# Virtual & Augmented Reality applications in Aeronautical Engineering

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## Abstract

1. This review examined the empirical studies and research papers published on the use of Virtual Reality (VR) / Augmented Reality (AR) techniques in Aeronautical Engineering applications. Qualitative content analysis was employed to investigate as to how exactly the science and methods of Virtual Reality (VR) were used in the advance aircraft manufacturing techniques, maintenance and overhaul procedures, quality control and reliability enhancement by VR integrated aircraft inspection process, Pilot training etc. Results of the review demonstrated that the augmented reality platform and a range of digital technologies, applications, and computational VR -based learning environments have been used to increase productivity and quality while cutting costs in the digital era. The use of VR / AR technology has motivated research engagement and participation in newer areas of aeronautics e.g. flight testing and evaluation of modification proposals in a virtual environment. Sufficient studies and analytical work has been undertaken by various researchers in order to enhance the pervasive e-education concept with augmented reality content for e-training to train pilots and aircraft technicians. Virtual training systems and e maintenance of aircraft and its sub systems is being undertaken using high-quality low-cost devices including Mobile Augmented Reality (MAR) applications on smart phones. Although, the Virtual training can be used in many different fields including aviation, dedicated industrial support is needed to ensure availability of VR enabled computational hardware and appropriate applications to make use in specific areas of Aeronautical Engineering. The review has identified research gap for establishing a full fledged Virtual Flight Test Bed and also the ongoing current research by the Original Equipment Manufacturers of various Aeronautical Engineering hardware in a collaborative manner with a massive budget of 750000 USD. In this work, Clear Science Corp. and Princeton University in the USA are developing appropriate VR and aeronautical computational software to accurately and efficiently simulate full set of physics associated with aircraft flight operations including flight control, propulsion system, separating stores and cargo, landing gear, aerodynamics, structural dynamics, aero-elasticity, aero-acoustics, and aerothermodynamics. The review also brings out the requirement of newer research areas of Virtual Flight testing wherein VR technology can be used to test aircraft modification proposals or integration aspects of newer equipments (eg replacing an imported sub system with an indigenous substitute) onboard an aircraft and measure their performance parameter without damaging the actual aircraft.

**Keywords**: Virtual Reality (VR), Augmented Reality (AR), e-learning, Flight Test Bed (FTB)

## Introduction

2. Virtual Reality is a computer-generated, mock environment that can allow users to interact with it in a seemingly real way by using certain types of specialized equipment. It empowers to explore the real world in a computed environment on a user friendly virtual platform. Augmented Reality on the other hand is a combination of the real world scenario with virtual items projected along with the real world also being visible. Although the design of hardware required for VR and AR is similar but the VR shows the reality in a virtual manner where as the AR projects additional information on top of the reality. The literature review exercise was undertaken to understand the current technological state of both the Virtual and Augmented Reality with specific reference to their utilization in Aeronautical Engineering applications.

## VR/AR Applications in Aeronautical Engg

### Design, Development & Manufacturing

3. **Virtual Environment**. The research work of Augster as part of his PhD thesis marks the beginning of utilizing virtual environment for design and manufacturing [1]. Subsequent to this, detailed chapter on the subject highlighting the intricacies of creating a virtual environment for aircraft has been published by the National Academies Press [2]. Shamus P. Smith and Michael D. Harrison [3] have researched on the current limitations of virtual environment in order to enhance user satisfaction. Their rearch concludes for adapting user centric approach in view of the integrated context of the virtual environments for aeronautical engineering applications.

