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Mathematical Programming Model for Fighter Training Squadron Pilot Scheduling

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MATHEMATICAL PROGRAMMING
MODEL FOR FIGHTER TRAINING
SQUADRON PILOT SCHEDULING

THESIS

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Abstract

The United States Air Force fighter training squadrons build weekly schedules using a long and tedious process. Very little of this process is automated and optimality of any kind is nearly impossible. Schedules are built to a feasible condition only to be changed with consideration of Wing level requirements. Weekly flying schedules are restricted by requirements for crew rest, days since a pilot's last sortie, sorties in the last 30 days, and sorties in the last 90 days. By providing a scheduling model to the pilot charged with creating the schedule, valuable pilot hours could be spent in the cockpit, simulator, or other required duty. This research effort presents a mathematical programming (MP) approach to the fighter squadron pilot training scheduling problem. The methodology presented is based on binary variables that will provide integer solutions to every feasible set of inputs. A simulator heuristic developed specifically for this problem assigns pilots to simulator sorties based on the feasible solutions obtained from two different formulation and solving approaches. One approach assigns training mission sorties and duties for the entire week, while the other approach breaks the week into ten successive sub-problems. The model constructs two feasible schedules in approximately 2.5 minutes.

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I would like to dedicate this effort to my grandfather who has always encouraged me to work hard while displaying honor and integrity. My grandfather has been and will always be my mentor, my pastor, and my hero.

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Thomas M. Newlon

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MATHEMATICAL PROGAMMING MODEL FOR FIGHTER TRAINING SQUADRON PILOT SCHEDULING

I. Introduction

1.1 Background

Scheduling the required training for fighter squadron personnel is a time consuming and mostly manual process that must take into account numerous factors. Due to the resource constraints and pilot requirements, building a monthly, weekly, and daily schedule can be challenging and require hours of time. The weekly flying schedule is restricted by requirements for crew rest, days since a pilot's last sortie, number of sorties in the last 30 days, and number of sorties in the last 90 days. Often, a lesser ranked and inexperienced pilot is tasked to build the weekly schedule. The development of a scheduling model is important and requires a great deal of analytical problem solving to overcome the complexities associated with the scheduling problem. By providing a scheduling model to the pilot charged with creating the schedule, valuable pilot hours could be spent in the cockpit, simulator, or other required duty.

A squadron is defined as the basic administrative aviation unit of the Army, Navy, Marine Corps, and the Air Force consisting of two or more flights of aircraft. Normally, all the aircraft are of the same type (i.e. an F-15 squadron). A flight is defined as the basic tactical unit in the Air Force consisting of four or more aircraft in two or more elements. A sortie is defined as an operational flight by one aircraft (DoD, 2001). Thus, Air Force squadrons generally consist of 12 to 24 aircraft and 25 – 45 pilots which perform 10 – 24 sorties per day.

The pilot building the schedule (i.e. the scheduler) must account for the squadron's training requirements and ensure that pilots are only scheduled for appropriate training missions. A pilot should not be scheduled to fly a training sortie for a qualification level he/she has already acquired. Additionally, the pilot should not be scheduled for training missions well above their current qualification level. Many training missions have prerequisite training missions. The scheduler should ensure that prerequisites are successfully met before a pilot is scheduled for a training mission. Then the schedule is built with an assumption of available resources and existing manpower. The schedule should reflect the Director of Operations (DO) preferences as much as possible. Additionally, the schedule must be flexible and adapt to meet real-time operational conditions. The weekly schedule may change drastically if anything prevents the success of all scheduled missions. The scheduler may spend valuable hours developing a feasible schedule that will later be changed to meet real-time demands and coordination constraints. The initial feasible solution is merely a starting point for the weekly schedule. A well-designed model that optimizes any portion of the scheduling process and provides an optimal or near optimal solution in fractions of an hour would vastly improve the existing process.

Training Background

Training is one of the most important aspects of any career. For United States Air Force (USAF) pilots, it could very well be the difference between life and death, gain or loss of air superiority, and therefore the ability to defend the nation. Therefore, training must be accomplished in the most effective and efficient manner possible. Pilot training is required for USAF pilots to progress from Initial Qualification Training (IQT), which occurs prior to the first squadron assignment, to Mission Qualification Training (MQT), which begins at the first operational squadron assignment. Afterwards, Continuation Training (CT) is used to maintain a pilot's current qualification status.

Mission readiness is the ultimate goal of MQT. MQT is used to get new or transferred pilots to a Basic Mission Capable (BMC) status within their current assignment. A pilot that completes the minimum requirement of MQT is at the Combat Mission Ready (CMR) status. Finally, re-qualification of previously CMR qualified pilots is accomplished with MQT. Continuation Training (CT) is the process used to maintain the BMC and CMR status of pilots. (DAF, 2004)

> *In order to preserve CMR status once qualified, pilots must pass periodic flight and ground evaluations, fly a certain number of training sorties per month, accomplish a number of specific training events on these sorties, and attend a number of ground training events. These ground training events include physiological training, instrument refresher course, life support training (egress, ejection, water survival, etc.), handgun training, intelligence training, combat survival training, chemical warfare defense training, situational emergency procedures training, and weapons and tactics academics* (Boyd et. al., 2006).

Operational squadrons have additional requirements for specialized training as well. Specialized training programs are used to prepare pilots with the following capabilities: Flight Lead Upgrade (FLUG), Instructor Pilot Upgrade (IPUG), Mission Commander, Night Vision Goggles (NVG), and Helmet Mounted Cueing System (Boyd et. al., 2006).

Specialized training, IQT, MQT, and CT, is outlined in AFI 11-2F-15V1, 19 July 2004, and the specific training missions are further detailed in the related upgrade program syllabus. Pilots may have different training requirements due to their specific qualification level or due to the subsequent level they are striving to achieve. The DO may request a specific pilot or group of pilots to fly a certain type of mission or to fly at a specific day or time. The schedule must account for additional duties, such as Designated Squadron Supervisor known as TOP 3 in AF vernacular and Supervisor of Flying-Operations (SOF). These duties are scheduling requirements which further restrict the problem. Schedules must also account for factors such as sortie rate, necessary ground and simulator training, unforeseen Duty to Not Include Flying (DNIF) status, leave, or other duties.

The total number of Ready Aircrew Program (RAP) sorties is the basic requirement for maintaining a qualification level. The number of RAP sorties and corresponding events that build pilot status for each qualification level are determined by Major Commands (MAJCOM) and unit commanders. Successful tactical mission profile or building block sorties are labeled effective RAP training sorties.

The Aviation Resource Management System (ARMS) Database is used to maintain all the data required to track RAP currencies and requirements. In each fighter squadron, the Operations Data Management (ODM) personnel manage the ARMS Database. All accomplished events are logged by the pilots and then passed to the ODM personnel. The ODM personnel then transfer the accomplished events information into the ARMS Database. Printed spreadsheet reports are prepared for the commander and squadron supervisors in order to ease tracking of squadron training activities.

Evaluation Background

Completed training does not always lead to successful preparation. There is a need to evaluate the success of the training program and the overall readiness of the individuals exposed to the training program. In the fighter squadron community, this is accomplished with the Stan/Eval program. The Stan/Eval programs in every unit are outlined by AFI 11-202 Vol 2 – Aircrew Standardization/Evaluation Program as well as aircraft specific AFI 11-2MDS-V2 series. Squadron flight examiners, designated as such by the squadron commander, are responsible for conducting a two phase evaluation for readiness specified by flight and ground responsibilities. Instrument Evaluation and Mission Evaluation are the most common types of aircrew evaluations.

Instrument Evaluation is used to verify that pilots are able to operate in conditions that restrict the ability to visually identify the horizon and thus require instrument utilization. For the flight phase of this type of evaluation, a pilot must demonstrate the ability to fly the aircraft by instrument flight rules including approaches at airfields other than home. The evaluator will be in a chase airframe or in the backseat of the fighter aircraft flown by the pilot (in airframes with two seats). The ground phase of Instrument Evaluation requires Instrument Refresher Course (IRC), IRC examination, closed and open book portions of the aircraft qualification examination, an Emergency Procedures Evaluations (EPE) Simulator, and a check of the pilot's flight publications. (Boyd et. al., 2006)

The flight phase of Mission Evaluation involves a scenario that is representative of the squadron's expected mission. Evaluators typically fly in another airframe, while the pilot's highest qualification dictates where he/she will fly the checkride utilizing the airframe formations and tactics of the unit's primary mission. During the ground phase of Mission Evaluation, pilots will complete an EPE simulation that emphasizes emergencies impacting the pilot's ability to employ weapons or operate in a tactical manner for the ground phase of Mission Evaluation. (Boyd et. al., 2006)

Scheduling

The scheduling process has seen little change in the past 25 years (Boyd et. al., 2006). However, technology has improved greatly and the resources are available to improve this process (Boyd et. al., 2006). As Force Shaping continues to be a standard practice, the United States Air Force must take advantage of the opportunity to achieve more with less. Decreasing the number of airmen requires jobs to be accomplished in a more efficient manner. Thus, building a model that accomplishes this time consuming task rapidly and effectively has value. Using technological advances to automate the scheduling process would provide a more efficient schedule building process and provide the possibility of optimally scheduling some or all of the weekly events.

1.2 Problem Objective and Limitations

The objective of the research is to create a model that produces a feasible training schedule for a fighter squadron. The following problem characteristics must be considered and modeled to the greatest extent possible. Creating the weekly flying schedule can be very time intensive and may require corrective action after the first weather cancellation, failed mission or other event that disrupts the schedule and causes a chain-reaction of schedule changes to occur. The weekly flying schedule is restricted by requirements for crew rest, days since a pilot's last sortie, number of sorties in the last 30 days, and number of sorties in the last 90 days. The feasibility of multiple sorties in a single day is limited by the requirement of a 12-hour flight duty period (FDP). This requirement prevents pilots from flying the airframe after 12 hours of duty. A typical fighter squadron may have a total of 22 sorties every day. These sorties are broken into configuration types and two time periods. Daily flying schedules usually consist of two sections. Each section is called a "GO" and contains the following information for that portion of the flying schedule: pilot to plane assignments, meeting schedule, simulator schedule, and additional duties. The first section is referred to as the AM GO and the second section is referred to as the PM GO. Table 1 shows that there are typically 12 sorties in the AM GO and 10 sorties in the PM GO, this type of daily schedule is called 12Turn10 in AF vernacular. Table 1 also shows the grouping of sorties and mission description.

Table 1. Typical Daily Sorties in a Fighter Squadron

Time	**Configuration**	**Number of Sorties**	**Description**
AM	C	4	Two fuel Tanks
AM	E	4	Air to Ground
AM	B	2	Air to Air
AM	B	2	Air to Air
PM	C	4	Two fuel Tanks
PM	E	2	Air to Ground
PM	B	2	Air to Air
PM	B	2	Air to Air

There are many mission types that need to be taken into account. Each of the mission types have differing requirements for the number and types of pilots that need to be assigned. In addition to the previously mentioned mission types (MQT, FLUG, IPUG, NVG, and helmet mounted cueing systems), the schedule should account for Mission Check (MSN CHK), Instrument Check (INST CHK), and CT in the following three areas: Basic Fighter Maneuvers (BFM), Situational Awareness Training (SAT), and Suppression of Enemy Air Defenses (SEAD). The specified crews for each type of mission consists of combinations of instructor pilots (IP), flight leads (FL), upgrade pilots (UP), and pilots (P). Several mission types and corresponding requirements are presented in the sample syllabus shown in Figure 1. Every 4-ship mission listed requires at least one FL and many require an IP. Additionally, an IP can fulfill the requirement for a second FL pilot in a 4-ship mission. Every 2-ship mission listed requires at least one FL. Thus, the majority of 4-ship mission types can be accounted for by requiring that at least one IP and one additional FL or higher qualified pilot are assigned to each 4-ship mission. The majority of 2-ship mission types can be accounted for by requiring that at least one FL or higher qualified pilot is assigned to every 2-ship mission. Multiple syllabus and mission types, various pilot qualification requirements for the mission types, and number of pilots required for each mission type adds complexity to the scheduling problem.

Sample Syllabus

Event	*Sorties*	*Crew*	*Configuration*	*Airspace*
MQT-2	2	IP / UP	A / B	A1 / A2
FLUG-3	4	UP / IP / FL / P	A / B	A1 / A2
MSN CHK	4	MP / FE / FL / P	C / D / E	S1 / S2
INST CHK	2	MP / FE	A / B / C / D / E	A1 / A2 / S1 / S2
IPUG-2	2	UP / IP (WIP Desired)	A / B	A1 / A2
FLUG-7	4	UP / IP / FL / P	D / E	S1 / S2
FLUG-2	2	UP / IP	A / B	A1 / A2
MQT-3	2	IP / UP	A / B	A1 / A2
FLUG-4	4	UP / IP / FL / P	A / B	A1 / A2
IPUG-6	7	UP / IP (WIP Desired) / FL / P / FL / P / FL	A / B	A1
IPUG-3	2	UP / IP (WIP Desired)	A / B	A1 / A2
FLUG-8	2	UP / IP	C / D / E	S1 / S2
CT-BFM	2	FL/ P	A / B	A1 / A2
CT-SEAD	2	FL / P	B / C / D	S1 / S2
CT-SEAD	4	FL / P / FL / P	B / C / D	S1 / S2
CT-BFM	2	FL/ P	A / B	A1 / A2
CT-SAT	2	FL / P	D / E	S1 / S2
CT-SAT	4	FL / P / FL / P	D / E	S1 / S2

Figure 1. Sample Syllabus (Boyd et. al., 2006)

1.3 Problem Modeling

A complete model would account for a priority list of DO specified requests, syllabus requirements, upgrade requirements, continuation training requirements and sortie count requirements. The syllabus defines all pre-requisites and training requirements needed for the successful completion of a specific course. A pilot involved in the FLUG program would need to complete all the training requirements outlined by the FLUG syllabus. A complete model would also account for the present qualification levels of each pilot and whether or not all prerequisite training had been accomplished prior to each scheduled mission. The model must be in accordance with (IAW) all governing AFIs and squadron level requirements. The scope of this problem is well beyond the capabilities of the basic Excel solver, which can only handle 200 integer variables in a single problem. Additionally, building a model with expensive solver software would not be useful to fighter squadrons without the purchase of that software package. Therefore, building a model that uses an affordable Excel based solver capable of handling larger problems makes sense.

The problem is further complicated by various sortie counts (15-day, 30-day, and 90-day), which have significant implications to the fighter pilot training mission. A pilot that exceeds 15 days without flying a sortie will be required to fly an additional sortie before returning to the training program. A pilot that fails to meet the 90-day requirement will lose that qualification. Therefore, finding appropriate priority weighting for these events is another difficulty associated with this problem.

Another area of difficulty is dealing with pilot availability. A pilot that is on leave, temporary duty (TDY), or deployed would be unavailable for any duty in the squadron. However, a pilot that is restricted to Duty to Not Include Flying (DNIF) would be available to perform TOP3, SOF, or other duties that do not involve flying. All other pilots are assumed to be available for any and all duties. However, availability may also be limited by the required crew rest of 12 hours.

Further complicating the problem formulation is the need to model various types of daily flight possibilities for each pilot. A pilot may be assigned to fly a single sortie, two sorties with separate briefings (Double Turn), or multiple sorties (2-3) from a single briefing each day. In the later case, the pilot remains in the aircraft with engines running and the aircraft is refueled between missions (Pit-N-Go). A key concern is that a pilot who flies a sortie later in the duty day must be able to be on the ground with engines shut down when they reach the twelve-hour point for the day. Therefore, special consideration must be taken for multiple events in a duty day which could include, but is not limited to, the combination of TOP3, SOF, simulator sorties, ground training, and mission/event sorties.

Additionally, assignment of pilots to aircraft becomes more complicated when two-seat fighters are included in the scheduling and when simulator check rides occur. Both of these events will require two pilots being assigned to a scheduled event that normally requires one pilot. Also, when scheduling a pilot for a double turn, a compound issue must be considered. If the flights are scheduled too far apart, the schedule is infeasible because the pilot cannot exceed a twelve-hour duty day and still be in the cockpit. Similarly, if the flights are scheduled too close together, the pilot will be unable to complete the first flight, debrief, and be ready for the next mission in time for take-off.

A weekly schedule can be formed in a number of ways. First, a model may be developed with the intent of building the entire schedule with a single run of a solver platform. However, there may be advantages to breaking the problem into smaller sub-problems. For example, the schedule could be built one day at a time. Each method has benefits and disadvantages. A single run of solver can account for a pilot's availability for the entire week. This approach benefits the final schedule when a pilot may be unavailable later in the week and needs to complete requirements earlier in the week. However, a disadvantage for this method is the complexity of modeling an "if-then" penalty scenario involved with the 15-day sortie count. The penalty increases until a pilot is assigned to a training mission sortie; then the penalty would reset to zero. A day by day method allows the model to account for what has been scheduled on the previous day(s), but it has increased complexity involved when trying to account for a pilot's availability for the entire week. Smaller periods of time allow a model to account for each GO, but adds complexity when accounting for the scheduled times for AM GO and PM GO as events may overlap and some duties may extend from AM GO to PM GO.

A prioritized list of requests from the DO may add an additional level of complexity. A DO request that identifies all of the pilots, specific mission/event and day is easier to account for in a model than a request that two pilots are assigned to a certain type of mission at some point during the week. The model would need to account for numerous combinations of missions that may accommodate the less specific request. Additionally, since DO requests will vary in information given, the model must be able to accept various types of DO request inputs.

Given a need for the automation and optimization of weekly flight schedules for fighter pilot training, a few questions need answers. What work has been accomplished toward this goal? How can the research build on this foundation work? Is it feasible to construct a mathematical programming (MP) model that will meet the various needs of a

USAF fighter squadron? Is the benefit of such a model worthy of the expected cost to implement such a model?

1.4 Scope

The scope of this thesis is to build a MP model to generate a weekly flying schedule for one fighter training squadron. The model accounts for two different areas of training (MQT and CT) and three different training arenas (flight, simulator, and other/ground) and allows for other responsibilities within the squadron such as Top 3 and SOF. One key area of focus is pilot availability to perform one sortie, one SOF or Top 3 duty, a combination of a SOF or Top 3 duty and sortie, or multiple sorties each day. Ensuring pilot availability is accomplished by sectioning the day into smaller time intervals and building a staggered schedule in which pilots have twelve-hour workdays during the squadron's sixteen-hour day. Schedules can be developed based on pilot availability, event start times, and expected length of time required by sorties, simulator sorties, and duties. The model should account for all requirements for each pilot's qualification level and pilots that are attempting to upgrade. Also, the model should allow for quick changes for unforeseen problems such as weather cancellation, non-effective missions, airframe availability, or airspace availability. Finally, the model must be user friendly. This is accomplished with the use of a Graphical User Interface (GUI) and spreadsheet fields that would ideally be populated automatically from a database.

1.5 Methodologies

A model is ideally constructed to find an optimal solution. However, in some instances, models that provide feasible solutions in a timely manner have value. The overall size and computation time required to solve the problem can be reduced by reducing the number of variables. One way of accomplishing this reduction is to combine variables. Another method is to remove some variables from the optimization process and use preprocessing or heuristic methods to account for those variables either before or after the optimization. Thus, optimizing parts of the weekly schedule and using scheduling principles can provide a feasible solution in a timely manner.

Ideally, the MP model would allow for changes to be made at any point in the existing schedule. Once changes are made, the model could be rerun and it would provide a solution for the remaining time in the week that continues to meet all constraints.

Additionally, the model must have a GUI. The model should be user friendly and thus allow for simple inputs such as number of pilots, unavailable pilots (leave, other duty), qualification level, BMC or CMR status, experienced or inexperienced pilot, mission times, simulator times, days since last sortie, 30-day sortie count, and 90-day sortie count.

The model is constructed in Excel utilizing the Premium Frontline Solver software. Additionally, VBA coding is used for the GUI and is also used in preprocessing and heuristic efforts.

1.6 Summary

Chapter 1 provides background for the scheduling of fighter pilot continuation and upgrade training. Additionally, the research objective was addressed and a scope for this thesis was outlined. Chapter 2 gives a literature review for sources of information helpful in addressing the problem. Chapter 3 explains how the problem was approached and modeled. Chapter 3 also details areas for future research. Chapter 4 provides a test plan, test results, and analysis of test results. The scenario is altered to verify that the model works on a variety of operational fighter squadron scenarios. Chapter 5 provides the conclusion and summarizes the research effort and results and restates recommendations for future research.

II. Literature Review

2.1 General

A great deal of review was necessary in order to provide a basis of information for the general operations and scheduling practices of a fighter squadron. Additionally, research was required to find previous methods addressing the scheduling problem and alternative approaches to similar types of problems. The review presents information from theses, articles, textbooks and Air Force Instructions (AFI).

2.2 Scheduling Theory

The scheduling textbook by Pinedo is an excellent resource for basic scheduling concepts. Of particular interest to this research is the scheduling of constrained events within a scheduling process and optimizing the benefits gained when scheduling the flexible events. The specific concepts of interest are tardiness, processing times, preemption, and precedence.

The tardiness of a job j is defined as the maximum value of lateness or zero, $T_j = \max(C_j - d_j, 0) = \max(L_j, 0)$. Lateness ($L_j$) is the difference of the actual job completion time (C_j) and the due date (d_j). Thus, while $L_j \leq 0$ the tardiness (T_j) = 0. The unit penalty is defined to equal one when $C_j > d_j$ and equals zero otherwise. The total weighted tardiness is an additional cost function that can be utilized to penalize tardiness. The total weighted tardiness is defined as $\sum w_j T_j$ where w_j is the weight associated with job j (Pinedo, 2000).

The processing time (p_{ij}) is the amount of time required to complete job j on machine i. When the processing time is the same for any machine, the i subscript may be dropped. When preemptions are allowed, a job may be interrupted to process another job. The processing time on the preempted job is not lost and only the remaining processing time is required when the original job returns to the machine (Pinedo, 2000).

Precedence constraints require that one or more jobs may have to be completed before another job is allowed to begin its processing. If each job has no more than one predecessor and one successor, then the constraints are referred to as chains (Pinedo, 2000).

2.3 Scheduling Requirements

After pilots complete IQT and MQT, they will be assigned to a CMR or BMC position (DAF, 2004). CMR pilots are required to be proficient in all primary missions of their unit and weapon systems, while BMC pilots are required to be familiarized in all primary missions of their unit and weapon system (DAF, 2004). The Ready Aircrew Program (RAP) is the CT designed to focus training on capabilities needed to accomplish a unit's core tasked missions (DAF, 2004). All active duty wing positions are CMR or BMC positions (DAF, 2004). Table 3 shows the RAP sortie requirements for F-15 pilots. For example, an experienced ACC pilot in a CMR slot would need to have flown 9 sorties in a 30-day lookback, 24 sorties in a 90-day lookback, and 98 sorties in a one year lookback. Experienced pilots are pilots with 500 hours logged flight time on the primary aircraft inventory (PAI), or 1000 hours logged flight time, of which 300 are PAI, or 600 fighter hours, of which 200 are PAI, or previously fighter experienced and 100 hours PAI (DAF, 2004). All other pilots are considered inexperienced pilots.

Table 2. Annual F-15 RAP Sortie Requirements (DAF, 2004)

MAJCOM	Cycle	BMC Inexp/Experienced	CMR Inexp/Experienced
ACC, USAFE, PACAF, AETC	RAP Total	72/60	110/98
	3-Month Lookback	18/15	27/24
	1-Month Lookback	6/5	10/9
ANG	RAP Total	72/60	90/76
	3-Month Lookback	18/15	23/18
	1-Month Lookback	6/5	7/6

For supervision purposes, a FL-qualified SQ supervisor or IP is a required part of any element unless specified otherwise (DAF, 2004). A pilot that exceeds 14 calendar days between sorties is required to fly an additional sortie before continuing in the program (DAF, 2004). The regression flow chart in Figure 2 below indicates the importance of the 1-month and 3-month lookback numbers from Table 2 above. A pilot that meets the 30-day lookback requirement will continue at their present level as indicated by the first decision block in Figure 2. If the 30-day lookback requirement has not been met, then the 90-day lookback will be examined. If the 90-day lookback requirement is met, then the pilot will continue at their present level. However, if the 90-day lookback has not been met, then the pilot will either be placed on a one month probation or will regress. Pilots that regress will be placed in re-certification status. Pilots on probation will be re-evaluated after 30 days. If the 30-day lookback is met at that point, the pilot will maintain their present level. If the 30-day lookback is not met after the probation period the pilot will regress.

