TP 13193E

Measurement and Monitoring of the Effects of Work Schedule and Jet Lag on the Information Processing Capacity of Individual Pilots

Prepared for

Transportation Development Centre

and

Civil Aviation Directorate
of
Safety and Security Group
Transport Canada

March 1998

TP 13193E

Measurement and Monitoring of the Effects of Work Schedule and Jet Lag on the Information Processing Capacity of Individual Pilots

by

H. Weinberg, J.J. Jantzen, and D. Cheyne
of
Applied Brain Behaviour Systems Ltd.

and

Paul Carson, Transport Canada, Civil Aviation
Rémi Joly, NavCanada
Alex Vincent, Transport Canada, Transportation Development Centre

March 1998

Un sommaire français se trouve avant la table des matières.

PUBLICATION DATA FORM

1. Transport Canada Publication No.	TP 13193E
2. Project No.	8594-95
3. Recipient's Catalogue No.	
4. Title and Subtitle	Measurement and Monitoring of the Effects of Work Schedule and Jet Lag on the Information Processing Capacity of Individual Pilots
5. Publication Date	March 1998
6. Performing Organization Document No.	
7. Author(s)	H. Weinberg, K.J. Jantzen, D. Cheyne, et al.
8. Transport Canada File No.	ZCD1455-264
9. Performing Organization Name and Address	Applied Brain Behaviour Systems Ltd. 2965 Sunnyside Road Anmore, B.C. V3H 4Y7
10. PWGSC File No.	XSD94-00208-(671)
11. PWGSC or Transport Canada Contract No.	T8200-4-4541/01-XSD
12. Sponsoring Agency Name and Address	Transportation Development Centre (TDC) 800 René Lévesque Blvd. West 6th Floor Montreal, Quebec H3B 1X9
13. Type of Publication and Period Covered	Final
14. Project Officer	Alex Vincent
15. Supplementary Notes (Funding programs, titles of related publications, etc.)	Co-sponsored by Transport Canada Civil Aviation

16. Abstract

The aim of this project was to develop methods for providing pilots, during flight, with a personalized index of their fatigue to allow them to monitor the state of their own readiness. After task analysis in Airbus 320 and Boeing 747 simulators, a multitasking software environment was designed to simulate the types of information processing required of pilots flying the Airbus 320. A two-channel battery-operated EEG system was designed to record pilots in the air while they were engaged in multitasking. Although the conditions for recording in flight were very difficult, the data suggested that, overall, both multitasking and gamma activity reflect fatigue. The increase in gamma activity is consistent with the interpretation that fatigue requires additional processing for tasks that would otherwise be more automatic because of training and practice.

17. Key Words	Pilot fatigue, fatigue measurement, information processing, gamma activity
18. Distribution Statement	Limited number of copies available from the Transportation Development Centre
19. Security Classification (of this publication)	Unclassified
20. Security Classification (of this page)	Unclassified
21. Declassification (date)	—
22. No. of Pages	xii, 20, apps
23. Price	—

Transports Canada / Transport Canada

FORMULE DE DONNÉES POUR PUBLICATION

1. N° de la publication de Transports Canada TP 13193E	2. N° de l'étude 8594-95	3. N° de catalogue du destinataire
4. Titre et sous-titre Measurement and Monitoring of the Effects of Work Schedule and Jet Lag on the Information Processing Capacity of Individual Pilots		5. Date de la publication Mars 1998 6. N° de document de l'organisme exécutant
7. Auteur(s) H. Weinberg, K.J. Jantzen, D. Cheyne, et al.		8. N° de dossier - Transports Canada ZCD1455-264
9. Nom et adresse de l'organisme exécutant Applied Brain Behaviour Systems Ltd. 2965 Sunnyside Road Anmore, B.C. V3H 4Y7		10. N° de dossier - TPSGC XSD94-00208-(671) 11. N° de contrat - TPSGC ou Transports Canada T8200-4-4541/01-XSD
12. Nom et adresse de l'organisme parrain Centre de développement des transports (CDT) 800, boul. René-Lévesque Ouest 6e étage Montréal (Québec) H3B 1X9		13. Genre de publication et période visée Final 14. Agent de projet Alex Vincent

15. Remarques additionnelles (programmes de financement, titres de publications connexes, etc.)

Projet coparrainé par Transports Canada, Aviation civile

16. Résumé

Ce projet avait pour but d'élaborer des méthodes visant à fournir aux pilotes, pendant le vol, un indice personnalisé de leur degré de fatigue, de façon qu'ils puissent contrôler leur niveau de capacité opérationnelle. Les travaux ont d'abord consisté en une analyse des tâches des pilotes, dans des simulateurs Airbus 320 et Boeing 747. Puis un programme multitâche a été développé, simulant les types de traitement de l'information exigés des pilotes aux commandes d'un Airbus 320. Un système d'enregistrement encéphalographique à deux canaux, à alimentation par piles, a été mis au point pour mesurer l'activité cérébrale des pilotes en vol, pendant l'administration de l'épreuve multitâche. Malgré des conditions d'expérimentation en vol très défavorables, les données recueillies donnent à penser que globalement, les résultats obtenus au test multitâche et le niveau d'activité gamma sont indicatifs du degré de fatigue. L'accroissement d'activité gamma avalise l'interprétation selon laquelle l'état de fatigue est associé à une intensification du traitement de l'information nécessaire à l'exécution de tâches qu'en temps normal, la formation et la pratique rendent davantage automatiques.

17. Mots clés Fatigue des pilotes, mesure de la fatigue, traitement de l'information, activité gamma	18. Diffusion Le Centre de développement des transports dispose d'un nombre limité d'exemplaires.

19. Classification de sécurité (de cette publication)	20. Classification de sécurité (de cette page)	21. Déclassification (date)	22. Nombre de pages	23. Prix
Non classifiée	Non classifiée	—	xii, 20, ann.	—

ACKNOWLEDGEMENTS

The authors of this study wish to acknowledge the valuable assistance and co-operation of the following:

M. Radomsky
Chief, Defence and Civil Institute of Environmental Medicine

M. Paul
Aerospace Medicine, Defence and Civil Institute of Environmental Medicine

LCol R.D. Banks
Head, Aerospace Life Support, Defence and Civil Institute of Environmental Medicine

the pilots and crew of Canadian Forces Squadron 437, without whose generous co-operation and help this study could not have been completed.

EXECUTIVE SUMMARY

The aim of this project was to develop methods for providing pilots, during flight, with a personalized index of their fatigue to allow them to monitor the state of their own readiness. After task analysis in Airbus 320 and Boeing 747 simulators, a multitasking software environment was designed to simulate the types of information processing required of pilots flying the Airbus 320. A two-channel battery-operated EEG system was designed to record pilots in the air while they were engaged in multitasking. Although the conditions for recording in flight were very difficult, the data suggested that, overall, both multitasking and gamma activity reflect fatigue. The increase in gamma activity is consistent with the interpretation that fatigue requires additional processing for tasks that would otherwise be more automatic because of training and practice.

A simple procedure was also designed in which MT and EEG were recorded during a 24-hour period of sleep deprivation, using students as subjects.

The results suggested that when pilots are fatigued, behaviours and information processing that are normally performed easily and automatically require additional effort, and the recombination of previously learned associations results in an increased mental workload. The study resulted in the following recommendations:

- Multitasking procedures similar to those used in this study should be developed for commercial airlines and tested with pilots who make long-haul flights.
- It should be determined whether multitasking could be an effective index of fatigue without the need to use EEG.
- It should be determined whether multitasking in flight could be useful in maintaining arousal and operational capabilities during periods of sleep loss and circadian disruption, in lieu of, or in addition to, napping.
- The multitasking test should be designed to be incorporated into the flight panel, for example, into the flight management system and hence be easily accessible to pilots in flight during periods when testing will not interfere with their normal duties.
- There should be continued development of a battery-powered EEG system, configured as a very small card that could be easily clipped to the collar of the pilot or fitted into the headset. This system should incorporate signal processing in hardware that automates the algorithms necessary for simple and direct on-line feedback to pilots about the influence of fatigue on their own brain function. The system should be capable of calibration for each individual and the procedures for that calibration should be developed.
- The effectiveness of individual countermeasures should be assessed using multitasking and EEG.

SOMMAIRE

Ce projet avait pour but d'élaborer des méthodes visant à fournir aux pilotes, pendant le vol, un indice personnalisé de leur degré de fatigue, de façon qu'ils puissent contrôler leur niveau de capacité opérationnelle. Les travaux ont d'abord consisté en une analyse des tâches des pilotes, dans des simulateurs Airbus 320 et Boeing 747. Puis un programme multitâche a été développé, simulant les types de traitement de l'information exigés des pilotes aux commandes d'un Airbus 320. Un système d'enregistrement encéphalographique à deux canaux, à alimentation par piles, a été mis au point pour mesurer l'activité cérébrale des pilotes en vol, pendant l'administration de l'épreuve multitâche. Malgré des conditions d'expérimentation en vol très défavorables, les données recueillies donnent à penser que globalement, les résultats obtenus au test multitâche et le niveau d'activité gamma sont indicatifs du degré de fatigue. L'accroissement d'activité gamma avalise l'interprétation selon laquelle l'état de fatigue est associé à une intensification du traitement de l'information nécessaire à l'exécution de tâches qu'en temps normal, la formation et la pratique rendent davantage automatiques.

