Calhoun: The NPS Institutional Archive
DSpace Repository

Theses and Dissertations 1. Thesis and Dissertation Collection, all items

2011-09

Robust analysis of the joint strike fighter integrated training center pilot scheduling

Davidson, Pornchai

Monterey, California. Naval Postgraduate School

https://hdl.handle.net/10945/5610

This publication is a work of the U.S. Government as defined in Title 17, United States Code, Section 101. Copyright protection is not available for this work in the United States.

Downloaded from NPS Archive: Calhoun

Calhoun is the Naval Postgraduate School's public access digital repository for research materials and institutional publications created by the NPS community. Calhoun is named for Professor of Mathematics Guy K. Calhoun, NPS's first appointed -- and published -- scholarly author.

Dudley Knox Library / Naval Postgraduate School
411 Dyer Road / 1 University Circle
Monterey, California USA 93943

http://www.nps.edu/library

NAVAL POSTGRADUATE SCHOOL

MONTEREY, CALIFORNIA

THESIS

ROBUST ANALYSIS OF THE JOINT STRIKE FIGHTER INTEGRATED TRAINING CENTER PILOT SCHEDULING

by

Pornchai Davidson

September 2011

Thesis Advisor:	Thomas W. Lucas
Second Reader:	Chad Seagren

Approved for public release; distribution is unlimited

THIS PAGE INTENTIONALLY LEFT BLANK

REPORT DOCUMENTATION PAGE	*Form Approved OMB No. 0704-0188*

Public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instruction, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302, and to the Office of Management and Budget, Paperwork Reduction Project (0704-0188) Washington DC 20503.

1. AGENCY USE ONLY *(Leave blank)*	**2. REPORT DATE** September 2011	**3. REPORT TYPE AND DATES COVERED** Master's Thesis

4. TITLE AND SUBTITLE Robust Analysis of the Joint Strike Fighter Integrated Training Center Pilot Scheduling	**5. FUNDING NUMBERS**
6. AUTHOR(S) Pornchai Davidson	
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) Naval Postgraduate School Monterey, CA 93943-5000	**8. PERFORMING ORGANIZATION REPORT NUMBER**
9. SPONSORING /MONITORING AGENCY NAME(S) AND ADDRESS(ES) N/A	**10. SPONSORING/MONITORING AGENCY REPORT NUMBER**

11. SUPPLEMENTARY NOTES The views expressed in this thesis are those of the author and do not reflect the official policy or position of the Department of Defense or the U.S. Government. IRB Protocol number N/A________________.

12a. DISTRIBUTION / AVAILABILITY STATEMENT Approved for public release; distribution is unlimited	**12b. DISTRIBUTION CODE** A

13. ABSTRACT (maximum 200 words)

This thesis focuses on analyzing factors that affect a student's time to train (TTT) as he/she completes the Joint Strike Fighters (JSF) pilot training syllabus at the Integrated Training Center (ITC) on Eglin Air Force Base. It identifies the most robust course of action (COA), provides accurate TTT estimates, and identifies a watch list of factors that have the most effect on TTT. The results of this thesis provide a basis and a justification for procurement and resource decisions for the JSF. They also provide a means to ensure a proper flow of pilots to operational commands, reduce unnecessary flights, and enable the ITC to complete its mission while remaining within monthly flight time and airframe limits. It can also help predict the impact of future resource decisions, and assist commanders in mitigating their operational effect.

The primary recommendation for reducing TTT is to have students work 11 hours per day and have the workday start at or after 0900. Increasing the number of full motion simulator (FMS), while reducing TTT, is not justified. Although a limited resource, airspace is not a potential bottleneck in the system and any change, short of elimination, has very little influence on TTT. Flight refly rates and aircraft failure rates above 12% and 13% respectively significantly increase TTT and must be carefully monitored.

14. SUBJECT TERMS Joint Strike Fighter, Integrated Training Center , Robust Analysis, Nearly Orthogonal Latin Hypercube, Design of Experiments, Simulation, Pilot Scheduling			**15. NUMBER OF PAGES** 71
			16. PRICE CODE
17. SECURITY CLASSIFICATION OF REPORT Unclassified	**18. SECURITY CLASSIFICATION OF THIS PAGE** Unclassified	**19. SECURITY CLASSIFICATION OF ABSTRACT** Unclassified	**20. LIMITATION OF ABSTRACT** UU

NSN 7540-01-280-5500

Standard Form 298 (Rev. 2-89)
Prescribed by ANSI Std. 239-18

THIS PAGE INTENTIONALLY LEFT BLANK

Approved for public release; distribution is unlimited

ROBUST ANALYSIS OF THE JOINT STRIKE FIGHTER INTEGRATED TRAINING CENTER PILOT SCHEDULING

Pornchai Davidson
Lieutenant Commander, United States Navy
B.S., University of North Carolina at Chapel Hill, 1996

Submitted in partial fulfillment of the
requirements for the degree of

MASTER OF SCIENCE IN OPERATIONS RESEARCH

from the

NAVAL POSTGRADUATE SCHOOL
September 2011

Author:	Pornchai Davidson
Approved by:	Thomas W. Lucas Thesis Advisor
	Chad Seagren Second Reader
	Robert F. Dell Chairman, Department of Operation Research

THIS PAGE INTENTIONALLY LEFT BLANK

ABSTRACT

This thesis focuses on analyzing factors that affect a student's time to train (TTT) as he/she completes the Joint Strike Fighters (JSF) pilot training syllabus at the Integrated Training Center (ITC) on Eglin Air Force Base. It identifies the most robust course of action (COA), provides accurate TTT estimates, and identifies a watch list of factors that have the most effect on TTT. The results of this thesis provide a basis and a justification for procurement and resource decisions for the JSF. They also provide a means to ensure a proper flow of pilots to operational commands, reduce unnecessary flights, and enable the ITC to complete its mission while remaining within monthly flight time and airframe limits. It can also help predict the impact of future resource decisions, and assist commanders in mitigating their operational effect.

The primary recommendation for reducing TTT is to have students work 11 hours per day and have the workday start at or after 0900. Increasing the number of full motion simulator (FMS), while reducing TTT, is not justified. Although a limited resource, airspace is not a potential bottleneck in the system and any change, short of elimination, has very little influence on TTT. Flight refly rates and aircraft failure rates above 12% and 13% respectively significantly increase TTT and must be carefully monitored.

THIS PAGE INTENTIONALLY LEFT BLANK

TABLE OF CONTENTS

I. INTRODUCTION 1
- **A. BACKGROUND 1**
- **B. PURPOSE 3**
  - **1. Literature Review 4**

II. DATA AND METHODOLOGY 7
- **A. METHODOLOGY 7**
- **B. MODEL INPUT AND OUTPUT 9**
  - **1. Resources 9**
  - **2. Inputs 10**
  - **3. Input Text Files 11**
    - ***a. Student Induction File 11***
    - ***b. Aircraft Induction File 12***
    - ***c. Instructor Pilot Induction File 12***
    - ***d. FMS Induction File 13***
  - **4. Outputs 13**
- **C. GROUND RULES AND ASSUMPTIONS 14**

III. DESIGN OF EXPERIMENTS 19
- **A. WHY DESIGN EXPERIMENTS? 19**
  - **1. Robustness 20**
  - **2. Factors and Levels 21**
- **B. AIRCRAFT UPGRADE AND MODIFICATION DESIGN MATRIX 21**
- **C. AIRSPACE EFFECTS ON TTT 26**
- **D. SYLLABUS VARIABLES 27**

IV. ANALYSIS 31
- **A. AIRCRAFT UPGRADE EFFECTS ON TTT 31**
  - **1. Partition Tree of Upgrade Data 33**
- **B. AIRSPACE AND TTT 34**
- **C. SYLLABUS VARIABLES AND TTT 37**
  - **1. Partition Tree 37**

V. RECOMMENDATIONS 43
- **A. BEST COURSE OF ACTION 43**
- **B. FURTHER STUDY 45**

LIST OF REFERENCES 47

INITIAL DISTRIBUTION LIST 50

THIS PAGE INTENTIONALLY LEFT BLANK

LIST OF FIGURES

Figure 1. Integrated Training Center Overview Diagram (From: Born, 2007)............ xvi
Figure 2. Full Mission Simulator (FMS) Event Flow (From: (Gray, 2010) 8
Figure 3. Integrated Training Center Graphical User Interface Page One......................10
Figure 4. Integrated Training Center Overview Diagram (From: Born, 2007).............14
Figure 5. Upgrade Design Multivariate Plot of Noise Factors..25
Figure 6. Airspace Design Multivariate Plot...27
Figure 7. Upgrade Experiment Histogram of Days to Train...32
Figure 8. Partition of Upgrade Data Including Signal and Noise Factors.......................33
Figure 9. Airspace versus Time to Train Experiment 1 35
Figure 10. Airspace Regression Statistics 36
Figure 11. Airspace Regression Reduced Levels Statistics 36
Figure 12. Partition Tree of Syllabus Data...37
Figure 13. Partition Tree for Two Students per Class...38
Figure 14. Partition Tree for Six Students per Class...39
Figure 15. Partition Tree for 10 Students per Class 40

THIS PAGE INTENTIONALLY LEFT BLANK

LIST OF TABLES

Table 1. Student Induction File..12
Table 2. Noise Factors Default Levels...21
Table 3. Upgrade Design Signal Factors 23
Table 4. Upgrade Design Schedule Induction File 23
Table 5. Upgrade Noise Factors Nearly Orthogonal Latin Hypercube..........................24
Table 6. Airspace Experiment Input Variables..26
Table 7. Syllabus Signal Factors..27
Table 8. Full-Factorial Design 29
Table 9. Analysis of Variance of Mean Time to Train of Upgrade Scenario................32

THIS PAGE INTENTIONALLY LEFT BLANK

LIST OF ACRONYMS AND ABBREVIATIONS

AC	Aircraft
AFI	Air Force Instruction
ASTOVL	Advance Short Take-off and Vertical Landing
COA	Course of Action
CQ	Carrier Qualification
CTOL	Conventional Take-off and Landing
FH/MO	Flight Hours per Month
FMS	Full Mission Simulator
GUI	Graphical User Interface
hrs	Hours
IP	Instructor Pilot (Military)
ITC	Integrated Training Center
JAST	Joint Advance Strike Technology
JSF	Joint Strike Fighter
ModSimIII	Modeling and Simulation III
MPS	Mission Planning Station
MOA	Military Operating Area
MRT	Mission Readiness Trainer
NOLH	Nearly Orthogonal Latin Hypercube
RMSE	Root Mean Square Error
STOVL	Short Take-off and Vertical Landing
SEED	Simulation Experiments and Efficient Designs
SD	Standard Deviation
SSE	Error Sum of Squares
TTT	Time to Train
USAF	United States Air Force
VMFAT-501	Marine Fighter Attack Training Squadron

EXECUTIVE SUMMARY

The United States' current inventory of fighter/attack aircraft is up against airframe time limits in the not too distant future. The United States Navy estimates a peak shortfall of 100 to 200 aircraft by 2018 (O'Rourke, 2009). A new, low-cost, highly capable, and advanced replacement needs to be produced.

In the early 90s, the Joint Advance Strike Technology Program (JAST) was created to bring together and mature the required technologies to create a new strike fighter capable of meeting the requirements of the Navy, Marines, and Air Force (Bolkcom, 2007). In 1994, Congress mandated that the JAST program be merged with the Advance Short Takeoff Vertical Landing program and the Joint Strike Fighter (JSF) was born.

Eventually, two manufacturers were selected to compete for the JSF contract. Boeing and Lockheed Martin began a 4-year-long concept and demonstration phase that included producing a flying prototype. The competition ended in October 2001, when Lockheed Martin won the competition with its X-35 prototype. The JSF is now known as the F-35.

The F-35 is produced in three variants. The F-35A is used by the Air Force and is a conventional takeoff and landing (CTOL) aircraft. It is a replacement for the F-16 and A-10, and will complement the F-22 for the Air Force's high-low mix (Gertler, 2010). The F-35B is used by the Marines and is short-takeoff-and-vertical-landing capable; a requirement for use on amphibious ships. It will replace the AV-8 Harriers and older generation F-18s for the Marine Corps (Gertler, 2010). The F-35C is used by the Navy; it has foldable wings and is aircraft-carrier-launch-and-recovery capable. The three variants have a 70% to 90% commonality in parts (Gertler, 2010). This is an inherent design philosophy to reduce manufacturing cost and serviceability, and made the project truly joint.

Unlike the F-22 Raptor, the F-35 is designed not just to be joint, but also multinational. To date, at least eight other countries, ranging from Australia to Turkey,

are expected to be partners in the production and procurement process (Bolkcom, 2007). One thing all the nations will have in common is that their pilots and maintainers will all initially be trained in the United States. The Integrated Training Center (ITC) is the multiservice, multinational schoolhouse for training personnel to pilot and maintain the F-35. The first ITC is located on Eglin Air Force Base in the Florida Panhandle. More training centers will be built as additional squadrons come on line and more aircraft enter service. The ITC has all the resources necessary to train U.S. and allied partners in flying and maintaining the F-35. It consists of an academic and operational side. The classrooms, simulators, and computer-based trainers are located on the academic side of the ITC, while the aircraft, brief rooms, and maintenance facilities are located on the squadron side of the ITC. The Navy, Marine Corps, and Air Force have separate squadrons and instructor pilots, but share all the resources that make up the ITC.

In order to procure the correct number of resources (simulators, classrooms, instructors, etc.) for the ITC, Lockheed Martin built a model to simulate the flow of students through the training syllabus. By adjusting parameter levels, along with a set of ground rules and assumptions, student throughput can be studied to see their effects on metrics such as time-to-train (TTT) and resource utilizations rates. These results are analyzed and used to justify the number and type of each resource needed to satisfy the metrics and meet any requirements as specified by the end user. The goal of the ITC is to provide fully trained pilots and maintainers to meet the security needs of the future, as stated in the Joint Contract Specification document for the JSF: "The JSF Air System shall provide throughput training capacity to meet both peacetime and wartime service requirements for pilots and maintainers" (Born, 2007, p. 8).

The ITC model simulates day-to-day ground and flight operations at the ITC. The model starts collecting data when students and resources, such as aircraft and flight simulators, are inducted into the system and ends when the last student graduates. Each student has a syllabus that lists all classes, meetings, and required activities that need to be finished before that student can graduate. Upon graduation of the last student, the ITC model produces detailed reports of each student's experience. The time they start and finish each event is recorded, as well and any delay and reason for delay of any syllabus event. Resource utilization rates are recorded and used as justification for procurement or as an explanation for bottlenecks in the system.

