Flight Crew Workload Evaluation Based on the Workload Function Distribution Method

Yiyuan Zheng; Yanyu Lu; Yuwen Jie; Shan Fu

BACKGROUND: The minimum flight crew on the flight deck should be established according to the workload for individual crewmembers. Typical workload measures consist of three types: subjective rating scale, task performance, and psychophysiological measures. However, all these measures have their own limitations. To reflect flight crew workload more specifically and comprehensively within the flight environment, and more directly comply with airworthiness regulations, the Workload Function Distribution Method, which combined the basic six workload functions, was proposed.

METHODS: The analysis was based on the different conditions of workload function numbers. Each condition was analyzed from two aspects, which were overall proportion and effective proportion. Three types of approach tasks were used in this study and the NASA-TLX scale was implemented for comparison.

RESULTS: Neither the one-function condition nor the two-function condition had the same results with NASA-TLX. However, both the three-function and the four- to six- function conditions were identical with NASA-TLX. Further, the significant differences were different on four to six conditions. The overall proportion was insignificant, while the effective proportions were significant.

DISCUSSION: The results show that the conditions with one function and two functions seemed to have no influence on workload, while executing three functions and four to six functions had an impact on workload. Besides, effective proportions of workload functions were more precisely compared with the overall proportions to indicate workload, especially in the conditions with multiple functions.

KEYWORDS: minimum flight crew, workload, workload functions.

Zheng Y, Lu Y, Jie Y, Fu S. *Flight crew workload evaluation based on the workload function distribution method.* Aerosp Med Hum Perform. 2017; 88(5):481–486.

The minimum flight crew on a flight deck, in accordance with airworthiness regulations[9] and the related advisory circular, should be established according to the workload for individual crewmembers. Inappropriate workloads, both excessive and insufficient, could result in unexpected task performance. Nevertheless, there remains a lack of consensus on the exact definition of workload. Several researchers have given out some acceptable explanations. Kramer and Sirevaag assumed that workload was the cost of performing a task in terms of a reduction in the capacity to perform additional tasks that use the same processing resource.[16] Stassen et al. defined workload as the mental effort that a human operator devotes to control or supervision relative to his capacity.[22] Eggemeier et al. held that mental workload refers to the portion of operator information processing capacity or resources that is actually required to meet system demands.[8] Although there are different opinions on the definition of workload, it should be considered a proportion of the capacity spent rather than an exact value in the task.

Typically, workload measurement consists of three types: subjective rating scale, task performance, and psychophysiological measures.[4] The subjective rating scale measure assumes that the different efforts of tasks could be appropriately assessed by individuals, and the most widely accepted measures include the Modified Cooper-Harper scale, NASA-TLX, and the Bedford Scale.[11] Among them, NASA-TLX is a multidimensional rating scale that assesses a subject's subjective workload on six 100-point scales related to a different aspect of workload: Mental Demand, Physical Demand, Temporal Demand, Performance,

From the Shanghai Aircraft Airworthiness Certification Center of CAAC and Shanghai Jiao Tong University, Shanghai, China.

This manuscript was received for review in June 2016. It was accepted for publication in January 2017.

Address correspondence to: Yanyu Lu, Ph.D., School of Electronic Information and Electrical Engineering, Shanghai Jiao Tong University, Shanghai, China; luyanyu@sjtu.edu.cn.

Reprint & Copyright © by the Aerospace Medical Association, Alexandria, VA.

