



**FLIGHTLINE SIMULATION MODELING OF A SQUADRON**

THESIS

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In Partial Fulfillment of the Requirements for the  
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Hüseyin MERT, BS

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**Abstract**

Military flight training is a long and costly process. Ensuring that the training aircraft are ready for flight is critical in processing pilots through training courses on schedule. Maintaining a high mission capable rate for training aircraft requires scheduled periodic maintenance and maintenance between sorties. Aircraft Ground Equipment (AGE) is used to service each aircraft to make it ready for the following flight. Having a sufficient amount of AGE available is critical, as cancelling or delaying sorties due to lack of AGE generally has a significant impact on the training schedule.

This work analyzes the AGE support equipment used in the Advanced flight training squadron flightline and investigate how the changes in the mix of equipment, operational rates, failure rates, and the other modeled characteristics impact scheduled training sorties. To do this the Advanced flight training flightline is modeled in a discrete event simulation software package.

*To my wife and sons for their loving support, patience, and for understanding of the long hours I spent working and to Family for their encouragement and love – Thank you all.*

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Hüseyin MERT

# Table of Contents

	Page
Abstract.....	iv
Acknowledgments.....	vi
Table of Contents .....	vii
List of Figures.....	ix
List of Tables .....	x
FLIGHTLINE SIMULATION MODELING OF A SQUADRON.....	1
I. Introduction .....	1
1.1    General Issue .....	1
1.2    Problem Statement.....	2
1.3    Scope.....	3
1.4    Thesis Organization.....	3
II. Literature Review.....	5
2.1    Chapter Overview .....	5
2.2    Flightline Procedures.....	5
2.3    Simulation.....	7
2.3.1 Simulation Classifications .....	8
2.3.2 Advantages and Disadvantages .....	8
2.3.3 Simulation Steps .....	9
2.4    Simio.....	10
2.5    Previous Studies.....	11
2.5.1 Bayer’s Study.....	11
2.5.2 Havlicek’s Study.....	12
2.5.3 Kaya’s Study.....	12
2.5.4 McKenna’s Study .....	13
2.5.5 O’Fearn’s Study .....	14
2.5.6 Tovrea’s Study.....	14
2.6    Summary.....	15
III. Methodology.....	16
3.1.    Chapter Overview .....	16
3.2.    Flightline Sortie Generation Process Model.....	16
3.2.1 Schedule Flight .....	17

3.2.2	Preflight Inspection.....	17
3.2.3	Go to Flight, Arrival and Landing, Taxi and Parking.....	17
3.2.4	Post Flight Inspection, Prepare for Next Flight.....	18
3.2.5	Unscheduled Maintenance Process.....	18
3.3	Model Development .....	19
3.3.1	Standard Library .....	19
3.3.2	Processes.....	20
3.3.2.1	Unscheduled Maintenance.....	21
3.3.2.2	Simulation Setup.....	22
3.3.3	Validation and Verification of the Model.....	23
3.4	Experiment for Analysis .....	24
3.5	Summary.....	25
IV.	Analysis and Results.....	27
4.1.	Chapter Overview .....	27
4.2.	Model Results .....	27
4.2.1	Scenario 1 (Baseline).....	28
4.2.2	Scenario 2 .....	28
4.2.3	Scenario 3 .....	28
4.2.4	Scenario 4 .....	29
4.2.5	Scenario 5 .....	29
4.2.6	Scenario 6 .....	30
4.2.7	Scenario 7 .....	30
4.2.8	SMORE Plots.....	30
4.3.	Summary.....	35
V.	Conclusions and Recommendations .....	36
5.1.	Chapter Overview .....	36
5.2.	Conclusions of Research.....	36
5.3.	Significance and Recommendations.....	37
5.4.	Recommendations for Future Research.....	37
	Bibliography .....	39
	Vita .....	40

## List of Figures

	Page
Figure 1. Ways to Study a System (Law, 2007) .....	7
Figure 2. Steps in a Simulation Study (Law, 2007) .....	10
Figure 3. Sortie Generation Process on Flightline .....	16
Figure 4. The Unscheduled Maintenance Process .....	22
Figure 5. The Experiment Window .....	25
Figure 6. SMORE Plots of Number of Flights for Scenarios 1-6.....	31
Figure 7. SMORE Plots of Total Maintenance Hours and Average Total Maintenance Hours for Scenarios 1-6.....	32
Figure 8. SMORE Plots of Power Generator Utilization for Scenarios 1-6 .....	33
Figure 9. SMORE Plots of Number of Flights for Scenario 1 and 7 .....	33
Figure 10. SMORE Plots of Total Maintenance Hours and Average Total Maintenance Hours for Scenario 1 and 7.....	34
Figure 11. SMORE Plot of Power Generator Utilization for Scenario 1 and 7.....	35

## List of Tables

	Page
Table 1. Simio Standard Library Objects (Pegden and Sturrock, 2013) .....	20
Table 2. Scenarios in the Model .....	24
Table 3. Initial Simulation Results for Scenarios 1-7 .....	27

# **FLIGHTLINE SIMULATION MODELING OF A SQUADRON**

## **I. Introduction**

### **1.1 General Issue**

Since the first flight of the Wright brothers in 1903, aircraft have evolved and gained new specifications and capabilities in parallel with technological developments. Currently, fifth generation military aircraft are becoming more common in the operational environment. As fighter aircraft are improved training aircraft are improved also.

Military flight training is a long and costly process. So, standard operations procedures should be well developed with a detailed timeline. Training courses are scheduled for completion according to a specific time frame to maintain a desired rate of combat ready pilots. Ensuring that the training aircraft are ready for flight is critical in processing pilots through training courses on schedule. Maintaining a high mission capable rate for training aircraft requires scheduled periodic maintenance and maintenance between sorties.

In the Turkish Air Force (TurAF), flight training is given in three phases with five different aircraft (A/C) types. These phases are Initial, Basic, and Advanced. The Initial phase employs SF-260 aircraft, the Basic phase employs KT-1T aircraft, and the Advanced phase employs T-38M, CN-235, and AS-532 aircraft.

The most important phases of the training are Basic and Advanced flight. In Basic flight, students begin to learn how to improve their flight handling capabilities, fly many different types of mission sorties (formation flight, instrument flight, night flight, etc.) in

preparation for the Advanced phase, and begin to improve their situational awareness in flight. In Advanced flight, students totally learn to assess their situational awareness in flight, learn how to fly in team work and learn basic leadership capabilities in preparation for the combat squadrons. Because of these training requirements, the total number of sorties flown in these phases is much higher than the Initial phase and the course lengths for these phases are longer.

## **1.2 Problem Statement**

On the flightline, maintenance staff is responsible for preparing the aircraft for flight and maintaining aircraft mission capability. To do this, they perform unscheduled maintenance between sorties along with a standard set of flightline services to each aircraft for assigned sorties. There are other scheduled maintenance activities, however, these are not considered for this study.

Aircraft Ground Equipment (AGE) is used to service each aircraft to make it ready for the following flight. AGE consists of various devices and equipment needed for both maintenance and services. Having a sufficient amount of AGE available is critical, as cancelling or delaying sorties due to lack of AGE generally has a significant impact on the training schedule.

Each squadron has a certain amount of aircraft. Advanced flight training squadron has 65 T-38M training aircraft (The aircraft was modernized in Turkish Aerospace Industries for Turkish Air Forces Command. M represents the word “modernized”). On the flightline of the squadron there is a certain amount of AGE to support the flights.

This research considers the question of what type and quantity of AGE are required to maintain enough mission capable aircraft to meet training sortie requirements.

The following investigative questions are answered to analyze the effect of AGE in sortie generation:

- What quantities and types of support equipment are possessed by Advanced flight training squadron?
- How are the support equipment currently allocated?
- What are the failure and repair rates of the possessed support equipment?
- What are the failure probabilities of an aircraft during the sortie generation process?
- What are the support equipment requirements to support the repair of each aircraft failure? (Bayer, 2003)

### **1.3 Scope**

The scope of this thesis is analyzing the AGE support equipment used in Advanced flight training on the squadron flightline and investigating how the changes in the mix of equipment, operational rates, failure rates, and the other modeled characteristics impact scheduled training sorties. To do this, the Advanced flight training flightline is modeled in Simio discrete event simulation software package.