The ITC model is designed to run in either “steady state” or “ramp up” mode. The ramp up mode is useful in predicting the impacts of different resource schedules. The resources that can be varied in the ramp-up mode are the number of full motion simulators (FMSs), training aircraft, and instructor pilots. These inputs are provided to the model in the form of a text file containing a column for the week and a column for the change in number of that resource. This is the mode that most accurately describes the ITC as it is stood up and is the one that is studied in this thesis. Figure 1 summarizes the process up to the analysis.

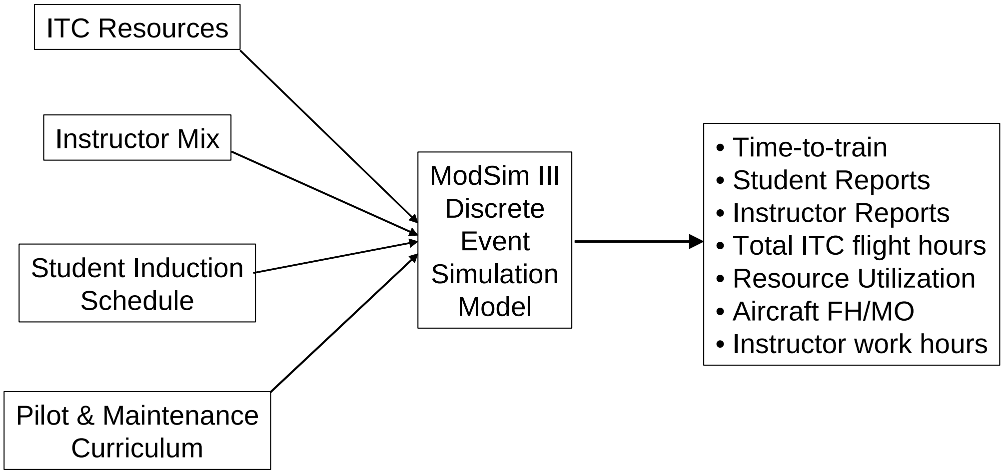


Figure 1. Integrated Training Center Overview Diagram (From: Born, 2007)

The objective of this thesis is to provide the Marine Corps with a consolidated plan that maximizes their resources and produces pilots for the JSF as quickly as the existing constraints will allow. With JSF production delays and the imminent loss of legacy aircraft, the Marines will soon be facing a fighter gap (O’Rourke, 2009). To keep readiness high, the Marine Corps must be able to depend on its organic air-to-air and air-to-ground capability in an increasingly complex threat environment. This all hinges on the deployment of operational squadrons in a timely manner, and the efficient and correct usage of resources at the ITC.

This thesis explains and demonstrates a method to develop a best COA, identifying the resources having the most effect on reducing TTT. It also identifies the resources, and the limits or levels of these resources, which have the most effect on TTT. The impact of aircraft upgrades, the availability of training airspace, and changes to the students' induction schedule and their effects on TTT are analyzed.

The primary motivation for this research is to help the Marine Fighter Attack Training Squadron (VMFAT-501) to effectively and efficiently train the next generation of pilots and maintainers. Communication with the squadron was essential and ongoing throughout the research, particularly in the design of each experiment. Their input narrowed the focus of the research and helped identify the most important aspects of the problem for further investigation. They were also important in validating the results from the perspective of the final customer.

The overall recommendation for reducing TTT is to have students work 11 hours per day and have the workday start at or after 0900. Increasing the number of FMS to five or six, while reducing TTT, is not justified. Likewise, increasing the hours the ITC remains open has no effect on reducing TTT and should be ignored. The current plan of having four aircraft reserved for training events, while the excess undergo upgrades, is the best and most robust COA to ensure a minimum TTT. The availability of airspace for training, short of eliminating this resource, did not present a bottleneck to training and did not change TTT.

The results produced by the ITC are inherently optimistic due to known deficiencies in how the model treats weather, maintenance, other stochastic elements, and in the strict scheduling of student events (Dummar, 2011). The ITC model uses means rather than distribution for its random variables, this also gives optimistic results. As a consequence, any reductions in TTT gained for choosing the COAs recommended in this thesis are also optimistic. These findings do provide a relationship between TTT and the controllable and uncontrollable factors. It is up to the commander and training officers to monitor these factors and use the COAs to help mitigate their effects.

ACKNOWLEDGMENTS

I would like to thank my wife and son, Barbara and Ethan, for their understanding and support during the last two years. I would like to also thank Professor Lucas, Steve Upton, Major Seagren, Major Lieberman, and Mary McDonald. Without their help, this would not be possible.

THIS PAGE INTENTIONALLY LEFT BLANK

I. INTRODUCTION

A. BACKGROUND

The United States' current inventory of fighter/attack aircraft will be up against airframe time limits in the not too distant future. The United States Navy estimates a peak shortfall of 100 to 200 aircraft by 2018 (O'Rourke, 2009). A new, low-cost, highly capable, and advanced replacement needs to be produced. The research into the replacement of the current inventory of aging third and fourth generation aircraft has been ongoing through the 1980s and 1990s, with no airframe making it to the production line. The early stages of the search for a new aircraft had the Navy, Marines, and Air Force seeking their own replacement, with different aircraft tailored to specific needs. In the early 90s, the Joint Advance Strike Technology Program (JAST) was created to bring together and mature the required technologies to create a new strike fighter capable of meeting the requirements of the Navy, Marines, and Air Force (Bolkcom, 2007). In 1994, Congress mandated that the JAST program be merged with the Advanced Short Takeoff Vertical Landing (ASTOVL) program and the JSF was born. ASTOVL was a project begun in 1983 by the Defense Advanced Research Agency to replace the aging AV-8 Harrier. It was designed to be a multiservice replacement aircraft and fit well into the framework of the JAST program.

Eventually, two manufacturers were selected to compete for the JSF contract. Boeing and Lockheed Martin began a 4-year-long concept and demonstration phase that included producing a flying prototype. The competition ended in October 2001, when Lockheed Martin won the competition with its X-35 prototype. The JSF is now known as the F-35.

The F-35 will be produced in three variants. The Air Force variant, the F-35A, is a conventional takeoff and landing (CTOL) aircraft. It is a replacement for the F-16 and A-10, and will complement the F-22 for the Air Force's high-low mix (Gertler, 2010). The Marine variant, the F-35B, is short-takeoff-and-vertical-landing capable; a requirement for use on amphibious ships. It is the most radical design of the three variants and, thus far, the most prone to setback (Majumdar, 2011). It will replace the AV-8 Harriers and older generation F-18s for the Marine Corps (Gertler, 2010). The Navy variant is the F-35C, which has foldable wings and is aircraft-carrier-launch-and-recovery capable. It is physically much larger than the two previous versions, due mainly to the requirement for airframe reinforcements because of the additional stress of catapult launches and arrested landing. It also has a larger wing area, due to the low speed approach profile required for a carrier-arrested recovery. The three variants have a 70% to 90% commonality in parts (Gertler, 2010). This is an inherent design philosophy to reduce manufacturing costs and serviceability, and made the project truly joint.

Unlike the F-22 Raptor, the F-35 is designed not just to be joint, but also multinational. To date, at least eight other countries, ranging from Australia to Turkey, are expected to be partners in the production and procurement process (Bolkcom, 2007). One thing all the nations will have in common is that their pilots and maintainers will all initially be trained in the United States. The Integrated Training Center (ITC) is the multiservice, multinational schoolhouse for training personnel to pilot and maintain the F-35. The first ITC is located on Eglin Air Force Base in the Florida Panhandle. More training centers will be built as additional squadrons come on line and more aircraft enter service. The ITC has all the resources necessary to train U.S. and allied partners in flying and maintaining the F-35. It consists of an academic and operational side. The classrooms, simulators, and computer-based trainers are located on the academic side of the ITC, while the aircraft, brief rooms, and maintenance facilities are located on the squadron side of the ITC. There will be three squadrons, one for each variant of the JSF. The Navy, Marine Corps, and Air Force have separate squadrons and instructor pilots, but share all the resources that make up the ITC.

In order to procure the correct number of resources (simulators, classrooms, instructors, etc.) for the ITC, Lockheed Martin built a model to simulate the flow of students through the training syllabus. By adjusting parameter levels, along with a set of ground rules and assumptions, student throughput can be studied to see their effects on metrics such as time-to-train (TTT) and resource utilizations rates. These results are analyzed and used to justify the number and type of each resource needed to satisfy the metrics and meet any requirements as specified by the end user. The goal of the ITC is to provide fully trained pilots and maintainers to meet the security needs of the future, as stated in the Joint Contract Specification document for the JSF: "The JSF Air System shall provide throughput training capacity to meet both peacetime and wartime service requirements for pilots and maintainers" (Born, 2007, p. 8).

B. PURPOSE

The objective of this thesis is to provide the Marine Corps with a consolidated method that maximizes their resources and produces pilots for the JSF as quickly as the existing constraints will allow. With JSF production delays and the imminent loss of legacy aircraft, the Marines will soon be facing a fighter gap (O'Rourke, 2009). To keep readiness high, the Marine Corps must be able to depend on its organic air-to-air and air-to-ground capability in an increasingly complex threat environment. This all hinges on the deployment of operational squadrons in a timely manner, and the efficient and correct usage of resources at the ITC. To address these issues, this thesis explains and demonstrates a method to:

- Develop a best Course of Action (COA), identifying the resources having the most effect on reducing TTT.
- Identify key resources, and the limits or levels of these resources that have the most effect on TTT.
- Examine airspace issues in the model. Current analysis has no limits on the airspace available. Airspace used for training can, and often needs to be, scheduled in advance. Some airspace is affected by prevailing weather conditions and may not be available for all training flights equally. A constraint on the availability of this resource will increase TTT.
- Analyze the impact of aircraft upgrades on the overall student TTT.

The primary motivation for this research is to help Marine Fighter Attack Training Squadron 501 (VMFAT-501) to effectively and efficiently train the next generation of pilots and maintainers. Communication with the squadron was essential and ongoing throughout the research, particularly in the design of each experiment. Their input narrowed the focus of the research and helped identify the most important aspects of the problem for further investigation. They were also important in validating the results from the perspective of the final customer.

1. Literature Review

There is almost no documentation for the ITC model itself. The model is proprietary software developed for Lockheed Martin and not meant for public use. The source code is unavailable and any change to the model must be made through the Joint Program Office and is dependent on funding availability. Of note, the model has been through the verification, validation, and accreditation process. It has been tested on several cases using the F-16, F-18, AV-8B, and GR-7 aircraft and their syllabuses. Two prior analyses of the ITC simulation exist. The latest was completed by Joe Dummar for his 2011 master's thesis, and the other by Marry McDonald, a Research Associate at the Naval Postgraduate School, in 2010.

Dummar's thesis shows that the weather model used by the ITC is wrong and gives inherently optimistic results. The ITC uses weather for all aircraft events. Weather is either good or bad, with a certain probability depending on the month. Each aircraft event has an independent roll of the dice to determine if weather is good and the flight can be completed. Dummar suggests changing the weather modeling in the ITC simulation to one that models weather using Markov chains and a weather resource, since weather conditions for consecutive events are not independent (Dummar, 2011). He finds that the improved approach significantly affects estimates of TTT.

McDonald's analysis shows the performance of the ITC model has very high variability between replication (McDonald, 2010). The longest delay for scheduled events resulted from "student match" and "night flight." Student match means a student had to wait for another student in order to complete an event requiring a minimum of two students. This is why all classes in the ITC are started in multiples of two students, so they can progress through the syllabus together. They stay synched together throughout their experience and, if one falls behind, the other student ends up waiting longer at an event queue requiring two or more pilots. This is a simulation limitation that can lead to longer training times for that class, but is an issue that can easily be resolved at the squadron level. Night flight delay means a student has run out of time to complete the night event before the ITC closes and it gets rescheduled for the next day. This is another simulation limitation that may lengthen training duration, which the squadron can easily manage.

THIS PAGE INTENTIONALLY LEFT BLANK

II. DATA AND METHODOLOGY

This chapter describes the ITC model's behavior, i.e., the inputs, outputs, and ground rules, and assumptions required to initiate a run. Descriptions of the student and resource induction files are also covered.

A. METHODOLOGY

The ITC model simulates day-to-day ground and flight operations at the ITC. The model starts collecting data when students and resources, such as aircraft and flight simulators are inducted into the system and ends when the last student graduates. Each student has a syllabus that lists all classes, meetings, and required activities that need to be finished before that student can graduate. It also lists the order in which they are taken. The model strictly enforces this order, with no exceptions. This aspect of the simulation is a departure from how training is actually completed at a squadron. This limitation is acknowledged by Lockheed Martin, who claims the problem is "not a critical one and may only tend to make the ITC throughput estimates conservative" (Born, 2007, p. 11). Upon graduation of the last student, the ITC model produces detailed reports of each student's experience. The time they start and finish each event is recorded, as well and any delay and reason for delay of any syllabus event. Resource utilization rates are recorded and used as justification for procurement or as an explanation for bottlenecks in the system.

The ITC model is a discrete-event, first-in first-out, queuing-based simulation. It is implemented in ModSim III version 2.1 (Kenney, 2009). Currently, all random behavior in the model is based on a uniform zero to one distribution. Each event in a syllabus depends on wait queues that holds students, instructors, and resources needed to complete the event. Figure 2 shows this process in more detail.

Prior to a flight or simulator event, the students must prepare for the event at the mission planning station (MPS). This takes a fixed period of time, which is entered via the user at the start of the simulation in the graphical user interface (GUI). Once planning starts, that student and MPS are made unavailable until completion of the planning, after which the MPS is returned to the MPS queue awaiting another user. The student then waits for an instructor to become available. Once that happens, the instructor is taken from his queue. The student briefs the event to the instructor for the time specified in the GUI; then both wait for a simulator to become available. Once a simulator is available, the mission is flown for a duration dependent on the student's syllabus. The instructor and student are not released from the event until after a debrief, which, again, takes a fixed period of time and is defined in the GUI. At that point, the instructor is returned to his queue and the student will move to his next event in the syllabus with a probability of success defined in the GUI. This same sequence occurs for each simulator, aircraft, and mission trainer, or any computer-based training requirement.

