Defence Science Journal, Vol. 68, No. 5, September 2018, pp. 425-431, DOI : 10.14429/dsj.68.12235

Development of a Full Mission Simulator for Pilot Training of Fighter Aircraft

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ABSTRACT

With aircraft becoming more complex and avionics intensive and flight being almost autonomous based on waypoint navigation, software and displays becoming a significant component of the all glass cockpit of the modern day fighter aircraft, it is imperative that pilots are trained on missions using ground based full mission simulator (FMS) for routine flight as well as advanced missions. A flight simulator is as good as the real system only when it is able to mimic the physical system, both in terms of dynamics and layout so that the pilot gets the complete feel of the environment as encountered during actual sortie. The objective of this research paper is to provide a detailed insight into the various aspects of development of a FMS for pilot training with minimal maintenance operations for long hours of realistic flight training on ground. The approach followed by ADE in developing a FMS using a healthy mix of conventional flight simulation methodologies and novel approaches for various simulator sub-systems to tailor and meet the specific training needs, one presented. The FMS developed by ADE is presently being used by Indian Air Force for flight and mission critical training of squadron pilots.

Keywords: Flight simulator; Real time simulator; Full mission simulator; Instructor operating station

1. INTRODUCTION

Simulators play a significant role in the life cycle of the development of a fighter aircraft from design to its production, both for design support during the development phase such as for flight control system design, cockpit ergonomics or for avionics architecture. When the aircraft development is complete and is moved to production, there is a need for a training simulator both for crew training and ground staff. The full mission simulator (FMS) plays a significant role in providing the training to the ab-initio pilots for carrying out the missions on the aircraft after practicing the same extensively on the FMS. Now-a-days in most of the countries, it is mandatory to undergo minimum number of training hours on the simulator before the sortie can be carried out on the aircraft. With airspace becoming a severe constraint and the cost of air training moving up the ladder, simulator training becomes all the more important for safety and cost reduction. In this context, the fighter aircraft is much more challenging as the missions expected to be carried out by these machines are complex and requires extensive practicing on ground to be prepared for exigencies and emergency handling.

This training calls for a simulator that faithfully replicates the behaviour of the aircraft throughout its flight envelope, cueing system to provide the feel of the environment, a cockpit setup with displays, controls and panels as in the real aircraft. With the vast experience of developing both design and training simulators, ADE had developed a FMS for an advanced fighter aircraft and the same is currently being used by the squadron pilots for training before carrying out sorties.

The Indian Air Force is the fourth largest Air Force in the world in terms of both personnel and aircraft (140000+ personnel and 1700+ aircraft). Given the rising costs and increasing complexities of aircraft and other weapon platforms, there is a requirement for infrastructure and resources to provide real life situations with a facility to record and analyse the performance of trainee pilots of the air force. One of the most important systems from the Air force point of view is a flight simulator. Simulators can bring about extended realism to training of an individual pilot and to an entire team. Simulators can be used to train operators in various skills while preserving the primary equipment for operational use.

The Indian Air Force requires and has been using a variety of flight training devices for their raw trainee pilots, starting from the link trainer (many decades ago), followed by hunter simulator, later the Ajeet and Kiran flight simulators and presently the Hawk Simulator which performs the major chunk of the initial training for ab-initio pilots. This is normally followed by training on simulators of specific combat aircraft simulators like MiG-21, Mirage, Jaguar and Su-30 simulators or helicopter simulators like Mi-17 Simulator, depending on the identified role of the air force pilot. In addition to these, there are a set of Flight training and pilot selection simulators which help in assessing the physiological and mental workloads

Received : 10 December 2017, Revised : 12 July 2018
Accepted : 18 July 2018, Online published : 12 September 2018

on a pilot during the course of his flying exercises and aid in identifying a candidate pilot for a particular role.

Aeronautical Development Establishment (ADE), which is a pioneering laboratory under the Aeronautical Cluster of DRDO labs, has a special core group exclusively working for development of flight simulators for the Indian Air Force (IAF). ADE has developed a variety of Simulators for the Indian Force over the last four decades. In this paper, a detailed brief on a Full Mission Simulator developed by ADE for an advanced fighter aircraft has been presented.

