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## A Mobile Solution to Enhance Training and Execution of Troubleshooting Techniques of the Engine Air Bleed System on Boeing 737

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### Abstract

The process of troubleshooting an aircraft engine requires highly skilled and trained personnel who must be able to respond effectively to any circumstance; therefore, new methods of training to accelerate the cognitive processes of technicians must be integrated in the industry. In this matter the Augmented Reality technology represents an innovative tool that can ensure the efficient and correct transfer of knowledge. The numbers of errors during maintenance tasks can be reduced, AR provides information that is generally not easily available during maintenance operations because, in general, the troubleshooting process for airplane engine is a highly complex task and the diagnosis of a failure is critical for the passengers' safety. This research focuses on training and execution of tasks where an aviation technician must be familiarized with a wide variety of technical data, physical components of mechanical systems and the regulations that must be followed to release an airplane for flight, the specialist must develop a correct mind map of the system and should be able to troubleshoot if necessary. The case of study is the 737 Engine Bleed Air System that is designed to provide engine compressed air to air conditioning pack with the purpose of air pressurization during flight; engine air from the compressor is used, from the 5° and the 9° stage in a safe and economical way, knowledge of the correct function of the components will increase safety and considerably reduce cost of maintenance operations. The purpose of the investigation was to develop an ergonomic tool that improves the cognitive process of technician during training for the troubleshooting techniques of the aircraft, but it also can be used to the everyday task by capturing the know-how and helpful tips from more experienced operators. A mobile solution that functions on regular tablets was delivered to enhance the troubleshooting techniques and maintenance procedures of the Engine Air Bleed System, the software can function on two aspects for training and in situ operations. A commercial aeronautical training kit was used to validate the Fault Isolation Software; the results showed that the augmented reality technique takes 17% less time and a quality increment of 24% for this complex assembly system.

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## 1. Introduction

The market for the maintenance, repair and overhauling (MRO) in aviation is very interesting from an economical perspective. According to the Aeronautical Repair Station Association [1] the civil aviation MRO market generated \$80B in economic activity in 2009, out of which \$39B were provided by USA. The opportunity for improvements in this market is latent to lower the actual costs of the MRO, this means that better service to customer can be offered along with excellent quality. On the other hand advances in technology and in commercial devices permit us to enhance visual field through the interaction of virtual animations or content within the real world. These devices also allow touch sensing capabilities as a way of interaction with software, the Augmented Reality (AR) technology allows the study of new possibilities for innovations in an wide range of applications, just as many as our own imagination limits. For the purpose of this work, AR along with mobile devices are tools considered for maintenance procedures and troubleshooting applications in the aeronautical industry.

When the airline needs to provide line maintenance, the operators become a main asset in the organization, since 88% of the work is performed by them and only 12% is done by outsourcing [1]. Previous knowledge of the systems and subsystems of the aircraft will impact in the efficiency of the service that is offered by the airline. In this kind of maintenance procedures, the transit, daily/weekly and “A” checks are done to ensure the security of the passengers. Every airline has developed a system to transfer the knowledge from the experienced operators to the new hired ones that must perform the checks with few contact with the physical systems of the aircraft.

Augmented Reality (AR) is a variation of Virtual Environments (VE), or Virtual Reality as it is more commonly called. VE technologies completely immerse a user inside a synthetic environment. While immersed, the user cannot see the real world around him. In contrast, AR allows the user to see the real world, with virtual objects superimposed upon or composited with the real world. Therefore, AR supplements reality, rather than completely replacing it [2]. Furthermore AR technology is particularly suited for maintenance industry, as it can be easily implemented in several processes. AR can enhance the user’s view of the surrounding scene with different content that include visual animations, sounds, written instructions or static images. Using AR can potentially reduce the numbers of errors during maintenance tasks; in fact AR provides information that is generally not easily available or whose retrieval is relatively demanding. In general many processes in manufacturing, aviation and automobile industry deal with assembly tasks. During maintenance operations, mechanics have to deal with a large amount of different parts that represents a large proportion of search time: standard manuals or handbooks can lead inexperienced operators to frustration and poor performance. This research is focused in the basic training and on the job training where the operator have to get familiar with the technical data of the manuals and the physical components of the systems, taking into account all the small details (torque of certain parts, warnings, checks, etc.) and regulations that must be followed to release the airplane, also the operator have to develop a mind map of the correct functioning of the system and he must be able to troubleshoot if necessary. In the next section the proposed model of training for this stage will be reviewed and compared to the current training model.