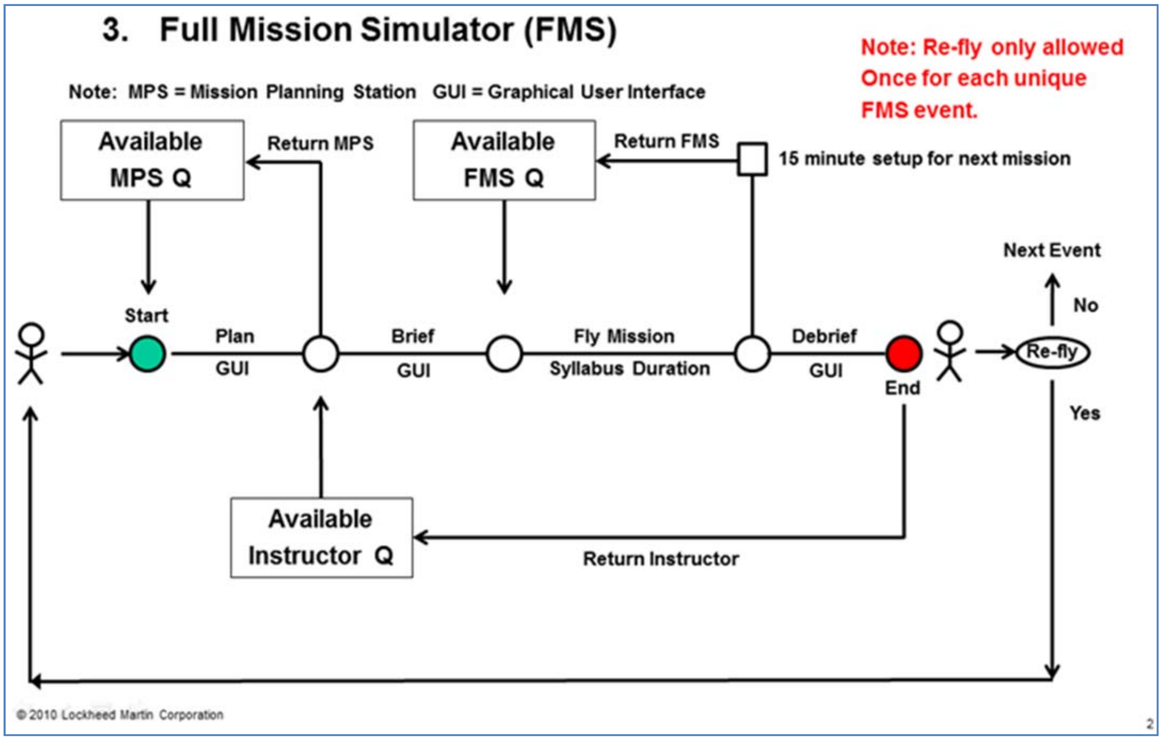


Figure 2. Full Mission Simulator (FMS) Event Flow (From: (Gray, 2010)

The ITC model is designed to run in either "steady state" or "ramp up" mode. The steady state mode is used once all the resources have arrived at the ITC and their numbers will remain relatively constant for the duration of the simulation's time horizon. This mode is useful in predicting the impacts of maintenance stand-downs, long-term runway closures, or any resource constraint that affects an already operational training squadron. The ramp up mode is useful in predicting the impacts of different resource arrival schedules. Depending on when the first students begin to arrive for training, not all the resources approved may be ready for use at the ITC. The resources that can be varied in the ramp up mode are the number of FMSs, training aircraft, and instructor pilots. These inputs are provided to the model in the form of a text file containing a column for the week and a column for the change in number of that resource. This is the mode that most accurately describes the ITC as it is stood up and is the one that is studied in this thesis.

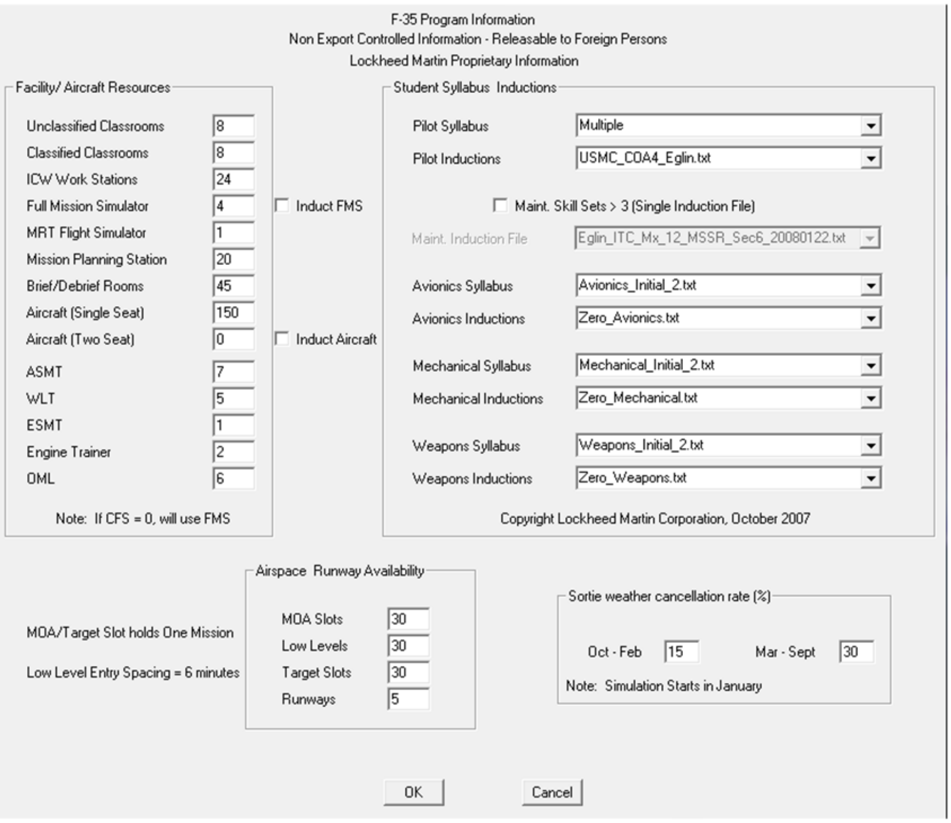
B. MODEL INPUT AND OUTPUT

1. Resources

The following is a list of resources accounted for in the ITC model (Kenney, 2009, p. 7):

- Training Devices
- Classrooms
- Self-paced Computer Based Training Work Stations
- Mission Brief/De-brief Rooms for completion of flight events brief/debrief
- Military Instructor Pilots (IPs)
- Military Maintainer Instructors
- Contract academic instructor pilots
- Training Aircraft
- Runways and training airspace (military operating areas, low level routes, scored target ranges).

Figure 3 shows an example of the GUI. On this page, changes can be made to the ITC facility resources, the air space resource, and the weather cancelation rates. The user can also specify the location of the pilot syllabus file and indicate whether to induct aircraft and FMSs, or use the steady state number shown on the GUI.



F-35 Program Information
Non Export Controlled Information - Releasable to Foreign Persons
Lockheed Martin Proprietary Information

Facility/ Aircraft Resources

Unclassified Classrooms	8
Classified Classrooms	8
ICW Work Stations	24
Full Mission Simulator	4
MRT Flight Simulator	1
Mission Planning Station	20
Brief/Debrief Rooms	45
Aircraft (Single Seat)	150
Aircraft (Two Seat)	0
ASMT	7
WLT	5
ESMT	1
Engine Trainer	2
OML	6

☐ Induct FMS

☐ Induct Aircraft

Note: If CFS = 0, will use FMS

Student Syllabus Inductions

Pilot Syllabus	Multiple
Pilot Inductions	USMC_COA4_Eglin.txt

☐ Maint. Skill Sets > 3 (Single Induction File)

Maint. Induction File	Eglin_ITC_Mx_12_MSSR_Sec6_20080122.txt
Avionics Syllabus	Avionics_Initial_2.txt
Avionics Inductions	Zero_Avionics.txt
Mechanical Syllabus	Mechanical_Initial_2.txt
Mechanical Inductions	Zero_Mechanical.txt
Weapons Syllabus	Weapons_Initial_2.txt
Weapons Inductions	Zero_Weapons.txt

Copyright Lockheed Martin Corporation, October 2007

MOA/Target Slot holds One Mission

Low Level Entry Spacing = 6 minutes

Airspace Runway Availability

MOA Slots	30
Low Levels	30
Target Slots	30
Runways	5

Sortie weather cancellation rate (%)

Oct - Feb	15
Mar - Sept	30

Note: Simulation Starts in January

Figure 3. Integrated Training Center Graphical User Interface Page One

2. Inputs

This is the collection of controlled and uncontrolled variables or factors to be adjusted in the design of experiments. The user can make inputs via a GUI or input text file (Kenney, 2009, p. 8).

- Student Induction Schedule (text file).
- Course Curriculum/Syllabus (text file).
- Training Equipment and Aircraft Resources (GUI).
- Instructor Resources (GUI).
- Airspace and Runway Resources (GUI).
- Weather Cancellation Rates (GUI).
- Full Mission Simulator Planning, Brief, Debrief duration (GUI).
- Probability of Aircraft Maintenance (GUI).
- Aircraft Repair Time (GUI).

- Aircraft Preparation Time for the Next Flight (GUI).
- Simulator Training Event Re-fly Rates (GUI).
- Aircraft Training Event Re-fly Rates (GUI).
- ITC Training Duration Days/Year (GUI).
- ITC Training Duration Hours/Day (GUI).

Within the input text file there are more parameters that can be varied. From the student induction file the number of students per class, student work day, and student start time can be changed. This is an exhaustive list of all factors the user can adjust. Not all of these factors are changed in every experiment.

3. Input Text Files

All of the experiments will use essentially the same induction file. Any modification of the default induction file for a particular experiment is explained in Chapter III, Design of Experiments.

a. Student Induction File

The student induction file tells the simulation what week a new class starts, how many students are in each class, what syllabus each class is assigned, the time their workday starts, and how long their workday is. The default induction file has 60 classes, with two students starting in each class. The first students start in week 83 and the last students start in week 230, a period of almost three years. The students all have a 0700 start time and a 9-hour workday. Each class is assigned one of 14 different syllabuses. Multiple classes can be inducted on the same week. Table 1 is an example of the default student induction schedule for the first 18 classes. The actual schedule is a text file and does not contain any of the header information.

Table 1. Student Induction File

Week	Schedule	Students	Start Hour	Length Day
83	DCMA_Initial_Cadre.txt	10	700	9
87	B1.0_TX_ALL_B_Eglin.txt	10	700	9
93	DCMA_Initial_Cadre.txt	10	700	9
93	TX3_B1.0.txt	10	700	9
93	TX4_B1.0.txt	10	700	9
98	B1.0_TX3_A_Eglin.txt	10	700	9
98	B1.0_TX4_A_Eglin.txt	10	700	9
104	TX3_B1.0.txt	10	700	9
108	B1.0_TX_ALL_B_Eglin.txt	10	700	9
111	TX4_B1.0.txt	10	700	9
111	TX4_B1.0.txt	10	700	9
111	TX3_B1.0.txt	10	700	9
117	B1.0_TX_ALL_B_Eglin.txt	10	700	9
120	TX3_B1.0.txt	10	700	9
123	TX3_B1.0.txt	10	700	9
123	TX4_B1.0.txt	10	700	9
129	TX4_B1.0.txt	10	700	9

b. Aircraft Induction File

This file tells the simulation at what week to change the aircraft inventory. Aircraft are added or removed from the inventory at the beginning of the week. There can never be a negative inventory and there is no maximum. The first aircraft are expected to arrive in week 83, which corresponds to October 2011, and the last aircraft is to arrive in September 2012. After September 2012, or approximately week 127 of the ITC calendar, there will be a total of 12 aircraft at the ITC. This schedule is based on VMFAT-501's fiscal year 2012 flight hour plan and is subject to change. For simulation purposes, the exact dates are not required as long as each experiment uses the same induction file.

c. Instructor Pilot Induction File

Instructor pilots are inducted at a slightly faster rate than the aircraft. Some of the instructors are removed to fill instructor roles at other squadrons. The end goal is to have the same number of instructors as training aircraft (Kenney, 2009). The induction file contains the week an instructor is added or removed from the ITC. Any changes take place at the beginning of the week. The inventory cannot go negative and there is no limit as to how many instructors are in the ITC. Unlike other resources, having too many instructors can affect the TTT. All winged aviators, including IPs, are required to maintain a minimum number of annual flight hours for proficiency (Operations, 2009). Individual squadrons or wings may further restrict the requirements to monthly minimums. Having too many instructors could lead to a loss of flight hours available for the students and increase their TTT. This is because there are limits to cumulative flight hours per month and flight hours per aircraft. These limits are not modeled in the ITC model. However, the ITC model records the levels used.

d. FMS Induction File

Flight simulators are an essential part of the ITC and are introduced in a similar fashion as the aircraft. As of spring 2011, VMFAT-501 is expecting four FMSs (A. C. Liberman, personal communication, April 18, 2011). The default FMS file has four FMSs arriving according to a schedule provided by VMFAT-501's training officer.

4. Outputs

After each run of the simulation, when the last student graduates, the following items are output by the model (Kenney, 2009, p. 8):

- Student Time-to-Train.
- Number of Students in training as a function of time (i.e., student on-board count).
- Resource Utilization Hours (classrooms, training devices, instructors, aircraft, ranges).
- Training Equipment Utilization Rates as a percentage of the training day for each month of the simulation run (this is also shown for each day of the simulation run for the FMS).
- Aircraft Flight Hours/month.
- Aircraft takeoff and landing times, including any delays experienced for the runway, airspace, and target ranges.
- The training day and number of instances on that day that a classroom was not available when required.

- Instructor training hours per week.

The output from all runs are merged to get a distribution of outcomes, which are analyzed to find important trends and decisions that minimize the student's TTT or maximize a training resource. Figure 4 summarizes the process up to the analysis:

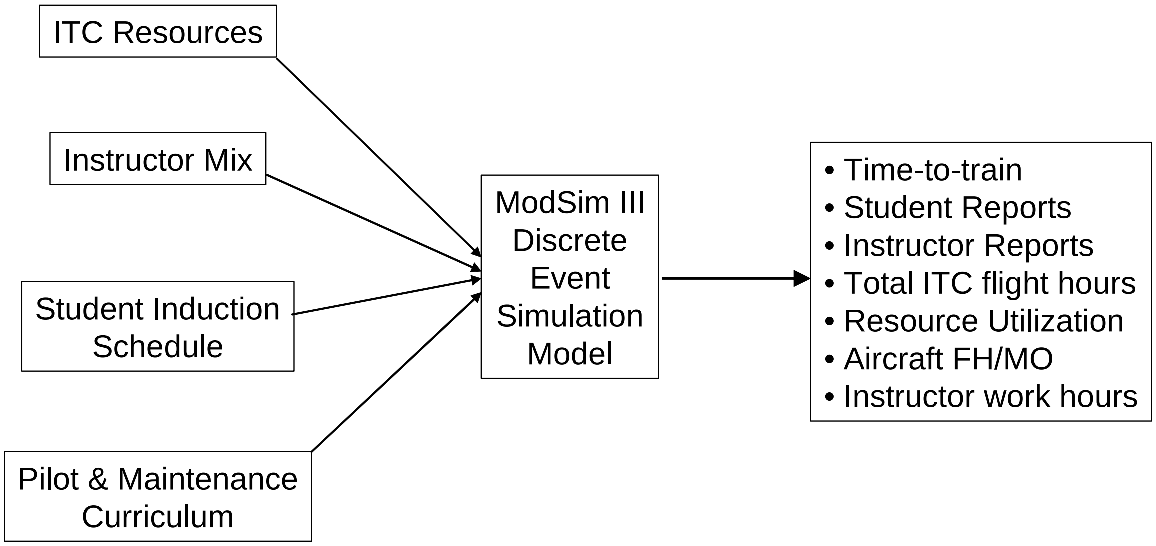


Figure 4. Integrated Training Center Overview Diagram (From: Born, 2007)

C. GROUND RULES AND ASSUMPTIONS

A basic understanding of the ground rules and assumption is important in understanding how the model attempts to imitate reality and where it can break down. It also helps in the design of experiments and how to interpret the results of the model. The following assumptions are verbatim from the "model accreditation support package" (Kenney, 2009, pp. 8-10).

