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A CASE STUDY ASSESSMENT OF OPERATIONAL EFFECTIVENESS FOR AN ADVANCED HELICOPTER FLIGHT SIMULATOR:

THE CH146 TACTICAL HELICOPTER MISSION SIMULATOR

A Thesis
Presented for the
Master of Science in Aviation Systems
Degree
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Robert Thomas Erdos
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DEDICATION

This thesis is dedicated to my parents

Joseph Erdos

and

Magda Erdos

in appreciation for having taught me to value learning.

ABSTRACT

Flight simulators are widely used for training in both military and civil aviation, and the scope of applications in simulation has expanded widely during approximately the last three decades. A fundamental question in the effective application of this technology is the extent to which training in a simulator constitutes adequate preparation for actual flight. The process of validation of simulator effectiveness is as yet not well defined, and the common, though mistaken, association of "high fidelity" with "high training effectiveness" clouds the determination of the degree of fidelity required to achieve specific training objectives. It is axiomatic in simulation that no ground-based training device can achieve perfect fidelity, and the present state of the art is such that incremental improvements in fidelity will yield diminishing returns in training effectiveness. Far greater benefits can be realized from attention to more effective utilization of the existing systems. This thesis details the difficulties inherent in the determination of training effectiveness for a mission simulator.

Experience with a specific military simulator acquisition project, the Canadian Forces' CH146 Griffon tactical helicopter mission simulator, is used in this paper to highlight the challenges inherent in validating simulator training effectiveness; particularly that of a tactical full-mission simulator. The author's experience indicates that the key limitations to achieving optimum training effectiveness lie not in maximizing the fidelity of the simulation, but in knowing how to effectively exploit its existing capabilities. Challenges remain in the areas of validation, syllabus design, instructional technique and user interface. The effective use of training technology has become of critical importance, given the technical sophistication of modern simulators. The understandable desire to extract maximum utilization from simulators has led to suboptimal use of very expensive investments.

TABLE OF CONTENTS

TITLE PAGE

PART I: INTRODUCTION

Background 1

PART II: SIMULATION IN FLIGHT TRAINING

A Brief History of Flight Simulator Technology 2
Helicopter Flight Simulation 3
The Challenge of Full-Mission Simulation 4
The Simulator Technical Specification 5
Categories of Simulator Fidelity 8
Requisite Fidelity 10

PART III: VALIDATION OF SIMULATOR OPERATIONAL EFFECTIVENESS

The Requirement for Validation 15
Simulator Effectiveness Evaluation 16
Context of Simulator Effectiveness Validation 21
Validation of Fidelity Outside the Flight Envelope 21
Simulator Instructional Technique 24

PART IV: OPERATIONAL EVALUATION OF THE CH146 MISSION SIMULATOR

BACKGROUND 26
- General 26
- CH146 Development and Acceptance Process 28

OBJECTIVES 29
- General 29
- Specific 29

METHOD 30
RESULTS AND DISCUSSION 31
- General 31

FUNCTIONAL UTILITY 31
- Height Perception 31
- Range Perception 31
- Autorotative Landing Flight Performance 32
- Crash Threshold Exceedance 32
- Ground Contact Effect 33
- Cockpit Ambient Lighting 33

TITLE PAGE

INSTRUCTIONAL UTILITY 34
Simulator Field of View 34
Simulator Use for Start Procedures 34
Map Reading 35
Visual System "Screen Saver" Mode 35
Instructional Technique 36
Initial Conditions Definition 37
IOS Screen Field of View 37
Player Control System Interface 38
Complexity of IOS Interface 38
Flight Engineer Participation in Crew Coordination 38
Scenario Development Utilities: Resource Requirements 39
Lesson Plan Editor 39
Demonstration Playback Utilities 39
SUPPORT AND LOGISTICS 40
Outstanding Deficiencies 40
Manning Requirements 42
Software Configuration Control 43

PART V: CONSIDERATIONS FOR OPTIMIZATION OF CH146 SIMULATOR TRAINING EFFECTIVENESS

Objectives of the Acceptance and Validation Process 44
Recommendations for Operational Employment 45

PART VI: CONCLUSIONS AND RECOMMENDATIONS

General 48
Specific 49

REFERENCES 50

APPENDICES

Appendix A: CH146 SIMULATOR SYSTEMS DESCRIPTION 55
Appendix B: SIMULATOR CAT III TEST MATRIX 62
Appendix C: DEFICIENCY CLASSIFICATION 63

VITA 65

LIST OF FIGURES

FIGURE		PAGE
Figure 1	A Sample Training Analysis Methodology	7
Figure 2	Hierarchy of Simulator Fidelity	14
Figure 3	Sample Data: Aircraft Training Requirements as a Function of Simulator Exposure	17
Figure 4	Sample Data: Total Training Costs/Savings as a Function of Simulator Exposure	18
Figure 5	Sample Data: Simulator Backward Transfer Study	20
Figure 6	Simulator Subjective Tuning Methodology	23
Figure 7	The CH146 Griffon Utility Tactical Transport Helicopter	26
Figure 8	The CH146 Mission Simulator	27
Figure 9	Relative Severity of Outstanding Deficiencies	41
Figure 10	Deficiency Type Distribution	42
Figure A-1	The CH146 Simulator Cockpit	55
Figure A-2	The Instructor Operator's Station	56
Figure A-3	Sample IOS Screen – Environmental Control Page	57
Figure A-4	Instructor Operator Station "EL" Panels	58
Figure A-5	Portable Control Unit, PCU-18	59
Figure A-6	The Debrief Station	60

LIST OF TABLES

TABLE		PAGE
Table 1	Pilot Performance Metrics	16
Table 2	Comparison of Aircraft versus Simulator Instructional Techniques	25

LIST OF ABBREVIATIONS

The following abbreviations/acronyms appear in this report:

AETE	Aerospace Engineering Test Establishment
AGL	Above Ground Level
AMS	Avionics Management System
AOP	Air Observation Post
ATP	Acceptance Test Procedure
BHTI	Bell Helicopters Textron Incorporated
CBT	Computer-Based Training
CDU	Control and Display Unit
CFB	Canadian Forces Base
CFUTTH	Canadian Forces Utility Transport Tactical Helicopter
CPT	Cockpit Procedures Trainer
CRM	Cockpit Resource Management
DBMS	Database Management System
DND	Department of National Defence
EL	Electroluminescent
FAC	Forward Air Controller
FE	Flight Engineer
FLIR	Forward Looking Infra-Red
IOS	Instructor Operator's Station
IP	Instructor Pilot
ITEMS	Interactive Tactical Environment Management System
LATEF	Land Aviation Test and Evaluation Flight
LCD	Liquid Crystal Display
LOFT	Line-Oriented Flight Training
LP	Lesson Plan
MDU	Map Data Unit
MPS	Mission Planning Station
NVG	Night Vision Goggles
OGE	Out of Ground Effect
PCU	Portable Control Unit
POC	Pilot's Operational Conversion
PMO	Project Management Office
RAP	Record and Playback
SAS	Simulator and Standards
TOT	Transfer of training
TSD	Tactical Situation Display
VDB	Visual Database
VFR	Visual Flight Rules
VNC	VFR Navigation Chart
10 TAG	10 Tactical Aviation Group, Canadian Forces

PART I - INTRODUCTION

Background. Flight simulators are firmly established as an integral part of the training infrastructure for both military and civil aviation. For reasons commonly associated with cost and safety, simulation is widely used, and the scope of applications for simulators has expanded widely with the gradual evolution of flight simulation technology in approximately the last three decades. Of fundamental interest in the effective application of this technology are questions regarding the extent to which training in a simulator constitutes adequate preparation for actual flight. The methodology for validation of the training effectiveness of a simulator is as yet not well defined, and determining the appropriate operational use of modern simulators remains a challenge. Furthermore, the common, though mistaken, association of "high fidelity" with "high training effectiveness" clouds the determination of the degree of fidelity required to achieve specific training objectives; an issue which complicates procurement of a device satisfactory to meet user training objectives.

It is axiomatic in simulation that no ground-based training device can achieve perfect fidelity, and the present state of the art is such that incremental improvements in fidelity will likely yield diminishing returns in training effectiveness. Far greater benefits can be realized from attention to more effective utilization of the existing systems. As such, the simulator should not be seen as an end in itself, but rather a part of an overall training system. Experience with a specific military simulator acquisition project, the Canadian Forces' CH146 Griffon tactical helicopter mission simulator, is used in this paper to highlight the particular challenges inherent in validating the training effectiveness of a modern full-mission simulator. This paper will establish requirements for the optimization of training effectiveness for a mission simulator.

The author's experience indicates that the key limitations to achieving improved training effectiveness lie not in the fidelity of the simulation, but in knowing how to effectively exploit its existing capabilities. Those challenges lie in the areas of validation, syllabus design, instructional technique and user interface. The determination of effective use of training technology has become of critical importance, given the sophistication of modern simulators. The understandable desire to extract maximum utilization from simulators has led to suboptimal use of very expensive simulator investments. Lessons from the field of instructional design offer insight into improved simulator utilization.

PART II - SIMULATION IN FLIGHT TRAINING

A Brief History of Flight Simulator Technology. It has long been recognized that the use of flight simulation is advantageous in aircrew training. The requirement for simulation emerged, interestingly, not long after the advent of the aircraft itself. Prior to the Wright Brothers, it had been assumed that aircraft would be inherently stable, as were airships and balloons, and would not require the acquisition of new skills. Experience in early aircraft proved otherwise, often with dramatic results. The earliest efforts to simulate the flying experience, such as the Saunders Teacher of 1910, used real aircraft attached to the ground and pivoting on a universal joint. Such devices used the aircraft's flight controls and, in the presence of a sufficient wind, served to demonstrate the primary effects of the aircraft's controls. Later developments employed various mechanical means to simulate flight. The nature of simulation was constrained however not so much by the state of the art technologically, than by the often mistaken understandings that prevailed regarding the essential skills required. Rolfe and Staples [F, p. 17] describe the Ruggles Orienter and the Antoinette Apprentice Barrel which operated on the then prevalent notion that vestibular cues enabled a person to remain oriented in flight, as on the ground. The former device was touted as being useful for "developing and training the functions of the semi-circular canals" and claimed that the aviator could be blindfolded "so that the sense of direction may be sensitized without the assistance of the visual senses" in order to train the pilot to fly in cloud or darkness without visual reference. In retrospect, the state of the art in simulation was limited by both analytical skills in aircraft modeling and by limited understanding of the human element in the system. By the 1920's academic understanding of aircraft behavior was likely adequate to devise a suitable flight model, but technology was not yet available to perform the requisite real-time processing. Later developments in control theory led to the design of more capable servomechanisms (actuators, relays, gyroscopes and analog circuits) that could be programmed empirically to simulate aircraft response. In 1927 Edward Link was granted the first patent for a flight training device, the reknowned Link Trainer. These systems were initially very simple, being empirically tuned only for rudimentary response of primary controls without any underlying analytical model. The advent of instrument flying in the 1930's led to requirements for more capable simulators. In 1929, Roeder received a patent for an airship simulator which utilized a hydromechanical computer system to correlate initial conditions and control displacements with instrument readings. This technology was picked up by Link for instrument flying training, with an early system sold to the US Army Air Corps. The first delivery of an airline training simulator was to American Airlines in 1937. By the outbreak of World War II, many air forces conducted their initial instrument instruction in Link Trainers.

Rapid developments in aircraft systems during the war years, such as constant speed propellers, retractable undercarriage and engine supercharging, rapidly outstripped the available modeling technologies. Instructors became aware of the limitations of existing equipment and made efforts to adapt. Cockpit procedures trainers were

constructed, using real aircraft cockpits or entire fuselages, and electrical and hydraulic systems were powered in order to allow crews to conduct familiarization training. Efforts were made to incorporate pneumatic control loading systems, sound and limited projection-based visual systems in order to enhance simulations. With the pace of activities spurred by the war, a "more is better" philosophy prevailed, and very little record exists of any efforts to validate this increased complexity with respect to training effectiveness.

Further efforts to increase the sophistication of flight simulators awaited the invention of the electronic computer. An MIT paper by Mueller in 1936 [F, p. 28] mentioned the prospect of applying an analog computer, then called a "differential analyzer" to the problem of conducting real-time, man-in-the-loop simulation of aircraft flight dynamics. This led to a 1943 contract between the US Navy and Bell Telephone Laboratories to construct an electronically-based operational flight trainer for the PBM-3 aircraft; a device which has been called the "first operational flight trainer that attempted to simulate the aerodynamic characteristics of a specific aircraft" [Dreves, Pomeroy and Voss (1971) from Reference F], however no record exists for data having been collected to characterize the real aircraft. Following the war, similar circumstances prevailed, as an increasingly complex variety of aircraft and systems were modeled often based on sparse data supported by trial-and-error and pilot opinion. By the 1950's the complexity of the flight models increased until it encroached upon the reliability available from banks of vacuum tubes. Later, in the early 1960's, flight simulators were among the first commercial applications of digital computers, which enabled the spiral of complexity to encompass motion hardware and visual systems. The trend continues to this day; the development of simulator technology being an iterative cycle of development within the seemingly ever-expanding bounds of available computational capabilities.

Helicopter Flight Simulation. The modern flight simulator came into widespread use in support of training for the fixed-wing airline industry, however the use of simulators has become more common in the helicopter industry as well. In civil aviation, helicopter simulator applications are limited mainly to instrument and recurrency training for larger models (e.g. Bell 222/230/430, Bell 212/412, Sikorsky S-76, and Aerospatiale AS-332L Puma). The implementation of simulators for training has certainly been slower in the helicopter industry than for fixed-wing operators, owing to a variety of differences in the operational, financial and regulatory environments. The following factors have contributed to the slower initial use of simulators in civil helicopter training:

a. helicopter operators tend to conduct a wider variety of missions than scheduled airlines;
b. commercial helicopter work tends to be widely disbursed geographically;
c. the scale of most commercial helicopter companies does not justify establishment of a dedicated training infrastructure;

d. helicopter operating costs often do not significantly exceed simulator hourly rates; and
e. government regulations were slower to offer credit for helicopter training (i.e. pilot proficiency checks or instrument training) than for fixed wing operators [U].

The slower implementation of simulators in the civil helicopter industry may also be attributed to the fact that simulation of helicopters is far more complex than for airplanes. Modeling the aerodynamics of the main rotor, the interactions between main and tail rotors and the higher order dynamics of the flight control system remain a challenge to the state of the art [U, Ch. 8, p. 197]. As a result, the data required to fully characterize a helicopter can be expensive to gather, increasing reliance on subjective input and rules of thumb in tuning the simulation.

The Challenge of Full-Mission Simulation. In military flight training, simulators have found widespread use in training for most operational roles. Owing to its flexibility, the simulator is an ideal training tool for helicopter operations. Despite some limitations, as the capabilities of modern simulators have grown, so too have the scope of the applications and training objectives intended for them. Beyond dedicated training applications, simulators have become widely used for a variety of applications including: research and development, military tactics development, rapid prototyping, systems integration and handling qualities investigations. A wide variety of devices, intended for a diverse range of applications, serve under the title "simulator". The term is found applied to both the simplest fixed-based desktop computer-based systems and the most complex integrated military full-mission training devices. Within the context of this paper, a serviceable definition of a flight simulator is as follows:

> "A simulator is a device that replicates operational aviation situations and provides a facility for practicing and maintaining previously acquired skills. Simulators differ from 'part-task trainers' or 'whole-task trainers only in degree, as all trainers simulate the operational situation at some level and also provide some level of practice (Hayes and Singer, 1989)". [EE, p. 3.1]

The current military training simulator is used for a wide variety of applications. This is particularly true for helicopter operations, which tend to be less restricted to enroute flying, and more varied in nature. The CH146 simulator is a good example of the broad range of objectives for which helicopter simulators are intended. The Detail Specifications for the CH146 Simulator [W] states ambitious pre-acquisition training objectives that include the following:

a. initial type conversion training;
b. general proficiency and recurrency training;
c. instrument proficiency training, including instrument check-rides;
d. training of maintenance test pilots;

e. night vision goggle (NVG) initial and recurrent training;
f. crew coordination and cockpit resource management training;
g. aircraft commander upgrading check-rides and evaluations;
h. Operational Test and Evaluation of new tactics, systems or procedures; and
i. rehearsal or preparation for deployments and operational missions.

Current generation simulators have gone beyond serving as a surrogate part-task training device, and are intended to perform the vast majority of the tasks of which the helicopter is capable. Inherent in the increasingly ambitious objectives for modern simulators, the utility of the simulator arises not merely from doing more safely or economically those tasks that may be performed in flight, but rather by conducting in simulation those activities which *cannot* be conducted in flight. This raises issues which are unique to this class of training device. During training, aircrew gain confidence in the simulation by subconsciously comparing the stimuli present in the simulator to their similar experiences in flight. However, in the case of full-mission simulation the ability to refer to actual experience in the assessment of simulation validity is frequently lost. This is the case, for example, when a simulator is used to train aircrew for immediate actions following catastrophic failure of a main driveshaft. In such a case, no means exists to conduct the same exercise in flight, and little or no engineering data exists from actual occurrence. Mission simulation, for the purpose of this paper, is defined *as simulation encompassing dynamic scenarios and/or interactions of multiple complex systems, which cannot practicably be conducted in flight*. By contrast, a *flight* simulator may be regarded as that class of training device which replicates a desired aircraft for the performance of maneuvers which can be conducted in flight. Examples include instrument, emergencies and procedures training, which for reasons of economy or safety may be *better* conducted in a simulator. Mission simulators provide the means to offer training that is simply not possible by any other means. Possible examples include:

a. training in the avoidance or evasion of anti-aircraft threats;
b. prosecution of high risk missions under fire or in a damaged aircraft; or
c. formation flight into adverse weather conditions.

