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**RTO LECTURE SERIES 215**

# Alternative Control Technologies: Human Factors Issues

(Techniques de pilotage alternatives – Le facteur humain)

*The material in this publication was assembled to support a Lecture Series under the sponsorship of the Human Factors and Medicine Panel and the Consultant and Exchange Programme of RTO presented on 7-8 October 1998 in Brétigny, France, and on 14-15 October 1998 at Wright-Patterson Air Force Base, Ohio, USA.*

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# Alternative Control Technologies: Human Factors Issues

## (RTO EN-3)

# Executive Summary

Ever since the origins of aviation, the various devices, instruments and aircraft systems involved have always, almost exclusively, been activated by manual controls. At the present time, the high degree of computerisation of all aircraft systems and the generalised use of fly-by-wire means that these systems could easily accommodate non conventional devices such as voice commands, head and eye movement commands etc. All these non conventional devices are often described generically as "alternative control technologies". These technologies are in fact capable of providing alternative solutions which are also redundant or complementary to manual control in the design of advanced man-machine interfaces. These new technologies could thus contribute to the enhancement of man-machine communications in both military and civil aviation.

The main aim of this Lecture Series is to provide a review of the technologies which can be envisaged at the present time, with their main characteristics, benefits and limitations. These lectures are essentially intended for scientific research workers and engineers involved in the field of man-machine interaction and the design of work stations for aeronautical applications. They may, however, be of interest to others who wish to obtain a summary of recent advances and of the state-of-the-art in this field.

The following questions will be dealt with:

- Operational justification for aeronautical technologies
- Technology and voice command applications
- Technology and head position detection applications
- Technology and eye position detection applications
- Technology and gesture control applications
- Technology and applications of control by biopotentials
- Human factors aspects linked to the integration of these technologies
- Summary and analysis of the benefits obtained

A round table discussion will be held at the end of the Lecture Series.

The material in this publication was assembled to support a Lecture Series under the sponsorship of the Human Factors and Medicine Panel and the Consultant and Exchange Programme of RTO presented on 7-8 October 1998 in Brétigny, France, and on 14-15 October 1998 at Wright Patterson Air Force Base, Ohio, USA.

# Techniques de Pilotage Alternatives - Le Facteur Humain

## (RTO EN-3)

# Synthèse

Depuis l'origine de l'aviation, les différents dispositifs, instruments et systèmes des aéronefs ont toujours presque exclusivement été mis en œuvre au moyen de contrôles manuels. A l'heure actuelle, les systèmes font que l'informatisation poussée de l'ensemble des systèmes avion et la généralisation des commandes de vol électriques pourrait aisément s'accorder des dispositifs non-conventionnels, comme la commande vocale, le mouvement de la tête et du regard, etc. L'ensemble de ces dispositifs non-conventionnels est souvent regroupé sous le vocable de « technologies de contrôles alternatives ». Ces technologies sont effectivement susceptibles d'offrir des solutions alternatives, mais aussi redondantes ou complémentaires au contrôle manuel dans la conception d'interfaces homme-machine avancées. Dans le domaine de l'aviation militaire, mais aussi dans celui de l'aviation commerciale, ces nouvelles technologies pourraient ainsi contribuer à l'amélioration de la communication homme machine.

L'objet principal de ce cycle de conférences est d'apporter une information synthétique sur l'ensemble des technologies qui peuvent actuellement être envisagées, détaillant leurs principales caractéristiques, leurs avantages et limitations. Ces conférences sont essentiellement destinées aux chercheurs scientifiques et ingénieurs travaillant dans le domaine de l'interaction homme - machine et la conception des postes d'équipage en aéronautique. Elles peuvent cependant intéresser d'autre personnes désirant obtenir une synthèse des progrès récents et de l'état de l'art du domaine.

Les sujets qui seront traités lors de ces conférences sont les suivants:

- Justification opérationnelle des technologies en aéronautique
- Technologie et applications de la commande vocale
- Technologie et applications de la détection de position de tête
- Technologie et applications de la détection du regard
- Technologie et applications de la commande gestuelle
- Technologie et applications du contrôle par biopotentiels
- Aspects facteurs humains liés à l'intégration des technologies
- Approche synthétique et analyse des bénéfices attendus.

