

# An Analysis of Pilot's Workload Evaluation Based on Time Pressure and Effort

Wenmeng Liu<sup>(✉)</sup>, Yanyu Lu, Dan Huang, and Shan Fu

School of Aeronautics and Astronautics, Shanghai Jiao Tong University,  
Shanghai 200240, People's Republic of China  
crysallwm@126.com

**Abstract.** Human factors has been playing more and more predominant role in aviation. Pilot workload evaluation is one of the most important fields in human factors to make thorough research. Among the various workload measure techniques, it is generally recognized that workload evaluation measurement is hard to elaborate. In this paper, the definition of workload is based on time pressure and effort. The relationship between time pressure and effort is the main focus to help the selection of workload evaluation approach. The models of workload evaluation are respectively set up in time pressure and effort. Heart rate, respiration rate, respiration depth, eye tracker data and control data were obtained in the flight experiment called double hydraulic failure. By comparison with the result of workload evaluation in time pressure and effort, it can indicate that the workload evaluation should take time pressure and effort altogether into account under double hydraulic failure condition. Eventually, the analysis on the relationship between time pressure and effort enables to proceed the research of workload evaluation.

**Keywords:** Workload evaluation · Time pressure · Effort · Physiological measurement

## 1 Introduction

Safety puts first priority in civil aviation. With the development of science and technology, the rates of flight accidents caused by has significantly decreased from 80% in the early 20th century to 3% at present [1]. However, there are still more than 60% flight accidents due to human factors. Under this circumstance, it is worthwhile to take scientific researches on human factors in civil aviation. Specifically, human factors play profound roles in the safety, comfort and efficiency of the aircrafts [2].

Pilot's workload can reflect the interaction of task factors, operator responses, operator performances and additional stressors [3]. Thus, evaluating pilot's workload can exert positive effect on the human factors research. It is hard to give a clear and comprehensive definition of pilot's workload. In general, workload measurement techniques are mainly divided into three categories: subjective rating scales technique, task performance measurement and physiological measurement [4–6].

Subjective rating scales technique mainly regards pilot's subjective experiences as their workload. NASA-TLX (Task Load Index), SWAT (Subjective Workload

Assessment Technique) and CH (Cooper-Harper Technique) are widely used in the field of subjective rating scales. Although it easily gets access to this approach, the result of it may not be reasonable and objective because of individual differences.

Task performance measurement is based on the completion of tasks and then work out pilot's workload. There are two aspects of this way, namely primary task performance measurement and secondary task performance measurement. Primary task performance measurement only values the pilot's completion of primary tasks while it neglects the pilot's efforts and initiatives. The pilot's completion of secondary task performance can reflect on the inability of primary task performance. Under this case, it may be time-consuming and involve in great efforts.

Physiological measurements rely on the changes of physiological signals to evaluate pilot's workload. There are mainly three varieties of physiological signals: ECG, EOG and EEG. Based on the previous studies, it was generally recognized that physiological signals enable to reflect on the changes of pilot's workload. Meanwhile the results of this approach can be objective and reasonable to some extent. Due to the multidimensional aspects of pilot's workload, single physiological signal cannot take all factors into account. Thus, it needs the multidimensional selections of physiological signals.

Based on the previous studies, it is generally recognized that the definition is hard to elaborate, which makes it difficult to select the proper approach to evaluate workload. In this paper, the definition of pilot's workload is based on time pressure and effort when the pilot proceeds a task, which can simultaneously take the pilot's physiological demands and psychological demands into account. Specifically, time pressure is whether there is sufficient time for the pilot to complete tasks under all expected conditions or not. The quantification and assessment of pilot's workload should take pilot's physical channels such as hand into account when the pilot takes actions. In time pressure aspect, it can reflect the combination of pilot's body movements, reactions and necessary perceptions during the flight. This approach involves in different pilot's body channels such as vision, hands, movements, sound and cognition. As for effort, it is whether the tasks can be accomplished without causing excessively physical load or not. The extent of pilot's effort cannot be directly observed during the flight based on the definition of effort. In this paper, physiological signals are used for reflecting the changes of pilot's workload because of its objectivity and capability. Under this case, it can successfully establish the model of pilot's workload based on effort.

With the help of these two models, the relationship between time pressure and effort is the main focus in this paper in order to evaluate workload. The reason for analyzing the relationship between time pressure and effort is aimed to find a proper approach to evaluate pilot's workload under the specific situation.

## 2 Method

In order to fulfill the pilot's workload, real flight experiments were undertaken in the flight simulator ARJ21-700. During this flight experiment, Heart rate, respiration rate, respiration depth, eye tracker data and control data were obtained in the flight experiment.