DOI: https://doi.org/10.3357/AMHP.4681.2017

Downloaded from https://prime-pdf-watermark.prime-prod.pubfactory.com/ at 2025-05-13 via free access

Effort, and Frustration.[14] The task performance measures, including primary task measures and secondary task measures, are dependent on the assumption that increased task complexity would give rise to an increase in workload demand. In most investigations, performance of the primary task will always be of interest as its generalization to in-service performance is central to the study. In secondary task methods, performance of the secondary task itself may have no practical importance and serves only to load or measure the load of the operator.[4] Psychophysiological measures are continual and objective, attempting to interpret the workload through the operator's physiological effects rather than through task performance or perceptual ratings.[18] This suggests that mental workload can be measured according to physiological activation, which is usually determined through eye movement and heart rate variability.[13] Ahlstrom found significantly shorter blink durations and larger pupil diameter when the controller operated traffic in conditions lacking a weather display, indicating a higher workload level.[1] Jorna compared heart rate and workload variations in actual and simulated flight, and concluded that cardiovascular measures were well suited to index different mental states of pilots.[15]

However, all these measures have their own limitations. Subjective rating scale measures are sometimes uncertain regarding the repeatability and validity, and data manipulations are often questioned as being inappropriate.[3] Some researchers even believed that the subjective feeling of workload was essentially dependent on the time stress involved in performing the task for time-stressed tasks only.[19] Wilson proposed that because of the compensatory effect of increased effort, measuring task performance is not sufficient to assess the state of the operator,[27] and Wickens noted that task performance measures may not be adequate if some other factors, such as strategy, affect performance and workload differently.[24] Psychophysiological measures are influenced by ambient environment and task duration,[2] e.g., pupil diameter generally increases with higher mental workload, especially cognitive processing; however, when overload occurs, it could become unresponsive to changes or even reverse its response.[27] Castor indicated that reliable measurement of heart rate and its variability required at least 30 s and no more than 5 min.[5]

In aviation, in order to ensure the minimum flight crew is sufficient for safe operations, airworthiness regulations require each crewmember workload determination must consider the following six basic functions, including flight path control, collision avoidance, navigation, communication, operation and monitoring of aircraft engines and systems, and command decisions. For the sake of reflecting flight crew workload more specifically and comprehensively within the flight environment, and more directly complying with airworthiness regulations, a workload measurement named the Workload Function Distribution Method was proposed based on the above six functions. In this study, the Workload Function Distribution Method was implemented in three different approach tasks: Standard Instrument Approach, Non-Precision Approach, and Loss of Autopilot Approach. The results of these three tasks were analyzed according to different conditions of workload function numbers, and each condition included two aspects: overall proportion and effective proportion. The overall proportion was the comparison between the occupying time of the certain function number with the overall task time, and the effective proportion was the comparison between the occupying time of the certain function number with the total workload function emerging time on the task. Simultaneously, NASA-TLX was selected as the comparative indication of the different flight tasks.

METHODS

Subjects

There were 12 pilots who were invited to take part in this study. Among them, 10 individuals are commercial airline pilots from China Eastern Airlines and the other 2 are test pilots from the Civil Aviation Administration of China. Their ages ranged from 30 to 53 yr old (mean = 37.2, SD = 7.89). Mean total flight hours ranged from 3000 to 18,000 h (mean = 6674; SD = 3228.6) and mean flight hours in the last 2 wk before the experiment were 9.23 (SD = 7.43). Each pilot had been either captain or co-captain of a CRJ-200 for more than 1 yr (Mean = 3.86, SD = 2.32). Simultaneously, they had all been recruited as captains or co-captains for other types of aircrafts (5 of the B737, 3 of the A320, and 4 of the B747). Before the experiment, all subjects signed the consent form, which was approved by the Institutional Review Board of Shanghai Jiao Tong University.

Equipment

The experiment was carried out in a CRJ-200 full-flight simulator. It is a qualified flight simulator (level D), conforming to the guidance presented in the Federal Aviation Administration Advisory Circular AC 120-40B–Airplane Simulator Qualification.[10] All of the configurations in the flight simulator are identical with the real aircraft. This flight simulator has also been used for pilot training for commercial airlines.

In addition to the flight simulator, an eye tracker (Tobii Glass, Danderyd, Sweden) with a sample rate of 30 Hz was used to determine the area of interests and the corresponding period that the subjects gazed at during the experiment. The minimum fixation period was defined as 200 ms. The area of interests included Primary Flight Display (PFD), Multi-Function Display (MFD), Engine Indication and Crew Alerting System (EICAS), and Out of Window (OTW).

