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Physiological measurement of the push-pull effect during flight

Stuart Lachlan McIntosh

To the Graduate Council:

I am submitting herewith a thesis written by Stuart Lachlan McIntosh entitled "Physiological measurement of the push-pull effect during flight." I have examined the final electronic copy of this thesis for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of Master of Science, with a major in Aviation Systems.

U. P. Solies, Major Professor

We have read this thesis and recommend its acceptance:

R. Kimberlin, F. Stellar

Accepted for the Council:
Carolyn R. Hodges

Vice Provost and Dean of the Graduate School

(Original signatures are on file with official student records.)

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Mr. F. Stellar

Accepted for the Council:

Interim Vice Provost
and Dean of the Graduate School

PHYSIOLOGICAL MEASUREMENT OF THE PUSH-PULL EFFECT DURING FLIGHT

A Thesis

Presented for the

Master of Science Degree

The University of Tennessee, Knoxville

Stuart Lachlan McIntosh

August 2001

DEDICATION

To my wife, Darlene, whose love always inspires me to do more.

ACKNOWLEDGEMENTS

The author would like to extend his sincere appreciation to key persons who made this work so enjoyable to accomplish. Firstly, to Capt Helen Wright and Dr Fred Buick, the principal and associate investigators from DCIEM, who initiated this research and gave us all purpose. Also, endless thanks to Capt Ruben Caballero, for his tireless efforts in supporting the instrumentation integration into the test aircraft. His commitment was inspirational.

ABSTRACT

The Push-pull In-flight Research Program was a Canadian Forces sponsored set of experiments conducted during flight to investigate the bodily responses to $+g_z$ exposure when preceded by low, or negative, g_z exposure. This type of exposure is known as the "push-pull" manoeuvre. It has been hypothesized that the physiological responses of the human body to this manoeuvre can lessen an individual pilot's g tolerance, thereby making him or her more susceptible to g-induced loss of consciousness. The overall aim of this thesis was to instrument an aircraft and perform in-flight research to collect data for evaluation of this hypothesis.

As a joint research venture, the Aerospace Engineering Test Establishment, in conjunction with the Defence and Civil Institute of Environmental Medicine, performed a series of in-flight trials using a highly-instrumented CF-18 aircraft to gather physiological data on a wide spectrum of test subjects. The end-goal of this flight testing and follow-on research is to design a microprocessor controlled anti-g valve for future use in high-performance aircraft.

This thesis evaluates the instrumentation approach, test procedures, and data gathering conducted during this test program. Preliminary results indicate the existence of a push-pull effect. Specific attention is given to the difficulties encountered with conducting experimental physiological research in an ejection seat equipped, high-performance fighter aircraft, and the methods and equipment developed to overcome these challenges.

PREFACE

The flight test results contained within this thesis were obtained during a Canadian Department of National Defence sponsored Associate Deputy Minister (Materials) program. The discussion of the methods, data, conclusions and recommendations presented are the opinion of the author and should not be construed as an official position of the Canadian Department of National Defence, the Associate Deputy Minister (Materials), the Defence and Civil Institute of Environmental Medicine, or the Aerospace Engineering Test Establishment.

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LIST OF ABBREVIATIONS

The following abbreviations appear in this thesis:

AC	Alternating Current
AETE	Aerospace Engineering Test Establishment
AGL	Above Ground Level
AGSM	Anti-g Straining Manoeuvre
ALSE	Aircrew Life Support Equipment
AOB	Angle of Bank
CE	Conducted Emissions
CF	Canadian Forces
dB	Decibel
DC	Direct Current
DCIEM	Defence and Civil Institute of Environmental Medicine
ECG	Electrocardiogram
EMC	Electromagnetic Compatibility
EME	Electromagnetic Environment
EMG	Electromyogram
EMI	Electromagnetic Interference
EPC	Electrical Power Characteristics
FTI	Flight Test Instrumentation
g	Unit of Acceleration

G-LOC	g-induced Loss of Consciousness
g_x	Longitudinal Acceleration Applied to Test Subject
g_y	Lateral Acceleration Applied to Test Subject
g_z	Normal Acceleration Applied to Test Subject
HUD	Head-up Display
Hz	Hertz
ILS	Instrument Landing System
INS	Inertial Navigation System
LED	Light-emitting Diode
LPSV	Life Preserver Survival Vest
MHz	Megahertz
mmHg	Millimetres of Mercury
MOR	Manual Override
NASA	National Aeronautics and Space Administration
PA	Pressure Altitude
PSI	Pounds per Square Inch
QD	Quick Disconnect
RE	Radiated Emissions
RSSK	Rigid Seat Survival Kit
TDCVRS	Triple Deck Cockpit Video Recording System
UHF	Ultra High Frequency

USAF	United States Air Force
VCU	Video Compression Unit
VHF	Very High Frequency

I - INTRODUCTION

BACKGROUND

The Push-pull In-flight Research Program was a Canadian Forces (CF) sponsored set of experiments carried out during flight to investigate the bodily responses to positive normal acceleration (g_z) exposure when preceded by low, or negative, g_z exposure. This type of exposure is known as the "push-pull" manoeuvre. It has been hypothesized that the physiological responses of the human body to this manoeuvre can lessen an individual pilot's g tolerance, thereby making him or her more susceptible to g-induced loss of consciousness (G-LOC).

As a joint research venture, the Aerospace Engineering Test Establishment (AETE), in conjunction with the Defence and Civil Institute of Environmental Medicine (DCIEM), performed a series of in-flight trials (Refs 1 and 2) using a highly-instrumented CF-18 aircraft to gather physiological data on a wide spectrum of test subjects. The aim of the flight testing conducted at AETE was to provide physiological truth data from a test subject flying in an aircraft, rather than a g-simulator or centrifuge. This intent of collecting this in-flight data is to allow follow-on research to design a microprocessor controlled anti-g valve for future use in high-performance aircraft.

Testing was divided into three phases at AETE. The first two phases, Escape Systems Clearance and Electromagnetic Compatibility (EMC) Testing, were conducted to ensure that the aircraft instrumentation configuration was safe and airworthy for flight of a physiologically instrumented test subject in the rear seat of the test aircraft. The third

phase of testing, In-flight Physiological Research, was conducted to collect the data required by DCIEM.

The author's involvement in this program was that of Project Officer. He was responsible for the management of the project from beginning to end, including test planning, test conduct and reporting of results. His duties included acting as project team lead, mission controller and test subject. Full bio-medical analysis of the data obtained is being conducted by DCIEM, and collected bio-medical data is proprietary to that institution. As such, the thrust of this thesis details the instrumentation approach, test procedures, and data gathering conducted during this test program. It also discusses the highlights, challenges, and preliminary results obtained. Specific attention is given to the difficulties encountered with conducting experimental physiological research in an ejection seat equipped, high-performance fighter aircraft, and the methods and equipment developed to overcome these unique difficulties.

Basic Physiology

To illustrate the push-pull effect, Figure 1 shows the recorded mean eye level blood pressure response in a test subject exposed to the push-pull manoeuvre in a centrifuge (Ref 3). The physiological response in an aircraft was not expected to be fundamentally different.

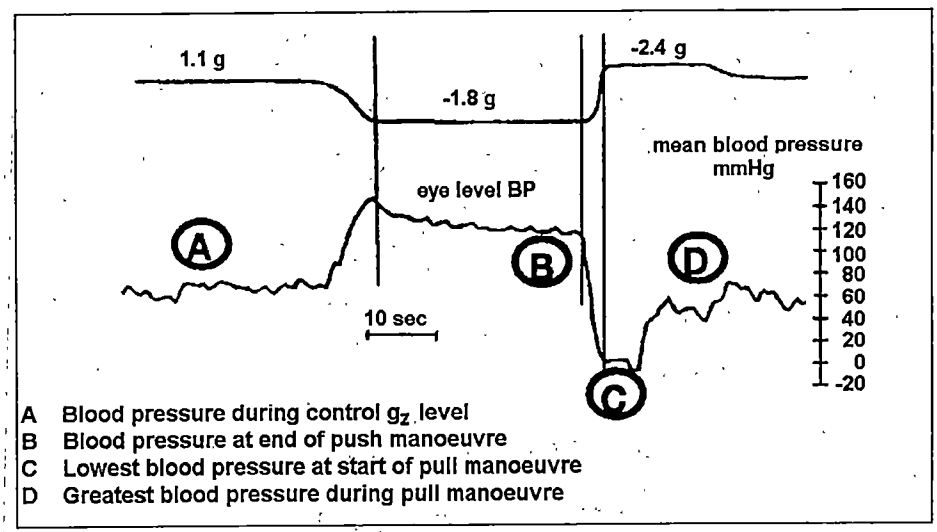

Figure 1. Eye Level Blood Pressure during Push-pull.

As detailed in Ref 3, the most important levels of pressure are at points B and C. Point A shows the resting (or control) blood pressure. Negative g_z then causes an increase in blood pressure at the carotid sinus that reflexively decreases heart and eye-level pressure over the next 5 to 20 sec (B). Then, exposure to + g_z levels increases the hydrostatic gradient for heart level blood pressure causing the greatly reduced pressure at eye level seen at C. This is the period of greatest risk for G-LOC. Compensatory reflexes then improve blood pressure by D.

Increasingly negative g_z levels will produce greater increases in eye level blood pressure. In turn, this produces stronger reflexes to lower the blood pressure. The stronger the reflex during $-g_z$, the "further behind" the body is at the start of a $+g_z$ pull. Therefore, the bigger the push, the lower the g_z tolerance during the pull.

Mishaps

Recent aircraft mishap data (as detailed at Refs 4 and 5) suggest that several scenarios, such as extending and pitching back into a fight or bunting to achieve a weapons solution on a surface target followed by a pullout, expose pilots to a sequence of positive, zero (or perhaps negative), then positive g_z. Such a time history has been implicated in the reduction of tolerance to high g and increased susceptibility to G-LOC (Refs 3, 6, 7, 8).

In July of 1995, the Canadian Air Force lost a pilot and a CF-18 Hornet aircraft (CF-188714) during an air combat manoeuvring mission to what was believed to be G-LOC. The push-pull effect was thought to be a significant contributing factor. Data from the accident was available since the aircraft was configured with an air combat manoeuvring instrumentation (ACMI) pod, which had telemetered data to the ACMI center. Figure 2 shows the accident g_z time history.

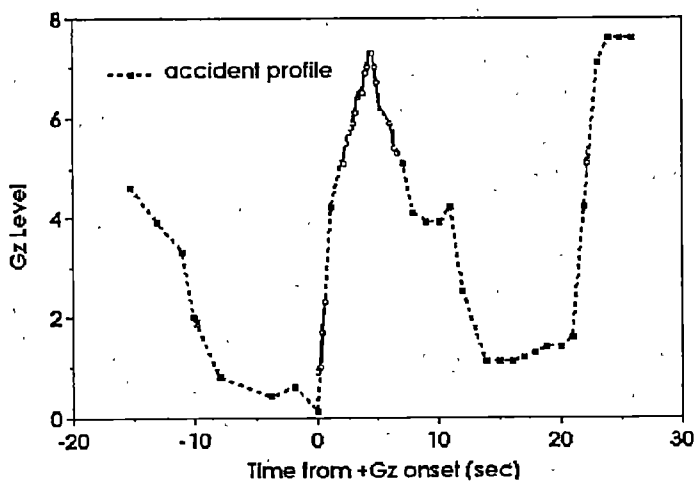

Figure 2.
Accident Time History

The final engagement of the sortie was a 1 v 1 setup. As CF-188714 manoeuvred to merge with the opposing fighter, a period of approximately 8 seconds below 1 g was flown to gain position and roll inverted above the opposing aircraft to set-up a split-S manoeuvre. The pilot then applied maximum $+g_z$ to engage the other fighter. Five seconds after onset, immediately after $+g_z$ peaked, g_z began to decrease as the aircraft assumed an inverted nose low attitude. The aircraft gradually entered a near vertical dive and impacted the ground at over Mach 1.12, Figure 3. Sadly, it appears that the pilot may have regained consciousness and cognition prior to impact, as an acceleration of 7.7 g_z was telemetered to ACMI just prior to aircraft impact with the ground.

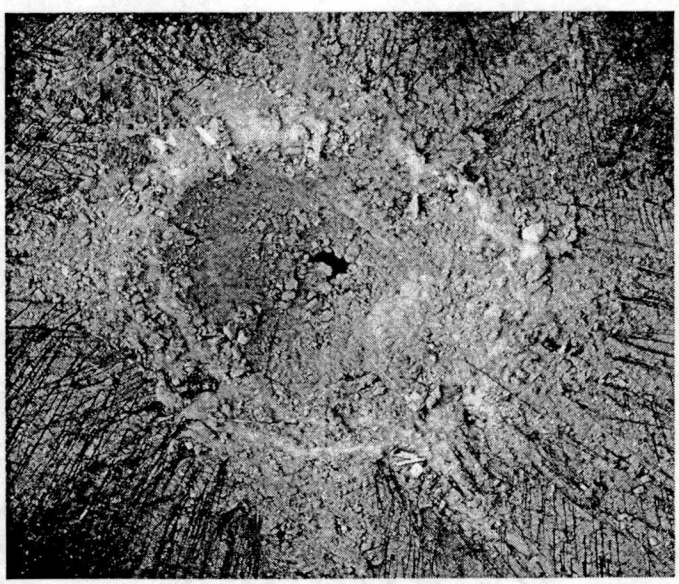

Figure 3.
Result of CF-188714 Accident

Requirement for Flight Test

There has been a great deal of research concerning acceleration effects on the human body, including the effect of baroreceptor stimulation on vasoactivation and heart rate (Ref 9). The physiological consequences of stimulation of the baroreceptors by $+g_z$ forces have been extensively studied and, to a lesser degree, stimulation by $-g_z$ has also been studied (Refs 10, 11, 12). The push-pull hypothesis is not new, and physiological research studies have already been conducted on the phenomenon. However, there was a clearly defined need to conduct flight test in support of DCIEM research. As discovered during recent centrifuge and limited in-flight studies, the possibility exists that the baseline g-force typically found in centrifuges (approximately $+1.4$ g_z) stimulates the cardiovascular system significantly in the form of vasoconstriction, heart rate increase, and cardiac contractility increase (Ref 4). This "priming" of the system is not seen in-flight, where a typical engagement may begin from 1 g_z or, in some critical cases, less than 1 g_z.

Flight test was the only means available to allay the concerns surrounding g-simulators. As such, this flight test program was undertaken jointly between AETE and DCIEM, with the aim being to measure the physiological response of relaxed test subjects, unprotected by anti-g suit, when exposed to the push-pull manoeuvre in-flight. This singular test case was chosen for safety of flight concerns as will be discussed fully in this thesis; and, to provide a simple set of flight test results against which g-simulator data could be compared. In doing so, it was hoped that the flight test data would validate

that obtained during centrifuge research. If proven to be the case, it will minimize the further requirement for expensive flight test and allow the majority of future research to take place in g-simulators, with lower effort and cost.

Future Work

Designing comprehensive protective strategies against acceleration effects requires a thorough understanding of the full consequences of the push-pull effect. New anti-g valves will likely be part of an advanced $+g_z$ protective system that includes protection against the push-pull problem. These valves will be microprocessor controlled and will monitor the g_z time history during flight to determine the optimum pressure schedule to be delivered to the anti-g garment in order to prevent or delay the onset of G-LOC. Eventually, the results from this test program will assist DCIEM in developing new anti-g life support systems that may take different approaches to the problem. Such systems will be vital for pilots of current and future high-performance military aircraft.

EQUIPMENT UNDER TEST

Test Aircraft

CF-18 Aircraft. The CF-18 was a high-performance, supersonic fighter/attack aircraft built by the McDonnell Douglas Corporation. Two General Electric F404-GE-400 low-bypass axial-flow turbofan engines with afterburner powered the aircraft, each rated at 10,700 lb of static thrust at military power and 16,000 lb of static thrust at maximum power

at sea level. Distinguishing features included: moderately swept mid-mounted wings, twin vertical stabilizers mounted 20° from the vertical, hydraulically actuated differential horizontal stabilizers, and leading edge extensions mounted on either side of the forward fuselage from the wing roots to just forward of the windscreen. The aircraft incorporated hydraulically actuated full-span leading edge flaps, inboard trailing edge flaps, and outboard ailerons on each wing. A more detailed description of the aircraft is given in the CF-18A/B Hornet Aircraft Operating Instructions (Ref 13).

