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AN ANALYSIS OF THE IMPLEMENTATION
PLAN FOR THE CONVERSION FROM
THE T-37 TO THE T-46 AIRCRAFT
IN UNDERGRADUATE PILOT TRAINING

THESIS

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The model has the inherent flexibility to model different scenarios, bases, and aircraft by changing input variables and distribution parameters to fit the environment being studied. The model can be used as a general production model which transforms periodic inputs (students) into outputs (pilots) using limited resources (instructors, aircraft, daylight, simulators) on a prescribed schedule (syllabus) with random variations (weather and maintenance cancels, et al.).

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AN ANALYSIS OF THE IMPLEMENTATION PLAN FOR THE

CONVERSION FROM THE T-37 TO THE T-46 AIRCRAFT

IN UNDERGRADUATE PILOT TRAINING

THESIS

Presented to the Faculty of the School of Engineering

of the Air Force Institute of Technology

Air University

In Partial Fulfillment of the

Requirements for the Degree of

Master of Science in Operations Research

Jack R. Dickinson, Jr., M.S.   Glenn E. Moses, B.S.

Major, USAF   Captain, USAF

March 1984

Preface

The purpose of this study was to provide insight and identify factors which significantly affect pilot production at Laughlin AFB during the conversion from the T-37 to the T-46.

The simulation models developed in this study could represent different bases or aircraft if the variables are changed to fit the environment of interest. In fact, the models can easily represent other input-output systems. The T-37 model transforms periodic inputs (students) into an output (pilots) using limited resources (sorties, instructors, aircraft, daylight) on a prescribed schedule (syllabus). Likewise, the T-46 model represents a system, which much change a primary component incrementally while continuing production (the T-37 to T-46). A knowledge of Fortran and SLAM is necessary to modify the present models.

In the development of this thesis, we are deeply indebted to our faculty advisors, Maj James R. Coakley and Lt Col Palmer W. Smith, for their patience and encouragement. We appreciate the outstanding support from the men in DOXX and DOXP at ATC Headquarters, who made analyzing an actual problem possible. Finally, we wish to thank our wives Libby and Sissy, the two people whose loving support made this thesis possible.
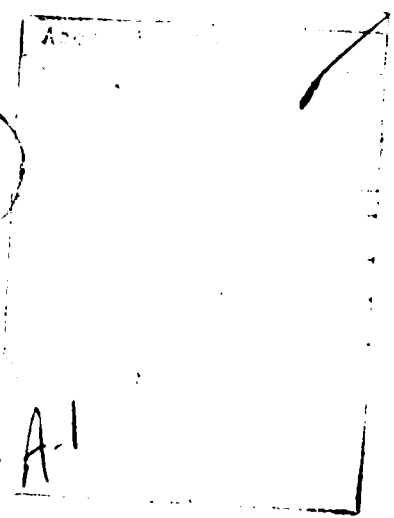
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Table of Contents

List of Figures

vi

List of Tables

AFIT/GST/OS/84M-8

Abstract

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statistically significant factors affecting the ability of
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while simultaneously converting from the T-37 to the T-46
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(syllabus) with random variations (weather and maintenance
cancels, et al.).

I Introduction

In 1987, Air Training Command (ATC) will begin
replacing the T-37 aircraft with a new aircraft, the T-46.
ATC is unable to shut down a training base during the
conversion period and still meet the annual demand for new
pilots; therefore, ATC is exploring plans which will
minimize the conversion period without reducing the student
pilot production at the base receiving the new aircraft.

Background

ATC has been essentially a steady state system for well
over 20 years using the T-37 and T-38 aircraft to train
student pilots. Although the annual demand for new pilots
changed, the system characteristics did not. This stability
enabled ATC to estimate pilot production and required
resources with very simple models (2).

In fact, the primary model in use for predicting the
number of students a base can train and the amount of
resources required for the training is the automated
training capability model which is based upon simple
analytical relationships using mean values; variance is not
considered. Once the capabilities of the base are
determined, the values are used to create the Program Flying
Training Document which projects the total training load and
flying requirements for all of ATC for the next five years.
The present model accepts mean parameters as inputs for use

in analytical relationships but cannot model the conversion
period without modification. In addition, the documentation
for the present model includes no data on factors screened
for significant effects upon model output; the model assumes
the factors limiting student training are the number of
instructors assigned, the number of daylight hours
available, the number of aircraft available and the number
of training days available (10). These factors are modeled
as independent constraints; no interactions are considered.
The model is the only computational aid available to the ATC
planners responsible for the formal conversion planning.

ATC has developed the T-46A Master Implementation
Plan for the conversion from the T-37 to the T-46;
however, no experimental model has been developed for
testing the plan. Presently, a manual approach is being
used to devise the plan (5). Due to the large number of
calculations involved, this severely limits the number of
options considered for implementing the conversion. In
addition, the manual approach forces ATC to estimate the
length of the conversion period and the expected pilot
production during the conversion using anticipated mean
parameter values with no estimated variance.

Statement of the Problem

The conversion to the T-46 aircraft must be given a
great deal of thought and planning. Indeed, a plan for the
future conversion exists and is periodically revised to

2

reflect new information and changes; however, no parametric

analysis of the proposed plan has been accomplished to

identify necessary changes. (Parametric analysis is a study

of quantifiable relationships using statistical techniques.)

There are several reasons for the lack of parametric

analysis. First, ATC's present model does not include the

changes occurring within the system during the conversion

process. Furthermore, it would be very difficult for the

Programs and Long Range Planning Division (XPX), the office

of primary responsibility for the implementation plan, to

incorporate appropriate revisions to the current model. The

division has limited access to computer resources and lacks

available personnel trained both in modeling and computer

programming to devote to the analysis. Consequently, a

thorough analysis of the implementation plan to identify

significant factors which can prevent its sucessful

implementation is needed (14). For the analysis to be

useful, it must focus upon measures of system effectiveness.

Measurements of Effectiveness

A primary goal of ATC is to have a "smooth flow" of

pilot production within the system. By smooth flow, ATC

means that when one class graduates, another starts so that

students progress on schedule through the training program

and resources are used efficiently. The smooth flow is

necessary because the major commands are unable to adapt to

sudden changes to the pilot production rate. ATC's ability

3

to attain smooth flow is measured by the number of days required to graduate each class. The conversion to the T-46 is expected to disrupt the smooth flow process; therefore, ATC is also interested in estimating the time required to complete the conversion. Consequently, a major goal of ATC during the conversion is to continue graduating classes within the alloted time frame and accomplish the conversion as expeditiously as possible (5).

While no absolute limiting values exist as criteria to judge the above measures, a qualitative ranking is clear. The conversion time can be minimized by transitioning classes before adequate T-46 resources arrive, but the classes would not be able to graduate on time. On the other hand, the conversion could be delayed until all resources are in place to decrease the risk of late flights; however, this also is undesireable. Delaying the conversion prolongs the period maintenance must maintain both aircraft, the amount of time extra instructor pilots must be at Laughlin, and may cause monetary penalties for delayed contracts such as the simulator conversions. Likewise, the conversion is expected to increase the number of days for classes to graduate. Obviously, the goals conflict; the goal of graduating classes on time is more important to ATC than minimizing the transition (5).

Research Question

The research question is: During the conversion from

4

the T-37 to the T-46 aircraft, what factors will
significantly affect the ability to produce new pilots on
schedule or significantly affect the time required to
complete the transition?

Objective of the Research

Based upon the previous discussion, objectives must be
accomplished in order to answer the research question. The
objectives will be satisfied under specified conditions
(scenario) and assumptions within the scope of the research.
The following sections present the objectives, scope,
scenario, and assumptions in detail.

Objectives. The overall objectives are as follows:

1. Identify those factors which significantly affect
   the time required to complete the conversion.

2. Identify the factors which significantly affect the
   average number of days required to graduate a
   flight during the transition.

Accomplishing these objectives will provide insight for
decision makers within ATC on the potential impact of their
decisions before and during the conversion.

Scope. The conversion process will involve
numerous agencies. The implementation plan provides
guidelines for plans, logistics, personnel, public affairs
and the inspector general, just to name a few of them. This
research will focus on the operational aspects of the plan.
Furthermore, the portion of the operations area that will be
analyzed is the ability of ATC to complete the conversion

expeditiously, while maintaining the pilot production for the Air Force.

Even though undergraduate pilot training is conducted at five bases, only Laughlin AFB will be examined and modeled. Laughlin was selected for the base case since it has been chosen as the first base to undergo the conversion. Any lessons or applications derived from this research effort can be used at the remaining bases.

Scenario. The scenario of the conversion will be as stated in the implementation plan devised by Air Traning Command. A prescribed concept of operation is set forth in the document. Briefly stated, these concepts state the conversion will start at Laughlin AFB in April of 1987. An initial Instructor Pilot (IP) Cadre of trained T-46 instructor pilots will be responsible for qualifying IP's at Laughlin AFB in the T-46. After 31 hours of academic training, each base assigned IP will receive 15 flights in the new aircraft under the guidance of a Cadre IP. A flight of approximately 17 base assigned IPs will be qualified in the T-46 before assigning the first student flight to the new aircraft (11).

Student training in the T-46 is expected to begin with class 88-10 which enters on July 6, 1987. At the present time, a new student class enters every six weeks; however, ATC plans to change to a three week entry cycle before the T-46 transition begins. A class entering on the three week

6

system will be approximately half the size of the current classes.

Presently, the students train in two T-37 simulator complexes; each complex contains four simulators. Prior to the first student class being assigned to the T-46, one T-37 simulator complex is to be converted into a T-46 simulator complex, which will also contain four simulators. Six months after the first class enters T-46 training, the second complex will begin its conversion to a T-46 complex. Simulator training requirements will be reduced and flying requirements increased when classes are not expected to have simulator facilities available or when classes have a higher than normal number of students using one simulator complex. The revised requirements are included in the implementation plan (11).

Assumptions. The following assumptions apply to this research effort:

1. The T-46A Master Implementation Plan contains the current ATC policy for implementing the conversion.

2. ATC will convert only one base at a time to the T-46.

3. The base is in a steady state condition when the conversion commences; no radical change from historical trends will occur immediately prior to the conversion period so that the parameters of the system can be estimated from historical data.

4. The students completing the T-37 or T-46 training
    are required to go through further training;
    therefore, graduating each class on time is
    necessary to preclude delaying other programs. A
    flight or class is considered late if any student
    assigned to that flight or class has training
    requirements (normally flying sorties) remaining
    after the last allotted training day (2).

Applied Methodology

The overall steps and methodology to be taken to

accomplish the proposed objective is as follows:

1. Understand the implementation plan as proposed by
    ATC.

2. Develop a concept of the system and determine the
    required data to be gathered.

3. Build a model that will adequately represent the
    system of concern before and during the conversion.

4. Verify and validate the model.

5. Change the values of selected variables and perform
    an analysis to identify factors which significantly
    affect the measurements of effectiveness.

Understanding the Plan. Although an implementation

plan has been proposed by ATC, the plan merely provides

overall guidance for a complex transition and lacks some of

the fine detail needed to model the conversion. Some of the

fine details are simply unknown at the present time and

cannot be explicitly stated in a proposal that is written

for future use. Revisions will be made to the plans as time

progresses and more information becomes available. For

example, the criteria for selecting the type aircraft for

the student classes is not in the plan.

Rather than blindly make assumptions on such key

issues, it is important to incorporate the judgment of the planners at ATC. Planners at ATC can only offer their educated guesses to answer these questions; however, their knowledge and visions of the conversion are likely to influence the future decisions. Therefore, a close working relationship with the ATC planners is important if the future system is to be successfully modeled today. For these reasons, the plan must be thoroughly understood and any questions concerning the plan must be answered to the best of the ATC planner's knowledge before a thorough concept of the system is possible.

Concept of the System. To develop a concept of the system, relationships between variables of the system are hypothesized based upon an understanding of the implementation plan and the operational experience of the modelers. Once this is accomplished then the necessary data can be gathered.

The UPT system is complex and many variables are present in the system. Because ATC is primarily responsible for training all potential USAF pilots, a great deal of forecasting and planning is done. Estimates for required pilot requirements are given five years in advance (12). This is helpful since the conversion will take place in 1987. Data on students per class, number of aircraft available (T-37 and T-46), IP's available, sorties required to graduate, days between class entries, proposed

9

utilization rate of aircraft, and arrival rate of new

aircraft are required and available from ATC. Not only is

proposed future data necessary but past historical data will

also be needed to form statistical distributions for random

variables. For example, data is required for weather and

maintenance, sortie cancel rate, student attrition, and

maintenance sortie production capability. Historical data

for all of these variables is also available from ATC. Once

a concept of the system is formed and the availability of

supporting data is assured, a model can be built to

accurately represent the system.

Model. One of the first tasks in formulating a

model is selecting appropriate output variables to represent

the measures of system effectiveness. The output variables

chosen for the model are the following:

1. The average number of days required for a class to
   graduate

2. The average number of sorties remaining for classes
   that graduate late

3. The number of days needed to complete the
   conversion to the T-46

The average number of days to graduate a class directly

represents one the measures of effectiveness used by ATC.

ATC considers a class late if any student in the class has

any sortie requirements remaining after the last scheduled

training day; therefore, the average number of days to

graduate does not indicate the precise amount of training

remaining on the scheduled graduation date (thirty-five

10

sorties remaining and one sortie remaining both equate to
one day late). If sorties remaining on the scheduled
graduation day is measured, this information is not lost;
however, the measurement of sorties remaining would be more
sensitive to small changes in input variables. Both of
these measures are surrogate measures of ATC's ability to
maintain a smooth flow and differ primarily in sensitivity
to changes in input variabes. The days required to complete
the conversion also directly represents one of the
measurements of effectiveness desired by ATC.

A model will be developed to produce these measures of
effectiveness: all input variables needed to produce these
measures will be inculded in the model. No explicit
relationship between measures of effectiveness will be
quantified for ranking alternatives in this study. Instead,
variables significantly changing any of the measures of
effectiveness will be identified to gain further insight
into the system.

Verification and Validation. If a model is not
verified and validated, erroneous results may be accepted
with disasterous consequences (32:29). In order to properly
verify and validate the model for this study, the model must
first represent the system as it exists today. This implies
that the model will be built with components unique to the
UPT environment with the T-37 aircraft. Once the model
representing the T-37 system is verified and validated,

11

components applicable to the conversion and T-46 aircraft can be added (such as the ability to generate T-46 flying and simulator sorties).

Although the T-46 model can be fully verified, no historical data exists for validation of the model containing components unique to the T-46 aircraft. For these components, hypothesized values for the variables must be set and the model checked for reasonable output and sensitivity to changes in the variables. After completing the verification and validation effort, the model can be used to identify the input variables which have a significant effect on the output variables.

Analysis of Significant Factors. To identify significant factors, high and low values within the anticipated range of the variables of interest will be selected for use as inputs to the model. An experimental design will be selected to determine the necessary combinations of variable values and the number of computer experiments using the model. Analysis of Variance (ANOVA) will be applied to the results to identify the significant factors.

In addition to ANOVA, it may be necessary to perform sensitivity analysis. Three cases which may require sensitivity analysis are:

1. A need to identify the effect of a random variable which was not included in the parametric analysis,

2. A need to examine the effect of varying an

12

assumption which affects the structural
relationships within the model, and

3. A need to examine the model output over a different
   range of values for a particular variable of
   interest.

The methodology is schematically depicted in Figure 1.
The process is iterative and regression to previous steps
will occur.

Summary

ATC is replacing the T-37 with the T-46 aircraft in
1987. Due to existing model limitations and resource
constraints, ATC has not conducted a parametric analysis to
determine what factors will significantly affect the pilot
training system during the conversion. This research is
limited to the scenario described in the T-46A Master
Implementation Plan for the conversion at Laughlin AFB.
An appropriate model will be formulated, verified, and
validated for the present system and modified to reflect the
changes occurring during the conversion. This study will
use ANOVA on the model output to identify the factors which
have a statistically significant effect on the average
number of days to graduate a class, the number of sorties
remaining at graduation for late classes, and the number of
days required to complete the conversion.
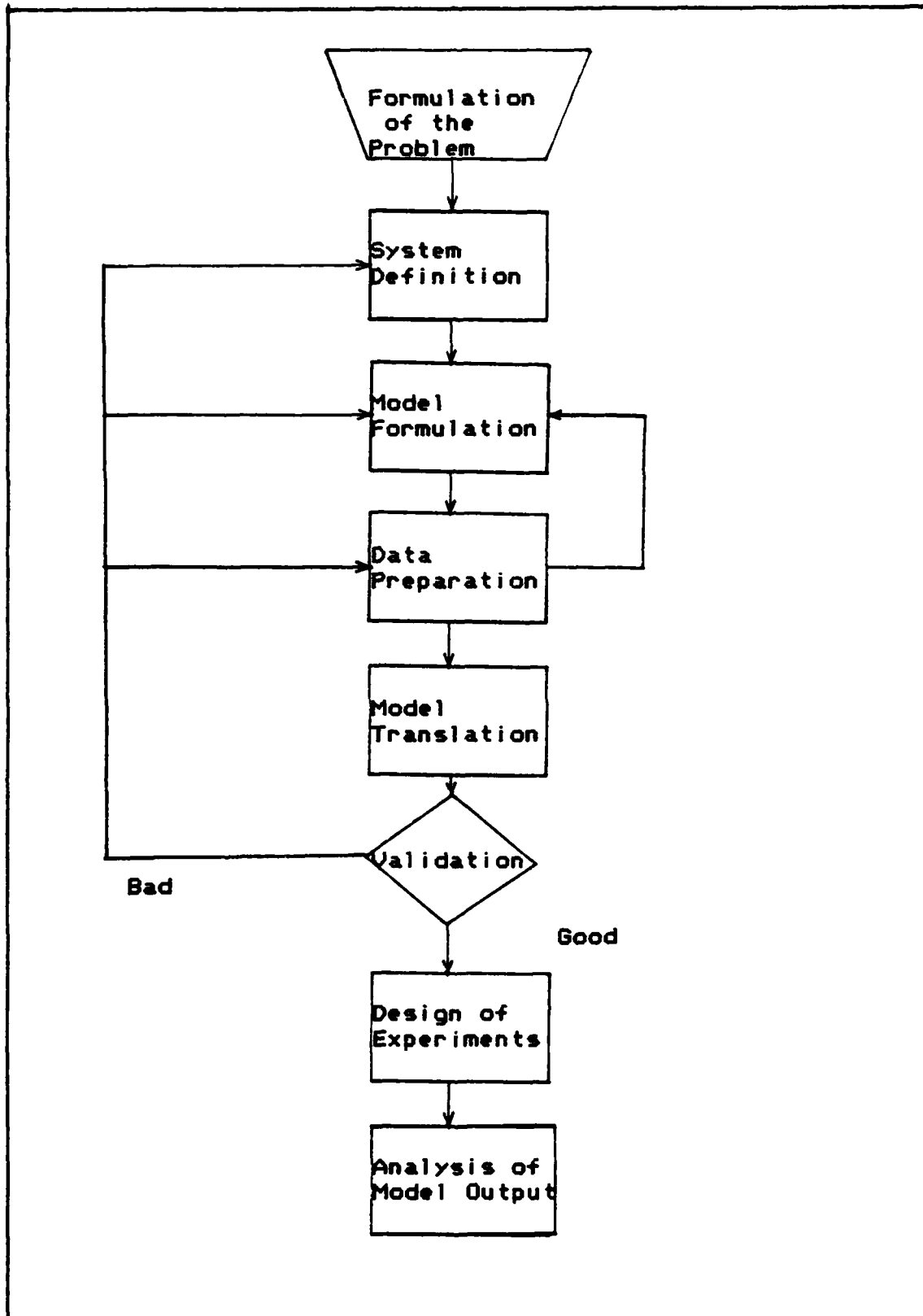
Figure 1. Problem Methodology

II Literature Review

Air Training Command's (ATC) effort to ensure that the
conversion process goes smoothly and student output does not
vary from Air Force needs is contained in the document
labeled T-46A Master Implementation Plan. This plan
contains a description of ATC's desired method and schedule
for implementing the change to the T-46A aircraft (hereafter
termed T-46) and converting the T-37 flight trainers into
T-46 flight trainers. The document is the combined effort
of the ATC staff to anticipate the actions needed to produce
an orderly conversion and tentative schedule of events.

In order to logically build the T-46 implementation
plan, several sources of information were used. All of
these sources are Air Training Command publications : the
Program Flying Training Publication, the automated training
capability model, and the syllabus of instruction for
undergraduate pilot training (5).

In addition to sources and manuals specifically
relating to the problem, similar problems and other
individual's approaches to these problems were investigated.
This section presents a description of material related to
the problem.

T-46A Master Implementation Plan (11)

As previously stated, the T-46A Master Implementation
Plan is the sole publication directed exclusively to the

conversion process. The office of primary responsibility for the plan is XPX, Headquarters, Randolph Air Force Base. The plan addresses objectives, assumptions and concepts of operations, not only in the operations area, but in the plans, logistics, personnel, public affairs, engineering and services, inspector general, and technical training areas. For the scope of this research, only plans for the operations area will be discussed.

The objective of the operations plan is to provide operational guidance for the integration of the T-46A aircraft and Instrument Flight Simulator (IFS) into the ATC Undergraduate Pilot Training (UPT) Program (11:i-1). The concept of operations is the heart of the implementation plan and herein lies the basis of the operational conversion to the T-46A.

The plan discusses all portions of the conversion that ATC deems critical. The plan states that T-46 aircraft delivery will begin at Laughlin AFB in Apr 1986. Additional manpower will be allotted to the base during the conversion. This manpower force will include instructor pilots responsible for training base assigned instructors in the T-46 aircraft and a flight of instructors to replace the first flight that will go into this transition training. (Each base has six flights and one flight at a time will transition into the T-46 aircraft). Each IP flight undergoing transition is given either 15 or 30 days to

become qualified in the T-46. Each flight checked out in the T-46 will replace a flight of T-37 qualified instructors (IP's) and the cycle will continue until all the IP's are T-46 qualified.

Student T-46 training is expected to begin with the class entering on 6 Jul 1987. Thereafter, the conversion will follow a planned schedule. The conversion will require a simulator swap-out. There are presently two T-37 simulator complexes, and each complex is to be modified into a T-46 complex. In order to maintain simulator availability, only one complex will be shut down at a time. Six months prior to the first class entry into the the T-46 program, one T-37 complex will be shut down. Hopefully, this will ensure that a T-46 simulator complex will be available for the initial T-46 class. The other T-37 simulator complex is scheduled to shut down six months after the first T-46 class enters and is expected to become an operational T-46 simulator complex in another six months. ATC has several alternative syllabii for the conversion period depending upon the simulator availablity and student load.

The final concept of operations is to convert the student class entry cycle from six weeks to three weeks. This change in entry cycle is in anticipation of a specialized undergraduate pilot training program in which students may change bases after the T-46 training for the

next phase of pilot training.

Program Flying Training Document(PFT) (12)

The purpose of the PFT is to provide class entry dates, student class size, and production schedules of USAF flying training programs conducted by ATC (PFT:) Additionally, the document includes resource requirements for planning and achieving these training objectives. The PFT is published February 1, June 1, and October 1 each year by ATC.

The Automated Training Capability Model (10)

The automated training capability model was developed to determine the maximum pilot training capability at each wing under specified conditions. The model was built to specifically provide the following:

1. Factors for distributing an equitible workload to each wing,

2. The impact of major program changes,

3. The best location for new training programs, and

4. An assessment of base requirements during periods of expanding or declining pilot production.

The model was intended to be an improvement over the manual process for determining wing capabilities. The model's primary task is to determine the number of students that can be sustained with a given sortie generating capability. The model operates in two basic steps. In the first step, equations are used to ascertain the sortie generating capability of a given base for each month of the

18

year based upon limited runway, aircraft and instructor pilot capability. Other factors considered are daylight hours per day, maintenance, and weather cancel rates. For the second step, flying training is simulated on a daily basis to determine the largest constant student load that can be sustained utilizing a number of sorties that varies from season to season.

The numbers used to determine the capability of each wing were based on several critical assumptions. Each of the following is estimated using an average value:

1. Monthly weather cancel rate,

2. An annual operations and maintenance abort rate,

3. Aircraft available each month, and

4. Student attrition per class.

It should be noted here that all inputs into the standard capability model are based on averages acquired over a period of several years of past history. Variables that vary significantly over time like student attrition, class progress, and weather and maintenance aborts are all input at the average level when operating the model.

The model was created in 1974 and evolved after an attempt by the OSD and the RAND corporation to create a capability model. Both models were discarded because they required special machines, skills and knowledge for operation beyond that available.

The capability model is not appropriate for analyzing

the conversion for several reasons. First, the model does not consider the variance of the model inputs. Second, the model will not be revised to reflect the changes occurring during the conversion (2). Third, the output of the model does not include appropriate measures of effectives for the conversion period.

Syllabus of Instruction for UPT (9)

The syllabus of instruction outlines the training required for graduates of UPT to achieve the proficiency specified by ATC. It prescribes the content of the course, instructions for conducting the training, and the approximate time required for an average student to successfully complete the individual subjects or phases. This completes the review of documents used by ATC in developing the plan; however, another study has been completed since the plan was written.

Related Studies

Another study which centers upon the planned T-46 conversion is a thesis by Major Seth Jensen. Major Jensen's thesis, like the capability model, uses average values for all data and fails to consider factors such as T-46 aircraft arrival rate, failure to meet the planned simulator complex conversion schedule, and varying T-46 utilization rates. In essence, there was no sensitivity analysis of critical factors. On the basis of a limited number of hand

20

calculations, Major Jensen concluded the plan is infeasible (18). Due to the complex nature of the problem and the large number of factors, sensitivity analysis in his study without computer assistance was extremely impractical. Considering the limitations of this study, a more detailed look at the plan is deemed necessary.

There have been aircraft conversions in other parts of the Air Force; however, the method of conversion differs. Operational units simply go non-combat ready until the personnel are qualified in the new aircraft (1), whereas ATC plans a gradual conversion while maintaining the programmed rate of pilot production (2).

Summary

The T-46 implementation plan is ATC's attempt to ensure a smooth conversion without a decrease in the rate of student training. The other manuals and documents referenced when the implementation plan was conceived are: the Program Flying Training Document (PFT), the Automated Training Capability Model, and the syllabus of instruction for Undergraduate Pilot Training (UPT). ATC has not conducted a parametric analysis of the conversion plan because no appropriate model exists for conducting the analysis. In a thesis, Maj Seth Johnson analyzed the plan using a limited number of hand calculations and concluded that it is infeasible as written. Other units aircraft conversions differ from the T-37 to T-46 conversion because

the other units simply go non-combat ready until the
personnel are qualified in the new aircraft while ATC must
continue to graduate student pilots during the conversion.

III System Structure

This section includes a discussion of the current Undergraduate Pilot Training (UPT) environment, the changes to that environment caused by the conversion, and the general structure necessary to translate that environment into a model. The intent is to provide an insight to the system structure by explaining the key operations, elements, and events of the pilot training process and to provide a logical framework for the computer model.

Purpose of the UPT Wing

The purpose of a UPT base is to qualify graduates of UPT for the aeronautical rating of pilot and to prepare them for their future responsibilities as military officers and leaders. This includes flying training to teach the principles and techniques used in operating high speed jet aircraft and ground training to supplement and reinforce flying training.

Presently, there are five UPT bases in the U.S. which train primarily United States Air Force (USAF) students. Forecasts are made to determine the quantity of USAF pilots required each year in order to fulfill Air Force (AF) requirements. Subsequently, students are assigned to a specific base to undergo pilot training. Due to various factors (weather, flying environment, base size, etc.) each base can adequately train only a certain number of students

23

per year. Because the capabilities of the bases and AF

needs change, the number of students undergoing training

varies from base to base and year to year. Although total

pilot production from year to year is expected to vary, a

large difference in production would prevent a steady flow

of graduates (2).

As briefly stated in Chapter 1, a goal AF pilot

training production is "smooth flow." This means that there

must be very few surges into the system. In other words,

the production process is analogous to a tank that is filled

at the top and emptied from a faucet at the bottom. The

tank is "filled" with students and the faucet will "empty"

graduates. It is undesirable to ever have the faucet

completely opened or closed for this can result in wasted

resources (aircraft and instructor pilots idle) or an

overtaxing of the entire process with spillover effects

outside of the UPT process. Any surge into the system

causes numerous complications and must be avoided whenever

possible. Therefore, a major goal of each wing is to

graduate students within a specified time span.

The length of the total UPT program is approximately 49

weeks. It is divided into three separate phases of

training. Phase I consists of 17 days of preflight training

which includes briefings, familiarization of the T-37

cockpit, study sessions and other activities that enhance

the student's training and preparation for Phase II. Phase

II training consists of flying the T-37 jet aircraft trainer, and 81 flying days are allotted to complete this phase. Finally, Phase III consists 108 flying days in the T-38 aircraft. Each type of aircraft (T-37, T-38) belongs to a separate squadron at each UPT wing. Because this research effort is concerned with Phase II training, only items relating to this phase will be discussed in detail.

UPT Class

Presently, eight classes per year arrive at each UPT base. The arrival date of a class for each base is identical, as is their designation. For instance, class 84-01 is the designation of every class that arrived at a UPT wing in November of 1982 and graduates as the first class of fiscal year 1984. The time span between class arrivals is spaced such that there is an equal amount of duty days between each class entry. This results in an unequal amount of actual calendar days between arrivals, since there is not an equal amount of duty days in each month. Whenever a class is scheduled to graduate from Phase II training, another class is scheduled to begin training. This occurs in order to ensure the smooth flow process discussed earlier. Upon entry into Phase II training, each class is divided evenly and assigned to one of six flights in the T-37 squadron.

T-37 Squadron

There are fifteen to twenty instructor pilots assigned to each flight. These instructor pilots fly only with students in their flight. The ratio of students to flight assigned IP's is approximately two to one. Other instructor pilots are assigned to the T-37 squadron but not assigned to any particular flight. These instructors are members of the squadron staff (assistant section commander, section commanders, operations officers, etc.). Staff instructors are allowed to fly with students in more than one flight but are available to fly on a limited basis only. In addition to the flight assigned and squadron assigned instructor pilots, other instructor pilots called "guest" or "attached" IP's may also fly with students.

"Guest" instructor pilots are not assigned to the T-37 squadron. These instructor pilots are either wing assigned or assigned to the academic squadron (which has the responsibility for ground training). In either case, these instructors are also qualified in the T-37 aircraft. These "guest" help IP's will normally fly with students in no more than two flights. The purpose of limiting the guest IPs to flying with only two flights is to ensure continuity of instruction for the students.

Training Process

The UPT course is designed to ensure adequate training for each student in a specified amount of time. The

26

syllabus of instruction is the sole document outlining the training requirements to graduate and is based upon the average student's learning and flying ability. The syllabus places many constraints and limitations upon the class during the training process; the major constraint is the amount of training allowed in one day. A class will be scheduled to fly approximately eight hours of each duty day. This eight hours is broken into two flying periods. A student can accomplish either one flying sortie or one simulator sortie in each period for a maximum of two syllabus activities per day. Once the eight hours has transpired, a class is "removed" from the flight line and their accomplishments are recorded.

A student will not be able to accomplish anymore than two syllabus training events because of the time element involved. Prebriefing, flying the sortie, and post briefing for two activities will consume most of the available time on the flight line. In addition to flying training, students are required to receive academic training during the portion of the day not spent on the flight line. Since academic training is required throughout the flying training course, a strong effort is made by each flight to ensure all students are available on time for each academic class.

Regardless of the type of training (flying or academic), the syllabus of instruction revolves around a prerequisite basis. All activities in the syllabus have

prerequisites, and the required syllabus sequence is enforced. Sometimes a student's progress halts until the prerequisites have been accomplished. For example, if a solo flight has to be accomplished in order for the student to progress, the student may not be permitted to fly other sorties until the weather permits the solo flights to launch (solo flights require better weather conditions than flights with instructors). The syllabus of instruction presently requires each student to accomplish 57 T-37 flying sorties (including 10 solo sorties) and 25 simulator sorties.

Scheduling Process

Like any complex organization living on a time schedule, forethought is required in order to optimize the use of the available resources. This is the underlying goal of scheduling in ATC. At the end of every week, each flight scheduler will put in a request for aircraft and simulator sorties for the upcoming week. Since only a limited number of aircraft and simulators are available for each week, it is paramount that each scheduler make a conscientious effort to ensure resources are used effectively. Requirements will be different for each flight because each one is at a different point in training and syllabus requirements are different throughout the course of training. Additionally, the number of students and IP's available for the upcoming week will vary from flight to flight.

Once the flights have put in for their desired weekly

sortie contract, a coordination branch will divide the available sorties among the flights in an equitable manner so that no flight is slighted and the class that is farthest along in training remains as close to their training schedule as possible. Ensuring that a class completes training on time is critical for two reasons. First, the class needs to progress to Phase III on time to prevent starting this phase behind schedule. Second, the class needs to make room for a new class to enter training in the same flight. It is possible to do some daily maneuvering of the schedule, but only a very few changes are possible since most flights hesitate giving up any of their allotted aircraft or simulator sorties.

The wing publishes weekly the position of each class lies in relation to the "time line". The required time line depicts the percentage of training the class should have completed for the number of days the class has been in the program (if the class is to graduate on time). The position of each flight in relation to the time line is used when the weekly schedule contract is finalized. As previously mentioned, priority is given to a senior class that is behind the time line.

There are several major limitations on the total number of sorties possible in one day. First, over 95% of all sorties must be flown during official daylight. Second, not all the assigned aircraft are operationally ready to fly

29

each day. Third, there is a maximum number of sorties per day per aircraft. Fourth, students may fly a maximum of two sorties per day. Fifth, the number of instructors is limited each day. Finally, air traffic control requires at least three minutes separation between aircraft takeoffs. Within these limitations, the available sorties are distributed among the classes.

The previous discussion is centered around how a UPT wing exists and operates today. When the time comes to initiate the conversion process, there will be some minor changes in the system, which nonetheless cannot be overlooked if an adequate analysis of the process is to be done.

Conversion Process (11)

Most of these system changes are as stated in the implementation plan and were discussed in Chapter II. It is appropriate though to expand upon some of these changes for they are fundamental to understanding the state of the system when the conversion is initiated.

Approximately one year prior to the initiation of the conversion process, T-46 aircraft will begin arriving at Laughlin AFB. When sufficient aircraft are available, a "bubble" of 30 additional IP's will arrive at Laughlin. Fifteen of the 30 IP's will replace the IP's in the flight that will train the first T-46 class. The other fifteen will be responsible for qualifying T-37 instructors at

Laughlin into the T-46 aircraft. This will result in IP's
and students training in the T-46 simultaneously. After a
flight of instructors is qualified in the T-46, they will
replace a flight of T-37 qualified IP's who then begin
qualification training in the T-46. The process will
continue until all base assigned IP's are qualified in the
T-46.

If sufficient resources are available, a new class will
train in the T-46; otherwise, the class will train in the
T-37. This will depend upon the number of aircraft
available, the number of IP's available, and the utilization
rate of the T-46 (the ATC Master Plan assumes that the T-46
aircraft will be capable of maintaining a 45 hour monthly
utilization rate throughout the entire conversion).

Six months prior to the first class entering T-46
training, one of the two T-37 simulator complexes will be
shut down and converted into a T-46 simulator complex. To
maintain maximum simulator availability, only one complex
will be shut down at a time. The first T-46 complex is
expected to be completed before the first T-46 student class
enters. The remaining T-37 complex will be used by those
students in T-37 training. If more than three flights are
using a single simulator complex, a 50% syllabus will be
used. This will change the number of flying and simulator
sorties required per student. The last T-37 complex is
scheduled for shut down six months after the first class

enters T-46 training and is expected to be operational six months later. If no simulator complex is available for students entering training, a no simulator syllabus is also available. The reduced simulator syllabii replace the lost simulator sorties with flying sorties. These are the major changes that will occur during the conversion.

The basic understanding of the UPT process enables the components, variables, and the relationships between them to be conceptualized. In order to build an accurate model of the UPT system during the conversion, conceptualization of the system is necessary.

Components and Variables

A thorough review of the UPT process identifies several components and variables that must be included in a model of the UPT system during the conversion. The components of the system are the students, instructor pilots, aircraft, runways, simulators, and the maintenance complex. The students are the key component, and all other components could be classified as resources. These resources are used daily in order to generate sorties. In order to generate and complete a sortie, all of the components listed above become involved. It is intuitive that each component is critical and must be included in any model to accurately describe the system. All variables in the system are related to these components. Identifying the variables that should be included in the model requires sound judgment,

insight, and experience.

For instance, the maintenance component is a very complex subsystem in itself. Should one include in the problem such variables as fuel available, ground support equipment, spare parts available, number of qualified personnel, etc.? If so, the model soon becomes unmanageable. The alternative approach is to aggregate or combine variables at the early stages with the idea of separating them later, if necessary, after better understanding the system and how it operates (32:61). An iterative process is then made to eventually separate all variables that should not be aggregated. This is the method that is used in determining the input variables for the model. This list is shown in Table I.

Table I
Input Variables for the Model
Student per Class Instructors per Flight Flying Sorties Required to Graduate Simulator Sorties Required to Graduate Starting Month for Transition Number of T-46 Aircraft Required to Start Transition Student to Aircraft Ratio Daylight Hours per Month Days to Transition IP's Flying Sorties to Transition an IP Number of IP's in the Cadre Days to Convert a Simulator Complex

Other variables exist which must be included in the model. Key outputs of the model (days to graduate a class,

sorties remaining for late classes, and the days to complete
the conversion) depend not only upon the variables listed in
Table I but also depend upon such factors such as weather,
maintenance, and student attrition. Since ATC has no
control over these variables, they are best represented as
random variables.

A random variable has a probability of equaling a
certain value. A probability distribution is any rule which
assigns the probability to each possible value of the random
variable. The characteristics of the probability
distribution are defined by the parameters of that
distribution. The determination of these unknown but fixed
parameters is discussed in the "Data" section of Chapter IV.
A complete list of the random variable to be used in the
model is shown in Table II. After identifying the
components and variables, the relationships between them can
be hypothesized.