### **1.4 Thesis Organization**

In this chapter, general information about the problem statement and flight training system in TurAF is given. In Chapter II, general information about the Advanced flight training squadron flight line is given along with a discussion of previous simulation research involving AGE. Chapter III discusses the methodology and presents the model

built in Simio. In Chapter IV, the results and conclusions are presented. Chapter V summarizes the previous chapters, highlights the important results and gives recommendations for future research.

## **II. Literature Review**

### **2.1 Chapter Overview**

This chapter first summarizes the flightline activities in Advanced flight training squadron, describing which procedures are done before and after the sorties. A general discussion of the simulation is then presented, along with application areas, advantages, and disadvantages. In addition the Simio simulation software used in this thesis is briefly discussed. The final section discusses previous research.

### **2.2 Flightline Procedures**

Maintenance staff on the flightline work in shifts. In the morning shift, the staff prepare the aircraft for the flight to include uncovering the aircraft, performing any required services, inspecting the physical condition of the aircraft, and inspecting the flightline for unwanted objects. Before launching the first sortie, the allocation section of the maintenance unit allocates the mission capable (MC) aircraft to the squadron and assigns a pilot to an aircraft. They also allocate machinists, the maintenance staff that perform the preflight check with pilots. When the pilots arrive to the flight line, they check the historical records of the aircraft for previous failures and for any specific need to know items before flight. After that, the pilot goes to the aircraft with the machinist and the pilot conducts an exterior check before getting into the aircraft. Then the pilot completes all the interior checks and starts the engines in coordination with the machinist. The machinist checks the aircraft once more after engine start for any breakdown or liquid leakage from the systems.

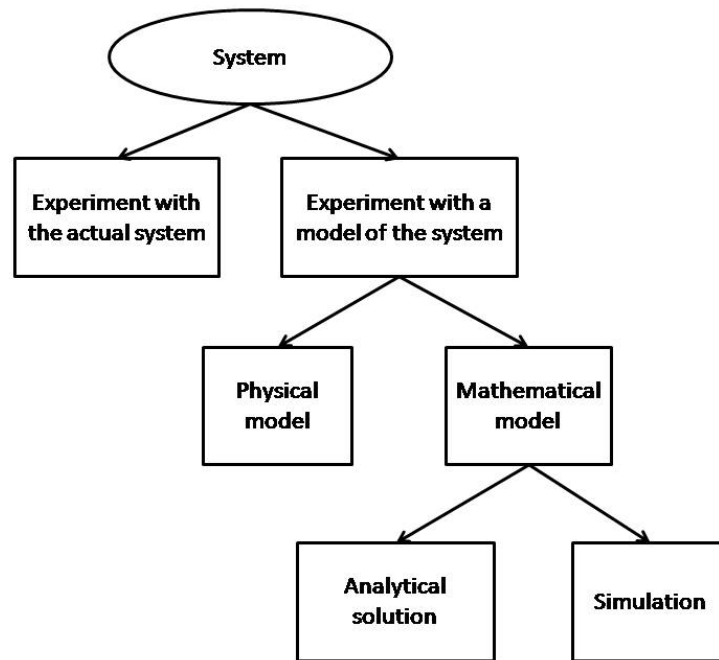
After completing a flight, the pilot parks the aircraft with the help of machinist. He or she briefs the machinist on any issues about the aircraft and informs the maintenance staff about any failures. For any failures, the maintenance staff decides whether the failure can be repaired before the next sortie. If so, maintenance staff and required AGE are allocated to attempt completion of required maintenance before the following flight.

In the Advanced training squadron flight line, the following types of equipment are used to service the aircraft and make them ready for sorties:

- Power Generator
- Oxygen Servicing Unit
- Pneumatic Test Unit
- Oil Servicing Unit
- Hydraulic Servicing Unit

In the TurAF, community decision makers face many constraints in planning. A variety of analytical methods and tools are used to evaluate and summarize the impact of these constraints on system performance in a short period of time for the decision makers. Time and costs are the most important factors typically identified by decision makers in developing and implementing a plan for system operation. Figure 1 (Law, 2007) maps out different ways in which a system might be studied. Simulation is often the most appropriate method to evaluate a complex system. A simulation approach is selected for

this research with a general discussion of characteristics of simulation in the following section.



**Figure 1. Ways to Study a System (Law, 2007)**

### **2.3 Simulation**

A simulation is the imitation of the operation of a real-world process or system over time. Whether done by hand or on a computer, simulation involves the generation of an artificial history of a system and the observation of that artificial history to draw inferences concerning the operating characteristics of the real system (Banks et al., 2015).

Simulation can be used for many purposes. Some systems from daily life follow:

- A road intersection control with traffic lights.
- A hospital emergency room with personnel, equipment and patients.
- A supermarket checkout section with cashiers and customers.
- An aircraft factory level maintenance unit with personnel, aircraft and equipment.

- A flightline of a flight training squadron.

### **2.3.1 Simulation Classifications**

There are three different dimensions of the simulation models. A static simulation model is a representation of a system at a particular time, or one that may be used to present a system in which time plays no role. On the other hand dynamic models represent a system as time changes (Law, 2007).

If a simulation model does not contain any random components, it is called a deterministic model. Stochastic simulation models have at least one random input component (Law, 2007). Some common examples of stochastic simulations are queuing and inventory systems.

In a continuous simulation the state variables of a system change continuously over time. Traffic density of a highway and water levels of a dam represent some examples of a continuous simulation model. On the other hand, in a discrete simulation model the state variables only change at discrete points in time (Law, 2007). Inventory level of a depot and number of customers in line for checkout in a market are some examples of discrete events.

### **2.3.2 Advantages and Disadvantages**

Simulation is widely used in various fields. There are advantages of using simulation as well as disadvantages. Some advantages are as follows:

- New policies and operating procedures can be easily explored without changing the real system.
- New designs and systems can be tested without physically building them. This prevents using resources unnecessarily.

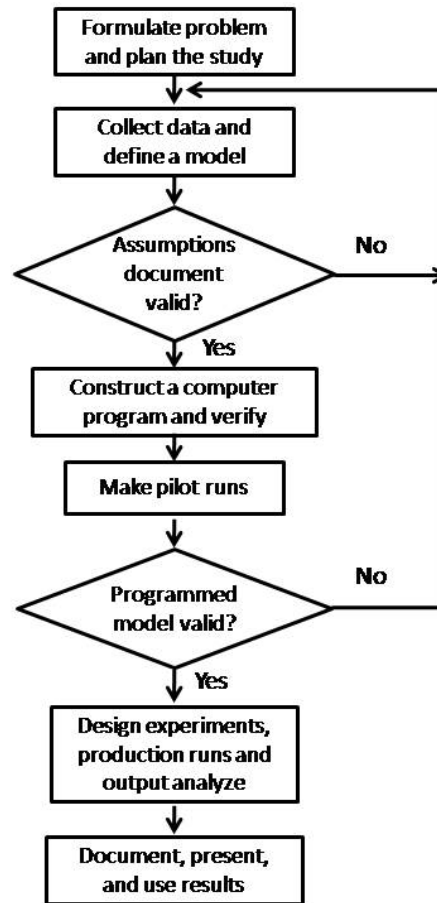
- By changing speed of a simulation, long lasting operations can be tested in a short period of time.
- Simulation helps to evaluate how the system operates and the performance of the system elements.
- Modeling complex systems is easier with simulation.
- Simulation helps to answer “what if” questions, especially for the new systems (Banks et al., 2015).

In some circumstances simulation may not be feasible or the most appropriate approach. Listed here are some disadvantages.

- Simulation modeling and analysis can be time consuming and expensive. Insufficient resource and data may result in an invalid simulation.
- Simulation results can be difficult to interpret. Due to the incorrect parameters and data the results may be irrelevant and meaningless.
- Simulation requires special training. Building a model depends on the user`s perspective and experience (Banks et al., 2015).