The specific test aircraft used for this flight testing was CF-188907. CF-188907 was a production Lot V, fully-instrumented, dual-seat aircraft. Key features of the baseline instrumentation system included a programmable conditioning unit utilizing a V-80 video format data recorder, and on-board S-Band telemetry capability. For this testing, CF-188907 was equipped with a modified Triple Deck Cockpit Video Recording System (TDCVRS). The TDCVRS was modified to record the Heads-up Display (HUD) and the right Digital Display Indicator in the front cockpit, with the third camera mounted to record the rear seat occupant during flight. The system incorporated three colour cameras and a vertical insertion time code to allow synchronized playback of all display imagery. The S-Band telemetry system, complete with video compression unit (VCU), allowed for the real-time data transmission of all test data, including rear cockpit video, to the flight test control room during flight.

Test Specific Installations

Although CF-188907 was used as the test vehicle during this flight test program, the data of primary interest were the physiological responses of the rear seat occupant, which were monitored in real-time by DCIEM medical and/or scientific personnel in the AETE control room. To provide these measurands, specialized bio-medical instrumentation was installed in CF-188907. A full description of the measurands required, and why each measurand was required in relation to the test methods used for the in-flight research, is given in the discussion of Test Methods, Results and Discussion, detailed later in this thesis.

As an equipment installation overview, the following describes the instrumentation items installed in CF-188907 for this test program; reference is given to the photographic documentation provided in Appendix A.

a. an armrest to support the arm and hand used for the *Portapres* blood pressure measurements was installed on the left console; aircraft throttles were removed from the rear cockpit (Fig A-1);

b. the third camera of the TDCVRS was mounted on the canopy cross-member, facing rearward, for in-flight monitoring of the test subject (Fig A-2);

c. a light bar (for test subject light loss qualification), complete with shroud, was mounted on the canopy cross-member (Fig A-2);

d. a control stick for test subject control of the abort light and central/peripheral shoot lights was mounted on the right console (Fig A-3);

e. two *Portapres* calibration units were mounted on the canopy frame, right side. A counterbalance was installed on the opposite side of the canopy for escape systems concerns (Fig A-4);

f. a *Biolog* medical signal conditioning unit for electromyogram (EMG) and electrocardiogram (ECG) was mounted on the aft coaming, behind the seat headbox, right hand side (Fig A-5);

g. two *Portapres* main units and pumps were mounted on the aft coaming, behind the seat headbox, left side (Fig A-6);

h. the ear opacity/pulse control unit was mounted behind the seat headbox, left side, above the *Portapres* mounts (Fig A-6);

i. the test subjects had two ear opacity sensors attached to their ears under the 190A helmet. The required wiring harness was attached to the external shell (Figs A-7 and A-8);

j. two reference tubes for hydrostatic correction of blood pressure were routed from the left pressure cuffs, under the flying clothing. One reference tube was attached via medical tape to the chest; the other was attached via velcro to the 190A helmet at eye level (heart level reference shown in Fig A-9);

k. three medical leads were attached to the torso for the ECG. Six more were attached for the EMG, three to the right side abdominal muscles and three to the vastus lateralis of the right leg. All leads were attached with medical tape (Fig A-10 and A-11);

l. all medical leads were configured such that the wiring was combined into 2 harness bundles. These bundles were routed through and attached to a strain relief vest designed to take all strain at the hips and not transfer any to the individual medical leads (Fig A-12 and A-13); and

m. the test subject was connected to the instrumentation via 2 quick disconnect (QD) cables. A 26-pin connector was used on the right side; a 10 pin connector was used on the left side. Both quick disconnects were configured for ejection and critical egress clearance from their attachment to aircraft wiring upon application of less than 20 lb force each (Fig A-14 and A-15).

Aircrew Life Support Equipment

To safely and effectively incorporate the physiological instrumentation into the rear cockpit of the CF-18, several non-standard Aircrew Life Support Equipment (ALSE) items and procedures needed to be developed. These items are described in the subparagraphs following, with reference to the photographic documentation provided in Appendix B. As far as possible, test subjects were dressed in CF standard flying clothing, and used fleet standard ALSE, with the following exceptions:

a. the left flying glove had the fingers removed to allow the *Portapres* blood pressure cuffs to be placed over the fingers. The flying glove was attached, via velcro, to a plastic molding which held the thumb and fingers in the proper position for blood pressure measurement (Fig B-1);

b. the flying suit was modified with an opening on each hip to allow the physiological wiring harnesses to pass through. From there the harnesses were configured for quick disconnect (Fig B-2);

c. the test subjects wore a National Aeronautics and Space Administration (NASA) modified United States Air Force (USAF) torso harness in lieu of the CF standard simplified combined harness. The modified torso harness was chosen for its superior restraint in the negative g regime (Fig B-3);

d. the test subjects wore a modified version of a Mustang Survival life preserver (model number MSV 971) for compatibility with the survival vest and modified torso harness (Fig B-3);

e. the test subjects did not wear any anti-g protection garments;

f. the rear cockpit SJU-9/A ejection seat was configured for use with the NASA modified USAF torso harness. This configuration incorporated the current CF-18 parachute headbox packed with a GQ 1000 parachute, rigged with United States Navy risers and H. Koch and Son male parachute disconnect fittings (Fig B-4);

g. the rigid seat survival kit (RSSK) lid was replaced with a NASA modified version that was compatible with the torso harness. For this RSSK lid, the emergency oxygen by-pass modification was removed. Emergency oxygen was fed through the standard Robert Shaw dilute demand oxygen regulator during any activation of the emergency system; and

h. the lid of the RSSK in the rear cockpit was fitted with a 3 in. memory foam cushion, covered with black sheepskin. This cushion was added for comfort of the test subjects during flight.

II - TEST CONCEPT

OVERVIEW

Testing was divided into three phases. The first two phases, Escape Systems Testing and EMC Testing, were conducted to ensure that the aircraft instrumentation configuration was safe and airworthy for flight of a physiologically instrumented test subject in the rear seat of the test aircraft. The third phase of testing, In-flight Physiological Research, was conducted to gather in-flight physiological data regarding the push-pull effect from a number of test subjects.

During Phase 1, Escape Systems Integration, test-specific procedures were developed for test subject dressing, strap-in, ingress/egress to the test aircraft, and emergency egress/ejection. In addition, human factors and engineering concerns associated with the integration of an instrumented human test subject into the harness and specially configured rear cockpit of the CF-18 were identified and rectified prior to the commencement of flight testing.

During Phase 2, the EMC of the bio-medical instrumentation systems with the test aircraft baseline systems was evaluated. Rectification of problem areas was completed, as required, to grant a project-specific, restricted safety of flight EMC clearance for Phase 3 in-flight research. In addition, limited data validity testing was conducted on-site by DCIEM.

The Phase 3 In-flight Physiological Research program represented one of the first in-flight test programs where comprehensive bio-medical research was conducted in an operational military aircraft. The overall aim of the test program was to measure the physiological responses of relaxed, unprotected test subjects when exposed to the push-pull manoeuvre during flight. The data collected during this undertaking was to be provided to DCIEM for their full and comprehensive bio-medical analysis. All bio-medical data was considered to be proprietary to DCIEM for their analysis; however, all results and findings were to be fully shared.

OBJECTIVES

The following paragraphs detail the specific test objectives for each of the three phases:

Phase 1. Escape System Clearance

The specific objectives of Phase 1 testing were to:

a. develop donning procedures for the flying clothing over the human-mounted instrumentation and ensure the functionality of the strain relief system;

b. develop test specific CF-18 ingress, egress and emergency egress checklists and training procedures;

c. evaluate the test subject's ability to perform all required in-flight duties while wearing all instrumentation, a flying suit, winter flying clothing, and the modified torso harness;

d. evaluate the rear cockpit to ensure that no test instrumentation caused interference with either the occupant or the escape/ejection path; and

e. perform testing to ensure that the instrumented test subject could perform all post-ejection drills.

Phase 2. EMC Testing

The specific objectives of Phase 2 testing were to:

a. conduct restricted EMC safety of flight testing on the VCU and the newly-located S-band telemetry antenna on door 3 of CF-188907;

b. evaluate, for project-specific restricted safety of flight purposes, the impact of the bio-medical instrumentation on aircraft EMC and provide airworthiness recommendations with respect to use of the bio-medical equipment during this test program; and

c. conduct limited data validity testing, in conjunction with DCIEM.

Phase 3. In-flight Physiological Research

The specific objectives of Phase 3 testing were to:

a. conduct flight testing, in conjunction with DCIEM, to measure the physiological responses of relaxed, unprotected test subjects when exposed to the push-pull manoeuvre in flight;

b. demonstrate the capability, for safety purposes, to monitor (in real-time from the control room) the physiology of relaxed, unprotected test subjects when exposed to the push-pull manoeuvre in flight; and

c. format and reduce measured data to allow DCIEM to compare it against data from g-simulators and use it during future research work.

III - PHASE 1, ESCAPE SYSTEMS INTEGRATION AND CLEARANCE PHILOSOPHY

From the outset, one of the largest drivers of this test program was ensuring that the cockpit environment, including the ability to perform critical egress and ejection from it, if required, was kept as safe and as close to the standard configuration as possible. Obviously, instrumenting the human occupant of the rear cockpit with 13 electrode leads, 2 reference tubes, and 3 blood pressure finger cuffs, all of which were routed through bio-medical signal conditioning boxes which ran on aircraft power, posed some unique challenges.

Through careful design and the ongoing technical consultation of escape systems experts, the final human instrumentation configuration was able to address these concerns, primarily by following two key philosophies. The first was to remove from the human subject as much instrumentation as possible. All signal conditioning units, many of which were designed to be mounted on or carried by the human during clinical trials, were mounted elsewhere in the cockpit. This necessitated the careful design and integration of mounting brackets and an instrumentation armrest, installed in place of the rear seat throttles. All mounted hardware was designed to remain clear of the ejection path. All mounts made on the canopy were appropriately counter-balanced to allow for proper jettison functionality. In total, some 20 lbs of instrumentation was kept off the test subject, free of the ejection path; a key factor in satisfying ejection concerns.

The second philosophy was to ensure that any connection made to the human body was strain relieved and configured for quick disconnection in the event of critical egress or ejection. Bio-medical leads were attached to the test subject's ears, chest, abdomen, leg, and left arm. All leads were reconfigured such that the wiring was combined into 2 harness bundles. These wire bundles were routed first to a strain relief vest then to quick disconnects configured to separate under application of less than 20 lbs force each. From these quick disconnects, appropriate wiring was routed to the signal conditioning units mounted in the aircraft. By design, these quick disconnects removed all human connection to the aircraft as soon as the test subject stood up during a critical egress, or as soon as the seat began to move up the rails during an ejection sequence. In addition, any pull force was taken at the hips via the strain relief vest. No local strain was transferred to any of the bio-medical lead attachment points.

The final Escape Systems issue, which was a major consideration during this test program, was the position of the ejection seat SAFE/ARM handle during the test points. During all testing, the ejection command selector valve was placed in the NORMAL position. Prior to commencement of the first test point, the rear ejection seat was put SAFE. At the completion of the last test point, once the test pilot and control room staff was satisfied with the cognition of the test subject, the rear ejection seat was ARMED until landing. Putting the seat SAFE during test points was done to ensure that the rear seat ejection control handle was not inadvertently actioned during or following any potential G-LOC episode. Notwithstanding the position of the rear seat SAFE/ARM

handle, the front seat test pilot retained the ability to eject both seats at any time, should an emergency situation have dictated such action.

CLEARANCE TESTING

Prior to allowing any test subjects to fly in the rear cockpit of the test aircraft, a full set of Escape Systems clearance tests were conducted in order to determine the airworthiness of the cockpit configuration for flight, and to assess the effectiveness of the philosophical approach taken. Primary concerns in this area were ensuring that the entire ejection system (canopy, seat, and occupant) would function as originally intended, with no degradation due to the installed test instrumentation. In addition, procedures needed to be developed for donning, ingress, egress, emergency egress and ejection that would encompass the additional needs of the installed instrumentation systems, yet still be straightforward and simple to accomplish in normal and emergency situations.

To complete this Escape Systems evaluation, the test subjects during applicable portions of the evaluation received a complete issue of modified flying clothing, ALSE, and human-mounted test instrumentation. All testing was done using a static CF-18 aircraft, the ejection training seat, the CF-18 flight simulator, the CF-18 parachute training rack, or the 4 Wing Cold Lake pool. All testing was qualitative, using hand recorded data and photo/video coverage.

Donning and Strap-in Procedures

Instrumentation, clothing, and flying equipment-donning procedures were established during the evaluation without the assistance of a DCIEM dressing assistant; unlike during the period of flight testing, where a DCIEM assistant was always present. Test subjects for this evaluation were instrumented with bio-medical sensors on their underwear (Figs A-9, A-10 and A-11) instead of the skin, as was the case during the actual in-flight research. Strap-in procedures were developed statically on the ejection training seat and on-board CF-188907 to provide the safest and most efficient method of strapping the test subject into the aircraft.

It became apparent that the procedures established for test subject dressing needed to remain flexible. The wiring harnesses utilized were one size only, which resulted in different amounts of wire needing to be routed and secured to the test subject, dependent upon their anthropomorphic size. During strap-in of the test subject into CF-188907, it also became apparent that the test subject was somewhat limited in his ability to perform his own strap-in duties without jeopardizing the integrity of the bio-medical instrumentation attachments. As such, the strap-in procedures for the instrumented test subject were developed with the caveat that all test subjects required the assistance of a qualified CF-18 ground crew trained in Push-Pull specific strap-in duties. Once the optimal donning and strap-in methods were established, formal procedures were documented on checklists that were used by the test team throughout the in-flight physiological research. These checklists are appended at Appendix C. The procedures

worked well throughout the test program, and the standardization techniques employed were essential to ensuring that 16 test subjects could be put through the program rapidly.

Strain Relief System

Functional evaluations on the effectiveness of the strain relief systems were conducted by pulling on each of the wiring harnesses and noting any movement/disconnect at the medical lead attachment points. To ensure that the strain relief system was functional and adequate for use during flight, Escape Systems personnel pulled on both wiring bundle QDs with as much force as possible. The results were that no bio-medical sensors pulled loose, nor did any of the extra wire from the strain relief vest pull loose. The strain relief system worked well throughout all flight testing and would have protected the test subject from injury during the event of an ejection.

CF-18 Emergency Egress Procedures

The current CF and modified NASA emergency egress procedures were used to establish a unique set of procedures that were designed to ensure that the test subjects could emergency egress from the SJU/9A ejection seat. This was accomplished by utilizing a standard CF-18 training seat fitted with the NASA modified USAF torso harness. The process was iterative and, once the optimal procedures were established, formal procedures were documented on a checklist to be memorized and carried by each test subject. These procedures are detailed at Appendix C.

For evaluation of these procedures in the actual test aircraft, the CF-188907 rear ejection seat was made safe from ejection via the standard ejection seat maintenance pin set. A fully instrumented test subject boarded the aircraft by use of the aircraft boarding ladder, then was strapped into the rear seat of CF-188907 in accordance with the checklist. All test instrumentation was then connected. The test subject then performed the authorized emergency egress to ensure that there were no unforeseen differences between the training seat and the actual rear cockpit environment of CF-188907.

What was made evident throughout the test program was the need for thorough training of each test subject on the emergency egress procedures, as the unique ALSE and instrumentation configuration required different procedures from those used in any CF aircraft. Test subjects were required to perform a minimum of 2 timed emergency ground egress trials from the training seat and achieve an egress time of less than 15 sec, prior to being granted clearance to fly. The emergency procedures (although never required for an actual emergency during test) and training procedures were highly effective.

Evaluation of In-flight Duties

While strapped into the rear seat of CF-188907, the canopy was lowered and the accessibility of the controls required for the project was evaluated. The instrumented test subject performed all in-flight duties required by DCIEM. This evaluation was conducted to ensure that the test subject was capable of performing all the required procedures and that the test instrumentation and operating procedures posed no safety hazards to the test

subject. There were no observed problems for the rear seat test subject in operating the controls as outlined by DCIEM under static 1 g conditions, nor were there any observed during the conduct of the in-flight research.

Rear Cockpit Evaluation for Ejection Path Clearance

Evaluation of the escape path for the SJU/9A ejection seat and the aircraft canopy was performed by visual inspection, in accordance with The Air Standardization Coordinating Committee Advisory 6V47 (Ref 14). For measurement of quick disconnect forces, MIL-C-83390 (USAF) (Ref 15), which dictates the maximum force for disconnecting an anti-g suit connector, was used as a standard for the force to disconnect the wiring harness QDs (attached to the test subject) from the aircraft.

The rear cockpit was evaluated by component (canopy, ejection seat, ejection seat clearance and bio-medical instrumentation). Each individual component was evaluated both in isolation and as part of the integrated system.