4. **Aircraft Design**. Feasibility work on using virtual reality for design of asemblability and designing of virtual assembly environment has been undertaken by Sankar Jayaram, et al [4], [5]. The virtual environment aids the mechanical engineering design process for assembly, design for maintainability and assembly planning. Useful research on Creation of concept shape designs via a virtual reality interface has been aptly described by Tushar H Dani and Rajit Gadh [6]. At reference [7], Jesipers work in the form of post doctoral dissertation on the human computer interaction design is a landmark research for both the virtual and augmented reality applications. Another relevant paper published is Prototyping and Design for Assembly analysis using Multimodal virtual Environments by Rakesh Gupta, Daniel Whitneyt and David Zeltzert [8]. X. Wang, S.K. Ong and A.Y.C. Nee in their research paper present a novel assembly simulation system incorporating real-virtual components interaction in an augmented-reality based environment [9] . Another useful piece of research for this project is the study on virtual manipulation technology in virtual reality systems undertaken by Xiaoyong Lei, Shuling Dai, Jihong Mei and Jin Zhang [10]. In the conference CIRPe 2015, Adelaide Marzano et al have presented a paper describing a unique environment whose features are able to satisfy requirements for both virtual maintenance and virtual manufacturing through the conception of original virtual reality (VR) architecture [11].

5. **Virtual Reality based Design Review.** Thalen and Vandervoot [12] have aptly highlighted the positive role of virtual reality to facilitate user involvement in product design and development threreby improving compliance with System design specifications and requirements. The application context describes technical implementation of an interactive walk through model of aircraft galley for re design with user involvement.

6. **Flight Simulation As An Aid To Advanced Project Design.** The Aero Engineering department at the University of New South Wales has an annual project design task of up to six aircraft [13] as part of academic delivery for their UG program in Aerospace Engg. The design process has now been supplemented by the university with flight simulator using the simulation software 'X-PLANE', wherein the flight characteristics are analysed in parallel to the design process. As per the published research, the integration of flight simulation has improved the advanced project design and enhanced efficiency of the design process. In a similar attempt, the research work of Arkadiy Turevskiy, Stacey Gage, and Craig Buhr [14] uses a combination of free and commercial off-the-shelf (COTS) modeling and flight simulation application to simplify and fast track the aircraft design process. Using an example The paper demonstrates optimization of vehicle's geometry of a new light-weight aircraft by calculating the stability and control derivatives, design flight controller and run a closed-loop simulation, all in a rapid iterative manner to meet system level requirements.

7. **Flight Test Engineering (FTE)** Design related research and development work on an aircraft gets accepted only thru flight testing. The flight test engineering therefore forms an important element of the Research & Development cycle of an aerial platform. The FTE facilities are also utilized as flying laboratories for evaluating aircraft performance, stability & control characteristics of the test aircraft. However, for obvious reasons including costs associated with initial investment, and continued operations, most of the aerospace engineering professionals are not exposed to hands-on experiences resulting from a course in FTE. A 'virtual' flight test can complement the learning of various aspects of aircraft performance, and stability & control. Planning, managing, executing and analysing data from such a virtual flight test mission provides additional opportunities to groom engineering students in these important skills. David W Bubka et al [15] have used simulation based environment for flight testing of Cessna 172 SP aircraft. The tests were conducted on two independently simulated environment using Laminar Research X plane application and also the Microsoft's Flight Simulator X (FSX). The results of three crucial flight tests i.e. Stalls, Steady turns and flight path stability are compared with the actual flight test data obtained by flying Cessna 172 SP over the San Luis Obispo County area.

8. **AR based Manufacturing**. The applications of Augmented Reality have also focused on aerospace manufacturing processes e.g. Lean Manufacturing. In the research article at reference 16, the researcher investigates the innovative aspects of integrating Augmented Reality (AR) - in the manufacturing industry. For that purpose, this research paper contributes by analyzing and synthesizing articles and case studies to identify the current and the potential future role of Augmented Reality in the manufacturing industry and its impact on different work processes. The research shows that theoretical proof of concepts articles mostly

focus on improving production operations, especially assembly processes, while majority of practical use cases of currently applied AR solutions involve maintenance and inspection processes.

9. **Assembly of Nano Satellites**. Dr Cecil of New Maxico University has extensively utilised Virtual Environment to support process design activities for developing nano satellite. His work [17] is a testimony to effective utilization of VR technology and has enabled active participation of the process engineers (responsible for assembly and integration of the satellites) during design process leading to early identification of potential problems crucial to the assembly of nano satellites.

