World Academy of Science, Engineering and Technology
International Journal of Health and Medical Engineering
Vol:14, No:1, 2020

Human Factors Considerations in New Generation Fighter Planes to Enhance Combat Effectiveness

Chitra Rajagopal, Indra Deo Kumar, Ruchi Joshi, Binoy Bhargavan

***Abstract*—**Role of fighter planes in modern network centric military warfare scenarios has changed significantly in the recent past. New generation fighter planes have multirole capability of engaging both air and ground targets with high precision. Multirole aircraft undertakes missions such as Air to Air combat, Air defense, Air to Surface role (including Air interdiction, Close air support, Maritime attack, Suppression and Destruction of enemy air defense), Reconnaissance, Electronic warfare missions, etc. Designers have primarily focused on development of technologies to enhance the combat performance of the fighter planes and very little attention is given to human factor aspects of technologies. Unique physical and psychological challenges are imposed on the pilots to meet operational requirements during these missions. Newly evolved technologies have enhanced aircraft performance in terms of its speed, firepower, stealth, electronic warfare, situational awareness, and vulnerability reduction capabilities. This paper highlights the impact of emerging technologies on human factors for various military operations and missions. Technologies such as 'cooperative knowledge-based systems' to aid pilot's decision making in military conflict scenarios as well as simulation technologies to enhance human performance is also studied as a part of research work. Current and emerging pilot protection technologies and systems which form part of the integrated life support systems in new generation fighter planes is discussed. System safety analysis application to quantify the human reliability in military operations is also studied.

***Keywords*—**Combat effectiveness, emerging technologies, human factors, systems safety analysis.

I. Introduction

THE pilots of the multirole fighter aircrafts are under high stress due to the requirement of executing multi tasks during the various missions and operations. The war scenarios are changing with the emergence of threats to fighter planes with higher range and precision capable of deploying various countermeasures and counter countermeasures. The fighter planes need to operate against highly sophisticated air defense systems which reduce its survivability significantly. The survivability of the modern aircraft can be enhanced if the pilot is provided with systems and technologies enhancing their overall situation awareness. Most of the systems aiding situation awareness are highly automated with a tendency towards a greater role of artificial intelligence.

Availability of a larger set of data to the pilot increases the workload and affects their performance adversely; so, the human factors consideration should be taken into account to increase mission effectiveness. Numerous references exist discussing the current state of human factors considerations in military aircrafts to enhance mission effectiveness [1], [2].

Chitra Rajagopal, Indra Deo Kumar, Ruchi Joshi, and Binoy Bhargavan are with the Defense Research & Development Organization, New Delhi-110011, India (e-mail: ccsam@ hqr.drdo.in, idkumar@hqr.drdo.in, ruchijoshi@hqr.drdo.in, binoykpy@gmail.com).

II. Aircraft Missions and Human Factors

Multirole fighter aircrafts are designed with the aim of using a common airframe for multiple tasks to increase its overall mission and cost effectiveness. Today's fighter aircrafts necessitate multirole design capable of engaging both air and land targets with equal precision. Missiles and advanced sensors allow for beyond the visual range engagements of aerial threats.

Multirole aircraft undertakes missions such as Air to Air combat, Air defense, Air to Surface role (including Air interdiction, Close air support, Maritime attack, Suppression and Destruction of enemy air defense), Reconnaissance, Electronic warfare missions etc. Some of the missions executed by multirole fighter planes are shown in Fig. 1. Success of the mission depends upon parameters such as aircraft maneuverability, range, handling qualities, persistence, stealth, resilience, target acquisition capability, availability of command, control and communication and other supporting systems, capability to operate in adverse terrain and weather conditions along with the lethality of the weapon system for different missions. Execution of these missions imposes stress of different levels on human pilots which varies from mission to mission.