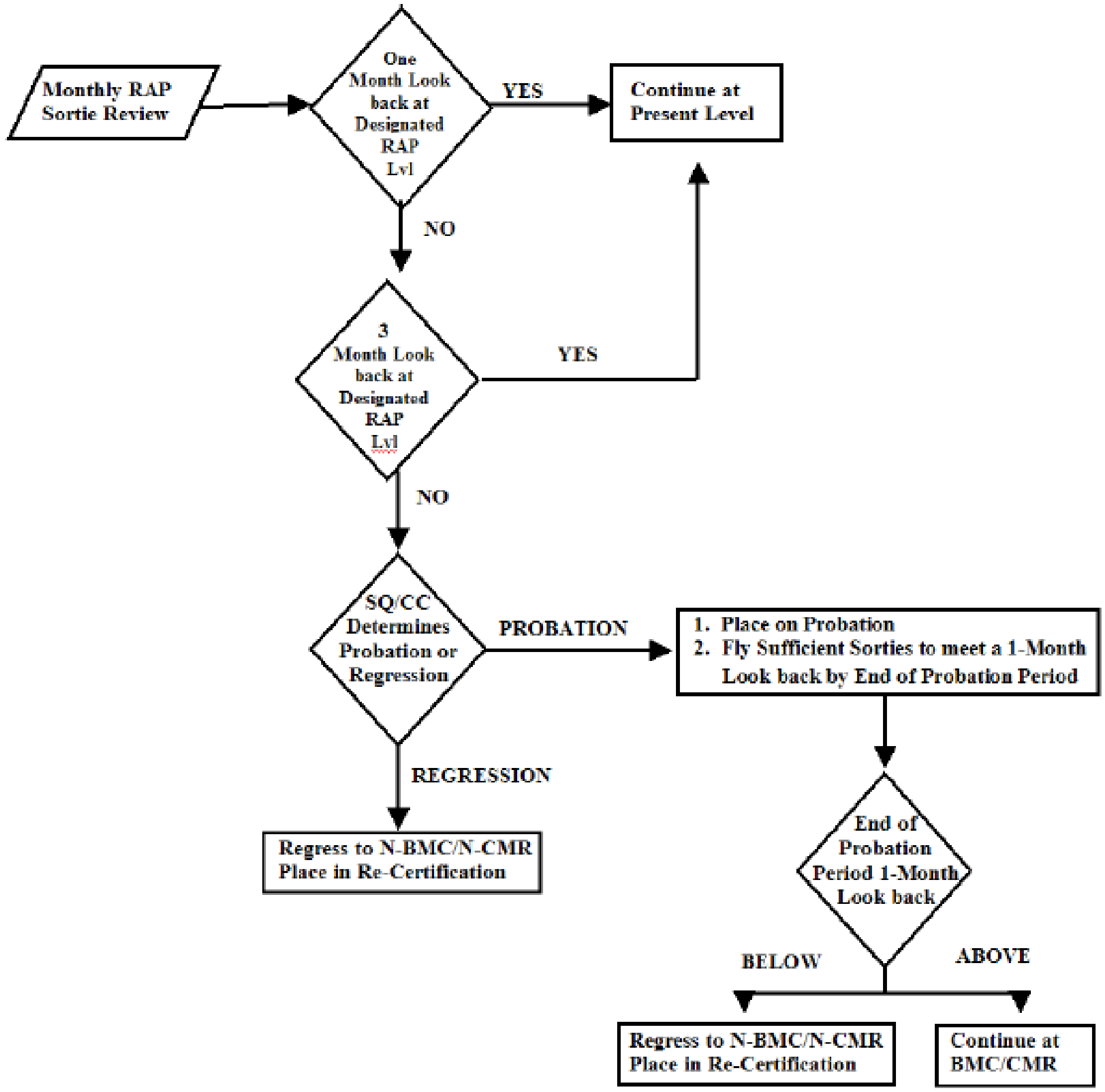


Figure 2. Regression Flow Chart (DAF, 2004)

This document also provides detailed information on required flight and ground training requirements for upgrade training, specialty training, and continuation training.

Chapter 9 of AFI 11-202 provides guidance for scheduling purposes. First, crew rest is normally a 12-hour minimum period before the flight duty period (FDP) begins (DAF, 2006). Therefore, a pilot that leaves at 1900 hours on Monday cannot begin the next FDP before 0700 hours on Tuesday. The purpose of crew rest is to ensure pilots are well rested before engaging in flying duties by providing an opportunity for the pilot to sleep (DAF, 2006). However, crew rest includes the following activities: meals, transportation, and sleep (DAF, 2006). Additionally, maximum flying limits are defined in AFI 11-202 as 56 hours logged flight time per seven consecutive days, 125 hours logged flight time per 30 consecutive days and 330 hours logged flight time per 90 consecutive days (DAF, 2006). The maximum FDP is 12 hours for all single seat aircraft or any other instance where only one pilot has access to the flight controls (DAF, 2006). If a pilot performs other duties beyond the 12-hour FDP, then crew rest begins at the termination of those duties (DAF, 2006).

2.4 Previous Methods

The feasibility of constructing a network flow model to build a weekly schedule for a fighter squadron is demonstrated in research accomplished by Boyd, Cunningham, Gray, and Parker in 2006. The use of a network flow model for scheduling problems is a fairly new approach. Their proof of concept model required 1990 variables, 3463 constraints, 1730 bounds and 260 integer variables. This was a minimum cost network flow model utilizing Premium Solver Platform Version 6.5 created by Frontline Systems (Boyd et. al., 2006). Figure 4 shows the network flow model for Monday's AM GO. According to the authors, this model is very simplistic and needs further research and development before it can be implemented in the USAF fighter squadron community.

The authors indicate limitations and areas for further research. However, all suggested items may not be necessary in developing a useful model and there may be unmentioned areas of research. First, this model divided the workday into AM and PM sections. This does limit the availability of the pilots for other assignments if they are scheduled for a mission sortie, simulator sortie, SOF duty, or Top 3 duty during one of the two periods. The suggested improvement is to divide the day into more than two parts. The authors recommend hourly increments and a sixteen-hour workday where each pilot is scheduled for a twelve-hour day. This would significantly increase the number of variables and constraints required to build the model. The solver platform used will only allow 8000 variables and 8000 constraints. Therefore, multiplying the time period variables by a factor of eight would exceed the capabilities of the Premium Solver Platform.

The next limitation addressed by the authors is the fact that the model only accounts for a small portion of the data that is required to build a fully effective scheduling process. The model, used by the authors, accounts for the 90-day sortie count, and pilot status as related to Combat Mission Ready (CMR) or Basic Mission Capable (BMC) and whether or not the pilot is flying at his/her highest qualification level (Boyd et. al., 2006). It is recommended that the operationally effective model would account for 15, 30, 60 and 90-day sortie counts. Additionally, the model should schedule pilots based on training and RAP requirements as well as the SAT mission requirements.

The authors also indicate a need for “hard schedule” priorities. This should be accomplished with a DO only input page which will add additional constraints to the model. This feature is not a part of the proof of concept model. The Letter of Xs is the source document for which pilots are qualified to fulfill specific tasks. A sample Letter of Xs appears in Appendix B. However, a flight commander or DO may desire to have a specific IP assigned to fly a specific student’s training mission. Addressing this limitation early may reduce the complexity of the overall problem. Pilots already assigned to missions may be removed from the formulation for that time period and those cockpits no longer have to be filled by the model (Boyd et. al., 2006).

There is an author concern that a pilot who has less flying time would be scheduled multiple times in a week. This would yield a "feast or famine" cycle in the scheduling process. This would occur because in the authors' model, the schedule is built based on recent flying that does not include the week being scheduled. There is no suggestion for solving this current limitation. Their research found that changing costs associated with flying later in the week based on previous flying affected the linearity of the model (Boyd et. al., 2006).

The final concern mentioned by the authors is that the model does not benefit by scheduling a pilot that is well ahead of his/her sortie count. The suggestion by the authors here is to use goal programming in an attempt to fly all available pilots at the BMC/CMR weekly requirement or greater each week (Boyd et. al., 2006). A successful method for this limitation may also remedy the "feast or famine" cycle.

Nguyen's research focused directly on IQT, so this research deals with a smaller set of requirements than the fighter squadron environment. However, some of the applications used in the model may be an excellent resource for model development in the fighter training squadron problem. Nguyen's model uses VBA to provide a GUI and to develop scheduling rules such that an initial feasible solution can be found. An attrition environment was created to account for the common occurrence that scheduled missions are not completed as scheduled (Nguyen, 2002).

Aslan's research focused on the F-16 fighter squadron and the scheduling of training events. His research provided a decision support tool to assist in the development of a Daily Flight Schedule (DFS). After using decision rules to develop an initial schedule, a bottleneck heuristic is used to create a suggested DFS. Additionally, a user interface allows the scheduler to interact with the decision support tool (Aslan, 2003). The author claims this tool can be used to either develop weekly schedules or develop the entire flight training program.

1. Persons are assigned to duties
2. Scheduler selects the MOL
3. The missions are ordered according to the selected priority rule
4. If needed, "must-fly" student missions are prioritized in the MOL
5. Ties are broken according to the LFJ-LFM first rule
6. DFS is generated and if needed missions can be altered or a new mission can be inserted
7. Other resources for the mission are recorded on the DFS
8. Simulator schedule is produced (if required)
9. Course work is scheduled.

Figure 3. Feasible Initial Solution Construction Heuristic (Aslan, 2003)

Aslan's heuristic, presented in Figure 3, orders each mission based on predefined rules and the type of initial solution chosen by the scheduler. Figure 4 demonstrates the software implementation of the construction heuristic in a flow chart. The scheduler has three choices for flight order rules to build the DFS. The model allows the scheduler to make iterative adjustments and check for improvements in the initial schedule (Aslan, 2003).

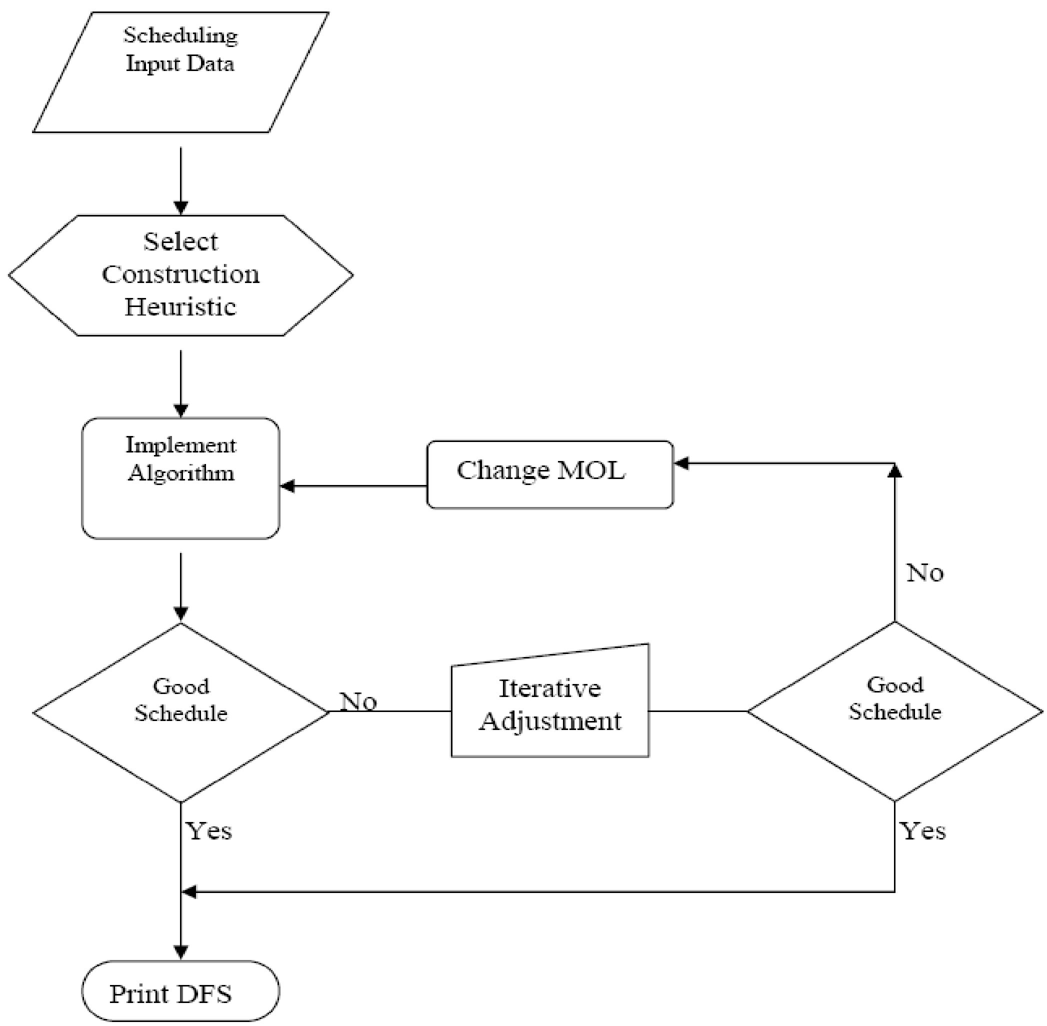


Figure 4. Software Implementation of Construction Heuristic (Aslan, 2003)

2.5 Similar Problems

A staffing problem for the four main Computer Labs at Arizona State University provides a similar problem. A mathematical programming (MP) approach to a generalized personnel tour scheduling problem based upon a minimum cost network-flow formulation with specialized side constraints is presented for this problem. The decomposition of personnel scheduling provides three primary sub-problems: demand modeling, shift selection, and rostering. The heterogeneous work force is a key factor in this problem. A heterogeneous workforce is a collection of personnel who have significantly different availabilities, skill sets, and seniorities. Additionally, rest between consecutive shifts is a realistic requirement in tour-scheduling continuous operations. Tour scheduling problems are essentially binary set-covering problems and as problem size increases, the efficiency of the associated integer program (IP) decreases rapidly. The formulation used for this problem allows very large problem instances to be solved extremely efficiently compared to the corresponding IP solution. The formulation allows for specialized constraints to accommodate continuous operations. This model can be modified to deal with varying availabilities. A network arc may be removed to prevent an unavailable employee from being scheduled. This is easy to program and has no effect on the integrality of solutions from the LP-network solution (Knighton et al., 2007). Knighton's research demonstrates the fairly new approach of using a network flow model to solve a scheduling problem.

Tanker Crew Scheduling provides a similar problem in that it deals with the effective scheduling of limited resources of pilots and aircraft. In this case, a hybrid tabu search approach is used with a set partitioning optimization approach (Combs 2002, Combs and Moore 2004). The vocabulary building scheme within the metaheuristic search is effective and can be applied to any set partitioning or set covering solution structure (Combs 2002, Combs and Moore 2004).

Cockpit crew scheduling for commercial aircraft provides a similar problem. Yan and Chang's article provides some insight into related issues. Scheduling of crew members is generally divided into two problems. First, crew scheduling involves the construction of pairings, for a legal sequence of duties performed by the same crew, which begins and ends at the home base and secondly, rostering involves linking the pairings into work schedules. The problem is formulated as a set-partitioning problem using a developed column generation-based algorithm and two networks, one for a standard crew, shown in Figure 5, and one for an augmented crew (Yan et al., 2002).

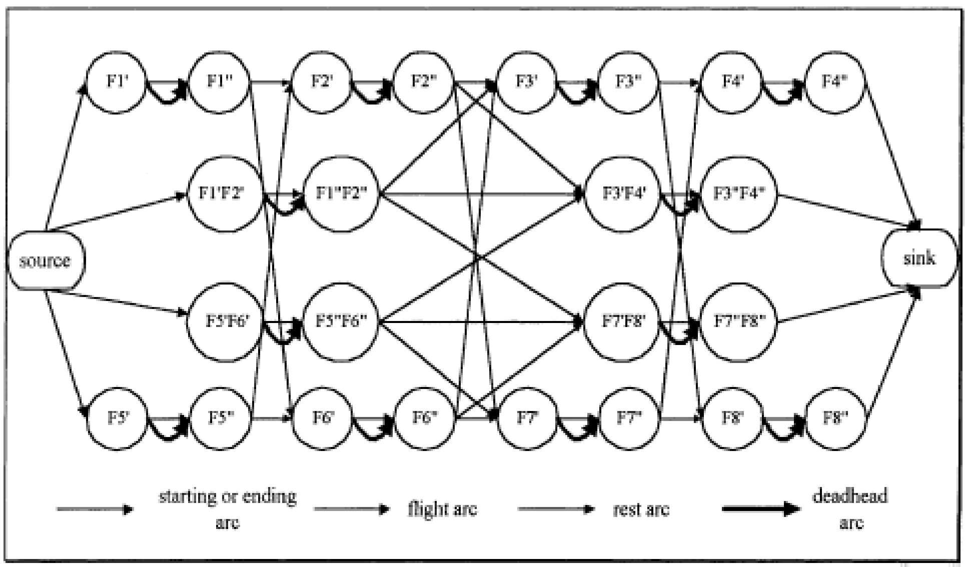


Figure 5. The standard crew network (Yan, 2003)

Scheduling ballistic missile crews requires the scheduler to examine qualification levels, availability, crew rest, and training. The missile crew scheduling problem is like many scheduling problems in that it has several possible objectives (Shirley, 1994). In Shirley's research effort, a heuristic is developed and preprocessing is utilized. Preprocessing, in this case, is applying a set of rules to the days before and the days after a day that is being considered for an alert. Thus, preprocessing helps reduce the complexity of the problem by eliminating infeasible results from the solution space before attempting to solve the problem.

Gronkvist also utilizes a preprocessing technique in the NP-hard Tail Assignment problem (Gronkvist, 2006). The generalized preprocessing technique is based on constraint propagation. This can dramatically reduce the size of the flight network. Unfortunately, column generation only solves the LP relaxation. The integration of constraint programming and column generation has great potential and may be very useful since the column generation process only looks at a restricted part of the problem at any given time and the constraint model has a global feasibility-focused view.

2.6 Summary

The methods and problems presented in this chapter provide a foundation for this research. The scheduling principles are directly applied to the MP model presented in Chapter 3. Preprocessing allows an overall reduction in the number of variables and constraints. The methodology of this research is described and then presented in a mathematical formulation. The heuristic for assigning pilots to simulators is presented. Also, a network representation of the problem is presented. Finally, suggestions for further research are discussed in detail.

III. Methodology

3.1 Overview

This chapter explains the details associated with the fighter training squadron scheduling problem. First, the overall objectives are outlined. Second, the assumptions for model development are specified. Next, the decision variables are defined. The decision variables affect many other parameters within the model. The function of each of these parameters is described by the decision variables associated to that parameter and the constraint the parameter establishes for building the schedule. Finally, the model constraints are defined in the context of a general formulation. These constraints vary based on the inputs to the model. However, the constraints are driven by the requirements as found in AFI 11-2F-15V1.

This chapter also presents the problem formulation and gives a detailed explanation of the penalties that are built into the model. A network diagram is provided to better show the flow of pilots to assignments. Finally, the simulator assignments and off-duty portions of the schedule are explained in detail.

3.2 Objectives

There are many ways to approach these types of problems. First, a feasible solution may suffice in a highly constrained problem with limited resources. However, optimality is often desired if it can be achieved with a reasonable amount of time, cost, and resources. In other cases, it may be preferable to solve portions of a problem or sub-problems to be combined into a complete answer. For example, some problems may remove constraints if certain requirements have already been met. For the fighter pilot scheduling problem, feasibility is a concern as current manually generated schedules necessitate pilots being pulled from other squadrons in order to meet the sortie demands.

With the assumptions mentioned above, this model can be broken into ten sub-problems. The first sub-problem would solve the Monday AM portion of the weekly schedule to optimality within the given constraints. There are sub-problems for the AM GO and the PM GO Monday through Friday. In using preprocessed penalties for each sub-problem, a penalty for a specific pilot can be removed in subsequent sub-problems after the requirements for that pilot have been met. However, any one of the sub-problems could require more pilots than are currently available within the squadron. Therefore, the model allows additional non-squadron pilots into the model for the specific sub-problems where infeasibility due to a lack of available pilots may occur. There is an associated cost with the use of non-squadron pilots. The model reports mission needs for additional pilots on the schedule sheets below each day's schedule. The user would need to find non-squadron pilot(s) available to fly the sorties scheduled to the generic pilot(s).

Therefore, the first objective is to make the scheduling process more efficient. The second objective is to make the pilot training squadron efficient and effective in the overall mission. The model objective used to accomplish the first two objectives is to minimize the penalties for pilots exceeding fifteen days without sorties, pilots falling below their 30-day sortie count requirement, and pilots falling below their 90-day sortie count requirement while effectively filling every cockpit with as many squadron pilots as possible. The penalties are a function of tardiness for each pilot in achieving their respective requirements for each of the RAP sortie count requirements. The penalty functions in the sub-problem formulation differ from the full week formulation.

The overall objectives of this research are to minimize the cost of utilizing non-squadron pilots and to minimize the penalties associated with non-compliance of 15-day, 30-day, and 90-day sortie requirements. Thus, the overall objective is to build a feasible schedule by solving for pilot assignments (training mission sorties, Top 3, and SOF), using as few non-squadron pilots as possible, based on sortie counts (15-day, 30-day, and 90-day), and filling simulator sorties with a heuristic developed for this problem as a response to the mission sortie, SOF duty and Top 3 duty assignments. This research attempts to meet these objectives by utilizing two approaches. The first approach is to solve the entire week as a single MP problem. The second approach divides the overall problem into several smaller problems which allows results from the previous sub-problem to be used as inputs for the successive sub-problem.

3.3 Assumptions

As with many problems, assumptions were made in order to achieve the overall objectives. The first assumptions define the time involved in events on the schedule. A sortie is approximately 1.5 hours in duration. However, in the model, a scheduled flying event begins with the pre-flight briefing and ends with the flight debrief. Thus, a flying event on the schedule is assumed to require at least 4.0 hours and no more than 6.0 hours of a pilot's schedule. Additionally, the simulator events were assumed to require 3.0 to 4.0 hours of the pilot's schedule. Briefings before consecutive simulator sorties are assumed to be 3.0 hours apart. TOP3 and SOF positions are generally an 8.0-hour duty.

However, the TOP3 and SOF positions are scheduled in 6.0-hour blocks to relax the constraint and provide increased opportunity for pilots assigned to these duties to be assigned to sorties and simulators. Thus, the daily schedule may require a pilot to perform TOP3/SOF duties and also fly a sortie. Therefore, the timing of the two events requires some flexibility. A 12Turn10 flying schedule is assumed to be in place everyday, and omitted missions would be treated as incomplete missions. It is also assumed that other pilots are available to fill any shortfalls the squadron has in filling the cockpits for the week.

The parameters that aid in building model constraints have differing levels of importance. The 15-day sortie count for instance may be more important than the 30-day sortie count. However, there is no specific guidance to the importance or priority levels for any of these parameters. If a pilot does not fly a sortie in 15 days, then that pilot must fly a CT sortie before returning to normal training activities. Therefore, this model assumes that the 15-day sortie count is the first priority and the scheduling constraints are driven by this parameter for each of the squadron's pilots. It is also assumed that simulator sorties should be evenly dispersed if possible. The model also assumes no pilot can fly more than two sorties on the same day. A pilot may be scheduled to fly a sortie and perform an extra SOF or Top 3 duty or fill a simulator seat on the same day. The schedule is built around the assumption that in a sixteen-hour day, every pilot will have four hours of the day off. The assumption of simulator availability requires that four simulators are available during two distinct and consistent time frames every duty day. Finally, each 4-ship or 2-ship training mission is limited to a maximum of one TOP3 qualified pilot.

3.4 Decision Variables

For a model to be useful, it must have clearly defined decision variables. Since this model is capable of scheduling a squadron of up to fifty pilots, the model has a variable for each mission associated with each pilot. Therefore, a 4-ship training mission scheduled for 0600 Monday morning would have fifty variables to represent each pilot's involvement in that mission. These variables are binary. A value of one indicates that a pilot is involved in this mission and a value of zero indicates that a pilot is not involved in this mission. Thus, the model has four variables with a value of one and 46 variables with a value of zero for this specific mission. Typically a squadron will have six total missions in a day, with up to fifty variables for each mission (this is dependant on the number of pilots, for example a squadron of 43 pilots would have 43 variables for each mission and the remaining seven variables would be forced to zero), the model has up to 300 binary variables associated with each day. Since the duty week is five days long, the model has up to 1500 binary variables built into a pilot to assignment matrix in order to fill the weekly flying schedule.

The next set of variables is reserved for the pilots within the squadron that are qualified to perform a TOP3 supervisor role. These variables are binary as well and indicate which pilots fill each responsibility. The model allows any of the 50 pilot slots to be TOP3 qualified. Thus, up to 50 pilots filling two responsibilities each day requires 100 binary variables per day. Thus, the model contains 500 binary variables to fill TOP3 positions for the week. The SOF position is a one time per day duty and the model allows for up to 50 pilots to be qualified to fill this position in the AM or PM case. Thus, the model has 100 binary variables per day to fill the SOF position or 500 binary variables for the SOF position for the week. Additionally, generic pilots are added to allow non-squadron pilots to be used when necessary. The model has 10 additional pilot slots (5 IP and 5 FL). Which are available as needed for any of the six missions each day. This provides an additional 60 variables per day or 300 variables for the week. Therefore, the model uses up to 560 variables per day, or 280 variables per GO. Thus, the week would require 2800 binary decision variables to complete the weekly schedule.

The Premium Solver version 7.0 by Frontline Systems will only handle 2000 integer variables. Therefore, in order to solve the weekly problem without using sub-problems, several new conditions were required. Since a squadron is very unlikely to have more than ten TOP3 qualified pilots, TOP3 variables were reduced to only include the top ten pilots in the list. This reduced the problem size by 400 integer variables. Additionally, a squadron is very unlikely to have more than 27 SOF qualified pilots in a squadron. Therefore, the SOF variables were limited to the top 30 pilots in the list. This provides an additional reduction of 200 binary variables. Finally, the ten binary variables representing non-squadron pilots were changed to two integer variables. Therefore, only two variables per mission are needed, one for IP pilots and one for FL pilots reducing the total number of integer variables by 240. Therefore, the weekly problem can be solved without sub-problems by using the Premium Solver version 7.0 platform and the remaining 1960 variables (60 integer variables and 1900 binary variables). The drawback with this reduction in variables is that now the user is required to ensure that TOP3 qualified pilots are listed in the top ten rows of all input sheets. Also, SOF qualified pilots would have to be listed in the first 30 rows of all input sheets.

Extending the reduction to the single go, the 1960 weekly variables implies 392 variables per day or 196 variables per GO. Thus, the model may be altered to work in a limited capacity without the Premium Solver platform to solve the weekly schedule using ten sub-problems. However, modifications would be required and a significant increase in time to solve would result. The modifications would include reduction of total variables from 280 to 196 per GO and rewriting the VBA code for the standard solver. On a test run of two sub-problems, the standard solver found a solution in seconds.

3.5 Parameters

This model uses many parameters that are not direct inputs or decision variables. However, the parameters are produced using decision variables, direct inputs, or both. The simulator parameters are binary and are derived using the decision variables and direct inputs for pilot availability. Thus, it is possible to have a day where only a few of the eight available simulator sorties are filled during the initial phase. The remaining simulator sorties are filled as the schedule is being built from the model output. The simulator assignments occur after the full week has been scheduled and is exactly the same for both formulations. The 15-day sortie count for each pilot is a direct input and then is updated based on the flight schedule produced for each sub-problem. A preprocessing technique is used to apply the results from the previous sub-problem to the next sub-problem. The model creates new penalties according to this information. However, in the full week formulation the preprocessing sets the 15-day penalties based on the initial input and no updating occurs.