**Academic Delivery**

10. **Complex Undergraduate courses on Aero Engineering** Lack of motivation for engineering courses in general and Aeronautical engineering in particular has been attributable to the conventional teaching methods as researched by various researcher in the United States of America [18-20]. It is in view of this undermining of Aero Engg education that an innovative approach to teaching fundamental concepts in Aircraft Dynamics and Control (ADC) was supported by NASA's E.2 Innovation in Aeronautics Instruction conducted at Arizona State University [21]. In most universities, such complex subjects are offered at undergraduate level (UG) following a basic course in aerodynamics. Although various simulation software such as Matlab, Ansys etc do help in solving complex problems, but the inability to visualize complicated, multimodal aircraft motions results in shallow understanding with lack of proper appreciation of Aero engineering subjects. Virtual Reality integrated Flight Simulation/Visualization software is being used mainly for Pilot's training [22]. Some aviation schools do utilize this technology for teaching advanced concepts of Aero Engg like control system design [23-26]. For the basic courses on Aero Engg, one example of an innovative pedagogical approach is the virtual immersion of the students in a "flying classroom" more elaborately described in the research work by Tomczyk [27]. This however involves utilisation of an actual aircraft and is therefore not cost effective. Several Aero Engg institutions in the advanced world, especially aviation schools are now using the VR based flight training devices [28], but again, the where with all tends to be expensive and not affordable by majority of the educational institutes.

11. **Cognitive learning benefits of AR** In the words of R. Brian Valimont [29], the synthesis of computer images and text in the real world provided by the AR technology affords a supplement to normal information acquisition that has yet to be fully explored and exploited. AR achieves a smoother and more seamless interface by complementing human cognitive networks, and aiding information integration through multi- modal sensory elaboration (visual, verbal, pro prospective, and tactile memory) while the user is performing real world tasks. AR also incorporates visuo-spatial ability, which involves the representations of spatial information in memory. The use of this type of information is an extremely powerful form of elaboration. This study examined four learning paradigms: print (printed material) mode, observe (video tape) mode, interact (text annotations activated by mouse interaction) mode, and select (AR) mode. The results of the experiment indicated that the select (AR) mode resulted in better learning and recall when compared to the other three conventional learning modes.

12. **Integrated Design, Build & Fly approach for Aero Engg Curriculum.** Effective conduct of Aeronautical Engineering curriculum both at UG and PG level is a challenging task considering the complexity involved and non availability of expensive lab equipment with majority of the academic institutions of higher learning. Several research papers are available in the open domain highlighting this difficulty and recommending innovative solutions towards an Integrated Design, Build & Fly approach. The presentation of Peter W Young et al during ASEE conference [30] and Elger et al during the 30th annual conference of The Frontiers in Education [31] focus on using the Integrated Design, Build & Fly approach. Similarly the research papers at reference [32] and [33] advocate integration of the design and laboratory work during the prestigious Flight Test Engineering course. A live example of this is Sophomore students at the Massachusetts Institute of Technology's Department of Aeronautics and Astronautics who work in small teams to design, build, and fly small radio-controlled electric propulsion aircraft as part of their 2nd term (spring) semester during Aero Engineering curriculum

**Flight Simulation**

13. **VR flight simulator**. The flight simulation usually need more space, more budgets, and high fidelity hardware so that the simulator can be operated as similar as possible to a real aircraft. The VR flight simulator is intended to act as the conventional flight simulator that simulates the environment of real flight. In addition, it can be used anywhere and anytime. The paper at reference [34] presents the flight simulation, and programming process of virtual reality flight simulator. Flight simulator using virtual reality is able to provide strong sensations like being in a plane cockpit.

14. **UAV Test Bed.** Reference [35] describes the efforts undertaken at the School of Aerospace Engineering at the Georgia Institute of Technology for the development of a low-cost Unmanned Aerial Vehicle (UAV) test-bed for educational purposes. The objective of this test-bed is to provide an avenue for the involvement of undergraduate students (primarily) and graduate students (secondarily) in UAV research. The complete design and development of all hardware interfaces of the UAV platform including the on-board autopilot is presented. Based on flight test data, a linear model has been developed for the lateral and longitudinal dynamics.