The operations of each pilot were recorded by a wide-angle video camera (pixels: 640×480, sampling frequency: 10 Hz) which was installed behind the emergency exit door on the flight deck. The recording accurately described the actions of pilots over time and space during the experiment.

Procedure

The Workload Function Distribution Method was developed based on the six basic workload functions in flight. The subject's

Downloaded from https://prime-pdf-watermark.prime-prod.pubfactory.com/ at 2025-05-13 via free access

behaviors in the flight tasks were distributed to the six functions according to the following rules:

1. Flight path control:
   a. If the subject operated the Flight Control Panel (FCP) or Control Wheel, including the moving time (i.e., hand moving from one device to another); or
   b. If the subject focused on the PFD.
2. Collision avoidance:
   a. If an alert from the Traffic Collision Avoidance System (TCAS) appeared.
3. Navigation:
   a. If the subject focused on OTW or on the MFD.
4. Communication:
   a. If the subject communicated with the other pilot or with an Air Traffic Controller (ATC).
5. Operation and Monitoring of aircraft engines and systems:
   a. If the subject focused on the EICAS; or
   b. If the subject operated the controls on the flight deck except for the FCP and Control Wheel.
6. Command decisions
   a. If the operations were not dependent on the checklist or quick checklist.

After distribution, the analysis was based on the different numbers of workload functions, including one-, two-, three-, and four- to six-workload function conditions. For example, the one-workload function condition indicated that pilots only executed one function at a time: they usually either observed the flight deck display or carried out an action on a control device. Under the two-workload function condition, they probably observed the display and carried out actions simultaneously. Each condition was analyzed from two aspects: overall proportion and effective proportion. The overall proportion (OP) was the comparison between the occupying time of the certain function number with the overall approach time as shown in the following equation:

$$OP = \frac{T_{certain\ function\ emerging}}{T_{Overall\ Approach}}$$

The effective proportion (EP) was the comparison between the occupying time of the certain function number with the total workload function emerging time as shown in the following equation:

$$EP = \frac{T_{certain\ function\ emerging}}{T_{total\ function\ emerging}}$$

The 12 pilots constituted 6 flight crews. In this study, three types of approach tasks were implemented, which were Standard Instrument Approach, Non-Precision Approach, and Loss of Autopilot Approach. Before the experiment, each subject was trained in the same flight simulator for 1 h to be familiar with the configurations and the procedures of the tasks. In the experiment, the three tasks were conducted sequentially. Simultaneously, one flight instructor, who was responsible for configuring each task and acted as the role of ATC if necessary, stayed with the flight crew in the simulator. After each task, every subject was asked to fill in the NASA-TLX scale. The total duration of the experiment was 2 wk. The configurations of the three different flight tasks were as follows.

Standard instrument approach. The flight task was carried out at Xi'an Xianyang International Airport. The task was started 40 nmi from the descending point. After slowing down to 145 kn and descending to 1500 ft, the aircraft was in a landing pattern. The subject executed a CAT I standard instrument approach procedure and landed on the runway.

Non-precision approach. The flight task was carried out at Xi'an Xianyang International Airport. The task was started 40 nmi from the descending point. After slowing down to 145 kn and descending to 1500 ft, the aircraft was in a landing pattern. The subject executed a non-precision approach procedure by using the very-high-frequency omnidirectional range (VOR) and landed on the runway.

Loss of autopilot approach. The flight task was carried out at Shanghai Pudong International Airport. The approach was started at 8000 ft and 250 kn with altitude and indicated airspeed failure. The subject executed a visual approach and landed on the runway according to the backup instrument without autopilot.

RESULTS

First, the NASA-TLX scale value of the three types of approach tasks are presented. Next, the results of the Workload Functions Distribution Method are given, based on the different conditions of workload function numbers: the one-function condition, two-function condition, three-function condition, and four- to six-function condition. In each condition, two kinds of proportions, including overall proportion and effective proportion, were analyzed. Only the behaviors of Pilots Flying (PF) were considered in this study.