The remaining parameters within the model are used within the model constraints. In both formulations, parameters are utilized to prevent assigning pilots to more than one activity at a time and to prevent assigning unavailable pilots to activities. Another parameter is used to prevent exceeding a twelve-hour work day for the sub-problem formulation.

3.6 Constraints

The constraints used in this model impose limits that lead to a realistic assignment for the scheduled sorties for the week, TOP3 positions, and SOF positions. However, the problem formulation does not have constraints for simulator sorties, ground training, and off-duty hours. This section explains the constraints used by the model in detail.

First, all decision variables (up to 1500 sortie variables, 100 to 500 TOP3 variables, and 300 to 500 SOF variables) are constrained to be binary values (1 indicates a specific pilot fills that assignment and 0 indicates a specific pilot does not fill that assignment). Additionally, the generic pilot slots are either 300 binary variables (60 binary variables associated with each of the ten sub-problems) or 30 integer variables used during the full week formulation. The next constraints require that every cockpit is assigned a pilot. This is accomplished by adding all the binary variables associated with each mission. If the mission is a 4-ship flight, then the sum is constrained to equal four, and for a 2-ship flight the sum is constrained to equal two. Additional requirements for 4-ship missions include: the sum of all IPs must be greater than or equal to one, the sum of IPs and FLs must be greater than or equal to two, and the sum of all TOP3 qualified pilots must be less than or equal to one. The additional requirements for 2-ship missions include: the sum of all IPs and FLs must be greater than or equal to one and the sum of all TOP3 qualified pilots must be less than or equal to one.

For each of the ten TOP3 positions during the week, the next set of constraints requires that the sum of all TOP3 qualified pilots assigned to each position is equal to one. Additionally, there is a constraint that for each TOP3 qualified pilot, the sum of each day's TOP3 and SOF position assignments is less than or equal to one. Also, the sum of all SOF qualified pilots, including the TOP3 qualified pilots, for the SOF assignment each day equals one. It is important that no SOF or Top 3 duty overlaps directly with a sortie; thus, a constraint is added that for all pilots qualified for SOF and TOP3 duties, the sum of the variables associated with those duties and the variables associated with sorties occurring in the same timeframe of the day is less than or equal to one. Additionally, there is a constraint that for each pilot, the sum of the variables associated with a single day's sorties is less than or equal to two.

Finally, the model is constrained by timing requirements. A pilot may perform an AM GO SOF or Top 3 duty and fly a PM GO sortie provided that the sortie will not require the pilot to be flying the aircraft at a point twelve hours later than the pilot's day started. Similarly, a pilot may fly an AM GO sortie and perform a PM GO SOF or Top 3 duty provided that the sortie does not require the pilot to be flying the aircraft during the SOF or Top 3 duty timeframe. Thus, the constraints require that the AM GO SOF or Top 3 duty scenario is linked only to a sortie that begins no later than eight hours into the pilot's daily schedule. For the PM SOF or Top 3 duty scenario, the AM GO flight briefing must begin at least four hours prior to the PM GO SOF or Top 3 duty.

The squadron's duty day for this model is defined as 0500 to 2100. In order to meet the timing requirements, every pilot would ideally be scheduled for four hours of off-duty time during this sixteen-hour period. The four hours of off-duty time should leave a consecutive grouping of twelve one hour time slots that make up the pilot's duty day. Thus, a pilot may have the first four 1-hour blocks (0500-0859) or the last four 1-hour blocks (1700-2100) designated as off-duty. Additionally, a pilot may have off-duty scheduled at both the beginning and end of the day. For example, 0700-1900 is a valid twelve-hour duty day with two hours of off-duty time scheduled at each end of the squadron's daily hours.

3.7 Problem Formulation

The overall formulation for this problem has 1960 variables and 2735 constraints. However, by solving the problem one GO at a time, the formulation for each GO has 280 variables and less than 450 constraints. The number of constraints for each GO will vary depending on circumstances. Monday's AM GO is not restricted by crew rest from the previous duty day or the need to work around events already scheduled for the day and thus only requires 114 constraints. However, the PM GO for each day must take into account the AM GO schedule to avoid conflicts and thus requires 443 constraints. The AM GO for every day other than Monday must account for crew rest from the previous duty day and therefore requires 164 constraints. The overall formulation is presented first and an individual GO formulation follows. In both cases, the purpose of each section of the formulation is briefly described.

In both formulations, a mission is any 2-ship or 4-ship training event. The formulation is based on the assumption that three 4-ship missions will occur in the AM GO, two 4-ship missions will occur in the PM GO, and one 2-ship mission will occur in the PM GO. The subscript *i* represents the pilot being assigned and ranges from 1 to 50. The subscript *j* represents the mission number for the day and ranges from 1 to 6, where mission 1 is the first AM mission, mission 5 is the last 4-ship PM mission, and mission 6 is the 2-ship PM mission. The subscript *k* represents the day of the week and ranges from 1 to 5, where $k = 1$ implies Monday and $k = 5$ implies Friday.

Variables:

$$\text{Let } M_{ij} = \begin{cases} 1 & \text{If pilot } i \text{ is assigned to mission } j \text{ on Monday} \\ 0 & \text{otherwise} \end{cases}$$

$$\text{Let } T_{ij} = \begin{cases} 1 & \text{If pilot } i \text{ is assigned to mission } j \text{ on Tuesday} \\ 0 & \text{otherwise} \end{cases}$$

$$\text{Let } W_{ij} = \begin{cases} 1 & \text{If pilot } i \text{ is assigned to mission } j \text{ on Wednesday} \\ 0 & \text{otherwise} \end{cases}$$

$$\text{Let } R_{ij} = \begin{cases} 1 & \text{If pilot } i \text{ is assigned to mission } j \text{ on Thursday} \\ 0 & \text{otherwise} \end{cases}$$

$$\text{Let } F_{ij} = \begin{cases} 1 & \text{If pilot } i \text{ is assigned to mission } j \text{ on Friday} \\ 0 & \text{otherwise} \end{cases}$$

The preceding variable set represents the decision variables for assigning a specific pilot to a specific training mission.

Let XIP_{kj} = the number of extra IP pilots required for day k mission j

Let XFL_{kj} = the number of extra FL pilots required for day k mission j

This variable set represents the decision variables for assigning a non-squadron pilot to a specific training mission.

Let $MAMT3_i = \begin{cases} 1 & \text{If pilot } i \text{ is assigned as Monday AM GO TOP3} \\ 0 & \text{otherwise} \end{cases}$

Let $MPMT3_i = \begin{cases} 1 & \text{If pilot } i \text{ is assigned as Monday PM GO TOP3} \\ 0 & \text{otherwise} \end{cases}$

Let $MAMSOF_i = \begin{cases} 1 & \text{If pilot } i \text{ is assigned as Monday AM GO SOF} \\ 0 & \text{otherwise} \end{cases}$

Let $MPMSOF_i = \begin{cases} 1 & \text{If pilot } i \text{ is assigned as Monday PM GO SOF} \\ 0 & \text{otherwise} \end{cases}$

Let $TAMT3_i = \begin{cases} 1 & \text{If pilot } i \text{ is assigned as Tuesday AM GO TOP3} \\ 0 & \text{otherwise} \end{cases}$

Let $TPMT3_i = \begin{cases} 1 & \text{If pilot } i \text{ is assigned as Tuesday PM GO TOP3} \\ 0 & \text{otherwise} \end{cases}$

Let $TAMSOF_i = \begin{cases} 1 & \text{If pilot } i \text{ is assigned as Tuesday AM GO SOF} \\ 0 & \text{otherwise} \end{cases}$

Let $TPMSOF_i = \begin{cases} 1 & \text{If pilot } i \text{ is assigned as Tuesday PM GO SOF} \\ 0 & \text{otherwise} \end{cases}$

Let $WAMT3_i = \begin{cases} 1 & \text{If pilot } i \text{ is assigned as Wednesday AM GO TOP3} \\ 0 & \text{otherwise} \end{cases}$

Let $WPMT3_i = \begin{cases} 1 & \text{If pilot } i \text{ is assigned as Wednesday PM GO TOP3} \\ 0 & \text{otherwise} \end{cases}$

Let $WAMSOF_i = \begin{cases} 1 & \text{If pilot } i \text{ is assigned as Wednesday AM GO SOF} \\ 0 & \text{otherwise} \end{cases}$

Let $WPMSOF_i = \begin{cases} 1 & \text{If pilot } i \text{ is assigned as Wednesday PM GO SOF} \\ 0 & \text{otherwise} \end{cases}$

Let $RAMT3_i = \begin{cases} 1 & \text{If pilot } i \text{ is assigned as Thursday AM GO TOP3} \\ 0 & \text{otherwise} \end{cases}$

Let $RPMT3_i = \begin{cases} 1 & \text{If pilot } i \text{ is assigned as Thursday PM GO TOP3} \\ 0 & \text{otherwise} \end{cases}$

Let $RAMSOF_i = \begin{cases} 1 & \text{If pilot } i \text{ is assigned as Thursday AM GO SOF} \\ 0 & \text{otherwise} \end{cases}$

Let $RPMSOF_i = \begin{cases} 1 & \text{If pilot } i \text{ is assigned as Thursday PM GO SOF} \\ 0 & \text{otherwise} \end{cases}$

$$\text{Let } FAMT3_i = \begin{cases} 1 & \text{If pilot } i \text{ is assigned as Friday AM GO TOP3} \\ 0 & \text{otherwise} \end{cases}$$

$$\text{Let } FPMT3_i = \begin{cases} 1 & \text{If pilot } i \text{ is assigned as Friday PM GO TOP3} \\ 0 & \text{otherwise} \end{cases}$$

$$\text{Let } FAMSOF_i = \begin{cases} 1 & \text{If pilot } i \text{ is assigned as Friday AM GO SOF} \\ 0 & \text{otherwise} \end{cases}$$

$$\text{Let } FPMSOF_i = \begin{cases} 1 & \text{If pilot } i \text{ is assigned as Friday PM GO SOF} \\ 0 & \text{otherwise} \end{cases}$$

This variable set represents the decision variables for assigning a specific pilot to each of the Top 3 and SOF duties for the week. The subscript i ranges from 1 to 10 for the Top 3 variable and i ranges from 1 to 30 for the SOF variables.

Parameters:

Let a = number of TOP3 qualified pilots in the squadron
Let b = number of IPs in the squadron (Non-TOP3)
Let c = number of 4-ship FLs in the squadron (Non-TOP3, Non-IP)
Let d = number of 2-ship FLs in the squadron (Non-TOP3, Non-IP, Non-4FL)

The set of parameters above is used to enumerate the pilots in five different qualification levels. These parameters are mainly used for ease in presentation of the formulation.

Let S_{kj} = briefing start time for mission j on day k, where $S_{kj} \in \{1, 2, \ldots, 13\}$
such that 1 = 0500-0600 time block, 2 = 0600-0700, ..., 13 = 1700-1800

The values for the parameter S_{kj} are directly associated to user inputs for the initial briefing time for each training mission. If the first training mission on Monday's AM GO has a brief time of 0615, then $S_{11} = 2$. This parameter is then used in constraints for crew rest and FDP.

Let MS_i = Maximum number of sorties flown on any single day by pilot i

The parameter MS_i is directly associated to decision variable values for training mission sorties for pilot *i*. These parameters are only used in the full week formulation to avoid penalizing a pilot for tardiness on the 15-day sortie count when they are flying two sorties on a single day.

Let $FDCount_i$ = number of days since last sortie for pilot i
Let $TDCount_i$ = number of sorties flown by pilot i in the last 25 days
Let $NDCount_i$ = number of sorties flown by pilot i in the last 85 days
Let RTD_i = number of sorties required for 30 day count for pilot i
Let RND_i = number of sorties required for 90 day count for pilot i

The parameters in this set are based on user inputs. The first three parameters are exact user inputs for 15-day, 30-day, and 90-day sortie counts. The last two parameters represent the requirements for 30-day and 90-day lookbacks for pilot *i* and are based on user inputs for pilot *i*'s experience level and staus (BMC or CMR).

$$\text{Let } SOFA = \begin{cases} 0 & \text{if the squadron is assigned to AM SOF duties} \\ 1 & \text{if the squadron is assigned to PM SOF duties} \end{cases}$$

$$\text{Let } SOFP = \begin{cases} 0 & \text{if the squadron is assigned to PM SOF duties} \\ 1 & \text{if the squadron is assigned to AM SOF duties} \end{cases}$$

The values for *SOFA* and *SOFP* represent a toggle between the AM and PM position for the squadron's SOF duty. This parameter is based on the user's input.

Preprocessing Parameters:

$$\text{Let } A_{ik} = \begin{cases} 0 & \text{if pilot } i \text{ is available for all duties on day } k \\ 1.5 & \text{if pilot } i \text{ is DNIF on day } k \\ 2 & \text{if pilot } i \text{ is unavailable for any duty on day } k \end{cases}$$

The parameter A_{ik} is set directly from the user's input associated with pilot *i*'s availability on day *k*.

$$\text{Let } P_{30ik} = \begin{cases} 0 & \text{if } TDCount_i \geq RTD_i \\ (RTD_i - TDCount_i) * (2 - \sum_{j=1}^{6} M_{ij}) & \text{if } TDCount_i < RTD_i \text{ and } k = 1 \\ (RTD_i - TDCount_i) * (2 - \sum_{j=1}^{6} T_{ij}) & \text{if } TDCount_i < RTD_i \text{ and } k = 2 \\ (RTD_i - TDCount_i) * (2 - \sum_{j=1}^{6} W_{ij}) & \text{if } TDCount_i < RTD_i \text{ and } k = 3 \\ (RTD_i - TDCount_i) * (2 - \sum_{j=1}^{6} H_{ij}) & \text{if } TDCount_i < RTD_i \text{ and } k = 4 \\ (RTD_i - TDCount_i) * (2 - \sum_{j=1}^{6} F_{ij}) & \text{if } TDCount_i < RTD_i \text{ and } k = 5 \end{cases}$$

$$\text{Let } P_{90ik} = \begin{cases} 0 & \text{if } NDCount_i \geq RND_i \\ (RND_i - NDCount_i) * (2 - \sum_{j=1}^{6} M_{ij}) & \text{if } NDCount_i < RND_i \text{ and } k = 1 \\ (RND_i - NDCount_i) * (2 - \sum_{j=1}^{6} T_{ij}) & \text{if } NDCount_i < RND_i \text{ and } k = 2 \\ (RND_i - NDCount_i) * (2 - \sum_{j=1}^{6} W_{ij}) & \text{if } NDCount_i < RND_i \text{ and } k = 3 \\ (RND_i - NDCount_i) * (2 - \sum_{j=1}^{6} H_{ij}) & \text{if } NDCount_i < RND_i \text{ and } k = 4 \\ (RND_i - NDCount_i) * (2 - \sum_{j=1}^{6} F_{ij}) & \text{if } NDCount_i < RND_i \text{ and } k = 5 \end{cases}$$

The parameters above are the size of the penalty for pilot i for the 30-day and 90-day sortie counts. The value of these parameters differ by day based on the number of sorties flown in that day by pilot i.

$$\text{Let } FDP_i = \begin{cases} 0 & \text{if } FDCount_i \leq 6 \\ 2 - MS_i & \text{if } 6 < FDCount_i \leq 10 \\ (FDCount_i - 9) * (2 - MS_i) & \text{if } FDCount_i > 10 \end{cases}$$

$$\text{Let } TDP_i = \begin{cases} 0 & \text{if } TDCount_i \geq RTD_i \\ (RTD_i - TDCount_i) * \text{Max}(P_{30ik}) & \text{if } TDCount_i < RTD_i \end{cases}$$

$$\text{Let } NDP_i = \begin{cases} 0 & \text{if } NDCount_i \geq RND_i \\ (RND_i - NDCount_i) * \text{Max}(P_{90ik}) & \text{if } NDCount_i < RND_i \end{cases}$$

These parameters are the actual penalty values in the objective function and are based on the inputs for 15-day, 30-day, and 90-day sortie counts and either maximum number of sorties in a single day or the maximum P_{30} or P_{90} values for pilot *i* during the week.

For the above, $i = 1, 2,\ldots, 50$; $j = 1, 2,\ldots, 6$; $k = 1$ (Monday), 2 (Tuesday),…, 5 (Friday).

Objective Function:

$$\text{Min } W = 10 * \sum_{k=1}^{5}\sum_{j=1}^{6}(XIP_{kj} + XFL_{kj}) + \sum_{i=1}^{50} FDP_i + 5 * \sum_{i=1}^{50} TDP_i + 10 * \sum_{i=1}^{50} NDP_i$$

The objective function is the minimum sum of the following: ten times the number of non-squadron pilots used in the weekly schedule, the sum of 15-day penalty parameters for all squadron pilots, five times the sum of all 30-day penalty parameters for all squadron pilots, and ten times the 90-day penalty parameters for all squadron pilots.

s.t.

Constraint Set 1

$$\sum_{i=1}^{50} M_{ij} + XIP_{1j} + XFL_{1j} = 4 \text{ for } j = 1, 2, 3, 4, 5$$

$$\sum_{i=1}^{50} M_{i6} + XIP_{16} + XFL_{16} = 2$$

$$\sum_{i=1}^{50} T_{ij} + XIP_{2j} + XFL_{2j} = 4 \text{ for } j = 1, 2, 3, 4, 5$$

$$\sum_{i=1}^{50} T_{i6} + XIP_{26} + XFL_{26} = 2$$

$$\sum_{i=1}^{50} W_{ij} + XIP_{3j} + XFL_{3j} = 4 \text{ for } j = 1, 2, 3, 4, 5$$

$$\sum_{i=1}^{50} W_{i6} + XIP_{36} + XFL_{36} = 2$$

$$\sum_{i=1}^{50} R_{ij} + XIP_{4j} + XFL_{4j} = 4 \quad \text{for } j = 1, 2, 3, 4, 5$$

$$\sum_{i=1}^{50} R_{i6} + XIP_{46} + XFL_{46} = 2$$

$$\sum_{i=1}^{50} F_{ij} + XIP_{5j} + XFL_{5j} = 4 \quad \text{for } j = 1, 2, 3, 4, 5$$

$$\sum_{i=1}^{50} F_{i6} + XIP_{56} + XFL_{56} = 2$$

Constraint set 1 ensures that the 4-ship missions (missions 1 to 5 each duty day) have four pilots assigned and that the 2-ship mission (mission 6 each duty day) has two pilots assigned.

Constraint Set 2

$$\sum_{i=1}^{a+b} M_{ij} + XIP_{1j} \geq 1 \quad \text{for } j = 1, 2, 3, 4, 5$$

$$\sum_{i=1}^{a+b+c} M_{ij} + XFL_{1j} \geq 2 \quad \text{for } j = 1, 2, 3, 4, 5$$

$$\sum_{i=1}^{a+b+c+d} M_{i6} + XFL_{16} \geq 1$$

$$\sum_{i=1}^{a+b} T_{ij} + XIP_{2j} \geq 1 \quad \text{for } j = 1, 2, 3, 4, 5$$

$$\sum_{i=1}^{a+b+c} T_{ij} + XFL_{2j} \geq 2 \quad \text{for } j = 1, 2, 3, 4, 5$$

$$\sum_{i=1}^{a+b+c+d} T_{i6} + XFL_{26} \geq 1$$

$$\sum_{i=1}^{a+b} W_{ij} + XIP_{3j} \geq 1 \quad \text{for } j = 1, 2, 3, 4, 5$$

$$\sum_{i=1}^{a+b+c} W_{ij} + XFL_{3j} \geq 2 \quad \text{for } j = 1, 2, 3, 4, 5$$

$$\sum_{i=1}^{a+b+c+d} W_{i6} + XFL_{36} \geq 1$$

$$\sum_{i=1}^{a+b} R_{ij} + XIP_{4j} \geq 1 \quad \text{for } j = 1, 2, 3, 4, 5$$

$$\sum_{i=1}^{a+b+c} R_{ij} + XFL_{4j} \geq 2 \quad \text{for } j = 1, 2, 3, 4, 5$$

$$\sum_{i=1}^{a+b+c+d} R_{i6} + XFL_{46} \geq 1$$

$$\sum_{i=1}^{a+b} F_{ij} + XIP_{5j} \geq 1 \quad \text{for } j = 1, 2, 3, 4, 5$$

$$\sum_{i=1}^{a+b+c} F_{ij} + XFL_{5j} \geq 2 \quad \text{for } j = 1, 2, 3, 4, 5$$

$$\sum_{i=1}^{a+b+c+d} F_{i6} + XFL_{56} \geq 1$$

Constraint set 2 ensures that every 4-ship mission has at least one pilot qualified at the IP level and one additional pilot qualified at the 4-ship FL level or higher assigned. This constraint set also ensures that every 2-ship mission has at least one pilot qualified as a 2-ship FL or higher.

Constraint Set 3

$$\sum_{i=1}^{a} M_{ij} \leq 1 \quad \text{for } j = 1, 2, 3, 4, 5, 6$$

$$\sum_{i=1}^{a} T_{ij} \leq 1 \quad \text{for } j = 1, 2, 3, 4, 5, 6$$

$$\sum_{i=1}^{a} W_{ij} \leq 1 \quad \text{for } j = 1, 2, 3, 4, 5, 6$$

$$\sum_{i=1}^{a} R_{ij} \leq 1 \quad \text{for } j = 1, 2, 3, 4, 5, 6$$

$$\sum_{i=1}^{a} F_{ij} \leq 1 \quad \text{for } j = 1, 2, 3, 4, 5, 6$$

Constraint set 3 prevents the model from assigning two or more TOP3 qualified pilots to any single mission.

Constraint Set 4

$$\sum_{i=1}^{a} MAMT3_i = 1$$

$$\sum_{i=1}^{a} MPMT3_i = 1$$

$$\sum_{i=1}^{a} TAMT3_i = 1$$

$$\sum_{i=1}^{a} TPMT3_i = 1$$

$$\sum_{i=1}^{a} WAMT3_i = 1$$

$$\sum_{i=1}^{a} WPMT3_i = 1$$

$$\sum_{i=1}^{a} RAMT3_i = 1$$

$$\sum_{i=1}^{a} RPMT3_i = 1$$

$$\sum_{i=1}^{a} FAMT3_i = 1$$

$$\sum_{i=1}^{a} FPMT3_i = 1$$

Constraint set 4 forces the model to assign exactly one TOP3 qualified pilot to each of the ten TOP3 requirements for the week.

Constraint Set 5

$$\sum_{i=1}^{30} MAMSOF_i + SOFA = 1$$

$$\sum_{i=1}^{30} MPMSOF_i + SOFP = 1$$

$$\sum_{i=1}^{30} TAMSOF_i + SOFA = 1$$

$$\sum_{i=1}^{30} TPMSOF_i + SOFP = 1$$

$$\sum_{i=1}^{30} WAMSOF_i + SOFA = 1$$

$$\sum_{i=1}^{30} WPMSOF_i + SOFP = 1$$

$$\sum_{i=1}^{30} RAMSOF_i + SOFA = 1$$

$$\sum_{i=1}^{30} RPMSOF_i + SOFP = 1$$

$$\sum_{i=1}^{30} FAMSOF_i + SOFA = 1$$

$$\sum_{i=1}^{30} FPMSOF_i + SOFP = 1$$

Constraint set 5 uses indicator variables from user inputs to assign exactly one SOF qualified pilot to the five required SOF duties for the week. The *SOFA* and *SOFP* indicator variables are unequal binary inputs. If the squadron is responsible for AM SOF duty, then *SOFA* = 0, which forces the model to assign one SOF qualified pilot to that duty. If the squadron is scheduling PM SOF duty, then *SOFA* = 1, which prevents the model from assigning any pilots to the AM SOF duty. The same methodology applies to the *SOFP* variable.

Constraint Set 6

$$MAMT3_i + MPMT3_i + MAMSOF_i + MPMSOF_i \leq 1 \text{ for } i = 1, 2, ..., 30$$

$$TAMT3_i + TPMT3_i + TAMSOF_i + TPMSOF_i \leq 1 \text{ for } i = 1, 2, ..., 30$$

$$WAMT3_i + WPMT3_i + WAMSOF_i + WPMSOF_i \leq 1 \text{ for } i = 1, 2, ..., 30$$

$$RAMT3_i + RPMT3_i + RAMSOF_i + RPMSOF_i \leq 1 \text{ for } i = 1, 2, ..., 30$$

$$FAMT3_i + FPMT3_i + FAMSOF_i + FPMSOF_i \leq 1 \text{ for } i = 1, 2, ..., 30$$

Constraint set 6 prevents any pilot from being assigned to more than one of the SOF and TOP3 duties in a single day. This will prevent time overlap of duties and duty days of 14 to 16 hours in length.

Constraint Set 7

$$MAMT3_i + MAMSOF_i + \sum_{j=1}^{3} M_{ij} \leq 1 \text{ for } i = 1, 2, ..., 50$$

$$MPMT3_i + MPMSOF_i + \sum_{j=4}^{6} M_{ij} \leq 1 \text{ for } i = 1, 2, ..., 50$$

$$TAMT3_i + TAMSOF_i + \sum_{j=1}^{3} T_{ij} \leq 1 \text{ for } i = 1, 2, ..., 50$$

$$TPMT3_i + TPMSOF_i + \sum_{j=4}^{6} T_{ij} \leq 1 \text{ for } i = 1, 2, ..., 50$$

$$WAMT3_i + WAMSOF_i + \sum_{j=1}^{3} W_{ij} \leq 1 \text{ for } i = 1, 2, ..., 50$$

$$WPMT3_i + WPMSOF_i + \sum_{j=4}^{6} W_{ij} \leq 1 \text{ for } i = 1, 2, ..., 50$$

$$RAMT3_i + RAMSOF_i + \sum_{j=1}^{3} R_{ij} \leq 1 \text{ for } i = 1, 2, ..., 50$$

$$RPMT3_i + RPMSOF_i + \sum_{j=4}^{6} R_{ij} \leq 1 \text{ for } i = 1, 2, ..., 50$$

$$FAMT3_i + FAMSOF_i + \sum_{j=1}^{3} F_{ij} \leq 1 \text{ for } i = 1, 2, ..., 50$$

$$FPMT3_i + FPMSOF_i + \sum_{j=4}^{6} F_{ij} \leq 1 \text{ for } i = 1, 2, ..., 50$$

Constraint set 7 prevents the model from assigning a pilot to time overlapping events in the AM GO or the PM GO by allowing a maximum of one assignment from the missions and duties in each GO. This does not preclude the pilot from other scheduling events such as simulator sorties and ground training.