Une table ronde sera organisée à l'issue de la série de conférences

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# Foreword

Currently, manual operation for all kinds of mechanically activated devices designed to control the functions of aircraft systems is used almost exclusively in the aeronautical and space environment, but also more generally in regard to all vehicular control. This has been the rule from the origin of aviation and it is obvious that there are good reasons to explain why this situation has lasted so long.

From the early origins of the species, the superior ability of humans to use their hands in interacting with the environment has been a major characteristic. Actually, mechanical action of the hand on elements of the environment, peculiarly « dumb » ones, such as mineral, and vegetable elements, forms part of the very basic skills of mankind. Quite naturally, the first flying machines were assemblies of wood, fabrics and metal parts. The only « intelligent agent » onboard was the pilot, so it is obvious that the only way to act on the few controls of the aircraft was by mechanical action. Nowadays, even with the introduction of electrical systems and computers, manual control is so robust, efficient and reliable that most interactions with aircraft systems are carried out using the manual mode. Physical contact with the control device provides good and immediate feedback on the action being carried out and generates a high level of confidence in the pilot's mind.

Interacting with other living creatures may, however, proceed from other mechanisms. Animals have many ways to control the behaviour of others without making physical contact, including postures, sounds and facial expressions. Such interaction modalities also exists in humans, but the acquisition of articulated speech introduced a new dimension into the ways of communicating with other individuals and even animals. It should be noted that the semantic contents of words is not the only information provided by speech, prosody and pitch being of great importance as military people recognised a long time ago. The use of voice to control and co-ordinate movements and actions of troops during battles has been the rule from antiquity to modern time. Moreover, heterogeneous redundancy, implying that an identical message transits through different modalities (voice and gesture for instance), is universally used, either to reinforce the content of the message or to complement it. Interestingly enough, the use of such remote control signals requires an « intelligent » agent as receiver.

And there we have the problem. Today, most modern aircraft are totally controlled by computers, which means that some kind of « intelligent agent » is mediating the pilot's actions on the various effector systems. As a matter of fact, the architecture of fly-by-wire aircraft mimics partly, and in a very simplified form, the nervous system of living creatures. All commands sent to the various aircraft systems are electrical signals, thus theoretically suppressing the absolute need for manual control. Some mechanical systems, manually operated, are however usually retained for back-up functions

The computers of the sixties and seventies had limited resources and « intelligence ». Indeed, programmers of this era had a hard time running real time programs with the small amount of memory available on the CPU. They had to put in a lot of effort and imagination to optimise their programs, using assembly languages and « tricks », in order to cope with such limited resources. On the other hand, the human operator is also known to have quite limited resources (perceptual, but also information acquisition, memory access). He is, however, intelligent, and knows how to use various strategies to overcome intrinsic resource limitations.

The situation on the machine side is now completely different. Computers still have poor « intelligence », but they have acquired almost unlimited resources compared to those of the human being. There is now a striking imbalance between a human operator, intelligent, but limited by his resources, and the machine, able to process enormous amounts of data, but still with quite limited « intelligence ». The difficulties encountered at the man/systems interface as a result of this situation have been extensively reported.

In order to improve the communication between the human operator and the machine it appears necessary to work on both sides of the problem: at the man/machine interface and on system design. Most authors agree that working only on the control and display « physical » aspects of the Man-Machine Interface would not produce completely satisfactory solutions. Giving the machine a kind of « Human-Like » intelligence, allowing it to accept high level instructions and to detect the intentions and needs of the operators, is definitely a long term challenge which has been taken up by engineers and cognitive scientists.

Meanwhile, most efforts are spent on the « machine-to-human » relationship, in an attempt to improve information displays and make the information output by the systems easier to perceive and interpret. Of the many concepts of « human-centred » Human-Machine Interface design, the « ecological interface » suggested by Rasmunssen and Vicente some years ago, appears in some aspects to be particularly attractive. This concept states that the interface should be designed in such a way as not to constrain the operator to work at a higher level of control than required by the situation. On the physical side of the interface, this implicitly means that such an « ecological » principle should also be respected with regard to control modalities (and displays). As an example: why should the pilot have to sequentially designate a series of alphanumerics on a display, when it is far easier to dictate it to an « intelligent » agent (speech recognizer), electronically linked to the aircraft systems?