1.1 Flight Simulators – Need and Cost Benefits

Simulation in a general sense refers to imitation of a real-time process usually with the help of a computer or similar technological devices, in order to provide a real-life-like experience. More technically, a simulator is a special category of training device that can replicate all or most of the functions of a system. Aircrafts are costly equipment and are even more costly for operations. In a flight training scenario, flying an aircraft for training a pilot is a very costly proposition both in terms of specialised equipment and technical manpower. Regular operations involve the use of large infrastructure and personnel for air traffic control, safety services and radio navigational aids. Modern day simulators, with rapid developments in computer science, can paint near-real scenarios and provide an opportunity to rehearse procedures for even the most unforeseen contingency, be it in flying or in other types of ground-based operations. It also provides the opportunity to train by day and night, irrespective of weather conditions, all this at a significantly lesser cost. The advantage of simulators is that aircrew continues to gain valuable training at a fraction of the cost and without the risk of losing lives or machines. To cite an example provided by the IAF, the newly acquired C-130 J costs Rs 12 lakh per h to operate, while the operation of its simulator costs only Rs 25,000 an hour, which provides huge savings in terms of cost and aircraft operational life. Table 1, provides a summary of operational and training costs of different types of aircraft.

Table 1. Operational and training costs on different aircraft

Fly Away Cost Per Aircraft		
Type of A/c	**($ Million)**	**(Rs. in Crore)**
C-17	250	1,375
C-130J	100	550
F-22	50	275
Rafale	80-90	440-495
Su-30 MKI	65	355
Cost of Training		
The cost of basic training of a pilot in Rupees through Stage I, II and III as projected by the IAF to the Ministry of Defence in 2010 was as under:-		
Fighters 952.72 lakh		
Transports 753.72 lakh		
Helicopters 291.79 lakh		

ADE has developed the following flight simulator systems with the IAF in mind. The first four are being extensively used by the IAF while the fifth one is a research project to aid in measuring and optimising the workload experienced by a fighter pilot while performing a set of secondary tasks over and above safely navigating the aircraft.

These simulator systems are:

(i) Real time simulator (RTS) and FMS for fighter aircraft.
(ii) RTS for medium altitude long endurance (MALE) unmanned aerial vehicles (UAVs)
(iii) Avionics part task trainer (APTT) for upgraded MiG-27 Aircraft
(iv) Computerised pilot selection system (CPSS)
(v) Pilot mental work load assessment simulator (PMWLAS)

2. FULL MISSION SIMULATOR AND ITS SUB-SYSTEMS

In this paper, the FMS for fighter aircraft training of ab-initio pilots is presented in detail. The objective of this research paper is to provide a detailed insight into the various aspects of development of a FMS with a view towards maximum Training Transfer to the trainee pilots with minimal maintenance operations for long hours of realistic flight training on ground. The Simulator has been developed using a healthy mix of conventional flight simulation methodologies and novel approaches for various simulator sub-systems to tailor and meet the specific training needs. The following paragraphs will explain various subsystems of the FMS:

2.1 System Architecture

Flight simulators employing distributed architecture are built around an Ethernet communication backbone which is used to communicate between the various simulator sub-systems[1-2]. Distributed computing proposes a high performance solution thanks to advances in network technology and usage of suitable middleware over HLA[3]. ADE has also adapted a distributed open architecture for the development of the simulators that can make use of heterogeneous hardware for realising various simulator functionalities. A high speed deterministic datalink interconnects all the sub systems of the simulator. In order to meet the aircraft LRU Data requirements, datalinks such a MIL 1553B and RS422 have also been incorporated. A combination of commercial operating system and Commercial off-the-shelf (COTS) based software tools have been used for the simulator application development. A COTS based data acquisition system (DAQ) has been developed to meet the I/O requirements of the cockpit signals. The Flight dynamics model incorporating the aircraft dataset for aerodynamics, mass, center of gravity and moment of inertia properties, engine, control system, the environment and atmosphere has been configured using a computing system with commercial OS and real-time patch for deterministic behaviour. The scheduler meets the aircraft update requirement and includes safety handlers. An instructor operator station (IOS) for monitoring and operational control of the Simulator has also been developed. In addition to above functions, the IOS is also used for post flight debriefing and analysing the performance of the trainee pilot. The system architecture of the FMS is presented in Fig. 1.

