AGARD-CP-579

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ADVISORY GROUP FOR AEROSPACE RESEARCH & DEVELOPMENT

7 RUE ANCELLE, 92200 NEUILLY-SUR-SEINE, FRANCE

AGARD CONFERENCE PROCEEDINGS 579

Neurological Limitations of Aircraft Operations: Human Performance Implications

(les Limitations neurologiques des opérations aériennes: les Conséquences pour les performances des équipages)

Papers presented at the Aerospace Medical Panel Symposium held in Köln, Germany from 9-12 October 1995.

NORTH ATLANTIC TREATY ORGANIZATION

Published April 1996

Distribution and Availability on Back Cover

Executive Summary

The Aerospace Medical Panel (AMP) of the Advisory Group for Aerospace Research and Development (AGARD) held a Symposium entitled "Neurological Limitations of Aircraft Operations: Human Performance Implications" at Deutsche Forschungsanstalt für Luft- und Raumfahrt, Cologne, Germany, 9 - 12 October 1995. The Symposium was held to address the factors which limit optimal functioning of the brain and other parts of the nervous system in air and support operations. Factors such as advancements in technology, information overload, hazardous conditions, workload fatigue and sleepiness, head injury, drugs and inexperienced crew all affect decision making and place limitations on air and ground crew performance. Also considered were the practical challenges for enhancing brain performance for different operational environments.

The Symposium addressed a number of topics that will benefit the military. These benefits include:

- new directions for studying G-induced loss of consciousness resulting from the transition from negative G to positive G (push-pull effect) in high performance aircraft manoeuvers
- consideration that candidates for pilot training demonstrating epileptic forms of brain waves not be selected as aircrew
- confirmation that new aircrew protective garmentry employing pressure breathing allow both physical endurance and full mental performance to high G
- indications that exposure to hypoxia may affect resistance to infection
- possibility of designing "smart garmentry" for detecting onset of hypoxia in the cockpit
- design of a computer administered system to detect subtle changes in mental function resulting from head injury
- development of a new method to detect alcohol consumption in pilots
- improved techniques for aircrew vision testing
- new insights on the effects of workload stress and the ability to cope with stress
- new drugs with no side effects for enhancing performance during sustained operations

Because of the rapid developments in the brain sciences and in new technologies, the recommendation is made that AGARD/AMP hold further activities and other symposia in the next few years that further address the limitations and enhancements of the nervous system for different operational conditions.

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TECHNICAL EVALUATION REPORT

by

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1. INTRODUCTION

The Aerospace Medical Panel (AMP) held a Symposium on "Neurological Limitations of Aircraft Operations: Human Performance Implications" at the research centre of the Deutsche Forschungsanstalt fur Luft- und Raumfahrt, Koeln, Germany, 9 - 12 October 1995. Thirty-seven papers and three invited Keynote Addresses were given by authors from nine NATO countries, Australia, The Czech Republic, and Sweden. There were 133 registrants at the Symposium.

2. THEME

NATO conceptualizes the use of multinational forces in the 1990s and beyond having improved capabilities for mobility, flexibility and rapid augmentation. A high level of situation awareness is envisioned, command and control will increase in importance, and the use of information processing technologies will be paramount for enhancing pilot performance. All of these conditions are dependent on the provision of optimal neurological performance by conscientious air and support crew. Accordingly, a full understanding is required of the functions and limitations of the brain in order to conduct effective performances under different operational conditions.

Effective aircrew performance in the modern cockpit requires intelligent decision-making and rapid reaction to threatening environments. The performance of the human brain in decision making can be enhanced by technological developments and training, and augmented by teamwork. However, factors such as head injury, sleep debt, degraded sensory information processing, inexperience, drugs, and behavioural deficits affect decision making and place neurological limitations on aircrew performance. This Symposium addressed the issues of neurological limitations and the enhancement of neurological performance in operational conditions from both the clinical and behavioural points of view.

3. PURPOSE AND SCOPE

Human performance limitations ultimately depend on the neurological limitations of the nervous system. Far too often, the brain's limitations and its performance enhancement capabilities have been overlooked, ignored or forgotten. The purpose of this Symposium was to bring together military and civilian specialists in clinical medicine and human performance to address some of the neurological issues that must be faced for effective aerospace operations into the next century.