La recherche comportait également un volet «au sol», soit une procédure simple qui consistait à soumettre des sujets non-pilotes, recrutés parmi des étudiants, au test multitâche conjugué à des enregistrements EEG, au cours d'une période de 24 heures de veille ininterrompue.

Les résultats laissent penser que lorsqu'ils sont fatigués, les pilotes doivent déployer des efforts supplémentaires pour s'acquitter de gestes et de processus mentaux qu'ils ont l'habitude d'accomplir facilement, voire automatiquement, en temps normal, et que la nécessité de reformer des associations apprises antérieurement mais «oubliées» sous l'effet de la fatigue alourdit leur charge de travail mental. L'étude a débouché sur les recommandations suivantes :

- Élaborer, à l'intention des compagnies aériennes, des tests multitâches semblables à celui utilisé dans la présente étude et les mettre à l'essai sur des pilotes affectés à des vols long-courrier.
- Déterminer si les tests multitâches peuvent générer à eux seuls (sans mesures EEG) un indice de fatigue fiable.
- Évaluer l'utilité d'un test multitâche administré en vol pour maintenir le degré de vigilance et de performance des pilotes dans des périodes de manque de sommeil et de perturbation de leur rythme circadien, en remplacement ou en complément de pauses pour dormir.
- Élaborer le test multitâche de façon qu'il puisse être incorporé au tableau de bord (p. ex., au système de gestion du vol), et ainsi être facilement accessible aux pilotes, au moment où l'auto-administration d'un tel test ne risque pas de nuire à leurs tâches normales.
- Poursuivre la mise au point d'un système EEG à alimentation par piles se présentant sous la forme d'un dispositif miniaturisé pouvant se fixer facilement

au col de chemise du pilote ou à l'intérieur de son casque d'écoute. Ce système doit incorporer une logique câblée de traitement des signaux qui met en oeuvre les algorithmes nécessaires à une rétroaction en ligne, simple et directe, informant les pilotes des effets de la fatigue sur leurs fonctions cognitives. Le système doit pouvoir être adapté à chaque pilote (mettre au point les procédures nécessaires à cette adaptation).

- Évaluer l'efficacité des contre-mesures à la fatigue, au moyen du test multitâche et des mesures EEG.

CONTENTS

LIST OF FIGURES

1 INTRODUCTION

An immense amount of research, particularly that carried out over the last 12 years under the NASA Ames Fatigue Countermeasures Program, has underscored the fact that irregular duty/rest cycles and the crossing of several time zones in quick succession, as experienced by pilots, are associated with a decrement in the capacity of the circadian pacemaker to synchronize the relevant shifts in daily geophysical and social cycles. Although there is substantial variability among individuals with respect to peak times of alertness, extent of adaptation to disruption of the circadian rhythm and sleep, and personal coping strategies, the frequency of pilot reports of loss of alertness and ability to concentrate on their tasks raises concerns regarding safe operational management. So compelling is the evidence that NASA has shifted its research to studying the effects of countermeasures such as planned cockpit naps, pilot education, and use of light, exercise, and caffeine. In Canada, the Transportation Safety Board has expressed concern regarding the potential of fatigue as a contributing factor in aviation accidents and incidents and, indeed, has recommended a series of countermeasures to reduce the effects of sleep loss and circadian disruption in long-haul flying (Air Carrier Advisory Circula, 1997).

While research on pilot fatigue has produced an impressive body of knowledge, there is still a need for investigation in one important area - the nature and measurement of fatigue on an individual so that:

- effects on information processing can take place;
- self-monitoring can take place; and

individual differences can be incorporated into intelligent computer scheduling systems in a way that is economically viable for airlines.

The overall aim of this project was to develop methods for giving pilots, during flight, information about the status of their own fatigue and how it could affect their performance.

The short-term goal of this study was to begin the process of developing methods for assessing levels of pilot fatigue in the air. These methods, if successful, could also be useful for establishing duty schedules that take into account individual variability of the effects of fatigue on performance. The long-term goal was to give individual pilots a personalized index of their fatigue in order to allow them to monitor the state of their own readiness.

For the purposes of this study, the term **fatigue** refers to deficits in the ability of pilots to process information as the result of prolonged periods of wakefulness. It is related to the pilot's level of attention, arousal, and alertness during flight.

The effects of fatigue are different for each person. The influence of fatigue on information processing and on performance, and the countermeasures appropriate for different levels of fatigue can be quite different for each pilot. These differences arise from the unique physiology of each pilot, age, personal history, and the interaction of those variables (Chidester, 1990; Gander, 1989, 1993; Samel, 1991). The recognition of this within various industrial contexts has led to methods for helping individuals maximize their potential under stress and fatigue. An increasingly used strategy is to give individuals an objective index of their fatigue so that they can utilize appropriate countermeasures. An understanding of how different pilots respond to the demands of different flight schedules could facilitate the development of scheduling procedures that maximize efficiency and safety, perhaps by including an index of fatigue within the flight crew bidding process (Wilse, 1982).

In modern aircraft, each pilot becomes part of an organizational and control system. If the failure of that interaction is attributable to the pilot, it is generally characterized as "human error". However, failure may be due to the way in which the was designed. If it is assumed that all pilots are identical, the organisational and control system design may be faulty. There is one thing that characterizes humans and it is that each human interacts differently with control systems. This difference can be minimized to some extent by training; however, training cannot control some human variations that are the result of subtle differences in their physiology and differences in personal environments and circumstances. It is generally agreed that as much as 80 percent of all aviation accidents, and 60 percent of all fatal accidents, are caused by "human error" (Thomas, 1989). Furthermore, fatal errors are frequently made by highly trained, skilled, and experienced professional pilots flying state-of-the-art equipment.

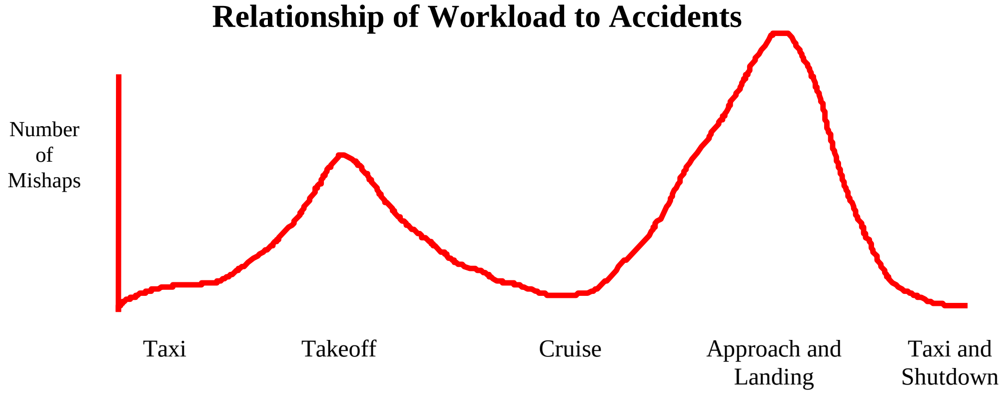
One of the most important factors influenced by fatigue is **critical performance during sustained operations**, which depends on complex information processing. Critical performance means that the consequences of failure are catastrophic, as they may be in flight (Angus et al. 1983, 1985, 1981; Pigeau, 1987).

If a method could be developed to estimate a probability of the failure of complex information processing for each individual, for example, failure that results from the disruption of sleep cycles, that method should be sensitive to other factors that contribute to the failure of information processing. In other words, measures of deficits in information processing caused by sleep loss and jet lag could be an index of generalized fatigue, resulting from the interaction of many other factors not necessarily evident in the immediate working environment, like those attributable to the pilot's age, health factors, and home and social environments (Gander et al. 1993; Wilse et al. 1982; Haugli, 1994; Mullaney, et al., 1983).

It has been shown that the number of mishaps is directly related to the complexity of information that must be processed during different phases of flight. This relationship was described 20 years ago and is still valid today (Richardson, 1978); see figure 1.