Realistically, although individual aircrew may be classified as operationally current, most have never experienced the threats inherent in actual combat operations. The capability to train crews in this environment has the potential to dramatically increase effectiveness in combat. The simulation of complex, dynamic and mission-representative scenarios are beyond the capabilities of the previous generation of flight simulators, and represent the biggest operational training advantage to be realized from this technology.

The Simulator Technical Specification. Efforts should begin early in the programmatic life span of the simulator to ensure that it meets the training objectives intended for it. The technical specification, prepared between the manufacturer and the customer, serves as the means to define the physical configuration and the functionality of the

simulator. Since cost is inevitably a factor, it is important that design requirements be firmly documented early in the developmental process. Figure 1 details a method for conducting an analysis of training requirements [K]. It effectively makes the point that a task analysis, leading to specific training objectives, must be prepared prior to specifying the configuration of a potential training device. Such a process should involve specialists in instructional design who can work closely with subject matter experts from the relevant operational discipline. Figure 1 describes an iterative process in which the configuration of the training device evolves as experience is gained in the conduct of actual training. This is indeed an idealized process. In practice, contractual realities dictate that few if any changes to the simulator will be feasible following the commencement of training. The conclusion is evident, however, that satisfaction with the simulator in operational training will be highly dependent upon a clear definition of requirements early in the developmental process. The involvement of end users can never happen too early in the development of the simulator. Even in the specification process, input from the user can be invaluable in making cost-benefit decisions regarding the types and levels of technology (motion, visual, etc.) that the manufacturer may propose.

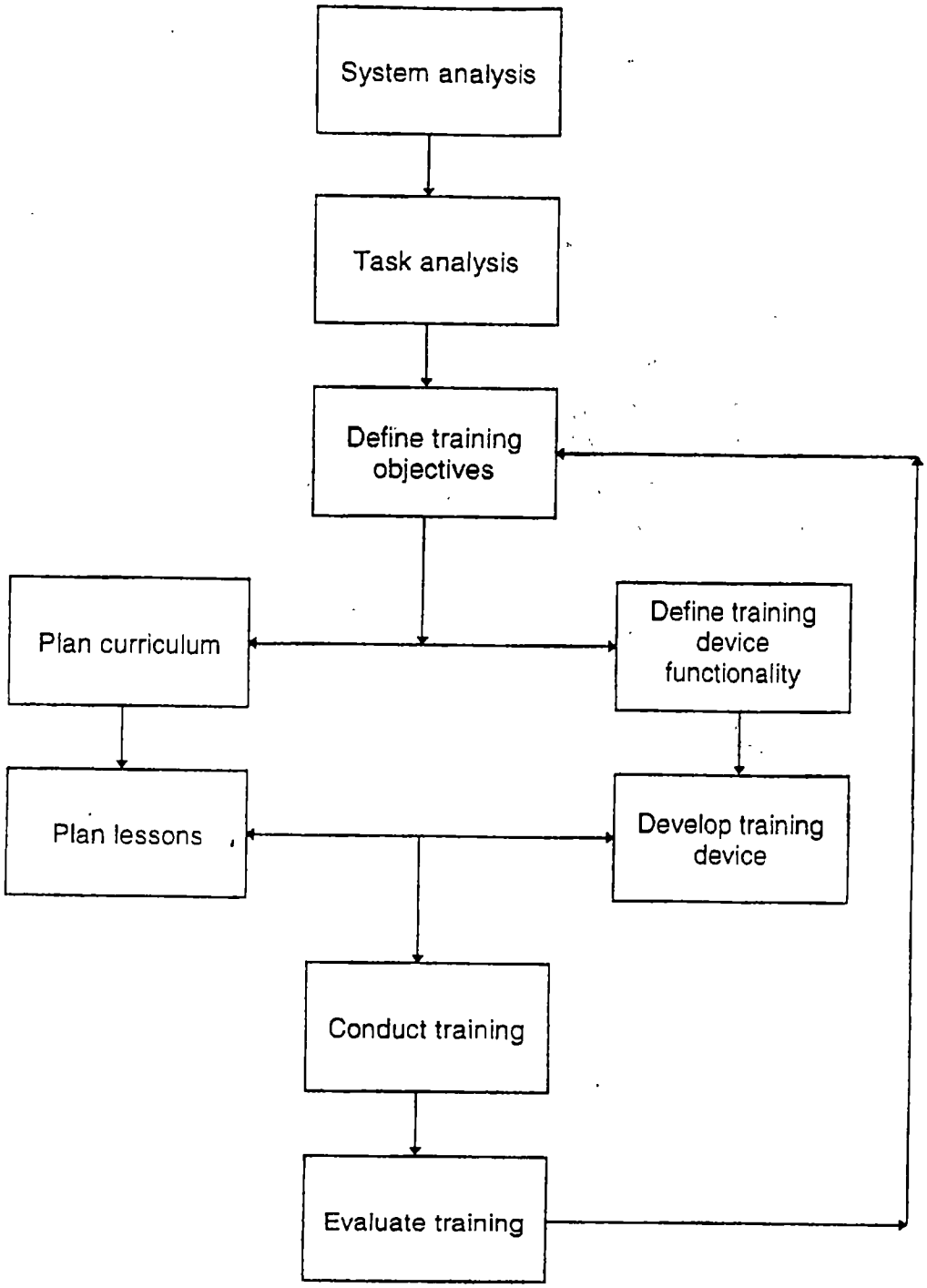

Figure 1
A Sample Training Analysis Methodology
[from Reference K]

Categories of Simulator Fidelity. Aircrew acquire operational skills directly from exposure to the simulator, but inherent in the conduct of mission simulation is the limitation that frequently the simulation itself is not directly based upon experience. In practice, the effectiveness of the training is based upon the assumption that high fidelity of the constituent systems and scenarios will yield a useful training environment. In the case of an individual component malfunction, such as a driveshaft failure, the simulation is based upon hopefully sound analyses, tempered by a degree of skepticism regarding the fidelity of the simulation outside of the normal flight envelope. Such skepticism is warranted by the inability to validate the effects of the model from actual experience. Furthermore, the implications of this inability to validate simulator modeling increase with the sophistication of the simulation. In the military context, the trend has been toward more comprehensive simulation of the operational theatre. Such simulations can include airborne and ground-based threats, integration of tactical systems and actual terrain databases. The intention of such comprehensive simulation environments is to integrate key features of the actual mission, ostensibly allowing crews to train more realistically and thoroughly than can be conducted in actual flight. Validation of such simulations relies heavily upon analysis, since inevitably the dynamics of such complex environments are remote from actual experience.

A simulator is necessarily based upon a degree of conformance with the flight environment. This is termed the *fidelity* of the simulation, and may be defined as "the physical and functional similarity of the training device to the actual equipment for which training is undertaken" [DD]. It would seem that every increment in simulation fidelity would benefit training, however the correlation between fidelity and training effectiveness is complex and not fully documented. Although in principle fidelity is a straightforward concept, measurement of flight simulator fidelity is far from simple. It is worthwhile to delve briefly into various definitions of simulator fidelity. The literature lists definitions for a variety of types of fidelity. Examples include: engineering fidelity, dynamic fidelity, equipment fidelity and psychological fidelity. For the purpose of this paper, these various definitions may be reduced to two categories: objective and subjective fidelity. They are defined as follows:

a. Objective Fidelity. The developmental process for the construction of a flight simulator employs a set of data, derived from flight tests, detailing the flying qualities and performance of the subject aircraft. Further data documents the functions of the aircraft's systems. Engineers and programmers formulate a mathematical model based on these source data, with the intention that the simulator replicate the data to a high degree. The quality of this modeling is termed the *objective fidelity*. It is easily quantifiable, usually in the form of overlay plots showing both aircraft and simulator behavior in response to selected flight conditions or control inputs; and

b. Subjective Fidelity. Notwithstanding the sophistication of modern simulators, an element of "feel" remains in assessing the similarity of the simulator to the aircraft. No data set can be comprehensive enough to capture every aspect of the pilot's interaction with the machine. Although a fairly high degree of objective fidelity is desirable, it has frequently been found that high objective fidelity does not necessarily result in a simulator that feels like the aircraft in the opinion of pilots experienced on the type. Owing to inherent limitations in the motion and visual systems, or compromises made regarding the complexity of the mathematical model, even a perfect overlay of aircraft performance will not feel perfectly like a flying aircraft when experienced on a fixed-base simulator. As well, some facets of simulator fidelity are inherently subjective in nature and are best validated on the basis of personal experience. The extent to which a simulator evokes the feel of the aircraft is termed *subjective fidelity* (sometimes termed *perceptual fidelity* [E, p. 1]). Subjective fidelity also accounts for the fact that even if certain stimuli are modeled with great objective precision, the subjective sense of realism might be compromised by the fact that the stimuli present are not necessarily those required to perform the selected tasks.

Both objective and subjective fidelity are concerned with the similitude between the aircraft and the simulator, and are sometimes collectively referred to as "physical fidelity" [V, p. 258]. In optimizing a simulator for a specific training task, both subjective and objective fidelity must be consciously balanced. During development of a simulator there is a temptation to rely upon the "expert opinion" of operational pilots, since such input can conveniently reduce the cost and time required for analytical modeling. However, excessively enthusiastic subjective "tuning" is fraught with danger, owing to limitations in the recollection of specific details of aircraft behavior, combined with the tendency of aircrew to ascribe unwarranted certainty to those same recollections. Similarly, rigid reliance upon quantitative data can likewise degrade the feel of the simulation. As expressed by Waag [C]:

> "Many a user of simulators can tell of devices which match the plots, well within tolerances, but do not 'feel' like the aircraft being simulated. The problem is that the industry does not yet know which stimuli (present or otherwise) are of primary importance in making the simulator feel like the aeroplane although everyone in simulation has his own ideas." [C]

With regard to the necessity to validate objective fidelity with reference to pilot experience and "feel", one can go so far as to conclude that simulation based entirely upon analytical, objective criteria will always result in a suboptimal simulation. All simulations make use of modeling techniques which are inevitably based upon a degree of approximation and simplification, incorporated to constrain developmental costs and computational requirements, or perhaps limited by the state of the art. In the

modeling of the aircraft handling qualities, the requirements for hands-on validation of the flight model is well understood [F], owing to our imperfect understanding of the actual cueing upon which pilots rely to control an aircraft. As the complexity of the simulation increases, the effects of these approximations become increasingly difficult to predict when applied to the interaction of multiple individually complex dynamic systems. Padfield [L] goes on to make the following point:

> It is convenient and also useful to distinguish between these two approaches [i.e. objective and subjective fidelity] because they focus attention on the two ends of the problem - have we modeled the physics correctly and does the pilot perceive that the simulation 'feels' right? It might be imagined that the one would follow from the other and while this is true to an extent, it is also true that simulation models will continue to be characterized by a collection of aerodynamic and structural approximations, patched together and each correct over a limited range, for the foreseeable future. It is also something of a paradox that the conceptual product of complexity and physical understanding can effectively be constant in simulation. The more complex the model becomes, then while the model fidelity may be increasing, the ability to interpret cause and effect and hence gain physical understanding of the model behavior diminishes. Against this stands the argument that, in general, only through adding complexity can fidelity be improved. A general rule of thumb is that the model needs to be as complex only as the fidelity requirements dictate; improvements beyond this are generally not cost-effective. [L, p. 53]

Requisite Fidelity. The above quotation poses the very relevant question of just how much fidelity is warranted for a given application. The objective must remain clearly in sight: to create an effective training environment, rather than merely a "realistic simulation". To this end, Randle and Sinacori [U, Ch. 11] have coined the term *training* (or *functional*) *fidelity* to characterize "the correspondence between the behaviors required for skilled performance in the aircraft and those behaviors developed by practice in the simulator." High training fidelity, although difficult to measure, would be indicative of a high degree of transfer of appropriate behavior from simulator to aircraft. In practice, direct tests of training fidelity (i.e. training effectiveness) are rarely accomplished. The specifications for simulators have traditionally been constrained by the presumption that the quality of the simulator is determined by the similarity of the device to the actual aircraft. The assumption has prevailed, often with the tacit encouragement of the simulator manufacturer, that increasing physical fidelity likewise results in increased training effectiveness. Randle and Sinacori [U, Ch. 11] further comment that:

> "By default, in the absence of these tests of functional fidelity, we insist on high physical fidelities, and more economical to forego training studies and the assessment of functional fidelity and to take the risk of

assuming a one-to-one correspondence between training efficacy and the physical fidelity of the simulator." [U, Ch. 11, p. 258]

This is certainly not the case. It has been shown that for selected tasks, improved training effectiveness may be realized in a simulator of lower complexity (i.e. reduced physical fidelity) [D], [F]. Furthermore, the incremental costs of increased physical fidelity may not be justified by similar increases in instructional effectiveness. At present, no specific methodology seems to be applied to the determination of the degree of fidelity required of a particular simulator. The state of the art in simulator requirements analysis is expressed well in the following observation:

> "oftentimes there was little correspondence between actual training requirements and training device functional capabilities. In fact, it often occurred that devices tended to drive the structure of training and that maximum fidelity capabilities available, rather than the minimum requirements for effective training, became the specification." [E, p. 7]

For example, motion systems are nearly universal on modern simulators, however ample evidence exists to show that complex motion systems do not necessarily yield improved training transfer [V, p. 336], [FF, p. 7.1]. Although pilots tend to believe that they rely heavily upon correct vestibular cues, the author has observed that in many instances pilots do not even notice when the motion system is turned off. At best, the motion system provides peripheral cues that enhance subjective fidelity. At worst, a mediocre motion system can increase susceptibility to motion sickness and reduce a student's ability to benefit from training. The actual validation of the costs versus benefits of motion for a given simulator application are rarely performed.

It is somewhat of a paradox that reduced physical fidelity, both in terms of subjective and objective fidelity, can yield enhanced training fidelity in some cases. The mistaken emphasis on "reality" undermines the value that can be realized through the addition "unrealistic" effects to facilitate training. Roscoe [V, p. 337] recommends the addition of visual effects such as velocity vectors, track lines, control force vectors, etc. to enhance training over what may be realized in actual flight. As a further example, some commercial flight simulation courses incorporate helicopter systems schematics into the visual system as an aid to teaching emergencies procedures. The ability to look "out the window" at the hydraulic system schematic, for instance, is far from realistic, but dramatically enhances training effectiveness. As a result of the sophistication of modern mission simulators, capabilities emerge which provide a unique training environment. Among the advantages realized through mission simulation, England [ref. D] cites the following:

a. the ability to train with active threats and/or multiple players in a mission environment;
b. fully reproducible conditions;
c. enhanced quantitative performance feedback;

d. enhanced teaching utilities, such as:
    i. debriefing stations;
    ii. record and playback of scenarios;
    iii. instructor-controlled players; and
    iv. replay from multiple points of view.

a. controllable training environment, in which gross weight, fuel consumption, handling qualities, etc. can be tailored;
b. no operational or airspace restrictions;
c. survivable in dangerous conditions; and
d. linkable to other simulators (frequently called *Distributed Interactive Simulation*).

The conclusion is implicit that in the interest of optimum training effectiveness a simulator use every means to stimulate pilots to behave optimally for their specific mission tasks, rather than to attempt to comprehensively replicate the experience of flight.

McIntosh and Popish [U, Ch 1] approach the issue of requisite fidelity differently, from within the discipline of instructional design. Three domains of human performance for aviation are defined: guidance and control, systems management and flight management. It is pointed out that guidance and control, the pilot's traditional "hands and feet skills", are no longer the weak link in the safety chain. Experience has shown that the last two domains – systems and flight management - are the most common causes of incidents and accidents, and therefore the areas most worthy of attention in training. They explain that, "emphasis is thus shifting from guidance and control, pilot-in-the-loop activities to that of the controller as communicator, decision-maker and executive." High objective fidelity is not a requirement for training in largely cognitive skills. Furthermore,

> "The exercise of honing of these capabilities is dependent not so much on simulation as dis-simulation, that is, pretending or playing the game in the interest of skill development and professional competency. Thus, the fidelity of interest in the near- and far-term will be that of environmental and operational fidelity in the creation of realistic, rich training scenarios. The training of intellectual performance does not require high physical fidelity; it requires comprehensive intellectual content and a full range of operational options." [U, Ch. 1, p. 8]

The foregoing discussion of training requirements evokes the definition of mission training detailed above. Although the term mission training is generally applied in a military context, there is considerable overlap with the concepts inherent in Cockpit Resource Management (CRM) or Line-Oriented Flight Training (LOFT), as they are applied in the civil aviation context. Both strive to create holistic scenarios in which cognitive and decision-making skills can be honed while mechanical skills are being exercised.

While training purely cognitive skills does not necessarily require high physical fidelity, most operational training is not that simple. In the context of mission simulation, the issue is further complicated by the requirements for fidelity among the myriad of players, systems, scenes and special effects evoked. If the aircrew are to be trained to make effective decisions in the use of complex systems, then those simulations must behave correctly. The overall fidelity requirements may be associated with the training tasks of the simulator, as depicted in Figure 2. In general, the more complex the mission simulation, the higher the requirements for fidelity of the constituent systems. Thus, it seems that a range of simulator applications as ambitious as those envisaged for the CH146 simulator require a relatively high degree of physical fidelity.