## 2. State of the art of Augmented Reality in mechanical assemblies and troubleshooting system

In 2009 Castellani et-al conducted an study to examine the properties of different assemblies of people, resources, technologies and spaces to inspire design for the different troubleshooting situations, they covered different dislocations between various aspects of the study in the two cases of troubleshooting self-conducted and expert-supported, the dislocations considered in the prototype were **physical** between the site of the

problem and site of problem solution, **conceptual** between the users and the expert and the **logical dislocations** between the support resources and the status of the ailing device itself, this study developed a set of integrated mechanisms and systems aimed at harmonizing the various elements and at capturing, where possible, the haecceities of the device [3]. The dislocations were covered by integrating troubleshooting software in the copy-machine and the call center of experts that could be consulted. In table 1 the principal implementations at the state of the art for troubleshooting systems that use the AR as guide when troubleshooting complex mechanical systems.

Table 1 Related work of the improvements of AR technology when compared to others in the maintenance & assembly domain

Contribution					
Author Year	Application	Modeling & Texturizing	Tablet (Android & iOS)	Communication	Gesturing interface
Mixed reality system to enhance troubleshooting and procedural task. Mail communication is allowed. Developed for tablets with Android or iOS operating system.					
Rios et al. 2012	Aeronautical BOEING 737	X	x	x	x
Mixed Reality (MR) system; It shows how remotely situated people can collaborate around physical objects which are not mutually shared, without introducing new interactional problems, such a representation can create reciprocal viewpoints. Identified physical, conceptual and logical dislocations					
-O'Neill, J et al. -Roulland et al. -Castellani et al. 2011	XEROX Copy machines. The mixed reality was for the expert far away from the machine	X		x	
Mixed Reality system that <b>can be</b> applied to interactive visualization scenarios in diverse human-assisted operations; By means of Tangible Interfaces gesturing recognition, it is possible to activate menus, browse and choose menu items or pick, move, rotate and scale 3D virtual objects					
Dias et al. 2003	Analysis of possible applications	x			x
TeleAdvisor is a novel solution designed to support remote assistance tasks in many real-world scenarios. It consists of a video camera and a small projector mounted at the end of a tele-operated robotic arm.					

Gurevich et al. 2012	Not specific (TV case) hands free, mounted on wrist			x	x
The “Sandra” project aims at even further refine – and to introduce a state of the art – fault isolation maintenance concept for the Saab JAS39 Gripen aircraft. Based on an easy-to-use PC based graphical tool, Fault Isolation on dedicated aircraft monitoring and safety check result data is specified.					
Peterson & Fransson 2007	Aeronautical Saab JAS39 aircraft			x	x
Troubleshooting task model of automobile chassis by using web-based system that guide the users with virtual animations and written instructions this prototype environment for distance learning.					
Liang 2008	Automobile chassis	x			
Developed a game engine to have a virtual operation system future applications could be the guide of user through routine troubleshooting. In addition to the proven applicability for training personnel. Development initiative between Chevron Corporation and SAIC					
Stafford & Hauser 2010	Simulation/modeling in the oil field environment	x		x	
Virtual reality and Augmented Reality software. Automatic path planning and collision avoidance					
Haist 2008	Set up and manage a remote maintenance operation for a thermonuclear fusion reactor	x		x	

### 3. Objectives

The purpose of this work is to propose an innovative tool than can potentially improve the cognitive process of training and troubleshooting techniques of the aircraft, but also can be used to the everyday task by capturing the know-how and helpful tips of more experienced operators, as shown in this tool will present the knowledge as a portable asset, giving all the information needed by only one touch apart from each other, the operator will be able to form a clear concept of the task and he will access the information at the right time like tables of normal functioning of the systems, written instructions of different manuals, images and virtual content to guide the task. This tool is not intended to suppress the process of certification of operators by the different entities in the aviation industry on the contrary is a proposal for enhance the current process of training and practical procedures at the hangar and this way reduce the accidents and efficiently take care of the aircraft troubleshooting and maintenance procedures.