The scope was broad, covering topics that addressed impairment of neurological function by the physical environment, sensory limitations, workload, disease and trauma. A panel discussion considered typical medical case studies and policy issues regarding neurological limitations in aircrew. A second panel discussion looked at the practical challenges of enhancing neurological performance in air and support operations. The symposium participants included military and civilian experts in aerospace medicine, neurology and neurophysiology, cognitive and experimental psychology, human factors, and bioengineering. Presentations were drawn from career pilots, flight surgeons, and investigators from defence research institutes, universities, and military and civilian medical centres and institutes.

4. SYMPOSIUM PROGRAM

The Symposium commenced with a Keynote Address that focused on the different strategies that must be considered in order for a pilot to effectively fly the modern high technology aircraft in threatening environments. This was followed by eight technical sessions, a special session and two panel discussions as follows, set out in chronological order:

a. Session I The Gz Environment: Neurological Implications and Enhancement of Performance
Chairmen: Dr J.P. Landolt, CA and
Mr J.L. Firth, UK

b. Session II The Hypoxia Environment: Neurological Implications and Assessment
Chairmen: Maj N.P.N. Ribero, PO and
Col Dr E. Roedig, GE

c. Panel Discussion: Neurological Limitations in Aircrew Environments: Clinical Case Studies and Policy Issues
Discussion Leaders: Mr J.L. Firth, UK and
Col Dr E. Roedig, GE

d. Session III Disease and Trauma: Neurological Implications and Assessment
Chairmen: Col Dr E. Roedig, GE and
Maj N.P.N. Ribero, PO

e. Session IV Neurosensory Limitations
Chairmen: Dr A. Leger, FR and
Dr J.P. Landolt, CA

f. Session V Workload: Evaluation and Measurement
Chairmen: Prof Dr W.J. Oosterveld, NE and
Cdr D.L. Dolgin, US

g. Session VI Stress Effects
Chairmen: Maj N.P.N. Ribero, PO and
Prof Dr W.J. Oosterveld, NE

h. Session VII Workload: Fatigue and Sleepiness
Chairmen: Mr J.L. Firth, UK and
Prof Dr W.J. Oosterveld, NE

i. Session VIII Sustained Operations and Strategies for Enhancement
Chairmen: Cdr D.L. Dolgin, US and
Dr A. Leger, FR

j. Special Session Enhancing Neurological Performance in Aerospace Operations: Practical Challenges
Chairmen: Cdr D.L. Dolgin, US and
Mr J.L. Firth, UK

k. Panel Discussion regarding Special Session
Discussion Leaders: Cdr D.L. Dolgin, US
and Mr J.L. Firth, UK

5. TECHNICAL EVALUATION

5.1 Keynote Address

In his Keynote Address on man in the modern military cockpit, Linder (Paper #K1) described three components considered essential for adjusting the high technology cockpit to the pilot's capabilities. They are:

- developing the right format for transferring the information optimally to the pilot,
- cognitively processing the information to enhance rational decision making, and
- optimally effectuating pilot decisions.

He spoke of the importance of human-decision making, fast reflexes, and good physical and mental health in flying the future agile aircraft. He considered that creativity and intuition will be just as important as technical knowledge in selecting future pilots.

5.2 The Gz Environment: Neurological Implications and Enhancement of Performance

Banks and Goodman (Paper #1) discussed in terms of the autonomic nervous system, the increased pilot susceptibility to G-induced loss of consciousness (G-LOC) when transitioning from -Gz to +Gz (push-pull effect). For -Gz exposures less than 5s, recovery of blood pressure matches the time of heart rate recovery. When exposure times are increased beyond 5s, blood pressure recovery is primarily mediated by the speed of vasoconstriction of the peripheral vascular beds. Banks and Goodman contended that designing adequate protection for pilots during the push-pull effect required further research on the response of the heart and vascular system to short-term parasympathetic and sympathetic influences. The recent fatal crash of a Canadian Forces F-18 aircraft due to the push-pull effect underscores the urgency in studying this issue.

Gray and Paul (#2) described the interesting experience of a pilot who was unable to maintain controlled flight in a simulator, following an episode of G-induced loss of consciousness during centrifuge training. In a real flight situation, this could have been a fatal accident. During the G-LOC incident on the centrifuge, the pilot experienced bilateral extremity jerking movements lasting 8s. Interestingly, on aircrew selection, his electroencephalograph (EEG) showed a 3 Hz slow wave activity, and he was classified as unacceptable. However, he was passed for pilot training based on a normal clinical neurologic review. Gray and Paul indicated that trained pilots showing such extreme motor activity during centrifuge training should be further screened for potential epileptiform EEG activity. Moreover, they argued strongly that candidates for pilot training with epileptiform EEG activity should not be accepted.