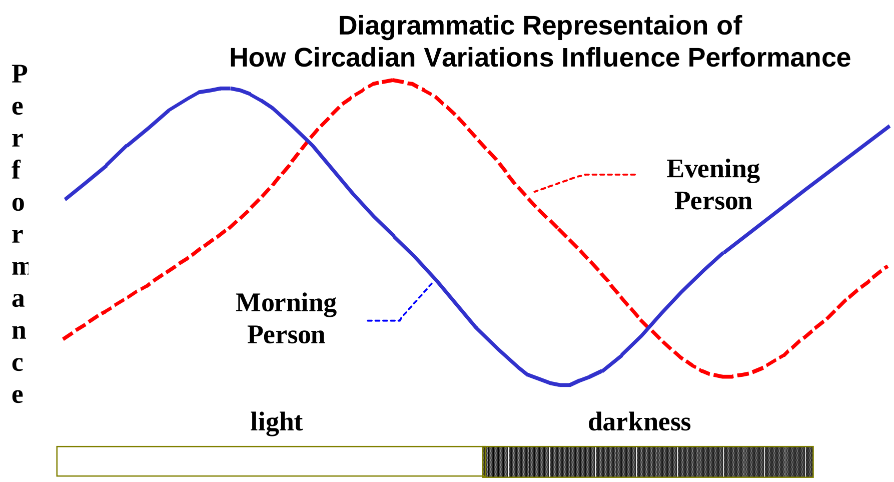
Fig. 1

Relationship of Workload to Accidents



As suggested above, one of the factors that contribute to fatigue is the way in which circadian variations modulate performance differently for different individuals, e.g., humans engaged in specific tasks do not always react in the same way at different times of day and night because perceptual and mental functions are subject to rhythmic variations over a 24-hour period. These variations are due in part to the fact that the relationship between arousal and light cycles vary from individual to individual. Generally speaking, peak performance is reached during the day with performance levels tapering off in the early morning hours. However, some individuals, characterized as "evening types", are more efficient at information processing and performance in the early hours of the evening than those who are "morning types" (see figure 2).

Fig. 2



2 AN INITIAL STUDY TO ESTABLISH VIABILITY OF METHODS

Two methods have been useful in other human factors contexts: (a) the direct measurement of brain function through Electroencephalography (EEG) and (b) the measurement of performance scores in a Multitasking (MT) procedure. The combination of these measures has been successfully used to assess performance in complex environments (Weinberg et al., 1991; 1994, a, b, 1995, 1996; Heron et al., 1994, Svoboda et al., 1991), but these procedures have never been previously used with pilots in flight, although EEG has been used to study fatigue in pilots during flight (Howitt, 1978).

2.1 The Concept of EEG for the Assessment of Information Processing

There is a long history of the use of brain electrophysiology to assess human information processing, primarily through the analysis of Evoked Potentials (EP), Event Related Potentials (ERP), and spontaneous rhythms of the brain (Electroencephalography or EEG). EPs are electrical events of the brain that are evoked by stimuli. ERPs are electrical events of the brain that are time-locked to input stimuli or occur preceding motor output. ERPs reflect the information properties of stimuli and preparation for output, whereas EPs primarily reflect the sensory properties of stimuli. Spontaneous EEG records electrical events that are not necessarily time-locked to input or to output.

2.1.1 Gamma EEG

Recently, there have been many studies of high frequency EEG activity in the 35-45 Hz range. This gamma band activity exists in a number of brain structures of different species, with different functional / behavioural correlates. This rhythm has dynamics in various structures that are influenced by different kinds of information processing. Gamma exists spontaneously but it can also be evoked or emitted with different latencies and relationships to sensory and cognitive events. Recent measurements of gamma band activity at both the macro and cellular levels have suggested functional relationships of gamma to cognition, such as the perceptual binding of previous memories and stimulus features (Basar-Eroglu et al., 1996). It has been shown that distributed gamma fields, measured in both humans and animals, may have multiple functions in what is termed "obligatory" sensory and in cognitive processing. With respect to the generators of gamma activity, experimental data hint at the existence of a widely distributed gamma system in the brain. Recent theories of intra-cerebral function suggest that these gamma band frequencies may be the result of "re-entrant processes" in the brain, reflecting the interaction between parts of highly complex and widely distributed systems in the brain. The analysis of gamma band activity, in conjunction with behavioural measures in multitasking environments, were successful in classifying the expertise of air traffic control experts (Weinberg, 1994 a, b), and have been used to study information processing in many other complex environments. It has recently been shown that efforts which require increased and focused attention for the performance of discrimination, especially those that require selective attention, result in an increase in gamma activity. Studies of parallel distributed networks in the brain suggest that gamma activity reflects the degree of "binding" that is necessary for the processing of information (e.g., Basar-Eroglu, 1996). Binding refers to the linking of different elements of the information that must be processed. For example, it may be the linking between auditory and visual input and linking of those with memories that must be retrieved for discrimination, decision, and action, all within a complex environment.

It appears that gamma activity indexes the degree to which active binding of memories and input is required for performance. It would therefore be expected that performance, which is ***not automated***, would be indexed by an **increase** in gamma activity. This is consistent with almost all of the research that has been reported. When cognitive processing ***becomes automated*** and results in well practiced and easily accessed performance, for example, in cognitive processes and performance which **do not require** an active searching through memories and complex preparation for output, (these include processes that are well established and easily performed), gamma activity should **decrease**.

If, as the result of sleep deprivation and fatigue, normally automated cognitive behavior and well practiced automated performance require more active binding, more active searching through memory, and more planning of the response to input, it would be expected that gamma activity would be **increased**.

2.2 The Concept of Multitasking

In recent years, it has been increasingly recognized that complex information processing always occurs in a context of multitasking. Even when there is apparently only one task required, that task frequently requires simultaneous performance of other tasks that are not overtly recognized. air traffic control is a good example. Controllers are required to use short-term and long-term memories that are both specific and non-specific to the particular configuration of aircraft they are dealing with. They must also use selective attention in both auditory and visual modalities and must continually adjust and coordinate auditory feedback and instructions to pilots. In addition, they are required to continually scan the visual field for the unexpected, and, depending on the circumstances, they may also be engaged in many other types of concurrent processing. These types of information processing can be studied separately, as is frequently done in a laboratory; however, in a real working environment, they are all occurring and interacting simultaneously. Since multitasking requires the simultaneous processing, perceptual organization, and presumably, binding of memories, it should be an ideal context in which to observe gamma activity.

Therefore, it is important to develop procedures for the measurement of how individuals function in MT environments, particularly, those environments that incorporate the types of information processing and performance that are required in critical environments.

In this study, the MT environment that was designed resulted from approximately eight months of observation, discussions with pilots, and task analysis in flight simulators, primarily the Airbus 320, the Boeing 747, and the Cessna Citation.

3 METHODOLOGY

3.1 Testing in Flight

The data was collected from 12 military pilots flying between Trenton and Zagreb. Typically, these flights left Trenton at about 18:00 Trenton time and arrived in Zagreb about 9:00 Zagreb time. Flying time for the outbound trip was approximately 9 hours. Pilots usually retired to a hotel for 4 or 5 hours of sleep, after which they had dinner at about 19:00, retired for additional sleep at about 22:00, awakened at about 10:00 the next morning, and began the return leg to Trenton about 13:00 Zagreb time. Landing in Trenton occurred at approximately 18:00 Trenton time. Flying time for the return trip was approximately 12 hours.

Pilots were asked to undergo testing with the MT and EEG procedures at least twice during the outbound trip and twice during the return leg of the trip. Because of differing exigencies in each flight, the testing times varied considerably, and in a number of flights, it was only possible to make one recording, usually during the outbound leg. The times of these recordings also varied considerably.

Pilots were informed that individual data would be coded and kept confidential. They were assured that, if abnormalities in the EEG were detected, a report of those abnormalities would be forwarded by double-registered mail to the individual. They were also informed that, if a report was mailed to individual pilots, the pilot's name would be removed from the code and it would be the responsibility of the individual to seek confirmation, or take other action, as deemed appropriate.

The multitasking and EEG devices were set up in the passenger compartment of the aircraft (Airbus 310) located in the rear of the aircraft. This is where the pilots were tested. During some flights there were passengers in the same area, reducing the degree of control possible within the testing environment, sometimes resulting in considerable distraction for the pilots. During some flights it was necessary to charge computer batteries between recordings; the outlets were forward of the freight compartment in the front of the aircraft. The experimental environments were very difficult but in many ways reflect the real world of aviation.