### **2.3.3 Simulation Steps**

A simulation study should be done systematically. Figure 2 (Law, 2007) shows a well-defined set of steps to conduct a simulation:



**Figure 2. Steps in a Simulation Study (Law, 2007)**

## 2.4 Simio

The Simio modeling software lets the user build and run dynamic 3D animated models for a wide range of systems – e.g. factories, supply chains, emergency departments, airports, and service systems (Pegden and Sturrock, 2013). Simio employs an object approach to modeling, whereby models are built by combining objects that represent the physical components of the systems. An object has its own custom behavior as defined by its internal model that responds to events in the system (Pegden and Sturrock, 2013). For example a flightline model can be built with objects that represent

schedule flight, preflight inspection, take off, flight, landing, taxi and parking, postflight inspection, etc.

## **2.5 Previous Studies**

Many previous studies examining AGE utilization on the flightline were done using simulation tools like Simio.

### **2.5.1 Bayer's Study**

In Bayer's (2003) study, he investigated the impact of the AGE management on home station sortie production. He modeled an F-16 squadron at Shaw AFB using the Scalable Integration Model for Objective Resource Capacity Evaluations (SIMFORCE). His research focused on maximizing sortie numbers at the home station with a number of aircraft deployed to another base (Bayer, 2003).

SIMFORCE is an affordable desktop tool and was developed by the Kelly Logistics Support Systems (KLSS) contracted by Air Force Research Laboratory (AFRL). SIMFORCE has capability of evaluating the impact of user specified operational tempos on logistics resource constraints and sortie rates. SIMFORCE was developed within ARENA software, a simulation tool like SIMIO. SIMFORCE uses a standard input, process, and output model (Bayer, 2003).

He used the following AGE in his study:

- High-Pressure Air Compressor—MC-1A
- Low-Pressure Air Compressor—MC-2A
- Liquid Nitrogen Servicing—N2 cart
- Cooling Air—AM32C-10

- Electrical Power Generator—AM32A-60
- Hydraulic Test Stand—MJ-2A
- External Lighting Unit—NF-2D

### **2.5.2 Havlicek's Study**

In Havlicek's (1997) study, the purpose was to identify what aircraft availability factors need more precise estimates to provide adequate aircraft availability comparisons of the percentage of canceled missions (PCM). He investigated the impact of four factors on aircraft availability: AGE design configuration, Mean Time between Failure (MTBF) of AGE, Mean Time to Repair (MTTR) AGE, and travel time to transport AGE on the flight line. The study's analysis highlighted how the design, reliability, maintainability, and availability of the AGE system influence the availability of aircraft (Havlicek, 1997).

Havlicek (1997) used the Integrated Model Development Environment (IMDE) tool in his study. IMDE is a computer aided software engineering tool that offers the benefits of object oriented programming. IMDE can take all the defined objects and generate an executable model using only the objects selected by the model developer. He studied the effects of AGE related factors on aircraft availability and deployability (Havlicek, 1997).

### **2.5.3 Kaya's Study**

Kaya's (2002) study noted that the USAF executes rapid global deployment all over the world. With a well-defined set of resources to support required sortie operations for deployed aircraft, AGE, which can amount to one third of deployment requirements,

plays a critical role in supporting these operations and should be reevaluated (Kaya, 2002).

His research focused on how to better manage the number and the type of AGE deployed with an Air Expeditionary Force (AEF), more specifically comparing single-function carts and multi-function carts on the flight line. Two hypotheses were examined for deployed AGE requirements: Systematically reducing; and replacing single function, weapon specific conventional AGE with the Modular Aircraft Support System (MASS) (Kaya, 2002).

Kaya (2002) used ARENA simulation tool with excel in his study. Input models were based on real data when available or from subject matter experts to appropriately simulate reliability, utilization, and time between failures for the subject AGE.

#### **2.5.4 McKenna's Study**

The purpose of McKenna's (2001) study was to illuminate crucial areas in analyzing AGE needs on an operational flight line and assist in determination of AGE inventory levels. This research focused on determining the actual amount of AGE necessary to meet requirements, regardless of the table of allowance values. The research used the Logistics Composite Model (LCOM) to determine desired AGE inventory level through an analysis of aircraft launches and wait time for AGE support by varying AGE mean time between failures (MTBF) and AGE inventory. The difference between previously mentioned studies and this study is that McKenna (2001) includes the delivery time of AGE.

LCOM is a discrete event simulation model developed by Air Force Logistics Command in 1960s. McKenna (2001) focused on refining and demonstrating a methodology for assessing AGE utilization in a given scenario. LCOM was used to drive demand for Self Generating Nitrogen Servicing Cart (SGNSC) with stochastic inputs from several sources and determined capacity and utilization (McKenna, 2001).

### **2.5.5 O’Fearna’s Study**

The main focus of this study was reducing the AGE requirements for AEF. As the USAF evolved into an AEF using tailored combat force packages to meet specific threats, the requisite support functions for the deployed forces required additional analysis. A discrete event simulation built with AWESIM was used for examining options to reduce the amount of support equipment deployed with a tailored force (O’Fearna et al., 2002).

### **2.5.6 Tovrea’s Study**

Tovrea’s (1997) research studied one portion of AGE mobility, the transportability characteristics of the Air Force’s current powered AGE. Transportability is defined as the ability to quickly and efficiently prepare an item for transport, load the item on the transportation asset, remove the item from the transportation asset and reconstitute the item for use. There are two options to reduce the amount of AGE. First, on-board equipment to fulfill the requirements for AGE. This option is applicable for large aircraft. Large aircraft usually have an on-board auxiliary power unit. But this option is not practical for smaller aircraft (fighter and trainer aircraft). The second option is to reduce the size and weight of the existing AGE or combine the functions of AGE. The Multi-function Aircraft Support System (MASS) program is an Air Force initiative

to reduce the size and weight of AGE (Tovrea, 2007). The MASS program could provide solutions for the study of transportability characteristics of newly designed AGE.

## **2.6 Summary**

This chapter presents the flightline procedures of the Advanced flight training squadron. Next, advantages, disadvantages and classification of simulation models along with some information on the Simio discrete event simulation software package are discussed to form a basis for Chapter 3. The discussion also reviewed previous research focusing on using AGE on the flightline, especially the effects of the AGE numbers on flight scheduling and sortie numbers. The approaches used in these previous studies aided the development of the methodology incorporated in this study in modeling AGE. Only Havlicek (1997) explicitly considered AGE reliability and this study uses a simplified approach to capture AGE failures, repairs, and utilizations.

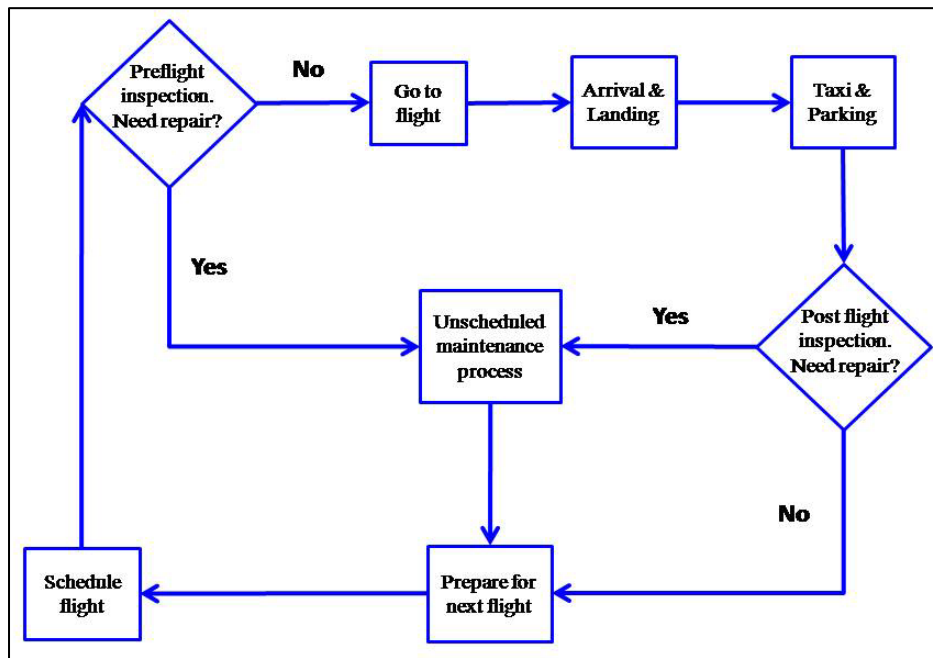
### III. Methodology

#### 3.1. Chapter Overview

This chapter focuses on the model built in Simio and describes the steps modeled in detail. Simio features are also discussed with and how they were used in building our simulation, verification and validation, and our analysis plan.