Cueing systems including a dome based visual projection system providing wide field-of-view (FOV) visual scenery to the trainee pilot, aural cue generation system for providing

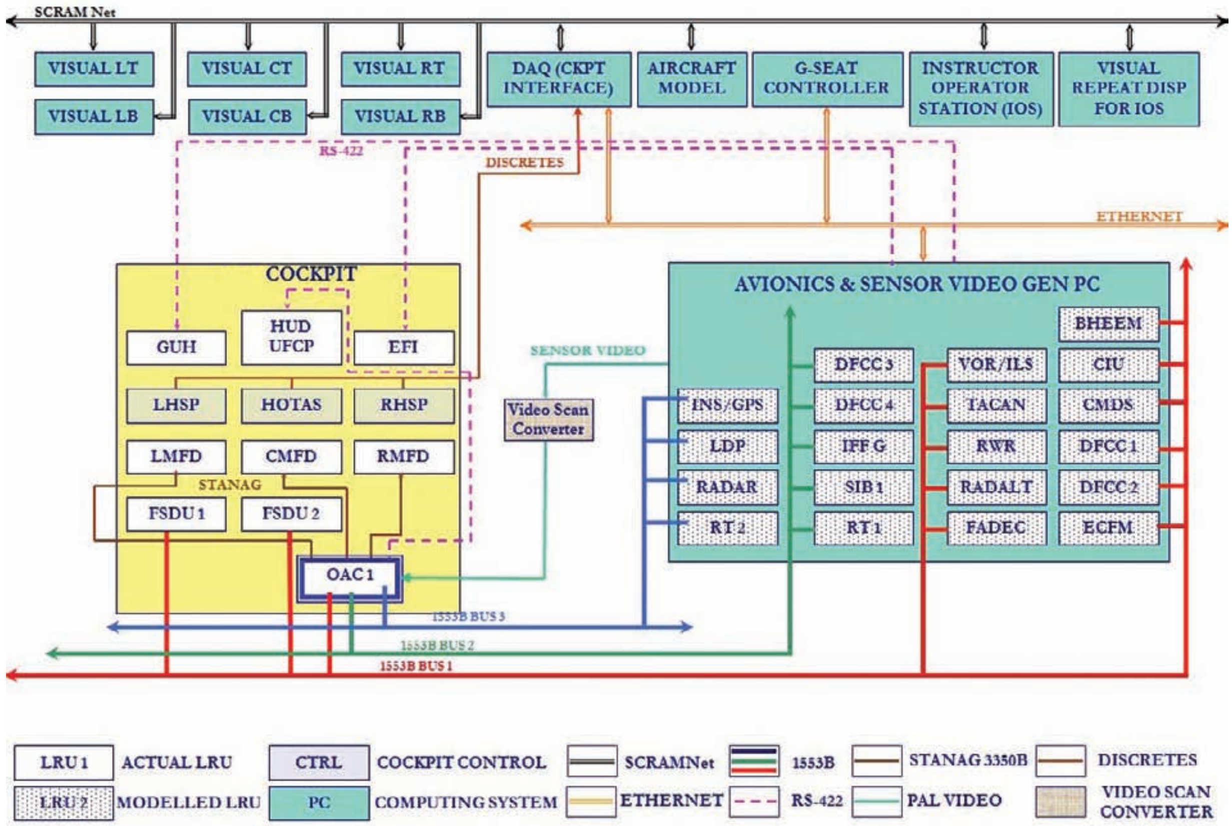

Figure 1. FMS architecture.

the sound environment experienced inside the cockpit, and G Seat cueing to provide limited motion cue is configured using a mockup of the actual seat used in the fighter aircraft. A extremely high level of equipment fidelity is provided by using actual aircraft instruments and displays in the simulator cockpit.