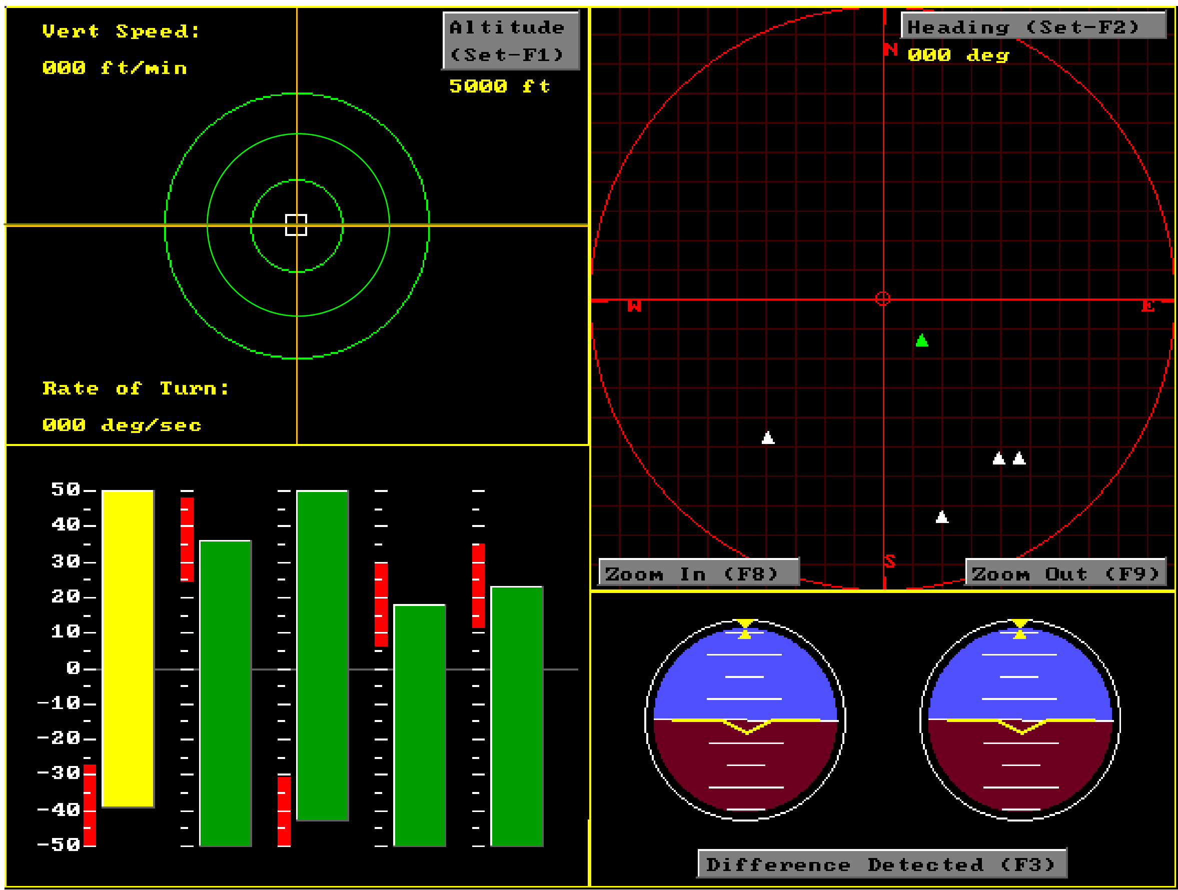
After application of the electrodes each testing session lasted 20 minutes during which the pilots were tested on MT. Ten second samples of spontaneous EEG were also recorded. As noted, the number of samples recorded varied depending on what was occurring in the cabin during the testing period.

3.2 Multitasking and EEG

The multitasking program was configured to run on a laptop computer. The program included four tasks that were presented simultaneously in four different quadrants of the screen as shown in Figure 3.

Fig. 3

Multitasking Display



The tasks included a visual-motor tracking task, a display of waypoints over which the pilot had to "fly", a display of two attitude indicators, which sometimes differed, and a series of histograms, the length of which changed from time to time. Two of the tasks directly interacted in the sense that they were linked. The tasks were complex and were described in detail in written instructions that were given to the pilots before testing.

The EEG recording device was designed and constructed specifically for this study. It consisted of a two-channel system powered entirely by four 9 V batteries. The pilot was completely isolated from any power source. The EEG amplifiers were contained within a small aluminum box 10 X 10 X 10 cm and connected by cable to an A/D card in a laptop computer, powered by batteries. Three electrodes were applied with a conductive paste that was water soluble. The electrodes were disposable, silver-silver-chloride discs approximately 5 mm in diameter. The procedure for applying the electrodes was to simply deposit a small amount of paste on the surface of the subject's scalp and press the electrode into the paste. The paste semi-hardened sufficiently to hold the electrode in place. Two electrodes were placed on the scalp, each on either side of the mid-line (which we called C3 and C4). One electrode was placed on an earlobe as the reference. Since all components were powered by battery and completely isolated from any other electrical sources, no ground was necessary. The electrodes were removed between recording sessions.

3.3 Sleep Deprivation

A simple procedure was designed to ensure that the effects on performance and gamma activity, seen in pilots, were consistent with the effects of sleep deprivation in non-pilot subjects in a laboratory environment. Five students at Simon Fraser University were recruited and paid for participation in a sleep deprivation study. The first recording period was of approximately 16:00, followed by one at 20:00, 24:00, 04:00, and 08:00. In this study, 21 electrodes were applied and EEG was recorded with an in-laboratory system. A laptop computer was used for the MT. Each recording session lasted twenty minutes.

3.4 Data Analysis

3.4.1 Multitasking

The MT program was configured to provide scores for:

1. Time off bearing, and time of altitude cross hairs
2. Detection of differences in matched attitude indicators with respect to
    - Average detection time and average decision time
    - Total hits
    - Correct hits
    - Incorrect hits
    - Misses
    - False alarms
3. Average time out of range for each of the five histograms
4. Waypoints
    - Number of waypoints reached
    - Time off waypoint heading
5. Altitude changes
    - Number of altitude changes
    - Average time off instructed altitude

Each of these measures was weighted differentially according to an algorithm to produce a final score. Thus, there were scores for each of the sub-tasks and a total error score for all of the sub-tasks combined.

3.4.2 EEG

For each trial, data were filtered between 35 and 45 Hz. The filtered data were then rectified and summed over the trial interval and the results for all trials in a session were averaged. This comprised the individual data. A summary of the data was compiled by averaging data across subjects for similar time intervals.

4 RESULTS

Data from flights in which there were multiple recordings were combined with data from flights in which there was only one recording. In these cases, the data from different subjects were combined for similar time periods, and are shown in the attached figures. The following observations are shown in the data.

4.1 Multitasking

1. Total pilot error in the multitasking, combined for all subjects is very high in the interval 23:00 to 02:00, compared with 10:00 to 15:00 or 16:00 to 17:00, Trenton Time (see figure 4).

2. The total error in multitasking during sleep deprivation, combined for all subjects, is much higher in the intervals 00:00 to 04:00 and 04:00 to 08:00 compared with 16:00 to 20:00 (see figure 5).

3. Adjusting the pilot and sleep deprivation data into three intervals and comparing pilots and students who are sleep deprived, shows the greatest error in the range of 23:00 to 08:00, compared with 10:00 to16:00 and 16:00 to 20:00. In general, pilots did much better than students who were sleep deprived, in all intervals (see figure 6).

4.2 Gamma Activity

1. In order to combine data recorded from different pilots at different times during flights, the recordings were designated Run 1 - 4. Run 1 and 2 were the first two successive recording sessions in the outgoing flight to Zagreb and Runs 3 and 4 were the second two successive recording sessions on the return flight to Trenton. Adjusting the times of recording for pilots into four ranges showed the greatest amount of gamma activity in Run 3 (the time period that was approximately 4 hours into the return leg), compared with Run 1 and Run 2. For Run 4 (approximately 2 hours before landing in Trenton) gamma activity was less than in Run 3 but greater than in Run 1 or Run 2 (see figure 7).

2. For the students who were sleep deprived, the gamma activity at 04:00 was very much greater than at any other deprivation period. At 00:00 gamma was greater than at 16:00, 20:00 and 08:00 and at 08:00 the amount of gamma was similar to that seen at 16:00 when the experiment began (see figure 5).

4.3 Comparison of Pilots and Sleep Deprivation Subjects

Pilot data were assigned to Runs 1 through Runs 4, corresponding to 1 to 4 recording intervals during flight and compared with Runs 1 to 4 in the sleep deprivation study corresponding to the four intervals of deprivation. Only student data for electrodes C3 and C4 (either side of the midline) were compared to pilot data that were derived from the same electrodes. The greatest increase in gamma for both pilots and students was in Run 3 followed by Run 4.

5 CONCLUSIONS AND RECOMMENDATIONS

5.1 Implications of the Data

Although the conditions for recording in flight were very difficult, the data does suggest that, overall, both multitasking and gamma activity index some elements of fatigue. This conclusion is supported by the comparison of data recorded from the pilots with that recorded from sleep deprived students. In both cases there is an increase in total error scores in multitasking and an increase in gamma activity. The increase in gamma activity is consistent with the interpretation that fatigue requires more processing for those tasks that would otherwise be more automatic because of training and practice. Taken together, what both measures suggest is that when subjects are fatigued, those brain systems involved in the "binding" and processing of information must become more active. This makes sense, particularly for pilots who are highly trained for the automated processing of information. This is particularly evident when pilots are required to constantly monitor information, as they are in glass cockpits of the kind found in all modern aircraft, and under critical circumstances are required to make accurate and rapid responses to that information. The data which show maximum effects in the latter stages of flight or in the latter stages of sleep deprivation cannot be attributable to practice, since practice would be expected to reduce errors not increase them. If gamma increases were simply the result of practice it would be expected that the greatest gamma would be seen in Run 4, where practice was maximized, but this was not the case.