- Normal operating hours for the Integrated Training Center are 0700-2300 Monday through Friday. Briefing rooms and equipment will be available to support a 0700 take off and commencement of simulator events at 0700. Simulation of a single shift operation can be accomplished by giving all students the same work day start time (i.e., 0800) with a work day length of 9 hours (workday ends at 1700).
- Students are inducted evenly throughout the year and commence training on Monday of their induction week. The induction files

can be adjusted to simulate a non-uniform flow of students into the ITC.

- More than one class may be inducted in the same week.
- The optimum pilot class size for JSF is six students. The current ITC classroom design for pilots can accommodate up to 12 students per class.
- Pilot and Maintainer classes are service unique.
- The first flight brief for the day occurs at 0445 for a 0700 takeoff.
- The first flight simulator brief of the day occurs at 0600 for a 0700 simulator event.
- The student workday is a 9.0 hour day (start to finish) and students are assigned a specific "start workday time." The intention of the 9.0 hour day is to give each student 8.0 hours per day when training can be accomplished and 1.0 hour per day for a meal break. Maintenance training for the U.S. Services is accomplished on two shifts.
- In no case will students and instructors be scheduled for a training event sooner than 12.0 hours following the completion of their last event from the previous day. As an example, a student and/or instructor who finishes a flight debrief at 2200 will not be scheduled for a training event before 1000 the next day.
- Maximum crew duty day for instructor pilots is 12.0 hours measured from the start of the first training event to engine shutdown. This ground rule is based on a USAF Instruction AFI 11-202 Volume 3 General Flight Rules, "For single seat aircraft or when only one pilot has access to the flight controls, the maximum flight duty period is 12 hours." The normal instructor work day is 9.0 hours.
- A Full Mission Simulator event and flight event will be permitted on the same day for the same student if they can both be accomplished within the students 9.0 hour work day.
- Flight simulator set up time is 15 minutes for each training event (after initial daily startup).
- Students will be permitted to fly more than one flight event on the same day. This only occurs for short flights such as Field Carrier Landing Practice events due to work day length restrictions.
- Student planning time for each flight event is 1.0 hour utilizing the Mission Planning Station.
- Brief time for training flights is 2.25 hours prior to takeoff.

- Flight debriefs end 3.0 hours after landing.
- Day flights land before 1900 and night flights takeoff after 1900.
- Airborne aggressor requirements are satisfied by Training Squadron JSF aircraft flown by Training Squadron instructor pilots.
- After landing, there is a 10% probability the aircraft will require repair. Time to repair is 3.0 hours followed by a 1.5 hour preparation time for the next flight event. These parameters are adjustable via the user interface.
- Aircraft turnaround time for the next flight event is 1.5 hours and is adjustable via the user interface.
- Cancellations for weather occur after student planning and prior to commencement of the flight brief. Weather cancellation rates are 5% and are adjustable via the user interface.
- Re-fly rates for flights and simulator events are 8% and 5% respectively and are adjustable via the user interface. The re-fly decision is made at the end of debrief.
- Navy Carrier Qualification (CQ) re-fly rate is 12.5%. Students who repeat CQ will re-fly all simulator and flight events associated with the CQ phase of training.
- Students will not re-fly the same flight or simulator event more than once.
- Student planning time for each Full Mission Simulator event is 30 minutes and is adjustable via the user interface. Student planning utilizes a Mission Planning Station.
- Full Mission Simulator brief time is 60 minutes and is adjustable via the user interface.
- Full Mission Simulator debrief time is 30 minutes and is adjustable via the user interface.
- The number of Military instructor pilots is equal to the number of training aircraft in accordance with direction received from the Services and the JSF Program Office. All airborne flight instruction is provided by Military instructor pilots.
- After completing a flight debrief, the instructor will not be scheduled for a subsequent flight brief for 1.0 hour.
- On each training day, there is a 2% probability that each instructor and student may be unavailable for a 2.0 hour time period. This is

intended to account for medical appointments and unexpected absences for both instructors and students.

- Minimum allowable spacing between flights on the same low-level route is 10 minutes.
- Landing aircraft have priority over departing aircraft for the runway.
- There are a total of 246 days per year that are available for [training]. This parameter is selectable via the user interface.
- Students will take a 15-minute break in between non-like training events (e.g. simulator to classroom, classroom to simulator, etc.). Breaks during successive classroom training events will be handled by the instructor.

The ITC model repeatedly uses a point estimate rather than a random draw from a distribution for its events. For some events, such as maintenance repair times, subject matter experts expect significant variability. Using point estimates in lieu of probability distributions, especially in high-utilization situations, will likely result in overestimating the system's throughput.

These model assumptions are used in conjunction with recommendations from VMFAT-501 to help design and analyze the experiment. Their contribution cannot be summarized in table form, but is an important part of how the simulations are designed and what factors need to be investigated. This helps reduce the complexity of the data and reduce the number of COAs to explore.

In Chapter III, these factors and assumptions are brought together to form an efficient design that can be used to get the most information from the model, while keeping within computational and time constraints. Emphasis is on what factors, at what levels, have the greatest effect on TTT and how VMFAT-501 can use that information to mitigate any unforeseen circumstances.

THIS PAGE INTENTIONALLY LEFT BLANK

III. DESIGN OF EXPERIMENTS

This chapter discusses how the experiments in this thesis are designed and the reason behind those designs. There are three separate experiments intended to answer the questions posed in Chapter I. The first experiment analyzes the effect of aircraft upgrades and modifications. The second experiment analyzes airspace and its effect on the ITC model. The last experiment analyzes syllabus variables—those factors that can be changed in the student induction files—and their effects on TTT. The noise factors, signal factors, and the levels of each in the three separate experiments are explained in detail.

The designs are run on a cluster of computers at the Naval Postgraduate School's Simulation Experiments and Efficient Designs (SEED) Center in Monterey, California. Each design point is repeated 50 times with different random number seed values. The outputs of each run are concatenated together to form output files representing all the runs and repetitions. This output is merged with the original design and analyzed using the JMP statistical package (Sall, Creighton, & Lehman, 2005).

A. WHY DESIGN EXPERIMENTS?

There are many different factors and levels of those factors in the ITC model to consider, and only a limited amount of computer resources and time to complete the study, thus an efficient design of experiments is crucial. With a proper design, all aspects of a complex model can be studied with greater fidelity and exponentially less time than looking at all combinations of factors and levels. The majority of the experiments use a mixed design, based on crossing a traditional factorial design with a nearly orthogonal Latin hypercube (NOLH) design (Cioppa & Lucas, 2007). The NOLH is the basis for all continuous factors of concern, while categorical factors use the factorial design. The algorithm used for their generation can be found on the SEED Center website (http://harvest.nps.edu/).

1. Robustness

The goal sometimes is not just finding a solution that maximizes or minimizes the metric of interest, but a solution that also looks at the variability of that optimal solution. A robust solution is one that may sacrifice mean performance to minimize variability. It is a solution that is stable around a larger variation of uncontrollable inputs with little change in output. This way of looking at and analyzing the data is useful when there is a lot of variability in the response, uncertainty in the inputs, and when the variance of the response is not constant for the entire range of the regressors. This condition applies to our situation.

The inputs consist of signal and noise factors. The signal factors are inputs that the user has control over. The number of aircraft, instructor working hours, and students per class are all signal factors. The weather's cancellation rate, aircraft repair times, and aircraft failure rates are all unknown and uncontrollable. They can best be described by a distribution, but the ITC simulation does not currently take probability distributions as input variables. Because the JSF is a new system, the distribution of failure rates and repair times are unavailable. The model uses point estimates for these and the other noise factors. Unfortunately, queuing theory tells us that this will likely bias the results (Ross, 2007).

In robust analysis, the intent is to look at the effect of the signal factors over the entire distribution of noise factors. To do this, both signal and noise factors are expanded into separate orthogonal or nearly orthogonal designs covering the full range of their values. These two separate designs are then crossed to form a master design. Once the data are generated, it is collapsed over the noise variables. That is, for a given signal design point, the response is generated by averaging all of the design points in the noise matrix. This gives a distribution of outcomes for each design point of the signal factors. This is better than using a single value for the noise factors, but not as good as using a distribution. It gives equal weight to all possible values of the noise factor when they are probably not all equal, and can lead to higher variability in the outcome. The methodology used for the robust analysis in this thesis is further described in Sanchez (2000).

2. Factors and Levels

The factors of concern, affecting TTT and their levels (or range of values), are dependent on the problem being studied. All factors come from the list of inputs shown in Chapter II or otherwise are explained separately. Not all of these factors are used in every experiment, nor will their ranges be the same. Each experiment has a specific goal, and thus the range and number of factors is adjusted to best match the need of the experiment. If the full values of each factors' ranges were used they may dominate the factors of interest and hide the response. This is a very important consideration when varying noise factors in the design, especially when all possible levels have a probability of occurrence. For example, having aircraft cancellation rates near 100% will dominate the output and make it difficult to see the effects of the signal factors. This narrowing down of the correct range for the each factor is an iterative process involving subject matter experts.

Unless otherwise stated in the experiment, the noise factors are at the default values used in historical analysis, shown in Table 2.

Table 2. Noise Factors Default Levels

Factor	Level	Factor	Level
MOA Slots	30	FMS Refly %	2
Low Level	30	Weather cnx Summer %	30
Target Slots	30	Weather cnx Winter %	15
Runways	5	AC Fail Rate %	50
Flight Refly %	15	AC Repair Time (hours)	3

B. AIRCRAFT UPGRADE AND MODIFICATION DESIGN MATRIX

Once aircraft are delivered to the ITC they will be basic aircraft with minimal flight clearances and not yet fully mission capable. As testing continues, and the aircraft are certified for different flight profiles, they will be upgraded at the ITC. This upgrade may be a simple software replacement or a complex process where a flight control surface, hydraulic, electrical, or structural component is replaced. When these aircraft undergo an upgrade, they are unusable for the period of time required to complete the upgrade. A question of interest to VMFAT-501 is what affect the upgrade process will have on TTT?

Aircraft module upgrade is not an input to the system. The only way to simulate this as a factor is by using a perturbation of the original aircraft induction file. The aircraft delivery schedule is known. By modifying when aircraft arrive and taking them out of service when they undergo upgrades, multiple scenarios can be explored and compared to a base case of no upgrades. Depending on the complexity of the upgrade, the aircraft downtime could be from a few days to a few weeks. The current plan is to keep four aircraft available for training at all times, while the other aircraft go through the upgrade process (A. C. Liberman, personal communication, April 18, 2011). With this COA, no upgrade is made until there are more than four aircraft in the inventory.

This perturbation of the aircraft induction schedule is based on the assumption that once the upgrade is made available, then all available aircraft—less those needed to complete training missions—will all undergo the upgrade at the same time and complete at the same time. The time needed to complete the upgrade depends on its complexity, but is assumed to be between one and three weeks for simulation purposes. If the upgrade is made available while there are only four aircraft in the inventory, none of those aircraft are upgraded until a new aircraft arrives. The upgrades are made as soon as the required minimum numbers of aircraft are present.

The idea is to ensure a minimum of two aircraft at all times to cover the flight schedule, while the extra two are used as backups for any maintenance issues that may come up. This strategy of four to make two may not be the best choice for all situations. Changes in upgrade completion time or aircraft failure rates may favor a different COA. To understand which COA is best, the following rules are used to simulate all possible decision policies with respect to how many aircraft to hold in reserve. The number of aircraft held in reserve is between two and five, and is designated A, B, C, or D, respectively. The time to complete is one, two, or three weeks. Although it may take a few days, the simulation only accepts integer values representing the week to make a change to the aircraft inventory. Added to this is a control design, designated A0, where upgrades are not required or they take zero time to complete, corresponding to the original aircraft induction schedule. This makes a total of 13 different aircraft induction schedules or design points to explore. This design is crossed with a 10 factor (noise) NOLH design of 33 design points, forming a mixed design with a total of 429 runs to fully explore the problem. The individual upgrade scenarios are shown in Tables 3 and 4. The value under the "week" column represents when the aircraft inventory will change and the value under "amount" column represents the number of aircraft added to the inventory.