2.2 System Details

2.2.1 Host System (Flight Dynamics System)

The host system incorporates the aircraft dataset (Wind tunnel/Computational). The database has been updated over a period of time with the flight data for improving the fidelity. The quadruplex flight control system (digital) is the heart of the system along with the propulsion, ground handling, the atmosphere and the environment. The close integration of vast repository of aircraft data with the aircraft dynamic equations and appropriately chosen mathematical routines for estimation ensures very close match between the aircraft and the simulator performance, thereby providing a trustworthy replication of aircraft performance for the trainee pilots. A COTS OS running on PC hardware with real time patches and tight scheduling ensures deterministic performance as per aircraft dynamics. The 6-dof flight dynamics model is verified by comparing the simulated aircraft responses between ADE-FMS and NAL Simulation model with multiple test cases. A typical test case with the comparison of responses is presented in Fig. 2. In addition, the FDS generates the data required for driving the cueing systems.

2.2.2 Cockpit

A cockpit as per aircraft standard populated with actual aircraft fitments, instrument panels & LRUs is provided as part of the simulator and presented to pilot to have the same look and feel of the aircraft. Fig. 3 gives the layout of the simulator aircraft cockpit with maximum equipment cues by using actual instruments and display surfaces. The cockpit instrument panels are driven by actual aircraft mission computer in the

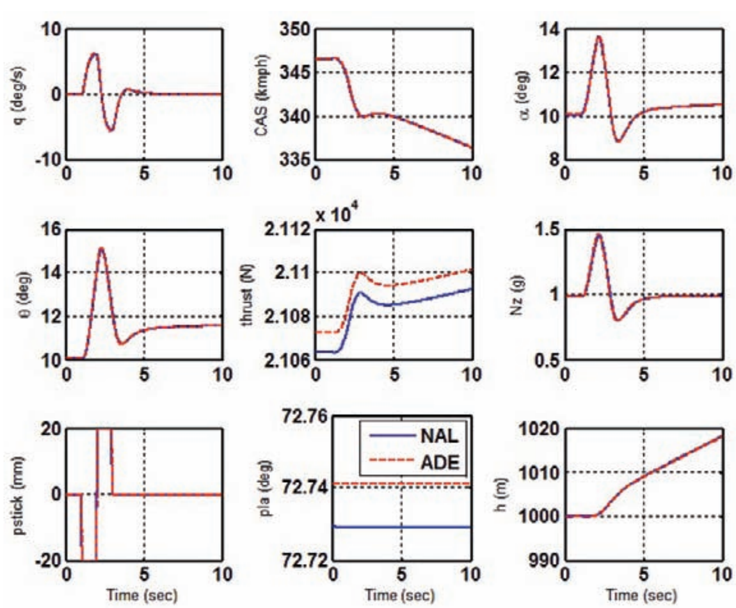

Figure 2. Typical cross-verification plot between ADE-FMS and NAL models.

Figure 3. Fighter aircraft cockpit layout in the FMS.

loop, which communicates with other simulated aircraft system models over MIL 1553B and RS422 interfaces.

2.2.3 Data Acquisition System and Datalinks

The objective of the data acquisition system in a flight simulator is to provide the interface between the simulation engine which runs in a computer and the instruments, controls and displays in the simulator aircraft cockpit[4]. A COTS industrial hardware system with cost effective DAQ peripherals is used for configuring the DAQ system to meet the cockpit signal interface. The cockpit signal consists of the analog voltages from the pilot controls and the discrete inputs from the cockpit switches. The indications and warnings are facilitated by the analog and discrete outputs. Device driver and application software is developed using COTS software. In addition a high speed deterministic datalink is configured using COTS system. As required in the aircraft for communication between aircraft systems, the Mil Std 1553B, RS422 interfaces have also developed and integrated in the simulator using COTS peripherals.