Table II
Random Variables in the Model
Sorties Lost Due to Weather Maintenance Capability to Generate Sorties (Utilization   Rate) Sorties Lost Due to Maintenance Student Attrition Additional IP's Available T-46 Delivery Rate

Relationships Among Components, Variables and Parameters

The relationships of the elements (components, input variables, parameters) for the specific problem is shown in the form of the causal diagrams in Figures 2 and 3. The diagrams display the proposed relationship or effect that each element will have on each other, as well as upon the output variables. This effect is in terms of a relative increase or decrease. The effect is portrayed in the figures by arrows connecting related elements and by algebraic signs showing the direction of change. The effect of increasing the element at the base of the arrow upon the element at the head of the arrow is shown by the sign (a circle with a plus sign implies an increase while a minus sign implies a decrease). A model is built to include the elements and proposed relationships, and these relationships can be tested in the validation phase of the applied methodology.
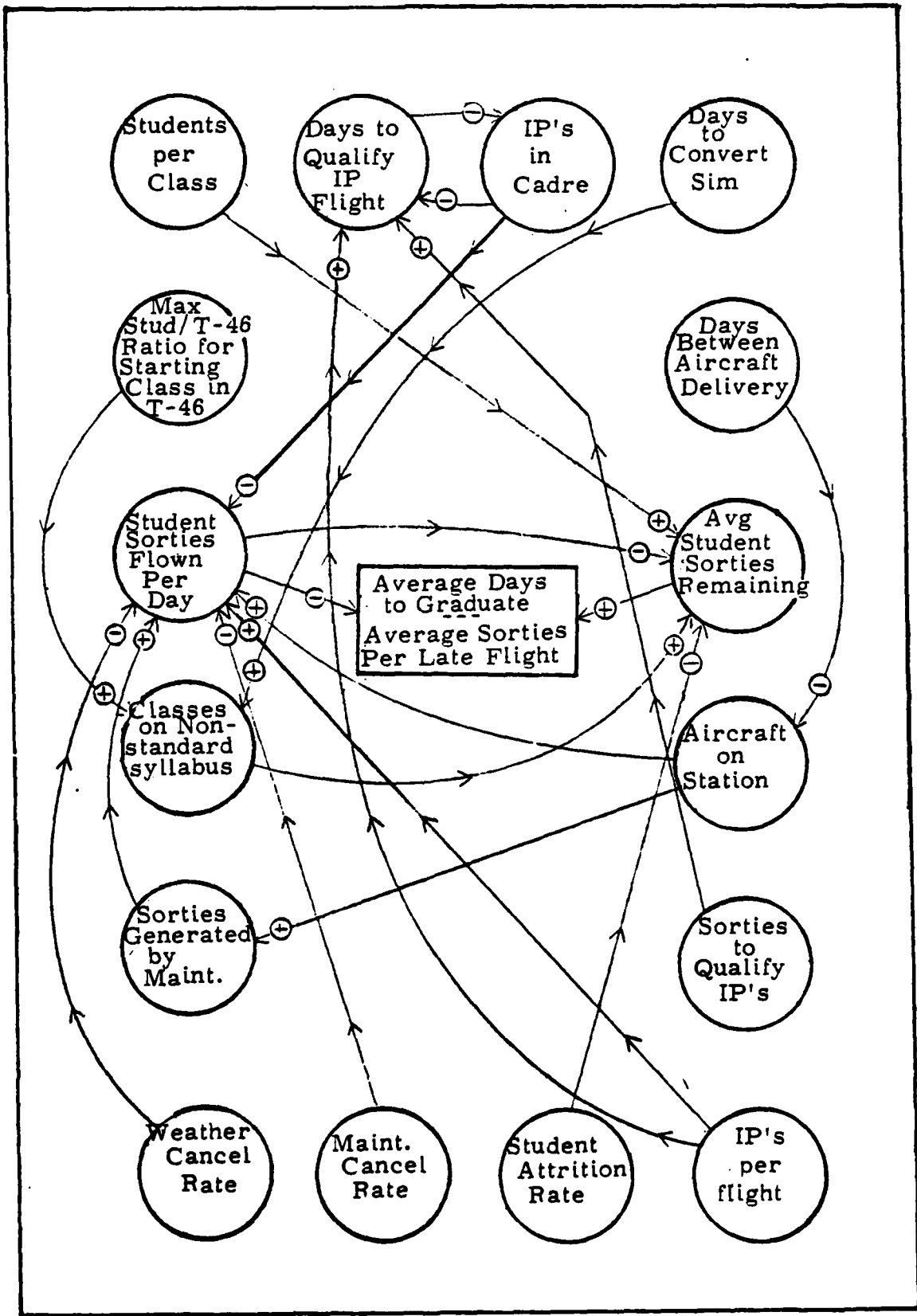
Figure 2. Causal Diagram of Relationships Affecting Days to Graduate or Sorties Remaining for a Late Class

36
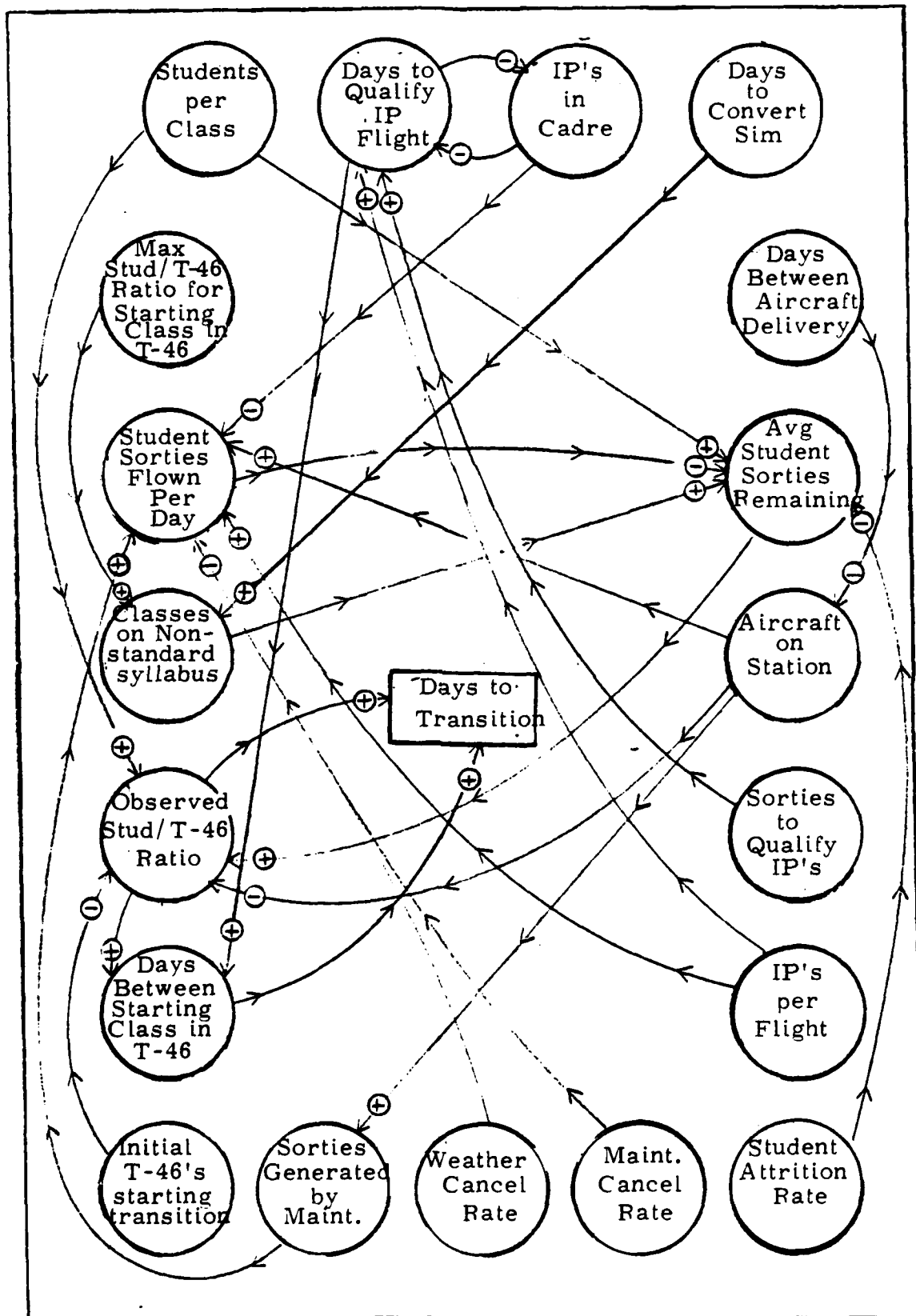
Figure 3, Causal Diagram of Relationships Affecting Days to
Complete the Transition

37

Summary

The purpose of the UPT program is to qualify individuals for the aeronautical rating of pilot. The program is divided into three phases. Phase I is 17 days of preflight training; Phase II is 81 flying days in the T-37 aircraft, and Phase III is 108 days in the T-38 aircraft. Eight classes per year arrive at each of the five UPT bases. After completing Phase I training, classes are assigned to one of the six T-37 flights. Students fly with only IPs assigned to their flight or guest IPs associated with their flight.

A goal of a UPT wing is to graduate students within the allotted time. The number of sorties a class may fly per day is limited by the number of aircraft, IPs, daylight hours, and students available. The number of sorties a class is scheduled to fly is based on these limitations, as well as class seniority and the class position in relation to the "time line".

Changes to the UPT system will occur before the conversion begins (the first student class training in the T-46 starts the conversion). T-46 aircraft will periodically arrive at Laughlin AFB (the first based to be converted), and a T-37 simulator complex will be converted to a T-46 complex. An additional 30 IPs will be assigned to Laughlin AFB. Fifteen of the IPs will be responsible for qualifying base assigned IPs in the T-46, and the remaining

15 IPs will replace the first base IP flight to undergo this training. A decision on the type aircraft a class will use is made when the class arrives. The conversion is complete when all classes are training in the T-46.

The study of the UPT system during the conversion is necessary to identify key components and variables. Understanding and organizing the interactions between the components and variables permits the creation of an accurate model (30:290). The variables to include in a model of the conversion are listed in Tables I and II. The hypothesized relationships of these variables are shown in Figure 2 and Figure 3.

IV Model Design and Development

After formulating the problem and reaching an understanding of the system, a model can be constructed to aid in accomplishing the research objective. The following steps used to create the model are discussed in this section:

1. Define the purpose of the model.

2. Select the type of model.

3. Gather the data and fit to known distributions if possible.

4. Identify constraints limiting the model.

5. Specify the assumptions which apply to the model.

6. Model the existing T-37 system.

7. Model the system during the conversion to the T-46.

8. Verify the models.

9. Validate the models.

10. Employ variance reduction techniques.

Purpose of the Model

The objective of this study requires a model to predict or forecast the future. The model must predict the pilot production capability of a UPT wing undergoing a conversion to a new aircraft and the number of days required to complete the conversion. (The pilot production capability is measured by observing the days required to graduate a class and the sorties remaining for a late class.) The model must provide insight as to which of the many variables

are most significant in affecting overall system performance. The model should also provide insight into the nature of the relationship among the more significant variables and the system's response.

Type of Model Selected

There are many classifications of models which include analytical models, simulation models, gaming models, judgmental models, schematic models and physical models (28:146). The above list is far from exhaustive. The purpose of this section is not to discuss each of the classifications listed above but to state why a simulation model was chosen for this research effort. It is apparent that a quantitative model is needed for the stated problem. Analytical and simulation models together constitute the class of mathematical or quantitative models (28:148). Therefore, a proper choice of a model would be based on either an analytical or simulation approach.

Presently, ATC is using an analytical approach in their capability model to form their conclusions about the system. The model is quite complex and involved and, therefore, requires computer assistance (2). As previously explained, the input values for all variables are based upon mean values. After a thorough study of the UPT system, it is apparent that there are many factors that are better represented by a random variable. For example, student attrition, sorties cancelled by weather, sorties cancelled

41

by maintenance, and the number of instructor pilots available to fly each day varies not only from class to class but from day to day. Entering mean vales for all of these variables may mask the full implications of any changes to the system. This does not imply that ATC is dissatisfied with their present capability model; however, a more in depth study can be accomplished with a model that includes some randomness.

Simulation is appropriate for this problem because it is an experimental and applied methodology which seeks to accomplish the following tasks (32:2):

1. Describe the behavior of systems.

2. Construct theories or hypotheses that account for the observed behavior of systems.

3. Predict future behavior based upon theories of system operation; that is, predict the effects that will result from changes in the system or in its method of operation.

Regardless of the type of model selected, the necessary data must be collected.

Data

A vast amount of data is required to model the UPT system. Not only are data required from past history, but several values relating to the future conversion must be known as well. ATC is cognizant of many of the factors that impact the time to graduate a class and the number of students it can adequately train. Therefore, ATC maintains records on variables which are of interest to the command.

42

The data are in useable form to ATC but not all are in the form a statistician would prefer. Nonetheless, available data must be used.

Data on all variables to be included in the model were gathered from DOX Headquarters ATC. The data included such forecasted items as student class size, IP manning, and number of base assigned aircraft, sortie requirements under varying syllabii, number of daylight hours per month, and percentage of checkride failures. A good deal of the data were estimated by ATC planners, and because they are only estimates, the model was built to accommodate any changes to them.

Most data values concerning the input variables were extracted from the implementation plan and from sources (capability model, syllabus, PFT) listed in Chapter II of this report. In addition to the data just listed, data were needed to estimate the random variables listed in Table II.

Empirical data were available on each of the random variables except the number of additional IP's available to fly per day and the T-46 delivery rate. Data collected on the random variables in Table II are used to form theoretical distributions. Before discussing specifics on any set of data relating to a unique distribution, the general approach taken to formulate these distributions is stated. Figure 4 is an outline of the process used to translate empirical data into a theoretical distribution.
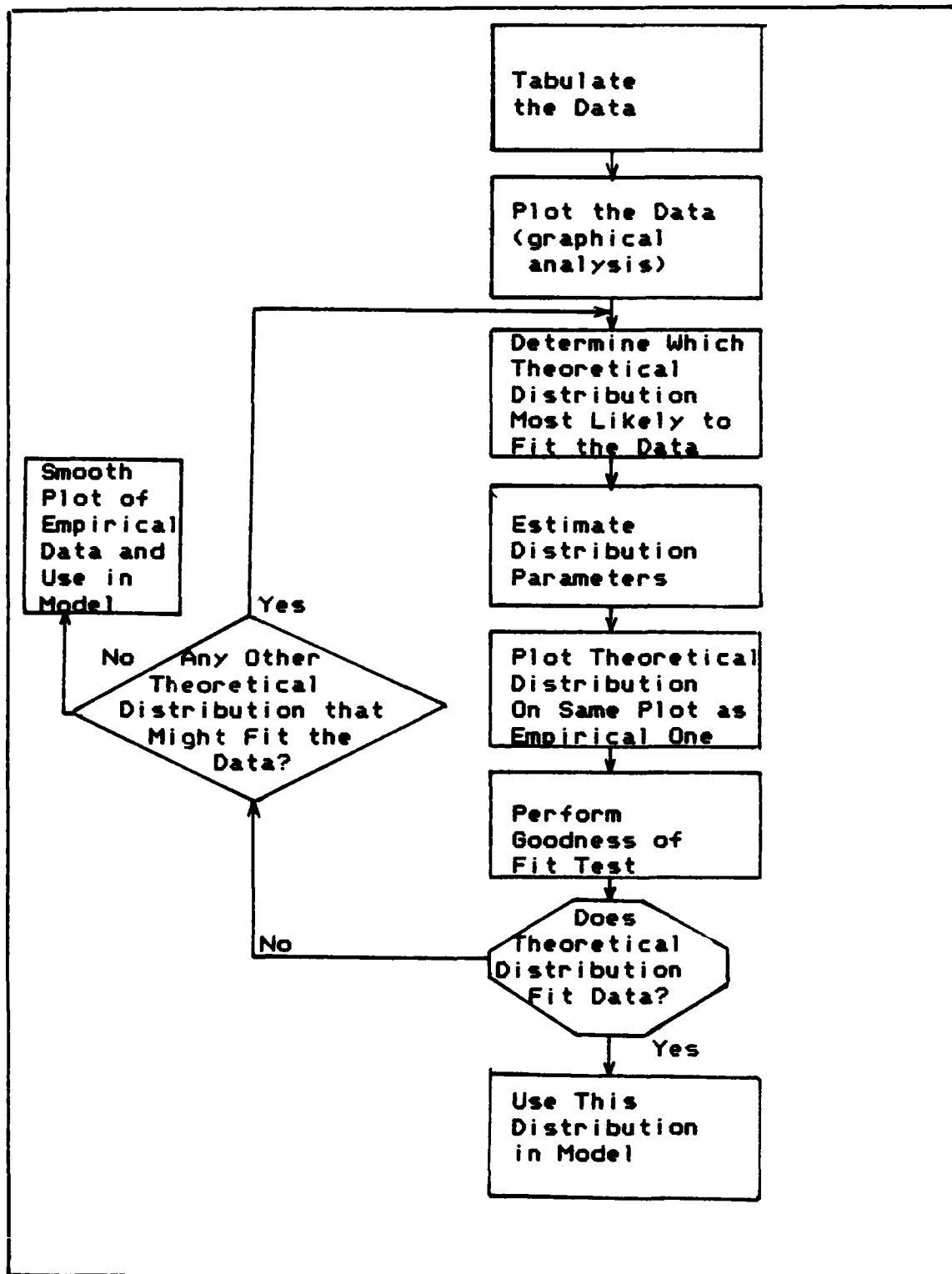
Figure 4. Procedure For Processing an Empirical Distribution

General Approach for Formulating Distributions.

The first step for formulating a distribution is to tabulate and organize the data for plotting. All plots are frequency tables--more commonly called histograms. The histogram is used to determine what distributions are likely to fit a given set of data. This is done by a visual comparison to find curves representing possible probability distributions. Density functions tend to have recognizable shapes; therefore, a graphical estimate of a density function (in terms of a histogram) should provide a clue to the potential distribution (23:39). Although the histogram will suggest the family of distributions the data may fit, estimating the parameters for the distribution is still necessary.

There are many ways to estimate the parameters of a distribution. The technique used in all cases is the maximum likelihood estimator (MLE). MLE's are used to estimate all parameters because MLE's have numerous desireable properties often not enjoyed by alternative methods of estimation (21:189). Once a distribution and its associated parameters are formulated, they are tested to determine whether the hypothesized distribution does indeed fit the data.

Two methods are used to determine if the theoretical distribution fits the data. The first method is to plot the hypothesized distribution over the plot of the data (histogram) and "eyeball" the fit. The other method uses a

statistical test, technically referred to as a goodness of
fit test. There are several statistical goodness of fit
tests, just like there are several parameter estimators.
The Kolmagorov-Smirnov (K-S) test is used to determine
whether the theoretical distribution fits the data. It is
suggested by various authors that for very small samples the
K-S test be used (32:79), and there is little reason not to
use the K-S test if N (sample size) is less than or equal to
99. Since all the data samples have less than 99
observations, the K-S test is appropriate for the goodness
of fit testing.

If the test cannot reject the hypothesis that the fit
is acceptable, the hypothesized distribution and parameters
are used in the model; otherwise, another hypothesized
distribution is selected and tested until satisfactory
results are obtained. If no theoretical distribution
properly fits the data, then a plot of the empirical data is
made and the empirical distribution can be used in the
model. For all groups of data collected, adequate
theoretical distributions are obtained so no empirical
distributions are used directly for obtaining parameter
values. Now that the general approach to transforming data
to a distribution has been presented, the application of the
method and results for the data used in this model are
discussed.

Distribution for Student Attrition. The first

group of data to be discussed is on student attrition.
Attrition data was collected on the last 22 classes to
finish Phase I training (T-37). The data are a ratio of the
number of students who do not finish the training over the
number of students who begin the training. Data are
collected on only the last 22 classes since this is the sum
total of all classes which have used the present syllabus
(21). Student attrition ranges from 5.6% to 23.5%. The
histogram formed from the data is shown in Figure 5.
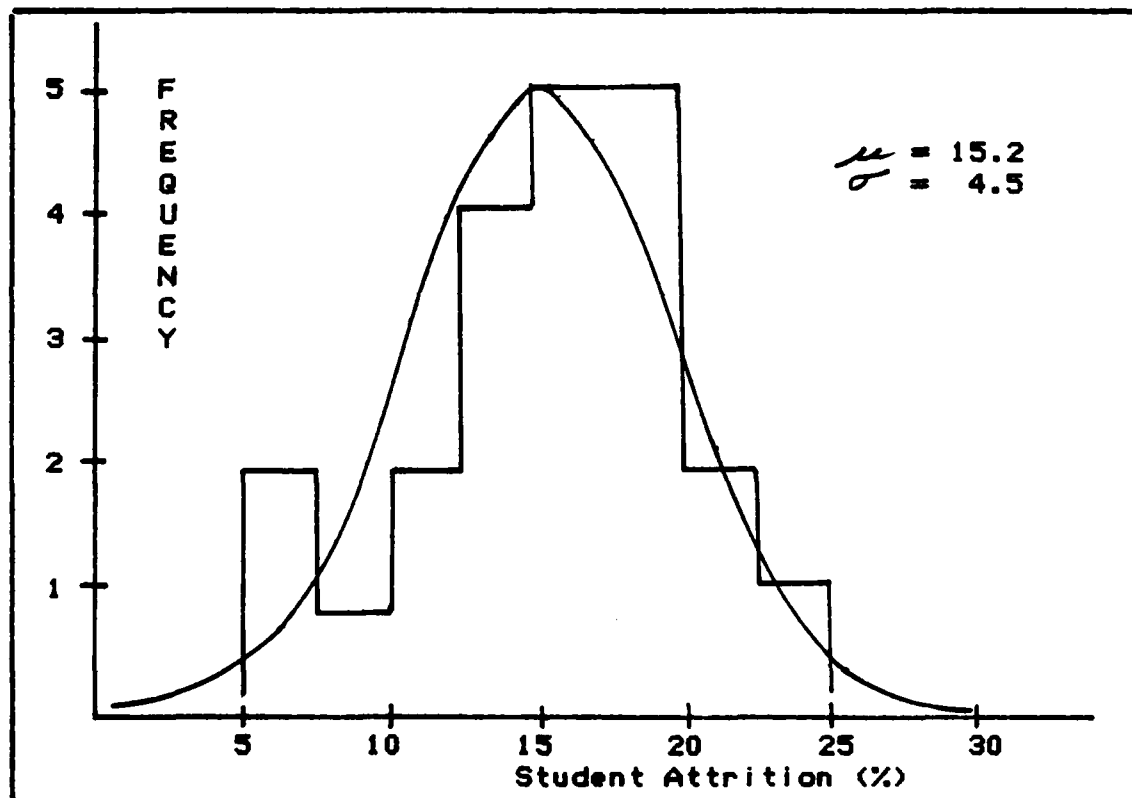
Figure 5. Student Attrition Distribution

A normally distributed function is hypothesized, and
the mean (15.2%) and standard deviation (4.5%) are
calculated using maximum likelihood estimates. The

resulting function is overlayed on the corresponding histogram. The function appears reasonable, and the K-S test does not reject the hypothesized distribution at the 0.05 significance level.

Distributions for Weather Cancellations. The available data consisted of weather cancels by month for the last three years. Here again, only the last three years of data is appropriate since this represents the length of time the current syllabus has been used. (Different syllabii have different requirements and result in different weather cancel rates.)

Several alternatives exist when working with the data. One alternative is take all 36 data points and form one distribution. This will result in every month having the same chance of a particular cancel rate. This is unrealistic since, historically speaking, a higher number of weather cancels occur in winter months than in summer months. A second alternative is to group the data according to months. This would result in 12 groups of three data points. The problem here is that the fewer the data points, the more difficult it is to hypothesize an accurate distribution. Therefore, these alternatives are discarded, and an alternative that grouped data according to seasons is selected instead.

The four season approach resulted in four groups of data with nine data points for each group. This eliminated

the possibility of a traditionally good weather month having a high weather cancel rate or the problem of having too few data points to adequately represent the "true" distribution. All histograms and hypothesized distributions are shown in Figure 6 through Figure 9. A normal distribution is hypothesized for each function, and again the K-S test fails to reject any of the hypothesis tests.

A review of the figures suggests a different parameter and distribution set may be hypothesized for each data set. For example, the mean in Figure 8 could be hypothesized to be lower and more aligned with the center of the "spike" in the plot. Also, a gamma function could be hypothesized to fit the histogram in Figure 7, or the beta distribution could be hypothesized to be more closely aligned to the histogram in Figure 8. In addition to data on student attrition and weather cancel rates, data were collected on the number of aircraft available to fly at the beginning of a day and the number of sorties cancelled per day due to maintenance.

49
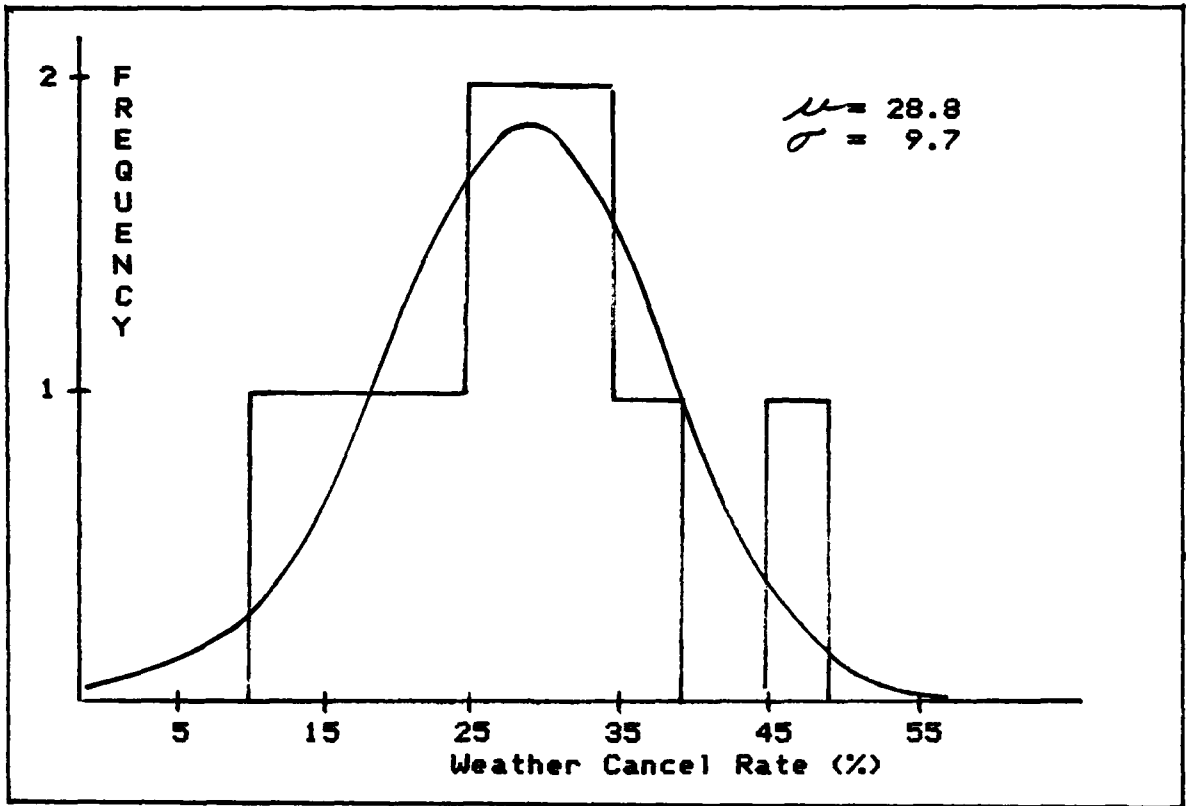
Figure 6.   Weather Attrition Distribution During Winter Months
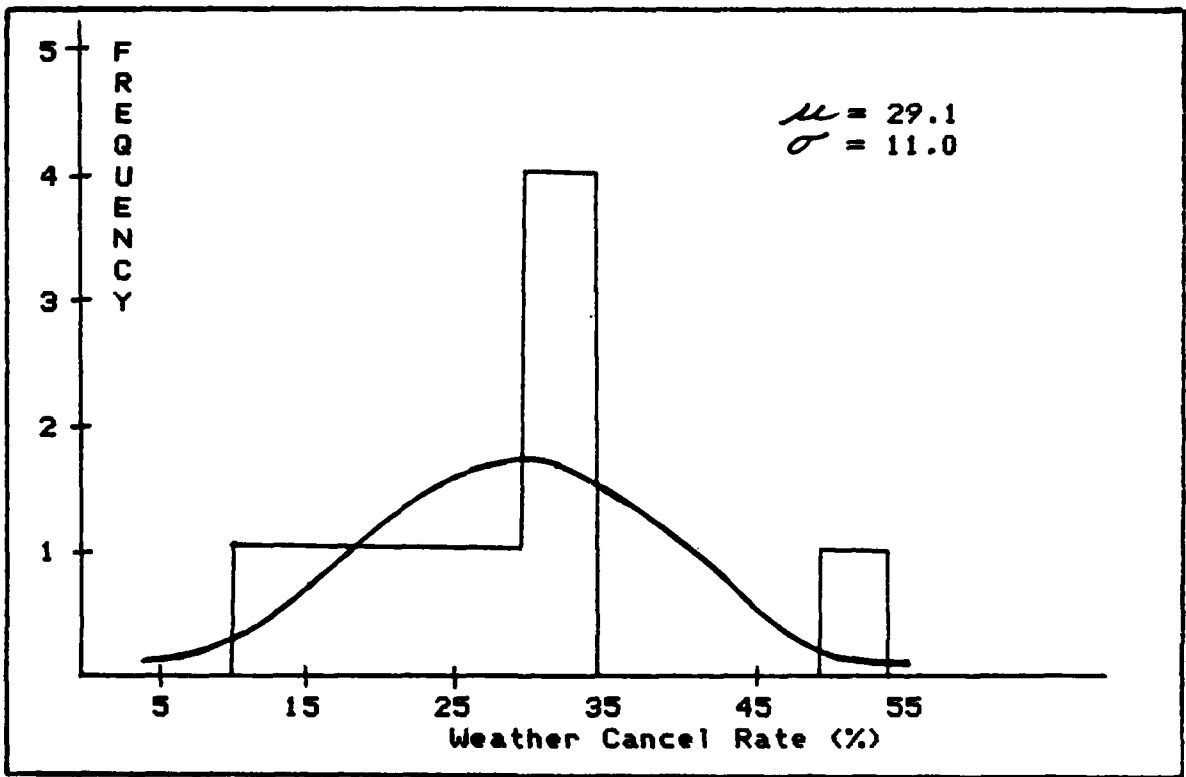
Figure 7.   Weather Attrition Distribution During Spring Months

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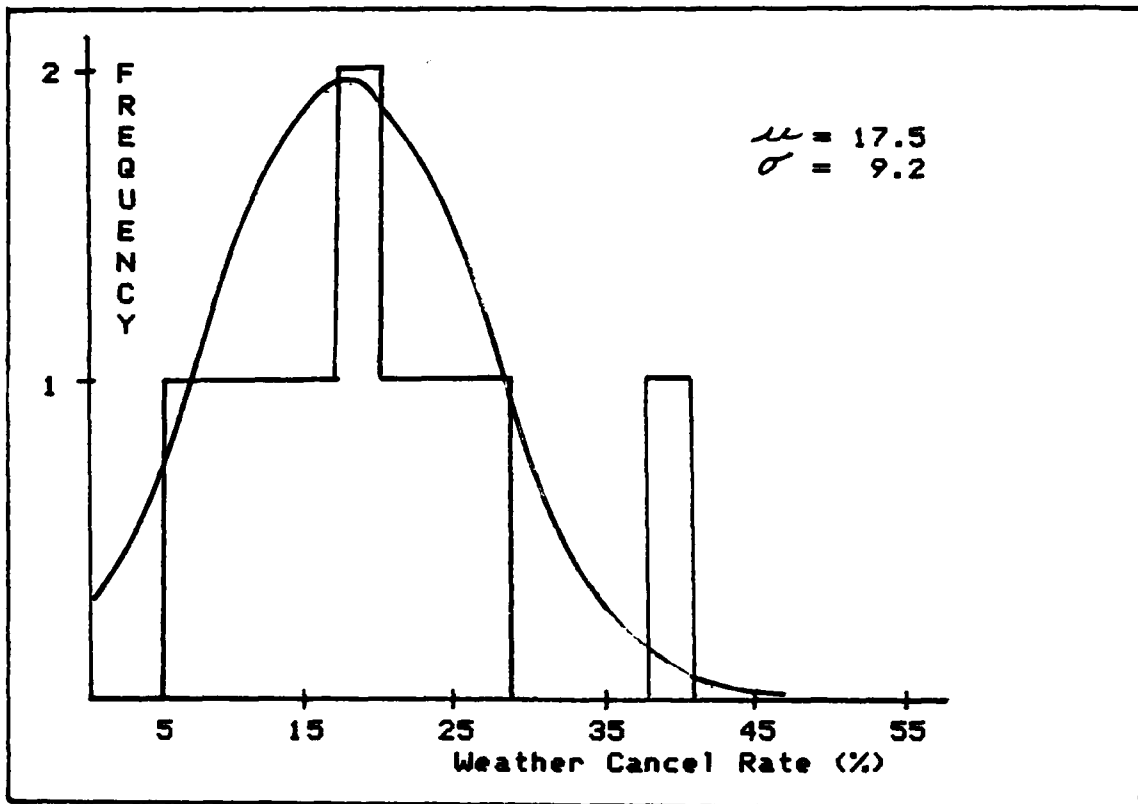
Figure 8.   Weather Attrition Distribution During Summer Months
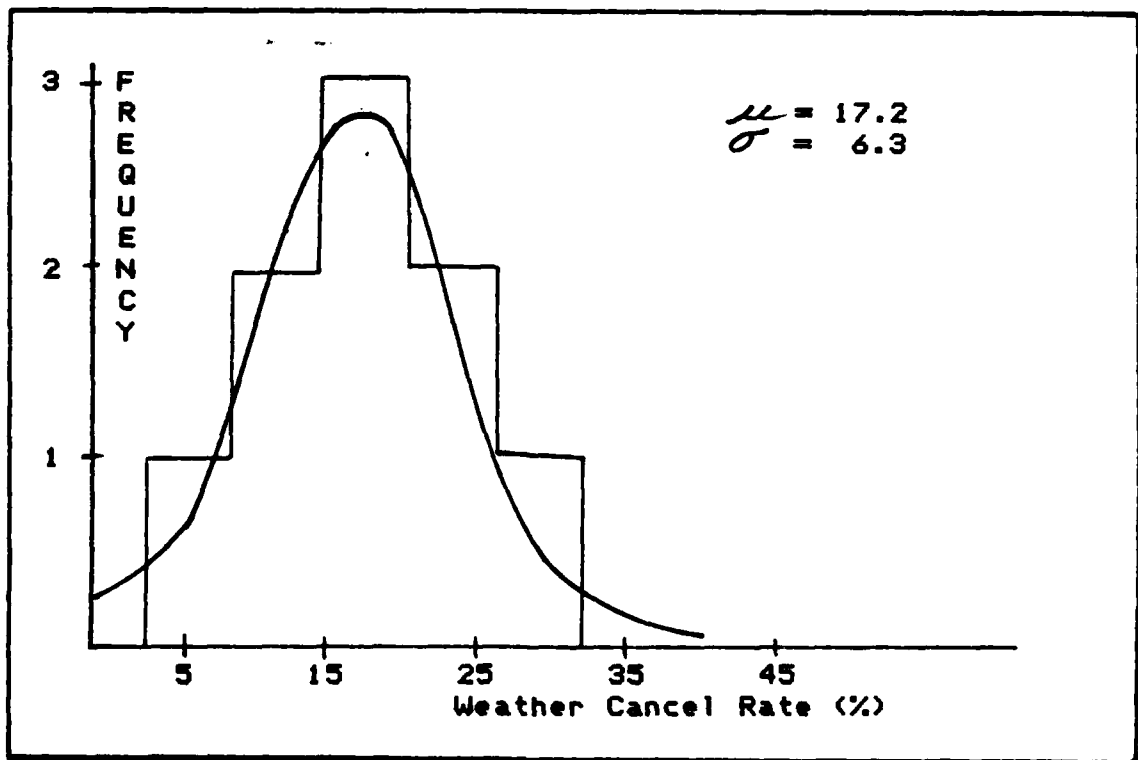
Figure 9.   Weather Attrition Distribution During Fall Months

51

Distribution for Maintenance Generation Capability.

Unfortunately, maintenance generation data were not
available on a daily basis but instead were given in terms
of a yearly average. This resulted in having to hypothesize
a distribution from four data points (averages from
1980-1983). Depending on the interval selected for a
histogram, a uniform or normal distribution could be
hypothesized. From prior knowledge of the random process, a
normal distribution is selected to be representative of the
distributions. Additionally, since the four data points are
an average of daily generation figures, the central limit
theorem implies a normal distribution in appropriate
(8:227-233). Therefore, a normal distribution with mean
equal to 70.7 and standard deviation of 1.5 was used for the
percentage of aircraft assigned that are operational and
ready to fly each day.

Although data points are limited, a poor fit will be
readily apparent in the validation process, because the
maintenance generation variable is closely related to the
monthly utilization rate for the aircraft. Data exist for
the range and mean of the aircraft utilization rate for the
T-37 and can be compared to the model output for aircraft
utilization rate. Although this information can add
credibility to the choice of distribution parameters, an
explicit mathematical relationship between the maintenance
generation capability and the aircraft utilization rate is

not feasible because the utilization rate is a function of several random factors. Since some of the generated aircraft may break before actually completing the attempted sorties, another distribution is required for maintenance cancellations of generated sorties.

Distribution for Maintenance Cancellations. Based on four data points (averages from 1980-1983), a normal distribution is hypothesized with mean of 2.9 and standard deviation equal to 0.71 to represent the percentage of missions cancelled per day due to maintenance. This number includes ground aborts as well as air aborts.