The greatest changes are in fact seen at times when, according to what is known about the effects of circadian rhythms on performance, one would expect to see the worst performance. It must be emphasized, however, that as was suspected, there is a great deal of variability in both gamma and multitasking indices. This was truer for pilots than for the student subjects who were sleep deprived. Part of this variability could be attributable to the extremely difficult experimental conditions within which the data were recorded from the pilots. However, it is also probable that the variability represents real individual differences in pilots. These differences are more evident because of the superimposition, or summation, of the effects of their job - flying the aircraft - on the multitasking and gamma indices. Students have only one thing to do - the multitasking. Pilots have many things to do during the flight, only one of which is the multitasking.

The fact that the results of multitasking and gamma activity are consistent suggests that multitasking may be able to index fatigue without EEG. Although at this point the data are only suggestive, it is clear from the data that it is feasible to implement both EEG measurements and multitasking in flight. It should be remembered that all measurements were made in passenger seats. The challenge of further study will be to develop a system that can be used in the cockpit, configured as part of the panel, or in a convenient place so that it can be accessed whenever the pilot wishes, without interfering with the pilot's normal duties. This can be accomplished for the multitasking tool and it may be achievable for EEG if a simple, easily applied "one electrode system" can be designed in which the EEG is automatically band-passed with hardware, rectified, integrated over a fixed recording interval, and displayed during the testing session.

If multitasking were used independently of EEG, or concurrently with it, separate displays could be designed: one for the total weighted error score combining multitasking and gamma indices, using an algorithm for their combination, and another for multitasking.

It must be emphasized again that the pilot experiments were carried out in an extremely difficult environment, and with a flight schedule that was arduous but not as severe as many in commercial aviation. The study was also confined to long-haul flights. It may be that the requirements of short haul-flights, during which there are many landings, and where pilots are continually in the midst of busy traffic, would be more fatiguing than these that result from sleep deprivation and jet lag.

5.2 Countermeasures and Self Reports

This study was not designed to study countermeasures of fatigue; however, the results suggest that multitasking and EEG could be used to index the effectiveness of countermeasures for individual pilots.

Countermeasures usually recommended include diurnal and nocturnal napping. **Diurnal napping** may be problematic in that the time slot in which the nap occurs may influence the following night's sleep. A nap at the start of the afternoon delays sleep onset and reduces the duration of deep sleep (Graeber et al.; 1990, Airbus Industries, 1995; Mullaney; 1993; Endo, 1981).

The **nocturnal nap** implies that there is sleep loss and the result is that the wakefulness period between the nocturnal nap and the next night's sleep is increased. There is also a rebound effect in which the duration of deep sleep, during which arousal is difficult, is increased in the first subsequent nocturnal sleep. These factors are important because stage 4 sleep (deep sleep) is necessary for recovery from previous sleep deprivation and if it is forced during duty hours, by previous deprivation, the pilot will have a very difficult time in quickly returning to adequate levels of arousal and wakefulness. Napping can also lead to sleep **inertia** in which there is transient disorientation and mental confusion upon waking. Sleep inertia occurs regardless of the time of day and whether or not there has been previous sleep deprivation. The longer a person is in deep sleep, which occurs after nocturnal napping, the greater is the sleep inertia. However, it has been generally shown that pilots, while resting in their seats, can quickly obtain short periods of sleep, and that naps decrease the number of spontaneous drowsiness episodes, as indicated by self reports and increased performance as assessed by reaction time (Airbus Industries, 1995). It should be pointed out that self reports are useful; however, it is also widely accepted that the judgments made by people who are fatigued, about the state of their own fatigue, are impaired by that same fatigued state (Mullaney et al., 1983).

Napping and rest during flight may not be the best countermeasure for fatigue in critical environments. An approach that should be studied is the development of procedures that ***maintain arousal and operational capabilities during the entire period of sleep loss and circadian disruption***, and the scheduling of sufficient time for recovery in non-operational periods after landing.

6 THE NEXT PHASE

These results indicate the feasibility of recording EEG in flight in conjunction with multitasking and the possibility of using these methods for giving pilots information about their own fatigue. The following recommendations can be made.

- Multitasking procedures similar to those used in this study should be developed for commercial airlines and tested with pilots who make very long-haul flights.

- It should be determined whether multitasking could be an effective index of fatigue without the need to use EEG.

- It should be determined whether multitasking in flight could be useful in maintaining arousal and operational capabilities during periods of sleep loss and circadian disruption, in lieu of, or in addition to, napping.

- The multitasking test should be designed to be incorporated into the flight panel, for example, into the Flight Management System, and hence be easily accessible to pilots in flight during periods when testing will not interfere with their normal duties.

- There should be continued development of a battery-powered EEG system, configured as a very small card that could be easily clipped to the collar of the pilot or fitted into the headset. This system should incorporate signal processing in hardware that automates the algorithms necessary for simple and direct on-line feedback to pilots about the influence of fatigue on their own brain function. The system should be capable of calibration for each individual and the procedures for that calibration should be developed.

- The effectiveness of individual countermeasures should be assessed using multitasking and EEG.

Fig. 4

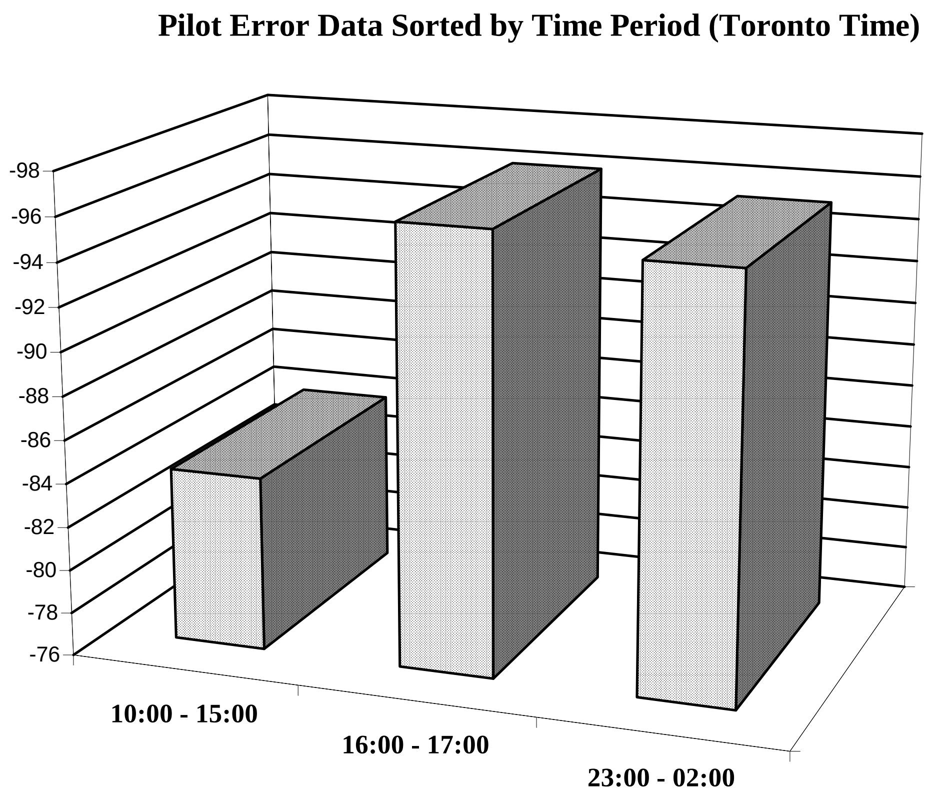
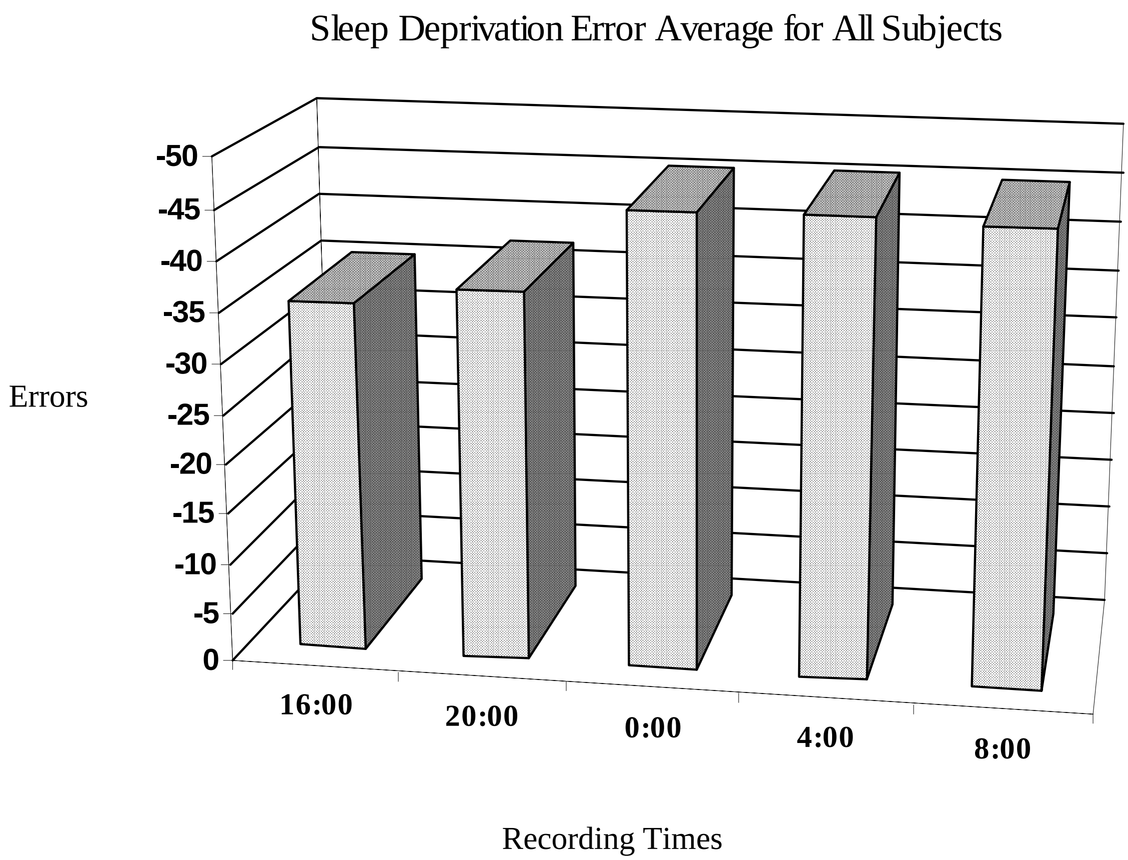