#### 3.2. Flightline Sortie Generation Process Model

The process can be illustrated as a cycle as shown in Figure 3 derived from Sevimli's (2016), Kaya's (2002) and O'Fearn's (2002) studies.



**Figure 3. Sortie Generation Process on Flightline**

The model includes the processes performed before and after a sortie in a flightline. In this model, AGE are represented as resources and aircraft as entities. There are seven steps in the model: schedule flight; preflight inspection; go to flight; arrival and landing; taxi and parking; post flight inspection; and prepare for next flight. In all steps

where maintenance personnel would be required, it is assumed that there are enough maintenance personnel on the flightline so the model does not include maintenance as a resource. This not only simplifies the construction of the simulation, but also focuses the analysis on AGE utilization. Detailed information about the steps is provided below.

### **3.2.1 Schedule Flight**

In the flightline, the allocation section determines which aircraft fly each day. The flight times are indicated on the flight program published by the squadron one day before. The aircraft are prepared to be ready on those flight times. If there are more aircraft than the flight schedule, they are assigned as spare aircraft. The simulation does not include any logic to assign instructor pilots or students to scheduled flight.

### **3.2.2 Preflight Inspection**

Before launching a sortie, maintenance personnel and machinists perform a preflight inspection using a power generator, servicing units (oxygen, oil and hydraulic) and a pneumatic test unit. During inspection, they check the exterior parts of the aircraft and liquids (gasoline, oil, oxygen, hydraulic, etc.). If they find any problem they try to solve it by themselves, otherwise they report the problem to the office and abort that aircraft. If a spare aircraft is available it is allocated for the scheduled sortie. Otherwise, the same sortie is planned for the following block or the following day.

### **3.2.3 Go to Flight, Arrival and Landing, Taxi and Parking**

If there are no problems after all checks, the pilot is clear to fly that mission. The length of a sortie depends on the mission. After the flight, the pilot lands the aircraft, taxis to the parking area and parks the aircraft. Generally the same machinist who

performed the preflight inspection meets the aircraft while parking. If an issue with the aircraft is identified during flight, the pilot first tells it to machinist and reports it to the maintenance office. If the issue is serious, the pilot records the problem in the aircraft history notebook. Sometimes the pilot may cancel the mission in the air because of an issue and return back to base. In that case the sortie becomes invalid and must be rescheduled for the affected pilot trainee. Inflight cancellations are not modeled.

#### **3.2.4 Post Flight Inspection, Prepare for Next Flight**

If an aircraft needs repair after flight, maintenance personnel try to solve the problem before the next sortie. If the maintenance effort is successful the aircraft is planned for the next sortie. Even if the pilot does not report a problem after the flight, the machinists check the aircraft before each sortie by using a power generator, servicing units (oxygen, oil and hydraulic) and a pneumatic test unit. If they find anything wrong with the aircraft, they try to solve it before the next sortie; otherwise a spare aircraft (if available) is planned for that sortie. Any canceled training sorties must be rescheduled for the affected pilot trainee.

#### **3.2.5. Unscheduled Maintenance Process**

The unscheduled maintenance process is performed by either the machinists or the repair personnel. If the problem is not solved by the machinists, then the aircraft is moved to a hangar in which the repair process is done by using all the AGE mentioned above. The repair time depends on the problem. If a spare part is needed, the aircraft may need to wait for weeks for that part.

Like the aircraft, the AGE may have problems during operation and servicing activities requiring repair. Based on subject matter expert (SME) input individual AGE failures are modeled as occurring about once a month (implemented as a random exponential failure time of 100 hours for each unit of AGE) for all types with a day (implemented as a constant 24 hours) to repair any AGE.

### **3.3 Model Development**

The flightline processes are modeled using Simio Simulation Software. Some of the features of the software that we used in the model are explained below.

#### **3.3.1 Standard Library**

Simio employs an object approach to modeling, whereby models are built by combining objects that represent the physical components of the systems. First step of building a model is dragging an object from the library into the facility window and connecting to other objects. Each object has its own properties. Processes can be defined to make the model more detailed. The standard library contains the objects in Table 1. Simio Standard Library Objects (Pegden and Sturrock, 2013)

**Table 1. Simio Standard Library Objects (Pegden and Sturrock, 2013)**

Object	Description
Source	Generates entity objects of a specified type and arrival pattern.
Sink	Destroys entities that have completed processing in the model.
Server	Represents a capacitated process such as a machine or service operation.
Workstation	Models a complex workstation with setup, processing, and teardown phases and secondary resource and material requirements.
Resource	A generic object that can be seized and released by other objects.
Worker	A moveable resource that may be seized and released for tasks as well as used to transport entities between node locations.
Combiner	Combines multiple member entities together with a parent entity (e.g. a pallet).
Separator	Splits a batched group of entities or makes copies of a single entity.
Vehicle	A transporter that can follow a fixed route or perform on demand transport pickups/drop offs.
BasicNode	Models a simple intersection between multiple links.
TransferNode	Models a complex intersection for changing destination and travel mode.
Connector	A simple zero-time travel link between two nodes.
Path	A link over which entities may independently move at their own speeds.
TimePath	A link that has a specified travel time for all entities.
Conveyor	A link that models both accumulating and non-accumulating conveyor devices.

### **3.3.2 Processes**

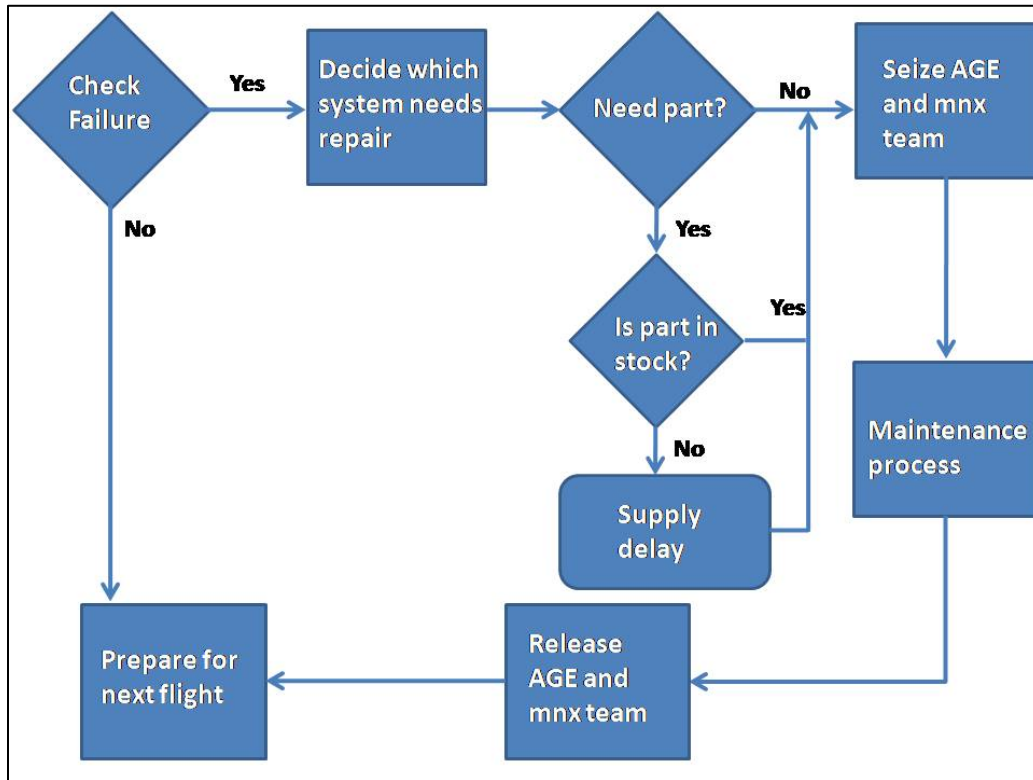
Object-based tools like Simio are very good for rapidly building models. Objects are dropped into the workspace, properties are set for each instance of those objects, and the model is ready to run. However the problem in this approach is modeling flexibility. It can be difficult to have a set of objects that work perfectly in all situations across multiple and disparate application areas without making the objects overly complicated and difficult to learn and use. The Simio Standard Library addresses this problem through

the concept of add-on processes (Pegden and Sturrock, 2013). In this simulation this feature is used to define a highly detailed unscheduled maintenance process.