Both of the maintenance distributions have a small standard deviation. If daily observations were available, the numbers would vary considerably. In fact, the mean value for each group of data could be used, and this would not differ much from the number obtained from the distribution "draw". However, it is believed that even small changes in either factor will have an impact on total effective sorties per day (which in turn effects the output variables). The only remaining distributions to be determined are the T-46 delivery rate and the additional IP's (guest or attached) that are available each day.

Distribution for the T-46 Delivery Rate.
Obviously, no data exists on the delivery rate of the T-46 aircraft. ATC expects the delivery rate to be five aircraft every calendar month (20 days for this model) as specified

in the procurement contract (11). However, there is some speculation whether this will actually occur. In order to capture the range for the delivery rate, the T-46 SPO was interviewed. The most likely delivery rate is five airplanes per month. No increase in the delivery rate is possible unless the Air Force is willing to renegotiate the contract and pay more money, which is not likely to occur. Contractual penalties make underproduction undesireable to the contractor; however, the project officer observed that the contractor has been somewhat optimistic with production estimates in the past so a drop to four airplanes a month is certainly possible (31).

Little risk is associated with the project since the training aircraft is well within existing technology. With this information, it is assumed that there is an equal probability of the contractor producing either four or five aircraft each month, which can be represented by a discrete uniform distribution with a mean of 4.5 aircraft (25:33).

Distribution for Guest Instructor Pilots. Because data on guest IPs available per day was not available from ATC Headquarters, schedulers at Laughlin were interviewed to determine the number of guest IPs that were available. The schedulers were asked to estimate the most likely number of guest IPs per day, the highest and lowest number of guest IPs available on any day, and the odds of the intermediate values occurring (15). The hypothesized distribution formed

from the data is a normal distribution with a mean of five and a standard deviation of one.

This concludes the discussion of distributions formed for the random variables listed in Table II. The distributions and parameters formulated to fit the data are summarized in Table III. It is noted that many different types of distributions could have been hypothesized as could the parameters of the distributions. Due to this fact, sensitivity analysis would be in order on selected parameters. The distributions can now be used in the computer models for the T-37 and T-46.

Table III

Summary of Distributions and Parameters

Data	Distribution	Parameters
Student Attrition	Normal	Mean 15.2% Standard Deviation 4.5%
Weather Cancels		
Winter	Normal	Mean 28.8% Standard Deviation 9.7%
Spring	Normal	Mean 29.1% Standard Deviation 11.0%
Summer	Normal	Mean 17.5% Standard Deviation 9.2%
Fall	Normal	Mean 17.2% Standard Deviation 6.3%
Maintenance Generation	Normal	Mean 70.7% Standard Deviation 1.5%
Maintenance Cancels	Normal	Mean 2.9% Standard Deviation 0.71%
T-46 Delivery	* Discrete Uniform	Mean 4.5 Low 4 High 5
Guest Instructors	* Normal	Mean 5 Standard Deviation 1

*   Indicates data obtained via interviews, all other data
    are historical

56

Model Constraints

The following constraints must be included in the model

of this system:

1. There is a maximum average number of sorties flown
   per student per day for each class. This varies
   with the length of time the class has been in
   training and is based upon the learning ability of
   the average student (10).

2. There is a three minute separation between aircraft
   takeoffs. This is necessary due to the capability
   of air traffic control facilities. Saturation of
   the airspace occurs if the interval is reduced
   which complicates the task of the air controllers
   and can lead to unsafe flying conditions (2).

3. Unless a class is scheduled to be on the flight
   line the entire day, a student can accomplish a
   maximum of two events (flying or simulator sorties)
   per day. If all academics have been completed and
   resources permit, a flight can remain on the flight
   line all day and possibly complete three flying
   events (3).

4. Ninety-five percent of all required syllabus
   sorties are required to be flown in daylight hours;
   therefore, takeoffs cease after official sunset
   (9).

5. The simulator complex is opertional 18 hours per
   day. Normal simulator maintenance may be perfor ed
   in the other six hours (6).

If ATC removed any of these constraints, the model

could be easily modified. In addition to the constraints,

numerous assumptions are applicable.

Model Assumptions

Assumptions simplify the model or provide the model

necessary but unavailable values. Valid assumptions will

not degrade the ability of the model to represent the

system; however, an invalid assumption does degrade the

57

models ability to represent the system and may even invalidate the study. In addition, clearly stating the underlying assumptions allows the users of this study to interpret the results in the proper context. The following assumptions are used in this model:

1. Instructor pilots assigned to the flight fly a maximum of twice a day while guest instructor pilots fly a maximum of once a day.

2. IP's, who are qualifying in the T-46, have a higher priority to fly than UPT students training in the T-46.

3. Not all instructor pilots assigned to the flight are available to fly every day. Duties such as Runway Supervisory Unit, Supervisor of Flying, and instructor flight check rides occur daily. On the average, three instructors per flight are not available each day.

4. Only one runway is available for T-37 or T-46 takeoffs. The number of T-37 or T-46 takeoffs from the T-38 runway is insignificant.

5. Ninety days will be the maximum allotted number of days to complete all UPT syllabus requirements for either aircraft.

6. Each class is scheduled on the flight line for two periods per day. The commander directed option of directing three periods on selected days to reduce the total days required for graduation is not currently modeled.

7. Syllabus daylight sorties are flown during the time from official sunrise to official sunset. All days of a particular month are assumed to have the the mean value of the daylight hours for that month.

8. Support personnel, materials, housing, and training facilities will be sufficient to support the training capability calculated from the constraints of runway, instructor pilot, and aircraft availability.

9. Since only 5% of the syllabus requirements are met through night flying, it is assumed that sufficient night capability exists to support these requirements.

10. A separate launch and recovery interval is allowed for each aircraft in a formation.

T-37 Model

The T-37 model must receive incoming students, assign them to a student flight organization, assign the flight instructor pilots, determine the amount of training needed to graduate the students, give the flights their appropriate share of the available resources on a daily basis while simulating the required student training events, graduate the flights when the required training is completed, and record the needed statistics to document the process.

In the first model concept, a T-37 model was developed in the language GGERT which simulated each individual and simulator sortie (26). The model was helpful in gaining insight into the system but was inefficient for this experiment which does not require the micro level of detail produced by that model. The approach taken in the final T-37 model is to aggregate individual events into individual flight events. In other words, instead of an individual attempting to fly a single sortie, a flight may attempt 35 sorties on a single pass through the system. This discussion is limited to the final T-37 model, which served as a basis for the T-46 conversion model. The role of time

in the model, sequence of events within the model, and
necessary information for each flight are explained in
detail.

Role of Time in the T-37 Model. Times of concern
in the model include minutes, hours, days, weeks, months,
and 90-day training periods. Each of these time units has a
use in describing the system.

The minute is the smallest time interval of
significance to the model. Because Air Traffic Control
limits aircraft takeoff intervals to one takeoff every three
minutes, the minutes of daylight can be converted into the
maximum number of daylight sorties which can be launched
from the T-37 runway by dividing the total daylight minutes
by three (assuming a plane is always ready for take-off).
The next larger time unit is the hour.

ATC projects the future demand for flying hours. The
flying hours projected for each month must be within the
allowable utilization rate for the aircraft (utilization
rate is the average number of flying hours per assigned
aircraft per month). Since student progress is normally
measured in effective training sorties rather than flying
hours, the model can measure effective training sorties and
convert sorties flown to flying hours using the mean sortie
length of 1.25 hours. Since sorties for each flight are
updated on a daily basis, flying hours can also be updated
daily. These updates do not require the hour to be the

60

basic unit of time for the model. The next time unit of interest is the day.

Resources for flying are generated on a daily basis. The number of aircraft, instructor pilots, weather conditions, and the amount of training remaining for each flight all vary on a daily basis. Flights train daily as resources and weather permit. Since most of the events in the model occur daily, the workday was selected as the fundamental time unit for the simulation model. Smaller times can be set as a fractional part of a day; larger times can be expressed as a number of days.

Larger times of interest are weeks, months, 90-day training periods, and years. The week is important because flying units project their future needs and revise the upcoming schedule weeky. A week is modeled as five workdays. The month is important because ATC changes the number of students in a flight according to the month the flight begins training. A month is modeled as 20 workdays. Finally, 240 workdays comprise a year. No effort was made to project the 240 training days onto the 365 day calendar by accounting for weekends and holidays. ATC has ten year future calendar projections and can easily convert transition length in work days to calendar dates if desired. These definitions coincide with those used within ATC. In addition to the role of time in measuring these items of interest within the T-37 system, time is used by the

simulation language to schedule and sequence the events
within the model.

New Class. The following event
sequence is repeated daily within the T-37 model:

1. A new class is created if appropriate (one every 30
    days).

2. Overall priorities between flights are set if
    appropriate (weekly).

3. Flying and simulator resources available are reset.

4. Training for each flight is simulated.

5. Training records for each flight are updated.

6. Late flights graduate students and have instructors
    reallocated if appropriate.

New Class. If a new class is due to arrive
today, the model creates a class, divides the class into two
flights, assigns students and instructor pilots to the
flights, computes the total flying and simulator sortie
requirements for each flight, and enters the flights into
the system before the daily training cycle begins. Having a
flight in the system go past its scheduled graduation date
complicates this process.

When weather prevents the senior flight from graduating
on time in the real T-37 system, one of the flights contains
both the most junior and the most senior students
simultaneously until the senior class graduates. The real
T-37 system is limited to six flights at all times; the
flight's instructors must be divided between the new and
late students in the flight. Because accounting for both

62

new and late students within the same flight severely complicates the problem of maintaining the necessary training records and statistics in the model, the model maintains the senior flight as a separate entity and permits more than six flights to exist within the system at one time. To preserve the essence of the real T-37 system, the new and old flights must share the same instructor resources; the late flight must pass instructors to the correct new flight when they are no longer needed. To accomplish this pairing of flights, a flight seniority system was devised.

Each flight is assigned an integer seniority number, which reflects the time the flight has been in the system relative to the other flights. A seniority number of one designates the newest flight; the largest seniority number designates the oldest or most senior flight. A difference of six in seniority numbers is used to pair the appropriate flights for exchanging instructors who are no longer needed by the late flight. Since two flights enter simultaneously in the present system, one is arbitrarily assigned the seniority number one, and the other is assigned the seniority number two. Except for the flight seniority number and possibly the number of instructor pilots assigned to the flight, the remaining characteristics of the newly created flights will be identical until training begins. The remaining characteristics needed to describe the new

63

flights are the number of students in the flight and the number of flying sorties, simulator sorties, and solo flying sorties required to graduate all students assigned to the flight.

The number of students assigned to a flight varies with the month the flight begins training; ATC uses this method to spread the heaviest flying load over the parts of the year with the most daylight and best weather. Since the student load for period being studied has already been published by ATC for each base, the model simply accesses a stored value to assign the appropriate number of students to each flight. The expected number of students per flight at Laughlin as a function of month is depicted in Table IV.

Table IV	
Students per Flight at Laughlin AFB (3)	
Month	Number of Students in the Flight
January	35
February	35
March	36
April	35
May	35
June	36
July	36
August	36
September	36
October	36
November	35
December	35

The total flying, simulator, and solo sortie

requirements for the new flights is simply the product of the assigned number of students and the sortie requirements per student specified by the course syllabus. The present syllabus programs 57 flying sorties and 25 simulator sorties for each student. The 57 flying sorties include 10 solo flying sorties, nine of which do not require instructor supervision. (The insturctor must observe the first student solo sortie and be available for instruction via radio, if necessary, for safe completion of the sortie.) The nine solo flights per student significantly increase the number of sorties which the flight can fly during the training day; therefore, the authorized daily solo rate and total remaining solo sorties must also be characteristics of the flight. Individual student solo flights do not begin until the fourth week of training so the initial daily solo rate is zero (9).

In the model, the total flying, simulator, and solo sortie requirement calculations presume all students will complete the training program and no students will require additional training during the program; therefore, the calculation is best considered as an estimate, which must be adjusted as a flight progresses. In addition to these characteristics, an artificial characteristic is needed which specifies the type of sortie the flight needs most, flying or simulator.

The model uses a training priority number to quantify

the relative progress of the flight in flying and simulator sorties. A new flight is given a training priority number of one which indicates the flight is not behind in flying or simulator training. The training priority number is discussed in more detail in the next section which describes the weekly review of the flights. Finally, the model schedules the arrival of the next new class at the appropriate time interval, presently 30 workdays.

Weekly Review of Flights. Prior to the first training day of the new week, each flight is examined individually to assess its training progress and establish the needed priorities for the upcoming week. The first task of the review in the model is to identify flights which are ready to begin flying solo missions. Flights about to begin the fourth week of training are authorized solo sorties. Solo sorties are evenly distributed over the next eighty percent of the remaining training days. Since only seventy percent of the attempted solo flights are expected to be effective (15), the desired daily solo rate is divided by 0.7 to calculate the number of solos the flight should attempt. To prevent authorizing too many solo flights, the authorized solo rate is not permitted to exceed the total remaining solo sortie requirements. In addition to computing the daily solo sortie rate, the weekly review must establish the maximum daily flying sortie rate (Figure 10) and maximum daily simulator sortie rate (Figure 11) which the students can absorb during the upcoming week.
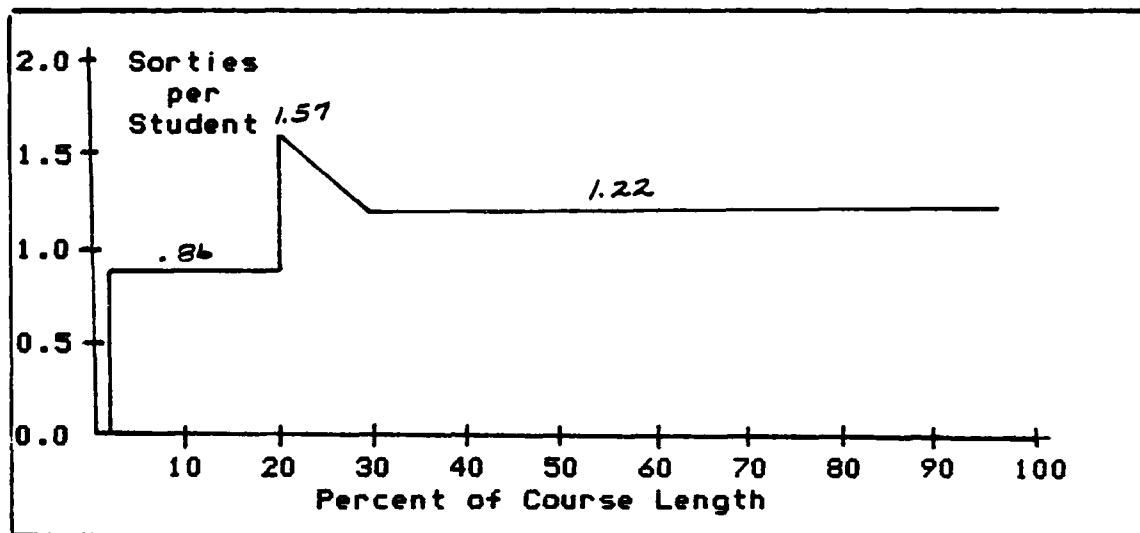
Figure 10.   Maximum Flying Sortie Rate Per Student
             Per Day (10)
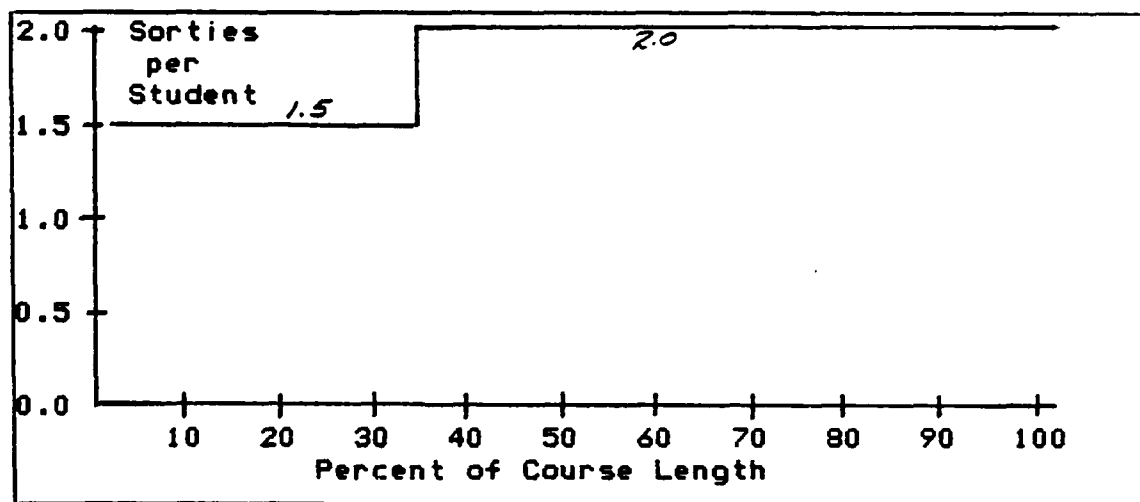
Figure 11.   Maximum Simulator Sortie Rate Per Student
             Per Day (4)

Unlike the evenly distributed solo rate, the other sortie rates change as a function of days the flight has already spent in the training program. As the graph in Figure 10 indicates, the maximum flying sortie rate for students rises from 0.86 sorties per student per day to a peak of 1.57 sorties per student per day then falls to a constant 1.22 sorties per student per day. Simulator

sorties are used to prepare the students for flying sorties.
As shown in Figure 11, the maximum simulator sortie rate
begins at 1.5 sortie per student per day and jumps to 2.0
simulator sorties per student per day as the students in the
flight prepare for the instrument phase of flying.

The maximum daily sortie rate for the flight is the
product of the number of students assigned to the flight and
the maximum daily sortie rates per student per day. The
maximum flying sortie rate includes any solo sorties the
flight may fly; the solo sortie rate is used only to relax
the constraint imposed on the flight by limited instructor
pilot resources. Having calculated the maximum sortie
capabilities for the flight, the model must still determine
whether flying sorties or simulator sorties is more
important to the flight in the upcoming week.

A training priority number is used to show the relative
importance between flying and simulator sorties. In
addition, the training priority number shows the progress of
the flight relative to the minimum sortie rate needed to
graduate the flight on time; the higher the training
priority number, the greater the risk of late graduation.
The minimum sortie rates for on-time graduation, as a
function of time in the training program, is derived from
the graphs in Figure 12 and Figure 13 furnished by ATC.
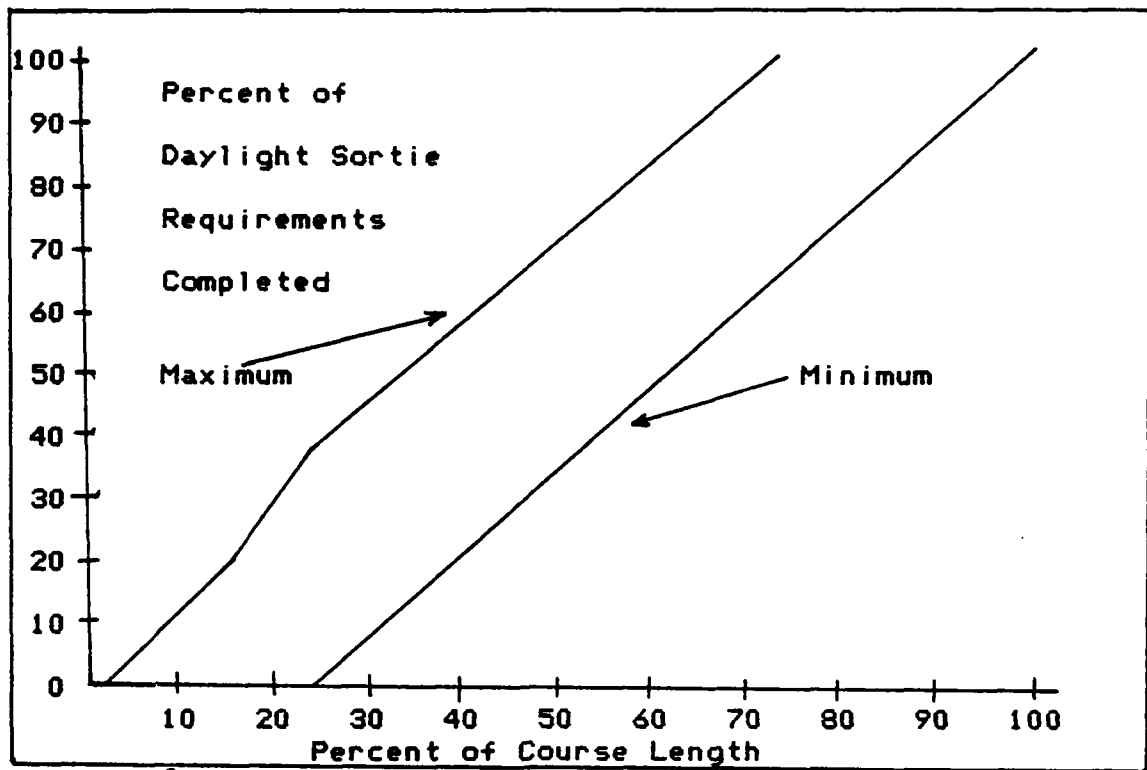
Figure 12. Required Flying Sortie Rate for On-Time
Graduation (10)
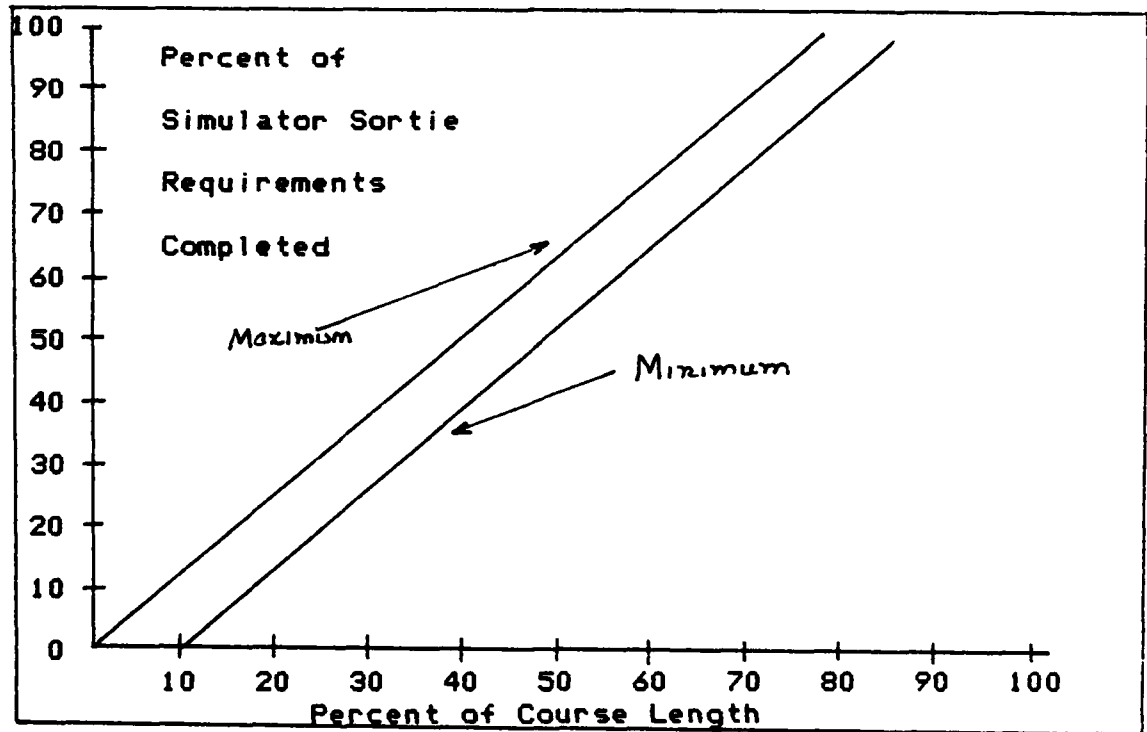
Figure 13. Required Simulator Sortie Rate for On-Time
Graduation (4)

A flight is late graduating if any sortie requirements remain after the allotted training period has passed; late flights have the highest training priority since they are delaying the T-38 follow on training program. Effective flying sorties are harder to achieve than effective simulator sorties due to the additional constraints imposed by daylight and weather which do not limit the simulator; therefore, the only time simulator sorties have more priority than flying sorties is when the flight is ahead on its flying sortie requirements and behind on its simulator sorties. The other possibilities are depicted in Table V. The training priority number is also used to determine the flight's priority for sorties relative to the other flights in the system.

Table V
Training Priority Number Decision Table

Time Status of Flight	Flying Sortie Status	Simulator Sortie Status	Training Priority Number
Late	Some Left	Some Left	5
On Time	Behind	Behind	4
On Time	Behind	Ahead	3
On Time	Ahead	Behind	2
On Time	Ahead	Ahead	1

The overall priority depends upon both the individual training priority and the seniority of the flight. Since a more senior flight has fewer days to make up lost sorties, the overall priority must favor the senior flight when the training priorities are equal. Obviously, a senior flight which is ahead of its required sortie rates should not have priority over a junior flight which is falling behind. In other words, training should be fairly evenly distributed over the length of the program so that all flights in the system are progressing rapidly enough to graduate on time, if possible. To solve the problem without having to perform a search and comparison algorithm, the model simply assigns each flight an overall priority number which is a function of both the training priority number and flight seniority. The training priority is weighted heavily so that seniority is only used as a tie-breaker for flights which have the same training priority number:

$$OP = 16 \ (\ TP \ ) + SN \qquad\qquad (1)$$

where

    OP = Overall Priority Number
    TP = Training Priority Number
    SN = Flight Seniority Number
    16 = Large Weight Relative to SN

The highest overall priority number represents the flight with the highest overall priority for training sorties. The simulation language of the model simply selects flights to enter the daily training system on the

71

basis of the overall priority number value. Since two flights have the same flight seniority number, no duplicate overall training priorities are possible. Although the computer model could easily adjust the overall priority daily, the computation is done only weekly to more closely parallel the actual T-37 system.

When the model has set the flight's maximum daily solo, flying sortie, and simulator sortie rates based upon student limits, has set the training priority number based on the flight's remaining training requirements, and set the overall priority based upon seniority and training priority, the model has finished the weekly review of that flight. When all flights in the system have been reviewed, the model schedules the next weekly review and begins computations to set the sortie resource levels for today.

Flying and Simulator Sortie Resources. The flying and simulator sortie resources available are reset daily prior to commencing student training. The sortie resources represent the number of sorties that maintenance and operations have both agreed to attempt for today. For flying sorties, the total number of sorties the system can generate is a function of the number of airplanes in the system and the number of daylight hours available. The maximum number of sorties maintenance could generate is estimated by taking the product of the airplanes on hand and the percent of airplanes which are operational times four

72

possible sorties per generated aircraft; ninety percent of the sorties generated by maintenance are for student use (10). With 86 assigned aircraft and the maintenance capability at Laughlin, the estimate of sorties that maintenance can schedule ranges from a low of approximately 209 to a high of 237 sorties with an average of 223. The relationship is summarized by the following equation:

$$ndlyas = (capmx)\ (AC)\ (4.0)\ (0.9) \qquad (2)$$

where
    ndlyas = number of daily aircraft sorties for students
    capmx = the percent of assigned aircraft maintenance
             can generate for flying today
    AC   = the number of aircraft assigned to the base
    4.0   = the expected number of sorties per day per
             generated aircraft
    0.9   = the portion of sorties used for student
             training

Since the students need daylight sorties, the estimate from Equation 2 for sorties generated by maintenance would be too high to represent the real system during winter months. Table VI, depicting the elapsed time from the first take-off to the last landing for the last generated aircraft, illustrates the problem.

Table VI			
Minimum Sortie Landing Times for the Last Generated Aircraft			
Number of Generated Aircraft	Landing Time for The Last Generated Aircraft			
	1st Landing	2nd Landing	3rd Landing	4th Landing
1	1 + 15	4 + 00	6 + 45	9 + 30
50	3 + 45	6 + 30	9 + 15	12 + 00
60	4 + 15	7 + 00	9 + 45	12 + 30
70	4 + 45	7 + 30	10 + 15	13 + 00

The average day is only 10 hours and 18 minutes long in December as opposed to 13 hours 48 minutes in June and July-- a three hour and 30 minute difference. Although the first aircraft launched always has time for four daylight sorties, the required three minute interval between take-offs makes it impossible to fly four sorties on all aircraft year round. A simple way to account for this limitation is to compute the number of useable sorties which can be launched with at least 30 minutes of useable daylight and to use the smaller of the two figures as the number of daylight sorties which can be scheduled. The first 30 minutes of the sortie must be daylight rather than the last 30 minutes so that the area work is accomplished while the student is fresh and has a safe fuel reserve (10). The maximum number of possible consecutive take-offs for daylight sorties is computed as follows:

$$ndlyas = (\ Hours - 0.5\ )\ (\ 60)\ /\ 3 \qquad (3)$$

where

```
ndlyas = number of daylight sorties
Hours  = number of hours of daylight today
0.5    = launch must permit minimum of
         30 minutes of daylight
60     = minutes per hour
3      = minimum take interval in minutes
```

The time interval between take-offs for the same aircraft is 2 hours and 45 minutes; thus, only 54 aircraft (62.8 % of the assigned aircraft) are needed to generate continuous take-offs at 3 minute intervals. In the real system, take-offs are normally scheduled every three minutes during the daylight window. As shown in Table VII, the combination of the daylight and maintenance limitations permit a scheduled sortie range from 196 to 237 sorties per day, which is consistent with historical data at Laughlin.

Table VII

Maximum Daylight Take-offs at Laughlin
(Three Minute Intervals)

Month	Daylight Hours	Maximum Sorties
Jan	10.6	202
Feb	11.3	216
Mar	12.1	232
Apr	13.0	250
May	13.7	264
Jun	13.8	266
Jul	13.8	266
Aug	13.1	252
Sep	12.2	234
Oct	11.3	216
Nov	10.6	202
Dec	10.3	196

The T-37 simulators are normally available with maintenance functions performed at night or during unscheduled hours; therefore, the portion of the simulator capability allotted to students is a constant 68 sorties per day from the two operational complexes. If one complex did have a maintenance problem, students would be given priority in the operational complex so that student training would not be delayed. The T-37 model offers 68 simulator sorties to the student flights daily.

Having calculated the number of flying and simulator sorties available, the model schedules another recomputation of flying and simulator sorties between the end of today's training and the start of tomorrow's training. For the next task, the model must allocate today's sorties to the

flights.

<u>Flights Request Sortie Resources</u>. The model
serves the flight with the highest overall priority number
first. At this point, the model has almost all the
information needed to process the flight's request for
sorties: the maximum student flying sortie capability, the
maximum student simulator capability, the number of
available flying and simulator sorties, the number of
instructor pilots in the flight, the number of requested
solo sorties for the flight, and the number of remaining
flying and simulator sortie requirements for the flight.

The number of instructor pilots assigned to the flight
must now be converted into the total number of sorties which
all the flight's instructor assets can support. A fully
manned flight normally has three assigned instructors, who
are not able to fly with the squadron due to other duties
such as manning the runway supervisory unit (RSU),
supervisor of flying (SOF), and other miscellaneous duties
(4). Each available instructor assigned to the flight can
support two student sorties each day, flying or simulator.
In addition, five guest instructor pilots are expected to
support five additional student flying sorties each day
(15). The guest instructor is a fully qualified instructor
pilot whose primary job leaves time to fly a student flying
training sortie two to three times a week. Student solo
flights do not require instructors; therefore, the model

77

adds the number of solo flights for today to the number of

available instructors for flying. The last calculation

needed to simulate training for today is the total number of

flying sorties that the flight instructor assets can support

using Equation (4).

$$FLYS = (2) (FIP - BUSYIP) + GIP + SOLO \qquad (4)$$

where

FLYS	= Number of flying sorties instructors can support
(2)	= Daily sortie limit for each flight assigned IP
FIP	= Total number of flight assigned IPs
BUSYIP	= Number of flight assigned IPs not available to fly
GIP	= Number of guest help IPs flying a sortie today
SOLO	= Number of student solo flights for today

If the flight training priority number is two, the

simulator has top priority so the model processes the

simulator sortie request first. Only flight assigned

instructor pilots perform simulator training; therefore, the

number of simulator sorties the flight will perform today is

the minimum of the following items:

1. Maximum simulator sorties authorized for the students,

2. Total remaining simulator sortie requirements for the flight,

3. Twice the number of available flight assigned IPs, and

4. The number of unused simulator sorties generated for today.

In addition to the other limits imposed upon the

students, each student is limited to two flying training periods each day. This means each student's flying and simulator training is limited to a maximum of two sorties each day. The previously calculated maximum sortie limits for flying and simulator were independent calculations which did not include this limit. Having already allocated simulator sorties to the flight, the model now allocates flying sorties giving the minimum of the following numbers:

1. The maximum flying sorties authorized for the students today,

2. Twice the number of students in the flight less the simulator sorties requested for today,

3. The total remaining flying sortie requirements for the flight,

4. The total number of flying sorties that the instructors can support (FLYS) less the number of simulator sorties requested for today, and

5. The number of unused flying sorties generated for students today.

If the flight being processed did not have the training priority number two, the flight needs flying sorties more than simulator sorties. In this case the model processes the flying request first and then constrains the simulator request. The number of flying sorties is the minimum of the following figures:

1. The maximum flying sorties authorized for the students today,

2. The total remaining flying sortie requirements for the flight,

3. The total number of flying sorties the instructors can support (FLYS), and

4. The number of unused flying sorties generated for students today.

Before the model can process the simulator sortie request, the number of instructors available for simulator training must be calculated. The model assumes that solo and guest instructor flying sorties are used first and that any additional flying sorties requested are supported by the flight assigned instructors. If the flight is not allocated enough flying sorties for the solo and guest help sorties, all the flight assigned instructors are still available for up to two simulator sorties each. (Guest IPs do not conduct simulator training.) Otherwise, some of the attached instructors are used for flying sorties, and the remaining instructor simulator sorties available is simply the total number of flying sorties the instructors can support (FLYS) less the flying sorties requested by the flight today. The model gives the flight simulator sorties equal to the mimimum of the following values:

1. The maximum number of simulator sorties authorized for the students today,

2. Twice the number of students less the number of flying sorties requested today,

3. The number of simulator sorties the flight assigned IPs can support,

4. The total remaining simulator sortie requirements for the flight, and

5. The unused simulator sorties generated for students today.

The flight currently being processed is assigned the number of flying and simulator sorties it is to attempt today. The sorties assigned to the flight are deducted from the available sortie resources for today, and the flight is sent to simulate the training. At this point, the model takes the flight with the next highest overall priority number and repeats the sortie allocation process. When all flights have been reviewed, the model schedules the next days's processing of flight sortie requests and begins the update of the flight records at the end of today's training.

Daily Simulation and Flight Record Update.
After receiving its share of the available flying and simulator sorties, the flight is delayed for four tenths of a day to simulate the training taking place. In the model, the delay for training to occur is necessary to insure proper sequencing of the various flight sortie requests; the simulation language used in the model continues to process the same flight until a delay is encountered (27). Without the delay, the model would give all the generated sorties to the one flight with the highest overall priority as it instantaneously passed through the system and returned for more sorties. After the delay for training, the flight's records are updated.

To update the flight records, the model must credit the flying, simulator, and solo sorties accomplished today, correct the flight's records for any student who quit today

without finishing the training, add any additional training sorties required for students who failed flight examinations today, and take the appropriate statistics before permitting the next day's cycle to begin. The discussion begins by considering the validity of assuming the cancellations are evenly distributed among all the flights and continues by describing the steps used to credit today's sorties.

To apply the distributions for weather and maintenance cancellations derived in the data section, the model assumes that the canceled sorties are evenly distributed among the flights. On a daily basis, this assumption is not valid (a thunderstorm or morning fog could wipe out all the sorties for the morning flights but not affect the afternoon sorties). The real system compensates for a disparity between flights if necessary. If one flight is getting an undue share of cancellations, the flight is assigned to fly during the period most likely to have good weather until it catches up with the other flights. Since the model statistics are for the entire training period rather than for specific days, the assumption that cancellations are evenly distributed among the flights is valid for this study.

To credit the flying sorties for today, the model must reduce the sorties attempted by the maintenance and weather cancellations which occur today. First, the model reduces the number of sorties the flight attempted by the number of

82

sorties lost to maintenance problems today. Then, the
remaining attempted sorties are reduced by the number of
sorties lost to weather today. The remaining attempted
sorties are considered effective training sorties, which are
used to update both the flying hours for the system and the
training requirements of the flight. The flying hours
accumulated by the system for this month are incremented by
the product of the number of effective sorties and the
expected sortie length (1 hour 15 minutes). The number of
effective sorties is subtracted from the flight's total
remaining flying sortie requirements. To prevent the
possibility of the flight making a meaningless request for a
negative number of sorties, the minimum value permitted for
total flying sorties remaining is zero.

To credit the simulator sorties for today, the model
simply subtracts the number attempted from the remaining
solo sortie requirements assuming a negligible cancellation
rate. As with flying sorties, the minimum value permitted
for remaining simulator requirements is zero.

Any solo missions flown were included in the total
effective flyng sorties already computed for today; however,
the number of effective solo sorties must also be counted
separately because the solo sorties decrease the daily
instructor requirements. Seventy percent of the attempted
solo sorties are considered effective; however, resources
may have prevented the flight from attempting all the solo

sorties it needed today so the number of effective solo

sorties is never allowed to exceed the number of effective

flying sorties for today. The flight's total solo sortie

requirements are reduced by the number of effective solo

sorties flown today. Again to prevent the flight from

requesting meaningless negatve solo sorties, the minimum

value permitted for total solo sorties remaining is zero.

When the flight's total solo sorties remaining is zero, the

authorized daily sortie rate is reset to zero to prevent the

flight from requesting more solo flights tomorrow. At this

point, credit has been given for all of today's training

sorties. The next task is to decide if there is any student

attrition today.