Table 3. Upgrade Design Signal Factors

Design	Aircraft to Keep	Upgrade Time
Control	4	0
A1	2	1
A2	2	2
A3	2	3
B1	3	1
B2	3	2
B3	3	3
C1	4	1
C2	4	2
C3	4	3
D1	5	1
D2	5	2
D3	5	3

Table 4. Upgrade Design Schedule Induction File

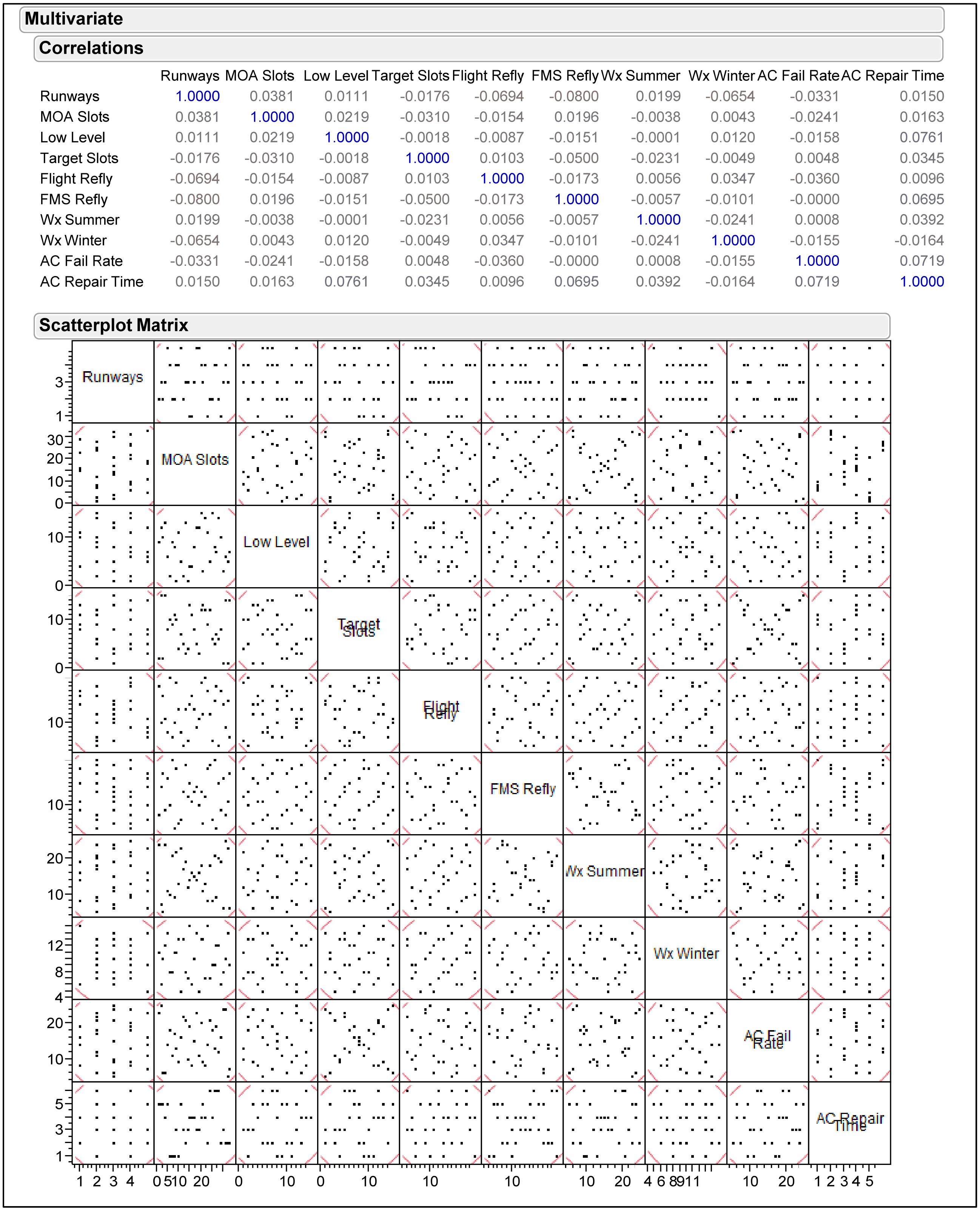
	week1	week2	week3	week4	week5	week6	week7	week8	week9	amount1	amount2	amount3	amount4	amount5	amount6	amount7	amount8	amount9
AC0	83	87	90	98	118	121	126	127	128	3	2	2	1	1	2	1	0	0
AC1	83	86	88	91	99	119	122	127	129	2	1	2	2	1	1	2	1	0
AC2	83	89	92	100	120	123	128	129	130	2	3	2	1	1	2	1	0	0
AC3	83	87	89	90	92	101	121	124	129	2	1	1	1	2	1	1	2	1
B1	83	89	90	91	99	119	122	127	128	3	1	1	2	1	1	2	1	0
B2	83	90	91	92	100	118	120	123	128	3	2	1	1	1	0	1	2	1
B3	83	93	96	101	121	124	129	130	131	3	3	1	1	1	2	1	0	0
C1	83	87	91	92	99	119	122	127	128	3	1	2	1	1	1	2	1	0
C2	83	87	91	94	100	120	123	128	129	3	1	1	2	1	1	2	1	0
C3	83	87	96	101	121	124	129	130	131	3	1	3	1	1	2	1	0	0
D1	83	87	93	94	99	119	122	127	128	3	2	1	1	1	1	2	1	0
D2	83	87	96	98	100	120	123	128	129	3	2	1	1	1	1	2	1	0
D3	83	87	98	99	121	124	129	130	131	3	2	1	2	1	2	1	0	0

The noise factors used in this experiment are shown in Table 5. The minimum and maximum value of each factor is also shown. The refly values represent the probability that a student will have to refly an aircraft or FMS event. "Wx Summer" and "Wx Winter" represent weather cancellation rates for each flight in the summer or winter, respectively. "Fail Rate" and "Repair Time" represent the probability that an aircraft will break down before the flight and how long it will take to repair the aircraft.

Table 5. Upgrade Noise Factors Nearly Orthogonal Latin Hypercube

Min	1	1	1	1	5	5	5	5	5	1
Max	5	33	15	15	20	20	25	15	25	6
run	Runways	MOA Slots	Low Level	Target Slots	Flight Refly	FMS Refly	Wx Summer	Wx Winter	AC Fail Rate	AC Repair Time
1	1	15	4	13	14	15	14	15	19	4
2	5	5	6	8	8	16	11	14	14	5
3	3	30	3	1	14	16	6	8	24	3
4	5	33	7	14	7	17	6	9	7	2
5	1	16	4	11	16	11	16	6	8	4
6	5	11	5	7	8	7	23	5	16	5
7	3	32	5	1	15	11	23	14	5	2
8	4	31	6	14	9	8	25	10	24	2
9	2	8	8	11	10	5	9	11	17	1
10	4	10	11	4	13	6	13	13	9	1
11	2	25	15	6	6	7	8	9	18	4
12	4	22	14	12	20	12	13	7	8	4
13	2	7	9	9	7	20	21	8	11	1
14	3	13	13	3	13	19	19	8	21	2
15	2	28	14	6	5	15	20	12	12	6
16	4	20	15	12	19	13	18	13	20	4
17	3	17	8	8	13	13	15	10	15	4
18	5	19	12	3	11	10	16	5	11	3
19	1	29	10	8	17	9	19	6	16	2
20	3	4	13	15	11	9	24	12	6	4
21	2	1	9	2	18	8	24	11	23	5
22	5	18	12	5	9	14	14	14	23	3
23	1	23	11	9	17	18	8	15	14	2
24	3	2	12	15	10	14	7	6	25	5
25	2	3	10	2	16	17	5	10	6	5
26	4	26	8	5	15	20	21	9	13	6
27	2	24	5	12	12	19	18	7	21	6
28	4	9	1	10	19	18	22	11	13	3
29	2	12	2	5	5	13	17	13	22	3
30	4	27	7	7	18	5	9	12	19	6
31	3	21	3	13	12	6	11	13	9	5
32	4	6	2	10	20	10	10	8	18	1
33	3	14	1	4	6	12	12	7	10	3

The correlation of this design and its space-filling property are shown in Figure 5. Correlation is a measure of linear dependence between two factors and is a value between 1 and –1. A zero correlation would mean the two factors have no linear dependence and is the goal in any designing. Correlation of 1 or –1 means a perfect positive or negative linear relationship between the two factors. The design is nearly orthogonal, with “FMS Refly” and “Runways” having the highest correlation of only 8%. This should not interfere with estimating the effects of different upgrade strategies. The scatterplot matrix shows the coverage achieved in the factor space with this design. Each point represents a specific run of the experiment. All pairs of signal and noise factors are plotted.



Multivariate

Correlations

	Runways	MOA Slots	Low Level	Target Slots	Flight Refly	FMS Refly	Wx Summer	Wx Winter	AC Fail Rate	AC Repair Time
Runways	1.0000	0.0381	0.0111	-0.0176	-0.0694	-0.0800	0.0199	-0.0654	-0.0331	0.0150
MOA Slots	0.0381	1.0000	0.0219	-0.0310	-0.0154	0.0196	-0.0038	0.0043	-0.0241	0.0163
Low Level	0.0111	0.0219	1.0000	-0.0018	-0.0087	-0.0151	-0.0001	0.0120	-0.0158	0.0761
Target Slots	-0.0176	-0.0310	-0.0018	1.0000	0.0103	-0.0500	-0.0231	-0.0049	0.0048	0.0345
Flight Refly	-0.0694	-0.0154	-0.0087	0.0103	1.0000	-0.0173	0.0056	0.0347	-0.0360	0.0096
FMS Refly	-0.0800	0.0196	-0.0151	-0.0500	-0.0173	1.0000	-0.0057	-0.0101	-0.0000	0.0695
Wx Summer	0.0199	-0.0038	-0.0001	-0.0231	0.0056	-0.0057	1.0000	-0.0241	0.0008	0.0392
Wx Winter	-0.0654	0.0043	0.0120	-0.0049	0.0347	-0.0101	-0.0241	1.0000	-0.0155	-0.0164
AC Fail Rate	-0.0331	-0.0241	-0.0158	0.0048	-0.0360	-0.0000	0.0008	-0.0155	1.0000	0.0719
AC Repair Time	0.0150	0.0163	0.0761	0.0345	0.0096	0.0695	0.0392	-0.0164	0.0719	1.0000

Scatterplot Matrix

Figure 5. Upgrade Design Multivariate Plot of Noise Factors

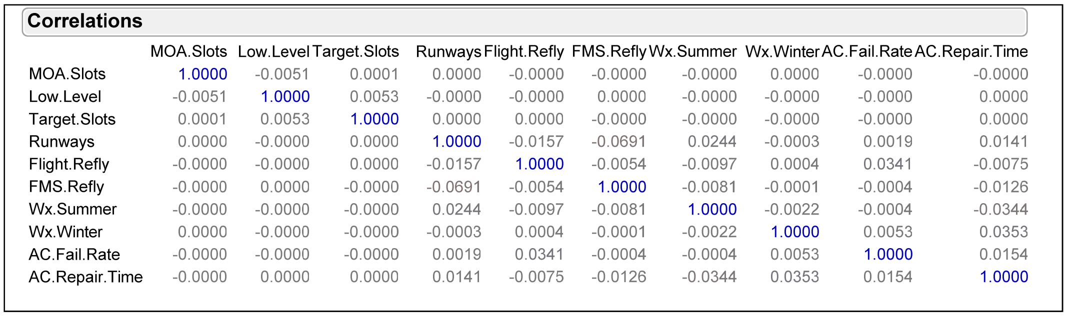
C. AIRSPACE EFFECTS ON TTT

This experiment focuses on limiting the number of Military Operating Areas (MOAs), low-level routes, and target slots available for training. Each syllabus flight event uses one or more of these resources to complete its mission. An MOA is airspace reserved for military training and test flights. Low-level routes are routes in an MOA, or other special-use airspace, where military aircraft can train at speeds and altitudes that are otherwise prohibited under Federal Aviation Administration rules. Target slots or ranges are usually located in restricted airspace and are used by the military for live-fire exercises. All of these areas are shared with other military organizations and scheduled through a local control authority. The availability of these resources could then affect TTT in their own way. The ITC has queues for each of the airspace factors and depending on when and how many students need these resources there may be a delay in its availability. For this experiment, the noise and signal factors, and their levels, are shown in Table 6.

Table 6. Airspace Experiment Input Variables

	SIGNAL			NOISE						
Min	1	1	1	1	5	0	5	0	5	1
Max	30	30	30	5	20	20	25	15	25	6
	MOA Slots	Low Level	Target Slots	Runways	Flight Refly	FMS Refly	Wx Summer	Wx Winter	AC Fail Rate	AC Repair Time
	10	30	25	2	20	16	13	4	24	4
	3	8	26	1	9	18	16	0	11	4
	5	14	3	2	12	1	10	9	21	6
	6	19	10	2	14	6	25	8	8	5
	23	28	14	4	19	9	8	5	5	5
	30	10	12	5	10	8	21	1	20	5
	19	6	30	4	8	20	11	13	14	6
	17	26	23	3	18	15	24	12	18	4
	16	16	16	3	13	10	15	8	15	4
	21	1	6	4	5	4	18	11	6	3
	28	23	5	5	16	3	14	15	19	3
	26	17	28	5	13	19	20	6	9	1
	25	12	21	4	11	14	5	7	23	2
	8	3	17	2	6	11	23	10	25	2
	1	21	19	1	15	13	9	14	10	2
	12	25	1	3	17	0	19	2	16	1
	14	5	8	3	7	5	6	3	13	3
	12	8	28	5	17	8	10	14	16	3
	17	1	10	2	18	11	5	5	18	1
	8	19	25	3	6	5	18	12	25	2
	30	17	5	4	10	20	16	2	20	2
	5	10	1	5	12	3	11	0	21	5
	25	3	23	2	11	16	6	11	23	6
	10	26	14	2	20	6	23	7	24	4
	28	25	19	5	16	19	21	9	19	4
	19	23	3	1	8	13	20	1	14	4
	14	30	21	4	7	9	25	10	13	6
	23	12	6	3	19	15	13	3	5	5
	1	14	26	3	15	0	14	13	10	5
	26	21	30	1	13	18	19	15	9	2
	6	28	8	4	14	4	24	4	8	1
	21	5	17	4	5	14	8	8	6	3
	3	6	12	2	9	1	9	6	11	3

Each design is created using an NOLH. The final design is a cross of the two separate designs to form a composite design with 1,089 design points, which allows us to examine the relationship between airspace availability and TTT. The multivariate correlation plot of the final design is shown in Figure 6. The highest correlation between the signal factors is a very low 0.0053.



Correlations

	MOA.Slots	Low.Level	Target.Slots	Runways	Flight.Refly	FMS.Refly	Wx.Summer	Wx.Winter	AC.Fail.Rate	AC.Repair.Time
MOA.Slots	1.0000	-0.0051	0.0001	0.0000	-0.0000	-0.0000	-0.0000	0.0000	-0.0000	-0.0000
Low.Level	-0.0051	1.0000	0.0053	-0.0000	-0.0000	0.0000	-0.0000	-0.0000	-0.0000	0.0000
Target.Slots	0.0001	0.0053	1.0000	0.0000	0.0000	-0.0000	-0.0000	-0.0000	-0.0000	0.0000
Runways	0.0000	-0.0000	0.0000	1.0000	-0.0157	-0.0691	0.0244	-0.0003	0.0019	0.0141
Flight.Refly	-0.0000	-0.0000	0.0000	-0.0157	1.0000	-0.0054	-0.0097	0.0004	0.0341	-0.0075
FMS.Refly	-0.0000	0.0000	-0.0000	-0.0691	-0.0054	1.0000	-0.0081	-0.0001	-0.0004	-0.0126
Wx.Summer	-0.0000	-0.0000	-0.0000	0.0244	-0.0097	-0.0081	1.0000	-0.0022	-0.0004	-0.0344
Wx.Winter	0.0000	-0.0000	-0.0000	-0.0003	0.0004	-0.0001	-0.0022	1.0000	0.0053	0.0353
AC.Fail.Rate	-0.0000	-0.0000	-0.0000	0.0019	0.0341	-0.0004	-0.0004	0.0053	1.0000	0.0154
AC.Repair.Time	-0.0000	0.0000	0.0000	0.0141	-0.0075	-0.0126	-0.0344	0.0353	0.0154	1.0000

Figure 6. Airspace Design Multivariate Plot

D. SYLLABUS VARIABLES

This last experiment tests the effect of changing student start time, workday length, number of FMSs, and ITC work hours on TTT. The first two experiments vary each signal factor over the entire range of noise factors, but for this experiment, the noise factors are kept constant at their default values. By looking at only the signal factor, the degree of complexity of the design is reduced and allows a full-factorial design to be used. The signal factors are listed in Table 7, with information on their levels and variable types.