CF-188907 Canopy. DCIEM required the installation of a light bar on the canopy cross member above the rear seat glare shield. Incorporated in the light bar was an aft facing video camera to monitor and record the test subject in-flight. In addition, *Portapres* calibration units were mounted on the canopy frame, right side, with a counterbalance weight mounted on the left side.

a. all three items (light bar, video camera, and the *Portapres* calibration units) required aircraft wiring routed to them; therefore, a method of

disconnecting the canopy wiring harness from the aircraft had to be established. The method chosen was to replace the current canopy wiring QD, 22-pin connector, with a 66-pin connector to accommodate the additional wires required for these three devices. The current 22-pin connector had an average disconnect force 10.5 lb and the 66-pin connector had an average disconnect force of 18.2 lb. However, fleet standard CF-18 aircraft equipped with dual deck video recording systems utilized a 26-pin connector that had an average disconnect force of 19.5 lb. This resulted in the test aircraft for this program requiring less pull force than fleet standard, which was acceptable;

b. the light bar and video camera caused no interference with respect to the escape clearance path, with or without the canopy being jettisoned; and

c. the *Portapres* calibration units and counterweights, on the left and right side of the canopy respectively, were securely mounted on the inboard side of the canopy sill. While the canopy was closed, a plumb line was dropped from each item and the distance from the line to seat was measured. Neither device obstructed the escape path for the case of a canopy-first ejection or a seat-through-canopy ejection.

In the tested configuration, which was used throughout Phase 3 in-flight physiological research, the aircraft canopy on CF-188907 caused no interference problems with any escape systems components.

SJU-9/A Seat and Aircraft Clearances. The distance between the existing Manual Override (MOR) linkage guard and the aircraft kick panels was used to determine safe clearance distances between the seat and the aircraft, as this was the part of the seat closest to the aircraft structure. With this dimension as the baseline, no instrumentation was closer than the MOR linkage guard.

Furthermore, the escape path for the ejection seat was evaluated to ensure that it was clear of all possible sources of injury to an ejecting test subject and/or sources of damage to the personnel protective clothing and equipment of an ejecting test subject. All aircraft mounted test instrumentation systems on the periphery of the ejection path were evaluated to ensure that no sharp edges, sharp corners, projecting bolts or hardware were capable of being contacted during an ejection, and that all QDs would be capable of disconnecting both automatically and manually. No anomalies were found during testing.

Bio-medical Instrumentation. All bio-medical instrumentation systems were installed clear of the ejection path and, to the maximum extent possible, off the test subject. The following subparagraphs detail the results of escape systems clearance testing for the major items of bio-medical instrumentation:

a. Armrest. The final version of the armrest was completely clear of the canopy during opening/closing and the ejection seat escape path. The quick release bracket designed for the *Portapres* telecom connector was effective. Three different test subjects evaluated the pull force required to disconnect the pump leads and wiring from the armrest in accordance with

the test-specific emergency egress procedures. All three were able to quickly and easily pull their hands clear of the wiring routed through the armrest in one quick pull.

b. *Portapres* Pumps and Ear Opacity Control Unit. After a number of iterations, the mounting boxes for these units were installed far enough aft on the aircraft coaming left and aft of the seat so that they remained clear of the seat's ejection path, determined by placing a straight edge along the angle of the aft firewall.

c. *Biolog.* After a number of iterations the mounting box for this unit was installed far enough aft on the aircraft coaming right and aft of the seat so that it remained clear of the seat's ejection path, determined by placing a straight edge along the angle of the aft firewall.

d. Light Bar Control Stick. After a number of iterations the control stick, when installed, caused no interference with either ingress/egress or the ejection seat escape path.

e. Quick Disconnects. The Reference 15 specification stated that the QD pull force should be not less than 5 lb or more than 20 lb. The average pull force for both the 10 pin and the 26 pin connectors was determined by having three test subjects dynamically pull the QDs free using a force gauge. In each case, the force was greater than 5 lb, yet less then 20 lb, and posed no problems in pull force testing.

In the tested configuration, which was used throughout Phase 3 in-flight physiological research, the bio-medical test instrumentation installed in CF-188907 caused no interference problems with any escape systems components.

Post-ejection Procedures

For this evaluation, test subjects were dressed and fully instrumented, then suspended in the CF-18 parachute training rack. The test subjects were required to demonstrate all post-ejection drills for open terrain, water and wooded landing scenarios. All scenarios were mandatory due to the diverse geography present in the Cold Lake flying area. In addition, in-water evaluations were performed to evaluate any adverse impact that the test instrumentation had on the current procedures for water entry and liferaft boarding. This testing was performed in calm waters at the 4 Wing Cold Lake pool. Current CF-18 post-ejection procedures were modified to encompass the additional/different actions required as a result of the test-specific instrumentation and ALSE used. All test subjects underwent training on these procedures and were required to memorize them prior to being granted clearance to fly.

The procedures developed for the three post-ejection scenarios evaluated are detailed in Appendix C. The test subjects easily grasped all procedures and thorough training ensured they were safe to fly with the added instrumentation.

SUMMARY

Based upon the results of the Escape Systems Clearance testing, the two key philosophies adopted to integrate the bio-medical instrumentation into the test aircraft (removal of equipment from the human and strain relief of all connections) proved to be highly effective. In addition, the Escape Systems Clearance Testing was highly successful in developing standardized procedures on which all test subjects could be effectively trained. These test procedures, and the methods developed to mount the bio-medical instrumentation (modified accordingly to encompass any future instrumentation or ALSE differences) should be utilized during any follow-on physiological flight testing conducted by AETE and DCIEM.

IV - PHASE 2, ELECTROMAGNETIC COMPATIBILITY TESTING

OVERVIEW

Phase 2, EMC Testing, was completed prior to commencement of research flying during Phase 3. Due to severe time constraints, only a project-specific restricted safety of flight evaluation was conducted for this test program. EMC testing was divided into three parts: investigative tests/emissions measurements, specification compliance testing, and compatibility assessment. The compliance tests were governed by References 16, 17, and 18. Where possible, test point frequencies were determined by analysis such that source-victim states were at maximum susceptibility. In addition, data validity testing was conducted prior to active flight test, in consultation with on-site DCIEM staff.

The author did not conduct the EMC testing; however, as Project Officer, he was responsible to oversee its conduct to ensure that the installed instrumentation systems did not affect safe operation of the test aircraft, nor did any of the standard aircraft systems degrade the operation of the test instrumentation. Full details of the testing conducted, including measurements taken, and recommendations made regarding EMC test procedures, were reported on in the EMC technical note in Reference 19. The results detailed in this thesis highlight the main findings given in that report.

INVESTIGATIVE TESTS/EMISSIONS MEASUREMENTS

These tests consisted of measuring the conducted and radiated emissions (CE and RE) from the newly-installed flight test instrumentation (FTI) active components judged to

be potential sources of significant unintentional emissions. The measurements were done in the ambient electromagnetic environment (EME) and corrected by extracting non-coherent, magnitude-only samples of the ambient EME from the emission samples. The components measured for CE and RE were:

a. the VCU, Lockheed Martin Conic model no. 600A;

b. direct current (DC)-to-DC converter board, local manufacture, drawing number 9826129X;

c. isolation amplifier board, local manufacture, drawing number 9826128X;

d. light bar randomizer board, local manufacture, drawing number 9726379X;

e. *Biolog*, UFI model no. 3992/10 "A";

f. two *Portapres* units, TNO Biomedical Instrumentation model no. 2.0;

g. ear opacity/pulse unit, manufactured by DCIEM, model no. n/a; and

h. digital temperature display, Omega model no. DP116-MC2-GR-9/26.

The emissions from the instrumentation pallet installed in the avionics bay of the test aircraft, the aft seat area, the canopy, and the VCU were measured relative to ambient levels to assist in predicting the potential for unintentional emissions to interfere with aircraft communication and navigation receivers. The result of the probing indicated that the VCU did emit a few strong narrowband components (i.e., > 30 decibels [dB] above ambient) in the very high frequency/ultra high frequency (VHF/UHF) bands, which could potentially degrade aircraft receivers. The strongest emission frequencies were included as test points in the Compatibility Assessment, Tunable Systems, discussed below.

SPECIFICATION COMPLIANCE TESTING

The following tests were conducted to evaluate the test items with respect to electrical bonding and electrical power characteristics (EPC):

a. electrical bonding measurement was conducted in accordance with Reference 16 classes H and R limits for metal-to-metal interfaces at enclosures and antennas, and class C limits for power return to the aircraft primary structure; and

b. EPC measurement was conducted in accordance with References 17 and 18 limits for transient and steady-state behaviour of FTI at points immediately connecting to the aircraft's power distribution system.

Electrical Bonding

All FTI components were well bonded except for the camera and the S-band telemetry antenna on door 3. The lack of bonding between the camera and the aircraft structure did not appear to pose an airworthiness risk and was deemed to be acceptable for Phase 3. The antenna bond was determined to be unsatisfactory since a poor bond between the antenna housing, adapter plate and aircraft skin could worsen with changes in temperature, pressure and vibration, thus creating unpredictable paths for p-static discharge. It was recommended that the antenna bond be improved. This was done prior to Phase 3 flight testing.

Electrical Power Characteristics

Transients. The transient EPC presented by the new FTI was measured at the aircraft's auxiliary power connector in the nose wheel well. The trigger threshold for DC measurements was +/-2 volts. External ground power was used with all four power control switches set to B, Inertial Navigation System (INS) in test mode, radar in standby, all Digital Display Indicators in the ON position and all up front control avionics in the ON position. The alternating current (AC) bus was monitored for relatively long transients using the Fluke Model 97 Scopemeter's record function. Transients on both the AC and DC busses were evaluated while switching the newly added FTI via the available FTI, Telemetry and TEAC pushbuttons in the forward cockpit. No significant transients were detected on either the DC or AC bus, which was satisfactory.

Steady State. The steady state loads presented by the FTI to the aircraft's 115 volts alternating current and 28 volts direct current power distribution were measured at the interface points to the aircraft power distribution system using a Kyoritsu Model 2004 clamp meter while connected to external ground power (Hobart #12). The load was measured with all bio-medical equipment, telemetry transmitters, VCU, and baseline FTI equipment powered on.

A significant AC component was observed on the DC bus. The DC bus was monitored for several minutes and the ripple was found to be aperiodic with periods on the order of 1 sec. The distortion factor of the aircraft's DC power, averaged over 2 min, was 1.1×10^{-2}. Similar voltage measurements of the DC power on CF-188796 (powered

via Hobart #1) yielded a distortion factor of 1.3 x 10^{-2}. The Reference 18 limit for the distortion factor on a DC Bus is 3.5 x 10^{-2} (and the distortion spectrum in Reference 18 is only defined to 10 Hertz [Hz] for the lower limit). Based on these EPC measurements and on the FTI's broadband switching effects reported below, the EPC were satisfactory.

COMPATIBILITY ASSESSMENT

The following tests were conducted to evaluate intrasystem compatibility. For expediency, the maximum number of victim systems were kept active, where possible, and monitored simultaneously while activating FTI as a potential source.

a. tunable system interaction tests included source-victim test points of maximum susceptibility based on analysis of the CE and RE data collected on the FTI equipment; and

b. non-tunable system interaction tests included source-victim test points the extent of which were based, in part, on the severity of the transients observed during the EPC measurements.

Tunable Systems

Interaction tests for tunable systems were completed with the following observations:

a. no degradation of Comm 1 VHF/UHF reception was detected at the Cold Lake active channels;

b. a maximum degradation of reception of 20 dB on Comm 1 and of 6 dB on Comm 2 was detected due to FTI Electromagnetic Interference (EMI) at 359.500 MHz, one of the strongest measured RE levels;

c. no degradation of Instrument Landing System (ILS) localizer or glideslope was detected at low, mid and high channels or at the ILS Cold Lake channel;

d. no degradation of tactical air navigation or distance measuring equipment tuned to ramp test set , channel 18X, was detected;

e. no degradation of the aircraft transponder tuned to a ramp test in mode 3/A was detected; and

f. no degradation of radar altimeter was detected.

Nontunable Systems

All test points for nontunable systems, which included the engines, the flight controls electronic set and the air data computer were completed with no interference due to FTI observed.

DATA VALIDITY

Data validity was ensured via a laboratory test of the entire instrumentation system prior to installation in the aircraft, followed by an evaluation of the bio-medical data integrity using the S-band telemetry link between CF-188907 and the flight test control

room with the aircraft running statically on the ground. Following these evaluations, a total of six instrumentation check flights were performed, during which the telemetry system was configured for optimal performance. During these check flights, DCIEM personnel performed on-site evaluation of telemetered bio-medical data and deemed the results acceptable for data analysis needs.

SUMMARY

EMC Testing to evaluate the suitability for flight of the test instrumentation systems in the aircraft identified only minor compatibility concerns. Inadequate bonding between the S-band telemetry antenna and the aircraft structure was identified and corrected prior to commencement of flight test. Compatibility testing between the aircraft and the bio-medical FTI installed for this test program, with the FTI treated as source, revealed 20 dB of degradation on a few Comm 1 UHF channels due to a FTI narrowband emissions but no EMI was found on Cold Lake active channels. The presence of EMI on certain Comm 1 channels was unsatisfactory; however, the lack of any EMI on active Cold Lake channels was acceptable for this test program.

Provided with the test results from this Phase, the test aircraft was granted a restricted safety of flight clearance for Phase 3, In-flight Physiological Research. This allowed the test aircraft to be flown within the local flying area, for test specific purposes only, which was acceptable for conduct of the test program.

V - PHASE 3, IN-FLIGHT PHYSIOLOGICAL RESEARCH

TEST APPROACH

The use of CF-188907, which was fully instrumented and extensively modified for this test program, allowed for the in-flight measurement of the physiology of the test subject, who occupied the rear seat. Obviously, in conducting testing of this nature, safety precautions were required to ensure that the flying pilot did not himself fall prey to the push-pull manoeuvre. To provide this margin of safety, the front seat pilot was equipped with anti-g garments and performed an anti-g straining manoeuvre (AGSM) whenever required. The rear seat test subject was not equipped with anti-g garments and performed no AGSM or straining of any sort during the test profiles. All testing was flown based upon the relaxed, unprotected g tolerance of the rear seat occupant.

The test profiles flown consisted of combinations of low positive or negative g_z followed by moderate $+g_z$. These profiles were designed to expose the unprotected test subject to push-pull manoeuvres of varying $+/-g_z$ intensities, eliciting physiological responses ranging from mild to moderately profound. The following paragraphs detail the methods of test used during this program. Attention is given not only to the actual in-flight test methods, but also to the methods used for test subject selection and training, test monitoring and control, and G-LOC prevention.

DATA GATHERING

Overview

The data of primary interest during this test program were the physiological responses of the rear seat occupant, which were monitored real-time by DCIEM medical and/or scientific personnel in the control room. The data to be collected during this test program were chosen with two aims: in-flight monitoring of the test subject from the control room, and data collection for use in later analysis of the push-pull phenomenon.

Physiological Measurands and Bio-medical Instrumentation

Measurements taken were both subjective and objective, and included measurements of the human response to the test manoeuvre, test profile environmental, and aircraft conditions. The specialized bio-medical monitoring systems installed in the aircraft provided researchers with the physiological measurands required. Test subject response to standardized questions was also used in the analysis. The following paragraphs detail the measurands required, why each measurand was required, and a brief description of the equipment used to obtain them.

Arterial Blood Pressure. Blood pressure indicated the fundamental ability of the subject to withstand $+g_z$ stress, as it quantified the ability of the body to circulate blood against hydrostatic gradients. Blood pressure was measured non-invasively with a *Portapres* unit. Miniature blood pressure cuffs were placed around two fingers of the left hand and cuff pressure was controlled automatically by the *Portapres* to yield beat-by-

beat readings, which were recorded onboard the aircraft and telemetered to the control room. The technique required that two adjacent fingers be monitored. An additional cuff was installed on a third finger to act as a backup. Via reference tube sensors, blood pressure measured from one finger was corrected to heart level blood pressure, while the reading from the second finger was corrected to eye level blood pressure. Recording errors were minimized by maintaining the hand near heart level during the entire mission through use of a specially designed armrest, installed in place of the rear cockpit throttle quadrant.

Ear Opacity/Pulse. Ear opacity/pulse was valuable as a direct indicator of the adequacy of blood pressure at head level and, when monitored continuously, helped to guard against inadvertent G-LOC. Ear opacity was measured non-invasively by measuring light transmission through the left and right ears of the test subject. This was used to indicate the subject's blood content at eye-level. The ear opacity sensors were positioned so that the pinna of the ear lay between and against the light emitter and photo-detector. In this manner, the unit provided continuous signals of light transmission through the ear.

Electrocardiogram. The ECG was used to monitor the heart's electrical activity, rhythm, and rate. Three electrodes were attached to the skin at specific points on the chest. Leads were connected between the electrodes and a *Biolog* signal conditioning box, where a resultant ECG waveform was produced for data recording and in-flight monitoring from the control room.