As discussed in the data section, the distribution of

student attrition was derived from historical data. The

distributions permit the model to forcast both the total

number of students a flight will los? and the time each

student quits. When it is necessary to drop a student

before he completes the training, the portion of the

remaining flying, simulator, and solo sorties belonging to

him are no longer needed. The model assumes the students in

the flight have completed approximately the same amount of

training; therefore, the reductions in remaining sorties for

losing one student are simply the total sorties remaining of

each type divided by the number of students in the flight

(including the one about to quit). Since the total sortie
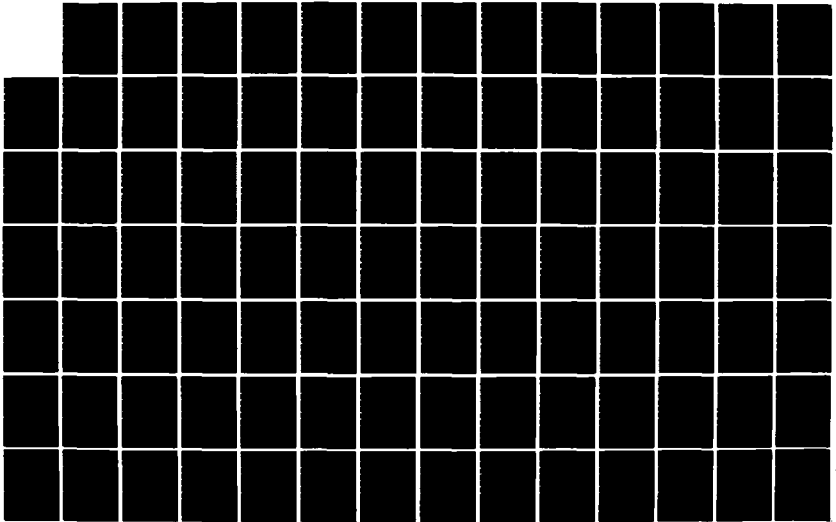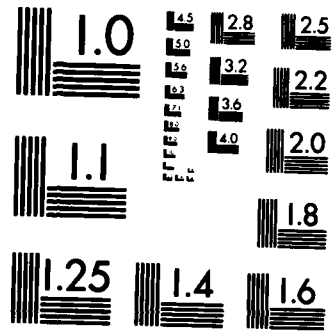
MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

requirements for the flight were calculated assuming all students would finish the training program, the reduction in future sortie requirements is also applied to the total sortie requirements for the flight.

Updating the total requirements for student attrition is necessary because the ratio of remaining sorties to total training requirements is used in the weekly review to assess whether a flight is ahead or behind in its training. If the flight had solo sortie requirements, the authorized daily solo rate for the flight is revised to distribute the remaining solo requirements over the next eighty percent of the remaining training days. The final adjustment to complete the attrition process is to decrease the number of students assigned to the flight. Having completed any necessary attrition calculations, the next task is determine if there is any change in flying sortie requirements as a result of today's flight evaluations.

The flying syllabus includes four flight evaluations for each student. Although all students cannot actually fly the evaluations the same day, the effect of the evaluations is modeled as a function of the number of students in the flight at the time the flight becomes eligible for each evaluation. Successful flight evaluations do not change the flight's sortie requirements; however, unsuccessful flight evaluations require a number of extra flying sorties to retrain the student in the deficient area. The number of

extra sorties for an unsuccessful evaluation has a different
historical distribution for each of the four evaluations.
As explained in the data section, the historical data was
used to derive a probability of failing each checkride and
the expected number of additional sorties required for each
student who fails. The number of expected additional
sorties is calculated on the appropriate day as follows:

$$xtrafs = (Pf) (Nstuds) (Esort) \qquad (5)$$

where

      xtrafs = the number of extra flying sorties
              for the flight
      Pf   = the probability a student failing
              this type flight evaluation
      Nstuds = the number of students to be evaluated
              (all the students remaining in the flight)
      Esort = the expected number of additional sorties
              for each unsuccessful evaluation

    The parameters used to calcuate the additional sorties
for failed flight evaluations are summarized in Table VIII.
Adding the extra sorties to both the total flying sortie
requirements and the remaining flying sortie requirements
for the flight completes the daily update of the flight's
training record. The model must gather statistics on the
flight, if necessary, before updating the next flight's
training records.

Table VIII			
Flight Evaluation Parameters (22)			
Flight Evaluation Number	First Training Day Elligible	Probability of Student Failing	Expected Additional Sorties
1	23	0.10	3.4
2	45	0.38	1.5
3	68	0.18	1.1
4	81	0.14	1.1

Statistics are collected on the flight the day all training requirements are completed. The number of days taken by the flight to complete the training is recorded. In addition, if the flight has completed the training before the last alloted training day, the number of sorties remaining at scheduled graduation is recorded as zero. This improves model efficiency by permitting the model to discard flights as soon as training is completed.

Statistics are also calculated at the end of the scheduled graduation day to measure the number of sorties remaining. Since most of the flights are expected to graduate on time with zero sorties remaining, a separate statistic on remaining sorties for late flights is taken to accurately represent the status of the late flights. The statistic on late flights is expected to be more sensitive to changes in factor levels and thus a better measure of the influence of a factor on the system. Once the statistics

have been gathered, the daily simulation and flight update process for the flight is complete.

The time and training status of the flight determines how the flight is processed. Late flights always receive additional processing to redistribute the instructor pilots. If flights within the allotted training period have any remaining sortie requirements, the flights are returned to the system to await the next days sorties. If a flight within the allotted training period has no remaining sortie requirements, the flight has served its purpose and is eliminated from the system simulating graduation. The process for redistributing instructors for late flights completes the discussion of the T-37 model.

<u>Reassignment of Instructors in Late Flights</u>. As mentioned earlier, the real system is limited to six flights, but the model is not limited to a specific number of flights. The model preserves the identity and statistical records of the flight when it becomes late but shares the assigned instructor pilots with the new flight. Since late flights have priority, sufficient instructors are retained to insure that instructor availability does not limit the late flights training rate. Since students and instructors are normally limited to two events per day, a one to one student to instructor ratio is sufficient as long as the instructors are exempted from additional non-flying duties (the model does exempt late flight instructors from

additional duties). To calculate the one to one ratio, the model must estimate the number of students remaining in the late flight.

The model assumes that the remaining students have the same number of training requirements since ATC was attempting to graduate them all on time. The first estimate of the number of remaining students in the flight is the higher of the flying sorties remaining or simulator sorties remaining. If this estimate is higher than the number of students currently assigned, no students have graduated. If the estimate is lower than the number of students currently assigned, the difference between the estimate and the number of students currently assigned is assumed to be the number of students who are ready to graduate. The number of students in the flight is revised downward to reflect the graduating students. If the number of remaining students is greater than the number of assigned instructor pilots, the difference between the two figures is the number of extra instructor pilots in the late flight. If the flight has extra instructors, the model must determine where to assign them.

In the model, a difference of six in seniority numbers identifies a new and old flight pair for sharing resources. Time delays are used to insure that all on time flights are available in a file when late processing begins. Since the T-37 model assumes all students fly the T-37, instructors

are merely reassigned to the lower numbered flight. Eventually, the late flight graduates all its students, and the new flight gets its full instructor allotment. This system is limited to two flights sharing the same instructors.

If the system ever became so backlogged that three flights had to share instructors, the instructor sharing procedure breaks down and the results are meaningless; however, this could only occur if classes were taking twice the allotted time to graduate which never occurs. Once the instructors have been reassigned, late flights with training sorties remaining are returned to await the next days sorties; flights without sorties remaining are discarded simulating graduation. This completes the procedure for reallocating instructor resources.

Throughout the above discussion, references have been made to information carried by the flight. For ease of reference, this information is consolidated in the next section.

Flight Description. Only the information needed to compute the training requirements, to record and adjust the flights progress and to compute statistics on the flight is essential. These items of information are considered attributes of the flight and are available whenever the flight is being processed; numbers preceded by an asterisk (*) are computed at the moment the flight is created; the

others are computed as the flight progresses through the
model. The attributes associated with a flight are:

* 1. The time the flight begins training,
* 2. The flight seniority number (one for newest),
* 3. The number of days allotted to complete the
     training,
* 4. The number of students in the flight,
* 5. The number of instructor pilots assigned to the
     flight,
* 6. The total number of flying sorties needed for all
     assigned students to complete the flying training
     specified by the syllabus,
* 7. The total number of simulator sorties needed for
     all assigned students to complete the simulator
     training specified by the syllabus,
* 8. The training priority of the flight (range is one
     to five with the higher number being the higher
     priority; two also means simulator training is
     more urgent than flying training),
  9. The overall priority of the flight for resources
     relative to the other flights (the higher the
     number, the higher the priority),
 10. The maximum number of flying sorties authorized
     for all the students in the flight today,
 11. The maximum number of simulator sorties
     authorized for all the students in the flight
     today,
 12. The number of flying sorties the flight is
     attempting to fly today,
 13. The number of simulator sorties the flight is   .
     attempting to fly today,
*14. The number of flying sortie requirements
     remaining for the flight,
*15. The number of simulator sortie requirements
     remaining for the flight,
 16. The number of training days the flight has
     completed,
 17. The number of solo flying sorties authorized for
     the flight each day this week,
 18. The number of guest help instructor pilots
     available to fly with the flight today,
*19. The number of remaining solo sorties needed by
     the flight,
*20. Reserved for type aircraft in later models (T-37
     is defined as 37; T-46 as 46),
*21. Total student attrition expected for the flight,
     and
 22. Total student attrition experienced thus far.

The information carried in the flight attributes uniquely describes each flight and enables the model to perform the tasks required to simulate the T-37 training system (same attributes are used in the T-46 conversion model). This completes the discussion of the T-37 model for the existing training system.

T-46 Model

The T-46 model structure closely resembles the T-37 model. Indeed, the T-46 model must include all the capabilities of the T-37 model. In addition, the T-46 model contains all the changes to the T-37 model needed to account for differences in the system during the conversion period. For example, the T-46 model must manage separate resources associated with each type aircraft, manage the instructor cadre flight, and determine when to transition an arriving student class into the new aircraft. Since the model so closely parallels the T-37 model which has already been described in detail, only differences from the T-37 model are described in this section. If the procedure being discussed exists in the T-37 model, the discussion of changes found in the T-46 model will have the same sub-heading as its counterpart in the T-37 model discussion. The first significant difference is that the daily sequence of events must include more items.

Daily Sequence of Events. The changes to each of the daily events needed to model the conversion are

92

discussed in this chapter in the sequence listed below. The
events in the list, which are preceded by an asterisk (*),
are unique to the T-46 model:

*1. Additional T-46 aircraft enter the system, if
    appropriate.

*2. Simulator conversions begin or end, if appropriate.

 3. A new class is created, if appropriate.

*4. IP flights begin training, if appropriate.

 5. Overall priorities between flights are set, if
    appropriate.

 6. Flying and simulator resources available are reset.

 7. Training for each flight is simulated.

 8. Training records for each flight are updated.

 9. Late flights have instructors reallocated.

10. Seasonal factors index is incremented monthly.

Deliver T-46 Aircraft. Only the T-46
deliveries made during the period that student flights are
attempting to transition need to be properly sequenced for
this problem. The implementation plan stipulates that 40
T-46 aircraft will be present before the first student
flight is assigned to the T-46; therefore, the model must
insure that 40 aircraft are available before the first
student class transition, continue deliveries at the
appropriate rate until all 86 aircraft are on station, and
then stop deliveries. A delivery is defined as the arrival
of two T-46 aircraft at Laughlin, because the initial
flights are likely to be flown in pairs to enchance safety.

93

The model insures the 40 aircraft will be available to start the transition by initializing the system to 38 aircraft and scheduling the first delivery of two more aircraft for the month the experimentor specifies for the start of the transition. (The month of July was specified during these experiments to reflect the implementation plan.) The appropriate delivery schedule could be maintained by using the distribution for aircraft deliveries described in the data section to compute the delay in days until the next delivery; however, the delivery rate was modeled as a constrant set at a low of 8 days or high of 10 days while screening for significant factors. Deliveries cease after 86 aircraft are on station.

The delivery of T-46 aircraft is assumed to be independent of the retirement schedule for the T-37, which is as yet unspecified and, therefore, not modeled. The assumption is that the commander will retain sufficient T-37 aircraft to meet the requirements of T-37 students but not so many that unnecessary impairment of the T-46 operation occurs. In addition to managing the aircraft arrivals, the model must manage the simulator conversions.

Simulator Conversions. The model uses the start conversion time specified in the input data to schedule the simulator conversion cycle. The first T-37 simulator complex is shut down six months before the conversion begins as specified in the implementation plan.

94

The amount of time required to complete the simulator conversion is also specified as an input variable. The model leaves the other T-37 complex in operation until six months of the conversion period have passed. Sufficient T-37 flights are expected to have transitioned to T-46 flights at this point to allow shutdown of the last T-37 simulator complex. Assuming contractual obligations leave little flexibility on the shutdown date, the model always shuts the last T-37 complex down at the end of the sixth month after the conversion begins. At this point, student flights with T-37 simulator requirements remaining have no simulator available to complete them; therefore, the model converts any remaining T-37 simulator sortie requirements into flying sorties on a one for one basis.

The time required to complete the conversion of the second simulator is assumed to be the same as the time required for conversion of the first simulator. This provides a conservative estimate of the conversion time since lessons learned during the first conversion are likely to enhance the second. Because the number of operational simulators is a factor in the choice of syllabus for arriving flights, the number of active simulator complexes for each type aircraft is maintained within this model segment. The model uses both the number of T-46 delivered and the number of simulators available when processing a new class.

95

New Class. If a new class is due to arrive
today, the T-46 model creates a class, assigns students and
instructor pilots to the flight, computes the total flying
and simulator sorties requirements for the flight, and
enters the flight into the system before the daily training
cycle begins. Although the tasks are similar to the T-37
model tasks, several changes are necessary in the T-46
model:

1. Classes arrive every three weeks instead of every
    six weeks; therefore, the classes have only enough
    students to make one flight.

2. The model must choose the appropriate type aircraft
    and syllabus for the new flight.

3. The model must schedule another cadre flight to
    begin training if the available qualified T-46
    instructors are assigned to the new flight.

4. Late flights may pass instructors to the new flight
    only if the flights are flying the same type of
    aircraft.

Choosing the appropriate aircraft and syllabus requires the
model to ascertain what kind of aircraft the graduating
flight was using and how many students are currently flying
the T-46.

The method for determining the type aircraft used by
the preceeding flight depends upon whether the flight begin
replaced has already graduated and departed or remains as a
late flight finishing training. If a flight finishes early,
the model must save the type of aircraft assigned to the
graduating flight for use in selecting the appropriate type
of aircraft for the replacement flight. In experimenting

96

with the model over broad variable ranges, more than one graduation may occur between creating new flights; however, the model can still obtain the appropriate type aircraft for the old flight from the value stored on the calendar. If the graduating flight is late, the flight is still available in the system, and the type of aircraft is read directly from the flight's information file.

The number of students and flights assigned to each type aircraft must be observed at the time the new flight is being made. The number of students assigned to each flight changes with time because some students are not able to complete the training. To account for the changes, the model observes each flight currently in the system and counts both the flights and the students currently using each type of aircraft. Instructor pilots assigned to the cadre flight to learn to fly the T-46 are counted as T-46 students. The flight count is restricted to the five junior classes because these classes have the bulk of the remaining simulator requirements.

If the graduating class was already flying the T-46, it continues to fly the T-46. If the new class is replacing a late class which still requires some instructors, the new class only gets the instructors no longer needed by the late one. The new flight is added to the number of flights currently using the T-46 simulator. The number of T-46 simulators in operation determines the type syllabus for the

97

new class. If the new class falls in this category, the
model assigns the syllabus. If not, the model must continue
to determine the proper type of aircraft.

If sufficient T-46 aircraft have arrived to start the
transition and the cadre has completed transitioning a
flight of instructor pilots to the T-46, a student to
aircraft ratio is used to decide if the new flight will
train on the T-46. The student to aircraft ratio which
would result if the new flight is assigned to the T-46 is
calculated by adding the number of students in the new
flight to the number of students already flying the T-46 and
then dividing by the number of T-46 aircraft on hand. If
the ratio is less than the maximum permitted with the
current simulator status, the new flight is assigned to the
T-46.

The new T-46 flight uses the instructors already
trained by the cadre and releases its previous instructors
to form a new cadre flight; therefore, the new flight
receives a full assignment of instructors even if the late
flight being replaced still requires some T-37 instructors.
The new flight is added to those already using the T-46
simulator. Again, the number of T-46 simulators in
operation determines the type syllabus for the new class.
If the new class falls in this category, the model assigns
the syllabus.

The last category is for classes which must fly the

T-37. If the graduating class is late and still requires some instructors, the new class receives only the instructors no longer needed by the late one. The new flight is added to the number of flights using the T-37 simulator. The number of T-37 simulators in operation determines the type syllabus for the new class.

The choice of syllabus depends both upon the number of simulator complexes in operation and the number of classes using them. If two complexes are operational, the new class follows the full simulator syllabus. If no complexes are available, the new class follows the no simulator syllabus. If one complex is available and three or less classes will be training on it, the new flight is also assigned the full simulator syllabus requirements. Otherwise, the one simulator complex will have to support more than the normal student load so the half simulator syllabus requirements are assigned to the flight. The number of sorties required by the flight is a simple product of the number of students in the class and the syllabus requirements as shown in Table IX.

Table IX

Sortie Requirements per Student by Type Syllabus

Type Syllabus	Flying Sorties	Simulator Sorties
Full Simulator	57	25
Half Simulator	71	12
No Simulator	81	0

If none of the six junior flights are training in the T-37 at this point, the conversion is completed. The statistic for time to complete the conversion is collected, and the results of the experiment are printed. If one of the six junior flights is training on the T-37, the model continues the simulation by setting the remaining flight characteristics.

The remaining characteristics are set as they were in the T-37 system model. This completes the procedure for creating new student flights. A different procedure is to create new cadre flights.

Cadre Flights. The first cadre flight is trained before the conversion begins (the conversion begins when the first student class transitions to the T-46 and ends when the 1 .. T-37 flight transitions to the T-46). The model does r   >licitly model the training of the first cadre flig ' out rather begins with one trained flight of instructors available at the time the conversion is to begin. Since .:!udents must share the available T-46

resources with the cadre during the conversion period, all other cadre flights are explicitly modeled. The new cadre flight carries the same type information as the student flight, but the values are different. The seniority number for the cadre flight is 46.0, which insures that it is always considered the most senior flight.

The course length for the cadre has not been finalized so the value is an input variable; the course lengths currently being considered by ATC are 15 or 30 days. The number of students (transitioning instructors) in the cadre flight is set equal to the number of T-37 instructors normally assigned to a student flight which is also an input variable (currently, 18 instructors are assigned to a flight). The number of T-46 qualified instructors assigned to the cadre flight with the primary responsibility for transitioning the T-37 IPs is also an input variable. Although ATC plans for the cadre to contain 15 T-46 instructors, not all of the pilots will be transitioning other instructor pilots as their primary duty. This division of responsibility for cadre instructors is modeled by only assigning to the flight the number of instructors who will have conducting flying training as their primary duty and treating the others T-46 IPs as guest instructors for the cadre.

Since a student flight cannot transition to the T-46 without trained instructors, the cadre flight always carries

101

a training priority number of five which insures the cadre flight carries the highest overall training priority whenever it is in the system. Since the cadre always has the highest priority, a difference in syllabus length for the cadre flights must be modeled as a limit on the number of sorties permitted each day for cadre students. A limit of two sorties per day per student is modeled for the 15 day syllabus while a limit of one sortie per day per student is used for the 30 day syllabus. Since the cadre instructors have no acadmic class limitations once the flying portion of the syllabus begins, cadre T-46 instructors are permitted an average of 2.5 sorties per instructor per day. The cadre syllabus also differs from the student syllabii in that the first five days are devoted exclusively to academic training with the remainder of the training days devoted exclusively to flying training.

No simulator training is required for the transitioning instructors. Finally, all the transitioning instructors are expected to finish the transition training successfully. Many of the values used in constructing the cadre flights are modeled as input variables to facilitate this study as well as make use of the model practical for other studies. Having constructed the necessary flight inforation file, the cadre flight will be inserted into the flying system after delaying for five days of classroom training. Although similar to student flights, the cadre flight is handled

differently during the weekly review of priorities.

Weekly Review of Priorities. As with the T-37 model, the weekly review of the classes examines each student class individually to assess its training progress and training priority with the exception of the cadre flight. If the flight pulled from the system happens to be the cadre, the number of students is added to the total number of T-46 students in the system this week, and the flight is simply reinserted into the system still carrying the top flight training priority number (five). For student flights, there is no change to the algorithm for assessing training progress and assigning priorities. In addition to determining priorities, the model accumulates the current number of students in the system assigned to each type aircraft for use in computing the number of sorties available for today.

Flying and Simulator Sortie Resources. As in the T-37 model, the number of flying sorties that maintenance can generate within the available minutes of daylight must be calculated. Unlike the T-37 model, the T-46 model must now use the appropriate generation function for each type aircraft and allocate the minutes of daylight between the aircraft types since the T-37 and T-46 will takeoff from the same runway. The total number of minutes of daylight is calculated as before. Next, the model uses the product of the total minutes of daylight and the number

of T-47 students divided by the total number of T-37 and
T-46 students to calculate the number of daylight minutes
allocated to the T-46. The remaining minutes are used for
the T-37. The number of flying sorties available for each
type aircraft for today is the minimum of what maintenance
can generate and the number of minutes of daylight for that
aircraft divided by the three takeoffs per minute allowed by
ATC.

The number of simulator sorties available for students
from an operational T-37 or T-46 simulator complex is
expected to be the same for each operational complex;
however, the number of complexes operational will vary
during the conversion. To calculate the sorties available
from each type of simulator complex, the expected number of
simulator sorties from two operational complexes is
multiplied by the actual number of operational complexes and
divided by two. After completing the sortie calculations,
the model is ready to simulate the flights training for
today.

Flights Request Sortie Resources. The flights
are sequenced for service by overall priority number as
before; however, some processing is necessary before the
model can allocate sorties to the flight. By checking the
flight seniority number, the model identifies the cadre
flight and sets the maximum instructor daily sortie rate at
2.5 for the cadre instructors and at 2.0 for the other

instructors. The cadre is able to use all its primary
assigned instructors for flying duties so the number of busy
instructors is zero for the cadre. By checking the type of
aircraft the flight needs, the routine can set the
appropriate resource identifiers. At this point, the sortie
requests are handled exactly as they are in the T-37 model
with one exception. Since the cadre instructor sortie per
day factor is not an integer, the routine must insure that
the sortie request is an integer. Since the sortie request
may be the maximum number of sorties authorized for the
flight, the integer is obtained by truncating the real
portion of the sortie request. After a 0.4 day delay to
simulate the training, the flight records must be updated.

Daily Simulation and Flight Record Update.

Because the T-46 student flight record is organized exactly
like the T-37 student record, the same update routine is
used for all but the cadre flight. Since the weather
restrictions are based upon the students rather than the
type aircraft, the weather cancellations function is
unchanged. For the maintenance cancellation function, the
T-37 has the advantage of being well known by the
maintenance personnel but the disadvantage of being an old
system which tends to decrease the mean time between
failures. The T-46 has the advantage of being a new system
which should decrease the mean time between failures once
the initial faults are worked out of the system, but it is

105

not well known by maintenance. Since the base will accumulate 40 aircraft and fly only the cadre flight for a significant period, maintenance should have time to adapt to the new aircraft before having to meet the high sortie rates required by student flights. In the absence of evidence to the contrary, the maintenance cancel rate is assumed to be similar to the T-37.

The monthly aircraft utilization rates are calculated separately for each type of aircraft. For flights graduating early, the variable corresponding to the type aircraft flown by the last graduating class is scheduled for update immediately prior to the scheduled arrival of the replacement flight. The last change gathers statistics by type of aircraft to give further insight into experimental results. The procedures for handling the loss of a student and failed checkrides are unchanged. If a flight is not late, it returns to the system for more training or graduates as appropriate. Late flights receive further processing to redistribute instructors just as in the T-37 model.

<u>Reassignment of Instructors in Late Flights</u>. The reassignment of instructors does not apply to the cadre flight. The only change to the process for redistributing instructors no longer needed by the late flight is the added stipulation that the type aircraft must match for the old flight to reassign instructors to the new flight. This

106

insures that instructors will be trained by the cadre before being assigned T-46 flying duties. After reasigning the extra instructors, the flight is returned to the system to await the next day's training sorties as before. This completes the last routine for processing student flights. The last process for cadre flights is the training record update at the end of the day.

Daily Flight Simulation and Cadre Record Update. This routine updates the training record of a cadre flight if one currently exists. The model only considers the cadre flight to exist when the assigned students still require flying training. The cadre flight is updated separately from the student flights because the procedure is much simpler and uses different distributions. Although the cadre still needs daylight sorties, the experience level of the transitioning instructors allows effective training in weather that would be unacceptable for students. The effective sortie rate is calcuated and used to update the training requirements and to calculate the flying hours contributed to the T-46 utilization rate. Appropriate statistics are gathered on the cadre flight just as they were on the student flights. If the cadre flight has sortie requirements remaining, the flight is returned to the system to await the next day's sorties. If no sorties remain, the cadre flight graduates making a flight of T-46 instructors available for transitioning a student flight to

107

the T-46. No new cadre flight is formed until the current cadre graduates are assigned to a student flight. This completes the procedure for updating the cadre flights.

This completes the discussion of the changes made to the T-37 system model to develop a T-46 system model. The changes enable the T-46 model to manage resources for two types of aircraft simultaneously, convert simulator complexes, transition T-37 IPs to T-46 IPs, choose the appropriate aircraft and syllabus for incoming classes, and recognize the end of the conversion period. The T-46 model gathers statistics by type aircraft to provide further insight into the system. To establish credibility for these models, verification and validation techniques are used.

Verification

Verification is testing a model to assure that it actually behaves as the programmer intended. Verification techniques were applied to subroutines of the model as it evolved to avoid the tedious, time-consuming task of debugging of a large complex model. Verification was completed prior to attempting validation--the process of showing that the model output represents accurately the real world system (16:75). The following techniques were used throughout the model development once the basic problem definition and system description had been developed (20:335-337).

1. Write and debug in modules or subprograms.

A. Do the simple version first.
B. Represent unwritten subroutines with "dummies or stubs".
C. Add only needed level of complexity.

2. Have other programmers review your code.

A. Have program copies for everyone.
B. Have author briefly go through the code line-by-line. Do not continue until all agree that the statement is correct.

3. Use the "trace" feature to insure the program is operating as intended.

A. Limit time and data so output is manageable.
B. Test each possible program path.
C. Test program ability to deal with extreme values.
D. For discrete event programs, trace after events.
E. For continuous event or mixed programs, trace before and after.
F. Use special input data, perhaps deterministic, for which hand calculator estimates of subroutine outputs is easy.

4. Run the combined simulation model under simplifying assumptions for which the model's true characteristics are known or easily computed.

This section will briefly describe how each of these steps was applied to the development of a model for the T-46 transition period.

The problem was carefully separated into the tasks to be performed which could be written as computer subprograms. These subprograms were further subdivided into two groups by the computer language likely to be used for programming. The tasks, which were associated with the time sequencing of events, were modeled as event networks with the simulation language SLAM. The tasks, which required complex

109

conditional statements or algebraic calculations, were best
modeled with Fortran subroutines which could communicate
with the SLAM network. Before programming began, the tasks
were even further subdivided into those tasks necessary to
model the existing T-37 system and those tasks necessary to
model the T-46 transition. The relationship between the
time of day for execution and the program modules is
summarized in Table X and Table XI.

Table X		
T-37 Model Modules		
Time of Day	SLAM Network	Fortran Subroutine Called By the SLAM Network
0.0	New Class	Makeft (Make Flight)
0.0	Month Counter	none
0.1	Weekly Priorities	Weekly
0.2	Resource Levels	Dlyres (Daily Resources)
0.3	Training Cycle	Reqst (Request Resources)
0.7	Training Cycle	Update
0.8	Training Cycle	Reip (Reassign IPs)

Table XI		
Additional T-46 Model Modules		
Time of Day	SLAM Network	Fortran Subroutine Called By SLAM Network
0.9	Simulator Cycle	Sm2flt (Simulator Sorties to Flight Sorties)
0.9	T-46 Delivery	none
0.0	New Class	Cadre (Start a Cadre Flight)
0.7	Training Cycle	Ipflt (Update Training of Cadre Instructor Flight)

The primary rule during model development was to start simple and grow only as complex as necessary to solve the problem. Random distributions were initially discarded and replaced by small whole numbers to simplify the calculations and make the program results totally deterministic and thus totally predictable. The variables were scaled down to small values to lessen the computer time and output needed to trace all network paths. Modules in Table X and Table XI were developed and debugged sequentially: first, the SLAM network was written with the Fortran routines as dummies which supplied constant values; second, the actual Fortran routines were added and debugged one by one.

When a routine was added, the flight attributes changed by the routine were traced during the computer run to insure the routine produced the expected results. If the number of attributes changed in the routine exceeded the trace

capacity of SLAM (five attributes), either multiple runs
tracing different attributes or print loops were used to
review all attributes of interest.

At times, several program versions were developed in
parallel to shorten the development time by simultaneously
testing different concepts. All runs were labeled with the
purpose of the modification and the time and date submitted.
All code developed by one author was reviewed and approved
by the other. The whole thrust of the procedure was to take
small simple steps forward from a verified base program so
that errors could be quickly isolated and identified. Once
confident that the basic structure was sound, mean parameter
values obtained from ATC were inserted for the simple values
used to develop the program.

The mean value model was used to determine the
necessary degree of complexity by comparing the days to
graduate a flight in the model with that of the system.
This comparison indicated the need to include additional
sortie requirements from failed flight evaluations and the
need to distribute students who drop out of training at
appropriate intervals in the syllabus. These modifications
produced a mean time to graduate of 89.9 days which was very
reasonable. At this point, the random distributions were
inserted with the mean parameters to attempt validation;
however, one step had been omitted which eventually caused
regression to the verification phase for the T-46 model.

112

The program had not been tested at extreme values. When runs with random distributions were made using wide ranging values rather than mean values, an extremely short time to graduate for some classes was drastically affecting the results. If a class graduated more than 15 days early, the new class was no longer replacing the correct old one which ultimately lead to some flights having to transition more than once. This was a classic example of a program being verified with variables at mid range values but not at extremes. Analysis of trace data showed that a few classes were just early enough to miss the final flight evaluation and thus missed the extra sortie requirements from failed flight evaluations. Rather than artificially limit the variance, the program was modified to take the last evaluation early and to always pair appropriate flights. The use of these techniques throughout the development process has produced a thoroughly verified model. The next task after verification is validation.

Validation

A model should be created for a specific purpose, and its adequacy or validity evaluated only in terms of that purpose. A goal, when generating a model, is to ensure it creates the same problems and behavior characteristics as the process or system being studied. There are many potential errors throughout the modeling and simulation process, and one must do everything possible to avoid them

(32:208).

The process of creating the model requires the
integrated inputs of many different specialists and
transpires over a period of time; therefore, the potential
always exists that the final result will not be what was
originally desired. Thus, proper validation techniques are
crucial to the acceptance of the model of the UPT system at
Laughlin AFB. The validation of the model was accomplished
in stages, building confidence into the model throughout the
development process. The validation process included the
following three steps (32:217):

   1. Constructing a set of hypotheses about the manner
       in which elements interact based upon all available
       information including observations, previous
       research, relevant theory and intuition

   2. Testing the internal structure of the model by
       verifying the assumptions, parameters, and
       distributions

   3. Comparing the input-output transformation of the
       model to those of the real world system

The procedures, used to accomplish the first step
listed above, have already been explained in detail. The
review of pertinent literature; selection of the major
components, input variables, and random variables; as well
as, the construction of the causal diagram portraying
assumed interactions and relationships, constituted the
first step in validation. It is in this step that
conceptualization is performed. This conceptualization
required information from ATC, observance of the UPT system,

114

and intuition based upon experience.

The actions taken to ensure that step two is accomplished have also been discussed. How the data obtained from ATC was processed into hypothesized distributions and then statistically tested for goodness of fit is discussed in the data section. This procedure ensured the internal structure of the model is sound and reasonable. Statistically testing the distributions and parameters chosen for the model builds confidence in the validity of the experimental inputs for the model. This establishes a basis for generating credible results. Only the third step in the validation process is done after the model is built and output is obtained.

The third step in validation is necessary in order to convince the user that the model does what one claims it will do, i.e., that it is useful. This step is highly critical to gaining the user's acceptance and implementation. The tools available to accomplish the third step range from highly technical mathematical techniques, such as spectral analysis as well as other goodness of fit tests, to behaviorally oriented techniques, such as the "Turing" test, to the running of practical demonstrations, such as prototype and field tests (32:216). Of these techniques, only the specific techniques used for final validation of the UPT model will be discussed.

In order to compare the input-output transformations of

115

the model to those of the real world system, statistical methods that test sample means and goodness of fit were used. Data is available on the number of days to graduate for the last eight classes at Laughlin AFB. Input variables for the model were set at levels indicative of the actual values over the past year at Laughlin AFB. The response for the number of days to graduate for eight classes was then obtained from the model. In order to be satisfied that the mean time to graduate obtained form the simulation model is the same (statistically speaking) as the actual time to graduate for the last eight classes at Laughlin AFB, a t-test was performed. At a significance level of alpha = .05, one fails to reject the hypothesis that the means of the two samples are equal; therefore, one can be satisfied that the average time to graduate obtained from the model is indicative of the average time to graduate in the real system.

In addition to showing the means to be statistically equivalent, it is also necessary to determine statistically if the data points (response numbers) from the model come from the same distrubution as the real world observations. The same goodess of fit test (K-S) used for testing a hypothesized distribution against real world data was used to test the similarity of the two samples. (The two samples are the times to graduate obtained from the model and the times to graduate in the real world.) Once again, at a

116

signifcance level of alpha = .05, the hypothesis that the two samples came from the same distribution is accepted. This implies that not only are the mean times to graduate equivalent, but that the model is returning a spread of graduating times indicative of those in the real world.

The three steps of validation occur in an iterative manner throughout the model development and implementation process. When a conscientious effort is made to obtain validity through steps one and two, then one can expect acceptable results when completing step three. Although the results of the third step are the most critical in terms of "selling" the model, positive results are only possible if steps one and two were properly accomplished. The careful application of all three steps establishes the credibililty of this model.

It is noted that step three of the validation process was performed on the model before the T-46 implementation process was added. The lack of historical data on the implementation process precluded using statistical comparison with historical data for the final model. Care was taken in the final model not to alter the basic logic of the system but to merely substitute T-46 components for T-37 components where appropriate.

Variance Reduction

Variance reduction techniques seek either an increase in the precision (decreased variance) for a fixed sample

117

size or a decrease in the sample size required to obtain a fixed degree of precision. It is not practical to discuss sample size for this specific simulation. The UPT system, with the T-46 implementation process included, was modeled in such a way that it is a terminating system. This means that the simulation run ends if a specified event (the end of the conversion) occurs. For this reason, the sample size (number of graduating classes) is determined once the simulation ends and is not predetermined per a confidence interval before the simulation. Consequently, the role of variance reduction for the T-46 model is to seek an increase in the precision of the output variables (response) for a fixed (uncontrolled) sample size. The techniques of variance reduction selected to satisfy this role are the use of common random numbers and synchronization.

Common random numbers is a technique that gives each stochastic input variable its own sequence of random numbers (19:201). When simulating the next system variant (same system with different values for input variables), the simulation will begin with the same initial values for the random number generators. Any variation in the response variables will then be more likely to be attributed to different input values versus randomness.

All distributions used in the model were given their own random number stream with the exception of the weather distributions. The same random stream number was used on

118

all four weather distributions since only one weather distribution is active on a particular day and the change in seasonal weather distributions is sequenced in exactly the same pattern across all variants. The common random number technique is sufficient for experiments on the T-37 model which terminate after a predetermined number of days; however, the T-46 model is self terminating after different time periods which disrupts the required synchronization in the random number streams.

Synchronization starts each system variant replication with a common initial seed value. This is accomplished by drawing a random number for each stream for each replication before the experiments begin: these same random seeds are used as starting points for all system variants. This results in keeping the events in the different experiments synchronized at the start of each replication which in turn reduces the variance.

Other techniques for variance reduction are available, but the two techniques discussed above are by far the simplest and most effective for this problem (19:238).

Summary

The model is an integral portion of the system analysis concept. The research objective dictates the purpose of the model, and this purpose determines the type of model to build. The research objective of this study requires a model to predict future behavior of the UPT system and

provide an insight as to which variables are the most significant in affecting overall system performance; therefore, a simulation model was selected.

Applicable data must be gathered prior to the creation of a model. Data were collected on all input variables and random variables in Tables I and II. The vast majority of data was used to hypothesize distributions relating to the random variables in Table II. These hypothesized distributions were compared to a graphical analysis (histogram) and their parameters computed using maximum likelihood estimators (MLE) and tested with the K-S goodness of fit test. The final results for the distributions and parameters used in the model are shown in Table III.

The model translation involves the actual formulation of the computer program. The constraints and assumptions sections of the report are considered when formulating the model. The T-37 system was modeled first in order to verify and validate the internal structure of the model. Subsequently, the T-46 implementation process was included in the model and again verification was performed.

Validation was accomplished in three steps which were done iteratively throughout the model development. The final step in validation (comparing simulation output to the real world data) showed that the response of the T-37 model is statistically equivalent to the response of the real T-37 system (i.e., unable to reject the hypothesis that the

120

responses were different).

Variance reduction techniques were also implemented in the model construction. Common random numbers combined with the necessary synchronization techniques were used to reduce the unidentified variance in the model response from the stochastic inputs.