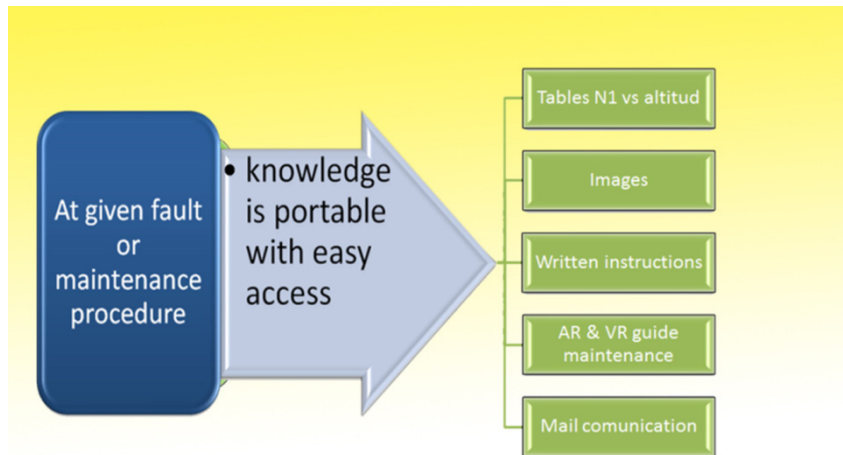


Fig. 1 Proposed solution to accelerate transfer of knowledge and troubleshooting techniques with all information in line system installed on mobile device

During the investigation is expected to accelerate the transfer of knowledge from the current manuals of maintenance and troubleshooting procedures of a company by using the augmented reality technology along with the several advantages that mobile devices have, like portability, low cost, friendly interaction and savings in printed manuals. The case of study on this project is the troubleshooting techniques and maintenance procedures of the engine air bleed system of the BOEING 737 aircraft that has two CFM56-7B engines. According to the company, the system is one of the most prone to failure or frequently recurring in repairs, thus requiring the most attention and thorough maintenance scheduled tasks.



Fig. 2 Mixed reality system for troubleshooting the bleed air system.

#### 4. The engine air bleed system

The BOEING 737 aircraft is equipped with two CFM56-7B engines that supply thrust for the airplane. The engines also supply power for these systems:

- Electric
- Hydraulic
- Pneumatic

The system is designed to provide engine compressed air to air conditioning pack with the purpose of pressurization during flight. To do so, engine air from the compressor is used, from the 5<sup>th</sup> and the 9<sup>th</sup> stage in a safe and economical way. The pneumatic system takes air from the Engine 9<sup>th</sup> Stage Compressor (High Stage) at low throttle settings and the 5th stage compressor (Low Stage) at higher throttle settings.

The 737 Bleed air system is design to the following:

1. Regulates engine bleed air to 42 +/-8 psi
2. Regulates engine bleed air temperature to 390-450 °F
3. Control 5 and 9 stage air to accomplish systems requirements
4. Prevents reverse flow to the engine compressor
5. Prevents the engine bleed air from getting hotter than 490 F

