Mathematical Modelling of Human Pilot Performance

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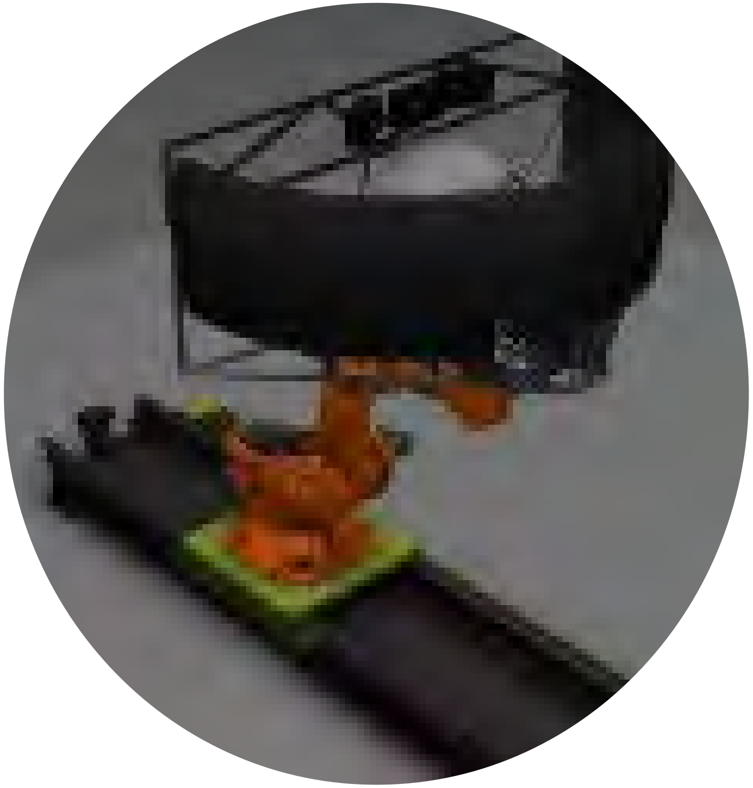
14th MODPROD Workshop 2020; LInköping; Sweden

SIVOR Flight Simulator at ITA based on Robot Platform



31st Congress of the International Council of the Aeronautical Sciences

Belo Horizonte, Brazil; September 09-14, 2018

EFFECTS OF TAILORED CONTROL SURFACE COMPLIANCE ON AIRCRAFT STABILITY AND CONTROL

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Keywords: *pitch stabilization, canard, human in the loop simulation*

Abstract

The aircraft design problem is an example of a highly integrated design, which calls for a multidisciplinary approach from the very beginning. With every generation of aircraft, it gets more difficult to make substantial improvements since so much have already been done to make aircraft as possible. Next generation civil aircraft needs to take every possibility to increase efficiency. One potential area of improvement is to reduce drag due to the requirement of positive stability. However, with the present state of the art it is difficult to get a system that can artificially stabilize an aircraft, certified. If this can be overcome, there are potential gains in drag, since all horizontal surfaces can be used for lift. Another advantage is that a wider range for center gravity can be allowed. In flight control the input signal to the aircraft are usually taken to be position of control surfaces. This is then translated to requirements on the actuation system, where the natural compliance of these systems is regarded, as something unwanted, when in fact it can also be used to tailor characteristics also at the aircraft level. This is relevant to both civil and military aircraft. The approach used here is to look at control surface actuators and different means to utilize also force control, possibly together with position control, and to introduce compliance in proper positions of the system. The pressure feedback is evaluated in a simulation environment using HOPSAN simulation package. Furthermore, an experiment is performed with the pilot in the loop to evaluate the different values of feedback gain. Statistical analysis of the results shows a significant influence of feedback level in the ability of the pilot to control the aircraft.

1 Introduction

Looking at future aircraft concept, one recurring concept is that of aft mounted prop fans. This is a problematic configuration from a center of gravity (CG) point of view, where a large portion of the weight is located aft. Therefore, the distance between wing and tail becomes short, resulting in considerable trim drag, unless a canard configuration is used. This is aggravated by the fact that the CG position is changing considerably between empty and fully loaded. One example of an aircraft using this three wing configuration is the Piaggio Avanti. However, in order to minimize drag the optimum lift distribution between the wing surfaces would result in an unstable configuration, Kendall [2].

Canard wing configuration is also common in military aircraft, pioneered in the Saab AJ37 Viggen in the sixties and subsequently in the Saab 39 Gripen, the Euorfighter Typhoon, the Dassault Rafale etc. Modern fighters are always are dynamically unstable and relay on an electronic control system for stabilization.

A hydraulic concept of a dynamic load trim actuator is shown in Fig. 1 as an example. It is essential that the solution is robust to ensure certification, e.g. implemented with passive control for civil aircraft. This system is nothing more than an adjustable spring, represented by the accumulator and thus need no active servo control.