V   The Experimental Design and Analysis

The purpose of this chapter is to explain the approach
taken (experimental design) to analyze the responses of the
model and the findings of that analysis. The areas considered
in the experimental phase are as follows:

1.   Selection of factors to be varied,

2.   Choice of levels of these factors, and

3.   Combinations of factor levels for the experiments.

Selection of the Factors to be Varied

The factors to be varied are chosen from the list of
variables depicted in Tables I and II. Some of these variables
are of interest to ATC either because ATC can control them and,
therefore, affect the overall performance of the system, or
because these variables will have an impact on decisions to be
made during the conversion. Those variables of interest to ATC
are the factors used in the experiment and are listed in Table
XII.

As previously stated, the variables in Table XII were
subjectively screened. Input variables such as the number of
instructors per flight, the number of flying sorties required
by each syllabus to graduate a student, or the number of flying
sorties required to qualify an IP were not selected as factors
because the values for these variables are not likely to be
changed for the conversion. The proposed values in the
implementation plan for the selected factors may be subject to

122

change prior to initiation of the conversion plan.

Table XII		
Factors and Levels for the Experiment		
Factor	Low Level	High Level
(a) Student to T-46 ratio	2.3	2.6
(b) Average number of students per class	31.5	35.5
(c) Days allotted to qualify an IP flight	15.	30.
(d) Number of T-46 IPs in the cadre	15.	20.
(e) Days to convert a simulator complex	100.	140.
(f) Days between T-46 aircraft deliveries	8.	10.

Several of the random variables in Table II are
expected to significantly affect the conversion and could be
considered as factors. All of the random variables used in
the model and the input variable for days to convert the
simulator in Table I are uncontrollable by ATC, and
uncontrollable variables are not normally selected as
factors of interest.

Even though the days to convert the simulator and the
days between aircraft deliveries are not controllable, they
will impact decisions during the conversion process. For
example, if the days to convert a simulator is longer than

expected, a new class entering may not train in the T-46 since more flying sorties will be required by the syllabus. Likewise, if the delivery rate of the aircraft decreases during the conversion, this will again influence the decision on the type aircraft a new class will use to train.

The remaining random variables in Table II are not of interest since no significant decisions will be made based upon the values of these variables. Nonetheless, they are included in the model because they will most likely significantly affect the outcome and undoubtedly increase the precision of the model's representation of the actual system. Each of the factors of interest have a range of possible values.

Choice of Factor Levels

Appropriate factor levels depend upon the experimental objective. The experimental objective for this study is to make a rather general investigation of the relationship of the response to the factors in order to determine the underlying mechanisms governing the process under study (24:338). This objective is most easily accomplished by setting each factor of interest to a high and low level and performing the simulation after combining these various factor values.

The high and low values for factors a through d were previously given in Table XII and, according to ATC, are respresentative of the possible range for each factor. The

124

likely range of values for factors e and f were obtained
after corresponding with the T-46 SPO (31) and the simulator
project officer (29). Once the factors to be varied and
their corresponding levels are determined, the design for
the experiment is selected.

The Design

The following questions are answered in the design
phase (17:21):

1. How long does one run the experiment?

2. How many total runs will be made?

3. How many replications of each run are required?

4. What mathematical model is used to describe the
   experiment?

Length of the Experiment. The technique used in
the model of the UPT system was to start the simulation in a
transient state with no classes in training. One class at a
time is created and divided into two flights which begin
training. Eventually, three classes (six flights) train
concurrently. Although this technique wastes the computer
time needed to pass through the transient state, it was
selected over choosing some starting conditions and taking
observations as soon as the simulation began to avoid
inadvertently biasing the results from the choice of
starting conditions. Since only steady state
characteristics are of interest, a decision must be made as
to when the observations (response variables) should be

125

collected.

This implies that we have to determine when the transient state is over and steady state operation starts. No foolproof method determines when steady state or equilibrium conditions have been obtained. However, a common method used is to compute a moving standard deviation of the output and to assume steady state occurs when the standard deviation no longer changes significantly over time (32:183-184). Table XIII shows the standard deviation for days to graduate as each class completes training. Observations are taken as a flight of students graduate. The standard deviations in Table XIII are based on the number of flights that have currently graduated. The length of this pilot run is 510 days. The standard deviation no longer changes significantly after 205 days into the simulation which indicates the system has probably reached steady state conditions. Therefore, the observations for days to graduate and days to transition begin after 210 days have been simulated.

Table XIII				
Standard Deviation for Days to Graduate				
Class Graduating	Number of Flights Graduating	Days Simulated	Standard Deviation	Change in Standard Deviation
2	4	125	3.21	--
3	6	150	3.78	.57
4	8	185	3.45	.33
5	10	205	4.07	.62
6	12	240	4.10	.03
7	14	270	3.96	.14
8	16	310	4.01	.05
9	18	335	4.10	.09
10	20	365	3.98	.12
11	22	390	3.82	.16
12	24	420	3.79	.03
13	26	445	3.95	.15
14	28	475	4.01	.06
15	30	510	3.99	.02

The following formula is useful in determining the number of observations needed during the computer run (32:189):

$$n = \frac{t^2 s^2}{d^2} \qquad (6)$$

where

    n = total number of observations
    t = tabulated t value for the desired confidence level
        and the degrees of freedom of the initial sample
    d = the half-width of the desired confidence interval
    s = the estimate of the standard deviation in the
        sample or pilot run

The formula was used to calculate the length of the computer run for the T-37 model validation. An arbitrary decision was made that a .9 probability of being within ± 1.5 days of the actual number of days to graduate was

127

sufficiently accurate for this study so that the total number of observations taken on graduating flights (n) in Equation (6) is 19.5. Since half a flight is difficult to measure, the average time to graduate for 20 flights (10 classes) should give the desired accuracy. To observe 20 flights graduating, the simulation must run for approximately 300 days. Adding 300 days to the 210 days required to reach steady state gives a total simulation length of 510 days, which is the simulation length used for validating the T-37 model.

The length of the computer simulation for the conversion to the T-46 aircraft has no meaning since the system terminates whenever the last flight transitions to the T-46. However, the model must begin with the T-37 system in steady state so observations begin after 210 days as in the T-37 model.

Number of Runs and Replications. There are six factors to consider for the T-46 implementation process. If each factor has two levels and one uses a full factorial design (all levels of a factor are combined with all other levels of every other factor), the experiment requires 64 total runs for each replication.

Since the use of a full factorial design can easily lead to an excessive computer time requirement, screening designs have been developed for identifying the most important subset of factors influencing the response with

128

fewer computer runs. If one is not interested in some higher order interactions, a great deal of information can be gained from running only a portion or fraction (1/2, 1/4, 1/8, etc.) of the total combinations (32:166). It is assumed among the factors in the T-46 transition that there are interactions (i.e., a combined influence of two or more factors on the response that is in addition to the individual influence or effects of these factors separately). Higher order interactions (among three factors and above) are assumed negligible, or at least too difficult to explain even if found significant. A fractional factorial can therefore be used to analyze the factors and their lower order interactions for significant effects.

The fractional factorial design selected is a 2^{7-3} resolution IV. This design is chosen based upon the number of factors to be varied and the assumed interactions present. The total runs required without replication is 16 as compared to 64. In terms of a fractional factorial design, this is a $(1/4) 2^6$ fractional factorial design (19:329).

Any time the experiment involves fewer samples than the full factorial, the penalty is confounding effects. Confounding means the statistics which measure one effect also measure another effect if it is present. For example, if a main effect is confounded with a higher order interaction, the two effects are so mixed that we cannot

separate them or distinguish between their effects. Thus,
if the analysis shows that some effect is present, the
response may be caused by the main effect, the interaction
effect, or some additive combination of the two (32:166).

When two or more effects are combined, they are said to
be aliases of each other. Not only does the 2^{7-3} resolution IV
design require confounding of effects, it also demands that no
main effect be confounded with a two-factor interaction since
two-factor interactions are assumed to be present. The
confounding and resulting aliases for this design are shown in
Table XIV. With this design, it is possible to determine the
effect for each factor since it is confounded with only
three-factor interactions (or higher) and all such interactions
are assumed negligible. Since the two-factor interactions are
confounded with other two-factor interactions, some ambiguity
is present for any significant two-factor effects. In some
cases, the ambiguity can be resolved from analysis of the data
and knowledge of the system.

```
                         Table XIV

                          7-3
          Aliases for a 2     Resolution IV Design (19:375)


Factor/Interaction                  Alias(es)

         a                          cdf + bef
         b                          cde + aef
         c                          bde + adf
         d                          bce + acf
         e                          bcd + abf
         f                          acd + abe
        ab                          ef
        ac                          df
        ad                          cf
        ae                          bf + abcd
        af                          cd + be
        bc                          de
        bd                          ce
```

Once the number of runs is determined, it is necessary
to determine the replications per run. This depends upon
the desired closeness of the estimate for the population
parameters. The formula used to determine the sample size
is Equation (6). To have a .95 confidence that the
estimated number of days to graduate is within 1/2 a day of
the true mean requires five observations. Thus, five
replications per cell are used for a total of 80 computer
simulations for the experiment (16 X 5).

Mathematical Model. The mathematical model used as
the basis for the analysis is as follows:

    Response = Mean + Main   + Interaction + Error
                       Effects   Effects

This statement says that any difference in the mean and the
model response must be due to the effect of some factor or

                            131

factor interactions and the experimental error present in the model. The statistical significance of these factors and their interactions can be determined by using analylsis of variance (ANOVA) (17).

Analysis

The results of the analysis reveal the statistically significant main effects and the possible statistically significant two-factor interactions. The effect of main factors and two-order interactions on the three measures of effectiveness are discussed.

Main Effects for Days to Graduate. The student to aircraft ratio, students per class, number of IP's in the Cadre, and the days to convert the simulator all have a statistically significant effect upon the number of days required to graduate a student class, while the days to qualify the IPs and days between aircraft deliveries do not. The values for the effect of each factor and two-factor interaction on the days to graduate are shown in Table XV. A graphical representation of these effects are depicted in Figure 14. The results for each main effect are explained in the following paragraphs.

Changing the number of students per entering class (factor b) from a mean of 31.5 to a mean of 35.5 increases the average days to graduate by seven days and has by far the most significant effect. This was expected since students place a daily demand on the system. Increasing the

132

Table XV

Effect on Days to Graduate

Factor/Factor Interaction	Effect			
	LL	LH	HL	HH
Student to Aircraft Ratio (a)	91.2	—	—	91.6
Students per Class (b)	88.0	—	—	94.7
Days to Qualify IPs (c)	91.3	—	—	91.4
Number of IPs in Cadre (d)	91.2	—	—	91.5
Days to Convert Simulator (e)	90.9	—	—	91.9
Days Between T-46 Delivery(f)	91.3	—	—	91.4
a X b	87.9	94.4	94.9	95.0
e X f	90.9	90.8	91.8	92.0
a X c	91.3	91.1	91.4	91.7
d X f	91.3	91.1	91.4	91.7
a X d	91.1	91.3	91.4	91.8
c X f	91.3	91.3	91.4	91.5
a X e	90.8	91.6	91.9	92.2
b X f	88.1	88.0	94.6	94.9
a X f	91.2	91.2	91.5	91.7
c X d	91.2	91.5	91.2	91.6
b X e	87.6	88.5	94.1	95.3
b X c	88.2	87.9	94.5	94.9
d X e	90.9	91.5	90.9	92.2
b X d	87.9	88.2	94.5	94.9
c X e	90.8	91.8	90.9	92.0
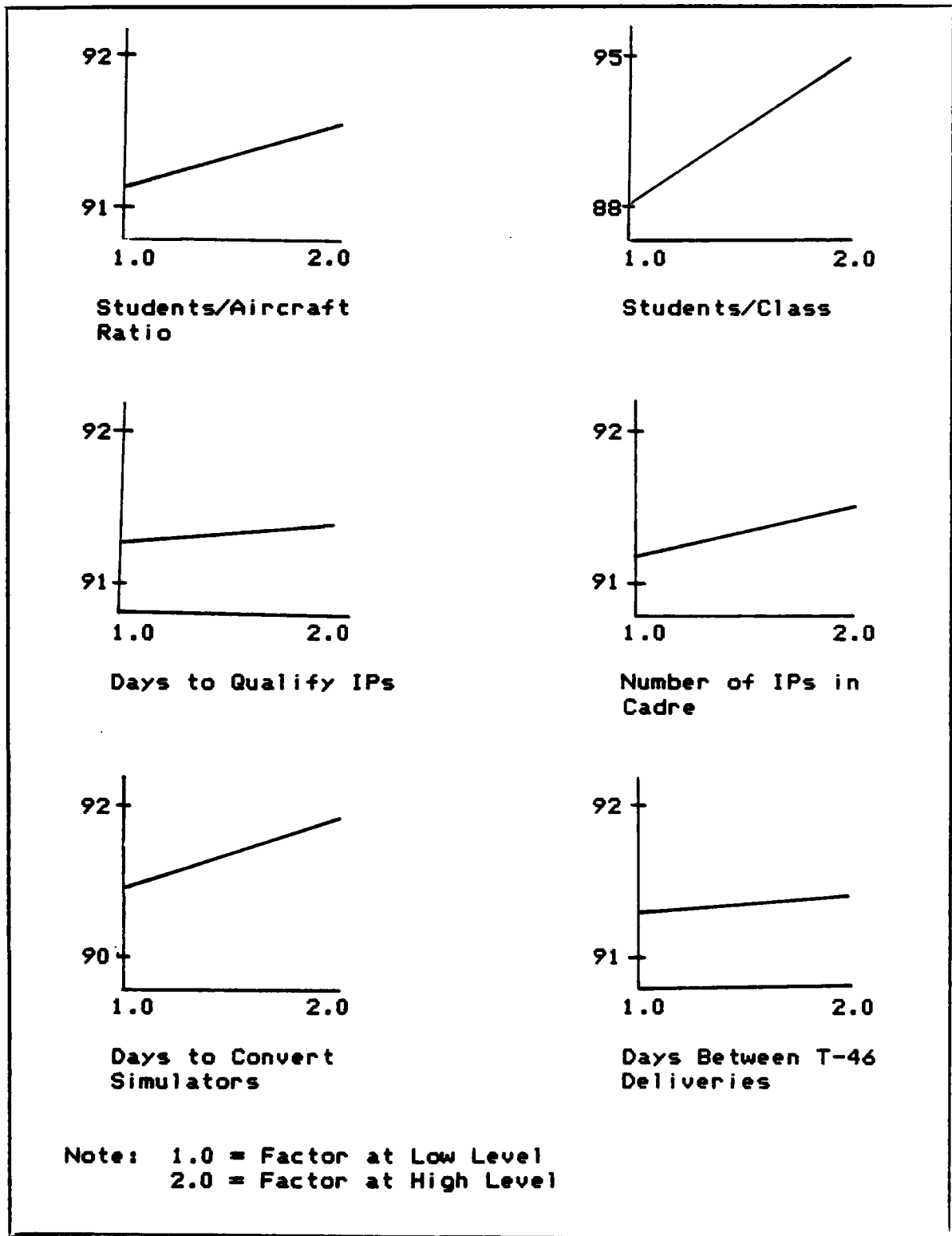
Figure 14. Graph of Effect on Days to Graduate

mean flight size by four students increases the daily

student sortie request beyond the capability of the flight's instructor assets. Flying the available instructors twice a day and the available guest IPs once a day limits the attempted sorties (flying and simulator) to 35 per day. Since most of the flights during the conversion will be forced to fly the 50% simulator syllabus, each student needs 71 flying sorties and 25 simulator sorties. Of these requirements, about 61 flying sorties and all 25 simulator sorties must have instructor pilot supervision.

Due to the effective sortie rate, each student must attempt approximately 81 dual (student with IP) flying sorties to accomplish 61 flying sorties. (For this rough estimate, solo sorties are assumed not to compete or conflict with the dual sorties.) With these assumptions and neglecting flight checks, the available instructors can train an average load of roughly 33 students per flight within the 90 days allotted. The results are consistent with this estimate since entering classes averaging 31.5 students required about 88 days while the classes averaging 35.5 students required almost 95 days. The next most statistically significant factor is the number of days to convert the simulator.

Changing the number of days to convert the simulator (factor e) from 100 to 140 days raises the mean days to graduate approximately one day. The syllabus that an arriving class will use is determined by the number of simulator complexes in operation. The longer delay in

135

simulator conversion results in a requirement for more flying sorties to graduate the same number of students. Each student requires an additional 14 flying sorties when using the 50% syllabus instead of the full simulator syllabus. Due to the effective sortie rate, students must attempt approximately 18 sorties to accomplish the 14 sorties. This results in a net increase of over five events per assigned student, which takes an additional four to five days to accomplish for the class sizes considered.

Similarly, students require an additional 25 flying sorties when using the no simulator syllabus instead of the full simulator syllabus. The effective sortie rate requires students to attempt approximately 32 sorties to complete the additional 25 sorties. This requires a net increase of seven events per student and takes an additonal six to seven days to accomplish for the class sizes considered.

The longer simulator conversion time causes several classes to use reduced simulator syllabii. The net effect is an increase of approximately 29 training days. Over all experiments, the average number of flights to graduate is about 22. Thus, the average increase per flight would be approximately 1.3 days if all the additional training was accomplished; however, the full effect is not seen because the simulation stops as soon as the last class is assigned to the T-46. The result is an increase of approximately one day in time to graduate. The next most significant factor is the student to aircraft ratio.

Changing the maximum student to aircraft ratio (factor a) from 2.3 to 2.5 with only one simulator complex available increases the days to graduate by 1/2 day. This is statistically significant because the higher ratio allows the earlier conversion of classes to the T-46. The T-46 system must support one additional class, on average, with the higher student to aircraft ratio. In this scenario, the lower ratio tends to balance the student load and the available resources slightly better than the higher ratio which accelerates the rate at which classes are allowed to transition. The last of the statistically significant factors is the number of IP's in the cadre.

Changing the number of IP's in the cadre (d) from 9 to 14 qualified T-46 instructor pilots increases the days to graduate by one third of a day. The low level of IPs in the cadre constrains the number of sorties available to the IPs qualifying in the T-46 using the 15 day syllabus to 27.5 sorties per day. At the high level, however, the sorties available increase to 36 per day. Thus, an additional 8.5 student sorties are lost to qualifying IPs using the 15 day syllabus.

The impact is more severe on the first student T-46 class because the 8.5 sorties is nearly 25% of the total T-46 daily sortie allocation. The impact is less severe when more student classes are using the T-46 because there are more sorties available and because the senior class has priority over the junior classes. The remaining factors are

not statistically significant.

Changing the number of days to qualify the IP's (factor c) has no significant effect upon the number of days to graduate the students. Two observations explain the lack of significance. First, both IP syllabii options require the same total number of sorties and both are short when compared to the student syllabii; therefore, it is likely that the same classes must give up the same total number of sorties to qualifying IPs regardless of the IP syllabus. Second, the aircraft delivery rate permits IPs to qualify before the T-46 IPs are needed, regardless of syllabus. The final factor to consider is the days between aircraft deliveries.

Changing the days between aircraft deliveries from 8 to 10 days has no effect upon the days to graduate. The reason for this phenomenon is that the decision to train a class in the T-46 is based upon the actual student to aircraft ratio. Since the delivery rates differ by only one aircraft per month, the same student to aircraft loading is experienced by the T-37 and T-46 sub-systems at both factor levels. This accurately models ATC's intent to avoid making decisions based upon speculated deliveries.

All six of the main factor results support the credibility and validity of the model in representing the system concept modeled in the causal relationship diagram shown in Figure 1. Only statistically significant two-factor interactions in Figures 15a-c are discussed.
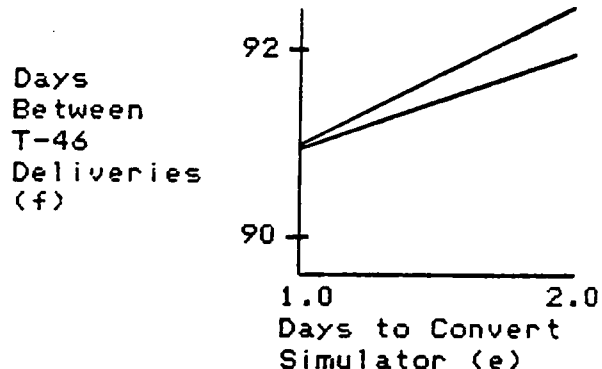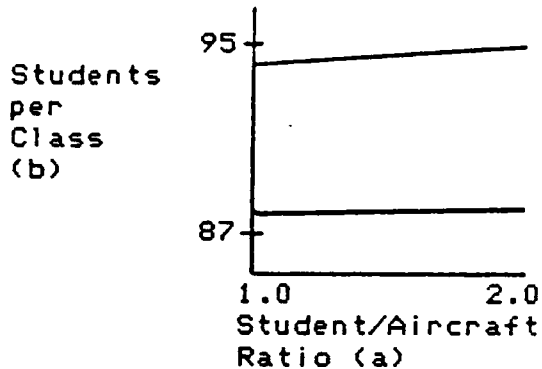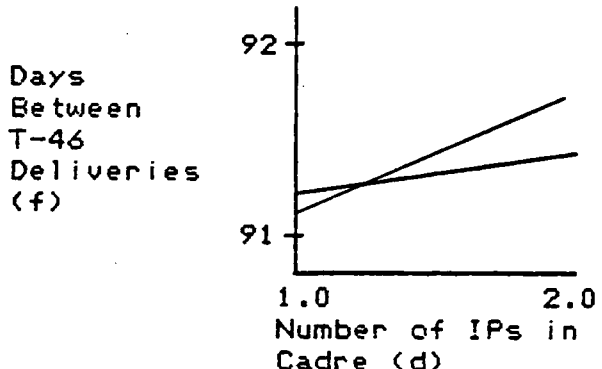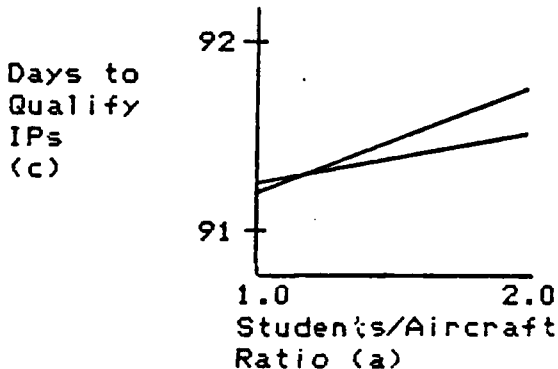
Figure 15a. Aliased Two-Factor Interactions for Days to Graduate

Days to
Convert
Simulator
(e)

93
90

1.0   2.0
Student/Aircraft
Ratio (a)

Days
Between
T-46
Deliveries
(f)

95
87

1.0   2.0
Students/Class
(b)

******** Aliases a X e and b X f ********

Days to
Qualify
IPs
(c)

95
87

1.0   2.0
Students/Class (b)

Days to
Convert
Simulator
(e)

93
90

1.0   2.0
Number of IPs in
Cadre (d)

******** Aliases b X c and d X e ********

Number
of IPs
in Cadre
(d)

95
87

1.0   2.0
Students/Class (b)

Days to
Convert
Simulator
(e)

92
90

1.0   2.0
Days to Qualify
IPs (c)
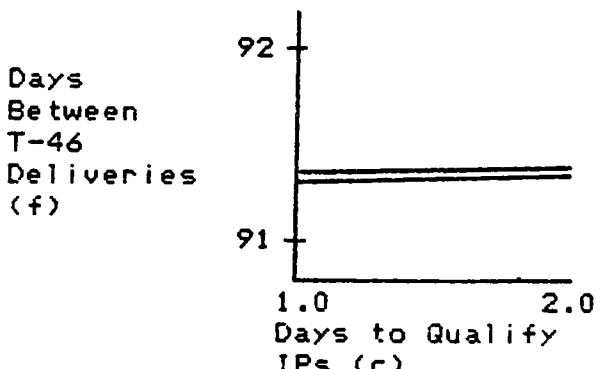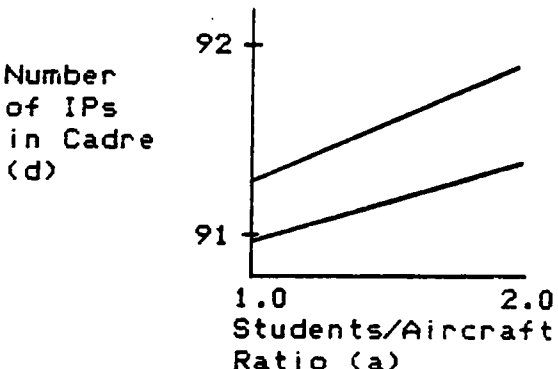
******** Aliases b X d and c X e ********

Note: 1.0 = Factor at Low Level, 2.0 = Factor at High Level

Figure 15b.   Aliased Two-Factor Interactions for Days to
              Graduate
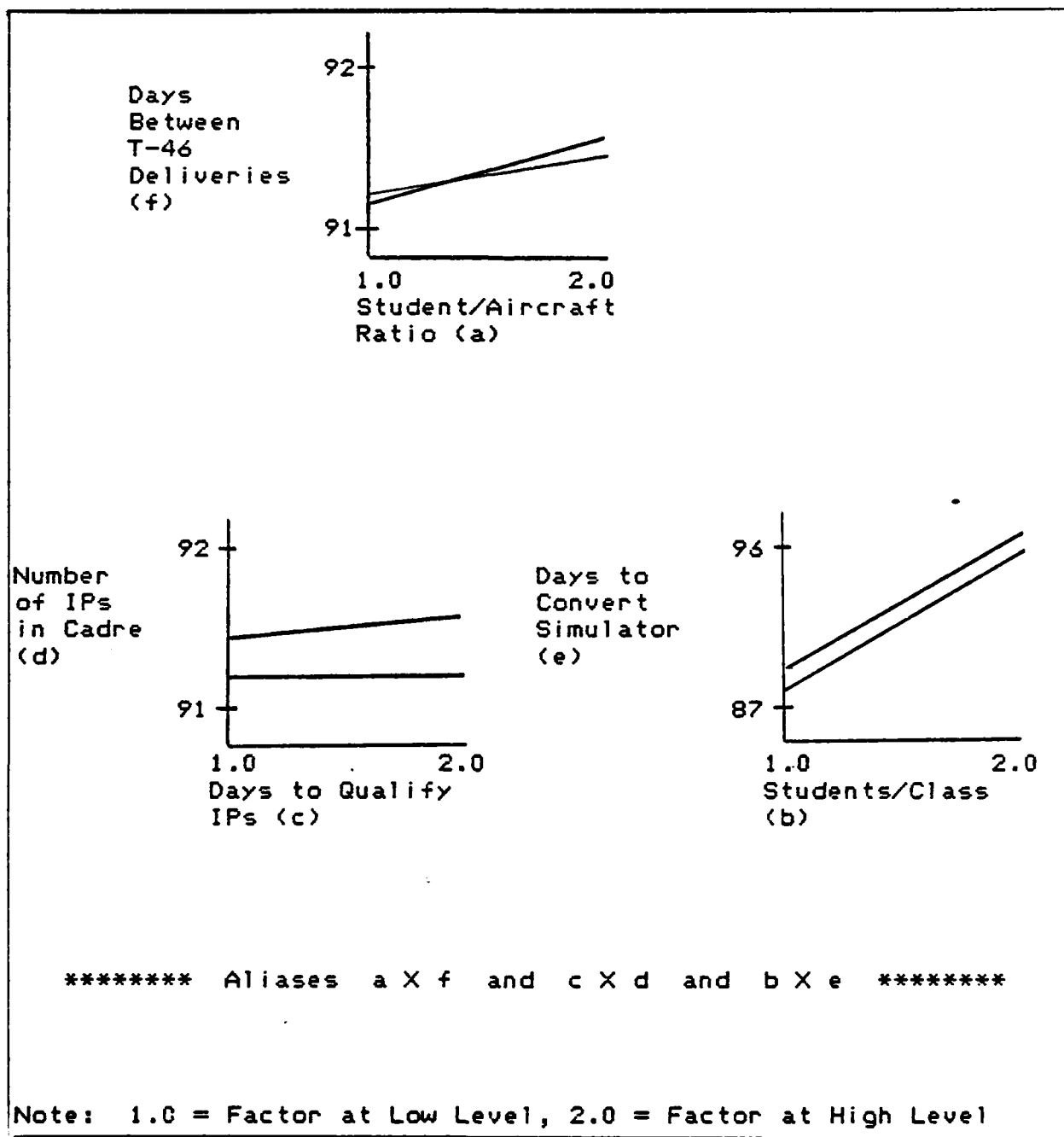
Figure 15c. Aliased Two-Factor Interactions for Days to Graduate

141

Significant Interactions for Days to Graduate. The
two-factor interactions in the resolution IV model are
confounded with other two-factor interactions so that
analysis of the graphs and system are necessary to
distinguish significant interactions. The significant
interactions for days to graduate involve the following
factor pairs:

1. Students per Class by days to qualify IPs (b X c)
    and number of IPs in the cadre by days to convert
    the simulator (d X e),

2. Student to aircraft ratio by days to convert the
    simulator (a X e) and students per class by days
    between aircraft deliveries (b X f), and

3. Student to aircraft ratio by days to qualify IPs (a
    X c) and number of IPs in cadre by days between
    aircraft delivery (d X f).

The significance of the confounded two-factor
interactions (b X c) and (d X e) is believed to be caused by
the d X e) interaction. Figure 15b suggests that the slopes
of (b X c) are essentially identical. Also, the main effect
of days to qualify IPs (factor c) is clearly not
significant. It appears that the interaction may be
explained the effect of the number of IPs in the cadre
(factor d) and the days to convert the simulator (factor e).
Both interactions have significant main effects.

As discussed under main effects, increasing the number
of IPs in the cadre can increase the number of T-46 sorties
per day devoted to qualifying IPs at the expense of T-46
students. Increasing the days to convert a simulator causes

142

more flights to use the reduced simulator syllabii, which increases the number of flying sorties required by the students to graduate. The combined effect is to ask for more student sorties while simultaneously decreasing the systems ability to supply them. Hence, a significant interaction effect occurs in the response.

The significance of the confounded two-factor interactions (a X e) and (b X f) appear to be caused by the (a X e) interaction. The slopes of (b X f) in Figure 15b are nearly identical. Also, the main effect of the days between aircraft deliveries (factor f) is clearly not significant; however, the student to aircraft ratio (factor a) and the days to convert a simulator (factor e) both have significant main effects.

Increasing the student to aircraft ratio tends to compress the time interval between assigning flights to the T-46. Increasing the time to complete a simulator conversion reduces the available simulator support, forcing flights to use the reduced simulator syllabus, which requires more flying sorties to graduate each flight. The combined effect is to require more sorties to graduate the same number of flights when both factors are at the high level than is required if either or both factors are at the low level. Hence, significant interaction effect is present.

Explaining the significance of the confounded interactions (a X c) and (d X f) is more complex since both

143

graphs intersect and both pairs involve the interaction of a significant main effect with a main effect which is not significant.

The student to aircraft ratio (factor A) and the days to qualify an IP (factor c) are logically related. Increasing the student to aircraft ratio (factor a) tends to speed the transition to the T-46, which increases the T-46 sorties needed. On the other hand, increasing the days to qualify the instructors (factor c) decreases the daily T-46 sortie demand while the cadre is in training. Thus, factor c may mitigate slightly the detrimental effect of factor a on T-46 sortie availablity.

Likewise, the number of IPs in the cadre (d) and the days between aircraft delivery (f) are logically related. Increasing the number of IPs in the cadre increases the cadre daily demand for sorties, which decreases the sorties available for students, thus increasing the time to graduate. Increasing the days between T-46 deliveries increases the observed student to aircraft ratio. The higher the observed ratio, the slower the system converts to the T-46, thus fewer T-46 sorties are needed. Considering the small magnitudes of the changes, the resulting significance appears to lie in the confounding of the interactions. Although this interaction is statistically significant, the interaction has little practical significance. If a full factorial run were made, the relationships described would probably not be statistically

144

significant by themselves.

As with the main effects, the analysis of two-factor
interactions show the model to be consistent with the
hypothesized relationships depicted in the causal diagram in
Figure 1. Interactions (d X e) and (a X e) seem to have a
significant effect on days to graduate; therefore, factor d
should not be changed without considering factor e and vice
versa. The same consideration is necessary for changes to
factor a and factor e. This concludes the analysis of
two-factor interactions on days to graduate. Since
three-factor and higher interactions are assumed to be
negligible, the next step in the analysis is to examine the
relationship between days to graduate a flight and sorties
remaining for late flights.

Main Effects for Late Flight Sorties Remaining.
The number of sorties remaining after the last scheduled
training day for classes that are late graduating is termed
sorties remaining in this section. The values for the
effect on each factor on the sorties remaining is shown in
Table XVI. Main effects are graphically portrayed in Figure
16. The response of this variable is related to the average
number of days to graduate, since both are measures of how
near to capacity the system is operating.

145

Factor/Factor Interaction		Effect			
		LL	LH	HL	HH
Student to Aircraft Ratio (a)		143.9	–	–	155.0
Students per Class	(b)	102.4	–	–	196.5
Days to Qualify IPs	(c)	141.6	–	–	157.3
Number of IPs in Cadre	(d)	139.0	–	–	160.0
Days to Convert Simulator	(e)	119.4	–	–	186.3
Days Between T-46 Delivery	(f)	143.9	–	–	155.0
a X b		98.1	189.7	106.7	203.3
e X f		115.1	123.7	141.5	186.3
a X c		143.1	144.8	140.1	169.9
d X f		140.4	137.5	147.4	172.5
a X d		139.3	148.6	138.7	171.3
c X f		141.9	141.3	145.9	168.7
a X e		123.8	164.1	115.1	195.0
b X f		106.8	98.1	181.1	212.0
a X f		144.2	143.7	143.7	166.4
c X d		136.9	146.3	141.1	173.6
b X e		78.2	126.7	160.7	232.4
b X c		101.6	103.3	181.6	211.4
d X e		116.0	162.0	122.9	197.0
b X d		92.0	112.8	186.0	207.1
c X e		111.6	171.6	127.2	187.5

Table XVI

Effect on Sorties Remaining for Late Class
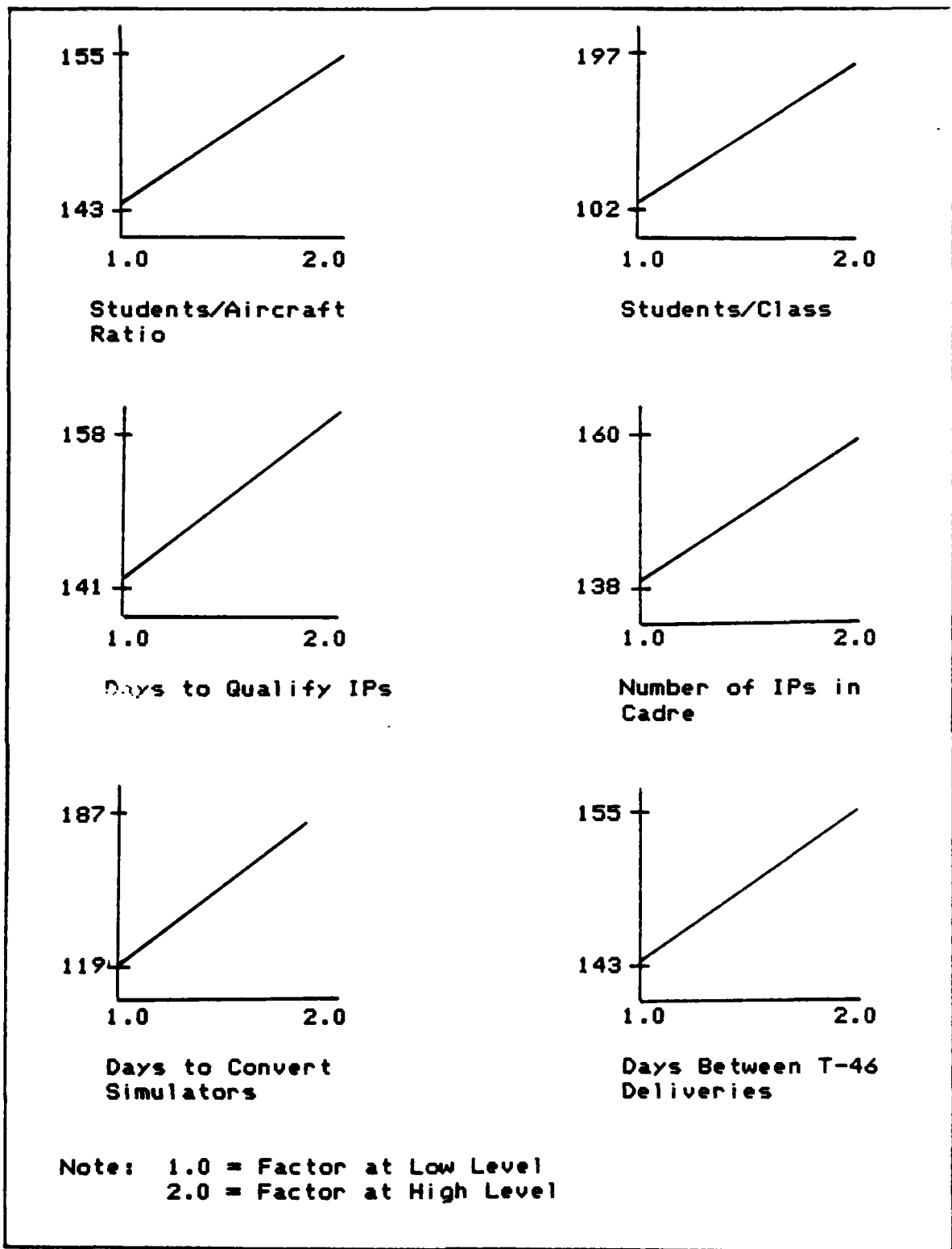
Figure 16.   Graph of Effects on Sorties Remaining For
Late Classes

The difference in the measures of effectiveness is apparent from the way the statistic is gathered. The average time to graduate was collected on all flights graduating from the time the transition begins; therefore, the effect of late flights is balanced to an extent by those finishing early or on time. On the other hand, the sortie remaining statistic is gathered strictly on flights which still have sorties remaining after the last scheduled training day, thus no balancing occurs.