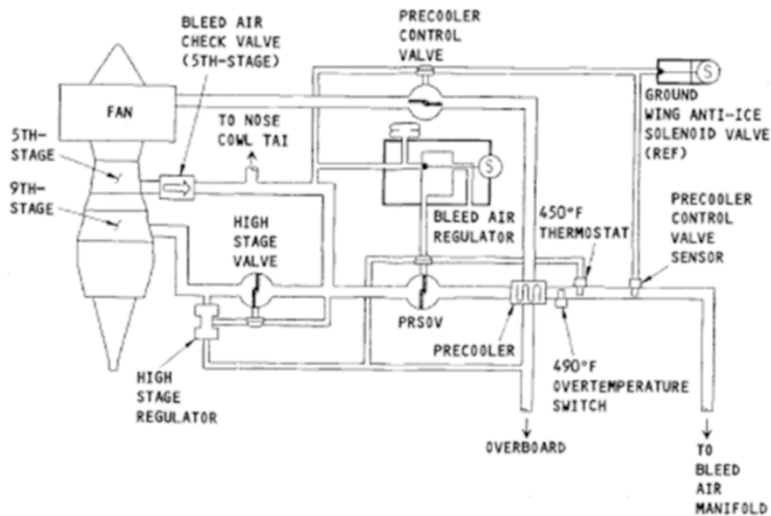


Fig 3 Air is taken from the 5<sup>o</sup> and 9<sup>o</sup> stages of the compressor section [4]

##### 4.1 Isolation of faults

Typically the pilot reports are of two types, one when the bleed trip light was illuminated and the other one is for low duct pressure, the personal in charge of maintenance have to process the available information like the phase of flight, pressure of the ducts, N1 revolutions of the engine, altitude among others. If some of the information is not available like N1 revolutions, the maintenance operator has to get the information by running the engine in the hangar.

The main task for the isolation procedures that correlated all the procedures related to pneumatics are the following:

- BLEED TRIP OFF Light On for both engines for high pressure or high temperature.
- Bleed valve: does not close when the bleed switches are moved to off, the engine is the bleed source.
- Duct pressure indication: high, low or zero, the engine is the bleed source.
- Isolation valve: does not operate correctly.
- Duct pressure indication: L and R pointers not the same (split), the engine is the bleed source.
- Duct pressure indication: L and R pointers not the same (split), the APU is the bleed source.

The technician must have knowledge about the specific use of each procedure and how it is connected to the removal and installation of components in the engine, at the end every minute spent in repair will affect the overall cost of the service provided by the airline.

## 5. Results

As shown in the previous section the main troubleshooting system calls the removal and installation of components. The troubleshooting software was developed in an iterative way for two reasons, the first one for testing the capacities of different tablets to hold all the information needed to perform the troubleshooting task efficiently and second the point of view of the customer, in this case the airline, to evaluate that the software is representative of the procedures according to the aeronautical norms and regulations. Two major structures were developed, in one side the main system that controls the troubleshooting of the engine, it deploys the information according to the need of the user, from the main system the Augmented Reality subsystem is called to deploy the removal and installation procedures for the aircraft, the subsystem is designed to show the details that experienced operators know from the everyday procedures. The Fault Isolation Software main function is to deploy information of the troubleshooting task in a timely manner but also it is linked to text files that can be updated every time that the current manual from Boeing company changes. This system allows mail communication from the user to other people involved in the repair of the engine and it also can access documentation in pdf format to deploy other manuals that are not included in the scope of this project but in the future the expansion to other tasks is designed. For the part of the system where the removal and installation of components is presented, the AR technology became a great opportunity to deploy the content to enhance operator ability of troubleshooting the bleed air system.

The timeframe for developing this project played an important role in the main findings of the software, as mentioned before, the iterative developing process had several milestones before the stable and complete version was ready for release, these milestones include both, the feedback for the airline and also the evaluation of the performance of the app when more documentation (Independent subsystems, 3D models, 2D images, big quantities of text) was added. To receive an insight in how much the AR subsystem works for the installation and removal of components is expected to improve the performance of the task, an experiment was designed parallel to the stages of developing of the app, this study was carefully proposed to be: representative of the assembly process in the aeronautical industry, introduce a high level of complexity to clearly identify the results, and independent of the gender of the person that was going to use the technology. It is worth to note that the assembly was chosen because of its characteristics, it has two mirror symmetry axes where the user is likely to ignore the labels that indicate the correct position of each piece. It was ensured that there is only one correct solution to the assembly.