Introducing « body language » at the interface level is not a new idea. Engineers and scientists have been working for a long time on enabling technology and the way to use it in the aerospace environment. Some of these non-conventional control technologies, as head-trackers or speech recognizers, are starting to be introduced onboard new generation aircraft as the EFA, the Rafale and the JSF.

Quite likely, the major difficulty in integrating more extensively alternative controls into cockpit design will arise paradoxically from the unique adaptive ability of the human being. As a matter of fact, the adaptive nature of the human would probably allow him to perform any task using any control modalities. Also, among individuals, various strategies using various modalities will be developed to successfully perform a similar task. From an engineering point of view, the challenge will be to determine precisely, among the various technologies and combination possibilities what to do, why and how to implement it at the lowest human and economical cost.

To make the best use of these system integration technologies, the ultimate goal should be to allow the user to adopt the most appropriate strategy for him to fulfil his objectives. To remain human-centred rather than technologically driven, great care should be given to identification of the cognitive and sensorimotor « invariants » relative to the use of each technology. On this basis, one of the keys to integrating alternative technology correctly could be seeking to minimise the cognitive and sensorimotor « energy cost » for a given procedure. Trade-off would have to be made between the level of performance required to reach a specific goal and the level of « energy » required to achieve it, including training efforts. Finally, optimising cockpit design by introduction of Alternative Control Technology would mean considering « cost » issues at two levels:

- For the crew, the aim of alternative technology should be to minimise the « cost of control » by making the best use of limited human resources and increasing the global effectiveness of human-machine coupling;
- For the Defence community, the smart integration of these new control technologies should result in training cost reduction, increased operational effectiveness and, eventually, cockpit simplification by using virtual controls.

We can already foresee the limitations of manual controls just looking at the current generation of aircraft under development. Aircraft have used for many years now the HOTAS concept, but the multiplicity of switches, sometimes multifunction, on the stick and throttle raises a lot of questions. Of course pilots can adapt, but this will be paid for through an increase in training needs and higher error rates. Saturation of the very limited and vulnerable short term memory constitutes a major risk here.

It looks as if it is time to increase the resources of the machine in different ways than pure computing power, allowing easier and optimally adapted control of the human over the systems. The motivation is there, the technology is beginning to be mature, operational implementation should now follow shortly.

Dr Alain Leger
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**14. Abstract**


With the increasing intelligence of computer systems, it is becoming more desirable to have an operator communicate with machines rather than simply operate them. In combat aircraft, this need to communicate is made quite crucial due to high temporal pressure and workload during critical phases of the flight (ingress, engagement, deployment of self-defence). The HOTAS concept, with manual controls fitted on the stick and throttle, has been widely used in modern fighters such as F16, F18, EFA and Rafale. This concept allows pilots to input real time commands to the aircraft system. However, it increases the complexity of the pilot task due to inflation of real time controls, with some controls being multifunction. It is therefore desirable, in the framework of "ecological interfaces", to introduce alternative input channels in order to reduce the complexity of manual control in the HOTAS concept and allow more direct and natural access to the aircraft systems.

Control and display technologies are the critical enablers for these advanced interfaces. There are a variety of novel alternative control technologies that when integrated usefully with critical mission tasks can make natural use of the innate potential of human sensory and motor systems. Careful design and integration of candidate control technologies will result in human-machine interfaces which are natural, easier to learn, easier to use, and less prone to error. Significant progress is being made on using signals from the brain, muscles, voice, lip, head position, eye position and gestures for the control of computers and other devices.

Judicious application of alternative control technologies has the potential to increase the bandwidth of operator-system interaction, improve the effectiveness of military systems, and realise cost savings. Alternative controls can reduce workload and improve efficiency within the cockpit, directly supporting the warfighter.

By the end of 1997, WG 25 had extensively reviewed human factor aspects of current and prospective alternative technologies along with operational needs and integration issues. Dissemination of the knowledge among Engineering and Human Factor communities has to be made as early as possible to facilitate implementation of these new technologies in future projects.

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