The reason for the different measures is to add flexibility in application of the model. For identifying significant factors using widely spaced high and low input values, sorties remaining for late flights is likely to be too sensitive a measure, which is always statistically significant. For sensitivity analysis or for fine tuning a response surface using small adjustments in input values, the late flight sorties remaining allows the experimenter to detect fine changes. Indeed, the screening experiment confirmed the expectation with all six main effects and five of seven possible two-factor interaction sets being statistically significant. Two-factor interactions are depicted graphically in Figures 17a through 17c. For this reason, no discrimination between factors is possible for this study from the sortie remaining statistic. The direction of movement will be confirmed for each main effect:
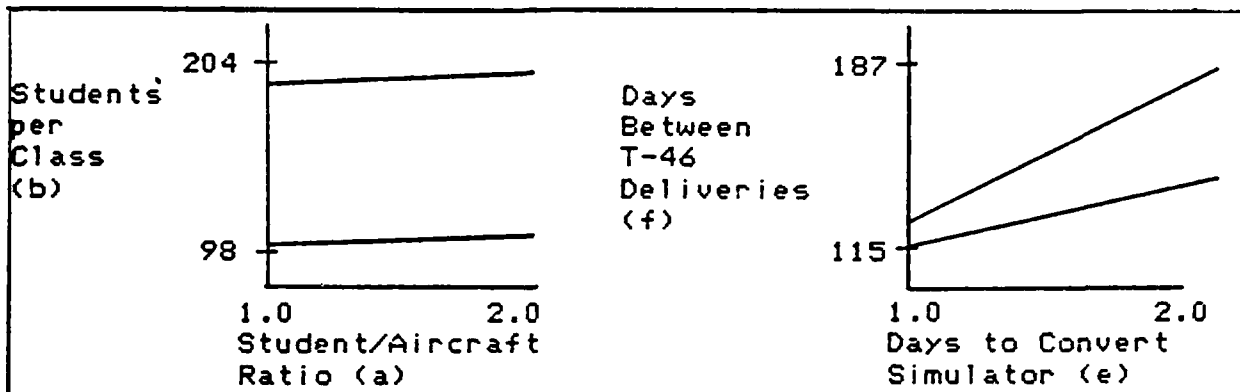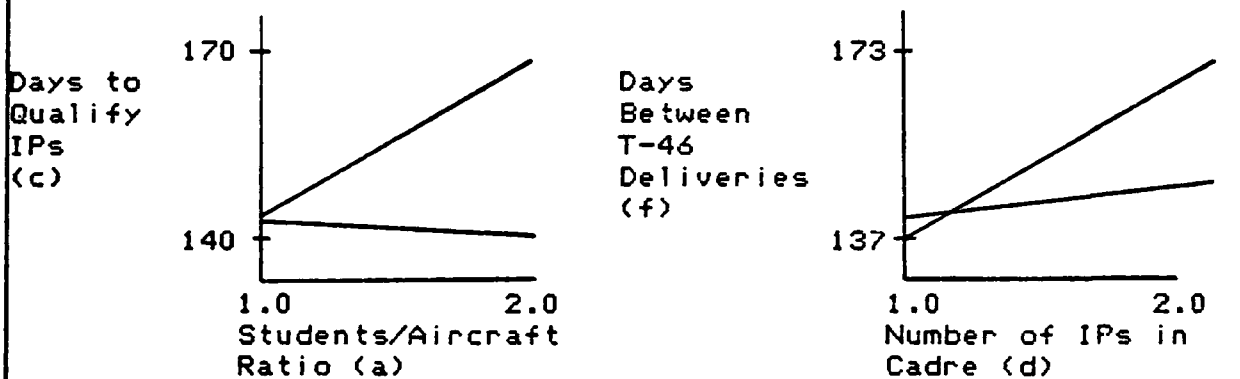
148
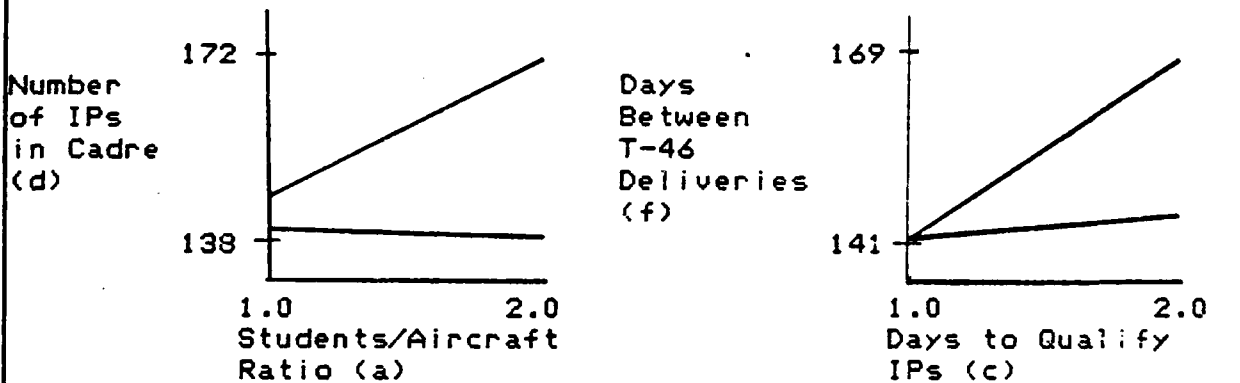
Note: 1.0 = Factor at Low Level, 2.0 = Factor at High Level

Figure 17a. Aliased Two-Factor Interactions for Sorties
Remaining for Late Class

Figure 17b. Aliased Two-Factor Interactions for Sorties
Remaining for Late Class
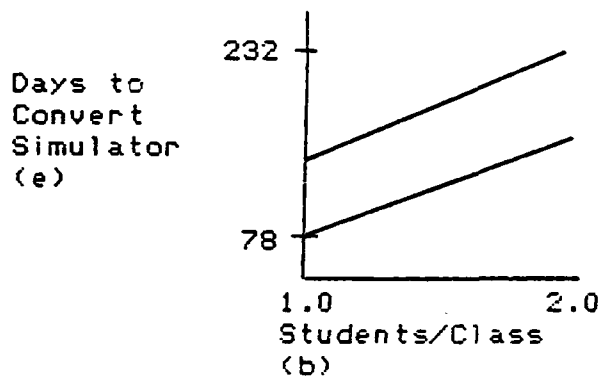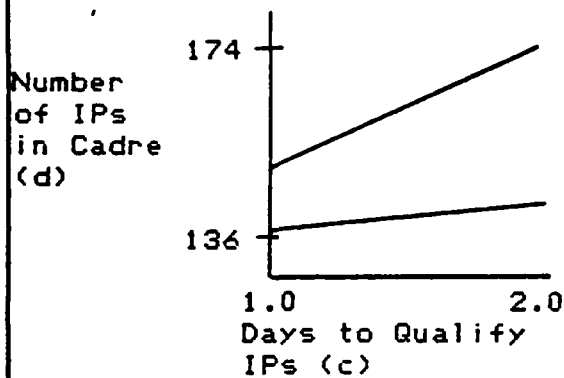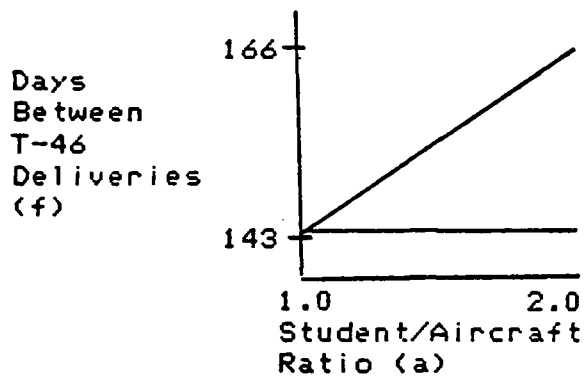
Figure 17c. Aliased Two-Factor Interactions for Sorties
Remaining For Late Class

1. As the student to aircraft ratio (factor a) goes
    from 2.3 to 2.5, the remaining sorties increase
    from 143 to 155.

2. As the average number of students per class (factor
    b) goes from 31.5 to 35.5, the remaining sorties
    increase from 102 to 197.

3. As the days to qualify the IPs (factor c) goes from
    15 to 30, the sorties remaining 141 to 158.

4. As the number of IPs in the cadre (factor d) goes
    from 15 to 20, the sorties remaining increase from
    138 to 160.

5. As the number of days to convert the simulator
    (factor e) increases from 100 to 140, the sorties
    remaining increase from 119 to 187.

6. As the days between aircraft deliveries goes up,
    the number of sorties remaining goes from 143 to
    155.

Both the direction of response and the associated

explanation are consistent with the explanations given in

the previous discussion of the model response for days to

graduate and will not be duplicated here. Instead, the time

to complete the transition period is analyzed.

Main Effects for Days to Complete the Transition.
The values for the effect of each factor on the days to

complete the transition are shown in Table XVII. A

graphical representation of the main effects is depicted in

Figure 18. The student to aircraft ratio, the number of

students per class, the number of days to convert the

simulator, and the number of days between aircraft

deliveries all have a statistically significant effect upon

the number of days required to complete the transition while

the number of days to qualify the IPs and the number of T-46

qualified IPs in the cadre flight do not. The effect of
each of these factors is discussed in this section.

Table XVII			
Effect on Days to Complete Transition			

Factor/Factor Interaction	Effect			
	LL	LH	HL	HH
Student to Aircraft Ratio (a)	237.7	–	–	189.4
Students per Class (b)	185.2	–	–	241.9
Days to Qualify IPs (c)	213.4	–	–	213.8
Number of IPs in Cadre (d)	210.0	–	–	217.1
Days to Convert Simulator (e)	187.1	–	–	240.0
Days Between T-46 Delivery(f)	197.6	–	–	229.5
a X b	206.2	269.3	164.3	214.5
e X f	168.0	206.3	258.5	257.8
a X c	238.5	237.0	188.3	190.5
d X f	195.0	225.0	200.3	234.0
a X d	234.0	241.5	186.0	192.8
c X f	197.2	229.5	198.0	229.5
a X e	206.2	269.3	167.8	210.8
b X f	164.2	206.3	231.0	252.8
a X f	228.0	247.5	167.3	211.5
c X d	216.0	210.8	204.0	223.5
b X e	165.0	205.5	209.3	274.5
b X c	184.5	186.0	242.3	241.5
d X e	183.0	237.0	191.3	243.0
b X d	186.0	184.5	234.0	249.8
c X e	191.2	235.5	183.0	244.5
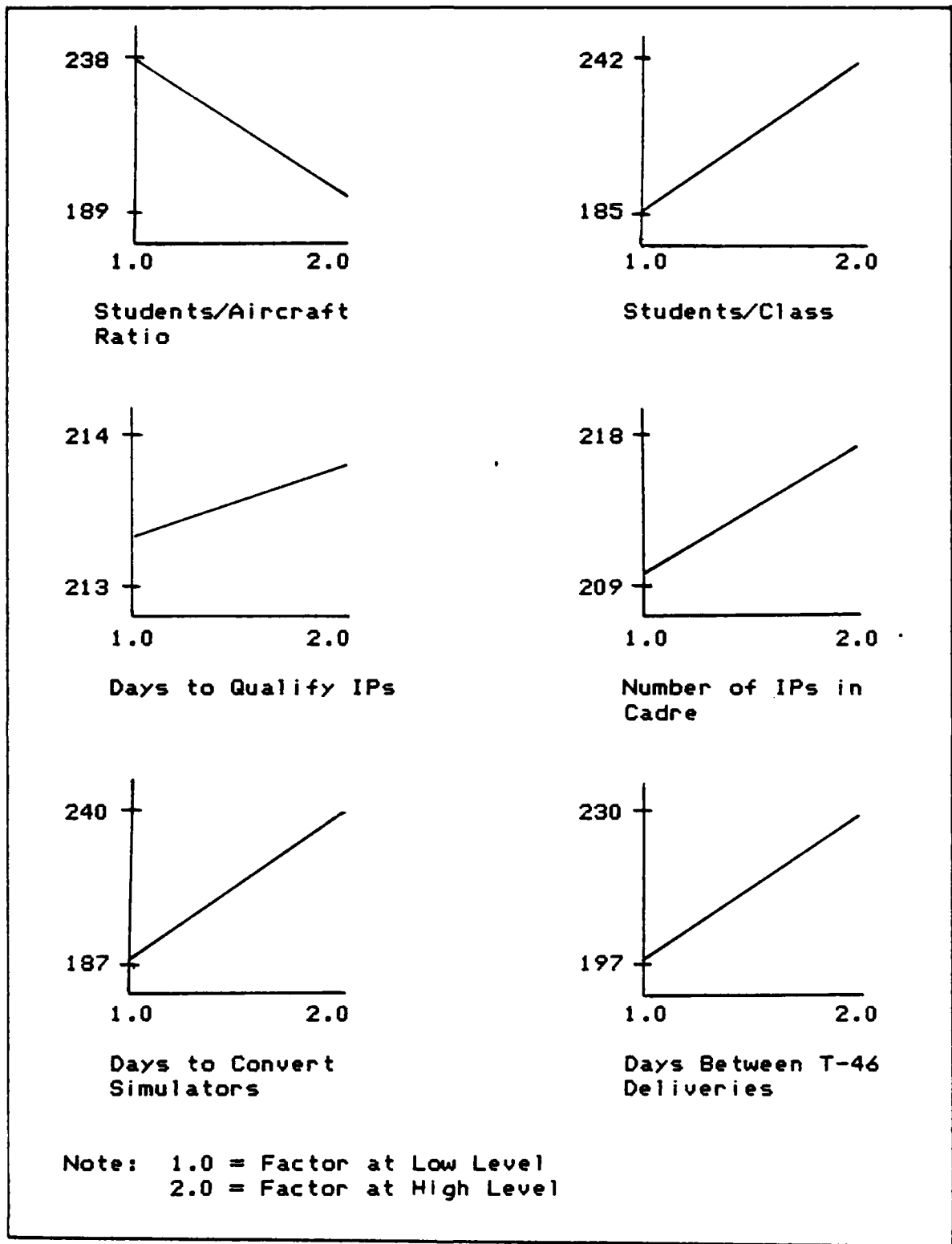
Figure 18. Graph of Effect on Days to Complete
            Transition

A class transitions to the T-46 if sufficient aircraft and T-46 instructors are available. Sufficient aircraft are available if the student to T-46 ratio that would result if the new class transitions to the T-46 is less that the maximum permitted during the simulator conversions. All the significant factor affects are directly related to this decision process.

Changing the number of students per entering class (factor b) from a mean of 31.5 to a mean of 35.5 raised the time to complete the transition by an average of 56 days. Since the decision to transition a flight is constrained by a fixed student to aircraft ratio, more aircraft must be delivered to support the transition of a larger class. Larger classes are also more likely to be late, which further increases the observed student to aircraft ratio. The higher ratio tends to delay the transition for some classes thus increasing the days to complete the transition.

Changing the days to convert the simulator (factor e) from 100 to 140 days increased the expected time to transition by 53 days. With the 100 day conversion time, one T-46 simulator is available at the start of the transition. With the 140 day conversion time, the first T-46 simulator is not available until 20 days after the transition begins. The worst of the impact occurs immediately since the first two classes must use the no simulator syllabus rather than the full simulator syllabus which requires 25 more effective flying sorties per student.

155

Since these classes take longer than normal to graduate, the student to aircraft ratio remains high for a longer period; therefore, some incoming classes which would have flown the T-46 must fly the T-37. The second simulator becoming available removes the maximum student to aircraft ratio constraint so that all entering classes may transition if instructors are available. The 100 day conversion cycle completes the last simulator 220 days into the transition, forty days before the 140 day conversion cycle is completed. Thus, the longer simulator conversion cycle makes transitioning classes more difficult throughout the transition period.

The next most significant factor is the maximum student to aircraft ratio with less than two T-46 simulator complexes in operation (factor a). Changing the permitted ratio from 2.3 to 2.5 reduces the expected time to transition by 49 days. Since the observed student to aircraft ratio must be less than the maximum permitted ratio to assign an incoming class to the T-46, the higher maximum student to aircraft ratio is less restrictive. This allows incoming classes to transition sooner than the lower ratio, thus decreasing the days to complete the transition.

The last of the statistically significant factors is the number of days between aircraft deliveries (factor f). Raising the days between deliveries from 8 to 10 days is expected to increase the days to transition by 32 days. Increasing the days between deliveries decreases the

aircraft delivery rate. The slower delivery rate increases the observed student to aircraft ratio, which delays the transition of some flights to the T-46. The trend is to increase the days required to complete the transition.

The two factors which do not have a significant effect on the days required to complete the transition are the number of T-46 qualified instructors assigned to the cadre flight (factor d) and the number of days alloted to qualify instructors in the T-46 aircraft (factor c). These two factors determine the number of days needed to qualify a new flight of instructor pilots.

The number of days alloted to qualify instructors in the T-46 aircraft (factor c) had no significant effect on the days to complete the transition. The longer syllabus length of 30 days is still shorter than the minimum time required to deliver enough aircraft to support a new class; therefore, no classes were forced to fly the T-37 due to non-availability of instructor pilots due to the longer syllabus.

Changing the number of IPs in the cadre (factor d) from 15 to 20 increased the expected time to complete the transition by only seven days which is not statistically significant. Increasing the number of IPs increases the daily capability of the cadre to fly by approximately nine sorties. Due to the high priority of the IPs in the cadre flight, the student flights must absorb the loss of sorties which may cause an additional flight to be late. The late

157

flight could keep the observed student to aircraft ratio high enough to delay the transition for an incoming class; therefore, the trend toward increasing the time to transition is reasonable though not statistically significant.

With four of the factors being statistically significant, it is reasonable to expect some of the two-factor interactions to be statistically significant. The discussion of two-factor interactions is again limited to those which are statistically significant.

Significant Interactions for Days to Complete the Transition. The significant two-factor interactions for the days to complete the transition involve the following aliased factor pairs which are graphically depicted in Figures 19a through 19c:

1. The student to aircraft ratio by days between T-46 deliveries (a X f) and the number of students per class by the days to convert the simulator (b X e) and the days to qualify IPs by the number of IPs in the cadre (c X d)

2. The student to aircraft ratio by the days to convert the simulator (a X e) and the number of students per class by the days between T-46 deliveries (b X f).

158

Note: 1.0 = Factor at Low Level, 2.0 = Factor at High Level
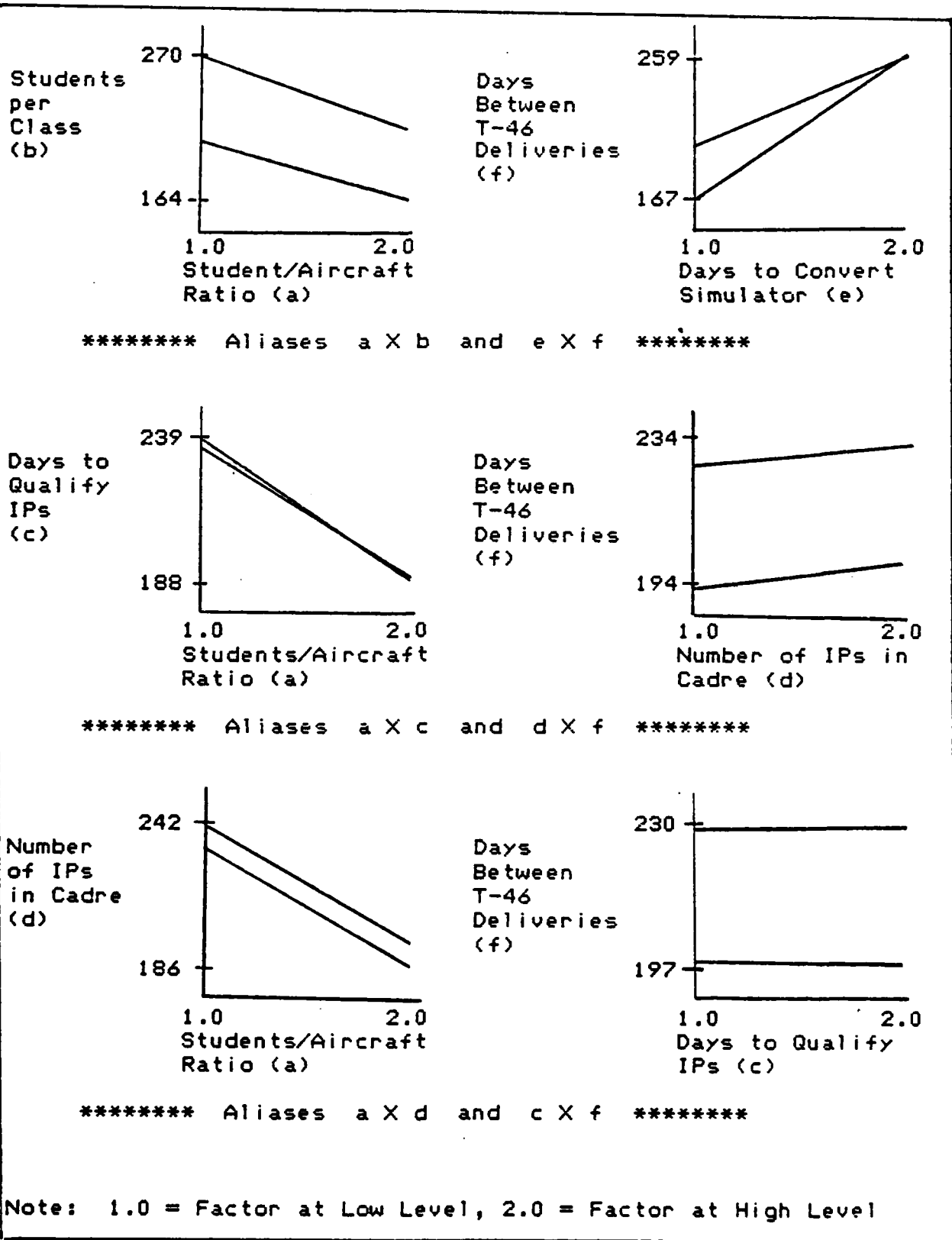
Figure 19a.   Aliased Two-Factor Interactions for Days to
              Complete Transition
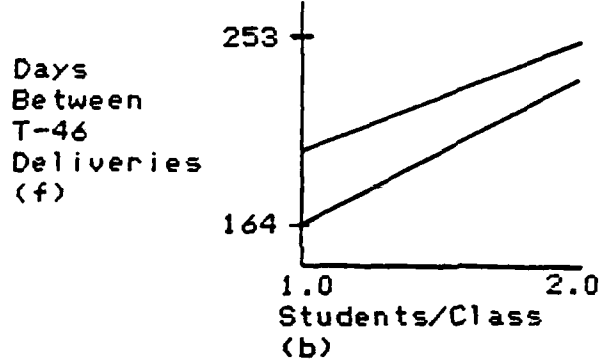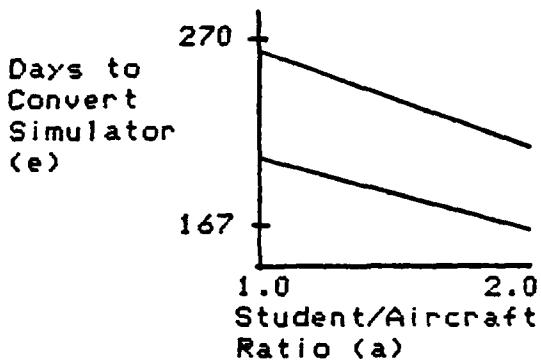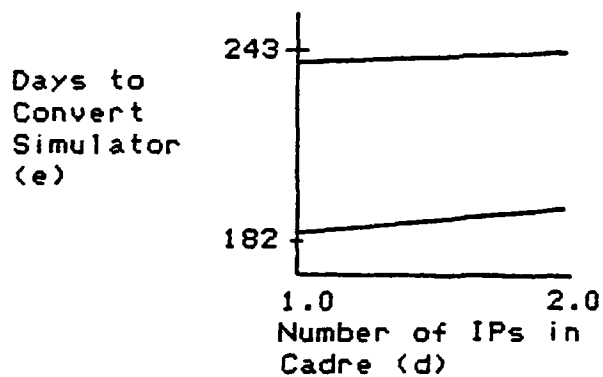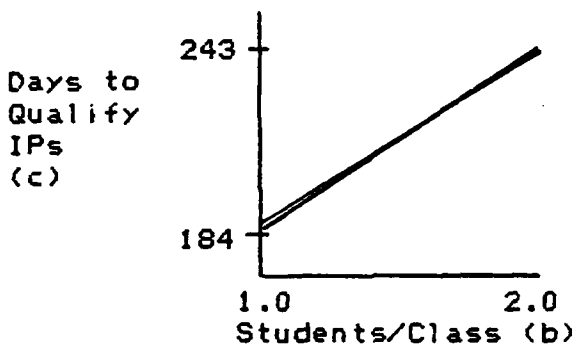
159
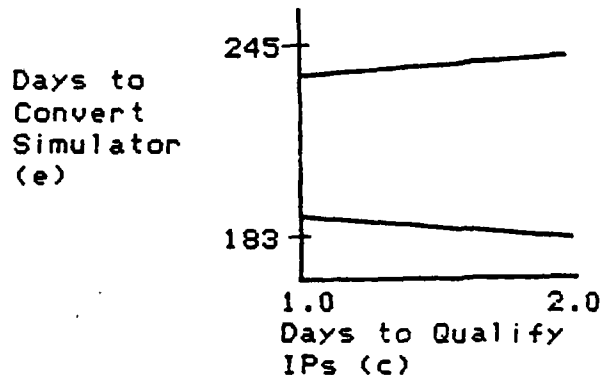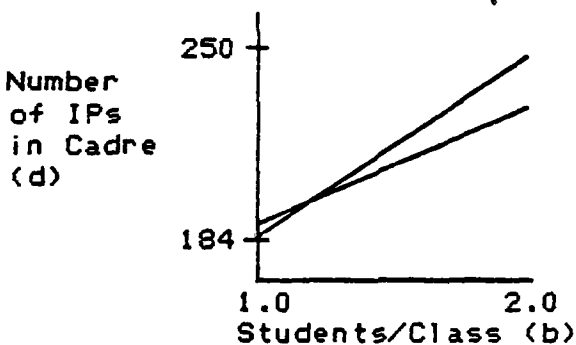
Figure 19b. Aliased Two-Factor Interactions for Days to Complete Transition
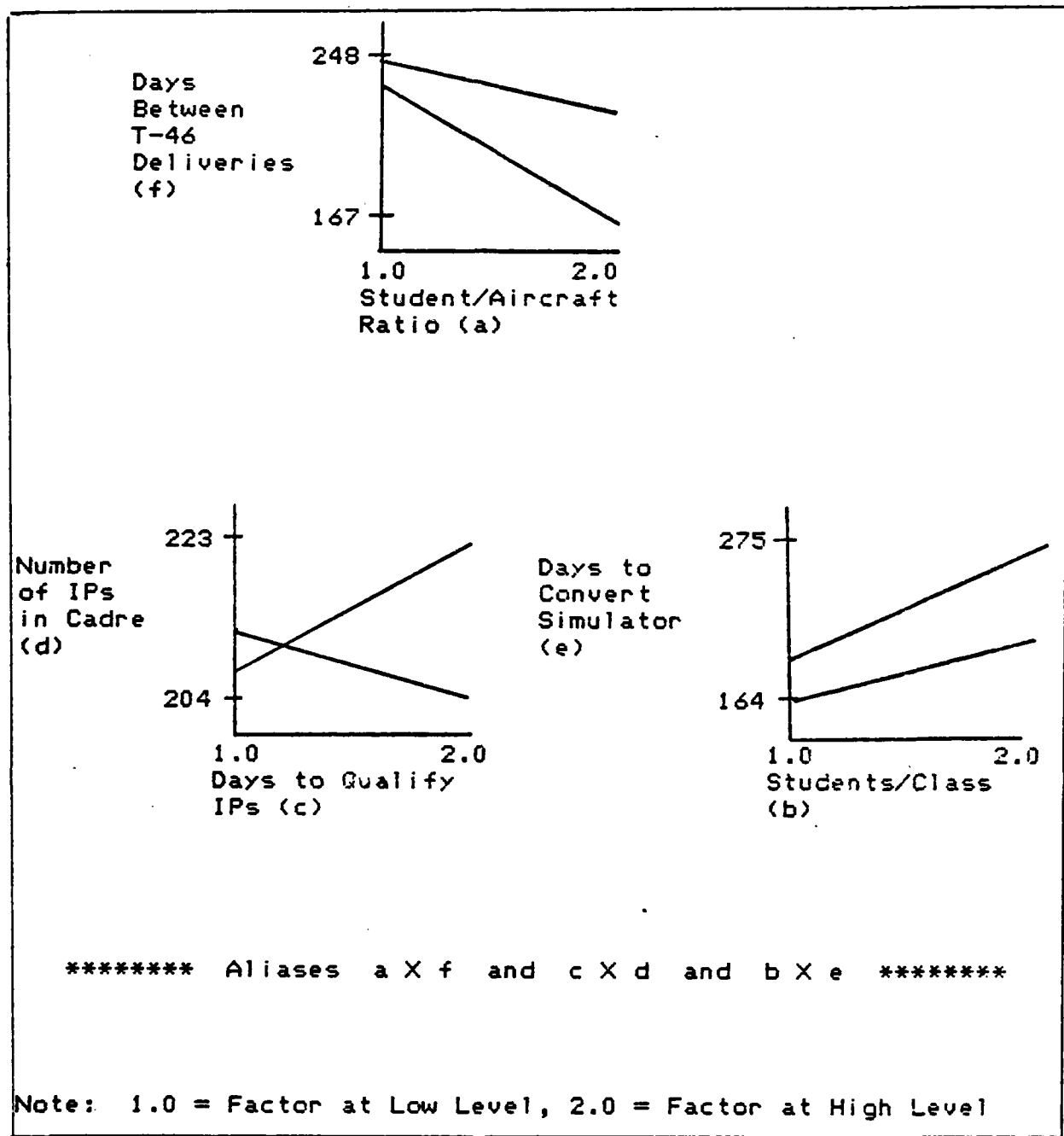
Figure 19c.   Aliased Two-Factor Interactions for Days to
              Complete Transition

The significance of the first set of aliased two-factor interactions (a X f, b X e, and c X d) cannot be attributed to a specific pair without doing additional computer runs under a different design because factors a, b, e, and f are each statistically significant factors and because the slopes of all three two-factor interaction graphs diverge. Thus, only the direction of movement of the interaction can be analyzed for consistency with the hypothesized relationships. Each of the pairs are discussed.

The student to aircraft ratio (a) by days between aircraft deliveries (f) may be significant. Increasing the authorized student to aircraft ratio tends to decrease the time to transition. On the other hand, increasing the days between aircraft deliveries slows the delivery rate which increases the observed student to aircraft ratio and tends to increase the time to transition. Of the two factors, the student to aircraft ratio has the greater influence so that the overall trend of the two-factor effect is to decrease the time to transition. Relaxing the student the aircraft ratio constraint combined with the higher aircraft delivery rate produces twice the decrease in time to complete the transition as relaxing the constraint at the lower delivery rate. Thus, a two-factor interaction with (a X f) is consistent with the hypothesized relationships and may be statistically significant.

Confounded with (a X f), the number of students per class by the days to convert the simulator (b X e) may also

be a statistically significant interaction. Increasing the number of students per class tends to increase the time to transition. Likewise, increasing the number of days required to convert the simulator tends to increase the time to complete the conversion. The overall trend of the two-factor effect is to increase the time for the conversion. The longer simulator conversion increases the number of students on reduced simulator syllabii who need more sorties to graduate; therefore, increasing the number of students per class intensifies the problem leading to a higher observed student to aircraft ratio which tends to postpone classes being assigned to the T-46 thus increasing the time to transition. Therefore, the two-factor interaction of (b X e) is also consistent with the hypothesized relationships.

Finally, the number of days to qualify the IPs by the number of IPs in the cadre (c X d) is also confounded with (b X e) and (a X f). Normally, only factors which produce a significant effect by themselves can combine to produce a significant interaction; however, the graph of interaction (c X d) does appear to show diverging slopes so the interaction is considered. On the 30 day syllabus, the cadre students are capable of only 18 sorties per day which both IP levels can supply. Since the average number of days to complete the transition increases by approximately 19 days as the T-46 IP level increases, the difference in response indicates that the random distributions for sortie

cancellations can easily cause the end of the transition to
vary by just over a one class delay (classes enter every 15
days). Conceptually, a single canceled sortie could prevent
a student in a late flight from graduating and thus cause an
observed student to aircraft ratio to exceed the maximum
authorized ratio thus delaying the transition by one class.
For these reasons, the (c X d) interaction is unlikely to be
significant.

The other significant confounded two-factor
interactions are the student to aircraft ratio by the days
to convert the simulator (a X e) and the number of students
per class by the days between aircraft deliveries (b X f).
Factors a, b, e, and f have significant individual effects
upon the time to transition so each pair may easily be
significant. Increasing the authorized student to aircraft
ratio tends to decrease the time required to transition
which offsets the tendency for an increase in the days to
convert a simulator to increase the transition period. The
easing of the ratio constraint on the decision to transition
has a greater effect when the system is strained by the
additional sorties for the no simulator syllabus students;
therefore significant interaction is very likely for
interaction (a X e).

Increasing the students per class tends to increase the
time to transition by requiring more aircraft to achieve the
necessary student to aircraft ratio for a new class to use
the T-46. The increase in the time to complete the

transition is offset somewhat by the T-46 deliveries. The graph of the interaction shows slightly divergent slopes which neither establish nor reject the possibility that the interaction is significant.

Although the screening design was helpful in identifying the factors which significantly effect the time to complete the transition, the aliased two-factor interactions involve too many significant factors to be resolved without additional experiments.

Summary

The first task of the experimental design and analysis section is to pick factors and appropriate factor levels as shown in Table XII. A resolution IV fractional factorial design is selected so that main effects and some two-factor interaction effects may be analyzed. This design requires 16 computer runs for each of the five replications resulting in a total requirement for 80 runs. A computer simulation length of 210 days is needed to reach steady state for the T-37 system; a length of 510 days is sufficient for validation runs of the T-37 model. The T-46 model stops the simulation when all six classes are flying the T-46. ANOVA was selected to determine the significance of the model responses.

The number of students per class, the number of days to convert the simulator, the student to aircraft ratio, and the numbers of IPs in the cadre each have a statistically

significant effect upon the days to graduate a class. In addition, statistically significant two-factor interactions affecting the days to graduate a class were identified between the following factor pairs:

1. The number of days to convert the simulator by the number of IPs in the cadre

2. The student to aircraft ratio by the number of days to convert the simulator

The practical meaning of a significant interaction is that ATC cannot change one of the above factors without also considering the other paired factor.

An additional surrogate measure of the system's ability to graduate students in a timely manner is the number of sorties remaining for late flights after the last syllabus training day. The measure was included to give the model the ability to detect the influence of small changes in factor levels as well as large ones. For this study, the sensitivity of the measure caused all factors to have a significant effect on sorties remaining.

The time to complete the transition is the last measurement taken. The student to aircraft ratio, the number of students per class, the number of days to convert the simulato, and the number of days between aircraft deliveries all have a statistically significant effect upon the number of days required to complete the comversion. In addition, several potentially significant two-factor interactions were identified. Ambiguity in the confounded interactions caused by the fractional factorial design

166

prevented isolation of the specific significant
interactions. The significant aliased interactions were as
follows:

1. The sutdent to aircraft ratio by the days between
   T-46 deliveries and the aliased interaction from
   the number of students per class by the days to
   convert the simulator, and

2. The student to aircraft ratio by the days to
   convert the simulator and the aliased interaction
   from the number of students per class by the days
   bewtween T-46 deliveries.

As with the previous two-factor interactions, one factor
should not be changed without considering the other.

VI Conclusions and Recommendations for Further Study

Conclusions

The Air Training Command (ATC) proposal for
transitioning UPT wings to the T-46 aircraft is outlined in
the T-46 Implementation Plan. Although subject to
modification, the plan specifically addresses the procedures
and factors ATC expects to use for accomplishing the
conversion. Prior to this study, no parametric analysis of
the proposed plan existed to support the identification of
the critical factors or to estimate the magnitude of the
change in the system responses from a change in factor
levels.

To provide the necessary analysis, a thorough
conceptualization of the UPT system was accomplished in
order to identify key components, variables, and their
relationships within the system. Using this information, a
simulation model of the UPT system at Laughlin AFB was
developed which simulates both present operations and
changes to those operations during the conversion to the
T-46. Verification and validation were accomplished
appropriately, and statistically sound results were obtained
from the model.

Variables under ATC control and likely to measureably
affect the system were subjectively selected from the input
variables as factors for the experiment. These factors and
their corresponding ranges for the experiment are shown in

Table XII. The system response was estimated by measuring the days required to graduate a class, the number of sorties remaining for late flights after the last training day, and the days required to compete the conversion.

The design chosen for the experiment assumed two-factor interactions as the highest order interactions to be considered. The design required a total of 80 computer simulations. The results showed that the number of students per class, the number of days to convert the simulator, the student to aircraft ratio, and the numbers of IPs in the cadre each have a statistically significant effect upon the days to graduate a class. In addition, statistically significant two-factor interactions affecting the days to graduate a class were identified between the following factor pairs:

1. The number of days to convert the simulator by the number of IPs in the cadre

2. The student to aircraft ratio by the number of days to convert the simulator

The practical meaning of a significant interaction is that ATC cannot change one of the above factors without also considering the other paired factor.

An additional surrogate measure of the system's ability to graduate students in a timely manner is the number of sorties remaining for late flights after the last scheduled syllabus training day. The measure was included to give the model the ability to detect the influence of small changes in factor levels as well as large ones. For this study, the

169

sensitivity of the measure caused all factors to have a significant effect on sorties remaining.