Results from centrifuge experiments conducted by Chelette and colleagues (#3) showed that the more advanced protective systems employing positive pressure breathing and full anti-G suit allow longer physical endurance to high G. Furthermore, based on the tests applied, these systems enable pilots to maintain full cognitive performance and mental workload throughout the extended exposure. Also, there were no neuropsychological decrements observed post exposure. Subjects in these studies repeatedly endured prolonged high-G exposures (some to +9Gz) to the point of subjective fatigue or painful discomfort

The thrust of Paper #4 by Firth was that there are multiple factors involved in dealing with the blood-brain barrier, and all of these must be designed into a G-exposure experiment.

There have been numerous studies that have accurately investigated the dynamics of head motion relative to the body during +Gz ejection. However, models generated from these studies do not consider the effects on the cervical spinal cord resulting from the sudden change in load caused by ejection from a high performance aircraft. Mazuchowski and colleagues (#5) used human cadavers, physical models and isolated tissue experiments to study the strain and strain rate produced in the head-neck region by the +Gz levels encountered in ejection. Results showed that neurological deficits will occur and pilot safety will be compromised during cockpit egress if the strain is >15% and the strain rate is >1/s. This implies that when the head centre of gravity is displaced, as is the case when wearing helmet mounted devices or ejecting with an improper body position, the potential for injury greatly increases. The authors further recommended that tests should be run to assess predicted strain differences in the male and female head-neck region under +Gz.

In a related study, using simple finite element analysis, Drew (#6) simulated the ejection of an aviator following an L5 hemilaminectomy. The model was subjected to the maximal G loading which occurs during ejection in a Martin-Baker seat. Although an increased stress to the L5 vertebra was indicated, at no vertebral location did the simulation exceed the maximal stress at which bone fracture occurs. This study demonstrated the usefulness of finite element analysis for determining ejection safety of an aviator having a diseased, surgically-intervened or otherwise abnormal spine.

5.3 <u>The Hypoxia Environment: Neurological Implications and Assessment</u>

Paper #7 by Neslein and K. Myhre addressed an important topic: the impairment of cellular phagocytic capacity in rats following repeated exposure to the stress of hypobaric hypoxia. Such a finding in the human may well mean that exposure to hypoxia adversely affects resistance to infection.

The belief has long been held that the accuracy of visual information processing is highly sensitive to hypoxia (MacFarland, 1969). This begs the question: Is the disruption by hypoxia specific to the visual system, and, if so, is it peripheral or central in origin? Fowler and Beach (#8), using kinaesthetic stimuli that bypass the visual centres, have demonstrated that central stages of information processing are unaffected by hypoxia, that slowing is specific to the peripheral visual system, and that this slowing may form a "bottleneck" on the nervous system as a whole to inhibit subsequent central information processing. The authors conjectured that application of this finding may permit pilots to accept a certain degree of stagnant hypoxia in return for an enlarged G envelope during sustained high G manoeuvres.

Skinner and Gray (#9) described the development of an automated system that uses frequency domain shifts of EEG in neural networks to detect incipient cerebral hypoxia. The neural networks are trained to detect EEG spectral shifts from normal frequencies for different physiological states. The authors discussed the technical considerations and limitations in applying the concept as a miniaturized unit in "smart garmentry" for military applications. Possible civilian applications include monitoring brain ischemia in critical care situations.

5.4 Disease and Trauma: Neurological Implications and Assessment

Paper #10 which was to have discussed the implications of neurologic conditions on aircraft operations was not presented.

Paper #11 was to have discussed how deterioration of mental ability with age in conducting multiple task operations can be circumvented partially by employing appropriate training strategies which enhance learning, performance and transfer of skills in both young and older adults. However, the authors were unable to make this presentation.

The paper by Konrad and Dosel (#12) discussed head injuries in Czech Air Force pilots. Most head injuries occur from leisure time and other non-military activities. Return to flying is permitted for minor and, in part, moderate head injuries. This is conditional on having had regular checkups by a specialist in aviation medicine.