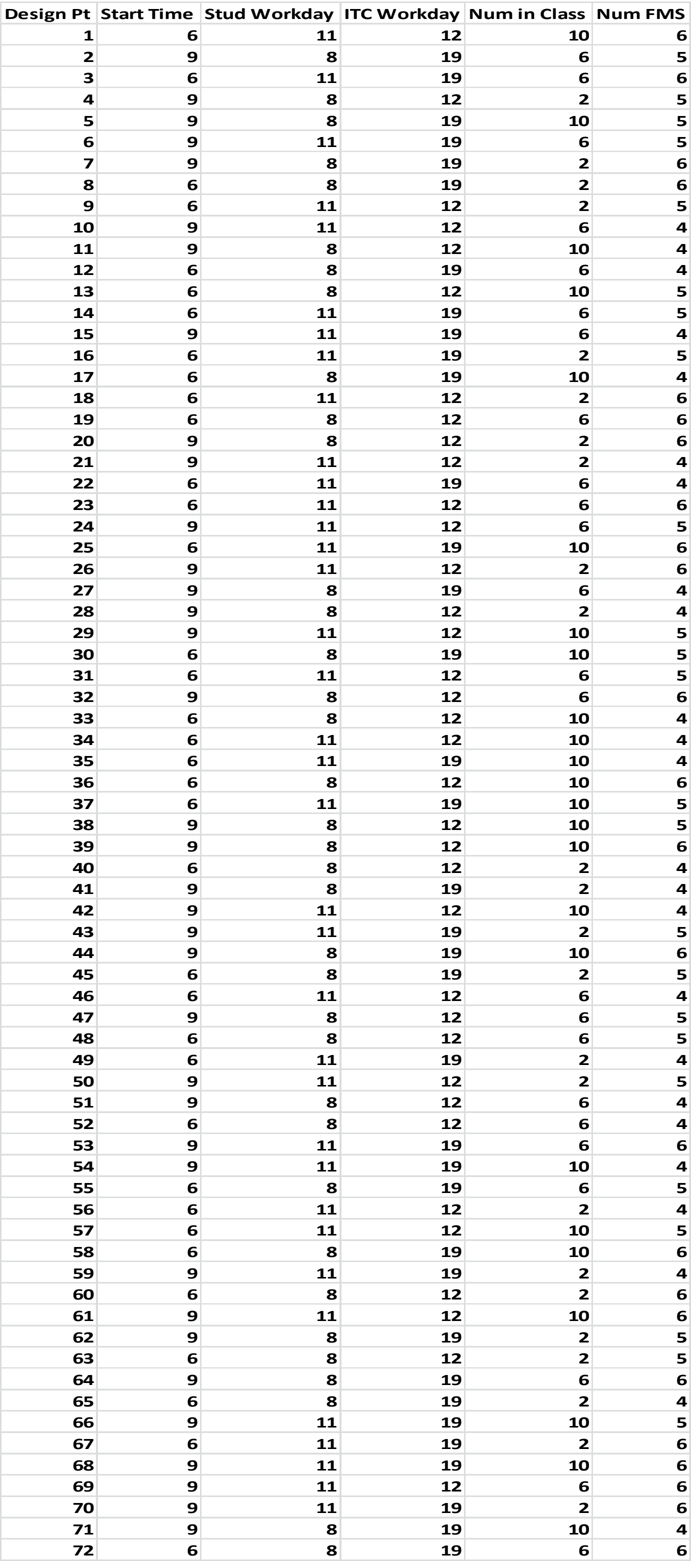
Table 7. Syllabus Signal Factors

Factor	Type	Levels
Number of students in class	Integer	2, 6, 10
Number of FMSs	Integer	4, 5, 6
Start time	Continuous (hrs)	0600, 0900
Length of workday	Continuous (hrs)	8, 11
Schoolhouse hours	Continuous (hrs)	12, 19

Increasing the class size directly affects TTT. As more students complete for a constant supply of resources, the availability of these resources become limiting and bottlenecks are created. This results in more time spent waiting in queues and increases TTT. This factor was added to get a sense of how much that increase is and how the other signal variables affect TTT as student numbers increase. The students have a default start time and workday length of 0700 and nine hours, respectively. Increasing or decreasing the student start time allows more day or night flight events to be completed. Changing the workday length allows a student more time to schedule and complete events each day. Increasing schoolhouse hours allows more time for simulator and academic events to be scheduled in a single day. Increasing the number of FMSs should result in a decrease in the average TTT; but at what level of class size will this have the most pronounced effect?

The goals for this experiment are screening the factors of interest, then learning what levels of those factors will minimize TTT. A full-factorial design is created with JPM software (Sall, Creighton, & Lehman, 2005). From the data, a meta-model of the system is created. Both linear regression and partition trees are used to explore the data. This design enables main effects and two-way interaction to be estimated with no confounding. Table 8 shows the design in tabular form.

Table 8. Full-Factorial Design



Design Pt	Start Time	Stud Workday	ITC Workday	Num in Class	Num FMS
1	6	11	12	10	6
2	9	8	19	6	5
3	6	11	19	6	6
4	9	8	12	2	5
5	9	8	19	10	5
6	9	11	19	6	5
7	9	8	19	2	6
8	6	8	19	2	6
9	6	11	12	2	5
10	9	11	12	6	4
11	9	8	12	10	4
12	6	8	19	6	4
13	6	8	12	10	5
14	6	11	19	6	5
15	9	11	19	6	4
16	6	11	19	2	5
17	6	8	19	10	4
18	6	11	12	2	6
19	6	8	12	6	6
20	9	8	12	2	6
21	9	11	12	2	4
22	6	11	19	6	4
23	6	11	12	6	6
24	9	11	12	6	5
25	6	11	19	10	6
26	9	11	12	2	6
27	9	8	19	6	4
28	9	8	12	2	4
29	9	11	12	10	5
30	6	8	19	10	5
31	6	11	12	6	5
32	9	8	12	6	6
33	6	8	12	10	4
34	6	11	12	10	4
35	6	11	19	10	4
36	6	8	12	10	6
37	6	11	19	10	5
38	9	8	12	10	5
39	9	8	12	10	6
40	6	8	12	2	4
41	9	8	19	2	4
42	9	11	12	10	4
43	9	11	19	2	5
44	9	8	19	10	6
45	6	8	19	2	5
46	6	11	12	6	4
47	9	8	12	6	5
48	6	8	12	6	5
49	6	11	19	2	4
50	9	11	12	2	5
51	9	8	12	6	4
52	6	8	12	6	4
53	9	11	19	6	6
54	9	11	19	10	4
55	6	8	19	6	5
56	6	11	12	2	4
57	6	11	12	10	5
58	6	8	19	10	6
59	9	11	19	2	4
60	6	8	12	2	6
61	9	11	12	10	6
62	9	8	19	2	5
63	6	8	12	2	5
64	9	8	19	6	6
65	6	8	19	2	4
66	9	11	19	10	5
67	6	11	19	2	6
68	9	11	19	10	6
69	9	11	12	6	6
70	9	11	19	2	6
71	9	8	19	10	4
72	6	8	19	6	6

THIS PAGE INTENTIONALLY LEFT BLANK

IV. ANALYSIS

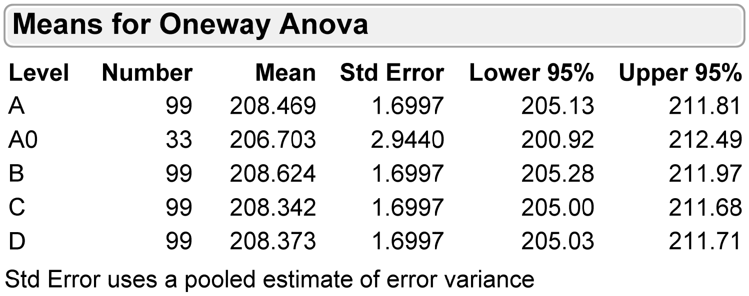
This chapter analyzes the results of all three experiments and points to a preferred set of conditions and action that can be implemented to help reduce TTT. The analysis is performed using the JPM statistical package. The data are analyzed using partition trees and linear regression to explain the hierarchical relationship between the factors of interest and their effect on TTT.

A. AIRCRAFT UPGRADE EFFECTS ON TTT

The experiment to determine effects of aircraft upgrades on TTT is run twice. The first run had two students arriving with each class. This number of students, coupled with the induction schedule of IPs, aircraft, and FMS, did not stress the system enough to make any significant difference in TTT. With so few students onboard, the resources were adequate to cover the entire range of noise and signal variables. TTT remained fairly constant and did not vary by more than 10% from any run. The utilization rate for the FMS was less than 10% and the flight hours per month for the IPs were similarly around 10 hours per month, which is below the recommended proficiency minimum. This means IPs did not fly enough flight events to satisfy the required minimum flight hours and would be required to fly non-student-related flights. This is inefficient, since these extra flights are not flown in conjunction with student events. To solve this problem, a second experiment is run with the number of students per class set to six, using the same design matrix.

The average utilization rate for FMS in this new design is 32%, while the average IP flight hours increased to 15 hours per month. For TTT, the result of this new design shows it is insensitive to which upgrade scenario is chosen. Table 9 shows how the mean TTT for all scenarios are statistically equal at a 95% confidence level.

Table 9. Analysis of Variance of Mean Time to Train of Upgrade Scenario



Means for Oneway Anova

Level	Number	Mean	Std Error	Lower 95%	Upper 95%
A	99	208.469	1.6997	205.13	211.81
A0	33	206.703	2.9440	200.92	212.49
B	99	208.624	1.6997	205.28	211.97
C	99	208.342	1.6997	205.00	211.68
D	99	208.373	1.6997	205.03	211.71

Std Error uses a pooled estimate of error variance

Because there is so little variability in mean TTT, a formal robust analysis of the result would prove fruitless and is not attempted for this experiment. However, it is interesting to note that the default scenario considered by VMFAT-501 of having four aircraft at all times for the flight schedule, mod C, does minimize the TTT and the standard error in all scenarios other than the control group, A0. Therefore, it is the most robust COA.

Further analysis of the TTT data for this experiment shows a nonnormal distribution of the TTT (see Figure 7). There are two peaks in the distribution, a lower peak of approximately 190 days and a high peak of approximately 225 days. These peaks can be explained by looking at the partition tree of the data by the noise variables.

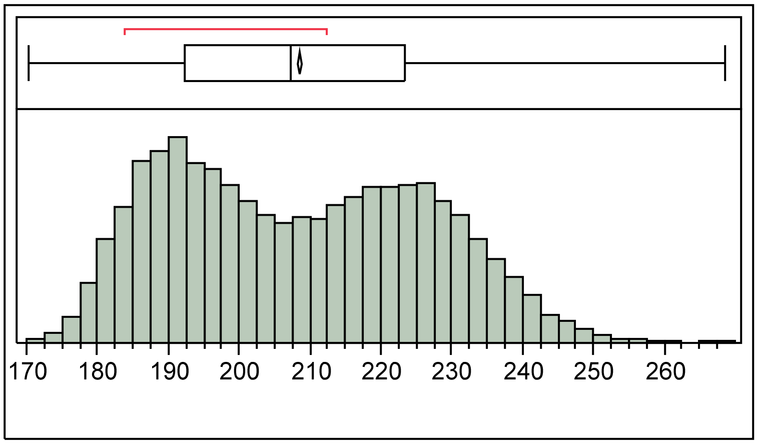


Figure 7. Upgrade Experiment Histogram of Days to Train

The majority of the cases with TTT in the left peak have refly rates less than 12% and four or more MOA slots. While the right peak is composed of cases where the refly rate is equal to or greater than 12% and aircraft failure rates at or above 13%. These factors and levels should be closely monitored in order to anticipate and rectify possible delays.

1. Partition Tree of Upgrade Data

Another way to visualize the important factors in determining TTT is through a partition tree. This method of modeling splits the data into groups so as to minimize the total sum of squares error (SSE). The factor and level of the factor to split is chosen by the algorithm, based on which maximizes the reduction in the total SSE. In other words, the data is partitioned into two groups according to which factor and level explains the majority of the variation in the data. In JMP, the splits are controlled manually until the desired degree of accuracy is achieved or the resulting pool of data has reached a minimum required for further splits because of insufficient observations or insufficient variability in the response (Sall, Creighton, & Lehman, 2005). The partition of the upgrade data is shown in Figure 8. There are no signal factors present after three splits. It is not until split 26 that the choice of upgrade scenario becomes a factor in determining TTT. This further confirms that TTT is insensitive to the chosen upgrade COA.

