Creating hybrid adaptive air vehicle technical work instructions using Augmented Reality and 2D Barcode visualization technologies

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ABSTRACT

Technical work instructions used by engineering technicians in aircraft maintenance, repair and overhaul (MRO) processes remain largely paper based in the industry. Technicians often encounter situations requiring additional support material, technical advice, or amplifying visual information requiring them to leave the work area to conduct additional technical data searches or seek technical support. A paper-based/electronic "hybrid" work instruction with network enabled data access via portable personal computing devices could offer the MRO industry one solution to modernizing current paper-only work instructions. As a work in progress, this project demonstrates "digital" data access and display capabilities for paper based instructions, using optical targets embedded within paper based procedural instructions. These can be scanned using lightweight handheld PCD platforms (smartphone and i-Pad) utilizing Quick Read 2D Barcode and Augmented Reality visualization technologies. With these capabilities the maintenance technician can be delivered high end graphics, native CAD file parts information, animations and other technical data directly to the point of maintenance. This type of adaptable work instruction preserves the human operator's choice in level of detail required. The goal is to improve maintenance task efficiency and accuracy while reducing time wasted searching for additional data or obtaining technical assistance.

INTRODUCTION

The current standard of display and use of technical work instructions (assembly, operational check and repair for example) in air vehicle lifecycle management is often paper based.

Work instructions for assembly or repair are typically issued to technicians, who utilize them for guidance on completing a multitude of tasks and operational checks on an air vehicle system or component. If it is the first time the technician has encountered the task or, if a change to the normal routine has

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been made, technicians must often cross reference other technical material or seek out amplifying, more detailed engineering documentation. In many cases, this requires the technician to leave the proximal work area, even if just to go ten feet to a computer work station. This decreases efficiency and erodes situational awareness, elevating the human factor risk of missed steps.

An emerging data gap exists in that modern technicians working within the advanced network enabled Next Generation Air Transportation System (FAA, 2010) –or NextGen - of computer and sensor driven aircraft, require more detailed and rapid technical data delivered to the point of maintenance than can currently be provided with paper or even flat file technical manuals (pdf etc.). This can impact efficiency and safety of modern maintenance processes as the aging global air fleet is replaced by aircraft born with NextGen technologies in their DNA.

To resolve this requires intuitive data delivery and visualization capabilities available on-demand. Unfortunately this is often well beyond what current Maintenance, Repair and Overhaul (MRO) provider's system capabilities can provide. Even with emerging use of personal computing devices (PCDs), maintenance job tasks and data searches are often still accomplished using some blend of manual/paper, in larger proportion than complete electronic systems (Block, Ropp & Speca, 2009).

The Adaptive Hybrid Work Instruction described here is being developed and tested in the Hangar of the Future research laboratory at Purdue University. It offers one potential solution to the need for rapid delivery of detailed technical data and graphics where traditional paper-only work instructions fall short.

In addition to development for maintenance procedures currently using Purdue's B727 transport category aircraft platform, Hangar of the Future partnered with MakerPlane Inc., an open source aviation organization in the Amateur Build Experimental (ABE) market. The aim of this collaboration was to extend the transfer of the same data delivery constructs to the ABE market in which the ABE builder/ owner/operator can access assembly and maintenance instructions within an on-demand interactive environment. This was incorporated into the research as a way to evaluate crossover use of the same hybrid, interactive work instructions in manufacturing and assembly oriented tasks. Future application could extend into the General Aviation MRO market for certified technicians as well.

The goal of this project was to leverage existing technologies to enable technical data access, including more detailed graphics, 3D model overlays and on-

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demand video tutorials, by the technician via a mobile handheld device (smart phone, tablet etc.) and existing commercial off the shelf (COTS) software. This will be done while preserving the use of paper based instructions where necessary or desired. The research presented in this report represents a work in progress demonstrating 2D barcode and Augmented Reality integration capabilities into an existing paper based work instruction format for air vehicle assembly and maintenance.

BACKGROUND

Two dimensional bar codes (2D Barcodes) and augmented reality (AR) technology is not new (Sundareswaran,1999). However as in the case of augmented reality, these technologies are application based and exhibit useful qualities to an end user aircraft technician (De Crescenzio, 2011).

These target based visualization technologies can bridge the gap between straight paper and next generation paperless e-systems by incorporating efficiencies of hyperlinks, auto-navigation and delivery of high fidelity graphics using standardized personal computing devices (smartphone, tablets) carried by most people on the job. It is believed that through controlled integration and use, MRO's could utilize this bridging capability now, to improve production efficiency and safety while migrating their legacy systems to NextGen standards.