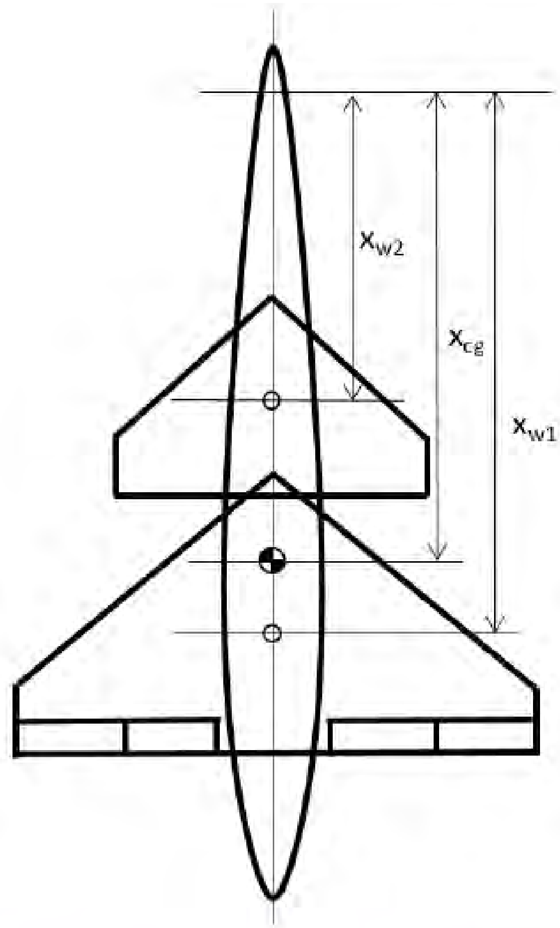


Fig. 3 Aircraft with canard configuration used for the simulations.

Servo with pressure feedback

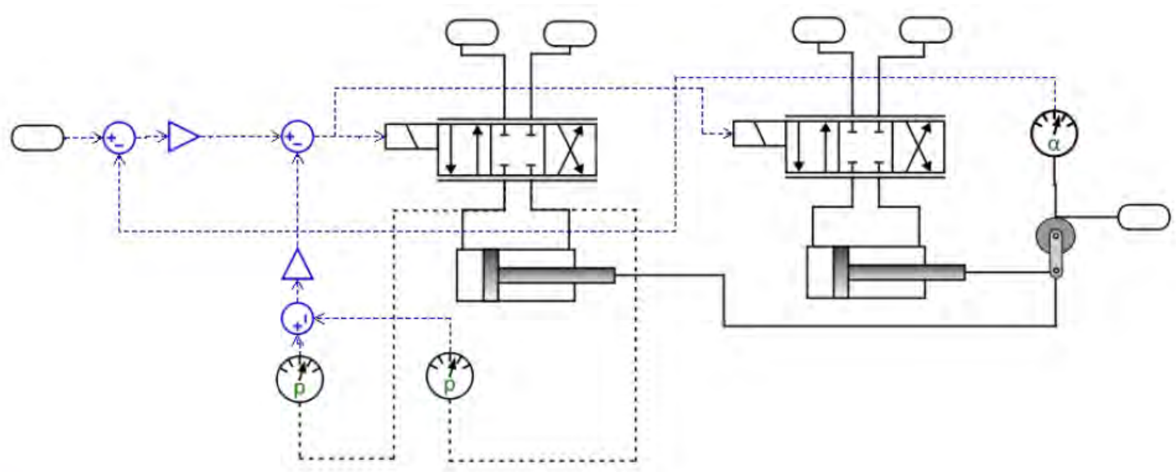
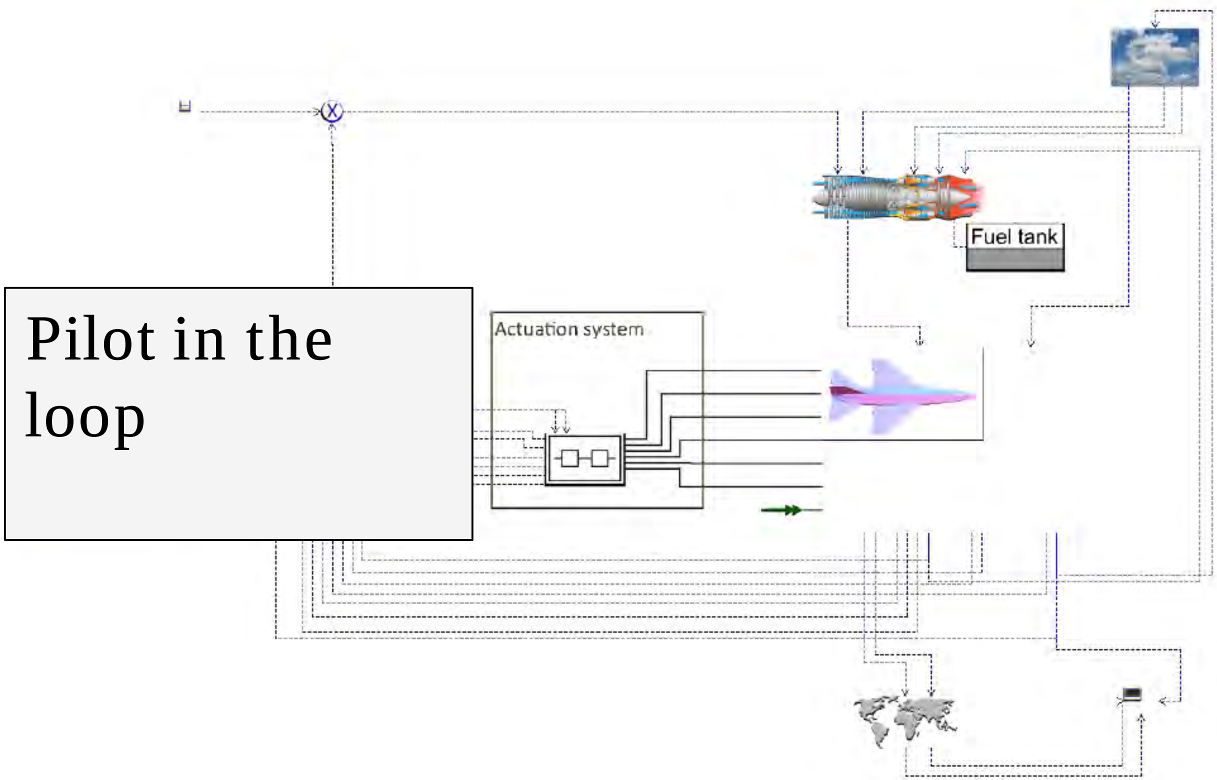