Extent of Visual Field. Visual field (both subjective and objective) was assessed throughout the test profiles. Three lights were installed on a shrouded light bar assembly, with two of the lights (green) situated bilaterally in the subject's peripheral visual field and the other (red) situated in the central field, directly in front of the test subject. These lights were frequently illuminated in a semi-random manner to objectively test the subject's vision. While focused on a point at the front center of the cockpit, the subject was required to extinguish the lights using switches mounted on a specially installed control stick on the right console of the rear cockpit. In addition, the subject was required to subjectively estimate the amount of visual field loss and report it to the control room following each profile. For this reporting, standardized categories were used.

Electromyogram. When the subject remained relaxed during $+g_z$ exposure, there should have been minimal contraction of the main muscles used for an AGSM. Signals from the EMG were monitored to confirm that no straining was being performed during the profile. The EMG recorded the electrical activity associated with contraction of skeletal muscle. Electrodes were placed on the abdominal muscles, and on the vastus lateralis of the right leg. The leads were routed through the *Biolog* signal conditioning box to generate a waveform for recording and telemetry to the control room.

Body Core Temperature. Increased body temperatures promote vasodilation, which in turn can lower blood pressure and therefore g_z tolerance. To monitor and record body temperature, the subject's oral temperature was measured twice, just after strap-in and again immediately after unstrapping from the test aircraft.

Physical Well Being. The physical well being of the test subject was constantly monitored during flight via the real-time video feed. In addition, subjective ratings of visual field loss, cognition, alertness and comfort were given by the subject after each test profile. A questionnaire was administered to each test subject following completion of their test sorties to obtain qualitative descriptions of the physical sensations they experienced during the test flights.

Physical Environment Measurands

The intent of these measurements was to record, as closely as possible, the physical environment to which the test subject was exposed in the rear seat of the test aircraft. For acceleration (g), the longitudinal, lateral, and normal axes (g_x, g_y and g_z) were measured to verify the exact g vectors that acted upon the test subject during the test profiles. All three measurands were taken from the INS of the aircraft, located just below the cockpit. Specialized accelerometers were also used as backups to these data. The primary measurand of interest was g_z, which represented the vector sum of inertial forces and gravitational acceleration acting on the test subject in the normal direction (perpendicular to the flight path). It was g_z that the test subject sensed as a downward force (from head to feet), which increased the hydrostatic gradient for heart level blood pressure, thereby reducing the pressure at eye level, and increasing the risk for G-LOC.

In addition, since large differences in cabin pressure and body oxygen between profiles could alter g_z tolerance, cabin pressure was kept constant during all test profiles

by flying between 8,000 and 23,000 ft pressure altitude (PA). In this altitude block, the environmental control system of the test aircraft maintained a constant cabin pressure of 8,000 ft PA.

Finally, since controlling and increasing blood pressure are more difficult when the body is overheated, cabin temperature was constantly recorded and displayed, in addition to the pre- and post-flight readings of body temperature.

TEST MONITORING AND CONTROL

An efficient flight test control room was essential to the conduct of this testing. Basically, the aim of the testing was to duplicate the research centrifuge environment in a high-performance aircraft, flying beyond the reach of medical and scientific research personnel. A high level of test team integration and cohesion was essential to meeting this aim. Although many additional personnel were involved in the preparation and insertion of the test subject into the test aircraft, the control room was manned essentially by two key personnel: the mission controller, and the run director.

The author acted as mission controller for all test sorties, excluding those where he acted as a test subject. In those cases, a fellow Qualified Flight Test Engineer from AETE performed the mission controller duties. The primary concern of the mission controller was to ensure that testing was conducted safely and effectively by maintaining a single point of control in the flight test control room and orchestrating all test team activities. Responsibilities included the coordination of aircraft setup prior to and during

test profiles; monitoring of test point flight conditions for validity; secondary in-flight monitoring of test subject physiology during the test profiles; and, an ability to call an ABORT at any time during the test runs.

The run director was a bio-medical research scientist from DCIEM, responsible for ensuring scientific validity and primary test subject monitoring throughout the test program. The run director's responsibilities included the selection of profiles to be flown and their sequence; primary in-flight monitoring of test subject physiology during the test runs; administration of the post-run questionnaire to the test subject during the rest period following each test run; and an ability to call an ABORT at any time during the test runs.

Video of the test subject and all flight test data were telemetered to the control room, in real-time, during the flight test. All bio-medical data were formatted and displayed in volts, as they consisted of simple bio-medical waveforms. The exception to this was blood pressure, which was formatted and displayed in millimetres of mercury (mmHg). All aircraft parameters (g level, cabin temperature and cabin pressure) were formatted and displayed in standard engineering units.

For in-flight monitoring, four multi-purpose displays driven through a *Loral System 500* were used. The first was configured to provide all aircraft data and g time histories to assist in ensuring that the test profiles were flown accurately and within tolerances. Provision was also made to allow the mission controller to monitor the subject shoot lights and the ABORT light. Two other screens provided all bio-medical measurands, as waveform time histories, to allow the DCIEM research scientist to

monitor the physiology of the test subject during the test profiles. A fourth video monitor was used to display in-flight video of the test subject. This combination of monitoring equipment allowed the control room personnel to effectively monitor all data and the status of the test subject from the control room. This allowed the team to accurately judge the g tolerance of the test subject and choose the sequence of points to be flown, which maximized the efficiency of each test sortie and minimized the risk to the test subject.

TEST SUBJECT SELECTION AND TRAINING

Participants

A total of 16 test subjects were used during this test program. Of the 16 test subjects, four were non-aircrew from DCIEM, who have participated in and will be available to participate in future centrifuge research. The other 12 test subjects were aircrew, two from DCIEM, with the remaining 10 recruited from AETE and 4 Wing Cold Lake. The mix of test subjects was designed to allow assessment of any skew in the data due to unfamiliarity or apprehension with the flying environment.

In addition, an interesting side benefit was obtained. Due to the participation of a large number of pilots from 4 Wing Cold Lake, the awareness of pilots to the push-pull effect was raised with minimal effort. Each test subject was well motivated during their participation and passed their experiences and sensations on to their flying peers. Active involvement of individuals from the target audience ensured that learning points were

passed on directly from the source of research. The use of fleet pilots during this in-flight physiological research program was key to advancing awareness of the problem which this research targeted. Future aeromedical research programs should endeavour to use operational flying personnel, when and where practical.

Pre-Flight Training

Although the majority of the test subjects were jet aircrew familiar with the demands of flying in high-performance aircraft, these test missions were decidedly different. As scientific research missions, all data had to be collected under highly controlled, standardized conditions to optimize the sensitivity and reliability required for statistical rigor. To achieve this level of reliability, test subjects were required to attend centrifuge training sessions at DCIEM and aircraft training sessions at AETE prior to participating in active flight test.

There were numerous aims for the training sessions. The first was to familiarize all test subjects on the goals and objectives of this study to help them understand the potential problems created by the push-pull manoeuvre for pilots. More important, however, was the procedural and experimental standardization training conducted, which provided the basis for scientific validity during this experiment.

Centrifuge training profiles mimicked the aircraft test profiles as closely as possible, given the restriction that the DCIEM centrifuge could not produce relative negative g. Test subjects were instructed on the operation of all bio-medical

instrumentation associated with the study, and learned to understand each item's use in quantifying acceleration effects. As the study was restricted to the single test case of relaxed test subjects, unprotected by anti-g suit, all participants were taught to remain completely relaxed during exposure to $+g_z$ in the human centrifuge by recognizing when their muscles were tensed. This was an important learning point for the aircrew, who tended to instinctively perform some sort of straining manoeuvre when exposed to $+g_z$. Training was conducted until each test subject became intimately familiar with his or her individual symptoms of $+g_z$ intolerance as related to time of exposure and $+g_z$ intensity.

Perhaps most important during the centrifuge sessions was the ability to define and practice interpreting visual light loss levels. Standardized categories of vision loss for both peripheral and central vision were developed and taught. To aid the test subject in judging peripheral/central light loss, the light bar assembly was used. Also, as shown at Figure 1, there is a reflexive response whereby the body raises blood pressure on its own during exposure to $+g_z$, even when the test subject remains relaxed. For this reason, vision loss was reported in terms of, "the worst that it became during the profile," and, "the best that it became during the profile, after having been at its worst." Table 1 shows the categories of light loss used during this test program. This categorization and training of subjects in its use was essential for standardizing the reported severity of vision loss, which was a key piece of data for this test program.

The final segment of training that was essential to the safe conduct of these tests was conducted at AETE prior to flight for all test subjects. Test subjects were extensively

Table 1. Light Loss Qualification

Vision Category	Description of Light Loss
Clear	No impairment. Visual field and light-emitting diodes (LEDs) as clear as at +1 g_z
Slight	1 to 9% of normal vision lost- only slight impairment of visual field – can still see LED(s)
Dim	10 to 49% of normal vision lost- noticeable impairment of visual field - can still see LED(s)
Grey	50 to 89% of normal vision lost- marked impairment of visual field – can still see LED(s)
Very Gray	90 to 99% of normal vision lost- severe impairment of visual field – can barely see LED(s)
Peripheral/Central light loss	100% of vision lost - unable to see peripheral/central LED(s)

briefed and trained on the test-unique ejection and egress procedures that were developed for flight of a fully instrumented human test subject in the rear seat of CF-188907, as detailed in Appendix C. Each subject was required to meet minimum time-to-egress standards and demonstrate comprehensive knowledge of emergency and ejection procedures prior to receiving clearance to fly.

The use of a standardized training program, which involved theoretical and centrifuge training sessions at DCIEM, followed by ALSE and on-aircraft training sessions at AETE, was beneficial during this research. Key to the DCIEM sessions was the knowledge gained regarding the push-pull effect, and the ability to learn to stay relaxed under $+g_z$ in the centrifuge. Most important, however, was the ability to define and practice the visual light loss levels used to collect data during this test program. Training sessions at AETE ensured that all test personnel were familiar and proficient in the test and emergency procedures required for operation of the bio-medical

instrumentation and ALSE in the rear cockpit environment of CF-188907. The training program used during this test program ensured standardization and thoroughly prepared all test subjects for the in-flight research. Future aeromedical research programs should ensure that proper training is provided to all test participants prior to any active flight test.

FLIGHT TEST TECHNIQUES

Aim

Since the physiological problem under study is created when a pilot is exposed to a period of less than one g_z, followed by time at varying levels of positive g_z, this scenario needed to be recreated during the experiment. The manoeuvre needed to be repeatable for all the subjects involved in the study. However, different test subjects were expected to have different physiological responses and $+g_z$ tolerances, therefore, the precise sequence and range of test points was not expected to be common to all individuals. While desirable, it was not necessary that each test subject's physiological end-point (defined by complete visual blackout) be determined.

The Manoeuvre

There were three phases to the manoeuvre used during this test program. For tolerances, all onset rates were flown at 2 g_z/sec $\pm$0.5 g_z/sec. Steady pushes and pulls were maintained $\pm$0.2 g_z. All timings were flown $\pm$1 sec with the exception of the pull, which may have terminated earlier based on the test subjects' g tolerance. The phases of

the manoeuvre are described as follows and may be referenced to the sample time history of a test profile shown in Figure 4.

a. **Push.** Following an onset rate of -2 g_z/s, the push ranged from +1.4 to -2 g_z, for a time interval of 5 sec, once stable at the target g_z level;

b. **Transition.** Following the push, a 2 g_z/sec transition was made into the pull; and

c. **Pull.** The $+g_z$ level during the pull ranged from +2.0 to +6.0 g_z in 0.5 g_z increments, with duration of approximately 15 sec, once stable at the target $+g_z$ level.

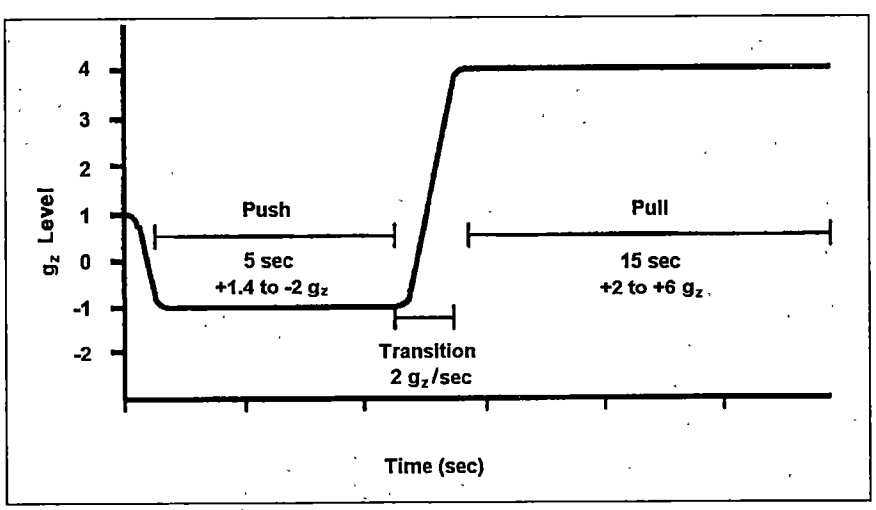

Figure 4. Sample Push-pull Test Profile

During initial profile developmental flights, experience showed that higher airspeeds and their associated larger turn radii for a given g_z level, allowed for more precise control of g_z throughout the test profile. Also, it was desirable to eliminate (or at least minimize) any g vectors other than the normal vector from acting on the test crew during the manoeuvre. As such, the test profiles were flown by establishing the aircraft at approximately 400 knots calibrated airspeed in a climb attitude sufficient to prevent an excessive nose-low attitude following the application of $-g_z$. The lower (or more negative) the push level, the larger the climb angle required.

Once cleared to proceed, the pilot gently rolled the aircraft to stabilize at 50° to 60° angle of bank (AOB). From there, he pushed and pulled the aircraft through the test manoeuvre as described above. The AOB attained prior to the push-pull allowed the aircraft to be maintained in one plane of motion (no rolling) throughout the manoeuvre, without having to pull into the pure vertical, losing airspeed and the ability to maintain a desired $+g_z$ level. Obviously, the push-pull manoeuvres were not flown in an operational manner. However, as experimental research manoeuvres, they provided a statistically significant and repeatable series of test points to be flown.

Operational Manoeuvres

At the end of the flight testing, two types of operational manoeuvres were flown to allow physiological comparison to the research test manoeuvres. These were an extension/pitchback manoeuvre and a 1 g roll and pull-through. To provide direct

comparison with the research test manoeuvres for the extension/pitchback, an individual test subject's $+g_z$ tolerance from a +0.5 g_z push was determined during the flight. This tolerance was then used to fly a 5 sec extension at 0.5 g_z, followed by a 2 g_z/sec transition into a pull at the subject's $+g_z$ tolerance. For the roll and pull-through, the individual test subject's $+g_z$ tolerance from +1.0 g_z was determined during the flight. The manoeuvre was then flown by establishing the aircraft in a 60° left or right bank, rolling over the top through 180°, then transitioning at 2 g_z/sec into a pull at the subject's $+g_z$ tolerance.

Physiological Point of View

From a physiological standpoint, the critical stage during these test profiles was the first eight seconds of the pull. This was the period in which G-LOC was most likely to occur (Refs 5, 20). If G-LOC did not occur in the first 8 seconds of the pull, it was expected that the body's cardiovascular reflexive response to the + g_z acceleration would prevent G-LOC following this time. However, vigilance in monitoring test subject physiology was required by the control room during the entire profile. The maximum length of the pull was 15 seconds, which was sufficient to record any reflexive response.

Following each test profile, a standard rest period of two minutes was observed, during which the aircraft was flown between +1 and +1.4 g_z, with less than 45° AOB. Previous research had shown that this period of time was sufficient to return the test subject's physiology to baseline prior to the commencement of the next profile. This was verified during this series of flight tests.

Test Matrix

Table 2 shows the test matrix, providing all the possible test points. At the left of the table is a column describing the range of g_z levels in the push. The columns on the right show the possible $+g_z$ plateau levels during the pull. As an example, the profile in the bottom right of this table begins at -2.0 g_z for 5 sec followed by a 2 g_z/s onset of g_z to a plateau of +4.5 g_z for 15 sec.

During the test flights, each subject was exposed to a range of profiles from the test matrix so that a variety of physiological responses were produced, with the more profound changes induced near his/her $+g_z$ tolerance end point. As individual g_z tolerance varied, some subjects experienced the range of responses using fewer profiles; some needed more; some profiles were repeated. The average subject flew approximately 40 profiles, which took 2 test sorties.