The time to complete the conversion is the last measurement taken. The student to aircraft ratio, the number of students per class, the number of days to convert the simulator, and the number of days between aircraft deliveries all have a statistically significant effect upon the number of days required to compete the conversion. In addition, several potentially significant two-factor interactions were identified. Ambiguity in the confounded interactions caused by the fractional factorial design prevented isolation of the specific significant interactions. The significant aliased interactions were as follows:

1. The student to aircraft ratio by the days between T-46 deliveries and the aliased interaction from the number of students per class by the days to convert the simulator

2. The student to aircraft ratio by the days to convert the simulator and the aliased interaction from the number of students per class by the days between T-46 deliveries

As with the previous two-factor interactions, one factor should not be changed without considering the other.

The experiment shows that there are a number of factors and interactions that affect the ability of ATC to maintain pilot production and complete the conversion efficiently. Due to the interactions, the degree of stochasticity, and the general complexity of the system, the specific results of the experiment could not be accurately predicted by hand

170

calculations. Although the trends were shown to be
consistent with the hypothesized relationships, too many
things occur during the transition to make hand calculated
predictions practical or accurate. Therefore, the model
provides a powerful tool for analyzing the impact of
potential changes to the plan both accurately and
efficiently.

The model not only gave consistent results with the
hypothesized relationships in the system, but also gave
valuable insight into the behavior of the system during the
conversion. Therefore, the model provides a powerful tool
for analyzing the impact of potential changes to the plan
both accurately and efficiently.

The model can accomodate a wide range of scenarios by
merely changing values of input variables. In addition to
the MOE's used in this study, the model provides other
output variables. The complete list of output variables
provided by the model follows:

1. The average days to graduate all students classes,

2. The average days to graduate T-37 student classes,

3. The average days to graduate T-46 student classes,

4. The average days to graduate an IP Flight,

5. The average flying sorties remaining for all
   student classes at scheduled graduation,

6. The average flying sorties remaining for all late
   student classes at scheduled graduation,

7. The average flying sorties remaining for all late
   T-37 student classes at scheduled graduation,

171

8. The average flying sorties remaining for all late T-46 student classes at scheduled graduation,

9. The average flying sorties remaining for all late IP flights,

10. The average simulator sorties remaining for all student classes at scheduled graduation,

11. The average simulator sorties remaining for all late student classes at scheduled graduation,

12. The average utilization rate (monthly) for the T-37,

13. The average utilization rate (monthly) for the T-46, and

14. The time to complete the conversion (transition).

For each of the output variables, the minimum value, the maximum value, and the standard deviation is computed automatically for each experiment. (Sample output is available in Appendix D.) ATC can use this model to assess the impact of decisions upon any of these output variables.

Recommendations for Further Study

Due to the scope of the research, not all aspects of the plan could be analyzed. There are several areas where further study can provide additional insight and information to ATC. Some of these areas are indicated in this section.

Similar to any model, the model of the UPT system incorporated many assumptions. Some assumptions may be altered as the conversion approaches:

1. Instructor pilots qualifying in the T-46 have a higher priority than students for the available flying sorties

2. The data for the T-46 is assumed to be similar to that for the T-37 for weather cancel rates, maintenance cancel rates, and checkride failure

172

rates

3. Students are available to fly for only two periods per day throughout the training program

4. No flying is accomplished on weekends

5. All T-37 aircraft are available during the conversion. No drawdown procedures for the T-37 have been developed by ATC.

Sensitivity analysis can be performed on all of these assumptions to determine the impact on the system responses. The simulation model is capable of showing the impact from any change of these assumptions. In fact, the model is constructed to support the application of response surface methodology to any factor of interest.

It was stated in the analysis section of Chapter V that it was difficult to identify some of the significant two-factor interactions without further computer runs. Having eliminated all but four factors as significant for both the days to graduate and days to complete the conversion measures, 16 more computer runs for each measure could remove the ambiguity in the identification of two-factor interactions.

Some of the data gathered for the model was an aggregate or average value. Data points that are averaged and represent several data points themselves tend to decrease the variance of the results. If the variability is of interest, then more data points representing a single datum point and not an average may be necessary. This applies to both the maintenance cancel rate and the

maintenance ability to generate sorties. These values were
a yearly average of 12 monthly maintenance generation and
cancel rates.

The simulation ceased when all classes were training in
the T-46. During several experiments, extremely overdue
classes were observed at the end of the conversion.
Valuable insight could be gained by extending the experiment
after the conversion is completed to determine when the T-46
system reaches steady state.

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Appendix A: T-37 Model (Fortran and SLAM)

178

```fortran
      program main
      dimension nset(5ØØØ)
      common/scom1/ atrib(1ØØ),dd(1ØØ),dd1(1ØØ),dtnow,ii,mfa,mstop,nclnr
     *,ncrdr,nprnt,nnrun,nnset,ntape,ss(1ØØ),ss1(1ØØ),tnext,tnow,xx(1ØØ)
      common qset(5ØØØ)
      equivalence (nset(1),qset(1))
      nnset=5ØØØ
      ncrdr=5
      nprnt=6
      ntape=7
      call slam
      stop
      end

      subroutine event(i)
c   file rant37: random t37 model as of 133Ø sat 28 jan
      go to (1,2,3,4,5,6),i
    1 call makeft
      return
    2 call weekly
      return
    3 call dlyres
      return
    4 call reqst
      return
    5 call update
      return
    6 call reip
      return
      end
c
c
      subroutine makeft
      common/scom1/atrib(1ØØ),dd(1ØØ),dd1(1ØØ),dtnow,ii,mfa,mstop,nclnr
     *,ncrdr,nprnt,nnrun,nnset,ntape,ss(1ØØ),ss1(1ØØ),tnext,tnow,xx(1ØØ)
      dimension a(24)
      flt7ip=Ø.Ø
      flt8ip=Ø.Ø
      nof=nnq(1)
      if (nof.gt.Ø) then
          do 2Ø i=1,nof
          call rmove(1,1,a)
          if (a(2).eq.5.Ø) then
              a(5)=min(a(4),a(5))
              flt7ip=a(5)
          endif
          if (a(2).eq.6.Ø) then
              a(5)=min(a(4),a(5))
              flt8ip=a(5)
          endif
          a(2)=a(2)+2.Ø
          call filem(1,a)
   2Ø     continue
      endif
      atrib(2)=1.Ø
      atrib(3)=xx(3)
      atrib(4)=xx(ii+62)
      atrib(5)=xx(5)-flt7ip
      atrib(6)=xx(4)*xx(6)
      atrib(7)=xx(4)*xx(7)
      atrib(8)=1.Ø
      atrib(14)=atrib(6)
      atrib(15)=atrib(7)
```

179

```
        atrib(17)=0.0
        atrib(19)=xx(4)*xx(42)
        atrib(21)=real(nint(rnorm(15.2,4.6,5)))*xx(ii+62)/100.0
        atrib(22)=0.0
        call filem(1,atrib)
        atrib(2)=2.0
        atrib(5)=xx(5)-flt8ip
        atrib(21)=real(nint(rnorm(15.2,4.6,5)))*xx(ii+62)/100.0
        atrib(22)=0.0
        call filem(i,atrib)
        return
        end
c
c
        subroutine reqst
        common/scoml/atrib(100),dd(100),ddl(100),dtnow,ii,mfa,mstop,nclnr
     *,ncrdr,nprnt,nnrun,nnset,ntape,ss(100),ssl(100),tnext,tnow,xx(100)
c  distribution for guest help
        atrib(18)=nint(rnorm(5.0,1.0,1))
        if (atrib(18).lt.0.0) atrib(8)=0.0
        if ((atrib(8).eq.5.0).or.(atrib(5).le.4.0)) then
            busyip=0.0
        else
            busyip=3.0
        endif
        flys=2*(atrib(5)-busyip)+atrib(18)+atrib(17)
        if (atrib(8).eq.2.0) then
            atrib(13)=min(atrib(11),atrib(15),
     *      2*(atrib(5)-busyip),real(nnrsc(1)))
            atrib(12)=min(atrib(10),2*atrib(4)-atrib(13),atrib(14),
     *      flys-atrib(13),real(nnrsc(2)))
        else
            atrib(12)=min(atrib(10),atrib(14),flys,real(nnrsc(2)))
            if (atrib(12).le.(atrib(17)+atrib(18))) then
                simip=2*(atrib(5)-busyip)
            else
                simip=flys-atrib(12)
            endif
            atrib(13)=min(atrib(11),2*atrib(4)-atrib(12),simip,
     *                    atrib(15),real(nnrsc(1)))
        endif
        return
        end
c
c
        subroutine reip
        common/scoml/atrib(100),dd(100),ddl(100),dtnow,ii,mfa,mstop,nclnr
     *,ncrdr,nprnt,nnrun,nnset,ntape,ss(100),ssi(100),tnext,tnow,xx(100)
        dimension a(24)
        studs=max(atrib(14),atrib(15))
        atrib(4)=min(studs,atrib(4))
        if (atrib(5).gt.atrib(4)) then
            myrank=nfind(1,1,2,0,atrib(2)-6.0,0.0)
            if (myrank.gt.0) then
                xtraip=atrib(5)-atrib(4)
                atrib(5)=atrib(4)
                call rmove(myrank,1,a)
                a(5)=a(5)+xtraip
                call filem(1,a)
            endif
        endif
        return
        end
```
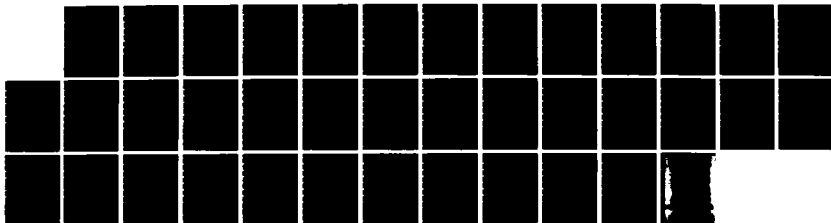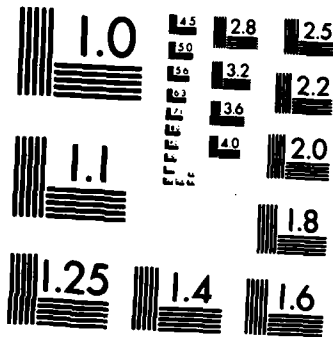
MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

```
c
c
      subroutine weekly
      common/scom1/atrib(100),dd(100),dd1(100),dtnow,ii,mfa,mstop,nclnr
     *,ncrdr,nprnt,nnrun,nnset,ntape,ss(100),ss1(100),tnext,tnow,xx(100)
      dimension a(24)
c    find number of flights in system
      nof=nnq(1)
c    from flight1 to highest flight, compute max daily sortie rate
      if (nof.gt.0) then
          do 40 i=1,nof
          call rmove(1,1,a)
c    solo requirements start in fourth week
          if (a(16).eq.15.0) then
              days=a(3)-a(16)
              if (days.le.0.0) days=1.0
              a(17)=real(nint(a(19)/(days*0.7*0.8)))
          endif
          if (a(17).gt.a(19)) a(17)=a(19)
c    from flight1 to senior flight, compute max daily sortie rate
          prcnt1=100*a(16)/a(3)
          if (prcnt1.le.11.1)then
              rate=0.86
          else if (prcnt1.le.22.3) then
              prcnt2=prcnt1+500/a(3)
              rate1=2.35-6.0*prcnt1/140.0
              rate2=2.35-6.0*prcnt2/140.0
              rate=(rate1+rate2)/2.0
          else
              rate=1.22
          endif
c    used max daily rate for students to compute max flight daily rate
          a(10)=real(nint(rate*a(4)))
          if (prcnt1.le.27.8) then
              rates=1.0
          else
              rates=1.5
          endif
          a(11)=real(nint(rates*a(4)))
c    used training remaining to determine flight and simulator priorities
          if (a(16).ge.a(3)) then
          a(8)=5.0
          else if (a(8).ne.0.0) then
              prcntf=100.0*a(14)/a(6)
              if (prcnt1.lt.25.0) then
                  fmaxr=100.0
              else
                  fmaxr=(100.0-prcnt1)*4.0/3.0
              endif
              prcnts=100.0*a(15)/a(7)
              if (prcnt1.lt.85.0) then
                  smaxr=100.0-prcnt1*100.0/85.0
              else
                  smaxr=0.0
              endif
              if ((prcntf.gt.fmaxr).and.(prcnts.gt.smaxr)) then
                  a(8)=4.0
              else if ((prcntf.gt.fmaxr).and.(prcnts.le.smaxr)) then
                  a(8)=3.0
              else if ((prcntf.le.fmaxr).and.(prcnts.gt.smaxr)) then
                  a(8)=2.0
              else
                  a(8)=1.0
              endif
```

```
            endif
c    compute overall scheduling priority using training and seniority
            a(9)=a(8)*16.0+a(2)
            call filem(1,a)
  40     continue
      endif
      return
      end
c
c
      subroutine dlyres
      common/scom1/atrib(100),dd(100),ddl(100),dtnow,ii,mfa,mstop,nclnr
     *,ncrdr,nprnt,nnrun,nnset,ntape,ss(100),ssl(100),tnext,tnow,xx(100)
      capmx=rnorm(72.0,1.5,2)/100.0
      ndlyas=int(capmx*0.9*xx(31)*4.0)
      if (tnow.ge.210) xx(38)=xx(38)+xx(31)
      ndlyss=int(xx(36))
      minday=int((xx(ii+50)-0.5)*60.0)
      nsortd=min(ndlyas,minday/3)
      nflys=nnrsc(2)
      call alter(2,nsortd-nflys)
      nsim=nnrsc(1)
      call alter(1,ndlyss-nsim)
      return
      end
c
c
      subroutine update
      common/scom1/atrib(100),dd(100),ddl(100),dtnow,ii,mfa,mstop,nclnr
     *,ncrdr,nprnt,nnrun,nnset,ntape,ss(100),ssl(100),tnext,tnow,xx(100)
      if (ii.le.2) then
          wxcx=rnorm(28.8,9.7,3)/100.0
      else if (ii.le.5) then
          wxcx=rnorm(29.1,11.0,3)/100.0
      else if (ii.le.8) then
          wxcx=rnorm(17.5,9.2,3)/100.0
      else if (ii.le.11) then
          wxcx=rnorm(17.2,6.3,3)/100.0
      else
          wxcx=rnorm(28.8,9.7,3)/100.0
      endif
      if (wxcx.lt.0.0) wxcx=0.0
      cxmx=rnorm(2.9,0.7,4)/100.0
      if (cxmx.lt.0.0) cxmx=0.0
c    credit today's sorties
      goodac=real(nint(atrib(12)*(1.0-cxmx)))
      efsort=real(nint(goodac*(1.0-wxcx)))
      if (tnow.ge.210) xx(37)=xx(37)+efsort*1.25
      efsolo=real(nint(atrib(17)*0.7))
      atrib(14)=atrib(14)-efsort
      atrib(15)=atrib(15)-atrib(13)
      atrib(16)=atrib(16)+1.0
      if (efsort.gt.efsolo) then
          atrib(19)=atrib(19)-efsolo
      else
          atrib(19)=atrib(19)-efsort
      endif
      if (atrib(19).le.0.0) then
          atrib(19)=0.0
          atrib(17)=0.0
      endif
c    if necessary attrit one student and update attributes
      if (atrib(16).le.25.0) then
          attpct=(6.0/7.0*atrib(16)+4.0)/100.0
```

```fortran
          else if (atrib(16).le.46.0) then
             attpct=(5.0/3.0*atrib(16)-16.0)/100.0
          else if (atrib(16).le.90.0) then
             attpct=(3.0/5.0*atrib(16)+46.0)/100.0
          endif
          if (atrib(22).ne.atrib(21)) then
             if ((real(int(attpct*atrib(21)))-atrib(22)).eq.1.0) then
                atrib(22)=atrib(22)+1.0
                flyatr=real(nint(atrib(14)/atrib(4)))
                simatr=real(nint(atrib(15)/atrib(4)))
                atrib(6)=atrib(6)-flyatr
                atrib(7)=atrib(7)-simatr
                atrib(14)=atrib(14)-flyatr
                if (atrib(14).lt.0.0) atrib(14)=0.0
                atrib(15)=atrib(15)-simatr
                if (atrib(15).lt.0.0) atrib(15)=0.0
                if (atrib(19).gt.0.0) then
                   atrib(19)=atrib(19)-real(nint(atrib(19)/atrib(4.0)))
                   days=atrib(3)-atrib(16)
                   if (days.le.0.0) days=1.0
                   atrib(17)=real(nint(atrib(19)/(days*0.7*0.8)))
                endif
                atrib(4)=atrib(4)-1.0
             endif
          endif
c   add additional sortie requirements for failed flight evaluations
          if (atrib(16).eq.real(int(0.25*atrib(3)))) then
             xtrafs=real(nint(xx(43)*atrib(4)*xx(44)))
          else if (atrib(16).eq.real(int(0.5*atrib(3)))) then
             xtrafs=real(nint(xx(45)*atrib(4)*xx(46)))
          else if (atrib(16).eq.real(int(0.75*atrib(3)))) then
             xtrafs=real(nint(xx(47)*atrib(4)*xx(48)))
          else if (atrib(16).eq.real(int(0.9*atrib(3)))) then
             xtrafs=real(nint(xx(49)*atrib(4)*xx(50)))
          else
             xtrafs=0.0
          endif
          atrib(6)=atrib(6)+xtrafs
          atrib(14)=atrib(14)+xtrafs
c   take statistics on early finishers
          if ((atrib(14).eq.0.0).and.(atrib(15).eq.0.0)) then
             call colct (atrib(16),1)
             if (atrib(16).lt.atrib(3)) then
                call colct(0.0,2)
                call colct(0.0,3)
             endif
          endif
c   take statistics at end of last alloted training day
          if (atrib(16).eq.atrib(3)) then
             call colct(atrib(14),2)
             call colct(atrib(15),3)
             if ((atrib(14).gt.0.0).or.(atrib(15).gt.0.0)) then
                call colct(atrib(14),4)
                call colct(atrib(15),5)
             endif
          endif
          return
          end
```

183

```
gen,dicmos,thesis,1/15/84,2,n,n,y,n,,72;
limits,5,22,30;
stat,1,days to comlete,20/80.0/1.0;
stat,2,fly sorties rem,20/0.0/10.0;
stat,3,sim sorties rem,20/0.0/10.0;
stat,4,late flt fly rem,20/0.0/10.0;
stat,5,late flt sim rem,20/0.0/10.0;
priority/1,hvf(9);
network;
      res/simsorte(1),2,5;
      res/flysorte(1),3,4;
      gate/lineup,close,1;

      create;                      month counter
      assign,ii=xx(33),xx(37)=0.0,xx(38)=0.0;   start month & t37 util
          act,20.0;
 next goon,2;
          act,,ii.lt.12,nmon;
          act,,ii.eq.12,fmon;
          act,,tnow.ge.230.0,util;
          act,20.0,,next;
 nmon assign,ii=ii+1;
      term;
 fmon assign,ii=1;
      term;
 util assign,xx(38)=xx(38)/20.0,xx(37)=xx(37)/xx(38); tot hrs ac
      colct,xx(37),t37 util rate,20/30.0/2.0,1;   t37 monthly util rate
      assign,xx(37)=0.0,xx(38)=0.0,1;
          act,20.0,,next;


      create,xx(40),0.0,1;       new class
      event,1;                   make flights
      term;
      enter,1;                   flight starts training
 bday await(1),lineup,1;
      event,4,1;         request resources
          act,0.4,atrib(12).eq.0.0.and.atrib(13).eq.0.0,eday;
          act,,atrib(13).eq.0.0.and.atrib(12).gt.0.0,flyo;
          act,,atrib(12).eq.0.0.and.atrib(13).gt.0.0,simo;
          act,,atrib(8).eq.2.0,sim;
          act;
 fly await(4),flysorte/atrib(12);
 simo await(5),simsorte/atrib(13);
          act,0.4,,eday;
 sim await(2),simsorte/atrib(13);
 flyo await(3),flysorte/atrib(12);
          act,0.4;
 eday event,5,1;        update requirements
          act,0.1,atrib(16).gt.atrib(3),rip;
          act,,atrib(14).gt.0.0.or.atrib(15).gt.0.0,bday;
          act/1;
 dntm term;
 rip  event,6,1;    reallocate ips for new/late flight
          act,,atrib(4).gt.0.0,bday;
          act/2;
 late term;

      create,xx(41),0.1;      set weekly priorities
      event,2;
      term;

      create,1.0,0.2;      set resource levels for today
      event,3;
```

```
        term;

        create,,Ø.3;              control loop to start & stop flying
   nday open,lineup;
        act,Ø.1;
        close,lineup;
        act,Ø.9,,nday;

        endnetwork;

init,Ø.Ø,51Ø.Ø;
seeds,Ø(8)/y;
seeds,Ø(9)/y;
intlc,xx(3)=9Ø.Ø;        total days alloted for training
intlc,xx(4)=36.Ø;        initial number of students in flight
intlc,xx(5)=18.Ø;        initial number of instructors in flight
intlc,xx(6)=57.Ø;         syllabus flying sorties/student
intlc,xx(7)=25.Ø;         syllabus sim sorties/student
intlc,xx(31)=86.Ø;        number of t37 assigned to base
intlc,xx(32)=Ø.Ø;        number of t46 assigned to base
intlc,xx(33)=1.Ø;
intlc,xx(34)=Ø.Ø;
intlc,xx(35)=Ø.Ø;
intlc,xx(36)=68.Ø; sim sorties available daily
intlc,xx(4Ø)=3Ø.Ø;        days between class entries
intlc,xx(41)=5.Ø;         days between resetting flight priorities
intlc,xx(42)=9.Ø;        required solo flights/student
intlc,xx(43)=Ø.1;        probability of failure 1st flight check
intlc,xx(44)=3.4;        extra sorties/student
intlc,xx(45)=Ø.38;        probability of failure 2nd flight check
intlc,xx(46)=1.5;        extra sorties/student
intlc,xx(47)=Ø.18;        probability of failure 3rd flight check
intlc,xx(48)=1.1;        extra sorties/student
intlc,xx(49)=Ø.14;        probability of failure 4th flight check
intlc,xx(5Ø)=1.1;        extra sorties/student
intlc,xx(51)=1Ø.6;        jan daylight hours
intlc,xx(52)=11.3;        feb
intlc,xx(53)=12.1;        mar
intlc,xx(54)=13.Ø;        apr
intlc,xx(55)=13.7;        may
intlc,xx(56)=13.8;        jun
intlc,xx(57)=13.8;        jul
intlc,xx(58)=13.1;        aug
intlc,xx(59)=12.2;        sep
intlc,xx(6Ø)=11.3;        oct
intlc,xx(61)=1Ø.6;        nov
intlc,xx(62)=1Ø.3;        dec daylight hours
intlc,xx(63)=35.Ø;        jan students in flight
intlc,xx(64)=35.Ø;        feb
intlc,xx(65)=36.Ø;        mar
intlc,xx(66)=35.Ø;        apr
intlc,xx(67)=35.Ø;        may
intlc,xx(68)=36.9;        jun
intlc,xx(69)=36.Ø;        jul
intlc,xx(7Ø)=36.Ø;        aug
intlc,xx(71)=36.Ø;        sep
intlc,xx(72)=36.Ø;        oct
intlc,xx(73)=35.Ø;        nov
intlc,xx(74)=35.Ø;        dec students in flight
simulate;
montr,clear,21Ø;
fin;
```

Appendix B: T-46 Model (Fortran and SLAM)

186

```fortran
      dimension nset(5000)
      common/scom1/ atrib(100),dd(100),ddl(100),dtnow,ii,mfa,mstop,nclnr
     *,ncrdr,nprnt,nnrun,nnset,ntape,ss(100),ssl(100),tnext,tnow,xx(100)
      common qset(5000)
      equivalence (nset(1),qset(1))
      nnset=5000
      ncrdr=5
      nprnt=6
      ntape=7
      call slam
      stop
      end

      subroutine event(i)

      common/scom1/atrib(100),dd(100),ddl(100),dtnow,ii,mfa,mstop,nclnr
     *,ncrdr,nprnt,nnrun,nnset,ntape,ss(100),ssl(100),tnext,tnow,xx(100)
c   rant46:   random t37 to t46 transition model
c     as of 13 Feb 84 at 1215
      go to (1,2,3,4,5,6,7,8,9,10),i
    1 call makeft
      return
    2 call weekly
      return
    3 call dlyres
      return
    4 call reqst
      return
    5 call update
      return
    6 call reip
      return
    7 call ipflt
      return
    8 call cadre
      return
    9 call sm2flt
      return
   10 xx(20)=atrib(20)
      return
      end
c
c
      subroutine makeft

      common/scom1/atrib(100),dd(100),ddl(100),dtnow,ii,mfa,mstop,nclnr
     *,ncrdr,nprnt,nnrun,nnset,ntape,ss(100),ssl(100),tnext,tnow,xx(100)
      dimension a(24)

      flt7ip=0.0
      fltn37=0.0
      fltn46=0.0
      xx(24)=0.0
      xx(25)=0.0
      nof=nnq(1)
      if (nof.gt.0) then
         do 10 i=1,nof
         call rmove(1,1,a)
            if (a(2).eq.46.0) then
               xx(25)=xx(25)+a(4)
            else
```

```
                      if (a(2).eq.6.0) then
                         a(5)=min(a(4),a(5))
                         flt7ip=a(5)
                         xx(20)=a(20)
                      endif
                      if (a(20).eq.37.0) then
                         xx(24)=xx(24)+a(4)
                         if (a(2).lt.6.0) fltn37=fltn37+1.0
                      else if (a(20).eq.46.0) then
                         xx(25)=xx(25)+a(4)
                         if (a(2).lt.6.0) fltn46=fltn46+1.0
                      endif
                      a(2)=a(2)+1.0
                   endif
                   call filem(1,a)
         10      continue
             endif
             atrib(2)=1.0
             atrib(3)=xx(3)
c    flight size varys by month
             atrib(4)=xx(11+62)
            .xx(90)=xx(90)+atrib(4)
             xx(91)=xx(91)+1.0
c    assign aircraft type and ips
             if (xx(32).gt.0.0) then
                stdacr=(xx(25)+atrib(4))/xx(32)
             else
                stdacr=0.0
             endif
             if (xx(20).eq.46.0) then
c flight is already flying t46
             atrib(20)=46.0
             atrib(5)=xx(5)-flt7ip
             simflt=fltn46+1.0
             simsup=xx(82)
             else if (xx(32).ge.xx(34).and.stdacr.le.xx(10)
           *.and.xx(79).ge.xx(5)) then
c    must transition t37 flight to t46
             atrib(20)=46.0
             atrib(5)=xx(79)
             xx(79)=0.0
             simflt=fltn46+1.0
             simsup=xx(82)
             call schdl(8,5.0,a)
             else
c    flight stays a t37 flight
             atrib(20)=37.0
             atrib(5)=xx(5)-flt7ip
             fltn37=fltn37+1.0
             simflt=fltn37
             simsup=xx(81)
             endif
c    transition complete if no t37 flights
             if (fltn37.eq.0.0) then
             call colct(tnow-xx(86),8)
             avgstd=xx(90)/xx(91)
             print 15
             print 20
             print 30,xx(35)
             print 40,avgstd
             print 50,xx(75)
             print 60,xx(77)
             print 70,xx(80)
             print 80,xx(85)
```

188

```fortran
                print 85
                mstop=-1
            endif
c     choose syllabus based upon sims in operation
            if (simsup.eq.2.0) then
c     full sim syllabus
                atrib(6)=xx(6)*atrib(4)
                atrib(7)=xx(7)*atrib(4)
            else if (simsup.eq.0.0) then
c     no sim syllabus
                atrib(6)=xx(23)*atrib(4)
                atrib(7)=0.0
            else if (simflt.le.3.0) then
c     full sim syllabus
                atrib(6)=xx(6)*atrib(4)
                atrib(7)=xx(7)*atrib(4)
            else
c     half sim syllabus
                atrib(6)=xx(21)*atrib(4)
                atrib(7)=xx(22)*atrib(4)
            endif
            atrib(8)=1.0
            atrib(14)=atrib(6)
            atrib(15)=atrib(7)
            atrib(17)=0.0
            atrib(19)=xx(42)*atrib(4)
            atrib(21)=real(nint(rnorm(15.2,4.6,1)))*xx(11+62)/100.0
            atrib(22)=0.0
            call filem(1,atrib)
   15   format(/,72('*'))
   20   format('*',16x,'FACTOR',t58,'VALUE',t72,'*',/'*',t72,'*')
   30   format('*',10x,'Student/T-46 Ratio',t60,f3.1,t72,'*')
   40   format('*',10x,'Avg Number Students/Class',t59,f4.1,t72,'*')
   50   format('*',10x,'Days Alloted to Qualify IP',t59,f4.1,t72,'*')
   60   format('*',10x,'Number of IPs in Cadre',t59,f4.1,t72,'*')
   70   format('*',10x,'Days to Convert Simulator',t58,f5.1,t72,'*')
   80   format('*',10x,'Days Between Deliveries of 2 T-46s',t59,f4.1,
       1           t72,'*')
   85   format(72('*'),/)
            return
            end
c
c
            subroutine reqst

            common/scom1/atrib(100),dd(100),ddl(100),dtnow,ii,mfa,mstop,nclnr
          *,ncrdr,nprnt,nnrun,nnset,ntape,ss(100),ssl(100),tnext,tnow,xx(100)

c     guest help distributions
            if (atrib(2).eq.46.0) then
                atrib(18)=nint(rnorm(5.0,1.0,2))
                facip=2.5
            else
                atrib(18)=nint(rnorm(5.0,1.0,2))
                facip=2.0
            endif
            if ((atrib(8).eq.5.0).or.(atrib(5).le.4.0)) then
                busyip=0.0
            else
                busyip=3.0
            endif
c     set resource levels for t37 or t46
            if (atrib(20).eq.37.0) then
                sres=real(nnrsc(1))
```

189

```fortran
          fres=real(nnrsc(2))
      else
          sres=real(nnrsc(3))
          fres=real(nnrsc(4))
      endif
      flys=facip*(atrib(5)-busyip)+atrib(18)+atrib(17)
      if (atrib(8).eq.2.0) then
          atrib(13)=min(atrib(11),atrib(15),
     *    facip*(atrib(5)-busyip),sres)
          atrib(12)=min(atrib(10),2*atrib(4)-atrib(13),atrib(14),
     *    flys-atrib(13),fres)
      else
          atrib(12)=min(atrib(10),atrib(14),flys,fres)
          if (atrib(12).le.(atrib(17)+atrib(18))) then
              simip=facip*(atrib(5)-busyip)
          else
              simip=flys-atrib(12)
          endif
          atrib(13)=min(atrib(11),2*atrib(4)-atrib(12),simip,
     *                  atrib(15),sres)
      endif
      atrib(12)=real(int(atrib(12)))
      atrib(13)=real(int(atrib(13)))
      return
      end
c
c

      subroutine reip

      common/scom1/atrib(100),dd(100),ddl(100),dtnow,ii,mfa,mstop,nclnr
     *,ncrdr,nprnt,nnrun,nnset,ntape,ss(100),ssl(100),tnext,tnow,xx(100)
      dimension a(24)

      studs=max(atrib(14),atrib(15))
      atrib(4)=min(studs,atrib(4))
      if (atrib(5).gt.atrib(4)) then
          myrank=nfind(1,1,2,0,atrib(2)-6.0,0.0)
          if (myrank.gt.0) then
              xtraip=atrib(5)-atrib(4)
              atrib(5)=atrib(4)
              call rmove(myrank,1,a)
              if (atrib(20).eq.a(20)) a(5)=a(5)+xtraip
              call filem(1,a)
          endif
      endif
      return
      end
c
c
      subroutine weekly

      common/scom1/atrib(100),dd(100),ddl(100),dtnow,ii,mfa,mstop,nclnr
     *,ncrdr,nprnt,nnrun,nnset,ntape,ss(100),ssl(100),tnext,tnow,xx(100)
      dimension a(24)

c     find number of flights in system
      nof=nnq(1)
      xx(24)=0.0
      xx(25)=0.0
c     from flight1 to highest flight, compute max daily sortie rate
      if (nof.gt.0) then
          do 40 i=1,nof
              call rmove(1,1,a)
```

```fortran
c   check cadre flight first
        if (a(2).eq.46.0) then
            xx(25)=xx(25)+a(4)
            call filem(1,a)
            go to 40
        endif
c    solo requirements start in fourth week
        if (a(16).ge.15) then
            days=a(3)-a(16)
            if (days.le.0.0) days=1.0
            a(17)=real(nint(a(19)/(days*0.7*0.8)))
        endif
        if (a(17).gt.a(19)) a(17)=a(19)
c    from flight1 to senior flight, compute max daily sortie rate
        prcnt1=100.0*a(16)/a(3)
        if (prcnt1.le.11.1)then
            rate=0.86
        else if (prcnt1.le.22.3) then
            prcnt2=prcnt1+500/a(3)
            rate1=2.35-6.0*prcnt1/140.0
            rate2=2.35-6.0*prcnt2/140.0
            rate=(rate1+rate2)/2.0
        else
            rate=1.22
        endif
c    used max daily rate for students to compute max flight daily rate
        a(10)=real(nint(rate*a(4)))
        if (prcnt1.le.27.8) then
            rates=1.5
        else
            rates=2.0
        endif
        a(11)=real(nint(rates*a(4)))
c    used training remaining to determine flight and simulator priorities
        if (a(16).ge.a(3)) then
            a(8)=5.0
        else if (a(8).ne.0.0) then
            prcntf=100.0*a(14)/a(6)
            if (prcnt1.lt.25.0) then
                fmaxr=100.0
            else
                fmaxr=(100.0-prcnt1)*4.0/3.0
            endif
            if (a(7).gt.0.0) then
                prcnts=100.0*a(15)/a(7)
            else
                prcnts=0.0
            endif
            if (prcnt1.lt.85.0) then
                smaxr=100.0-prcnt1*100.0/85.0
            else
                smaxr=0.0
            endif
            if ((prcntf.gt.fmaxr).and.(prcnts.gt.smaxr)) then
                a(8)=4.0
            else if ((prcntf.gt.fmaxr).and.(prcnts.le.smaxr)) then
                a(8)=3.0
            else if ((prcntf.le.fmaxr).and.(prcnts.gt.smaxr)) then
                a(8)=2.0
            else
                a(8)=1.0
            endif
        endif
        if (a(20).eq.46.0) then
```

191

```
                    xx(25)=xx(25)+a(4)
              else
                    xx(24)=xx(24)+a(4)
              endif
c     compute overall scheduling priority using training and seniority
              a(9)=a(8)*16.0+a(2)
              call filem(1,a)
   40      continue
         endif
         return
         end
c
         subroutine dlyres

         common/scoml/atrib(100),dd(100),dd1(100),dtnow,ii,mfa,mstop,nclnr
        *,ncrdr,nprnt,nnrun,nnset,ntape,ss(100),ss1(100),tnext,tnow,xx(100)
         dimension a(24)
         studs=xx(24)+xx(25)
c     proportion mintues between t37 & t46
         minday=int((xx(ii+50)-0.5)*60.0)
         min46=nint(minday*xx(25)/studs)
          min37=minday-min46
c     compute t37 resources
         capmx=rnorm(70.7,2.0,3)/100.0
         ndlyas=int(capmx*0.9*xx(31)*4.0)
         ndlyss=int(xx(36)*xx(81)/2.0)
         nsortd=min(ndlyas,min37/3)
         nflys=nnrsc(2)
         call alter(2,nsortd-nflys)
         nsim=nnrsc(1)
         call alter(1,ndlyss-nsim)
c     compute t46 resources
         if (tnow.ge.xx(86)) xx(38)=xx(38)+xx(32)
         capmx=rnorm(xx(87),2.0,3)/100.0
         ndlyas=int(capmx*0.9*xx(32)*4.0)
         ndlyss=int(xx(36)*xx(82)/2.0)
         nsortd=min(ndlyas,min46/3)
         nflys=nnrsc(4)
         call alter(4,nsortd-nflys)
         nsim=nnrsc(3)
         call alter(3,ndlyss-nsim)
         return
         end
c
c
         subroutine update

         common/scoml/atrib(100),dd(100),dd1(100),dtnow,ii,mfa,mstop,nclnr
        *,ncrdr,nprnt,nnrun,nnset,ntape,ss(100),ss1(100),tnext,tnow,xx(100)

c compute cancel rates
         if (ii.le.2) then
             wxcx=rnorm(28.8,9.7,4)/100.0
         else if (ii.le.5) then
             wxcx=rnorm(29.1,11.0,4)/100.0
         else if (ii.le.8) then
             wxcx=rnorm(17.5,9.2,4)/100.0
         else if (ii.le.11) then
             wxcx=rnorm(17.2,6.3,4)/100.0
         else
             wxcx=rnorm(28.8,9.7,4)/100.0
         endif
         if (wxcx.lt.0.0) wxcx=0.0
         cxmx=rnorm(2.9,0.71,5)/100.0
```

```fortran
      if (cxmx.lt.0.0) cxmx=0.0
c credit sorties for today
      goodac=real(nint(atrib(12)*(1.0-cxmx)))
      efsort=real(nint(goodac*(1.0-wxcx)))
c T-46 util rate
      if (atrib(20).eq.46.0.and.tnow.ge.xx(86)) then
         xx(37)=xx(37)+efsort*1.25
      endif
c T-37 util rate
      if (atrib(20).eq.37.0.and.tnow.ge.210.0) then
         xx(94)=xx(94)+efsort*1.25
      endif
      efsolo=real(nint(atrib(17)*0.7))
      atrib(14)=atrib(14)-efsort
      atrib(15)=atrib(15)-atrib(13)
      atrib(16)=atrib(16)+1.0
      if (efsort.gt.efsolo) then
         atrib(19)=atrib(19)-efsolo
      else
         atrib(19)=atrib(19)-efsort
      endif
      if (atrib(19).le.0.0) then
         atrib(19)=0.0
         atrib(17)=0.0
      endif
c   if necssary attrit one student and update attributes
      if (atrib(16).le.25.0) then
         attpct=(6.0/7.0*atrib(16)+4.0)/100.0
      else if (atrib(16).le.46.0) then
         attpct=(5.0/3.0*atrib(16)-16.0)/100.0
      else if (atrib(16).le.90.0) then
         attpct=(3.0/5.0*atrib(16)+46.0)/100.0
      endif
      if (atrib(22).ne.atrib(21)) then
         if ((real(int(attpct*atrib(21)))-atrib(22)).eq.1.0) then
            atrib(22)=atrib(22)+1.0
            flyatr=real(nint(atrib(14)/atrib(4)))
            simatr=real(nint(atrib(15)/atrib(4)))
            atrib(6)=atrib(6)-flyatr
            atrib(7)=atrib(7)-simatr
            atrib(14)=atrib(14)-flyatr
            if (atrib(14).lt.0.0) atrib(14)=0.0
            atrib(15)=atrib(15)-simatr
            if (atrib(15).lt.0.0) atrib(15)=0.0
            if (atrib(19).gt.0.0) then
               atrib(19)=atrib(19)-real(nint(atrib(19)/atrib(4)))
               days=atrib(3)-atrib(16)
               if (days.le.0.0) days=1.0
               atrib(17)=real(nint(atrib(19)/(days*0.7*0.8)))
            endif
            atrib(4)=atrib(4)-1.0
         endif
      endif
c   add additional sortie requirements for failed flight evaluations
      if (atrib(16).eq.real(int(0.2*atrib(3)))) then
         xtrafs=real(nint(xx(43)*atrib(4)*xx(44)))
      else if (atrib(16).eq.real(int(0.4*atrib(3)))) then
         xtrafs=real(nint(xx(45)*atrib(4)*xx(46)))
      else if (atrib(16).eq.real(int(0.6*atrib(3)))) then
         xtrafs=real(nint(xx(47)*atrib(4)*xx(48)))
      else if (atrib(16).eq.real(int(0.8*atrib(3)))) then
         xtrafs=real(nint(xx(49)*atrib(4)*xx(50)))
      else
         xtrafs=0.0
```