As named, adaptive hybrid work instructions are a concept that will bring real time amplifying reference data to the technician in a utilitarian modality. It is believed that the blended use of existing 2D barcode and Augmented Reality (AR) visualization technologies with traditional paper based task instructions offers one solution to help bridge the transition gap from paper to the digital workspace. This new development will aid in meeting the increasing need for broader and more user-adaptable data on demand by the front line technician working on "smart" NextGen aircraft.

2D Barcodes are an extension of the traditional and more familiar vertically lined barcodes. Originally created in the mid-1990's they were initially used within the automotive industry for parts marking and tracking. Now somewhat mature, they are an almost ubiquitous icon associated more with advertising for smartphone devices.

Augmented Reality (AR) applications have had a slow start, emerging more recently as a novelty smartphone application in search of a problem. However, AR applications have progressed to a usability level where it can be leveraged into work environments more effectively, including

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technical maintenance processes. Cox, (2010), describes a prototype smartphone AR system with a headset for mechanics doing maintenance work on light-armored vehicles. The system displayed text instructions, floating labels, 3-D arrows pointing to various components, and animated 3-D models of tools and steps in the repair process. Results indicated AR mechanics were significantly faster in finding and initiating repair tasks compared to a control group using a headset that only showed text instructions, and another group on a computer workstation.

This supports previous research through Purdue's Hangar of the Future showing that properly applied visualization and component presentation of technical or complex systems is critical for improving daily maintenance tasks in both efficiency and accuracy (Kim, et.al., 2010; Woo, et.al., 2009).

Efficiency, work accuracy and ultimately airworthy work are particularly critical for modern maintainers within the Maintenance Repair and Overhaul industry (MRO). This can prove difficult in that MROs struggle with cost constraints and long learning curves when evolving traditional paper-based processes to meet the challenging and unchanging safety and efficiency demands of emerging high-tech, digitally networked "smart" aircraft like the B787 or A380. These modern aircraft have been developed around the FAA's Next Generation Air Transportation System (NextGen) (FAA, 2010). The NextGen initiative has driven evolution of "smart" aircraft, with sophisticated and integrated operating systems. Thus the approach to lifecycle maintenance of these vehicles must reflect the same technology data construct, delivery and interface.

Aviation organizations however, struggle to make the transition to more complete IT-centric data delivery systems in which legacy in-house systems are sometimes incompatible; they also struggle with complexity and maintainability of new systems (Cox, 2010) especially when entirely new software platforms are introduced.

There is similar potential for improving efficiency and accuracy within the ABE market. The ABE aircraft builder, on average, does not have experience in reading and interpreting aircraft blueprints. Many ABE aircraft construction manuals assume technical literacy and can be confusing to the lay-person. Historically, up to 62% of ABE aircraft kits and plans only built aircraft projects are abandoned before completion and much of this can be attributed to poorly written technical material (Kitplanes, 1998).

A need exists for enabling wireless, highly visual technical data delivery to the point of maintenance, while minimizing end users having to learn an entire in-house proprietary system.

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DESIGN METHOD

The initial goal of this project was to facilitate rapid access to network-enabled amplifying data, that would augment existing paper based air vehicle maintenance work instructions. Data to be displayed would need to be in the form of 3D (CATIA based) graphics, animation, and mpeg instructional videos for a given task.

These supporting technical data sources would be delivered directly to the point of maintenance, on demand, and must be usable across a variety of PCDs carried by the engineering technician.

The triggering technologies to be used were 2D Barcode and Augmented Reality optical imaging technologies studied previously within the Hangar of the Future laboratory using commercially available software applications for parts visualization (Ropp, et.al., 2011).

Researchers were constrained to the assumption of industry's continued use of some form of paper based work instructions. Paper in fact can still be the preferred method in some instances of harsh environments or where confined space or physical orientation of the human being into small working spaces is required. Thus, explicit use of just hand held PCDs was not an option. The work instruction used was adapted from a real work instruction created within the Aeronautical Engineering Technology curriculum for live training maintenance tasks performed on the Aviation Technology Department's laboratory B727 transport aircraft.

The specific task selected was removal, inspection and reinstallation of the aircraft Nose Gear Shock Strut door, as this allowed easy access and a workspace with multiple complex component geometries to test fidelity and precision of graphics based targets (Figure 1).