Fig. 2 Hydraulic tandem servo with pressure feedback

Model for full system simulation



Reference Maneuver for Human Pilot
(Using desktop simulation)

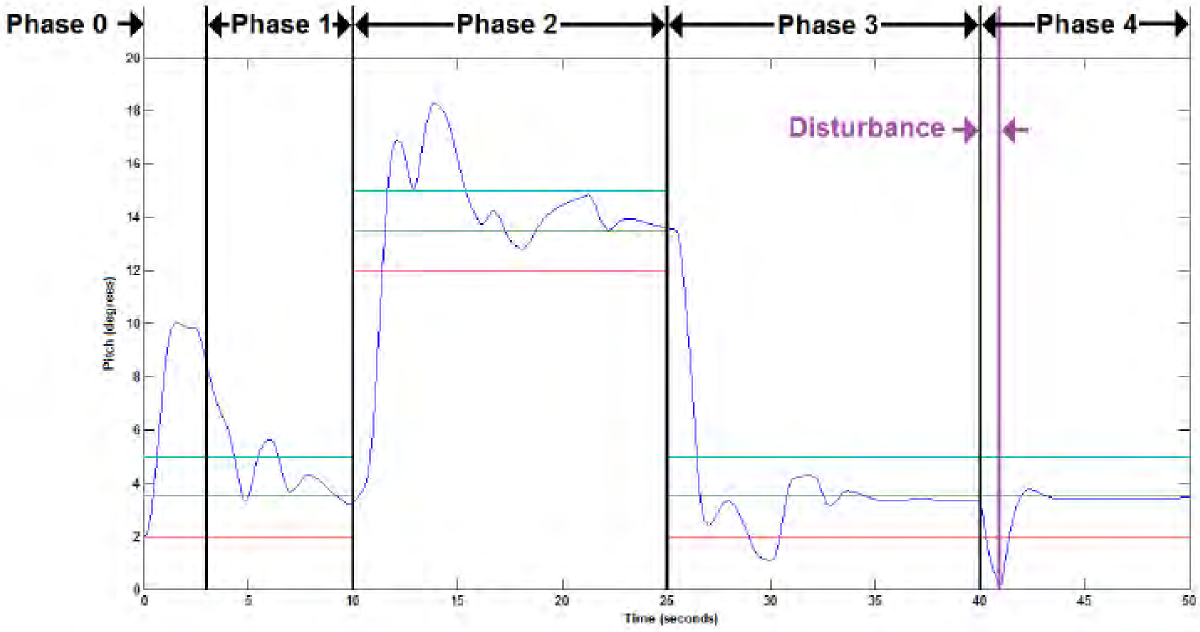


Fig. 5 Reference maneuver with disturbance

Analysis

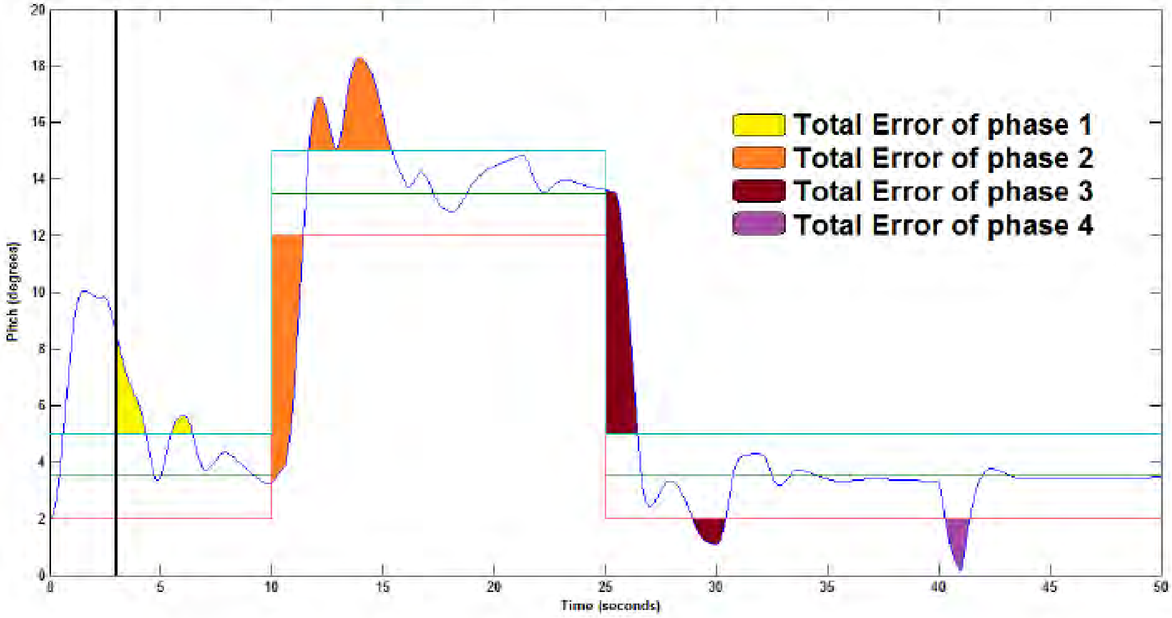