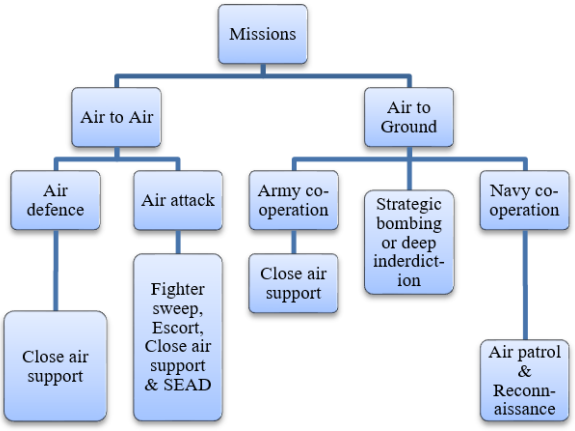

Fig. 1 Multirole fighter missions

A. Air-to-Air Missions

The situation awareness is one of the important elements of air-to-air combat missions [3]. The situational awareness depends upon the fusion of information or data available by

the means of various sensors and deriving useful intelligence out of this information. The details, like identification of friend or foe (IFF), spatial geometry, aircraft energy level, sensors mode and coverage area, flight envelope, availability of weapons, and g-limit are some of the required information the pilot needs in order to access the current and future scenarios and activities. This information helps the pilot to execute an effective mission. Most of the kills are aimed at beyond visual ranges, in such a scenario, the details such as sensors search and track modes, multi target tracks while scanning, seeker lock-on modes, and air combat acquisitions modes are the necessary information. The effectiveness of the air-to-air combat missions depends on the availability of critical information to the pilots and the pilot's capability to interpret and use it. Availability of the optimal set of information to the pilot is a necessity for enhanced situational awareness with reduced workloads. The human factor requirements vary during execution of different missions. Some of the missions need more pilot responses than other missions as mentioned below.

Suppression of Enemy Air Defense (SEAD): SEAD missions are intended to make the enemy missile air defense systems inactive, mainly by destroying their radar sites using anti-radiation missiles or other precision guided weapons. It is a dynamic mission and needs extensive training, as well as a crew with good knowledge of electronic warfare is needed to execute the mission. The emergence of low observable platforms and deployment of multi-layered air defense systems has made SEAD missions more dangerous.

Fighter sweep: Fighter sweep is an aggressive counter air patrol to destroy enemy aircraft without taking any losses. High level of situational awareness, real-time data transfer with friendly forces, aircraft maneuverability, and the capability of the weapons are some of the factors which effects fighter sweep mission effectiveness. The pilots need only critical information during the combat; the availability of huge amounts of non-critical information or data can confuse the pilots and leads to more mental stress conditions. The introduction of an automated g-limit safety will help the pilot to execute more maneuvers without exceeding the g-limits.

B. Air-to-Ground Missions

For Air-to-Ground Missions, spatial details such as information related to key installations, landmarks, threat information and ground terrain features are important. Other factors such as the sun's positions, clouds, and weather affecting visibility of the fighter planes including the present and future flight tactics information is needed. Some of the air-to-ground missions and specific human factor requirements are mentioned below.

Close air support: An air strike intended to destroy the hostile targets in close proximity to the friendly forces. Operations conducted in steep broken terrain and narrow valleys make a mission more difficult and dangerous for pilots. The high survivability of the aircraft is required to protect the pilot especially from gun attackers. Excellent low speed maneuverability and handling quality are the requirements of this mission. High co-ordination with the ground troops is a necessity for the close air support missions. The simulation based training provides good confidence and experience to the pilot to increases the mission effectiveness. During close air support, it is also needed to engage the enemy forces with minimum or reduced collateral damage to friendly forces.

Reconnaissance missions: It aims gathering necessary information for the intelligence purpose, surface surveillance, warning to the battle group as well as engaging the enemy vessels. Compared to all other above mentioned missions, the reconnaissance mission imparts less stress to the pilot. Currently, unmanned aircrafts are mostly assigned for surveillance and reconnaissance missions.

Each mission needs specific information, therefore while introducing new technologies like automation, the designer should ensure effective pilot-vehicle interfaces. All the automation should ensure that the pilot receives critical information as per the mission requirements. A battle in an integrated air defense environment requires proper automation which should support the multirole and swing role capability of the fighter aircrafts for higher probability of success.