CogScreen-Aeromedical Edition (CogScreen-AE) is a computer administered and scored cognitive screening instrument designed to detect subtle changes in cognitive function. If left undetected, this could result in poor pilot judgement or slow reaction time in critical operational situations. Moore and Kay (#13) described its use in the evaluation of head injured military flight personnel. Results showed that, in comparison to conventional neuropsychological assessments, the CogScreen test hastened the return of head injured military aviators to flying duty.

Excessive body mass, when combined with factors such as cholesteremia, smoking, etc. represented a high risk condition for a cerebrovascular incident. Glaser (#14) studied the epidemiology of this risk in the German Air Force, and suggested a prospective study for an intervention strategy based on behaviour therapy to reduce obesity and cerebrovascular risk.

Alcohol abuse disqualifies many pilots from flight duty. Freund (#15) discussed the use of a new marker, Carbohydrate Deficient Transferrin (CDT), that the German Air Force Institute of Aviation Medicine introduced in 1994 as a diagnostic tool for determining alcohol consumption. CDT has demonstrated a 69% effectiveness in evaluating alcohol consumption in pilots, especially in those whose liver enzymes are elevated. From the same laboratory, Paper #16 was to have reported the results of psychometric tests given to pilots suspected of toxic brain damage. This paper, however, was not given.

5.5 Neurosensory Limitations

Visual-vestibular interactions during angular acceleration have been studied extensively. Correia in his Keynote Address (#K2) described results obtained from examining the infrequently studied case of visual-vestibular interaction during pure linear acceleration. Experiments conducted using a programmable elevator having a twelve-metre excursion demonstrated that there are fundamental differences in eye movements according to the nature of the visual-vestibular interaction during linear acceleration. Eye movements were enhanced or reduced in velocity according to the direction of visual target motion. These finding may have important consequences for pilots visually following a target during linear acceleration of the aircraft such as that which occurs during vertical take-off and landing, steep ascents and turbulence.

Rabin (#17) described the Small Letter Contrast Test (SLCT) as a powerful approach for extending the range of vision testing. (The SLCT has 14 lines of same-size, small letters and 10 letters per line. Lines vary in contrast in 0.1 log steps, and contiguous line letters differ in contrast by 0.01 log units. Normal room illumination is used for diagnosis.) The SLCT is much more sensitive than standard visual tests for assessing and monitoring a number of clinical conditions. It could also be applied in assessing vision loss in pilot trainees and in aging pilots.

Burroughs and colleagues (#18) contended that formal visual field testing is necessary to properly evaluate an aviator with a condition such as optic nerve head drusen. They reviewed the pertinent aeromedical data of 18 evaluees diagnosed with optic nerve head drusen. Visual acuity, pupillary function, colour vision, depth perception and other measures of visual function were assessed. The results of ancillary tests such as those from imaging techniques and electrophysiological measurement of optic nerve function were also evaluated. The authors concluded that this defect can be compatible with the continuation of an aviator's career, provided acceptable levels of visual field function are maintained.

The most common etiological factors, including those from both Central Nervous System (CNS) and systemic causes, that contribute to transient vision loss in aircrew were considered in a second paper by Burroughs and colleagues (#19). The management and disposition of aircrew with these problems often represents a unique occupational predicament.

Paper #20 was to have demonstrated that a non-standard discrimination test, with phonetically unbalanced high frequency words in the presence of background noise, best correlates high-tone hearing loss with subjective complaints in aircrew. However, this paper was not presented.

Cavonius and colleagues (#21) considered the case of stimulus-response compatibility in a complex manual tracking task. Target tracking performance varied according to the complexity of the relationship between target trajectory and response tracking. These investigators concluded that stimulus-response compatibility needs to be considered in designing any manual control task requiring the operator to track a visual signal.

A paper by Diamantopoulas and Kechagiadakis (#22) discussed CNS impairment in perception, function and performance as imposed by vibration in flight. A companion paper (#23) was to have discussed motion sickness and disorientation as limitations in the perceptual orientation process. However, this paper was not presented.

The vestibulo-ocular reflex (VOR) assists stabilization of the retinal image by rotating the eyes to compensate for movements of the head. The standard VOR is characterized by its gain relating output (eye velocity) to input (head velocity) in one dimension. The Keynote Address by Fetter (#K3) discussesd a three-dimensional characterization of the gain in terms of the three component angular vectors of the eye and the head that make up the VOR in the real world. This generalization of the gain is a 3 x 3 matrix describing the dependence of all three components of eye velocity on all three components of head velocity. Experiments have shown this approach to be a better representation of vestibular function and disfunction than the standard method of obtaining the VOR. For example, tests on patients with the new method have demonstrated convincingly that vestibular neuritis may involve more than one division of the vestibular nerve.