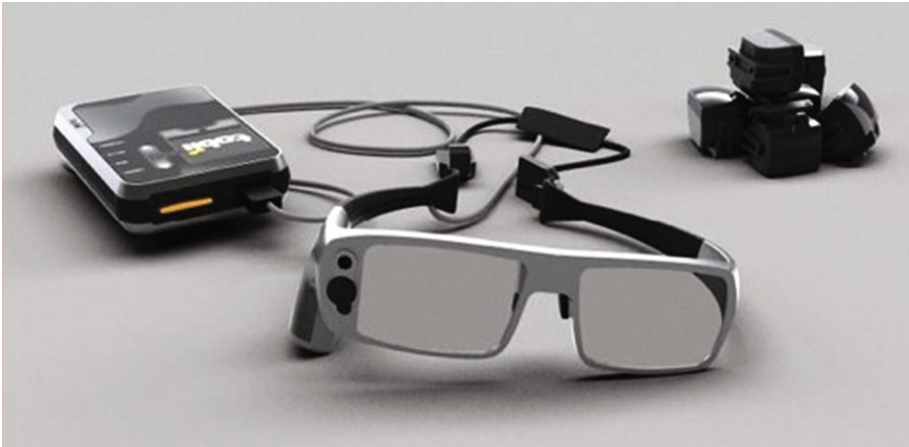
## 2.1 Participants

There were two pilots as subjects who have rich experience in flight between 30 – 60 years old. These participants were required to accomplish flight tasks according to the procedures.

## 2.2 Apparatus

There are two parts of the flight simulator: the outside view and the flight deck. Inside the flight deck, the arrangements of it consists of control instruments and display instruments. Thus, the flight data such as speed of the aircraft could be obtained from these instruments with the sample rate of 30 Hz.

The Zephyr Bioharness device [7] with the sample rate of 1 Hz was used for the collection of heart rate, respiration rate and respiration depth. Pupil diameter, fixation duration and saccade frequency were recorded by Smart Eye Pro [8], the eye tracker with the sample rate of 30 Hz (Figs. 1 and 5).



**Fig. 1.** Tobbi glasses eye tracker record device

## 2.3 Procedure

The day before flight experiment, all subjects were required to keep in good spirit so that they could perform the flight experiment properly. Meanwhile, light condition on the inner cockpit kept stable and all simulation tasks were taken under daytime. The temperature in cockpit stayed the same as real cockpit temperature. The participants were required to accomplish the flight task named double hydraulic failure.

During the experiment, the aircraft firstly kept in the initial state and it was controlled by the flight control system. While the aircraft was in the night cruise flight state, the teacher station set No. 2 hydraulic system failure and hydraulic pressure reduced from 3000 psi to 1800 psi below. Under this case, the pilot found out this fault

and he was in accordance with the prescribed procedures for disposal. With the help of the instructor, the pilot guided the aircraft to the scheduled airport. Meanwhile, the pressure alarm of No. 2 hydraulic system lasted for 15 min, two electric pumps of No. 3 hydraulic system malfunctioned. In order to fix this problem, the pilot disconnected the autopilot function and the aircraft continued to fly to the scheduled airport. Under the instructor's command, the aircraft succeeded to navigate to the end of the designated airport landing phase.

In the experiment, the data were collected by the devices stated above. When the experiment carried out, the experimenter paid attention to the devices because the devices had to work properly. At the end of the experiment, the participant had a short break and the data was carefully saved.

## 2.4 Data Process

A three-way set of system was used to obtain the data in this experiment, namely the flight recorder, Tobbi Glasses eye tracker and BioHarness Wireless Physiology device. However, the data obtained by these devices was under different sample rate and the start-up time of these devices was not the same. In this paper, the method called first timeline synchronization calibration [9] was performed before the multi-dimensional integrated data analysis. Under this way, a multi-channel data on the time can not only achieve multi-dimensional integrated data acquisition system within different terminals, but also it would be easy to add or remove arbitrary data acquisition terminal.

There were noise and lost-detection occurred during the experiment. The noise in the experiment may result from various reasons such as the environmental factor and the reason for lost-detection may be because of the poor sensor. In order to handle out this problem, Hanning window [10] was applied to filter and smooth these physiological signal data. The reason for Hanning window is capable to deal with this problem. If the physiological signal feature is over 15% data lost in a trial, this trial data should be discarded.

