROUNDTIME

Figure 36. Userform, Input Ground Time Data


```
Private Sub CmdContCycleTimeCalc_Click()
' Ensures appropriate number has been entered for total ground time and assigns the value
to the ground time variable
    With GroundTimeBox
        If .Value = "" Or Not IsNumeric(.Value) Then
            MsgBox "Please enter a numeric value for the Total Ground Time."
            .SetFocus
            Exit Sub
        End If
        TotalGroundTime = GroundTimeBox
        If TotalGroundTime < 0 Then
            MsgBox "Please enter a nonnegative value for the Total Ground Time."
            .SetFocus
            Exit Sub
        End If
    End With
    If HoursOption = False And MinutesOption = False Then
        MsgBox "Please indicate if this is in hours or minutes."
        Exit Sub
    ElseIf MinutesOption = True Then
        TotalGroundTime = TotalGroundTime \ 60
    End If
    Unload Me
End Sub


Private Sub CmdKC10CycleInfo_Click()
' Displays message box with typical ground times for KC-10
```

```
    MsgBox "Typical Ground times for KC-10 are as follows: (More details later)", , "KC-
10 Typical Ground Times"
End Sub

Private Sub CmdKC135TGTInfo_Click()
' Displays message box with typical ground times for KC-135
    MsgBox "Typical Ground times for KC-135 are as follows: (More details later)", ,
"KC-135 Typical Ground Times"
End Sub
```

INPUTAIRCRAFTDATA

Figure 37. Userform, Input Aircraft Generation Data

Option Explicit

Dim TempAssigned As Integer, TempNMC As Integer, TempOther As Integer, _
    TempAvailable As Single, TempTankUtilization As Double, _
    BoxCheck As Integer, OneAircraftDailyGeneration As Double

Private Sub UserForm_Initialize()

' Enters sortie generation capability into form
    If CycleTime = 0 Then
        Exit Sub
    End If
    OneAircraftDailyGeneration = 24 / CycleTime
    OneAircraftDailyGeneration = RoundNear(OneAircraftDailyGeneration, 0.01)

```
      OneAircraftSortieGenBox.Value = OneAircraftDailyGeneration
End Sub
Private Sub CmdCalcAircraftInt_Click()
   BoxCheck = 0
' Calls subroutine to check if inputs are valid
   Call CheckInputs
   If BoxCheck = 1 Then
      Exit Sub
   End If
'Calculate Available Aircraft
   TempAvailable = (TempAssigned - TempNMC - TempOther) * TempTankUtilization
'Calculate Aircraft Interval
   AircraftInt = TempAvailable * OneAircraftDailyGeneration
   AircraftInt = RoundNear(AircraftInt, 0.1)
   If AircraftInt < 0 Then
      AircraftInt = 0
   End If
   TempAircraftSortieGenBox = AircraftInt
End Sub

Private Sub CmdCancel_Click()
' Returns user to previous form without saving data
   Unload Me
End Sub

Private Sub CmdInstructions_Click()
   InstructionsAircraftInt.Show
End Sub

Sub CheckInputs()
' Checks to ensure users inputs are numeric,  the utilization is between 0 and 1, _
' and that NMC and Other aircraft total does not exceed the available aircraft
' Assigns users inputs to temporary variables to calculate available aircraft required
   With OneAircraftSortieGenBox
      If .Value = "" Or Not IsNumeric(.Value) Then
         MsgBox "Please enter a numeric value for the daily sortie generation capability
of one aircraft."
         .SetFocus
         BoxCheck = 1
         Exit Sub
      End If
      OneAircraftDailyGeneration = OneAircraftSortieGenBox
      If OneAircraftDailyGeneration < 0 Then
         MsgBox "Please enter a nonnegative value for the daily sortie generation
capability of one aircraft."
         .SetFocus
```

```vba
      BoxCheck = 1
      Exit Sub
    End If
  End With
  With AssignedBox
    If .Value = "" Or Not IsNumeric(.Value) Then
      MsgBox "Please enter a numeric value for the Total Assigned Aircraft."
      .SetFocus
      BoxCheck = 1
      Exit Sub
    End If
    TempAssigned = AssignedBox
    If TempAssigned < 0 Then
      MsgBox "Please enter a nonnegative value for the Assigned Aircraft."
      .SetFocus
      BoxCheck = 1
      Exit Sub
    End If
  End With
  With NMCBox
    If Not IsNumeric(.Value) Then
      MsgBox "Please enter a numeric value for the Non Mission Capable Aircraft."
      .SetFocus
      BoxCheck = 1
      Exit Sub
    End If
    TempNMC = NMCBox
    If TempNMC < 0 Then
      MsgBox "Please enter a nonnegative value for the Non Mission Capable
Aircraft."
      .SetFocus
      BoxCheck = 1
      Exit Sub
    End If
    If TempNMC > TempAssigned Then
      MsgBox "The number of the Non Mission Capable Aircraft must be less than " &
_
        "the number of Assigned Aircraft." & vbCrLf & vbCrLf _
        & "Please reenter the number."
      BoxCheck = 1
      .SetFocus
      Exit Sub
    End If
  End With
  With OtherBox
    If Not IsNumeric(.Value) Then
```

```
        MsgBox "Please enter a numeric value for the Aircraft Unavailable for Other
Reasons."
        .SetFocus
        BoxCheck = 1
        Exit Sub
      End If
      TempOther = OtherBox
      If TempOther < 0 Then
        MsgBox "Please enter a nonnegative value for the Aircraft Unavailable for Other
Reasons."
        .SetFocus
        BoxCheck = 1
        Exit Sub
      End If
      If TempOther > TempAssigned Then
        MsgBox "The number of the Aircraft Unavailable for Other reasons must " & _
          "be less than the number of Assigned Aircraft." & vbCrLf & vbCrLf _
          & "Please reenter the number."
        BoxCheck = 1
        .SetFocus
        Exit Sub
      End If
    End With
    If TempNMC + TempOther > TempAssigned Then
      MsgBox "The number of Non Mission Capable Aircraft plus the Aircraft
Unavailable for Other " & _
        "Reasons must total less than the number of Assigned Aircraft." & vbCrLf &
vbCrLf _
        & "Please recheck and reenter these numbers."
      BoxCheck = 1
      Exit Sub
    End If
    With QEfficiencyBox
      If .Value = "" Or Not IsNumeric(.Value) Then
        MsgBox "Please enter a numeric value for the Aircraft's Utilization."
        .SetFocus
        BoxCheck = 1
       Exit Sub
      End If
      TempTankUtilization = QEfficiencyBox
      If TempTankUtilization < 0 Or TempTankUtilization > 1 Then
        MsgBox "Please enter a number between 0 and 1 for the Aircraft's Utilization."
        .SetFocus
        BoxCheck = 1
       Exit Sub
      End If
```

```
    End With
End Sub

Private Sub ReturnCmd_Click()
'Unload the form
    InputAircraftIntData.Hide
End Sub
```