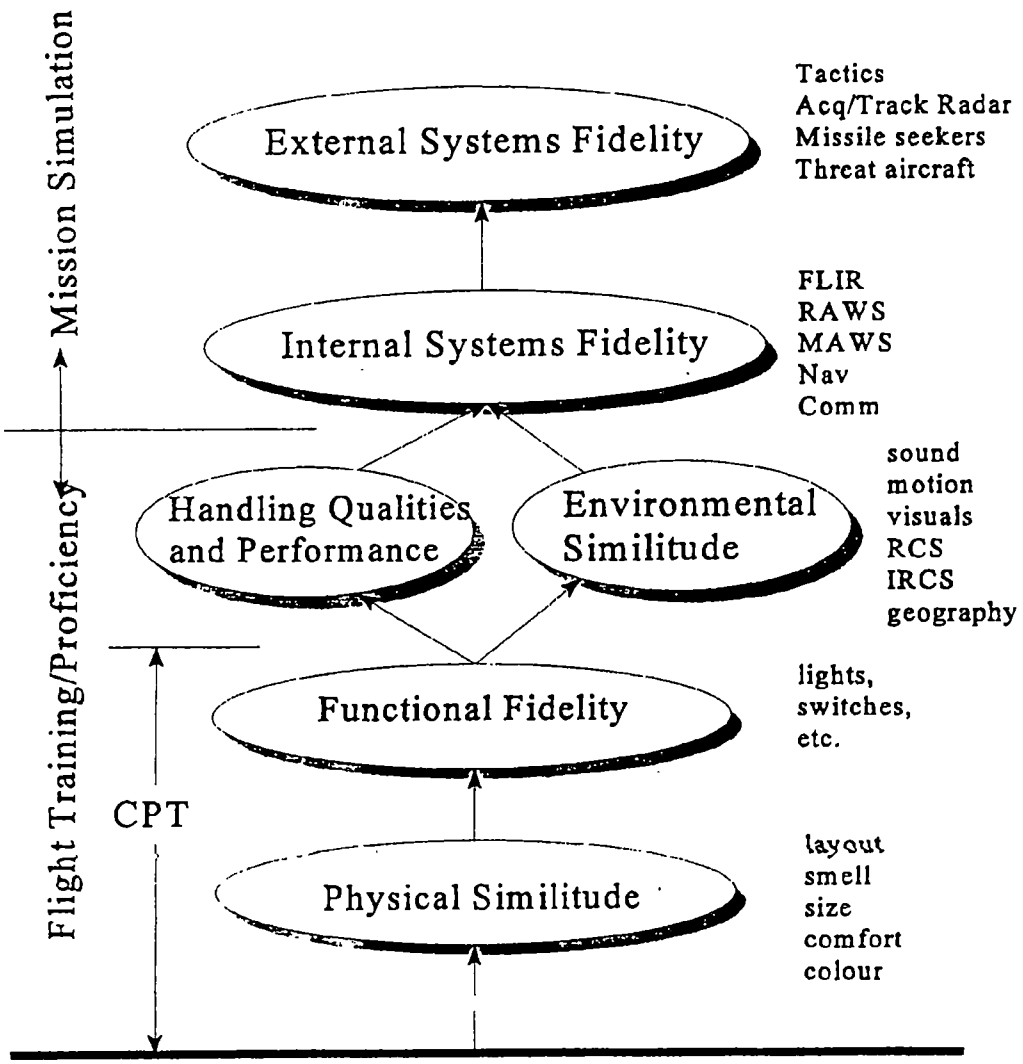

Figure 2
Hierarchy of Simulator Fidelity
[Reference DD]

PART III - VALIDATION OF SIMULATOR OPERATIONAL EFFECTIVENESS

The Requirement for Validation. Notwithstanding the widespread use of simulators for aircrew training, insufficient attention has been paid to the validation of training effectiveness [C], [U], [CC]. As a minimum, inappropriate use of flight simulator training will fail to reduce training costs. In the worst case, errors in technique introduced due to poor simulator training may cause accidents, as pilots transfer inappropriate learning into the aircraft. Although there is a tendency to equate limitations in training with poor fidelity, this association is often not warranted since every ground based training device, no matter the level of complexity, will have limitations in fidelity. The error, rather, is in the inappropriate application of the simulator. Since every flight simulator will have limitations, the challenge in effective training is to determine the specific applications for which a simulator should and should not be used. A flight simulator may be considered to have a specified training envelope, analogous to the flight envelope of an aircraft. In the case of the aircraft, the envelope is defined as the set of flight conditions in which operations may safely be conducted. In the case of a simulator, it is the set of procedures and maneuvers which provide positive training transfer to the airborne environment. In the interest of optimizing the utilization of a simulator for training, an essential step is the identification of this "training envelope", so that it is clearly identified which tasks can be taught in the simulator, and equally importantly, which tasks must *not* be taught in it. Dohme [U, p. 103] notes however that, "surprisingly, little research has been done to functionally analyze the contribution of simulator training to the overall flight training mission".

The necessity of validating the training envelope of the simulator becomes clear in the development of an instructional syllabus. The understandable desire to realize a high utilization rate for the simulator can easily drive the syllabus into areas in which real training may not occur. Feedback from pilots under instruction is rarely helpful in avoiding this trap. In the author's experience, pilots seem to respond most favorably to the slope of their own learning curve. Even when the simulator does not behave at all like the aircraft, they often comment favorably on the exercise when a situation is handled well. When an exercise is handled poorly, pilots often just try harder. Compensation is a highly evolved and subconscious process for most trained pilots. Randle and Sinacori [U, Ch. 11] call this *dissimulation*, and point out:

> "When we are in a simulator it is easy to dissimulate and to pretend we are flying the simulated aircraft. If the training is intense, and if we are being evaluated for our ability to handle several unpracticed emergency situations, we soon forget that it is a simulator. If we do well, we applaud the simulator for its ability to prepare us for the aircraft; if we do poorly, we say the simulator is nothing like the aircraft." [U, Ch. 11]

Simulator instructors must be prudent to avoid reinforcing this behavior. The best approach is to identify and avoid exercises in which the simulator has low training fidelity.

Simulator Effectiveness Evaluation. The classic technique used to evaluate the training effectiveness of a simulator is the Transfer of Training (TOT) study [Q] [CC]. The simplest transfer of training analysis methodology requires an experimental group of simulator-trained pilots and a control group of pilots who were initially trained only on the aircraft. Both groups would be trained to proficiency standards in the aircraft. Table 1 lists performance metrics that can be used to measure proficiency. Such an experiment would allow comparison of the performance of the simulator-trained students against those who did not receive training in the simulator, and might lead to conclusions as to whether the simulator provided any net advantage to pilots when they begin their flight training.

Quantitative Metrics	Qualitative Metrics
repetitions to proficiency errors to reach proficiency errors per trial/task errors on first exposure attrition rate training dollars to proficiency	Instructor's grades/comments check ride scores

Table 1
Pilot Performance Metrics [C]

Such a methodology is limited in that it only measures the effectiveness of using the simulator as tested versus not using the simulator at all. A far more difficult problem is resolving variations in training effectiveness as a result of changes in fidelity, syllabus design or instructional technique. Confounding factors in such a study might include: the amount of simulator training, the initial experience level of the trainees, task complexity, and trainee motivation [A]. A simple variation upon the experimental design would involve several experimental groups, each receiving incremental amounts of simulator training prior to flight training to proficiency standards. Figure 3 depicts sample data from such an experiment. The graph illustrates that while simulator training reduced the requirements for subsequent flight training, each increment in simulator training yielded diminishing savings in aircraft time. However, such data are not sufficient to determine the optimum amount of simulator training required. Cost data are also required. Figure 4 depicts the total cost of training and the cost savings (with respect to zero simulator training) for each experimental group. From such data one can determine that, for the sample data, approximately 15 to 20 hours of simulator training resulted in minimized training costs.

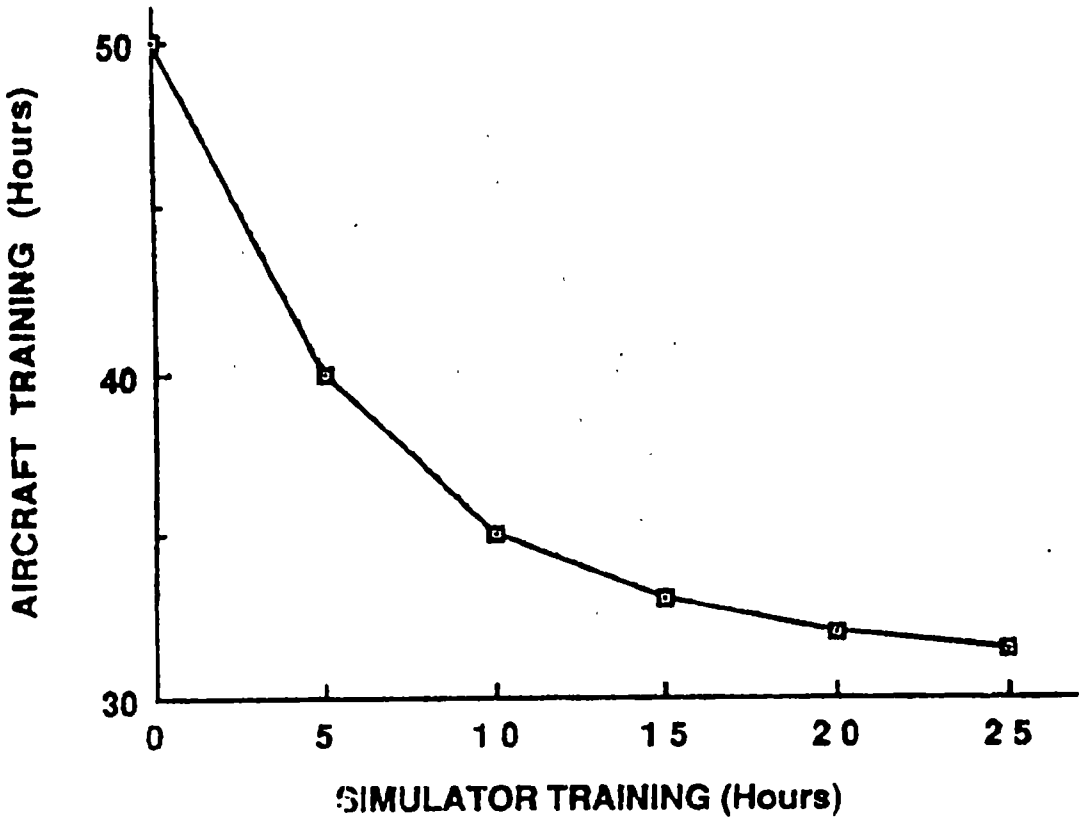

Figure 3
Sample Data: Aircraft Training Requirements as a Function of Simulator Exposure
[adapted from Reference Q]

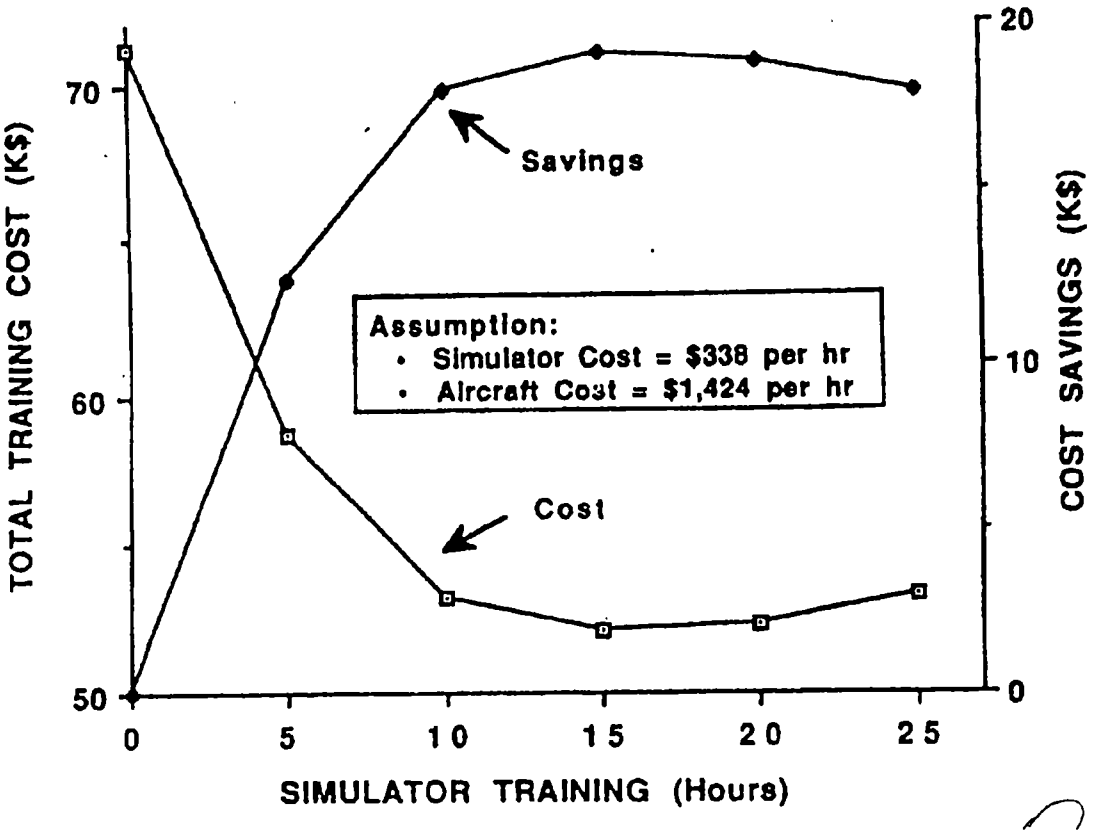

Figure 4
Sample Data: Total Training Costs/Savings as a Function of Simulator Exposure
[adapted from Reference Q]

Although well known, there are several limitations of the classic transfer of training design. Firstly, it requires that a control group of pilot trainees be denied training in the simulator in order to conduct the experiment, and training supervisors can be understandably reluctant to authorize such a plan. A further limitation of the method is that it is limited to analysis of the simulator for skills-acquisition training. The utility of this scheme for determining the effectiveness of the simulator for either proficiency checking or skills-sustainment training is limited. Also, the above method yields only a composite measure of the overall simulator training effectiveness, and while it could be used to determine *how much* simulator training was warranted, it would not offer any insight into *what* simulator training was effective. It is unlikely that all training conducted in the simulator had identical training transfer, and indications of a moderately effective simulator can result from some very positive training transfer that is offset by some very negative training transfer. Furthermore, *any* negative training has implications for the cost effectiveness of the training program, not to mention potential safety concerns. The above methodology is often called a "forward transfer study", in that it seeks to measure the extent to which skills learned in the simulator transfer to the aircraft. A variation upon this methodology, called a "backward transfer study", seeks to ascertain the training effectiveness of individual maneuvers, and is useful in assessing the constituent parts of a training syllabus [Q]. The procedure involves the selection of an experimental group of pilots who are experienced and proficient at the maneuvers under evaluation, and who have had little or no exposure to the simulator. The pilots are tasked to fly the maneuvers in the aircraft and are scored for performance. A variety of performance metrics can conceivably be used. The maneuvers are then repeated in the simulator, and the pilots are again scored for performance upon initial exposure to the simulator. It is important that the assessment be based upon *initial* exposure, usually inferred to mean the first three repetitions of the maneuver, since pilots can adapt to the simulator in a very short time [Q, p. 83]. The assumption underlying this method is that if the skills required to perform the task in the simulator are the same as those required in the aircraft, then initial performance should be high. Alternately, if a trained pilot has difficulty achieving satisfactory initial performance in the simulator, it is indicative of problems with the simulator. Figure 5 shows sample data for a backward transfer study. While the performance ratings themselves form the core of the data, the pilot's comments also form an invaluable aid in determining specifically what was wrong with the simulator. Although evaluators should be circumspect in considering pilot judgment about a simulator, a consistent criticism regarding variance of technique between the aircraft and the simulator must be taken seriously. In this way the simulation of individual maneuvers can be honed and improved.

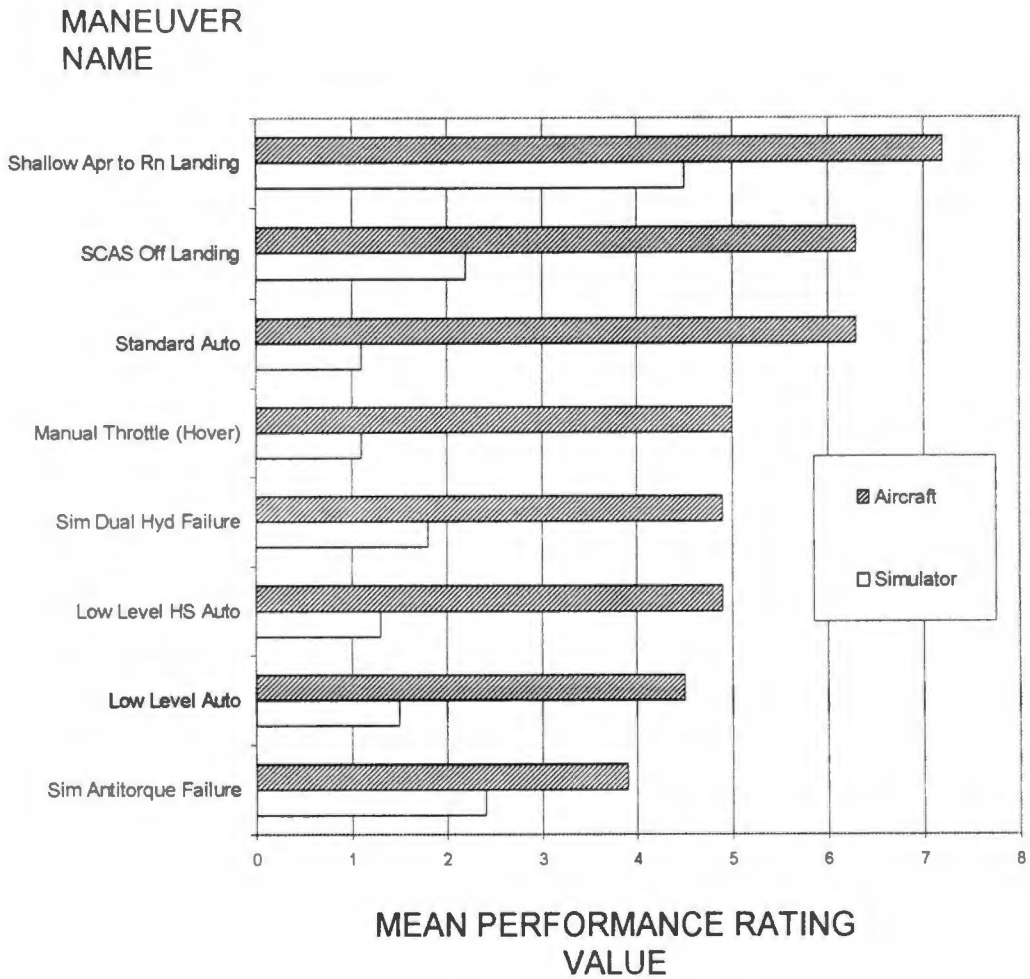

Figure 5
Sample Data: Simulator Backward Transfer Study
[adapted from Reference Q]

Context of Simulator Effectiveness Validation. Traditional measures of simulator effectiveness focus extensively on the simulator itself as the item under evaluation. In its proper context, the simulator is a device which is a part of an overall training program, rather than an end in itself. A study by Hayes and Singer [U] points out the importance of the overall training program in determining the effectiveness of the simulator:

> "No matter how a training device is designed, no matter what its level of fidelity, it will not be an effective trainer if it is not used properly. Likewise, it is not possible to design an effective device if the task to be trained is not understood and if the context of the instruction is not compatible with the training device. A total training system perspective must guide training development to insure that the most effective training strategies are followed." [U, Ch. 3, Ref. 16]

The validation of the effectiveness of a simulator for training must ideally be accomplished in the context of the total training system, including the aircraft, academic instructional syllabus (including classroom instruction, computer-based training, etc.), cockpit procedures trainers, the in-flight instructional syllabus and other training resources. In particular, the assessment of the effectiveness of the simulator must consider these and other alternative training strategies. In spite of the ostensibly high level of fidelity offered by a mission simulator, indications exist that a reduced fidelity training environment may in some instances actually enhance training transfer, owing to the elimination of extraneous cueing [D]. In the analysis of the quality of training offered by a simulator, the question must be asked whether the same training might be better conducted elsewhere, and how such a choice might affect training costs.