### **3.3.2.1 Unscheduled Maintenance**

In the Postflight Inspection step of the model, four main systems are defined to check individually for any maintenance issue with an aircraft. Those four systems are: Airframe, Engines, Flight Controls (avionics), and Hydraulics. To capture failures and repairs of these systems in the simulation required information on total flight hours, number of breaks, and down time for a selected number of fighters. Data are compiled from unclassified USAF logistics and maintenance resources to represent breaks for these four major systems individually and associated not mission capable time due to supply and maintenance. To simplify supply logic a single number is used to represent stockage effectiveness (is a required part available). This is set this at 95% for the baseline and data from our logistics and maintenance resources for each of our four modeled systems are used to represent the required supply time when a part is needed for each system as a normal distribution (four unique distributions). Likewise there are separate maintenance times to represent maintenance time for a failure of each of the systems. A single value represents the MTBM for any of the four systems. This is modeled as a fleet clock, meaning an initial failure time is drawn (which is reset after failure as well as the total flight hours) for the failure clock from an exponential distribution using the MTBM. Then when the total flight hours (sum of all sorties flying) exceed that time, the fighter that caused it to go over is treated as a failure. A random number is drawn to determine which system failed and another random draw checks to see if the part is on hand. Then

all failures go through some unscheduled maintenance time based on the system that failed. The unscheduled maintenance process is shown in Figure 4. The Unscheduled Maintenance Process.



**Figure 4. The Unscheduled Maintenance Process**

### 3.3.2.2 Simulation Setup

The model is constructed to run five days in a week with no weekends since there are no flights on weekends. There are two flying blocks; morning block and an afternoon block. The morning block starts at 08:00 and the afternoon block starts at 14:00. In each block ten aircraft fly, so twenty aircraft fly in a day with an average individual flight time of 3.25 hours. For each type of AGE 12 hour resource schedules are set.

Each simulation replication runs for 360 days with a 60 day warm-up period to have the model in reasonable starting conditions before collecting data. Twenty replications are performed to meet required statistical conditions (independent, identically distributed and approximately normal) for all metrics to obtain reasonable confidence intervals for the results. Logic is also included in the simulation model to ensure all AGE resources are available before seizing any of them. This logic is used in all the steps that need multiple types of AGE to perform an action.

### **3.3.3 Validation and Verification of the Model**

Verification is the process of ensuring that the model behaves in the way it was intended according to the modeling assumptions made. Verification is not a onetime process; it should be done in every step throughout the model. There are various techniques which can be used to verify the model. While building a large and complex model, it is suggested that another person review the model for verification. This technique is called a structured walk-through of the program. Another technique involves running the simulation with different input data and checking the outputs to see whether they are reasonable. In this research the simulation is run with different control settings and a number of output metrics are analyzed including the utilization results of the different types of AGE.

In most cases, animation can be used as a tool to aid in verification. The animation feature in Simio is another major technique used to verify this model. Whenever additional logic or a new sub model is inserted, the simulation is run with animation enabled to check for the proper flow of entities and use of resources. In

addition someone familiar with the system reviewed the model. The model was reviewed by both the pilots who have flown at the flight training squadrons for more than one year and the maintenance personnel working on the flightline of the flight training squadron.

Validation is the process of establishing that the model accurately represents the real system. In this model face validity was the primary validation technique. The same pilots and maintenance who helped verify the model also reviewed the model for validation.

### 3.4 Experiment for Analysis

The analysis investigates seven different scenarios with different inputs to answer the questions in this thesis. The first one is the baseline scenario with low rate of preflight maintenance, high level of stockage effectiveness, and the SME recommended quantities for all AGE. Quantities of all types of AGE are modeled as a single factor and the study doesn't explore changing the number for individual types of AGE. In other scenarios these three factors are changed to compare the effect of different system configurations.

The scenarios and levels of factors for each are listed in Table 2.

**Table 2. Scenarios in the Model**

Scenarios	Preflight Fault %	MTBM (hours)	Stockage Effectiveness %	Power Generator	Oil Servicing	Hydraulic Servicing	Pneumatic Test	Oxygen Servicing
1 (Baseline)	2	332.49	95	10	4	4	3	2
2	2	332.49	90	10	4	4	3	2
3	5	332.49	95	10	4	4	3	2
4	5	332.49	90	10	4	4	3	2
5	10	332.49	95	10	4	4	3	2
6	10	332.49	90	10	4	4	3	2
7 (Half AGE)	2	332.49	95	5	2	2	2*	1

\*For Pneumatic Test 2/3 of the original number

The first scenario represents the baseline and has the best settings for each factor to provide the highest level of system performance. Mean time between maintenance (MTBM) is the time that an aircraft has flown until a break occurs and is the same in all scenarios. Scenarios 2 – 6 vary the preflight fault and stockage effectiveness percentages while Scenario 7 simulates a deployment situation with the number of the AGE decreased to half for each type. These properties (named as Controls in the experiment window) are set in desired combinations to describe the design points of interest for analysis. For the analysis values are varied for preflight failures, stockage effectiveness, and quantities for each type of AGE. These model properties are then referenced by one or more objects in the model as each scenario is simulated individually (Pegden and Sturrock, 2013). The experiment window for the study is shown in Figure 5.

Scenario			Replications		Controls							
<input checked="" type="checkbox"/>	Name	Status	Required	Completed	PF %	MTBM (Hours)	SE	Num_PG	Num_OS	Num_HS	Num_PT	Num_OX
<input checked="" type="checkbox"/>	1. Baseline (PF 2% and SE 95%)	Idle	20	20 of 20	0,02	332,49	0,95	10	4	4	3	2
<input checked="" type="checkbox"/>	2. PF 2% and SE 90%	Idle	20	20 of 20	0,02	332,49	0,9	10	4	4	3	2
<input checked="" type="checkbox"/>	3. PF 5% and SE 95%	Idle	20	20 of 20	0,05	332,49	0,95	10	4	4	3	2
<input checked="" type="checkbox"/>	4. PF 5% and SE 90%	Idle	20	20 of 20	0,05	332,49	0,9	10	4	4	3	2
<input checked="" type="checkbox"/>	5. PF 10% and SE 95%	Idle	20	20 of 20	0,1	332,49	0,95	10	4	4	3	2
<input checked="" type="checkbox"/>	6. PF 10% and SE 90%	Idle	20	20 of 20	0,1	332,49	0,9	10	4	4	3	2
<input checked="" type="checkbox"/>	7. Baseline with half AGE	Idle	20	20 of 20	0,02	332,49	0,95	5	2	2	2	1

**Figure 5. The Experiment Window**

### 3.5 Summary

This chapter focused on a description of flightline procedures, the concept of building the simulation model, and application of the steps for building a simulation model. Details are provided to explain the real flightline system steps along with a

description of the analysis plan. The following chapter discusses the results of the simulation and presents the analysis.

## IV. Analysis and Results

### 4.1. Chapter Overview

The previous chapter defined and explained the model used in this research. This chapter discusses the organization of the analysis and the results from the simulation runs.

### 4.2. Model Results

The scenarios described in the previous chapter were run with all the results shown in Table 3 along with discussion highlighting and explaining differences seen between the scenarios. Six overall performance metrics are presented for each scenario along with scheduled utilization values for each type of AGE. Values listed are the mean and 95% confidence interval half-width for 20 replications.