Figure 1 – B727 Nose Gear Components

The standard paper based instruction was then enhanced with integration of 2D barcodes for use by a PCD.

In late Fall of 2012 and Spring of 2013, the research team collaborated with John Nicol of MakerPlane to explore the use of AR in the ABE construction and assembly process. MakerPlane is in the process of designing and building an open source 2-seat experimental composite aircraft. They provided 3D models and CAD drawings of the aircraft to the research team for ongoing

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assessment of large and small aircraft components.

On MakerPlane's recommendation, the team switched from an existing AR application to the Aurasma AR application enabling parts and components themselves to become the visual triggers, eliminating the need for paper-based targets (the aircraft part or structure image itself is captured as a graphic and becomes the activating target).

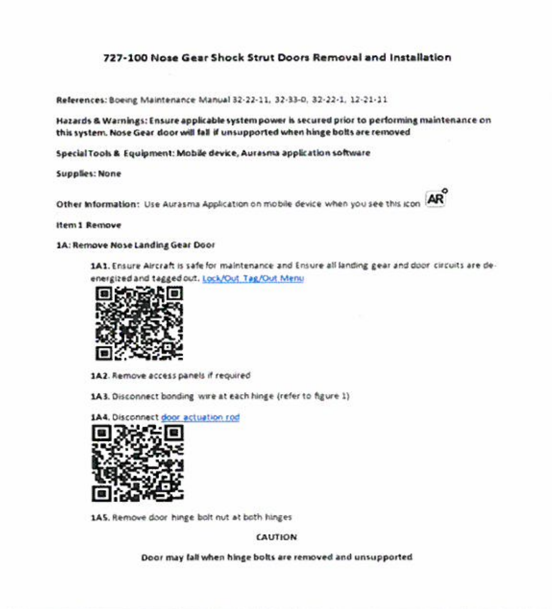
Aurasma is an AR application allowing direct use objects as targets, rather than a specific printed target, as cues to trigger and deliver desired information. This capability is very attractive because the information can not only be called forward while accessing the job card, but also while using the aircraft itself as the cue.

With these technologies embedded, technicians can gather extra helpful information about the procedure being performed by: 1) scanning the printed paper job card 2) accessing the hyperlinks while viewing the job card electronically 3) scanning the actual airplane itself using any handheld device with a camera capable of accessing the Aurasma application.

The work instruction utilized was a removal, inspection and reinstallation of the left forward nose gear shock strut door from Purdue's B727 transport aircraft, a non- flying laboratory platform with fully functional engines and systems.

The team was able to embed and enable delivery of 3D CAD files, installation photos, and even assembly videos, accessibly via QR and AR links printed on the work instruction, (Figure 2) as well as making the nose gear strut door itself the activating target.

These codes were hyperlinked to navigate the user to an intranet database URL containing typical original equipment manufacturer (OEM) technical maintenance data.



727-100 Nose Gear Shock Strut Doors Removal and Installation

References: Boeing Maintenance Manual 32-22-11, 32-33-0, 32-22-1, 12-21-11

Hazards & Warnings: Ensure applicable system power is secured prior to performing maintenance on this system. Nose Gear door will fall if unsupported when hinge bolts are removed

Special Tools & Equipment: Mobile device, Aurasma application software

Supplies: None

Other Information: Use Aurasma Application on mobile device when you see this icon AR

Item 1 Remove

1A: Remove Nose Landing Gear Door

1A1. Ensure Aircraft is safe for maintenance and Ensure all landing gear and door circuits are de-energized and tagged out. Lock/Out Tag/Out Menu

1A2. Remove access panels if required

1A3. Disconnect bonding wire at each hinge (refer to figure 1)

1A4. Disconnect door actuation rod

1A5. Remove door hinge bolt nut at both hinges

CAUTION

Door may fall when hinge bolts are removed and unsupported

Figure 2 – Paper work instruction with integrated 2D and AR targets

The display developed for testing was a Catia rendered 3D drawing of the nose landing gear shock strut door drawn by

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the student research team. Figure 3 shows this drawing as it is displayed on the user's PCD. The drawing is also animated and rotates.

This graphics format enables that graphic to become a carrier of additional information such as dimensional data and parts lists, presented in one viewing.