15. **Software Simulation of an Auto Land System**. VR enabled software simulations are being used to certify an autoland system due to the stringent regulatory requirements. The simulated environment is integrated with the related virtual systems to emulate the performance of guidance signals, the airborne sensor, the autoland system and the physical environment. The software runs the Monte-Carlo iterations by assuming the probability of various types of failures and environmental variables. The overall performance of the system can then be verified to the required confidence level under given set of conditions. As elaborated in the research work by Bernard Devesa et. all [36], the additional advantage of evaluating aircraft system's performance by simulation is the ability to evaluate the system under extreme conditions such as wind shear or loss of guidance that would be unsafe from operational perspective.

16. **Flight Simulation Environments With Agent-oriented approach** Automation of control to move a vehicle has been the favourite research destination of many researchers. While these efforts have led to discovery of automatic transmission in the premier car segment, the aircraft at large are equipped with an autopilot system that automates the motion of the primary control surfaces of an aircraft as per requirements. The research work at reference [37] envisages an agent-oriented approach, wherein a group of aircraft are able to communicate amongst themselves, and plan their mission by taking real-time decisions based on information gathered during formation flying. The researcher envisages use of flight simulation environments that can be adapted to follow this approach.

**Virtual Flight Testing**

17. **Virtual Flight Test** The research paper [38] describes a virtual flight test approach for learning practical aspects of flight mechanics and also the stability and control characteristics of an aircraft. Several virtual flight test scenarios have been developed to understand related concepts. Details of a virtual flight test to estimate the neutral point of an aircraft are provided in the paper. The virtual environment is PC based running freeware and commercial off-the-shelf software. While the approach can be used on desktop PCs, a setup with three large out-of-window views driven by three LCD projectors and PCs is used to enhance the realism of the experience. It has been observed consistently that an environment in which students are passive participants is less conducive to learning than an environment in which students are actively engaged. The virtual flight testing in this research proves to be an Effective Pedagogical Approach.

18. **Experimental Evaluation Of Unmanned Aerial Vehicle System Software.** Large number of studies are available to build a standalone control system for an Unmanned Aerial Vehicle (UAV). As the UAV technology matured, the operational requirements called for a network-centric control system for multiple UAV systems. Enabling the design of such complex systems in easily understandable format, Hansol et all [39] have proposed an experimental evaluation of the Time-triggered Message-triggered Object (TMO) structuring scheme in the design of the UAV control system. The system was validated by use of environment simulator based on Flight Gear flying simulator.

19. **Wind Tunnel Based Virtual Flight Testing Techniques for Evaluation of Flight Control Systems (Min Huang)** The research work by Min Huang at reference [40] has proposed wind tunnel based Virtual Flight Testing (VFT) for dynamic tests and evaluation of the flight control systems (FCS) in a realistic virtual environment. It integrates the flight control system with a computational aerodynamic engine for FCS evaluation. The instant method is superior to the traditional ground evaluation procedure like Hardware-in-the-Loop Simulation (HILS). With FCS evaluated by VFT before flight test, the risk of flight test will be further reduced. In this paper, the background, progress, and prospects of VFT are systematically summarized. The research work highlights VFT evaluation of flight control systems as a solution to remove the deficiencies of traditional dynamic wind tunnel tests and other evaluation methods .

20. **Simulating Civil aircraft evacuation.** Zhi Ming Fang [41] research has virtually reproduced the passenger compartment of Airbus A 380 aircraft to study the aircraft emergency evacuation . The VR simulation was undertaken in an efficient and effective manner using the finer grid aircraft evacuation model. The simulation considers all the relevant factors including pedestrian hesitation before leaving exits. The research recommends the safest evacuation procedure based on the passengers normal preference and hesitation to exit during an emergency.

21. **UAV Hardware in loop test bed** Reference [42] gives an account of a student project of Dept of Aerospace Engineering at the IOWA state university using hardware-in-the-loop simulation (HILS) for certification of onboard flight computer system of an aircraft. The primary focus of this research includes dynamic analysis of UAV and the development of HILS. The research gives a methodology for analysing UAV dynamics using MATLAB/Simulink simulation and mounting the flight computer on the embedded system. The flight computer gathers the virtual sensor data and delivers the control output to the simulation. The simulation updates dynamics status of UAV based on the received control input and displays with graphic user interface (GUI) that exploits external stick commands and 3-D visualization. The project envisages use of virtual flight test data to compute flight stability and control derivatives.