**Table 3. Initial Simulation Results for Scenarios 1-7**

	Scen 1	Scen 2	Scen 3	Scen 4	Scen 5	Scen 6	Scen 7
<b>Num Flights</b>	5591 34.64	5592.45 40.59	5294.85 50.21	5305.95 50.42	4485.25 72.05	4522.85 71.89	4853.30 85.75
<b>Flight Hours</b>	19567.76 120.88	19576.27 142.11	18528.66 176.41	18567.61 175.41	15696.16 251.91	15828.77 251.42	16985.12 300.17
<b>Preflight Mnx Hours</b>	931.91 106.21	1000.32 95.51	3026.92 342.38	2964.37 353.82	10751.87 824.98	10458.90 752.28	2083.93 248.99
<b>Avg. Total Mnx Hours</b>	15.08 0.81	15.89 1.32	14.60 1.22	14.61 1.18	24.04 1.64	23.51 1.70	30.12 3.33
<b>Total Mnx Hours</b>	2588 165.12	2757.59 235.90	4849.56 476.77	4787.42 432.89	13040.23 995.11	12686.43 869.78	4379.30 546.39
<b>Num Preflight Breaks</b>	118.15 5.22	117.25 5.29	279.15 8.73	275.50 7.16	498.05 11.48	496.75 9.74	98.50 4.12
<b>PG Util</b>	16.86 0.62	17.11 0.78	21.92 0.62	21.48 0.91	27.52 0.70	27.59 0.93	26.39 0.92
<b>PT Util</b>	52.13 1.58	53.21 2.05	67.34 1.76	66.34 2.04	86.83 1.44	86.71 2.33	63.81 1.92
<b>HS Util</b>	34.44 1.33	34.17 1.31	43.66 2.16	43.80 1.47	57.28 1.95	56.87 1.76	49.41 1.65
<b>OS Util</b>	33.26 1.00	35.22 1.50	44.02 1.82	44.23 1.82	57.33 1.71	57.06 1.36	49.34 1.85
<b>OX Util</b>	70.32 1.83	73.03 2.93	91.41 2.71	90.03 1.86	118.40 2.26	117.49 1.99	109.38 2.82

#### **4.2.1 Scenario 1 (Baseline)**

Scenario 1 represents the baseline and has the best settings for each factor to provide the highest level of system performance (low rate of preflight maintenance, high level of stockage effectiveness, and the SME recommended quantities for all AGE). As expected, number of flights and total flight hours are very high while AGE utilizations are average.

The utilization of oxygen service unit is the highest one among the AGE. That is because of the number of the oxygen service unit is the lowest among the AGE. This scenario gives a starting point to decision makers for making situational assessments for future operations.

#### **4.2.2 Scenario 2**

In Scenario 2 the stockage effectiveness for the spare parts is decreased by five percent. This made minor changes in the set of primary metrics. Total maintenance hours increased because the number of aircraft that needed to wait for spare parts increased. AGE utilizations are almost the same, because we didn't change the preflight fault percentage.

#### **4.2.3 Scenario 3**

Scenario 3 increased the preflight faults to five percent. The number of flights and total flight hours decreased in comparison with Scenario 1 because the number of unavailable aircraft for the related sortie increased. Total preflight maintenance hours and total maintenance hours are significantly increased. In parallel with that, the number of preflight breaks increased along with AGE utilizations.

#### **4.2.4 Scenario 4**

Scenario 4 also increased the preflight faults to five percent and decreased the stockage effectiveness by five percent. The results in Scenarios 3 and 4 are similar, likely because preflight fault percentages in both scenarios are the same. AGE utilizations are similar to Scenario 3 with slight differences. Utilizations of oxygen servicing unit are above 90 % in Scenarios 3 and 4. That is because the number of the oxygen servicing unit is two. These results show that a small increase in preflight fault percentage causes significantly lower flight hours and higher maintenance times. The five percent reduction in stockage effectiveness appeared to have very little impact on any of the primary metrics.

#### **4.2.5 Scenario 5**

Scenario 5 increased the preflight faults to ten percent. The number of flights and total flight hours decreased compared with Scenario 1. Total preflight maintenance hours, total maintenance hours and number of preflight breaks are significantly increased. In parallel with that AGE utilizations also increased. Utilization of oxygen servicing unit exceeds 100 %. This result means that number of oxygen servicing unit are being used beyond its scheduled hours and is a good indication that the current number for that AGE is not sufficient.

#### **4.2.6 Scenario 6**

Scenario 6 also increased the preflight faults to five percent and decreased the stockage effectiveness by five percent. The results in Scenarios 5 and 6 are similar with slight differences because preflight fault percentages in both scenarios are equal. Oxygen servicing unit utilization is over 100 % again. For the metrics in Scenario 6, the current number for oxygen servicing unit is not sufficient either. Once again the impact of the decrease in stockage effectiveness is dwarfed by the impact of the preflight fault increase.

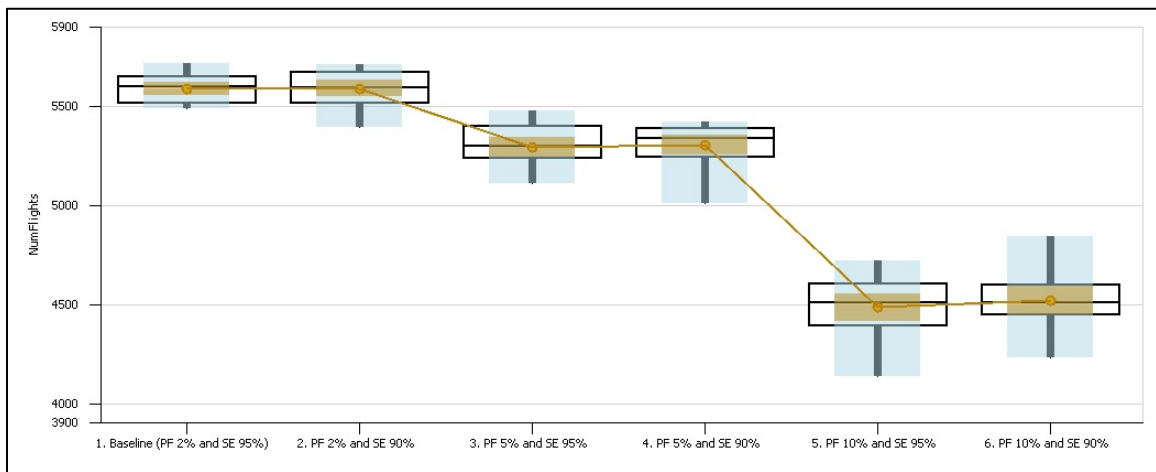
#### **4.2.7 Scenario 7**

Scenario 7 starts with the parameters of the Baseline scenario with the number of AGE decreased to half for each type (for Pneumatic Test  $2/3$  of the original number) to represent a situation where half of the AGE was used to support a deployment of some other active fighter unit. In a deployed environment we assume that the sortie number produced in one day decreases to  $3/5$  of original number (decreases to 12 from 20). The number of flights and total flight hours decreased by about  $4/5$  from Baseline Scenario values. Preflight maintenance and total maintenance hours increased because AGE numbers decreased to half. Number of preflight breaks decreased because number of sorties flown in a day decreased. All the AGE utilizations increased since the number of AGE decreased by half but the number of sorties decreased by a smaller rate.

#### **4.2.8 SMORE Plots**

For all SMORE plots presented in this section, the mean confidence intervals (brown rectangles) and quartile intervals (25<sup>th</sup> and 75<sup>th</sup> with blue rectangles) are at 95%. Figure 6 shows the SMORE plot of number of flights for Scenarios 1-6. This figure

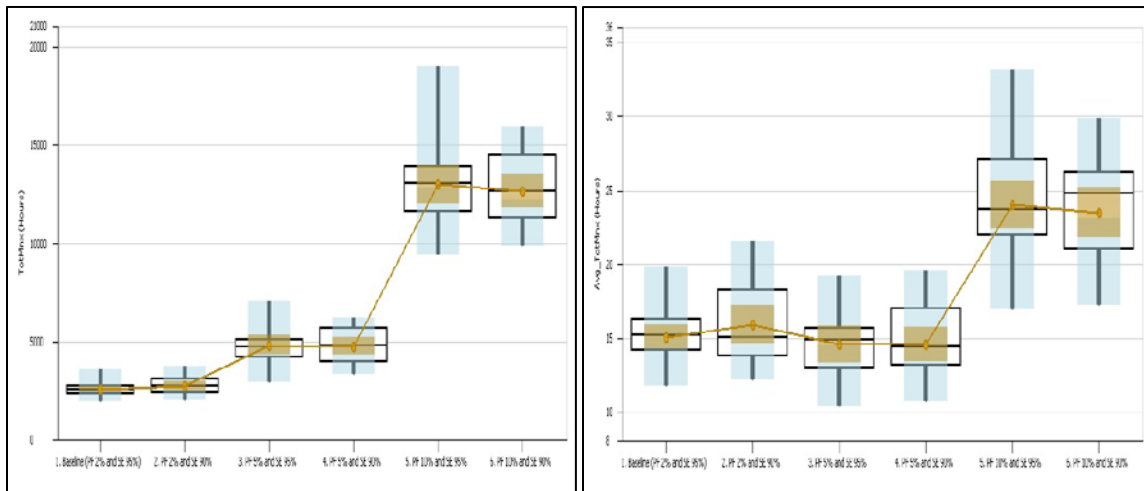
clearly shows the effect of changing the preflight fault percentage and stockage effectiveness in the plots. For scenario pairs 1 and 2; 3 and 4; and 5 and 6 the preflight failure percentage is the same in each pair with a 5% drop in the stockage effectiveness for the second scenario in the pairs. There is no statistical difference between any of these pairs at the 95% level of significance. However, looking at the differences at the SMORE plots between these three pairs, there is a statistically significant drop in the average number of flights with an increase in preflight failure percentage from 2%, to 5%, to 10% respectively.