2.2.4 Cueing System

Cueing systems provide the real world environment feel through the sensory organs of the human beings. The cueing system in general consists of the following viz. Visual system, aural system, motion system, force feel system. All of these have been incorporated in the simulator developed at ADE.

2.2.4.1 Visual System

One of the important sub systems of the Simulator is the Visual System that provides out-the-window (OTW) visual scenery to the simulator pilot. The system can provide vivid 3D scenes and effective flight information including realistic flight environment and flight attitude. Flight equipment operations can be quickly, safely and skillfully mastered by using the system[5]. The simulator aircraft cockpit is housed inside a large diameter FRP dome. The inner surface of the dome is used as the projection screen for projecting the visual scenery to provide the immersion level required. A wide FOV scenery is provided using a projection system which is configured using multiple projectors. The projection system renders the seamless, edge blended scenery to the simulator pilot. COTS Image Generators using high performance computing systems with graphics processing units (GPUs) are used for generating the visual database for the gaming area around the airfield of interest. The gaming area of the visual scene is created using a combination of satellite imagery of various resolutions; digital elevation models (DEMs), vector data and synthetic graphical entities. The imagery is rendered in real time at sustained update rate to provide jitter free imagery during the flight sortie. An optimal visual scene rendering of the area is incorporated by using suitable high end GPU technologies and concepts of large area database management and paging in software.

2.2.4.2 Aural Cueing System

In order to provide the aural environment as in the actual aircraft during flight, an aural cueing system is incorporated. The recording of sound in the actual aircraft cockpit from taxiing to engine run to take off is used for generating the audio stream. The audio file is rendered in real time as function of the engine power and in addition the discrete event based sounds like under carriage thud, tyre screech are also part of the audio cueing system.

2.2.4.3 Motion Cueing System

Simulators create a realistic flight feeling using motion information feedback and to get closer to real flight feeling, a robust motion cueing algorithm is required[6]. In order to provide motion cue to the simulator pilot, a mockup seat that is a replica of the actual aircraft seat is used. This seat is integrated with actuators that are controlled by the G levels of the aircraft during the flight. Within the permissible limit, the motion cue simulates the G cueing to the simulator pilot. In addition to the G seat, a G-suit system is also incorporated in the simulator. This can inflate/deflate the pilot's actual anti-g suit when it is used in the simulator for providing onset g-cues as in the aircraft. Fig. 4 gives the details of various aspects of the motion cueing incorporated as part of the FMS.

2.2.5 Instructor Operator Station

A COTS based IOS with multiple displays is used for monitoring and controlling the operation of the simulator. The Instructor would be able to configure the training session conduct and evaluate the training. The provision for taking over the control order to demonstrate certain manoeuvers or to fly from the IOS is also part of the system developed. The simulation sortie data is recorded with time stamping and a replay system for the trainee to understand and correct if required are also incorporated. In addition the IOS has a graphical user interface (GUI) based malfunction injection system and the effect of the failure and action taken by the