Validation of Fidelity Outside the Flight Envelope. The techniques for validating the objective fidelity of a flight simulator are specific and well documented. This process involves the comparison of simulator behavior to aircraft data for a comprehensive range of stability and control and performance parameters. The amount and type of source data for the aircraft are necessarily limited, and place bounds on the scope and effectiveness of any objective fidelity assessment [Y]. It is often the case that the training intended for a flight simulator goes well beyond the normal flight envelope of the aircraft, and consequently little or no objective data exists to validate the performance of the simulator in these regimes. Three possible examples include emergencies such as loss of tail rotor thrust, main drive shaft failure or transmission seizure. In the case of such simulated effects, there is currently no means to validate that the simulator behaves exactly as would the aircraft. In lieu of precise replication of aircraft behavior, a degree of latitude exists in the subjective tuning of these effects. This procedure must be approached with caution. Fig. 6 depicts the author's tuning/validation methodology, as employed during the acceptance testing of the CH146 simulator. In many cases there is a necessity to refine a particular simulated effect subjectively, and there is a degree of risk in deviating from exact aircraft

behavior. In these cases, the critical determinant is the utility of the simulation with regard to positive training transfer; the "programming" of the student taking the place of objective fidelity in defining the suitability of the effect. In the absence of data to validate the effect, it must be understood that use of the simulation was based on the assumption that training in order to stimulate some specific desired behavior may be better than no training at all. For example, little or no engineering data exists for the characteristics of the aircraft following departure of the tail rotor and gearbox. In lieu of tuning for objective fidelity, the decision might alternately be made to tune such that the student is taught to immediately lower the collective and maintain airspeed. In such a case, use of the simulator for training would be based not on the quality of the stimulus (i.e. fidelity) but on the appropriateness of the response, in one's best estimation. Given the residual risk inherent in this approach, it is recommended that training only be conducted in these cases where such training is deemed essential.

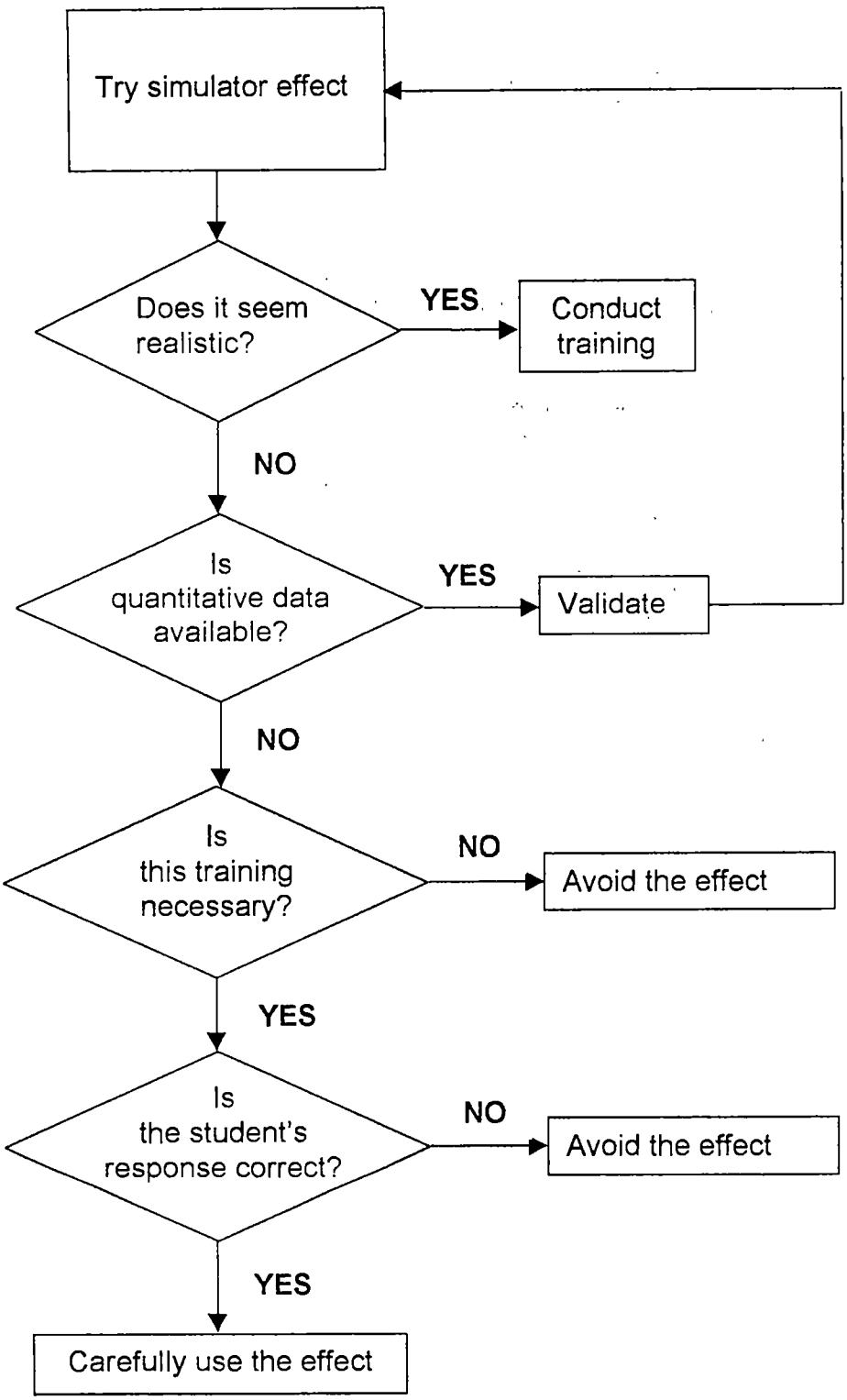

Figure 6
Simulator Subjective Tuning Methodology

Simulator Instructional Technique. The paradigm for the conduct of simulator-based training is flight instruction. The implicit assumption is that the ideal environment for perfect training "realism" is the cockpit of an actual aircraft. In a sense, the aircraft becomes the denominator of the "realism equation". This is not necessarily true. Larsen et al. argue that "beyond ab initio training, the aircraft is a poor training device; it is uneconomical, inefficient, and unsafe, and is a poor place in which to learn and assimilate new material and to practice newly acquired skills" [U]. Whether desirable or not, validation of a simulator's effectiveness with reference to actual flight is ingrained in experience. It is easily forgotten that airborne instruction is subject to numerous constraints and compromises, few of which are necessary in a simulator-based lesson. A simulator allows almost complete "reality management" of the instructional environment, and limitations such as weather, noise, fuel consumption, airspace restrictions, etc. need not interfere. Table 2 lists considerations for tailoring the simulator instructional environment for optimal training effectiveness, and are taken from the author's experience. It should be noted that not all of the techniques suggested below need apply to every simulator lesson. Ab initio or conversion students should be expected to conduct start and shut-down procedures, for example. However, the effectiveness of the training can indeed be enhanced by deleting from the exercise those activities that are not specific training objectives. Just because something is "realistic" in actual flight does not imply that it contributes to training. In the event, effective simulator-based learning can be considerably different from in-flight instruction, and an instructional technique must be adopted to optimize the advantages of the simulator environment.

Airborne Instructional Technique/Constraint	Simulator Instructional Alternative
Making configurations changes is time consuming and difficult, so aircraft are usually flown "as is".	Aircraft configurations may be preset to allow students to experience a variety of handling qualities and performance.
Time is necessarily spent conducting start and shut-down procedures.	Missions may be commenced with the aircraft prestarted or "quick started".
Time is required to transit to the training area.	The mission may be commenced with the aircraft pre-positioned at any desired location.
There is limited fuel available	Routine refueling or fuel freeze may be selected.
The occasional requirement exists to accommodate undesirable weather or lighting conditions.	Missions may be conducted at any hour with simulated weather tailored to mission requirements.
Training is restricted to specified weather minima for safety.	Training may be conducted in any weather conditions, and weather may be controlled in order to challenge students as desired.
Constraints on training for emergency procedures are required in the interest of safety.	Crews needn't pretend to actuate switches, or overshoot from simulated emergencies. Crashing can be very instructive.
Debriefing of crew errors must be delayed to more appropriate circumstances.	Missions can be frozen or entire sequences can be replayed immediately.
Feedback to the student is limited to the subjective impressions of the instructor.	Feedback can include "record and playback" features, multiple repetitions and detailed review of performance on a debrief station.

Table 2
Comparison of Aircraft versus Simulator Instructional Techniques

PART IV - OPERATIONAL EVALUATION OF THE CH146 MISSION SIMULATOR

BACKGROUND

General. In conjunction with the acquisition of the CH146 Griffon Utility Tactical Transport Helicopter (UTTH), the Canadian Forces contracted for delivery of a full mission flight simulator to supplement operational training. The simulator was delivered to 403 Helicopter Operational Training Squadron at CFB Gagetown in July 1995 and limited operational training began in September 1996. Annex A is a detailed system description of the simulator.



Figure 7
The CH146 Griffon Utility Tactical Transport Helicopter
[courtesy Canadian Forces Photo Archives]

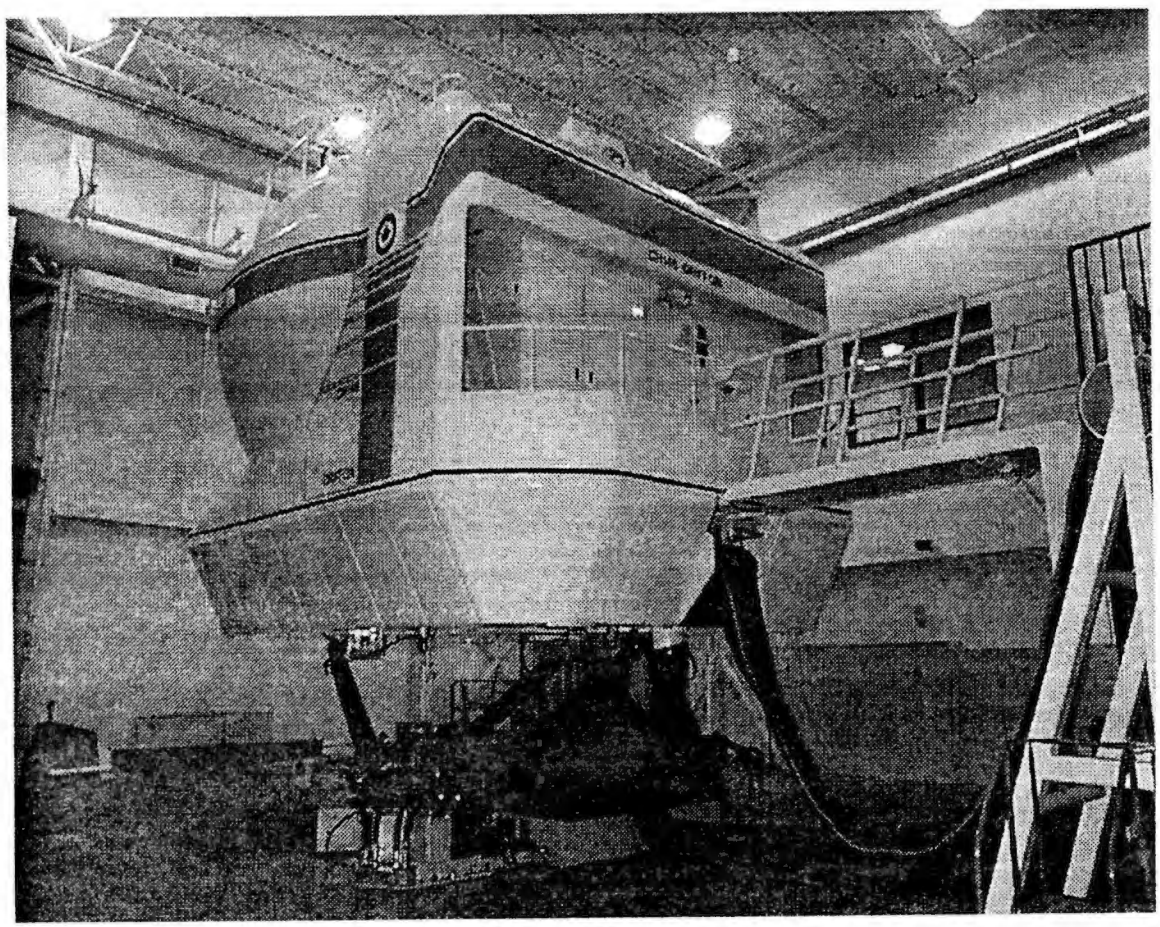

Figure 8
The CH146 Mission Simulator

Acceptance testing of the simulator prior to initial operational employment consisted largely of functional testing conducted in accordance with the manufacturer's Acceptance Test Plan (ATP). These tests involved a thorough check-out of the simulator's systems and rectification of malfunctions. The ATP's did not, however, address questions related to the effectiveness of the simulator as a training tool. A steep learning curve was experienced in the implementation of the CH146 mission simulator, and an operational test and evaluation (OT&E) program was a requirement to determine the operational effectiveness of the simulator, and as a means to document the ongoing improvements to the simulator for the training role. This section details the results of the Operational Test and Evaluation program for the CH146 mission simulator.

CH146 Development and Acceptance Process. The acceptance process for the CH146 mission simulator began with in-plant acceptance at the CAE Ltd. facility in Montreal. From approximately November 1994 until June 1995, a detachment of Canadian Forces personnel was stationed at the factory to conduct comprehensive functional checks of the simulator. The detachment consisted of test pilots and flight test engineers from the Aerospace Engineering Test Establishment (AETE) and instructor pilots from 403 Helicopter Operational Training Squadron. Administrative support was provided by the Project Management Office, Canadian Forces Utility Tactical Transport Helicopter project (PMO CFUTTH). The acceptance process consisted of the execution of the Acceptance Test Procedures (ATP's), which were developed by the Contractor, and constituted a thorough system-by-system checkout of the simulator. The tests were designed to assess both simulator functionality and fidelity, based on aircraft source data supplied by Bell Helicopters Textron Incorporated (BHTI). For functional tests, each step in the ATP's included explicit pass/fail criteria. Testing for fidelity was somewhat more complex. Where flight test data was available, CAE constructed the ATP's with reference to selected flying qualities and performance plots; the tests consisting of a computer-generated graphical overlay of aircraft versus simulator response. In selected cases, test team personnel opted to reproduce the aircraft data conditions with manually flown inputs. In other cases, the tests were based on subjective input from the test team. Such exercises in "subjectively tuning" the simulator, as it came to be called, were frequently relied upon to supplement quantitative data. This process must be understood to appreciate the developmental history of the simulator. As outlined earlier, it is in the nature of ground-based simulation, with its inherent limitations in motion and visual system fidelity, that deviations occur from perfect aircraft-simulator similitude. As a consequence, the near-perfect implementation of aircraft flight data, experienced in a simulator environment, can result in evidently objectionable flying qualities. Subjective input during the development/acceptance process was an accepted means to moderate the computer model in the interest of optimum balance of fidelity, and this technique was applied often during the development of the CH146 simulator. As well, tuning was relied upon in cases where quantitative data were not available, such as specific subjective visual or sound effects, or very subtle aircraft-specific cues, for which the manufacturer relied upon pilot experience.

Throughout the acceptance process, deficiencies were logged in a common database, accessible to both CAE and DND personnel. A number of deficiencies remained outstanding at the time of delivery of the simulator to Gagetown, and a second phase of on-site acceptance was planned. As a part of this second phase, AETE conducted a limited fidelity assessment of the simulator [Y]. Owing to operational pressures to commence simulator training, their evaluation was limited to a thirty day period during which they were given dedicated access to the simulator, with the intention of conducting a quantitative comparison between simulator and aircraft data. The evaluation focused on handling qualities and performance in the interest of contractual specification compliance, and was centered on selected outstanding deficiencies.