AIRCRAFT INSTRUCTIONS
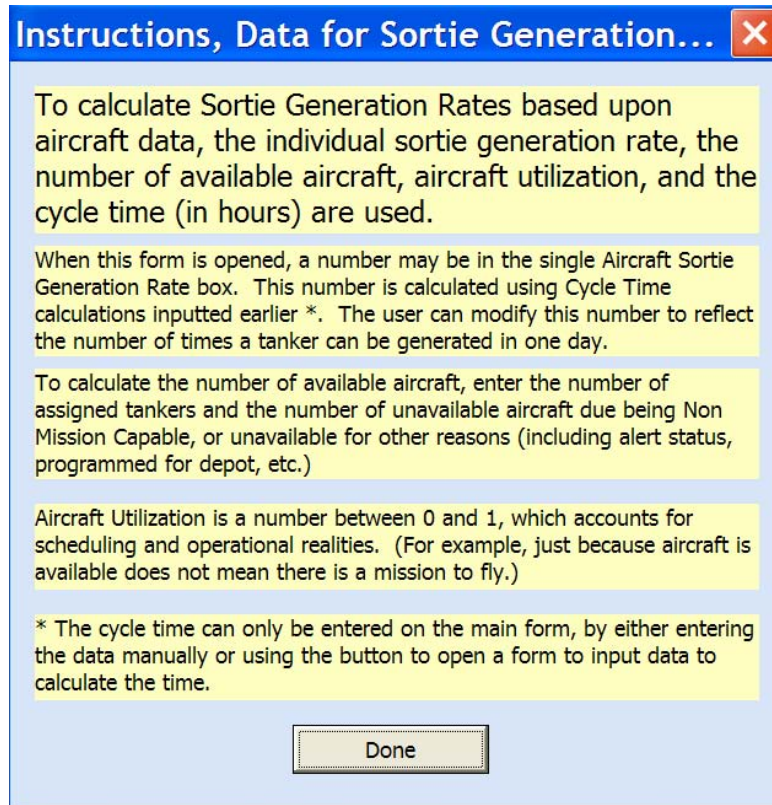
Figure 38. Userform, Aircraft Generation Instructions

```
Option Explicit

Private Sub CmdCancel_Click()
    Unload Me
End Sub
```

INPUTAIRCREWDATA

Figure 39. Userform, Input Aircrew Generation Data

Option Explicit
   Dim TempAssigned As Integer, TempNonAvail As Integer, TempTimeFrame As Double, _
      TempAvail As Double, TempCrewUtilization As Double, _
      WeekMaxHrs As Double, MonthMaxHrs As Double, ThreeMonthMaxHrs As Double, _
      TempWeek As Double, TempMonth As Double, TempThreeMonth As Double, _
      BoxCheck As Integer, HoursCheck As Integer