**Figure 6. SMORE Plots of Number of Flights for Scenarios 1-6**

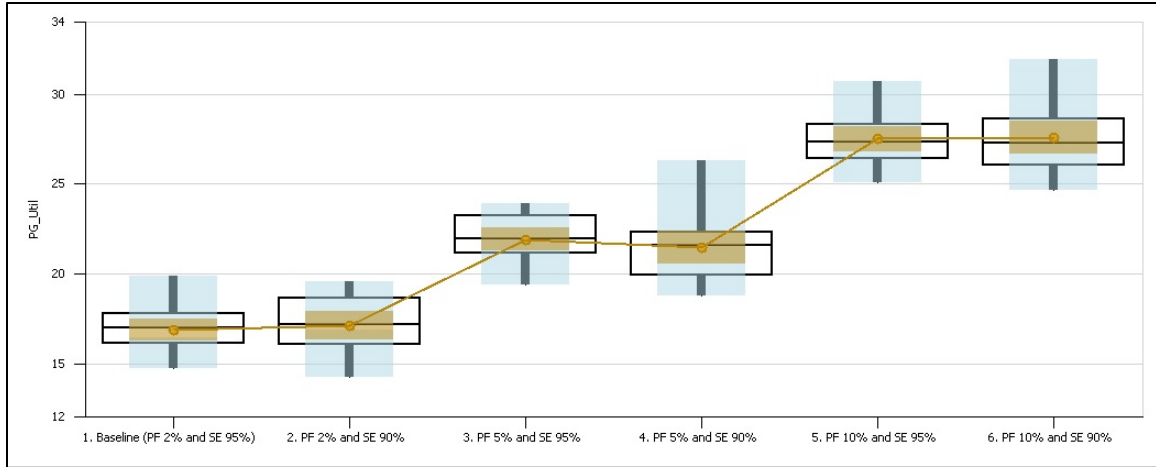
Figure 7 shows the SMORE plots of total maintenance hours and average total maintenance hours respectively for Scenarios 1-6. This figure shows the effect of increasing the preflight fault percentage in Scenarios 2 and 3. A small amount of increase in preflight fault percentage caused a slight increase in total maintenance hours. Similar to Figure 6, the decrease in stockage effectiveness doesn't show as much impact to the total maintenance hours as the preflight fault percentage. The average total maintenance

hours plot shows a decrease between Scenarios 2 and 3, although there is an increase in the total maintenance hours plot. Scenarios 4 and 5 show an increase in both plots. For both comparisons, the number of breaks observed increased due to the increase in preflight fault percentage. But the increase rate of breaks observed between Scenarios 2 and 3 is higher than the rate between Scenarios 4 and 5.



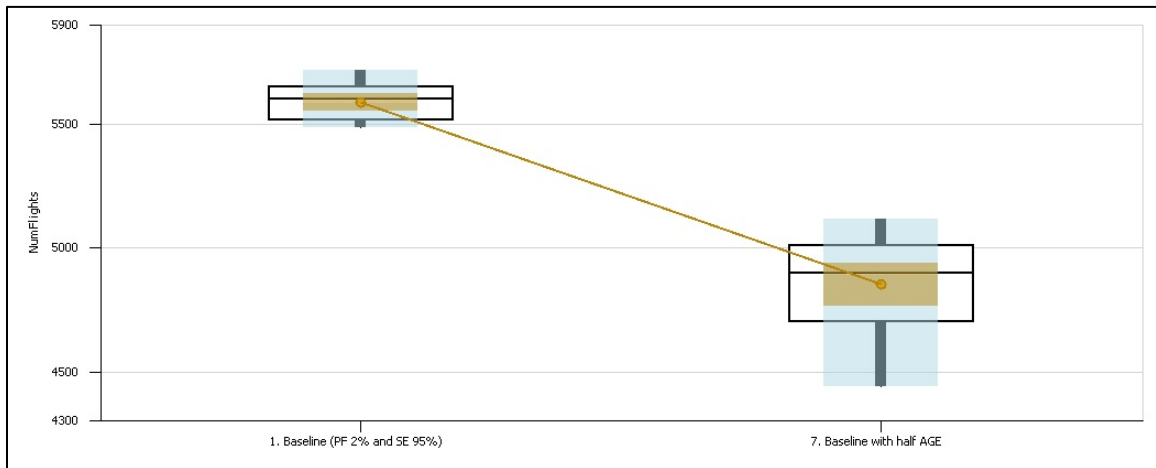
**Figure 7. SMORE Plots of Total Maintenance Hours and Average Total Maintenance Hours for Scenarios 1-6**

Figure 8 shows the SMORE plot of power generator utilization for Scenarios 1-6. This figure shows a significant increase in Scenarios 2 and 3. A small amount of increase in the preflight fault percentage caused a larger increase in power generator utilization. The reason is that the power generator unit is not only used for preflight inspection but also for preflight maintenance, prepare for next flight, and unscheduled maintenance. Remaining AGE all follow the same pattern between scenarios.



**Figure 8. SMORE Plots of Power Generator Utilization for Scenarios 1-6**

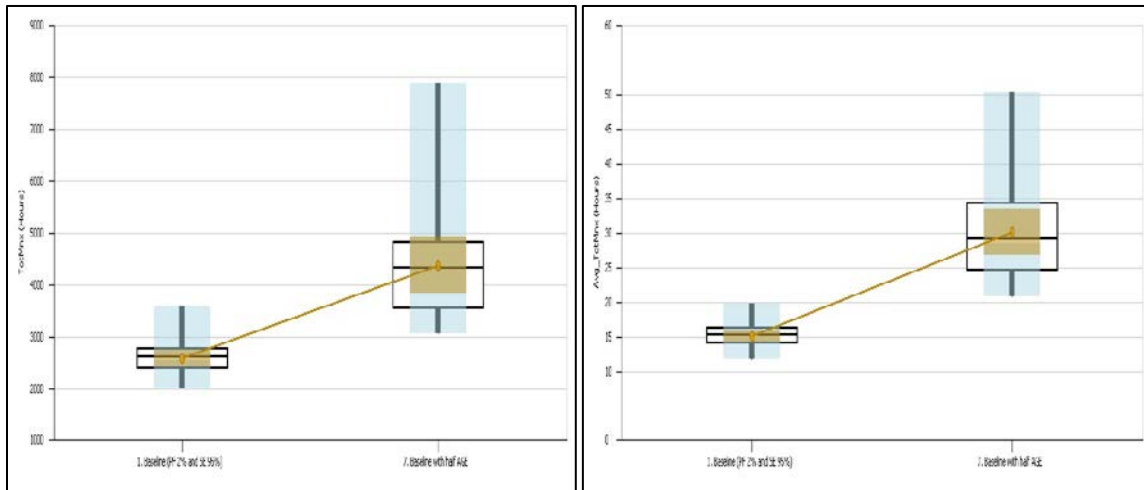
Figure 9 shows the SMORE plot of number of flights for Scenarios 1 and 7. In a deployment situation, the number of flights decreased significantly to about 4/5 of original number.