Following completion of the acceptance testing, an operational evaluation was conducted by the Land Aviation Test and Evaluation Flight (LATEF).

OBJECTIVES

General. The general objective of the operational test and evaluation of the CH146 simulator was to assess the operational capabilities and limitations of the simulator to support 10 TAG's training requirements.

Specific. The following specific objectives were addressed:

a. to document observations related to the effectiveness of the simulator for training;

b. to determine the logistical and support requirements in support of mission simulation;

c. to review the manning requirements for simulator instructors;

d. to comment on the merits of the simulator as an instructional tool, and to determine any simulator-specific training requirements for instructors; and

e. to provide feedback to instructional staff in the process of syllabus development.

Annex B details the test matrix for the OT&E of the CH146 simulator, and is excerpt from the OT&E Test Plan [AA].

METHOD

This evaluation was composed of the following items:

a. participation as an observer during scheduled simulator training, including POC training and recurrency training;

b. participation in the CAE IOS Instructor's Course;

c. conduct of selected operational missions in the simulator with qualified aircrew;

d. interviewed SAS Flight personnel to gather experiences and observed deficiencies;

e. reviewed outstanding deficiencies as listed in the simulator deficiency database; and

f. conduct of functional and ergonomic evaluation of the IOS console and debrief station interfaces.

Qualitative assessments of the performance of the simulator and its systems included the assignment of deficiencies, conducting in accordance with the standardized deficiency classification, detailed in Annex C.

RESULTS AND DISCUSSION

General. The following paragraphs list specific observations and deficiencies documented in the conduct of the combined acceptance and operational testing of the CH146 simulator. The observations in general relate to deficiencies which would restrict or undermine the training effectiveness of the simulator.

FUNCTIONAL UTILITY

Height Perception. The height perception of personnel undergoing simulator training was evaluated subjectively during various mission tasks. The apparent eye height of the simulator made itself evident to almost every student and test subject on initial exposure to the simulator. Upon entering the simulator, with the ownship (i.e. the simulated helicopter) on the ground, most trainees felt that their eye position was too high. Common responses included comments such as, "are we really on the ground?", and "I feel like I'm in a Sea King". Initial estimates of eye height ranged from eight to fifteen feet AGL. Students were subsequently queried regarding their estimate of skid height during various phases of flight. Hover tasks showed a highly increased reliance on the radar altimeter, and hard or unintentional landings were common in the first few hours in the simulator. Student pilots, who are taught to hover at a four foot skid height in the aircraft, showed a considerable variance in hover heights in the simulator; hovering at heights from approximately two to ten feet in the simulator was not uncommon. In forward flight, height perception was similarly impaired, with forward flight altitude errors frequently exceeding 300 feet for daylight visual tasks. The manufacturer advised that the degree of texture in the visual scene was optimized to facilitate training at specific altitude ranges, with more texture in areas where low flying or landings were anticipated, such as selected " high definition confined areas". Errors in height perception were most acute in areas of relatively reduced terrain texture. Dohme [ref. U] refers to a study by Hamilton and Wightman in which aviator's ability was assessed to maintain altitude below 25 feet at an airspeed of 40 knots. The study determined that the inclusion of trees in the visual scene increased height control somewhat, but that more detailed surface texture resulted in a significant improvement in the control of altitude. The poor height perception cueing of the simulator will distract students and will interfere with the utility of the device for most simulator training applications. Students learning initial aircraft handling in the simulator will exhibit altitude control errors when transitioning to the aircraft. The poor height cueing of the simulator was unacceptable and must be improved.

Range Perception. The performance of pilots under training to discern the range to objects in the visual database was observed during numerous low-level flight scenarios. In general, pilots expressed difficulty ranging objects, both in the near field for obstacle avoidance and in the far-field during navigational tasks. The degradation in range perception was observed during instances such as "ground rush" during autorotative landings, and during maneuvering in confined areas, where increased

aircraft displacements and cyclic workload were observed to maintain separation from obstacles. This difficulty can be attributed to the difference in the relationship between visual resolution and distance in the aircraft versus the simulator. Under real-world conditions, the resolution of detail on objects increases gradually and linearly with decreasing distance, which in combination with normal stereoscopic vision, facilitates depth perception. In the simulated visual scenes, resolution of detail did not appear to be linearly related to distance, but was constrained rather by the maximum number of pixels that could be processed by the visual system. Aircrew will experience difficulty in accomplishing tasks requiring range perception routinely performed in flight, limiting the effectiveness of the simulator for a variety of operational tasks. The limited range perception available with the CH146 simulator visual system was unsatisfactory. It is recommended that simulator instructors assess mission scenarios for situations in which deficient range perception will interfere with performance, and either modify the scenarios or assist the crew, as practicable. Instructors should be likewise aware not to reduce crew performance evaluations as a result of errors that could be attributed to deficiencies in the visual system.

Autorotative Landing Flight Performance. The flight performance of the simulator in the conduct of autorotative landings was evaluated subjectively during a wide variety of simulated flight profiles. In all cases, the simulator exhibited significantly increased collective cushion effectiveness and longer post-flare duration of flight, as compared to flight experience in the aircraft. In one exercise, the ownship was flown in the Gagetown database toward the 403 Squadron hangar from the direction of the simulator building at 80 KIAS at approximately 30 feet AGL. The winds were calm. Approximately half-way between the buildings (at an approximate range of 200 meters from the landing pad), and well-below the height of the hangar, the throttles were both retarded to idle. Following entry to autorotation, the ownship was flared over the hangar and the landing was extended to a point beyond the helipad. During the application of collective pitch, the landing could be delayed until approximately 60% rotor RPM. No reduction in control response was evident at this highly decayed rotor speed. Autorotative performance and handling of a CH146 are significantly short of permitting such a maneuver to be accomplished. The autorotative landing flight performance of the simulator will encourage pilots to overestimate the capabilities of the CH146 during an actual power-off landing, resulting in aircraft damage and personnel injury. The autorotative landing flight performance of the CH146 was unacceptable. Ref. A found the autorotative performance of the simulator likewise deficient. It is recommended that further aircraft data be gathered to validate and correct the performance of the simulator in autorotative landings. It is further recommended that training in autorotative landings in the simulator be restricted to those conditions which may be validated as realistic, in order to reduce the effects of negative training transfer. It is further recommended that crews be briefed regarding the limitations of the simulator's autorotative performance model.

Crash Threshold Exceedance. The crash threshold of the simulator was observed in many instances during simulator training. In the event that the program detected an

exceedance of a critical flight parameter, such as normal acceleration, airspeed or touchdown descent rate, the simulator was designed to emulate a crash response. In these cases, the visual scene would project a red overlay on the exterior view. In the case of a crash upon landing, the simulator would emulate roll-over behavior of the helicopter. The indications of crash threshold exceedance were dramatic, giving pilots the impression that the outcome of the maneuver was catastrophic. The imagery was frequently described as disorienting. On occasion, the crash threshold was found to be obtrusive, with exceedance indications occurring during relatively benign flying. In particular, crash threshold exceedance occurred during running landings at very low, and frequently visually undetectable, sideslip angles. In other instances, crash threshold exceedance occurred following landings at what subjectively seemed to be easily survivable rates of descent. During routine training missions, pilots will be unable to conduct emergency simulations to touchdown, such as tail rotor control malfunctions, without experiencing crash threshold exceedance. The crash threshold settings of the CH146 simulator were unsatisfactory. It is recommended that an investigation proceed, in coordination with the Contractor, to validate the settings for crash threshold exceedance, and that less obtrusive settings be installed, if practicable. In the interest of giving crews improved feedback regarding the outcome of their maneuvers, it is further recommended that the visual indications of crash threshold exceedance be graduated, to yield several levels of incrementally more dramatic indications at larger levels of exceedance.

Ground Contact Effect. The ground contact dynamics of the simulator were evident during touchdown of the ownship with the motion base activated. In comparison to a CH146 over a similar type of surface, the ground contact model was very rigid and jarring, and gave the impression of a hard landing even at very low rates of descent. The cueing, in both the motion and visual systems, stimulated the pilot to moderate or modify the control strategy during landing in an effort to soften the touchdown. The resulting control strategy was unlike that used in the CH146 and evidently effected performance during touchdown for the majority of pilots. Such a variation in technique was an evident case of negative training transfer from the simulator. Pilots who transition to the CH146 through simulator training will use unnecessarily high control activity on landing, and will be averse to employing the aggressive touchdown techniques that are common to tactical landings. Pilots will take longer to train to proficiency on the aircraft. Furthermore, the repeated hard contact with the surface undermined the pilots confidence in the simulation. The ground contact effect simulation was unsatisfactory and should be corrected.

Cockpit Ambient Lighting. The cockpit lighting of the CH146 mission simulator was observed in the conduct of numerous day and night mission scenarios. All interior lighting and controls were fully functional, and replicated the arrangement found in the CH146. During daylight simulations, the ambient light level in the cockpit was found to be significantly dimmer than real daylight, owing to the low overall level of illumination provided by the visual system projectors. In compensation, all cockpit lighting was routinely turned to full intensity. As well, a series of fiber optic lights

were hidden in the forward, overhead cockpit structure. These lights were designed to render the interior ambient lighting brighter and more uniform. In spite of these efforts, much of the cockpit interior remained in shadow. During daylight mission simulations, aircrew will have difficulty reading maps and finding equipment in the darkened cockpit. The low interior ambient light level during daylight simulations was unsatisfactory.

INSTRUCTIONAL UTILITY

Simulator Field of View. The field of view from the simulator cockpit was frequently commented upon unfavorably by aircrew undergoing initial and recurrent training. During proficiency flying involving circuit patterns, crews became uncertain of their location with respect to the landing point once it had passed beyond the edges of the visual system. One crew became lost on the downwind leg, requiring the assistance of the IP, using the tactical situation display (TSD) on the IOS, to locate the landing point. Crews will adopt inappropriate techniques to compensate for restricted field of view during confined area recce patterns. During circuits, crews will adopt unrealistic techniques to orient themselves, resulting in suboptimal training transfer to the aircraft. The field of view of the simulator visual system was unsatisfactory. It is recommended that students be apprised of the requirements to modify normal techniques to accomplish circuits in the simulator, and that the simulator IP be apprised of the potential requirement to verbally assist the crew in locating objects beyond the boundaries of the visual system. Crew performance assessments should not be degraded due to navigational errors or transient loss of situational awareness resulting from limitations in the simulator field of view.

Simulator Use for Start Procedures. The CH146 simulator was used to teach start procedures and cockpit checks to students on the POC course. Of the sixteen lesson plans that constituted the POC syllabus, the first two were devoted to learning cockpit procedures. Such lessons consisted of a full dress rehearsal of normal aircraft start-up procedures, with the motion, visual and sound systems engaged. There is reason to believe that such a comprehensive simulation was suboptimal use of the simulator. Reference U points out that:

> "It has been demonstrated that training devices that are low in physical fidelity can nonetheless be effective for teaching procedures. Prophet and Boyd found that aircraft-procedures training in a cockpit mock-up made of plywood, photographs, and dowel rods transferred to an aircraft as well as did corresponding training in a high physical fidelity device. Photographs of cockpit switches in the mock-up symbolized the real switches in the aircraft, and the symbolic process of pretending to reposition those switches was just as useful when learning to perform cockpit procedural tasks and their sequences as when the tasks were trained in the aircraft." [U]

The above quotation is intended to point out that not all training benefits from high fidelity. In fact, there are indications that in some circumstances use of a high fidelity simulator may actually reduce training effectiveness. Reference D shows that for simple procedural training tasks, transfer of training is enhanced by selectively low fidelity, due to reduction of extraneous stimulus upon the trainee. Conducting start procedures in the simulator will unnecessarily occupy available simulator resources, without justifiable improvement in transfer of training. The introduction of a cockpit procedures trainer (CPT), as was being considered, would provide an improved instructional environment for procedures training over the simulator. It is likely that other types of training, such as IFR procedures, do not require the fidelity of the full mission simulator, and may be effectively conducted in a CPT as well. It is recommended that a cockpit procedures trainer (CPT) be acquired to supplement the CH146 mission simulator for selected training tasks. Based on experience with the CH146 mission simulator, it is further recommended that a follow-on training transfer study be conducted prior to the operational implementation of the CPT to validate the CPT's range of effective training.

Map Reading. Aircrew performance in the conduct of pilotage was observed during both routine recurrent training and several dedicated simulator evaluation missions. Map reading was performed by both day and night in the Gagetown visual database using a simulator-specific 1:50,000 scale tactical map, and in one scenario during day flying in the Arctic visual database using a standard 1:500,000 scale Alert VFR Navigation Chart (VNC). A comprehensive assessment of map reading in the other visual databases was not feasible, owing to the lack of simulator-specific maps at the time of the assessment. Within the scope of the evaluation, experienced aircrew were consistently able to conduct realistic and reliable navigation with reference to the map and visual features in the database. In practice, the very specific shapes of features in the database, such as distinctive polyhedral patterns to tree lines, rivers and roads, made the identification of ground features somewhat easier than real flight when using the simulator-specific maps. The techniques of pilotage that are applicable in flight, such as "watch-map-ground" navigation and map orientation gave reliable results in the simulator. Simulator scenarios requiring experienced aircrew to conduct accurate map navigation may successfully be conducted in the simulator. The fidelity of the simulator visual databases to support pilotage tasks was satisfactory. However, the utility of the simulator to conduct this type of skills-sustainment training for experienced aircrew does not guarantee that the simulator would be useful for skills development training. It is recommended that further assessments be conducted to validate the effectiveness of the simulator to teach initial tactical map reading to inexperienced aircrew.

Visual System "Screen Saver" Mode. The visual system incorporated a "screen saver" type function which was designed to black out the visual system if the generated image has not varied for fifteen minutes. The system was designed to avoid damage to the image generators whenever the simulator was left powered but unattended. Recovery of the visual scene required the instructor to manually select the Visual System button

to On, on the Visual Controls page of the IOS. In the course of training missions, frequent procedural operations such as engine starting or instrument checks exceeded this duration, with the result that the crew experienced a momentary unexpected loss of visual cues. During one mission the visual system went black following the start sequence as crew was preparing to lift the helicopter into the air. This effect caused distraction to both the instructor and crew, and increased the workload on the instructor. As well, the "screen saver" feature interfered with subjective realism of the mission, and detracted from mission training value. The behavior of the visual system "screen saver" was unsatisfactory. It is recommended that a means be incorporated to lengthen or disable this feature during training missions. Alternately, the bypass function of the screen saver could be modified to include displacement of the flight controls, a seat sensor, IOS movement or a cabin motion detector.

Instructional Technique. Just as being a flight instructor requires specialized skills and training distinct from operational piloting, effective instruction in the simulator requires the instructor to learn those characteristics of the simulator that serve to optimize it as an instructional environment. At 403 Squadron, all simulator IP's had previously been CH146 flight instructors and retained currency in the CH146 while serving in the simulator. As well, each underwent a short course of instruction to introduce them to the basics of the simulator's instructional utilities. In this way, they could combine experience at flight instruction with understanding of the use of the simulator's systems. Experience showed, however, that this combination of skills did not guarantee effectiveness at instruction in the simulator. Initially, in the interest of "realism", instructors were encouraged to treat the simulator identically to an aircraft. Crews were required to wear helmets, gloves and safety vests, and to conduct start-up procedures and preflight checks as they were done in the aircraft. This approach had benefits and disadvantages. It is wise to respect the limitations of the simulated aircraft, so as not to habituate crews to exceedance of the aircraft's operational limitations, however the simulator possessed significant benefits over the aircraft as an instructional tool that would be severely suboptimized if training were conducted with the same inherent constraints as the aircraft. Since the simulator did not exhibit many of the restrictions that apply to a real aircraft, the simulator allowed considerable flexibility in instructional technique, letting the instructor tailor the experience to the learning style of the individual student. Unfortunately, the potential of the simulator in this regard was not self-evident to the instructional staff, and simulator training was frequently patterned on instructional experience in the aircraft. For example, emergency procedures conducted in the simulator were frequently performed to the degree of completion common in airborne training. During simulated emergencies, instructors rarely required students to actually transmit "Mayday" messages or select emergency settings on the transponder. Similarly, simulations of active ground threats (e.g. radar warning receiver annunciations) commonly elicited mention of the use of countermeasures, but crews frequently refrained from actuating the associated switches, ostensibly because they had become accustomed to *not* doing so during flight training. A survey of instructional sorties in the simulator showed infrequent use of such features as flight freeze, prerecorded demonstrations, or the record and

playback utility. To a minor extent, these shortcomings could be attributed to deficiencies in the usability of the interface, however instructors did not appear to appreciate the instructional advantages of many of these features. Effective instruction in the simulator required an instructional technique optimized for that environment, and stood to benefit from a formal analysis of the instructional methodology employed. Clearly, the "helicopter in a box" paradigm did not adequately exploit the capabilities of the simulator. Instructors who conduct training in the simulator without prior training in its use will not be prepared to exploit the unique instructional advantages of the device. It is recommended that training in appropriate instructional technique for flight simulators be required prior to conducting training in the simulator.

Initial Conditions Definition. The IOS software facilitated the definition of desired initial conditions for lesson plans. These functions were accessed via the IOS console. Data included ownship configuration, fuel state, weight and balance, weather (wind, temperature aloft, turbulence and shear, cloud type and opacity, visibility and precipitation), and initial location. It took a particularly experienced IP (in fact, the designer of the IOS interface) 15 minutes to input the initial conditions for an IFR recurrency training mission. Furthermore, malfunctions could be defined for execution in accordance with a set of Boolean operators, including time, airspeed, altitude, heading, etc. Manually defining the malfunction set for even a simple mission would add at least ten minutes to the mission set-up time. The time required to perform these functions manually required the dedicated attention of the IP, and seriously detracted from the time available for training. The use of the Lesson Plan Editor to preconfigure lessons should be considered essential. It is recommended that a set of initial conditions be established for each scheduled lesson plan.