The big issue of data process is about the selection of parameters for time pressure aspect and effort aspect. For effort aspect, the parameters of effort are mainly from physiological signals based on the definition of effort in this paper. Based on the previous studies, heart rate, respiration rate, respiration depth and pupil diameter can take physiological reactions when the pilot take actions [9]. Thus, these factors were selected as the parameters of effort aspect. Under this case, physiological parameters can objectively represent the changes of pilot's workload based on the effort definition stated above. The data of these four physiological signals should take preliminary process before establishing the model of pilot's workload evaluation based on effort. During the data process, the absolute values of these physiological data were meaningless due to the differences among participants. Under this case, the method of z-scores were applied to cope with the above problem.

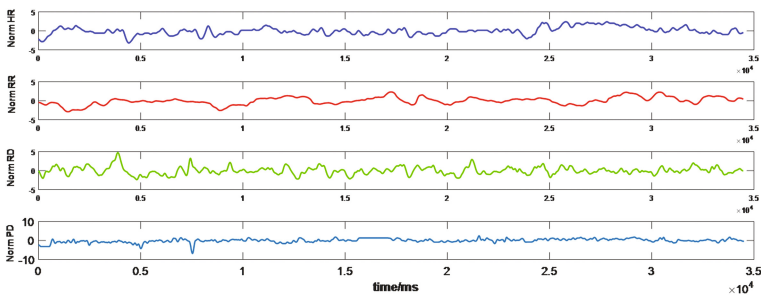
As for time pressure aspect, the selection of parameters were the combination of cognition and physical motion because time pressure for pilot workload evaluation are divided into two categories: physical motion and cognition. The parameters of physical motion are from flight data, namely control time of instruments and control speed of

instruments. The reason for selecting these two factors is that the control time of instruments and control speed of instruments can have the ability to reflect the physical aspect of the pilot to control the flight. For cognition aspect, the parameters of cognition are from eye movement data, namely fixation duration and saccade frequency. In the experiment, the data of fixation duration and saccade frequency cannot be directly obtained. The definition of these two factors are based on the cognition process. In this paper, it mainly focuses on the information process not the whole process of cognition.

Based on the above mentioned, the definition of all parameters were given clear translation and considered specific details in experiment. With the help of MATLAB programming, the data process can be successfully finished.

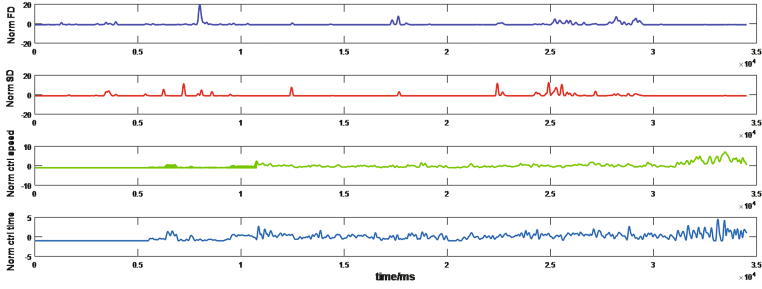
### 3 Result

From the Fig. 2 stated above, the physiological parameters of pilot can vividly represent the changes of pilot's workload. The trend of heart rate can show that the pilot took actions to cope with the emergency situations in the experiment. Meanwhile, the respiration rate and respiration depth are associated with activities of sympathetic nervous system [11]. Based on the previous studies, the respiration depth is sensitive to some typical events. It can represent the changes of pilot's workload. Under this case, multi-dimensional physiological parameters are regarded as the input of effort pilot workload model. Pupil diameter can show that the changes of pilot's workload when pilots performed monitor tasks.



**Fig. 2.** Results of effort parameters

From the Fig. 3 stated above, control time and control speed of the devices can represent the pilot abilities of physical motion. The pilot followed the procedures of the experiment and took specific actions of the devices. In this paper, the definition of the control speed is the difference between the start-point and the end-point of each motion while the definition of the control time is the difference between the start-point of nonzero control speed and the end-point of zero control speed at one time. Control time can indicate the time of the pilot to take physical actions while control speed can represent the speed of the instrument when the pilot control the instrument. With the help of control time and control speed, the physical motion of pilots can be



**Fig. 3.** Results of time pressure parameters

mathematically modeled. In cognitive aspect, the parameters of fixation duration and saccade frequency can represent the time of a pilot to acquire information [12]. The longer fixation duration is; the more cognition activities may be performed by the pilot.

After the above data process results, the model of pilot's workload evaluation in effort aspect can be mathematically set up while the model of pilot's workload evaluation in time pressure can also be mathematically established in the below.