Private Sub UserForm_Initialize()
' Hides hours boxes and units until a time frame is selected
   OneWeekHrsBox.Visible = False
   OneMonthHrsBox.Visible = False
   ThreeMonthHrsBox.Visible = False

```vb
    OneWeekHrsLbl.Visible = False
    OneMonthHrsLbl.Visible = False
    ThreeMonthHrsLbl.Visible = False
    InsertMaxFlyHrsLbl.Visible = False
End Sub

Private Sub ConsiderAllOption_Click()
' Unhides the appropriate box for user to enter max flying hours for all time frames
    OneWeekHrsBox.Visible = True
    OneWeekHrsLbl.Visible = True
    OneMonthHrsBox.Visible = True
    OneMonthHrsLbl.Visible = True
    ThreeMonthHrsBox.Visible = True
    ThreeMonthHrsLbl.Visible = True
    InsertMaxFlyHrsLbl.Visible = True
End Sub

Private Sub OneMonthOption_Click()
' Unhides the appropriate box for user to enter max flying hours for one month
    OneWeekHrsBox.Visible = False
    OneWeekHrsLbl.Visible = False
    OneMonthHrsBox.Visible = True
    OneMonthHrsLbl.Visible = True
    ThreeMonthHrsBox.Visible = False
    ThreeMonthHrsLbl.Visible = False
    InsertMaxFlyHrsLbl.Visible = True
End Sub

Private Sub OneWeekOption_Click()
' Unhides the appropriate box for user to enter max flying hours for one week
    OneWeekHrsBox.Visible = True
    OneWeekHrsLbl.Visible = True
    OneMonthHrsBox.Visible = False
    OneMonthHrsLbl.Visible = False
    ThreeMonthHrsBox.Visible = False
    ThreeMonthHrsLbl.Visible = False
    InsertMaxFlyHrsLbl.Visible = True
End Sub

Private Sub ThreeMonthOption_Click()
' Unhides the appropriate box for user to enter max flying hours for three months
    OneWeekHrsBox.Visible = False
    OneWeekHrsLbl.Visible = False
    OneMonthHrsBox.Visible = False
    OneMonthHrsLbl.Visible = False
    ThreeMonthHrsBox.Visible = True
```

```vb
      ThreeMonthHrsLbl.Visible = True
      InsertMaxFlyHrsLbl.Visible = True
End Sub


Private Sub CmdCalcAircrewInt_Click()
' Initializes NonAvailBox to allow users to assume all crews are avaialable
      BoxCheck = 0
' Calls subroutine to check if inputs are valid
      Call CheckInputs
      If BoxCheck = 1 Then
         Exit Sub
      End If
' Calculate Available Aircrew
      TempAvail = (TempAssigned - TempNonAvail) * TempCrewUtilization
' Calculate Aircrew Interval
      AircrewInt = TempAvail * TempTimeFrame / RTFT
       If AircrewInt < 0 Then
         AircrewInt = 0
      End If
    TempAircrewSortieGenBox = AircrewInt
End Sub


Private Sub CmdCancel_Click()
'Closes the form without saving any data
      Unload Me
End Sub


Private Sub CmdInstructions_Click()
   InstructionsAircrewInt.Show
End Sub


Private Sub ReturnCmd_Click()
' Returns used to the main form, saving data by hiding the form
      InputAircrewIntData.Hide
End Sub


Sub CheckInputs()
'Assigns users inputs to temporary variables to calculate available aircrew required
      With AssignedBox
        If .Value = "" Or Not IsNumeric(.Value) Then
           MsgBox "Please enter a numeric value for the Total Assigned Aircrew."
           BoxCheck = 1
           .SetFocus
           Exit Sub
        End If
        TempAssigned = AssignedBox
```

```
      If TempAssigned < 0 Then
         MsgBox "Please enter a nonnegative value for the Assigned Aircrew."
         .SetFocus
         BoxCheck = 1
         Exit Sub
      End If
   End With
   With NonAvailBox
      If Not IsNumeric(.Value) Then
         MsgBox "Please enter a numeric value for the Unavailable Crews."
         BoxCheck = 1
         .SetFocus
         Exit Sub
      End If
      TempNonAvail = NonAvailBox
      If TempNonAvail < 0 Or TempNonAvail > TempAssigned Then
         MsgBox "Please enter a nonnegative value between 0 and " & TempAssigned & "
for Unvailable Crews."
         BoxCheck = 1
         .SetFocus
         Exit Sub
      End If
   End With
   With CrewUtilizationBox
      If .Value = "" Or Not IsNumeric(.Value) Then
         MsgBox "Please enter a numeric value for the Aircrew's Utilization."
         BoxCheck = 1
         .SetFocus
         Exit Sub
      End If
      TempCrewUtilization = CrewUtilizationBox
      If TempCrewUtilization < 0 Or TempCrewUtilization > 1 Then
         BoxCheck = 1
         MsgBox "Please enter a number between 0 and 1 for the Aircrew's Utilization."
         .SetFocus
         Exit Sub
      End If
   End With
' Assings a number to the hourscheck variable to let CheckFlyingHoursInput proceedure
know which box to check
' Calls proceedure to check box and uses BoxCheck variable to determine if inputs are
acceptable
   If OneWeekOption = True Then
      HoursCheck = 1
      CheckFlyingHoursInput
      If BoxCheck = 1 Then
```

```
            Exit Sub
        End If
        TempTimeFrame = WeekMaxHrs / 7
    ElseIf OneMonthOption = True Then
        HoursCheck = 2
        CheckFlyingHoursInput
        If BoxCheck = 1 Then
            Exit Sub
        End If
        TempTimeFrame = MonthMaxHrs / 30
    ElseIf ThreeMonthOption = True Then
        HoursCheck = 3
        CheckFlyingHoursInput
        If BoxCheck = 1 Then
            Exit Sub
        End If
        TempTimeFrame = ThreeMonthMaxHrs / 90
    ElseIf ConsiderAllOption = True Then
' Determines the most confining variable from max flying hours per time frames
        HoursCheck = 4
        CheckFlyingHoursInput
        If BoxCheck = 1 Then
            Exit Sub
        End If
        TempWeek = WeekMaxHrs / 7
        TempMonth = MonthMaxHrs / 30
        TempThreeMonth = ThreeMonthMaxHrs / 90
        If TempWeek < TempMonth And TempWeek < TempThreeMonth Then
            TempTimeFrame = TempWeek
        ElseIf TempMonth < TempWeek And TempMonth < TempThreeMonth Then
            TempTimeFrame = TempMonth
        Else
            TempTimeFrame = TempThreeMonth
        End If
    Else
        MsgBox "At least one time frame must be selected."
            BoxCheck = 1
        Exit Sub
    End If

End Sub

Sub CheckFlyingHoursInput()
'Assigns users inputs for max flying hours to temporary variables to calculate
TempTimeFrame
' Exits proceedure if entry to box does not meet appropriate criteria
```

```vba
If HoursCheck = 1 Or HoursCheck = 4 Then
    With OneWeekHrsBox
        If .Value = "" Or Not IsNumeric(.Value) Then
            MsgBox "Please enter a numeric value for the maximum number of hours a
crew can fly in one week."
            BoxCheck = 1
            .SetFocus
            Exit Sub
        End If
        WeekMaxHrs = OneWeekHrsBox
        If WeekMaxHrs < 0 Or WeekMaxHrs > 168 Then
            BoxCheck = 1
            MsgBox "Please enter a number between 0 and 168 for the maximum number
of hours a crew can fly in one week."
            Exit Sub
        End If
    End With
End If
If HoursCheck = 2 Or HoursCheck = 4 Then
    With OneMonthHrsBox
        If .Value = "" Or Not IsNumeric(.Value) Then
            MsgBox "Please enter a numeric value for the maximum number of hours a
crew can fly in one month."
            BoxCheck = 1
            .SetFocus
            Exit Sub
        End If
        MonthMaxHrs = OneMonthHrsBox
        If MonthMaxHrs < 0 Or MonthMaxHrs > 720 Then
            BoxCheck = 1
            MsgBox "Please enter a number between 0 and 720 for the maximum number
of hours a crew can fly in one month."
            Exit Sub
        End If
    End With
End If
If HoursCheck = 3 Or HoursCheck = 4 Then
    With ThreeMonthHrsBox
        If .Value = "" Or Not IsNumeric(.Value) Then
            MsgBox "Please enter a numeric value for the maximum number of hours a
crew can fly in three months."
            BoxCheck = 1
            .SetFocus
            Exit Sub
        End If
        ThreeMonthMaxHrs = ThreeMonthHrsBox
```

```
            If ThreeMonthMaxHrs < 0 Or ThreeMonthMaxHrs > 2160 Then
                BoxCheck = 1
                MsgBox "Please enter a number between 0 and 2160 for the maximum number
    of hours a crew can fly in three months."
                Exit Sub
            End If
        End With
      End If
    End Sub
```