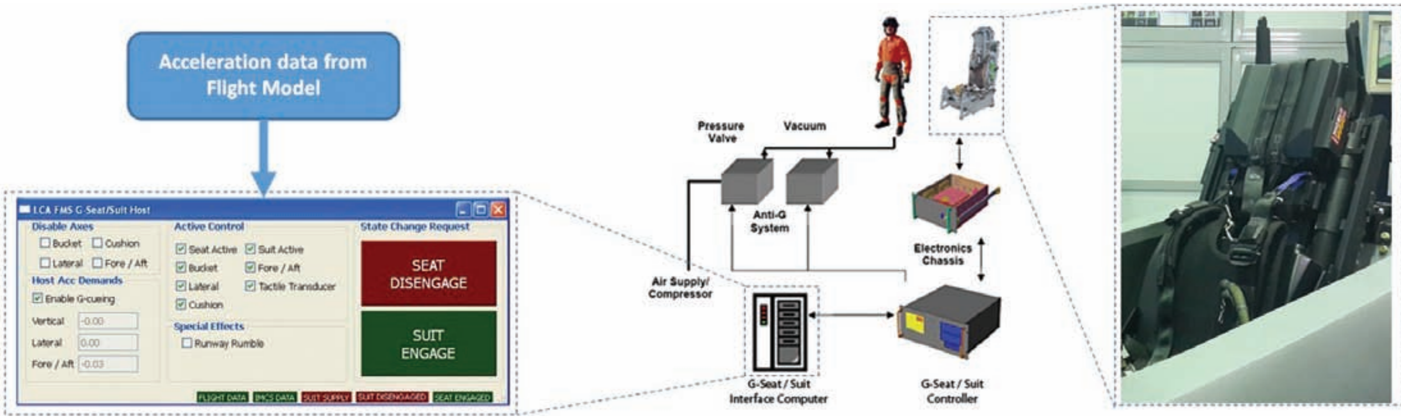

Figure 4. G seat/suit system.

trainee is recorded. The emergency handling procedures and preparedness of the trainee in case of such eventuality happening in air is also monitored in the IOS. The IOS can be expanded to include the tactical control station for carrying out preplanned mission scenarios which mimic the actual combat scenarios for attack, weapon deployment training, etc. involving multiple friendly and enemy entities in the scenario. The layout of the IOS and few sample IOS pages are as shown in Figs. 5 and 6, respectively.

Figure 5. IOS layout.

2.2.6 *Systems Simulation*

One of the most important elements of the training is the aircraft systems simulation and their effective training to the pilots. The systems on the aircraft consist of electrical, hydraulic, engine, fuel, brake management etc. The systems simulation could be indicative or functional depending on the level of availability of systems details. The full-fledged simulation model would enable effective training and high level of preparedness of the pilots to handle faults and emergencies during the mission. A combination of the above has been implemented as part of the simulator.

Another important element of the mission training is the sensors and weapon simulation. A framework has been established for bringing in their models, physical behavior to the extent of data availability etc. that could be implemented and used for crew training. Photo shots of some of the views as seen by the pilot during various phases of the flight mission are as shown in Fig. 7.

2.2.7 *Air to Air Refueling*

Modern aircraft needs to be airborne for extended time to carry out the intended mission effectively. This calls for replenishment of the fuel in mid air by a tanker from a