Pilot Error Data Sorted by Time Period (Toronto Time)
-98
-96
-94
-92
-90
-88
-86
-84
-82
-80
-78
-76
10:00 - 15:00
16:00 - 17:00
23:00 - 02:00

Fig. 5



Sleep Deprivation Error Average for All Subjects
Errors
-50
-45
-40
-35
-30
-25
-20
-15
-10
-5
0
16:00
20:00
0:00
4:00
8:00
Recording Times

Fig. 6

Average Pilot Error Compared with Average Sleep Deprivation Effects

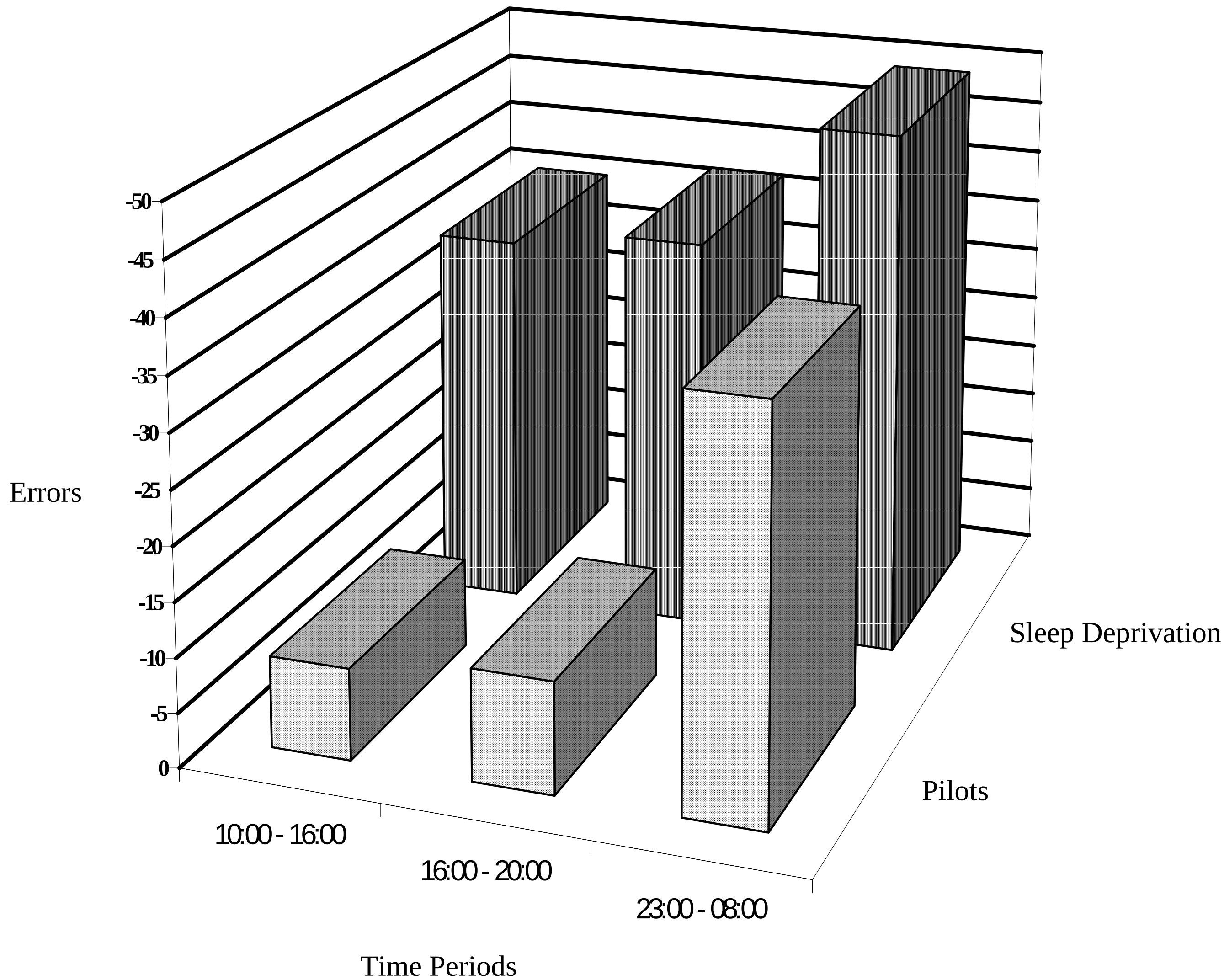


Fig. 7

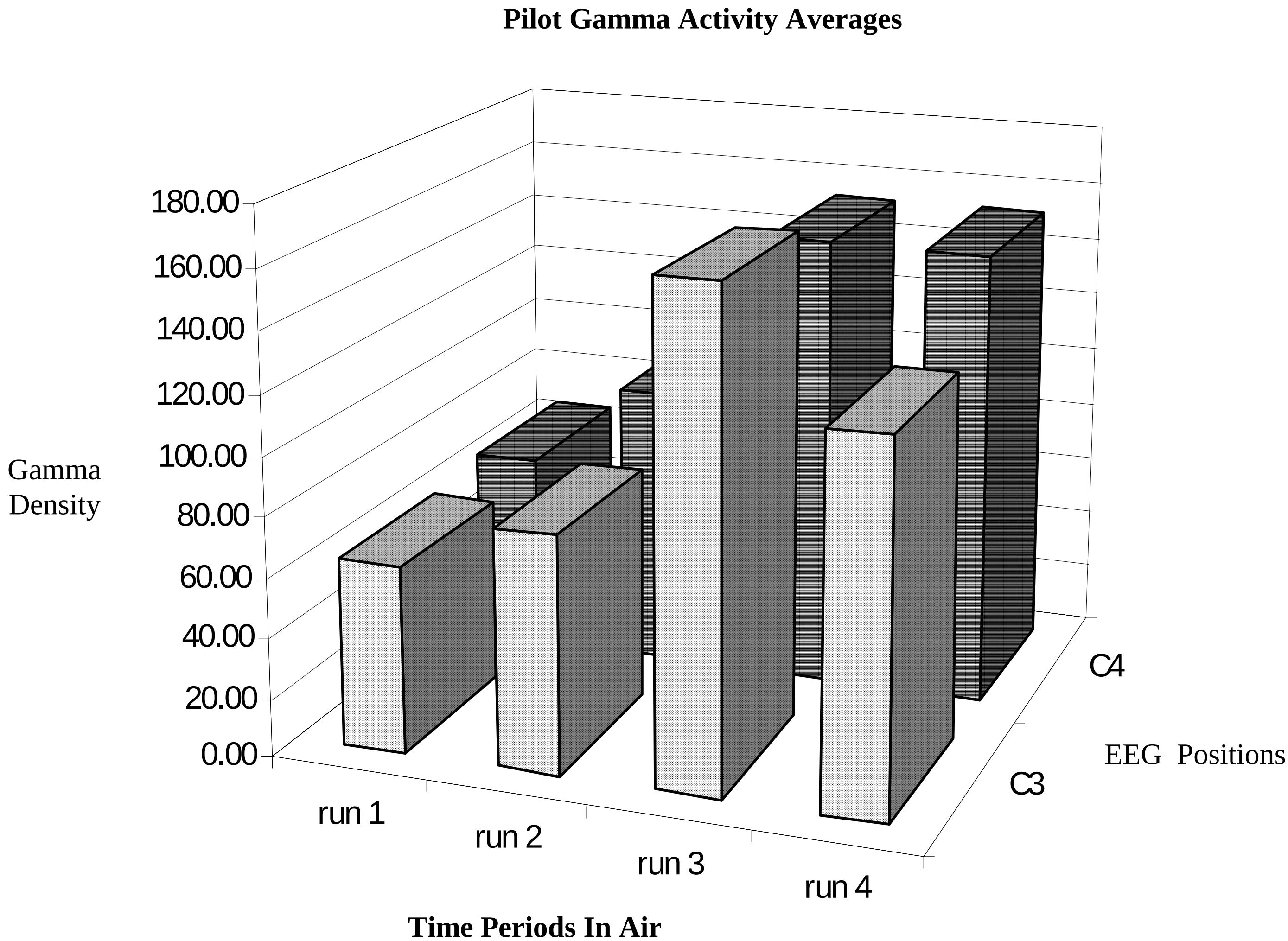
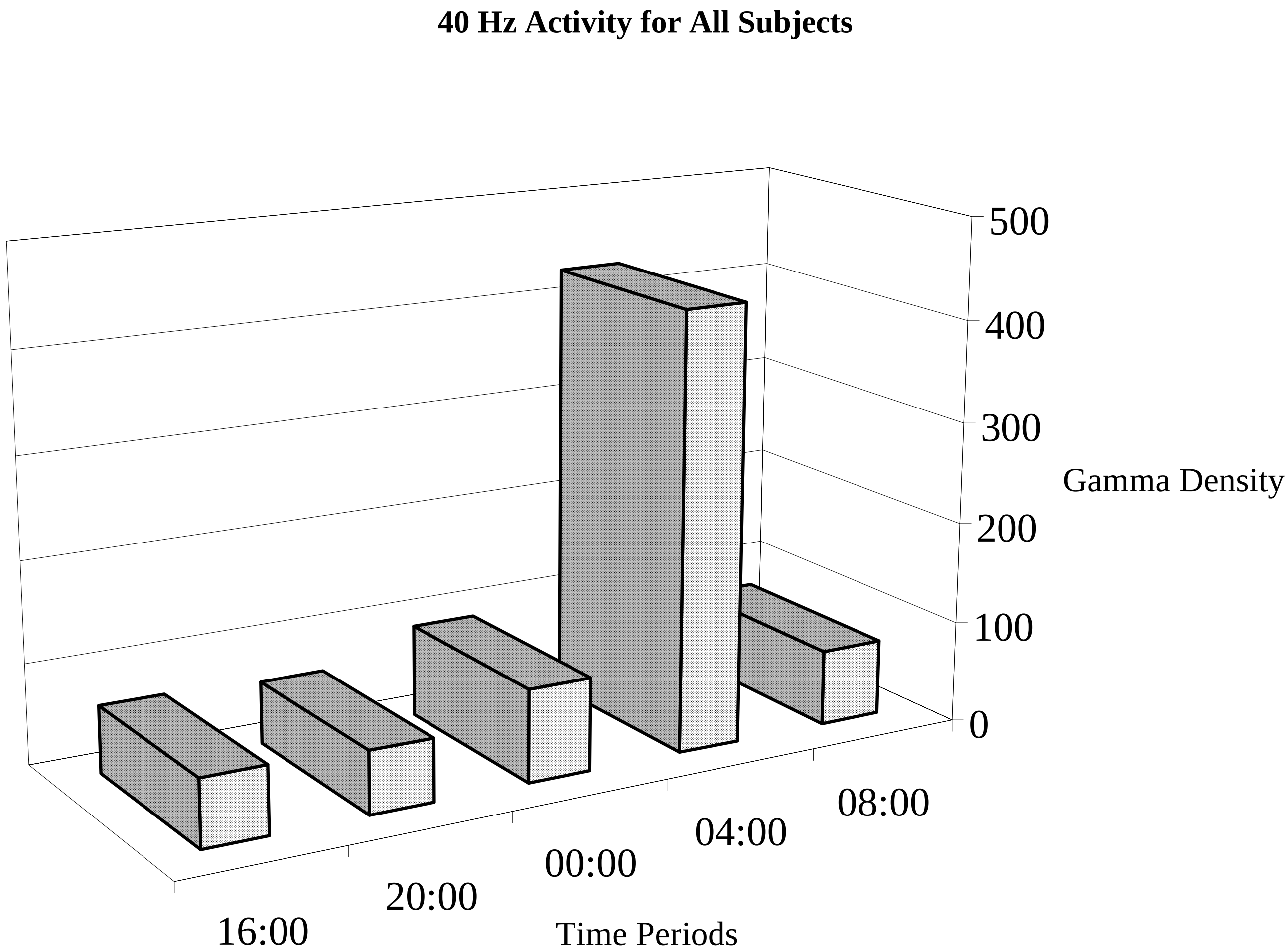

Pilot Gamma Activity Averages
180.00
160.00
140.00
120.00
100.00
80.00
60.00
40.00
20.00
0.00
Gamma Density
run 1
run 2
run 3
run 4
Time Periods In Air
C4
C3
EEG Positions

Fig. 8


40 Hz Activity for All Subjects
500
400
300
200
100
0
Gamma Density
16:00
20:00
00:00
04:00
08:00
Time Periods

REFERENCES

Airbus Industries (1995), Coping With Long Range Flying: Recommendations for Crew Rest and Alertness. A1/ST-F 472 7057, 172 - 174.

Air Carrier Advisory Circular (1997) Managing Fatigue in Flight Operations. Transport Canada ACAC No. 0137, 1 - 10.

Angus, R.G. and Helsgrave, R.J. (1985), The effects of sleep loss on sustained cognitive performance. Behav. Res. Methods. Instrum. Comput. 17, 55 - 67.

Angus, R.G. and Heslegrave, R.J. (1983), The effects of sleep loss and sustained mental work: Implications for command and control performance (NATO Report AGARD-CP-388). In *Sustained Intensive Air Operations: Physiological and Psychological Aspects.* Paris: NATO Advisory Group for Aerospace Research and Development, 11.1 11.21.

Angus, R.G., Pearce, D.G., and Olsen, L. (1981), Vigilance performance of men sleeping under arctic condtions. Aviation Space Environmental Medicine, 50, 692 - 696.

Basar-Eroglu, C., Struber, D., Schurmann, M., Stadler, M. and Basar, E. (1996), Gamma-band responses in the brain: a short review of psychophysiological correlates and functional significnce. International J. Psychophysiol., 24, 101 - 112.

Chidester, T.R. (1990), Trends and Individual Differences in Response to short-haul flight operations. Aviation Space, and Environmental Medicine, 132 - 137)