Table 2. Push-pull Test Matrix

PUSH		PULL								
Push Level (g_z)	*Push Time* (sec)	*Pull Level (g_z) - all pulls for 15 sec duration* 2	2.5	3	3.5	4	4.5	5	5.5	6
1.4	5	X	X	X	X	X	X	X	X	X
1.0	5	X	X	X	X	X	X	X	X	X
0.5	5	X	X	X	X	X	X	X	X	
-0.5	5	X	X	X	X	X	X	X		
-1.0	5	X	X	X	X	X	X	X		
-1.5	5	X	X	X	X	X	X			
-2.0	5	X	X	X	X	X	X			

Test Point Sequencing

There was no fixed sequence of test points. It is known from previous research that the higher the level of $+g_z$ exposure during the pull, the greater the physiological impairment. Tolerance to $+g_z$ was also expected to decrease as the $-g_z$ level of the push was increased. In general terms, profiles in the upper left section of the matrix were regarded to be the least stressful physiologically, whereas those of the lower right were the most stressful. Although the run director did not follow any formalized pattern in selecting test points, test point selection tended to progress from left to the right in any row of the matrix and from top to bottom in row selection. In this manner, a build-up approach was followed so that the physiological stress did not inadvertently exceed the visual blackout boundary of the test subject and cause him/her to experience G-LOC.

Notwithstanding buildup, the profile order was varied between subjects, and between sorties for any given subject, in order to satisfy statistical analysis concerns. The alteration in order was essential to prevent cumulative effects of g_z exposure, such as fatigue, from biasing certain profiles and confounding any of the main effects of the $-g_z$ /+ g_z sequence.

Selection and sequencing of each test point were performed dynamically by the run director during the sorties. The goal of test point sequencing was to present the test subject to a range of profiles evoking the expected symptoms within their individual physiological envelope. An individual's physiological envelope with respect to push-pull could be defined by considering the test matrix described in Table 2. Within any given

row, the lower boundary of physiological change was the most stressful g_z exposure that induced no change to visual status; the upper boundary of physiological change was complete visual blackout of the test subject. The run director's focus was to use the limited number of test points available during flight to explore each subject's physiological response within these boundaries for each row of the test matrix. The mission controller's focus was to ensure that the test points were flown within tolerances, and that the flying operation proceeded smoothly, safely, and effectively. Live telemetry of physiological data and visual symptoms were used to predict profiles that would elicit responses within the desirable boundaries.

G-LOC Prevention

During the flight testing, G-LOC was to be avoided. Since the influence of G-LOC on the subsequent response to g_z was not understood, any G-LOC was cause for termination of the test sortie. The three strategies used to prevent G-LOC were:

a. the human body's own safety margin between visual blackout and G-LOC. As discussed above, the upper boundary of physiological stress desired in this research was complete visual blackout of the subject. From previous research (Refs 3, 4) it was known that there is generally a margin of 0.5 to 1.0 g_z between visual blackout and G-LOC;

b. real-time bio-medical monitoring from the control room. Previous centrifuge research (Ref 4) had shown that, using a combination of

physiological stress build-up within the test matrix and close monitoring of real-time bio-medical data feeds, G-LOC could be avoided; and

c. clearly defined ABORT procedures. To stop a test profile in the event of imminent G-LOC, clearly defined procedures were devised. The term "ABORT" was used to cease the test profile at any time by the mission controller, run director, test pilot, or test subject. Also, if the test subject chose to ABORT, he was able to simply release a dead-man trigger on the instrumented control stick used to control the shoot lights. This signaled the front seat pilot via an ABORT light mounted adjacent to the HUD in the front cockpit. In the event of an ABORT, the test pilot's immediate action was to return the aircraft to 1 g, wings-level flight.

Utilization of the control room monitoring equipment was invaluable throughout the test program. The use of a physiological build-up approach and close monitoring of the test subject through real-time data feeds allowed advancement to an individual subject's endpoint (desirably, complete visual blackout) to be conducted slowly and cautiously, but with confidence. In fact, educated physiological monitoring was often able to detect the onset of G-LOC before a test subject could. This gave certain test subjects the confidence to explore their endpoints at will; whereby they could fly a test point with no vision whatsoever, yet remain fully cogniscent of the their situation.

Numerous ABORTs took place in cases where the control room staff, or the test subject, was uncomfortable with continuing a test point. Following such ABORTs,

follow-on action (repeat of the same test point, declaration of an endpoint and proceeding to a new row in the test matrix, or cessation of the sortie) was taken based upon the reason for the ABORT and consultation with the test team.

As a result of the procedures developed, no G-LOC incidents occurred during the conduct of the test program. Two G-LOC incidents did occur; however, both incidents took place during pre-test instrumentation check flights where, due to initial telemetry capability development, real-time bio-medical monitoring was not yet available.

FLIGHT TEST RESULTS

Test Sortie Generation

The test program was highly successful in capturing the research data required by DCIEM. Forty CF-18 test aircraft sorties, for a total of 55.5 flight hours, were flown in support of this test program. This encompassed 34 in-flight physiological research test flights, for a total of 47.7 flight hours; as well as 6 instrumentation check flights, for a total of 7.8 flight hours. One CF-18 photo chase mission, 1.4 hr in duration, was also flown. For all flights, the test aircraft configuration was: stations 3 and 7 configured with 330 United States gallon external fuel tanks; station 5 configured with a centreline pylon only; and, all other stations clean. This configuration provided sufficient fuel to conduct, on average, 20 test profiles per sortie while maintaining the required manoeuvrability to conduct the profiles. The test sorties flown are summarized in Table D-1.

Data Reduction and Formatting

The prime objective of this entire program was collecting and processing the data required by DCIEM for their bio-medical research. In this endeavour, the test team was highly successful, despite some initial formatting difficulties. In consultation with the DCIEM research scientists, and by using the event start/stop times hand recorded in the control room during the test sorties, the required time slices were determined for data analysis. The time slices were approximately 60 to 70 sec in duration, consisting of 30 sec prior to the manoeuvre, 20 sec during the manoeuvre and 15 sec following the manoeuvre. There were approximately 20 time slices per mission. Table E-1 details the measurands recorded for analysis during each time slice.

Regarding Table E-1, the final three measurands: ECGD, REPD, and LEPD were ECG1, REPM and LEPM corrected to a zero level using a software package called *PVWAVE*. The *PVWAVE* program, AETE_SIGPRO, was designed as a digital filter routine to remove the DC values of the signal and therefore shift the signal to a zero DC voltage level. The *PVWAVE* routine used a fifth order, Butterworth low pass filter, with a 1.0 Hz cutoff frequency. The low pass filtered signal was removed (by subtraction) from the original signal to produce the result, as requested by DCIEM.

Further, the original sample rate shown in Table E-1 describes that originally specified by DCIEM. However, due to difficulties in data correlation, all data were eventually recorded and transferred to DCIEM at a rate of 100 samples per second. For transfer of data, all data files were formatted in an ASCII format. They were then

compressed using *WinZip* and copied to a *Zip Drive* disk for forwarding to DCIEM. A full discussion of the data capture, calibration, and formatting performed during this test program is given at Reference 21.

Upon resolving the formatting concerns, the data captured during this test program fully met the specifications put forth by DCIEM and has allowed them to progress with their full bio-medical analysis effort. It is recommended that the collected bio-medical data be analyzed fully by DCIEM to gain comprehensive knowledge of the physiology of the push-pull effect, and to determine whether data obtained during flight test correlates with that obtained during centrifuge research.

Findings

It must be emphasized that the following findings were taken from one source of data only; namely, reported visual symptoms of the test subjects. However, this was a significant source of data as it represented an operational limit for the pilot of an aircraft. Also, the findings were confirmed by a "first look" at the data time histories of the bio-medical measurands. For a full and comprehensive approach, the data will be further subjected to a beat-by-beat analysis by the statistical procedure of repeated measures analysis of variance. Blood pressure and g_z tolerance are expected to be affected by three variables: the preceding push level, the rate of g_z increase, and the subsequent plateau level. The magnitude of the influence of each variable will be assessed by multiple regression analyses. All data analysis will be conducted by DCIEM and will be reported

in a separate document. The following findings are presented, based upon reported visual symptoms only and a "first-look" at the bio-medical data, with the concurrence of DCIEM. Three case studies are discussed to demonstrate some of the pertinent findings of this research.

Principally, clear evidence of a "push-pull effect" was demonstrated during this test program. It was confirmed that $-g_z$ produces an increase in eye level blood pressure, which, in turn, produces a strong physiological reflex to lower the blood pressure. Furthermore, the stronger the reflex while under $-g_z$, the "further behind" the body was at the start of a $+g_z$ pull. Therefore, the bigger the push, the lower the g_z tolerance during the pull. This physiological concept was borne true by the sensations reported by the majority of test subjects. As subjects gained experience throughout their test sorties, they proved to be very capable of predicting a decreased g_z tolerance with increasingly negative push levels.

Furthermore, it was shown that a certain variance was present in the response of individual test subjects to $-g_z/+g_z$ exposure. For all test subjects, increasingly negative push levels resulted in a decrease in $+g_z$ tolerance. This variance in response is shown graphically in Figures 5 and 6. In both cases, a decrease in $+g_z$ tolerance can be seen as the magnitude of the preceding push level was increased. However, in Case 1 (Figure 5), the test subject displayed a +4.0 g_z tolerance from +1.4 g_z. When preceded by a –2.0 g_z push, his $+g_z$ tolerance decreased to +3.0 g_z. This represented a decrease in g_z tolerance of 1.0 g_z (or 25% from his +1.4 g_z level).

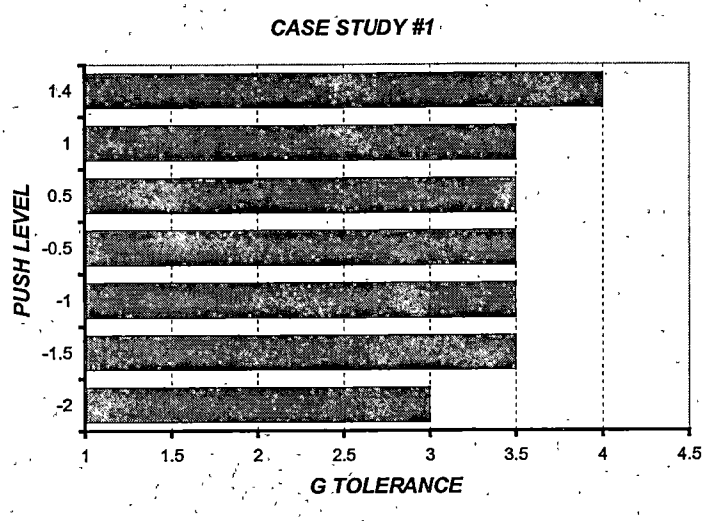

Figure 5.
Push-Pull Effect – Case 1

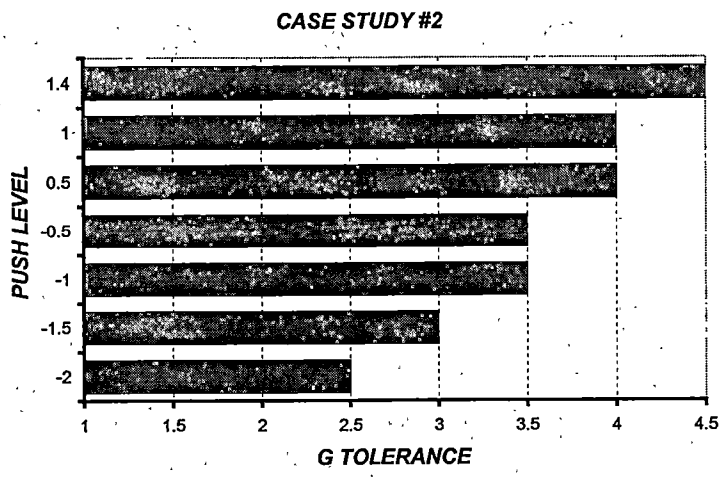

Figure 6.
Push-Pull Effect – Case 2

In Case 2 (Figure 6), it can be seen that the test subject's response to push-pull was more severe. This test subject's g_z tolerance from a +1.4 g_z "push" was +4.5 g_z. Following a –2.0 g_z push, this value decreased to +2.5 g_z, a decrease in g tolerance of 2.0 g_z (or 44%).

For other test subjects, some notable results occurred with their decrease in g_z tolerance. An example is shown in Figure 7. It can be seen that the test subject's g_z tolerance decreased quite quickly with the magnitude of the preceding push, down to -0.5 g_z. However, below pushes of -0.5 g_z his +g_z tolerance remained rather constant. In other words, this test subject had lost as much g_z tolerance at -0.5 g_z as he had at –2.0 g_z. Persons with this type of response are feared to be the most susceptible to push-pull during normal operational flying.

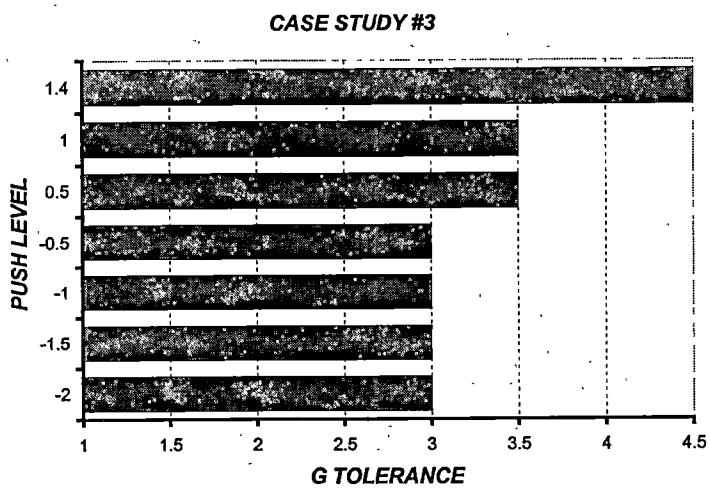

Figure 7.
Push-Pull Effect – Case 3

This is due to the fact that these individuals lost as much g_z tolerance (on the order of 1.5 g_z or 33%) at push levels in the range of zero g_z, where other test subjects needed pushes of up to –2.0 g_z to demonstrate the same aggregate loss in g_z tolerance. Operationally, push levels of –2.0 g_z are not normally flown in combat aircraft; whereas, push levels in the range of zero g_z commonly are.

Regarding the comparison of the research manoeuvre to the operational manoeuvres flown as available towards the end of the test program, no discernable difference was noted. The extension/pitchback and roll and pull-through manoeuvres resulted in similar physiological symptoms as the research manoeuvres flown to the same g_z levels.

VI - CONCLUDING MATERIAL

GENERAL

The Push-Pull flight test program was a new type of research venture for both AETE and DCIEM, and represented one of the first in-flight test programs where comprehensive bio-medical research was conducted in an operational military aircraft. The overall aim of this thesis was to instrument a high-performance aircraft and perform in-flight research to collect data for evaluation of the push-pull hypothesis. As reported herein, this test program successfully accomplished that aim.

CONCLUSIONS AND RECOMMENDATIONS

Based upon the completed testing and the analysis conducted to date, the following conclusions and recommendations are made.

Firstly, this test program demonstrated that bio-medical research can be carried out in high performance, ejection seat aircraft, provided that a careful and methodical approach to systems integration is taken. Electromagnetic Compatibility and Escape systems issues must be given full consideration from the beginning of any design integration effort of this nature to ensure that the test aircrew are subjected to minimal risk.

Based upon the results of the Escape Systems Clearance testing, the two key philosophies adopted to integrate the bio-medical instrumentation into the test aircraft

(removal of equipment from the human and strain relief of all connections) proved to be highly effective. In addition, the Escape Systems Clearance Testing was highly successful in developing standardized procedures on which all test subjects could be trained. These test procedures, and the methods developed to mount the bio-medical instrumentation (modified accordingly to encompass any future instrumentation or ALSE differences) should be utilized during any follow-on physiological flight testing which uses the CF-18 aircraft.

EMC Testing to evaluate the suitability for flight of the test instrumentation systems in the aircraft identified only minor compatibility concerns. Provided with the test results from this Phase, the aircraft was granted a restricted safety of flight clearance for Phase 3, In-flight Physiological Research. This allowed the test aircraft to be flown within the local flying area, for test specific purposes only, which was acceptable for conduct of the test program.

The mix of test subject participants, and the use of a standardized training program, which involved theoretical and centrifuge training sessions at DCIEM, followed by ALSE and on-aircraft training sessions at AETE, was beneficial during this research. Future aeromedical research programs should ensure that comprehensive training is administered to all test subjects prior to their participation in research flights.