C. Mechanisms to Capture Human Factor Requirements for New Generation Fighters

Multirole fighters are capable of executing more than one mission such as air-to-air and air-to-ground missions. In such a scenario, the multirole fighters should have the capability to handle role change (swing role) scenario. The human factor associated with all these missions requires effective situational awareness. The level of stress of the pilots varies for each mission. The situational awareness requirements for each mission, generally gets captured from the interviews with the pilots and domain experts.

The pilot performance and in turn the mission effectiveness in the operational scenarios, is increased by proper training using flight simulators. The current flight simulators are not able to replicate the complete situational awareness capability of the fighter planes. So, the flight simulators with acceptable level of situational awareness are used to enhance the confidence of the pilots to execute various missions. The measures should be also taken to reduce the stress level of the pilot because a high stress level increases the chance of degradation of mission effectiveness. The stress level directly depends upon the complexity of the missions to be executed by the pilots. The physiological and psychological stress of the pilot needs to be reduced in the mission in order to enhance the mission performance. Management of a high amount of the data available to pilots will require application of emerging technologies such as augmented human performance, artificial intelligence and advanced analytics and computing.

Most of the pilot's interview data suggests that pilots are happy with the automation system but they also believe that sometimes it increases the mental workload. The pilot's mental workload needs to be reduced by providing them with an adequate level of training. The importance of situational awareness and its impact on the pilot's work load is discussed

in a research paper [4].

III. Emerging Technologies and Its Impact on Human Performance

Advanced technology is introduced in modern fighters with the aim to enhance mission effectiveness and pilot safety. The advancement in aircraft technologies has shifted the role of the pilot from controller to supervisor. The technological changes of recent times impacting human performances are mentioned below.

A. Cockpit Technologies

Most of the new technological evolution impacting human performance has happened in the cockpit [5]. Due to cockpit automation, the pilot has access to more information but has a limitation of processing and interpreting all the data. Processing and interpretation of large set of data increases the pilot's workload. The other factors such as cockpit conditioning, cockpit layout, pressurization, air flow, air distribution, temperature control, control accessibility etc. also affects the performance of the pilot. Any failure of the helmet mounted display or head down display will dramatically affect the mission efficiency.

B. Communication and Navigation

New generation fighter planes operate in a network centric environment, capable of communication and receiving data from space, air and ground platform-based sensors. The introduction of technologies such as data fusion, secure communication, GPS, caution and warning system increases the situational awareness of the pilot.

C. Search/ Identification/Track

The modern fire control radar can detect and track multiple targets at long ranges with high precision and accuracy. It can also provide a wider view in terms of coverage in elevation and azimuth planes for both air-to-air and air-to-ground missions including terrain mapping capabilities. The sensors like electro-optical targeting system have the capability of not being intercepted by the enemies. The distributed aperture system (DAS) provides vision through the body of the aircraft which helps with the 360 degree of passive environmental information to the pilot by using infra-red cameras. The DAS system sometimes gets disoriented under adverse operating conditions which cause degradation in situational awareness of the pilot.

D. Controls

Some of the emerging and novel controls technologies such as eye tracking, hands on throttle, direct voice input etc., increases the situational awareness of the pilot and helps in reducing the pilot work load. The impacts of the emerging technologies on human performance are shown in Table I.

E. Life Supporting and Protecting System

The life supporting and protecting systems reduce the physical stress of the pilot. The pilot needs to protect against rapid decompression, high g loads, thermal stress, sound, visual and facial hazards, fire and heat impact. The safe ejection system is also an important element of the life supporting system. It has been observed that during high maneuvers, anti-g suites proved not so effective yet. Improving the physical comfort of the pilot enhances the mission effectiveness. The anti-g protection and ejection seats are needed with maximum comfort. The minor discomforts can affect the pilot's performance for operations with long durations such as combat air patrol.