Constraint Set 8

$$A_{i1} + \sum_{j=1}^{6} M_{ij} + 0.3 * (MAMT3_i + MPMT3_i + MAMSOF_i + MPMSOF_i) \leq 2 \text{ for } i = 1, 2, ..., 50$$

$$A_{i2} + \sum_{j=1}^{6} T_{ij} + 0.3 * (TAMT3_i + TPMT3_i + TAMSOF_i + TPMSOF_i) \leq 2 \text{ for } i = 1, 2, ..., 50$$

$$A_{i3} + \sum_{j=1}^{6} W_{ij} + 0.3 * (WAMT3_i + WPMT3_i + WAMSOF_i + WPMSOF_i) \leq 2 \text{ for } i = 1, 2, ..., 50$$

$$A_{i4} + \sum_{j=1}^{6} R_{ij} + 0.3 * (RAMT3_i + RPMT3_i + RAMSOF_i + RPMSOF_i) \leq 2 \text{ for } i = 1, 2, ..., 50$$

$$A_{i5} + \sum_{j=1}^{6} F_{ij} + 0.3 * (FAMT3_i + FPMT3_i + FAMSOF_i + FPMSOF_i) \leq 2 \text{ for } i = 1, 2, ..., 50$$

Constraint set 8 uses inputs of pilot availability to ensure that only pilots available for missions and duties are assigned. A pilot that is on leave, TDY, deployed or for some other reason unavailable for any mission, SOF duty, or Top 3 duty will not be assigned. However, a DNIF pilot can still be assigned to TOP3 or SOF duties if they are qualified.

Constraint Set 9

$M_{i4} * S_{14} + M_{i5} * S_{15} + M_{i6} * S_{16} + 4 * (MAMT3_i + MAMSOF_i) \leq 13$ for $i = 1, 2, ..., 50$

$M_{i4} * S_{14} + M_{i5} * S_{15} + M_{i6} * S_{16} + 7 * (1 - (M_{i4} + M_{i5} + M_{i6} + MAMT3_i + MAMSOF_i))$

≥ 0 for $i = 1, 2, ..., 50$

$T_{i4} * S_{24} + T_{i5} * S_{25} + T_{i6} * S_{26} + 4 * (TAMT3_i + TAMSOF_i) \leq 13$ for $i = 1, 2, ..., 50$

$T_{i4} * S_{24} + T_{i5} * S_{25} + T_{i6} * S_{26} + 7 * (1 - (T_{i4} + T_{i5} + T_{i6} + TAMT3_i + TAMSOF_i))$

≥ 0 for $i = 1, 2, ..., 50$

$W_{i4} * S_{34} + W_{i5} * S_{35} + W_{i6} * S_{36} + 4 * (WAMT3_i + WAMSOF_i) \leq 13$ for $i = 1, 2, ..., 50$

$W_{i4} * S_{34} + W_{i5} * S_{35} + W_{i6} * S_{36} + 7 * (1 - (W_{i4} + W_{i5} + W_{i6} + WAMT3_i + WAMSOF_i))$

≥ 0 for $i = 1, 2, ..., 50$

$R_{i4} * S_{44} + R_{i5} * S_{45} + R_{i6} * S_{46} + 4 * (RAMT3_i + RAMSOF_i) \leq 13$ for $i = 1, 2, ..., 50$

$R_{i4} * S_{44} + R_{i5} * S_{45} + R_{i6} * S_{46} + 7 * (1 - (R_{i4} + R_{i5} + R_{i6} + RAMT3_i + RAMSOF_i))$

≥ 0 for $i = 1, 2, ..., 50$

$F_{i4} * S_{54} + F_{i5} * S_{55} + F_{i6} * S_{56} + 4 * (FAMT3_i + FAMSOF_i) \leq 13$ for $i = 1, 2, ..., 50$

$F_{i4} * S_{54} + F_{i5} * S_{55} + F_{i6} * S_{56} + 7 * (1 - (F_{i4} + F_{i5} + F_{i6} + FAMT3_i + FAMSOF_i))$

≥ 0 for $i = 1, 2, ..., 50$

Constraint set 9 ensures that if a pilot is assigned to a AM GO SOF or Top 3 duty and a PM GO flight, the allowable FDP is not exceeded with the pilot still flying a sortie.

Constraint Set 10

$M_{i1} * S_{11} + M_{i2} * S_{12} + M_{i3} * S_{13} - 4 * (MPMT3_i + MPMSOF_i) +$

$4 * (1 - (M_{i1} + M_{i2} + M_{i3})) \geq 0$ for $i = 1, 2, ..., 50$

$6 * (MPMT3_i + MPMSOF_i) - (M_{i1} * S_{11} + M_{i2} * S_{12} + M_{i3} * S_{13}) +$

$8 * (1 - (MPMT3_i + MPMSOF_i)) + \geq 0$ for $i = 1, 2, ..., 50$

$T_{i1} * S_{21} + T_{i2} * S_{22} + T_{i3} * S_{23} - 4 * (TPMT3_i + TPMSOF_i) +$

$4 * (1 - (T_{i1} + T_{i2} + T_{i3})) \geq 0$ for $i = 1, 2, ..., 50$

$6 * (TPMT3_i + TPMSOF_i) - (T_{i1} * S_{21} + T_{i2} * S_{22} + T_{i3} * S_{23}) +$

$8 * (1 - (TPMT3_i + TPMSOF_i)) + \geq 0$ for $i = 1, 2, ..., 50$

$W_{i1} * S_{31} + W_{i2} * S_{32} + W_{i3} * S_{33} - 4 * (WPMT3_i + WPMSOF_i) +$

$4 * (1 - (W_{i1} + W_{i2} + W_{i3})) \geq 0$ for $i = 1, 2, ..., 50$

$6 * (WPMT3_i + WPMSOF_i) - (W_{i1} * S_{31} + W_{i2} * S_{32} + W_{i3} * S_{33}) +$

$8 * (1 - (WPMT3_i + WPMSOF_i)) + \geq 0$ for $i = 1, 2, ..., 50$

$R_{i1*} S_{41} + R_{i2*} S_{42} + R_{i3*} S_{43} - 4 * (RPMT3_i + RPMSOF_i) +$
$4 * (1 - (R_{i1} + R_{i2} + R_{i3})) \geq 0$ for $i = 1, 2,......, 50$
$6 * (RPMT3_i + RPMSOF_i) - (R_{i1*} S_{41} + R_{i2*} S_{42} + R_{i3*} S_{43}) +$
$8 * (1 - (RPMT3_i + RPMSOF_i)) + \geq 0$ for $i = 1, 2,......, 50$
$F_{i1*} S_{51} + F_{i2*} S_{52} + F_{i3*} S_{53} - 4 * (FPMT3_i + FPMSOF_i) +$
$4 * (1 - (F_{i1} + F_{i2} + F_{i3})) \geq 0$ for $i = 1, 2,......, 50$
$6 * (FPMT3_i + FPMSOF_i) - (F_{i1*} S_{51} + F_{i2*} S_{52} + F_{i3*} S_{53}) +$
$8 * (1 - (FPMT3_i + FPMSOF_i)) + \geq 0$ for $i = 1, 2,......, 50$

Constraint set 10 ensure that a pilot performing an AM GO sortie and a PM GO SOF or Top 3 duty will only be scheduled for 12 hours and that the AM GO sortie does not conflict with the pilot's availability for the PM GO SOF or Top 3 duty.

Constraint Set 11

$$S_{14} * ((\sum_{j=1}^{3} M_{ij}) - 1) + S_{11} *(1 - (\sum_{j=4}^{6} M_{ij})) + (\sum_{j=4}^{6} (M_{ij} * S_{1j}) - \sum_{j=1}^{3} (M_{ij} * S_{1j})) +$$
$$4 * (1 - \sum_{j=1}^{6} M_{ij}) \leq 4 \text{ for } i = 1, 2,...., 50$$

$$S_{13} *(1 - (\sum_{j=4}^{6} M_{ij})) + (\sum_{j=4}^{6} (M_{ij} * S_{1j}) - \sum_{j=1}^{3} (M_{ij} * S_{1j})) + 4 * (1 - \sum_{j=1}^{6} M_{ij}) \geq 0 \text{ for } i = 1, 2,..., 50$$

$$S_{24} * ((\sum_{j=1}^{3} T_{ij}) - 1) + S_{21} *(1 - (\sum_{j=4}^{6} T_{ij})) + (\sum_{j=4}^{6} (T_{ij} * S_{2j}) - \sum_{j=1}^{3} (T_{ij} * S_{2j})) +$$
$$4 * (1 - \sum_{j=1}^{6} T_{ij}) \leq 4 \text{ for } i = 1, 2,...., 50$$

$$S_{23} *(1 - (\sum_{j=4}^{6} T_{ij})) + (\sum_{j=4}^{6} (T_{ij} * S_{2j}) - \sum_{j=1}^{3} (T_{ij} * S_{2j})) + 4 * (1 - \sum_{j=1}^{6} T_{ij}) \geq 0 \text{ for } i = 1, 2,..., 50$$

$$S_{34} * ((\sum_{j=1}^{3} W_{ij}) - 1) + S_{31} *(1 - (\sum_{j=4}^{6} W_{ij})) + (\sum_{j=4}^{6} (W_{ij} * S_{3j}) - \sum_{j=1}^{3} (W_{ij} * S_{3j})) +$$
$$4 * (1 - \sum_{j=1}^{6} W_{ij}) \leq 4 \text{ for } i = 1, 2,...., 50$$

$$S_{33} *(1 - (\sum_{j=4}^{6} W_{ij})) + (\sum_{j=4}^{6} (W_{ij} * S_{3j}) - \sum_{j=1}^{3} (W_{ij} * S_{3j})) + 4 * (1 - \sum_{j=1}^{6} W_{ij}) \geq 0 \text{ for } i = 1, 2,..., 50$$

$$S_{44} * ((\sum_{j=1}^{3} R_{ij}) - 1) + S_{41} *(1 - (\sum_{j=4}^{6} R_{ij})) + (\sum_{j=4}^{6} (R_{ij} * S_{4j}) - \sum_{j=1}^{3} (R_{ij} * S_{4j})) +$$

$$4 * (1 - \sum_{j=1}^{6} R_{ij}) \leq 4 \text{ for } i = 1, 2,...., 50$$

$$S_{43} *(1 - (\sum_{j=4}^{6} R_{ij})) + (\sum_{j=4}^{6} (R_{ij} * S_{4j}) - \sum_{j=1}^{3} (R_{ij} * S_{4j})) + 4 * (1 - \sum_{j=1}^{6} R_{ij}) \geq 0 \text{ for } i = 1, 2,..., 50$$

$$S_{54} * ((\sum_{j=1}^{3} F_{ij}) - 1) + S_{51} *(1 - (\sum_{j=4}^{6} F_{ij})) + (\sum_{j=4}^{6} (F_{ij} * S_{5j}) - \sum_{j=1}^{3} (F_{ij} * S_{5j})) +$$

$$4 * (1 - \sum_{j=1}^{6} F_{ij}) \leq 4 \text{ for } i = 1, 2,...., 50$$

$$S_{53} *(1 - (\sum_{j=4}^{6} F_{ij})) + (\sum_{j=4}^{6} (F_{ij} * S_{5j}) - \sum_{j=1}^{3} (F_{ij} * S_{5j})) + 4 * (1 - \sum_{j=1}^{6} F_{ij}) \geq 0 \text{ for } i = 1, 2,..., 50$$

Constraint set 11 ensures that any pilot assigned to fly in both an AM GO mission and a PM GO mission has a minimum of four hours between mission start times and a maximum of eight hours between mission start times.

Constraint Set 12

$$\sum_{j=1}^{3} (T_{ij} * S_{2j}) + TAMSOF_i + TAMT3_i - (\sum_{j=4}^{6} (M_{ij} * (S_{1j} - 8)) + MPMSOF_i * 2 +$$
$$MPMT3_i * 4) \geq 0 \text{ for } i = 1, 2,..., 50$$

$$\sum_{j=1}^{3} (W_{ij} * S_{3j}) + WAMSOF_i + WAMT3_i - (\sum_{j=4}^{6} (T_{ij} * (S_{2j} - 8)) + TPMSOF_i * 2 +$$
$$TPMT3_i * 4) \geq 0 \text{ for } i = 1, 2,..., 50$$

$$\sum_{j=1}^{3} (R_{ij} * S_{4j}) + RAMSOF_i + RAMT3_i - (\sum_{j=4}^{6} (W_{ij} * (S_{3j} - 8)) + WPMSOF_i * 2 +$$
$$WPMT3_i * 4) \geq 0 \text{ for } i = 1, 2,..., 50$$

$$\sum_{j=1}^{3} (F_{ij} * S_{5j}) + FAMSOF_i + FAMT3_i - (\sum_{j=4}^{6} (R_{ij} * (S_{4j} - 8)) + RPMSOF_i * 2 +$$
$$RPMT3_i * 4) \geq 0 \text{ for } i = 1, 2,..., 50$$

Constraint set 12 ensures that every pilot has a minimum of twelve hours crew rest from every weekday PM GO (except Friday) to the following day's AM GO.

All XIP_{kj}, XFL_{kj}, and $S_{kj} \geq 0$ and integer, All other variables are binary

Sub-Problem Formulation:

Tuesday's PM GO formulation is presented as a sample sub-problem formulation. A key issue in PM GO formulations is feasibility of assigning a PM GO sortie, SOF duty, or Top 3 duty to a pilot already assigned to an AM GO sortie, SOF duty, or Top 3 duty.

Variables:

$$\text{Let } T_{ij} = \begin{Bmatrix} 1 & \text{If pilot } i \text{ is assigned to mission } j \text{ on Tuesday} \\ 0 & \text{otherwise} \end{Bmatrix} \text{ where } j = 4, 5, 6$$

The preceding variable set represents the decision variables for assigning a specific pilot to a specific training mission during Tuesday's PM GO.

Let XIP_{2j} = the number of extra IP pilots required for mission j where j = 4, 5, 6
Let XFL_{2j} = the number of extra FL pilots required for mission j where j = 4, 5, 6

This variable set represents the decision variables for assigning a non-squadron pilot to a specific training mission during Tuesday's PM GO.

$$\text{Let } TPMT3_i = \begin{Bmatrix} 1 & \text{If pilot } i \text{ is assigned as Tuesday PM GO TOP3} \\ 0 & \text{otherwise} \end{Bmatrix}$$

$$\text{Let } TPMSOF_i = \begin{Bmatrix} 1 & \text{If pilot } i \text{ is assigned as Tuesday PM GO SOF} \\ 0 & \text{otherwise} \end{Bmatrix}$$

This variable set represents the decision variables for assigning a specific pilot to each of the Top 3 and SOF duties for the week. The subscript i ranges from 1 to 50.

Parameters:

Let a = number of TOP3 qualified pilots in the squadron
Let b = number of IPs in the squadron (Non-TOP3)
Let c = number of 4-ship FLs in the squadron (Non-TOP3, Non-IP)
Let d = number of 2-ship FLs in the squadron (Non-TOP3, Non-IP, Non-4FL)

The preceding parameter set enumerates the pilots in five different qualification levels. These parameters are mainly used for ease in presentation of the formulation.

$$AMcheck_i = \begin{cases} 1 & \text{If pilot } i \text{ performed an AM duty (SOF or TOP3)} \\ 0 & \text{If pilot } i \text{ was not assigned to a duty or sortie in the AM GO} \\ -1 & \text{If pilot } i \text{ was assigned to fly a sortie in the AM GO} \end{cases}$$

This parameter is an indicator of what has occurred for pilot *i* in the AM GO. This parameter can be used to cancel out constraints that are not required in the PM GO. For example, if a pilot is assigned to the AM SOF duty, then there is no need to determine the feasibility of flying an AM GO sortie and a PM GO sortie.

$$\text{Let } A_{i2} = \begin{cases} 0 + \sum_{j=1}^{3} T_{ij} + 0.3 * (TAMT3i + TAMSOFi) & \text{if pilot } i \text{ is available for all duties} \\ 1.5 + 0.3 * (TAMT3i + TAMSOFi) & \text{if pilot } i \text{ is DNIF} \\ 2 & \text{if pilot } i \text{ is unavailable for any duty} \end{cases}$$

The parameter A_{i2} is from user input for pilot *i*'s availability on Tuesday.

Let S_{2j} = briefing start time for mission j where j = 4, 5, 6

The values for parameter S_{2j} are directly associated to user inputs for the initial briefing time for each training mission. This parameter is then used in FDP constraints.

Let $FDCount_i$ = number of days since last sortie for pilot *i*
Let $TDCount_i$ = number of sorties flown by pilot *i* in the last 26 days
Let $NDCount_i$ = number of sorties flown by pilot *i* in the last 86 days
Let RTD_i = number of sorties required for 30 day count for pilot *i*
Let RND_i = number of sorties required for 90 day count for pilot *i*

The values for this set of parameters are based on user inputs. The first three parameters are user inputs for 15-day, 30-day, and 90-day sortie counts. However, in the sub-problem formulation these parameters are updated after each sub-problem. For example, a pilot that begins Tuesday with a 90-day sortie count of 14 and is assigned to an AM GO training mission will have a 90-day sortie count of 15 for the PM GO sub-problem. The last two parameters represent pilot *i*'s requirement for 30-day and 90-day lookbacks and are based on pilot *i*'s experience level and status (BMC or CMR).

$$\text{Let } SOFP = \begin{cases} 0 & \text{if the squadron is assigned to PM SOF duties} \\ 1 & \text{if the squadron is assigned to AM SOF duties} \end{cases}$$

The value for *SOFP* represents a toggle between the AM and PM position for the squadron's SOF duty. This parameter is set directly from the user's input.

$$\text{Let } P30_{ik} = \begin{cases} 0 & \text{if } TDCount_i \geq RTD_i \\ (RTD_i - TDCount_i) * (2 - \sum_{j=1}^{6} T_{ij}) & \text{if } TDCount_i < RTD_i \end{cases}$$

$$\text{Let } P90_{ik} = \begin{cases} 0 & \text{if } NDCount_i \geq RND_i \\ (RND_i - NDCount_i) * (2 - \sum_{j=1}^{6} T_{ij}) & \text{if } NDCount_i < RND_i \end{cases}$$

The parameters above are the size of the penalty for pilot *i* for the 30-day and 90-day sortie counts on the Tuesday PM GO sub-problem.

$$\text{Let } FDP_i = \begin{cases} 0 & \text{if } FDCount_i \leq 11 \\ 1 - \sum_{j=4}^{6} T_{ij} - 0.5 * A_{i2} & \text{if } 11 < FDCount_i \leq 13 \\ 2 - 2 * \sum_{j=4}^{6} T_{ij} - 0.5 * A_{i2} & \text{if } FDCount_i > 13 \end{cases}$$

These parameters are the actual penalty values for the 15-day sortie counts for each pilot. These parameters are based on the updated 15-day sortie count, pilot availability and pilot assignment for Tuesday's PM GO.

For the above, $i = 1, 2, \ldots, 50$; $j = 1, 2, \ldots, 6$; $k = 1$ (Monday), 2 (Tuesday),…, 5 (Friday).

Objective Function:

$$\text{Min } W = 10 * \sum_{j=4}^{6} (XIP_{2j} + XFL_{2j}) + 25 * \sum_{i=1}^{50} FDP_i + 10 * \sum_{i=1}^{50} P_{30i2} + 25 * \sum_{i=1}^{50} P_{90i2}$$

The objective function is the minimum sum of the following: ten times the number of non-squadron pilots used in Tuesday's PM GO, 25 times the sum of Tuesday PM GO 15-day penalties for all squadron pilots, ten times the sum of Tuesday PM GO 30-day penalties for all squadron pilots, and 25 times the sum of Tuesday PM GO 90-day penalties for all squadron pilots.

s.t.
Constraint Set 1

$$\sum_{i=1}^{50} T_{ij} + XIP_{2j} + XFL_{2j} = 4 \quad \text{for } j = 4, 5$$

$$\sum_{i=1}^{50} T_{i6} + XIP_{26} + XFL_{26} = 2$$

Constraint set 1 ensures that the 4-ship missions (missions 4 and 5) have four pilots assigned and that the 2-ship mission (mission 6) has two pilots assigned.

Constraint Set 2

$$\sum_{i=1}^{a+b} T_{ij} + XIP_{2j} \geq 1 \quad \text{for } j = 4, 5$$

$$\sum_{i=1}^{a+b+c} T_{ij} + XFL_{2j} \geq 2 \quad \text{for } j = 4, 5$$

$$\sum_{i=1}^{a+b+c+d} T_{i6} + XFL_{26} \geq 1$$

Constraint set 2 ensures that each 4-ship mission has at least one pilot qualified at the IP level and one additional pilot qualified at the 4-ship FL level or higher assigned. This constraint set also ensures that the 2-ship mission has at least one pilot qualified as a 2-ship FL or higher assigned.

Constraint Set 3

$$\sum_{i=1}^{a} T_{ij} \leq 1 \text{ for } j = 4, 5, 6$$

This constraint set ensures at most one Top 3 pilot is assigned to each mission.

Constraint Set 4

$$\sum_{i=1}^{a} TPMT3_i = 1$$

This constraint requires that one Top 3 qualified pilot is assigned to the Tuesday PM GO Top 3 duty.

Constraint Set 5

$$\sum_{i=1}^{30} TPMSOF_i + SOFP = 1$$

Constraint set 5 ensures that the Tuesday PM SOF duty is filled for a squadron performing PM SOF duties.

Constraint Set 6

$$TAMT3_i + TPMT3_i + TAMSOF_i + TPMSOF_i \leq 1 \text{ for } i = 1, 2, ..., 30$$

Constraint set 6 prevents any pilot from being assigned to more than one of the SOF and TOP3 duties during Tuesday. This will prevent time overlap of duties and a duty day on Tuesday of 14 to 16 hours in length.

Constraint Set 7

$$TPMT3_i + TPMSOF_i + \sum_{j=4}^{6} T_{ij} \leq 1 \text{ for } i = 1, 2, ..., 50$$

Constraint set 7 prevents the model from assigning a pilot to time overlapping events in the PM GO by allowing a maximum of one assignment from the training missions and SOF or Top 3 duties in the PM GO. This does not prevent the pilot from other scheduling events such as simulator sorties and ground training.

Constraint Set 8

$$A_{i2} + \sum_{j=4}^{6} T_{ij} + 0.3 * (TPMT3_i + TPMSOF_i) \leq 2 \text{ for } i = 1, 2, \ldots, 50$$

Constraint set 8 uses inputs of pilot availability to ensure that only pilots available for missions and duties are assigned.

Constraint Set 9

$$T_{i4} * S_{24} + T_{i5} * S_{25} + T_{i6} * S_{26} + 4 * (TAMT3_i + TAMSOF_i) \leq 13 \text{ for } i = 1, 2, \ldots, 50$$

Constraint set 9 ensures that if a pilot is assigned to a Tuesday AM GO SOF or Top 3 duty and a Tuesday PM GO flight, the allowable FDP is not exceeded with the pilot still flying a sortie.

Constraint Set 10

$$AMcheck_i * (1 - 0.5 * (1 - AMcheck_i)) * \left(\sum_{j=4}^{6} (T_{ij} * S_{2j}) - 7 * \sum_{j=4}^{6} T_{ij} \right) \leq 2$$

$$AMcheck_i * (1 - 0.5 * (1 - AMcheck_i)) * \left(\sum_{j=4}^{6} (T_{ij} * S_{2j}) - 7 * \sum_{j=4}^{6} T_{ij} \right) \geq 0$$

$$AMcheck_i * (-1) * (0.5 * (1 + AMcheck_i) - 1) * \left(\sum_{j=1}^{3} (T_{ij} * S_{2j}) - 4 * \sum_{j=1}^{3} T_{ij} \right) \leq 1$$

$$AMcheck_i * (-1) * (0.5 * (1 + AMcheck_i) - 1) * \left(\sum_{j=1}^{3} (T_{ij} * S_{2j}) - 4 * \sum_{j=1}^{3} T_{ij} \right) \geq 0$$

Constraint set 10 ensures a pilot performing a Tuesday AM GO sortie and a Tuesday PM GO SOF or Top 3 duty will only be scheduled for 12 hours and the AM GO sortie does not conflict with the pilot's availability for the PM GO SOF or Top 3 duty.

Constraint Set 11

$$0.5 * AMcheck_i * (AMcheck_i - 1) * \left(\sum_{j=4}^{6} \left(T_{ij} * \left(S_{2j} - \sum_{j=1}^{3} (T_{ij} * S_{2j}) \right) \right) - 4 * \sum_{j=4}^{6} T_{ij} \right) \leq 5$$

$$0.5 * AMcheck_i * (AMcheck_i - 1) * \left(\sum_{j=4}^{6} \left(T_{ij} * \left(S_{2j} - \sum_{j=1}^{3} (T_{ij} * S_{2j}) \right) \right) - 4 * \sum_{j=4}^{6} T_{ij} \right) \geq 0$$

Constraint set 11 ensures that any pilot assigned to fly in both a Tuesday AM GO mission and a Tuesday PM GO mission has a minimum of four hours between mission start times and a maximum of eight hours between mission start times.