Endo, S., Toshinori, K., Yamamoto, T., Fukuda, H., Sasaki, M., and Ohta, T. (1981), Sleep, 4, 319 - 328.

Gander, P.A., Myhre, G., Graeber, R.C., Andersen, H.T., and Lauber, K. (1989), Adjustment of sleep and the circadian temperature rhythm after flights across nine time zones. Aviation, Space and Environmental Medicine, 733 - 742.

Gander, P.H., De Nguyer, B.D., Rosekind, M.R., and Connel, L.J. (1993), Age, circadian rhythms, and sleep loss in flight crews, Aviation, space and Environmental Medicine 64, 3, 189 - 195.

Graeber, C., Rosekind, M.R., Connell, L.J., and Dinges, D.F. (1990), Cockpit napping. ICAO Journal, 5 - 10.

Haugli, L., Skogstad, A. and Hellosoy, O.H. (1994), Aviation, Space, and Environmental Medicine, 27 - 34.

Heron, R.M., Svoboda, J.V., and Weinberg, H. (1994), Performance measurement techniques for microprocessor-based simulator technology. International Congress of Ergonomics, Toronto.

Howitt, J.S., Hay, A.E., Shergold, G.R., and Farres, H.M. (1978), Workload and fatigue-In-flight EEG changes. Aviation, Space and Environmental Medicine, 1197 - 1202.

Mullaney, D. J., Kripke, D.F., Fleck, P.A., and Johnson, L.C. (1983), Sleep loss and nap effects on sustained continuous performance. Psychophysiology, 20, 6, 643 - 651.

Pigeau, R.A., Helsgrave, R.J., and Angus, R.G. (1987) Psychophysiological measures of drowsiness as estimators of mental fatigue and performance degradation during sleep deprivation. In: *Electrical and Magnetic Activity of the Central Nervous System: Research and Clinical Applications in Aerospace Medicine.* Paris: NATO Advisory Group for Aerospace Research and Development 22.1 - 21.6.

Richardson, J. (1978), "Takeoffs and Judgment" Aerospace Medicine 38, 1117 - 1119.

Samel, A., Wegmann, H.M., Summa, W., and Naumann, M. (1991) Aviation, Space, and Environmental Medicine, 661 - 669.

Svoboda, J.V., Heron, R.M. and Weinberg, H. (1991), Microprocessor based driving simulator for the assessment of brain damaged individuals. Prepared for the Transportation Development Centre, Policy and Coordination, Transport Canada, TP 8855.

Thomas, M. (1989) Managing Pilot Stress. Mcmillan, 77 - 79.