AIRCREW INSTRUCTIONS
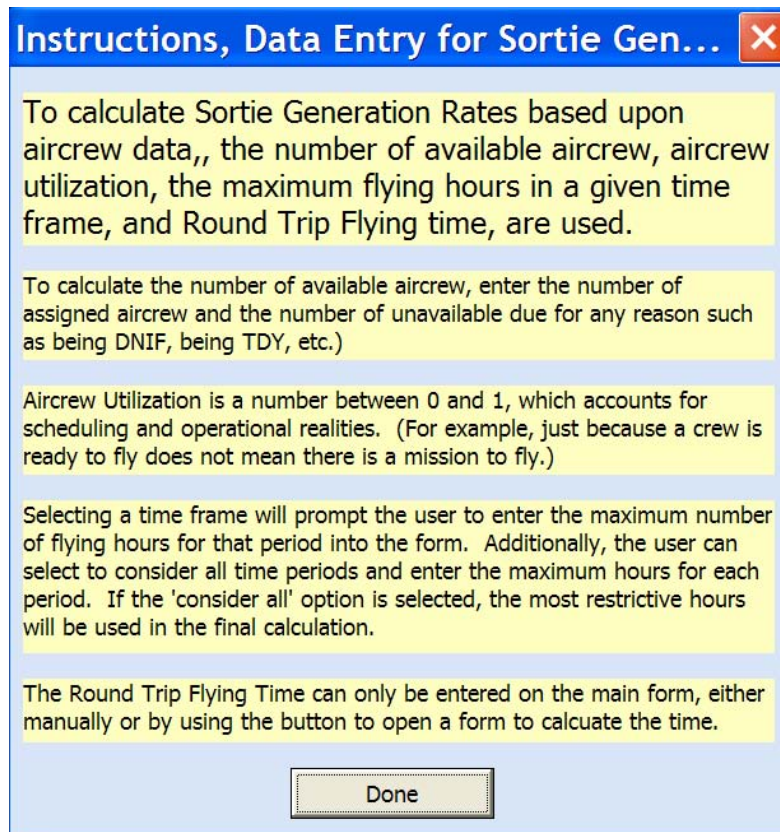
Figure 40. Userform, Aircrew Generation Instructions

```
Option Explicit

Private Sub CmdCancel_Click()
    Unload Me
End Sub
```

INPUTBASEDATA

Figure 41. Userform, Input Base Generation Data

Option Explicit
    Dim TempMOG As Double, TempOpHours As Double, TempQFactor As Double, _
        TempBaseFuel As Double, BoxCheck As Integer, _
        MOGCapability As Double, FuelCapability As Double