5.6 Workload: Evaluation and Measurement

Pongratz and colleagues (#24) described the Flight Orientation Trainer (FOT) of the German Air Force Institute of Aviation Medicine in terms of its capacity for demonstrating the psychophysical load of flying personnel. The FOT provides a highly complex combination of specific indicators for assessing the degree of activation of the autonomic nervous system, CNS and humoral systems to multimodal stress demands. In particular, the FOT will be used as a training aid and research device in assessing pilot spatial disorientation.

Paper #25 was to have discussed the use of psychophysiological measures to assess cognitive activity when conducting complex tasks in simulation and flight environments. However, it was not presented.

Paper #26 was to have discussed current imaging techniques, such as positron emission tomography and functional magnetic resonance for assessing, evaluating and enhancing air crew performance. However, it was not presented.

Weinberg and colleagues (#27) described studies in which electrophysiological measures and neural net analysis were combined with behavioural measures to assess individual capabilities and limitations in processing complex multitask information. Two pilot studies were reported. In one, EEG activity was recorded during a simulated complex multitask exercise employed by Air Traffic Controllers. In this study, high gamma activity in the EEG was a better discriminator of performance than were evoked potentials. In the second study, both the EEG and magnetoencephalograph (MEG) were recorded in an environment where sleep deprived subjects were required to conduct a complex task. In this study, temporal lobe gamma activity in the MEG indexed performance better than did measures of event-related signals from the MEG or the EEG. The two studies taken together demonstrated the promise of using neural net analysis of the MEG and EEG as predictors of performance. This method has application in the training, assessment and identification of individuals for specific job requirements.

Investigating vigilance in detecting aircraft during NORAD surveillance operations was the thrust of a study conducted by Pigeau and colleagues (#28). Aircraft on display consoles employing a distinctive symbology were more easily detected than other targets. As might be expected, results showed that the midnight shift was particularly sensitive to decrements in vigilance. Also of interest is the observation that decrements in vigilance are not as strong in a real world task as those reported in laboratory studies. The authors suggest that, through the use of appropriate motivational factors, it may be possible to eliminate vigilance decrements entirely.

5.7 Stress Effects

The relationship between the immune system, CNS and the neuroendocrine system has been studied extensively, but has seldom been applied in aviation medicine. Medialdea Cruz and colleagues (#29) combined immunological techniques with conventional psychological questionnaire testing on Spanish Air Force pilots flying high performance aircraft to assess the effects of stressors on the immune system. They concluded that the method, although promising, requires further investigation for the detection and prevention of stressors in aircrew.

Glaser (#30) drew attention to the emotional stress such factors as divorce, health problems, etc. have on pilot performance. Pilots unable to cope with emotional stress are more likely to make errors leading to mishaps than those having no emotional problems. Strategies for improving the ability to cope with stress were discussed.

Fonne and G. Myhre (#31) addressed the issue of stress and coping factors during helicopter ambulance services. Stress during such missions include both physical and psychological factors. Previous studies have shown that emotional reactions to different stressful situations are reflected in neurohormonal activation. This study further demonstrated that there are individual differences in crewmember response relative to mission type, area of responsibility, and psychological coping strategies and the use of defence mechanisms. The authors indicated that further studies are required to determine the relationship between physiological reaction to stress and psychological coping styles.

5.8 Workload: Fatigue and Sleepiness

Porcu' and colleagues (#32) gave a good review of the current knowledge of fatigue and its effect on performance. They pointed out the differences between fatigue imposed by workload and that of operator effort, between physical exhaustion and psychological fatigue, and the distinctions between acute, cumulative and chronic fatigue. The relationship between fatigue and performance is also complicated by the interaction of variables such as motivation and the ability to cope with stress. These investigators recommended that the aeromedical community should identify early indicators of fatigue, establish useful diagnostic means for detecting and countering the different types of fatigue, and optimize the management of activities leading to fatigue.