Fig. 6 Output variables from the experiment

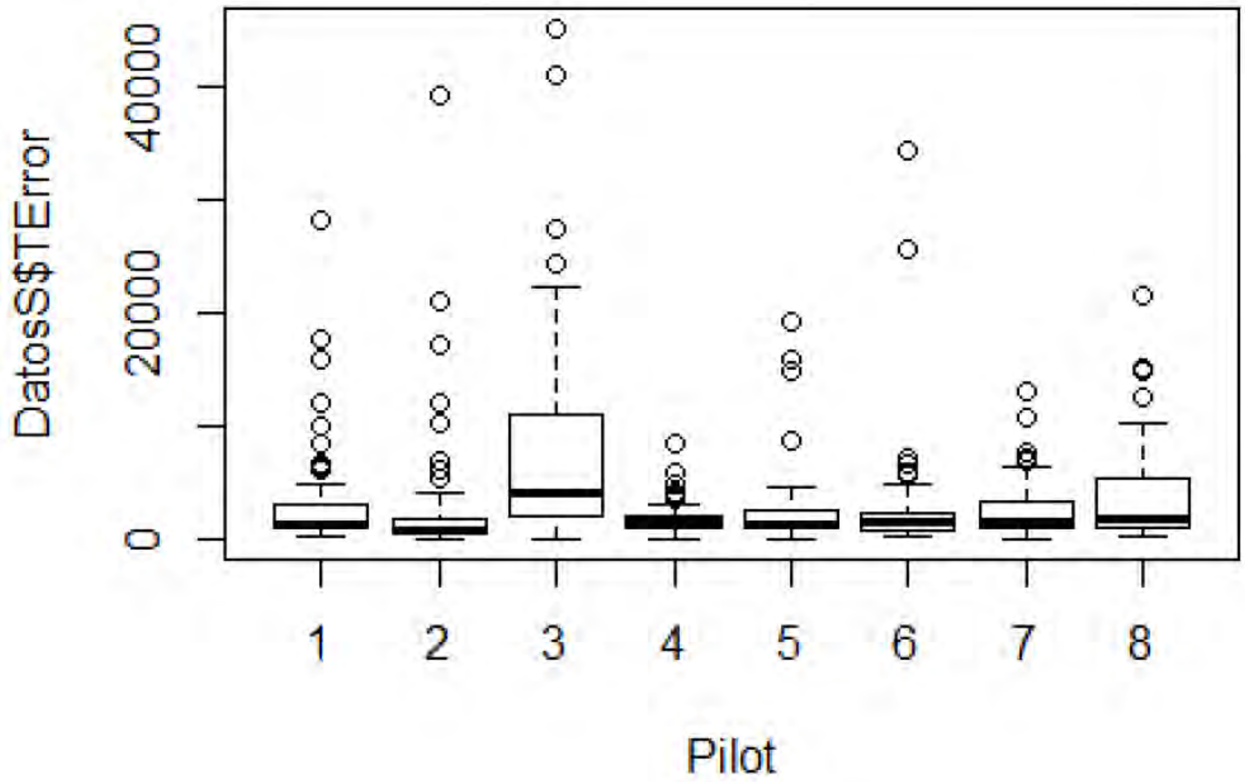


Fig. 7 Boxplot for factor B (Pilot) - Dataset with 8 pilots

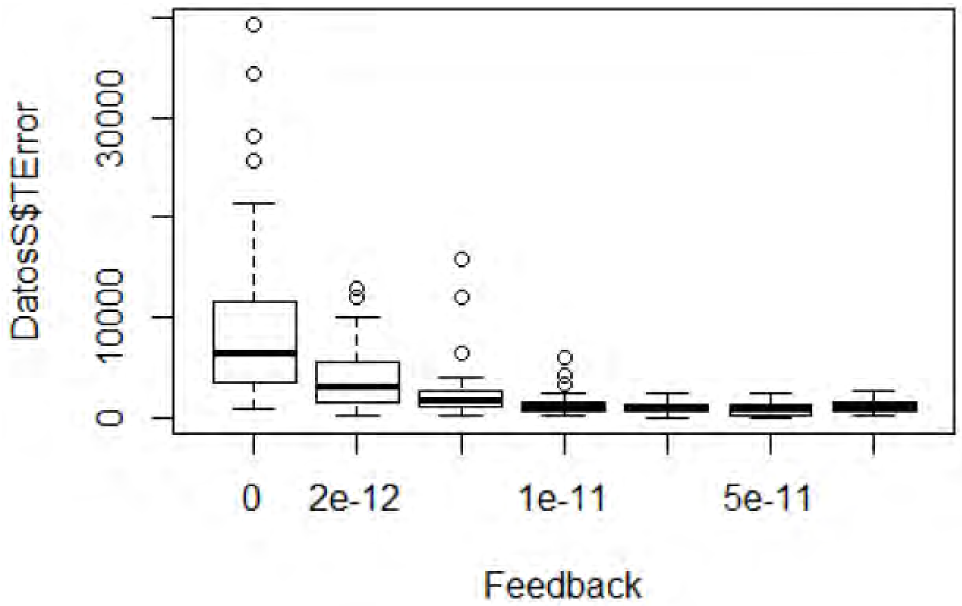


Fig. 8 Boxplot for factor A (Gain) - Dataset with 7 pilots

McRuer (1974)