Private Sub UserForm_Initialize()
' Checks to see if tanker fuel was inputted before during available fuel calculations
' If it was, value is inputted into the box
    If Not TankerFuelUsed = 0 Then
        TankerFuelUsedBox.Value = TankerFuelUsed
        TankerPoundsOption = True
    End If
End Sub
Private Sub CmdCalcStationInt_Click()
    BoxCheck = 0
' Calls subroutine to check if inputs are valid
    Call CheckInputs
    If BoxCheck = 1 Then
        Exit Sub
    End If

```vb
'Calculate Sortie Generation based on base's data considering MOG and time and fuel
capacity
    MOGCapability = TempMOG * TempOpHours / TotalGroundTime * TempQFactor
    FuelCapability = TempBaseFuel / (TankerFuelUsed + OffloadReq)
    If MOGCapability < FuelCapability Then
        BaseInt = MOGCapability
    Else
        BaseInt = FuelCapability
    End If
    If BaseInt < 0 Then
        BaseInt = 0
    End If
    TempBaseIntBox = BaseInt
End Sub


Private Sub CmdCancel_Click()
' Closes the form without saving any data
    Unload Me
End Sub


Private Sub InstructionsCmd_Click()
    InstructionsBaseInt.Show
End Sub


Private Sub ReturnCmd_Click()
    InputBaseIntData.Hide
End Sub


Sub CheckInputs()
'Assigns users inputs to temporary variables to calculate Station Interval
    With MOGBox
        If .Value = "" Or Not IsNumeric(.Value) Then
            MsgBox "Please enter a numeric value for the base's Maximum Aircraft on
Ground."
            .SetFocus
            BoxCheck = 1
            Exit Sub
        End If
        TempMOG = MOGBox
        If TempMOG < 0 Then
            MsgBox "Please enter a nonnegative value for the base's Maximum Aircraft on
Ground."
            .SetFocus
            BoxCheck = 1
            Exit Sub
        End If
```

```
   End With
   With OpHoursBox
      If .Value = "" Or Not IsNumeric(.Value) Then
         MsgBox "Please enter a numeric value for the base's Operating Hours."
         .SetFocus
         BoxCheck = 1
         Exit Sub
      End If
      TempOpHours = OpHoursBox
      If TempOpHours < 0 Or TempOpHours > 24 Then
         MsgBox "Please enter a number between 0 and 24 Hours for the base's Operating
Hours."
         .SetFocus
         BoxCheck = 1
         Exit Sub
      End If
   End With
   With BaseFuelBox
      If .Value = "" Or Not IsNumeric(.Value) Then
         MsgBox "Please enter a numeric value for the fuel available from the base."
         .SetFocus
         BoxCheck = 1
         Exit Sub
      End If
      TempBaseFuel = BaseFuelBox
      If TempBaseFuel < 0 Then
         MsgBox "Please enter a non negative value for the fuel available from the base."
         .SetFocus
         BoxCheck = 1
         Exit Sub
      End If
   End With
   If PoundsOption = False And GallonsOption = False Then
      MsgBox "Please indicate if base fuel is in pounds or gallons."
      BoxCheck = 1
      Exit Sub
   ElseIf GallonsOption = True Then
      TempBaseFuel = TempBaseFuel * 6.79
   End If
   With QFactorBox
      If .Value = "" Or Not IsNumeric(.Value) Then
         MsgBox "Please enter a numeric value for the base's Queuing Efficiency."
         .SetFocus
         BoxCheck = 1
         Exit Sub
      End If
```

```
        TempQFactor = QFactorBox
        If TempQFactor < 0 Or TempQFactor > 1 Then
            MsgBox "Please enter a number between 0 and 1 for the base's Queuing Factor."
            .SetFocus
            BoxCheck = 1
            Exit Sub
        End If
    End With
    With TankerFuelUsedBox
        If .Value = "" Or Not IsNumeric(.Value) Then
            MsgBox "Please enter a numeric value for the fuel used by the Tanker."
            .SetFocus
            BoxCheck = 1
            Exit Sub
        End If
        TankerFuelUsed = TankerFuelUsedBox
        If TankerFuelUsed < 0 Then
            MsgBox "Please enter a non negative value for the fuel used by the Tanker."
            .SetFocus
            BoxCheck = 1
            Exit Sub
        End If
    End With
    If TankerPoundsOption = False And TankerGallonsOption = False Then
        MsgBox "Please indicate if tanker fuel is in pounds or gallons."
        Exit Sub
    ElseIf TankerGallonsOption = True Then
        TankerFuelUsed = TankerFuelUsed * 6.799
    End If
End Sub
```

BASE INSTRUCTIONS
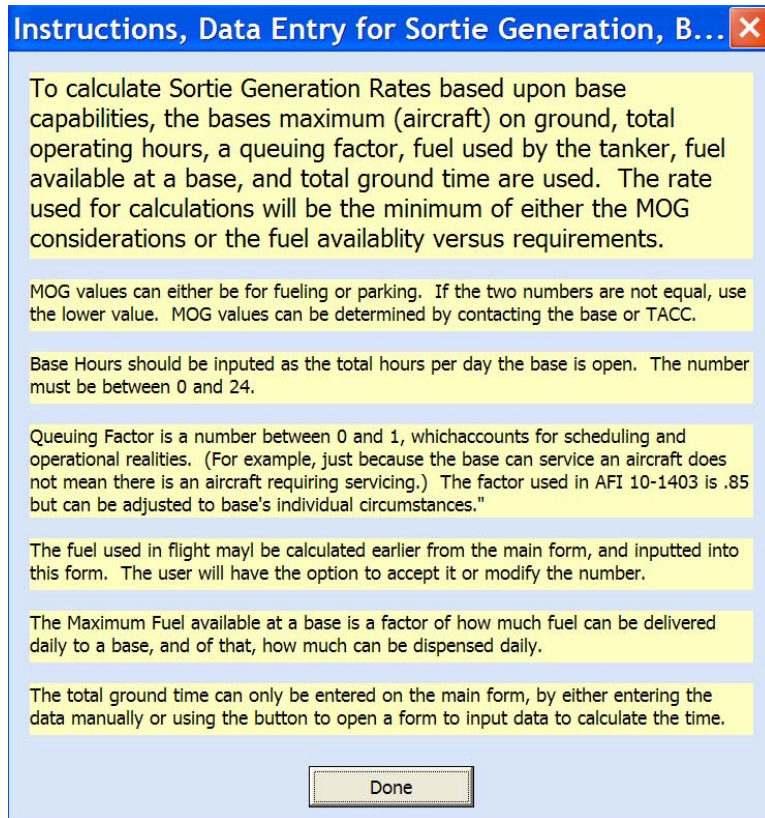
Figure 42. Userform, Base Generation Instructions