The subjective workloads were significantly different among the three types of approach tasks according to the results of NASA-TLX [$F(2, 15) = 17.902$, $P < 0.0001$]. Among them, the Loss of Autopilot Approach (LAA) had the maximum average workload (mean = 68, SD = 15), the Non-Precision Approach (NPA) was the minimum (mean = 32, SD = 5), and the Standard Instrument Approach (SIA) was in the middle (mean = 43, SD = 10).

Both proportions of the one-workload function condition had significant differences among the three types of approach tasks [$F_{OP}(2, 15) = 8.624$, $P = 0.003$; $F_{EP}(2, 15) = 11.915$,

Downloaded from https://prime-pdf-watermark.prime-prod.pubfactory.com/ at 2025-05-13 via free access

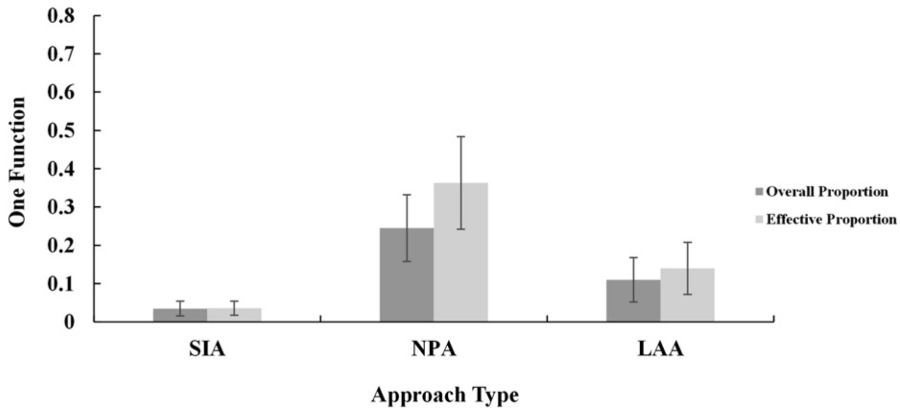

Fig. 1. The two kinds of mean proportions of one-workload function. The error bars stand for the difference of one function proportions in three different flight tasks.

$P = 0.001$]. However, other than the results of the NASA-TLX, the Non-Precision Approach had the most one-workload functions, the Loss of Autopilot Approach was in the middle, and the Standard Instrument Approach was least (**Fig. 1**).

Both overall proportion and effective proportion of the two-workload functions condition were maximum among the three different types of approach tasks. Furthermore, both proportions had significant differences [$F_{OP}(2, 15) = 14.768$, $P < 0.001$; $F_{EP}(2, 15) = 11.255$, $P = 0.001$]. However, unlike the results of the NASA-TLX, the Standard Instrument Approach had the most two-workload functions, the Non-Precision Approach was in the middle, and the Loss of Autopilot Approach was least (**Fig. 2**).

Both proportions of three-workload functions had significant differences among the three types of approach tasks [$F_{OP}(2, 15) = 7.202$, $P = 0.006$; $F_{EP}(2, 15) = 5.791$, $P = 0.014$]. Furthermore, as with the results of the NASA-TLX, the Loss of Autopilot Approach had the most three-workload functions, the Standard Instrument Approach was in the middle, and the Non-Precision Approach was least (**Fig. 3**). The correlation analysis indicated that both the overall proportion and the effective proportion were related to the results of the NASA-TLX ($R_{OP} = 0.569$, $P = 0.014$; $R_{EP} = 0.653$, $P = 0.003$). However, comparing the Loss of Autopilot Approach and the Standard Instrument Approach alone, neither overall proportion ($t = 0.852$, $P = 0.414$) nor effective proportion ($t = 1.649$, $P = 0.130$) had a significant difference.