- Pioneered a linear dynamics model of pilot

AD-775 905

MATHEMATICAL MODELS OF HUMAN PILOT BEHAVIOR

Duane T. McRuer, et al

Advisory Group for Aerospace Research and Development
Paris, France

January 1974

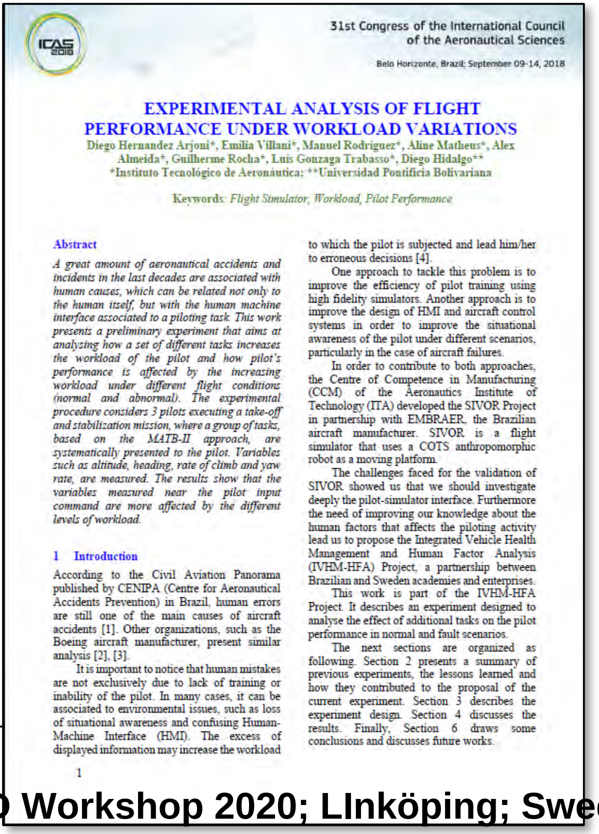
GAIN	PURE TIME DELAY	SERIES EQUALIZATION	VERY-LOW-FREQUENCY LAG-LEAD	NEUROMUSCULAR ACTUATION SYSTEM

$$Y_p = K_p \quad e^{-j\omega\tau} \quad \left(\frac{T_L j\omega + 1}{T_I j\omega + 1}\right) \quad \underbrace{\left[\frac{T_K j\omega + 1}{T'_K j\omega + 1}\right]}_{e^{-j\alpha/\omega}} \quad \underbrace{\left\{\frac{1}{(T_{N_1} j\omega + 1)\left[\left(\frac{j\omega}{\omega_N}\right)^2 + \frac{2\zeta_N s}{\omega_N} j\omega + 1\right]}\right\}}_{\frac{1}{T_N j\omega + 1} \text{ or } e^{-j\omega T_N}} \qquad (32)$$

Pilot Modelling

- There are well established models for the regulating task of piloting that can be used to close the control loop in a simulation model.
- Another field is to study the capacity of a pilot to do secondary tasks, e.g. discrete tasks.
- Is it possible to have a common model for both?

Arjoni et al 2018


31st Congress of the International Council of the Aeronautical Sciences

Belo Horizonte, Brazil; September 09-14, 2018

EXPERIMENTAL ANALYSIS OF FLIGHT PERFORMANCE UNDER WORKLOAD VARIATIONS

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Keywords: *Flight Simulator, Workload, Pilot Performance*

Abstract

A great amount of aeronautical accidents and incidents in the last decades are associated with human causes, which can be related not only to the human itself, but with the human machine interface associated to a piloting task. This work presents a preliminary experiment that aims at analysing how a set of different tasks increases the workload of the pilot and how pilot's performance is affected by the increasing workload under different flight conditions (normal and abnormal). The experimental procedure considers 3 pilots executing a take-off and stabilization mission, where a group of tasks, based on the MATB-II approach, are systematically presented to the pilot. Variables such as altitude, heading, rate of climb and yaw rate, are measured. The results show that the variables measured near the pilot input command are more affected by the different levels of workload.

1 Introduction

According to the Civil Aviation Panorama published by CENIPA (Centre for Aeronautical Accidents Prevention) in Brazil, human errors are still one of the main causes of aircraft accidents [1]. Other organizations, such as the Boeing aircraft manufacturer, present similar analysis [2], [3].

It is important to notice that human mistakes are not exclusively due to lack of training or inability of the pilot. In many cases, it can be associated to environmental issues, such as loss of situational awareness and confusing Human-Machine Interface (HMI). The excess of displayed information may increase the workload to which the pilot is subjected and lead him/her to erroneous decisions [4].

One approach to tackle this problem is to improve the efficiency of pilot training using high fidelity simulators. Another approach is to improve the design of HMI and aircraft control systems in order to improve the situational awareness of the pilot under different scenarios, particularly in the case of aircraft failures.

In order to contribute to both approaches, the Centre of Competence in Manufacturing (CCM) of the Aeronautics Institute of Technology (ITA) developed the SIVOR Project in partnership with EMBRAER, the Brazilian aircraft manufacturer. SIVOR is a flight simulator that uses a COTS anthropomorphic robot as a moving platform.

The challenges faced for the validation of SIVOR showed us that we should investigate deeply the pilot-simulator interface. Furthermore the need of improving our knowledge about the human factors that affects the piloting activity lead us to propose the Integrated Vehicle Health Management and Human Factor Analysis (IVHM-HFA) Project, a partnership between Brazilian and Sweden academies and enterprises.

This work is part of the IVHM-HFA Project. It describes an experiment designed to analyse the effect of additional tasks on the pilot performance in normal and fault scenarios.