Option Explicit

Private Sub CmdCancel_Click()
    Unload Me
End Sub

Appendix B. Maximum Fuel Available, First Analysis of Utilization Factors

Table 15. Complete Data for Initial Analysis of Utilization Factors

Sortie Gen Utilizations				Max Fuel Available per Day			
Aircraft	Aircrew	Base		Offload = 1	Offload = .75	Offload = .5	Offload = .25
1	1	1		1,368,406.1	1,026,304.5	684,203.0	342,101.5
1	1	0.75		1,368,406.1	1,026,304.5	684,203.0	342,101.5
1	1	0.5		1,368,406.1	1,026,304.5	684,203.0	342,101.5
1	1	0.25		1,368,406.1	1,026,304.5	684,203.0	342,101.5
1	0.75	1		1,026,304.5	769,728.4	513,152.3	256,576.1
1	0.75	0.75		1,026,304.5	769,728.4	513,152.3	256,576.1
1	0.75	0.5		1,026,304.5	769,728.4	513,152.3	256,576.1
1	0.75	0.25		1,026,304.5	769,728.4	513,152.3	256,576.1
1	0.5	1		684,203.0	513,152.3	342,101.5	171,050.8
1	0.5	0.75		684,203.0	513,152.3	342,101.5	171,050.8
1	0.5	0.5		684,203.0	513,152.3	342,101.5	171,050.8
1	0.5	0.25		684,203.0	513,152.3	342,101.5	171,050.8
1	0.25	1		342,101.5	256,576.1	171,050.8	85,525.4
1	0.25	0.75		342,101.5	256,576.1	171,050.8	85,525.4
1	0.25	0.5		342,101.5	256,576.1	171,050.8	85,525.4
1	0.25	0.25		342,101.5	256,576.1	171,050.8	85,525.4
0.75	1	1		1,368,406.1	1,026,304.5	684,203.0	342,101.5
0.75	1	0.75		1,368,406.1	1,026,304.5	684,203.0	342,101.5
0.75	1	0.5		1,368,406.1	1,026,304.5	684,203.0	342,101.5
0.75	1	0.25		1,368,406.1	1,026,304.5	684,203.0	342,101.5
0.75	0.75	1		1,026,304.5	769,728.4	513,152.3	256,576.1
0.75	0.75	0.75		1,026,304.5	769,728.4	513,152.3	256,576.1
0.75	0.75	0.5		1,026,304.5	769,728.4	513,152.3	256,576.1
0.75	0.75	0.25		1,026,304.5	769,728.4	513,152.3	256,576.1
0.75	0.5	1		684,203.0	513,152.3	342,101.5	171,050.8
0.75	0.5	0.75		684,203.0	513,152.3	342,101.5	171,050.8
0.75	0.5	0.5		684,203.0	513,152.3	342,101.5	171,050.8
0.75	0.5	0.25		684,203.0	513,152.3	342,101.5	171,050.8
0.75	0.25	1		342,101.5	256,576.1	171,050.8	85,525.4
0.75	0.25	0.75		342,101.5	256,576.1	171,050.8	85,525.4
0.75	0.25	0.5		342,101.5	256,576.1	171,050.8	85,525.4
0.75	0.25	0.25		342,101.5	256,576.1	171,050.8	85,525.4
0.5	1	1		1,368,406.1	1,026,304.5	684,203.0	342,101.5
0.5	1	0.75		1,368,406.1	1,026,304.5	684,203.0	342,101.5
0.5	1	0.5		1,368,406.1	1,026,304.5	684,203.0	342,101.5
0.5	1	0.25		1,368,406.1	1,026,304.5	684,203.0	342,101.5
0.5	0.75	1		1,026,304.5	769,728.4	513,152.3	256,576.1

0.5	0.75	0.75		1,026,304.5	769,728.4	513,152.3	256,576.1
0.5	0.75	0.5		1,026,304.5	769,728.4	513,152.3	256,576.1
0.5	0.75	0.25		1,026,304.5	769,728.4	513,152.3	256,576.1
0.5	0.5	1		684,203.0	513,152.3	342,101.5	171,050.8
0.5	0.5	0.75		684,203.0	513,152.3	342,101.5	171,050.8
0.5	0.5	0.5		684,203.0	513,152.3	342,101.5	171,050.8
0.5	0.5	0.25		684,203.0	513,152.3	342,101.5	171,050.8
0.5	0.25	1		342,101.5	256,576.1	171,050.8	85,525.4
0.5	0.25	0.75		342,101.5	256,576.1	171,050.8	85,525.4
0.5	0.25	0.5		342,101.5	256,576.1	171,050.8	85,525.4
0.5	0.25	0.25		342,101.5	256,576.1	171,050.8	85,525.4
0.25	1	1		756,028.9	567,021.7	378,014.5	189,007.2
0.25	1	0.75		756,028.9	567,021.7	378,014.5	189,007.2
0.25	1	0.5		756,028.9	567,021.7	378,014.5	189,007.2
0.25	1	0.25		756,028.9	567,021.7	378,014.5	189,007.2
0.25	0.75	1		756,028.9	567,021.7	378,014.5	189,007.2
0.25	0.75	0.75		756,028.9	567,021.7	378,014.5	189,007.2
0.25	0.75	0.5		756,028.9	567,021.7	378,014.5	189,007.2
0.25	0.75	0.25		756,028.9	567,021.7	378,014.5	189,007.2
0.25	0.5	1		684,203.0	513,152.3	342,101.5	171,050.8
0.25	0.5	0.75		684,203.0	513,152.3	342,101.5	171,050.8
0.25	0.5	0.5		684,203.0	513,152.3	342,101.5	171,050.8
0.25	0.5	0.25		684,203.0	513,152.3	342,101.5	171,050.8
0.25	0.25	1		342,101.5	256,576.1	171,050.8	85,525.4
0.25	0.25	0.75		342,101.5	256,576.1	171,050.8	85,525.4
0.25	0.25	0.5		342,101.5	256,576.1	171,050.8	85,525.4
0.25	0.25	0.25		342,101.5	256,576.1	171,050.8	85,525.4