IOS Screen Field of View. All data presented to the IP during training missions is projected upon the two IOS screens situated in front of the IP's console. The data presentation was largely graphical or color-coded text, and was easily readable from either the right-front seat or the right rear seat. Data could include the status of preset emergency conditions, the locations of companion aircraft or ground threats. Movement of the IP at the IOS console was evident in the peripheral vision of the pilot in the right-front seat, and may cause distraction or a desire to "peek" at the upcoming scenario. Often, movement of the IP served as an indication of the imminent actuation of an emergency or critical event. During recurrency training, 403 Squadron manned the right-rear seat with a Flight Engineer (FE). The IOS displays are almost directly in the FE's line of sight as he looks forward into the cockpit, with the result that he must exert an effort not to glance at the IOS screens. The visibility of the IOS displays from the right seats has the potential to undermine training and distract aircrew. It is recommended that future simulator layouts incorporate an IOS design which keeps the displayed data and the IP's movements out of the field of view of the aircrew under training.

"Player" Control System Interface. The IOS was configured with generic controls which were designed to allow the instructor to exercise manual control of selected players in the database. The controls consisted on a small throttle-style controller on the left and a joystick mounted on the right. With such a capability, the instructor could ostensibly enter the simulation in order to force an error by the ownship, or to otherwise enhance a scenario for instructional purposes. It was intended that the instructor "fly" the player (whether helicopter, aircraft, truck, or fixed weapons facility) with reference to the TSD, which could be configured to display a view from the players' point of view. In practice, control of the players was subject to objectionable processor time lags, making satisfactory control of dynamic players impracticable. The augmented modes (e.g. altitude hold or attitude mode) were helpful, but in some circumstances the IP will desire to manually take control of a selected player. Intervention upon a scenario in progress by the IP will be reduced by the poor handling qualities of the players under manual control, compromising the ability of the instructor to exercise real-time control and judgment during scenario execution. The handling qualities of the players from the IOS were unsatisfactory.

Complexity of IOS Interface. Use of the IOS was observed during normal simulator mission training conducted by numerous IP's. Among those IP's with considerable exposure to and experience with the IOS, a very high level of proficiency was observed. In some instances, such as POC course lesson plans, IP's from the flight line were tasked to conduct the training. In these situations, a much lower level of comfort and proficiency with the interface was evident. Training in the simulator benefits from the application of utilities which have no parallel in the aircraft, and with which the IP is likely to be unfamiliar. In order to make optimal use of the simulator training environment, the IP must have a high degree of familiarity with such features as the LP editor, the debrief station, the record and playback (RAP) system, snapshots and demonstrations playback controls. Other features, such as the use of scenarios, players and moving models requires considerable experience and training, and will likely remain beyond the grasp of casual users. In order to ensure that simulator IP's have sufficient proficiency to conduct meaningful training, the following is recommended:

a. simulator IP's from the flight line attend initial and recurrent training in the instructional use of the simulator utilities; and
b. mission simulations involving the use of complex simulator utilities such as scenarios be conducted by dedicated, full-time simulator IP's.

Flight Engineer Participation in Crew Coordination. The flight engineer (FE) is a normal part of the CH146 crew complement for operational missions, and numerous operational tasks require considerable input and participation of the FE. During simulation of certain operational tasks, it was observed that normal crew coordination procedures could not be employed, due to limitations in the simulation for the FE. Specifically, the conduct of hoisting, slinging and confined areas require that the FE provide position cues to the flying pilot with respect to external references beneath the

aircraft. To a limited extent, the hoisting and slinging pages on the IOS could be used by the FE as a surrogate for external references, however this method suffered from the disadvantages of monopolizing the IOS display from the IP, and did not provide sufficient cueing to allow mission-representative position calls from the FE. Furthermore, situating the reference point for the load at a selected ground position proved very time consuming for the IP. In one instance during recurrency training, the crew became disoriented during the final approach to a confined area and was required to overshoot. In preparation for a subsequent approach, the IP instructed the crew to "continue inbound without the FE's calls, and form a mental picture of the area". While such compensation will help habituate crews to the simulator, habits thus formed will have a detrimental effect of crew coordination in flight. The lack of realistic cues to allow the FE to verbally position the helicopter was unsatisfactory. It is recommended that training requiring positioning calls from the FE not be conducted in the simulator.

Scenario Development Utilities: Resource Requirements. Scenarios were developed on the debriefing station, using a software utility within ITEMS™ called the Database Management System (DBMS). The process required that the scenario be coded and compiled for execution by the host computer. Subsequently, most scenarios required several iterations, involving numerous man-hours, to debug the scenario. The only means to test a scenario was in the simulator; a process which monopolized the device. Scenario development requiring dedicated use of the simulator will consume simulator time which will be required for student training. The inability to test a scenario without using the simulator was unsatisfactory, and should be corrected. It is recommended that a workstation be configured to facilitate testing of scenarios without interfering with simulator training.

Lesson Plan Editor. The use of the Lesson Plan (LP) Editor utility was observed during several recurrent training missions, conducted with aircrew visiting from other squadrons. The outline of the mission had been entered into a lesson plan format which could be recalled by the IP at the IOS, including pushbuttons which could be used to activate programmed malfunctions or other selected events. Use of the LP Editor afforded the IP an increased opportunity to concentrate his attention on the aircrew vice manipulating the IOS. It also allowed increased flexibility to tailor the mission to the particular requirements of the crew under training; events were deleted, repeated or rescheduled as the IP felt the need. In one instance where a simulated mission was flown without prior preparation using the LP editor, manual configuration of the simulator (including location, configuration, fuel, weather, etc.) consumed the IP's attention for fifteen minutes in the simulator prior to the lesson; a significant portion of the time available for training. Use of the LP editor increased the efficiency of the simulated training mission and was an enhancing feature in the simulator.

Demonstration Playback Utilities. Applications of the capability to replay prerecorded demonstrations (demos) in the simulator were observed during recurrent training. In practice, demos were included in the programmed syllabus lesson plans, and were

prepared using the LP Editor. A limit of up to twenty demos could be recorded. When executed from the IOS, the demos reproduced in entirety a selected flight sequence, including control movements, instrument displays, visuals, motion and even cockpit audio. Applications of the demo feature could range from initial procedural training in circuit patterns to complex tactical scenarios. Crews conducting mission training in the simulator will be able to observe comprehensive full-cockpit demonstrations of selected maneuvers at a low workload level and in a consistent, repeatable manner. The availability of a demonstration playback utility is an enhancing feature of the simulator. The number of useful demos anticipated in support of the syllabus considerably exceeded the number that were available. It is recommended that the maximum number of available recorded demos be increased.

SUPPORT AND LOGISTICS

Outstanding Deficiencies. Deficiencies observed during simulator training were routinely logged on a Flight Simulator Deficiency Report. A Deficiency Report could be filed by any simulator IP, and was submitted for entry into a Deficiency Report Log. The Report documented the nature of the deficiency. A deficiency database coordinator, who was also a simulator IP, was later responsible for conducting further diagnostic tests in the interest of validation and assigning the relative severity of the deficiency. Although the simulator had begun operational training, deficiencies and malfunctions were still being found on a continuing basis. A review of the Deficiency Report Log from 30 September to 27 November 1996 found 87 entries. The severity of the deficiencies is classified as follows:

a. Vital: the deficiency will routinely interfere with most common training tasks, or students will experience negative training transfer;
b. Urgent: the deficiency can interfere with some common training tasks, or students will be distracted by the effect; and
c. Routine: correction of the deficiency would facilitate training or improve the effectiveness of the simulator.

Figure 9 depicts the relative severity of the deficiencies outstanding once the simulator had begun initial training. It can be seen that although few of the remaining deficiencies individually threaten to seriously undermine training, the accumulation of outstanding items is considerable. Although a small minority of the deficiencies were classified as vital, the effect of these items was that they reduced the capacity of the simulator to reproduce complex training scenarios.

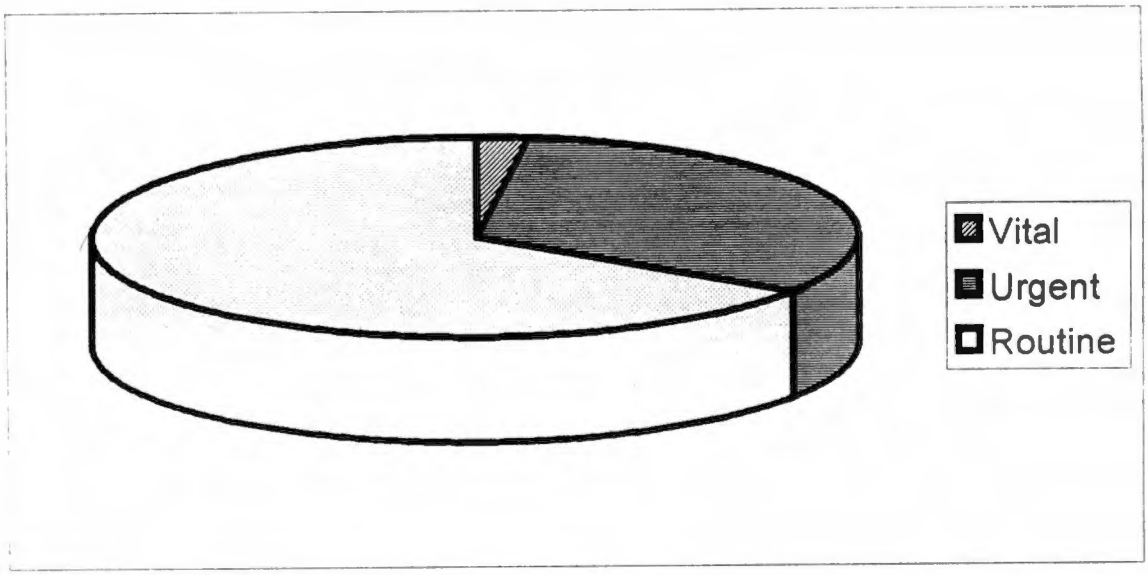

Figure 9
Relative Severity of Outstanding Deficiencies

The effect on training can be better visualized by looking at the distribution of different systems and features against which deficiencies had been logged. Taken from a sample of 87 outstanding logged deficiencies, they are categorized by type as follows:

a. selected emergency/malfunction **effect** is incorrect or requires validation (E);
b. a selected item does not **function** (F);
c. fidelity/**realism** issues outstanding (R);
d. malfunction related to instructional **utilities** (U);
e. a simulator effect requires correction or **tuning** (T);
f. **visual** database problem (V);
g. malfunction related to the **IOS** (I); and
h. **hardware** malfunction (H).

Figure 10 depicts the distribution of functions and systems for which deficiencies had been logged. The intention of the chart is to portray the breadth of outstanding malfunctions remaining in the simulator. Since deficiencies existed, to some extent, in most of the systems and utilities of the simulator, it became difficult to construct realistically complex training scenarios without some degree of interference from the above deficiencies. The presence of numerous documented deficiencies in the

simulator will reduce its effectiveness for mission simulation and was unsatisfactory. It is recommended that efforts continue to promptly identify and rectify simulator deficiencies.

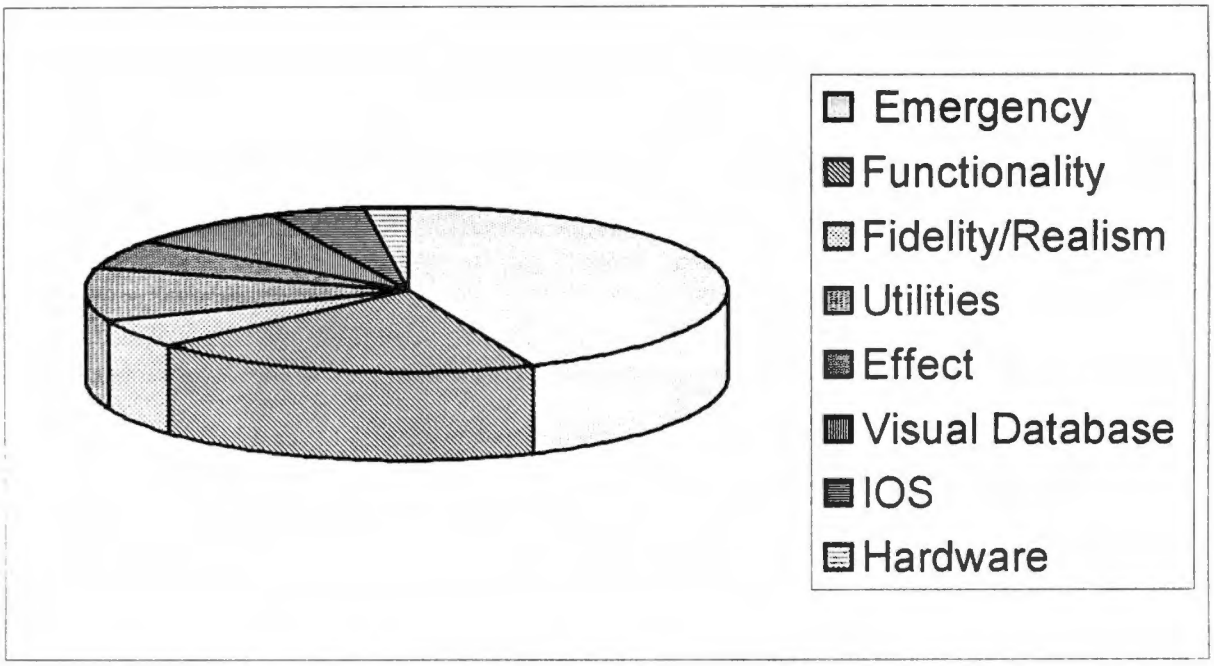

Figure 10
Deficiency Type Distribution

Manning Requirements. In the process of communicating deficiencies to headquarters and the Contractor for rectification, each reported deficiency had to be thoroughly validated. The validation and documentation of these malfunctions represented a considerable investment in man-hours for the simulator staff. Each malfunction had to be logged, and then follow-up action was required to facilitate rectification. This could include replication of the malfunction to document the conditions of the occurrence, technical research to validate the reported discrepancy and liaison with headquarters and Contractor personnel to communicate the observations. These duties were assigned to one of the IP's assigned to the simulator, and was considered a secondary duty. It was estimated that those duties accounted for between one-third and one-half of his time. Experience has shown that the identification of deficiencies and malfunctions promises to be an ongoing process. The manning level dedicated to operation of the simulator was unsatisfactory. It is recommended that the workload requirements for this function be thoroughly documented, and that manpower be made available for this process in order to preclude manning shortages in operating the simulator.

Software Configuration Control. Owing to the presence of numerous deficiencies, the simulator's software remained frequently under revision, with regular visits by Contractor personnel to work on updates. The modified software was subsequently tested for effect in the simulator, but the revision history of the software was not adequately controlled. This caused problems in the tracking of the current software load. Other unanticipated but related problems arose as a result of inadequate configuration control. Instances of problems included the following:

a. programmers modifying the visual database code to correct a reported deficiency, which had the follow-on effect of changing the terrain contours, thereby reducing the utility of the simulator paper maps for navigation;
b. Contractor personnel inadvertently trying to implement software fixes on the wrong copy of the code; and
c. the main software load inadvertently being removed from the simulator site with only a backup of uncertain configuration remaining.

Inadequate software configuration control will cause deficiencies to recur and will result in wasted efforts and degraded simulator utility. The configuration control process of simulator software was unsatisfactory. It is recommended that an individual on site at 403 Squadron be appointed with the responsibility for simulator software configuration control, and that all software changes be approved and tracked by that individual. It is further recommended that the appointment of a full-time dedicated simulator system manager be investigated.

PART V: CONSIDERATIONS FOR OPTIMIZATION OF CH146 SIMULATOR TRAINING EFFECTIVENESS

Objectives of the Acceptance and Validation Process. The operational use of a simulator is ultimately intended to impart effective training to aircrew. Since the simulation model incorporates inherent limitations and compromises in both the motion and visual systems and in the flight model, it follows that the value of the simulation for training has limitations as well. The objective of the validation process should be the determination of the range of training exercises which impart positive training transfer. The established methodology for conducting this validation was described in Part III, however in the case of the CH146 simulator the application of these methods suffered from the following limitations:

a. pressure existed to hasten operational implementation of the simulator, resulting in limited time during which the simulator and personnel could be dedicated to addressing issues of validation;
b. the personnel tasked to conduct the acceptance and validation were largely from other than the user unit, leading to poor communication of the intent and progress of the planned validation process to the operational unit;
c. those personnel were initially unfamiliar with the established methodologies used in simulator effectiveness validation; and
d. most significantly, the conventional methodologies for validation of simulator effectiveness were not compatible with many of the complex mission scenarios intended for the CH146 simulator. Both the forward transfer and the backward transfer of training analysis techniques require that simulator performance be directly compared to aircraft performance for selected tasks. In the case of many of the mission training objectives, it was not feasible to gather data on crew performance in the aircraft. For example, it was not possible to obtain data on the success rate for evasion of missile threats in the aircraft. Consequently, there could be no direct analysis of whether the simulator effectively taught correct techniques. In the author's experience, the scope of this problem, in relation to the validation of training effectiveness for mission training, was not sufficiently understood to have been addressed during initial implementation of the simulator.

In the event, the validation of operational effectiveness of the CH146 simulator did not benefit from a structured analysis of aircrew mission performance in the aircraft in comparison to the simulator, nor did it clearly establish bounds for positive training transfer. It is unlikely that sufficient experience or data existed during initial implementation of the simulator to facilitate such a study. However, such a process of validation need not end with operational implementation of the simulator for training. Experience gained during service should be continually integrated into ongoing improvement; a process that would require dedicated commitment of resources to syllabus development.