The next sections are organized as following. Section 2 presents a summary of previous experiments, the lessons learned and how they contributed to the proposal of the current experiment. Section 3 describes the experiment design. Section 4 discusses the results. Finally, Section 6 draws some conclusions and discusses future works.

1

Studying the effect of workload on Piloting performance

Table 4. Normal flights (P-values).

Condition	Altitude	Rate of Climb	Heading	Yaw Rate	CII
Shapiro-Wilk	0.0481	0.1542	0.1135	0.0695	0.6559
Bartlett W	0.0683	0.8517	0.0773	0.7585	0.7102
Bartlett P	0.2361	0.1618	0.0001	0.0447	0.1519
Workload Influence	-	0.1230	0.2106	0.4169	0.7055
Pilot Influence	-	0.0000	0.0003	0.0147	0.0002
Interaction influence	-	0.3290	0.1409	0.3506	0.8272

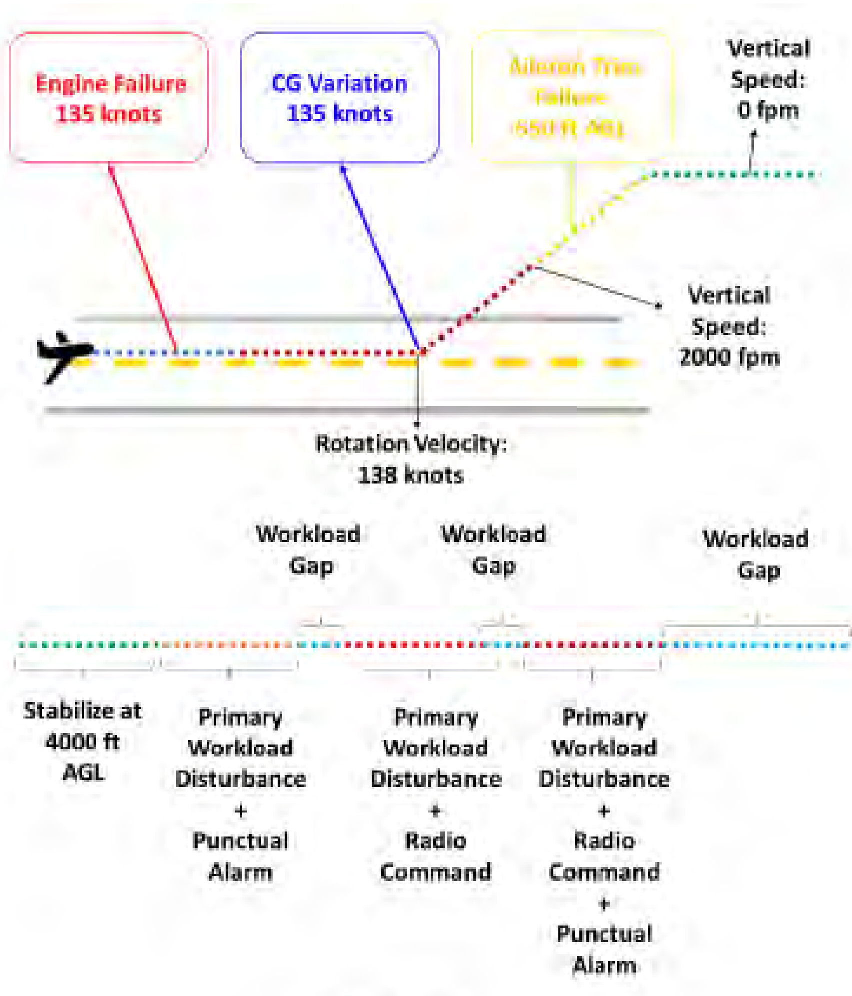


Fig. 2. Flight mission.

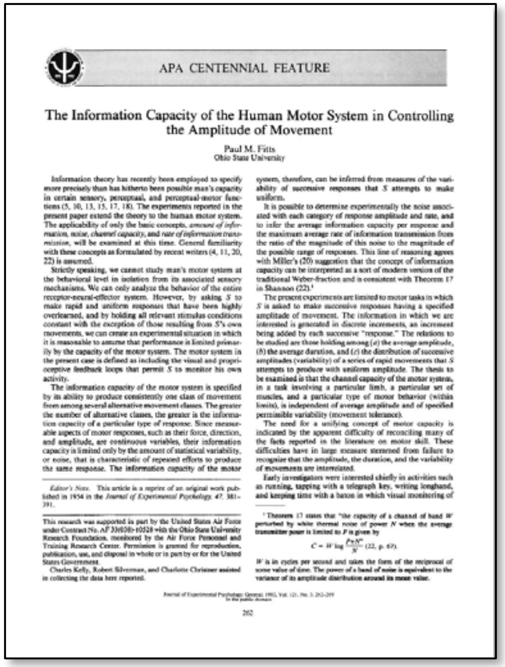
Bit rate of Human Consciences (Encyclopedia Britannica)

- When researchers sought to measure information processing capabilities during "intelligent" or "conscious" activities, such as reading or piano playing, they came up with a maximum capability of less than 50 bits per second.
- For example, a typical reading rate of 300 words per minute works out to about 5 words per second. Assuming an average of 5 characters per word and roughly 2 bits per character yields the aforementioned rate of 50 bits per second.