TABLE I
Emerging Technologies and Its Impact on Human Performance

Technology domains	Emerging technologies	Impact on human performance
Cockpit technologies	Pilot Vehicle-Interface Helmet mounted display Head-down display Augmented reality 3D Audio Warning panels	Increases the situational awareness, and mental workload
Communication and navigation	Data fusion Secure communication GPS Caution and warning System Intercom	Increases the situational awareness, data fusion, decreases the mental workload
Search/ Identification/ Track	Electro-optical Targeting system Terrain mapping Distributed aperture system	Increases the situational awareness
Controls	Eye tracking Hands on throttle Direct voice input Novel STOVL controls	Reduces both physical and mental workload

IV. Technologies Enhancing Human Performance

A. Co-Operative Knowledge-Based Systems

The concept of cooperative knowledge-based systems is introduced to reduce the workload, enhance situational awareness, and also to increase the safety and reliability in a stressful environment. It is a pilot support system consisting of embedded computer technologies, software engineering, information processing and knowledge-based techniques [6]. Cooperative knowledge-based systems advice the pilot in a stressful condition to make effective and efficient decision making. The pilot associate program built on co-operative knowledge based systems and advanced computing technologies helps in increasing the survivability of the fighter planes [7]. The cooperative knowledge-based system also helps in achieving greater aerodynamics and propulsion efficiency of the aircrafts enhancing the combat effectiveness by utilization of the optimal flight envelope in terms of altitude, Mach no. and maneuverability.

The cooperative knowledge-based system is mainly used for situation assessment, mission planning, tactical planning and pilot vehicle interface. This technology helps in reducing the pilot workload and increasing the situational awareness of the pilot resulting in enhanced mission effectiveness. The co-operative knowledge-based system incorporating human mental capability will be an efficient technology for future combat aircrafts to enhance the overall effectiveness.

B. Simulation Technologies to Enhance Human Performance

The simulators based on the embedded algorithms are primarily used for training purposes to execute various missions and tasks in the operational scenarios [8]. The flight simulators are also used with an aim of making pilots adapt to new technologies. This can be also used as a research platform to evaluate pilot's decision-making capabilities in various operational scenarios. The simulation technologies also help to understand the mental, physical and emotion characteristics of the pilot using the human-in-loop simulation setup. The mental workload assessment simulator (MWAS), as shown in Fig. 2, at the Defense Research and Development Organization (DRDO), is used to capture real time data for mental workload studies [9], [10]. The data collection during simulated scenarios with human-in-loop helps in building a statistical model to quantify the pilot workload for a given mission or task. The engineering flight simulator (EFS), as shown in Fig. 3, at DRDO is used to develop pilot vehicle interfaces for military platforms [11].

Fig. 2 MWAS

Fig. 3 EFS for PVI research

The objective assessment tools provide instructors with a net set of information which contains flight parameters fused with the psychophysical state of the pilot [12].

C. Human-Centered Automation (HCA)

Automation with greater role of AI is the emerging trend in new generation fighter aircrafts. The advancements in the human-centric advance automation technologies helps in the realization of high performance aircraft. Sometimes the new technologies are developed without considering the capability of the human. The need for human-centered automation is essential for the improvement of the overall mission performance. The HCA is mainly done by collecting data through the interviews with pilots. Requirements for HCA should form the guidelines that should be incorporated during the design phase of the aircraft [13]. The automation helps in increasing the situational awareness [14] of the pilot but sometimes it can also lead to an increase in the workload [15] of the pilot and degradation of human performance. In order to increase the mission effectiveness, the automation is to be designed in such a manner that it can be handled by the pilots more efficiently and safely. The automation also needs to be designed with the capability to detect any inappropriate data input by the pilot. Each multirole fighter aircraft mission needs different level of situational awareness. Some critical information for one mission may not be critical for other missions, so the automation should be designed as per the requirement of a specific mission. The highly human cooperative automation helps in the success of mission.

Integration of the human reliability component with human-centered automation process: Fighter planes operating in diverse operational and environmental conditions impose unique physical and psychological challenges to the pilots. Pilot's roles and responsibilities are also going through a transition phase due to the perceived role of artificial intelligence technologies in multirole fighter planes. Ideally, designers need to design out all possibility of human error. Human reliability analysis methods such as the technique for human error rate prediction (THERP), human error assessment and reduction technique (HEART) etc. are used for quantifying the share of human error during the missions executed by fighter planes. In specific cases of quantifying the probability of human error during air-to-air and air-to-ground missions by the fighter planes, action oriented task analysis techniques such as hierarchical task analysis and operator action event tree (OAET) along with critical action and decision event tree (CADET) for cognitive task analysis can be applied. The computed probability of human error can be integrated with the probability of failure of subsystems or components using system safety analysis tools such as fault tree analysis, event tree analysis, failure mode and effects analysis to compute the overall reliability of the system.