Weinberg, H. (1994a), The assessment and classification of complex information processing in multi-tasking environments. Presented to the International Congress of Ergonomics, Toronto.

Weinberg, H. (1994b), The use of EEG and MEG to Study Rail Operator Fatigue. Prepared for the Transportation Development Centre Policy and Coordination, Transport Canada, TP12254E.

Weinberg, H. (1995), The use of multitasking to determine transfer of training factors for ATC students and selection criteria for applicants. Prepared for the Transportation Development Centre, Policy and Coordination, Transport Canada, TP 12246E.

Weinberg, H., Heron, R.M. and Svoboda, J.V. (1991), Use of EEG and MEG in the development of an assessment modules for a driving simulator. Prepared for the Transportation Development Centre, Policy and Coordination, Transport Canada, TP 8855.

Wilse, B.W. and Levy, C.M. (1982), Age, sleep deprivation and performance. Psychophysiology, 19, 272 - 274.

Appendix A

Description of Experiment

This experiment is a joint effort by Transport Canada and DND to establish whether it is feasible to give pilots an objective index of their level of fatigue during flight. We are testing two methods and hope to combine them as a single index, Multitasking and EEG. The multitasking is a computer display that requires visuo-motor co-ordination and other types of information processing. The tasks are described in the Instructions For Multitasking that are attached.

The second method, EEG, is to get an index of the efficiency of brain function during flight and particularly during the period when you will be doing the multitasking. We will be analysing the EEG in the laboratory and combining those measures with the Multitasking scores. We will be asking you to complete the multitasking approximately every three hours when it does not interfere with your duties. The Multitasking is configured on a lap-top computer that is powered by batteries and may be moved to any convenient location. The Multitasking will take approximately 15 minutes to complete. When you are using the Multitasking programme we wish to record EEG from two electrodes placed on your scalp and one ear. The scalp electrodes measure how alert you are during the Multitasking - they are applied by pressing them into a small glob conductive paste that is pressed into the hair and makes contact with the scalp. The paste is water soluble and can be removed easily with a wet cloth.

All data is completely confidential and automatically coded so that the data cannot be associated with any individual. However, if you want us to send you a summary of your data, both Multitasking and EEG, and our initial interpretations, please indicate that on the consent form and we will be happy to do so. After the data has been sent to you, if you wish us to do so the data will be permanently de-identified.

In addition you will be asked to fill out a Sleep Log at your convenience but before the end of the flight - the log is attached.

If at any time when you are engaged in testing that you wish to terminate or suspend the procedure simply let the experimenter know and he or she will remove the electrodes and close the programmes.

If at any time that your duties require it you may remove the electrodes you self by simply pulling them out of the paste and you may simply put aside the lap-top.

On behalf of DND and Transport Canada we would like to thank you for participating in this experiment which we believe may lead to a method for pilots to objectively assess their own levels of fatigue during difficult flight schedules.

Appendix B

Participant's Instructions for Use of Multitasking

General Description.
When the program is running you will see four separate displays on the screen which represent four different tasks that must be performed simultaneously. These tasks resemble flying an aircraft through a simulated airspace to specific targets or "waypoints" as described below.

TRACKING TASK
The upper left display (referred to hereafter as the "Tracking Task") represents a aircraft control panel in which a small white box shows the action of the aircraft control column (this can be controlled at any time by motions bank the aircraft to the left or right increasing or decreasing the rate of turn in relation to the aircraft's heading, in degrees per second. Up and down pitches aircraft up or down, increasing or decreasing the rate of change of altitude in feet per minute. These values are displayed on the panel along with the current aircraft heading and altitude which will change accordingly. In addition, there are flight director "cursors" (shown in orange on the same display) which help guide the change of aircraft climb/descend rate and heading based on what has been entered into the "flight computer". Thus, these cursors move accordingly if the current target values are changed by using the F1 and F2 keys and typing in new values and will indicate the necessary flying pattern needed to achieve the new heading and/or altitude. When the program starts the aircraft will already be on the entered heading (0.0 degrees) and altitude (5,000 ft). The object of this task is to maintain the aircraft on the current target heading and altitude that is entered into the flight computer, i.e.., to try to bring the orange cursors into the centre of the screen and maintain them in this position. However, the values that should be entered into the computer at any time ("target heading" and "target altitude") will be dictated by the Waypoint Task described below.

WAYPOINT TASK
The upper right display (referred to hereafter as the "Waypoint Task") shows a map of the ground viewed from the aircraft. Straight up on the display represents the "front" of the aircraft (i.e.., the current direction of the aircraft). You will see a number of small triangles which represent waypoints, one of which will be solid green in colour which represents the currently active or "target" Waypoint. As soon as the correct heading of the target relative to your current position can be determined this value should be entered into the flight computer as the "target heading" (see Tracking Task"). If the target Waypoint is not visible the range of view of the "map" can be incrementally increased or decreased by a factor of 2 using the Zoom in and Zoom out keys (F8 and F9) as shown until it is found. Similarly, the map can be zoomed in for a more detailed view of the target Waypoint once it is in close range of the aircraft. The object of this task is to fly towards the "target Waypoint" as efficiently as possible until it is

intersected by the aircraft. Successful "capture" of the Waypoint is achieved if the centre of the triangle passes through the small circle in the centre of the screen.

IT IS IMPORTANT TO TRY TO MINIMISE THE AMOUNT OF TIME THAT THE TARGET HEADING IS DIFFERENT FROM THAT NEEDED TO INTERCEPT THE WAYPOINT.

Your score is reduced for the amount of time spent flying towards the target without changing the target heading to be as close to the necessary heading as possible. Once a Waypoint is intercepted, it will flash briefly and a new triangle will become the target.

A second task in this display is the instruction to change the target altitude to a new altitude (using the F1 button as described in the "Tracking Task"). This will occur periodically and will consist of the new target altitude being presented for 5 seconds at the upper left corner of the map accompanied by a short beeping sound. It is important to note these values immediately - once the display disappears from the screen it cannot be retrieved. You will also be scored on the amount of time the target heading is set to the correct value.

INSTRUMENT TASK

The lower right display (referred to hereafter as the "Instrument Task") shows two "artificial horizon" attitude indicators, which will reflect the current attitude of the aircraft as determined by the rate of turn and climb shown in the Tracking Task display. In addition, the deviation of the current aircraft heading from the target heading is shown by a small arrow around the outside of the attitude indicator. This arrow will come into line with the top of the display as the target heading is reached.

Periodically, you will notice discrepancies in the information (e.g., angle of bank or pitch) being provided by these two instruments where one instrument only will show the correct information. The object of this task is to press the "difference detected" button (F3) as soon as you notice these differences. Two buttons will appear below each instrument indicating which key (F4 or F5) to press to indicate the instrument that is showing the correct information, after which the two instruments will again display the same information. There will be scores deducted for failure to notice these differences in sufficient time as well as "false" alarms and incorrect choice of the instrument showing the correct or "true" information.

BAR TASK

The lower left display (referred to hereafter as the "Bar Task") will show a number of vertical bars which will change in their length. Beside each bar there is a red line indicating the desired length or "target zones" of the bar. The object of this task is to keep the end of the bars within this range at all times. The bars will change their length periodically and target zones may also change. The length of the bars can be changed in the following way. Use the left and right ARROW KEYS to select a bar (this will be indicated in a change in the colour of the bar). Then use the up and down ARROW KEYS to increase the rate of movement of the bar in the appropriate direction. NOTE: pressing the key once increases the rate of change by one speed in single steps up to a maximum rate. Therefore when the target zone is reached the arrow keys should be used to slow down and or reverse the change in length of the bar to keep it within the target zone. (Note that the bar task does not interact with any changes in the other three tasks.)

Appendix C

Informed Consent of Participants

Study to Determine the Effectiveness of Measures of Fatigue During Flight

I have read the experimental procedures described in "Description Of Experiment" and understand them. I have had the opportunity to discuss the procedures with the experimenter and to clarify any questions I may have had. I consent to these procedures. I understand that I may ask for my participation in the experiment to be terminated at any time by informing the experimenter before or during flights.

I understand that if I have complaints that arise from the procedures I may contact: Col. Robert Banks of DCIEM, Dr. H. Weinberg of the Brain Behaviour Laboratory, Dr. Paul Carson of Transport Canada or Mr. Rémi Joly of the Transportation Development Centre.

I understand I may request that the data and interpretations collected from myself be forwarded to me and that all data will be coded to insure complete confidentiality of results, and that my name will not be identified with any results without my written permission.

I understand that if any abnormalities are observed in the EEG that information will be forward to me by double-registered mail and will not be made available to any other person without my written permission.

I wish my data and results to be forwarded to me by double-registered mail at the following address. I understand that failure to sign this request and indicate an address will result in the data not being forwarded.

Please forward my data to the following address :

____

Signature for forwarding of data: _____________________________________

==

I give my consent for my participation in the experiment as outlined in the "Description of Experiment"

Signature ______________________________ Date _____________