In effort aspect, workload evaluation model can be integrated by the following equation:

$$Workload = a_1HR + a_2RR + a_3RD + a_4PD \quad (1)$$

Where:

- Heart Rate, Respiration Rate, Respiration Depth and Pupil Diameter are the results of physiological parameters stated above.
- $a_1, a_2, a_3$  and  $a_4$  are the weights to represent the contributions of heart rate, respiration rate, respiration depth and pupil diameter. They are set by the algorithm called PCA (Principal Component Analysis).

In this paper, PCA is used to quantify the contributions of these factors (heart rate, respiration rate, respiration depth and pupil diameter). The essence of PCA is the process of transforming the high-dimensional space into low-dimensional space, which makes the problem become more intuitionistic and simple [13]. Each principal component obtained by this method is independent of each other and is a linear combination of original variables. These principal components can reflect most of the information of the original variables, and there is no overlap between them.

Based on the above analysis, the model of pilot's workload in effort can be worked out in Fig. 4. From the Fig. 4, it can indicate that pilot's workload has changed a lot under double hydraulic failure. The peak of pilot's workload happened when the complexity of procedures increased. Specifically, double hydraulic failure involved complex procedures to cope with emergencies. Under this case, pilot's physiological parameters can show this trend. The overall trend of pilot's workload under double hydraulic failure condition is changeable with the time domain. Analyzing the bottoms of the pilot's workload arrives at simple situations or familiar situations. For example, when the first alarm of double hydraulic failure occurred, the pilot had to take

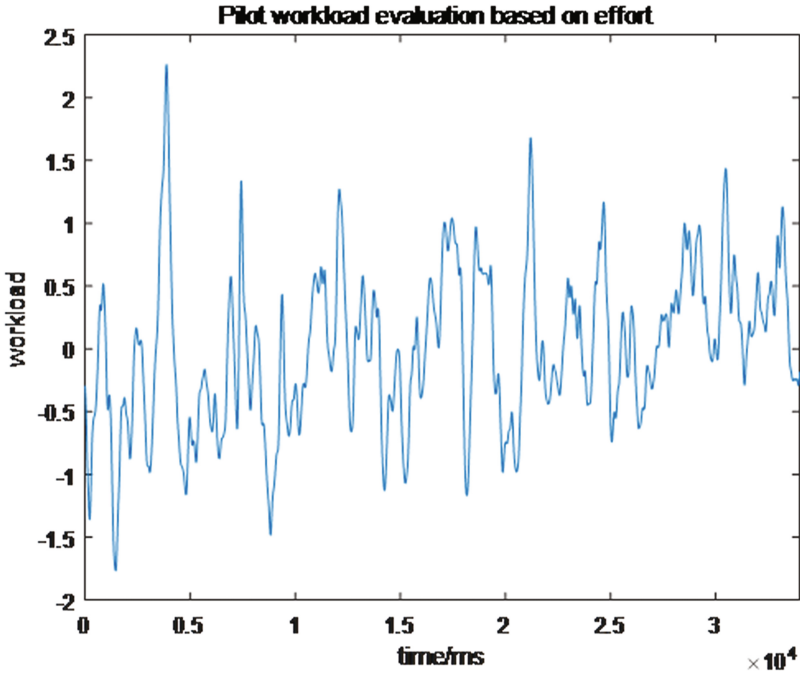


Fig. 4. Result of workload evaluation in effort

immediate action to deal with this emergency and adapted himself into this situation. Under this case, it would result in the changes of pilot’s psychological parameters ups and downs.

In time pressure aspect, workload evaluation can also be integrated by the following equation

$$Workload = b_1 \frac{t_{control\_time}}{T_{control\_time}} + b_2 \frac{t_{control\_speed}}{T_{control\_speed}} + b_3 \frac{t_{fixation\_duration}}{T_{fixation\_duration}} + b_4 \frac{t_{saccade\_frequency}}{T_{saccade\_frequency}} \quad (2)$$

Where:

- $t_{control\_time}$ ,  $t_{control\_speed}$ ,  $t_{fixation\_duration}$  and  $t_{saccade\_frequency}$  are the results of parameters in time pressure stated above.  $T_{control\_time}$ ,  $T_{control\_speed}$ ,  $T_{fixation\_duration}$  and  $T_{saccade\_frequency}$  are the baseline of four activities. The baseline data comes from the training data.
- $b_1, b_2, b_3$  and  $b_4$  are the weighs to represent the contributions of physical motion and cognition activity. The PCA algorithm calculates them.