All XIP_{kj}, XFL_{kj}, and $S_{kj} \geq 0$ and integer, All other variables are binary

This formulation is representative of all PM GO sub-problems. The constraint sets are labeled to allow a side by side comparison with the formulation of the entire week. Constraint set 1, for example, is used to ensure that four pilots are assigned to every 4-ship mission and two pilots are assigned to every 2-ship mission. The full week formulation has twelve constraint sets and the Tuesday PM GO formulation above has eleven constraint sets. Constraint set 12 is used to ensure that 12 hours of crew rest occurs from the end of a PM GO on one day to the start of AM GO duties the next day. Therefore, the PM GO formulation above does not require this constraint set. However, in the AM GO formulations (except Monday's AM GO), constraint set twelve is required and other constraint sets may be omitted. The advantage of using sub-problems is found in the constraints relating to multiple assignments in a duty day. For example, a pilot may fly both AM GO and PM GO sorties in the same duty day. In the weekly formulation, constraint set 11 ensures the feasibility of a pilot flying any two sorties. Each of these constraints depend on six variables (three AM GO and three PM GO). However, the PM GO sub-problem only uses three variables and the known result of the AM GO sub-problem. Thus, the other three variables are now constants. This constraint ensures feasibility of a single pilot flying two sorties based on a known time frame for the first of the two sorties. Therefore, constraint set 11 has the same purpose in both formulations (weekly and PM GO), but the constraints themselves are different.

The indicator variable *AMcheck* is used to indicate what has occurred in the AM GO. If a pilot is assigned to an AM GO SOF or Top 3 duty, then *AMcheck* = 1 and constraint set 9 ensures the feasibility of the same pilot being assigned to a PM GO sortie. Constraint sets 10 and 11 for that pilot equal zero and are irrelevant since the pilot did not fly in the AM GO. If a pilot is unassigned in the AM GO, then *AMcheck* = 0 and constraint sets 10 and 11 for that pilot equal zero and are irrelevant. If the pilot is assigned to an AM GO sortie, then *AMcheck* = -1 and constraint set 9 for that pilot is irrelevant since the pilot did not perform an AM GO SOF or Top 3 duty. Constraint sets 10 and 11 are used to ensure the feasibility of the same pilot being assigned to a PM GO SOF or Top 3 duty (constraint set 10) or flying a sortie in the PM GO (constraint set 11).

Another advantage of using sub-problems is the ability to update sortie counts. The updated values of these parameters are compared with sortie count requirements. Using simple programming, preprocessing of the sortie count penalty functions can be accomplished. For example, a pilot's 30-day sortie count is 4 and the requirement is 6. Thus, the pilot must fly at least two sorties during the week to fulfill the requirement. If the requirement is met on Tuesday, then the penalty function for this pilot's 30-day sortie count goes to zero for the remainder of the week. In the sub-problem, this is a linear function based on known results of previous sub-problems. In the full week formulation, this penalty function could not be based on known results from early points in the week. The penalty functions for pilot sortie counts in the full week formulation are smooth nonlinear functions. The penalty terms are $\sum TDP_i$ and $\sum NDP_i$ for i = 1 to 50 where:

$$\text{Let } TDP_i = \begin{cases} 0 & \text{if } TDCount_i \geq RTD_i \\ (RTD_i - TDCount_i) * \text{Max}(P_{30ik}) & \text{if } TDCount_i < RTD_i \end{cases}$$

$$\text{Let } NDP_i = \begin{cases} 0 & \text{if } NDCount_i \geq RND_i \\ (RND_i - NDCount_i) * \text{Max}(P_{90ik}) & \text{if } NDCount_i < RND_i \end{cases}$$

Since a maximum value formula is associated with these parameters, the penalty terms are clearly nonlinear. However, the P_{30} and P_{90} parameters will have a value of 0, 1, or 2. Thus, the full week formulation has smooth nonlinear 30 and 90-day penalty functions.

3.8 Simulator Heuristic

In both formulations of this problem, the number of variables is reduced by excluding the simulator sorties from the problem. However, a simulator heuristic was developed to ensure the simulator sorties are populated with pilots. The heuristic is designed using VBA programming and is applied to the overall problem after the previously mentioned formulations have been solved. Thus, training mission, SOF duty, and Top 3 duty assignments are used as inputs for the heuristic. The heuristic is designed to spread the simulator sorties to as many of the squadron pilots as possible. Thus, Monday's simulator sorties are assigned first and each successive day is scheduled such that available pilots with the fewest simulator sorties for the week are assigned first.

The initial phase of the simulator heuristic looks for available pilots that have not been assigned to a training mission on a given duty day. A pilot meeting this criteria is assigned to a simulator sortie provided they have not already been assigned to two simulator sorties for the week. After the initial phase, the weekly schedule is populated with simulator and training mission sorties, Top 3 and SOF duties, and off-duty time.

The second phase of the simulator heuristic counts the number of simulator sorties filled for each day. If any day has not been filled, then the schedule for that day is examined. Beginning with the first pilot and proceeding down the list, the heuristic searches for pilots with the required block of time unscheduled. If a pilot has the time available and has fewer simulator sorties than the incremented variable for each pass, then that pilot is assigned to a simulator. The incremented variable *simtot* starts at three and is incremented to ten. No pilot can fill more than ten simulator sorties in a week. However, the heuristic should disperse the simulator assignments such that no pilot exceeds four simulator sorties for the week. If all simulator sorties have not been filled, then no squadron pilots are available to fill the requirement and the simulator slot is lost.

3.9 Network Representation

The network representation for a single day is shown in Figure 6. The source nodes (T3 1, T3 2,…,P d) and the "Other Pilots" node represent the available pilots. Flow moves toward the sink node ("Ground Training"). The sink node also includes activities such as: TDY, deployment, leave, ground training, classes, professional military education (PME), and relief of non-squadron pilots. There are several side constraints to the MP model. First, no pilot can be assigned to multiple events occurring at the same time. Therefore, a pilot acting as the TOP3 in the AM GO cannot then be assigned as the IP pilot for a 0900 AM GO sortie. However, the 12Turn10 does not have set time restrictions. Thus, AM GO sorties could be scheduled after noon, or PM GO sorties could be scheduled before noon. Therefore, a pilot may perform PM GO SOF or Top 3 duties after a PM GO flight that begins at 0900. However, the current model does not allow a PM GO sortie to be scheduled before 1000. Also, each pilot may only have one sortie, SOF duty, or Top 3 duty per GO. Next, the SOF duty may be AM or PM and not all FL qualified pilots are eligible to fill this position. Additionally, the SOF assigned pilot flows into the "P" node, but this pilot may fill a seat in any mission up to the pilot's highest qualification level. Finally, FLs are further divided into two categories: 4-ship FL and 2-ship FL. A 4-ship mission cannot use a 2-ship FL as the FL for the mission. However, a 4-ship FL can fill the FL role in a 2-ship or a 4-ship mission.

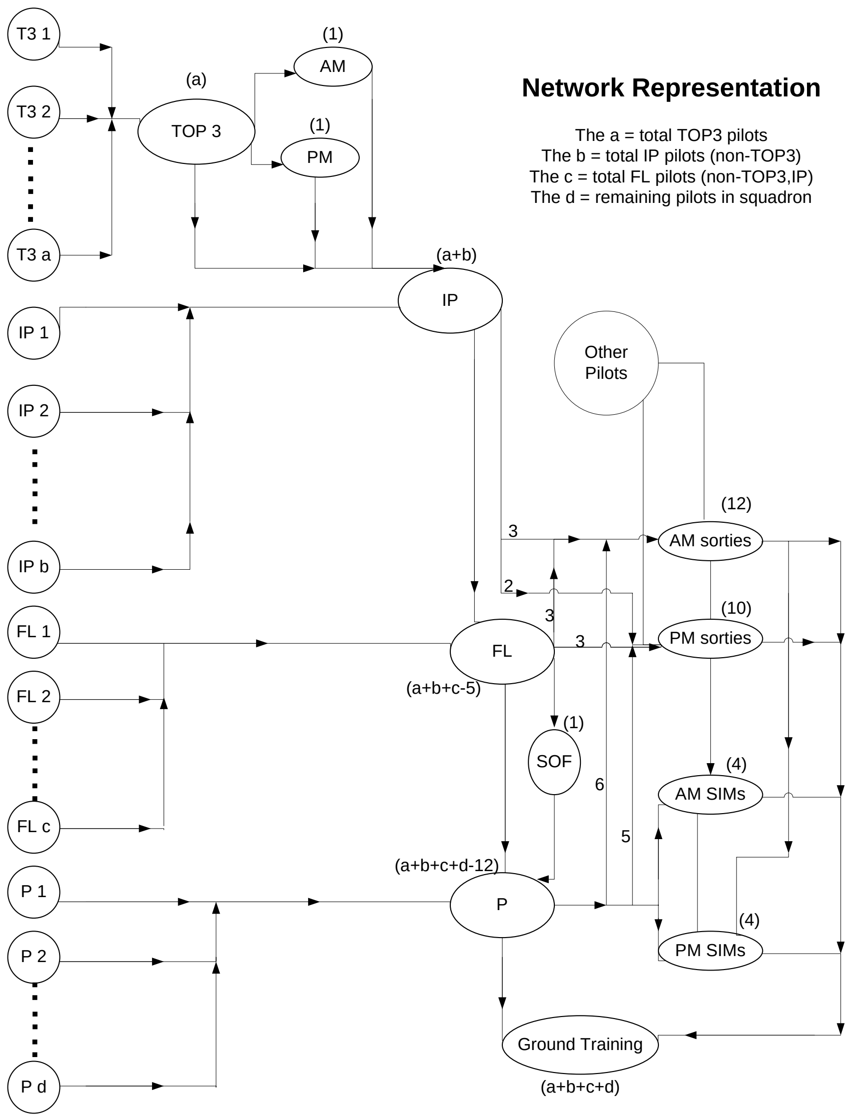


Figure 6. Single Day Network Representation

The network representation in Figure 6 also shows demands on certain nodes and arcs. The min and max capacity on all arcs from the pilot nodes to the qualification nodes (TOP3, IP, FL, and P) is 1. There is exactly one pilot at each pilot node, and each pilot must flow to a qualification level. The squadron has "*a*" pilots qualified at the TOP3 level and thus the "TOP3" node has a demand of "*a*." Additionally, the "AM" and "PM" TOP3 nodes have a demand of 1. Therefore, the arc from "TOP3" to "IP" has a flow of "*a*-2" and arcs "AM" to "IP" and "PM" to "IP" both have a flow of 1. Thus, all of the TOP3 qualified pilots flow into the "IP" node and all IP pilots that are not TOP3 qualified flow into the "IP" node. Since the squadron has "*b*" IP pilots that are not TOP3 qualified, the demand at the "IP" node is "*a+b*."

There are three missions in the AM sorties which require an IP pilot and two missions in the PM sorties which require an IP pilot. Thus, the arc from "IP" to "AM sorties" has a maximum capacity of 3 and the arc from "IP" to "PM sorties" has a maximum capacity of 2. The total IP demand for the day is five, but a single IP pilot may fly an AM sortie and a PM sortie in that role. All remaining pilots in the "IP" node will flow to the "FL" node as they are qualified for FL duty. Thus, the minimum demand at the "FL" node is "*a+b*-5" plus the number of FL (non-IP and non TOP3) pilots in the squadron, "*c*."

The arcs from "FL" to "AM sorties" and "FL" to "PM sorties" both have a maximum capacity of 3. However, a FL pilot may fill the FL role in both an AM sortie and a PM sortie. The total FL demand for the day is six. Additionally, one pilot qualified to fill the SOF position will fill the SOF demand and flow from the "FL" node to the "SOF" node and on to the "P" node. All remaining pilots in the "FL" node will flow directly to the "P" node. Thus node "P" has a minimum demand of "$a+b+c$-12" plus "d," the remaining pilots in the squadron (non-TOP3, non-IP, and non-FL). From node "P" all remaining or unfilled demand in nodes "AM sorties", "PM sorties", "AM SIMs" and "PM SIMs" will be filled. The total node demands are as follows: "AM sorties" demand is 12, "PM sorties" demand is 10, "AM SIMs" demand is 4 and "PM SIMs" demand is 4. Therefore, a total of three duties are filled and 30 pilot assignments are filled. Then all pilots flow into the "Ground Training" node. Thus, the minimum demand at the "Ground Training" node is "$a+b+c+d$." The demand at this node will only increase if pilots from outside the squadron are used to fill the sortie demands. The maximum capacity on the "AM sorties" to "Ground Training" node is 12. The maximum capacity of the "PM" sorties to "Ground Training" node is 10. The maximum flow from either of the "SIMs" nodes to the "Ground Training" node is 4.

The cost associated with the arc from "Other Pilots" to "AM sorties" and "Other Pilots" to "PM sorties" is 10. All other arcs have a cost of 0. Additional costs are built into the model with the use of penalties. The unit penalty concept mentioned in Chapter 2 was used to assign penalties to pilots that were "tardy" according to the 15-day sortie count. Anytime a pilot has not flown for 15 days, a cost penalty of 50 occurs, and each successive day will bring another cost of 50. If the pilot is assigned to a sortie in subsequent days, then the cost will be 25. If the pilot is assigned to two sorties the following day, the cost will be 0. This works very well when the problem is broken into sub-problems. However, this approach is nonlinear and non-smooth when applied to the problem of simultaneously solving the entire week. Therefore, the weighted total tardiness concept mentioned in Chapter 2 is used to calculate costs associated with the

15-day sortie count when solving the entire week at once. Additional cost penalties occur when a pilot fails to meet the 30-day or 90-day requirements commensurate with their qualification and experience levels.

The sub-network shown in Figure 7 is a visual representation of the expected flow of SOF qualified pilots. A pilot filling PM GO SOF duties should be available for either AM GO sorties or AM GO SIMs. A pilot filling the AM GO SOF duties should be available to fill PM GO sorties or PM GO SIMs. A SOF pilot not being used in the SOF role would be available for any other single assignment. However, since AM GO sorties are not necessarily scheduled in the 0500-1200 timeframe and the PM GO sorties are not necessarily in the 1200-2100 timeframe, the flow may differ. This expected flow is also applicable to pilots in the TOP3 position. Additionally, pilots not being utilized in a SOF or TOP3 role are available for up to two other assignments as shown in the sub-network in Figure 8.

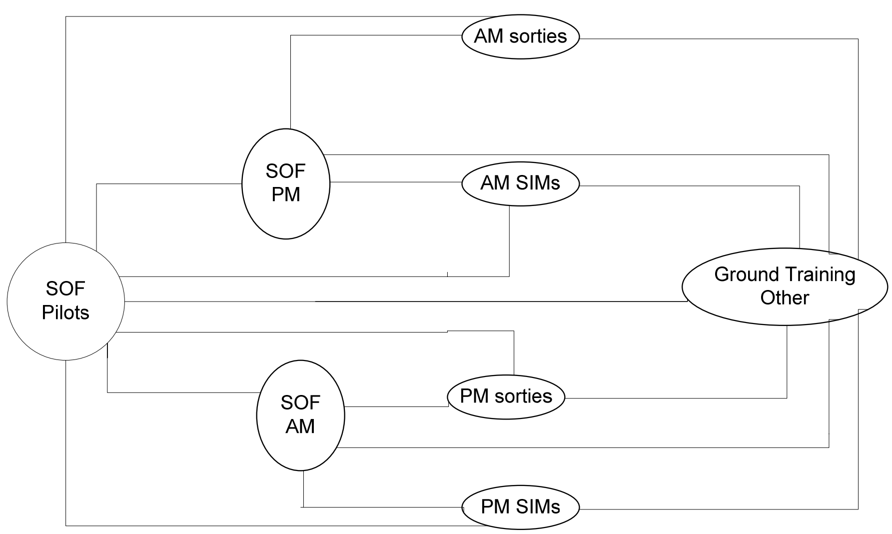


Figure 7. SOF Duty Network Representation

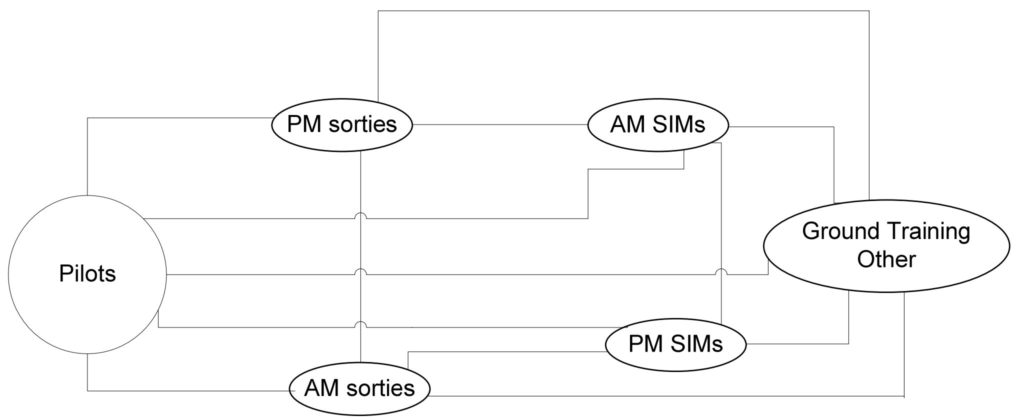


Figure 8. Sortie and Simulator Network Representation

The sub-network in Figure 9 shows a sample mission. A FLUG mission has a requirement for one IP pilot to fill the IP role. The requirement for one FL may be filled by a FL pilot or an IP pilot. The requirement for a P qualified pilot may be filled by any pilot in the squadron other than the upgrade pilot which fills the fourth and final sortie of the FLUG training mission. The "AM sorties" node is comprised of three 4-ship missions similar to the FLUG mission. The "PM sorties" node is comprised of two 4-ship missions and one 2-ship mission.

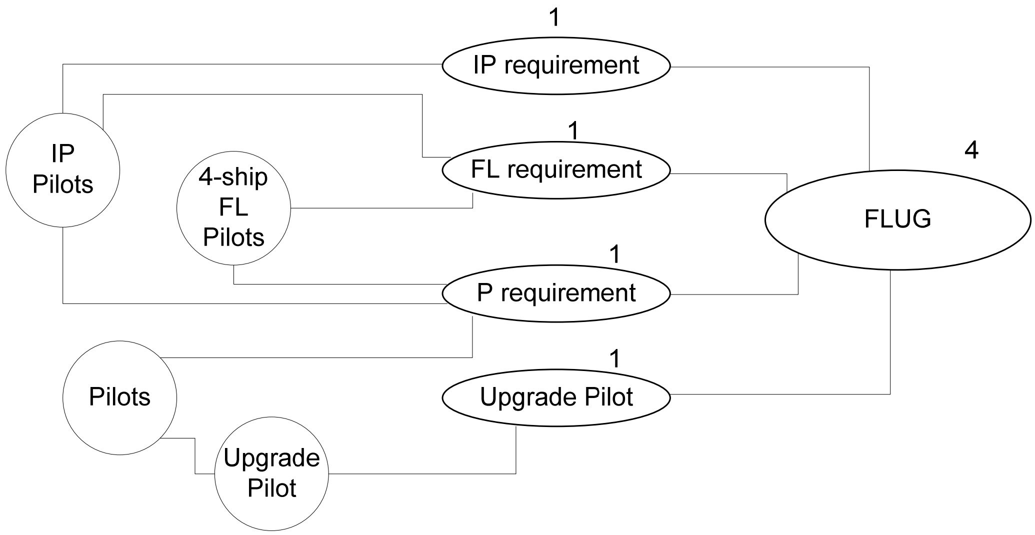


Figure 9. FLUG Mission Network Representation.

In this model, actual flying times for each mission are expected to be inputs. Airspace is assumed to be in place for each of the missions. The schedule is then built based on inputs of the actual flying times. The remainder of the schedule is built around the flying times and the pilots assigned to each of those sorties. This allows for the schedule to be built based on the length of each scheduled event and avoids the need for variables associated with every hour of a pilot's schedule for each day. This allows the number of variables to be reduced from over 4000 to 1960.

3.10 Future Research

There are several areas for future research related to this problem. The recommendations for future research presented in this section are only a subset of the possibilities. To improve upon the model developed in this research effort, future research could be conducted in the following areas: optimization of simulator assignments, more extensive breakdown of pilot qualifications, incorporation of airspace assignments and requirements, more pilot availability options, and development of a DO input page.

The model developed in this research effort optimizes pilot assignments to training mission sorties, TOP3 duties, and SOF duties. Simulator sorties are assigned with VBA code based on training mission assignments and duties. This method allowed for a decrease in the number of variables required to solve the weekly formulation. Frontline's Premium Solver Platform provides a LP/QP engine with a limit of 8000 variables and 8000 constraints. However, the LP/QP engine is limited to 2000 integer variables. Therefore, possible ways to implement optimization of the simulator sorties would include: a reduction of integer variables by utilizing up to 6000 non-integer variables, an additional sub-problem for simulator optimization, or upgrading to Frontline's Large Scale LP/QP Solver. The Large Scale LP/QP solver provides two options. A standard option with limits of 32,000 variables and 32,000 constraints is available. However, the extended version has no set limits. Therefore, the limitation is only time and computer memory (Frontline Systems, 2007).

The breakdown of pilot qualifications in this research is limited by time and lack of subject matter experience. Specialized training provides additional qualifications that are not accounted for in this model. A few of the qualifications not used in this research effort include: Joint Helmet Mounted Cueing Systems (JHMCS) IP, Night Vision Goggles (NVG) FL, NVG IP, and Mission Commander (MCC). Pilots with these qualifications may be required in certain training missions.

A weighted matching of mission type to assigned training missions would provide a name for each training mission. In the current model, training missions are numbered 1 through 6 each day. Each of these training missions should be named according to the individuals assigned to the mission and their respective training program. For example, a pilot in the FLUG program may be ready for FLUG-3 (Night Intercepts). The FLUG-3 mission requires a 4-ship mission with the UP, an IP, a 4-ship FL, and an additional pilot. This mission also requires a night time sortie and either a F-15A or F-15B configuration. Thus, this mission cannot be accomplished in a week where the UP is only assigned to daytime AM sorties. If the UP is in a night time sortie that qualifies for the mission, it may not be the highest priority training mission that can be accomplished with the given set of pilots. Another pilot assigned to the same mission may be ready for a NVG mission with a higher priority. This could be accomplished with extensive programming to account for all the various mission types and respective requirements. Additional formulations to solve the weighted matching problem after each GO would also be required.

In addition to assigning mission types based on qualification of the assigned pilots, number of aircraft in the mission, training priorities, and aircraft configuration, some airspace restrictions eliminate the possibility of accomplishing certain training missions. The airspace restrictions will vary from base to base. Additionally, some squadrons may have to share limited airspace resources with other base units. Therefore, this research area may be squadron specific or base specific.

In this research effort, pilot availability is characterized in three ways (Available, Unavailable and DNIF). However, pilot availability is not always that easily defined.

Some pilots may be available for only portions of a duty day. Additionally, some pilots may be available for only day time sorties, simulator sorties, or duties. Therefore, it may be necessary to further breakdown pilot availabilities in order to ensure a feasible solution is realized.

Finally, DO inputs into the scheduling process are not accounted for in this research effort. This should be accomplished with a DO only page. A DO input of specific pilot to specific training mission on a specified day is easier to incorporate than a vague request that the new pilot needs to be assigned to a mission with a specified IP sometime this week. For example, pilot 7 is to fly mission 2 on Monday. Preprocessing this request, $M_{i2} = 1$ and solver will fill the remaining three sorties in mission 2. However, the vague request is harder to preprocess. One possible method would be to iteratively assign the two pilots to each of the thirty possible missions for the week. Then run solver on each combination, keeping only the best schedule after each successive combination. Another possibility would be to use the underlying code to add additional constraints to the model based on the DO inputs. Then run the solver application based on the existing model with the additional DO input constraints.

3.11 Summary

In this chapter, a general presentation of the methodology was given. The objectives of this research effort were presented along with the assumptions used to meet those objectives. The decision variables were presented along with related parameters and constraints required for the problem formulation. Two approaches to problem formulation were provided along with detailed descriptions. The problem was graphically displayed in a network representation with sub networks for more detail. Finally, future research areas were presented. The simulator heuristic was introduced and explained. Chapter 4 presents the test plan, test events, and results of the testing.

IV. Testing, Results, and Analysis

4.1 General

In this chapter, the test plan and rational are presented. The results of the testing are presented and analyzed. Corrections to the model based on test results are explained in detail. Follow on testing is presented. Finally, the results and analysis of the follow on testing are presented.

4.2 Test Plan

In order to effectively test the model, design of experiments (DOE) was utilized. First, the factors were listed. Then, the list of factors was reduced to a smaller set that is considered representative of the main effects. A full factorial will test all possible combinations for all settings of the remaining factors.

In development of the test plan, 11 factors were considered. The initial values of the factors are based on user inputs. The factors include: number of pilots, availability of pilots, 15-day sortie count, 30-day sortie count, 90-day sortie count, scheduled training mission times, scheduled simulator times, SOF (AM or PM), pilot qualifications, pilot experience levels, and CMR status. The model utilizes two methods of building the weekly schedule (full week formulation and sub-problems). Thus, the model is really two models rolled into one application as explained in Chapter 3. Therefore, the method used could be a factor. Additionally, the method that utilizes sub-problems allows the user to indicate a subset of the sub-problems to solve. However, in this case a comparison of the two methods is preferred. Therefore, all ten sub-problems were selected for each test run. Thus, in both cases, a full weekly schedule is developed.