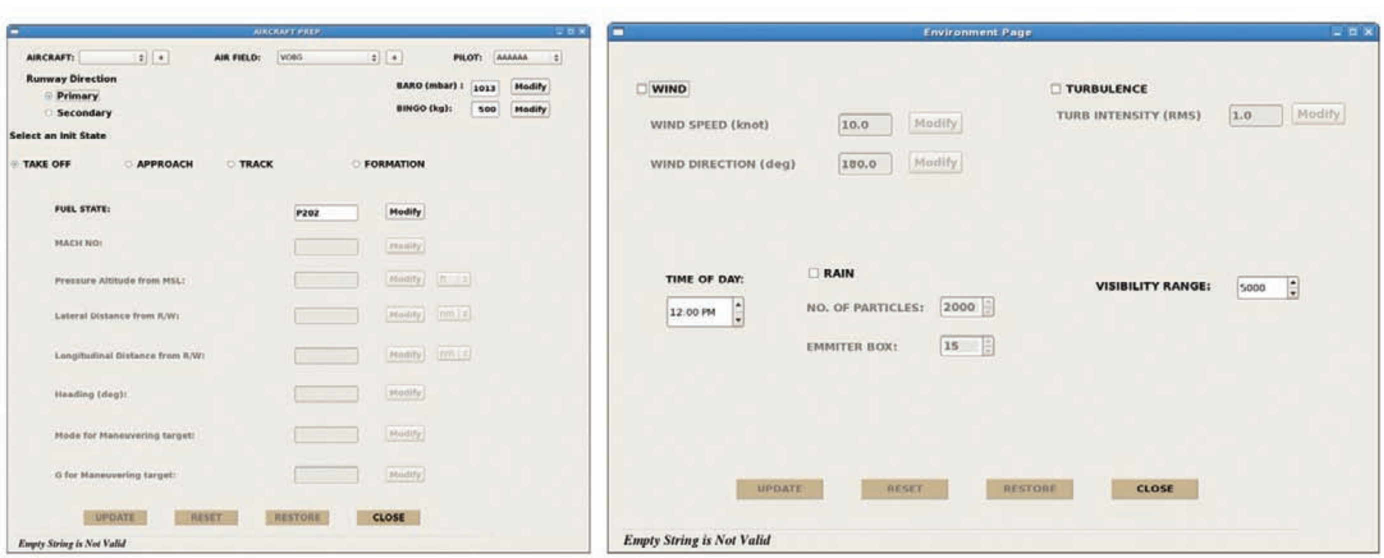

Figure 6. IOS sample pages.