In addition, an interesting side benefit was obtained due to the participation of a large number of fleet pilots: the awareness of pilots to the push-pull effect was raised with minimal effort. Test subjects from the fleet were able to personally corroborate test

results during post-test briefings provided by the test team to other fleet pilots. Active involvement of individuals from the target audience ensured that the learning points were passed on directly from the source. Future aeromedical research programs should endeavour to use operational flying personnel when practical.

The test control and monitoring procedures utilized during this test program worked extremely well. The responsibilities assigned to the mission controller and run director maximized test conduct efficiency while ensuring the safety of the test subject. Utilization of the control room monitoring equipment was invaluable. The use of a physiological build-up approach and monitoring of the test subject through real-time data feeds allowed advancement to an individual subject's endpoint to be conducted slowly and cautiously, but with confidence. Future aeromedical research programs conducted jointly between AETE and DCIEM should use similar procedures and equipment.

Collection and processing of bio-medical data for research was the prime objective of this test program, and was completed successfully. It is recommended that the collected bio-medical data be analyzed fully by DCIEM to gain comprehensive knowledge of the physiology of the push-pull effect, and determine whether data obtained during flight test correlates with that obtained during centrifuge research. Specifically, in the near term, the data should be used to assist researchers and engineers in developing algorithms for proposed g-valves to counter the effects of acceleration on pilots. In the future, it should form a basis for use in future design and development of anti-g life support systems.

Regarding conclusions that can be made without full statistical analysis of the bio-medical data: considering the reported visual symptoms, and a "first-look" at the data, it can be seen that the push-pull effect does exist. For each test subject, as the magnitude of $-g_z$ exposure (push) was increased, the lower the $+g_z$ (pull) tolerance became. Pilots must be aware that exposure to $-g_z$ immediately prior to aggressive $+g_z$ manoeuvring will lower their g_z tolerance.

Results also indicate that there exist different levels of susceptibility to push-pull for different individuals. Pilots must be cogniscent of their own susceptibility to push-pull. Furthermore, knowledge of variance between pilots will make design initiatives for anti-g protection challenging.

This test program represented a positive merger of capabilities between a bio-medical research center and a military test flying establishment. The combined capabilities of AETE and DCIEM were able to overcome the unique challenges associated with this research program. For the aeromedical research community, it represented the first time that some highly researched and hypothesized theories could be put to the full test of flying. As such, the results from this test program represent significant findings for the aeromedical research community.

Finally, this test program demonstrated the value of flight test, particularly when evaluating whether in-flight conditions can be accurately replicated in simulators (i.e. centrifuges). Validation of centrifuge testing may allow future research to be carried out in g simulators with lower effort and cost; however, because of this test program, results

from future research will always be firmly rooted to actual flight test data. In the future, when testing any new designs for anti-g protection, it is planned to use limited but focused flight test efforts to ensure that this trend continues.