In an effort to develop a reasonable test plan, four factors (SOF AM/PM, experience, BMC/CMR status, and qualification level) were excluded from the formal testing and the remaining factors were aggregated into three factors (number of available pilots, level of difficulty imposed by mission times, and percentage of pilots eligible for sortie count penalties) for the formal testing. Many of the factors have several combinations of possible inputs. Therefore, a full factorial of all the factors would be tedious and time consuming. The SOF input was eliminated from the factors and set as an AM GO duty for the formal testing. Additionally, pilot qualification, pilot experience, and pilot status (BMC or CMR) were eliminated from the formal testing. Pilot qualifications, experience, and CMR status were set proportional to the number of pilots at a level such that feasible schedules should be attainable. The number of pilots and pilot availability were aggregated into a two-level factor (Factor A, number of available pilots). Thus, for testing, all pilots were assumed to be available for duty each day. The two-levels of pilots used were 23 and 43 to represent extreme cases. Both methods optimally assign 22 sorties and three duties per day to the available pilots. Thus 23 pilots is less than the number of daily assignments, while 43 is an excess setting. The three sortie count factors were aggregated into a two-level factor (Factor C, percentage of pilots eligible for sortie count penalties) such that either 25% of the available pilots may be penalized for failing to meet sortie count requirements or 75% of the available pilots may be penalized for failing to meet sortie count requirements. These pilots need to fly soon and may need multiple sorties during the week to meet 30-day and 90-day requirements. Finally, the scheduled training mission times and the scheduled simulator times were aggregated into a two-level factor (Factor B, level of difficulty imposed by mission times). Factor B is categorical in nature. A set of training missions and simulator times were designed such that it would be easy to assign a single pilot to multiple duties. This set of times is the "easy" setting. Another set of times were designed such that on four of the five days no pilot could perform two sorties in a single day and no pilot could perform a sortie and a SOF or Top 3 duty on the same day. However, simulators could still occur in conjunction with a sortie, SOF duty, or Top 3 duty. Tuesday was designed such that dual flights could occur, but were at the extreme allowances of the FDP. This set of times is the "hard" setting.

Now that the factors have been reduced to three two-level factors, the test plan uses a 2^3 full factorial as shown in Table 3. Since Factor B (mission difficulty) is categorical in nature, a true center run is not feasible. The response (sortie count failure rate) is a percentage derived from the total number of pilots penalized in the final schedule divided by the total number of pilots eligible to be penalized. This metric is used for comparing the two methods. The objective function values are not identically computed for both methods and therefore cannot be used as a comparative response.

Table 3. Test Plan 2^3 Full Factorial

2^3 Factorial	Factors		
Run	A	B	C
1	-	-	-
2	+	-	-
3	-	+	-
4	+	+	-
5	-	-	+
6	+	-	+
7	-	+	+
8	+	+	+

Factor A is the number of available pilots (- implies 23 and + implies 43)
Factor B is the level of difficulty imposed by mission times (- implies hard and + implies easy)
Factor C is the % of pilots eligible for sortie count penalties (- implies 75% and + implies 25%)

4.3 Test Results

Table 4 presents test results for the full week formulation. Table 5 presents test results for the formulation which breaks the weekly schedule into ten sub-problems.

Table 4. Test Results for Full Week Formulation

Full Week Formulation				
Run	Time Required to Solve	Feasible Solution	Penalized Pilots of Eligible	Sortie Count Failure Rate
1	0:01:25	No	17 of 17	100.0%
2	1:09:43	No	32 of 32	100.0%
3	0:01:33	Yes	5 of 17	29.4%
4	0:01:31	Yes	19 of 32	59.4%
5	0:00:14	No	6 0f 6	100.0%
6	0:01:44	No	11 of 11	100.0%
7	0:01:38	Yes	0 0f 6	0.0%
8	0:00:13	Yes	1 of 11	9.1%

Table 5. Test Results for Sub-Problems Formulation

Sub-Problems Formulation				
Run	Time Required to Solve	Feasible Solution	Penalized Pilots of Eligible	Sortie Count Failure Rate
1	0:00:37	No	0 of 17	0.0%
2	0:00:40	No	0 of 32	0.0%
3	0:00:37	Yes	0 of 17	0.0%
4	0:00:39	Yes	0 of 32	0.0%
5	0:00:37	No	0 of 6	0.0%
6	0:00:43	No	0 of 11	0.0%
7	0:00:34	Yes	0 of 6	0.0%
8	0:00:40	Yes	0 of 11	0.0%

The results of this test demonstrate that both methods find a feasible schedule for only 50% of the test runs. However, the sub-problem methodology still has a 0% failure rate for every run. The Thursday PM GO sub-problem was infeasible. Thus, the sub-problem method solved each of the nine remaining sub-problems and a schedule was built based on those results. However, the full week formulation provides no schedule when infeasibility occurs.

4.4 Analysis of Test Results

The test results presented in Tables 4 and 5 indicate that the model has errors in the formulations. In each of the test runs, a feasible schedule should be achieved. Therefore, Design Expert was utilized in order to further analyze the results. The half normal plot in Figure 10 indicates that Factor B is the most significant factor.

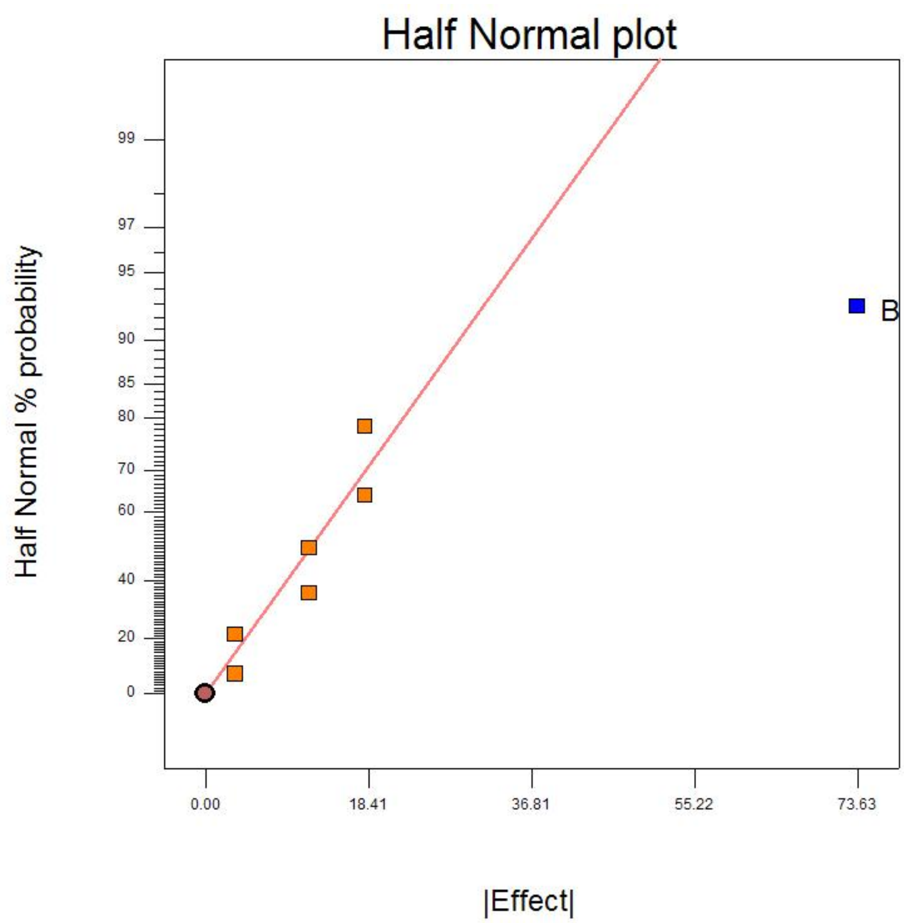


Figure 10. Half Normal Plot

Additionally, the Analysis of Variance (ANOVA) Table shown in Table 6 confirms that Factor B is the most significant factor. The single factor plot shown in Figure 11 indicates that response values (percentage of penalized pilots) are higher when Factor B is set at the “hard” setting.

Table 6. ANOVA Table

Response:	Failure Rate					
Source	Sum of Squares	DF	Mean Square	F Value	Prob > F	
Model	10841.28125	1	10841.28125	34.43411958	0.0011	significant
B	10841.28125	1	10841.28125	34.43411958	0.0011	
Residual	1889.0475	6	314.84125			
Cor Total	12730.32875	7				

R-Squared	0.85161047
Adj R-Squared	0.826878882

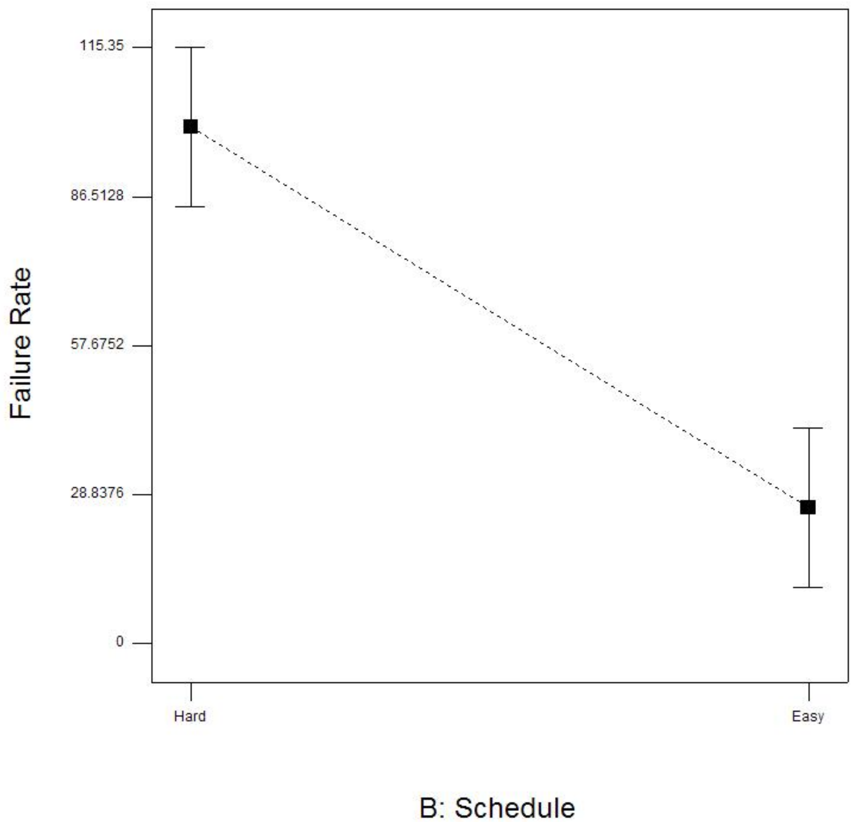


Figure 11. Single Factor Plot

Since the “hard” setting for Factor B is identified as the problem, and specifically on Thursday’s PM GO, the training mission times for Thursday’s PM GO were examined further. The times assigned to Thursday’s PM GO did not appear to have any impact on the infeasibility of that particular sub-problem. However, the sub-problem for Thursday’s PM GO is dependent upon results from Thursday’s AM GO. Therefore, Thursday AM GO training times were examined further. This is the only point at which an AM GO training mission is scheduled later than 0959. According to the formulation presented in Chapter 3, this should not be a problem. However, the formula in the model used to determine the feasibility of a pilot performing two sorties in a single day contained an extra element which added the time stamp of the AM GO flight. The time stamp used in the formulation is 1 = 0500-0559, 2 = 0600-0659, …..16 = 2000-2100. Therefore, any AM GO sortie before 1000 is not a problem as it adds 5 or less to a formula that is constrained to be less than or equal to 5. However, any AM GO flight after 0959 would add 6 or more to the formula which is constrained in the PM GO. Thus, the PM GO sub-problem becomes infeasible.

The full week formulation did not have the same problem. The formula used in the full week formulation for the feasibility of a pilot to perform two sorties in a single day is different than the one used in the sub-problems. Therefore, further investigation was required to identify the problem with the full week method. The formula used to ensure that crew rest requirements were met did not properly account for the timing of the AM GO sortie. Therefore, when the AM GO sortie occurred at a later time, the problem became infeasible due to the crew rest constraint. The results of this test highlight the importance of conducting a structured test on modeling efforts.

4.5 Follow On Testing and Results

After model corrections were made, the test was re-accomplished with only one modification. The number of pilots eligible for penalization on Monday was increased such that it would not be possible to avoid all penalties. This change was applied to the 75% setting by increasing the 15-day sortie counts. A maximum of 22 pilots can be assigned to training mission sorties on Monday. Therefore, if more than 22 pilots are eligible for penalties on Monday, all penalties cannot be avoided. Thus, the only modification to the test was imposed to increase the overall difficulty of the actual test. The results for the full week formulation are presented in Table 7. The results for the sub-problems formulation are presented in Table 8.

Table 7. Follow On Test Results for Full Week Formulation

Full Week Formulation				
Run	Time Required to Solve	Feasible Solution	Penalized Pilots of Eligible	Sortie Count failure rate
1	0:01:45	Yes	0 of 17	0.0%
2	0:01:46	Yes	9 of 32	28.1%
3	0:01:39	Yes	5 of 17	29.4%
4	0:01:45	Yes	20 of 32	62.5%
5	0:01:53	Yes	0 of 6	0.0%
6	0:01:48	Yes	0 of 11	0.0%
7	0:01:52	Yes	0 of 6	0.0%
8	0:01:44	Yes	0 of 11	0.0%

Table 8. Follow On Test Results for Sub-Problems Formulation

Sub-Problems Formulation				
Run	Time Required to Solve	Feasible Solution	Penalized Pilots of Eligible	Sortie Count failure rate
1	0:00:38	Yes	0 of 17	0.0%
2	0:00:40	Yes	7 of 32	21.9%
3	0:00:38	Yes	0 of 17	0.0%
4	0:00:43	Yes	7 of 32	21.9%
5	0:00:39	Yes	0 of 6	0.0%
6	0:00:44	Yes	0 of 11	0.0%
7	0:00:40	Yes	0 of 6	0.0%
8	0:00:40	Yes	0 of 11	0.0%

The results from the follow on testing demonstrate that both models were able to construct a feasible solution for every test run. The sub-problem formulation builds a weekly schedule in less than half the time it takes for the full week formulation to build a weekly schedule for the same test case. Also, the sub-problem method had a better sortie count failure rate in the three test cases where the full week formulation was unable to provide a 0.0% sortie count failure rate. Additionally, examination of the actual schedules shows that the full week formulation tends to create a "feast or famine" cycle for the pilots. The sub-problems method does not appear to create a "feast or famine" cycle. Sample schedules can be found in Appendix B. Also, the model will correctly run both formulations and provide two schedules in approximately 2.5 minutes. This allows the user to have a side by side comparison of the two schedules and select the one best suited for the squadron in a particular week.

4.6 Summary

In Chapter 4 test plans were explained, test results were presented, test failures were addressed, and follow on testing with results were presented. Chapter 5 provides conclusions from the overall research effort and the testing.

V. Conclusions

5.1 General

This chapter reviews the key elements of this research effort and discusses the research conclusions. This chapter also makes recommendations for future research and for model usage. The fighter training squadron pilot scheduling problem is complex. The current process is tedious and mostly manual. Often, inexperienced pilots are charged with the task of building the weekly schedule. These inexperienced pilots lose hours of valuable training time.

The problem background is presented in Chapter 1. A list of factors and scheduling considerations are also presented in Chapter 1. Scheduling problems exists in many areas and a great deal of research has been conducted on the various types of scheduling problems. Chapter 2 presents the literature reviewed for this research. The problems presented in Chapter 2 reflect scheduling research related to the fighter training squadron pilot scheduling problem. Two methodologies are presented in Chapter 3. A full week methodology with a single formulation is presented. Then a sub-problem methodology that consists of ten sub-problems is presented. Chapter 3 also presents a formulation for each methodology. Then Chapter 4 presents the test plan and results.

5.2 Key Elements

The idea of building a solution based on partial solutions as presented by Combs and Moore presents an approach for dealing with large scale scheduling problems (Combs 2002, Combs and Moore 2004). Preprocessing is a key element used to define the costs associated with penalties and with assigning non-squadron pilots to sorties. Preprocessing is presented in Chapter 2 in the discussion of Shirley's research (Shirley, 1994). In the two methodologies presented in Chapter 3, preprocessing is used to set the parameters for each formulation (full week and each of the ten sub-problems). The ten sub-problems provide partial solutions that are combined to provide an overall solution.

5.3 Research Conclusions

This research effort provides an approach for dealing with the many complexities of the fighter training squadron pilot scheduling problem. The approach used here minimized the overall size of the problem with the use of preprocessing and development of a heuristic to assign pilots to simulator sorties. Additionally, the MP model is relaxed to ensure that a feasible solution will be found. The test results demonstrate the models ability to solve both formulations (full week and sub-problems) and construct a feasible schedule based on those solutions and the simulator heuristic. However, a violation of any of the assumptions presented in Chapter 3 may make finding a feasible solution impossible.

5.4 Recommendations for Future Research

Recommended areas of future research include the following: optimization of simulator assignments, more extensive breakdown of pilot qualifications, incorporation of airspace assignments and requirements, more pilot availability options, and development of a DO input page. Each of these areas of research is discussed in more detail in Chapter 3. Future research is not limited to these areas. However, the incorporation of these problem characteristics along with a heuristic to set up a weighted matching problem for assigning specific training mission types (i.e. FLUG-2, IPUG-3, NVG-3) missions should result in a highly effective and useful model.

The sub-problem methodology is recommended for use with future research. The sub-problem methodology appears to be more efficient and prevents the "feast or famine" cycle. Additionally, the 280 integer variables used in each sub-problem will allow incorporation of new integer variables. The Premium Solver platform from Frontline Systems has a limit of 2000 integer variables. The full week formulation uses 1960 integer variables and is very close to the limit.

5.4 Recommendations for Model Usage

The model developed in this research, inclusive of both formulations, may be useful in its current state. However, the pilot responsible for building the weekly schedule must assign names to the missions on the final schedule. This model is designed to schedule a single squadron of up to 50 pilots for training missions, TOP3 and SOF duties, and simulator sorties only. A user manual is presented in Appendix C to address the specific details for using this model.

Appendix A: Acronyms

AFI	Air Force Instruction
ANOVA	Analysis of Variance
ARMS	Aviation Resource Management System
BFM	Basic Fighter Maneuvers
BMC	Basic Mission Capable
CMR	Combat Mission Ready
CT	Continuation Training
DAF	Department of the Air Force
DFS	Daily Flying Schedule
DNIF	Duty to Not Include Flying
DO	Director of Operations
DOE	Design of Experiments
EPE	Emergency Procedures Evaluation
FDP	Flight Duty Period
FL	Flight Lead
FLUG	Flight Lead Upgrade Program
GUI	Graphical User Interface
IAW	In Accordance With
IP	Instructor Pilot or Integer Program
IPUG	Instructor Pilot Upgrade
IQT	Initial Qualification Training

IRC	Instrument Refresher Course
JHMCS	Joint Helmet Mounted Cueing System
LFJ	Least Flexible Job
LFM	Least Flexible Machine
LP	Linear Program
MAJCOM	Major Command
MCC	Mission Commander
MOL	Mission Order List
MP	Mathematical Programming
MQT	Mission Qualification Training
NP	Nondeterministic Polynomial-time
NVG	Night Vision Goggles
ODM	Operations Data Management
PEP	Production Eagle Package
PEX	Patriot Excalibur Scheduling Software
PME	Professional Military Education
QP	Quadratic Program
RAP	Ready Aircrew Program
SAT	Surface Attack Tactics
SEAD	Suppression of Enemy Air Defenses
SIM	Simulator
SOF	Supervisor of Flying
TDY	Temporary Duty

TOP 3	Designated Daily Squadron Supervisor
UP	Upgrade Pilot
VBA	Visual Basic for Applications

Appendix B: Sample Documents and Schedules

	Rank	Assigned	Position	RAP	w IP	DEROS	API	FLT	WX CAT	MSN CC	FLT LD	FCF	SOF	SEFE	Top 3	EG/HH Instr	NVG	IRC	Rear CPT	SEAD	Maverick	TGT Pod	Link 16	HMCS	RCO	FECOC	30/60/90	F
1	LTC	Specht, John	EPCE	CMR			6		B	X	IP			X	X		IP			IP	IP	IP	IP	IP			26	
2	LTC	Youtsey, David	EPCE	CMR	X		6		B	X	IP			X	X		IP			IP	IP	IP	IP	IP			38	
1	Capt	Cockrum, Jason	IPCE	CMR			1		B	X	IP		X		X		IP			IP	IP		IP	IP			35	
2	Capt	Cole, Tim	MPCE	CMR			1		B	T	4		X				4			4			X	X			41	N
3	Capt	Friedel, Jesse	EPCE	CMR	X		1		B	X	IP		X	X			IP			IP	IP	IP	IP	IP			42	
4	Capt	Garrison, Matt	IPCE	CMR			1		B	X	IP		X				IP			IP	IP		IP	IP			45	
5	Capt	Gump, James	MPCN	CMR			1		B								X			X			X	X			31	
6	Capt	Johnston, Mike	MPBE	CMR			1		B	T	4R	X	X				X			4R	X		X	X			33	D
7	Capt	Kopacek, Chris	MPCE	CMR			1		B		T						X			X	X	4T	X	X			34	
8	Capt	Locke, Joseph	IPCE	CMR			1		B	X	IP		X				IP			IP	X		IP	IP			31	
9	Capt	Lord, Kevin	MPCN	CMR			1		B								X			X			X	X			30	
10	Capt	Mann, Sam	IPCE	CMR	X		1		B	X	IP						IP			IP	IP	IP	IP	IP			36	
11	Capt	Murray, Rich	FPCE	MQT			1		C								T			T			T	T			15	
12	Capt	Penrod, Sean	MPCN	CMR			1		B		T						X			X			X	X			29	
13	Capt	Perkins, Chris	MPCN	CMR			1		B		T						XR			X			X	X			36	N
14	Capt	Reed, Jeremiah	MPCN	CMR			1		B								X			X			X	X			35	
15	Capt	Sabia, Jay	MPCE	CMR			1		B	X	IPT		X				4			X	X	4	X	X			32	
16	Capt	Shultz, Johathan	MPCE	CMR			1		B	T	4R		X				XR			4R	X		X	X			26	N
17	Capt	Willingham, Paul	MPCN	CMR			1		B		4		X				4			4		4T	X	X			38	
18	LT	Connellan, Pat	MPCN	CMR			1		B								T			X			X	X			35	
19	LT	Gaona, Joey	MPCN	CMR			1		B								X			X			X	X			29	
20	LT	Johnston, Cheryl	FPMN	MQT			1		E											T							0	
21	LT	Jones, Dave	MPCN	CMR			1		B								X			X			X	X			36	
22	LT	Kellam, Brian	FPMN	MQT			1		C								T			T			T	T			14	
23	LT	McCarthy, Mike	MPCN	CMR			1		B								X			X			X	X			39	
24	LT	Moeller, Chris	FPMN	MQT			1		C								T			T			T	T			12	
25	LT	Reynolds, Matthew	MPCN	CMR			1		B								X			X			X	X			25	
1	GEN	Foglesong, Robert	MPBE	BMC			8		B											X							2	
2	LTC	Bishop, Scott	IPBE	NBMC	X		8		B	X	IP									4	IP		IP				2	N
3	MAJ	Boyd, Jay	EPBE	BMC			8		B	X	IP			X			IP			IP	IP	IP					3	
1	COL	Goldfein, Dave	EPCE	BMC	X		6		B	X	IP			X			IP			IP	IP	IP	X	X			22	
2	LTC	Berghoff, Tom	IPCE	NBMC			6		B	X	IP						IP			4	IP	IP	X	X			31	N
3	LTC	Bowen, Scott	MPBE	BMC			6		B		T									X			X	X			28	
4	LTC	Neumann, Brian	IPBE	NBMC			6		B	X	IP						IP			IP	X		IP	IP			23	
5	LTC	Woodcock, Bill	IPBE	NBMC			6		B	X	IP						IP			IP	IP	IP	IP	IP			34	
6	MAJ	Forkner, William	MPBE	NBMC			6		B								X			X	X	X	X	X			26	
7	MAJ	Mcatee, Thomas	IPBE	BMC	X		6		B	X	IP		X				IP			IP	IP	IP	IP	IP			41	
8	MAJ	Nichols, Ryan	EPCE	CMR			6		B	X	IPR		T	X			X			IPR	IP		IP	IP			30	D
9	CAPT	Rassas, Sean	IPCE	CMR			6		B	X	IP		X				IP			IP	X	IPT	IP	IP			26	
10	CAPT	Lyons, Dave	IPCE	CMR			6		B	X	IP		X				IP			IP	IP	IP	IP	IP			32	

Sample Letter of Xs (Boyd et. al., 2006)

The following schedules were the results from test run 7. Thus, the schedules represent a squadron of 23 pilots with 6 pilots eligible for penalties during the week. The scheduled timing was set at the “easy” level.