Information transmission rates of the senses	
sensory system	**bits per second**
eyes	10,000,000
skin	1,000,000
ears	100,000
smell	100,000
taste	1,000

Gaming

- The best players in Warcraft has up tp 200 actions per minute.
  - If each action was only binary it would represent 200/60=3.33 bits /s.
  - Some actions are probably more bits. To point at a figure that occupy maybe one 1/64=6 bits/s in one direction and maybe 5bits in the other it is a total of 11 bits.
  - The true value would therefore be somwhere between 3 and 70 bits/s


APA CENTENNIAL FEATURE

The Information Capacity of the Human Motor System in Controlling the Amplitude of Movement

Paul M. Fitts
Ohio State University

Information Entropy in Control and Human factors (Fitt's law)

Fitts' law [3] describes the relationship between movement time, distance, and target width, for people engaged in rapid aimed movements. See Figure 1.

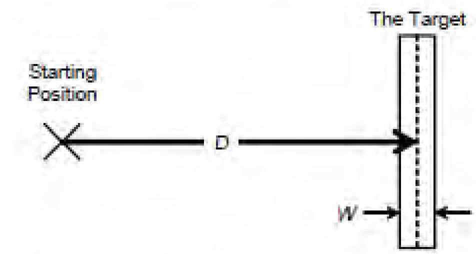
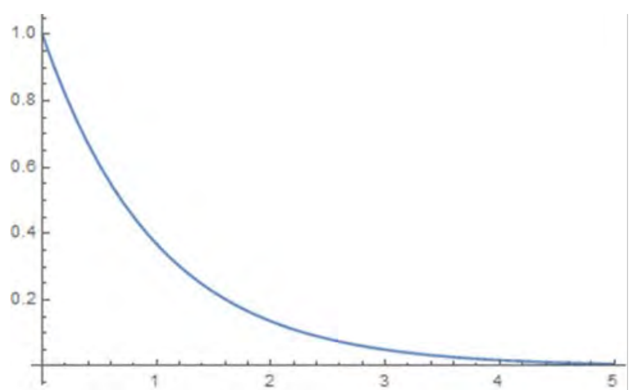
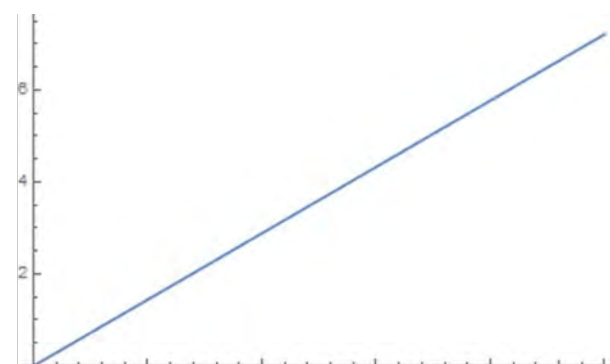


Fig. 1. The Fitts' law movement paradigm.

$$y = e^{-t\omega_f} \qquad bitrate = -\frac{\omega_f}{ln2}$$





Michon (1985)

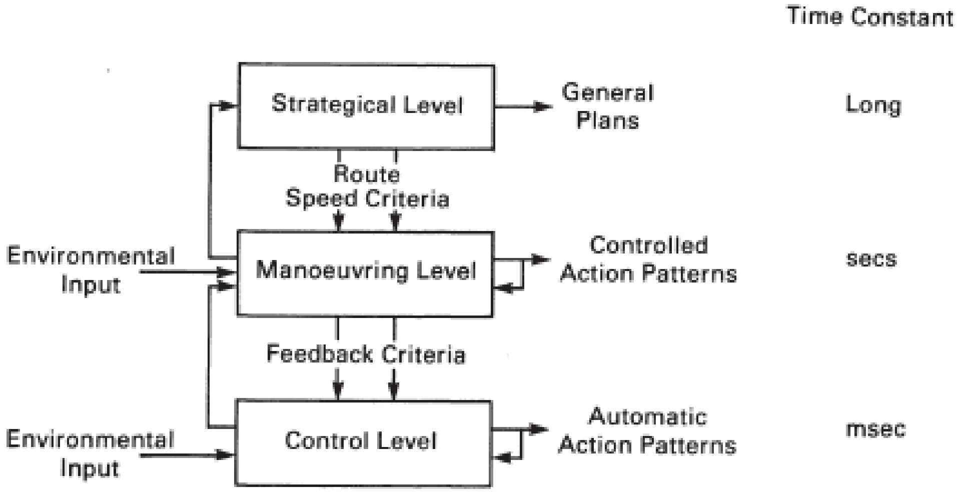
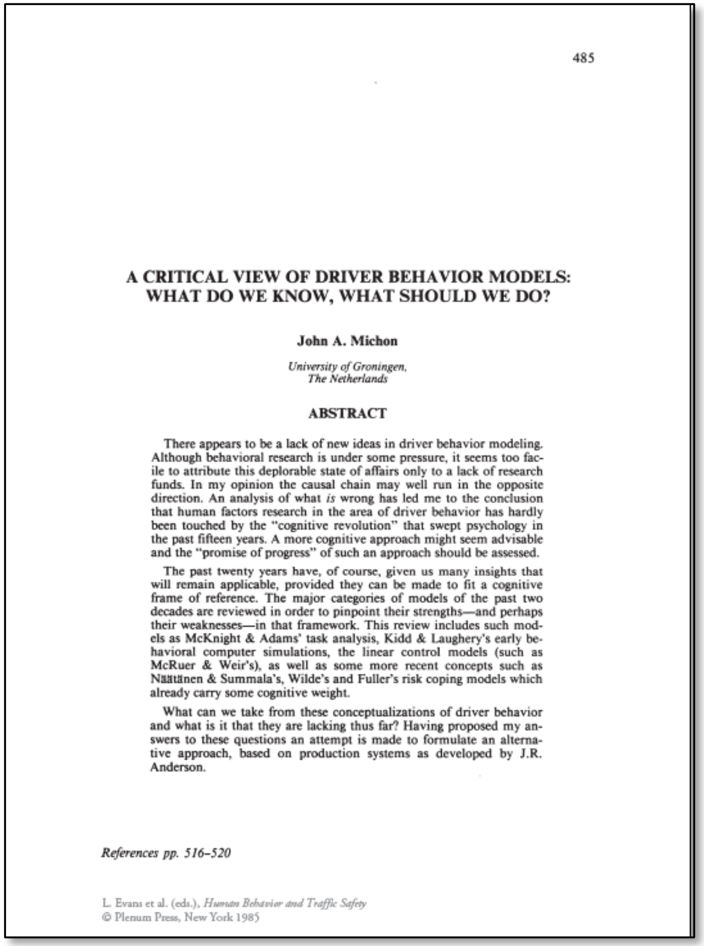