In all three different types of approach tasks, the proportions of four- to six-workload functions were minimal. Furthermore, identical with the results of the NASA-TLX, the Loss of Autopilot Approach had the most three-workload functions, the Standard Instrument Approach was in the middle, and the Non-Precision Approach was least (**Fig. 4**). However, the correlations with the results of the NASA-TLX were weaker than the three-workload function condition ($R_{OP} = 0.302$, $P = 0.223$; $R_{EP} = 0.377$, $P = 0.123$). The significant differences of overall proportion and effective proportion were different. The overall proportion was insignificant [$F_{OP}(2, 15) = 2.380$, $P = 0.127$], while the effective proportion was significant [$F_{EP}(2, 15) = 4.195$, $P = 0.036$].

DISCUSSION

The recommended approach for determining whether the workload is appropriate for a minimum number of flight crewmembers on the flight deck is timeline analysis, which computes the ratio of time required to time available for each section of the task. Timeline analysis is used as an analytical tool to make a priori predictions regarding the task demands imposed on the flight crew. However, a serious criticism is the serial approach it takes in calculating task execution when it is known that pilots can conduct multiple actions concurrently.[6] In this study, although the Workload Functions Distribution Method is also calculated based on timeline, it considers the workload function combinations and the conditions of multiple functions that are processed simultaneously. Furthermore, this method is not restricted by the limitations of traditional workload measurements. It could reflect flight crew workload more specifically and comprehensively with flight environment, and more directly comply with airworthiness regulations.

The results of the NASA-TLX were used as a baseline workload comparison of the three types of tasks in this study. The results showed that the Loss of Autopilot Approach had the maximum average subjective workload, the Non-Precision Approach was minimum, and the Standard Instrument Approach was in the middle. However, the workload results of the Non-Precision Approach and the Standard Instrument Approach were in conflict with the automation levels of these two types of approach tasks to some extent. According to the Master Minimum Equipment

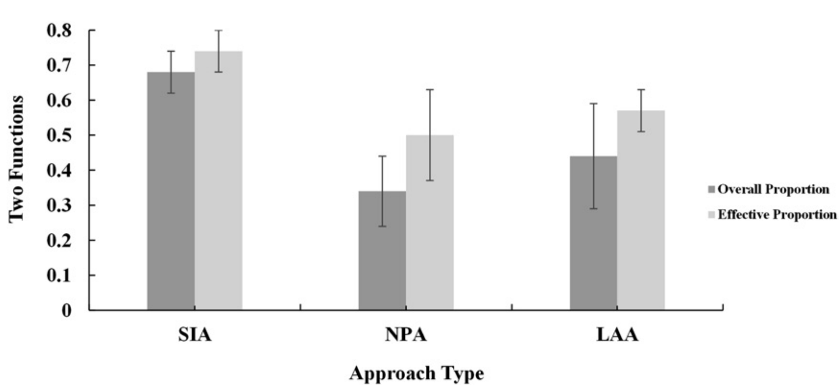

Fig. 2. The two kinds of mean proportions of two-workload functions. The error bars stand for the difference of two functions proportions in three different flight tasks.

Downloaded from https://prime-pdf-watermark.prime-prod.pubfactory.com/ at 2025-05-13 via free access

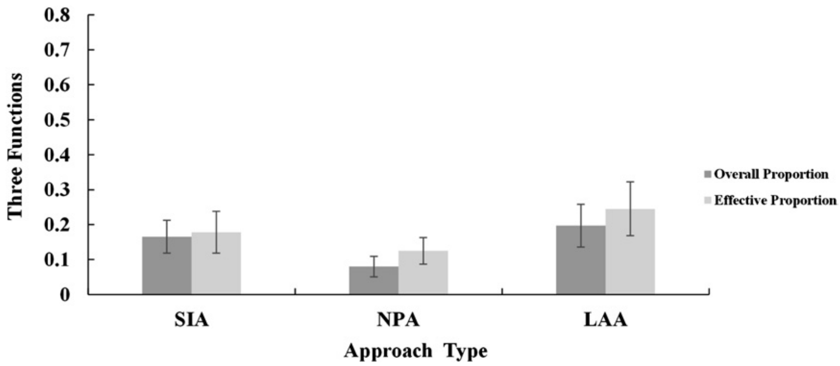

Fig. 3. The two kinds of mean proportions of three-workload functions. The error bars stand for the difference of three functions proportions in three different flight tasks.