Recommendations for Operational Employment. Until follow-on studies can establish a more detailed training envelope for the CH146 simulator, the following is intended to serve as an interim set of limitations and guidelines for the conduct of operational training:

a. Syllabus Documentation. The concept of a "training envelope" was introduced in Part III of this thesis as a proposal to define the range of simulator activities that would deliver positive training transfer to the student. Just as it would be unwise to exceed the approved flight envelope of an aircraft, there can be risks associated with the conduct of unvalidated training in a simulator. Furthermore, just as the flight envelope of an aircraft is well defined, so should the training envelope of a simulator. It is recommended that the entirety of the approved syllabus be documented and that training be explicitly constrained to those items. Implementation of training beyond the scope of the approved syllabus should be predicated upon satisfactory results of validation tests. Instructors should be made aware that the risk of unvalidated training is negative training transfer, which implies that the trainee may learn "skills" that could be unsafe or ineffective in flight.

b. Instructional Technique. Part III of this thesis outlined reasons why training in the simulator will require instructors to adopt different techniques to those employed during flight training. Fundamental to this requirement is the necessity to be aware of instances where the student is learning, but is adopting new strategies that would not transfer well to the aircraft. In planning and conducting lessons, instructors should attempt to construct training in order to avoid or mask simulator events which are known to have deficiencies in positive training transfer (such as height and range perception, and simulator field of view) in order to circumvent adoption of inappropriate skills by the student. For example, exercises that require accurate maintenance of hover height would benefit from being conducted in the vicinity of trees, houses or areas of enhanced surface texture [U]. Similarly, navigational exercises should be planned such that waypoints and salient ground features remain within the field of view of the visual system. A goal in the conduct of simulator lessons should be to make deficiencies in the simulator as transparent as possible to the trainee. Likewise, care should be taken by instructors not to offer criticism to crews for errors that are likely induced by limitations in the simulator. There is little benefit to teaching crews how to modify skills acquired in the aircraft in order to perform more effectively in the simulator. Since instructional technique in the simulator differs considerably from training conducted in flight, instructors will require a specialized course of training prior to progressing from the flight-line to the simulator. Such training should be considered essential prior to assuming instructional duties in the simulator.

c. Conduct of Emergency Training. Emergency procedures training conducted in the simulator benefits from the ability to proceed beyond the recognized safe limits of training for flight operations, and consequently such training often occurs in

regimes beyond the normal flight envelope of the helicopter. Such training conducted outside of the envelope should be performed with awareness that these effects are largely unvalidated against aircraft data, and that the objective fidelity of the simulation in these regimes is necessarily suspect [U, Ch. 7, p. 170]. IP's should strive to teach recognition of the symptoms and the critical and/or initial actions required for such malfunctions, but should take care not to dwell on technique to the extent of potentially "tuning" the trainee for the idiosyncrasies of the simulation. Given the knowledge that the simulation has limitations in these areas, a degree of "coaching" by the IP may be warranted to encourage the trainee to adopt control strategies appropriate to the helicopter. For example, although autorotation training in the simulator is an essential part of the students preparation for operational flying, autorotations in the simulator suffered from the deficiency that landings could be effectively delayed until the rotor speed had decayed to very low values (approximately 65% Nr). In these circumstances the potential for negative training transfer can be mitigated to some extent by encouraging the trainees to land prior to an arbitrary minimum rotor speed value. Although such intervention would add a degree of "dissimulation" to the exercise, it would serve to focus the trainee to adopt a more appropriate strategy.

d. Conduct of Mission Training Scenarios. Mission training scenarios anticipated for the CH146 simulator suffer from limitations similar to those outlined above regarding emergency training. Such scenarios can involve interactions of systems which may not have been fully validated with quantitative data. Consequently, the behavior of such scenarios can have unexpected effects. Instructors are cautioned not to place excess emphasis on the "win/lose" aspects of the scenario to the expense of concentrating on the fundamental decision-making and operational skills of the crew. To some extent, the success of the crew in executing the mission scenario is at the discretion of the IP, rather than merely being an output of the software. Ideally, the crew will succeed in the mission when they perform well and fail in the mission when there remain essential lessons to be learned. Making such a choice is the task of the IP, *not* the simulator software, and the IP is furnished with utilities that would facilitate subtle intervention in the scenario for the desired effect. However, the IP can be faced with a busy task during a complex mission simulations [BB], and workload management must be kept in mind if the salient details of crew performance are to be effectively observed.

e. Facilities Development. There is evidence to conclude that not all the exercises required for the training of tactical helicopter pilots benefited from the complexity of a full-mission simulator [D],[F]. Other facilities could deliver effective training, and deserve attention in the optimization of the syllabus. Examples include Computer Based Training (CBT) and a fixed-base Cockpit Procedures Trainer (CPT). Both items were under consideration for acquisition concurrently with the implementation of the CH146 simulator. In particular, the CPT would potentially offer an effective facility for the conduct of procedural training and instrument flying training, and its use could be integrated into the overall instructional

syllabus. In lieu of a CPT, instruction in the simulator for systems-related procedures should be conducted with the motion and visual systems off, in order to reduce the distracting influence of extraneous cues on the trainees. As a further development, such training could be enhanced through integration of animated systems schematics or instructional graphics into the visual system to aid trainee comprehension of the function of the helicopter's systems.

f. Specifying the Type of Training. There are several forms that simulator training can take: skills development training for ab initio trainees or type conversion training, skills-sustainment training for proficiency of trained crews, and skills assessment training such as check rides and evaluations. Care should be taken not to assume that a training exercise validated for one purpose will be effective for other purposes. For example, there was evidence that the simulator visual system was satisfactory for the conduct of exercises that required map reading for experienced crews [BB]. However, this should not be inferred to mean that the simulator would be effective in teaching map reading skills. Likewise, recurrency training in emergency procedures was conducted satisfactorily, however simulator effectiveness for initial training in emergency procedures is not necessarily as high. To date, experience may not be sufficient to answer these questions, however the concept should remain clear that skills-sustainment, skills development and skills evaluation are different training objectives and must be treated as independent dimensions of any further syllabus validation activities.

PART VI – CONCLUSIONS AND RECOMMENDATIONS

General. A review of the literature about flight simulation makes clear that it is an altogether different challenge to *build* a simulator than to effectively *use* a simulator, and considerable fundamental research remains to be done in determining appropriate methodologies for validating flight simulator training effectiveness. Simulation literature abounds with titles such as "Training Transfer: Can We Trust Flight Simulation?" [CC], "Simulator Qualification: Just As Phony As It Can Be" [V], and "Myth and Folklore in Helicopter Simulation" [G]. Dohme [U, Ch. 5] confirmed the paucity of research in the field of training effectiveness validation. In a literature survey of 247 papers ostensibly dealing with the subject of training effectiveness validation, only 7 papers were found in which data were presented actually comparing simulator versus aircraft training. He concluded that:

> "From this meta-analysis of the rotary-wing simulator effectiveness literature, the most obvious conclusion is that more work is needed. Specifically, what is needed is research using empirical criteria for pilot evaluation, employing the same criteria in the simulator and the aircraft, using operational aviators (or trainees) as research subjects, measuring TOT, and presenting sufficient data to support future meta-analysis. Meeting these criteria makes the research effort expensive and time-consuming, but the alternative is what we have now - no clear guidance regarding the most effective and efficient design for rotary wing training simulators." [U, Ch. 5]

The simulator user may be tempted to assume that training effectiveness is adequately addressed during the initial acceptance of the simulator, however this is far from a certainty. Carlton and Francis [U, Ch. 7] explain that the mandated in-plant acceptance tests focus largely on hardware functionality. They conclude as follows:

> It is important to realize that these tests concern equipment functions and standards of performance. They do *not* imply that flight crews will be able to perform adequately in their workplaces – this outcome is dependant on the application of training regulations and standards as embodied in a curriculum and facilitated by expert instructors, using the simulator as a training tool." [U, Ch. 7, p. 172].

To date, it is clear that simulators are far from plug-and-play appliances. The development of a training syllabus for a simulator, or the integration of a simulator's capabilities into an existing syllabus remain a considerable challenge. It is paramount that users of simulators have a clear concept of what can and, equally importantly, what cannot be effectively conducted in their specific device. It is foreseen that coming developments in simulator acceptance and testing methodology will include, as a routine part of the certification of flight simulators, testing to define the specific "training envelope" of the device.

Specific. Notwithstanding the recommendations for formal analysis of training transfer presented in this paper, the operational implementation of the CH146 Griffon simulator was constrained by the same factors that commonly effect such programs. Pressure to begin operational training was considerable, and the largely qualitative observations presented in Part III constituted the entirety of the formal training effectiveness validation conducted by the user. These data suffice to provide a limited determination of the effectiveness of the device for selected operational training tasks, however the utility of the simulator for comprehensive mission training is as yet largely unknown. Part V details interim recommendations for improving training effectiveness of the simulator. The most cogent conclusion from the validation conducted to date remains that the commitment of sufficient resources for a thorough analysis of training effectiveness remains a necessity.

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APPENDICES

APPENDIX A

CH146 SIMULATOR SYSTEMS DESCRIPTION

General. The CH146 Griffon simulator was a full-motion, visual flight simulator which was designed as a full-mission tactical training device. It incorporated a six degree of freedom motion base and an enhanced CAE Maxvue™ visual system, which provided a field of view of 210° horizontally by 40° vertically. The visual system incorporated eight channels. The five forward visual channels projected upon a mylar dome in front of the cockpit. Two further visual display system channels utilized color video display units situated in the lower outboard sections of the crew's cockpit field of view. One video display channel was dedicated to FLIR video imagery. All of the CH146's onboard systems were simulated, including the communication radios, navigation systems, countermeasures systems and FLIR. Airworthy aircraft control and display units (CDU's) were installed in the simulator; the simulator interfacing with the CDU's by stimulating operational Avionics Management System (AMS) software via simulated databus traffic. The simulator cockpit is shown in Figure A-1.

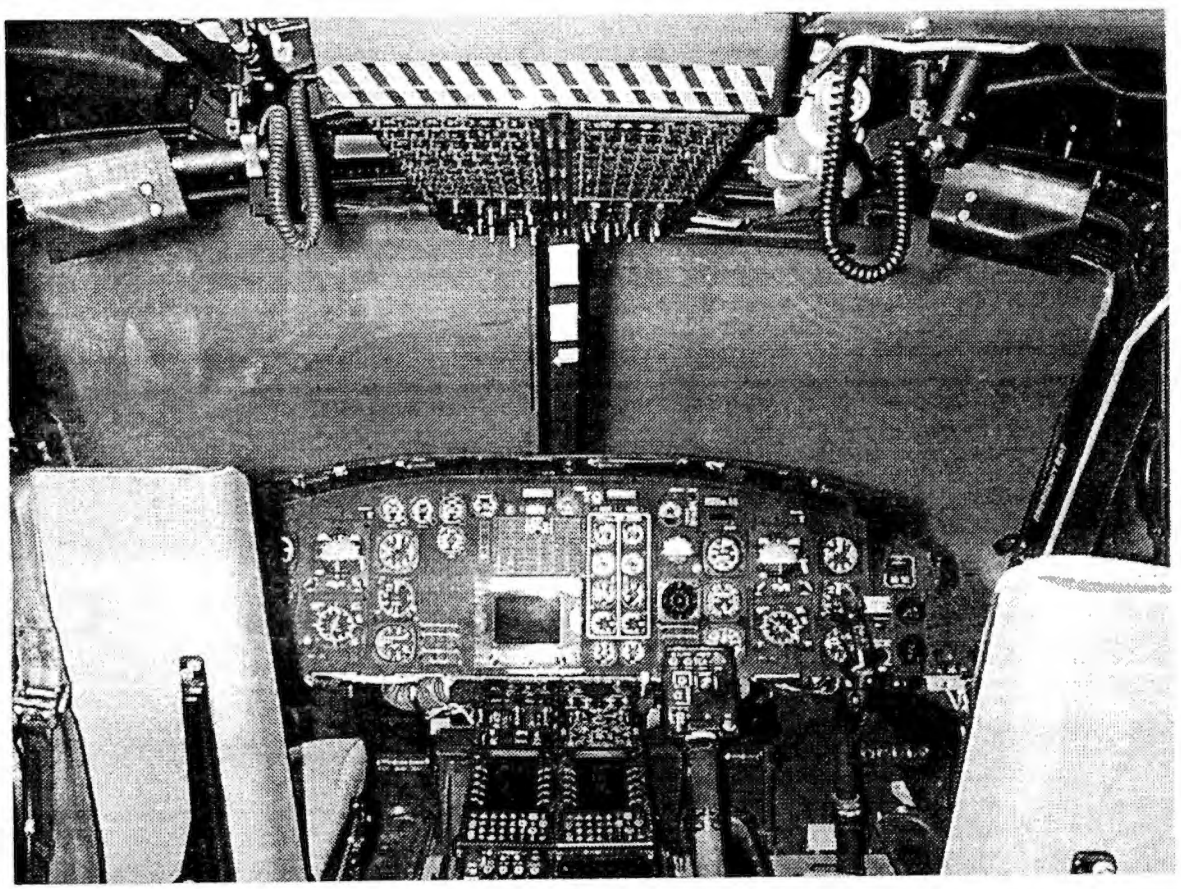

Figure A-1
The CH146 Simulator Cockpit

The simulator cabin incorporated two pilots seats in a replica CH146 cockpit, one instructors station and a crewman's/passenger's seat in the right-rear cabin.

Instructional Interface and Utilities. The simulator was furnished with a selection of software utilities to enhance mission simulations and operational training, including the following:

a. Instructor Operator's Station: The facility for the real-time control of the simulator by the instructor, called the Instructor Operator's Station (IOS), is depicted in figure A-2. Figure A-3 is a sample IOS control page. The station consisted of two touch screen video displays, two electroluminescent control panels, a pair of hand controllers for instructor-controlled players, and associated switches and displays. The electroluminescent control panels, called "EL panels" (Figure A-4) were designed to serve as quick access pushbuttons to selected IOS pages and features, as well as serving to control the IP's audio system;