193

```
          endif
          atrib(6)=atrib(6)+xtrafs
          atrib(14)=atrib(14)+xtrafs
c   set ac type for graduating flt and take stats for early finisher
          if ((atrib(14).eq.0.0).and.(atrib(15).eq.0.0)) then
              if (atrib(16).le.atrib(3)) call schdl(10,atrib(1)+atrib(3)
     1                                              -tnow-0.1,atrib)
c   days to complete statistics
          call colct(atrib(16),1)
          if (atrib(20).eq.37.0) then
              call colct(atrib(16),9)
          else
              call colct(atrib(16),10)
          endif
          if (atrib(16).lt.atrib(3)) then
              call colct(0.0,2)
              call colct(0.0,3)
          endif
          endif
c   take statistics at end of last alloted training day
          if (atrib(16).eq.atrib(3)) then
              call colct(atrib(14),2)
              call colct(atrib(15),3)

c   flying sorties remaining stat
          if (atrib(14).gt.0.0) then
              call colct(atrib(14),4)
              if (atrib(20).eq.37.0) then
                  call colct(atrib(14),11)
              else
                  call colct(atrib(14),12)
              endif
          endif
c   simulator sorties remaining stat
          if (atrib(15).gt.0.0) call colct(atrib(15),5)
          endif
          return
          end
c
          subroutine sm2flt
          common/scom1/atrib(100),dd(100),ddl(100),dtnow,ii,mfa,mstop,nclnr
     *,ncrdr,nprnt,nnrun,nnset,ntape,ss(100),ssl(100),tnext,tnow,xx(100)
          dimension a(24)
c   last t37 sim down change rem flts to sims
          nof=nnq(1)
          if (nof.gt.0) then
              do 60 i=1,nof
              call rmove(1,1,a)
              if (a(20).eq.37.0.and.a(15).gt.0.0) then
                  a(6)=a(6)+a(15)
                  a(14)=a(14)+a(15)
                  a(7)=a(7)-a(15)
                  a(15)=0.0
              endif
              call filem(1,a)
60        continue
          endif
          return
          end
c
          subroutine cadre

          common/scom1/atrib(100),dd(100),ddl(100),dtnow,ii,mfa,mstop,nclnr
     *,ncrdr,nprnt,nnrun,nnset,ntape,ss(100),ssl(100),tnext,tnow,xx(100)
```

```
        dimension a(24)
c   create a cadre flight
        a(1)=tnow
        a(2)=46.0
        a(3)=xx(75)
        a(4)=xx(5)
        a(5)=xx(77)
        a(6)=a(4)*xx(76)
        a(7)=0.0
        a(8)=5.0
        a(9)=126.0
        if (xx(75).le.15.0) then
           a(10)=real(nint(a(4)*xx(8)))
        else
           a(10)=real(nint(a(4)*xx(9)))
        endif
        a(11)=0.0
        a(12)=min(2.5*a(5),a(10))
        a(13)=0.0
        a(14)=a(6)
        a(15)=0.0
        a(16)=5.0
        a(17)=0.0
        a(18)=0.0
        a(19)=0.0
        a(20)=46.0
        a(21)=0.0
        a(22)=0.0
        call filem(1,a)
        return
        end


        subroutine ipflt
        common/scom1/atrib(100),dd(100),dd1(100),dtnow,ii,mfa,mstop,nclnr
       *,ncrdr,nprnt,nnrun,nnset,ntape,ss(100),ss1(100),tnext,tnow,xx(100)

c   end of day update for cadre flight
        efsort=real(nint(atrib(12)*rnorm(0.8,0.05,4)))
        if (tnow.ge.xx(86)) xx(37)=xx(37)+efsort*1.25
        atrib(14)=atrib(14)-efsort
        if (atrib(14).lt.0.0) atrib(14)=0.0
        atrib(16)=atrib(16)+1.0
c   take statistics
        if (atrib(14).eq.0.0) then
           call colct(atrib(16),6)
           xx(79)=xx(79)+atrib(4)
           atrib(4)=0.0
        endif
        if (atrib(16).eq.atrib(3)) then
           if (atrib(14).gt.0.0) call colct(atrib(14),7)
        endif
        return
        end
```

```
gen,dicmos,thesis,1/15/84,5,n,n,y,n,,72;
limits,9,22,40;
stat,1,days to complete;
stat,2,fly sorties rem;
stat,3,sim sorties rem;
stat,4,late flt fly rem;
stat,5,late flt sim rem;
stat,6,days for cadre;
stat,7,late fly cadre;
stat,8,t46 transition;
stat,9,days complete 37;
stat,10,days complete 46;
stat,11,late fly rem 37;
stat,12,late fly rem 46;
priority/1,hvf(9);
network;
      res/sims37(1),2,5;
      res/flys37(1),3,4;
      res/sims46(1),6,9;
      res/flys46(1),7,8;
      gate/lineup,close,1;

      create;
      assign,ii=xx(33),
             xx(37)=0.0,
             xx(38)=0.0,
             xx(1)=xx(86)+20.0;               start month, t46 util, t46 stats
          act,20.0;
 next goon,2;
          act,,ii.lt.12,nmon;
          act,,ii.eq.12,fmon;
          act,,tnow.ge.xx(1),util;
          act,20.0,,next;
 nmon assign,ii=ii+1;
      term;
 fmon assign,ii=1;
      term;
 util assign,xx(38)=xx(38)/20.0,
             xx(37)=xx(37)/xx(38);             mon hrs/avgac
      colct,xx(37),t46 util rate,20/20.0/2.0,1;  t46 monthly util rate
      assign,xx(37)=0.0,xx(38)=0.0,1;          reset t46 hrs & ac
          act,20.0,,next;

      create,,210.0;                           t37 monthly util rate
      assign,xx(94)=0.0;                       t37 hour accumulator
          act,20.0;
 ut37 assign,xx(94)=xx(94)/86.0;               hours/t37
      colct,xx(94),t37 util rate,20/20.0/2.0,1;
      assign,xx(94)=0.0,1;                     reset t37 hours
          act,20.0,,ut37;
      create,xx(40),0.0,1;                     new class
      event,1;                                 make flights
      term;
 bday await(1),lineup,1;
      event,4,1;                               request resources
          act,,atrib(20).eq.46.0,t46;
          act,0.4,atrib(12).eq.0.0.and.atrib(13).eq.0.0,eday;
          act,,atrib(13).eq.0.0.and.atrib(12).gt.0.0,fo37;
          act,,atrib(12).eq.0.0.and.atrib(13).gt.0.0,so37;
          act,,atrib(8).eq.2.0,s37;
          act;
  f37 await(4),flys37/atrib(12);
 so37 await(5),sims37/atrib(13);
          act,0.4,,eday;
```

196

```
        s37 await(2),sims37/atrib(13);
       fo37 await(3),flys37/atrib(12);
            act,Ø.4;
       eday event,5,1;                                  update requirements
            act,Ø.1,atrib(16).gt.atrib(3),rip;
            act,,atrib(14).gt.Ø.Ø.or.atrib(15).gt.Ø.Ø,bday;
            act/1;
       dntm term;
       rip  event,6,1;                                  reallocate ips for
            act,,atrib(4).gt.Ø.Ø,bday;                  new/late flight
            act/2;
       late term;
        t46 goon,1;
            act,,atrib(13).eq.Ø.Ø.and.atrib(12).gt.Ø.Ø,fo46;
            act,,atrib(12).eq.Ø.Ø.and.atrib(13).gt.Ø.Ø,so46;
            act,Ø.4,atrib(2).eq.46.Ø,cdre;
            act,Ø.4,atrib(12).eq.Ø.Ø.and.atrib(13).eq.Ø.Ø,eday;
            act,,atrib(8).eq.2.Ø,s46;
            act;
        f46 await(6),flys46/atrib(12);                  fly t46 as 1st priority
       so46 await(7),sims46/atrib(13);                  sim t46 as 2nd priority
            act,Ø.4,,eday;
        s46 await(8),sims46/atrib(13);                  sim t46 as 1st priority
       fo46 await(9),flys46/atrib(12),1;                fly t46 as 2nd priority
            act,Ø.4,atrib(2).ne.46.Ø,eday;
            act,Ø.4;
       cdre event,7,1;                                  update cadre flt at
            act,,atrib(4).gt.Ø.Ø,bday;                  end of day
            act/3;
        ips term;

            create,xx(41),Ø.1;                          set weekly priorities
            event,2;
            term;

            create,1.Ø,Ø.2;                             set resource levels y
            event,3;                                    for today
            term;

            create,,Ø.3;                                control loop to start
       nday open,lineup;                                and stop flying
            act,Ø.1;
            close,lineup;
            act,Ø.9,,nday;

            create;                                     schedule sim conversions
            assign,xx(83)=xx(86)-12Ø.Ø,xx(35)=xx(1Ø);
            act,xx(83);                                 run with 2 t37 sims
       simd assign,xx(81)=xx(81)-1.Ø;                   lose t37 sim
            act,,xx(81).eq.Ø.Ø,n37s;
            act,xx(8Ø);                                 convert sim
       simu assign,xx(82)=xx(82)+1.Ø,xx(78)=xx(86)+12Ø.Ø,
                 xx(78)=xx(78)-tnow,1;                  gain t46 sim
            act,xx(78),xx(81).gt.Ø.Ø,simd;             more t37 sims
            act;
            assign,xx(1Ø)=xx(11);                       update max stud/ac ratio
            term;
       n37s event,9;                                    change rem sims to flts
            term;

            create;                                     t46 delivery cycle
            assign,xx(32)=38.Ø;
            act,xx(86);                                 delay til start transition
       more assign,xx(32)=xx(32)+2.Ø,1;                 two t46s arrive
```

```
            act,xx(85),xx(32).lt.86.0,more;
            act;
        term;

        endnetwork;
    init,0.0,690.0;
    intlc,xx(3)=   90.0;      total days alloted for training
    intlc,xx(5)=   18.0;      initial number of instructors in flight
    intlc,xx(6)=   57.0;      syllabus flying sorties/student
    intlc,xx(7)=   25.0;      syllabus sim sorties/student
    intlc,xx(8)=    2.0;      max daily sorties/ip on 15 day syllabus
    intlc,xx(9)=    1.0;      max daily sorties/ip on 30 day syllabus
    intlc,xx(10)=   2.3;      max stud/t46 ratio with 1 sim complex
    intlc,xx(11)=   2.6;      max stud/t46 ratio with 2 sim complexes
    intlc,xx(20)= 37.0;       initially all t37 flights
    intlc,xx(21)= 71.0;       flying sorties 50% sim syllabus
    intlc,xx(22)= 12.0;       sim sorties 50% sim syllabus
    intlc,xx(23)= 81.0;       flying sorties no sim syllabus
    intlc,xx(24)=   0.0;      current number of students in t37
    intlc,xx(25)=   0.0;      current number of students in t46
    intlc,xx(31)= 86.0;       number of t37 assigned to base
    intlc,xx(32)=   0.0;      current number of t46 assigned to base
    intlc,xx(33)=   7.0;      starting month
    intlc,xx(34)= 40.0;       number of t46s needed to start transition
    intlc,xx(36)= 68.0;       sim sorties from 2 active complexes
    intlc,xx(40)= 15.0;       days between class entries
    intlc,xx(41)=   5.0;      days between resetting flight priorities
    intlc,xx(42)=   9.0;      required solo flights/student
    intlc,xx(43)=   0.1;      probability of failure on 1st flt check
    intlc,xx(44)=   3.4;      extra sorties per student.
    intlc,xx(45)=   0.38;     probability of failure on 2nd flt check
    intlc,xx(46)=   1.5;      extra sorties per student
    intlc,xx(47)=   0.18;     probability of failure on 3rd flt check
    intlc,xx(48)=   1.1;      extra sorties per student
    intlc,xx(49)=   0.14;     probability of failure on 4th flt check
    intlc,xx(50)=   1.1;      extra sorties per student
    intlc,xx(51)= 10.6;       jan daylight hours
    intlc,xx(52)= 11.3;       feb daylight hours
    intlc,xx(53)= 12.1;       mar daylight hours
    intlc,xx(54)= 13.0;       apr daylight hours
    intlc,xx(55)= 13.7;       may daylight hours
    intlc,xx(56)= 13.8;       jun daylight hours
    intlc,xx(57)= 13.8;       jul daylight hours
    intlc,xx(58)= 13.1;       aug daylight hours
    intlc,xx(59)= 12.2;       sep daylight hours
    intlc,xx(60)= 11.3;       oct daylight hours
    intlc,xx(61)= 10.6;       nov daylight hours
    intlc,xx(62)= 10.3;       dec daylight hours
    intlc,xx(63)= 31.0;       jan flt size
    intlc,xx(64)= 31.0;       feb  "    "
    intlc,xx(65)= 32.0;       mar  "    "
    intlc,xx(66)= 31.0;       apr  "    "
    intlc,xx(67)= 31.0;       may  "    "
    intlc,xx(68)= 32.0;       jun  "    "
    intlc,xx(69)= 32.0;       jul  "    "
    intlc,xx(70)= 32.0;       aug  "    "
    intlc,xx(71)= 32.0;       sep  "    "
    intlc,xx(72)= 32.0;       oct  "    "
    intlc,xx(73)= 31.0;       nov  "    "
    intlc,xx(74)= 31.0;       dec  "    "
    intlc,xx(75)= 30.0;       days to transition ip
    intlc,xx(76)= 14.0;       flying sorties/ip transition
    intlc,xx(77)=  9.0;       cadre ips
    intlc,xx(79)= 18.0;       current number t46 ips ready for students
```

```
intlc,xx(80)=140.0;      days to convert t37 sim to t46 sim
intlc,xx(81)=  2.0;      current number of t37 sims active
intlc,xx(82)=  0.0;      current number of t46 sims active
intlc,xx(85)= 10.0;      delay between arrival of 2 t46s
intlc,xx(86)=329.9;      time plan to start student transition
intlc,xx(87)= 72.0;      mean prcnt t46 on fly schedule/day
montr,clear,210.0;
simulate;
montr,clear,210.0;
seeds,1009732(1),3754204(2),0842268(3),9901902(4),1280799(5);
simulate;
montr,clear,210.0;
seeds,6606574(1),3106010(2),8526977(3),6357332(4),7399645(5);
simulate;
montr,clear,210.0;
seeds,9852017(1),1180505(2),8345299(3),8868540(4),9959467(5);
simulate;
montr,clear,210.0;
seeds,6548117(1),8012435(2),7435099(3),6991626(4),0989320(5);
fin;
```

200

Standard Deviations for 510 Day Simulation

The standard deviation for days to graduate was recomputed as each flight graduated. The time and corresponding standard deviation are shown below:

```
.4510e+02    .0000e+00
.5010e+02    .0000e+00
.5510e+02    .0000e+00
.6010e+02    .0000e+00
.6510e+02    .0000e+00
.7010e+02    .0000e+00
.7510e+02    .0000e+00
.8010e+02    .0000e+00
.8510e+02    .0000e+00
.9010e+02    .0000e+00
.9510e+02    .0000e+00
.1001e+03    .0000e+00
.1051e+03    .0000e+00
.1101e+03    .0000e+00
.1151e+03    .0000e+00
.1201e+03    .0000e+00
.1251e+03    .3214e+01
.1301e+03    .3214e+01
.1351e+03    .3214e+01
.1401e+03    .3214e+01
.1451e+03    .3214e+01
.1501e+03    .3782e+01
.1551e+03    .3782e+01
.1601e+03    .3782e+01
.1651e+03    .3782e+01
.1701e+03    .3782e+01
.1751e+03    .3782e+01
.1801e+03    .3688e+01
.1851e+03    .3450e+01
.1901e+03    .3450e+01
.1951e+03    .3450e+01
.2001e+03    .3450e+01
.2051e+03    .4076e+01
.2101e+03    .4076e+01
.2151e+03    .4076e+01
.2201e+03    .4076e+01
.2251e+03    .4076e+01
.2301e+03    .4076e+01
.2351e+03    .4076e+01
.2401e+03    .4300e+01
.2451e+03    .4300e+01
.2501e+03    .4300e+01
.2551e+03    .4300e+01
.2601e+03    .4300e+01
.2651e+03    .4300e+01
.2701e+03    .4144e+01
.2751e+03    .3968e+01
.2801e+03    .3968e+01
.2851e+03    .3968e+01
.2901e+03    .3968e+01
.2951e+03    .3968e+01
.3001e+03    .3968e+01
.3051e+03    .3965e+01
.3101e+03    .4015e+01
.3151e+03    .4015e+01
.3201e+03    .4015e+01
.3251e+03    .4015e+01
.3301e+03    .4015e+01
.3351e+03    .4100e+01
.3401e+03    .4100e+01
.3451e+03    .4100e+01
.3501e+03    .4100e+01
.3551e+03    .4100e+01
.3601e+03    .4084e+01
```

```
.3651e+03      .3980e+01
.3701e+03      .3980e+01
.3751e+03      .3980e+01
.3801e+03      .3980e+01
.3851e+03      .3980e+01
.3901e+03      .3812e+01
.3951e+03      .3812e+01
.4001e+03      .3812e+01
.4051e+03      .3812e+01
.4101e+03      .3812e+01
.4151e+03      .3812e+01
.4201e+03      .3794e+01
.4251e+03      .3794e+01
.4301e+03      .3794e+01
.4351e+03      .3794e+01
.4401e+03      .3794e+01
.4451e+03      .3959e+01
.4501e+03      .3959e+01
.4551e+03      .3959e+01
.4601e+03      .3959e+01
.4651e+03      .3959e+01
.4701e+03      .3959e+01
.4751e+03      .4028e+01
.4801e+03      .4028e+01
.4851e+03      .4132e+01
.4901e+03      .4132e+01
.4951e+03      .4132e+01
.5001e+03      .4132e+01
.5051e+03      .4132e+01
.5100e+03      .3990e+01

minimum      .0000e+00

maximum      .4300e+01
```

Plot of Standard Deviations vs Days Simulated

```
                              **plot number   1**
                               run   number   1

                                    scales of plot
        d=st deviation .000e+00              .250e+01              .500e+01
                         0    10    20    30    40    50    60    70    80    90   100  dups
        time

        .0000e+00    d                              +                        +
        .5000e+01    d                              +                        +
        .1000e+02    d                              +                        +
        .1500e+02    d                              +                        +
        .2000e+02    d                              +                        +
        .2500e+02    d                              +                        +
        .3000e+02    d                              +                        +
        .3500e+02    d                              +                        +
        .4000e+02    d                              +                        +
        .4500e+02    d                              +                        +
        .5000e+02    d                              +                        +
        .5500e+02    d                              +                        +
        .6000e+02    d                              +                        +
        .6500e+02    d                              +                        +
        .7000e+02    d                              +                        +
        .7500e+02    d                              +                        +
        .8000e+02    d                              +                        +
        .8500e+02    d                              +                        +
        .9000e+02    d                              +                        +
```

```
.9500e+02  d                        +                        +
.1000e+03  d                        +                        +
.1050e+03  d                        +                        +
.1100e+03  d                        +                        +
.1150e+03  d                        +                        +
.1200e+03  d                        +                        +
.1250e+03  +                        +      d                 +
.1300e+03  +                        +       d                +
.1350e+03  +                        +       d                +
.1400e+03  +                        +       d                +
.1450e+03  +                        +        d               +
.1500e+03  +                        +           d            +
.1550e+03  +                        +           d            +
.1600e+03  +                        +            d           +
.1650e+03  +                        +            d           +
.1700e+03  +                        +             d          +
.1750e+03  +                        +             d          +
.1800e+03  +                        +            d           +
.1850e+03  +                        +        d               +
.1900e+03  +                        +        d               +
.1950e+03  +                        +        d               +
.2000e+03  +                        +         d              +
.2050e+03  +                        +            d           +
.2100e+03  +                        +            d           +
.2150e+03  +                        +            d           +
.2200e+03  +                        +            d           +
.2250e+03  +                        +            d           +
.2300e+03  +                        +            d           +
.2350e+03  +                        +            d           +
.2400e+03  +                        +             d          +
.2450e+03  +                        +             d          +
.2500e+03  +                        +             d          +
.2550e+03  +                        +             d          +
.2600e+03  +                        +             d          +
.2650e+03  +                        +             d          +
.2700e+03  +                        +           d            +
.2750e+03  +                        +          d             +
.2800e+03  +                        +          d             +
.2850e+03  +                        +          d             +
.2900e+03  +                        +          d             +
.2950e+03  +                        +          d             +
.3000e+03  +                        +          d             +
.3050e+03  +                        +          d             +
.3100e+03  +                        +          d             +
.3150e+03  +                        +          d             +
.3200e+03  +                        +          d             +
.3250e+03  +                        +          d             +
.3300e+03  +                        +          d             +
.3350e+03  +                        +         d              +
.3400e+03  +                        +         d              +
.3450e+03  +                        +          d             +
.3500e+03  +                        +          d             +
.3550e+03  +                        +          d             +
.3600e+03  +                        +          d             +
.3650e+03  +                        +         d              +
.3700e+03  +                        +         d              +
.3750e+03  +                        +         d              +
.3800e+03  +                        +         d              +
.3850e+03  +                        +          d             +
.3900e+03  +                        +      d                 +
.3950e+03  +                        +      d                 +
.4000e+03  +                        +      d                 +
.4050e+03  +                        +      d                 +
.4100e+03  +                        +      d                 +
```

```
.415Øe+Ø3  +                          +              d           +
.42ØØe+Ø3  +                          +              d           +
.425Øe+Ø3  +                          +              d           +
.43ØØe+Ø3  +                          +              d           +
.435Øe+Ø3  +                          +              d           +
.44ØØe+Ø3  +                          +              d           +
.445Øe+Ø3  +                          +               d          +
.45ØØe+Ø3  +                          +               d          +
.455Øe+Ø3  +                          +               d          +
.46ØØe+Ø3  +                          +               d          +
.465Øe+Ø3  +                          +               d          +
.47ØØe+Ø3  +                          +               d          +
.475Øe+Ø3  +                          +               d          +
.48ØØe+Ø3  +                          +               d          +
.485Øe+Ø3  +                          +                d         +
.49ØØe+Ø3  +                          +                d         +
.495Øe+Ø3  +                          +                d         +
.5ØØØe+Ø3  +                          +                d         +
.5Ø5Øe+Ø3  +                          +                d         +
.51ØØe+Ø3  +                          +                d         +
           Ø   1Ø   2Ø   3Ø   4Ø   5Ø   6Ø   7Ø   8Ø   9Ø  1ØØ dups
time
```

```
output   consists   of     1Ø3 point sets (    1Ø3 points)
storage allocated for    1935 point sets (   387Ø words )
storage   needed   for     1Ø3 point sets (    2Ø6 words )
```

Appendix D: Sample T-46 Model Output

206

```
***************************************************************
*              FACTOR                          VALUE          *
*                                                             *
*         Student/T-46 Ratio                     2.3          *
*         Avg Number Students/Class             35.5          *
*         Days Alloted to Qualify IP            15.0          *
*         Number of IPs in Cadre                 9.0          *
*         Days to Convert Simulator            140.0          *
*         Days Between Deliveries of 2 T-46s     8.0          *
***************************************************************
```

1

s l a m   s u m m a r y   r e p o r t

simulation project thesis   by dicmos

date 1/15/1984   run number   2 of   5

current time   .6150e+03
statistical arrays cleared at time   .2100e+03

statistics for variables based on observation

	mean value	standard deviation	coeff. of variation	minimum value	maximum value	no.of obs
days to complete	.955e+02	.769e+01	.805e-01	.840e+02	.115e+03	27
fly sorties rem	.151e+03	.245e+03	.163e+01	.000e+00	.958e+03	27
sim sorties rem	.626e+01	.270e+02	.431e+01	.000e+00	.138e+03	27
late flt fly rem	.194e+03	.263e+03	.136e+01	.200e+01	.958e+03	21
late flt sim rem	.845e+02	.757e+02	.895e+00	.310e+02	.138e+03	2
days for cadre	.186e+02	.548e+00	.294e-01	.180e+02	.190e+02	5
late fly cadre	.358e+02	.383e+01	.107e+00	.330e+02	.420e+02	5
t46 transition	.285e+03	.000e+00	.000e+00	.285e+03	.285e+03	1
days complete 37	.962e+02	.819e+01	.851e-01	.840e+02	.115e+03	18
days complete 46	.941e+02	.681e+01	.723e-01	.860e+02	.110e+03	9
late fly rem 37	.223e+03	.294e+03	.132e+01	.200e+01	.958e+03	15
late fly rem 46	.120e+03	.162e+03	.135e+01	.700e+01	.441e+03	6
t46 util rate	.319e+02	.735e+01	.231e+00	.163e+02	.431e+02	13
t37 util rate	.260e+02	.147e+02	.567e+00	.610e+01	.463e+02	20

resource statistics

resource number	resource label	current capacity	average util	standard deviation	maximum util	current util
1	sims37	16301	14807.50	1917.085	****	****
2	flys37	76827	60316.86	14152.115	****	****
3	sims46	6785	1944.68	2189.218	6751	6751
4	flys46	34771	9964.96	10985.436	****	****

resource number	resource label	current available	average available	minimum available	maximum available
1	sims37	0	6.3268	0	34
2	flys37	0	22.4273	0	236
3	sims46	34	9.3263	0	68
4	flys46	0	18.8920	0	222

```
                         mean      standard  coeff. of  minimum    maximum    no.of
                         value     deviation variation  value      value      obs

  t46 util rate          .319e+02  .735e+01  .231e+00   .163e+02   .431e+02     13
```

histogram number14
t37 util rate

```
obs   rela   upper
freq  freq   cell lim  0           20          40          60          80          100
                       +     +     +     +     +     +     +     +     +     +     +
  8   .400  .200e+02   +*********************
  0   .000  .220e+02   +                             c
  2   .100  .240e+02   +*****                              c
  2   .100  .260e+02   +*****                                    c
  0   .000  .280e+02   +                                         c
  1   .050  .300e+02   +***                                         c
  0   .000  .320e+02   +                                           c
  1   .050  .340e+02   +***                                           c
  0   .000  .360e+02   +                                             c
  0   .000  .380e+02   +                                             c
  0   .000  .400e+02   +                                             c
  0   .000  .420e+02   +                                             c
  2   .100  .440e+02   +*****                                            c
  2   .100  .460e+02   +*****                                               c
  2   .100  .480e+02   +*****                                                  c
  0   .000  .500e+02   +                                                       c
  0   .000  .520e+02   +                                                       c
  0   .000  .540e+02   +                                                       c
  0   .000  .560e+02   +                                                       c
  0   .000  .580e+02   +                                                       c
  0   .000  .600e+02   +                                                       c
  0   .000    inf      +                                                       c
 ---                   +     +     +     +     +     +     +     +     +     +     +
  20                   0           20          40          60          80          100
```

statistics for variables based on observation

```
                         mean      standard  coeff. of  minimum    maximum    no.of
                         value     deviation variation  value      value      obs

  t37 util rate          .260e+02  .147e+02  .567e+00   .610e+01   .463e+02     20
```

histogram number13
t46 util rate

```
obs   rela   upper
freq  freq   cell lim  0           20          40          60          80          100
                       +     +     +     +     +     +     +     +     +     +     +
  1   .077  .200e+02   +****
  1   .077  .220e+02   +****     c
  0   .000  .240e+02   +         c
  0   .000  .260e+02   +         c
  1   .077  .280e+02   +****           c
  2   .154  .300e+02   +********             c
  0   .000  .320e+02   +                     c
  2   .154  .340e+02   +********                  c
  2   .154  .360e+02   +********                        c
  1   .077  .380e+02   +****                              c
  2   .154  .400e+02   +********                                  c
  0   .000  .420e+02   +                                          c
  1   .077  .440e+02   +****                                          c
  0   .000  .460e+02   +                                                  c
  0   .000  .480e+02   +                                                  c
  0   .000  .500e+02   +                                                  c
  0   .000  .520e+02   +                                                  c
  0   .000  .540e+02   +                                                  c
  0   .000  .560e+02   +                                                  c
  0   .000  .580e+02   +                                                  c
  0   .000  .600e+02   +                                                  c
  0   .000    inf      +                                                  c
 ---                   +     +     +     +     +     +     +     +     +     +     +
  13                   0           20          40          60          80          100
```

statistics for variables based on observation

Appendix E: Validation Data

```
.86ØØØØØØØe+Ø2
.88ØØØØØØØe+Ø2
.9ØØØØØØØØe+Ø2
.94ØØØØØØØe+Ø2
.95ØØØØØØØe+Ø2
.97ØØØØØØØe+Ø2
.93ØØØØØØØe+Ø2
.95ØØØØØØØe+Ø2
```

———

s l a m   s u m m a r y   r e p o r t

simulation project thesis   by dicmos

date 1/15/1984   run number   1 of   5

current time   .35ØØe+Ø3
statistical arrays cleared at time   .21ØØe+Ø3

statistics for variables based on observation

	mean value	standard deviation	coeff. of variation	minimum value	maximum value	no.of obs
days to comlete	.923e+Ø2	.335e+Ø1	.417e-Ø1	.86Øe+Ø2	.97Øe+Ø2	8
fly sorties rem	.355e+Ø2	.388e+Ø2	.1Ø9e+Ø1	.ØØØe+ØØ	.89Øe+Ø2	8
sim sorties rem	.ØØØe+ØØ	.ØØØe+ØØ	.1ØØe+Ø5	.ØØØe+ØØ	.ØØØe+ØØ	8
late flt fly rem	.568e+Ø2	.335e+Ø2	.59Øe+ØØ	.18Øe+Ø2	.89Øe+Ø2	5
late flt sim rem	.ØØØe+ØØ	.ØØØe+ØØ	.1ØØe+Ø5	.ØØØe+ØØ	.ØØØe+ØØ	5
t37 util rate	.359e+Ø2	.115e+Ø1	.319e-Ø1	.35Øe+Ø2	.379e+Ø2	6

210

```
.850000000e+02
.860000000e+02
.870000000e+02
.910000000e+02
.960000000e+02
.960000000e+02
.960000000e+02
.980000000e+02
```

. . .   .

1

s l a m   s u m m a r y   r e p o r t

simulation project thesis   by dicmos

date 1/15/1984   run number   2 of   5

current time   .3500e+03
statistical arrays cleared at time   .2100e+03

statistics for variables based on observation

	mean value	standard deviation	coeff. of variation	minimum value	maximum value	no.of obs
days to comlete	.919e+02	.528e+01	.574e-01	.850e+02	.980e+02	8
fly sorties rem	.526e+02	.580e+02	.110e+01	.000e+00	.132e+03	8
sim sorties rem	.575e+01	.151e+02	.262e+01	.000e+00	.430e+02	8
late flt fly rem	.842e+02	.507e+02	.602e+00	.100e+01	.132e+03	5
late flt sim rem	.920e+01	.189e+02	.206e+01	.000e+00	.430e+02	5
t37 util rate	.352e+02	.263e+01	.748e-01	.322e+02	.390e+02	6

```
 .840000000e+02
 .880000000e+02
 .880000000e+02
 .920000000e+02
 .920000000e+02
 .970000000e+02
 .950000000e+02
 .960000000e+02
1
```

                 s l a m   s u m m a r y   r e p o r t

     simulation project thesis   by dicmos

     date   1/15/1984   run number   3 of   5

     current time   .3500e+03
     statistical arrays cleared at time   .2100e+03

                    statistics for variables based on observation

	mean value	standard deviation	coeff. of variation	minimum value	maximum value	no.of obs
days to comlete	.915e+02	.454e+01	.496e-01	.840e+02	.970e+02	8
fly sorties rem	.306e+02	.407e+02	.133e+01	.000e+00	.960e+02	8
sim sorties rem	.325e+01	.919e+01	.283e+01	.000e+00	.260e+02	8
late flt fly rem	.490e+02	.422e+02	.860e+00	.600e+01	.960e+02	5
late flt sim rem	.520e+01	.116e+02	.224e+01	.000e+00	.260e+02	5
t37 util rate	.355e+02	.170e+01	.478e-01	.333e+02	.376e+02	6

```
1
 .9100000000e+02
 .8500000000e+02
 .8600000000e+02
 .9100000000e+02
 .9200000000e+02
 .9600000000e+02
 .9600000000e+02
 .9500000000e+02
 .9600000000e+02
1
```

                        s l a m   s u m m a r y   r e p o r t

    simulation project thesis   by dicmos

    date 1/15/1984   run number   4 of   5

    current time   .3500e+03
    statistical arrays cleared at time   .2100e+03

                    statistics for variables based on observation

                         mean   standard coeff. of minimum   maximum no.of
                         value   deviation variation   value   value   obs

    days to comlete   .920e+02   .424e+01 .461e-01   .850e+02   .960e+02   9
    fly sorties rem   .399e+02   .443e+02 .112e+01   .000e+00   .112e+03   8
    sim sorties rem   .800e+01   .226e+02 .293e+01   .000e+00   .640e+02   8
    late flt fly rem .532e+02   .444e+02 .834e+00   .100e+01   .112e+03   6
    late flt sim rem .107e+02   .261e+02 .245e+01   .000e+00   .640e+02   6
    t37 util rate   .353e+02   .182e+01 .516e-01   .323e+02   .380e+02   6

213

```
     .
   .840000000e+02
   .870000000e+02
   .880000000e+02
   .890000000e+02
   .900000000e+02
   .950000000e+02
   .940000000e+02
   .940000000e+02
1
```

simulation project thesis   by dicmos

date   1/15/1984   .   run number   5 of   5

current time   .3500e+03
statistical arrays cleared at time   .2100e+03

          statistics for variables based on observation

	mean value	standard deviation	coeff. of variation	minimum value	maximum value	no.of obs
days to comlete	.901e+02	.391e+01	.434e-01	.840e+02	.950e+02	8
fly sorties rem	.135e+02	.223e+02	.169e+01	.000e+00	.640e+02	8
sim sorties rem	.000e+00	.000e+00	.100e+05	.000e+00	.000e+00	8
late flt fly rem	.360e+02	.244e+02	.679e+00	.190e+02	.640e+02	3
late flt sim rem	.000e+00	.000e+00	.100e+05	.000e+00	.000e+00	3
t37 util rate	.345e+02	.982e+00	.284e-01	.328e+02	.359e+02	6

214

Validation Results

Historical Data	Experimental Data				
	Run 1	Run 2	Run 3	Run 4	Run 5
85	86	85	84	91	84
86	88	86	88	85	87
92	90	87	88	86	88
97	94	91	92	91	89
99	95	96	92	92	90
94	97	96	97	96	95
90	93	96	95	96	94
86	95	98	96	95	94

VITA

Maj Jack R. Dickinson was born on 17 January 1949 in Harlan, Kentucky. He graduated from the United States Air Force Academy in 1971 receiving a Bachelor of Science degree in computer science. After earning his navigator rating in April 1972, he was assigned to the 36th TAS as a C-130E navigator, where he accumulated 2000 flying hours and served as both an instructor navigator and flight examiner. Leaving the 36th TAS, he was assigned to the group command post at Kadena AB Okinawa as an Emergency Actions Officer. During this tour, he earned a Master of Science degree in System Management from the University of Southern California graduating in January 1979. His next assignment was to the 16th Special Operations Squadron navigating the AC-130H gunship, commonly called Spectre. In the 16th, his duties included instructor navigator, aircrew scheduler, maintenance liason officer, current operations officer, and chief of training for the 275 man squadron. While in special operatons, he helped demonstrate the responsiveness of the gunship by a record setting 29 hour 43 minute non-stop deployment from Hurlburt AFB to Guam. In August of 1982, he entered the school of engineering at the Air Force Institute of Technology in the Graduate Strategic and Tactical Science Program.

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216

VITA

Captain Glenn E. Moses was born on 13 February 1951 in New Castle, Pennsylvania. Upon graduating from high school in 1969 in Indianapolis, Indiana, he attended the United States Air Force Academy from which he received a Bachelor of Science degree in mathematics in 1973. In the summer of 1973, he attended Undergraduate Pilot Training in Columbus, Mississipi and received his wings in October of 1974. He remained at Columbus Air Force Base where he was an instructor pilot and flight examiner in the 14th Fying Training Wing, qualified in the T-37 aircraft. He then was reassigned in April 1979 to the 14th Military Airlift Squadron at Norton Air Force Base California and flew as an instructor pilot and flight examiner in the C-141 aircraft until entering the School of Engineering, AFIT, in September 1982.

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Indianapolis, IN 46229

END

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