List and Standard Operating Procedure, when conducting a standard instrument approach, advanced devices are provided to flight crew and they are more dependent on autopilot than on visual perception compared with a non-precision approach. Nevertheless, the results indicated that with the improvement of the automation level, the flight crew workload increased. This phenomenon could be explained from two aspects. First, the Non-Precision Approach is the one with the most training in flight tasks. With increased practice and experience, the resources demanded for accomplishing a task could be decreased until it becomes automatic.[25] At this point, the operating procedure of a non-precision approach becomes a kind of subconscious action of pilots, fast and error-free. Second, any attempt to introduce new technology involves some kind of change in the task, environment, and tools. Change can produce uncertainty, feelings of lack of control, and increased workload, which are well-known sources of psychological stress.[21] Similarly, Kramer et al. found there were no appreciable differences in workload ratings for the 2400-ft (Standard Cat I approach) and 1800-ft runway visual range (RVR) conditions comparing head-up display with head-down display. Even though statistically significant differences between these two RVR values and the 1200-ft RVR were found, operationally these differences were not substantial.[17] In other words, the introduction of new technology on the flight deck is a tradeoff between safety and workload.

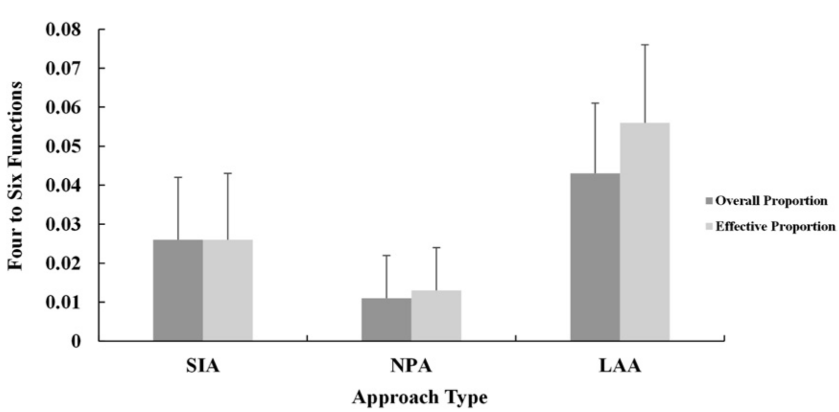

Fig. 4. The two kinds of mean proportions of four- to six-workload functions. The error bars stand for the difference of four to six functions proportions in three different flight tasks.

Considering the results of the Workload Functions Distribution Method, the Non-Precision Approach had the most one-workload functions, which was opposite to the result of the NASA-TLX. In the two-workload function condition, the result was still inconsistent with the NASA-TLX. However, in both the three- and four- to six-workload function conditions, the results were the same as the NASA-TLX scale. Therefore, the most impact on workload occurred when the flight crew was required to carry out multiple functions (actions) in parallel, especially more than two functions. This conforms to multiple resource theory, which suggests that if different resource channels are occupied simultaneously, the mental workload of operators increases dramatically.[23] Additionally, if the occupied channels conflict, it could jeopardize the task. Under the condition of one function, usually either the visual channel or manual channel was occupied. Under the condition of two functions, both the visual channel and manual channel were occupied simultaneously. Under the condition of three functions, the auditory channel was added. However, under the condition of four- to six-functions, flight crew were usually involved in a multiple task situation, where channel conflict might exist. Although even when the multiple tasks required similar responses and training could increase the speed of information processing in the brain, thereby allowing multiple tasks to be processed in rapid succession,[7] flight crew errors were inclined to emerge under the high workload situation. Wiegmann suggested that the inattention that resulted from a high workload situation could manifest as failing to monitor critical flight instruments, the failure to accomplish required in-flight checklist items, or the gradual, inadvertent loss of airspeed, all of which would appear as skill-based errors.[26]