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LIST OF REFERENCES

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APPENDICES

APPENDIX A

BIO-MEDICAL INSTRUMENTATION

BIO-MEDICAL INSTRUMENTATION

Figure A-1. Armrest for *Portapres* Blood Pressure Installation

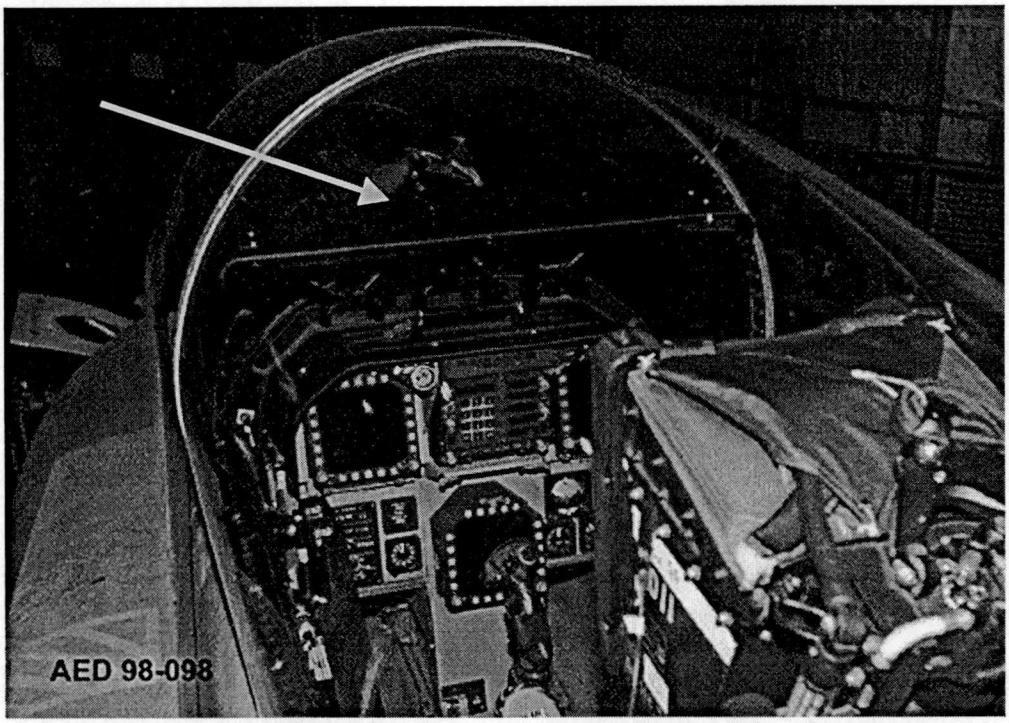

Figure A-2. Light Bar Installation with Rearward Facing Colour Camera

Figure A-3. Abort and Central/Peripheral Shoot Light Control Stick

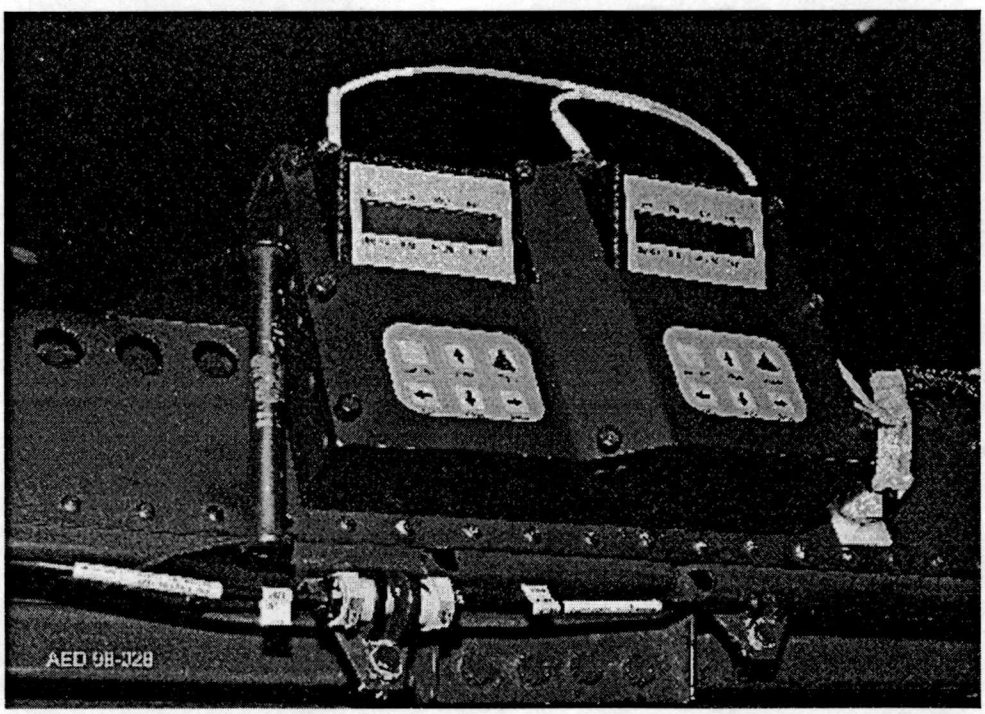

Figure A-4. *Portapres* Control Units

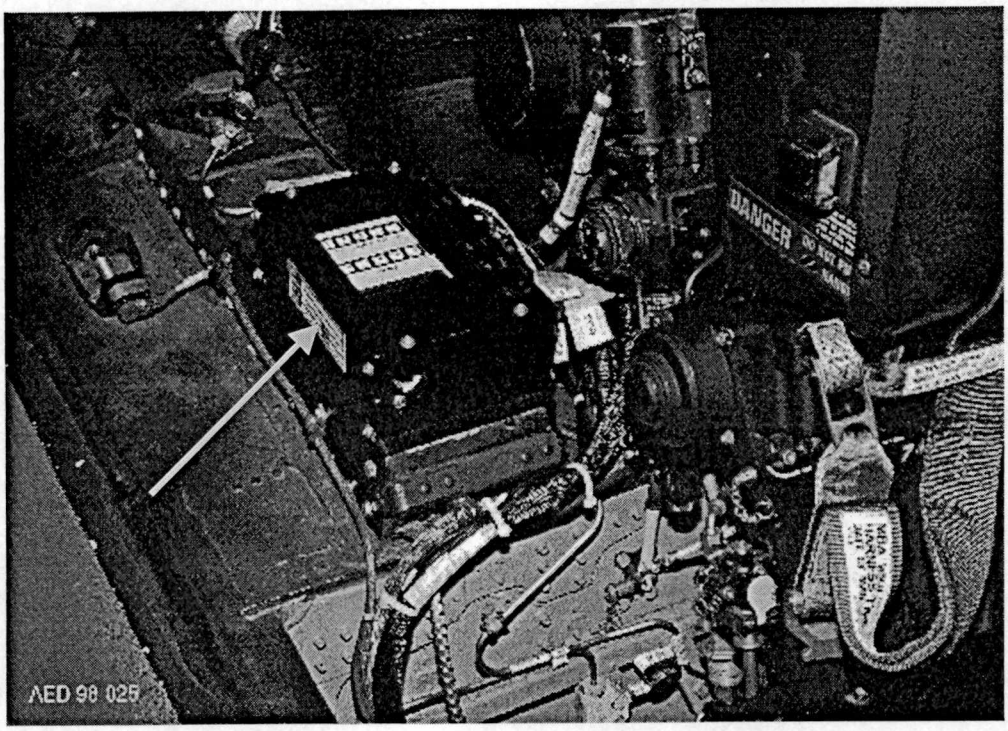

Figure A-5. *Biolog* Medical Signal Conditioning Unit

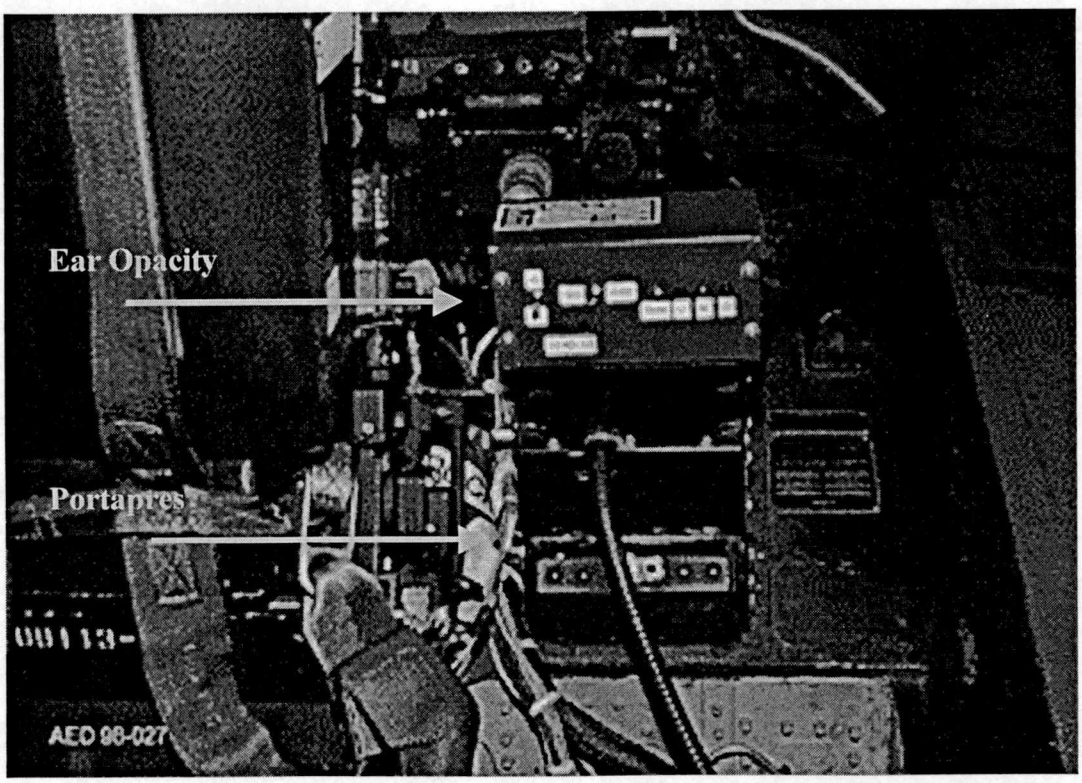

Figure A-6. *Portapres* Main Units/Pumps and Ear Opacity/Pulse Control Unit

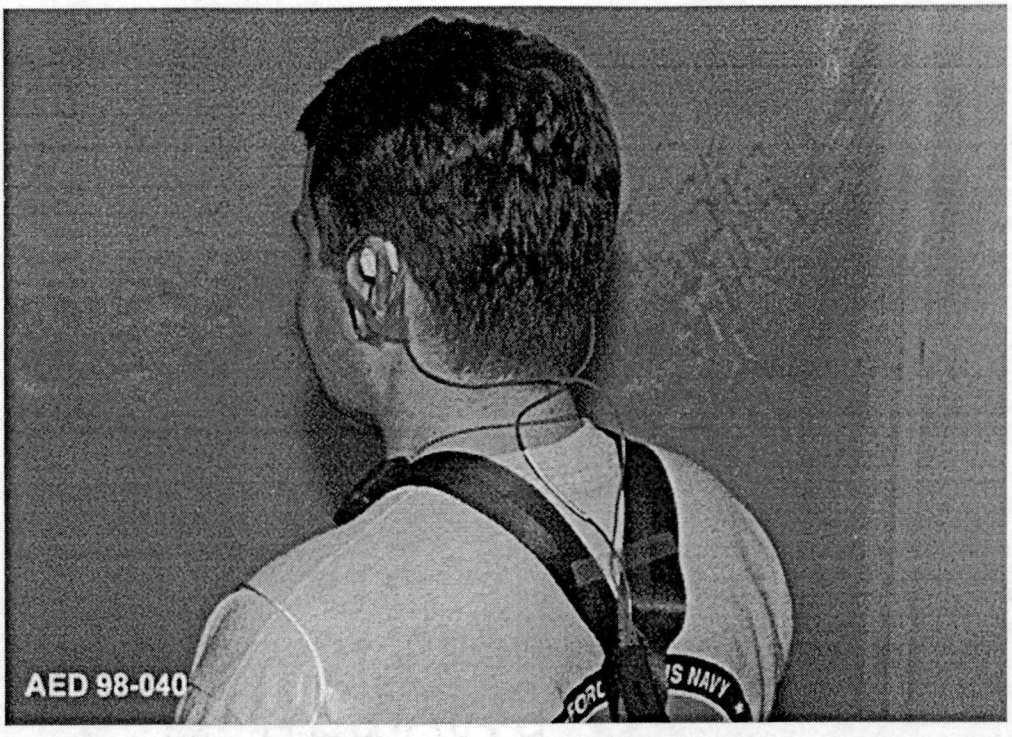

Figure A-7. Ear Opacity Sensors – Left Side

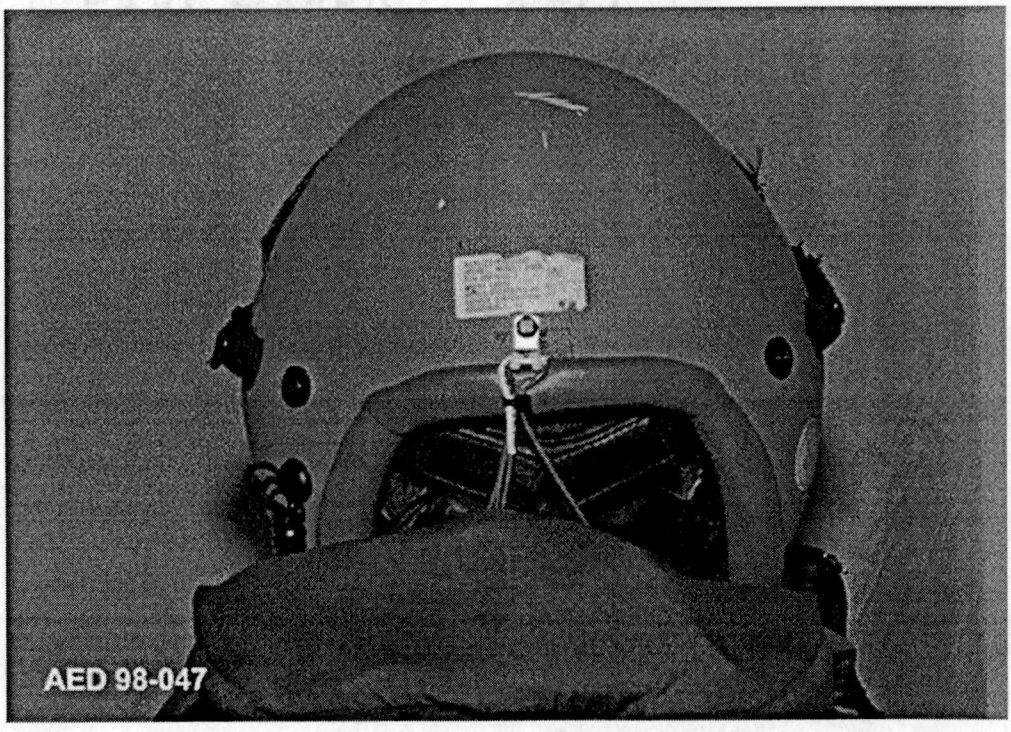

Figure A-8. Ear Opacity Sensor Strain Relief

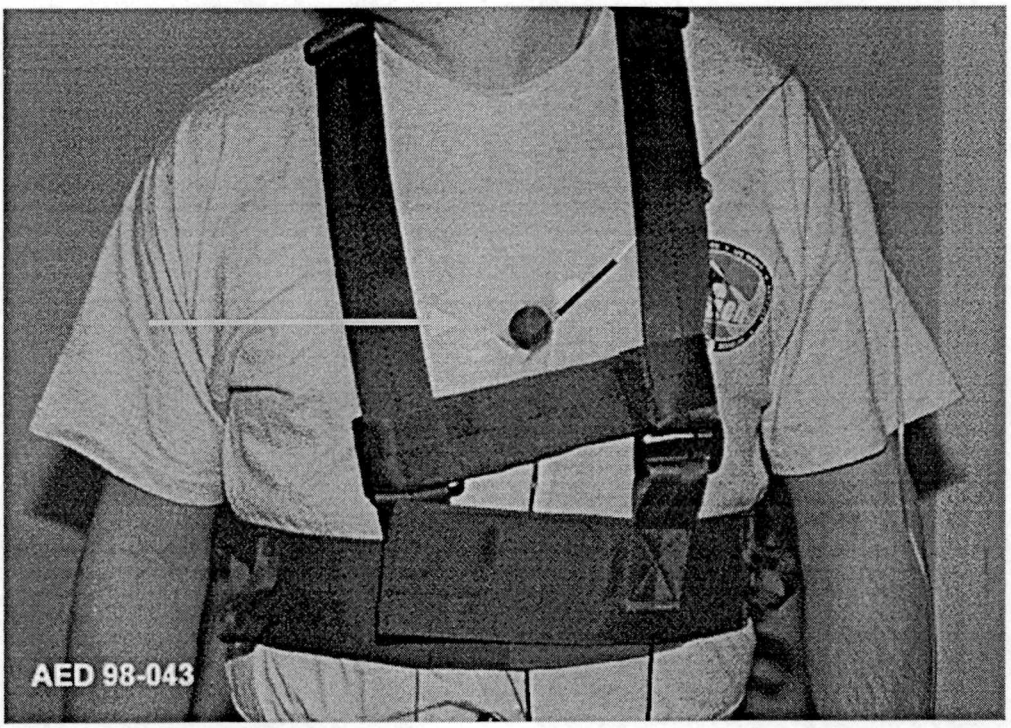

Figure A-9. Heart Reference Hydrostatic Correction Tubing
(attached to skin for in-flight physiological research)

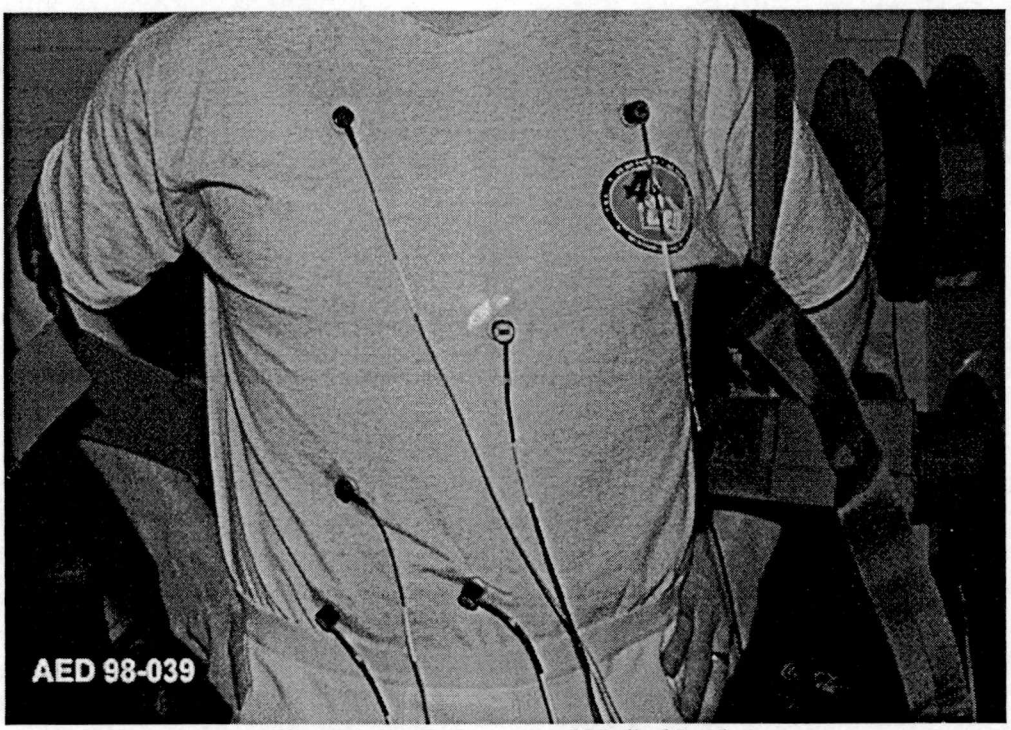

Figure A-10. Torso-mounted Medical Leads
(Escape Systems clearance testing locations shown; actual in-flight physiological research positions similar, with attachment to skin)

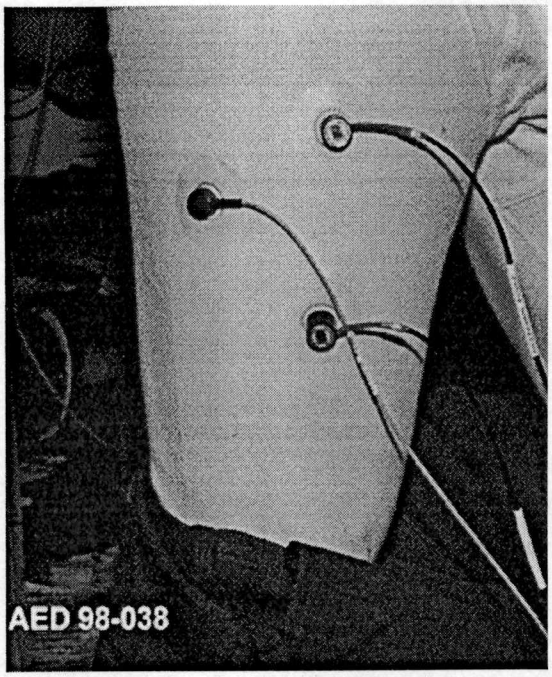

Figure A-11. Leg-mounted Medical Leads
(Escape Systems clearance testing locations shown; actual in-flight physiological research positions similar, with attachment to skin)

Figure A-12. Strain Relief Vest – Rear View

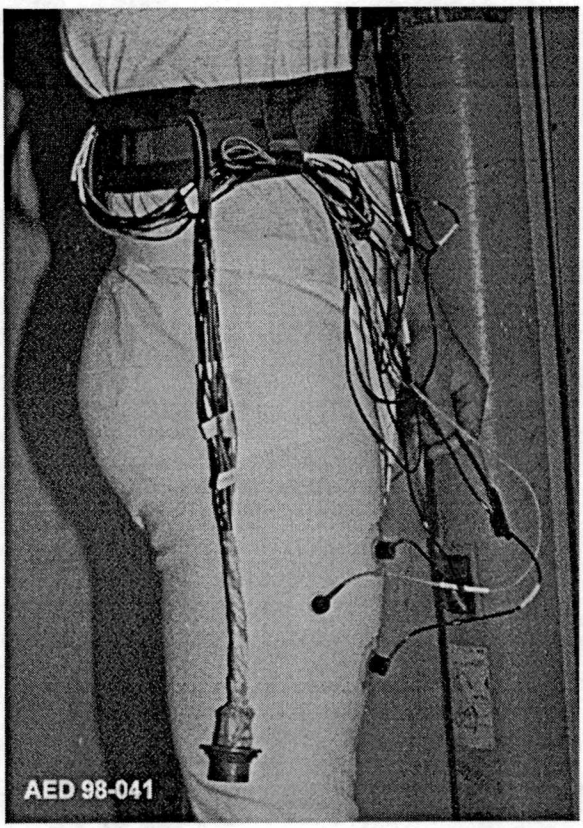

Figure A-13. Strain Relief Vest with 26-pin Connector – Side View

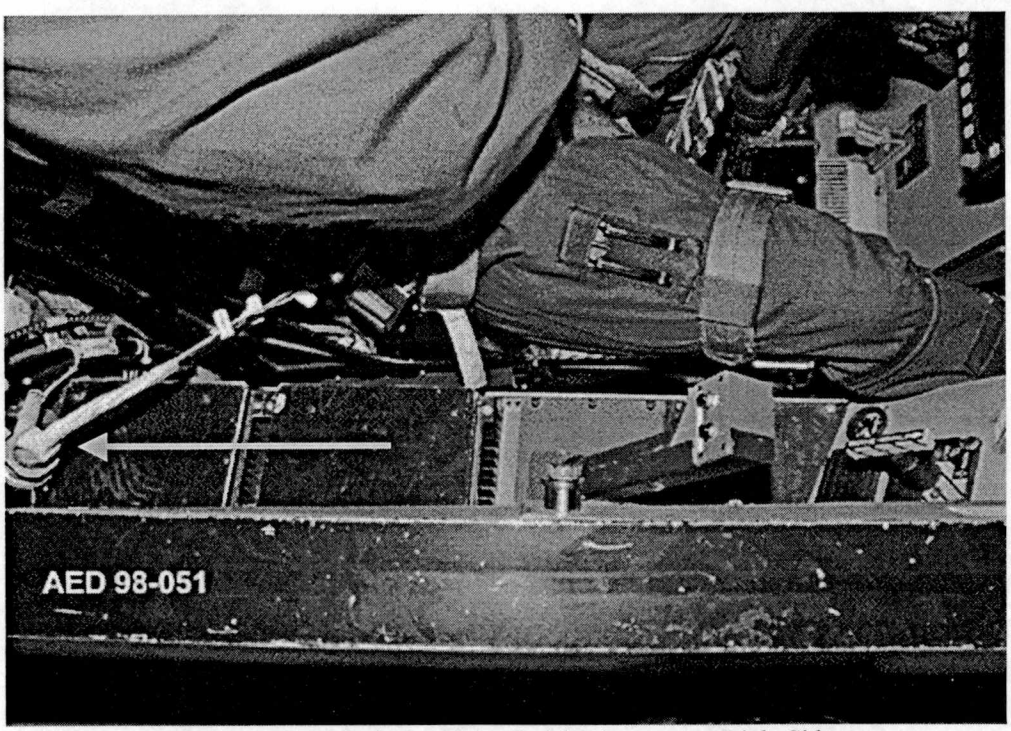

Figure A-14. 26-pin Connector Quick Disconnect – Right Side

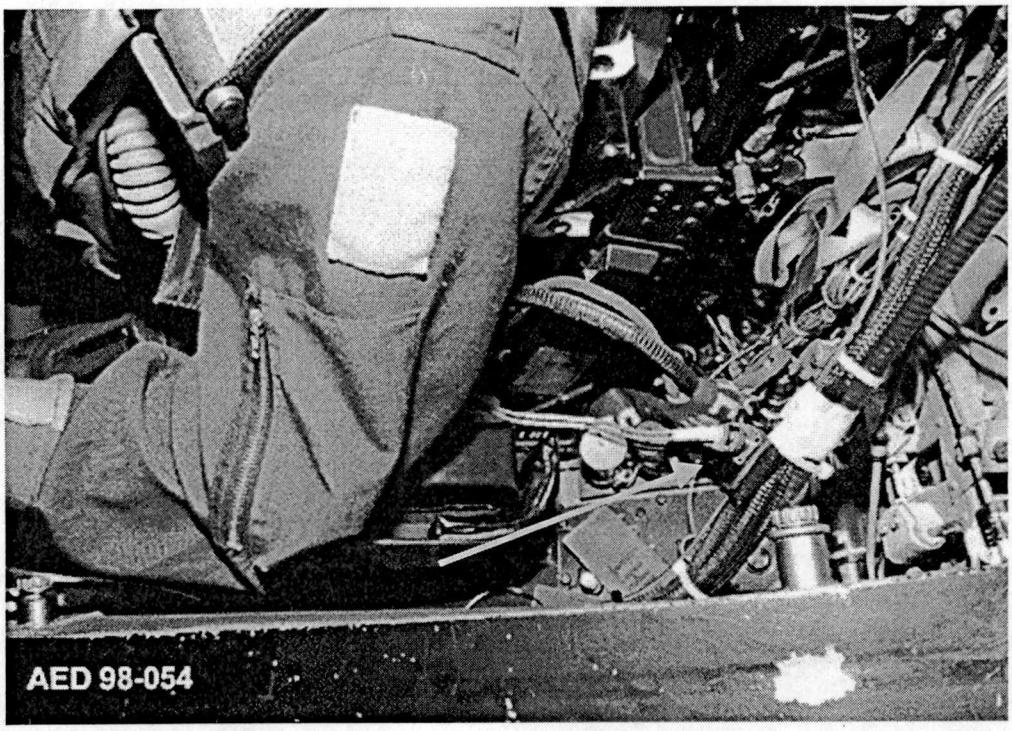

Figure A-15. 10-pin Connector Quick Disconnect – Left Side

APPENDIX B

AIRCREW LIFE SUPPORT EQUIPMENT

Figure B-1. Modified Flying Glove and Hand Mold

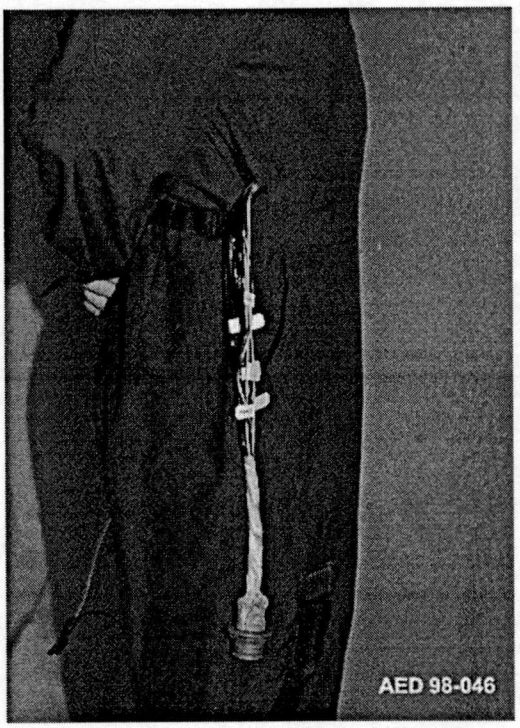

Figure B-2. 26-pin Wiring Harness through Flight Suit, Right Side
(10-pin connector routed in same manner through left side)