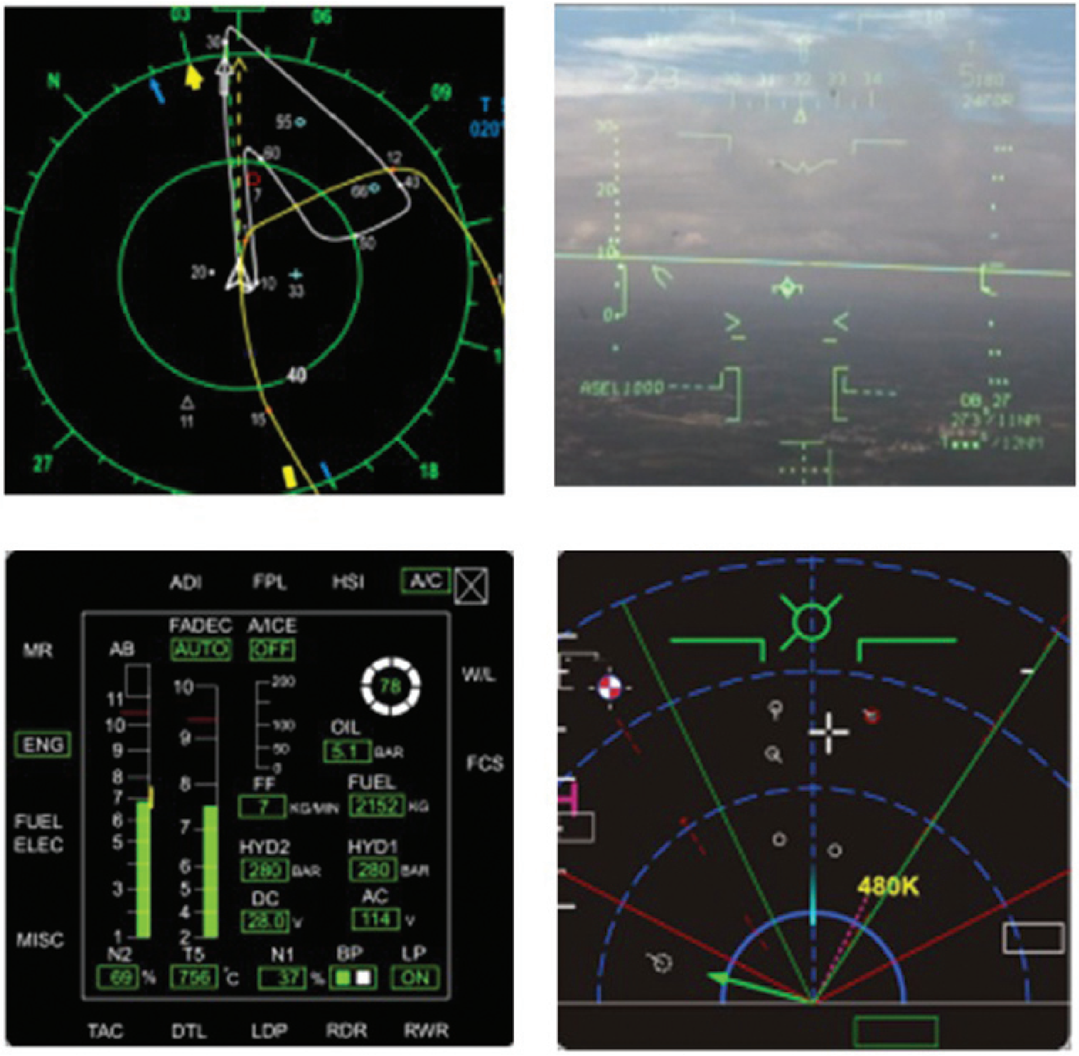

Figure 7. Multi-function display (MFD) and Head-up display (HUD) views (systems simulation).

tanker aircraft with a mechanism of drogue and probe. This training is also important and needs to be practiced by the pilots on ground using the simulator before it is attempted in air. The standard of preparation of the air to air refueling (AAR) system and the procedure to be followed for carrying out the activity can be finalised on the simulator for their thorough evaluation before it is activated on the aircraft.

2.2.8 Other System Features

The simulator could be configured for both training and evaluation by a simple re-configuration and hence serve the dual purpose of design and training support on a time sharing basis.

With COTS in place, technology obsolescence has been effectively managed by periodic upgrade of the hardware and software patches for making the application compatible with new environment.

A built in test (BIT) feature for all the systems of the simulators is used to look at the health of the subsystems before the system is offered to the pilots for training. An exhaustive data logging of all the systems ensures faster debugging and quick identification of the fault and rectification.

3. CONCLUSIONS

Simulators developed by ADE have been used extensively by the Indian Air Force. Starting from development of fighter aircraft, pilot selection and in-depth training and recently leading up to measurement of mental workload for better utilisation of pilots, simulators developed by ADE have played a key role for the Indian Air Force.

A Full Mission Simulator for ab-initio pilot training has been set up to meet the training needs of the fighter aircraft pilots. By the use of up-to-date technologies and COTS systems, the system is immune to technology changes and obsolescence. With architecture being open distributed, it is possible to enhance the scope of the simulator to meet the ever growing needs of the user or take up development of the simulators for other programs such as UAVs, Rotary aerial platforms. The turnaround time for any of these programs will be minimal as the re-usability with limited modifications to the systems already developed is very much feasible. It is possible to shrink the development time of these systems to meet the ever growing needs of shrinking the timelines.

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In the present paper, he has contributed for literature study, the overall system architecture of full mission simulator, identification of sub-systems and their design & development methodologies.

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In the present paper, he has contributed for literature survey, various data links used in the simulators and data acquisition systems used in the simulators.

Mr Yashpal Bhatia, Scientist 'E' is presently working in the development of Flight Model for various aircraft, its integration and testing with various subsystems of the simulators, at Flight Simulation Division, ADE.
In the present paper, he has contributed towards the areas of flight dynamics simulation and integration with actual & simulated aircraft systems.

Mr G. Magesh, Scientist 'E' is presently working in the design and development of Flight Simulators, specifically flight dynamics simulation and aircraft systems simulation and overall integration and testing of simulator sub-systems at Flight Simulation Division, ADE.
In the present paper, he has contributed towards literature survey, development of Instructor Operator Station, simulation of aircraft systems, generation of motion and aural cues for flight simulator.

Mr Bineshkumar K., Scientist 'E' is working in the areas of visual and sensor scenes simulation & simulation of aircraft avionics sub-systems for various Flight Simulator projects at Flight Simulation, ADE.
In the present paper, he has contributed towards literature survey, generation of realistic visual cues, COTS based Image Generators and simulation of EW systems and ranging sensors on the aircraft, as part of the simulator.

Mr Hemanth Kumar V., Scientist 'E' is working in the field of Design and Development of Mechanical sub-systems of various Flight Simulator Projects at Flight Simulation Division, ADE.
In the present paper, he has contributed towards development of high fidelity cockpit environment and integration of pilot controls, cockpit switch panels and pilot seat in the simulator.