Under the four- to six-function conditions, the discrepancy of the significant differences between the overall proportions and the effective proportions was obvious. In other words, because of the small amounts, the periods during which no function occurred influenced the result. However, what directly affected the flight crew workload should be the periods when multiple functions occurred. Similarly, the correlation comparison analyses under the three- and four- to six-function conditions with the results of the NASA-TLX also proved that the effective proportions could reflect the workload more precisely. The conditions with multiple functions could be regarded as short-term high-intensity tasks, and the peak effect dominated flight crew experience with workload judgment.[12]

In this study, the Workload Functions Distribution Method was established according to six basic workload functions in flight. The workload of three types of approach tasks were analyzed based on the method, and the

Downloaded from https://prime-pdf-watermark.prime-prod.pubfactory.com/ at 2025-05-13 via free access

NASA-TLX scale was used as a comparative indication. From the results, the one-function and two-function conditions appeared to have few effects on flight crew workload. Meanwhile, the three- and four- to six-function conditions had the same results as the NASA-TLX. Effective proportion was more precisely compared with the overall proportion to reflect workload, especially on the conditions with multiple functions. Thus, when implementing the Workload Functions Distribution Method, the effective proportions of three- and four- to six-function conditions should be carefully analyzed.

Further study of the Workload Functions Distribution Method should be performed from two aspects: the appropriate range of proportions for all the conditions should be analyzed specifically, since workload characterizes the demand imposed by tasks on a human's limited mental resources, whether considered as single or multiple;[20] and the implementation of the method of evaluating the standard operating procedure. A desirable procedure should contain as few as possible of the three- and four- to six-function conditions.

ACKNOWLEDGMENTS

Authors and affiliations: Yiyuan Zheng, Ph.D., and Yuwen Jie, Professor, Shanghai Aircraft Airworthiness Certification Center of CAAC, Shanghai, China; Yanyu Lu, Ph.D., and Shan Fu, Professor, School of Electronic Information and Electrical Engineering Shanghai Jiao Tong University, Shanghai, China.