Monday	Sub-problem Method															
Pilot/ Time	**5:00**	**6:00**	**7:00**	**8:00**	**9:00**	**10:00**	**11:00**	**12:00**	**13:00**	**14:00**	**15:00**	**16:00**	**17:00**	**18:00**	**19:00**	**20:00**
Ace	*off-duty*	*off-duty*	*off-duty*	other	fly 3	fly 3	fly 3	fly 3	fly 3	TOP3	TOP3	TOP3	TOP3	TOP3	TOP3	*off-duty*
Bullet	other	TOP3	TOP3	TOP3	TOP3	TOP3	TOP3	other	other	other	other	other	*off-duty*	*off-duty*	*off-duty*	*off-duty*
Charger	*off-duty*	*off-duty*	*off-duty*	other	fly 2	fly 2	fly 2	fly 2	fly 2	fly 4	fly 4	fly 4	fly 4	fly 4	fly 4	*off-duty*
Dart	other	SOF	SOF	SOF	SOF	SOF	SOF	other	other	other	other	other	*off-duty*	*off-duty*	*off-duty*	*off-duty*
East	other	other	other	other	other	other	other	other	other	other	other	other	*off-duty*	*off-duty*	*off-duty*	*off-duty*
Fireball	other	other	other	other	other	SIM	SIM	SIM	SIM	other	other	other	*off-duty*	*off-duty*	*off-duty*	*off-duty*
Gunner	*off-duty*	*off-duty*	*off-duty*	other	fly 1	fly 1	fly 1	fly 1	fly 1	fly 5	fly 5	fly 5	fly 5	fly 5	fly 5	*off-duty*
Homer	other	other	other	other	other	SIM	SIM	SIM	SIM	other	other	other	*off-duty*	*off-duty*	*off-duty*	*off-duty*
Ice	other	other	other	other	other	SIM	SIM	SIM	SIM	other	other	other	*off-duty*	*off-duty*	*off-duty*	*off-duty*
Jumper	other	other	other	other	other	SIM	SIM	SIM	SIM	other	other	other	*off-duty*	*off-duty*	*off-duty*	*off-duty*
Killer	*off-duty*	*off-duty*	*off-duty*	other	fly 3	fly 3	fly 3	fly 3	fly 3	fly 5	fly 5	fly 5	fly 5	fly 5	fly 5	*off-duty*
Looper	*off-duty*	*off-duty*	*off-duty*	other	fly 2	fly 2	fly 2	fly 2	fly 2	fly 5	fly 5	fly 5	fly 5	fly 5	fly 5	*off-duty*
Mustang	*off-duty*	*off-duty*	*off-duty*	other	fly 1	fly 1	fly 1	fly 1	fly 1	fly 6	fly 6	fly 6	fly 6	fly 6	fly 6	*off-duty*
Needle	*off-duty*	*off-duty*	*off-duty*	other	fly 2	fly 2	fly 2	fly 2	fly 2	fly 6	fly 6	fly 6	fly 6	fly 6	fly 6	*off-duty*
O'Land	*off-duty*	*off-duty*	*off-duty*	other	fly 1	fly 1	fly 1	fly 1	fly 1	fly 4	fly 4	fly 4	fly 4	fly 4	fly 4	*off-duty*
Pullup	*off-duty*	*off-duty*	*off-duty*	other	fly 3	fly 3	fly 3	fly 3	fly 3	fly 5	fly 5	fly 5	fly 5	fly 5	fly 5	*off-duty*
Quasar	other	other	other	other	fly 3	fly 3	fly 3	fly 3	fly 3	fly 3	other	other	*off-duty*	*off-duty*	*off-duty*	*off-duty*
Red	other	other	SIM	SIM	SIM	SIM	other	other	other	other	other	other	*off-duty*	*off-duty*	*off-duty*	*off-duty*
Shooter	*off-duty*	*off-duty*	*off-duty*	other	fly 1	fly 1	fly 1	fly 1	fly 1	fly 4	fly 4	fly 4	fly 4	fly 4	fly 4	*off-duty*
Trigger	other	other	SIM	SIM	SIM	SIM	other	other	other	other	other	other	*off-duty*	*off-duty*	*off-duty*	*off-duty*
U-turn	other	other	SIM	SIM	SIM	SIM	other	other	other	other	other	other	*off-duty*	*off-duty*	*off-duty*	*off-duty*
Vertical	*off-duty*	*off-duty*	*off-duty*	other	fly 2	fly 2	fly 2	fly 2	fly 2	fly 4	fly 4	fly 4	fly 4	fly 4	fly 4	*off-duty*
Winger	other	other	SIM	SIM	SIM	SIM	other	other	other	other	other	other	*off-duty*	*off-duty*	*off-duty*	*off-duty*

Monday	Full Week Method															
Pilot/ Time	**5:00**	**6:00**	**7:00**	**8:00**	**9:00**	**10:00**	**11:00**	**12:00**	**13:00**	**14:00**	**15:00**	**16:00**	**17:00**	**18:00**	**19:00**	**20:00**
Ace	*off-duty*	*off-duty*	*off-duty*	other	fly 1	fly 1	fly 1	fly 1	fly 1	TOP3	TOP3	TOP3	TOP3	TOP3	TOP3	*off-duty*
Bullet	other	other	other	other	fly 3	fly 3	fly 3	fly 3	fly 3	fly 3	other	other	*off-duty*	*off-duty*	*off-duty*	*off-duty*
Charger	*off-duty*	*off-duty*	*off-duty*	other	fly 2	fly 2	fly 2	fly 2	fly 2	fly 5	fly 5	fly 5	fly 5	fly 5	fly 5	*off-duty*
Dart	other	TOP3	TOP3	TOP3	TOP3	TOP3	TOP3	other	other	other	other	other	*off-duty*	*off-duty*	*off-duty*	*off-duty*
East	other	other	other	other	fly 1	fly 1	fly 1	fly 1	fly 1	fly 1	other	other	*off-duty*	*off-duty*	*off-duty*	*off-duty*
Fireball	other	other	other	other	fly 2	fly 2	fly 2	fly 2	fly 2	fly 2	other	other	*off-duty*	*off-duty*	*off-duty*	*off-duty*
Gunner	*off-duty*	*off-duty*	*off-duty*	other	fly 1	fly 1	fly 1	fly 1	fly 1	fly 4	fly 4	fly 4	fly 4	fly 4	fly 4	*off-duty*
Homer	other	other	other	other	fly 2	fly 2	fly 2	fly 2	fly 2	fly 2	other	other	*off-duty*	*off-duty*	*off-duty*	*off-duty*
Ice	other	SOF	SOF	SOF	SOF	SOF	SOF	other	other	other	other	other	*off-duty*	*off-duty*	*off-duty*	*off-duty*
Jumper	other	other	other	other	other	SIM	SIM	SIM	SIM	other	other	other	*off-duty*	*off-duty*	*off-duty*	*off-duty*
Killer	*off-duty*	*off-duty*	*off-duty*	other	fly 1	fly 1	fly 1	fly 1	fly 1	fly 5	fly 5	fly 5	fly 5	fly 5	fly 5	*off-duty*
Looper	*off-duty*	*off-duty*	*off-duty*	other	other	SIM	SIM	SIM	SIM	fly 6	fly 6	fly 6	fly 6	fly 6	fly 6	*off-duty*
Mustang	*off-duty*	*off-duty*	*off-duty*	other	fly 3	fly 3	fly 3	fly 3	fly 3	fly 5	fly 5	fly 5	fly 5	fly 5	fly 5	*off-duty*
Needle	*off-duty*	*off-duty*	*off-duty*	other	other	SIM	SIM	SIM	SIM	fly 6	fly 6	fly 6	fly 6	fly 6	fly 6	*off-duty*
O'Land	*off-duty*	*off-duty*	*off-duty*	other	fly 2	fly 2	fly 2	fly 2	fly 2	fly 4	fly 4	fly 4	fly 4	fly 4	fly 4	*off-duty*
Pullup	*off-duty*	*off-duty*	*off-duty*	other	other	other	other	other	other	fly 5	fly 5	fly 5	fly 5	fly 5	fly 5	*off-duty*
Quasar	other	other	other	other	other	SIM	SIM	SIM	SIM	other	other	other	*off-duty*	*off-duty*	*off-duty*	*off-duty*
Red	other	other	SIM	SIM	SIM	SIM	other	other	other	other	other	other	*off-duty*	*off-duty*	*off-duty*	*off-duty*
Shooter	*off-duty*	*off-duty*	*off-duty*	other	fly 3	fly 3	fly 3	fly 3	fly 3	fly 4	fly 4	fly 4	fly 4	fly 4	fly 4	*off-duty*
Trigger	other	other	SIM	SIM	SIM	SIM	other	other	other	other	other	other	*off-duty*	*off-duty*	*off-duty*	*off-duty*
U-turn	other	other	SIM	SIM	SIM	SIM	other	other	other	other	other	other	*off-duty*	*off-duty*	*off-duty*	*off-duty*
Vertical	*off-duty*	*off-duty*	*off-duty*	other	fly 3	fly 3	fly 3	fly 3	fly 3	fly 4	fly 4	fly 4	fly 4	fly 4	fly 4	*off-duty*
Winger	other	other	SIM	SIM	SIM	SIM	other	other	other	other	other	other	*off-duty*	*off-duty*	*off-duty*	*off-duty*

Tuesday	Sub-problem Method															
Pilot/ Time	**5:00**	**6:00**	**7:00**	**8:00**	**9:00**	**10:00**	**11:00**	**12:00**	**13:00**	**14:00**	**15:00**	**16:00**	**17:00**	**18:00**	**19:00**	**20:00**
Ace	*off-duty*	*off-duty*	other	fly 2	fly 2	fly 2	fly 2	fly 2	fly 4	fly 4	fly 4	fly 4	fly 4	fly 4	*off-duty*	*off-duty*
Bullet	*off-duty*	*off-duty*	other	fly 3	fly 3	fly 3	fly 3	fly 3	fly 5	fly 5	fly 5	fly 5	fly 5	fly 5	*off-duty*	*off-duty*
Charger	*off-duty*	*off-duty*	*off-duty*	fly 1	fly 1	fly 1	fly 1	fly 1	fly 1	TOP3	TOP3	TOP3	TOP3	TOP3	TOP3	*off-duty*
Dart	other	TOP3	TOP3	TOP3	TOP3	TOP3	TOP3	other	other	other	other	other	*off-duty*	*off-duty*	*off-duty*	*off-duty*
East	other	SOF	SOF	SOF	SOF	SOF	SOF	other	other	other	other	other	*off-duty*	*off-duty*	*off-duty*	*off-duty*
Fireball	other	other	SIM	SIM	SIM	SIM	other	other	other	other	other	other	*off-duty*	*off-duty*	*off-duty*	*off-duty*
Gunner	other	other	SIM	SIM	SIM	SIM	other	other	other	other	other	other	*off-duty*	*off-duty*	*off-duty*	*off-duty*
Homer	other	other	other	other	other	SIM	SIM	SIM	SIM	other	other	other	*off-duty*	*off-duty*	*off-duty*	*off-duty*
Ice	other	other	other	other	other	SIM	SIM	SIM	SIM	other	other	other	*off-duty*	*off-duty*	*off-duty*	*off-duty*
Jumper	other	other	other	other	other	SIM	SIM	SIM	SIM	other	other	other	*off-duty*	*off-duty*	*off-duty*	*off-duty*
Killer	other	other	SIM	SIM	SIM	SIM	other	other	other	other	other	other	*off-duty*	*off-duty*	*off-duty*	*off-duty*
Looper	*off-duty*	*off-duty*	other	fly 1	fly 1	fly 1	fly 1	fly 1	fly 4	fly 4	fly 4	fly 4	fly 4	fly 4	*off-duty*	*off-duty*
Mustang	*off-duty*	*off-duty*	other	fly 1	fly 1	fly 1	fly 1	fly 1	fly 4	fly 4	fly 4	fly 4	fly 4	fly 4	*off-duty*	*off-duty*
Needle	*off-duty*	*off-duty*	other	fly 2	fly 2	fly 2	fly 2	fly 2	fly 4	fly 4	fly 4	fly 4	fly 4	fly 4	*off-duty*	*off-duty*
O'Land	*off-duty*	*off-duty*	other	fly 3	fly 3	fly 3	fly 3	fly 3	fly 5	fly 5	fly 5	fly 5	fly 5	fly 5	*off-duty*	*off-duty*
Pullup	*off-duty*	*off-duty*	other	fly 1	fly 1	fly 1	fly 1	fly 1	fly 5	fly 5	fly 5	fly 5	fly 5	fly 5	*off-duty*	*off-duty*
Quasar	*off-duty*	*off-duty*	other	fly 2	fly 2	fly 2	fly 2	fly 2	fly 5	fly 5	fly 5	fly 5	fly 5	fly 5	*off-duty*	*off-duty*
Red	*off-duty*	*off-duty*	other	fly 2	fly 2	fly 2	fly 2	fly 2	fly 6	fly 6	fly 6	fly 6	fly 6	fly 6	*off-duty*	*off-duty*
Shooter	*off-duty*	*off-duty*	other	fly 3	fly 3	fly 3	fly 3	fly 3	fly 6	fly 6	fly 6	fly 6	fly 6	fly 6	*off-duty*	*off-duty*
Trigger	other	other	other	fly 3	fly 3	fly 3	fly 3	fly 3	fly 3	other	other	other	*off-duty*	*off-duty*	*off-duty*	*off-duty*
U-turn	other	other	other	other	other	SIM	SIM	SIM	SIM	other	other	other	*off-duty*	*off-duty*	*off-duty*	*off-duty*
Vertical	other	other	SIM	SIM	SIM	SIM	other	other	other	other	other	other	*off-duty*	*off-duty*	*off-duty*	*off-duty*
Winger	other	other	other	other	other	other	other	other	other	other	other	other	*off-duty*	*off-duty*	*off-duty*	*off-duty*

Tuesday	Full Week Method															
Pilot/ Time	**5:00**	**6:00**	**7:00**	**8:00**	**9:00**	**10:00**	**11:00**	**12:00**	**13:00**	**14:00**	**15:00**	**16:00**	**17:00**	**18:00**	**19:00**	**20:00**
Ace	*off-duty*	*off-duty*	*off-duty*	fly 2	fly 2	fly 2	fly 2	fly 2	fly 2	TOP3	TOP3	TOP3	TOP3	TOP3	TOP3	*off-duty*
Bullet	other	TOP3	TOP3	TOP3	TOP3	TOP3	TOP3	other	other	other	other	other	*off-duty*	*off-duty*	*off-duty*	*off-duty*
Charger	*off-duty*	*off-duty*	other	fly 1	fly 1	fly 1	fly 1	fly 1	fly 4	fly 4	fly 4	fly 4	fly 4	fly 4	*off-duty*	*off-duty*
Dart	other	SOF	SOF	SOF	SOF	SOF	SOF	other	other	other	other	other	*off-duty*	*off-duty*	*off-duty*	*off-duty*
East	other	other	SIM	SIM	SIM	SIM	other	other	other	other	other	other	*off-duty*	*off-duty*	*off-duty*	*off-duty*
Fireball	other	other	SIM	SIM	SIM	SIM	other	other	other	other	other	other	*off-duty*	*off-duty*	*off-duty*	*off-duty*
Gunner	*off-duty*	*off-duty*	other	fly 3	fly 3	fly 3	fly 3	fly 3	fly 5	fly 5	fly 5	fly 5	fly 5	fly 5	*off-duty*	*off-duty*
Homer	other	other	SIM	SIM	SIM	SIM	other	other	other	other	other	other	*off-duty*	*off-duty*	*off-duty*	*off-duty*
Ice	other	other	SIM	SIM	SIM	SIM	other	other	other	other	other	other	*off-duty*	*off-duty*	*off-duty*	*off-duty*
Jumper	other	other	other	other	other	SIM	SIM	SIM	SIM	other	other	other	*off-duty*	*off-duty*	*off-duty*	*off-duty*
Killer	*off-duty*	*off-duty*	other	fly 3	fly 3	fly 3	fly 3	fly 3	fly 5	fly 5	fly 5	fly 5	fly 5	fly 5	*off-duty*	*off-duty*
Looper	*off-duty*	*off-duty*	other	fly 2	fly 2	fly 2	fly 2	fly 2	fly 6	fly 6	fly 6	fly 6	fly 6	fly 6	*off-duty*	*off-duty*
Mustang	*off-duty*	*off-duty*	other	fly 3	fly 3	fly 3	fly 3	fly 3	fly 6	fly 6	fly 6	fly 6	fly 6	fly 6	*off-duty*	*off-duty*
Needle	*off-duty*	*off-duty*	other	fly 2	fly 2	fly 2	fly 2	fly 2	fly 4	fly 4	fly 4	fly 4	fly 4	fly 4	*off-duty*	*off-duty*
O'Land	*off-duty*	*off-duty*	other	fly 1	fly 1	fly 1	fly 1	fly 1	fly 4	fly 4	fly 4	fly 4	fly 4	fly 4	*off-duty*	*off-duty*
Pullup	*off-duty*	*off-duty*	other	fly 1	fly 1	fly 1	fly 1	fly 1	fly 5	fly 5	fly 5	fly 5	fly 5	fly 5	*off-duty*	*off-duty*
Quasar	other	other	other	fly 1	fly 1	fly 1	fly 1	fly 1	fly 1	other	other	other	*off-duty*	*off-duty*	*off-duty*	*off-duty*
Red	other	other	other	other	other	SIM	SIM	SIM	SIM	other	other	other	*off-duty*	*off-duty*	*off-duty*	*off-duty*
Shooter	*off-duty*	*off-duty*	other	fly 2	fly 2	fly 2	fly 2	fly 2	fly 5	fly 5	fly 5	fly 5	fly 5	fly 5	*off-duty*	*off-duty*
Trigger	other	other	other	other	other	SIM	SIM	SIM	SIM	other	other	other	*off-duty*	*off-duty*	*off-duty*	*off-duty*
U-turn	other	other	other	other	other	SIM	SIM	SIM	SIM	other	other	other	*off-duty*	*off-duty*	*off-duty*	*off-duty*
Vertical	*off-duty*	*off-duty*	other	fly 3	fly 3	fly 3	fly 3	fly 3	fly 4	fly 4	fly 4	fly 4	fly 4	fly 4	*off-duty*	*off-duty*
Winger	other	other	other	other	other	other	other	other	other	other	other	other	*off-duty*	*off-duty*	*off-duty*	*off-duty*

Wednesday	Sub-problem Method															
Pilot/ Time	5:00	6:00	7:00	8:00	9:00	10:00	11:00	12:00	13:00	14:00	15:00	16:00	17:00	18:00	19:00	20:00
Ace	off-duty	other	fly 1	fly 1	fly 1	fly 1	fly 1	fly 4	fly 4	fly 4	fly 4	fly 4	fly 4	off-duty	off-duty	off-duty
Bullet	off-duty	other	fly 2	fly 2	fly 2	fly 2	fly 2	fly 5	fly 5	fly 5	fly 5	fly 5	fly 5	off-duty	off-duty	off-duty
Charger	off-duty	off-duty	off-duty	fly 3	fly 3	fly 3	fly 3	fly 3	fly 3	TOP3	TOP3	TOP3	TOP3	TOP3	TOP3	off-duty
Dart	other	TOP3	TOP3	TOP3	TOP3	TOP3	TOP3	other	other	other	other	other	off-duty	off-duty	off-duty	off-duty
East	other	SOF	SOF	SOF	SOF	SOF	SOF	other	other	other	other	other	off-duty	off-duty	off-duty	off-duty
Fireball	other	other	other	other	other	SIM	SIM	SIM	SIM	other	other	other	off-duty	off-duty	off-duty	off-duty
Gunner	other	other	SIM	SIM	SIM	SIM	other	other	other	other	other	other	off-duty	off-duty	off-duty	off-duty
Homer	other	other	other	other	other	SIM	SIM	SIM	SIM	other	other	other	off-duty	off-duty	off-duty	off-duty
Ice	other	other	other	other	other	SIM	SIM	SIM	SIM	other	other	other	off-duty	off-duty	off-duty	off-duty
Jumper	other	other	other	other	other	other	other	other	other	other	other	other	off-duty	off-duty	off-duty	off-duty
Killer	other	other	SIM	SIM	SIM	SIM	other	other	other	other	other	other	off-duty	off-duty	off-duty	off-duty
Looper	off-duty	off-duty	other	fly 3	fly 3	fly 3	fly 3	fly 3	fly 6	fly 6	fly 6	fly 6	fly 6	fly 6	off-duty	off-duty
Mustang	off-duty	other	fly 1	fly 1	fly 1	fly 1	fly 1	fly 4	fly 4	fly 4	fly 4	fly 4	fly 4	off-duty	off-duty	off-duty
Needle	off-duty	other	fly 1	fly 1	fly 1	fly 1	fly 1	fly 4	fly 4	fly 4	fly 4	fly 4	fly 4	off-duty	off-duty	off-duty
O'Land	off-duty	other	fly 2	fly 2	fly 2	fly 2	fly 2	fly 5	fly 5	fly 5	fly 5	fly 5	fly 5	off-duty	off-duty	off-duty
Pullup	off-duty	other	fly 1	fly 1	fly 1	fly 1	fly 1	fly 4	fly 4	fly 4	fly 4	fly 4	fly 4	off-duty	off-duty	off-duty
Quasar	off-duty	other	fly 2	fly 2	fly 2	fly 2	fly 2	fly 5	fly 5	fly 5	fly 5	fly 5	fly 5	off-duty	off-duty	off-duty
Red	off-duty	other	fly 2	fly 2	fly 2	fly 2	fly 2	fly 5	fly 5	fly 5	fly 5	fly 5	fly 5	off-duty	off-duty	off-duty
Shooter	off-duty	off-duty	SIM	SIM	SIM	SIM	other	other	fly 6	fly 6	fly 6	fly 6	fly 6	fly 6	off-duty	off-duty
Trigger	other	other	other	fly 3	fly 3	fly 3	fly 3	fly 3	fly 3	other	other	other	off-duty	off-duty	off-duty	off-duty
U-turn	other	other	other	fly 3	fly 3	fly 3	fly 3	fly 3	fly 3	other	other	other	off-duty	off-duty	off-duty	off-duty
Vertical	other	other	SIM	SIM	SIM	SIM	other	other	other	other	other	other	off-duty	off-duty	off-duty	off-duty
Winger	other	other	other	other	other	SIM	SIM	SIM	SIM	other	other	other	off-duty	off-duty	off-duty	off-duty

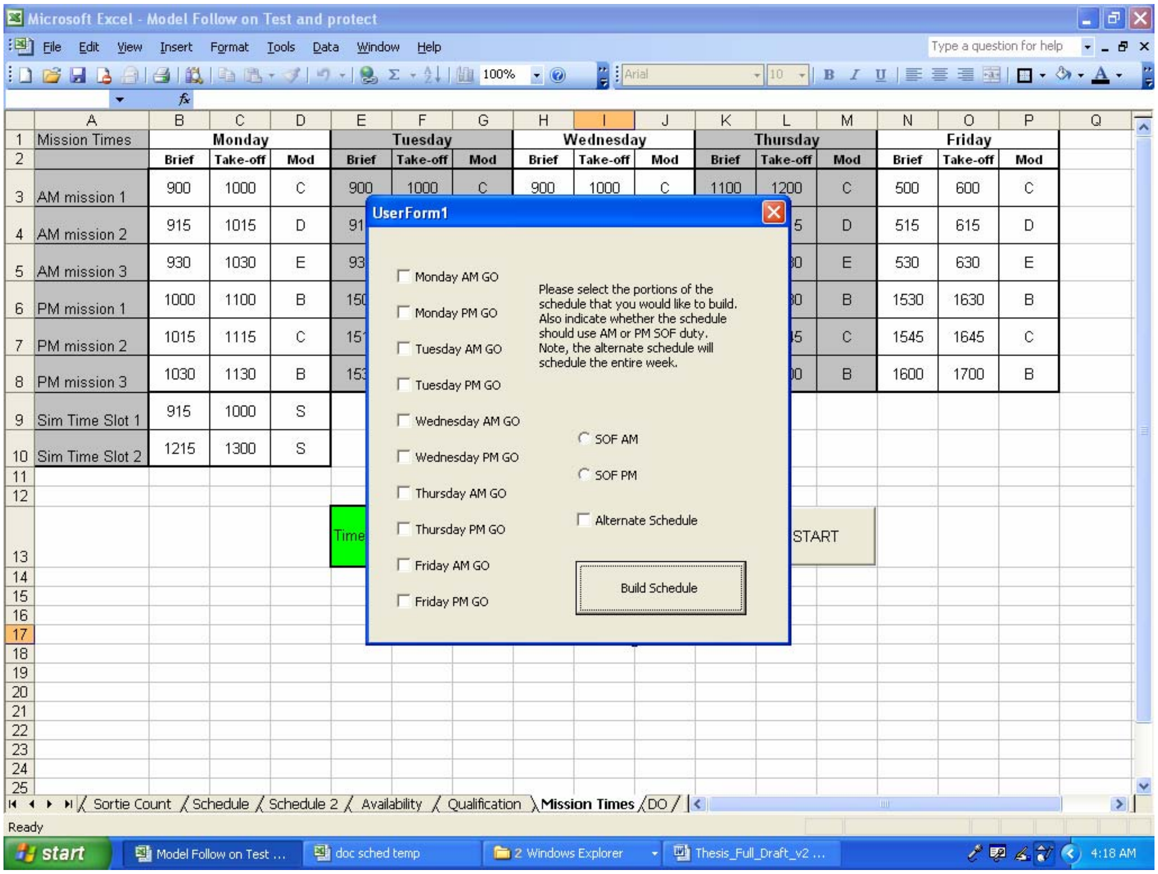
Wednesday	Full Week Method															
Pilot/ Time	5:00	6:00	7:00	8:00	9:00	10:00	11:00	12:00	13:00	14:00	15:00	16:00	17:00	18:00	19:00	20:00
Ace	off-duty	off-duty	off-duty	fly 3	fly 3	fly 3	fly 3	fly 3	fly 3	TOP3	TOP3	TOP3	TOP3	TOP3	TOP3	off-duty
Bullet	other	TOP3	TOP3	TOP3	TOP3	TOP3	TOP3	other	other	other	other	other	off-duty	off-duty	off-duty	off-duty
Charger	off-duty	other	fly 1	fly 1	fly 1	fly 1	fly 1	fly 4	fly 4	fly 4	fly 4	fly 4	fly 4	off-duty	off-duty	off-duty
Dart	other	other	fly 2	fly 2	fly 2	fly 2	fly 2	fly 2	other	other	other	other	off-duty	off-duty	off-duty	off-duty
East	other	other	other	fly 3	fly 3	fly 3	fly 3	fly 3	fly 3	other	other	other	off-duty	off-duty	off-duty	off-duty
Fireball	other	SOF	SOF	SOF	SOF	SOF	SOF	other	other	other	other	other	off-duty	off-duty	off-duty	off-duty
Gunner	off-duty	other	fly 1	fly 1	fly 1	fly 1	fly 1	fly 5	fly 5	fly 5	fly 5	fly 5	fly 5	off-duty	off-duty	off-duty
Homer	other	other	fly 1	fly 1	fly 1	fly 1	fly 1	fly 1	other	other	other	other	off-duty	off-duty	off-duty	off-duty
Ice	other	other	fly 1	fly 1	fly 1	fly 1	fly 1	fly 1	other	other	other	other	off-duty	off-duty	off-duty	off-duty
Jumper	other	other	other	other	other	SIM	SIM	SIM	SIM	other	other	other	off-duty	off-duty	off-duty	off-duty
Killer	off-duty	off-duty	fly 2	fly 2	fly 2	fly 2	fly 2	fly 2	fly 6	fly 6	fly 6	fly 6	fly 6	fly 6	off-duty	off-duty
Looper	off-duty	other	SIM	SIM	SIM	SIM	other	fly 4	fly 4	fly 4	fly 4	fly 4	fly 4	off-duty	off-duty	off-duty
Mustang	off-duty	off-duty	fly 2	fly 2	fly 2	fly 2	fly 2	fly 2	fly 6	fly 6	fly 6	fly 6	fly 6	fly 6	off-duty	off-duty
Needle	off-duty	other	SIM	SIM	SIM	SIM	other	fly 5	fly 5	fly 5	fly 5	fly 5	fly 5	off-duty	off-duty	off-duty
O'Land	off-duty	other	other	fly 3	fly 3	fly 3	fly 3	fly 4	fly 4	fly 4	fly 4	fly 4	fly 4	off-duty	off-duty	off-duty
Pullup	off-duty	other	SIM	SIM	SIM	SIM	other	fly 4	fly 4	fly 4	fly 4	fly 4	fly 4	off-duty	off-duty	off-duty
Quasar	other	other	SIM	SIM	SIM	SIM	other	other	other	other	other	other	off-duty	off-duty	off-duty	off-duty
Red	other	other	other	other	other	SIM	SIM	SIM	SIM	other	other	other	off-duty	off-duty	off-duty	off-duty
Shooter	off-duty	other	other	fly 3	fly 3	fly 3	fly 3	fly 5	fly 5	fly 5	fly 5	fly 5	fly 5	off-duty	off-duty	off-duty
Trigger	other	other	other	other	other	SIM	SIM	SIM	SIM	other	other	other	off-duty	off-duty	off-duty	off-duty
U-turn	other	other	other	other	other	other	other	other	other	other	other	other	off-duty	off-duty	off-duty	off-duty
Vertical	off-duty	other	fly 2	fly 2	fly 2	fly 2	fly 2	fly 5	fly 5	fly 5	fly 5	fly 5	fly 5	off-duty	off-duty	off-duty
Winger	other	other	other	other	other	SIM	SIM	SIM	SIM	other	other	other	off-duty	off-duty	off-duty	off-duty