Figure 2 The hierarchical structure of the road user task. Performance is tructured at three levels that are comparatively loosely coupled. Internal and external outputs are indicated (after Janssen, 1979).



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A CRITICAL VIEW OF DRIVER BEHAVIOR MODELS: WHAT DO WE KNOW, WHAT SHOULD WE DO?

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University of Groningen, The Netherlands

ABSTRACT

There appears to be a lack of new ideas in driver behavior modeling. Although behavioral research is under some pressure, it seems too facile to attribute this deplorable state of affairs only to a lack of research funds. In my opinion the causal chain may well run in the opposite direction. An analysis of what *is* wrong has led me to the conclusion that human factors research in the area of driver behavior has hardly been touched by the "cognitive revolution" that swept psychology in the past fifteen years. A more cognitive approach might seem advisable and the "promise of progress" of such an approach should be assessed.

The past twenty years have, of course, given us many insights that will remain applicable, provided they can be made to fit a cognitive frame of reference. The major categories of models of the past two decades are reviewed in order to pinpoint their strengths—and perhaps their weaknesses—in that framework. This review includes such models as McKnight & Adams' task analysis, Kidd & Laughery's early behavioral computer simulations, the linear control models (such as McRuer & Weir's), as well as some more recent concepts such as Näätänen & Summala's, Wilde's and Fuller's risk coping models which already carry some cognitive weight.

What can we take from these conceptualizations of driver behavior and what is it that they are lacking thus far? Having proposed my answers to these questions an attempt is made to formulate an alternative approach, based on production systems as developed by J.R. Anderson.

References pp. 516–520

L. Evans et al. (eds.), *Human Behavior and Traffic Safety*

Behavioral Entropy as a Measure of Driving Performance (Boer 2001)

- Tries to make a model to mix entropy from steering with entropy for secondary tasks.
- Tasks competing for resources

BEHAVIORAL ENTROPY AS A MEASURE OF DRIVING PERFORMANCE

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Summary: Delayed event detection and degraded vehicle control are observed when drivers fuel their need to perform extra-driving activities. Vehicle control and event detection are shown to degrade most if the in-vehicle task requires spatial cognitive resources and/or if the activity requires visual perception and/or manual control manipulation. In-vehicle tasks with auditory input and/or voice output that primarily demand low levels of verbal cognitive resources appear to affect event detection only to a small degree and seem to have no effect on vehicle control. A theory-based approach to measure, analyze, and interpret these performance assessments. Results from our SAE paper #1999-01-0892 are used as a vehicle to demonstrate that steering entropy (a measure of vehicle control) in conjunction with reaction times to unpredictable peripheral events (a surrogate measure for event detection) offer clear insight into the safety consequences of various in-vehicle tasks. These results are here discussed in the context of a simple linear predictive model that is based on Wickens' theory of multiple resources. The model is shown to offer useful predictions about and interpretations of the effects that various in-vehicle tasks have on driving performance in general and driver distraction in particular.

INTRODUCTION

Key to enriching our understanding of human drivers is to understand how they view performance. Drivers interject corrective control actions when the driving situation reaches an unacceptable state. Acceptability is the decision threshold that bounds the safety-zone within which drivers prefer to operate. This decision threshold is modeled as the outcome of a satisficing decision maker who seeks domains of operation that are more beneficial than costly. By categorizing drivers' needs in terms of motivational (beneficial) and constraining (costly) components, we can employ formal tools to explain within- and between-driver variability and obtain a method to quantify performance (Boer et al., 1998). The key to monitoring driver performance is not to measure variability but to quantify the corrective actions that signal drivers' dissatisfaction with the current driving state. By defining workload as the effort required to maintain the driving state within the subjective safety zone, subjective performance and (subjective) workload become anti-correlates. Subjective performance is a complex construct that can be linked to the degree of understanding about the situation or the degree to which the operator feels in control of the situation. The signature of a lack of understanding and a lack of control is an erratic, unpredictable, and inefficient behavior that we quantify with an entropy measure (Boer, 2000). These signatures are also observed in eye-movements, in interaction with interfaces, and in control of dynamical systems.

Corrective actions are often the result of prolonged attention diversions or other interferences caused by extra-driving activities such as changing a CD or eating. A measurement technique that captures these corrective responses offers a means to quantify how distracted (inattentive) a driver is and a

Conclusions

- The area of modelling of human operators is not a mature area. I.e. there is not on agreed upon model for competing regulating and discrete work tasks.
- The information entropy seems like a promising candidate to involve in such an effort as suggested by Boer (2001).
- However, the relationship cannot be simply additive since there is some capability for parallel tasks