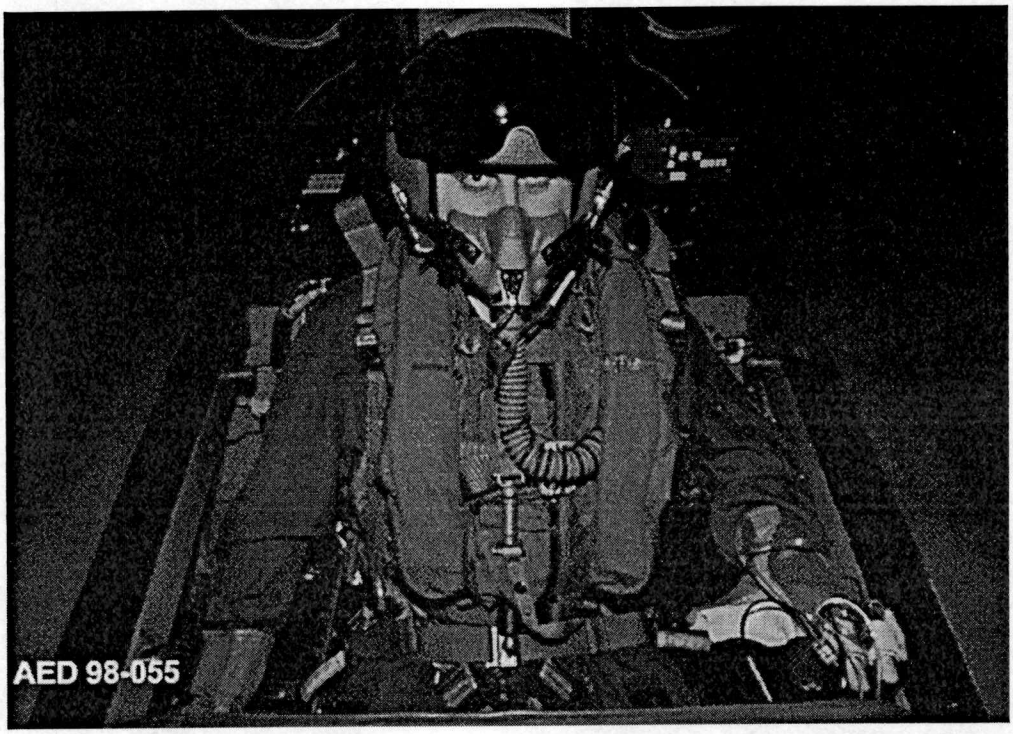

Figure B-3. Test Subject Dressed in NASA Modified USAF Torso Harness and Mustang Survival MSV 971 Modified Life Preserver with Survival Vest

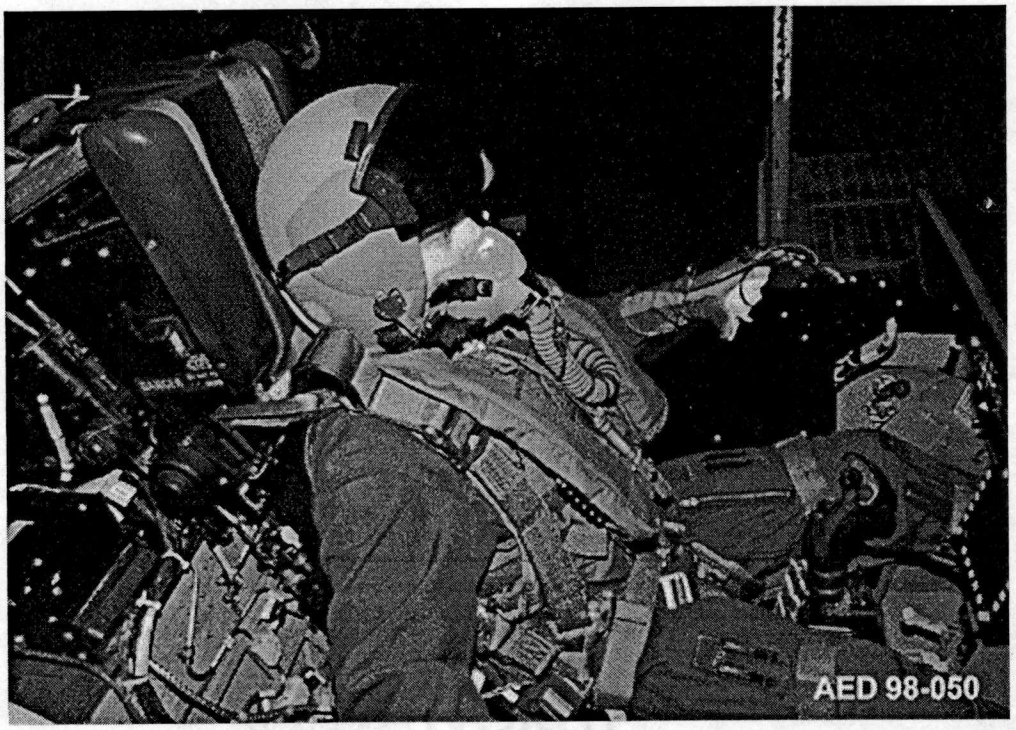

Figure B-4. Test Subject Strapped into SJU-9/A Ejection Seat Configured for use with NASA Modified USAF Torso Harness

APPENDIX C

ESCAPE SYSTEMS PROCEDURES

ESCAPE SYSTEMS PROCEDURES

DONNING PROCEDURES

1. Attach all bio-medical leads on the test subject's skin with medical tape, as directed by DCIEM personnel. Tape wire loop adjacent to each lead as an additional measure of strain relief. Route the wiring harness through the test subject's long underwear as one bundle and tape together to even the lengths;
2. Secure heart and eye reference tubing in place, then route over the left shoulder. Tape at the shoulder blade and on the arm about two inches down from the elbow;
3. Don the strain relief vest over the subject's long underwear and adjust to ensure a proper fit above the waistline and below the bust line;
4. Pass the wiring harness through the velcro securing flap on the right side of the strain relief vest at least once, then route through the sewn loop on the right side of the strain relief vest. Tie-wrap the wiring bundle to the sewn webbing loop to ensure that is where all strain will be taken at this point. It is critical that sufficient wire is left to ensure that 20 in. of wiring remains hanging out of the aircrew flying suit for connection to the aircraft;
5. Pass the ear opacity sensors and wires up through the channel in back of the strain relief vest, ensuring sufficient wire remains at the top to allow for installation on the ears and to attachment to the helmet. The wiring bundle is to be tie-wrapped to the sewn webbing loop to ensure this point is where all strain is taken. It is critical that sufficient wiring remains to ensure 20 in. of wire is protruding from

the aircrew flying coveralls for connection to the aircraft during strap-in;

6. Don aircrew coveralls and pass the QDs and through the appropriate openings in the flight suit (10-pin left side, 26-pin right side). Route the heart and eye reference tubing through the left sleeve;'
7. Don modified life preserver survival vest (LPSV) and adjust as required;
8. Don torso harness and adjust as required;
9. Install lower leg garters in leg openings of the flight suit;
10. DCIEM to connect the ear opacity sensors. Test subject then dons the helmet. Secure the wiring harness to the clamp on the outside of the helmet to provide strain relief using a tie-wrap, ensuring that full head movement is unrestricted;
11. DCIEM staff to functionally check the bio-medical instrumentation system; and
12. Don flight gloves, hand mold, and finger pressure cuffs after strap-in to the test aircraft.

Strap-in Procedures

1. The aircraft will be boarded in the hangar then towed out once strap-in is complete (temperature dependent, as the test subject will have three fingers missing from the left glove);
2. Prior to boarding the aircraft ladder, strap-in assistant to confirm that a minimum of 20 in. of wire is protruding from the test subject's flying clothing for each QD;
3. Test subject to step into the aircraft; strap-in assistant will connect the lower leg garters to the seat leg restraint system prior to the test subject sitting down;

4. Strap-in assistant to ensure seat cushion is clear of all lap belt components, and clear the 70 pounds per square inch (PSI) oxygen line (left side aft), the 10-pin connector (left side aft) and the 26-pin connector (right side aft) from the test subject;

5. Strap-in assistant connects upper leg garters;

6. Connect maritime lanyard;

7. From the left side, the strap-in assistant will connect left airloc from RSSK to torso harness, connect the 70 PSI oxygen line to the RSSK, and the 10-pin male connector QD from the test subject to the female portion on the aircraft;

8. Strap-in assistant to cross over to right side of aircraft cockpit and connect right airloc from RSSK to torso harness, and connect the 26-pin male connector QD from the test subject to the female portion on the aircraft;

9. Strap-in assistant to connect left and right Koch fittings on the parachute risers to the NASA modified USAF torso harness;

10. Test subject to connect and tighten the lap belt;

11. Place modified flying glove and three finger pressure cuffs on the left hand, then place hand mold on the glove;

12. Strap-in assistant to adjust the height of arm rest so that the finger tips are at heart level. The test subject will then place their hand on the arm rest while the strap-in assistant places arm pads appropriately to hold the arm in place;

13. DCIEM personnel will then connect two of the three pressure cuffs to the *Portapres* units installed in the arm rest and connect the telecom type connector

from the heart and eye reference tubes to the arm rest. Velcro the free ends to each of the pressure cuffs;

14. DCIEM personel will then conduct functional/nulling procedures on the *Portapres*, calibrate the ear opacity sensors, and take an oral temperature reading;

15. Prior to departing, the strap-in asistant will ensure visor cover is off, and remove the seat and canopy safety pins. They will also ensure oxygen, hot mic, seat unlock, and ejection select selections are appropriately set; and

16. Test subject to ensure all wiring/instrumentation is clear prior to lowering canopy.

Emergency Egress Procedures

1. Safe seat (right hand);

2. Pull left hand clear from arm rest connections then, with the right hand, remove the hand mold and three finger pressure cuffs;

3. Release both left and right parachute riser Koch fittings;

4. Disconnect maritime lanyard connector;

5. Open lap belt (left hand);

6. Release both left and right Airloc connectors;

7. Stand up while activating the manual override (MOR) with the right hand and disconnecting the 70 PSI oxygen line from the RSSK with the left hand; and

8. Evaluate the escape route, and egress.

Post Ejection Procedures

Open Terrain:

(1) Check canopy;

(2) Discard finger pressure cups and hand mold;

(3) Discard oxygen mask;

(4) Deploy RSSK (500-1000 ft above ground level [AGL]);

(5) Prepare for landing; and

(6) Once on the ground immediately release one or both parachute Koch fittings. The release of one will collapse the parachute and prevent drag, releasing both will totally discard the canopy.

Wooded Terrain:

(1) Check canopy;

(2) Discard finger pressure cups and hand mold;

(3) Check for visors still present and, if available, lower them;

(4) Prepare wooded terrain landing; and

(5) Once all movement has stopped, if suspended in trees, assess the situation before releasing the Koch fittings. If distance above ground is not excessive both fittings should be released simultaneously, as the parachutist will immediately fall free of the parachute (if only one at a time is released, a greater potential for personal injury exists).

Water:

(1) Check canopy;

(2) Discard finger pressure cups and hand mold;

(3) Discard oxygen mask;

(4) Deploy RSSK (500-1000 ft AGL);

(5) Prepare for water entry landing;

(6) Do not pre-inflate LPSV, allow the automatic inflation device to accomplish this task;

(7) Immediately release one or both parachute Koch fittings. The release of one will collapse the parachute and prevent drag, releasing both will totally discard the canopy; and

(8) Avoid any leg kicking in the water and pull the liferaft to yourself, then perform normal liferaft boarding procedures.

APPENDIX D

TEST SORTIE SUMMARY

Table D-1. In-flight Physiological Test Sorties Flown

DATE	TEST SUBJECT	TEST PILOT	SORTIE TITLE	DURATION (hr)
14 Apr 98	Eichel	Lcdr Webb	Eichel #1	1.6
15 Apr 98	Wright	Maj Whitley	Wright #1	1.2
16 Apr 98	Eichel	Maj Whitley	Eichel #2	1.3
17 Apr 98	Wright	Maj Whitley	Wright #2	1.3
20 Apr 98	Lebouthillier	Maj Kissmann	Lebouthillier #1	1.6
21 Apr 98	Crosby	Maj Whitley	Crosby #1	1.4
21 Apr 98	Will	Kissmann	Will #1	1.4
22 Apr 98	Ormsby	Maj Ward	Ormsby #1	1.5
28 Apr 98	Brush	Maj Kissmann	Brush #1	1.3
28 Apr 98	Goodman	Maj Ward	Goodman #1	1.6
29 Apr 98	Lebouthillier	Maj Ward	Lebouthillier #2	1.5
29 Apr 98	Wong	Maj Kissmann	Wong #1	1.1
30 Apr 98	Brush	Maj Ward	Brush #2	1.3
30 Apr 98	Wong	Maj Kissmann	Wong #2	1.3
1 May 98	Goodman	Lcdr Webb	Goodman #2	1.5
4 May 98	Crosby	Lcdr Webb	Crosby #2	1.5
5 May 98	Whitley	Lcdr Webb	Whitley #1	1.4
6 May 98	Whitley	Lcdr Webb	Whitley #2	1.5
6 May 98	Will	Lcdr Webb	Will #2	1.6
7 May 98	Hasiak	Maj Whitley	Hasiak #1	1.4
7 May 98	Ormsby	Lcdr Webb	Ormsby #2	1.4
8 May 98	Hasiak	Lcdr Webb	Hasiak #2	1.5
12 May 98	Holland	Maj Ward	Holland #1	1.3
14 May 98	Holland	Maj Whitley	Holland #2	1.4
14 May 98	McIntosh	Lcdr Webb	McIntosh #1	1.6
15 May 98	Lebouthillier	Lcdr Webb	Lebouthillier #3	1.3
19 May 98	McIntosh	Lcdr Webb	McIntosh #2	1.7
20 May 98	Sparks	Maj Kissmann	Sparks #1	1.5
20 May 98	Ormsby	Lcdr Webb	Ormsby #3	1.4
21 May 98	Sherwood	Lcdr Webb	Sherwood #1	1.4
21 May 98	Sparks	Maj Whitley	Sparks #2	1.5
22 May 98	Allan	Maj Whitley	Allan #1	0.7
25 May 98	Allan	Maj Kissmann	Allan #2	1.5
26 May 98	Sherwood	Maj Kissmann	Sherwood #2	1.2

APPENDIX E

BIO-MEDICAL DATA RECORDED

Table E-1. Bio-Medical Measurands Recorded for Data Analysis

MEASURAND	SYMBOL	UNITS	ORIGINAL SAMPLE RATE samples per second (sps)	FINAL SAMPLE RATE (sps)
Hours	TIM1	hr	185.19	100
Minutes	TIM2	min	185.19	100
Seconds	TIM3	sec	185.19	100
Mach Number	NA05	Mach	20.58	100
True Angle of Attack	NA12	degrees	20.58	100
Baro Corrected Pressure Altitude	NA16	ft	20.58	100
Longitudinal Acceleration – INS	N125	g	20.58	100
Lateral Acceleration – INS	N126	g	20.58	100
Normal Acceleration - INS	N127	g	20.58	100
Blood Pressure - Head	BPHD	mmHg	555.57	100
Blood Pressure – Heart	BPHT	mmHg	555.57	100
Electrocardiogram	ECG1	volts	185.19	100
Electromyogram – Abdomen	EMG1	volts	185.19	100
Electromyogram – Leg	EMG2	volts	185.19	100
Left Ear Opacity	LEOM	volts	555.57	100
Left Ear Pulse	LEPM	volts	185.19	100
Pressure – Cabin Ambient	PCAM	mmHg	185.19	100
Right Ear Opacity	REOM	volts	555.57	100
Right Ear Pulse	REPM	volts	185.19	100
Abort Light – Cockpit	SALC	volts	185.19	100
Shoot Light – Central	SSLC	volts	185.19	100
Shoot Light – Peripheral	SSLP	volts	185.19	100
Temperature – Cabin Ambient	TCAM	°C	185.19	100
Corrected Electrocardiogram	ECGD	volts	-	100
Corrected Right Ear Pulse	REPD	volts	-	100
Corrected Left Ear Pulse	LEPD	volts	-	100

VITA

Stuart Lachlan McIntosh was born in Vancouver, British Columbia, Canada on 12 December, 1967. He graduated from Abbotsford Senior Secondary School in 1985, and enrolled in the Canadian Air Force in July of that year. His first four years of service were at Royal Roads Military College where, in 1989, he graduated with a Bachelor of Science Degree in Physics. He then commenced training as an Aerospace Engineering Officer and, in 1990, was posted to Canadian Forces Base Baden Soellingen, Germany, where he served as an Engineering Officer on 409 and 439 Tactical Fighter Squadrons, as well as 1 Air Maintenance Squadron. While serving on 409 Squadron, he deployed to Doha, Qatar during the Persian Gulf conflict, where he acted as the Aircraft Engineering Officer for Canada's 24-aircraft contribution to that effort. Upon completion of his tour in Germany, he was selected to undergo Flight Test Engineer Training, and graduated from the Empire Test Pilots' School in December, 1994. He was then posted to the Aerospace Engineering Test Establishment in Cold Lake, Alberta, Canada where he served as Project Officer and Flight Test Engineer on numerous flight test projects involving the CF-18 Hornet, CT-133 Silver Star, and CT-114 Tutor aircraft. He has flown over 650 hours of flight test time as a Flight Test Engineer in military aircraft, and is a licensed private pilot. Since May, 2000, he has been employed as the Senior Engineering Officer on 410 Tactical Fighter (Operational Training) Squadron in Cold Lake, Alberta.