REFERENCES

1. Ahlstrom U, Friedman-Berg FJ. Using eye movement activity as a correlate of cognitive workload. Int J Ind Ergon. 2006; 36(7):623–636.
2. Allanson J, Fairclough SH. A research agenda for physiological computing. Interact Comput. 2004; 16(5):857–878.
3. Annett J. Subjective rating scales: science or art? Ergonomics. 2002; 45(14):966–987.
4. Cain B. A review of the mental workload literature. Toronto (Canada): Defence Research and Development Canada-Toronto, Human System Integration Section; 2007. Report No.: RTO-TR-HFM-121-Part-II.
5. Castor M. Group for Aeronautical Research and Technology in Europe (GARTEUR). GARTEUR Handbook of mental workload measurement. GARTEUR, Group for Aeronautical Research and Technology in Europe, Flight Mechanics Action Group FM AG13, 2003. [Accessed 8 Feb. 2017]. Available from: http://www.garteur.org/Technical%20Reports/FM_AG-13_TP_145.pdf.
6. Corwin WH. Sandry-Garza DL, Biferno MH, Boucek GP Jr., Logan AL, et al. Assessment of crew workload measurement methods, techniques and procedures. Vol. 1: Process, methods and results. Wright-Patterson AFB (OH): Cockpit Integration Directorate, Wright Research and Development Center, Air Force Systems Command; 1989. [Accessed 8 Feb. 2017]. Available from: http://www.dtic.mil/dtic/tr/fulltext/u2/a217699.pdf.
7. Dux PE, et al. Training improves multitasking performance by increasing the speed of information processing in human prefrontal cortex. Neuron. 2009; 63(1):127–138.
8. Eggemeier FT, Wilson GF, Kramer AF, Damos DL. Workload assessment in multi-task environments. In: Damos D, editor. Multiple task performance. London (UK): Taylor & Francis; 1991:207–216.
9. FAA. Title 14 of the Code of Federal Regulations. 14 CFR 25.1523: Minimum flight crew. Washington (DC): GPO; 2009.
10. FAA. AC Airplane Simulator Qualification (AC 120-40B). Washington (DC): Federal Aviation Administration; 1991. AFS-205.
11. Farmer E, Brownson A. Review of workload measurement, analysis and interpretation methods. European Organisation for the Safety of Air Navigation; 2003:33. CARE-Integra-TRS-130-02-WP2. [Accessed 8 Feb. 2017]. Available from http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.121.3382&rep=rep1&type=pdf.
12. Fredrickson BL. Extracting meaning from past affective experiences: the importance of peaks, ends, and specific emotions. Cogn Emotion. 2010; 14(4):577–606.
13. Haapalainen E, Kim SJ, Forlizzi JF, Dey AK. Psycho-physiological measures for assessing cognitive load. In: Proceedings of the 12th ACM International Conference on Ubiquitous Computing, Copenhagen, Denmark, September 26–29, 2010. New York (NY): ACM; 2010.
14. Hart SG. NASA-task load index (NASA-TLX); 20 years later. In: Proceedings of the Human Factors and Ergonomics Society Annual Meeting. 2006; 50(9):904–908.
15. Jorna PG. Heart rate and workload variations in actual and simulated flight. Ergonomics. 1993; 36(9):1043–1054.
16. Kramer AF, Sirevaag EJ, Braune R. A psychophysiological assessment of operator workload during simulated flight missions. Hum Factors. 1987; 29(2):145–160.
17. Kramer LJ, Williams SP, Bailey RE, Glaab LJ. Synthetic vision systems: operational considerations simulation experiment. Proc. SPIE 6559. Enhanced and Synthetic Vision 2007. 655903 (April 27, 2007).
18. Mandryk RL, Atkins MS, Inkpen KM. A continuous and objective evaluation of emotional experience with interactive play environments. In: Proceedings of the SIGCHI Conference on Human Factors in Computing Systems; Montreal, Quebec, Canada; April 22–27, 2006. New York (NY): ACM; 2006:1027–1036.
19. Meshkati N, Hancock PA, Rahimi M, Dawes SM. Techniques in mental workload assessment. In: Wilson JR, Corlett EN, Editors. Evaluation of human work: a practical ergonomics methodology. Boca Raton (FL): CRC Press; 1995.
20. Moray N. Mental workload: Its theory and measurement, vol. 8. New York (NY): Springer Science & Business Media; 2013.
21. Smith MJ, Carayon P. New technology, automation, and work organization: stress problems and improved technology implementation strategies. Int J Hum Factors Manuf. 1995; 5(1):99–116.
22. Stassen H, Curry R, Jex H, Levison W. Final report of control engineering group on mental load. In: Moray N, editor. Mental workload: its theory and measurement. New York (NY): Springer Science & Business Media; 1979:235–252.
23. Wickens CD. Multiple resources and mental workload. Hum Factors. 2008; 50(3):449–455.
24. Wickens CD, Huey BM. Workload transition: implications for individual and team performance. Washington (DC): National Academies Press; 1993.
25. Wickens CD, McCarley JS. Applied attention theory. New York (NY): Taylor & Francis; 2007.
26. Wiegmann DA, Boquet A, Detwiler C, Holocomb K, Shappell S. Human error and general aviation accidents: a comprehensive, fine-grained analysis using HFACS. Oklahoma City (OK): Federal Aviation Administration; 2005.
27. Wilson AGF. Operator functional state assessment for adaptive automation implementation. Proceedings of SPIE. 2005; 5797:100–104.

Downloaded from https://prime-pdf-watermark.prime-prod.pubfactory.com/ at 2025-05-13 via free access