Appendix C. Maximum Fuel Available, Second Analysis of Utilization Factors

Table 16. Complete Data for Second Utilization Factor Analysis

Sortie Gen Utilizations				Max Fuel Available per Day			
Aircraft	Aircrew	Base		Offload = 1	Offload = .95	Offload = .9	Offload = .85
1	1	1		1,368,406.1	1,299,985.8	1,231,565.5	1,163,145.2
1	1	0.95		1,368,406.1	1,299,985.8	1,231,565.5	1,163,145.2
1	1	0.9		1,368,406.1	1,299,985.8	1,231,565.5	1,163,145.2
1	1	0.85		1,368,406.1	1,299,985.8	1,231,565.5	1,163,145.2
1	0.95	1		1,299,985.8	1,234,986.5	1,169,987.2	1,104,987.9
1	0.95	0.95		1,299,985.8	1,234,986.5	1,169,987.2	1,104,987.9
1	0.95	0.9		1,299,985.8	1,234,986.5	1,169,987.2	1,104,987.9
1	0.95	0.85		1,299,985.8	1,234,986.5	1,169,987.2	1,104,987.9
1	0.9	1		1,231,565.5	1,169,987.2	1,108,408.9	1,046,830.6
1	0.9	0.95		1,231,565.5	1,169,987.2	1,108,408.9	1,046,830.6
1	0.9	0.9		1,231,565.5	1,169,987.2	1,108,408.9	1,046,830.6
1	0.9	0.85		1,231,565.5	1,169,987.2	1,108,408.9	1,046,830.6
1	0.85	1		1,163,145.2	1,104,987.9	1,046,830.6	988,673.4
1	0.85	0.95		1,163,145.2	1,104,987.9	1,046,830.6	988,673.4
1	0.85	0.9		1,163,145.2	1,104,987.9	1,046,830.6	988,673.4
1	0.85	0.85		1,163,145.2	1,104,987.9	1,046,830.6	988,673.4
0.95	1	1		1,368,406.1	1,299,985.8	1,231,565.5	1,163,145.2
0.95	1	0.95		1,368,406.1	1,299,985.8	1,231,565.5	1,163,145.2
0.95	1	0.9		1,368,406.1	1,299,985.8	1,231,565.5	1,163,145.2
0.95	1	0.85		1,368,406.1	1,299,985.8	1,231,565.5	1,163,145.2
0.95	0.95	1		1,299,985.8	1,234,986.5	1,169,987.2	1,104,987.9
0.95	0.95	0.95		1,299,985.8	1,234,986.5	1,169,987.2	1,104,987.9
0.95	0.95	0.9		1,299,985.8	1,234,986.5	1,169,987.2	1,104,987.9
0.95	0.95	0.85		1,299,985.8	1,234,986.5	1,169,987.2	1,104,987.9
0.95	0.9	1		1,231,565.5	1,169,987.2	1,108,408.9	1,046,830.6
0.95	0.9	0.95		1,231,565.5	1,169,987.2	1,108,408.9	1,046,830.6
0.95	0.9	0.9		1,231,565.5	1,169,987.2	1,108,408.9	1,046,830.6
0.95	0.9	0.85		1,231,565.5	1,169,987.2	1,108,408.9	1,046,830.6
0.95	0.85	1		1,163,145.2	1,104,987.9	1,046,830.6	988,673.4
0.95	0.85	0.95		1,163,145.2	1,104,987.9	1,046,830.6	988,673.4
0.95	0.85	0.9		1,163,145.2	1,104,987.9	1,046,830.6	988,673.4
0.95	0.85	0.85		1,163,145.2	1,104,987.9	1,046,830.6	988,673.4
0.9	1	1		1,368,406.1	1,299,985.8	1,231,565.5	1,163,145.2
0.9	1	0.95		1,368,406.1	1,299,985.8	1,231,565.5	1,163,145.2
0.9	1	0.9		1,368,406.1	1,299,985.8	1,231,565.5	1,163,145.2
0.9	1	0.85		1,368,406.1	1,299,985.8	1,231,565.5	1,163,145.2
0.9	0.95	1		1,299,985.8	1,234,986.5	1,169,987.2	1,104,987.9
0.9	0.95	0.95		1,299,985.8	1,234,986.5	1,169,987.2	1,104,987.9

0.9	0.95	0.9		1,299,985.8	1,234,986.5	1,169,987.2	1,104,987.9
0.9	0.95	0.85		1,299,985.8	1,234,986.5	1,169,987.2	1,104,987.9
0.9	0.9	1		1,231,565.5	1,169,987.2	1,108,408.9	1,046,830.6
0.9	0.9	0.95		1,231,565.5	1,169,987.2	1,108,408.9	1,046,830.6
0.9	0.9	0.9		1,231,565.5	1,169,987.2	1,108,408.9	1,046,830.6
0.9	0.9	0.85		1,231,565.5	1,169,987.2	1,108,408.9	1,046,830.6
0.9	0.85	1		1,163,145.2	1,104,987.9	1,046,830.6	988,673.4
0.9	0.85	0.95		1,163,145.2	1,104,987.9	1,046,830.6	988,673.4
0.9	0.85	0.9		1,163,145.2	1,104,987.9	1,046,830.6	988,673.4
0.9	0.85	0.85		1,163,145.2	1,104,987.9	1,046,830.6	988,673.4
0.85	1	1		1,368,406.1	1,299,985.8	1,231,565.5	1,163,145.2
0.85	1	0.95		1,368,406.1	1,299,985.8	1,231,565.5	1,163,145.2
0.85	1	0.9		1,368,406.1	1,299,985.8	1,231,565.5	1,163,145.2
0.85	1	0.85		1,368,406.1	1,299,985.8	1,231,565.5	1,163,145.2
0.85	0.95	1		1,299,985.8	1,234,986.5	1,169,987.2	1,104,987.9
0.85	0.95	0.95		1,299,985.8	1,234,986.5	1,169,987.2	1,104,987.9
0.85	0.95	0.9		1,299,985.8	1,234,986.5	1,169,987.2	1,104,987.9
0.85	0.95	0.85		1,299,985.8	1,234,986.5	1,169,987.2	1,104,987.9
0.85	0.9	1		1,231,565.5	1,169,987.2	1,108,408.9	1,046,830.6
0.85	0.9	0.95		1,231,565.5	1,169,987.2	1,108,408.9	1,046,830.6
0.85	0.9	0.9		1,231,565.5	1,169,987.2	1,108,408.9	1,046,830.6
0.85	0.9	0.85		1,231,565.5	1,169,987.2	1,108,408.9	1,046,830.6
0.85	0.85	1		1,163,145.2	1,104,987.9	1,046,830.6	988,673.4
0.85	0.85	0.95		1,163,145.2	1,104,987.9	1,046,830.6	988,673.4
0.85	0.85	0.9		1,163,145.2	1,104,987.9	1,046,830.6	988,673.4
0.85	0.85	0.85		1,163,145.2	1,104,987.9	1,046,830.6	988,673.4