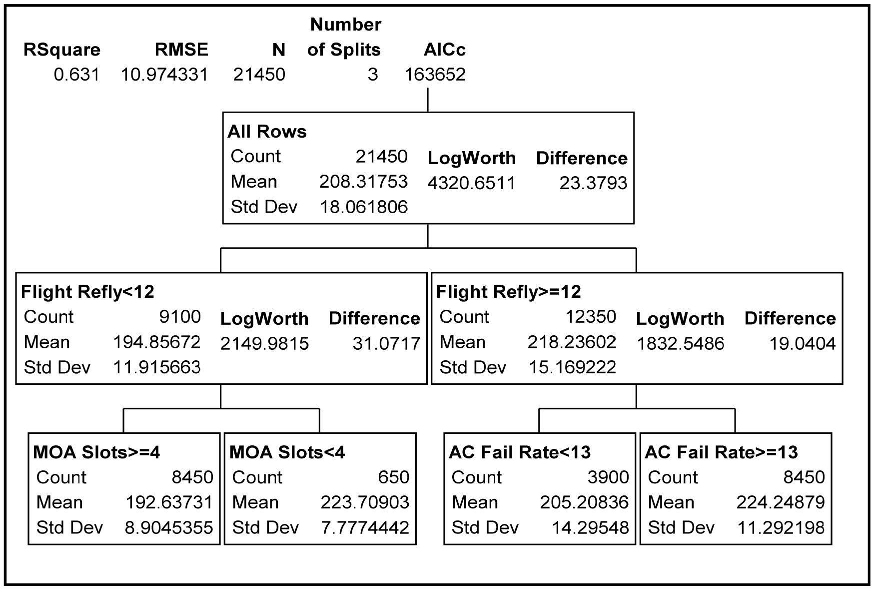


Figure 8. Partition of Upgrade Data Including Signal and Noise Factors

By further expanding the partition tree, the upper and lower tails of the distribution can be explored. Design points with an average TTT near 181 days form the lower tail. They are composed of situations where flight refly is below 12%, MOA slots are greater than four, FMS refly is below 14%, winter cancellation rates are below 16%, and there are 11 or more target slots available each day. The upper tail is composed of situations with flight refly greater than 12%, aircraft failure greater than 13%, aircraft repair time greater than five hours, and less than 26 MOA slots. Looking at the partition tree with the noise data is not useful since these are things that cannot be changed. Looking at the partition only as a function of the signal factors will also be of little use since the means of each COA are so close. The difference in each COA is not enough to explain the variation in TTT. When it comes to what decisions to make that will help reduce TTT, the choice of what upgrade scenario to use should not be a factor to consider.

B. AIRSPACE AND TTT

Airspace is an important factor in the smooth operation of an ITC. Results from the upgrade experiment shows how important the number of MOA slots is in reducing TTT. The design described in Chapter III brings the other two elements of air space, target slots and low-level routes, into a full experiment to explore the impact of these resources on TTT.

Results from this experiment are similar to those for the upgrade scenario. There is no relationship between airspace and TTT. This can be seen in a simple plot of TTT versus airspace resources (see Figure 9).

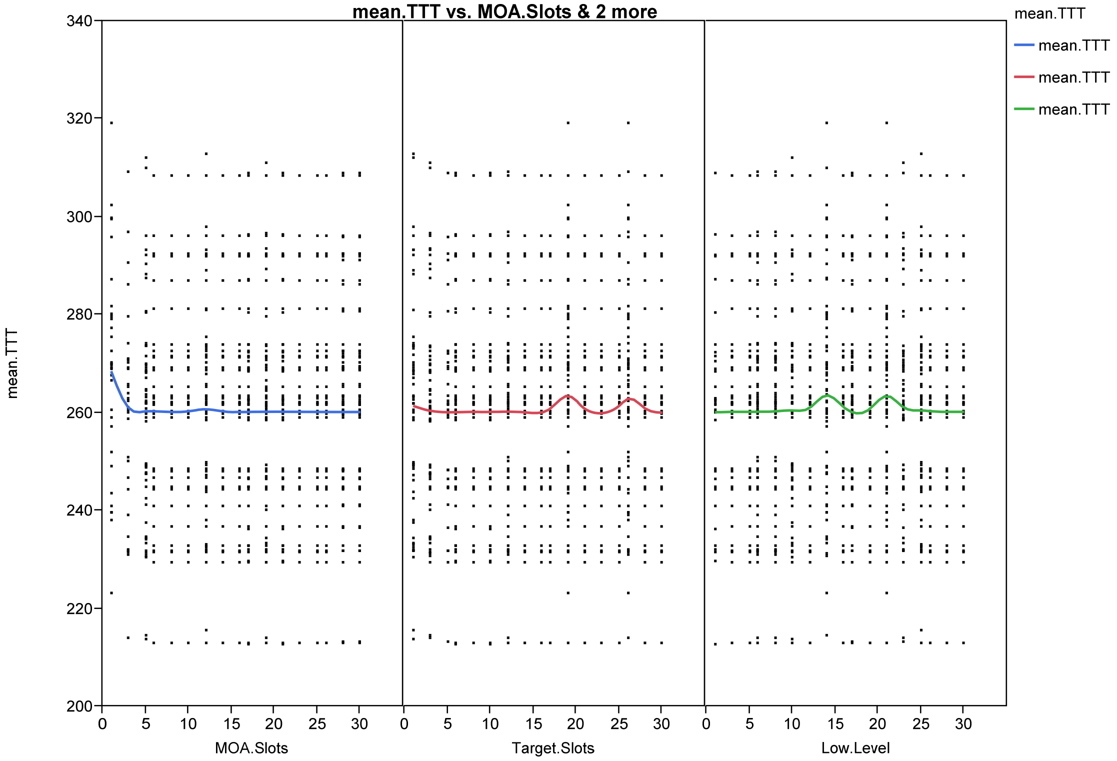
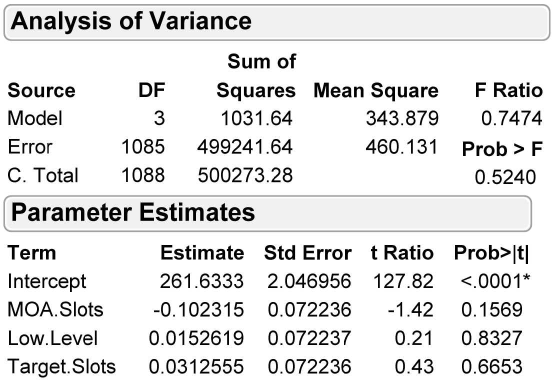


Figure 9. Airspace versus Time to Train Experiment 1

The plot is fairly stable, with the average TTT around 260 and with very little variation. The MOA plot shows a tendency toward higher TTT as the number of MOA slots decrease. This behavior is expected, but not present, in either of the other two plots. Instead, they are fairly constant except for two excursions above the mean at 20 and 25 and 15 and 20 for the target and low-level plots, respectively. A linear regression of the data verifies what the plots show—there is no relationship between TTT and airspace (see Figure 10).



Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	3	1031.64	343.879	0.7474
Error	1085	499241.64	460.131	**Prob > F**
C. Total	1088	500273.28		0.5240

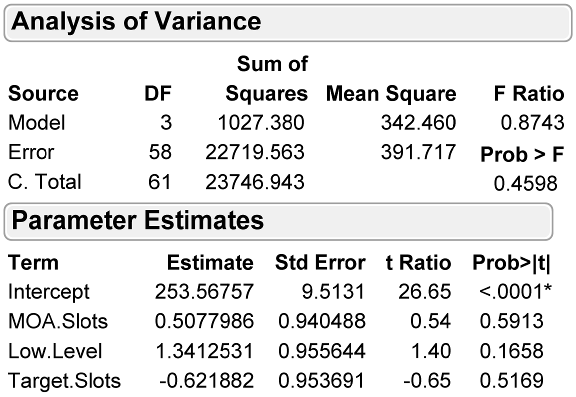
Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	261.6333	2.046956	127.82	<.0001*
MOA.Slots	-0.102315	0.072236	-1.42	0.1569
Low.Level	0.0152619	0.072237	0.21	0.8327
Target.Slots	0.0312555	0.072236	0.43	0.6653

Figure 10. Airspace Regression Statistics

The F statistic, the mean square of the model divided by the mean square of the error, shows the model is statistically insignificant. Mean TTT is a better predictor of actual TTT than any relationship between the number and type of airspace available. The parameter estimates show the factors have no significant effect on TTT.

To verify these findings, and ensure that the 1 to 30 range in the airspace factors is not too large and thus masking a relationship with TTT, a second experiment is run. The parameters remain unchanged, and the design is an NOLH with 65 design points. The airspace factor levels in the second experiment are reduced by a factor of three. Airspace values can now range from 1 to 10, and should provide greater resolution on the effects, if any, of airspace on TTT. To reduce the amount of computation required, the number of repetitions is reduced to 35 at each design points. Figure 11 shows the linear regression of the second experiment.



Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	3	1027.380	342.460	0.8743
Error	58	22719.563	391.717	**Prob > F**
C. Total	61	23746.943		0.4598

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	253.56757	9.5131	26.65	<.0001*
MOA.Slots	0.5077986	0.940488	0.54	0.5913
Low.Level	1.3412531	0.955644	1.40	0.1658
Target.Slots	-0.621882	0.953691	-0.65	0.5169

Figure 11. Airspace Regression Reduced Levels Statistics

The results from both regressions confirm that airspace and TTT have no relationship in the present scenario. The best conclusions made from this experiment is that airspace is not a potential bottleneck in the system and any change short of elimination of the airspace will have very little influence on TTT.

C. SYLLABUS VARIABLES AND TTT

The data from this experiment are analyzed using both a linear regression model and a partition tree. The regression produces a good fit to the data, but does not explain or provide a set of rules or guidelines for the commander to use. Both courses of analysis do agree on what factors are most important. The partition tree is the best model because of its simplicity to view, understand, and explain.

1. Partition Tree

Figure 12 shows a partial regression tree to three levels. This tree explains the majority of the variability in the data, with a resulting R-squared over (0.99). The data used on the partition tree includes all 50 repetitions of the original 72 design points.

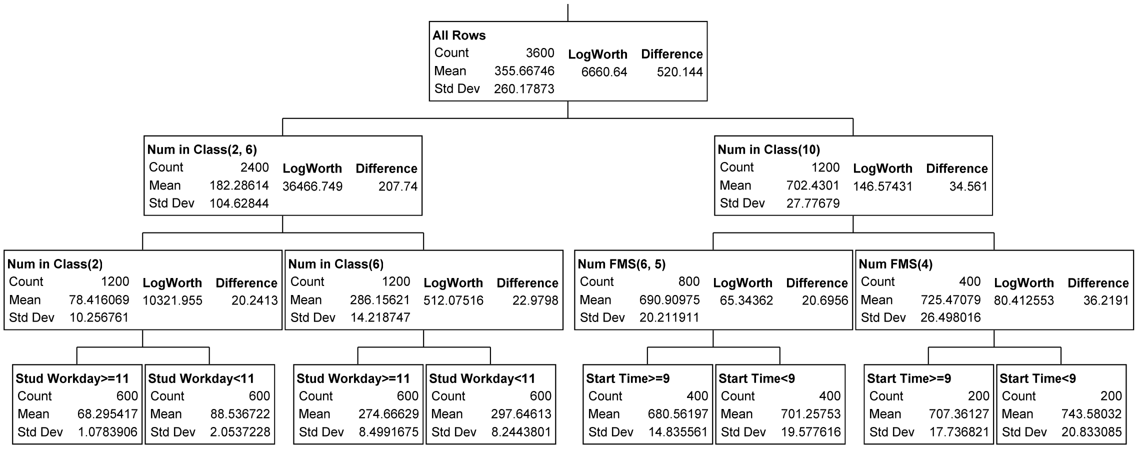


Figure 12. Partition Tree of Syllabus Data

The most influential factor affecting TTT is the number of students in each class. The mean TTT with 2, 6, or 10 students per class is 78, 286, and 702 days, respectively. Because of this, the analysis is broken down into three scenarios based on how many students are in the classes.

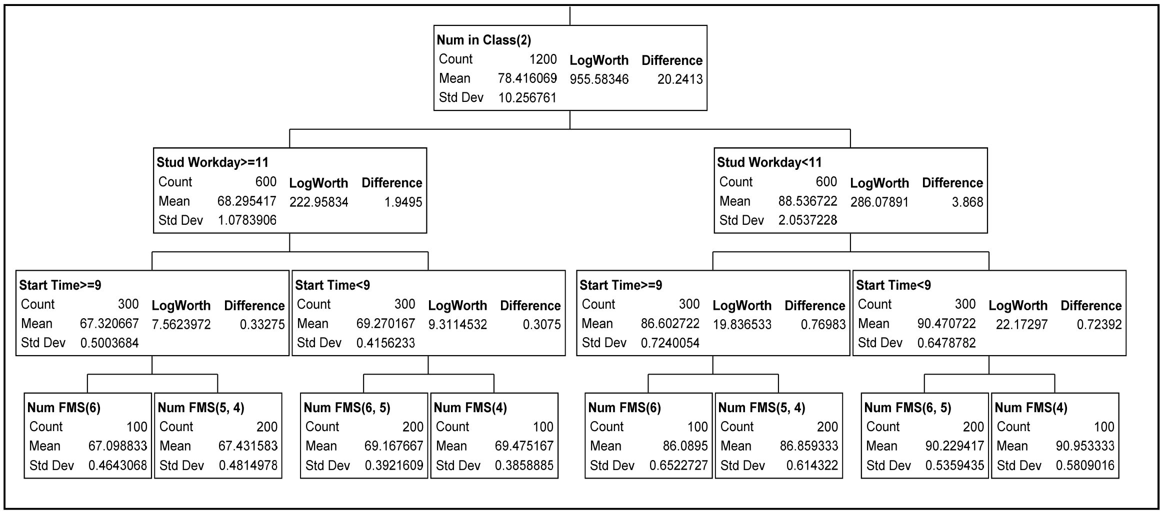


Figure 13. Partition Tree for Two Students per Class

Scenario 1 is shown in Figure 13. If there are only two students per class, then it is recommended to have their workday set at 11 hours or more and start at 0900 or later. These factors, at these levels, would produce a TTT of approximately 67 days with a standard deviation (SD) of 0.5 days. Having student workdays of less than 11 hours, and starting before 0900, gives a mean TTT of 90 days with an SD of 0.6 days. It is interesting to note that if the number of FMSs could be increased for this group, it would only decrease TTT by no more than 0.5 days. This group is more sensitive to start times and workday lengths than to the number of FMSs, and adding additional FMSs would not help to significantly reduce the TTT.