**Flight Safety, Operations and maintenance**

22. **Aerospace Safety and Inspection.** Research in activities involved in inspection and safety has revealed the importance of empowering the inspectors with VR tools. The research concludes that we need to provide aircraft inspectors with tools to help enhance their inspection skills and improve performance. In response to this need, a Virtual Reality (VR) based simulator was developed for visual inspection task of an aft cargo bay. Presence and performance validation studies were conducted to evaluate the simulator and are described as part of this paper [43]. The main benefit is, that the end users are enabled to better perceive complex, technical facts, systems and components thereby improving the quality and reliability of aircraft inspection performance. Introduction of VR hardware also resolves the inspection issues arising out of individual and group differences aptly researched by Weiner E [44].

23. **Pilot Vision Analysis**. Ergonomic evaluation of pilot vision becomes crucial under extreme time constraint experienced during flying operation of a high speed combat aircraft. Sougata karmakar et all [45] have undertaken ergonomic evaluation of pilot's vision in a jet aircraft in virtual environment utilizing the vision analysis tools of digital human modeling software. The research generates a total of three dynamic digital pilot models, representative of smallest, average and largest Indian pilot population from anthropometric database and interfaced with digital prototype of the cockpit in Jack software for analysis of vision within and outside the cockpit. The vision analysis tool was also used for studying kinematic changes of pilot's body joints during simulated gazing activity. From present study, it can be concluded that vision analysis tool of digital human modeling software was found very effective for virtual evaluation of the cockpit environment for developing a physical prototype.

24. **Control of Tactical UAVs** Research work at [46] highlights inadequacies in the control of tactical UAVs in a rapidly changing uncertain environment. The essence of research lies in autonomous control of in-flight re planning under uncertainty which has been cast as a large optimization or decision problem. The research analyses both the Monolithic and decomposition techniques for solution of large decision problems and finds that the Hierarchical decomposition to be the most promising approach but suffers from an inadequate theoretical basis. Finally, VR based research areas are proposed to address the decomposition problem.

25. **Aircraft Maintenance.** Haritos and Macchiarella [47] have presented a mobile application for the aircraft maintenance training. The work highlights examples from ultralight / light sport aircraft maintenance and show how to apply this technology generically. Execution aspects of variety of aircraft maintenance activities and test procedures get simplified in the hands of aircraft technicians by the introduction of VR technology. This provides a useful app in the mobile with ready to use maintenance manual, elaborate checklist for various snags and virtual description of snag rectification and servicing procedures. Based on the VR / AR interfaces for e training, Johannes Christian [48] describes a realistic example of aircraft maintenance training application for light aircraft maintenance schedule.

26. **Virtual Maintenance** Kouroush Jenab [49] uses Virtual Maintenance as a branch of virtual reality to train aeronautical engineers for a certain task. These tasks could include repair, overhaul and servicing to maintain certain equipment. In this paper, the fields of Virtual Maintenance largely includes aviation (including military training), military (combat and training), and civil (medical and gaming). In aviation it has multiple uses, from training of pilots all the way to the maintenance personnel who take care and build the aircraft. In the words of the researchers, simulators prepare pilots to learn how to fly and execute emergency procedures without even stepping foot inside an actual aircraft. At the same time, maintenance personnel can study and learn how systems function and how to perform maintenance task to reduce the risk of damage to parts and the aircraft.

**VR / AR Peripherals.**

27. **Display of Flight parameters on AR Goggles**. As per the research work of Leonardo Macena Silveira [50], the Augmented Reality has been used for many years to assist pilots, primarily for military purposes. His research work used the Epson Moverio BT-300 glasses, with sample code based on an open source code called GPS Raw. The code was developed to display two essential parameters for the user: altitude and ground speed. The goal was to verify the information gathered from the glasses is the same or similar to the data collected from the aircraft instruments.