Appendix D. Data and Results for Forecast

Table 17. Data and Results for Forecasting with TEM

Day	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Aircraft Assigned	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15
Crews Assigned	23	23	23	23	23	23	23	23	23	23	23	23	23	23	23	23
(NMC/PMC) Aircraft	5	5	5	6	4	5	3	4	3	5	4	3	3	4	3	3
Ground Alert Aircraft	1	1	1	1	1	1	1	3	1	1	1	2	1	1	1	1
Actual Sorties	11	8	10	10	8	9	9	12	9	11	11	14	11	6	9	10
Base Fuel Capacity (million gallons)	4900	4900	4900	4900	4900	4900	4900	4900	4900	4900	4900	4900	4900	4900	4900	4900
Sortie Duration (hrs)	67.4	58.6	63.6	75.4	69.2	79.5	57.5	75.4	54.3	59.8	65.9	80.9	88.5	37.3	56.6	67.4
Avg Offload (1,000 lbs)	82.91	68.99	76.86	97.97	80.58	91.16	68.30	74.49	84.34	80.99	77.34	68.16	93.05	82.50	61.17	69.40
Avg Sortie Duration (hrs)	6.13	7.33	6.36	7.54	8.65	8.83	6.39	6.28	6.03	5.44	5.99	5.78	8.05	6.22	6.29	6.74
Total Actual Offload (1,000 lbs)	912	551.9	768.6	979.7	644.6	820.44	614.7	893.9	759.1	890.9	850.7	954.2	1023.6	495	550.5	694
Model	1137.3	951.4	1095.7	924.2	805.6	788.9	1090.7	1109.1	1155	1281.9	1163.2	1205.9	866.2	1120.9	1108.1	1033.9
Actual Difference	225.3	399.5	327.1	-55.5	161	-31.54	476	215.2	395.9	391	312.5	251.7	-157.4	625.9	557.6	339.9
% Difference	124.70%	172.39%	142.56%	94.34%	124.98%	96.16%	177.44%	124.07%	152.15%	143.89%	136.73%	126.38%	84.62%	226.44%	201.29%	148.98%

Day	17	18	19	20	21	22	23	24	25
Aircraft Assigned	15	15	15	15	15	15	15	15	15
Crews Assigned	23	23	23	23	23	23	23	23	23
(NMC/PMC) Aircraft	3	4	5	4	4	4	2	3	3
Ground Alert Aircraft	1	1	1	1	3	2	1	1	1
Actual Sorties	8	8	9	11	13	11	10	12	11
Base Fuel Capacity (million gallons)	4900	4900	4900	4900	4900	4900	4900	4900	4900
Sortie Duration (hrs)	66.6	46.4	64.6	85.4	91.3	78	67.8	72.6	79
Avg Offload (1,000 lbs)	72.86	77.25	84.68	66.42	73.06	77.70	79.26	74.47	94.81
Avg Sortie Duration (hrs)	8.33	5.80	7.18	7.76	7.02	7.09	6.78	6.05	7.18
Total Actual Offload (1,000 lbs)	582.9	618	762.1	730.6	949.8	854.7	792.6	893.6	1042.9
Model	837.1	1201.5	970.9	897.6	992.3	982.8	1027.8	1151.9	970.3
Actual Difference	254.2	583.5	208.8	167	42.5	128.1	235.2	258.3	-72.6
% Difference	143.61%	194.42%	127.40%	122.86%	104.47%	114.99%	129.67%	128.91%	93.04%

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14. ABSTRACT

The Air Force's aerial refueling tanker aircraft provide essential support for deployment and employment of combat and combat support aircraft, by extending their endurance and enhancing fighting efficiency. As the lead command for air refuelers, Air Mobility Command (AMC) must frequently examine the capability of current and proposed tanker fleets to meet mission requirements due to limited tanker resources. Analysts in AMC primarily use the Combined Mating and Ranging Plans System to provide actual tanker/receiver aircraft schedules and flight plans that take into account numerous system constraints. However, this tool can take weeks to run. Even recently developed quick look tools, aimed at optimization of the fleet, can take 1/2 hour or more. Additionally, most of these more recent studies and tools assess the feasibility of deployments. Less attention has been given to the employment phase of missions. AMC lacks a quick look tool to quickly perform rough cut capacity analysis for tanker use and assess the feasibility of proposed employment of tankers.

To develop a feasibility quick look tool, the basic formulae for computing tankers missions must be understood. While the airlift community has defined million ton miles per day as their keystone metric, the tanker community -- concerned with being on time, on target, with fuel -- lacks such a definitive metric. This thesis describes fundamental algebraic relations that characterize employment of air refueling aircraft, employing rough cut capacity planning to determine feasibility of tanker employment with a given amount of resources. The Tanker Employment Model provides AMC with an efficient tool for quickly assessing tanker employment capabilities.

15. SUBJECT TERMS
Refueling in Flight, Tanker Aircraft, Rough Cut Capacity, Employment Problem, Models, Algebra, Tanker Scheduling

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