Based on the above analysis, the model of workload evaluation in time pressure can be mathematically worked out. The trend of workload evaluation in time pressure is associated with the tasks. The peak of workload in time pressure arrives at the latter of the experiment because the pilot had to accomplish more than one task simultaneously,

which may largely increase the time pressure on the pilot. Meanwhile, the latter of workload evaluation in time pressure has changed a lot than the former one, which can also indicate that the pilot may take more actions during that time. The essence of time pressure is aimed to analyze the changes of pilot's workload associated with pilot's physical motion activity and cognition activity. Under this case, physical motion and cognition can indicate the actions taken by the pilot and then figure out the changes of pilot's workload. The overall trend of pilot's workload in time pressure can be divided into three parts: the stable segment, ups and downs segment, and the ascent segment. According to the procedures of the experiment, it can easily reflect on the complexity of tasks under double hydraulic failure condition. At the beginning of the experiment, the pilot took simple actions before the alarm of the emergency. Thus, the pilot's workload arrives at stable state. When the pilot coped with the emergency, he should take cognition as well as physical motion measures. When the complexity of task increased, it might increase the time pressure on the pilot. Under this case, the pilot's workload in time pressure increased as well.

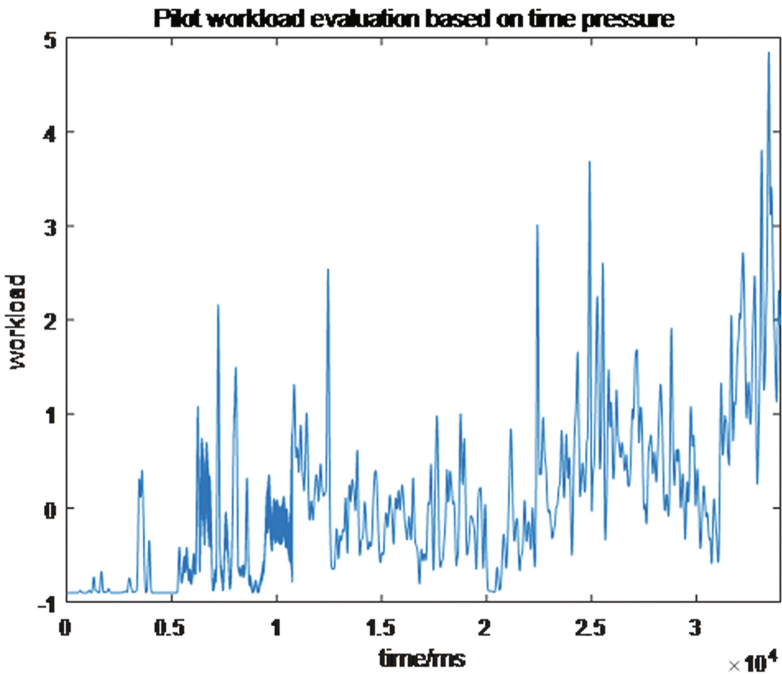


Fig. 5. Result of workload evaluation in time pressure



## 4 Discussion

By comparison with the result of pilot's workload in effort and the result of pilot's workload in time pressure, the trend of them were not the same. During the experiment of double hydraulic failure, the changes of pilot's workload in effort occurred only when the physiological parameters changed. However, the changes of pilot's workload in time pressure occurred when the cognition parameters changed or the physical motion parameters changed. Due to the complexity of the double hydraulic failure, the pilot had to pay diligent attention on the following emergencies of the experiment. Under this case, the mechanism of pilot's workload evaluation should take time pressure and effort altogether into account. In this paper, the reason for doing the double hydraulic failure experiment is that this experiment is a typical flight mission and involved a lot of actions taken by the pilot. Thus, analyzing this typical flight mission is easily to figure out the relationship between the time pressure and effort when evaluating the pilot's workload.

The relationship between the time pressure and effort under the double hydraulic failure condition is irrelevant. The pilot's workload evaluation should take these two aspects into account. However, the relationship between the time pressure and effort in other cases may be relevant. Under this case, it should focus on the analysis of tendency on time pressure and effort. After this necessary analysis, the pilot's workload evaluation should establish specific model under the specific case.

## 5 Conclusion

In this paper, workload evaluation has been measured into two aspects namely effort and time pressure, which is aimed to research the essence of workload. From the experimental results, it can indicate that the results of workload evaluation in effort are not the same as that in time pressure. Under this case, the workload evaluation of the experimental situation has to take the time pressure together with effort into account. Yet, the result of workload evaluation in effort may be similar with that in time pressure. Under this condition, it is not necessary to consider the overlap sections when calculating the result of workload evaluation. Overall, the essence of workload is hard to understand. The proposed method of workload evaluation is aimed to proceed the workload evaluation based on real pilot experiments. The reliability of this approach will be tested in the future with more thorough experiments.

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