Sleepiness is a well recognized neuropsychological limitation on effective aircrew operations. A study by Porcu' and colleagues (#33) of an acute night shift operation, reported that the relationship between sleepiness, alertness and performance is complex. These authors concluded that in subjective and behavioural measures testing, each test plays a role in modifying the neuropsychological condition of the subject. Moreover, they indicated that a diverse set of subjective variables must be considered in order to obtain a true picture of this relationship.

The distinction between prospective (an expected judgement of time) and retrospective (unexpected temporal judgement) perception of elapsed time during an acute night shift was the subject of a study by Dell'Erba and colleagues (#34). The drug, temazepan or a placebo was taken in the afternoon prior to the night shift. Preliminary results indicated that both prospective and retrospective time estimations were not affected by night sessions and drug condition.

Mollard and colleagues (#35) have proposed a model to characterize and detect fatigue under laboratory conditions and in flight. The model takes into consideration such aspects as environmental conditions, circadian cycles (jet lag), work cycles, and work characteristics (type, duration and level of difficulty). These components are associated with interpersonal variations in fatigue. Long flights with their propensity for sleep deprivation, monotony and jet lag, and intense operations with their ability to rapidly induce mental fatigue are two particular scenarios that will be modelled.

5.9 Sustained Operations and Strategies for Enhancement

The effect of moderate sleep deprivation (twice for 27 hours) on vigilance and performance during a simulated sustained air mission was the basis of a study by Lagarde and colleagues (#36). Signs of disturbed vigilance and psychomotor performance were observed. Moreover, appropriately placed naps are adequate for recovery for limited sleep deprivation, but other countermeasures such as the use of drugs are required for recovery to repeated limited sleep deprivation.

The use of the psychostimulant drug, d-amphetamine to extend flight operations was the subject of two papers. Cornum and colleagues (#37) reported that the majority of F-15 pilots responding to a survey, used d-amphetamine on low task missions during Operation Desert Shield. Many pilots commented that it was necessary to take this drug during long duration, mostly night time, missions to prevent falling asleep. Caldwell and Crowley (#38) showed that d-amphetamine prevented flight performance decrements attributable to sleep loss in males and females in controlled laboratory studies in a UH-60 helicopter simulator. Sleep recovery was less restful under the drug, but, practically speaking, this is minimal given the pressure to sleep when sleep deprived. Caldwell and Crowley recommended administrating d-amphetamine prophylactically to prevent deterioration associated with sleep loss in sustained operations.

Pigeau (#39) compared the effects of modafinil and d-amphetamine on cognitive performance and core temperature during sixty-four hours of sustained work. Modafinil is an alerting substance that is considered safer than d-amphetamine with fewer side effects. Subjective estimates of mood and objective measures of mental performance were superior with both modafinil and amphetamine compared to that of a placebo. Pigeau suggested that modafinil may be an attractive alternative to d-amphetamine for maintaining or recovering performance because of its comparable effectiveness with fewer side effects.

The pineal hormone signals the nocturnal phase of the human circadian cycle. Experiments have shown that melatonin administered orally prior to undergoing diurnal sleep extended average sleep times compared to that when taking a placebo. Furthermore, no side effects from melatonin have been reported. French (#40) studied melatonin's effect on C-5 flight crew during a staged eastward deployment to Europe lasting 6 - 12 hours. He noted that subjects' circadian rhythms were comfortably adjusted within 24 hours of arrival.

5.10 Enhancing Neurological Performance in Aerospace Operations: Practical Challenges

Papers in this special session were solicited to address the neurological implications of enhancing performance in:

- heavy jet operations,
- rotary wing operations,
- air traffic control operations, and

• ground and support operations.

Fry (#S1) focussed on the major issue of concern in heavy jet operations: a commitment to safety through a systems approach. This takes into account new technology, training, human factors, support systems and external factors. Fry acknowledges that "...some impressive engineering solutions ... have resulted in only scant consideration of the 'man-machine' interface." Human factors training is now mandatory for initial and recurrent training of flight crew of airlines operating internationally.

Flying helicopter missions requires more cognitive and sensorimotor demands than is the case with fixed wing operations. There are the stresses imposed by flying nap-of-the-earth while encumbered by night vision devices, the oppressive thermal conditions that may persist throughout the mission, and now the attendant hazards of sleep deprivation and circadian desynchronization resulting from the rapid deployment of helicopter crews to distant lands. There are also the attentional demands of mastering a complex computer system while simultaneously flying. Crowley (#S2) suggested that improvements in the quality of information presented to aircrew would reduce workload and the number of accidents due to disorientation. Improved night vision systems, better instrumentation and three-dimensional audio systems are some of the ways this could be achieved. Also, neurological performance under stress could be maintained by developing a customized crew endurance plan that addressed work/rest cycles and operational medications for different combat environments.