**Figure 9. SMORE Plots of Number of Flights for Scenarios 1 and 7**

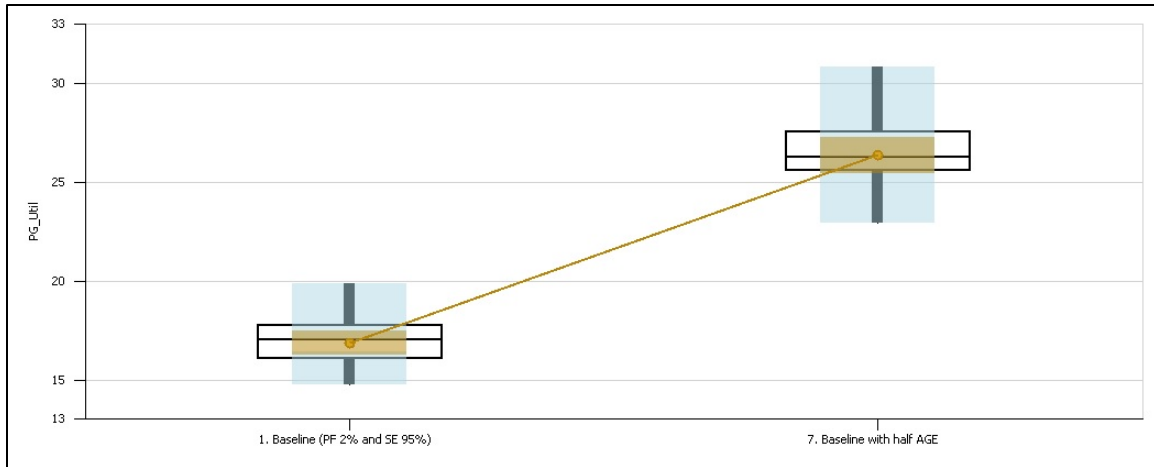
Figure 10 shows the SMORE plots of total maintenance hours and average total maintenance hours respectively for Scenarios 1 and 7. As the sortie numbers decreased, total maintenance hours and average total maintenance hours increased. Since the number

of AGE decreased to half, duration of the performed maintenance actions extended. As a result total maintenance hours increased although the number of breaks observed for Scenario 7 is less than Scenario 1. In parallel with total maintenance hours, average total maintenance hours increased because the increased rate of total maintenance hours is higher than the decreased rate for number of breaks observed.



**Figure 10. SMORE Plots of Total Maintenance Hours and Average Total Maintenance Hours for Scenarios 1 and 7**

Figure 11 shows the SMORE plot of power generator utilization for Scenarios 1 and 7. This figure clearly shows a significant increase with Scenario 7. In a deployment situation the sortie number decreased to 3/5 of original number and the number of power generator decreased to half, resulting in a higher utilization for the smaller number of power generators available.



**Figure 11. SMORE Plot of Power Generator Utilization for Scenarios 1 and 7**

### 4.3. Summary

These scenarios and the analysis results presented can help decision makers assess certain situations involving the maintenance issues and aid them in finding an appropriate solution. A commander can gain good insight with these scenarios which cover different variables and factors. They form a basis for maintenance staff, planners, and commanders to see how the changes in variables affect the flightline procedures. For example preflight fault percentage is a very important variable for the flightline. A small change in preflight fault percentage can result in big changes in the number of flights, maintenance times, and AGE utilizations. On the other hand, stockage effectiveness does not affect the AGE utilization as much as the preflight fault percentage. That is because AGE is used in both maintenance procedures and preflight/postflight services.

## **V. Conclusions and Recommendations**

### **5.1. Chapter Overview**

This chapter concludes important points discussed in this research. In the first chapter, the main problem is defined with investigative questions. Then, previous studies concerning the AGE utilization on the flightline are discussed in the second chapter. Next, a description of the simulation developed is explained along with a discussion of important features. Finally, the previous chapter defines results from the performed analysis. After forming the problem, determining the methodology, and analyzing the results, conclusion and recommendations are made. This section now summarizes the impact and significance of these findings. In addition, suggestions and recommendations for future research are included.

### **5.2. Conclusions of Research**

The main purpose of this study was to simulate the flightline of a flight training squadron to investigate the AGE utilization and impact of the change in AGEs to flight numbers. The simulation developed along with the analysis created different scenarios with selected parameters to investigate AGE utilization and provide insight regarding the investigative questions. Some parameters directly affect the AGE utilizations and flights but some parameters slightly affect AGE utilizations. For example, when we increase preflight fault percentage, both AGE utilization and maintenance hours increase while number of flights decrease. Changes in stockage effectiveness showed much smaller impact on AGE utilization and number of flights as compared to changes in preflight fault percentage. At this point, we need to take the number of breaks into consideration. Even if the number of breaks is low, when there is a need for spare parts and stockage

effectiveness is low, then the number of flights decreases because the aircraft need to wait for spare parts. Vice versa, if stockage effectiveness is high, the number of flights may increase although number of breaks is high.

### **5.3. Significance and Recommendations**

For a squadron commander, the number of flights flown in a period of time is a critical factor. Maintenance is one of the most important factors that impact flight schedules. This research highlights the effect of selected parameters on the number of flights, maintenance times, along with AGE utilization. This study gives commanders a basis before making important decisions.

This study can be applied to other areas as well. These areas are as follows:

- Serving as a baseline for AGE and aircraft estimates before deployments,
- Informing decision-makers on modifying specific functions in the maintenance process to improve sortie numbers and AGE utilizations,
- Observing the effect on the sortie numbers during a new platform entering the inventory where there are several issues during flights (e.g. KT-1T basic flight training aircraft in TurAF), or a modernization process of an aircraft (e.g. T-38M advanced flight training aircraft in TurAF).

### **5.4. Recommendations for Future Research**

The model can be improved by expanding the scope of this study. This study modeled the flightline procedures of Advanced flight training squadron with some limitations and assumptions, such as not including maintenance personnel in the model. By adding maintenance personnel into the model more detailed system performance can be obtained. The simulation created for this study dealt with a flight training schedule but could also be easily modified to analyze a fighter or a transportation squadron. Quantities

of all types of AGE were modeled as a single factor and didn't explore changing the number for individual types of AGE. For future studies, the number of a specific AGE can be changed to more thoroughly analyze the effect of this AGE utilization to system performance. In addition to, or as a replacement of preflight fault percentage and stockage effectiveness parameters, more detailed inputs such as inflight failure rates, spare aircraft, and so on could be included.

Four main aircraft systems (airframe, engines, flight controls and hydraulics) were defined in the model to check individually for any maintenance issue with an aircraft. More systems can be defined and included in the model. Lastly, this study didn't include the squadron sortie planning process. Future studies could include a sortie generation model to allow a more detailed analysis of day to day operations and AGE reliability.

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## **Vita**

Hüseyin MERT was born in Ankara. He graduated from Air Force Academy in İstanbul, in 2004 and he earned the degree of Bachelor of Science in Electronic Engineering. In the same year, he began his flight training in the 2nd Main Jet Base in İzmir. In 2006, after graduating from F-4 Basic Training Program, he was assigned to the 171<sup>st</sup> Squadron, Malatya as a wingman. In 2009, he was assigned to 122<sup>nd</sup> flight training squadron as an instructor pilot. In 2011, he was selected to Air War College and graduated in 2013. Next, he was assigned to Turkish Air Force Headquarter as a project officer. In 2015, he applied and selected for Operations Research Master Program in Graduation School of Engineering and Management, Air Force Institute of Technology.

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<b>14. ABSTRACT</b> Military flight training is a long and costly process. Ensuring that the training aircraft are ready for flight is critical in processing pilots through training courses on schedule. Maintaining a high mission capable rate for training aircraft requires scheduled periodic maintenance and maintenance between sorties. Aircraft Ground Equipment (AGE) is used to service each aircraft to make it ready for the following flight. Having a sufficient amount of AGE available is critical, as cancelling or delaying sorties due to lack of AGE generally has a significant impact on the training schedule. In this work, we analyze the AGE support equipment used in the Advanced flight training squadron flightline and investigate how the changes in the mix of equipment, operational rates, failure rates, and the other modeled characteristics impact scheduled training sorties.					
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