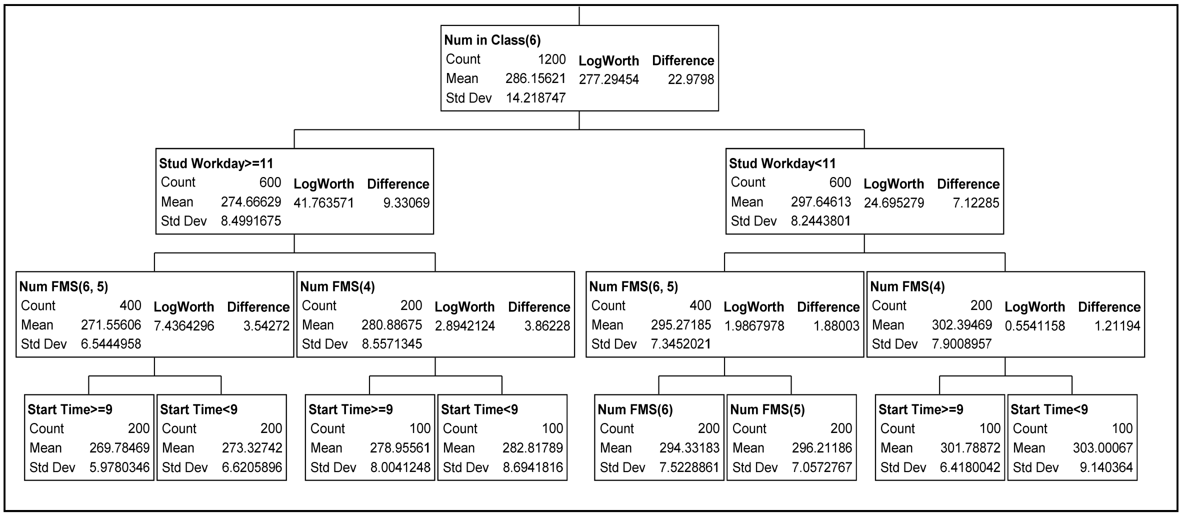


Figure 14. Partition Tree for Six Students per Class

Scenario 2 is shown in Figure 14. If there are six students, the best setting of factors is to increase the student workday to 11 or more hours and have them start at 0900 or later. With four FMSs, this gives a TTT of 280 days with an SD of eight days. The effect of having more FMSs is now significant. Having five or more FMSs would decrease TTT by nine days, or about two weeks of training time. This benefit may justify the additional cost of more FMS resources. Not only does it decrease TTT, but the SD is also reduced, making it a robust decision. Another interesting outcome of more students is the increase in the variability of their TTT. The SD has gone from about 1%, with two students per class, to 4% of mean TTT, with six students per class.

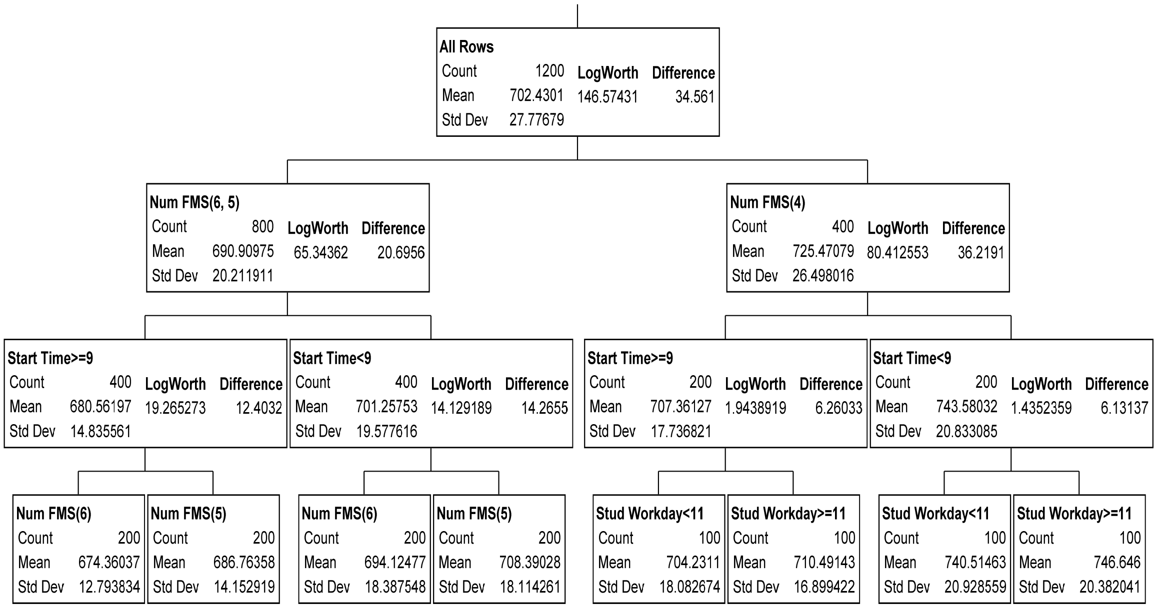


Figure 15. Partition Tree for 10 Students per Class

Any desire to further decrease TTT would have to focus on other resources that are limiting production. In this case, FMS, by itself, is not a bottleneck in the system. The next likely bottleneck may be from the number of IPs or training aircraft.

Scenario 3 is shown in Figure 15. If there are 10 or more students, the most important factor in reducing TTT is the number of FMSs. A reduction of 35 days is achieved by having five or more FMSs, along with reducing the SD by over six days.

The next most important factor is increasing student start time. This is a change from the last two scenarios, where student workday was more important than student start time. Having students start at 0900 or later reduces TTT by 20 to 35 days, depending on the number of FMSs available.

Of note is how little effect the student workday day has on the overall TTT. In scenarios one and two, it was the primary factor in reducing TTT. With 10 or more students, the advantages of longer workdays are almost insignificant. In one instance, having student workdays at or greater than 11 hours only reduces TTT by less than 0.2 days. This is due to other constraints in the ITC such as instructors and/or classroom availability. Even with longer workdays, the student is unable to utilize the limited resources.

Clearly, having students take almost three years to complete training is unacceptable. No levels of the signal factor looked at in this experiment can decrease the TTT to an acceptable level. To further explore the best ways to decrease TTT when there are 10 or more students arriving with each class, this experiment needs to be expanded to look at other factors in the model. Possible candidate factors are number of aircraft, instructors, runways, and airspace available. Each of these factors will increase the TTT if they are in short supply, but collectively, as a group, their effects are magnified. Fortunately, this work is ongoing and research already begun to explore these additional factors as well as the inclusion of noise variables.

THIS PAGE INTENTIONALLY LEFT BLANK

V. RECOMMENDATIONS

A. BEST COURSE OF ACTION

The following recommendations are made to help VMFAT-501 reduce TTT as they stand up the first JSF ITC at Eglin Air Force Base. These recommendations are based on analysis of three experiments over a finite time period with constrained resources, and are described in Chapters III and IV.

The choice of upgrade scenarios and resulting loss of training aircraft from one to three weeks have very little effect on TTT when there are six or less students per class. The choice of using four aircraft to support flight operations, while excess aircraft undergo upgrades, is the most robust choice of the 12 scenarios looked at in the experiment, not including the control scenario. This is the current scenario VMFAT-501 intends to implement. Factors to watch that could lead to increasing TTT are having flight and FMS refly rates above 12% and 14%, respectively, and winter cancellation and aircraft failure rates above 16% and 13%, respectively. All factors that have a significant effect on TTT are uncontrollable, and must be continuously monitored in order to have reasonable estimates and to anticipate changes to a student's TTT.

Airspace was also another factor that had little effect on TTT. The availability of airspace for training, short of eliminating this resource, did not present a bottleneck to training and did not change TTT.

The most profound recommendations come from the last experiment. The recommendations all depend on the number of students per class. As student numbers increase from 2 to 10 students per class, so does the TTT. Increasing the class size directly affects TTT if the resources are kept constant. As the number of students increases, the magnitude of the effects also increases and the hierarchy of significant factors changes. The factors do not have the same weight for class sizes of 2, 6, or 10 personnel.

Start time was significant in all three cases, as determined by the partition tree in Chapter III. The commander's best decision, regardless of the number of students, is to have students start at or after 0900, to reduce the average TTT. This reduces TTT by 2, 4, and 20 days for class sizes of 2, 6, and 10 personnel, respectively. This may be due to bottlenecks in the system for the schedule and completion of night events. The ITC is very strict and inflexible when it schedules students for events, which is very different from how a squadron runs its flight schedule.

Student workday length was significant in only two of the cases tested. With 10 or more students, the length of a student's workday had no significant effect on reducing the TTT. With six or less it was the dominate factor in determining the TTT, reducing it by more than 20 days in both cases. A commander's best decision is to have student workdays of 11 hours or more, if there are six or less students per class.

FMSs are an expensive resources and their effect on TTT must be significant enough to justify their increased expense. The number of FMSs was significant in only two of the cases tested. With two students per class, increasing the number of FMSs beyond four has no significant contribution to decreasing TTT. With six students per class, the TTT only decreased by nine days, or almost two training weeks at the ITC, which is a significant amount of time. When compared to an average TTT of over a year, the two weeks may not be significant enough to justify more FMSs; rather, there may be other constraints that are more economically feasible and easier to overcome. When there are 10 students per class, the reduction in TTT is greater than 30 days, which is significant, but compared to the two plus years of TTT, it is not enough to justify more FMSs. In this case, the increase in TTT is due to constraints in other resources. Potential sources of this constraint are the number of IPs, aircraft, classrooms, or runways available for training. Interestingly, ITC operational hours have no effect on the TTT.

The overall recommendation for reducing TTT is to have students work 11 hours per day and have the workday start at or after 0900. Increasing the number of FMS to five or six, while reducing TTT, is not justified. Likewise, increasing the hours that the ITC remains open has no effect on reducing TTT and should be ignored. The current plan of having four aircraft reserved for training events, while the excess undergo upgrades, is the best and most robust COA to ensure a minimum TTT.

The results produced by the ITC are inherently optimistic due to deficiencies in how the model treats weather, maintenance, other stochastic elements, and in the strict scheduling of student events (Dummar, 2011). The ITC model also uses means rather than distribution for its random variables, this also gives optimistic results. As a consequence, any reductions in TTT gained for choosing the COAs recommended in this thesis are also optimistic. These findings do provide a relationship between TTT and the controllable and uncontrollable factors. It is up to the commander and training officers to monitor these factors and use the COAs to help mitigate their effects.

B. FURTHER STUDY

The metric of focus has been TTT, but there are other factors that could also be included to build a more dynamic model of the process. Flight hours per aircraft and per IP are very important and highly correlated to the TTT. The JSF, like any other machine, will have mechanical, maintenance, and administrative limits driven by utilization that cannot be breached. Once the squadron receives its first aircraft, it will also receive an allotment of funds for fuel purchases each quarter. This allotment and the current cost of fuel will determine a flight-hour budget and a maximum total number of flight hours per month that the squadron can fly. This factor is not simulated in the ITC, but is recorded as part of the output. There are no limitations placed on how many hours or sorties an aircraft can fly, as there are limits on how many hours a student or instructor can work in a day. To capture this effect, an experiment would have to be designed to look at aircraft utilization for each month, coupled with a predicted flight-hour budget, to see which scenarios are fiscally possible and to help predict what level of funding to request for training. This can also help predict a more reliable estimate of TTT by ruling out infeasible scenarios.

An investigation of other resources, not explored in this thesis, may be helpful in discovering other bottlenecks in the system. A study of the delays in completing events could help pinpoint a general direction in which to find and fix these bottlenecks. The explanations of these delays are often vague and may require multiple designs to properly investigate them. Combining designs of experiment one, two, and three into one grand design may produce a better understanding of the relationship between all factors.

This thesis looked at the ITC model during the ramp-up mode. Further studies in the steady state mode would be of value, especially once reliable statistics become available with respect to aircraft failure rates and repair times, as well as student attrition rates and weather cancellation rates. Without actual data on JSF training times, the ITC model can continue to be a reliable predictor and tool for the commander when faced with unforeseen changes in resources or unexplained changes in some of the noise factors.

LIST OF REFERENCES

A. C. Liberman, M. U. (2011, April 18). email correspondence.

Bolkcom, C. (2007). *F-35 Lightning II Joint Strike Fighter (JSF) Program: Background, Status, and Issues.* Washington, DC: Congressional Research Service.

Born, G. (2007). Joint strike fighter modeling and simulation accreditation assessment for the ITC simulation model. Arlington: Joint Strike Fighter Program Office.

Cioppa, T. M., & Lucas, T. W. (2007). Efficient nearly orthogonal and space-filling Latin hypercubes. *Technometrics*, *49*(1), 45-55.

Dummar, J. (2011). *Improving the Integrated Training Center (ITC) model to achieve More accurate time to train estimatest.* (Operations Research Master's thesis). Naval Postgraduate School, Monterey, CA.

Gertler, J. (2010). F-35 joint strike fighter (JSF) program: Background and issues for congress. Congressional Research Sevice.

Gray, G. W. (2010, October 28). F-35 Integrated Training Center Model Assumptions Document October 28, 2010. *Power Point Presentation*. Lockheed Martin.

Kenney, P. (2009). Joint strike fighter integrated training center simulation model accreditation support package (Integrated training center development for SDD). Tampa: Paul Kenney.

Majumdar, D. (2011, January 10). *Lockheed: One F-35B Problem Fixed.* Retrieved August 19, 2011, from DefenseNews: http://www.defensenews.com/story.php?i=5422990

McDonald, M. (2010). Overview of "experiment 5" analysis. PowerPoint briefing. Naval Postgraduate School, Monterey, CA.

Operations, C. O. (2009, November 23). NATOPS General Flight and Operating Instructions. *OPNAV 3710.7U*. Washington, District of Columbia, USA: US NAVY.

O'Rourke, R. (2009). Tactical aircraft modernization: Issues for congress. Washington D.C.: Congressional Research Service.

Ross, S. M. (2007). *Introduction to probability models* (9th ed.). T. Singer (Ed.). Berkley, CA: Academic Press.

Sall, J., Creighton, L., & Lehman, A. (2005). *JMP Start Statistics.* Belmont, CA: Thomson Brooks Cole.

Sanchez, S. M. (2000). Robust design: Seeking the best of all possible worlds. *Proceedings of the 2000 Winter Simulation Conference* (J. A. Joines, R. R. Barton, K. Kang, & P. A. Fishwick (Eds.) Monterey, CA: Naval Postgraduate School.

THIS PAGE INTENTIONALLY LEFT BLANK

INITIAL DISTRIBUTION LIST

1. Defense Technical Information Center
   Ft. Belvoir, Virginia

2. Dudley Knox Library
   Naval Postgraduate School
   Monterey, California

3. Marine Corps Representative
   Naval Postgraduate School
   Monterey, California

4. Director, Training and Education
   MCCDC, Code C46
   Quantico, Virginia

5. Director, Marine Corps Research Center
   MCCDC, Code C40RC
   Quantico, Virginia

6. Marine Corps Tactical Systems Support Activity
   (Attn: Operations Officer)
   Camp Pendleton, California

7. Director, Studies and Analysis Division
   MCCDC, Code C45
   Quantico, Virginia

8. LtCol Villalobo
   F-35 Lightning II Program Office
   Arlington, Virginia

9. Director, SEED Center
   Naval Postgraduate School
   Monterey, California

10. Maj Lieberman
    USMC AETC VMFAT-501/S-3
    Eglin AFB, Florida

11. LCDR Davidson
    Naval Postgraduate School
    Monterey, California