The case of study was the RV training project-1 was chosen shown in figure 4, this is a training project used to introduce prospective RV aircraft builders to the materials and techniques used in putting together an RV-10 airplane. The user assembled a short section of the flight control surface and, in the process, learned the basic skills needed during actual aircraft construction [5]. To reduce the time of sample and for safety issues the kit was properly prepared before the test, holes were drilled to size of rivets and the image targets of AR technology were positioned also every piece of the assembly was identify for the two sides: up/down faces. After the preparation, only the manual of assembly (AR or written), rivets and rivet-gun was necessary to finish. All operations could be performed with non-considerable physical effort, also all the labelled pieces belong to only one place to clearly identify when the user committed a mistake.

Two instructional procedures were prepared for the evaluation, one with written instructions similar to the sheets given to the user in the Aircraft procedures, the other was developed with Augmented Reality technology deploy with web cam and computer screen. According to the design of experiment theory the test has one factor (method of knowledge transference), 2 levels (Traditional Written Instructions like process sheets and Augmented Reality Instructions) and 2 outputs (time for completing the assembly and quality). For the quality assessment a total of 46 points were assigned to the perfect assembly for the principal characteristics of the RV training kit, then the number of faults were summarize to see the effect of the process followed by the user.

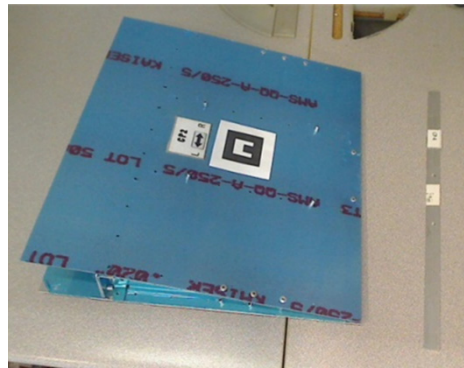


Figure 4 RV training project-1

Table 2 Results of study: AR vs Traditional Written Instructions

N	Assembly Type	Average Assembly Time [Minutes]	Average Quality of Assembly
17	TRADITIONAL	50.16	76.60%
17	AR	41.52	94.63%

Table 2 summarize the results found in the experiment for the two methods of assembly for RV training kit: The time for assembly was 17.22% lower for the AR technique than the traditional written instructions, also the quality of the assembly was seriously improved when using AR. it reached a 94.63% compared to the 76.60% of the written instructions method, which represents a 24% increment in the quality with respect to the current methods in the company, this sample was composed by random male or female senior students of mechanical engineering with no previous knowledge of the task to ensure gathering of the learning curve while doing the test.

It is expected that the mobile solution for troubleshooting techniques and maintenance procedures will enhance the abilities of the users by not only taking the benefits of changing the current training methods in the company but also taking advantage of the mobility of the hardware with dual system with Augmented Reality



& Virtual Reality, the touch capabilities of the state of the art tablets make the app friendly and easy to understand the great amount of information related to the isolation of faults, the formal evaluation and impact of the software presented in this project will be done in a second stage of development, the reader should take into account that most of the information is property of the company and it cannot be published.

## 6. Conclusions

A mobile solution to enhance the troubleshooting techniques and maintenance procedures of the Engine Air Bleed System of the BOEING 737 aircraft was proposed and developed in this investigation with the objective of improving the current processes of the Aeromexico Airline, the system can function on two aspects for training and for in situ operations, both of them use the same isolation system but for the installation and removal of engine components the system is able to run not only with Augmented Reality but also with Virtual Reality, this concept is commonly known as a Mixed Reality system. The software can be compiled for Android (Galaxy tab, Motorola XOOM) & iOS (iPads, iPhones) operating systems to use the existent and new devices in the company. It is expected that the mobile solution for the troubleshooting techniques and maintenance procedures will enhance the abilities of the users by not only taking the benefits of changing the current training methods in the company but also taking advantage of the mobility of the hardware with dual system with Augmented Reality & Virtual Reality, the touch capabilities of the state of the art tablets make the app friendly and easy to understand the great amount of information related to the isolation of faults.

The final challenge to overcome is the acceptance of final users to take the system in the everyday environment, once the app is released in the hangar it will be of interest to study the resiliency of the engineers and operators (new & experienced) for using the technology; also the feedback from them will be of great importance to make the proper changes in the structure of the system.

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