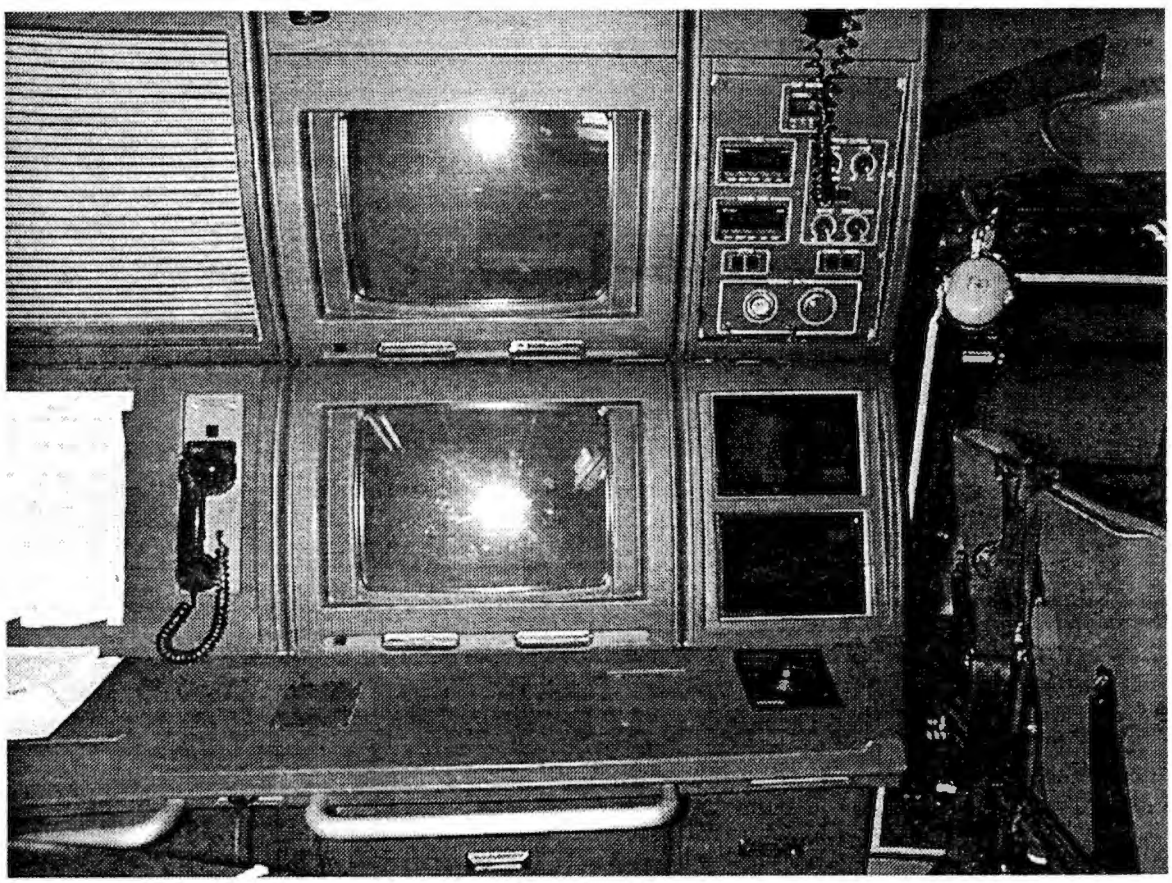

Figure A-2
The Instructor Operator's Station

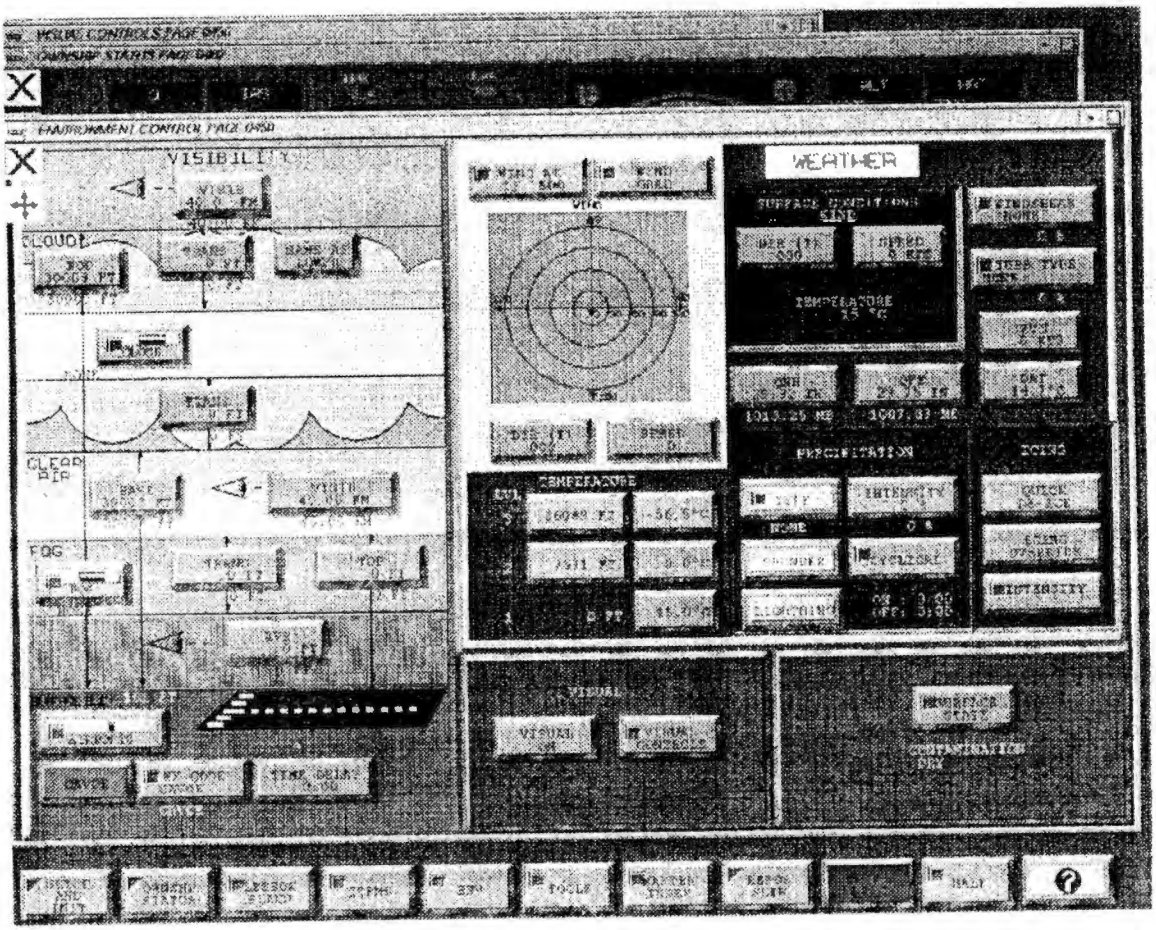

Figure A-3
Sample IOS Screen – Environmental Control Page

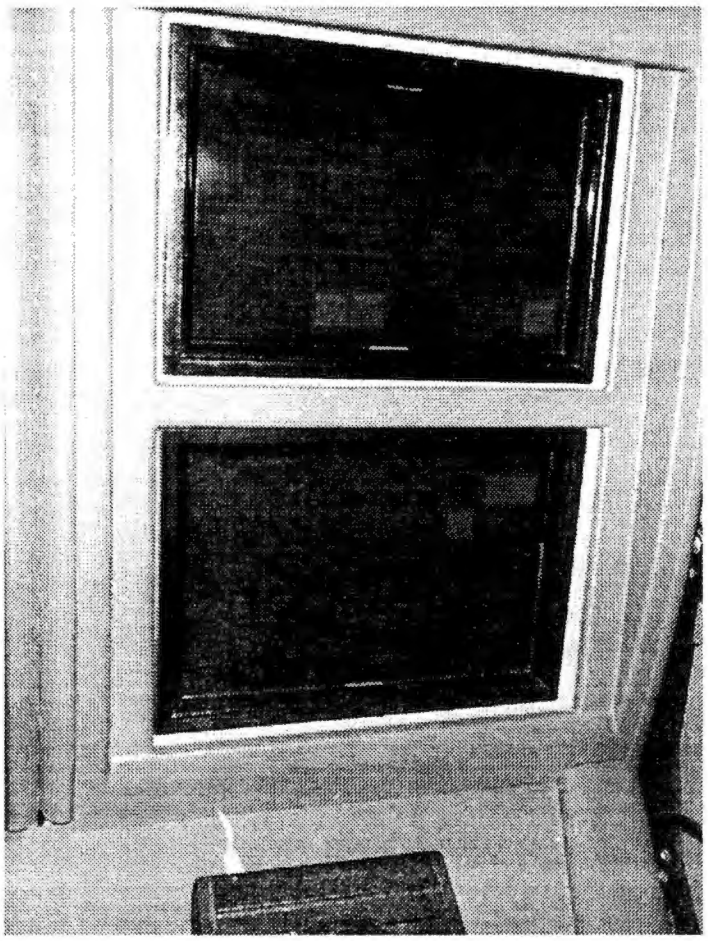

Figure A-4
Instructor Operator Station "EL" Panels

b. Portable Control Unit: A hand held controller, called the PCU-18 (Figure A-5), was connected via coiled cord to a socket behind the pilot's seat. The unit was designed to facilitate portable access to a subset of the simulator control functions, allowing control of the simulator by an IP or student from either cockpit seat. The unit had 18 variable function pushbuttons with integral LCD labeling;

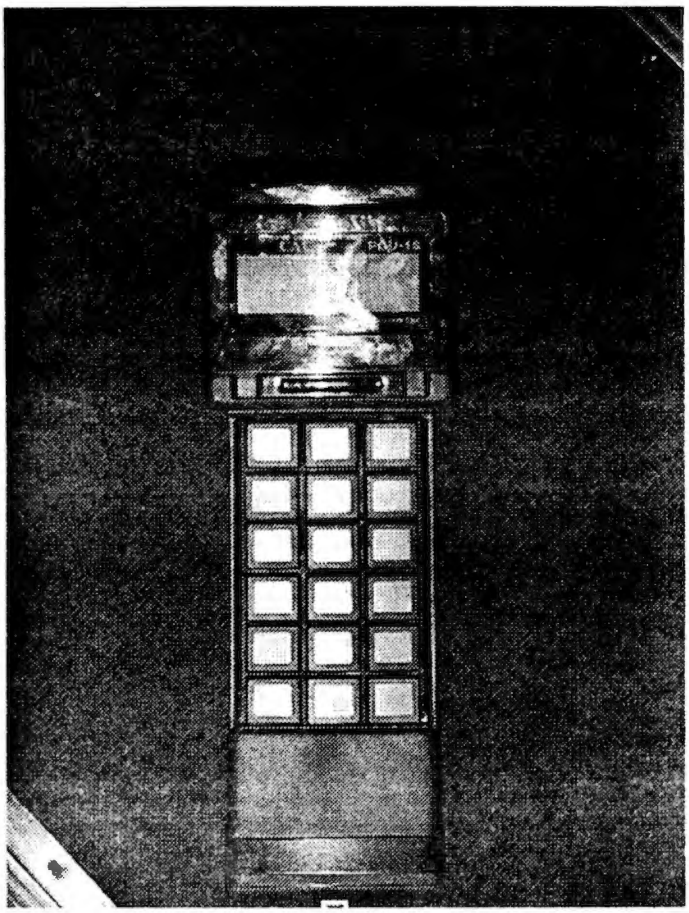

Figure A-5
Portable Control Unit, PCU-18

c. The Debrief Station: The debrief station, depicted in figure A-6, was the facility designed for the development and implementation of simulator scenarios, and for post-mission debriefing of crews following training. It consisted of a computer-controlled videotape replay system which was linked to a cockpit-mounted color video camera, and a 21 inch computer monitor upon which could be displayed tactical plots of missions. Scenarios were constructed using CAE-developed Interactive Tactical Environment Management System (ITEMS™), a UNIX-based graphical development environment; and

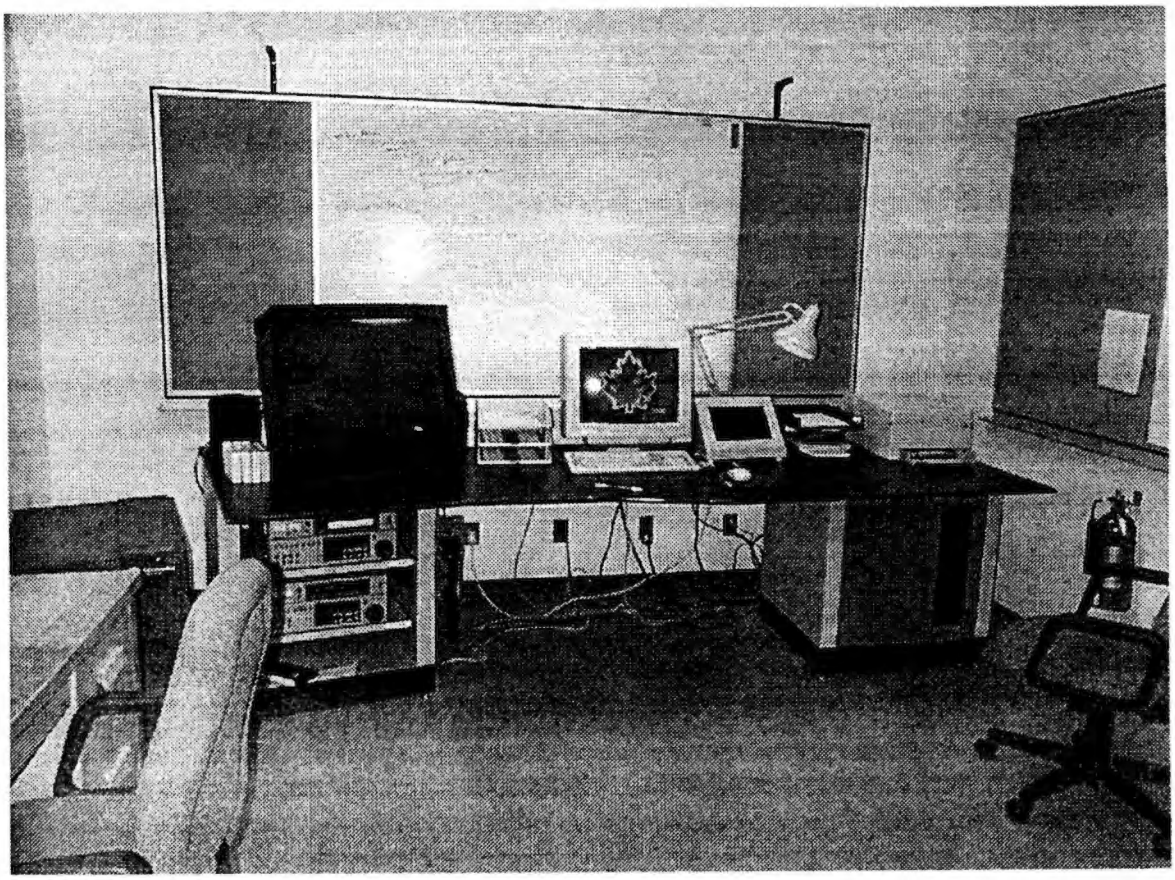

Figure A-6
The Debrief Station

d. Lesson Plan Editor: Another software utility supported on the debrief station was the Lesson Plan (LP) Editor, which was designed to allow the automation of detailed training sequences and aircraft operating conditions. In practice, the LP Editor allowed instructors to enter such items as aircraft initial configuration, weather conditions, gaming area, preset malfunctions and recorded simulator flight demonstrations for recall in the simulator.

Mission Environment Simulation. The simulator was designed to incorporate a host of features to emulate in detail the tactical mission environment. These features included the following:

a. Visual Databases: twelve visual databases which were based, to varying extents, on real cartographical data for selected regions and topographies. The visual databases were simplified representations of salient terrain details, intended to facilitate contact navigation in common training areas. These regions included:

i. CFB Gagetown (summer and winter scenes);
ii CFB Valcartier (summer and winter scenes);
iii. Quebec City;
iv. CFB Wainwright;
v. Penticton (mountain);
vi. Victoria (coastal);
vii. Europe;
viii. Desert;
ix. Jungle;
x. Arctic; and
xi. Generic.

The simulator training system was designed to include for the provision of realistic paper charts based on the visual databases, which were intended to facilitate contact navigation and realistic pre-flight crew mission planning; and

b. Moving Models: interactive visual moving models which could include an assortment of fixed-wing and rotary-wing aircraft, tracked and wheeled ground vehicles and ships. Each of the models could be configured with a selection of sensors and weapons systems to emulate a desired tactical system. Scenarios could incorporate up to 16 moving models, up to eight of which could be simultaneously active Only three moving models could be displayed visually at any time.

APPENDIX B

SIMULATOR CATEGORY III TEST MATRIX

The table below is excerpt from the Test Plan for the CH146 Mission Simulator Category III (OT&E) Evaluation [AA]. This Annex is included to detail the scope of the evaluation, and some considerations in the validation of a mission simulator.

PHASE	SUB-PHASE	SAMPLE OBJECTIVES
Envelope Definition	Basic Handling	What are the limits of positive training transfer? To what extent does the pilot have to compensate for the sim? Are the simulated indications realistic and sufficient? Does the sim adequately simulate the tactical environment?
	Instrument Flying	Are there limitations in the use of the simulator for instrument check rides?
	Emergencies	Can the simulator serve as an acceptable surrogate for in-flight training in critical emergencies such as touchdown autorotations and tail rotor malfunctions?
Mission Environment Assessment	Night Flying / NVG	Does the simulated NVG visual acuity represent actual NVG flight? Can pilots be initially trained to use NVG in the simulator? Will the crew be able to map-read under NVG?
	Combat SAR/Support	Is the FLIR imagery realistic?
	Hoisting / Slinging	Can the FE be integrated into the crew? Can the pilot hover OGE with realistic accuracy and workload?
	Air Observation Post (AOP) and Forward Air Control (FAC)	Is the instructor's workload manageable during AOP missions? Can the crew estimate distances adequately? Can the FAC communications be simulated without distracting the crew or instructor?
	Formation / Airmobile Mission	Is workload during formation flight representative of the CH146? Do simulated formation aircraft behave realistically in all tactical situations?
Instructional Utility Validation	IOS	Is the interface sufficiently intuitive? What are the training/currency requirements for the sim IP's?
	Scenario Development	What are the time and experience requirements to develop scenarios? Does the scenario management software address all desired tactical situations?
	MPS/MDU Integration	Can sim missions be planned as in the aircraft? Are the sim database maps valid and readable?
	RAP/Debrief Utility	What is the utility of the instructional debriefing features for student training?

APPENDIX C

DEFICIENCY CLASSIFICATION

In the context of this report, the classification and assignment of deficiencies conforms to a standardized format. This classification is common in the flight test community, and is conformant with the classification format in use by the Canadian Forces [Y]. The substantiating terminology is based upon the work of Cooper and Harper [Z]; the seminal reference in handling qualities flight testing. In order to reduce potential misinterpretation of deficiencies, keywords are proscribed to qualitative assessments in accordance with the following definitions:

1. Acceptable. An acceptable simulator, simulator system or subsystem is one that exhibits adequate performance and can be effectively employed in its designated or intended role. A simulator or system deemed acceptable should be further categorized as being satisfactory or unsatisfactory, which are defined as follows:

   a. Satisfactory. This includes:
      i. desired or clearly adequate performance is attainable without pilot compensation;
      ii. good enough without improvement; or
      iii. only minor deficiencies. A minor deficiency is one that can be tolerated since it is merely annoying or slightly unpleasant or would be uneconomical or impracticable to correct on a particular simulator or system. Although not normally rectified, minor deficiencies should still be recorded so that they can be avoided on future designs; and

   a. Unsatisfactory. This includes:
      i. adequate performance is attainable but requires pilot compensation;
      ii. has deficiencies which warrant improvement either before or after acceptance, depending on the circumstances; or
      iii. an unsatisfactory simulator or system is one which has deficiencies that degrade performance, effectiveness, safety, reliability or maintainability and or demand significant operator compensation to achieve the desired level of performance; however, the simulator or system being evaluated is still capable of accomplishing the mission with an acceptable level of safety and effectiveness; and

2. Unacceptable. An unacceptable simulator, system or subsystem is one that exhibits inadequate performance and major deficiencies even with maximum tolerable operator compensation. A major deficiency is one that must be corrected before a simulator or system can be accepted since it adversely effects:
   a. airworthiness and safety;
   b. the ability of the simulator or equipment to accomplish its primary or secondary mission or intended use; and/or

c. the effectiveness of the crew or the integrity of an essential subsystem. In this regard, a real likelihood of injury or damage exists. Remote possibilities predicated on multiple failure states or unlikely sequences of events are not used as a basis for deficiencies under this category.

VITA

Robert Erdos was born in Toronto, Canada on 26 February 1963. He attended Royal Roads Military College and the Royal Military College of Canada, and graduated in 1986 with a Bachelor's degree in Mechanical Engineering. Following completion of pilot training, he served as a Search and Rescue pilot with 442 SAR Squadron in Comox, British Columbia. In 1991 he attended the U.S. Naval Test Pilot School at Patuxent River, Maryland. He subsequently served as an engineering test pilot at the Aerospace Engineering Test Establishment, Canadian Forces Base Cold Lake, Alberta.

Robert Erdos is presently employed as an experimental test pilot with the Flight Research Laboratory of the National Research Council of Canada, in Ottawa. He is a member of the Society of Experimental Test Pilots and a registered Professional Engineer.