28. **HUD versus Head Worn Displays**. In the research paper of Randall E. Bailey [51], Head-Worn Displays for NextGen, Flight deck display and decision support technologies are analysed to overcome aircraft safety barriers. One such technology is the very lightweight, unobtrusive head-worn display (HWD). HWDs with an integrated head-tracking system are being researched as they offer significant potential benefit under emerging operational concepts. Two areas of benefit are defined. First, the HWD may be

designed to be equivalent to the Head-Up Display (HUD) using Virtual HUD concepts. Second, the HWD provides unique display capabilities, such as an unlimited field-of-regard. The paper details recent research results, current HWD technology limitations, and future technology development needed to realize HWDs as an enabling technology for NextGen.

29. **HUD versus AR system for pilots**. As per Andrey L. Gorbunov [52], the Head-up displays (HUDs) have become common equipment in aircraft cockpits. One of the uses of HUDs is to provide a specific visual interface for pilots in the form of what is called a "tunnel-in-the-sky" (i.e. 3D geometry for the navigation path displayed on a flat screen). According to recent studies the subject approach does not provide crucial advantages in comparison with more traditional methods of presenting navigation information to pilots. This research considers a stereoscopic version of the 3D "tunnel-in-the-sky" realized as an augmented reality (AR) pocket-size system with see-through light-weight AR glasses. The results of the experiments with desktop simulators of different AR pilot's interfaces (2D, 3D and stereo 3D conditions) have been analysed with a conclusion of better effectiveness of the proposed stereo AR solution. The researcher has also undertaken flight test of the prototype of the developed AR system on Cessna 172 aircraft to prove the hypothesis.

**Research Gap**

30. In order to meet future technical and economic challenges in aeronautical engineering, it is essential to simulate a real aircraft with all multidisciplinary interactions covering the entire flight envelope, and to have the ability to provide data with guaranteed accuracy required for development and certification. However, despite the significant research work in various facets of Aero Engg as outlined above, there exist research gaps in the development of numerical methods, physical modeling and the integration of flight computational models for multidisciplinary analysis in the VR / AR technology integrated environment.

**Ongoing VR based collaborative Research Project by world majors**

31. Clear Science Corp. and Princeton University in the USA are developing and demonstrating application software suite to accurately and efficiently simulate the full set of physics associated with aircraft flight operations including flight control, propulsion systems, separating stores and cargo, landing gear, aerodynamics, structural dynamics, aeroelasticity, aero-acoustics, and aerothermodynamics. With a massive budget of 750000 USD, the funding for this project is being shared by Air Force Research Laboratory (AFRL), Air Vehicles Directorate (Wright-Patterson Air Force Base (AFB)) , AFRL Munitions Directorate (Eglin AFB) , 412th Test Wing (Edwards AFB) , Lockheed-Martin, Raytheon, Sikorsky Aircraft and Air Force Seek Eagle Office (***AFSEO***) , High Performance Computing Modernization Program (HPCMP) held in. Williamsburg in the USA. In this research work, Computationally efficient reduced-order models constructed from relatively small sets of high-fidelity computational fluid dynamics (CFD) data enable accurate, real-time flight simulations for the design of guidance, navigation, and control systems, pilot training, simulated flight testing to reduce risks to test pilots and aircraft, and the development of advanced control systems.

**Conclusion**

32. From the above case studies and analysis, it can be stated that the Virtual and Augmented Reality technologies have played a vital role in the advancement and growth of Aeronautic sector with specific reference to following major research areas:

- Research and development work to explore newer areas and technologies for aircraft design.
- Virtual flying platform for training ab initio pilots and also continuity training of line pilots. This forms the most cost effective option being fuel efficient and also saves the engine and aircraft run time.
- Academic Delivery for Aero Engg students to understand complexities of aircraft dynamics and its systems.
- Virtual flight test beds can reduce the in-flight operational needs, saves time and effort of flight test crew and maintenance technicians.
- Real time cockpit and engine analysis.
- Increase productivity and quality while cutting costs in the digital era.
- Aerospace Safety and training.
- Aircraft maintenance training and practice.

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