Thursday	Sub-problem Method															
Pilot/ Time	**5:00**	**6:00**	**7:00**	**8:00**	**9:00**	**10:00**	**11:00**	**12:00**	**13:00**	**14:00**	**15:00**	**16:00**	**17:00**	**18:00**	**19:00**	**20:00**
Ace	other	TOP3	TOP3	TOP3	TOP3	TOP3	TOP3	other	other	other	other	other	off-duty	off-duty	off-duty	off-duty
Bullet	other	SOF	SOF	SOF	SOF	SOF	SOF	other	other	other	other	other	off-duty	off-duty	off-duty	off-duty
Charger	off-duty	off-duty	off-duty	other	fly 1	fly 1	fly 1	fly 1	fly 1	fly 4	fly 4	fly 4	fly 4	fly 4	fly 4	off-duty
Dart	off-duty	off-duty	off-duty	other	fly 2	fly 2	fly 2	fly 2	fly 2	TOP3	TOP3	TOP3	TOP3	TOP3	TOP3	off-duty
East	off-duty	off-duty	off-duty	other	fly 3	fly 3	fly 3	fly 3	fly 3	fly 5	fly 5	fly 5	fly 5	fly 5	fly 5	off-duty
Fireball	other	other	other	other	other	SIM	SIM	SIM	SIM	other	other	other	off-duty	off-duty	off-duty	off-duty
Gunner	other	other	SIM	SIM	SIM	SIM	other	other	other	other	other	other	off-duty	off-duty	off-duty	off-duty
Homer	other	other	other	other	other	SIM	SIM	SIM	SIM	other	other	other	off-duty	off-duty	off-duty	off-duty
Ice	other	other	other	other	other	other	other	other	other	other	other	other	off-duty	off-duty	off-duty	off-duty
Jumper	other	other	SIM	SIM	SIM	SIM	other	other	other	other	other	other	off-duty	off-duty	off-duty	off-duty
Killer	other	other	SIM	SIM	SIM	SIM	other	other	other	other	other	other	off-duty	off-duty	off-duty	off-duty
Looper	off-duty	off-duty	off-duty	off-duty	fly 1	fly 1	fly 1	fly 1	fly 1	fly 1	fly 6	fly 6	fly 6	fly 6	fly 6	fly 6
Mustang	off-duty	off-duty	off-duty	other	fly 2	fly 2	fly 2	fly 2	fly 2	fly 5	fly 5	fly 5	fly 5	fly 5	fly 5	off-duty
Needle	off-duty	off-duty	off-duty	other	fly 2	fly 2	fly 2	fly 2	fly 2	fly 5	fly 5	fly 5	fly 5	fly 5	fly 5	off-duty
O'Land	off-duty	off-duty	off-duty	other	fly 3	fly 3	fly 3	fly 3	fly 3	fly 4	fly 4	fly 4	fly 4	fly 4	fly 4	off-duty
Pullup	off-duty	off-duty	off-duty	other	fly 2	fly 2	fly 2	fly 2	fly 2	fly 4	fly 4	fly 4	fly 4	fly 4	fly 4	off-duty
Quasar	off-duty	off-duty	off-duty	other	fly 1	fly 1	fly 1	fly 1	fly 1	fly 4	fly 4	fly 4	fly 4	fly 4	fly 4	off-duty
Red	off-duty	off-duty	off-duty	other	fly 1	fly 1	fly 1	fly 1	fly 1	fly 5	fly 5	fly 5	fly 5	fly 5	fly 5	off-duty
Shooter	other	other	other	other	fly 3	fly 3	fly 3	fly 3	fly 3	fly 3	other	other	off-duty	off-duty	off-duty	off-duty
Trigger	other	other	other	other	fly 3	fly 3	fly 3	fly 3	fly 3	fly 3	other	other	off-duty	off-duty	off-duty	off-duty
U-turn	off-duty	off-duty	SIM	SIM	SIM	SIM	other	other	other	other	fly 6	fly 6	fly 6	fly 6	fly 6	fly 6
Vertical	other	other	other	other	other	SIM	SIM	SIM	SIM	other	other	other	off-duty	off-duty	off-duty	off-duty
Winger	other	other	other	other	other	SIM	SIM	SIM	SIM	other	other	other	off-duty	off-duty	off-duty	off-duty

Thursday	Full Week Method															
Pilot/ Time	**5:00**	**6:00**	**7:00**	**8:00**	**9:00**	**10:00**	**11:00**	**12:00**	**13:00**	**14:00**	**15:00**	**16:00**	**17:00**	**18:00**	**19:00**	**20:00**
Ace	off-duty	off-duty	off-duty	other	fly 1	fly 1	fly 1	fly 1	fly 1	TOP3	TOP3	TOP3	TOP3	TOP3	TOP3	off-duty
Bullet	other	SOF	SOF	SOF	SOF	SOF	SOF	other	other	other	other	other	off-duty	off-duty	off-duty	off-duty
Charger	off-duty	off-duty	off-duty	other	fly 2	fly 2	fly 2	fly 2	fly 2	fly 4	fly 4	fly 4	fly 4	fly 4	fly 4	off-duty
Dart	other	TOP3	TOP3	TOP3	TOP3	TOP3	TOP3	other	other	other	other	other	off-duty	off-duty	off-duty	off-duty
East	other	other	SIM	SIM	SIM	SIM	other	other	other	other	other	other	off-duty	off-duty	off-duty	off-duty
Fireball	other	other	SIM	SIM	SIM	SIM	other	other	other	other	other	other	off-duty	off-duty	off-duty	off-duty
Gunner	off-duty	off-duty	off-duty	other	fly 3	fly 3	fly 3	fly 3	fly 3	fly 5	fly 5	fly 5	fly 5	fly 5	fly 5	off-duty
Homer	other	other	SIM	SIM	SIM	SIM	other	other	other	other	other	other	off-duty	off-duty	off-duty	off-duty
Ice	other	other	SIM	SIM	SIM	SIM	other	other	other	other	other	other	off-duty	off-duty	off-duty	off-duty
Jumper	other	other	other	other	other	SIM	SIM	SIM	SIM	other	other	other	off-duty	off-duty	off-duty	off-duty
Killer	off-duty	off-duty	off-duty	other	fly 3	fly 3	fly 3	fly 3	fly 3	fly 5	fly 5	fly 5	fly 5	fly 5	fly 5	off-duty
Looper	off-duty	off-duty	off-duty	off-duty	fly 3	fly 3	fly 3	fly 3	fly 3	fly 3	fly 6	fly 6	fly 6	fly 6	fly 6	fly 6
Mustang	off-duty	off-duty	off-duty	off-duty	fly 1	fly 1	fly 1	fly 1	fly 1	fly 1	fly 6	fly 6	fly 6	fly 6	fly 6	fly 6
Needle	off-duty	off-duty	off-duty	other	fly 3	fly 3	fly 3	fly 3	fly 3	fly 5	fly 5	fly 5	fly 5	fly 5	fly 5	off-duty
O'Land	off-duty	off-duty	off-duty	other	fly 2	fly 2	fly 2	fly 2	fly 2	fly 4	fly 4	fly 4	fly 4	fly 4	fly 4	off-duty
Pullup	off-duty	off-duty	off-duty	other	fly 2	fly 2	fly 2	fly 2	fly 2	fly 4	fly 4	fly 4	fly 4	fly 4	fly 4	off-duty
Quasar	other	other	other	other	fly 1	fly 1	fly 1	fly 1	fly 1	fly 1	other	other	off-duty	off-duty	off-duty	off-duty
Red	other	other	other	other	other	SIM	SIM	SIM	SIM	other	other	other	off-duty	off-duty	off-duty	off-duty
Shooter	off-duty	off-duty	off-duty	other	fly 2	fly 2	fly 2	fly 2	fly 2	fly 5	fly 5	fly 5	fly 5	fly 5	fly 5	off-duty
Trigger	other	other	other	other	other	other	other	other	other	other	other	other	off-duty	off-duty	off-duty	off-duty
U-turn	other	other	other	other	other	SIM	SIM	SIM	SIM	other	other	other	off-duty	off-duty	off-duty	off-duty
Vertical	off-duty	off-duty	off-duty	other	fly 1	fly 1	fly 1	fly 1	fly 1	fly 4	fly 4	fly 4	fly 4	fly 4	fly 4	off-duty
Winger	other	other	other	other	other	SIM	SIM	SIM	SIM	other	other	other	off-duty	off-duty	off-duty	off-duty

Friday	Sub-problem Method															
Pilot/ Time	**5:00**	**6:00**	**7:00**	**8:00**	**9:00**	**10:00**	**11:00**	**12:00**	**13:00**	**14:00**	**15:00**	**16:00**	**17:00**	**18:00**	**19:00**	**20:00**
Ace	*off-duty*	*off-duty*	*off-duty*	*off-duty*	fly 3	fly 3	fly 3	fly 3	fly 3	fly 3	fly 5	fly 5	fly 5	fly 5	fly 5	fly 5
Bullet	other	TOP3	TOP3	TOP3	TOP3	TOP3	TOP3	other	other	other	other	other	*off-duty*	*off-duty*	*off-duty*	*off-duty*
Charger	*off-duty*	*off-duty*	*off-duty*	*off-duty*	fly 1	fly 1	fly 1	fly 1	fly 1	fly 1	fly 4	fly 4	fly 4	fly 4	fly 4	fly 4
Dart	*off-duty*	*off-duty*	SIM	SIM	SIM	SIM	other	other	other	TOP3	TOP3	TOP3	TOP3	TOP3	TOP3	*off-duty*
East	other	other	SIM	SIM	SIM	SIM	other	other	other	other	other	other	*off-duty*	*off-duty*	*off-duty*	*off-duty*
Fireball	other	other	other	other	fly 2	fly 2	fly 2	fly 2	fly 2	fly 2	other	other	*off-duty*	*off-duty*	*off-duty*	*off-duty*
Gunner	other	SOF	SOF	SOF	SOF	SOF	SOF	other	other	other	other	other	*off-duty*	*off-duty*	*off-duty*	*off-duty*
Homer	other	other	other	other	fly 1	fly 1	fly 1	fly 1	fly 1	fly 1	other	other	*off-duty*	*off-duty*	*off-duty*	*off-duty*
Ice	other	other	other	other	fly 3	fly 3	fly 3	fly 3	fly 3	fly 3	other	other	*off-duty*	*off-duty*	*off-duty*	*off-duty*
Jumper	other	other	other	other	fly 3	fly 3	fly 3	fly 3	fly 3	fly 3	other	other	*off-duty*	*off-duty*	*off-duty*	*off-duty*
Killer	other	other	other	other	other	SIM	SIM	SIM	SIM	other	other	other	*off-duty*	*off-duty*	*off-duty*	*off-duty*
Looper	*off-duty*	*off-duty*	*off-duty*	*off-duty*	fly 1	fly 1	fly 1	fly 1	fly 1	fly 1	fly 4	fly 4	fly 4	fly 4	fly 4	fly 4
Mustang	*off-duty*	*off-duty*	*off-duty*	*off-duty*	fly 1	fly 1	fly 1	fly 1	fly 1	fly 1	fly 4	fly 4	fly 4	fly 4	fly 4	fly 4
Needle	*off-duty*	*off-duty*	*off-duty*	*off-duty*	fly 2	fly 2	fly 2	fly 2	fly 2	fly 2	fly 4	fly 4	fly 4	fly 4	fly 4	fly 4
O'Land	*off-duty*	*off-duty*	*off-duty*	*off-duty*	fly 2	fly 2	fly 2	fly 2	fly 2	fly 2	fly 5	fly 5	fly 5	fly 5	fly 5	fly 5
Pullup	*off-duty*	*off-duty*	*off-duty*	*off-duty*	fly 3	fly 3	fly 3	fly 3	fly 3	fly 3	fly 5	fly 5	fly 5	fly 5	fly 5	fly 5
Quasar	*off-duty*	*off-duty*	SIM	SIM	SIM	SIM	other	other	other	other	fly 5	fly 5	fly 5	fly 5	fly 5	fly 5
Red	*off-duty*	*off-duty*	SIM	SIM	SIM	SIM	other	other	other	other	fly 6	fly 6	fly 6	fly 6	fly 6	fly 6
Shooter	*off-duty*	*off-duty*	*off-duty*	*off-duty*	other	SIM	SIM	SIM	SIM	other	fly 6	fly 6	fly 6	fly 6	fly 6	fly 6
Trigger	other	other	other	other	other	SIM	SIM	SIM	SIM	other	other	other	*off-duty*	*off-duty*	*off-duty*	*off-duty*
U-turn	other	other	other	other	other	SIM	SIM	SIM	SIM	other	other	other	*off-duty*	*off-duty*	*off-duty*	*off-duty*
Vertical	other	other	other	other	other	other	other	other	other	other	other	other	*off-duty*	*off-duty*	*off-duty*	*off-duty*
Winger	other	other	other	other	fly 2	fly 2	fly 2	fly 2	fly 2	fly 2	other	other	*off-duty*	*off-duty*	*off-duty*	*off-duty*

Friday	Full Week Method															
Pilot/ Time	**5:00**	**6:00**	**7:00**	**8:00**	**9:00**	**10:00**	**11:00**	**12:00**	**13:00**	**14:00**	**15:00**	**16:00**	**17:00**	**18:00**	**19:00**	**20:00**
Ace	*off-duty*	*off-duty*	*off-duty*	other	fly 1	fly 1	fly 1	fly 1	fly 1	TOP3	TOP3	TOP3	TOP3	TOP3	TOP3	*off-duty*
Bullet	other	other	other	other	fly 3	fly 3	fly 3	fly 3	fly 3	fly 3	other	other	*off-duty*	*off-duty*	*off-duty*	*off-duty*
Charger	*off-duty*	*off-duty*	*off-duty*	*off-duty*	fly 2	fly 2	fly 2	fly 2	fly 2	fly 2	fly 4	fly 4	fly 4	fly 4	fly 4	fly 4
Dart	other	TOP3	TOP3	TOP3	TOP3	TOP3	TOP3	other	other	other	other	other	*off-duty*	*off-duty*	*off-duty*	*off-duty*
East	other	other	other	other	fly 2	fly 2	fly 2	fly 2	fly 2	fly 2	other	other	*off-duty*	*off-duty*	*off-duty*	*off-duty*
Fireball	other	other	other	other	fly 1	fly 1	fly 1	fly 1	fly 1	fly 1	other	other	*off-duty*	*off-duty*	*off-duty*	*off-duty*
Gunner	*off-duty*	*off-duty*	*off-duty*	*off-duty*	fly 1	fly 1	fly 1	fly 1	fly 1	fly 1	fly 5	fly 5	fly 5	fly 5	fly 5	fly 5
Homer	other	other	other	other	fly 2	fly 2	fly 2	fly 2	fly 2	fly 2	other	other	*off-duty*	*off-duty*	*off-duty*	*off-duty*
Ice	other	SOF	SOF	SOF	SOF	SOF	SOF	other	other	other	other	other	*off-duty*	*off-duty*	*off-duty*	*off-duty*
Jumper	other	other	other	other	other	SIM	SIM	SIM	SIM	other	other	other	*off-duty*	*off-duty*	*off-duty*	*off-duty*
Killer	*off-duty*	*off-duty*	*off-duty*	*off-duty*	fly 1	fly 1	fly 1	fly 1	fly 1	fly 1	fly 5	fly 5	fly 5	fly 5	fly 5	fly 5
Looper	*off-duty*	*off-duty*	SIM	SIM	SIM	SIM	other	other	other	other	fly 4	fly 4	fly 4	fly 4	fly 4	fly 4
Mustang	*off-duty*	*off-duty*	*off-duty*	*off-duty*	fly 2	fly 2	fly 2	fly 2	fly 2	fly 2	fly 5	fly 5	fly 5	fly 5	fly 5	fly 5
Needle	*off-duty*	*off-duty*	SIM	SIM	SIM	SIM	other	other	other	other	fly 4	fly 4	fly 4	fly 4	fly 4	fly 4
O'Land	*off-duty*	*off-duty*	*off-duty*	*off-duty*	fly 3	fly 3	fly 3	fly 3	fly 3	fly 3	fly 6	fly 6	fly 6	fly 6	fly 6	fly 6
Pullup	*off-duty*	*off-duty*	SIM	SIM	SIM	SIM	other	other	other	other	fly 4	fly 4	fly 4	fly 4	fly 4	fly 4
Quasar	other	other	SIM	SIM	SIM	SIM	other	other	other	other	other	other	*off-duty*	*off-duty*	*off-duty*	*off-duty*
Red	other	other	other	other	other	other	other	other	other	other	other	other	*off-duty*	*off-duty*	*off-duty*	*off-duty*
Shooter	*off-duty*	*off-duty*	*off-duty*	*off-duty*	fly 3	fly 3	fly 3	fly 3	fly 3	fly 3	fly 6	fly 6	fly 6	fly 6	fly 6	fly 6
Trigger	other	other	other	other	other	SIM	SIM	SIM	SIM	other	other	other	*off-duty*	*off-duty*	*off-duty*	*off-duty*
U-turn	other	other	other	other	other	SIM	SIM	SIM	SIM	other	other	other	*off-duty*	*off-duty*	*off-duty*	*off-duty*
Vertical	*off-duty*	*off-duty*	*off-duty*	*off-duty*	fly 3	fly 3	fly 3	fly 3	fly 3	fly 3	fly 5	fly 5	fly 5	fly 5	fly 5	fly 5
Winger	other	other	other	other	other	SIM	SIM	SIM	SIM	other	other	other	*off-duty*	*off-duty*	*off-duty*	*off-duty*



GUI: UserForm1

Appendix C: User Manual

The user manual is designed outline input cells, explain the content for each tab within the excel workbook, and provide guidance for unique circumstances. It is important to note that the user must only change the input cells on the "Sortie Count," "Mission Times," and "Availability" worksheets. Additionally, the user should not modify any cells on the "Matrix" and "SIMs" worksheets.

User Inputs:

The user should input the pilot names in Column A on worksheet "Qualification." The remaining worksheets will automatically be populated with the pilot names. Additionally, the user should indicate the pilot's status (BMC or CMR) and experience level by placing an "x" in the appropriate columns. Also, the user should indicate all qualifications of the pilot by placing an "x" in the appropriate columns (IP, 4-FL, 2-FL, SOF, and Top 3).

On worksheet "Sortie Count," each pilots sortie counts should be inserted in the input column for each category. Thus, the input column for 15-day sortie count should contain the number of days since the pilot's last sortie. The 30-day sortie count input should contain the number of sorties flown by the pilot in the last 25 days. The 90-day sortie count should contain the number of sorties flown by the pilot in the last 85 days.

On worksheet "Availability," each pilot's availability should be indicated for each day (columns B, C, D, E, and F). An unavailable pilot would receive a "U" in the column for every day that the pilot is unavailable. A DNIF pilot would receive a "D" in the column for every day that the pilot is DNIF. Any other input or a blank cell indicates the pilot is available.

On worksheet "Mission Times," the user should indicate the start times for mission briefings and simulator briefings. Additionally, the user should input mission times, simulator times, and configurations. Simulator configuration is optional. Additionally, the model will indicate an error for the inputs on this page when an initial brief time is scheduled later than the take-off time, when the mission times exceed the schedule boundaries (0500-2000), when there is missing information, and when there is less than 15 minutes between brief time and take-off time. These errors will be indicated by red blocks and an error message. When the times are set for the model message will change to "Times are set for the model" and the block will turn green. However, the model will still run with the error message. However, the results may or may not be useful.

Running the Model:

After all the inputs are correctly made, the user will click the "START" button on the "Mission Times" worksheet. The model will then clear all cells used by the solver. After the cells are cleared, a GUI will appear. The user will select what portion of the weekly schedule the model should build, AM or PM SOF setting, and alternate schedule (if desired). After completing the selections, the use will click the "Build Schedule" button. The schedules will be constructed and may be viewed on worksheets "Schedule" and "Schedule 2." The alternate schedule is the full week method and will be presented on worksheet "Schedule 2." Once the schedules are built it is recommended to copy and paste the schedules into another spreadsheet for any modifications. The user may move off-duty time and other time. Additionally, the user may choose to move a simulator assignment from one pilot to another. However, if flight times need to change it is recommended that the model is rerun with the correct times.

Schedules:

The resulting schedules are independent of each other. Thus, it is recommended that the user does NOT use days from one schedule with days from the other schedule. This may result in violations of crew rest. If the model is unable to fill all of the mission sortie demands with the pilots listed by the user, then below that days schedule will be a message indicating which mission needs a pilot and what qualification level that is required. Ultimately, it is the responsibility of the scheduler and the individual pilots to ensure that the schedule is acceptable and that FDP and crew rest restrictions are not violated.

Unique Circumstances:

There are unique circumstances in which the model will not produce a useful schedule. A few cases are presented with suggestions for resolving the issue. If a squadron has only one Top 3 qualified pilot available, the model will fail to solve the weekly schedule. However, if the user places this pilot in the list twice and marks the availability as DNIF. The model will then assign the first occurrence of this pilot to one Top 3 duty (AM GO or PM GO) and the second occurrence will be assigned to the other Top 3 duty.

Next, if the model is assigning all the Top 3 qualified pilots to AM GO mission sorties and Top 3 or SOF duty. A circumstance may result that the model does not solve the PM GO for that day because there are no available Top 3 pilots for the PM GO Top 3 duty. The user may select one of the Top 3 qualified pilots being assigned to an AM GO sortie and set the availability of that pilot to “D”. Then the model should assign that pilot in the PM GO Top 3 duty.

Finally, one or more pilots in the squadron may require additional time in the simulator. The model may be assigning this pilot to other activities that prevent simulator time. To resolve this issue the user can mark this pilot as DNIF or unavailable on the “Availability” worksheet. Then, after the model has finished running, copy the final schedule into another spreadsheet and manually move simulator sorties to the required pilot(s).

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Vita

Lieutenant Thomas M. Newlon graduated from Buckhannon-Upshur High School in Buckhannon, West Virginia. He entered undergraduate studies at West Virginia Wesleyan College in Buckhannon, West Virginia but left the school after completing his sophomore year. Three years later he returned to undergraduate studies at Fairmont State College (now a university) in Fairmont, West Virginia where he graduated with a Bachelor of Science degree in Mathematics and a Bachelor of Arts degree in Education, specializing in Mathematics 5-12, May 1999. He was commissioned through the Officer Training School at Maxwell Air Force Base on 4 April 2003.

His first assignment was at Eglin AFB as an operations analyst for Air Force Operational Test and Evaluation Center (AFOTEC) Detachment 2 in April 2003. During this period of time he worked mostly with the Operational testing of the Large Aircraft Infrared Countermeasures (LAIRCM) System. He also Flew 16 testing sorties as a Flight Test Engineer (FTE) in support of the testing effort. He also worked with the Advanced Strategic and Tactical Expendable (ASTE) and Miniature Air Launch Decoy (MALD) programs. In August 2005, he entered the Graduate School of Engineering and Management, Air Force Institute of Technology. Upon graduation, he will be assigned to Air Combat Command Headquarters (ACC/HQ) at Langley AFB.

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14. ABSTRACT

The United States Air Force fighter training squadrons build weekly schedules using a long and tedious process. Very little of this process is automated and optimality of any kind is nearly impossible. Schedules are built to a feasible condition only to be changed with consideration of Wing level requirements. Weekly flying schedules are restricted by requirements for crew rest, days since a pilot's last sortie, sorties in the last 30 days, and sorties in the last 90 days. By providing a scheduling model to the pilot charged with creating the schedule, valuable pilot hours could be spent in the cockpit, simulator, or other required duty. This research effort presents a mathematical programming (MP) approach to the fighter squadron pilot training scheduling problem. The methodology presented is based on binary variables that will provide integer solutions to every feasible set of inputs. A simulator heuristic developed specifically for this problem assigns pilots to simulator sorties based on the feasible solutions obtained from two different formulation and solving approaches. One approach assigns training mission sorties and duties for the entire week, while the other approach breaks the week into ten successive sub-problems. The model constructs two feasible schedules in approximately 2.5 minutes.

15. SUBJECT TERMS

Integer Programming, Scheduling, Preprocessing, Heuristic Methods, Penalties

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