V. Conclusion

Human factor considerations in new generation fighter planes will help in efficient execution of missions assigned to the pilots. Realization of technologies supporting the pilot with a greater component of artificial intelligence for better decision making is a way forward to enhance the pilots' performance and aircraft effectiveness in future war scenarios. Automation also comes with limitations such as degradation in the decision-making capability of the pilots, which may adversely affect the pilots' performance in critical mission scenarios. Scenario-based training is suggested as one of the cost effective methods to enhance pilot performance and preparedness in combat scenarios.

ACKNOWLEDGMENT

The authors acknowledge Ms. Nabanita R Krishnan, Director General (System Analysis & Modeling), DRDO and Dr. N. Ranjana, Director Systems & Technology Analysis, DRDO for valuable inputs and encouragement during the course of research work.

REFERENCES

[1] Shappell, S. A., and D. A. Wiegmann. "HFACS analysis of military and civilian aviation accidents: A North American comparison." Proceedings of the Annual Meeting of the International Society of Air Safety Investigators. Australia: Gold Coast, 2004.

[2] Edkins, Graham D. "A review of the benefits of aviation human factors training." Human factors and Aerospace safety 2.3 ,2002: 201-216.

[3] Endsley, Mica R. "A survey of situation awareness requirements in air-to-air combat fighters." The International Journal of Aviation Psychology 3.2,1993: 157-168.

[4] Emerson, Terry J., John M. Reising, and Harold G. Britten-Austin. Workload and situation awareness in future aircraft. No. 871803. SAE Technical Paper, 1987.

[5] Endsley, Mica R. "The application of human factors to the development of expert systems for advanced cockpits." Proceedings of the Human Factors Society Annual Meeting. Vol. 31. No. 12. Sage CA: Los Angeles, CA: SAGE Publications, 1987.

[6] Chin, Hubert H. "Knowledge-based system techniques for pilot aiding." Control and Dynamic Systems V54: System Performance Improvement and Optimization Techniques and Their Applications in Aerospace Systems: Advances in Theory and Applications 54, 2012:69.

[7] LaPuma, Alfonso, and Carol Marlin. "Pilot's Associate-A synergistic system reaches maturity." 9th Computing in Aerospace Conference. 1993.

[8] Joe, Hyunsik, et al. "Air-to-air and air-to-ground engagement modeling for the KAI embedded training system." AIAA Modeling and Simulation Technologies Conference and Exhibit. 2008.

[9] Singh, Anju L., Trayambak Tiwari, and Indramani L. Singh. "Performance feedback, mental workload and monitoring efficiency." J Indian Acad Appl Psychol 36.1,2010: 151-8.

[10] Sharma, Neelam, Maheshkumar H. Kolekar, and Sushil Chandra. "Synthetic Perception: New Era of Virtual Reality in Mental Health Care." CSI Communications 33,2012: 413.

[11] Harinarayana, K., S. C. Shrimali, and P. Biswas. "Indian light combat aircraft (LCA)-lessons learnt in R&S during development." Annual Reliability and Maintainability Symposium, 2003. IEEE, 2003.

[12] Zasuwa, Maciej, Grzegorz Ptasinski, and Antoni Kopyt. "Automated, Objective Assessment of Pilot Performance in Simulated Environment."vol:13,2019.

[13] Alfredson, Jens, et al. "Applied cognitive ergonomics design principles for fighter aircraft." International Conference on Engineering Psychology and Cognitive Ergonomics. Springer, Berlin, Heidelberg, 2011.

[14] Helldin, Tove, and Göran Falkman. "Human-centered automation for improving situation awareness in the fighter aircraft domain." 2012 IEEE International Multi-Disciplinary Conference on Cognitive Methods in Situation Awareness and Decision Support. IEEE, 2012.

[15] Svensson, Erland, et al. "Information complexity-mental workload and performance in combat aircraft." Ergonomics 40.3 ,1997: 362-380.