Performance in air traffic control operations is dependent on the internal working environment, weather conditions, traffic workload and the individual characteristics of the air traffic controller. Della Rocco and colleagues (#S3) focussed on the effect of fatigue induced by rapidly-rotating shift work on controller performance in both the laboratory and the operational work environment. Coping strategies, including management of sleep cycles, circadian rhythms and work schedules, and modifications to the environment were some of the countermeasures that could be implemented to enhance performance.

Barker and Hain (#S4) considered the challenges facing naval aviation leaders in improving performance in flight deck personnel during ground and support operations aboard an aircraft carrier. The environment on an aircraft carrier during duty is intense, prolonged and potentially dangerous. Conditions such as high workload, sustained operations, heat and cold, wind and rain, noise and vibration, neurosensory deficiencies, and emotional and interpersonal problems are some of the major factors that impose neurological limitations on flight deck personnel. The challenge is to find better ways to screen, evaluate, educate and train flight deck personnel, and devise better ways to handle morale issues to enhance flight deck performance. Additionally, current research findings must be more quickly and effectively applied to enhance performance (e.g., the use of performance enhancing drugs).

6. CONCLUSIONS AND RECOMMENDATIONS

In 1990, the United States designated the following ten years as the decade of the brain. The focus was to be on prevention, research, treatment and rehabilitation of brain related diseases and disorders. Following the urging of the World Health Organization in 1991 that all governments should do the same, many countries passed a similar initiative including the member states of the European Community and Canada. It is timely and appropriate, therefore, that this Panel in 1995 should capitalize on the relevant advances made by researchers in these countries and apply the knowledge to a better understanding of the limitations of, and the practical challenges for, enhancing nervous system function in the aerospace environment.

This Symposium has drawn attention to some very interesting and important research developments in the neurosciences that the aviation community is exploiting to enhance performance. However, the field of neuroscience is so large that it is not possible to cover every facet that impacts on the issue in a single symposium. For example, Banks and Goodman spoke of the role played by the autonomic nervous system on G-LOC when transitioning within the Gz environment. However, no one has explored GLOC and recovery from GLOC at the cellular brain level in the search for protective measures against this deleterious phenomenon. Similarly, Correia described the implications of following a target visually during linear accelerations, and he spoke of the great strides made in our understanding of the effects of angular acceleration on visual-vestibular interactions. Again, no one has considered the mechanisms and protective measures required to counter the disorienting neurosensory mismatches that will be imposed by the combinatorial translational accelerations and angular motions encountered in enhanced manoeuvreability aircraft. It is an issue that needs to be addressed rigorously before consideration is given to further develop these aircraft for combat roles.

Even those papers that were presented on the application of new advances to issues of human performance and safety in air operations are just the beginning of research in this area. For example, although the important topic of impact head injury was addressed in this Symposium, new knowledge of injury mechanisms and trauma treatment including drug intervention, new advances in protective countermeasures, etc. were not discussed. There are sufficient new advances on impact head injury alone to hold a separate symposium. This also applies for other topics in this Symposium.

The excellent presentations and the ensuing panel discussion at the Special Session have shown that there are many research challenges for enhancing human performance in air and support operations. Regardless of the mission, however, all of the operations discussed in the Special Session are faced with the same problems of adaptation to new technology, information overload, hazardous conditions, workload fatigue and the requirement for teamwork and training. Most importantly, these papers identified, or inferred , the areas that need to be resolved if enhancing neurological performance in the aviation environment is to become a reality. The challenge is there for the AGARD aeromedical community to resolve these issues.

This is the second symposium that the AMP has held which addressed the human performance implications of neurological function. In 1987, a very successful meeting was held in Tronheim, Norway on the electric and magnetic activity of the CNS and its implications to aerospace operations (Conference Proceedings AGARD-CP-432). It would be prudent for the AMP to monitor progress in the neurosciences and hold further activities and a third symposium within the next few years to remain abreast of developments in this burgeoning discipline.

7. ACKNOWLEDGEMENTS

I thank Mrs N. Wisteard for preparation of this manuscript.

DCIEM No. 95-30.

#506956