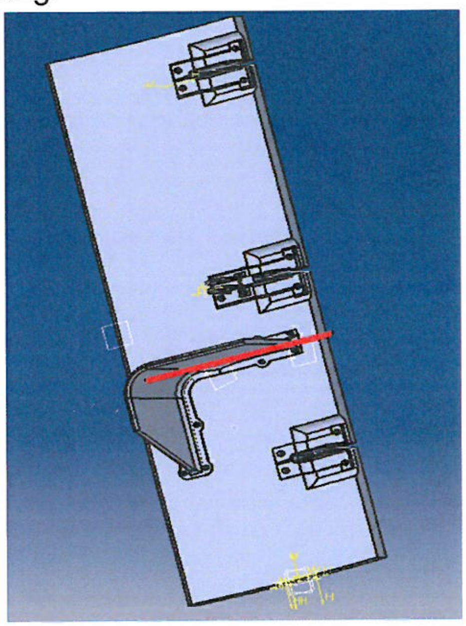

Figure 3 – CATIA 3D drawing of nose landing gear shock strut door

Other information can be tagged and accessed in the form of text based checklist procedures direct from what might normally be a 500 page maintenance manual.

In addition, more in depth structural drawings, allowing simulated three-dimensional walk through of other sub-systems deeper within the airframe structure can be provided to the user as well.

RESULTS

In controlled lighting environments such as an indoor hangar area, both 2D barcode and AR target activation were found to be consistent and reliable when using a smart phone, I-pad or slightly larger touch tablet PC.

Therefore, initial testing focused primarily on distance and lighting sensitivity both indoors and outdoors.

2D Barcode results

The 2D barcodes proved to be the most robust and consistent across a variety of indoor and outdoor lighting conditions and devices. The embedded codes within the paper work instruction can be read by most devices even after having been crumpled and re-smoothed and at varying angles and distances. If there are two targets close together on the paper job card it is beneficial to hold the handheld device closer to the paper, so as to be sure that the application is recognizing the intended target and not the one nearby.

Augmented Reality (AR) results

Consistent with other AR applications both paper and physical target based, the Aurasma application was occasionally inconsistent in given light conditions outside. While indoor reliability and sensitivity to trigger remained consistent from distances of 3

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– 9 feet, lighting and distance variations became more light dependent outdoors, especially as component geometry became more complex.

When using a physical object or aircraft part as the target for Aurasma, the lighting, object focus time and distance from the object become much more crucial to the success of the reading. When using the B727 front landing gear door as a cue while indoors (removed and on a maintenance stand indoors), the results were fairly consistent. Using AR with the I-pad researchers measured consistent activation within an 8-10 foot distance and up to 120 degree viewing angle of the door's target surface. When using the aircraft as the cue while out on the airport ramp in the sunlight, the results varied. Activation took longer in more subdued light in the afternoon. However, target activation was still possible. Testing indicated that the glare of the materials in use as well as dynamic shadows outside caused some difficulty in getting a consistent reading of the part being used as a cue. To resolve this the team discovered that using a larger and less intricate part of the aircraft, like a nose gear tire (Figure 4), was more effective across a wider variation of outdoor daylight than using a small and precise part, such as a connecting rod eye bolt (Figure 5).

Figure 4 – Tire target

Figure 5 – Connecting rod eyebolt target

Using a larger part also increases standoff distance the user can be from the aircraft in order to activate the cue. When using the eyebolt, the device had to be held within 1-2 feet of the bolt itself and activation became much more light-dependent. These results represent only initial testing trials to set up and demonstrate capability. More detailed measures and performance testing including planned cross-sectional testing among users of varying skill levels is ongoing.

DISCUSSION AND NEXT STEPS

Converting to completely paperless work instructions can represent an

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unrealistic cost and learning curve time for MRO operators. However, as described in this work- in- progress report, embedded AR and QR technologies offer MRO operators a reasonable "bridge" step for integrating NextGen systems capabilities that could positively impact task efficiency as well as task safety and quality (first time fixes).

As this project continues, experimentation of optimum lighting and distance readings for aircraft components will continue. In addition, more robust data storage and delivery, as well as security, version control and access issues related to regulated technical data will be evaluated.

Again, the results discussed here represent only first step development and testing. Even so, results show much promise for enabling aerospace manufacturers, suppliers, airlines, MROs and even private builders within the Amateur Built Experimental and General Aviation markets to leverage existing off the shelf technologies as low cost alternatives as supplemental, assistive data delivery strategies within an MRO or manufacturing. The result could be higher quality workmanship, reduced time on task and more precise and cost effective management over the lifecycle of the air vehicle.

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